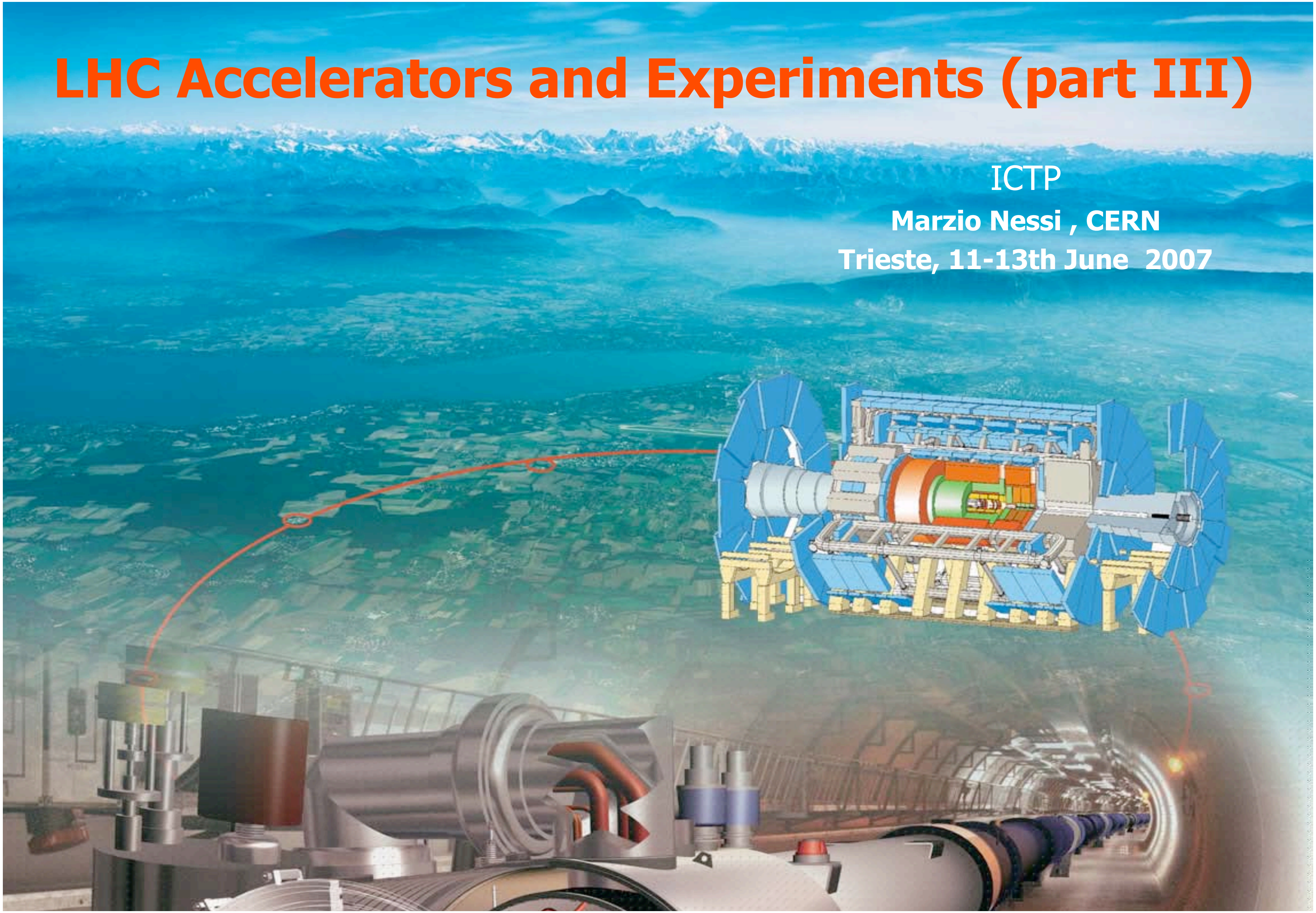
SMR/1847-4

Summer School on Particle Physics

11 - 22 June 2007

LHC Accelerators and Experiments (part III)

Marzio Nessi
CERN, Switzerland



LHC Accelerators and Experiments (part III)

ICTP

Marzio Nessi , CERN

Trieste, 11-13th June 2007

ICTP-2007 The LHC project

Part I : motivation, the LHC accelerator

Part II : experimental goals, ATLAS and CMS detectors

Part III : LHCb and Alice experiments,
luminosity measurements,
early discovery potential

- *This will be a set of experimental lectures, with the goal of giving you an impression of the complexity and challenges of this project*
- *My deep involvement in the design and construction of the ATLAS detector will bias me towards it as a showcase … sorry!*

Table of Content (Part III)

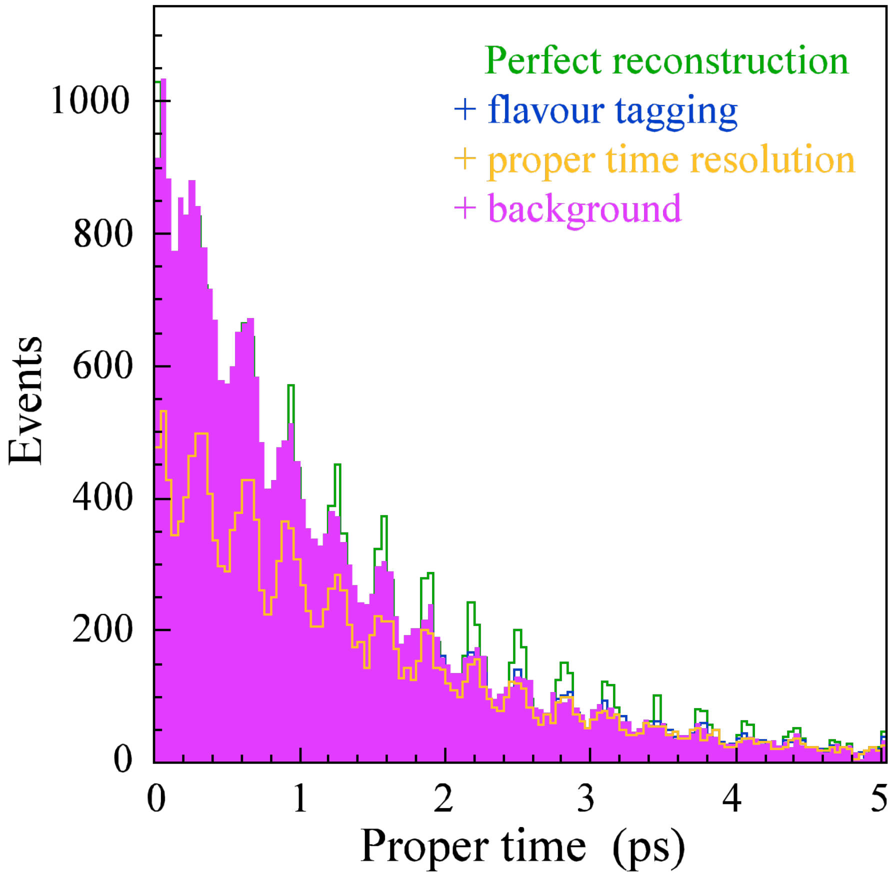
- ✓ The LHC-b Experiment
- ✓ The heavy ion program: ALICE
- ✓ How do you measure the beam Luminosity
- ✓ The GRID project (offline computing)

- ✓ The early Physics Discoveries

B Physics at LHC

LHC will act as a **b**-factory with large b-quark production rate including B_s, allowing to improve the CKM consistency test and to look for deviations from the SM rare processes (dedicated experiment LHCb + ATLAS & CMS)

- ✓ *All* b hadron species are produced:
  B^0, B^+, B_s, B_c, b-baryons
  Expected fractions ~ 40 : 40 : 10 : 0.1 : 10 %
- ✓ One of the first physics goals: observation of B_s oscillation
- ✓ Best mode: $B_s \rightarrow D_s^- \pi^+$



Plot made for 1 year of data (80k selected events, LHCb) for Δm_s = 20 ps^{-1} (SM preferred)

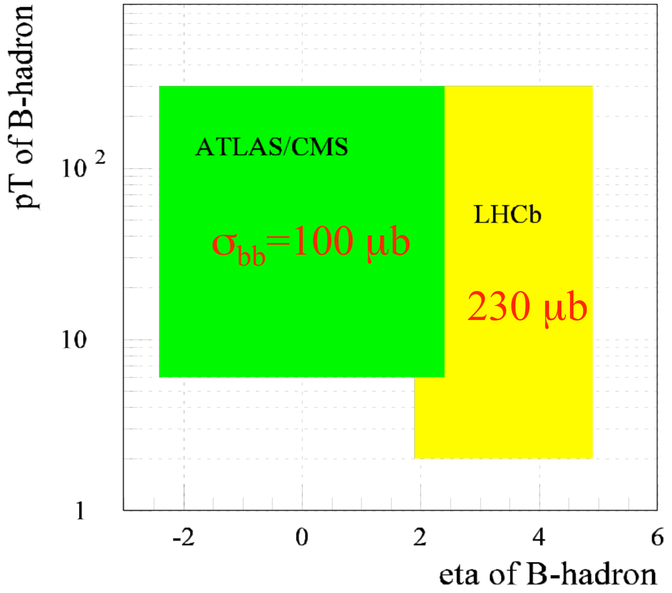
New Physics in the B sector

LHCb is dedicated to the Search for New Physics in CP violation and Rare B decays

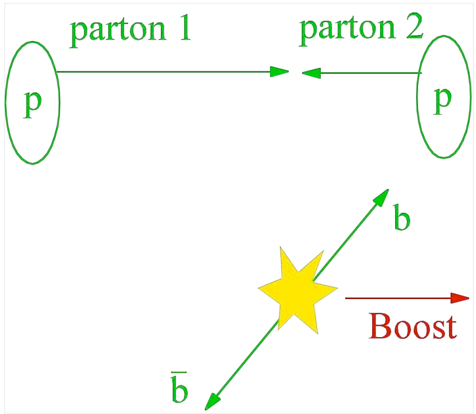
- Measure processes which are very suppressed in SM
  - ✓ CP in B_s mixing
    - $B\ B_s \rightarrow J/\Psi\Phi_s \rightarrow J/\Psi\Phi$
  - ✓ Radiative and very rare B decays
    - $B_d \rightarrow K^*\gamma$, $B_s \rightarrow \Phi\gamma$, $B_d \rightarrow K^*\mu\mu$, $B_{d,s}$
  - ✓ Rare D decays and D^0 mixing
  - ✓ Lepton flavour violating decays

- Precision measurements of CKM elements
  - ✓ B_s oscillations
  - ✓ Compare pure tree level processes with processes sensitive to NP
    - $\sin 2\beta$ $B_d \rightarrow J/\Psi K_s$ vs $B_d \rightarrow \Phi K_s$
    - γ $B \rightarrow DK$ vs $B \rightarrow \pi\pi/KK$
  - ✓ Measure all angles and sides in many different ways. Any inconsistency will be evidence for NP

LHCb looking for Matter-Antimatter Asymmetry in B-mesons



B hadrons have a mass of ~ 5 GeV and therefore tend to be produced with asymmetric *x* values of the partons --> boosted along the beam direction



✓Cross section for bb production at 14 TeV:

$\sigma_{bb} \sim 500\ \mu b$

Enormous production rate at LHCb: $\sim 10^{12}$ bb pairs per year!

→ much higher statistics than the current B factories

✓However, $\sigma_{bb} < 1\%$ of inelastic cross-section

more background from non-b events →
challenging trigger and high energy →
more primary tracks

✓Expect ~ 200,000 reconstructed $B^0 \rightarrow J/\psi\ K_S$evts/y

cf current B-factory samples of ~ 4000 ev.
→ precision on sin 2β ~ 0.02 in one year
(similar to current *world average precision)*

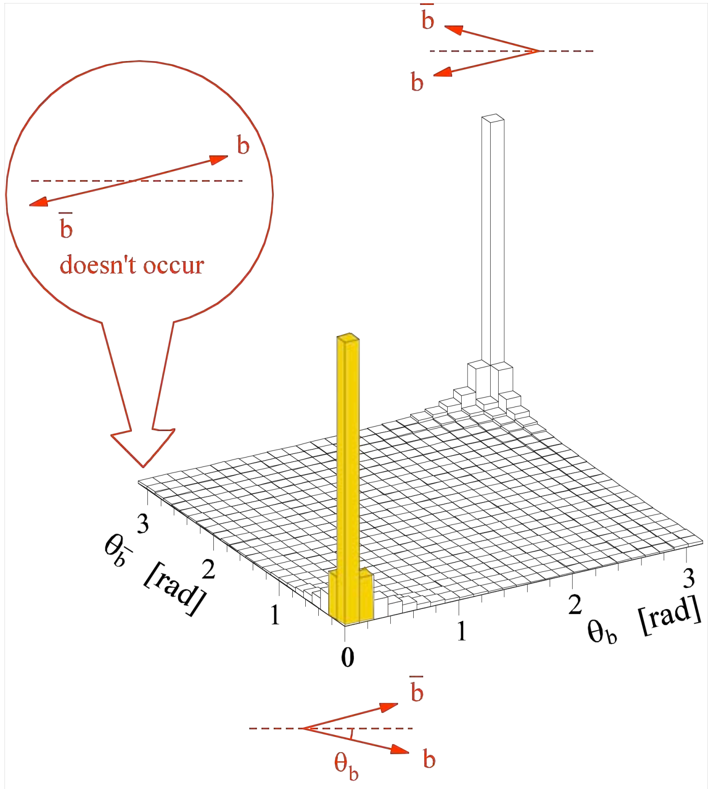
✓But in addition, *all* b-hadron species are produced:

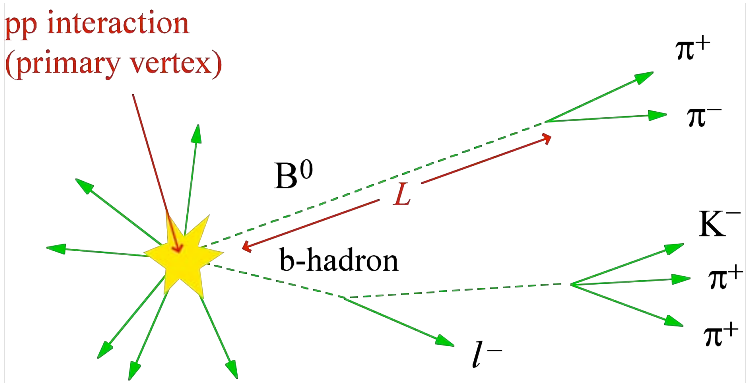
$B^0, B^+, B_s, B_c\ , \Lambda_b\ \ldots$

In particular can study the B_s (bs) system, inaccessible at the B factories

Detector requirements

b and $\bar{b}$ quarks are produced in pairs (mostly in the forward direction)



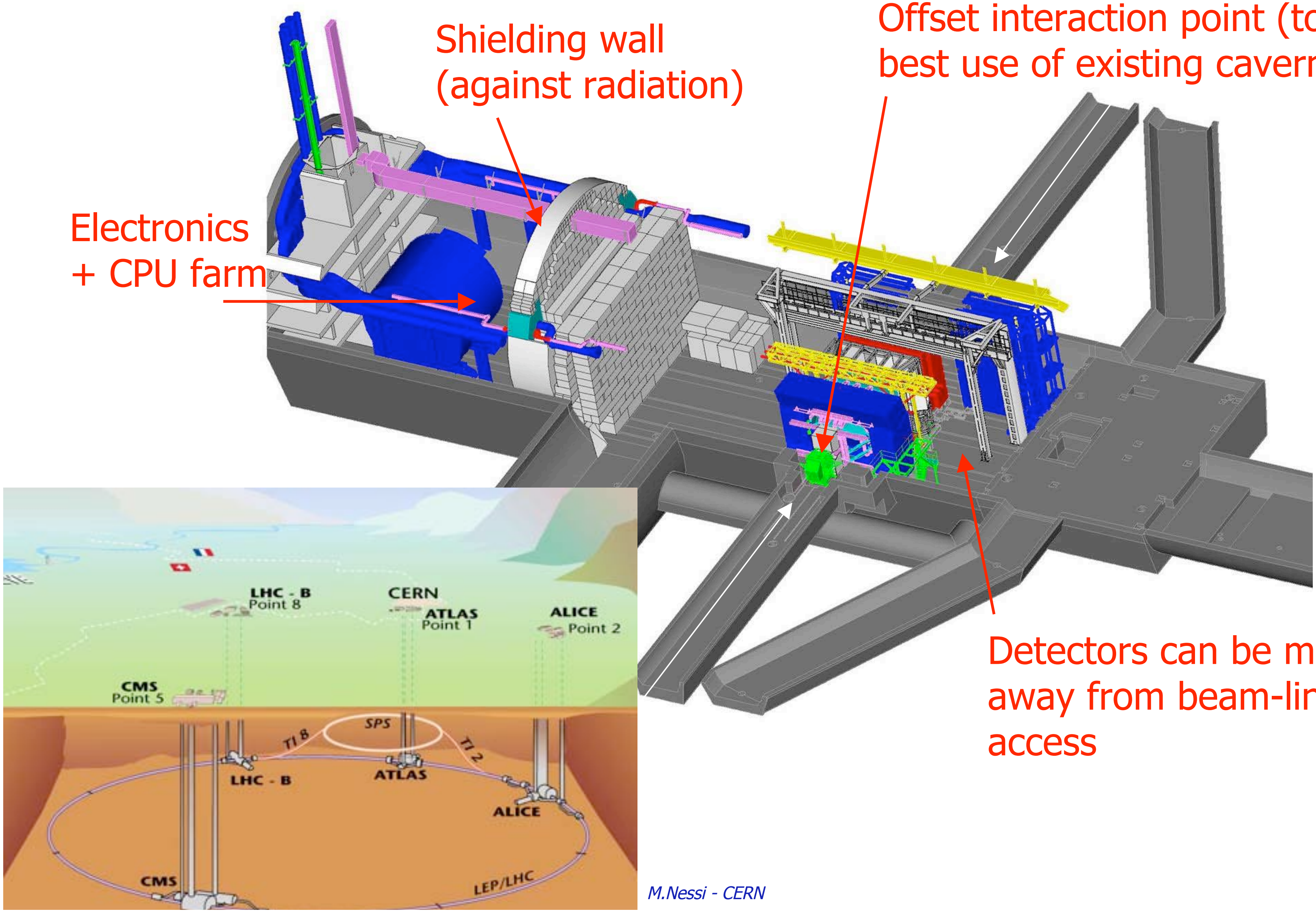


- Need to measure proper time of B decay:

  $t = m_B L / pc$

  hence decay length L (~ 1 cm in LHCb) and momentum p from decay products (which have ~ 1–100 GeV)
- Also need to tag *production* state of B: whether it was B or $\overline{B}$. Use charge of lepton or kaon from decay of the *other* b hadron in the event
- Need excellent particle identification to avoid huge combinatorial background

LHC-b in its cavern



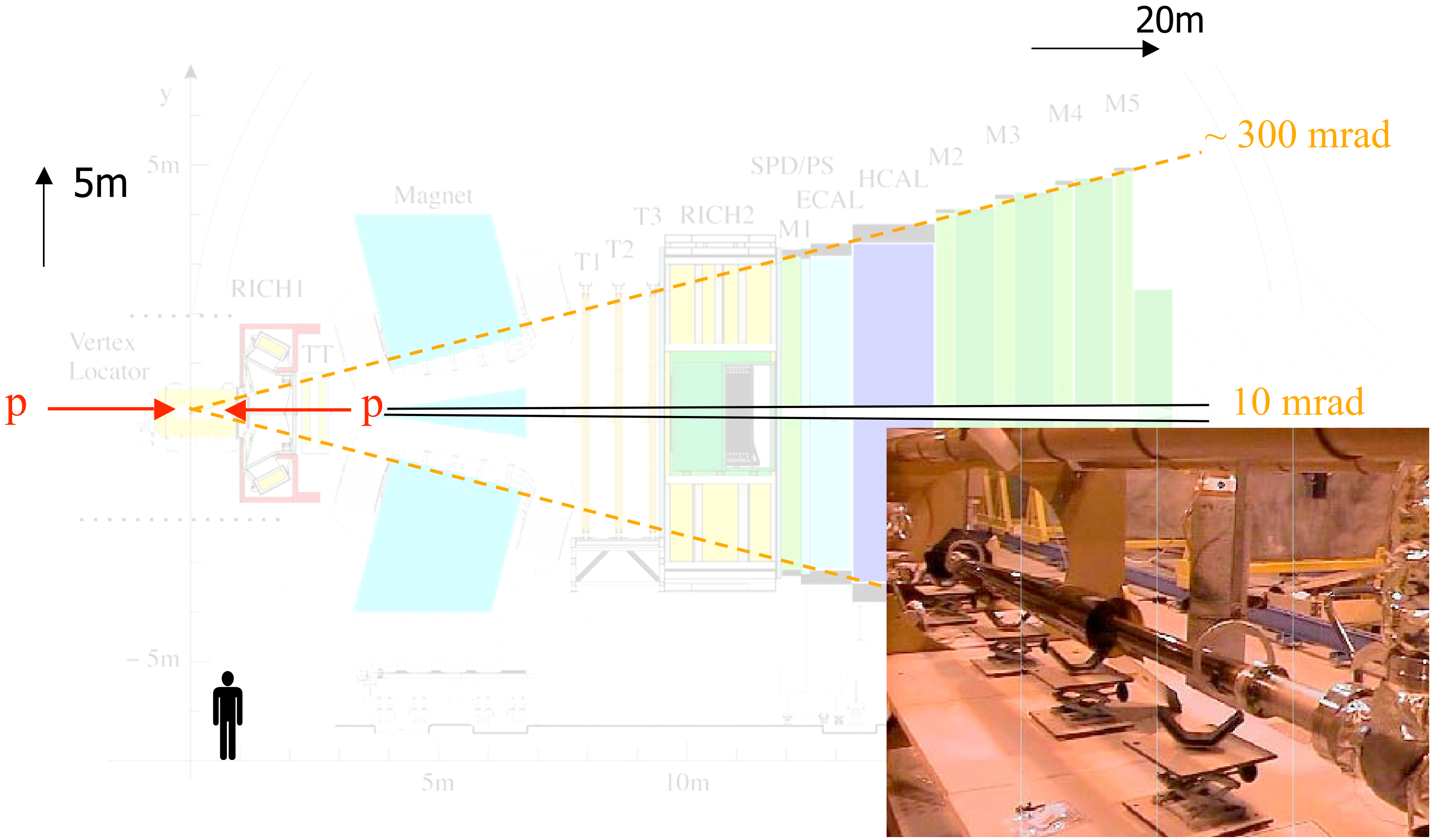
Shielding wall (against radiation)

Offset interaction point (to make best use of existing cavern)

Electronics + CPU farm

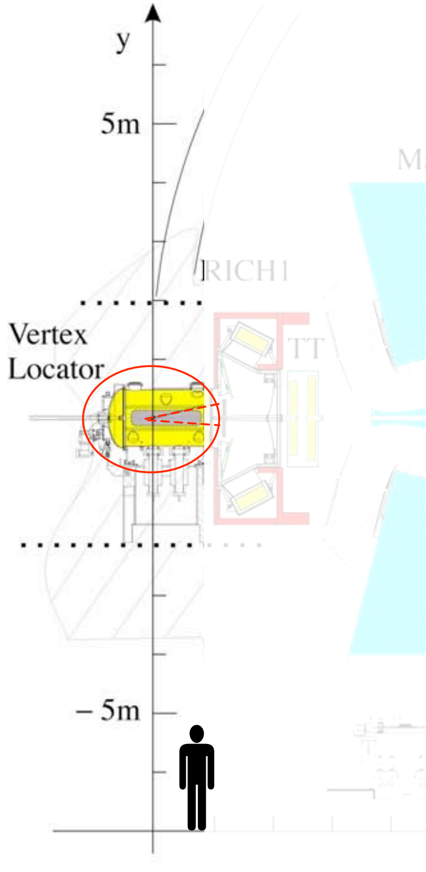
Detectors can be moved away from beam-line for access

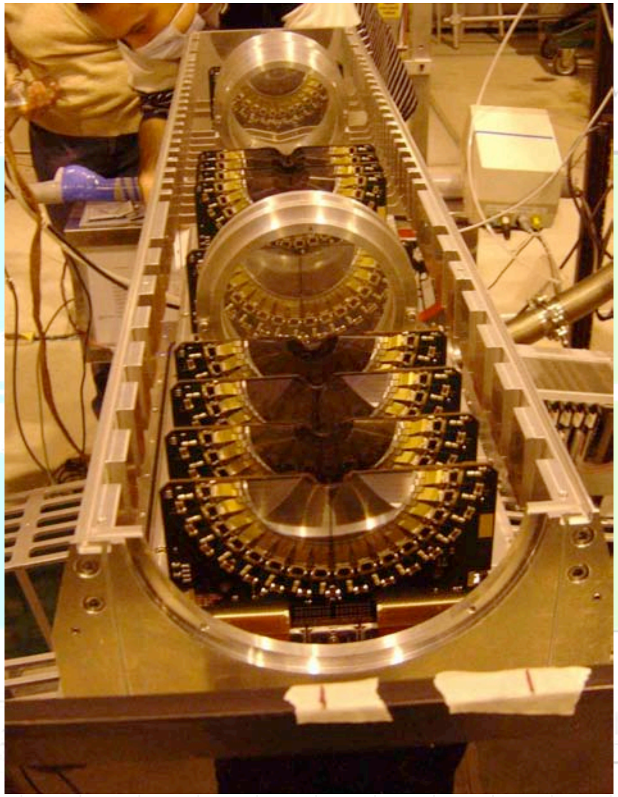
The LHCb detector



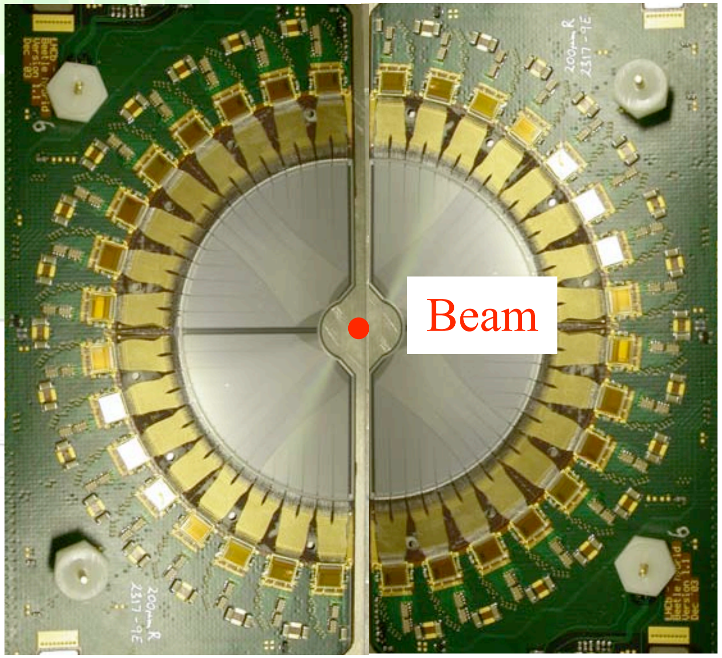
Forward spectrometer (running in pp collider mode)
Inner acceptance 10 mrad from conical beryllium **beam pipe**

Vertex Locator





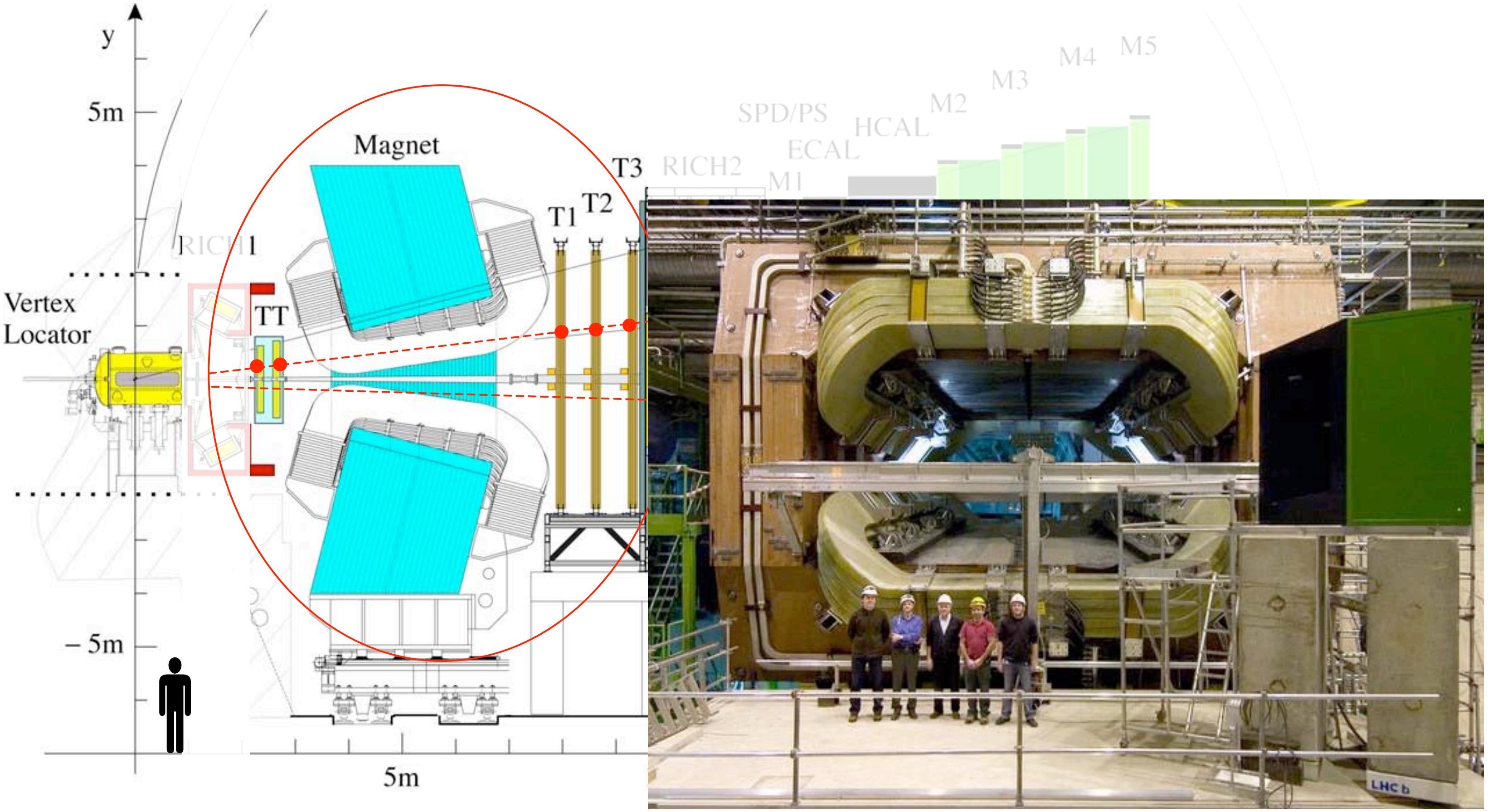
- ✓ Vertex detector has silicon microstrips whose rϕ geometry reaches 8 mm from the beam (inside a complex secondary vacuum system)
- ✓ Gives excellent proper time resolution of ~ 40 fs (important for B_s decays)



Vertex locator around the interaction region

Silicon strip detector with ~ 30 mm impact-parameter resolution, particularly important for triggering

