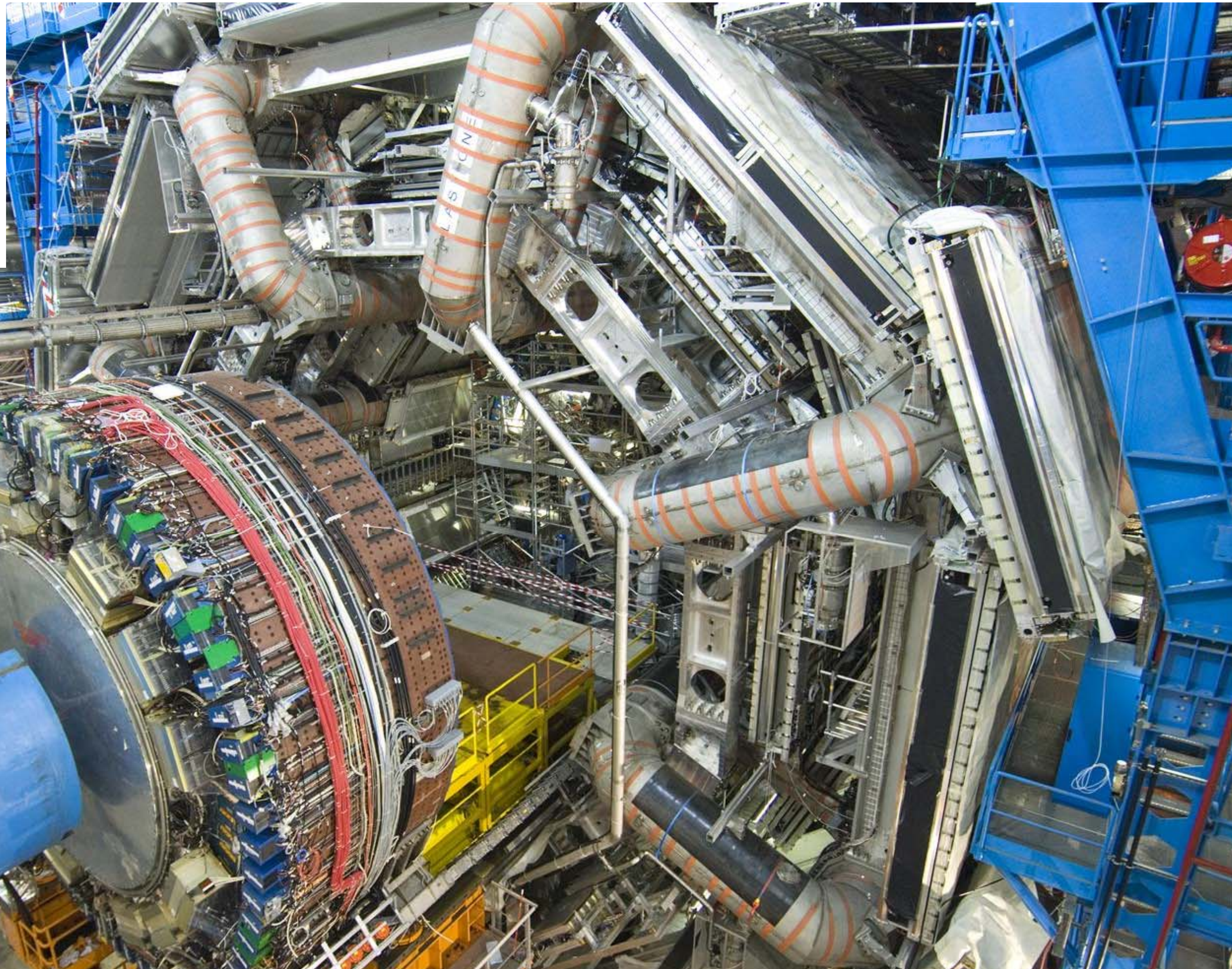


Perspectives expérimentales au LHC

La physique des particules expérimentales: 25 ans de 1983 à 2008

✦ C'est souvent le hasard qui guide nos pas en passant de l'enfance à l'âge adulte. De 1971 à 1976, j'ai personnellement évolué des maths, à la physique théorique, puis à la physique expérimentale en hautes énergies.

✦ Les Français disent souvent: "un expérimentateur = un théoricien raté"

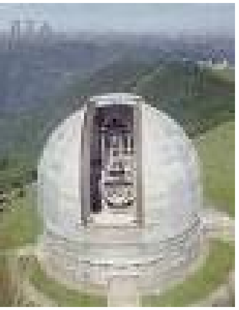
✦ J'étais également attiré par l'astrophysique mais à l'époque cela ressemblait un peu trop à de la zoologie: on élargit le catalogue des observations sans une théorie prédictive sous-jacente de l'évolution de l'univers.

✦ Dans la naïveté de ma jeunesse, je croyais vraiment que la recherche fondamentale impliquait des avancées majeures et régulières de notre compréhension des lois de la nature.

✦ Avec de l'expérience (et aussi en écoutant le discours de D. Gross, prix Nobel de physique en 2004), je pense qu'il est plus humble de dire que les 25 dernières années ont fait grimper à notre compréhension des lois de la physique fondamentale plusieurs marches importantes d'un escalier qui est probablement sans fin et qui se découvre à nous peu à peu.

Big Bang: il y a ~14 milliards d'années

Comment comprendre notre univers?



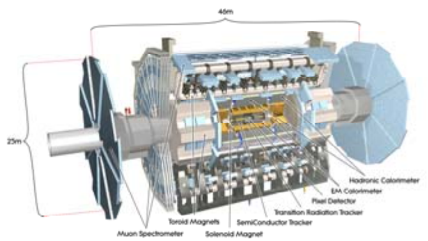
- Astrophysique:
  une explosion de résultats
  depuis 15 ans!

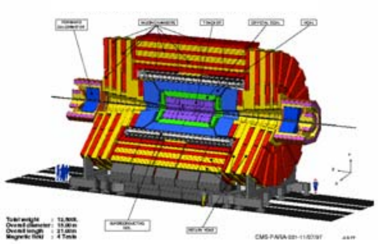
- Physique des particules:

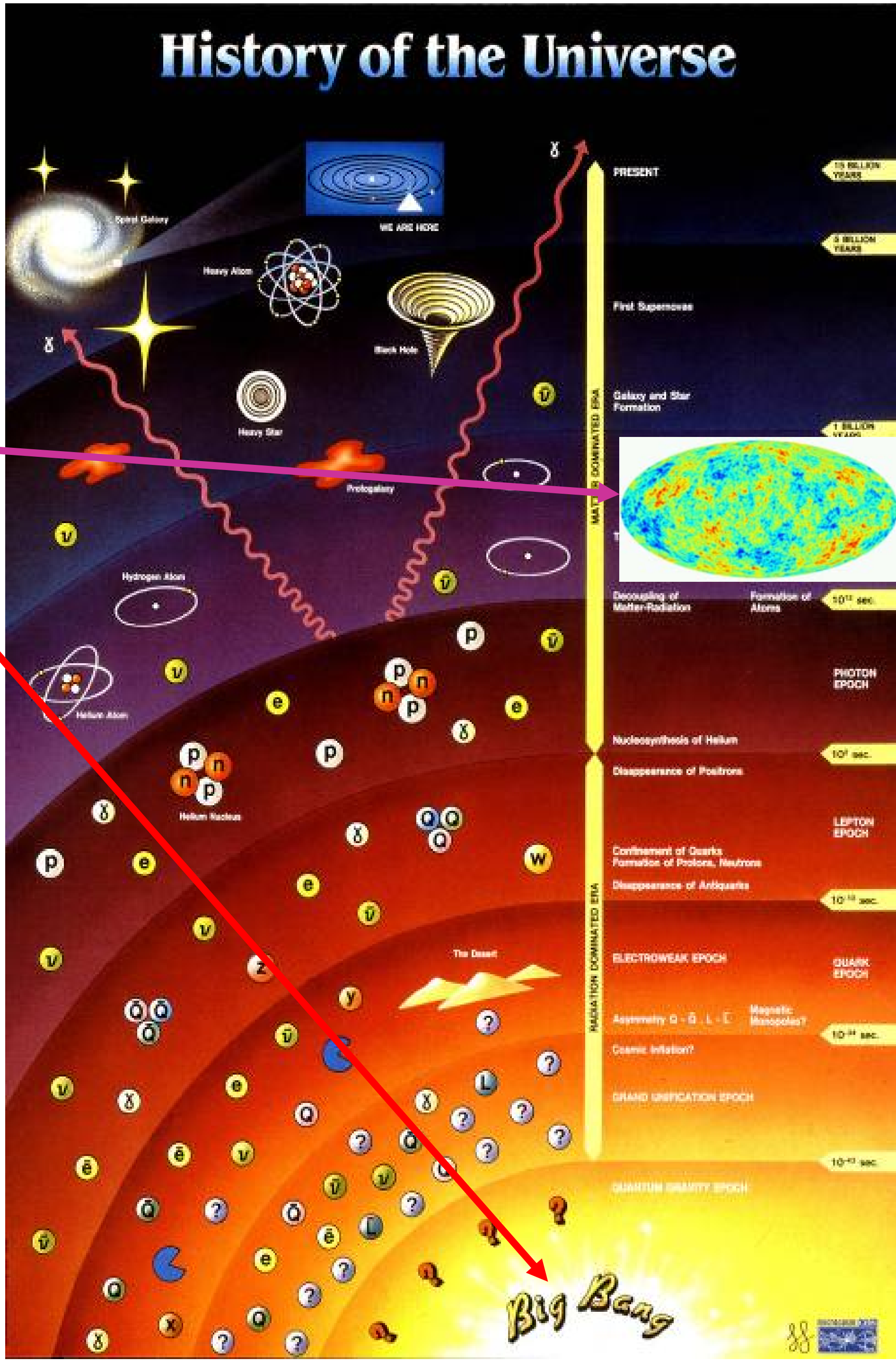
  - découverte du quark top
    il y a 13 ans…

  - oscillations neutrinos
    sur les 10 dernières années

  - explosion de nouveaux résultats
    sur les 10 prochaines années?

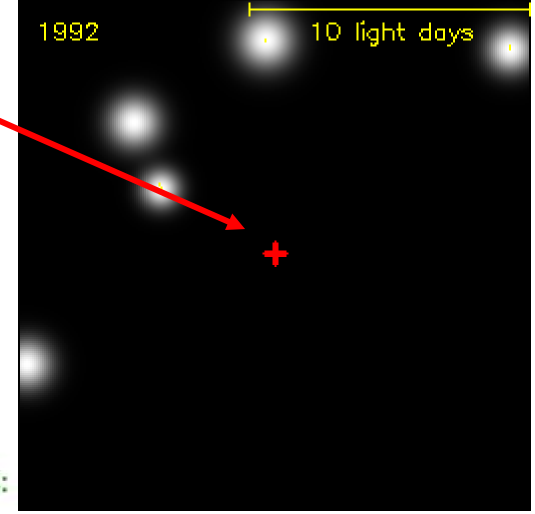


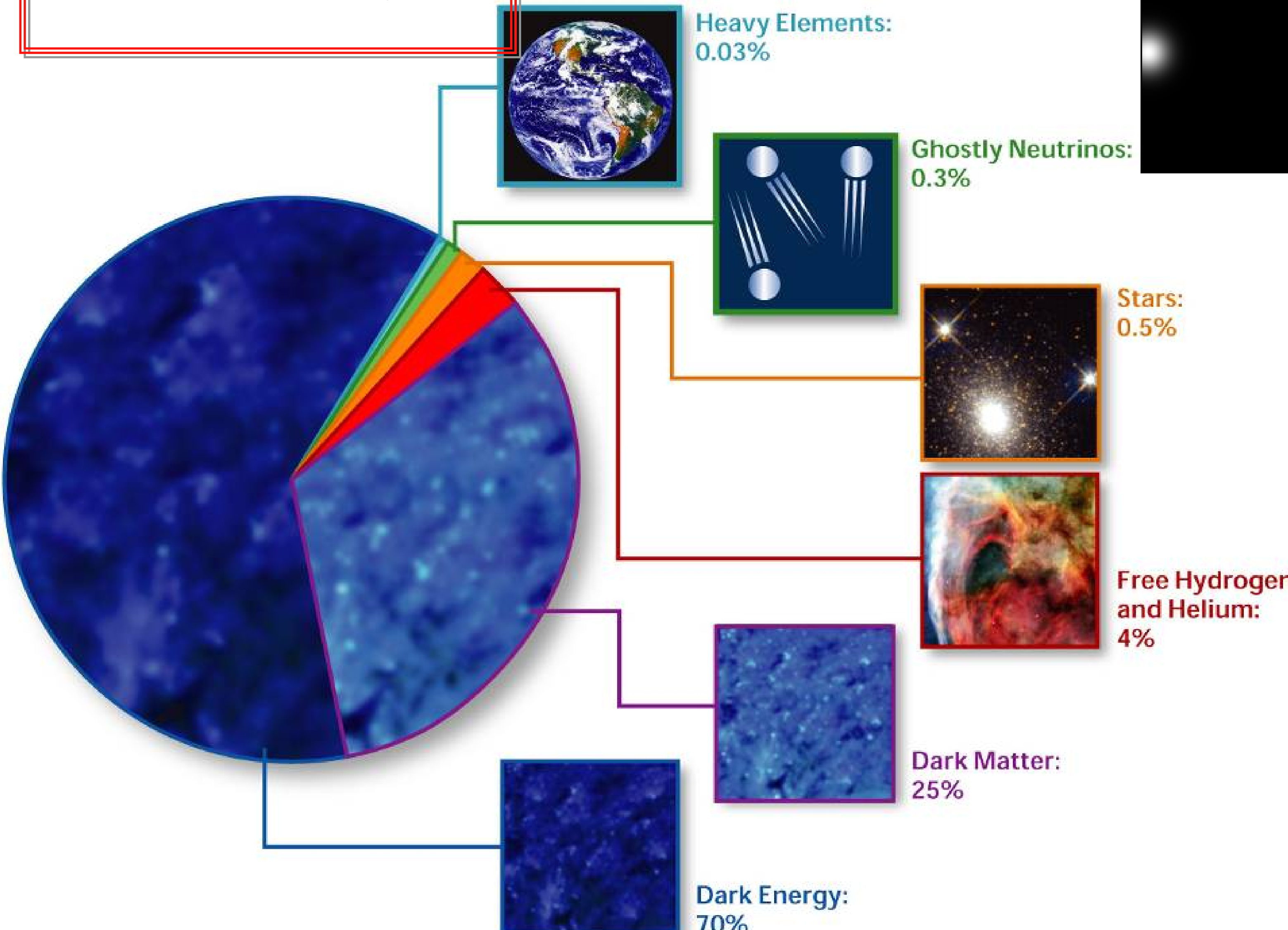




> 90%
de la composition de notre univers est inconnue!

Trou noir





La physique des particules expérimentales: 25 ans de 1983 à 2008

✦ Aujourd'hui nous sommes capables de poser des questions que nous n'aurions pas su formuler il y a 25-30 ans quand j'étais étudiant:

- ✓ Pourquoi seulement trois neutrinos, trois familles de quarks?
- ✓ Qu'est-ce que la matière noire? Comment est-elle distribuée?
- ✓ Quelle est la nature de l'énergie noire? La relativité générale est-elle correcte à très grande échelle?
- ✓ La mécanique quantique peut-elle être mise en défaut pour les distances très petites, pour des systèmes conscients, ailleurs?
- ✓ Quelle est l'origine de la violation de CP, des baryons, qu'en est-il de la durée de vie du proton?
- ✓ Quel est le rôle de la théorie des cordes, de la dualité?

✦ Certaines de ces questions pourraient bien me faire pencher vers l'astrophysique ou les astro-particules aujourd'hui!

✦ Plus nous progressons, plus l'intervalle de temps augmente entre les reformulations successives des questions fondamentales que nous nous posons quant à notre univers, sa complexité et les lois qui le régissent. Cet intervalle est déjà aussi long que la durée de vie professionnelle utile d'un être humain. Cela pose de réels problèmes structurels et de continuité de l'effort.

Où en étions-nous en 1983?

- ✦ Aspects technologiques :
  - ✓ Chambres à bulles versus expériences avec électronique
  - ✓ Pas encore de Silicium à l'horizon
  - ✓ Aimants supra très rares
  - ✓ Outils informatiques vus comme l'âge de pierre aujourd'hui:
    - Peu d'intelligence en ligne
    - Cartes perforées, pas de bureautique (ou alors avec 1kB de "disque dur" avec ZX81 Sinclair), grosses bécanes pédalant à 75 kHz
    - Peu d'outils graphiques
    - Pas de C^{++}, pas ou peu de design des logiciels hors ligne
    - Pas de courriels!
    - Peu de sécurité en informatique

Où en étions-nous en 1983?

- ✦ Aspects simulation:
  - ✓ Logiciels souvent écrits par les étudiants (très formateur!)
  - ✓ Pas de boîtes noires (Pythia)!
- ✦ Aspects sociologiques:
  - ✓ Expériences à taille humaine (de ~ 5 à 100 personnes, de 2 à 10 ans)
  - ✓ Thèses de doctorat ≡ résultats d'analyse de l'expérience
  - ✓ Documentation, graphes, et présentations sur papier
- ✦ Et la physique à l'époque?
  - ✓ Pas de quark top, à peine W/Z
  - ✓ N_ν encore inconnu ($N_\nu \leq 4$ de l'astrophysique), $m_\nu = 0$
  - ✓ Début du puzzle des ν solaires
  - ✓ Pas de limites expérimentales sur la désintégration du proton, modèles grand-unifiés très populaires

Théories et modèles

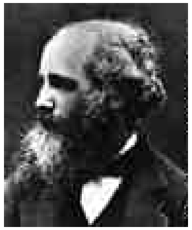
Unification de la gravitation terrestre et céleste

- **Newton 1680**

Unification de l'électricité et du magnétisme

- **Faraday & Ampère 1830**

Unification de l'optique et de l'électromagnétisme



- **Maxwell 1890**

Unification de l'espace-temps

- **Einstein 1905**

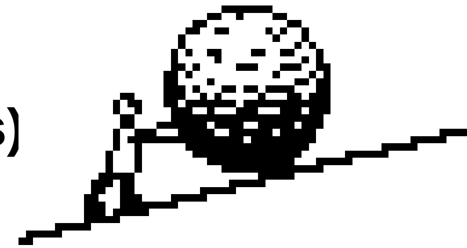
Unification de la gravitation et de l'électromagnétisme

- **Kaluza 1919** **(5 dimensions, 4 pour l'espace et une pour le temps, la courbure de la dimension supplémentaire engendre les forces électromagnétiques)**

Unification des interactions électromagnétiques et faibles

- **Glashow, Weinberg, Salam 1967**

Le cycle sans fin de la vie du physicien expérimentateur: mesurer, modéliser, parler aux théoriciens …



Observations (mesures: construction de détecteurs)

- Une pomme tombe d'un arbre
- Il y a quatre forces + les particules de matière

Modèles (simulations)

- $P = GmM/R^2$
- Modèle Standard

Prédictions

- Position des planètes dans le ciel
- Boson de Higgs, particules supersymétriques, matière noire?

Enorme succès du Modèle Standard en physique des particules:

Prédictions en accord avec les mesures, précision de 0.1%

Moment magnétique de l'électron:

accord jusqu'au 11ème chiffre significatif entre théorie et expérience!

Découverte de bosons W, Z, quark top, neutrino ν_τ

Après prédiction par la théorie!

⬇

Encore incompatibles aujourd'hui d'un point de vue théorique!

⬆

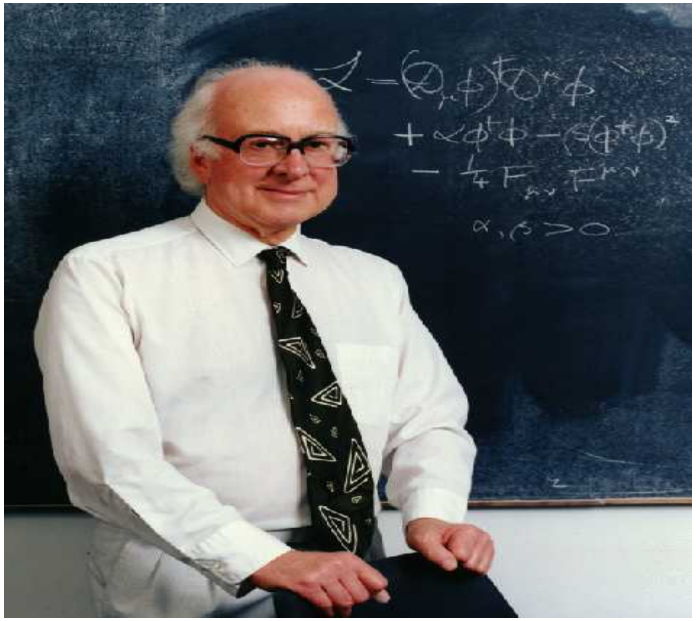
Principal succès de la relativité générale:

Prédictions en accord avec les mesures, précision de 0.1%

Et le boson de Higgs dans tout cela?

Il nous accompagne depuis quelques décennies comme:

1. un concept théorique,
2. un champ scalaire lié au vide quantique,
3. un sombre recoin du Modèle Standard,
4. une incarnation du Parti Communiste, puisqu'il contrôle les masses (L. Alvarez-Gaumé dans ses cours pour l'école d'été du CERN à Alushta, Crimée, 1989),
5. une partie douloureuse du premier chapitre de notre thèse



P.W. Higgs, Phys. Lett. 12 (1964) 132

Synopsis

- **Performances attendues des détecteurs ATLAS et CMS**

- **Quelles leçons apprises en 2008?**
  Beaucoup (pas assez?) de rayons cosmiques et ε de faisceau

- **Les collisions à haute énergie cette année (?) seront essentielles pour mettre en route le déclenchement à tous les niveaux et pour cartographier les performances initiales réelles du détecteur**

L'année qui vient va voir l'aboutissement du travail de milliers de personnes à travers le monde entier pendant une vingtaine d'années: l'excitation va évidemment aller croissante au fur et à mesure que la prise de données avec des collisions à 10 TeV se rapproche!

Generic features required of ATLAS and CMS

- **Detectors must survive for 10 years or so of operation**
  - Radiation damage to materials and electronics components
  - Problem pervades whole experimental area (neutrons): NEW!
- **Detectors must provide precise timing and be as fast as feasible**
  - 25 ns is the time interval to consider: NEW!
- **Detectors must have excellent spatial granularity**
  - Need to minimise pile-up effects: NEW!
- **Detectors must identify extremely rare events, mostly in real time**
  - Lepton identification above huge QCD backgrounds (e.g. e/jet ratio at the LHC is ~ 10^{-5}, i.e. ~ 100 worse than at Tevatron)
  - Signal X-sections as low as 10^{-14} of total X-section: NEW!
  - Online rejection to be achieved is ~ 10^7: NEW!
  - Store huge data volumes to disk/tape (~ 10^9 events of 1 Mbyte size per year: NEW!

