PSD9
9th International Conference on POSITION SENSITIVE DETECTORS

LHC Detectors overview

Emphasis on ATLAS

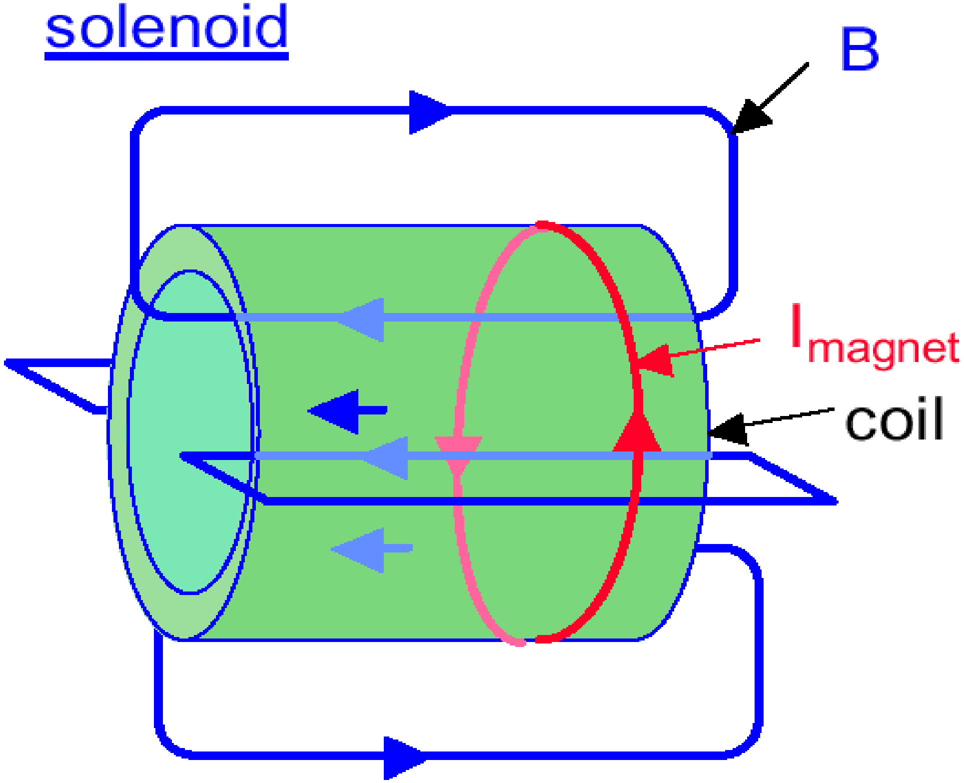
Bonus material

Beniamino Di Girolamo
CERN

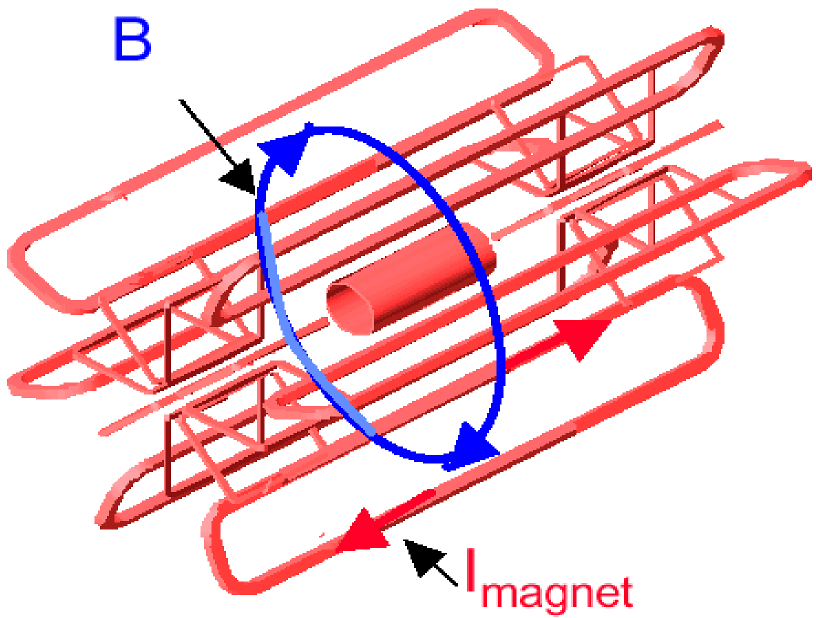
Magnetic configurations

Magnetic field configurations:

solenoid



toroid

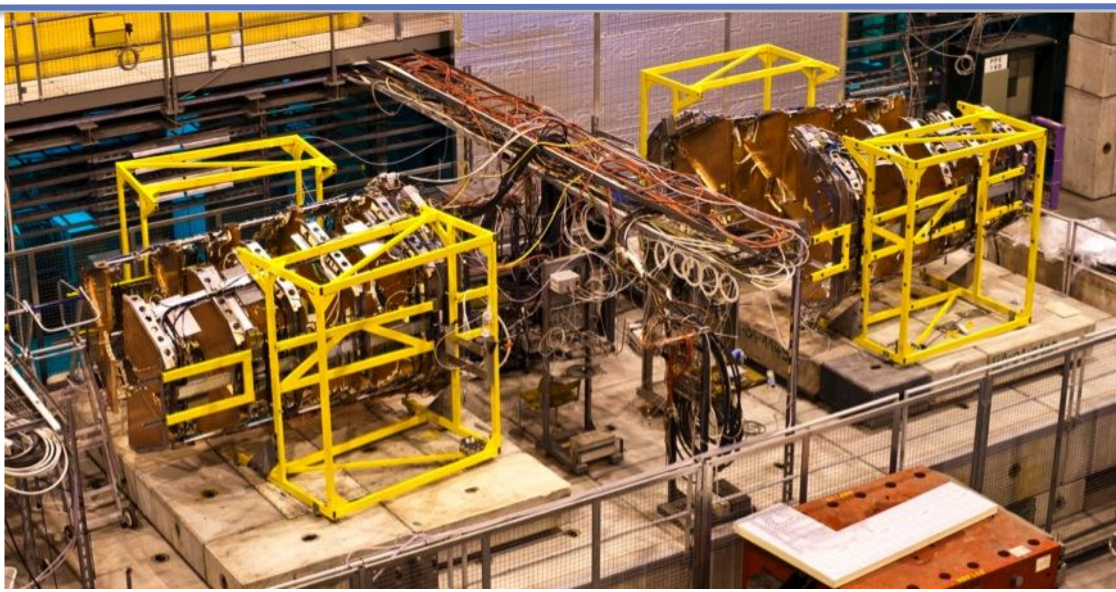


- Different choices: CMS smaller, but heavier

Complementary approaches

	ATLAS ≡ A Toroidal LHC ApparatuS	CMS ≡ Compact Muon Solenoid
MAGNET (S)	Air-core toroids + solenoid in inner cavity (4 magnets) Calorimeters in field-free region	Solenoid Only 1 magnet Calorimeters inside field
TRACKER	Si pixels+ strips TRT → particle identification B=2T $\sigma/p_T \sim 3.8\times10^{-4}\, p_T \oplus 0.015$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\times10^{-4}\, p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segm.
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → $\sigma/p_T \sim$ 10 % at 1 TeV standalone (~ 7% combined with tracker)	Fe → $\sigma/p_T \sim$ 15-30% at 1 TeV standalone (5% with tracker)

TOTEM telescopes



T1

At ±10.5m from IP5

T1: 3.1 < |η| < 4.7

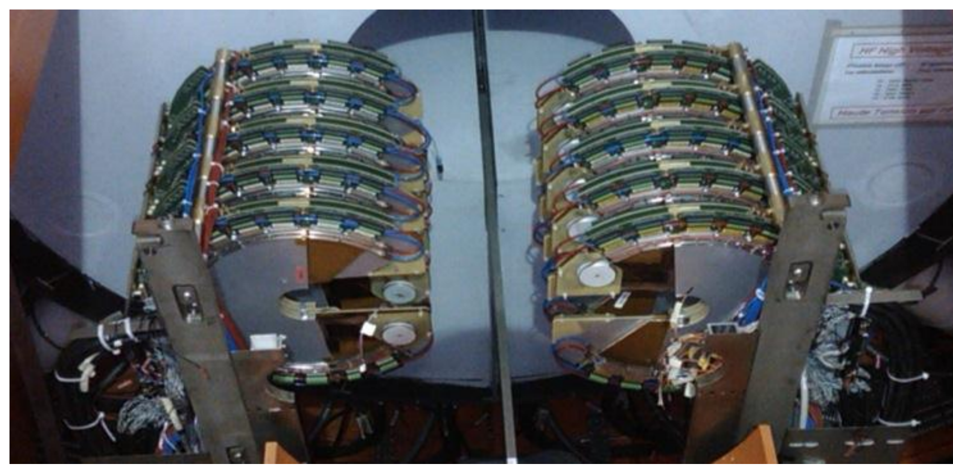
Cathode strip Chamber

T2

At ~ ± 14 m from IP5

T2: 5.3 < |η| < 6.5

Triple Gas Electron Multiplier

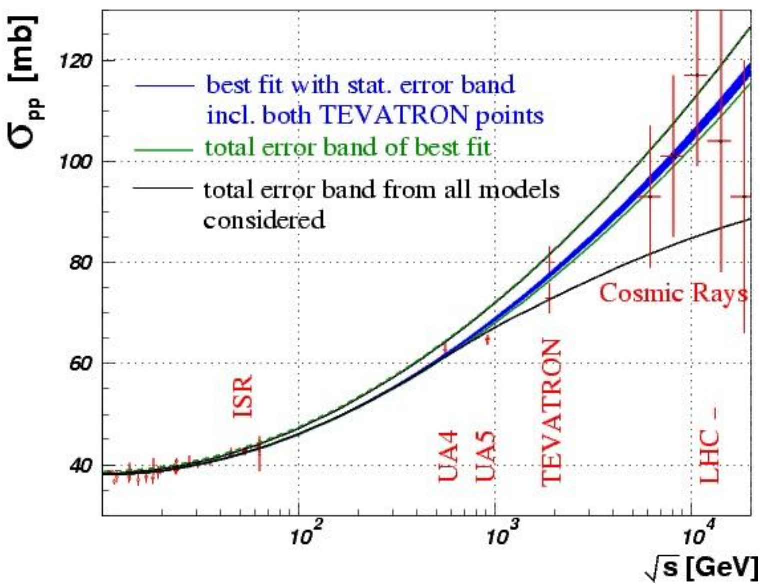


TOTEM Physics Objectives

TOTEM is dedicated to the measurement of the total cross section, elastic scattering and diffraction dissociation at the LHC.

total cross section

- Current models predict large uncertainty at the LHC energies (90-130 mb)
- Aim of TOTEM: ~1% accuracy



Measure the total cross-section σ_{tot} independently of the luminosity (Optical Theorem)

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

t 4-momentum transfer squared

Observables

N_{el} *rate of elastic events*

N_{inel} *rate of inelastic events*

$(dN_{el}/dt)|_{t=0}$

Measurement of Forward Protons

Measuring scattering at small angles >>

Proton detection far away from IP

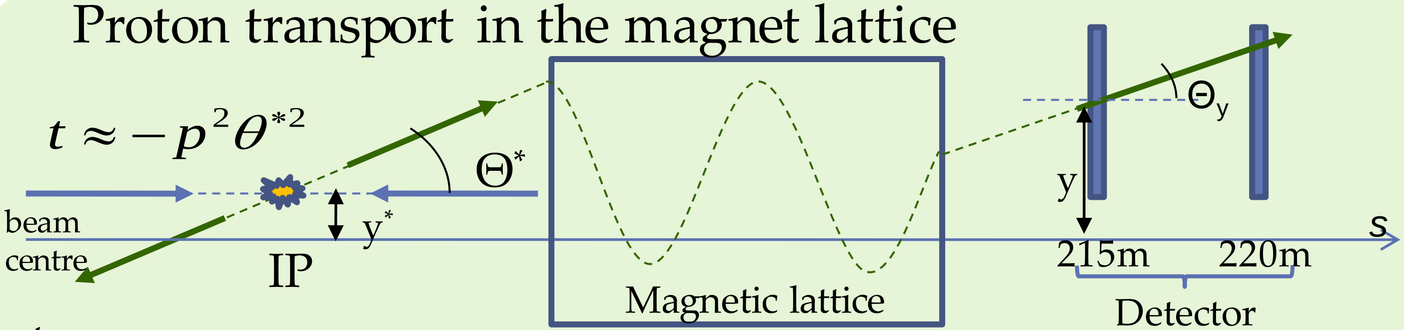
Extrapolating at t=0 >>

Approach the beam as much as possible (Edgeless Detectors)

How to correlate the measurement in the roman pots with the scattering in IP?

Proton transport in the magnet lattice

$$t \approx -p^2\theta^{*2}$$



transverse coordinate $$y(s) = L_y(s,\xi)\theta_y^* + \upsilon_y(s,\xi)y^* + D_y(s,\xi)\xi$$

$\xi=\Delta p/p$ fractional momentum loss in the collision

L (effective length)
v (magnification)
D (dispersion)

depend on the tuning of the magnet lattice

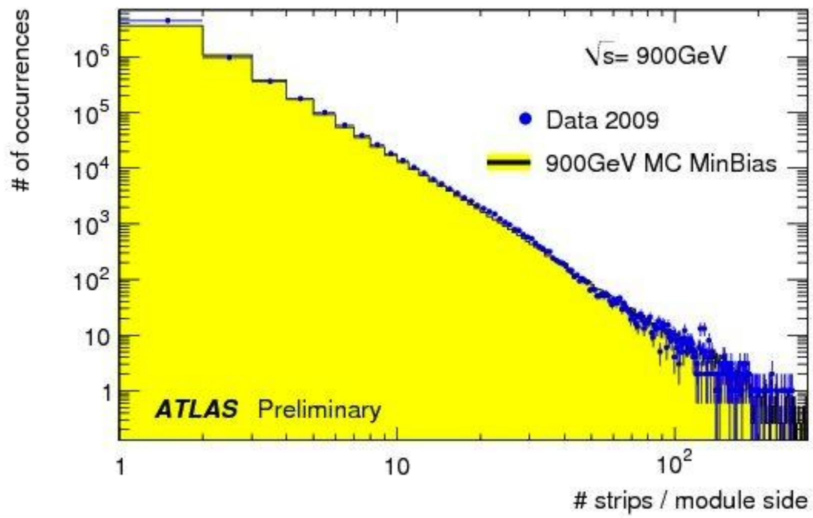
Deep knowledge of the magnet lattice tuning is needed
Special Beam Optics "ease" the measurements

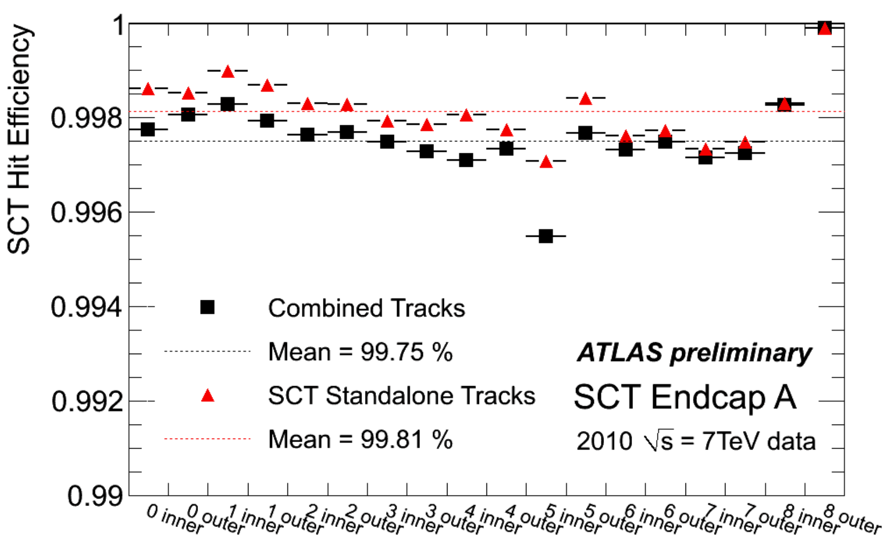
TOTEM

Vertex: High luminosity, high multiplicity

- The choice is natural to keep the occupancy at few % level
- The limit for deploying pixels at large radii: cost
- Granularity
  - Smaller in rϕ: magnetic field direction
  - Larger in z in ATLAS: pattern recognition helped by outer layers
  - Space requirement for electronics
- Geometry
  - As close to beam pipe as possible for the central barrel region
  - LHCb needs a forward geometry with stations along z for VELO
  - ATLAS and CMS have disks for the forward region
  - ATLAS has the outer part of the tracker, after strips, with straw-tubes
  - ALICE has silicon drift detectors between pixel and strips

ATLAS: Hit Strips, Efficiency, Occupancy

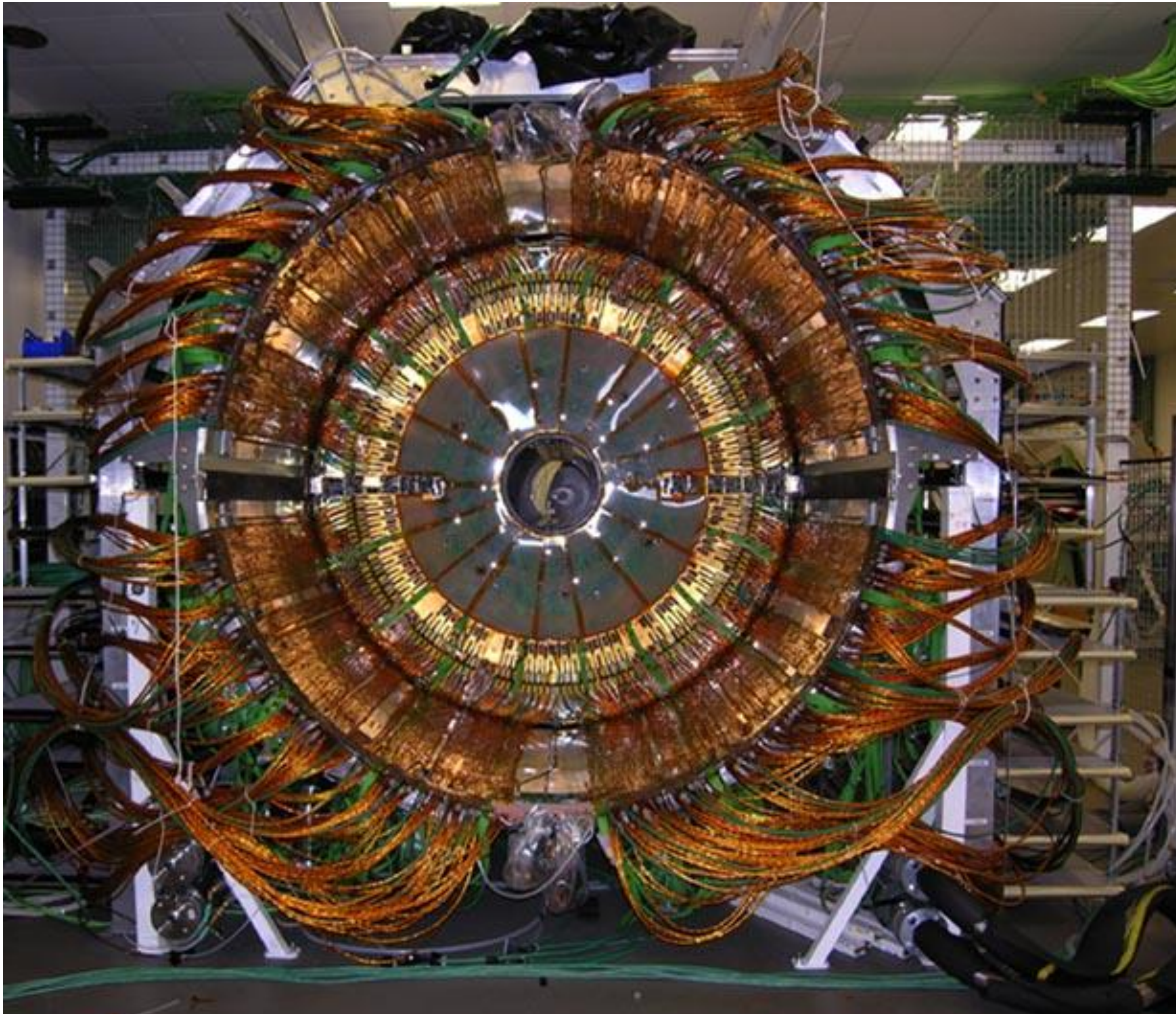




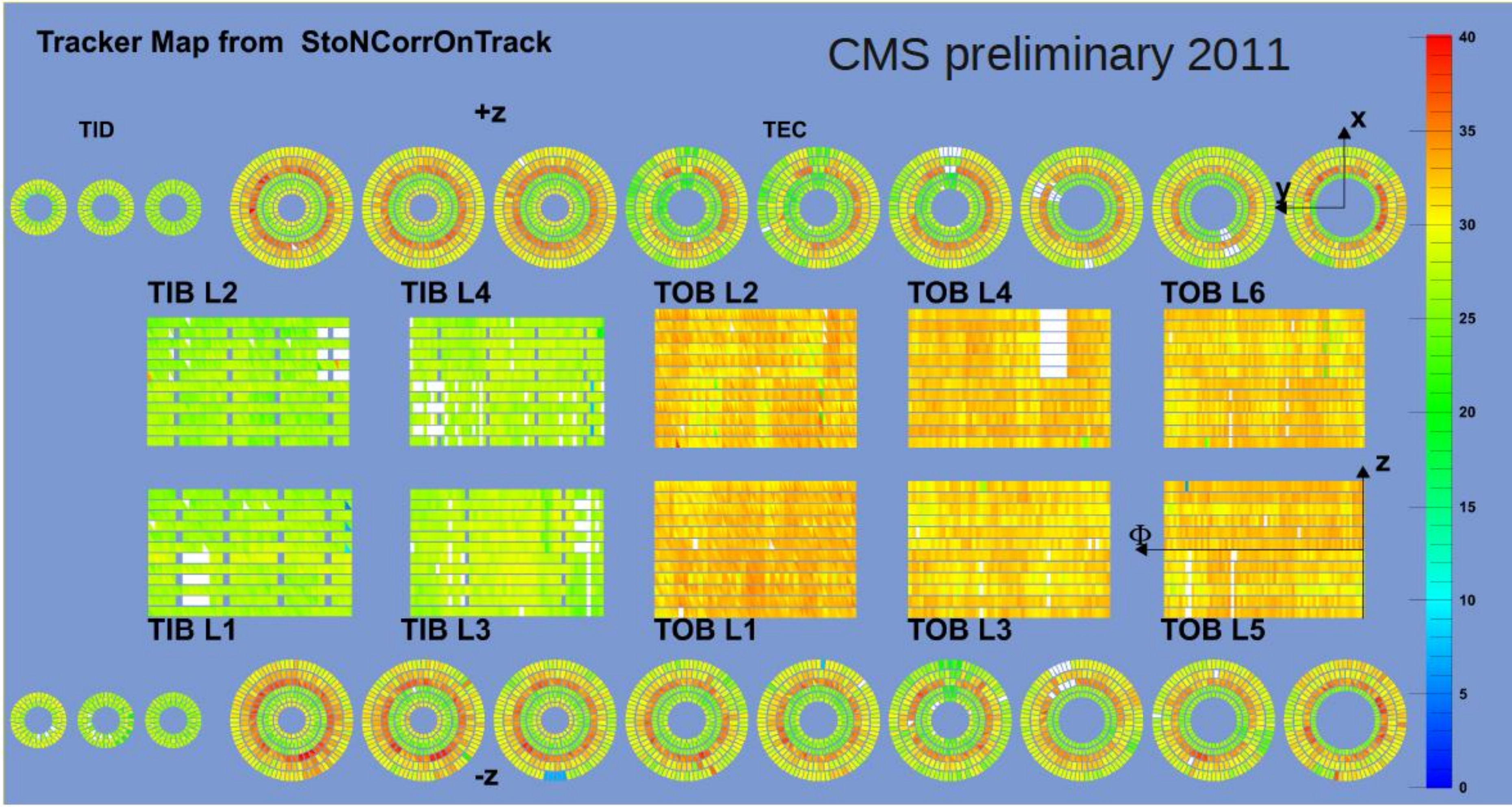
N(vertex)	Avg. Occupancy (Barrel, innermost layer)
5	0.41 %
10	0.66 %
15	0.89 %