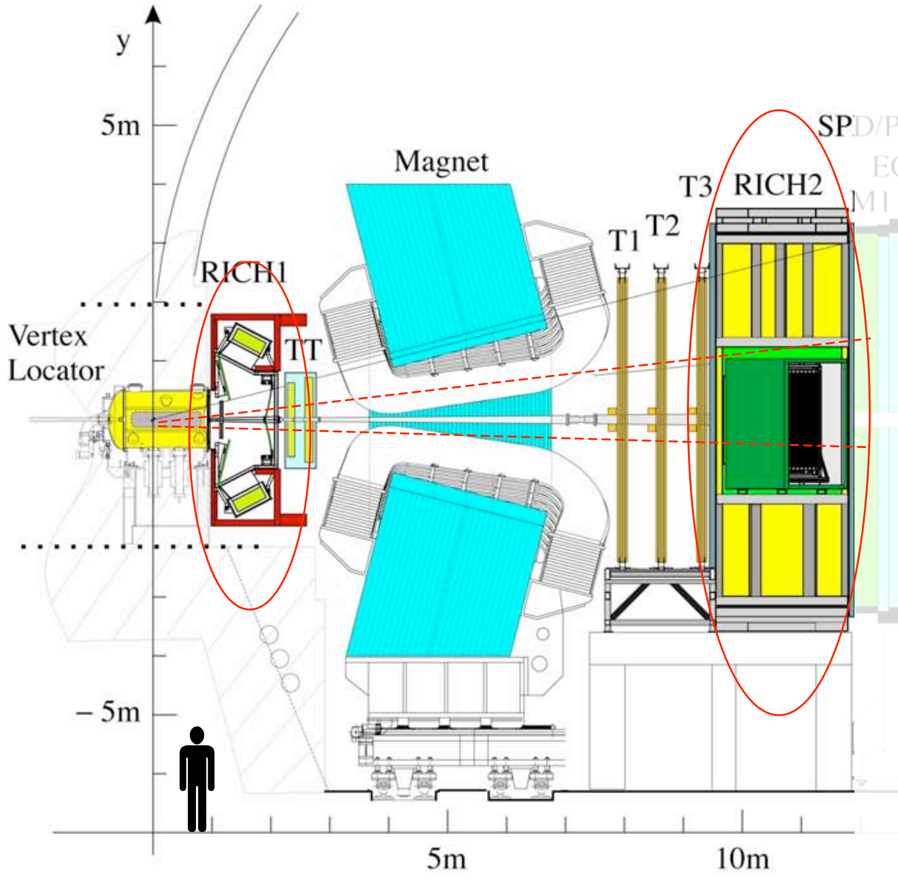
Tracking System



Tracking system and dipole magnet to measure angles and momenta

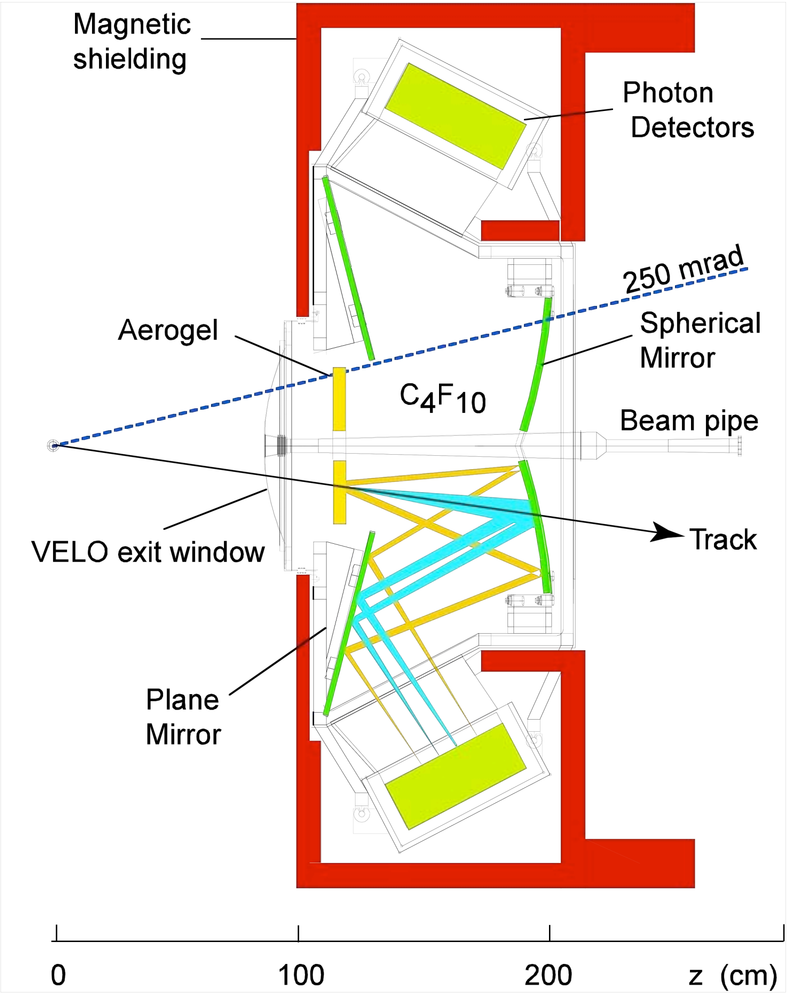
$\Delta p/p \sim 0.4\ \%$, mass resolution ~ 14 MeV (for $B_s \rightarrow D_s K$)

RICH detectors *(Ring Imaging Cherenkov)*



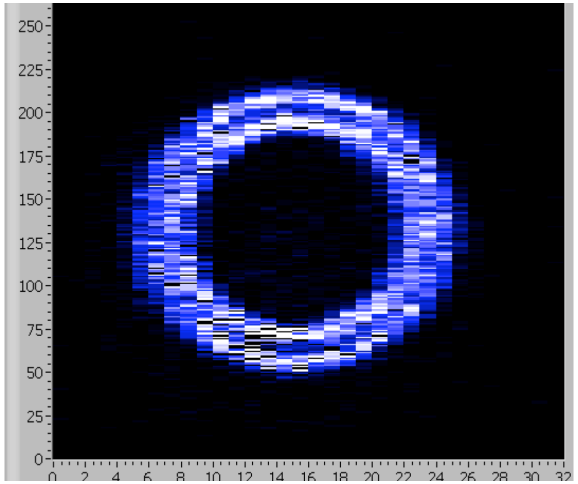
Two **RICH** detectors for charged hadron identification (π, K, p), important for hadronic decays as $B_s^0 \rightarrow D_s^- K^+ \rightarrow K^+ K^- \pi^- K^+$

RICH detectors

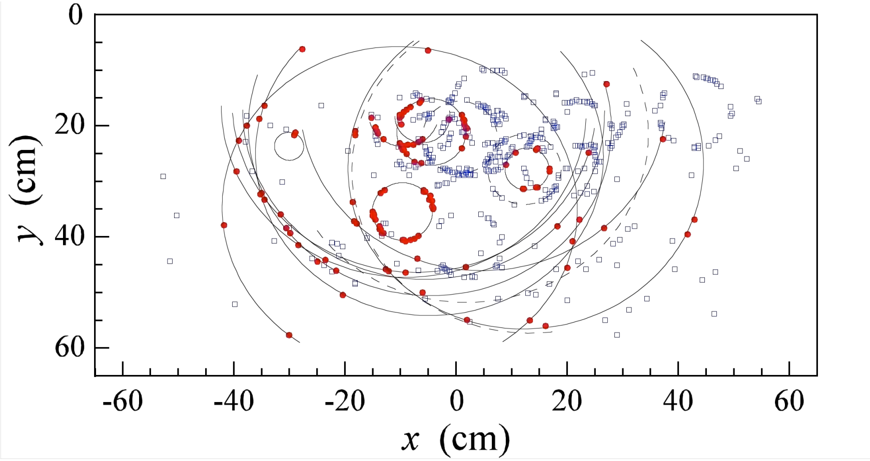


By measuring the radius of the ring, the velocity of the particle is found
Then, with knowledge of its momentum, the mass of the particle can be found

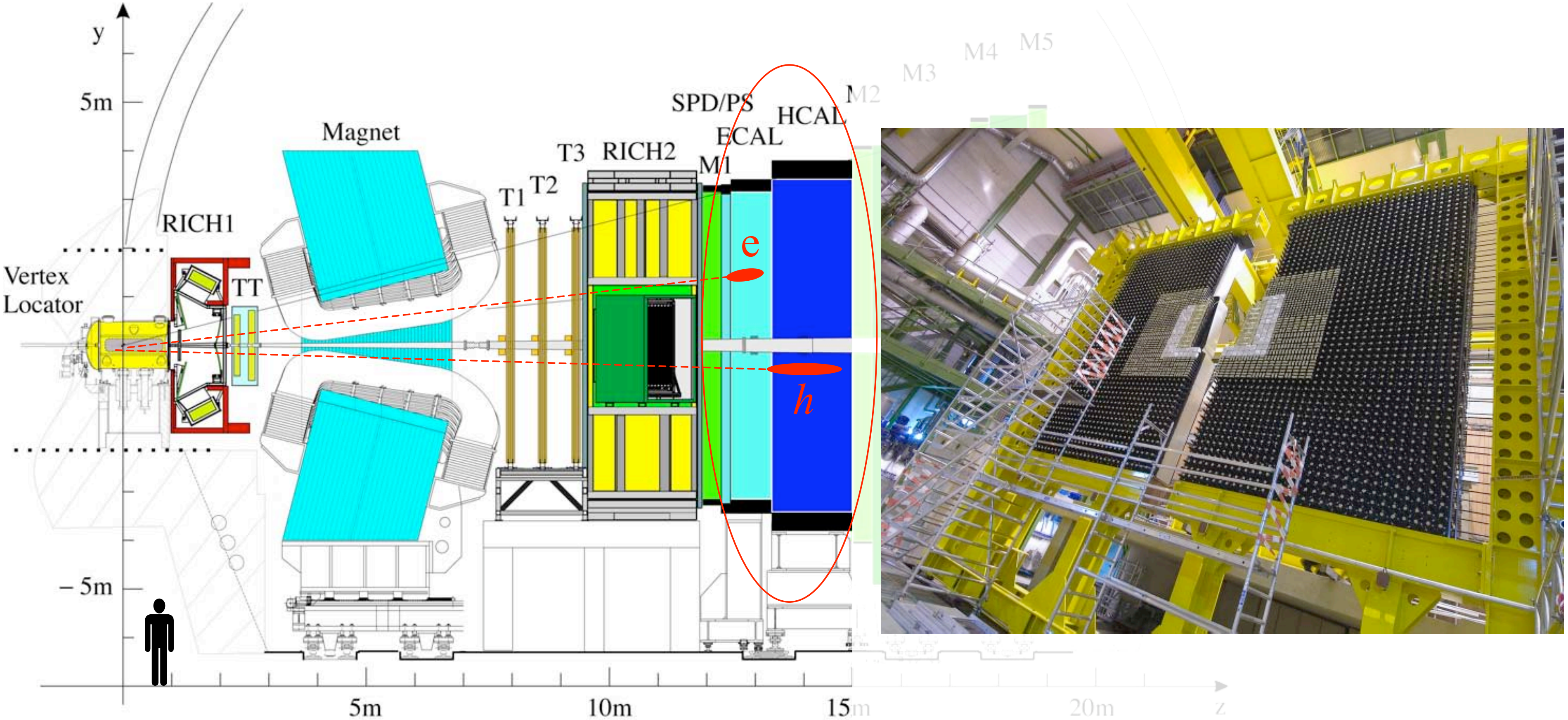
Test-beam image of Cherenkov rings from 50 GeV e + π beam



Typical event: complex pattern recognition!



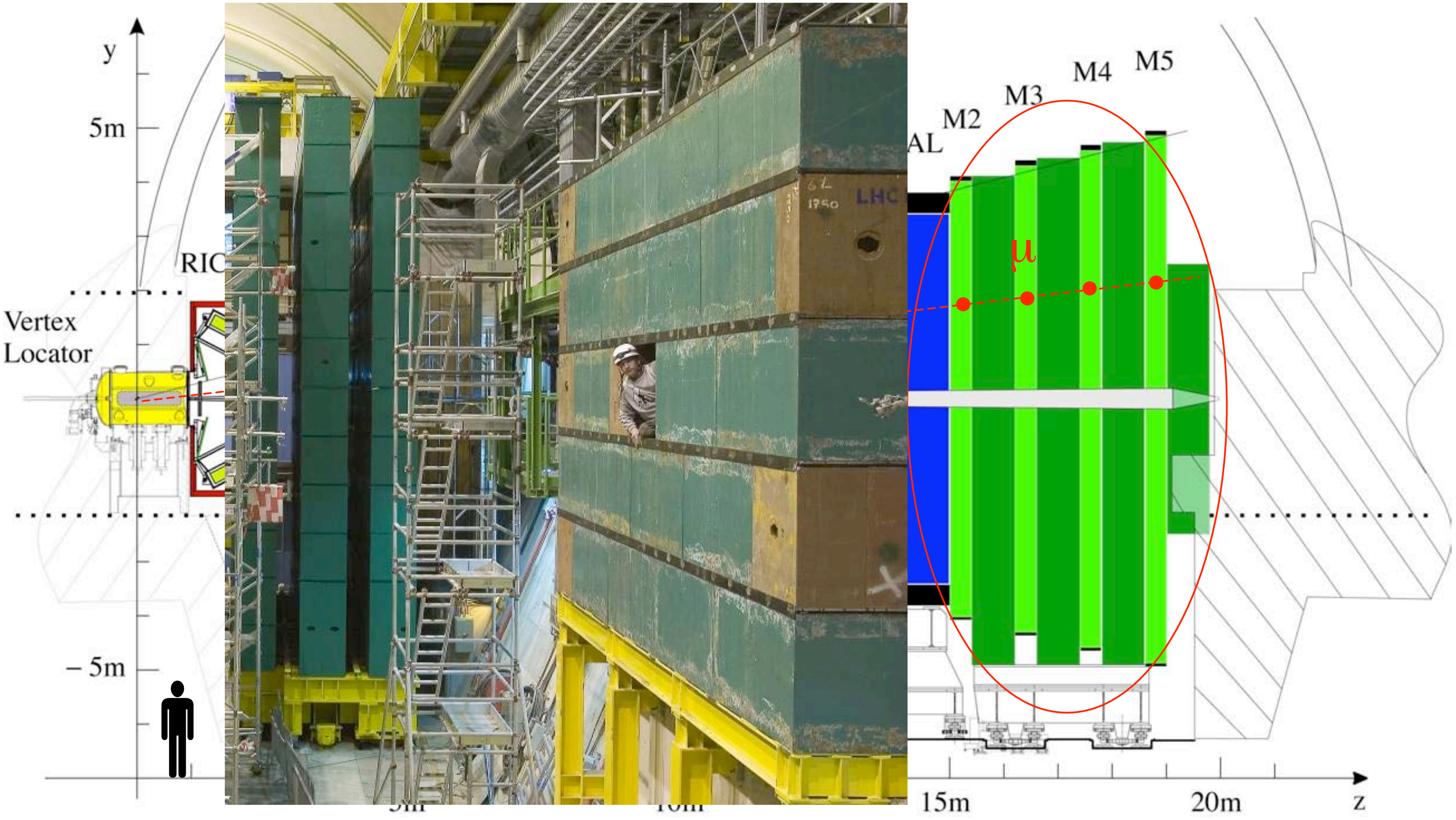
Calorimeters



Calorimeter system to identify electrons, hadrons and neutrals

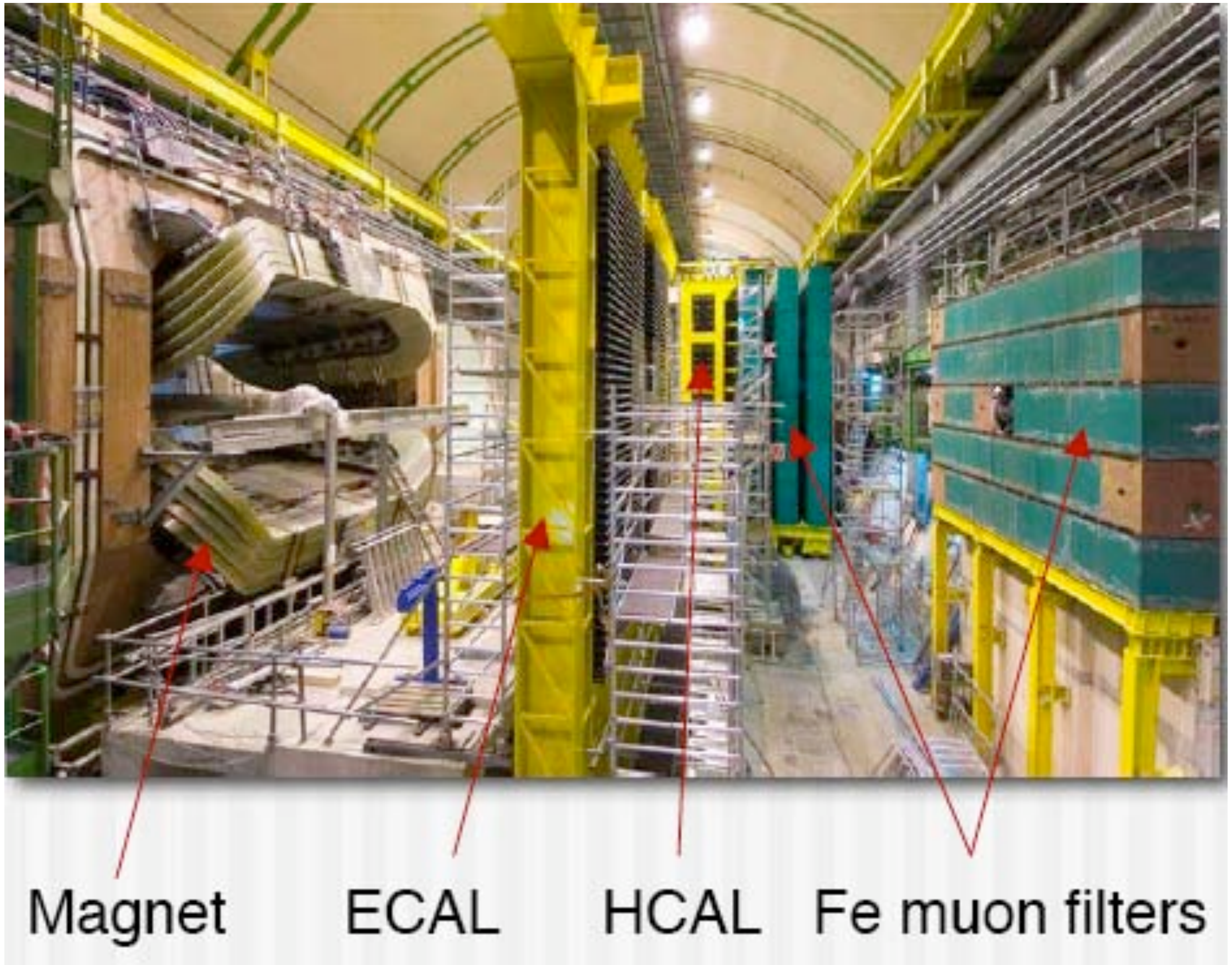
Important for the first level of the trigger

Muon System

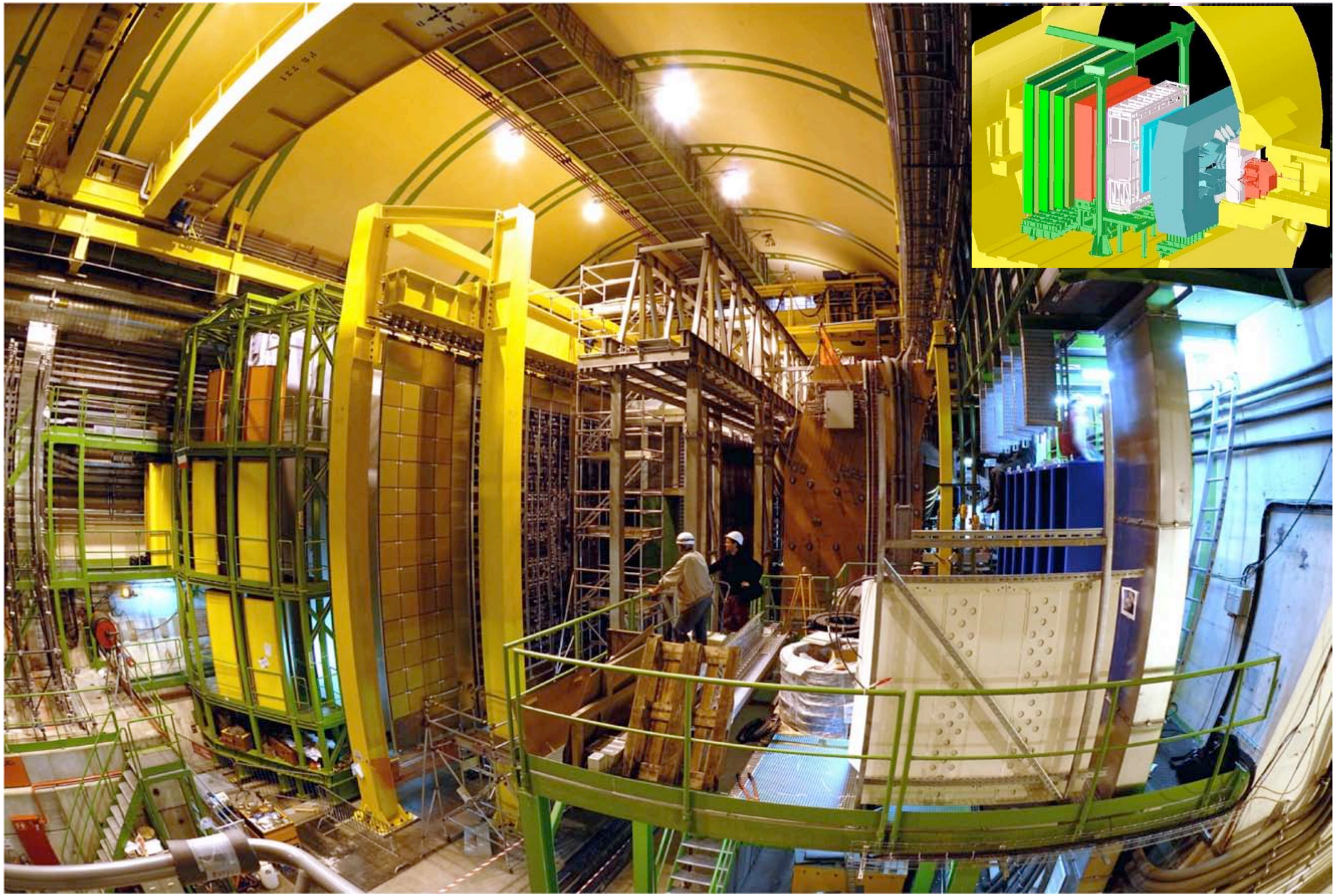


Muon system to identify muons, also used in the first level of the trigger

Overall view



Overall view



Trigger strategy

Front-end

40 MHz

L0: high p_T (μ, e, γ, h) [hardware, 4 μs]

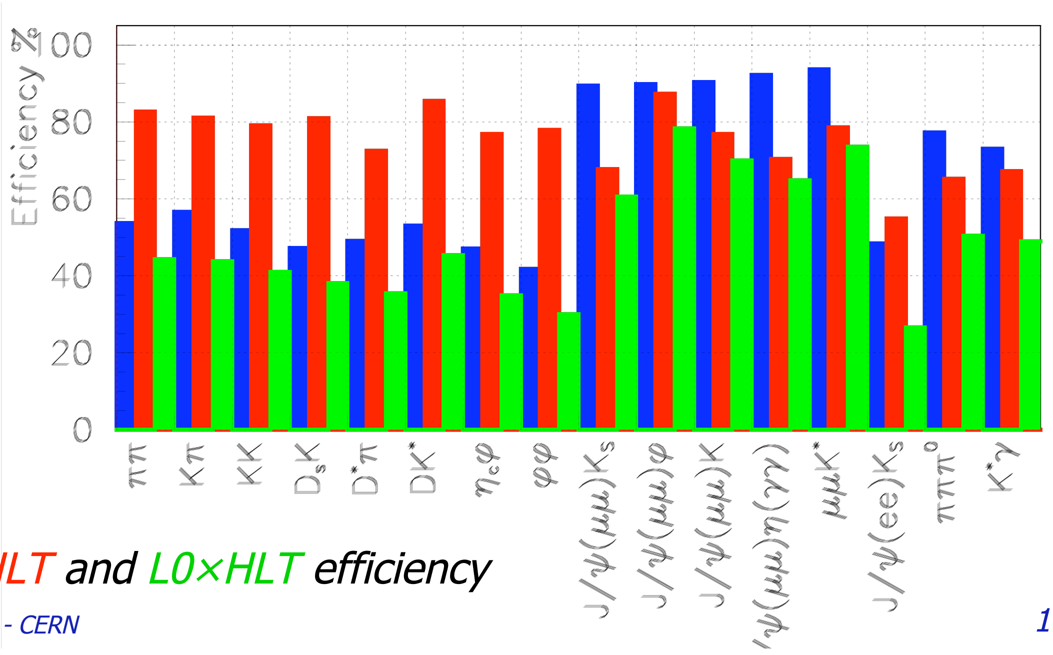
1 MHz

HLT: high IP, high p_T tracks [software]
then full reconstruction of event

2 kHz

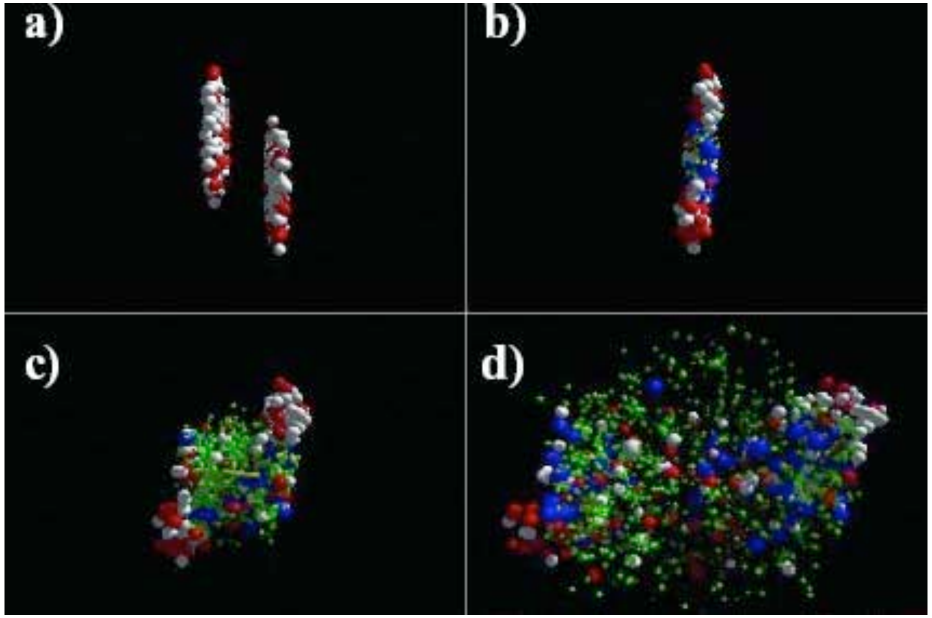
Storage
(event size ~
50 kB)

- *LHCb chooses to run at few × 10^{32} cm^{-2}s^{-1}.*
  dominated by single interactions
- *Makes it simpler to identify B decays*
  from their vertex structure
  and will also reduce the radiation
  dose (issue in the forward region)
- *Beams are defocused locally, can maintain*
  optimum luminosity even when
  ATLAS/CMS run at 10^{34}



L0, HLT and L0×HLT efficiency

Ion physics @ LHC



- ✓ *Global Characteristics of the event*
  multiplicites, η distributions
- ✓ *Degrees of freedom as a function of T*
  hadron ratios and spectra, dilepton continuum, direct photons
- ✓ *Collective effects*
- ✓ *Energy loss of partons in the QGP*
  jet quenching, high p_T spectrum, open c and b
- ✓ *Deconfinement*
  charmonium and bottomonium
- ✓ *Chiral symmetry restauration*
  Neutral to charged ratios, resonance decays
- ✓ *Fluctuations and critical behaviour*
  event-by-event particle composition and spectra

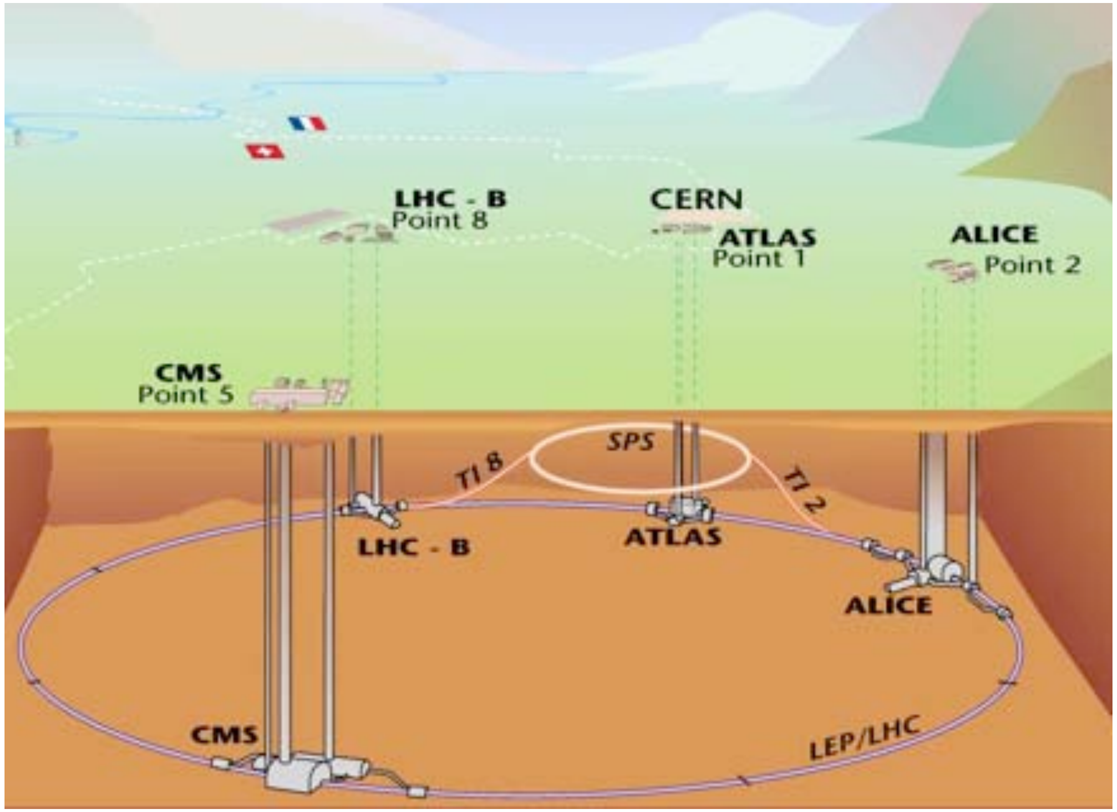
- Machine
  - ⇨ energy: E_{beam} = 7 x Z/A [TeV] => $\sqrt{s}$ = 5.5 TeV/A or 1.14 PeV (Pb-Pb)
  - ⇨ beams: ~ 4 weeks/year(10^6 s effective); typically after pp running (like at SPS)
  - ⇨ luminosity:
    - ✪ 10^{27} $cm^{-2}s^{-1}$ (Pb) to >10^{30} (light ions), => rate 10 kHz to several 100 kHz
    - ✪ integrated luminosity 0.5 nb^{-1}/year (Pb-Pb)

