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

Activities' review and Master thesis proposals

Daniele del Re

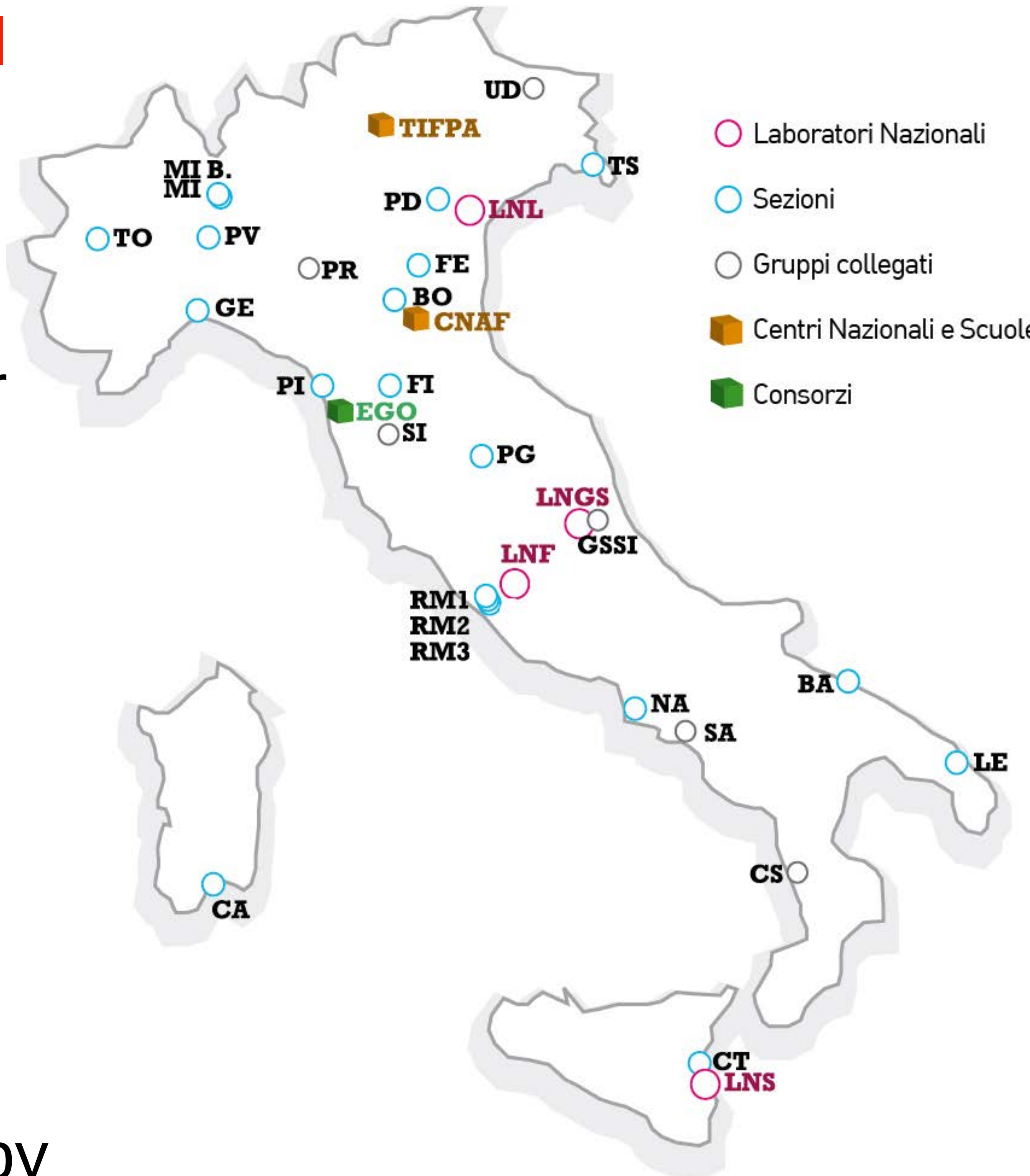
CSN1 coordinator of INFN Sezione Roma

SAPIENZA UNIVERSITÀ DI ROMA

INFN Istituto Nazionale di Fisica Nucleare

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**



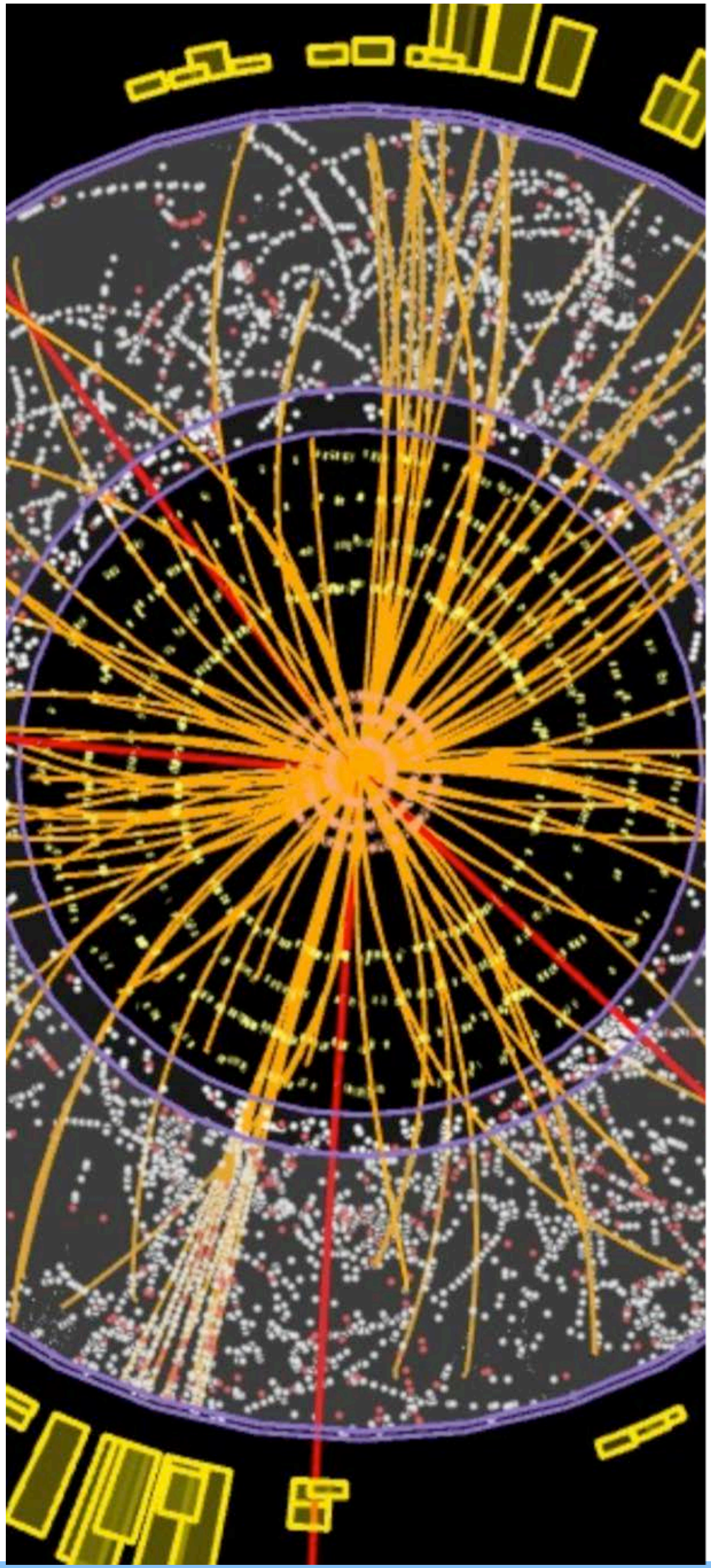
INFN: Research Topics

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.: Evaristo Cisbani):**
  - 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.: Paolo Valente):**
  - technological and inter-disciplinary research, including promotion of the use of fundamental physics instruments, methods and technologies in other sectors

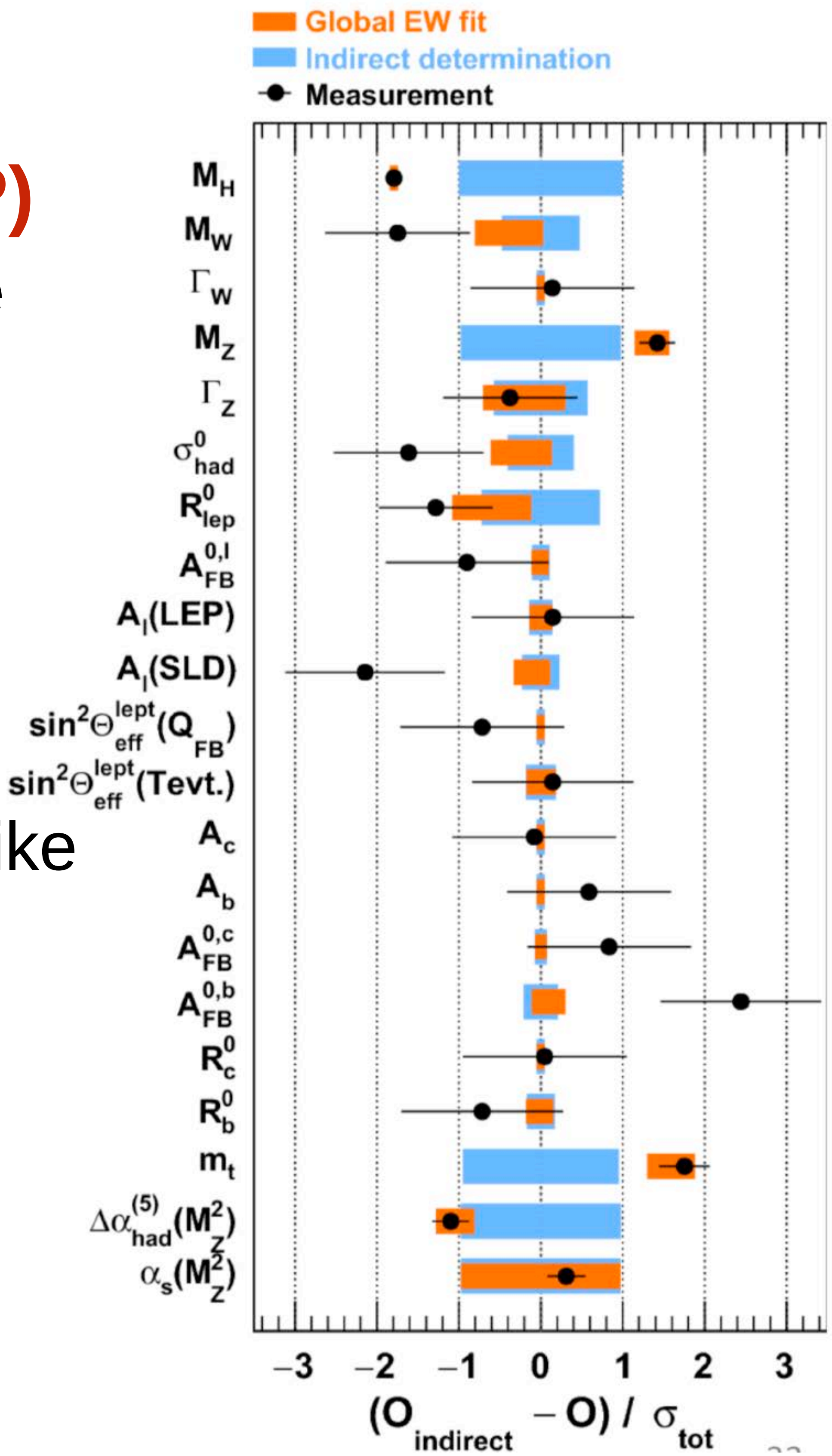
Fundamental Physics at Accelerators

- 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**

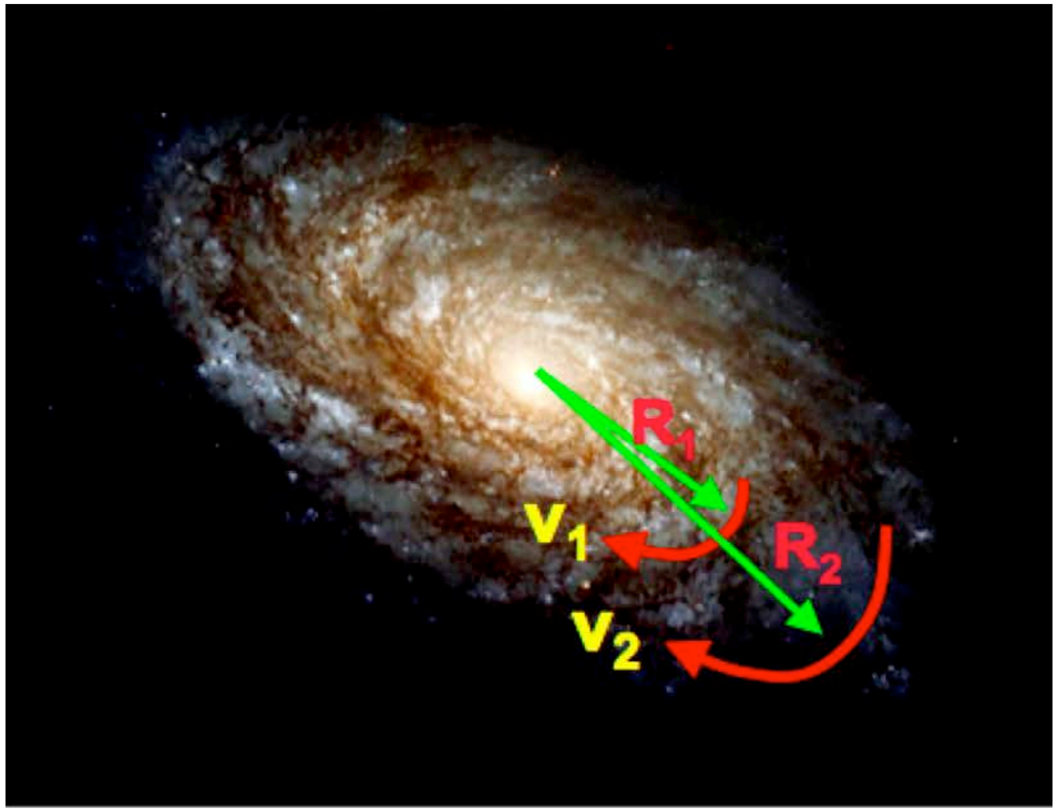
$$\frac{mv^2(r)}{r} = \frac{mM(r)G}{r^2}$$

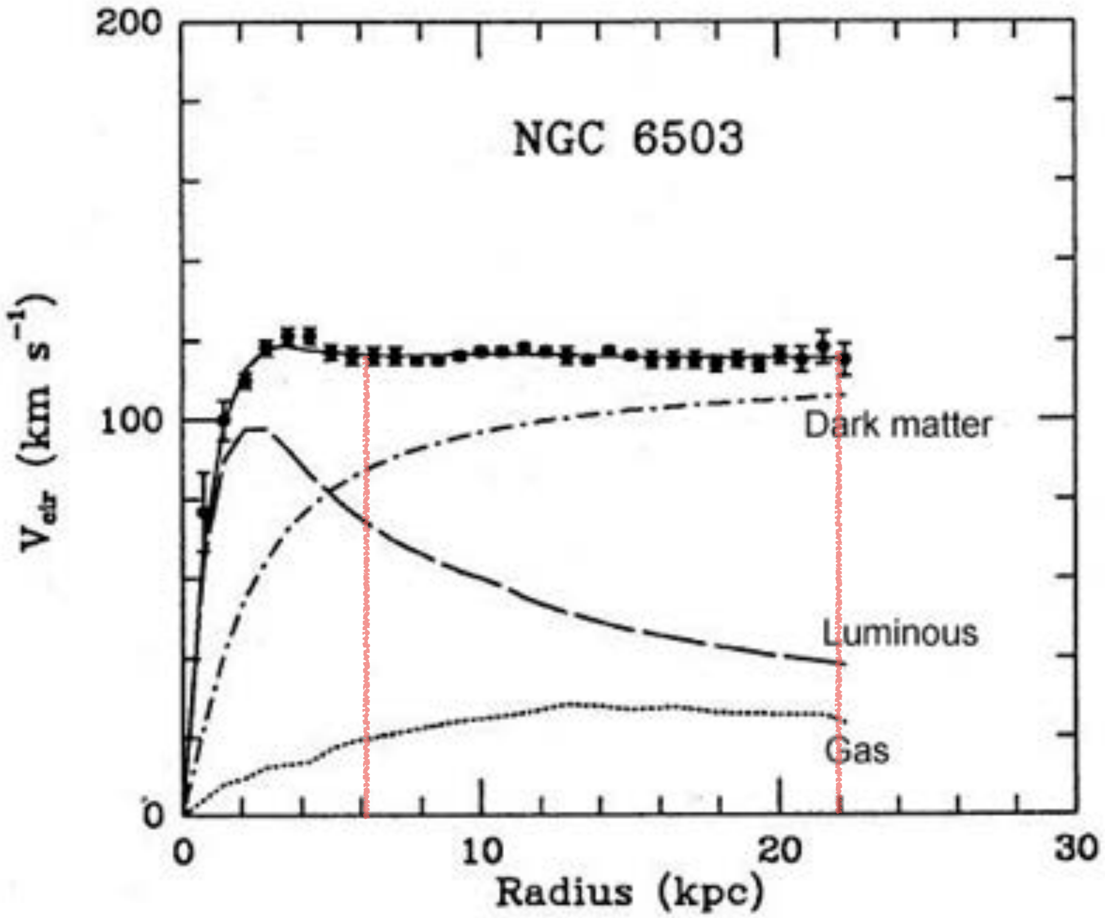
- **Galaxy** mass mainly within **core radius of R**

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

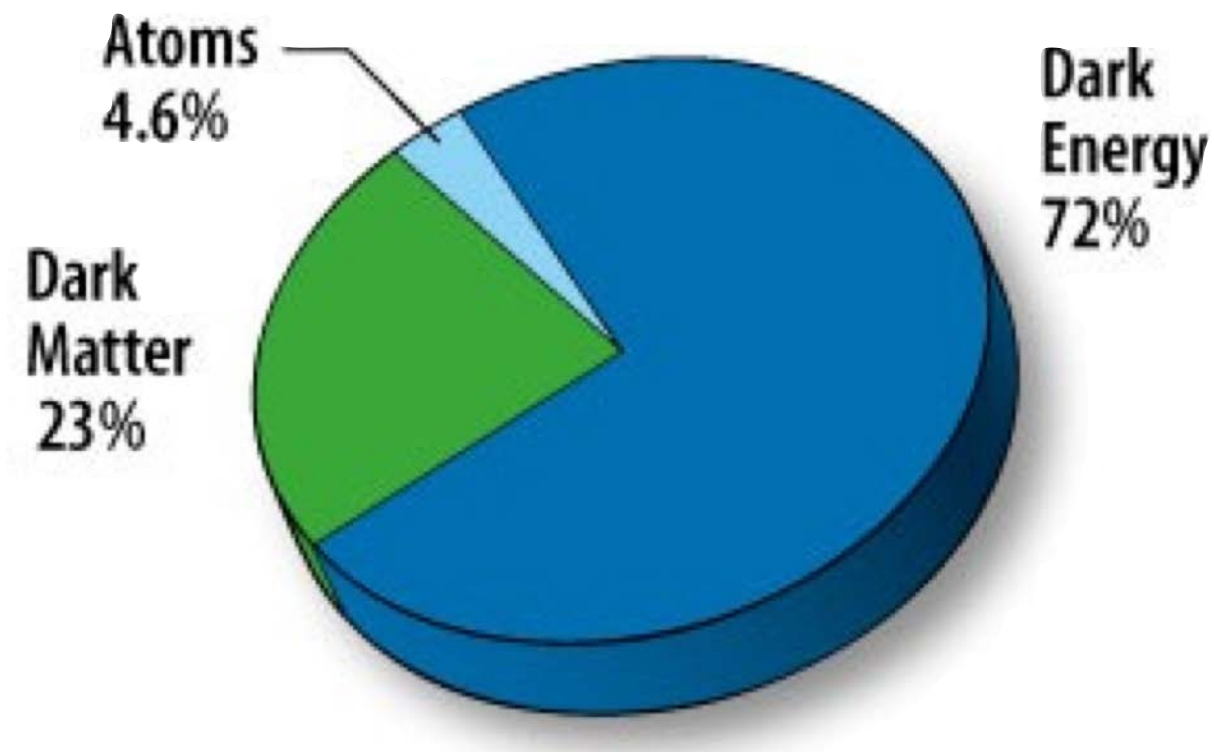
$$v(r) = \begin{cases} \propto r & r < R_0 \\ \propto r^{-1/2} & r \geq R_0 \end{cases}$$

- **Galaxy rotation velocity**



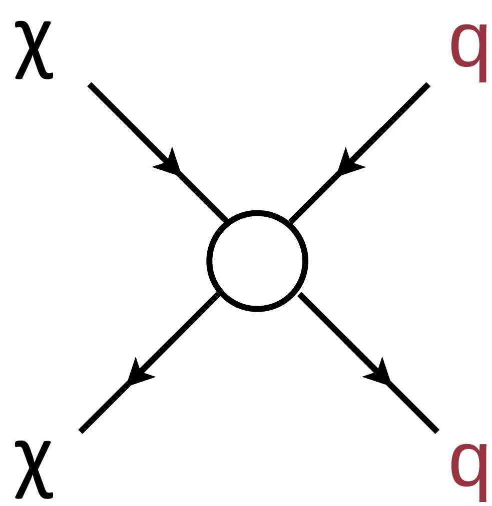


Dark Matter

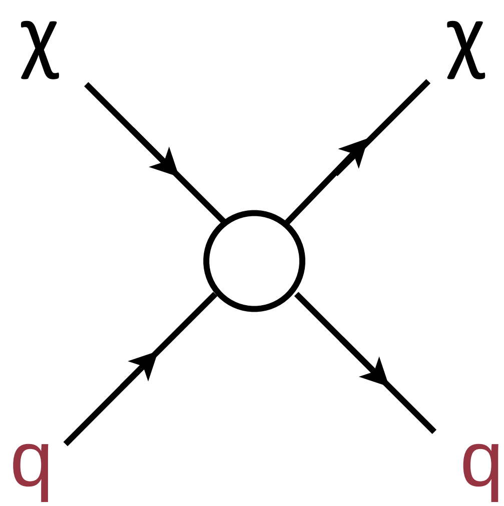


- **Properties**
  - stable
  - no electric or color charge
  - very weak interaction with Standard Model particles
  - subject to gravity interaction
- **Several potential candidates fulfilling these requirements for dark matter**
  - Dark: weakly interacting with electromagnetic radiation
  - Hot & dark: ultra-relativistic velocities
    - neutrinos
  - Warm & dark: very high velocity
    - sterile neutrinos, gravitinos
  - Cold & dark: moving slowly
    - Lightest SUSY particle (neutralino, gravitino as LSP)

