The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

SMR 1773 - 21

SCHOOL ON PHYSICS AT LHC: "EXPECTING LHC"
11 - 16 September 2006

LHC: Machine and Detectors
(LHC Collider and Experiments)
Part III

Albert DE ROECK
C.E.R.N.
European Organization for Nuclear Research
CH-1211 Geneva 23, Switzerland

These are preliminary lecture notes, intended only for distribution to participants.

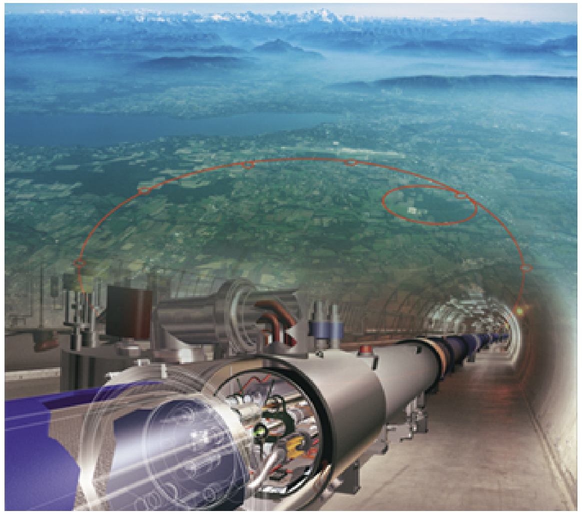
LHC Collider and Experiments

Albert De Roeck/CERN
ICTP 11-6/09/06

LHC@ICTP 2006

The Abdus Salam International Centre for Theoretical Physics

INFN Istituto Nazionale di Fisica Nucleare



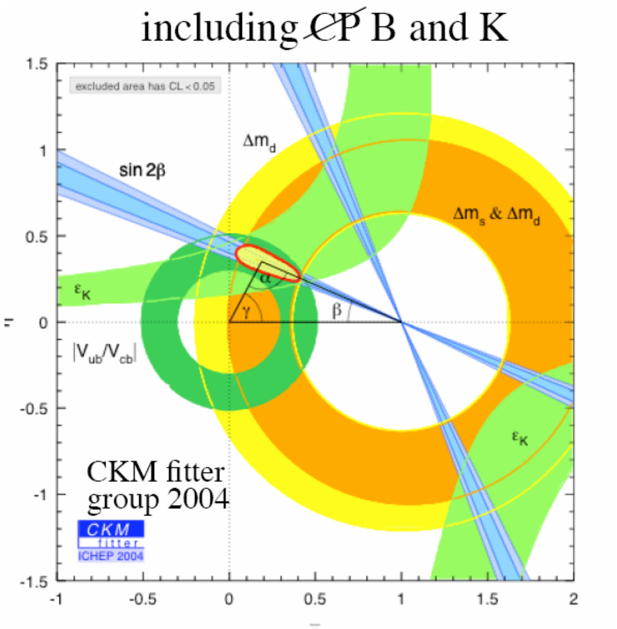
Lecture Plan

- The LHC Collider
  - Introduction to the LHC
  - Experimental challenges
- The ATLAS and CMS experiments
- The specialised experiments
  - The LHCb experiment
  - The ALICE experiment
  - The forward experiments (TOTEM, LHCf) and MOEDAL
- Startup scenarios and first physics at the LHC

LHCb: b-physics at the LHC

Examples

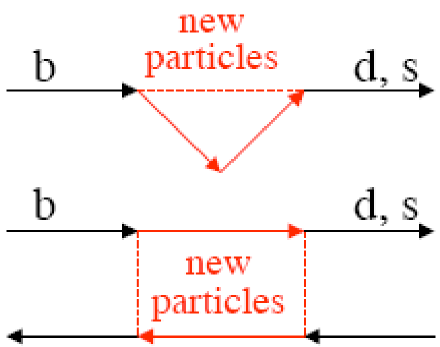
CKM triangle



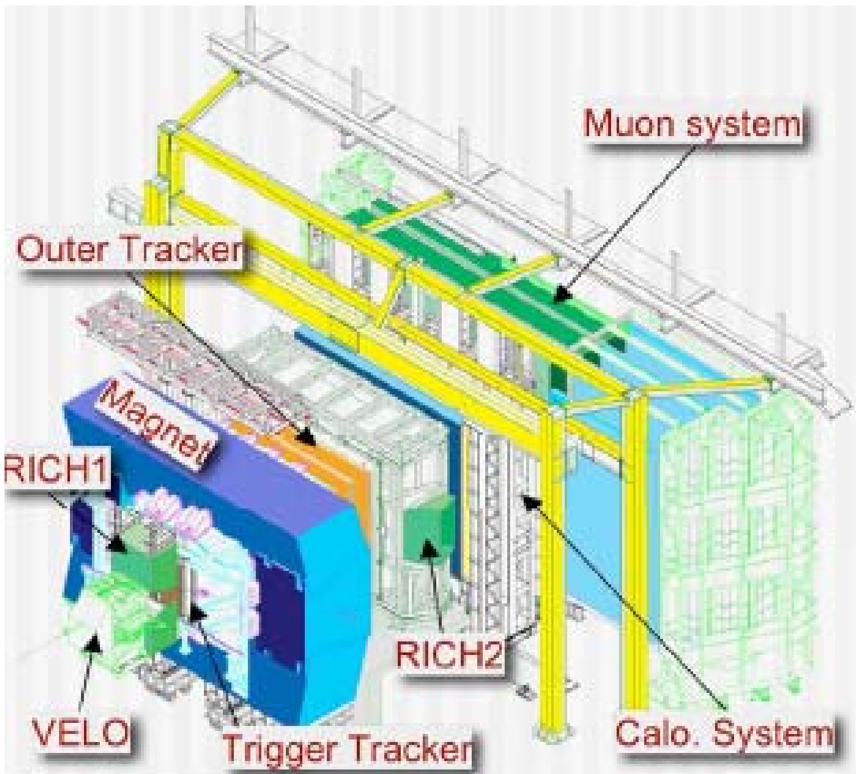
$B_s \rightarrow J/\psi\,\phi$ 120k signal events/year in LHCb

$\sigma(\sin\phi_s) \sim 0.06$, $\sigma(\Delta\Gamma_s/\Gamma_s) \sim 0.02$

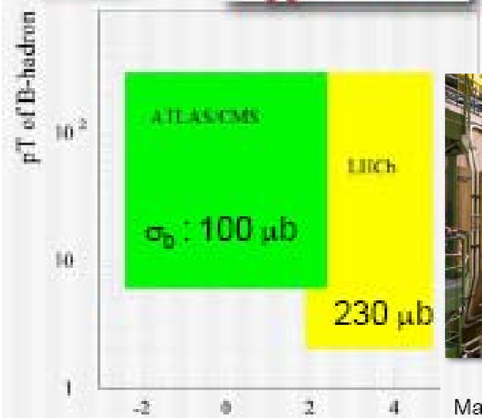
Measurement of B_s–$\overline{B}_s$ oscillation

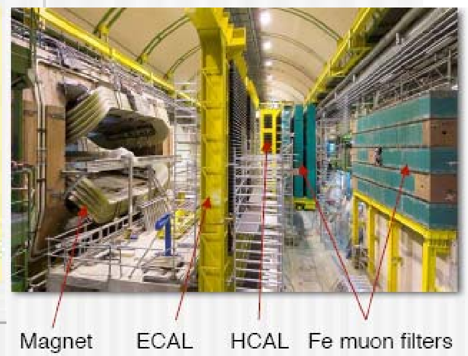


Sensitive to new physics complementary to ATLAS/CMS

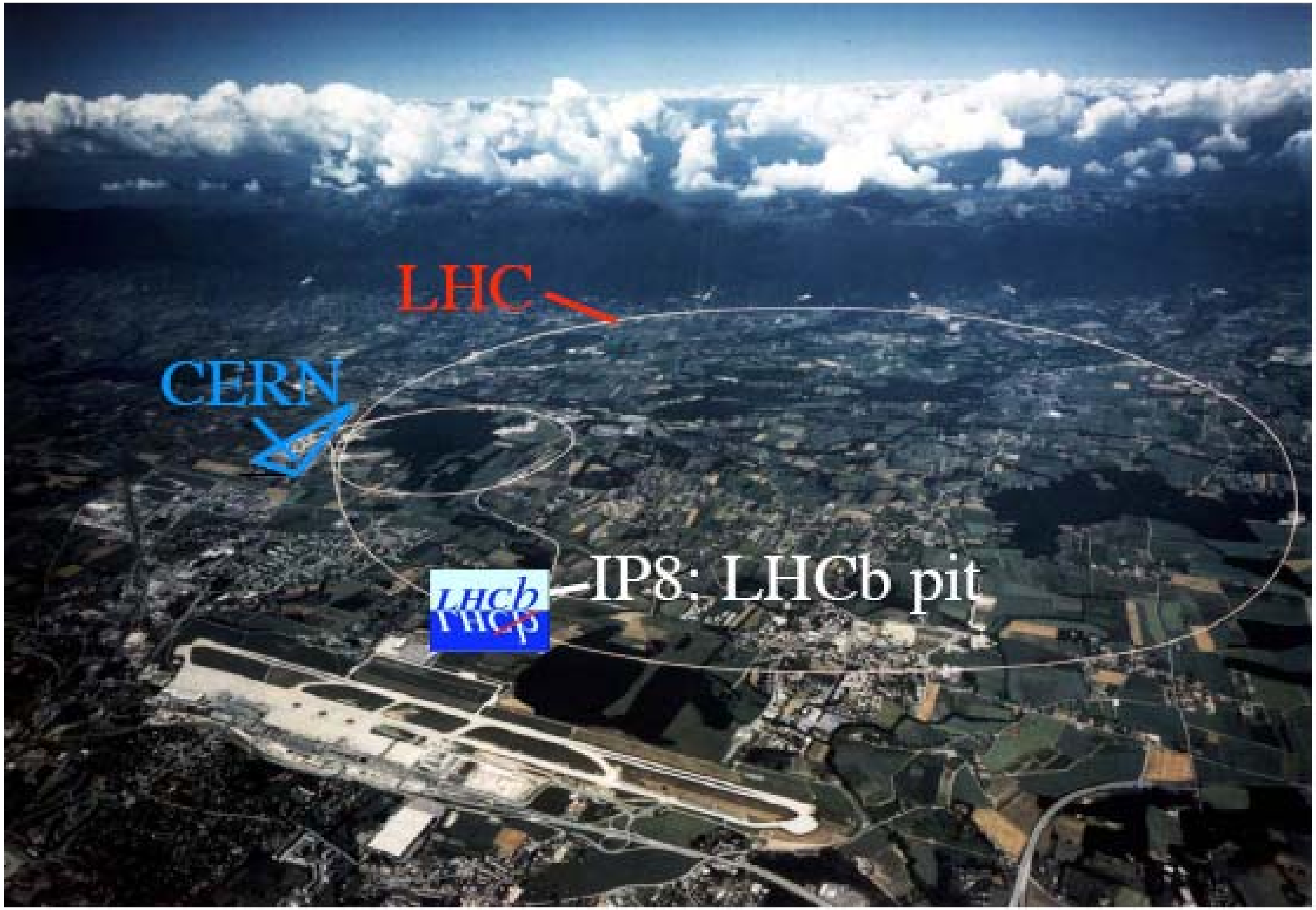


$L \sim 2\times10^{32}\,cm^{-2}s^{-1}$



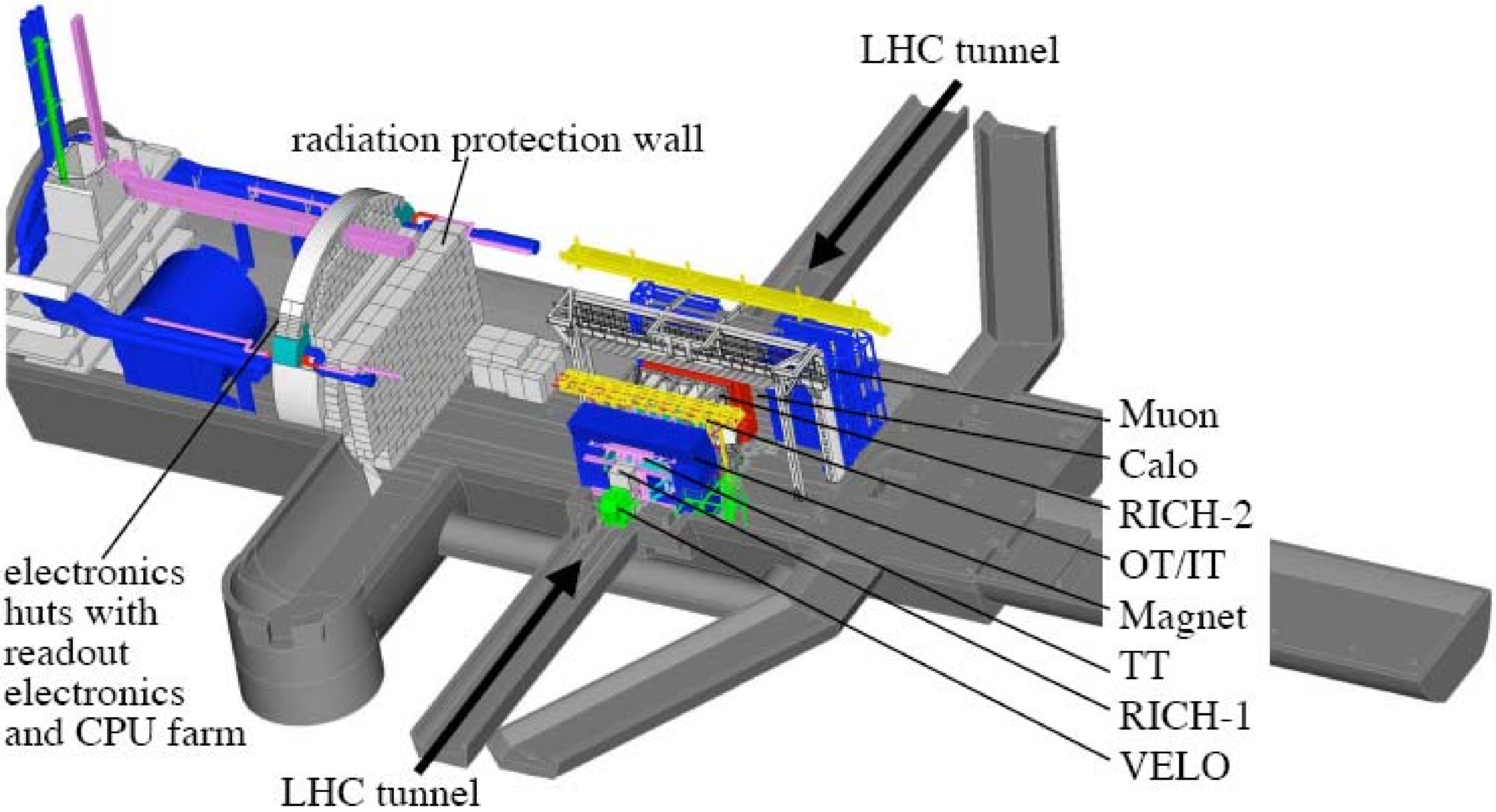


The LHCb experiment



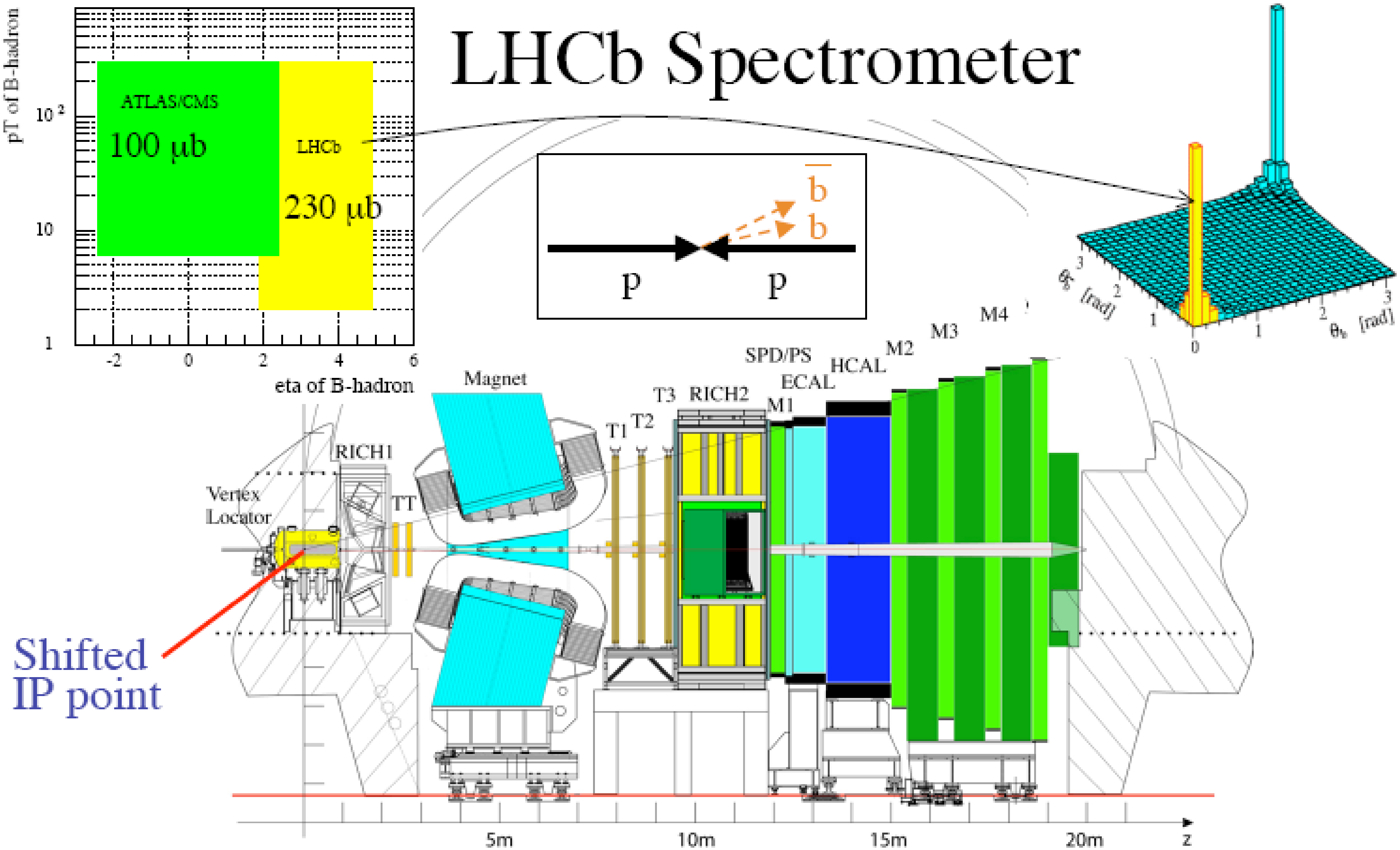
Brazil, China, France, Germany, Italy, Netherlands, Poland, Romania, Russia, Spain, Switzerland, UK, Ukraine, USA
600 people, 75 MCHF

LHCb Cavern



$\langle L \rangle \sim 2\times10^{32}$ ($L_{nominal} = 10^{34}$), $\sigma_b = 500\ \mu b$ ($\sigma_{inelastic} = 80$ mb),
$10^{12}\ b\bar{b}/10^7$ sec $B_{u,d,s,c}$, Λ_b, Σ_b, and other b-hadrons

LHCb Spectrometer

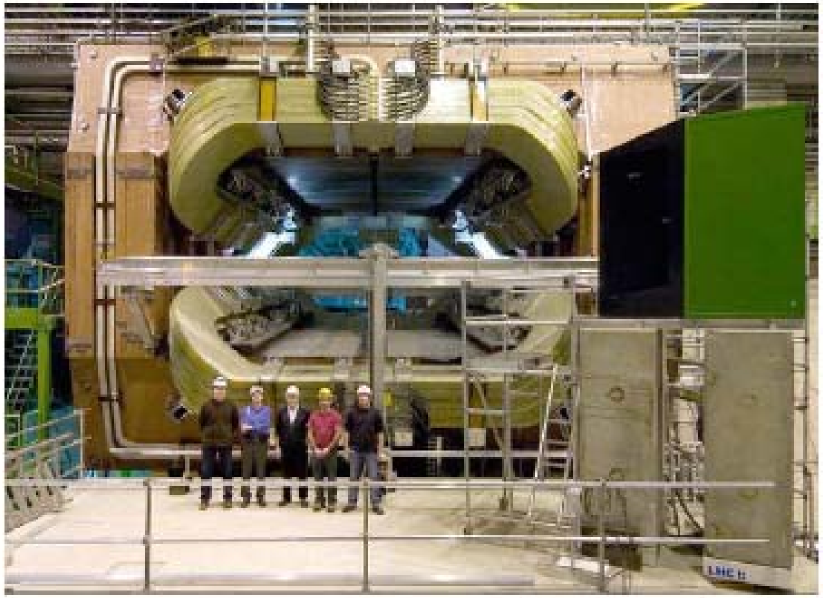


Good mass and eigentime resolution: VELO + tracking system
Hadron identification: RICH system
L0 Lepton and Hadron p_T trigger: Calorimeter and muon system