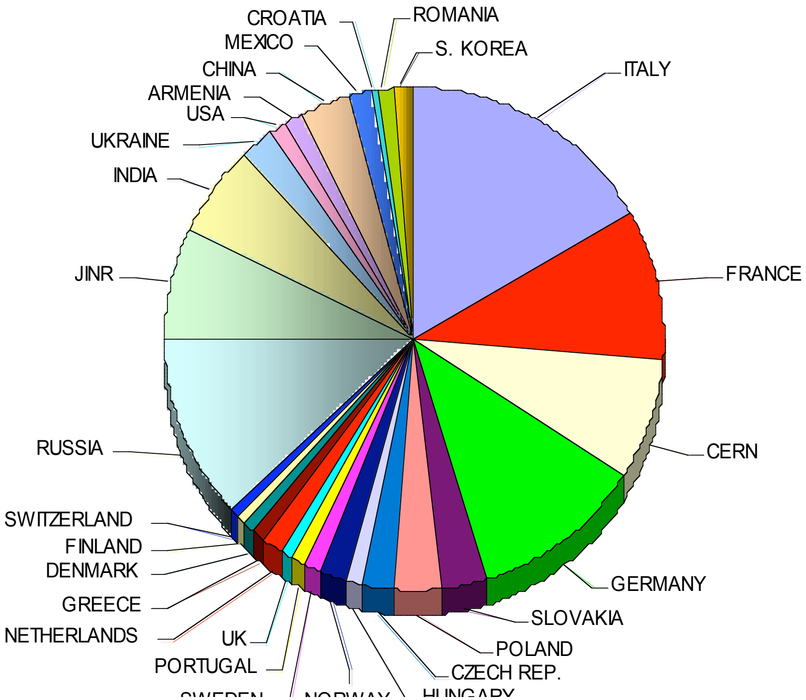
ALICE multipurpose detector

Detector challenge:

- ✓ *Identify and track most of the hadrons from soft to hard processes (100 MeV/c to P_T of ~ 100 GeV/c) up to 1.8 η units*
- ✓ *Vertex recognition of D/B mesons and hyperons in a very high density environment of up to $dN/d\eta$ ~8000*
- ✓ *Special effort to detect and identify di-lepton decays*
- ✓ *Excellent photon detection*
- ✓ *A smart trigger system and very powerful data flow processing*

ALICE Collaboration





~ 1000 Members

(63% from CERN MS)

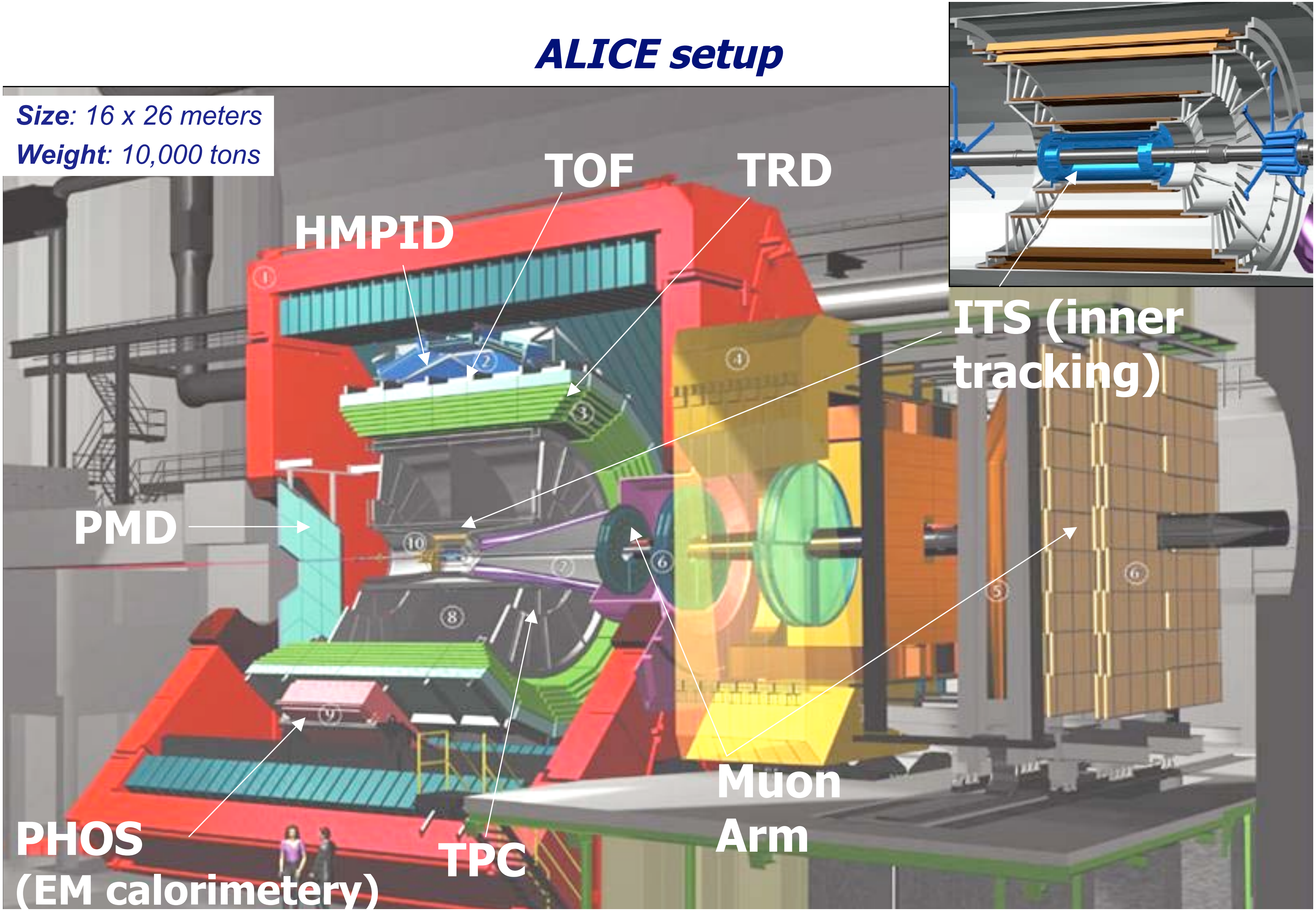
~30 Countries

~90 Institutes

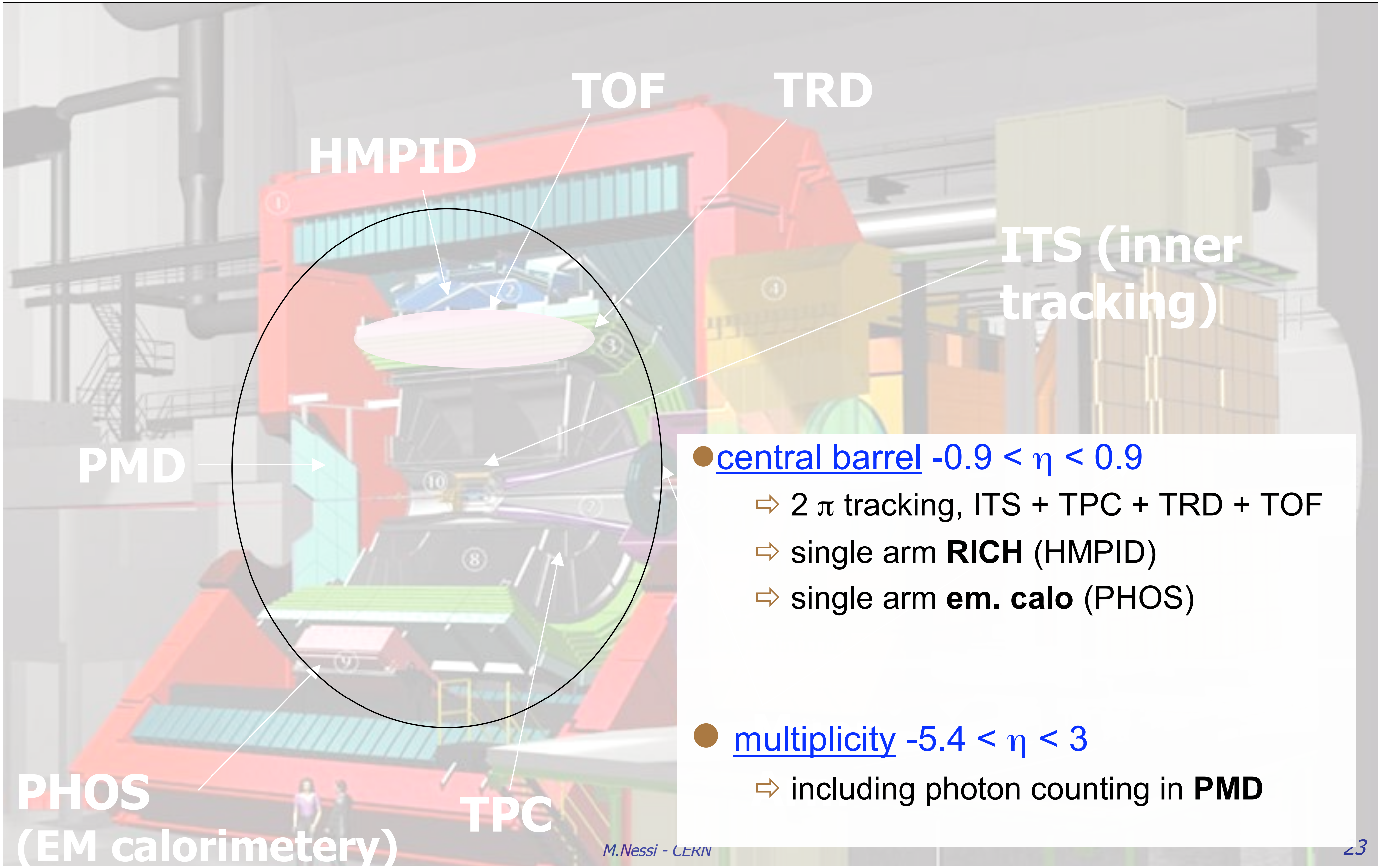
ALICE setup

***Size**: 16 x 26 meters*

***Weight**: 10,000 tons*

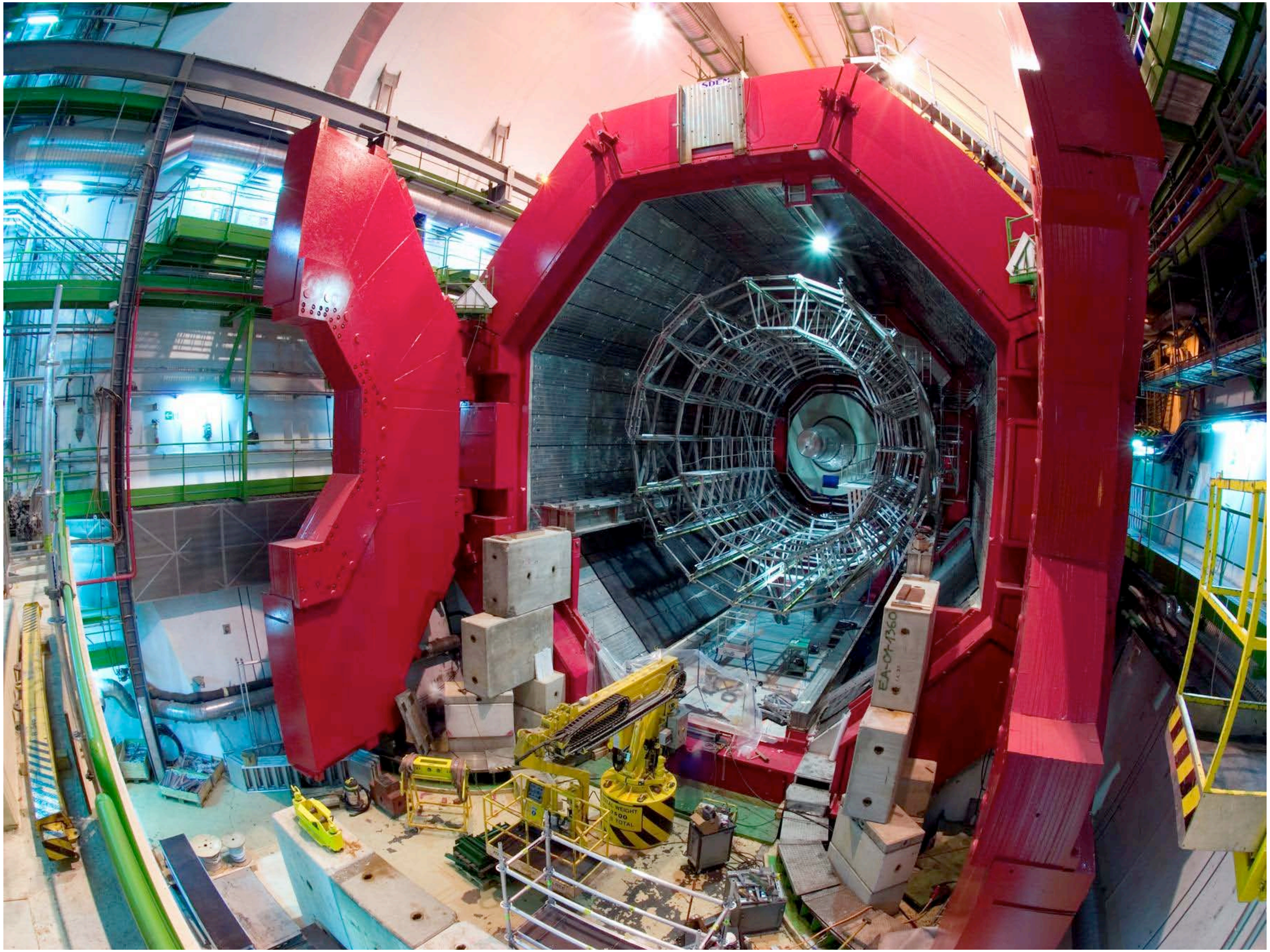


ALICE setup



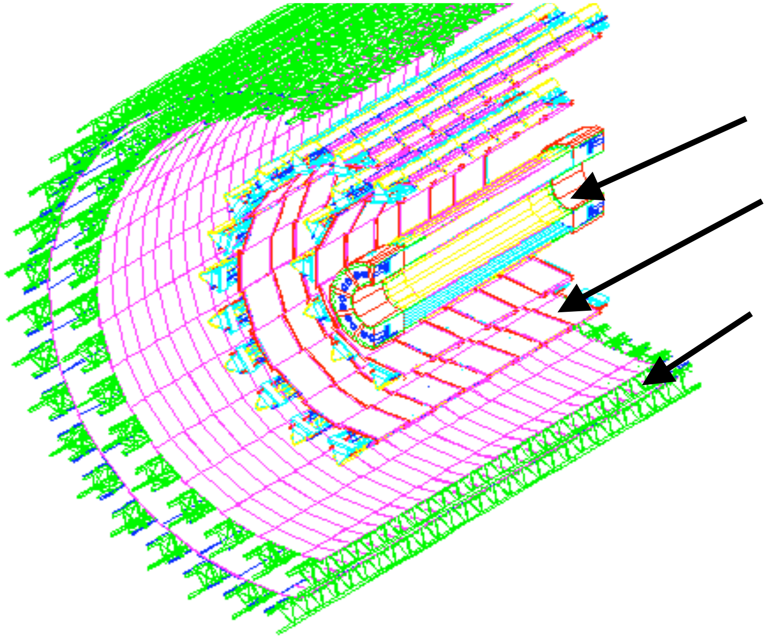
- central barrel $-0.9 < \eta < 0.9$
  - ⇨ 2 π tracking, ITS + TPC + TRD + TOF
  - ⇨ single arm **RICH** (HMPID)
  - ⇨ single arm **em. calo** (PHOS)
- multiplicity $-5.4 < \eta < 3$
  - ⇨ including photon counting in **PMD**

Magnet (from L3)



ITS

Six Layers of silicon detectors for precision tracking in $|\eta| < 0.9$

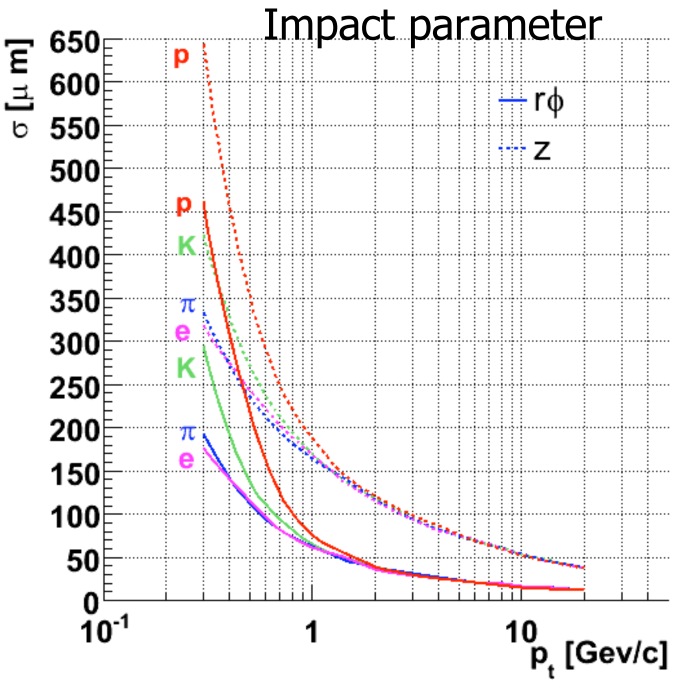


Three tecnhnologies:

SPD - Silicon Pixel

SDD - Silicon Drift

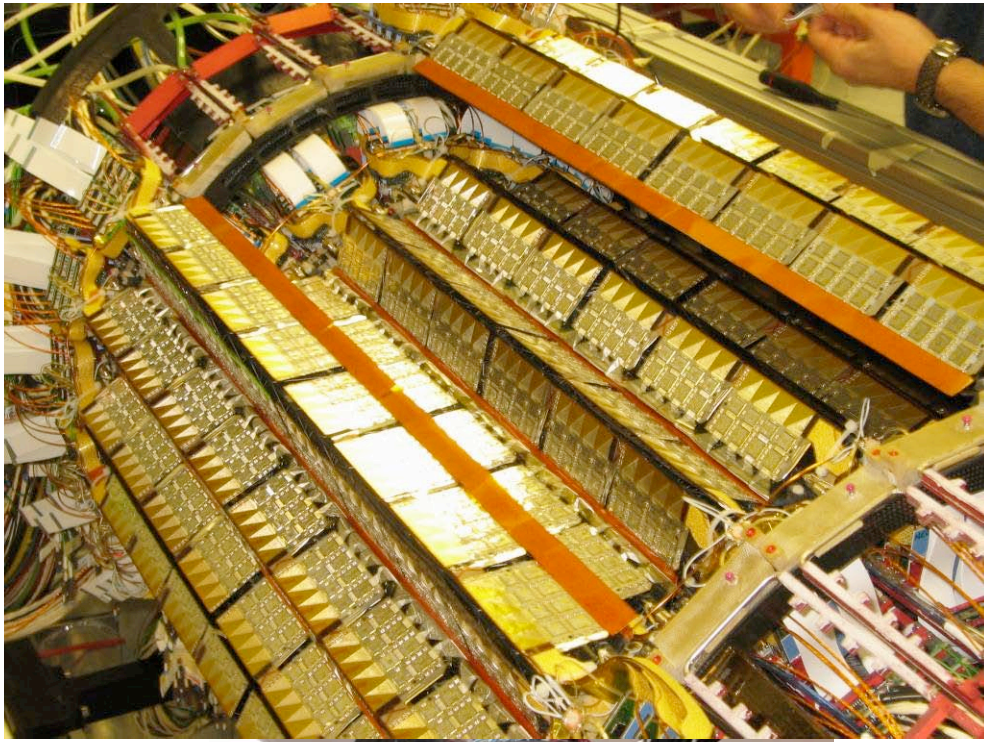
SSD - Silicon Strip



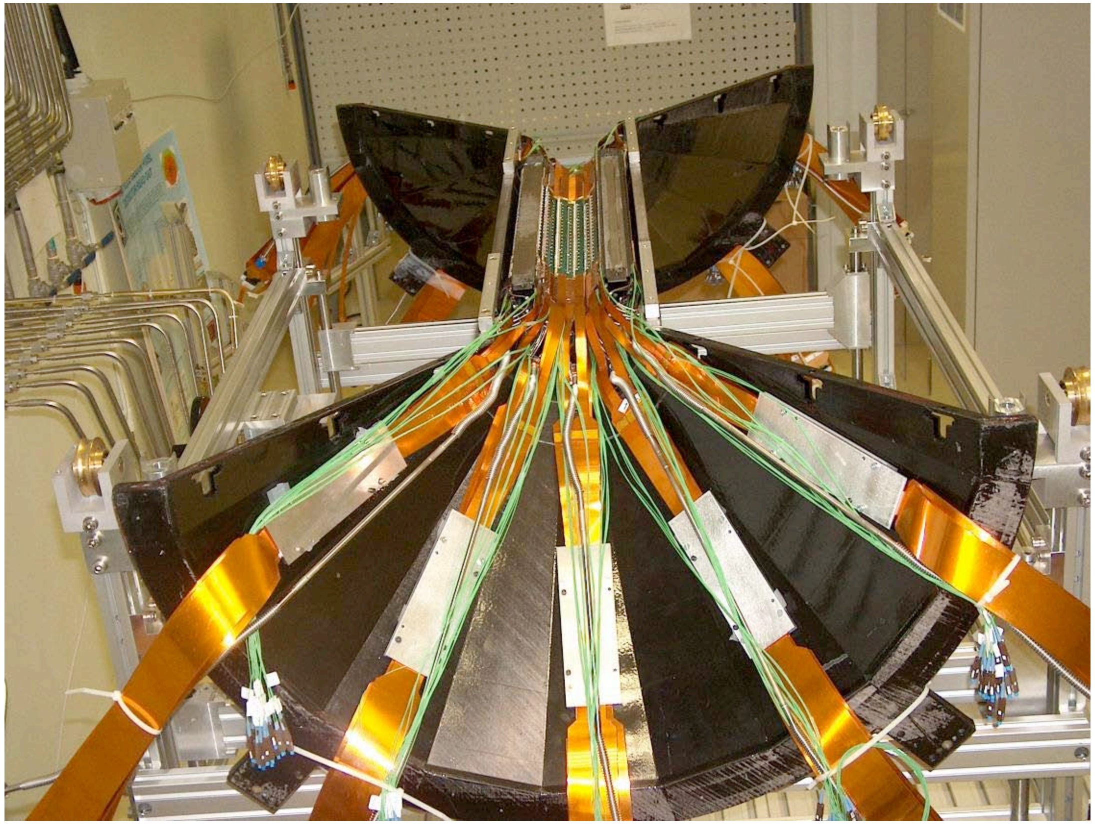
- 3-D reconstruction (< 100μm) of the **Primary Vertex**
- **Secondary vertex** Finding (Hyperons, D and B mesons)
- **Particle identification** via dE/dx for momenta < 1 GeV
- **Tracking+Standalone reconstruction** of very low momentum tracks

IST

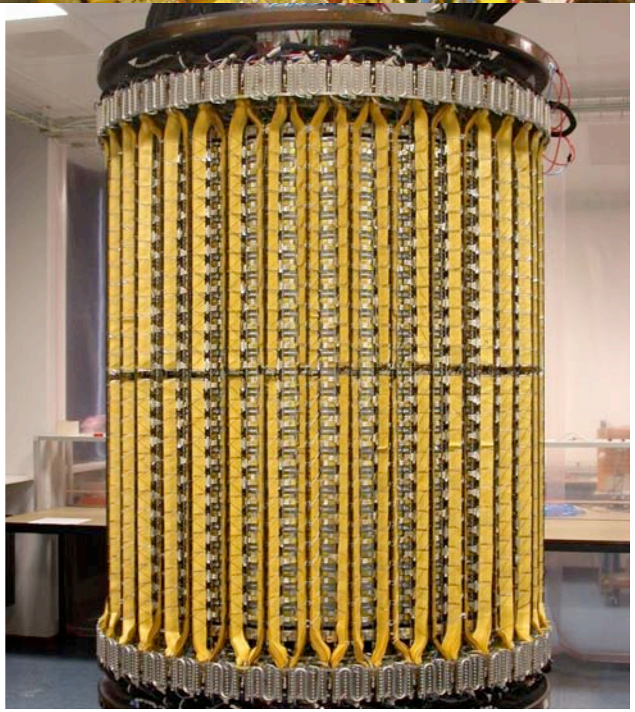
SDD - Silicon Drift



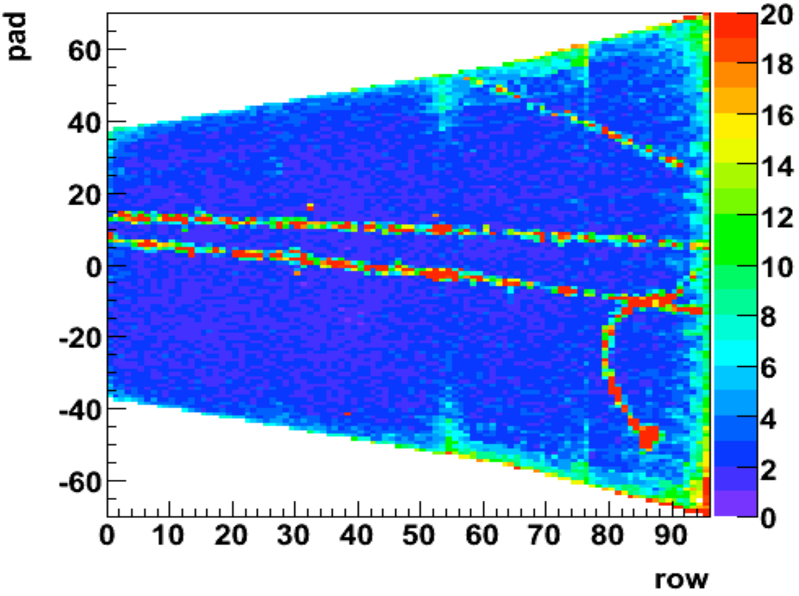
SPD - Silicon Pixel

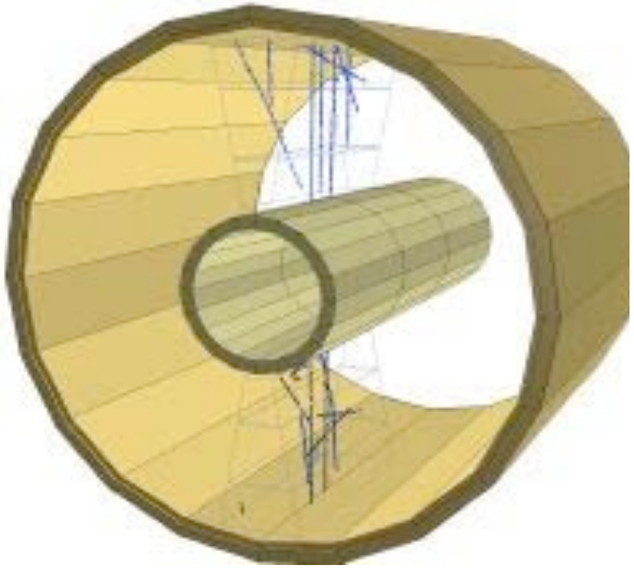


SSD - Silicon Strip



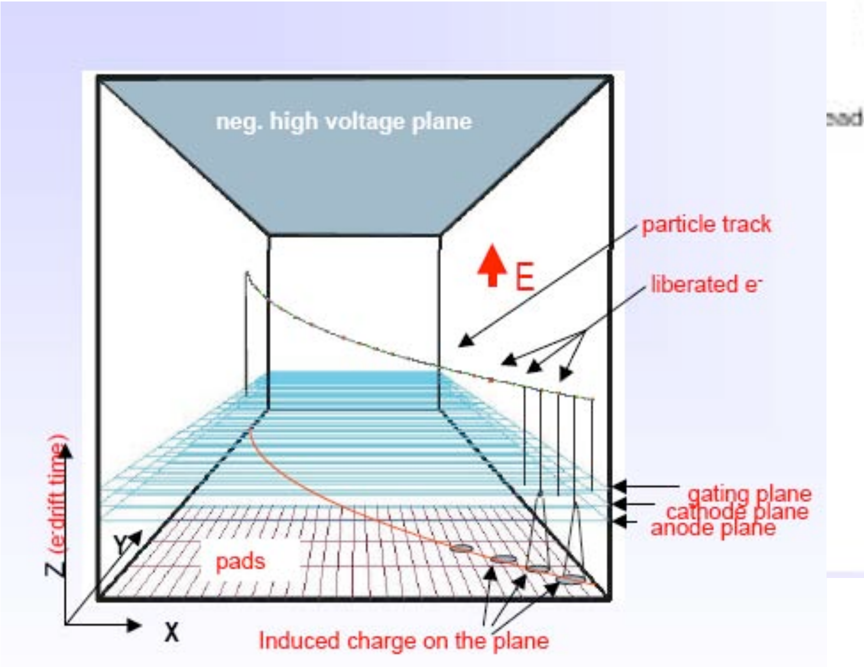
TPC (Time Proportional Chamber)

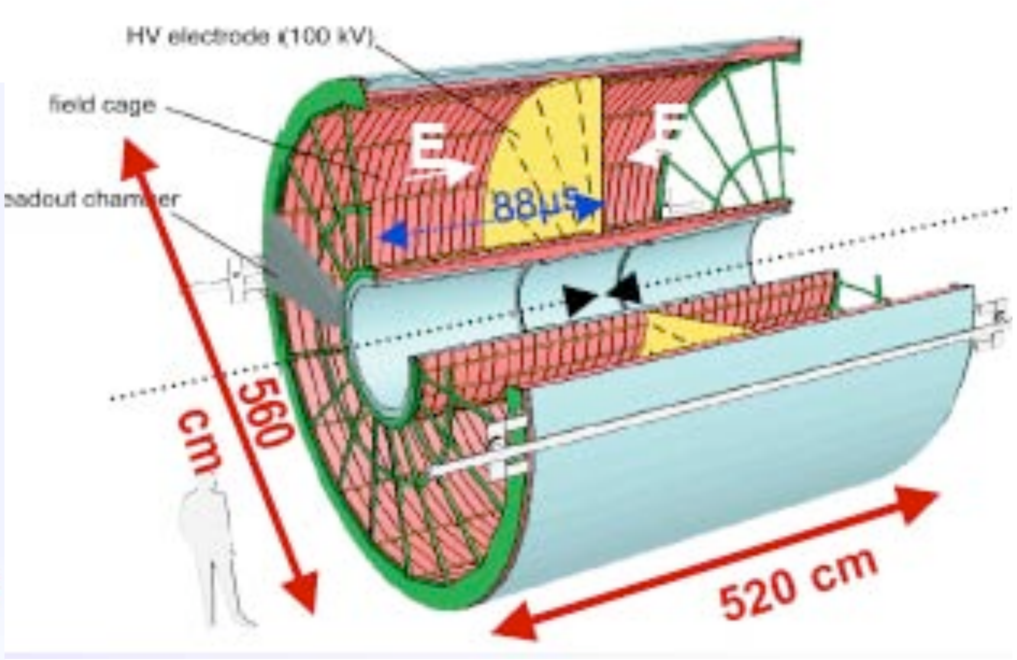




Time Projection Chamber – TPC

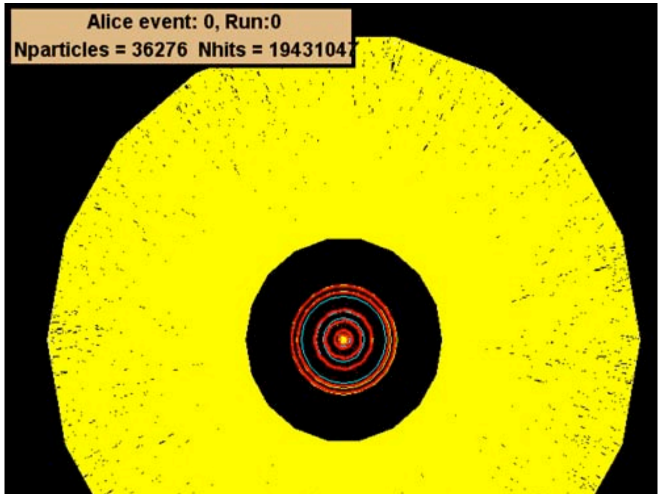
Conventional TPC optimized for extreme track densities