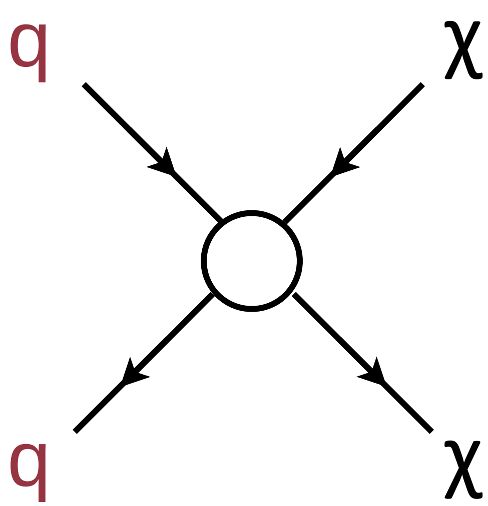
DARK MATTER INTERACTION



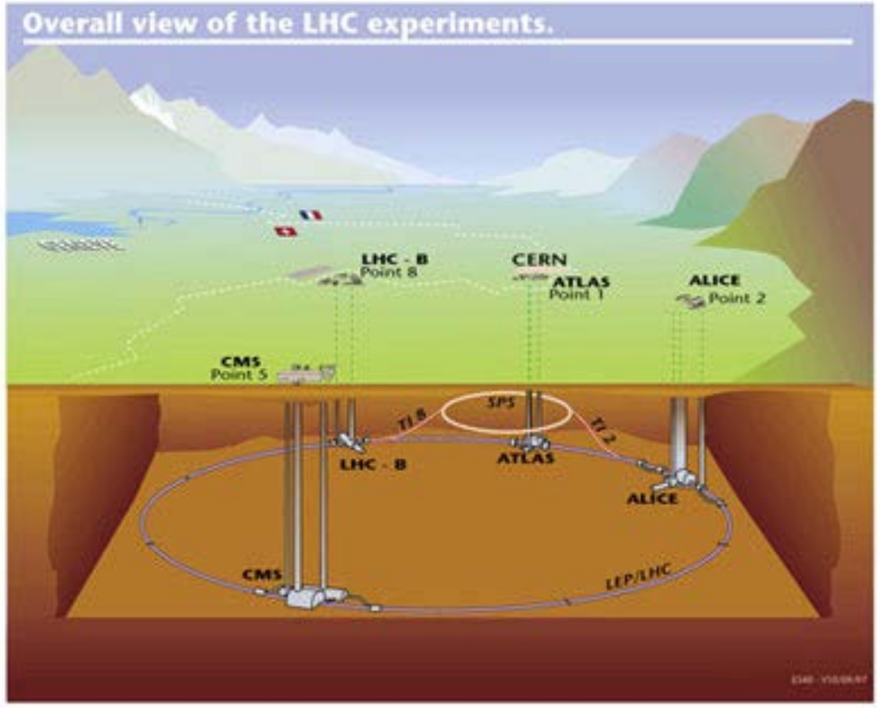
Indirect Detection



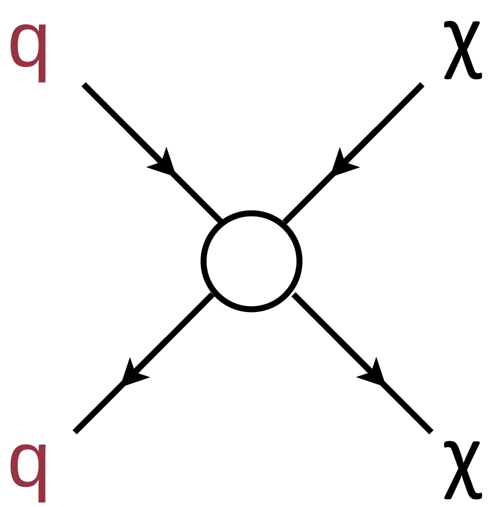
Direct Detection



Production at Colliders

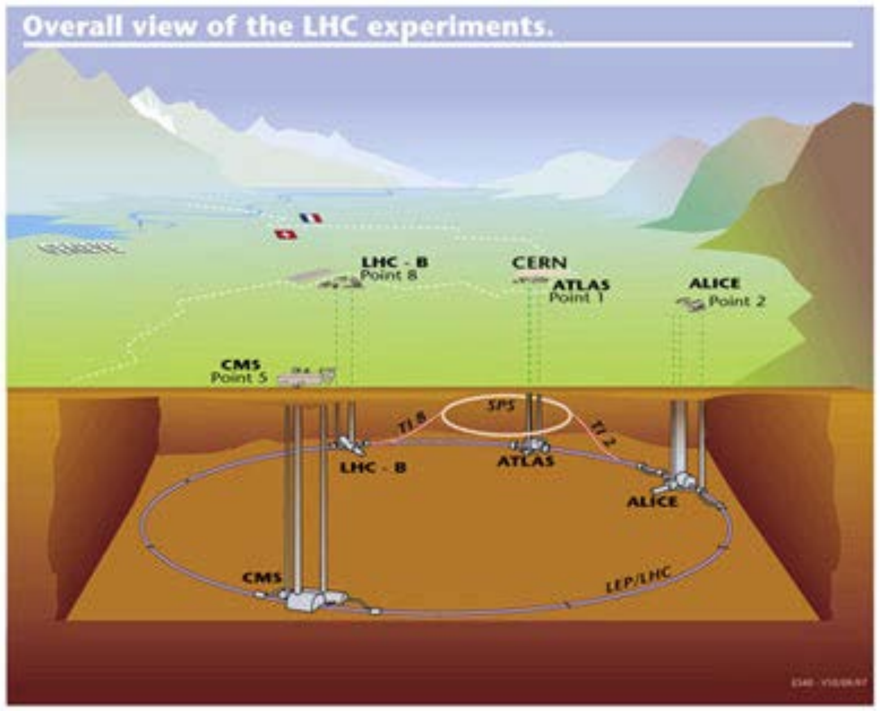


DARK MATTER INTERACTION



- **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

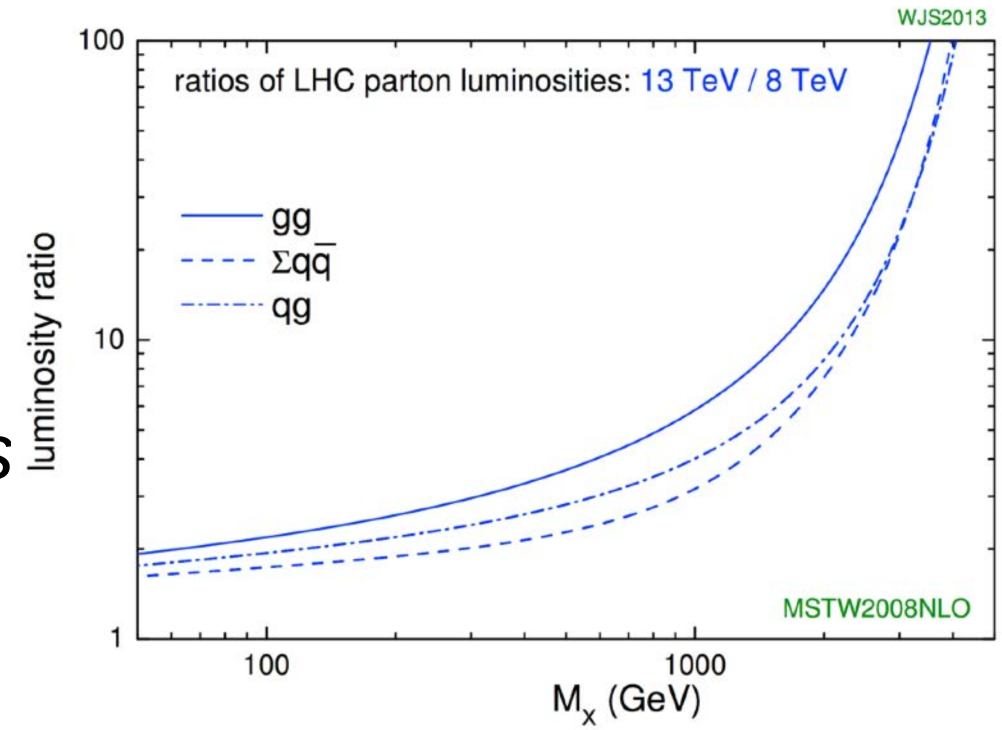
Production at Colliders



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, Belle2, MEGII, KLOEII, PADME*

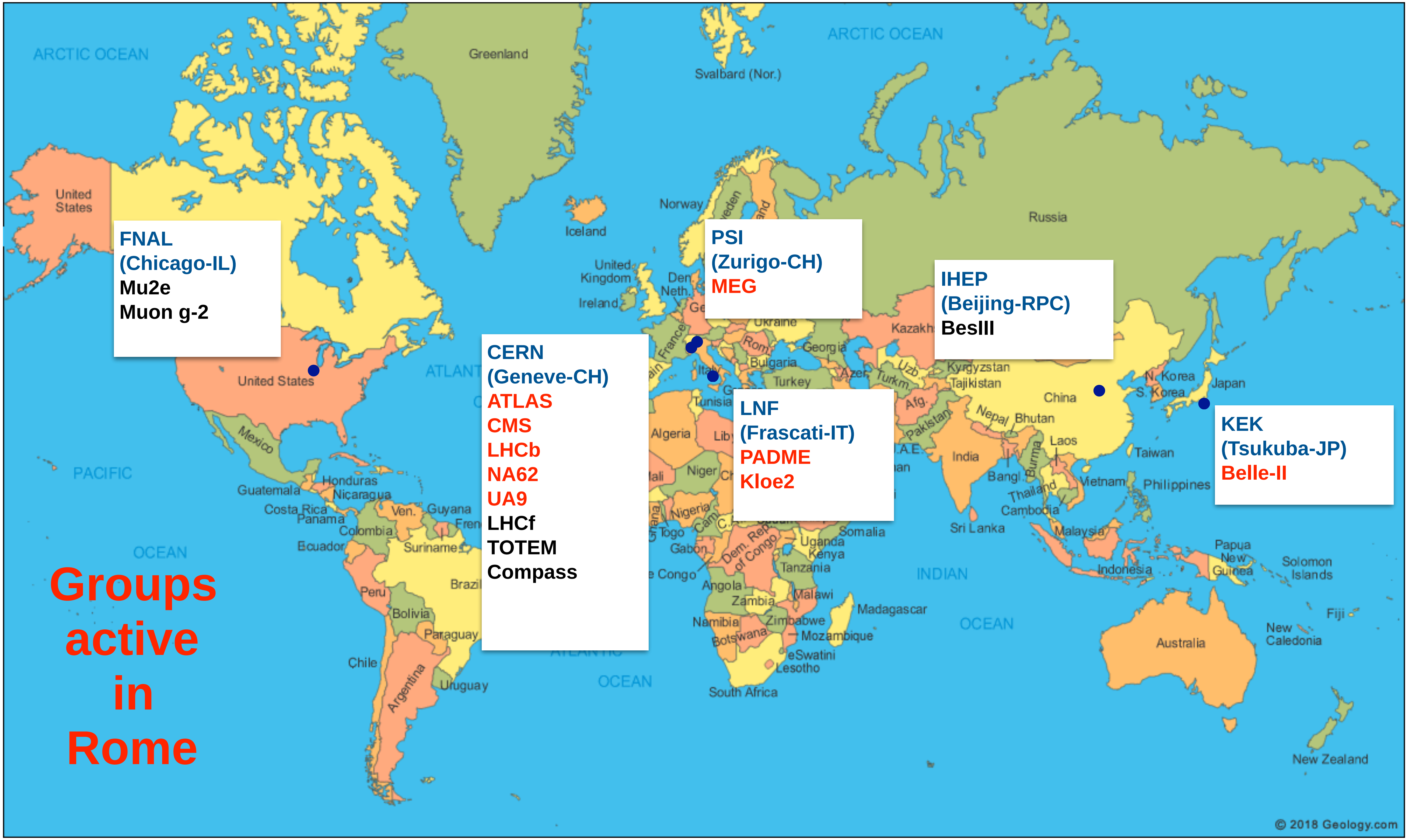
Luminosity [Machine parameter]

$$N = L \cdot \sigma$$

Event Rate [Measured]

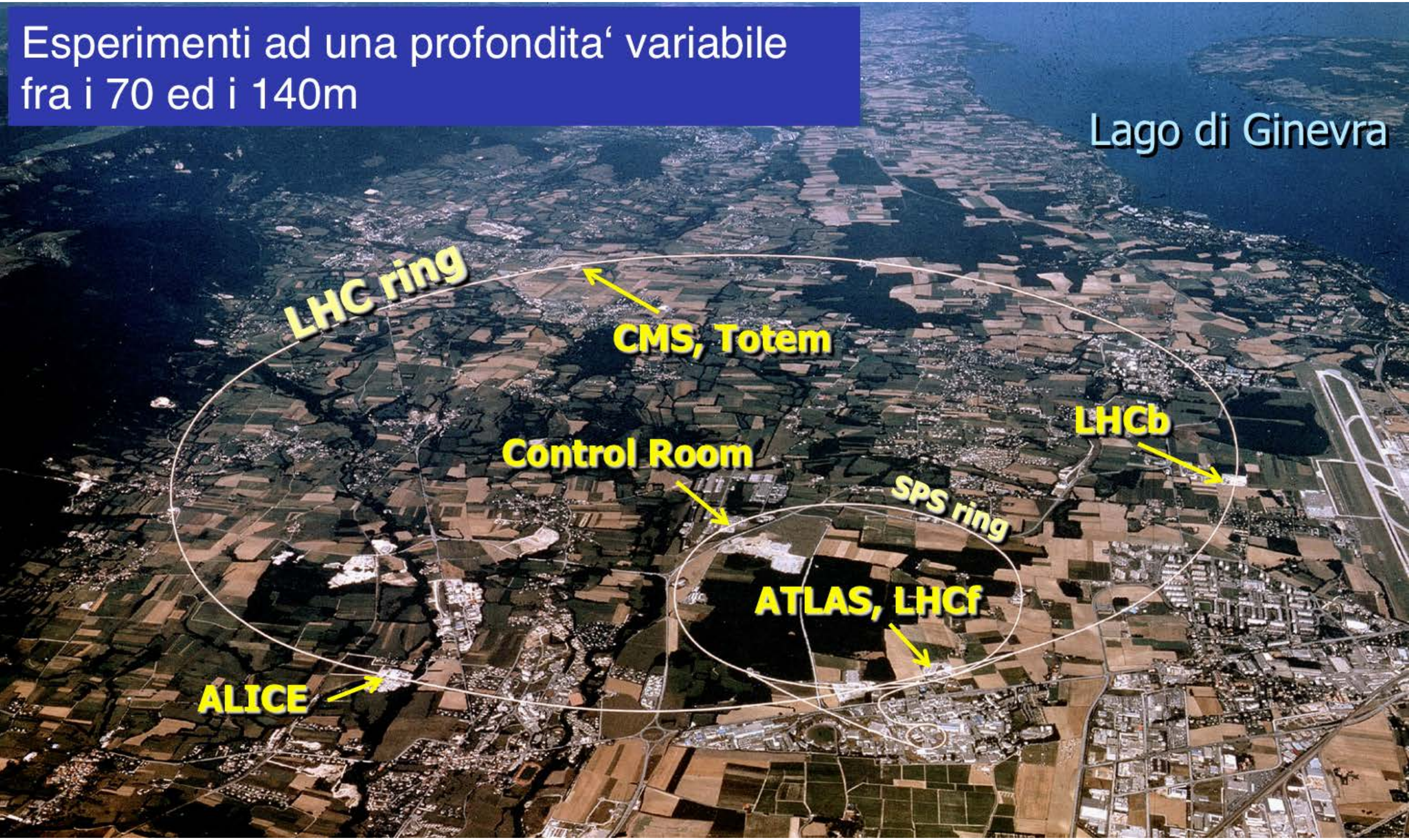
Cross Section

EXPERIMENTS AND ACCELERATORS

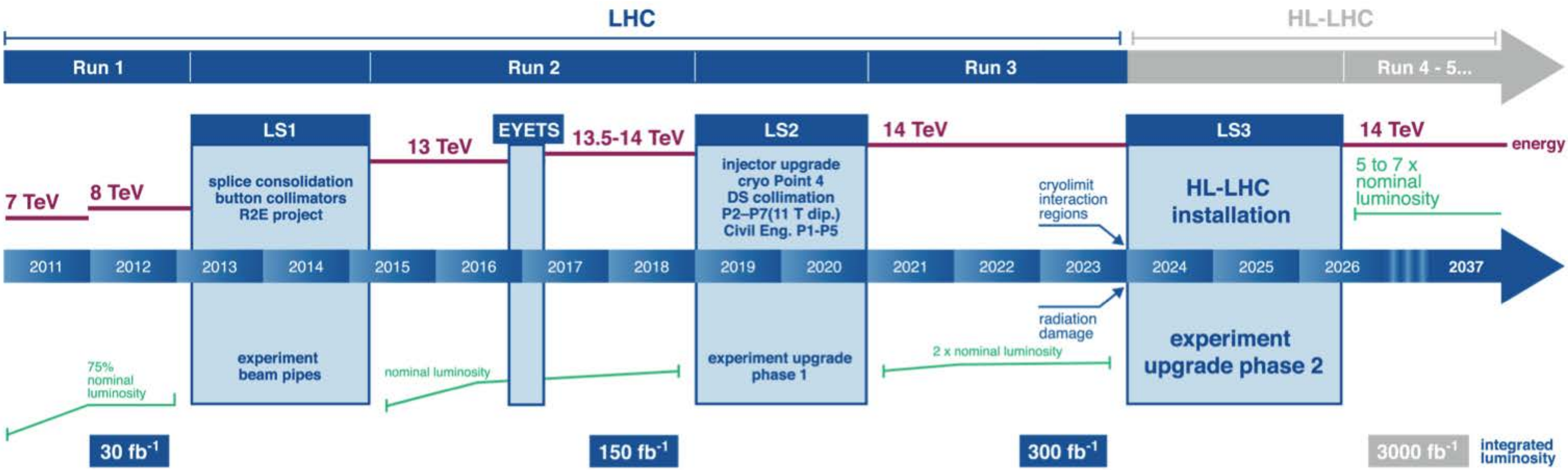


LHC

LHC ACCELERATOR



LHC SCHEDULE



Run 1

Magnet splice update

Run 2 at ~full design energy

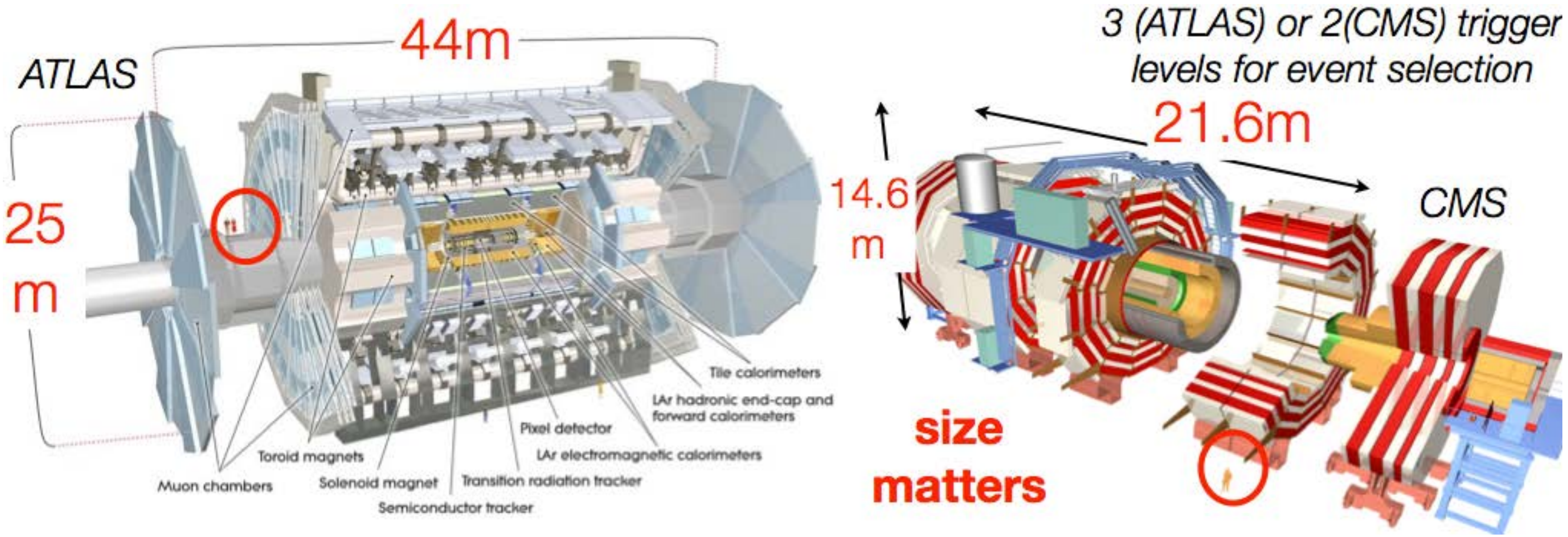
Phase I upgrades (injectors)

Run 3 → original design lumi

Phase II upgrades (final focus)

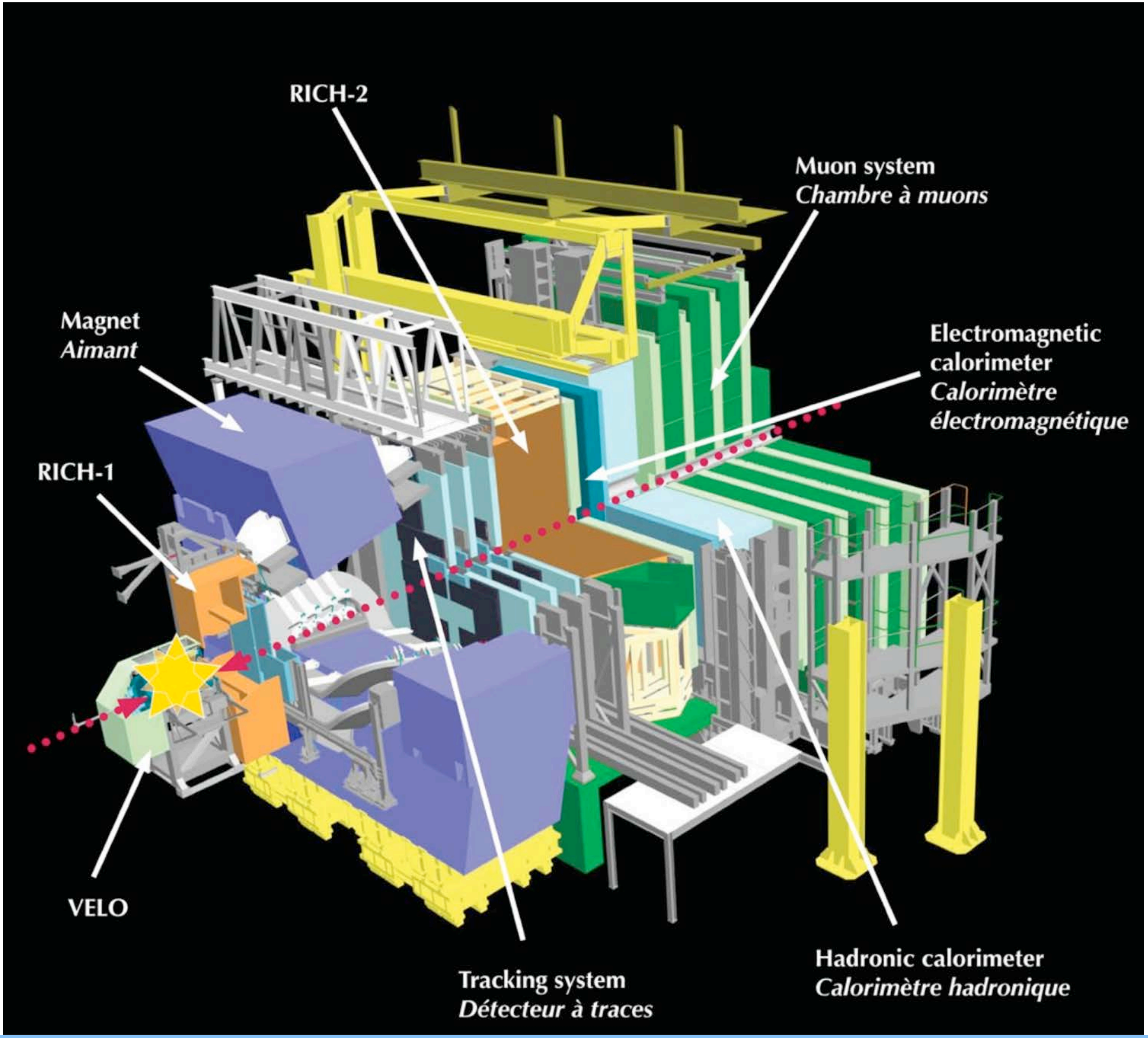
HL-LHC: ten times design lumi

ATLAS AND CMS



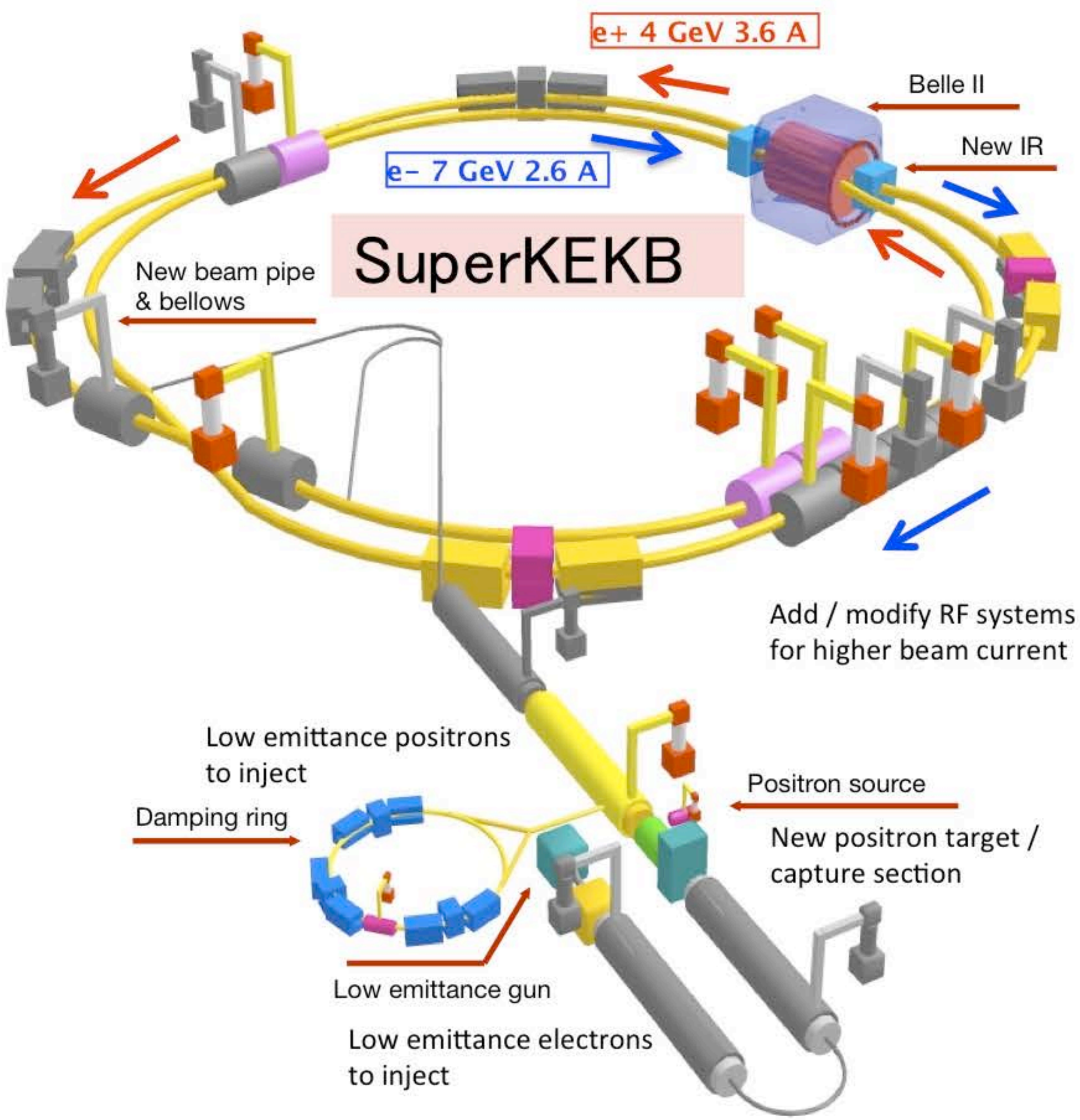
	ATLAS	CMS
Magnetic Field	solenoid (2 T) + toroid (0.5÷1T)	3.8 T solenoid + return yoke
Tracker	Si pixel, strips + TRT	Si pixel, strips
EM Calorimeter	Pb + LAr	PbWO4 crystals
Had Calorimeter	Fe+scint./Cu+LAr/W+Lar (≥11λ)	Brass+scintillator(≥7λ)/Fe+quartz
Muon	air-toroid muon spectrom.	iron return-yoke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

