

PARTICLE PHYSICS AND FUNDAMENTAL INTERACTIONS: RESEARCH IN THE ROMA1 INFN SECTION

Activities' review and Master thesis proposals

Daniele del Re

CSN1 coordinator of INFN Sezione Roma

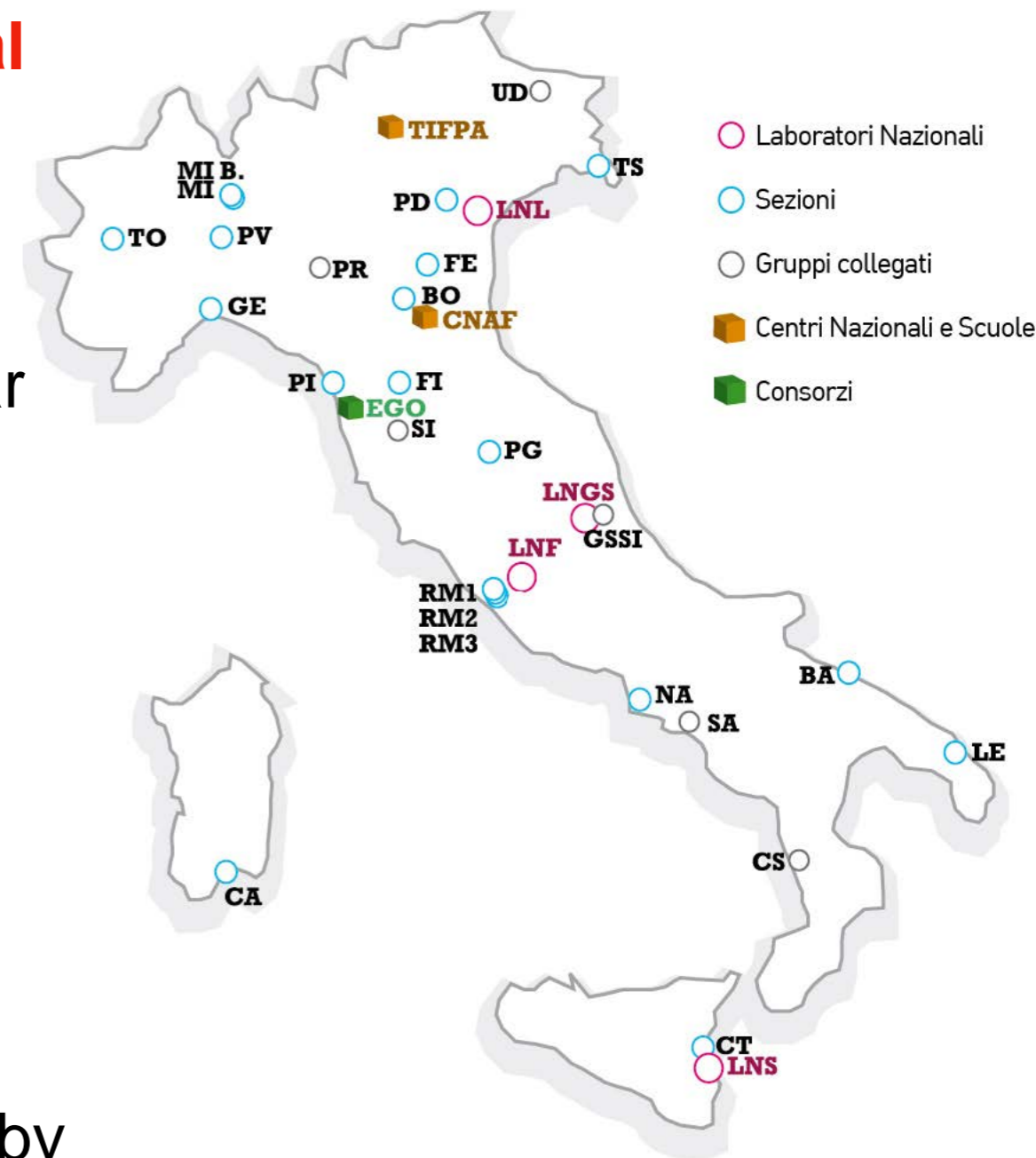


SAPIENZA
UNIVERSITÀ DI ROMA



ISTITUTO NAZIONALE DI FISICA NUCLEARE (INFN)

- The **National Institute for Nuclear Physics** (INFN) is the Italian research agency dedicated to the **study of the fundamental constituents of matter and the laws that govern them**
- It conducts **theoretical and experimental** research in the fields of subnuclear, nuclear and astroparticle physics.
- All of the INFN's research activities are undertaken within a framework of **international competition, in close collaboration with Italian universities**
- Fundamental research in nuclear, subnuclear and astroparticle physics requires the use of **cutting-edge technology and instruments**, developed by the **INFN at its own laboratories and in collaboration with industries**



INFN: RESEARCH TOPICS

In Rome:

- **Commissione Scientifica Nazionale 1 (coord.: Daniele del Re):**
 - subnuclear physics and study of the fondamentale interactions
- **Commissione Scientifica Nazionale 2 (coord.: Fabio Bellini):**
 - astroparticle physics, gravitational waves and neutrino physics (with and w/o particle accelerators)
- **Commissione Scientifica Nazionale 3 (coord.: Carlo Gustavino):**
 - study of structure and dynamics of nuclear matter and nuclei under extreme conditions (quark-gluon plasmas)
- **Commissione Scientifica Nazionale 4 (coord.: Luca Silvestrini):**
 - theoretical physics research: developing hypotheses, models and physics theories to explain the results of experiments and open up new scenarios for physics
- **Commissione Scientifica Nazionale 5 (coord.: Alessandro Lonardo):**
 - technological and inter-disciplinary research, including promotion of the use of fundamental physics instruments, methods and technologies in other sectors

LINES OF RESEARCH

1 PARTICLE
physics



2 ASTROPARTICLE
physics



3 NUCLEAR
physics



4 THEORETICAL
physics

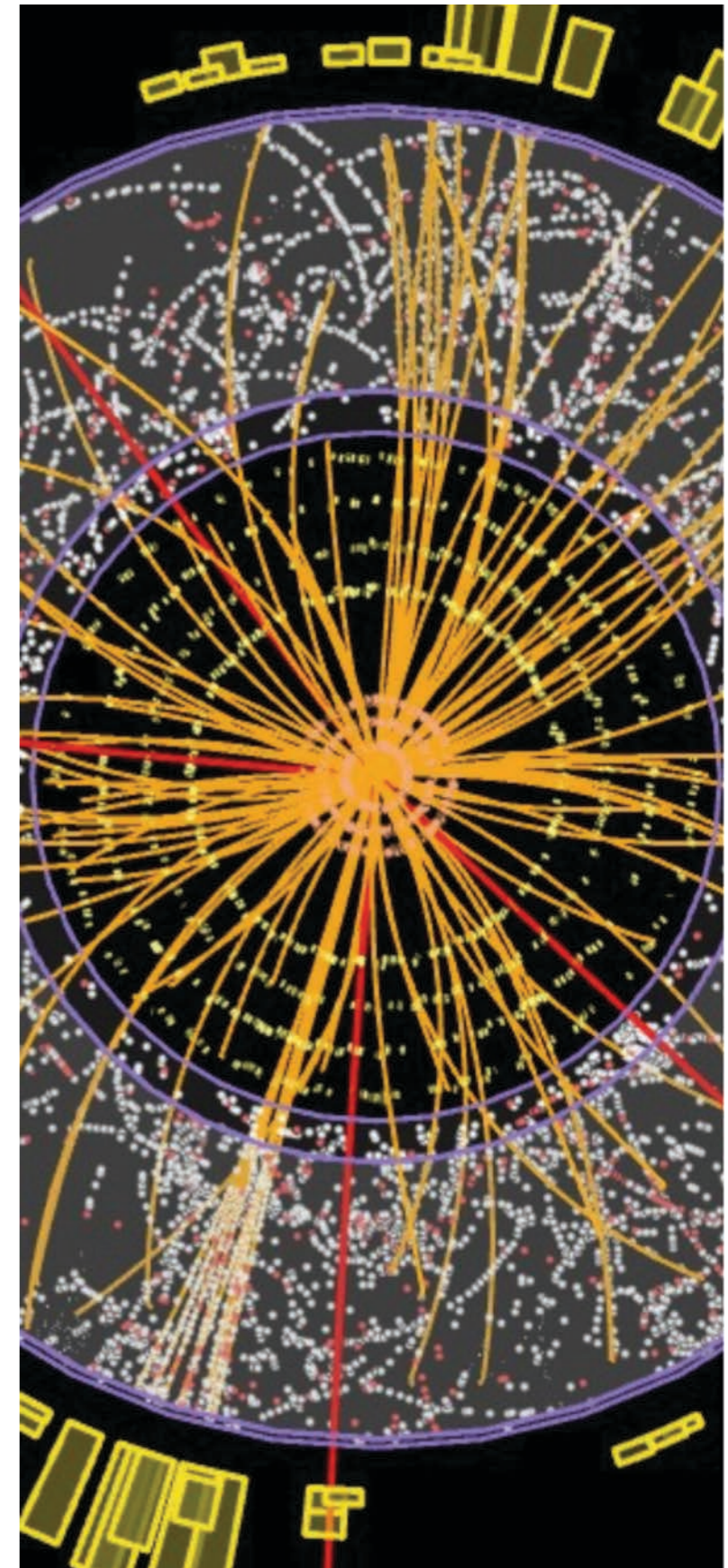


5 TECHNOLOGICAL
physics



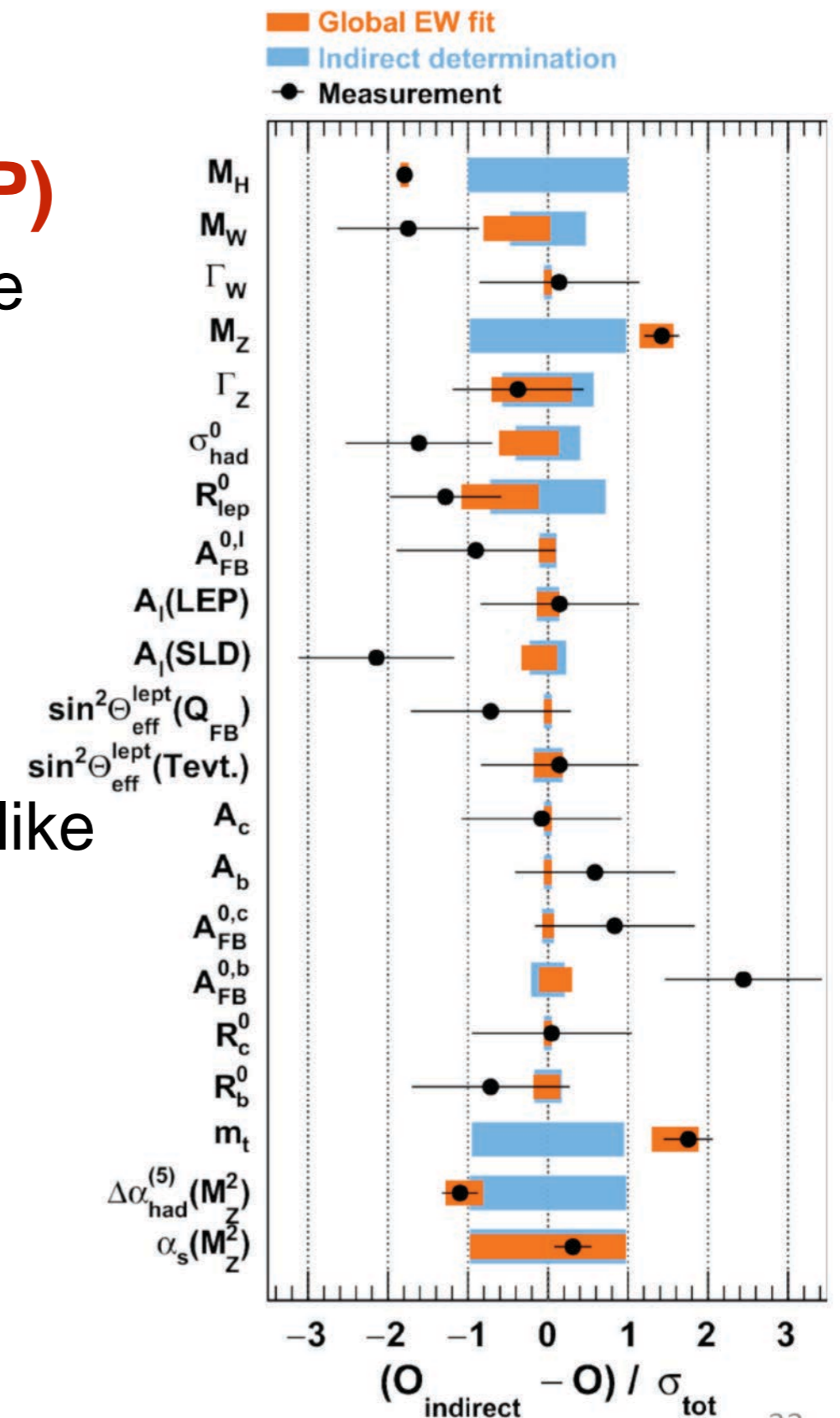
FUNDAMENTAL PHYSICS AT ACCELERATORS

- Benchmark to **study SM interactions**
 - em, strong, weak
- Benchmark to **study particle properties**
 - e.g. top quark, B meson, W, Z, Higgs bosons
- Create **possible new particles**
 - with large energies of the beam (e.g. SUSY)
 - look for unconventional signatures (e.g. DM)
- **Look for new processes**
 - new interactions (e.g. to extend SM)
 - prohibited decays in SM (e.g. $\mu \rightarrow e\gamma$)



WHY NEW PHYSICS? SM LOOKS HEALTHY

- **Precision tests successful (e.g. LEP)**
 - small discrepancies but not so worrisome
- **Higgs was predicted and then discovered (by LHC)**
 - present measurements indicate it is SM-like
- **Why looking for something else?**



MAIN QUESTIONS

Several open issues implying Physics beyond Standard Model. Some **examples**:

1. Why only **three families of leptons and quarks**?
2. Why **four fundamental interactions and not one**?
 - unification is impossible even at very large energies
3. Why **gravity is so weak**?
 - 40 orders of magnitude weaker than e-m!
4. Why only **5% of matter is made of ordinary SM particles**?
 - what is the dark matter?
5. Why the most massive particle (**top**) is “**only**” **200 time heavier than the proton**?
 - desert above 170 GeV

A FEW SOLUTIONS

- **Supersimmetry**
 - may predict heavy resonances
 - may explain dark matter
 - some new SUSY particles can be long-lived
- **Extra Dimensions**
 - to include gravity
 - may predict heavy resonances
- **Weakly interacting particles**
 - candidates for dark matter
 - interact with ordinary matter via new mediators (which would represent new resonances)
- ...

GALACTIC ROTATION VELOCITY

- For a star of mass m at distance r from center of the galaxy

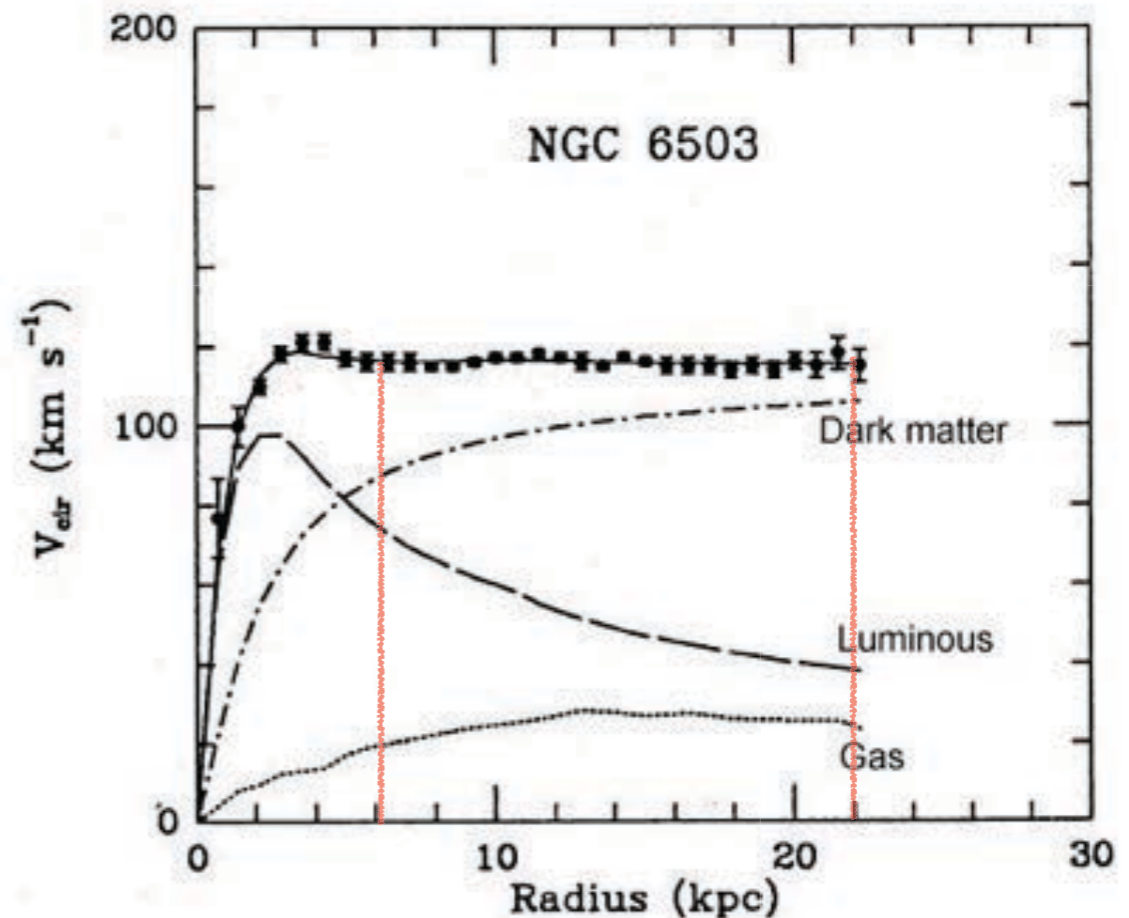
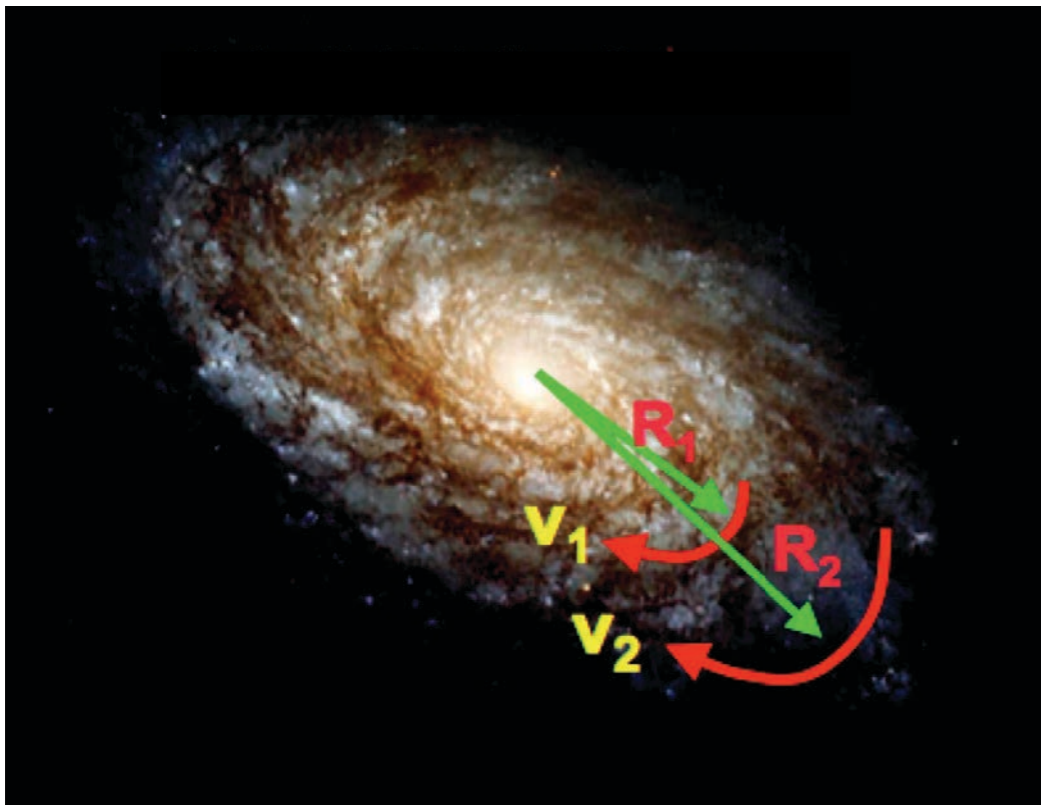
$$\frac{mv^2(r)}{r} = \frac{mM(r)G}{r^2}$$

- **Galaxy** mass mainly within **core radius of R**

$$M(r) = \begin{cases} \rho r^3 & r < R_0 \\ \rho R_0^3 & r \geq R_0 \end{cases}$$

- **Galaxy rotation velocity**

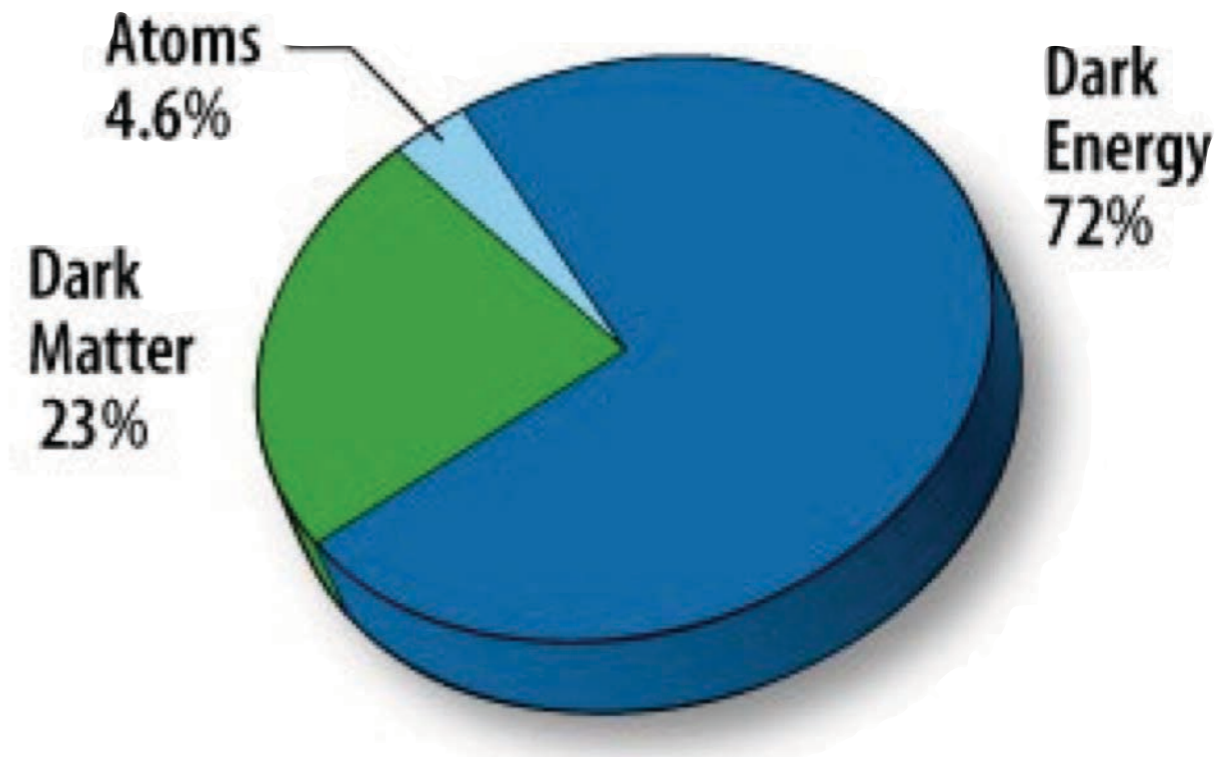
$$v(r) = \begin{cases} \propto r & r < R_0 \\ \propto r^{-1/2} & r \geq R_0 \end{cases}$$



DARK MATTER

- **Properties**

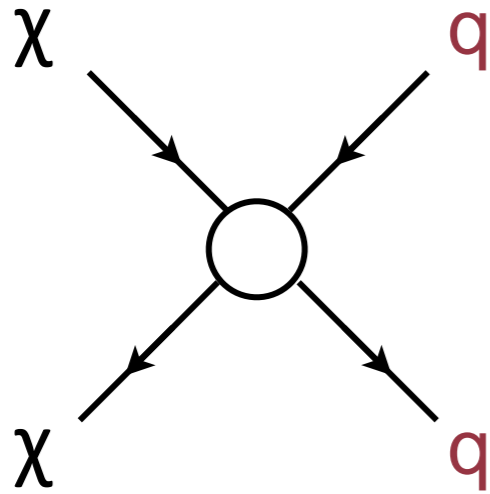
- stable
- no electric or color charge
- very weak interaction with Standard Model particles
- subject to gravity interaction



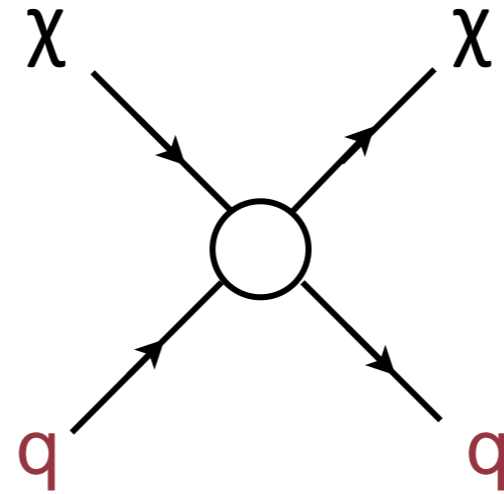
- **Several potential candidates fulfilling these requirements for dark matter**

- Dark: weakly interacting with electromagnetic radiation
- Hot & dark: ultra-relativistic velocities
 - ▶ neutrinos
- Warm & dark: very high velocity
 - ▶ sterile neutrinos, gravitinos
- Cold & dark: moving slowly
 - ▶ Lightest SUSY particle (neutralino, gravitino as LSP)

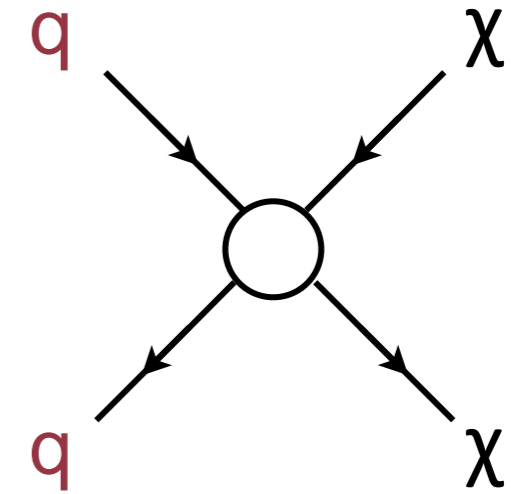
DARK MATTER INTERACTION



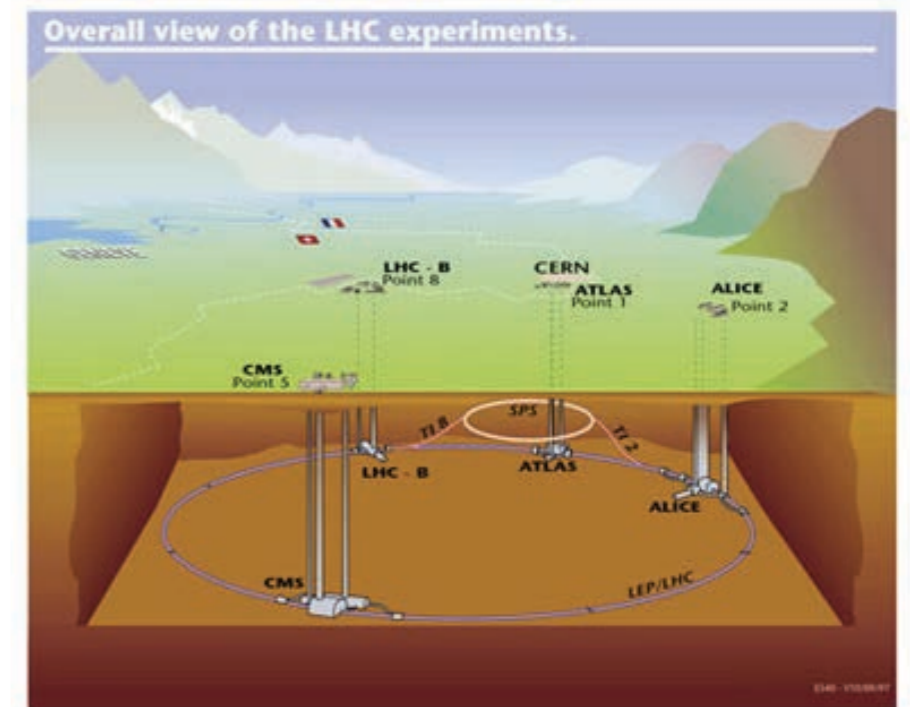
Indirect Detection



Direct Detection



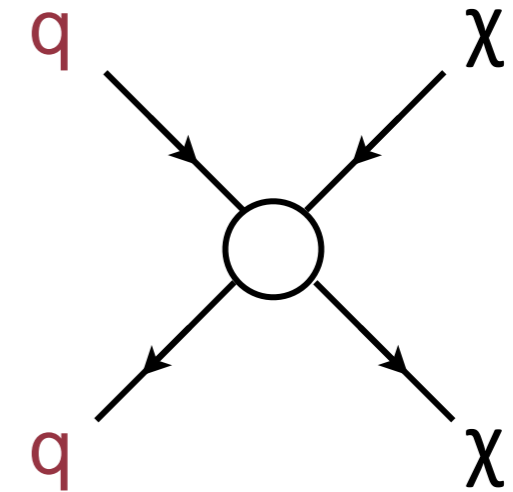
Production at Colliders



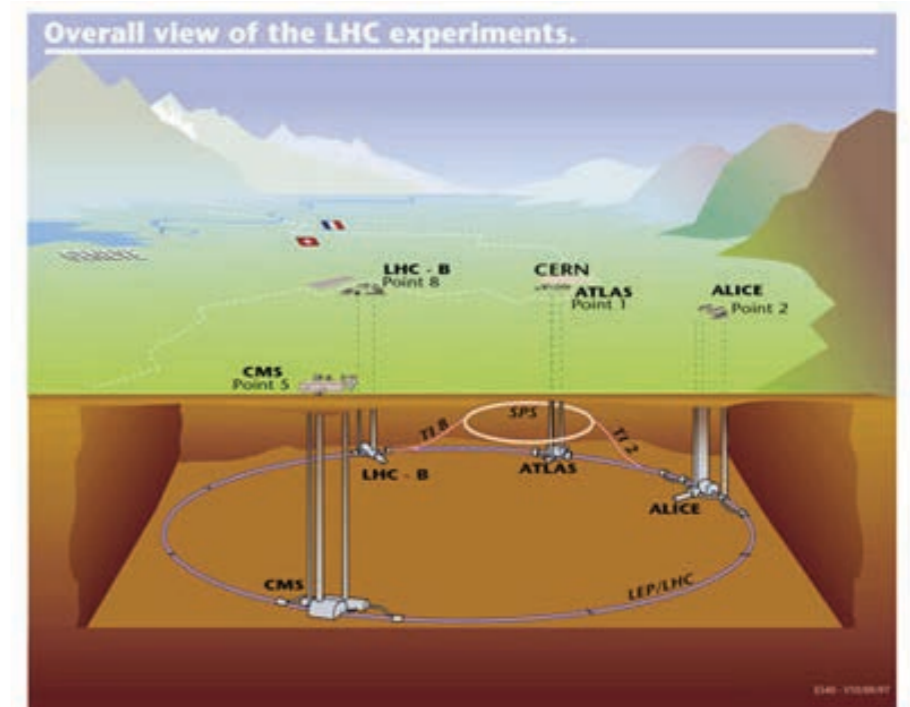
DARK MATTER INTERACTION

- **Pair production at LHC**

- DM candidates escape the detector (weekly interacting)
 - large missing energy
- need to identify (“tag”) events of interest with some extra object
 - otherwise you see nothing in the detector



Production at Colliders

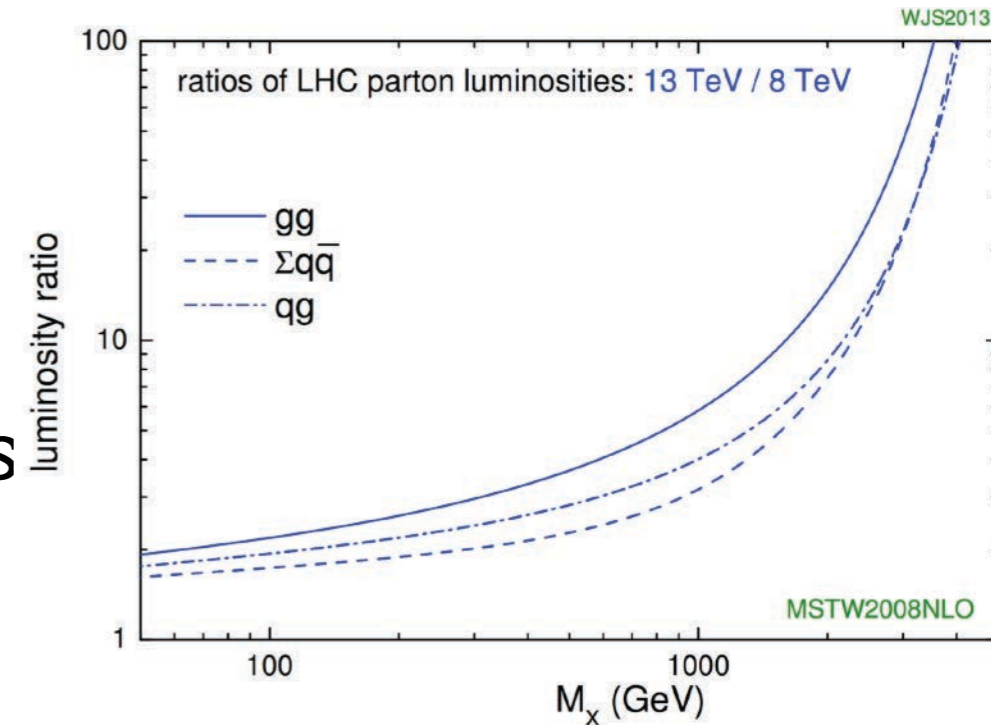


ENERGY VS INTENSITY FRONTIER

Two ways to tackle issue with accelerators:

1. Large center of mass energy

- search for new massive particles
- *LHC, ATLAS, CMS, next gen accelerators*



2. Large luminosity to reproduce same experiment several times (intensity)

- study SM processes in detail
- search for rare decays
- *LHCb, MEGII, KLOEII, PADME*

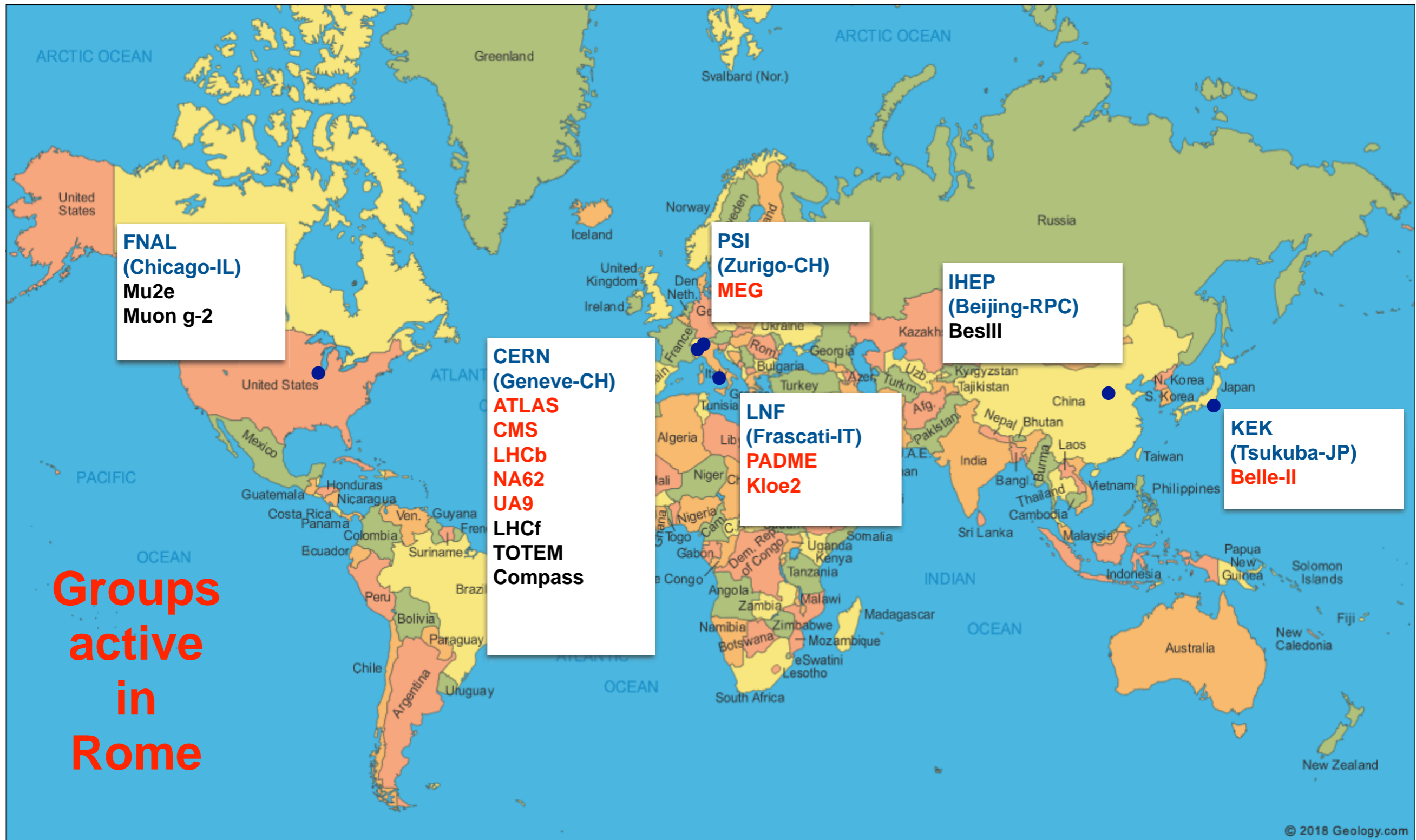
$$N = L \cdot \sigma$$

Event Rate [Measured] (under N)

Luminosity [Machine parameter] (under L)

Cross Section (under σ)

EXPERIMENTS AND ACCELERATORS

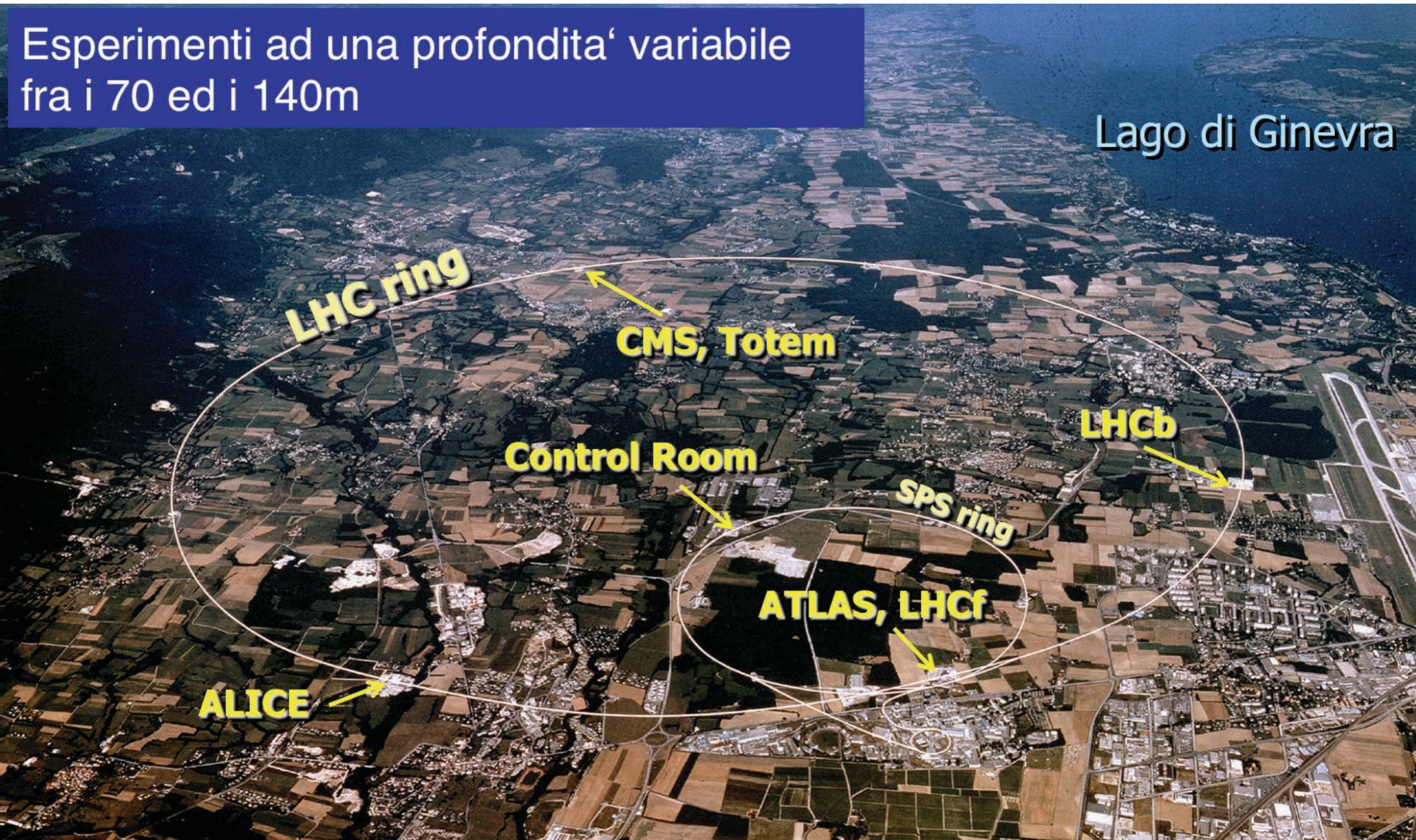


LHC

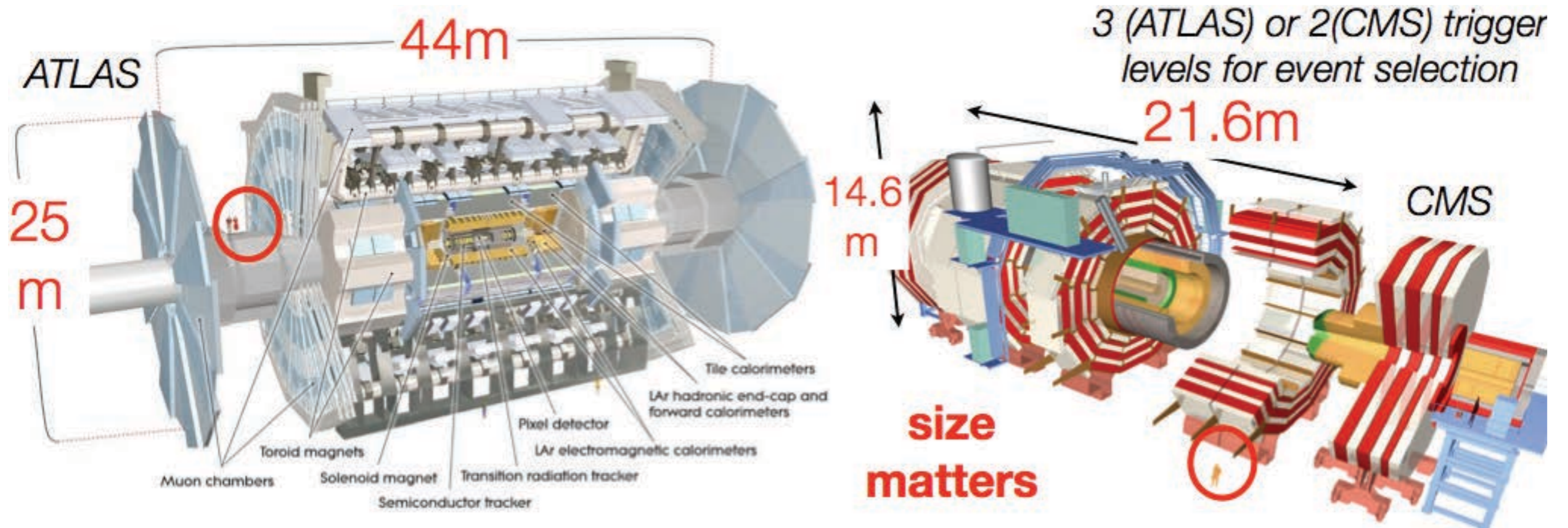
LHC ACCELERATOR

Esperimenti ad una profondita' variabile fra i 70 ed i 140m

Lago di Ginevra

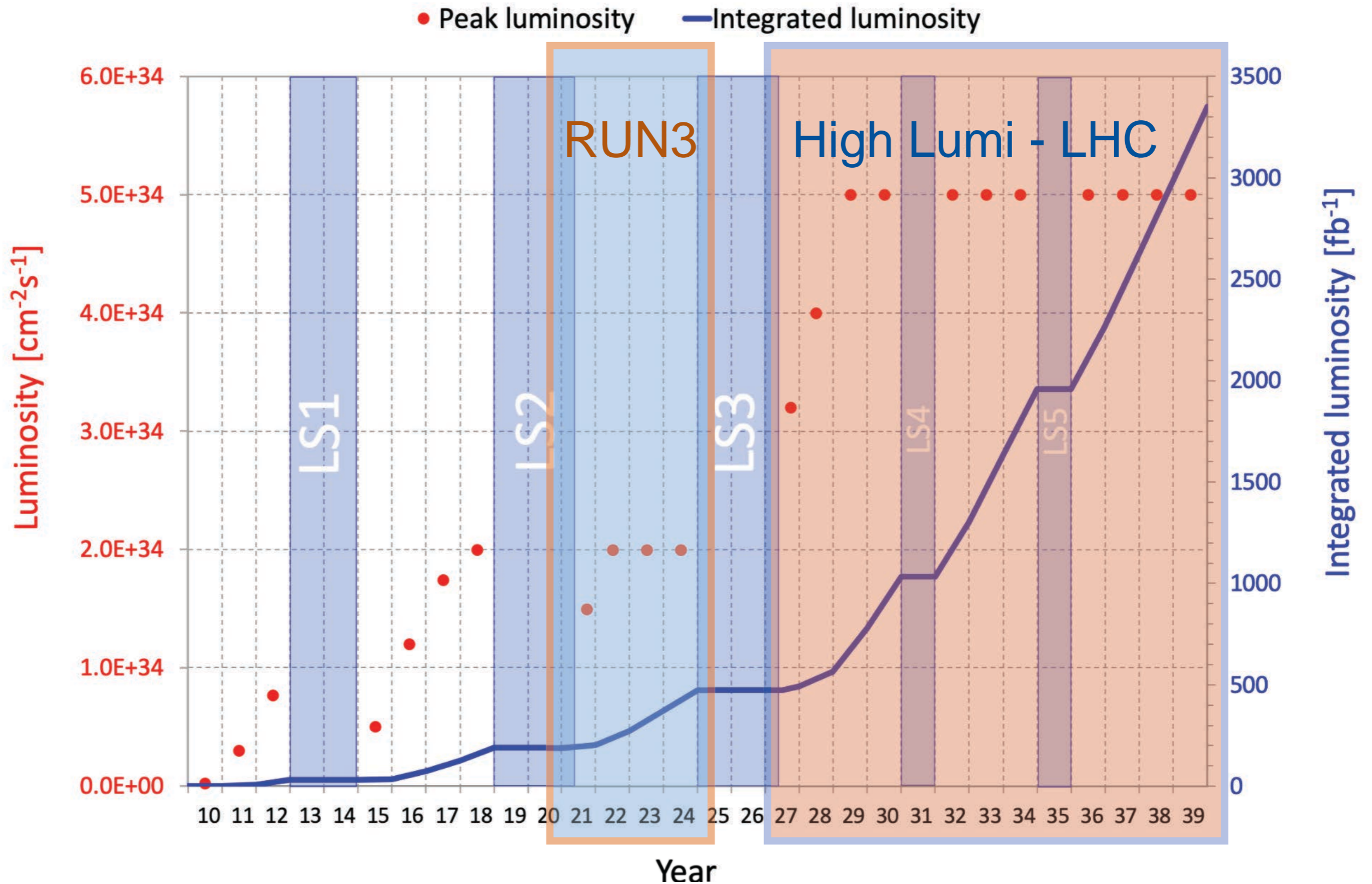


ATLAS AND CMS



	ATLAS	CMS
Magnetic Field	solenoid (2 T) + toroid (0.5÷1T)	3.8 T solenoid + return yoke
Tracker	Si pixel, strips + TRT	Si pixel, strips
EM Calorimeter	Pb + LAr	PbWO4 crystals
Had Calorimeter	Fe+scint./Cu+LAr/W+Lar ($\geq 11\lambda$)	Brass+scintillator($\geq 7\lambda$)/Fe+quartz
Muon	air-toroid muon spectrom.	iron return-yoke muon spectrom.
Trigger	L1+RoI-based HLT	L1+HLT

FUTURE LHC PROGRAM



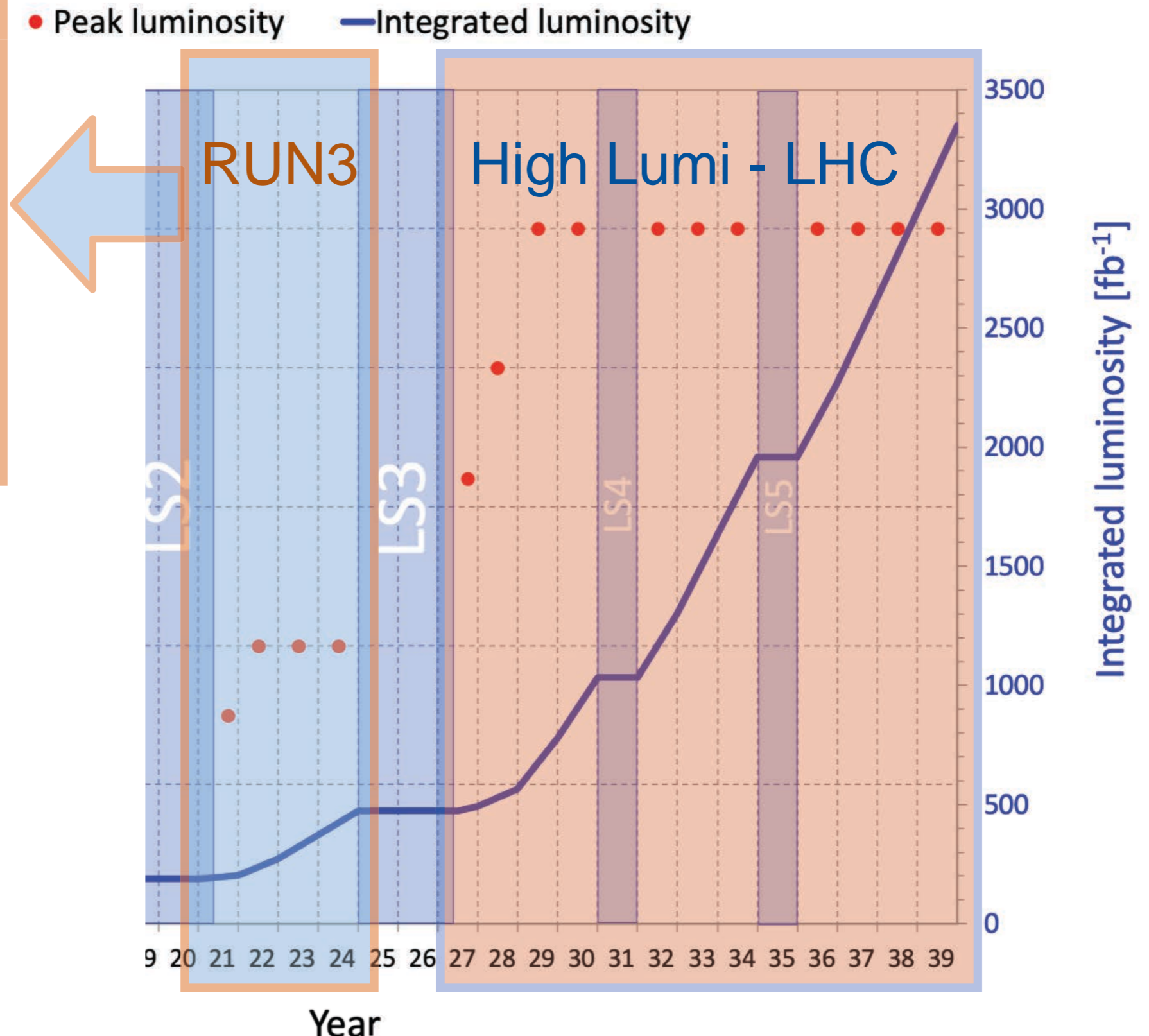
FUTURE LHC PROGRAM

- **13.6 TeV**

- small increase in \sqrt{s}
- no giant leap for new resonance searches

- **Additional $\sim 300 \text{ fb}^{-1}$**

- crucial to further investigate Higgs and discrepancies in SM



FUTURE LHC PROGRAM

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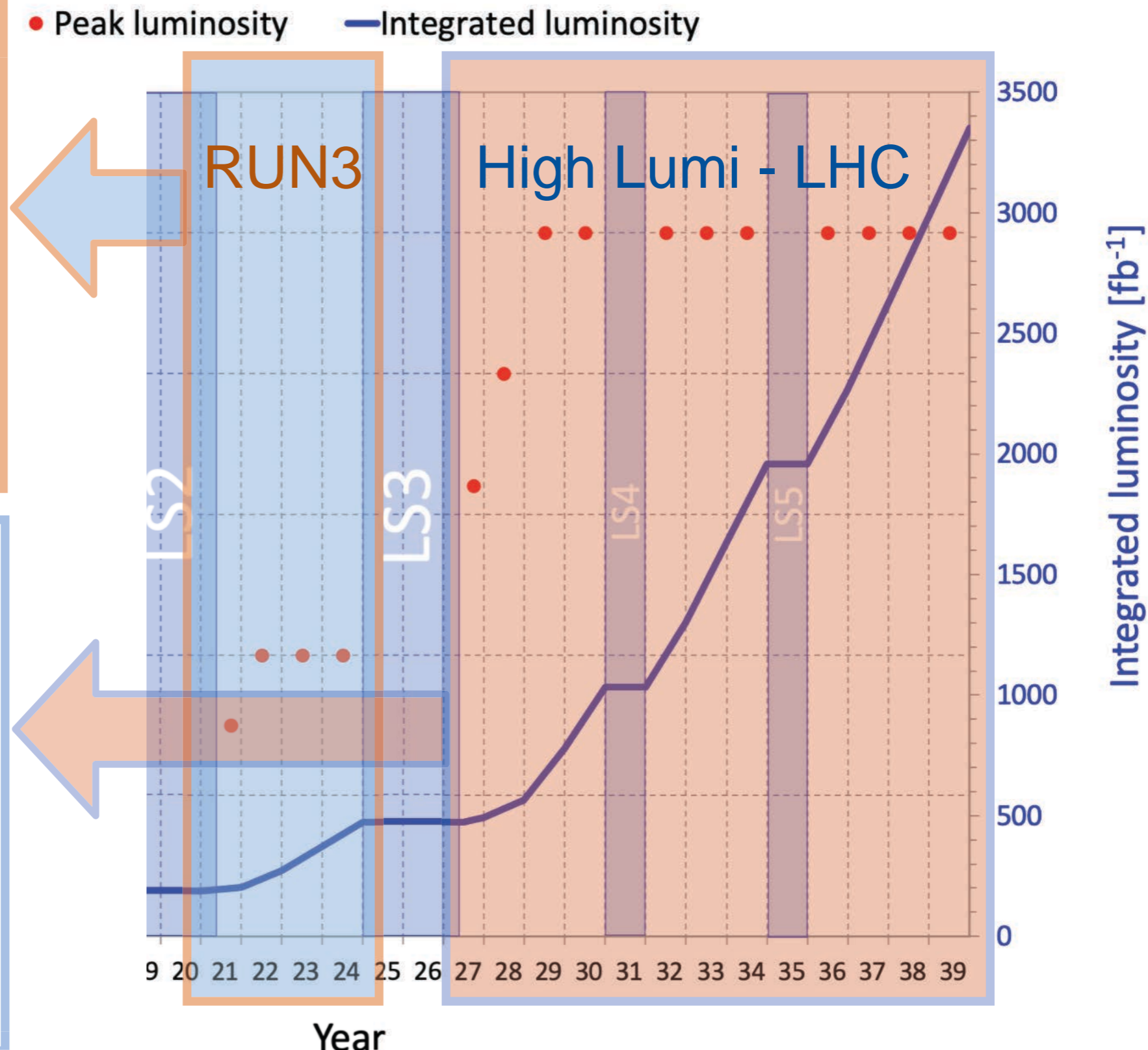
- crucial to further investigate Higgs and discrepancies in SM

- **14 TeV**

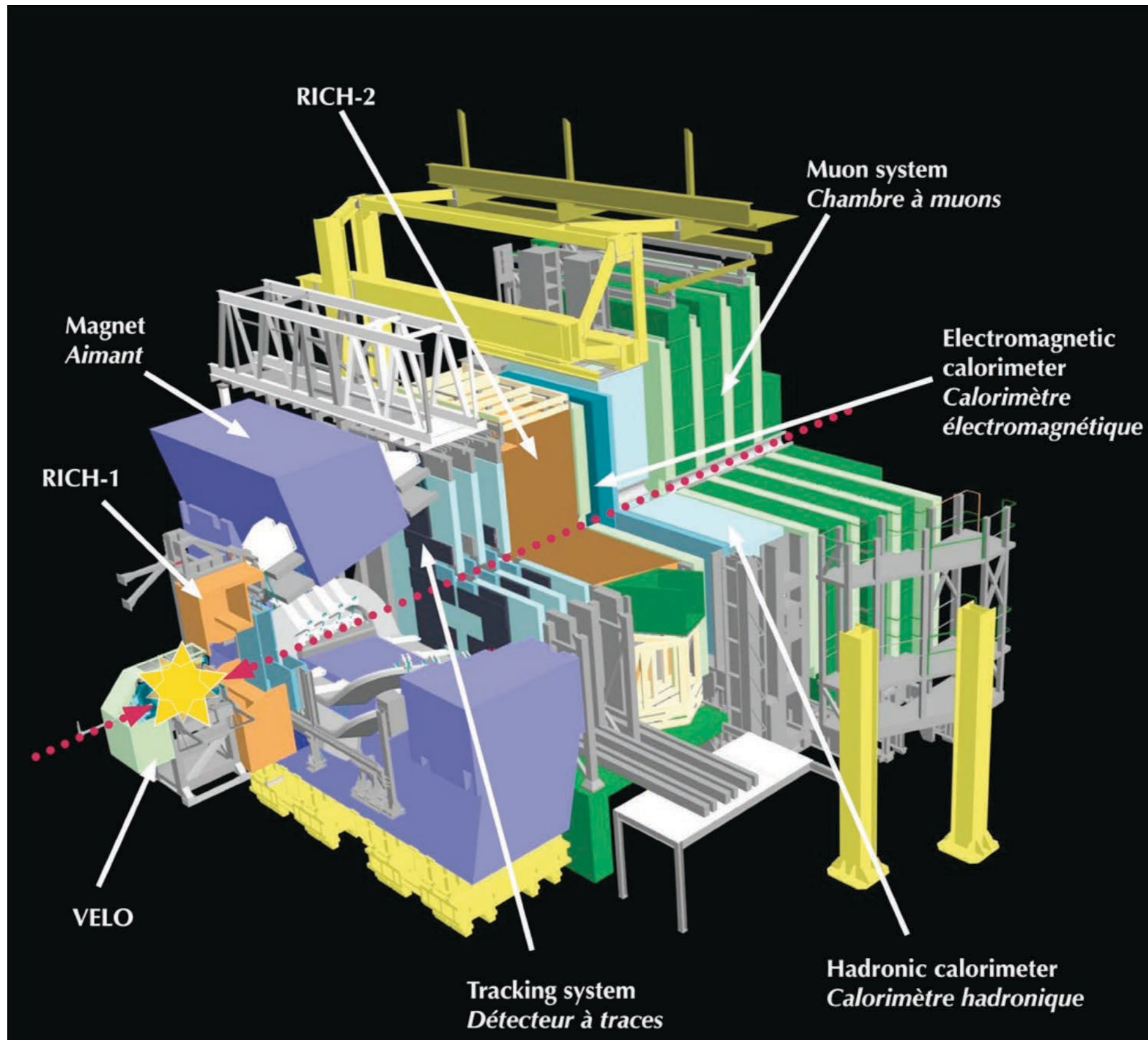
- small increase in \sqrt{s}

- **Additional $\sim 3 \text{ ab}^{-1}$**

- \sim complete rebuilding of detectors to fight background increase
- a new paradigm for LHC physics with high statistics

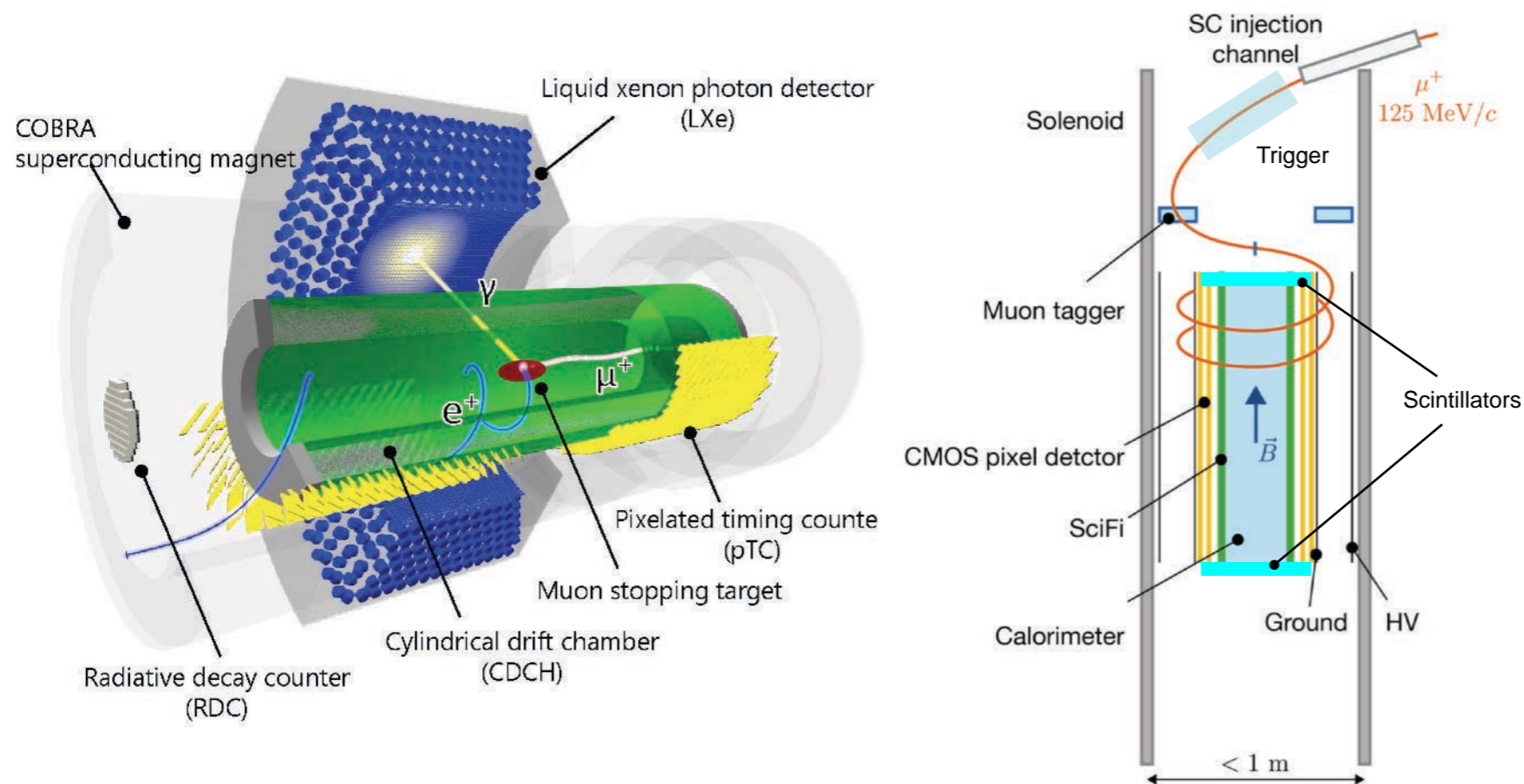


LHCb



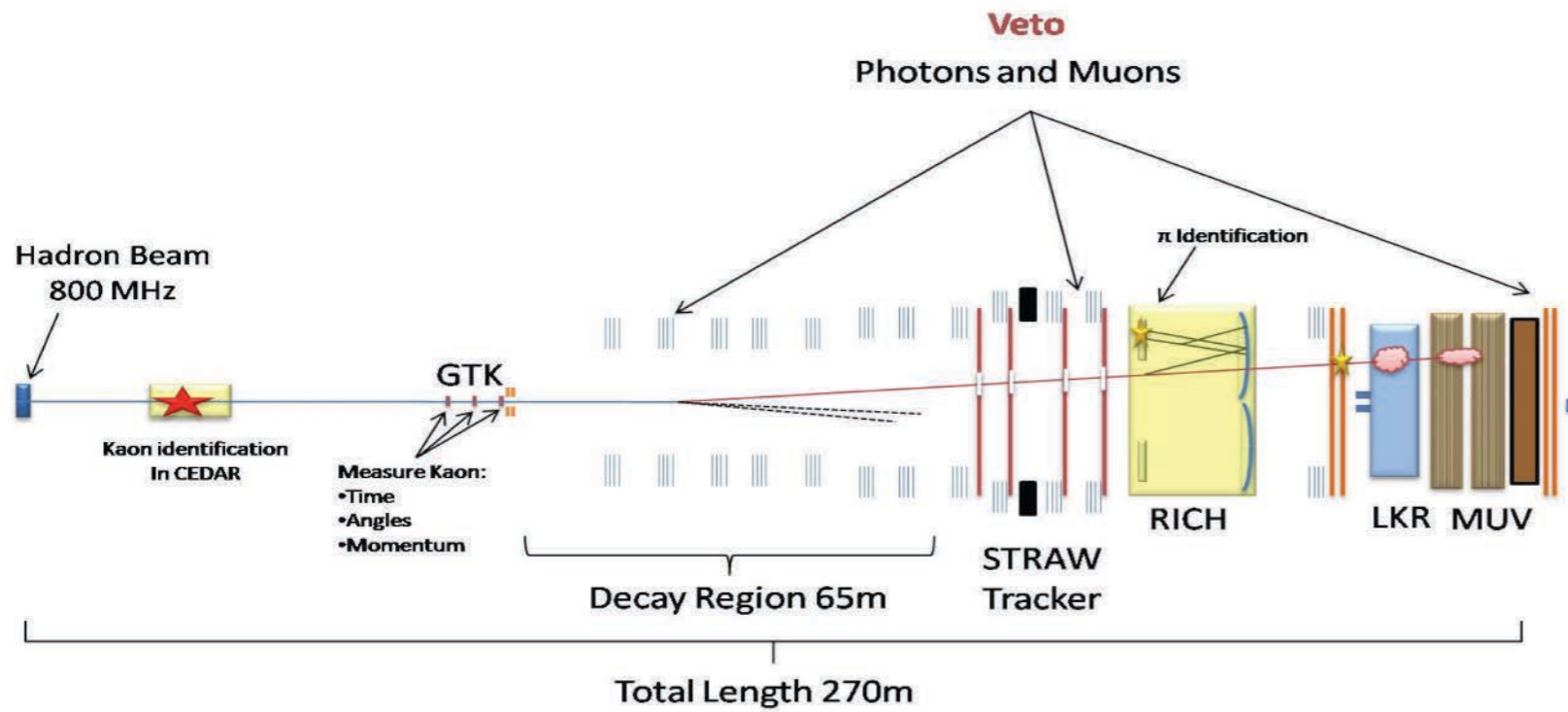
NON-LHC

SEARCH FOR NEW PHYSICS AT THE INTENSITY FRONTIER



Muon Physics at PSI

SEARCH FOR RARE PROCESSES



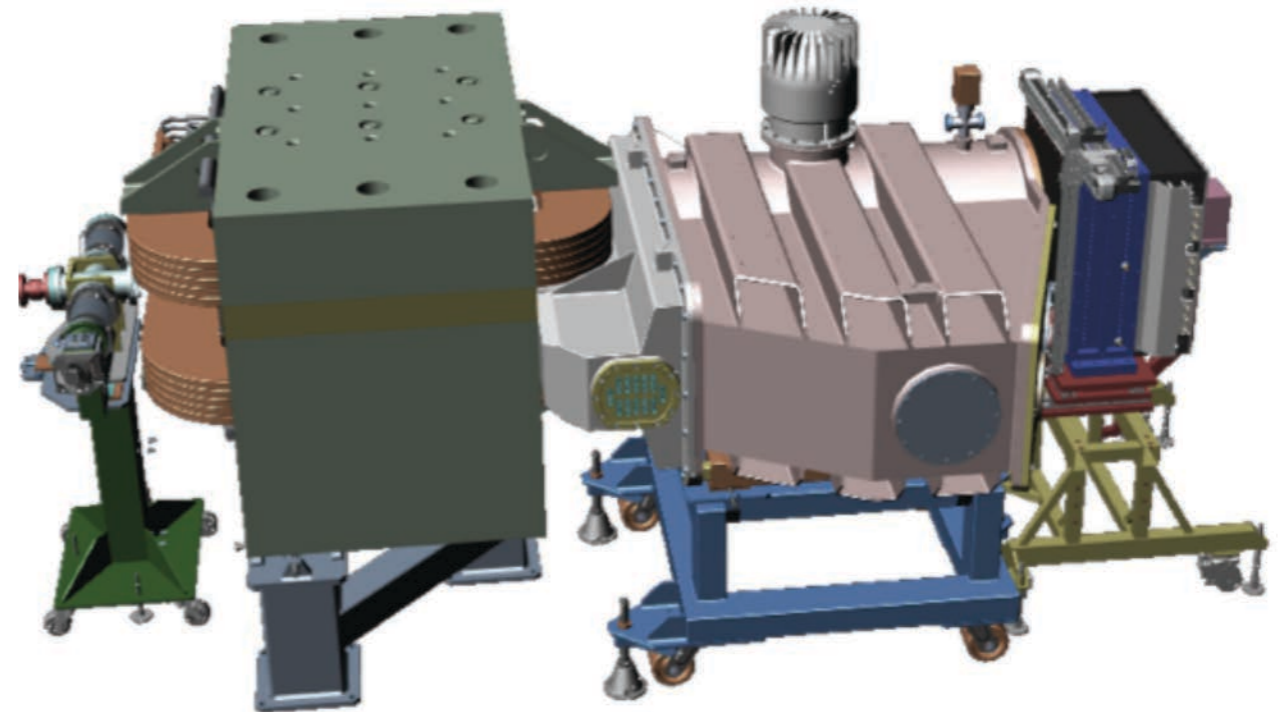
NA62

10.12.09

Na62 Physics Handbook Workshop

1

PADME

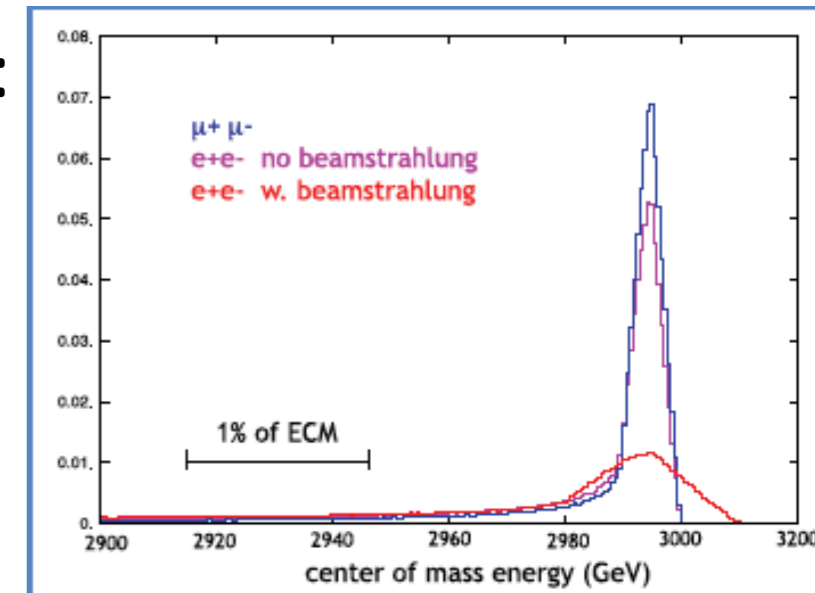


MUON COLLIDERS

$$\begin{array}{lll}
 m_\mu = 105.7 \text{ MeV}/c^2 & \frac{m_\mu^2}{m_e^2} \cong 4 \times 10^4 & \mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu \\
 \tau_\mu = 2.2 \text{ } \mu\text{s} & & \mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu
 \end{array}$$