LHCb Magnet

Magnet

BDL = 4 Tm, Power = 4.2 MW, Yoke = 1450 t

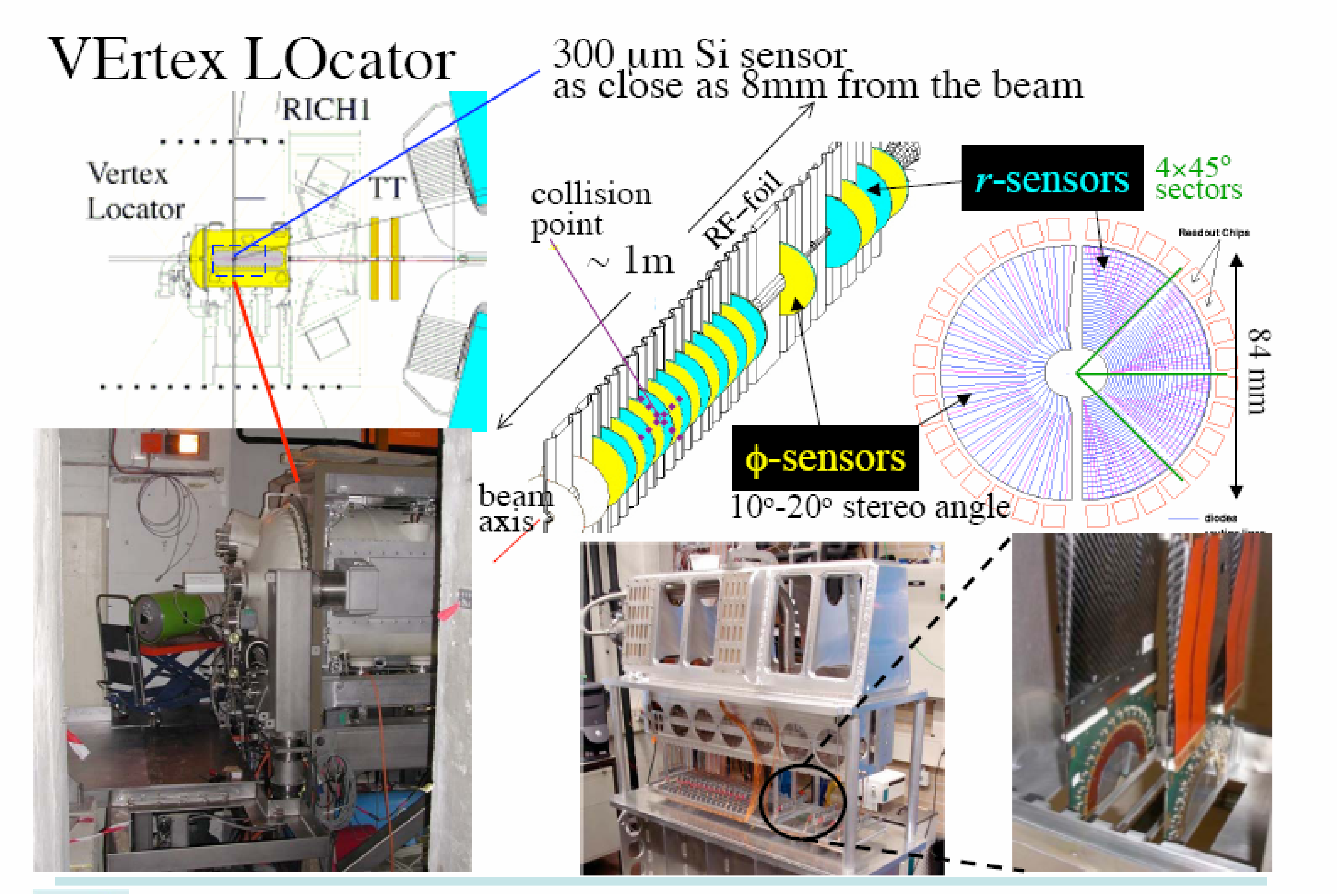


assembled, positioned, aligned, and field map measured

- the field was measured with a precision of 3×10^{-4} →fulfils the requirement
- good symmetry between the two polarities: $\Delta B/\langle B\rangle \sim 3\times10^{-4}$ →small "fake" P violation

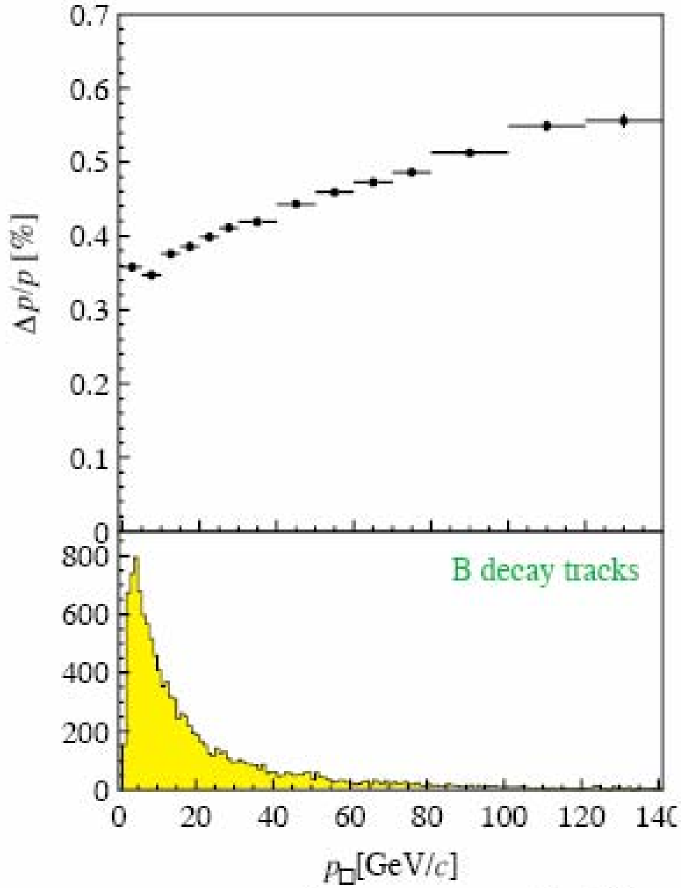
Magnet is now operational

VErtex LOcater

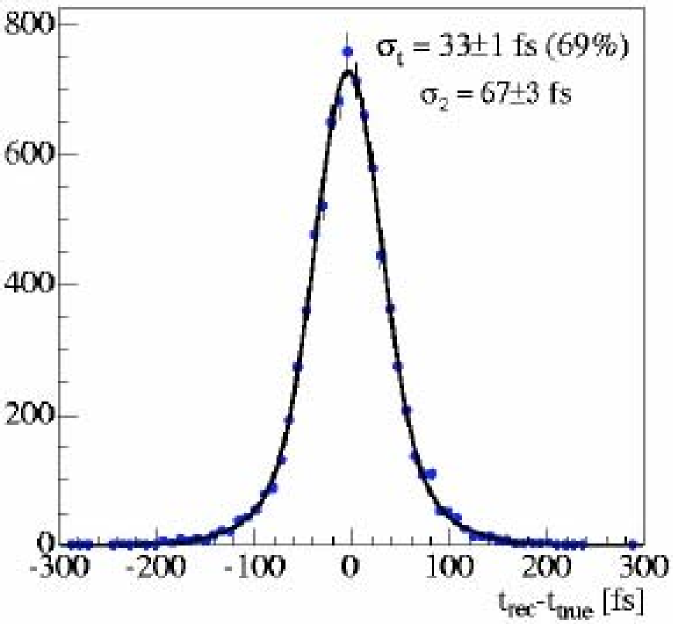


LHCb tracking performance

VELO + ST + OT + Magnet



momentum resolution



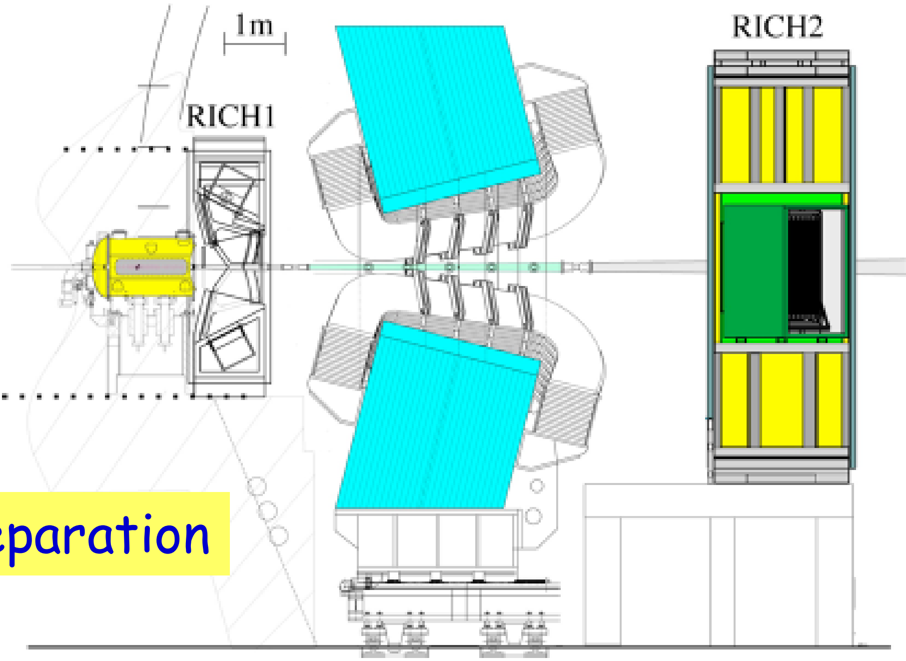
Proper time resolution ~ 40 fs

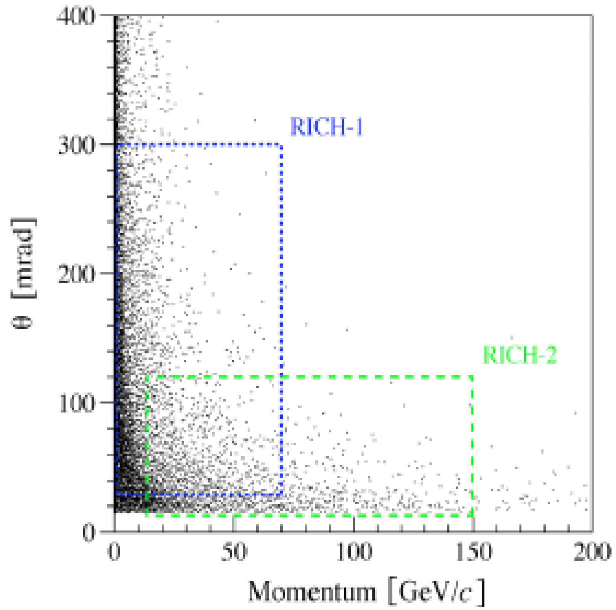
$B_s \rightarrow D_s^- \pi^+$

LHCb Particle identification

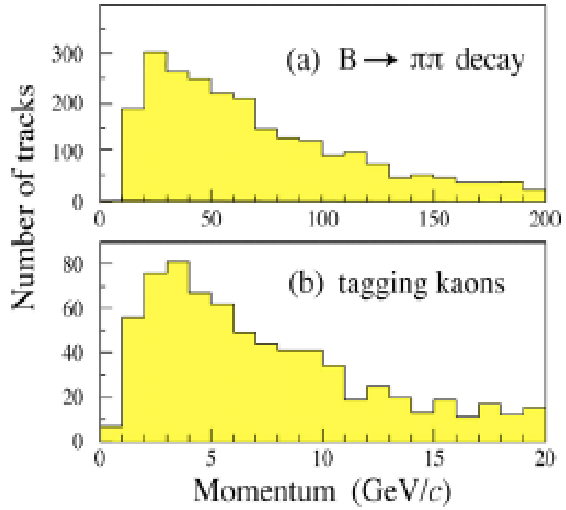
Based on cherekov light emission

RICH Ring Imaging Cherenkov





π, K, p separation



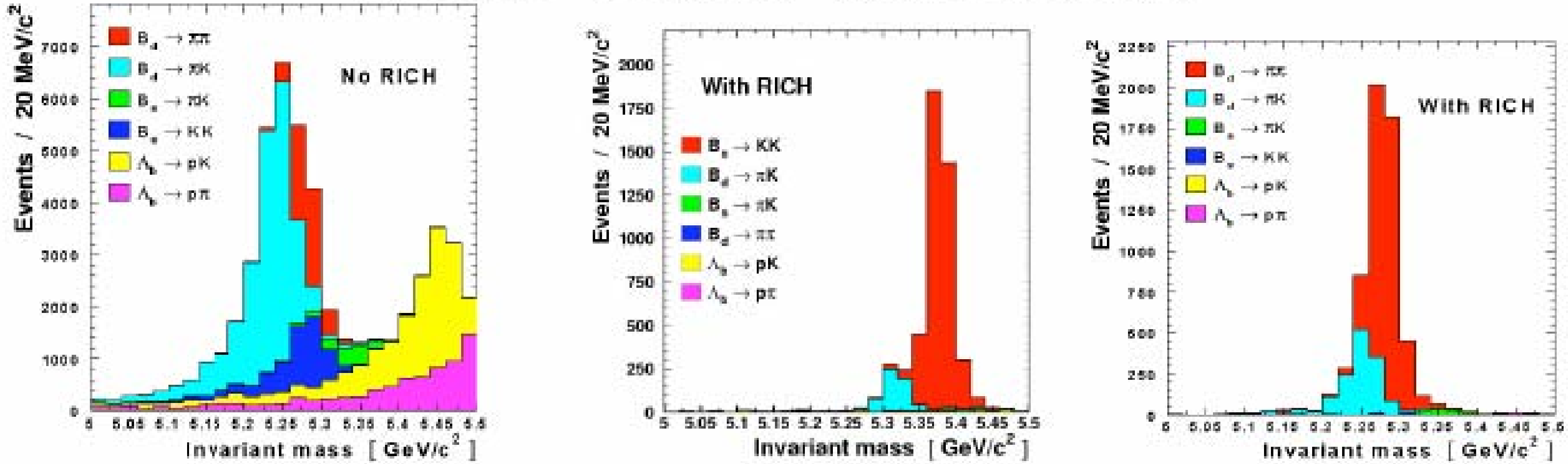
Two RICH with three radiators

Aerogel, C_4F_{10} } RICH1 (25-300 mrad)

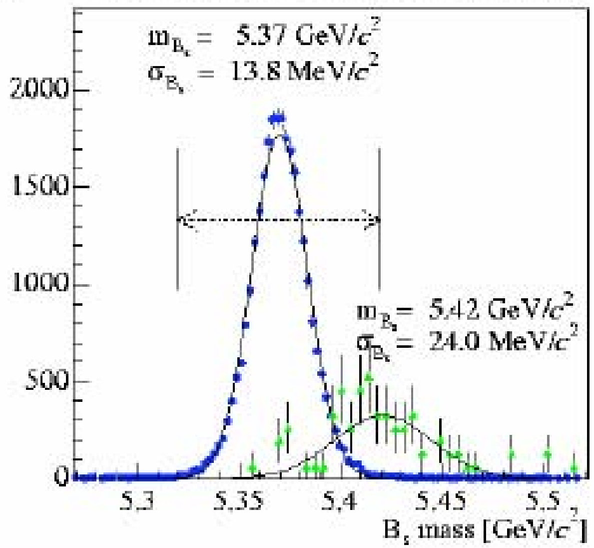
CF_4 RICH2 (15-120 mrad)

Paticle identification

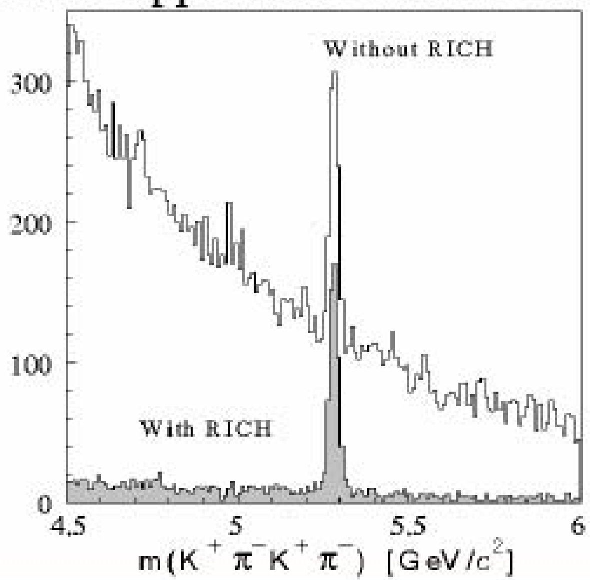
PID for B→ππ and B_s→KK reconstruction



$B_s \to D_s\pi$ suppression with PID for $B_s \to D_s K$



Comb. suppression with PID for $B \to DK^{*0}$



LHCb Trigger

Select interesting B-meson decays

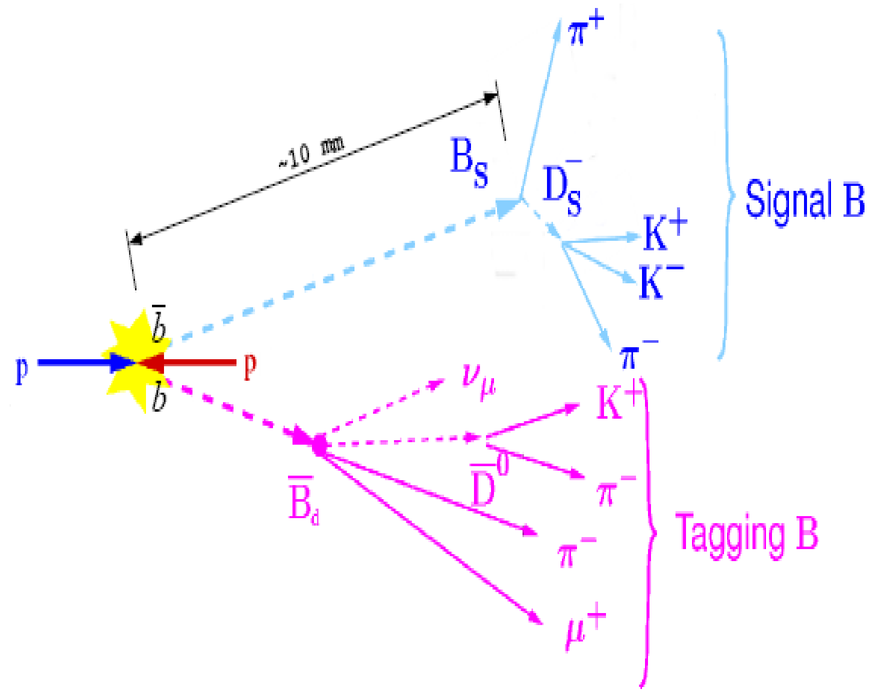
- large background/signal ratio

  $\sigma_{inelastic} / \sigma_{b\bar{b}}$ ~160
- small branching ratios (<10^{-3})
- limited detector acceptance

Require selective/efficient trigger

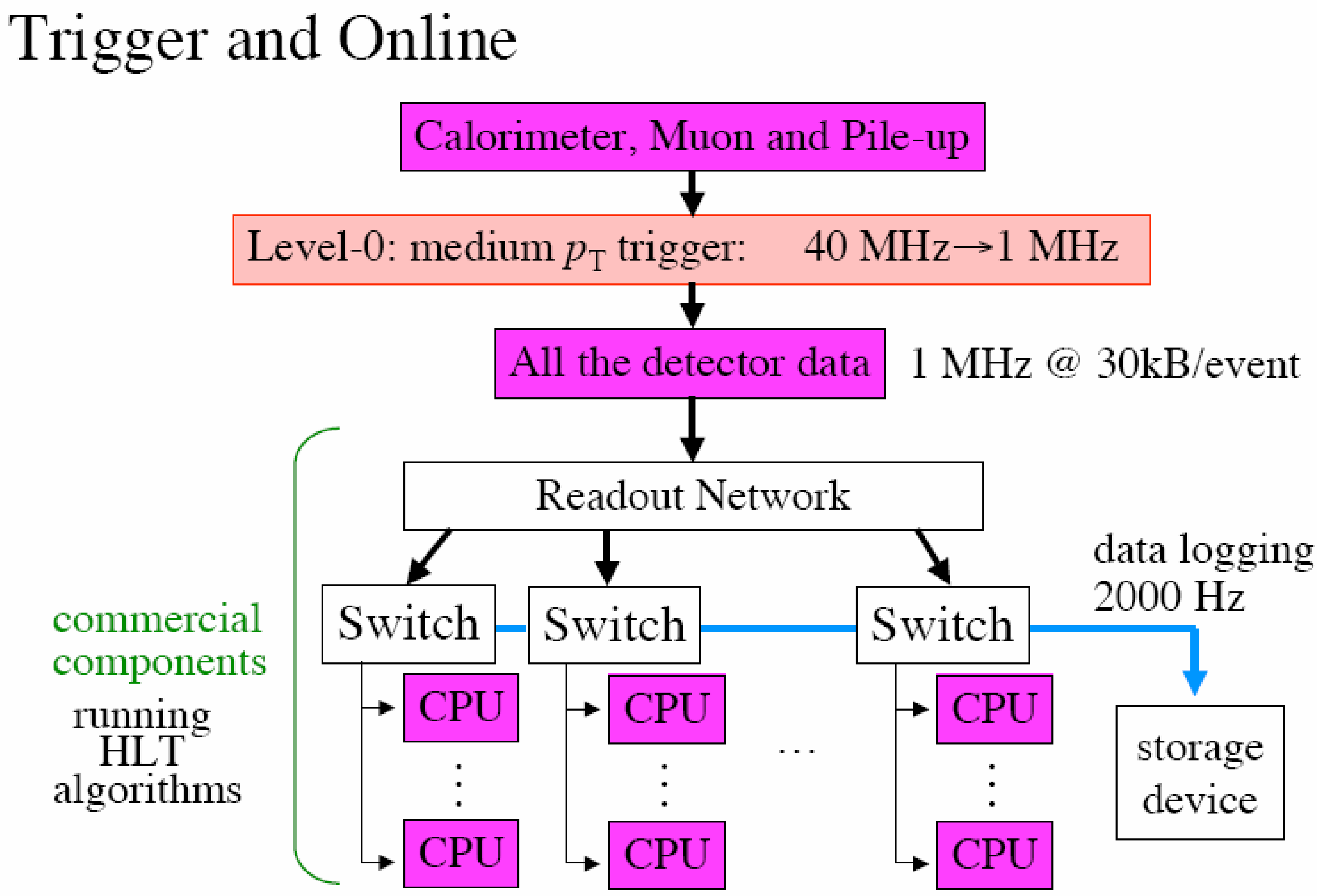
B-meson signatures:

- leptons, hadrons with large Pt
- secondary vertices
- tracks with large impact parameter



