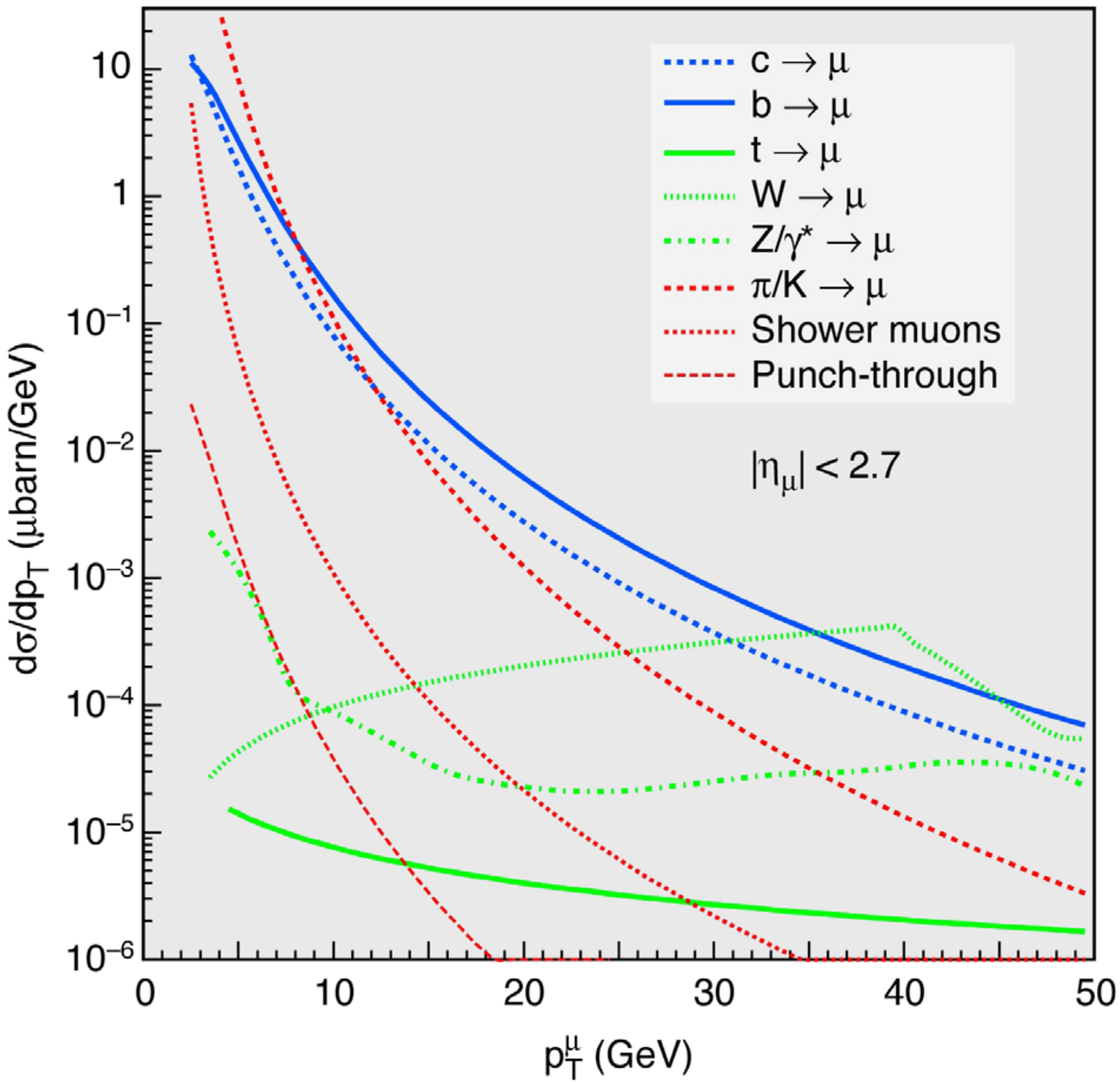
Muons, Electrons and Photons

- Muon spectrometers
- EM calorimeters
- Trackers
- Electron and Photon ID

Muon identification and measurement(1)

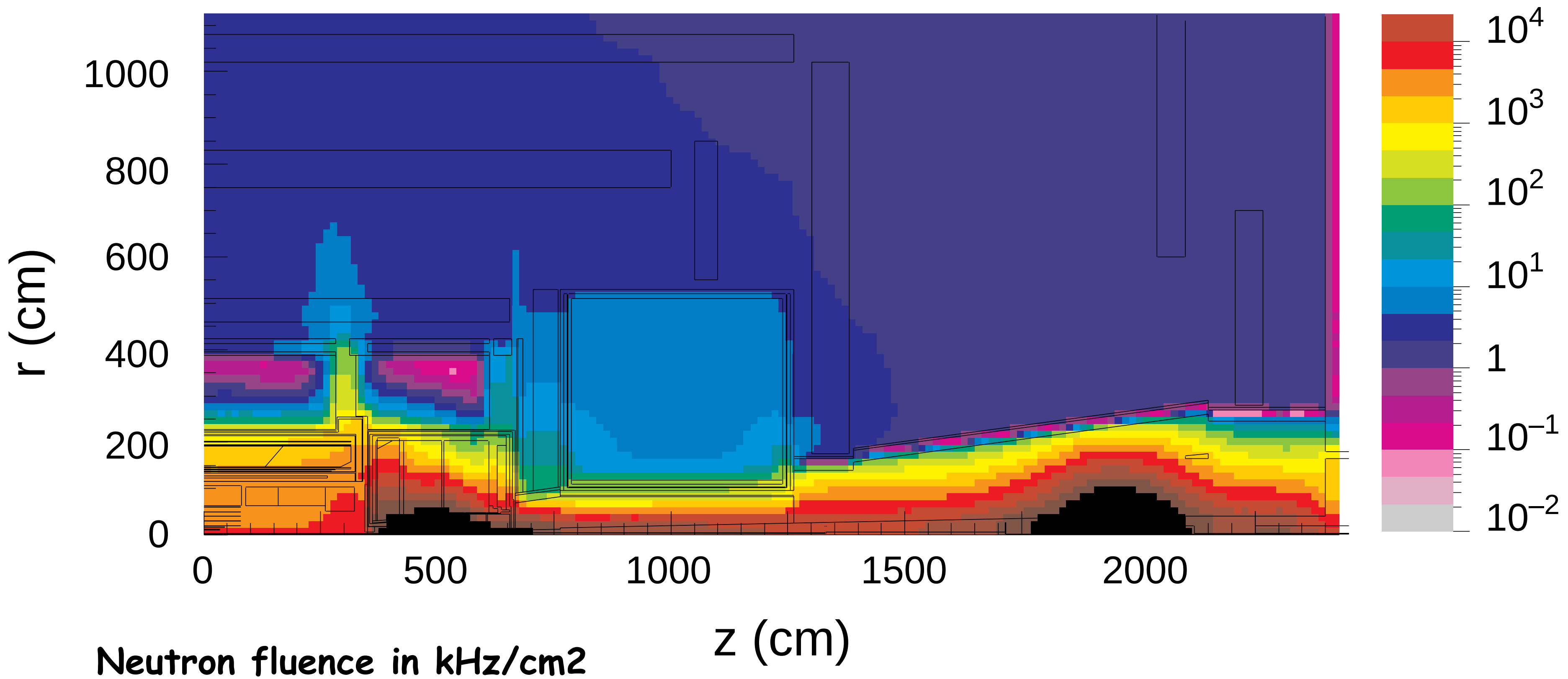
Example of what is expected to be found behind the ATLAS calorimeter (>12λ)

- Real muons ("prompt" and secondaries)
- "punch-through"
- Uncorrelated hits (from neutron and photon gas)



Muon id(2) : neutron induced hits

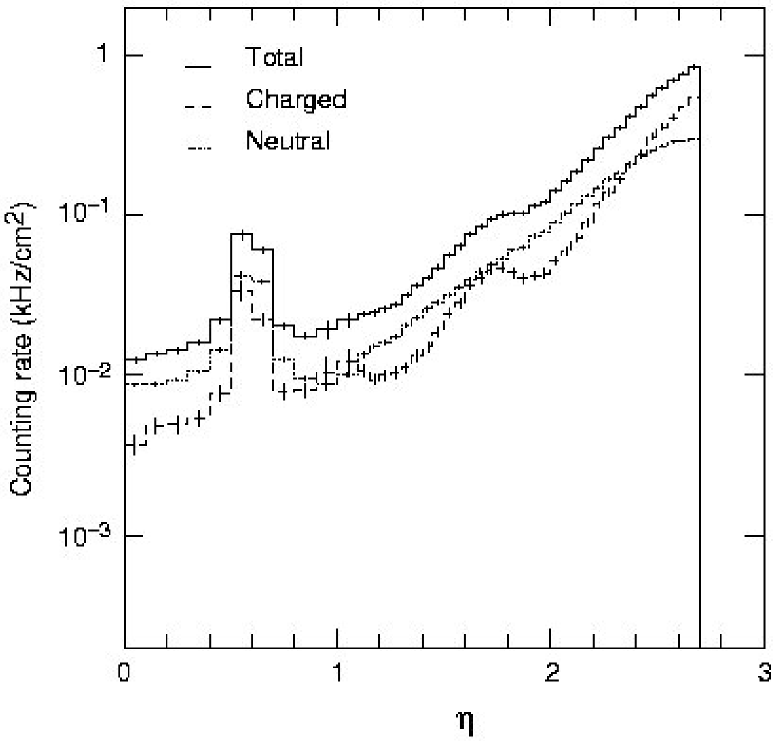
- Slow neutrons linger around for ms before being captured,
- Radiative captures in turn produce photons
- Both interact(n:10^{-4}, γ :10^{-2})with the muon chamber gas $\rightarrow$random hits

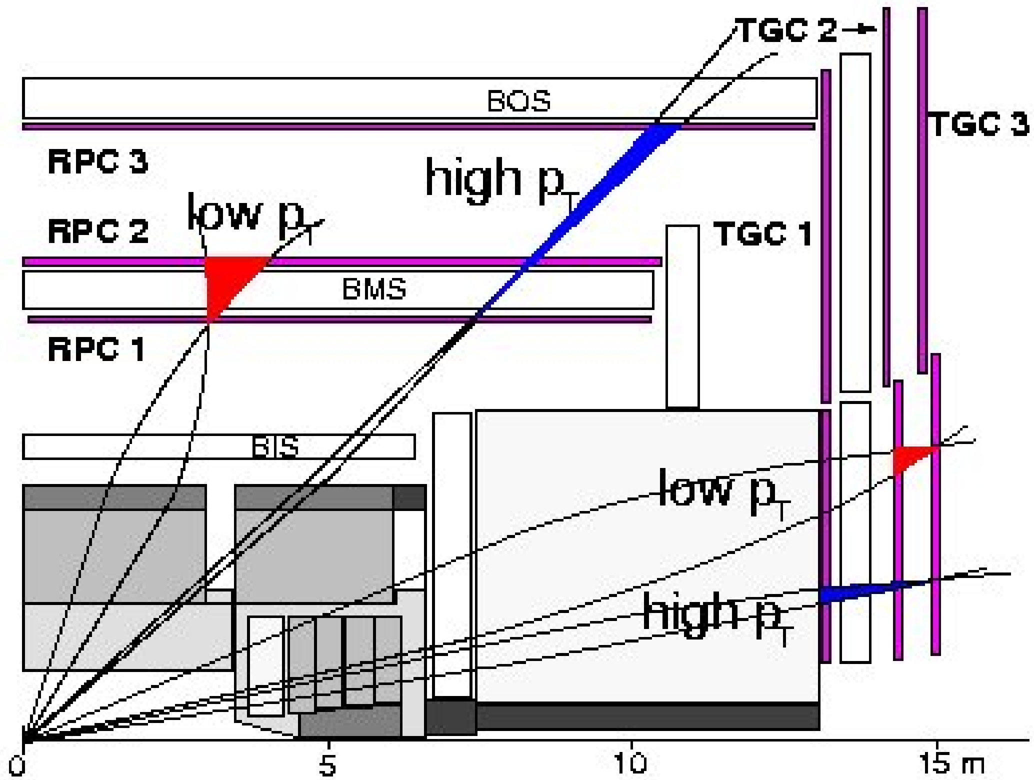


Neutron fluence in kHz/cm2

ATLAS Muon id(3) : find tracks

And cut on transverse momentum...





3 stations of precision chambers (drift tubes) interleaved with Trigger chambers

LVL1 Trigger Chambers= fast response (25 ns)

$\rightarrow$ lower rate area (barrel)=RPC- higher rate=TGC

ATLAS LVL1 Muon

- Hit in RPC1
- Extrapolates straight from VX to RPC2 ⊕ window for coincidence=low p_T
- Extrapolates to RPC3 ⊕ window for coincidence=high p_T

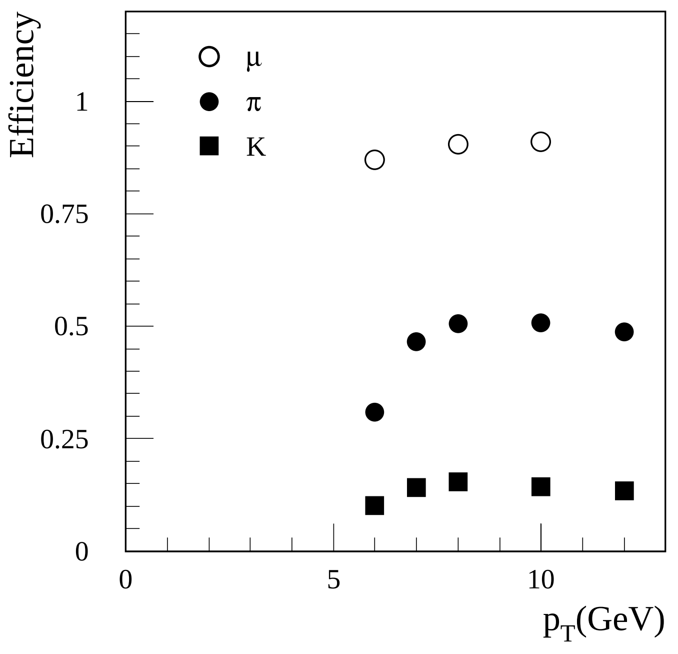
	Process	Barrel	End-cap	Combined system	
Low-p_T (6 GeV)	π / K decays	7.0	9.8	16.8	
10^{33}	b	1.9	2.1	4.0	
	c	1.1	1.3	2.4	
	W	0.004	0.005	0.009	
	Total	10.0	13.2	23.2	kHz
High-p_T (20 GeV)	π / K decays	0.3	1.8	2.1	
	b	0.4	0.7	1.1	
10^{34}	c	0.2	0.3	0.5	
	W	0.035	0.041	0.076	
	Total	0.9	2.8	3.8	kHz

Further Muon ID(5)

Further ID steps:

- Reconstruct track in spectrometer $\rightarrow$momentum (LVL2,LVL3,offline)
- Extrapolate to tracker; do combined fit (LVL2,LVL3,offline)

  allows some rejection of π/**K** decays (low L, low Eth)
- Check signals in calorimeter (last layers of HCAL are quiet)
- Look for non-zero impact parameter $\rightarrow$prompt/secondary
- Identify the sign (lepton or antilepton….$\rightarrow$W' flavour/asymetry,..)



CMS Muon ID(1)

- Chambers “embedded” in iron flux return after ~8λ
- Punch-through more important in first layers
- Include precision chambers (Drift Tubes) at LVL1 for better low momentum rejection

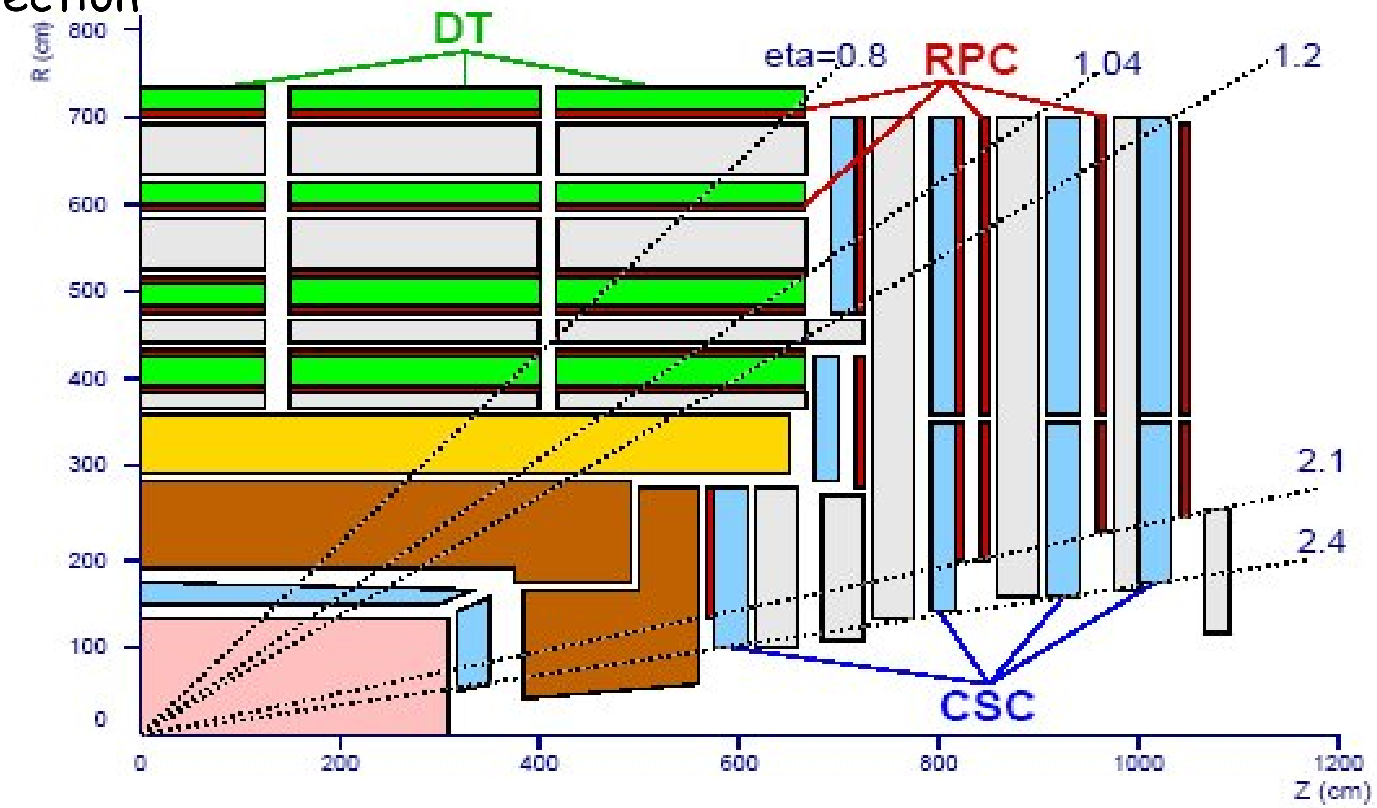


Figure 1: Layout of the CMS muon system.