2010	Run Type	Max. Occ.
09. Apr	Cosmics	4%
09. Apr	Beam, non colliding	6%
25. Apr	Squeezed beam, colliding	20%
10. Jun	Single high occ. event	32%
29. Oct	Bunch trains	20%
09. Nov	Heavy Ion	37%

CMS Tracker

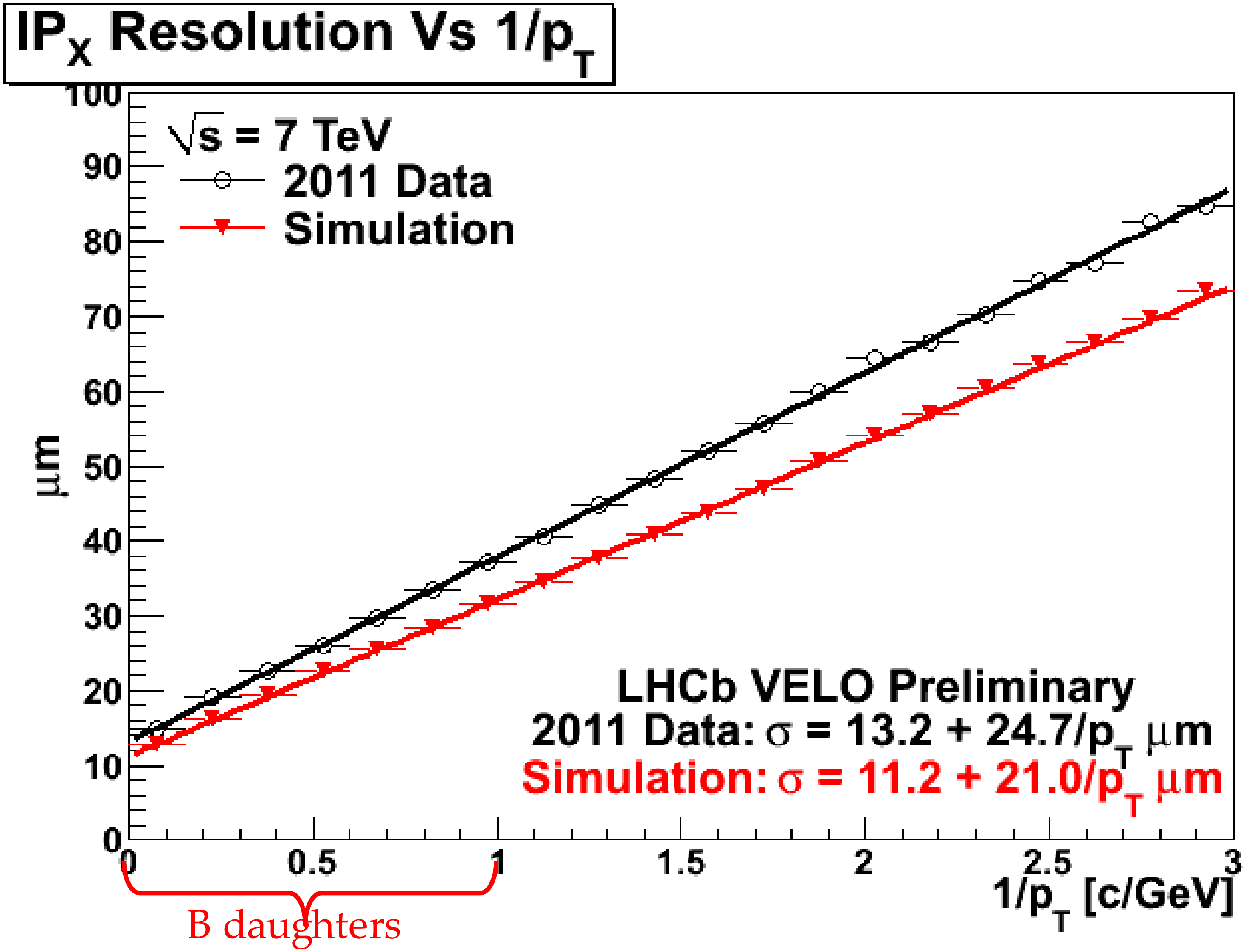


CMS Tracker: S/N distribution



S/N~20 for thin silicon (300 μm); S/N~30 for thick silicon (500 μm)

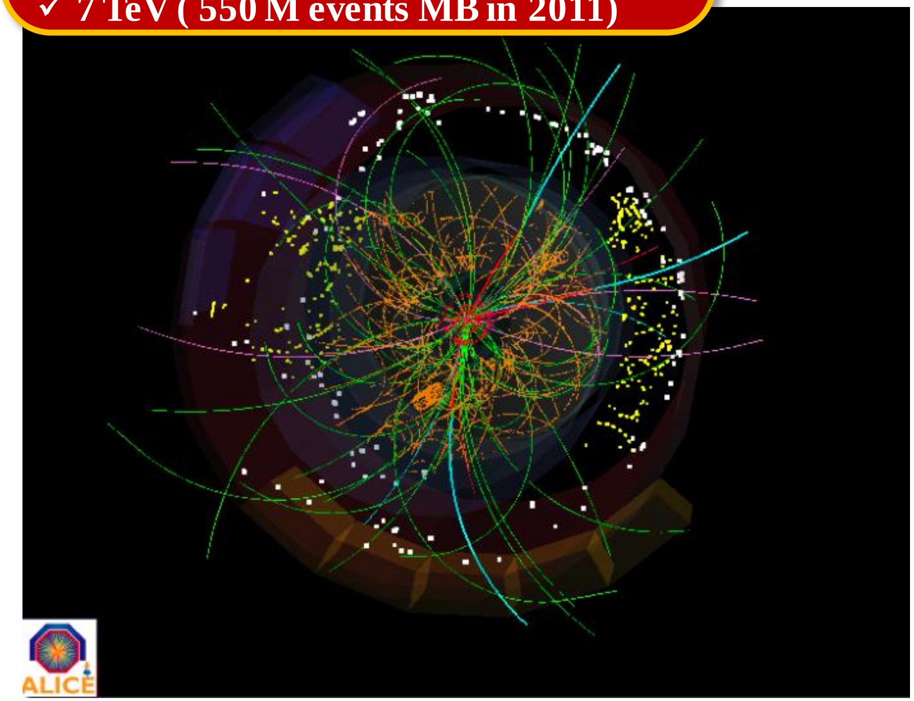
LHCb VELO: IP resolution



ALICE ITS: event display

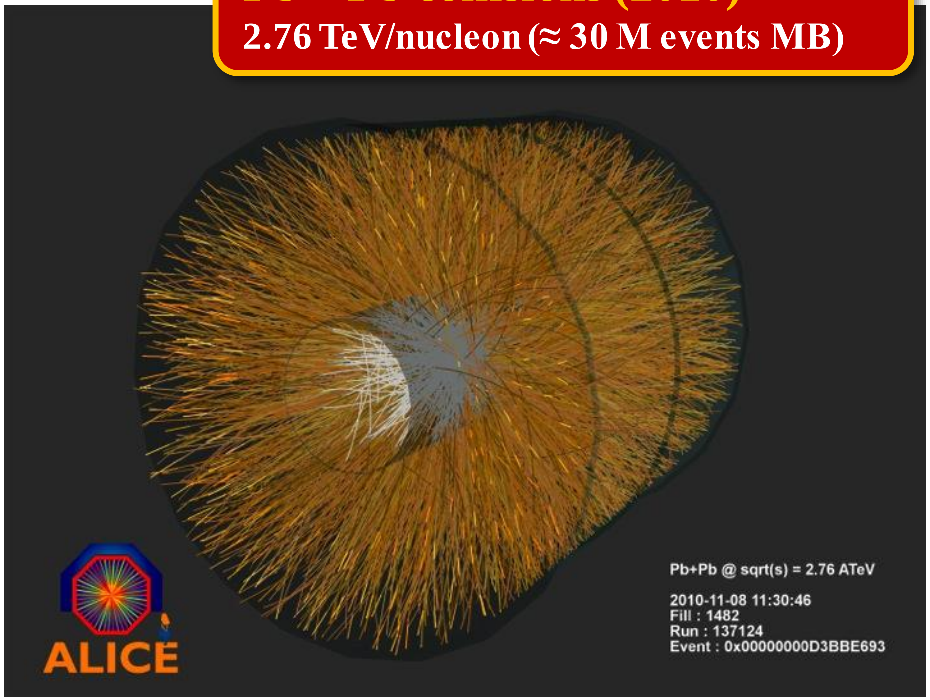
p – p collisions (2010 – 2011)

- ✓ 900 GeV (300 K + 8 M events MB)
- ✓ 2.36 TeV (40 K events)
- ✓ 2.76 TeV (70 M events MB)
- ✓ 7 TeV (800 M events MB in 2010)
- ✓ 7 TeV (550 M events MB in 2011)



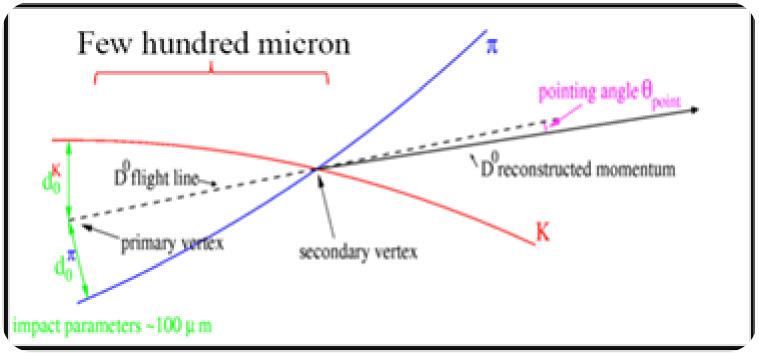
Pb – Pb collisions (2010)

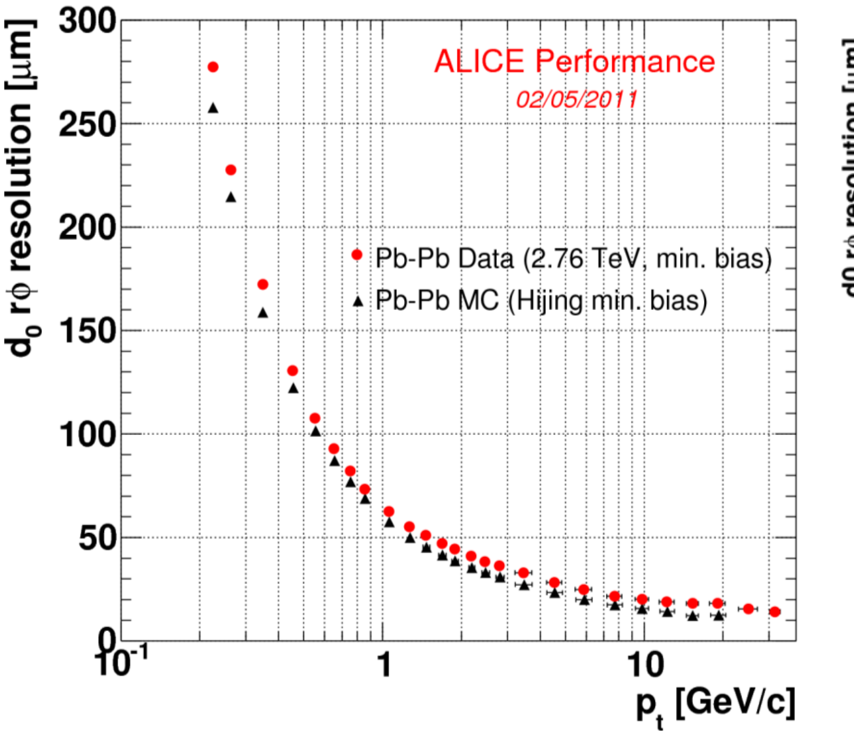
2.76 TeV/nucleon (≈ 30 M events MB)

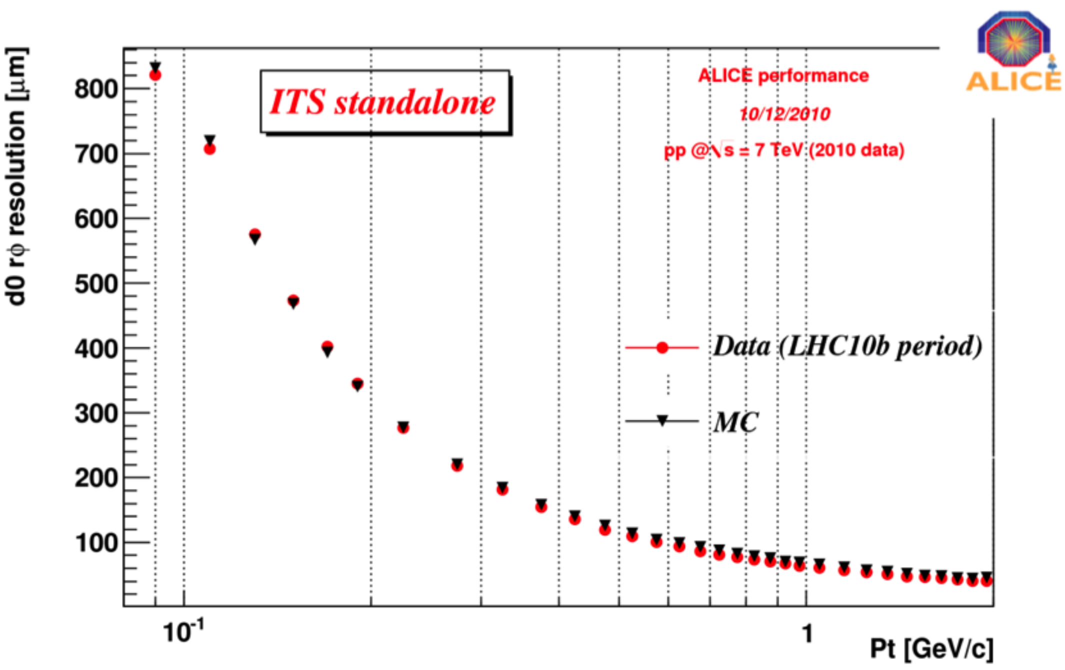


ALICE ITS: Transverse impact parameter

- A key plot to quote the tracker performance in terms of track and vertex reconstruction is the transverse impact parameter in the bending plane: $d_0(r\varphi)$
  - Distance between the track projection and the vertex position reconstruction in the bending plane
- The material budget mainly affect the performance at low p_t (multiple scattering)
- The point resolution of each layers drives the asymptotic performance







Radiation levels for Si detectors

	TID [kGy]	Fluence 1 MeV neq [cm-2]	Time [y]
ATLAS Pixel	500	1.0E+15	10
ATLAS Strips	100	2.0E+14	10
CMS Pixel	840	3.0E+15	10
CMS Strips	70	1.6E+14	10
ALICE Pixel	2.7	3.5E+12	10
LHCb VELO	50	1.3E+14	1

ALICE TPC: impressive!

- A TPC is the perfect detector for HI collisions
  - the whole volume is active
  - minimal scattering due to minimal radiation length (field cage, gas)
  - easy pattern recognition (continuos tracks)
  - PID information from ionization measurements (very powerful especially in the low energy region where energy loss $\propto 1/\beta^2$; $p \leq 1\,GeV/c$)
  - transversal diffusion of the drifting electrons may be minimized by choosing a gas mixture with $\omega\tau>1$ and a configuration with B and E fields parallel
- … but …
  - relatively slow (at least as compared to most LHC detectors): Maximum readout speed is dominated by electron drift time (and event sizes)

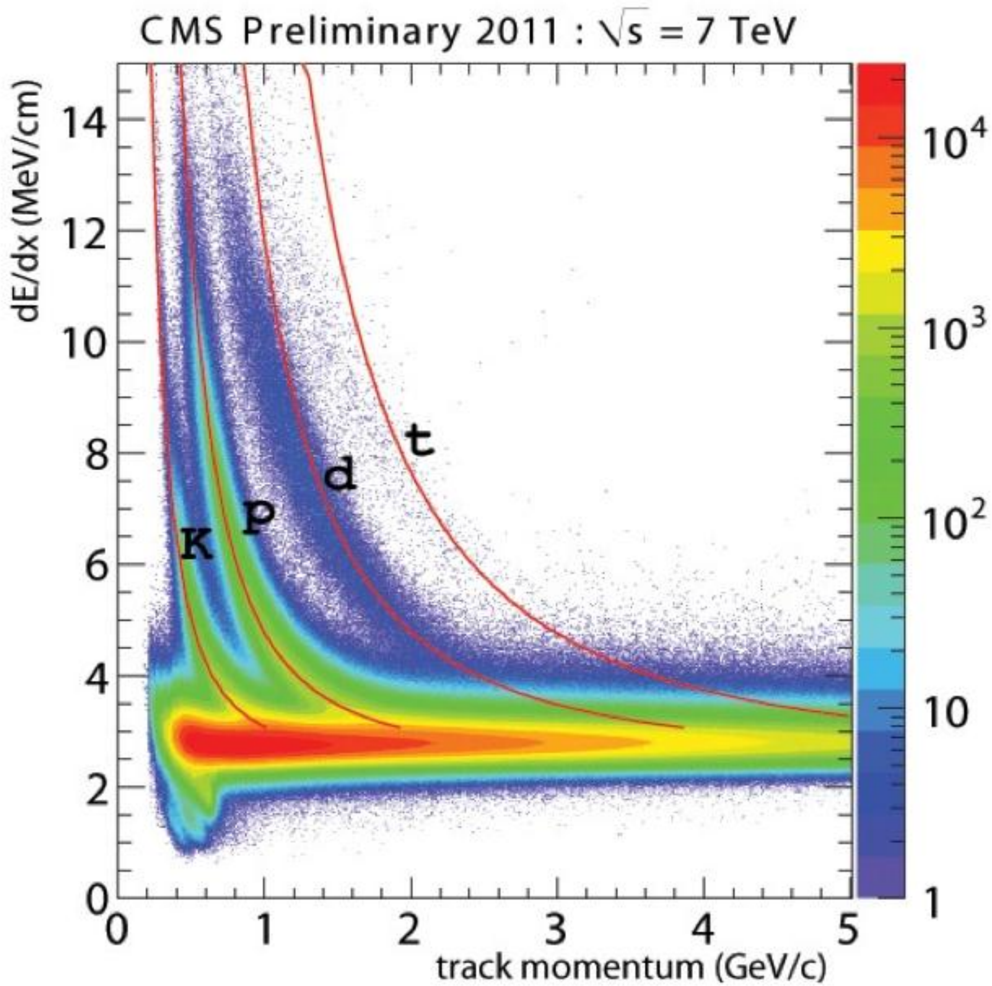
PID in Silicon: CMS strips

The dE/dx measurement of a track is obtained from all values of the hits (~10 points).

Kaons, protons, deuterons and tritium are visible.

• Red lines are Bethe-Bloch expectations extrapolated from a fit of the proton line.

• Small deviation at large dE/dx from saturation.



Calorimetry and Muon systems

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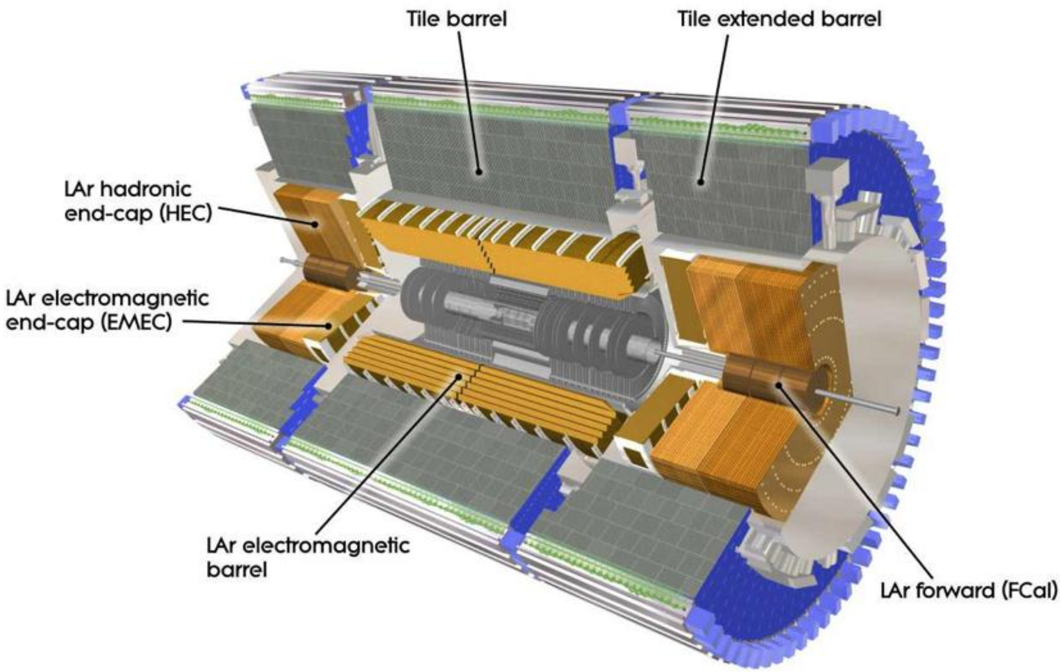
A variety of technologies

Different choices

- ATLAS, CMS and LHCb have e.m. and hadron calorimetry based on different technologies
  - LHCb and ALICE: the advantage of designing later, re-using part of ATLAS and CMS technologies
- CMS has the calorimetry in magnetic field
  - A clear need of containing dimensions not to have a even more challenging 4 T solenoid
  - Very elegant, compact and dense e.m. calorimeter based on $PbWO_4$
  - Challenging readout for the hadronic calorimeter and reduced dimensions, brass-scintillator with WLS fibres
- ATLAS approach more conservative
  - Elegant LAr-based calorimetry with barrel cryostat shared with solenoid
  - Central hadronic calorimetry based on Fe-Scintillator with WLS fibres with a novel geometry
- More similarities for ATLAS and CMS Muon chambers

The ATLAS calorimetry



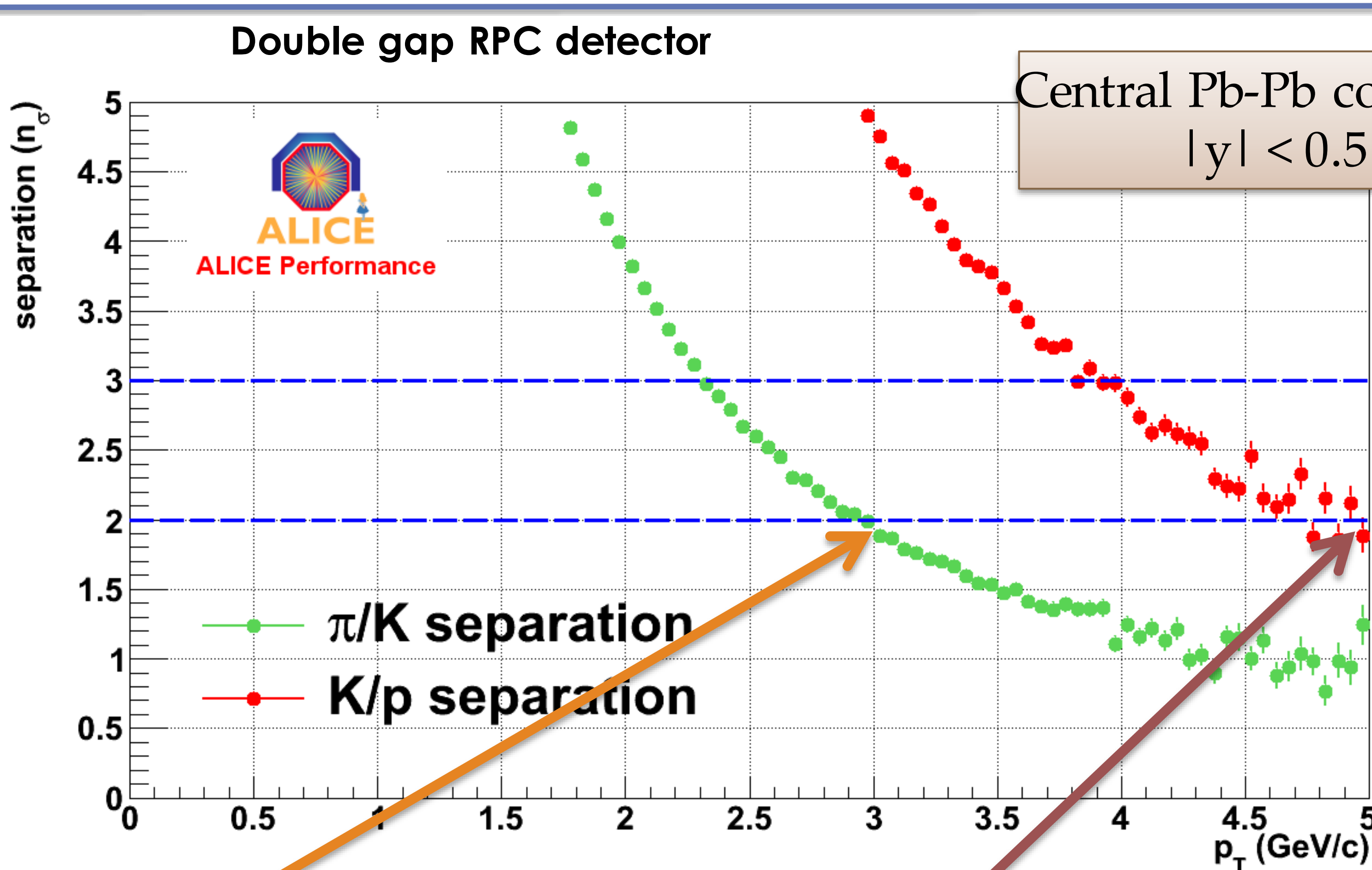
electrons: using information from the calorimeter, tracker and matching between them ; using 3 series of cuts for identification selection with increasing jet rejection power

photons: energy clusters in the EM calorimeter not matched to a track, or matched to a conversion vertices (for converted photons) ; using two series of selection cuts with increasing fake rate power

Jets: calorimeter topological clusters using anti-KT (cone-like) algorithm of cone R=0.4,0.6 Jets are reconstructed using weighting techniques to correct for the "non compensating" ATLAS calorimeters (response of hadrons lower than electrons) and to energy losses in front and between the calorimeters.