- A $\mu^+\mu^-$ collider offers an ideal technology to extend lepton high energy frontier in the multi-TeV range:

- No synchrotron radiation (limit of e^+e^- circular colliders)
- No beamstrahlung (limit of e^+e^- linear colliders)
- But muon lifetime is 2.2 μs (at rest)

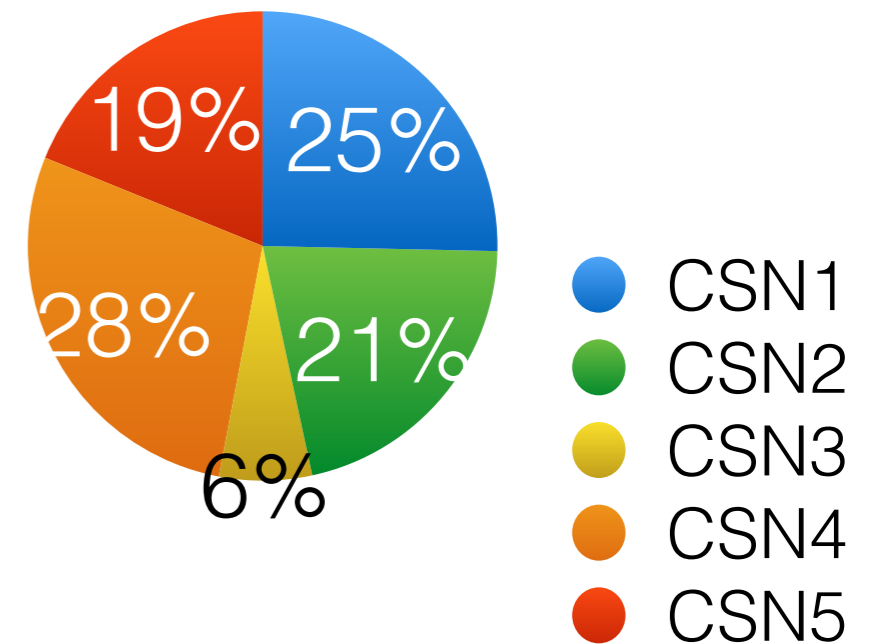


- Best performances in terms of luminosity and power consumption
- Very challenging but also great potentiality for discoveries
- **The full center-of-mass energy available for physics** \rightarrow for $\sqrt{s} > 10 \text{ TeV}$ competitive with FCC-hh in several new-physics scenarios

ACTIVITIES IN ROME

THE ROMA1 INFN SECTION

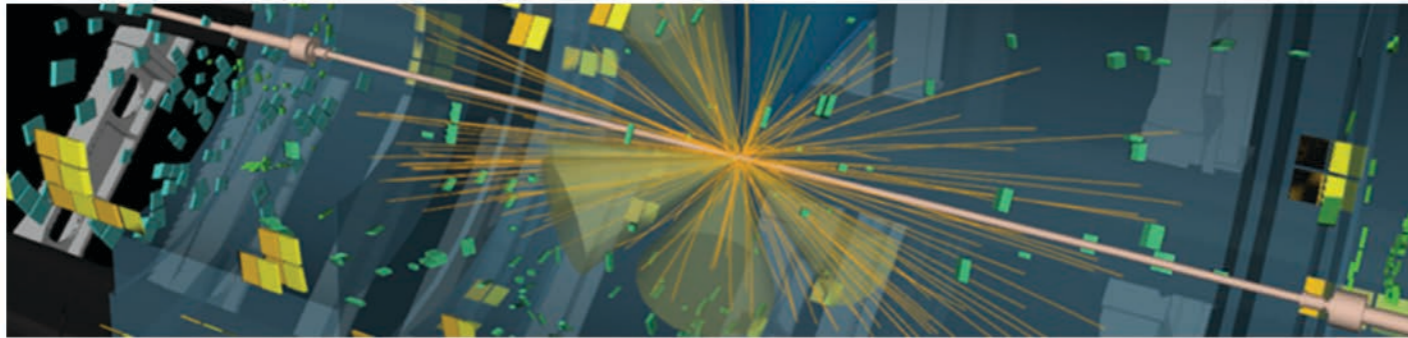
- About **200 physicists and technicians** involved in INFN research activities in Rome



- CSN1 Experiments in Roma1:**

Exp.	Acceleratore	Responsabile	E-mail
ATLAS	LHC @ CERN	M.Corradi	massimo.corradi@cern.ch
CMS	LHC @ CERN	R.Paramatti	riccardo.paramatti@roma1.infn.it
KLOE-2	Dafne @ LNF	P.Gauzzi	paolo.gauzzi@roma1.infn.it
LHCb	LHC @ CERN	R.Santacesaria	davide.pinci@roma1.infn.it
MEG-2	PSI @ Zurigo	C.Voena	cecilia.voena@roma1.infn.it
NA62	Fixed Target SPS @ CERN	P.Valente	paolo.valente@roma1.infn.it
PADME	BTF @ LNF	M.Raggi	mauro.raggi@roma1.infn.it
RD_MUCOL	-	F. Anulli	fabio.anulli@roma1.infn.it

ACTIVITIES IN ROMA1



Fisica delle Particelle CSN1

L'obiettivo delle ricerche coordinate dalla Commissione Scientifica Nazionale 1 (CSN1) è lo studio delle interazioni dei costituenti fondamentali della materia attraverso esperimenti con gli acceleratori di particelle.

La teoria che definisce le nostre attuali conoscenze di fisica subnucleare è chiamata Modello Standard. Le ricerche attuali si propongono di giungere a una comprensione più profonda di alcuni suoi aspetti, per esempio il meccanismo con cui si genera la massa delle particelle. In questo senso la scoperta e lo studio delle proprietà del bosone di Higgs sarebbero un decisivo avanzamento delle nostre conoscenze.

I fisici puntano, con gli esperimenti in corso, anche alla scoperta di fenomeni nuovi, che portino a superare il Modello Standard. Un esempio sarebbe la rivelazione sperimentale di particelle supersimmetriche, alcune delle quali sono candidate a costituire la materia oscura (sappiamo che quest'ultima è largamente prevalente nel cosmo, ma non riusciamo a rivelarla né a spiegarne la natura). Altri esempi sarebbero la scoperta di nuovi segnali che diano ragione dell'asimmetria tra materia e antimateria nel nostro Universo, oppure ancora la prova dell'esistenza di ulteriori dimensioni spazio-temporali.

Coordinatore

Daniele Del Re

Fisica delle Particelle

Esperimenti

ATLAS

CMS

CRYSBEAM

KLOE2

LHCb

MEG

NA62

PADME

RD_FCC

ACTIVITIES FOR STUDENTS

Data analysis

- **learn about physics** (broad physics program and different processes)
 - *it's all about SM*
- **learn about advanced analysis methods** (machine learning)
 - *you are not alone, have to get the best from your data*
- **learn about statistics**
 - *statistics means counting*
- **learn about modern programming**
 - *c++, python, etc...*
- **interact with many people** (and learn from them)
- **learn how to present your results**

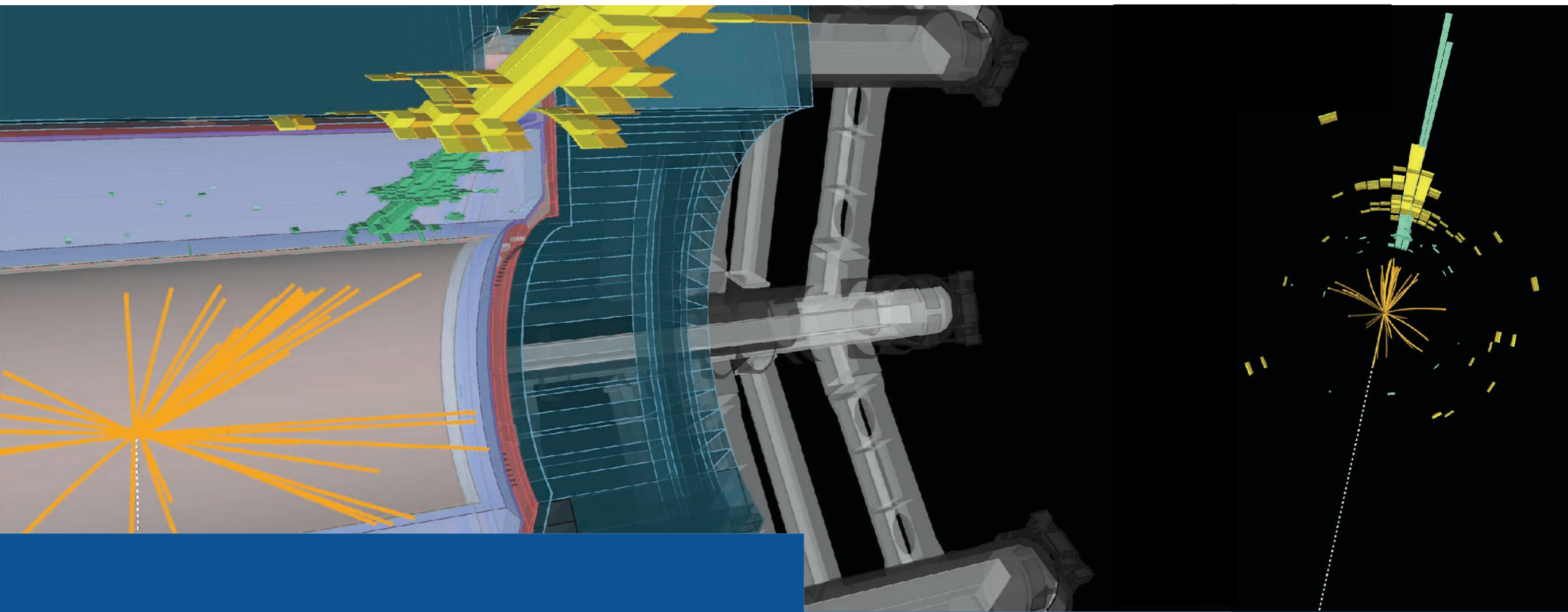
ACTIVITIES FOR STUDENTS (II)

Hardware

- learn about **electronics and modern devices**
- learn about **building a small experiment** (usually this is what you do at the beginning for any big experiment)
- have **everything under control**
- **work in teams**, often locally

Future experiments and simulations

- **designing future experiments and accelerators via simulations**
- learn what are the **critical aspects** of an experiment
- **influence next gen experiments**



ATLAS - Roma1 activities

<http://www.roma1.infn.it/exp/atlas/it/home-it/>



ATLAS: HIGGS PHYSICS

One of the main LHC goals is to measure the Higgs properties with increasing precision

Roma has been studying Higgs mass and couplings to **b, t, W, μ , Z**

Ongoing activities:

H \rightarrow WW*

- full Run-1+Run-2 analysis

Higgs-top Yukawa coupling (y_t)

- $t\bar{t}H$: precise measurement of $|y_t|$
- tH : direct probe of the sign of y_t (via tH/WWH interf.)

Search for double-Higgs production HH

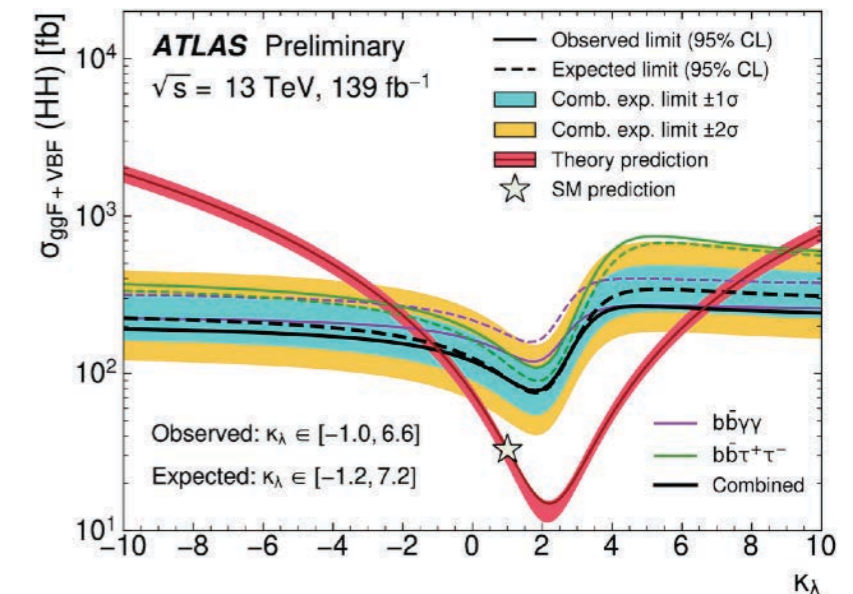
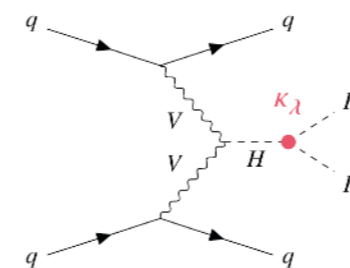
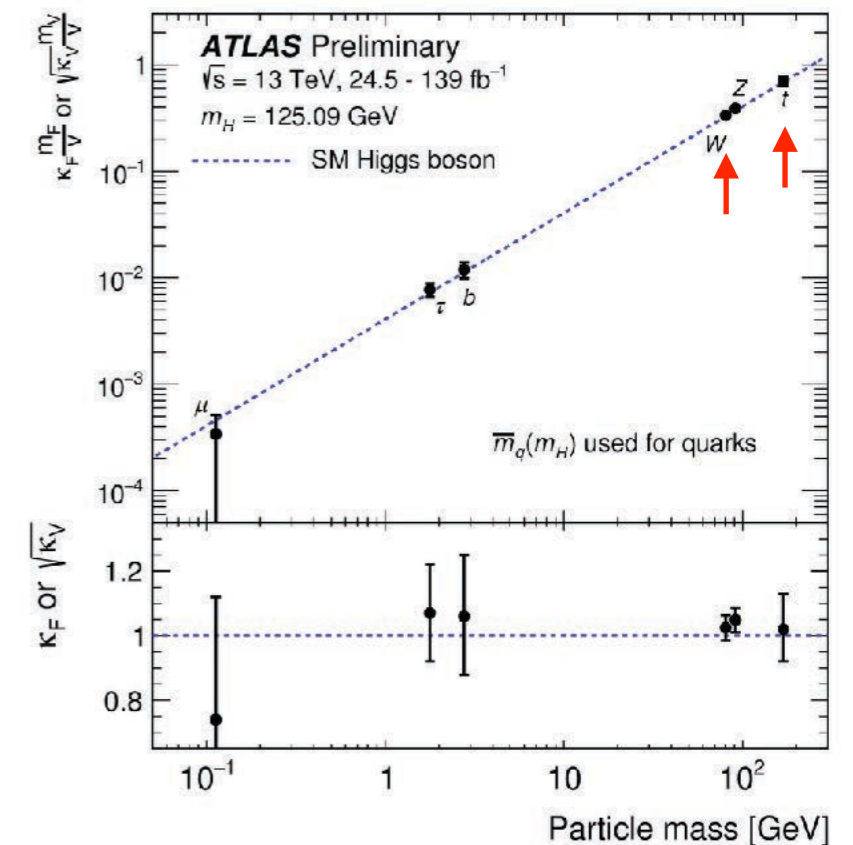
- limits on anomalous Higgs self interaction

Higgs mass

- Final Run-2 mass measurement

Contacts:

C. Bini, S. Rosati, N. Bruscano, A. Betti, G. Artoni



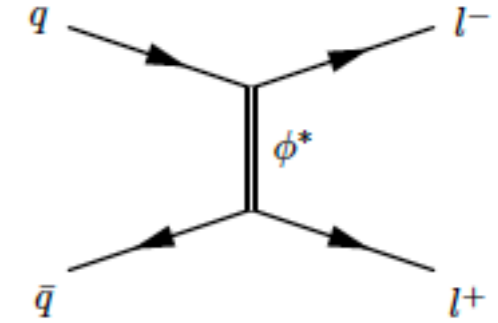
ATLAS: SEARCHING FOR NEW PHYSICS

Indirect searches:

Precise measurement of di-tau cross sections

BSM physics may show up as small deviations from SM in processes involving 3rd generation fermions (example 3rd generation lepto-quark).

measurements of $\tau+\tau^-$ pair cross sections with full Run-2 data both high-mass and at Z peak
AI techniques for reconstruction of hadronic tau decays



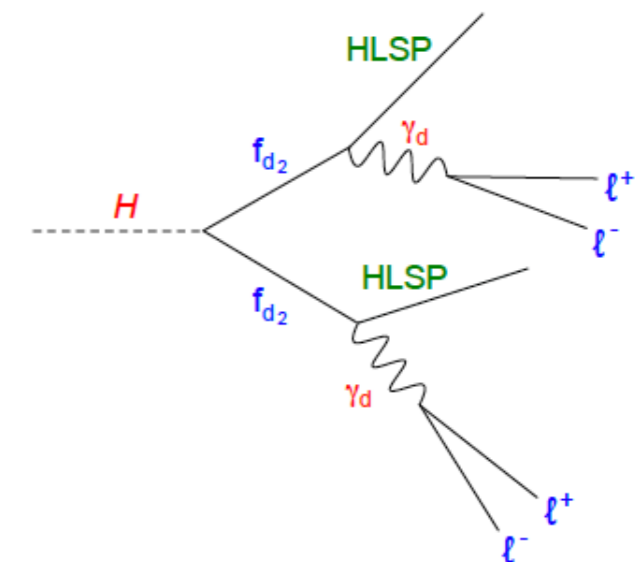
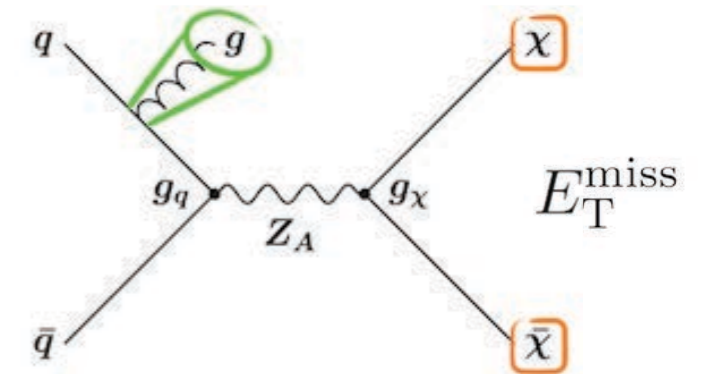
Direct searches:

Mono-jets

Looking for invisible particles (e.g. Dark Matter) through missing E_T

Long-Lived Particles

Looking for displaced decay vertices produced by new long-lived particles (e.g. Dark Photons): unconventional signatures



Contacts: S. Giagu, M. Bause, V. Ippolito

ATLAS: UPGRADE FOR RUN-3

ATLAS is being gradually upgraded to cope with the higher collision rates provided by LHC and to improve performance.

New Small Wheels

Replacement of innermost muon detector layer in the end-caps, to cope with higher luminosity and backgrounds

First large area Micro-Megas detectors in a HEP experiment

Just installed, integration within ATLAS ongoing, looking forward to take first collision data this summer !

Roma has been involved in Micro-Megas construction,

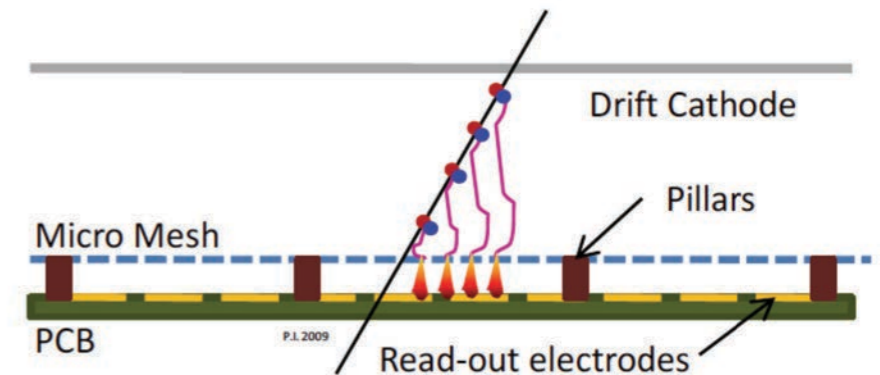
Ongoing activities:

- system commissioning
- data acquisition
- muon reconstruction

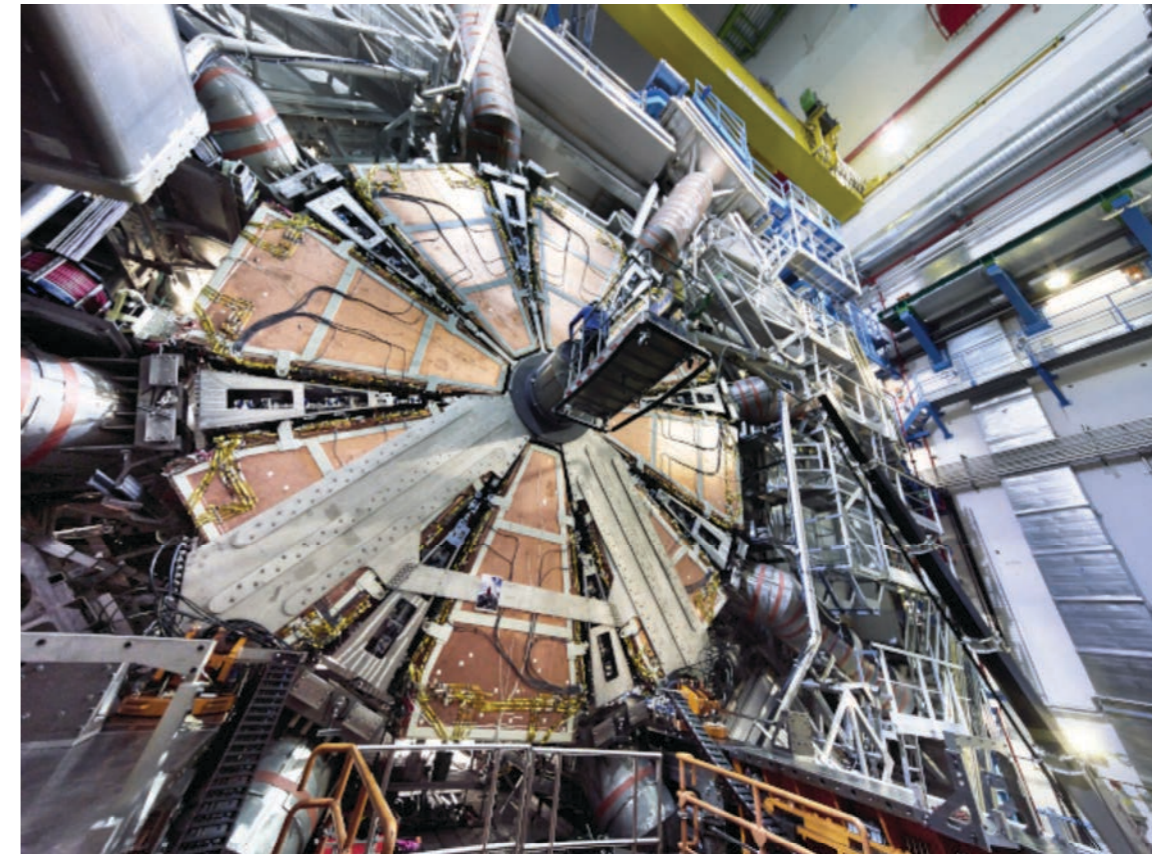
Contacts:

P. Bagnaia, C. Bini, F. Lacava, S. Rosati, E. Pasqualucci

MicroMegas detector



Small wheel being installed in ATLAS



ATLAS: MUON TRIGGER UPGRADE

A major Trigger and DAQ system upgrade is in preparation for the high-luminosity phase of LHC

Level-0 Barrel Muon Trigger

Roma is responsible for the full upgrade of the muon trigger system in the "barrel" region

New on-detector electronics will collect data from RPC detectors and send it to powerful FPGA-based boards that will run advanced trigger algorithms and provide muon candidates within few hundreds of ns.

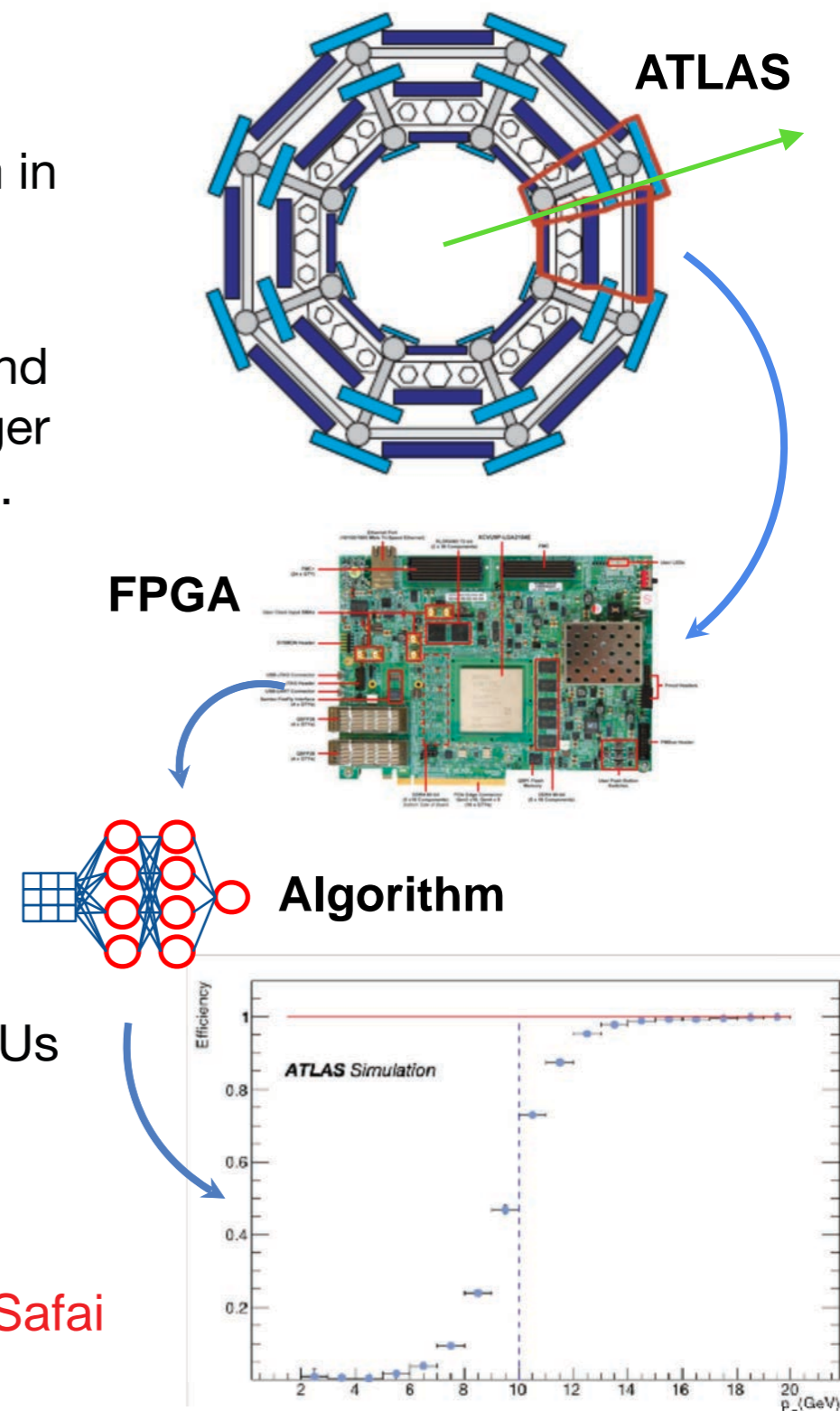
Current activities:

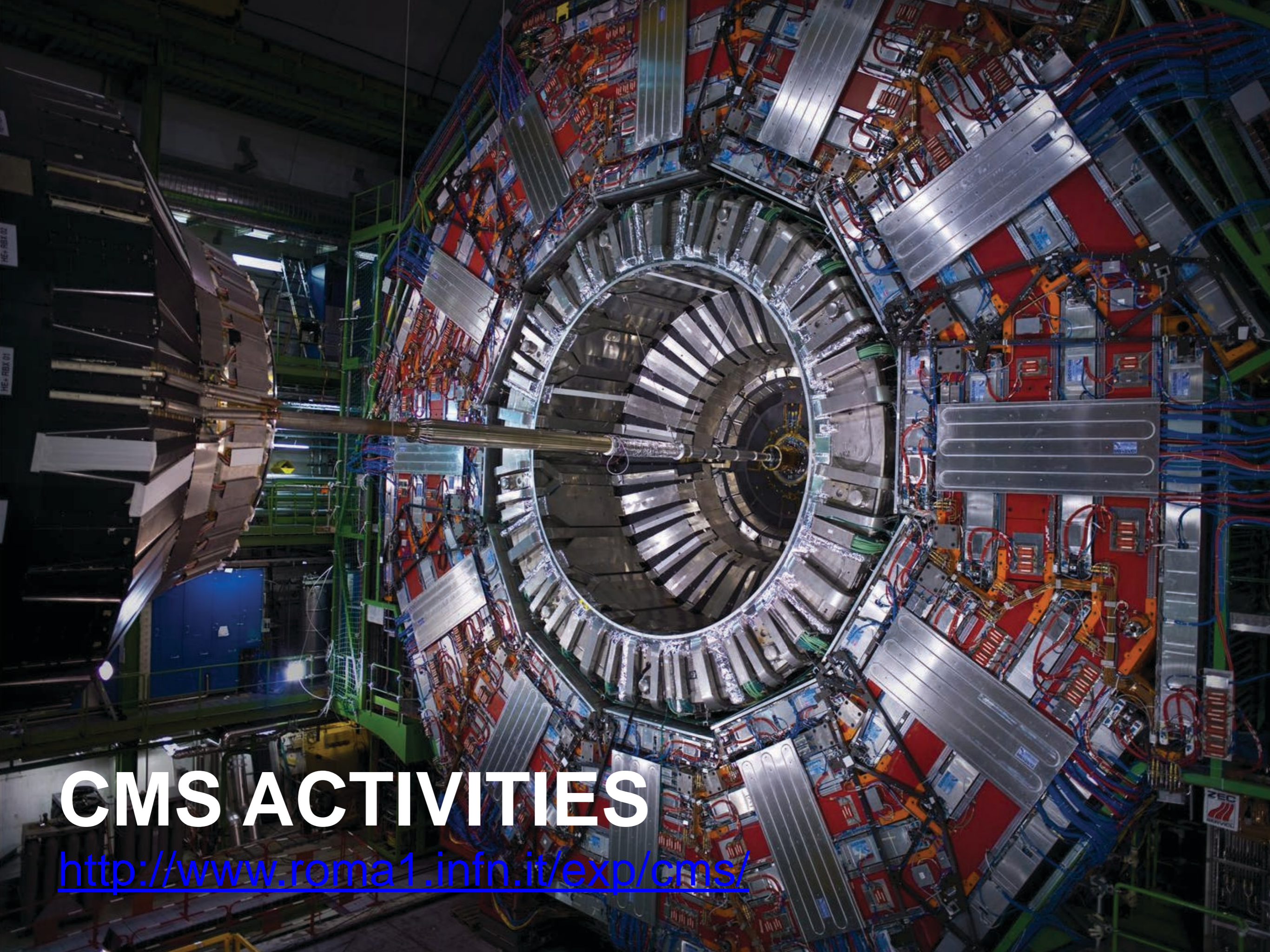
- System design and simulation
- hardware and firmware design
- test of prototypes