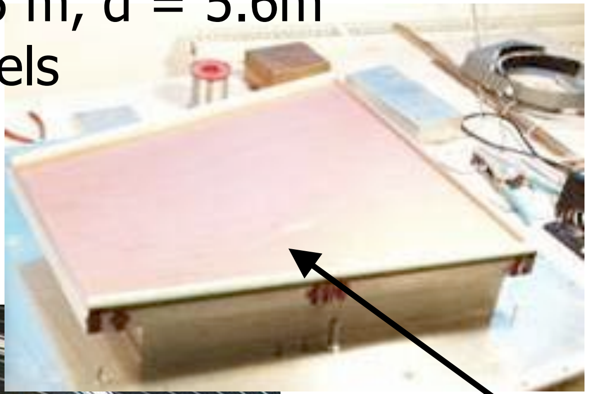
Space-Point resolution 0.8 (1.2) mm in xy,(z), occupancy from 40% to 15%

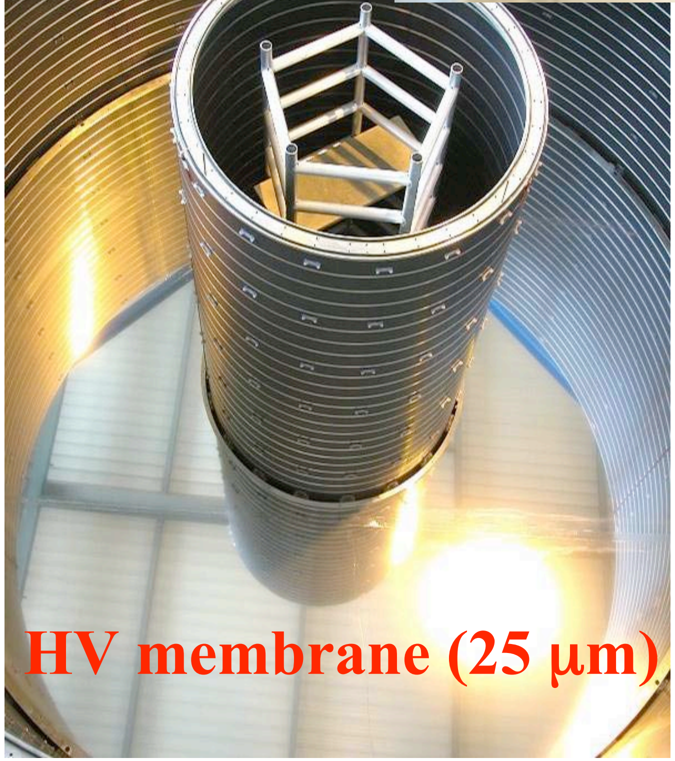
- Efficient (>90%) tracking in $\eta < 0.9$
- $\sigma(p)/p < 2.5\%$ up to 10 GeV/c
- Two-track resolution < 10 MeV/c
- p ID with dE/dx resolution < 10%



TPC

- ✓ 88 m^3, l = 5 m, d = 5.6m
  570 k channels

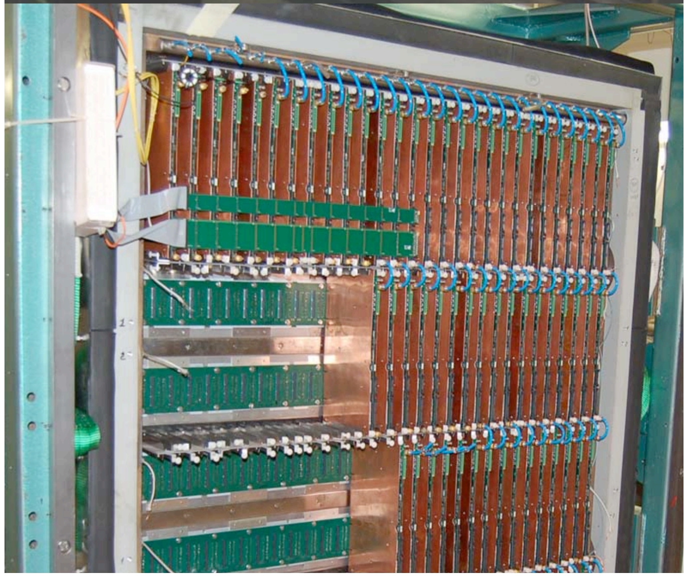




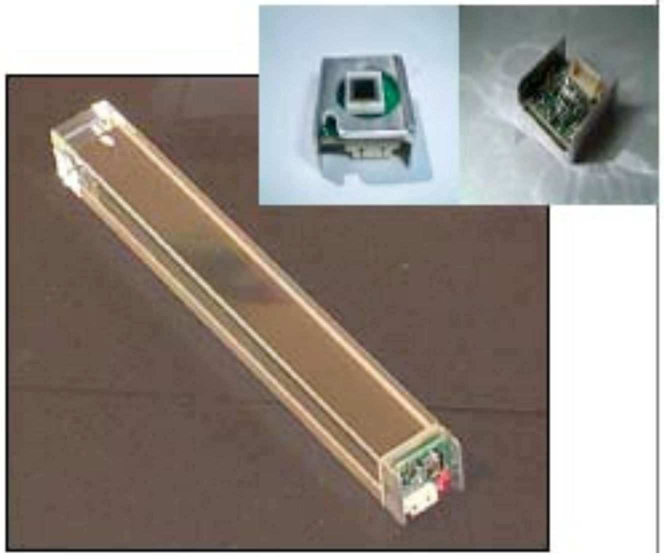
HV membrane (25 μm)

Field Cage

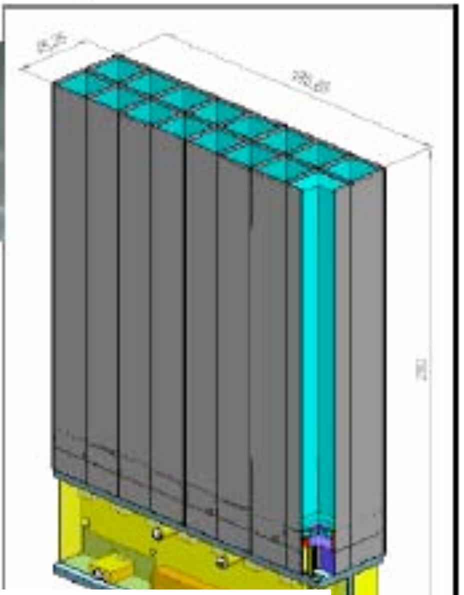
drift gas
Ne - CO_2 – N_2 (86/9/5)

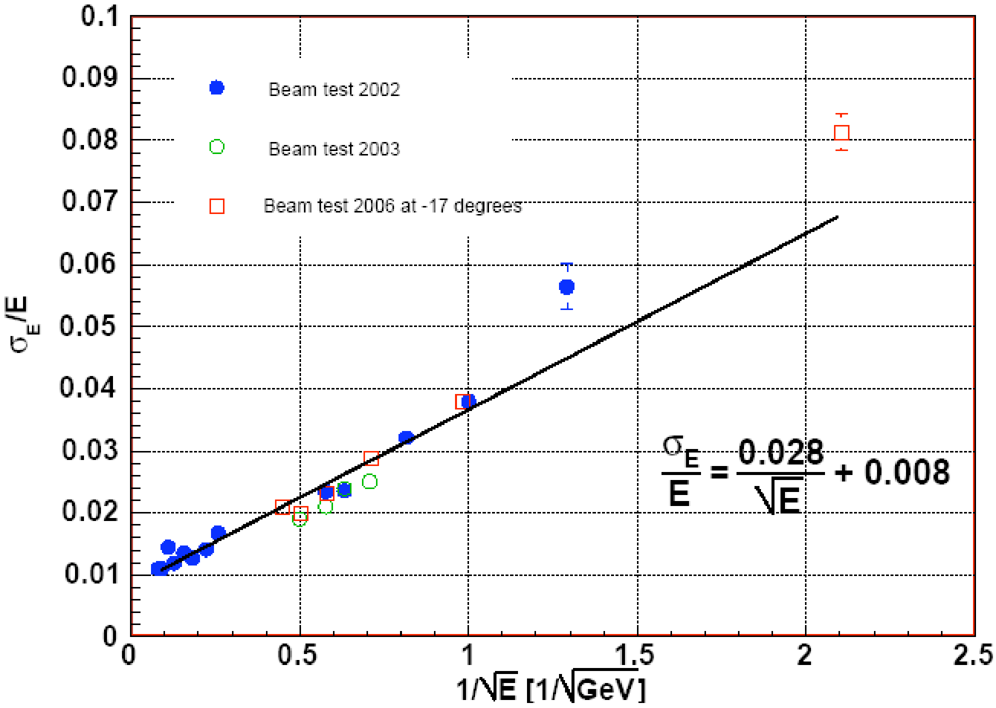


EM PbWO4 Calorimeter



Crystal detector unit

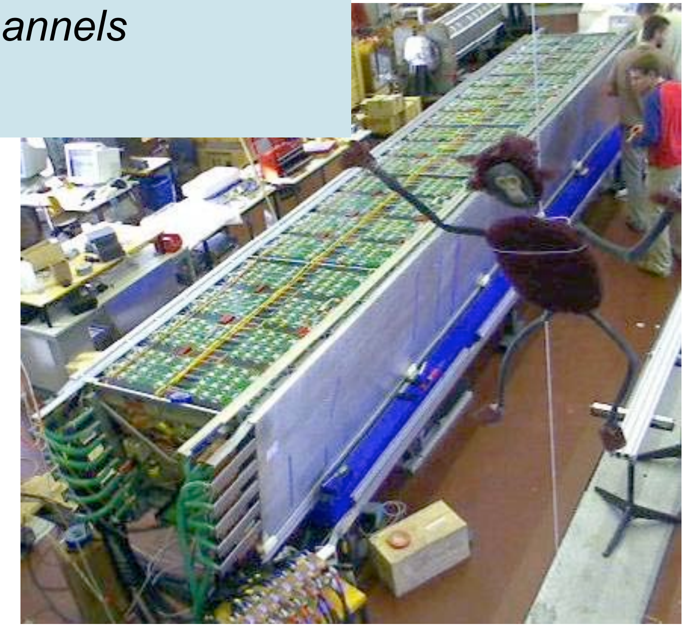


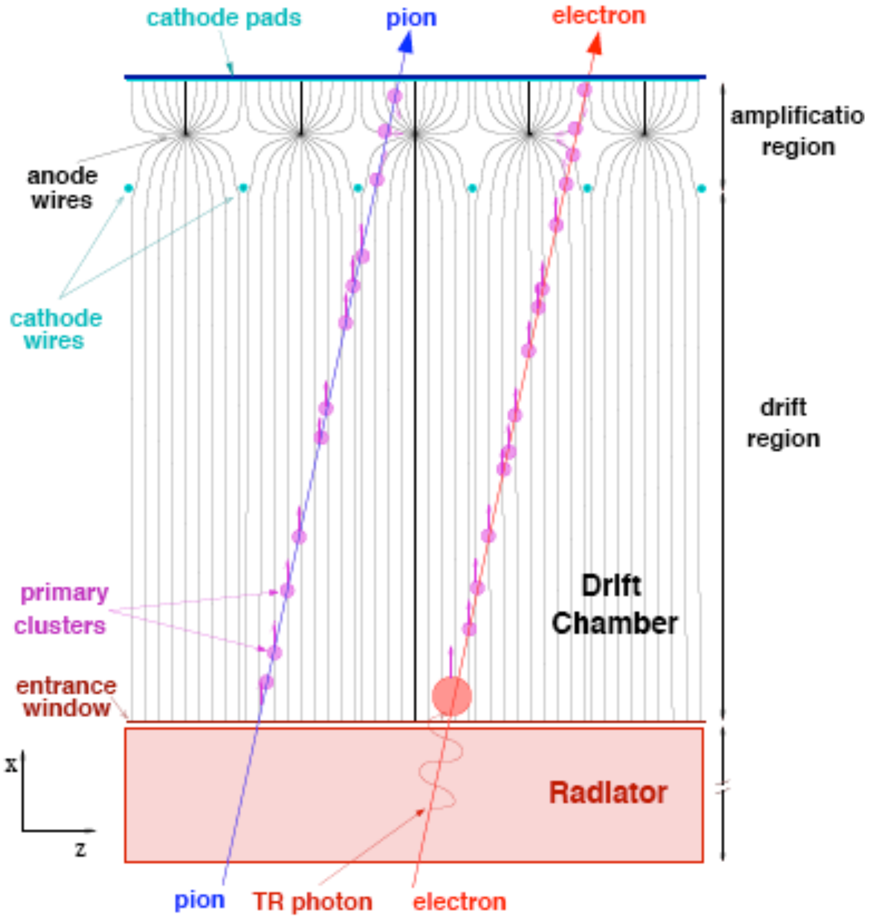


TRD (Transition Radiation Detector)

- ***Purpose:***
  - *Electron ID in the central barrel at $p > 1$ GeV/c*
  - *Fast (6 μs) trigger for high-p_t Particles ($p_t > 3$ GeV/c)*
- ***Parameters:***
  - *540 modules → 767 m^2 area*
  - *18 “supermodules”*
  - *6 layers, 5 longitudinal stacks*
  - *Length: 7 m*
  - *28 m^3 Xe/CO_2 (85:15)*
  - *1.2 M read out channels*

The TRD is directly located outside the TPC starting at a radius of 2.9 m and extending to 3.7 m. It covers a rapidity range between -0.9 to 0.9. The total radiation thickness is X/X0 = 15%

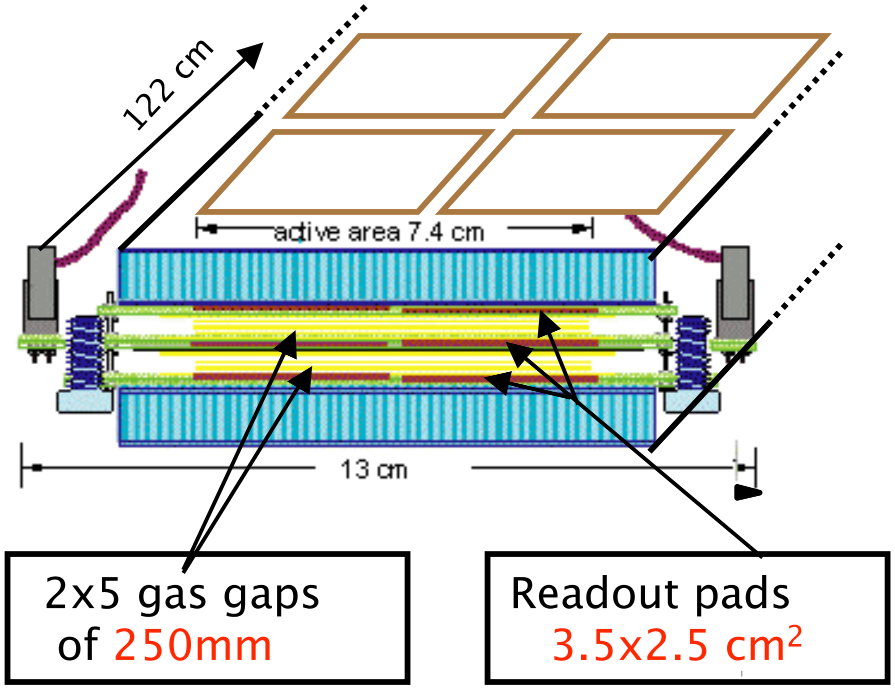




TOF (Time of Flight detector)

Large array at R ~ 3.7 m, covering | η| < 0.9 and full ϕ

- TOF basic element: double-stack **Multigap RPC** strip
- Occupancy < 15% (**O**(10^5) readout channels)



2x5 gas gaps of 250mm

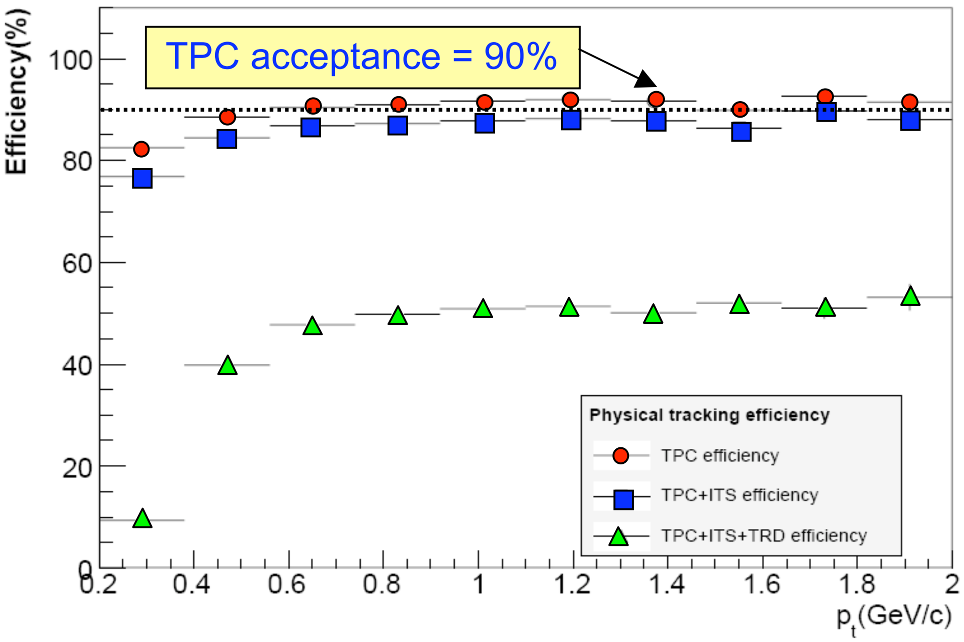
Readout pads 3.5x2.5 cm^2

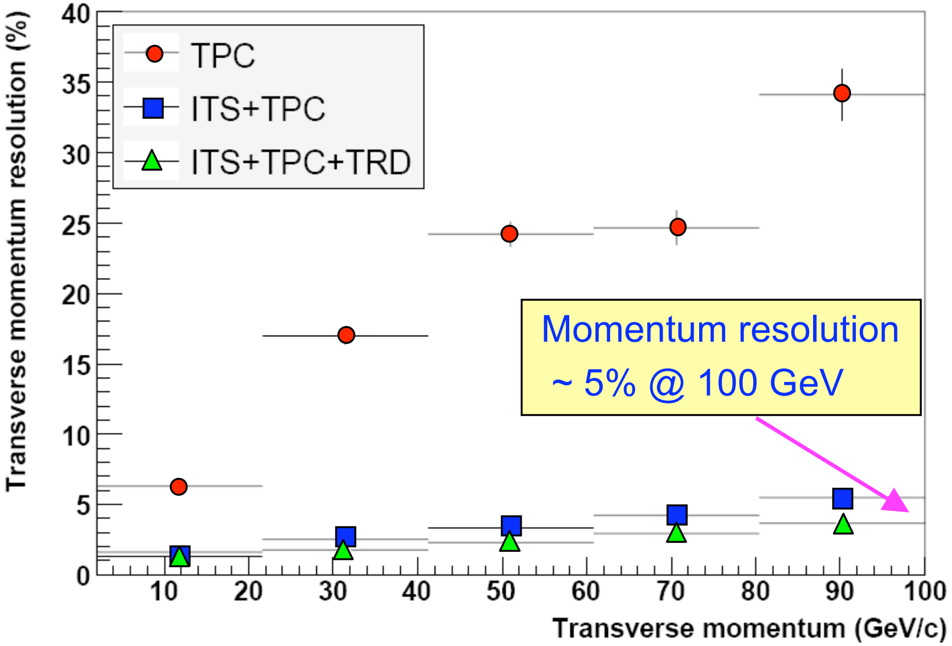
- Intrinsic Resolution ~ 40 ps
- Efficiency > 99%

ALICE central tracking

robust, redundant tracking from 100 MeV to 100 GeV

- ✓ modest soleniodal field (0.5 T) => easy pattern recognition
- ✓ long lever arm => good momentum resolution
- ✓ small material budget < 10% X_0 vertex -> end of TPC
- ✓ **Silicon Vertex Detector** (ITS) 4 cm < r < 44 cm
  stand-alone tracking at low p_t (**6 layers**, >6 m^2)
- ✓ **Time Projection Chamber** (TPC) 85 cm < r < 245 cm
- ✓ **Transition Radiation Detector** (TRD) 290 cm < 370 cm (6x3 cm tracks)


TPC acceptance = 90%


Momentum resolution ~ 5% @ 100 GeV

ALICE particle identification

stable hadrons (π, K, p): 100 MeV < p < 50 GeV

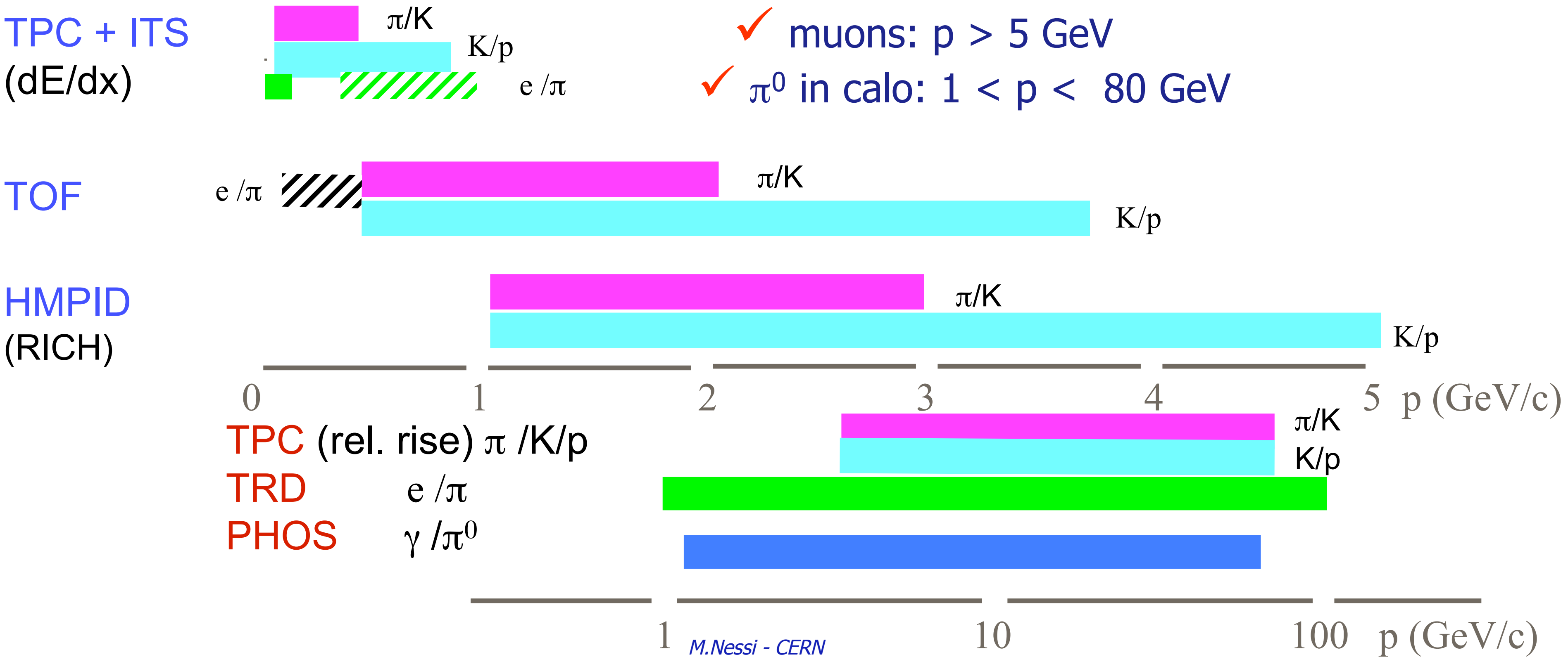
- ✓ dE/dx in silicon (ITS) and gas (TPC) + Time-of-Flight (TOF) + Cherenkov (RICH)
- ✓ dE/dx relativistic rise => extend PID to several 10 GeV

decay topology (K^0, K^+, K^-, Λ, D^+,…)

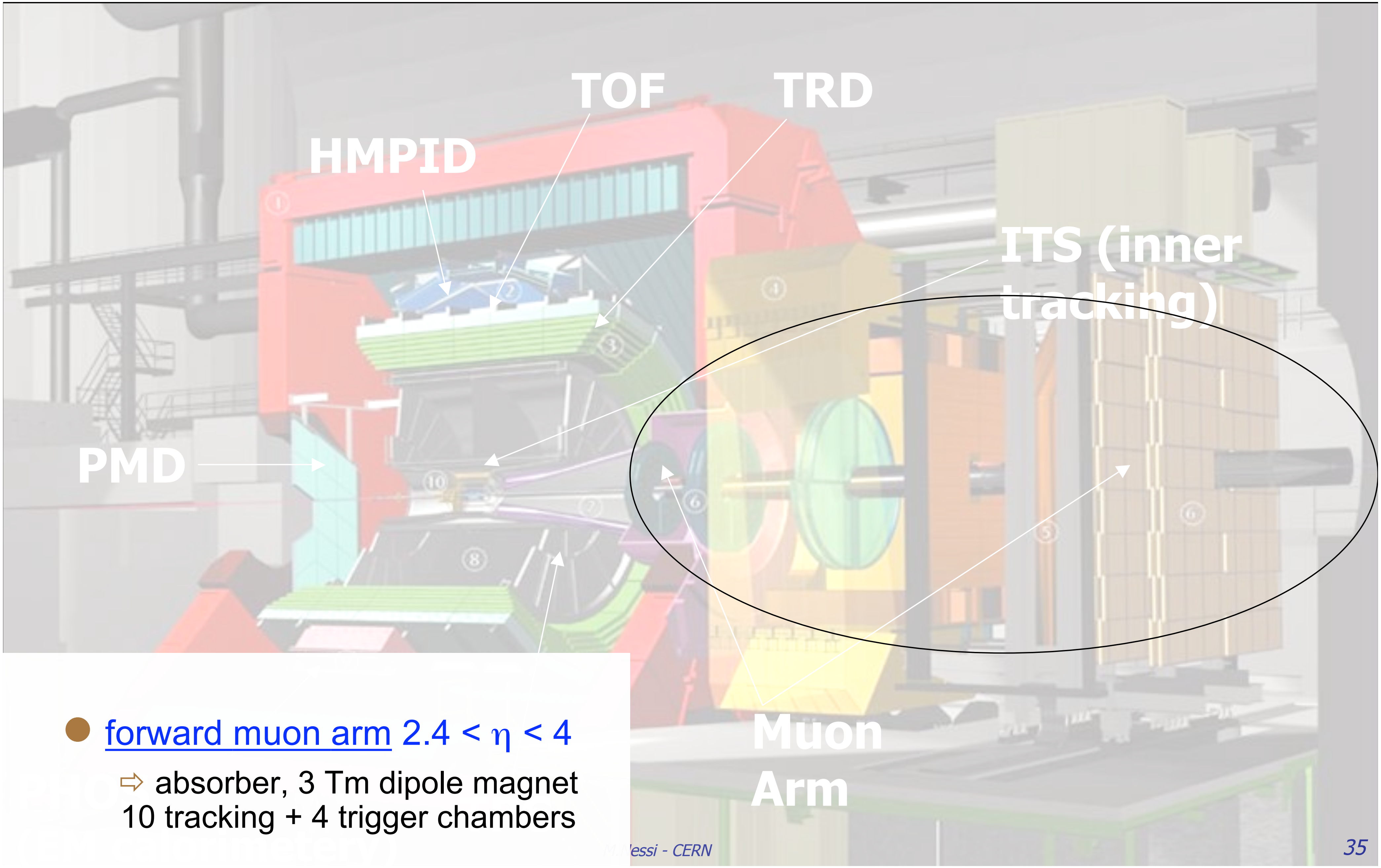
- ✓ K and Λ decays up to > 10 GeV

leptons (e, μ), photons, η,π^0

- ✓ electrons in TRD: p > 1 GeV
- ✓ muons: p > 5 GeV
- ✓ π^0 in calo: 1 < p < 80 GeV



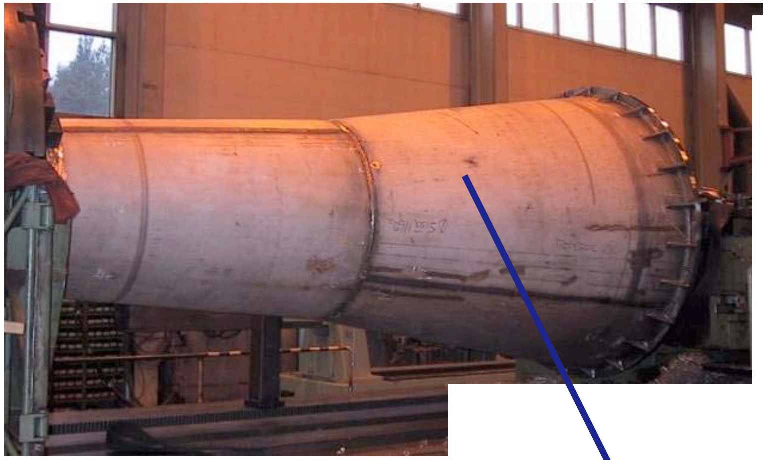
ALICE setup



- forward muon arm $2.4 < \eta < 4$
  - ⇨ absorber, 3 Tm dipole magnet
    10 tracking + 4 trigger chambers