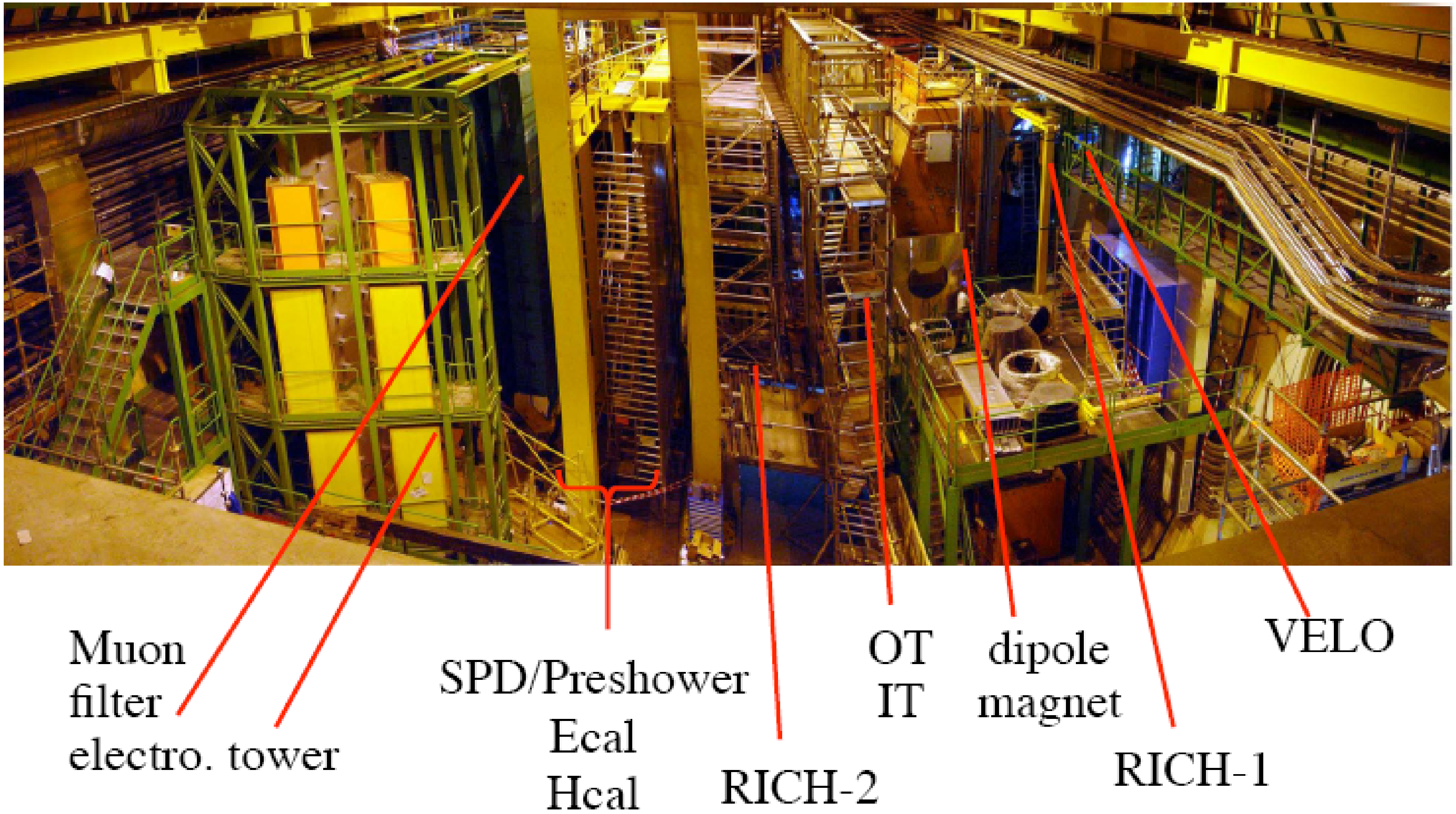
Trigger for LHCb is very challenging

LHCb Trigger



LHCb in the Cavern

Current view of the pit (IP8)



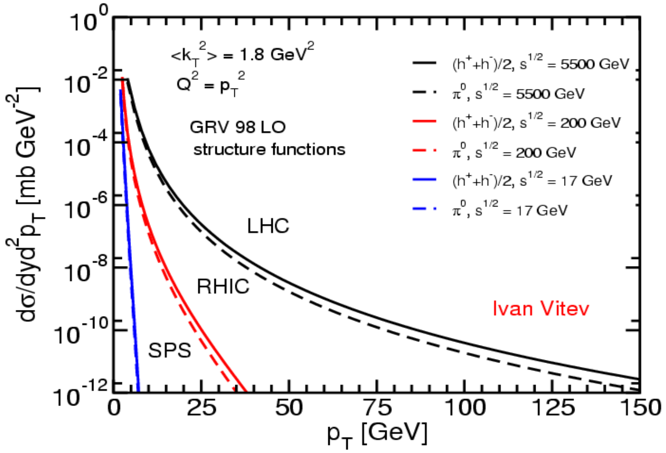
Preparing for data in 2007/2008

LHCb Summary

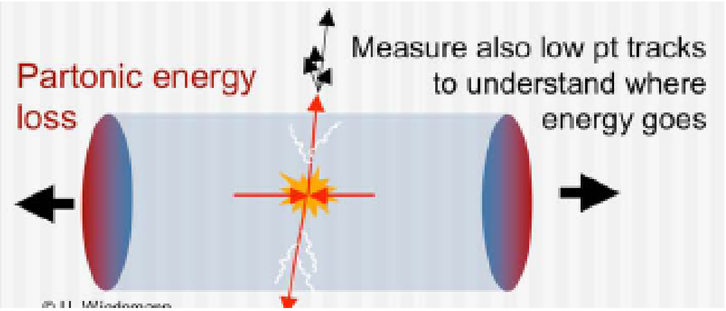
- LHCb expects to take B physics a significant step further than the B factories:
  - access to other b hadron species + high statistics
  - excellent vertexing and particle ID
  - flexible and efficient trigger, dedicated to B physics

  Many channels with different sensitivities to new physics
- Construction of the LHCb detector is advancing well
- Low luminosity ($\sim 10^{32}$) required for the LHCb experiment will allow to exploit full physics potential from the beginning of the LHC operation, and we will be ready for the pilot run in 2007 and the start of physics exploitation in Spring 2008

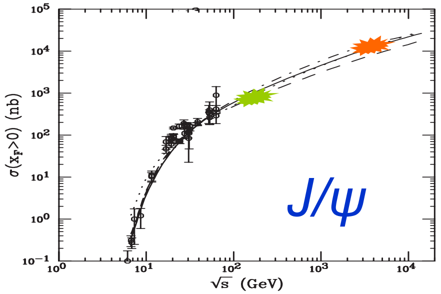
Heavy Ion Physics at the LHC

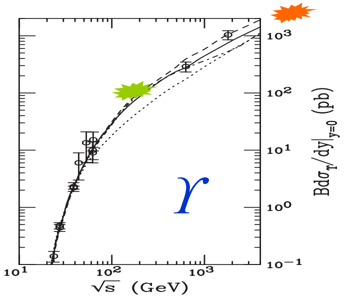


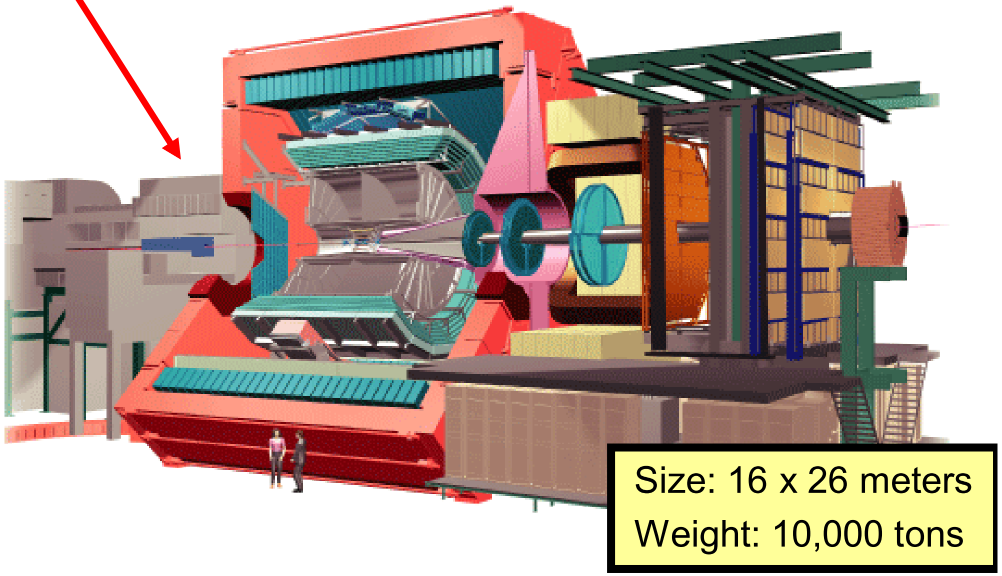
High P_T particle and jet production Jet-quenching



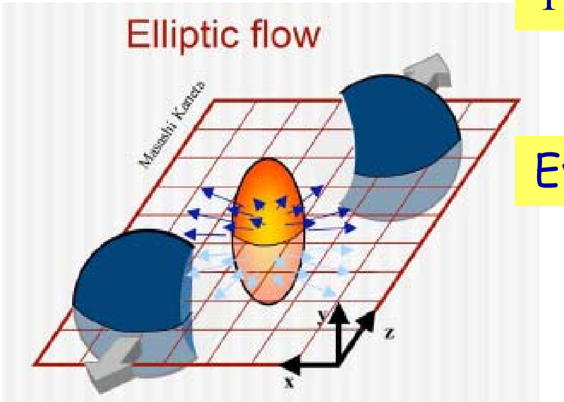
Heavy ions part of the LHC physics program with ALICE, but also CMS and ATLAS







Υ melt down



Event shapes

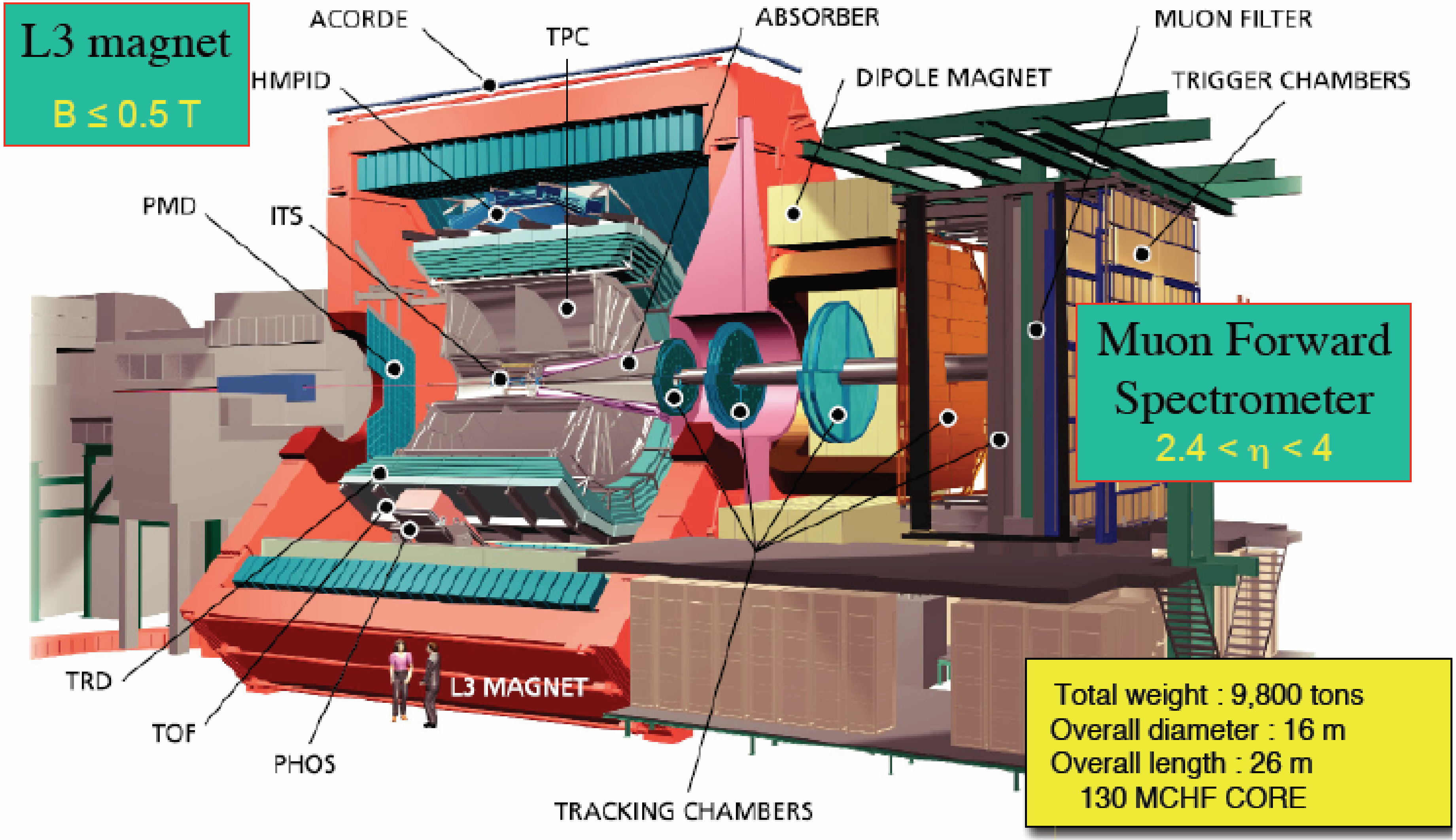
LHC ready for heavy ions in 2008?

LHC: pp / heavy ion comparison

		pp	**HI**	
Energy per nucleon	E	7	2.76	TeV
Dipole field at 7 TeV	B	8.33	8.33	T
Design Luminosity*	$\mathcal{L}$	10^{34}	10^{27}	$\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
Bunch separation		25	100	ns
No. of bunches	k_B	2808	592	
No. particles per bunch	N_p	1.15×10^{11}	7.0×10^{7}	
Collisions				
RMS beam radius at IP	σ^*	16.7	15.9	μm
Luminosity lifetime	τ_L	15	6	hr
Number of collisions/crossing	n_c	≈ 20	–	

Running time: ~ 4 weeks/year (10^6 s effective); typically after pp running
Luminosity: 10^{27} (Pb) to >10^{30} (light ions) $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ $\Rightarrow$ rate from 10 kHz to several 100 kHz; Integrated luminosity 0.5 nb^{-1}/year (Pb-Pb)

ALICE Experimental Layout



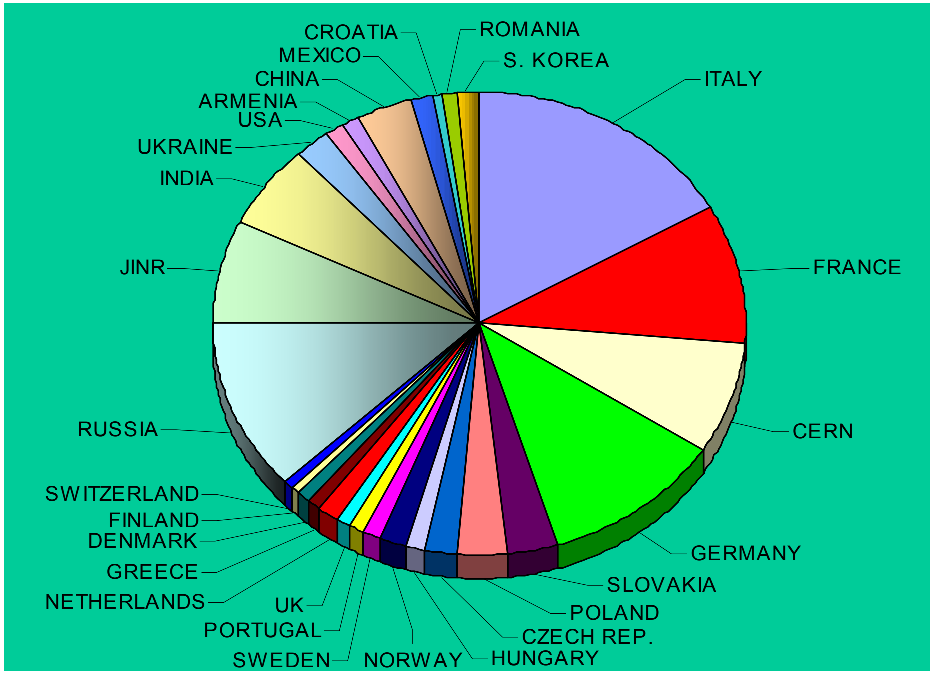
The ALICE Collaboration

~1000 collaborators total

~ ½ ATLAS,CMS; ~ 2x LHCb

30 Countries

90 Institutions



A large community which has been constantly growing over the years, and still grows:

Spain just joined

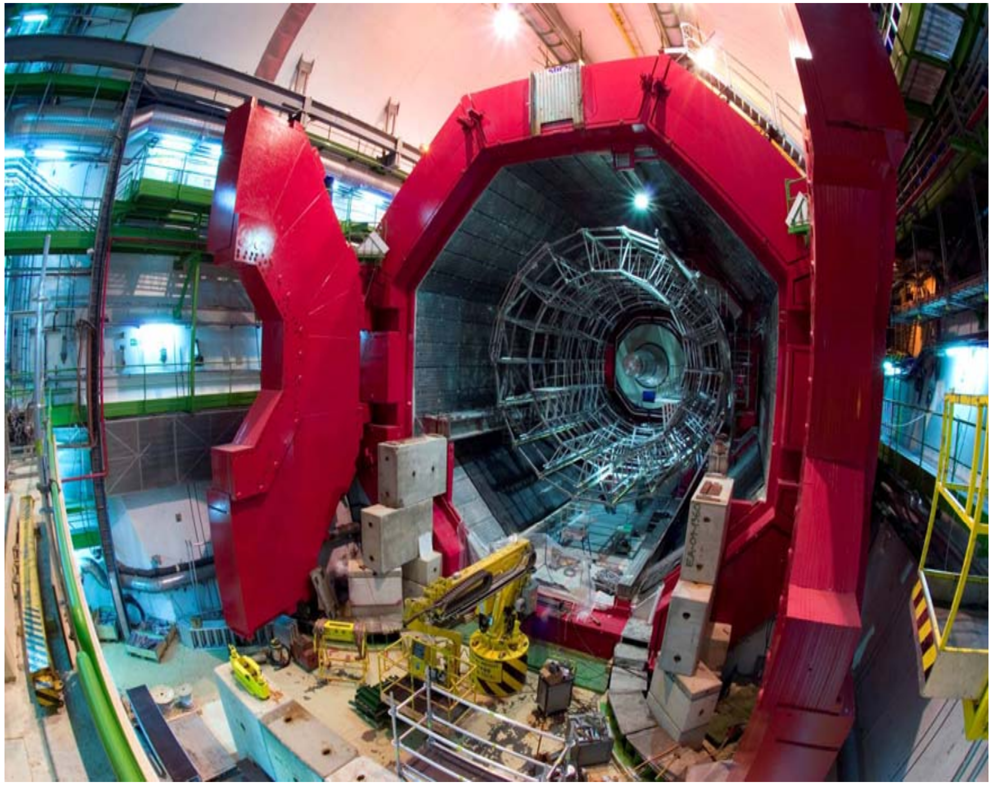
13 US institutions submitted a proposal to DOE of about 10 M$ for a large EMCAL in ALICE

Brazil is applying for membership

ALICE Design Parameters

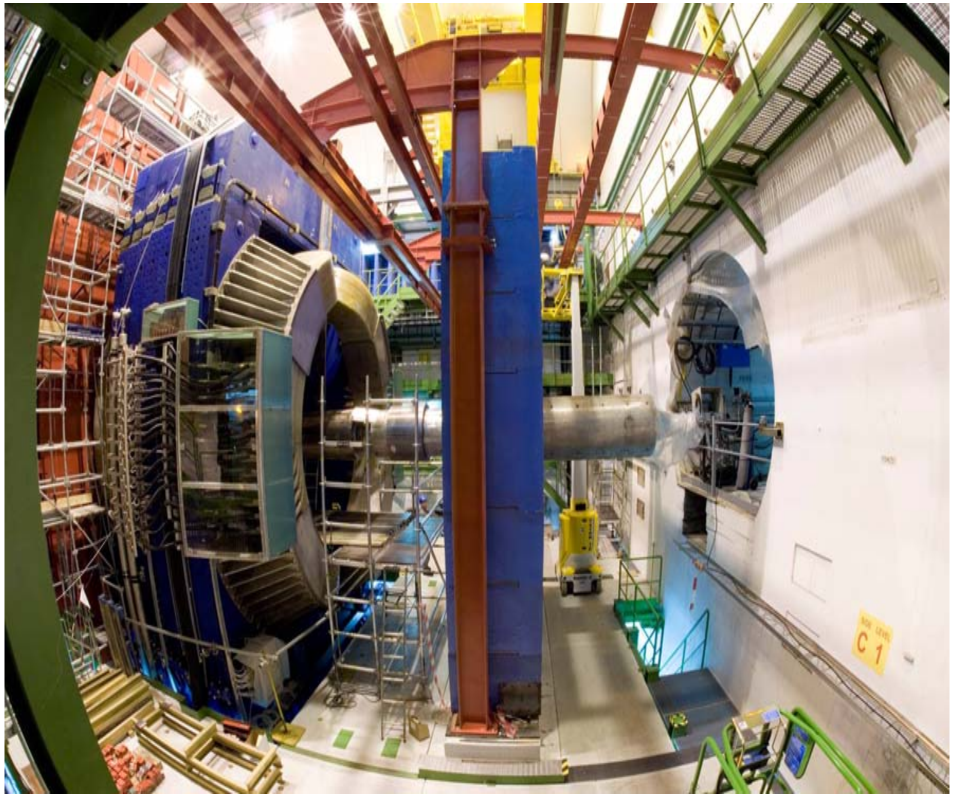
- Guideline: to measure flavor content and phase-space distribution event-by-event
  - Track and identify most (2π * 1.8 η units) of the hadrons from very low (< 100 MeV/c; soft processes) up to fairly high p_T (~100 GeV/c; hard processes)
  - Vertex recognition of hyperons and D/B mesons in an environment of very high charged-particles density (up to $dN/d\eta$ = 8000)
  - Dedicated & complementary systems for di-electrons and di-muons
  - Excellent photon detection (in $\Delta\varphi$ =45° and 0.1 η units)
  - High throughput DAQ system + powerful online intelligence ('PC farm')

