Particle ID in high P_T reactions(2)

- oEM calorimeters
- oEM shower ID
- oTrackers
- oElectron and Photon ID
- oTau ID
- oJets and Missing E_T,neutrino
- oTrigger strategy and rates
- oW and Zs

EM calorimeter requirements

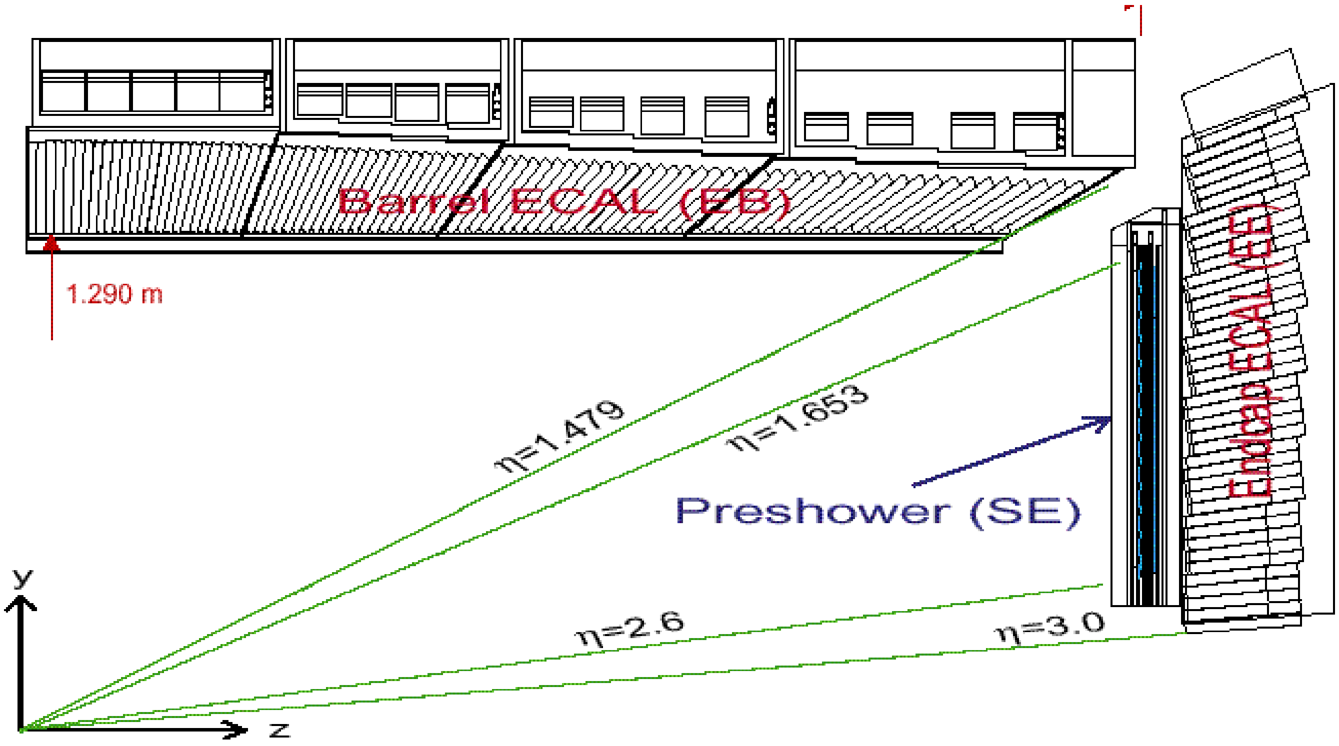
- “flag” EM showers from overwhelming jet “background” already at LVL1 ie every 25 ns a new collision of bunches (fast)

- Provide accurate energy measurement (precise, stable, uniform)
  -H→γγ most demanding dM/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

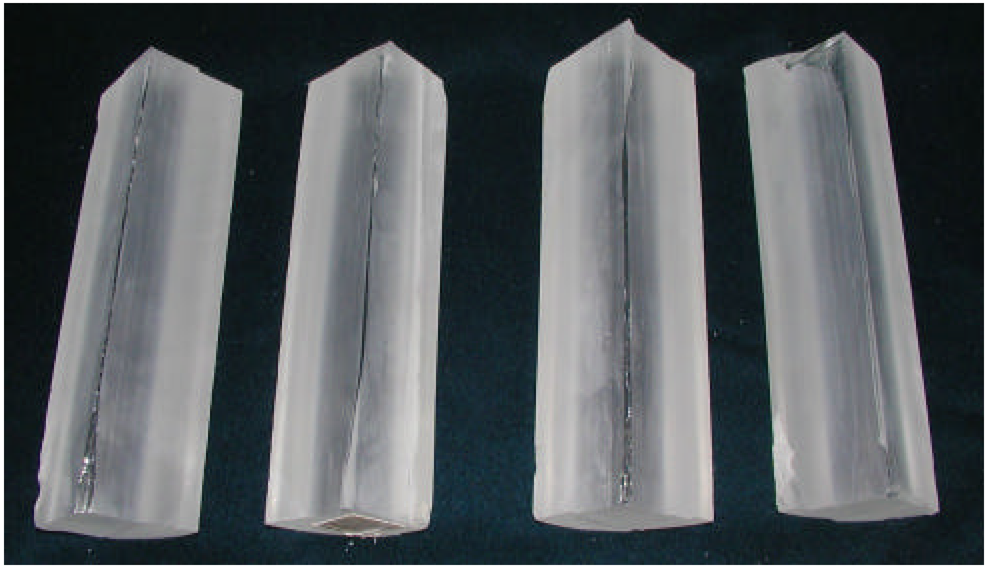


$PbW0_4$:
- -radiation hard (but…)
- -fast(80% in 25ns)
- -compact X_0=0.9 cm R_M=2.2 cm
- -4T→APD
- -low LY: 6 photo-electrons/MeV

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

CMS $PbWO_4$ crystals

4 crystals from 1 boule

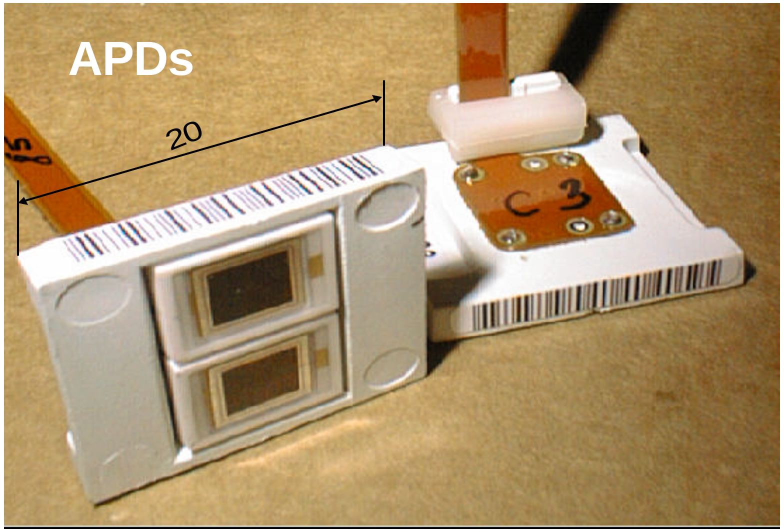


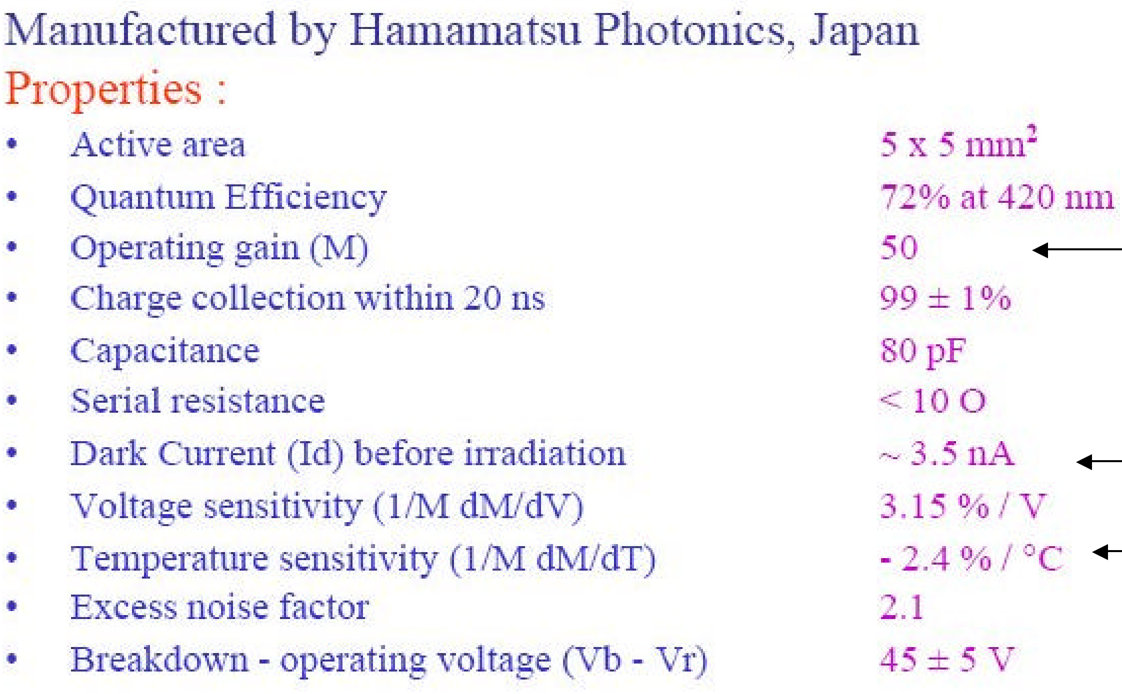
25 k crystals out of 62 k delivered (barrel)
103k out of 130k APDs delivered

Front End Electronics

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

CMS $PbWO_4$ APDs





Manufactured by Hamamatsu Photonics, Japan

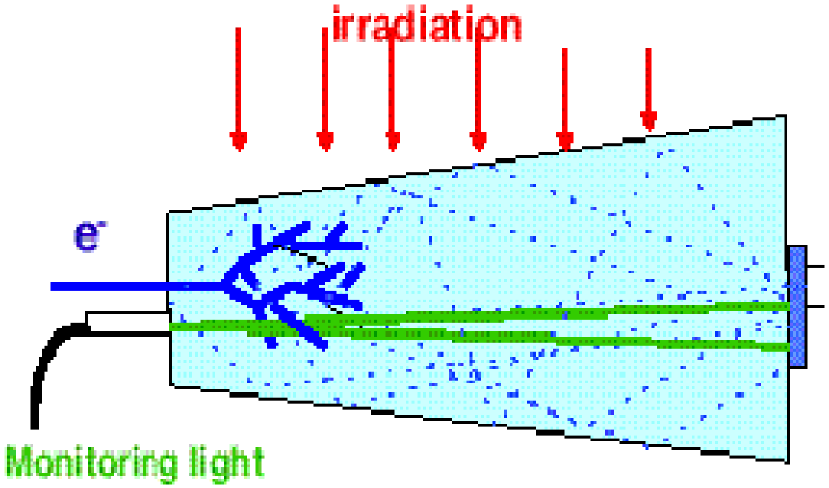
Properties :

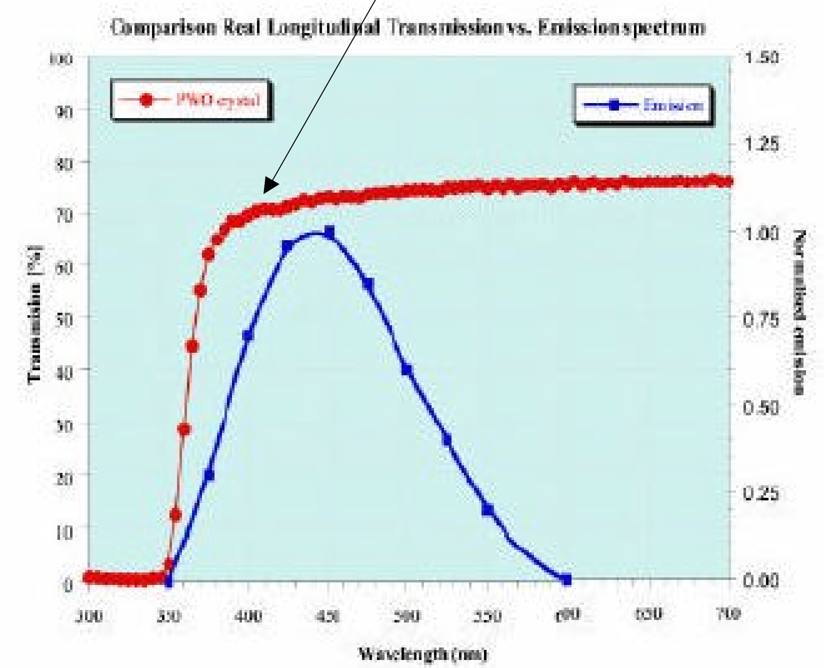
Active area	5 x 5 mm^2
Quantum Efficiency	72% at 420 nm
Operating gain (M)	50
Charge collection within 20 ns	99 ± 1%
Capacitance	80 pF
Serial resistance	< 10 O
Dark Current (Id) before irradiation	~ 3.5 nA
Voltage sensitivity (1/M dM/dV)	3.15 % / V
Temperature sensitivity (1/M dM/dT)	- 2.4 % / °C
Excess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

-2% for crystal as well

CMS crystals: light transmission/irradiation

Critical area



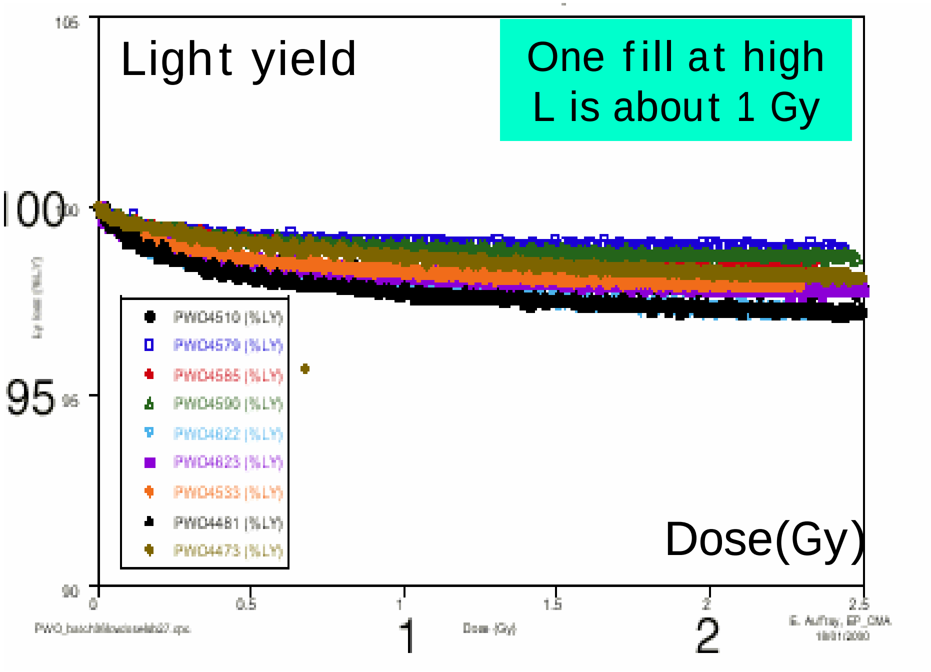


- Light spectrum: broad peak around 450 nm (blue)
- Light transmission drops/recover by few % under irradiation:
→monitoring by laser pulses at several wavelengths (time scale=hours)

Crystal calibration

Calibration strategy:

