Particle ID in high P_T reactions(1)

o Parton reactions,QCD effects

o Parton fragmentation -jets

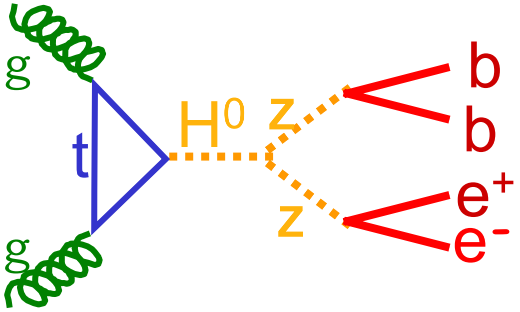
o Showering/absorption in calorimeters

o ATLAS and CMS design principles

o Muon identification

o Some photos of hardware...

Parton reactions, QCD effects



Exemple of interesting reaction:
Final state looks simple :
2 b-quark-partons
2 electrons
Each quark-parton will materialize as a jet.

However QCD coupling α_S is large enough that, with sizeable probability:

- -further gluon lines are attached to initial gluons (or quarks) = ISR
- -gluon lines are attached to final quarks (FSR)

Depending on the random occurrence of ISR/FSR,and on the $P_T$threshold to define a jet, the "bare" graph above will lead to a final state with 2,3,4… Jets (plus the electrons..)

Parton reactions and background

- The "candidate" reaction $gg \rightarrow H \rightarrow ZZ \rightarrow bbee$ is expected to have a σ.BR of ~10 fb if M(H)~150 GeV

- Events with 4 jets or more, of p_T 50GeV ore more are produced with a cross-section of ~30nb from which the candidate reaction should be distinguished. A rejection >>10^6 is needed

  The task is not simple!......

  Fortunately an electron appears extremely different from a jet.....

But

- Among the background are tt events, Zbb events,..containing also jets and electrons with a σ BR of ~ 1pb for the former....
- And another problem is pile-up

  In average 7 x 23 x5 ~ 800 charged, and as many neutrals soft particles are produced in any bunch-crossing, complicating significantly the electron-jet identification at high luminosity

THREE STEPS for particle ID:
Understand the lepton signatures
Understand the jet background= fragmentation
Understand the experimental effects (resolution, pile-up,..)

Parton fragmentation -jets(1)

Two main quantities of interest:
- -transverse momentum of fragment/jet axis.
- -fraction x of longitudinal parton momentum taken by fragment.

Best info from e+e- ,in particular LEP/Z^0

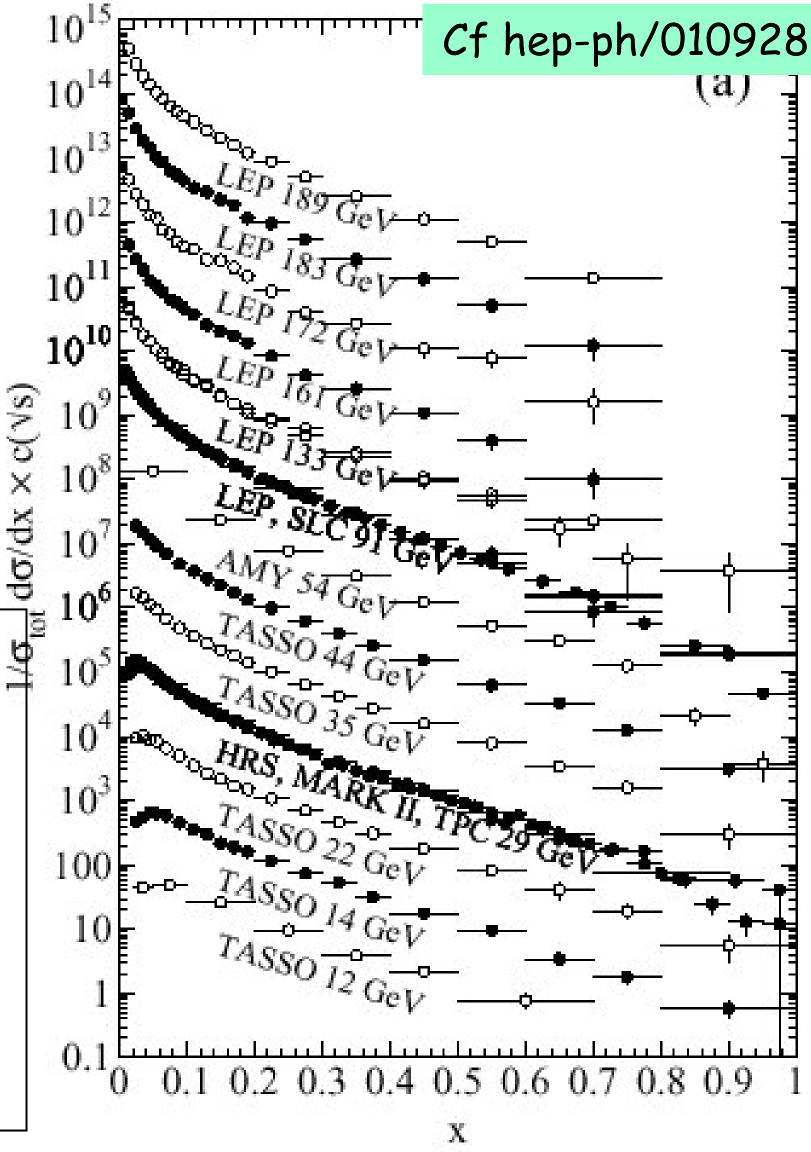
$$F^h(x,s) = \frac{1}{\sigma_{\rm tot}}\frac{d\sigma}{dx}(e^+e^- \to V \to hX)$$

$$F^h(x,s) = \sum_i \int_x^1 \frac{dz}{z} C_i(s;z,\alpha_s) D_i^h(x/z,s) .$$

$D^h_i(x/z,s)$ = parton fragmentation function
In lowest order $C_g=0$, $C_i=g_i(s)\,\delta(1-z)$

Evolution of D(x,t) - increase at low x- is reproduced by DGLAP equations.

This effect governs multiplicity increase (at the Z0 pole <Nch>=20)



Cf hep-ph/0109282

Parton fragmentation (2)

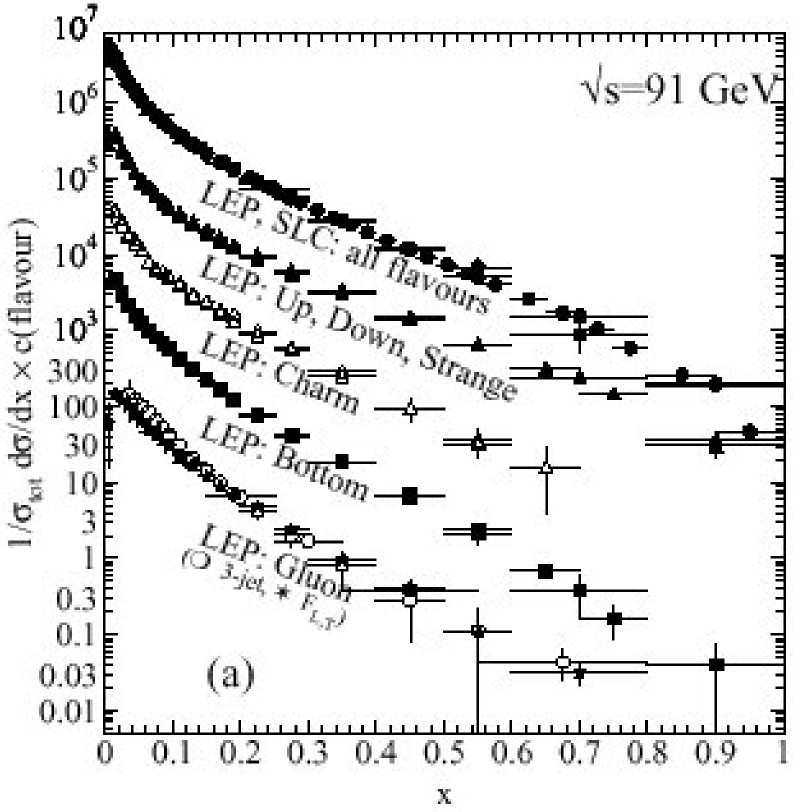
Flavor tagging allows to separate charm jets, bottom jets,and also Gluons jets as “third jet” in bbg 3 jet events.