CMS muon ID(2)

Global Muon Trigger Overview

calo

252 MIP bits
252 Quiet bits

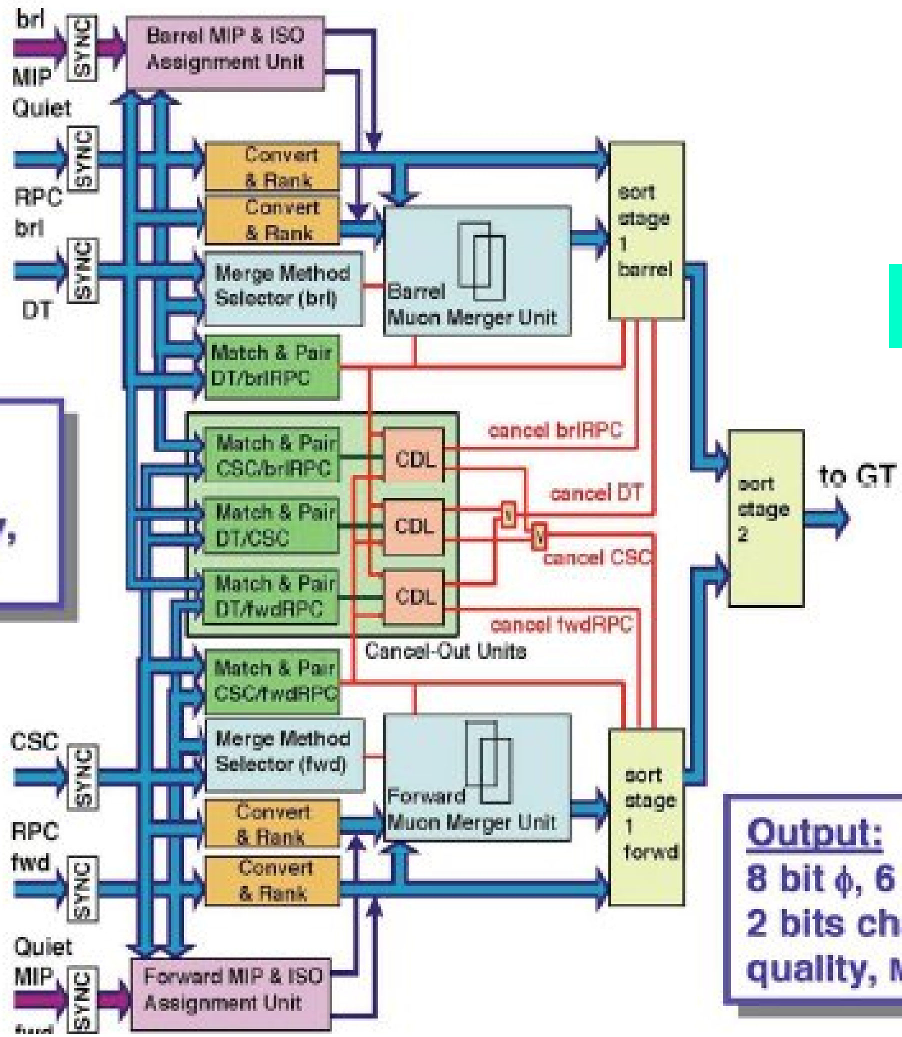
4 μ RPC brl

4 μ DT

Inputs:
8 bit ϕ, 6 bit η, 5 bit p_T,
2 bits charge, 3 bit quality,
1 bit halo/h fine-coarse

4 μ CSC

4 μ RPC fwd



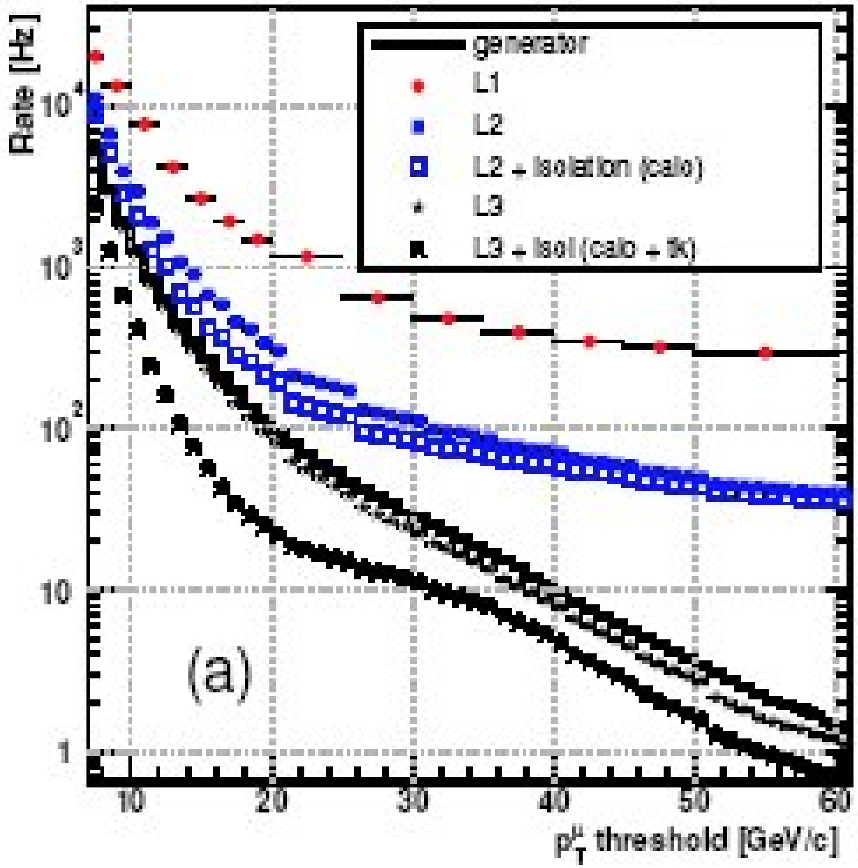
16→4 candidates

Best 4 μ

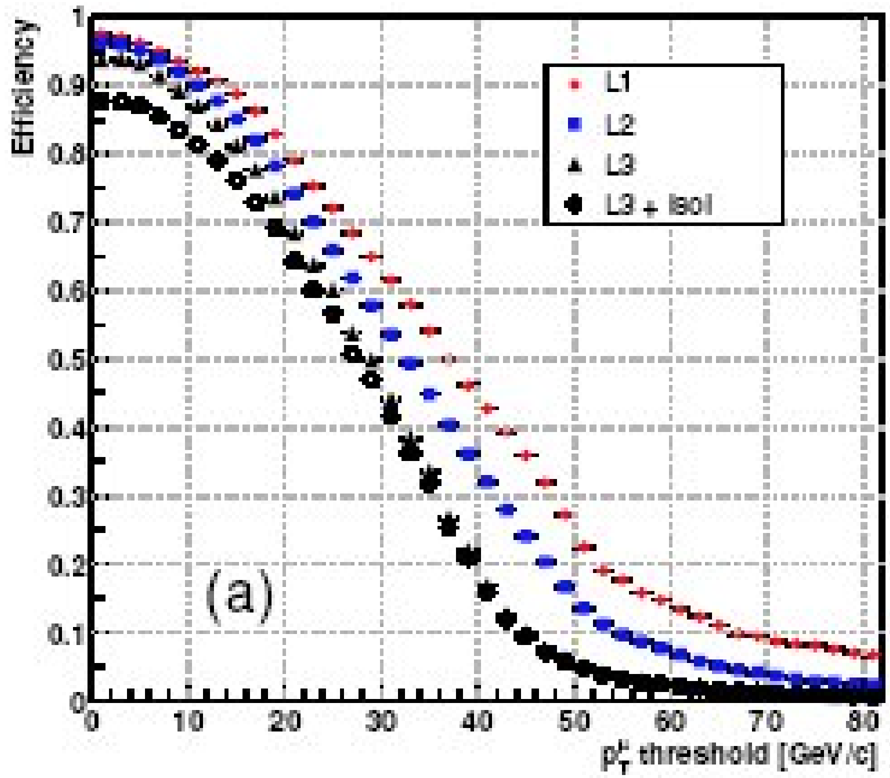
Output:
8 bit ϕ, 6 bit η, 5 bit p_T,
2 bits charge/synch, 3 bit quality, MIP bit, Isolation bit

CMS Muon ID(3)

10^{33}



Combined mu-ID at LVL3



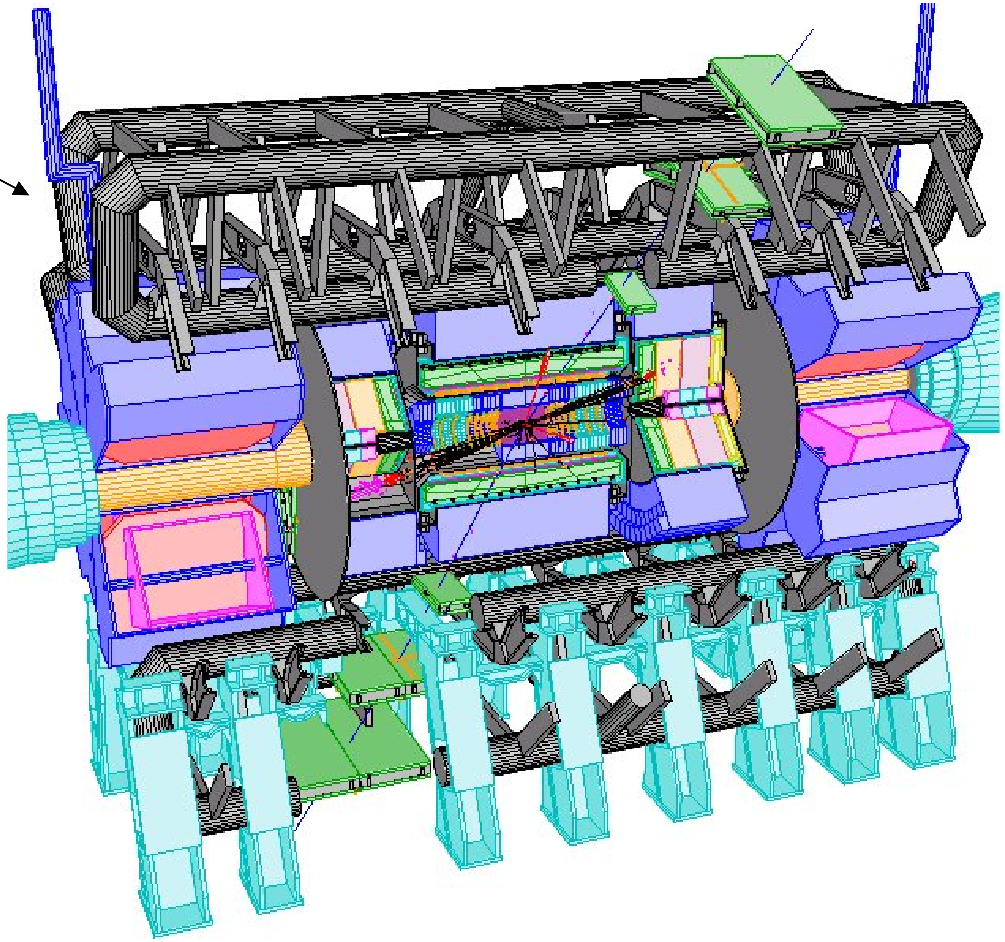
Rate against efficiency (W decay)

Muon trigger and identification summary

- Instrumental BG : showers debris, random (n-induced) hits
- Fast pattern recognition needed
- LVL1 rate dominated by real muons
- Final rate strongly linked to threshold
- Final Strategy depends on Luminosity and Physics
  - low L /B physics : threshold down to ~6 GeV/c desirable
  - high L threshold to be raised up to 20 GeV/c p_T

Magnets and muon measurements : ATLAS Barrel Toroid

8 separate coils



BT Parameters

25.3 m length

20.1 m outer diameter

8 coils

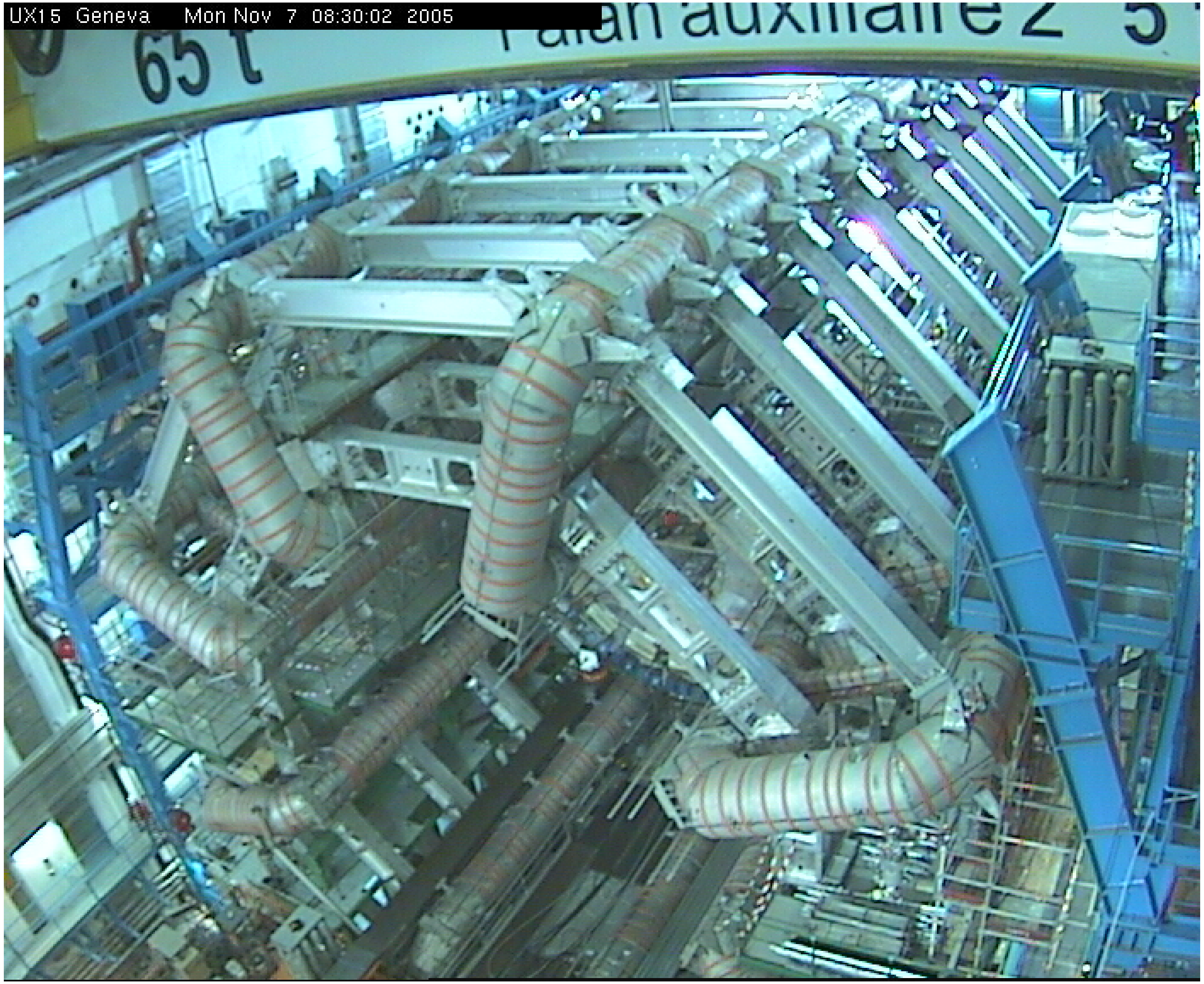
1.08 GJ stored energy

370 tons cold mass

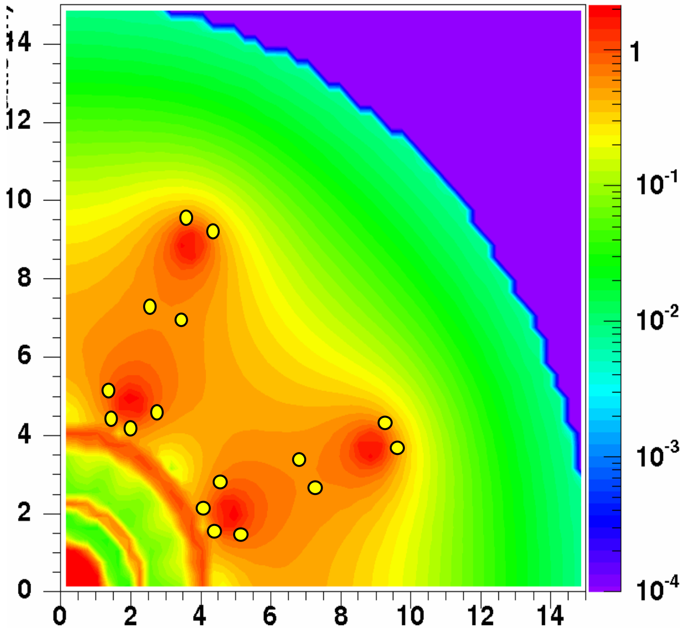
56 km Al/NbTi/Cu conductor

20.5 kA nominal current

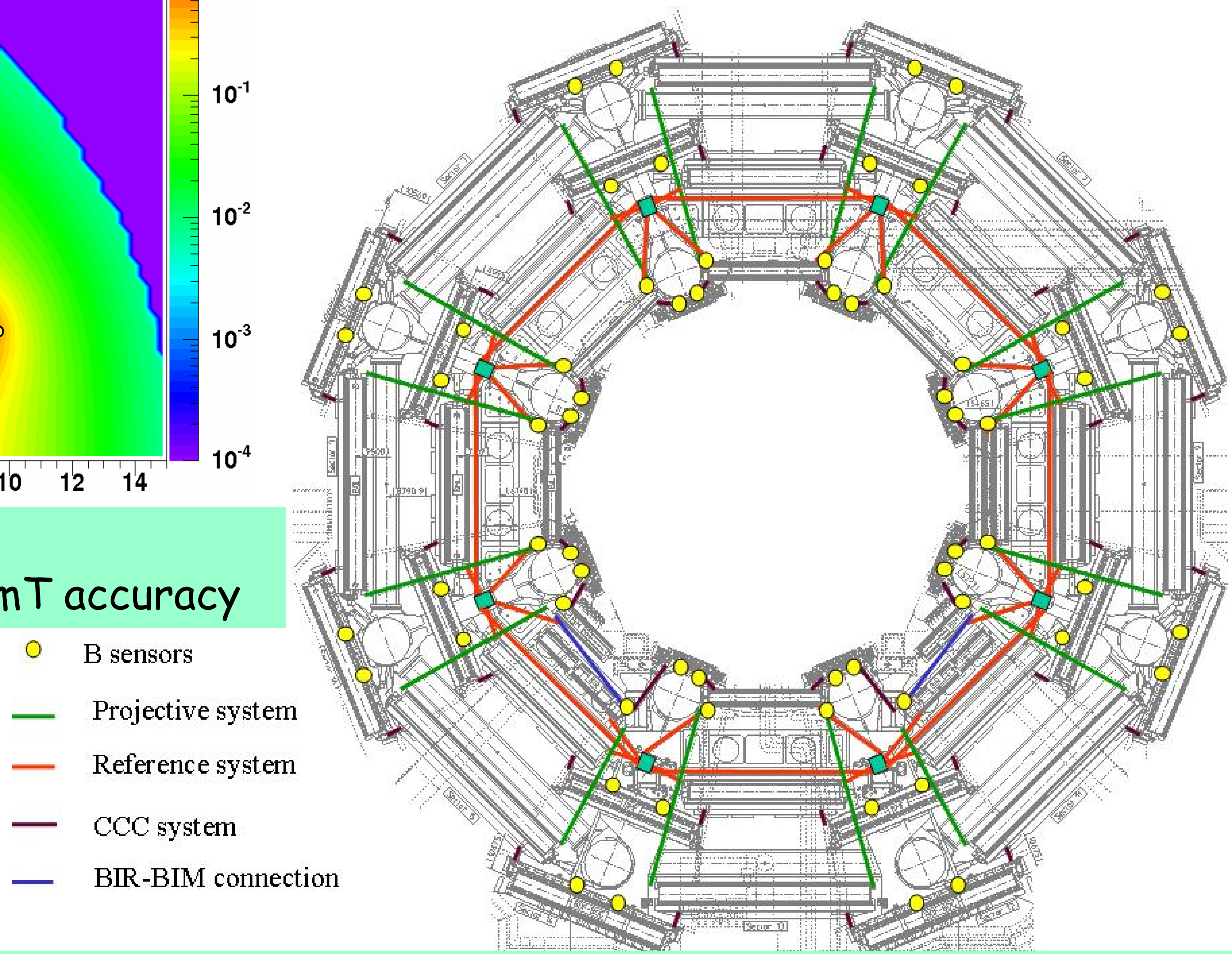
Atlas toroid magnet : barrel assembled



Atlas toroid : measure and describe the B-field

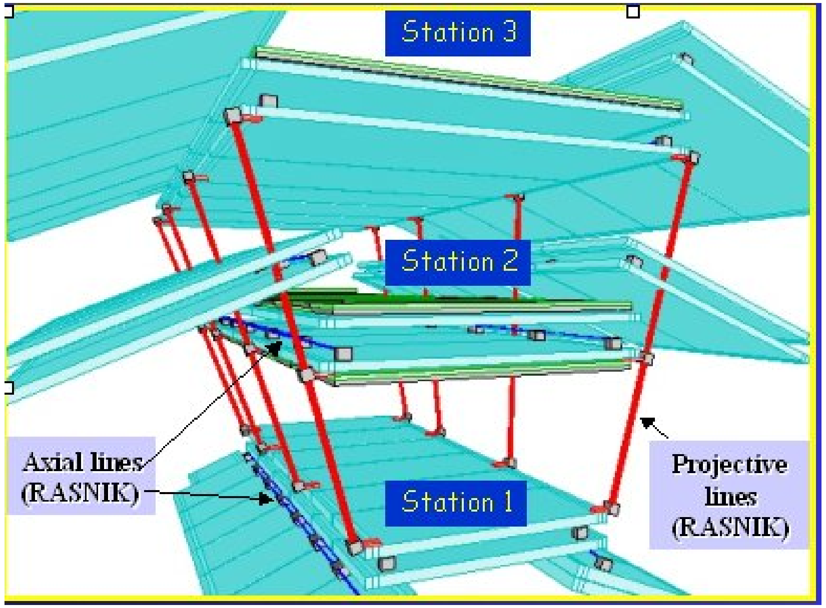


Bmax ~ 1Tesla
described with 5 mT accuracy

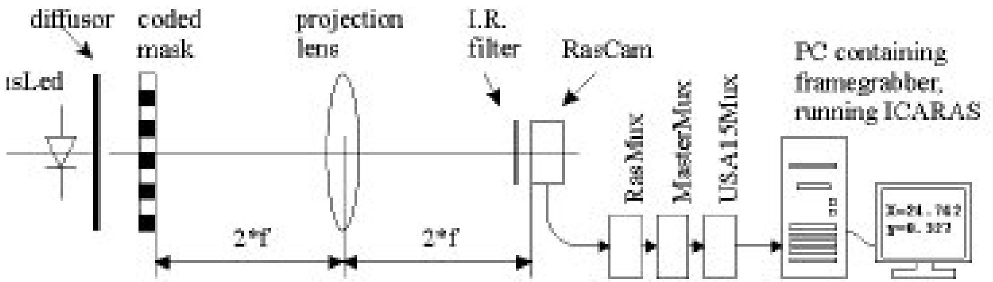


Strategy : from Hall probes recalculate conductor position, then deduce B everywhere

Atlas muon alignment system



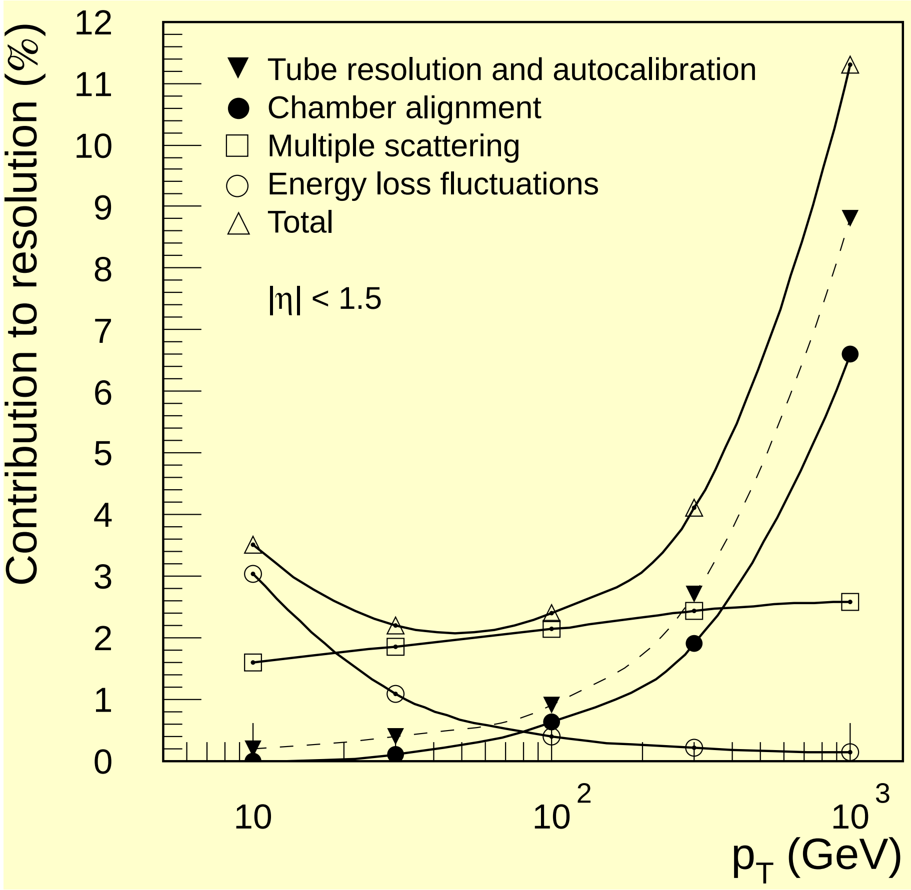
- Goal:control positions to< 30microns/10m
- Uses light (IR) rays, masks and sensors
  - ➢projective to monitor plans
  - ➢ axial to monitor within plans
- About 10 000 sensors overall



Tested successfully (15 µm rms when displacing one chamber) in CERN H8 beam line comparing alignment obtained with tracks and sensors.

