Physics at hadron collider with Atlas

1st lecture

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on behalf of Atlas Collaboration

Outline

- **Introduction to Hadron Collider Physics**
- 1st: LHC and ATLAS detector
- Test of Standard Model at LHC
  - Parton distribution function
  - QCD + jet physics
  - 2nd: Electroweak physics (Z/W –bosons)
  - Top physics
- 3rd: Search for Higgs boson
- 4th: Supersymmetry
- Conclusions

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The Standard Model of Particle physics

- The building blocks of matter are fermions

Leptons $\begin{pmatrix} \nu_e \\ e \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$

Quarks $\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$

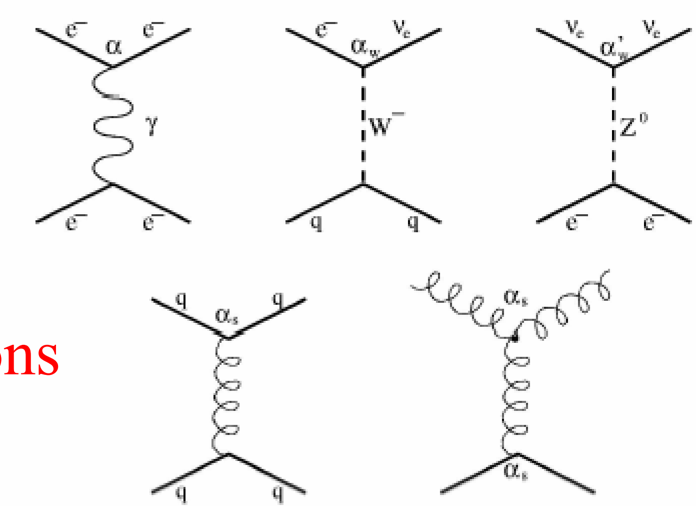
$\longrightarrow$

mass

- The force carriers (bosons)

Electroweak interaction : γ, $W^{\pm}$, Z
$m_\gamma = 0$, $M_w = 80.425 \pm 0.034$ GeV/c^2
$M_z = 91.1785 \pm 0.0021$ GeV/c^2

QuantumChromodinamics (QCD): gluons
$m_g=0$

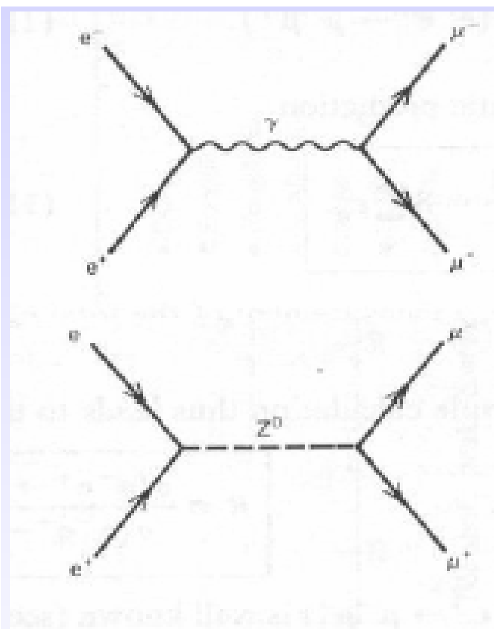


LEP legacy

• e^+e^- colliders are excellent machines for precision physics

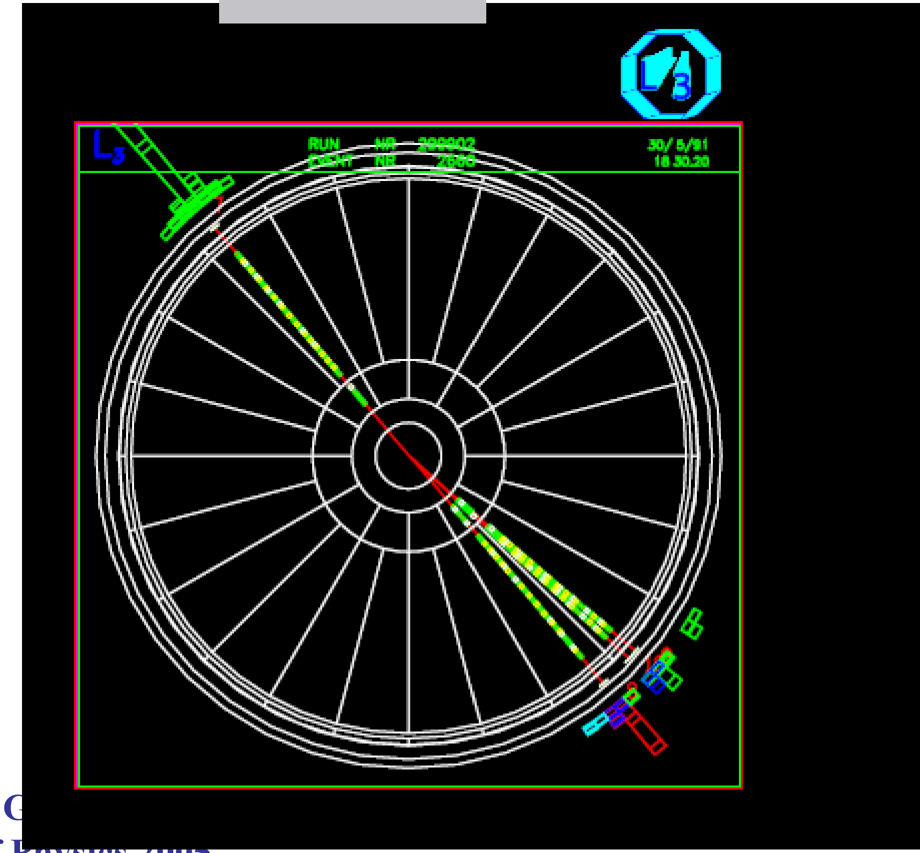
e^+e^- are point like particles, no structure →clean events

Complete annihilation, center-of-mass system, kinematics fixed.



$e^+ e^- \rightarrow \mu^+\mu^-$

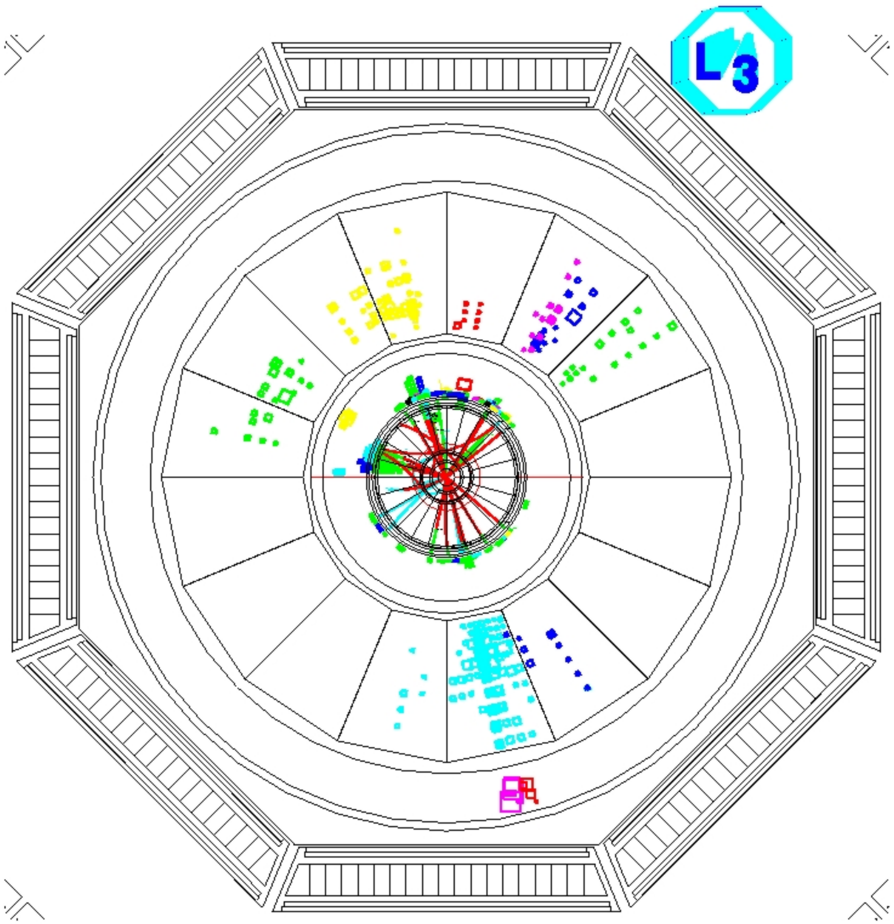
$Z \rightarrow \tau^+ \tau^-$



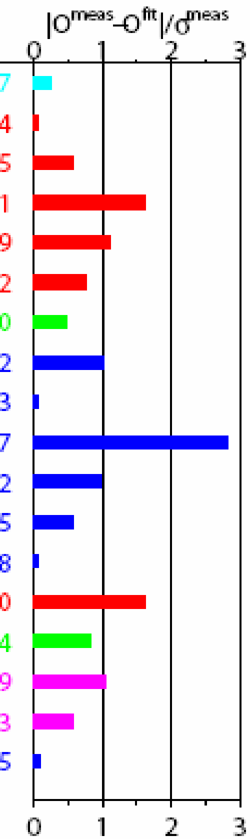
LEP legacy

Summer 2005

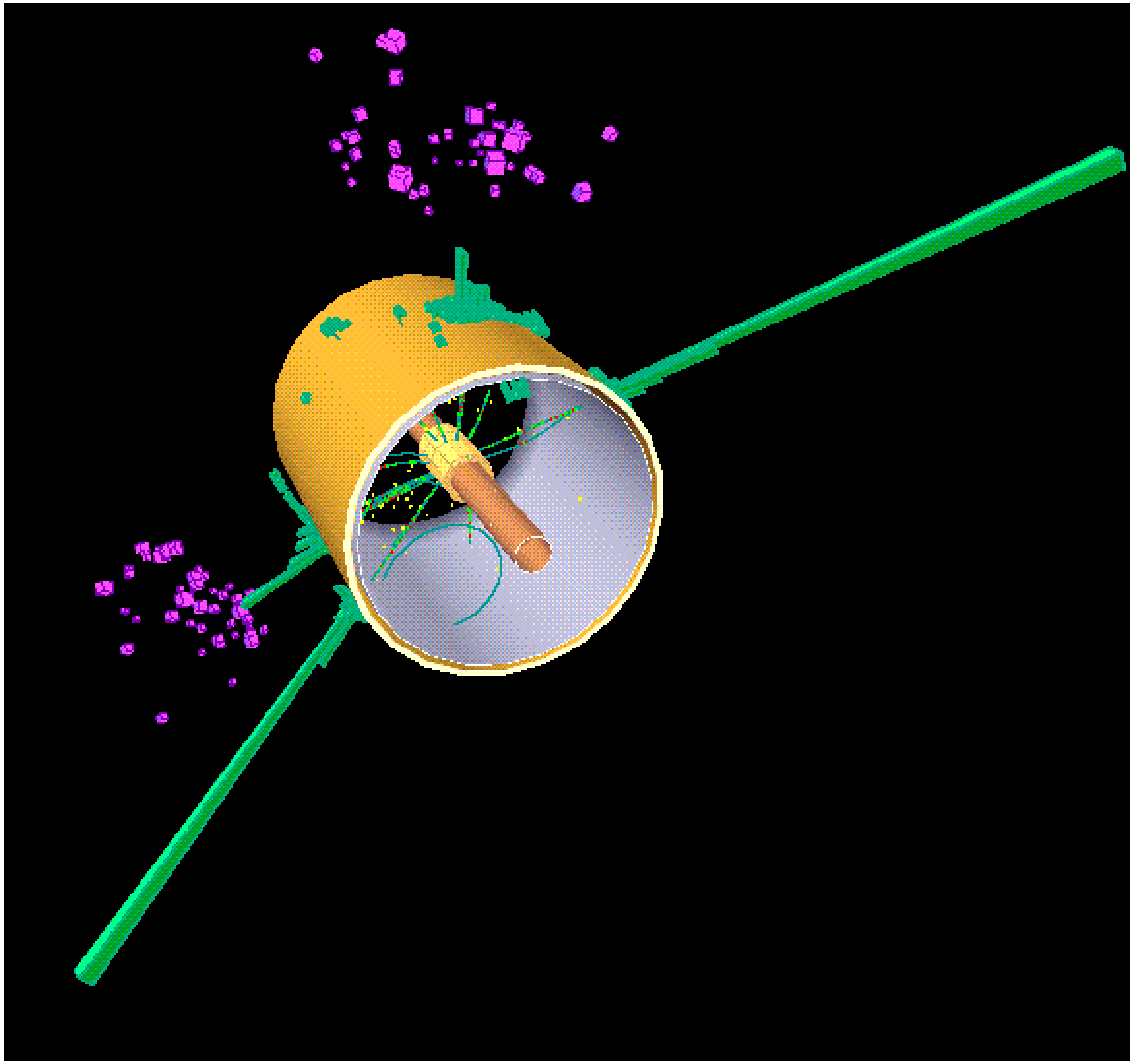
W^+W^- in hadrons



	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4965
σ_{had}^0 [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01642
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21562
R_c	0.1721 ± 0.0030	0.1723
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1037
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.389
Γ_W [GeV]	2.133 ± 0.069	2.093
m_t [GeV]	178.0 ± 4.3	178.5



LEP



- L3 **ZZ**

ZZ → qqee at 200 GeV;

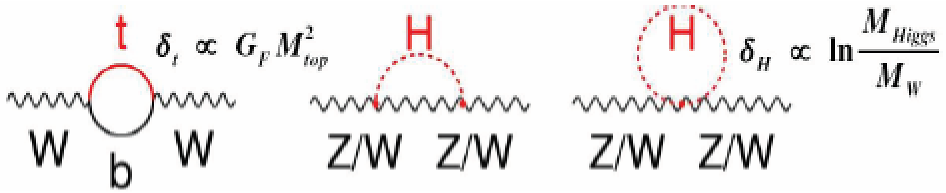
- the mass of the qq system is 95.0 GeV,
- the mass of the ee system is 92.8 GeV,
- the 5C fit gives a mass of 93.8 GeV

Status of SM model

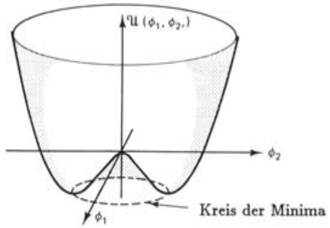
- ➢**High precision measurements→ Test of Standard Model**
- ▪**1000 data points combined in 17 observables calculated in SM**

  – α_{em}(precision 3 10^{-9}) (critical part $\Delta\alpha_{had}$)
  - G_F (precision 9 10^{-6}) (→M_W)
  - M_z(precision 2 10^{-5})from line-shape
  – $\alpha_s(M_z)$ precision 2 10^{-2} hadronic observable

M_{top} and M_{Higgs}



LEP legacy

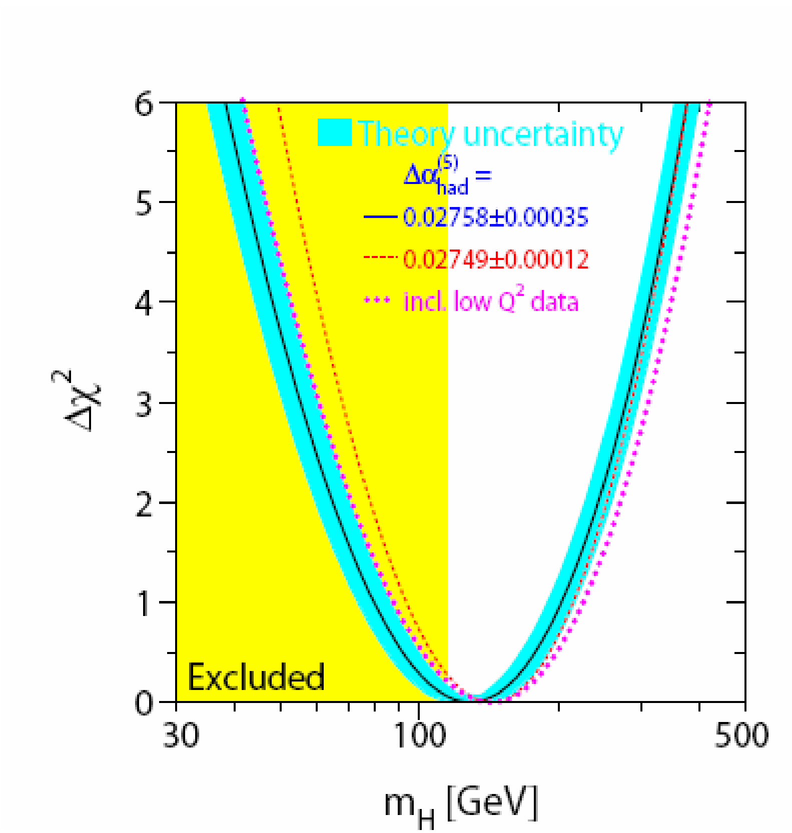


Direct limit M_H > 114.4 GeV

Indirect constraints < 208 GeV

LP2005

With m_t Tevatron
(174.3 ±3.9 GeV)



EPS 2005
m_t Tevatron
(172.7 ±2.9 GeV)

e+ e$^-$ accelerators

- Energy loss due to syncroton radiation

-radiated power, R= radius
E= energy

$$P = \frac{2\, e^2\, c}{3\, R^2} \left(\frac{E}{mc^2} \right)^4$$

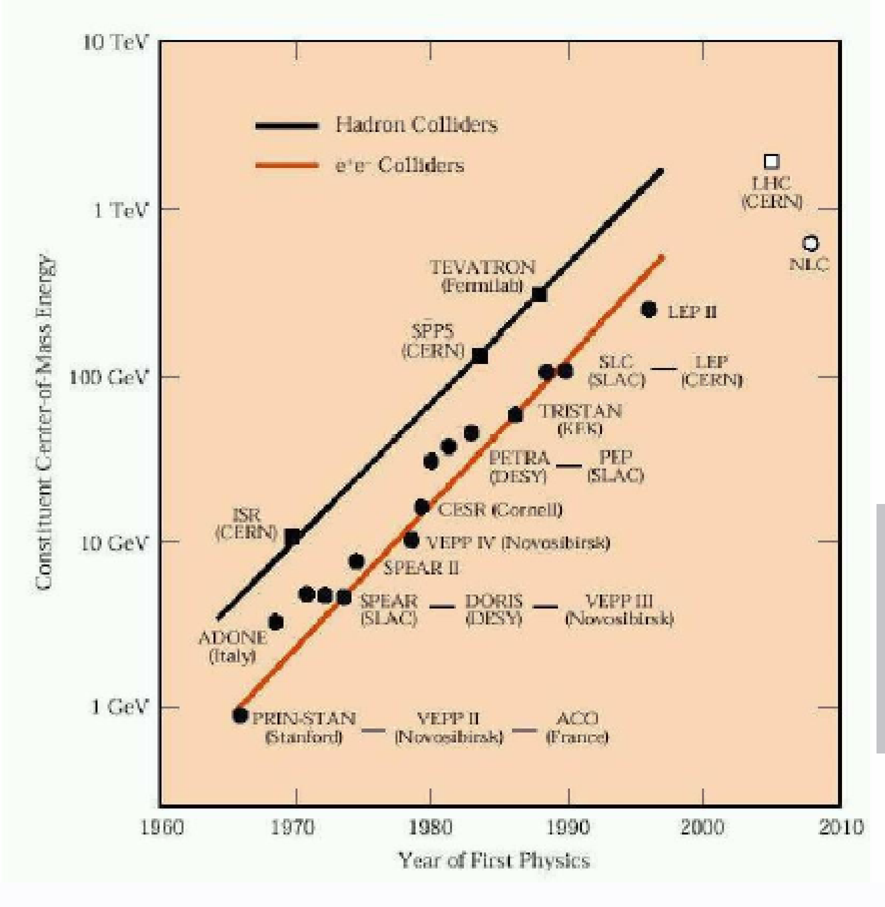
-energy loss per

$$-\Delta E \approx \frac{4\, \pi\, e^2}{3\, R} \left(\frac{E}{mc^2} \right)^4$$

-ratio of the energy loss between
Protons and electrons

$$\frac{\Delta E(e)}{\Delta E(p)} = \left(\frac{m_p}{m_e} \right)^4 \sim 10^{13}$$

