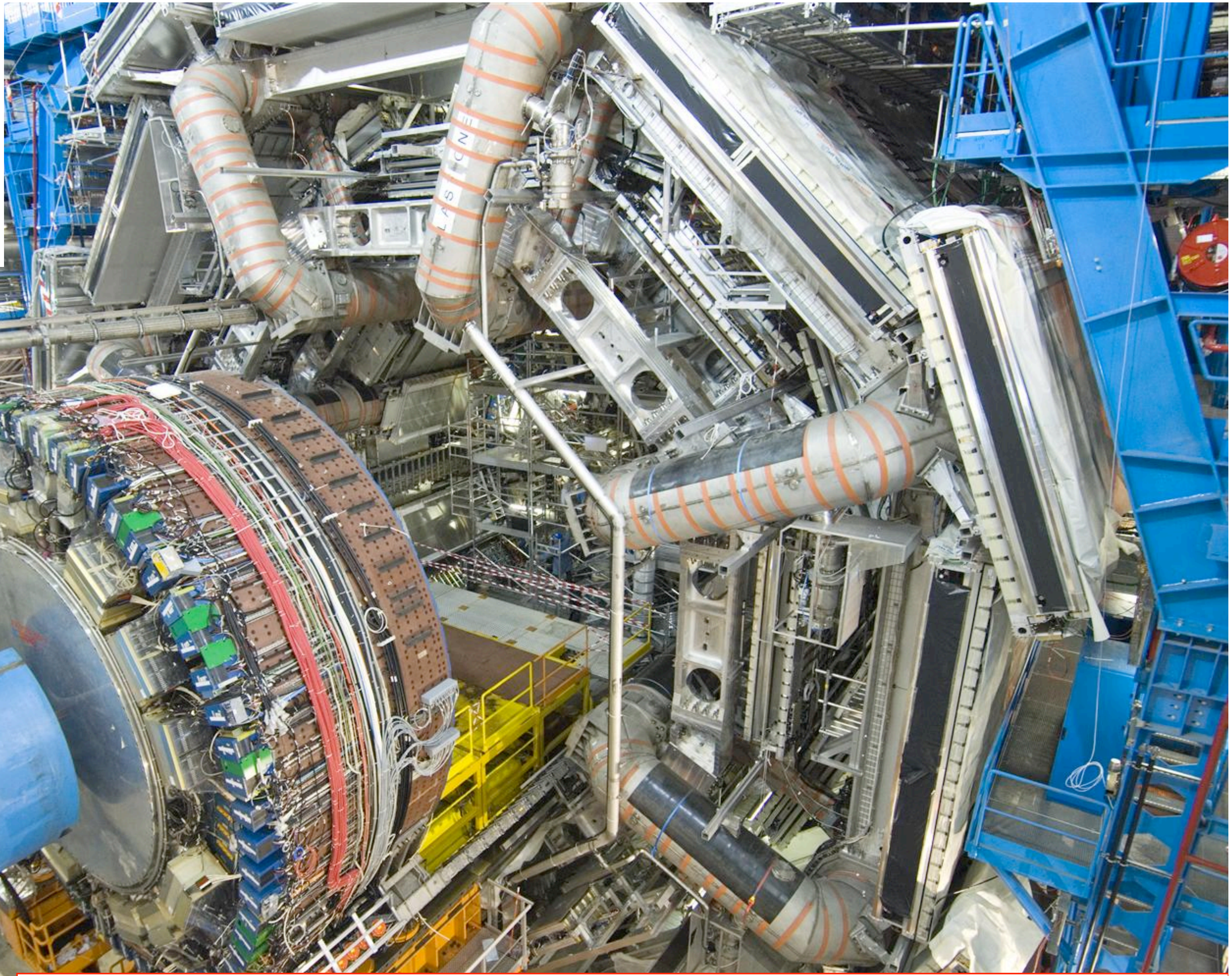


Experimental prospects at the LHC

Outline

- **Expected performance of ATLAS and CMS detectors**
- **What have the experiments learned this fall?**
- **Early physics: a few examples**

Next year is at last going to see the culmination of the work of thousands of people across the world over some 20 years: the excitement is really growing in the experiments as data-taking with proton-proton collisions at ~ 10 TeV approaches

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

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

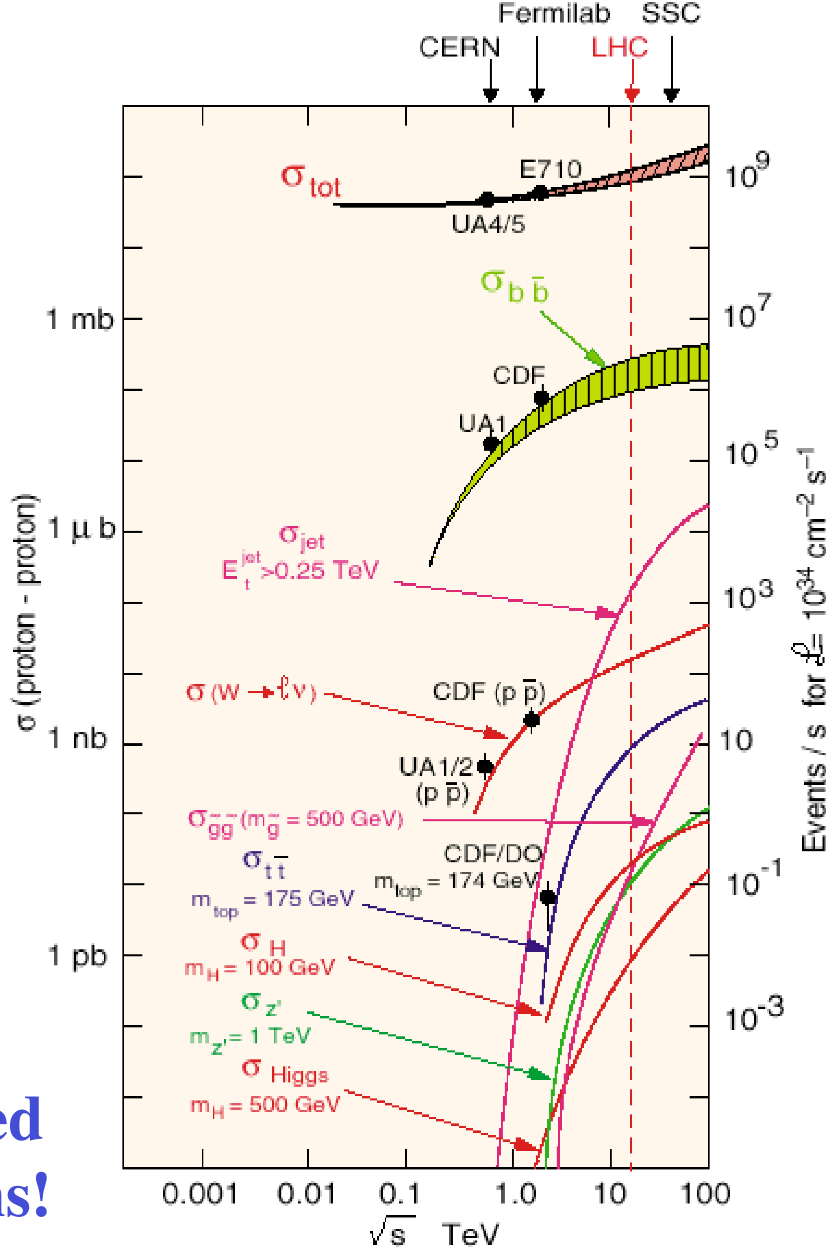
Orders of magnitude of event rates for various physics channels:

- **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

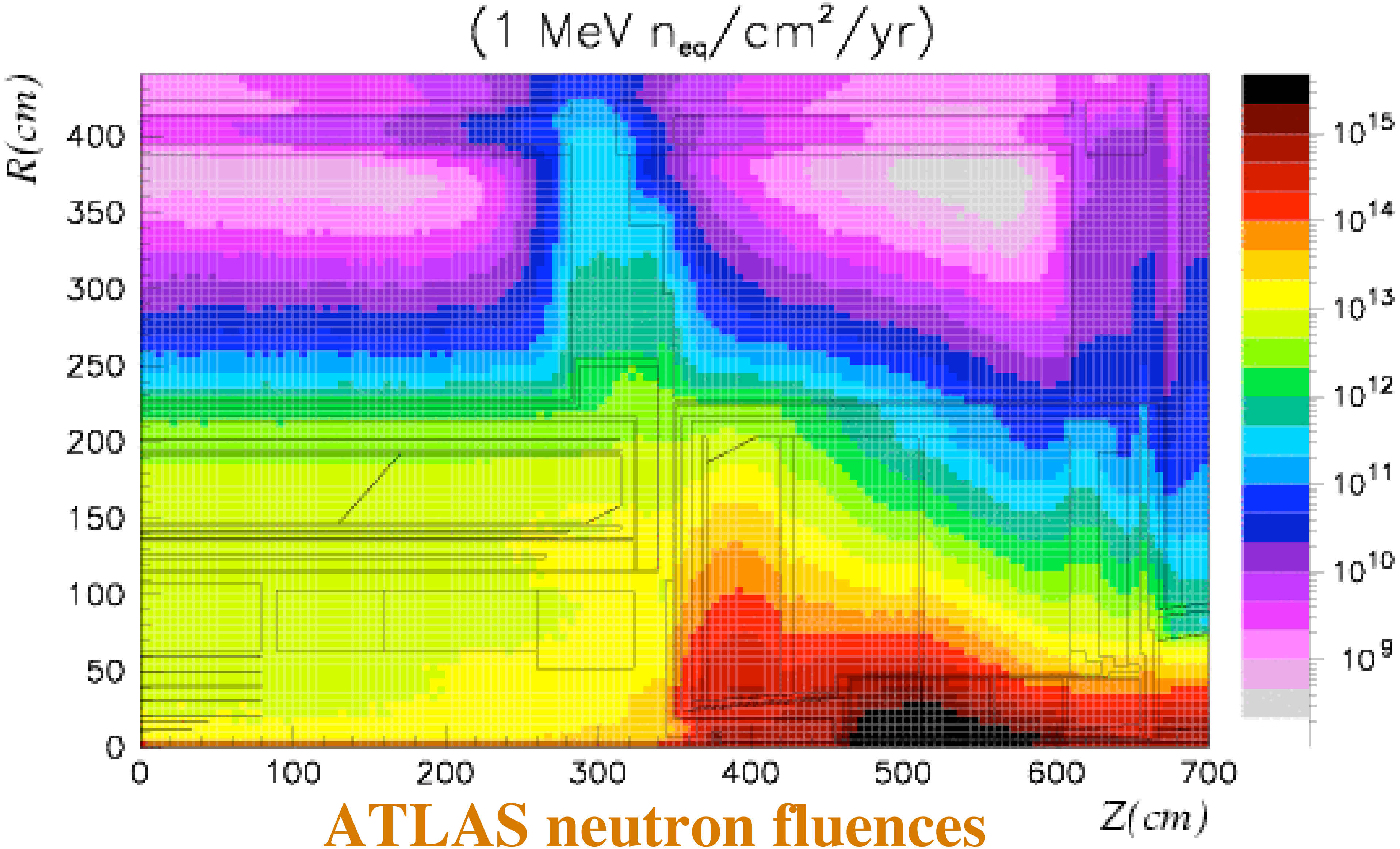
(and include branching ratios: ~ 10^{-2})

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!



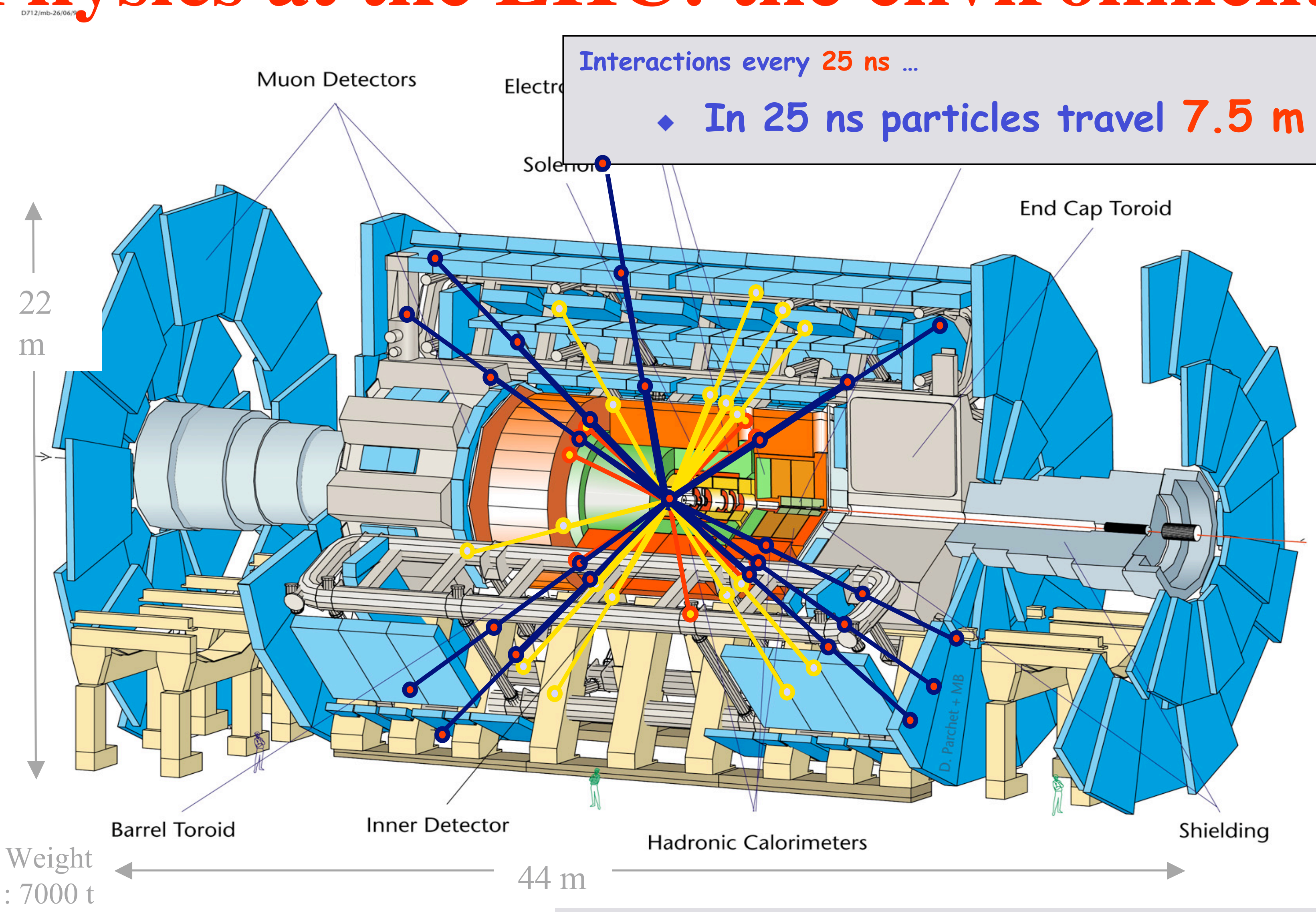
Physics at the LHC: the environment



ATLAS neutron fluences

Physics at the LHC: the environment

Time-of-flight



Interactions every 25 ns …

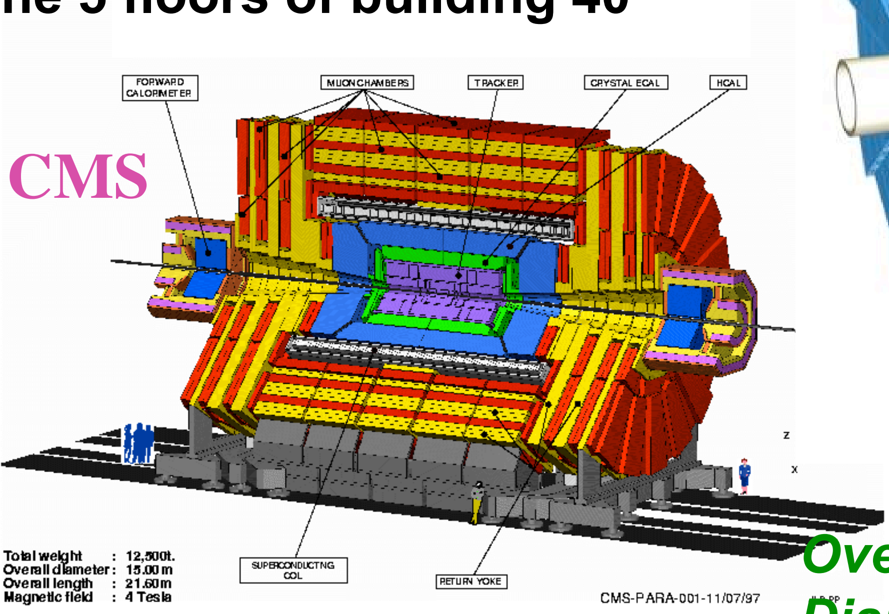
- ◆ In 25 ns particles travel 7.5 m

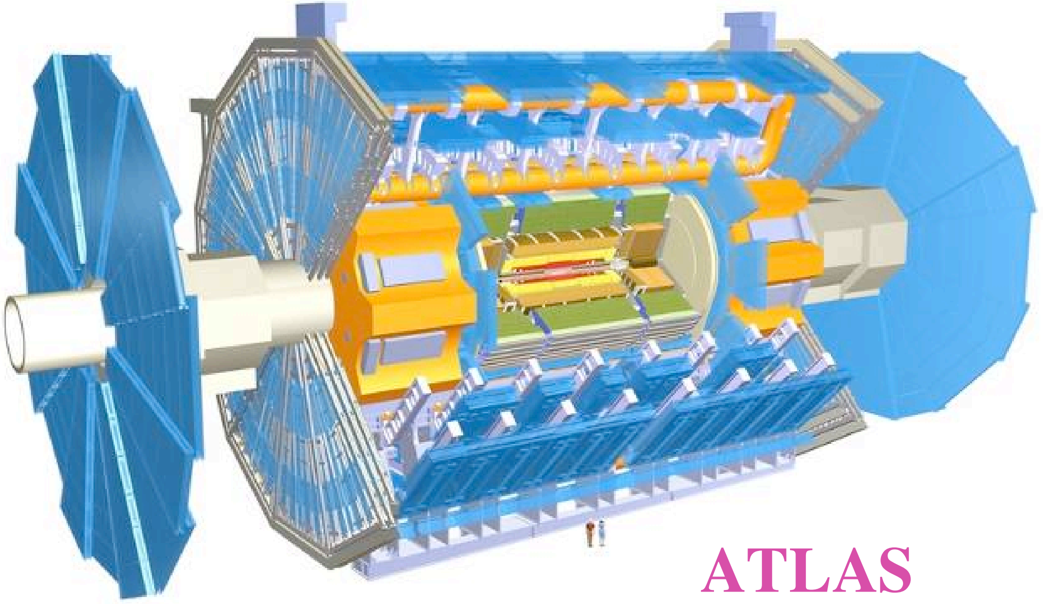
Cable length ~100 meters …

- ◆ In 25 ns signals travel 5 m

How huge are ATLAS and CMS?