Physics at the LHC: the challenge

Small x-sections

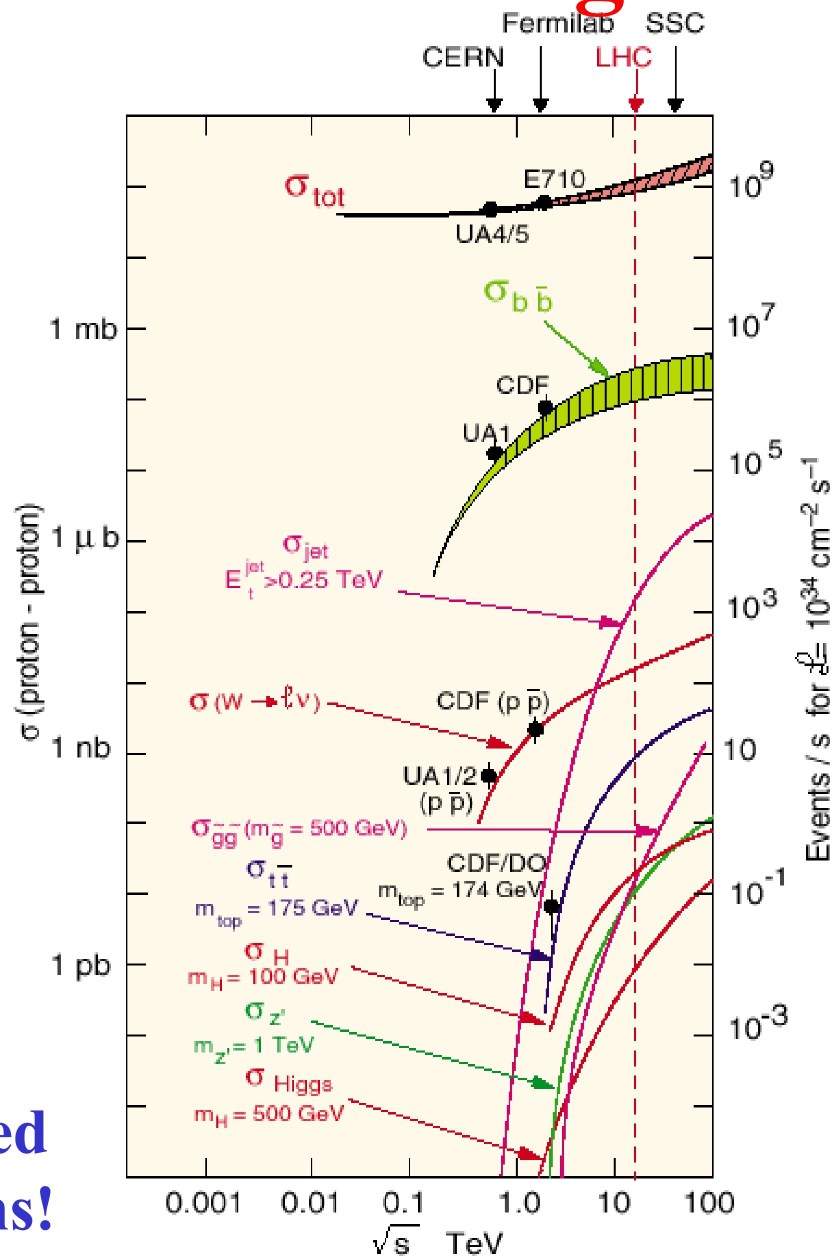
need highest luminosity

$L = 10^{34-35}\ cm^{-2}s^{-1}$

Orders of magnitude of event rates for various physics channels:

- Inelastic : 10^{10} Hz
- W -> lν : 10^{3} Hz
- tt production : 10^{2} Hz
- Higgs (m=100 GeV) : 1 Hz
- Higgs (m=600 GeV) : 10^{-1} Hz

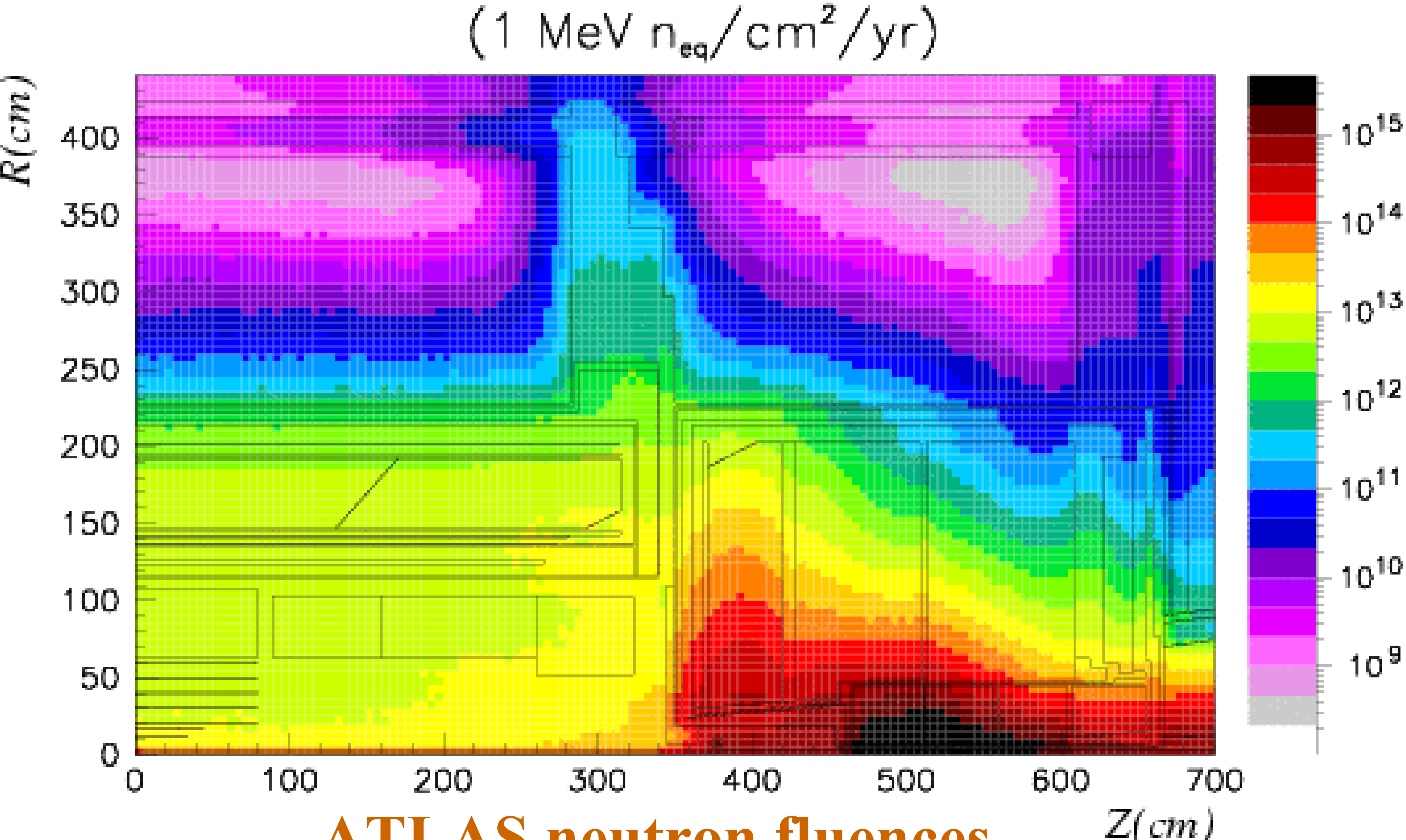
(and include branching ratios: $\sim 10^{-2}$)



Selection power for Higgs discovery ≈ 10^{14-15}

i.e. 100 000 times better than achieved at Tevatron so far for high-p_T leptons!

Physics at the LHC: the environment



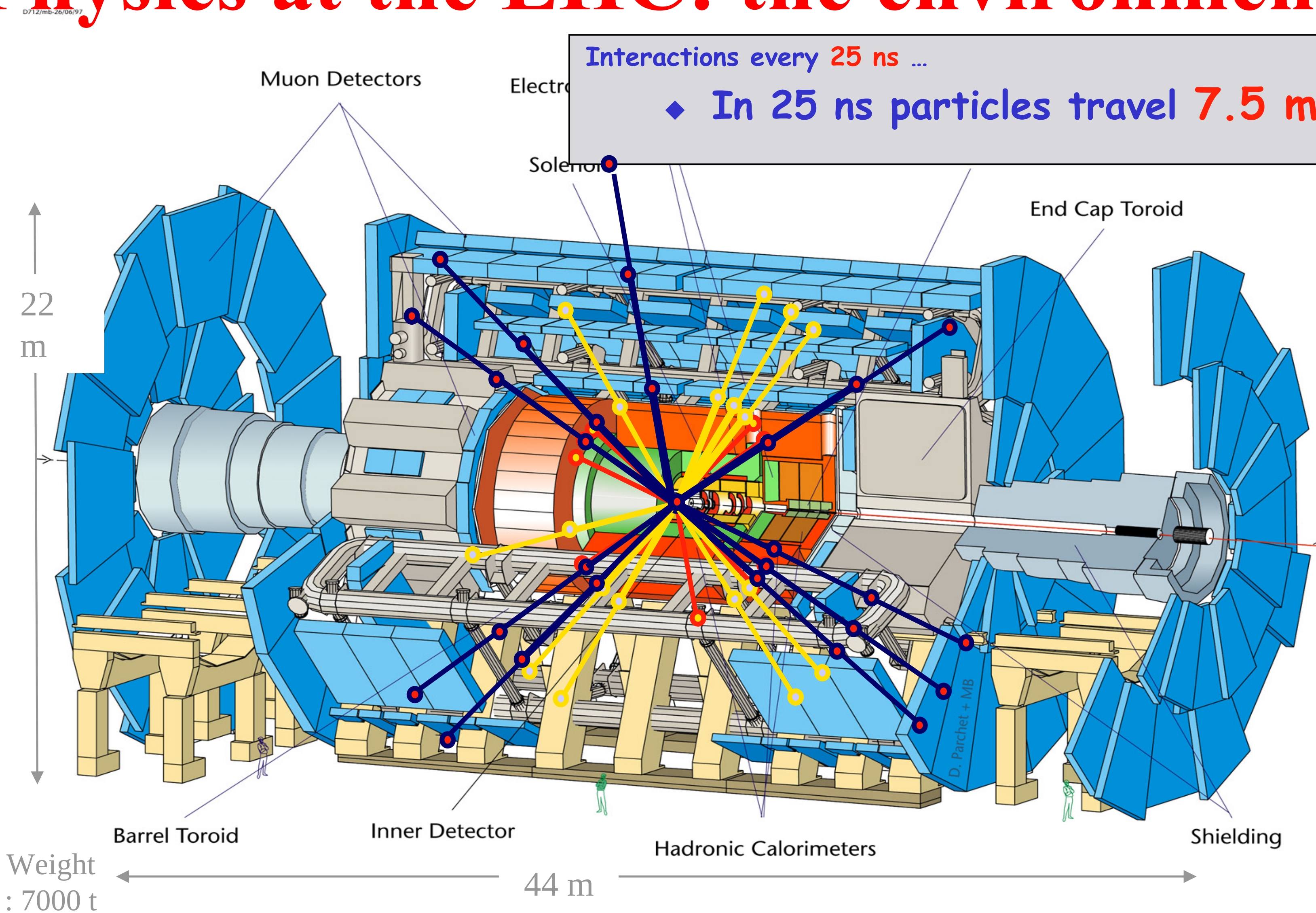
ATLAS neutron fluences

Physics at the LHC: the environment

Time-of-flight

Interactions every 25 ns …

- In 25 ns particles travel 7.5 m



Cable length ~100 meters …

- In 25 ns signals travel 5 m

D. Froidevaux (CERN)

How huge are ATLAS and CMS?

- Size of detectors
  - Volume: 20 000 m^3 for ATLAS
  - Weight: 12 500 tons for CMS
  - 66 to 80 million pixel readout channels near vertex
  - 200 m^2 of active Silicon for CMS tracker
  - 175 000 readout channels for ATLAS LAr EM calorimeter
  - 1 million channels and 10 000 m^2 area of muon chambers
  - Very selective trigger/DAQ system (10^7 rejection online!)
  - Large-scale offline software and worldwide computing (GRID)
- Time-scale will have been about 25 years from first conceptual studies (Lausanne 1984) to solid physics results confirming that LHC will have taken over the high-energy frontier from Tevatron (early 2009?)
- Size of collaboration
- Number of meetings and Powerpoint slides to browse through

Main specific design choices of ATLAS/CMS

- **Size of ATLAS/CMS directly related to energies of particles produced: need to absorb energy of 1 TeV electrons (30 X_0 or 18 cm of Pb), of 1 TeV pions (11 λ or 2 m Fe) and to measure momenta of 1 TeV muons outside calorimeters (BL^2 is key factor to optimise)**

- **Choice of magnet system has shaped the experiments in a major way**
  - **Magnet required to measure momenta and directions of charged particles near vertex (solenoid provides bend in plane transverse to beams)**
  - **Magnet also required to measure muon momenta (muons are the only charged particles not absorbed in calorimeter absorbers)**
  - **ATLAS choice: separate magnet systems ("small" 2 T solenoid for tracker and huge toroids with large BL^2 for muon spectrometer)**
  - **Pros: large acceptance in polar angle for muons and excellent muon momentum resolution without using inner tracker**
  - **Cons: very expensive and large-scale toroid magnet system**
  - **CMS choice: one large 4 T solenoid with instrumented return yoke**
  - **Pros: excellent momentum resolution using inner tracker and more compact experiment**
  - **Cons: limited performance for stand-alone muon measurements (and trigger) and limited space for calorimeter inside coil**

Main specific design choices of ATLAS/CMS

- At the LHC, which is essentially a gluon-gluon collider, the unambiguous identification and precise measurement of leptons is the key to many areas of physics:
    - electrons are relatively easy to measure precisely in EM calorimeters but very hard to identify (imagine jet → leading π^- with π^- → leading π^0 very early in shower)
    - muons in contrast are relatively easy to identify behind calorimeters but very hard to measure accurately at high energies

→ This has also shaped to a large extent the global design and technology choices of the two experiments

- EM calorimetry of ATLAS and CMS is based on very different technologies
    - ATLAS uses LAr sampling calorimeter with good energy resolution and excellent lateral and longitudinal segmentation (e/γ identification)
    - CMS use $PbWO_4$ scintillating crystals with excellent energy resolution and lateral segmentation but no longitudinal segmentation
    - Broadly speaking, signals from $H \rightarrow \gamma\gamma$ or $H \rightarrow ZZ^* \rightarrow 4e$ should appear as narrow peaks (intrinsically much narrower in CMS) above essentially pure background from same final state (intrinsically background from fakes smaller in ATLAS)

ATLAS/CMS: from design to reality

TABLE 3 Main parameters of the CMS and ATLAS magnet systems

	CMS	ATLAS		
Parameter	**Solenoid**	**Solenoid**	**Barrel toroid**	**End-cap toroids**
Inner diameter	5.9 m	2.4 m	9.4 m	1.7 m
Outer diameter	6.5 m	2.6 m	20.1 m	10.7 m
Axial length	12.9 m	5.3 m	25.3 m	5.0 m
Number of coils	1	1	8	8
Number of turns per coil	2168	1173	120	116
Conductor size (mm^2)	64×22	30×4.25	57×12	41×12
Bending power	$4\ T \cdot m$	$2\ T \cdot m$	$3\ T \cdot m$	$6\ T \cdot m$
Current	19.5 kA	7.6 kA	20.5 kA	**20.5 kA**
Stored energy	2700 MJ	38 MJ	1080 MJ	206 MJ

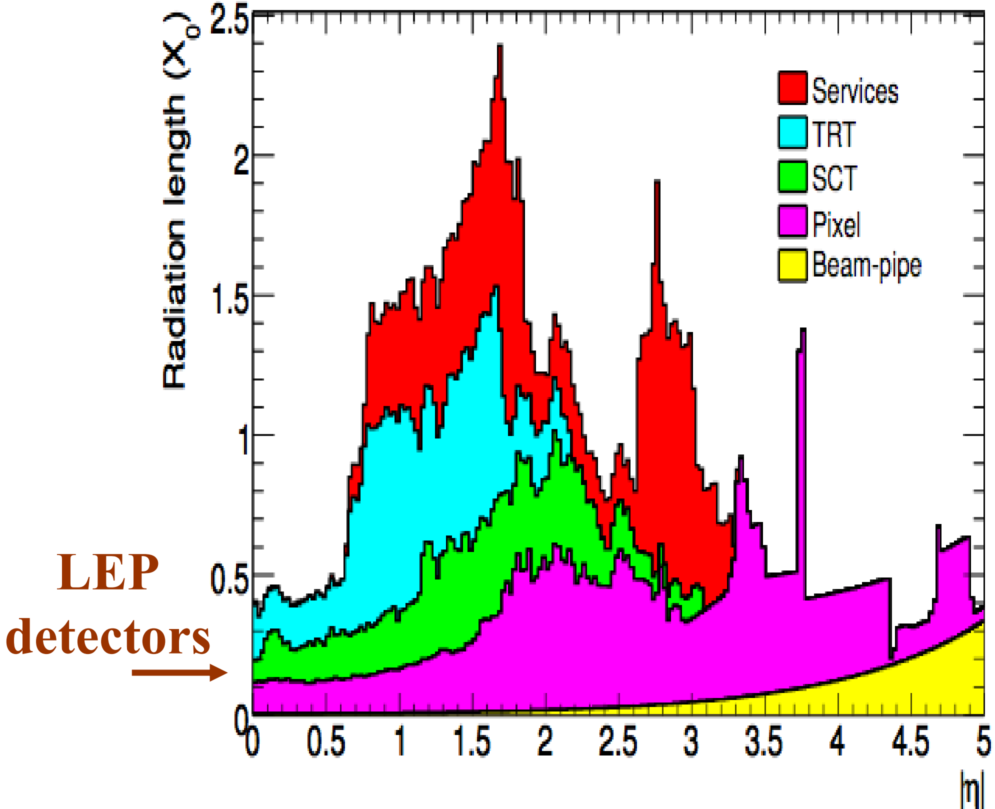
Three magnets have reached their design currents: a major technical milestone!

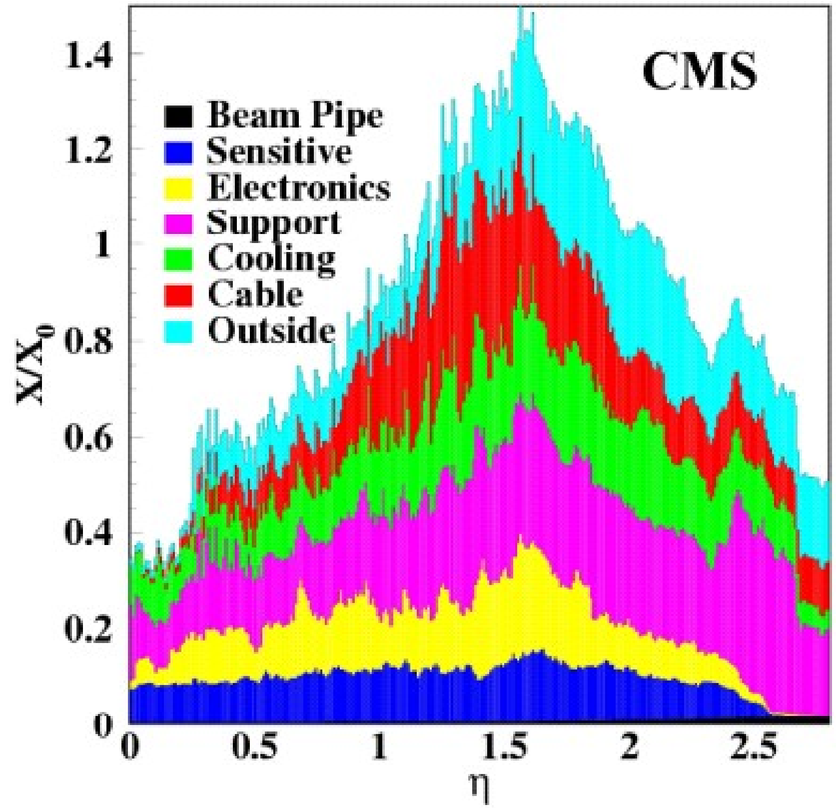
ATLAS/CMS: from design to reality

Amount of material in ATLAS and CMS inner trackers

Weight: 4.5 tons

Weight: 3.7 tons





- Active sensors and mechanics account each only for ~ 10% of material budget
- Need to bring 70 kW power into tracker and to remove similar amount of heat
- Very distributed set of heat sources and power-hungry electronics inside volume: this has led to complex layout of services, most of which were not at all understood at the time of the TDRs

ATLAS/CMS: from design to reality

TABLE 5 Evolution of the amount of material expected in the ATLAS and CMS trackers from 1994 to 2006

Date	ATLAS $\eta \approx 0$	$\eta \approx 1.7$	CMS $\eta \approx 0$	$\eta \approx 1.7$
1994 (Technical Proposals)	0.20	0.70	0.15	0.60
1997 (Technical Design Reports)	0.25	1.50	0.25	0.85
2006 (End of construction)	0.35	**1.90**	0.35	1.50

The numbers are given in fractions of radiation lengths (X/X_0). Note that for ATLAS, the reduction in material from 1997 to 2006 at $\eta \approx 1.7$ is due to the rerouting of pixel services from an integrated barrel tracker layout with pixel services along the barrel LAr cryostat, to an independent pixel layout with pixel services routed at much lower radius and entering a patch panel outside the acceptance of the tracker (this material appears now at $\eta \approx 3$). Note also that the numbers for CMS represent almost all the material seen by particles before entering the active part of the crystal calorimeter, whereas they do not for ATLAS, in which particles see in addition the barrel LAr cryostat and the solenoid coil (amounting to approximately $2X_0$ at $\eta = 0$), or the end-cap LAr cryostat at the larger rapidities.

- **Material increased by ~ factor 2-2.5 from 1994 (approval) to now (end constr.)**
- **Electrons lose between 25% and 70% of their energy before reaching EM calo**
- **Between 20% and 65% of photons convert into e^+e^- pair before EM calo**
- **Need to know material to ~ 1% X_0 for precision measurement of m_W (< 10 MeV)!**

ATLAS/CMS: from design to reality

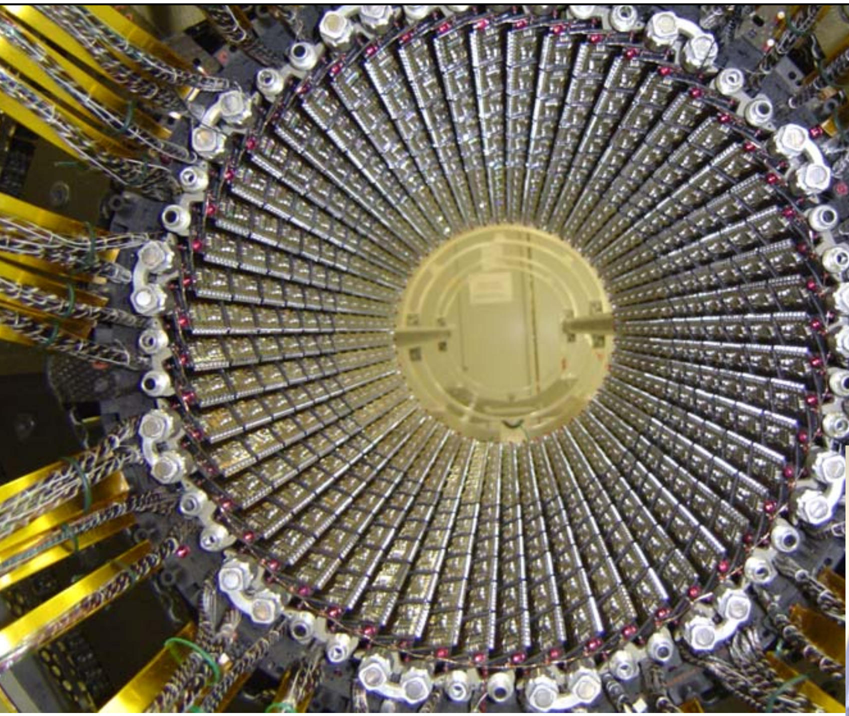
TABLE 7 Main performance characteristics of the ATLAS and CMS trackers

	ATLAS	CMS
Reconstruction efficiency for muons with $p_T = 1$ GeV	96.8%	97.0%
Reconstruction efficiency for pions with $p_T = 1$ GeV	84.0%	80.0%
Reconstruction efficiency for electrons with $p_T = 5$ GeV	90.0%	85.0%
Momentum resolution at $p_T = 1$ GeV and $\eta \approx 0$	1.3%	0.7%
Momentum resolution at $p_T = 1$ GeV and $\eta \approx 2.5$	2.0%	2.0%
Momentum resolution at $p_T = 100$ GeV and $\eta \approx 0$	3.8%	1.5%
Momentum resolution at $p_T = 100$ GeV and $\eta \approx 2.5$	11%	7%
Transverse i.p. resolution at $p_T = 1$ GeV and $\eta \approx 0$ (μm)	75	90
Transverse i.p. resolution at $p_T = 1$ GeV and $\eta \approx 2.5$ (μm)	200	220
Transverse i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 0$ (μm)	11	9
Transverse i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 2.5$ (μm)	11	11
Longitudinal i.p. resolution at $p_T = 1$ GeV and $\eta \approx 0$ (μm)	150	125
Longitudinal i.p. resolution at $p_T = 1$ GeV and $\eta \approx 2.5$ (μm)	900	1060
Longitudinal i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 0$ (μm)	90	22–42
Longitudinal i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 2.5$ (μm)	190	70

Performance of CMS tracker is undoubtedly superior to that of ATLAS in terms of momentum resolution. Vertexing and b-tagging performances are similar. However, impact of material and B-field already visible on efficiencies.

Remember that tracking at the LHC is a risky business!

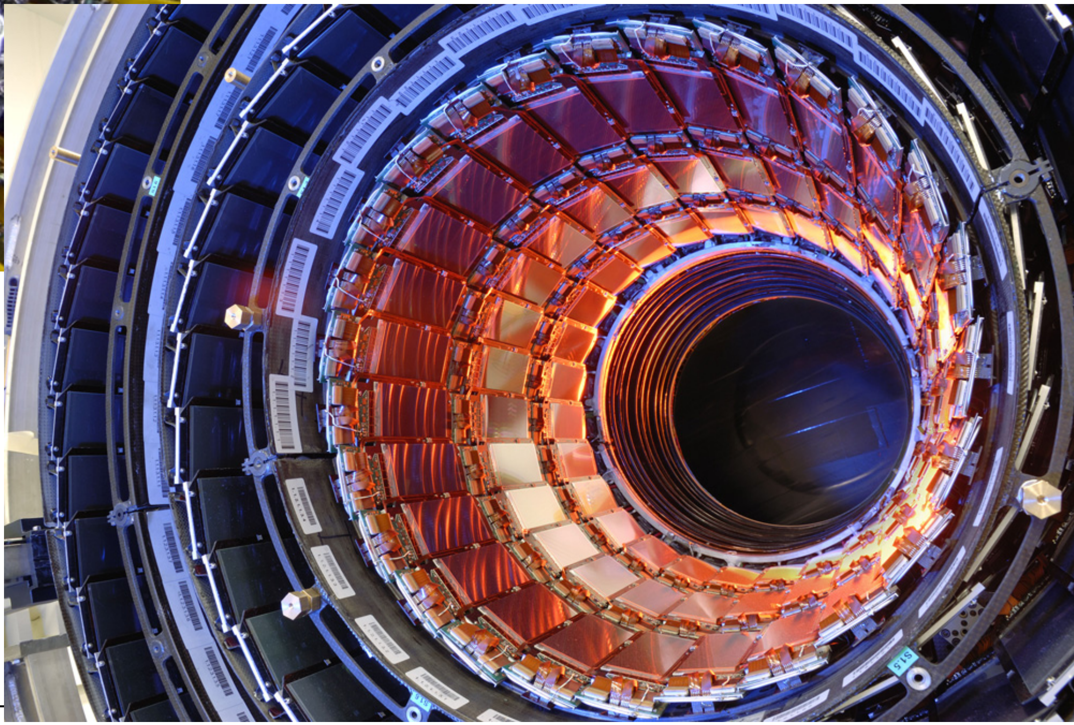
ATLAS pixels, September 2006



- All modules and services integrated and tested
- 80 million channels !
- 10%-scale system test with cosmics done at CERN
- Inst. in ATLAS: June 2007

CMS silicon strips

- 200 m^2 Si, 9.6 million channels
- 99.8% fully operational
- Signal/noise ~ 25/1
- 20% cosmics test under way
- Inst. in CMS: August 2007



CMS Tracker Inner Barrel, November 2006

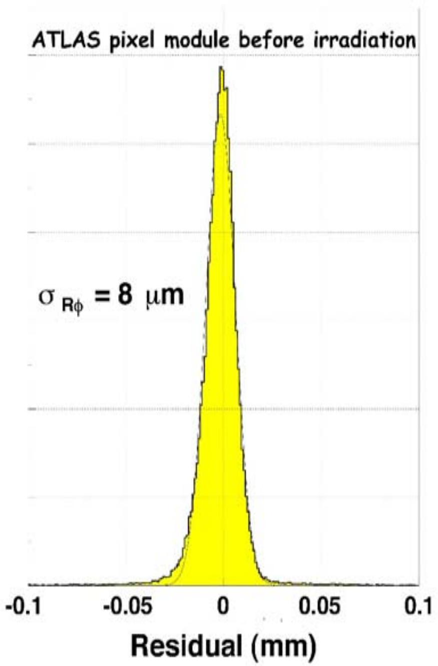
Remember that tracking at the LHC is a risky business!