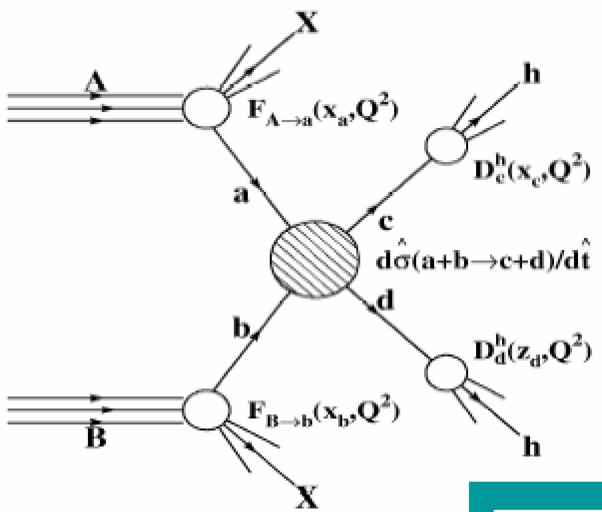
Energy of machines



The kinematic limit is the center-of-mass energy :
$\sqrt{s} = 2\, E_{beam}$

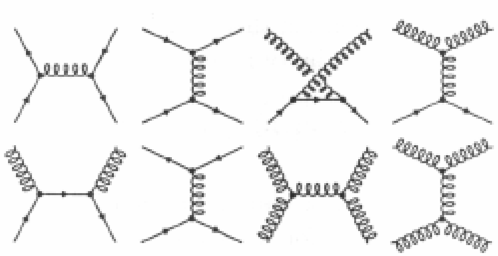
LHC is 14 TeV proton-proton startup planned for 2007

Physics at Hadron Colliders



•Protons are complex objects:
Partonic substructure : Quarks & gluons

• Hard scattering processes (large moment transfer):
- quark-quark
- quark-gluon scattering or annihilation
- gluon-gluon



➢**Hard scattering** (high p_T processes)
Represent only a tiny fraction of total inelastic pp cross section

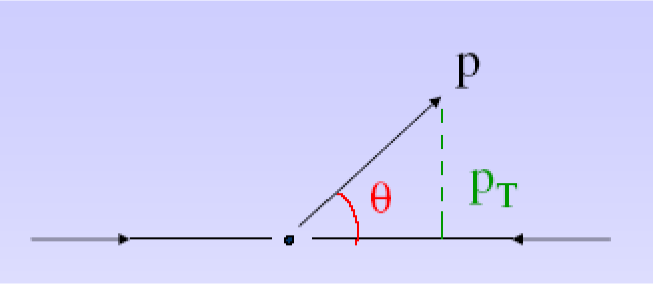
➢ **Total inelastic pp cross section**:
$\sigma_{pp} \sim$ **70 mb** (huge)
dominated by events with small momentum transfer

Variables used in pp collisions

- **P_T transverse momentum:**

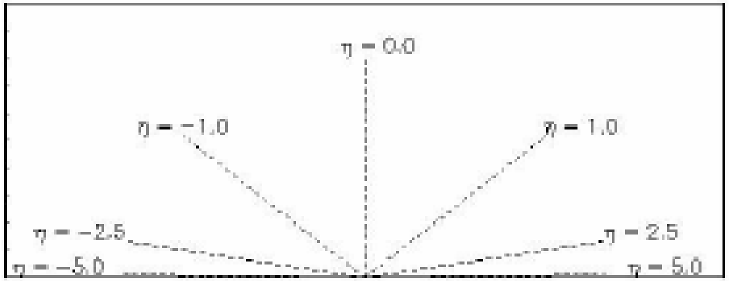
In the plane perpendicular to the beam

$$P_T = p \sin \theta$$



- **Pseudo-rapidity:**

$$\eta = -\ln \tan \frac{\theta}{2}$$



$\theta = 0 \rightarrow \eta = 0$

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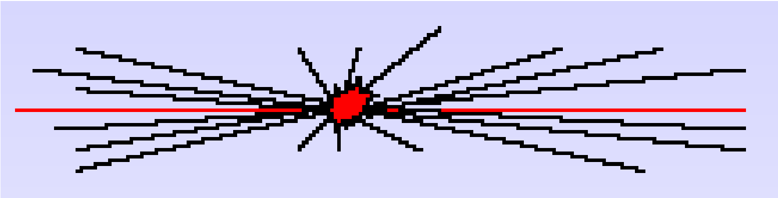
rapidity $$y = \frac{1}{2}\frac{E + p_z}{E - p_z} \approx \eta$$

Inelastic low p_T collisions

- **Most interactions** are due to interactions at large distance between incoming protons→ **small momentum transfer,** particles in the final state have large longitudinal momentum, but **small transverse momentum**



$< P_T > \sim 500$ MeV

of charged Particles in the final state

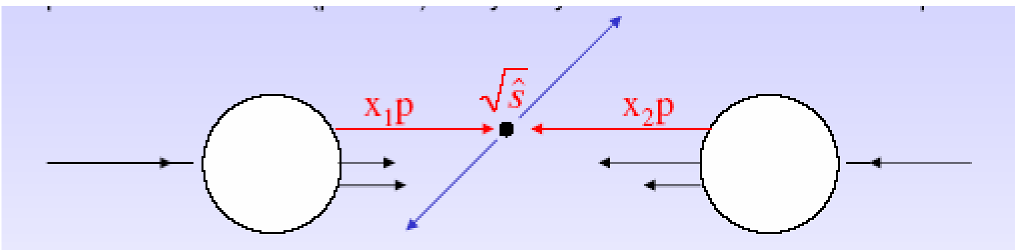
$$\frac{dN}{d\eta} \approx 7$$

- approx 7 charged particles per η unit in central part of detector
- uniformly distributed in Φ

- **Minimum bias events**

Hard scattering process

- The partons, proton constituents carry only a fraction $0 < x < 1$ of proton momentum



$$\begin{cases} p_1 = x_1 = p_A \\ p_2 = x_2 = p_B \\ p_A = p_B = 7\ \text{TeV} \end{cases}$$

- The effective-centre-of-mass-energy $\sqrt{\hat{s}}$ of $\sqrt{s}$ incoming proton s

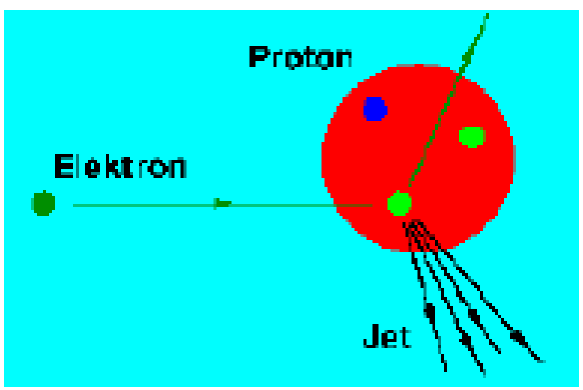
$$\sqrt{\hat{s}} = \sqrt{x_1 x_2 s} = x\sqrt{s}$$

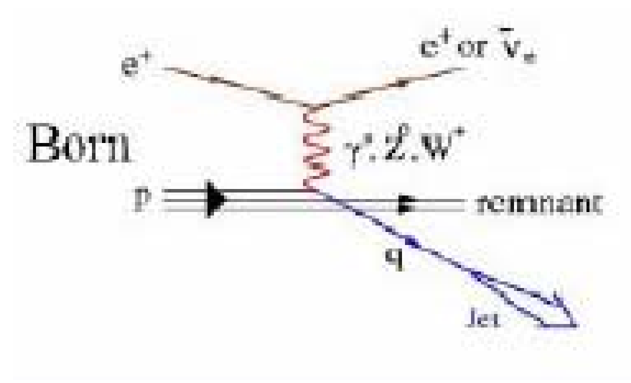
$(x_1=x_2)$

To produce a mass at LHC of:
100 GeV: $x \sim 0.007$
5 TeV : $x \sim 0.36$

Knowledge of x-value

- The structure of proton is investigated from **deep inelastic scattering.**
- Scattering of 30 GeV electrons on 900 protons (HERA)





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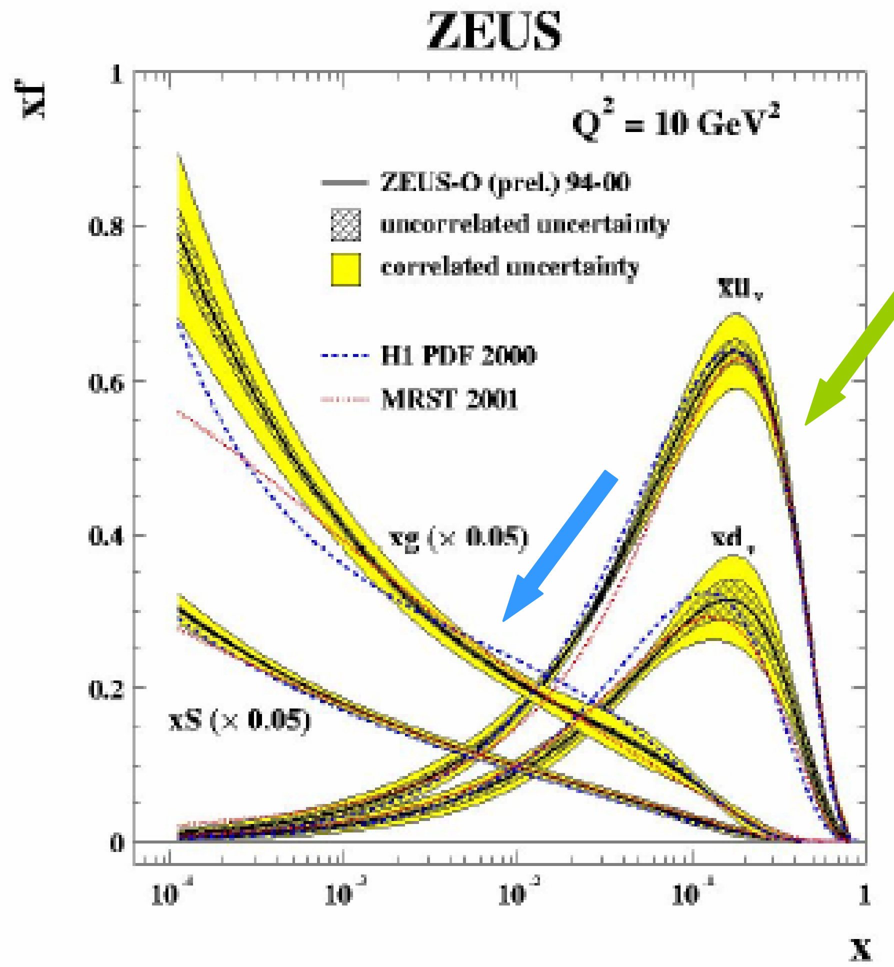
Gomel School of Physics 2005

x - values



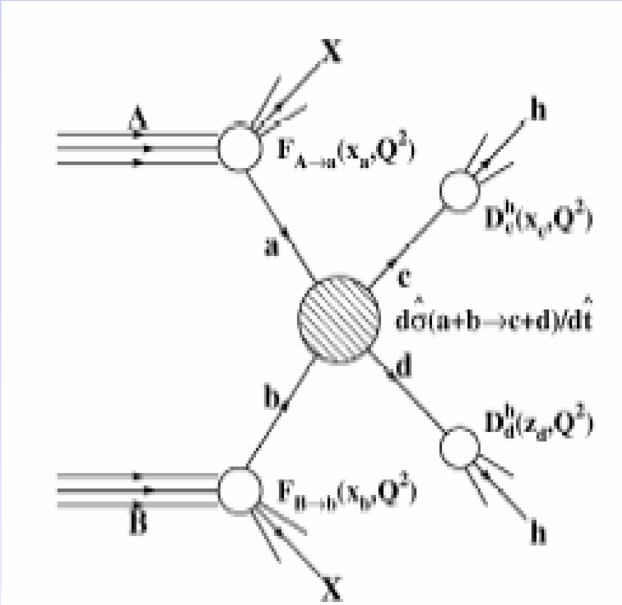
Parton-gluon density function (pdf):

•u , d quarks at large x-value

•gluons dominate at small x

Incertaintaies in the pdf expecially of gluons at small x

Calculation of cross sections



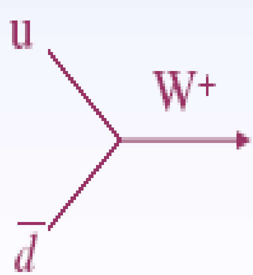
$$\sigma = \sum_{a,b} \int dx_a \, dx_b \, f_a(x_a, Q^2) \, f_b(x_b, Q^2) \, \hat{\sigma}_{ab}(x_a, x_b)$$

Sum over initial partonic states a,b

$\hat{\sigma}_{ab} \equiv$ hard scattering cross-section

$f_i(x, Q^2) \equiv$ parton density function

Example: W-production: (leading order diagram)



$\sigma(pp \rightarrow W) \sim 150$ nb $\sim 2 \cdot 10^{-6} \, \sigma_{tot}(pp)$

from K.Jacobs

... + higher order QCD corrections (perturbation theory)

Physics goal

- The physics goal is a main discovery: SM Higgs, Supersymmetry, extradimensions…. Unexpected physics
- To do that we **have to prove** to be able to understand the known physics (e.g. background)

- See lectures of Tim Christiansen and Filip Moortgart for the topics briefly discussed

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- **LHC and ATLAS detector**
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  - Top physics
- Search for Higgs boson
- Supersymmetry
- Conclusions


There is already a tunnel long enough to produce multi-TeV energies if equipped with super-conducting magnets and filled with protons
... the LEP at CERN

The Large Hadron Collider

- pp machine:

$\sqrt{s}$ = 14 TeV ~ 7 times higher than present highest energy machine (Tevatron/Fermilab: 2 TeV)

→ **search for new massive particles up to m ~ 5 TeV**

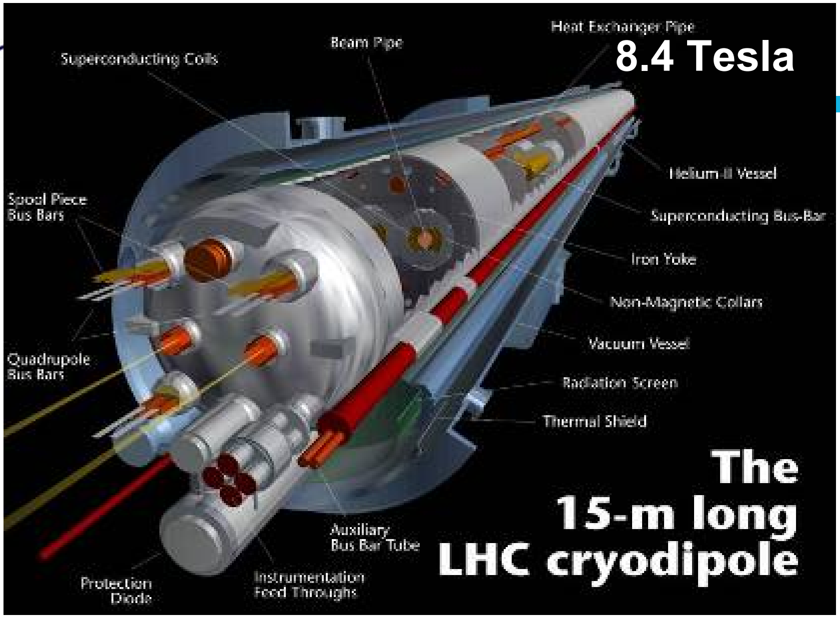
$$L \propto \frac{N_1 \; N_2}{\delta x \; \delta y} = 10^{34}\ \text{cm}^{-2}\ \text{s}^{-1}$$ ~ 10^2 larger than present machines (LEP2,Tevatron)

→ **search for rare processes with small σ (N = Lσ)**

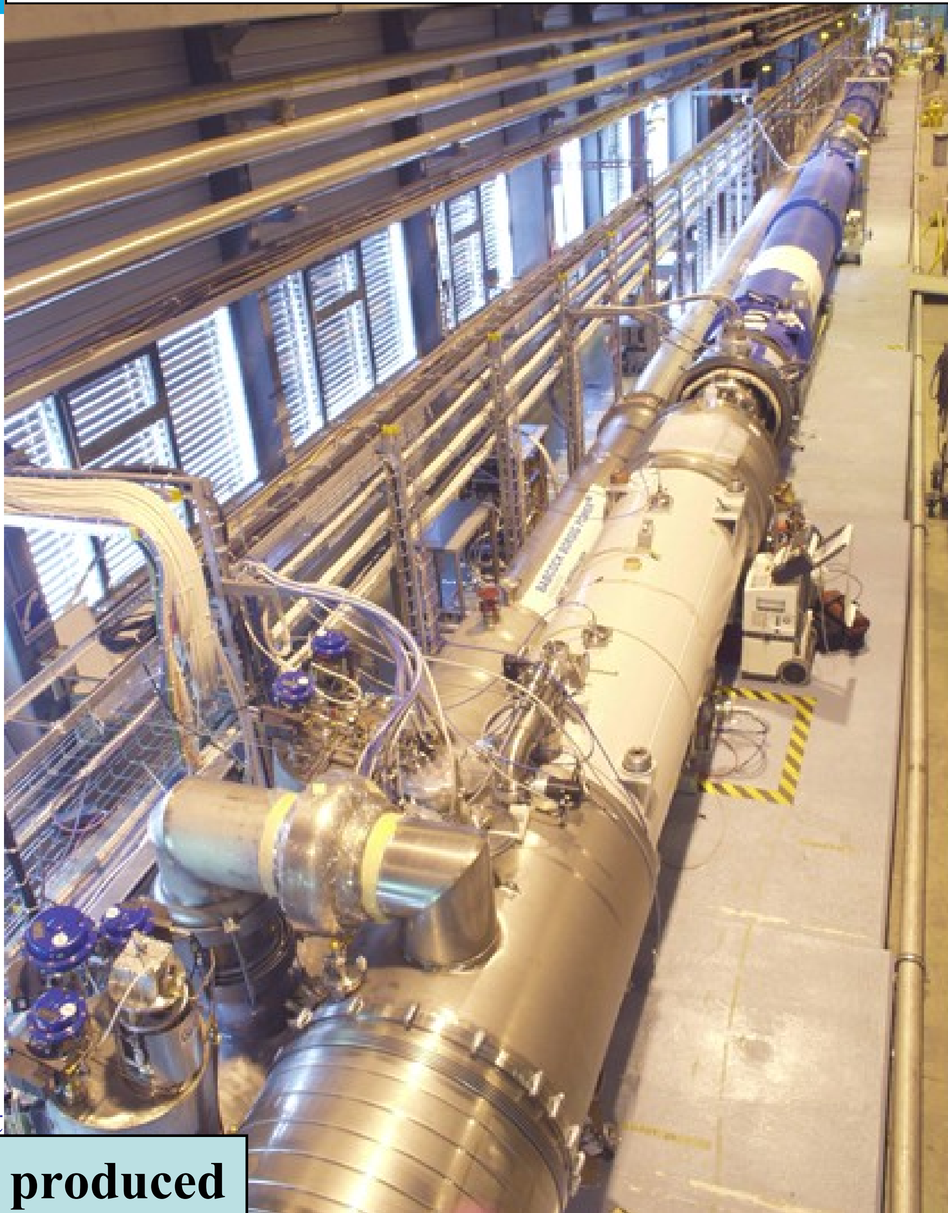
Components of LHC

- Superconducting dipole magnets
  - Magnetic filed 8.4 Tesla
  - 1300 magnet, each 15 m long
  - Operation temperature 1.9K
- Eight superconducting accelerator structures acceleration gradient of 5MV/m
- In production