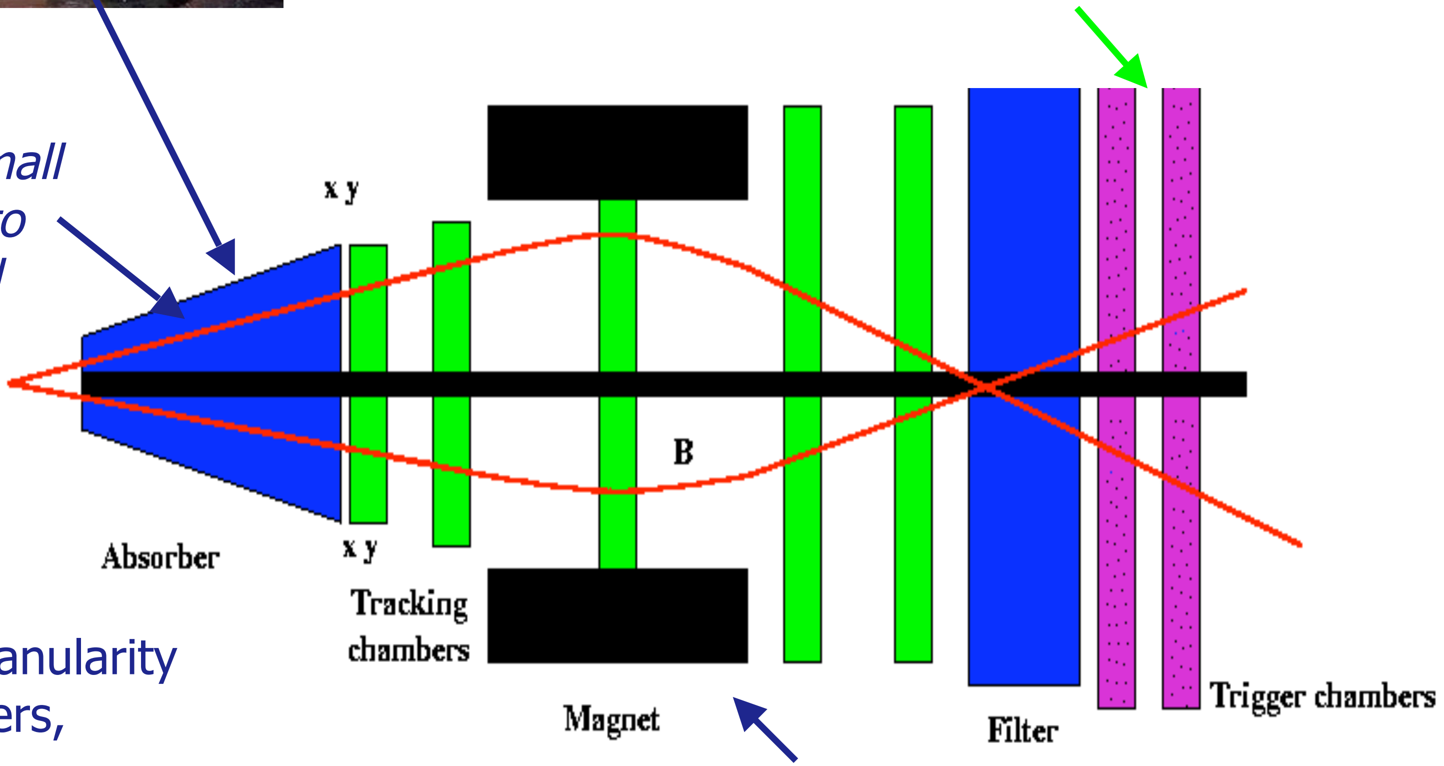
Dimuon Spectrometer

- ✓ To study the production of the **J/Ψ, Ψ', Υ, Υ', Υ''** decaying in 2 muons, $2.4 < \eta < 4$
- ✓ Resolution: 70 MeV for J/Ψ , 100 MeV for Υ



Complex absorber/small angle shield system to minimize background (90 cm from vertex)

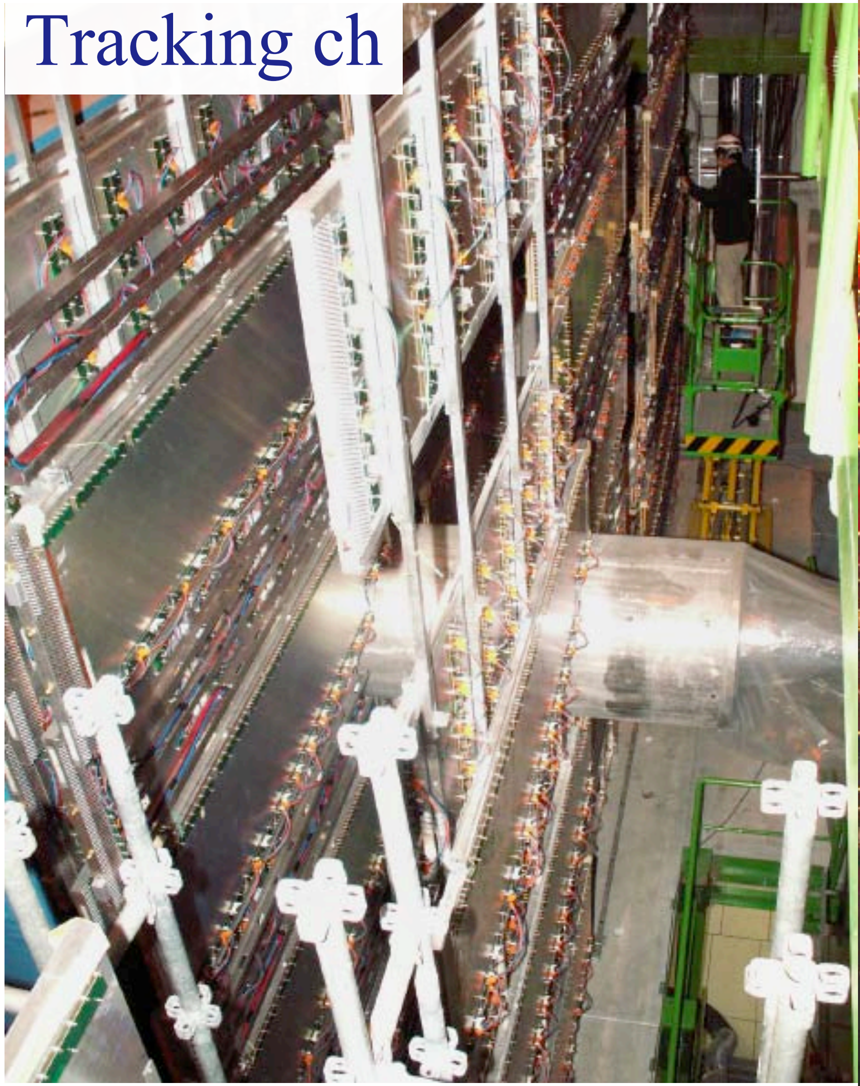
4 RPC Trigger Chambers

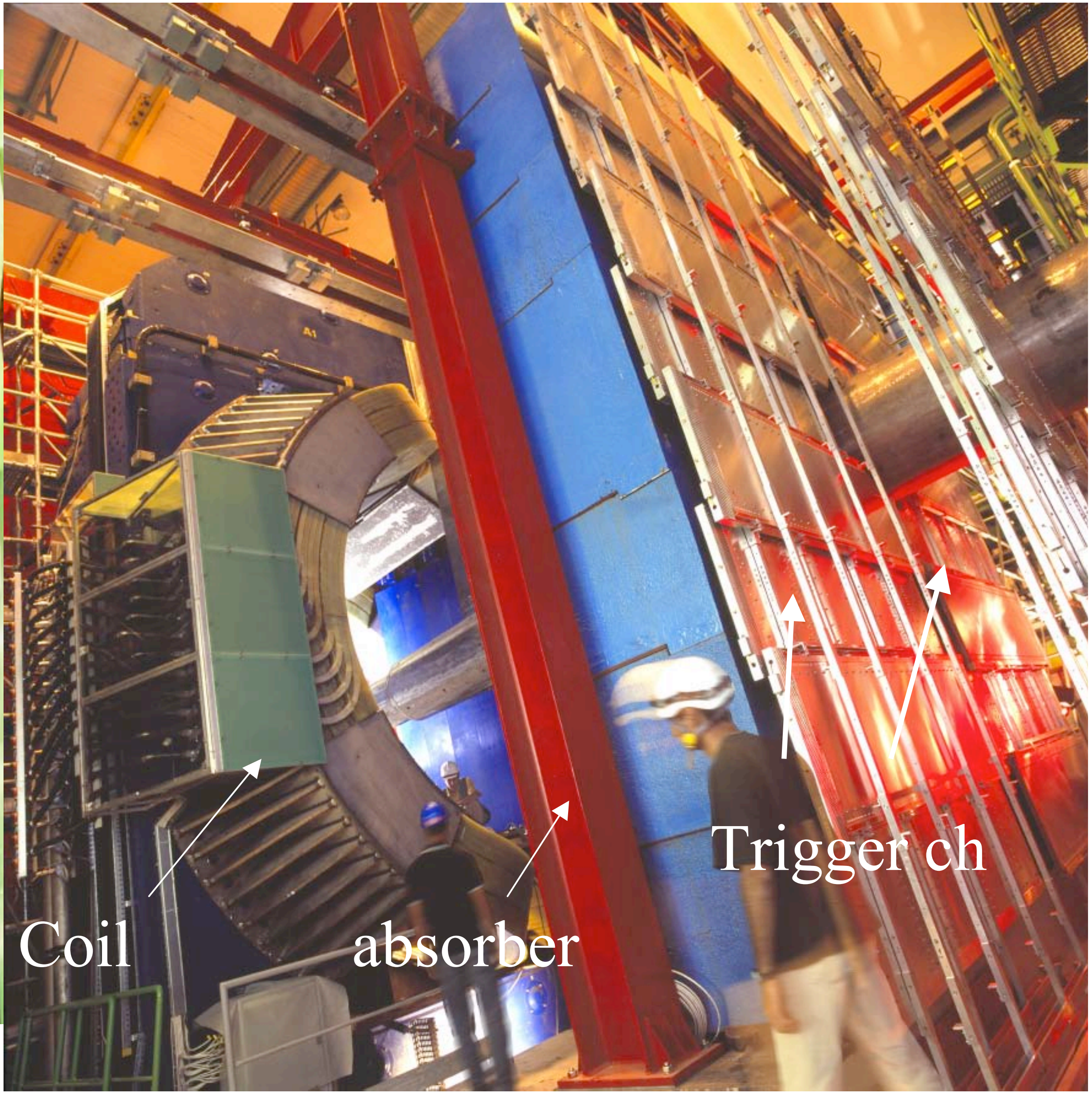


10 planes of high granularity pad tracking chambers, over 800k channels

Dipole Magnet: bending power 3Tm

Muon Spectrometer





How to measure luminosity ?

First …. Why ?

Cross sections for “Standard “ processes

- ✓ t-tbar production
- ✓ W/Z production
- ✓ …….

$$L = \frac{N}{\sigma}$$

Theoretically known to better than 10% ……will improve in the future

New physics manifesting in deviation of σ x BR relative the Standard Model predictions

Strategy:

1. *Measure the absolute luminosity with a precise method at optimum conditions*
2. *Calibrate luminosity monitor with this measurement, which can then be used at different conditions*

Goal: Measure $\mathcal{L}$ with $\lesssim$3% accuracy (long term goal)

How? Three major approaches

- ✓LHC Machine parameters
- ✓Rates of well-calculable processes:e.g. QED (like LEP), EW and QCD
- ✓Elastic scattering

- ✓*Optical theorem: forward elastic rate + total inelastic rate:*
- ✓*Luminosity from Coulomb Scattering*
- ✓*Hybrids*
  - ✓*Use σ_{tot} measured by others*
  - ✓*Combine machine luminosity with optical theorem*

Luminosity from machine parameters

Luminosity depends exclusively on beam parameters:

$$\mathcal{L} = \frac{N^2 f_{\text{rev}} n_b}{4\pi\sigma^{*2}}$$

Depends on f_{rev} revolution frequency, n_b number of bunches
N number of particles/bunch
σ beam size or rather overlap integral at IP*

$$\sqrt{1+\left(\frac{\theta_c\sigma_z}{2\sigma^*}\right)^2}$$

The luminosity is reduced if there is a crossing angle (300 µrad)
1 % for $\beta^* = 11$ m and 20% for $\beta^* = 0.5$ m

Luminosity accuracy limited by

✓extrapolation of σ_x, σ_y (or ε, β_x^*, β_y^*) from meas. of beam profiles elsewhere to IP; knowledge of optics, …
✓Precision in the measurement of the the bunch current (parasitic particles)
✓beam-beam effects at IP, effect of crossing angle at IP, …

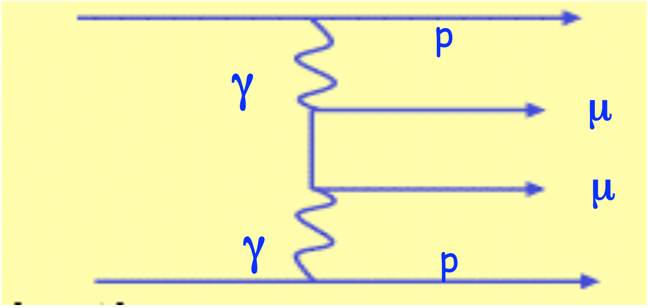
Calibration runs : i.e calibrate the relative beam monitors of the experiments during dedicated calibration runs with simplified LHC conditions

✓Reduced intensity
✓Fewer bunches
✓No crossing angle
✓Larger beam size
✓….

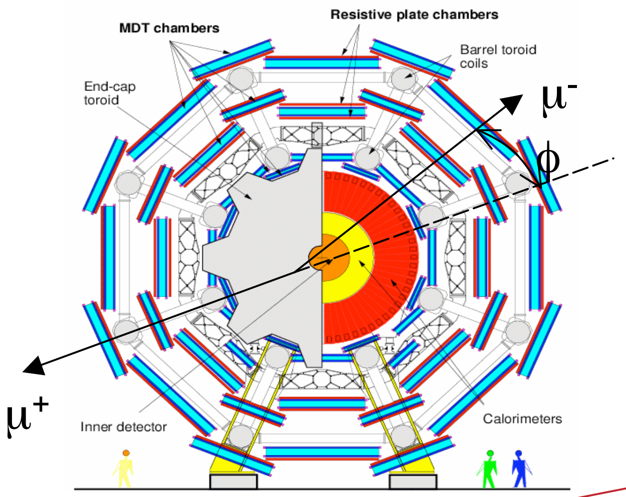
Better than ~5 % precision might be in reach (it will take some time !)

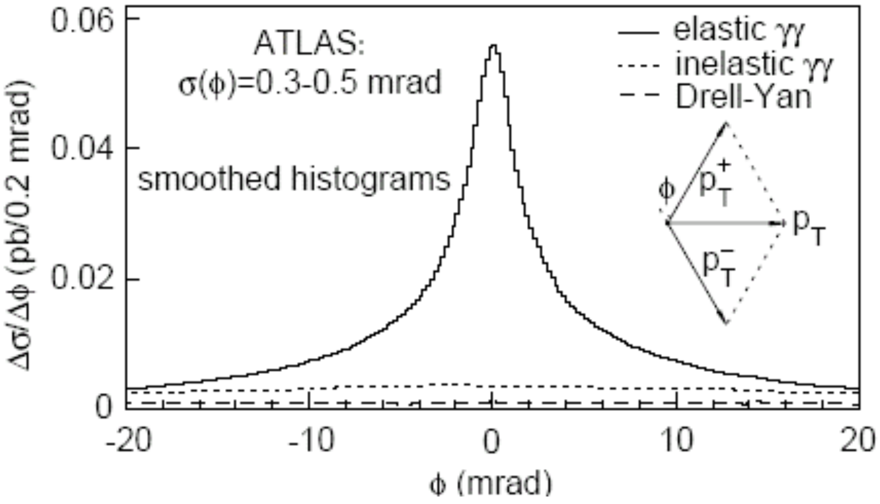
Luminosity from well know physics channels (1)

Two photon production of muon pairs-QED



- Pure QED
- Theoretically well understood
- No strong interaction involving the muons
- Proton-proton re-scattering can be controlled
- Cross section known to < 1 %



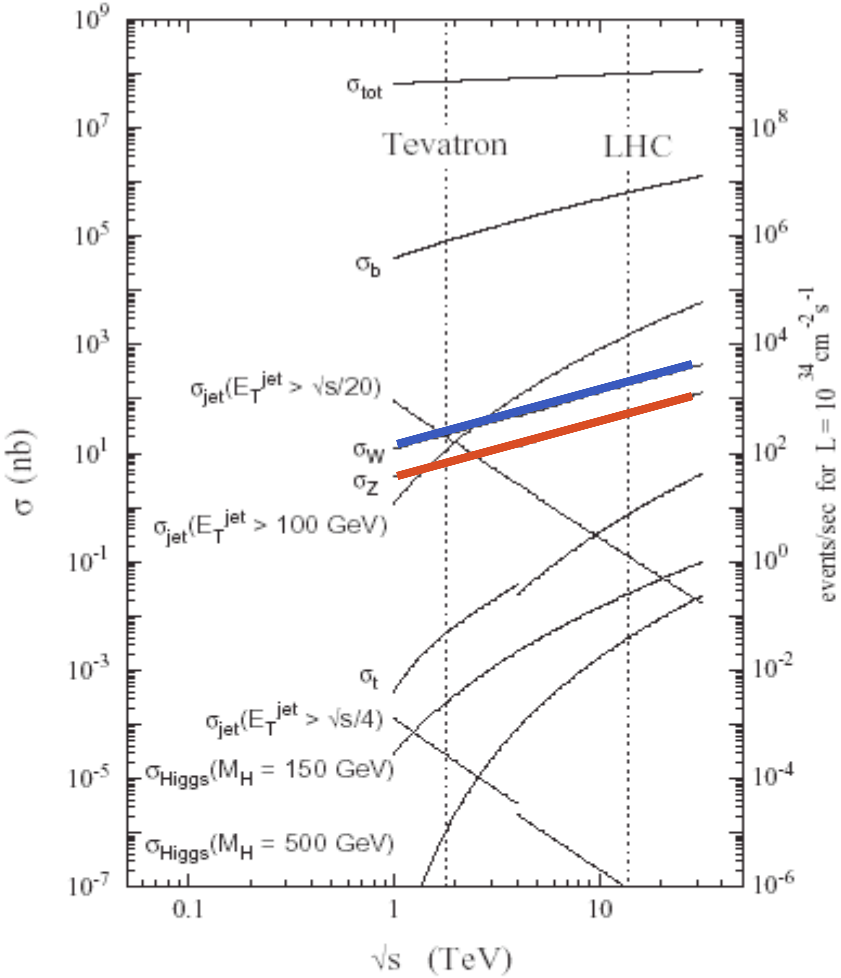


- μ P_T equal, $\eta < 2.5$
- μ almost back to back
- No other charged tracks

$\sigma \sim 1$ pb, 1.5 years of running at $L=10^{33}$ for 1% statistics

Luminosity from well know physics channels (2)

W, Z counting



- Clean signature via leptonic decays
- σ_{th} is the convolution of the Parton Distribution Functions (PDF) and of the partonic cross section
- The uncertainty of the partonic cross section is available to NNLO in differential form with estimated scale uncertainty below 1 % (PRD 69, 94008.)
- PDF's more controversial and complex (today 8%)
- Aiming at a final precision 3-5 % after several years
- Requires perfect knowledge of the detector

$$\mathcal{L} = (N - BG)/ (\varepsilon \times A_W \times \sigma_{th})$$

$\mathcal{L}$ is the integrated luminosity

N is the number of candidates

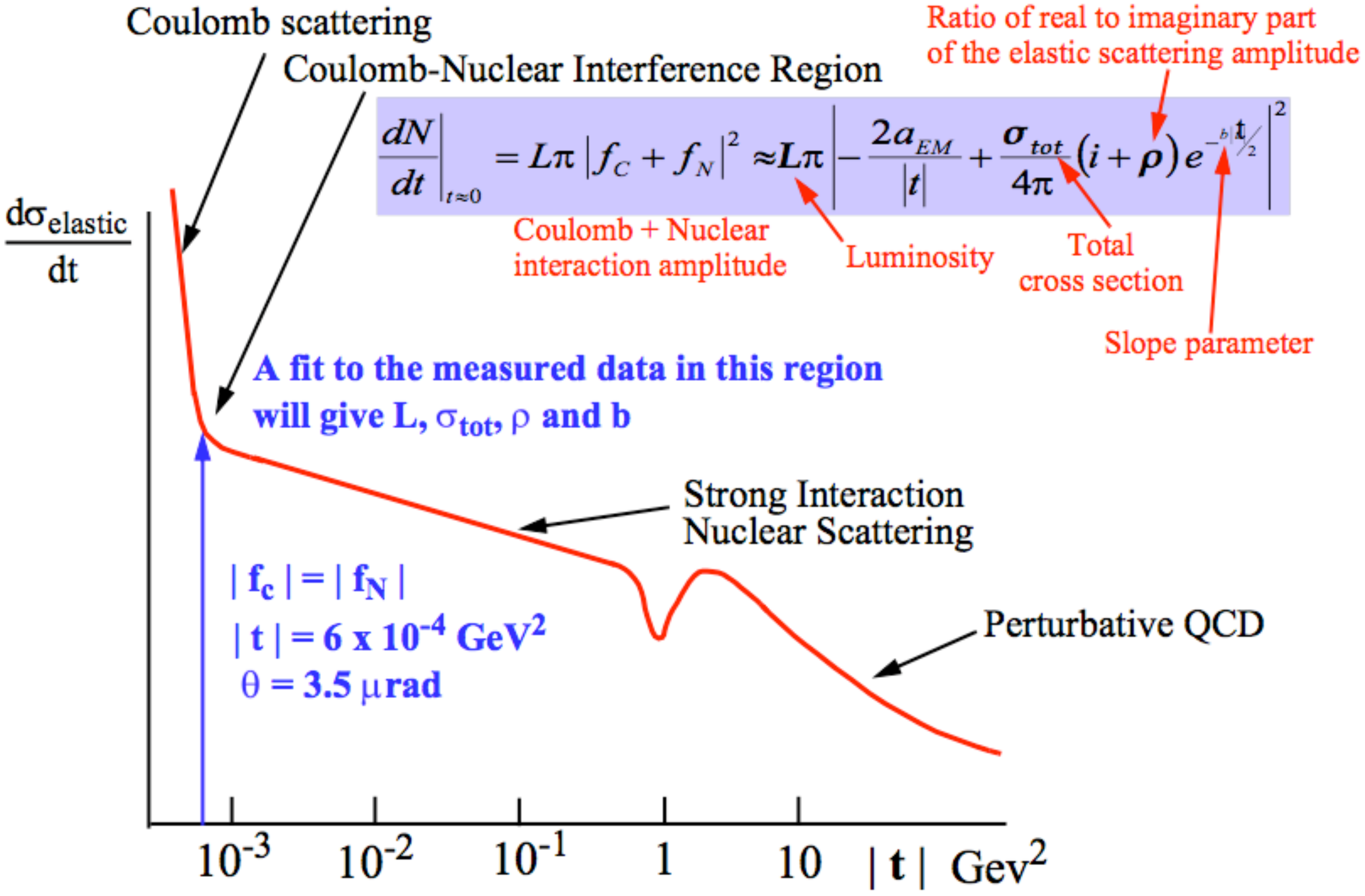
BG is the number of background events

ε is the efficiency for detecting W,Z decay products

$A_{W,Z}$ is the acceptance

σ_{th} is the theoretical inclusive cross section

ATLAS ALFA approach



$$\left.\frac{dN}{dt}\right|_{t\approx 0} = L\pi \left|f_C + f_N\right|^2 \approx L\pi \left| -\frac{2\alpha_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-b|t|/2}\right|^2$$

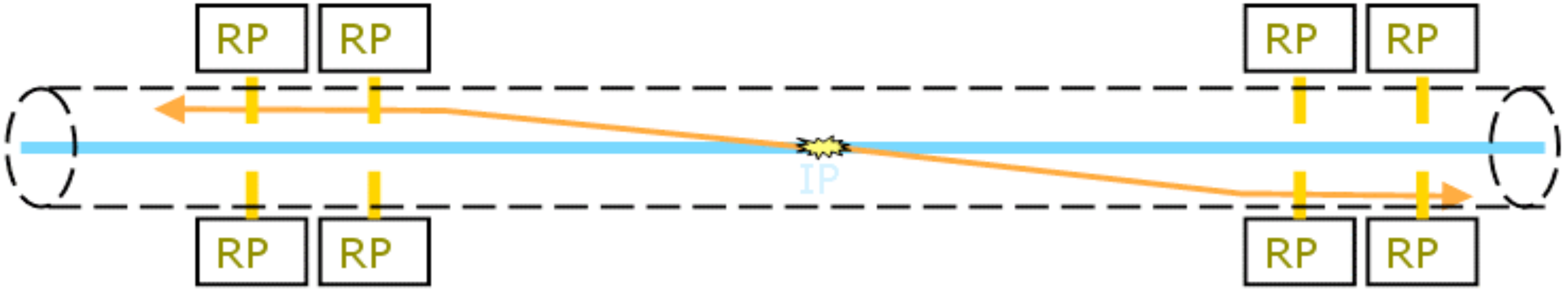
A fit to the measured data in this region will give L, σ_{tot}, ρ and b

$|f_c| = |f_N|$

$|t| = 6 \times 10^{-4}$ GeV^2

$\theta = 3.5\ \mu$rad

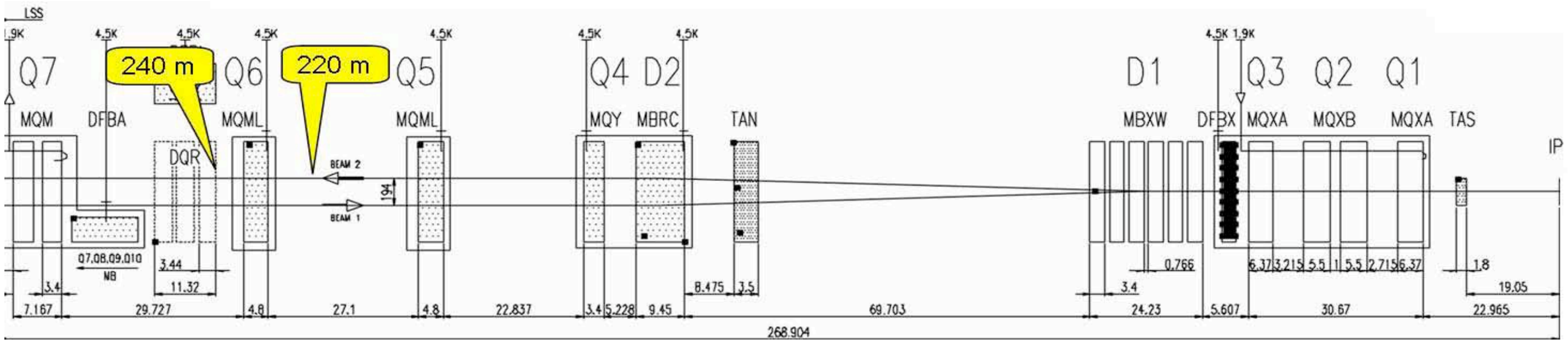
Elastic scattering at very small angles (ATLAS ALFA)



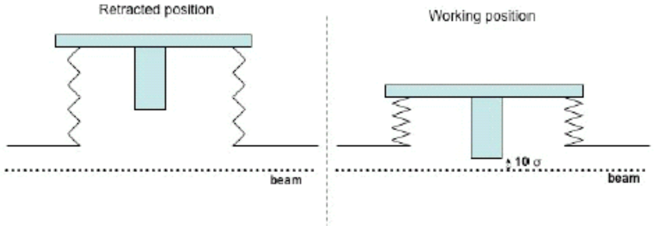
- ✓ Measure elastic scattering at such small t-values that the cross section becomes sensitive to the Coulomb amplitude
- ✓ Effectively a normalization of the luminosity to the exactly calculable Coulomb amplitude
- ✓ No total rate measurement and thus no additional detectors near IP necessary
- ✓ UA4 used this method to determine the luminosity to 2-3 % at the SPS

Need to measure extremely small angles using detectors in "Roman pots" far away from the IP (~220m)

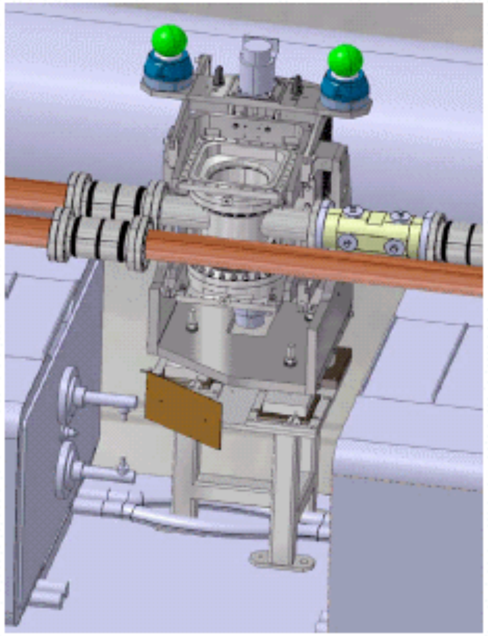
Coulomb amplitude » Strong amplitude for $-t < 0.00065\,\mathrm{GeV}^2$,this corresponds to 3.5 mrad

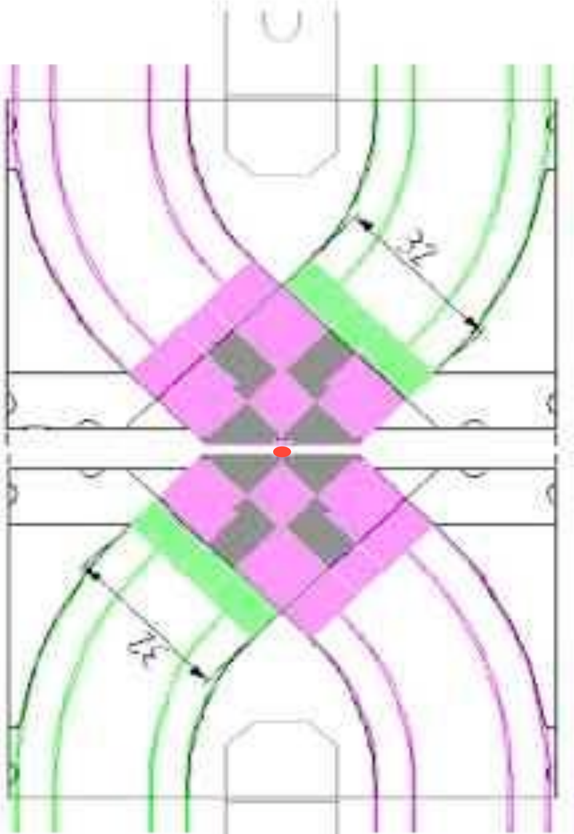


ATLAS ALFA detector



The Roman Pot Unit



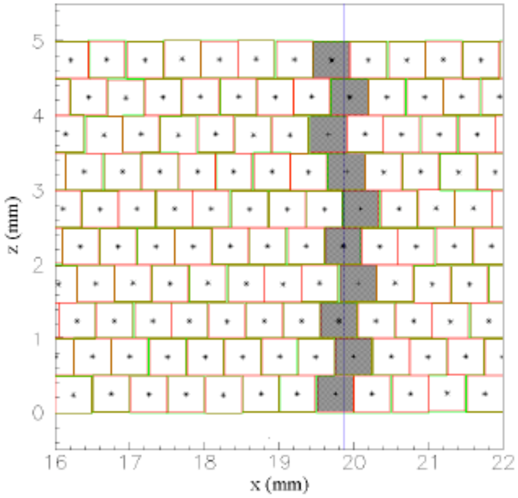


- scintillating fibres
- 0.5 mm^2 square

planes are horizontally staggered by multiples of 70.7 microme

- The active area has to be very close to the beam (~1.5 mm)
- The detector has to be far away from the interaction point (240m)
- The dead space at the edge of the detector has to be small (< 100 μm)
- The detector resolution has to be about 30 μm
- The times resolution has to be about 1 ns.