In Atlas pit plan to take some data with field-off to have straight tracks -> initial values of relative positions well controlled ; then follow-up with alignment system.

Contributions to Atlas muon resolution



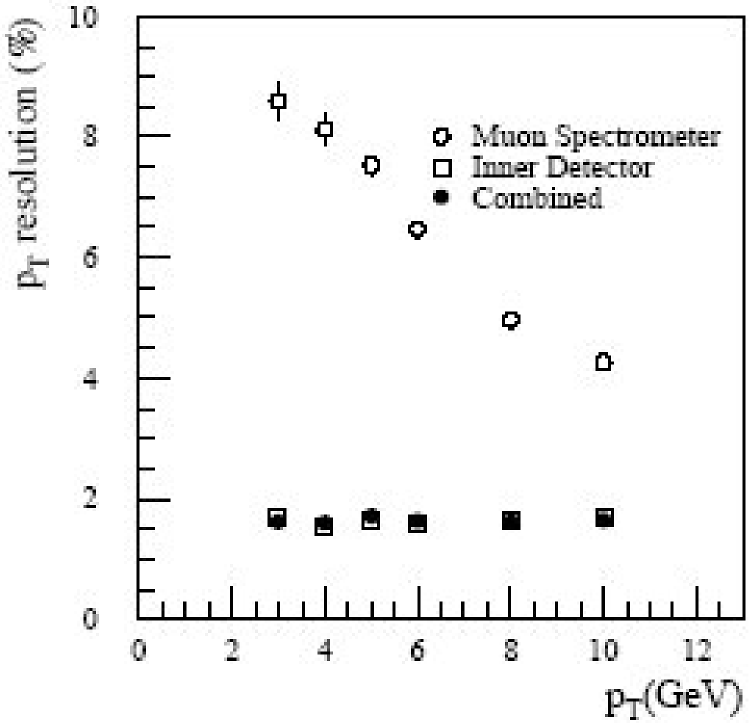


Figure 8-10 p_T resolution of track reconstruction in Muon System (refitted), in Inner Detector and of combined tracks using MUID procedure as a function p_T.

Muon spectrometer only

Combined with tracker(low energy part)

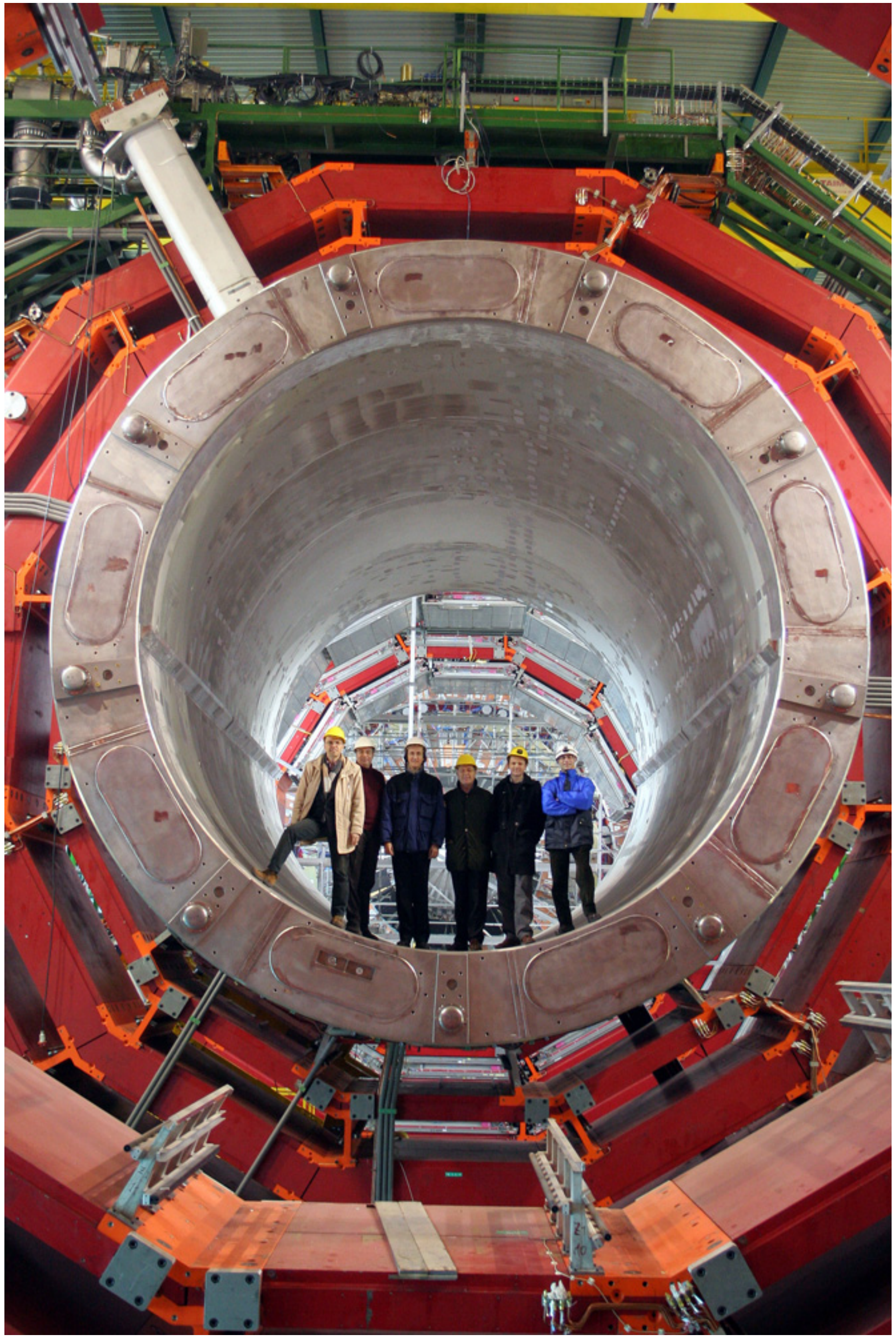
CMS solenoid

Main parameters

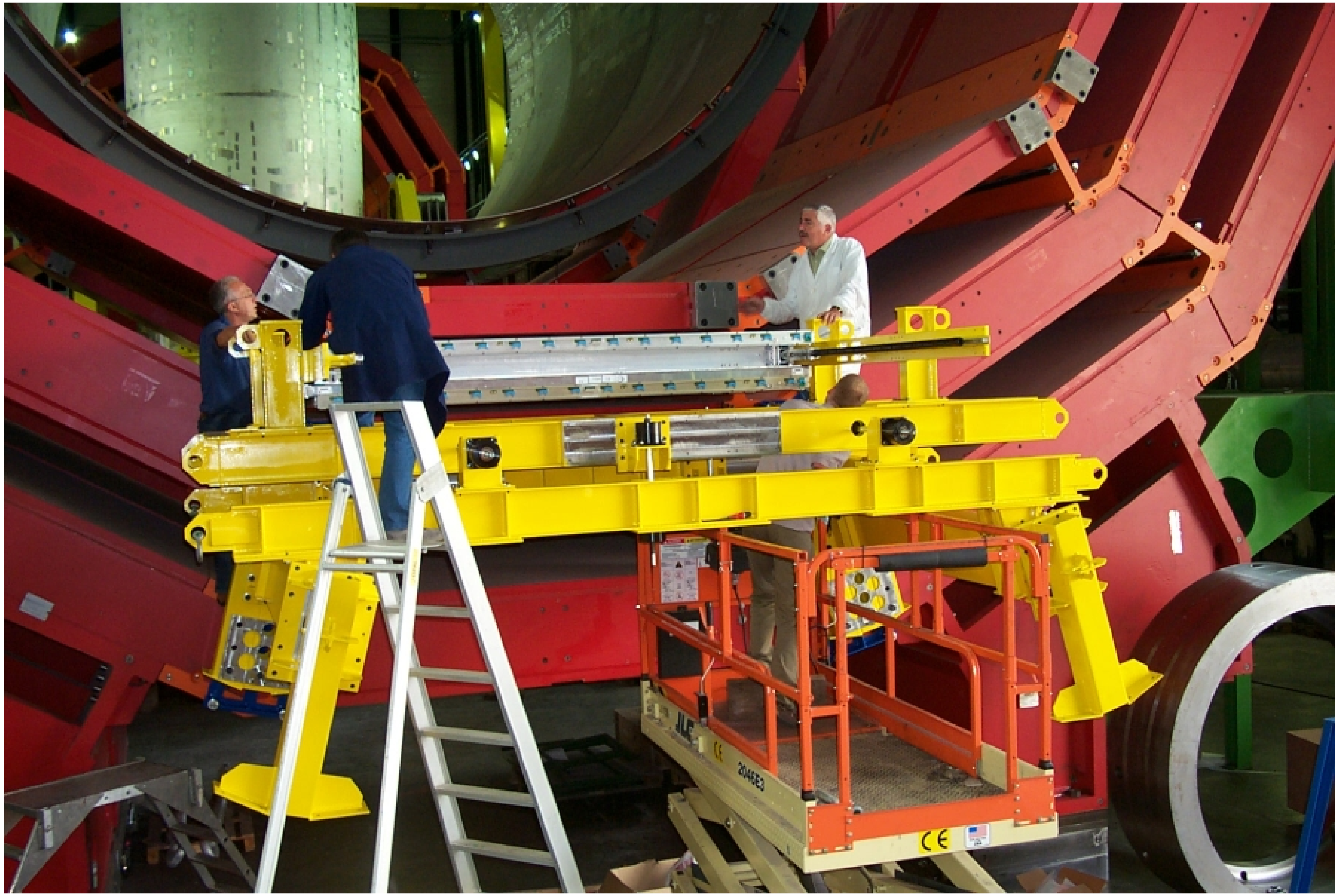
- 4 Teslas
- 7m diameter, 15 m length,
- 2.5 GJ stored

- Coil is made of 5 modules (CB-2 $\rightarrow$CB+2),each with 4 layers

- Cold test on surface :
  Just starting now. Coil is cold !



CMS : DT module insertion



Contributions to CMS muon resolution

Track momentum is measured both:
- in the DT interleaved with iron flux return where it was identified
- in the central tracking system after suitable extrapolation and combined fit

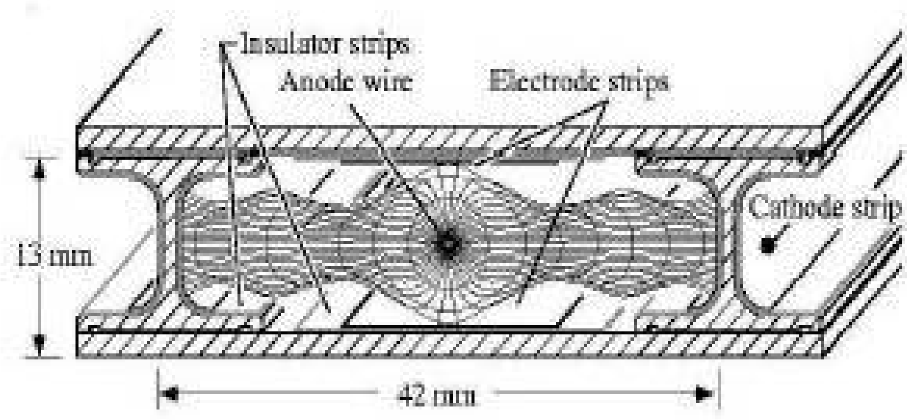
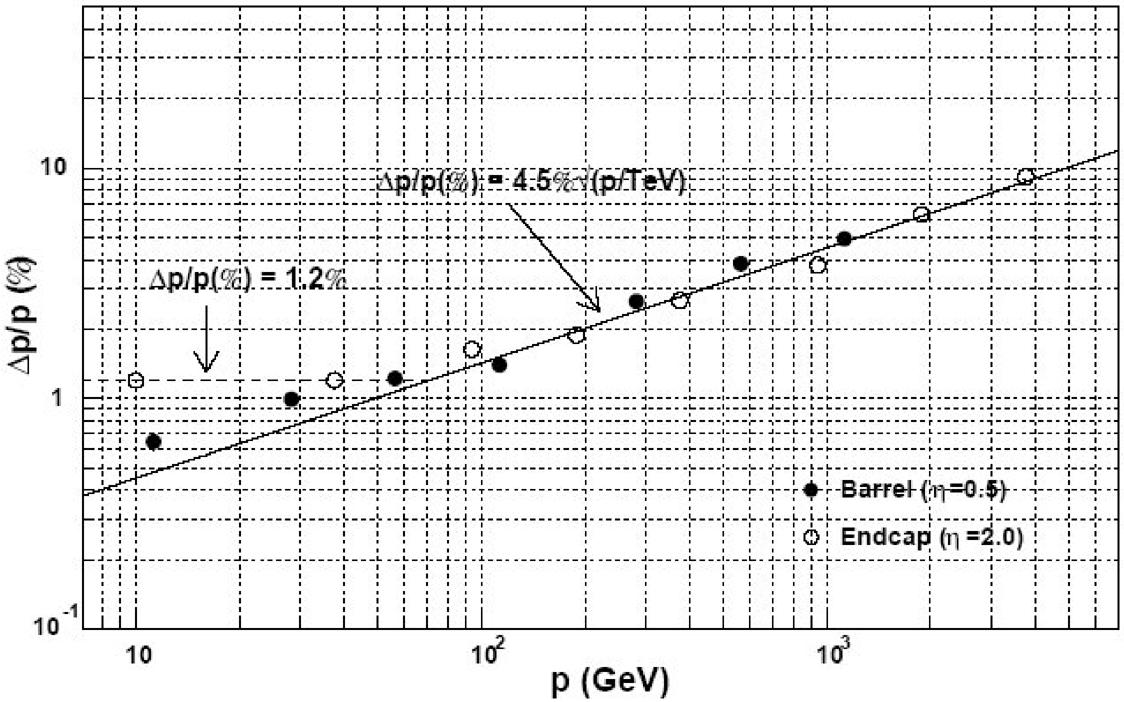


Figure 2: Schematic view of a drift cell with electric field lines.

As opposed to the "round" tubes of Atlas, the time to position relation is in CMS rectangular tubes **linear**

CMS muon resolution(ID and spectro combined)



Alignment less demanding than for ATLAS

More accurate than Atlas. On the other hand Atlas spectrometer measurements take place in a cleaner environment (air instead of iron, and after >~12 λ)

EM calorimeter requirements

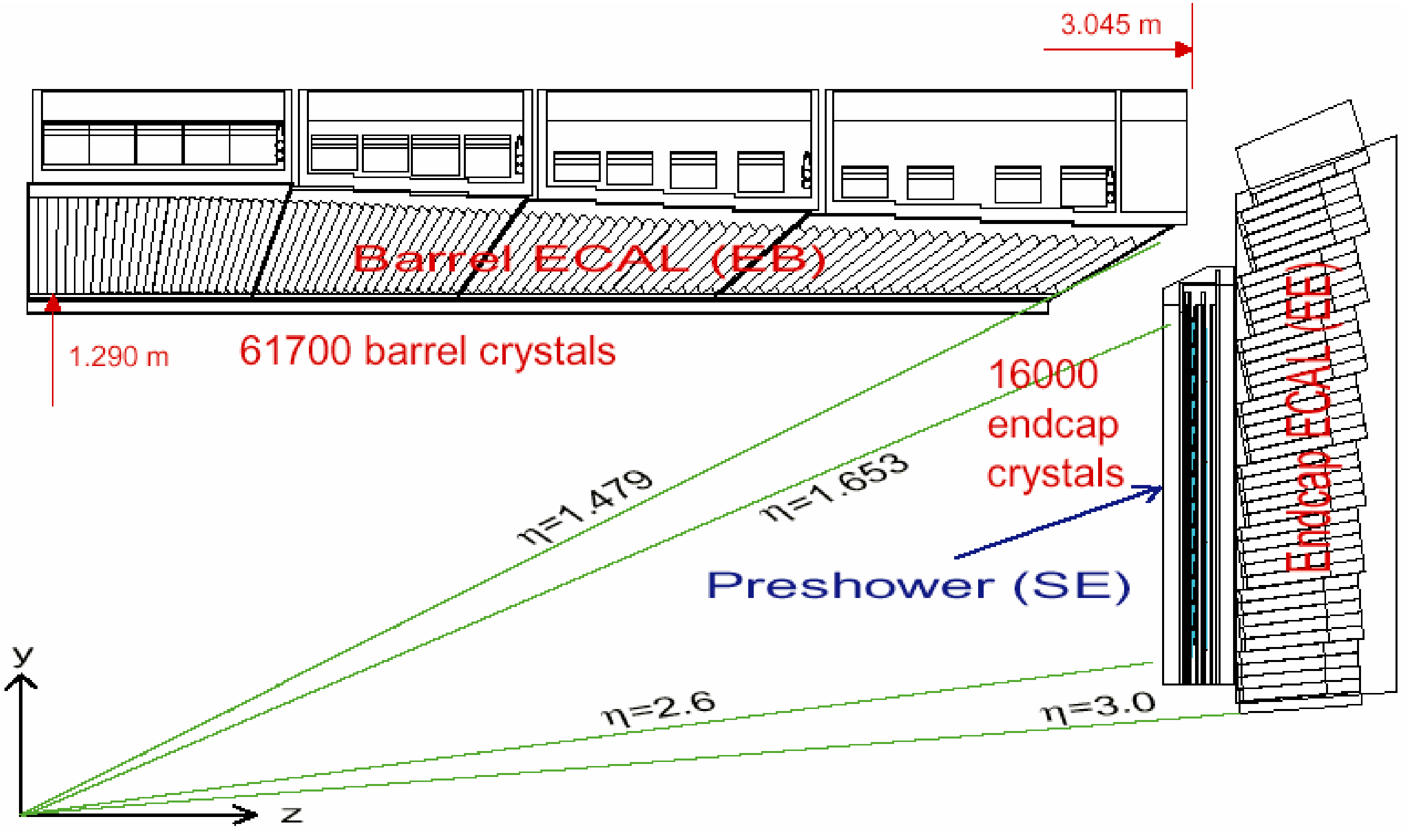
- "flag" EM showers from overwhelming jet "background"
  already at LVL1 ie every 25 ns (fast)

- Provide accurate energy measurement (precise, stable, uniform)
  -$H \rightarrow \gamma\gamma$ most demanding $\delta M/M$=1% or better at ~120 GeV
  -large dynamic range few MeV (noise) to several TeV

- Provide position measurement
  -link with electron track
  -direction of photon from vertex point
- Provide accurate timing (100 ps=3cm)
- Provide some angular measurement
- Provide jet-electron and jet-photon rejection at high level (granular)
- Keep performance after several years of irradiation (rad resistant)