ALICE in the cavern today



Solenoid ('L3') and Muon Dipole:
assembled and commissioned
field mapping done

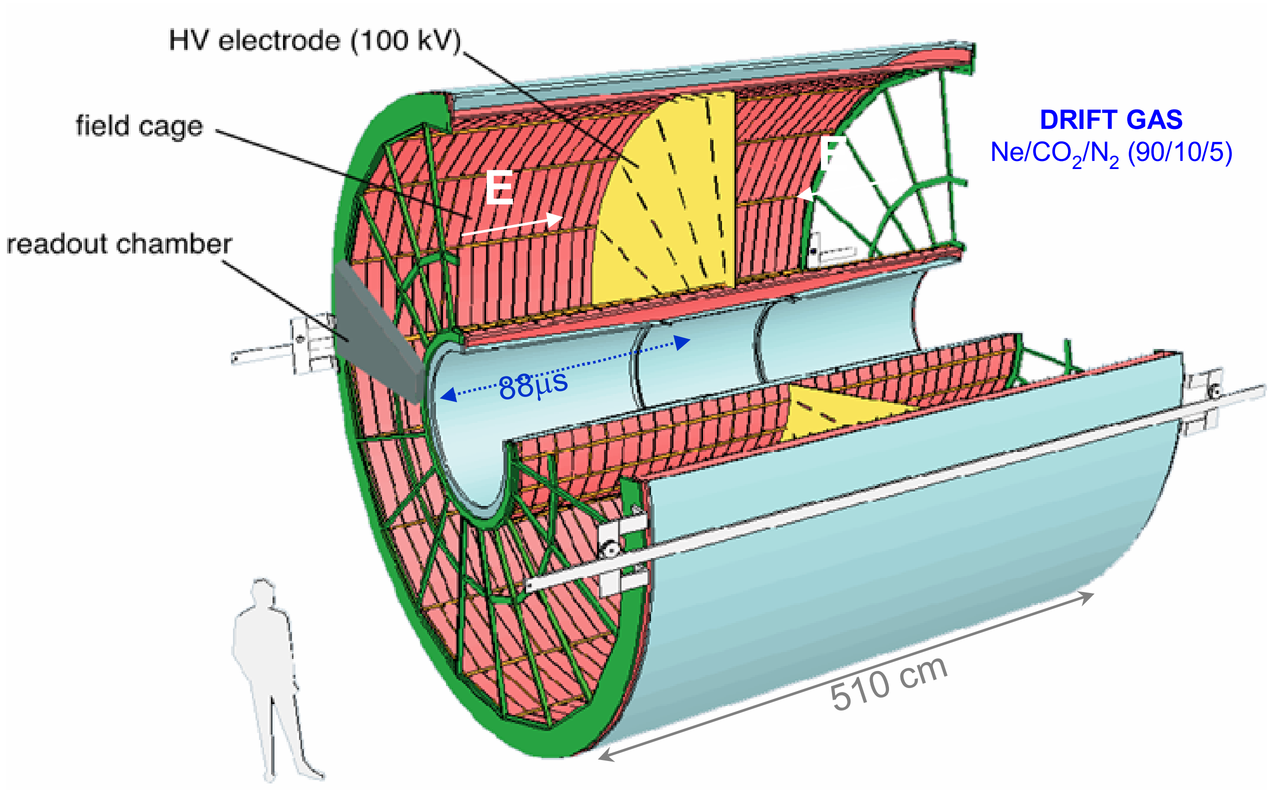
Space frame, Muon Filter and Absorber: installation completed



Time Projection Chamber

the largest gaseous detector ever built (95 m^3)

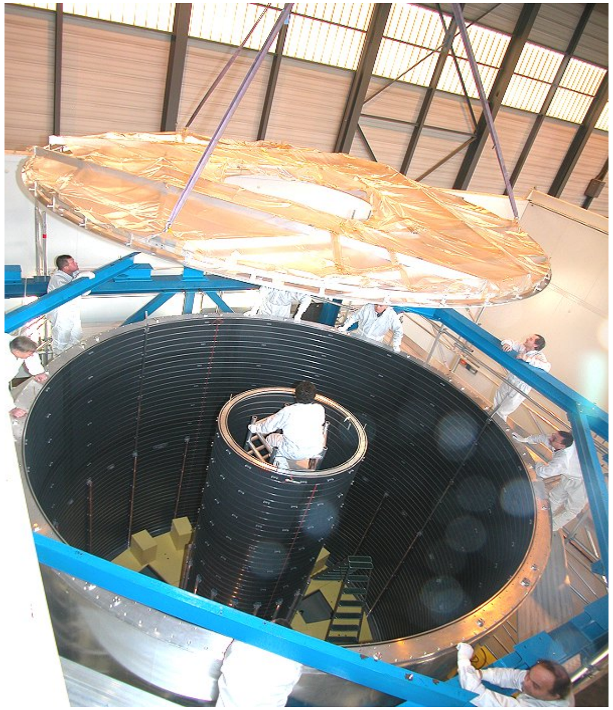
# of Pixels:570,132 pads x 500 time bins
corresponding to ~3x10^8 pixels in space



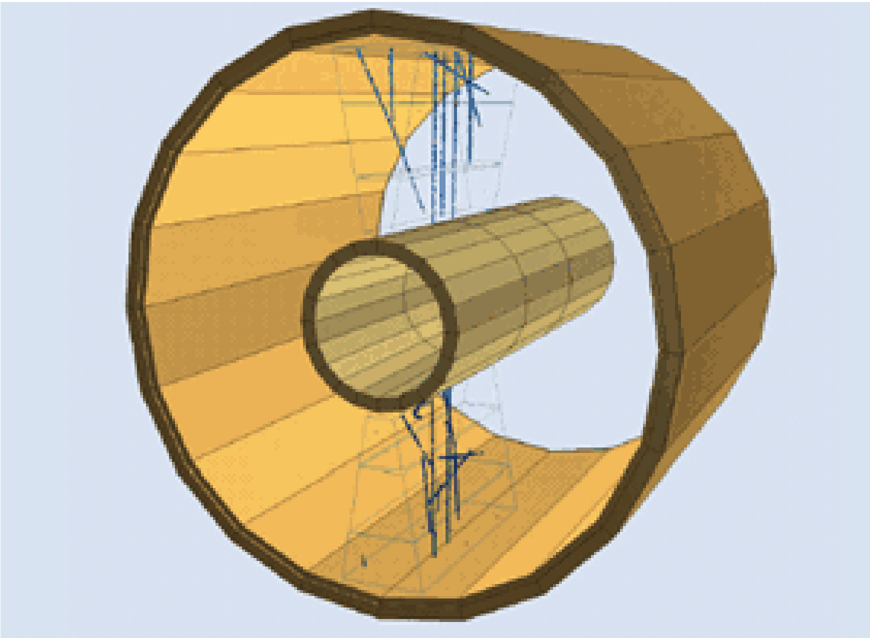
__Readout plane segmentation__
18 trapezoidal sectors each covering 20 degrees in azimuth

High structural integrity with low-mass and low-Z material (composite structures: Nomex, Tedlar, fiber matrices) X/X0~3%

TPC Field Cage and RO Chamber Installation



ALICE: cosmics seen in the TPC



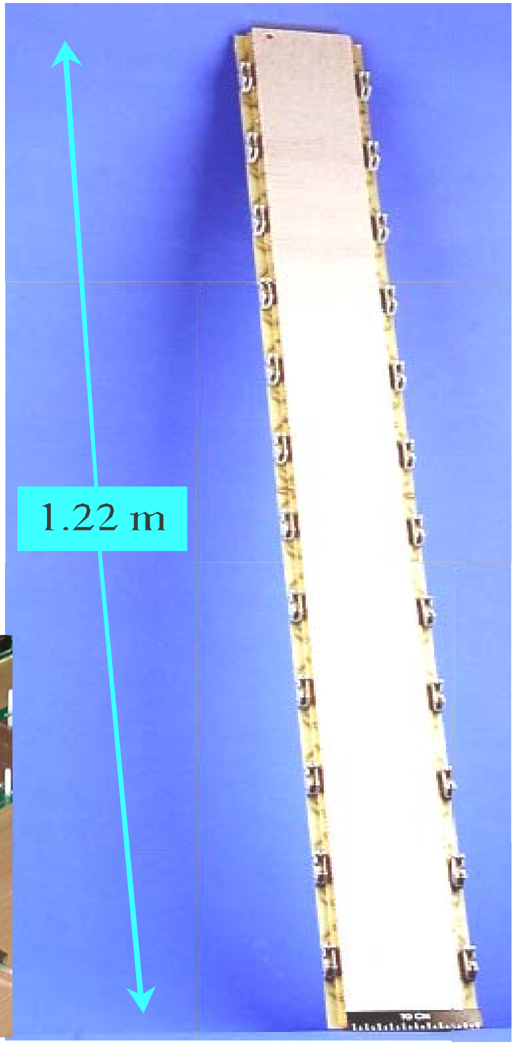
First results from analysis of commissioning data:
Features very close to TDR specifications
Start instalation in Nov. 06

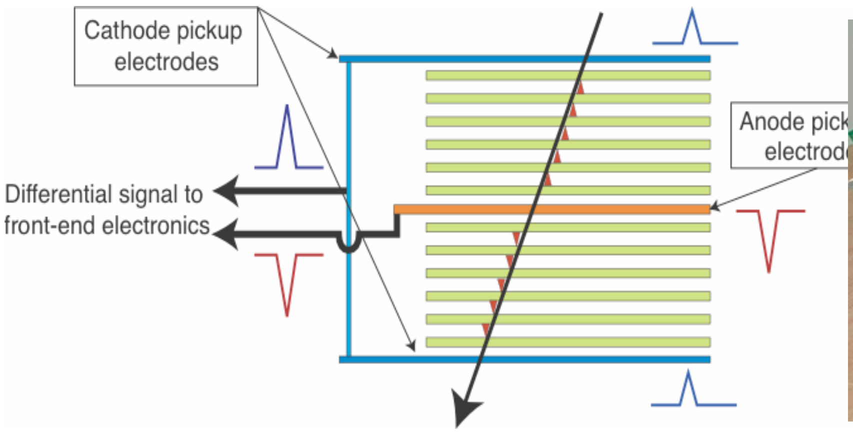
Time of Flight Detector

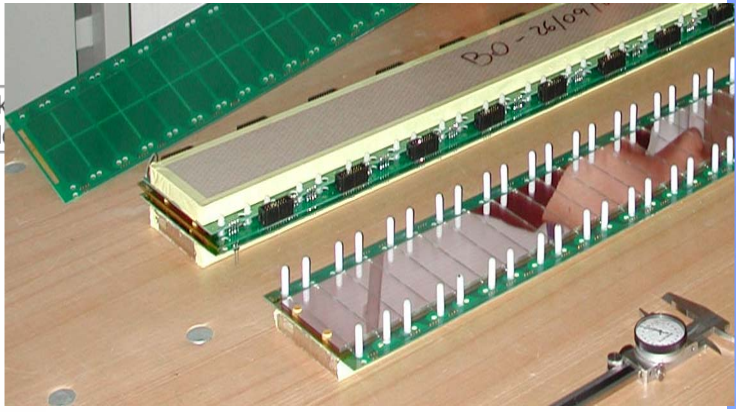
A revolution in technology: a standard TOF system built of fast scintillators + photomultipliers would cost > 100 MCHF

157,248 channels
total sensitive area: ~150 m^2

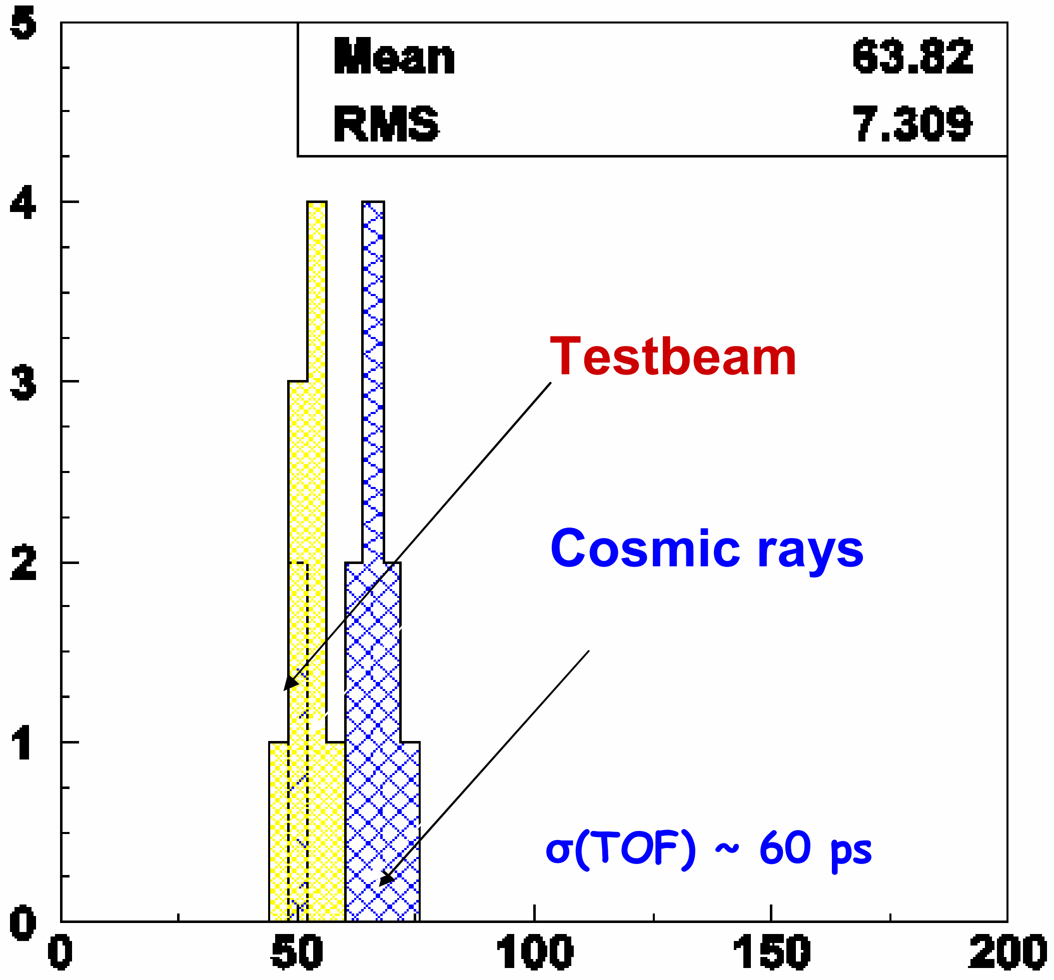
Multi-gap Resistive Plate Chamber (MRPC):
10 gas gaps, each of 250 micron width
built in the form of strips (1600 in total), each with an active area of 120 x 7 cm^2, readout by 96 pads (each 2.5 x 3.5 cm^2)







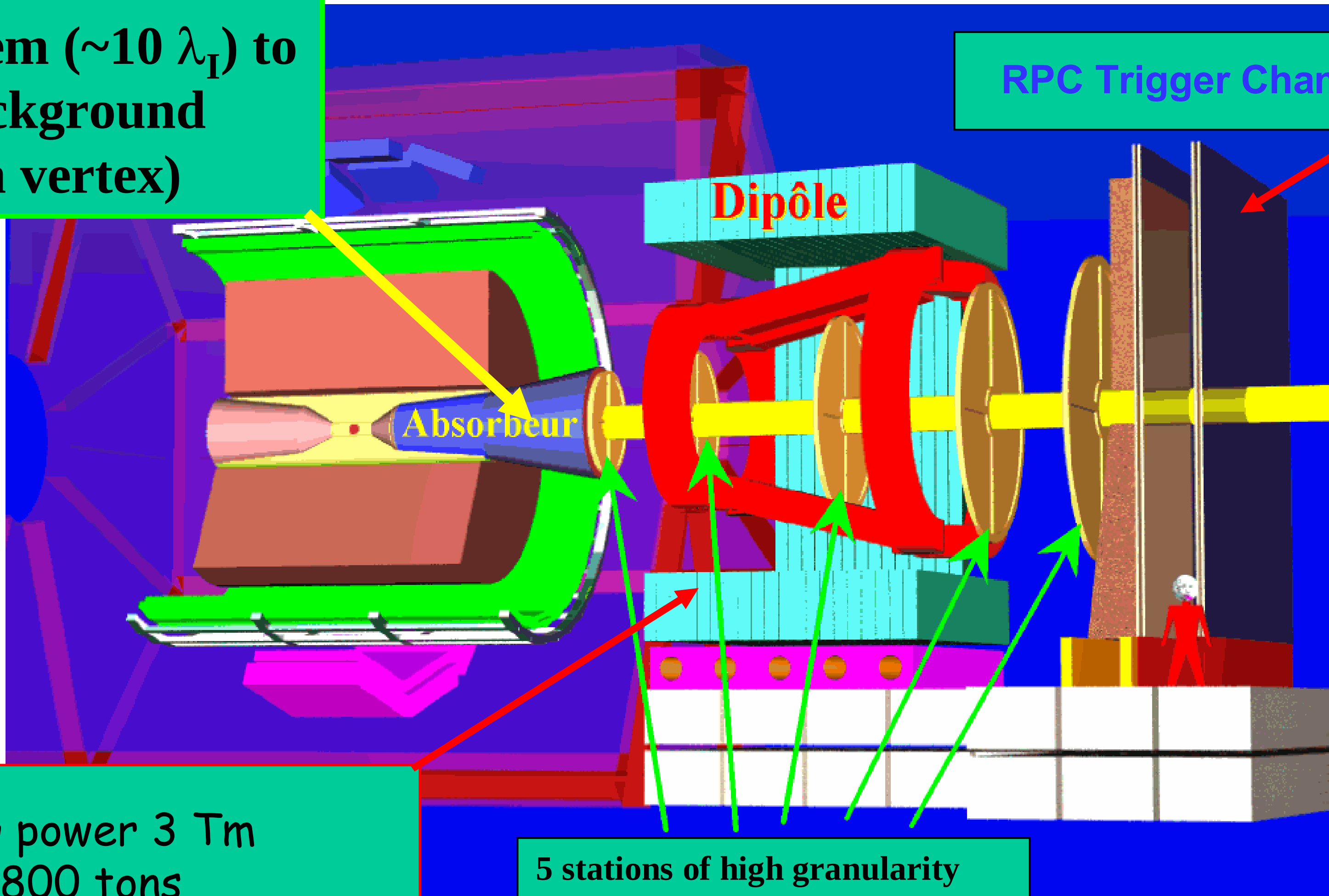
Time of Flight Detector



Muon arm of ALICE

Complex absorber/small angle shield system (~10 λ_I) to minimize background (90 cm from vertex)

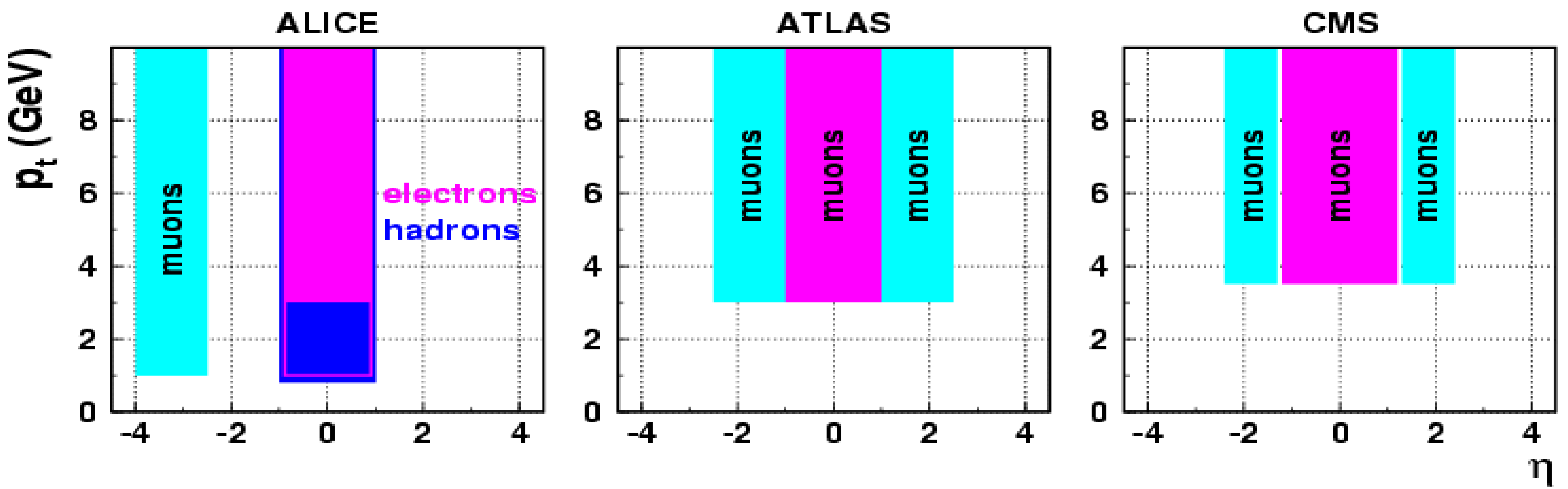
RPC Trigger Chambers



- 0.7 T, bending power 3 Tm
- 4 MW power, 800 tons
- World's largest warm dipole

5 stations of high granularity pad tracking chambers, over 1 million channels

ALICE vs ATLAS/CMS acceptance



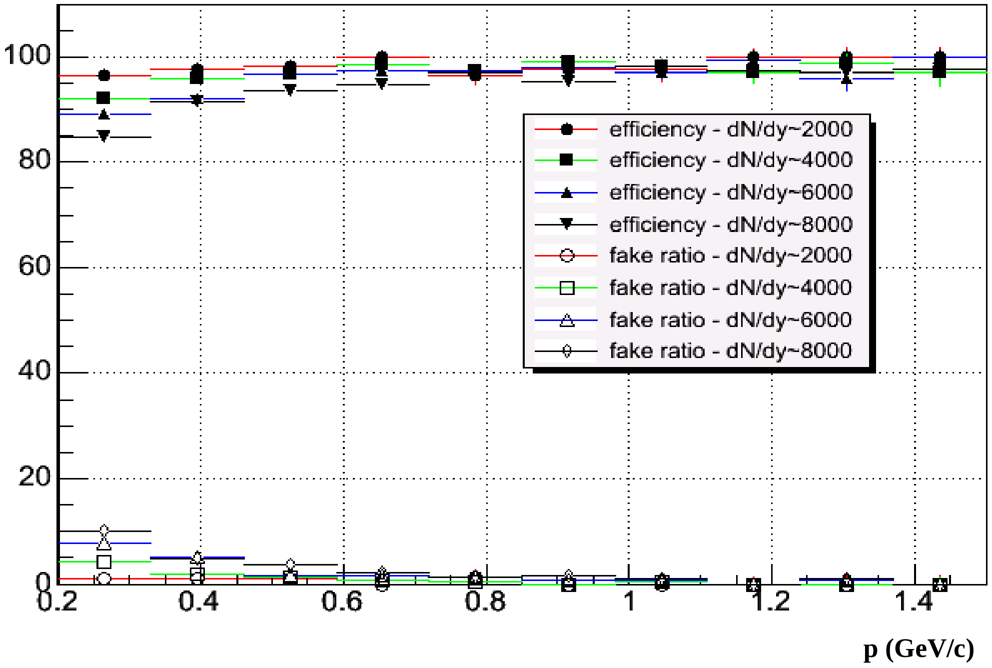
ATLAS & CMS present a large lepton acceptance $|\eta|<2.4$