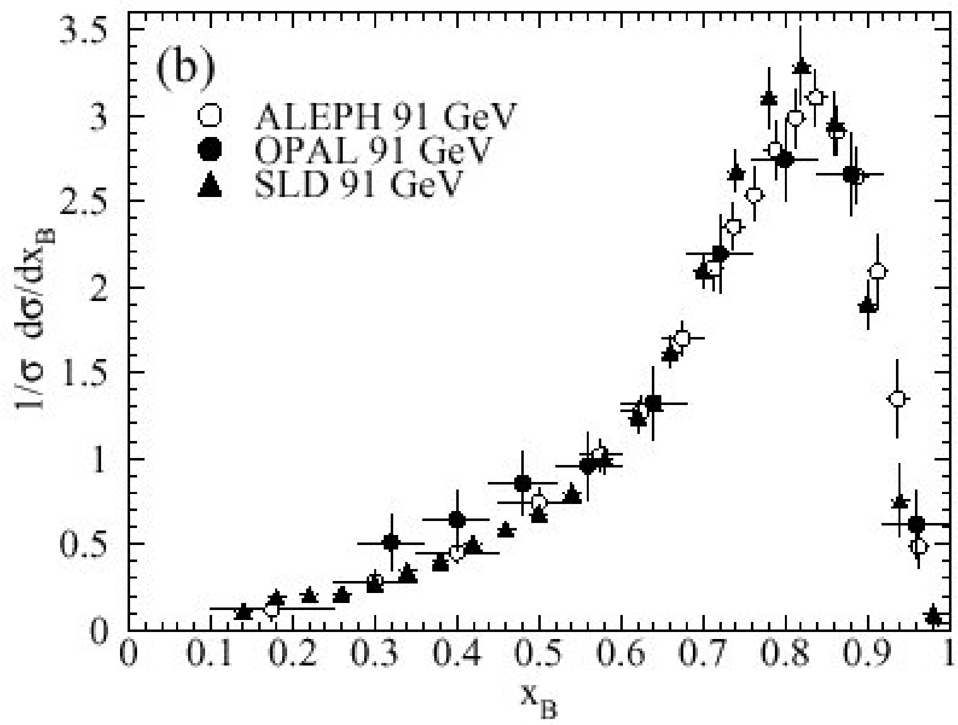
Gluon fragmentation also from $\sin^2(\theta)F_L(\mathbf{x})$ term in $d\sigma/dxd\cos(\theta)$:

$1/\sigma\ d^2\sigma/dxd\cos(\theta)=3/8(1+\cos^2(\theta))F_T+3/4\sin^2(\theta)F_L(\mathbf{x})+3/4\cos(\theta)\mathbf{F}_A$

→b jets and gluon jets give softer particles than light quarks

→however fragmentation of b parton in b hadron is very hard





Parton fragmentation (3)

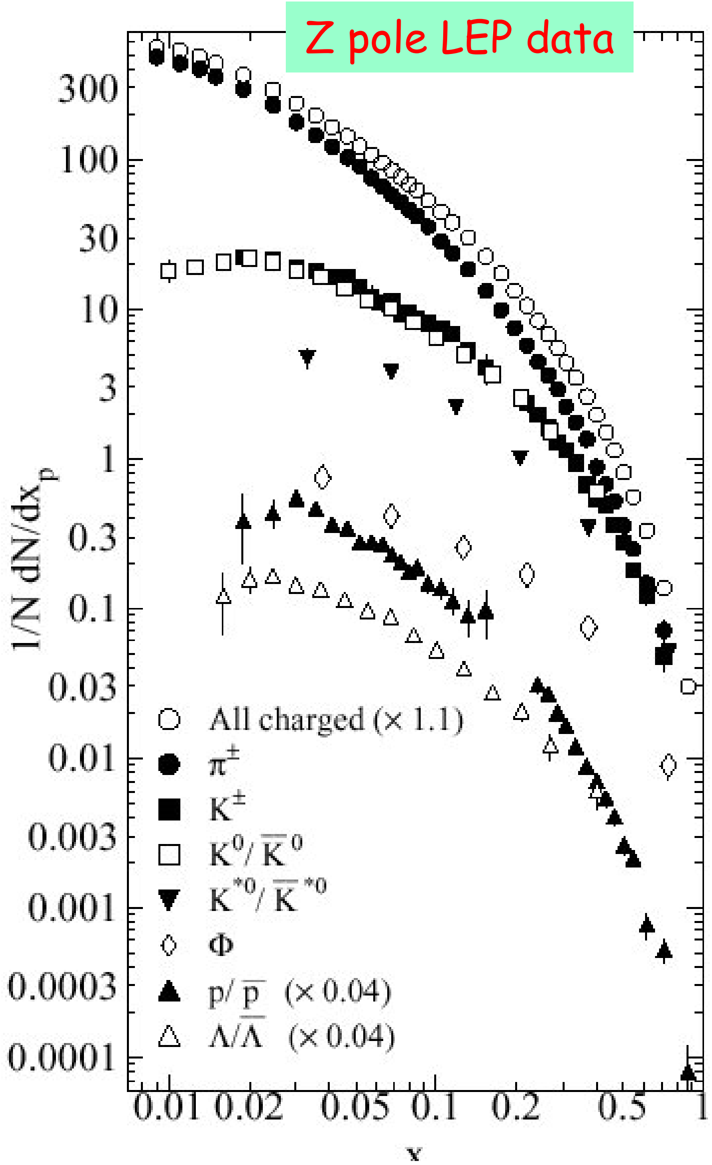
Monte-Carlo modelisation : string model

A string representing the QCD colour field is "stretched' between partons:

If energy stored is sufficient:
A qq pair is emitted from vacuum

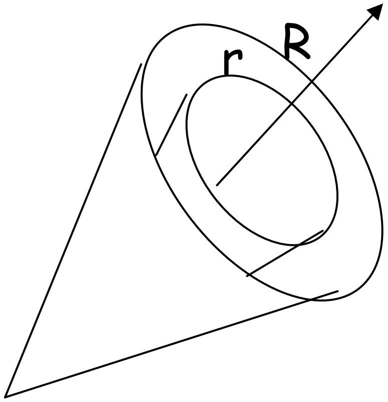
$P(\text{pair creation}) \alpha \ \exp-(-\pi m^2_{qT}/\kappa)$ where
κ=string tension ~ 1GeV/fm
$m^2_{qT} = m^2_q + p^2_q$
$f(z)=1/z(1-z)^{\alpha} \exp-(bm^2_{qT}/z)$
heavy hadrons-even kaons-
heavily suppressed

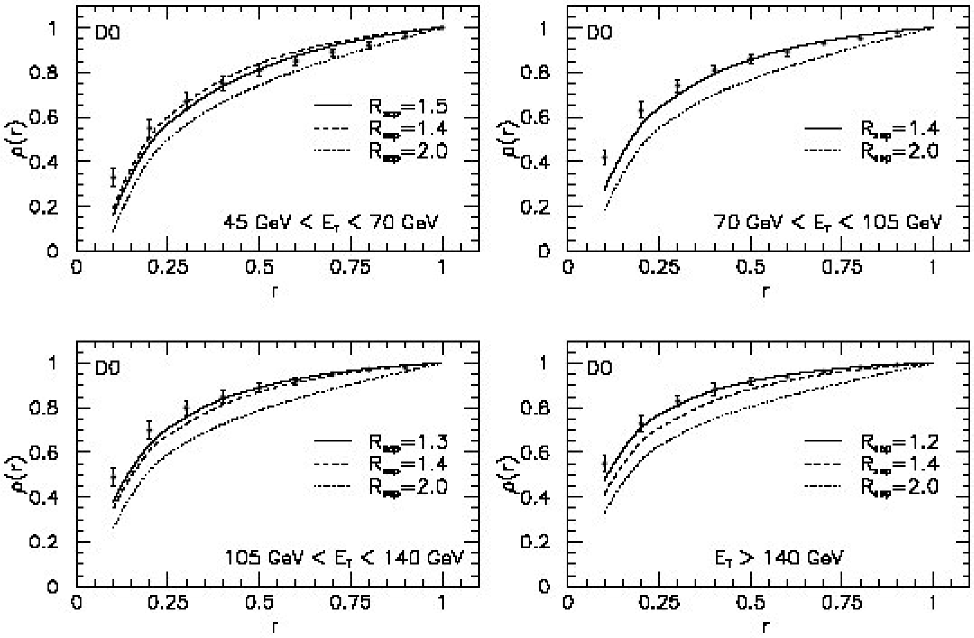
When x→1 the jet has only one hard particle,….plus pile-up


Z pole LEP data

Parton fragmentation (4)

- The transverse momentum structure of a jet is analyzed measuring the fraction ρ of energy contained in a cone of radius r as compared to a radius R taken as reference.
- Data from HERA and Tevatron are well reproduced by NLO calculations.
- Jets defined in this way (cone) vary only slowly in shape with E_T





D0 data
NLO calculations
Separation between jets as parameter

Showering in calorimeters

Particles from the jets go through the "light" tracking systems with a minimum of interactions. Then showering in calorimeters starts

Two rather well separated processes take place:

Electromagnetic showers: photons(prompt or from π^0,..)electrons

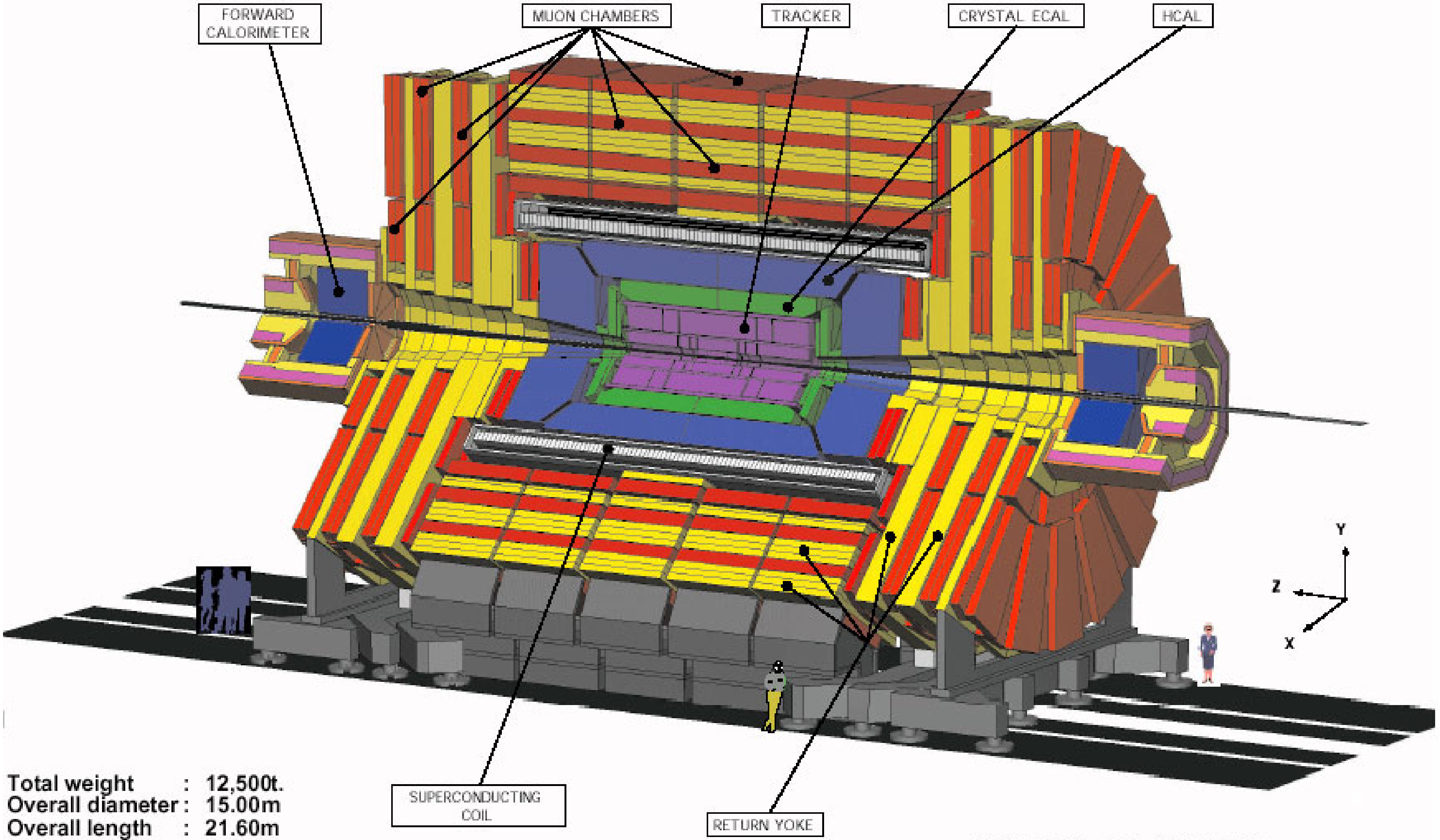
Hadronic showers: charged pions, kaons, nucleons,,,from jets

While the hadronic shower develops, secondary π^0 π^+ π^- are produced with equal probability (isospin invariance), and thus a hadronic-initiated shower develops an EM component.
The reverse is not true: an EM initiated shower remains EM (to ~10^{-3})

Muons ,like electrons have "only" EM interactions, but at a much reduced rate due to the $(e^2/m)^2$ factor in radiative cross-sections: Except at the highest energies they "happily" cross through several meters of iron.

→This gives a robust way of identifying them.

CMS
A Compact Solenoidal Detector for LHC

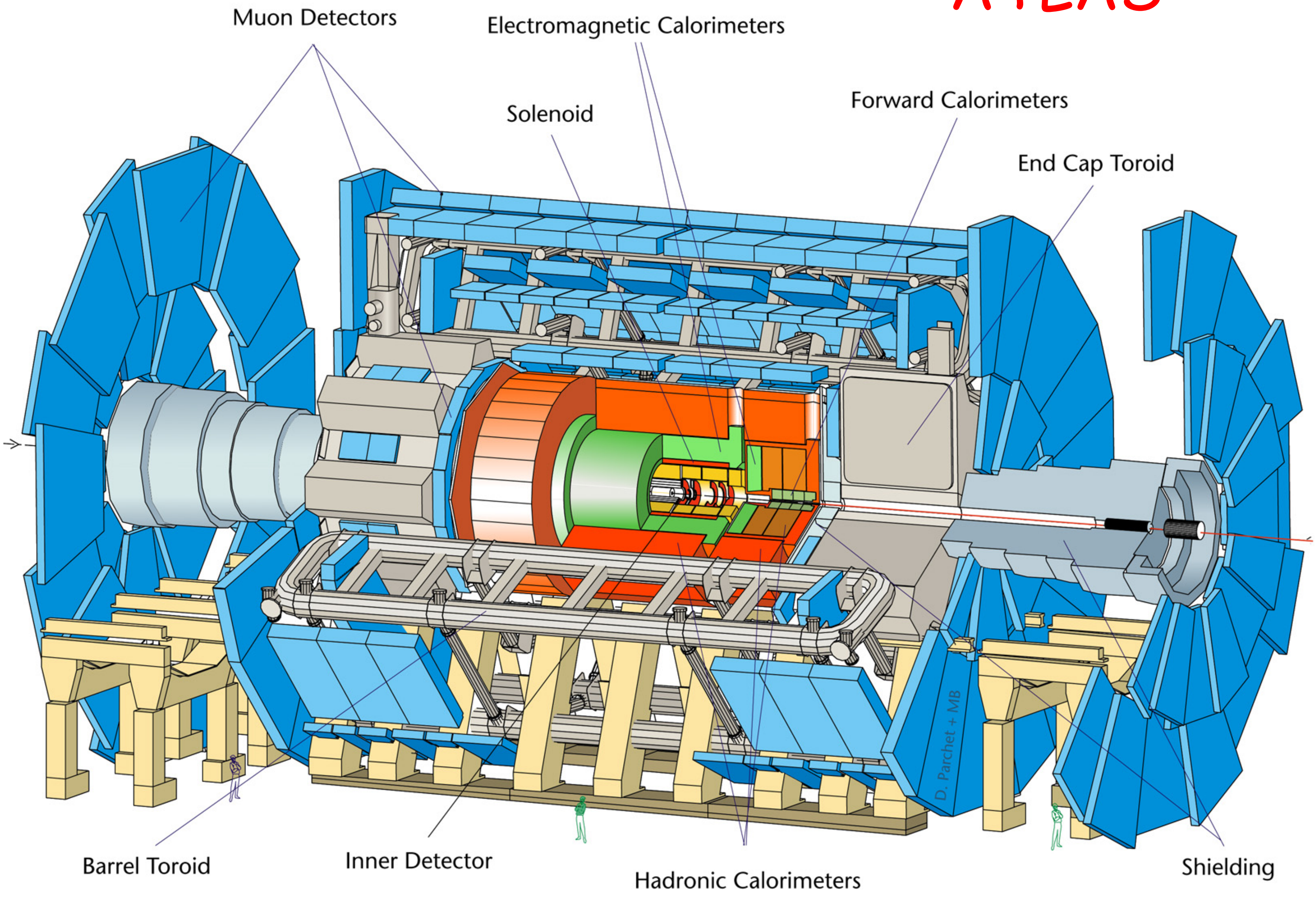


Total weight : 12,500t.
Overall diameter : 15.00m
Overall length : 21.60m
Magnetic field : 4 Tesla