- Two Different techniques ATLAS = LAr   CMS = Crystals

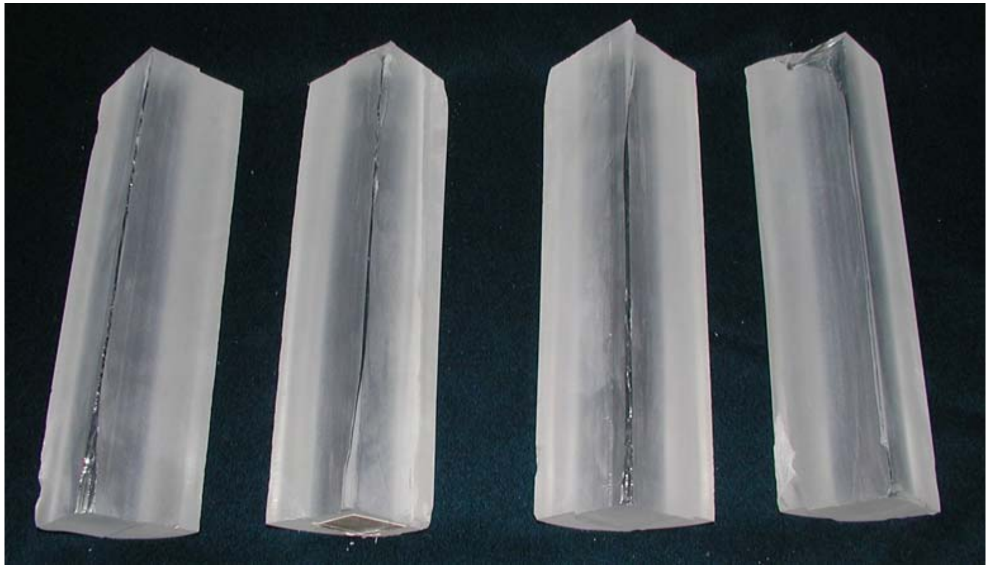
CMS $PbWO_4$ crystal calorimeter



$PbWO_4$:
- radiation hard (but…)
- fast(80% in 25ns)
- compact X_0=0.9 cm R_M=2.2 cm
- 4T→APD
- low LY: 6 photo-electrons/MeV

- barrel: 62k crystals 2.2 x 2.2 x23cm
- end-caps: 15k crystals 3 x 3 x 22 cm

CMS $PbWO_4$ crystals

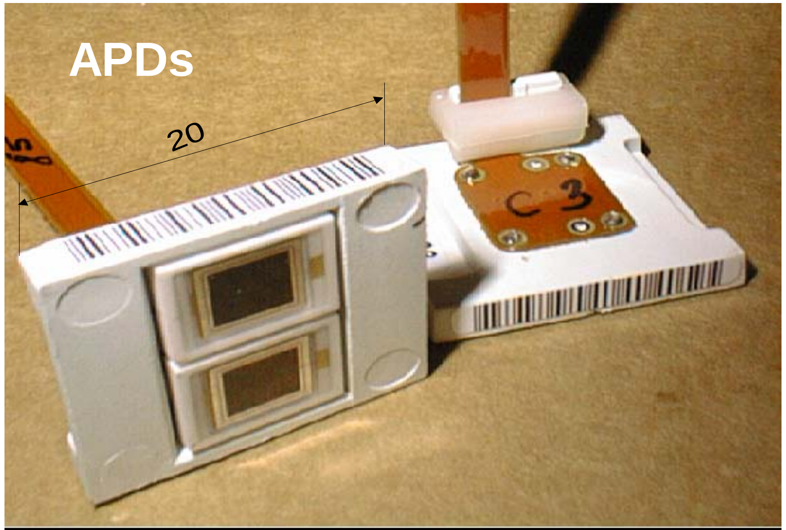


50k crystals out of 62 k delivered (barrel)
all APDs and VPT delivered

Front End Electronics

- preamplifier/shaper in CMOS-0.25μm
- 3 gains, with 1 adc/gain (12 bits)
- noise ~ 40 MeV

CMS $PbWO_4$ APDs



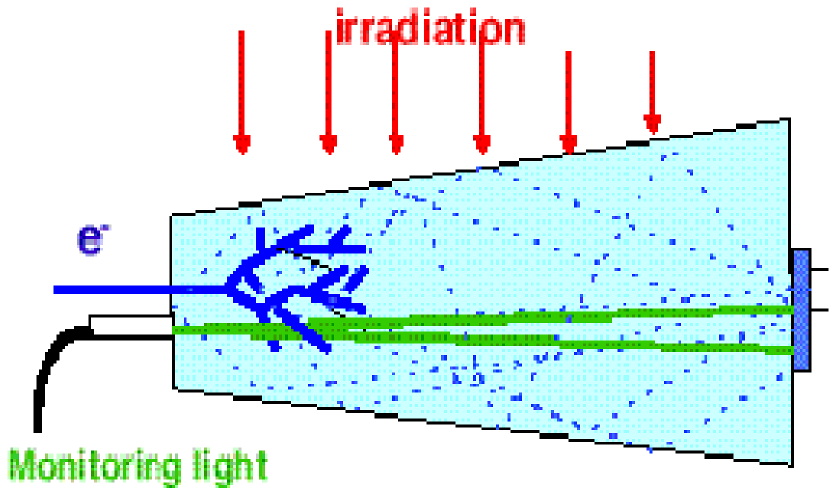
Manufactured by Hamamatsu Photonics, Japan

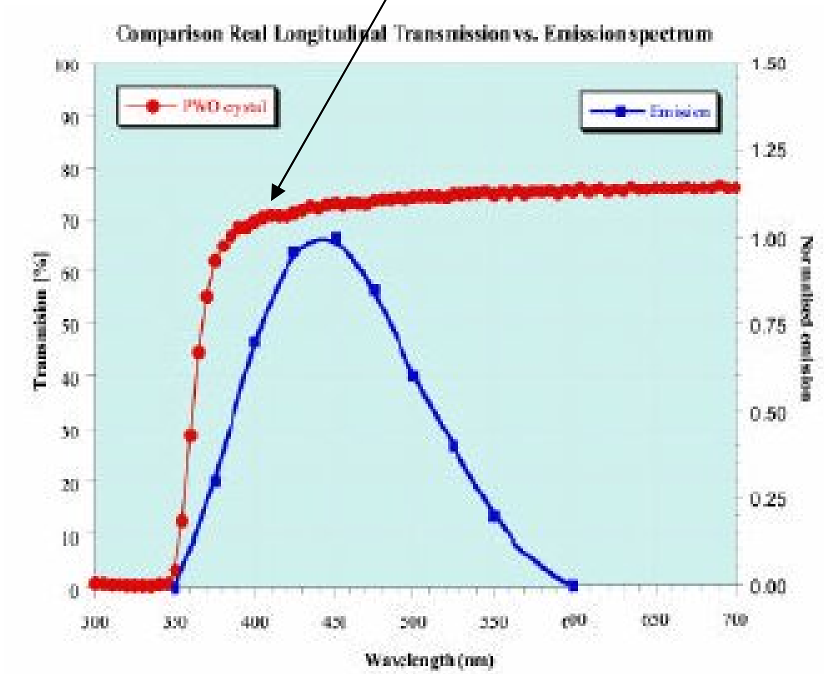
Properties :

• Active area	5 x 5 mm^2
• Quantum Efficiency	72% at 420 nm
• Operating gain (M)	50
• Charge collection within 20 ns	99 ± 1%
• Capacitance	80 pF
• Serial resistance	< 10 O
• Dark Current (Id) before irradiation	~ 3.5 nA
• Voltage sensitivity (1/M dM/dV)	3.15 % / V
• Temperature sensitivity (1/M dM/dT)	- 2.4 % / °C -2% for crystal as well
• Excess noise factor	2.1
• Breakdown - operating voltage (Vb - Vr)	45 ± 5 V

CMS crystals: light transmission/irradiation

Critical area





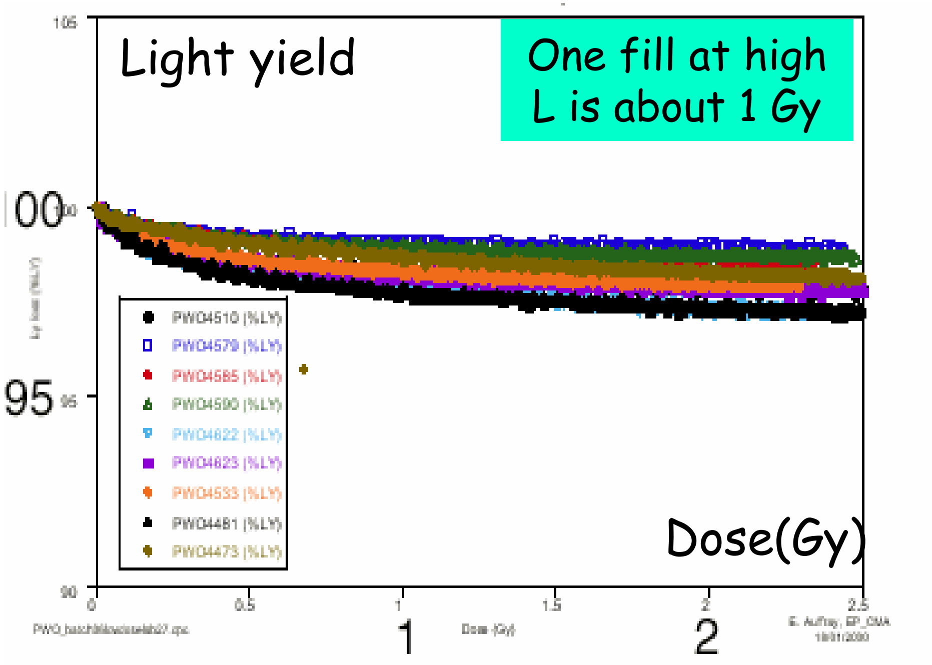
•Light spectrum: broad peak around 450 nm (blue)

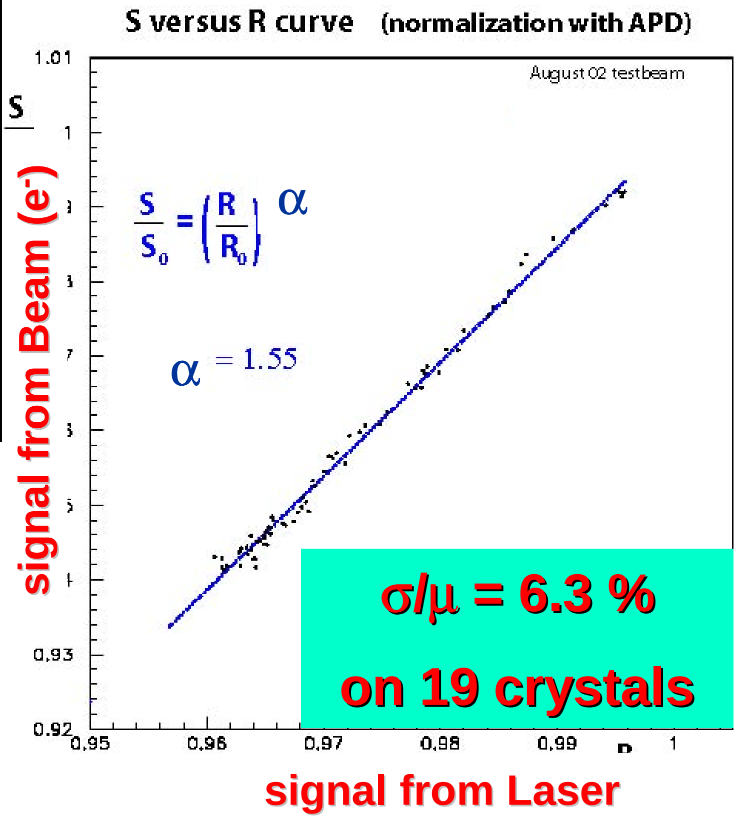
•Light transmission drops/recover by few % under irradiation:
→monitoring by laser pulses at several wavelengths (time scale=hours)

Crystal calibration(I)

Calibration strategy:

- Need cell to cell calibration / particles
- from bench test at production: 4% rms
- from azimuthal symmetry
- From cosmics on surface (new) : 2 % rms
- from W electrons (E/p) and Z^0 mass : 0.5% rms(several months for crystal calibration 1 by 1)
- laser monitoring : absorb short-term variations



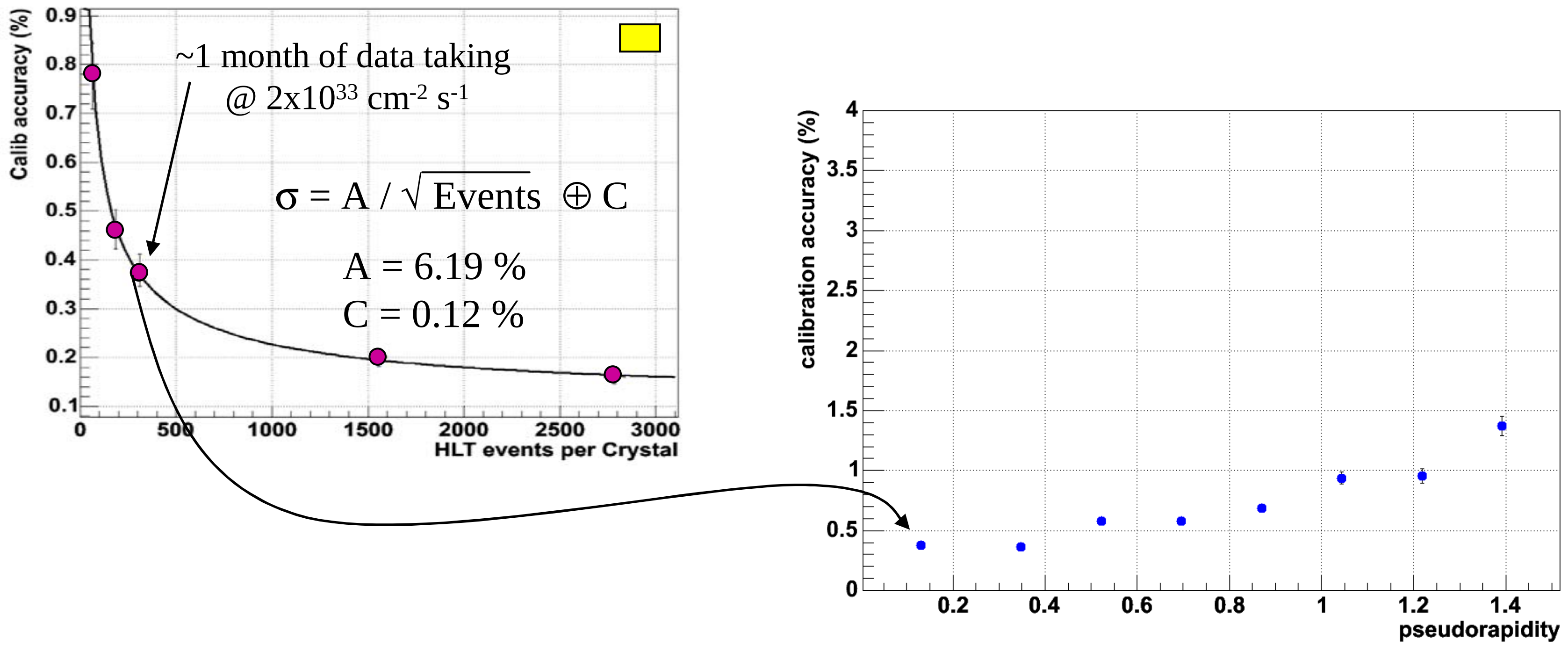


Laser monitoring

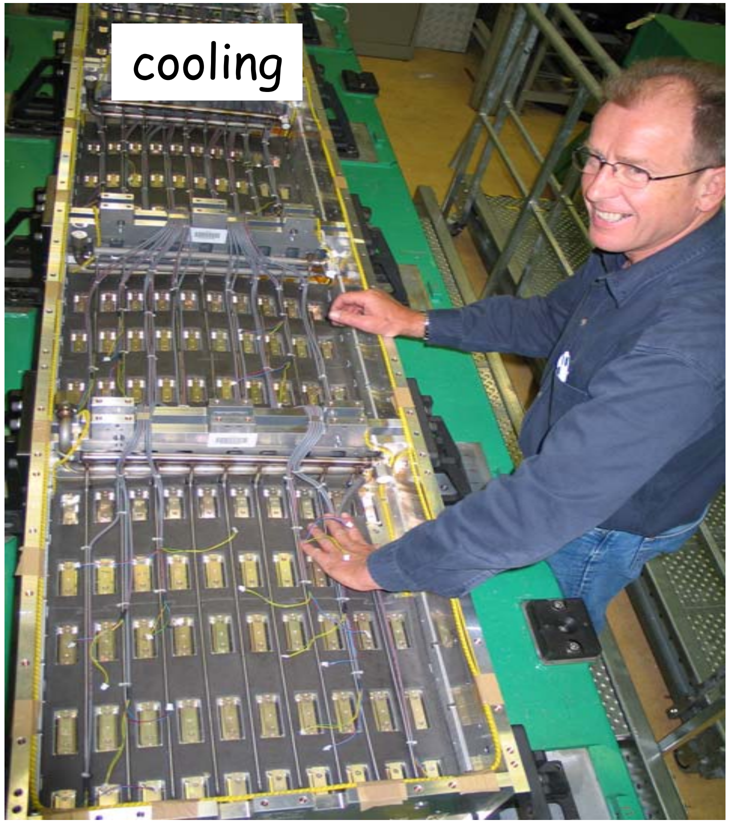
"universal ratio" makes task much easier

CMS ECAL calibration strategy (II)

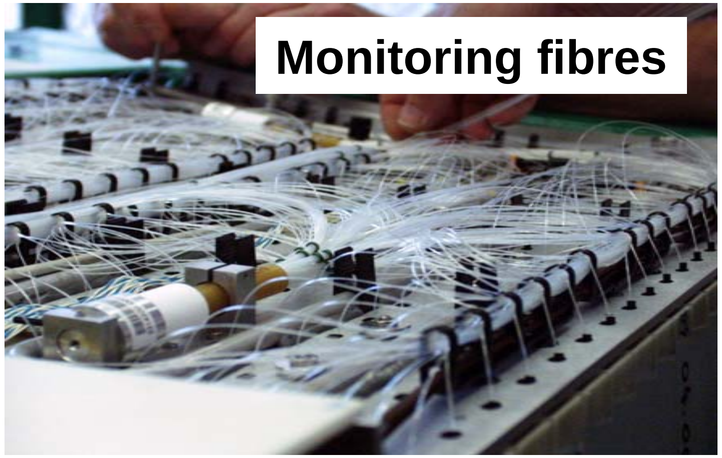
- *~1 month continuous data taking at $2x10^{33}$ $cm^{-2}s^{-1}$*
- *Corresponds to 3-4 months real LHC running?*

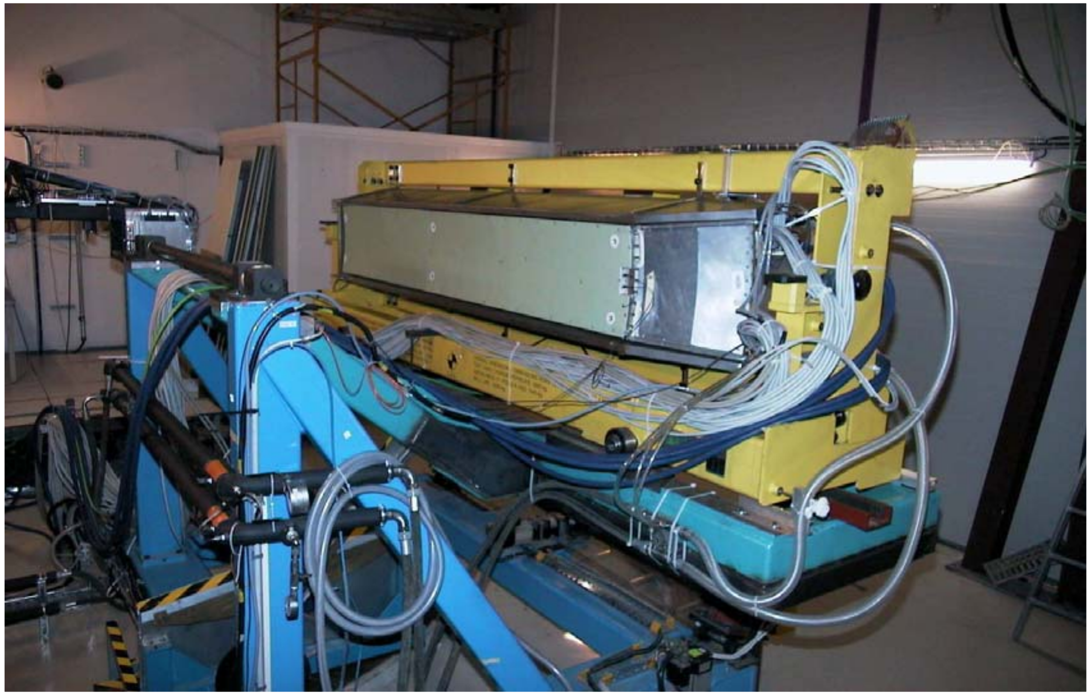


Super modules assembly and test beam

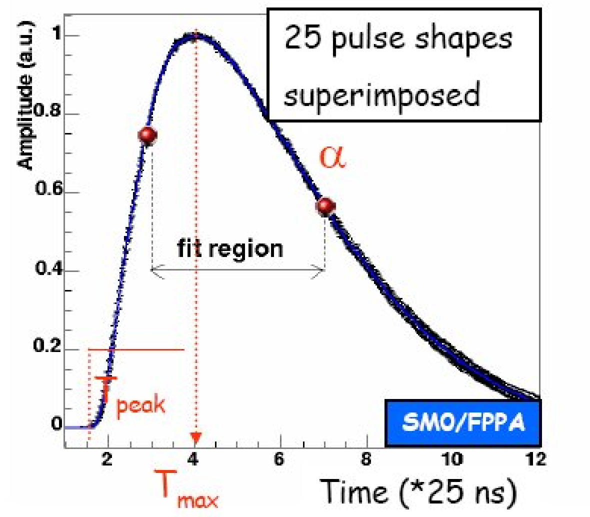


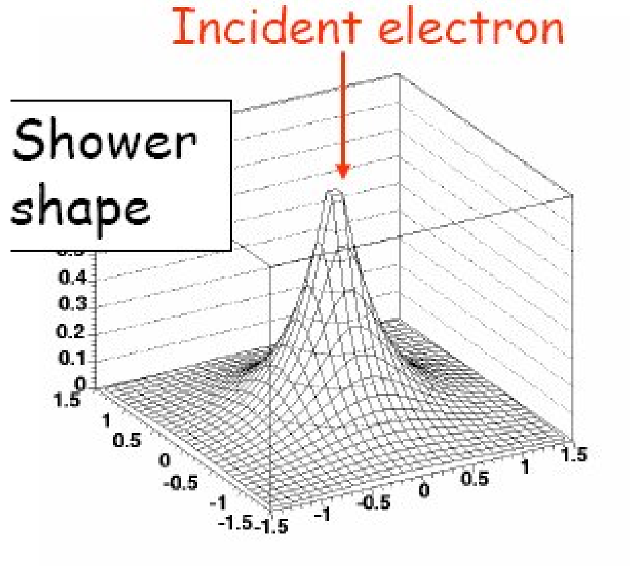
- 32/36 SM ready for lowering in 2006
- EC lowered during 2007/2008 shutdown