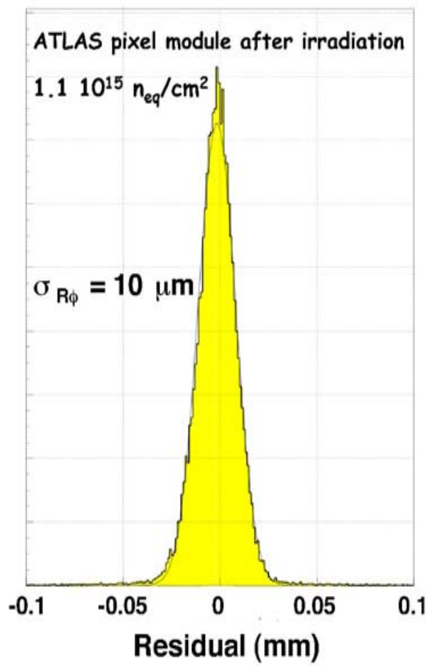
ATLAS pixel beam tests:
intrinsic resolution in bending plane before and after irradiation to a fluence of 10^{15} neutrons$_{equ}$ per cm^2

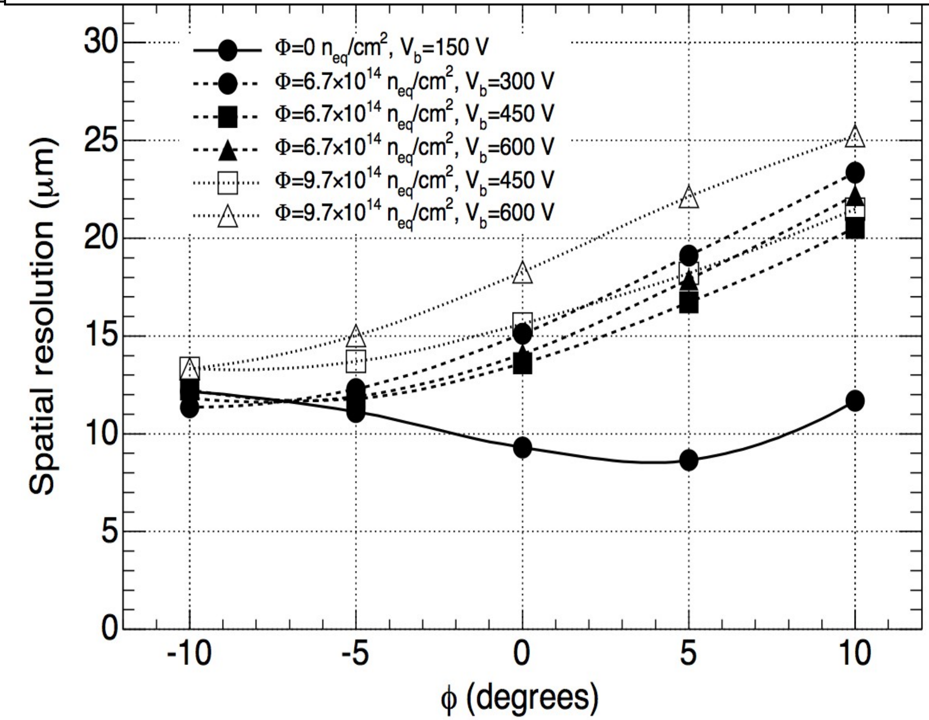
Pixel size is 50 μm x 400 μm in Rϕ x z

CMS pixel beam tests in 3T field:
extrapolate by simulation to expected behaviour versus incidence angle, voltage bias and total neutron fluence collected in 4T field

Pixel size is 150 μm x 150 μm in Rϕ x z







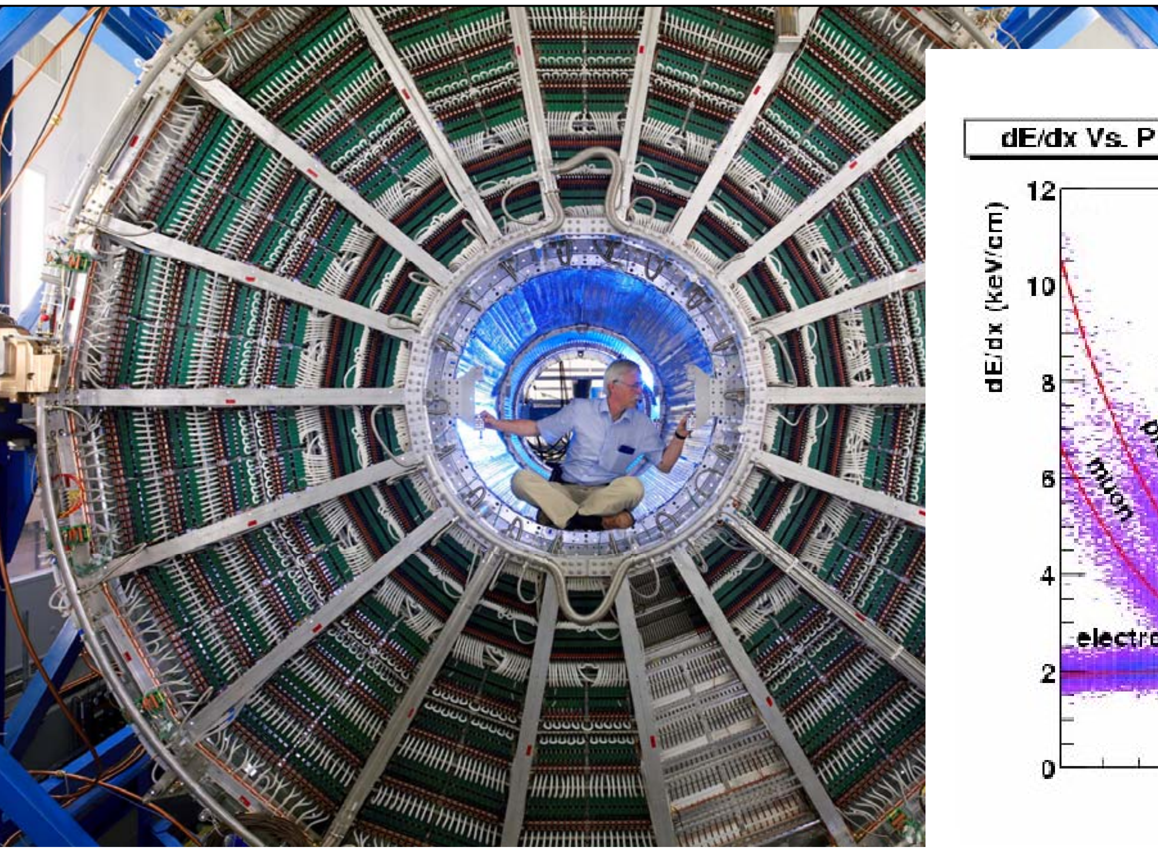
But ATLAS/CMS tracking specs do not marry well with detailed particle-ID

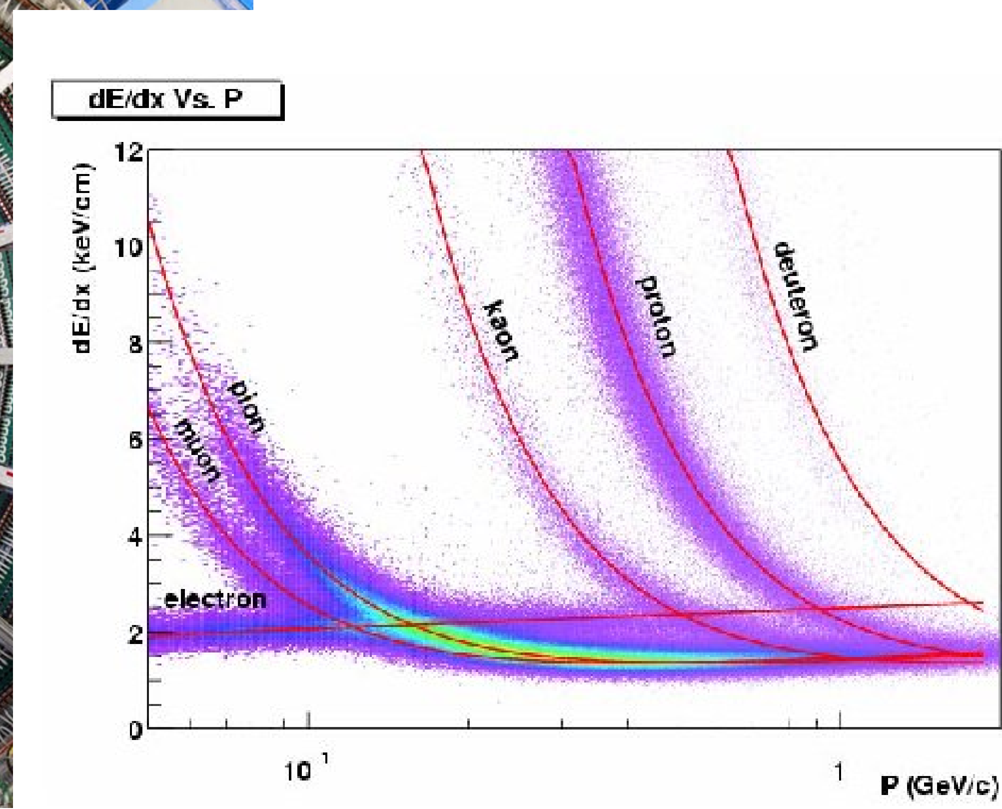
What are the limitations of ATLAS/CMS tracking detectors in terms of particle-ID? Look at ALICE/LHCb

ALICE TPC (Time Projection Chamber)

- Measure many samples of dE/dx per track (need >> 25 ns!!)
- At low momenta, non-relativistic particles can be separated from each other through precise dE/dx measurements:

Bethe-Bloch: $-\langle dE/dx \rangle = k\, 1/\beta^2 \left(0.5 \,\mathrm{Log}(2 m_e c^2 \beta^2 \gamma^2 T_{max}/I^2) - \beta^2 - \delta/2 \right)$





What are the limitations of ATLAS/CMS tracking detectors in terms of particle-ID? Look at ALICE/LHCb

Overall particle-ID in ALICE for heavy-ion physics

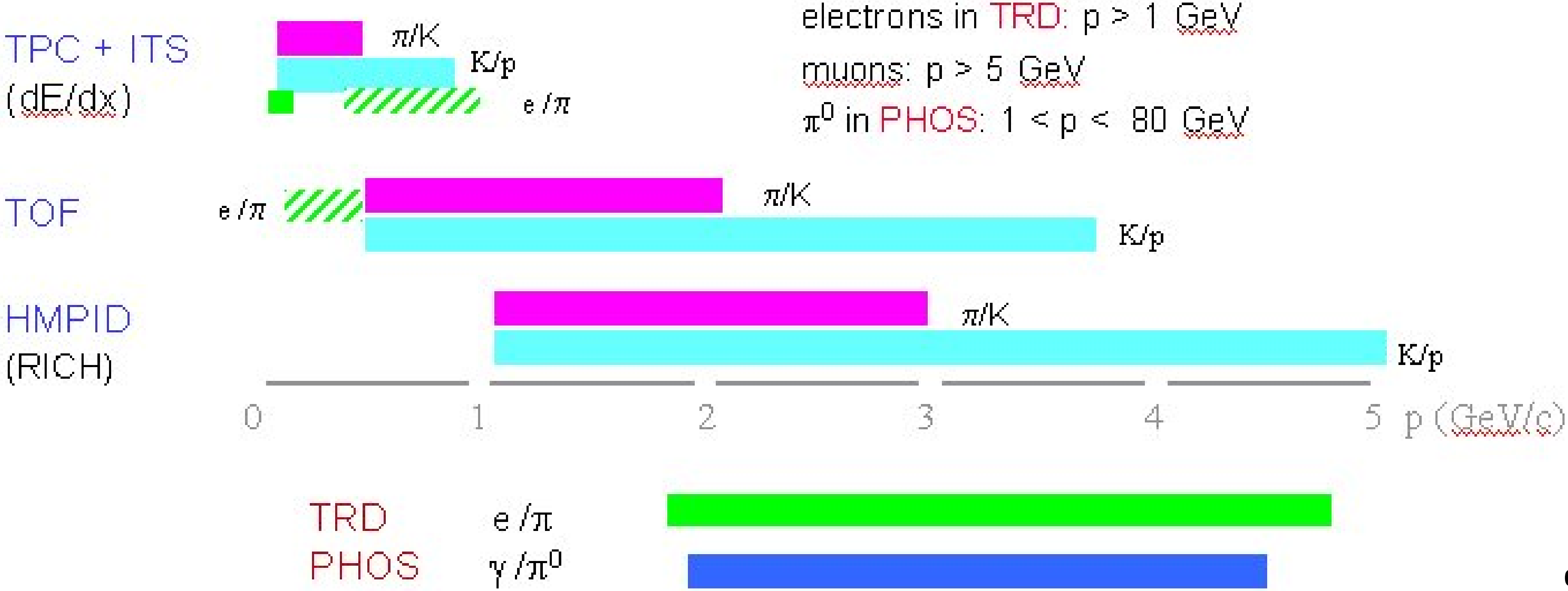
- **stable hadrons (π, K, p): 100 MeV < p < 5 GeV**
  - ⇨ dE/dx in silicon (ITS) and gas (TPC) + Time-of-Flight (TOF) + Cerenkov (RICH)
  - ⇨ dE/dx relativistic rise under study => extend PID to several 10 GeV ??
- **decay topology (K^0, K^+, K^-, Λ)**
  - ⇨ still under study, but expect K and Λ decays up to at least 10 GeV
- **leptons (e, μ), photons, π^0**

Alice uses ~ all known techniques!

electrons in TRD: p > 1 GeV

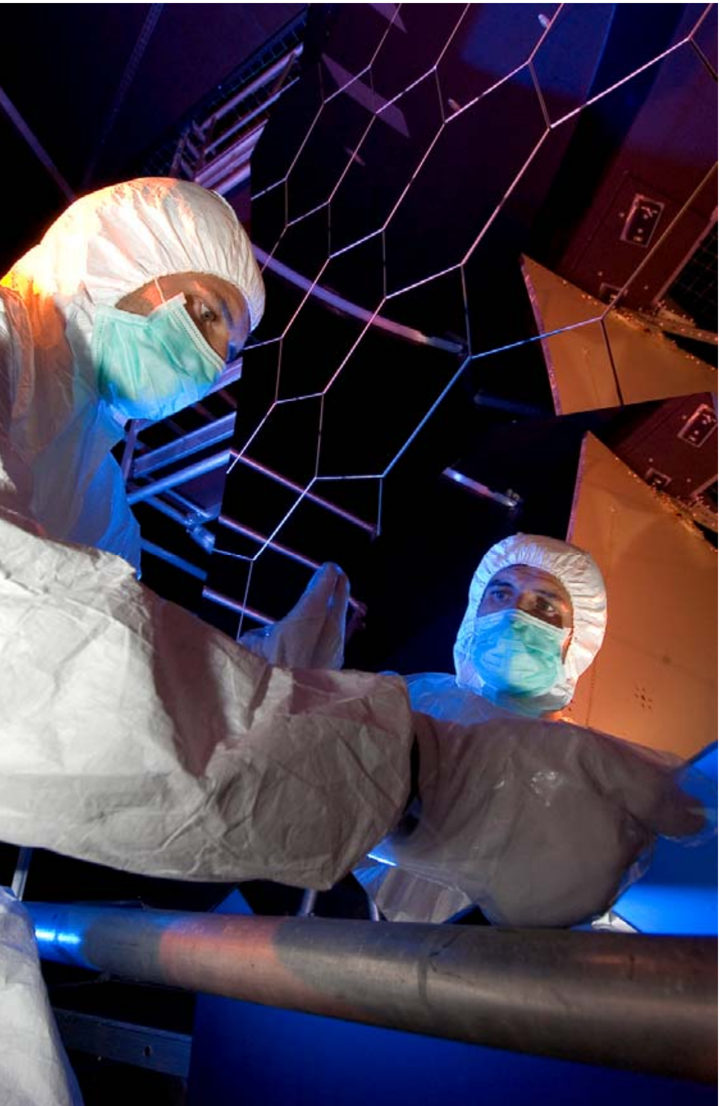
muons: p > 5 GeV

π^0 in PHOS: 1 < p < 80 GeV



What are the limitations of ATLAS/CMS tracking detectors in terms of particle-ID? Look at ALICE/LHCb

LHC-b RICH detectors



C_4F_{10}	3 GeV	30 GeV
β (pion) θ (Cerenkov)	0.9989 0.160 rad	0.999989 0.0526 rad
β (kaon) θ (Cerenkov)	0.9864 0.020 rad	0.99986 0.0502rad

RICH1:

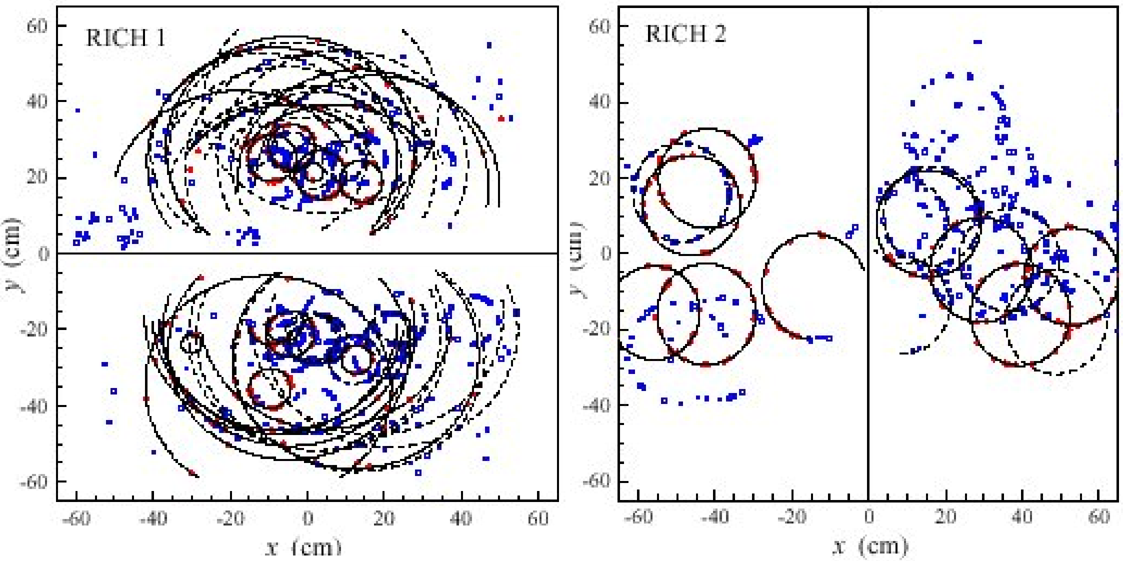
larger solid angle,lower part of momentum spectrum

- **Aerogel (hygroscopic…)**
  - **-n=1.03→ θ (β=1)=242 mrad**
  - **-thickness=5 cm**
  - **-nb detected photons=~7/ring (β=1)**
- **C_4F_{10} p=1013 mb at –1.9C**
  - **-n=1.0014 /260 nm θ (β=1)=53 mrad**
  - **-thickness=85cm**
  - **-nb photons=~30/ring**

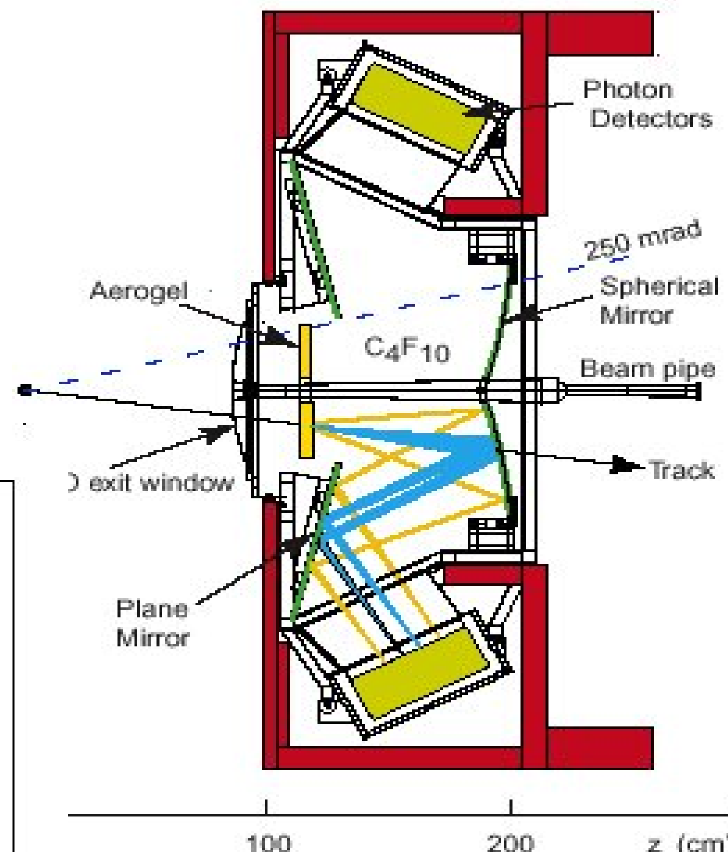
RICH2:

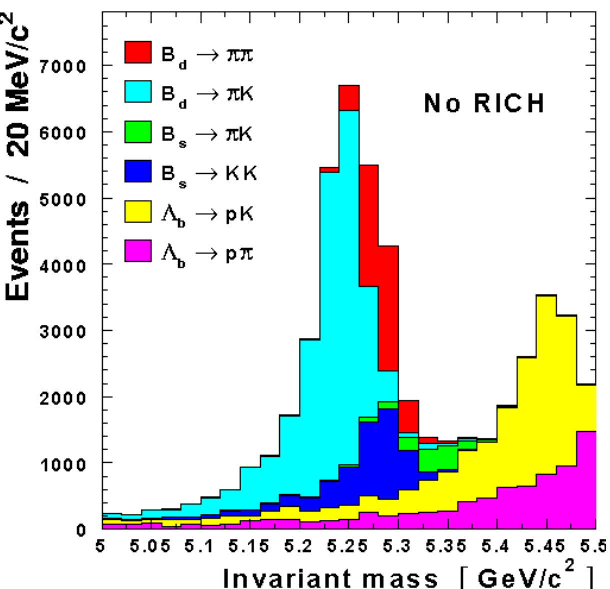
- **CF_4 -n=1.0005 /260 nm θ (β=1)=32 mrad**
  - **-thickness=180cm**
  - **-nb photons=~30/ring**

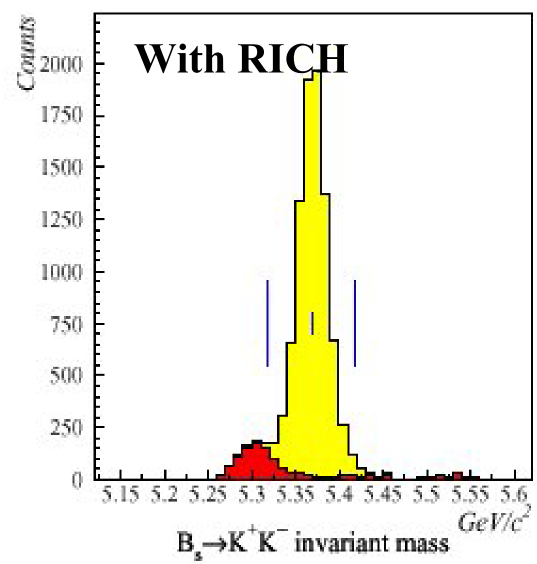
What are the limitations of ATLAS/CMS tracking detectors in terms of particle-ID? Look at ALICE/LHCb