The LHC machine



First full LHC cell (~ 120 m long) :
6 dipoles + 4 quadrupoles;
successful tests at nominal current (12 kA)



More than half of the 1232 dipoles are produced

Lowering of the first dipole into the tunnel (March 2005)

The magnet production proceeds very well and is on schedule, also the quality of the magnets is very good

Luminosity

- The rate of produced events for a given physics process

$N = L\,\sigma$

L = luminosity
σ = cross section

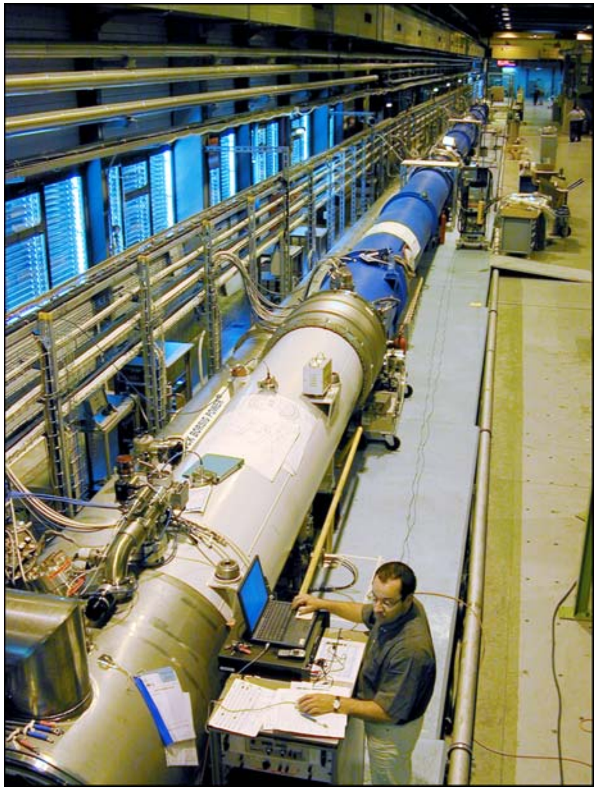
Dimension $s^{-1} = cm^{-2}\,s^{-1} \cdot cm^{2}$

1000 times larger than LEP2

- **One experimental year has $\sim 10^{7}$ s**

Large Hadron Collider

- Official Starting Date April 2007
- Initial Luminosity: ~ 10^{33} cm^{-2} s^{-1} , E_b=7 TeV
- Design Luminosity: 10^{34} cm^{-2} s^{-1} after 2-3 years



- 10 fb^{-1} per year at low lum.
- 100 fb^{-1} per year at high lum. per experiment
- 300 fb^{-1} ultimate
- fully performant detectors

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Events Statistics at low luminosity ($L=10^{33}$ cm^{-2} s^{-1})

Process	Events/s	Events/year	Other machines
$W \to e\nu$	15	10^8	10^4 LEP / 10^7 Tev.
$Z \to ee$	1.5	10^7	10^7 LEP
$t\bar{t}$	0.8	10^7	10^4 Tevatron
$b\bar{b}$	10^5	10^{12}	10^8 Belle/BaBar
$\tilde{g}\tilde{g}$ (m=1 TeV)	0.001	10^4	—
H (m=0.8 TeV)	0.001	10^4	—
QCD jets $p_T > 200$ GeV	10^2	10^9	10^7

➢ LHC is a B-factory, top factory, W/Z factory, Higgs factory, SUSY factory

EVENT RATE

- **N = no. events / sec**
- **L = luminosity =** 10^{34} cm^{-2} s^{-1}

  σ_{inel} **= inel. cross-section =** 70 mb
- **E = no. events / bunch xing**

  Δt **= bunch spacing =** 25 ns
- 3564 **no of bunches places**
- 2835 **no of bunches really filled**

- $N = L \times \sigma_{inel}$

  = 10^{34} cm^{-2} s^{-1} **x** $7\ 10^{-26}$ cm^2

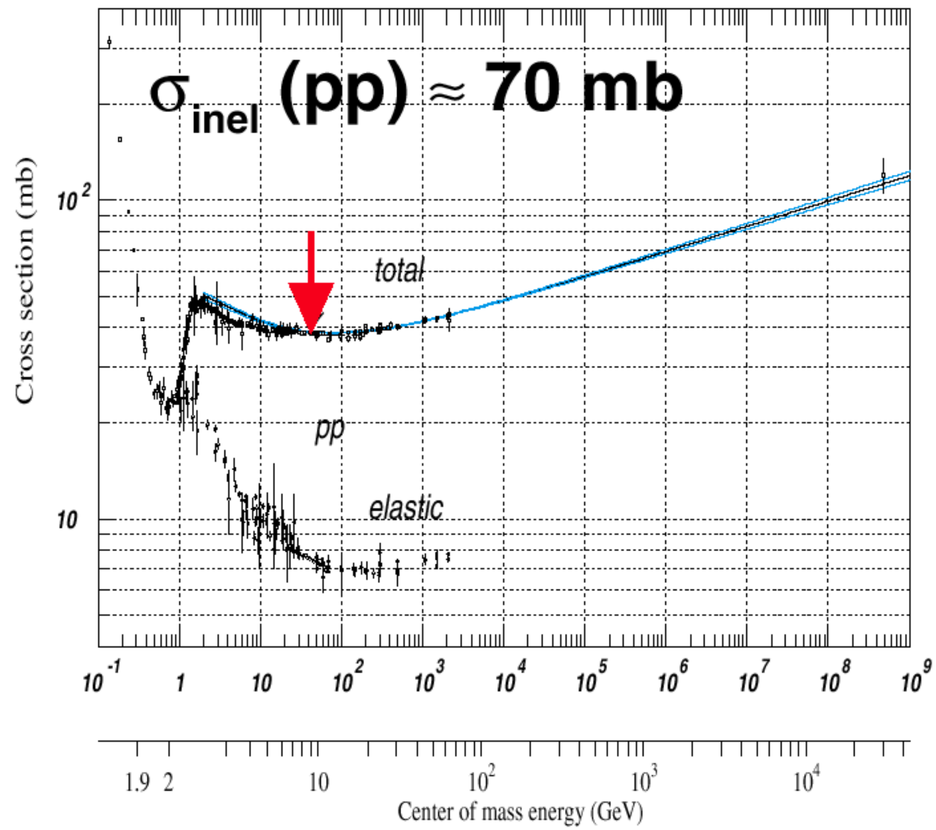
  $= 7\ 10^8$ Hz
- $E = N / \Delta t$

  $= 7\ 10^8\ s^{-1} \times 25\ 10^{-9}\ s = 17.5$

  (not all bunches are filled)

  $= 17.5 \times 3564 / 2835$

  = 22 events / bunch xing



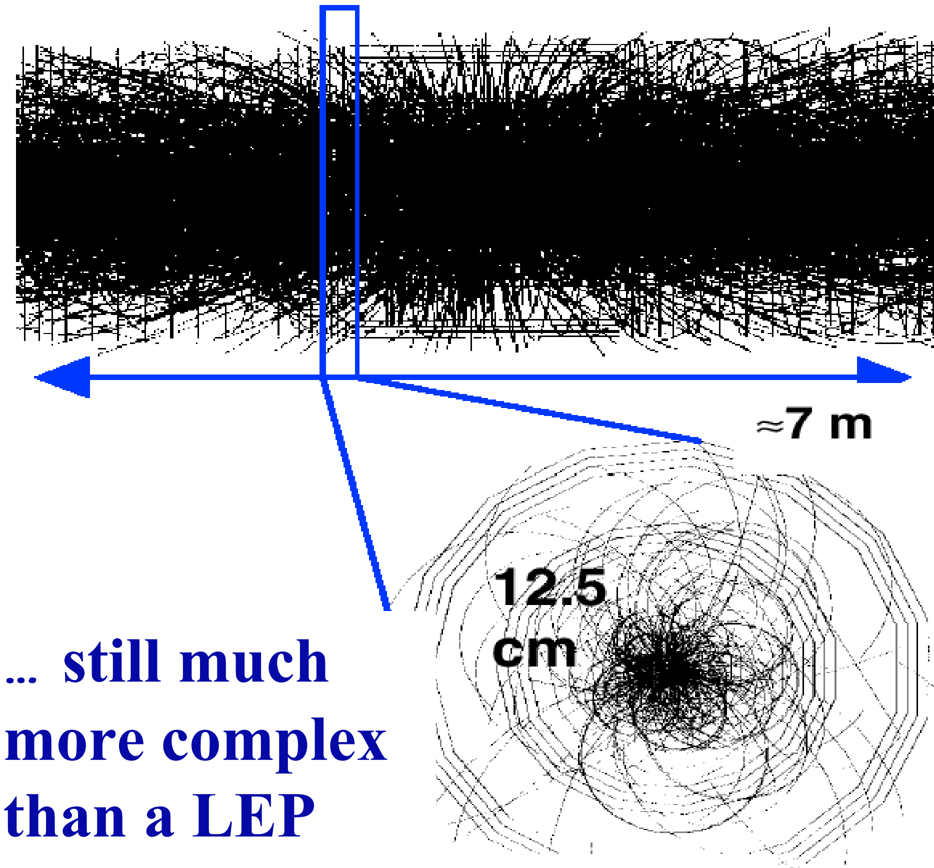
LHC produces 22 overlapping p-p interactions every 25 ns

Particle multiplicity

η = rapidity log(tgθ/2)(longitudinal dimension)

- u_{ch} = no. charged particles unit-η = 7 **(indicated as h)**
- n_{ch} = no. charged particles interaction
- N_{ch} = no. charged particles bunch xing
- N_{tot} = no. particles / bunch

- $\mathbf{n_{ch}} = u_{ch} \times h = 6 \times 7 = \mathbf{42}$
- $\mathbf{N_{ch}} = n_{ch} \times 22 = \sim \mathbf{900}$
- $\mathbf{N_{tot}} = N_{ch} \times 1.5 = \sim \mathbf{1400}$



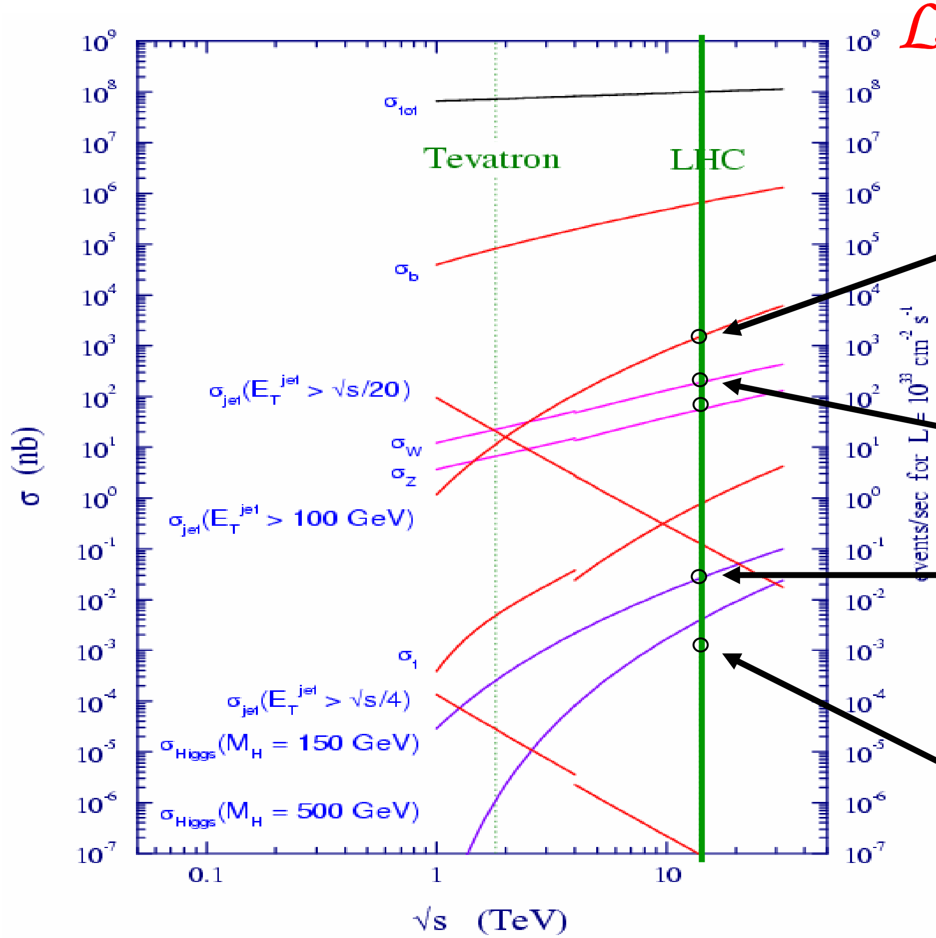
… still much more complex than a LEP event

The LHC flushes each detector with ~1400 particles every 25 ns

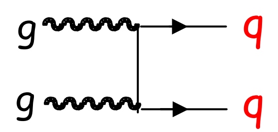
(p-p operation)

Physics processes

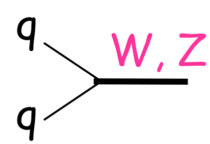
$\mathcal{L}= 10^{33}\ cm^{-2}\ s^{-1}$(LHC)



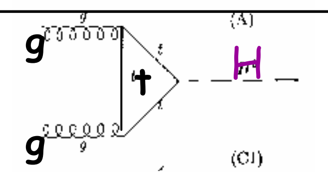
High-p_T QCD jets



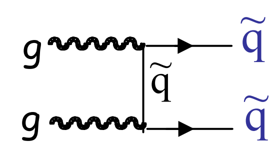
W, Z



Higgs m_H=150 GeV



$\tilde{q}, \tilde{g}$ pairs $m \sim 1$ TeV



Cross Section and production rate

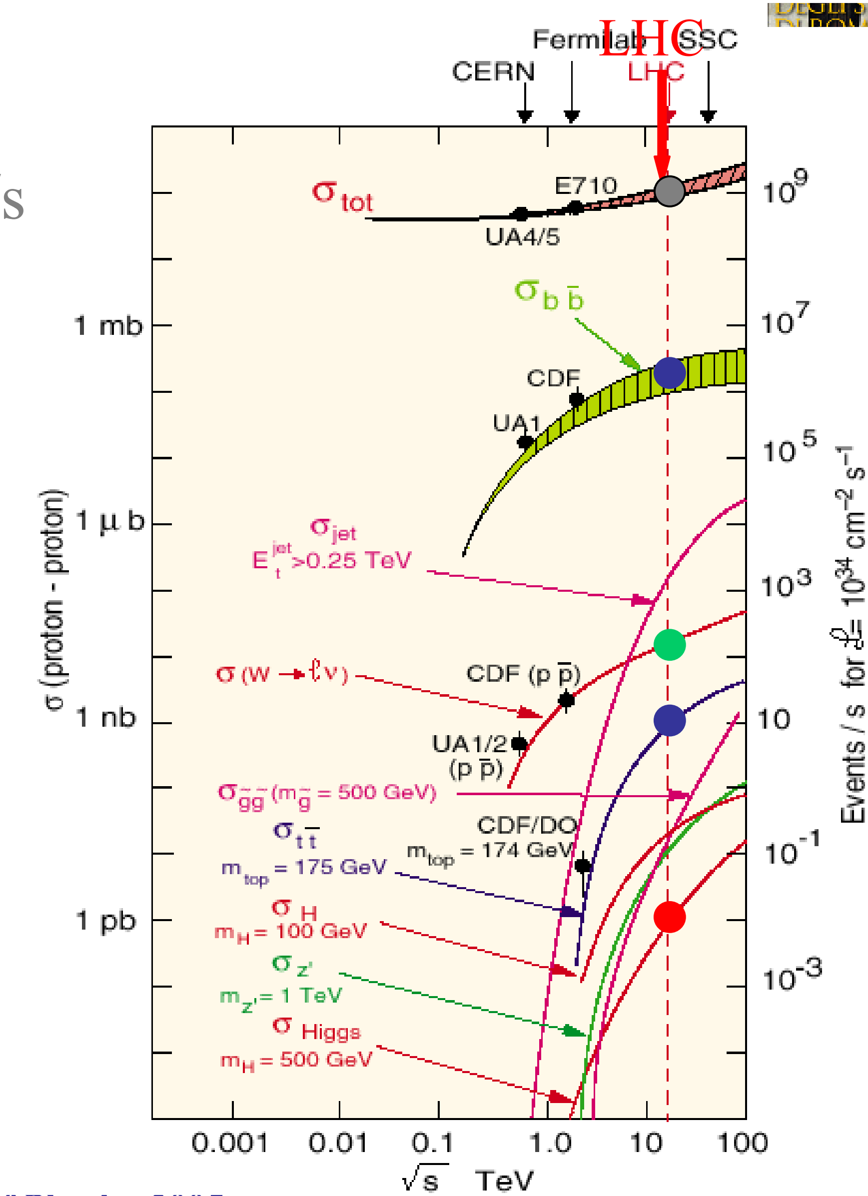
Rates for $\mathcal{L}$= 10^{34} cm^{-2} s^{-1}(LHC)