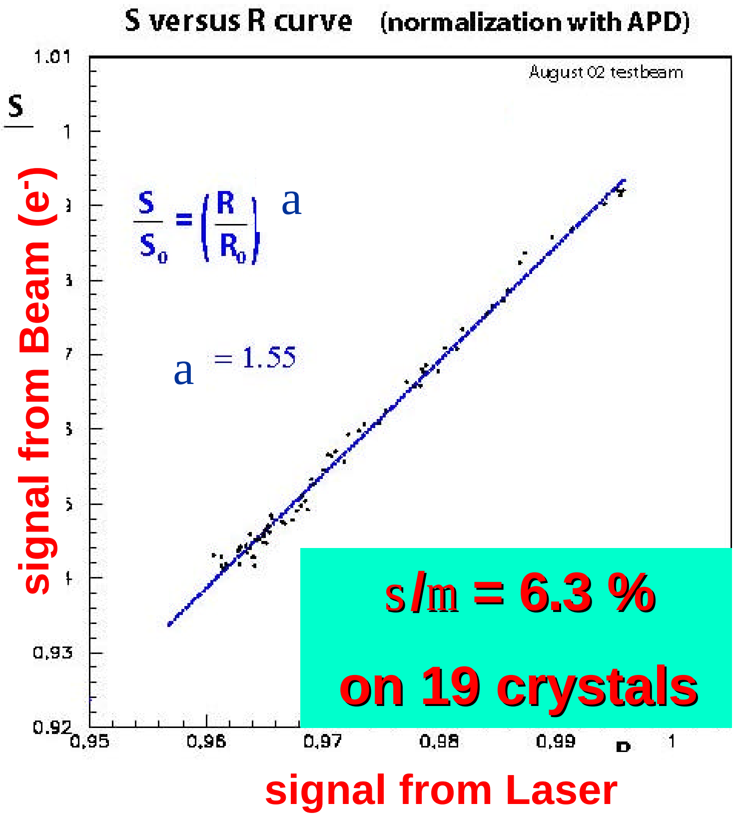
- Need cell to cell calibration / particles
- from bench test at production: 5% rms
- from azimuthal symmetry : 2 % rms
- from W electrons (E/p) and Z^0 mass : 0.5% rms(several months for crystal calibration 1 by 1)
- laser monitoring : absorb short-term variations



Light yield

One fill at high L is about 1 Gy

Dose(Gy)



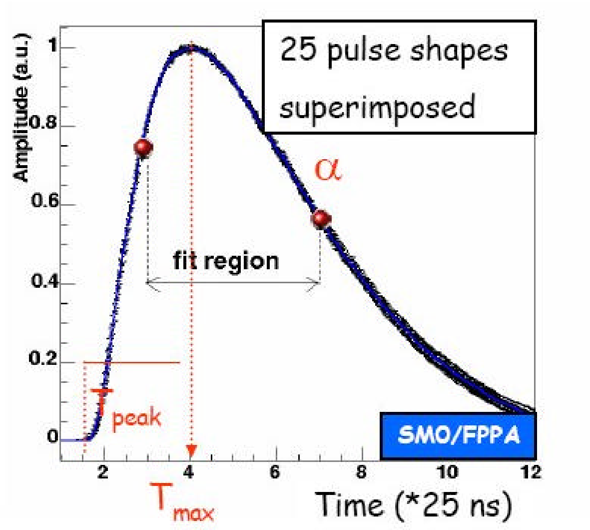
s/m = 6.3 %

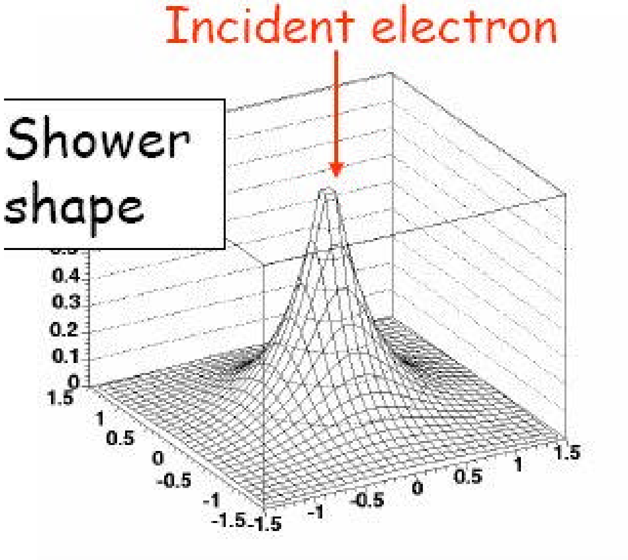
on 19 crystals

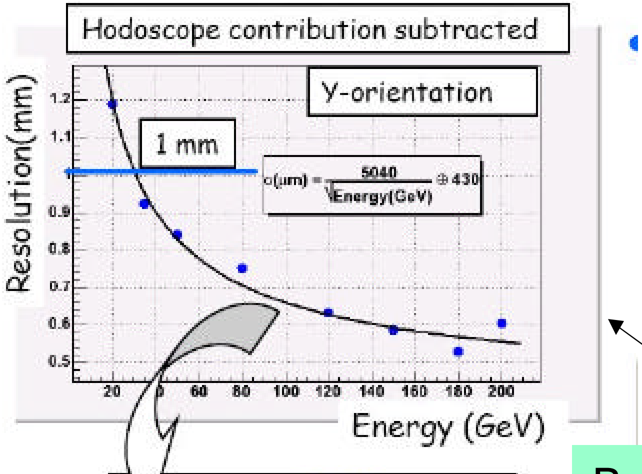
Laser monitoring

“universal ratio” makes task much easier

CMS crystals : selected test beam results

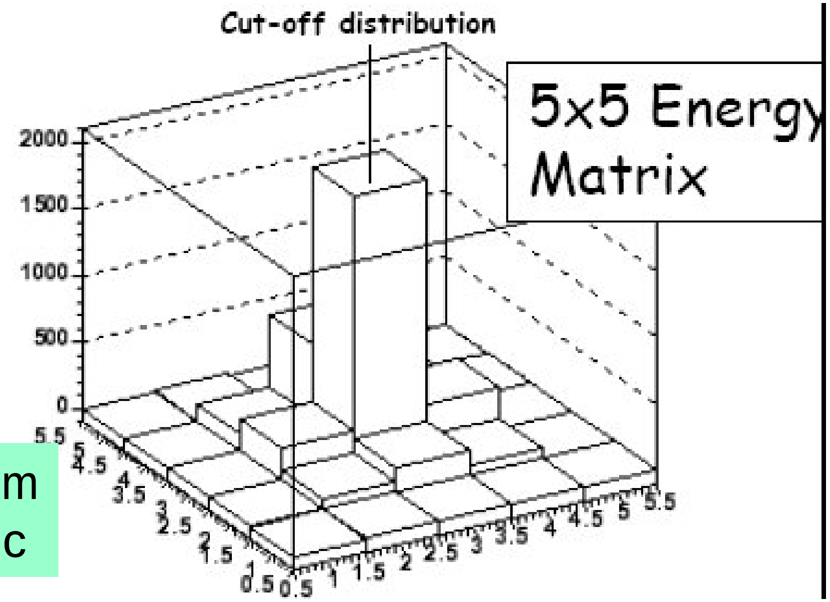




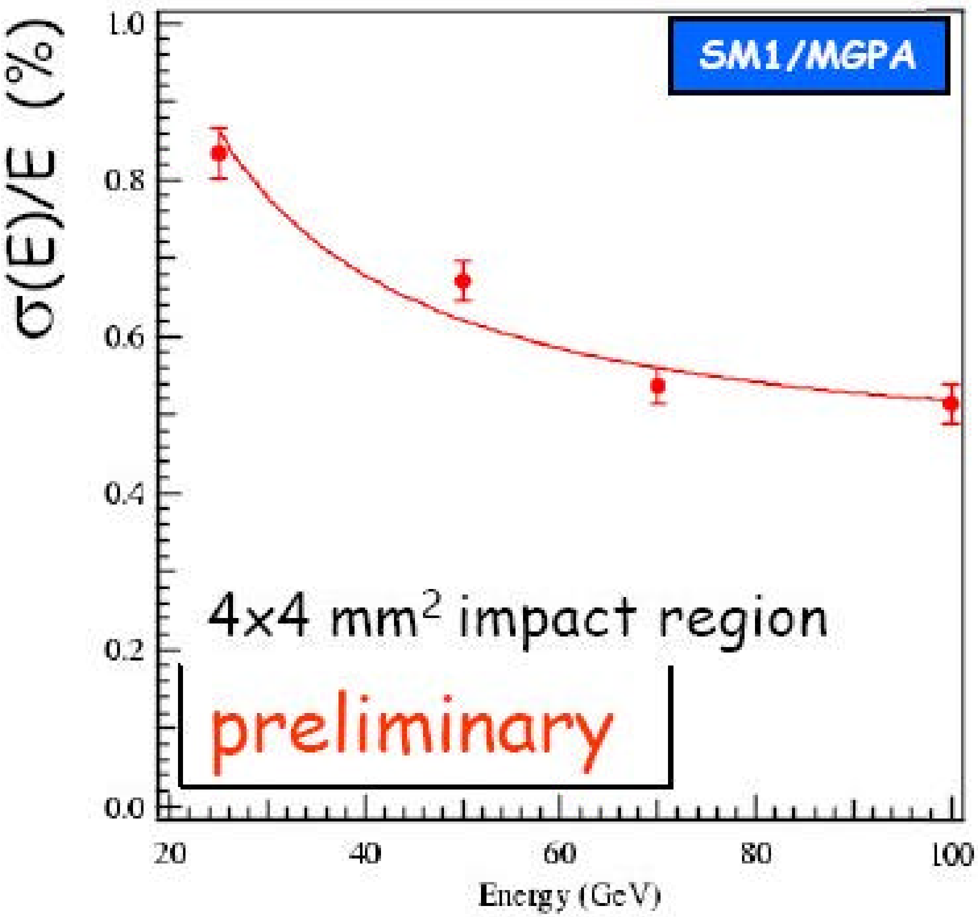


$$\sigma_Y\,(\mu m) = \frac{5040}{\sqrt{E}} \oplus 430$$

Better than 1mm
Above 30 GeV/c



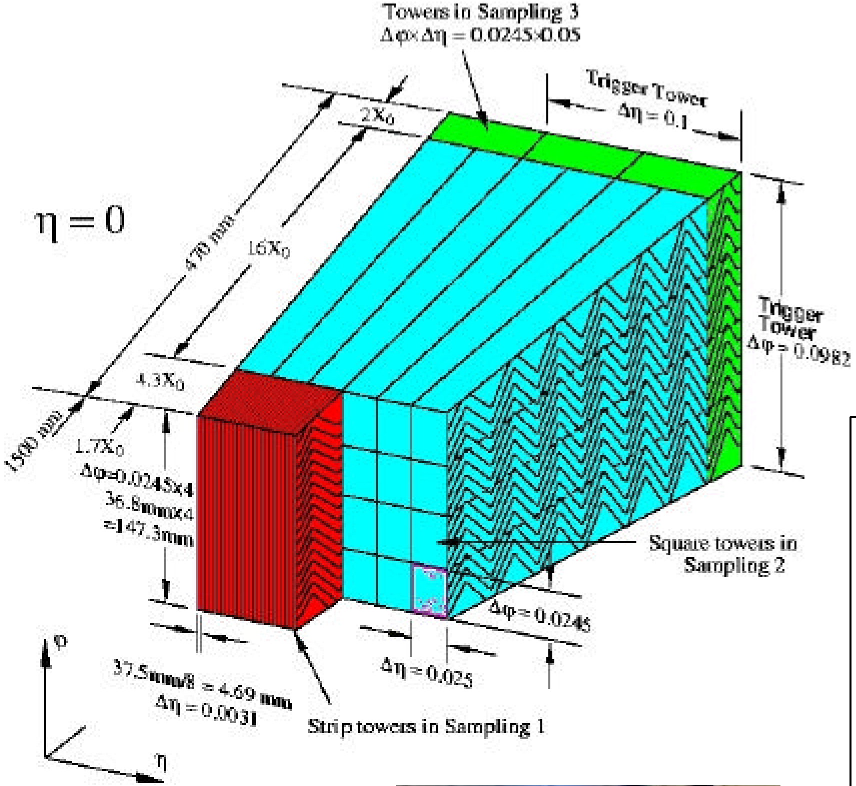
CMS crystals: Energy resolution



New DSM electronics

$$\frac{\sigma(E)}{E} = \frac{2.4\%}{\sqrt{E}} \oplus \frac{142\,\mathrm{MeV}}{E} \oplus 0.44\ \%$$

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)