ALICE combines muonic and electronic channels

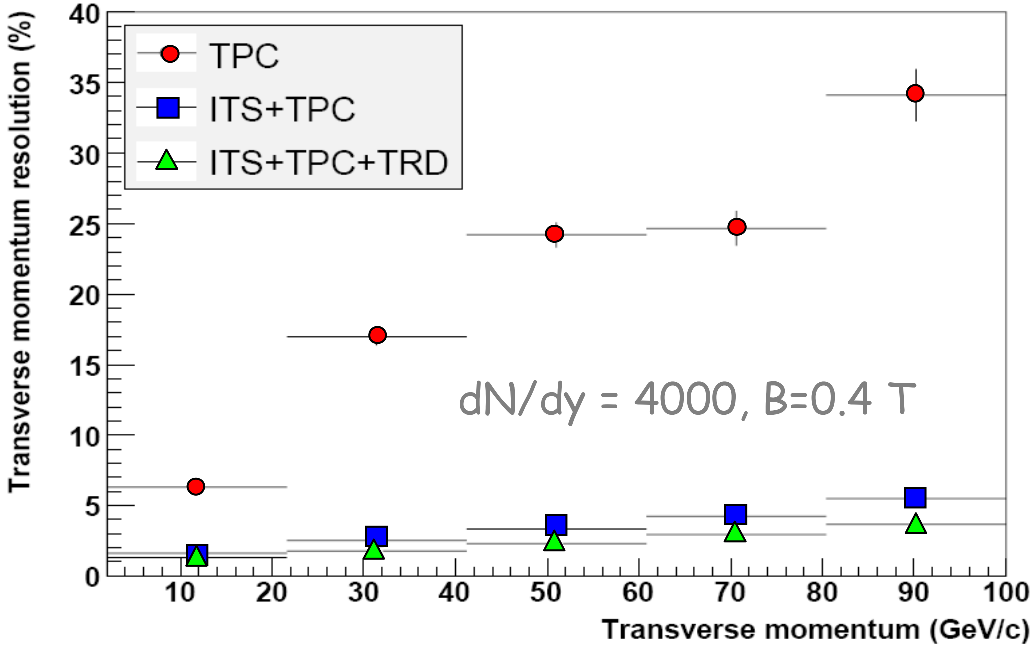
- covers the low p_T region (quarkonia)

- covers the forward region $2.5<\eta<4.0$

ALICE Tracking performance

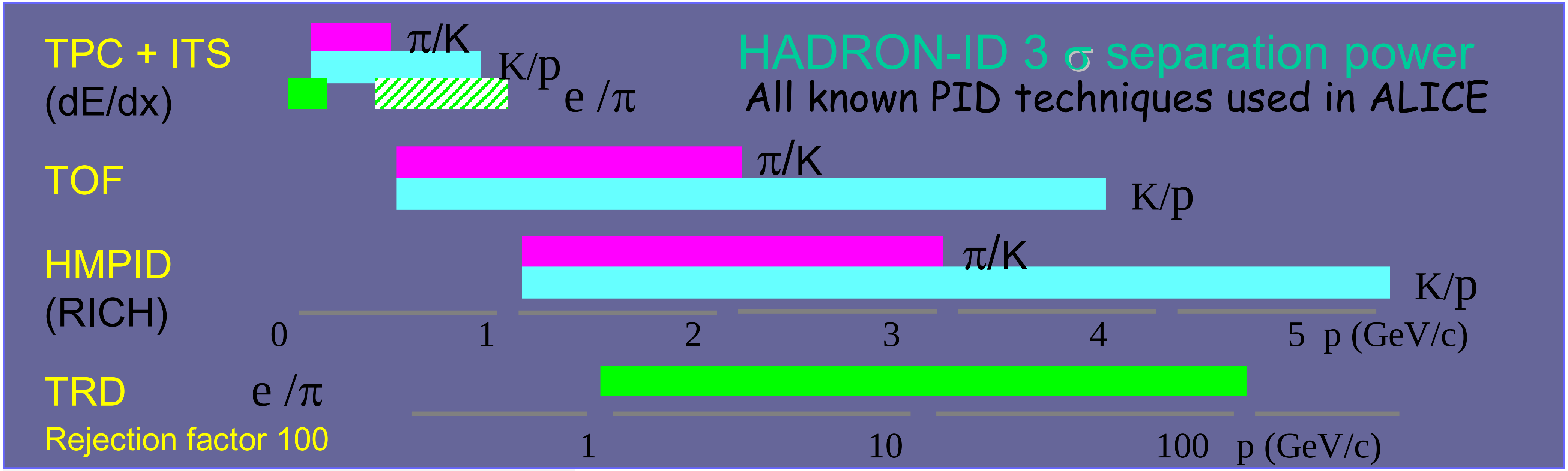


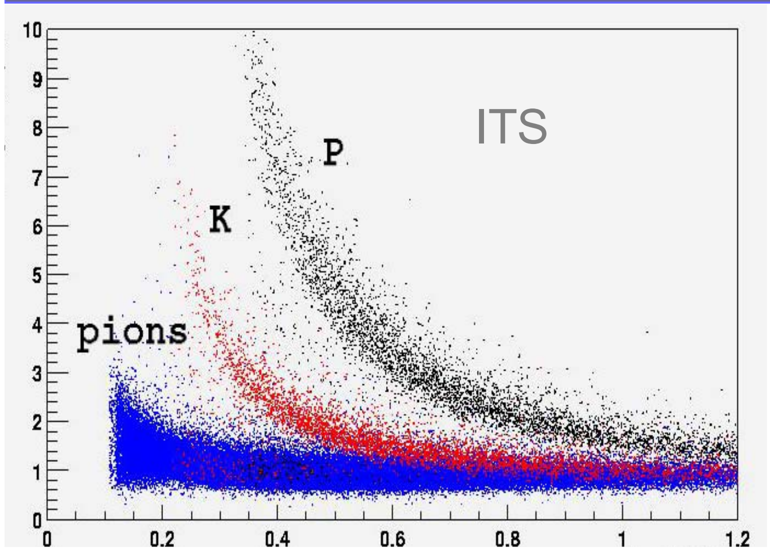
resolution ~ 5% at 100 GeV/c
excellent performance in hard region!

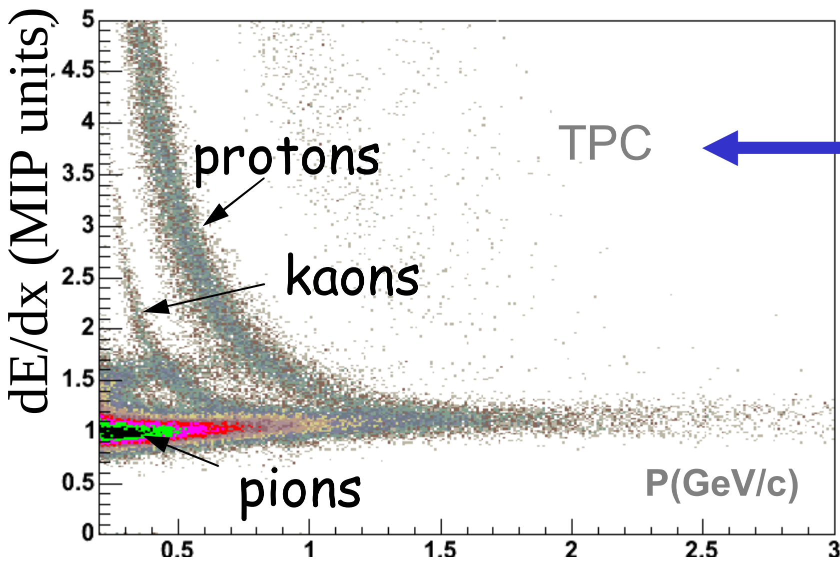


For track densities dN/dy = 2000 - 4000, combined tracking efficiency well above 90% with <5% fake track probability

Charged Particle Identification



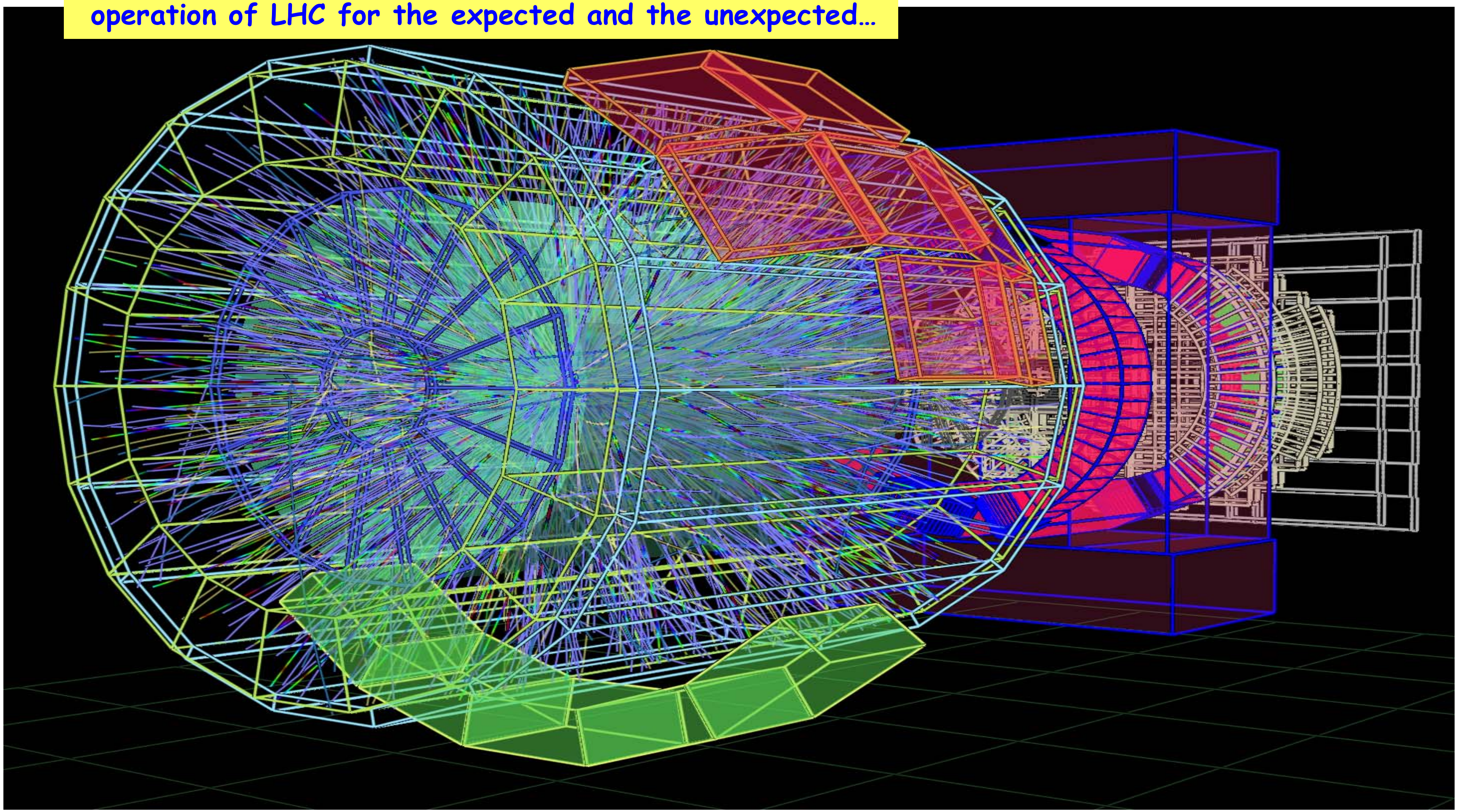




$s_{dE/dx}$ = 6.8%
at dN/dy=8000
(5.5% for
isolated tracks)

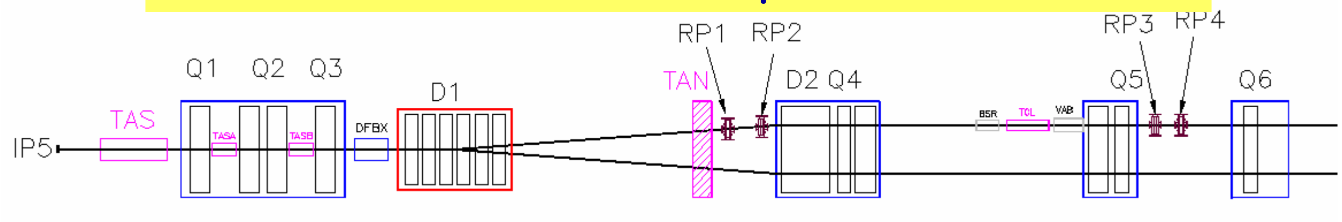
Summary on ALICE

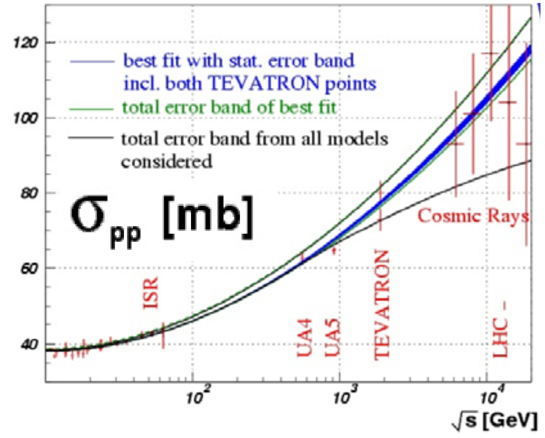
- ALICE is taking shape
- All large structures are installed and integration of detector subsystems will start in August
- The ALICE Collaboration looks forward to first operation of LHC for the expected and the unexpected…



Forward Coverage: TOTEM/LHCf

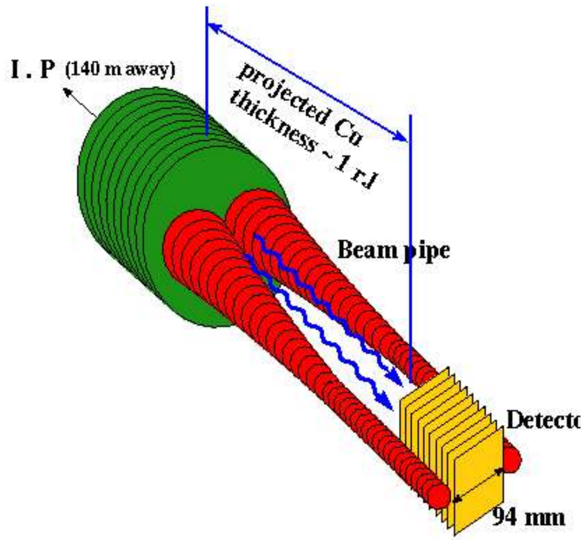
TOTEM: measuring the total, elastic and diffractive cross sections
Add Roman pots (and inelastic telescope) to CMS interaction regions.
Common runs with CMS planned

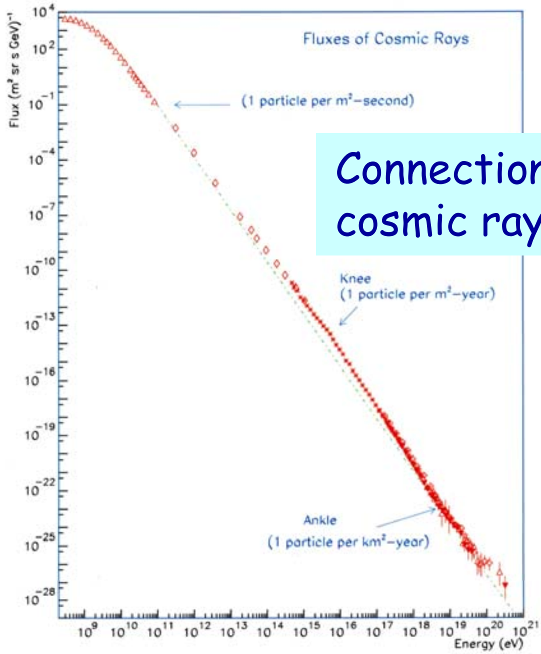




LHCf: measurement of photons and neutral pions in the very forward region of LHC

Add a EM calorimeter at 140 m from the Interaction Point (of ATLAS)





Connection with cosmic rays

Physics program

Total cross-section with a precision of 1%

Elastic pp scattering in the range $10^{-3} < t = (p\theta)^2 < 10\ GeV^2$

Soft diffraction

Measurement of leading particles

Particle and energy flow in the forward direction

Soft and hard diffraction in Single and Double Pomeron Exchange
production of jets, W, heavy flavours.....

Central Exclusive particle production

Low-x physics

$\gamma\gamma$ and γp physics

WITH CMS

pp Total Cross-Section

Current models predict for
14 TeV: 90 – 130 mb

Aim of TOTEM: ~ 1% accuracy

Luminosity independent method:

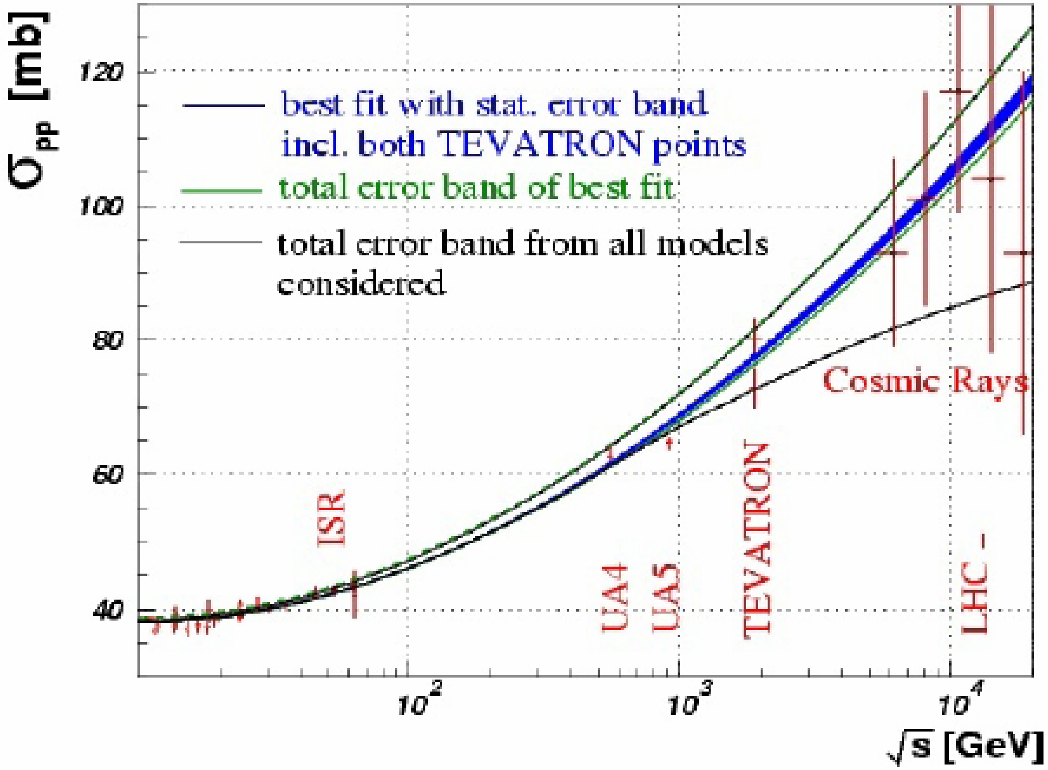
Optical Theorem $$L\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \left.\frac{dN}{dt}\right|_{t=0}$$

$$L\sigma_{tot} = N_{elastic} + N_{inelastic}$$

⇩

$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{\left.(dN/dt)\right|_{t=0}}{N_{el} + N_{inel}}$$

COMPETE Collaboration:

