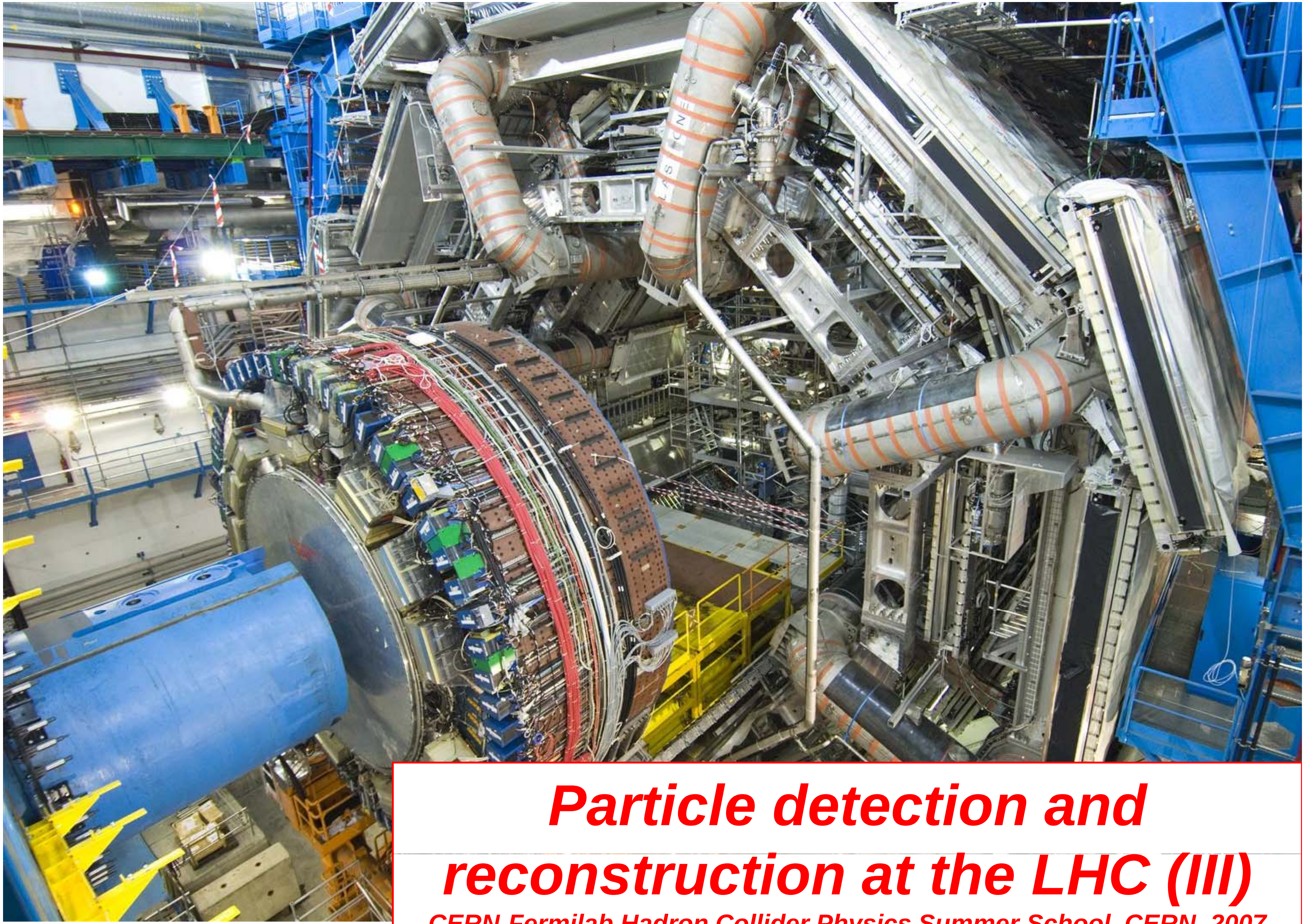


Particle detection and reconstruction at the LHC (III)

CERN-Fermilab Hadron Collider Physics Summer School, CERN, 2007

11th to 14th of August 2007 (D. Froidevaux, CERN)

Particle detection and reconstruction at the LHC (and Tevatron)

Lecture 1

- Historical introduction: from UA1/UA2 to ATLAS/CMS

Lecture 2

- Experimental environment, main design choices and intrinsic performance

Lecture 3

- Global performance overview, electrons and photons (and particle-ID in ALICE/LHCb)

Lecture 4

- Muons and hadronic jets

Not covered here

- Trigger, data acquisition and offline (see lectures by A. Yagil)
- Calibration, alignment and commissioning (see lectures by D.

ATLAS/CMS: from design to reality

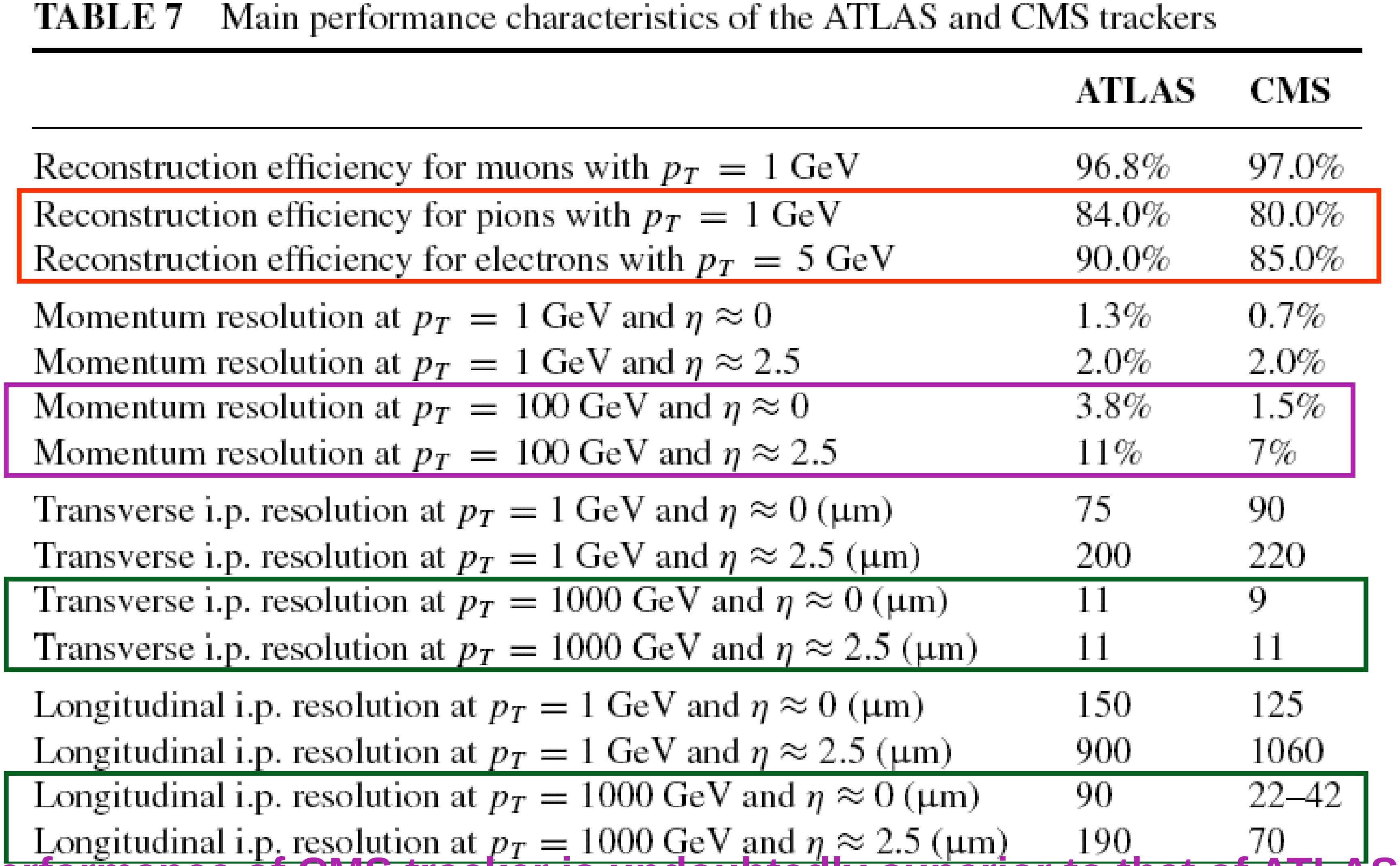


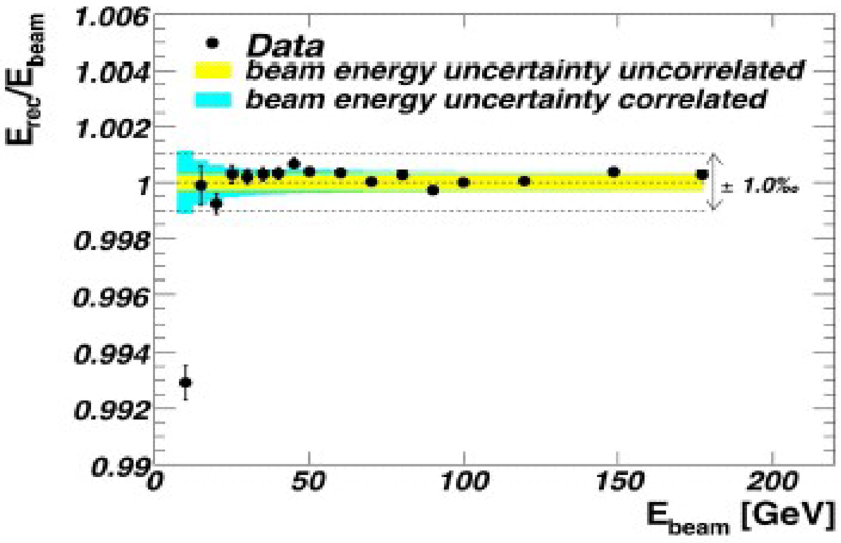
TABLE 7 Main performance characteristics of the ATLAS and CMS trackers

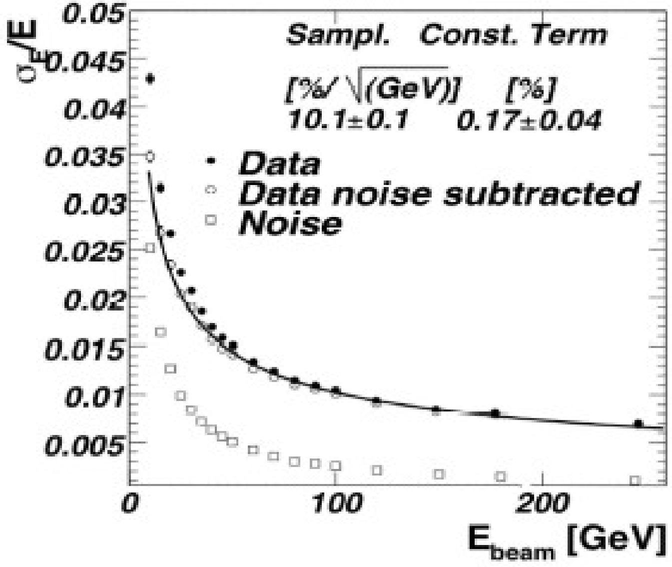
	ATLAS	CMS
Reconstruction efficiency for muons with $p_T = 1$ GeV	96.8%	97.0%
Reconstruction efficiency for pions with $p_T = 1$ GeV	84.0%	80.0%
Reconstruction efficiency for electrons with $p_T = 5$ GeV	90.0%	85.0%
Momentum resolution at $p_T = 1$ GeV and $\eta \approx 0$	1.3%	0.7%
Momentum resolution 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

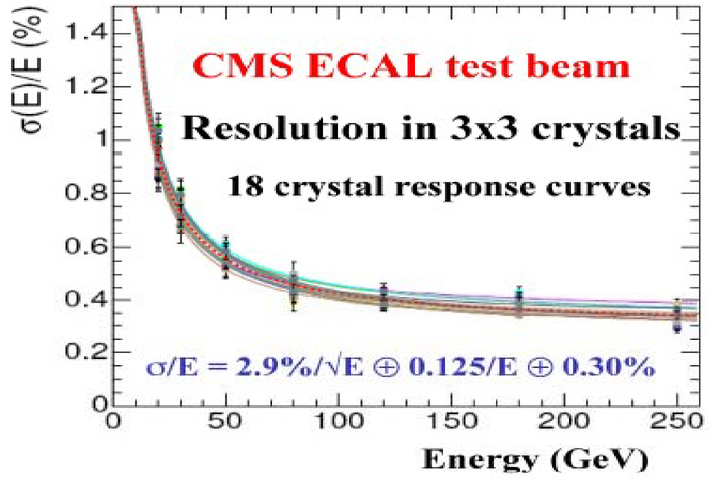
Performance of CMS tracker is undoubtedly superior to that of ATLAS in terms of momentum resolution. Vertexing and b-tagging performances are similar. However, impact of material and B-field already visible on efficiencies.

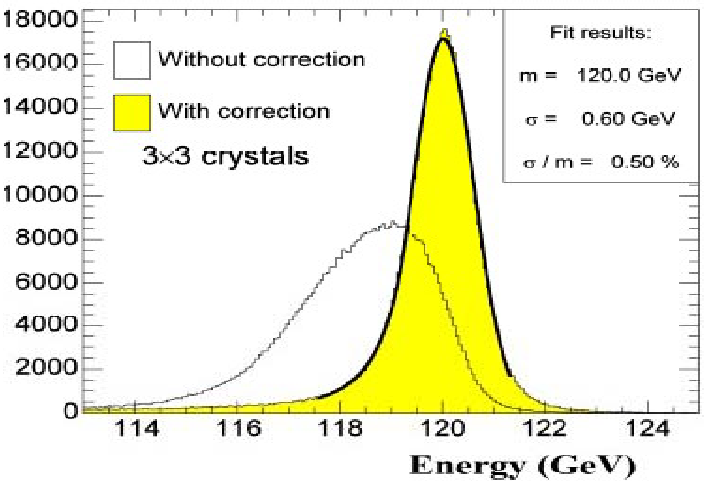
ATLAS/CMS: from design to reality

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







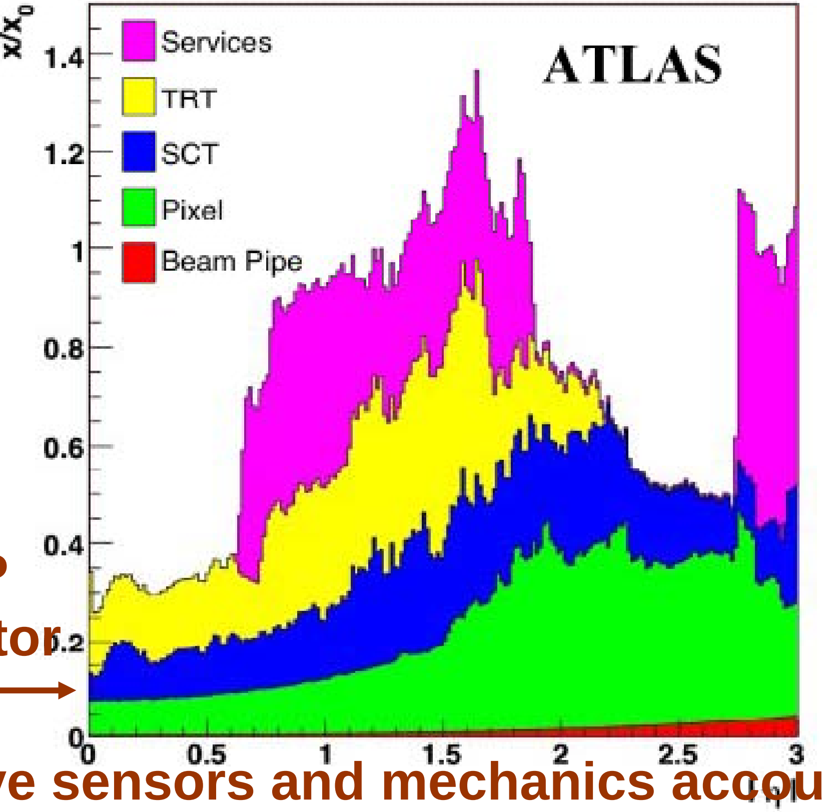


- Stand-alone performance measured in beams with electrons from 10 to 250 GeV

ATLAS/CMS: from design to reality

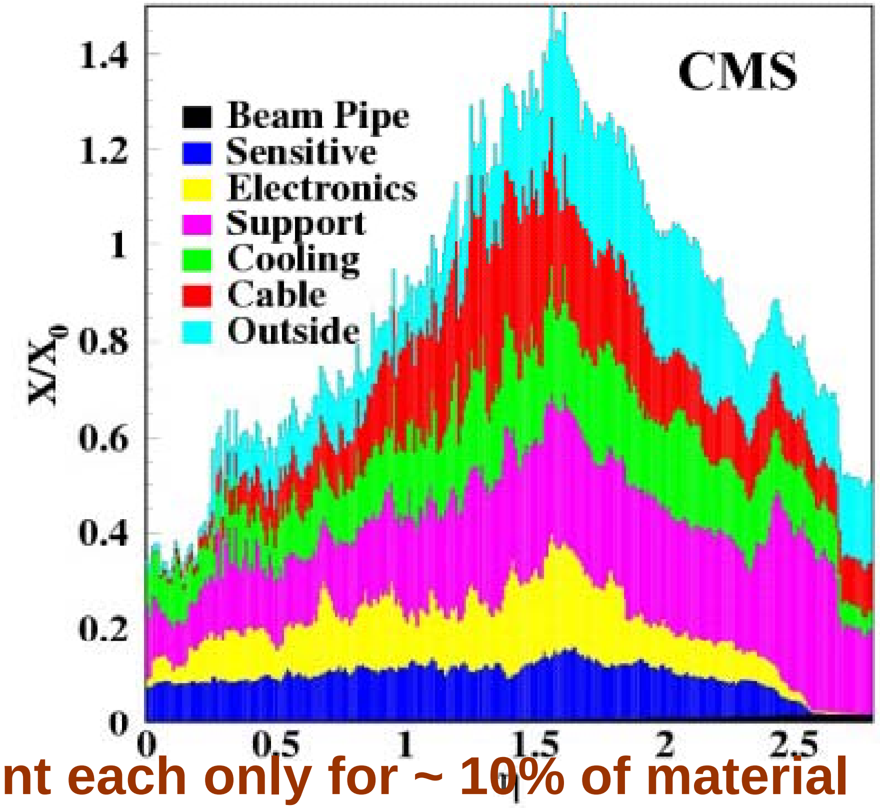
Amount of material in ATLAS and CMS inner trackers

Weight: 4.5 tons



LEP detectors →

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

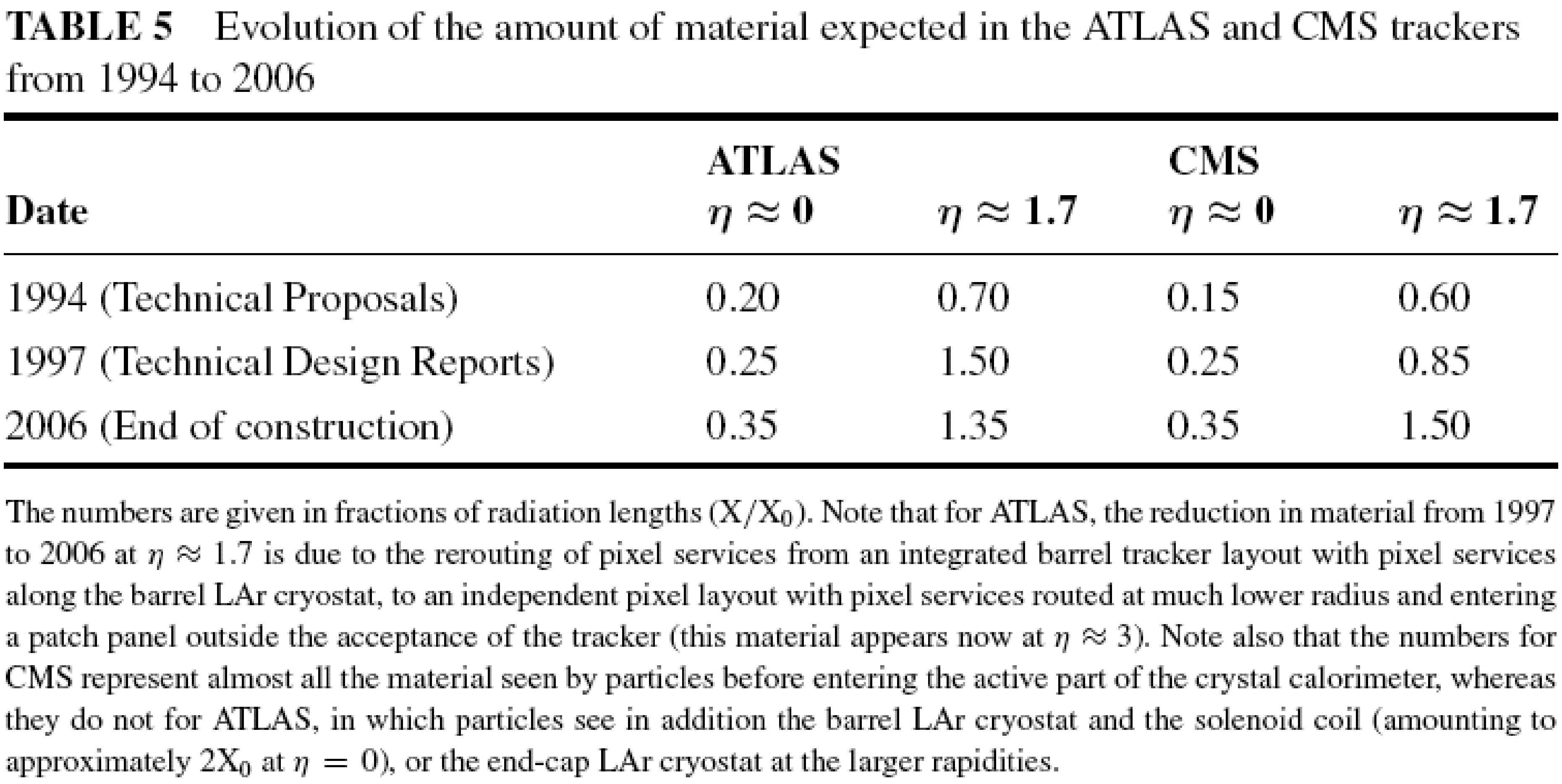


TABLE 5 Evolution of the amount of material expected in the ATLAS and CMS trackers from 1994 to 2006

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	1.35	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.