A.I. techniques on hardware accelerators

- Exploit new techniques for fast tracking exploiting FPGAs and GPUs
- Applications both for **Level-0** and **higher-level triggers**

Contacts: R. Vari, M. Corradi, S. Giaqu, S. Veneziano, S. Rosati, F. Safai





CMS ACTIVITIES

<http://www.roma1.infn.it/exp/cms/>

CMS ROME GROUP

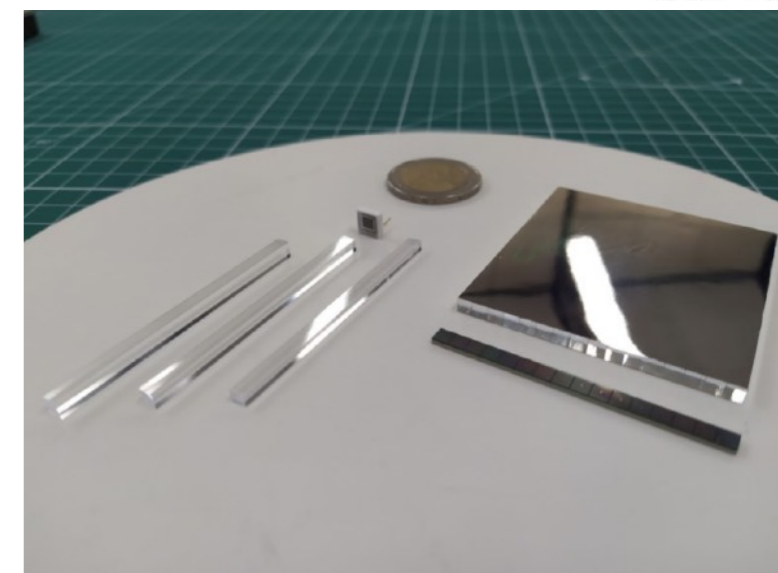
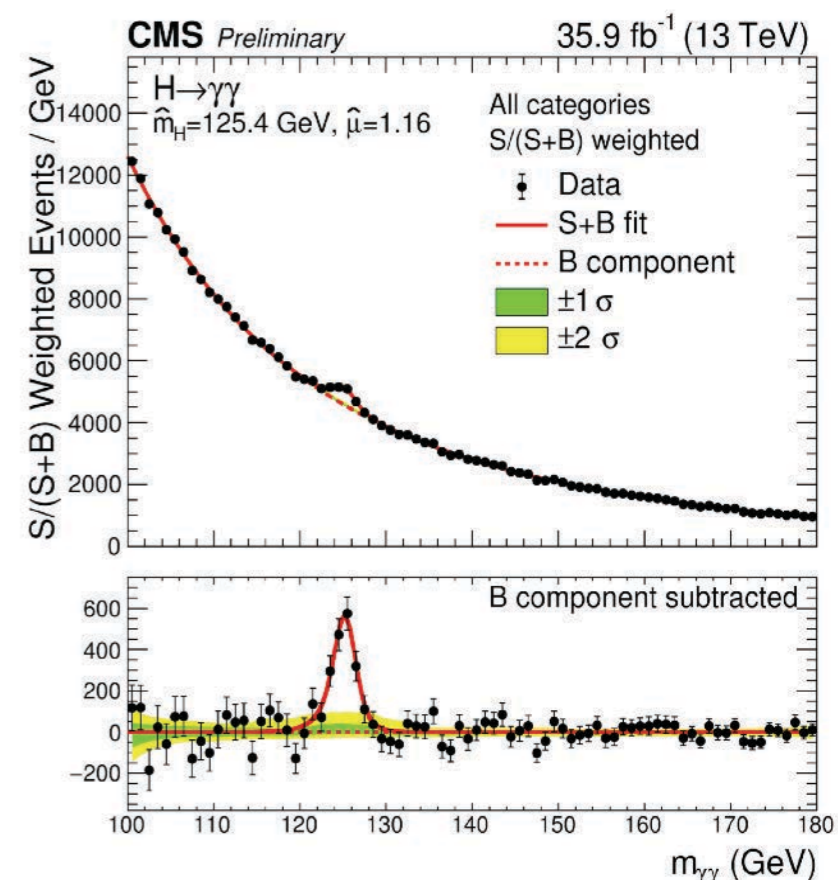
- Composizione: 6 staff Sapienza, 7 staff INFN, 3 post-doc, 2 PhD students, 2 master students (**50% F, 50% M**)

- **Attività di analisi:**

- Studio delle proprietà del **bosone di Higgs**
- Ricerca di **nuova fisica** attraverso lo studio del decadimento dei mesoni B.
- Ricerca di nuove **particelle a lunga vita media**.
- Tecniche di **Machine Learning** per ricostruzione, identificazione e selezione di eventi.

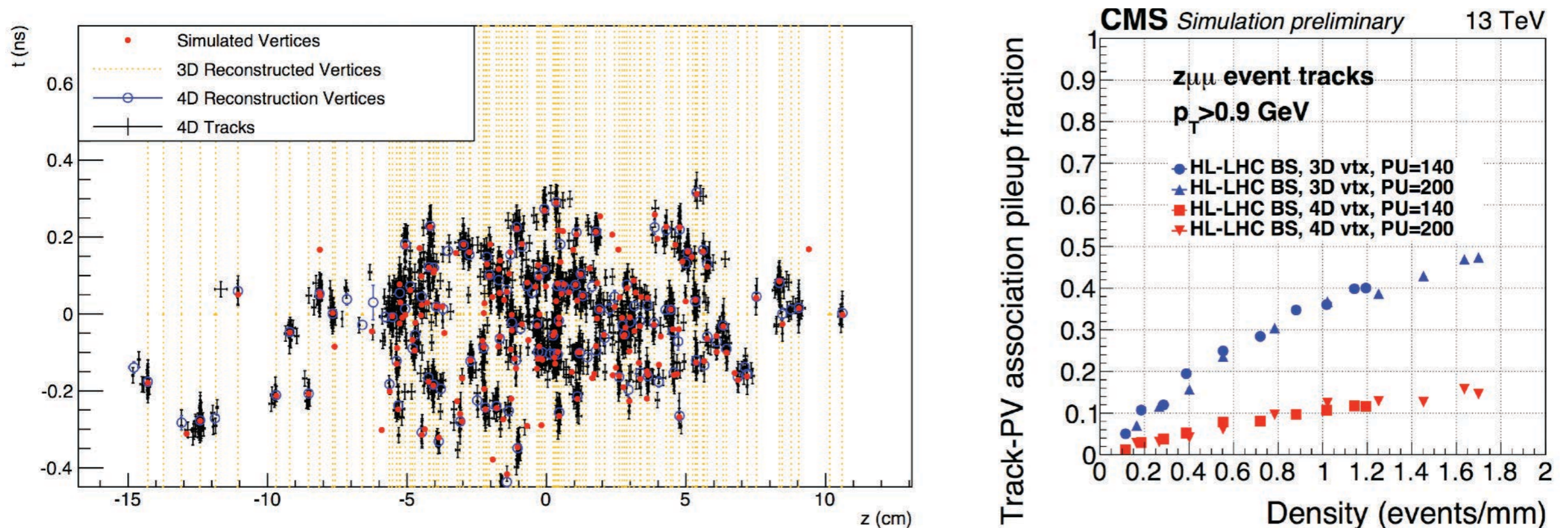
- **Attività di detector:**

- Upgrade del **calorimetro elettromagnetico**
- Costruzione del nuovo **timing detector** di CMS per High Luminosity LHC.



HIGH PRECISION TIMING DETECTOR

- Nella **fase 2 di LHC (HL-LHC)** ad alta luminosità ci saranno **150-200 interazioni concomitanti** per collisione
 - condizioni estreme: fondo da rimuovere per studiare collisioni hard
- **Nuovo rivelatore per misurare il tempo delle tracce**
 - posto tra il tracciatore e il calorimetro em
- **Rivelatore in fase di sviluppo e progettazione**
 - studi di **simulazione e impatto sulla fisica**

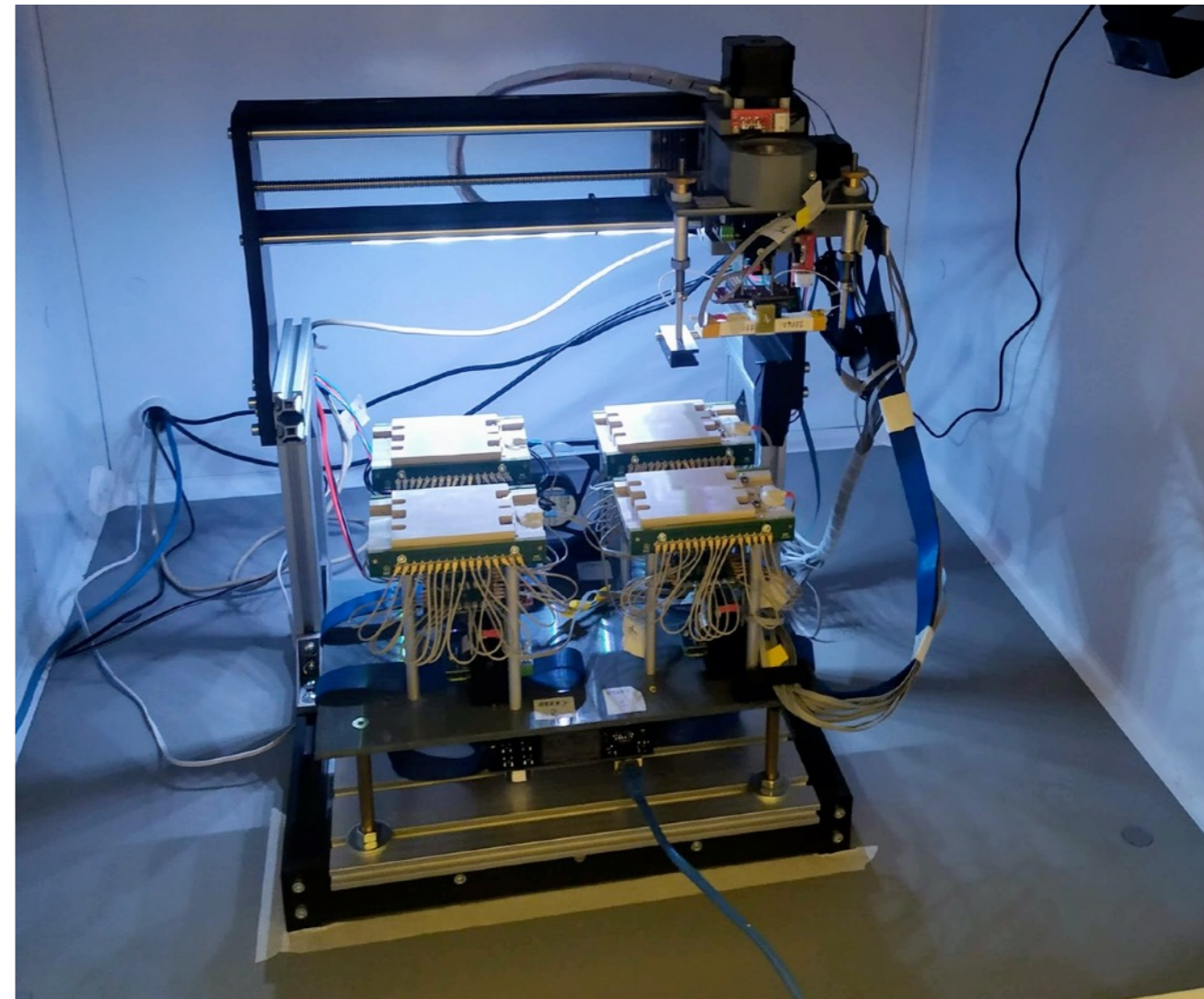


CHARACTERIZATION OF LYSO CRYSTALS

- **Characterization of LYSO crystal arrays for the new CMS Timing Detector**

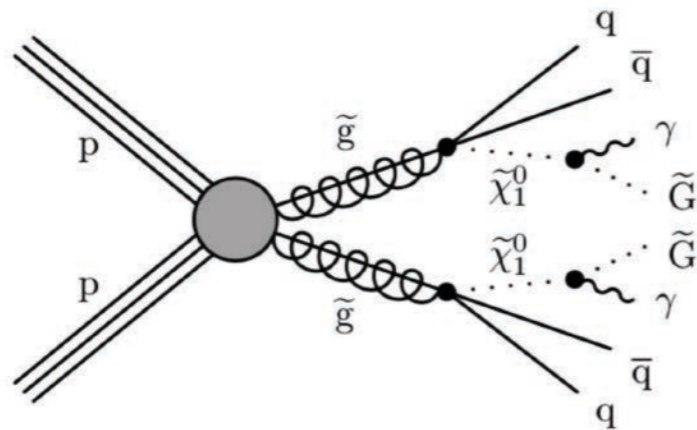
- Crystal dimensions, planarity and density
- Light Output, Decay Time and Time resolution
- Optical cross talk
- Radiation resistance with photons and neutrons in Casaccia - ENEA

**You're welcome to visit
CMS lab where this
activity takes place
(Marconi building
third floor – room n. 340)**

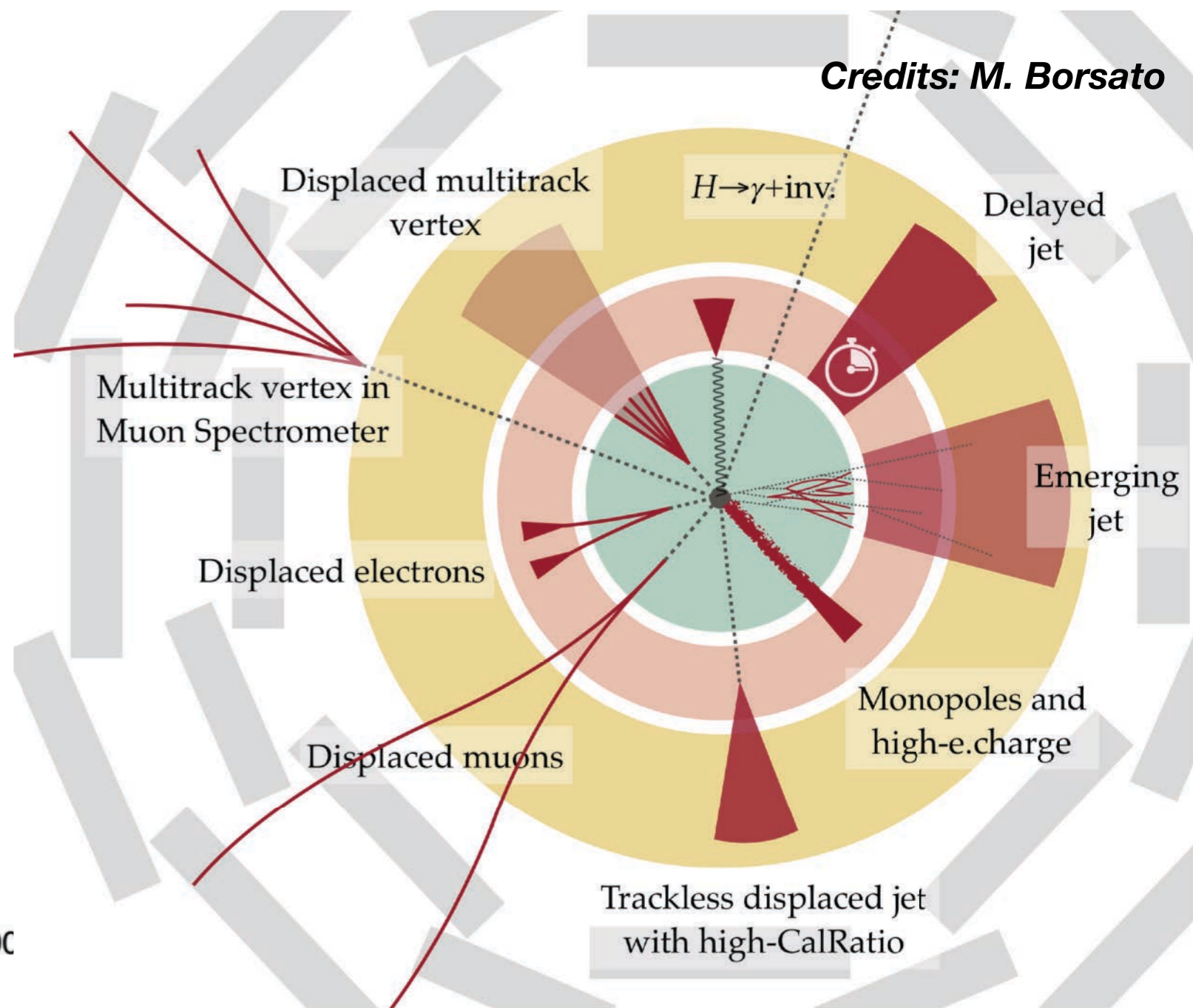
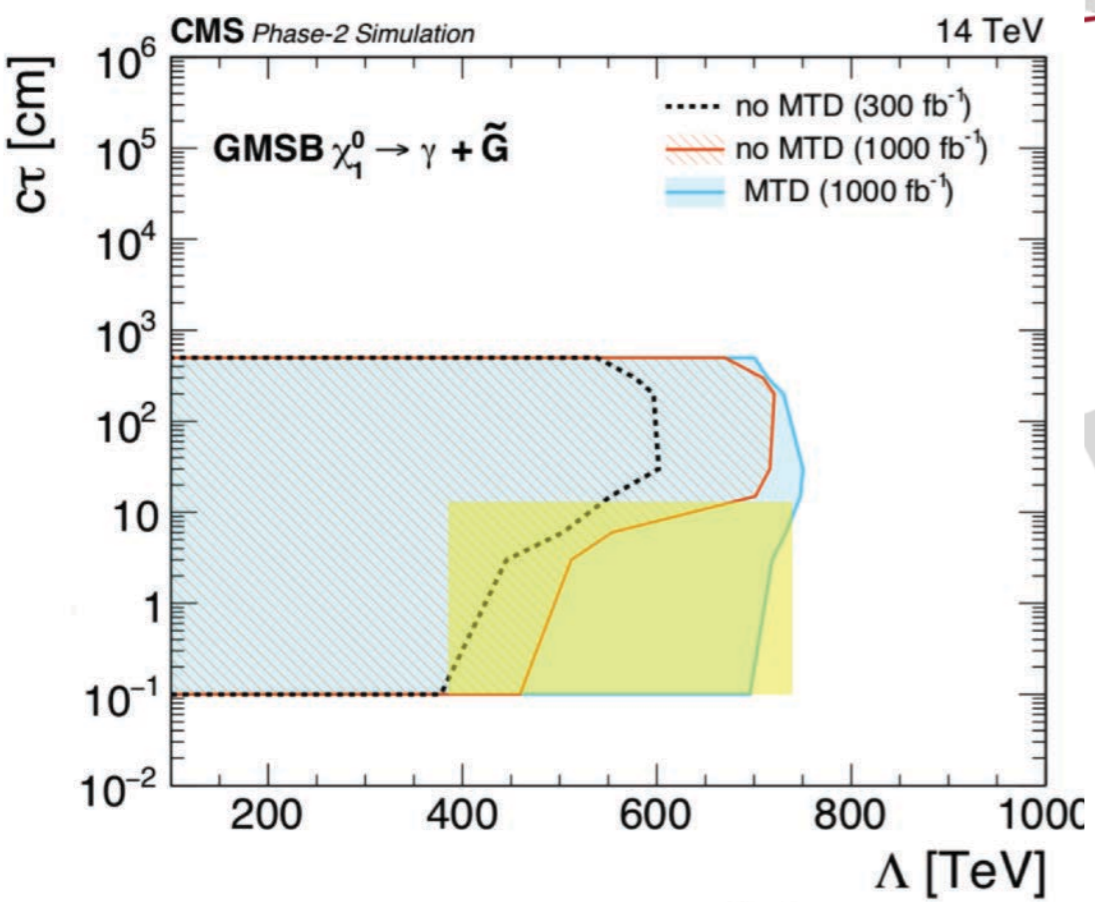


SEARCH FOR NEW PHYSICS WITH MTD

Long-lived (LL) and unconventional exotic particles with striking signatures predicted by many extensions of the SM.



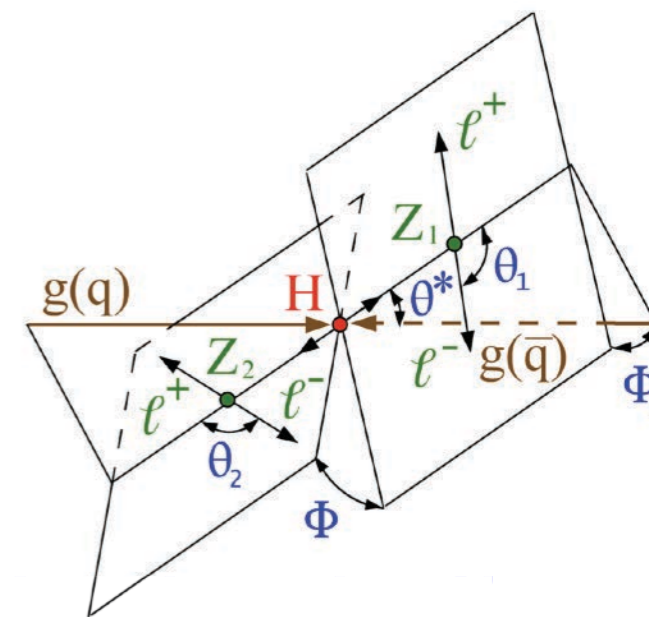
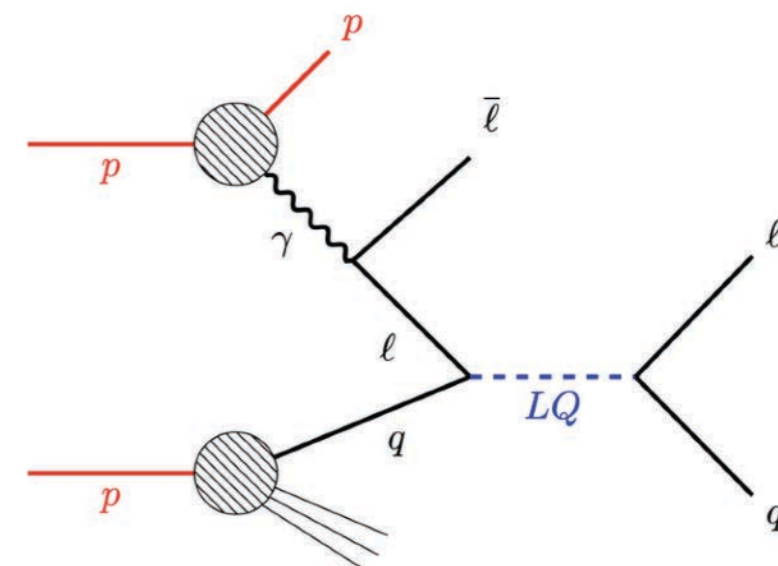
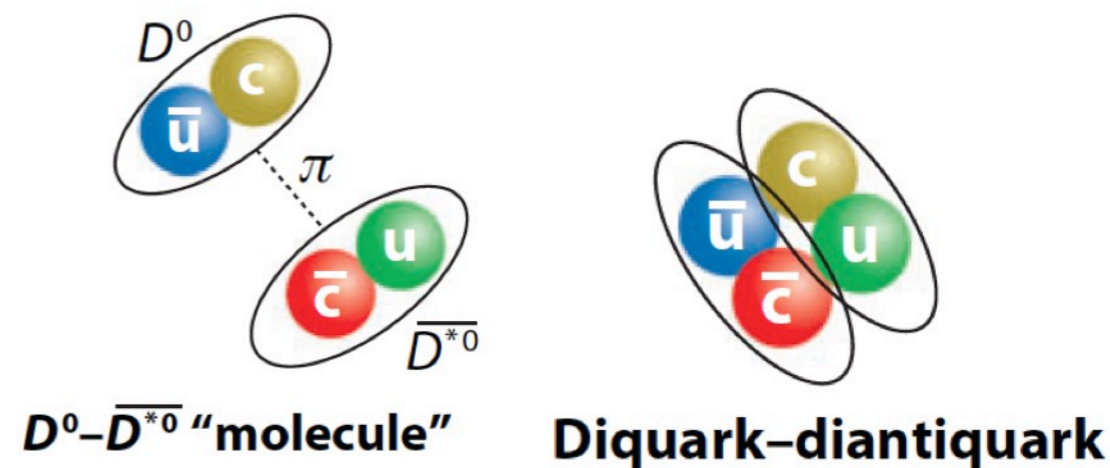
Credits: M. Borsato

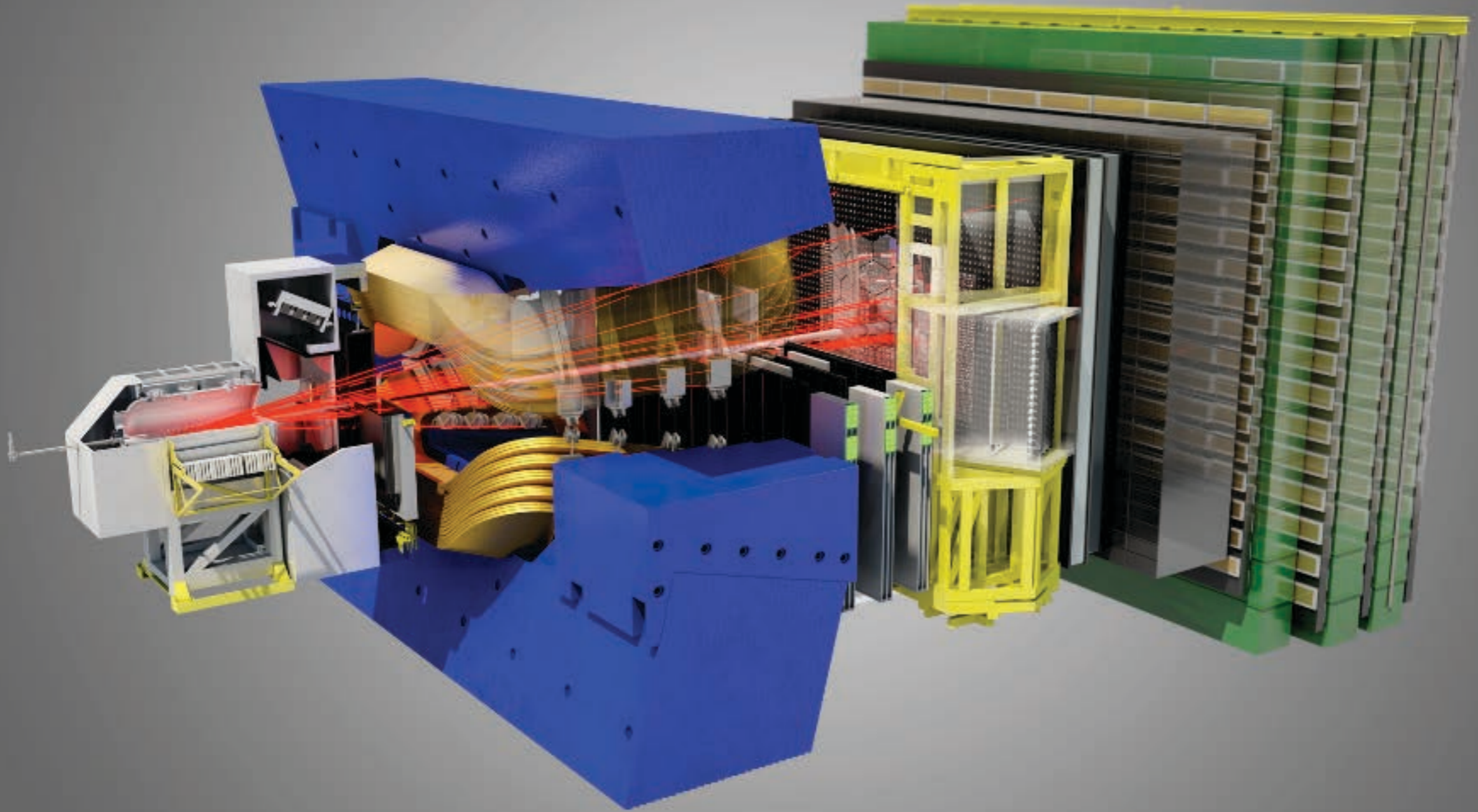


TESI DISPONIBILI

- **Search for tetraquarks at CMS**
- **Study of B Mesons Decays with the CMS detector, as Indirect Probe for Physics Beyond the Standard Model**
- **LHC as a lepton-quark collider: a novel search for leptoquarks at the CMS experiment**
- **Machine Learning for Event Reconstruction at HL-LHC with the CMS MIP Timing Detector**
- **Search for New Long-Lived Particles with the Future CMS Mip Timing Detector**
- **Study of Time Resolution and Characterization of LYSO:Ce Scintillator Crystals for the New CMS Mip Timing Detector**
- **Anomalous Higgs Couplings with CMS Data**

(maggiori dettagli e contatti in <https://www.roma1.infn.it/ProposteTesi.html>)

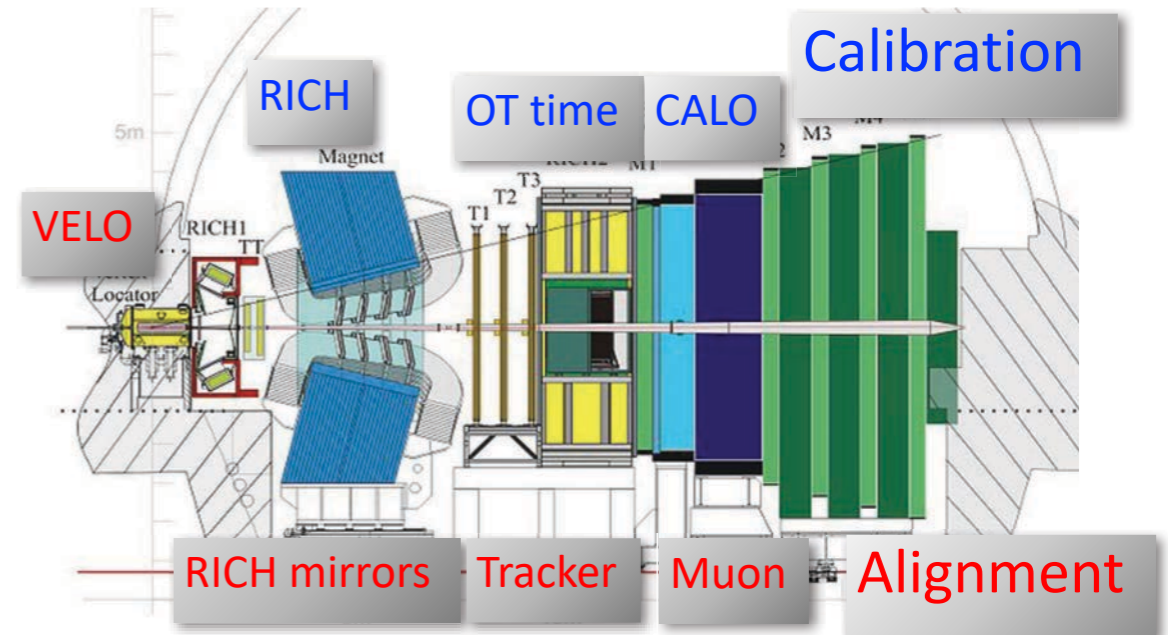




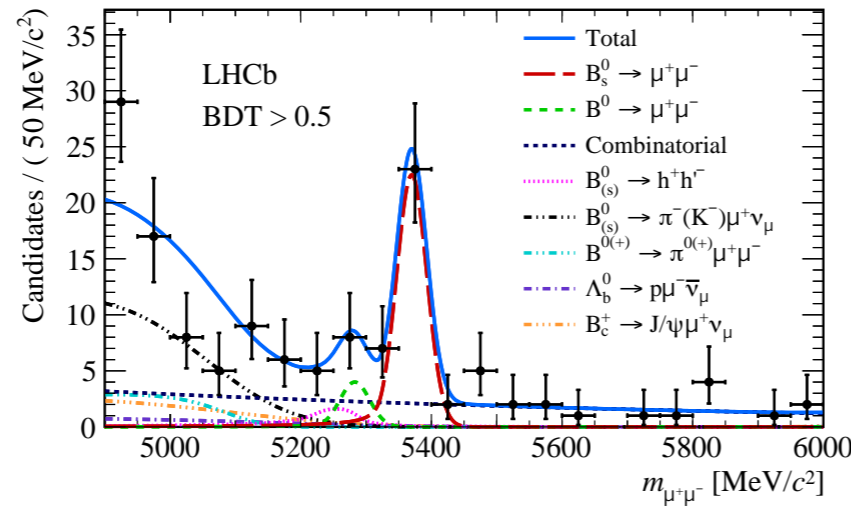
LHCb ACTIVITIES

BEAUTY AND CHARM PHYSICS AND MUCH MORE

- Tests of Lepton Flavour Universality
tension in several channels
- Rare decays, window for New Physics



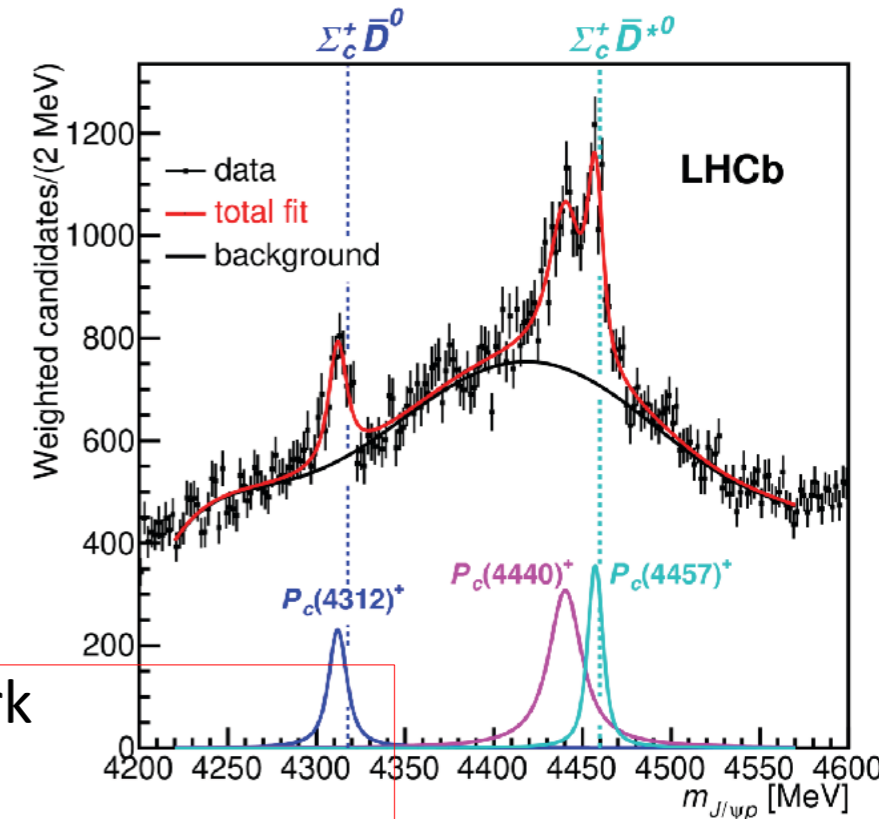
B_s to $\mu\mu$
(BF $\sim 10^{-9}$)
 $\sim 8\sigma$ obs. of a
single
experiment!