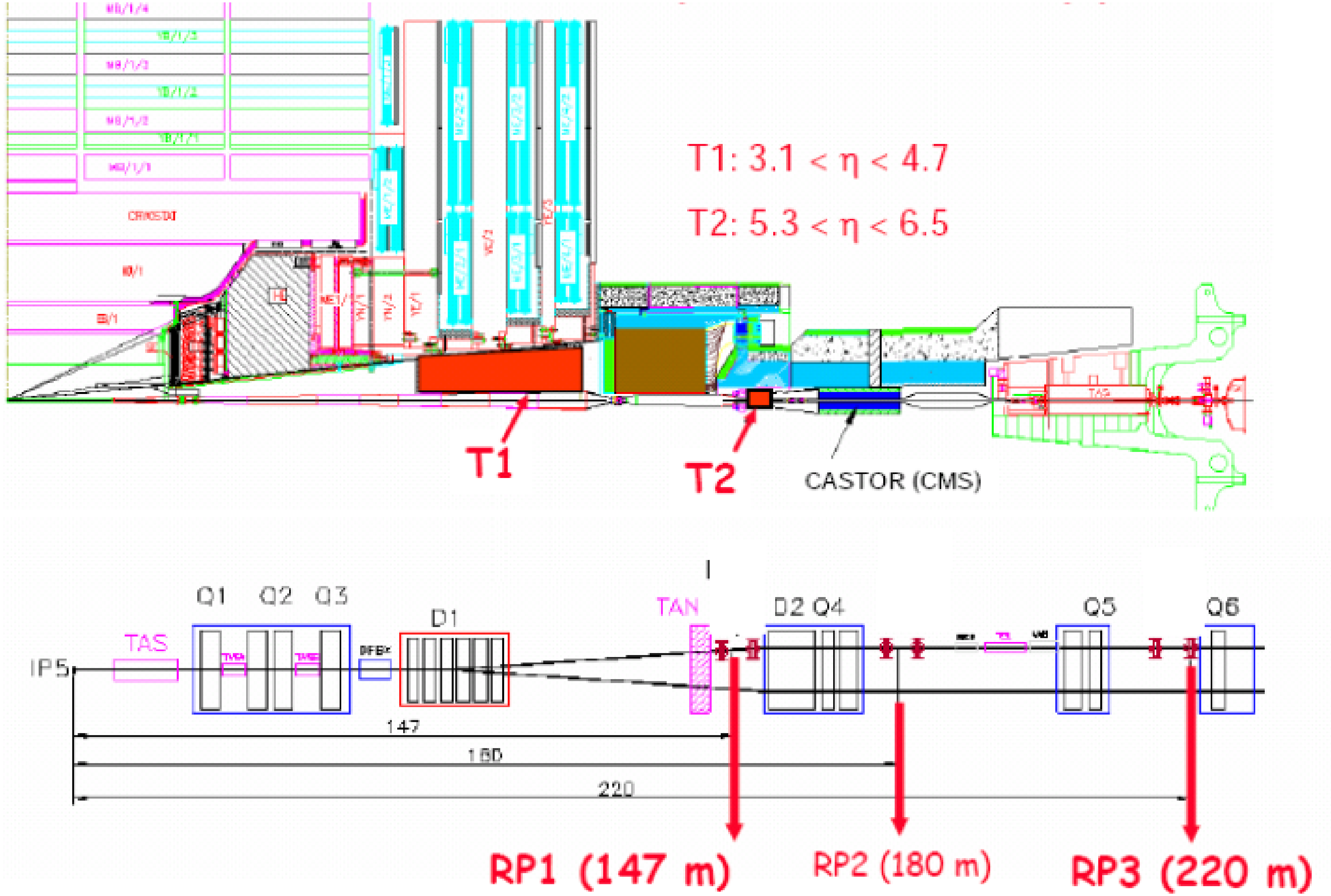


COMPETE Collaboration fits all available hadronic data and predicts at LHC:

$$\sigma_{tot} = 111.5 \pm 1.2 \begin{smallmatrix} +4.1 \\ -2.1 \end{smallmatrix} \text{ mb}$$

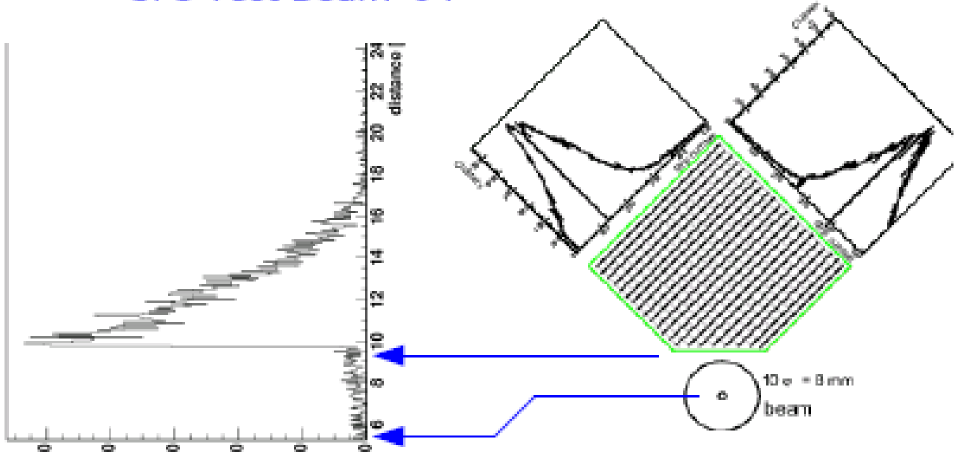
PRL 89 201801 (2002)]

Experimental apparatus

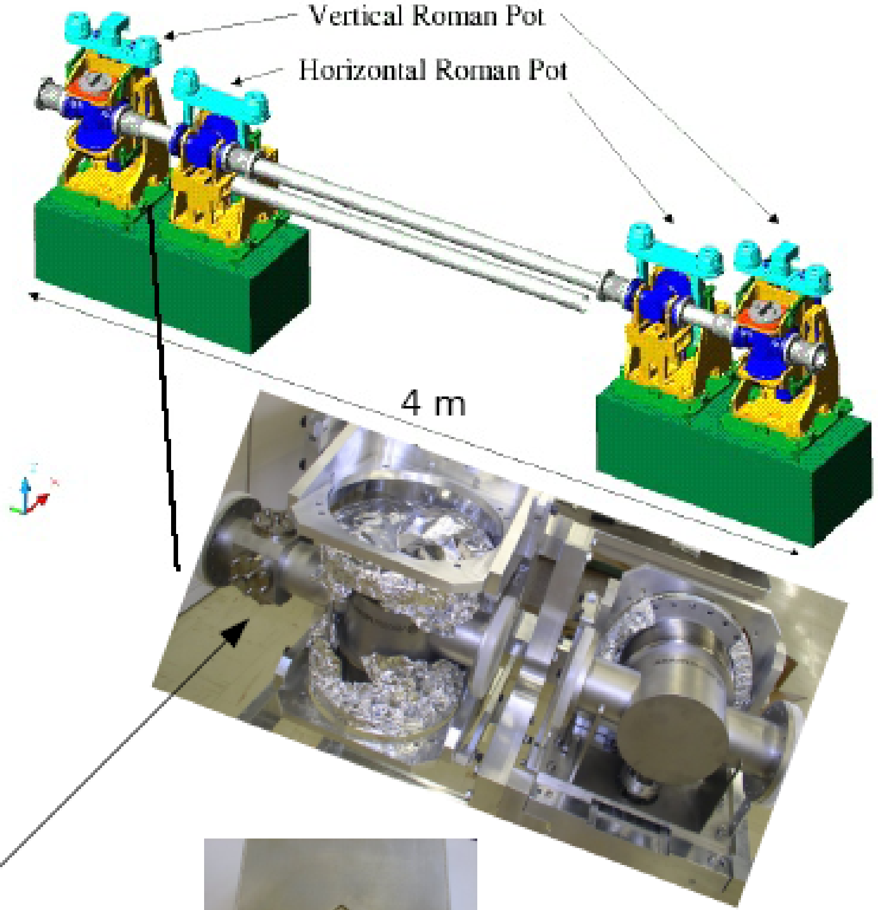


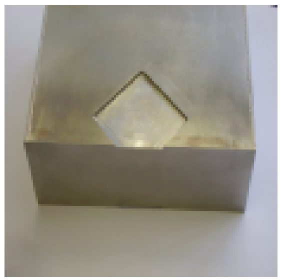
Roman Pot

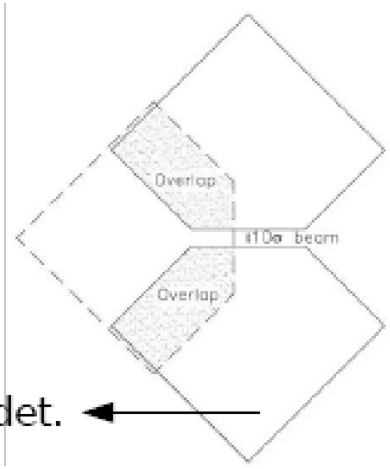
SPS Test Beam '04



reconstructed track







Roman Pot unit:

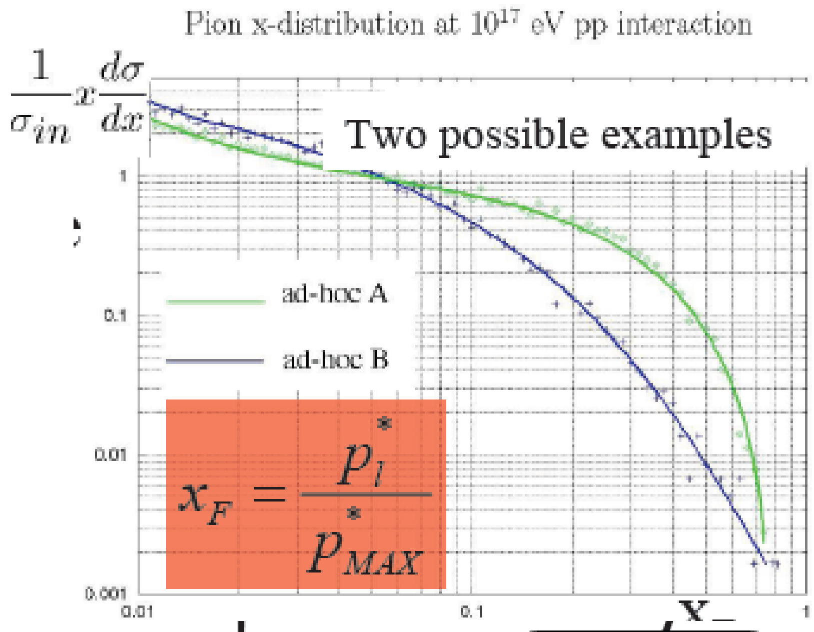
- Measurement of very small p scattering angles (few μrad)
- Vertical and horizontal pots mounted as close as possible
- BPM fixed to the structure gives precise position of the beam
- TOTEM at the RP: $\sigma_{beam} \approx 80$ μm
- Leading proton detection at distances down to $10\ \sigma_{beam} + d$
- Need "edgeless" detectors that are efficient up to the physical edge to minimize "d"

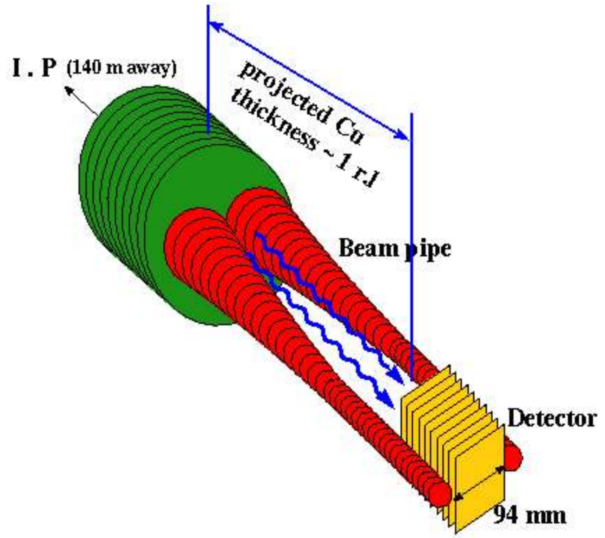
10 planes
Si edgeless det.

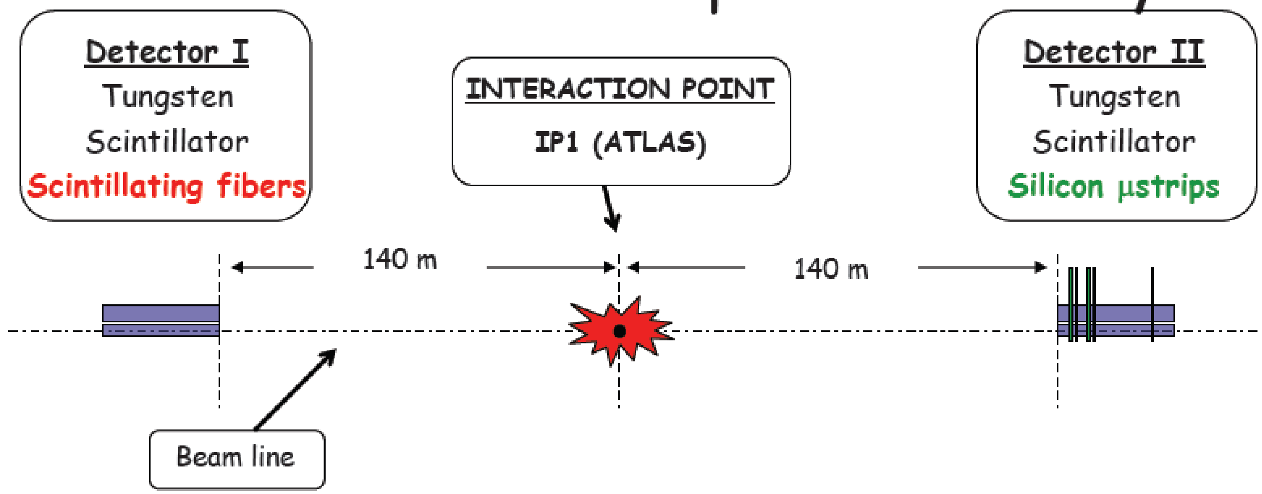
LHCf: an LHC Experiment for Astroparticle Physics

LHCf: measurement of photons and neutral pions and neutrons in the very forward region of LHC

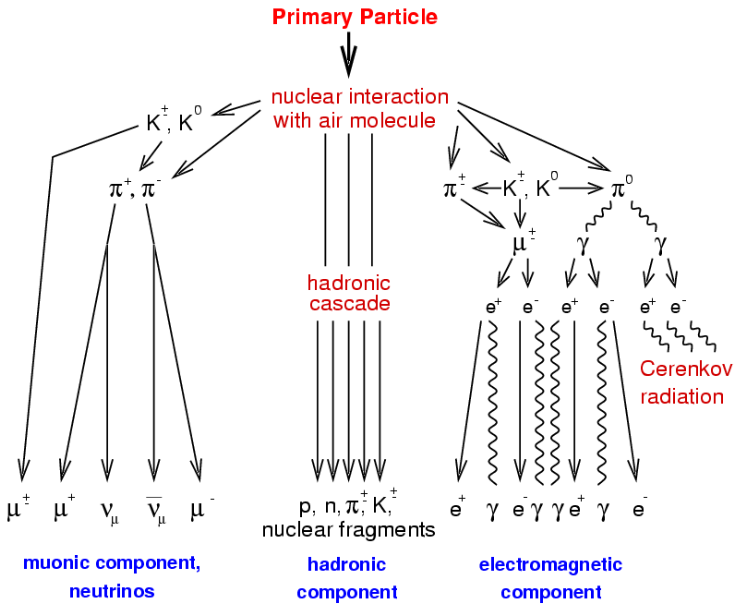
Add an EM calorimeter at 140 m from the Interaction Point (IP1 ATLAS)
For low luminosity running

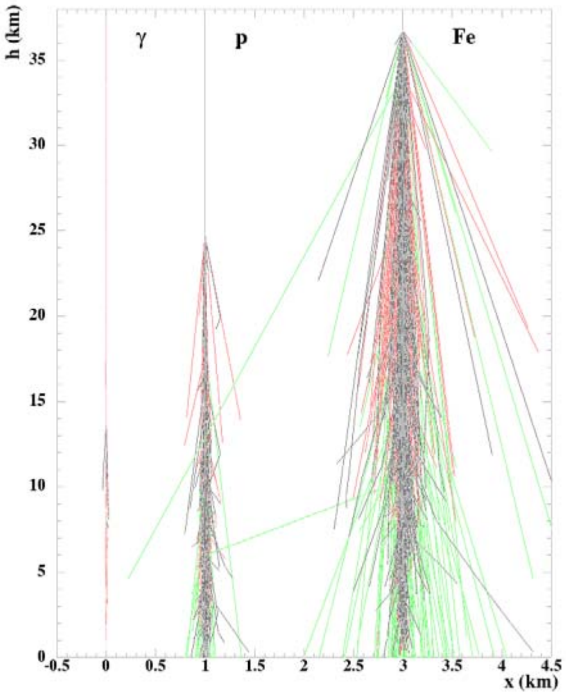




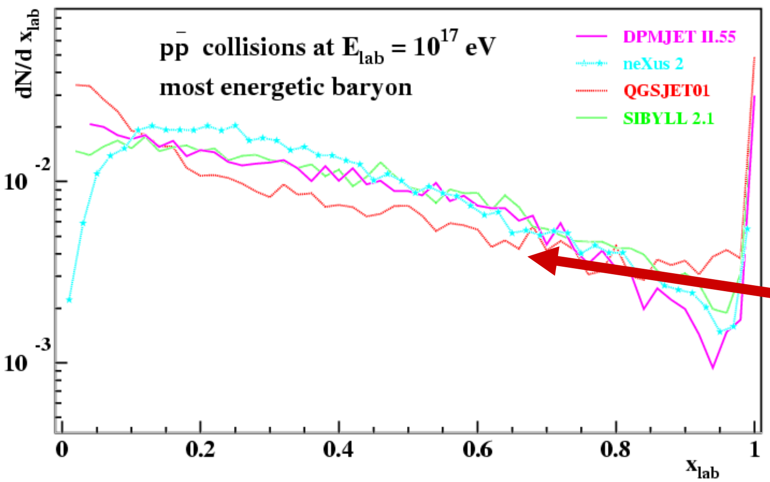


High Energy Cosmic Rays



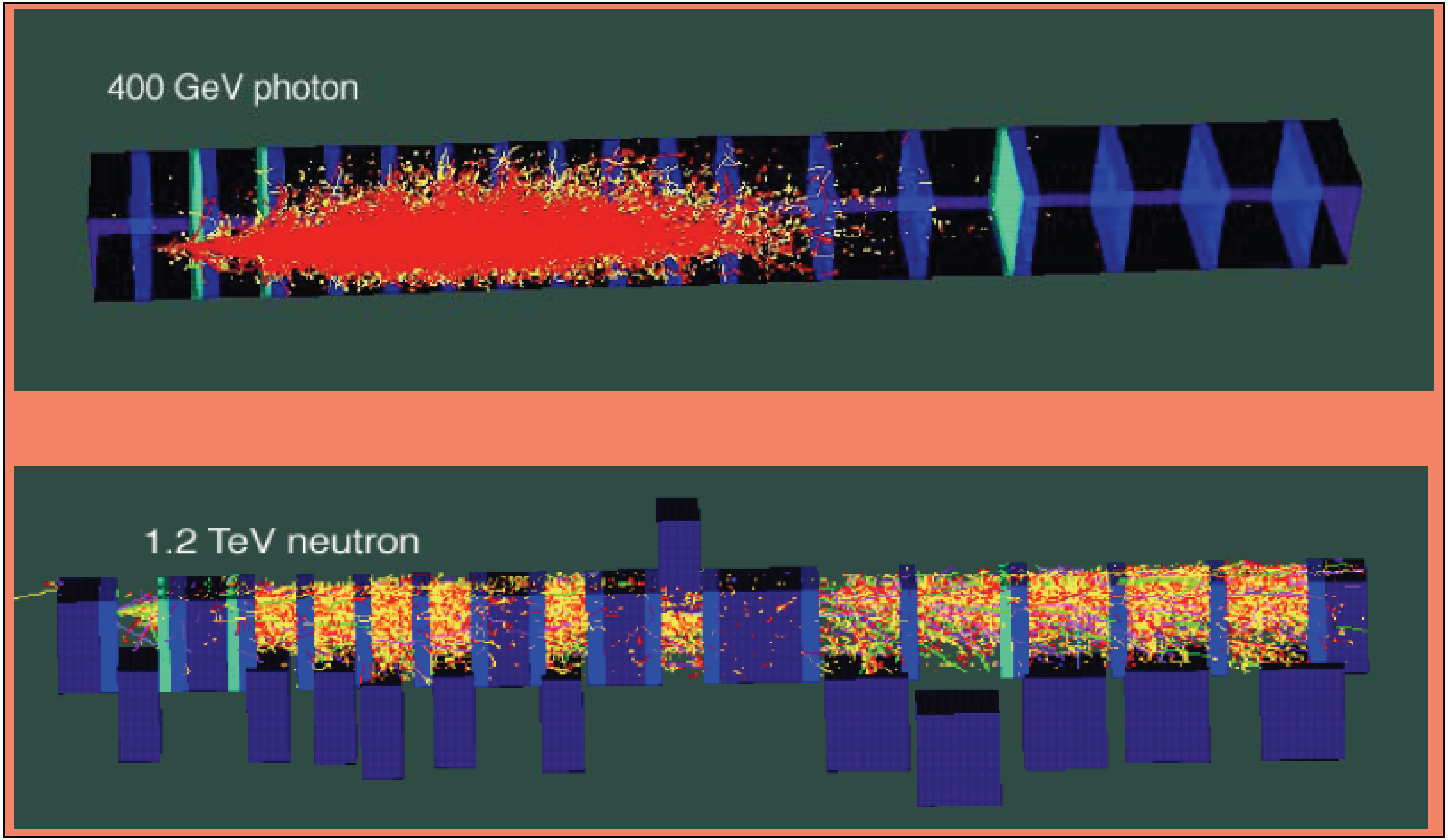


Cosmic ray showers:
Dynamics of the high energy particle spectrum is crucial



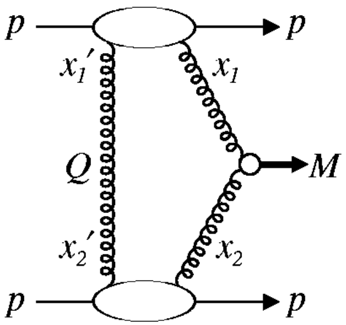
Interpreting cosmic ray data depends on hadronic simulation programs
Forward region poorly know/constrained
Models differ by factor 2 or more
Need forward particle/energy measurements
e.g. $dE/d\eta$…