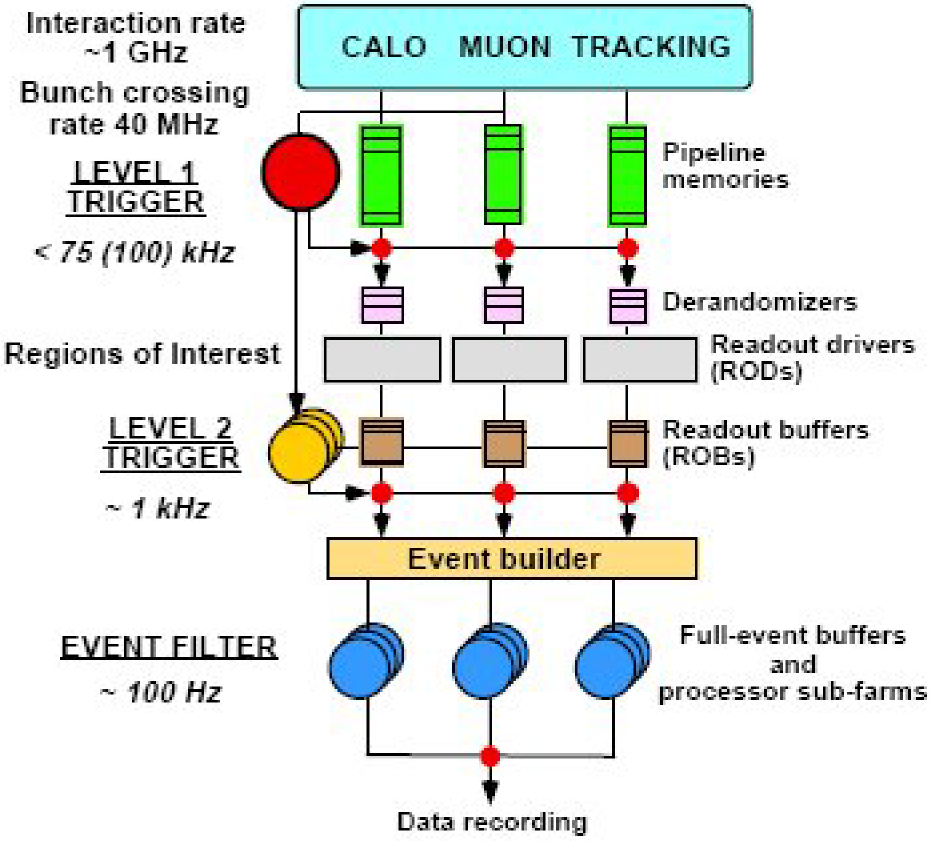
CMS-PARA-001-11/07/97 JLB.PP

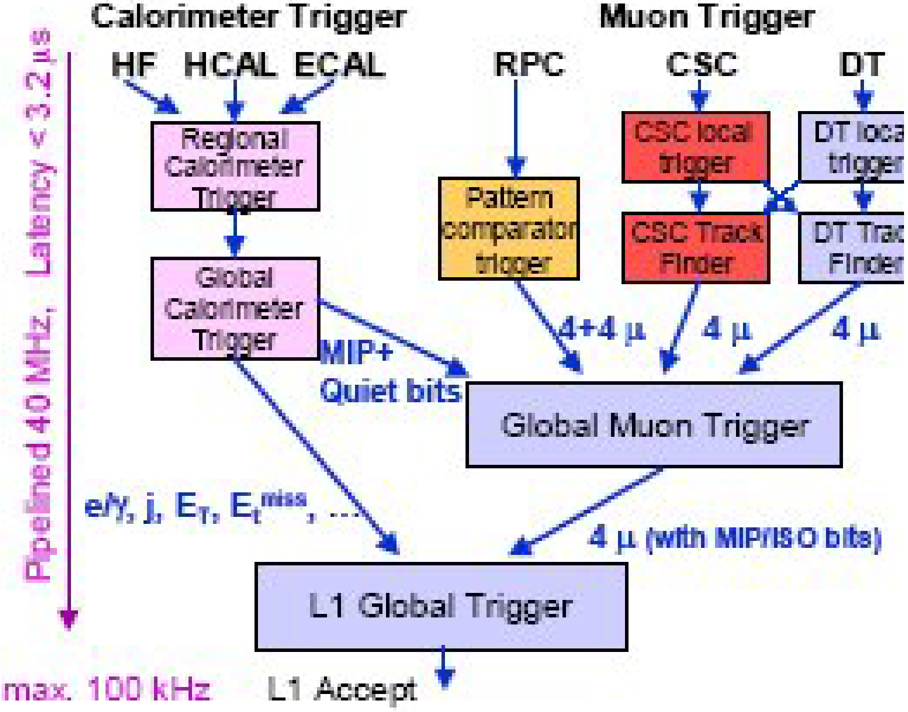
D712/mb-26/06/97

ATLAS



Pipelined-multilevel-triggers





40 MHz LVL1 → 100 kHz (LVL2+LVL3) → 100Hz

synchronous 3 µs

asynchronous

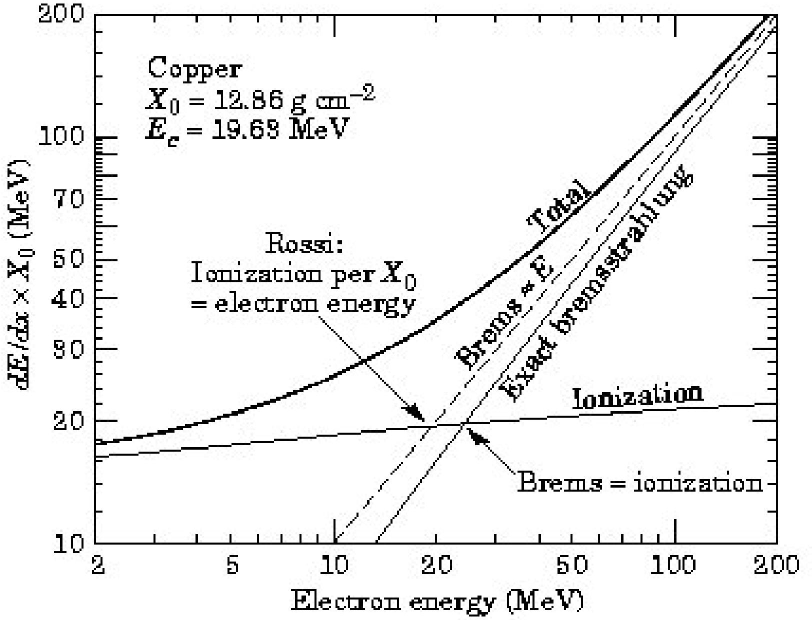
EM showers(1)

High energy photons and electrons interactions with matter are governed by the radiation length :X_0(g/cm²) =716 A/Z(Z+1)log(287/ √Z) (lead X_0 = 6 mm)

- Electron bremsstrahlung <Eel> after l : $E=E_0 \exp(-l/X_0)$
- Pair creation: mean free path of photon=9/7 X_0

At any energy electrons are subject, like any other charged particle to energy loss by ionisation (and Cerenkov if v/c>1/n)

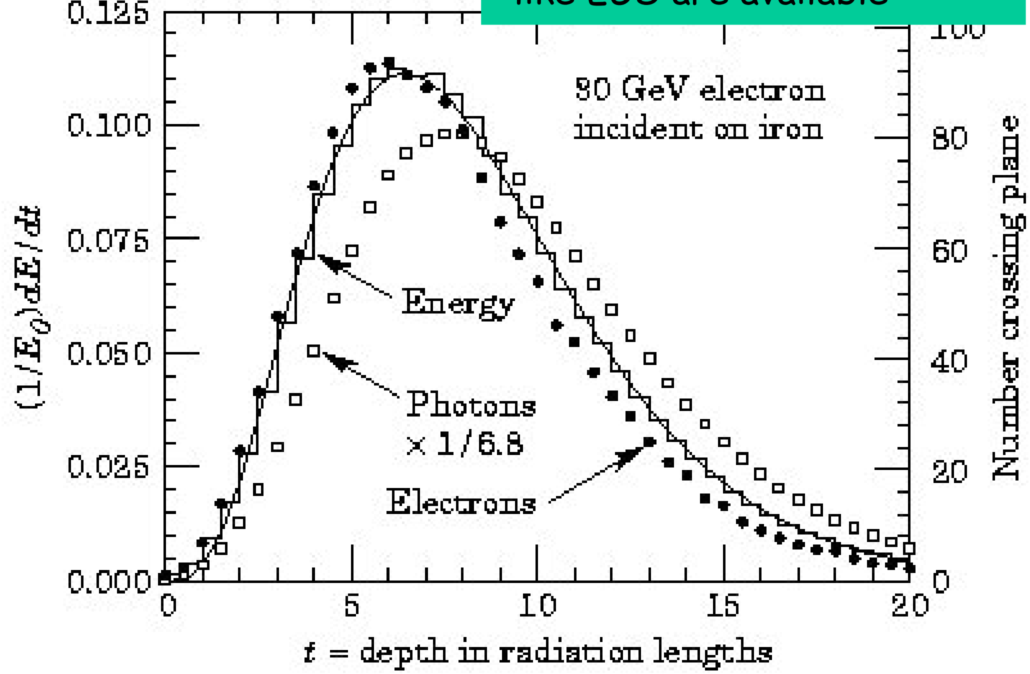
- The energy where the two losses are equal is the critical energy Ec.
- The process of bremsstrahlung remains dominant until E~Ec
- Small values of Ec and X_0 give better sampling calorimeters. For lead Ec=7MeV