LHC-b RICH detectors

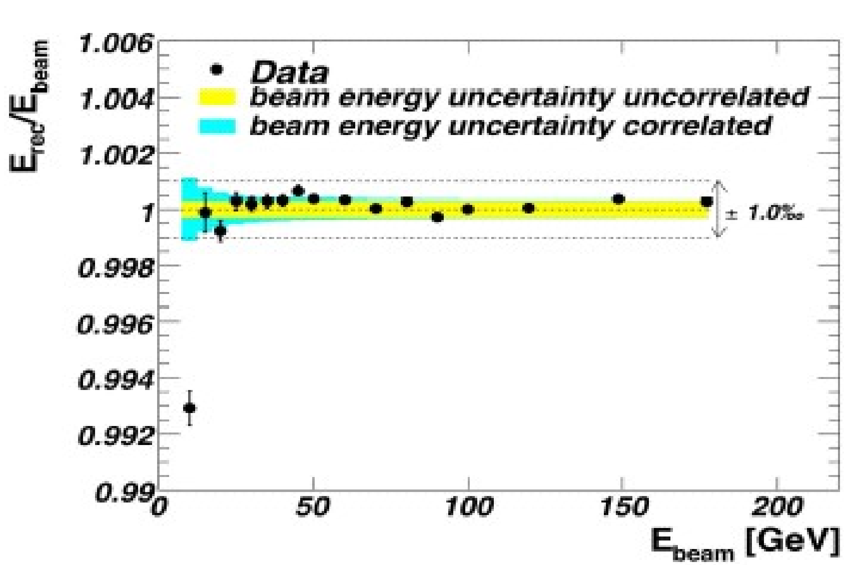


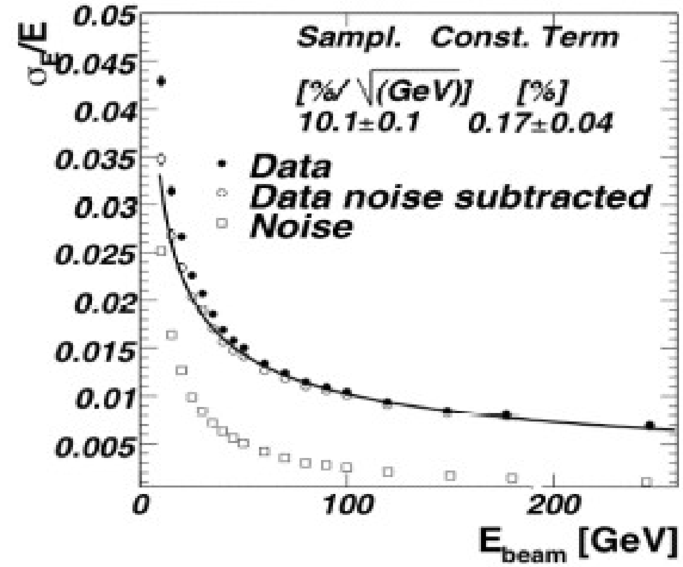


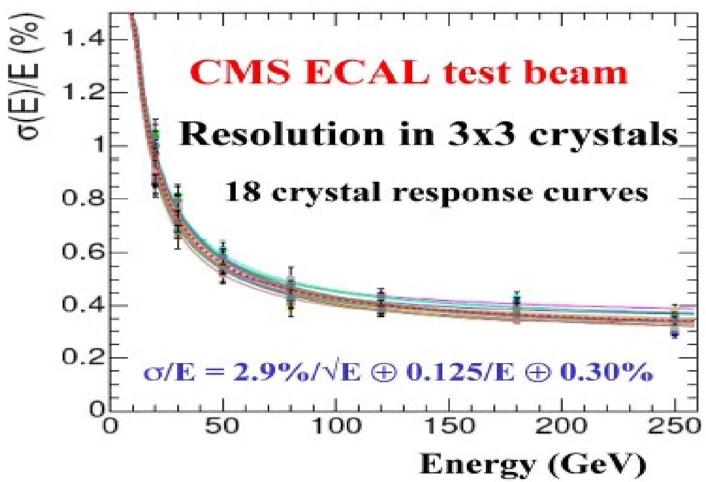


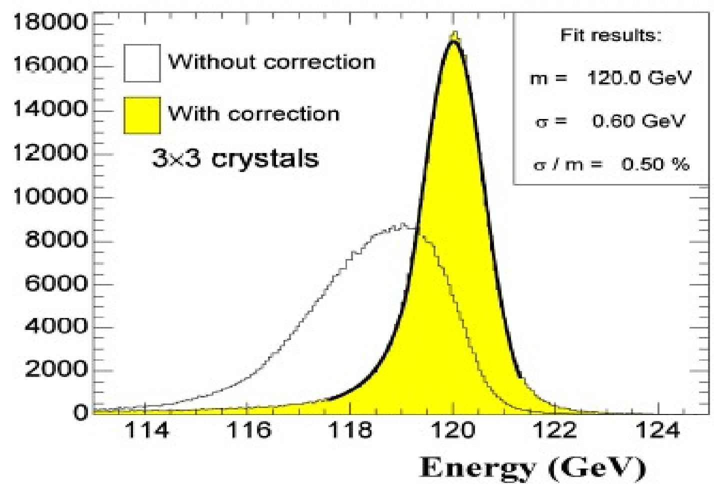
ATLAS/CMS: from design to reality

R&D and construction for 15 years → excellent EM calo intrinsic performance









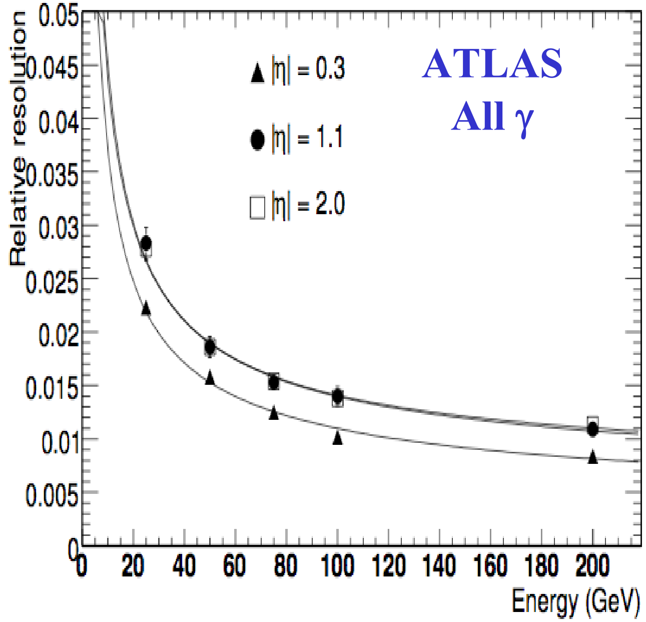
- Stand-alone performance measured in beams with electrons from 10 to 250 GeV

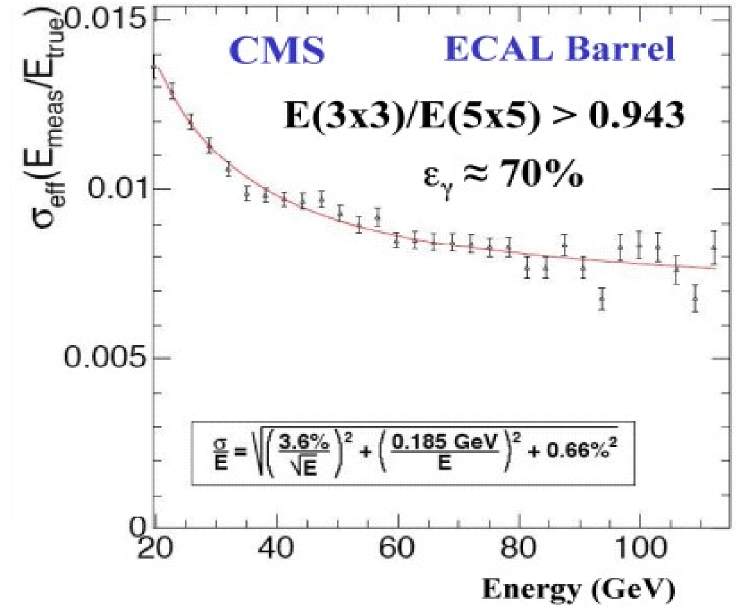
ATLAS/CMS: from design to reality

Actual performance expected in real detector quite different!!

Photons at 100 GeV

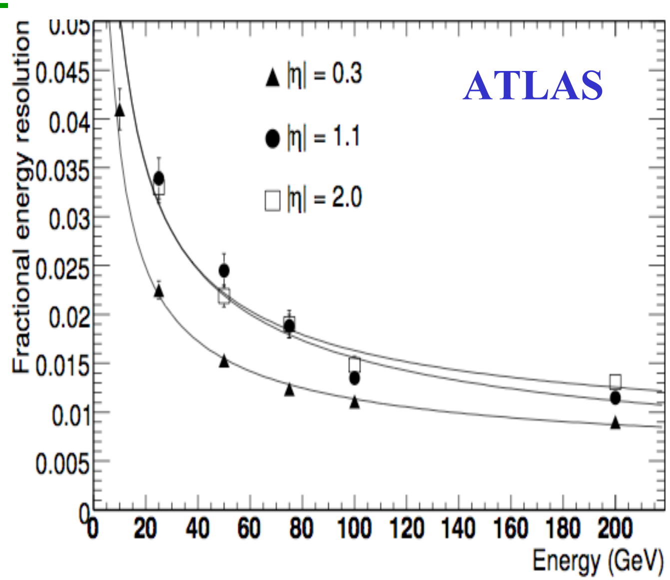
ATLAS: 1-1.5%
energy resol. (all γ)
CMS: 0.8%
energy resol.
($\varepsilon_\gamma \sim 70\%$)

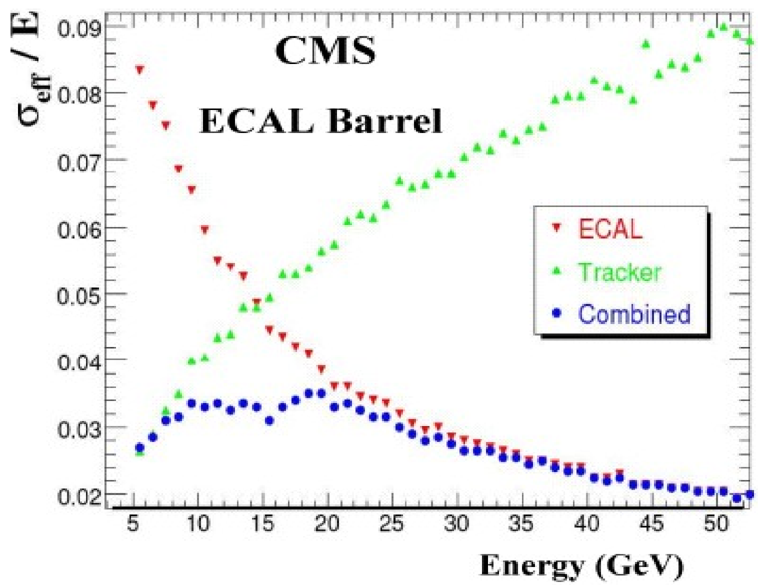




Electrons at 50 GeV

ATLAS: 1.5-2.5%
energy resol.
(use EM calo only)
CMS: ~ 2.0%
energy resol.
(combine EM calo
and tracker)





ATLAS/CMS: from design to reality

TABLE 10 Main performance parameters of the different hadronic calorimeter components of the ATLAS and CMS detectors, as measured in test beams using charged pions in both stand-alone and combined mode with the ECAL

	ATLAS					
	Barrel LAr/Tile		**End-cap LAr**		**CMS**	
	Tile	**Combined**	**HEC**	**Combined**	**Had. barrel**	**Combined**
Electron/hadron ratio	1.36	1.37	1.49			
Stochastic term	$45\%/\sqrt{E}$	$55\%/\sqrt{E}$	$75\%/\sqrt{E}$	$85\%/\sqrt{E}$	$100\%/\sqrt{E}$	$70\%/\sqrt{E}$
Constant term	1.3%	2.3%	5.8%	$< 1\%$		8.0%
Noise	Small	3.2 GeV		1.2 GeV	Small	1 GeV

The measured electron/hadron ratios are given separately for the hadronic stand-alone and combined calorimeters when available, and for the contributions (added quadratically except for the stand-alone ATLAS tile calorimeter) to the pion energy resolution from the stochastic term, the local constant term, and the noise are also shown, when available from published data.

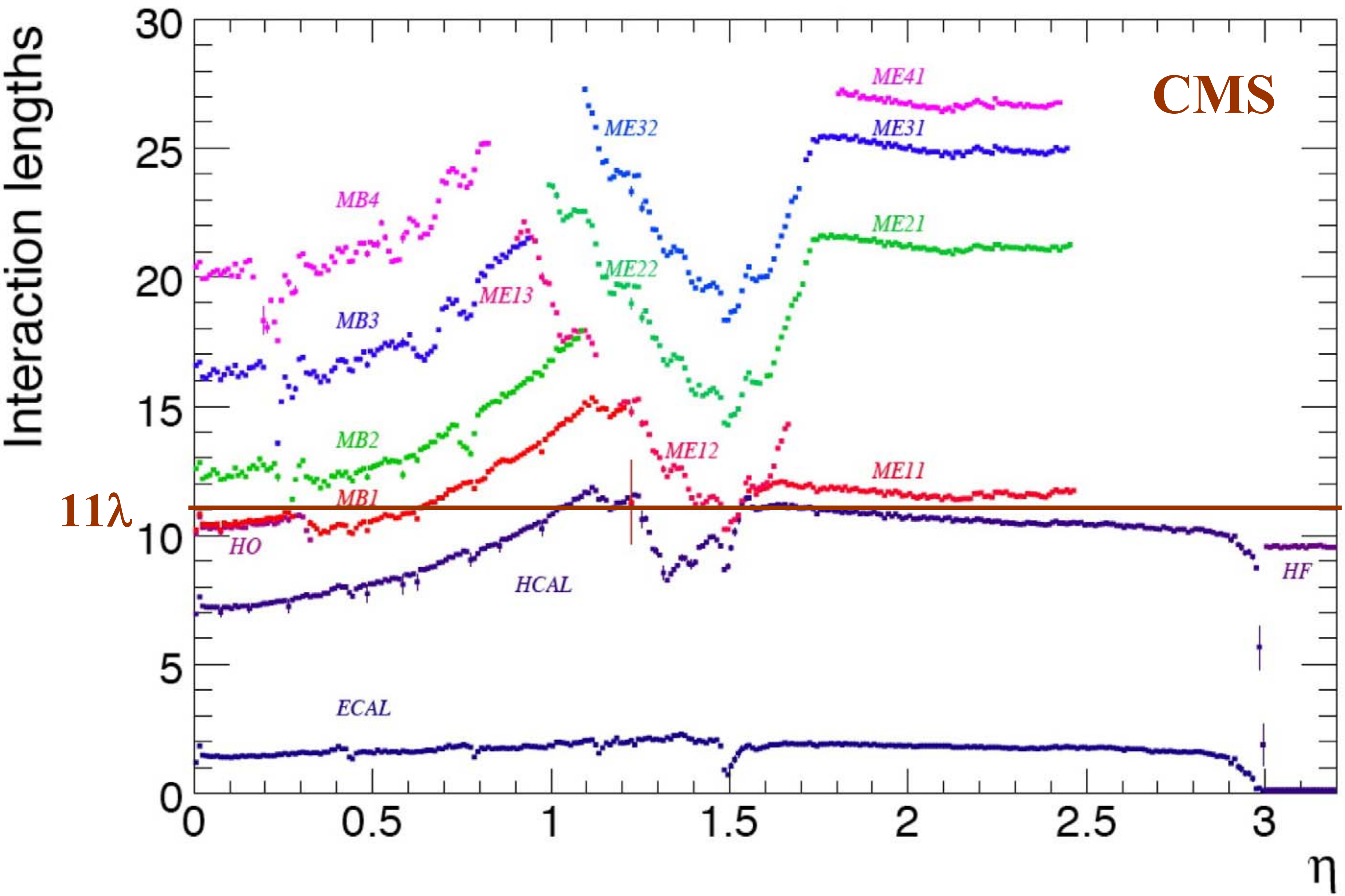
Huge effort in test-beams to measure performance of overall calorimetry with single particles and tune MC tools: not completed!

ATLAS/CMS: from design to reality

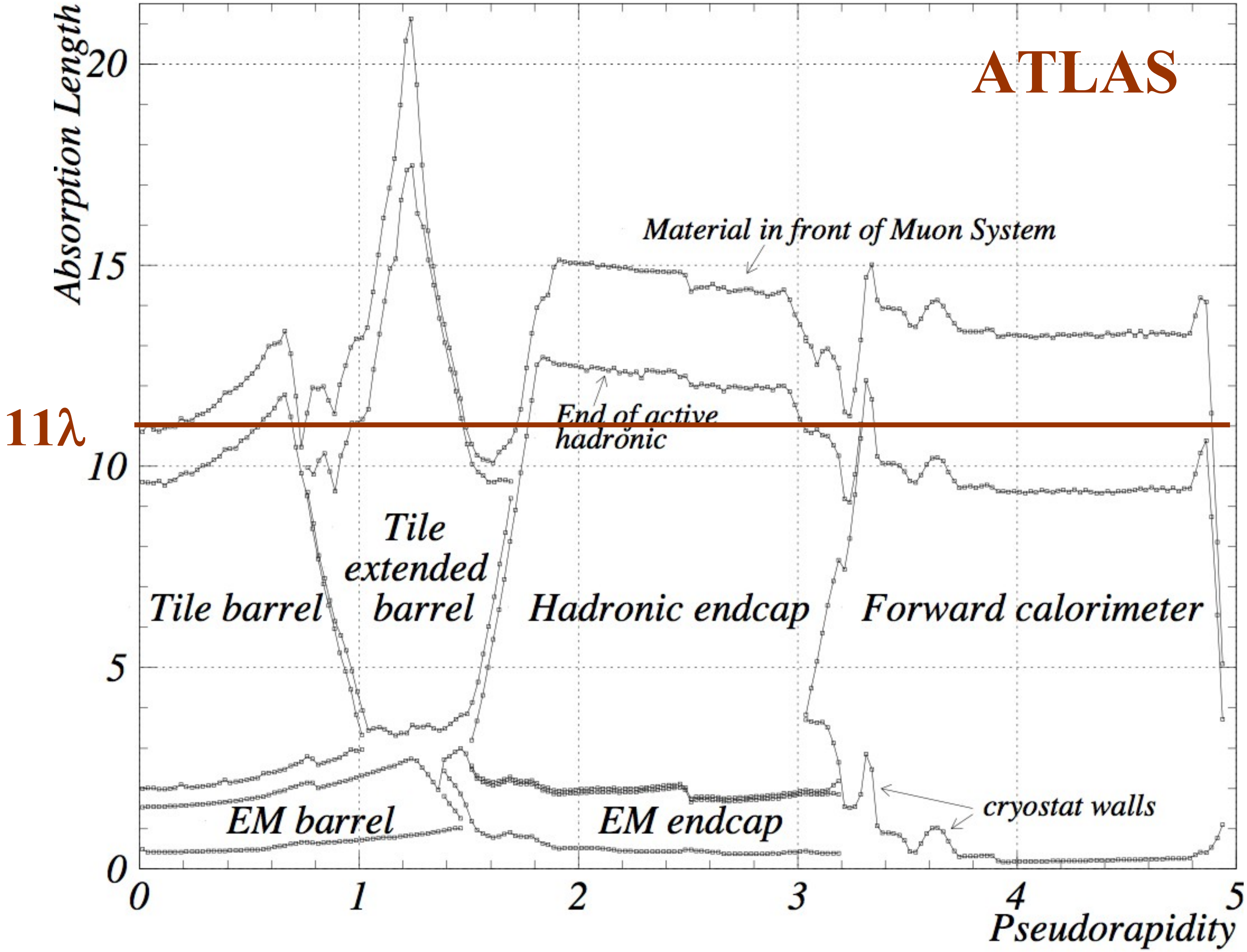
One word about neutrinos in hadron colliders:

- ✓ since most of the energy of the colliding protons escapes down the beam pipe, one can only use the energy-momentum balance in the transverse plane
  - → concepts such as E_T^{miss}, missing transverse momentum and mass are often used (only missing component is E_z^{miss})
  - → reconstruct "fully" certain topologies with neutrinos, e.g. $W \rightarrow l\nu$ and even better $H \rightarrow \tau\tau \rightarrow l\nu_l\nu_\tau\ h\nu_\tau$
- ✓ the detector must therefore be quite hermetic
  - → transverse energy flow fully measured with reasonable accuracy
  - → no neutrino escapes undetected
  - → no human enters without major effort (fast access to some parts of ATLAS/CMS quite difficult)

ATLAS/CMS: from design to reality

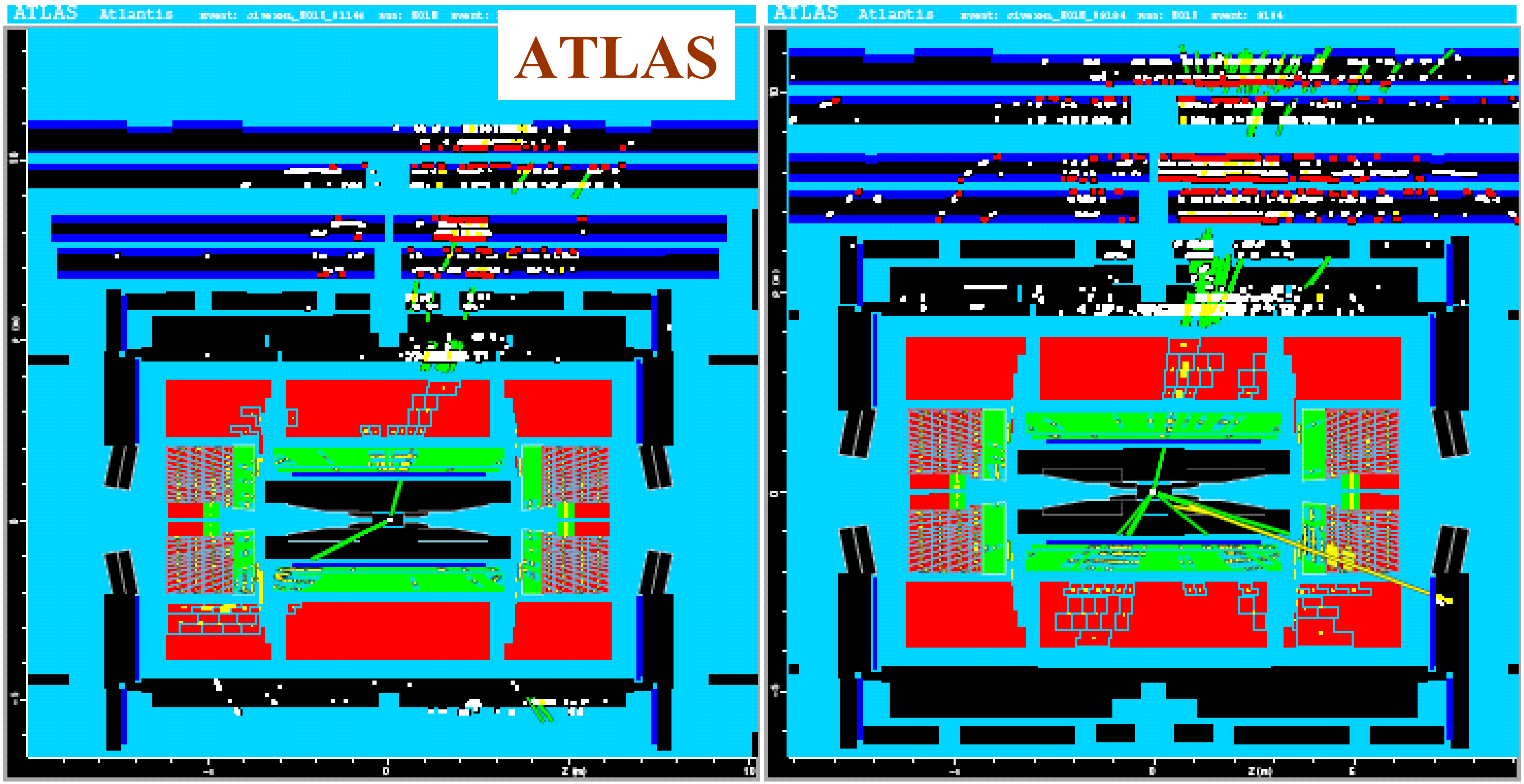


ATLAS/CMS: from design to reality



ATLAS/CMS: from design to reality

For an integrated luminosity of ~ 100 pb^{-1}, expect a few events like this?
This is apparent E_T^{miss} occurring in fiducial region of detector!