PRL 118 (2017) 191801

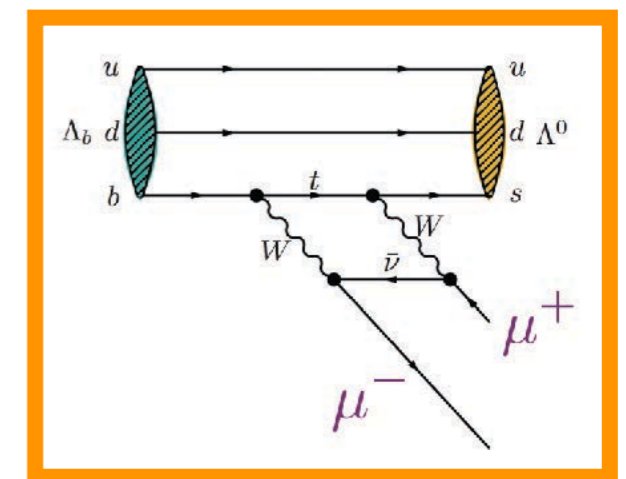
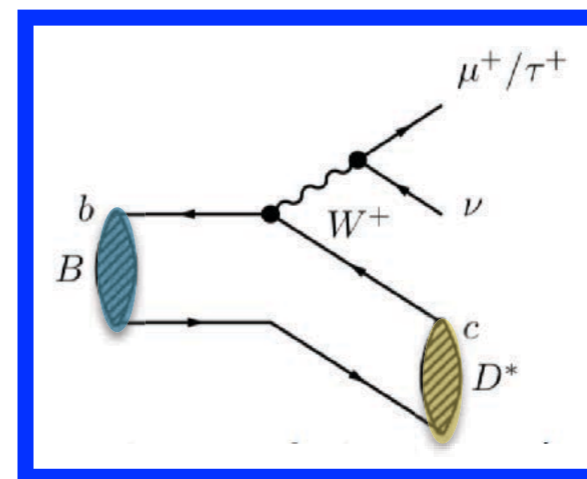
- Parameters of CKM matrix
- Lifetimes
- Spectroscopy, observation of new hadron states
not simply qqq or qq states- **tetra or pentaquark**
-

Recently New Pentaquark
states in J/ψ p final state



LHCB – UPGRADE OF THE DETECTOR

- **Aim: run at factor 5 higher luminosity $L=2 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$**
 - Increase sensitivity to rare decays, CP and Flavor Violation, precision measurements
 - Subdetectors replaced or modified: lot of HW-related work
- Already collected a huge amount of data, ready to be scrutinised to look for NP performing high precision measurements!
- Rome group involved in **muon detector related activities and analyses:**
 - Look for anomalies (deviations from SM) in **tree** and **loop** decays:
 - **Semi-leptonic decays**
 - **Λ_b decays**
 - Upgrade of muon detector



LHCB: THESIS ON DATA ANALYSIS

Area of interest of the group are **rare leptonic and semileptonic decays**

- Exploiting the know-how gained in the study of $B_s \rightarrow \mu\mu$ decays (still being analysed and close to be published again) the group now is targeting the study of $\Lambda_b \rightarrow \Lambda e^+e^-$, $\Lambda_b \rightarrow \Lambda\mu^+\mu^-$ decays (anomalies in the loop transitions) and $B_s \rightarrow D_s^*TV$, $B_s \rightarrow D_s^*\mu\nu$ decays (tree decays anomalies)..
- There is the opportunity to contribute to a lot of key analysis aspects: signal selection, efficiency studies, trigger studies, background characterisation, fit ..

Proposed Thesis subject:

Study of the ratio of Lambda and Bs to Ds decays to provide complementary information to the R_K and R_{K^*} anomalies that recently triggered a lot of interest!!

Analysis already started and in good shape, opportunity to join the efforts with the LNF and CERN teams

Contacts: Davide.Pinci@roma1.infn.it, stanza 228-c, Edificio G.Marconi

Contact Roberta.Santacesaria@roma1.infn.it, stanza 317, Ed. G. Marconi

LHCB: THESIS ON DATA ANALYSIS

Area of interest of the group are **charmonium exotic states**

- First observation of X(3872) state at e^+e^- machines by BaBar and Belle in the early 2000's Many other states have been observed at the Tevatron and LHC
- not possible to interpret as states with 2 or 3 quarks as normal hadrons
- Different models in literature, but the nature of these states not yet determined in a unequivocal manner
- Analysis published by the group on $Z(4430) \rightarrow \pi \psi(2s)$, tetraquark Phys. Rev. D 92, 112009 (2015)

Proposed Thesis subject:

Study of the $J/\psi \omega$ mass spectrum in the $B^+ \rightarrow K^+ J/\psi \omega$ decay, observation of the decays $X(3872) \rightarrow J/\psi \omega$ and $X(3915) \rightarrow J/\psi \omega$ with $\omega \rightarrow \pi^+ \pi^- \pi^0$

Analysis already started and in good shape, to be done efficiency determination, study of systematics

Contact Roberta.Santacesaria@roma1.infn.it , stanza 317, Ed. G. Marconi

LHCb: THESIS ON INSTRUMENTATION

Area of interest is the **Luminosity Measurement for the LHCb experiment**

- The Control System of Front-End electronics (hardware and software) was developed and realized by the Roma1 group
- Muon System is able to provide a very precise (‰) evaluation of LHCb Luminosity, crucial for Physics studies
- Data analysis and tests at CERN



Article

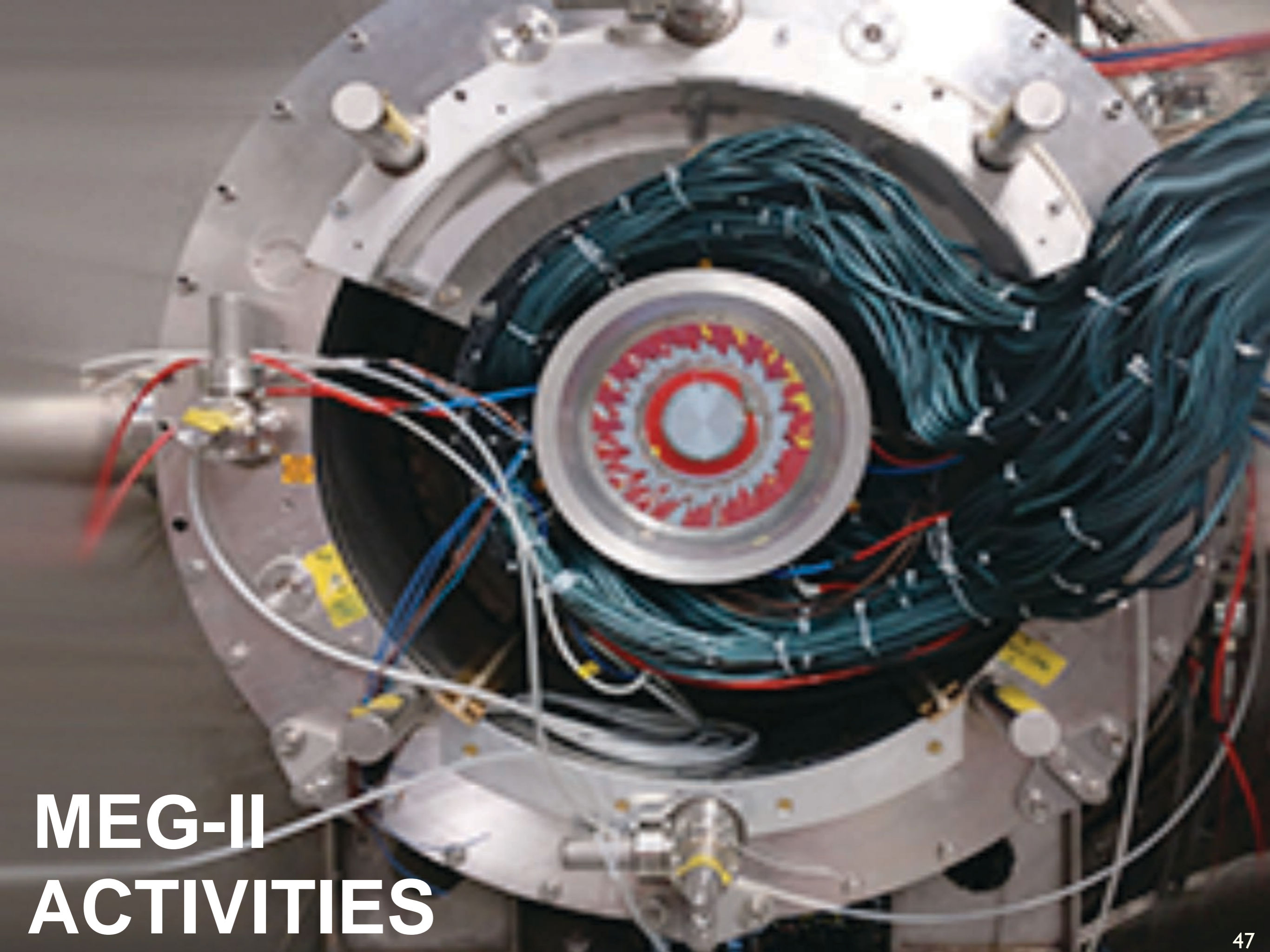
A Method Based on Muon System to Monitor LHCb Luminosity

Pietro Albicocco¹, Wander Baldini², Samuel Belin³, Valerio Bocci⁴, Nikolay Bondar⁵, Davide Brundu⁶, Sandro Cadeddu⁶, Alessandro Cardini⁶, Maurizio Carletti¹, Giacomo Chiodi⁴, Alexsei Chubykin⁵, Vladimir Chulikov⁵, Paolo Ciambrone¹, Liliana Congedo⁷, Andrea Contu⁶, Francesco Debernardis⁷, Marco Antonio Desideri⁴, Marilisa De Serio⁷, Patrizia De Simone¹, Daniele Di Bari¹, Maurizio Gatta¹, Dmitrii Ilin⁵, Anatoly Kashchuk⁵, Sofia Kotriakhova², Adriano Lai⁶, Roman Litvinov⁶, Angelo Loi⁶, Oleg Maev⁵, Giuseppe Martellotti⁴, Matteo Palutan¹, Alessandra Pastore⁷, Davide Pinci⁴, Biagio Saitta⁶, Roberta Santacesaria⁴, Marco Santimaria¹, Emanuele Santovetti⁸, Alessandro Saputi¹, Celestina Satriano^{4,9,*}, Alessia Satta⁸, Barbara Sciascia^{1,10}, Saverio Simone⁷ and Stefania Vecchi²

Proposed Thesis subject:

Proposal for a novel LHCb Luminosity Meter based on the muon detector for the experiment upgrade

*Contacts: Davide.Pinci@roma1.infn.it, stanza 228-c, Edificio G.Marconi
Roberta.Santacesaria@roma1.infn.it, stanza 317, Ed. G. Marconi*

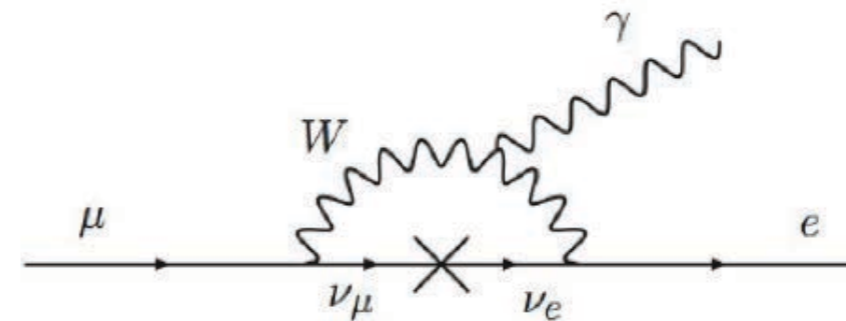


MEG-II ACTIVITIES

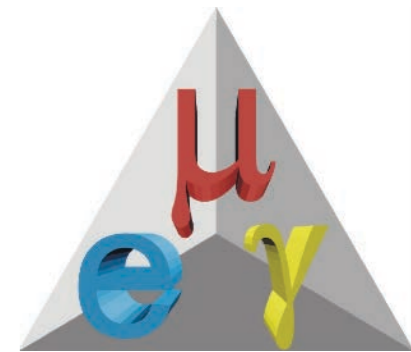
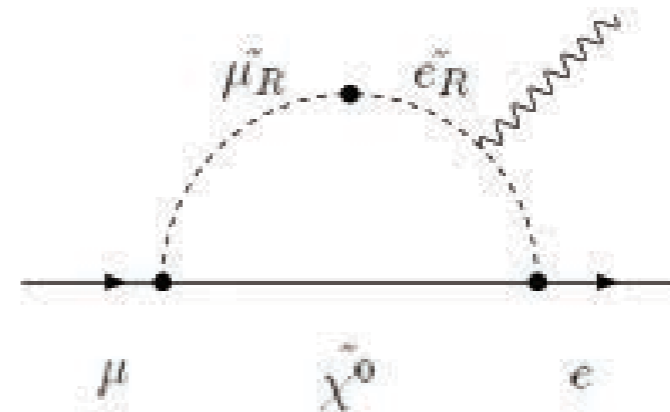
NEW PHYSICS SEARCHES WITH MUONS: MEGII

Search of New Physics at the intensity frontier in the charged lepton flavor violating decay $\mu \rightarrow e\gamma$

Standard Model: practically forbidden

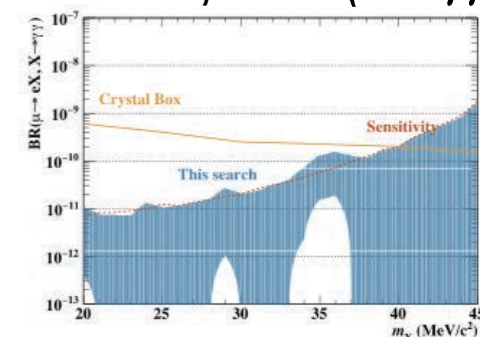


Allowed in most New Physics models: e.g. SUSY



- **Complementary** to New Physics search at the energy frontier (LHC)
- Sensitivity to New Physics at very **high mass scale**
- **Not only $\mu \rightarrow e\gamma$: Search for new particles (X17, axions..)**

Search for $\mu \rightarrow eX(X \rightarrow \gamma\gamma)$



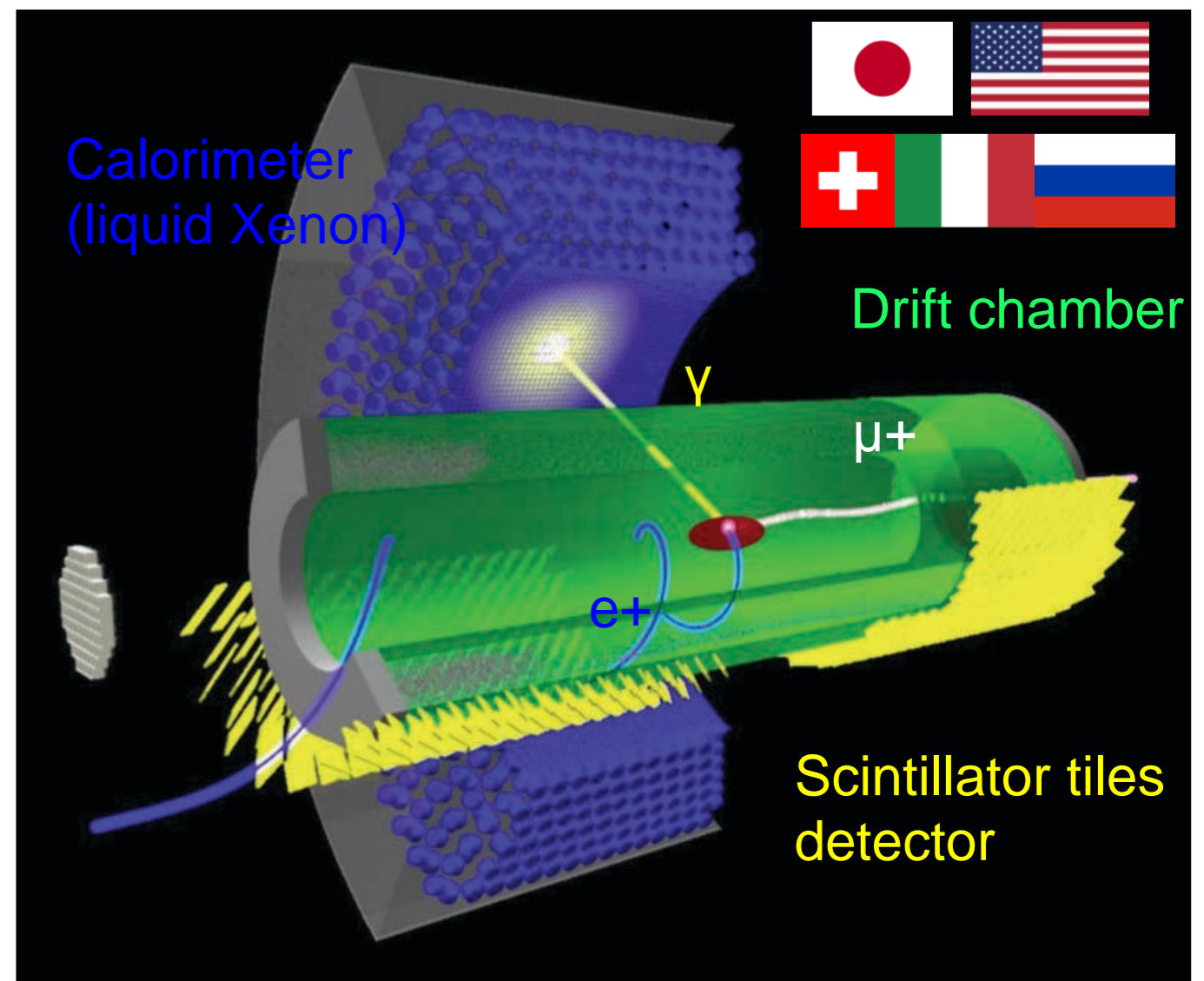
THE MEGII EXPERIMENT

Present best world limit:

$BR(\mu \rightarrow e\gamma) < 4.2 \times 10^{-13}$ at 90% C.L. *EPJC 76(8),434(2016)*

- **MEGII goal**: improve the sensitivity by **1 order of magnitude** in 3 years of data-taking
- MEGII detector fully commissioned
- **First Physics Run starts 1st July 2022**

*Paul Scherrer Institute (Villigen, Zurich):
most intense continuous muon beam in
the world*



MEGII ROME GROUP ACTIVITIES

MEGII@Roma:

<https://www.roma1.infn.it/exp/meg/tesi.htm>
cecilia.voena@roma1.infn.it

G. Cavoto
K. Guven
F. Renga
V. Pettinacci
C. Voena

- Drift chamber operations and commissioning (gas system, HV system)
- Drift chamber calibration and reconstruction
- Positron tracking and analysis
- Target position measurement system
- $\mu \rightarrow e\gamma$ physics analysis
- Search for new particles– X17

Available theses (hardware and analysis)

- 1) Drift chamber analysis
- 2) Search for the new X17 particle
- 3) Positron tracking with Neural Networks
- 4) Feasibility studies for axion searches

MEGII PROPOSED THESES

1) Drift chamber analysis:

Characterization of the DCH gas mixture, calibrations.

2) Search for new X17 particle

Data analysis of first data taken in 2022. Hardware theses on the preparation of the next X17 run (2023).

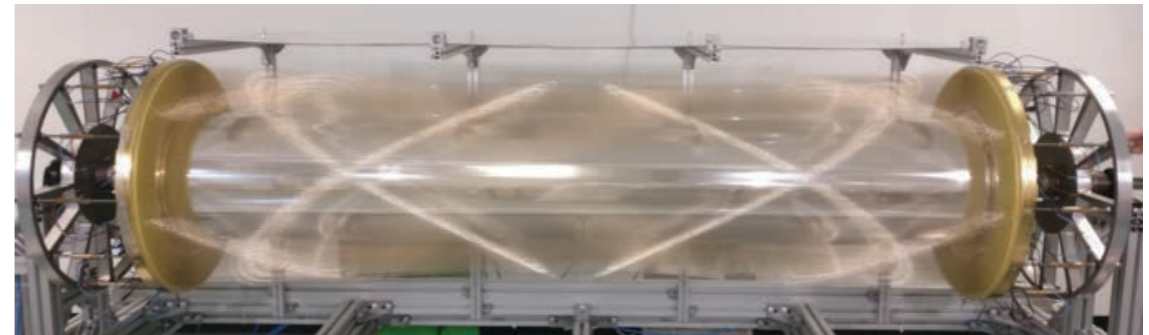
3) Positron tracking with Neural Networks

Development of a track finder based on NN optimized for the high pile-up MEGII environment.

4) Feasibility studies for axion searches

Monte Carlo based feasibility study for the search of $\mu \rightarrow e a \gamma$

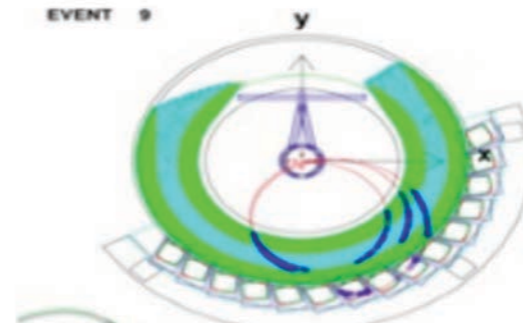
The MEG II drift chamber



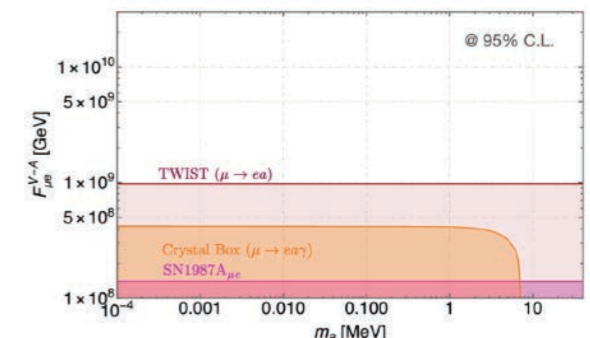
${}^7\text{Li}(p, X(e+e-))$ reaction



A positron track in the DCH

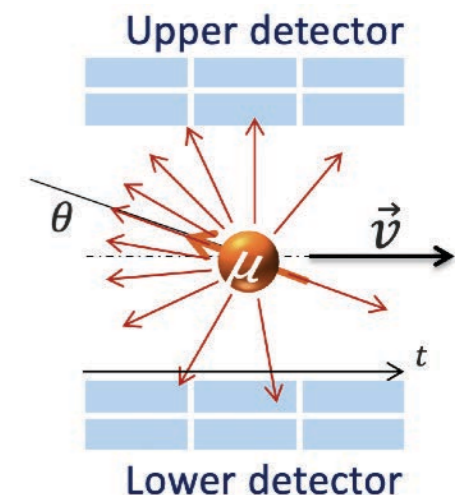
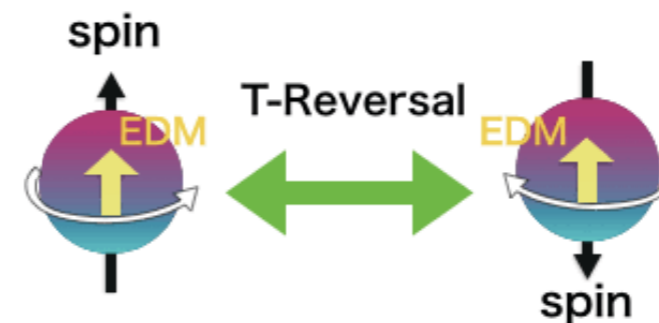
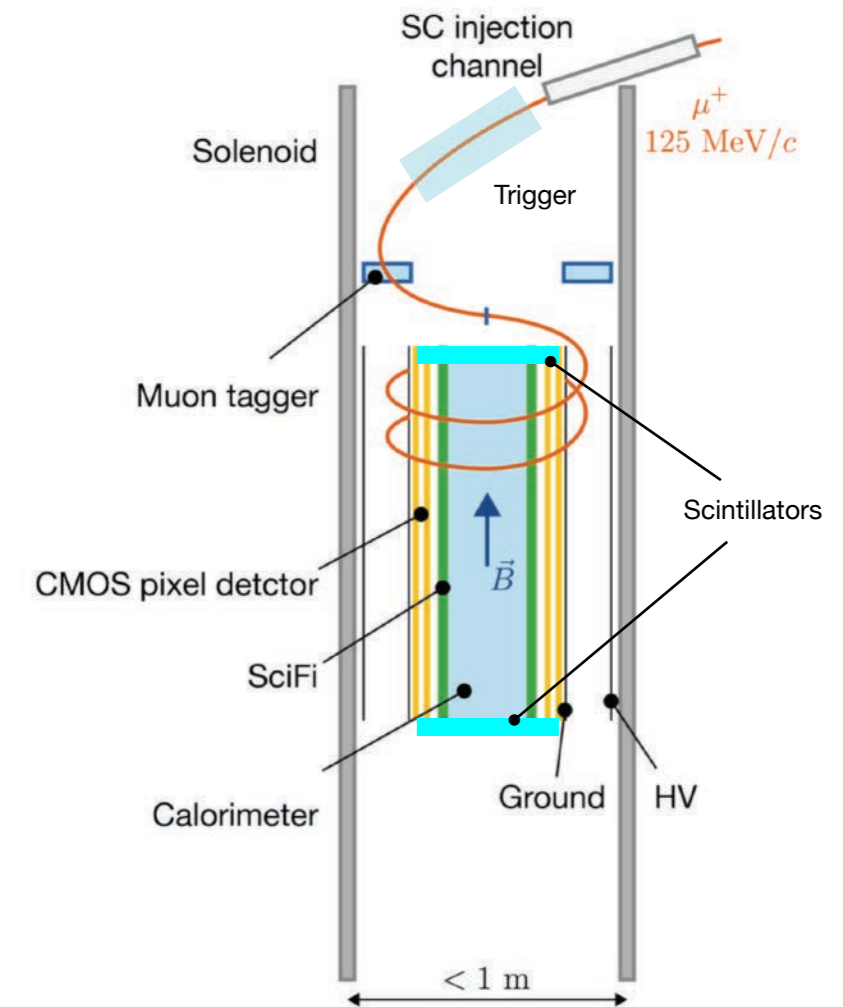


Status of left-handed LFV ALP



NEW PHYSICS SEARCHES WITH MUONS: MUONEDM

- The matter-antimatter asymmetry of the Universe requires new sources of CP Violation (CPV)
- A search for an **Electric Dipole Moment of the muon**
 - practically zero in the SM
 - sensitive to new sources of T Violation (and hence CPV from CPT theorem)
- Look for a **tiny precession of the spin of muons** orbiting in orthogonal magnetic and electric fields



Goal: improve the current limits by 3 orders of magnitude

MUONEDM PROPOSED THESES

Construction and test of a muon tagger prototype for the muonEDM experiment

A critical aspect of the muonEDM experiment is the capability of capturing a sufficiently high rate of muons inside the magnet. For this reason, the characterization of the muon beam will be a key task during the commissioning of the experiment. It will require tracking muons after the injection in the solenoid and, due to their relatively low momentum (25 or 125 MeV/c), an extremely light detector has to be developed. A prototype for a gaseous Time Projection Chamber (TPC) with a high granularity readout will be built and tested in Rome using radioactive sources and laser beams, and then moved to PSI for tests with some of the most intense muon beams in the world.

Optimisation of the muon injection for the muonEDM experiment

Capturing a high statistics of muons in a stable orbit inside the muonEDM magnet, while keeping a trigger rate low enough to avoid dead time, requires an optimisation of the muon beam line, and the design of collimators to select only muons within acceptance. Simulations of the muon injection will be performed, in collaboration with CERN and PSI groups, to explore innovative technologies and select the best suited option for this experiment.