- Inelastic proton-proton reaction 10^9/s

- bb pairs $5 \cdot 10^6$/s
- tt pairs 8 /s

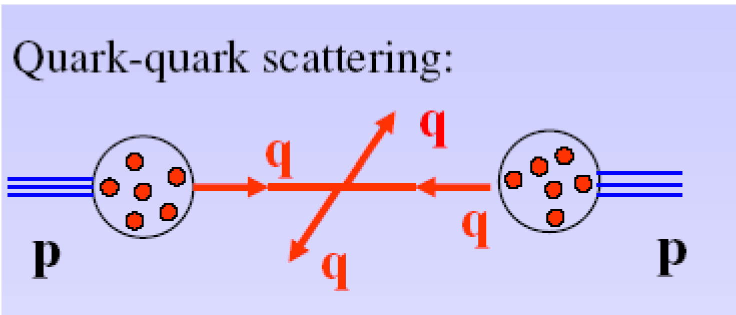
•W→ e ν 150/s
•Z→ e ν 15/s

•Higgs (500 GeV) 0.2/s
•Gluino,squarks (1TeV) 023/s



Experimental signatures

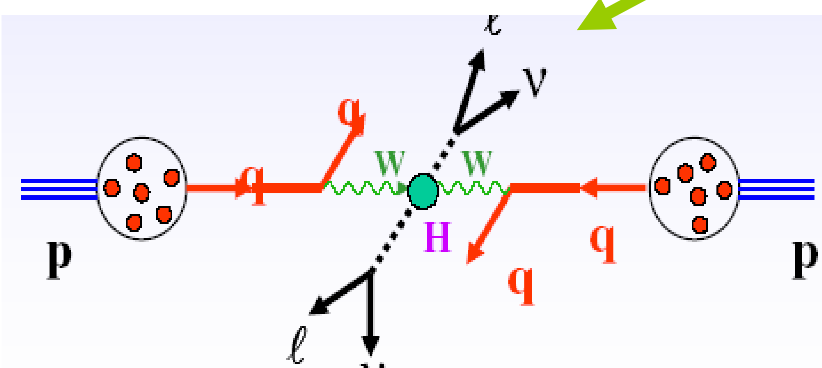
➢ **LHC is a factory for top-quarks, b-quarks W, Z,…. Higgs**



- No hope to observe the fully-hadronic final states $\rightarrow$ **rely on ℓ, γ**
- **Fully-hadronic** final states only with **hard O(100 GeV) p_T cuts**

Signature: Lepton & photons
Missing energy

Lepton with high P_T

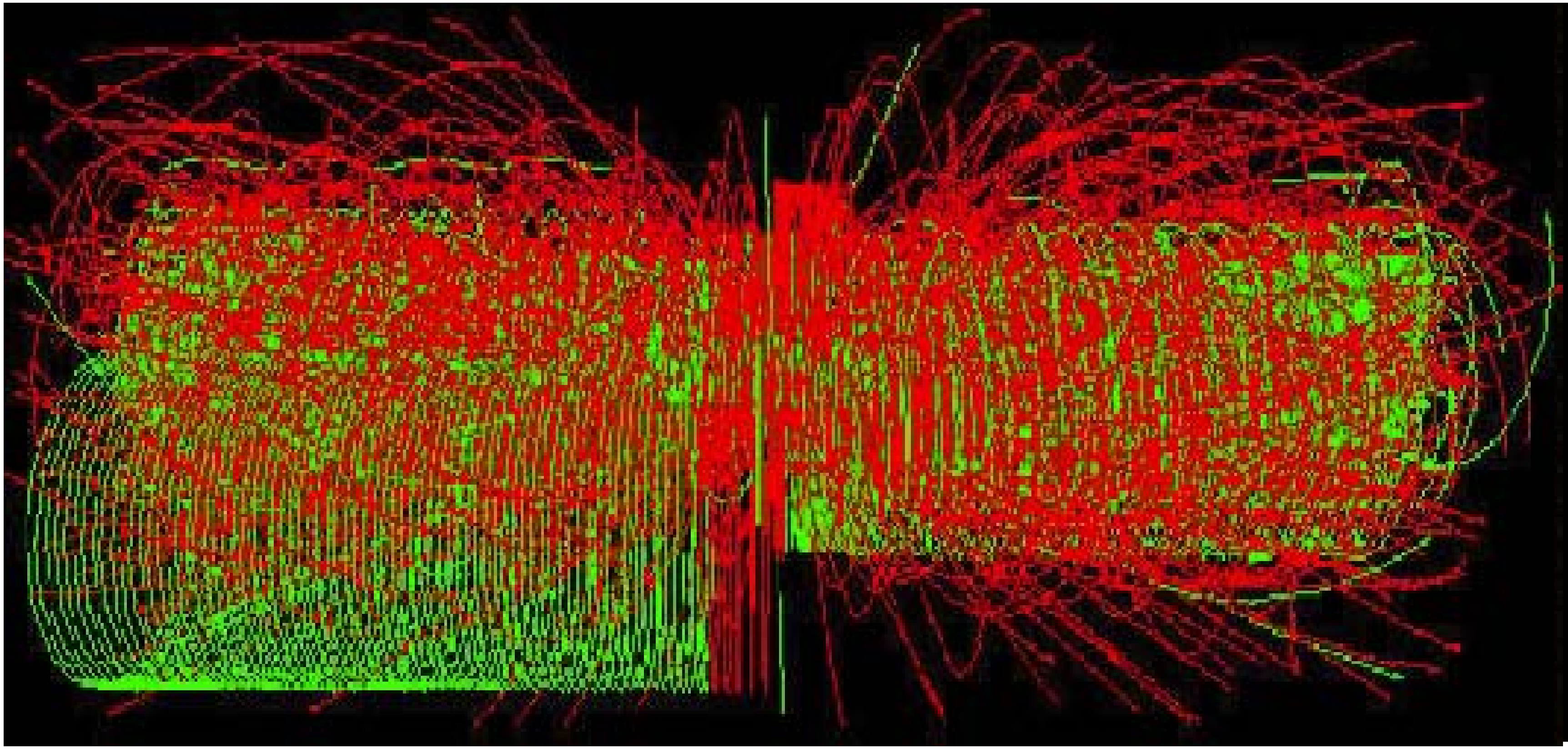


HIGGS

- **Mass resolutions of ~1% (10%) needed for ℓ, γ (jets)**
- Excellent particle identification: e.g. **e/jet ratio pT > 20 GeV is 10^{-5}**

The Challenge

How to extract this... … from this …

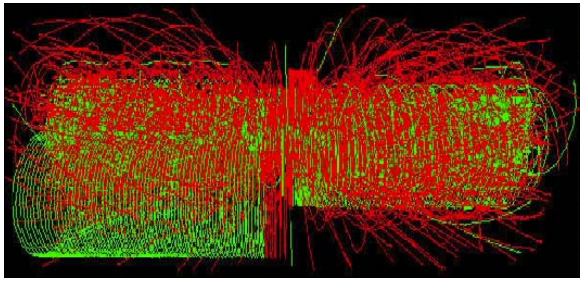


Higgs -> 4μ **+30 MinBias**

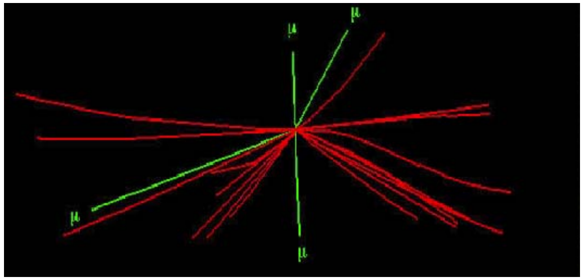
The Challenge

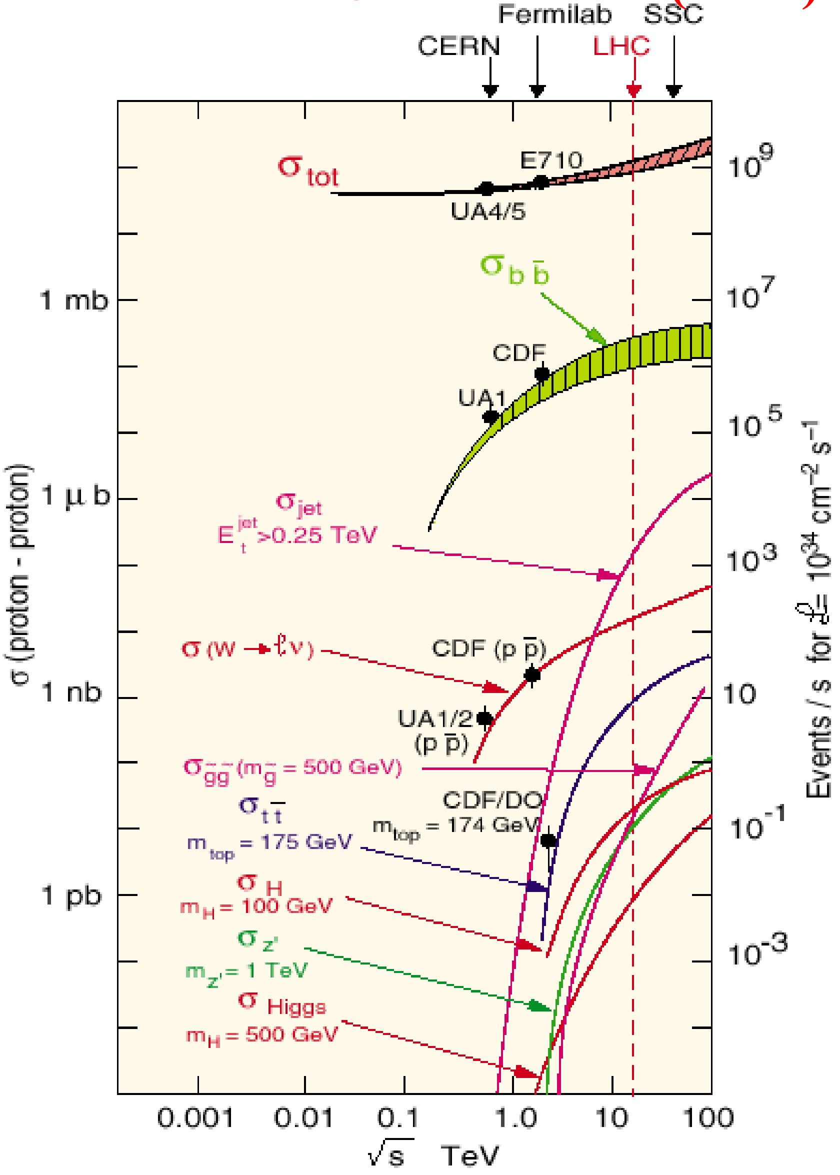
$\mathcal{L} = 10^{34}\ cm^{-2}\ s^{-1}$(LHC)

Knowing that there are 10 thousands billions of:



for ONE of:





Detector Requirement:Physics

- Good measurement of leptons and photons with high P_T
- Good measurement of missing transverse energy (E_T^{miss})
- Efficient b-tagging and τ identification.

Resolving individual tracks, in-and-outside the calorimeters
Measuring energy depositions of isolated particles and jets
Measuring the vertex position.

Detector size and granularity is dictated by
… the required (physics) accuracy
… the particle multiplicity.
Size + granularity determine
… the no. of measuring elements
… i.e. the no. of electronics channels.

Requirements from enviroment

- Detectors must have **fast response** to avoid to integrate too much bunch crossings → too large pile-up
- Response time :20-50 ns.

→ integration on 1-2 bunch crossings

→ pile-up 25-50 minimum bias events ➡ severe requests on readout electronics

- **High granularity** minimize the probability that pile-up particles be in the same detector elements as interesting object → large number of electronic channels, high cost
- **Radiation resistency :** high flux of particles from pp collisions → high radiation enviroment.

e.g. forward calorimeters: up to 10^7 n/cm^2 in 10 years of LHC operation

Trigger

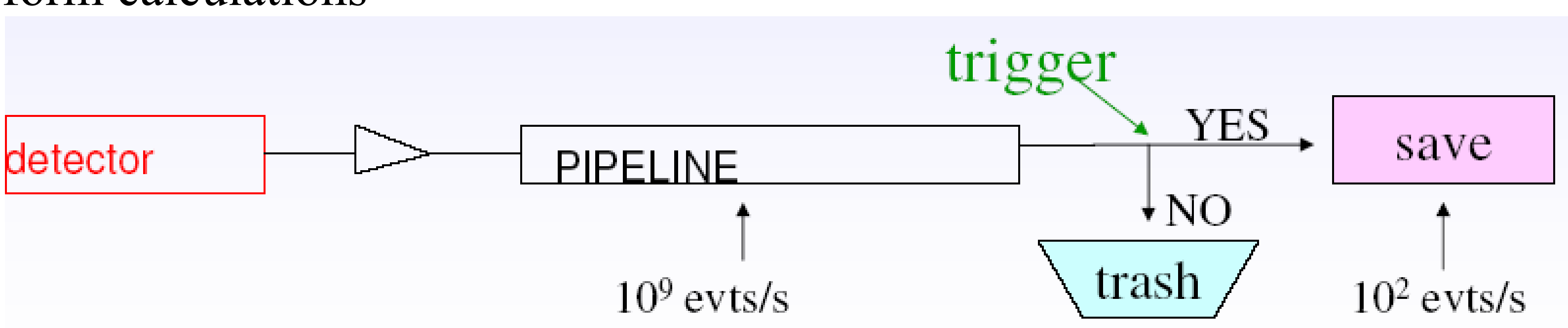
Design of trigger system more complex than e^+e^- machine

- Interaction rate ~ 10^9 events/s
- Record capability ~ 10^2 events/s (1MB)

Trigger rejection ~ 10^7

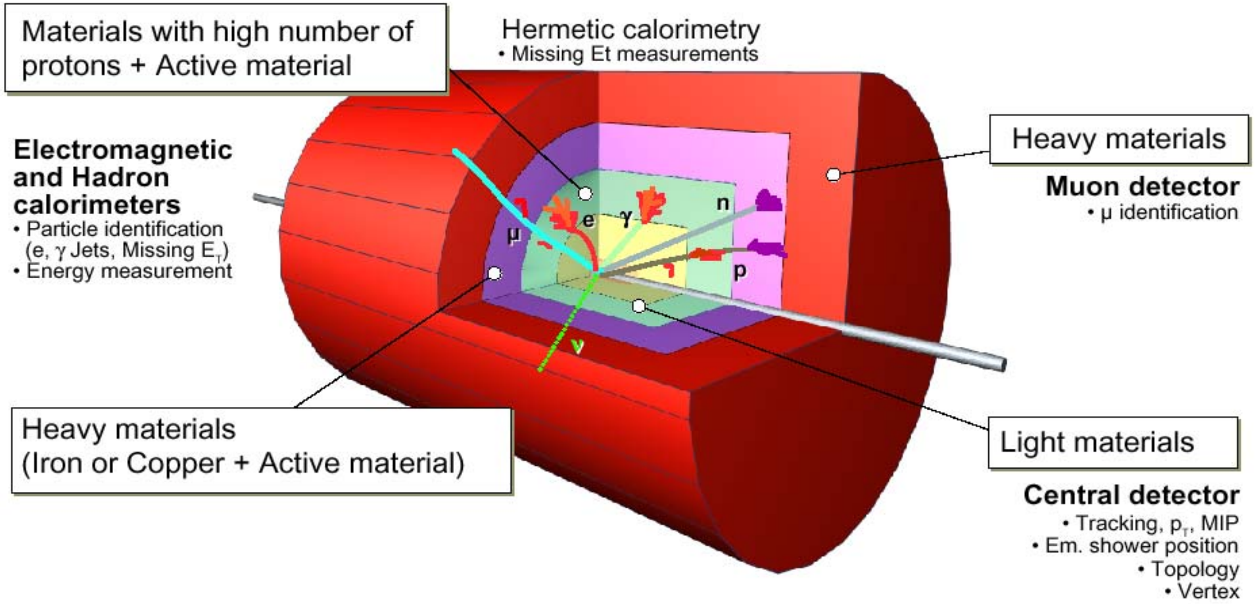
Trigger decision ≈ μs → large then interaction rate 25 ns

Store massive amount of data in pipelines while a special trigger processors can perform calculations

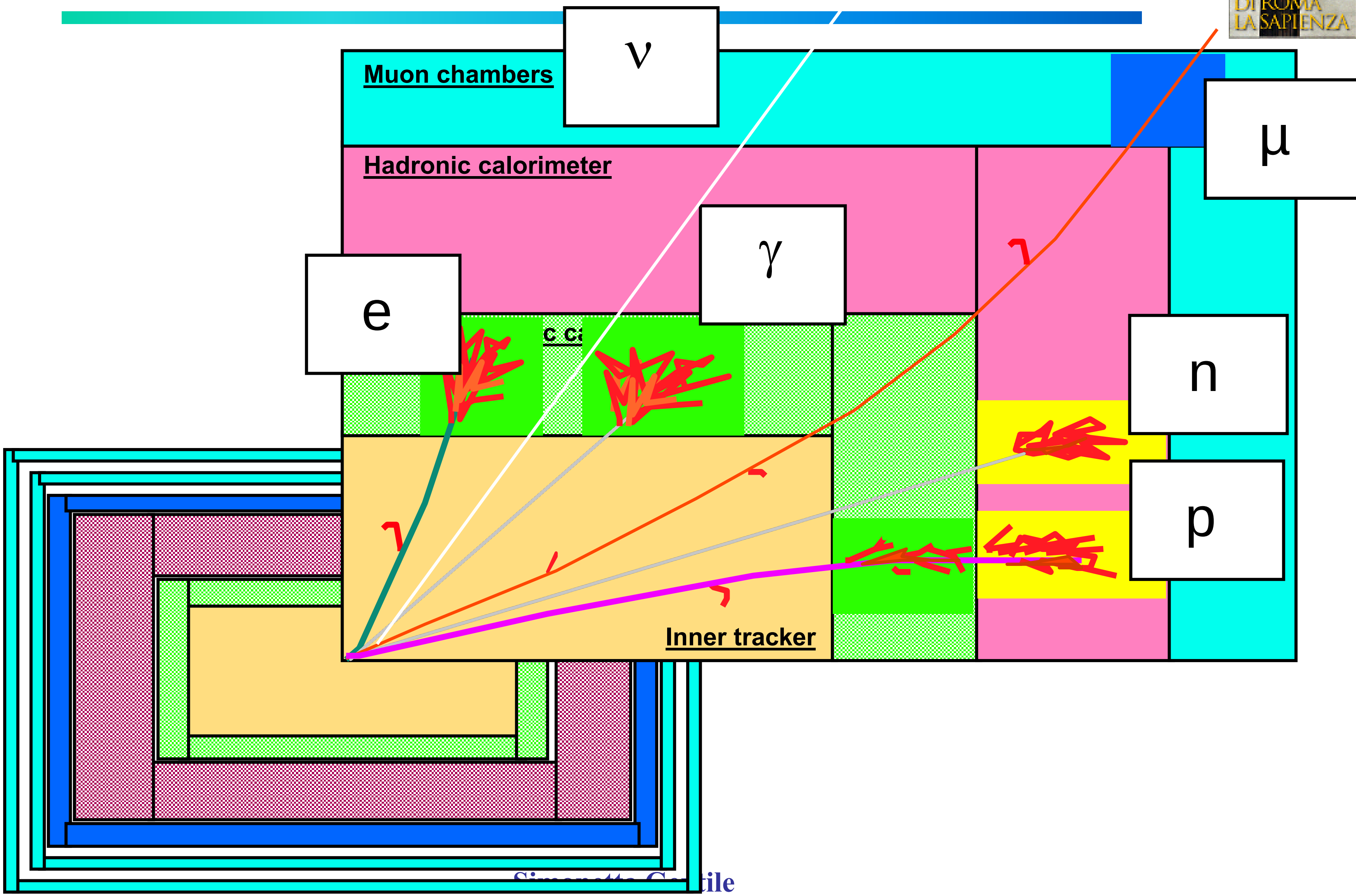


General purpose detector

- Identification …
  - for event selection
- … and measurement
  - for event reconstruction.
- For both, need different stages:
  - Inner tracker
  - Calorimeters
  - Muon system (trigger and precision chambers)