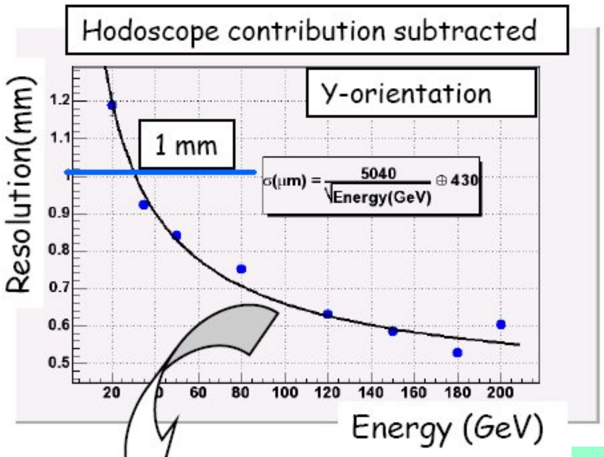




CMS crystals : selected test beam results

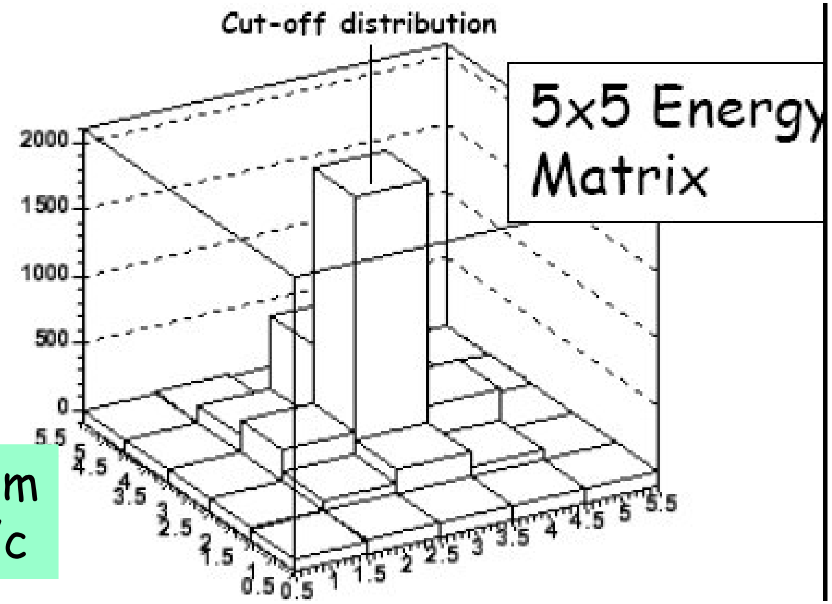




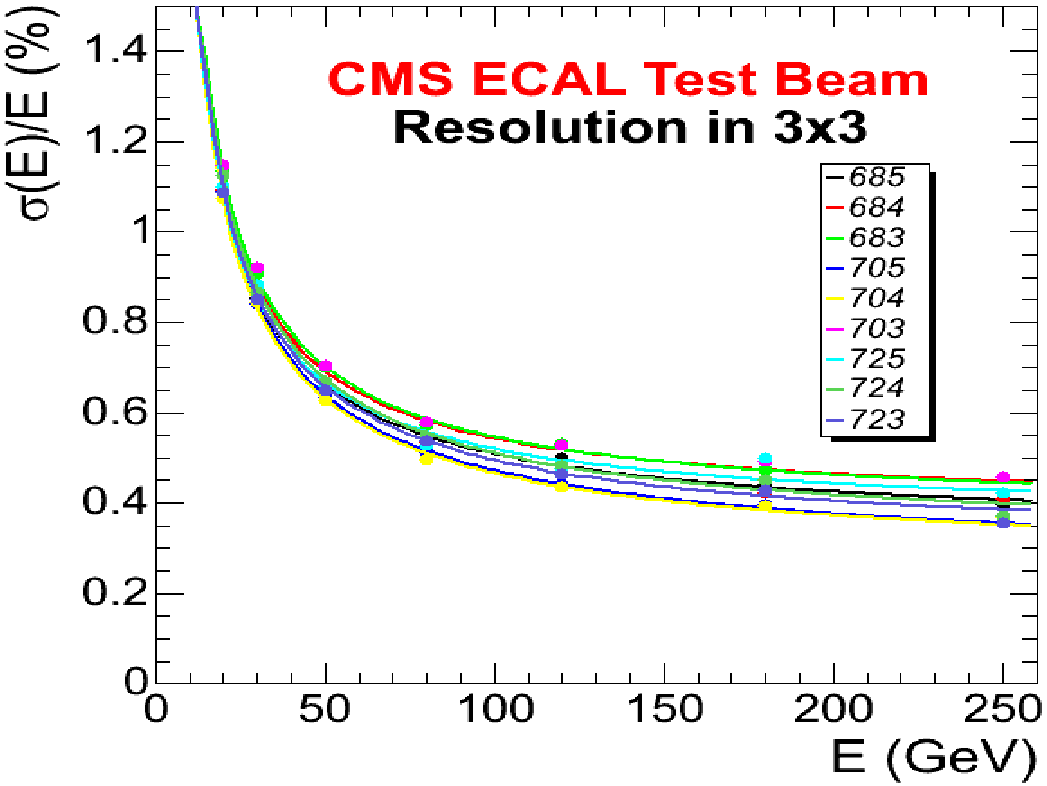


$$\sigma_Y\,(\mu m) = \frac{5040}{\sqrt{E}} \oplus 430$$

Better than 1mm
Above 30 GeV/c



CMS crystals: Energy resolution in test beam

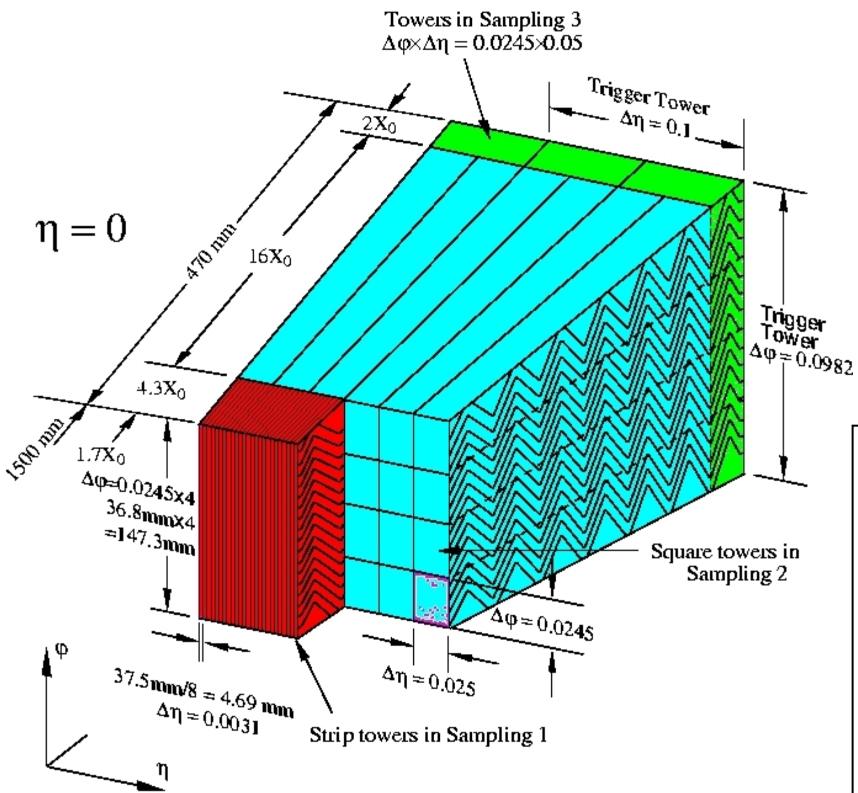


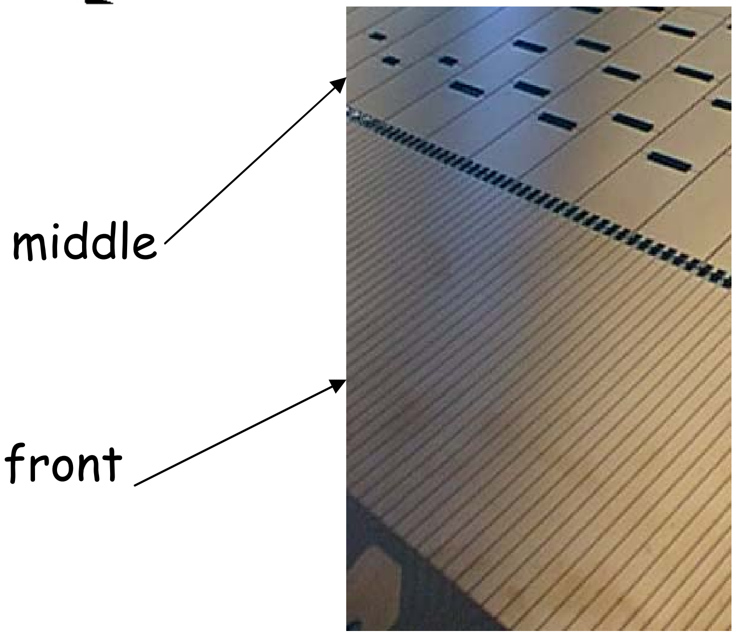
- 3 x 3 and 5 x 5 very similar
- 0.3% local constant term
- Excellent sampling term

40 MeV/crystal

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.9\%}{\sqrt{E}}\right)^2 + \left(\frac{125(MeV)}{E}\right)^2 + (0.30\%)^2$$

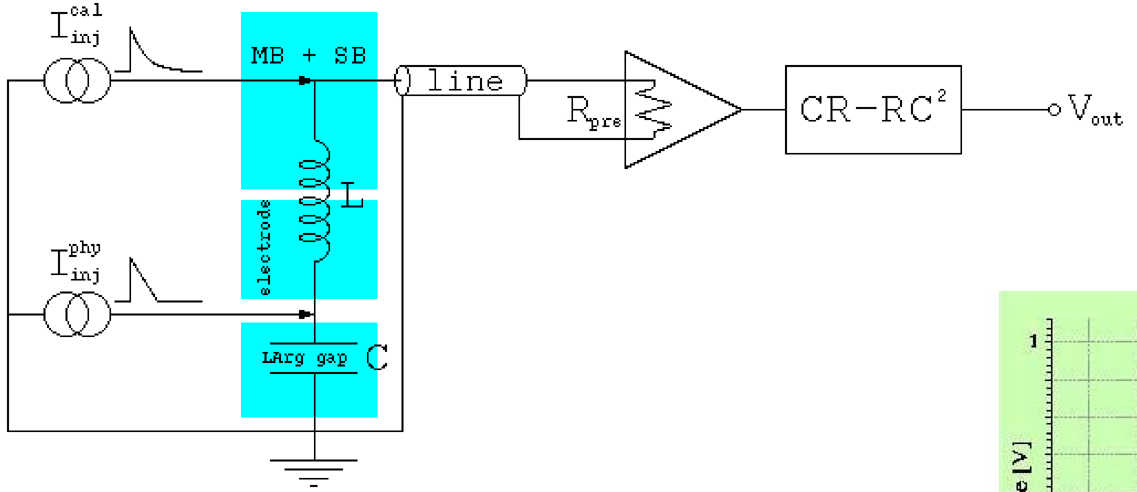
Atlas Liquid Argon EM calorimeter



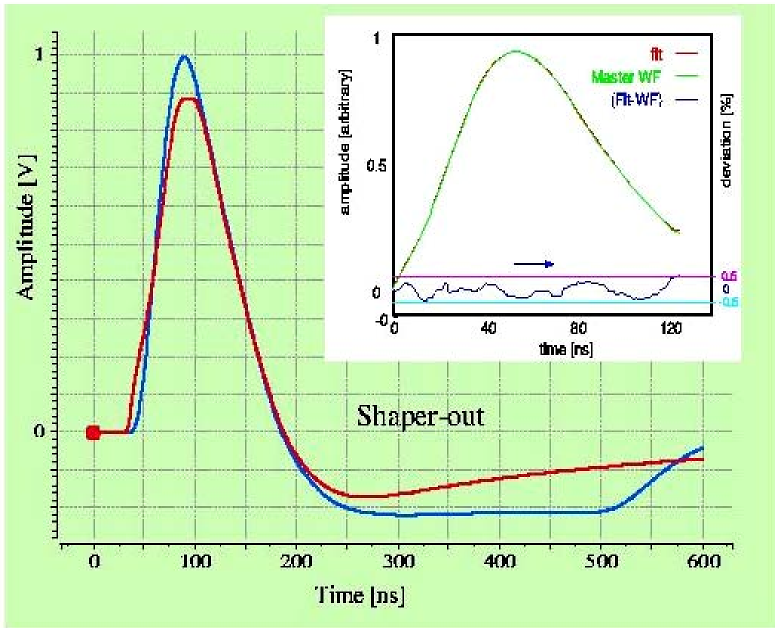


Lead-Liquid argon:
- -radiation hard, stable, uniform
- -fast (accordion + el-shaping)
- -"easily" granular-3 samplings in depth
  - front .008 x .1
  - middle .025 x .025
  - back .050 x .025
- -less compact/crystals
  X_0 =2 cm, R_M~4cm (93% in 3x3)
- -sampling→10%/√E
- -noise: ~30 MeV/central cell
- -3 gains + analog sum/LVL1
- -180 kchannels in total
- -cell to cell calibration purely electronic

Atlas LAr-EM: ionisation and calibration signals

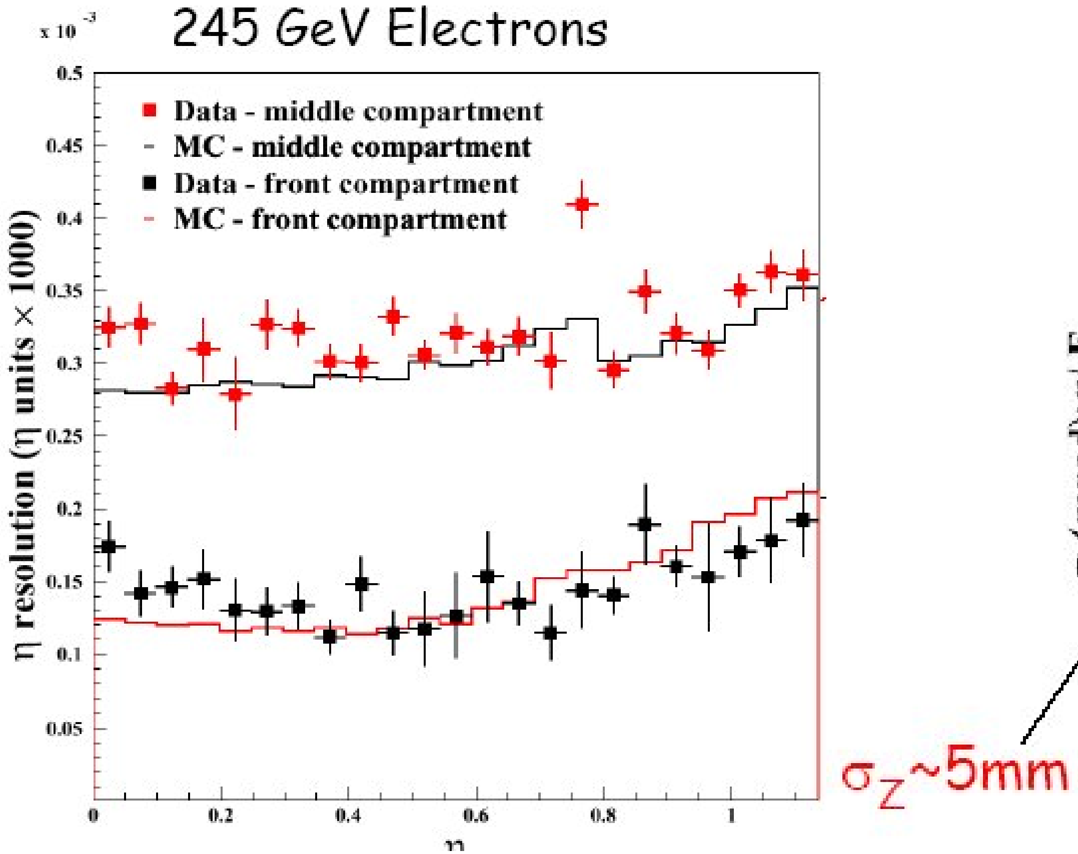


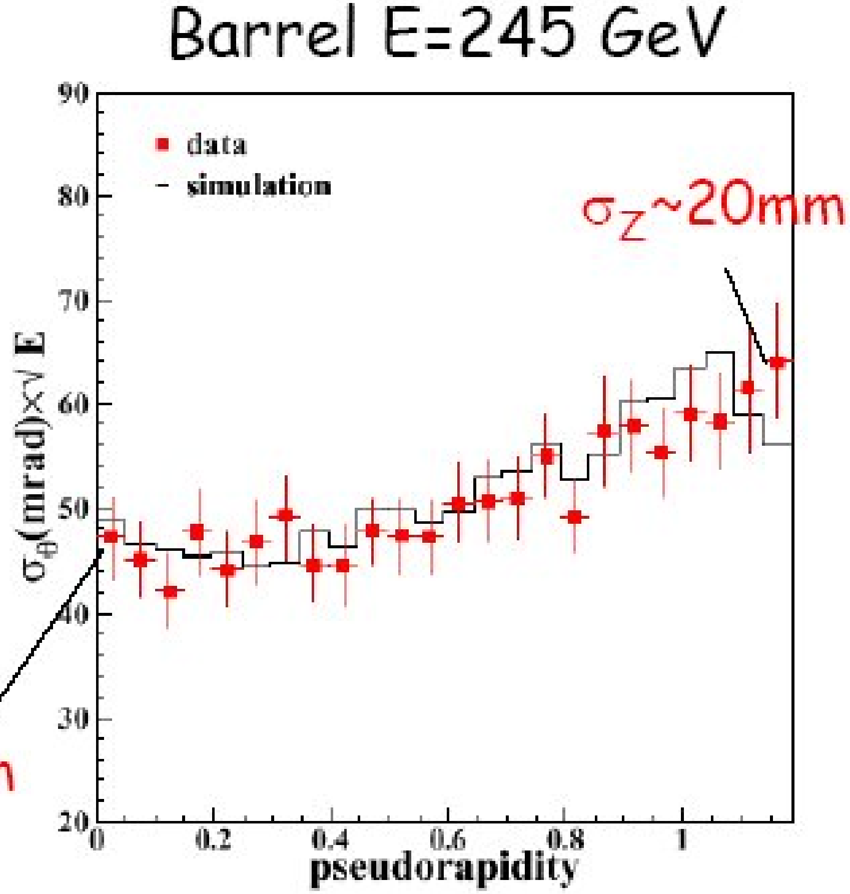
Electronics calibration (with correction for injection point) demonstrated to be OK for < 0.5% uniformity in areas 0.4 x 0.4



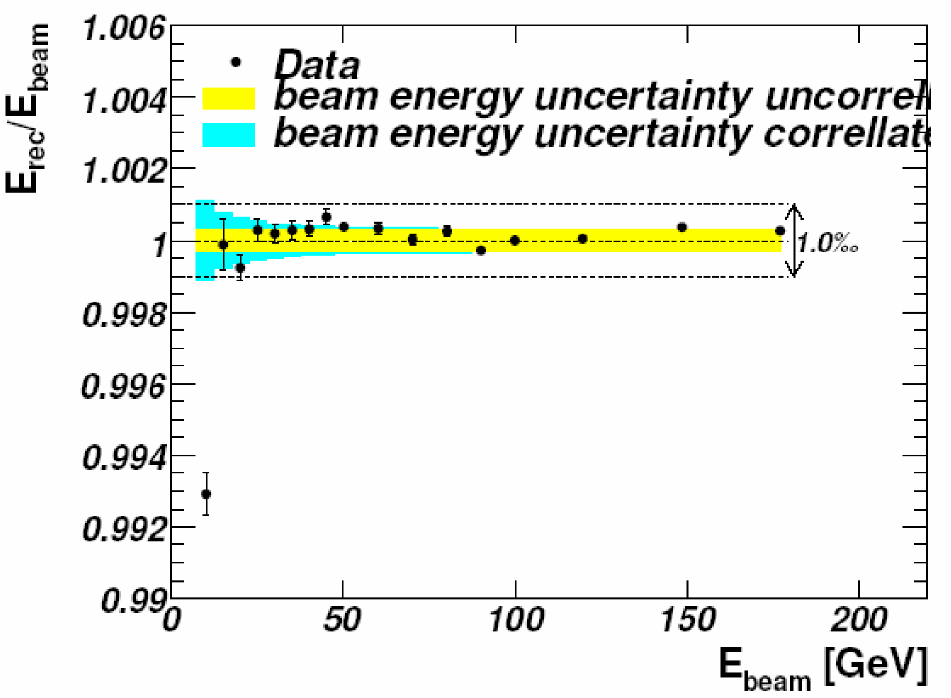
Calibration of "regions" with Z_0 mass constraint should be fast ("days" at low L)