ATLAS superimposed to the 5 floors of building 40





	ATLAS	***CMS***
Overall weight (tons)	*7000*	*12500*
Diameter	*22 m*	*15 m*
Length	*46 m*	*22 m*
Solenoid field	*2 T*	*4 T*

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
  - 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

ATLAS Collaboration

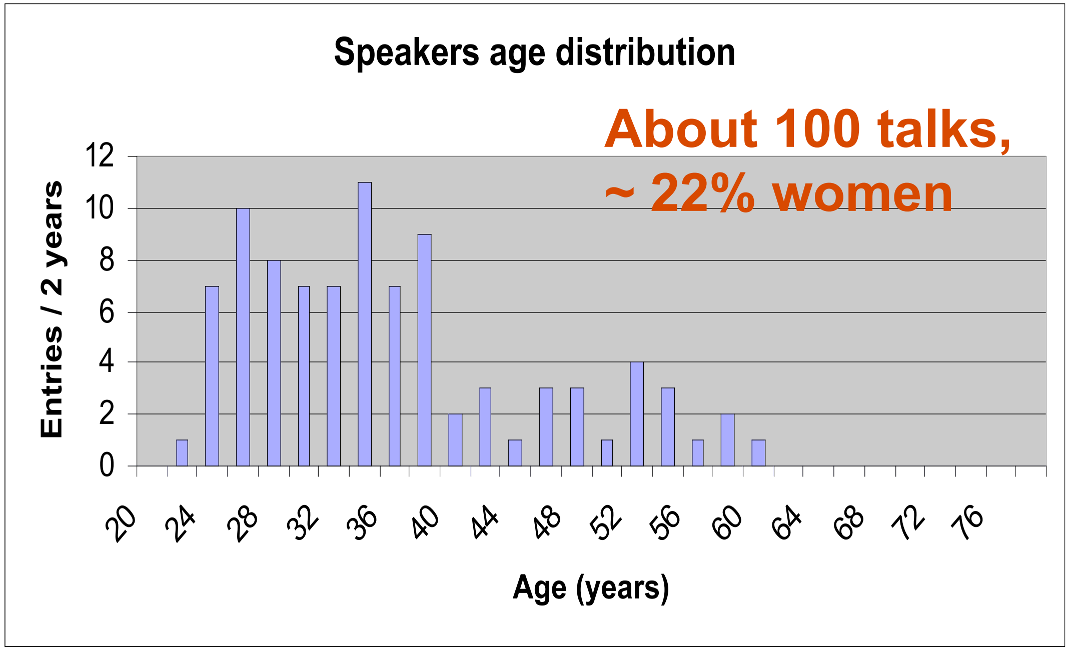
(As of July 2006)

35 Countries
162 Institutions
1650 Scientific Authors
(1300 with a PhD)

Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
China
Czech Republic
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan
Morocco
Netherlands
Norway
Poland
Portugal
Romania
Russia
Serbia
Slovakia
Slovenia
Spain
Sweden
Switzerland
Taiwan
Turkey
UK
USA
CERN
JINR

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, Bern, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Humboldt U Berlin, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Naples, Naruto UE, New Mexico, New York U, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Ritsumeikan, UFRJ Rio de Janeiro, Rochester, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, Southern Methodist Dallas, NPI Petersburg, SLAC, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, Wisconsin, Wuppertal, Yale, Yerevan

ATLAS physics workshop in Rome (June 2005)



About 100 talks, ~ 22% women

~ 450 participants

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

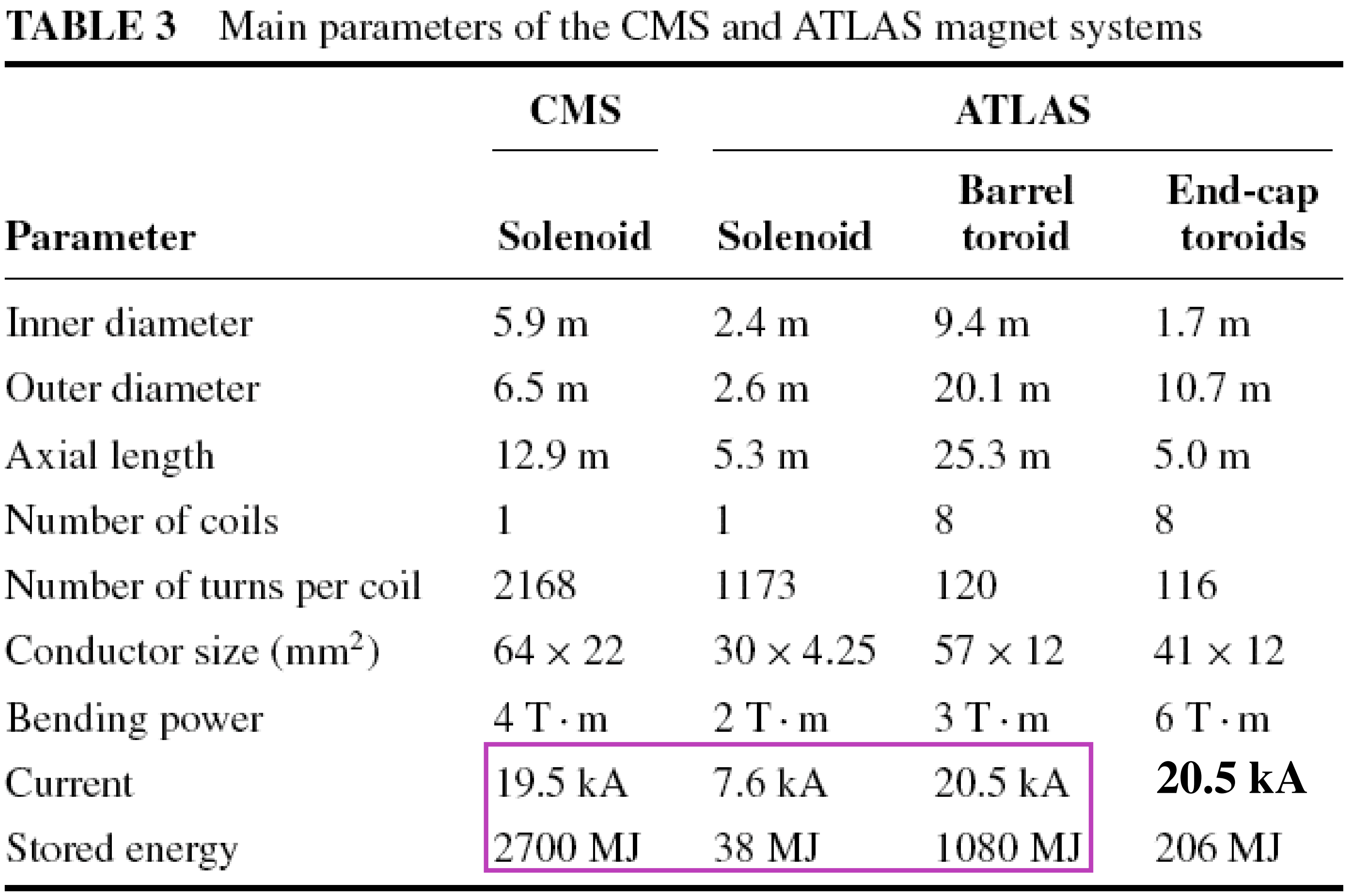


TABLE 3 Main parameters of the CMS and ATLAS magnet systems

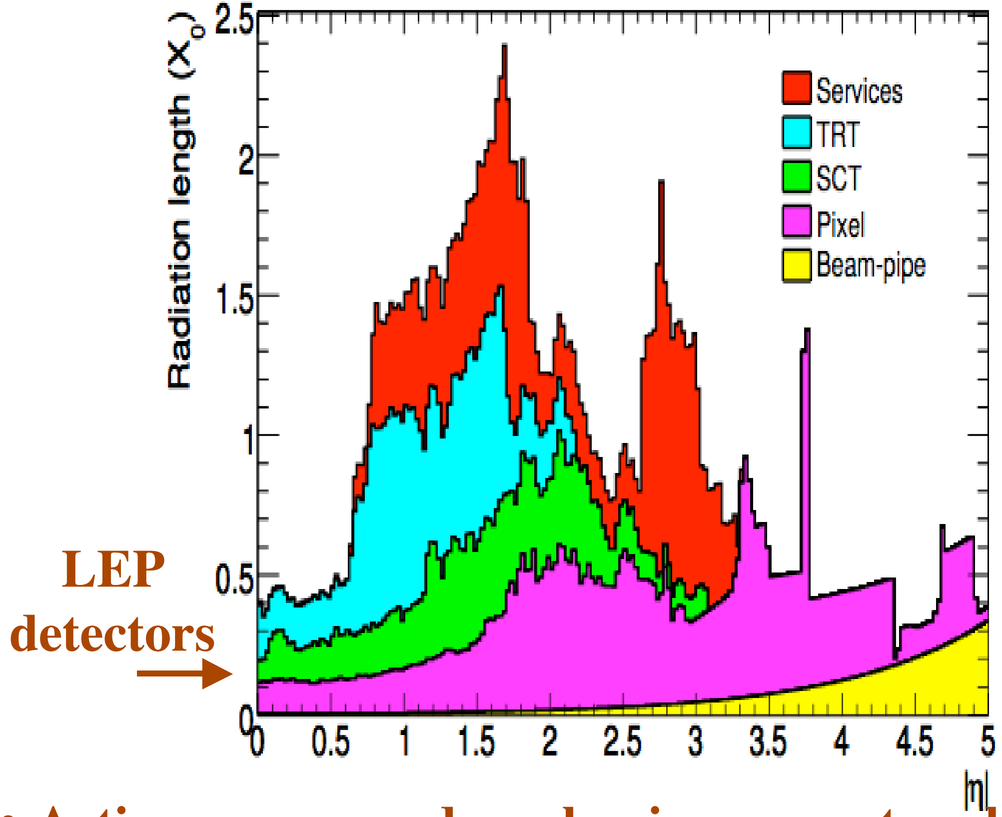
	CMS	**ATLAS**		
Parameter	**Solenoid**	**Solenoid**	**Barrel toroid**	**End-cap toroids**
Inner diameter	5.9 m	2.4 m	9.4 m	1.7 m
Outer diameter	6.5 m	2.6 m	20.1 m	10.7 m
Axial length	12.9 m	5.3 m	25.3 m	5.0 m
Number of coils	1	1	8	8
Number of turns per coil	2168	1173	120	116
Conductor size (mm^2)	64 × 22	30 × 4.25	57 × 12	41 × 12
Bending power	4 T · m	2 T · m	3 T · m	6 T · 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

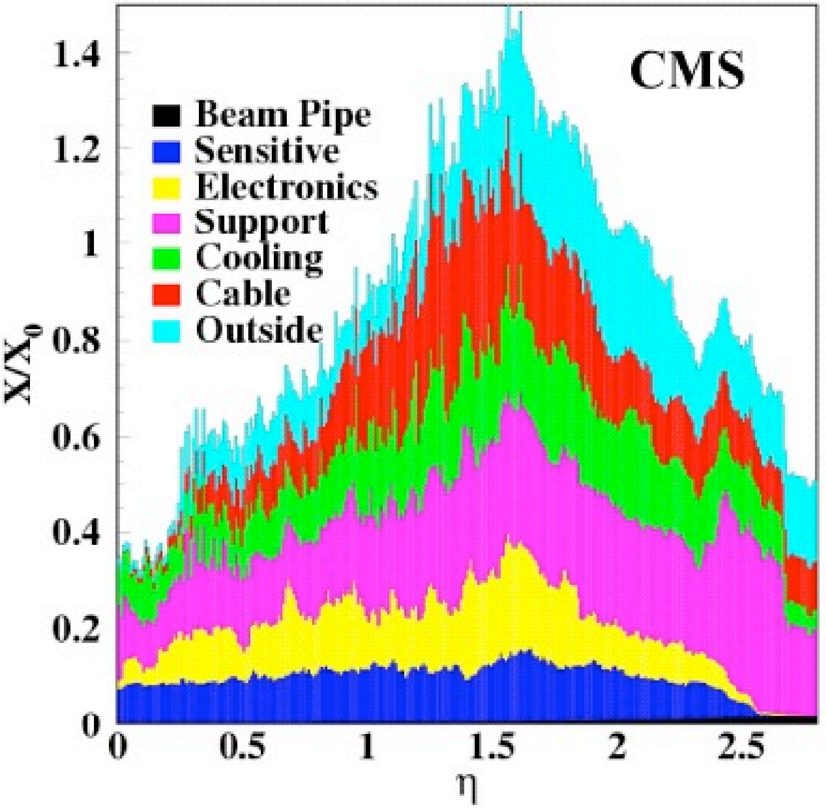
Amount of material in ATLAS and CMS inner trackers

Weight: 4.5 tons



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

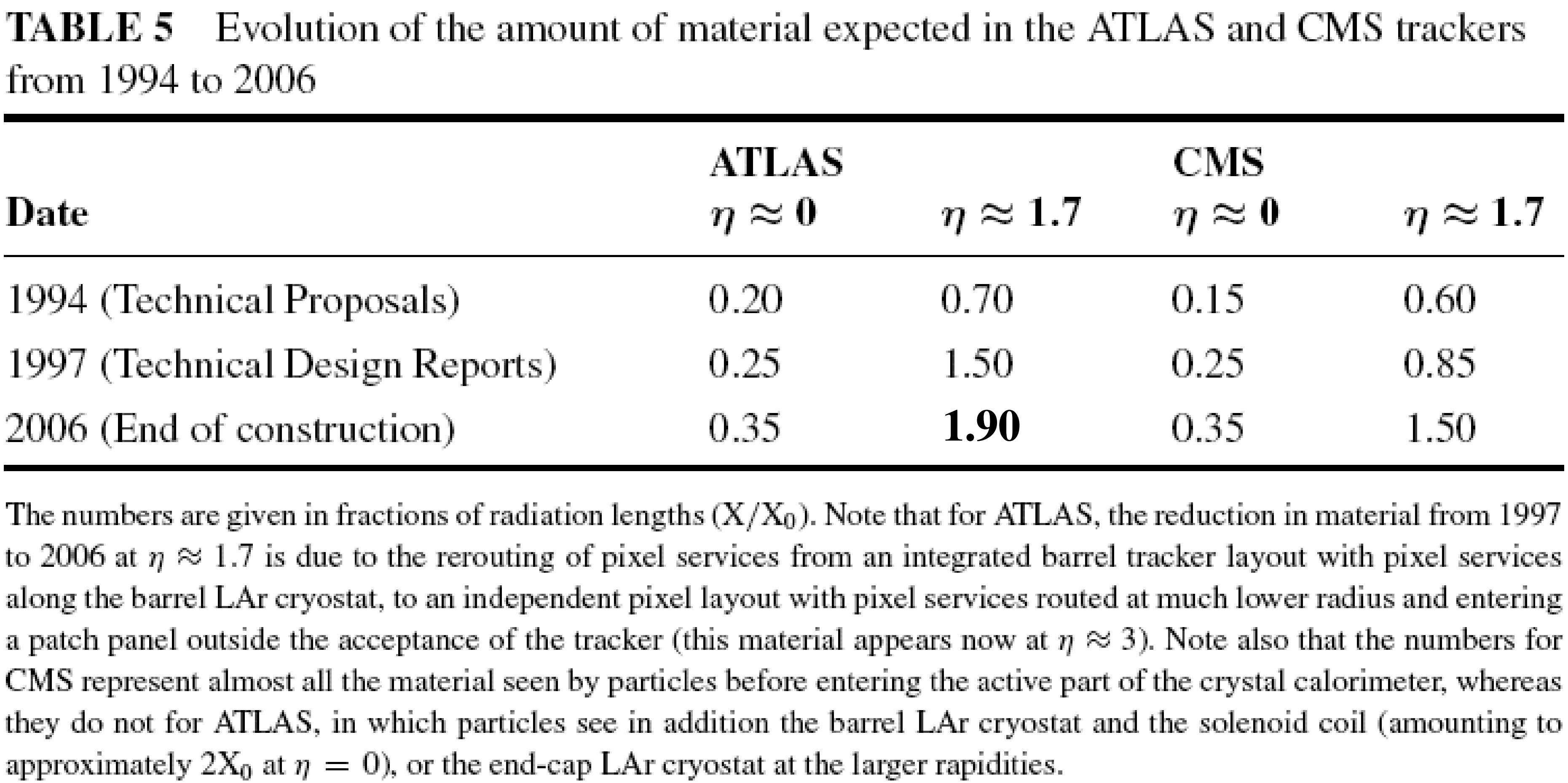


TABLE 5 Evolution of the amount of material expected in the ATLAS and CMS trackers from 1994 to 2006

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	**1.90**	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