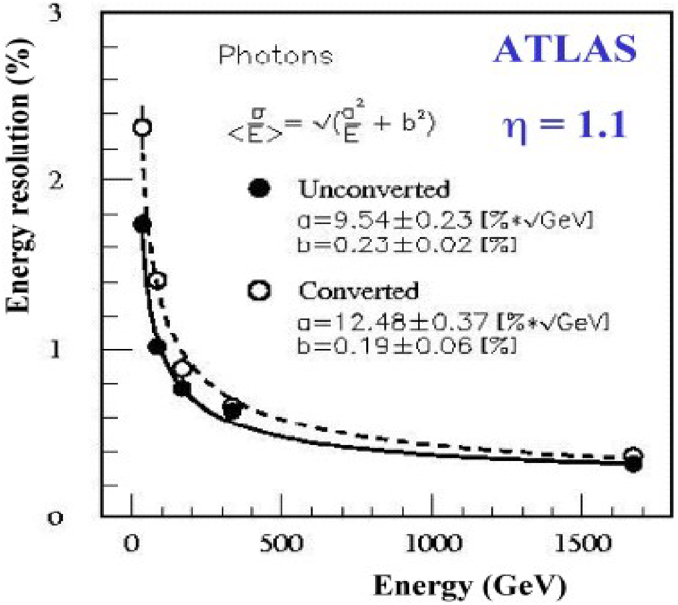
constr.)

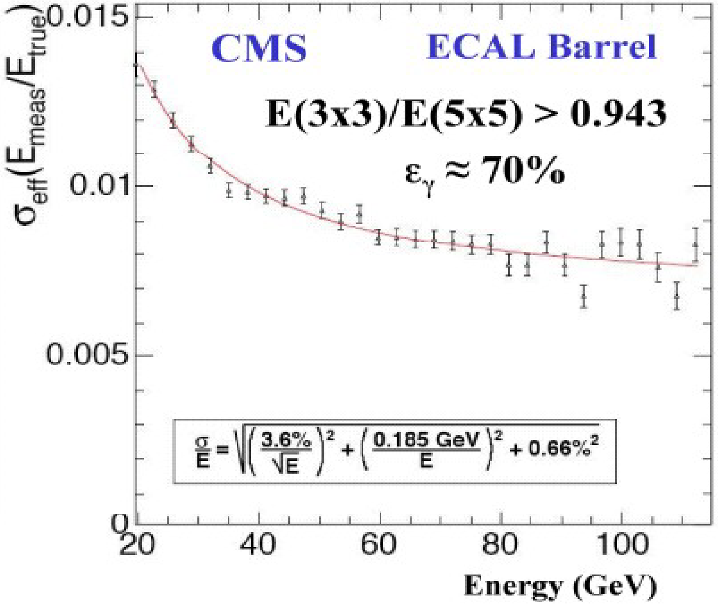
- **Electrons lose between 25% and 70% of their energy before reaching EM calo**
- **Between 20% and 65% of photons convert into e^+e^- pair before EM calo**
- **Need to know material to ~ 1% X_0 for precision measurement of m_W (< 10 MeV)!**

ATLAS/CMS: from design to reality

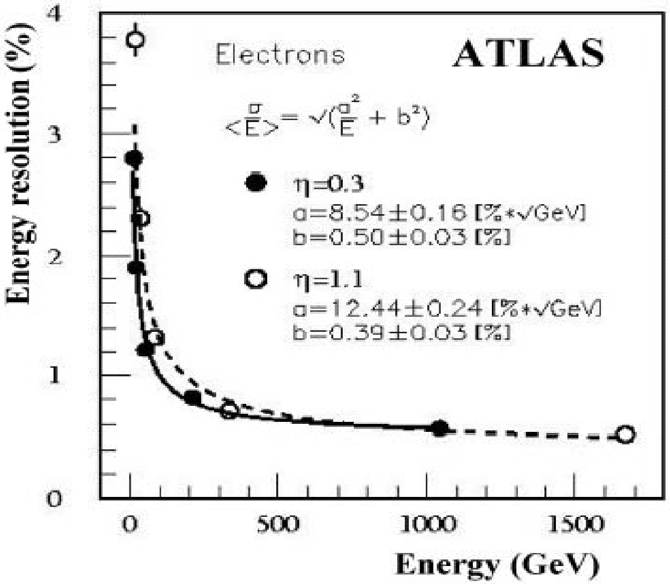
Actual performance expected in real detector quite

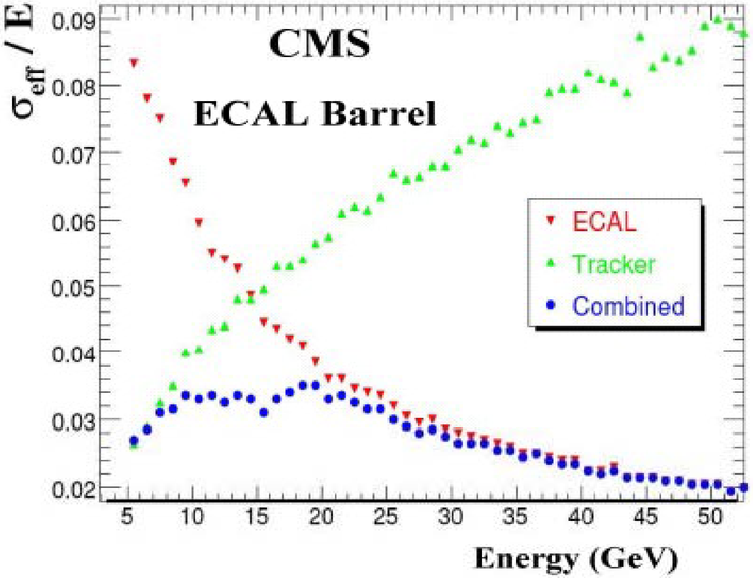
Photons at 100 GeV ATLAS: 1-1.5% energy resol. (all γ) CMS: 0.8% energy resol. (ε_γ ~ 70%)





Electrons at 50 GeV ATLAS: 1.3-2.3% energy resol. (use EM calo only) CMS: ~ 2.0% energy resol. (combine EM calo and tracker)





ATLAS/CMS: from design to reality

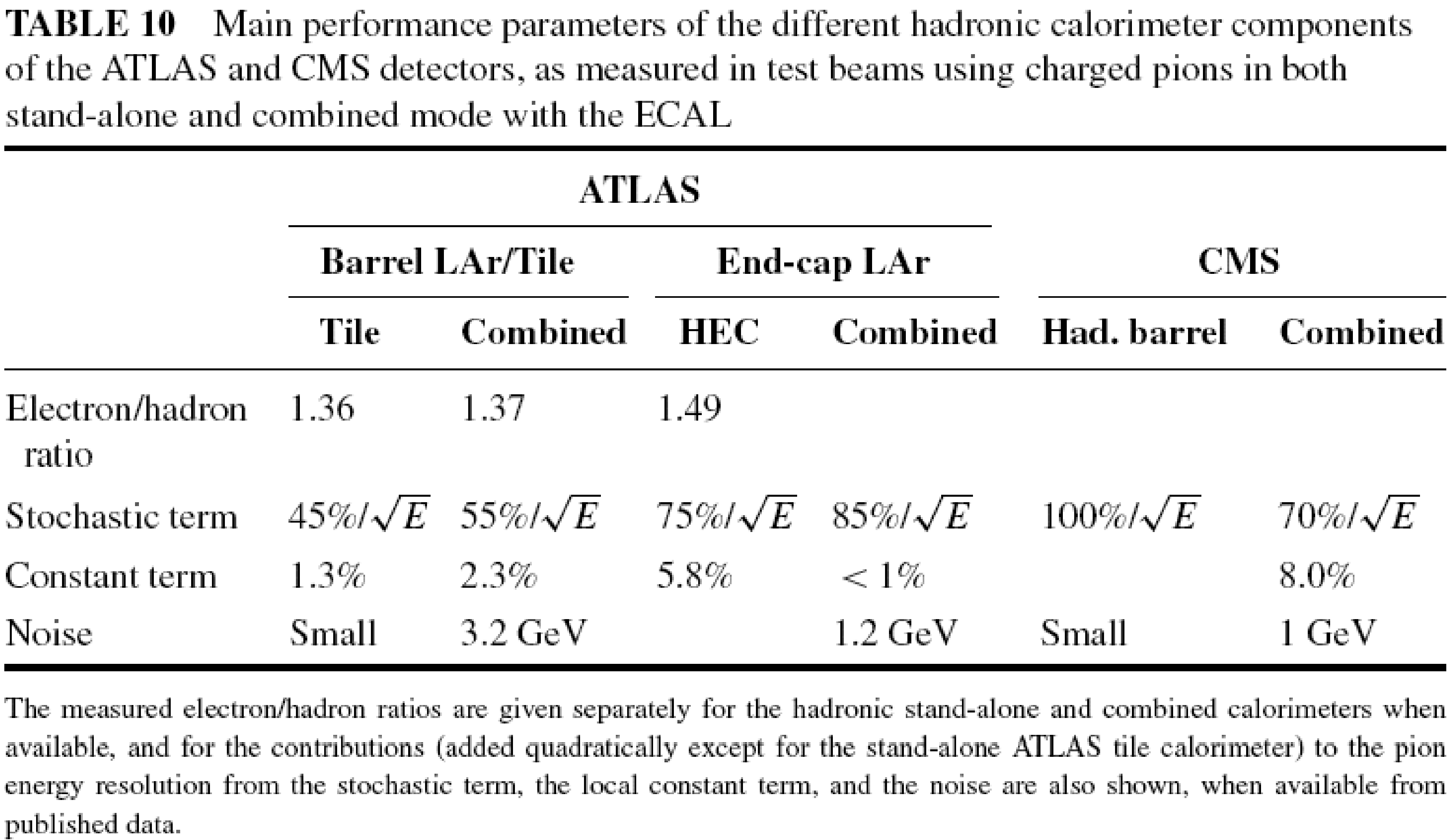


TABLE 10 Main performance parameters of the different hadronic calorimeter components of the ATLAS and CMS detectors, as measured in test beams using charged pions in both stand-alone and combined mode with the ECAL

	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

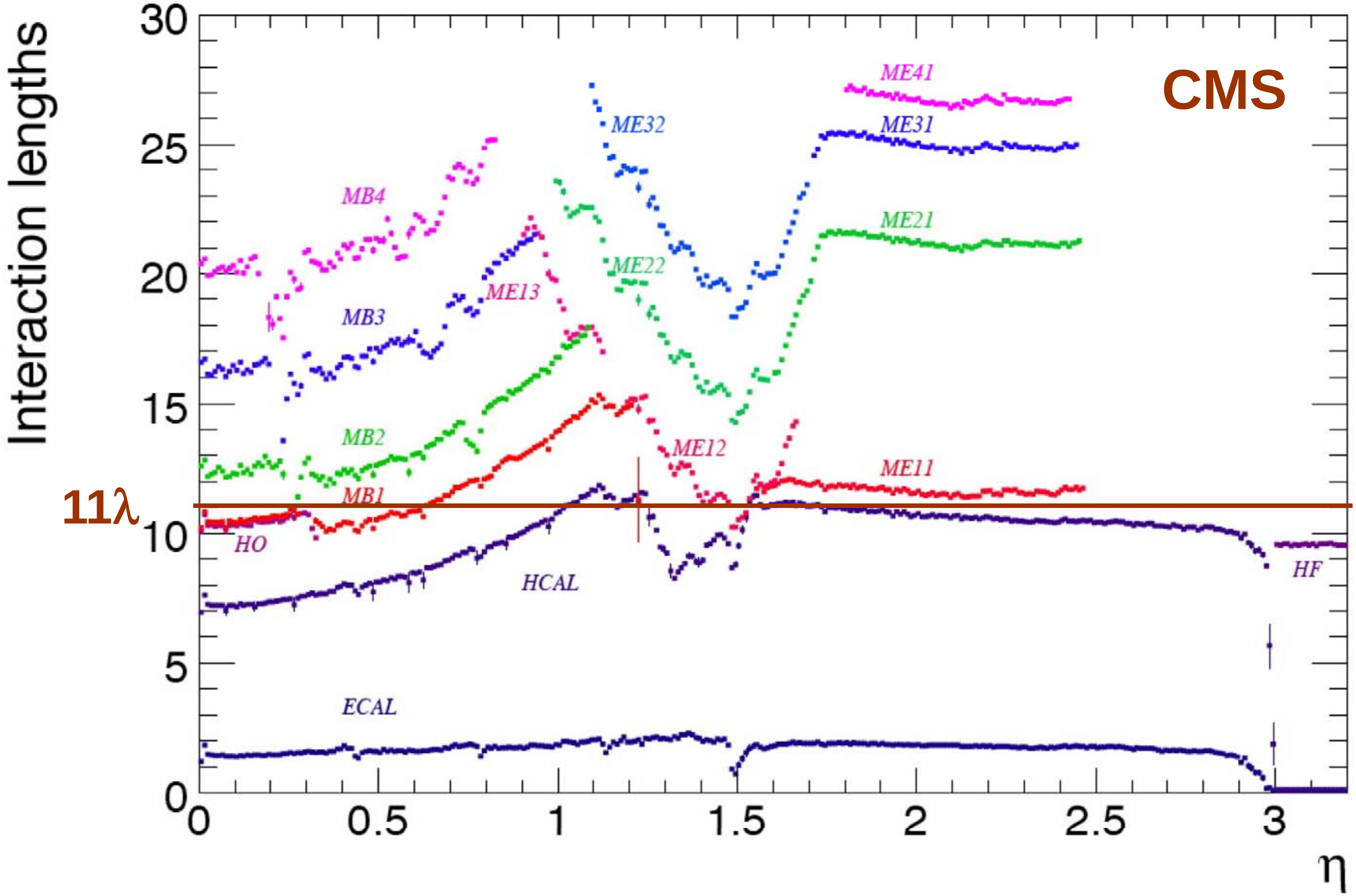
→ transverse energy flow fully measured with reasonable accuracy

→ no neutrino escapes undetected

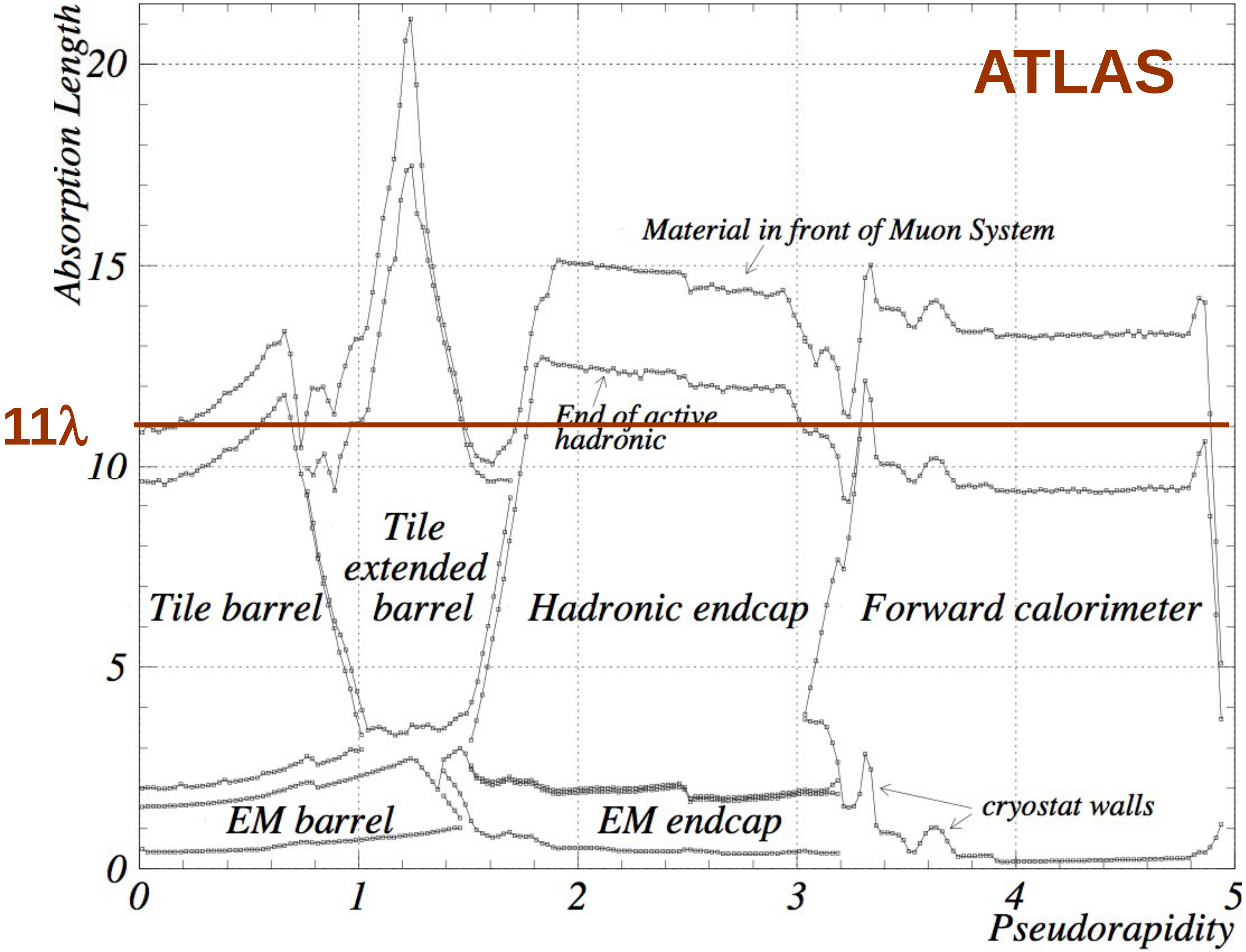
→ no human enters without major effort

(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!

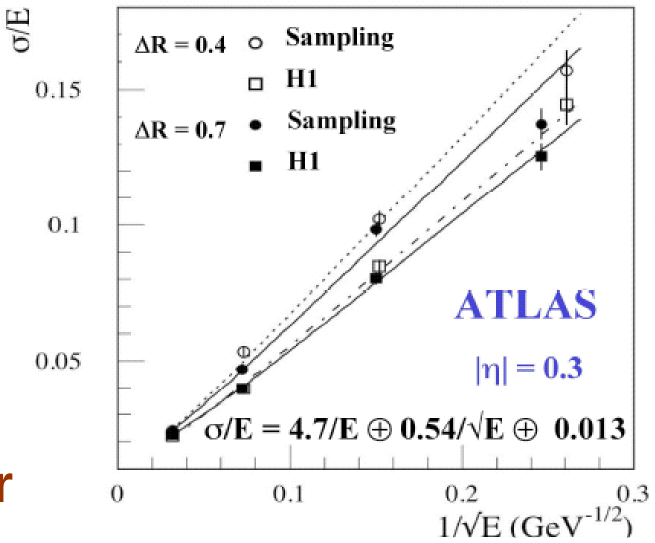
ATLAS/CMS: from design to reality

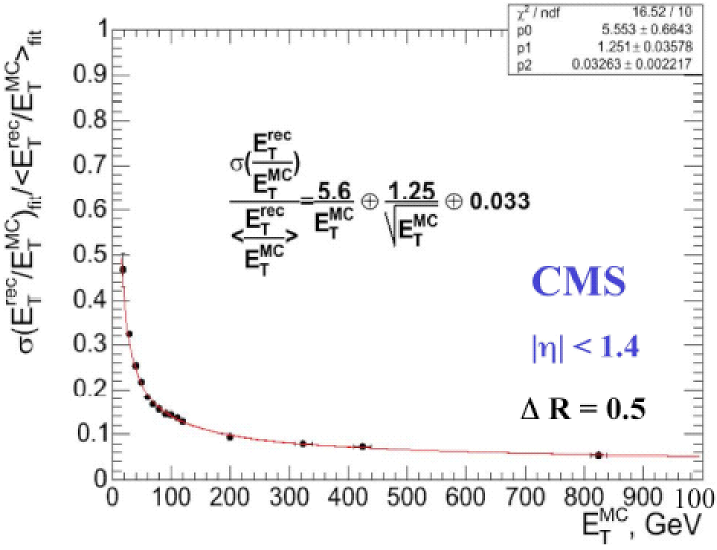
Biggest difference in performance perhaps for hadronic scale

Jets at 1000 GeV

ATLAS ~ 2% energy resolution

CMS ~ 5% energy resolution, but expect sizable improvement using tracks (especially at lower E)