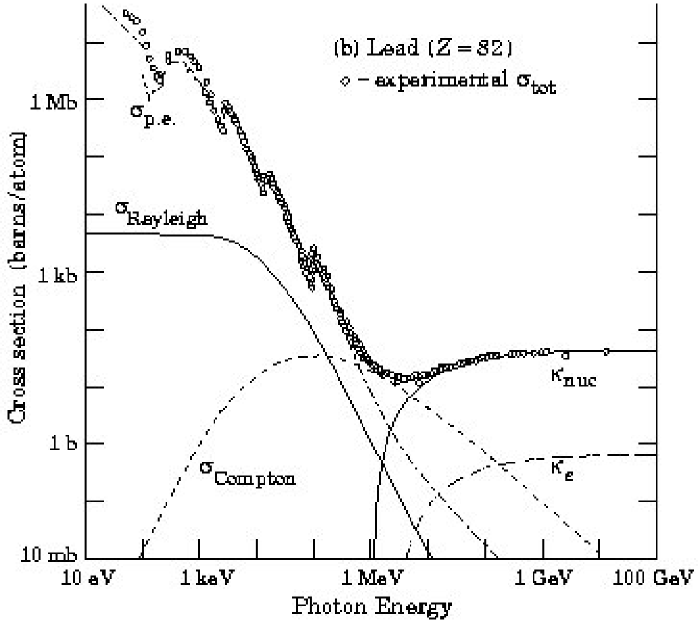


EM showers(2)

- The longitudinal profile of showers expressed in X_0 is almost material independent, and depends only logarithmically of E
  ~30 X_0 (18 cm lead equivalent)is enough to absorb a TeV EM shower
- The transverse profile is driven by multiple scattering (Es=21 MeV) of electrons. It is almost energy independent, and characterized by
  $R_M = X_0 Es/Ec$ the Moliere radius , proportional to the material density
- At high enough energy EM shower fluctuations in shape&size are limited

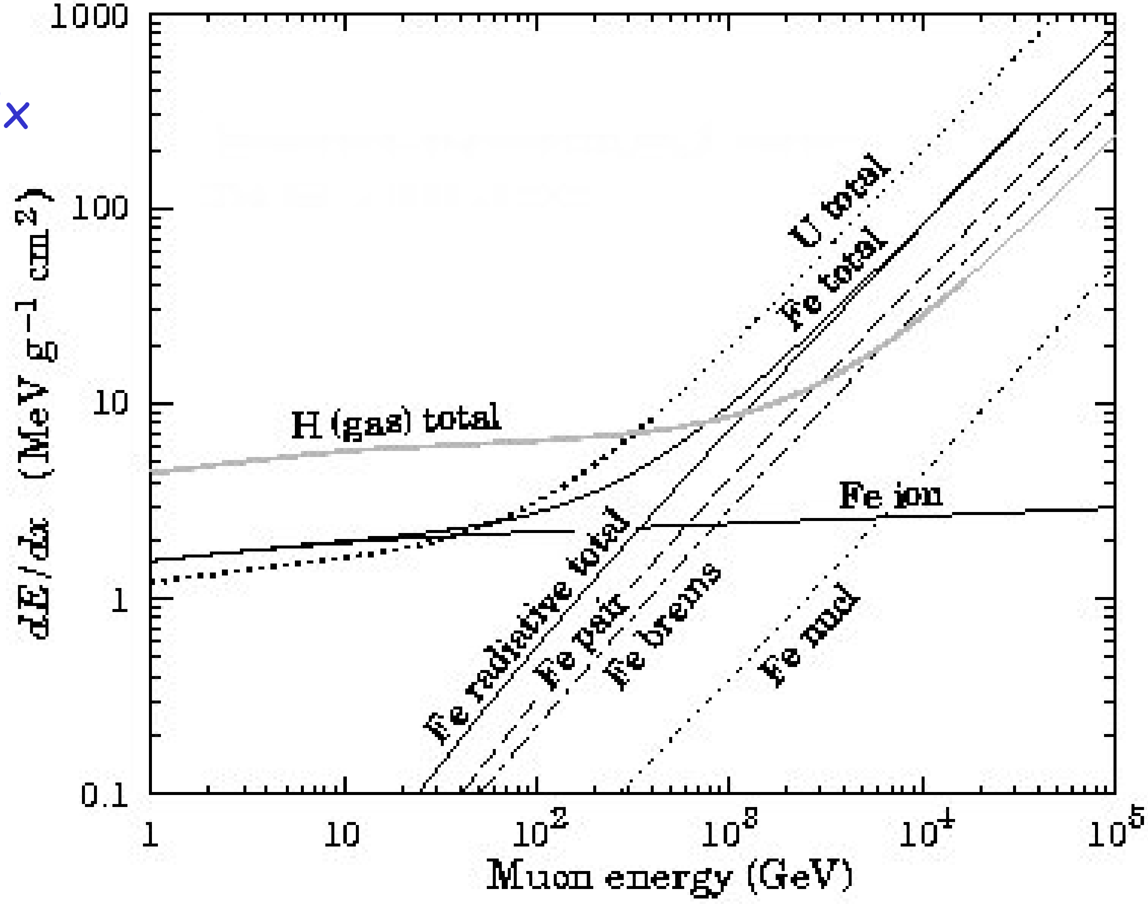
High quality simulation codes like EGS are available





High energy muons in material

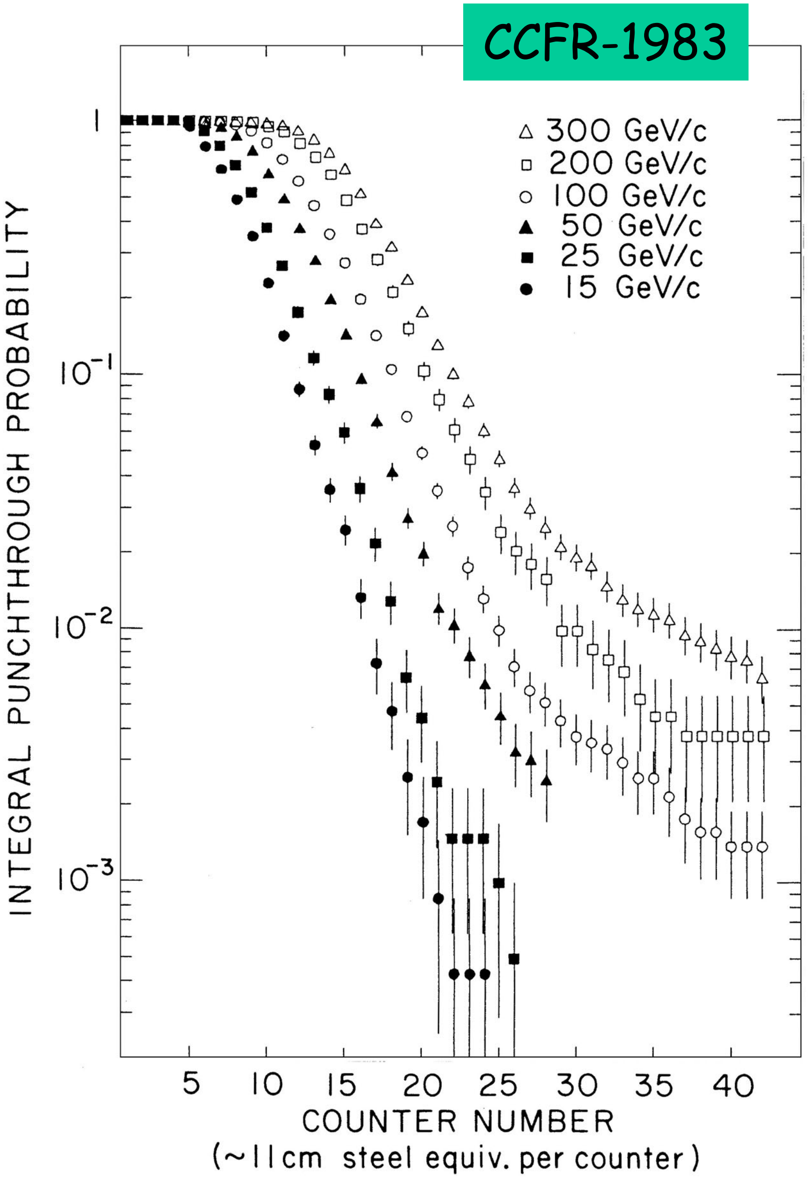
- At high E radiative dE/dx (prop to E) becomes larger than ionisation dE/dx.
- In iron the cross-over (critical energy) is around 200 GeV



Hadronic showers(1)