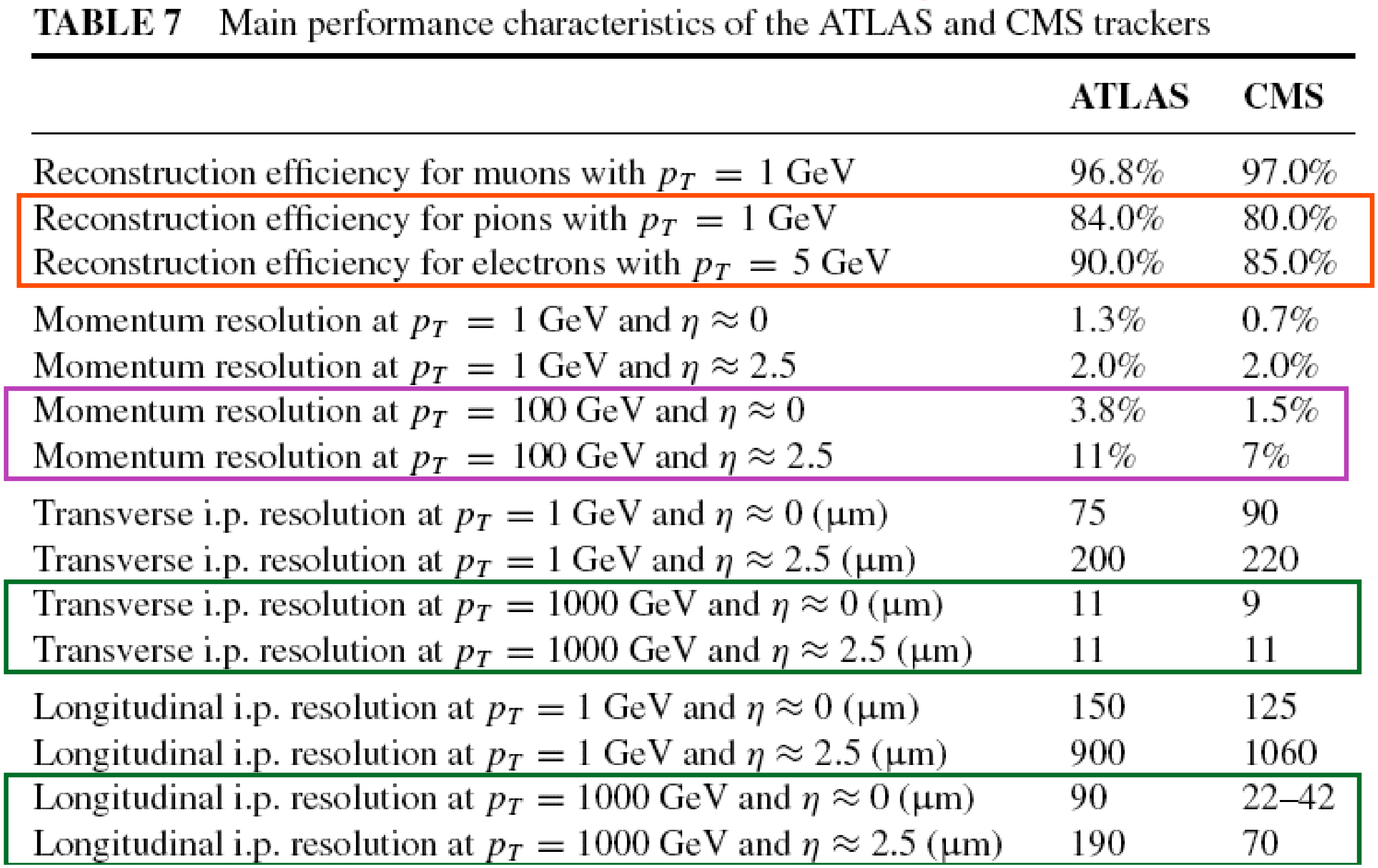


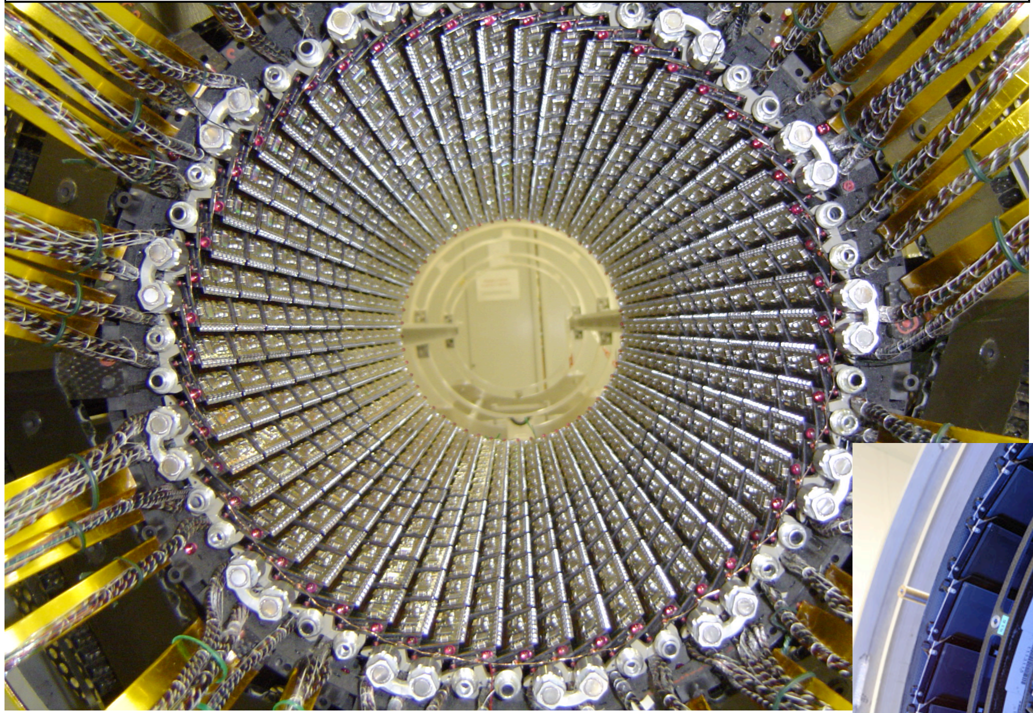
TABLE 7 Main performance characteristics of the ATLAS and CMS trackers

	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!

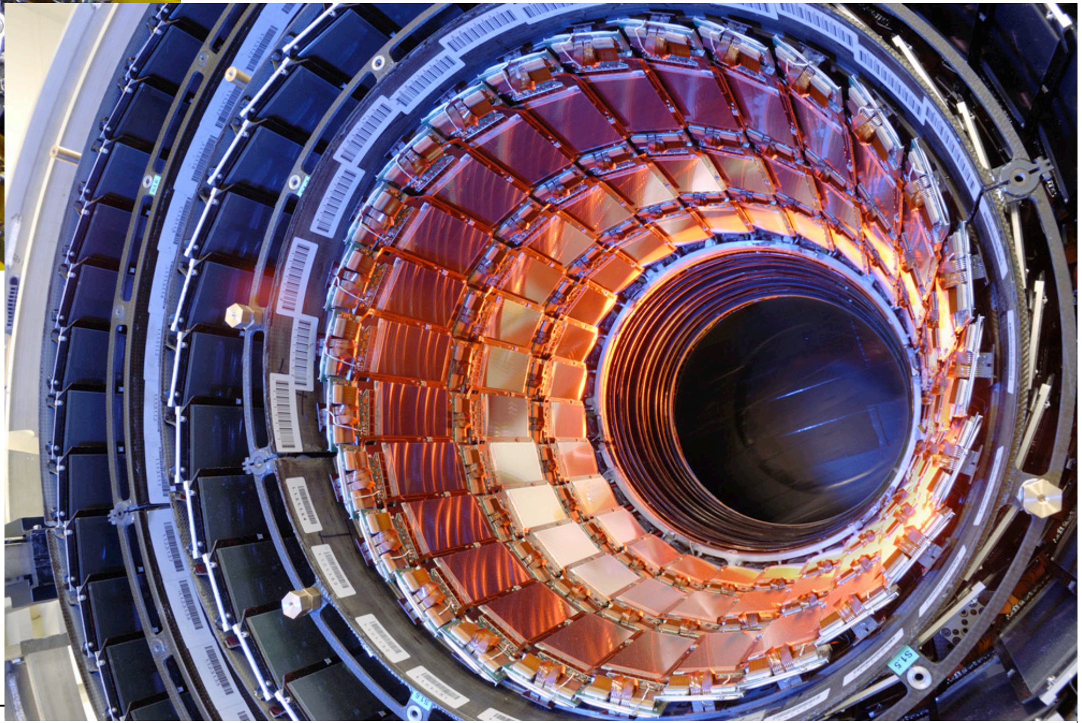
ATLAS pixels, September 2006



- 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

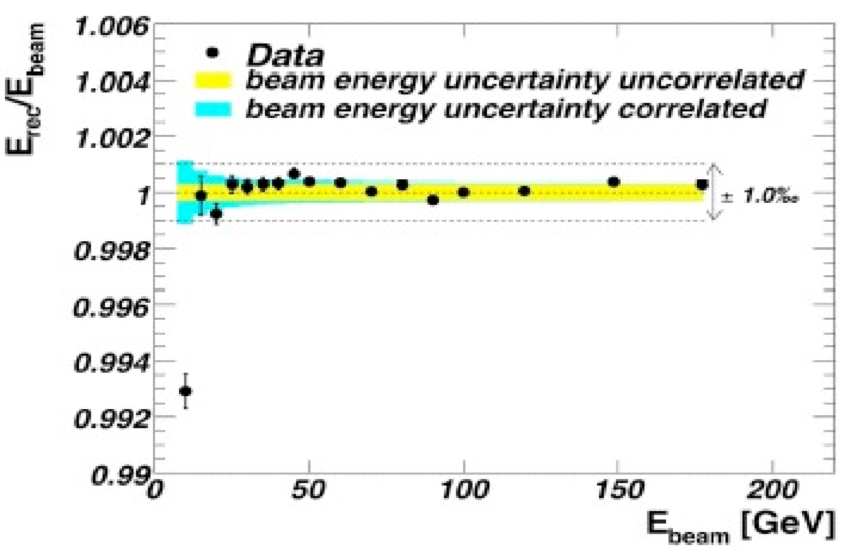


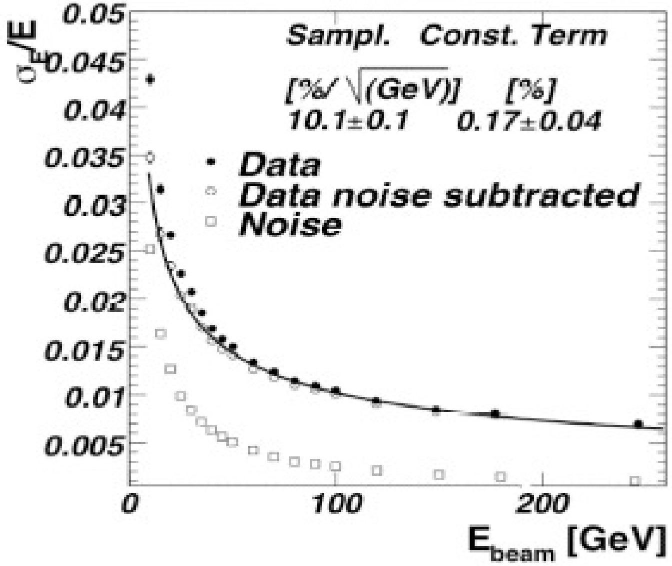
CMS Tracker Inner Barrel, November 2006

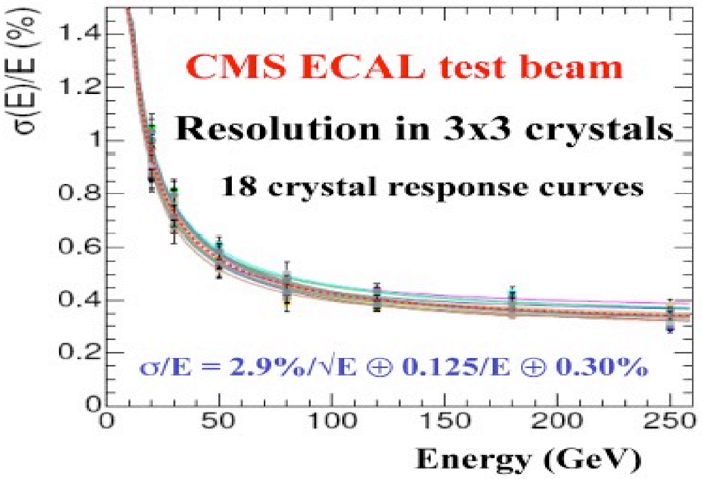
D. Froidevaux (CERN)

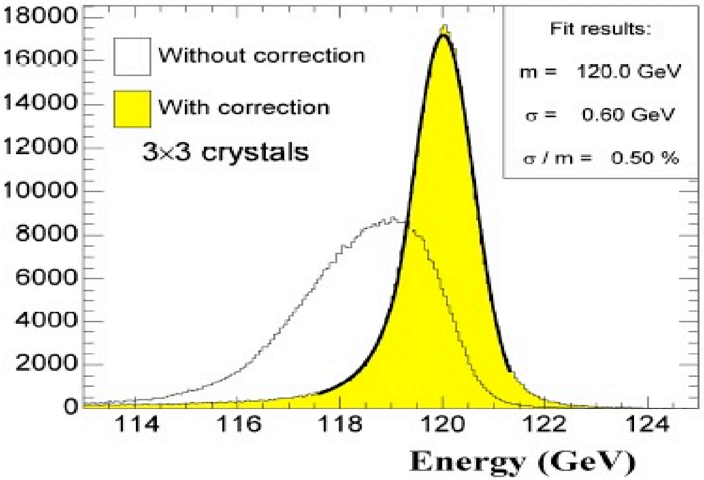
ATLAS/CMS: from design to reality

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









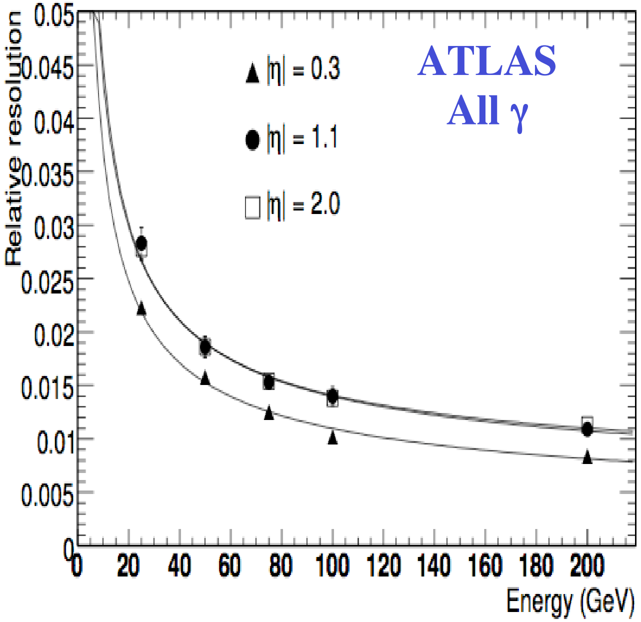
- **Stand-alone performance measured in beams with electrons from 10 to 250 GeV**

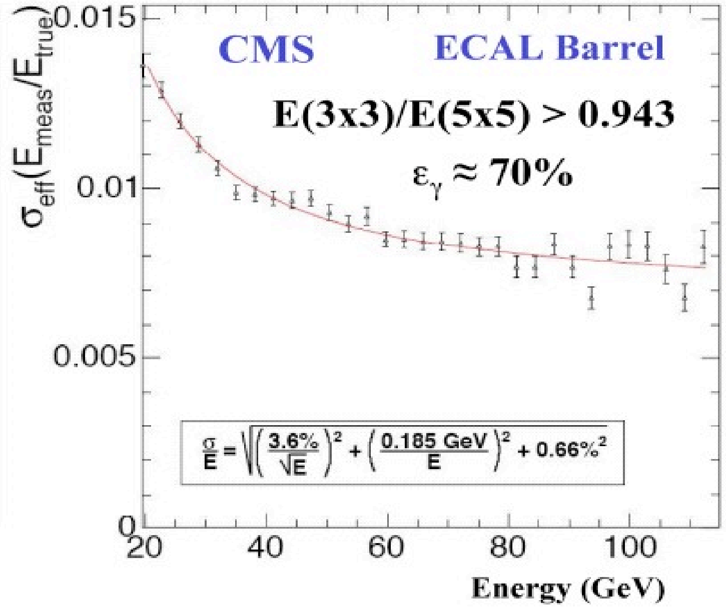
ATLAS/CMS: from design to reality

Actual performance expected in real detector quite different!!

Photons at 100 GeV

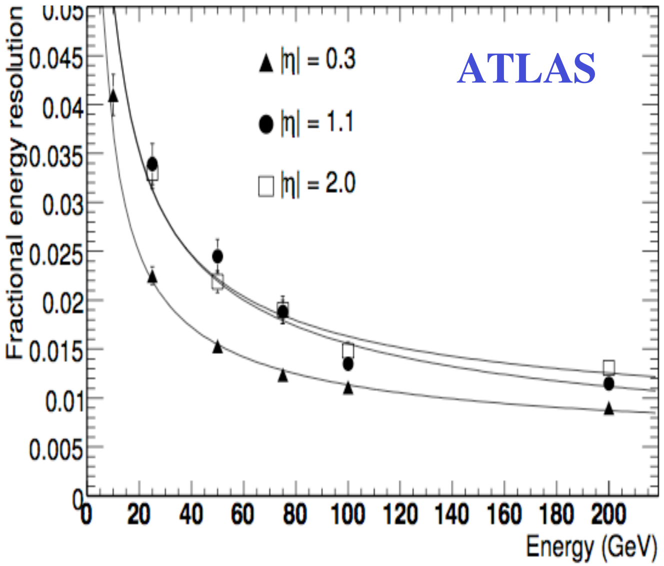
ATLAS: 1-1.5%
energy resol. (all γ)
CMS: 0.8%
energy resol.
(ε_γ ~ 70%)

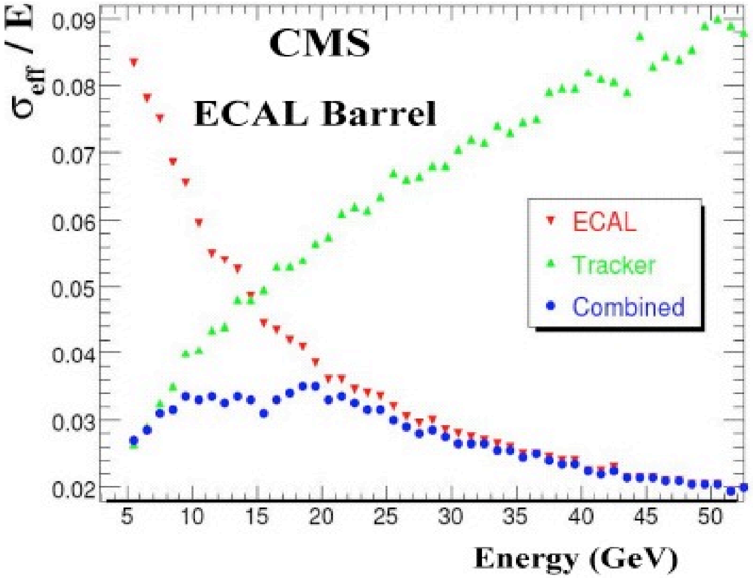




Electrons at 50 GeV

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





D. Froidevaux (CERN)

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 $H \rightarrow \tau\tau \rightarrow l\nu_l\nu_\tau \; h\nu_\tau$