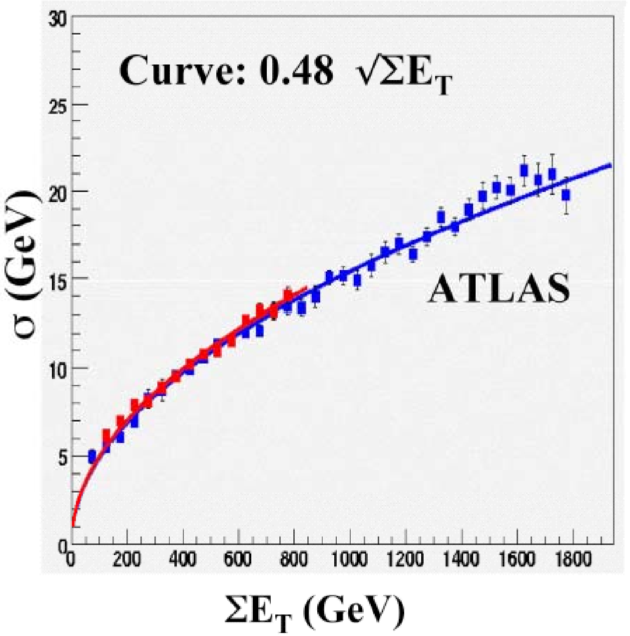


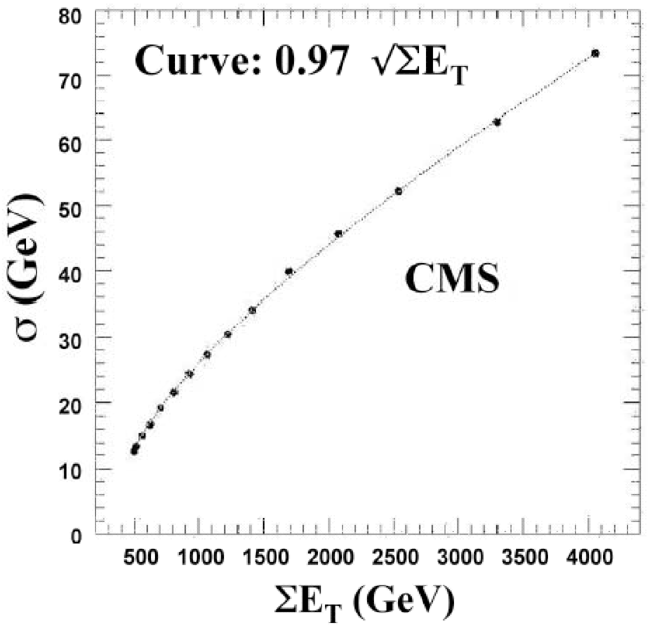


E_T^{miss} at ΣE_T = 2000 GeV ATLAS: σ ~ 20 GeV

CMS: σ ~ 40 GeV

This may be important for high mass H/A to ττ





D. Froidevaux, CERN

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 → bb)

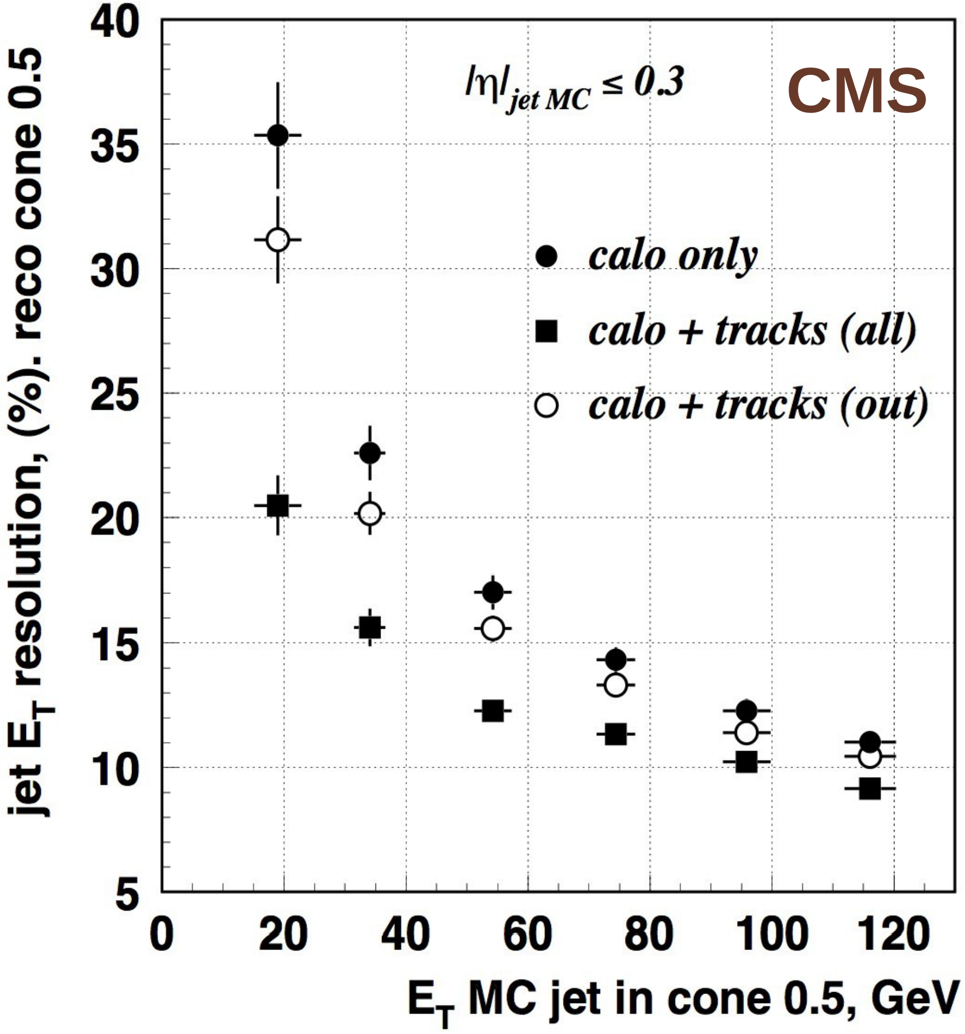
For E_T ~ 50 GeV in barrel:

ATLAS: ~ 10% energy resolution

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

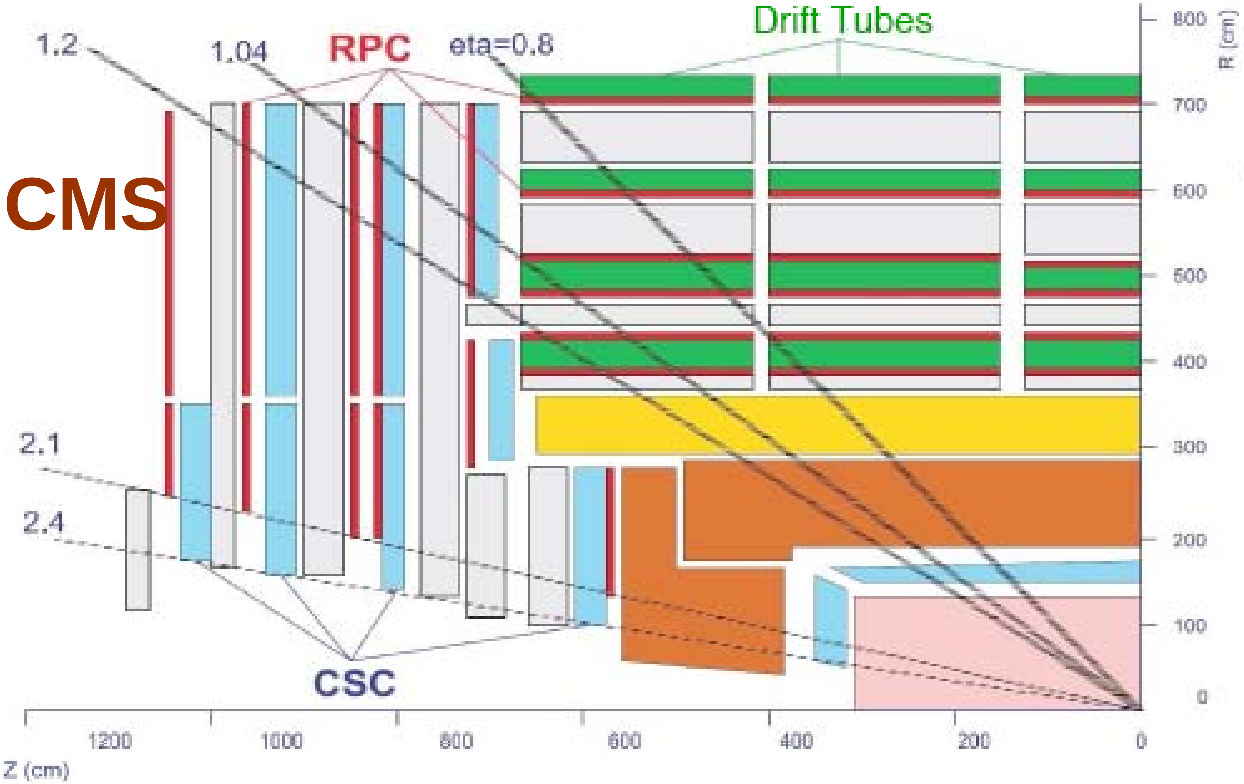
Some words of caution though:

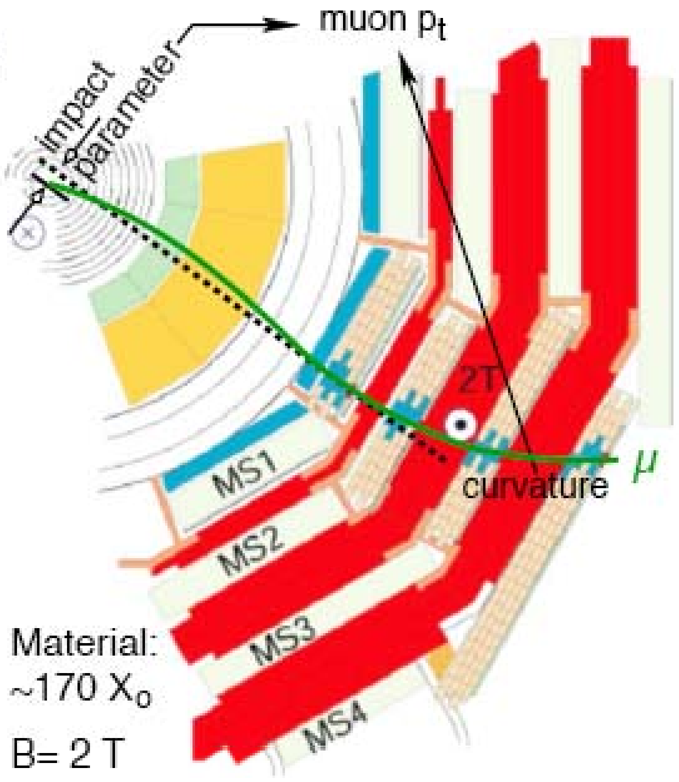
- danger from hadronic interactions in tracker material → non-Gaussian tails in response
- gains smaller at large η (material) and at high energy
- linearity of response at low



ATLAS/CMS: from design to reality

CMS

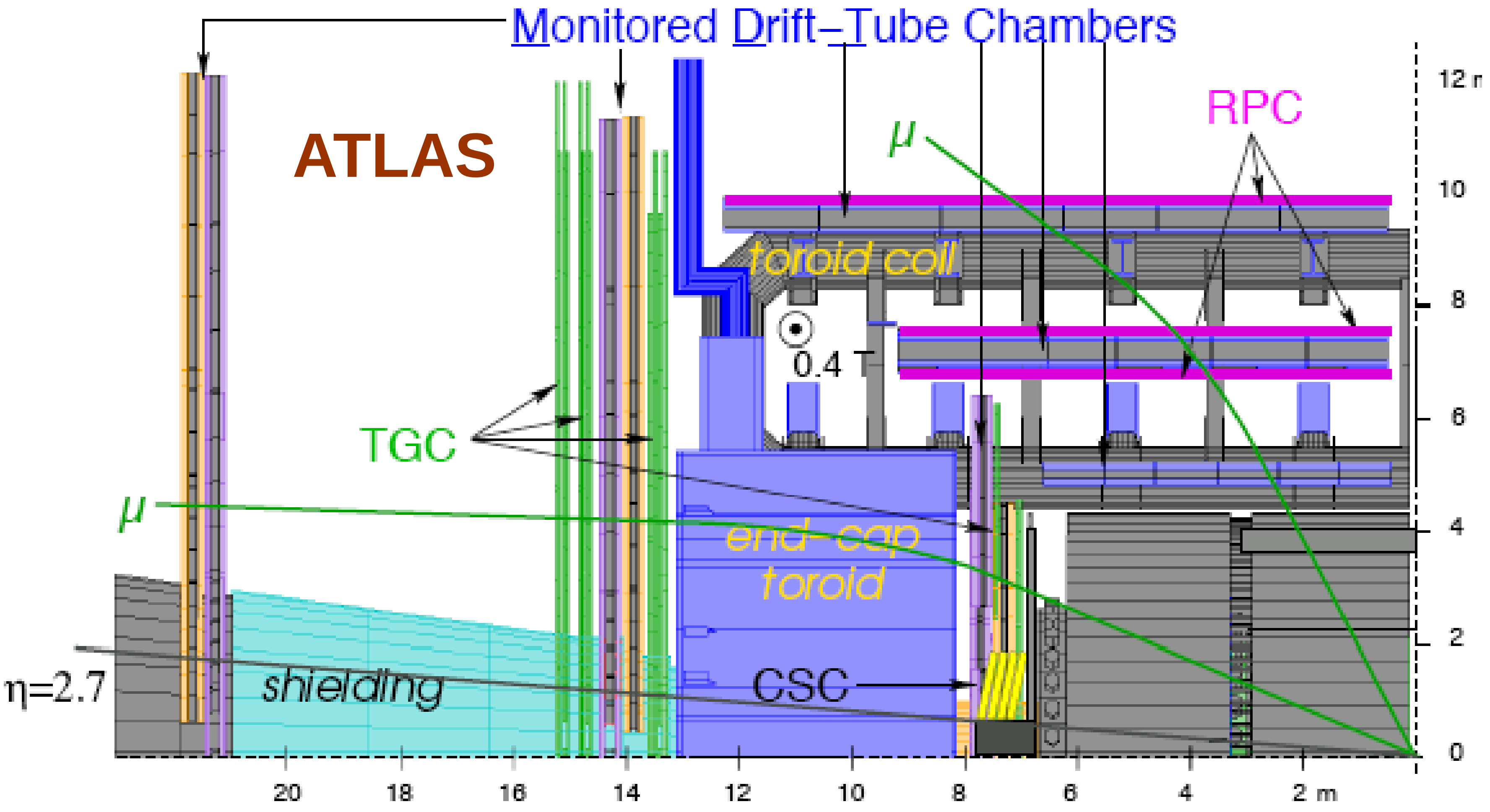




CMS muon spectrometer

- 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 (|η| > 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

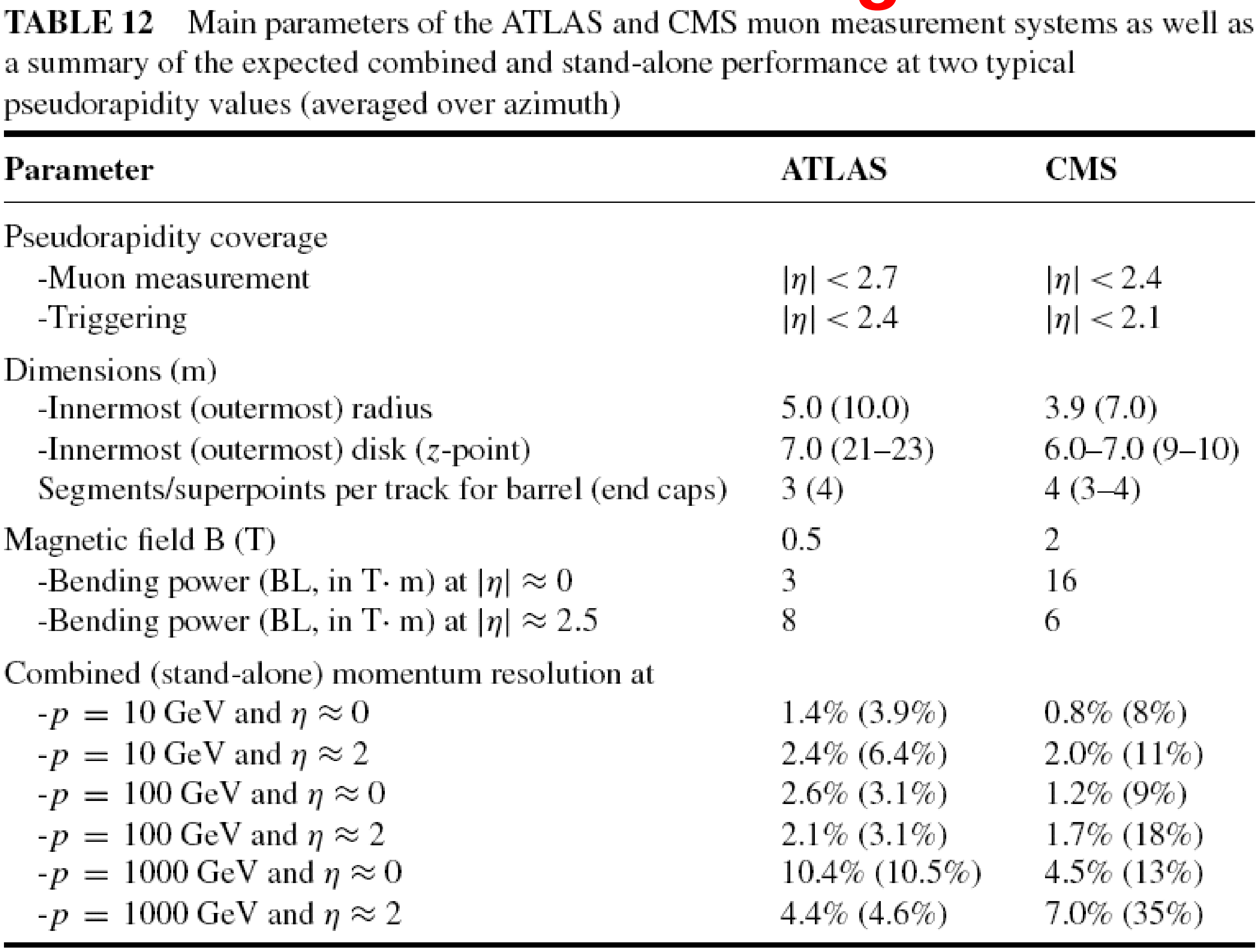


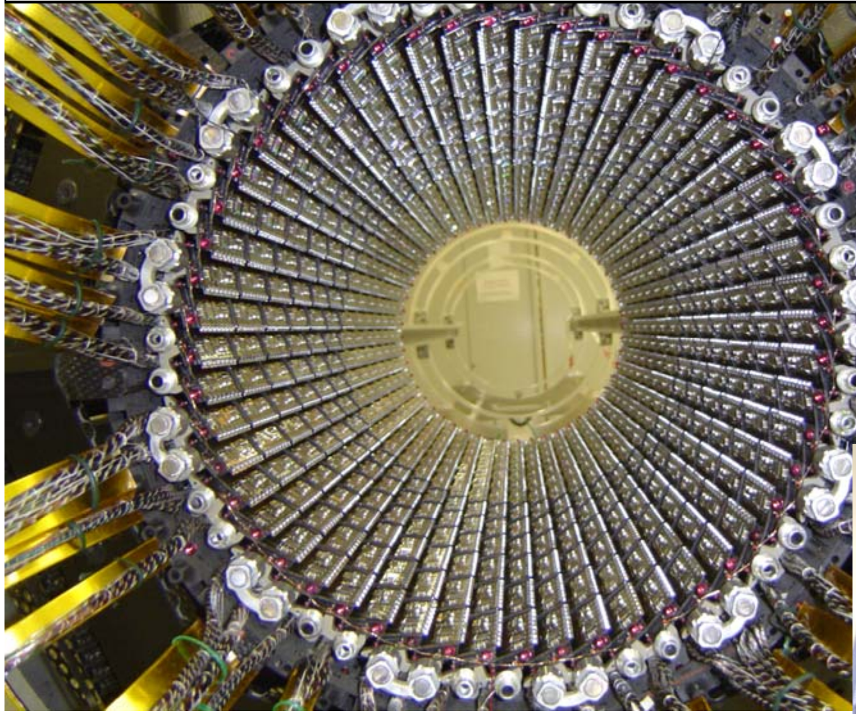
TABLE 12 Main parameters of the ATLAS and CMS muon measurement systems as well as a summary of the expected combined and stand-alone performance at two typical pseudorapidity values (averaged over azimuth)

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
-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 η ~ 0
ATLAS muon stand-alone performance excellent over whole η range

Remember that tracking at the LHC is a risky business!