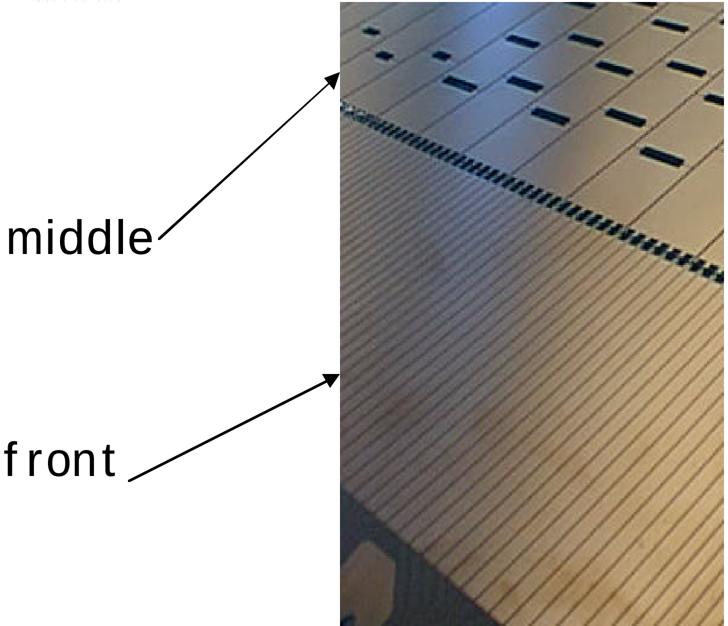
-sampling→10%/√E

-noise: ~30 MeV/central cell

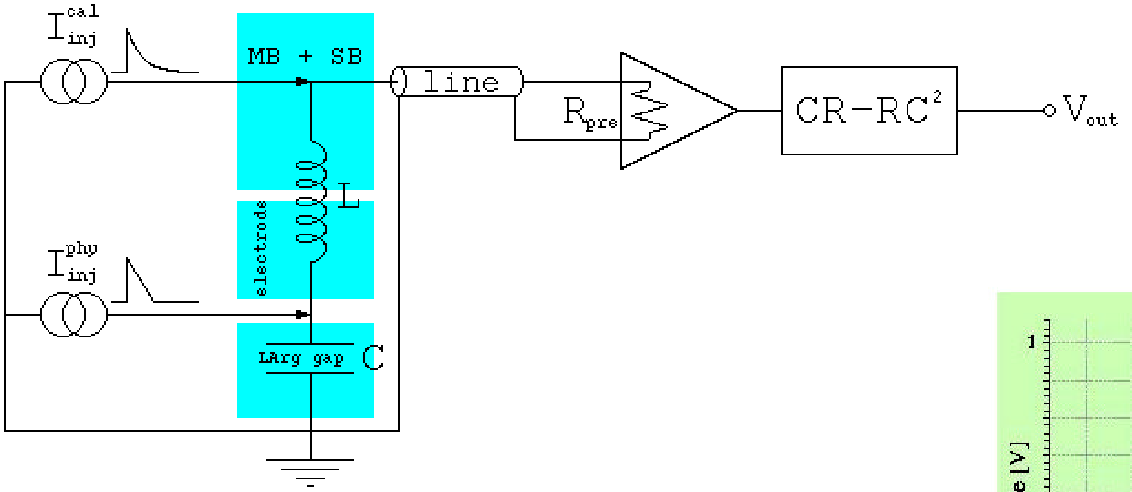
-3 gains + analog sum/LVL1

-180 kchannels in total

-cell to cell calibration purely electronic

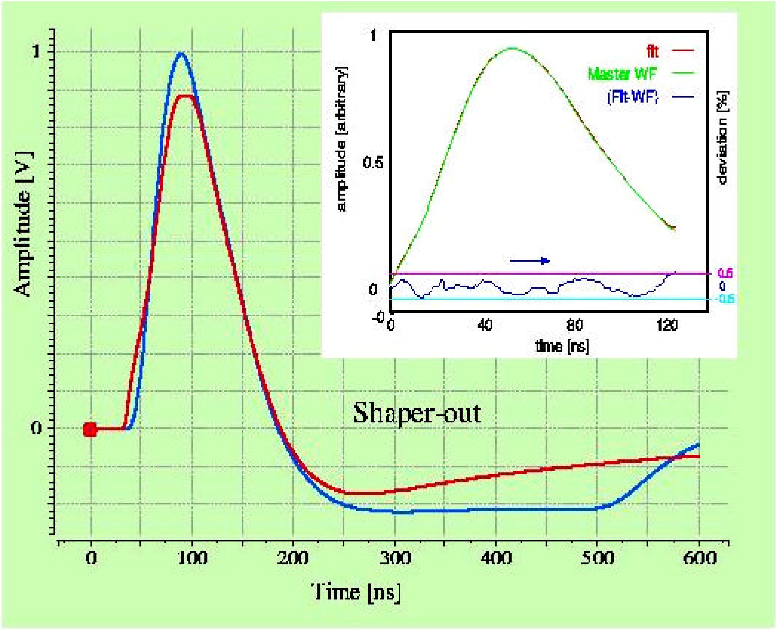


Atlas LAr-EM: ionisation and calibration signals

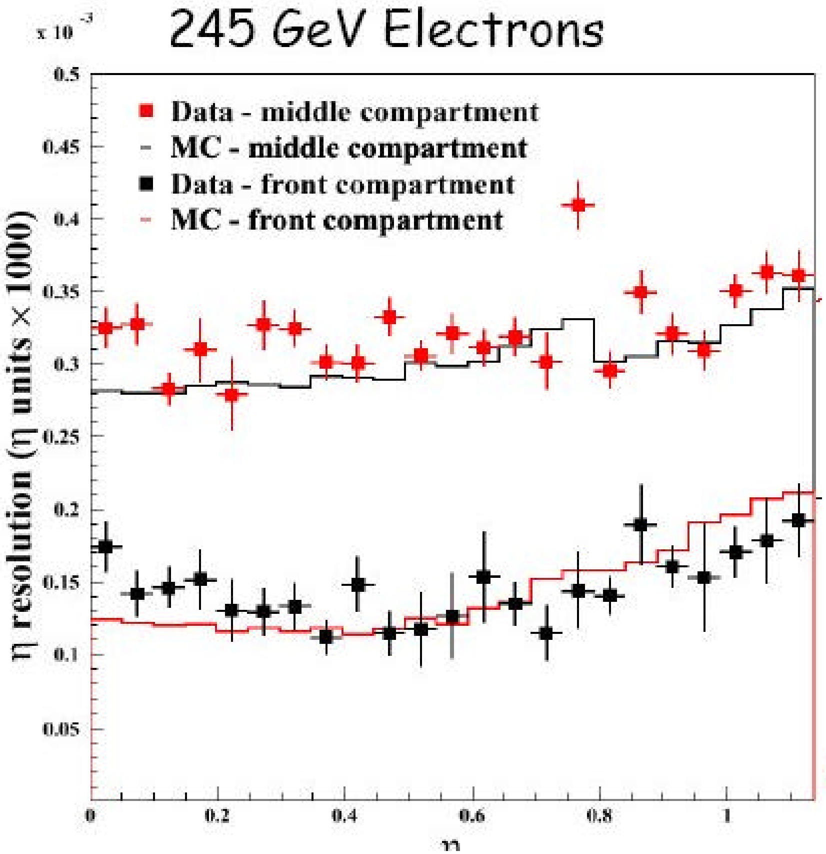


Electronics calibration (with correction for injection point) demonstrated to be OK for < 0.5% uniformity in areas 0.4 x 0.4

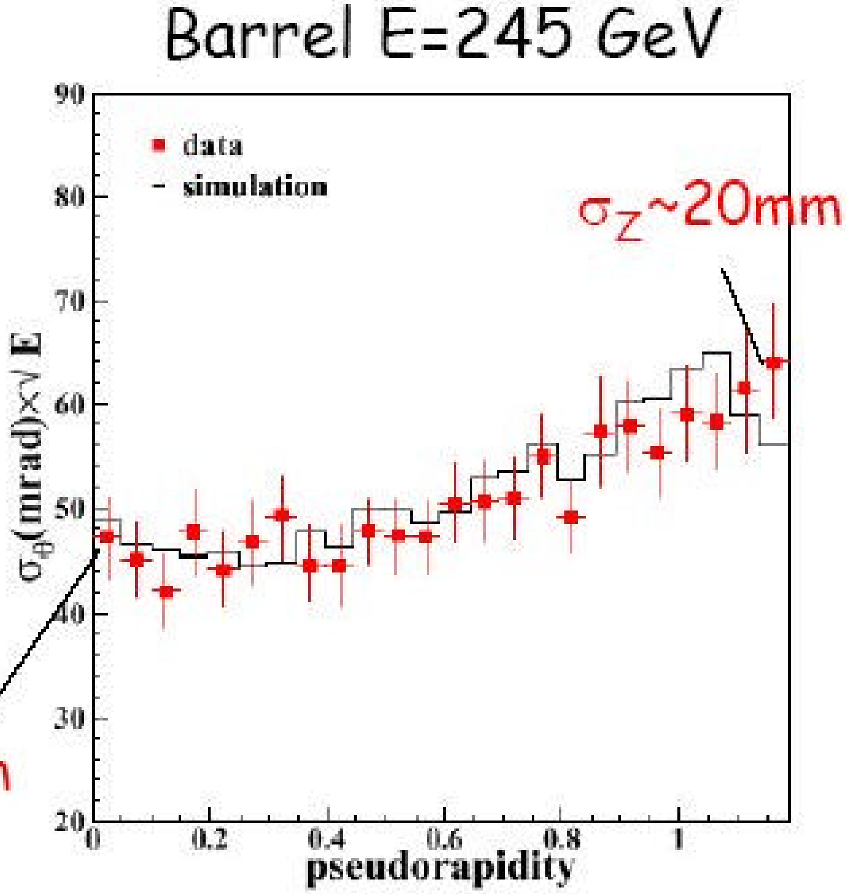
Calibration with Z_0 mass constraint should be fast ("days" at low L)



Atlas LAr-EM: selected test beam results

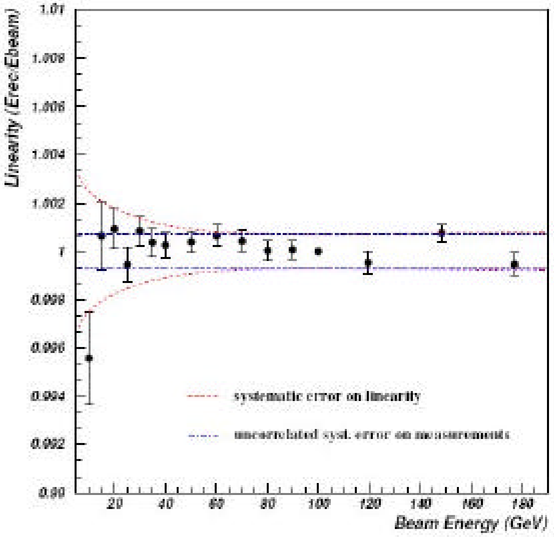


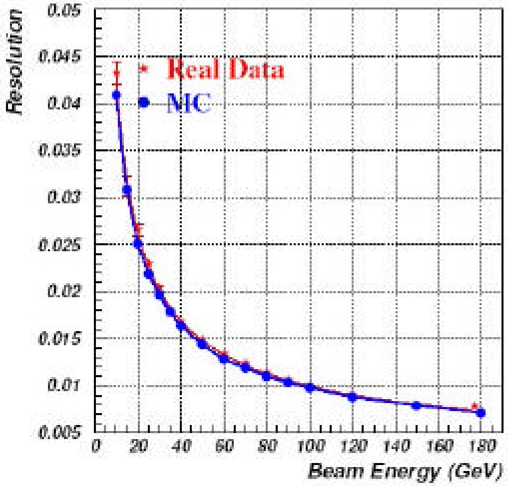
σ_Z~5mm



σ_Z~20mm

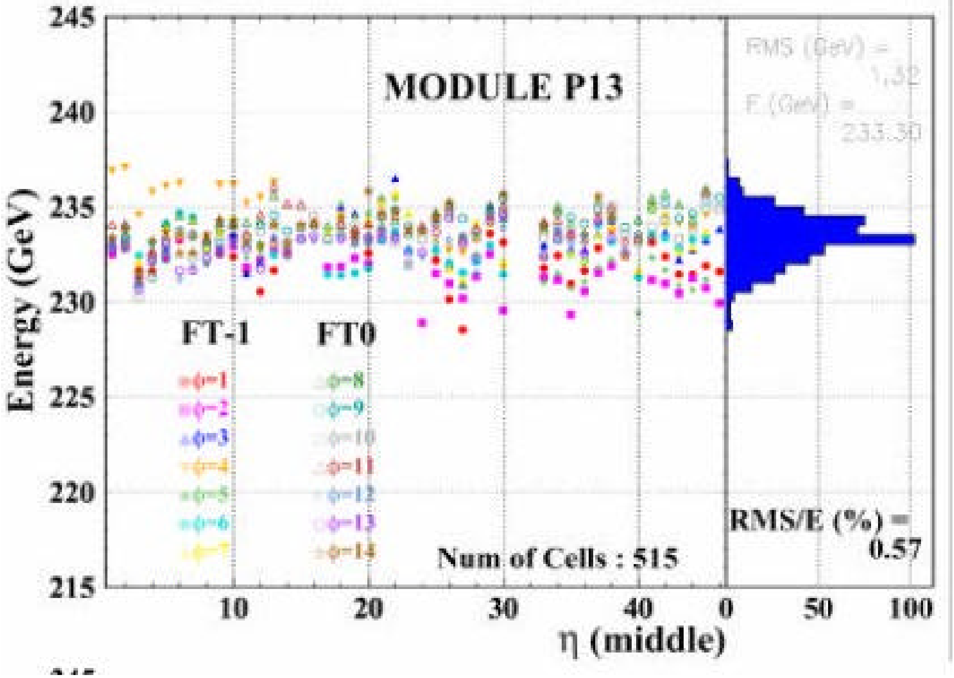
Atlas LAr-EM: selected test beam results





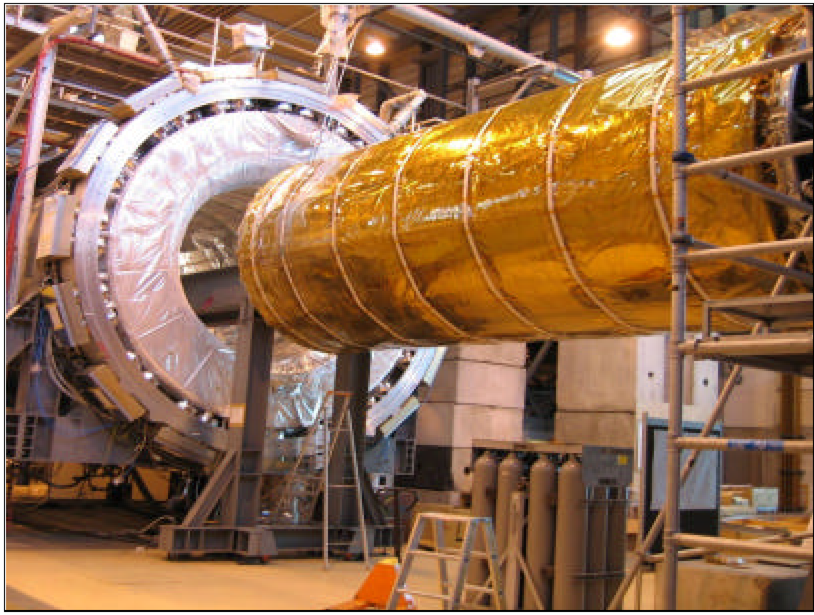
Linearity: 10^{-3}

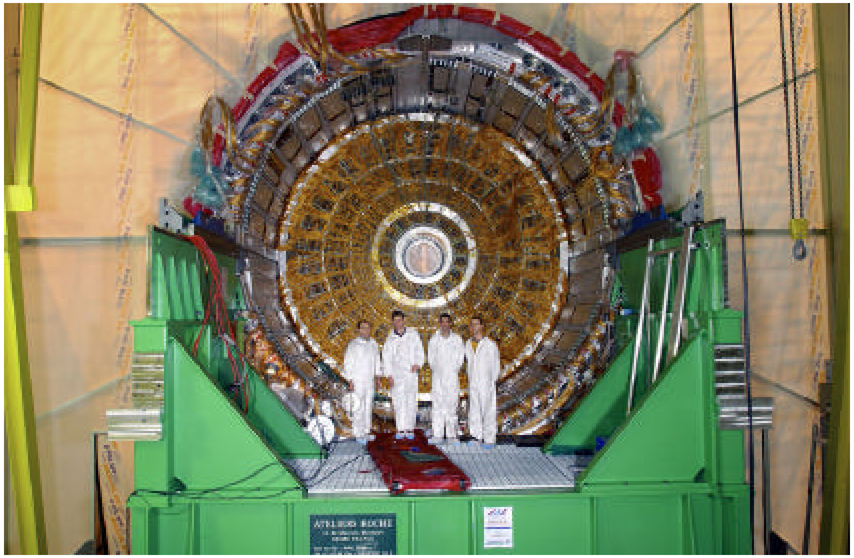
Energy resolution:
$10\%/\sqrt{E} \oplus 0.3\%$ local



Uniformity: 0.57% on
One full module 0.4x 1.4

Atlas LAr-EM: some pictures….





Barrel cool-down in progress. Today 200K

EM shower ID at LVL1

Basic approach:

"digitize and sum" (CMS) or "sum and digitize" (ATLAS) signals from a "small" dh **x** df region of EM calorimeter, but "large enough" to fully contain an EM shower and compare to threshold.

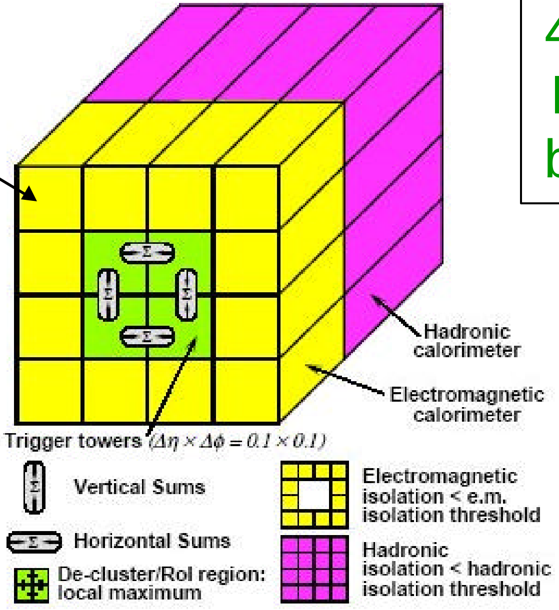
Jet background:

-huge, but decrease fast with E_T

-jets are broad →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 h and f,...