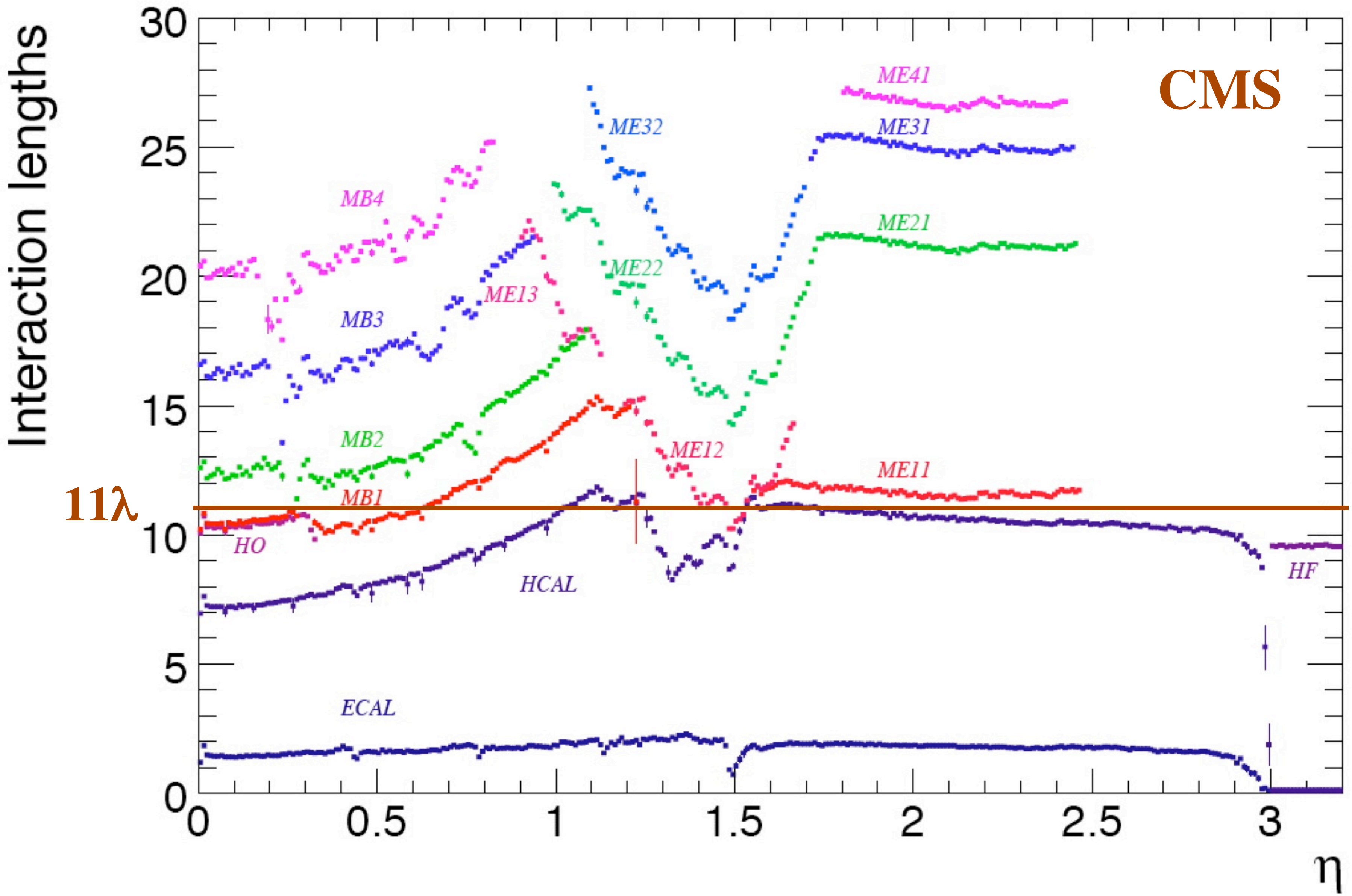
✓ the detector must therefore be quite hermetic

→ transverse energy flow fully measured with reasonable accuracy

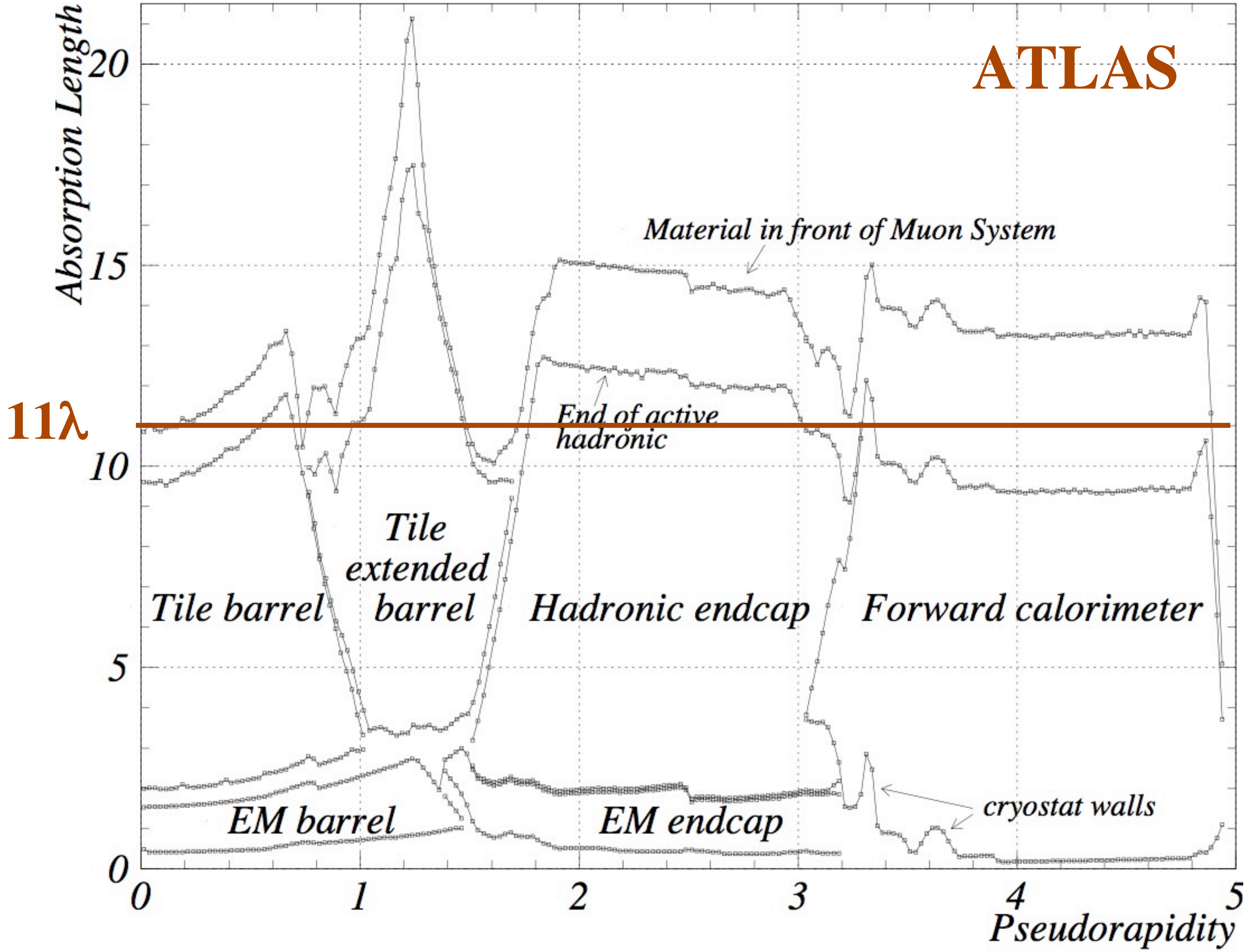
→ no neutrino escapes undetected

→ no human enters without major effort (fast access to some parts of ATLAS/CMS quite difficult)

ATLAS/CMS: from design to reality

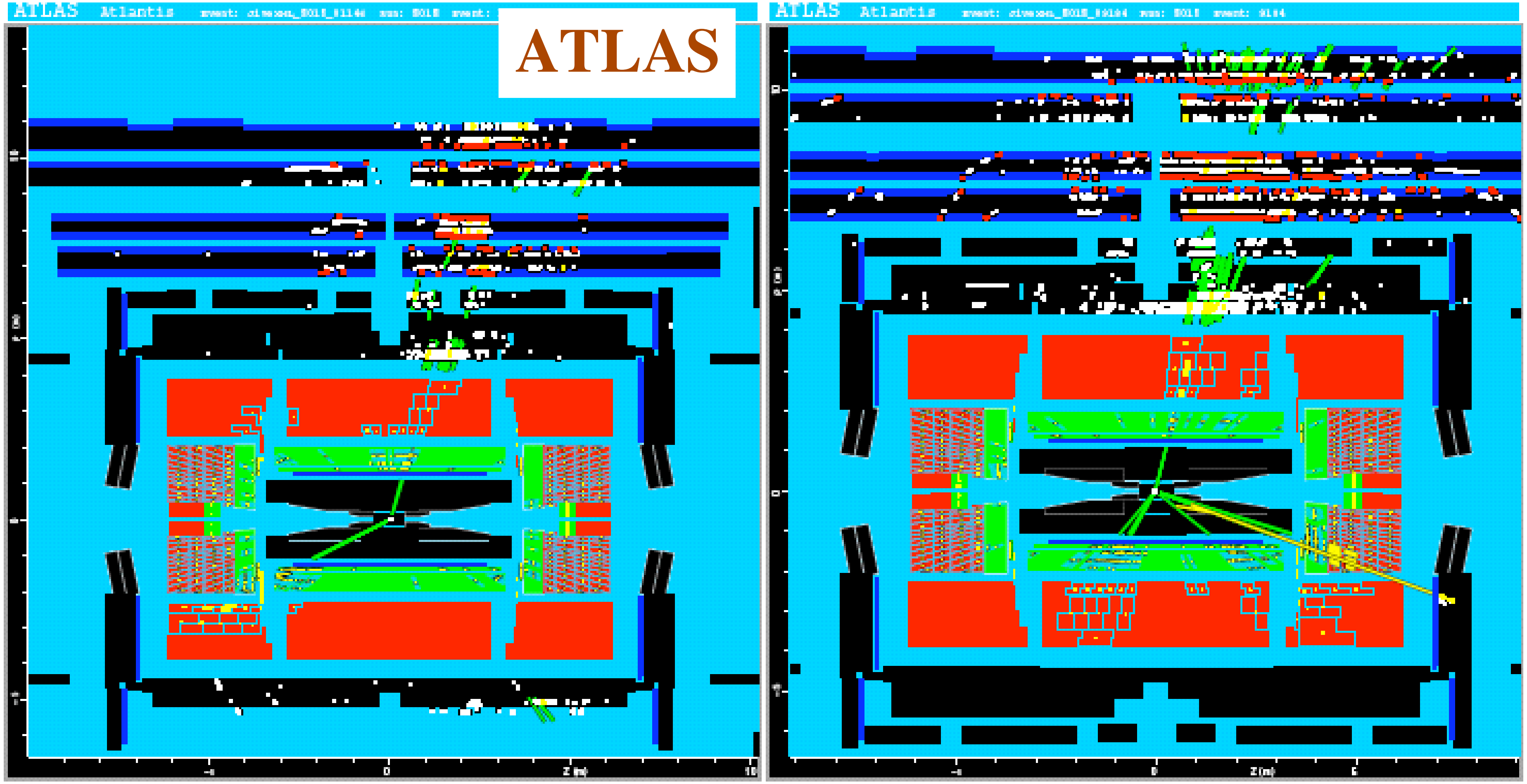


ATLAS/CMS: from design to reality



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!

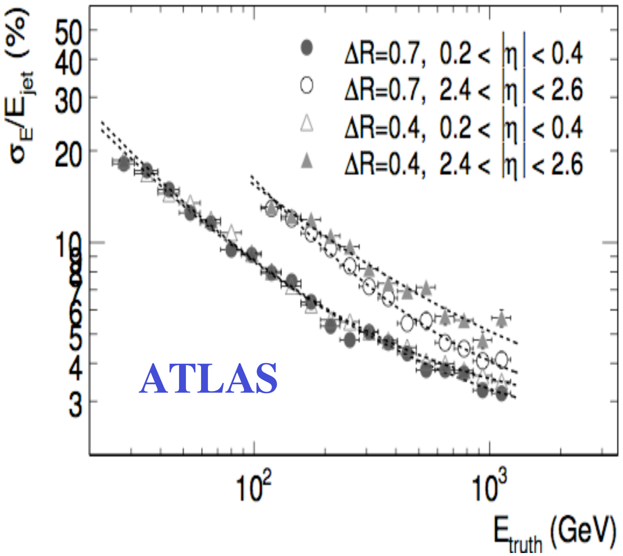


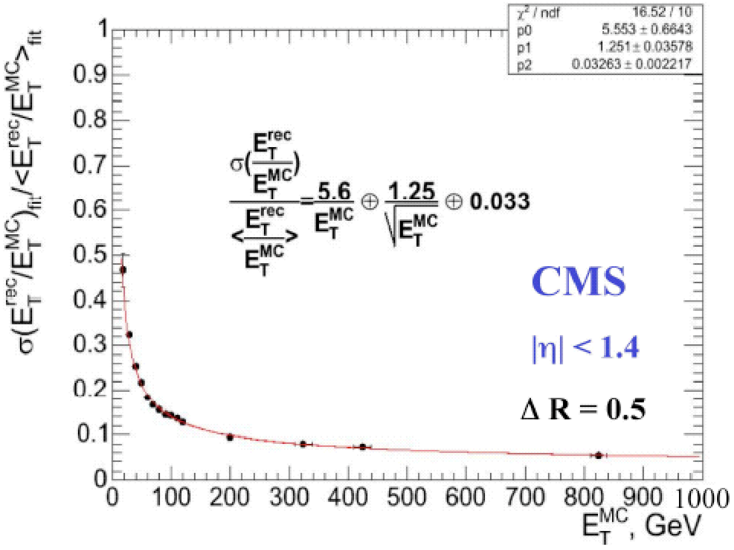
ATLAS/CMS: from design to reality

Biggest difference in performance perhaps for hadronic calo

Jets at 1000 GeV

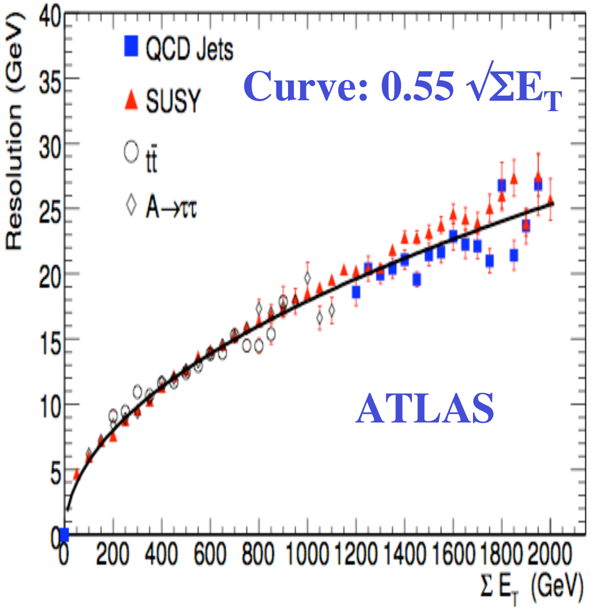
ATLAS ~ 3%
energy resolution
CMS ~ 5%
energy resolution,
(but expect sizable
improvement
using tracks at lowe
energies)

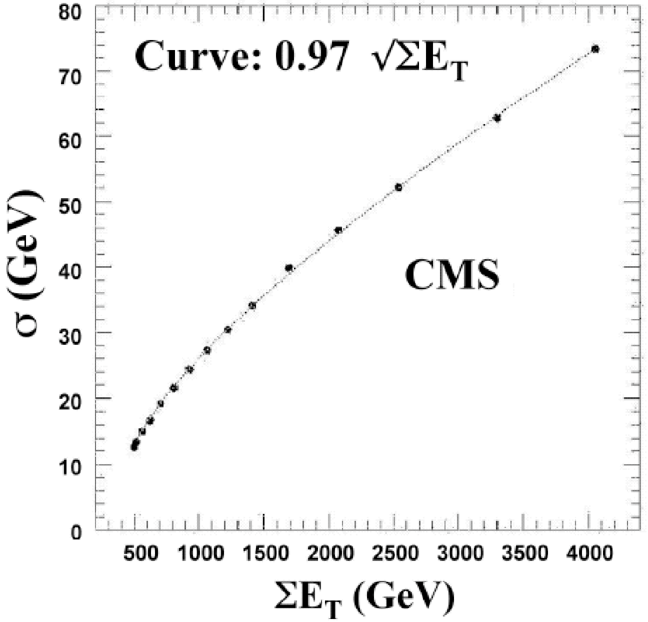




E_T^{miss} at ΣE_T = 2000 GeV

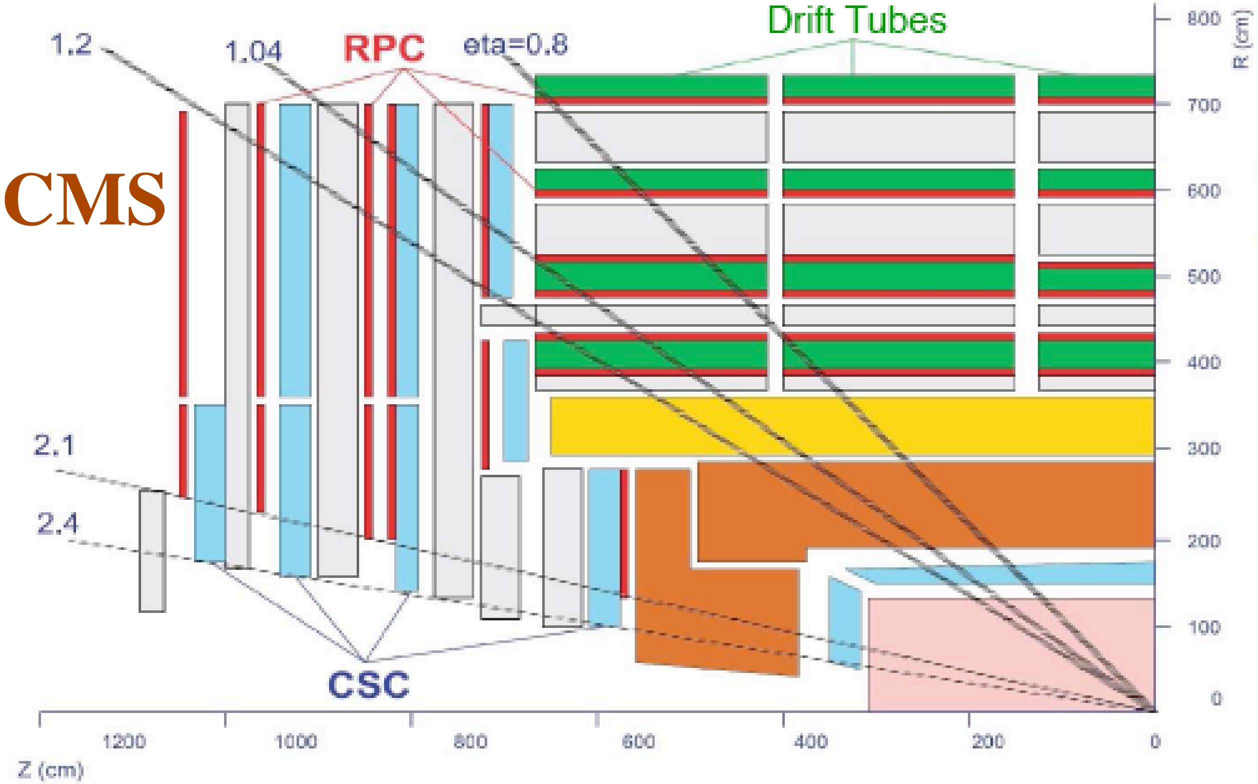
ATLAS: σ ~ 25 GeV
CMS: σ ~ 40 GeV
This may be important
for high mass H/A to ττ