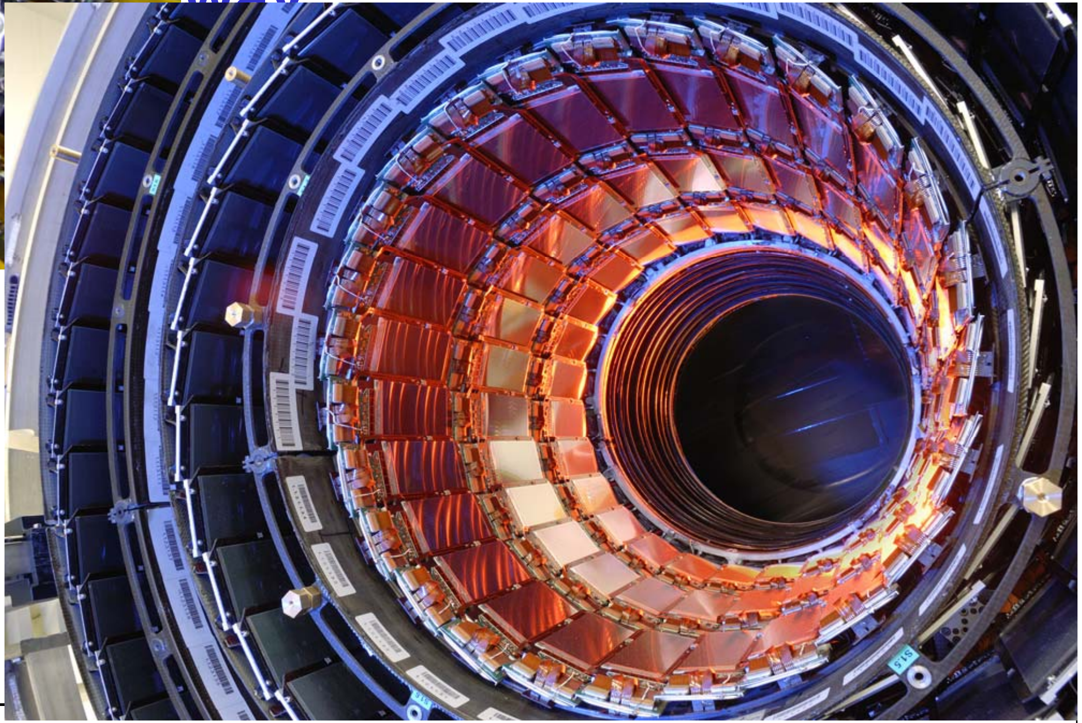
ATLAS pixels, September 2006



- All modules and services integrated and tested
- 80 million channels !
- 10%-scale system test with cosmics done at CERN

CMS silicon strips

- 200 m^2 Si, 9.6 million channels
- 99.8% fully operational
- Signal/noise ~ 25/1
- 20% cosmics test under way



CMS Tracker Inner Barrel, November 2006

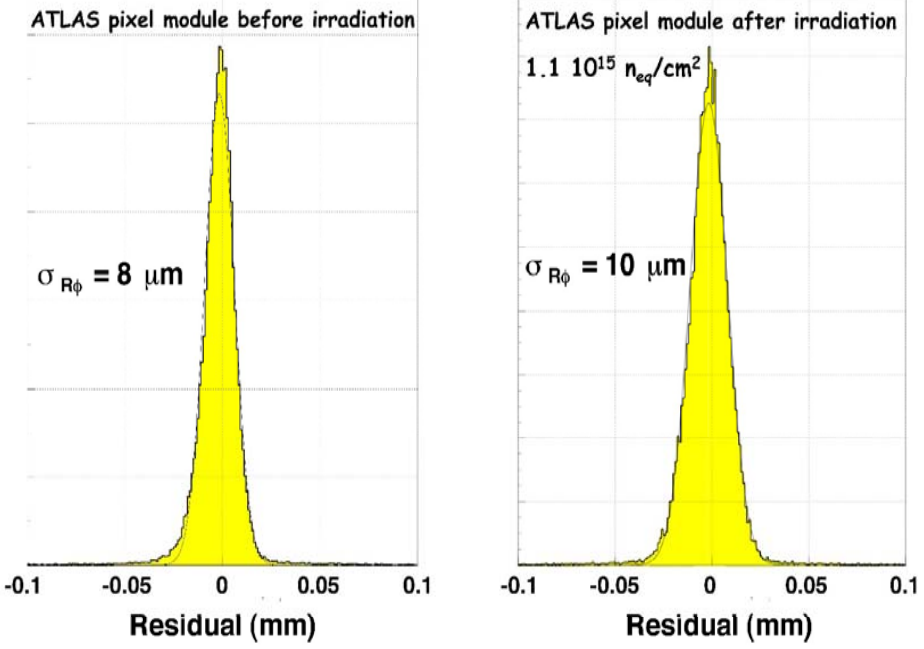
Remember that tracking at the LHC is a risky

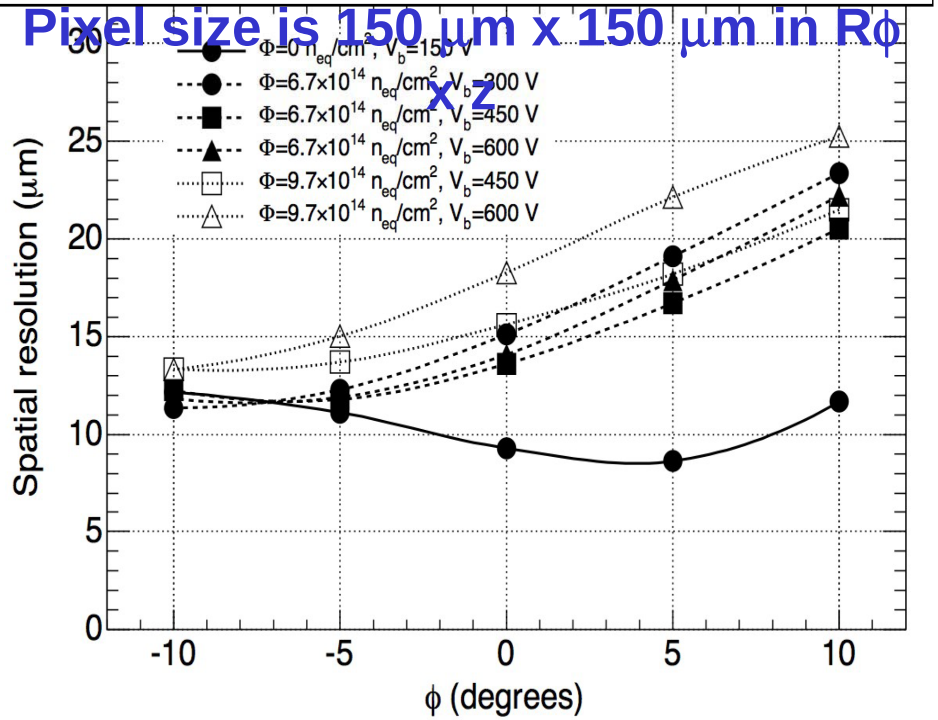
ATLAS pixel beam tests:
intrinsic resolution in bending plane before and after irradiation to a fluence
of 10^{15} $\text{neutrons}_{\text{equ}}$ per cm^2

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 50 µm x 400 µm in Rϕ x z

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





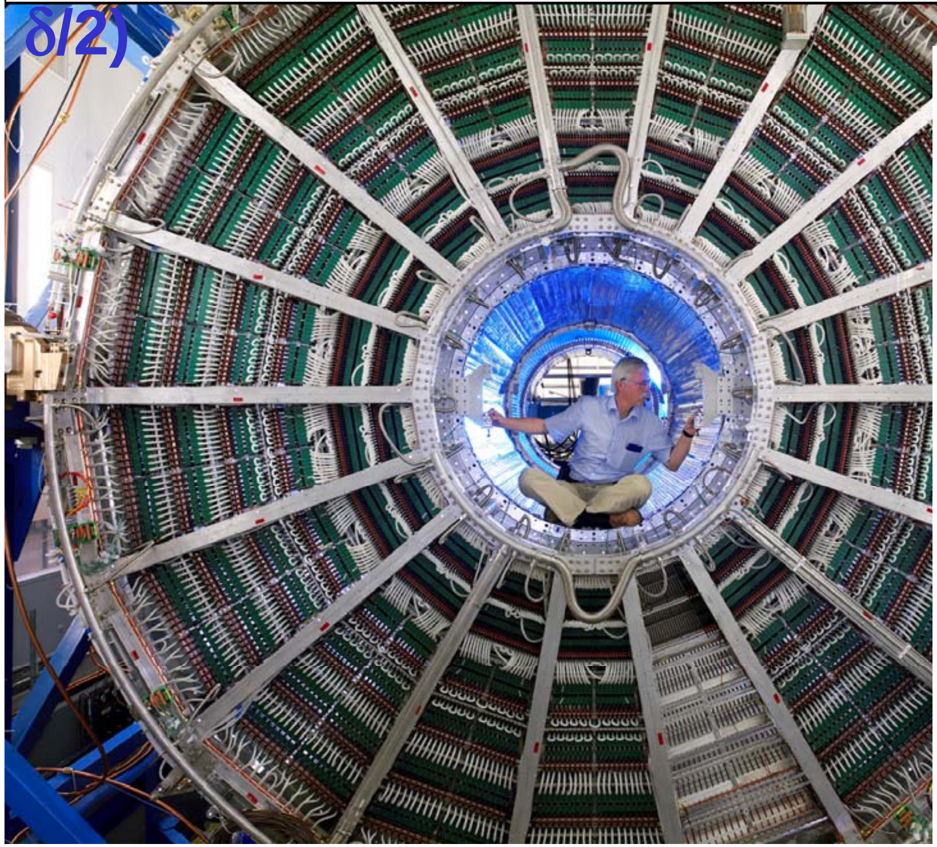
But ATLAS/CMS tracking specs do not marry well with detailed particle-ID

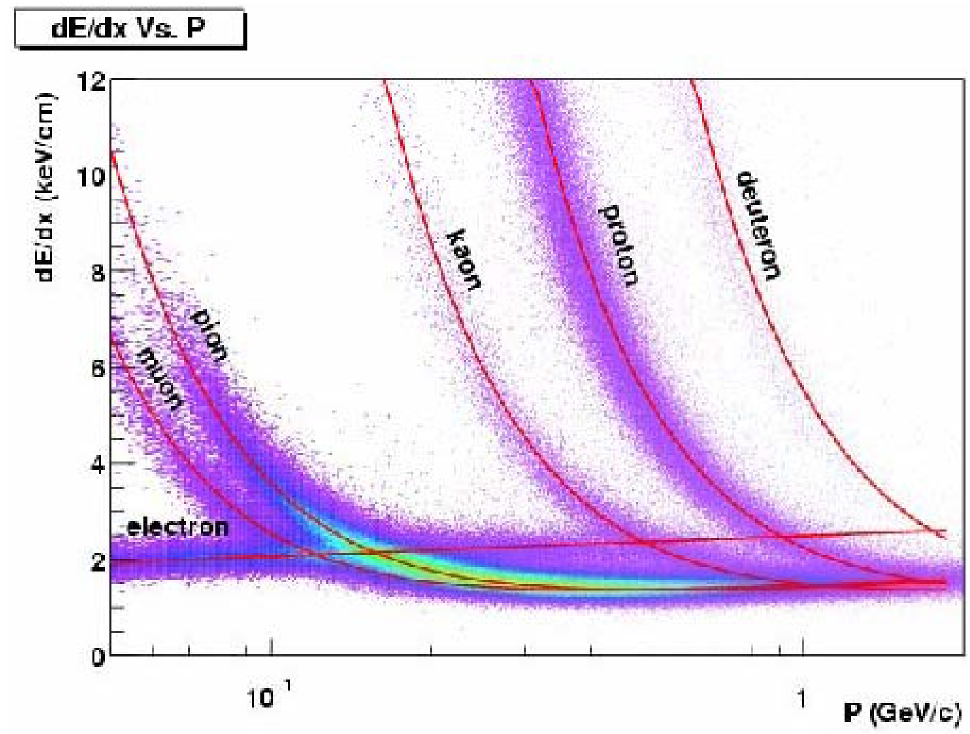
What are the limitations of ATLAS/CMS tracking detectors in terms of particle-ID? Look at

ALICE 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:

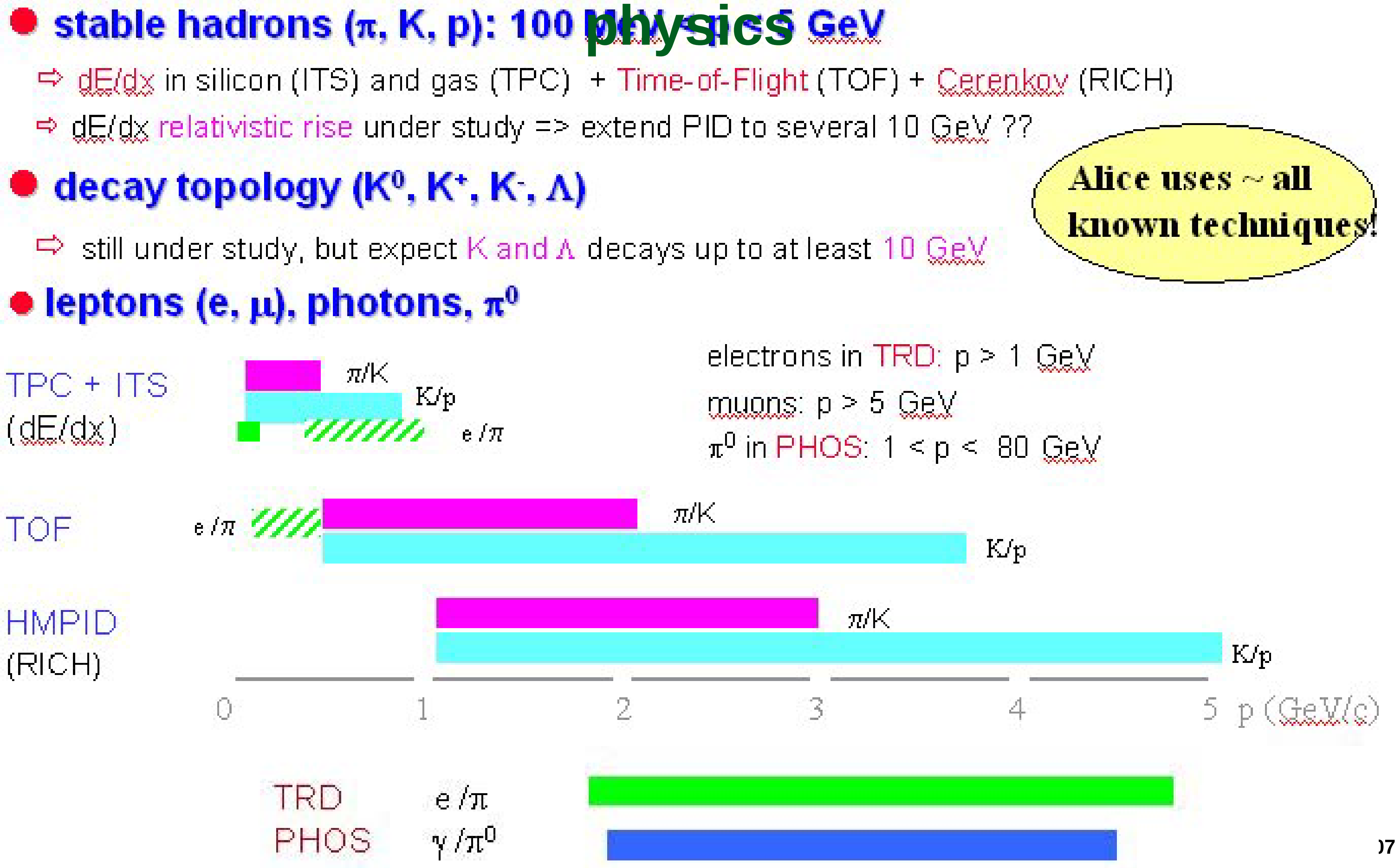
Bethe-Bloch: $-\langle dE/dx \rangle = k\ 1/\ \beta^2\ (\ 0.5\ \mathrm{Log}(2 m_e c^2 \beta^2 \gamma^2 T_{max}/I^2) - \beta^2 - \delta/2)$





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

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)	0.9989	0.999989
θ (Cerenkov)	0.160 rad	0.0526 rad
β (kaon)	0.9864	0.99986
θ (Cerenkov)	0.020 rad	0.0502rad

RICH1:

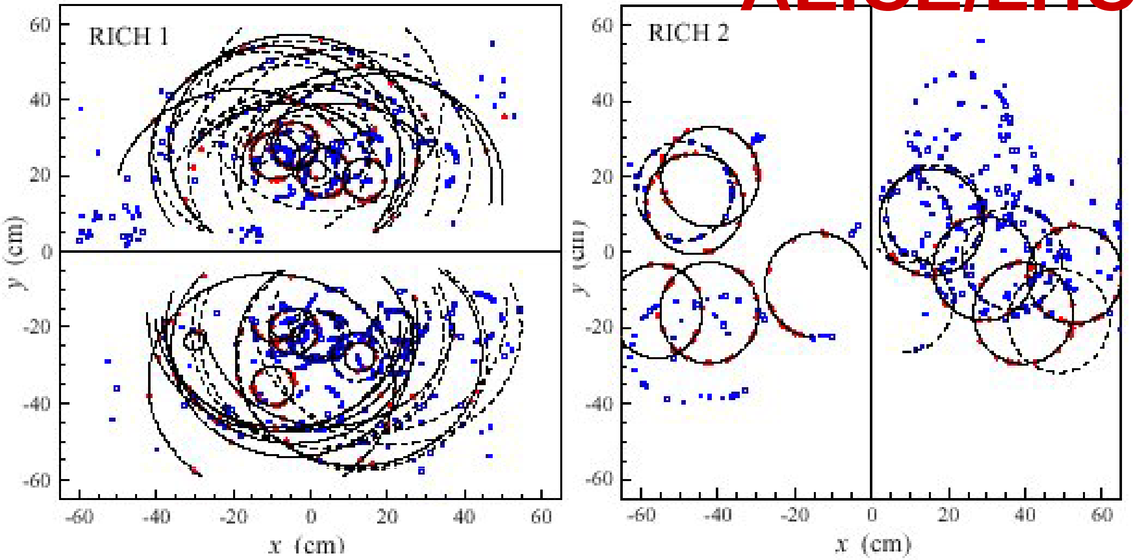
larger solid angle,lower part of momentum spectrum

- 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

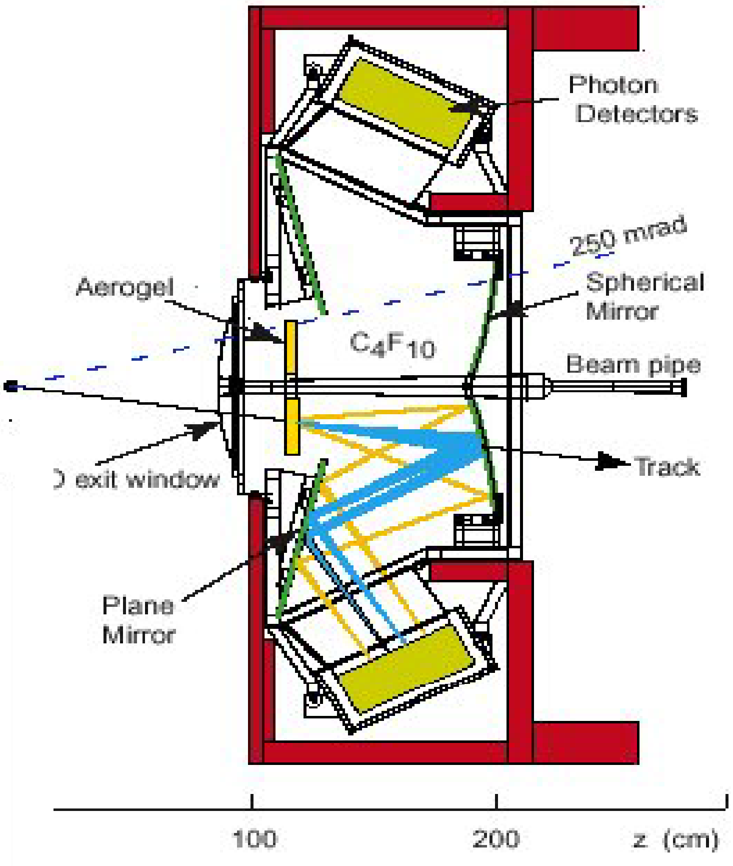
RICH2:

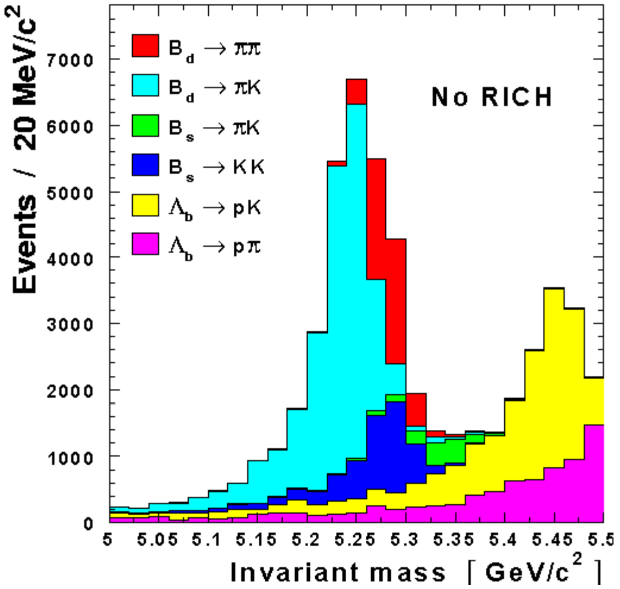
- CF_4 -n=1.0005 /260 nm θ (β=1)=32 mrad
  - -thickness=180cm
  - -nb photons=~30/ring

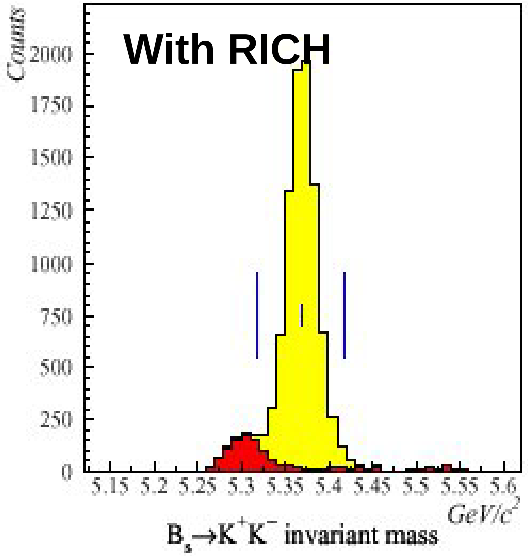
What are the limitations of ATLAS/CMS tracking detectors in terms of particle-ID? Look at ALICE/LHCb