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

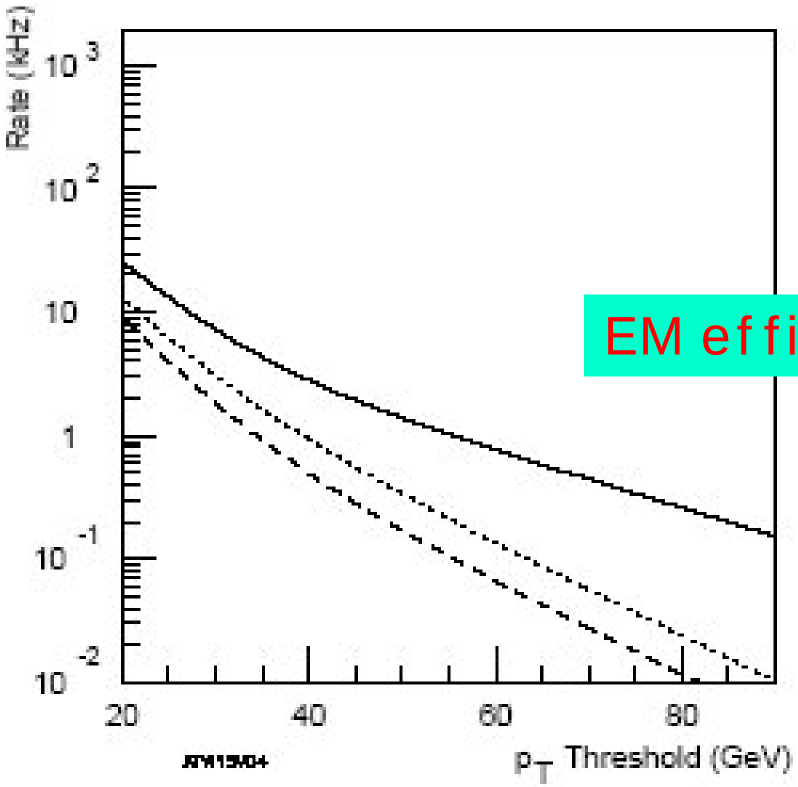


Figure 4-15 Inclusive electron trigger rate for luminosity 10^{33} cm^{-2}s^{-1}, without isolation (solid), requiring only hadronic isolation (dotted) and requiring both electromagnetic and hadronic isolation (dashed).

EM efficiency 95%

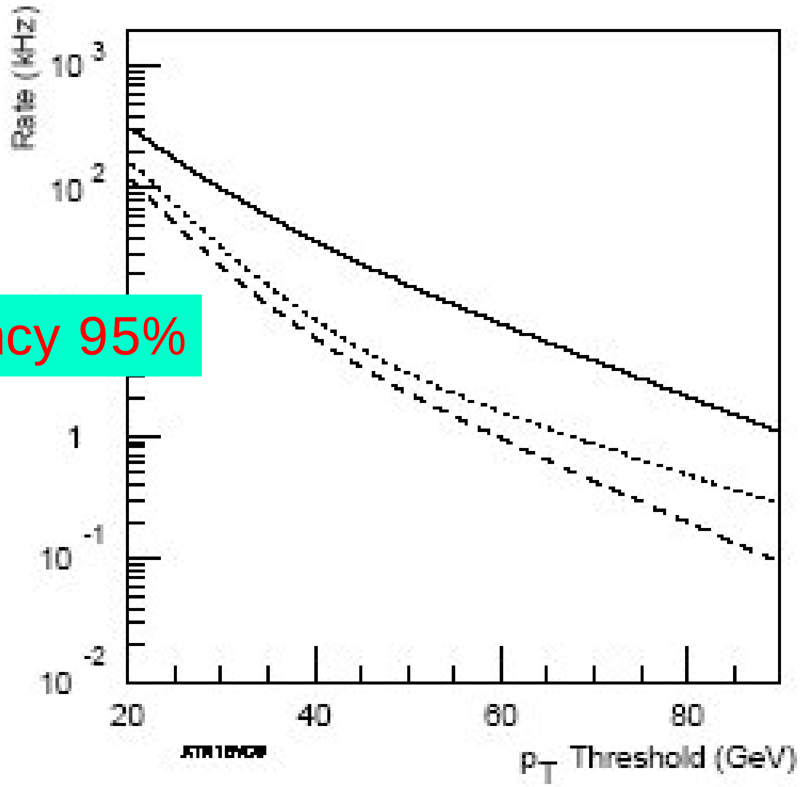
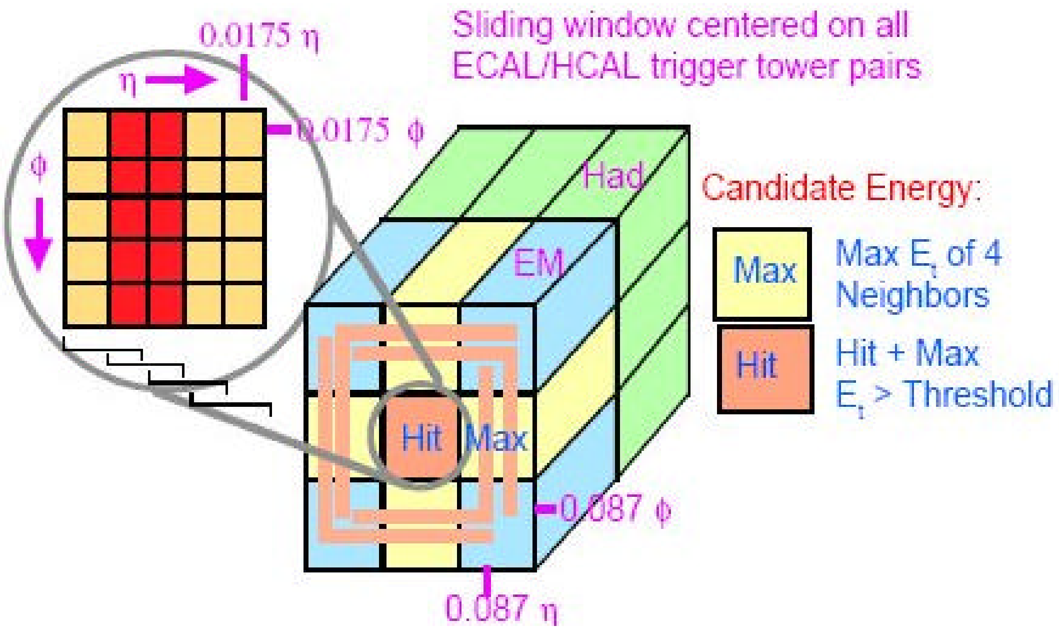


Figure 4-16 Inclusive electron trigger rate for luminosity 10^{34} cm^{-2}s^{-1}, without isolation (solid), requiring only hadronic isolation (dotted) and requiring both electromagnetic and hadronic isolation (dashed).

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 h profile in Hit cell (1 x 5 crystals)

(in ATLAS the equivalent is possible only at LVL2)

EM shower ID : LVL1 in CMS

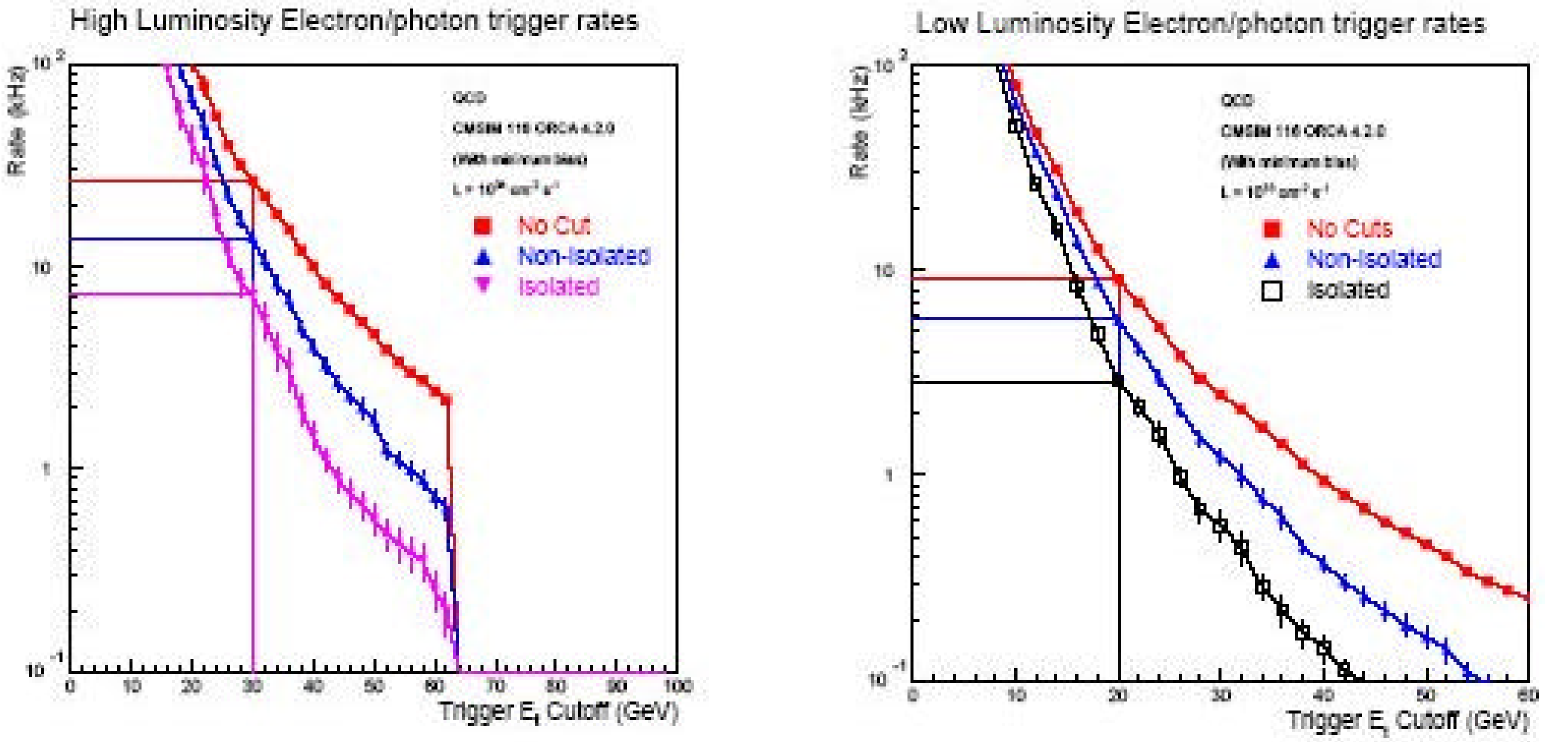
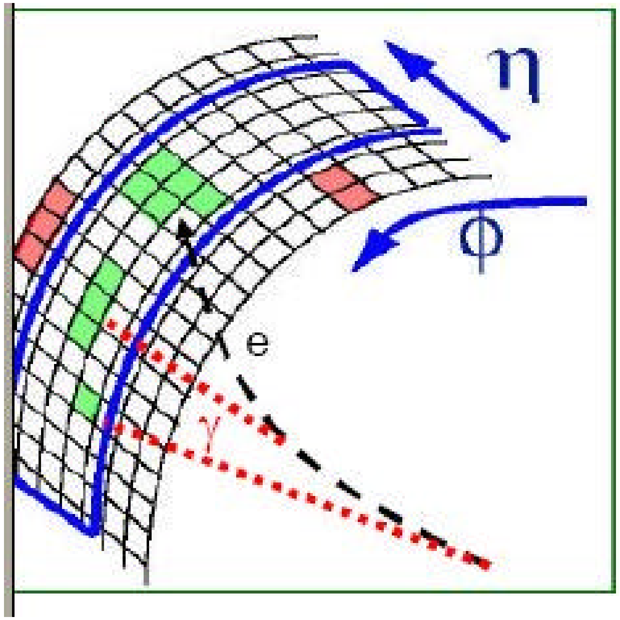


Fig. 3.12: The integrated QCD background rate above electron/photon trigger E_T cutoff is plotted versus the E_T cutoff for high and low luminosity operation of the LHC. Data for both isolated and non-isolated electrons are shown.

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

EM shower→ e/g: need tracker information



Basic approach :

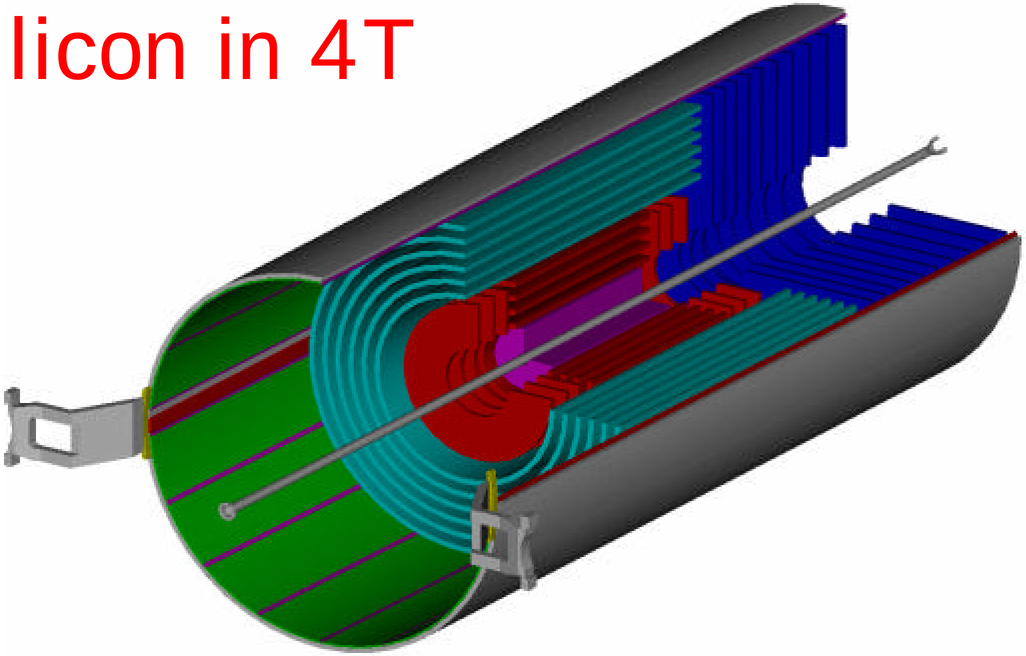
-electron:
a track points to the EM cluster with E/p~1,
but brems...