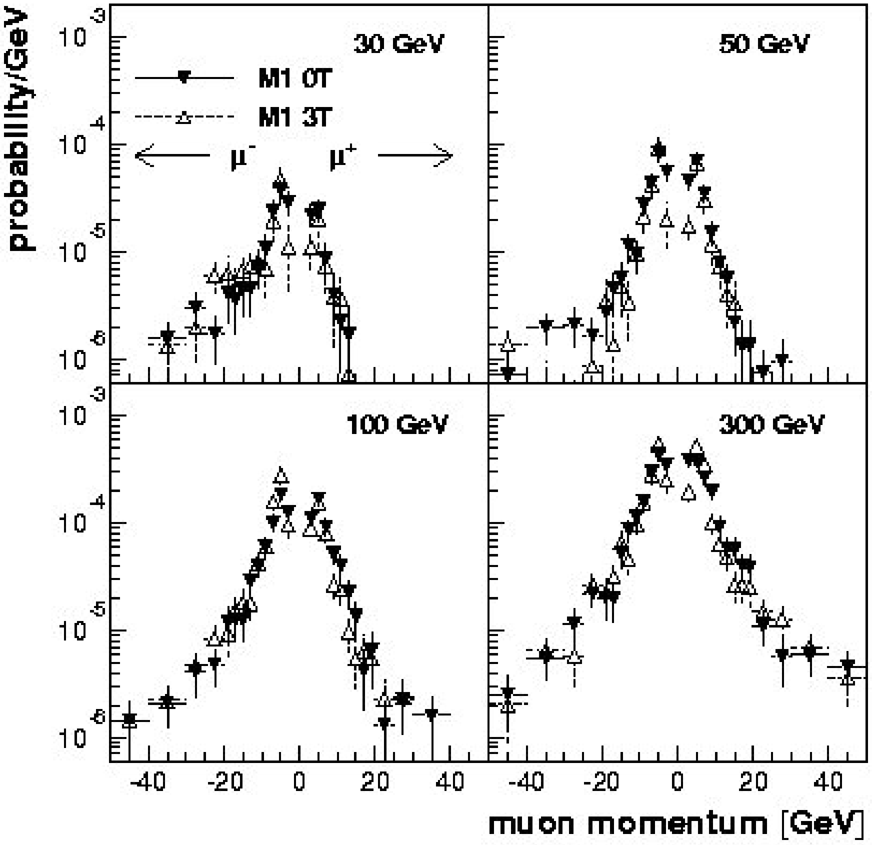
- Theory of hadron-nucleus collisions not able to reproduce data ,with multiparticle final states in a reliable way.Rely on models interpolating tabulated cross-sections,
- Analog of X_0 is the interaction length λ,mean free path before the next inelastic collision of a hadron. λ goes with $A^{1/3}$.
- In general $\lambda > X_0$. For iron(lead) λ =17cm(18cm),X_0 = 17,6 mm(6mm)
- Hadronic interactions are more “inelastic” than EM ones,and ~12 λ are enough to absorb a TeV pion
- The choice of material is dictated by density, cost, ease of machining, (non) magnetic properties (copper/iron),..
- In general a hadronic calorimeter is “non-compensating” ($e/\pi > 1$). This is an important limitation which –to some extend- can be alleviated using (depleted) uranium as an absorber.
- Transverse behavior in showers is dominated by p_T of hadronic process
- Monte-Carlo simulations not yet at the level of EM ones. Geant4/LHEP,Geant4/QGSP, FLUKA,…

Hadronic showers(2) -tails


CCFR-1983

"punch-through"

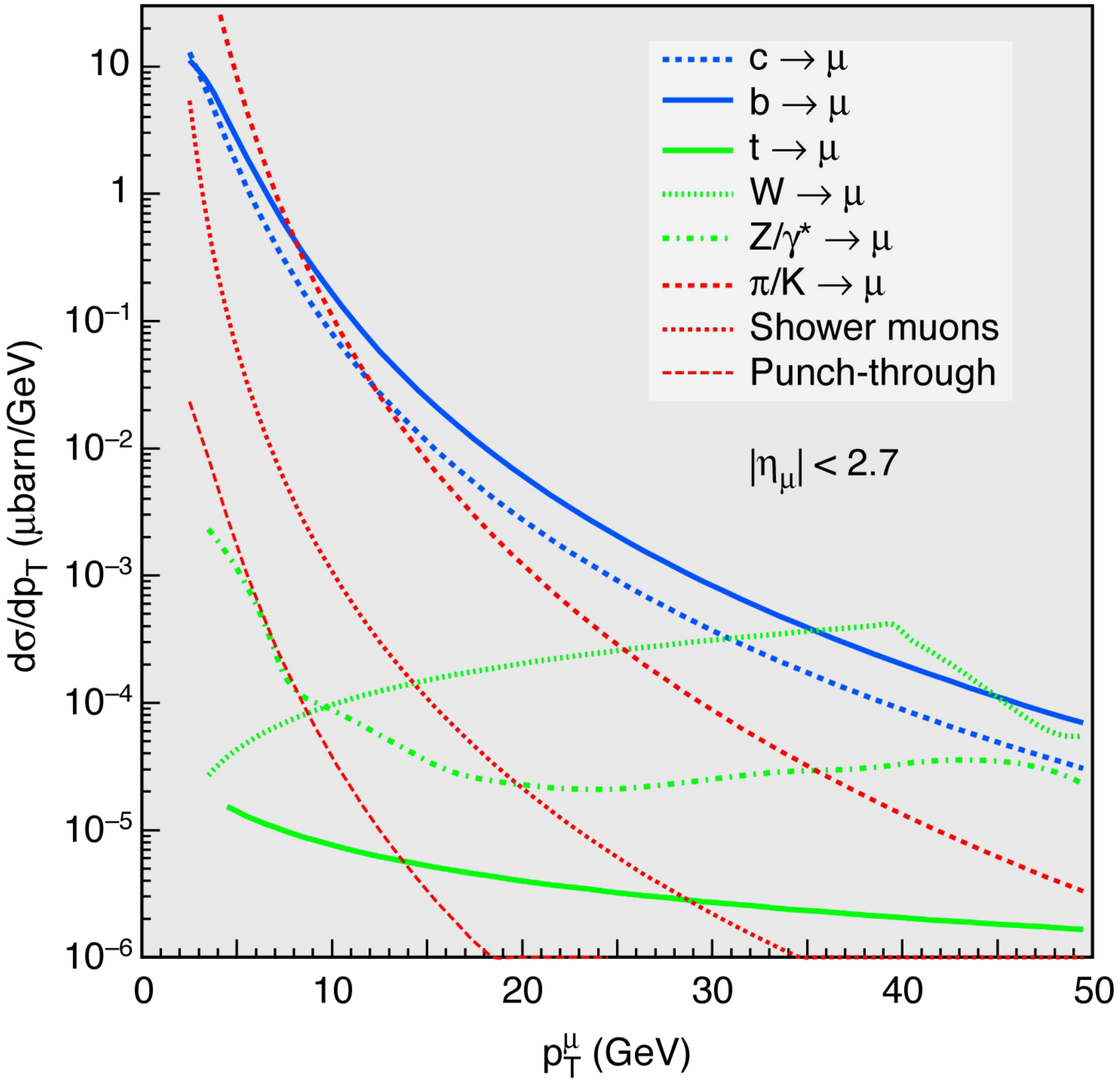
probability of π^+ after 10λ
as measured by RD-5



Muon identification(1)

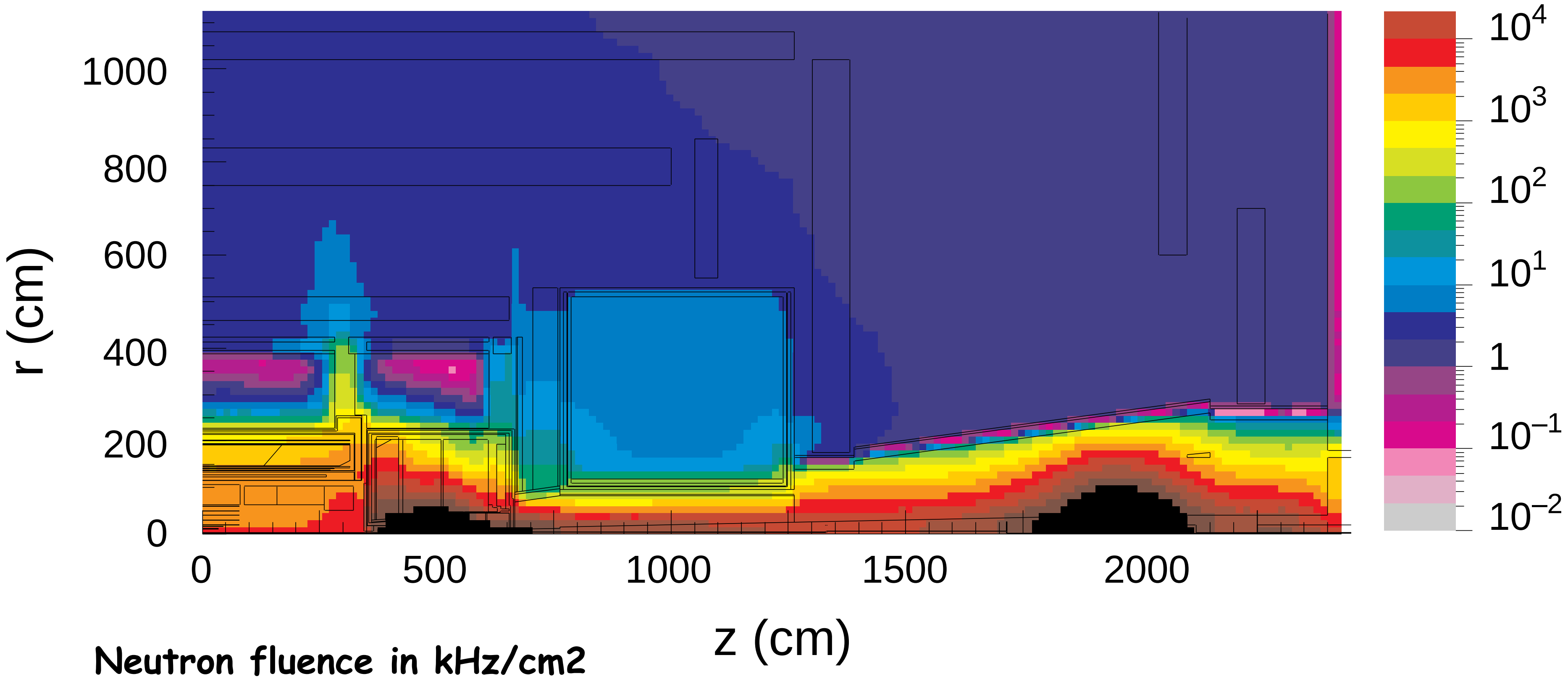
Example of what is expected to be found behind the ATLAS calorimeter (>12λ)