KLOE2

ACTIVITIES

KLOE2

- **KLOE-2 @ DAΦNE (LNF):**
 $e^+e^- \rightarrow \phi(1020)$ @ $\sqrt{s} = M_\phi^2$
- **Data taking ended in March 2018**
 $\Rightarrow 5.5 \text{ fb}^{-1}$ collected

KLOE + KLOE-2 data sample:

- $\sim 8 \text{ fb}^{-1} \Rightarrow 2.4 \times 10^{10} \phi$'s produced
- \Rightarrow the largest sample ever collected at a ϕ -factory

$\phi \rightarrow K_S K_L$: Production of entangled kaon states

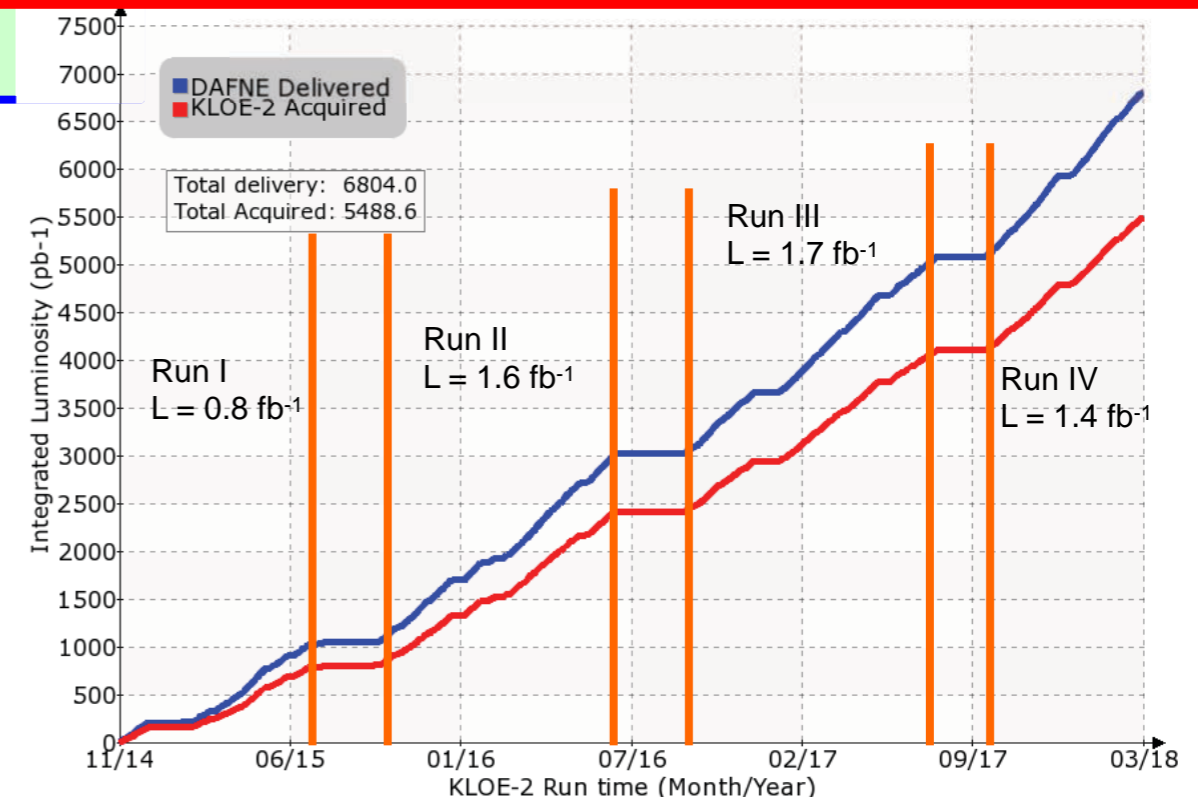
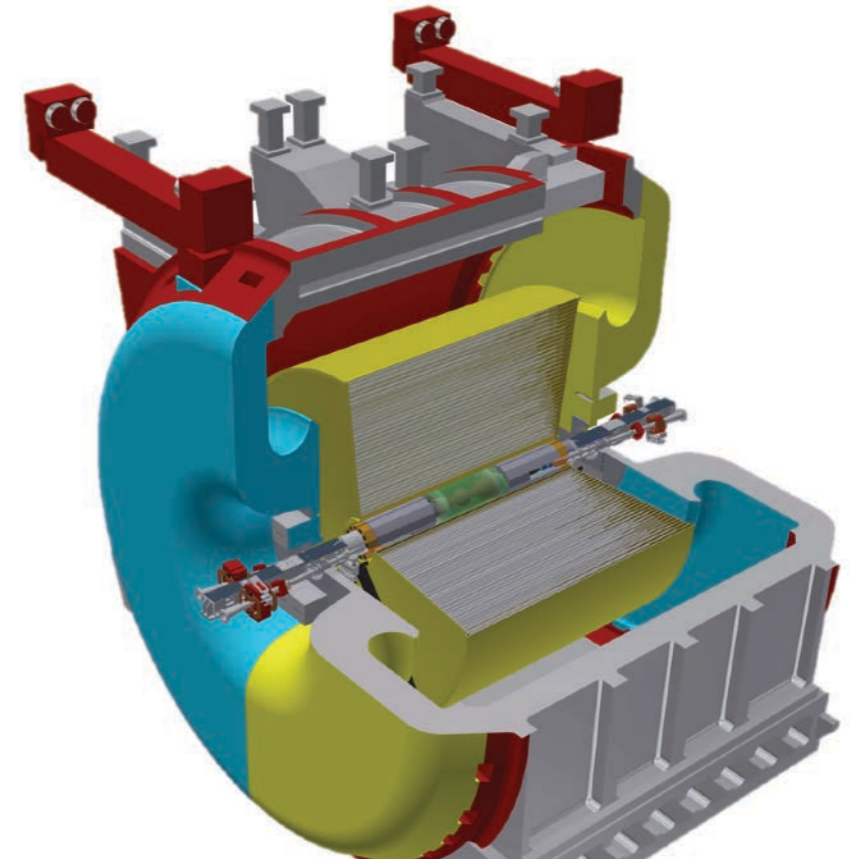
- Flavor physics and Rare Kaon decays
- Study of discrete symmetries: CP, CPT, T
- Quantum Mechanics tests

Other hadronic final states:

- rare decays of η meson
- $\gamma\gamma$ fusion : $\gamma\gamma \rightarrow \pi^0$
- Scalar mesons (tetraquark states)

Dark matter searches

- Dark Photons
- Leptophobic B-boson: $B \rightarrow \pi^0 \gamma$ in $\phi \rightarrow \eta \pi^0 \gamma$ e
 $\phi \rightarrow \eta \gamma \rightarrow \pi^0 \gamma \gamma \gamma$
- Axion-like particles: ($a \rightarrow \gamma \gamma$) in $e^+e^- \rightarrow 3\gamma$

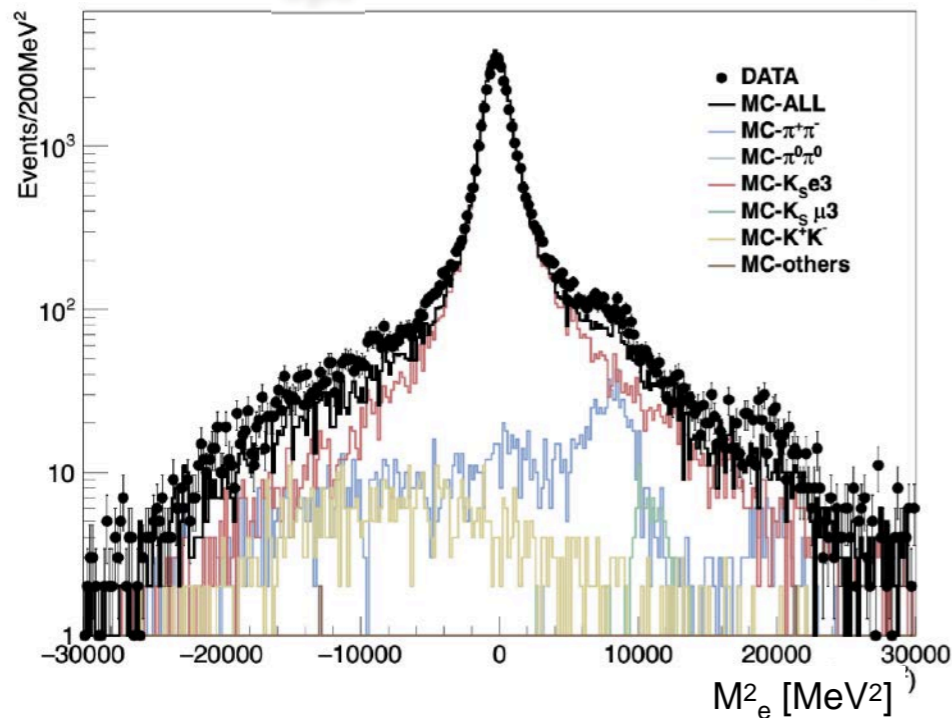


$K_S \rightarrow \pi e \nu$ AND V_{us} MATRIX ELEMENT

- The V_{us} element of the CKM matrix is best measured from K semileptonic decays

$$\Gamma_{K\ell 3} = \frac{G_F^2 M_K^5}{192\pi^3} S_{EW} (1 + \delta_K^\ell + \delta_{SU2}) C^2 |V_{us}|^2 |f_+(0)|^2 I_K^\ell$$

- $Br(K_S \rightarrow \pi e \nu)$ is the less precise contribution to V_{us} (after $K_{S\mu 3}$, also measured by KLOE)



L = 1.7 fb⁻¹ analyzed
Fit to M_e^2 to evaluate the signal

$$Br(K_S \rightarrow \pi e \nu) = (7.211 \pm 0.046 \pm 0.052) \times 10^{-4}$$

- Combination with the previous KLOE result [*Phys.Lett.B* 636 (2006)] :

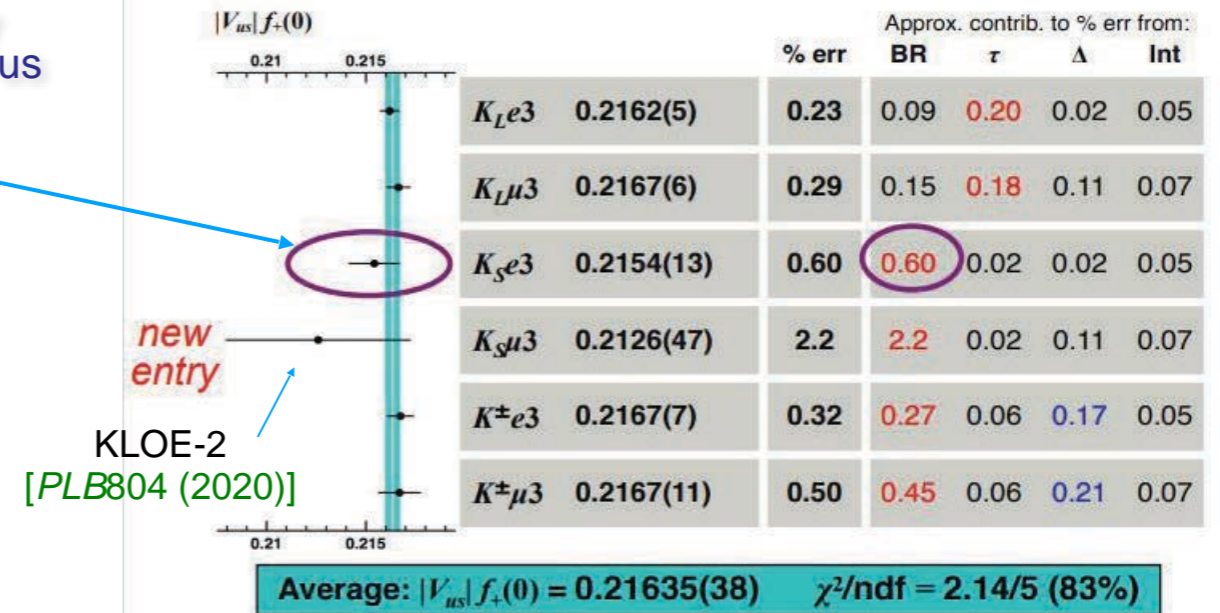
$$Br(K_S \rightarrow \pi e \nu) = (7.153 \pm 0.037 \pm 0.043) \times 10^{-4}$$

- We can extract the V_{us} element times the Form Factor at zero momentum transfer

$$f_+(0) |V_{us}| = 0.2170 \pm 0.0009$$

M. Moulson and E. Passemar, CKM2021, November 2021

$|V_{us}| f_+(0)$ from world data: Update

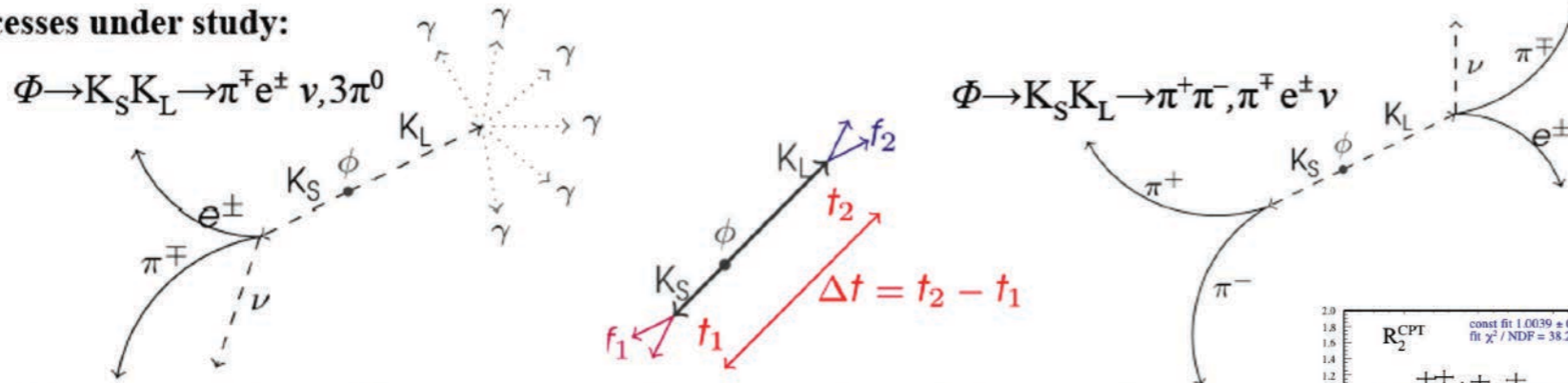


CPT AND T TESTS WITH NEUTRAL KAONS

[J. Bernabeu, A. Di Domenico, P. Villanueva-Perez:
NPB868(2013)102, JHEP1510(2015)139]

- First direct test with kaons, model independent

Processes under study:



- Observables (for $\Delta t \gg \tau_S$): T and CPT sensitive

$$R_2^T(\Delta t) = \frac{P[K^0(0) \rightarrow K_-(\Delta t)]}{P[K_-(0) \rightarrow K^0(\Delta t)]} = \frac{I(\pi^+ e^- \bar{\nu}, 3\pi^0; \Delta t)}{I(\pi^+ \pi^-, \pi^- e^+ \nu; \Delta t)} \times \frac{1}{D}$$

$$R_4^T(\Delta t) = \frac{P[\bar{K}^0(0) \rightarrow K_-(\Delta t)]}{P[K_-(0) \rightarrow \bar{K}^0(\Delta t)]} = \frac{I(\pi^- e^+ \nu, 3\pi^0; \Delta t)}{I(\pi^+ \pi^-, \pi^+ e^- \bar{\nu}; \Delta t)} \times \frac{1}{D}$$

$$R_2^{CPT}(\Delta t) = \frac{P[K^0(0) \rightarrow K_-(\Delta t)]}{P[K_-(0) \rightarrow \bar{K}^0(\Delta t)]} = \frac{I(\pi^+ e^- \bar{\nu}, 3\pi^0; \Delta t)}{I(\pi^+ \pi^-, \pi^+ e^- \bar{\nu}; \Delta t)} \times \frac{1}{D}$$

$$R_4^{CPT}(\Delta t) = \frac{P[\bar{K}^0(0) \rightarrow K_-(\Delta t)]}{P[K_-(0) \rightarrow K^0(\Delta t)]} = \frac{I(\pi^- e^+ \nu, 3\pi^0; \Delta t)}{I(\pi^+ \pi^-, \pi^- e^+ \nu; \Delta t)} \times \frac{1}{D}$$

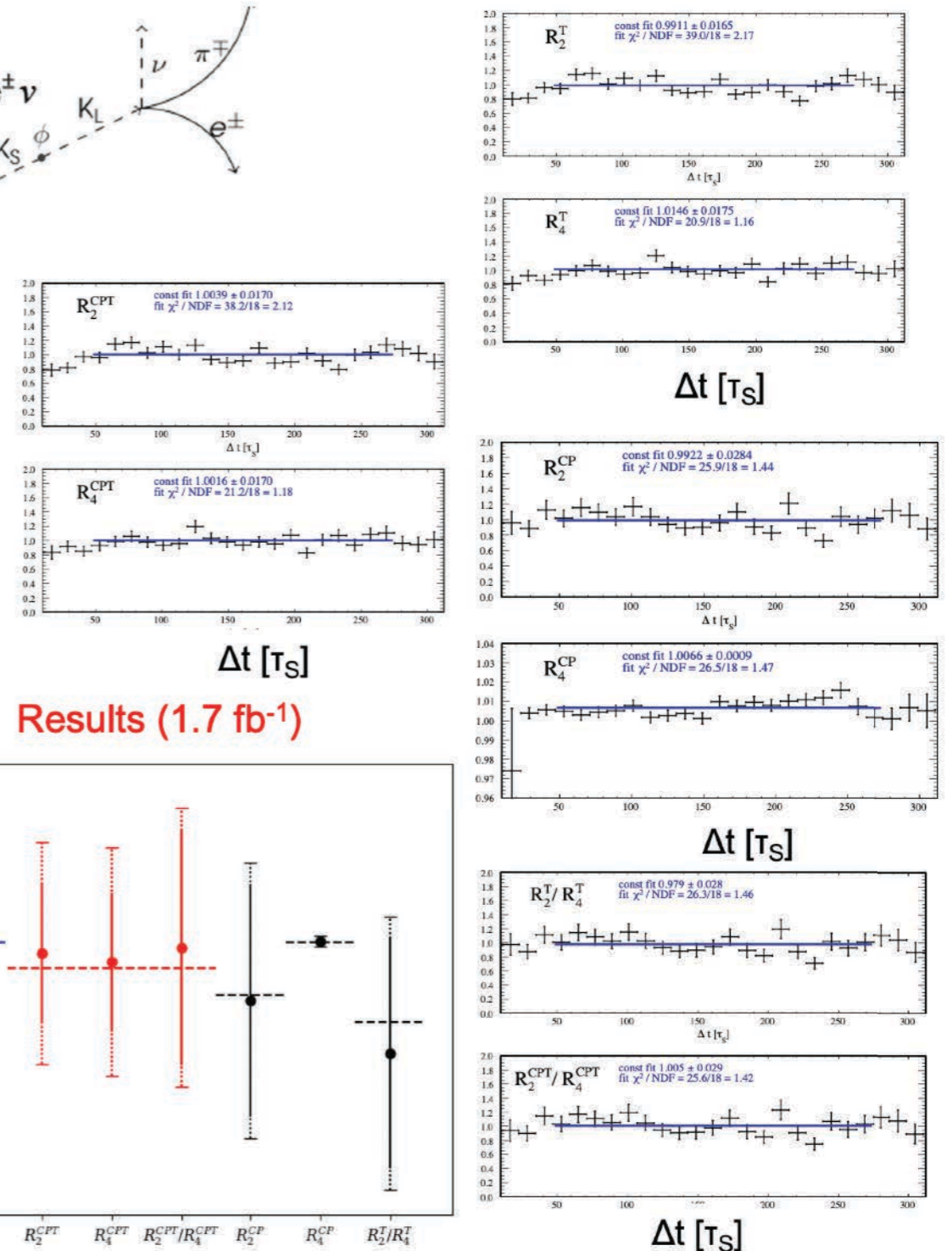
DOUBLE RATIOS.

$$\frac{R_2^T}{R_4^T}(\Delta t) = \frac{I(3\pi^0, e^-) I(\pi^+ \pi^-, e^-)}{I(3\pi^0, e^+) I(\pi^+ \pi^-, e^+)}$$

$$\frac{R_2^{CPT}}{R_4^{CPT}}(\Delta t) = \frac{I(3\pi^0, e^-) I(\pi^+ \pi^-, e^+)}{I(3\pi^0, e^+) I(\pi^+ \pi^-, e^-)}$$

Expected:

- T viol. from CP viol. assuming CPT
- CPT invariance (exp. ratios = 1)
- CP viol. from PDG

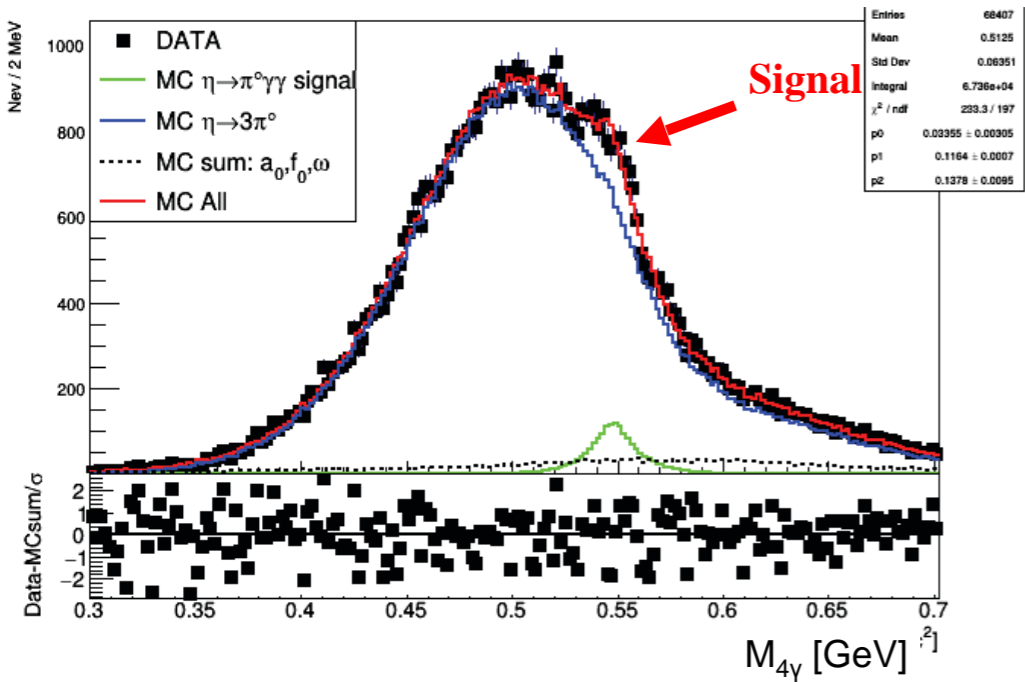


RARE HADRON DECAYS

$\eta \rightarrow \pi^0 \gamma \gamma$: sensitive to $O(p^6)$ terms of χ PT

$\text{Br} = (22.1 \pm 2.4 \pm 4.7) \times 10^{-5}$ CB@AGS(2008)

$\text{Br} = (25.2 \pm 2.5) \times 10^{-5}$ CB@MAMI(2014) (A2)

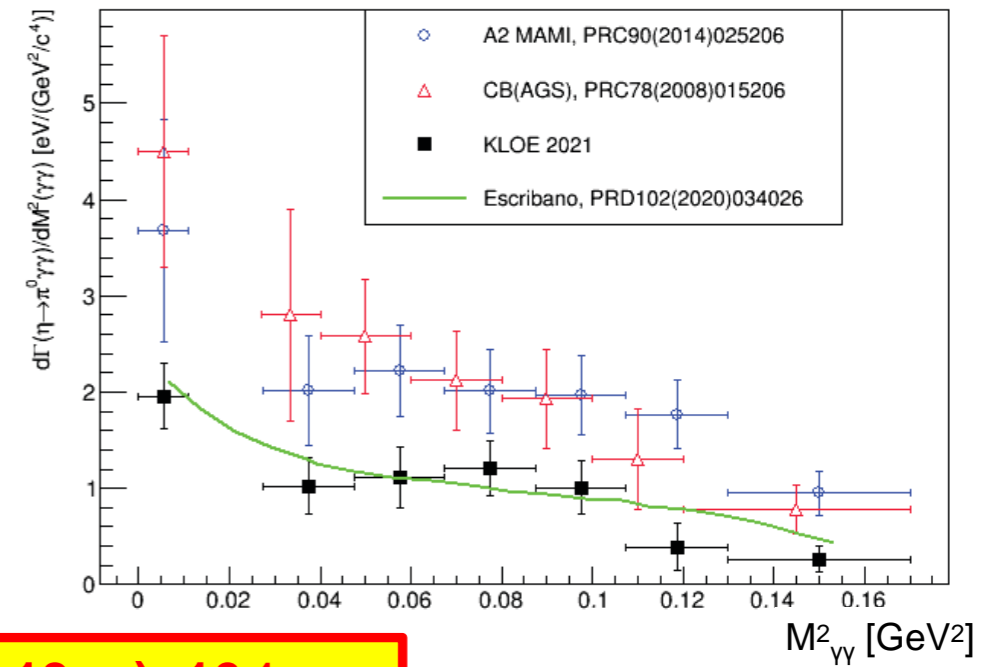


Tension with the old KLOE preliminary (2008): $(8.4 \pm 3.0) \times 10^{-5}$ ($L = 450 \text{ pb}^{-1}$, ~ 70 evts.)

$L = 1.7 \text{ fb}^{-1}$
 $\sim 1.2 \text{ keVts. for signal}$

$\text{Br}(\eta \rightarrow \pi^0 \gamma \gamma) = (1.21 \pm 0.13_{\text{stat}}) \times 10^{-4}$

$d\Gamma(\eta \rightarrow \pi^0 \gamma \gamma) / dM^2(\gamma \gamma)$ comparison



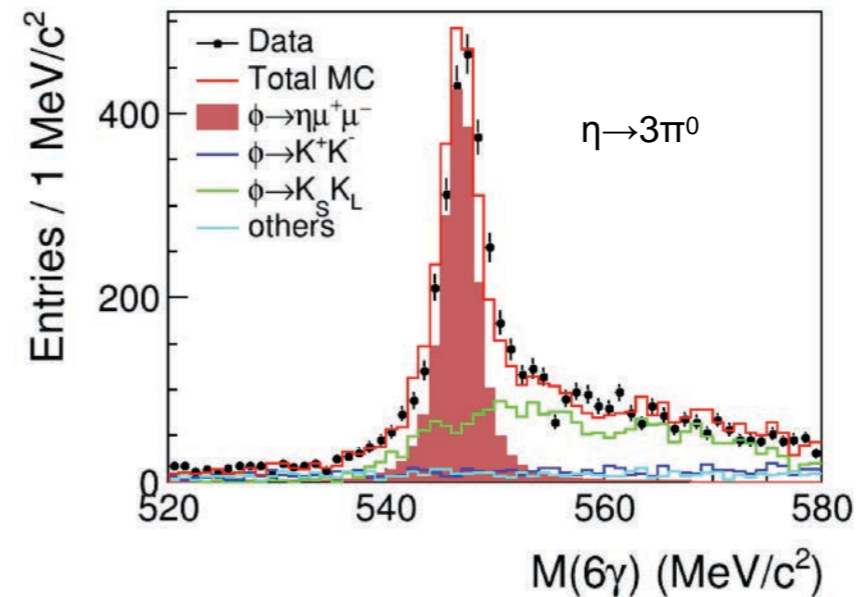
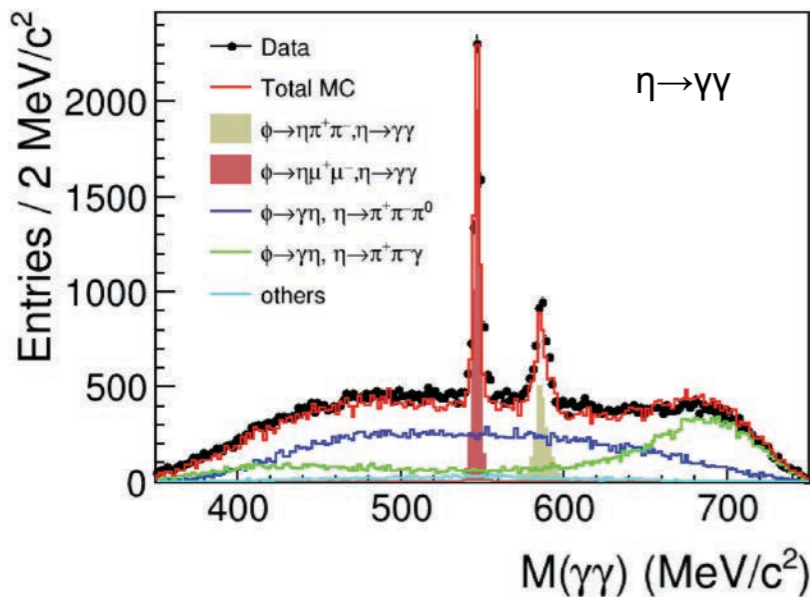
$\phi \rightarrow \eta \pi^+ \pi^-$, $\phi \rightarrow \eta \mu^+ \mu^-$: at present only upper limits from CMD-2 (Novosibirsk)

$\text{Br}(\phi \rightarrow \eta \pi^+ \pi^-) < 1.8 \times 10^{-5}$ @ 90% C.L. [PLB491(2000)81]

$\text{Br}(\phi \rightarrow \eta \mu^+ \mu^-) < 9.4 \times 10^{-6}$ @ 90% C.L. [PLB501(2001)191]

$L = 1.6 \text{ fb}^{-1}$

KLOE-2 preliminary



ARGOMENTI DI TESI

- **Puo' il futuro influenzare il passato in stati entangled di mesoni K ? (A.Di Domenico):** L'entanglement di una coppia di mesoni K neutri mostra un nuovo e apparentemente paradossale effetto "dal futuro al passato" a causa della natura non-locale della QM, che puo' essere osservato per la prima volta con i dati di KLOE/KLOE-2 studiando le correlazioni fra i decadimenti dei K (e-Print: 1912.04798 [quant-ph])
- **Test diretto della simmetria CPT nelle transizioni di mesoni K correlati a KLOE/KLOE-2 (A.Di Domenico):** sfruttando le proprieta' della coppia "entangled" di mesoni K neutri prodotti nel decadimento $\phi \rightarrow K_S K_L$ e' possibile effettuare il primo test preciso della simmetria CPT direttamente nei processi di transizione dei mesoni K.
- **Ricerca di Axion-Like Particles (ALPs) a KLOE-2 (P.Gauzzi):** le ALPs sono particelle scalari o pseudoscalari previste da alcune estensioni dello SM, e potrebbero contribuire a spiegare la discrepanza di $(g-2)_\mu$ fra teoria e esperimenti. Nella regione di massa minore di 1 GeV possono essere studiate con i dati di KLOE-2 in stati finali contenenti due fotoni.
- **Ricerca di nuovi bosoni di gauge in stati finali che contengono $\pi^0\gamma$ a KLOE-2 (P.Gauzzi):** nuovi bosoni di gauge mediatori di Dark Forces che si accoppiano principalmente a $q\text{-}q\text{bar}$, possono essere cercati come risonanze $\pi^0\gamma$ nei decadimenti radiativi di mesoni ϕ e ω

Sito web: www.lnf.infn.it/kloe2

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giulio.dagostini@roma1.infn.it
paolo.gauzzi@roma1.infn.it

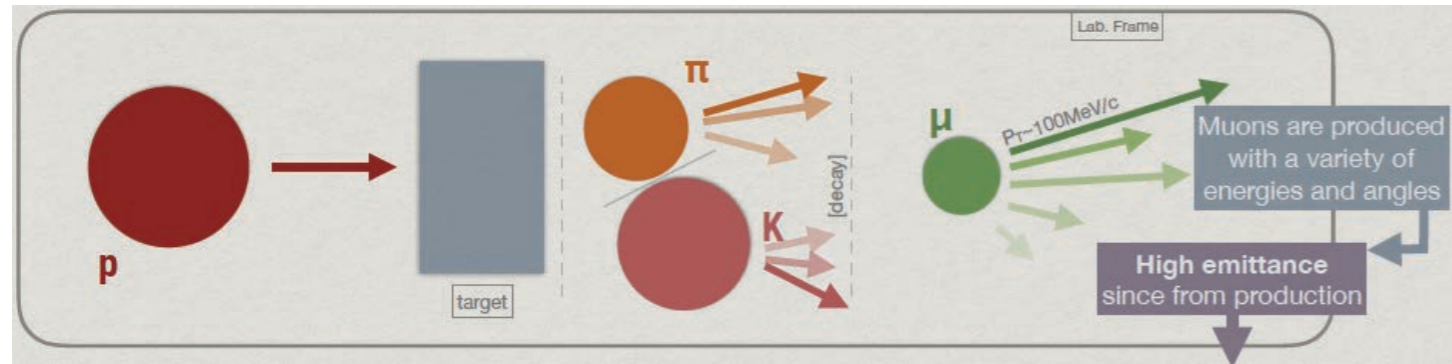


Muon Collider ACTIVITIES

MUON SOURCES

Conventional: Proton-based production

muons obtained as tertiary particles (from pion decays) with typically $P_T^\mu \sim 100 \text{ MeV}$



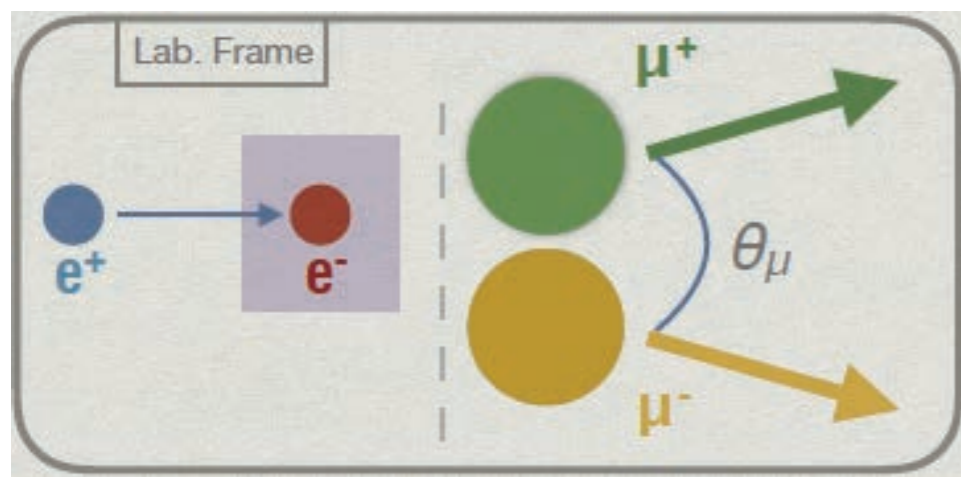
Pro: high production cross section
Contra: high muon-beam emittance

→ muon **COOLING** mandatory

Rate $> 10^{13} \mu/\text{se}$; $N_\mu = 2 \times 10^{12} / \text{bunch}$

Positrons on target (LEMMA proposal): $e^+e^- \rightarrow \mu^+\mu^-$ close to production threshold

$E(e^+) \sim 45 \text{ GeV} \Rightarrow E(\mu) \sim 22 \text{ GeV}$, $\gamma(\mu) \sim 200 \Rightarrow \tau_{\text{LAB}} \sim 500 \mu\text{s}$



- Very small emittance is obtainable
 \Rightarrow **no cooling needed!**
- Low background
- Large boost at production
 - Reduced losses from muon decays
- **Much smaller muon production cross section**
 - **$\sim 1 \mu\text{b}$ for e^+ source vs $\sim 1 \text{mb}$ for proton source**

(NIM A807, 101 (2016)
[arXiv:1509.04454])

RD_MUCOL

- RD_MUCOL is the INFN research program dedicated to studies related to muon colliders
- Main activities with INFN involvement (within CSN1):
 - R&D of detectors for an experiment at a muon collider
 - Study of the Machine-detector Interface (MDI)
 - Study of the safety issues due to neutrino-induced radiation
 - R&D related to the LEMMA project

The group in **Rome** is growing and is already working on **several aspects** of the projects:

- theory studies to establish the physics reach of a multi-TeV muon collider
- study of the Machine-Detector Interface
- LEMMA:
 - study of the thermo-mechanical stresses of the target for the muon production
 - Test beam campaigns to measure the muon production with a 45 GeV positron beam

RD_MUCOL in Rome: Fabio Anulli (R.L) , Gianluca Cavoto, Roberto Li Voti, Barbara Mele, Matteo Bauce, Francesco Collamati, Stefano Rosati, Ilaria Rago, Emanuele Gueli, Fausto Casaburo,

TEST BEAM AT THE CERN NORTH AREA

Motivations:

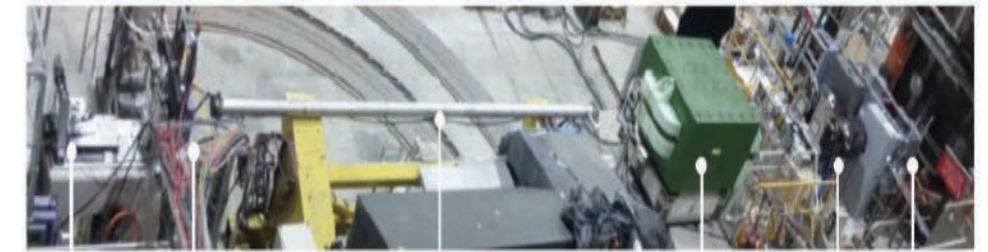
- Experimentally measure the key parameters of the LEMMA approach
 - Emittance of emerging μ beam
 - $\mu^+ \mu^-$ production cross-section at threshold
 - properties of spent e^+ beam (transverse emittance and energy spectrum)
 - Effect of the target material/thickness