Missing transverse energy E_T^{miss}: Includes contributions from ET deposits in the calorimeters, corrections for energy losses in the cryostat and measured muons.

PID with ALICE TOF



Central Pb-Pb collisions
|y| < 0.5

2σ π/K separation up to 3 GeV/c

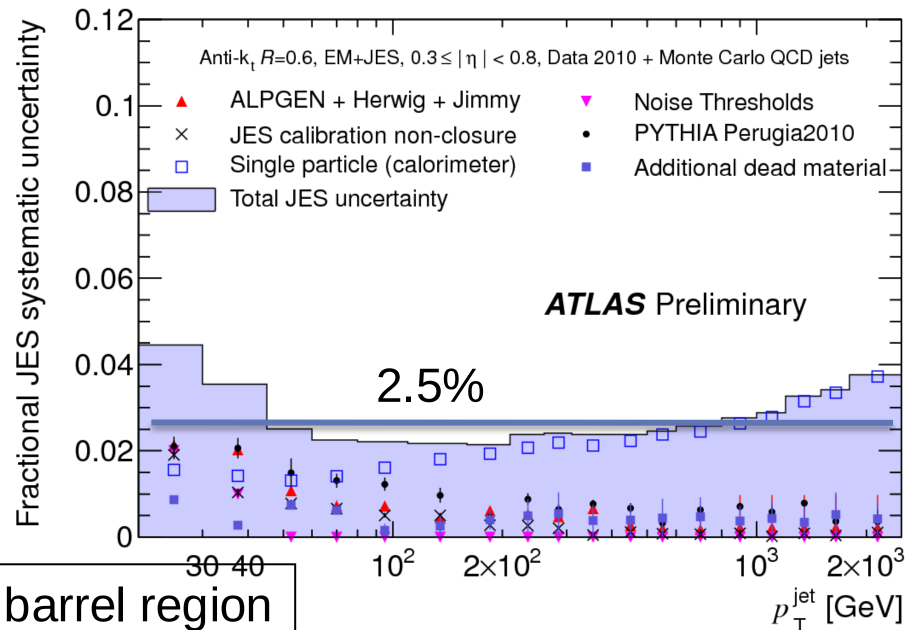
2σ K/p separation up to 5 GeV/c

system time resolution in Pb-Pb (~85ps) – better than in p-p (~110ps)

ATLAS Jets: energy scale uncertainty

Estimate jet energy scale (JES) uncertainty on data (Jets with P_T>20 GeV).

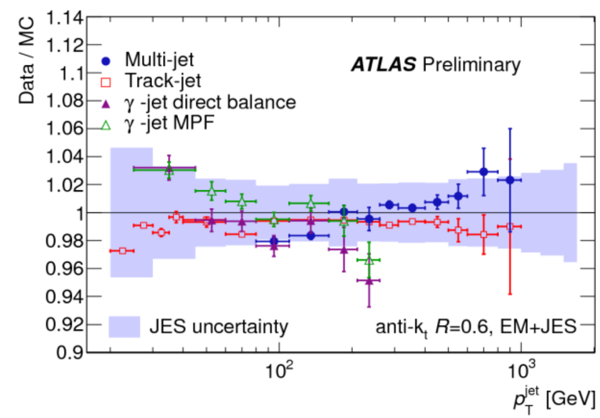
Different sources of systematic uncertainties studied in detail.



barrel region

JES and uncertainty evaluated up to 3.5 TeV, |η|<4.5

Data/MC ratio for different in situ techniques test the JES

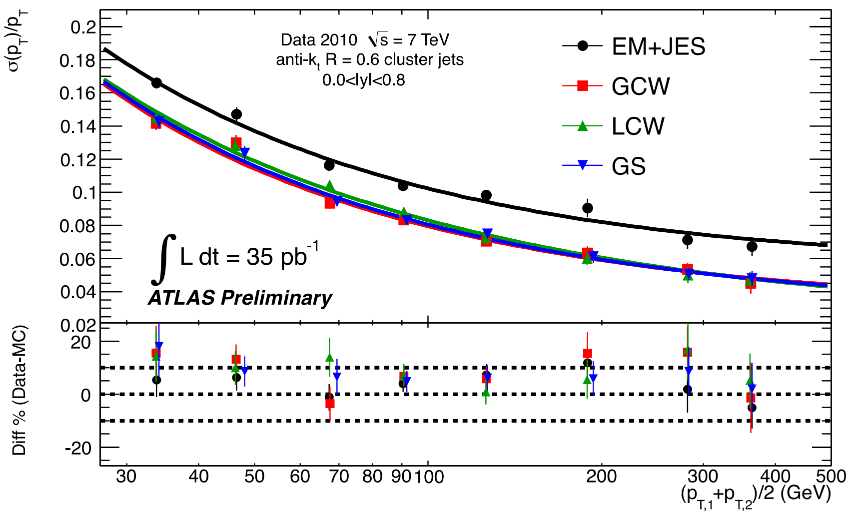


η region	Maximum fractional JES Uncertainty		
	p_T^{jet} = 20 GeV	p_T^{jet} = 200 GeV	p_T^{jet} = 1.5 TeV
$0 < \|\eta\| < 0.3$	4.6%	2.3%	3.1%
$0.3 < \|\eta\| < 0.8$	4.5%	2.2%	3.3%
$0.8 < \|\eta\| < 1.2$	4.5%	2.4%	3.4%
$1.2 < \|\eta\| < 2.1$	5.5%	2.5%	3.5%
$2.1 < \|\eta\| < 2.8$	7.1%	2.5%	
$2.8 < \|\eta\| < 3.2$	8.5%	3.0%	
$3.2 < \|\eta\| < 3.6$	8.7%	3.0%	
$3.6 < \|\eta\| < 4.5$	12.6%	2.9%	

ATLAS-CONF-2011-032

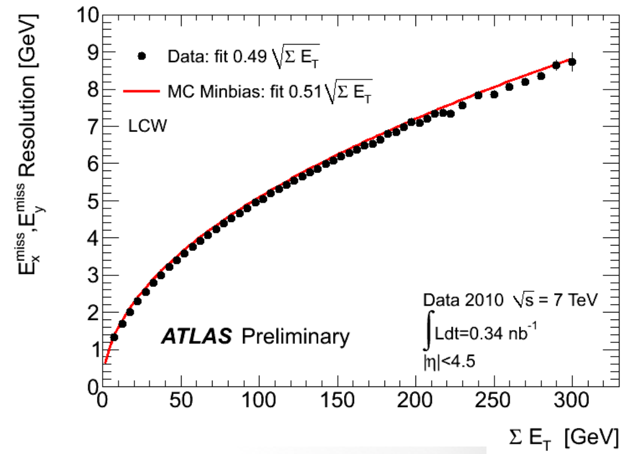
ATLAS Jet energy, E_T^{miss} resolution

Different calibration schemes exist for the hadronic energy deposits in calorimeters with corrections for non compensating calorimeters and inactive materials.



Relative uncertainty (Data/MC) of 10%

E_T^{miss} sensitive to calorimeter performance (in terms of noise, dead cells, miscalibrations e.t.c) and beam backgrounds and cosmics



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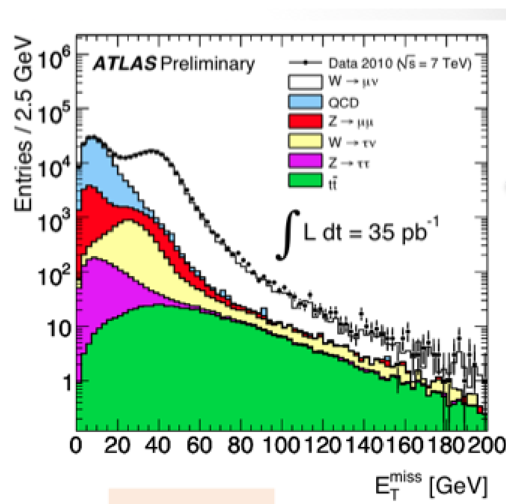
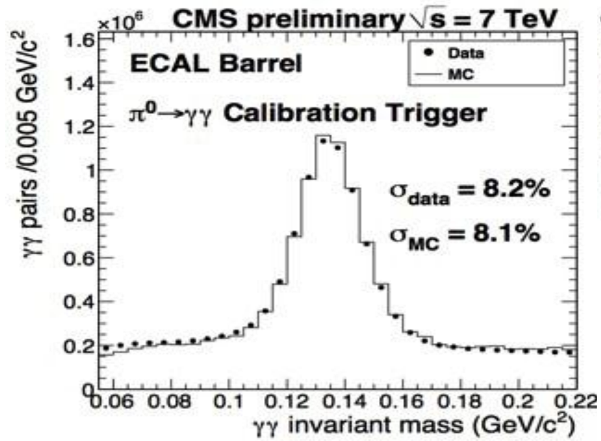


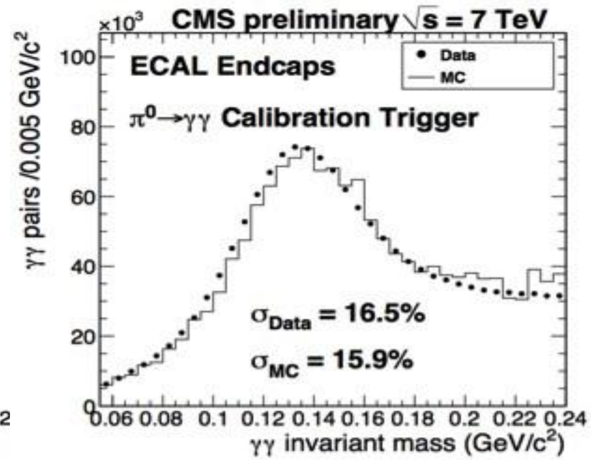
Resolution on data consistent with simulation

example of E_T^{miss} tested on data in inclusive lepton samples

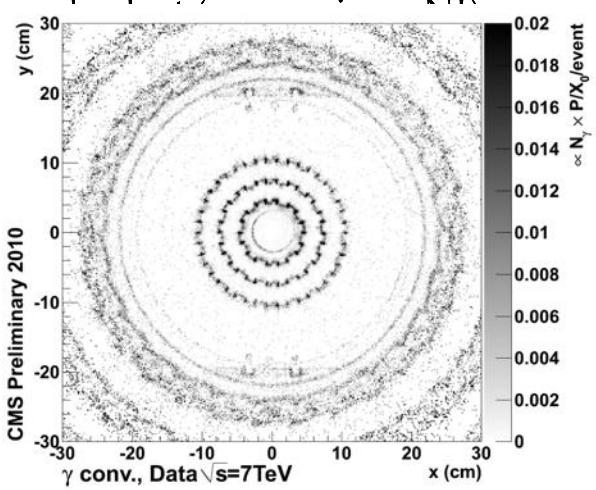
CMS ECAL, photon and electron performance

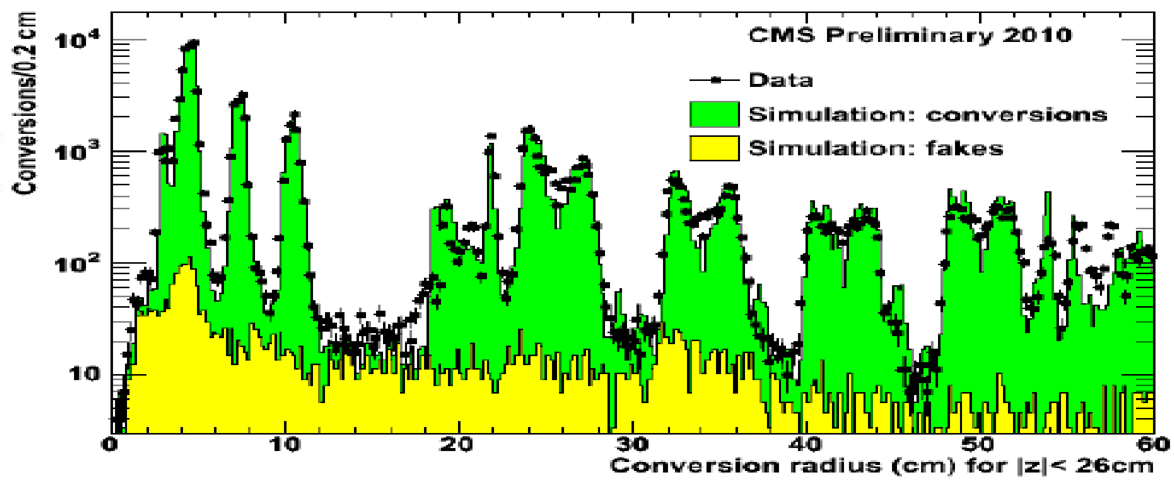
- ECAL provides very good energy resolution down to low energies
- Performance in agreement with expectations
- At high ET the scale in the barrel region is now set by the π^0 calibration (correct to 1%); 3% shift in the endcap region





- Good knowledge of material





Particle identification

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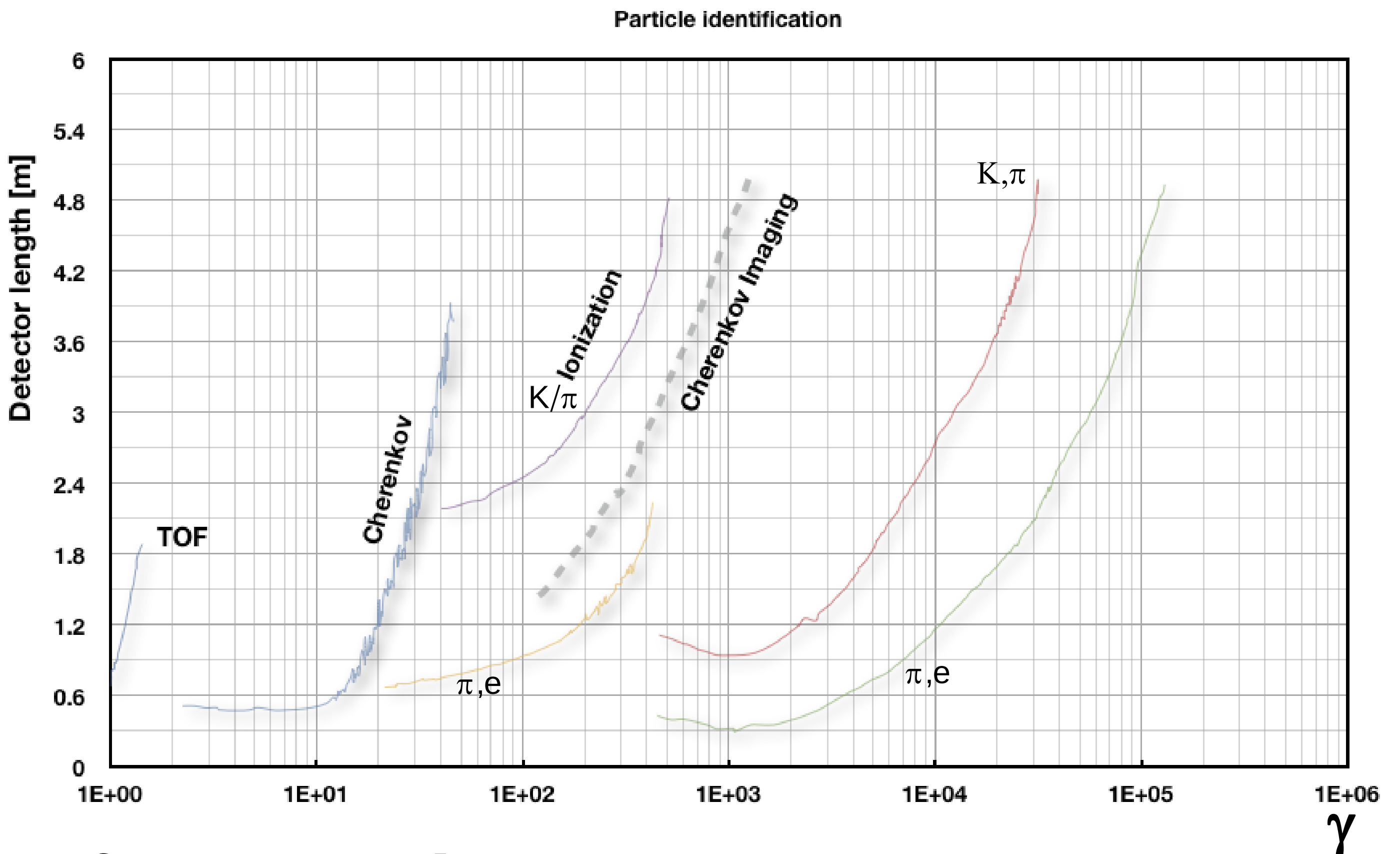
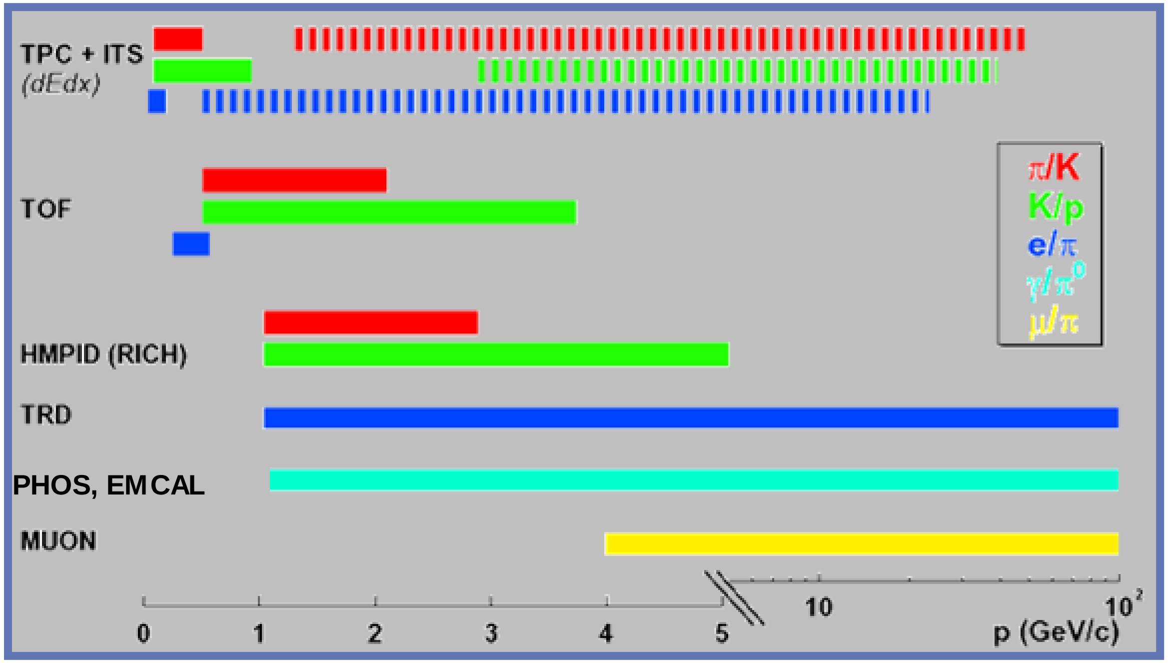
Not only gas detectors

PID in one slide



- Low E, TOF measures p,v ➔ m
- Higher E, Cherenkov threshold v > c/n discriminates between particles
- For $\gamma \sim 100$ identification via dE/dx
- Cherenkov angle measurement $\cos\theta > 1/n\beta$
- For high γ the transition radiation

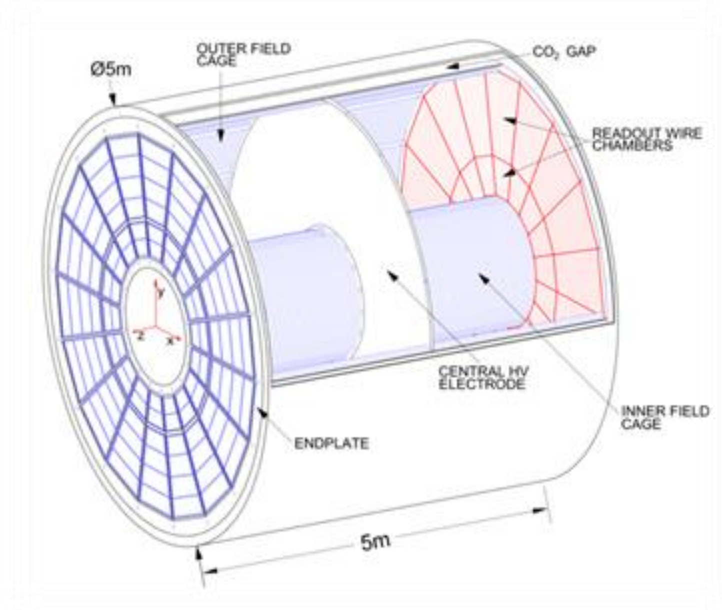
PID in ALICE



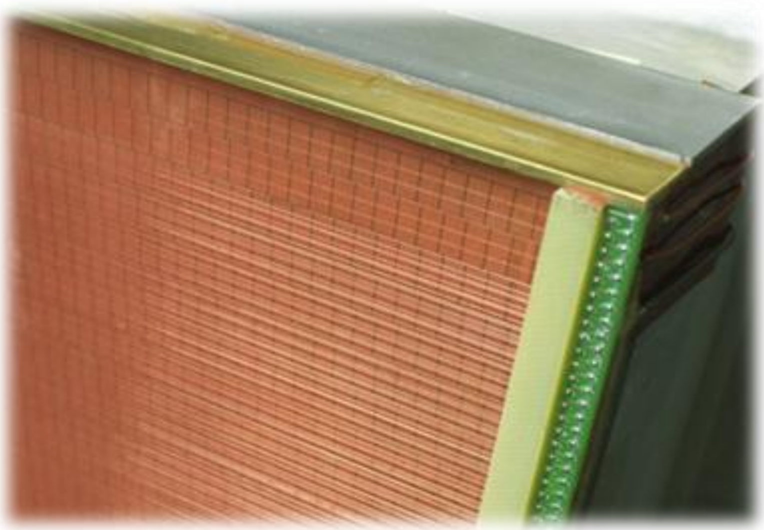
- 'stable' hadrons (π, K, p): 100 MeV < p < 5 GeV   (several 10 GeV)
  - dE/dx in silicon (ITS) and gas (TPC) + time-of-flight (TOF) + Cherenkov (HMPID)
- decay topologies (K, Λ, ϕ, Ω, D)
  - K and Λ decays beyond 10 GeV
- leptons (e, μ), photons η,π^0
  - electrons TRD: p > 1 GeV, muons: p > 5 GeV, π^0 in PHOS, EMCAL: 1 < p < 80 GeV