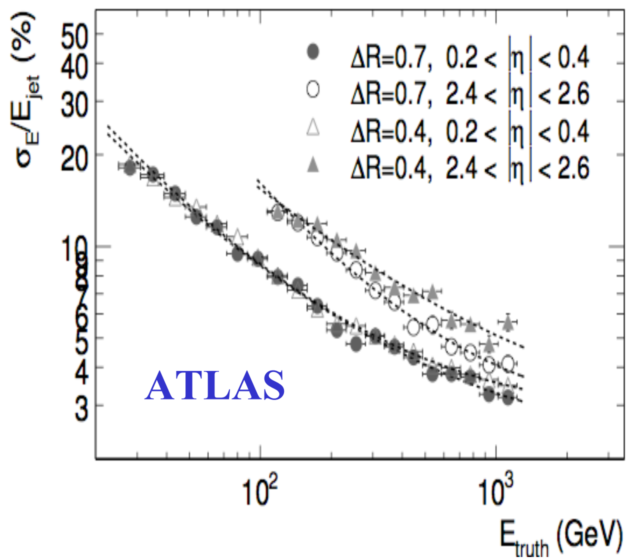


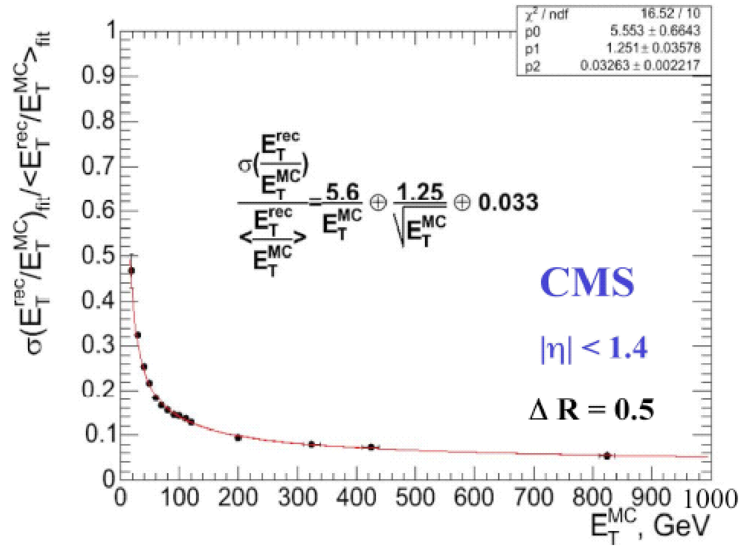
ATLAS/CMS: from design to reality

Biggest difference in performance perhaps for hadronic calo

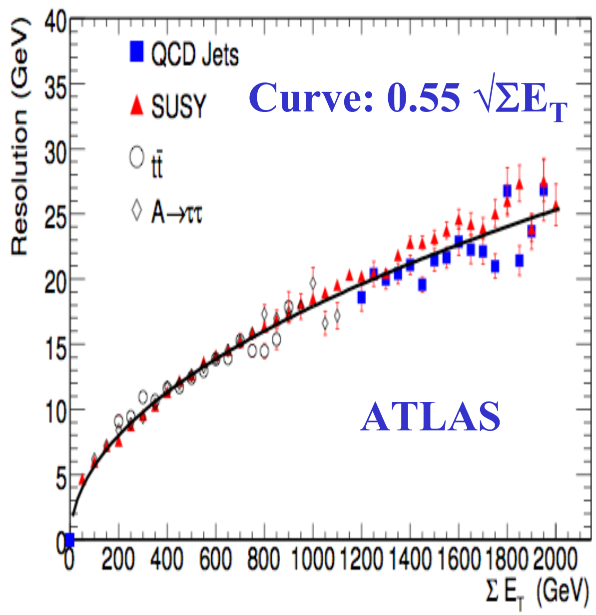
Jets at 1000 GeV

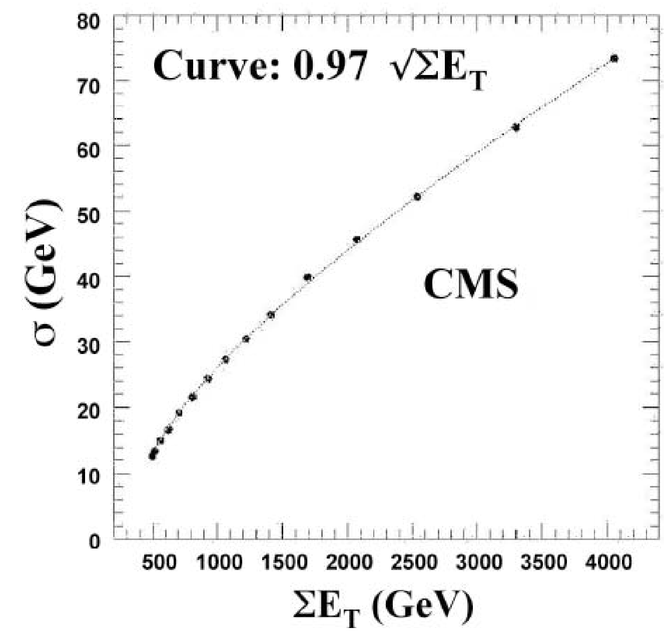
ATLAS ~ 3%
energy resolution
CMS ~ 5%
energy resolution,
(but expect sizable
improvement
using tracks at lowe
energies)





E_T^{miss} at ΣE_T = 2000 GeV
ATLAS: σ ~ 25 GeV
CMS: σ ~ 40 GeV
This may be important
for high mass H/A to ττ





ATLAS/CMS: from design to reality

Biggest difference in performance perhaps for hadronic calo: how much can be recovered using energy-flow algorithms?

Jets in 20-100 GeV range are particularly important for searches (e.g. $H \rightarrow bb$)

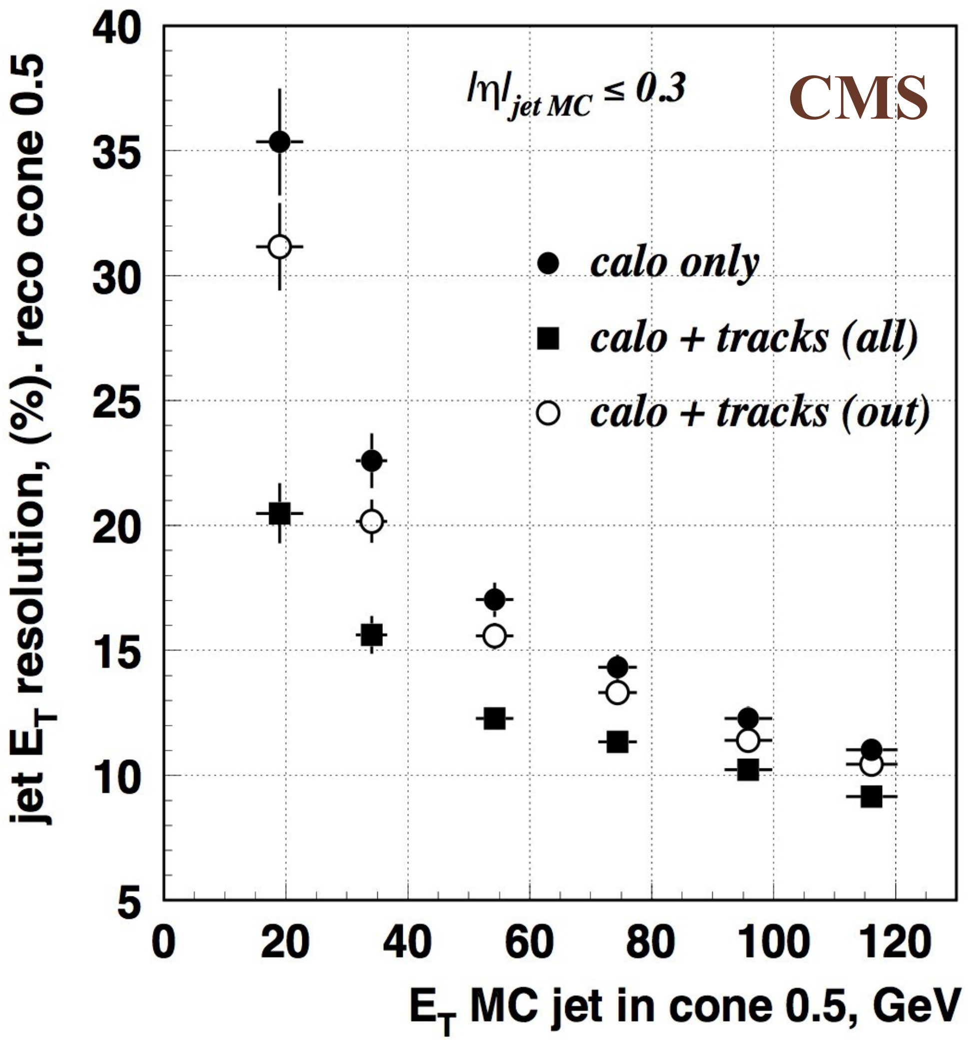
For $E_T \sim 50$ GeV in barrel:

ATLAS: ~ 10% energy resolution

CMS: ~ 19% energy resolution (with calo only), ~ 14% energy resolution (with calo + tracks)

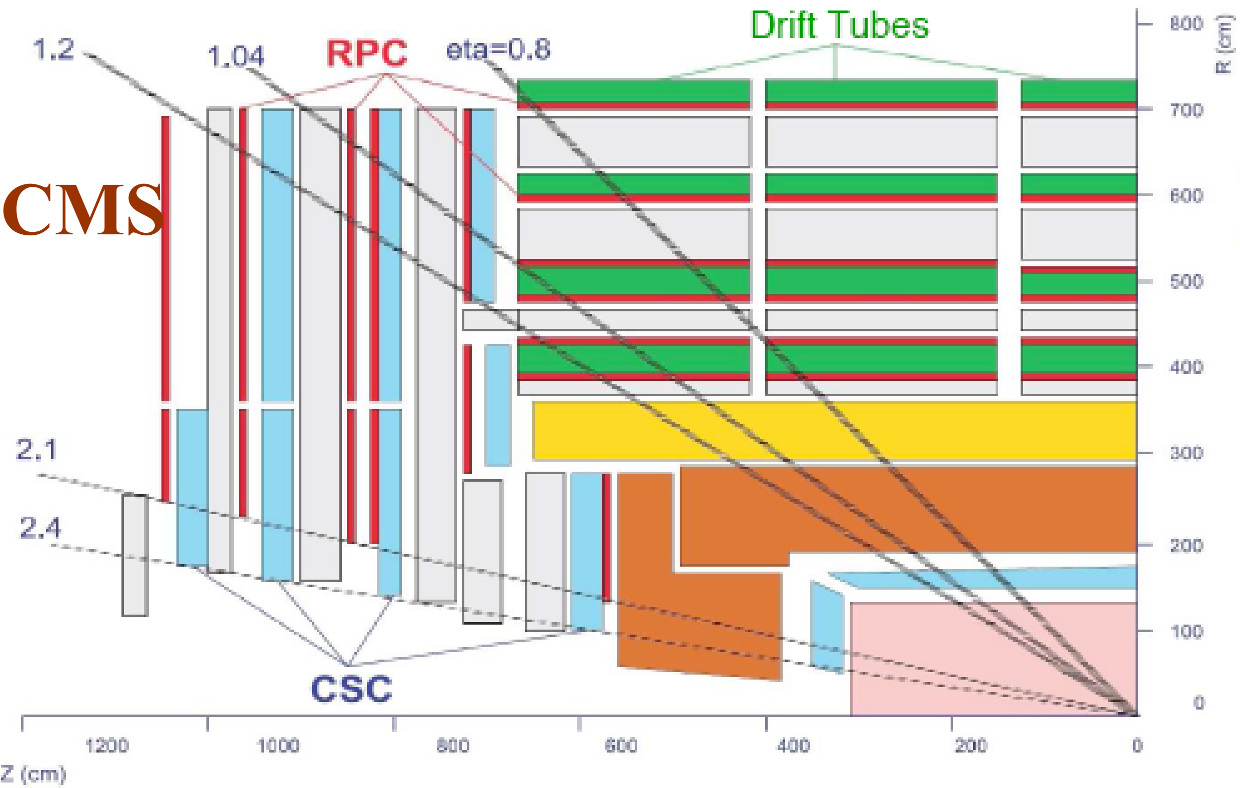
Some words of caution though:

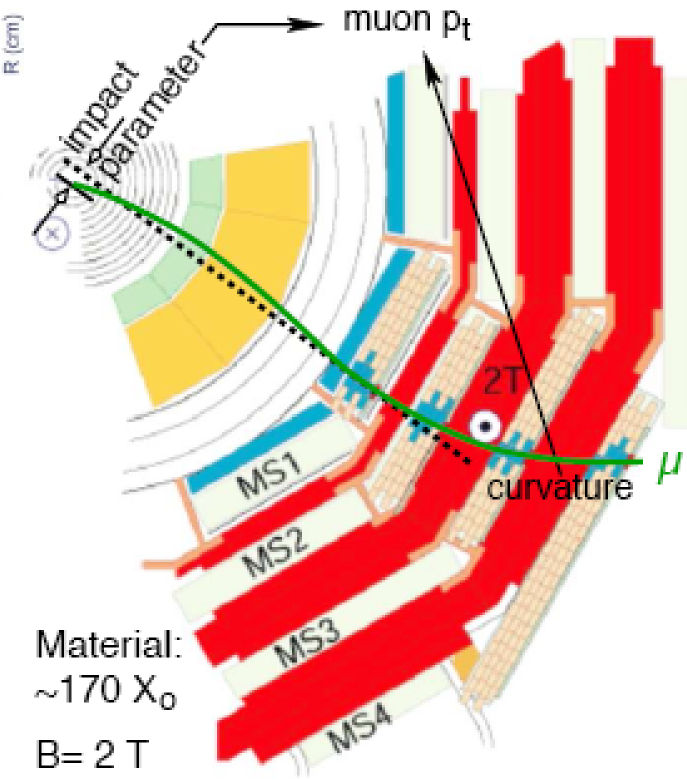
- danger from hadronic interactions in tracker material
$\rightarrow$ non-Gaussian tails in response
- gains smaller at large η (material) and at high energy
- linearity of response at low energy!



ATLAS/CMS: from design to reality

CMS

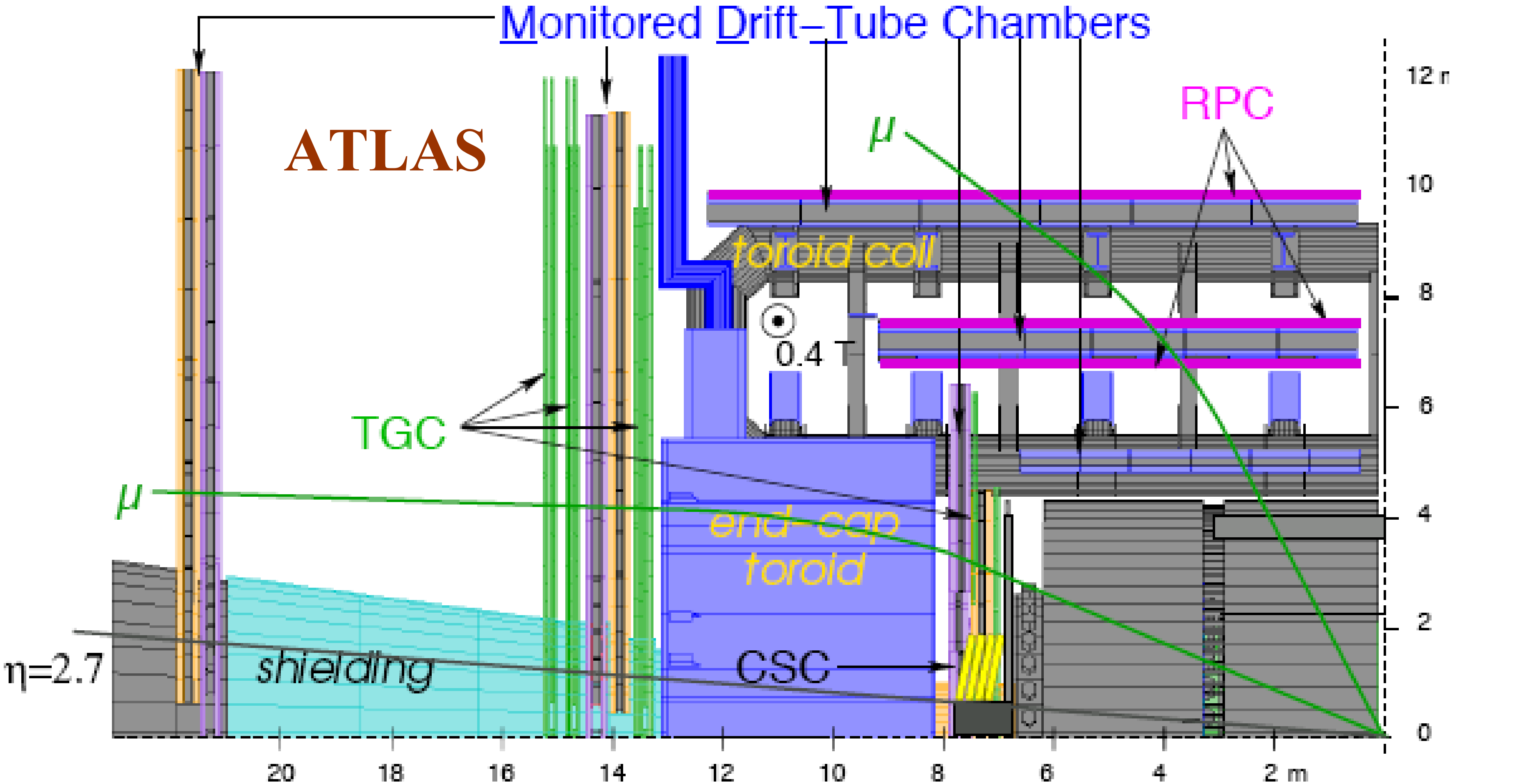




CMS muon spectrometer

- Superior combined momentum resolution in central region
- Limited stand-alone resolution and trigger (at very high luminosities) due to multiple scattering in iron
- Degraded overall resolution in the forward regions ($|\eta| > 2.0$) where solenoid bending power becomes insufficient

ATLAS/CMS: from design to reality



ATLAS muon spectrometer

- Excellent stand-alone capabilities and coverage in open geometry
- Complicated geometry and field configuration (large fluctuations in acceptance and performance over full potential η x ϕ coverage (|η| < 2.7)

ATLAS/CMS: from design to reality

TABLE 12 Main parameters of the ATLAS and CMS muon measurement systems as well as a summary of the expected combined and stand-alone performance at two typical pseudorapidity values (averaged over azimuth)

Parameter	**ATLAS**	**CMS**
Pseudorapidity coverage		
-Muon measurement	$\|\eta\| < 2.7$	$\|\eta\| < 2.4$
-Triggering	$\|\eta\| < 2.4$	$\|\eta\| < 2.1$
Dimensions (m)		
-Innermost (outermost) radius	5.0 (10.0)	3.9 (7.0)
-Innermost (outermost) disk (z-point)	7.0 (21–23)	6.0–7.0 (9–10)
Segments/superpoints per track for barrel (end caps)	3 (4)	4 (3–4)
Magnetic field B (T)	0.5	**2(+4)**
-Bending power (BL, in T· m) at $\|\eta\| \approx 0$	3	16
-Bending power (BL, in T· m) at $\|\eta\| \approx 2.5$	8	6
Combined (stand-alone) momentum resolution at		
$-p = 10$ GeV and $\eta \approx 0$	1.4% (3.9%)	0.8% (8%)
$-p = 10$ GeV and $\eta \approx 2$	2.4% (6.4%)	2.0% (11%)
$-p = 100$ GeV and $\eta \approx 0$	2.6% (3.1%)	1.2% (9%)
$-p = 100$ GeV and $\eta \approx 2$	2.1% (3.1%)	1.7% (18%)
$-p = 1000$ GeV and $\eta \approx 0$	10.4% (10.5%)	4.5% (13%)
$-p = 1000$ GeV and $\eta \approx 2$	4.4% (4.6%)	7.0% (35%)

CMS muon performance driven by tracker: better than ATLAS at $\eta \sim 0$
ATLAS muon stand-alone performance excellent over whole η range

How operational will LHC detectors be in summer 2009?

Current status of ATLAS: installation and global commissioning finished

All measurements below given in situ after installation, cabling and sign-off (but not always for 100% of all channels)

ATLAS sub-detector	Nb of channels	Non-working channels(%)
Pixels	80×10^6	0.4
Silicon strip detector (SCT)	6×10^6	0.3
Transition Radiation Tracker (TRT)	3.5×10^5	1.5
Electromagnetic calorimeter	1.7×10^5	0.04
Fe/scintillator (Tilecal) calorimeter	9800	0.8
Hadronic end-cap LAr calorimeter	5600	0.09
Forward LAr calorimeter	3500	0.2
Barrel Muon Spectrometer	7×10^5	0.5
End-cap Muon Spectrometer (TGC)	3.2×10^5	0.02

Current status of CMS:

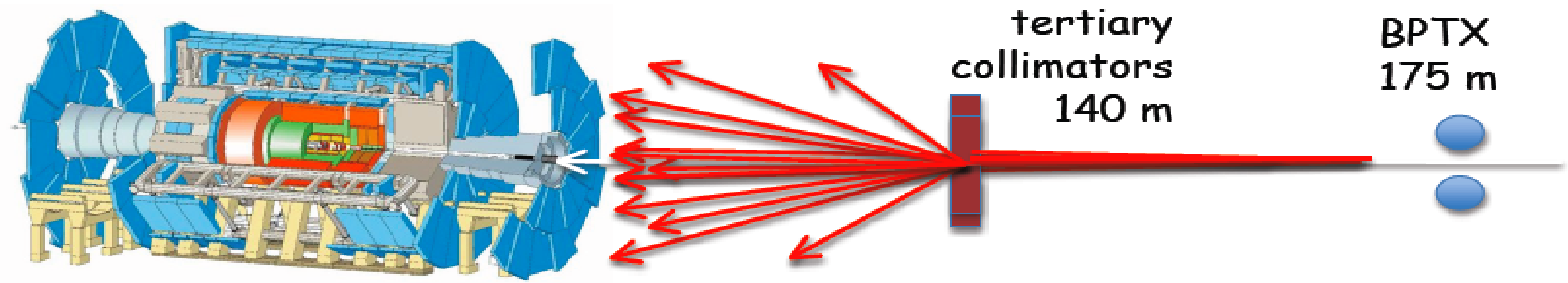
Pixels and end-cap crystals installed last summer, a real feat: just in time!

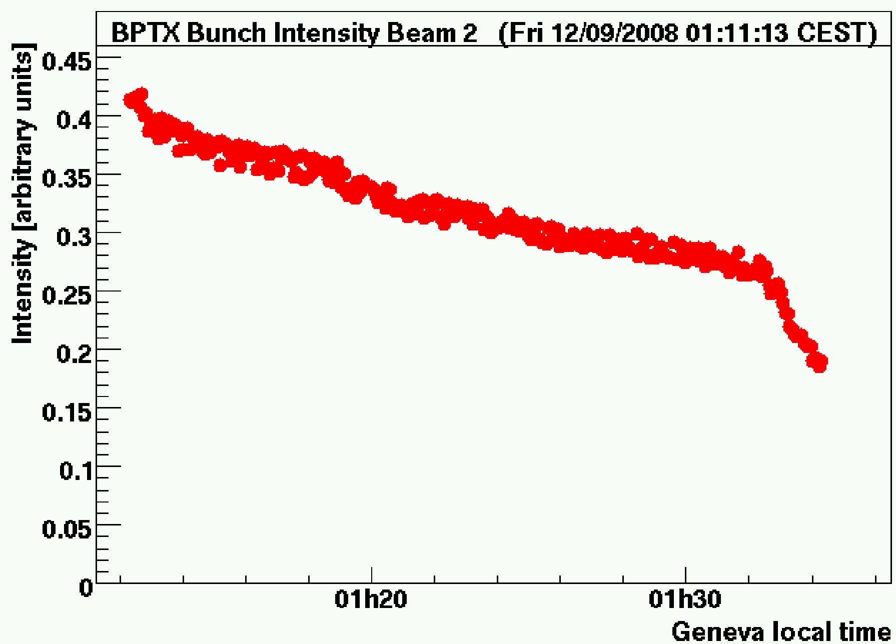
Preshower detectors in front of end-cap crystals also installed very recently!

First beams: a time of excitement (and panic!)…

The beginning of any experiment is exhilarating and fraught with stress:

- ✓ Are we going to be ready from detector to online to Grid distribution of data?
- ✓ How soon can we see all detectors switched on?
- ✓ When are we really going to need trigger switched on fully?





Bunch intensity measured by the beam pick-up monitoring system during a coast of more than 20 minutes of beam 2 on 12/09/2008.

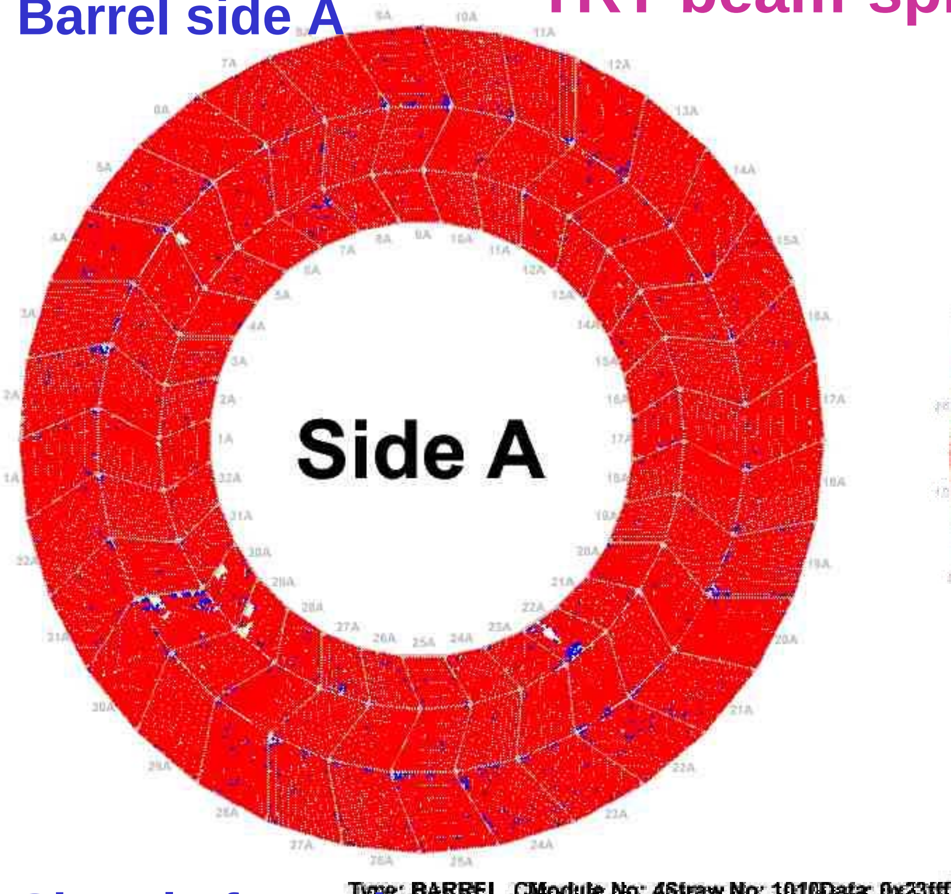
The relative precision determined from the scatter of data points is 10%.