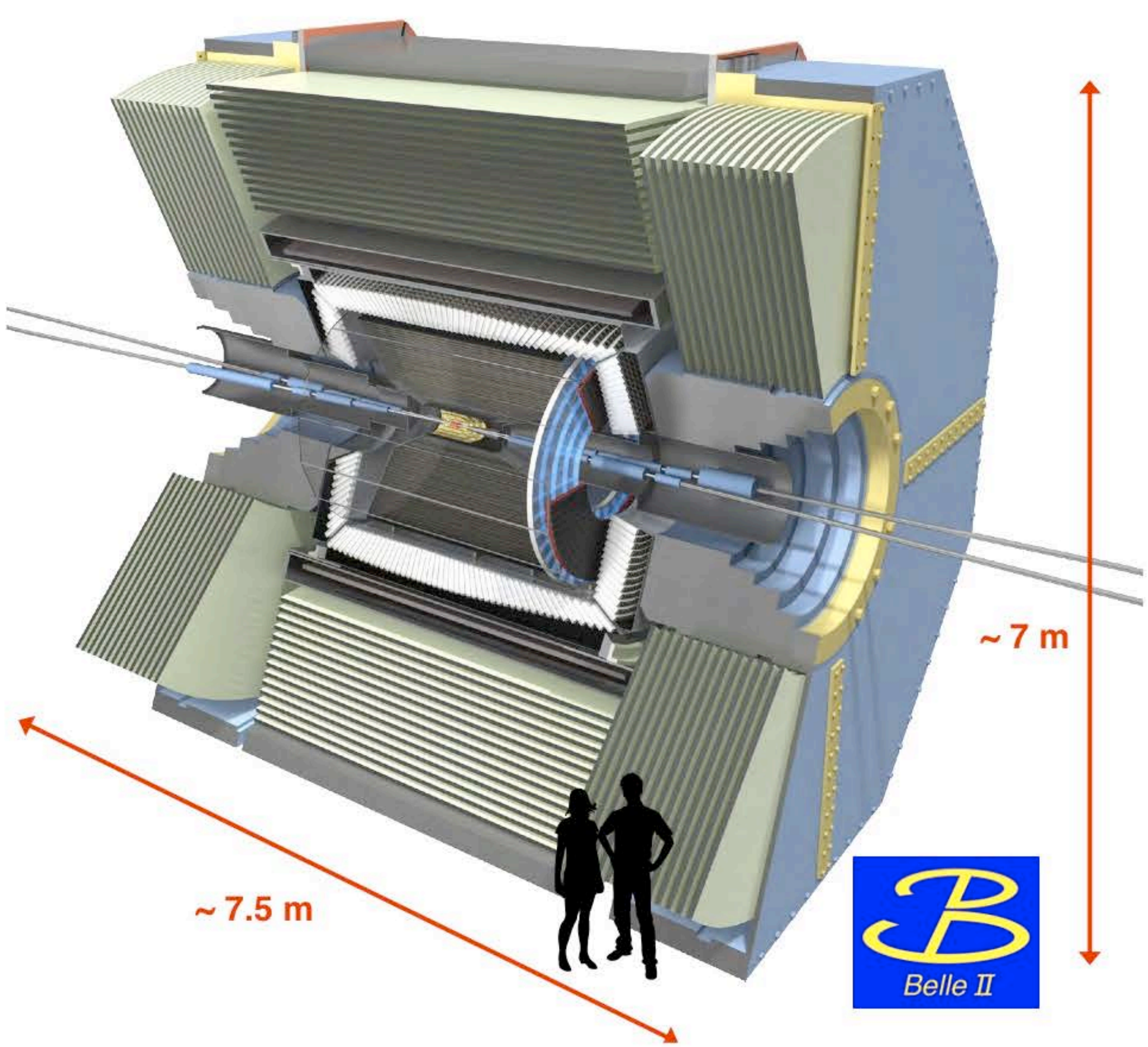
LHCb


RICH-2
Muon system
Chambre à muons
Magnet
Aimant
Electromagnetic
calorimeter
Calorimètre
électromagnétique
RICH-1
VELO
Tracking system
Détecteur à traces
Hadronic calorimeter
Calorimètre hadronique

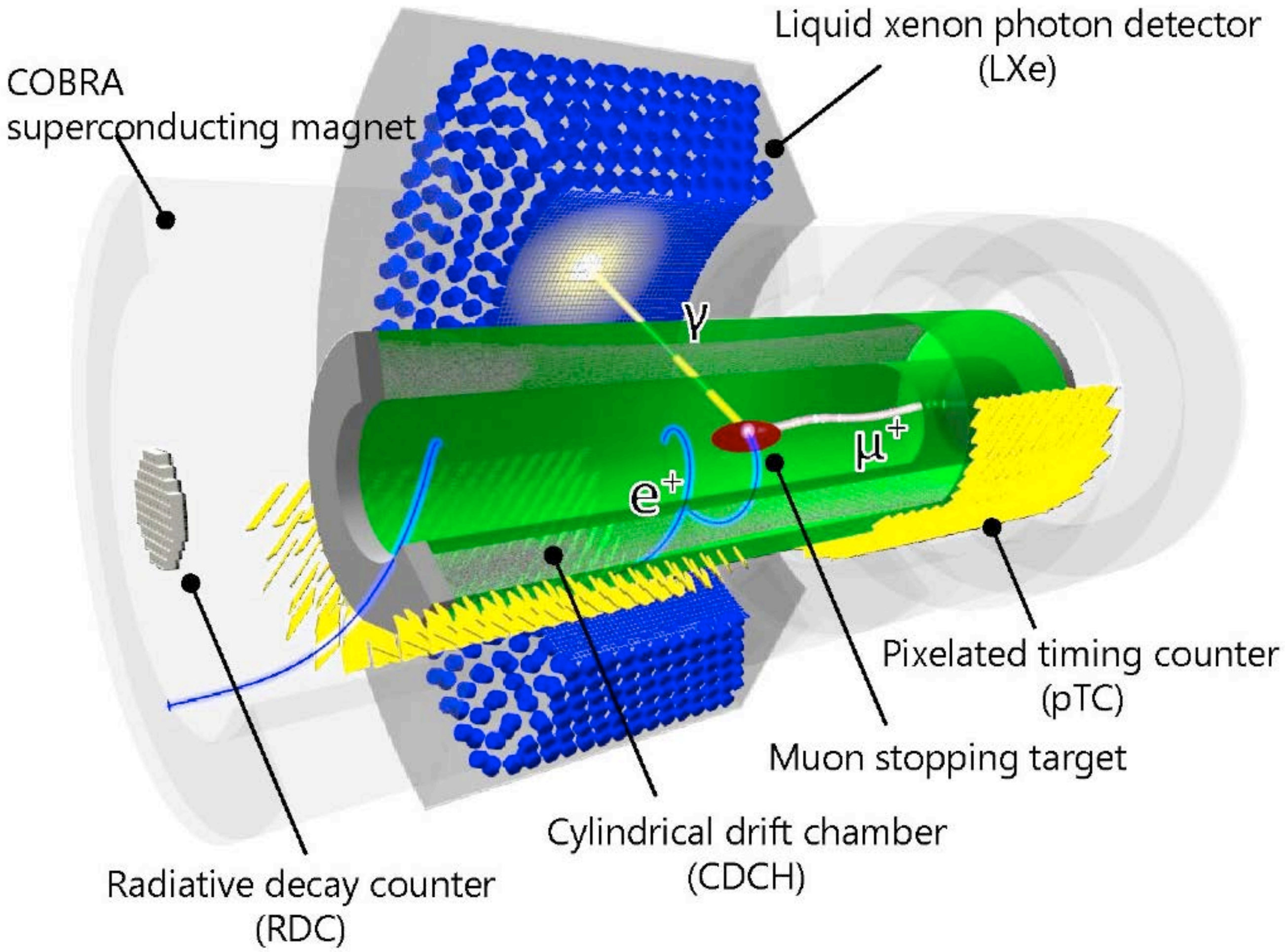
Non-LHC

B Factories


e+ 4 GeV 3.6 A
Belle II
New IR
e− 7 GeV 2.6 A
SuperKEKB
New beam pipe
& bellows
Add / modify RF systems
for higher beam current
Low emittance positrons
to inject
Damping ring
Positron source
New positron target /
capture section
Low emittance gun
Low emittance electrons
to inject

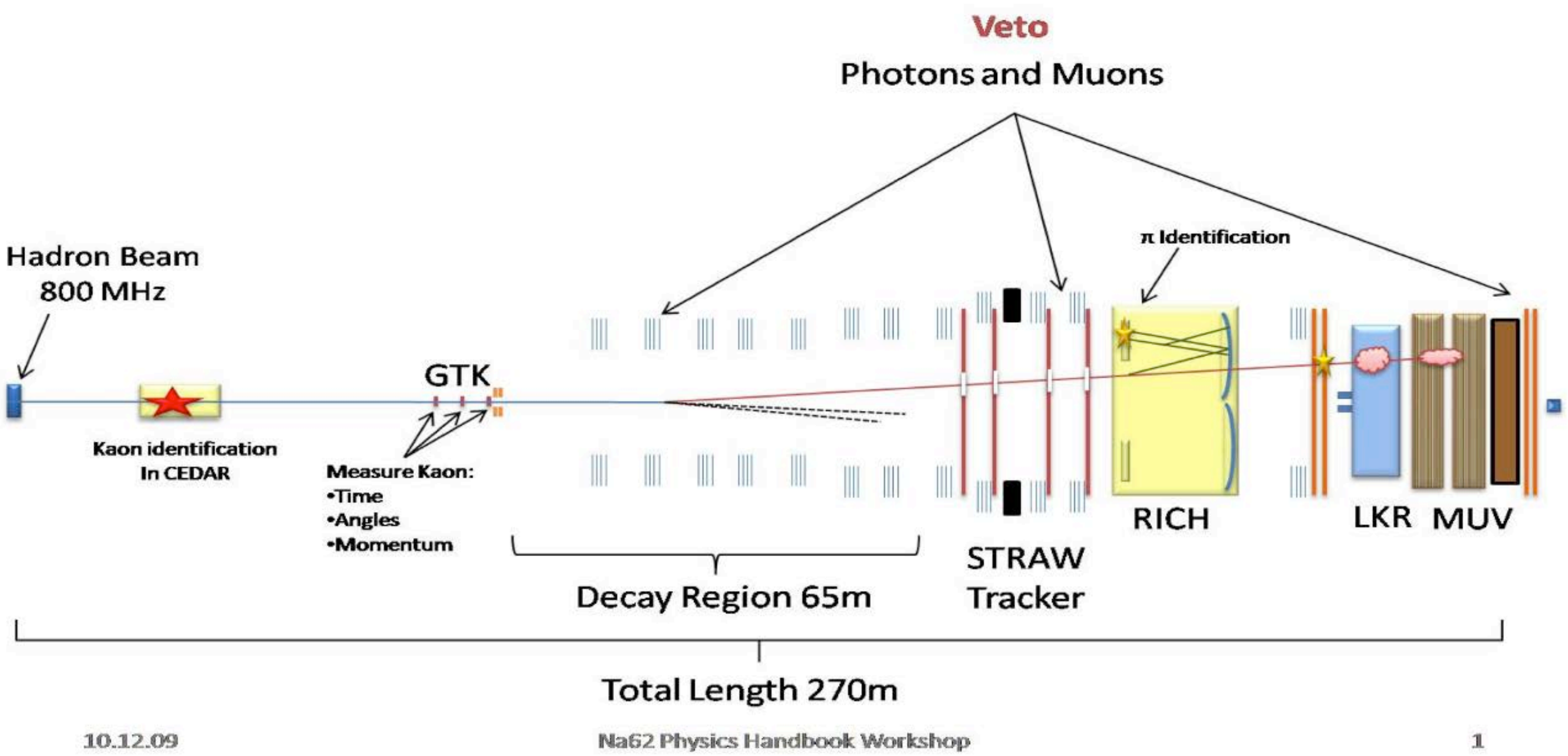

~ 7 m
~ 7.5 m
Belle II

Search for Rare Processes



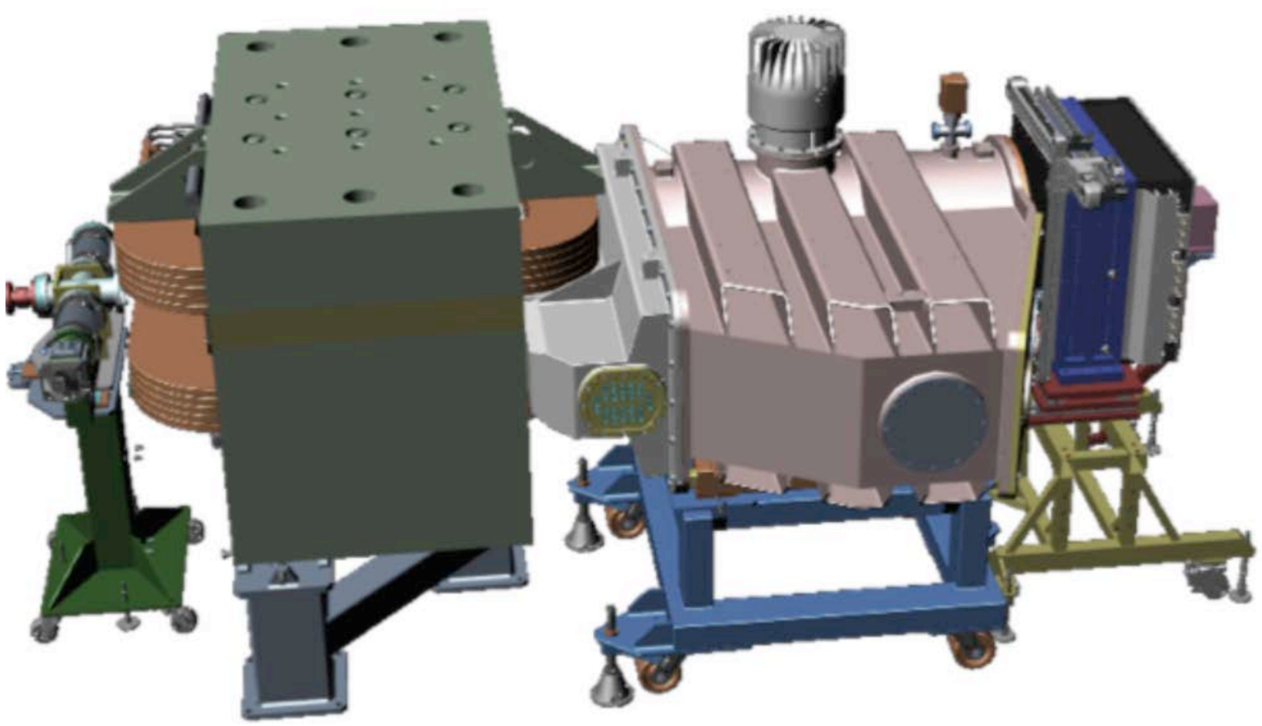
MEGII

SEARCH FOR RARE PROCESSES



NA62

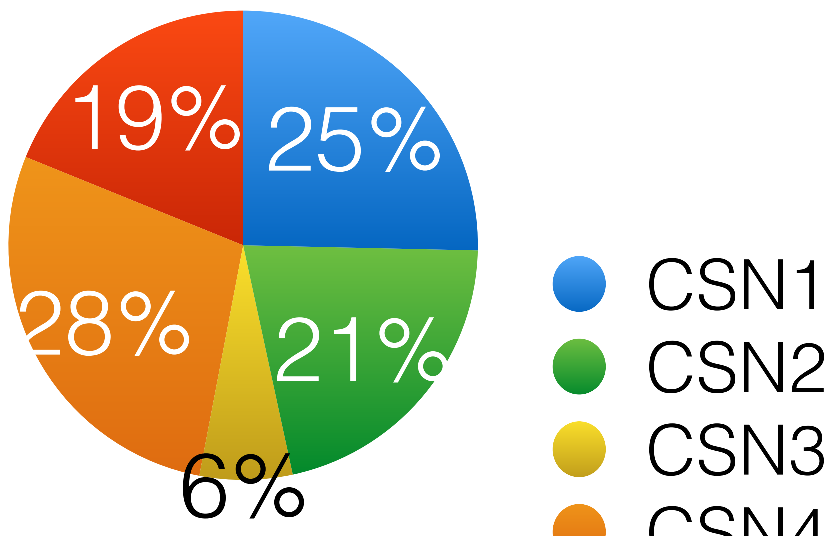
PADME



Activities in Rome

THE ROMA1 INFN SECTION

- About **212 physicists and technicians** involved in INFN research activities in Rome



- **CSN1 Experiments in Roma1:**

Esperime	Acceleratore	Responsabil	E-mail
ATLAS	LHC @ CERN	A.Nisati	aleandro.nisati@cern.ch
Belle-2	SuperKEKB @ @ KEK	F.Ameli	fabrizio.ameli@roma1.infn.it
CMS	LHC @ CERN	D.Del Re	daniele.delre@roma1.infn.it
KLOE-2	Dafne @ LNF	P.Gauzzi	paolo.gauzzi@roma1.infn.it
LHCb	LHC @ CERN	R.Santacesari	roberta.santacesaria@roma1
MEG-2	PSI @ Zurigo	C.Voena	cecilia.voena@roma1.infn.it
NA62	Fixed Target SPS @	P.Valente	paolo.valente@roma1.infn.it
PADME	BTF @ LNF	M.Raggi	mauro.raggi@roma1.infn.it
UA9	SPS/HC @ CERN	G.Cavoto	gianluca.cavoto@roma1.infn.

ACTIVITIES IN ROMA1

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**

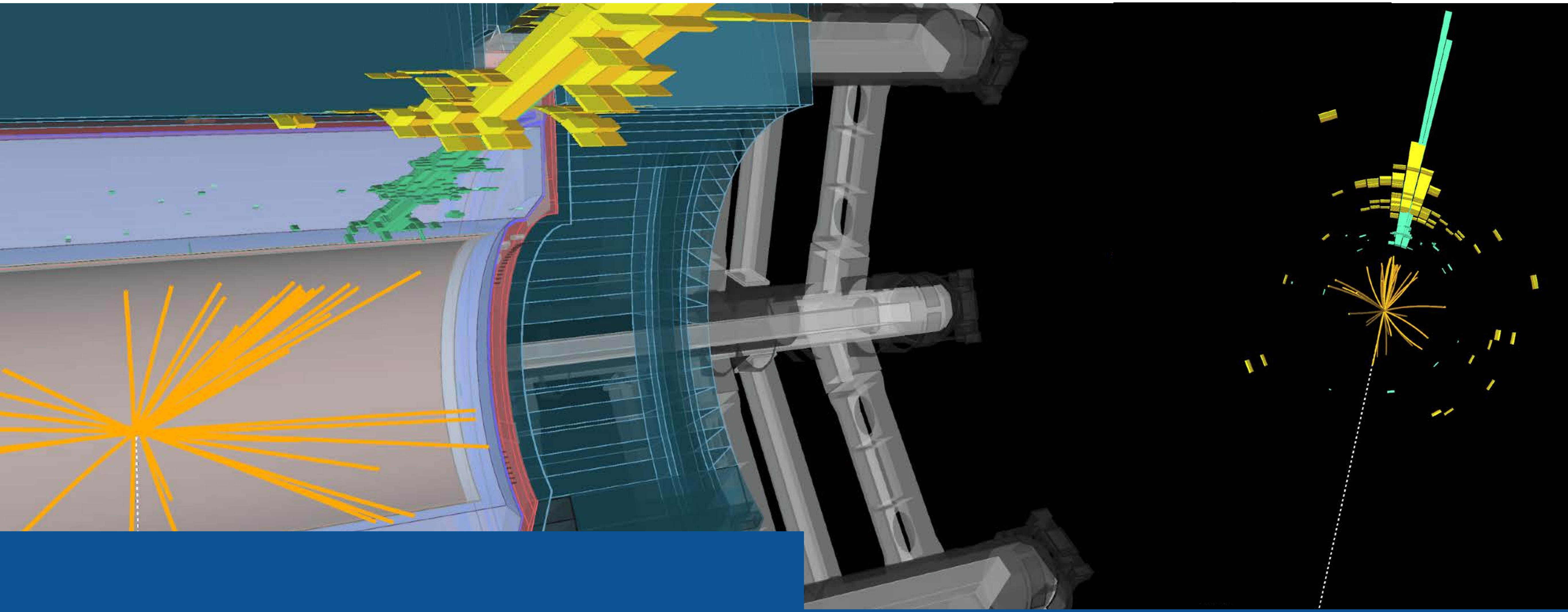
ACTIVITIES FOR STUDENTS (II)

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**

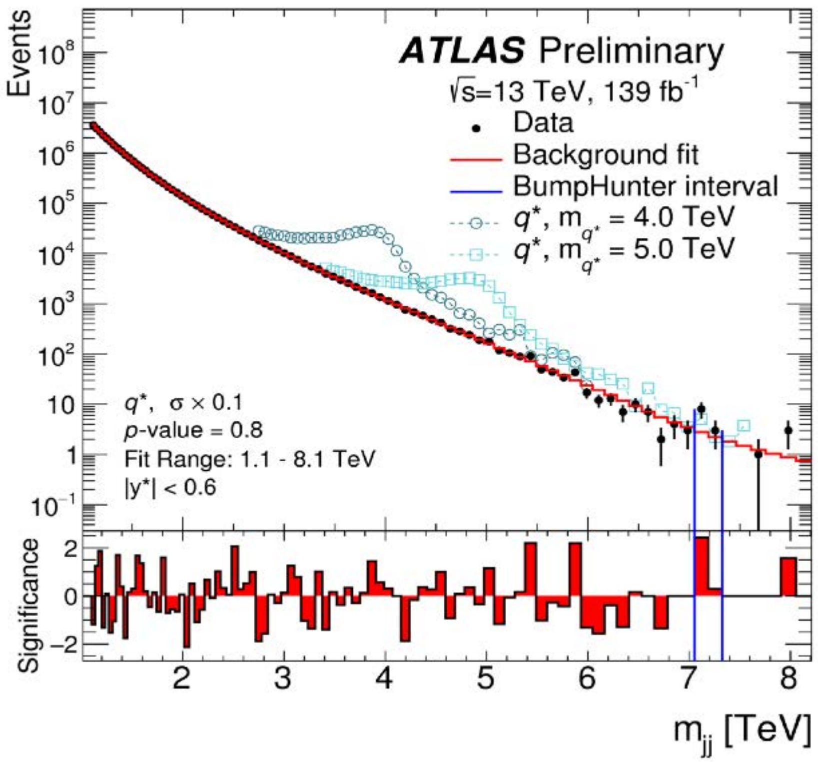


ATLAS - Roma1 activities

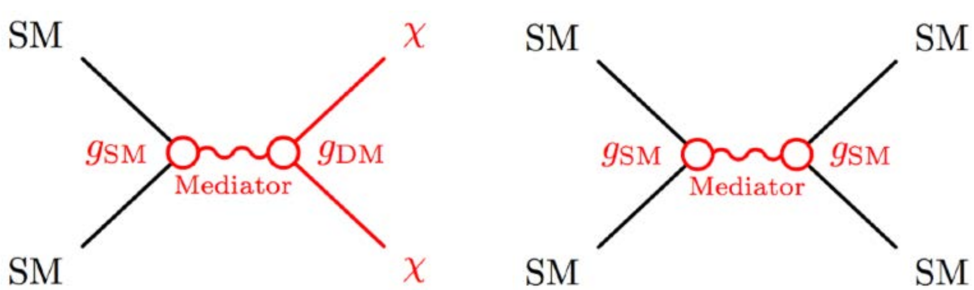
http://www.roma1.infn.it/exp/atlas/it/home-it/

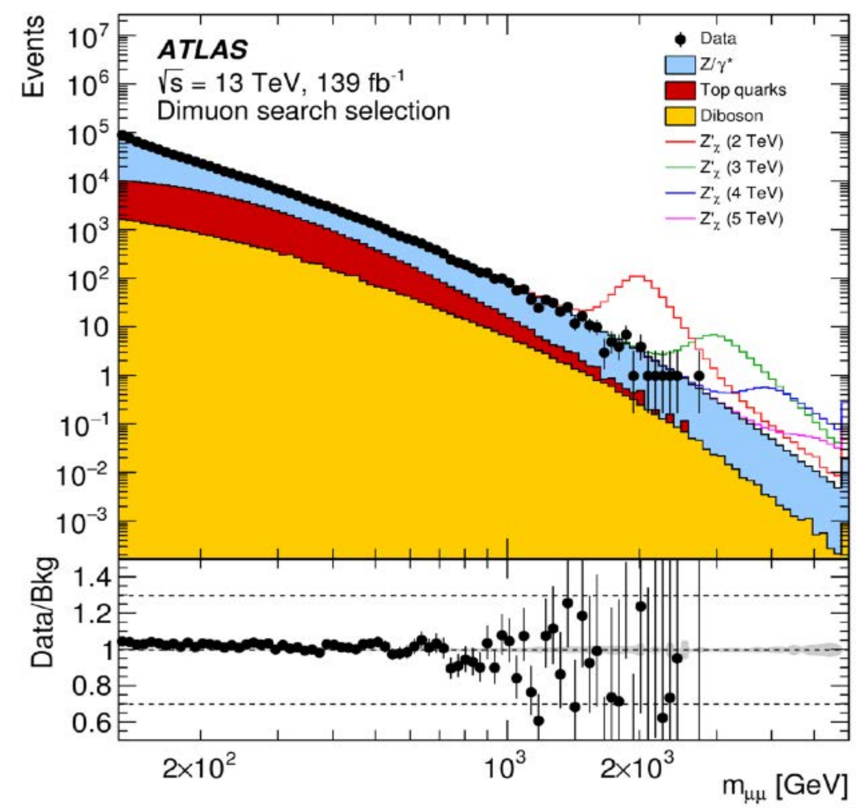
ATLAS
ROMA1

ATLAS: HIGH-MASS RESONANCE SEARCHES



Search for **bumps** over smoothly falling background:
- exploring high-mass regions
- testing SM extensions
- searching for **Dark Matter** mediators
- strong impact of reconstruction performance