LHC-b RICH detectors







Electrons and photons in ATLAS/CMS

- Electron identification
  - Isolated electrons: e/jet separation
    - R_{jet} ~ 10^5 needed in the range p_T > 20 GeV
    - R_{jet} ~ 10^6 for a pure electron inclusive sample (ε_e ~ 60-70%)
  - Soft electron identification – e/π separation
    - B physics studies (J/ψ)
    - soft electron b-tagging (WH, ttH with H → to bb)
- Photon identification
  - γ/jet and γ/π^0 separation
    - main reducible background to H → γγ comes from jet-jet and is 2x10^6 larger than signal
    - R_{jet} ~5000 in the range E_T >25 GeV
    - R (isolated high-p_T π^0) ~3
  - Conversion identification

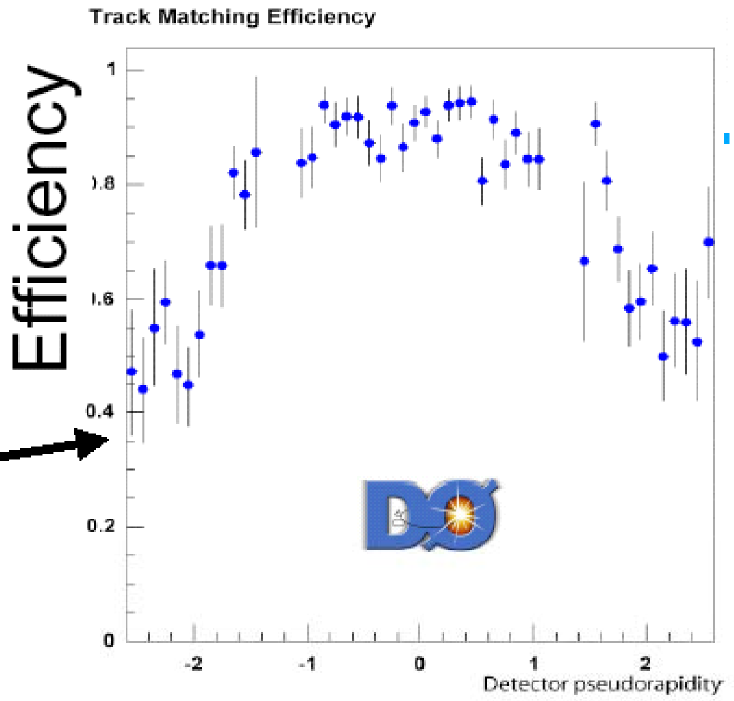
General detector requirements for e/γ id at the LHC:

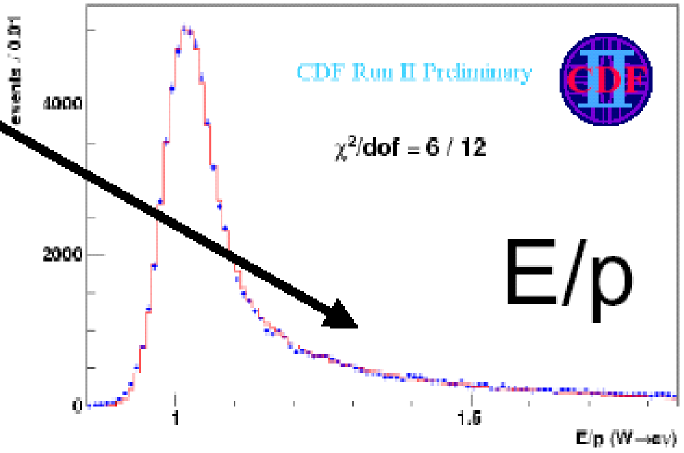
- Trigger efficiency
- Understanding of detector (alignment, material)
- Momentum measurement in the Inner Detector
- ECAL calibration

Can lessons be learned from Tevatron?

ID: Tracking

- Tracking important part of electron/photon ID
- Requiring or vetoing a high p_T track reduces background by x10
- Tracking more difficult in forward regions
- Very sensitive to the amount of material
  - ➔ Radiation reduces track p_T
  - ➔ Converted photons are lost
  - ➔ Uncertainty in acceptance dominated early W/Z cross section mesurements
    - ➢ 5.5% X_0 uncertainty in material gave a 4.7% uncertainty in the acceptance for Z→ee

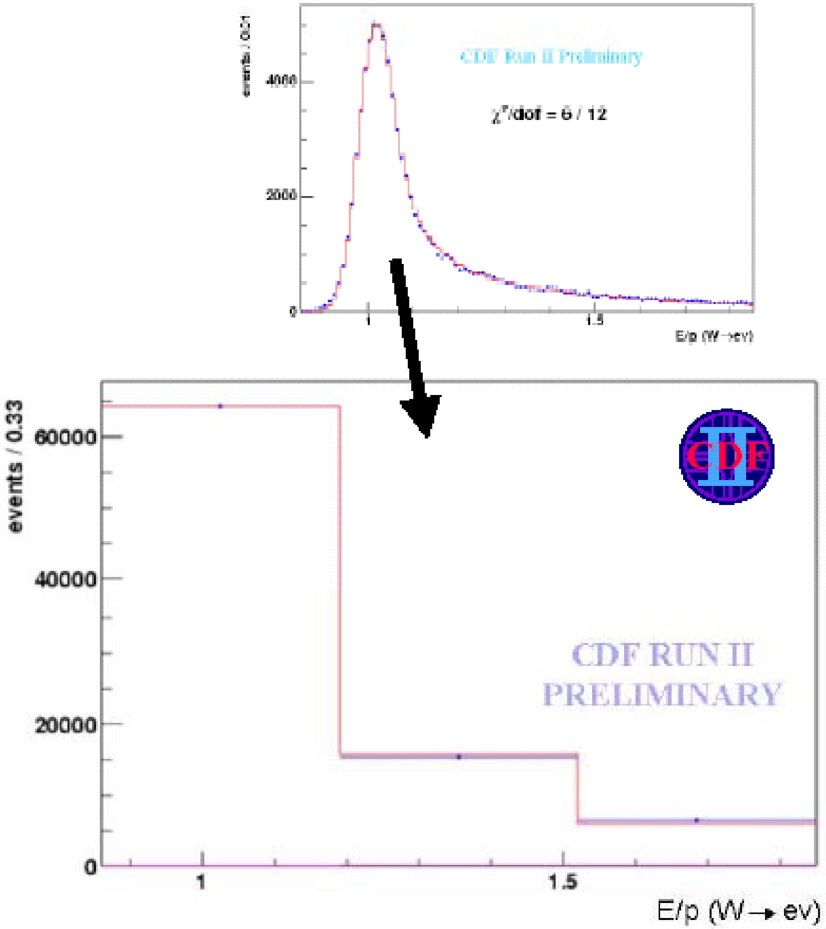




Can lessons be learned from Tevatron?

Material from E/P

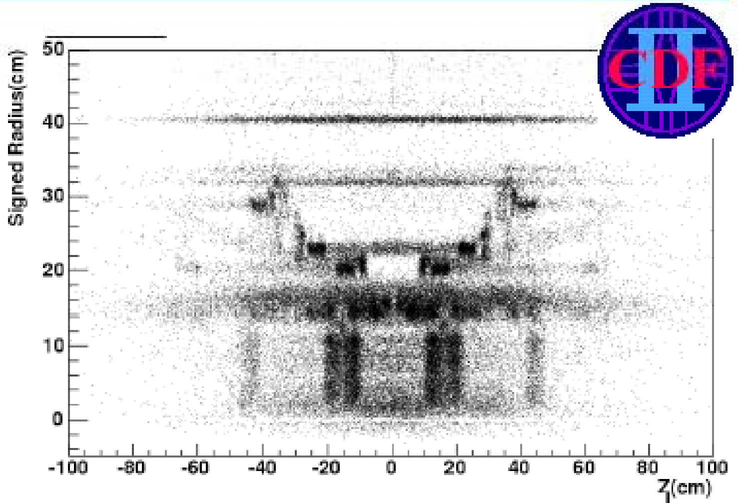
- Use radiative tail of E/P to measure material
- Gives average material
- Can be combined with energy-loss measurements of muons (J/ψ) to give roughly type of material
  - → CDF discovered it was missing Copper cables this way

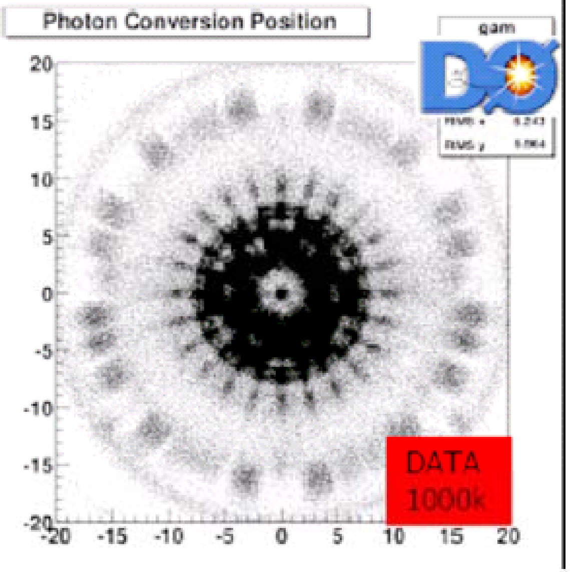


Can lessons be learned from Tevatron?

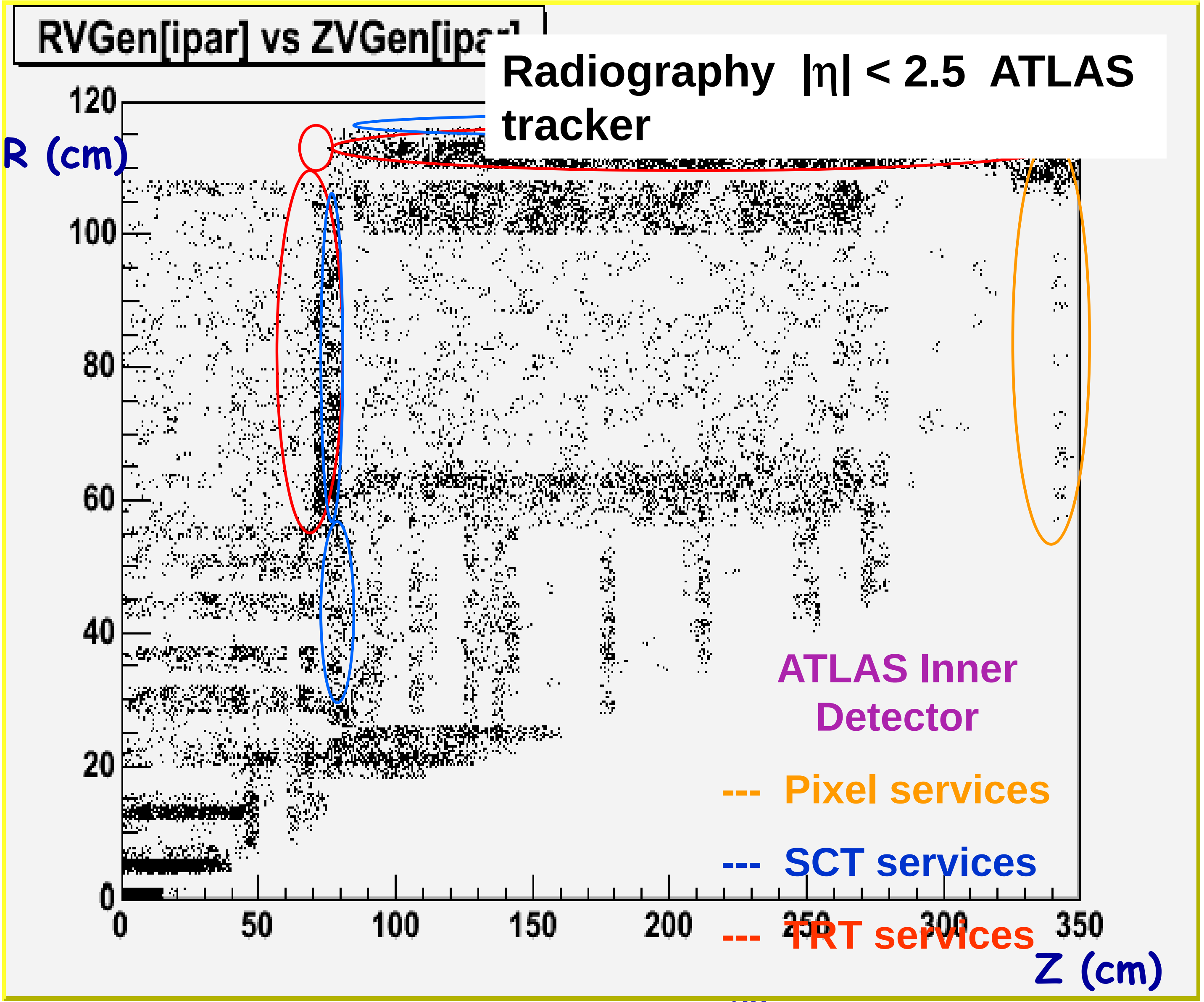
Material: X-raying the detector

- Conversions can indicate location of material in detector
  - ➔Normalized to inner cylinder of tracking chamber
  - ➔Overall normalization difficult
    - ➢ Acceptance and efficiency depend on r
- Useful to find missing (or misplaced!) pieces





Electrons and photons in ATLAS/CMS



Radiography |η| < 2.5 ATLAS tracker

ATLAS Inner Detector

--- Pixel services

--- SCT services

--- TRT services

Electrons and photons in ATLAS/CMS

ATLAS and CMS will know the amount of material
in their Inner Detector sub-systems very well
(15 years of simulation work and preparation).
But there is a lot more material than in Tevatron/LEP detectors
(0.4 to 1.5 X_0 compared to 0.1-0.2 X_0)!!

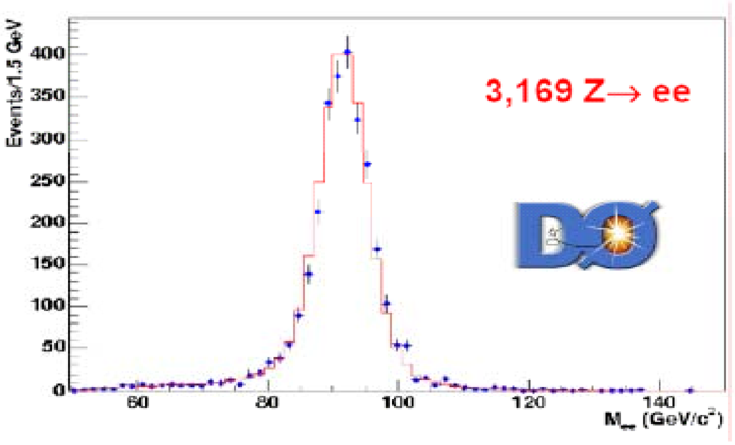
Example: weight of an ATLAS pixel stave (2005)

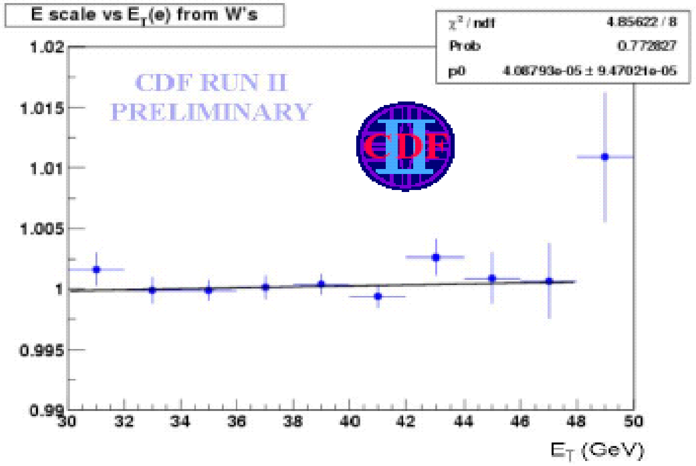
	Simulation (2003)	Measurement
13 Modules	25.48 g	25.74 g
TMT+omega+Tube (no liquid)	32.35 g	37.95 g +glue
Cooling liquid	~ 4.2 g	10.9 g (estimate)
Pigtails+connectors+ cables	6.39 g	7.8+13.2=21.0 g

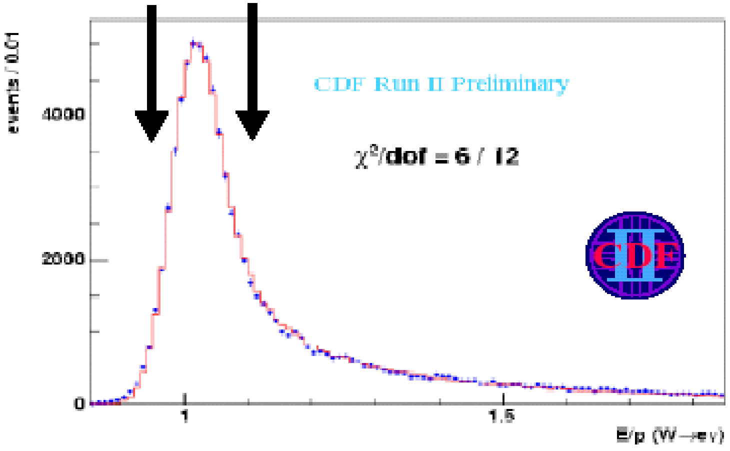
Can lessons be learned from Tevatron?

Energy calibrations II

- Generally calibrated to Z→ee resonance
- E/P can give another handle
  - → **Track momentum scale is measured with muons from J/ψ, ϒ, and Z→μμ**



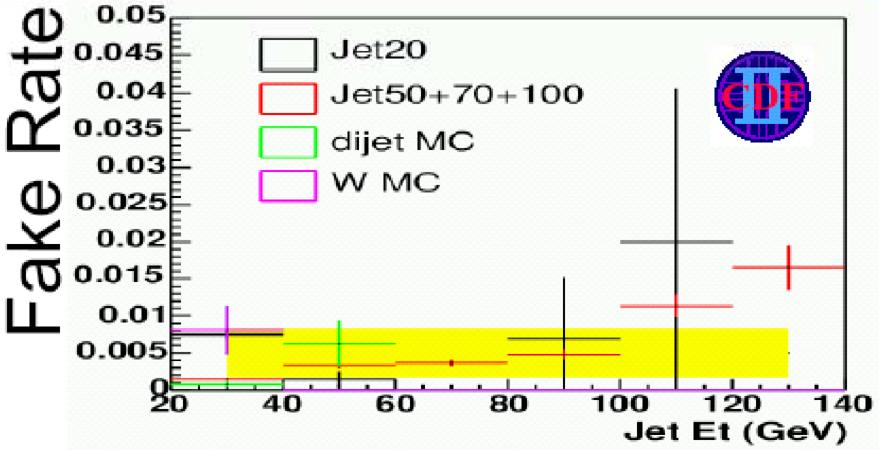


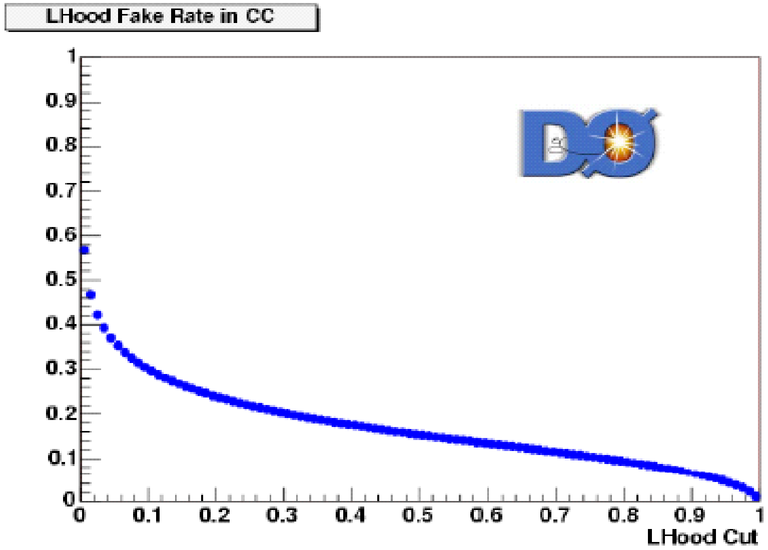


Can lessons be learned from Tevatron?