Particle identification



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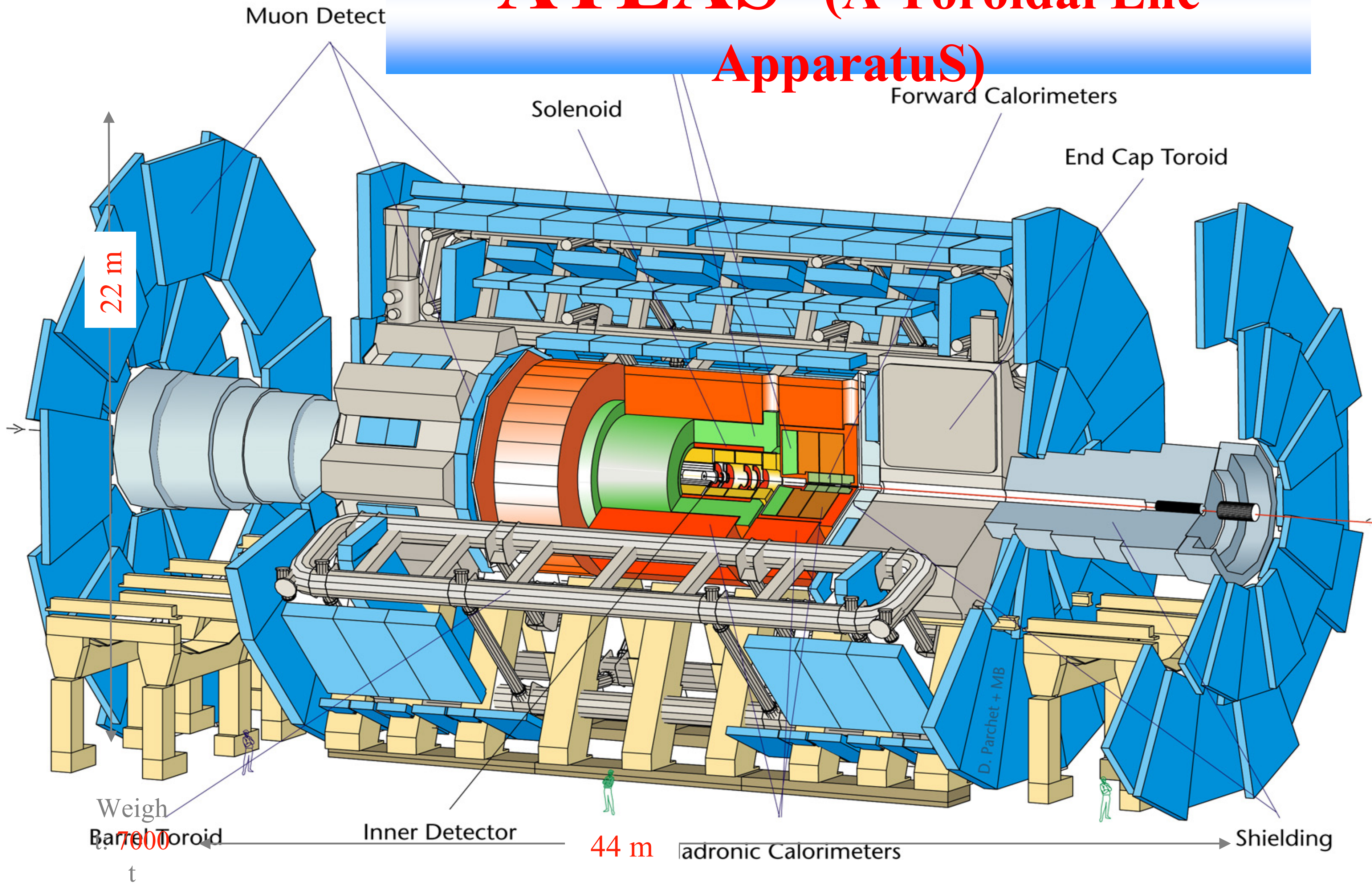
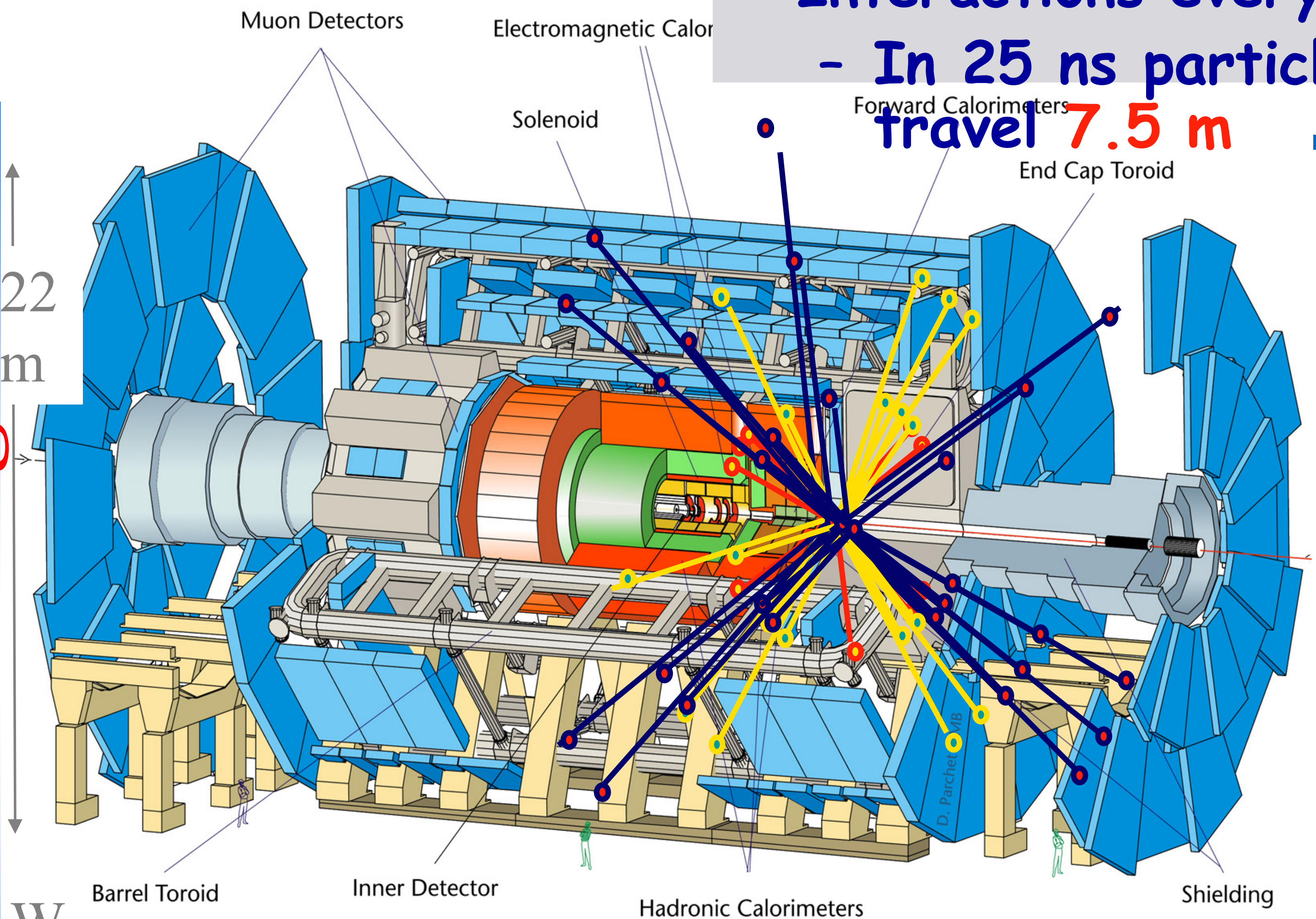
ATLAS (A Toroidal Lhc ApparatuS)



Time-of-flight

- **Interactions every 25 ns**
  - **In 25 ns particles travel 7.5 m**



W

weight 7000 Tons

44 m

- Cable length ~100 meters …
  - In 25 ns signals travel 5 m

The ATLAS Detector

Length: ~44 m

Radius: ~12 m

Weight: ~ 7000 t

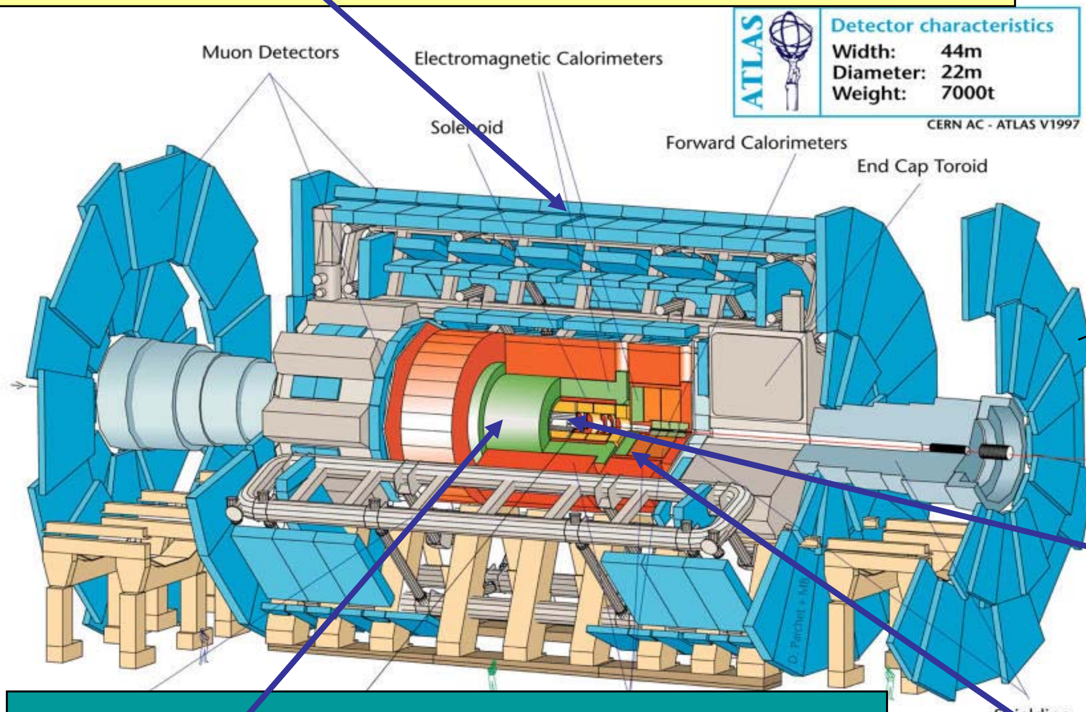
E l. Channels: ~10^8

Cables: ~3000 km

Precision Muon Spectrometer $\sigma / pT \sim 10\%$ at 1 TeV/c

Fast response for trigger

Good *p* resolution (e.g., A/Z' $\rightarrow \mu\mu$)



Inner Detector

$\sigma / p_T \sim 5 \cdot 10^{-4}\, p_T \oplus 0.001$

Good impact parameter res.

(e.g., H $\rightarrow$ bb)

EM Calorimeters

excellent electron/ph $\sigma / E \sim 10\% / \sqrt{E(GeV)}$

Good *E* resolution (e.g., H$\rightarrow\gamma\gamma$)

Hadron Calorimeters

Good jet and E_T miss performance

(e.g., H $\rightarrow\tau\tau$) $\sigma / E \sim 50\% / \sqrt{E(GeV)} \oplus 0.03$

Thin Superconducting Solenoid
(B=2T)

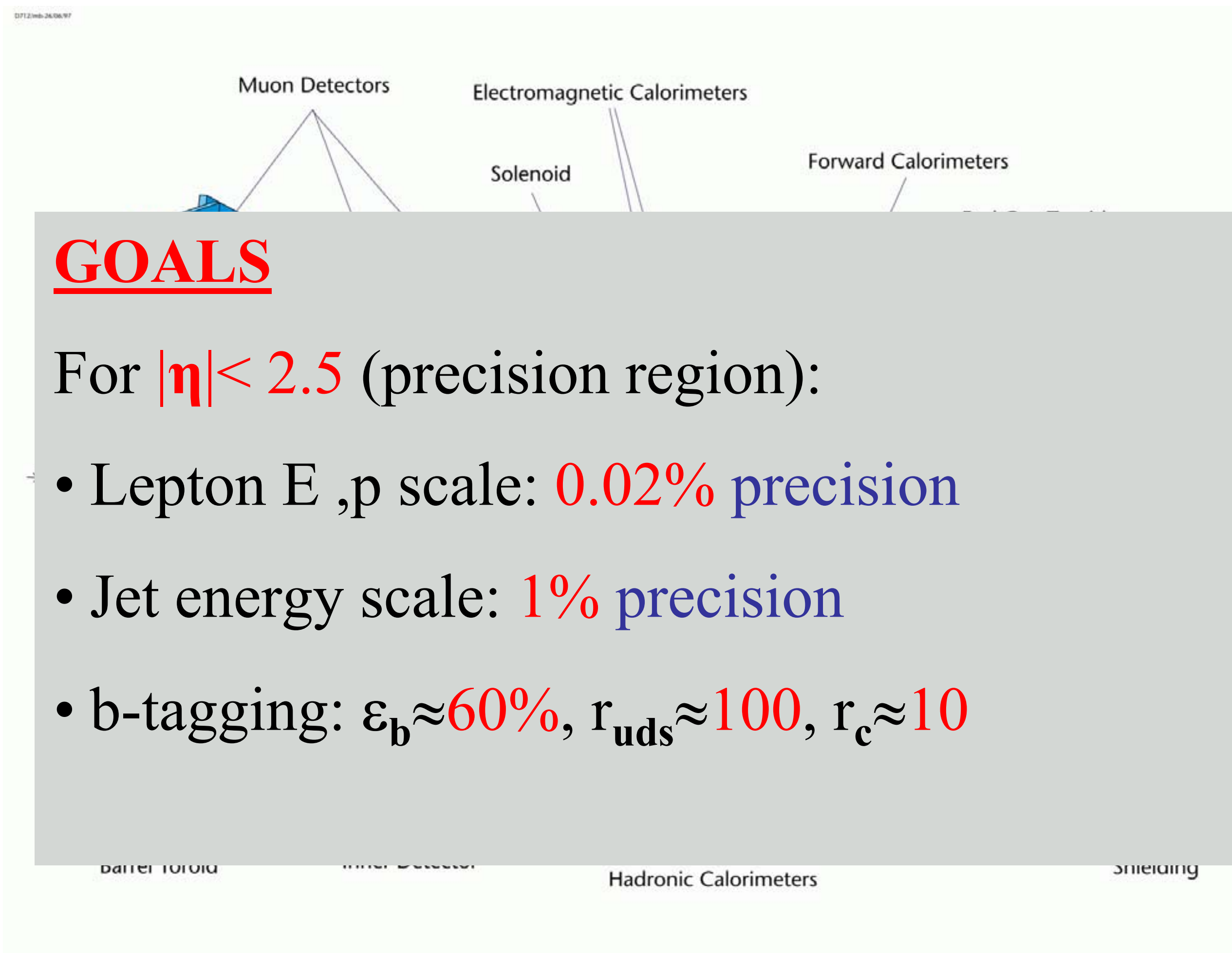
LAr Electromagnetic Calorimeter :
L × R = 13.3m×2.25m
$|\eta| \leq 3.2$ (4.9)
$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$

Hadronic Calorimeter :
Endcaps LArg
Barrel Scintillator-tile
L × R = 12.2m×4.25m
$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$
($|\eta| \leq 3$)

Large Superconducting Air-Core Toroids

Muon Spectrometer
L × R = 25 (46) m×11m
$|\eta| < 2.7$

Inner Detector :
Semiconductor Pixel and Strips
Straw Tube Tracking Detector (TRT)
L × R = 7m×1.15m
$\sigma_{R\phi}$=12-16μm, σ_Z=66-580μm
$|\eta| < 2.5$

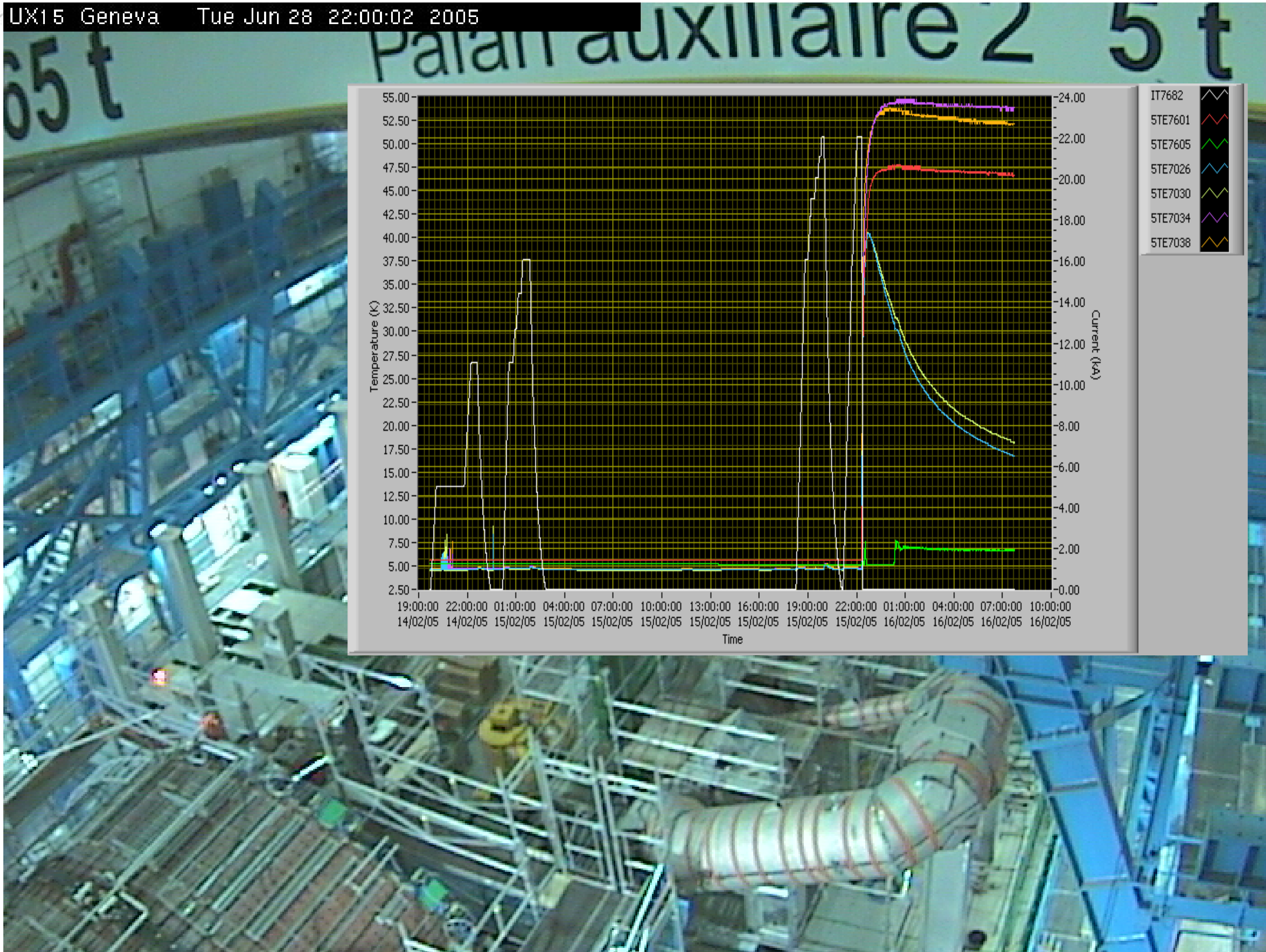


GOALS

For $|\eta| < 2.5$ (precision region):