Atlas LAr-EM: selected test beam results



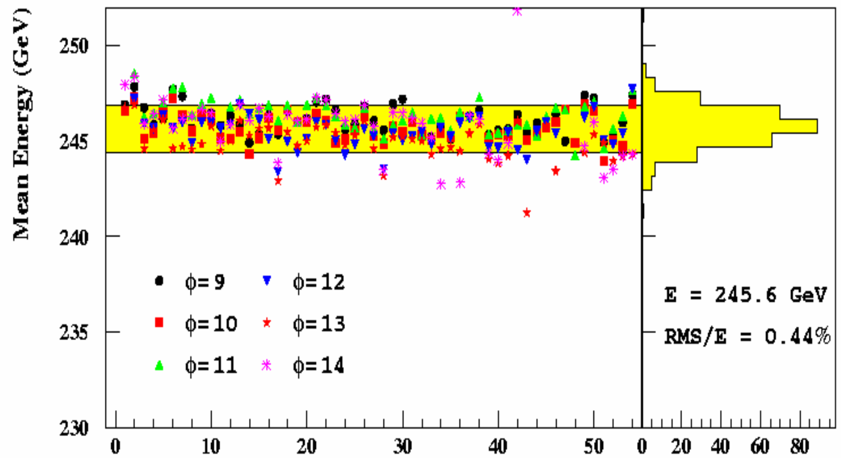


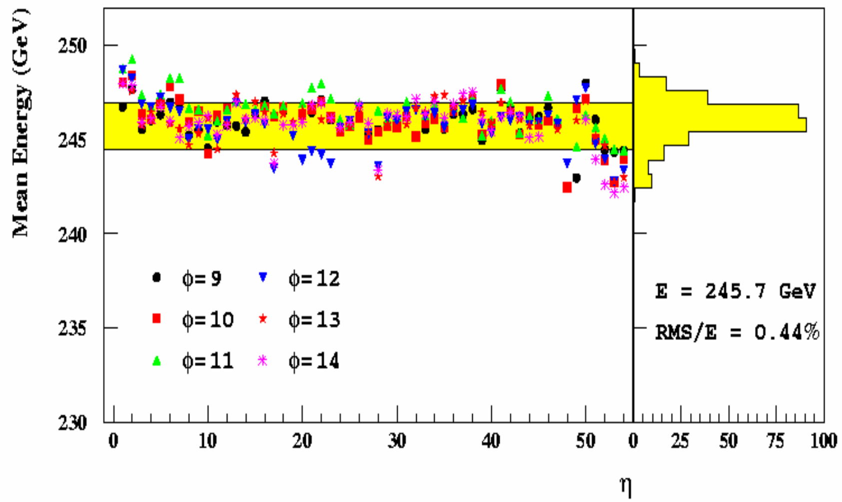
Atlas LAr-EM: selected test beam results



Linearity :
10^{-3} between 10 and 180 GeV
2×10^{-4} between $m_{W/2}$ and $M_{Z/2}$

OK for M_W measurement down to 15 MeV

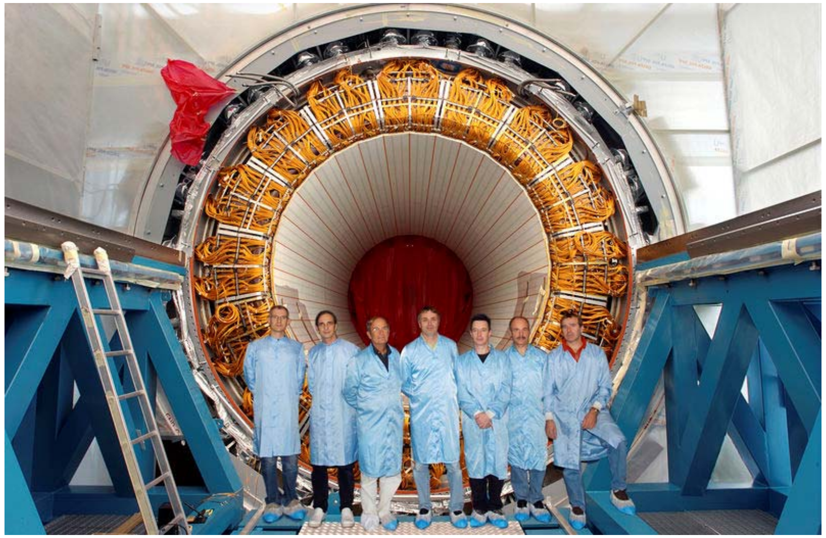


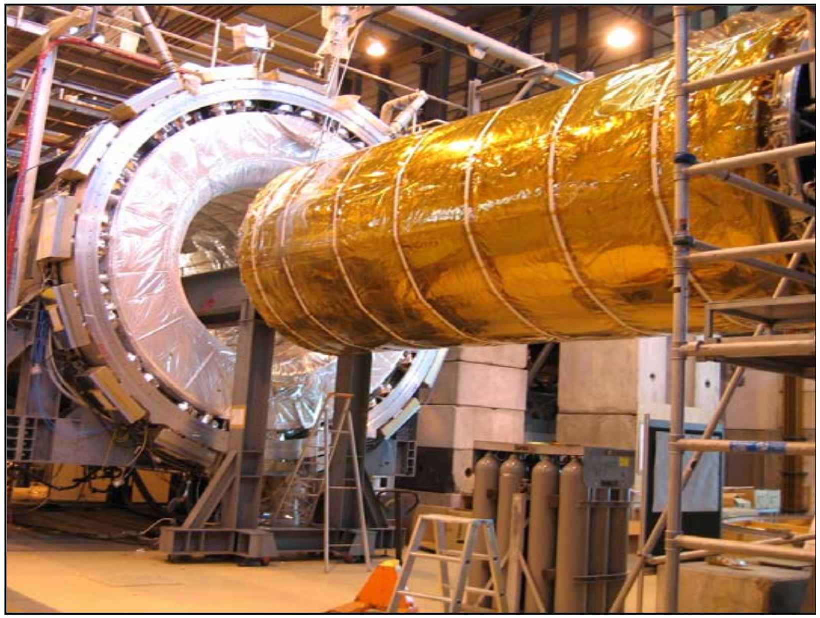


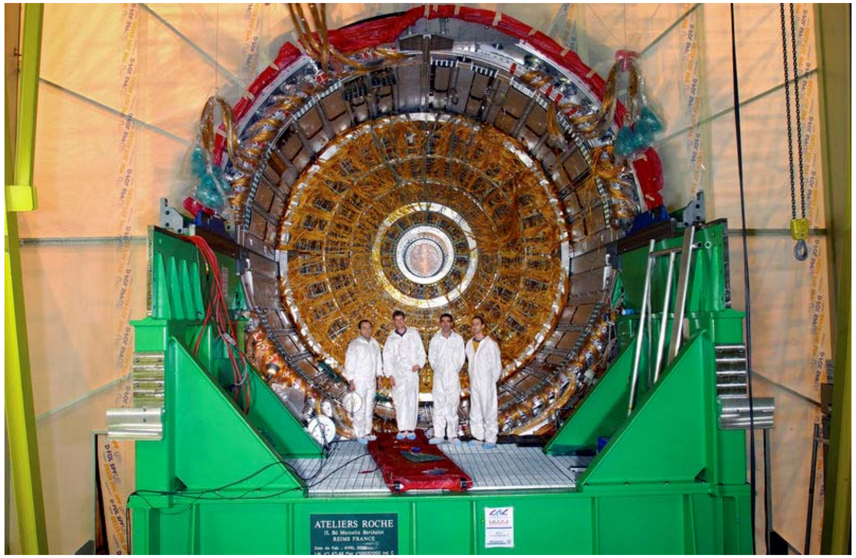
Uniformity:
- 0.44% on two half modules 0.2x 1.4
- < mod13>-< mod15> = 0.05%

Energy resolution:
$10\%/\sqrt{E} \oplus 0.3\%$ local

Atlas LAr-EM: some pictures....







- Detectors fully cold tested on surface
- Barrel cool down in final position in the pit starting April 06

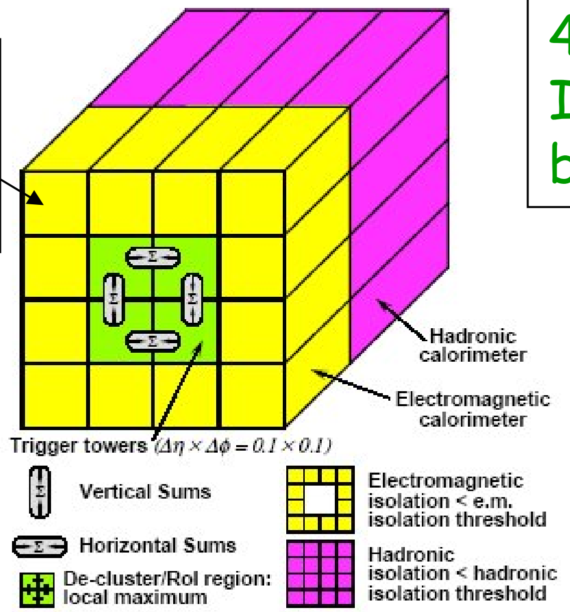
EM shower ID at LVL1

Basic approach:
"digitize and sum" (CMS) or "sum and digitize" (ATLAS) signals from a "small" $\delta\eta \times \delta\phi$ region of EM calorimeter, but "large enough" to fully contain an EM shower and compare to threshold.

Jet background:
- huge, but decrease fast with E_T
- jets are broad $\rightarrow$ask for "isolation",...but pile-up may kill good candidates

ATLAS

4000 towers 0.1 x 0.1



} isolation

4 sums 2 x 1 compared to E_T threshold, In parallel treat all windows shifted by 0.1 in η and ϕ,...

Every 25 ns get a new answer: yes or no this bc contains at least an EM shower candidate

EM shower ID : LVL1 in ATLAS

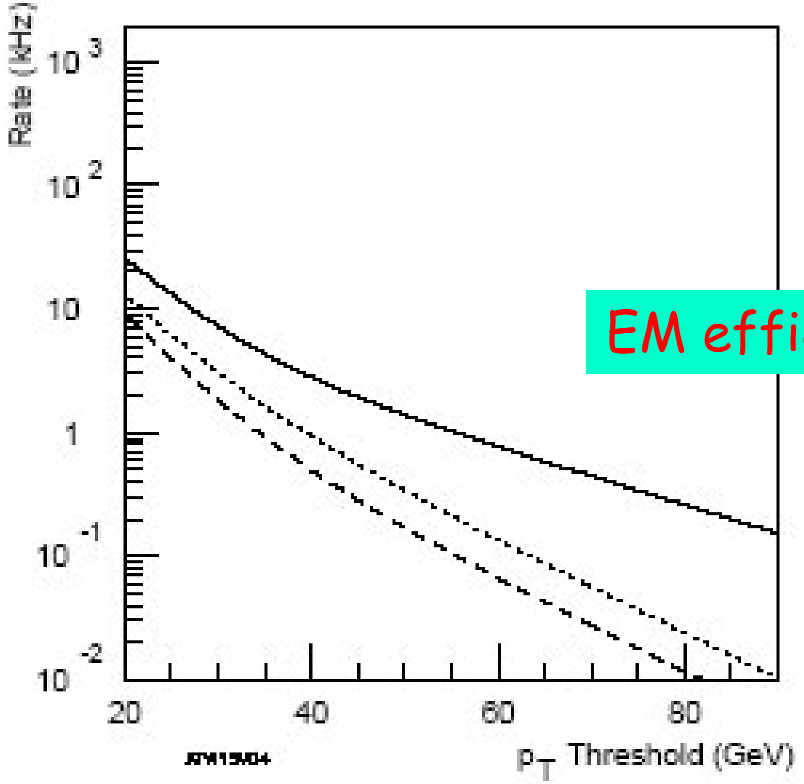


Figure 4-15 Inclusive electron trigger rate for luminosity 10^{33} $cm^{-2}s^{-1}$, without isolation (solid), requiring only hadronic isolation (dotted) and requiring both electromagnetic and hadronic isolation (dashed).

EM efficiency 95%

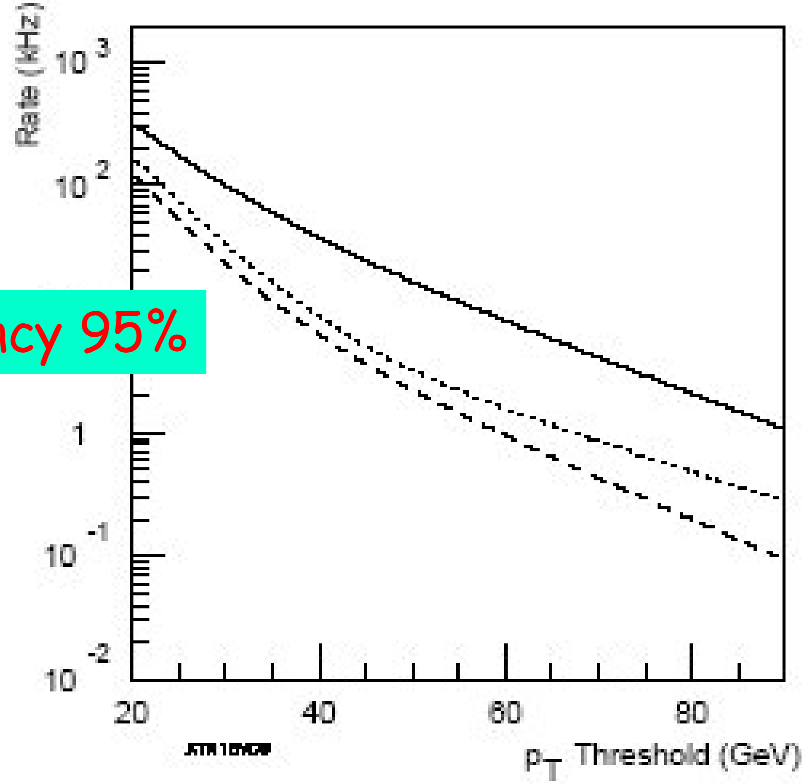
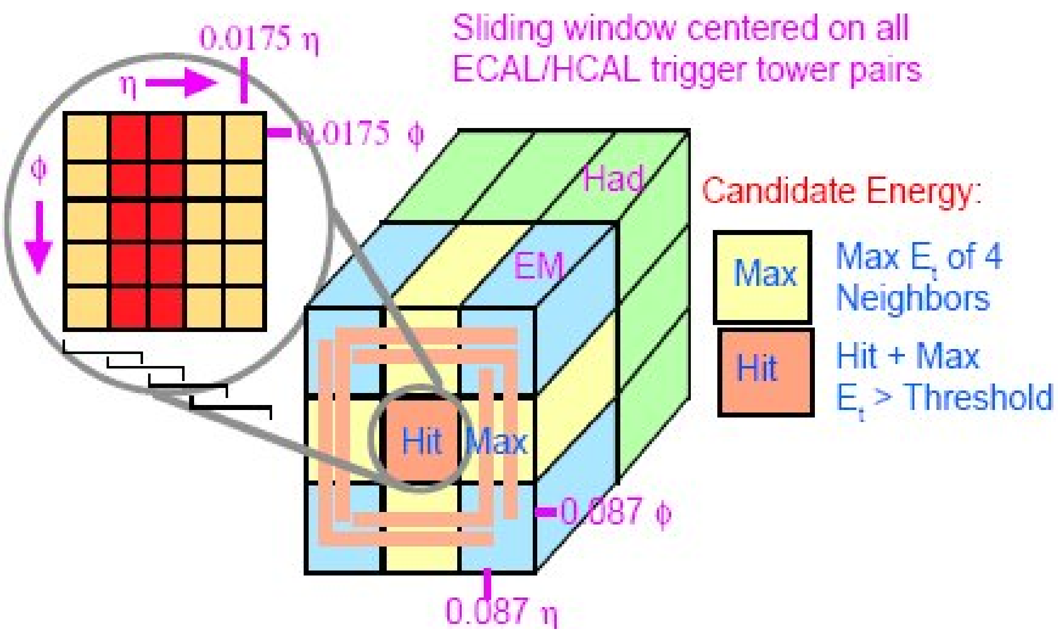


Figure 4-16 Inclusive electron trigger rate for luminosity 10^{34} $cm^{-2}s^{-1}$, without isolation (solid), requiring only hadronic isolation (dotted) and requiring both electromagnetic and hadronic isolation (dashed).

Isolation (mostly hadronic-less pileup-threshold~3 GeV/10^{34}) helps

EM shower ID : LVL1 in CMS



Granularity a bit better than ATLAS at LVL1

- Trigger towers .087 x .087 (5 x 5 crystals-1x1 HCAL)
- "Hit+max" equivalent to 2 x 1 of ATLAS
- 3 x 3 window for HCAL isolation
- Fine grain cut on η profile in Hit cell (1 x 5 crystals)

(in ATLAS the equivalent is possible only at LVL2)

EM shower ID : LVL1 in CMS

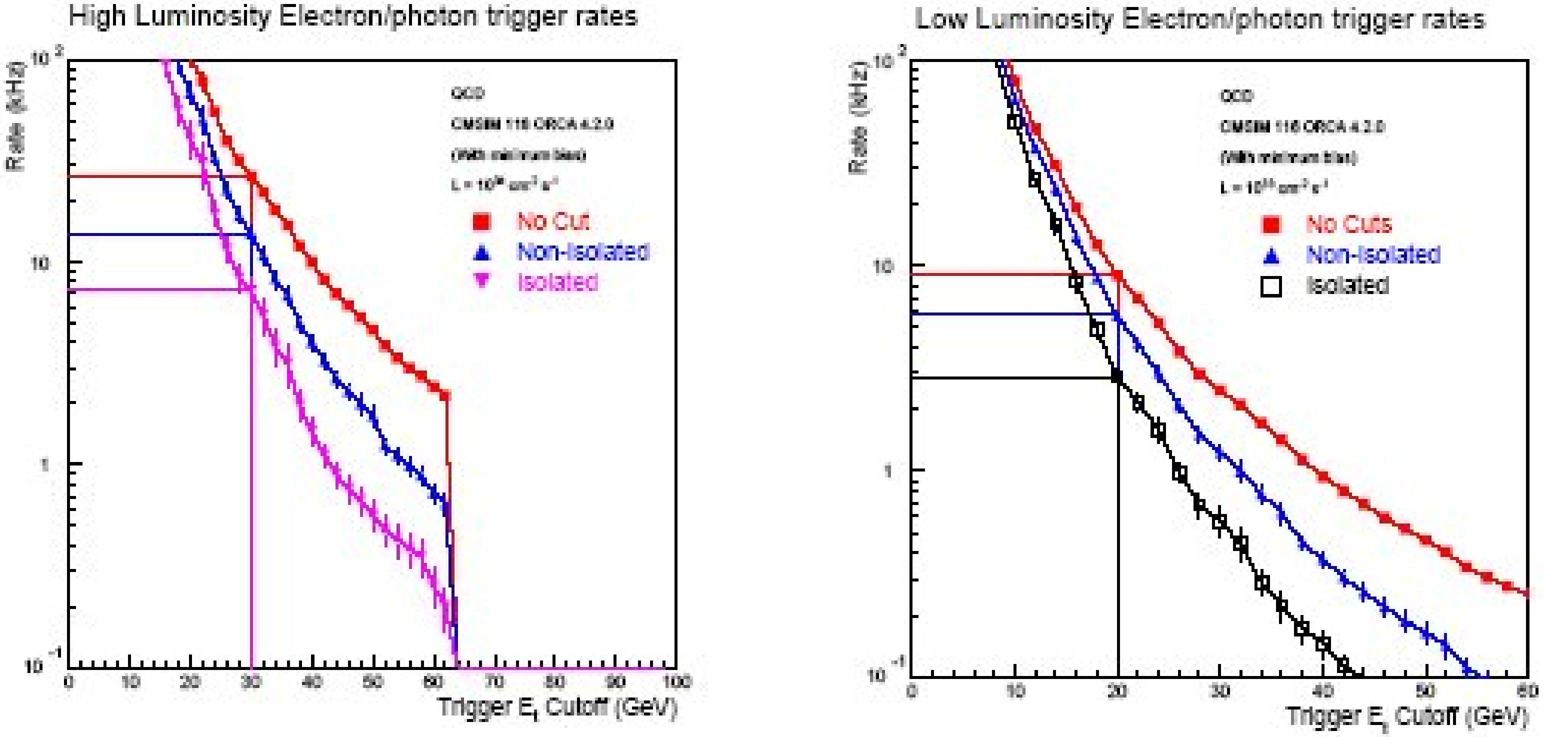


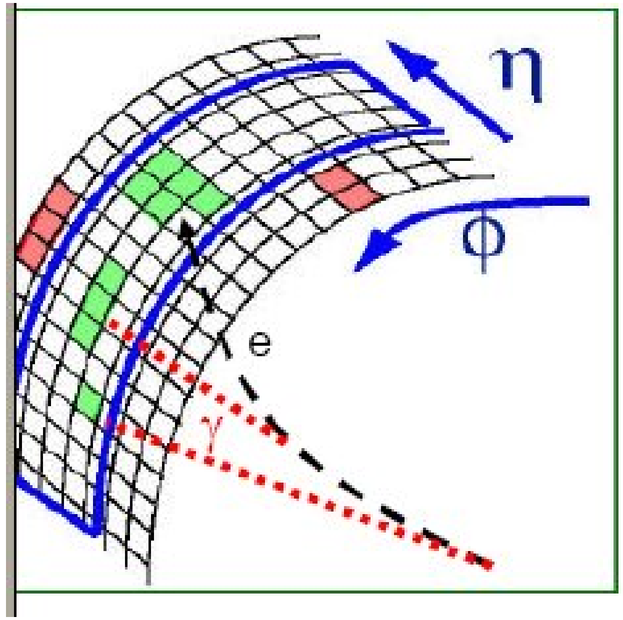
Fig. 3.12: The integrated QCD background rate above electron/photon trigger E_T cutoff is plotted versus the E_T cutoff for high and low luminosity operation of the LHC. Data for both isolated and non-isolated electrons are shown.