Background Estimation: e

- Sources:
  - → **b decays semi-leptonically**
  - → **π^0 & $\pi^\pm$ give EM and track**
  - → **Photon conversions**
  - → **Composition depends on cuts**
- Fake rates are common way to measure backgrounds
  - → **Measure rate of jets and electrons in jet triggered events**
  - → **Apply to sample with signal topology with jet instead of electron**
- Generally, jet background is small, but has large uncertainty (~25-50%)
  - → **Absolute rates ~ 10^{-3}-10^{-4}**





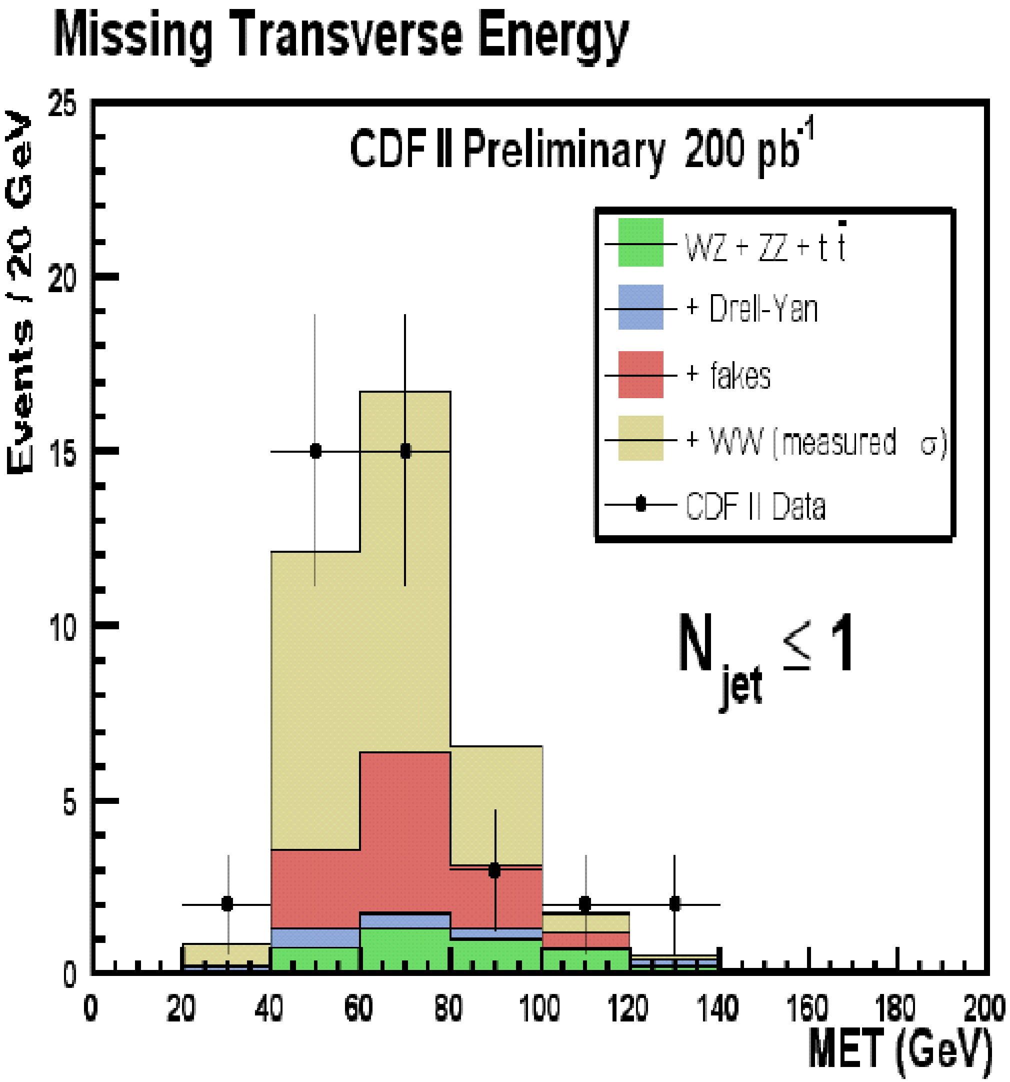
Gregory Veramendi

Electron and Photons at the

Can lessons be learned from Tevatron?

From CDF RUN II
WW dileptons channel
Fakes are QCD dijets

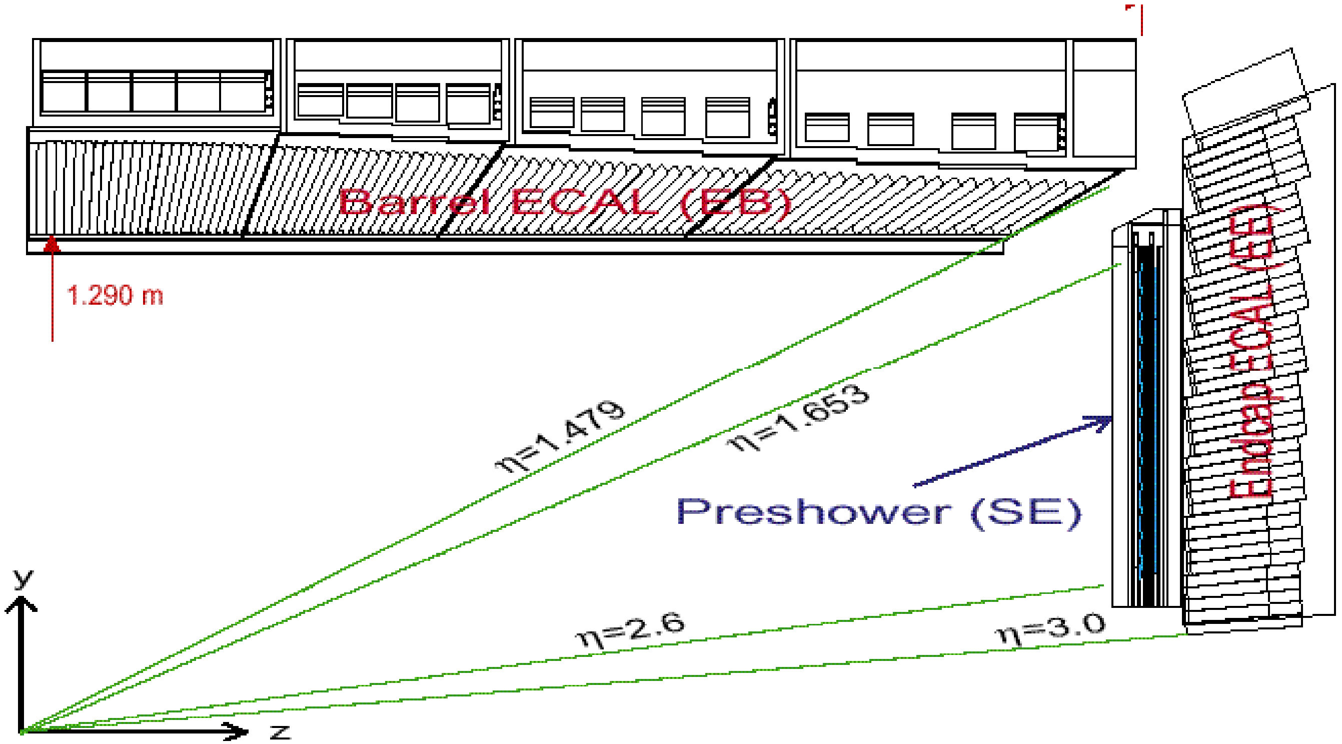
Could be a problem for
Letpton (s) channels
@ LHC



These results may seem quite surprising but remember that cuts are often loosened to improve sensitivity in searches for rare processes!

Electrons and photons in ATLAS/CMS

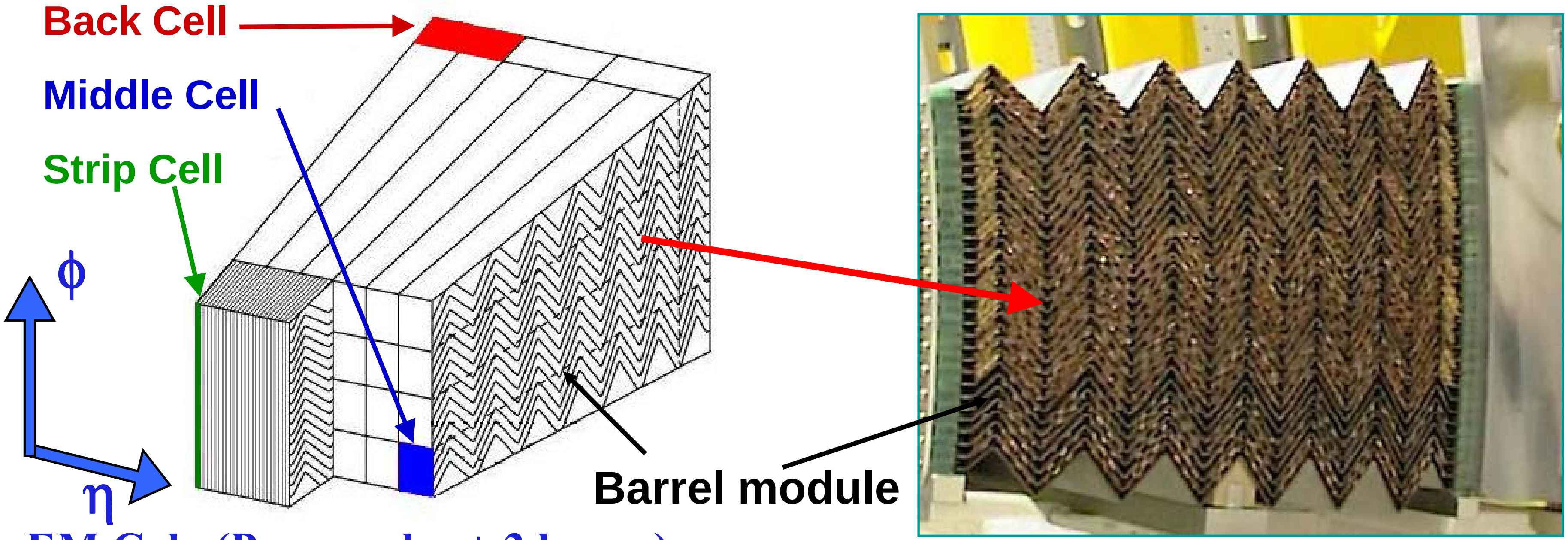
CMS $PbWO_4$
crystal
calorimeter



- Barrel: 62k crystals 2.2 x 2.2 x23 cm
- End-caps: 15k crystals 3 x 3 x 22 cm

Electrons and photons in ATLAS/CMS

ATLAS LAr EM Calorimeter description



EM Calo (Presampler + 3 layers):

- **Presampler** 0.025x0.1 (ηxϕ)
  ⇒ Energy lost in upstream material
- **Strips** 0.003x0.1 (ηxϕ)
  ⇒ optimal separation of showers in non-bending plane, pointing
- **Middle** 0.025x0.025 (ηxϕ)
  ⇒ Cluster seeds
- **Back** 0.05x0.025 (ηxϕ)
  ⇒ Longitudinal leakage

•LAr-Pb sampling calorimeter (barrel)

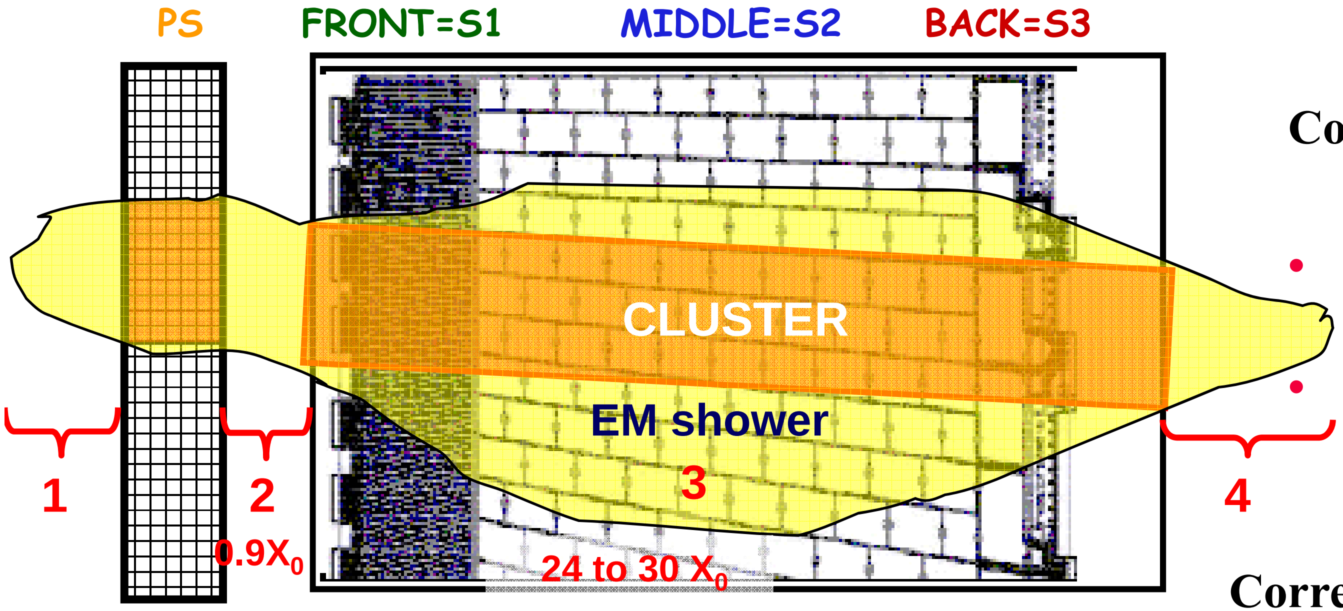
•Accordion shaped electrodes

•Fine longitudinal and transverse segmentation

•EM showers (for e$^{\pm}$ and photons) are reconstructed using calorimeter cell-clustering

Electrons and photons in ATLAS/CMS

ATLAS EM Calorimeter energy reconstruction



Corrections due to cluster position:

- **Δη (S-shape modulation) ±0.005**
- **Δϕ (offset in accordion) ±0.001**

Two main clusterization methods:

- **Fixed size sliding window:**
  - 3×3, 3×7… cells, 2nd sampling η×ϕ;
  - Some energy left out, especially for small sizes.
- **Topological clusters:**
  - Variable size cluster, minimize noise impact;
  - Additional splitting algorithm is also provided.

Corrections for energy losses:

1. **Before PS**
2. **Between PS & Calo**
3. **Outside cluster: depends on clustering method**
4. **After calorimeter: ~ Energy in BACK**

2-7% overall energy correction

>7% at low energy, high η

ATLAS: e/jet separation in simulated data

- **Results for inclusive electrons with p_T > 20 GeV**
  - **for ε_e= 70% (flat in η), a jet rejection factor of >10^6**
  - **importance of TRT which improves final purity**
  - **rejection can be improved using multivariate analysis**

Results at low luminosity

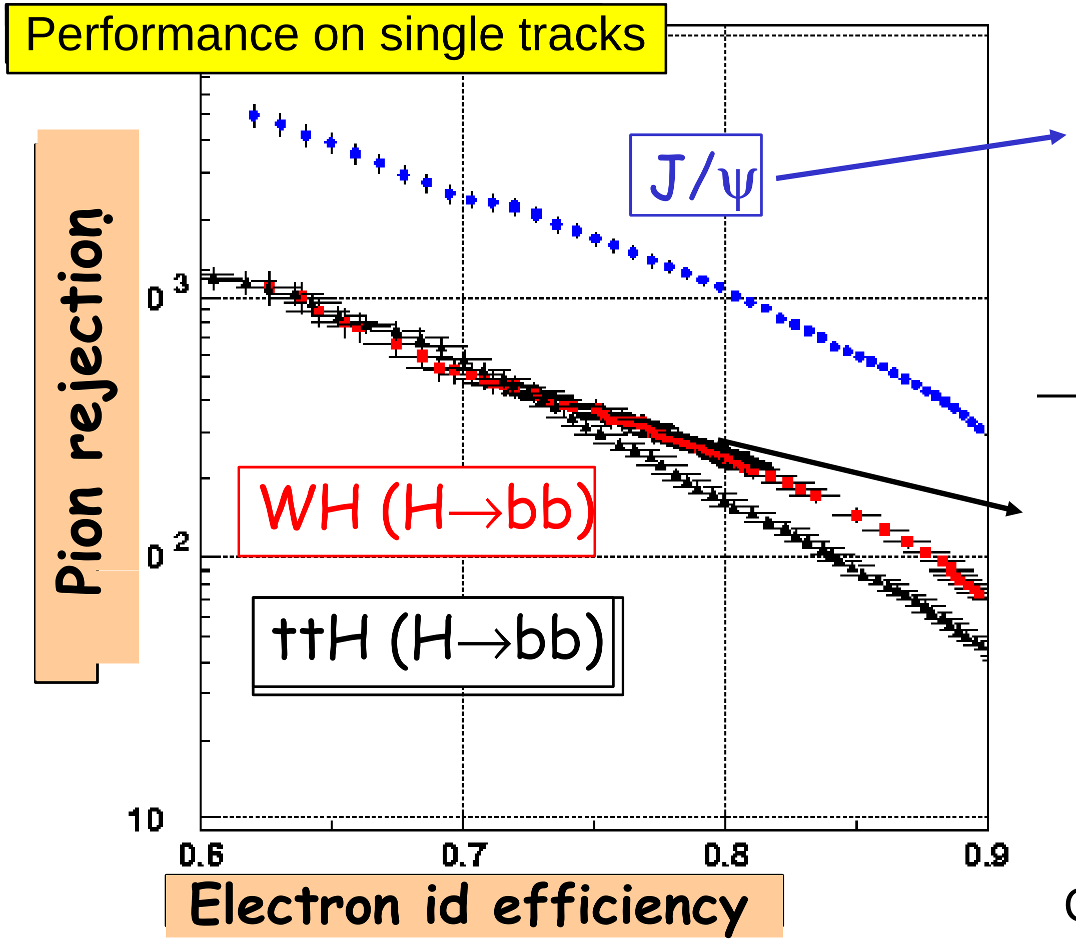
	ε (%)	R_{jet} (E_T > 17 GeV)
Calo	91.5±0.4	3000
∃ track	87.4±0.5	36000
matching	82.2±0.6	103000
TRT/conv.	70.0±1.0	> 10^6

TRT important!

- **Cross checks**
  - **electrons from W/Z: ε_e=69±5% with purity > 0.9**
  - **electrons from heavy flavour decays: ε_e=2 5±1% (non isolated electrons !)**

ATLAS: low p_T electron identification in simulated data

Start with a track as a seed. Extrapolate it to calorimeters and build cluster around
Discriminating variables are similar : use of TRT + shower shapes in calorimeter



$\varepsilon_{e\text{-}id}$ (J/ψ)= 80%
R_π (bb→μX)= 1050 ± 50

Allows a S/B ~2 in the J/ψ mass window after vertex refitting

---

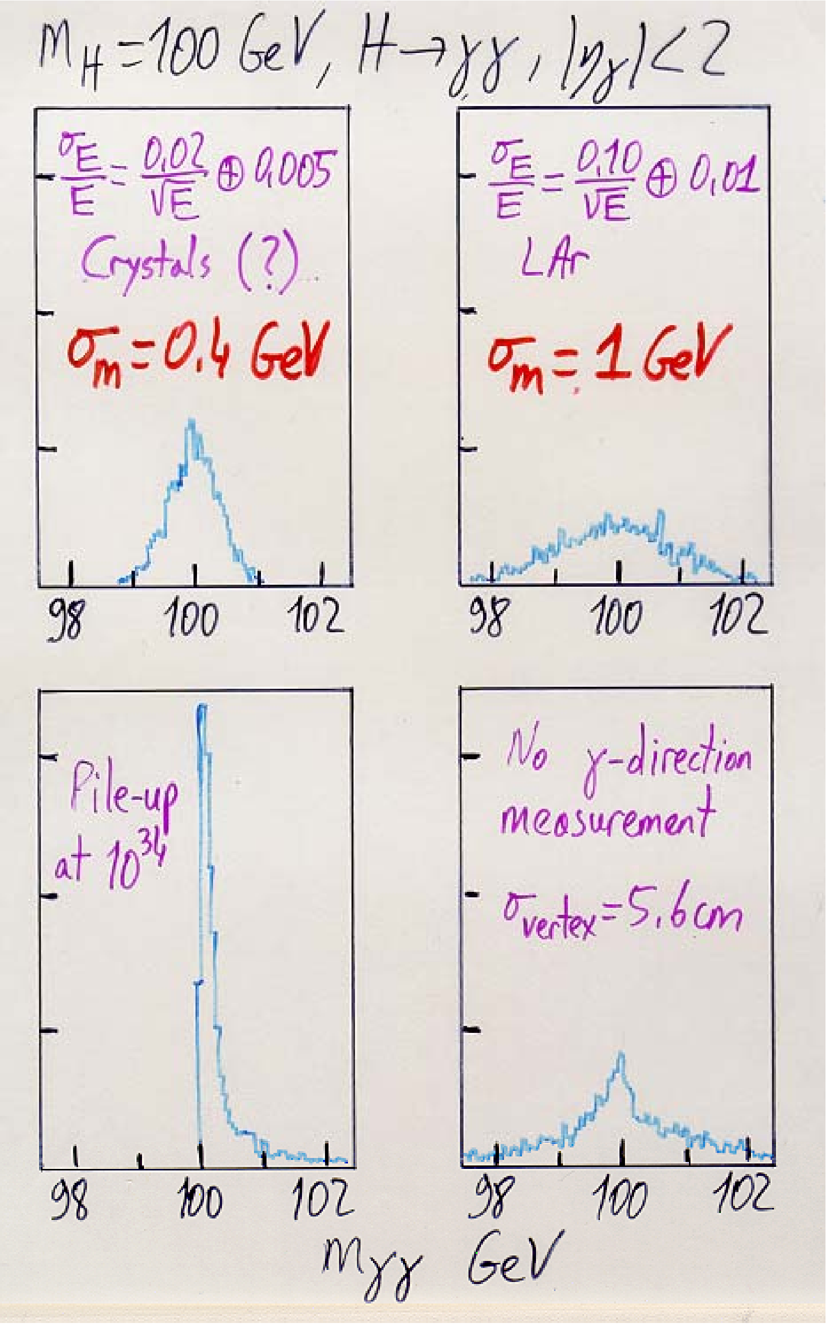
$\varepsilon_{e\text{-}id}$ (WH_{120})= 80%
R_π (WH)= 245 ± 17

Once electron is identified inside a jet it can be used for b-tagging

$\varepsilon_{b\text{-}id}$ = 60%
R_π (WH_{120})= 151 ± 2

Complementary to standard vertexing method R_u (WH_{120})= 115 BUT
$\varepsilon = \varepsilon_{b\text{-}id}$ (60%)* BR ~ 8%

SM H → γγ



Signal reconstruction

One wants to reconstruct:

$$M_{\gamma\gamma}^2 = 2\, E\gamma_1 E\gamma_2 (1-\cos\theta_{12})$$

What contributes to resolution on $m_{\gamma\gamma}$?