ALICE TPC details

- Gas volume ~92 m^3
- Material budget 3% X_0 at $\eta=0$
- 72 (=18×2×2) Readout chambers: MWPCs with cathode pad readout



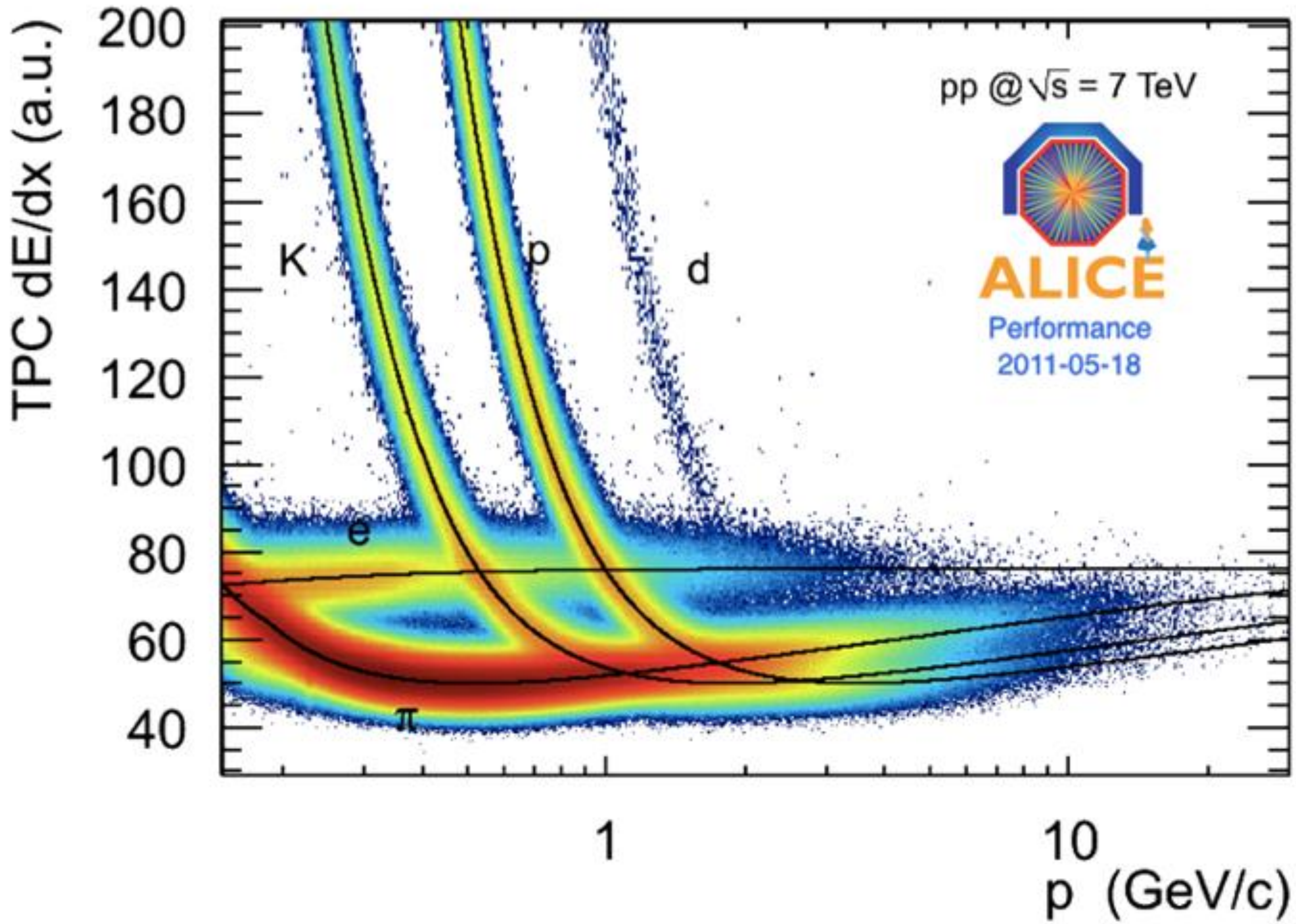
Low mass, high precision field cage



Detail of one readout chamber

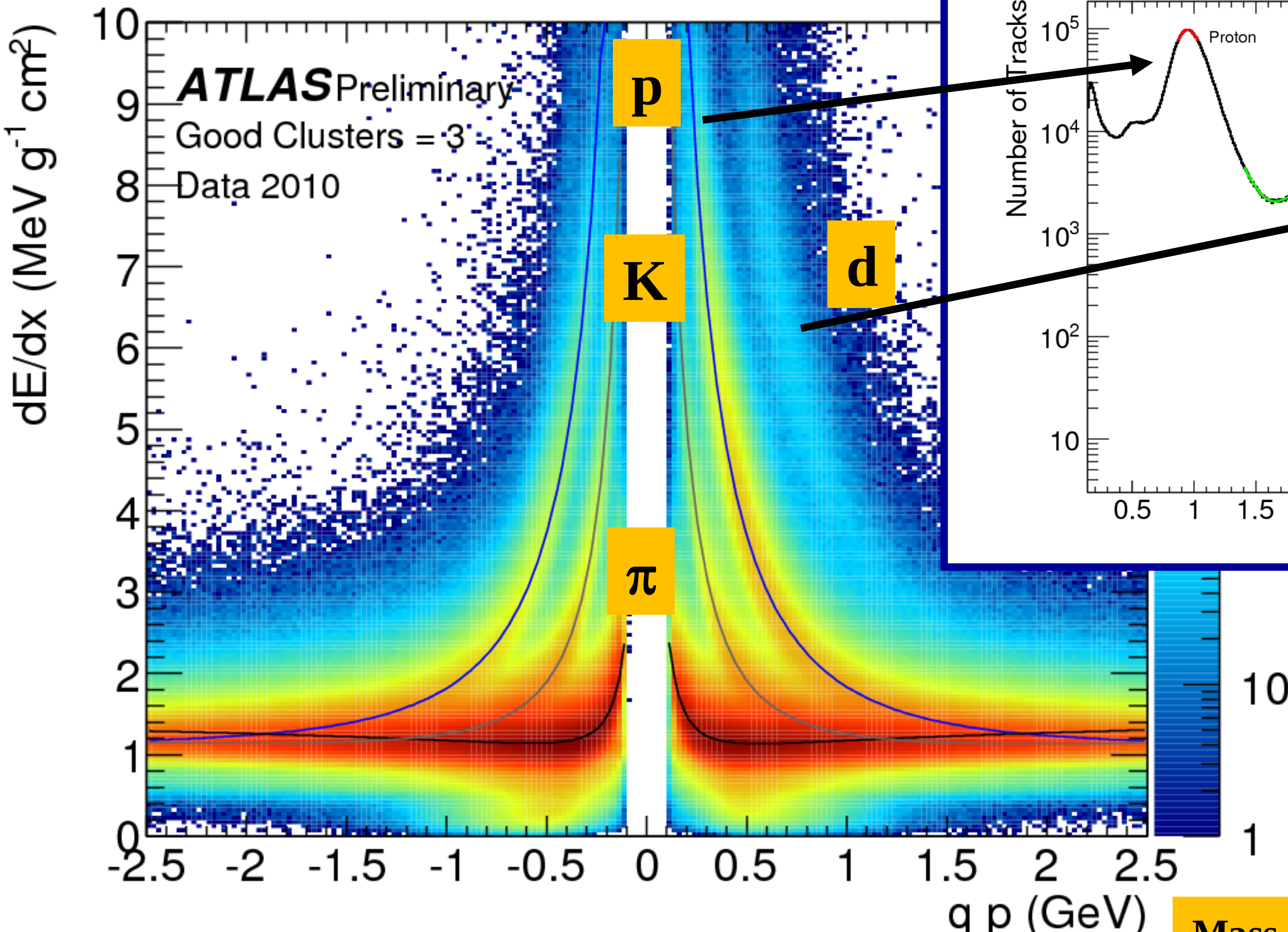
Gas mixture: Ne, CO_2 (90-10)
Maximum electron drift time (250 cm drift) : ~92 µs
557 568 read out pads and FEE channels

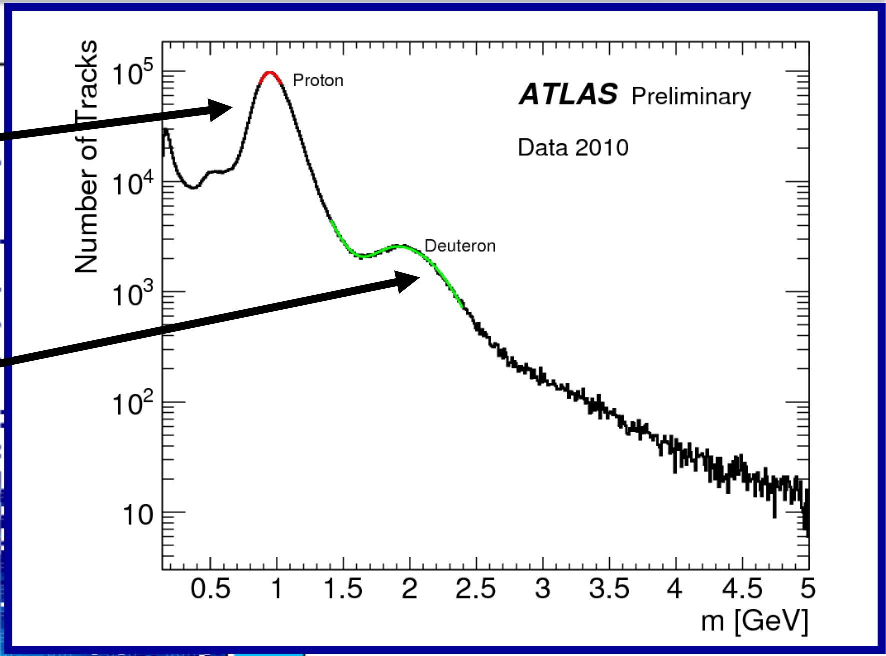
ALICE TPC: dE/dx



10 bit ADC: Dynamic range up to 26×MIP. σ ~ 5%

dE/dx in Silicon: ATLAS Pixels





σ ~ 12%

Mass determination inverting Bethe-Bloch energy loss relation

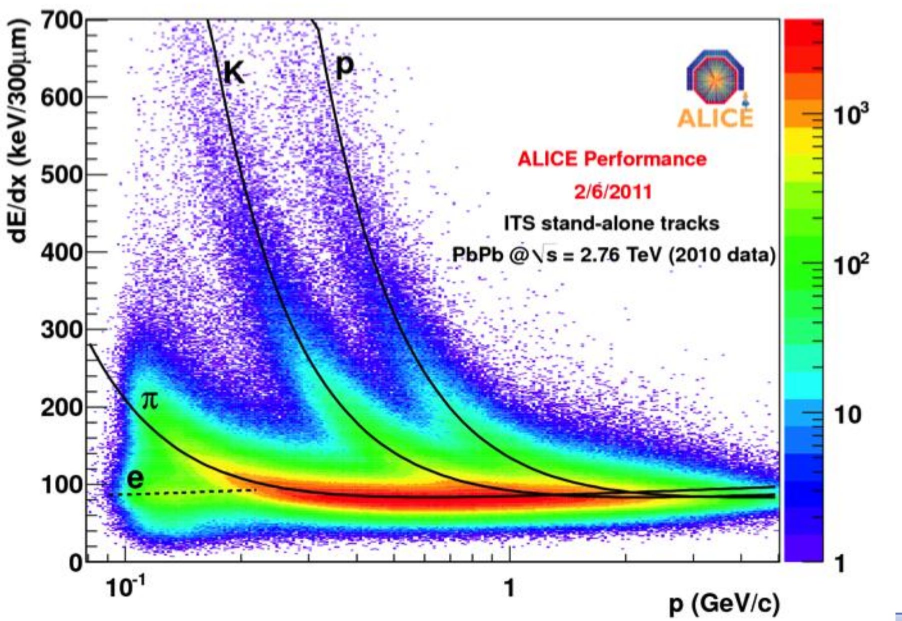
PID in Silicon: ALICE ITS

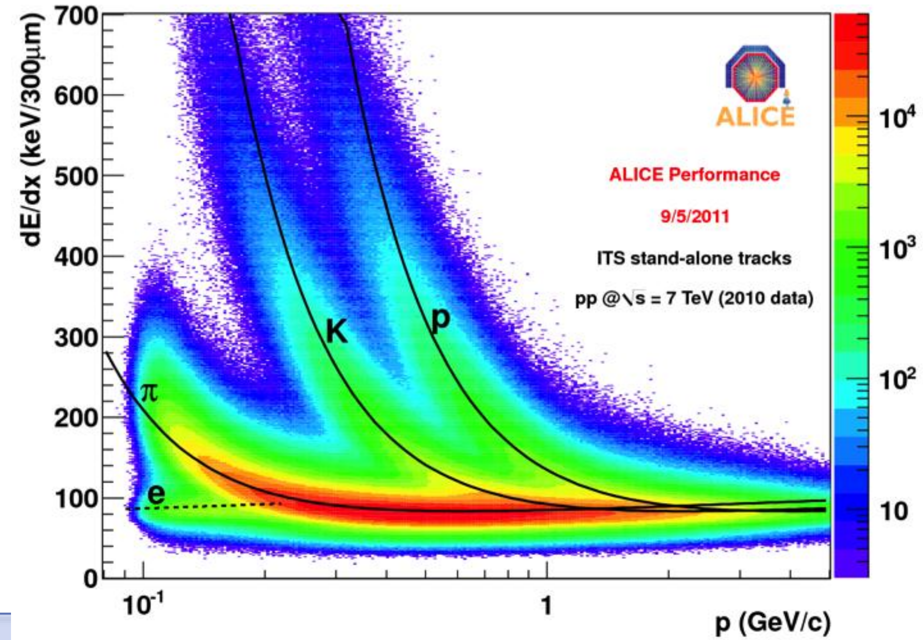
4 out of 6 silicon layers with analogue information (SDD and SSD)

- Energy loss (dE/dx)
- Truncated mean to account for long tails in the Landau distribution
- Tracks path length correction

Results for particle identification in p-p and Pb-Pb data

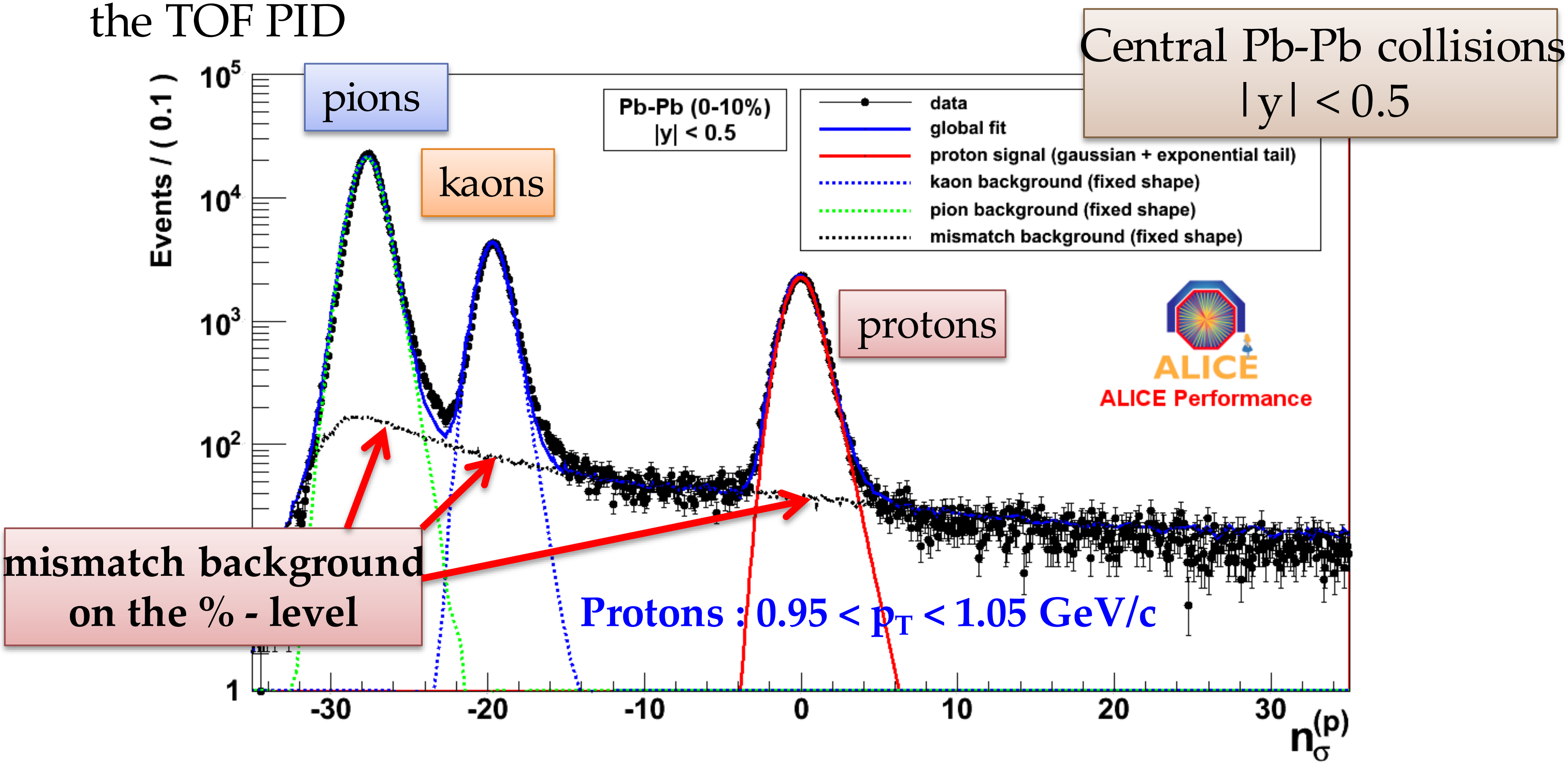
- ITS standalone tracks
- Hadron separation below 100 MeV/c
- Good pions / kaons separation up to 0.5 GeV/c
- Good pions and protons separation up to 1 GeV/c





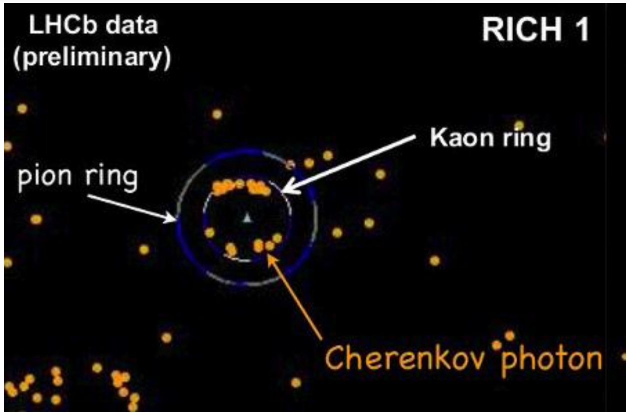
ALICE TOF PID

Raw yields: a global fit of **Time-Of-Flight** signal - ***mass hypotesis* *i* (π, K, p)** constrains the integral of the fit to the total number of entries in the TOF PID

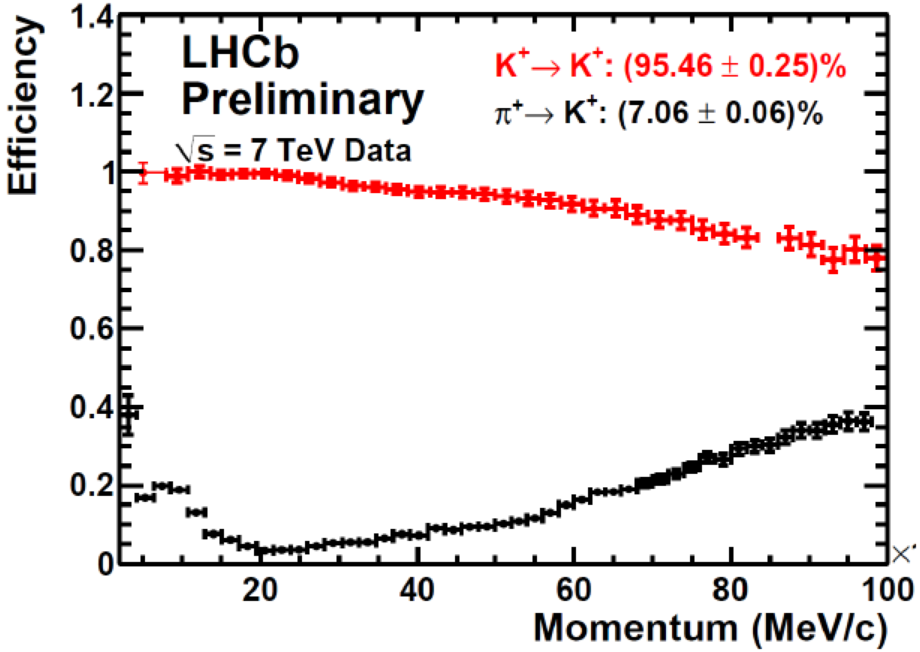


LHCb: π/K separation

- Particle identification with the RICH
  - About 500 HPD devices, 32x32 cells each.
    - ½ million cells!
  - A charged particle produces Cherenkov photons, that are located on a ring centred around the track's position
  - 2 detectors, the first one with 2 radiators
    - Gives π/K separation for a large momentum range

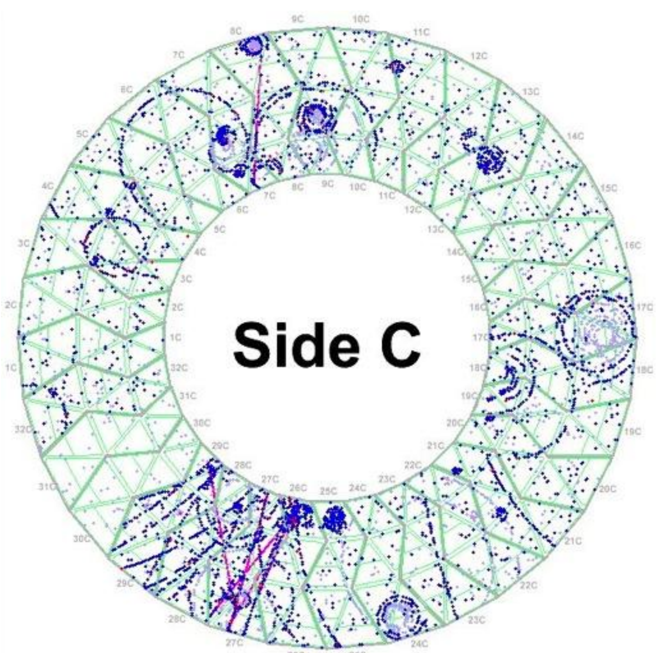


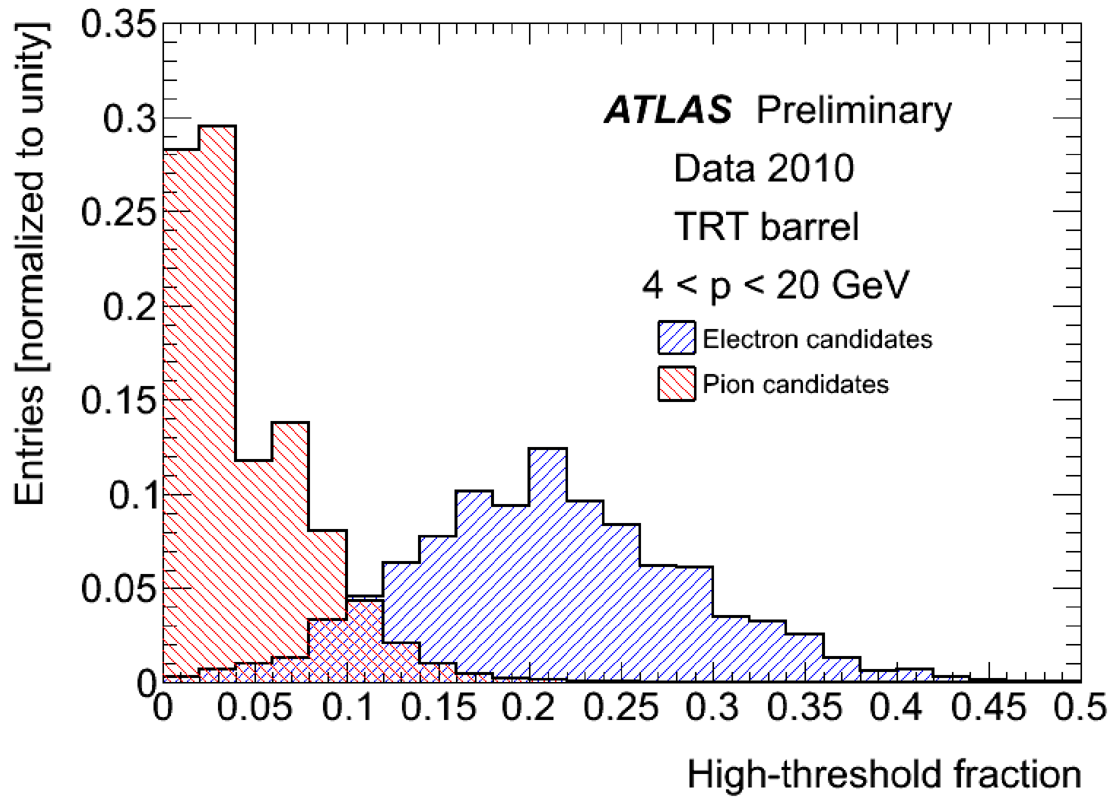
- Careful alignment required
  - The HPD are sensitive to magnetic field
  - Variation of the gas refractive index with temperature...