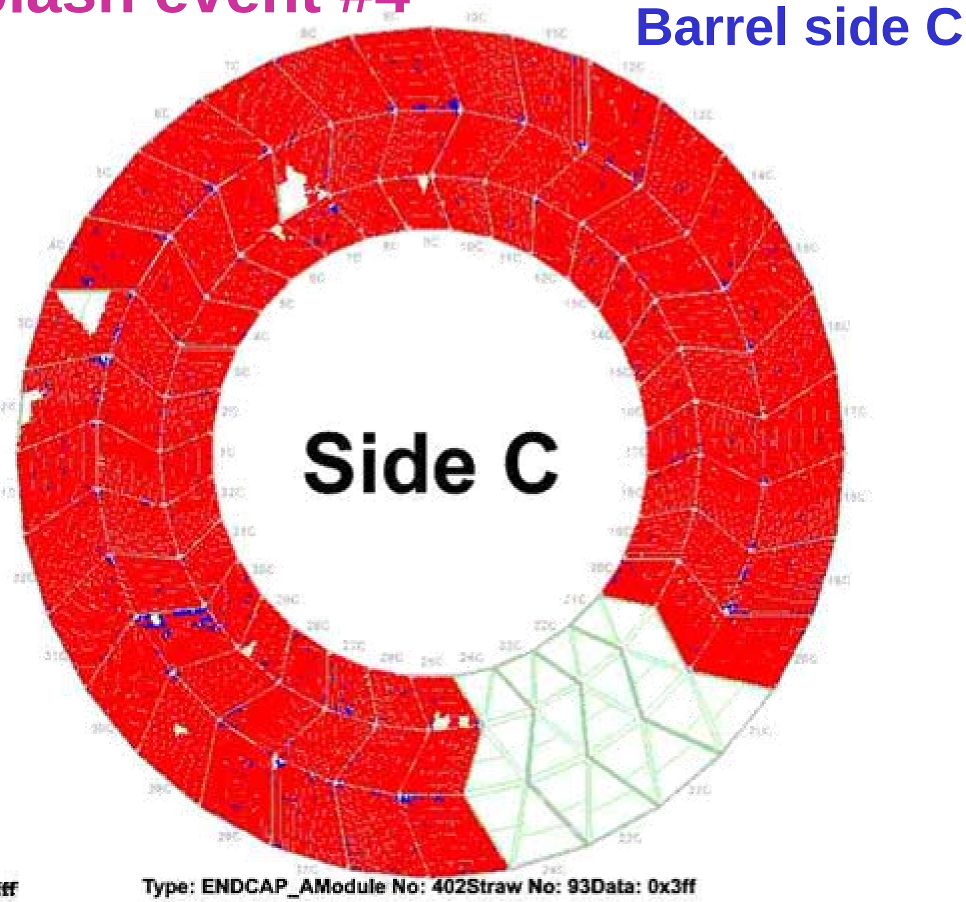
The absolute intensity value is not calibrated yet and corresponds roughly to unit of 10^{10} protons.

Beam splash from collimators in front of ATLAS

TRT beam-splash event #4

Barrel side A | **Barrel side C**

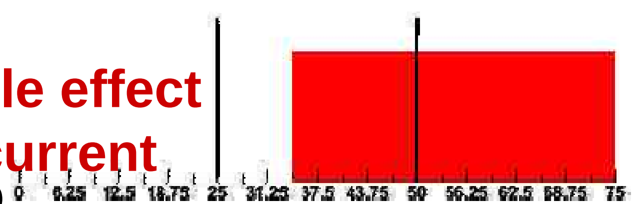


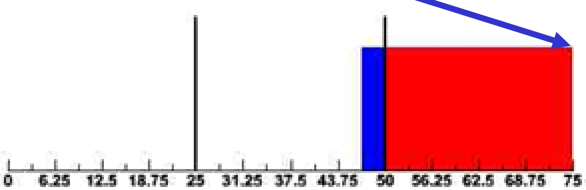


Signals from the straw

Red colour means HL threshold fired.

Each straw signal has a trailing edge at 75ns



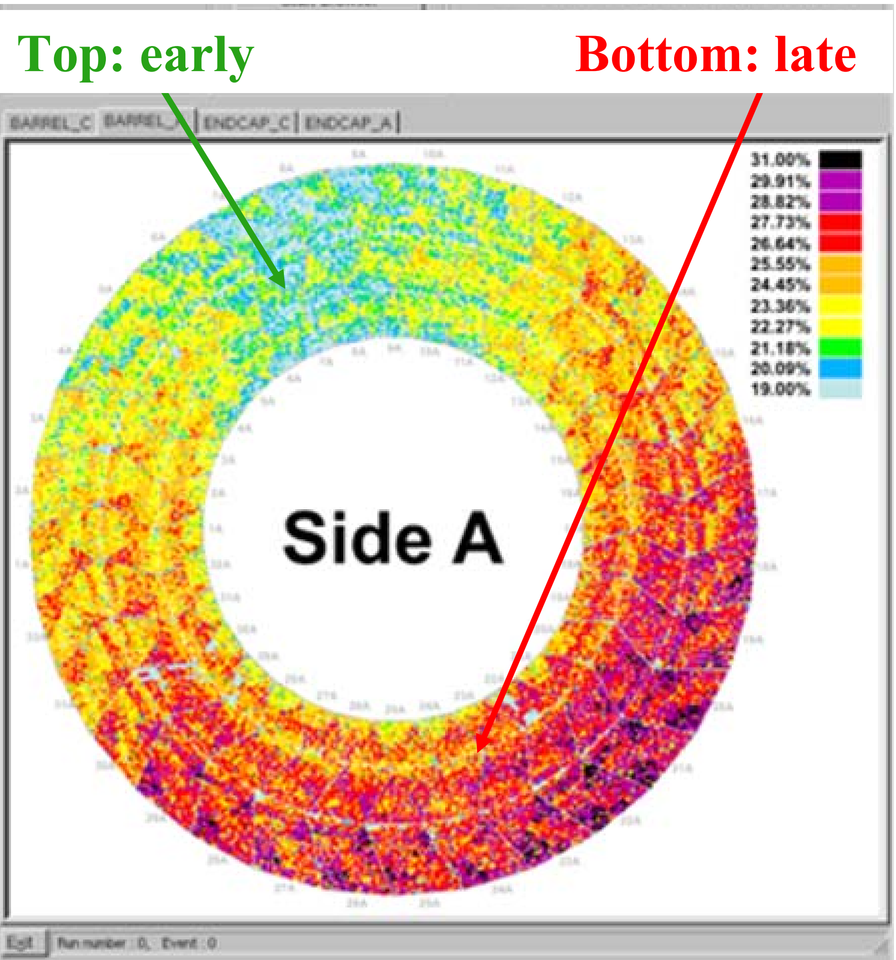


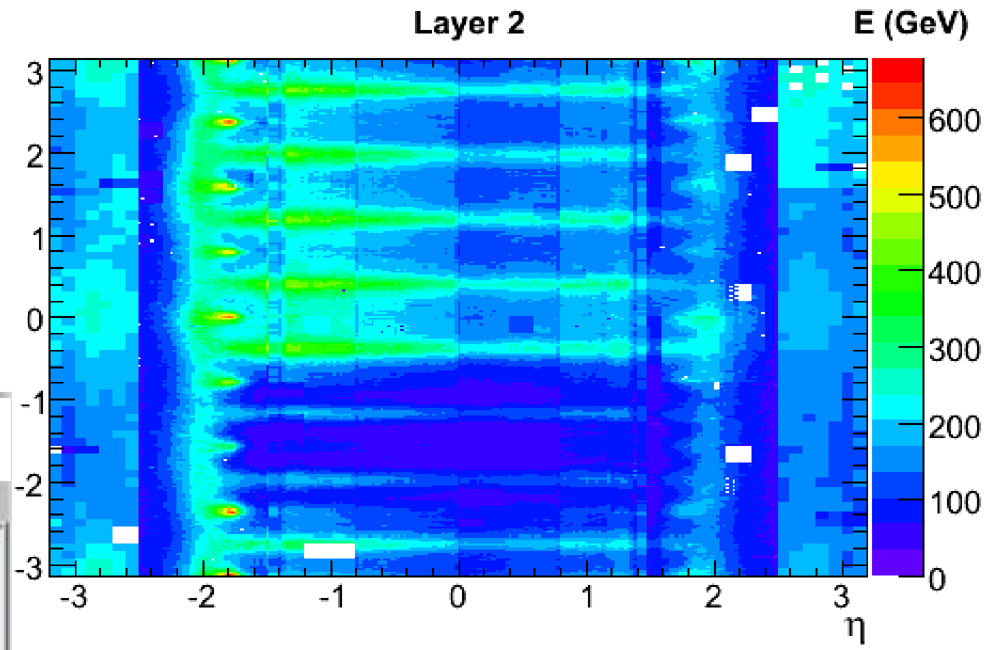
No noticeable effect on the HV current

Beam splash from collimators in front of ATLAS

Timing of all TRT readout channels could be performed with accuracy of ~ 1 ns per event!

Differences in colour due to cosmic timing:

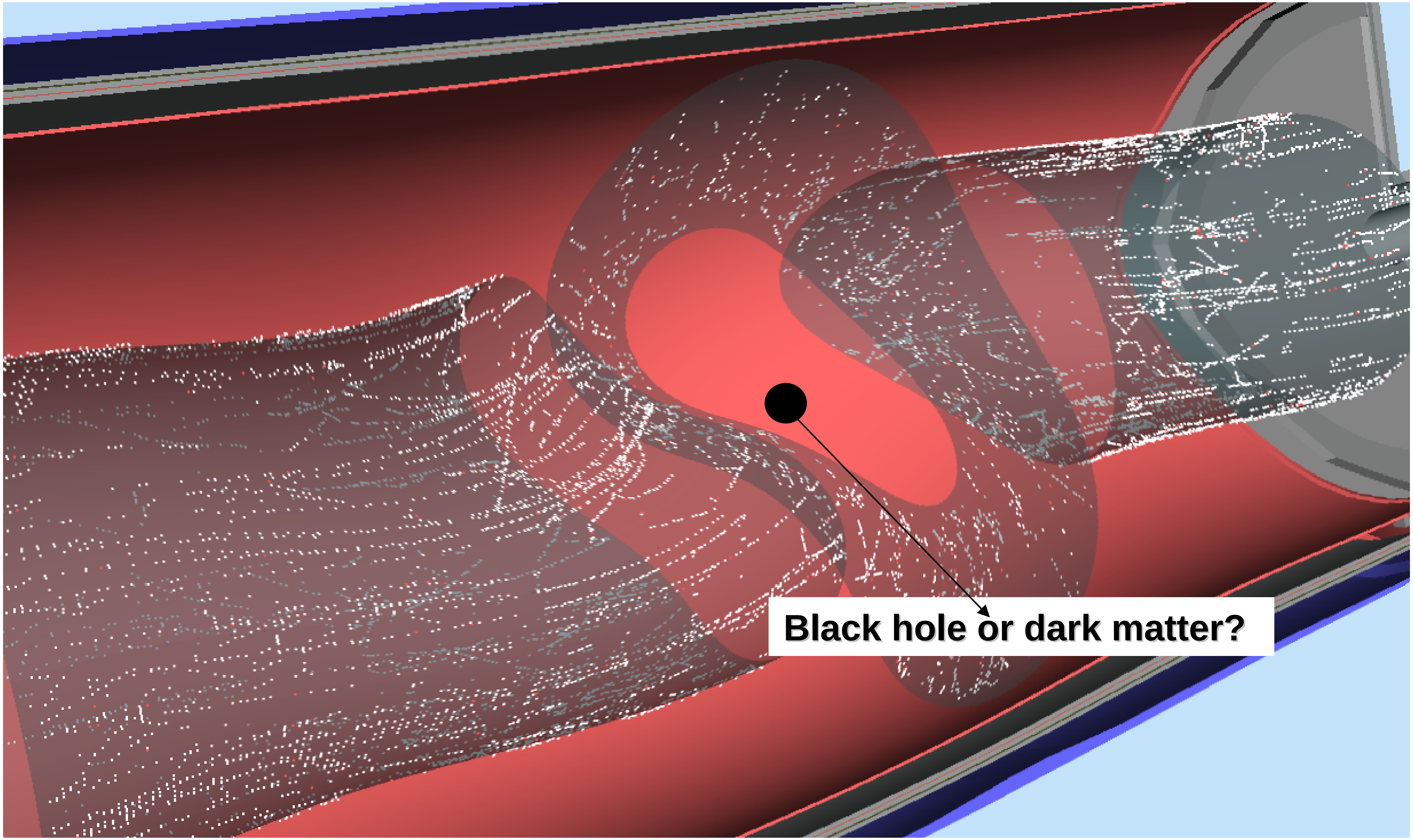




2D display in η–ϕ of energy deposited in LAr EM calorimeter per cell (layer 2):

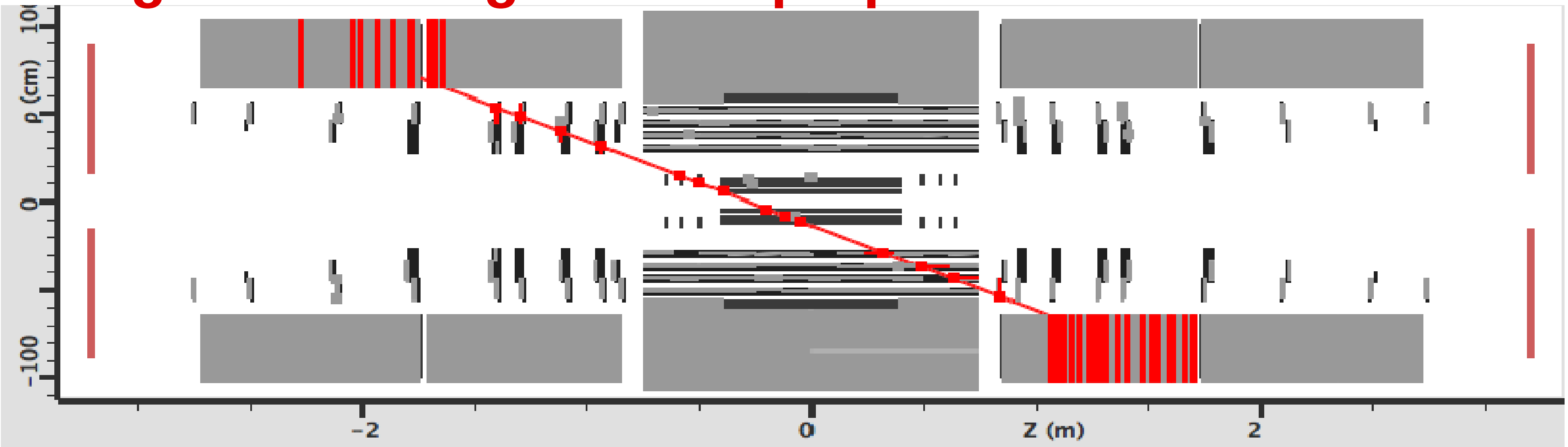
- structures seen are due to material between collimators and calorimeter (mostly 8-fold structure of end-cap toroid coils)
- energy seen per event is huge!

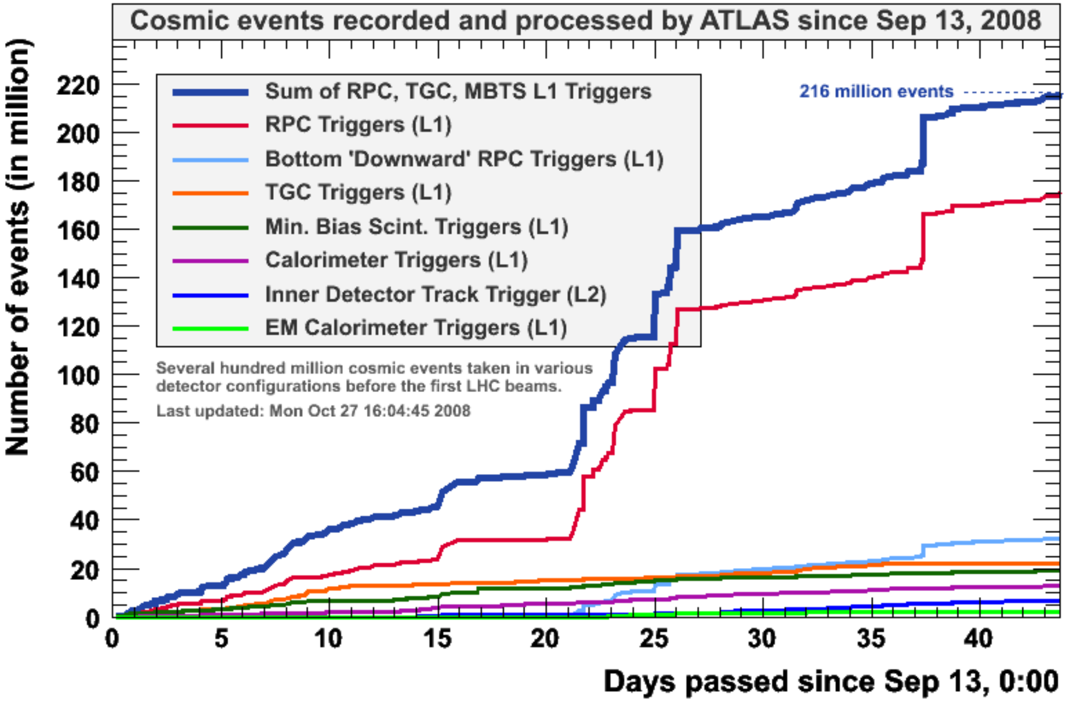
Artist view of beam halo event in ATLAS TRT

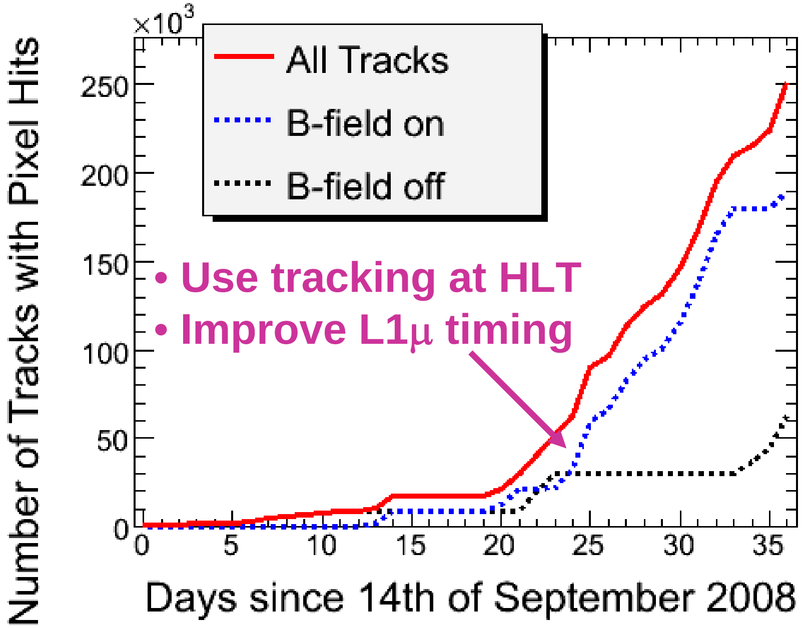


Note that beam conditions were not yet considered safe enough to operate ATLAS silicon-strip or pixel detectors at nominal settings

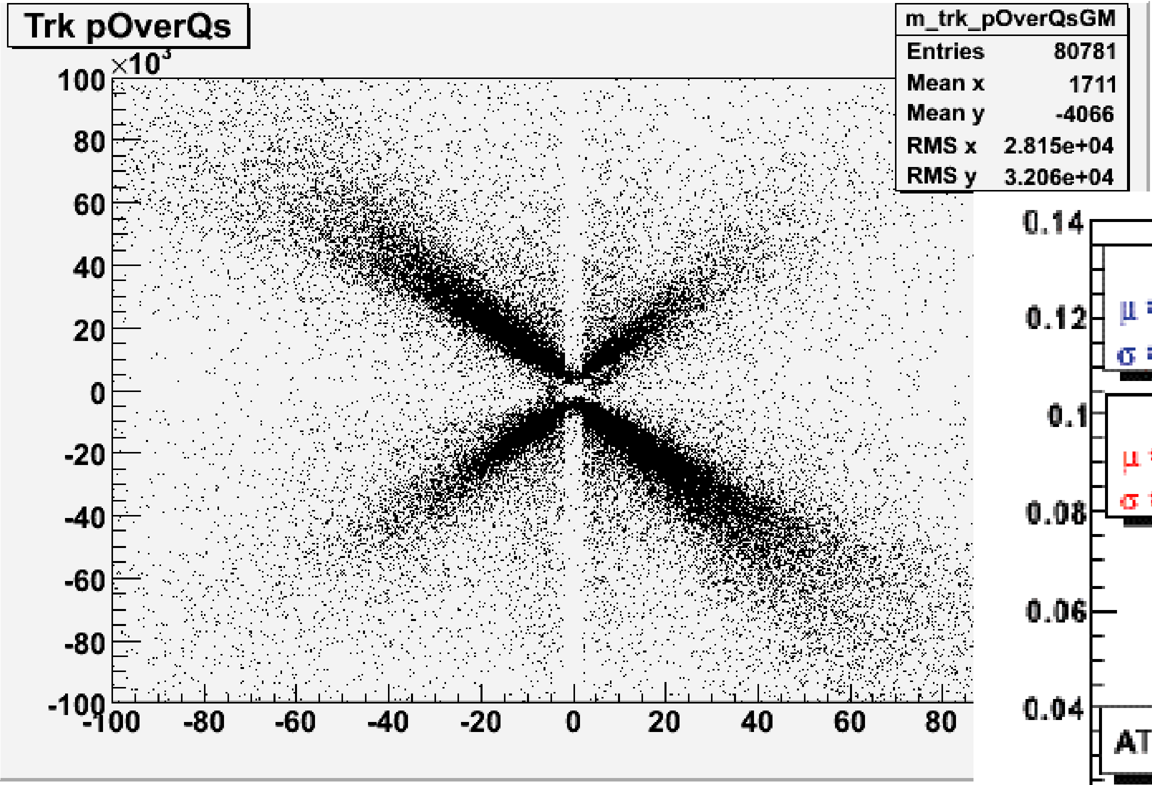
Global cosmics: accumulate data for calibration and alignment and get better prepared for 2009 collisions

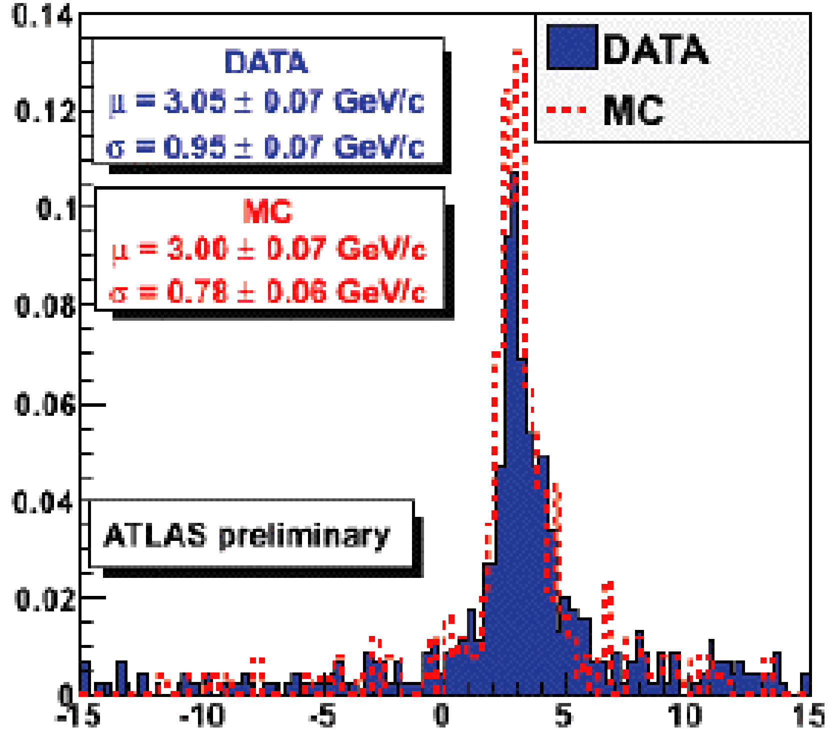






Global cosmics: accumulate data for calibration and alignment and get better prepared for 2009 collisions





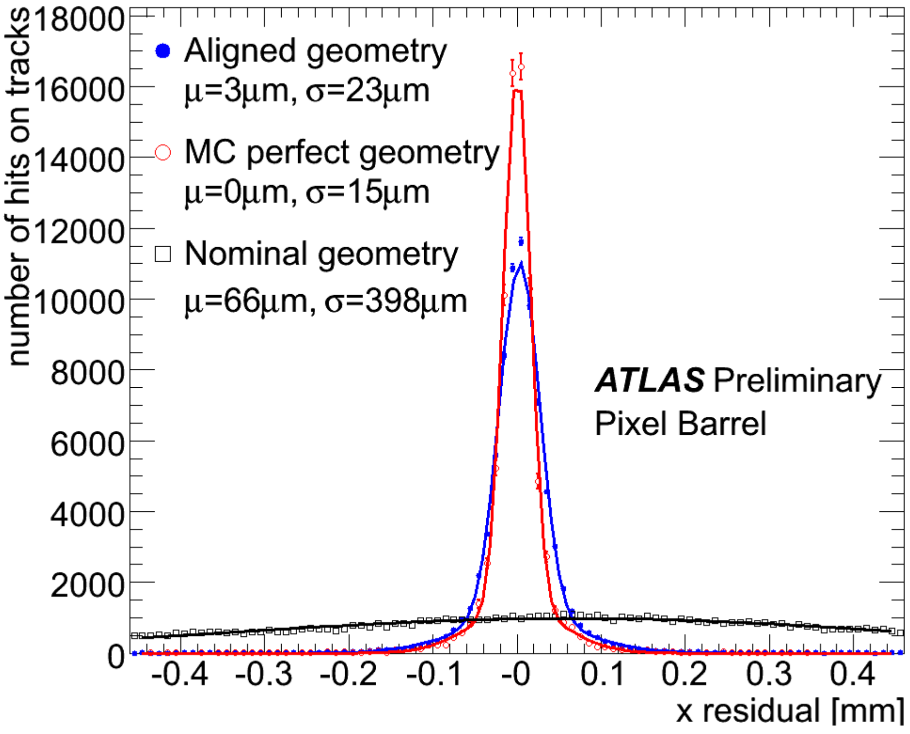
Cosmic-ray data particularly useful for tracking detectors:

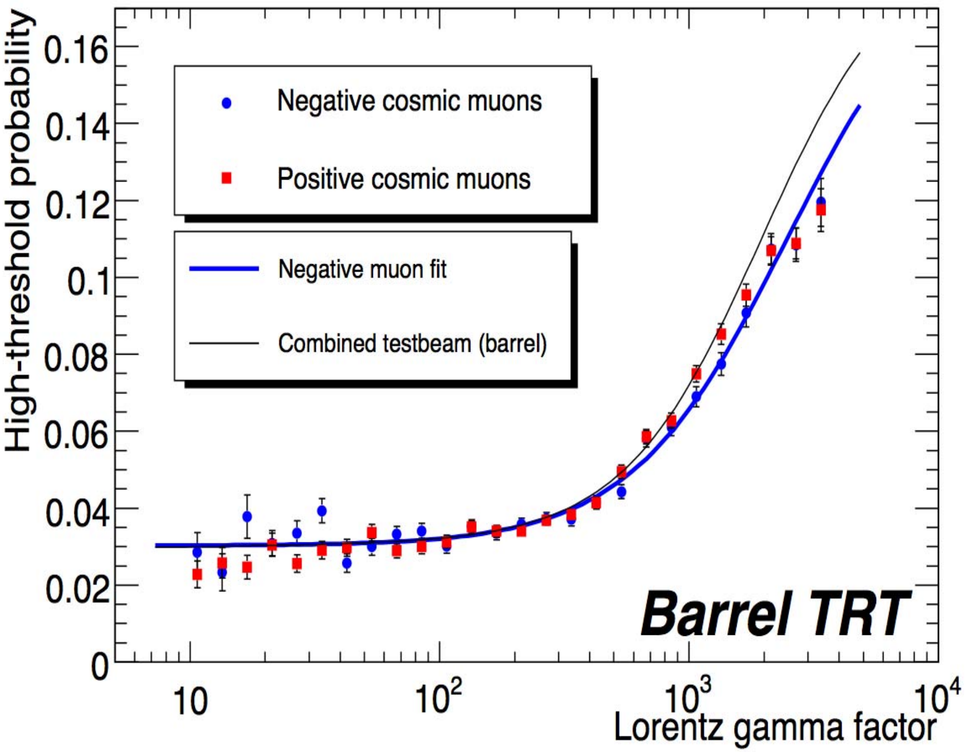
- Global alignment of inner detector and muon spectrometer (and calorimeters?)
- Correlation between two measurements reasonable, energy loss in calorimeters as expected

Global cosmics: accumulate data for calibration and alignment and get better prepared for 2009 collisions

Cosmic-ray data with solenoid on: look at 200k tracks going through pixels

Cosmic-ray data with solenoid on: look at 2M tracks going through barrel TRT





Cosmic-ray data particularly useful for tracking detectors:

- **Calibration of gaseous detectors (e.g. high threshold for TRT)**
- **Alignment of inner detector and muon spectrometer systems (e.g. pixels)**

Search for electrons from ionisation in 2008 cosmic-ray data

Input for analysis: 3.5 million events with high-level trigger (L2) track candidate reconstructed online in barrel inner detector. Most tracks are only measured in TRT because of geometrical acceptance.