Estimated rate lower than ATLAS (at 30GeV HL: 15 kHZ against 30)

EM shower$\rightarrow$ e/γ: need tracker information

Basic approach :
-electron:
 a track points to the EM cluster with E/p~1,
  but brems…

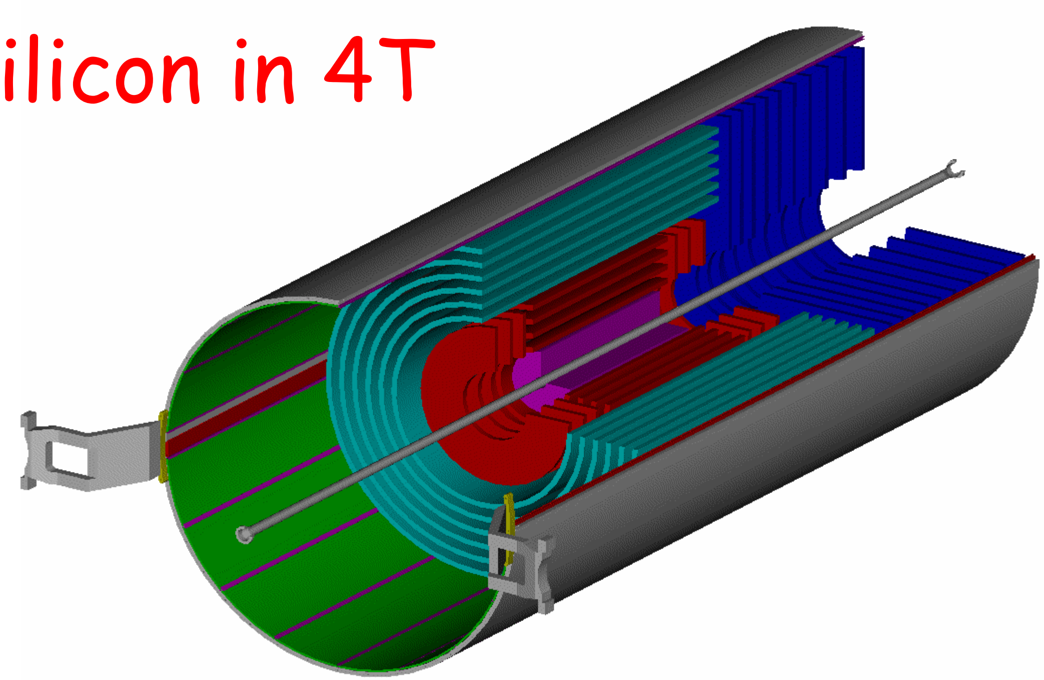
-photon: nothing in front of EM cluster,..
  but conversion, Dalitz, pile-up

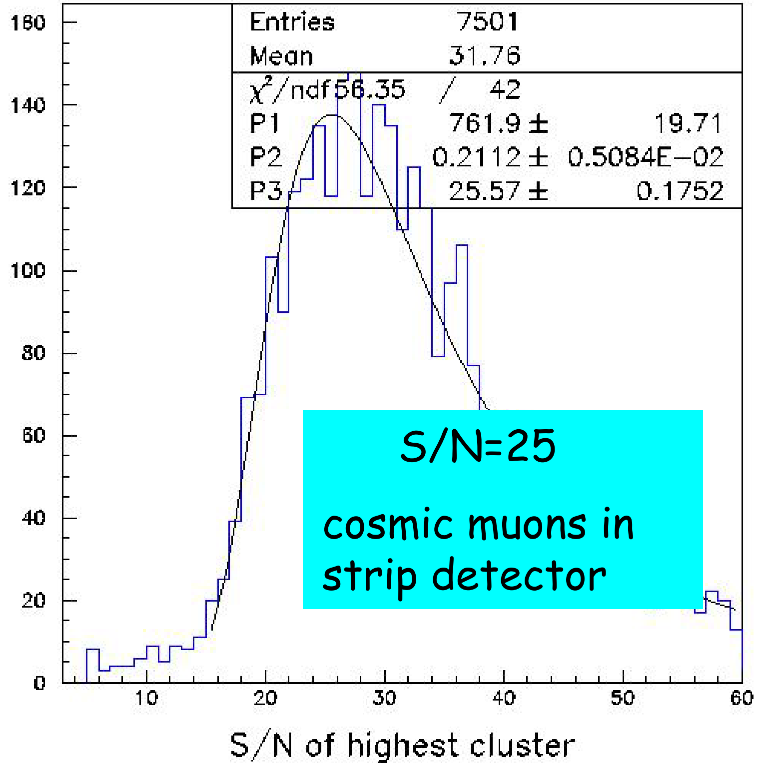


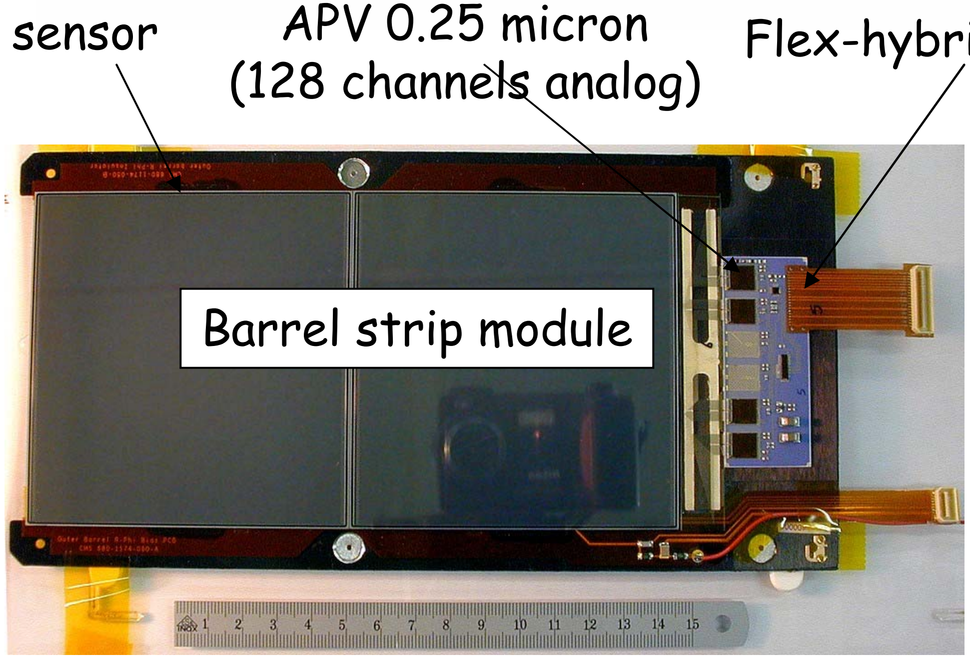
Beforehand,
  since rates are high at LVL1,
use at LVL2 the full granularity information from EM calorimeter

CMS tracker: full Silicon in 4T

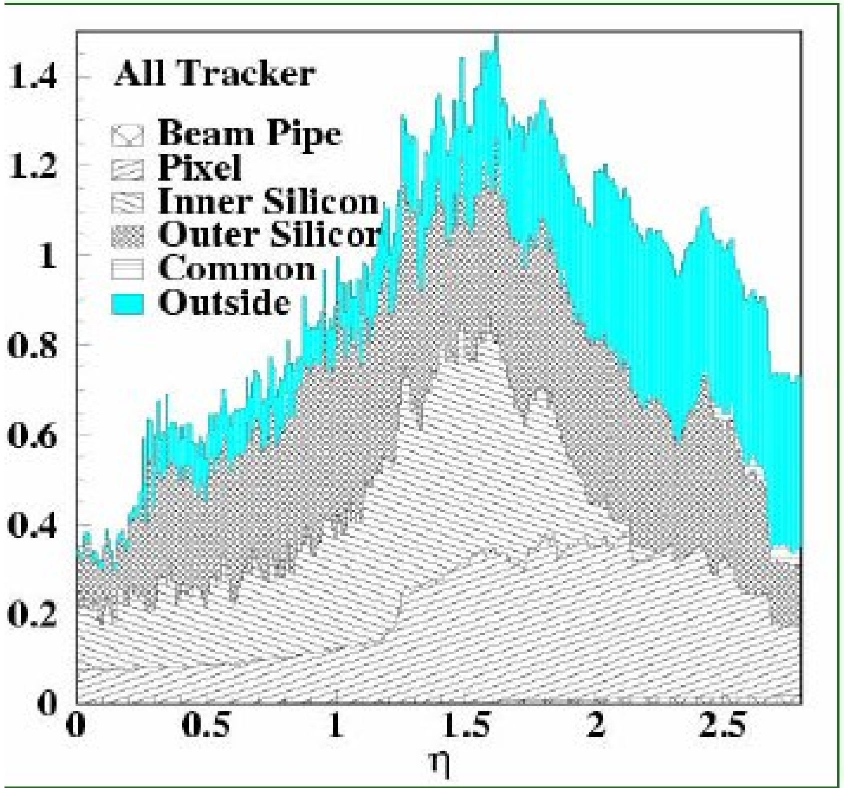
- 5.4 m long, barrel and disks
- 210 m² Si sensors
- Full volume (24 m3) at -10°C
- 10M strips
- 67M pixels (100 x 150 μm)

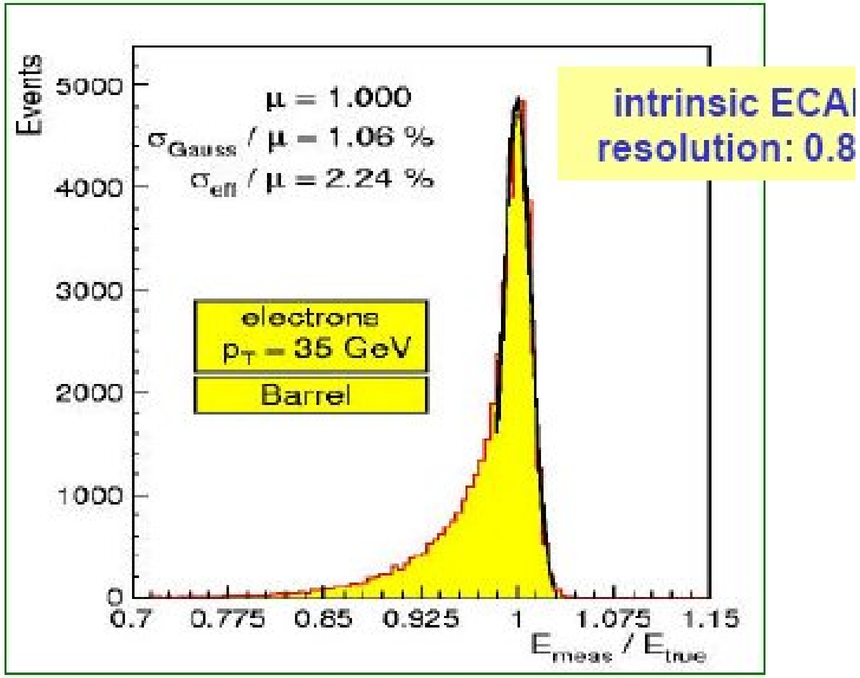




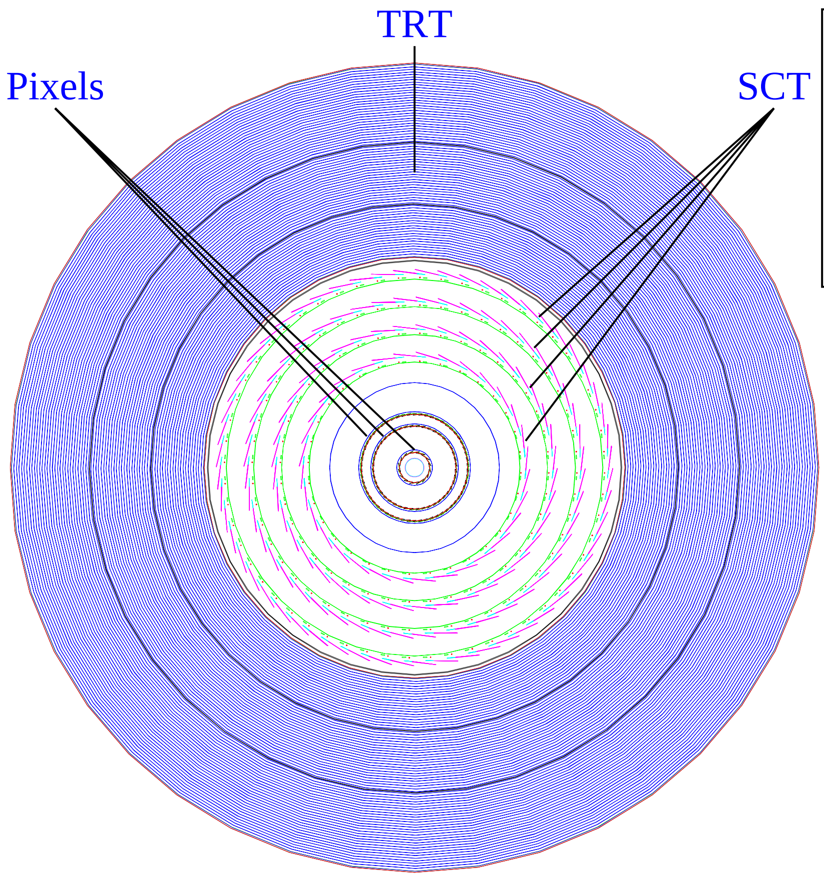


CMS ID material





ATLAS tracker: Si and TRT in 2T



Transition Radiation Tracker:
-long(70cm) straws→high occupancy
-large number of crossed straws(~30)
→"easy" pattern

Transition radiation:
-charged particle crossing
N thin foils(CH_2)/vacuum transitions
emits photons in X range if γ>>1

I(emitted energy) α γ

N(photons>E_{th}) α $\log^2\gamma$

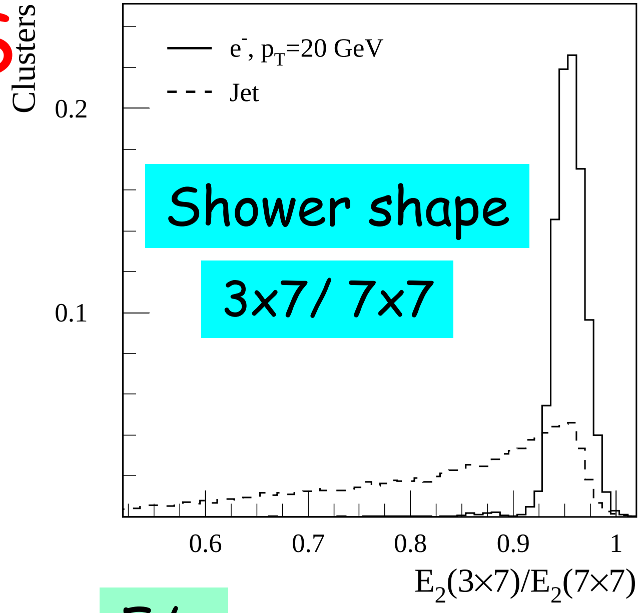
-X-rays materialize in Xenon rich gas giving large signals (>~6 keV against ~2 keV for dE/dx)

Amount of material similar to CMS…

Electron ID: LVL2 in ATLAS

Further to LVL1 selection with rate of
~30 kHz for 30 GeV E_T at 10^{34}
~12 kHz for 25 GeV E_T at 2 10^{33}

LVL2 requires:
- A shower shape matching an EM cluster



- A track in the ID (using calorimeter cluster as seed) in $\delta\eta \times \delta\phi$ =0.1 x 0.1

- A track-cluster matching (position: $\delta\eta \times \delta\phi < 0.02 \times 0.02$, and E/p)

- A TRT signature (option)

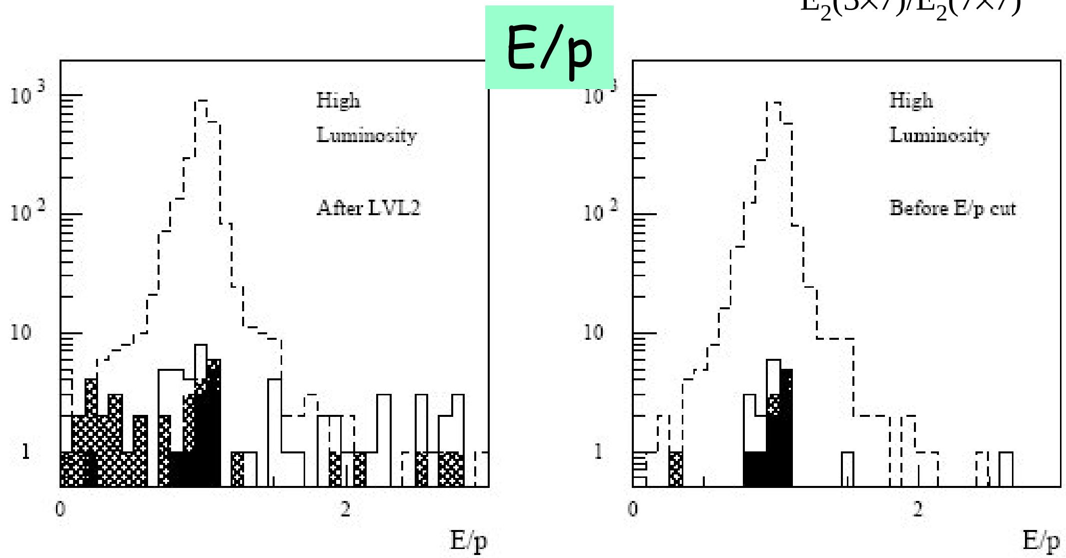


Figure 7-28 Ratio between energy of EM clusters to momentum of reconstructed charged tracks for electrons (dashed) and jets. For the 'jet' sample, various components are shown: electrons from *W*'s and *Z*'s (black), electrons from heavy flavour (dense hatch), conversions (light hatch) and hadrons (open). The normalisation between the single electrons and the jet sample is arbitrary.

Electron ID:ATLAS overall

- With the stat generated (10^6 jets) above 17 GeV E_T the rejection run out of statistics.