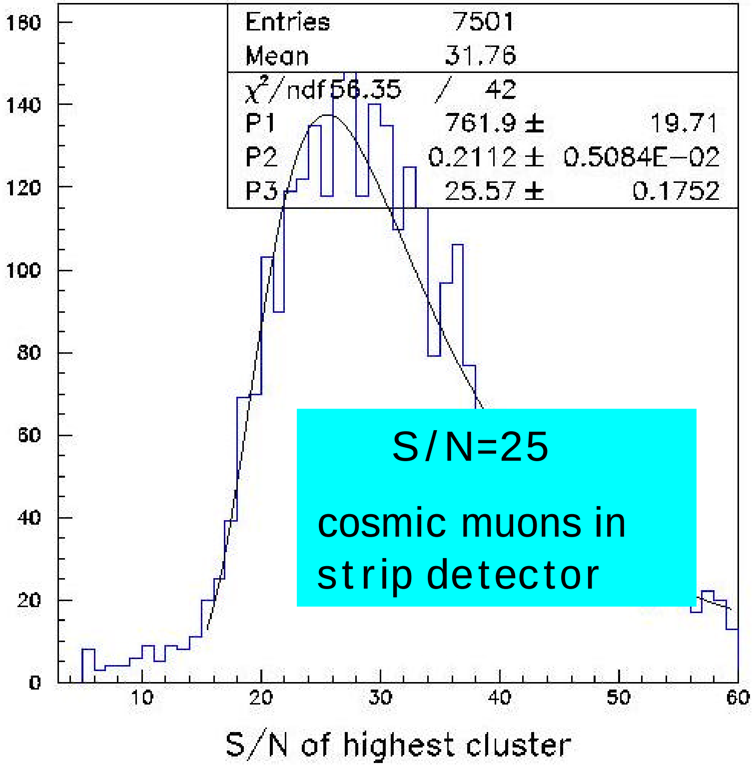
-photon: nothing in front of EM cluster,..
but conversion, Dalitz, pile-up

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 m^2 Si sensors
- Full volume (24 m3) at –10ºC
- 10M strips
- 67M pixels (100 x 150 mm)





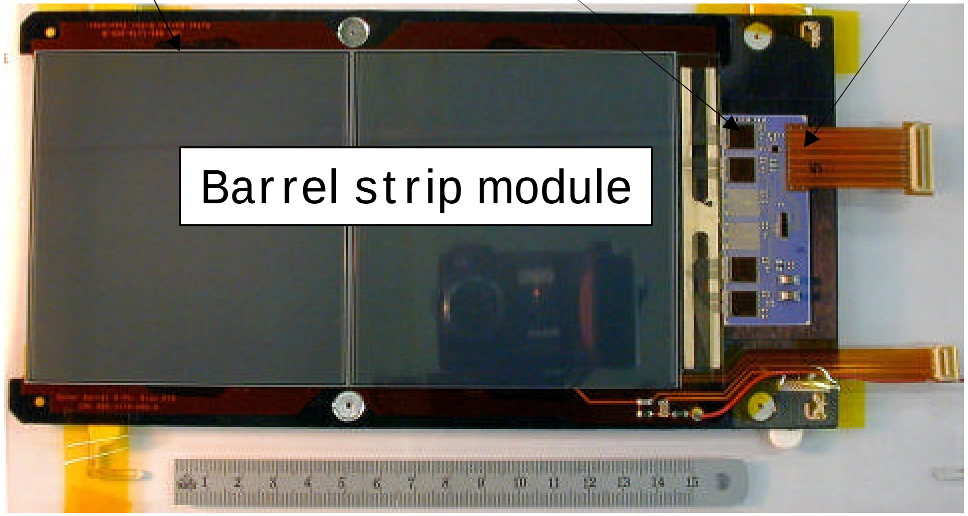
S/N=25

cosmic muons in strip detector

sensor

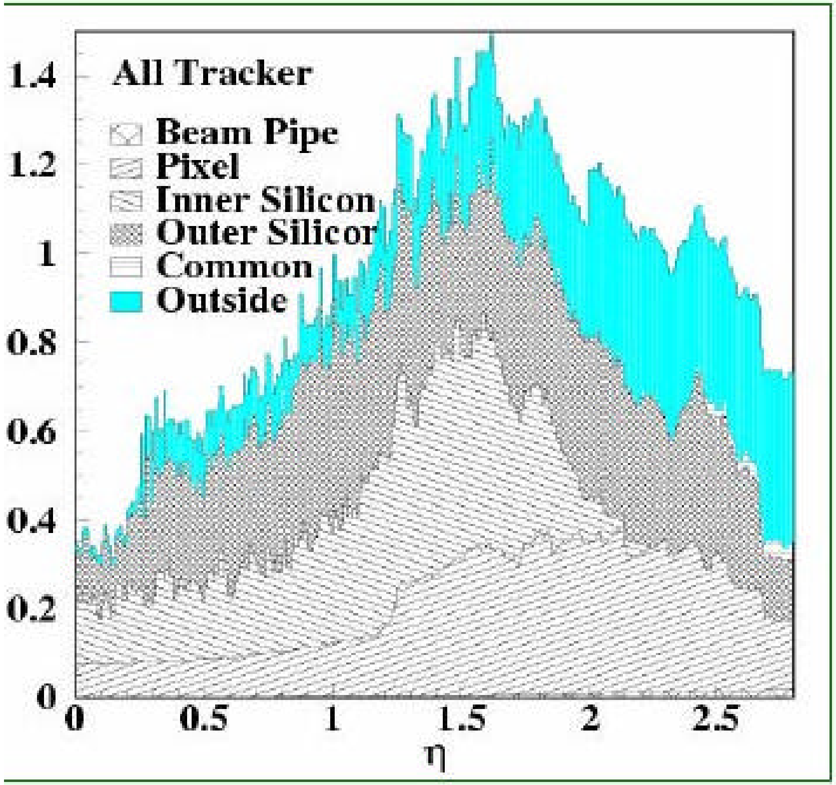
APV 0.25 micron (128 channels analog)

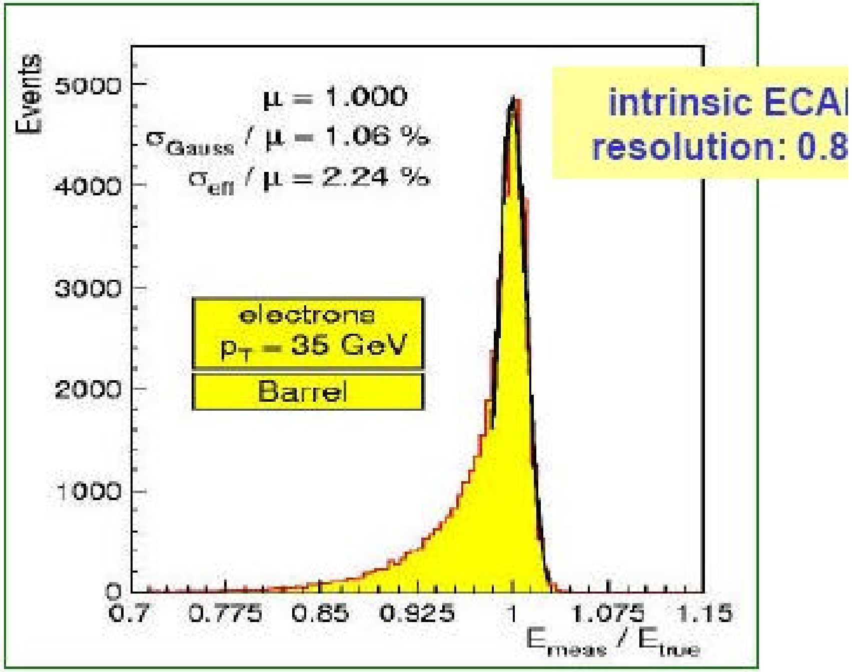
Flex-hybrid



Barrel strip module

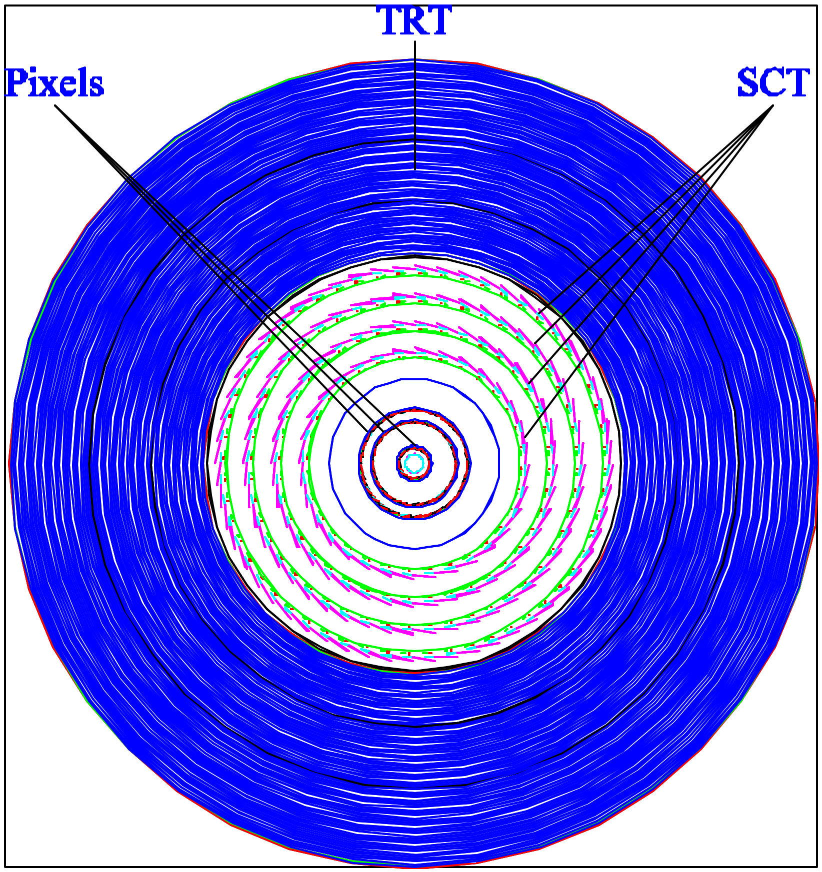
CMS ID material





intrinsic ECA
resolution: 0.8

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 g>>1
I(emitted energy) α g
N(photons>E_{th}) α $\log^2 g$
-X-rays materialize in Xenon rich gas giving large signals (>~6 keV against ~2 keV for dE/dx)

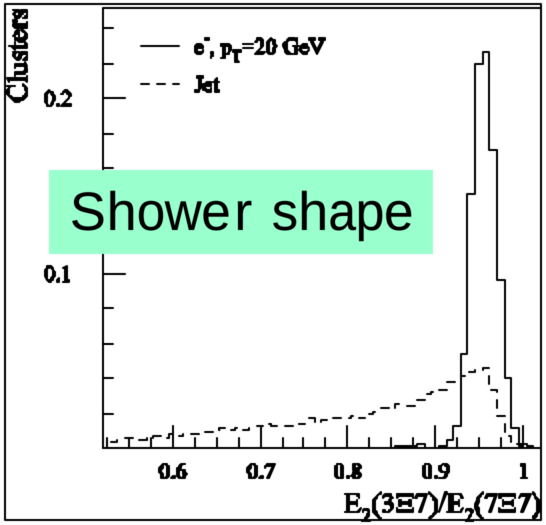
Amount of material similar to CMS...

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



Shower shape

- A track in the ID (using calorimeter cluster as seed) in dh**x** df =0.1 x 0.1
- A track-cluster matching (position: dh**x** df< 0.02 x 0.02 , and E/p)
- A TRT signature

E/p

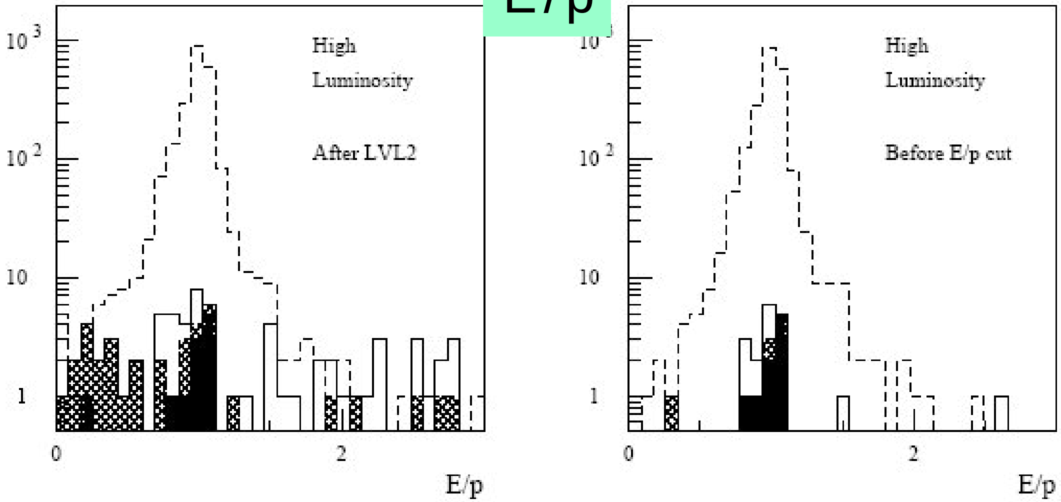
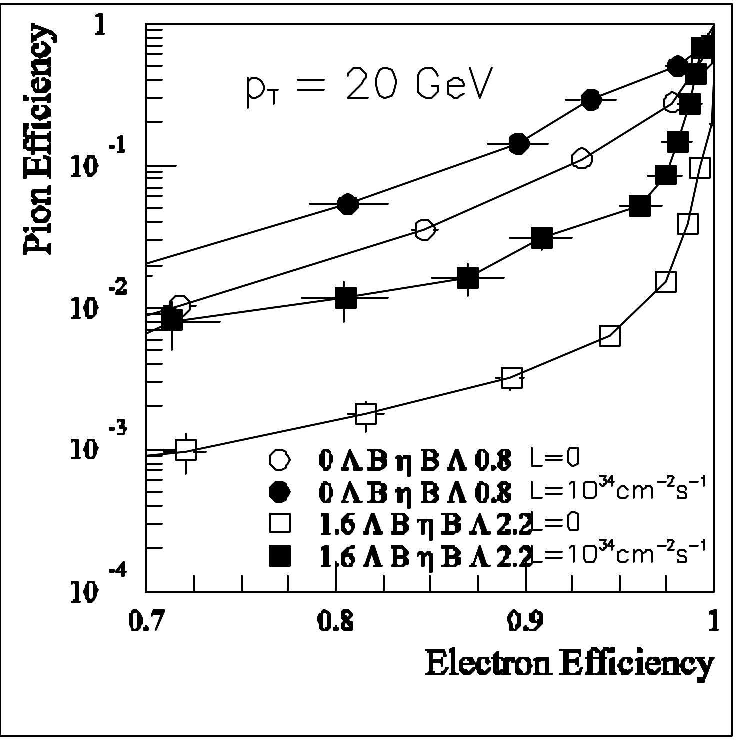
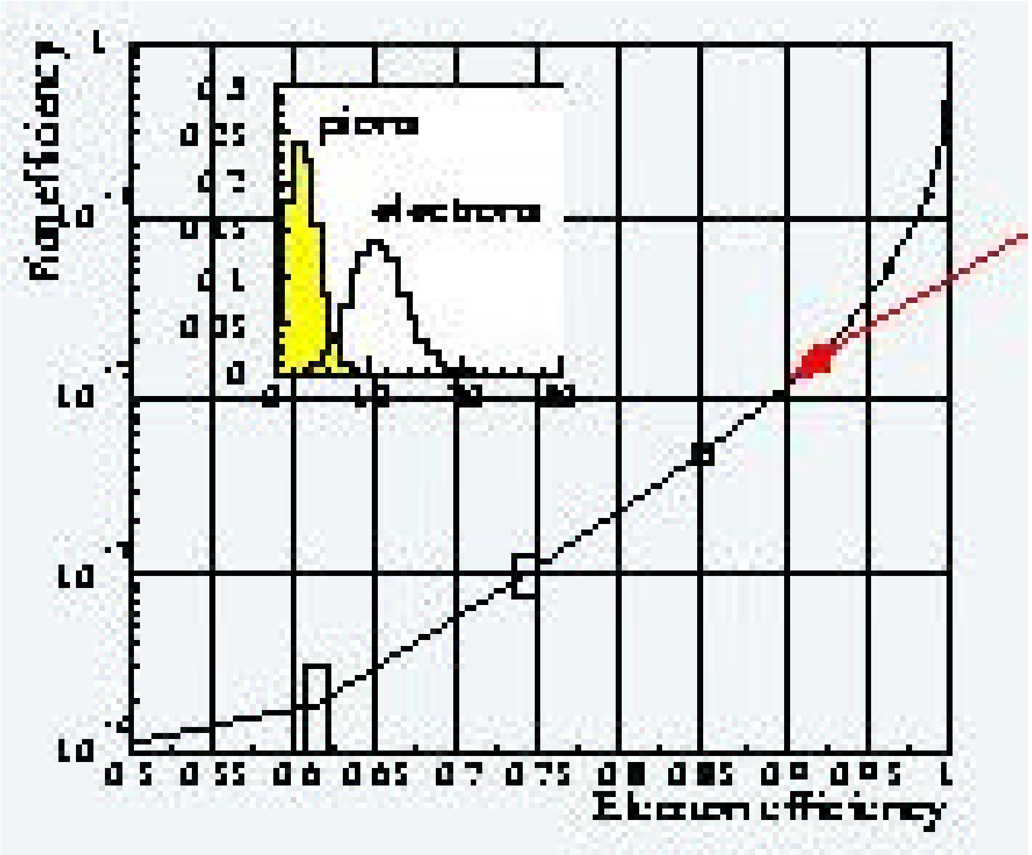