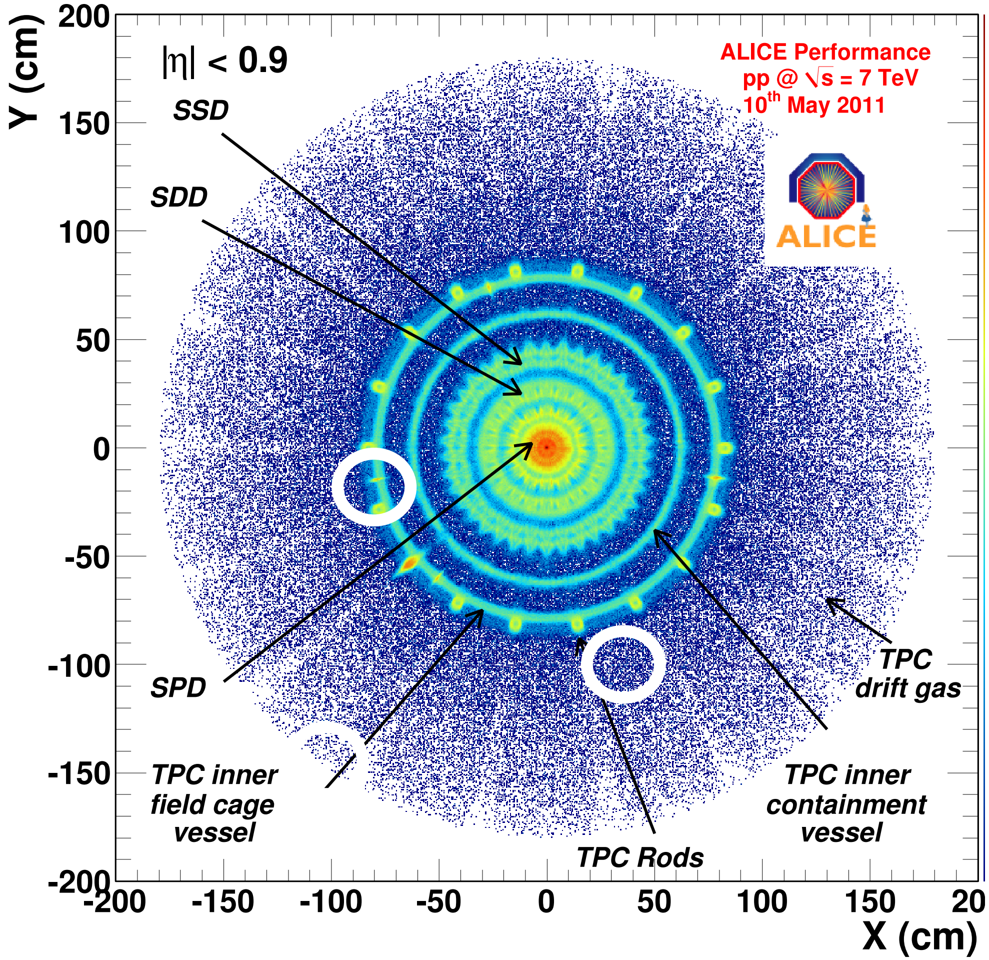
ATLAS TRT: transition radiaton at work

- Barrel shown here, same for endcaps
- ALICE has equally nice results





ALICE: Material Budget



γ-ray image of ALICE photon conversion vertices

ALICE π^0 and η (and γ) Reconstruction

$pp \rightarrow \pi^0 + X_n$

$\searrow \gamma\gamma$

$\searrow e^+e^-e^+e^-$

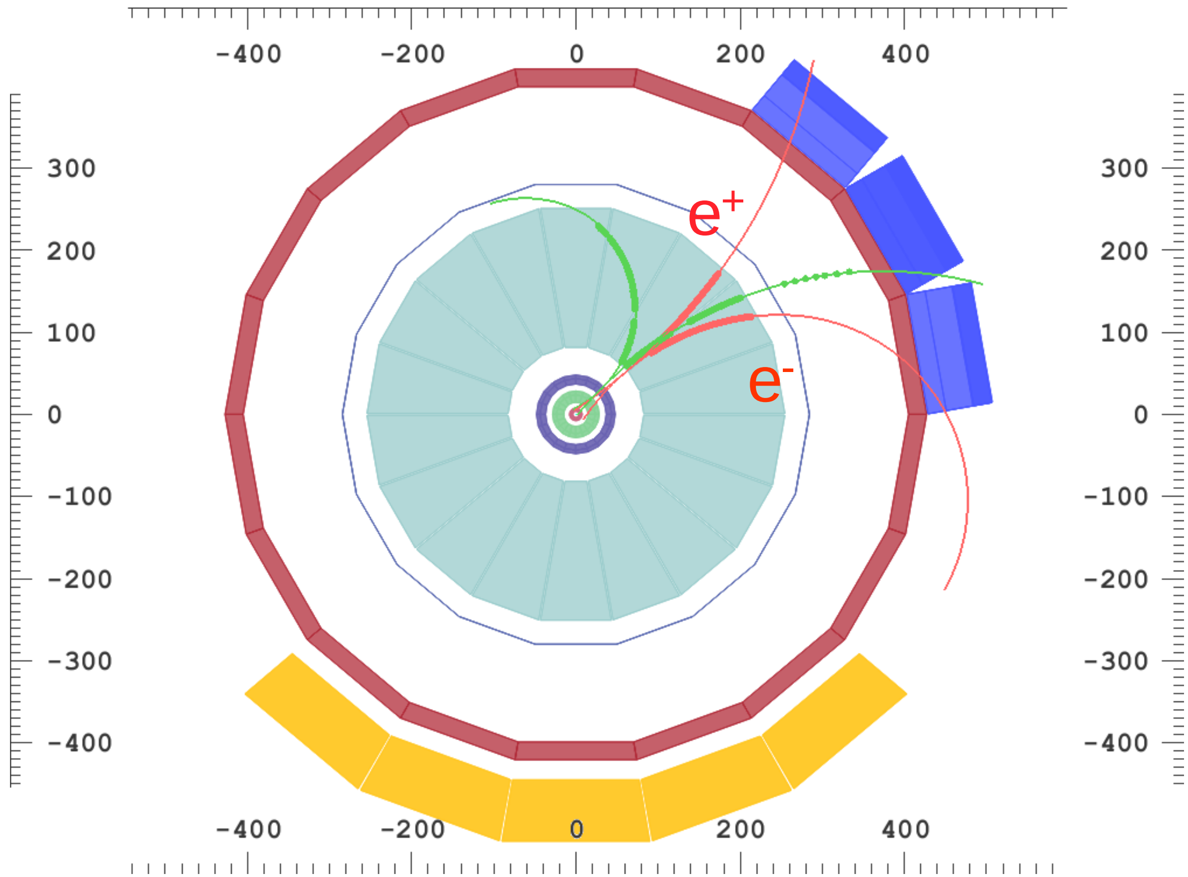
($m_{\pi 0}$ = 0.135 GeV/c², BR = 0.988)

$pp \rightarrow \eta + X_n$

$\searrow \gamma\gamma$

$\searrow e^+e^-e^+e^-$

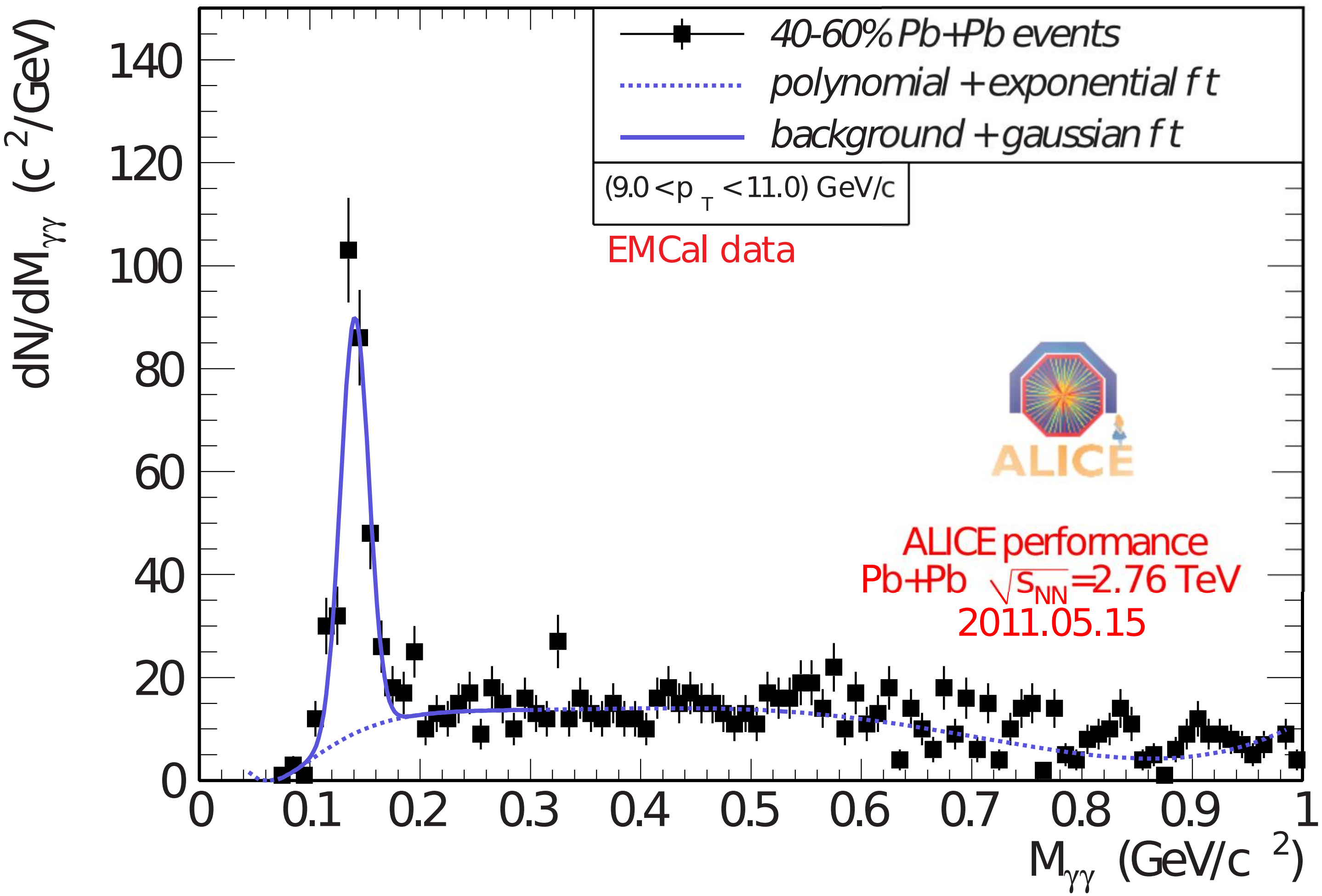
(m_η = 0.548 GeV/c², BR = 0.393)



run 104792, event 2248

3 independent measurements:
Conversions, PHOS, EMCAL

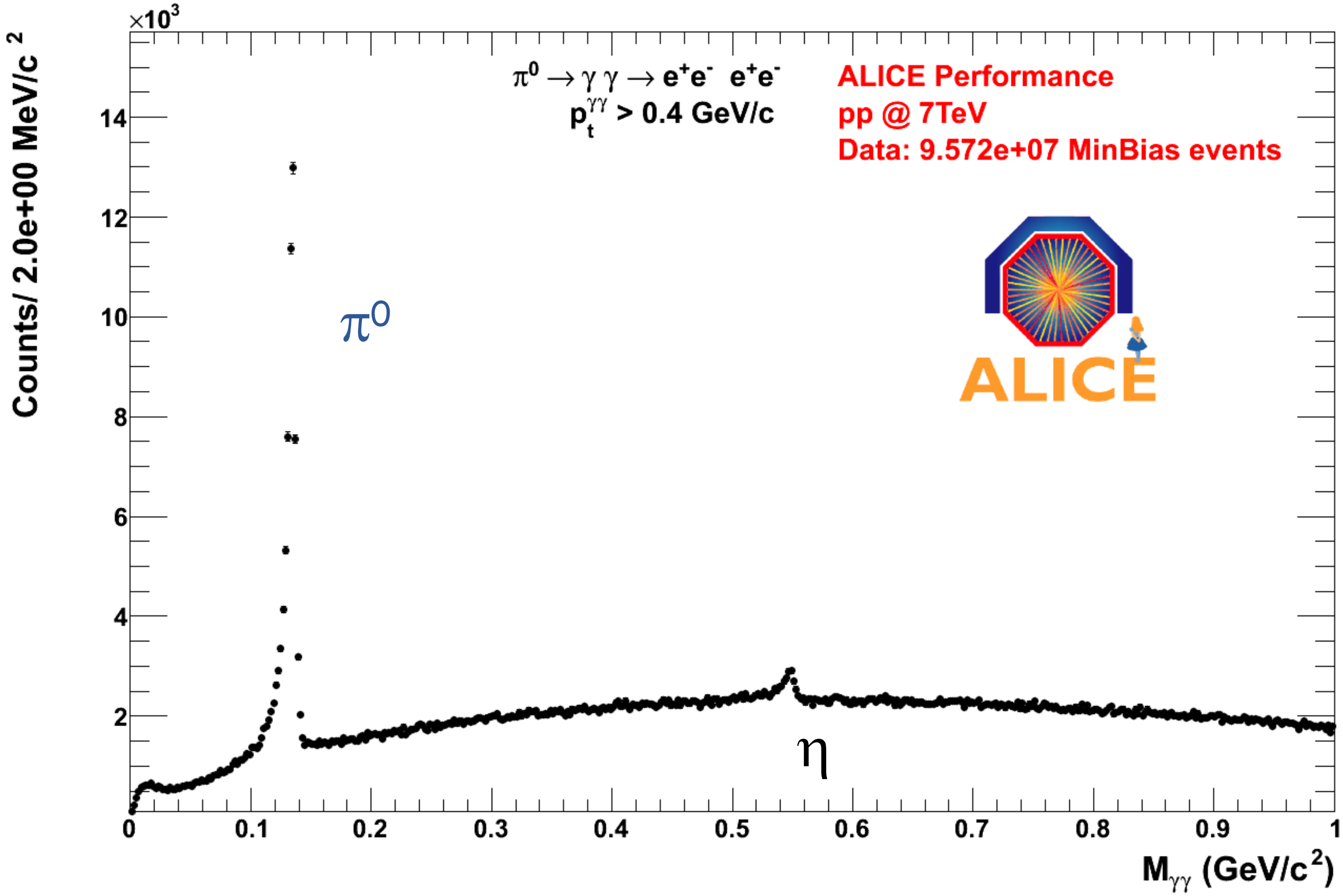
ALICE: π^0 Reconstruction in EMCAL



Reconstruction of π^o invariant mass in semi-central Pb-Pb collisions

ALICE: π^0 and η from conversions

$$M_{\gamma_1\gamma_2} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{\gamma_1\gamma_2})}$$



Inventory of Gas detectors

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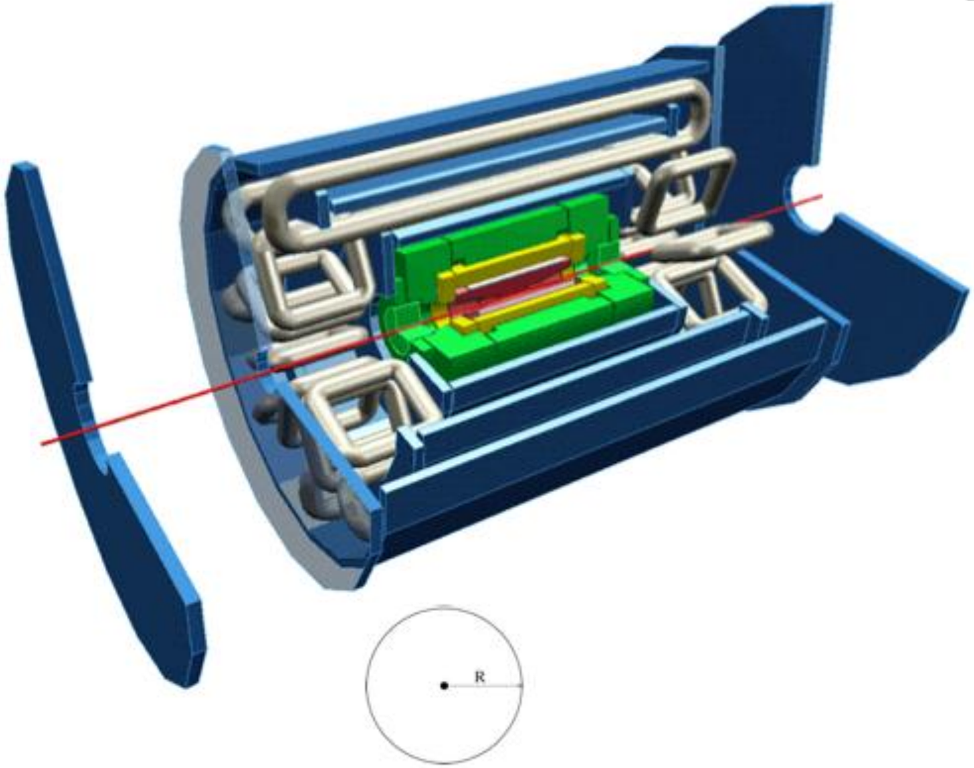
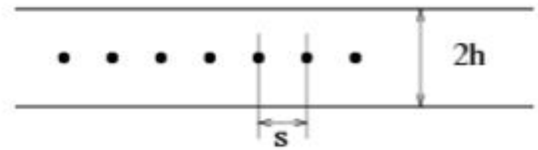
Muon detection and more

Inventory by W. Riegler

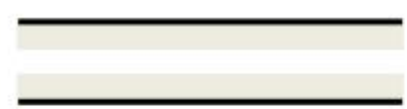
ATLAS





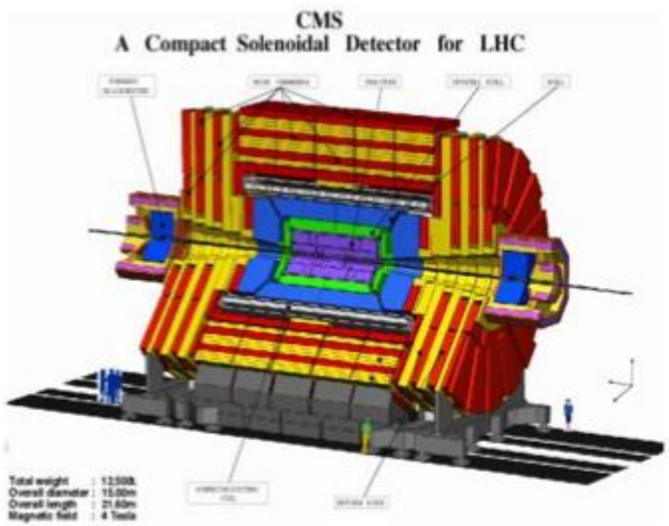
- Cathode Strip Chambers (Tracking):
  - h=2.54mm, s=2.54mm
  - 67k cathode channels
  - $Ar/CO_2/CF_4$
  - < 60 μm
- Thin Gap Chambers (Trigger)
  - h=1.4mm, s=1.8mm
  - 440k cathode and anode channels
  - n-Pentane /CO_2 45/55
  - < 99% in 25ns with single plane

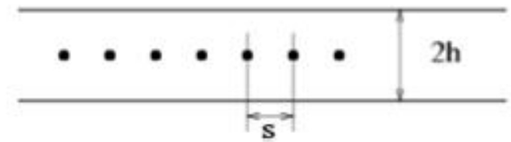
- Monitored Drift Tubes (Tracking)
  - R=15mm
  - 370k anode channels
  - Ar/CO_2 93/7 (3 bars)
  - < 80μm
- Transition Radiation Tracker (Tracking)
  - R=2mm
  - 372k anode channels
  - $Xe/CO_2/CF_4$ 70/10/20
  - $Xe/CO_2/O_2$ 70/27/3
  - < 150 μm



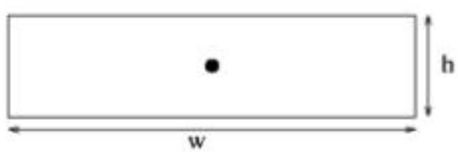
- RPCs (Trigger):
  - g=2mm, 2mm Bakelite
  - 355k channels
  - $C_2F_4H_2$/Isobutane/SF_6 96.7/3/0.3
  - < 98% with a single plane in 25ns

CMS





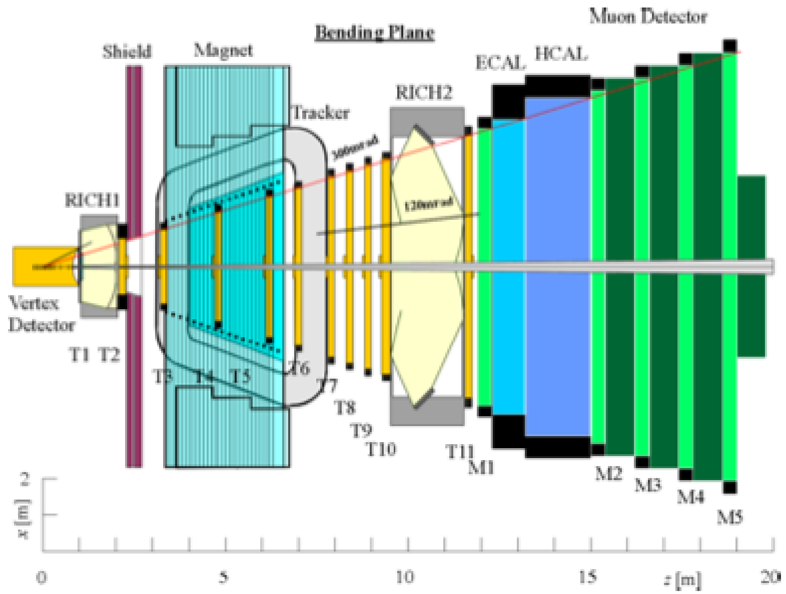
- **Cathode Strip Chambers (Trigger, Tracking):**
  - h=4.25mm, s=3.12mm
  - 211k anode channels for timing
  - 273k cathode channels for position
  - $Ar/CO_2/CF_4$ 30/50/20
  - < 75-150 μm

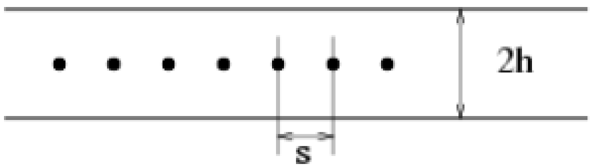


- **Rectangular 'Drift Tubes' (Trigger, Tracking)**
  - w=42mm, h=10.5mm
  - 195k anode channels
  - Ar/CO_2 85/15
  - < 250 μm

- **RPCs (Trigger):**
  - g=2mm, 2mm Bakelite
  - Many k channels
  - $C_2F_4H_2$/Isobutane/SF_6 96.5/3.5/0.5
  - < 98% with a single plane in 25ns