- Already before E/p and TRT cuts the background is dominated by real electrons (b/c and conversions)

- TRT is most useful at lower energy where bkg is worse

Cuts	High luminosity			
	Eff e_{30} (%)		Rej jets (10^3)	
LVL1	96.1		0.09	
LVL2 Calo	92.1	(95.6)	0.48	(5.2)
LVL2 ID	82.5	(89.5)	3.7	(7.8)
Offline Calo	81.1	(98.3)	8.4	(2.2)
Offline ID	77.2	(93.6)	22.7	(2.7)
Matching	75.3	(97.4)	35.8	(1.6)
TR	67.5	(89.7)	>45	

$2\ 10^{33}$

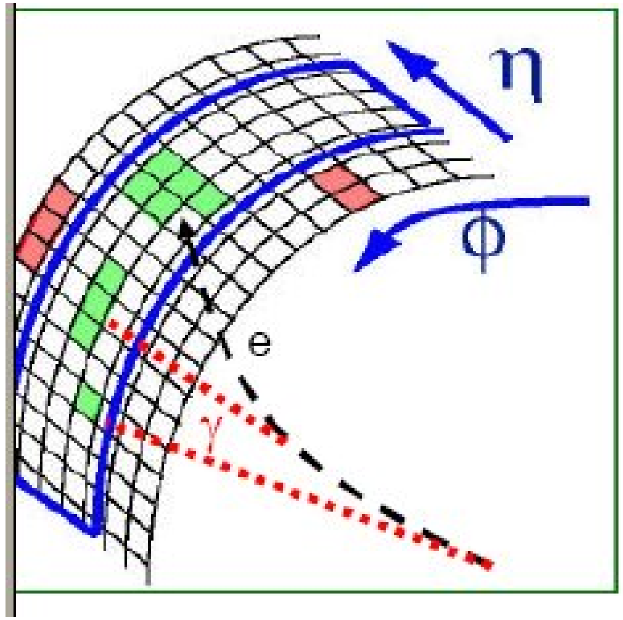
25 GeV E_T

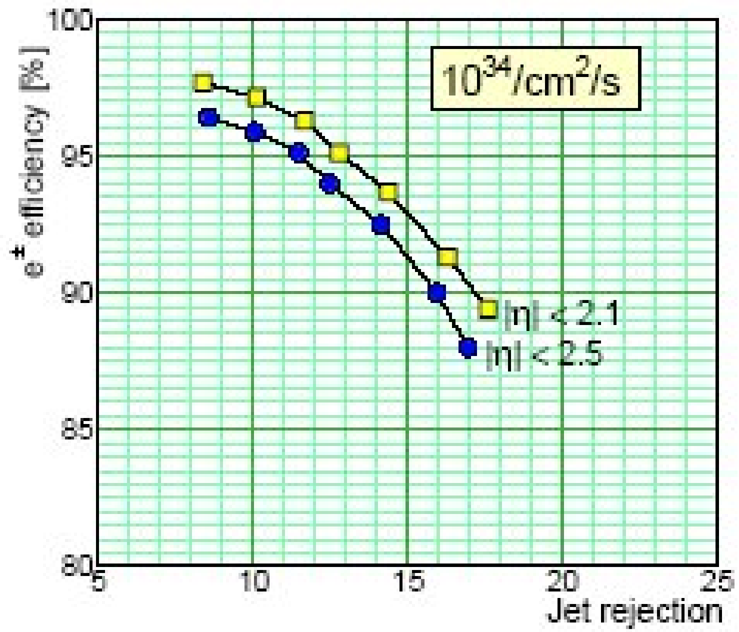
Trigger Step	Rate (Hz)	Efficiency (%)
LVL2 Calo	2114 ± 48	95.9 ± 0.3
LVL2 Tracking	529 ± 24	88.0 ± 0.5
LVL2 Matching	137 ± 12	86.6 ± 0.6
EF Global	30 ± 5	79.0 ± 0.7

Electron ID : LVL2 in CMS

Starting from LVL1 isolated clusters(5 x5) the following steps are made:

•Reconstruct a "super-cluster" and apply E_T threshold (95% eff as LVL1)
(thresholds estimated to be ,at 10^{34}, 31 GeV for SC against 30 for LVL1)





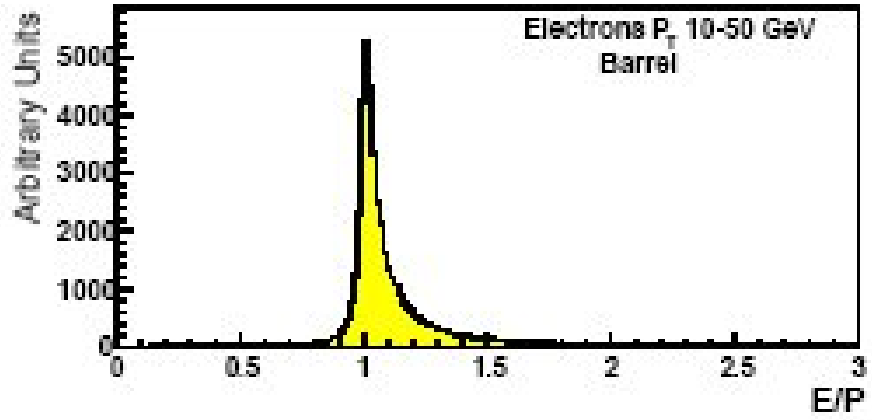
•Find corresponding hits in the pixels
-takes advantage that CoG in calo is independent of brems)
-extrapolate in rϕ to innermost pixel layer
-if successful extrapolates to 2nd and 3d pixel layer (rϕ and z)
-repeat for other sign hypothesis

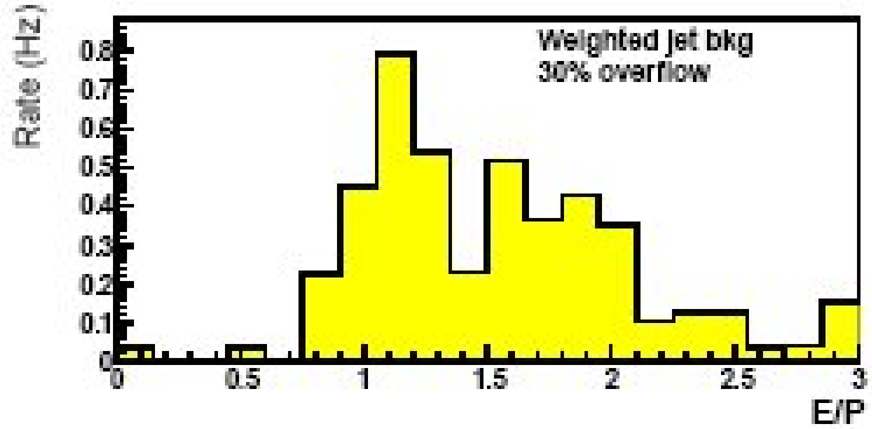
Electron ID: LVL2 and 3 in CMS

- Tracking : use calo Super Cluster and corresponding pixel hits as seed.
- LVL3=Apply loose track cuts, position and E/p match

Rate estimated at 10^{34} and Eth=30 GeV

signal	background
$W \rightarrow e\nu$ =35 Hz	Charged/neut π overlap =15Hz
	π^0 Dalitz and conversions=19Hz
	$b/c \rightarrow e+X$ = 6Hz
Total=35Hz	Total=40 Hz





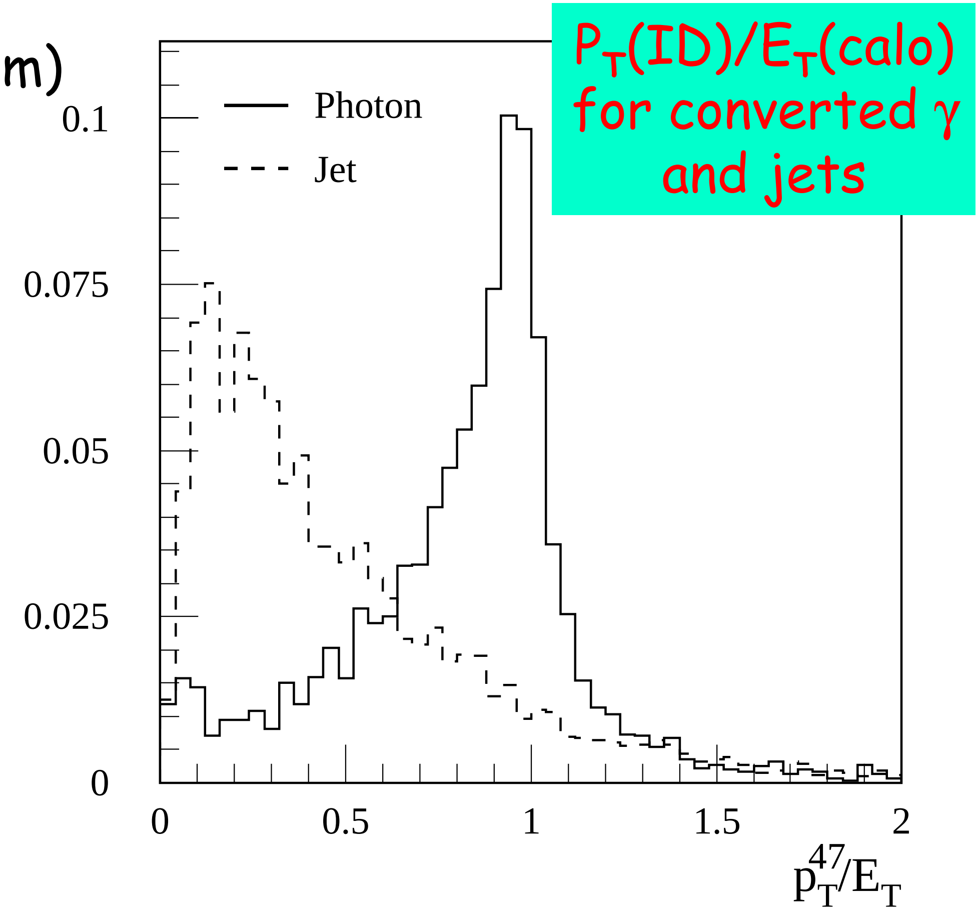
What about Photons ?

- Similar "shower shape" criteria as electrons
- No track match
- No E/p
- "absence of a track" is a weak criterium, especially with pile-up…

$\rightarrow$harder to identify than electrons… In fact: two classes

- Converted photons ~30%(R<~80cm) resemble more electrons (track match and E/p)

- Unconverted photons ~70%
  - track veto necessary
  - and single π^0 calo rejection

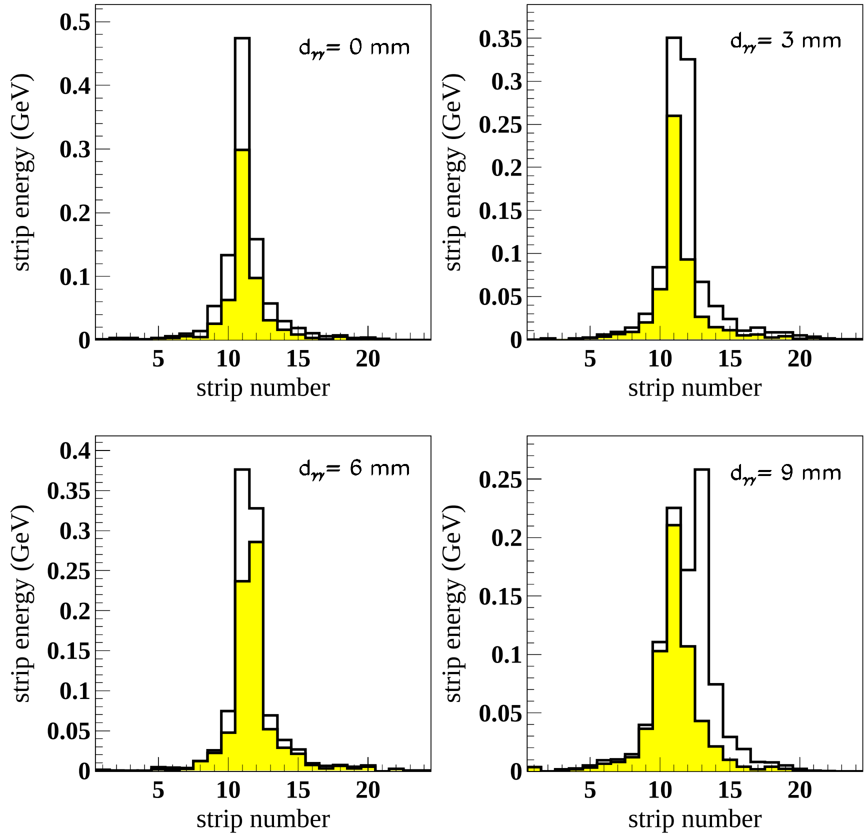


Photon ID in ATLAS

Test beam:
- single photons
- 2 overlapped photons

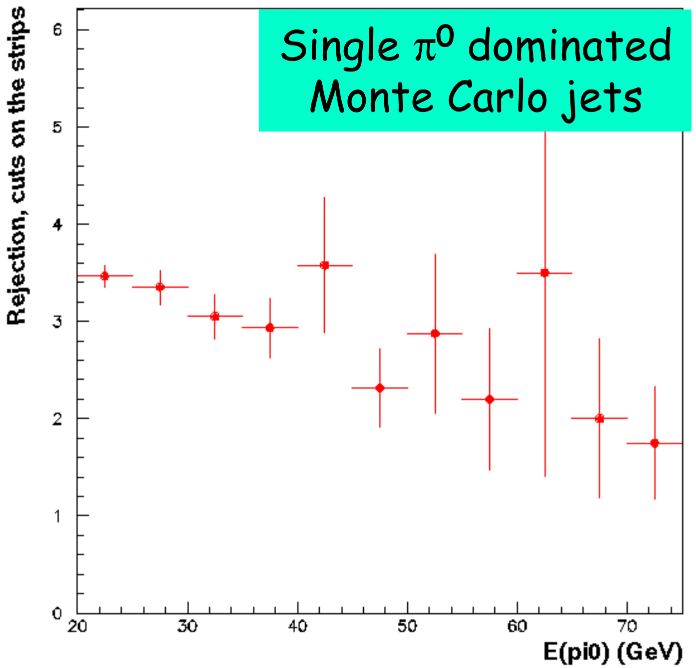
Jet background composition
(true photons removed-quark brem,..)
after "general" calorimeter cuts:

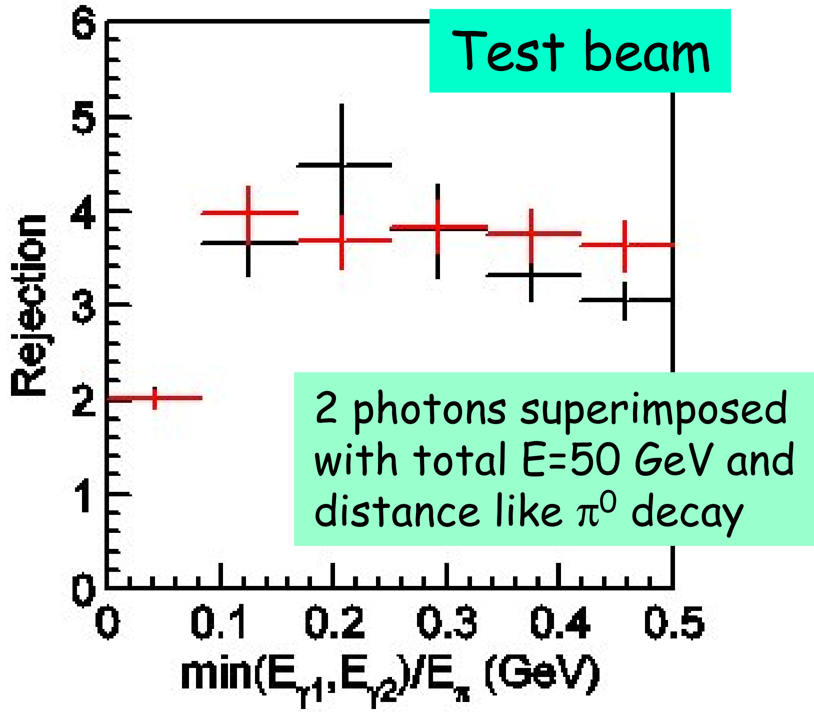
« Isolated » π^0	72%
$\eta \to \gamma\gamma$, $\omega \to \gamma\, \pi^0$,KS$\to 2\pi^0$	13%
« multi » π^0	4%
electron	4%
single charged hadron	4%
single neutral hadron	1%
Others	2%



- 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)





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

-1050 for quark jets
-6000 for gluon jets $\rightarrow$Ultimate performance process dependant!
(probability of a high x isolated π^0 is higher in a quark jet than in a gluon jet)

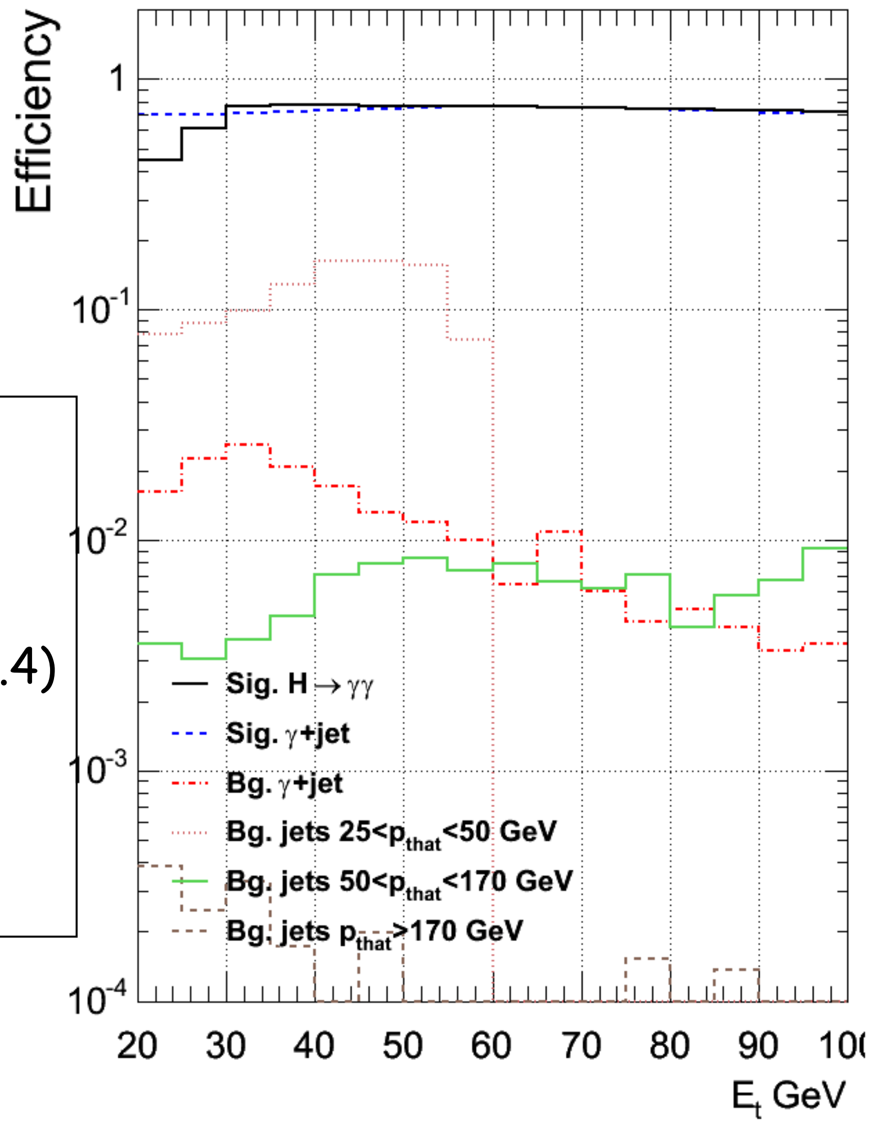
Photon ID in CMS

Estimated from γ + jet events with
kinematics similar to $\gamma\ \gamma$ events
from a 120 GeV mass Higgs decay.

Use as discriminating variables:

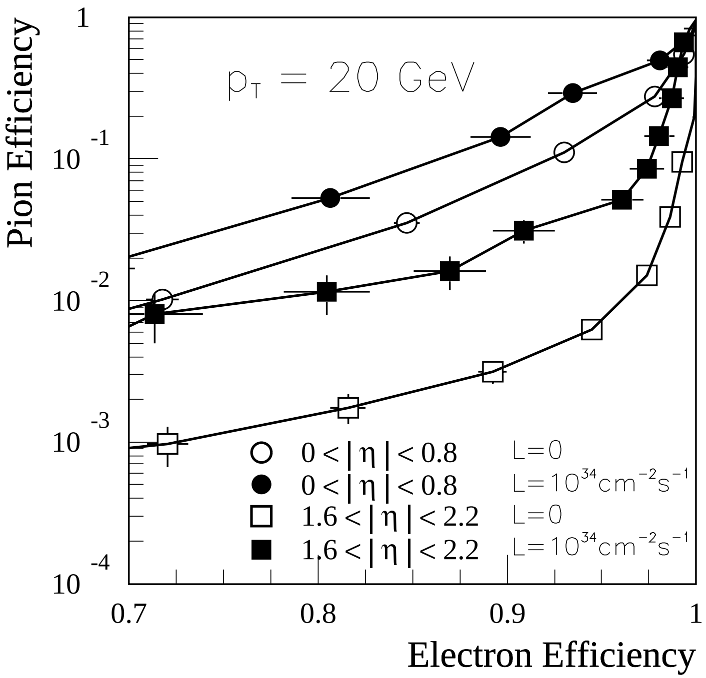
- Shower shape in ECAL(transverse only)
- Isolation in ECAL(<4 GeV in .06< <.35)
- Energy leakage in HCAL (<8 GeV in ΔR=0.4)
- Track isolation

(no track of pT>1.5 GeV
-except matched conversion- in ΔR=0.3)

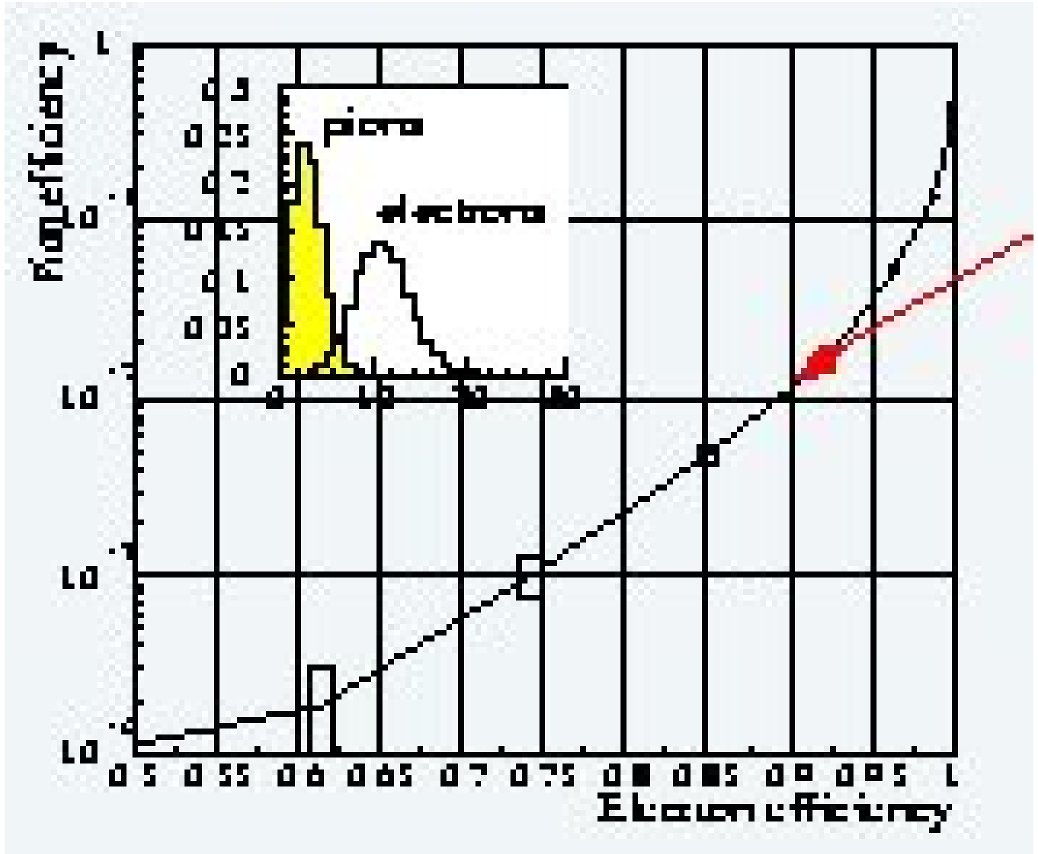


Back-up slides

Electron ID with TRT



simulation



testbeam

TRT suited for "pure" electron sample, but implies reduced efficiency