Figure 7-28 Ratio between energy of EM clusters to momentum of reconstructed charged tracks for electrons (dashed) and jets. For the 'jet' sample, various components are shown: electrons from *W*'s and *Z*'s (black), electrons from heavy flavour (dense hatch), conversions (light hatch) and hadrons (open).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

Electron ID with TRT



simulation



testbeam

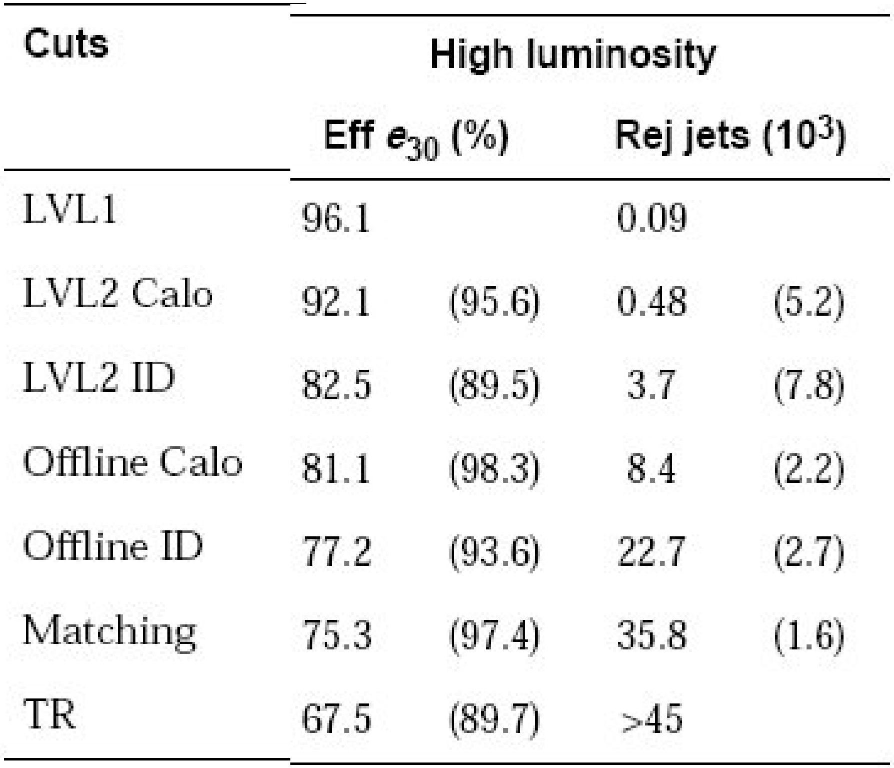
TRT suited for “pure” electron sample, but implies reduced efficiency

Electron ID:ATLAS overall

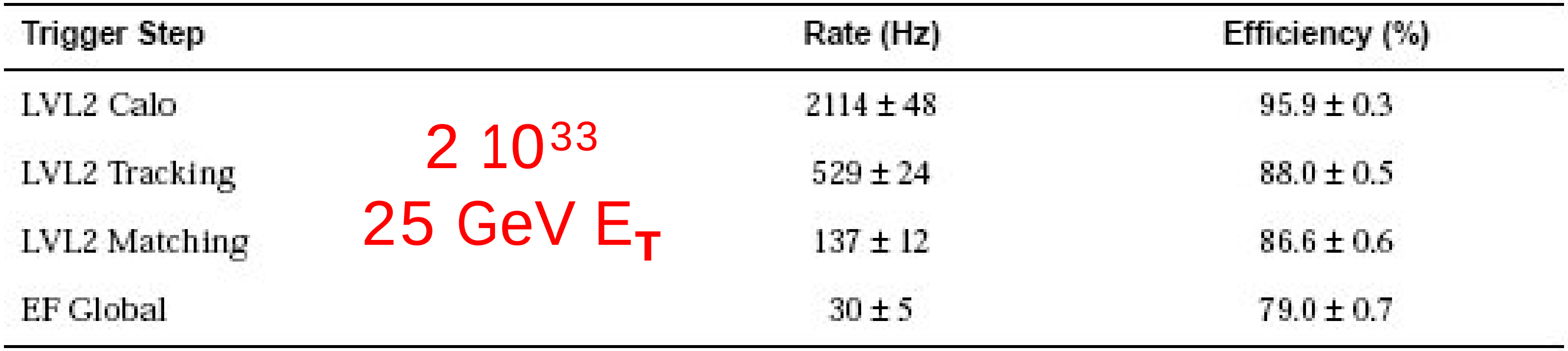
- With the stat generated (10^6 jets) above 17 GeV E_T the rejection run out of statistics.

- 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	



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

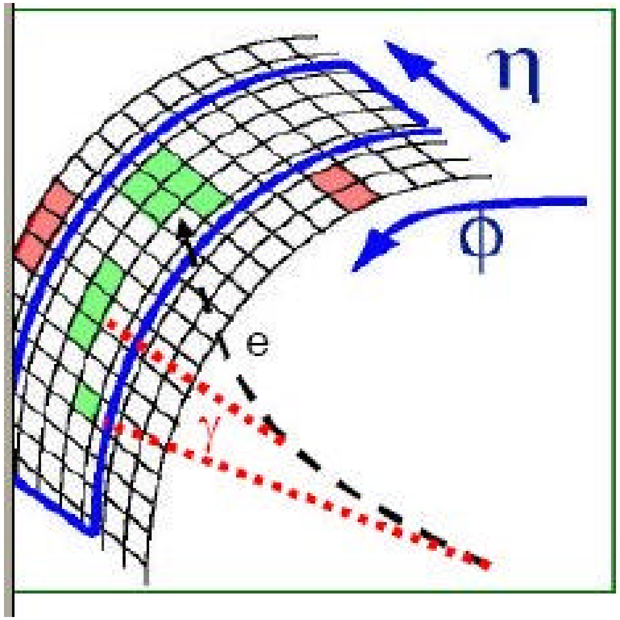
$2\ 10^{33}$

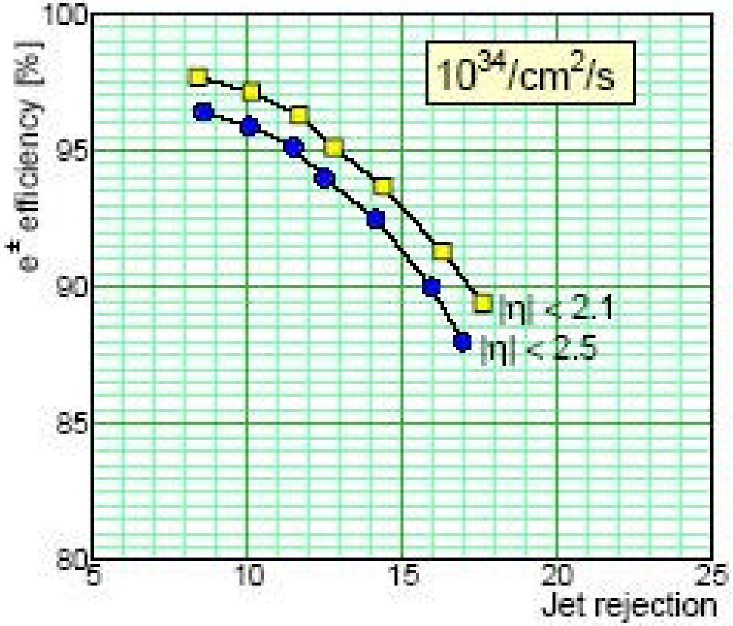
25 GeV E_T

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)

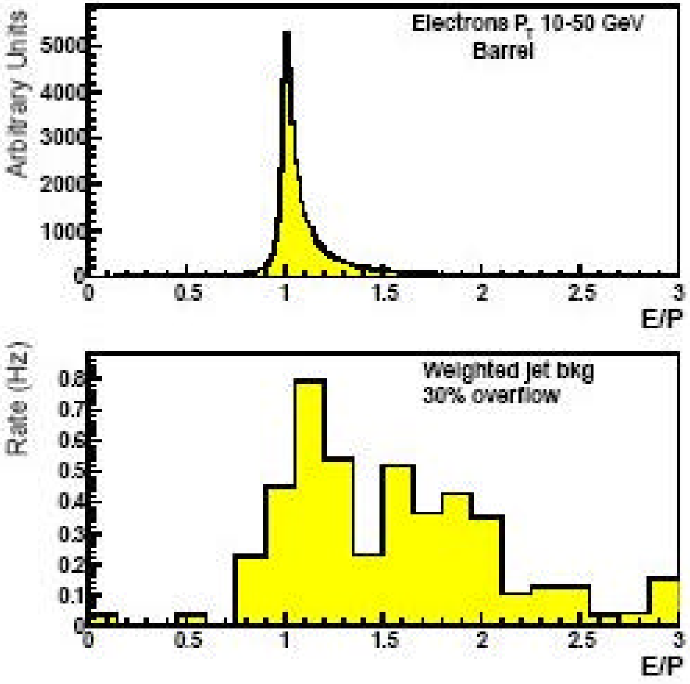
-repeat for other sign hypothesis

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→eν =35 Hz	Charged/neut p overlap =15Hz
	p^{0} Dalitz and conversions=19Hz
	b/c→e+X = 6Hz
Total=35Hz	Total=40 Hz



What about Photons ?

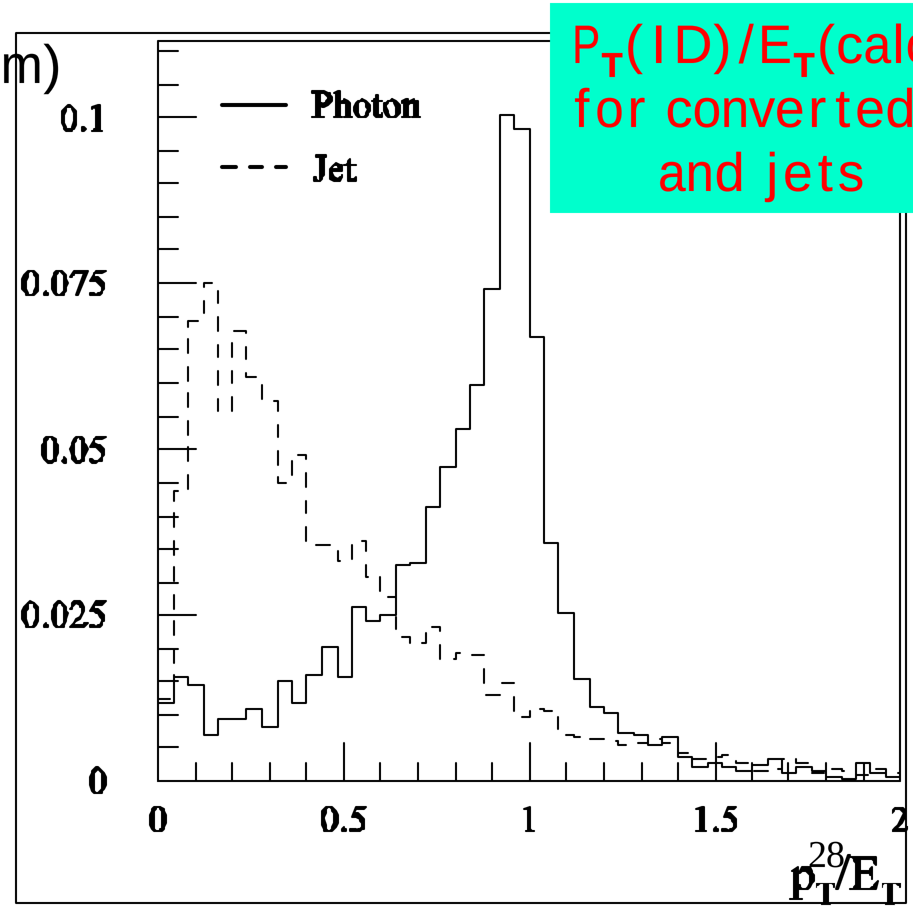
- Similar “shower shape” criteria as electrons
- No track match
- No E/p
- “absence of a track” is a weak criterium, especially with pile-up…

→harder to identify than electrons… In fact: two classes

- Converted photons ~20%(R<~80cm)
  resemble more electrons
  (track match and E/p)

- Unconverted photons ~80%
  -track veto necessary
  -and single π^0 calo rejection

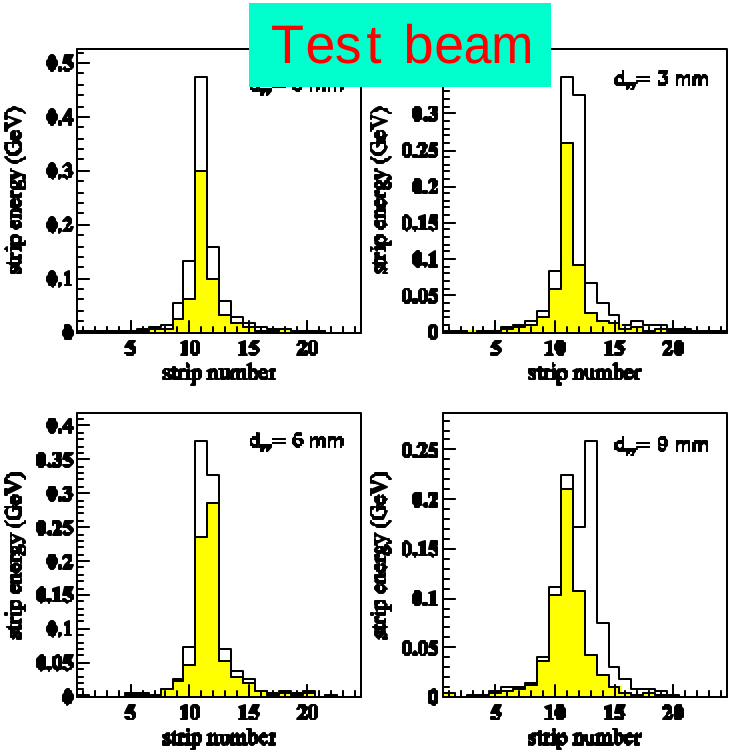
P_T(ID)/E_T(calo) for converted g and jets



Photon ID in ATLAS

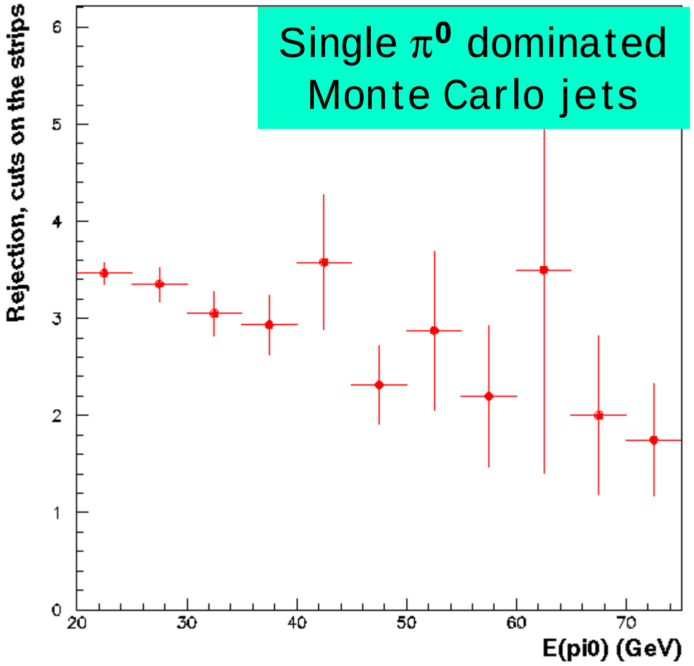
Jet background composition
(true photons removed-quark brem,..)
after "general" calorimeter cuts:

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

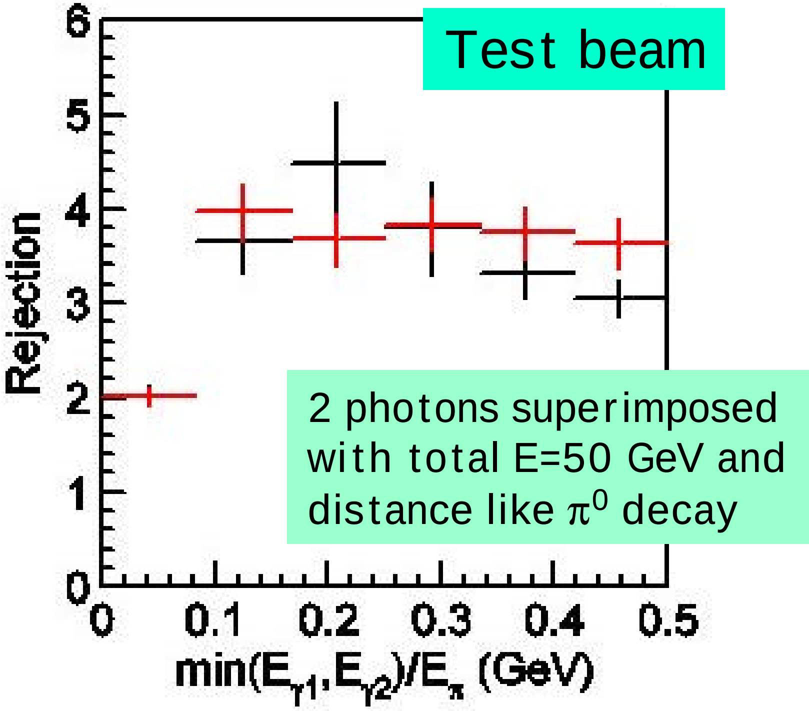


- Further rejection of π^0 can be obtained exploiting the fine granularity of the first sampling (dh=.003 or 5mm).The two photons of a 60 GeV E_T symmetric π^0 decay are separated by >7mm at the calorimeter face!