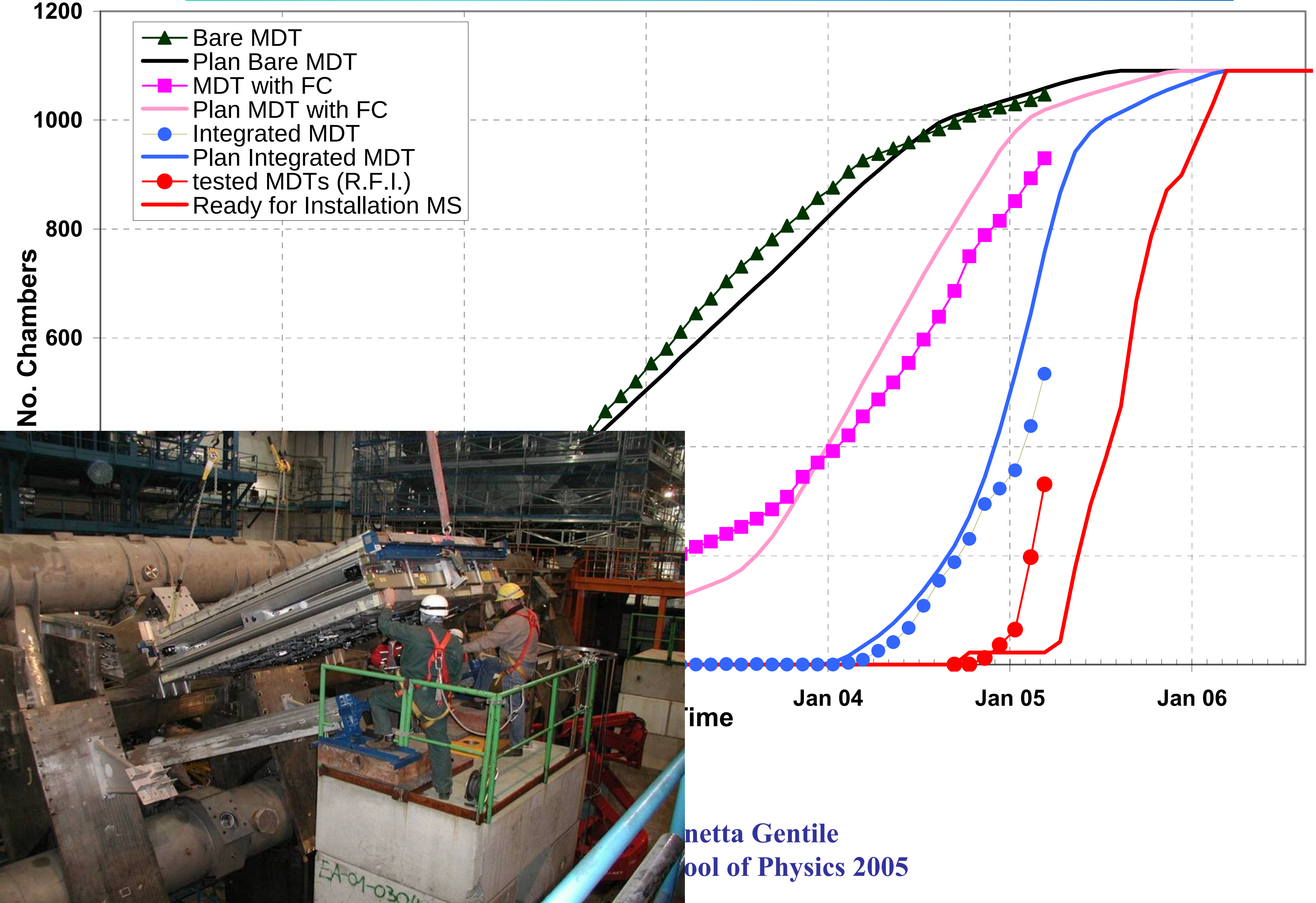
- Lepton E ,p scale: 0.02% precision
- Jet energy scale: 1% precision
- b-tagging: $\varepsilon_b \approx 60\%$, $r_{uds} \approx 100$, $r_c \approx 10$

ATLAS Installation



5 out of 8 coils installed End of coil installation by july 05

ATLAS MDT Chamber production



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ATLAS LAr EM Barrel Calorimeter and Solenoid Commissioning

The barrel EM calorimeter is installed in the cryostat, and after insertion of the solenoid, the cold vessel was closed and welded

A successful complete cold test (with LAr) was made during summer 2004 in hall 180

End of October the cryostat was transported to the pit, and lowered into the cavern

LAr barrel EM calorimeter after insertion into the cryostat

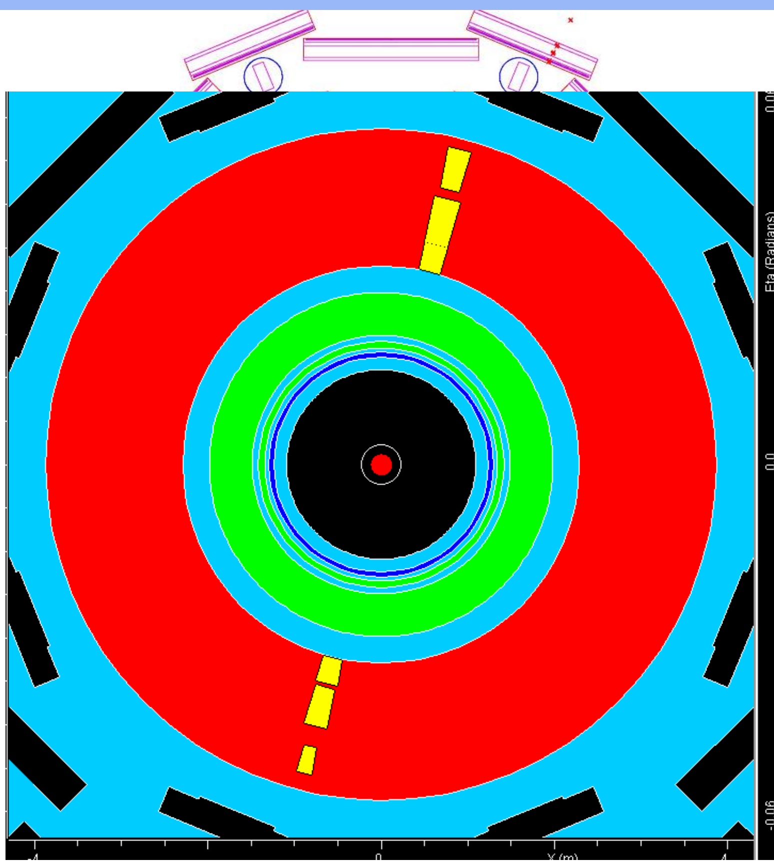
Solenoid just before insertion into the cryostat

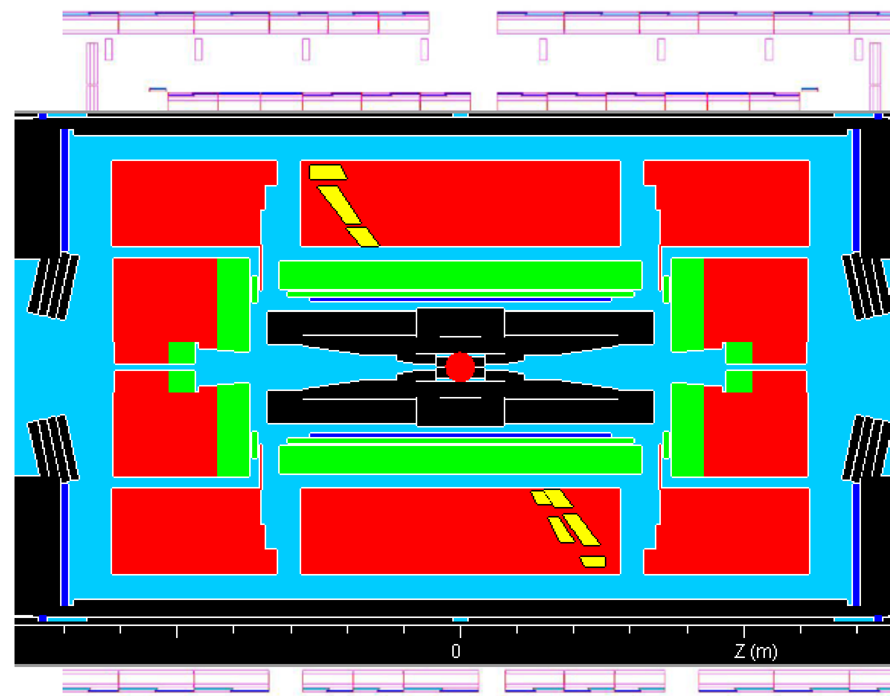
ATLAS Commissioning

- Commissioning with physics data proceeds in four phases:
  - Phase 3 : Cosmics running
    - ➔ initial physics alignment / calibration of the detector
    - ➔ debugging of sub-systems, mapping dead channels etc.
  - Phase 4 : One beam in the machine
    - ➔ beam-halo muons and beam-gas events
    - ➔ more detailed alignment / calibration etc.
  - Phase 5 : First pp collisions : prepare the trigger and the detector
    - ➔tune trigger menus / measure efficiencies
    - ➔begin to measure reconstruction efficiencies, fake rates, energy scales, resolutions etc.
  - Phase 6 : Commissioning of physics channels
    - ➔Improve measurements
    - ➔begin to understand backgrounds to discovery channels …

ATLAS Commissioning – cosmic rays

First Cosmic ray observed by ATLAS Hadron Tilecal calorimeter in the pit on June 20th





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ATLAS Status

- Component construction is (almost) complete for several sub-systems, The completion of the Inner detector is proceeding with very tight planning.
- emphasis has shifted to integration, installation and commissioning
- Large-scale surface system tests, in particular the combined test beam runs, have been a very major activity in 2004
- There is very good progress of the schedule-critical magnet assembly, and on the general installation status and activities in the cavern
- The commissioning has started: organization, planning, activities

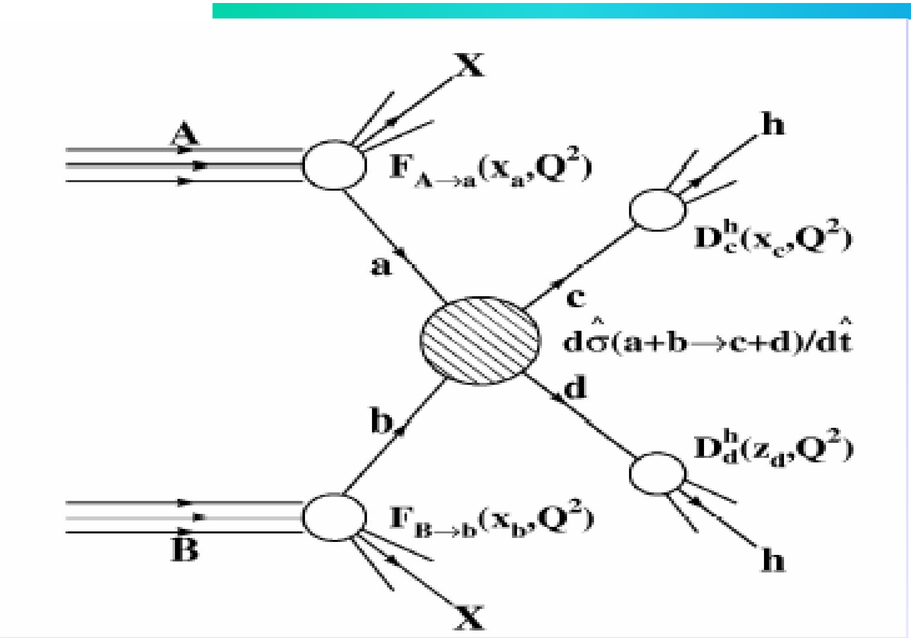
Atlas is on Track for collisions in summer 2007 and physics still in 2007

Outline

T o d a y

- Introduction to Hadron Collider Physics
- LHC and ATLAS detector
- **Test of Standard Model at LHC**
  - Parton distribution function
  - QCD + jet physics
  - Electroweak physics (Z/W – bosons)
  - Top physics
- Search for Higgs boson
- Supersymmetry
- Conclusions

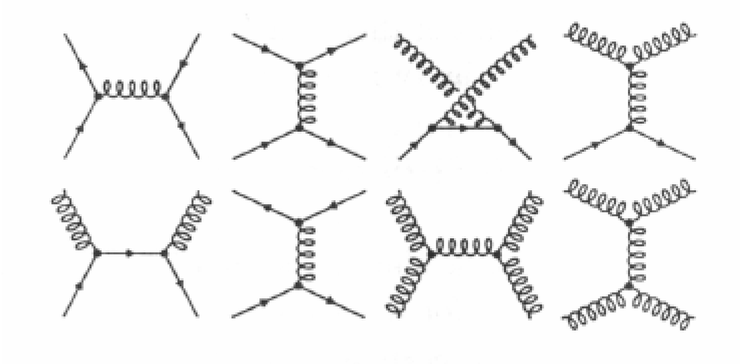
QCD process at hadron collider



- Hard scattering processes are dominated by QCD jet production
- Originating from quark-quark, quark-gluon and gluon-gluon scattering
- Fragmentation of quarks and gluons in final state hadrons →

Jets with large transverse momentum P_T

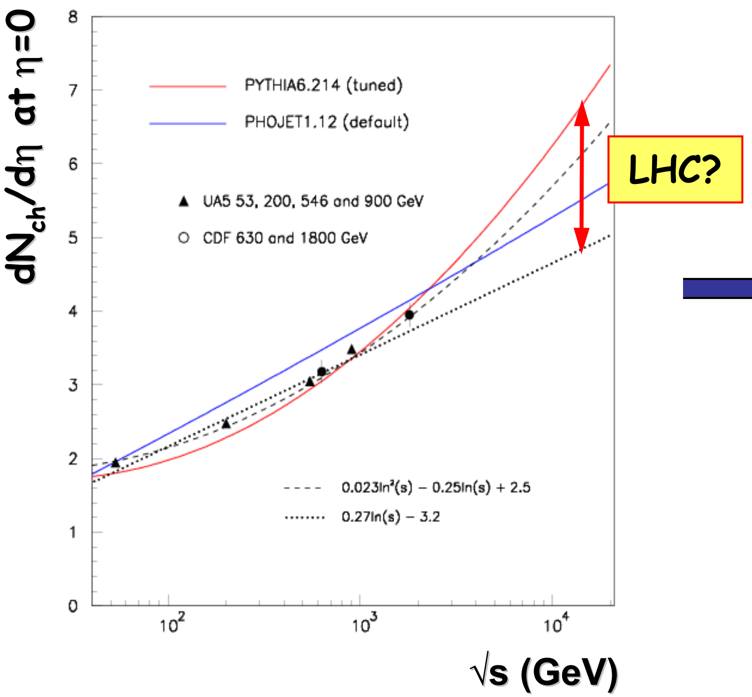
- Cross section can be calculated in QCD (perturbation theory)

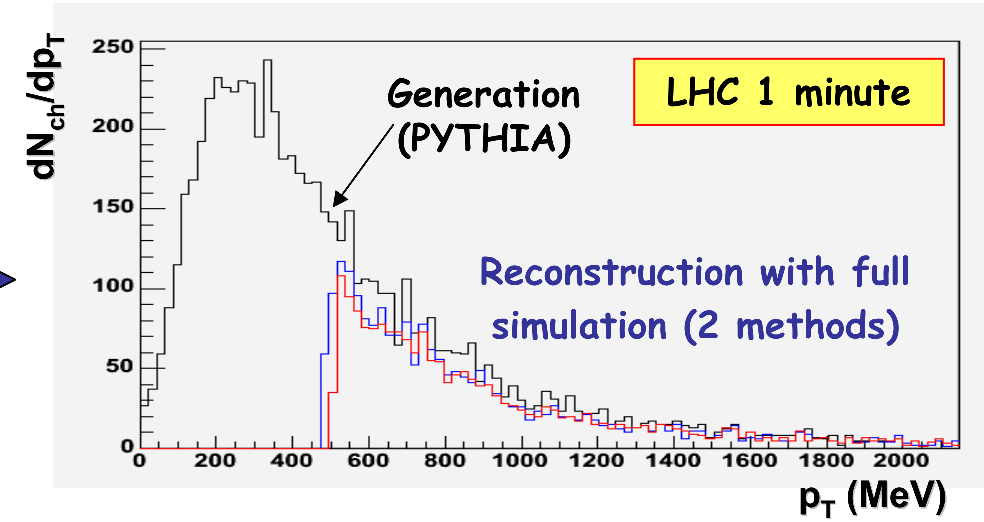


Comparison with experimental data

Minimum bias

- **Need to control this background** (Ex. : Number of charged tracks, N_{ch})



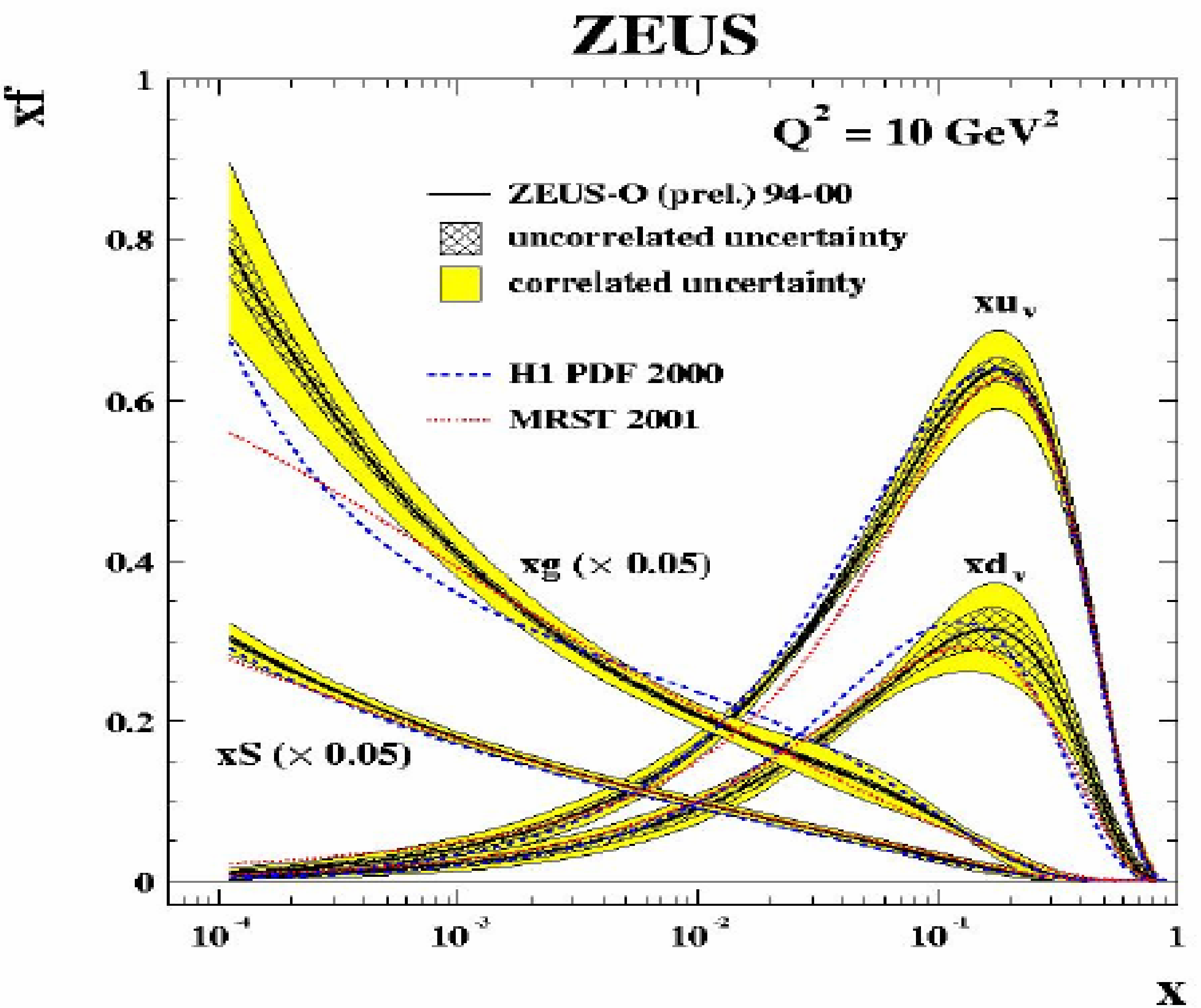


- Check MC with data during commissionning
- Limited to ~500 MeV by track efficiency