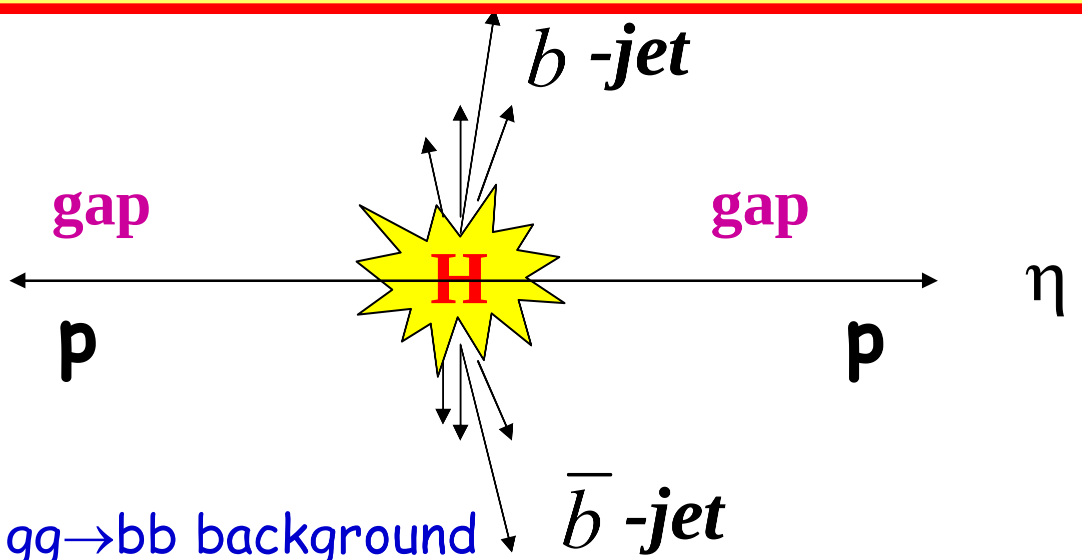
Particle response



Roman Pots at 420m: FP420 R&D Project

A recent development: search for exclusive Higgs production:
Exclusive diffractive Higgs production pp→ p +H+ p : 2-100 fb SM/MSSM



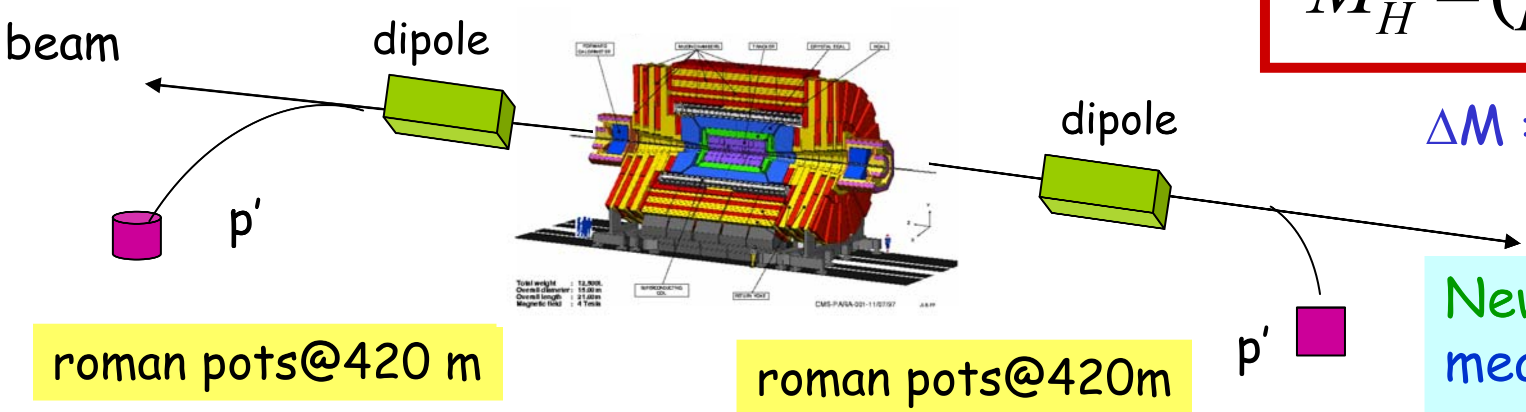


Advantages Exclusive:

- Jz=0 suppression of gg→bb background
- Mass measurement via missing mass

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

ΔM = O(1.0 - 2.0) GeV



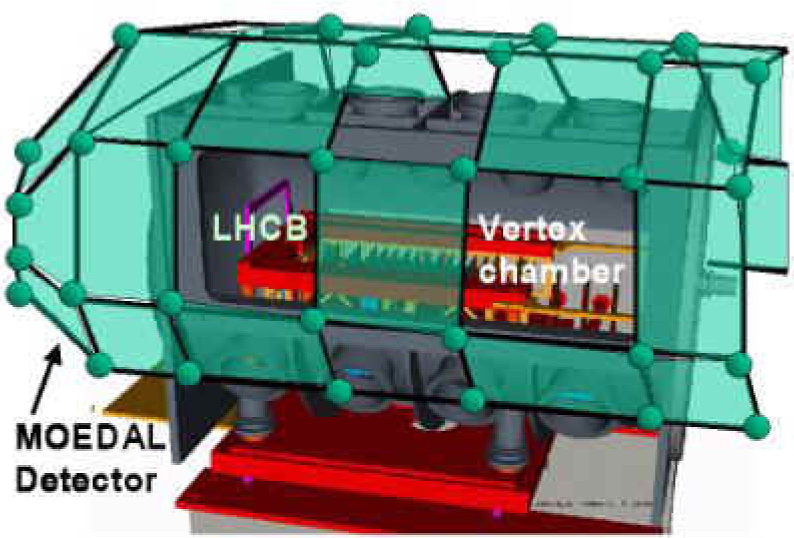
New: allows to measure CP quantum numbers of the Higgs

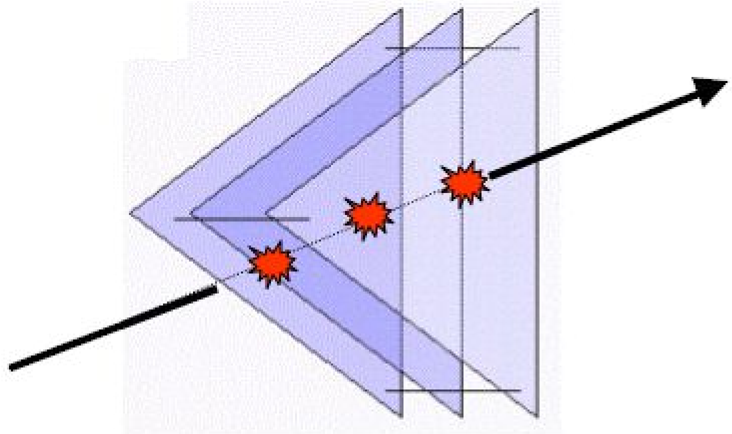
Baseline Detector Coverage

- ATLAS, CMS
  - → Tracking and muon system $|\eta| < 2.5$
  - → Calorimetry $|\eta| < 5$
- ALICE
  - → Tracking (TPC, vertexing) $|\eta| < 0.9$
    - and several other specialized detectors
  - → Muon spectrometer $2.4 < \eta < 4$
  - → Zero-Degree Calorimeter (ZDC)
- LHCb
  - → Forward spectrometer $1.9 < \eta < 4.9$
- TOTEM
  - → Roman Pots for leading protons
  - → Tracking for charged particles $3 < |\eta| < 7$
- LHCF
  - → Neutral particles at zero degrees

MOEDAL: the 7th experiment?

MOEDAL is an experiment so search for monopoles or other heavy ionizing particles
Detector: plastic track-etch sheets (50-70% of the solid angle)
Location: Around the LHC-b vertex chamber
Status: Proposal





Signal: set of collinear etch pits in the sheets

Remove the sheets after some running time and inspect for 'holes'

LHC Startup & first Data

2007: 450 GeV – Calibration Run

- Aims:
  - Commission essential safety systems
  - Commission essential beam instrumentation
  - Commission essential hardware systems
  - Perform beam based measurements to check:
    - Polarities
    - Aperture
    - Field characteristics
  - Establish collisions
  - Provide stable two beam operations
  - Interleave with further machine development, in particular, the ramp.

Should provide a firm platform for eventual commissioning to 7 TeV and provide lead time for problem resolution.

450 GeV - Performance

			Reasonable	All out max
k_b	43	43	156	156
i_b (10^{10})	2	4	4	10
β^* (m)	11	11	11	11
intensity per beam	$8.6\ 10^{11}$	$1.7\ 10^{12}$	$6.2\ 10^{12}$	$1.6\ 10^{13}$
beam energy (MJ)	.06	.12	.45	1.1
luminosity	10^{28}	$7.2\ 10^{28}$	$4.8\ 10^{29}$	$3\ 10^{30}$
event rate [1](kHz)	0.4	2.8	10.3	64
W rate [2] (per 24h)	0.5	3	11	70
Z rate [3] (per 24h)	0.05	0.3	1.1	7

Several days →

1. Assuming 450GeV inelastic cross section 40mb
2. Assuming 450GeV cross section $W \rightarrow l\nu$ 1nb
3. Assuming 450GeV cross section $Z \rightarrow ll$ 100pb

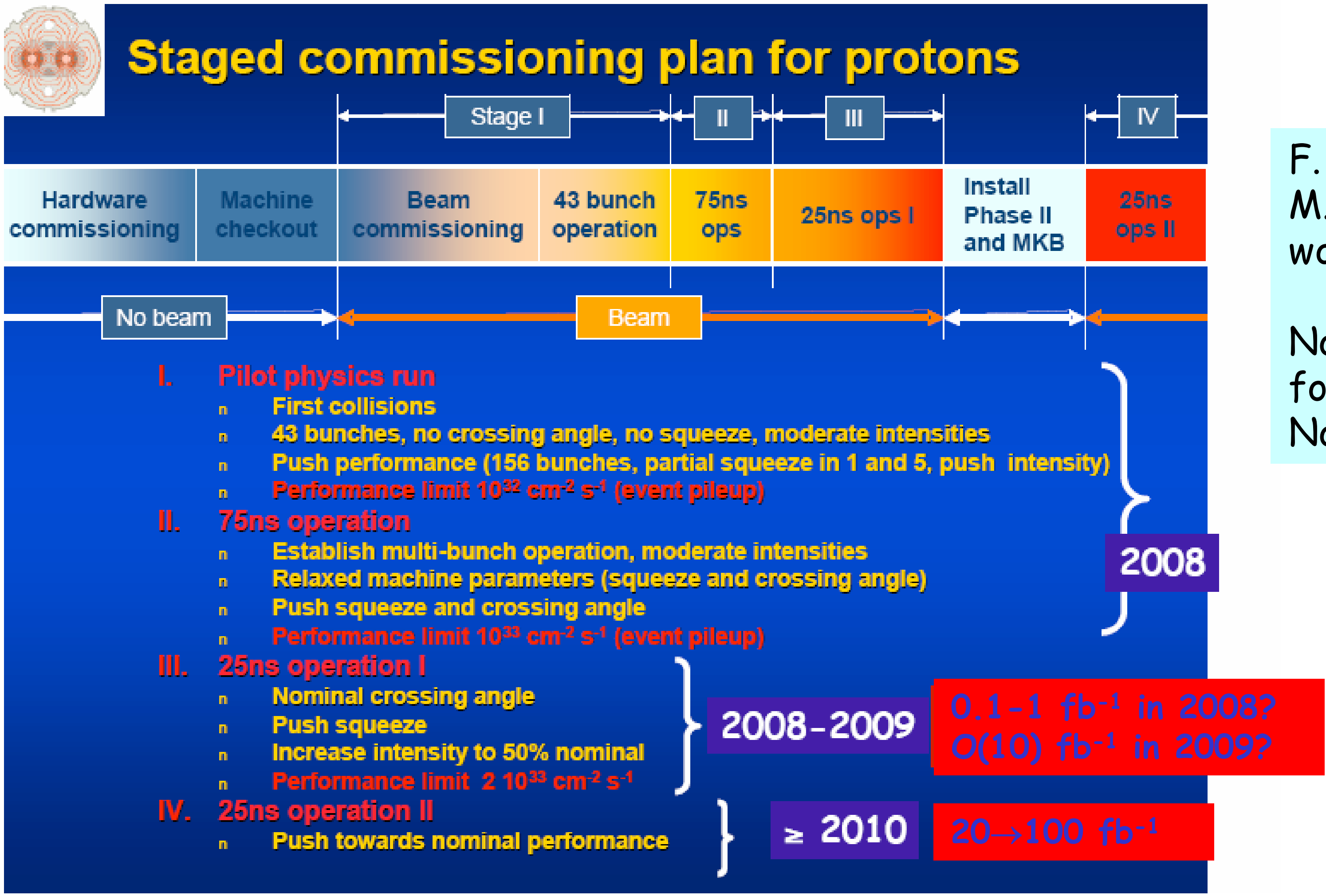
Event rates in 2007

- 6 weeks beam time⇒
- 3 weeks beam commissioning
  - Essentially single beam, low intensity for the most part
- 3 weeks collisions
  - Low intensities initially, with staged increase to an optimistic 156 x 4 x 10^{10}
  - Interleafed with low intensity single beam MD
    - ramp to 1.1 TeV etc
- L = $4.8.10^{29}$, 3 weeks of collisions with 450 GeV beams
  - σ_{inel} = 40 mb → 10.3 kHz
  - $\sigma(W \rightarrow l\ \nu)$ =1 nb → 11 evts/24h
  - $\sigma(Z \rightarrow l\ l)$=100 pb → 1.1 evts/24h

From Mike Lamont 05/09/06 at Alignment workshop

Machine expectations 2007/2008

2008: 7 TeV beam collisions for roughly 4 months

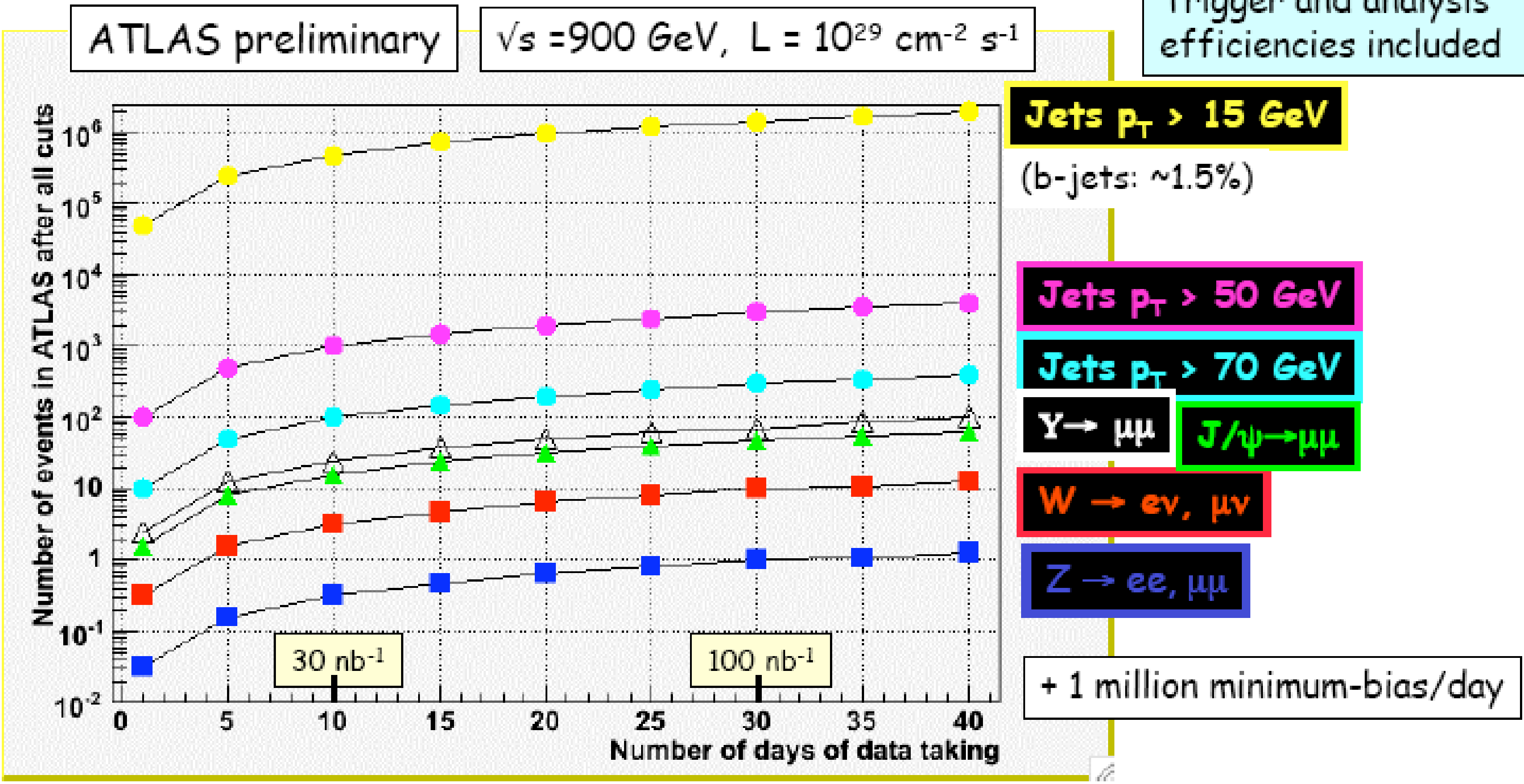


F. Gianoti: ICHEP06
M. Lamont: alignement workshop

Note: The estimates for lumi are mine
Not official numbers!

What data samples in 2007 ?

30% data taking efficiency included (machine plus detector)
Trigger and analysis efficiencies included

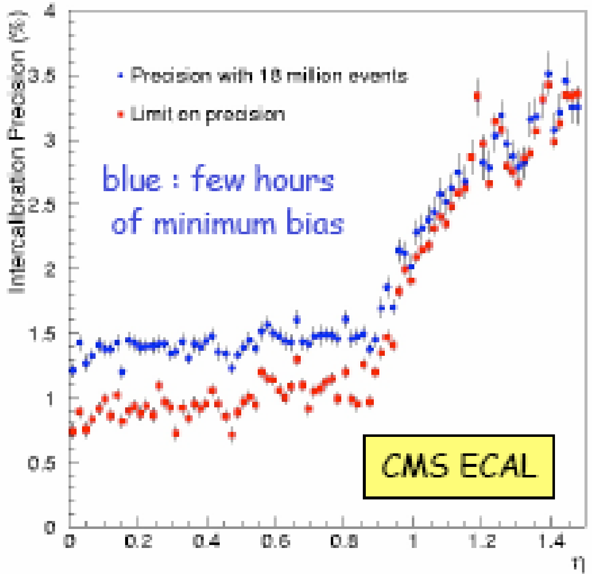


- Start to commission triggers and detectors with collision data (minimum bias, jets, ..) in real LHC environment
- Maybe first physics measurements (minimum-bias, underlying event, QCD jets, ...) ?
- Observe a few $W \to l\nu$, $\Upsilon \to \mu\mu$, $J/\psi \to \mu\mu$?

First Data: Calibration of the Detector

Which detector performance on day one ?

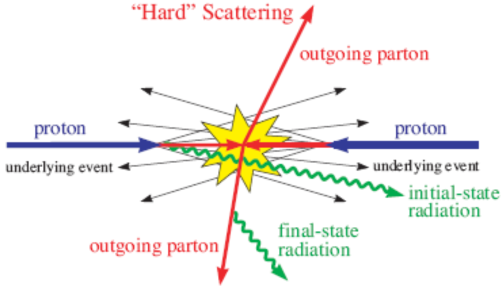
A few examples and educated guesses
based on test-beam results and simulation studies

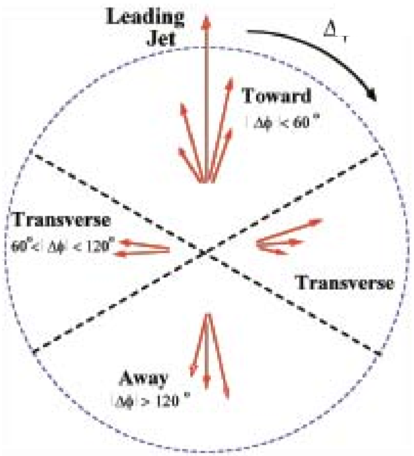


	Expected performance day 1	Physics samples to improve (examples)
ECAL uniformity e/γ scale	~ 1% (ATLAS), 4% (CMS) 1-2 % ?	Minimum-bias, Z→ ee Z → ee
HCAL uniformity Jet scale	2-3 % < 10%	Single pions, QCD jets Z (→ ll) +1j, W → jj in tt events
Tracking alignment	20-500 μm in Rϕ ?	Generic tracks, isolated μ , Z → μμ

Ultimate statistical precision achievable after few days of operation. Then face systematics ....
E.g. : tracker alignment : 100 μm (1 month) → 20μm (4 months) → 5 μm (1 year) ?

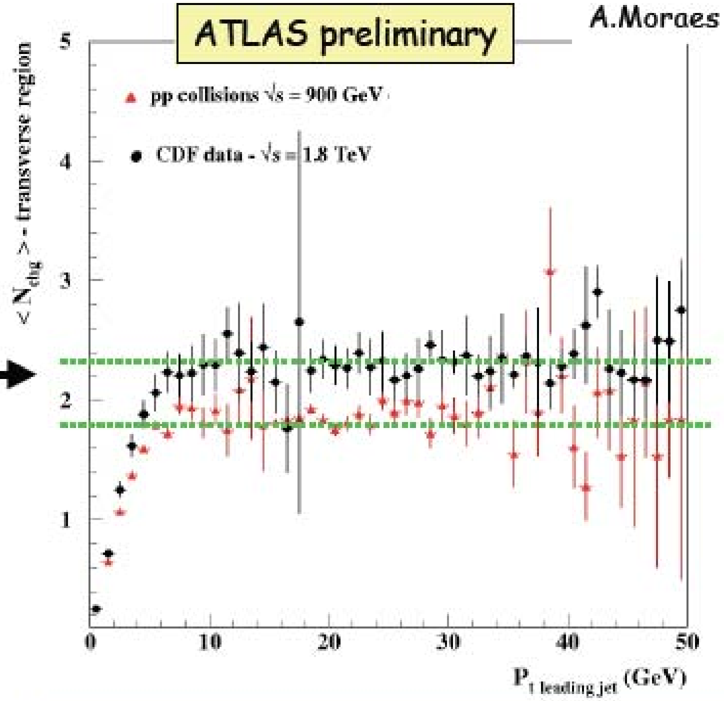
First data: understanding underlying event





Particle multiplicity of underlying event obtained from the region transverse to the leading jet.