After filtering for electromagnetic cluster candidates with transverse energy above ~ 3 GeV and with a loose track match in ϕ (pointing downwards), about 11 000 candidates remain.

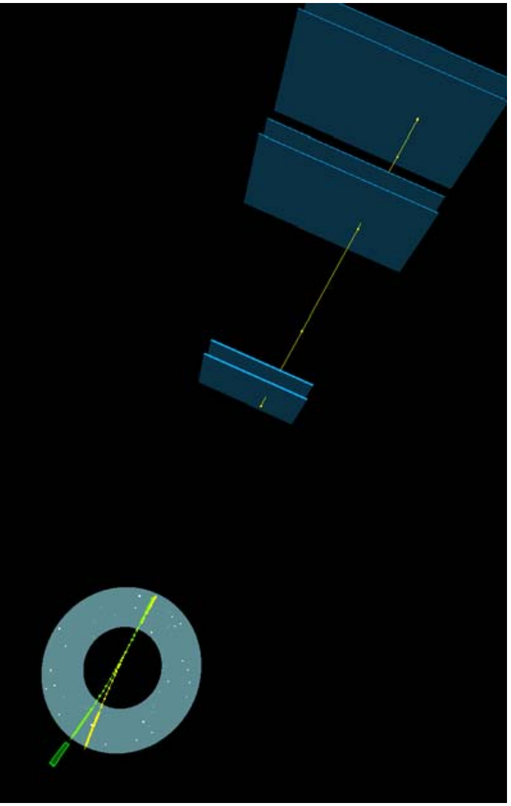
These are required to satisfy medium electron cuts (lateral shower shapes in first and second layers of EM calorimeter and track-cluster matching in ϕ for tracks with at least 25 TRT hits) and are then split into two categories:

a) a sample consisting of 1229 muon bremsstrahlung candidates, with only one track reconstructed in the barrel inner detector

b) a sample consisting of 85 ionisation electron candidates, with at least two tracks reconstructed in the barrel inner detector

Search for electrons from ionisation in 2008 cosmic-ray data

How can electrons occur in cosmic events?



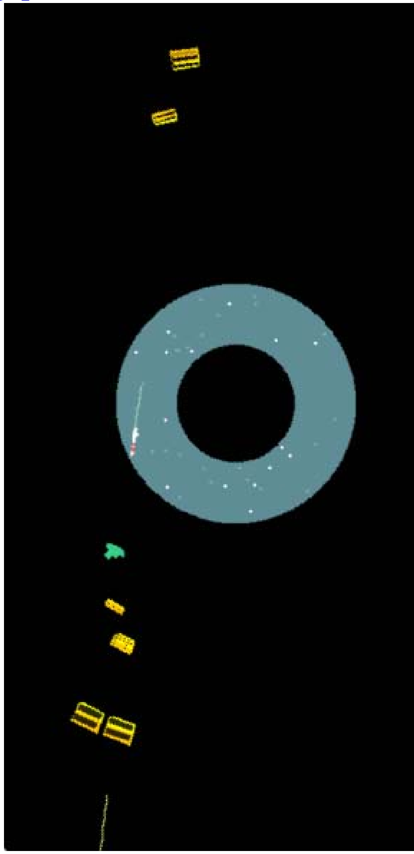
Ionisation (signal)

1) Produced by ionisation in tracker volume (δ-rays)

2) Faked by overlap of brem photon energy and muon track

Difference will be in track multiplicity in tracker

One might also expect a certain number of photon conversions and a very few electrons from muon decay



Muon brem (background)

Back-of-the-envelope expectation for δ-electrons from ionisation of atoms in Inner Detector volume:

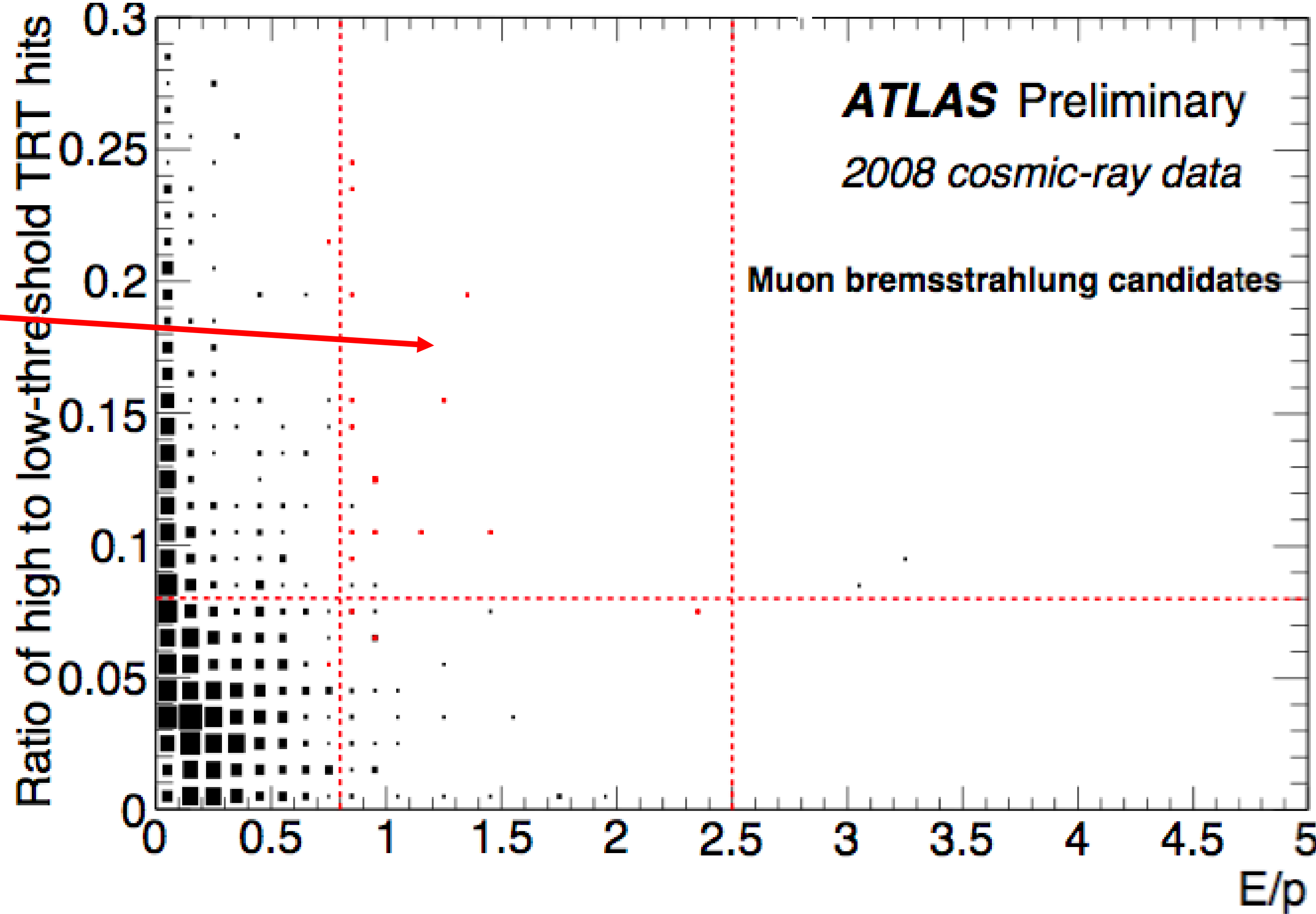
- Probability for production of δ-ray of ~ 100 keV in Argon (gas) is 10^{-3} per cm
- Extrapolation to ~ 1 X_0 and 1 GeV yields again ~ 10^{-3}
- In cosmic MC, 207 true electrons with E > 1 GeV (40000 cosmic muons): ~ $5*10^{-3}$

Ratio of high to low-threshold TRT hits versus E/p for bremsstrahlung candidates

The red boxes correspond to candidates satisfying additional cuts defined for standard tight high-p_T electron identification in ATLAS at $\eta \sim 0$. These cuts are p_T and η-dependent and the ones applied to most of the events are illustrated by the dashed red lines in slides 3 and 4: $0.8 < E/p < 2.5$ and high to low-threshold TRT hit ratio > 0.08 (indicating the detection of transition radiation produced only by relativistic particles).

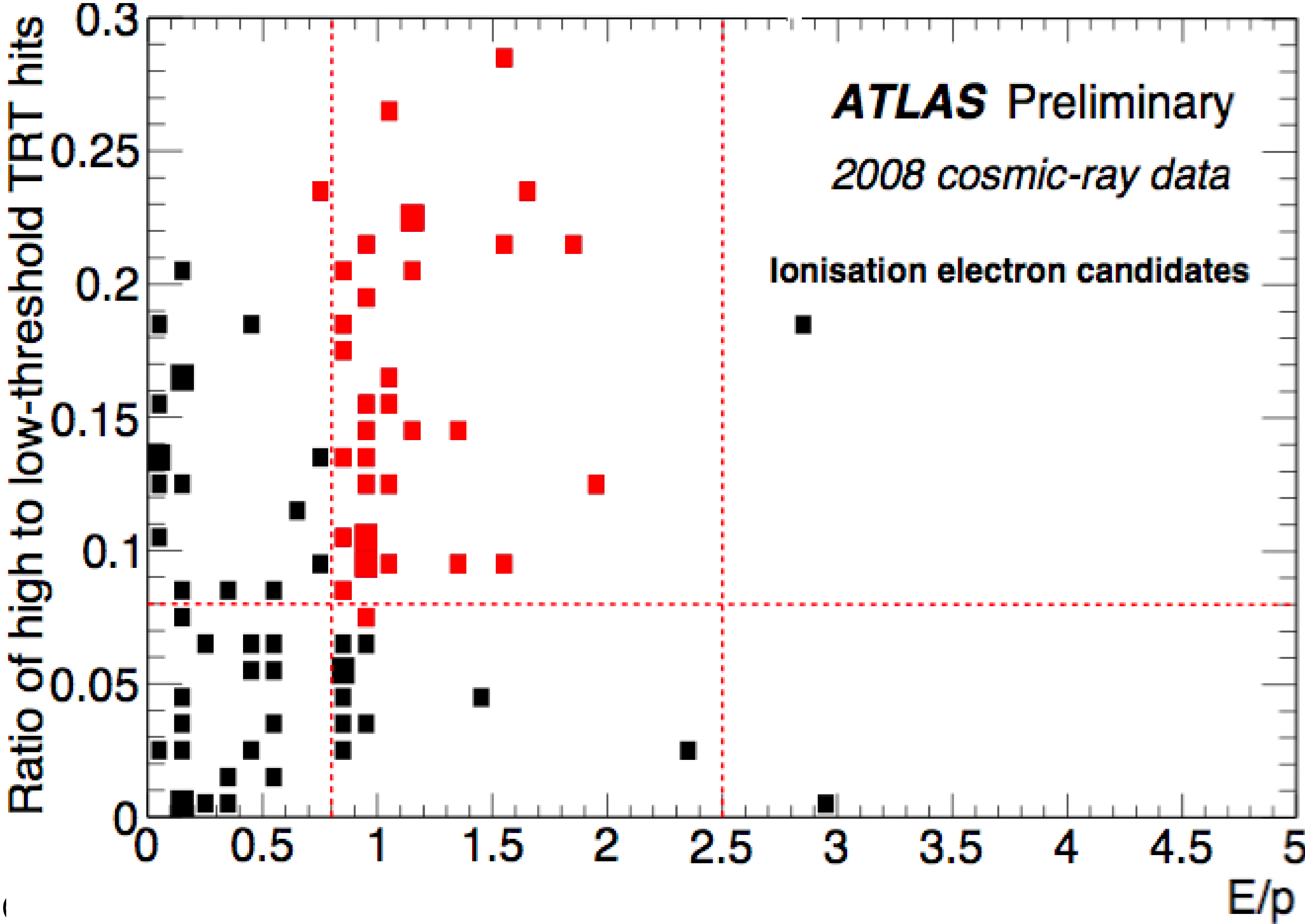
Area where signal from electrons is expected

Here see only 19/1229 candidates



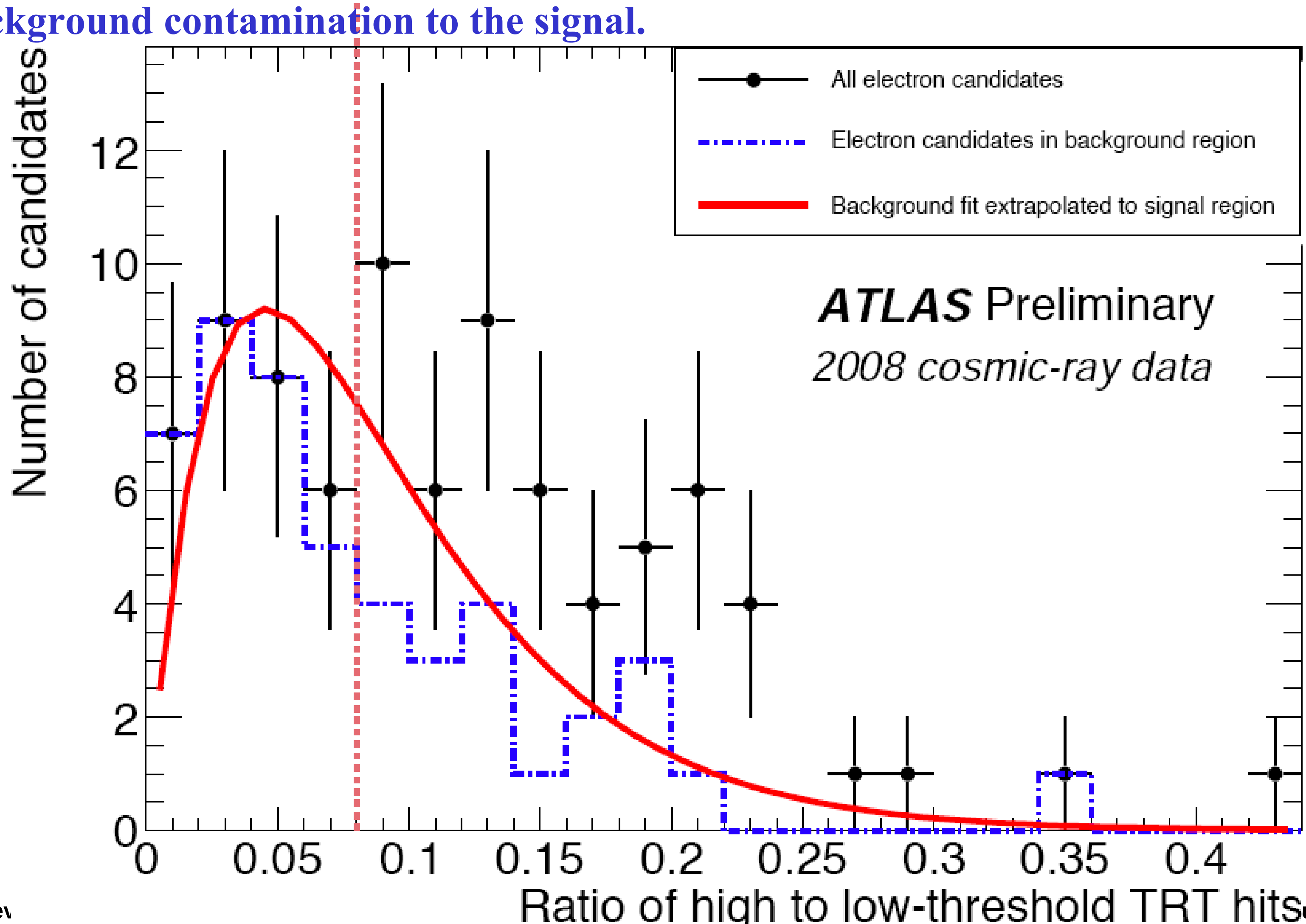
Ratio of high to low-threshold TRT hits versus E/p for ionisation candidates

Here see 36 out of 85 candidates in signal region!



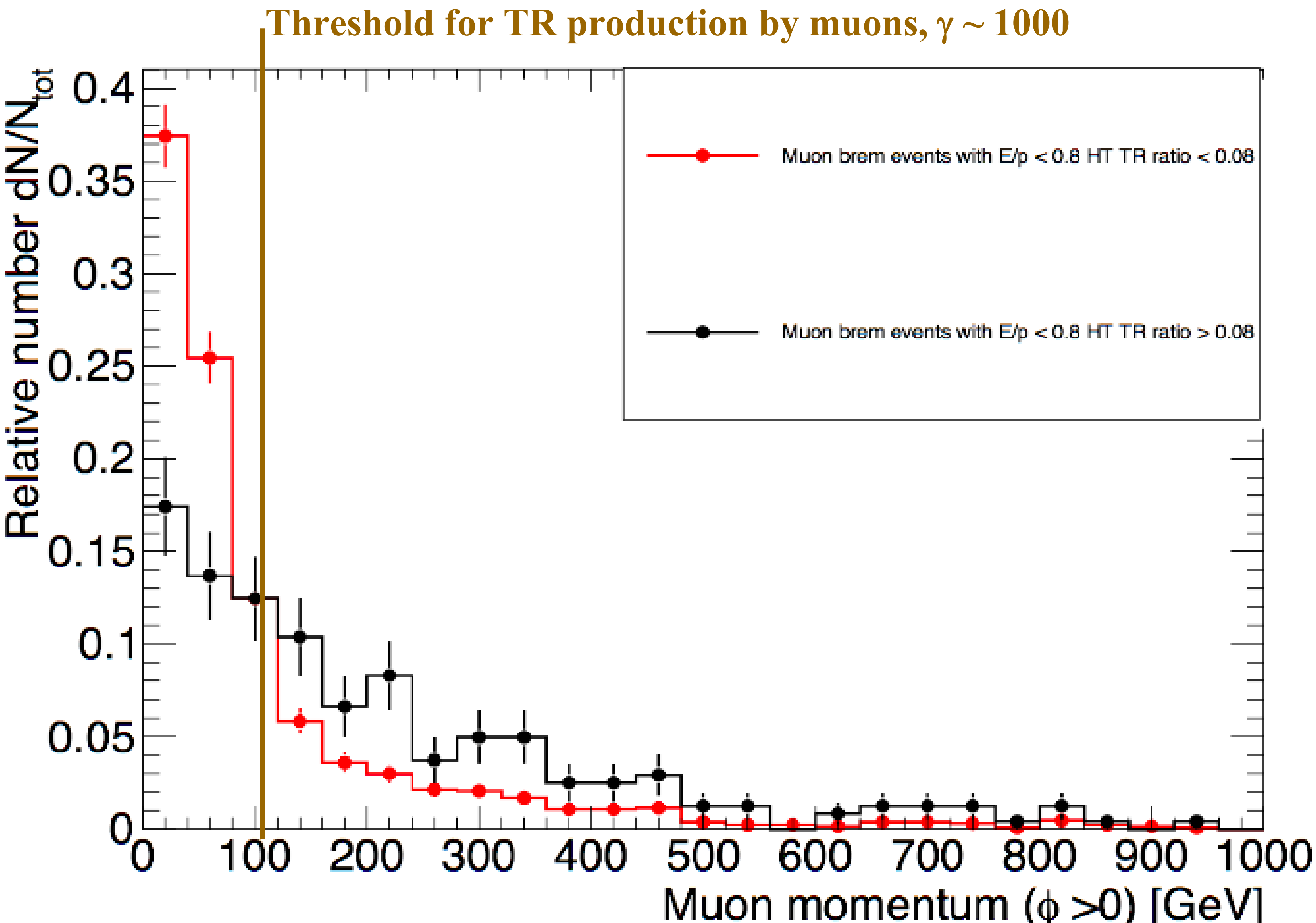
Distribution of the ratio of the high to low-threshold TRT hits for the 85 ionisation electron candidates (black) and for the 49 candidates failing the final signal criteria (blue)

The red curve is the projection of a 2d binned maximum likelihood fit to the ionisation sample excluding the signal candidates. This fit is used as one of the methods to estimate the background contamination to the signal.



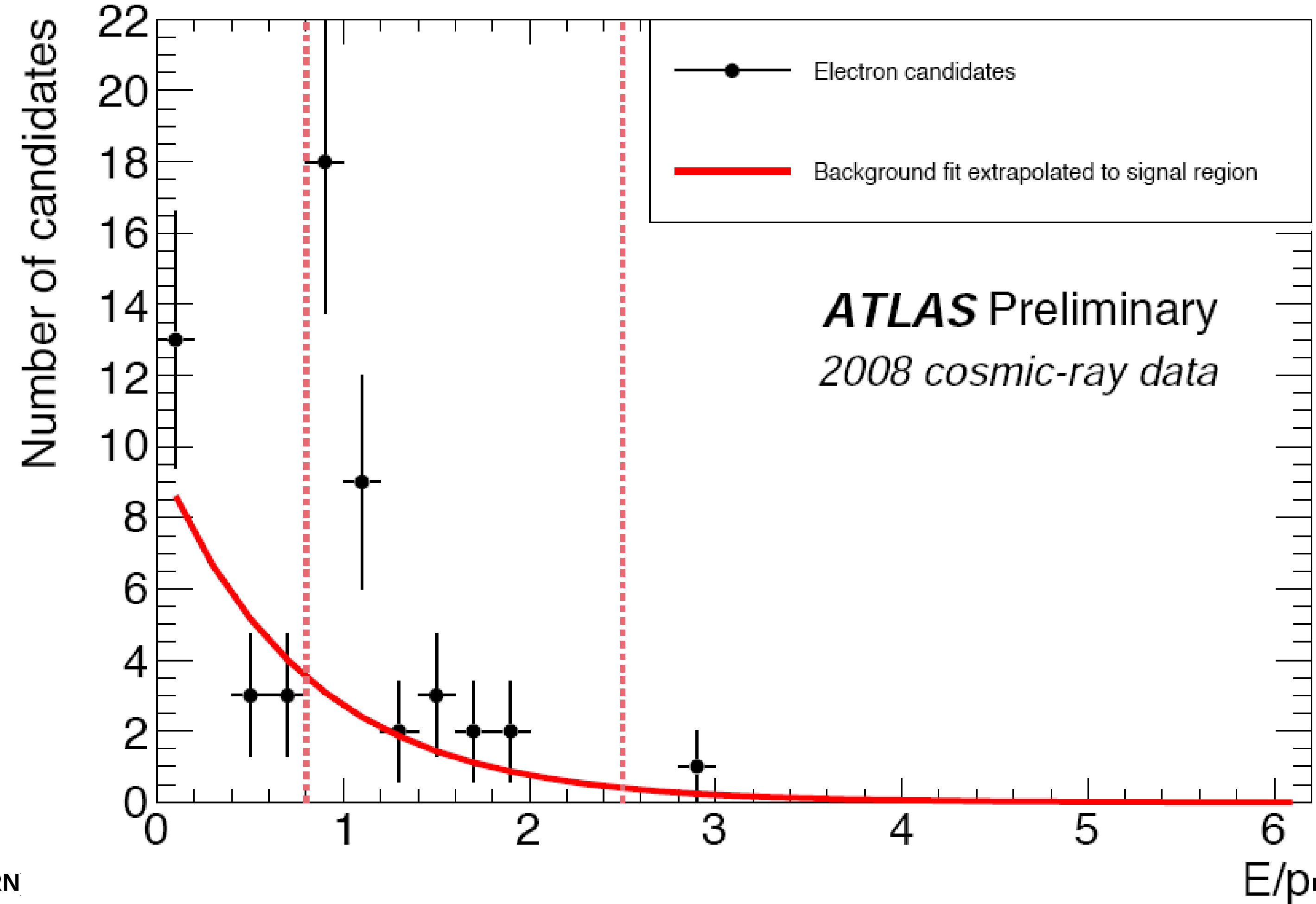
What are the candidates with low E/p and high TR hit ratio?