Difficult to predict LHC minimum bias

Take special runs with lower central magnetic field to reach p_T~200 MeV

Particle distribution function



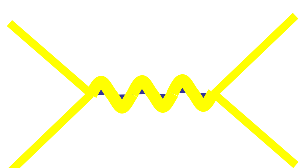
Parton Distribution Functions (PDF)

LHC is a proton-proton collider

But fundamental processes are the scattering of

- **Quark – Antiquark**
- **Quark – Gluon**
- **Gluon – Gluon**

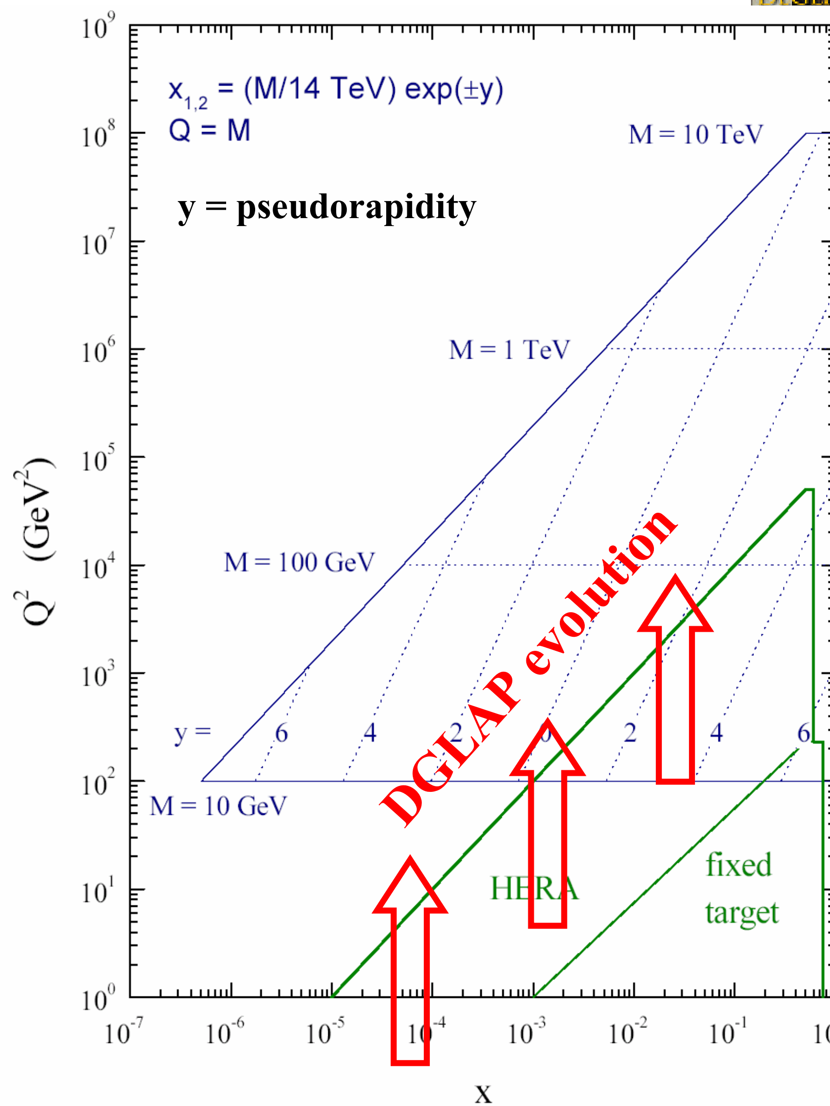
Examples:



$q\bar{q} \rightarrow W \rightarrow l\nu$

$gg \rightarrow H$

⇒ need precise pdf(x,Q^2)
+ QCD corrections (scale)



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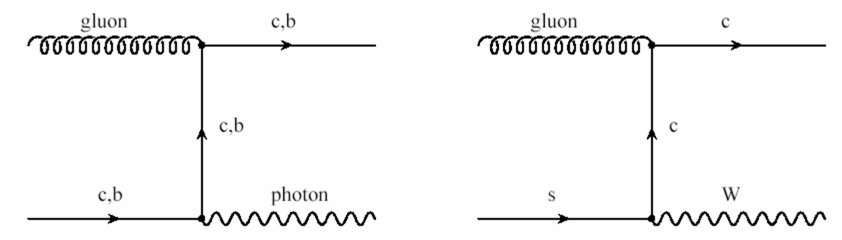
Extracting PDF

➢ PDF from W/Z production

- p_T and rapidity distributions are very sensitive to pdf

Example: study for 0.1 fb^{-1}, i.e. $2 \cdot 10^6$ $W \rightarrow \mu\nu$ produced
Sensitive to small differences in sea quark distribution

➢ PDF of s, c and b quarks

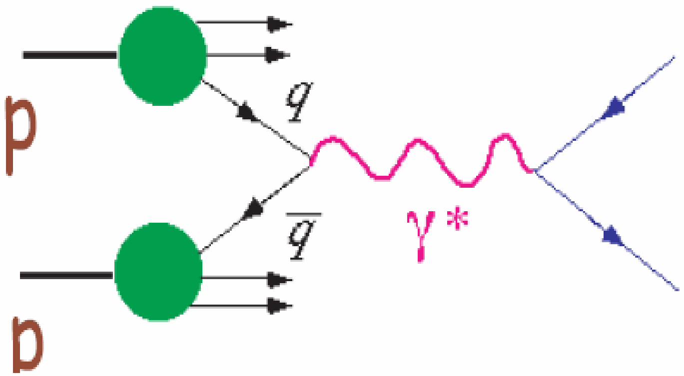


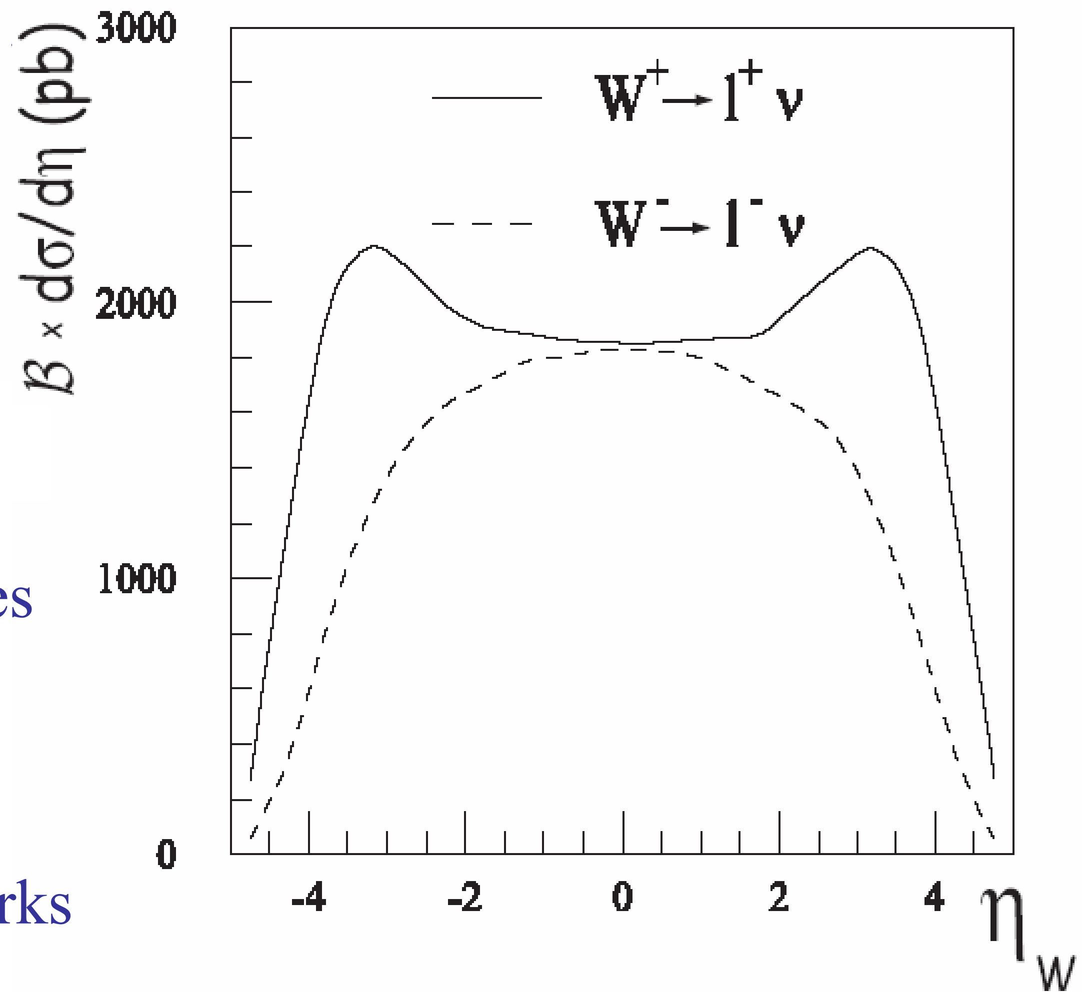
Isolated high p_T γ + jet with incl. μ

Isolated high p_T e/ μ + jet with incl. μ

Estimate 5-10% accuracy on pdf

Vector boson production and Drell-Yan Process

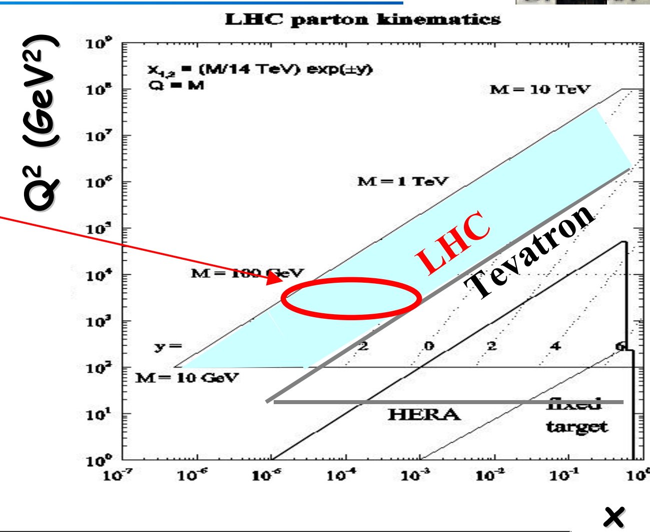


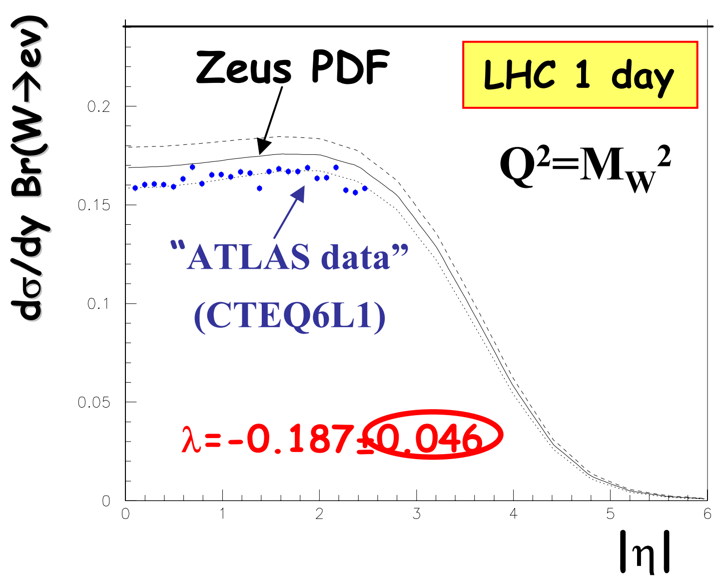


Quark and antiquark densities
Inside the proton differ from
each other:
This can be used to measure
p.d.f.'s for up and down quarks
separatly

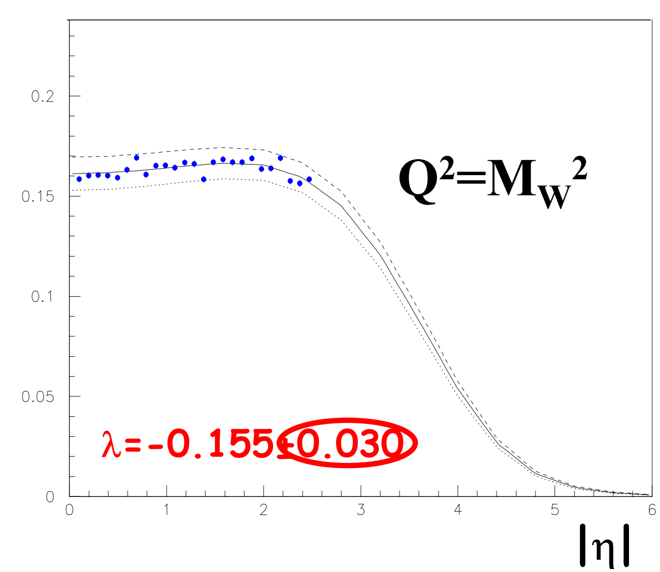
Constraining PDF

- Use W to probe low-x gluon PDF at $Q^2 = M_W^2$
- Example: $W^+ \rightarrow e^+\nu$ rapidity spectrum is sensitive to gluon shape parameter λ ($xg(x)=x^{-\lambda}$)
  - ➔ Reduce error by 40% including "ATLAS data"





Include "ATLAS data" in global PDF fits



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Parton Distribution Functions (PDF)

$$\sigma = \sum_{a,b} \int dx_a \, dx_b \, f_a(x_a, Q^2) f_b(x_b, Q^2) \, \hat{\sigma}_{ab}(x_a, x_b)$$

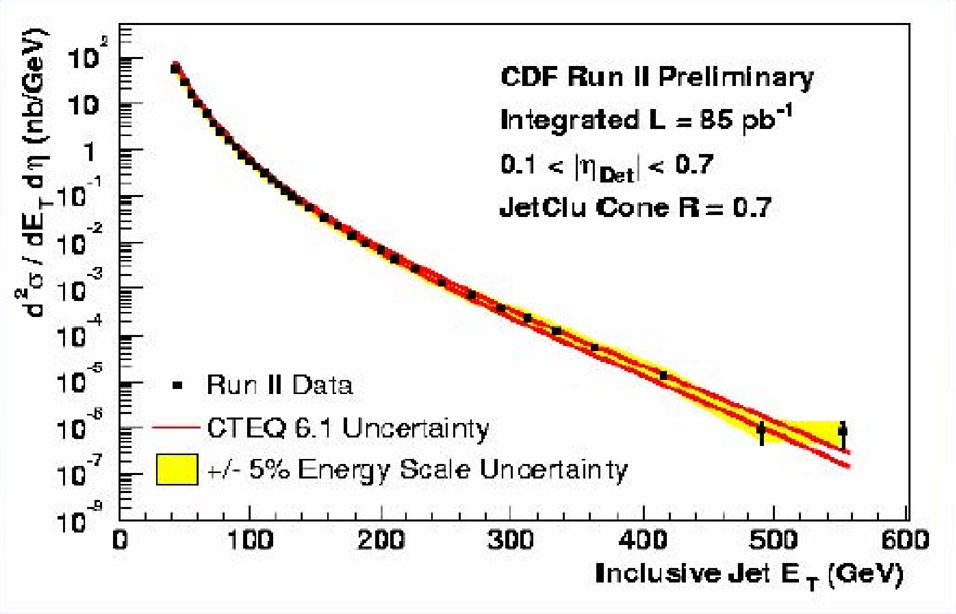
Measurements of PDFs from SM processes:

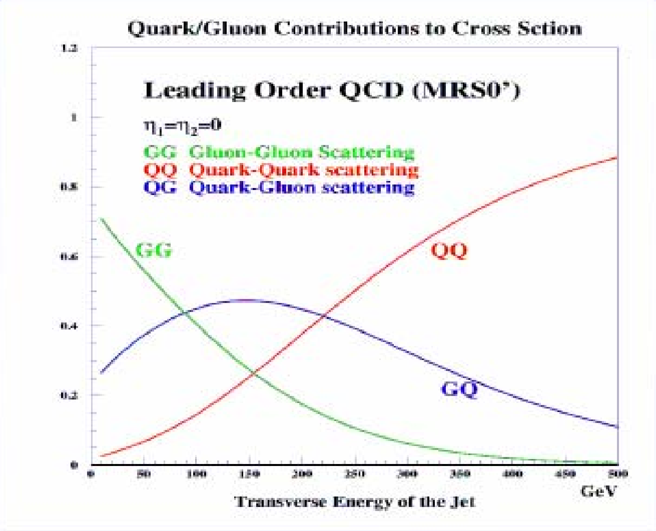
Process:	Constraning PDF of:
Di-jets	Quarks and Gluons
Jet + photon(s)	Quarks and Gluons
Jet + W	Quarks and Gluons
W and Z	Quarks
Drell-Yan	Quarks