2018 Test beam:

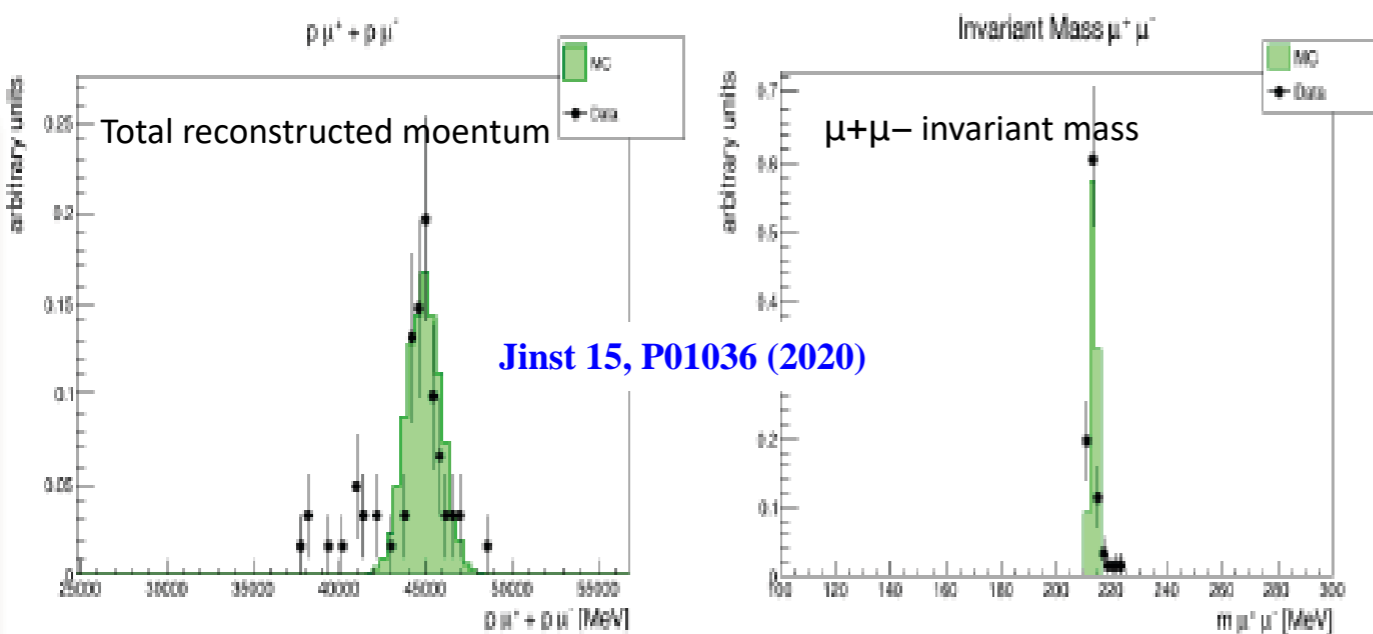
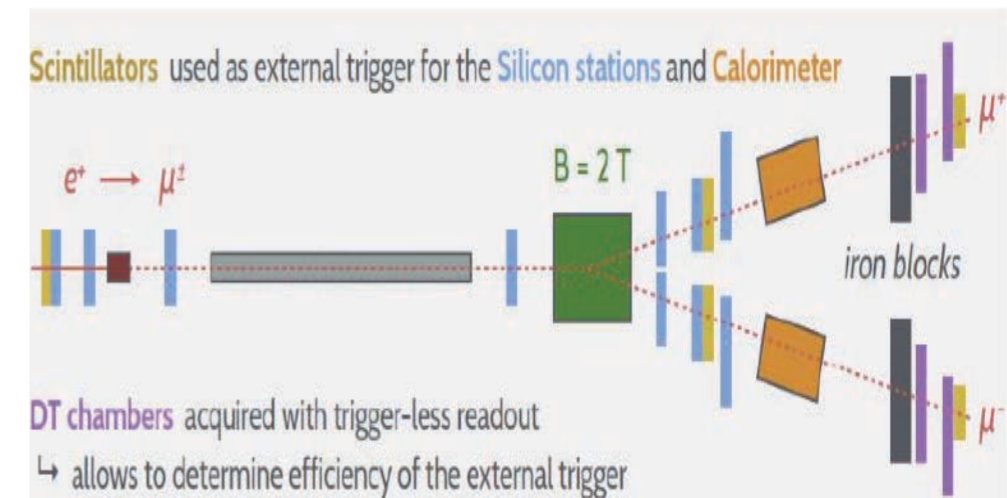
- Low-budget: mostly re-use available detectors and DAQ
- Lot of experience gained, decent result published (JINST 15 P01036)
- However, severe limitations in the setup did not allow pursuing high precision measurements
 - Resolution of the available tracking system too modest
 - Too large trigger/DAQ dead time
 - A single week of data taking barely sufficient to set up detectors and trigger properly

Layout of the experimental setup:

August 2018



target Be or C Si microstrip stations vacuum beam pipe dipole magnet CAL DT



Proposal submitted for a TB in 2023

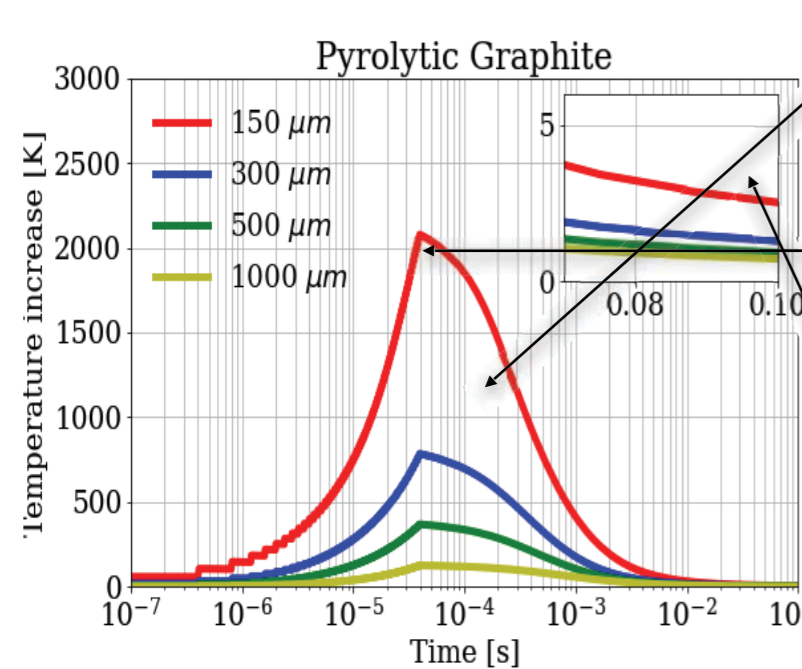
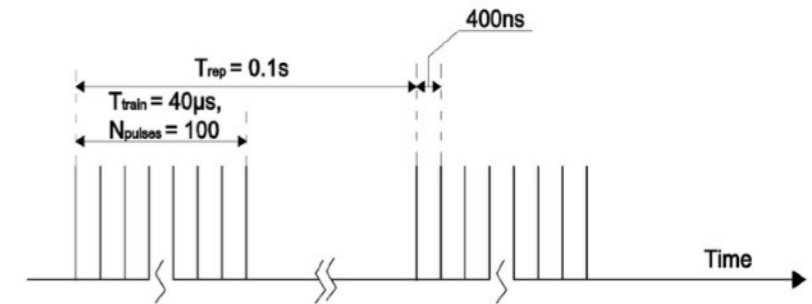
- Request for 3-weeks beam time in H4
- Experiment being redesigned (in particular new tracking and new DAQ)
- <http://cds.cern.ch/record/2712394>

Studio degli stress termo-meccanici di bersagli solidi per produzione di muoni nello schema LEMMA

Attività teorica svolta nell'ultimo anno

1. Simulazione con FLUKA e GEANT dell'energia depositata da un fascio di positroni su bersagli di diversi materiale e forme geometriche
2. Sviluppo di un modello teorico per la simulazione dell'aumento di temperatura del bersaglio
3. Simulazione numeriche per la valutazione degli stress termo-meccanici sui bersagli
4. Fit teorico-sperimentale per la determinazione dei parametri termici di bersagli di berillio e di carbonio (grafite)

e^+ beam: $E=45$ GeV, 3×10^{11} e^+ /bunch, gaussian shape ($\sigma=150-1000 \mu\text{m}$). train of 100 bunches $40 \mu\text{s}$ long, with 10Hz repetition rate

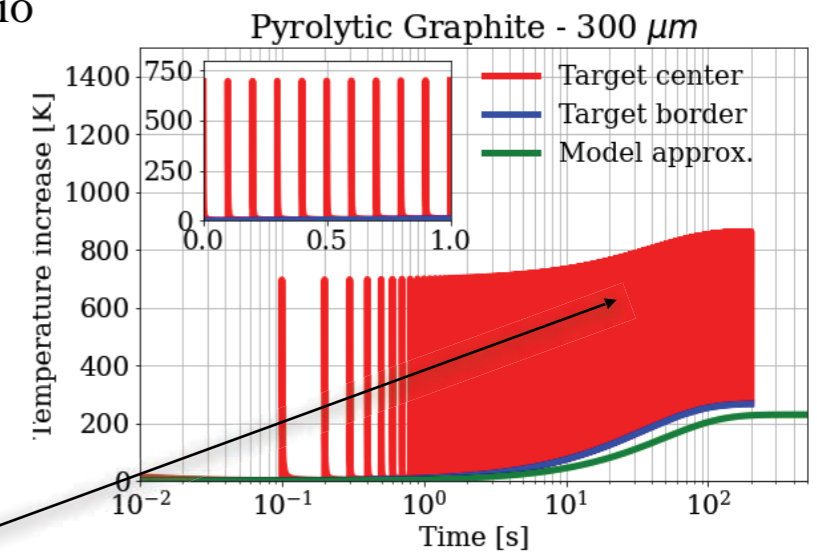


Aumento della temperatura al centro del bersaglio per il passaggio di un treno di 100 bunches di particelle.

Il picco è in corrispondenza della fine del treno ($40 \mu\text{s}$).

Non tutto il calore viene dissipato prima dell'arrivo del prossimo treno.

Il calore si accumula al passaggio dei treni successivi fino a raggiungere una situazione di equilibrio



Programma 2022-23: Misure in laboratorio da confrontare con i risultati del modello sviluppato

- Misura delle proprietà termoelastiche di targhette di carbonio (grafite).
- Misura della diffusività termica ed emissività infrarossa con radiometria fototermica e termografia infrarossa.
- Rivelazione di possibili danneggiamenti e stress termomeccanici quando la targhetta è sottoposta a fasci laser intensi.
- Test su fasci di particelle (elettroni) ad alta intensità

Argomenti di Tesi

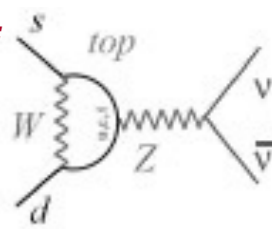
- Preparazione e partecipazione ai Test beam LEMMA 2023 al CERN
 - simulazione in GEANT dell'esperimento. Studio dei processi fisici di segnale e fondo per l'ottimizzazione dell'apparato sperimentale
- Studio degli stress termo-meccanici dei bersagli per muoni
 - misure in laboratorio del comportamento dei bersagli soggetti a un fascio laser, analisi dei dati e confronto con modello teorico
 - partecipazione a test beam con fasci di elettroni e conseguente analisi dei dati
- Studi teorici per physics reach di un muon collider a diverse energie nel centro di massa e su diversi casi di fisica



NA62 ACTIVITIES

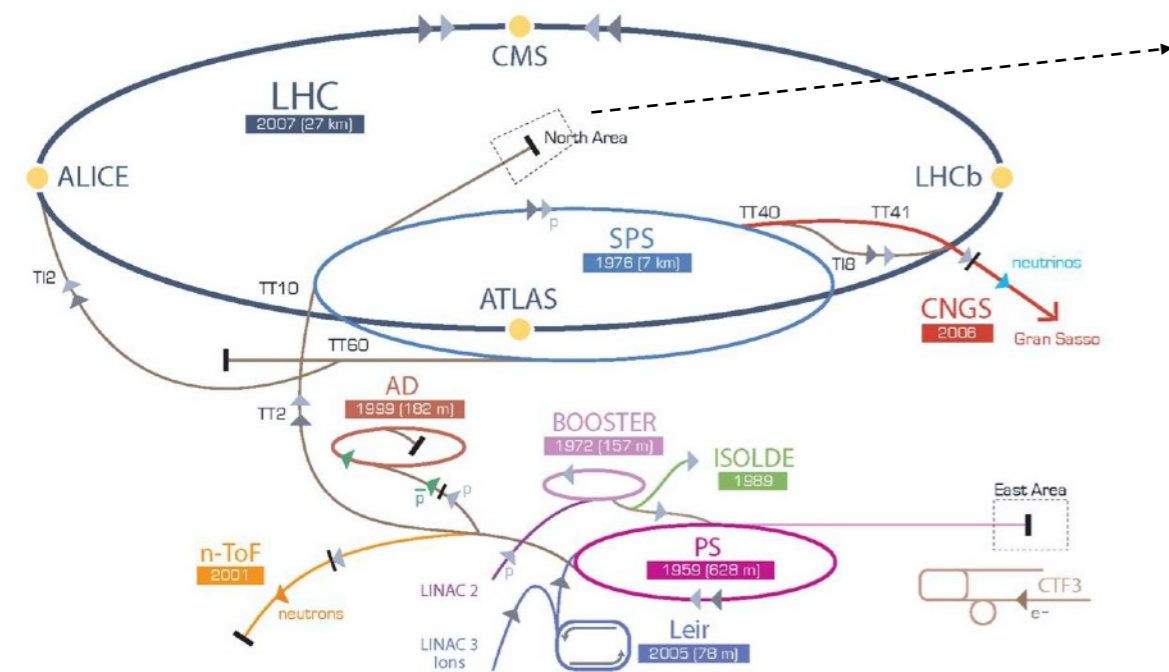


Esperimento su fascio estratto all'SPS del CERN per studiare decadimenti estremamente rari: $K \rightarrow \pi \nu \nu$



Perché questo esperimento è interessante nell'era di LHC?

Misure di precisione molto utili per discriminare la struttura del Flavor della "nuova fisica": approccio complementare a quello degli esperimenti al LHC



- **K di alto impulso** per ridurre il fondo da π^0
- **Decadimento in volo** per limitare scattering e fondi dal target

1. **Timing molto preciso** per associare il π^+ finale al K^+ iniziale
2. **Reiezione cinematica** dei fondi a due e tre corpi (spettrometro al silicio per K , a straw in vuoto per π)
3. **Particle-Id** e rivelatori di **veto**, in particolare per **fotoni** (calorimetro + i "nostri" rivelatori) e **muoni** (RICH, ferro/scint.)

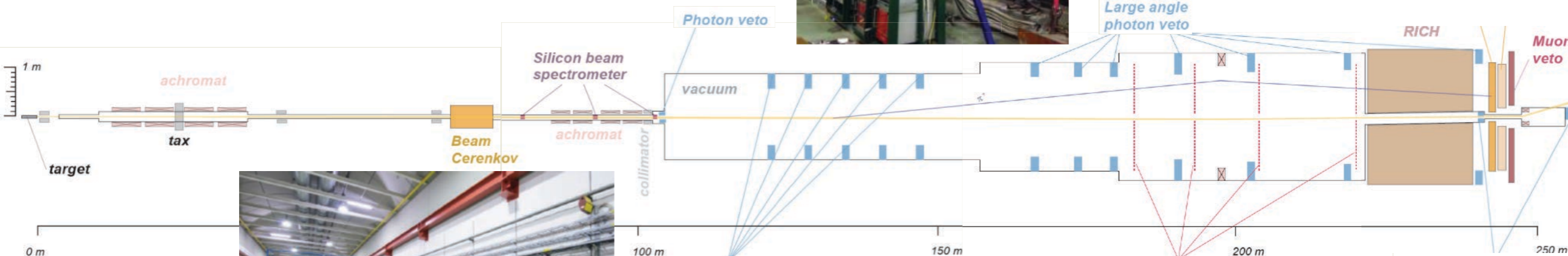
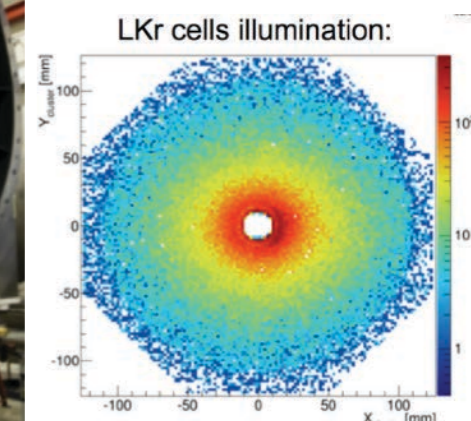
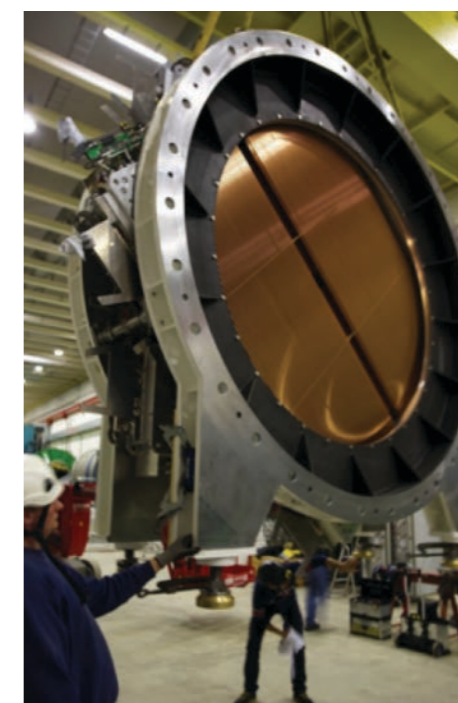
Perché questo esperimento è interessante nell'era di LHC?

- Processi Flavour Changing Neutral Current → sensibili alla fisica oltre il Modello Standard
 - Misure di precisione per discriminare la struttura del Flavor della “nuova fisica”
 - Frontiera dell'intensità, approccio complementare a quello dell'energia (LHC)
- Grande contributo “short-distance” → predizioni teoriche molto precise

Ma i branching ratio (Standard Model) sono $<10^{-10}$!

La sfida è abbattere i fondi con un buon rapporto segnale/rumore, ad un costo ed in tempi ragionevoli ...

- Riutilizzo “creativo” di parte dell'apparato di NA48 (calorimetro a Krypton liquido, tubo da vuoto, magneti, ecc.)
- Fascio esistente e 50 volte più intenso
- Nuovi rivelatori
- Nuovo trigger, DAQ, computing, software...



Veti per fotoni

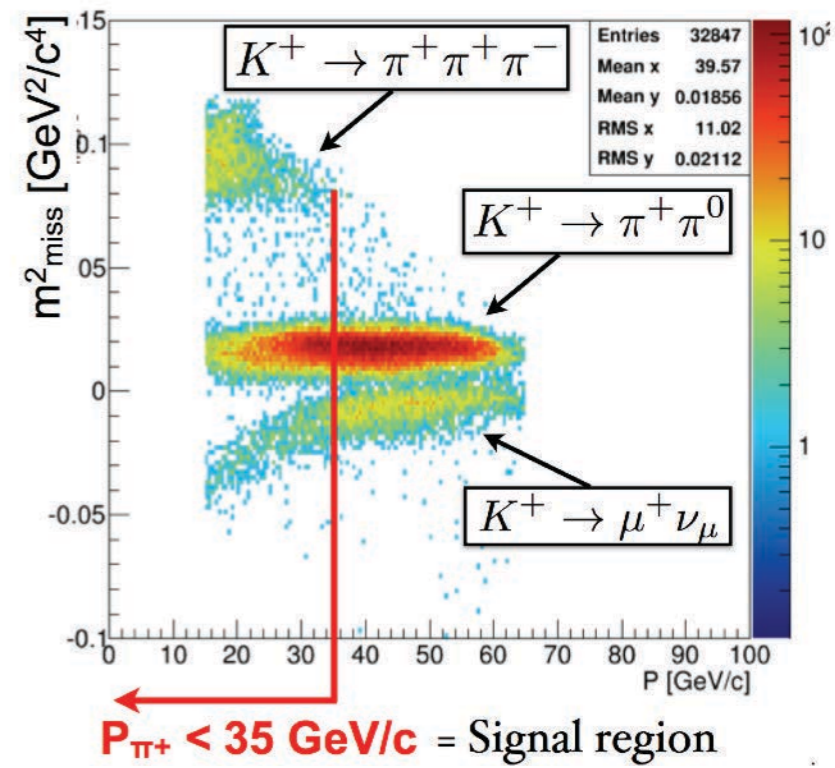
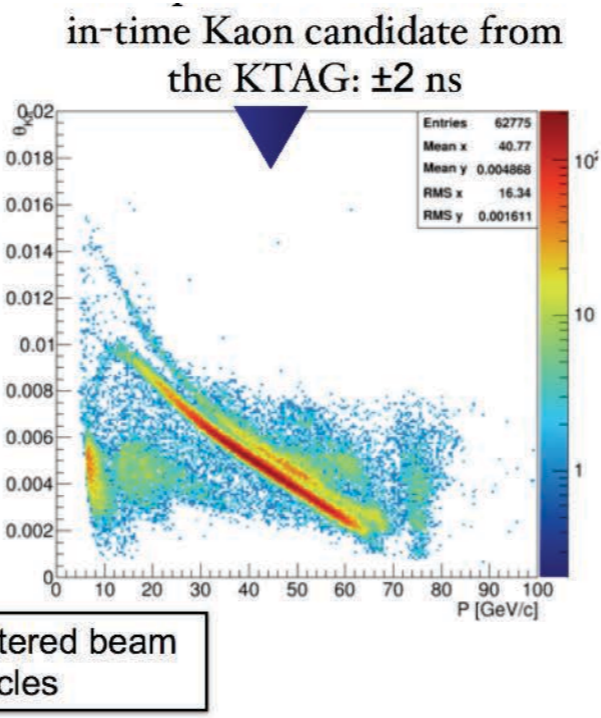
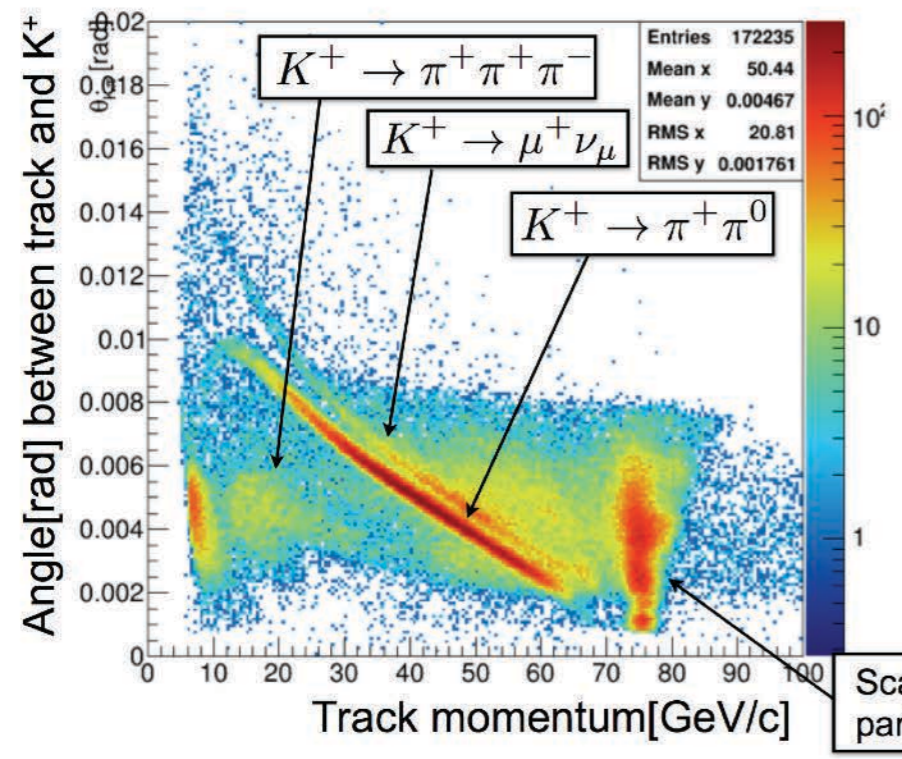
Tracciatori straw

- Prima presa dati con fascio e primi eventi di fisica nel 2015
- tre anni di run e analisi dati 2016, 2017 e 2018
- ...e altri tre anni di presa dati 2021-22-2



Eventi a una traccia nello spettrometro...

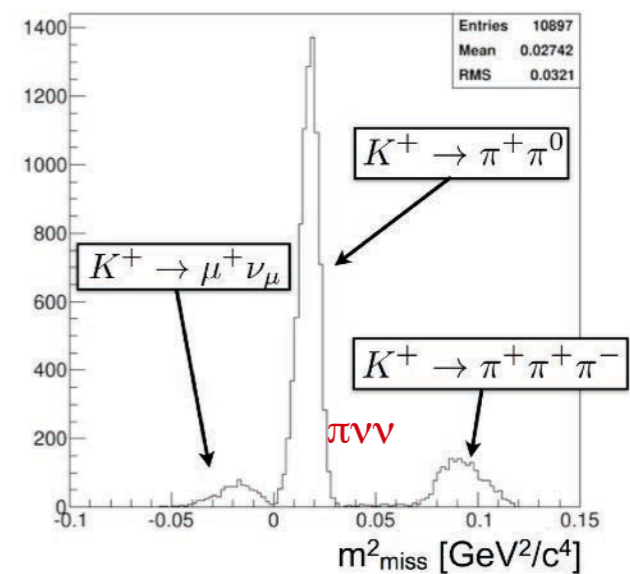
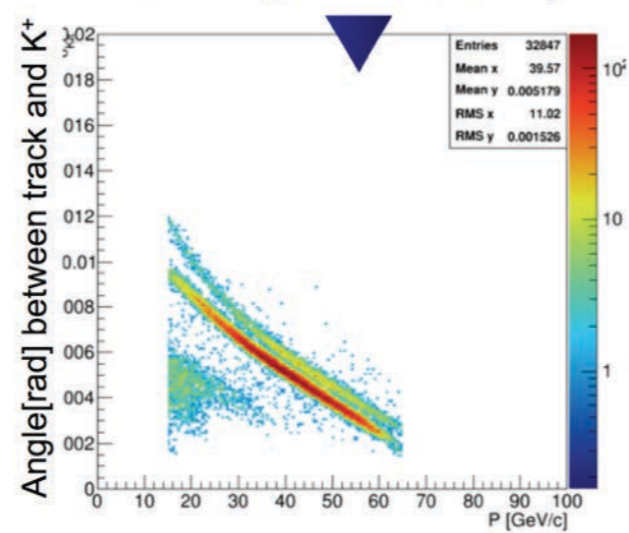
... in tempo con il Cherenkov e...



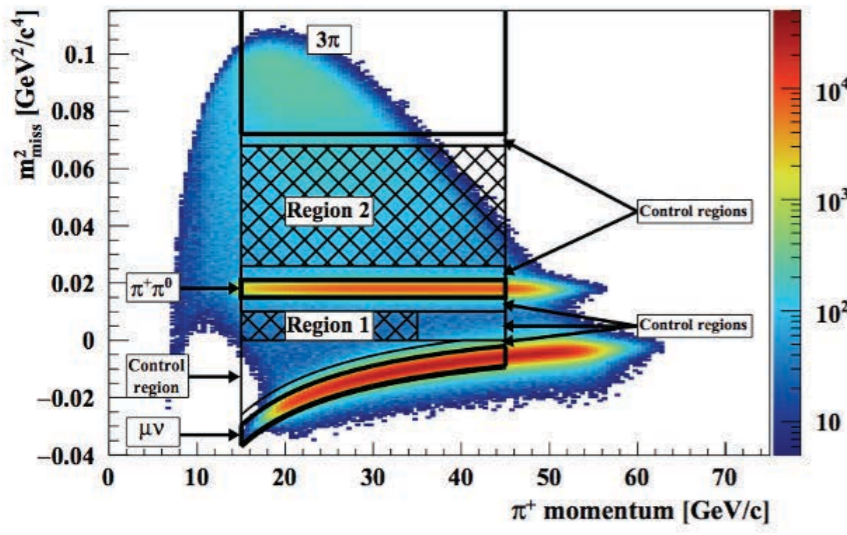
...nel volume fiduciale

$$105 < Z_{VTX} < 165 \text{ m}$$

$$15 < P_{\pi^+} < 65 \text{ GeV}/c$$

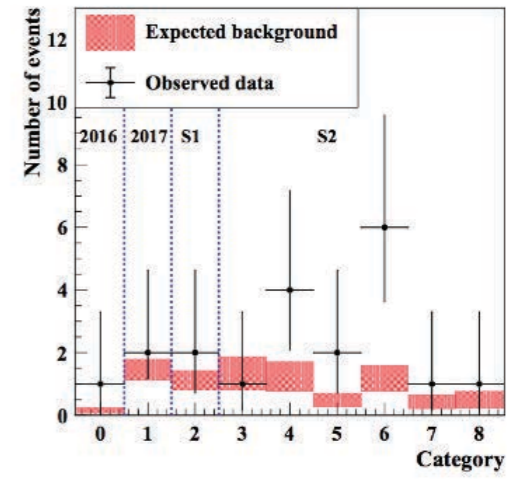
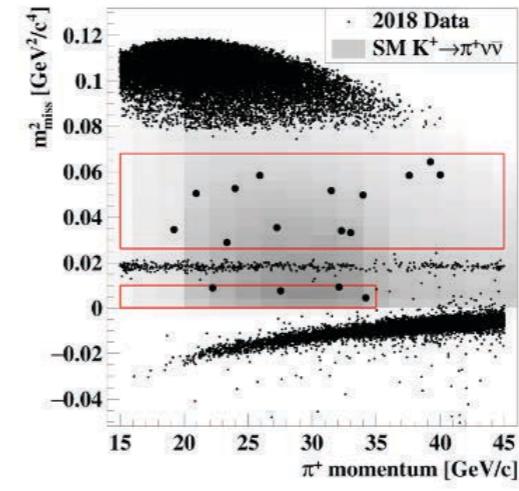


Physics analysis



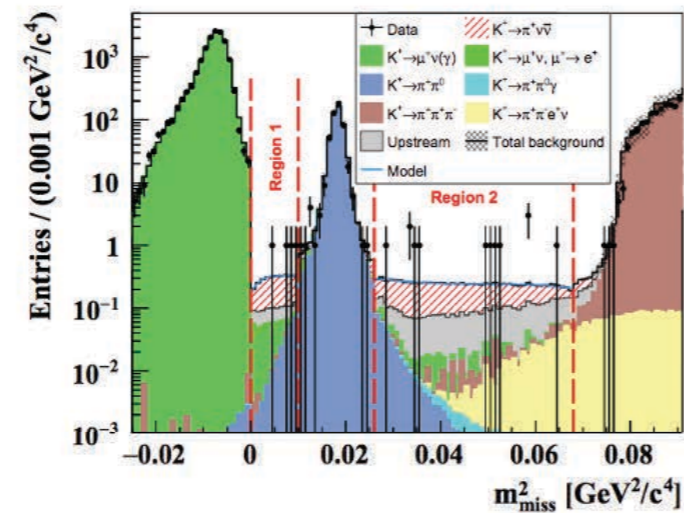
Study the signal selection using MC simulations

Unblind the signal regions and

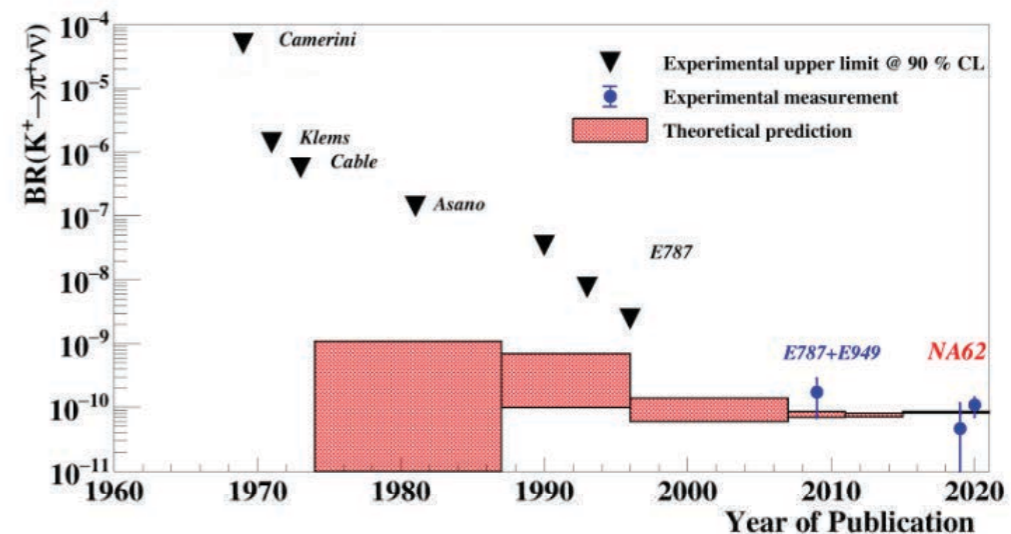


Compare data-MC and predict background and signal

Background	Subset S1	Subset S2
$\pi^+\pi^0$	0.23 ± 0.02	0.52 ± 0.05
$\mu^+\nu$	0.19 ± 0.06	0.45 ± 0.06
$\pi^+\pi^-e^+\nu$	0.10 ± 0.03	0.41 ± 0.10
$\pi^+\pi^+\pi^-$	0.05 ± 0.02	0.17 ± 0.08
$\pi^+\gamma\gamma$	< 0.01	< 0.01
$\pi^0l^+\nu$	< 0.001	< 0.001
Upstream	$0.54^{+0.39}_{-0.21}$	$2.76^{+0.90}_{-0.70}$
Total	$1.11^{+0.40}_{-0.22}$	$4.31^{+0.91}_{-0.72}$



Best measurement of the $K^\pm \rightarrow \pi^\pm \nu \bar{\nu}$



$$SES = (0.839 \pm 0.053_{\text{sys}}) \times 10^{-11},$$

$$N_{\pi\nu\bar{\nu}}^{\text{exp}} = 10.01 \pm 0.42_{\text{sys}} \pm 1.19_{\text{ext}},$$

$$N_{\text{background}}^{\text{exp}} = 7.03^{+1.05}_{-0.82}$$

$$BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (10.6^{+4.0}_{-3.4}|_{\text{stat}} \pm 0.9_{\text{sys}}) \times 10^{-11} \text{ at } 68\% \text{ CL},$$

<https://cds.cern.ch/record/2752286/files/CERN-EP-2021-050.pdf>

Tesi di impronta Hardware

“NA62 L0TP trigger upgrade” prof. M. Raggi, O. Frezza

In view of the the CERN RUN III starting in 2021, the NA62 experiment is upgrading his FPGA based L0 trigger processor board. The system is based on modern fast FPGA technology. The candidate will be involved in the FPGA programming in both VHDL and with modern high level systesis languages, as well as on the hardware tests.