10 layers of square 0.5 x 0.5 mm scintillating fibers



TOTEM

The optical theorem relates the total cross section to the forward elastic rate

$$\sigma_{tot} = 4\pi \, \mathrm{Im} \; f_{el}(0) \longrightarrow \boxed{L = \frac{1+\rho^2}{16\pi} \frac{N_{tot}^{\;2}}{\left.\frac{dN_{el}}{dt}\right|_{t=0}}}$$

- ✓ Extrapolate the elastic cross section to t=0
- ✓ Measure the total rate
- ✓ Use best estimate of ρ ($\rho \sim 0.13 \pm 0.02$ ⇨ 0.5 % in $\Delta L/L$)

- $\left. dN_{el}/dt \right|_{t=0}$ requires small $-t \sim 0.01$ GeV^2
  - ⇨ $\theta \sim 15$ μrad (nominal divergence is 32 μrad)
  - ⇨ beam with smaller divergence
  - ⇨ large $\beta^* \sim 1000$ m (divergence $\propto 1/\sqrt{\beta^*}$)

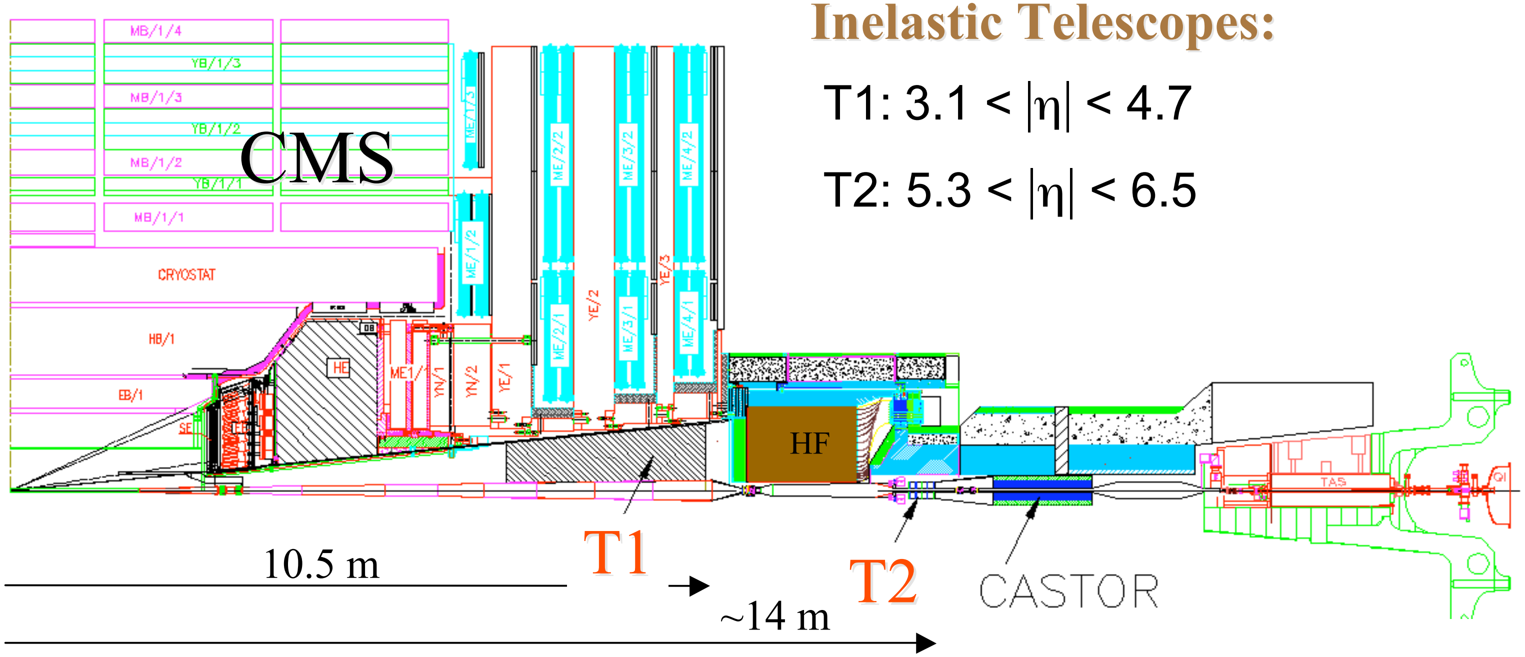
- Zero crossing angle ⇨ fewer bunches
  - ⇨ Special run at low luminosity

TOTEM detectors

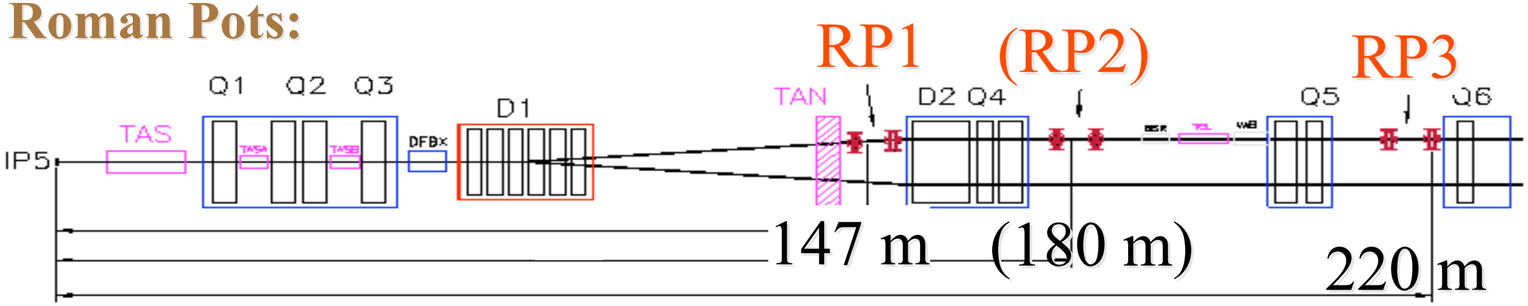
Inelastic Telescopes:

T1: $3.1 < |\eta| < 4.7$

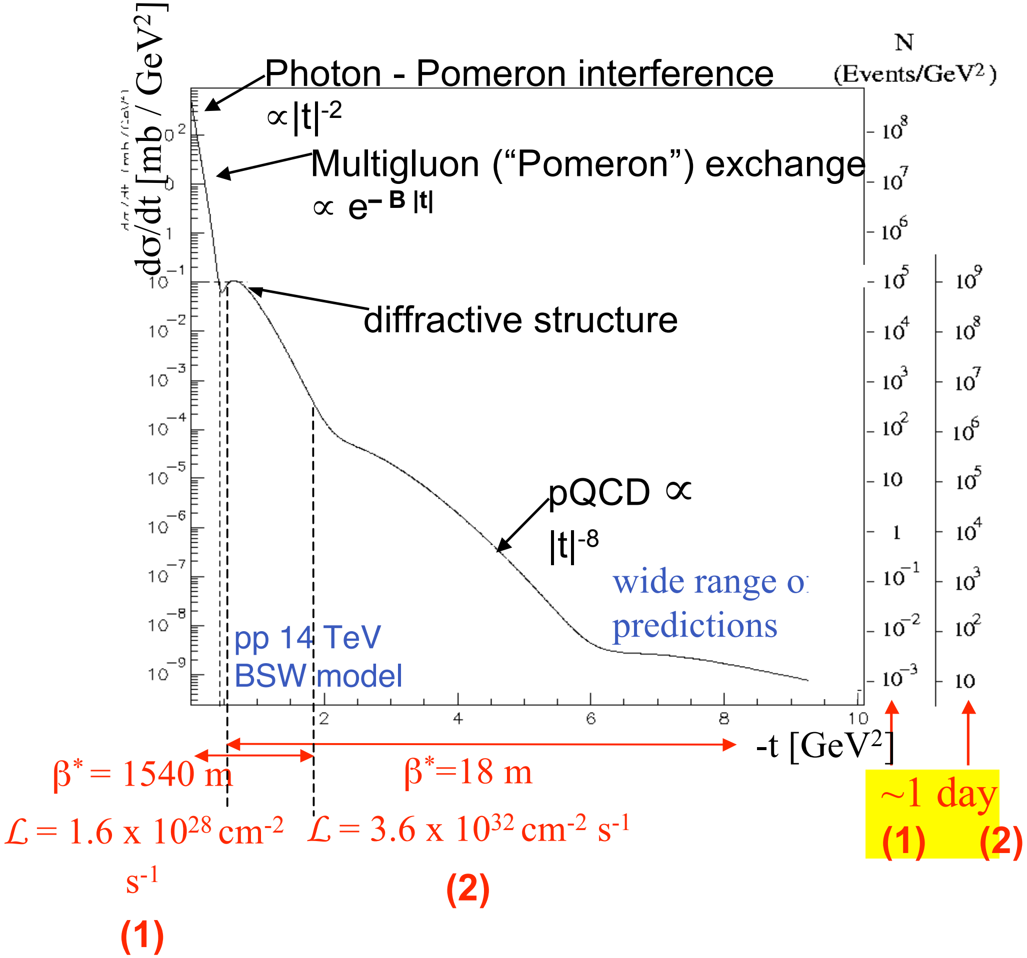
T2: $5.3 < |\eta| < 6.5$

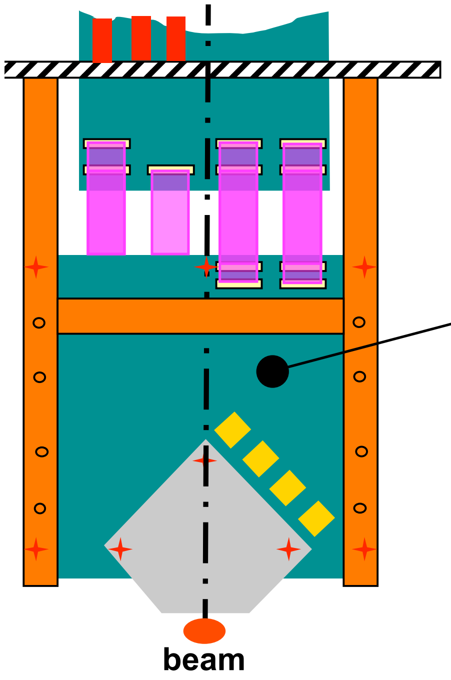


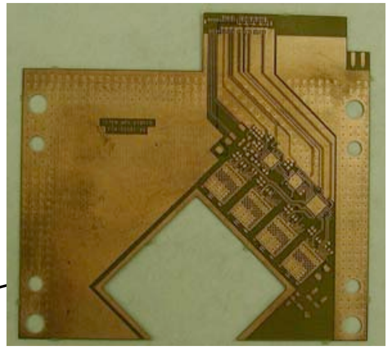
Roman Pots:



TOTEM Roman Pots

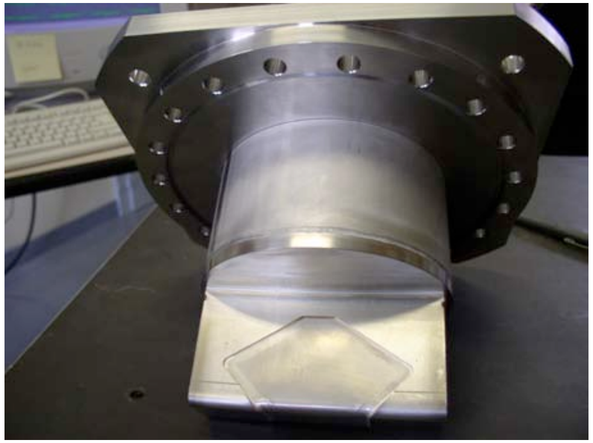






TOTEM APV hybrid

Edgeless Silicon strip detectors



- Measurement of dσ/dt in a wide range of t:
  10^{-3} GeV² < –t < 8 GeV²

- Special beam optics designed
- High statistics in a few days of running (<1%)

LHC computing effort ?

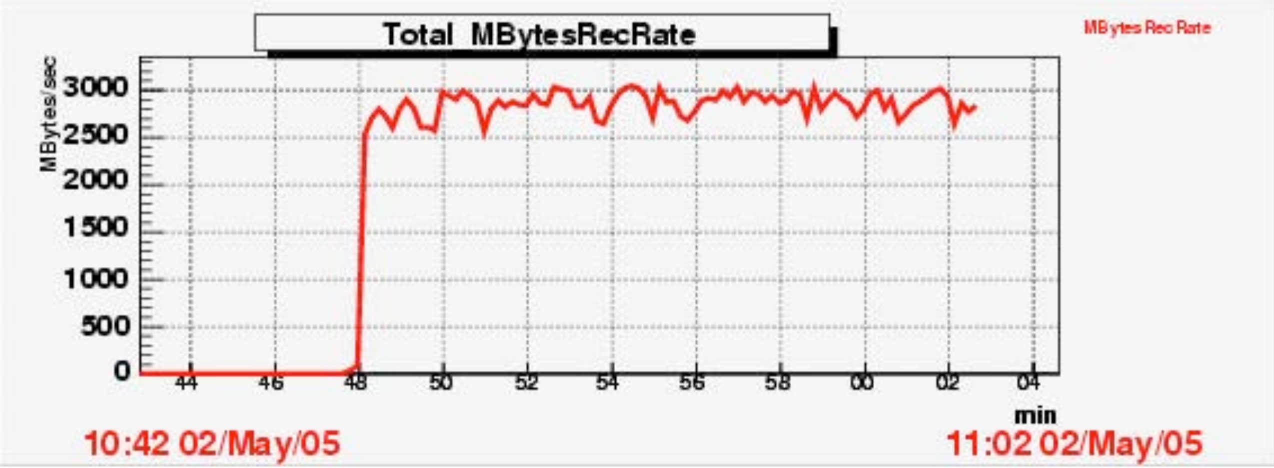
The offline Data Processing (GRID project)

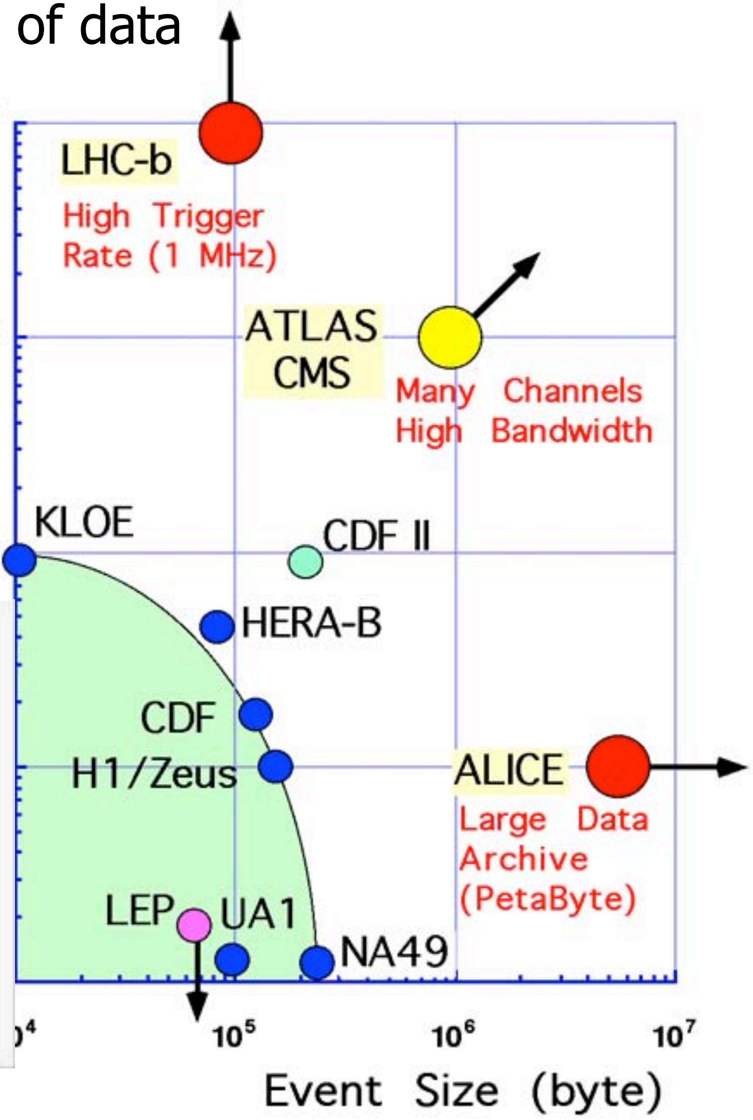
- ✓ The amount of data produce by the 4 experiments will just be enormous, no single computer center can handle such amount of data

- ✓ Online: storing up to > 1 Gbyte/s per experiment

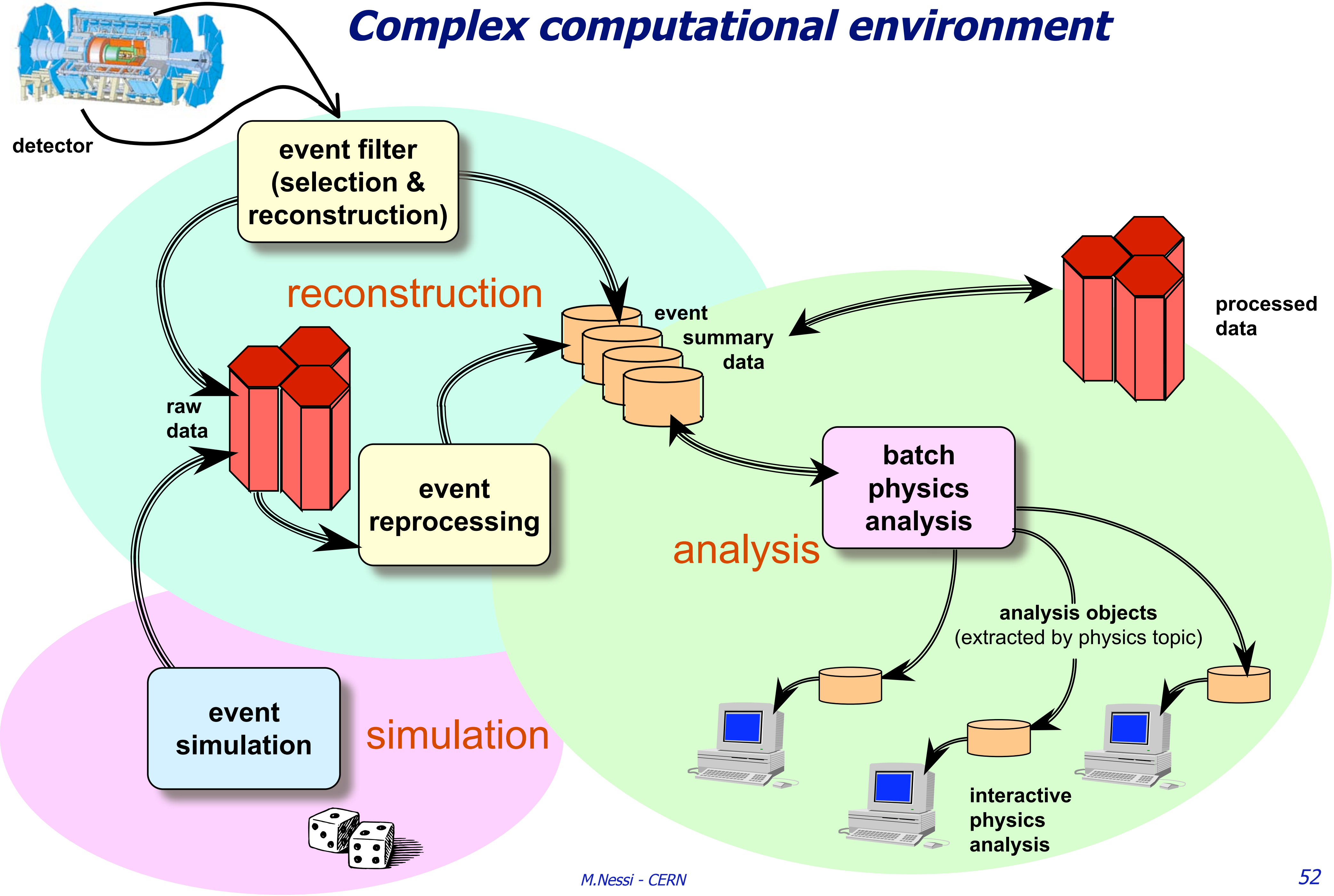
  --> *> 2 Pbyte/year/exp raw data*

Example ALICE event building (achieved)





Complex computational environment



detector

event filter (selection & reconstruction)

reconstruction

event summary data

processed data

raw data

event reprocessing

batch physics analysis

analysis

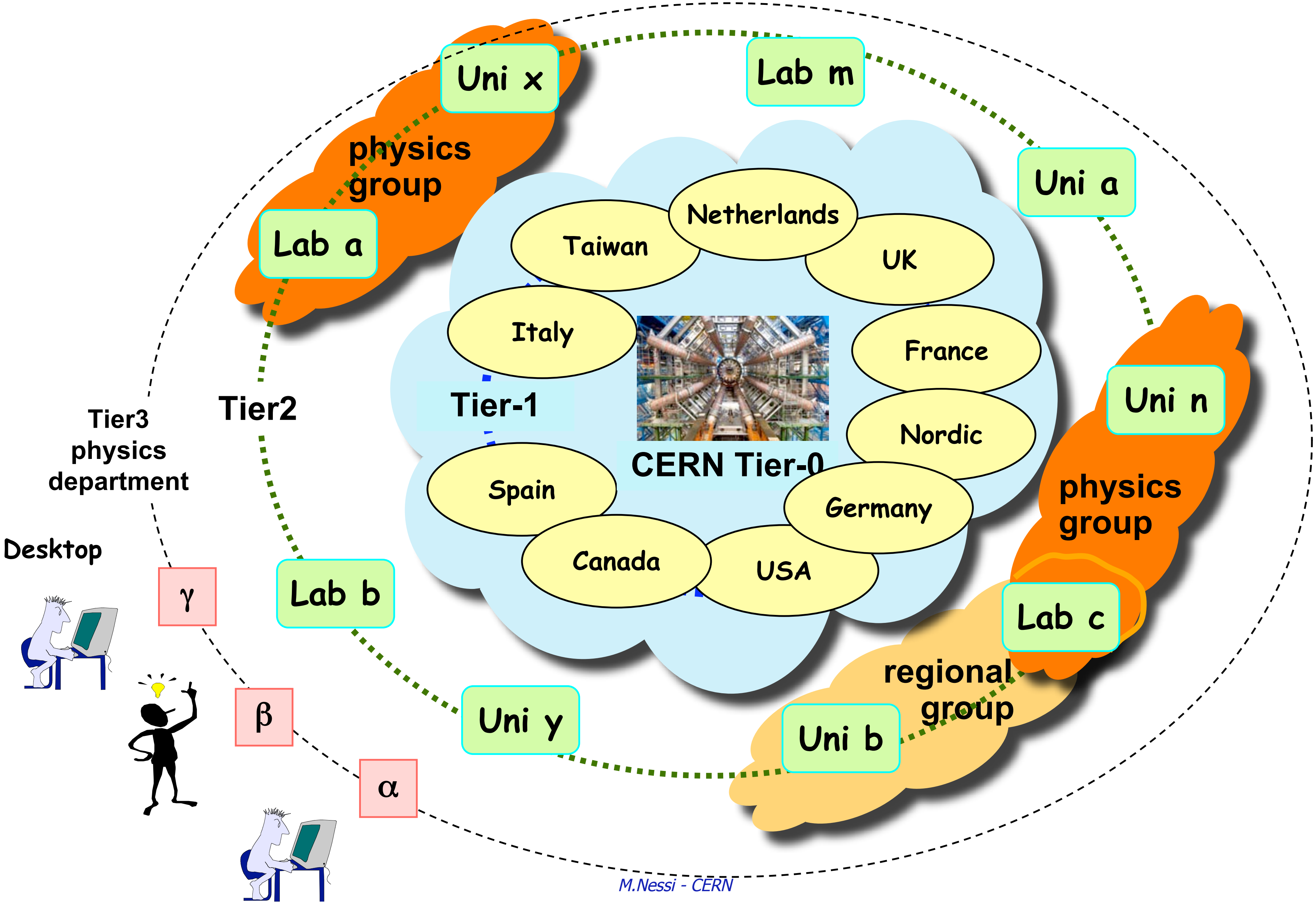
analysis objects (extracted by physics topic)

event simulation

simulation

interactive physics analysis

The GRID (ATLAS example)



Uni x

Lab m

physics group

Lab a

Uni a

Netherlands

Taiwan

UK

Italy

France

Tier-1

Nordic

CERN Tier-0

Spain

Germany

Canada

USA

Uni n

physics group

Tier2

Tier3 physics department

Desktop

γ

β

α

Lab b

Lab c

regional group

Uni y

Uni b

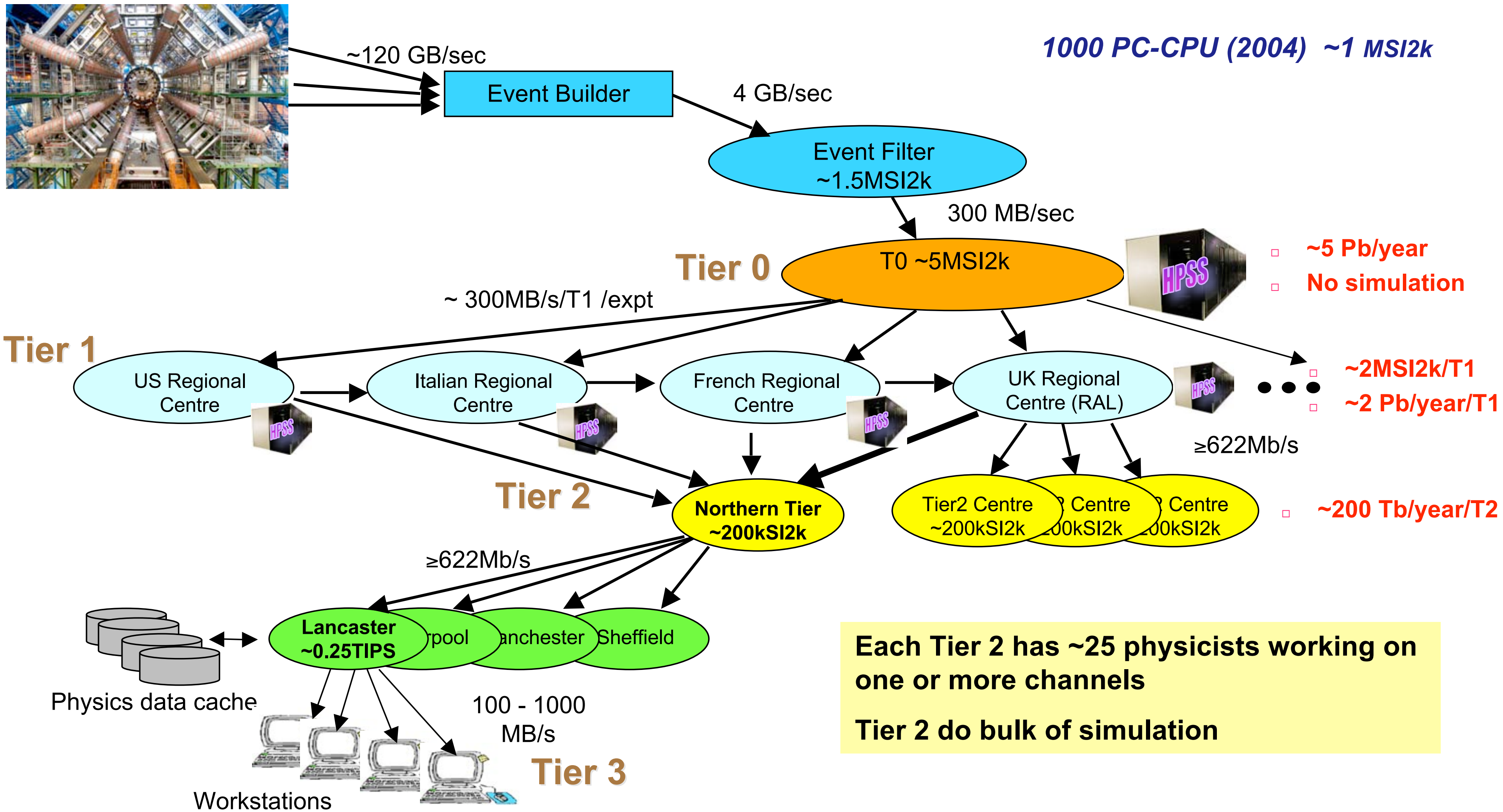
The GRID : how it works

*The **World Wide Web** provides seamless access to information that is stored in many millions of different geographical locations*

*The **Grid** is an infrastructure that provides seamless access to computing power and data storage capacity distributed over the globe*

- ✓ It relies on special software, called **middleware**
- ✓ Middleware automatically finds the **data** the scientist needs, and the **computing power** to analyse it
- ✓ Middleware balances the load on different resources. It also handles **security, accounting, monitoring** and much more

ATLAS computing model



1000 PC-CPU (2004) ~1 MSI2k

~120 GB/sec

Event Builder

4 GB/sec

Event Filter
~1.5MSI2k

300 MB/sec

Tier 0

T0 ~5MSI2k

HPSS

- ~5 Pb/year
- No simulation

~ 300MB/s/T1 /expt

Tier 1

US Regional Centre

Italian Regional Centre

French Regional Centre

UK Regional Centre (RAL)