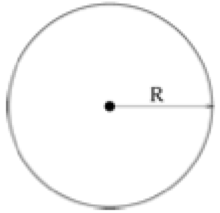
LHCb





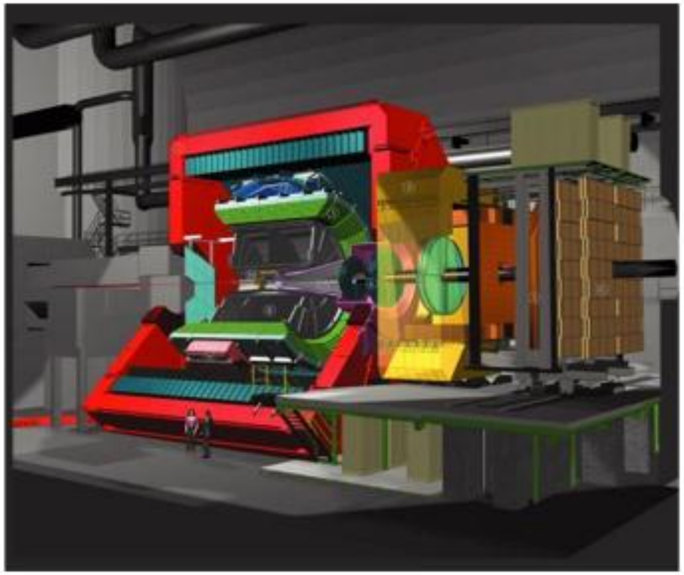
- **Muon Chambers (Trigger):**
  - h=2.5mm, s=2mm
  - 125k cathode and anode pads
  - $Ar/CO_2/CF_4$ 40/55/5
  - < 3ns for two layers

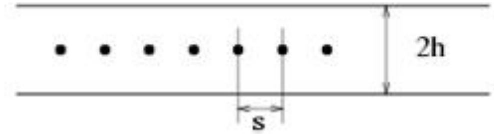
- **GEM (Trigger):**
  - 5k channels
  - $Ar/CO_2/CF_4$ 75/10/15
  - <4.5 ns for one triple GEM



- **Outer Tracker (Tracking):**
  - R=2.5mm
  - 51k anode channels
  - $Ar/CO_2/CF_4$ 75/10/15
  - < 200 μm

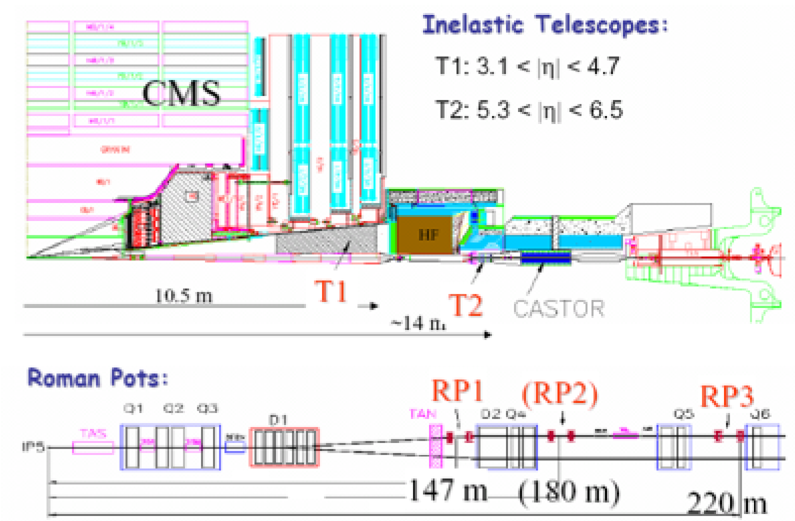
ALICE

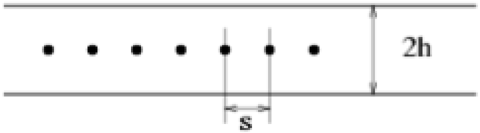




- **TOF RPCs**
  - G=0.25mm, 0.4mm glass, 10gaps
  - 160k channels
  - <50ps/10gaps
  - $C_2F_4H_2$/Isobutane/SF_6 96.5/3.5/0.5
- **Trigger RPCs**
  - G=2mm, 2mm bakelite
  - Ar/Isobutane/$C_2F_4H_2$/SF_6 49/7/40/4
  - 21k channels
- **TPC with wire chamber cathode pad readout**
  - 1.25-2.5mm wire pitch
  - 2 - 3 mm plane separation
  - 570k Readout Pads
  - Ne/CO_2 90/10
- **TRD**
  - 1160 k channels
  - Xe/CO_2 85/15
  - s=5mm, h=3.5mm
- **HMPID**
  - s=2mm, h=2mm
  - Methane
  - 160k channels
- **Muon Chambers**
  - 1000k channels
  - <100um
  - S=2.5mm, h=2.5mm
  - Ar/CO_2 80/20

TOTEM

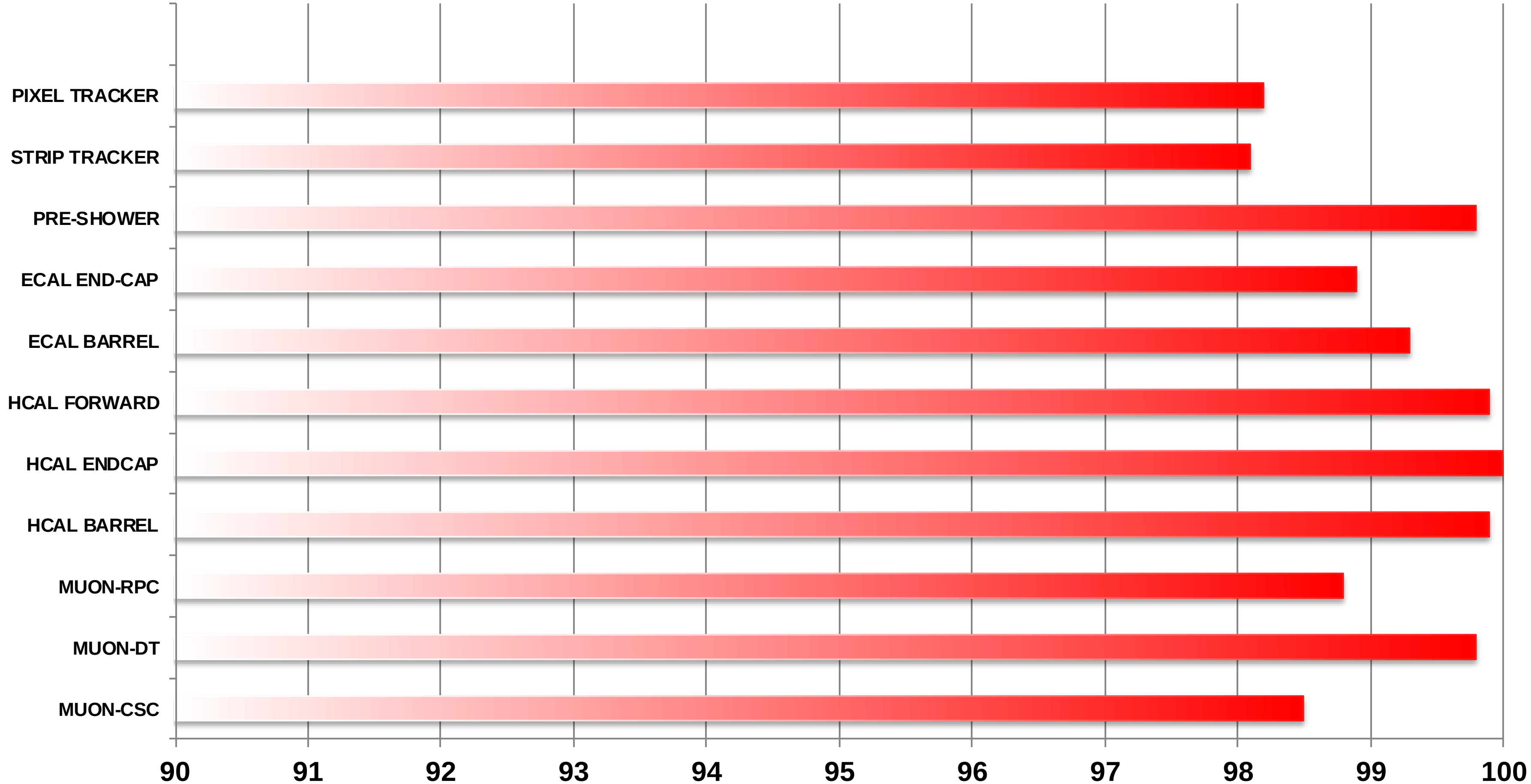




- **T1: CSCs**
  - 13k anode channels
  - 21k cathode channels
  - s=3mm, h=5mm
  - Ar/CO_2 50/50

- **T2: GEMs**
  - Ar/CO_2 50/50
  - 24.5k channels

CMS status

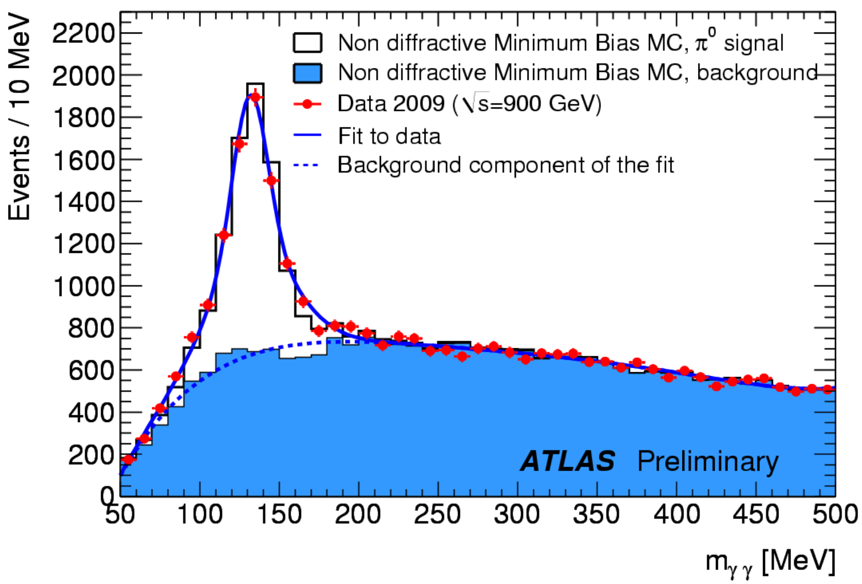


	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER	
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2	

ATLAS: e.m. energy scale

EM scale: initial study/validation from test beam measurements

Checked on $\pi^0 \rightarrow \gamma\gamma$ event **(2%)**



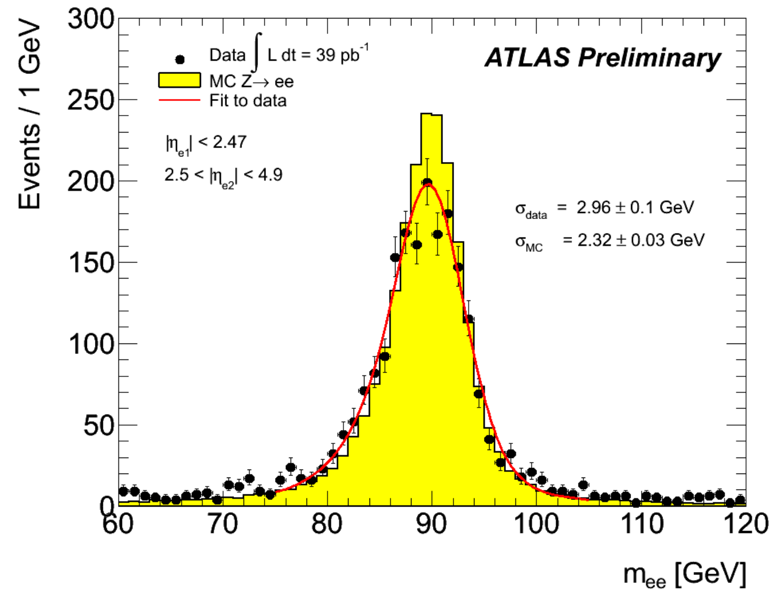
ATLAS-CONF-2010-006

Central forward region $Z \rightarrow e^+e^-$ mass

reconstruction identification of electrons at |n|>2.5 beyond tracker acceptance

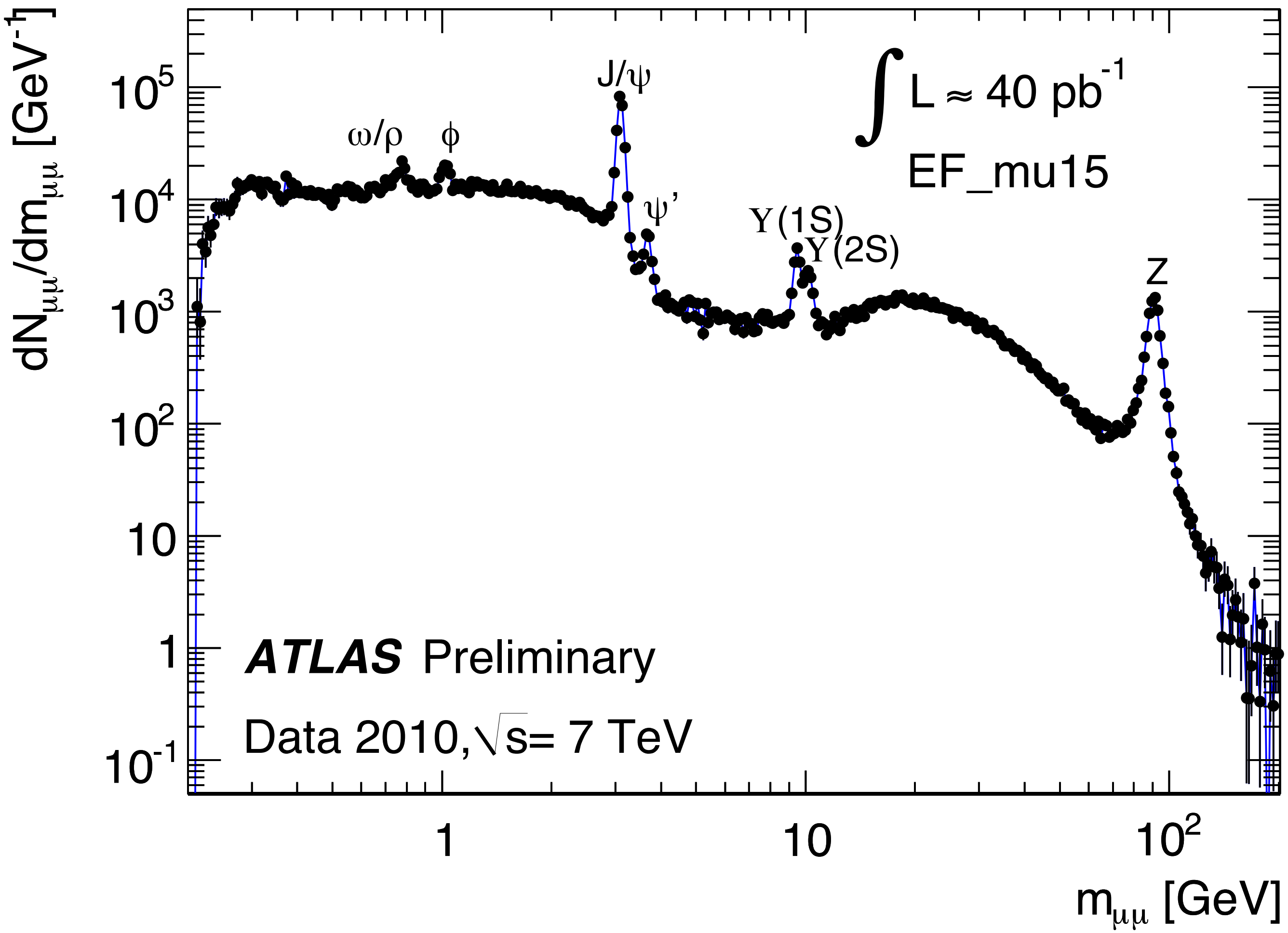
Events with 2 electrons with E_T>20 GeV with one electron found in the central region and the other in the forward.

Apply the em energy scale corrections

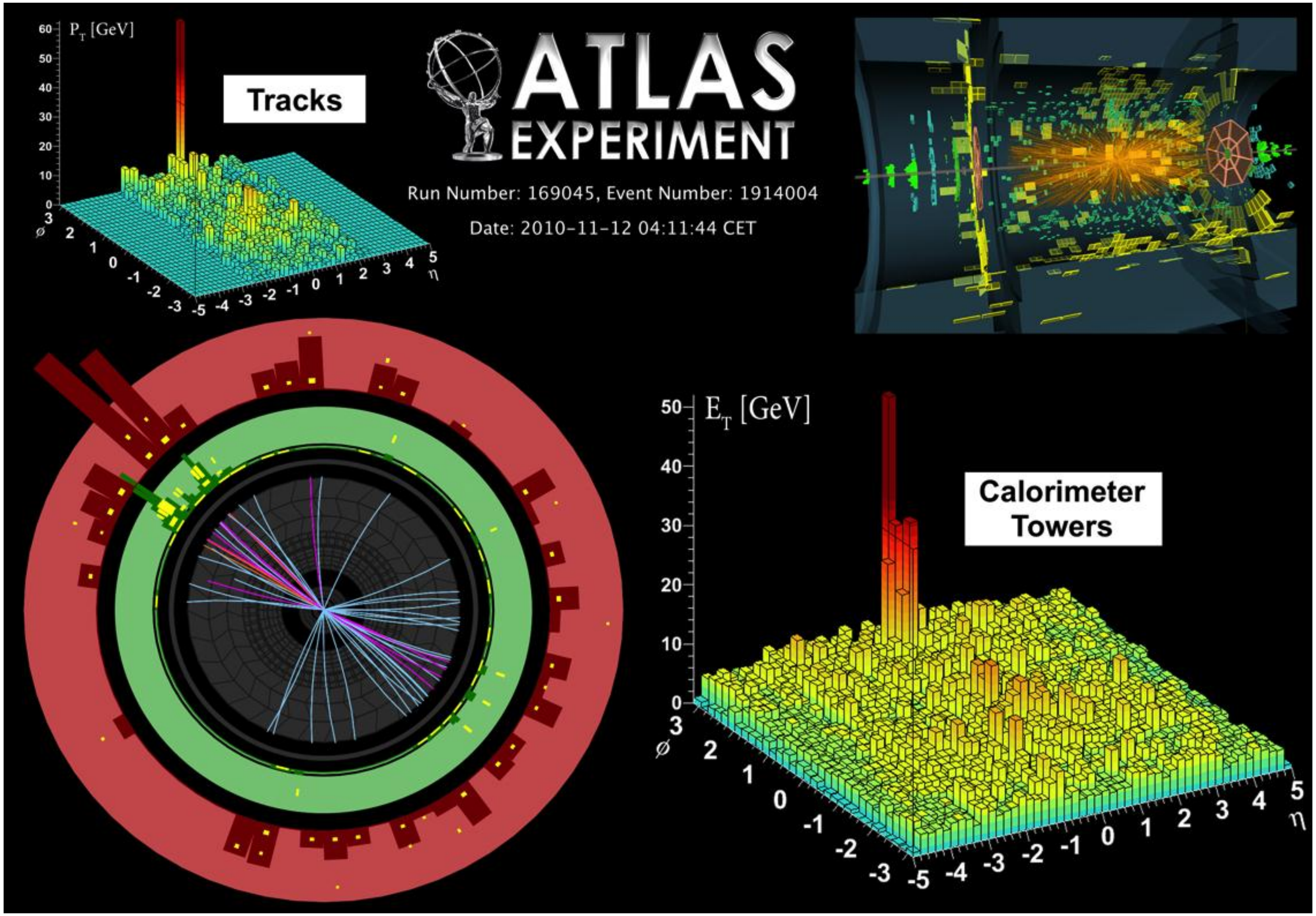


Capability to reconstruct and identify $e^{\pm}$ in the forward region

ATLAS "calibration" particles

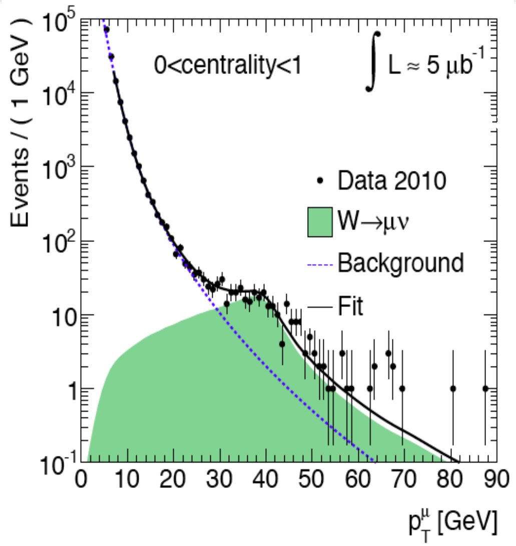


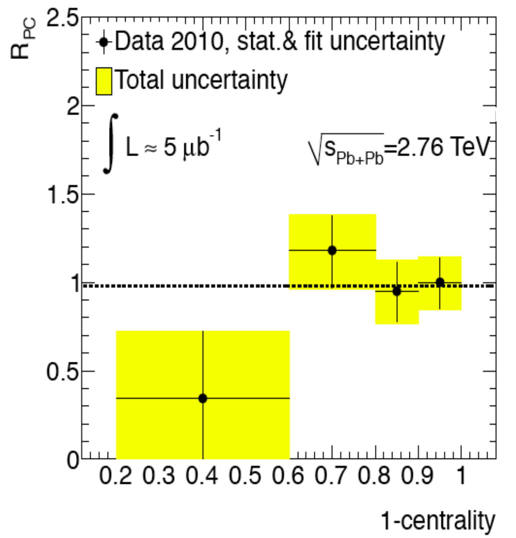
Heavy ions in ATLAS



Heavy ions in ATLAS

- First direct observation of Jet Quenching
- First publication on J/Psi suppression and Z production in HI at LHC.
    - Both papers sent to journals before Xmas 2010.
- New:
    - Measurement of relative yield (wrt most central bin) of W production in HI vs centrality
    - + many other new measurements (jet quenching, particle flow etc.)