Other experiments

From K. Jacobs

Similar data for the CDF experiment

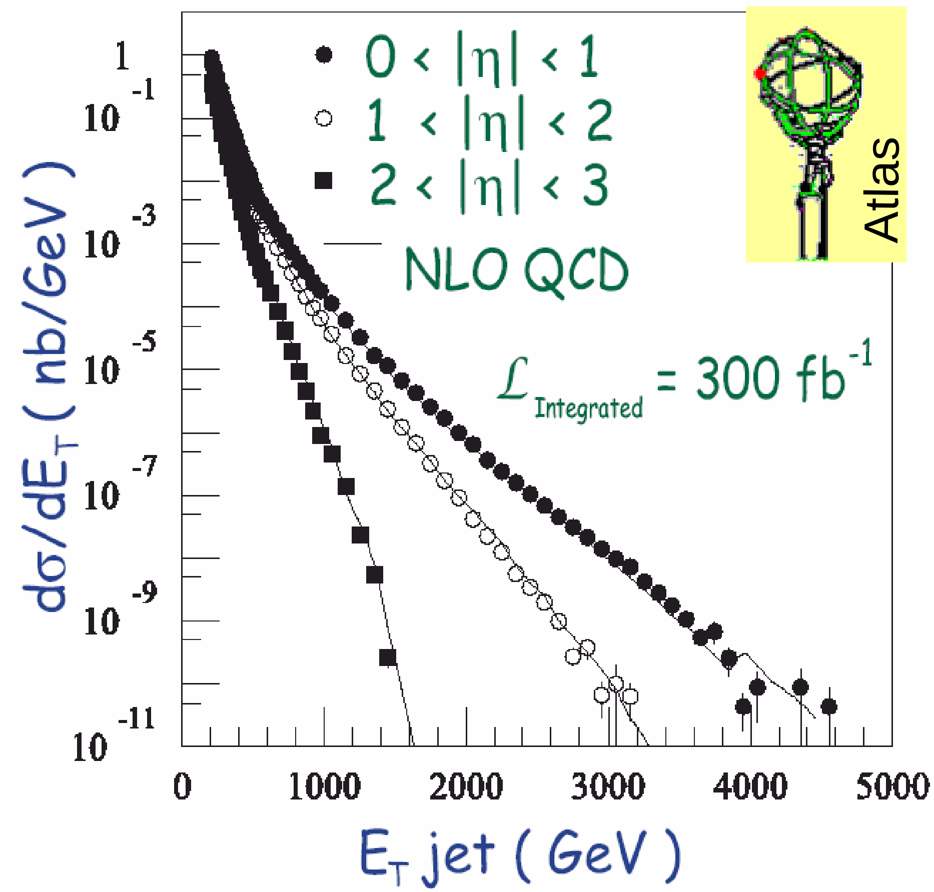




contributions of the various sub-processes to the inclusive jet cross section

Jet Physics

- Measure jet E_T spectrum, rate varies over 11 orders of magnitude
- Test QCD at the multi-TeV scale



Inclusive jet rates for 300 fb^{-1}:

E_T of jet	Events
> 1 TeV	$4 \cdot 10^6$
> 2 TeV	$3 \cdot 10^4$
> 3 TeV	400

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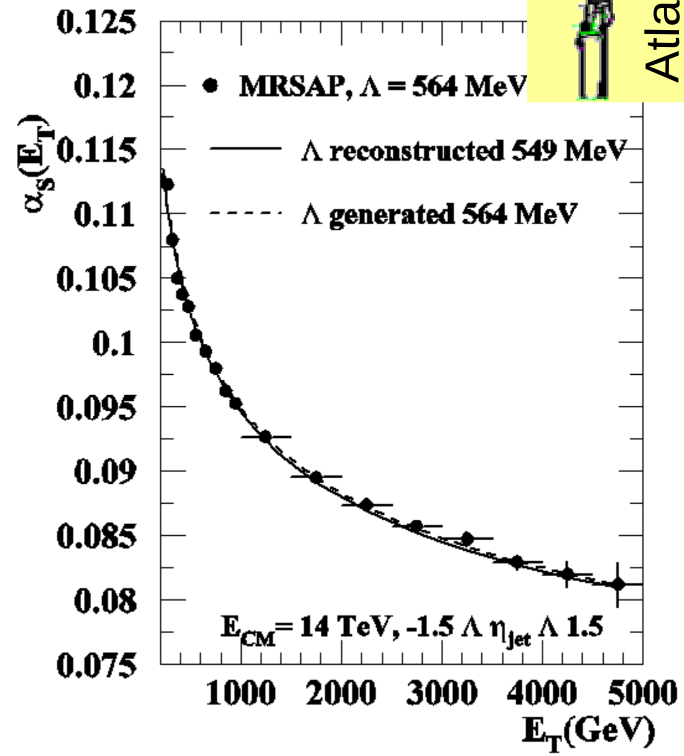
QCD

Measurement of α_s at LHC limited by

- **PDF (3%)**
- **Renormalisation & factorisation scale (7%)**
- **Parametrisaton (A,B)**

$$\frac{d\sigma}{dE_T} \sim \alpha_S^{\,2}(\mu_R)A(E_T) + \alpha_S^{\,3}(\mu_R)B(E_T)$$



- A and B are functions evaluated from P.D.F's

For a given E_T. But P.D.F were obtained for a particular value of α_s

- **10% accuracy $\alpha_s(m_Z)$ from incl. jets**
- **Improvement from 3-jet to 2-jet rate?**

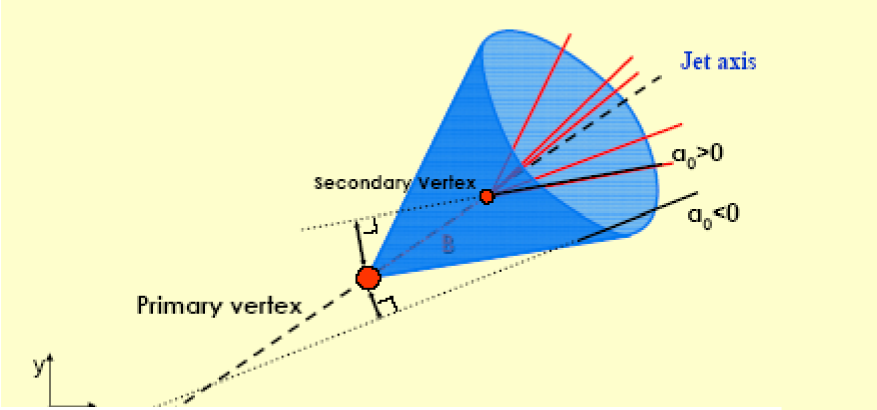
Verification of running of α_s and test of QCD at the smallest distance scale

- **α_s = 0.118 at m_Z**
- **$\alpha_s \approx$ 0.082 at 4 TeV (QCD expectation)**

Experimental problems

- A jet is NOT a a well defined object (fragmentation, detector response). Algorithm to define a jet and measurements of energy (.e.g a cone around local energy maximum in the calorimeter, cone size adapted such that a large fraction of jet energy is collected.

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2} = 0.7$$



- Cluster energy ≠ parton energy

•Problems : Calorimeters show different response to electron/photons
- Subtraction of offset energy not originating from hard scattering
- (inside the same collisions, use minimum bias data to extract this)
- correction for jet energy in/out cone

(corrected with jet data +Monte Carlo simulation)

Cross Section of Various SM Processes

The LHC **uniquely** combines the two most important virtues of HEP experiments:

1. High energy 14 TeV
2. and high luminosity $10^{33} - 10^{34}/cm^2/s$

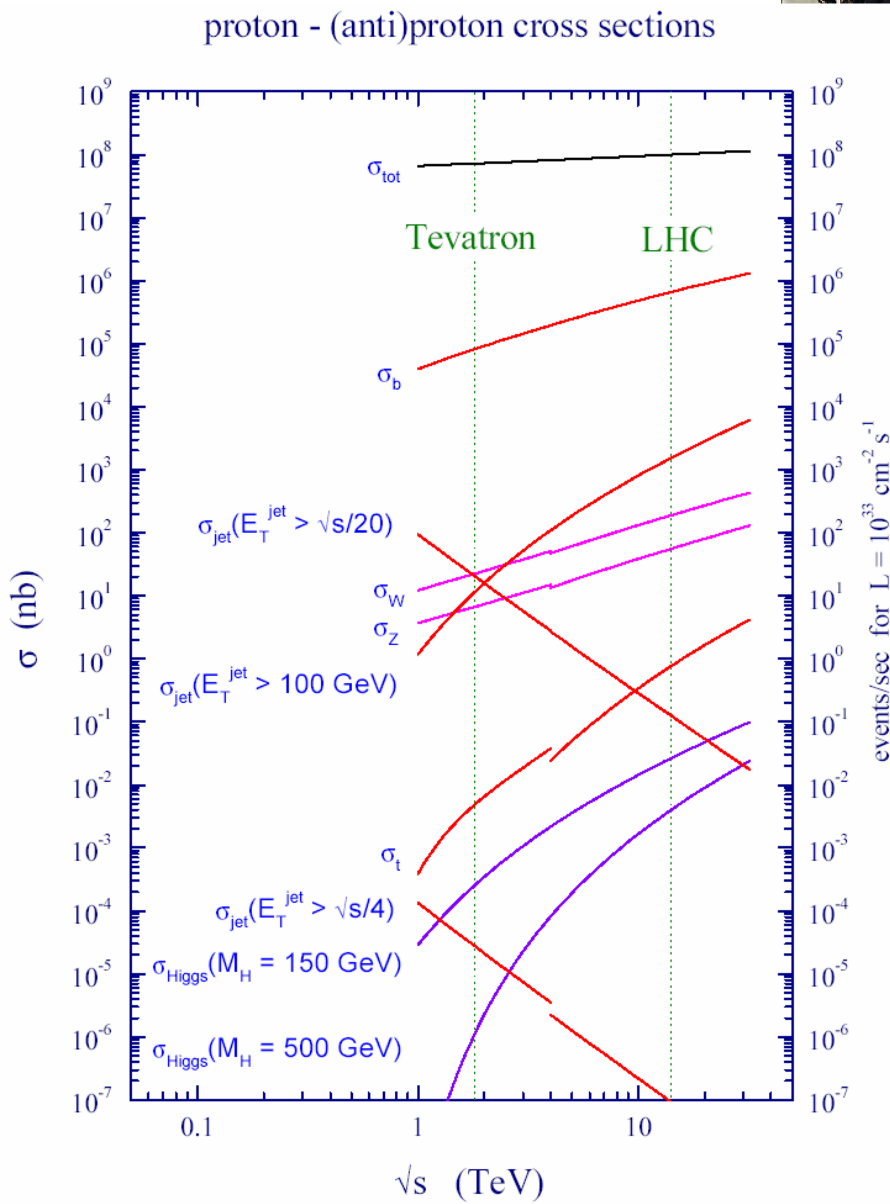
$\Rightarrow$ Low luminosity phase

$10^{33}/cm^2/s = 1/nb/s$

approximately

- 200 W-bosons
- 50 Z-bosons
- 1 tt-pair

will be produced per second!



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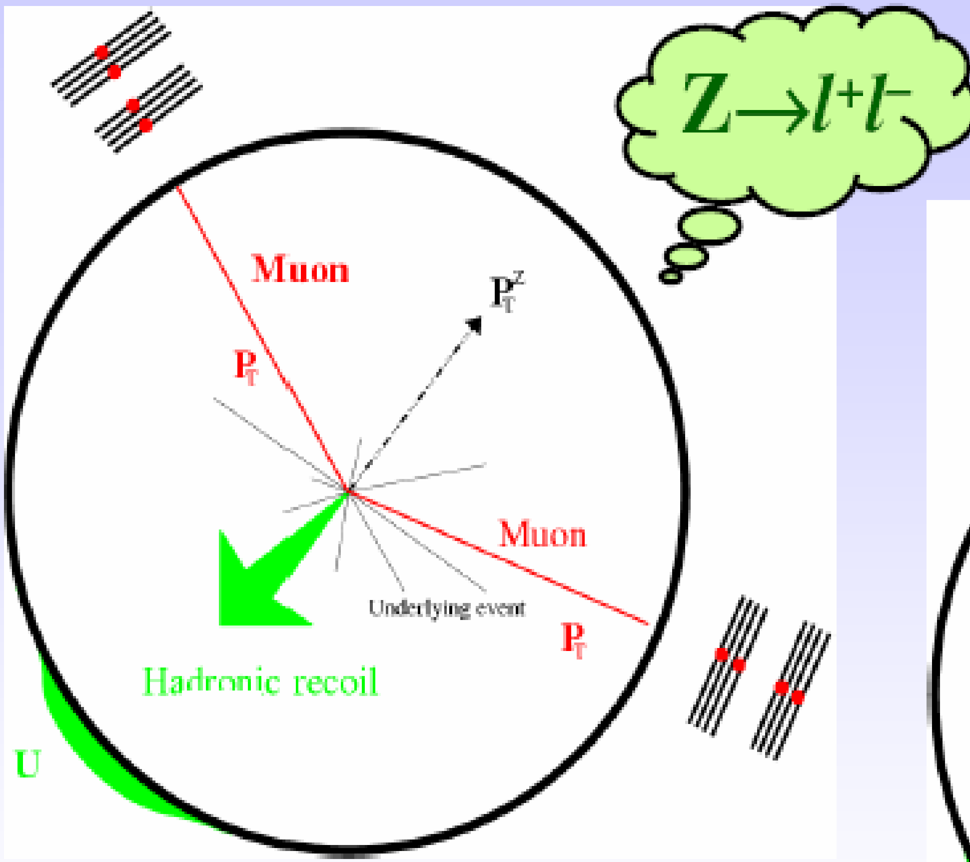
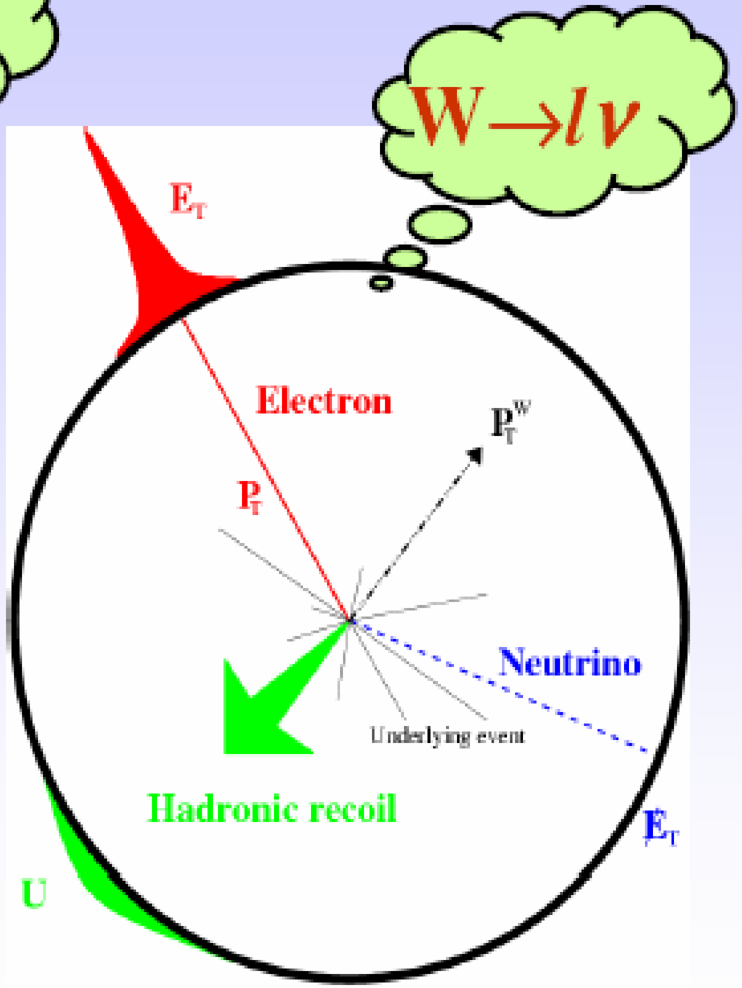
Signature of Z and W decays





K.Jacobs

Detector performance requirements

- **Lepton measurement**: $p_T \approx$ GeV $\rightarrow$ 5 TeV
  (b $\rightarrow \ell X$, W'/Z')
- **Mass resolution** (m ~ 100 GeV) :
  - $\approx$ 1 % (H $\rightarrow \gamma\gamma$, 4ℓ)
  - $\approx$ 10 % (W $\rightarrow$ jj, H $\rightarrow$ bb)
- **Calorimeter coverage** : $|\eta| < 5$
  (E_T^{miss}, forward jet tag)
- **Particle identification** : e, γ, τ, b

Three crucial parameters for precise measurements

- **Absolute luminosity** : **goal < 5%**

  Main tools: machine, optical theorem, rate of known processes (W, Z, QED pp $\rightarrow$ pp $\ell\ell$)

- **ℓ energy scale** : goal **1‰** most cases

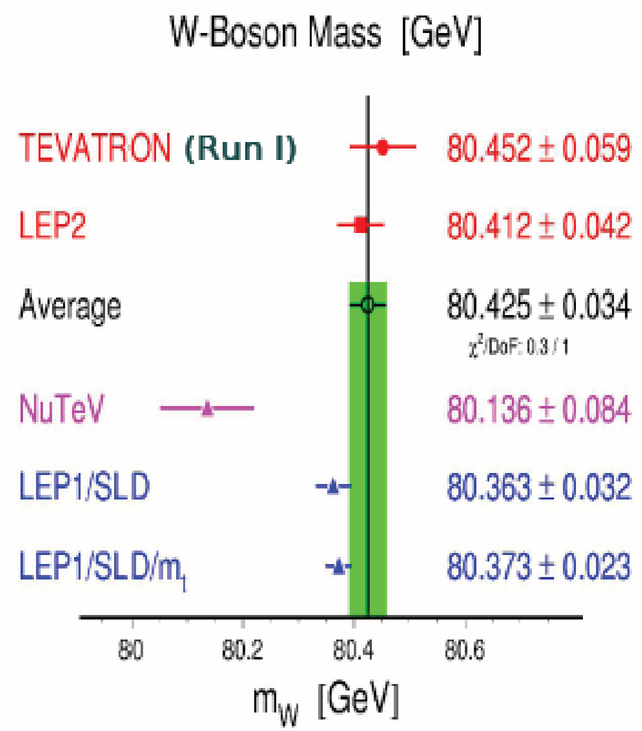
  0.2‰ W mass

  Main tool: large statistics of **Z** $\rightarrow \ell\ell$ (close to m_W , m_H)

- **jet energy scale**: goal **1%** (m_{top}, SUSY)

  Main tools: Z+1jet (Z $\rightarrow \ell\ell$) , **W $\rightarrow$jj** from top decay

LEP



New published OPAL: M_W=80.415±0.052 (preliminary error was 67 MeV)

Analysis in progress at Tevatron Run II: $M_{W,}$ Br(W→τ)

M_w is an important parameter in precison test of SM

- **M_W=80.425 ± 0.034 GeV**.
- 2007 M_w 80…± 20 MeV (Tevatron Run II)

2.9σ

Improvement at LHC requires Control systematic better 10^{-4} level

W mass measurements motivation

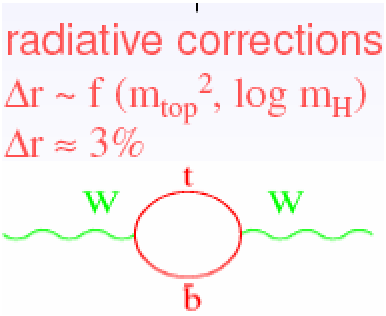
- m_w m_t are fundamental parameters of Standard Model; there are well defined relations between m_w,m_t,m_H.

Dependance on top and Higgs mass via loop corrections

$$M_W^2 = \frac{\pi \cdot \alpha}{\sqrt{2} \cdot G_F} \cdot \frac{1}{\sin^2 \theta_w \cdot (1 - \Delta r)}$$

$$\Delta r \approx m_t^2$$

$$\Delta r \approx \log M_H$$



- α electromagnetic constant Measured in atomic transitions, e+e- machines
- G_F Fermi constant measured in muon decay
- Sin θ w measured at LEP/SLC
- **Δ r radiative corrections**

- $G_{F,}$ α, sin θ $_w$ are known with high precision precise measurements of W mass an top-quark mass constrains Higgs boson mass

- To match precision of top mass measurement of 2 GeV: ΔM_W=15 MeV

$\Delta m_W \sim 0.7 \times 10^{-2} \Delta m_t$