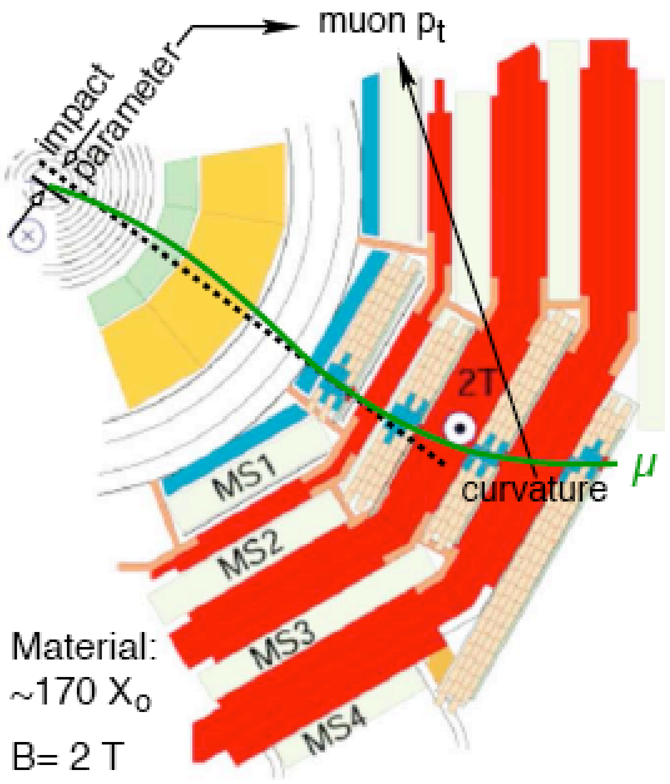




ATLAS/CMS: from design to reality

CMS

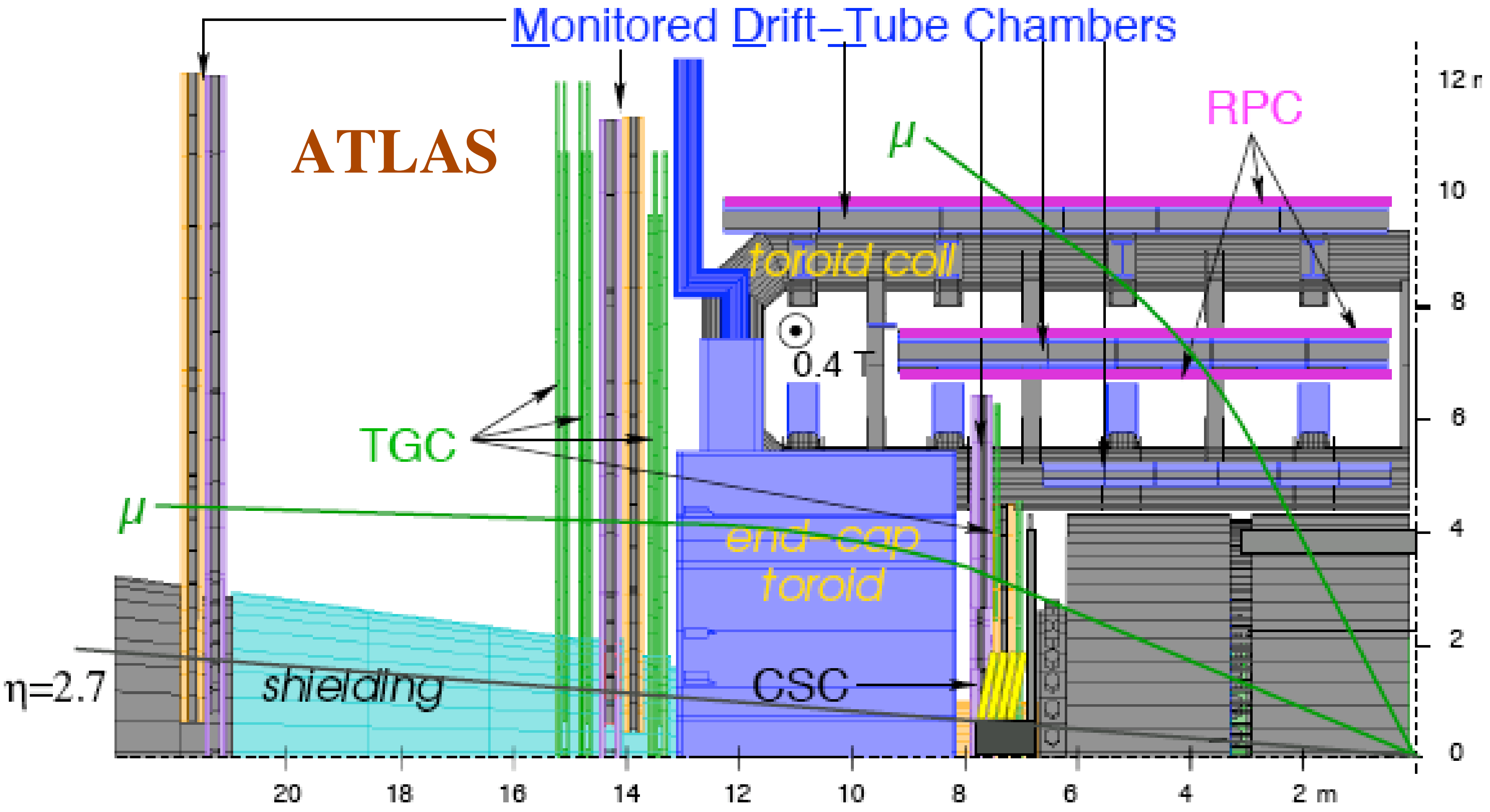




CMS muon spectrometer

- 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 $\eta \times \phi$ coverage ($|\eta| < 2.7$)**

ATLAS/CMS: from design to reality

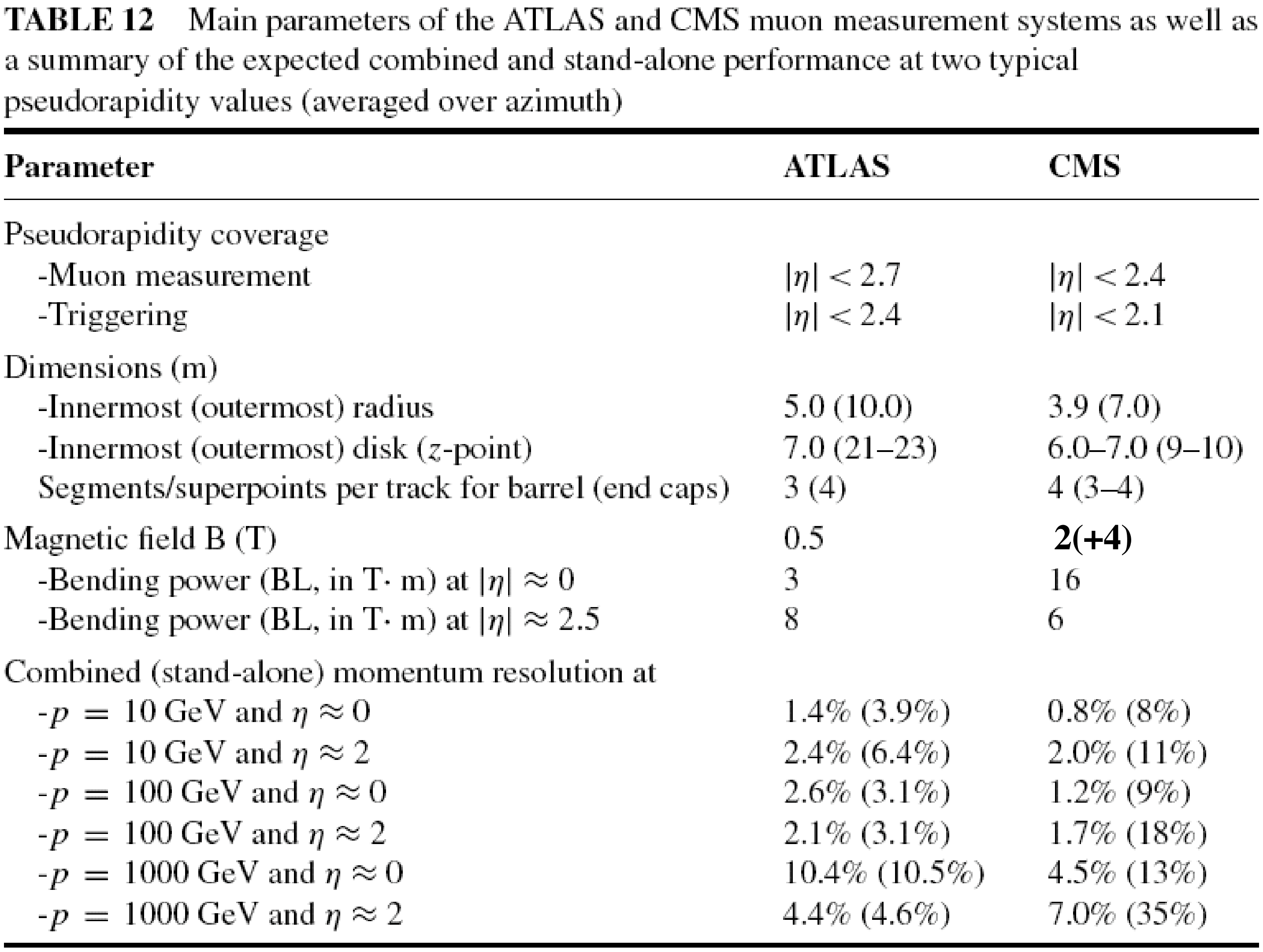


TABLE 12 Main parameters of the ATLAS and CMS muon measurement systems as well as a summary of the expected combined and stand-alone performance at two typical pseudorapidity values (averaged over azimuth)

Parameter	**ATLAS**	**CMS**
Pseudorapidity coverage		
-Muon measurement	$\lvert\eta\rvert < 2.7$	$\lvert\eta\rvert < 2.4$
-Triggering	$\lvert\eta\rvert < 2.4$	$\lvert\eta\rvert < 2.1$
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 $\lvert\eta\rvert \approx 0$	3	16
-Bending power (BL, in T· m) at $\lvert\eta\rvert \approx 2.5$	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

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

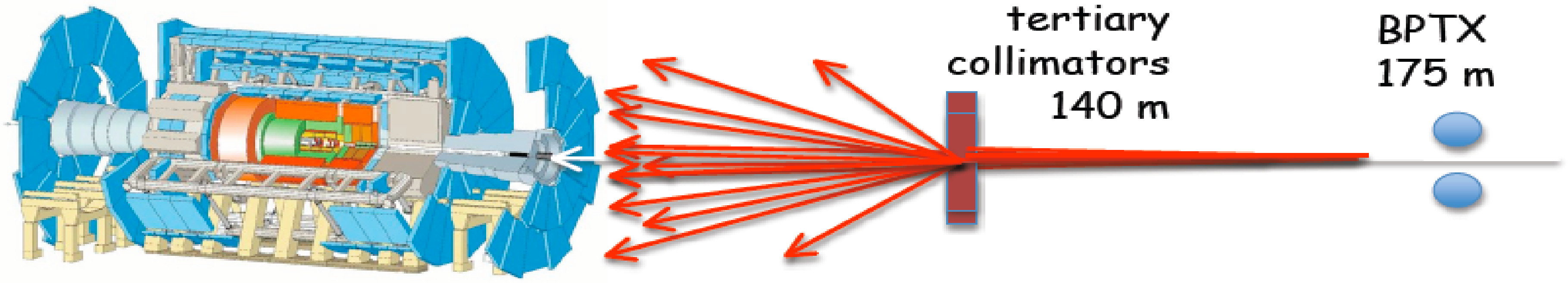
Current status of CMS:

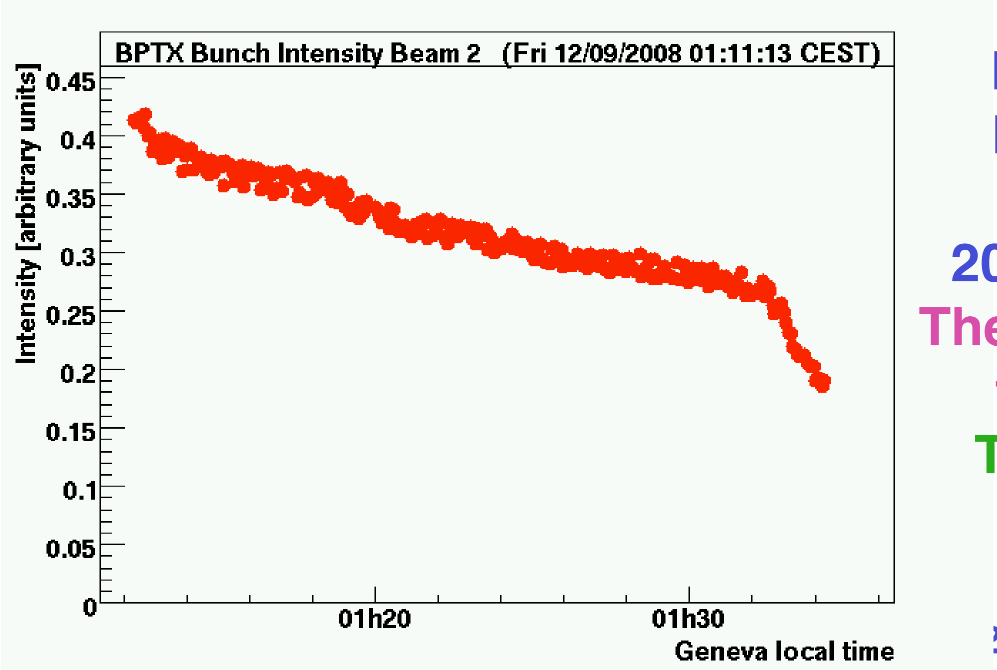
pixels and end-cap crystals installed last summer, a real feat: just in time!

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.

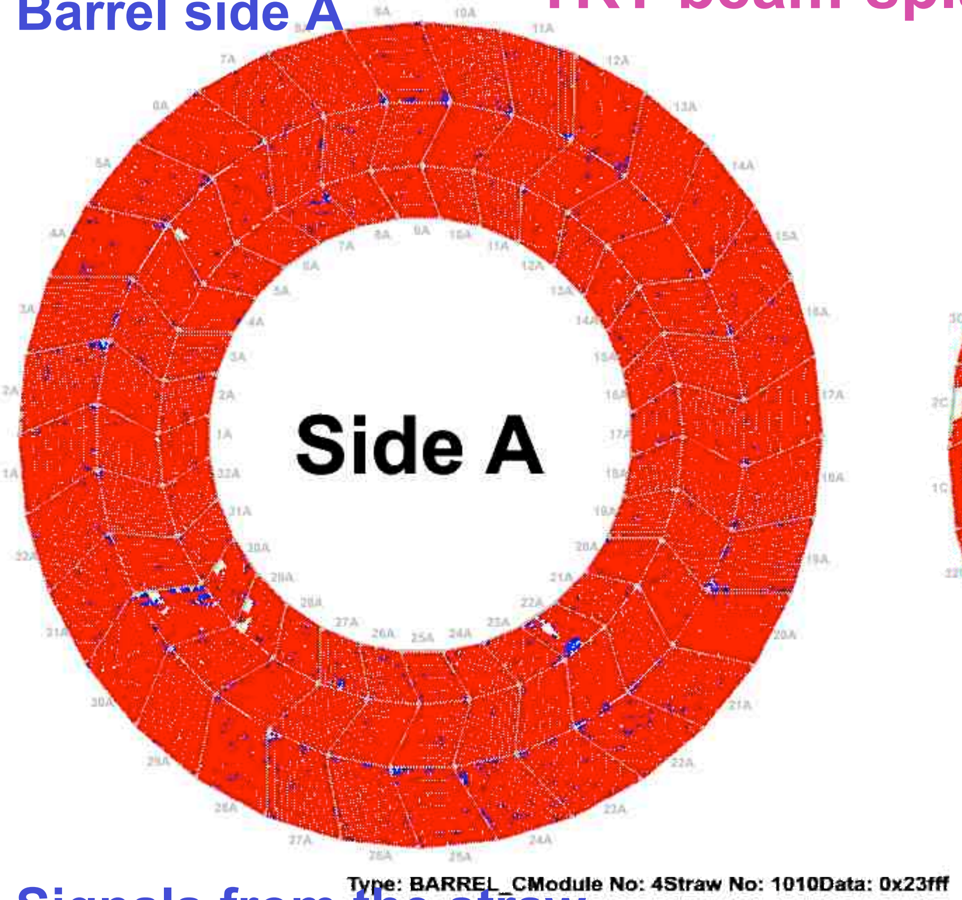
The relative precision determined from the scatter of data points is 10%.

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

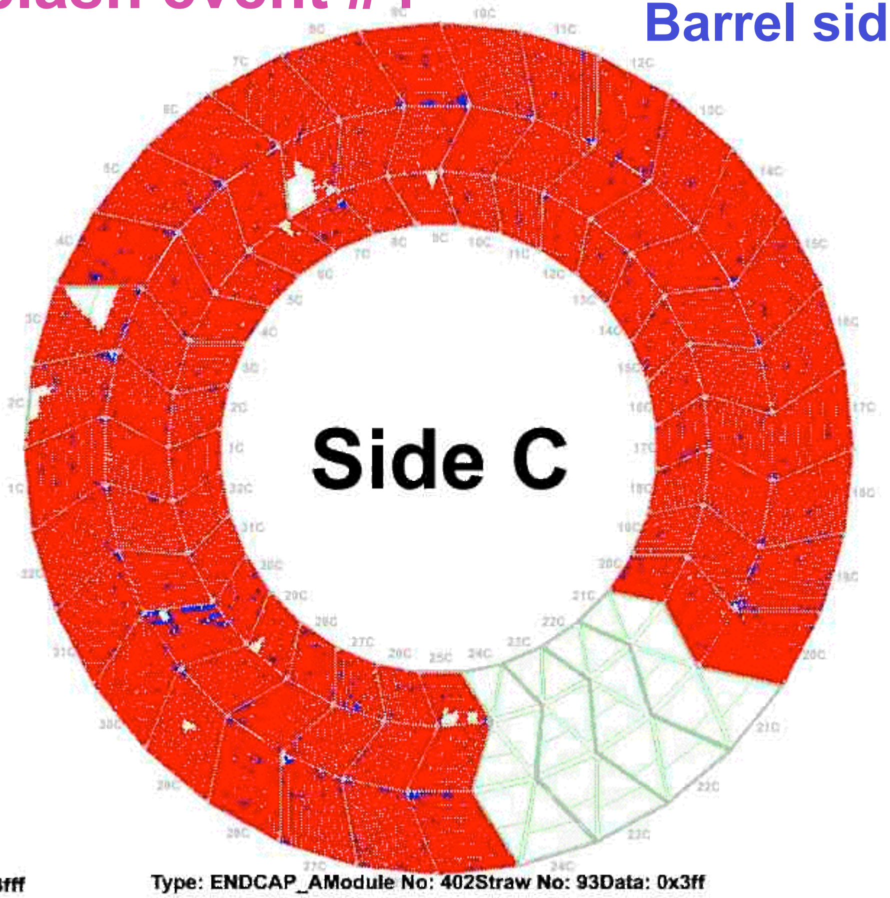
Beam splash from collimators in front of ATLAS

TRT beam-splash event #4

Barrel side A



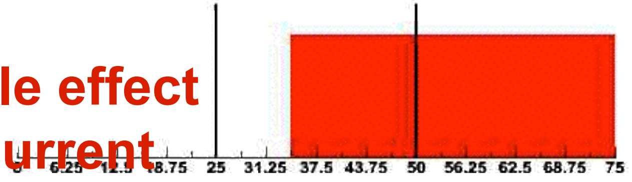
Barrel side C

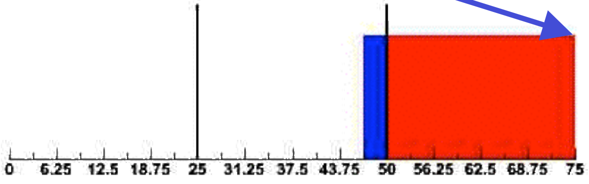


Signals from the straw
Red colour means HL
threshold fired.