• • •

- ~2MSI2k/T1
- ~2 Pb/year/T1

≥622Mb/s

Tier 2

Northern Tier
~200kSI2k

Tier2 Centre
~200kSI2k

Centre
00kSI2k

Centre
00kSI2k

- ~200 Tb/year/T2

≥622Mb/s

Lancaster
~0.25TIPS

rpool

anchester

Sheffield

Physics data cache

100 - 1000 MB/s

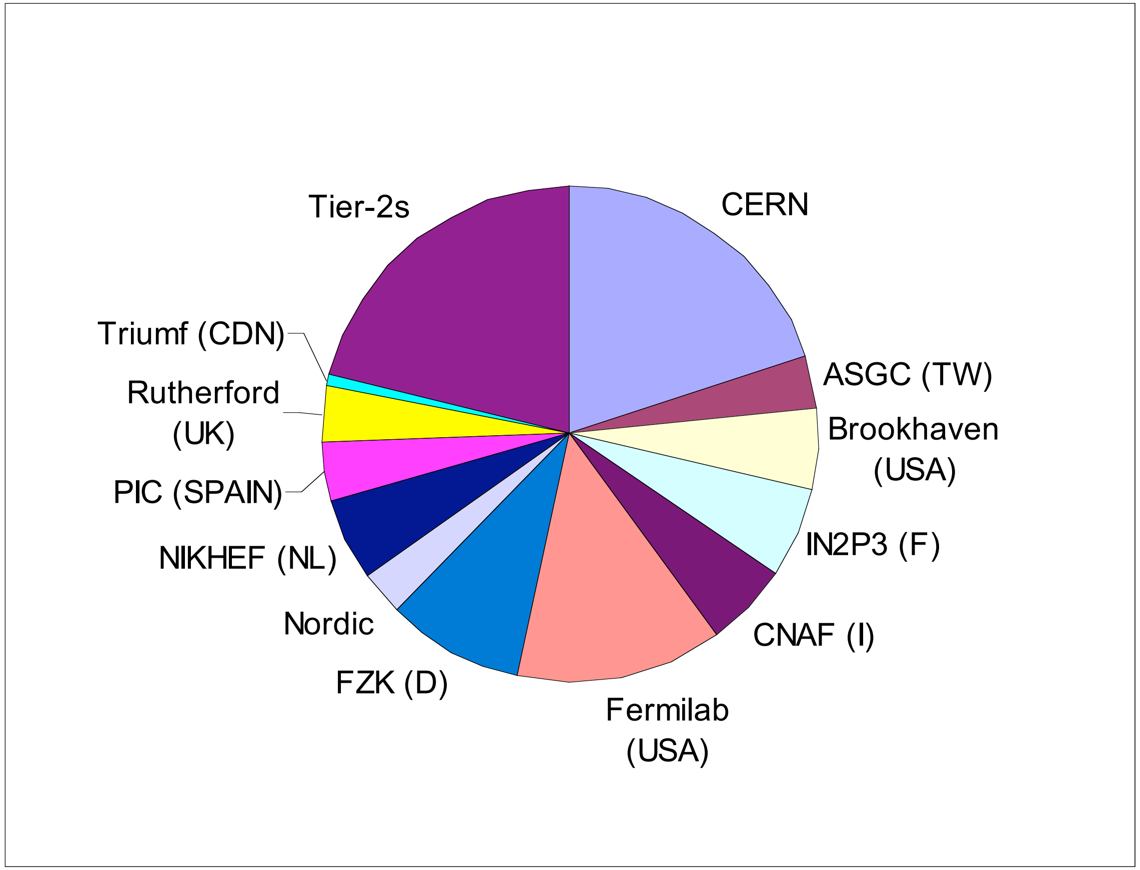
Tier 3

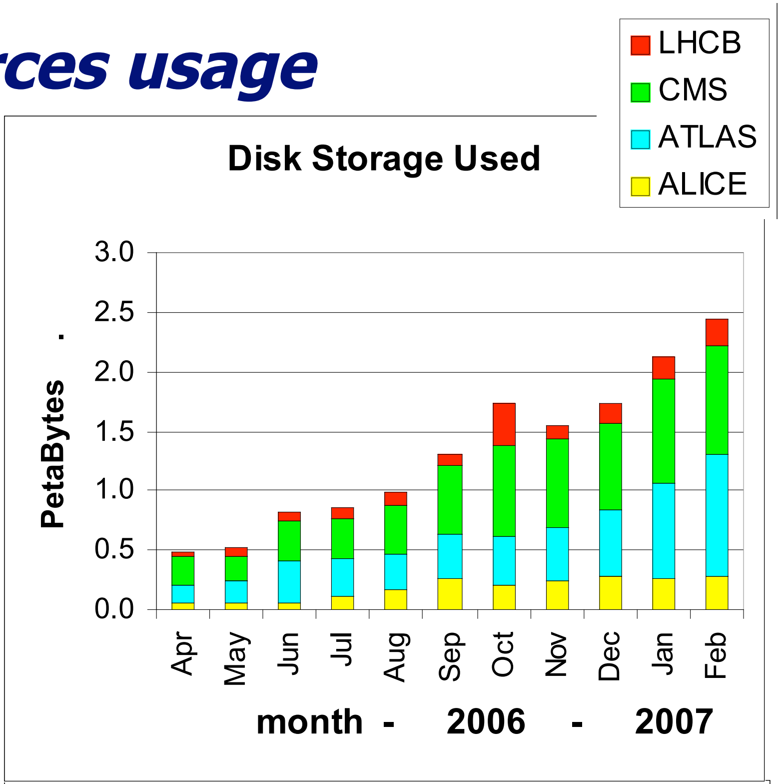
Workstations

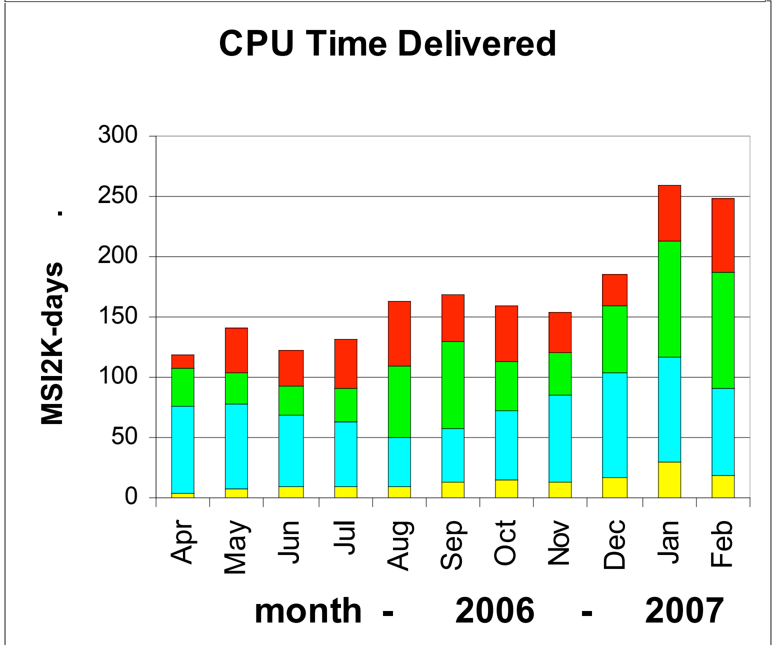
Each Tier 2 has ~25 physicists working on one or more channels

Tier 2 do bulk of simulation

CERN and Tier-1/2 resources usage

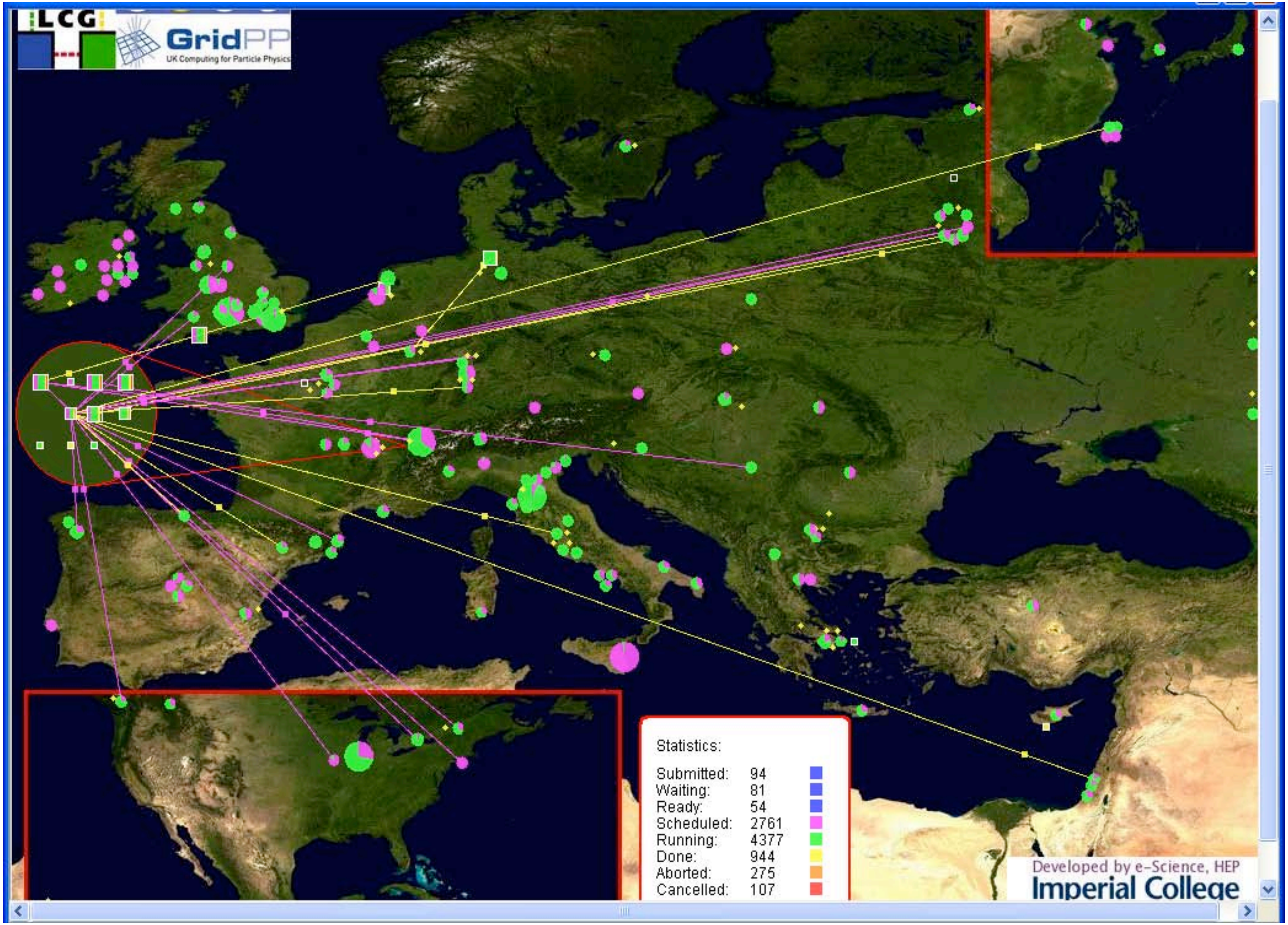






- ✓ CPU usage increased by factor of 2 over past year
- ✓ Disk usage by a factor of 4.9
- ✓ Expect new important increase during data taking at the level of 15 PetaBytes/year

http://gridportal.hep.ph.ic.ac.uk/rtm/



Statistics:

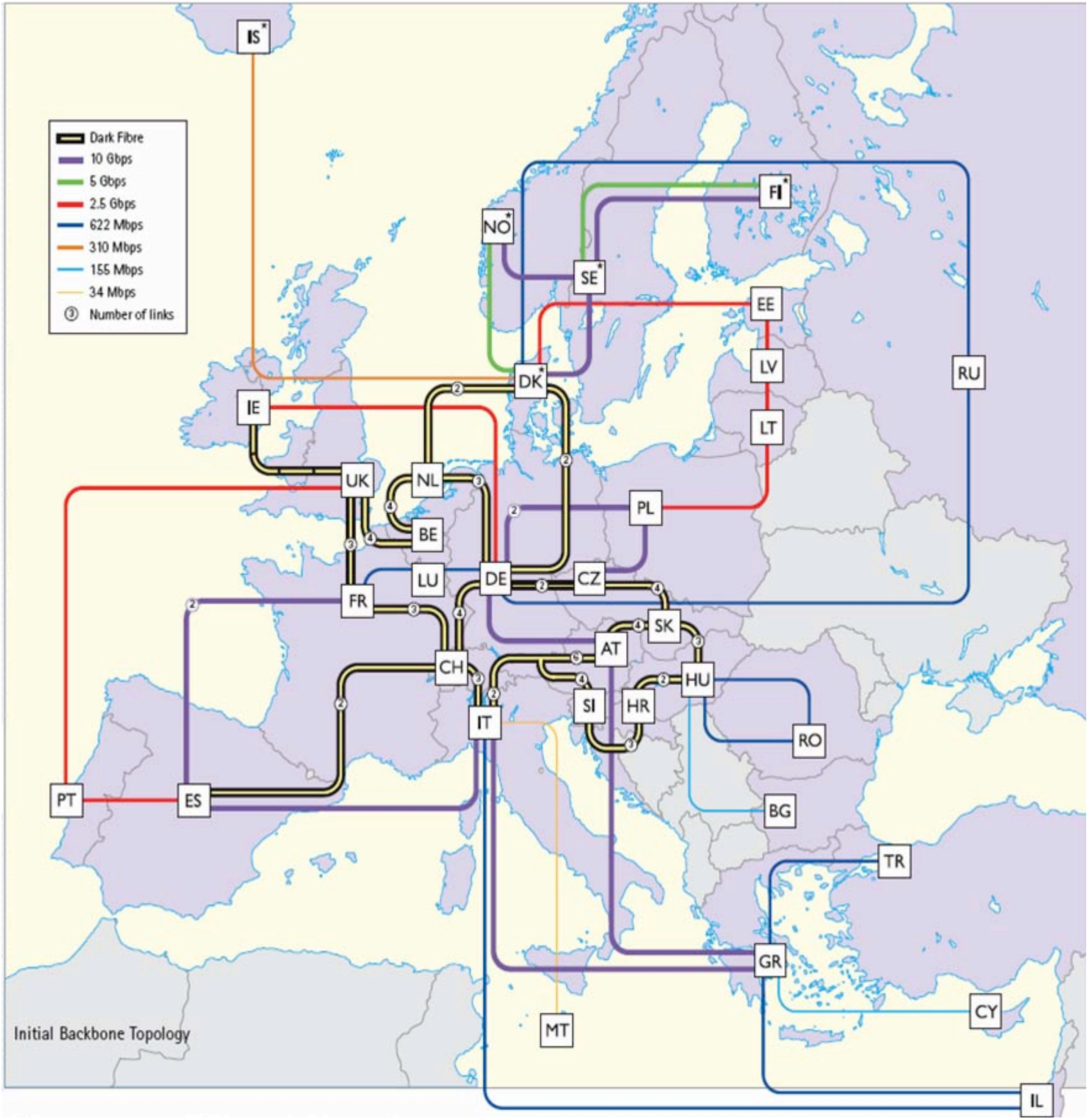
Submitted:	94	🟦
Waiting:	81	🟦
Ready:	54	🟦
Scheduled:	2761	🟪
Running:	4377	🟩
Done:	944	🟨
Aborted:	275	🟧
Cancelled:	107	🟥

European Research Network

- New GÉANT 2 – research network backbone

- Strong correlation with major European LHC centres (Swiss PoP at CERN)

- Core links are fibre



The LHC computing grid status

The LHC physics data analysis service distributed across the world

- ✓ CERN, 11 large *Tier-1* centres, over 100 active *Tier-2* centres

Status at April 2007

- ✓ Established the 10 Gigabit/sec optical network that interlinks CERN and the Tier-1 centres
- ✓ Demonstrated data distribution from CERN to the Tier-1 centres at 1.3 GByte/sec – the rate that will be needed in 2008
- ✓ ATLAS and CMS can each transfer 1 PetaByte of data per month between their computing centres
- ✓ Running ~2 million jobs each month across the grid
- ✓ The distributed grid operation, set up during 2005, has reached maturity, with responsibility shared across 7 sites in Europe, the US and Asia
- ✓ End-user analysis tools enabling “real physicists” to profit from this worldwide data-intensive computing environment

Early Physics Scenario

Step by step

Goal # 1

Understand and calibrate detector and trigger in situ using well-known physics samples

e.g. - $Z \to ee, \mu\mu$ tracker, ECAL, Muon chambers calibration/alignment, …
- $tt \to bl\nu\ bjj$ jet scale from $W \to jj$, b-tag performance, etc.

Understand basic SM physics at $\sqrt{s}$ = 14 TeV --> first tuning of Monte Carlo
Understand the timing of all components --> use minimum bias

Main candles: W, Z, tt, minimum bias, QCD jets
e.g. - measure cross-sections (initially to ~ 20 %),
look at basic event features, first constraints of PDFs, etc.
- measure top mass (to ~ 7 GeV) → give feedback on detector performance
Note : statistical error negligible after few weeks run

it will take time

Goal # 2

Prepare the road to discovery:
measure backgrounds to New Physics : e.g. tt and W/Z+ jets (omnipresent …)

Goal # 3

Look for New Physics potentially accessible in first year(s)
(e.g. $Z' \to ee$, SUSY, some Higgs ? …)

Expected knowledge of the detector at the beginning

months	@Day 1 (examples)	After a few months	Needed physics samples
ECAL uniformity	~1%	~ 0.7 %	Minimum-bias, $Z \to ee$
e/γ scale	~2 %	~ 0.1 % ?	~ 10^5 $Z \to ee$
HCAL uniformity	3 %	~1%	Single pions, QCD jets
Jet scale	< 10%	<5%	$Z (\to ll) +1j$, $W \to jj$ in tt events
Tracking alignment (in Rϕ Pixels/SCT/μ)	20-200 μm ?	10-20μm	Generic tracks, isolated μ , $Z \to \mu\mu$
B-Field Solenoid	2-4 G	2-4 G	
B-Field Toroids	10-50 G	5-20 G	

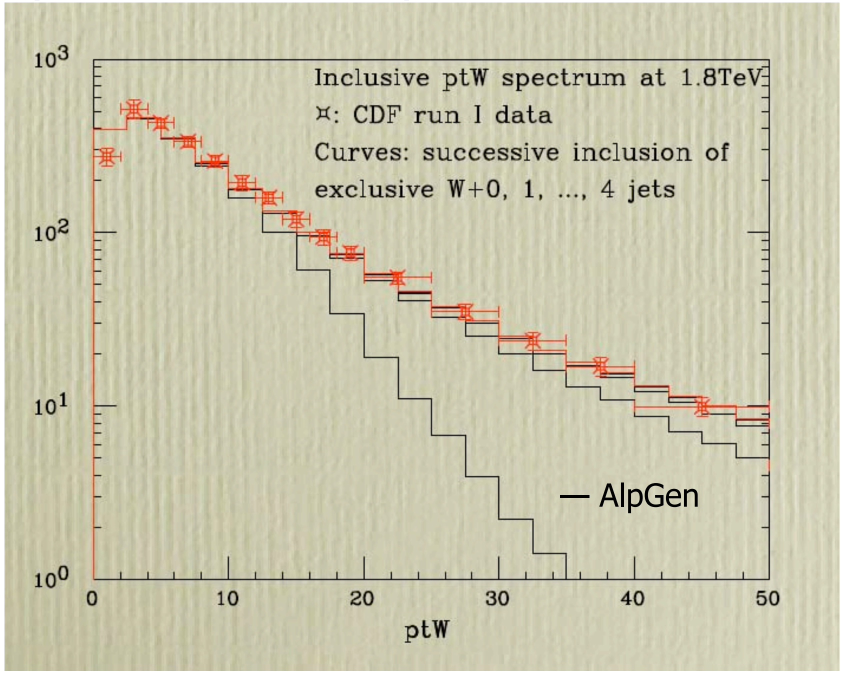
- ✓ determine detector "operation" parameters: timing, voltages, noise, relative positions, initial calibration and alignment, etc.
- ✓ reach "day 1" performance and understand several systematic effects (material, B-field, ..)
  --> gain time and experience before commissioning with cosmics or single beams
- ✓ we will go gradually to nominal conditions : first 75ns and 43x43 bunches, then 156x156 and just partial squeezing of the beam ($L = 10^{28}$-10^{32}), then 25 ns

First SM physics to cross check

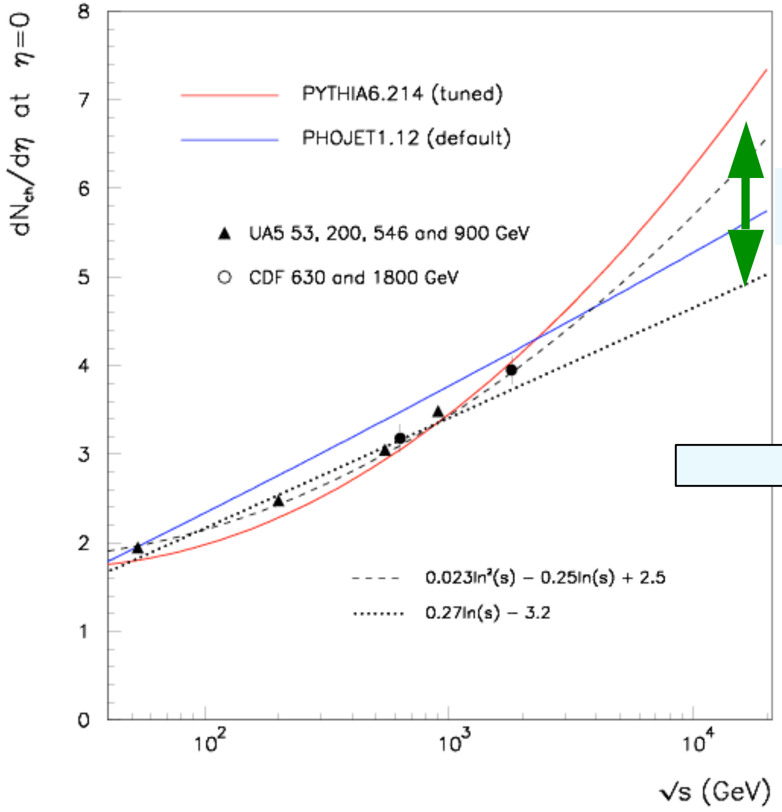
W, Z cross-sections: to 3-4%
(NNLO calculation -> dominated by PDF)

tt cross-section to ~7% (NLO+PDF)

Lot of progress with NLO matrix element MC interfaced to parton shower MC (MC@ NLO, AlpGen,..)



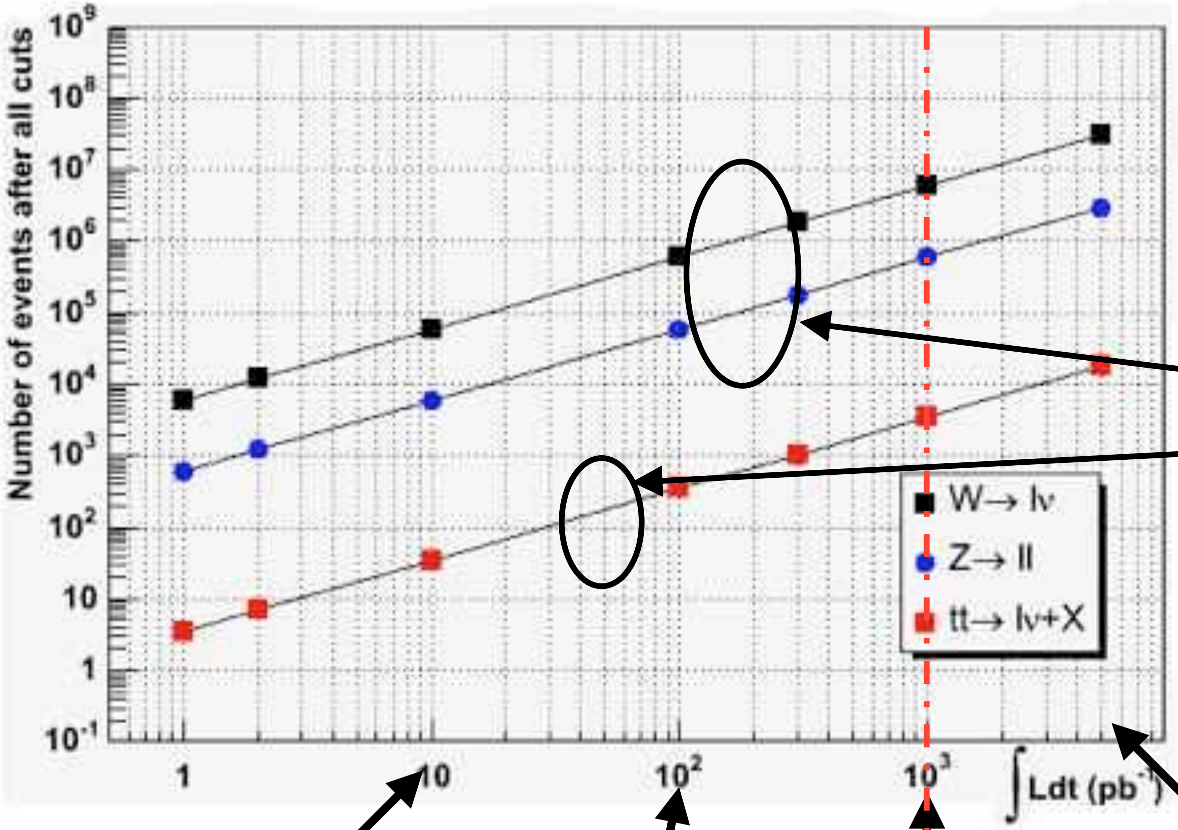
$\langle N_{ch} \rangle$ at η =0 for generic pp collisions
(minimum bias)



LHC ?

Candidate to very early measurement:
few 10^4 events enough to get $dN_{ch}/d\eta$, dN_{ch}/dp_T
->tuning of MC models
->understand basics of pp collisions,
occupancy, pile-up, …

To arrive to today's status (D0&CDF)



+ > 10^6-10^7 minimum bias and QCD jets p_T > 150 GeV (if 1% of trigger bandwidth)

similar statistics to CDF, D0 today

l ≡ e or μ

10 pb^{-1} ≡ 1 month at 10^{30} + < 2 weeks at 10^{31}, ε=50%

100 pb^{-1} ≡ a few days at 10^{32} , ε=50%

1 fb^{-1} ≡ 6 months at 10^{32}, ε=50%

5 fb^{-1} ≡ 3 months at 10^{32} + 3 months at 10^{33}, ε=50%

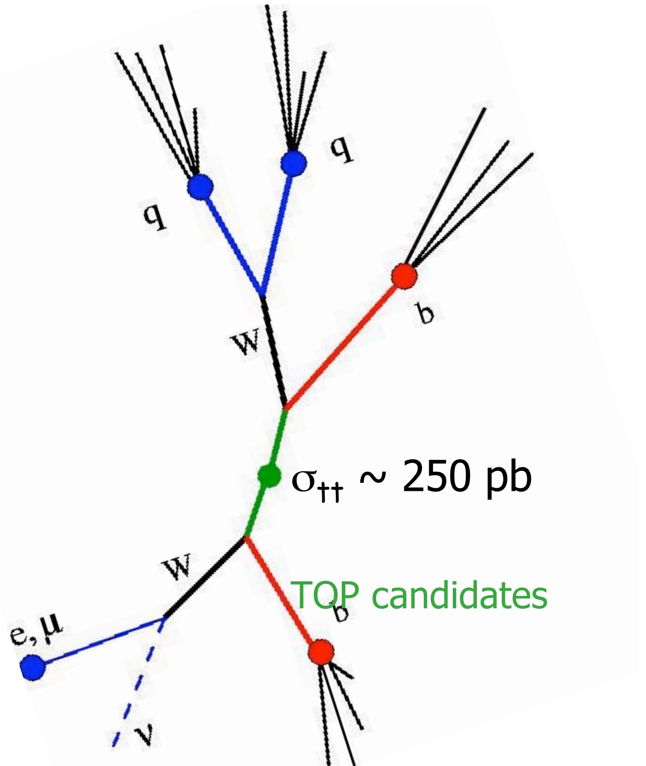
end 2008 ?

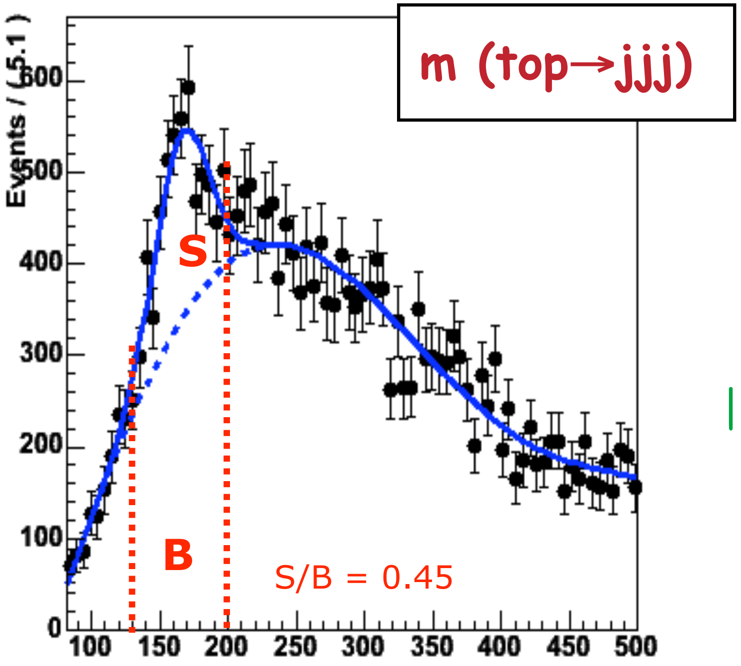
What about top physics ?

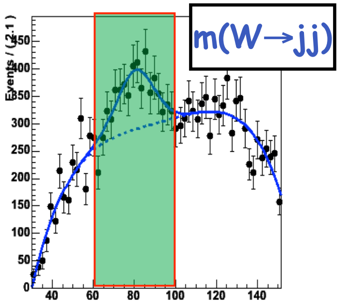
Analysis strategy:

- ✓ *use simple and robust selection cuts:*
  - *$p_T(\ell) > 20$ GeV*
  - *$E_T^{miss} > 20$ GeV*
  - *only 4 jets with $p_T > 40$ GeV*

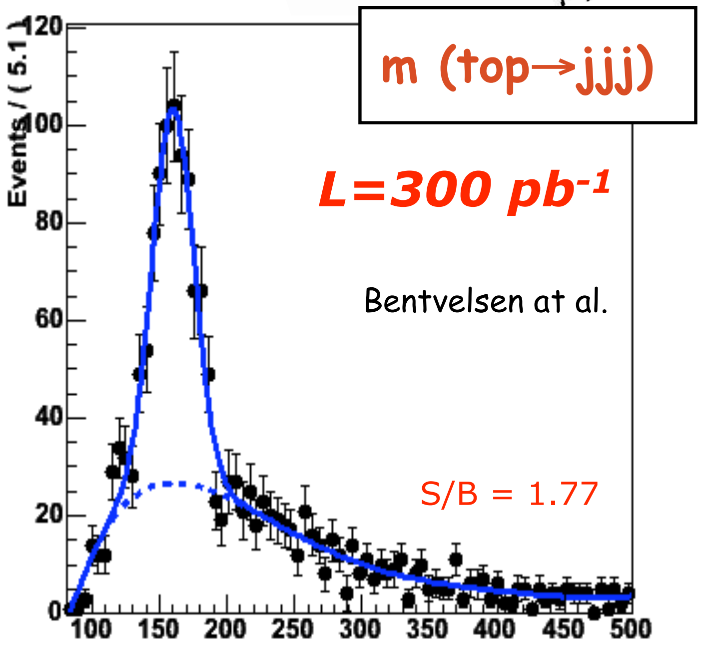
  } *$\varepsilon \sim 5\%$*
- ✓ *no b-tagging required (too early …)*
- ✓ *m (top → jjj) from invariant mass of 3 jets giving highest top p_T*
- ✓ *m (W→jj) from 2 jets with highest momentum in jjj CM frame*







$|m_{jj}-m_W| < 10$ GeV



Early Top will mean :

Expect ~ **100** (1000) events inside mass peak for **30** (300) pb^{-1}

→ top signal observable in early days with no b-tagging and simple analysis

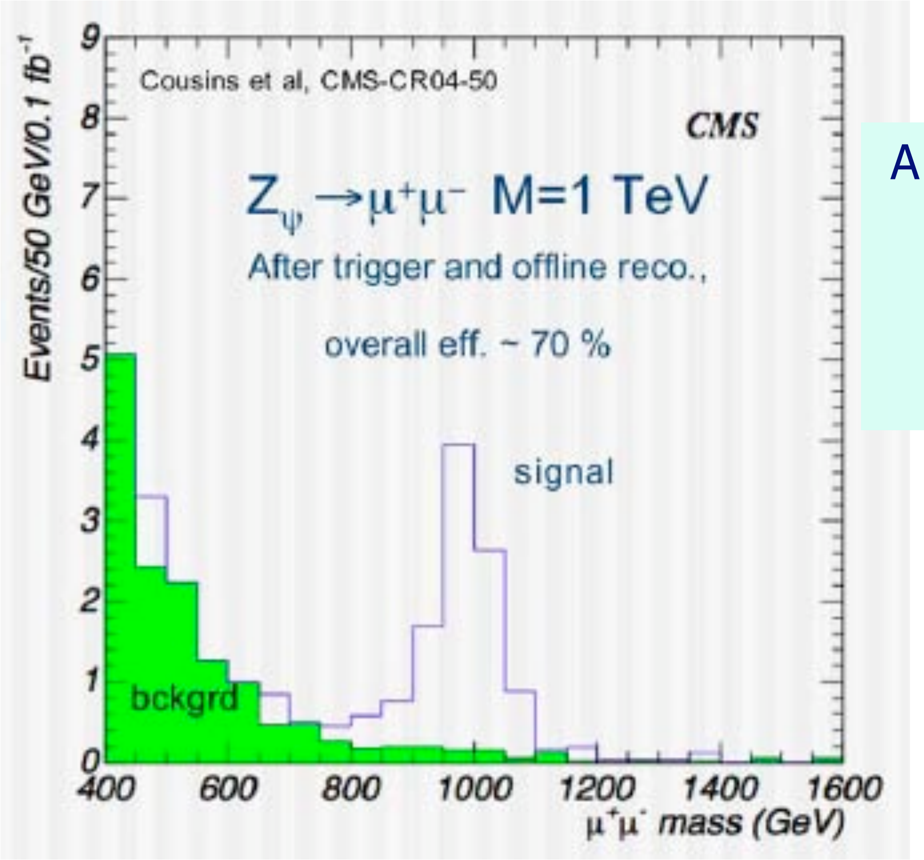
Cross-section to 20%, m_{top} to 7 GeV (LHC goal ~1 GeV) with 100 pb^{-1} ?