Photon ID in ATLAS (2)



Single π^0 dominated Monte Carlo jets



Test beam

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 dependant!

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

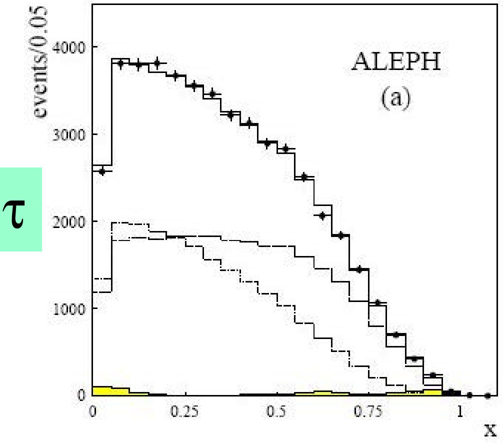
Tau identification (1)

- Another lepton for EW signatures
- Much more potential for Higgs Physics:

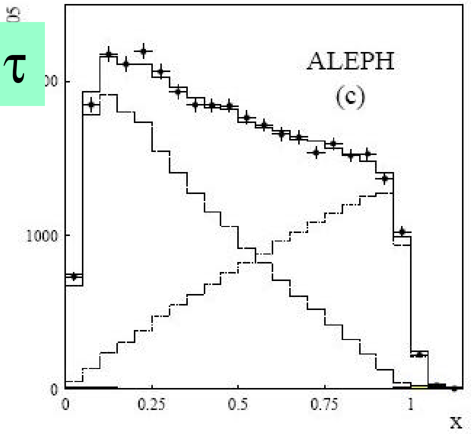
  coupling prop to mass

  m_t / m_m / me = 1777/106/0.5 MeV
- Lifetime 0.3 ps ie 89 microns x g
- Main decay modes

Eel/Eτ



Eh/Eτ



mode	$e\nu\nu$	$\mu\nu\nu$	$\pi^-\nu$	$\pi^-\nu$ +neut	$\pi^-\pi^+\pi^-\nu$	$\pi^-\pi^+\pi^-\nu$ +neut	rest
BR	17 %	17 %	11 %	38%	9%	5%	3%

- leptonic modes found through e,m signatures, with reduced efficiency given the loss of E_T to n
- Non leptonic modes as "1 or 3 prongs super narrow jets" when E_T increases
- energy carried out by neutrinos to be calculated from "missing E_T "

Tau identification (2)

In CMS the steps to select taus in HLT are :

-start from a LVL1 tau trigger(2 cells-.087x.087- only of a nonet- >Eth)

-request isolation in the EM calorimeter E_T(DR=0.4- DR=0.13) < Eth

-find tracks in the pixels pointing to the small cluster and request isolation around them (DRiso as a parameter)

-reconstruct with complete tracker all “pixel tracks”

-ask for no track above p_T=1 GeV in the isolation cone

- The estimated performance is :

-~1 kHz for LVL1 tau trigger>100 GeV E_T

-60% acceptance per tau jet>100 GeV E_T

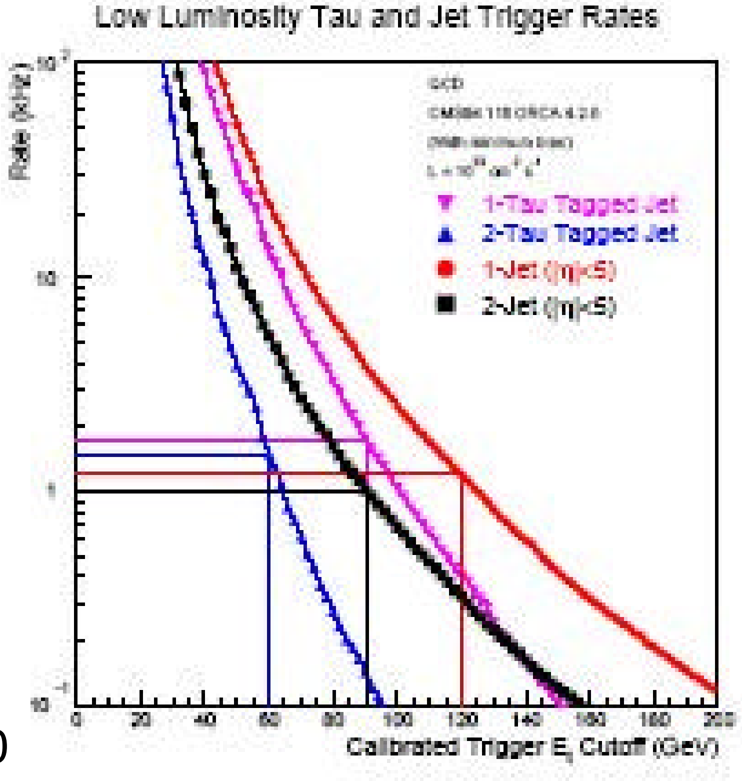
-3% acceptance for QCD jets

(averaged over 50-170 GeV E_T)

Giving ~30Hz at HLT output

- Additional requirements asking for one tau + E_T miss or two taus can then be added to limit the rate

The requirement of 100GeV E_T on the tau Jet means reduced efficiency slowly starts at 100



Jets and missing E_T

- Jets are comparatively easier to trigger on and reconstruct.
- Cross-section decreases very fast with E_T
  accurate E_T measurement at trigger level is important
  → large cluster size like 0.8 x 0.8 or more
  →correct weighting of EM and HCAL energies (ATLAS and CMS calorimeters are non-compensating...)
- Ability to separate nearby jets→ smaller cluster size preferred

- ATLAS works with 4x4 trigger cells of 0.2x0.2
- A LVL1 internal logic eliminates dble counting and finds core of triggering jet, which defines RoI for HLT

....all that every 25ns for the whole solid angle...

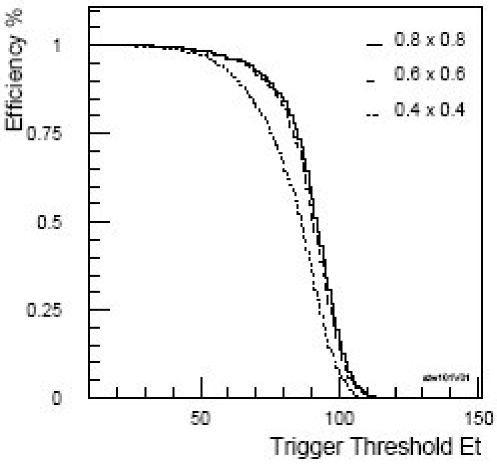


Figure 4-31 Jet trigger efficiency curves for 100 GeV E_T jets, for different cluster sizes, at luminosity 10^{33} cm^{-2}s^{-1}.

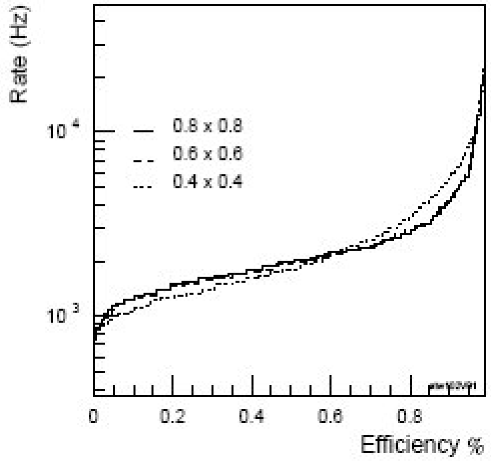


Figure 4-32 Trigger rate vs. efficiency for 100 GeV E_T jets, for different cluster sizes, at luminosity 10^{33} cm^{-2}s^{-1}.

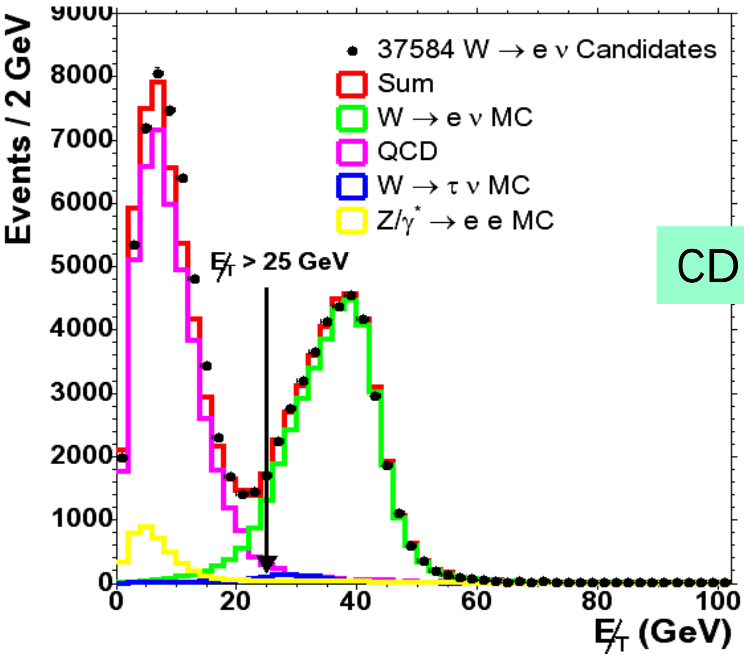
Missing E_T

- From the position and energy of each of the trigger cells, are calculated, every 25 ns, summing on EM and HCAL sections.

-SE_x and SE_y a 2-vector in the transverse plane whose modulus is E_T miss

-SE_T in the transverse plane, also called "total E_T"

- If there are no missing particles $SE_x=0$ and $SE_y=0$,ie $E_T$miss=0
- Accuracy limited by :
  - -fluctuations of sampled energies, and noise (option=threshold)
  - -uncovered solid angle (h>5),(high E, but *sin(q)→0=OK)
  - -cracks,...
- Conversely E_T miss ¹ 0 signs a missing particle: a neutrino(s) or something more exotic....



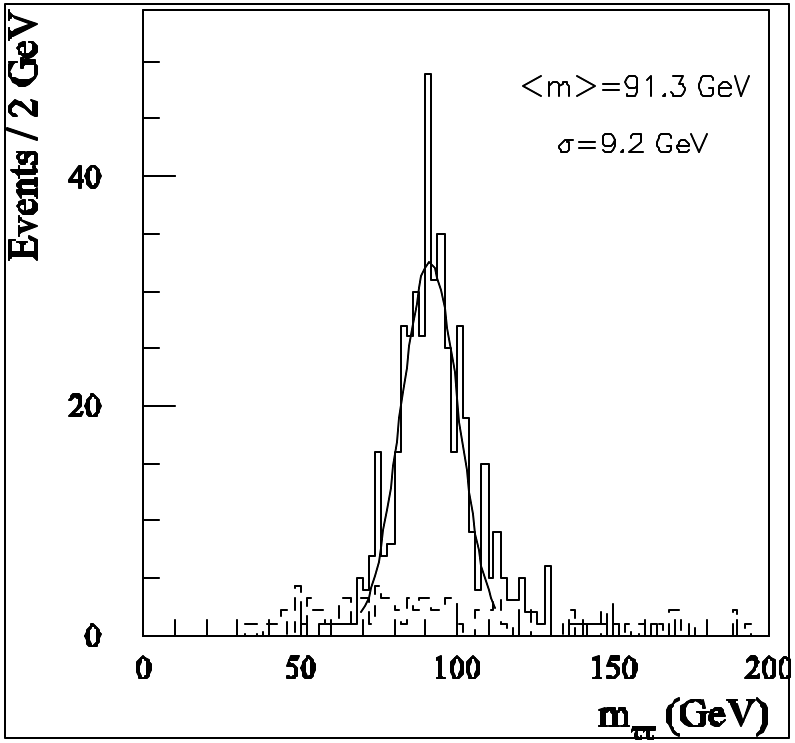
CDF 72pb^{-1}

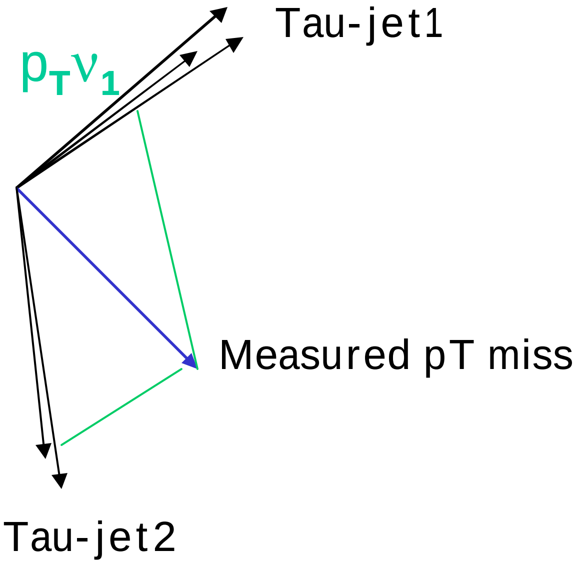
From missing E_T to missing particle(s)

Need hypotheses….to be confirmed by event analysis:

- Single particle missing (n,neutralino,..) $E_T$miss = transverse momentum
- Two particles missing =ambiguous in the transverse plane.