Each straw signal has a trailing edge at 75ns

No noticeable effect
on the HV current



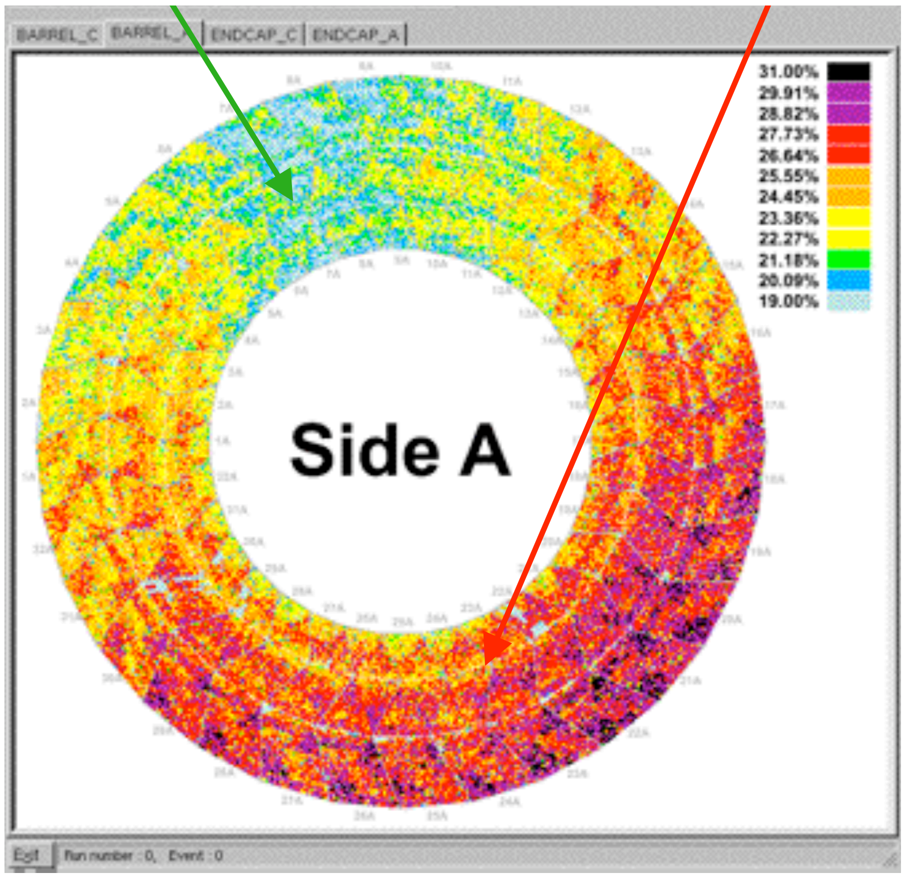


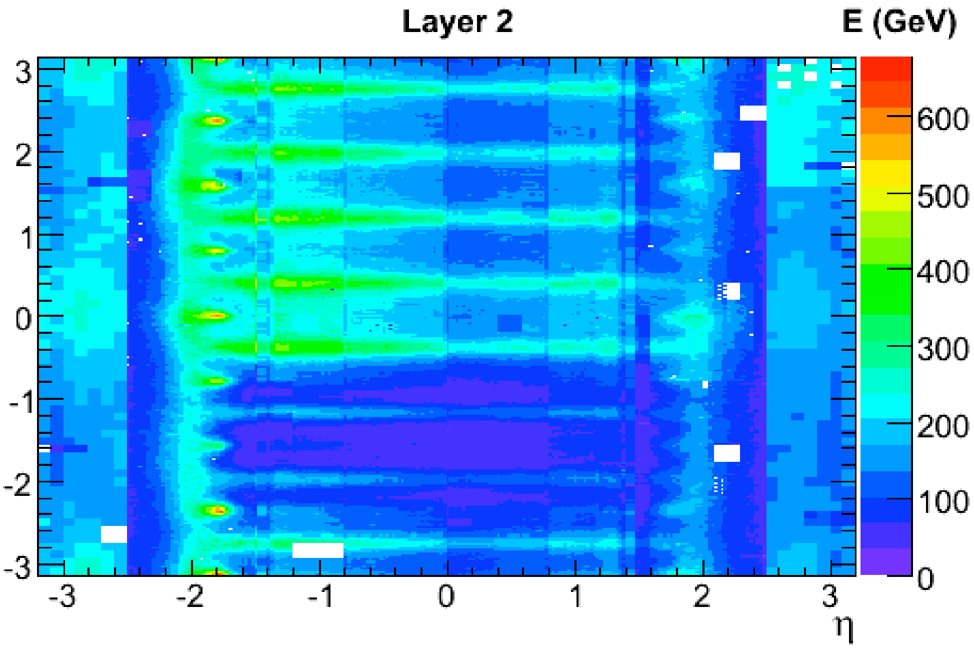
Beam splash from collimators in front of ATLAS

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

Differences in colour due to cosmic timing:

Top: early **Bottom: late**



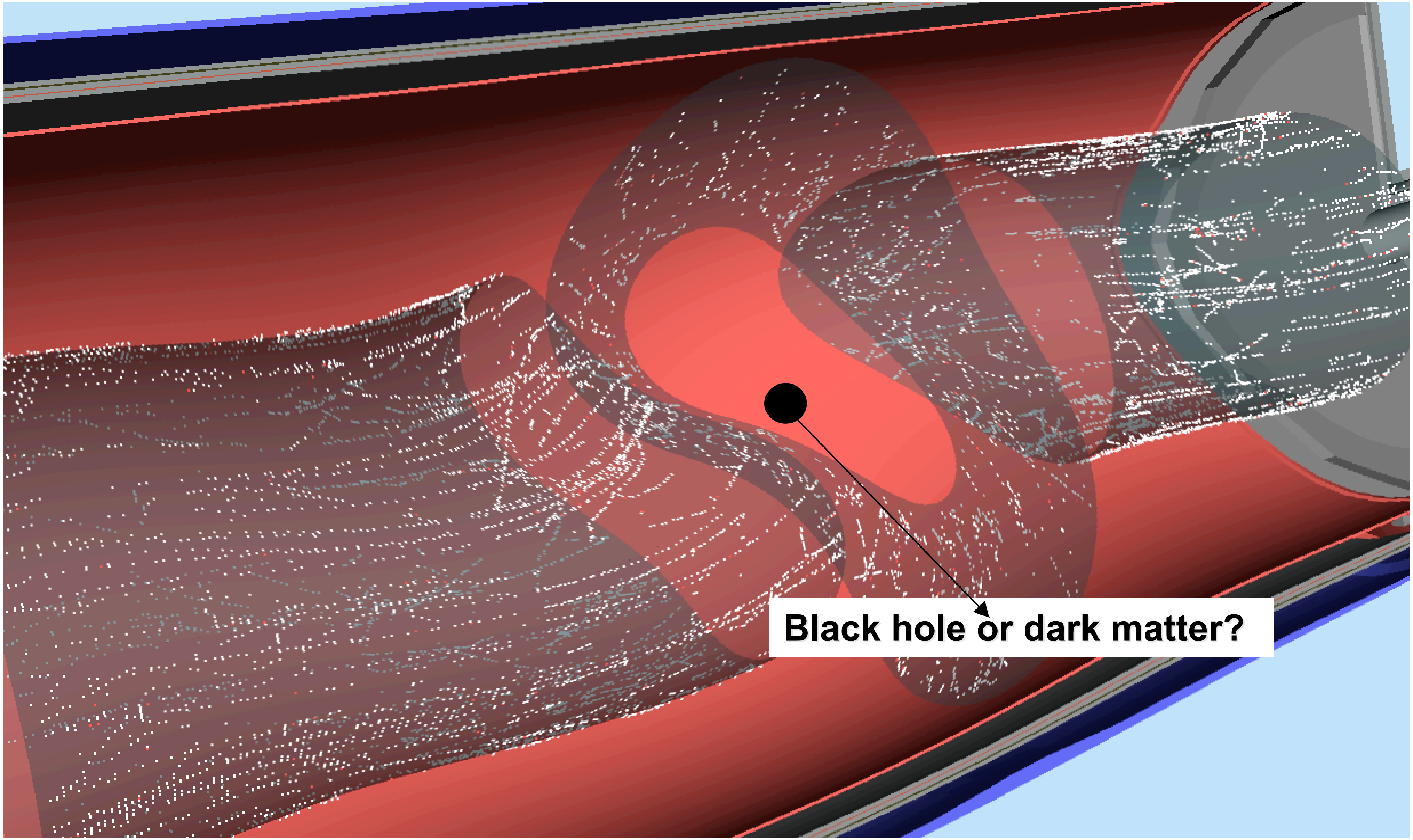


2D display in $\eta-\phi$ of energy deposited in LAr EM calorimeter per cell (layer 2):

- structures seen are due to material between collimators and calorimeter (mostly 8-fold structure of end-cap toroid coils)

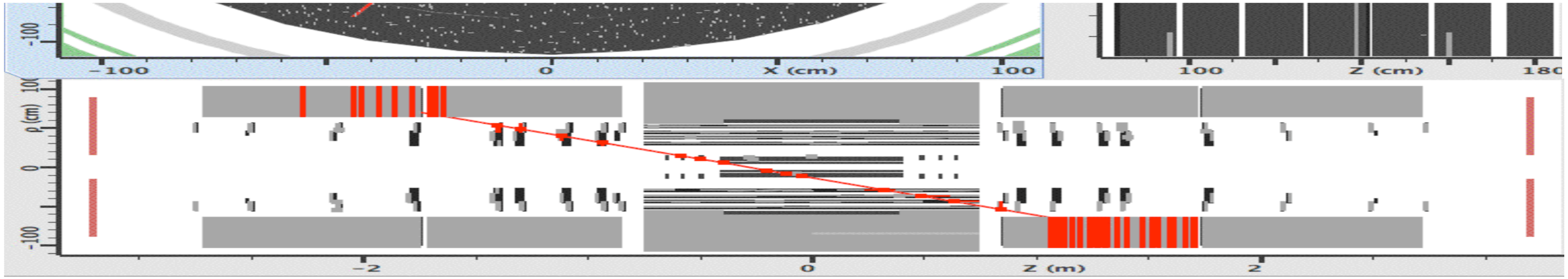
- energy seen per event is huge!

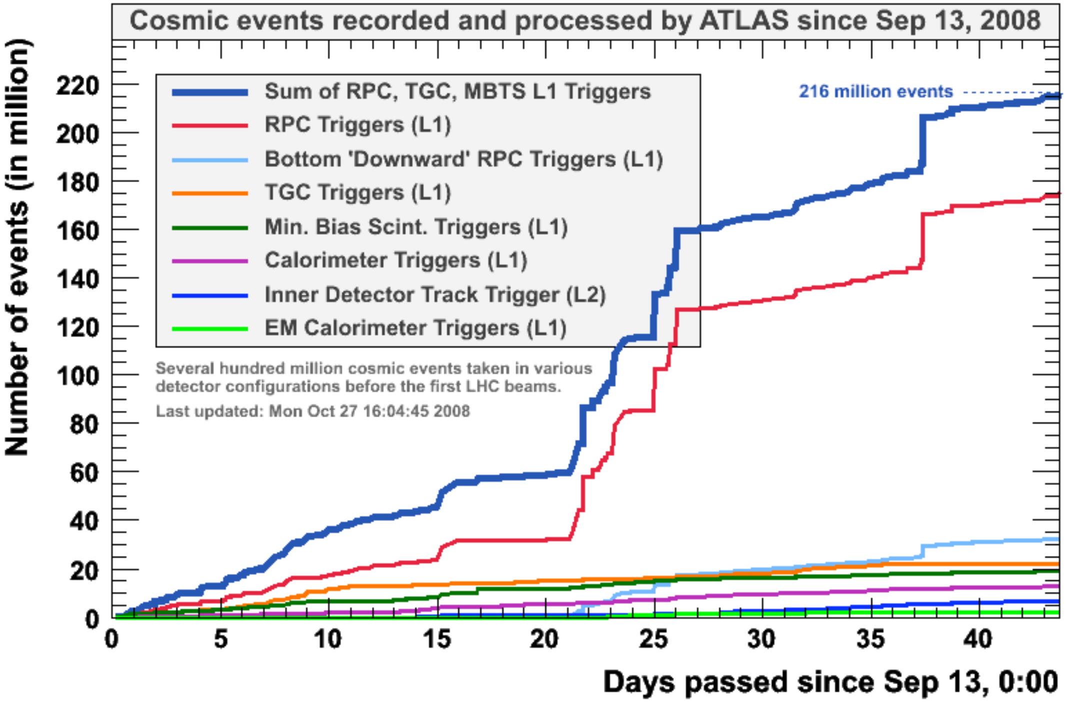
Artist view of beam halo event in ATLAS TRT

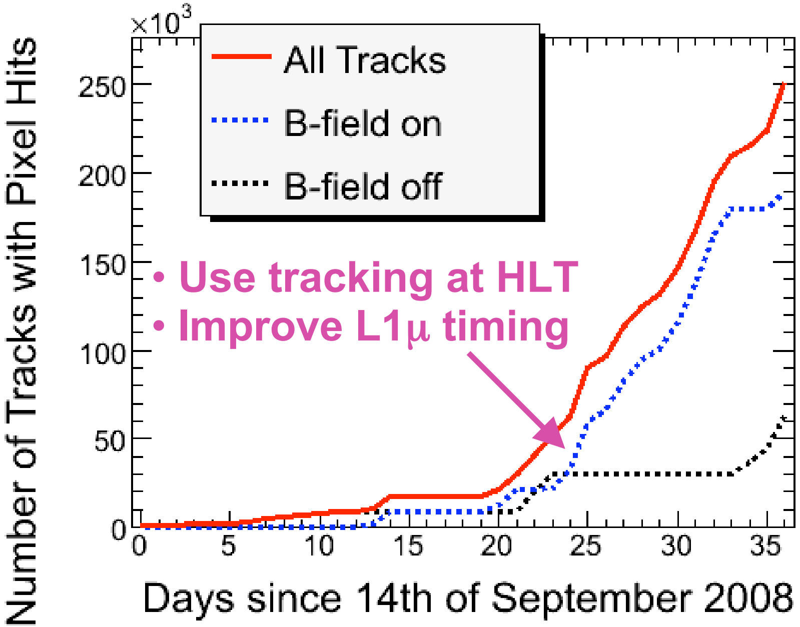


Note that beam conditions were not yet considered safe enough to operate ATLAS silicon-strip or pixel detectors at nominal settings

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



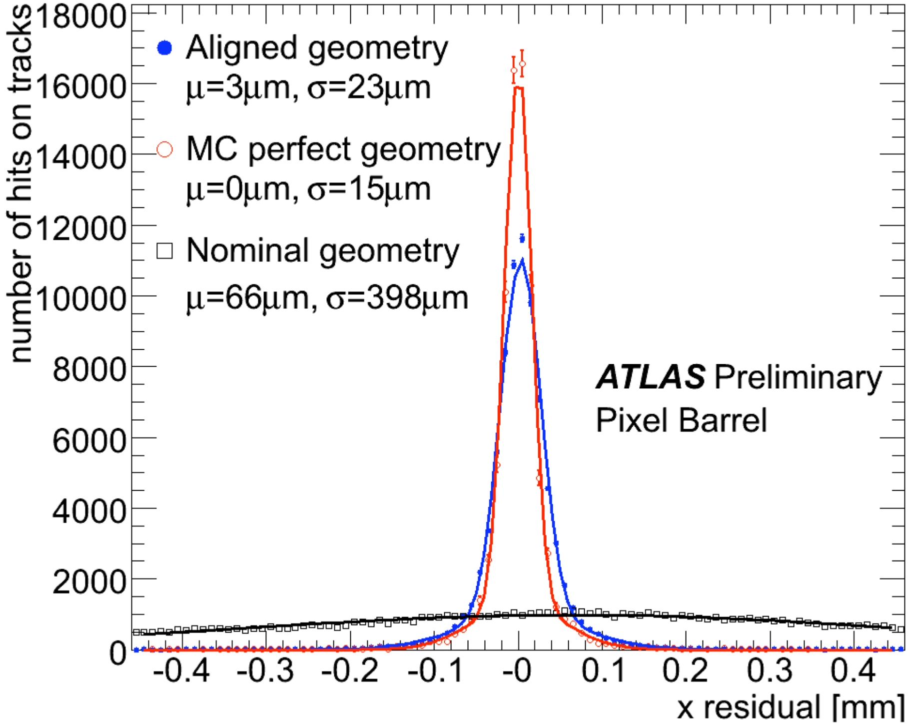




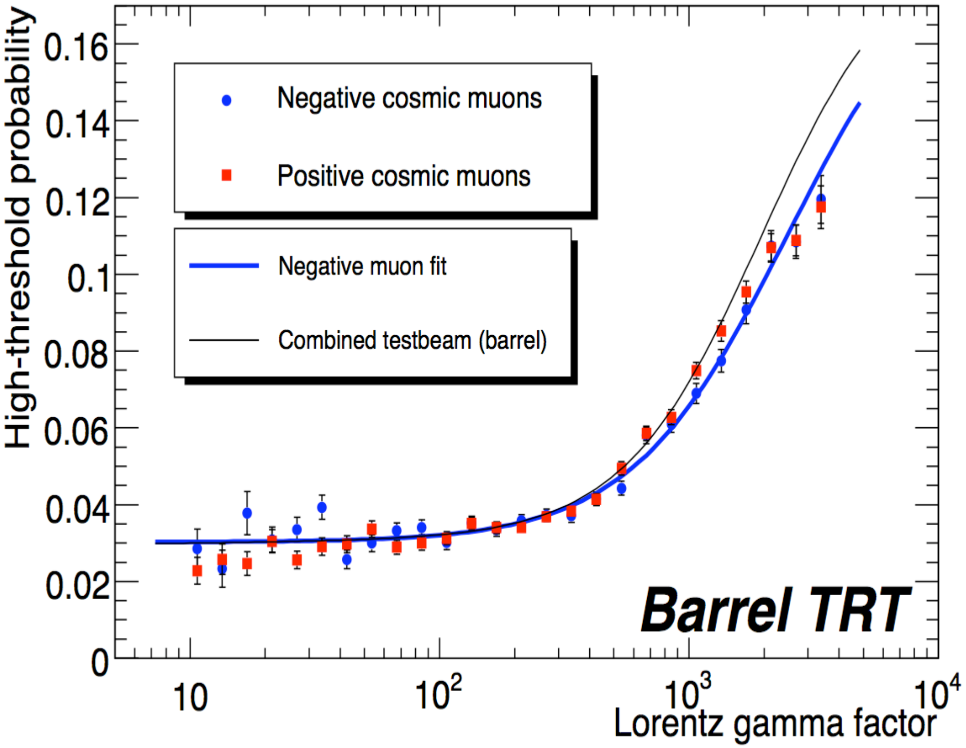
- Use tracking at HLT
- Improve L1μ timing