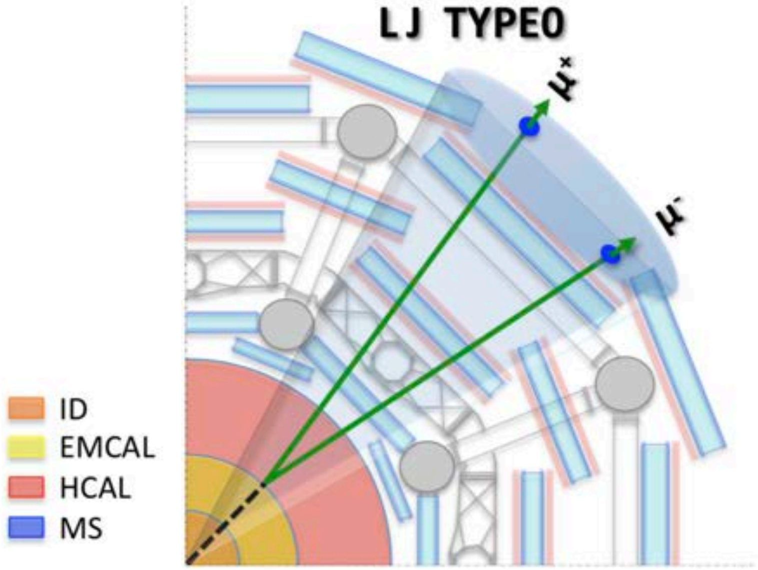


contacts: S. Giagu, M. Bauce, S. Rosati

ATLAS: Searches for non resonant processes

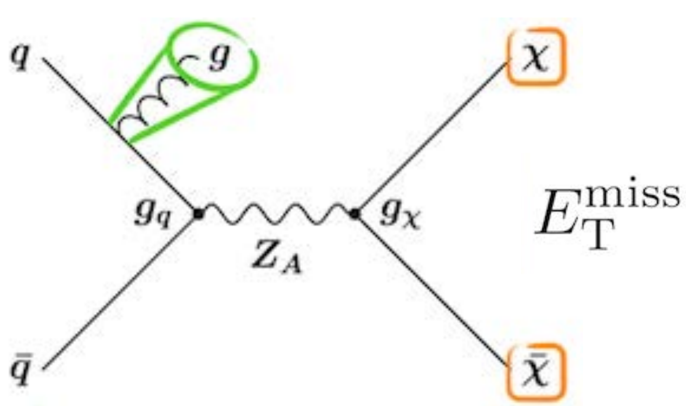
Search for long-lived particles:

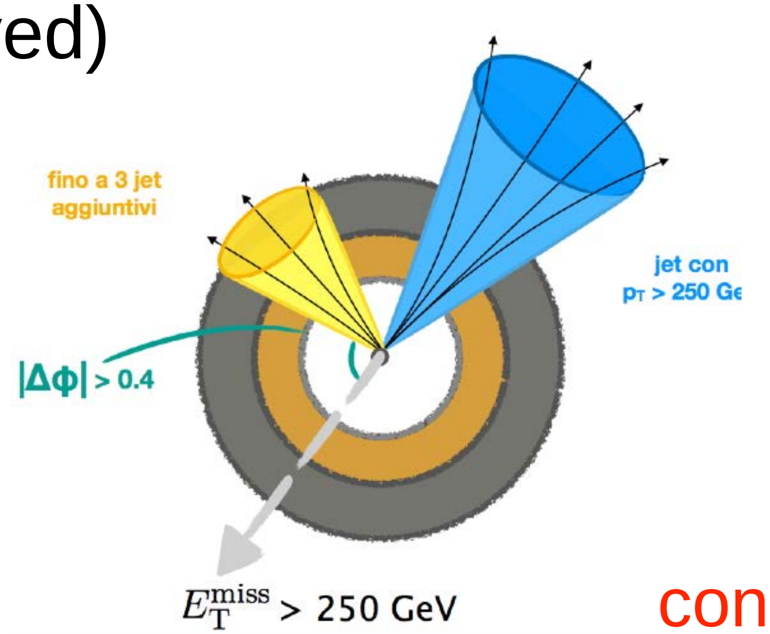
- Looking at **displaced decay vertices**
- Exploits **unconventional triggers** and **machine learning techniques**

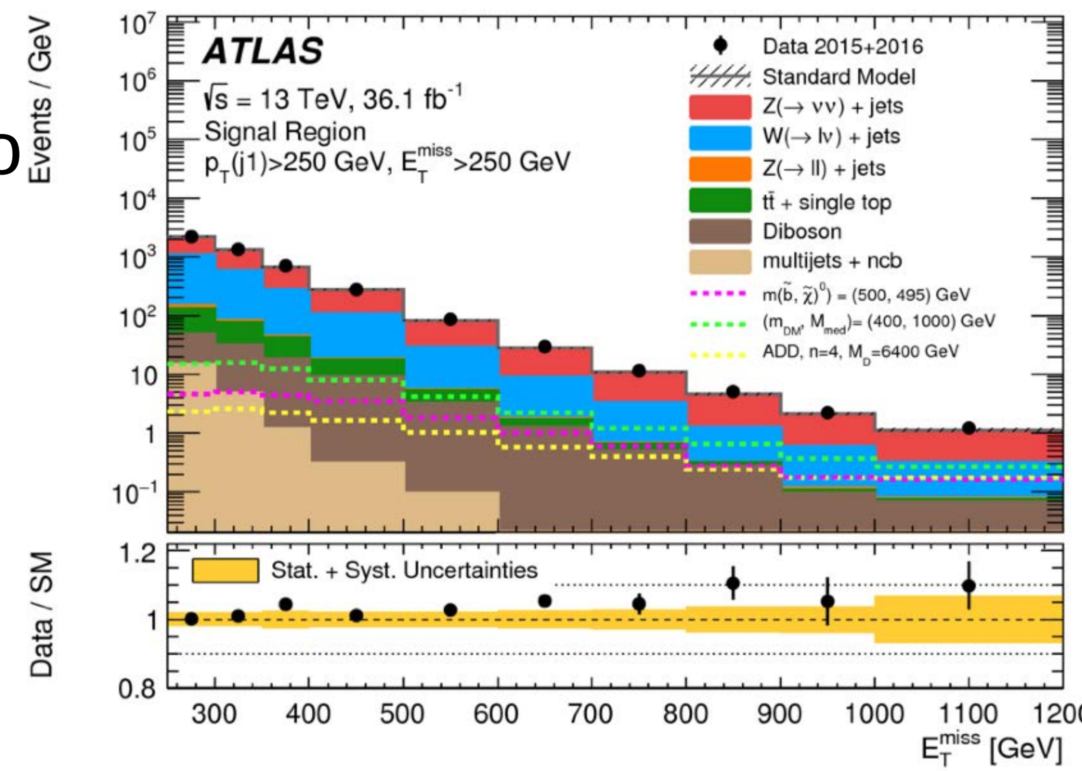


Search for New Phenomena unbalanced events in the transverse plane

- **Large missing transverse momentum** recoiling against high pT jet
- Large variety of testable models (DM, higgs to invisible, neutral long-lived)



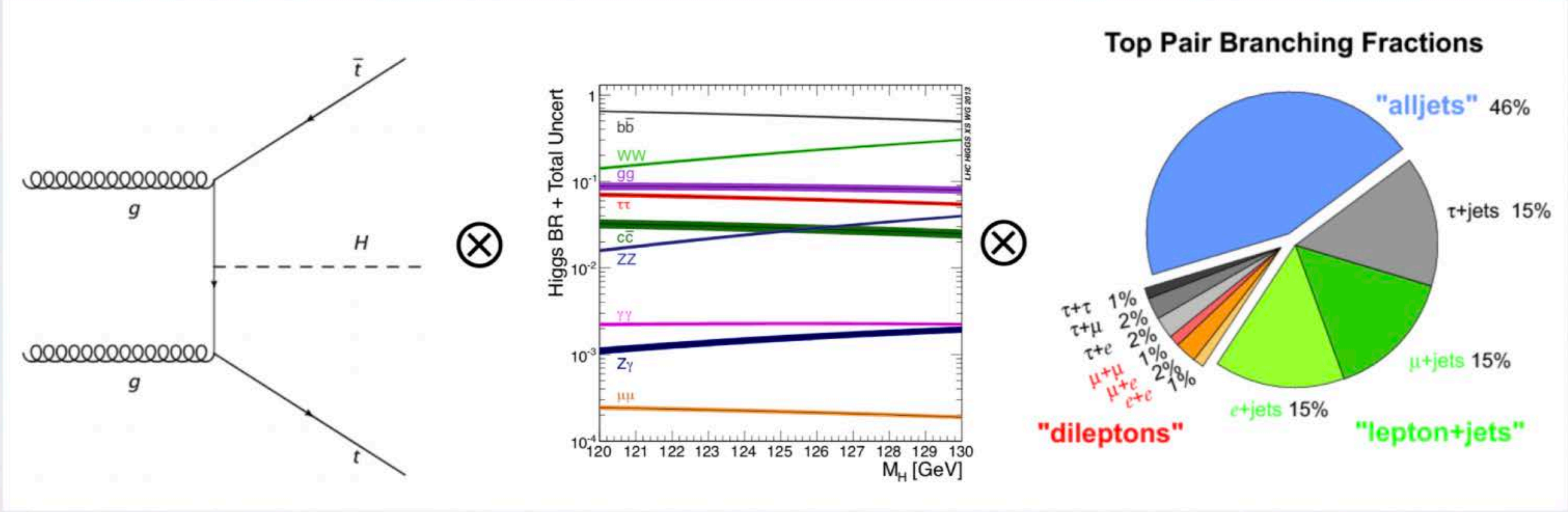




contacts: S. Giagu, V. Ippolito

TTH @ ATLAS

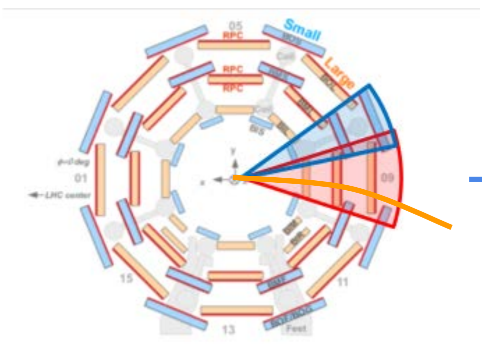
- The Yukawa coupling of the Higgs boson to the top quark is a key parameter of the Standard Model (SM) → deviations from Standard Model predictions would be evidence of new physics BSM. It can be determined:
  - from the cross section of gg → H production through a top quark loop, but deviations from the SM can be masked by other new phenomena in loop
  - from the cross section of the process **gg/qq → ttH**, which is a tree-level process (507 fb x-section in SM, 1% of the total Higgs x-section!)
- **ttH: EXPERIMENTAL CHALLENGE**
  - Wide range of analyses designed to target the various Higgs boson decays + additional consideration to the top decay
  - Final states with many objects: jets, b-jets, e, μ, hadronic τ, photons → many experiment handles to identify signal events
  - Multivariate analysis approach to extract signal

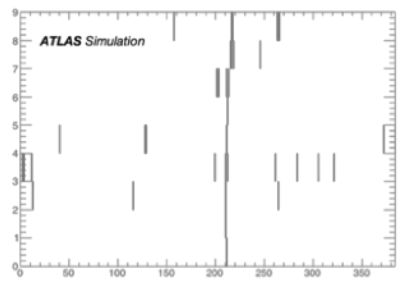


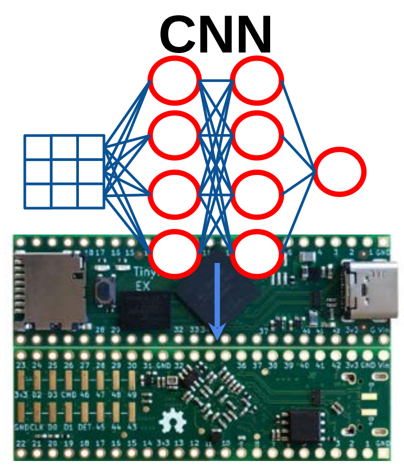
- Update cross section measure with available analyses using 13 TeV 2015-2017 data (80 fb^{-1}): $670 \pm 90(stat.)^{+110}_{-100}$ (syst) fb
- **ttH to multi-lepton final state is the most sensitive in ttH analyses**: targeted Higgs decays: WW*, ττ, ZZ*
  - 13 TeV 2015-2018 data (140 fb^{-1}) analysis just starting!

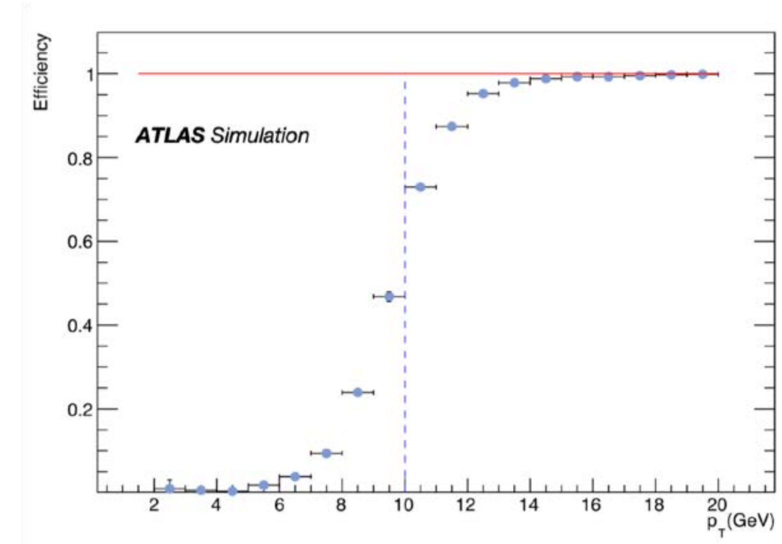
contacts: S. Gentile

ATLAS: More on Trigger and Performance



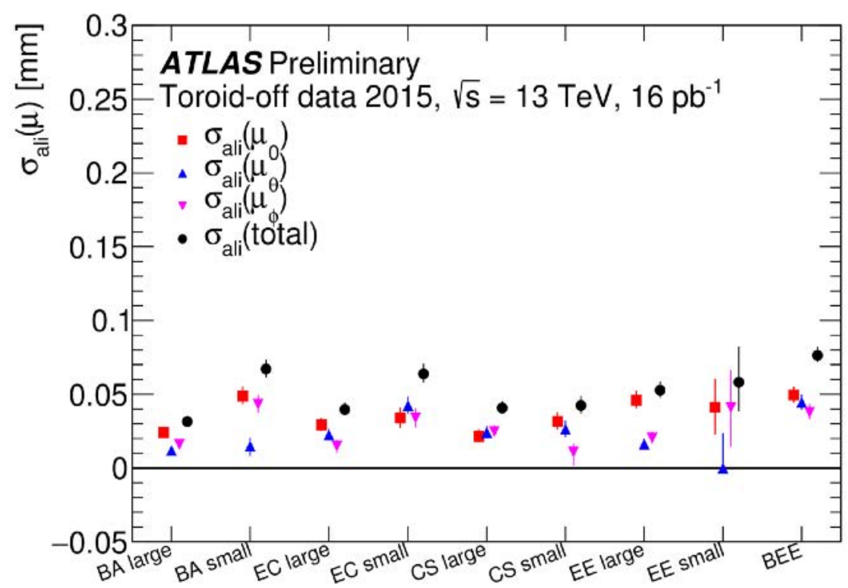




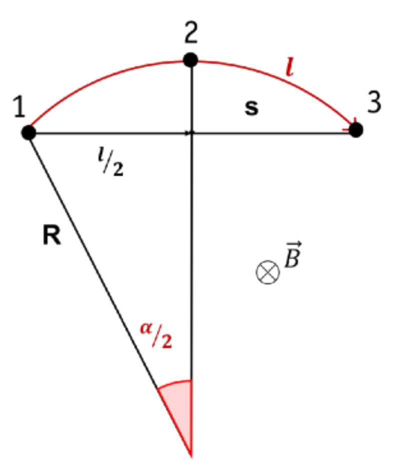


High-pTmuons (~TeV) are:

- typical signature of high-mass resonances (Z′→μμ, W′→μν)
- very hard experimental challenge (almost-straight tracks)
  @1TeV → sagitta ≈ 500 μm….
  very very small!



Exploiting the new **FPGA** processor (to be installed for the ATLAS upgrade) is possible to use a fast **Convolutional Neural Network (CNN)** for the **Level-0 muon trigger**



contacts: S. Giagu, R. Vari, M. Corradi, S. Rosati

Knowledge of precision chambers alignment in all spectrometer with an average total uncertainty of **only** σ_{ali} (total)~50 μm!

Crucial for pT measurements for new high-mass resonances searches! (Z′,W′)

ATLAS: THESES OPPORTUNITIES

contact: S.Giagu

Development of Novel Deep Neural Networks with Attention mechanism for event reconstruction and identification with the ATLAS experiment at LHC

Attention is a deep learning method that tries to mimic the human visual attention behaviour which allows to focus on a certain region for example of an image with "high resolution" while perceiving the surrounding image in "low resolution", and then adjust the focal point or do the inference accordingly. This behaviour can be exploited in designing deep neural networks that have to cope with informations that are highly sparse like the ones typically produced by the detectors of the LHC experiments. The goal of the thesis work is to apply the Attention mechanism to improve Convolutional and Recurrent neural network based algorithms developed for particle identification and jet reconstruction in the ATLAS experiment and to apply them to measurements and searches based on data collected by ATLAS during the Run-2 of LHC

contact: S. Gentile

Study of Yukava coupling of the Higgs boson with the top quark with the ultimate LHC Run2 integrated luminosity

description: The Yukawa coupling of the Higgs boson to the top quark is a key parameter of the StandardModel (SM). It can be determined from the cross section of the process gg/qq -> ttH, which is a tree-level process at lowest order in perturbation theory. This measurement has the potential to identify and disambiguate new physics effects that can modify the cross section relative to the SM expectation. The thesis work will be focused on a new analysis method based on the multivariate techniques, exploiting new kinematical and geometrical variables to separate efficiently signal from backgrounds, focusing on the multi-lepton final state.

contact: C.Bini / F.Lacava

Studio delle proprietà e test delle camere micromegas per le New Small Wheel dell'esperimento ATLAS

descrizione: Durante la tesi saranno considerate le caratteristiche e le performances delle camere micromegas in preparazione per le New Small Wheel dell'esperimento ATLAS a LHC. Il lavoro di tesi comprende il test di funzionamento delle camerecon raggi cosmici o con sorgenti (a LNF e/o al CERN) e poi lo studio di possibili modi per migliorarne le prestazioni (per es. uso di diverse miscele di gas).

contact: M.Kado

Study of the V-jets Background Process to the Measurement of the the Higgs Boson Decays to b quarks and the use of GANs for the fast simulation of backgrounds

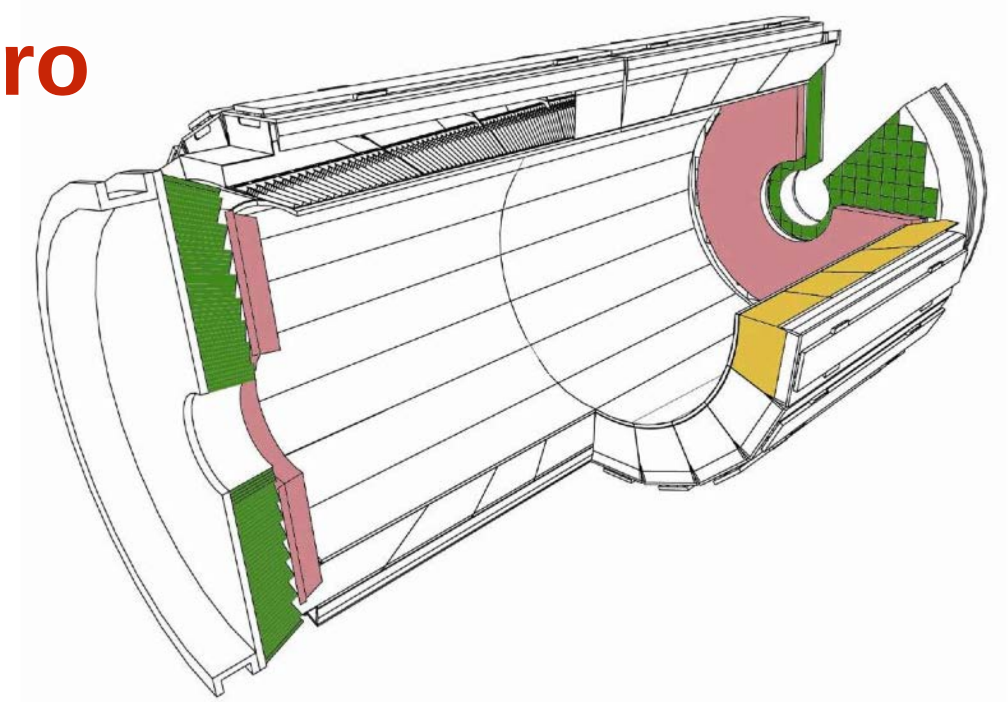
description: One of the main backgrounds for the measurement of Higgs boson decays to b quarks is the associated production of a vector boson with jets. This process is particularly difficult to model as it relies on the additional radiation of jets and in particular Heavy Flavor jets. State of the art simulation for this process are regularly updated and tuned and require checks and validation before use in the analysis. Part of the project is to participate in the probe of state of the art simulation of this process. Another part of the project will be devoted to investigating the use of Generative Adversarial Neural Networks for a fast simulation of this process in remote areas of phase space.

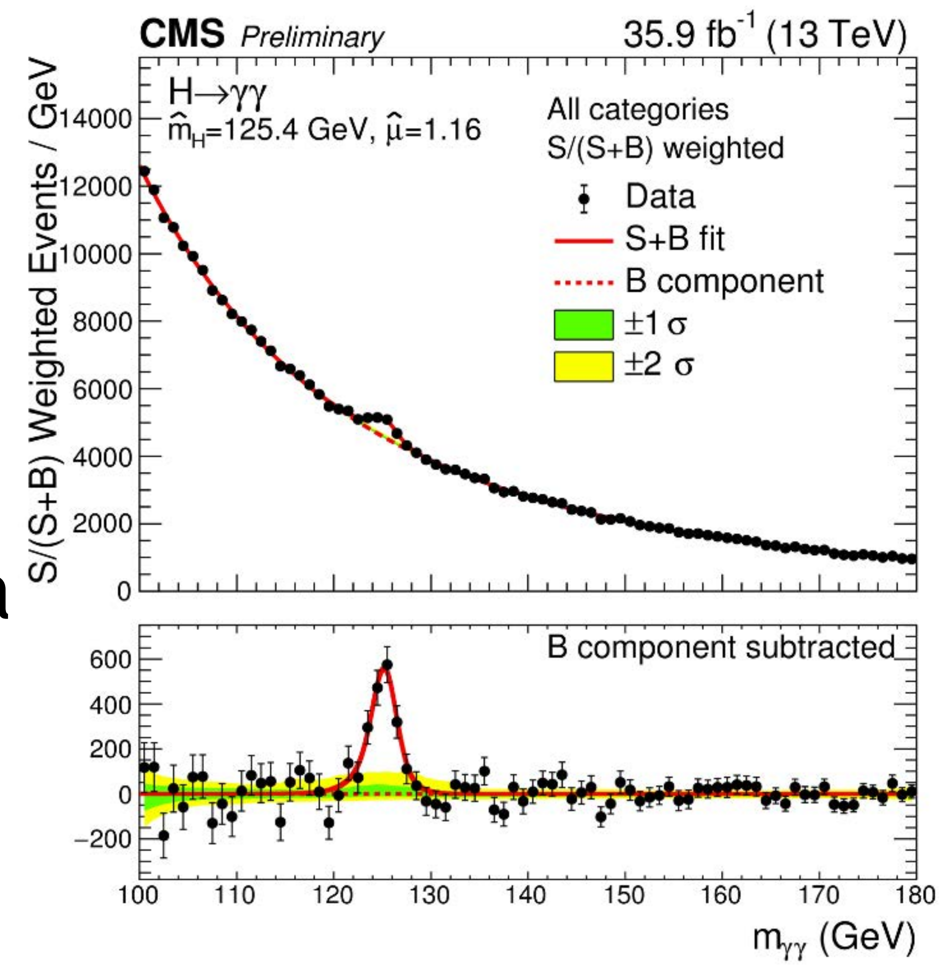
see also for additional topics: http://www.roma1.infn.it/people/organtini/showcase/Showcase.html


CMS ACTIVITIES
http://www.roma1.infn.it/exp/cms/

ECAL E UPGRADE

- Storicamente impegnati sul **calorimetro em dell’esperimento (ECAL)**
  - **costruzione e test cristalli, ruoli di coordinamento**
  - implementazione e maintanance del **sistema di HV** del settore barrel
  - **calibrazione** della risposta in energia e degli oggetti collegati (fotoni, elettroni, jet)
    - **cruciale per Higgs in due fotoni**