Clearly, there is a correlation between the TR hit ratio and the muon momentum



Distribution of E/p for the electron candidates after applying the cut on the ratio of high to low-threshold TRT hits.

The red curve shows the background projected on the E/p distribution. The background under the signal is estimated to be (8.7 ± 3.1) events with this method.



A second independent method to estimate the background uses the measured ratio of negatively to positively charged muons coupled to the fact that the electron ionisation signal should contain no positrons:

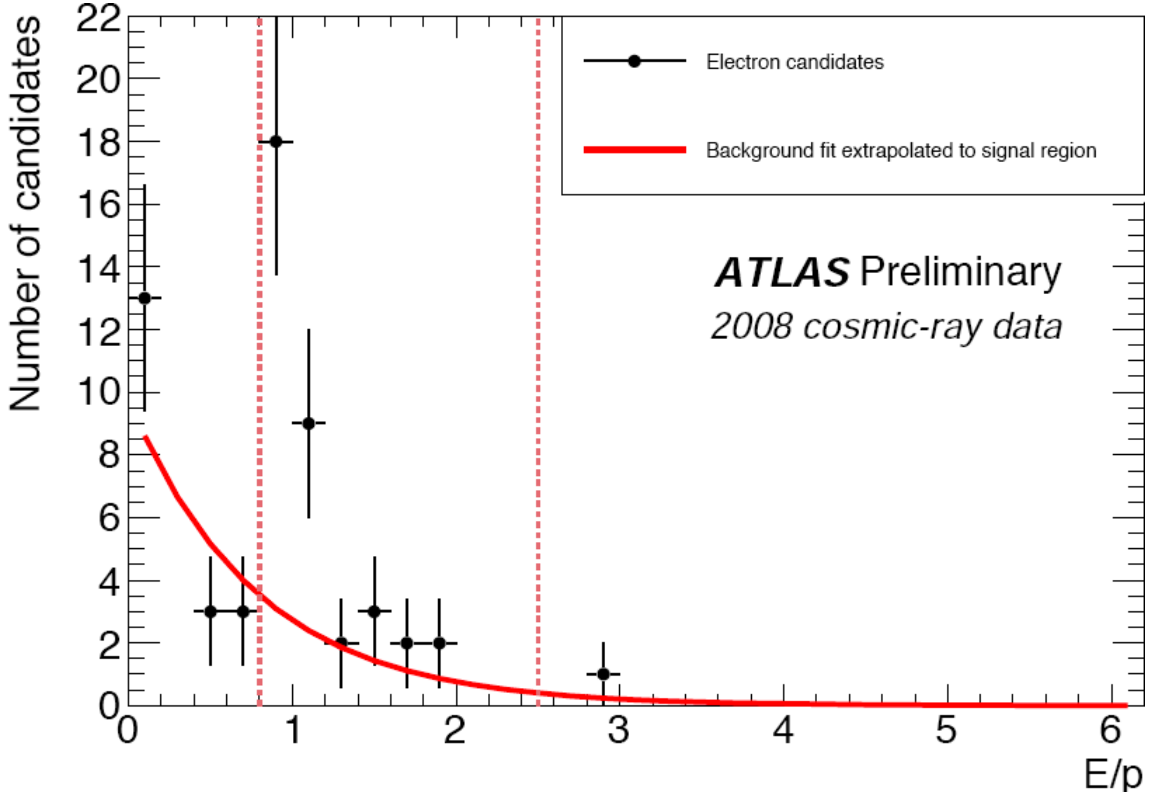
- the μ^-/μ^+ ratio obtained from the muon bremsstrahlung sample is ~ 0.70

-out of the 36 signal candidates, four have a positive charge, leading to an expectation of (6.8 ± 3.4) background events in the signal sample

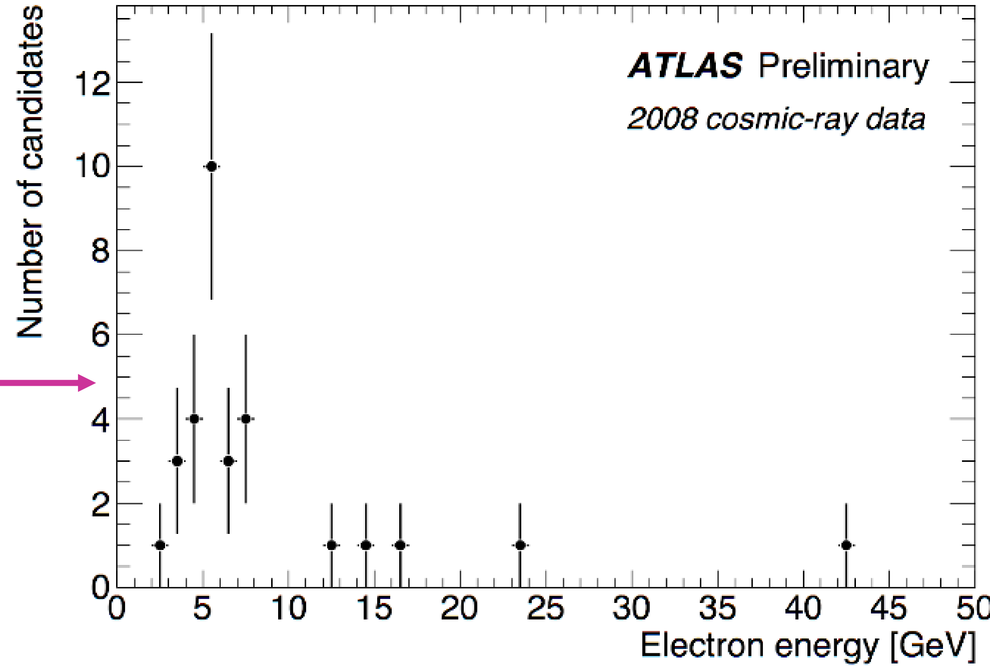
Good agreement with the background estimate from the first method.

The final sample consists of the 32 candidates with measured negative charge.

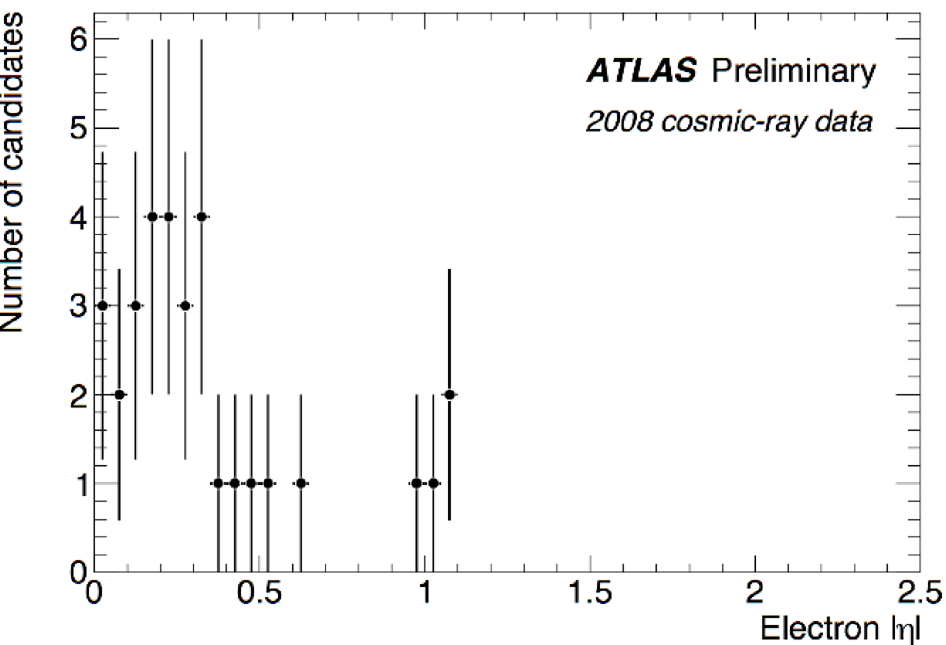
This is the first observation of electrons in the ATLAS detector !



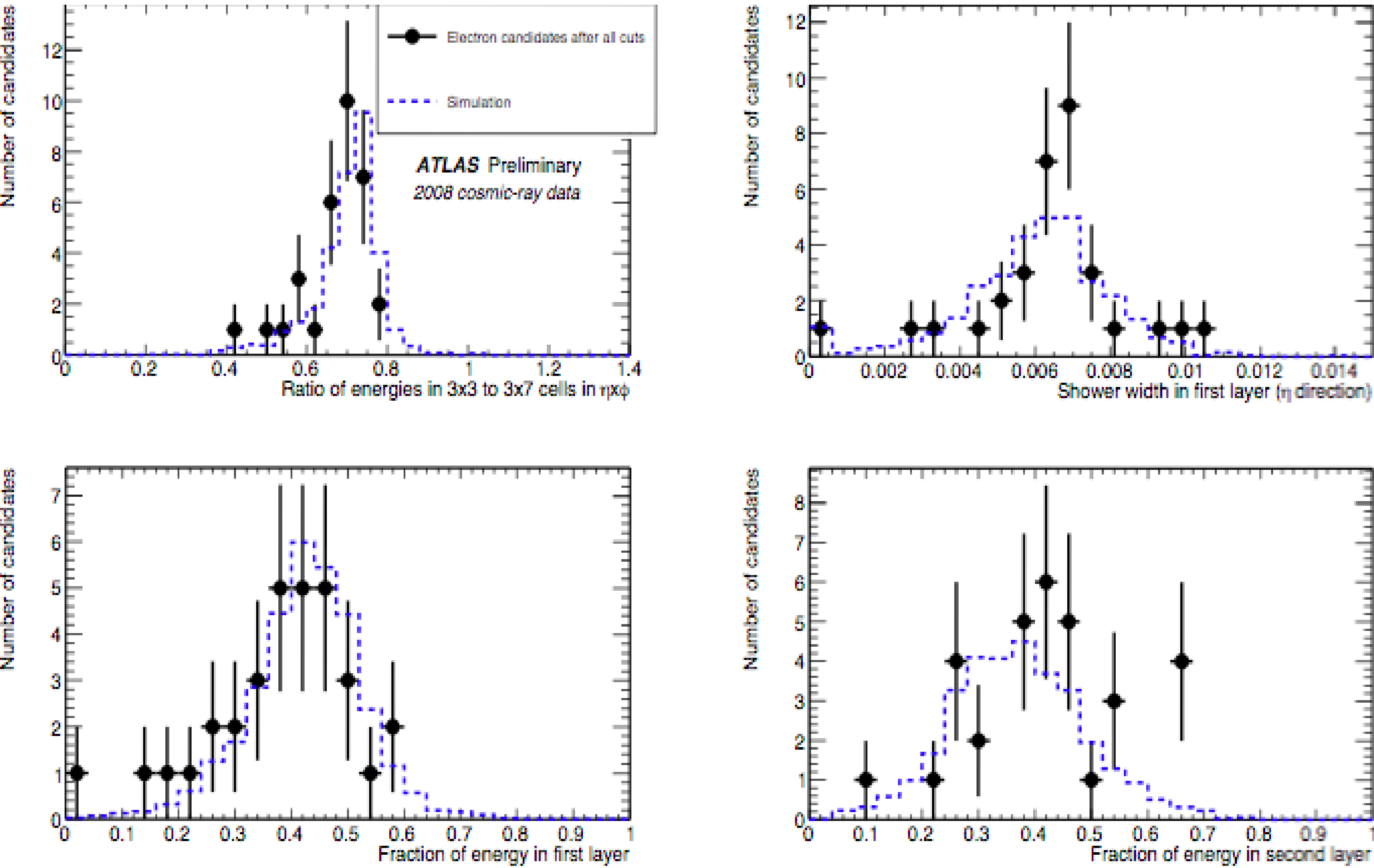
Distribution of the energy measured in the electromagnetic calorimeter for the final 32 ionisation electron candidates.

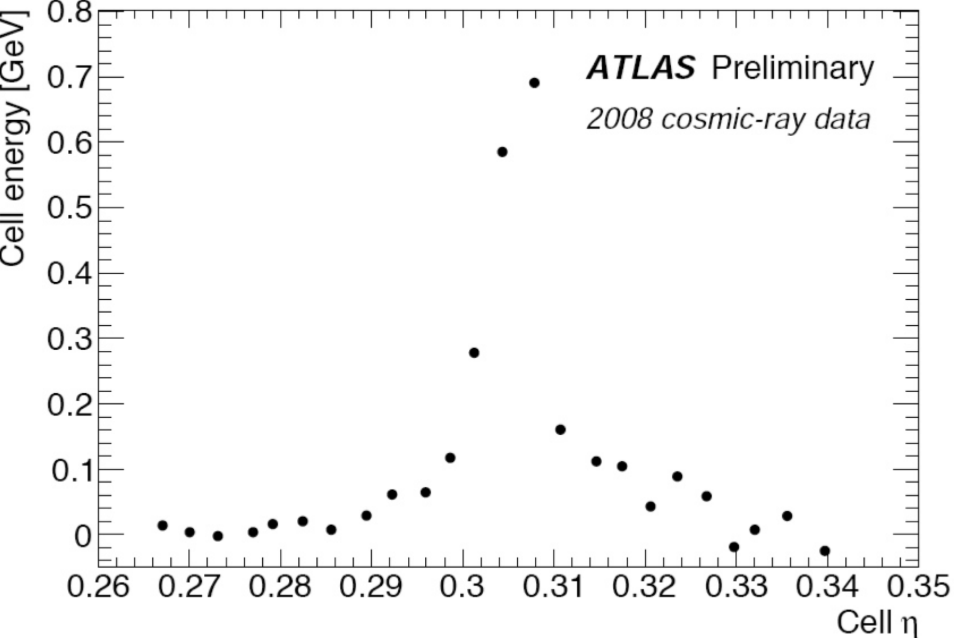


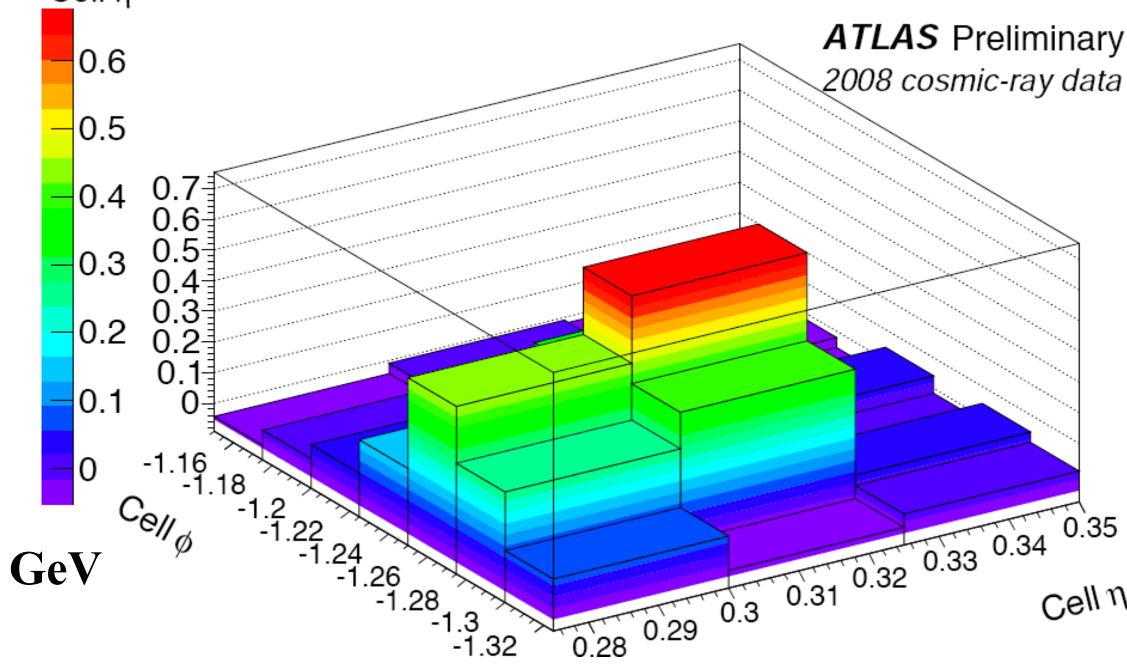
As expected for electrons from ionisation in the inner detector volume, the energy spectrum shows an accumulation at low energies, near the seed threshold of 3 GeV (in transverse energy) used to build the electromagnetic clusters.



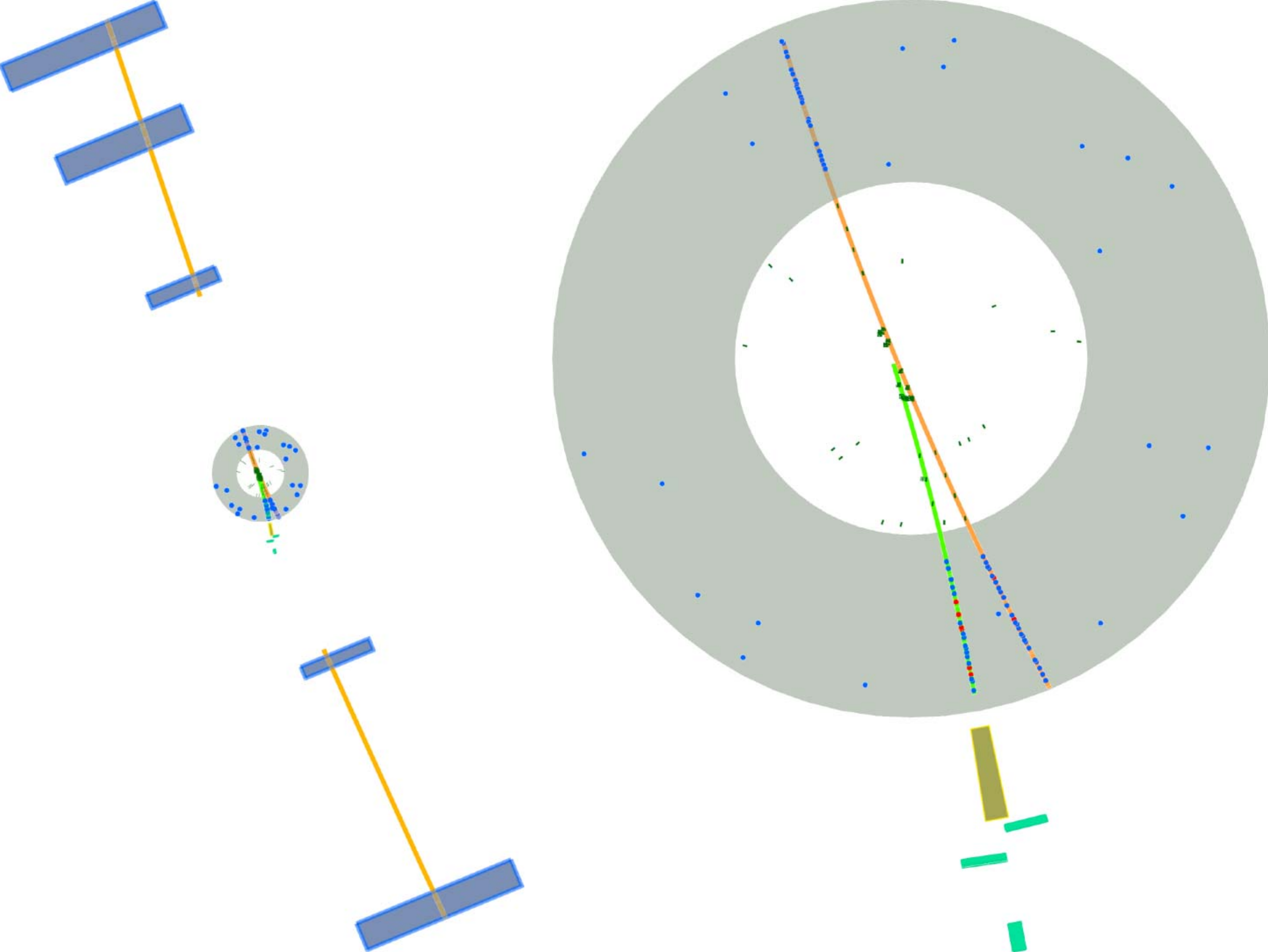
Shower shape variables for electron candidates compared to simulation

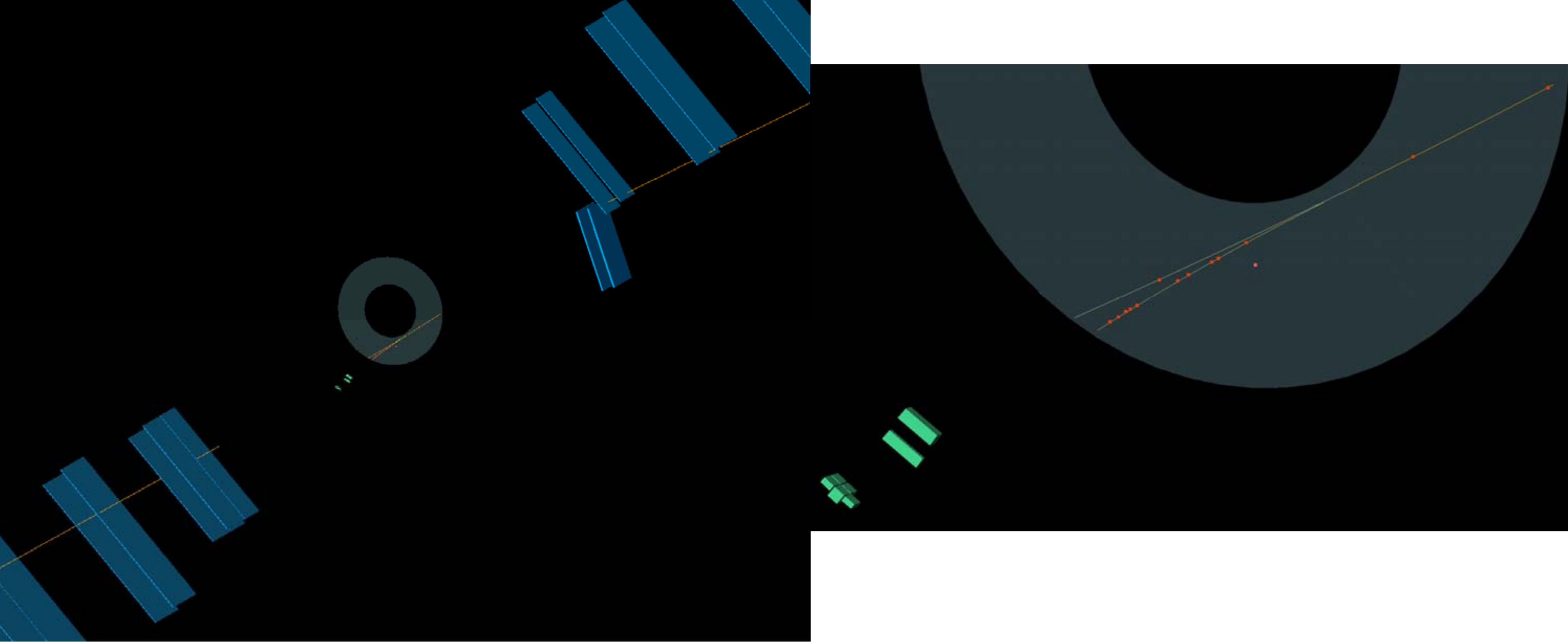






Energy deposits in the first layer along η (left) and in the second layer in η versus ϕ (right) for one of the electron candidates.





Event display of an electron candidate from ionisation in the inner detector volume. The incoming and outgoing muons are clearly seen on the left-hand plot, as reconstructed in three muon stations each (orange tracks) and in the inner detector (yellow track).

The zoomed view on the right shows the electron track and its associated electromagnetic cells (in green). The red dots indicate the measured high-threshold TRT hits, characteristic of transition radiation.

Quid des 25 prochaines années?

Faut-il craindre que la physique des hautes énergies soit une espèce en voie de disparition à cause de son gigantisme et de ses échelles de temps?

- **Certains aspects de notre science deviennent difficiles à contrôler à l'échelle humaine. Cela fait 20-25 ans que certains travaillent sur le projet LHC. La plupart de l'analyse des données sera faite par des jeunes qui n'ont aucune idée de ce qui compose les 7000 tonnes de l'expérience ATLAS. Peu se souviennent qu'en 1988 encore, la plupart des physiciens considéraient que ce serait impossible de construire un détecteur de traces chargées qui survive près du point d'interaction.**
- **Les enjeux sont majeurs: on ne peut se permettre de réaliser des expériences qui ne remplissent pas leurs objectifs à cette échelle, on ne peut plus se permettre d'approuver la construction de l'accélérateur suivant avant d'avoir digéré les résultats obtenus auprès de celui qui est actuellement en opération. Ces résultats nous indiqueront le chemin à suivre, du moins peut-on l'espérer…**
- **La théorie n'a pas été nourrie par des résultats expérimentaux lui ouvrant de nouvelles perspectives depuis trop longtemps.**


Quid des 25 prochaines années?

C'est pourquoi le défi du LHC est si passionnant! Une bonne part de l'avenir de notre discipline dépendra de la moisson de physique obtenue à cette échelle d'énergie nouvelle. Que sera cette moisson: ordinaire ou extraordinaire? Seule la nature le sait.

N'oublions pas que la physique des particules expérimentale n'est pas composée uniquement par ses dinosaures! Elle a su se diversifier et s'ouvrir de nouveaux horizons dans des domaines au-delà de son champ d'action d'il y a 25 ans!