Multiplicity of charged particles with $p_T > 0.5$ GeV and $|\eta| < 1$ in region transverse to leading jet



Comparison of plateau's between LHC and Tevatron will tell if detector performance, reconstruction tools and physics are under control

~ 15 days of data taking in 2007 enough to cover up to p_T(leading jet) ~ 40 GeV

2008 data: SM process

$1\ fb^{-1}$ ($100\ pb^{-1}$) ≡ 6 months (few days) at $L = 10^{32}\ cm^{-2}s^{-1}$
with 50% data-taking efficiency
→ may collect a few fb^{-1} per experiment by end 2008

Channels (examples ...)	Events to tape for $100\ pb^{-1}$ (per expt: ATLAS, CMS)	Total statistics from some of previous Colliders
$W \to \mu\nu$	$\sim 10^6$	$\sim 10^4$ LEP, $\sim 10^6$ Tevatron
$Z \to \mu\mu$	$\sim 10^5$	$\sim 10^6$ LEP, $\sim 10^5$ Tevatron
$tt \to WbWb \to \mu\nu + X$	$\sim 10^4$	$\sim 10^4$ Tevatron
QCD jets $p_T > 1$ TeV	$> 10^3$	---
$\tilde{g}\tilde{g}$ m = 1 TeV	~ 50	---

With these data:

- Understand and calibrate detectors in situ using well-known physics samples

  e.g. - $Z \to ee, \mu\mu$ tracker, ECAL, Muon chambers calibration and alignment, etc.

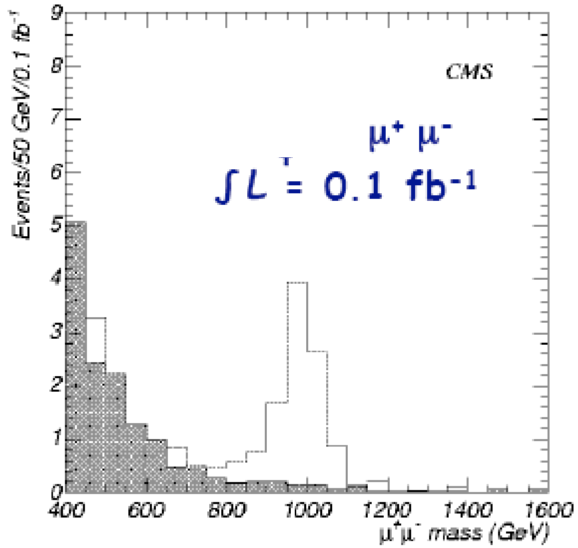
  - $tt \to bl\nu\ bjj$ jet scale from $W \to jj$, b-tag performance, etc.

- Measure SM physics at $\sqrt{s} = 14$ TeV : W, Z, tt, QCD jets ...
  (also because omnipresent backgrounds to New Physics)

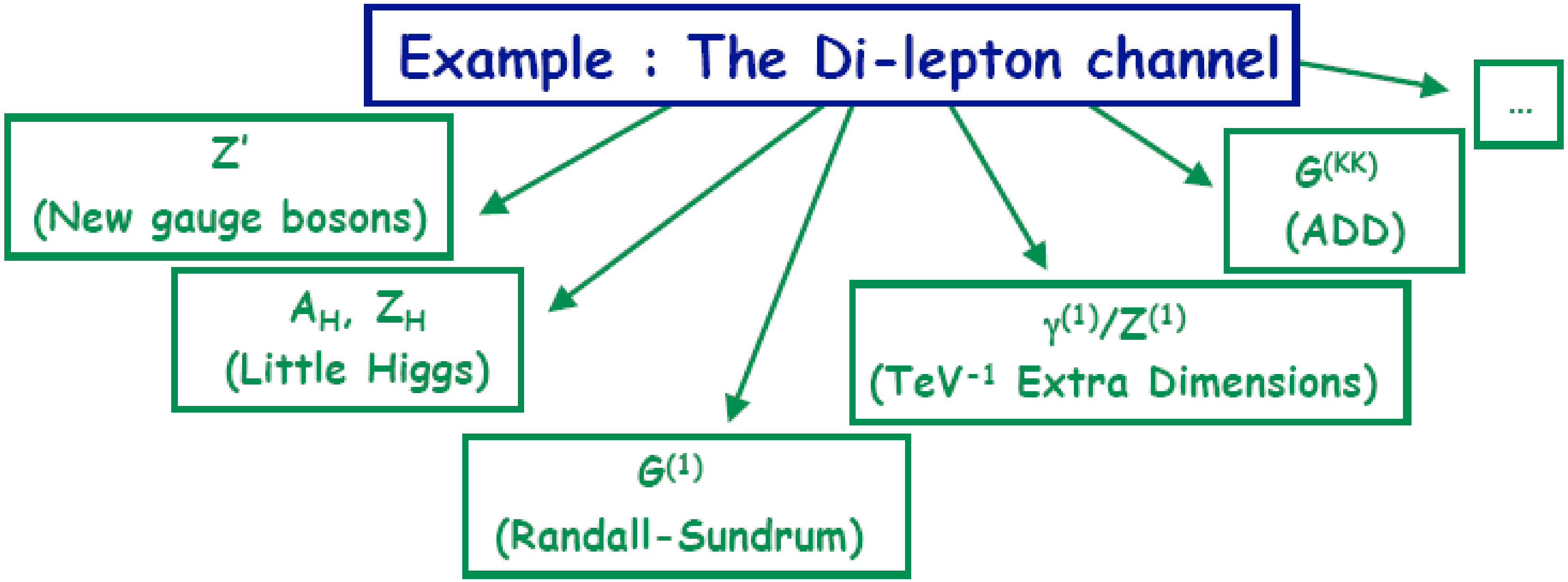
→ prepare the road to discovery ...... it will take time ...

Early Discoveries possible?
Example: a di-lepton resonance

May be seen very early: first weeks



$pp \rightarrow \mu\mu + X$

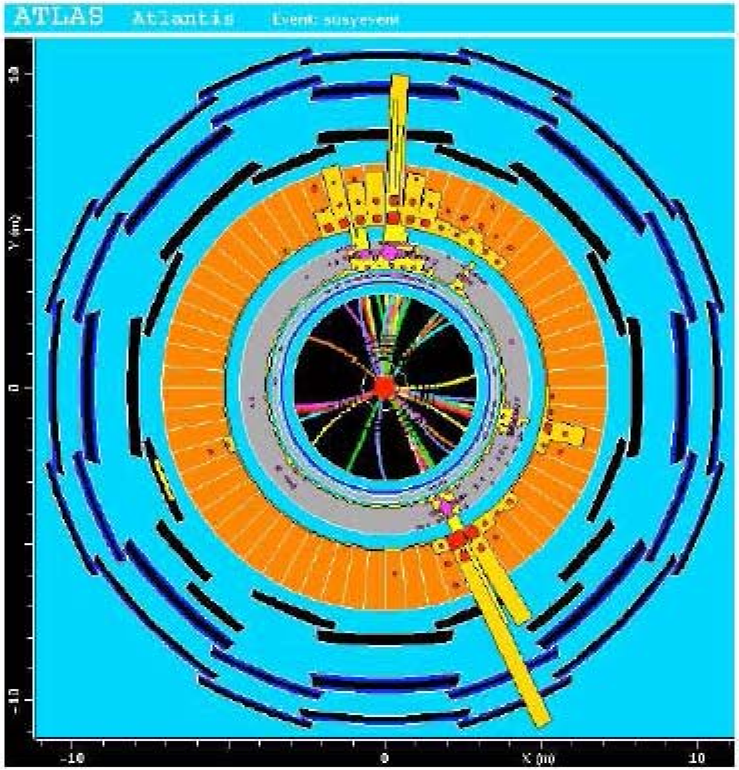


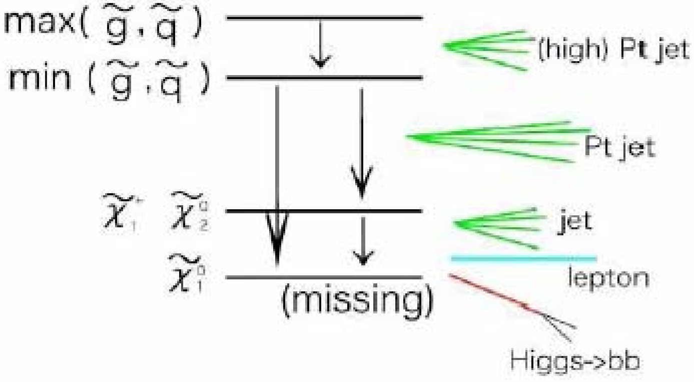
Early Supersymmetry?

SUSY could be at the rendez-vous very early on!

M_{sp}(GeV)	σ (pb)	Evts/yr
500	100	10^6-10^7
1000	1	10^4-10^5
2000	0.01	10^2-10^3

$10 fb^{-1}$





event topologies of SUSY

	multi	leptons
$\not{E}_T$ +	High P_T jets +	b-jets
		τ-jets

Therefore: SUSY one of the priorities of the "search" program

Main signal: lots of activity (jets, leptons, taus, missing E_T)

Note: establishing that the new signal is SUSY will be more difficult!

And Maybe…

6 December 2008

Evidence for squark and gluino production in pp collisions at $\sqrt{s}$ = 14 TeV

CMS collaboration

Abstract

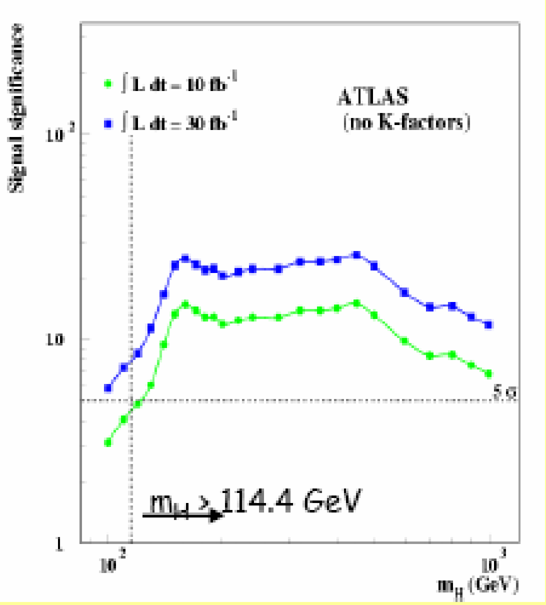
Experimental evidence for squark and gluino production in pp collisions $\sqrt{s}$ = 14 TeV with an integrated luminosity of 97 pb^{-1} at the Large Hadron Collider at CERN is reported. The CMS experiment has collected 320 events of events with several high E_T jets and large missing E_T, and the measured effective mass, i.e. the scalar sum of the four highest P_T jets and the event $\not{E}_T$, is consistent with squark and gluino masses of order of 650 GeV/c^2. The probability that the measured yield is consistent with the background is 0.26%.

Submitted to *European Journal of Physics*

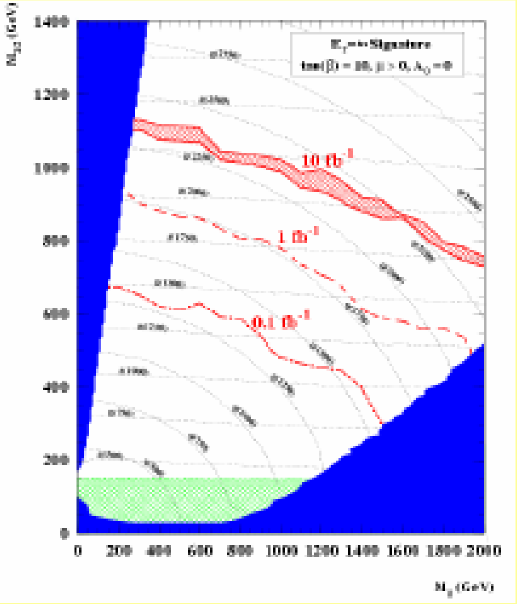
What can we expect in 2010 with 10 fb^{-1}?

"Early discoveries" at LHC

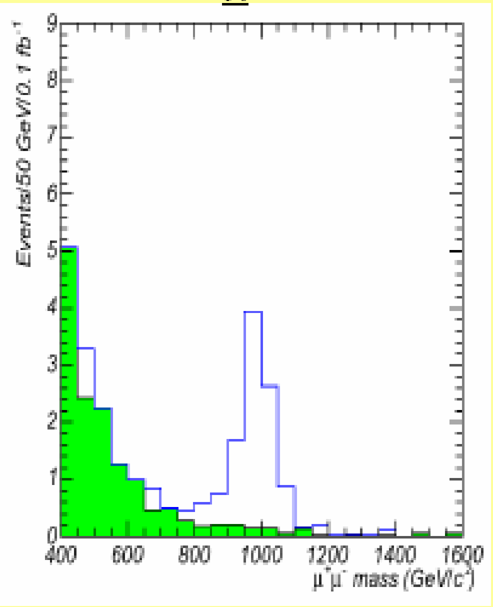
SM/MSSM Higgs



inclusive SUSY



di-lepton resonance
(Z',RS,Z_H,...)



with 10 fb^{-1}:

full range

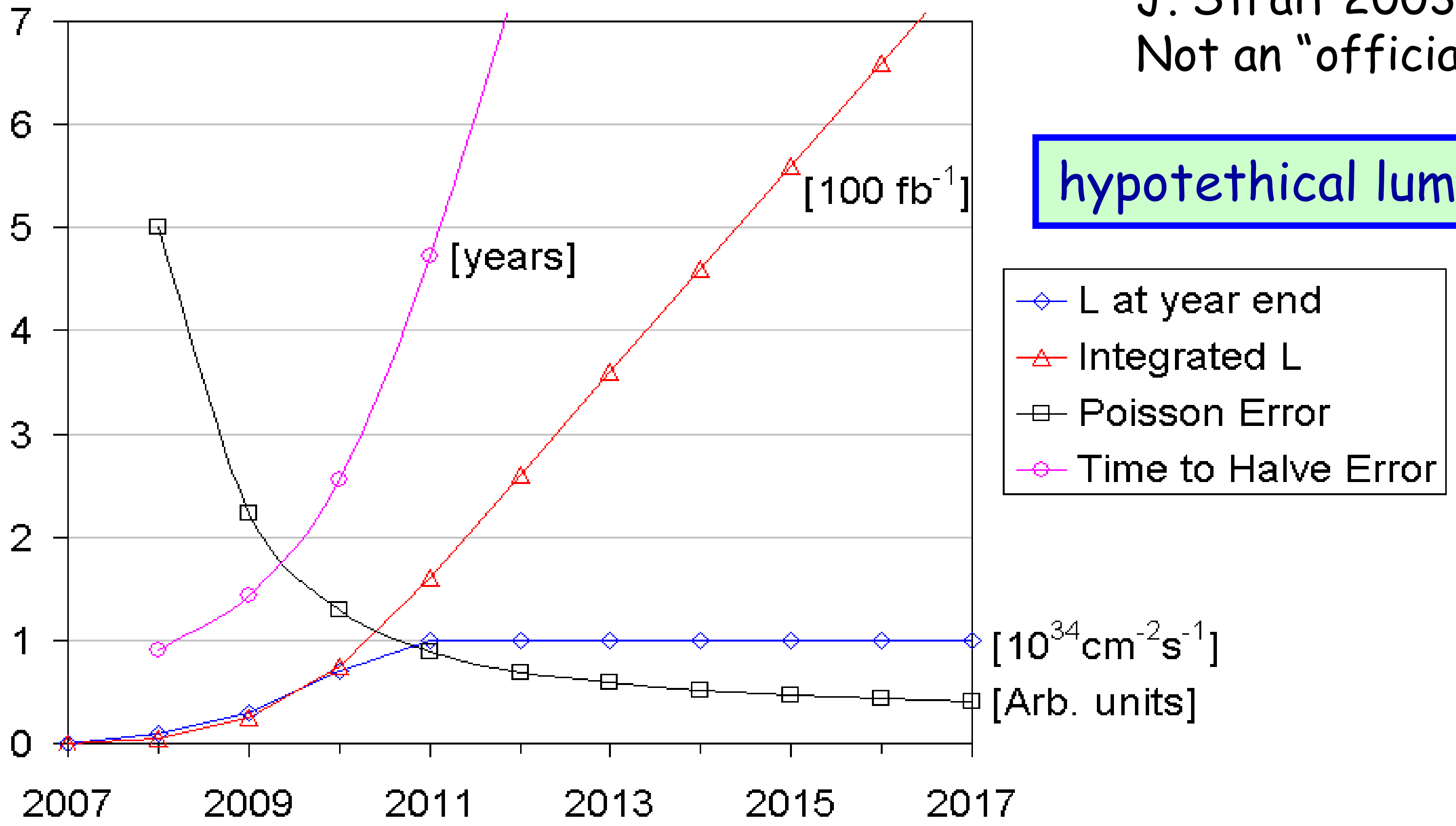
$m_{sq,gl}$<2-2.5 TeV
in mSugra

m<~3 TeV
dep. on model

Upgrades of the LHC

J. Strait 2003:
Not an "official" LHC plot

hypotethical lumi scenario



If startup is as optimistic as assumed here (10^{34} $cm^{-2}s^{-1}$ in 2011 already)
⇒After ~3 years at maximum luminosity the simple continuation becomes less exciting
⇒Time for an upgrade?

The LHC upgrade: SLHC/DLHC

Already time to think of upgrading the machine if wanted in ~10 years

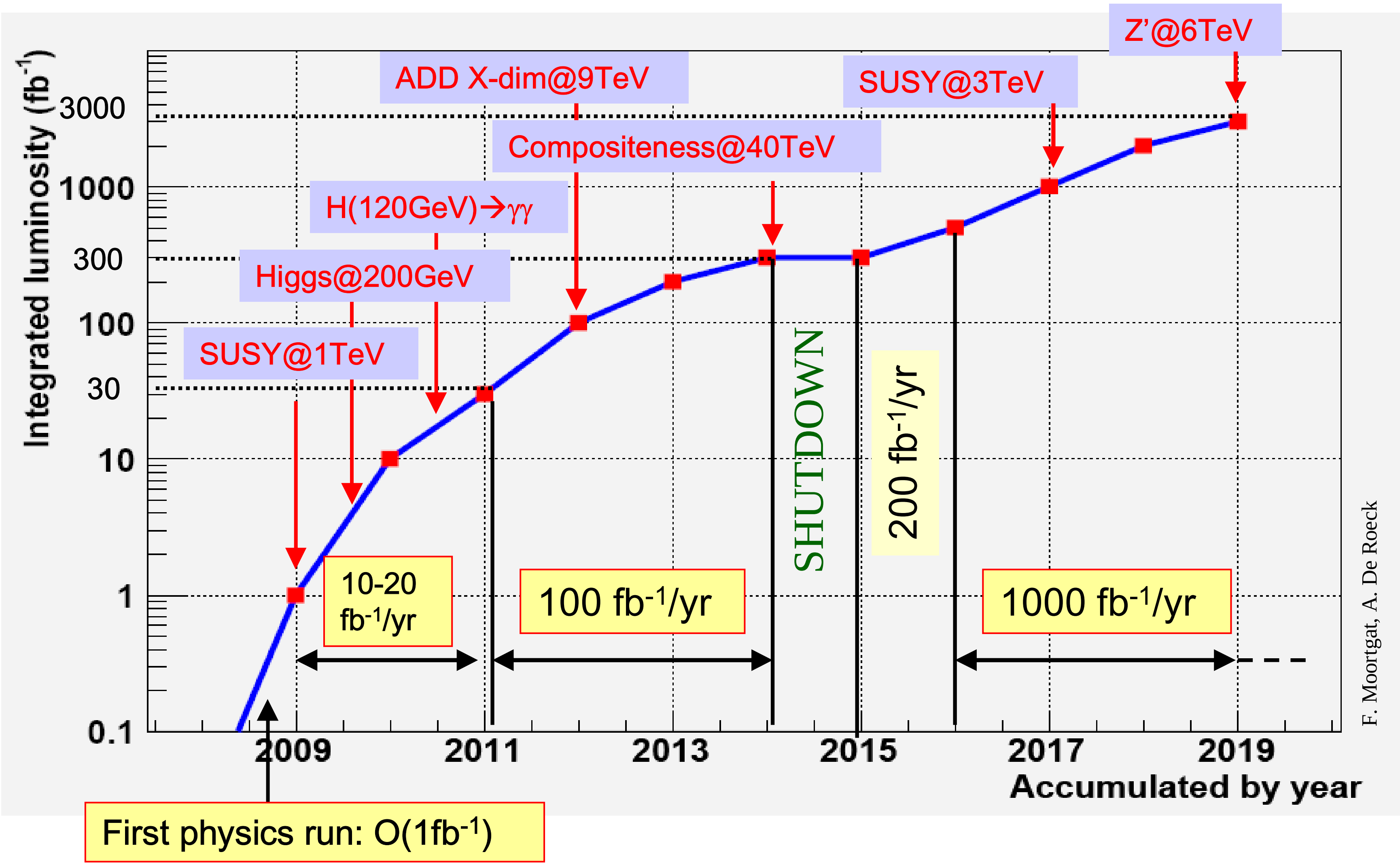
Two options presently discussed/studied

- Higher luminosity ~10^{35}cm^{-2} s^{-1} (SLHC)
  - Needs changes in machine and and particularly in the detectors
  - ⇒ Start change to SLHC mode some time 2013-2016
  - ⇒ Collect ~3000 fb^{-1}/experiment in 3-4 years data taking.

- Higher energy? (DLHC)
  - LHC can reach $\sqrt{s}$ = 15 TeV with present magnets (9T field)
  - $\sqrt{s}$ of 28 (25) TeV needs ~17 (15) T magnets ⇒ R&D needed!
  - Even some ideas on increasing the energy by factor 3 (P. McIntyre)

	Run I $\sqrt{s}$	Run I $\sqrt{s}$	Int Lumi	Int. Lumi (expected)
Tevatron	1.8 TeV	1.96 TeV	100 pb	~4-8fb
HERA	300 GeV	320 GeV	100 pb	~500 pb

LHC Luminosity/Sensitivity with time…



Summary of Lecture 3

- Large variety of experiments at the LHC
  - Will cover a large physics program, more that searches for new physics or the Higgs boson
  - Most of the experiments will be ready in time for 2007 data.
- First data in 2007/2008 is eagerly awaited for. It will be used to calibrate the experiments and for measuring Standard Model processes
- Early discoveries are possible so we should always stay alert
- …and maybe we can celebrate soon

End of these lectures