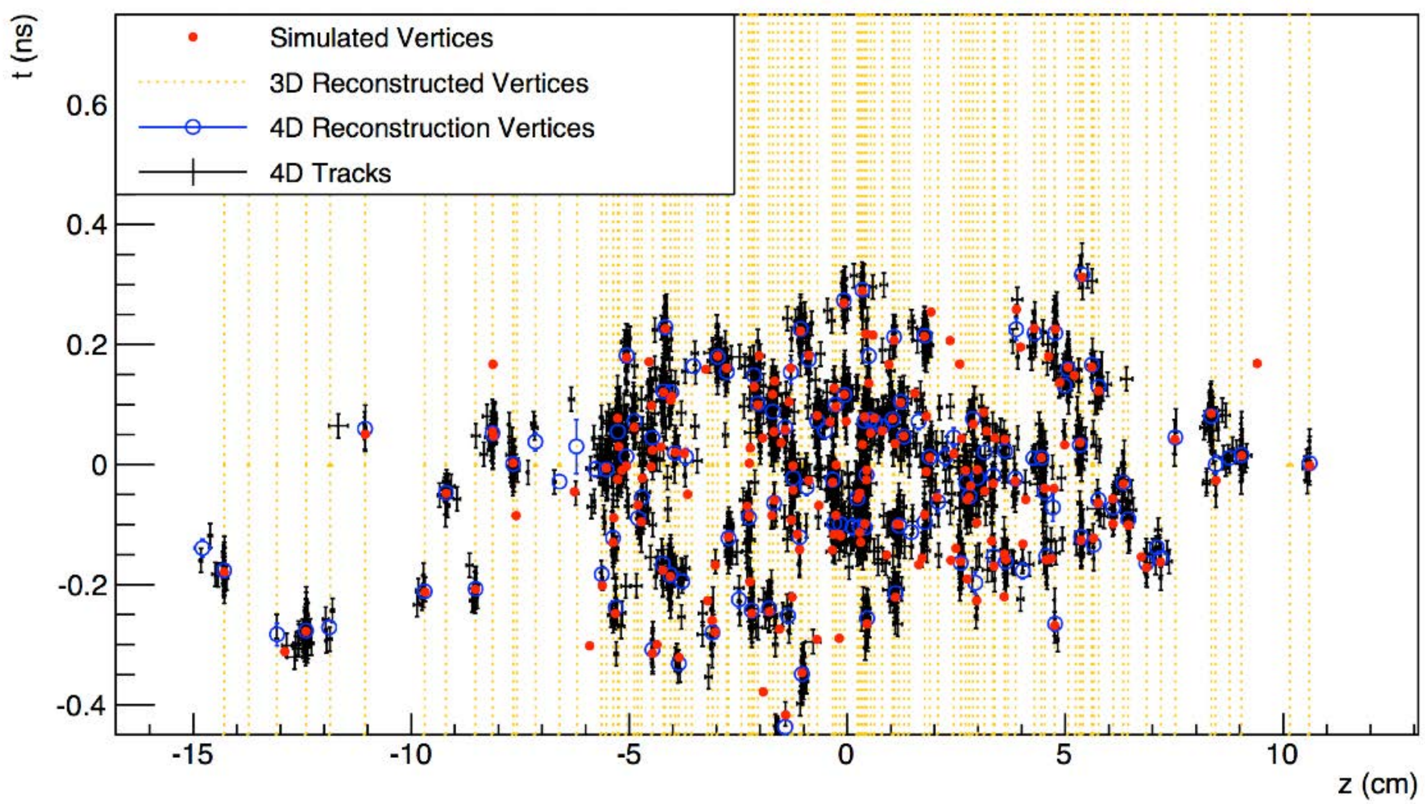


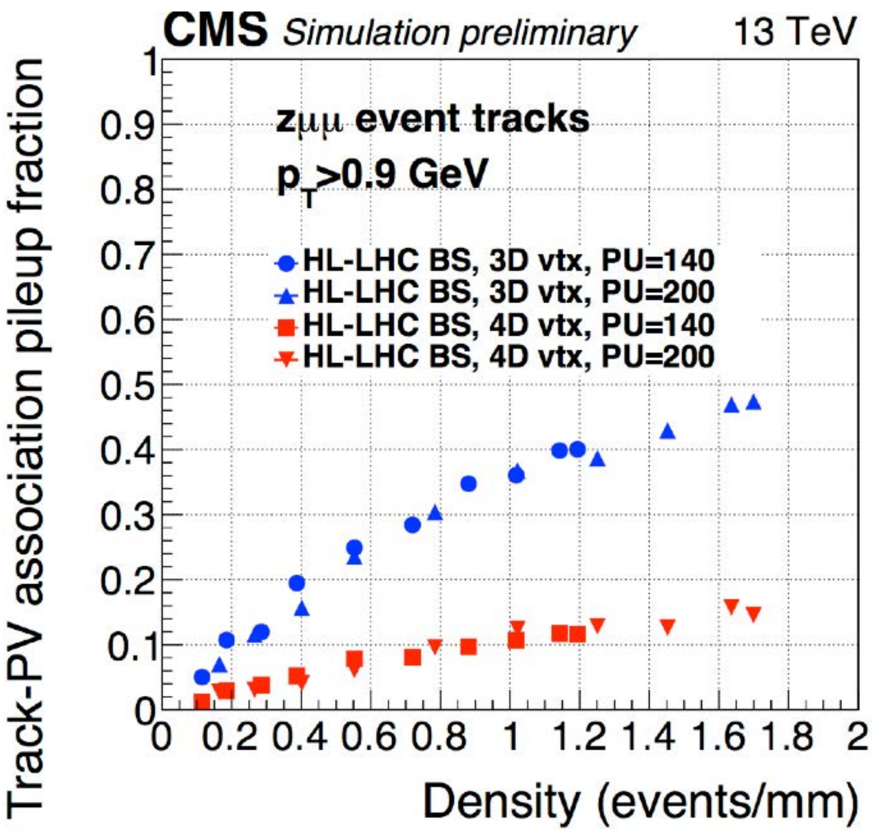


- **Oggi:**
  - **miglioramento calibrazione oggetti** (fotoni, elettroni)
  - **upgrade** del calorimetro per la fase ad alta luminosita’
    - nuova elettronica
    - misura tempo ad alta precisione

HIGH PRECISION TIMING DETECTOR

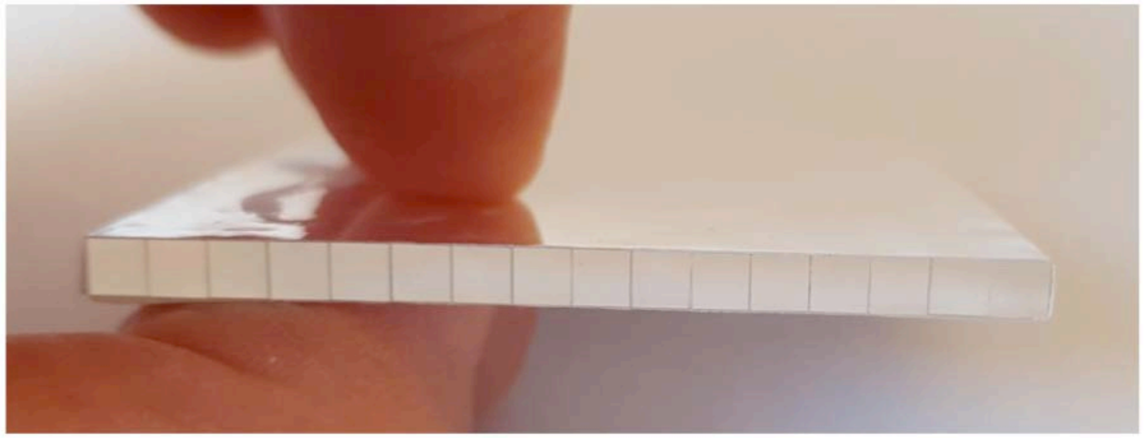
- Nella **fase 2 di LHC (HL-LHC)** ad alta luminosità ci saranno **150-200 interazioni concomitanti** per collisione
  - condizioni estreme: fondo da rimuovere per studiare collisioni hard
- **Nuovo rivelatore per misurare il tempo delle tracce**
  - posto tra il tracciatore e il calorimetro em
- **Rivelatore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

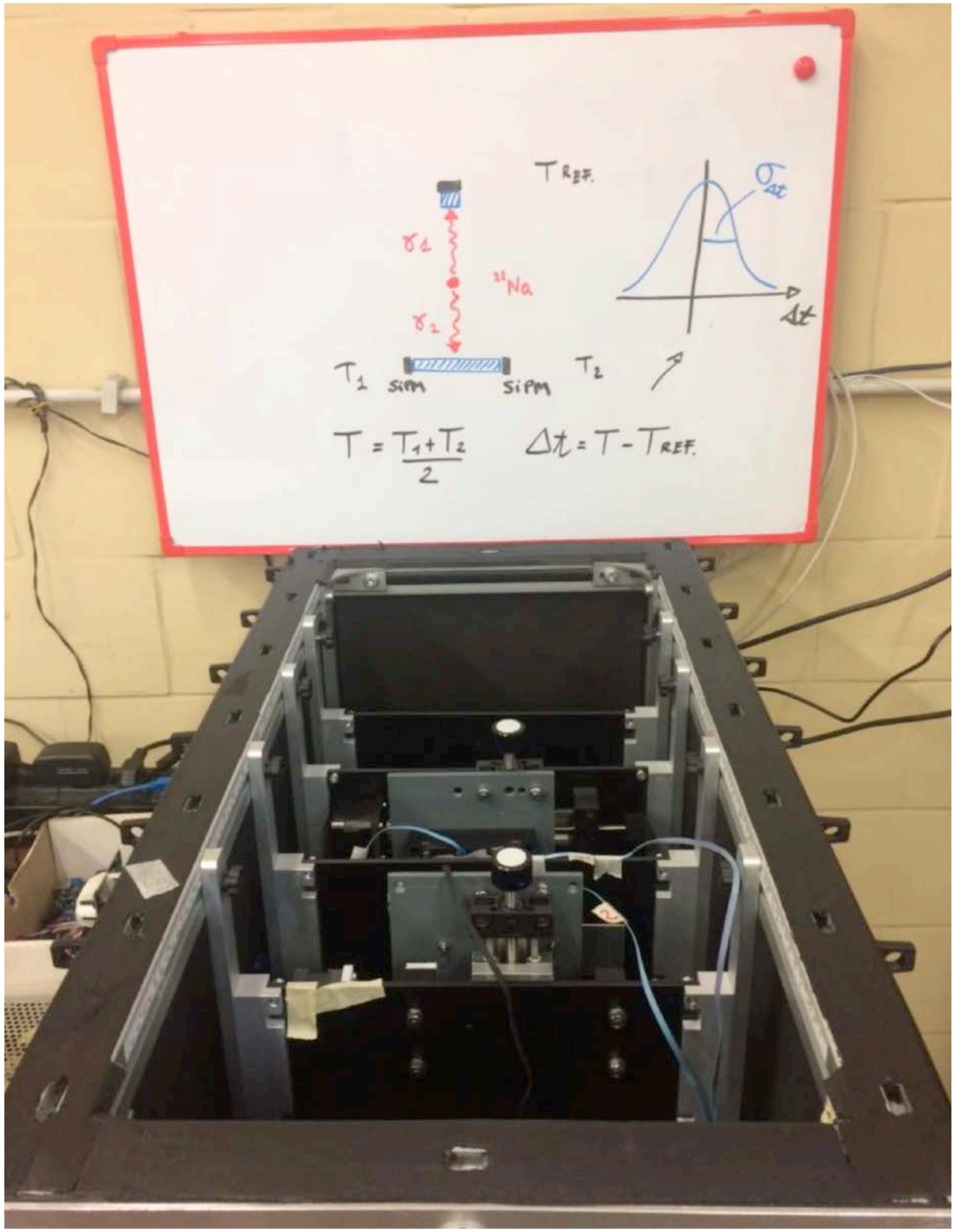




CHARACTERIZATION OF LYSO CRYSTALS

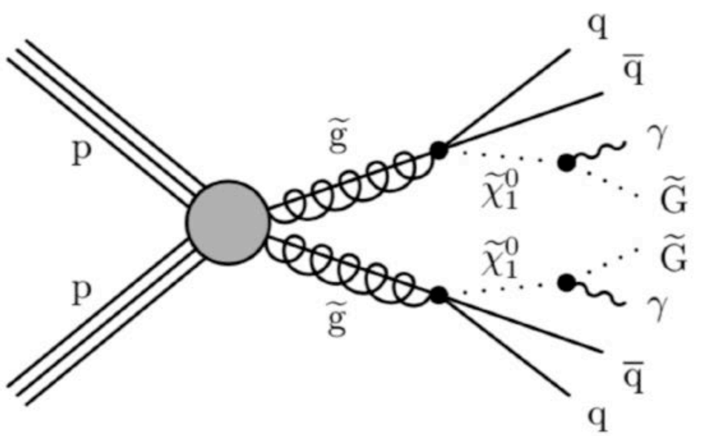
- **Characterization of LYSO crystals**
  - Crystal dimensions, planarity and density
  - Light Output and energy resol.
  - Time resolution
  - Decay time
  - Optical cross talk
  - Radiation resistance with photons in Casaccia - ENEA
- **Activity in Sapienza (lab Segrè)**

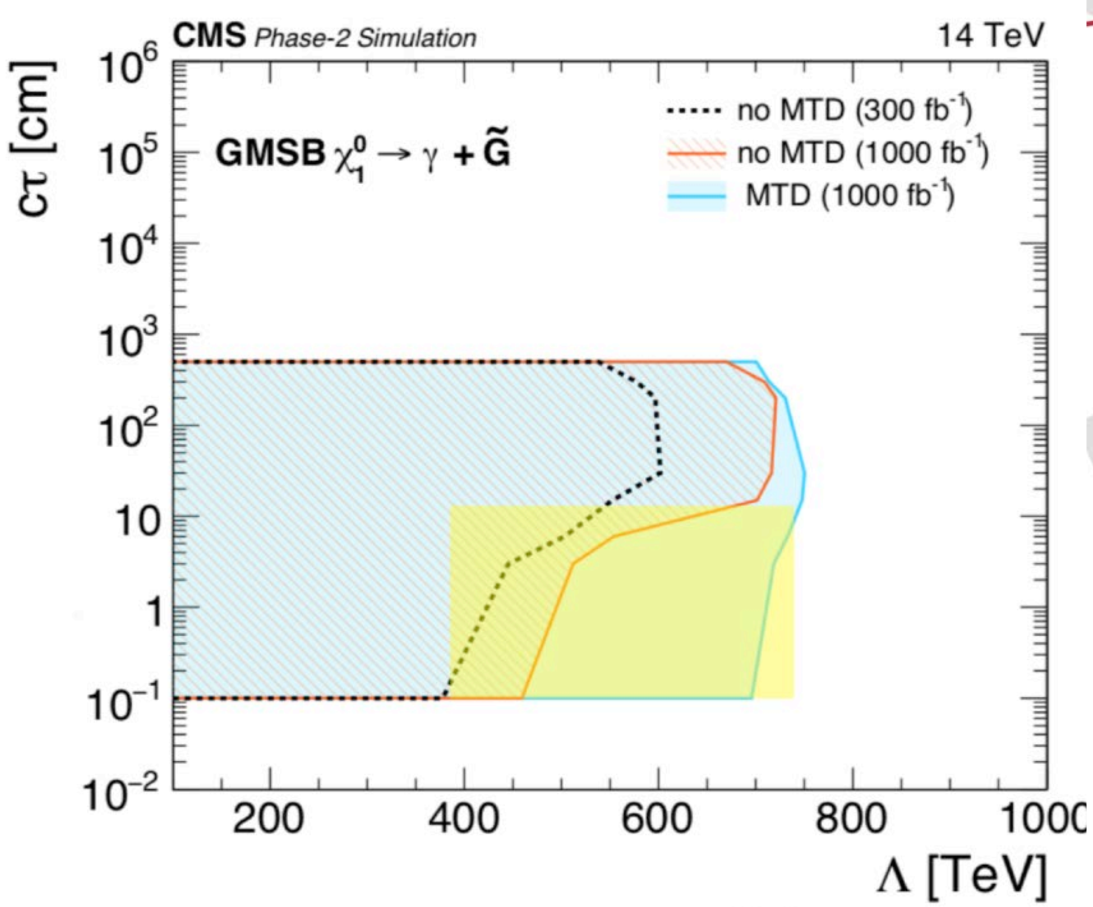


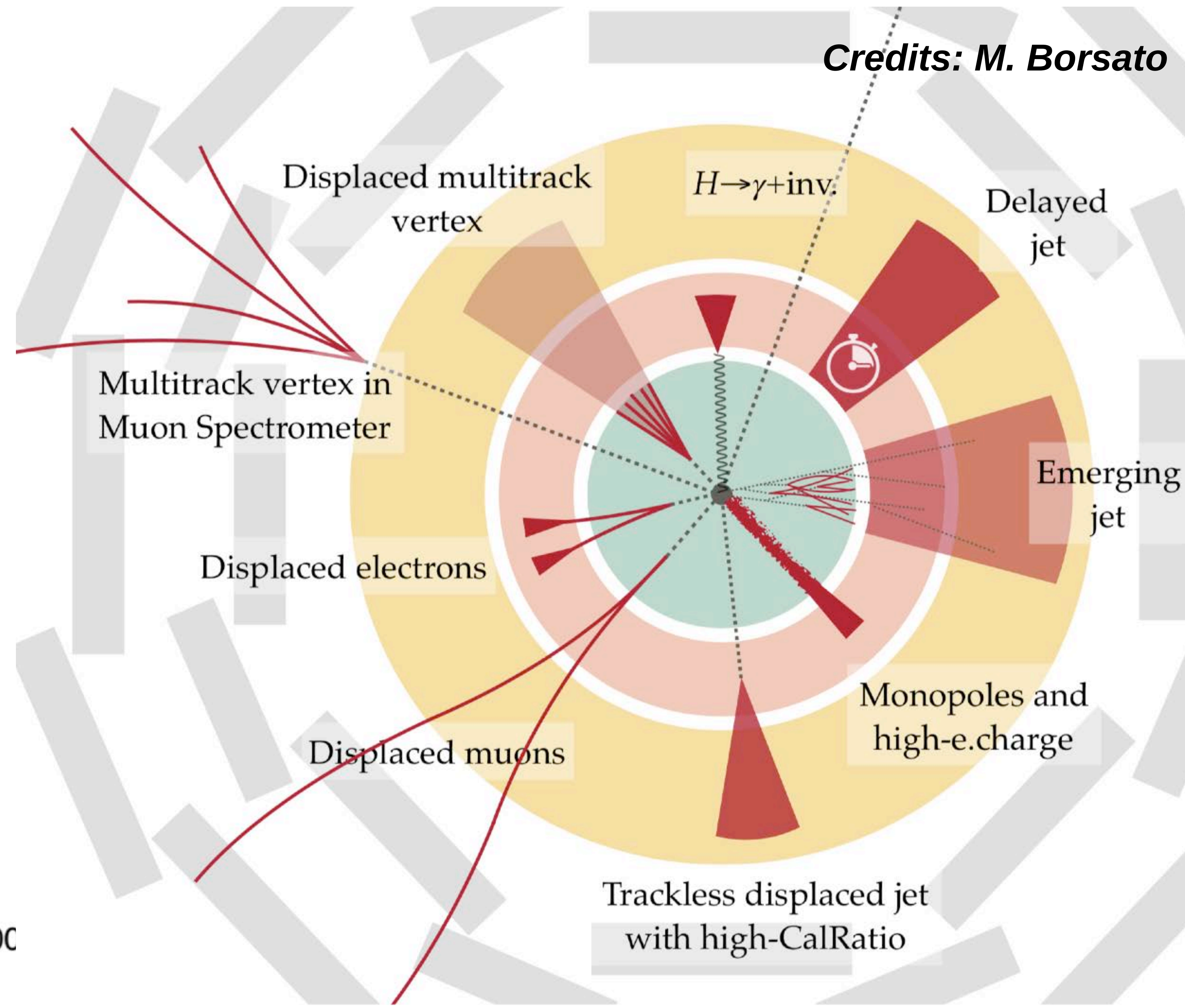


SEARCH FOR NEW PHYSICS WITH MTD

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







TESI DISPONIBILI

Francesco Pandolfi e Riccardo Paramatti

Reconstruction of Photon Conversions with the CMS Mip Timing Detector

In the context of the upgrade program for HL-LHC running, the CMS experiment will install a new timing detector for charged particles (MTD) made of a thin layer of LYSO crystals, placed between the silicon tracker and the electromagnetic calorimeter (ECAL). While designed to measure charged particles, we show that it would benefit also the reconstruction of high-energy photons, such as those produced in the decay of a Higgs boson. If a photon converts to an electron-positron pair while traversing the MTD layer, which happens in about 20% of the cases, it will release a localized signal, which will pin-point its direction with a resolution of a few millimeters. This information can be combined with the centroid of the energy deposit in the ECAL to estimate the photon direction, and therefore reduce the uncertainty on the primary vertex identification, which is a long-standing problem in final states with neutral particles at CMS.

Livia Soffi, Daniele del Re e Shahram Rahatlou

Probing new physics with precision timing at CMS

The CMS experiment is foreseeing, for the High Luminosity phase of the LHC, the construction of a new timing detector for charged particles, the MTD. This detector will provide an entirely new handle in the search for beyond the standard model physics at colliders, with unique sensitivity to non-zero lifetime particles. These long lived objects travel inside the detector and decay to standard model (SM) particles which reach the detector with a delay with respect to analogous objects produced in SM processes. This research project consists in developing novel strategies to identify long lived particles at CMS, in leptonic and hadronic fi nal states, exploiting precision timing information as a new tool to enhance search sensitivities order of magnitudes beyond traditional searches.

Francesco Santanastasio e Riccardo Paramatti

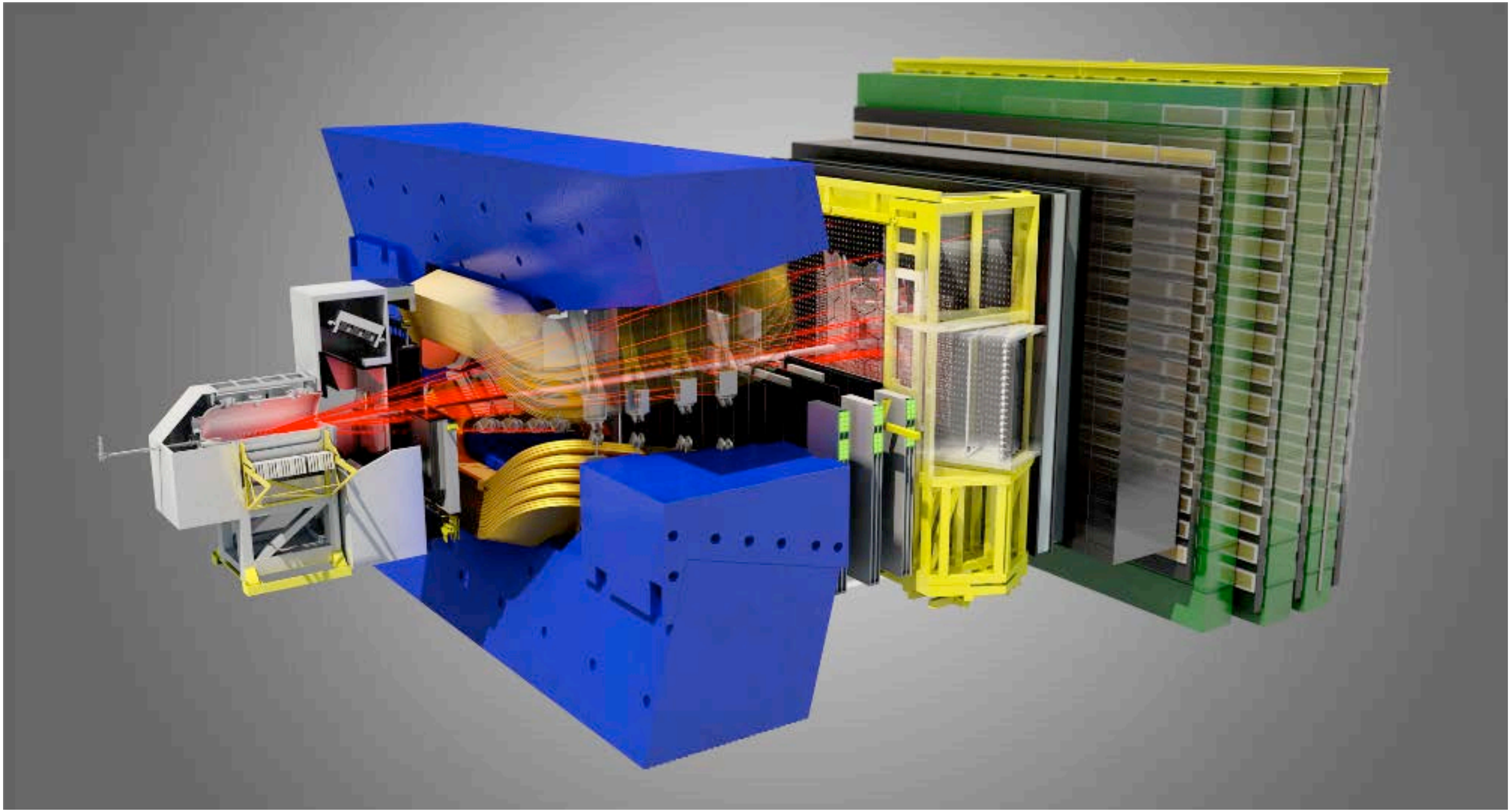
Characterisation of LYSO crystal arrays for the CMS Barrel Mip Timing Detector

The CMS experiment has proposed within the upgrade program for HL-LHC a novel hermetic timing detector for charged particles (MTD) with a target resolution of 30ps. The barrel part of the detector will use as sensors small LYSO crystal bars arranged into arrays and readout by Silicon Photomultipliers (SiPMs). This research project aims at the characterisation of crystal arrays which will be delivered during the pre-production phase in 2020. The analysis will focus on several aspects including light yield measurements, study of optical cross-talk, and effect of radiation damage on the timing resolution.

Daniele del Re / Francesco Santanastasio / Shahram Rahatlou

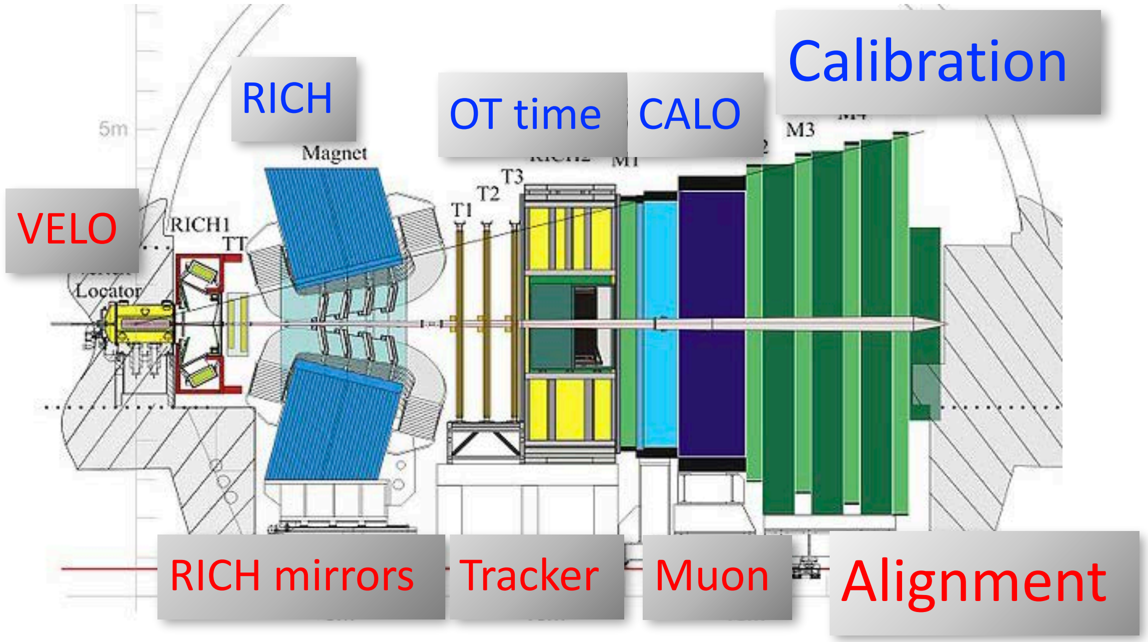
Ricerca di nuove risonanze che decadono in tre jet

Lo studio di risonanze massive che decadono in tre jet rappresenta una nuova segnatura sperimentale per la ricerca di nuova fisica oltre il Modello Standard al LHC del CERN. Lo scopo della tesi è quello di definire la strategia di analisi ed analizzare la grande quantità di dati raccolti dall'esperimento CMS a partire dal 2016. Tecniche innovative per lo studio della sottostruttura dei jet e metodi alternativi per la selezione online degli eventi (trigger) sono tra gli argomenti che rendono questo lavoro di tesi originale e rilevante da un punto di vista sperimentale.