Forward physics detectors

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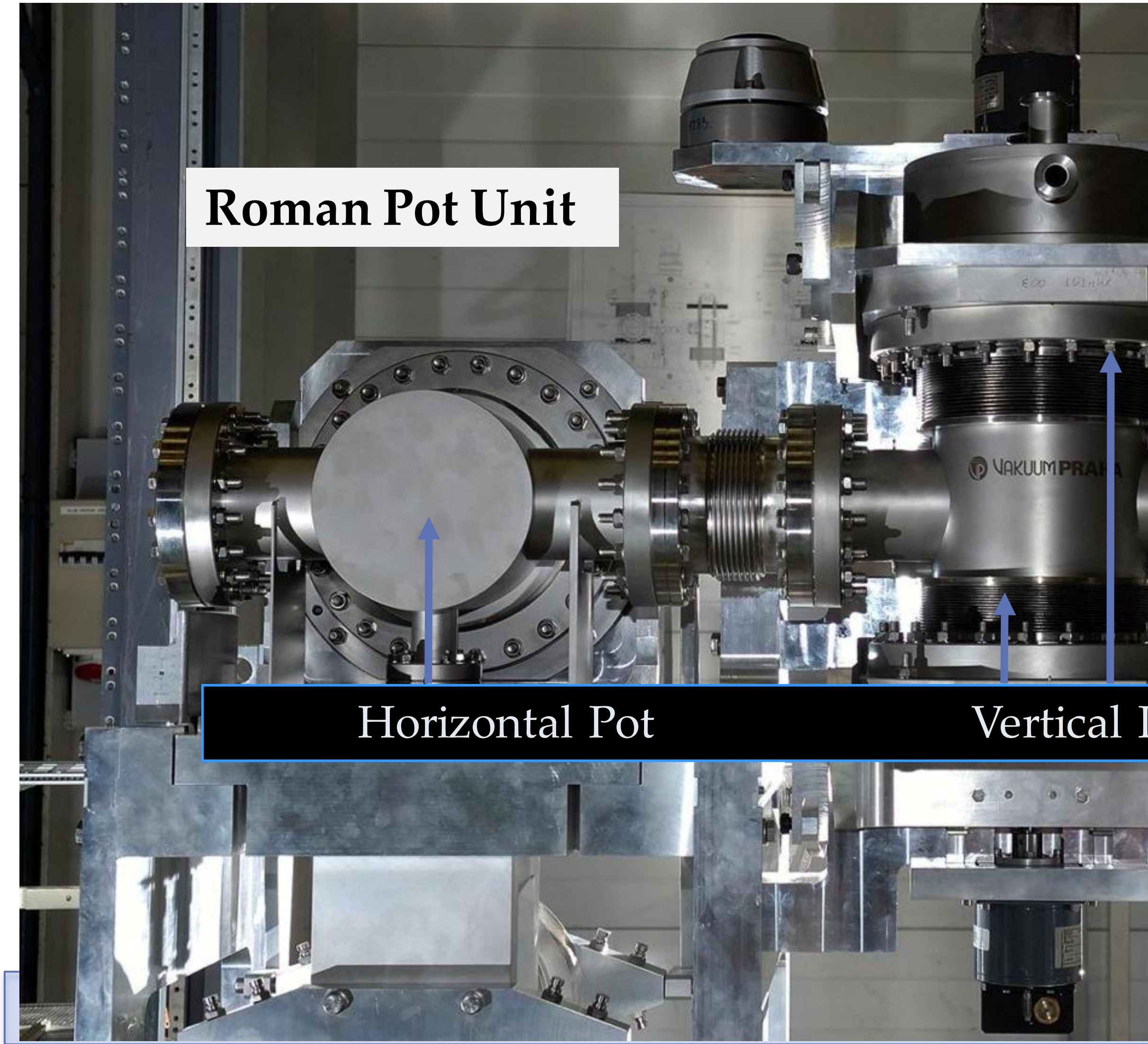
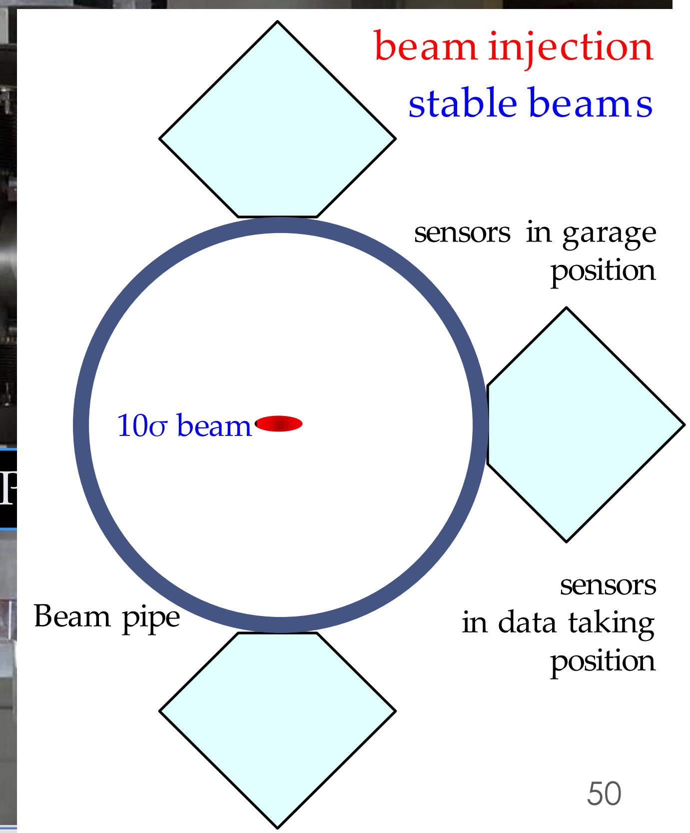
Far from IP

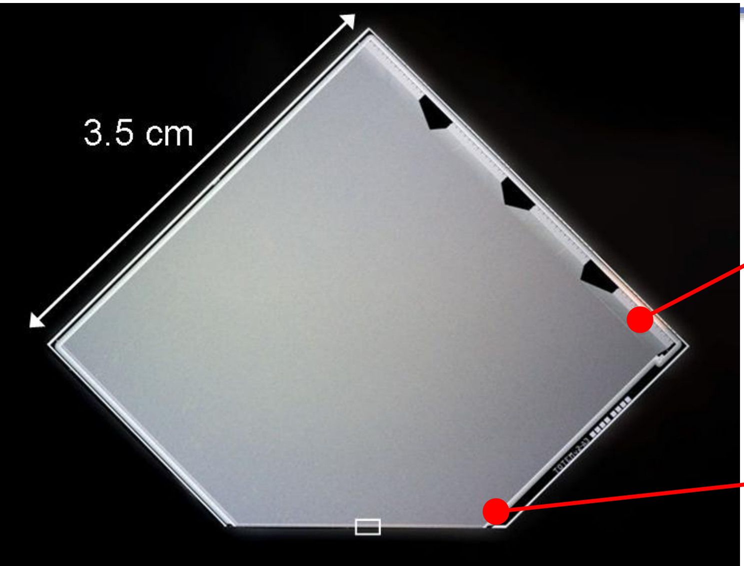
The TOTEM Roman Pot Station

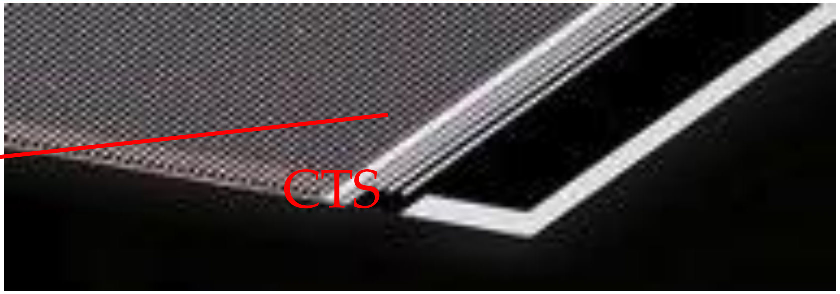
Four Roman Pot Station on both sides of IP5 (± 147m and ± 220m)
Each station is made of two units



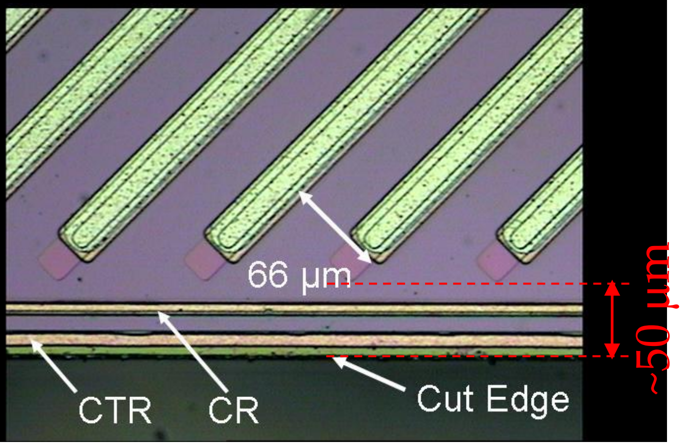


The TOTEM Edgeless Sensor





VTS



Only 50µm from end of strip to end of sensor!!!

Technology

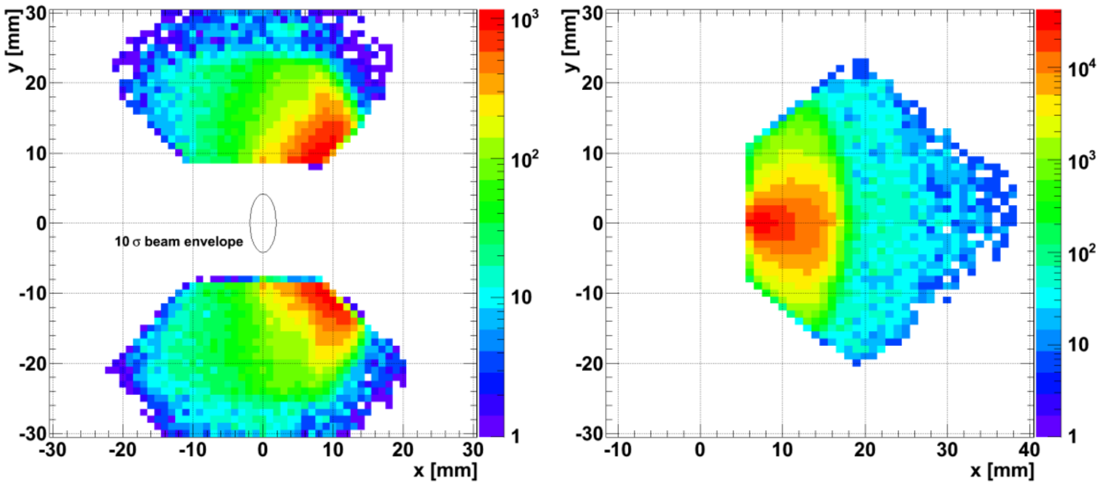
- Very High Resistivity Si n-type <111>, 300um thick, Vdep ~20V
- Standard planar technology fabrication
- Dicing with diamond saw
- AC coupled strip (punch-through)

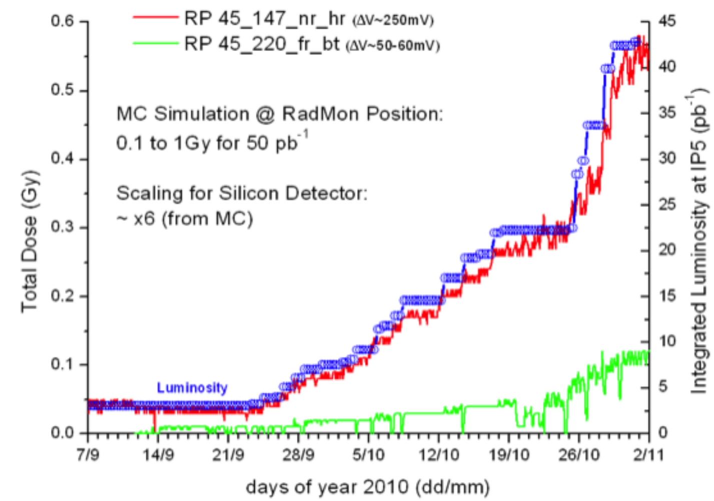
Design

- Single sided detector, 512 microstrips (pitch 66um)
- strips at 45° from the "sensitive" edge
- Voltage Terminating Structure (VTS) on non sensitive edges
- Current Terminating Structure (CTS) on sensitive edges (50 µm)

Protons, background and radiation dose

Tracks distribution in the vertical RPs (left) and horizontal RP (right).



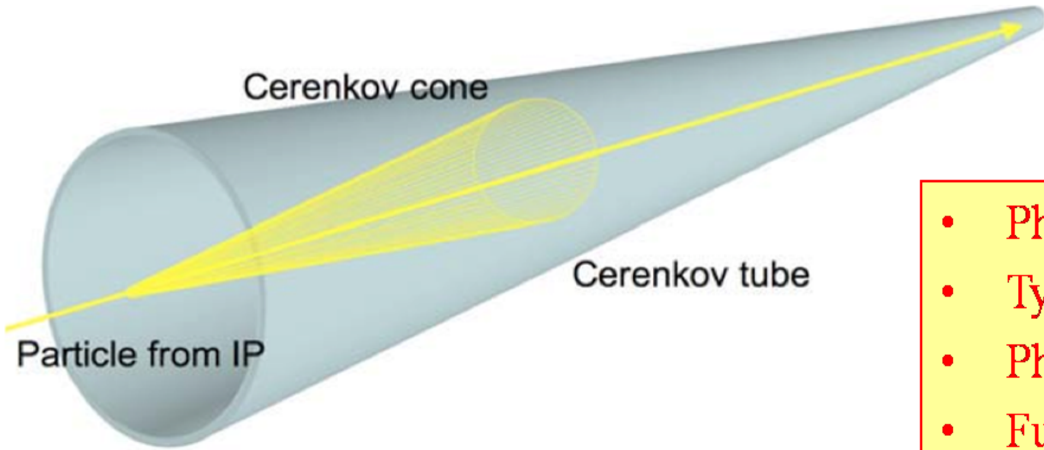


(note: different colour scale in the two panels)

Radiation dose highest in the horizontals due to diffraction
Higher dose foreseen in the Stations at 147m
Peaked at the detector's edge and leads to differences of $>10^4$ in accumulated dose in the same sensor!!!

Problem: how to determine the life time of the sensors?

LUCID detector principle



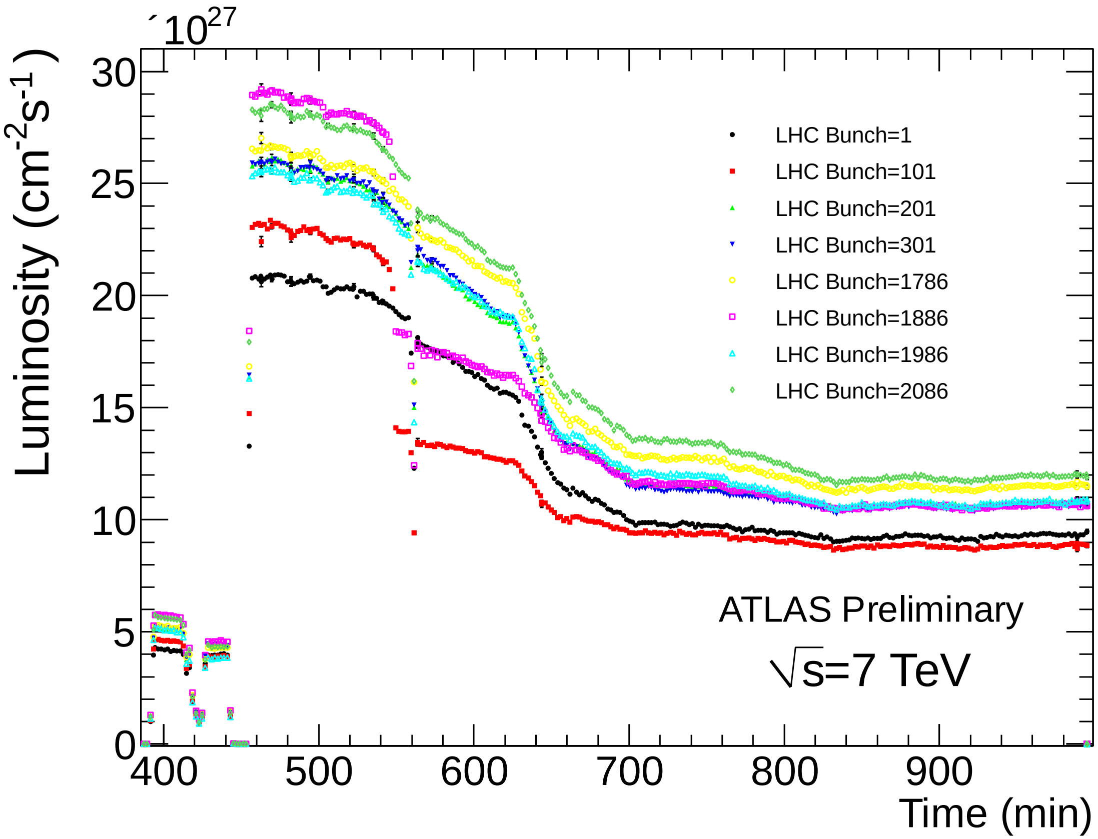
PMT read-out

- Photons are emitted at 3°
- Typically 3 reflections inside the tubes
- Photons are read-out by PMT
- Further photons radiated inside PMT

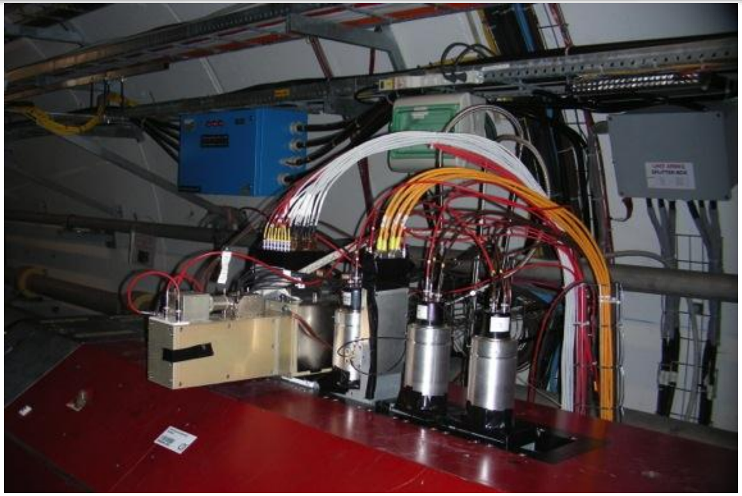
- Background suppression:
  - Cherenkov threshold: 10 MeV for e^- and 2.8 GeV for π, in the gas
  - Geometry: tubes are pointing to the *pp* interaction region.
- The fast response (few ns) allows for single bunch crossing detection.

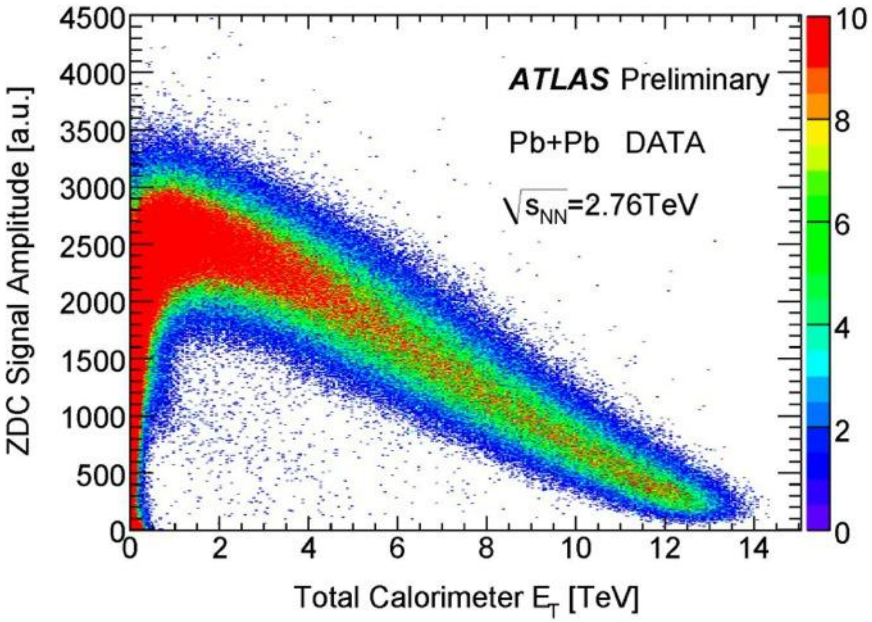
LUCID results

- The instantaneous luminosity measured by LUCID at 7 TeV for 8 different colliding bunches in the machine.
- The plot shows that the time development of the different bunches is different. The bunch-to-bunch variations in the luminosity is up to 40% at the start of the fill



ATLAS ZDC

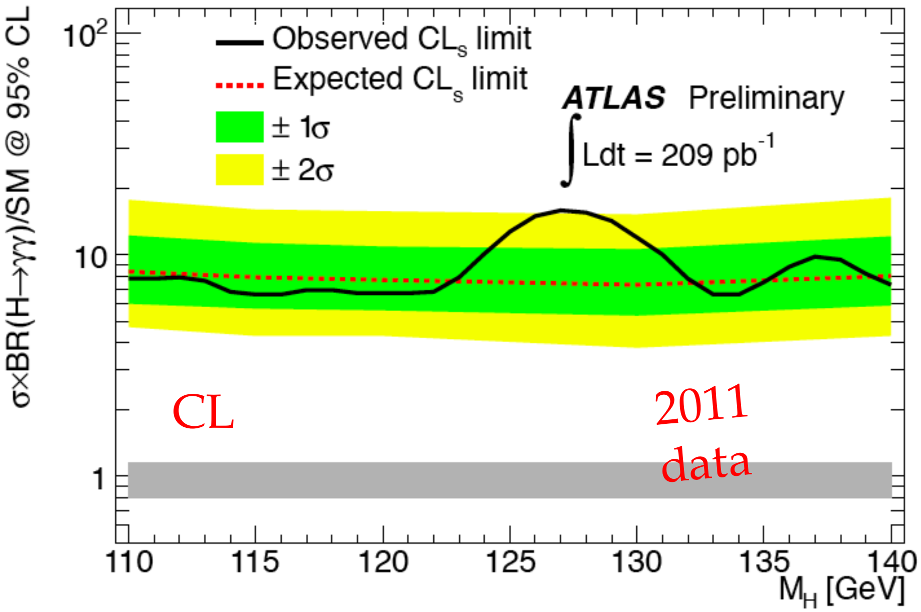


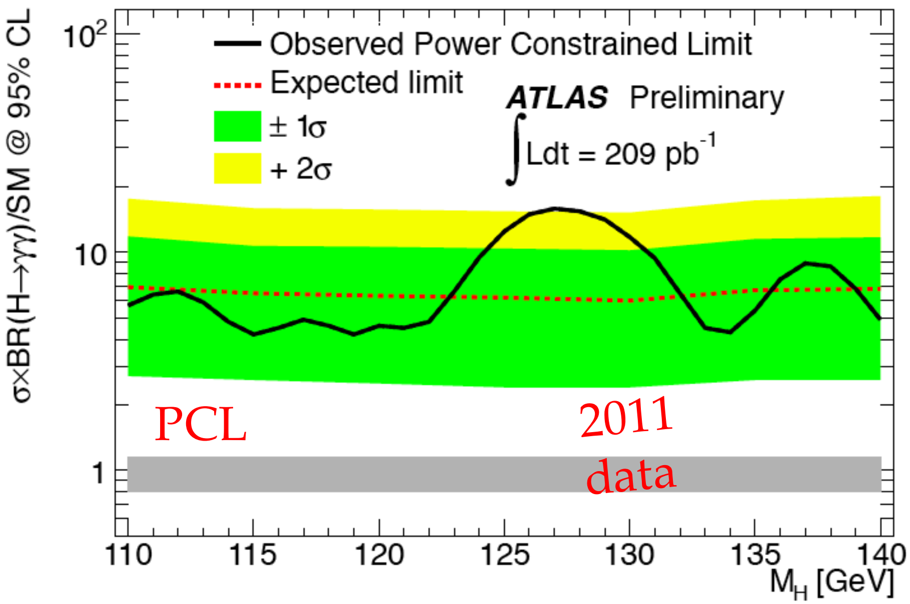


- The ZDC has been designed and optimized for low luminosity HI run (nominal L=10^{27} cm^{-2} s^{-1} and nominal bunch spacing= 100 ns) :
  - Event characterization via the detection of the spectator neutrons
  - Orientation of the reaction plane
  - Minimum bias trigger
  - Luminosity monitoring measuring the rate of the mutual electromagnetic dissociation in the neutron channel
- In the picture correlation between the total transverse energy deposited in ATLAS calorimeters and the amplitude signal from the ATLAS ZDC.
  - The correlation seen corresponds to the interplay between hadronic interations of the colliding nuclei and Coulomb interactions of the colliding nuclei in Ultra-Peripheral Collisions

H->γγ

- No significant excess seen
  - New Limit≈(4.2-15.8) × SM

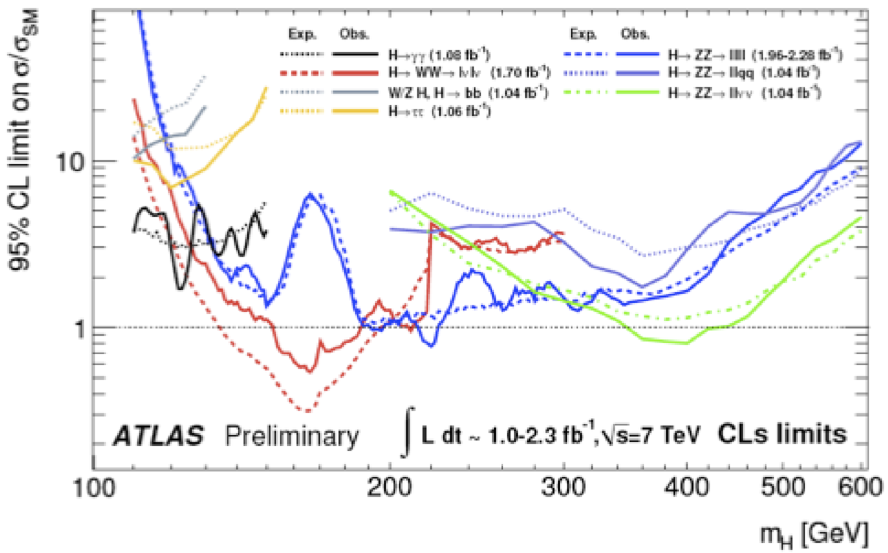




ATLAS: Higgs combination

Channels used in the Combination:

1. ***H→ γγ***
2. ***VH,H→bb***
3. ***H→ττ***
4. ***H→WW(*)→lνlν***
5. ***H→ZZ(*)→llll***
6. ***H→ZZ(*)→llνν***
7. ***H→ZZ(*)→llqq***

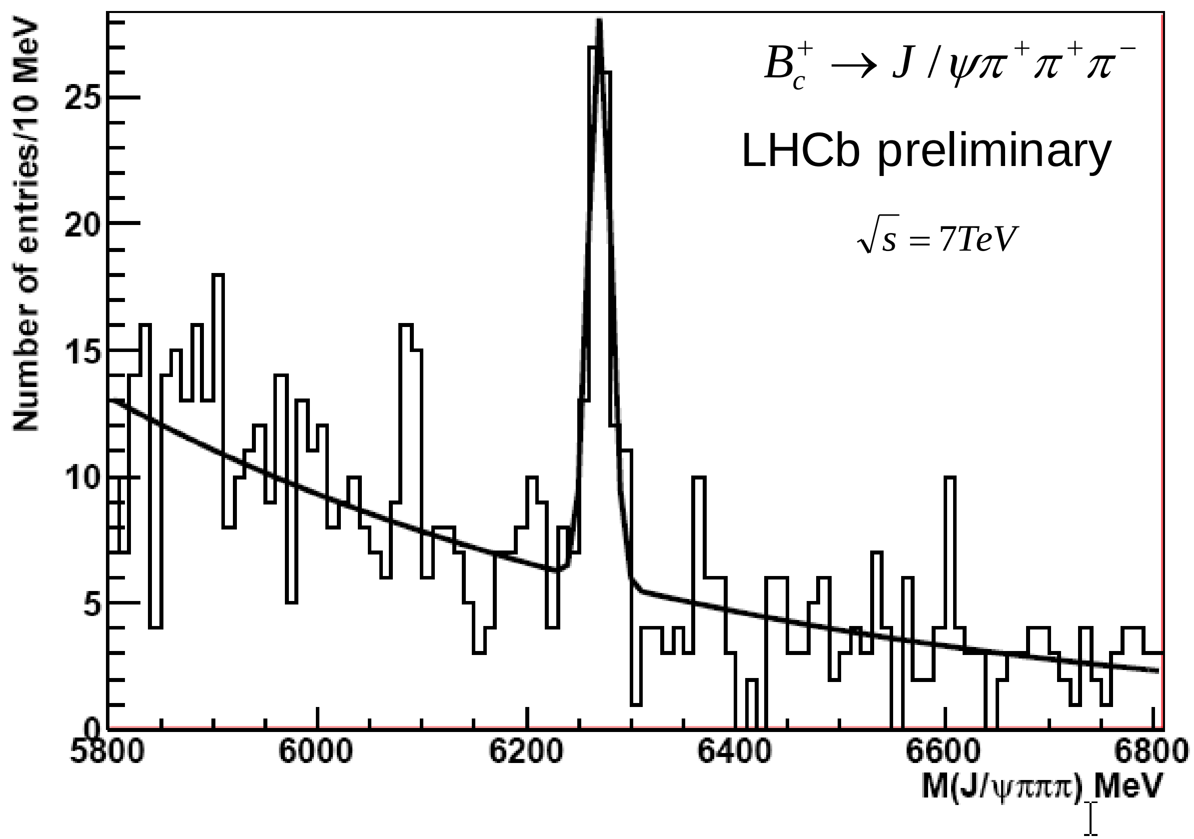


The expected (dashed) and observed (solid) cross-section limits for the individual search channels, normalized to the Standard Model Higgs boson cross section, as functions of the Higgs boson mass.