This tt sample is excellent to:

- ✓ commission b-tagging, set jet E-scale using W -> jj peak
- ✓ understand detector performance and reconstruction of several physics objects (e, μ, jets, b-jets, missing ET, ..)
- ✓ understand / tune MC generators using e.g. p_T spectra
- ✓ measure background to many searches

What about new physics ~ 1 fb^{-1} ?

An early di-lepton resonance ?



A new (narrow) resonance of mass ~ 1 TeV decaying into e^+e^- or $\mu^+\mu^-$

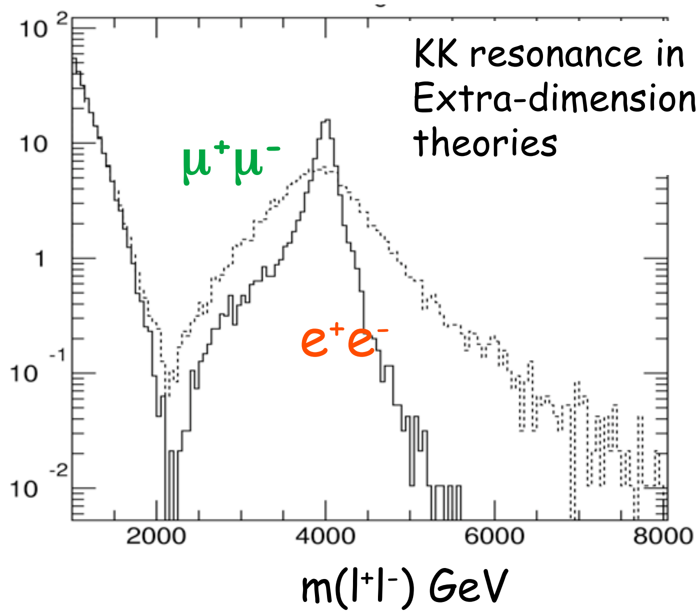
e.g. a Z' or a Graviton or extra dimensions or ..

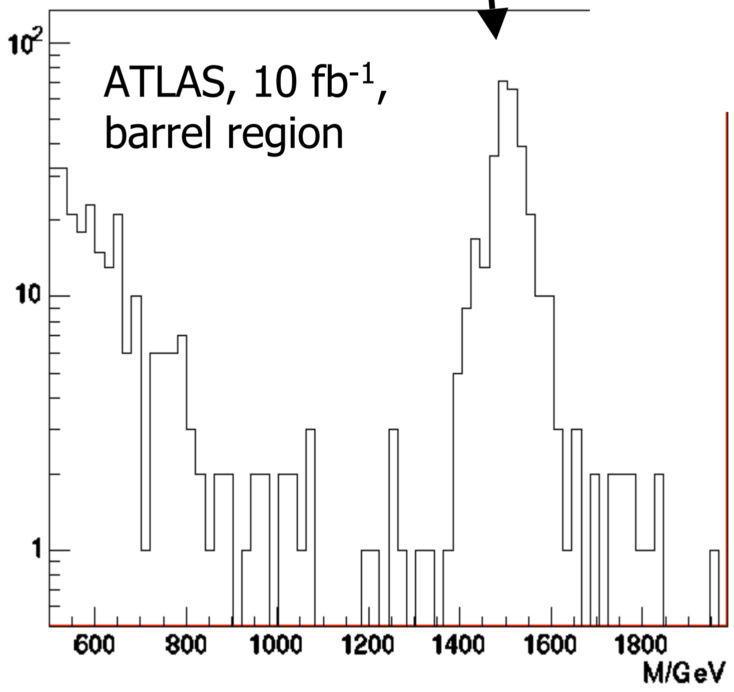
might be the easiest new particle to find …

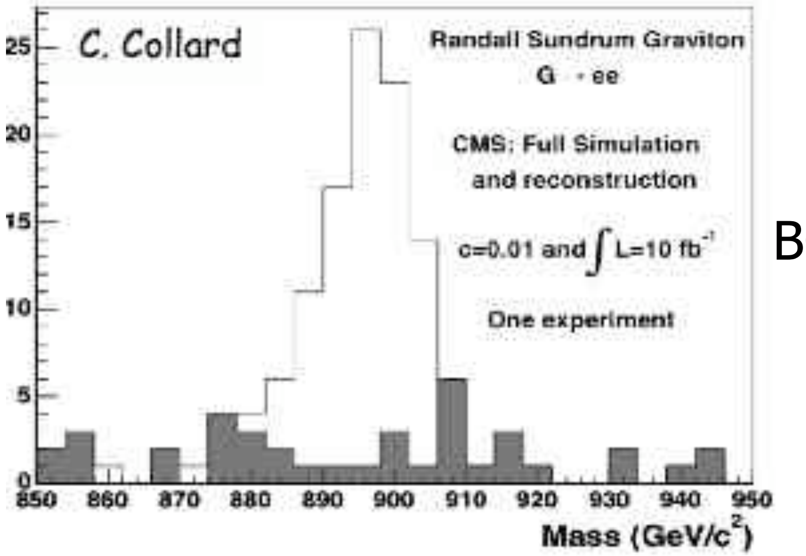
Many models would then join in !

e,e might be really easier

	$Z' \rightarrow ee$, SSM	$G \rightarrow ee$
(10 observed evts)	Mass	Mass
~ 70 pb^{-1}	1.0 TeV	0.9 TeV
~ 300 pb^{-1}	1.5 TeV	1.1 TeV
~ 1.5 fb^{-1}	2.0 TeV	1.25 TeV


KK resonance in Extra-dimension theories


ATLAS, 10 fb^{-1}, barrel region


C. Collard

Randall Sundrum Graviton
G → ee

CMS: Full Simulation and reconstruction

c=0.01 and $\int L=10\ fb^{-1}$

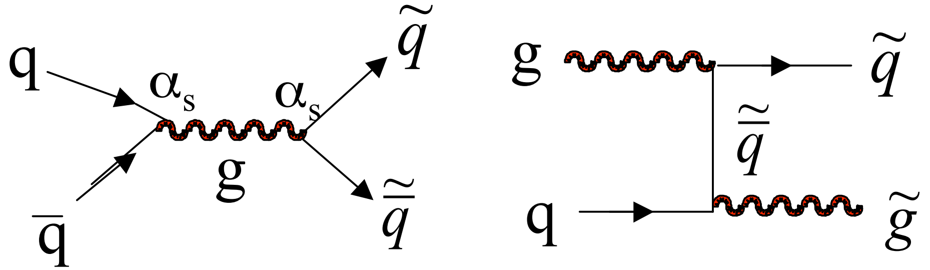
One experiment

BG: Drell-Yan

What about SUSY discovery < 1 fb^{-1} ?

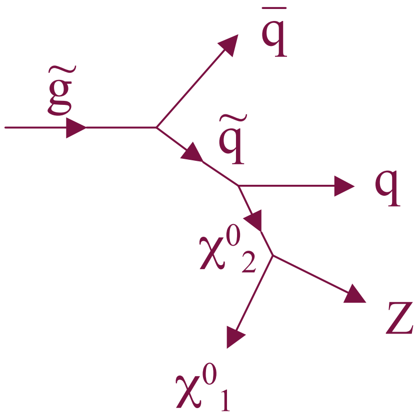
Squarks and gluinos produced via strong processes → large cross-section

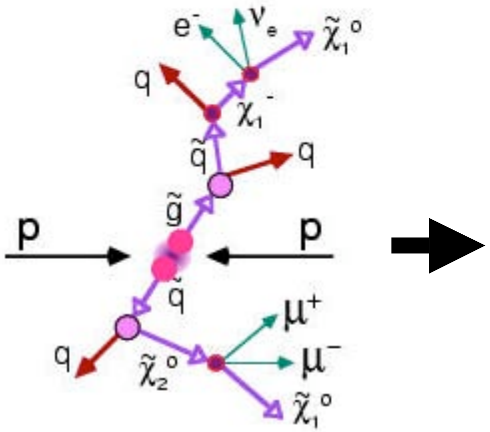
E.g.:

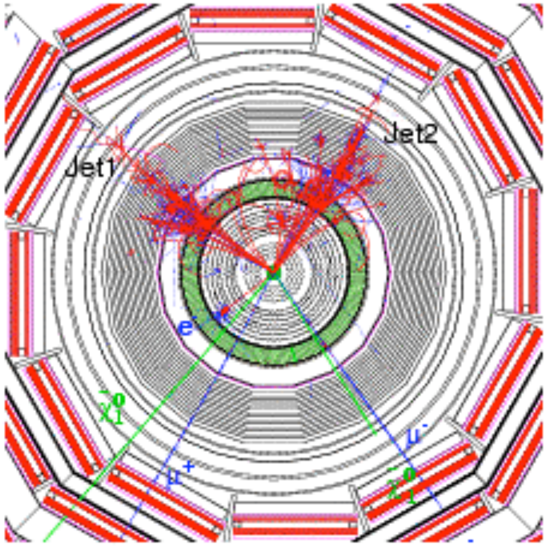


M(TeV)	σ(pb)	Ev/fb^{-1}
0.5	100	10^5
1.0	1	10^3
2.0	0.01	10

$\tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ production are dominant SUSY processes at LHC, if accessible







→ **spectacular signatures**
(many jets, missing transverse energy, leptons)

What about SUSY discovery ? (2)

But …. very difficult BG

- W/Z + jets with $Z \rightarrow \nu\nu$, $W \rightarrow \tau\nu$; tt; etc.
- QCD multijet events with fake ETmiss from jet mis-measurements (calorimeter resolution and non-compensation, cracks, …)
- cosmics, beam-halo, detector problems overlapped with high-p_T triggers, …

How to clean the sample:

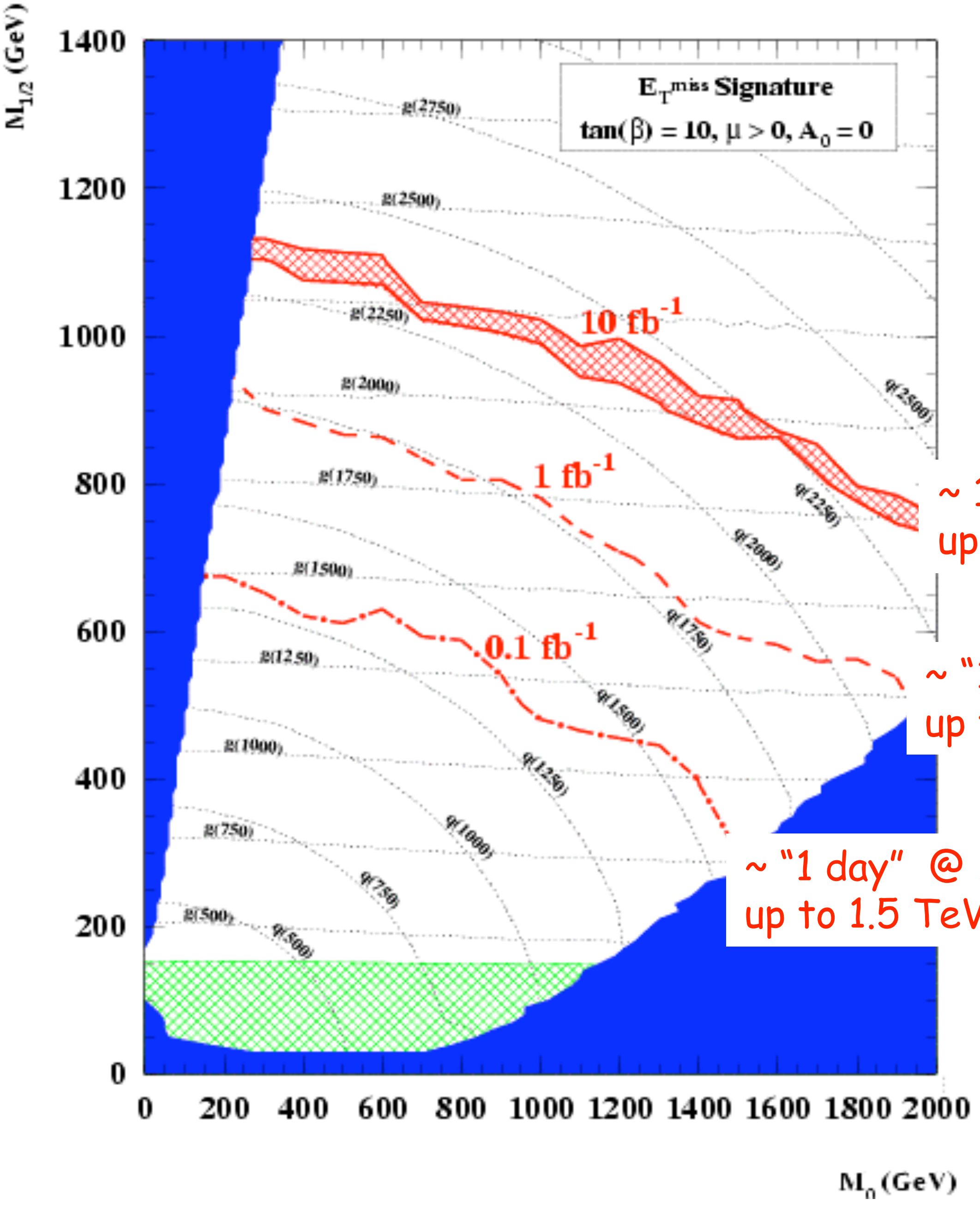
- ✓ at least 2-3 jets with p_T>80-100 GeV, E_T^{miss} > 80-100 GeV (for masses at overlap with Tevatron reach, higher otherwise)
- ✓ good event vertex
- ✓ no jets in detector cracks
- ✓ p_T^{miss} vector not pointing along or opposite to a jet in transverse plane

Estimate backgrounds using as much as possible data (control samples) and MC

Normalise MC to data at low E_T^{miss} and use it to predict background at high E_T^{miss} in "signal" region

It will be a long and difficult process !

Discovery reach with jets + E_T^{miss} signature *(most model-independent)*



ATLAS
5σ discovery curves

band indicates factor ± 2 variation
in background estimate

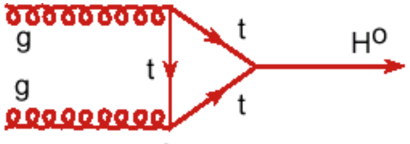
~ 100 days :
up to 2.3 TeV

~ "10 days" :
up to 2 TeV

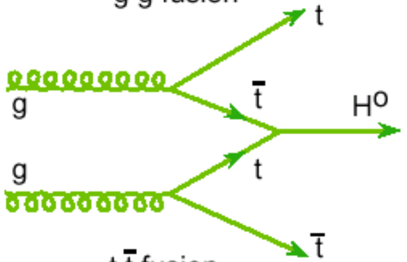
~ "1 day" @ 10^{33}:
up to 1.5 TeV

But it will take a lot time to understand the detectors and the backgrounds …

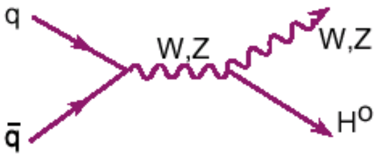
What about early Higgs ?



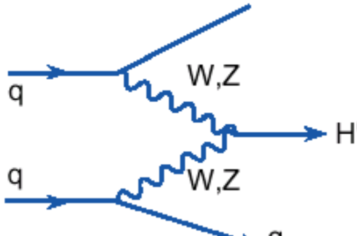
g g fusion



t t̄ fusion

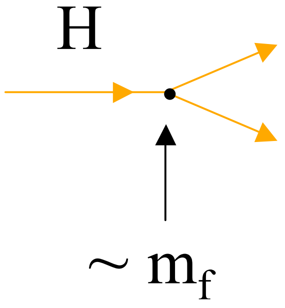


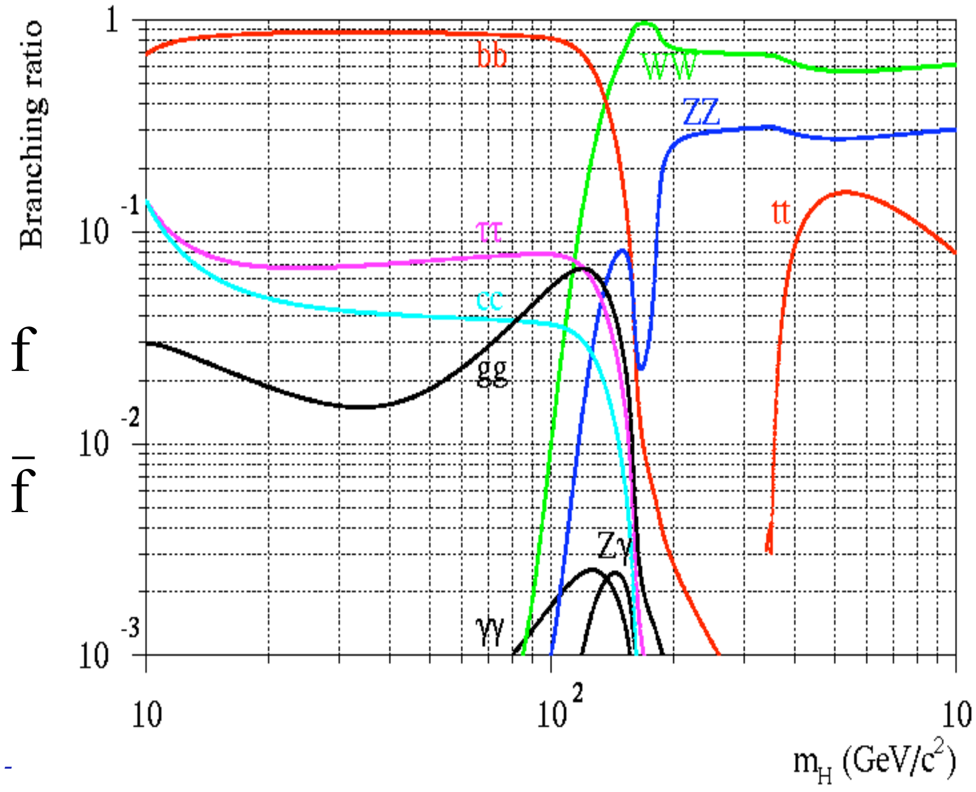
W, Z bremsstrahlung



WW, ZZ fusion

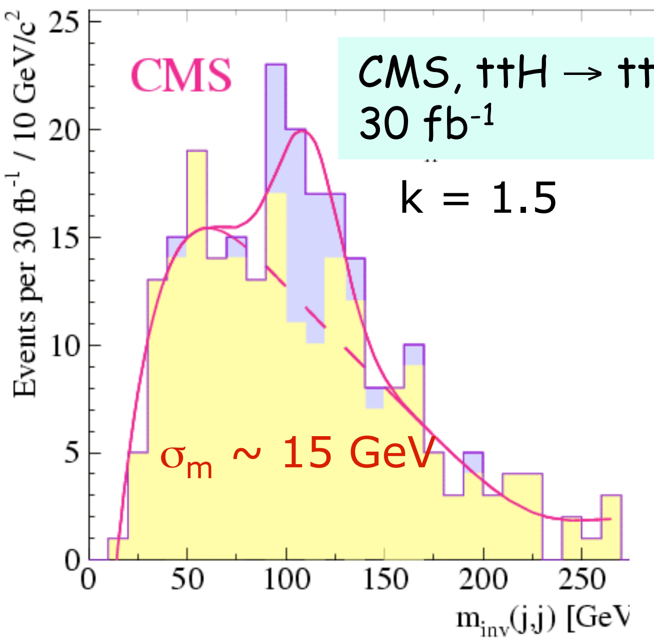
- *m_H < 120 GeV: H → bb dominates*
- *130 GeV < m_H < 2 m_Z : H → $WW^{(*)}$, $ZZ^{(*)}$*
- *m_H > 2 m_Z : 1/3 H → ZZ , 2/3 H → WW*
- *important rare decays : H → $\gamma\gamma$*



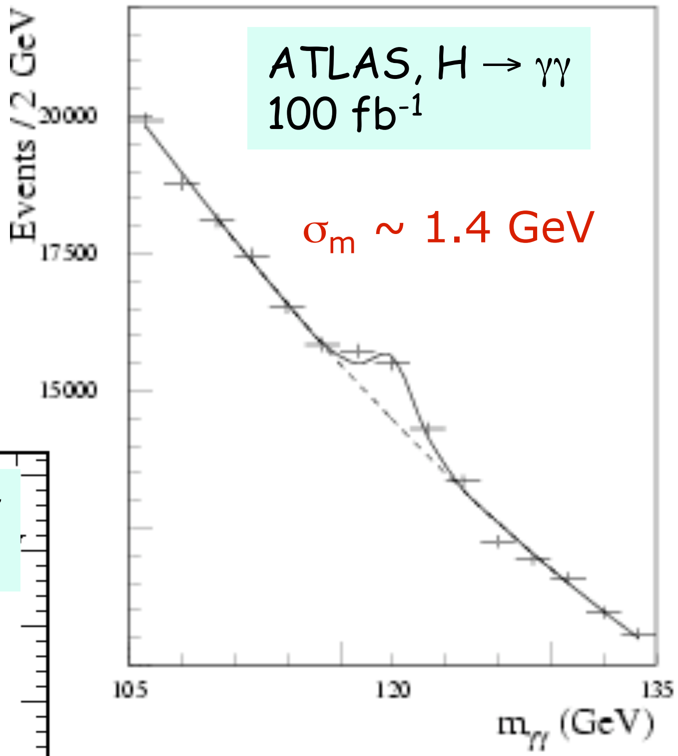


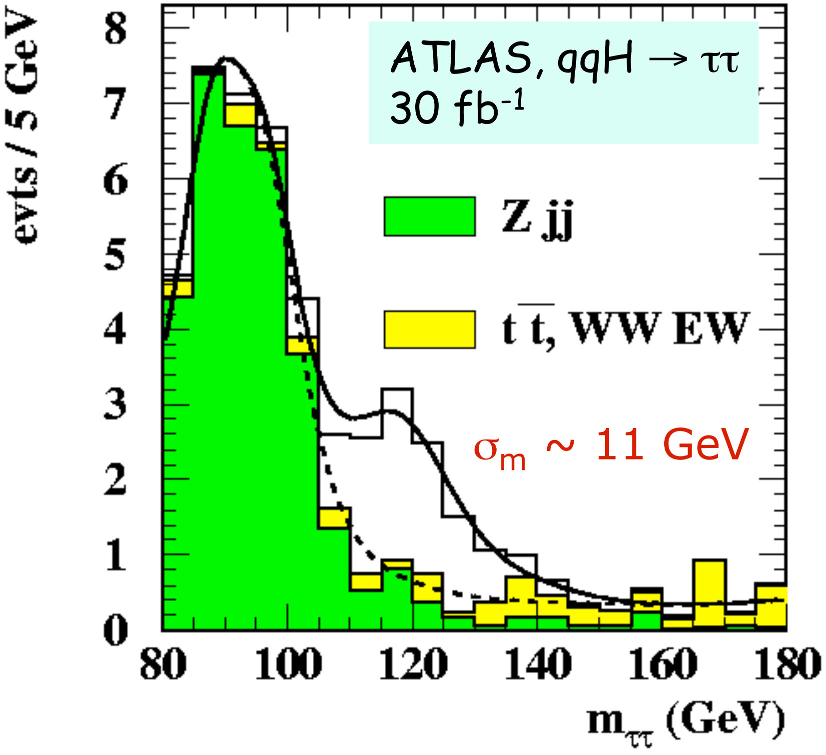
N. B.: $\Gamma_H \sim m_H^3$

Low mass higgs, will not be easy in an early stage



$m_H \sim 120$ GeV





All this will be very difficult and will require a good detector knowledge !

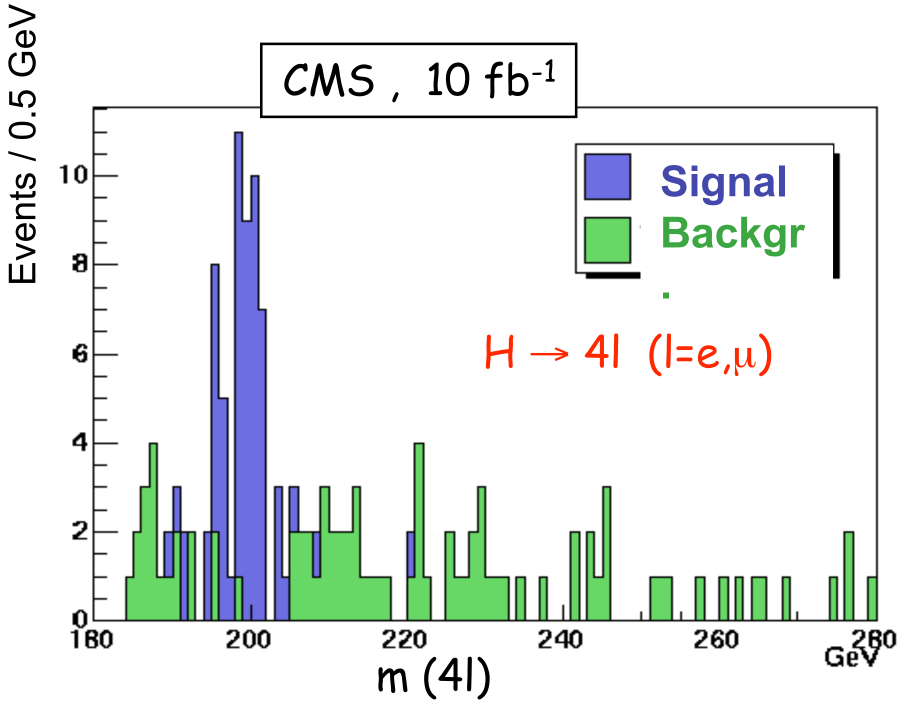
BG dominated by irreducible components

M > 130 GeV

$m_H > 130$ GeV : $H \to ZZ^{(*)} \to 4l$ (gold-plated), $H \to WW^{(*)} \to l\nu\, l\nu$

$H \to ZZ \to ll\, \nu\nu$
$H \to ZZ \to ll\, jj$
$H \to WW \to l\nu jj$

also contribute for $m_H > 300$ GeV



May be observed with 3-4 fb^{-1}

$H \to 4l$: low-rate but very clean : narrow mass peak, small background

- requires:
  - ~ 90% e, μ efficiency at low p_T
  - σ/m ~ 1%, tails < 10% ® good quality of E, p measurements in ECAL and tracker
- background dominated by irreducible ZZ production (tt and Zbb rejected by Z-mass constraint, and lepton isolation and impact parameter)

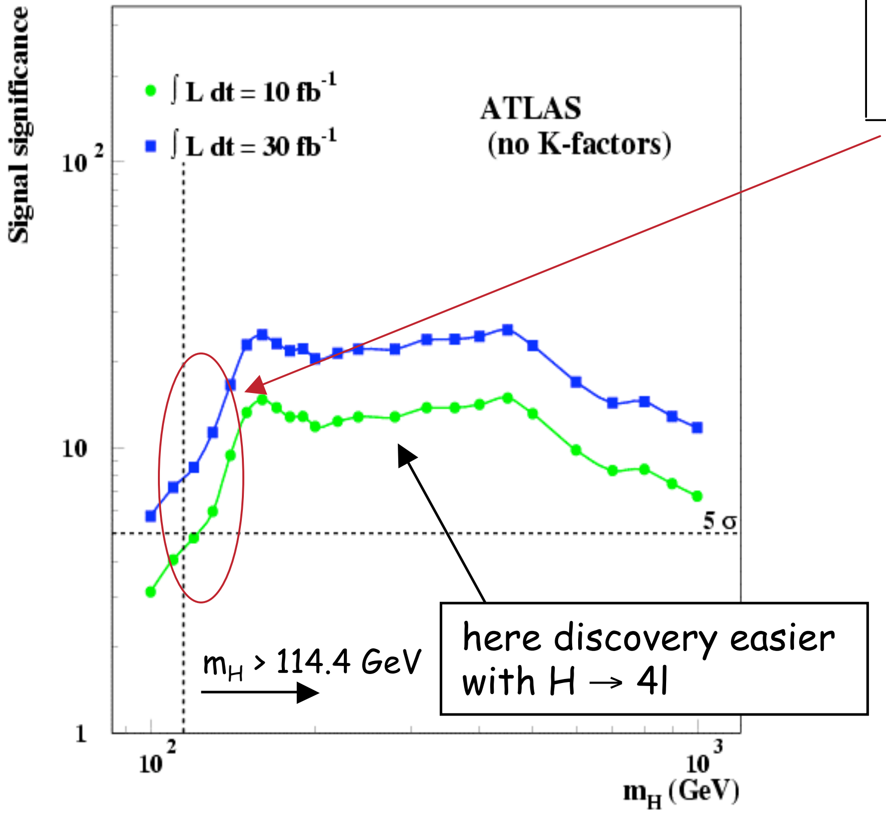
$H \to WW \to l\nu l\nu$: high rate (~ 100 evts/expt) but no mass peak

→ not ideal for early discovery …

Early Higgs discovery potential

ATLAS $10 fb^{-1}$	$H \to \gamma\gamma$	$ttH \to ttbb$	$qqH \to qq\tau\tau$ (ll + l-had)
S	130	15	~ 10
B	4300	45	~ 10
$S/\sqrt{B}$	2.0	2.2	~ 2.7

K-factors ≡ σ(NLO)/σ(LO) ≈ 2 <u>not</u> included



here discovery easier with $H \to 4l$

- ✓ different production and decay modes
- ✓ different backgrounds
- ✓ different detector/performance requirements:

-- ECAL crucial for $H \to \gamma\gamma$ (in particular response uniformity) : $\sigma/m \sim 1\%$ needed

-- b-tagging crucial for ttH : 4 b-tagged jets needed to reduce combinatorics

-- efficient jet reconstruction over $|\eta| < 5$ crucial for qqH → qqtt : forward jet tag and central jet veto needed against background

Overall discovery potential : our best guess