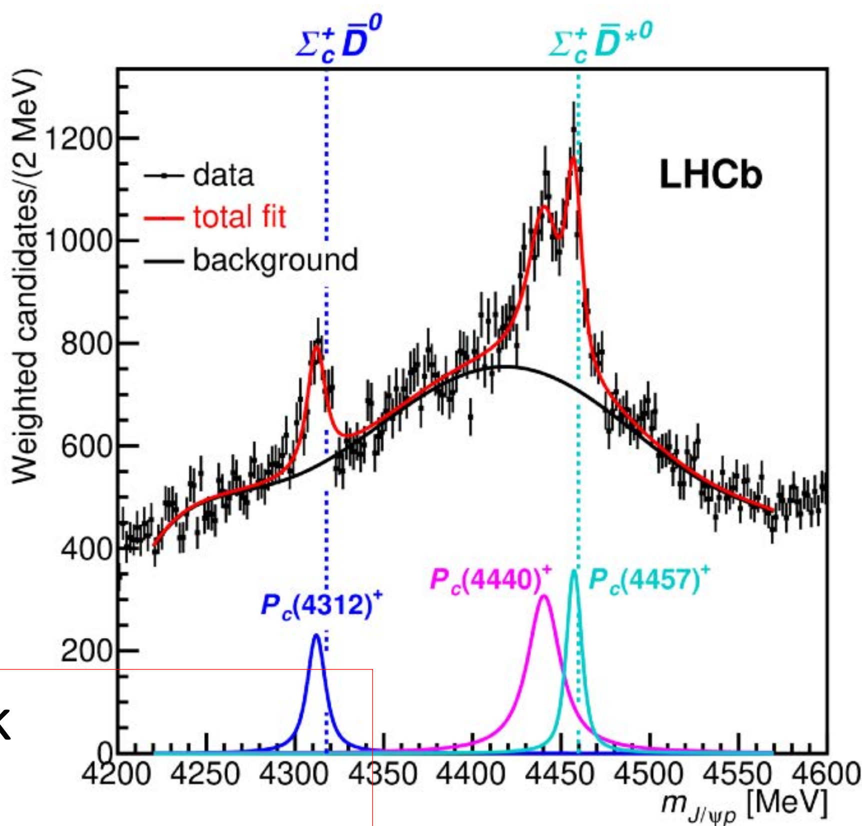


LHCb ACTIVITIES

BEAUTY AND CHARM PHYSICS AND MUCH MORE



- **$\not{C}P$: *recently first observation of CP violation in charm***
  $\Delta A_{CP} = (-15.4 \pm 2.9)\times10^{-4}$
- Tests of Lepton Flavour Universality
  tension in several channels
- Rare decays, window for New Physics
- Parameters of CKM matrix
- Lifetimes
- Spectroscopy, observation of new hadron states not simply *qqq* or *qq* states- tetra or pentaquark
- ....

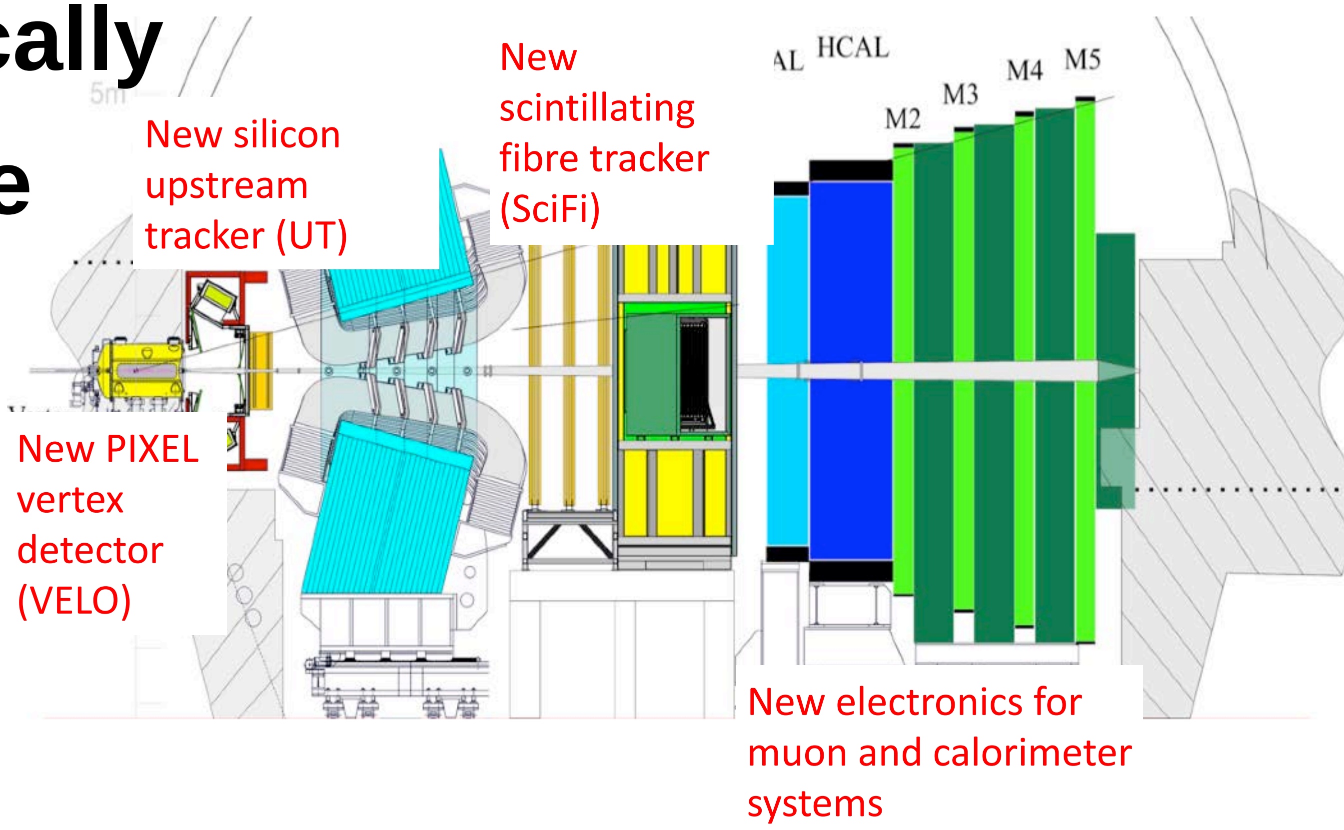


Recently New Pentaquark states in J/ψ p final state

LHCb – UPGRADE OF THE DETECTOR

- **Aim: run at factor 5 higher luminosity L=2 x $10^{32}cm^{-2}s^{-1}$**
  - Increase sensitivity to rare decays, CP and Flavor Violation, precision measurements
  - Subdetectors replaced or modified

- Rome group involved in the **muon detector electronics specifically in the Control System for the muon Front-end electronics**



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 interprete 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 **control system of the front-end electronics of the muon system**

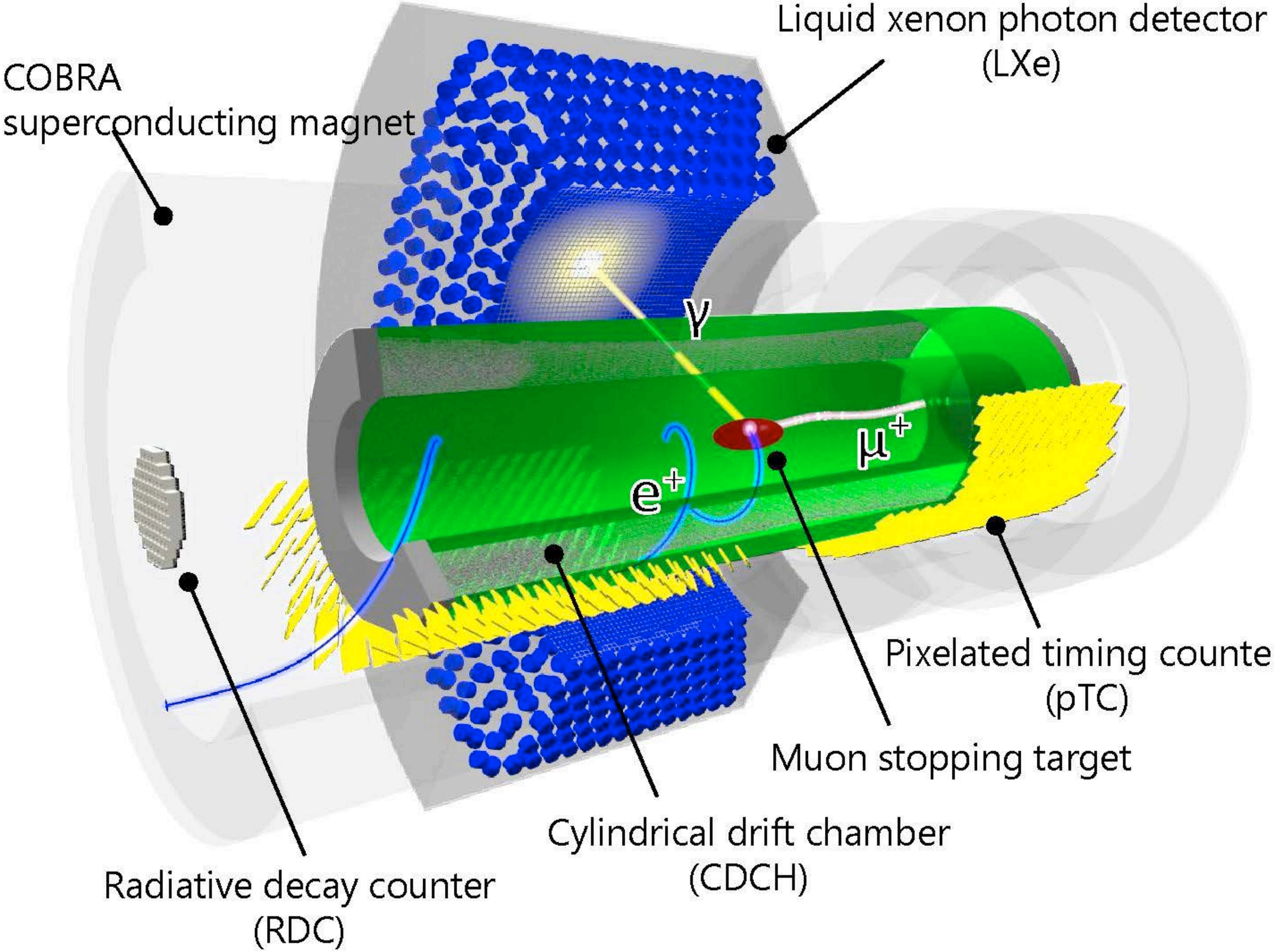
- About 150 electronic boards have been designed within the group and are being produced by the farm now
- Laboratory activity is required to test the boards, activity at CERN to install the boards, software development to operate them, firmware development to implement functionalities.

Proposed Thesis subject:

Test and optimization of the system to configure, monitor and synchronize the front-end electronics of the muon detector of the LHCb upgrade

Contacts: Davide.Pinci@roma1.infn.it, stanza 030-a, Edificio G.Marconi

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

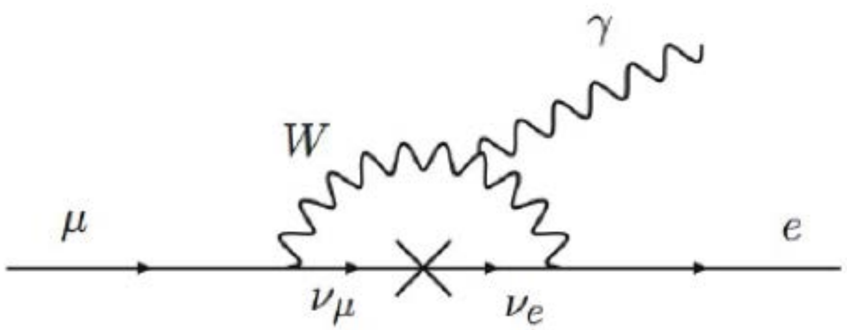


MEGII ACTIVITIES

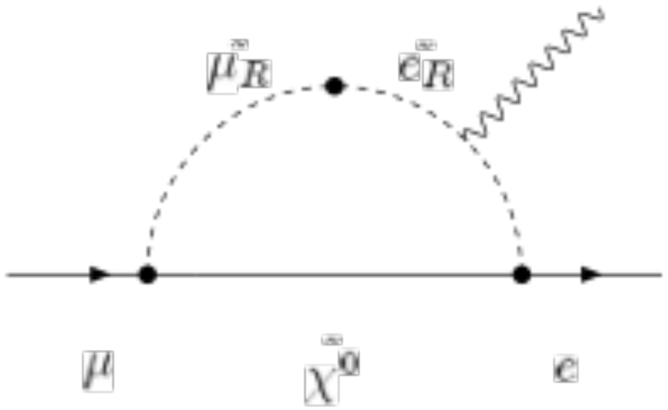
New Physics searches with muons: MEGII

Search of New Physics at the intensity frontier in the charged lepton flavor violating decay μ → eγ

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**

THE MEGII EXPERIMENT

Present best world limit:

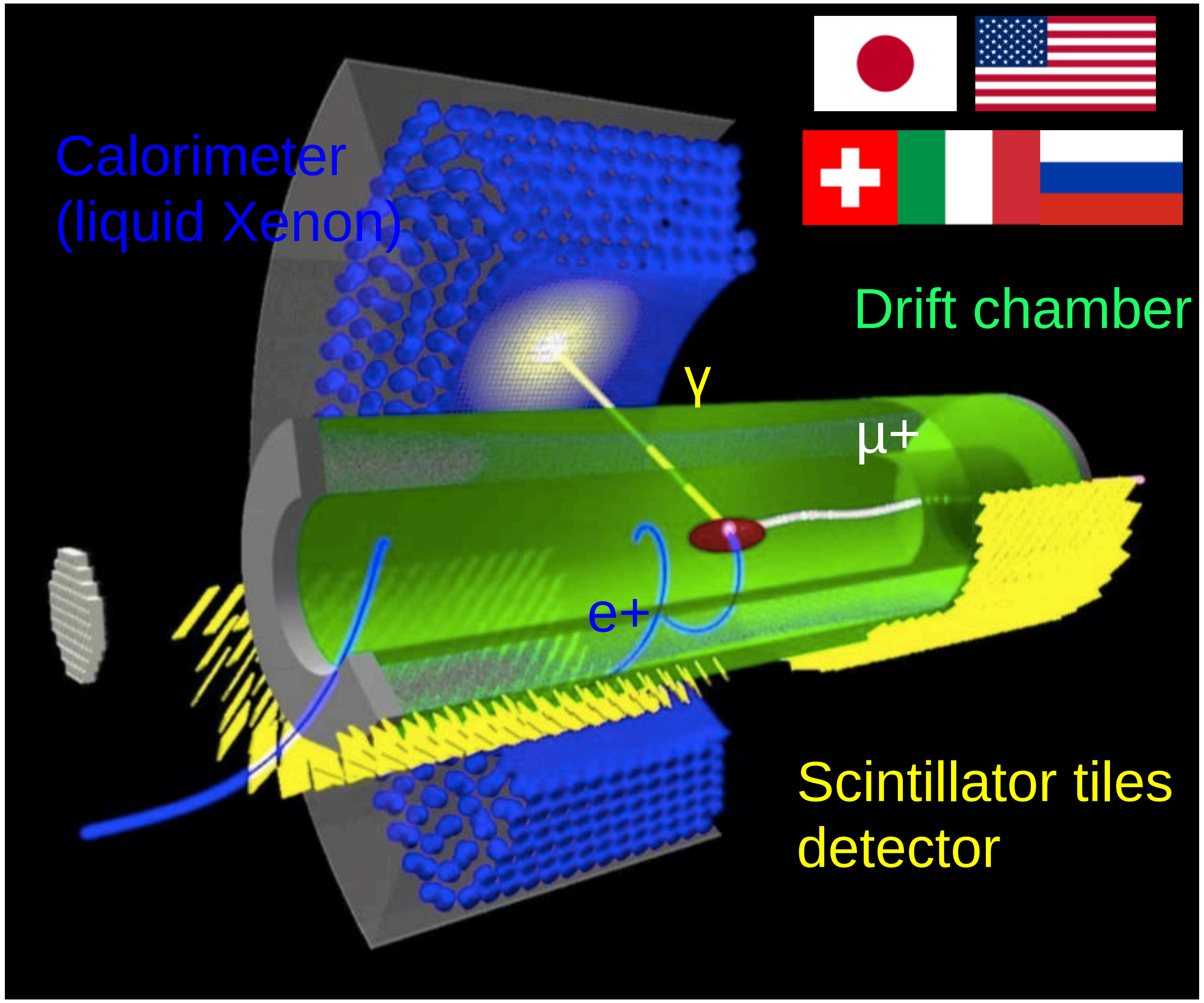
BR (μ→eγ) < 4.2x 10^{-13} at 90% C.L. *EPJC 76(8),434(2016)*

- **MEGII target**: improve the sensitivity by **1 order of magnitude** in 3 years of data-taking

- MEGII detector presently **under commissioning**

- **Engineering run in fall 2019**

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



MEGII ROME GROUP ACTIVITIES

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

MEGII@Roma:

G. Cavoto
G. Chiarello
M.V. Gianfelici
F. Renga
V. Pettinacci
C. Voena

- **Drift chamber operations and commissioning** (gas system, HV system)
- Drift chamber **calibration and reconstruction**
- **Target position measurement system**
- **$\mu \rightarrow e\gamma$ physics analysis**
- **Search for 5th force** – X boson (16.7MeV)

Available theses (hardware and analysis)

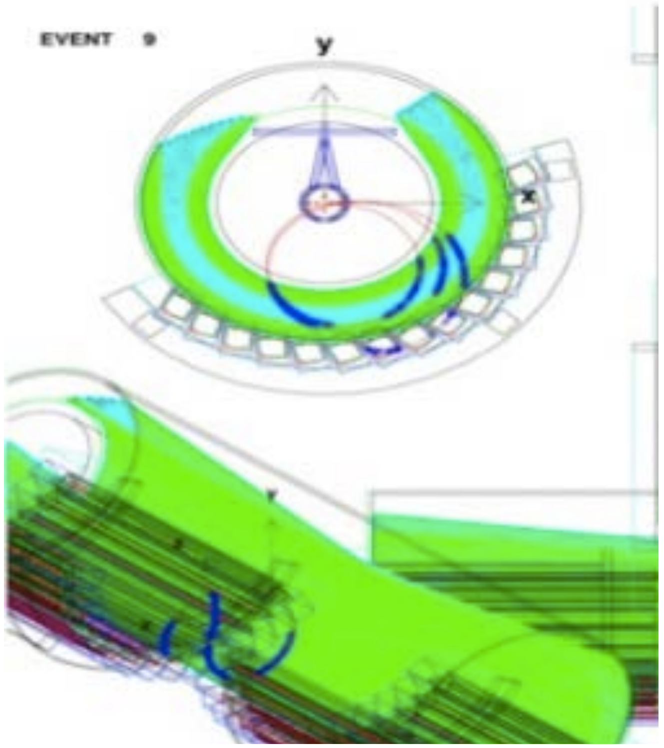
1) Drift chamber calibration/simulation and data analysis
2) Development of a machine learning algorithm for the MEGII tracking
3) Search of the 5th force – X boson (16.7MeV)

MEGII PROPOSED THESES

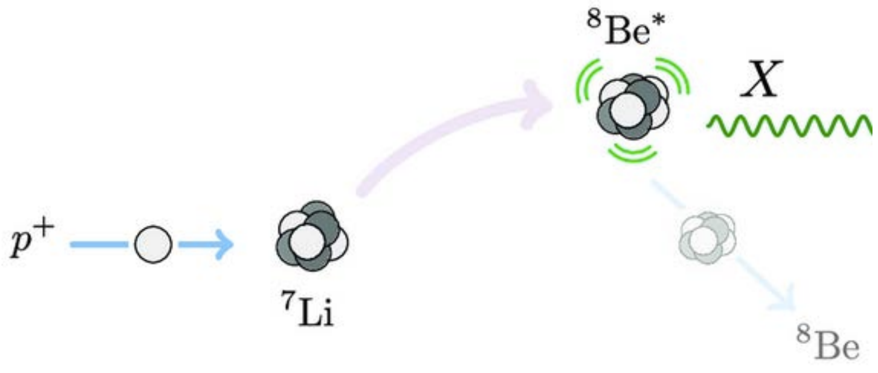
1) Making a detector work:
Theses on drift chamber calibrations, simulations and data analysis are available.

The MEGII drift chamber

2) Tracking challenge:
The very high muon rate causes a high occupancy in the tracking detector that makes track finding difficult with standard algorithms. Theses on machine learning based track finding algorithms are available.



3) "Unconventional" search for New Physics:
It is also possible to search for New Physics in nuclear transitions generated by a Cockroft-Walton accelerator, normally used for the MEG-II detector calibrations. Theses on measurement set-up, simulation and data analysis on this topic are available.



MEGII PROPOSED THESES

Machine learning based algorithm for track finding for the MEG-II experiment

The MEG-II experiment is in the commissioning phase at the Paul Scherrer Institut in Villigen (Zurich). The experiment searches for New Physics in the muon decay into a positron and a photon which is forbidden in the Standard Model. The very high muon rate causes a high occupancy in the tracking detector that makes track finding difficult with standard algorithms. Theses on machine learning based track finding algorithms are available.

Searches for New Physics in the mu->egamma decay

The MEG-II experiment is in the commissioning phase at the Paul Scherrer Institut in Villigen (Zurich). The experiment searches for New Physics in the muon decay into a positron and a photon which is forbidden in the Standard Model. Theses on detector calibrations, simulations and data analysis, in particular on the drift chamber, are available.

Search for New Physics in nuclear transitions in the MEG-II experiment

The MEG-II experiment is in the commissioning phase at the Paul Scherrer Institut in Villigen (Zurich). The experiment searches for New Physics in the muon decay into a positron and a photon which is forbidden in the Standard Model. It is also possible to search for New Physics in nuclear transitions generated by a Cockroft-Walton accelerator, normally used for the MEG-II detector calibrations. Theses on measurement set-up, simulation and data analysis on this topic are available.