Tesi orientate all’analisi

“Ricerca di particelle oscure interagenti con l’esperienza NA62” Prof. M. Raggi and T. Spadaro

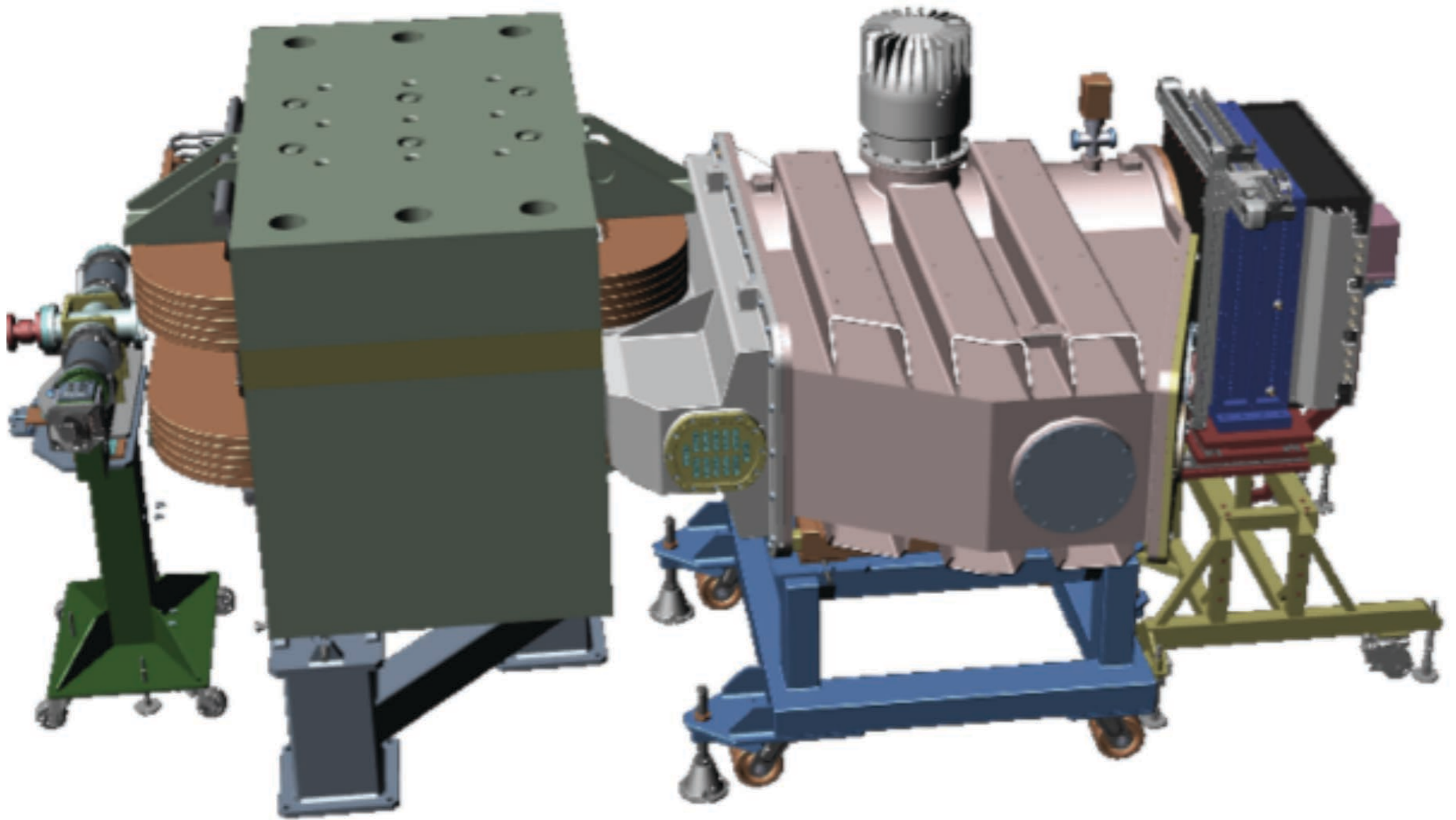
L’esperienza NA62 attualmente in corso all’SPS del CERN è stato disegnato per misurare il BR del decadimento carico $K^+ \rightarrow \pi^+ \nu \nu$ con una precisione che, raggiungendo quella teorica, potrebbe fornire indizi di nuova fisica o alternativamente dare nuovi vincoli alle teorie oltre il modello standard. Grazie alla flessibilità del sistema di trigger e alle performance molto spinte dei rivelatori NA62 può risultare ideale anche per la ricerca di decadimenti visibili di Dark Photon (A'), Heavy Neutral Leptons (N), Axion-Like Particles (a) e Dark Scalars (S). Il lavoro di tesi si propone di partecipare all’analisi per la ricerca di una di queste particelle attraverso la selezione di uno specifico modo di decadimento (es: $A' \rightarrow e^+ e^-$, $A' \rightarrow \mu^+ \mu^-$, $N \rightarrow \pi e$, $N \rightarrow \pi \mu$, $a \rightarrow \gamma \gamma$, ecc.)

“Ricerca di fotoni oscuri in transizioni invisibili con l’esperienza NA62” Prof. M. Raggi and S. Martellotti

I decadimenti dei mesoni K in $\pi \nu \nu$ sono estremamente soppressi nel SM ed i loro BR, dell’ordine di 10^{-11} , sono predetti con una precisione teorica mai raggiunta dai risultati sperimentali. Misure precise di questi BR fornirebbero nuovi vincoli alla matrice CKM e permetterebbero di mettere in evidenza eventuali effetti di nuova fisica oltre lo SM. L’esperienza NA62 attualmente in corso all’SPS del CERN è stato disegnato per misurare il BR($K^+ \rightarrow \pi^+ \nu \nu$) con una precisione del 10%. Uno dei fondi principali di tale misura è costituito da decadimenti $K^+ \rightarrow \pi^+ \pi^0$ (BR= 20%) che sono oltre 10^8 volte più abbondanti. Un sistema di veti per fotoni, permette di rigettare efficacemente questo pericoloso fondo e fornisce inoltre la possibilità di ricercare segnali di nuova fisica altrimenti inaccessibili. Il lavoro di tesi è orientato ad evidenziare l’eventuale produzione di Dark Photons (A') così debolmente interagenti con le particelle dello Standard Model da sfuggire la rivelazione diretta nell’apparato. Queste ricerche sono effettuate nelle transizioni $K^+ \rightarrow \pi^+ \pi^0$ seguita da $\pi^0 \rightarrow A' \gamma$ e $K^+ \rightarrow \pi^+ \pi^0 A'$.

“Sviluppo di un’analisi multivariata per l’identificazione del decadimento $KL \rightarrow \pi^0 \nu \nu$ con l’esperienza KLEVER”, M. Raggi and M. Moulson

Il fondo principale nella ricerca del decadimento $K_L \rightarrow \pi^0 \nu \nu$ è costituito da decadimenti $K_L \rightarrow \pi^0 \pi^0$, oltre 10^7 volte più abbondanti, in cui due dei quattro fotoni dello stato finale non vengono rivelati. Anche i decadimenti in π^0 dei barioni Λ prodotti nel fascio insieme con i KL possono costituire un fondo importante. Le diverse grandezze misurate, quali i segnali lasciati nei sistemi di veto e le informazioni geometriche e cinematiche risultanti dalla ricostruzione del decadimento, consentono la discriminazione tra segnale e fondo, ma queste grandezze devono essere combinate in modo ottimale per raggiungere il livello di reiezione richiesta dalla misura, fornendo al contempo un indicatore statistico della probabilità che un evento sia dovuto a segnale o fondo.



PADME ACTIVITIES

RICERCA DI NUOVE FORZE A PADME AI LNF

La ricerca di soluzioni al problema della materia oscura è uno dei problemi fondamentali della fisica moderna. Una delle possibilità è di introdurre una nuova forza “quinta forza” ed un nuovo bosone mediatore. Queste forze sono molto deboli e possono essere esplorate con piccoli esperimenti di grande precisione.

L'esperimento **PADME** ai Laboratori Nazionali di Frascati dell'INFN ha iniziato la sua presa dati a giugno del 2018. Numerosi stati finali di nuova fisica sono accessibili all'esperimento con la possibilità di lavorare su dati appena acquisiti.

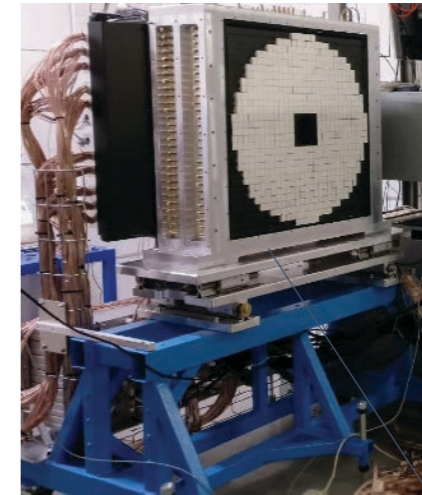
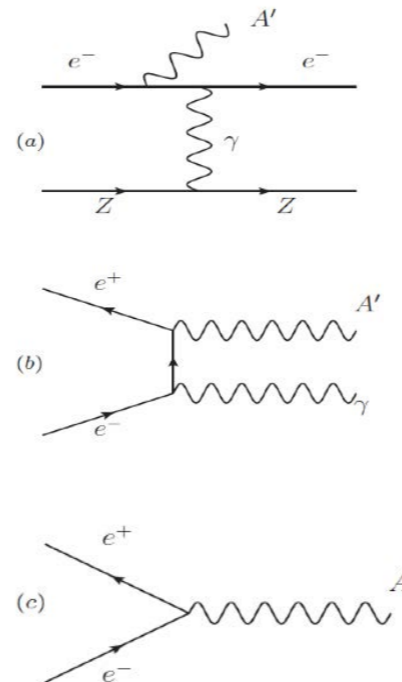
for more info:

mauro.raggi@roma1.infn.it,

paolo.valente@roma.infn.it,

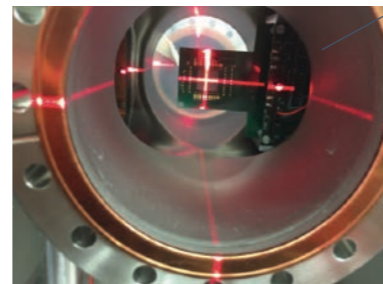
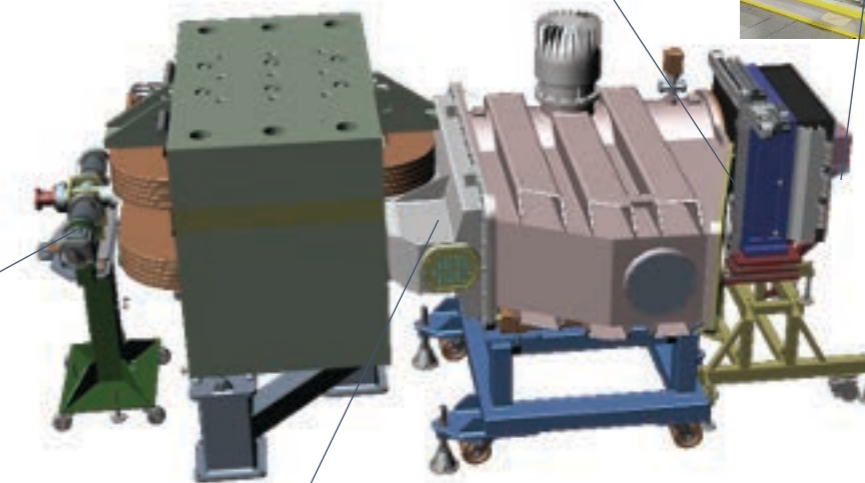
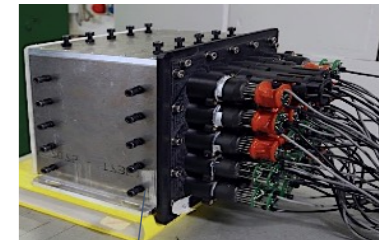
giovanni.organtini@uniroma1.it

<http://www.lnf.infn.it/acceleratori/padme/>



Calorimetro a cristalli BGO

Calorimetro a cristalli PbF₂

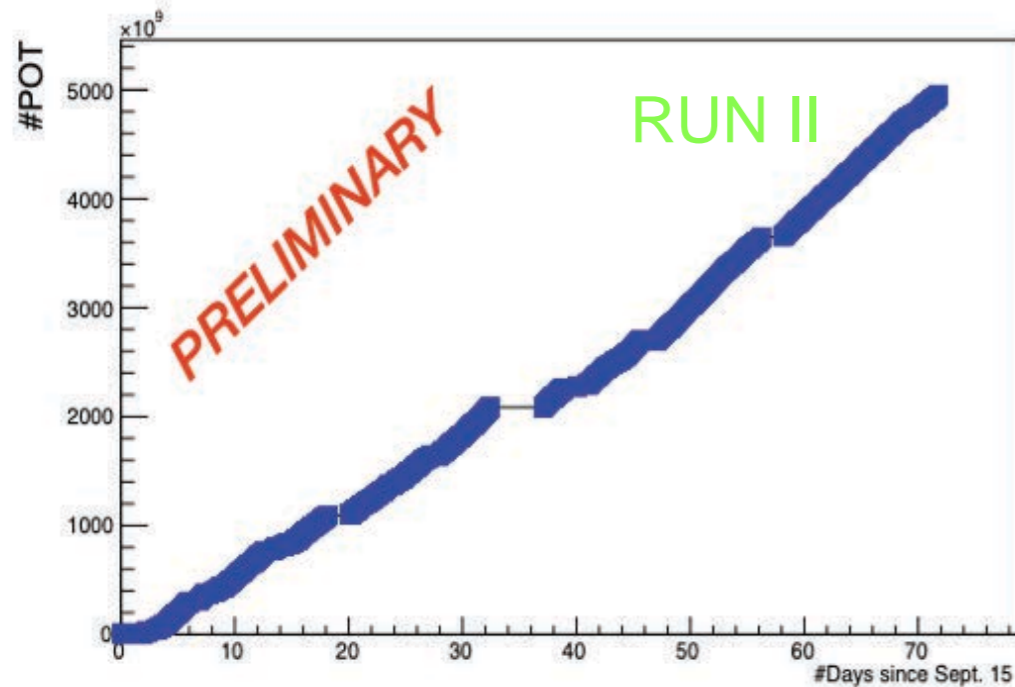
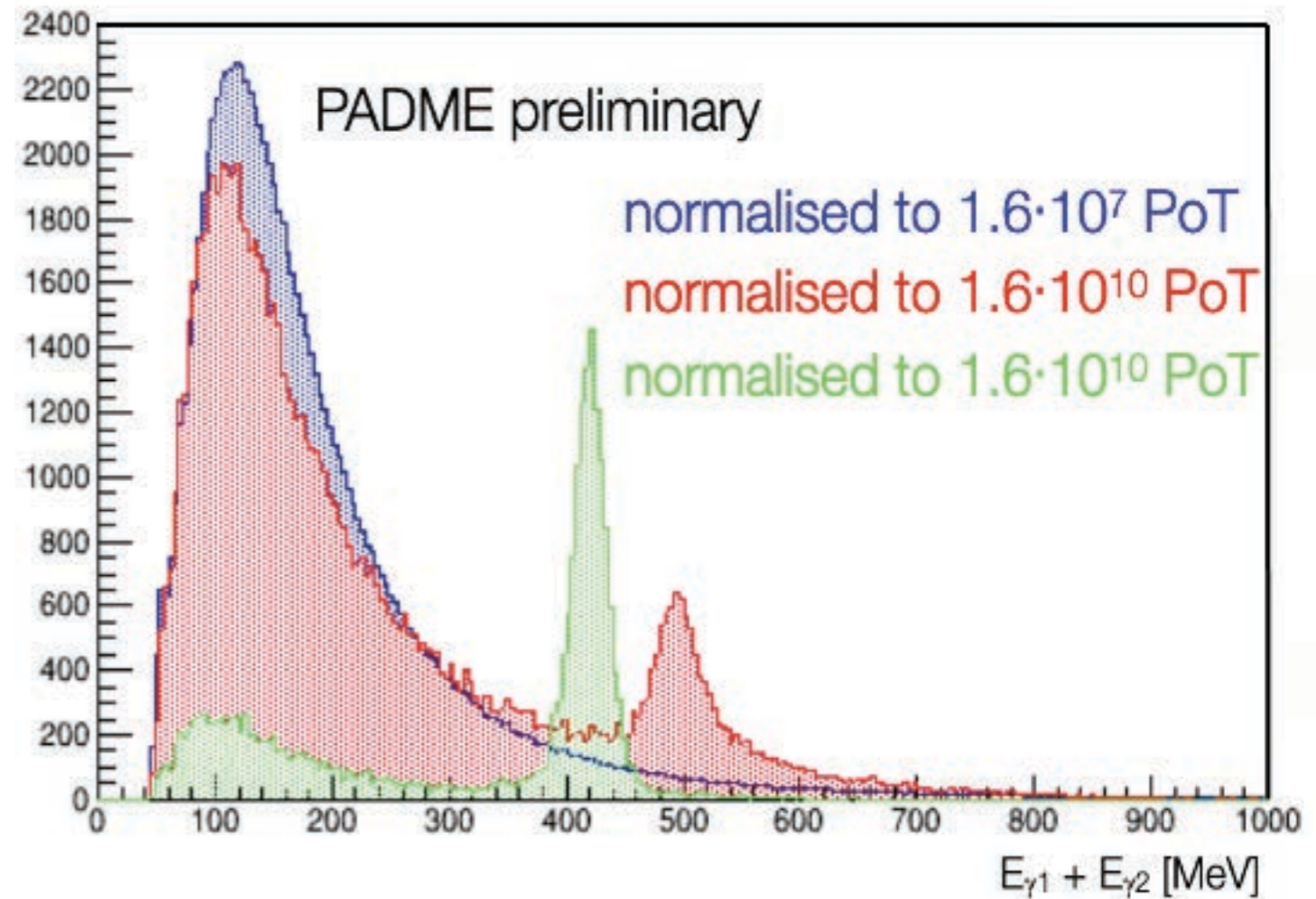
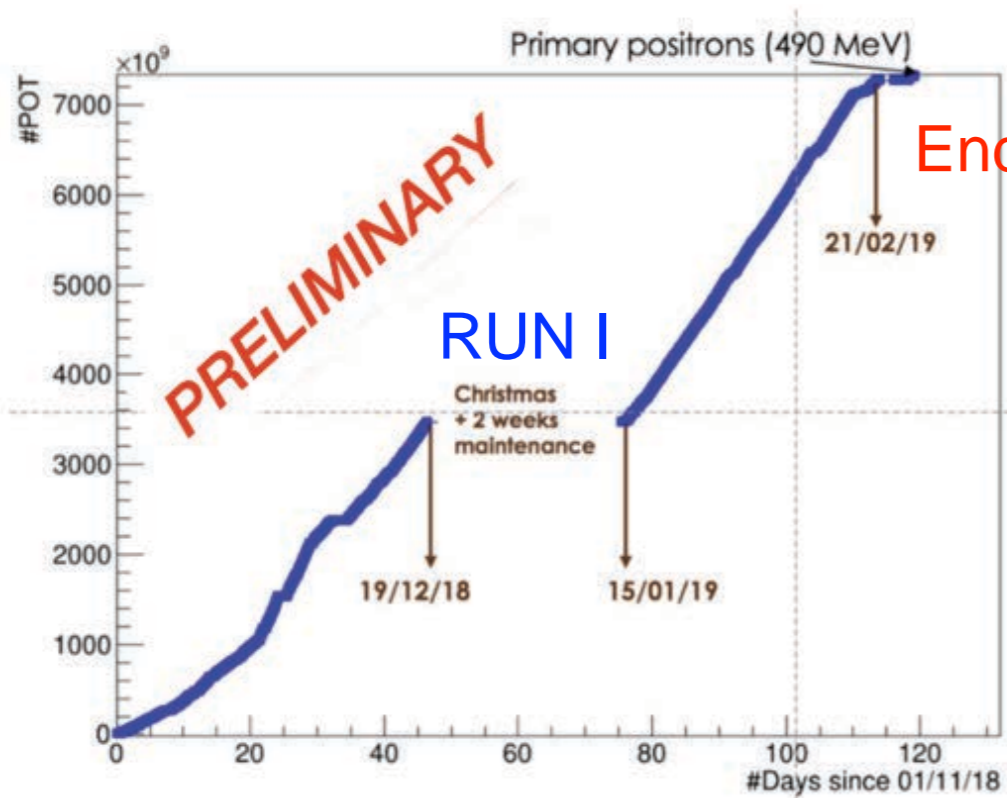


Bersaglio attivo in diamante con strip grafite in vuoto



Rivelatore a barre di scintillatore in vuoto

TESI DISPONIBILI A PADME



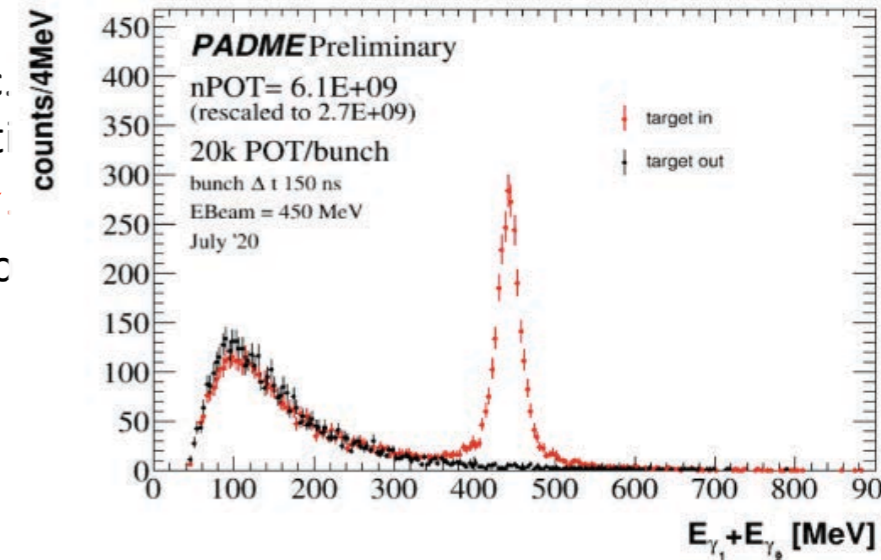
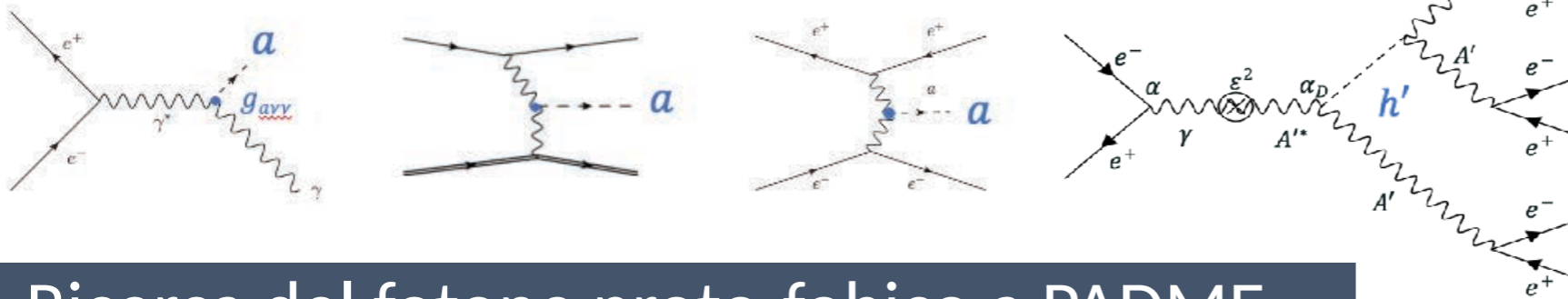
Beam quality dramatically improved in RUN II compared to RUN I.
Data sample of similar size $\sim 6E12$ POT

TESI DISPONIBILI A PADME

Analisi dei dati a PADME

Dopo il Run I terminato in Feb. 2019 si è svolta una seconda presa dati RUN II tra Sett-Dic. 2020. Oltre alla ricerca di segnali di **dark photon** con segnatura di massa mancante in eventi $e^+e^- \rightarrow \gamma + \text{invisibili}$, è possibile studiare con precisione canali di fisica come $e^+e^- \rightarrow \gamma\gamma$. Sono possibili ricerca di altri segnali di nuova fisica, come **axion-like particles** $e^+e^- \rightarrow a\gamma$ e anche **dark Higgs** (in 4 o 6 leptoni).

ALPs [2012.07894](#) : Dark Higgs :[2012.04754](#)

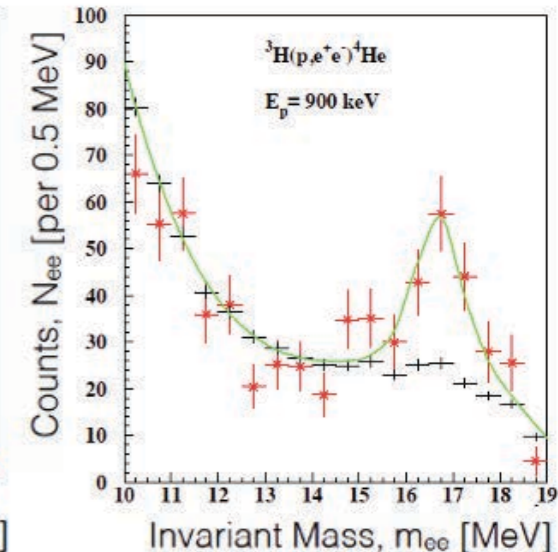
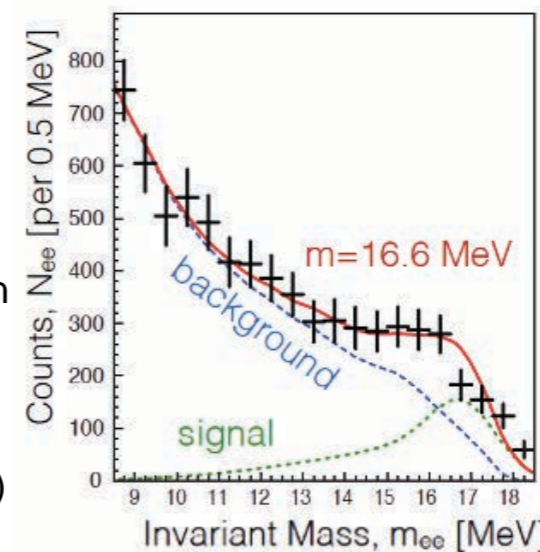


Ricerca del fotone proto-fobico a PADME

E' stato osservata dal laboratorio MTA ATOMKI di Debrecen (Ungheria) un eccesso di eventi e^+e^- di massa 16.7 MeV nelle transizioni del ^8Be che sarebbe compatibile con l'esistenza di una **nuova forza oscura** e del suo mediatore bosone X che decadrebbe in coppie.

Recentemente il risultato è stato rafforzato da un'analogia osservazione nelle transizioni dell' ^4He . La miglior verifica dell'ipotesi particellare proposta per spiegare l'anomalia, sarebbe l'osservazione del processo inverso $e^+e^- \rightarrow X$. L'esperimento PADME ha a disposizione un fascio di positroni di energia adatta a produrre in maniera risonante il bosone X potendo così verificarne l'esistenza con grande sensibilità. Il lavoro di tesi consisterà in uno studio fenomenologico della sensibilità dell'esperimento PADME a tale nuova particella.

A. J. Krasznahorkay, et al. Phys. Rev. Lett. 116, 042501, <https://arxiv.org/abs/2104.10075v1>



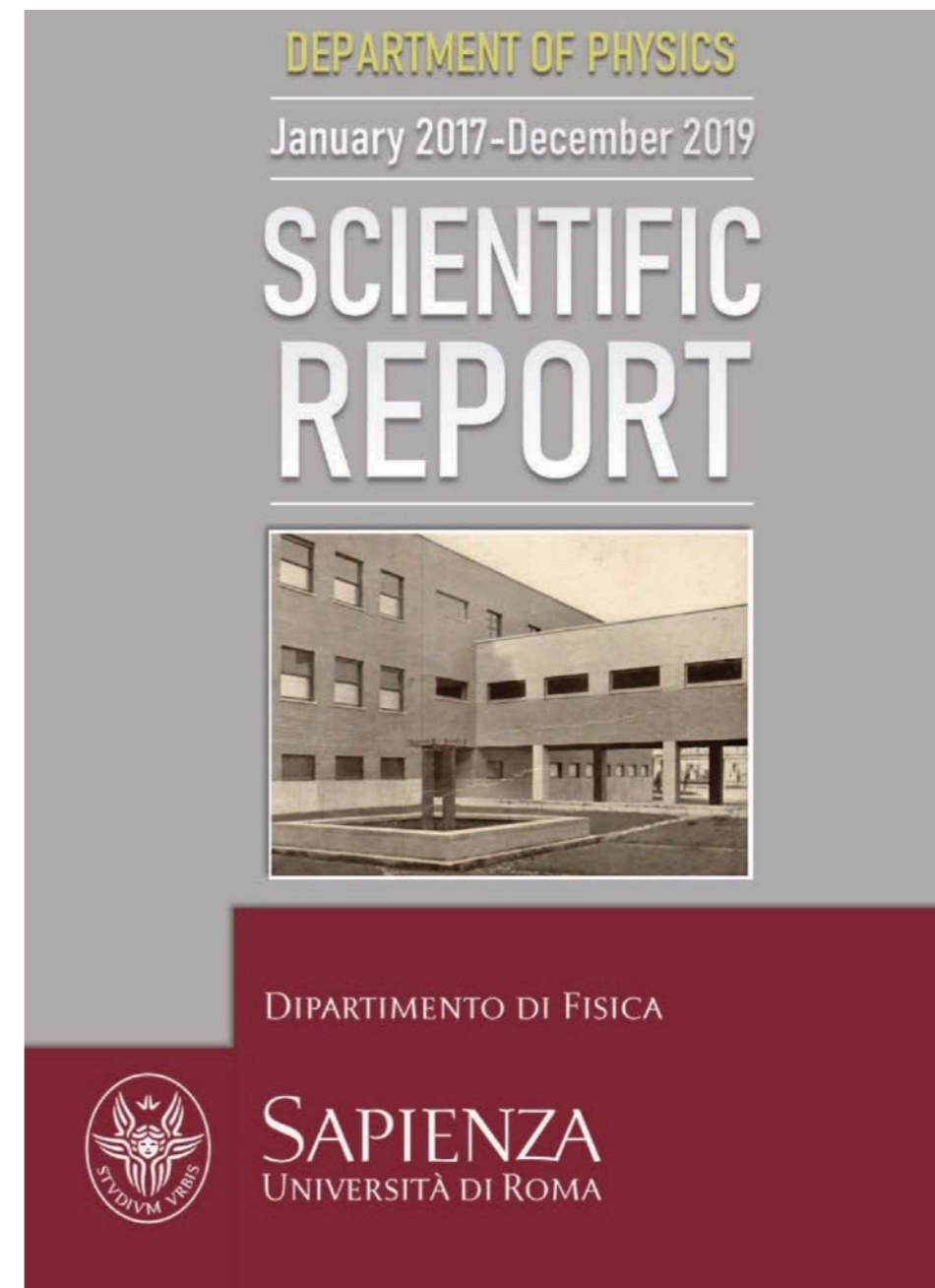
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<http://www.lnf.infn.it/acceleratori/padme/>

SCIENTIFIC REPORT OF DEPARTMENT

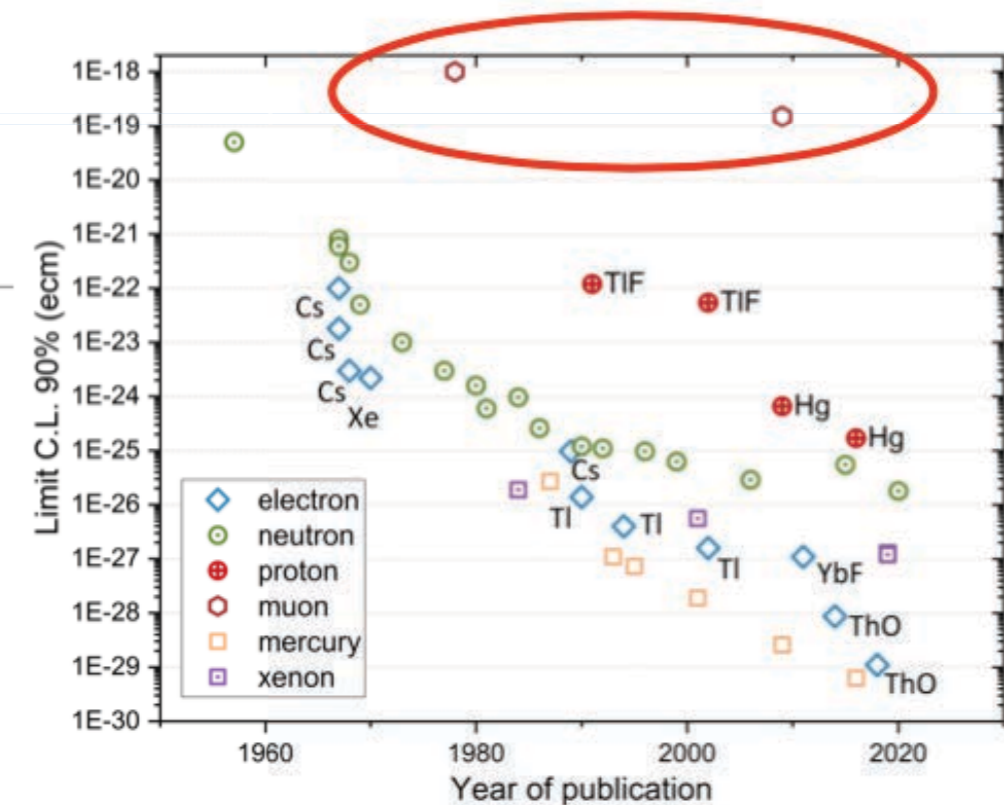
- A **recent (2017-2019) and complete insight** on the physics department and INFN section activity
- Particle Physics and Fundamental Interactions described in a specific section of the report
- <http://www.phys.uniroma1.it/fisica/ricerca/scientific-report>



BACKUP

Electron and muon EDM

- The need of non-standard CPV sources to explain the **matter-antimatter asymmetry of the Universe** motivates many searches for EDMs
- Strong constraints exist on the electron EDM (spin precession in molecular systems excited by lasers):



- the muon EDM was somehow experimentally overlooked, due to the indirect constraint coming from the electron EDM under minimal flavour violation (MFV) assumptions

$$|d_e|_{\text{exp}} \leq 8 \times 10^{-30} e \text{ cm} \quad \xrightarrow{\text{MFV}} \quad |d_\mu|_{\text{ind}} \leq 1.6 \times 10^{-27} e \text{ cm}$$

$$|d_\mu|_{\text{exp}} \leq 1.5 \times 10^{-19} e \text{ cm}$$

- Current muon EDM limits produced as by-product of g-2 experiments
- **Indeed the existing tensions, pointing toward LFUV, challenge the MFV scenario and make a dedicated experiment to search for a muon EDM of great interest**