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



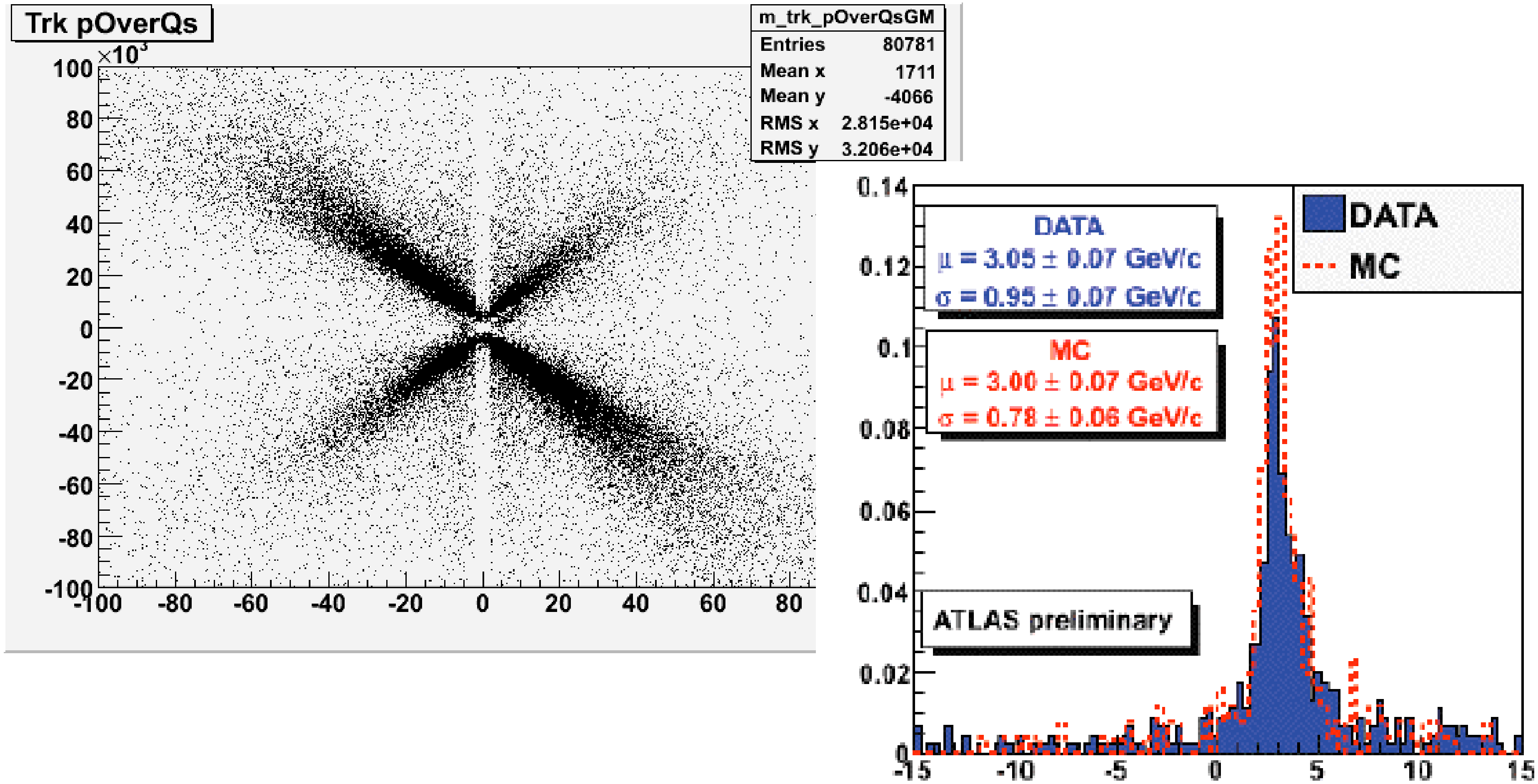
Cosmic-ray data with solenoid on:
look at 2M tracks going through barrel TRT



Cosmic-ray data particularly useful for tracking detectors:

- See talks by M.-J. Costa and T. Rodrigo on ATLAS/CMS commissioning
- Calibration of gaseous detectors (e.g. high threshold for TRT)
- Alignment of inner detector and muon spectrometer systems (e.g. pixels)

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

A realistic luminosity scenario for 2009 and beyond?

Parameter	Phase A	Phase B	Phase C	Nominal
k / no. bunches	43-156	936	2808	2808
Bunch spacing (ns)	2021-566	75	25	25
N (10^{11} protons)	0.4-0.9	0.4-0.9	0.5	1.15
Crossing angle (μrad)	0	250	280	280
$\sqrt{(\beta^*/\beta^*_{nom})}$	2	$\sqrt{2}$	1	1
σ^* (μm, IR1&5)	32	22	16	16
L ($cm^{-2}s^{-1}$)	6×10^{30}-10^{32}	10^{32}-10^{33}	$(1\text{-}2)\times10^{33}$	10^{34}
Year ("revised" schedule)	2009	2010	2010-2012	> 2012
$\int$Ldt (crystal ball)	10-100 pb^{-1}	0.5-2 fb^{-1}	o(10 fb^{-1})	o(100 fb^{-1})
Energy (if not 14 TeV)	8-10 TeV			

Based on J.Wenninger
CERN-FNAL School
June 2007

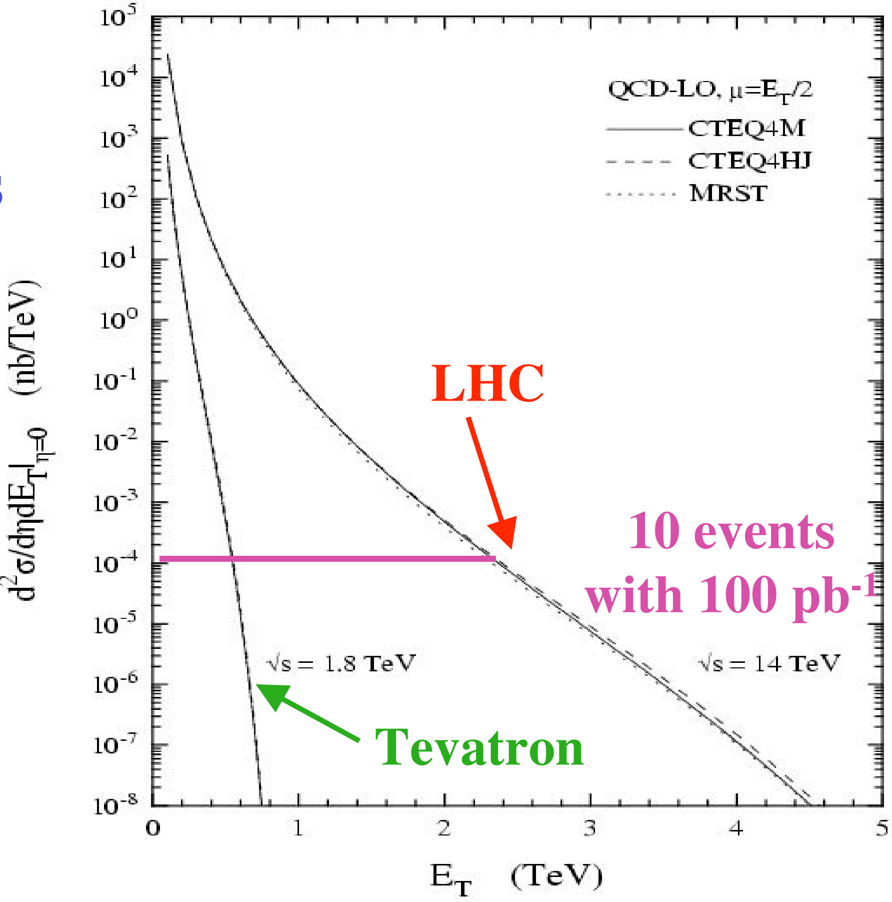
Note: for ~ 6×10^6 s of pp physics running per year,
Expect: ~ 0.6 fb^{-1} /year if L = 10^{32}
~ 6 fb^{-1} /year if L = 10^{33}
~ 60 fb^{-1} /year if L = 10^{34}

First physics with early data: a few examples …

Main point is that this is going to be unchartered territory!

However, early data analysis will focus mostly on SM processes with two goals:

1. understand performance of complex detector
2. measure basic SM processes and compare to theory and various MC tools

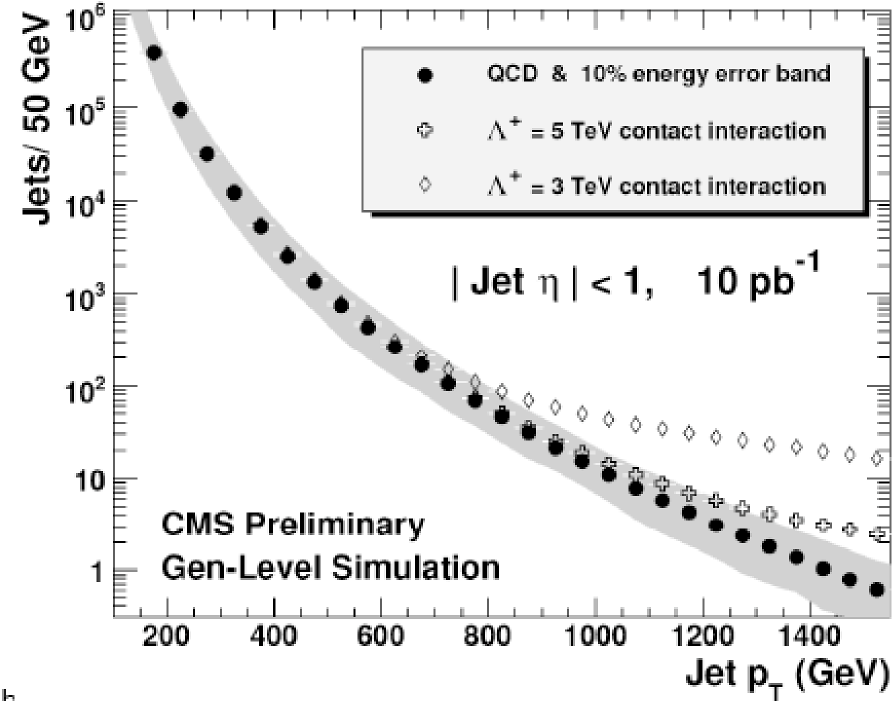


This is far more important than superseding e.g. Tevatron Higgs-boson limits, in the cases where they are not at the level of the expected rates for a SM Higgs boson

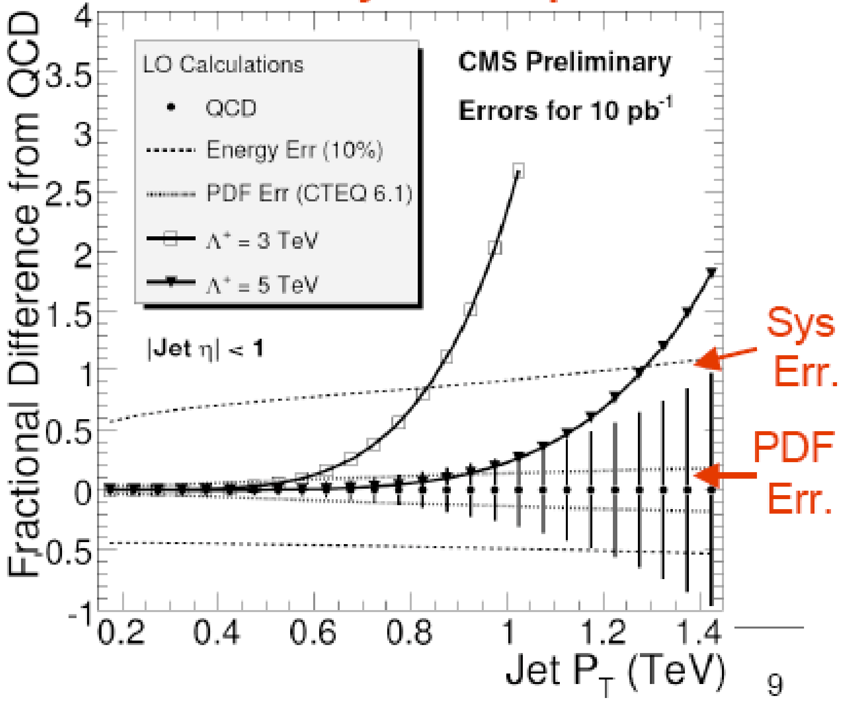
Jets are going to be everywhere…
Look for the unexpected!

- **Contact interactions create large rate at high P_T and immediate discovery possible**
  - **Error dominated by jet E-scale (~10%) in early running (10 pb^{-1})**
    - **ΔE~ 10% not as big an effect as Λ^+= 3 TeV for P_T>1 TeV.**
- **10 pb^{-1}: reach beyond Tevatron exclusion $\Lambda^+ <$ 2.7 TeV.**

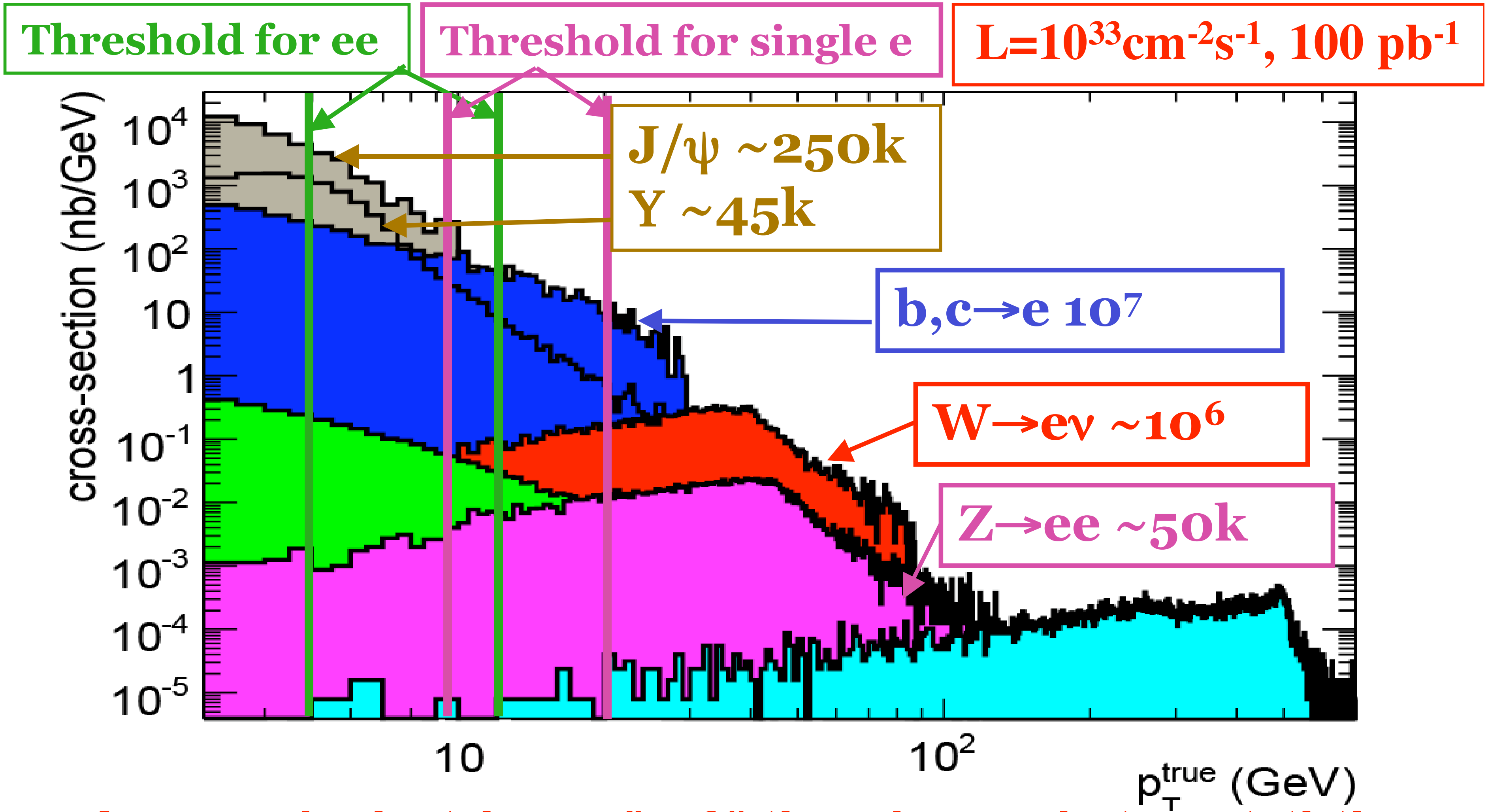
Rate of QCD and Contact Interactions



Sensitivity with 10 pb^{-1}



Electrons pairs in ATLAS at low luminosity



Threshold for ee

Threshold for single e

L=10^{33}cm^{-2}s^{-1}, 100 pb^{-1}

J/ψ ~250k
Υ ~45k

b,c→e 10^7

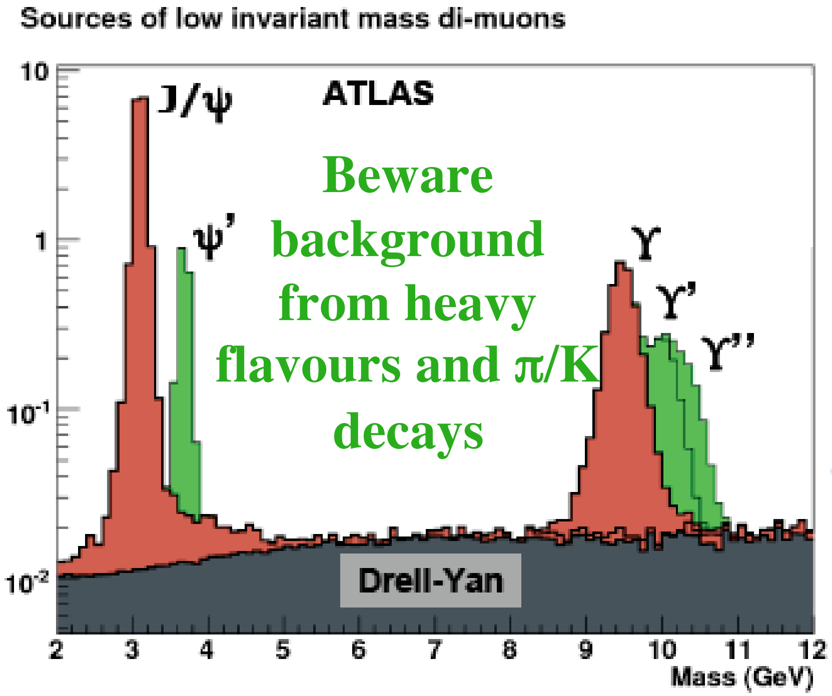
W→eν ~10^6

Z→ee ~50k

Low-p_T physics triggers for 10 times larger electron statistics

Crucial for early understanding of detector and trigger

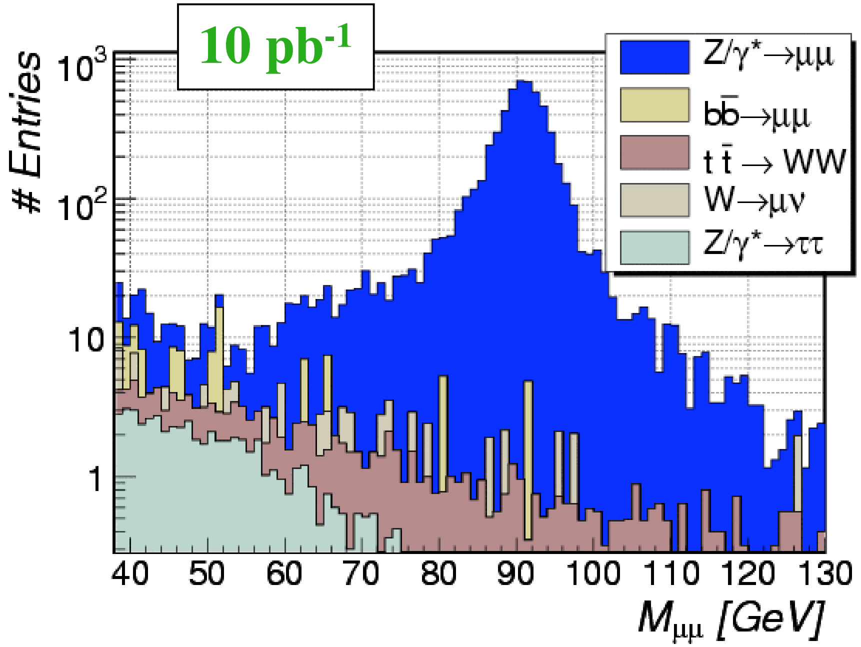
Same with muons …



Beware background from heavy flavours and π/K decays

After all cuts:
~ 4200 (800) J/ψ (Υ) → μμ evts per day at L = 10^{31}
(for 30% machine x detector data taking efficiency)