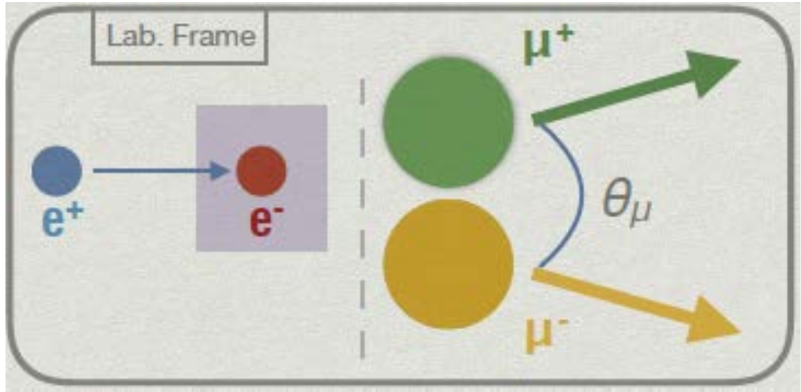
LEMMA ACTIVITIES

LEMMA (Low Emittance Muon Accelerator)

A. Allegrucci, F. Anulli, M. Bauce, G. Cavoto, F. Casaburo, G. Cesarini, F. Collamati, R. Li Voti

LEMMA project aims to study a '**novel' muon production** concept based on direct μ-pair production via **$e^+e^- \rightarrow \mu^+\mu^-$ just above the production threshold** ($\sqrt{s}$=212 MeV), by using an **e^+ beam of ~45 GeV** against a thin target (NIM A807, 101 (2016) [*arXiv:1509.04454*])

Main goal is to demonstrate that **high-intensity and very-low-emittance muon beams to supply a future muon collider** can be obtained with this method

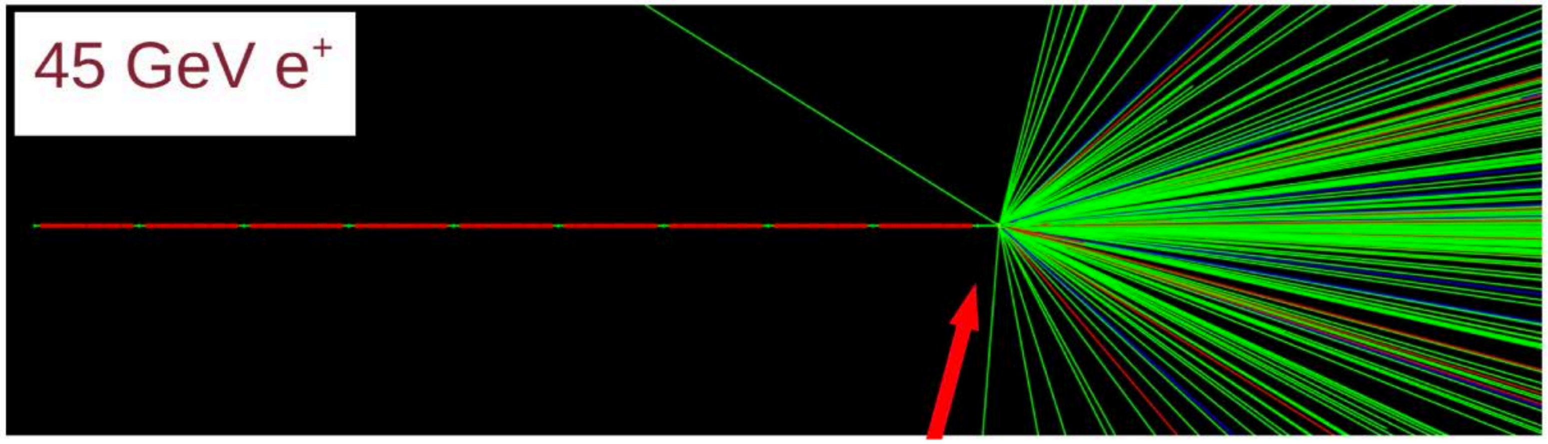


$E(e^+) \sim 45$ GeV => $E(\mu^\pm) \sim 22$ GeV,
$\gamma(\mu) \sim 200$ => $\tau_{LAB} \sim 500\mu s$

The LEMMA scheme presents **several advantages** w.r.t. the traditional muon production based on the use of a proton beam, **but** it is also **very challenging**, primarily because of the very **small muon production cross section: ~1μb for e^+ source *vs* ~1mb for proton source**

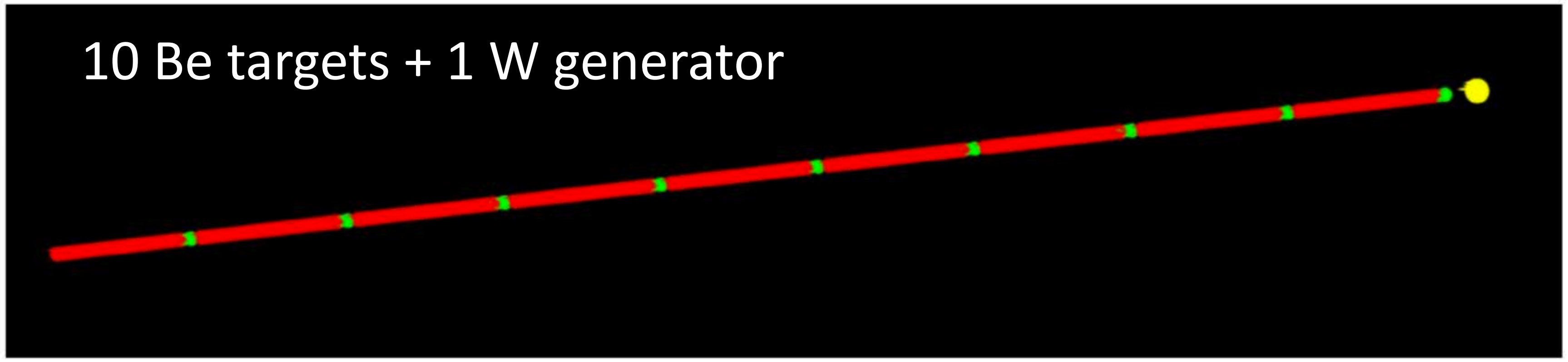
The group in **Rome** is working on **several aspects** of the project:
- study of the thermo-mechanical stresses of the target for the muon production
- optimization of the e^+-target interaction region
- analysis of test-beam data for the study of the muon production with Be and C targets

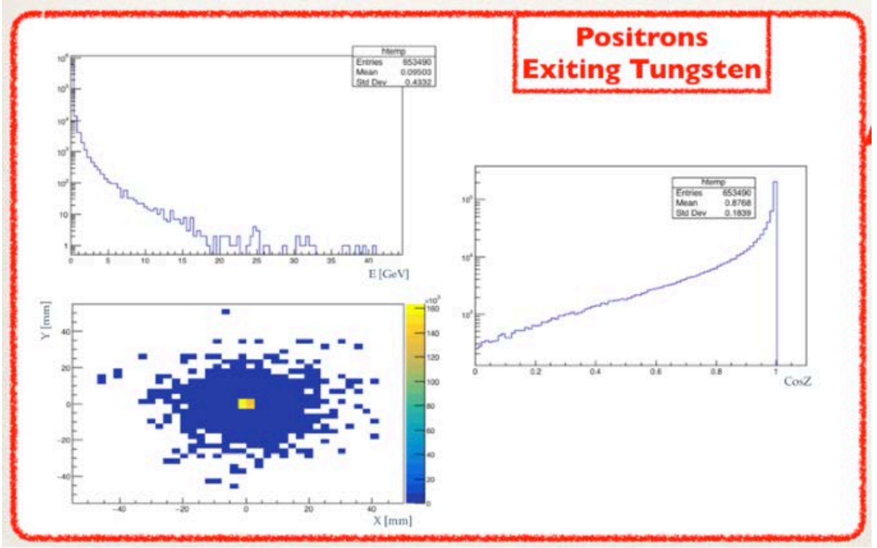
LEMMA: ACCELERATOR STUDIES



e.g.: is it possible to use photons produced in the target to generate new positrons?

Here: Geant4 simulation of the current-design multi target line



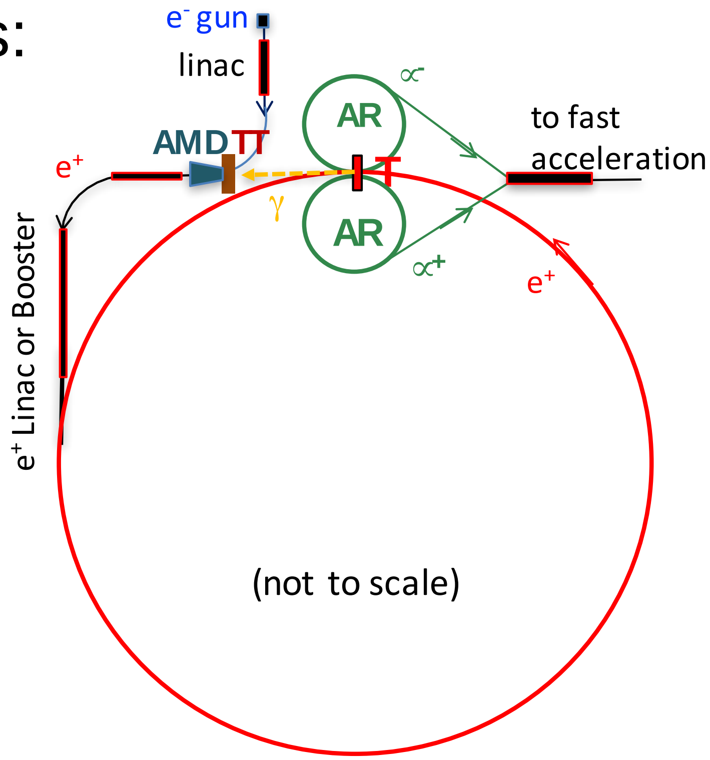


Tight collaboration with INFN-LNF

Lots of possible **Monte Carlo** studies:
- Beam bacgkrounds into detectors
- Muon decay backgrounds

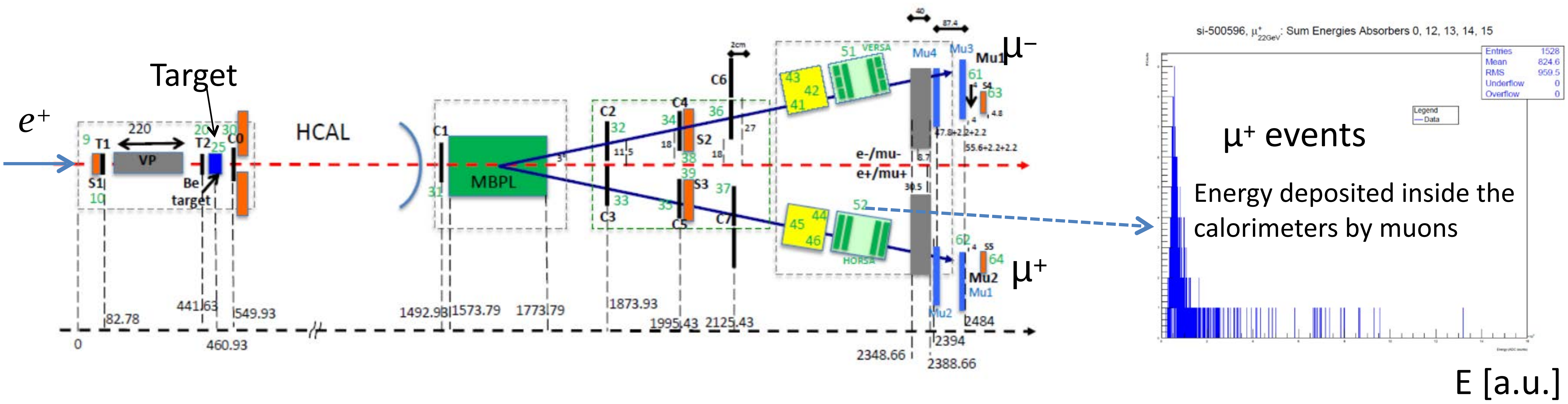
+

Machine optics optimization
- Maximise positron ring energy acceptance
- Minimize ring emittance
- Muon accumulator..



LEMMA: Test beam at CERN

Two test beams have been performed last Summer at CERN for **studying the rate and the kinematic properties of muon production with a 45 GeV positron beam**



- Experimental setup consisted of several tracking detectors, calorimeters, and plastic scintillator for triggering purposes
- A ~3.5 Tm dipole magnet was used to separate opposite-charge particles
- **Huge background from radiative Bhabha events and bremsstrahlung**
- **Difficult analysis** to extract the relatively few muon events

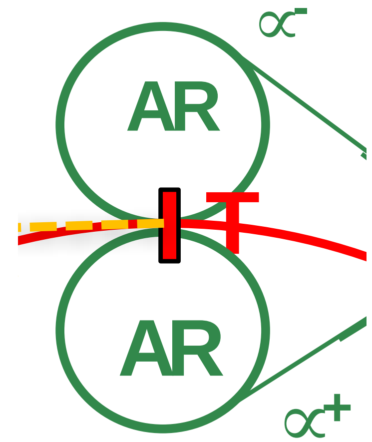
Rome group involved in the operation of the calorimeters and in the **data analysis**, studying in particular the performances of the calorimeters and their use to reject radiative Bhabha events.

LEMMA: Muon production Targets

$$N_{\mu^+\mu^-} = N_{e+} \cdot \rho_{e-} \cdot L \cdot \sigma(e^+e^- \to \mu^+\mu^-)$$

Maximize the rest

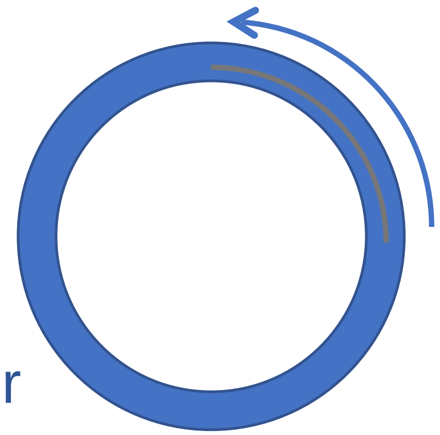
Small cross section: O(1 μb)



O(100 kW) Power load expected

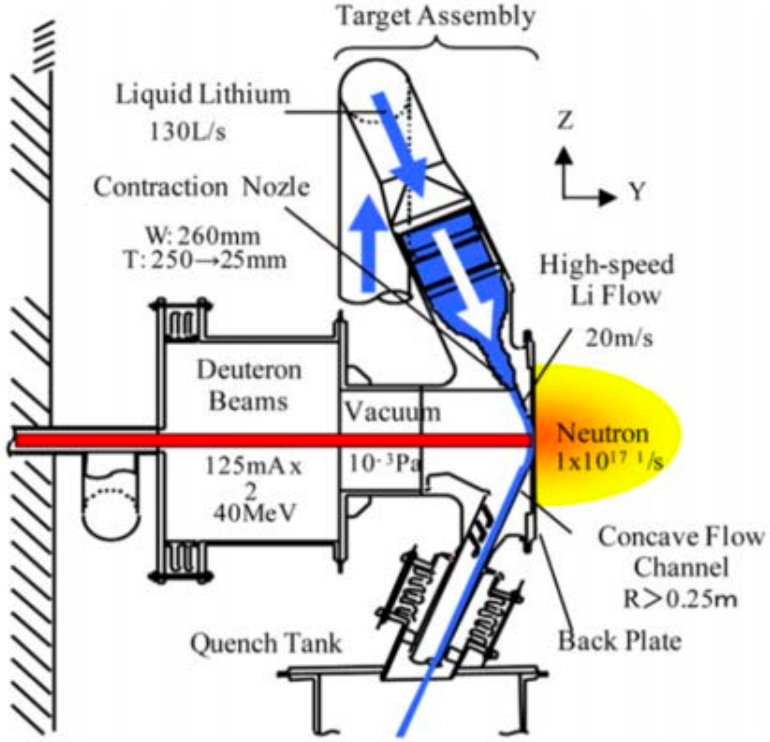
Investigate **best compromise as a target for low emittance muon-beam production**:

- Heavy material in a thin target
  - High e^+-beam loss, low μ production
- Very-light material in a thick target
  - Increasing emittance, hard power handling
- **Not too heavy materials: Li, Be, C**
  - good compromise for good efficiency and low emittance

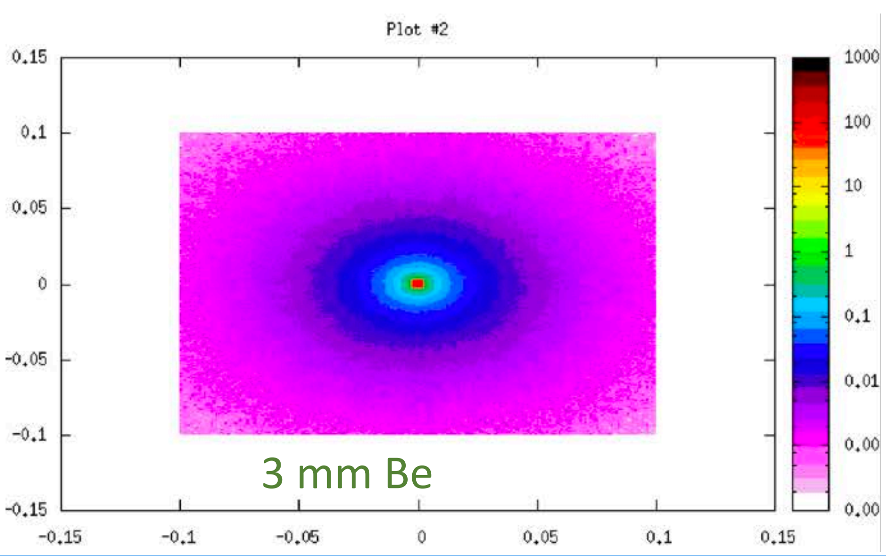


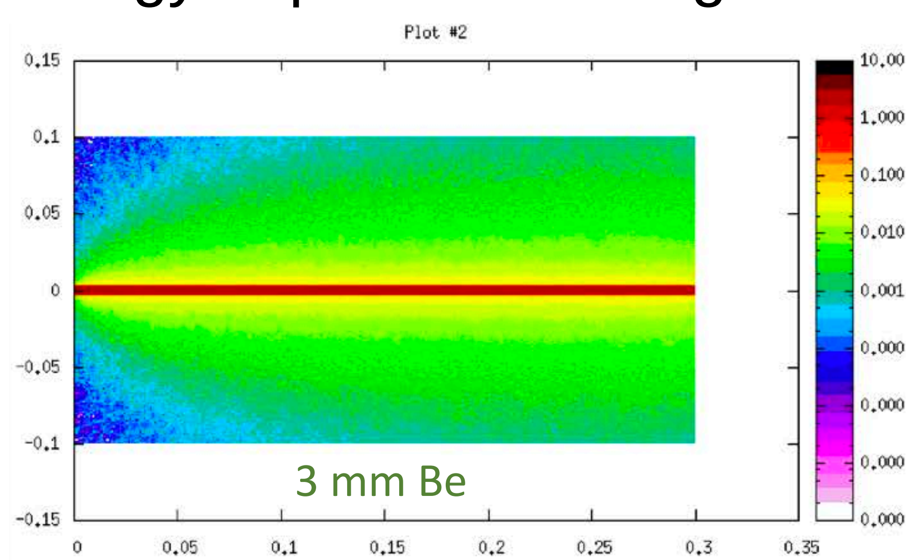
Rotating target cools down faster

Liquid targets are exploited in nuclear physics, might be a good option to study



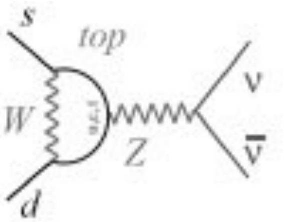
➤ Fluka/Autodyn simulation of energy deposit in the target





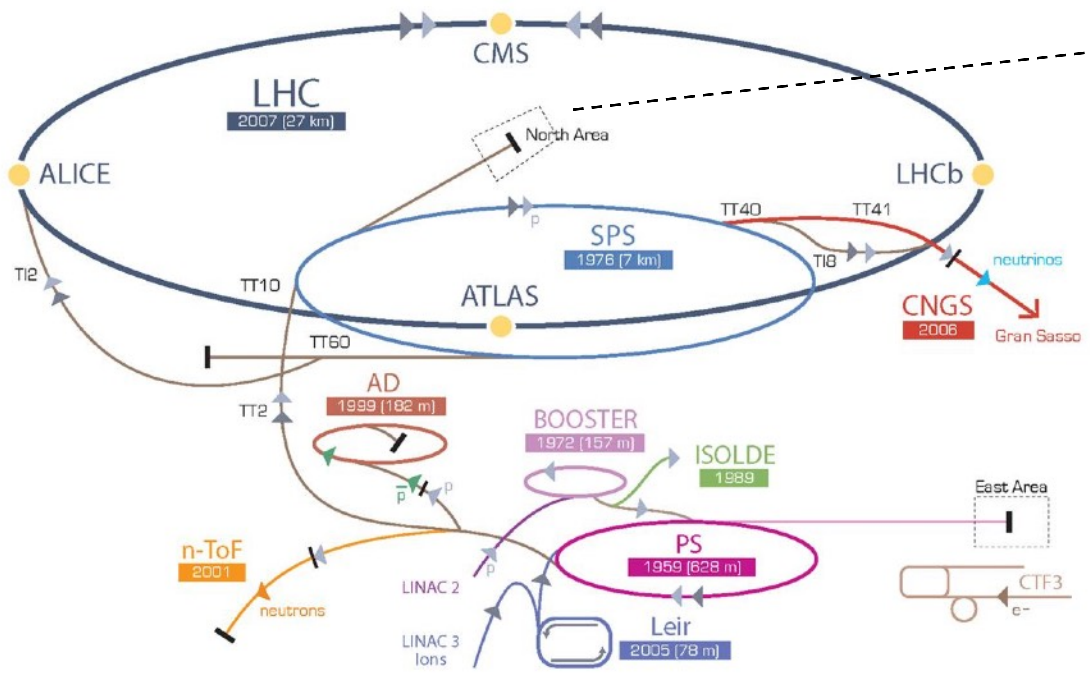
NA62 ACTIVITIES

*Esperimento su fascio estratto all'**SPS** del **CERN** per studiare decadimenti **estremamente rari**: K → πνν*



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.)*

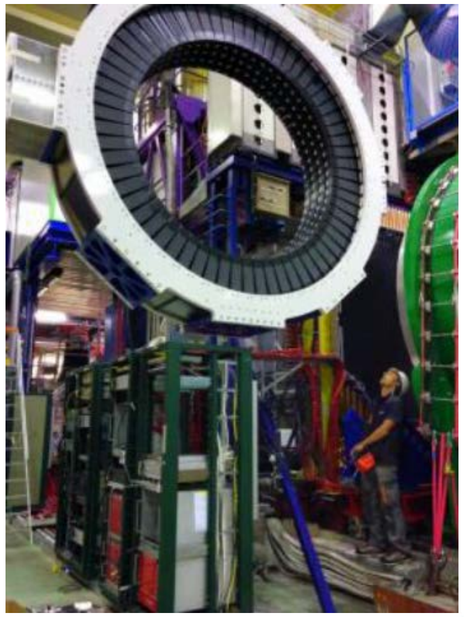
Perché questo esperimento è interessante nell'era di LHC?

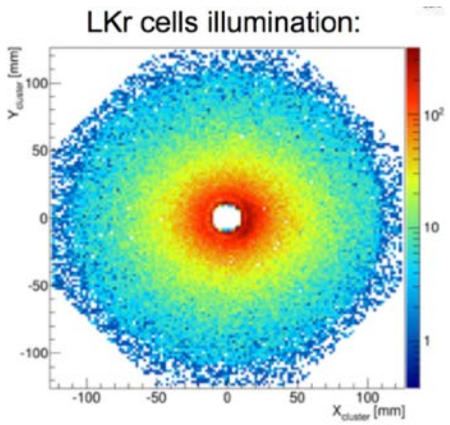
- **Processi Flavour Changing Neutral Current → sensibili alla fisica oltre il Modello Standard**
  - ***- Misure di precisione per discriminare la struttura del Flavor della "nuova fisica"***
  - ***- Frontiera dell'intensità, approccio complementare a quello dell'energia (LHC)***
- **Grande contributo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

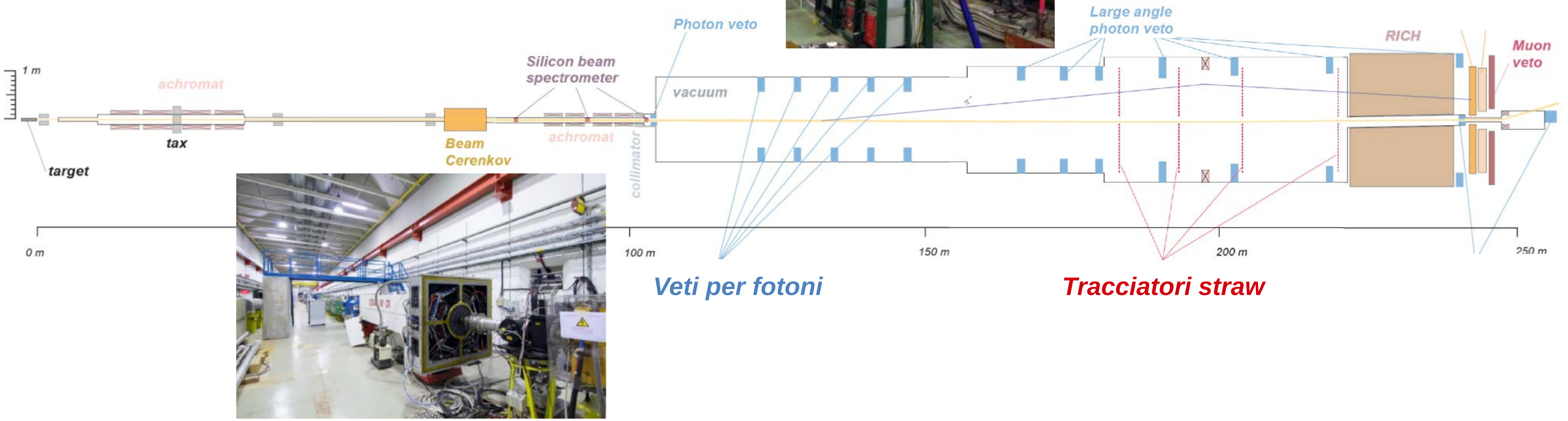
Ma i branching ratio (Standard Model) sono <10^{-10}!