- Correlated uncertainties (Jet Energy Scale, Luminosity, etc) taken into account
- In other cases, e.g. background estimates estimated via method data-driven, the uncertainties are uncorrelated
- Careful treatment of theory uncertainties; Higgs boson cross-section uncertainties in QCD scale and PDF+αs taken into account. PDF uncertainty is fully correlated among different channels and it is included in the combination.

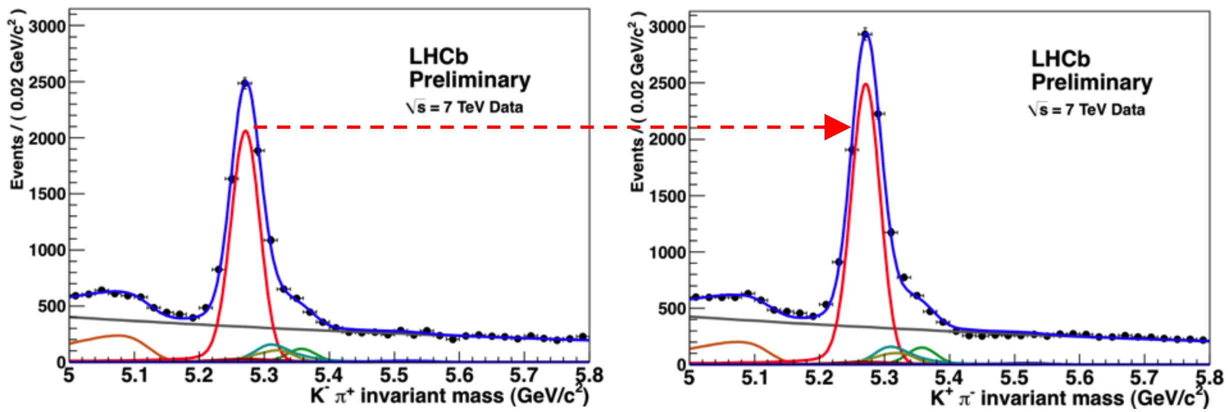
LHCb results: new decay modes

- First observation of $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$
- Branching ratio
  - BR($B_c^+ \to J/\psi\pi^+\pi^+\pi^-$)/BR($B_c^+ \to J/\psi\pi^+$) = 3.0 ± 0.6 ± 0.4



LHCb: CP asymmetries

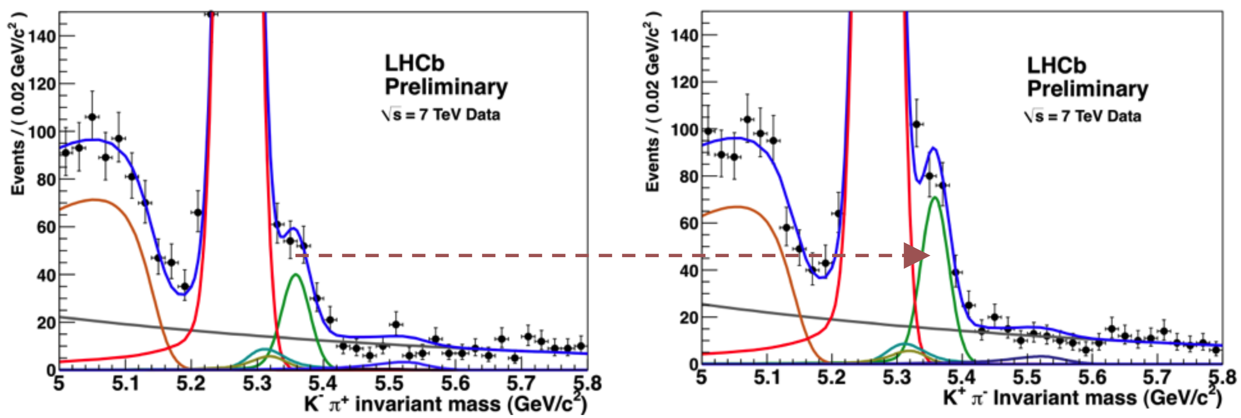
- Raw asymmetries are clear: particle/antiparticle



B^0

$$B^0 \to K^+\pi^-$$
$$\overline{B}^0 \to K^-\pi^+$$

Selection optimized for $A_{CP}(B^0 \to K\pi)$
Asymmetry = -0.095 ± 0.011



B^0_S

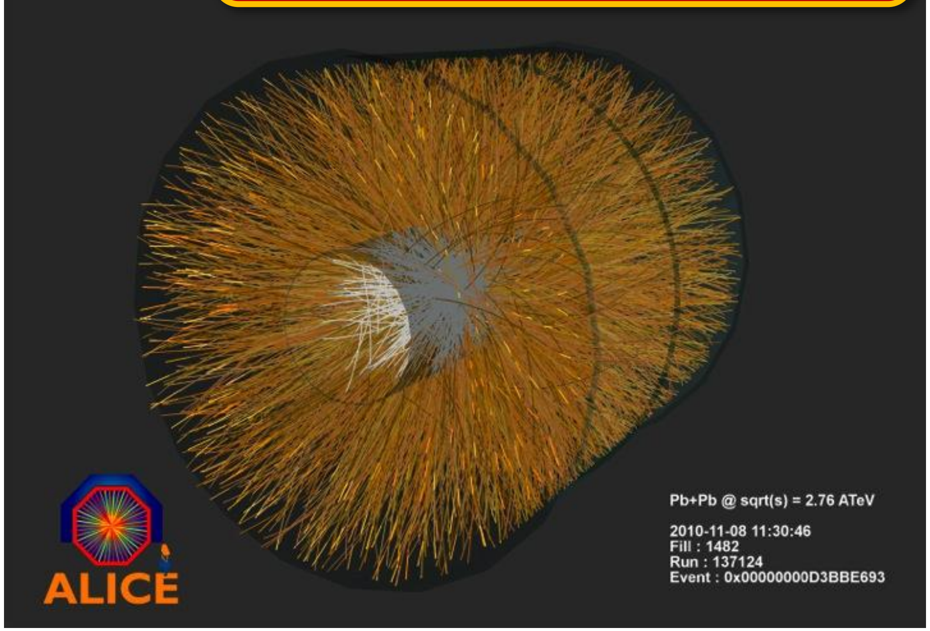
Selection optimized for $A_{CP}(B_S^0 \to \pi K)$
Asymmetry = 0.28 ± 0.08

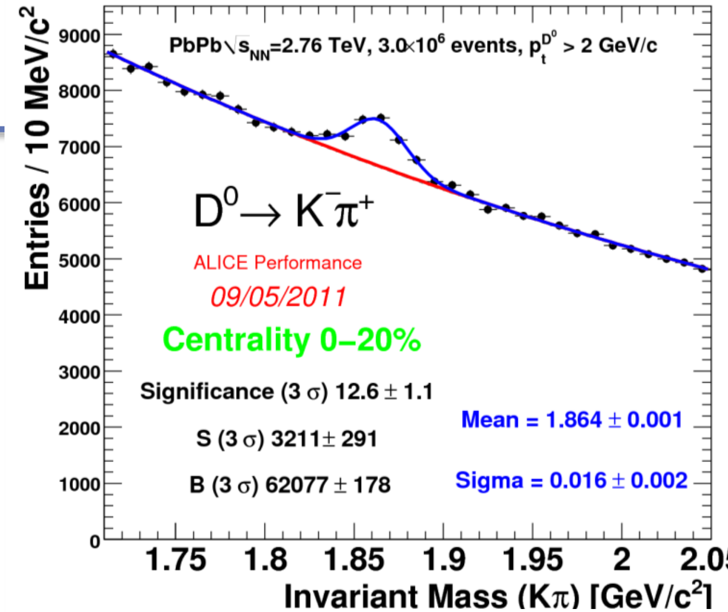
$$B_s^0 \to K^-\pi^+$$
$$\overline{B}_s^0 \to K^+\pi^-$$

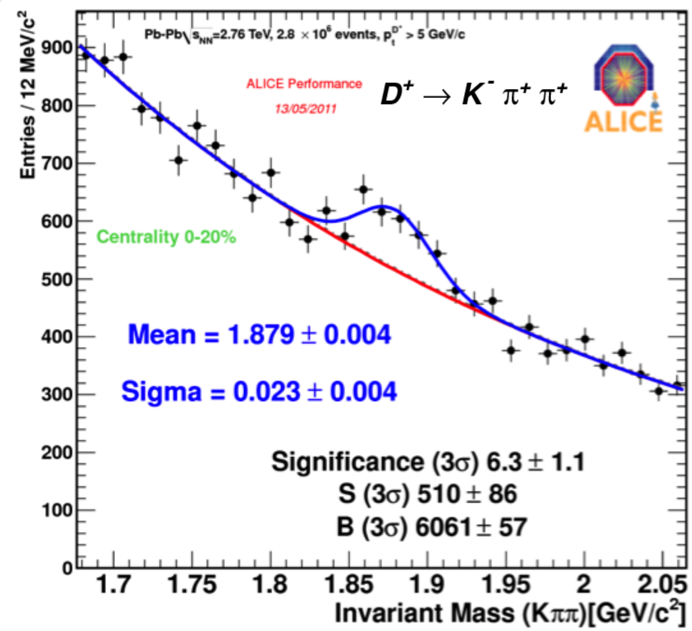
$A_{CP}(B_S^0 \to \pi^+K^-) = 0.27 \pm 0.08\ (stat) \pm 0.02\ (syst)$ (preliminary)
First evidence of CP violation in $B_S \to \pi K$

ALICE: D^0 and D^+ reconstruction in Pb-Pb

Pb – Pb collisions (2010)
2.76 TeV/nucleon (≈ 30 M events MB)





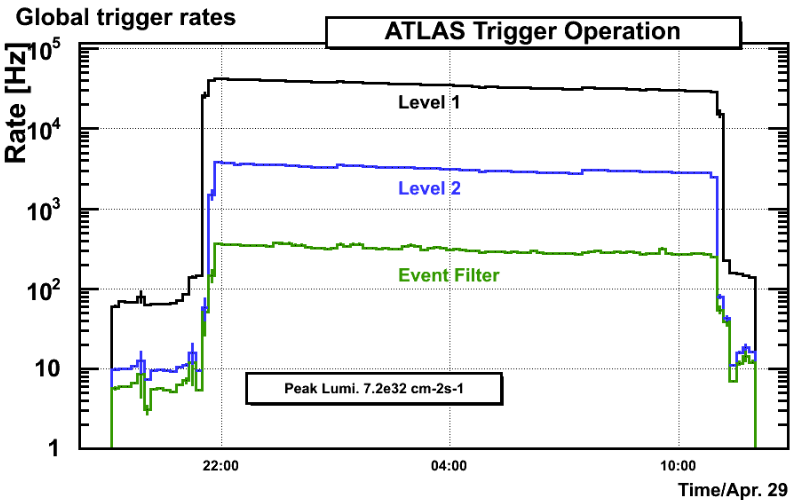


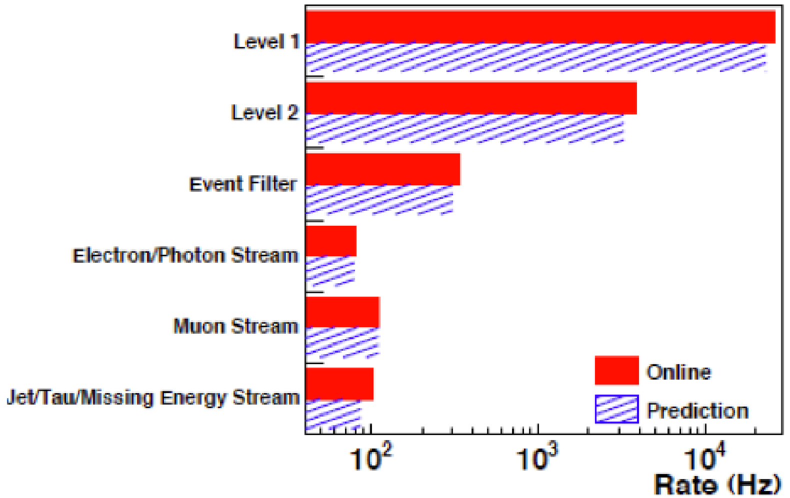
How to find a charm decay in such an environment?

Thanks to the Inner Tracking System impact parameter resolution this is possible

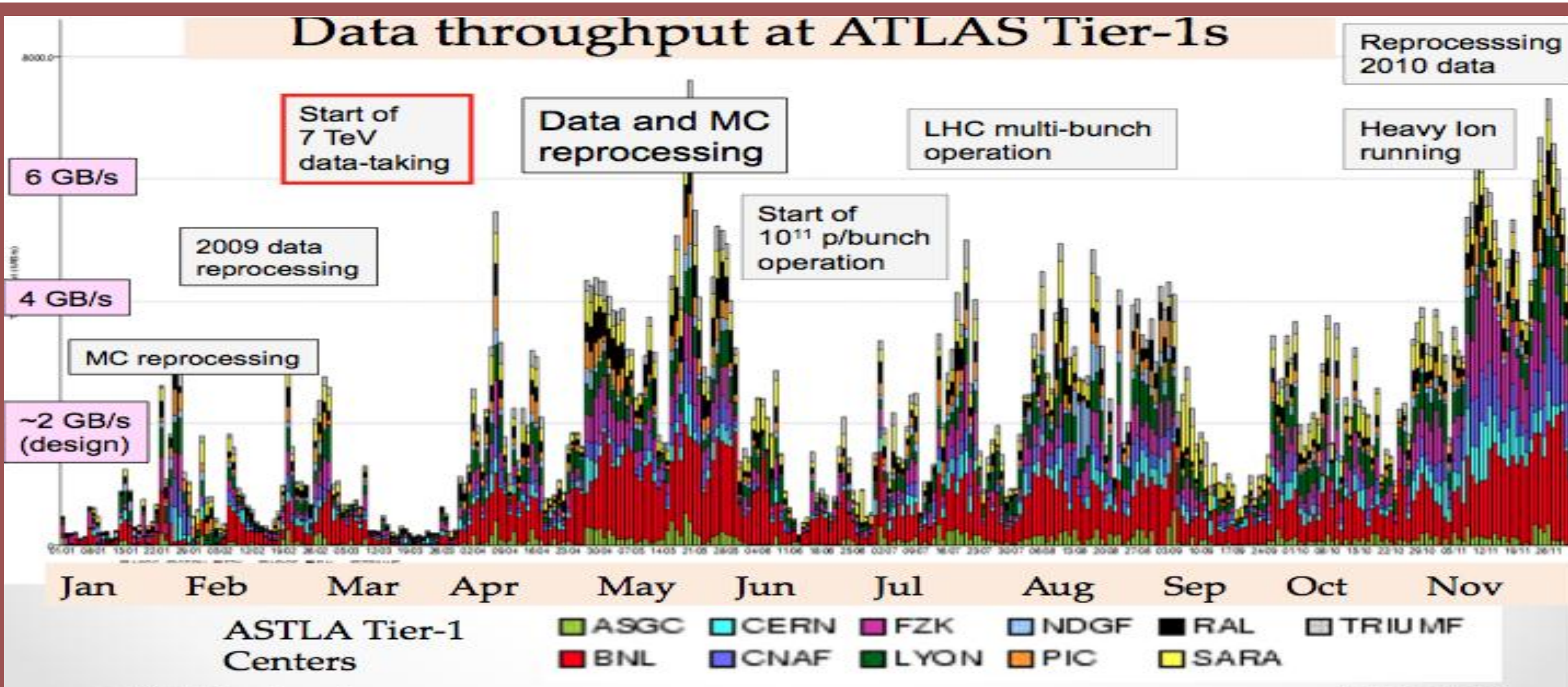
ATLAS trigger operations

- Trigger organized in 3 levels
  - LVL1 (50 KHz): Hardware
  - LVL2 (4 KHz): Software on reduced granularity (regions of interest)
  - EF (≈300 Hz): Based on Offline Reconstruction Full Granularity
- Rates of physics objects very well understood and under control.
- Recorded physics rate ≈300 Hz





ATLAS: Analysis jobs on the GRID



- 10Gb/s peak during data and MC processing (although 2GB/s design)
- >1000 users analyzing data on the GRID
- Totality of data and MC reprocessing during LHC data/taking

ATLAS upgrades

- Phase1 – 2017/18 – 2x design Luminosity
  - Increase of cavern background: fix muon spectrometer
    - Innermost forward wheel with improved rate capabilities and insertion in L1 trigger. Candidates: MDT, TGCs, μMegas
  - LAr calorimeter: high rate in forward region
    - Placing a warm calorimeter in front of FCAL. Cu absorber and diamond sensors on ceramic
  - L1&L2 trigger upgrade
    - Topological trigger for L1
    - Fast track finding and fitting at L2
- Phase2 – 2022 – 5x design luminosity
  - Magnets, muon, calorimeters mostly OK
  - Changes
    - Trigger and DAQ
    - Some Muon chambers for high bkg rate
    - Possible endcap and forward calorimeters
    - New calorimeter readout for trigger upgrade
    - New Inner Detector

CMS upgrades

- Phase1 – 2017/18 – 2x design Luminosity
  - New 4-layers Pixel: limitations at 2E34 $cm^{-2} s^{-1}$, inner regions need replacement after 350 fb^{-1}. Material reduction
  - Trigger upgrade: regional calorimeter trigger, μTCA-based infrastructure for higher BW, faster FPGA and additional channels for muon trigger
  - DAQ to adress larger data size and readout channels
  - Beam Instrumentation and luminosity monitoring
  - Common infrastructure: beam pipe, safety systems, shielding
- Phase2 – 2022 – 5x design luminosity
  - Building on Phase1 upgrade work
  - Replacement of the Inner Detector
    - R&D on sensors, CO_2 cooling, power distribution, trigger functionality
  - Work on Muon system: replacement of ASICs with FPGA for CSCs, new chambers to extend RPC η range (R&D on GEMs)
  - Calorimeter readout: replace HPD with SiPM, more rad-hard PMTs and with MAPMTs (thinner window); depth segmentation in HB/HE
  - Trigger electronics upgrades: 2x latency, L1 tracking integration

ALICE upgrades

- Motivations
  - Open physics issues not addressed by current setup: increase of coverage and measurement capabilities
    - Heavy flavour production, hadronization, p and nuclei small-x, large range rapidity correlations
- Inner Tracking System and Muon Forward Tracker
  - Heavy flavour baryons, charm coverage at low p_T, b-tagging for muons, measurements of exclusive B-decays
  - Modification of beam pipe and integration of the MFT with the ITS
  - Technology change proposal for MFT: monolithic pixels
  - Reduction of beam pipe diameter and innermost layer at 20-22 mm
  - Reduction of material budget and pixel size (20-30 μm in rϕ, possibly in z)
  - 3 pixel layers followed by 3-4 strip layers
  - Trigger capabilities (L2 ~ 100 μs): topological trigger, fast-OR and fast-SUM at L0/L1 (1.2 μs/7.7 μs)
  - Increased acceptance ($|\eta| > 0.9$)

ALICE upgrades

- Forward e.m. calorimeter (FOCAL)
  - Low-x in pA, AA, photon/pion discrimination
  - Large rapidity coverage ($2.5 < \eta < 4.5$)
  - π^0/γ discrimination at ~ 200 GeV/c, high granularity, at ~ 350 cm from IP
  - Si+W based calorimeter, Si pads or pixels
- Particle ID upgrade (VHMPID)
  - Extend p_T range to O(20) GeV/c
  - Focusing RICH with spherical or parabolic mirror; C_4F_{10} radiator; photon detector MWPC with CH_4 using CsI photocathode or thick GEM and CsI coating; same readout as HMPID
- TPC readout upgrade
  - Faster gas, increased readout speed: increased rate capabilities
- DAQ and HLT upgrades
  - More sophisticated and selective triggers

LHCb upgrades in ~ 2018

- Goal for the first phase s to reach 5 fb^{-1} before the 2^{nd} LHC shutdown
- Need of increasing L0 efficiency at increasing luminosity
  - 40 MHz DAQ readout rate and fully software trigger
- Rebuild of all silicon detectors (now 1 MHz readout)
  - New VELOPIX (Diamond 55 μm square pixels, TimePIix FE)
  - Strip detector with 30 μm pitch
  - OT straws ok, replace IT and TT Si-strip with Si-strip and new FE at 40 MHz or 250 μm SciFi tracker with far SiPMT
- May be remove too occupied detectors
  - RICH1-aerogel, M1, SPD and PS
- Improve PID at low momenta
  - Replace HPD with MAPMTs for readout and 40 MHz ASICs
  - TORCH: TOF based on 1 cm quartz plate for PID of p < 10 GeV hadrons cmbined with DIRC technology
- Calorimeters: replace FE
- Muons already at 40 MHz, remove M1, place for TORCH
  - Investigations on MWPC ageing and rate limitations
- In this way expand the physics program:
  - Lepton flavour physics
  - Electroweak physics
  - Exotic searches