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



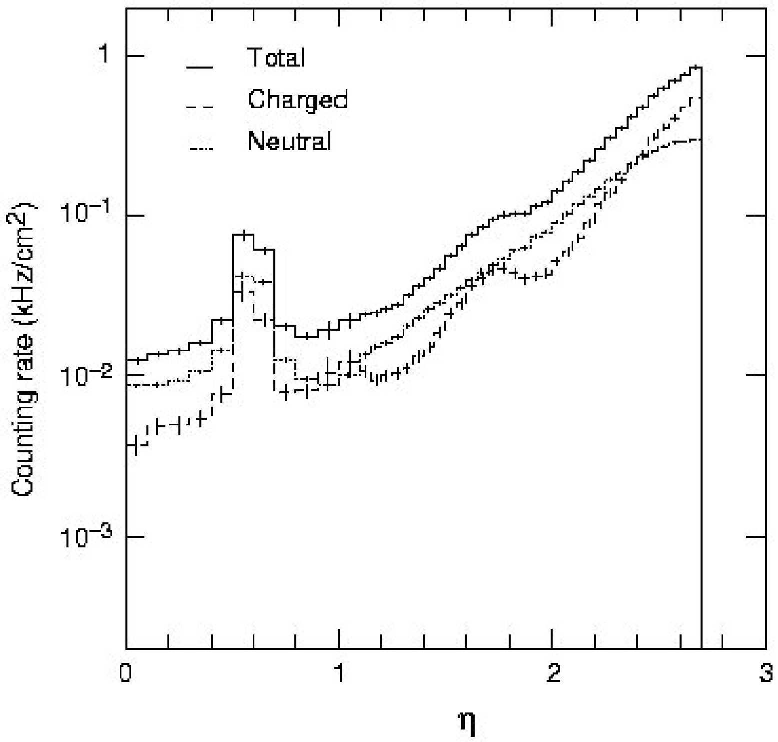
Muon id(2) : neutron induced hits

- 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 →random hits

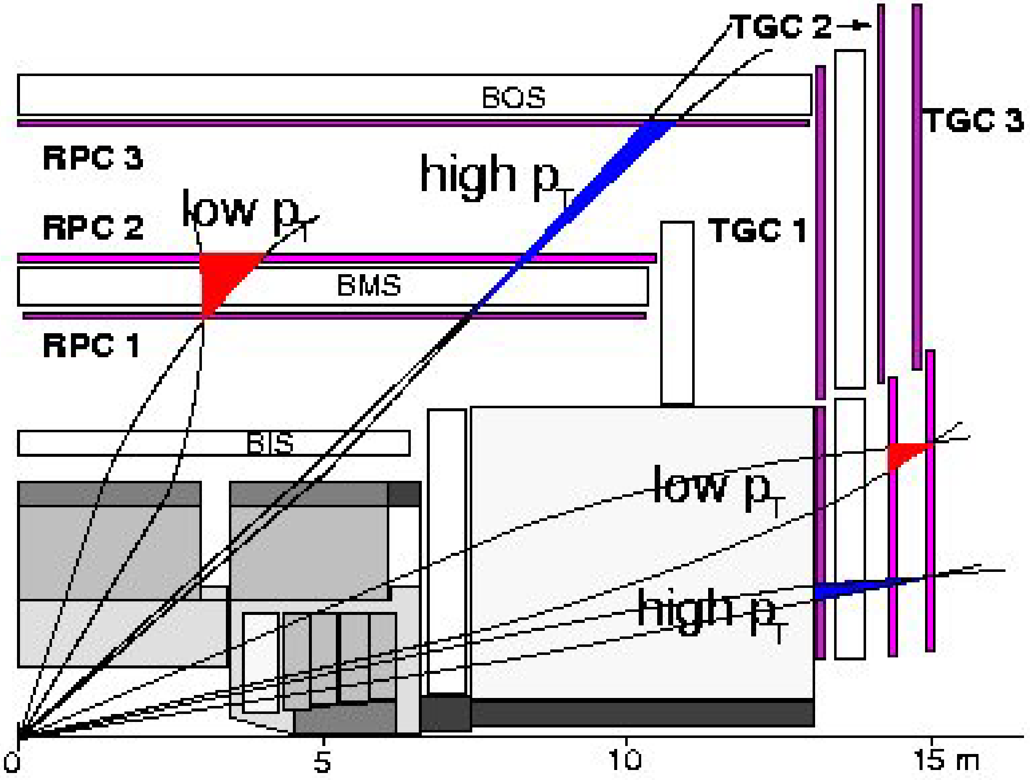


Neutron fluence in kHz/cm2

ATLAS Muon id(3) :find tracks



And cut on transverse momentum…

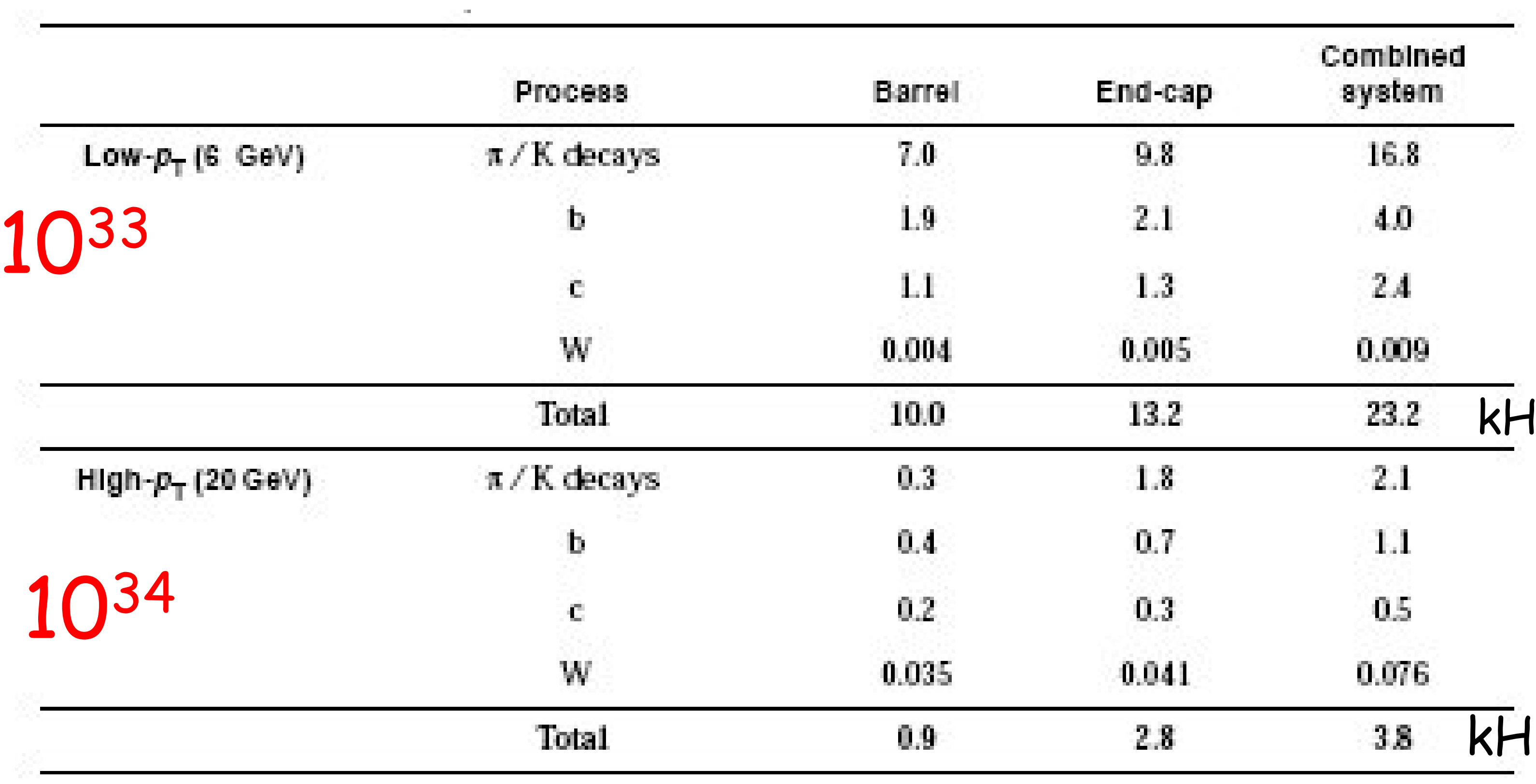


3 stations of precision chambers (drift tubes) interleaved with Trigger chambers

LVL1 Trigger Chambers= fast response (25 ns)
→ 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