1) **Measurement of E_γ:**
   - **Intrinsic resolution of calo**
   - **Calibration/uniformity of calo**
   - **Pile-up effects**

2) **Measurement of θ_{12}**
   - **Measurement of position and direction of em showers**

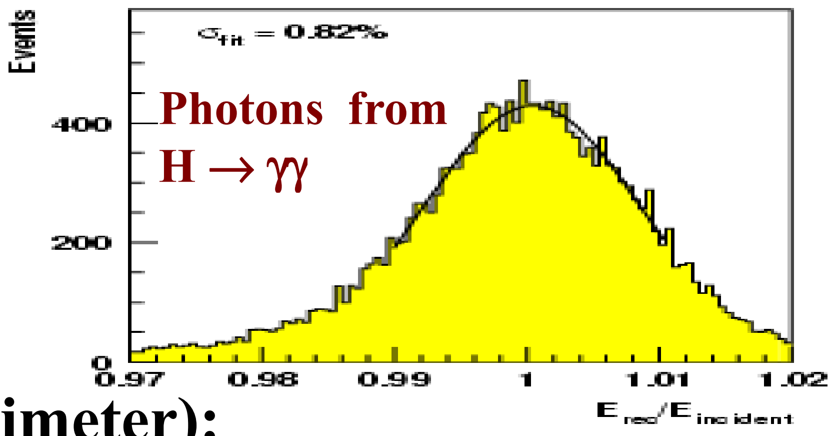
SM H→ γγ

Energy resolution

CMS EM calorimeter
(crystals):

$$\frac{\sigma(E)}{E} \approx \frac{3-5\%}{\sqrt{E}}$$

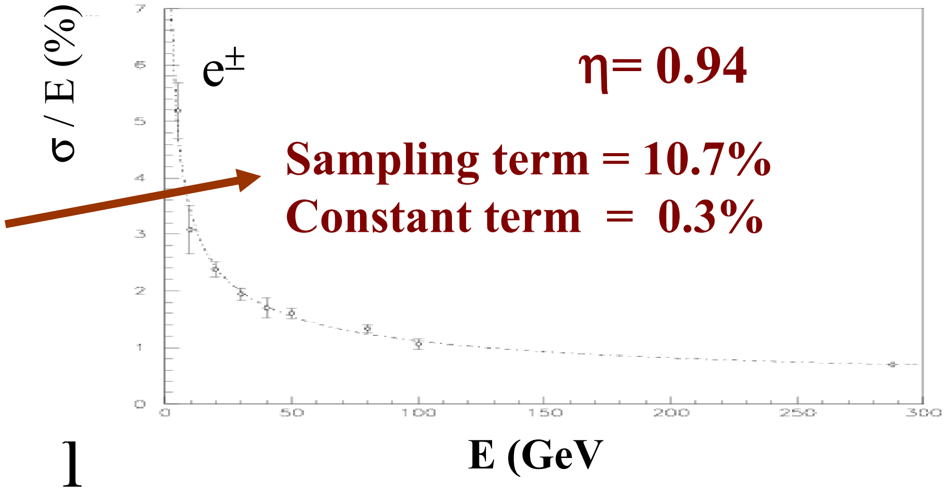
CMS, full simulation high L



ATLAS EM calorimeter
(liquid-argon/lead sampling calorimeter):

$$\frac{\sigma(E)}{E} \approx \frac{10\%}{\sqrt{E}}$$

Module zero test beam data



Sampling term = 10.7%
Constant term = 0.3%

Mass resolution
(m_H=100 GeV, low L):
ATLAS : 1.1 GeV
CMS : 0.6 GeV

$$\frac{S}{\sqrt{B}} \sim \frac{1}{\sqrt{\sigma_m}}$$

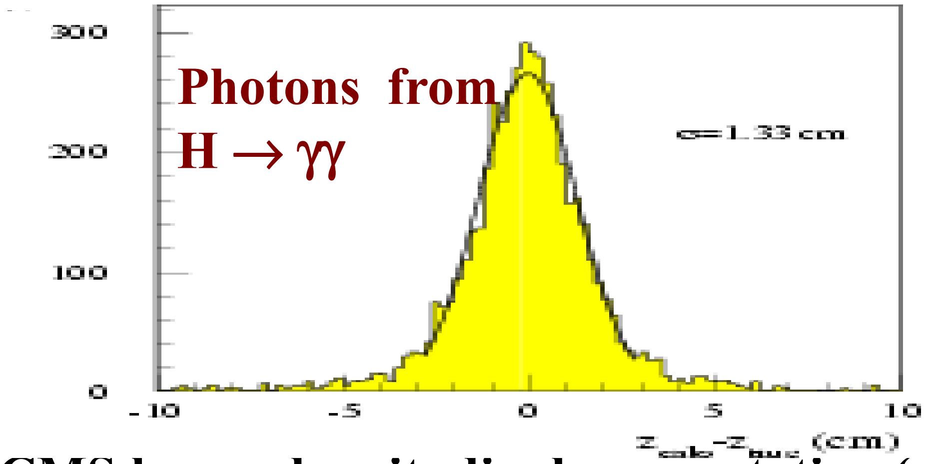
SM H$\rightarrow\gamma\gamma$

Angular resolution and acceptance

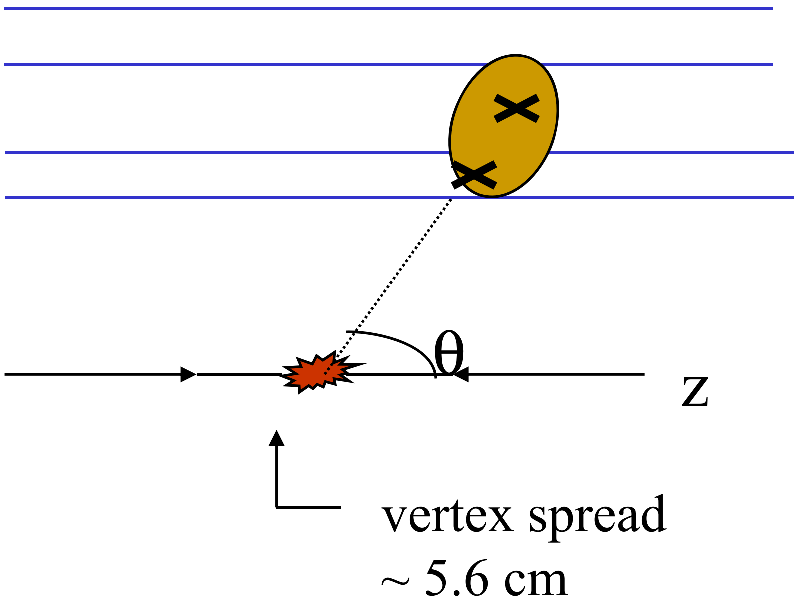
- ATLAS calorimeter has longitudinal segmentation

→ **can measure γ direction**

ATLAS, full simulation
Vertex resolution using EM calo longitudinal segmentation



Photons from H → γγ



θ

z

vertex spread
~ 5.6 cm

$$\sigma(\theta) \approx \frac{50\ \text{mrad}}{\sqrt{E}}$$

CMS has no longitudinal segmentation (and no preshower in barrel)
→ vertex measured using secondary tracks from underlying event
→ often pick up the wrong vertex
→ smaller acceptance in the Higgs mass window

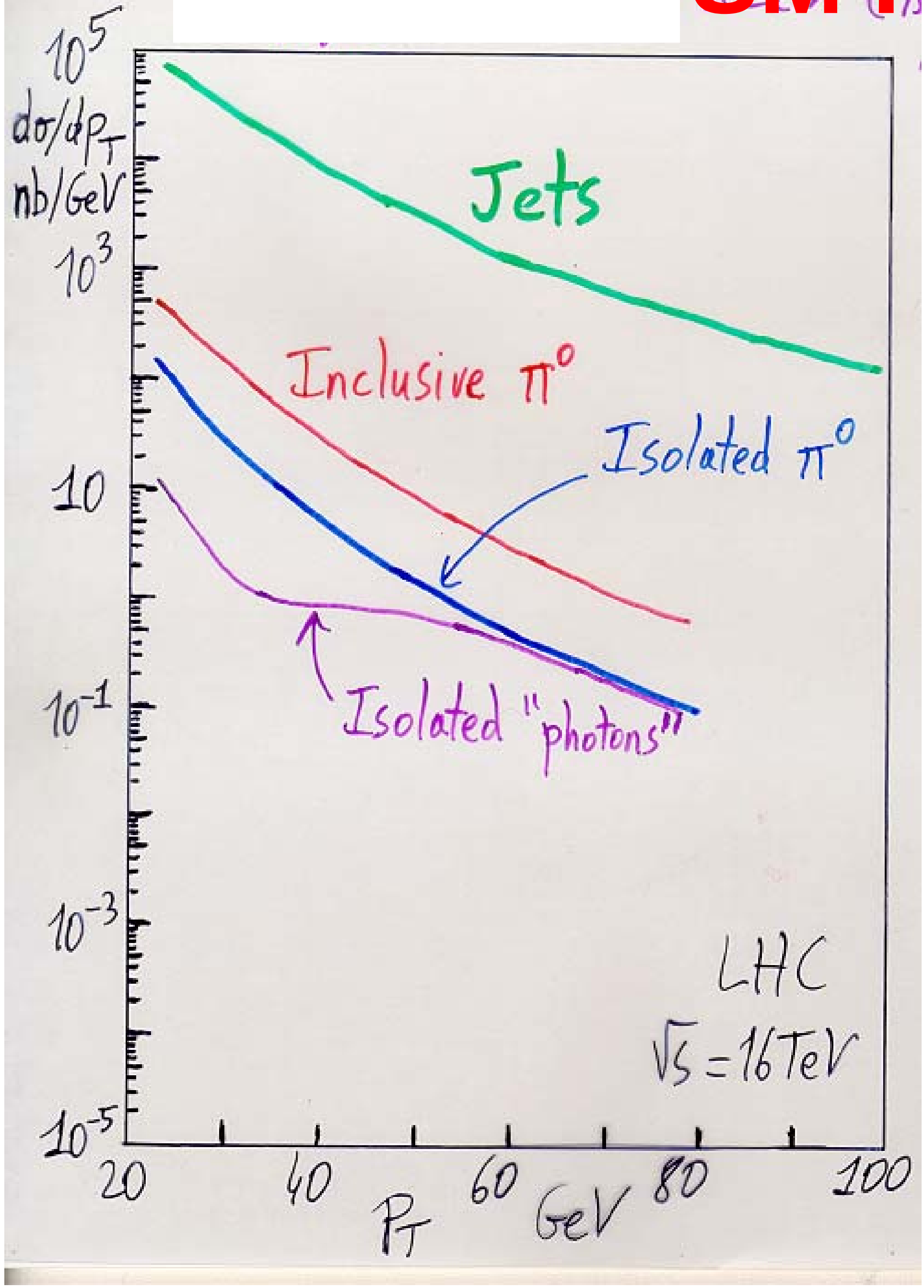
SM $H \to \gamma\gamma$

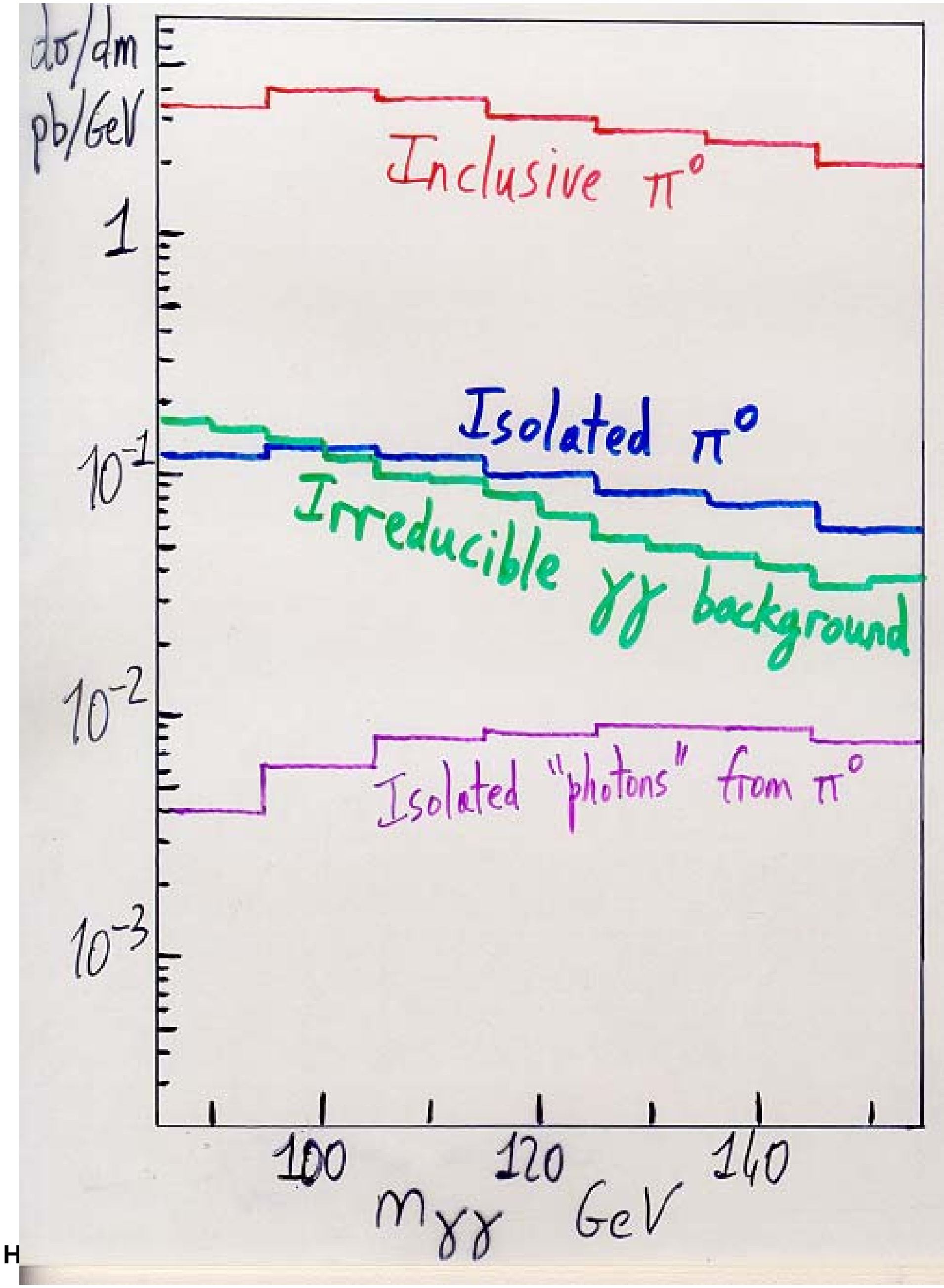
Backgrounds

1) Irreducible background from qq → $\gamma\gamma$ and gg → $\gamma\gamma$ (box)

2) Reducible background from π^0,η (→ $\gamma\gamma$) in jet fragmentation:
   - final states with many photons → look for single photons
   - non-isolated photons inside jets → look for isolated photons
   - Very difficult problem: at $p_T \approx$ 50 GeV, jet-jet / $\gamma\gamma \approx 10^7$
     → need to reject each jet by a factor 10,000 to bring the reducible background well below the irreducible one
   - However, at $p_T \approx$ 50 GeV, π^0/jet $\approx 10^{-3}$
     → separate isolated photons from π^0 decays at 50 GeV
     → photons from π^0 decays will be distant by $\approx$ 1 cm
     → need granular position detector after ~ 4-5 X_0 in

SM H→ γγ

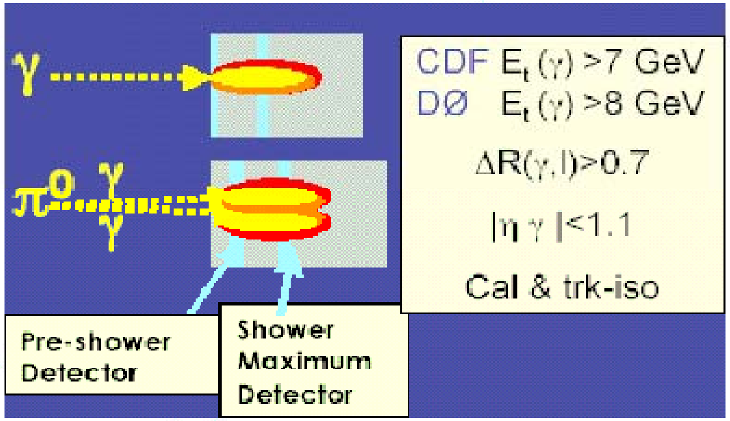

10^5
dσ/dp_T nb/GeV
10^3
10
10^-1
10^-3
10^-5
Jets
Inclusive π°
Isolated π°
Isolated "photons"
LHC
√s = 16TeV
20
40
60
80
100
P_T GeV


dσ/dm pb/GeV
1
10^-1
10^-2
10^-3
Inclusive π°
Isolated π°
Irreducible γγ background
Isolated "photons" from π°
100
120
140
m_γγ GeV

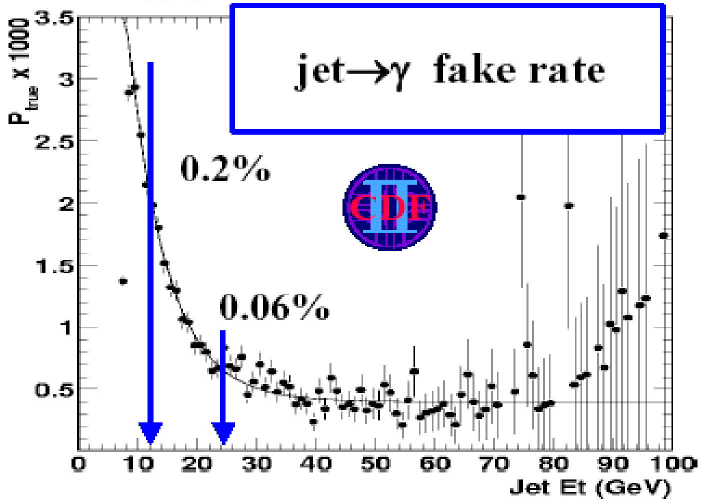
Can lessons be learned from Tevatron?

Background Estimation: γ

- Major Source
  - → $\pi^0 \rightarrow \gamma\gamma$
- Fake rate measured in similar way to electrons
  - → Prompt photons need to be removed
  - → Rates from different jet samples are compared for systematic
  - → If jets are E_T-ordered, find rate is different for 1st, 2nd, and lower E_T jets
- Rates ~ 5×10^{-4} for high E_T



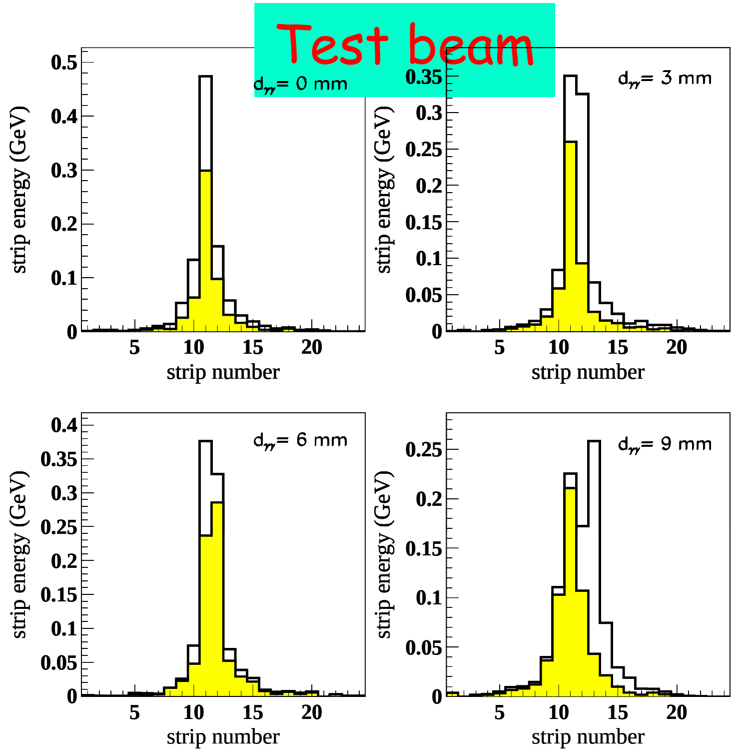
CDF $E_t(\gamma) > 7$ GeV
DØ $E_t(\gamma) > 8$ GeV
$\Delta R(\gamma, l) > 0.7$
$|\eta\ \gamma| < 1.1$
Cal & trk-iso



Photon ID in ATLAS

Jet background composition
 (true photons removed-quark brem,..)
after "general" calorimeter cuts:

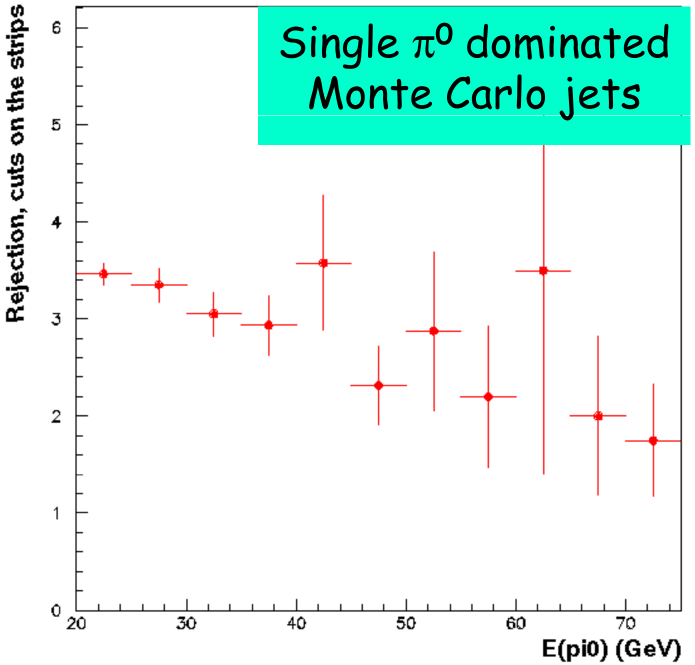
« Isolated » π^0	72%
$\eta\to\gamma\gamma$, $\omega\to\gamma\,\pi^0$,$K_S\to 2\pi^0$	13%
« multi » π^0	4%
electron	4%
single charged hadron	4%
single neutral hadron	1%
Others	2%

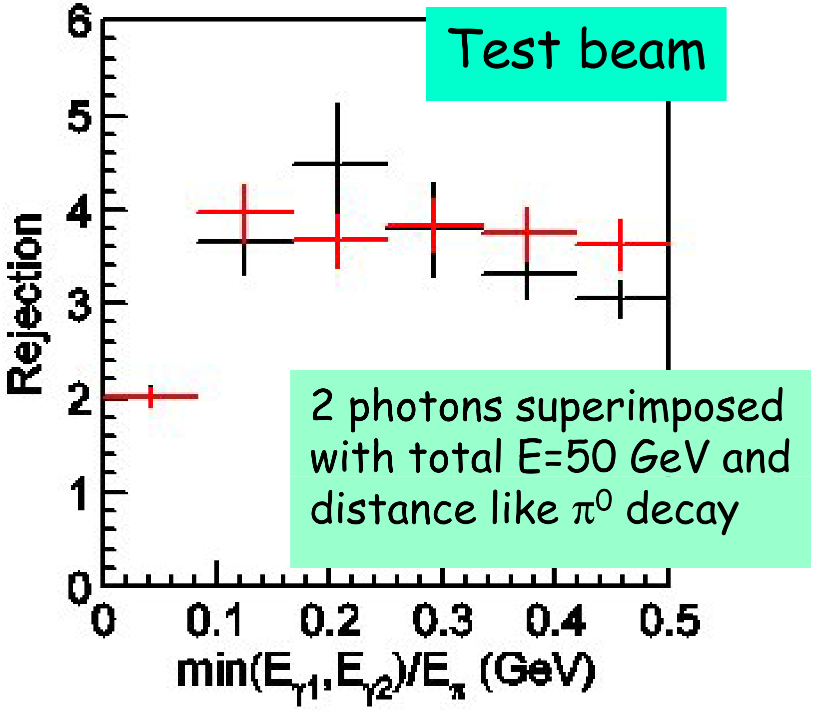


Test beam

- Further rejection of π^0 can be obtained exploiting the fine granularity of the first sampling ($\delta\eta$=.003 or 5mm).The two photons of a 60 GeV E_T symmetric π^0 decay are separated by >7mm at the calorimeter face!