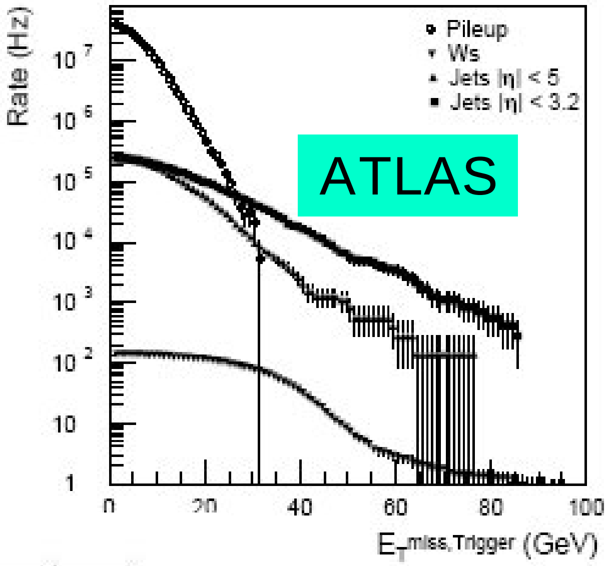
  can be solved if missing particles are decay products of two "massless" parents, like taus, of which other decay particules are identified (as a narrow jet)





Missing E_T in the trigger….

LVL1 $E_{T\ miss}$ trigger for QCD jets and single W evts:
→too high rate in stand alone to catch for example W→tn
®use it combined with other signatures:
-E_T miss +taus
-E_T miss +jets (SUSY),….



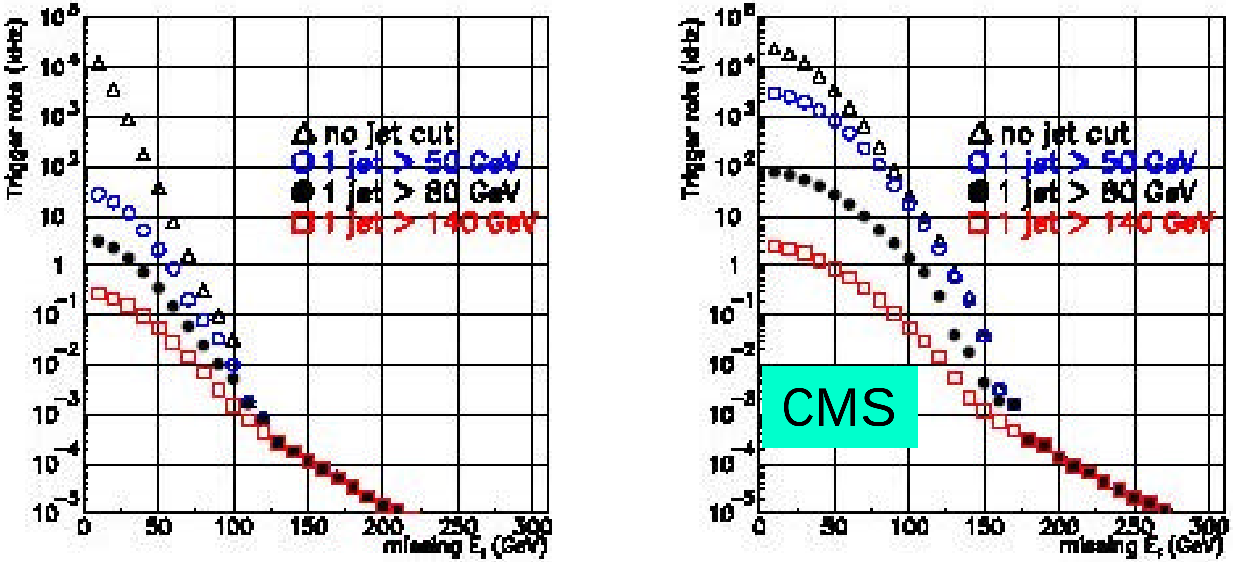


Figure 15-47 Event rates as function of E_T^{miss} when requiring a jet above various thresholds. Left: low luminosity; right: high luminosity.

Expected LVL1 rates at “low” L

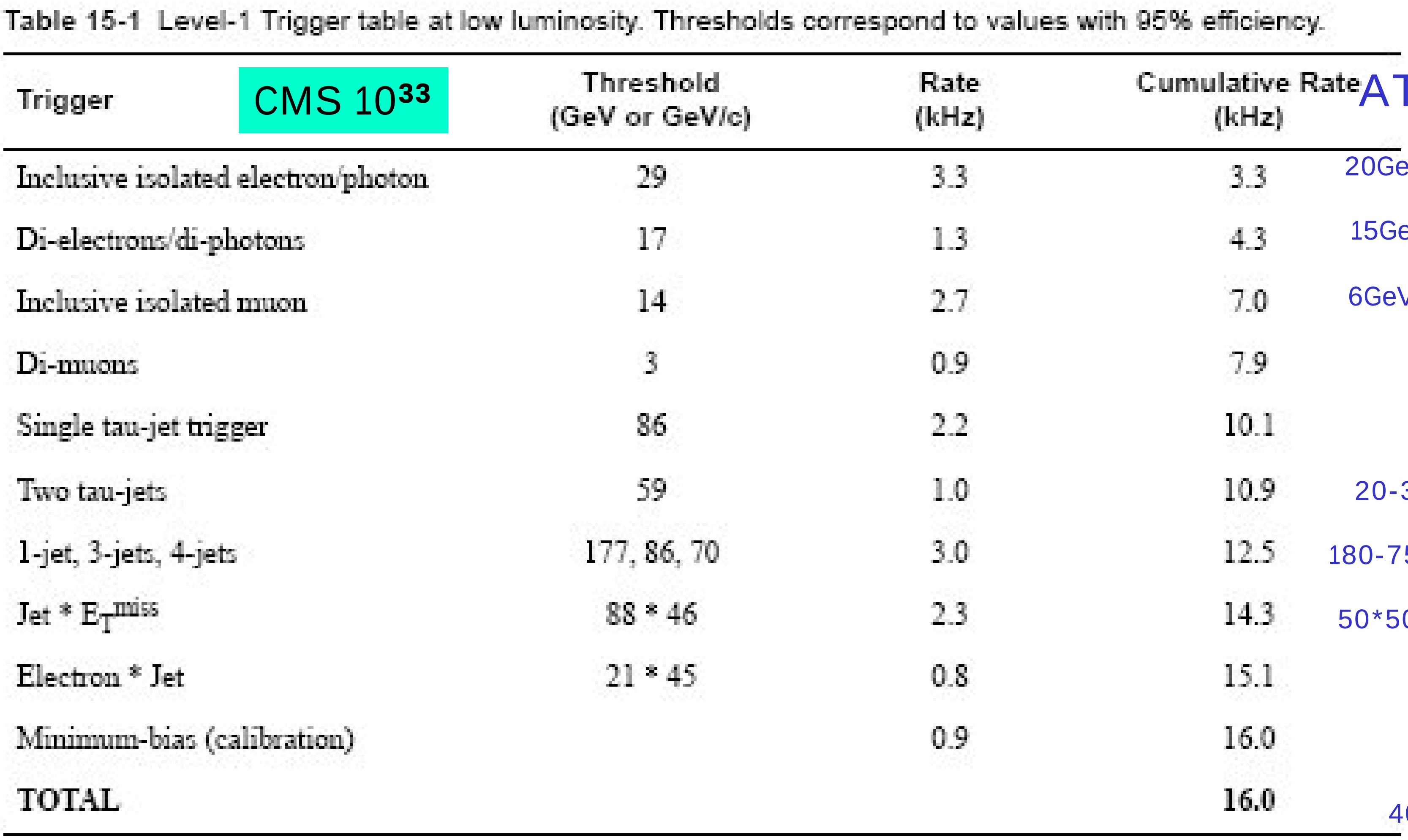
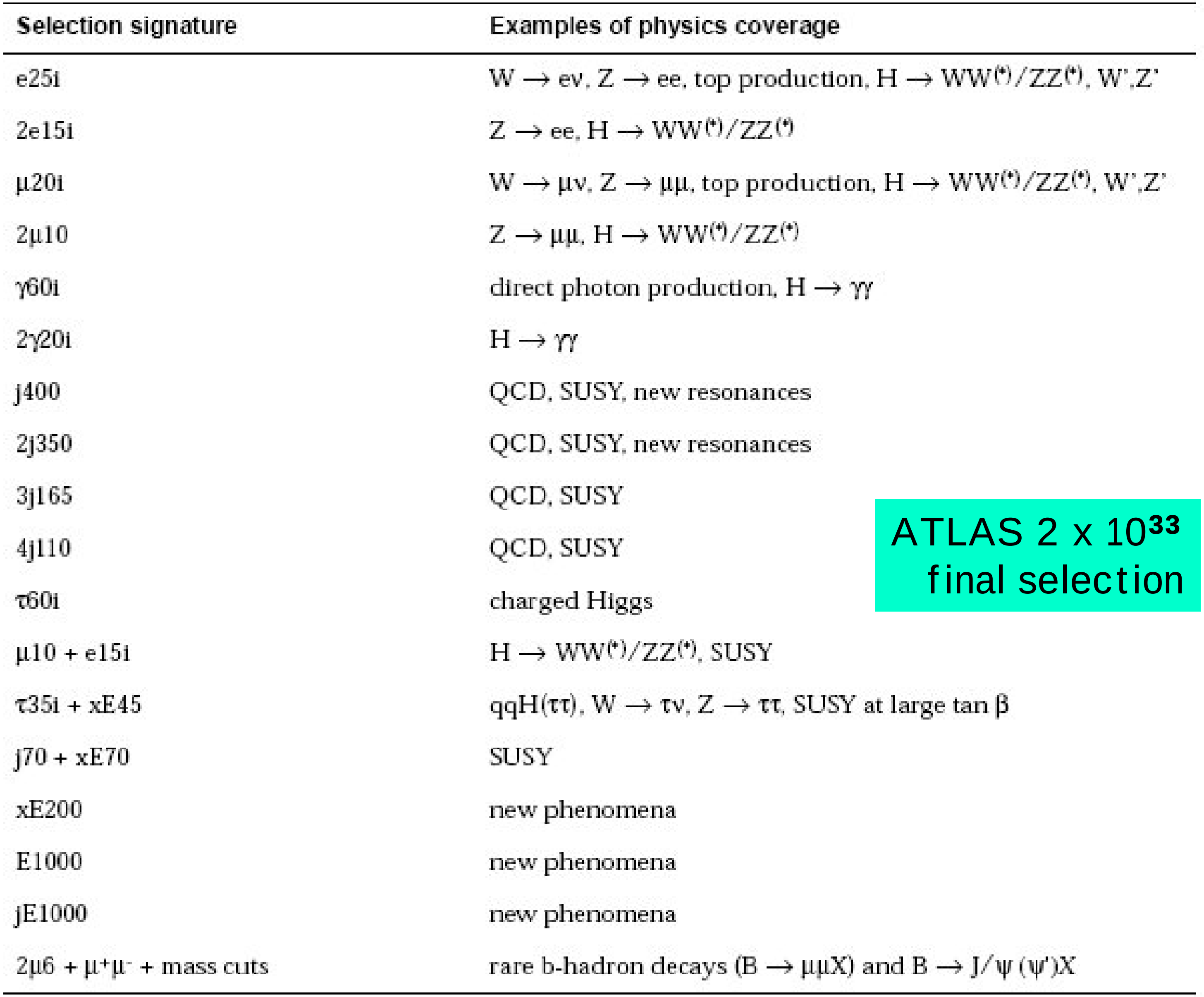


Table 15-1 Level-1 Trigger table at low luminosity. Thresholds correspond to values with 95% efficiency.

Trigger CMS 10^{33}	Threshold (GeV or GeV/c)	Rate (kHz)	Cumulative Rate (kHz)	ATLAS 10^{33}
Inclusive isolated electron/photon	29	3.3	3.3	20GeV/11 kHz
Di-electrons/di-photons	17	1.3	4.3	15GeV/2 kHz
Inclusive isolated muon	14	2.7	7.0	6GeV/23 kHz
Di-muons	3	0.9	7.9	
Single tau-jet trigger	86	2.2	10.1	
Two tau-jets	59	1.0	10.9	20-30/2kHz
1-jet, 3-jets, 4-jets	177, 86, 70	3.0	12.5	180-75-55/0.6 k
Jet * E_T^{miss}	88 * 46	2.3	14.3	50*50/0.4 kHz
Electron * Jet	21 * 45	0.8	15.1	
Minimum-bias (calibration)		0.9	16.0	
TOTAL			**16.0**	40 kHz

HLT reduce to <~200 Hz the rate to ”permanent storage”, keeping the thresholds energies at or very close to the LVL1

A possible strategy



Selection signature	Examples of physics coverage
e25i	$W \to e\nu$, $Z \to ee$, top production, $H \to WW^{(*)}/ZZ^{(*)}$, W',Z'
2e15i	$Z \to ee$, $H \to WW^{(*)}/ZZ^{(*)}$
μ20i	$W \to \mu\nu$, $Z \to \mu\mu$, top production, $H \to WW^{(*)}/ZZ^{(*)}$, W',Z'
2μ10	$Z \to \mu\mu$, $H \to WW^{(*)}/ZZ^{(*)}$
γ60i	direct photon production, $H \to \gamma\gamma$
2γ20i	$H \to \gamma\gamma$
j400	QCD, SUSY, new resonances
2j350	QCD, SUSY, new resonances
3j165	QCD, SUSY
4j110	QCD, SUSY
τ60i	charged Higgs
μ10 + e15i	$H \to WW^{(*)}/ZZ^{(*)}$, SUSY
τ35i + xE45	$qqH(\tau\tau)$, $W \to \tau\nu$, $Z \to \tau\tau$, SUSY at large tan β
j70 + xE70	SUSY
xE200	new phenomena
E1000	new phenomena
jE1000	new phenomena
2μ6 + $\mu^+\mu^-$ + mass cuts	rare b-hadron decays ($B \to \mu\mu X$) and $B \to J/\psi\ (\psi')X$

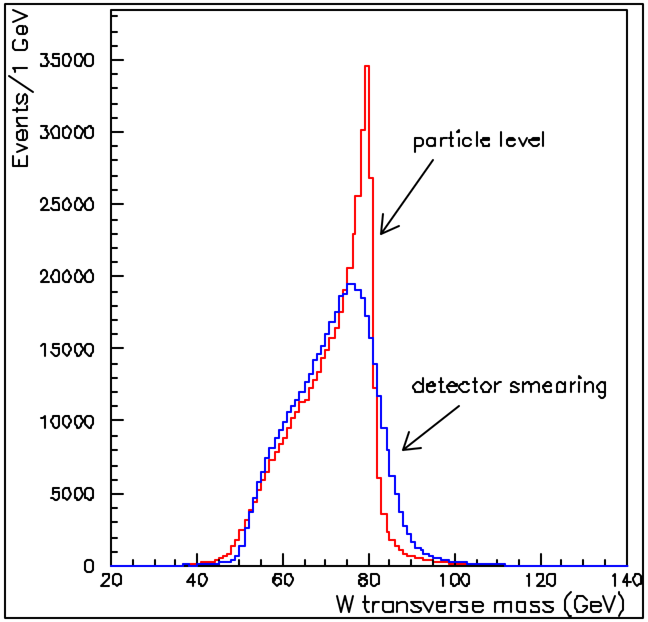
ATLAS 2 x 10^{33}
final selection

W and Zs to calibrate the detector and make already important measurements

From cross-section, acceptance (h<2.5 and trigger) & luminosity ⇒event rate .Assuming 100 days at $2\ 10^{33}$ gives:

-$5\ 10^{6}$ Z→ee and $5\ 10^{6}$ Z→mm to mass storage
-$5\ 10^{7}$ W→en and $5\ 10^{7}$ W→mn “” “”

Using the Z mass constraint (known to $2\ 10^{-5}$)
-calibrate the EM calorimeter and muon spectrometer
-calibrate the E_T miss scale
-measure the W mass to ~20 MeV/expt
using lepton + $E_T$miss evts (“transverse mass”)
-calibrate the jet scale using Z+jet events
and g +jet evts (using p_T balance)
Remember that:
-no inclusive Z → jet-jet evts (QCD background)
-no inclusive W→jet-jet evts (but wait/top...)
-no inclusive Z→tt (QCD background...)



From WW, WZ, Zg, ZZ,..in the final sate determine Triple Gauge bosons couplings and probe SM.