Tracker momentum scale, trigger performance, detector efficiency, …



10 pb^{-1}

After all cuts:
~ 160 Z → μμ evts per day at L = 10^{31}
Note: σ_Z(LHC)/σ_Z(Tevatron) ~ 10

Muon spectrometer alignment, ECAL uniformity, energy/momentum scale of full detector, lepton trigger and reconstruction efficiency, …

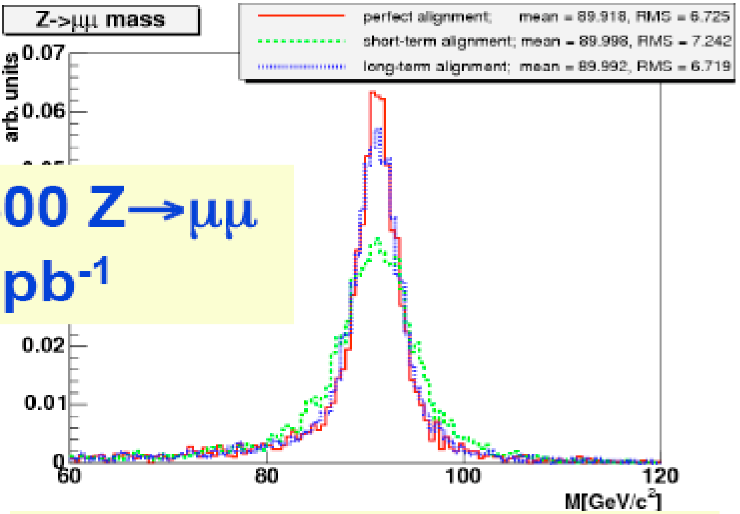
Precision on σ (Z→μμ) with 100 pb^{-1}: < 2% (exp. error), ~10% (luminosity error)

Z decays to leptons: a tool for precise understanding of the detector

First few pb^{-1}'s: tracker & calorimeters

- **Tracker Alignment**

	Expected Day 0	Goals for Physics
Tracker alignment	20-200 μm in Rϕ	O(10 μm)



600 Z→μμ / pb^{-1}

Z peak visible even with initial (rough) alignment

- **Calorimeter calibration**

	Expected Day 0	Ultimate goals
ECAL uniformity	~4%	< 1%
Lepton energy	0.5-2%	0.1%
HCAL uniformity	2-3%	< 1%
Jet energy	<10%	1%

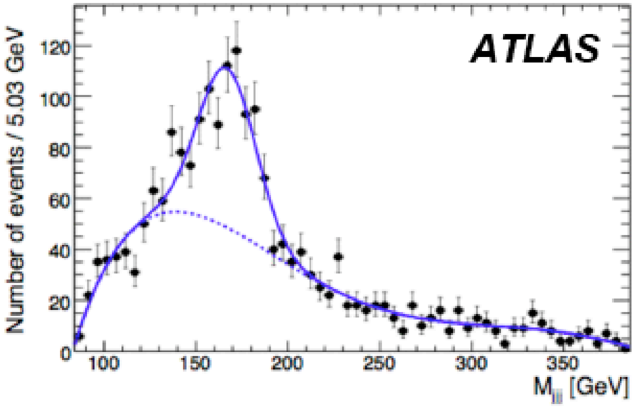
ECAL, HCAL: intercalibration using azimuthal symmetry (min bias).

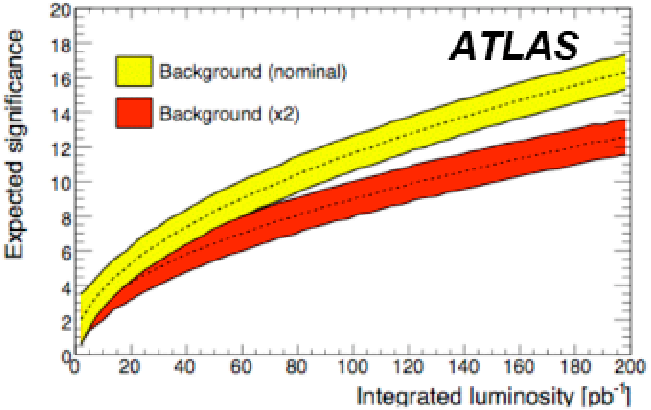
ECAL: π^0 calibration, then electrons

HCAL: di-jet balancing; check with photon+jets; Jet Energy Scale set by W→jj in top events

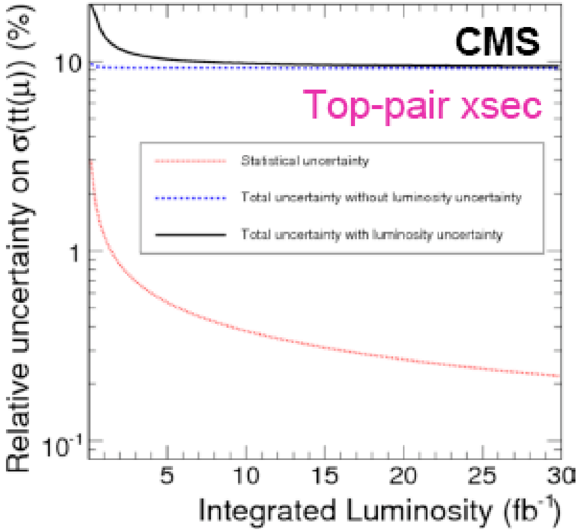
First top quarks seen outside Fermilab: top-pair cross-section through semileptonic channel

- Extract signal using event counting or fit to M_{jjj} distribution
  - Can establish signal for 100 pb^{-1} even with pessimistic background





- With 100 pb^{-1} expect to commission b-tagging and understand efficiency to ~5% - use in selection
  - Require 1 or 2 b-tagged jets, reduces non-tt b/g and helps select correct combination
- For O(fb^{-1}), b-tagging, PDFs & luminosity become important



Expt	Int.L	Method	Stat (%)	Syst (%)	Lumi (%)
ATLAS	100 pb^{-1}	count (W→e)	2.5	14	5
ATLAS	100 pb^{-1}	likelihood	7.4	15	5
CMS	1 fb^{-1}	count	1.2	9.2	10
CMS	10 fb^{-1}	count	0.4	9.2	3

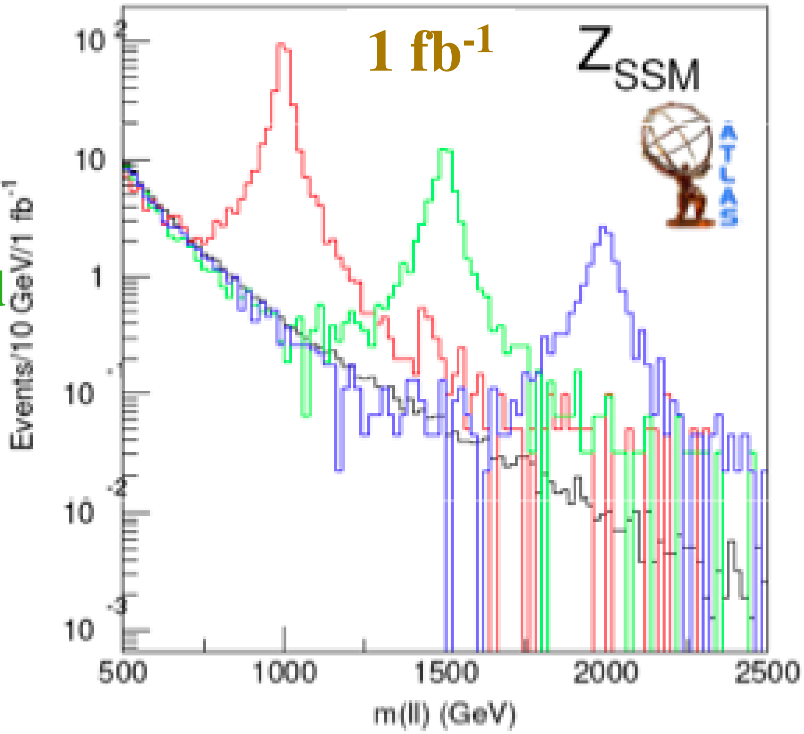
Obvious candidates for first searches: heavy resonances decaying to leptons (e.g. Z'_{SSM})

Mass	Expected events for 1 fb^{-1} (after all analysis cuts)	Integrated luminosity needed for discovery (corresponds to 10 observed events)
1 TeV	~ 160	~ 70 pb^{-1}
1.5 TeV	~ 30	~ 300 pb^{-1}
2 TeV	~ 7	~ 1500 pb^{-1}

- ✓ With 100 pb^{-1} large enough signal for discovery up to m > 1 TeV
- ✓ Signal is (narrow) mass peak on top of small Drell-Yan background
- ✓ Ultimate calorimeter performance not needed

Tevatron reach (5σ, 7 fb^{-1}): ~ 1 TeV

Ultimate ATLAS reach (300 fb^{-1}): ~ 5 TeV



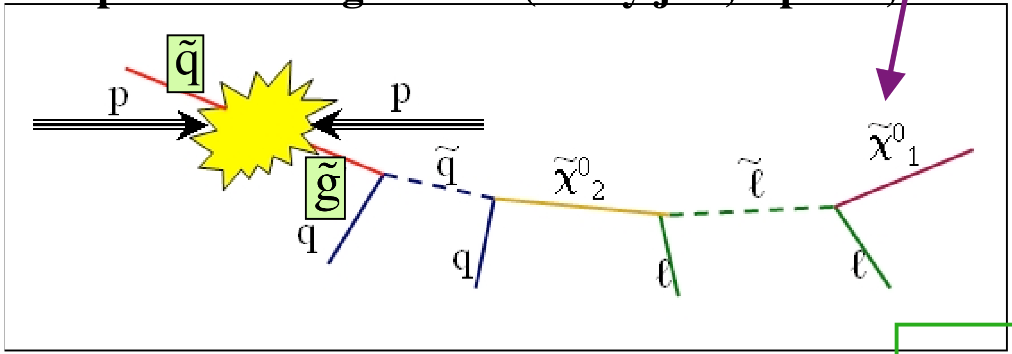
D. Froidevaux (CERN)

Obvious candidates for first searches: R-parity conserving SUSY

If it is at the TeV scale, it should be found "quickly" ….

✓ **Large (strong) cross-section for** $\tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{g}\tilde{g}$ production

✓ **Spectacular signatures (many jets, leptons, missing E_T)**

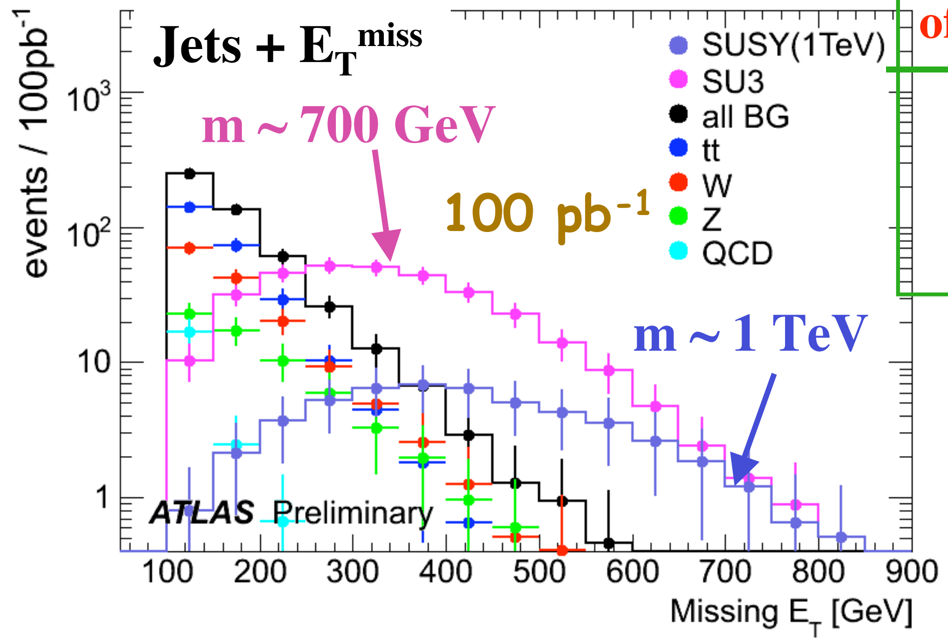


Tevatron 95% C.L. reach: up to ~400 GeV

At the LHC, for $m_{squark,gluino} \sim$ 1 TeV, expect 10 events/day at $L=10^{32}$

LHC reach for gluino mass

∫Ldt of well understood data	Discovery (95% C.L. exclusion)
0.1-1 fb^{-1} (2009) ≥1 fb^{-1} (2009-2010) 300 fb^{-1} (ultimate)	~1.1 TeV (1.5 TeV) ~1.7 TeV (2.2 TeV) up to ~ 3 TeV



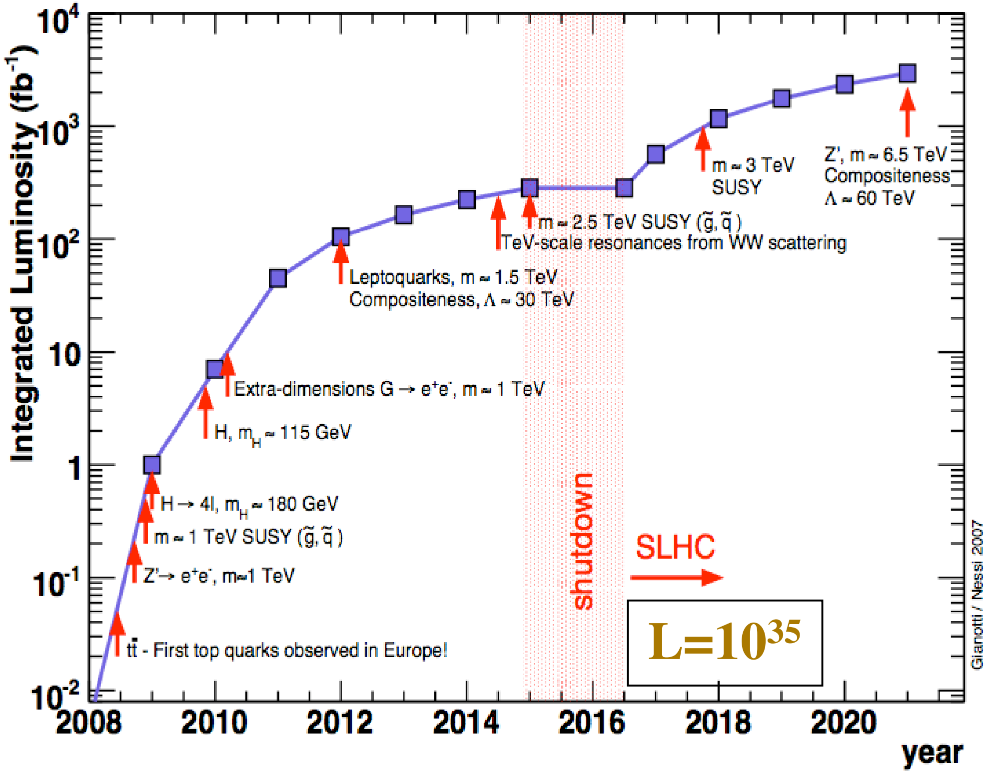
Hints with only 100 pb^{-1} up to m ~ 1 TeV, but precise understanding of backgrounds will require ~1 fb^{-1}

Eventual discovery reach of the LHC

Excited quarks $q^* \rightarrow \gamma q$: up to $m \approx 6$ TeV
Leptoquarks: up to $m \approx 1.5$ TeV
Monopoles $pp \rightarrow \gamma\gamma pp$: up to $m \approx 20$ TeV
Compositeness: up to $\Lambda \approx 40$ TeV
$Z' \rightarrow ll$, jj: up to $m \approx 5$ TeV
$W' \rightarrow l\nu$: up to $m \approx 6$ TeV
etc.... etc….

- **Opportunities for discoveries of new physics are numerous and detectors have been optimised using benchmarks from many models**
- **But some things might be beyond reach of LHC (and even SLHC!):**
  - ✓ **Higgs-boson self-coupling**
  - ✓ **Charginos and neutralinos in most scenarii**

LHC discovery potential versus time



What next?

Why this fear that experimental particle physics is an endangered species?

- The front-wave part of this field is becoming too big for easy continuity between the generations. I have been working on LHC for 25 years already. Most of the analysis will be done by young students and postdocs who will have no idea what the 7000 tonnes of ATLAS is made of. More importantly, fewer and fewer people remember for example that initially most of the community did not believe tracking detectors would work at all at the LHC.
- The stakes are very high: one cannot afford unsuccessful experiments (shots in the dark) of large size, one cannot anymore approve the next machine before the current one has yielded some results and hopefully a path to follow
- Theory has not been challenged nor nourished by new experimental evidence for too long

This is why the challenge of the LHC and its experiments is so exhilarating! A major fraction of the future of our discipline hangs on the physics which will be harvested at this new energy frontier.

How ordinary or extraordinary will this harvest be? Only nature knows.

Fortunately, there is much more to experimental particle physics than its dinosaurs!