Photon ID in ATLAS (2)





2 photons superimposed with total E=50 GeV and distance like π^0 decay

<u>Overall jet rejection obtained in MC</u>:

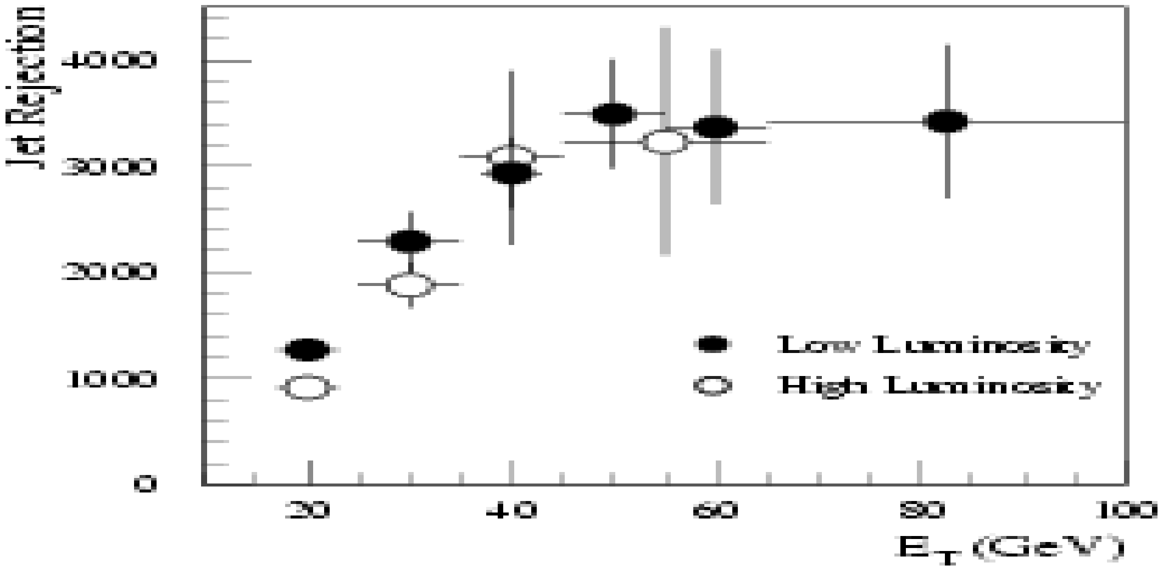
-1050 for quark jets

-6000 for gluon jets →Ultimate performance process dependent!

(probability of a high x isolated π^0 is higher in a quark jet than in a gluon jet)

SM H→ γγ

Rejection of QCD jet background



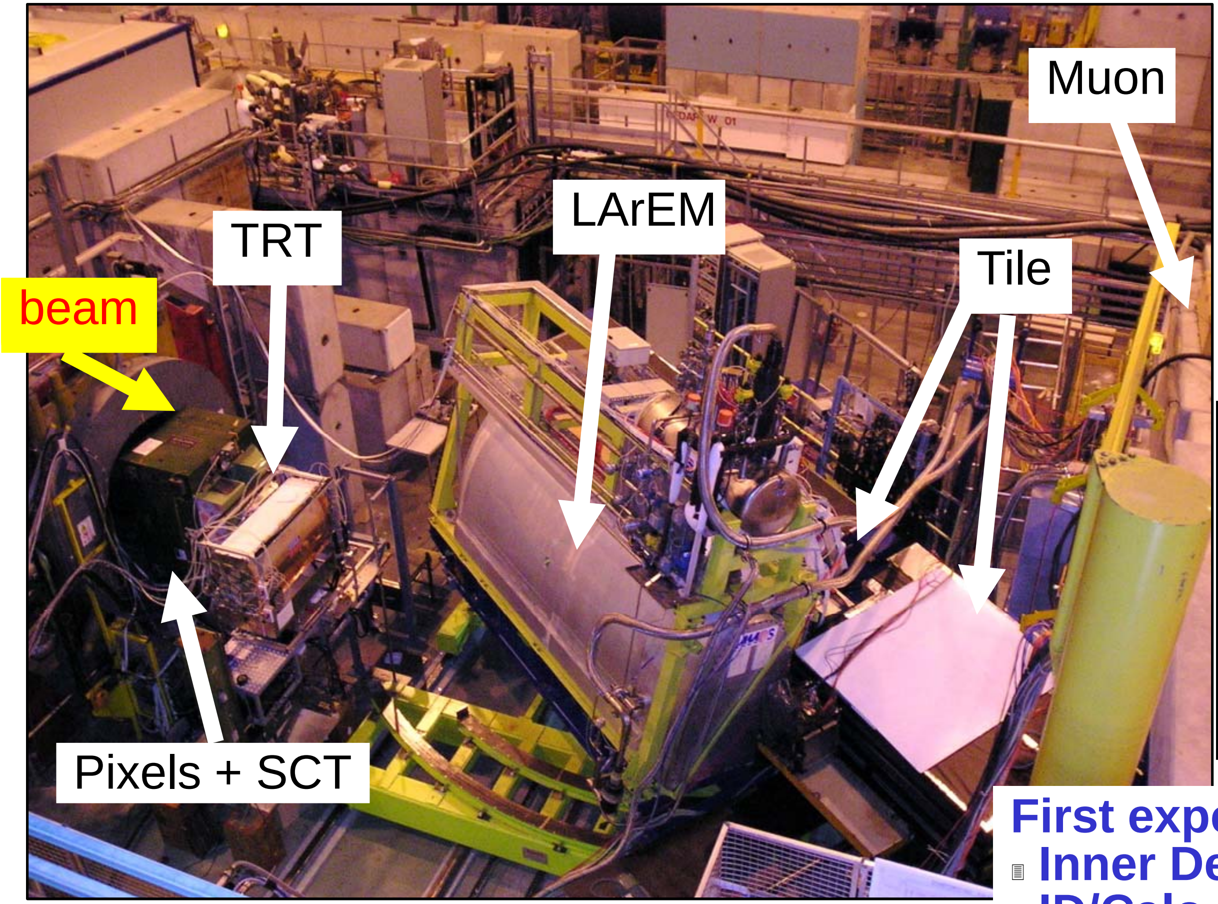
ATLAS EM calo : full simulation

ε_{γ} =80%

Most rejection from longitudinal calo segmentation and 4 mm η-strips in first compartment (γ / π^0 separation)

Towards the complete experiment:
ATLAS combined test beam 2004

Full « vertical slice » of ATLAS tested on CERN H8 beam line May-November 2004



- **90 million events collected**
- **4.6 Tbytes of data**
- **Beams:**
  - **e ,π 1→ 250 GeV**
  - **μ ,π ,p → 350 GeV**
  - **γ ~20-100 GeV**
- **B from 0 →1.4 T**

For the first time, all Atlas sub-detectors integrated and run together with:
- « final » electronics
- common DAQ
- common Atlas software to analyse the data

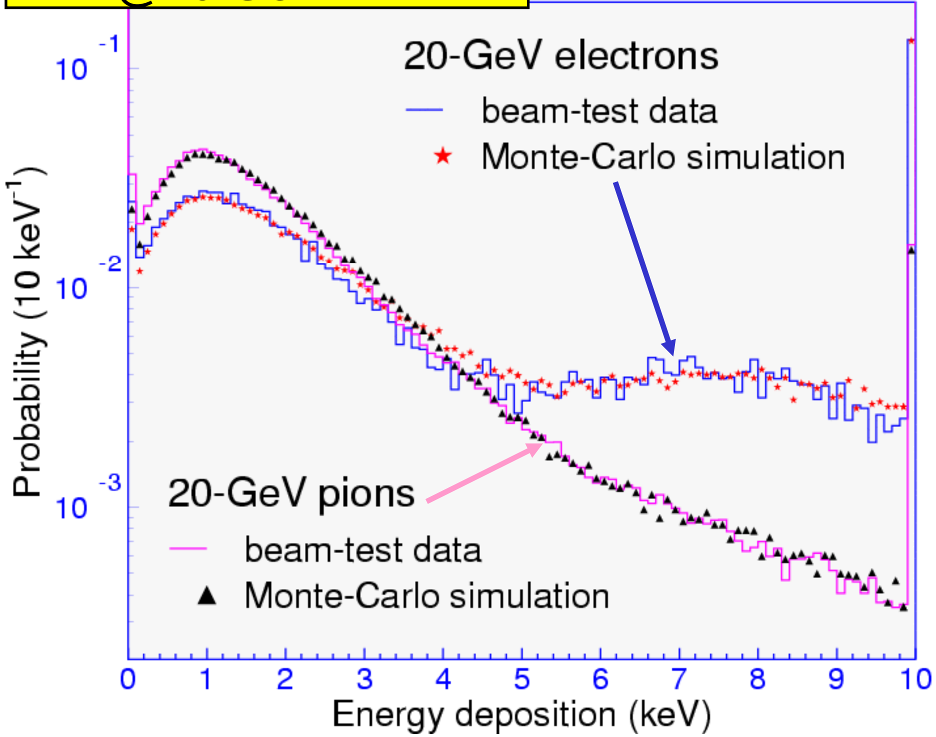
First experience with:

- **Inner Detector alignment**
- **ID/Calo alignment**
- **ID/Calo track matching**
- **ID/Calo combined reconstruction**
- **ID/muon combined reconstruction**

e/π separation using the barrel TRT and LAr EM calorimeter with mixed e/π low-energy beams

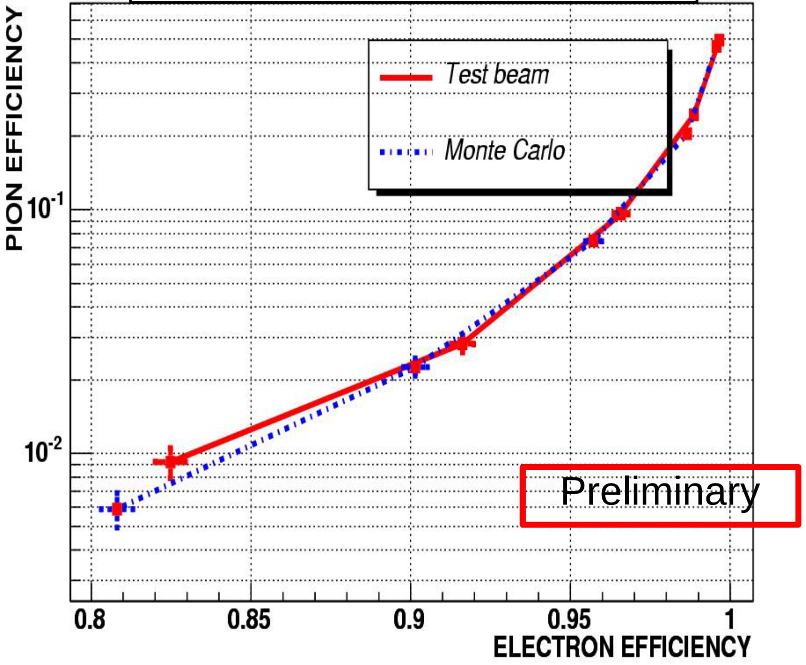
Electron identification makes use of the large energy depositions
due to the transition radiation (X-rays) when they traverse the radiators

Results from TB 2002
@20 GeV



Typical TR photon energy
depositions in the TRT are 8-10 keV
Pions deposit about 2 keV

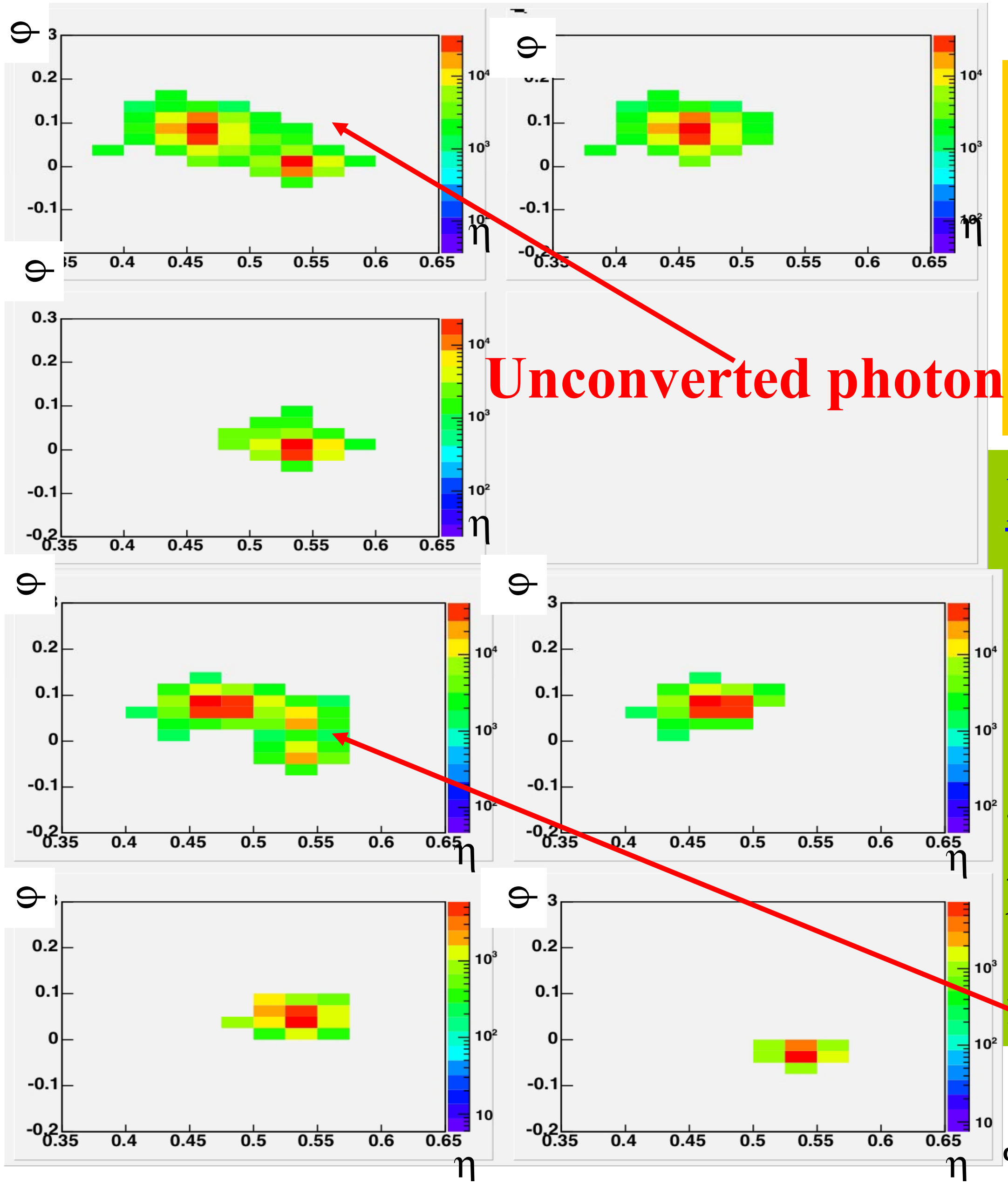
Results from CTB2004
@9 GeV



90% electron efficiency
2×10^{-2} pion efficiency

Topological clusterisation for photon runs

S. Menke



Unconverted photon

Converted photon

Parameters for the EM portion only:

- Seed Threshold > 6σ
- Neighbour Threshold > 3σ
- Cell Threshold > 3σ

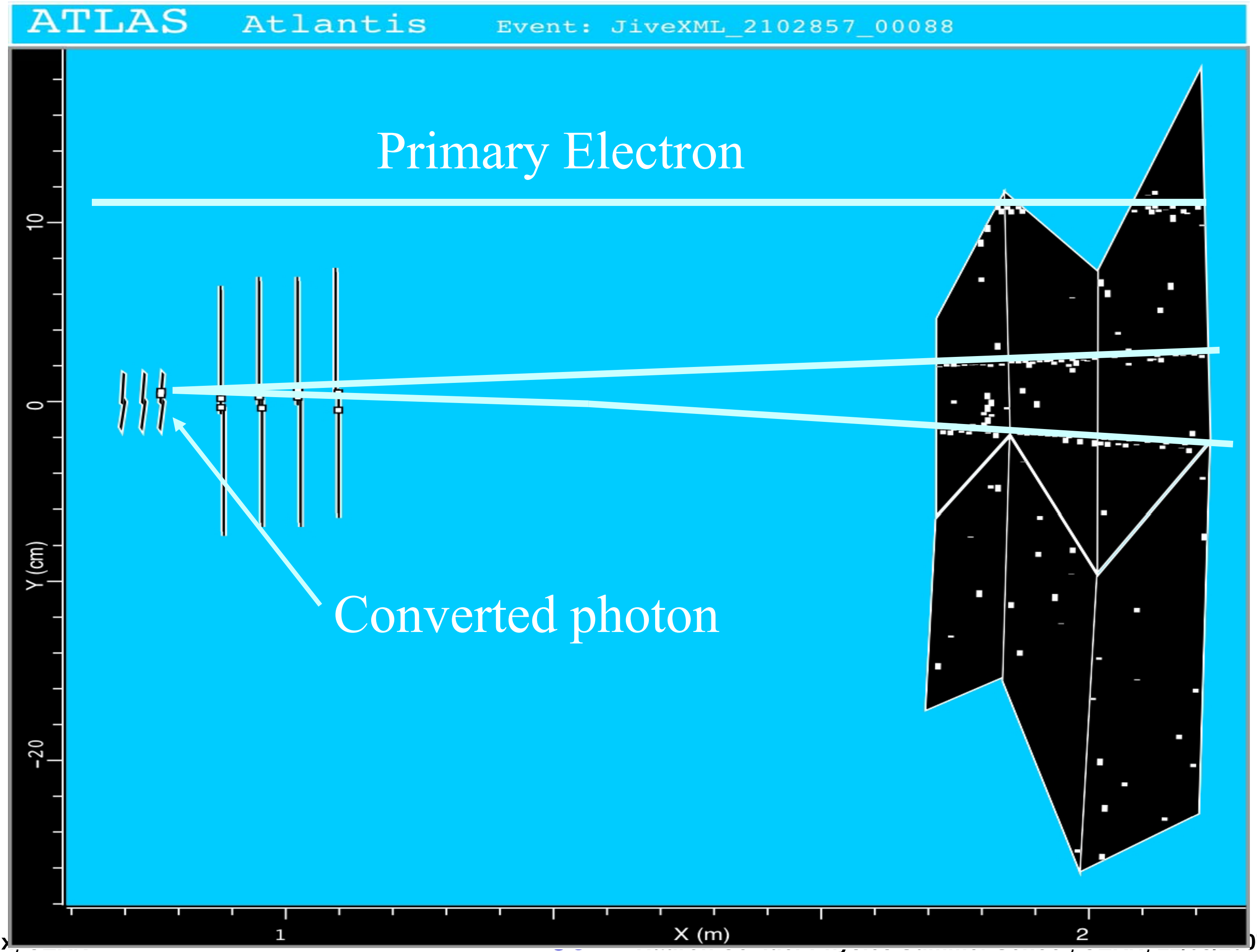
In addition:

1) Use only samplings 2 & 3 for splitting clusters, sampling 1 having a very coarse φ granularity;

2) Introduce energy sharing between common cluster cells in sampling 1.

Matching tracks to clusters

Photon Run 2102857 event # 88



Primary Electron

Converted photon

Electrons and photons in ATLAS/CMS: conclusions

Electron/photon ID in ATLAS and CMS will be a challenging and exciting task (harsher environment than at Tevatron, larger QCD backgrounds, more material in trackers)

But LHC detectors are better in many respects! Software is on its way to meet the challenge!

Huge effort in terms of understanding performance of detectors as installed ahead of us (calibration of calorimeters and alignment of trackers, material effects)