*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, magnete, ecc.)*
- *Fascio **esistente** e **50 volte più intenso***
- ***Nuovi rivelatori***
- ***Nuovo trigger, DAQ, computing, software…***

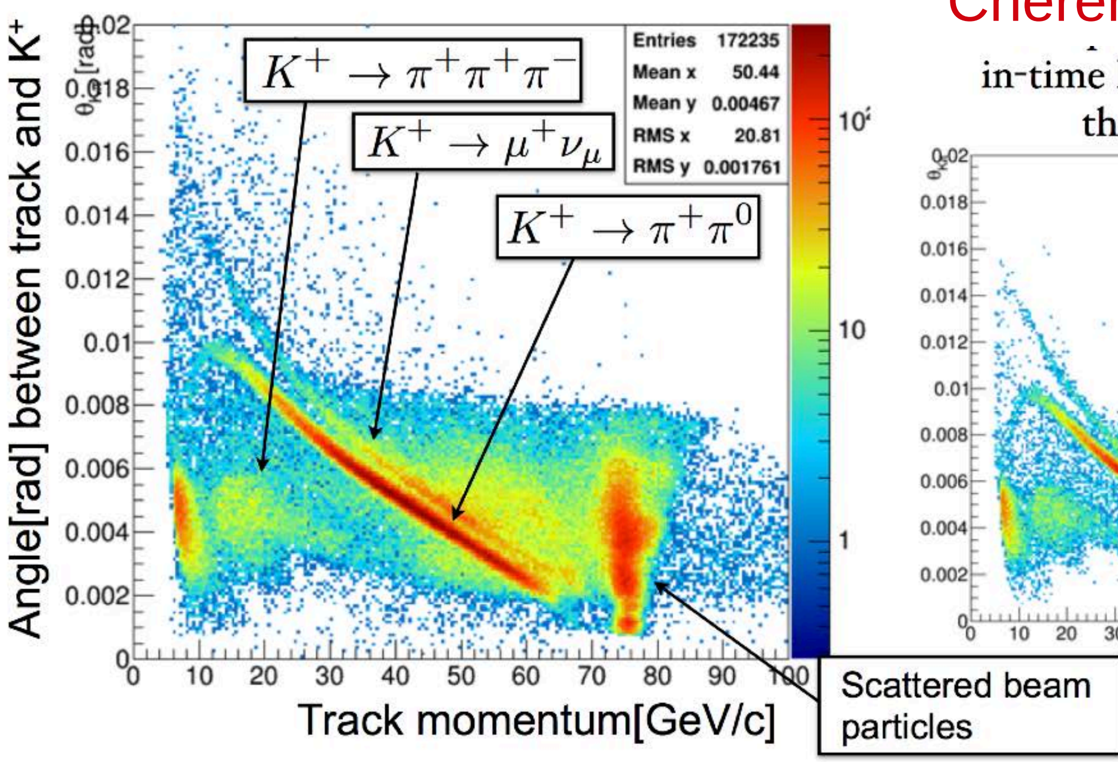




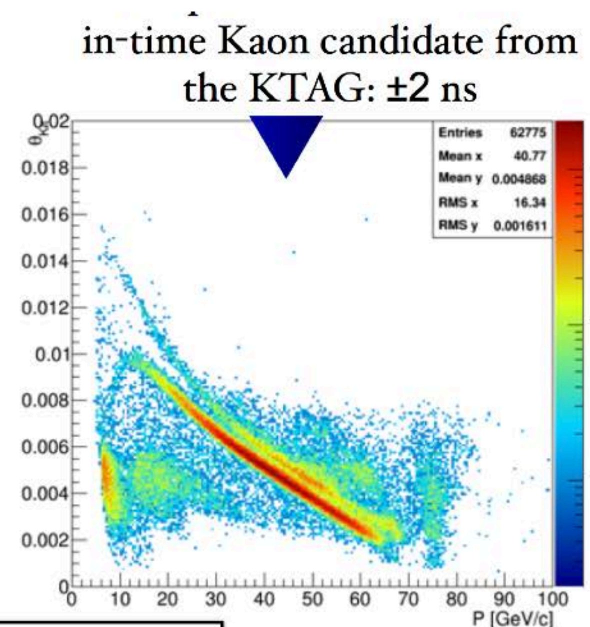


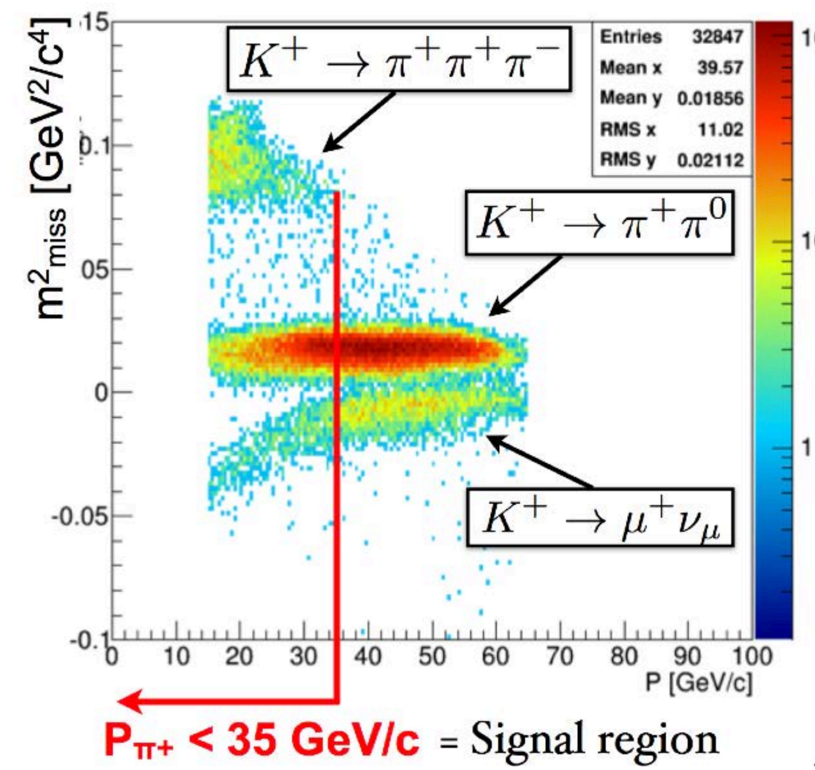
- Prima presa dati con fascio e primi eventi di fisica nel 2015
- Tre anni di run e analisi dati 2016, 2017 e 2018

Eventi a una traccia nello spettrometro…



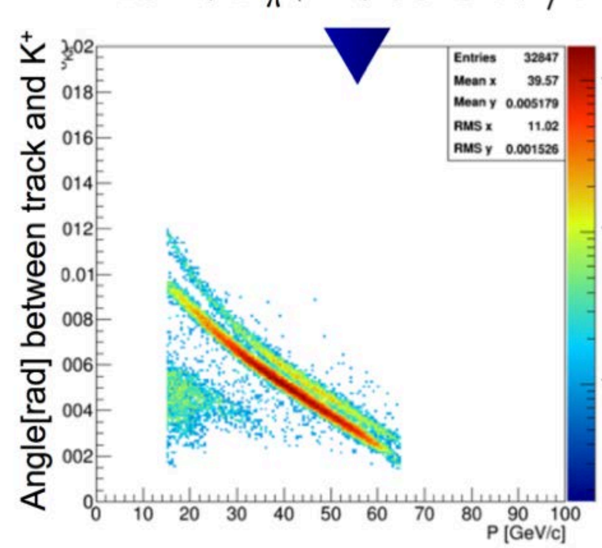
… in tempo con il Cherenkov e…

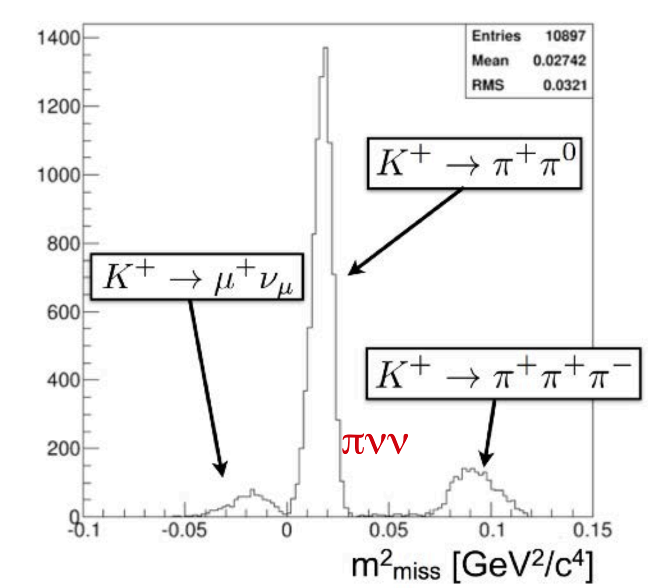




…nel volume fiduciale

$$105 < Z_{VTX} < 165\ m$$
$$15 < P_{\pi^+} < 65\ GeV/c$$





Physics studies

- Lepton Flavour Violation
- $\pi \nu\nu$
- Hidden sector, heavy neutrinos with Kaons and beam dump

“Effetti di trigger sulla valutazione della reiezione dei pioni neutri nell’esperimento NA62"

I decadimenti rari dei mesoni K in un pione, un neutrino e un antineutrino (K ➝ πνν) sono estremamente soppressi nel Modello Standard e i loro BR, che sono 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 il Modello Standard. L’esperimento NA62 attualmente in corso all’SPS del CERN è stato disegnato per misurare il BR del decadimento carico K+ ➝ π+νν con una precisione del 10%. Uno dei fondi principali nella ricerca del decadimento K+ ➝ π+νν è costituito da decadimenti K+ ➝ π+π0, che con un BR(K+ ➝ π+π0) ≃ 20% sono oltre 108 volte più abbondanti, in cui i due fotoni emessi nel decadimento del π0 (π0 ➝ $\gamma\gamma$) vengono persi. Al fine di pubblicare la misura sperimentale più precisa mai realizzata del BR(K+ ➝ π+νν), che sarà in grado di rivelare nuova fisica o di fornire nuovi vincoli alle teorie oltre il modello standard, è fondamentale calcolare l’efficienza di reiezione dei π0 garantita dal sistema di calorimetri di NA62. Questo sistema è composto da un calorimetro al Kripton liquido, due calorimetri Shashlik a piccolo angolo e 12 stazioni di calorimetri Čerenkov composti di cristalli di vetro al piombo disposti lungo i 65 metri del volume di decadimento dei K. Il trigger per la selezione degli eventi K+ ➝ π+νν utilizza diversi algoritmi che coinvolgono anche le informazioni fornite da questi calorimetri. Il lavoro di tesi è orientato a studiare i possibili bias introdotti dalle richieste del trigger nella stima del potere di reiezione dei fotoni prodotti dai pioni neutri.
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“Efficienza di trigger per la selezione di stati finali di decadimento di particelle esotiche con l’esperimento NA62”

L’esperimento NA62 attualmente in corso all’SPS del CERN è stato disegnato per misurare il BR del decadimento carico K+ ➝ π+νν con una precisione che, raggiungendo quella teorica, potrebbe fornire indizi di nuova fisica o alternativamente dare nuovi vincoli alle teorie oltre il modello standard. Questo esperimento ad alta intensità, grazie alla flessibilità del sistema di trigger e alle performance molto spinte dei rivelatori che lo compongono può risultare ideale anche per la ricerca di particelle esotiche a lunga vita media che si possono creare nell’interazione dei protoni con il bersaglio insieme ai Kaoni e raggiungere il volume di decadimento dell'esperimento, o che possono apparire nei decadimenti di K e π grazie a flebili accoppiamenti con le particelle del Modello Standard. Queste particelle sono i Dark Photon (A), gli Heavy Neutral Lepton (N), e le Axion Like Particle (ALP). Per selezionare i decadimenti di queste particelle sono stati sviluppati degli algoritmi di trigger altamente efficienti che collezionano candidati esotici senza interferire con l’efficienza del flusso dominante di eventi da selezione per la misura del decadimento principale K+ ➝ π+νν. Come 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’➝e+e-, A’➝μ+μ-, A’➝invisible, K+➝e+N, K+➝μ+N, N➝πe, N➝πμ, ALP➝γγ) e in particolare di calcolare l’efficienza dell’algoritmo di trigger, che coinvolge diversi rivelatori dell’apparato, per la selezione degli eventi, fondamentale per la pubblicazione di un risultato finale.
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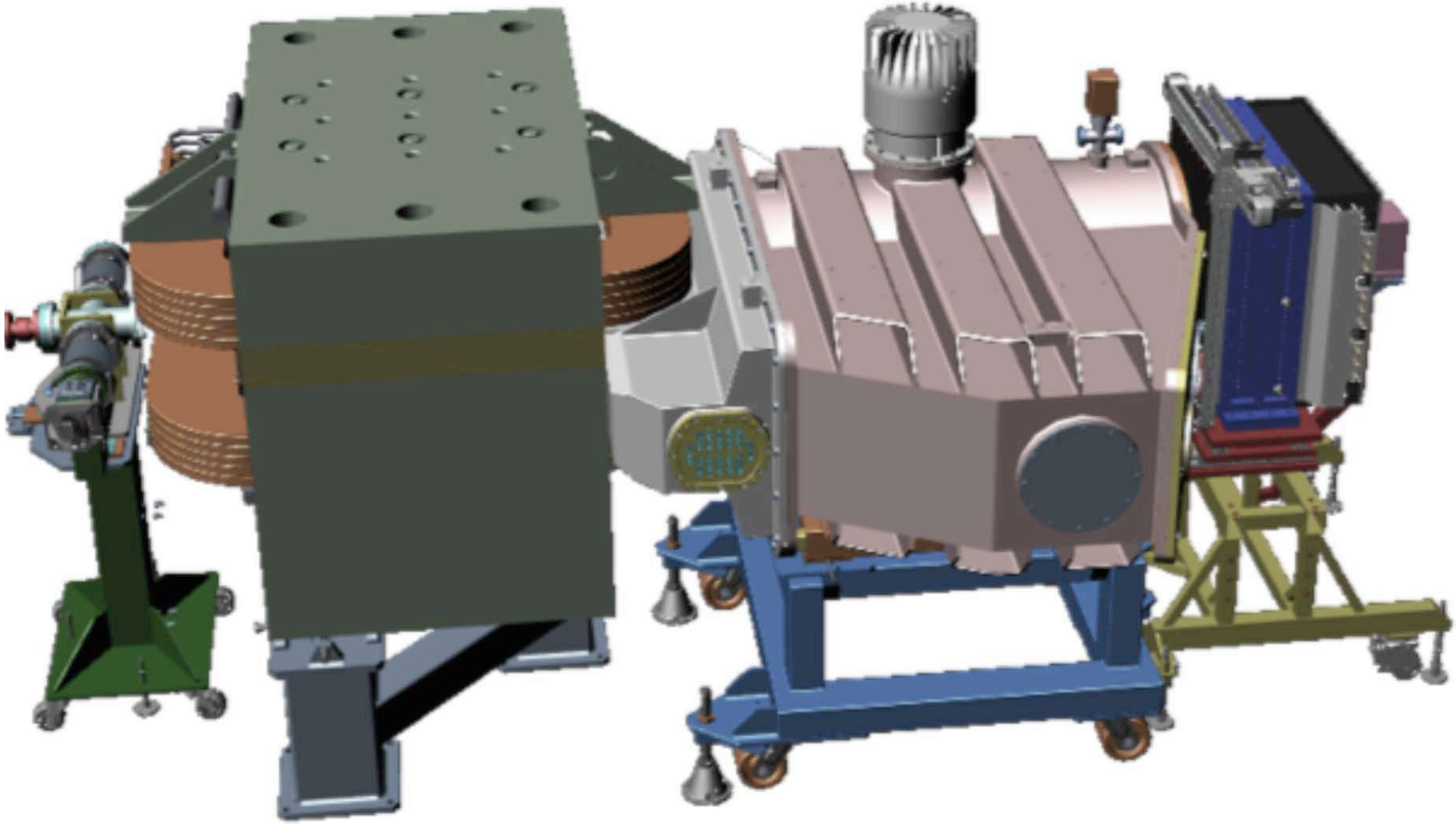

PADME ACTIVITIES

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 inizierà la sua presa dati a giugno del 2018. Numerosi stati finali di nuova fisica saranno accessibili all’esperimento con la possibilità di lavorare su dati appena acquisiti.

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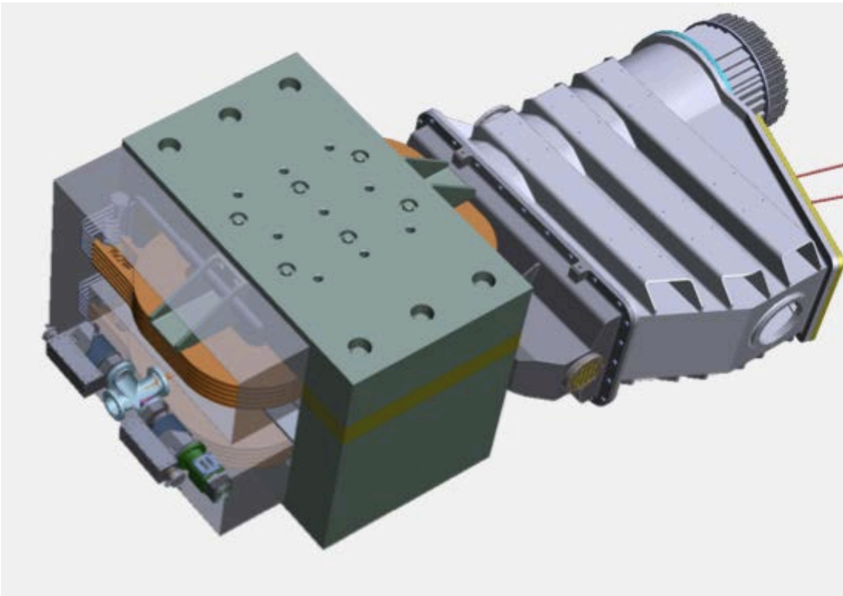

Analisi dei dati a PADME

Tra ottobre 2018 e marzo 2019 si è svolta una prima presa dati, e una nuova presa dati è prevista a partire da novembre 2019. Oltre alla ricerca di segnali di fotone oscuro con segnatura di massa mancante in eventi $e^+e^- \rightarrow \gamma$ + massa mancante, è possibile studiare con precisione canali di fisica come $e^+e^- \rightarrow \gamma\gamma$.

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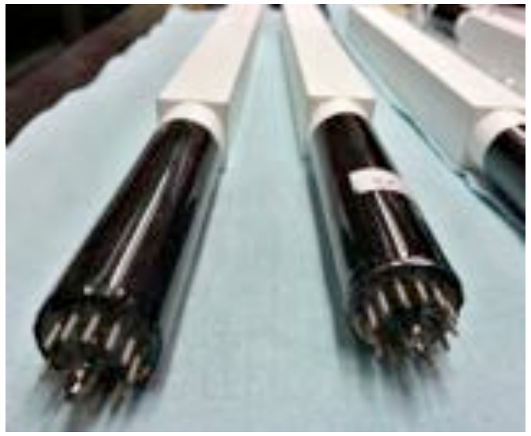

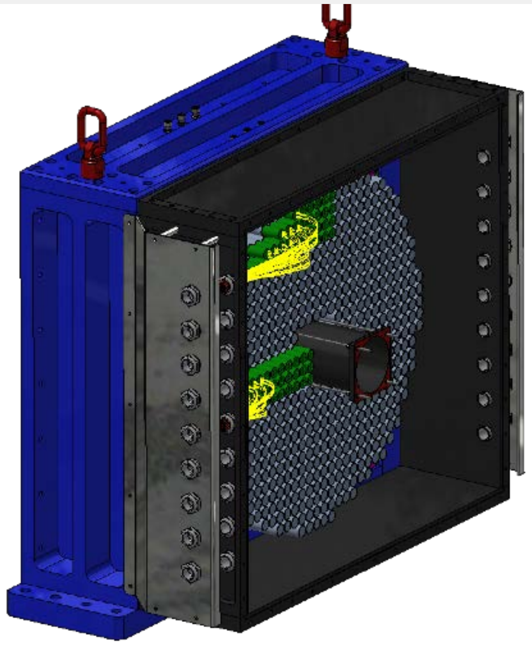

ALLA RICERCA DEL FOTONE PROTO-FOBICO A PADME

E' stato recentemente osservata dal laboratorio MTA ATOMKI di Debrecen (Ungheria) un eccesso di eventi $e^+ e^-$ di massa 16.7 MeV che sarebbe compatibile con l'esistenza di una nuova forza oscura e del suo mediatore bosone X che decadrebbe in coppie. 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 sensitività dell'esperimento PADME a tale nuova particella.

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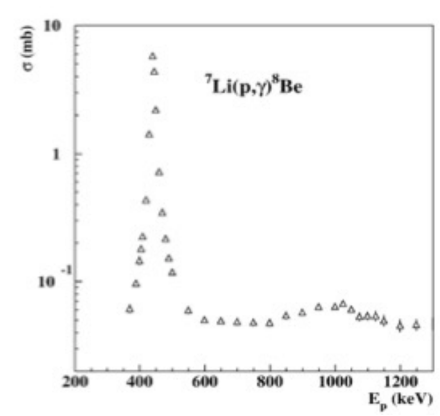
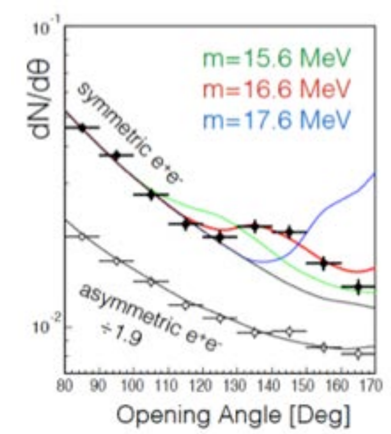
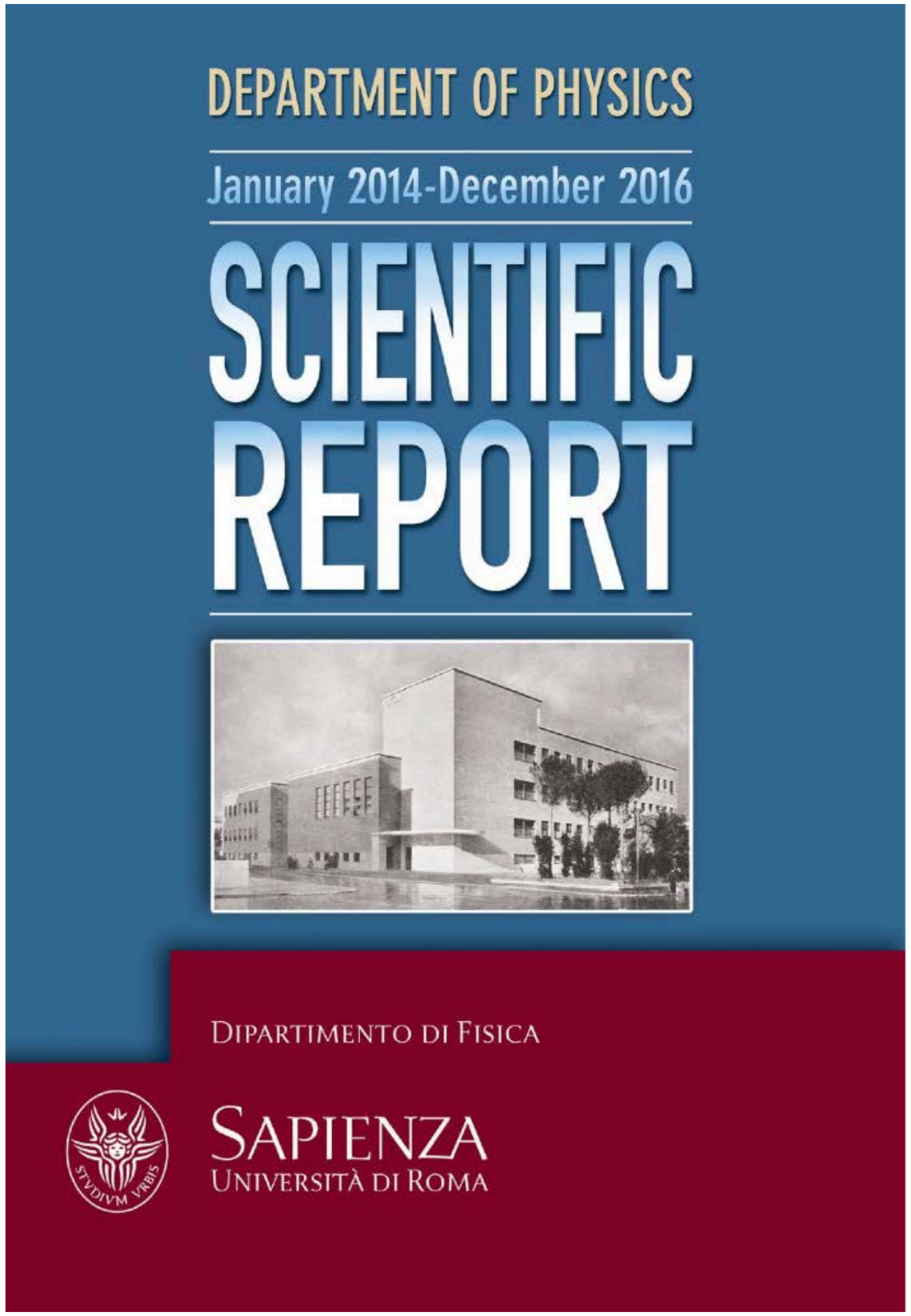




SCIENTIFIC REPORT OF DEPARTMENT

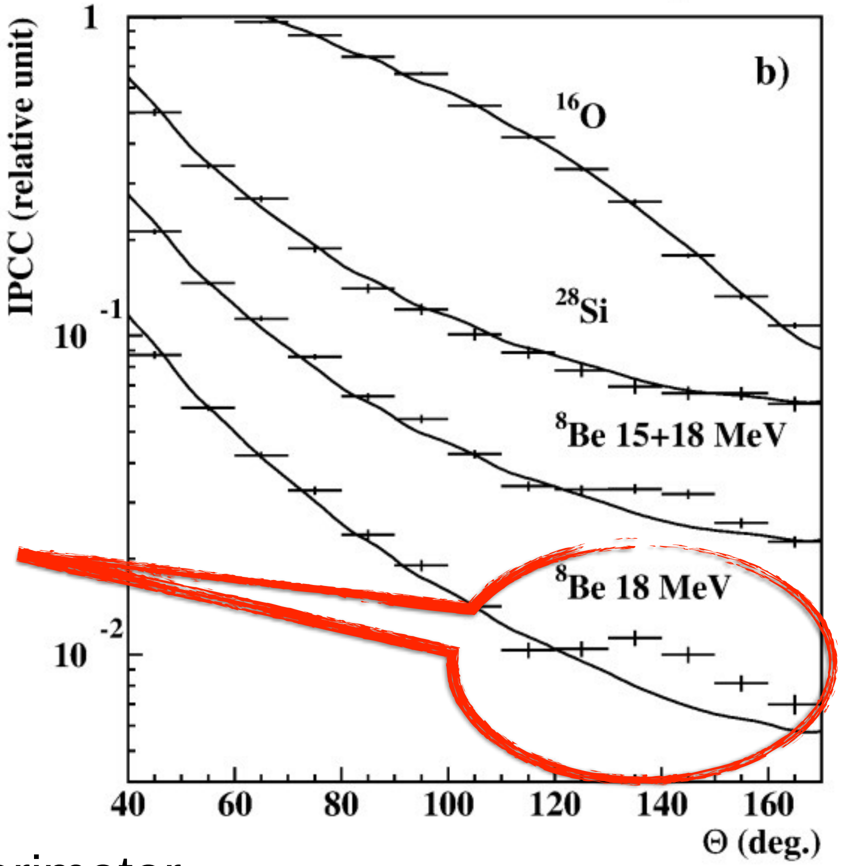
- A **quite recent (2014-2016) and complete insight** on the physics department and INFN section activity
- Particle Physics and Fundamental Interactions described in a specific section of the report
- http://www.phys.uniroma1.it/fisica/ricerca/scientific-report



BACKUP

Search for X(16.7 MeV) @ MEG2

- Anomaly observed in 2016 by a low-energy nuclear physics experiment at the ATOMKI institute in Hungary:
  - thin foil of lithium atoms bombarded with protons to induce nuclear reactions
  - lithium-7 nuclei transition into unstable isotope beryllium-8 that decays by emitting an e^+e^- pair
  - SM predict that the decay rate drops with increase of the angle between e^+e^- pair, instead has been found that some of electrons and positrons flew away at a much wider angle.
  - this could happen if they were born from the decay of an invisible particle with a mass of ~17 MeV, that can be the dark-photons of DarkSector models



At MEG2:

- Cockroft-Walton accelerator to generate nuclear reactions to calibrate calorimeter
- MEG2 drift chamber to reconstruct e^+e^- pairs
- Thesis activities: optimisation of experimental setup using simulation, partecipation to the measurement setup and commissioning