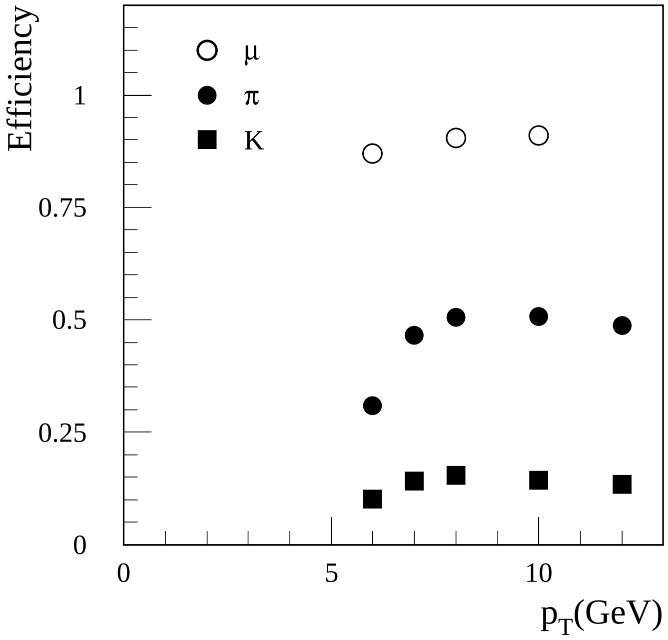
	Process	Barrel	End-cap	Combined system	
Low-p_T (6 GeV)	π / K decays	7.0	9.8	16.8	
10^{33}	b	1.9	2.1	4.0	
	c	1.1	1.3	2.4	
	W	0.004	0.005	0.009	
	Total	10.0	13.2	23.2	kHz
High-p_T (20 GeV)	π / K decays	0.3	1.8	2.1	
	b	0.4	0.7	1.1	
10^{34}	c	0.2	0.3	0.5	
	W	0.035	0.041	0.076	
	Total	0.9	2.8	3.8	kHz

Further Muon ID(5)

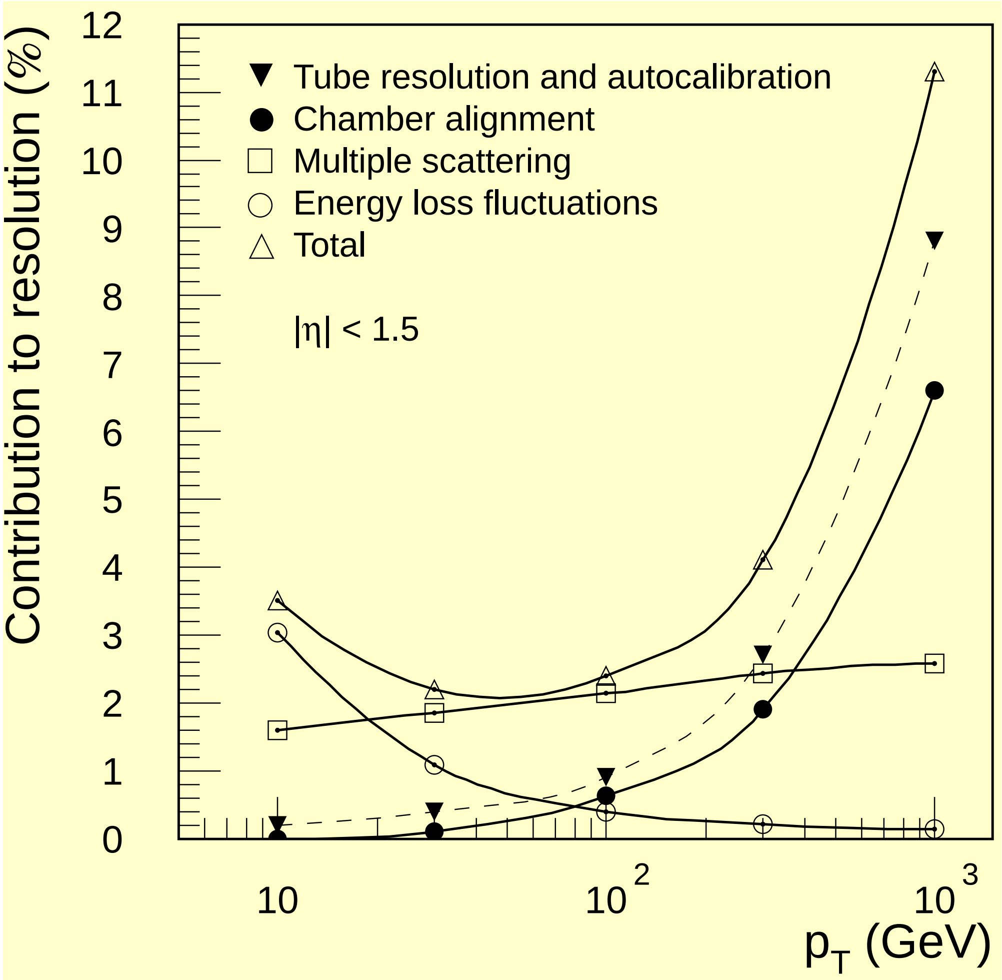
Further ID steps:

- Reconstruct track in spectrometer →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 →prompt/secondary
- Identify the sign (lepton or antilepton….→W' flavour/asymetry,..)



Contributions to muon resolution



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

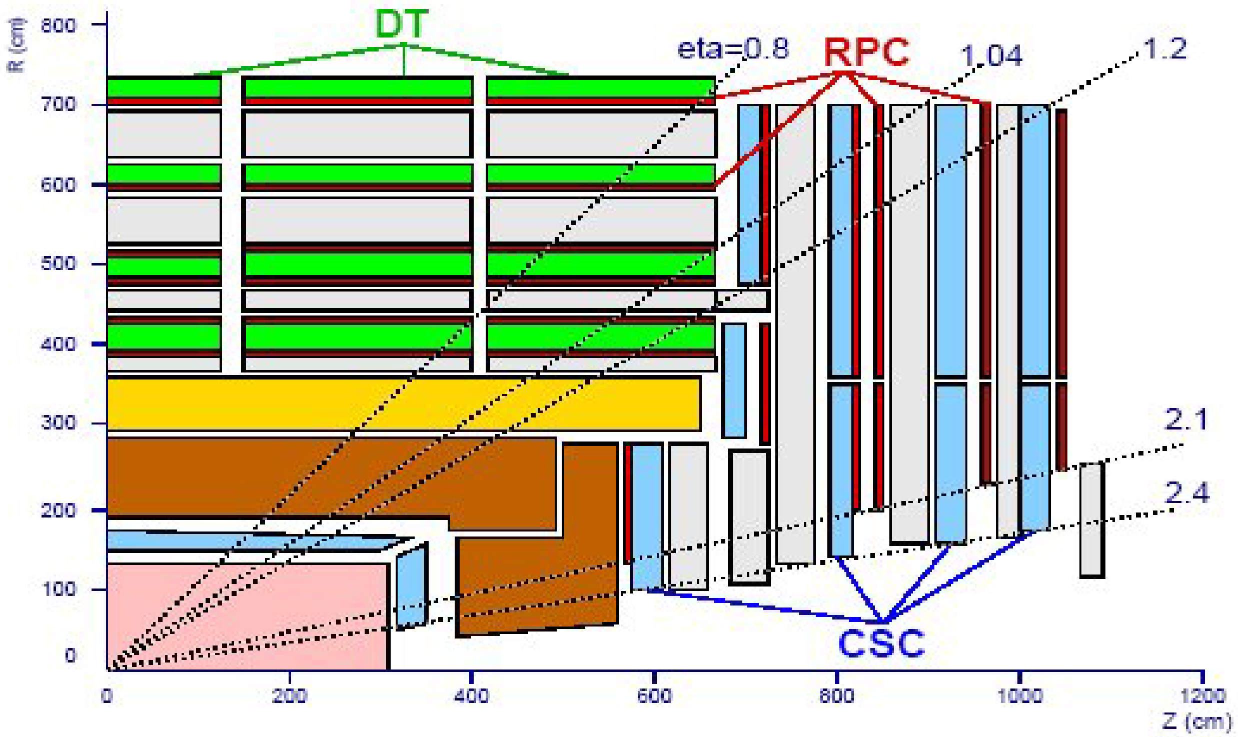


Figure 1: Layout of the CMS muon system.

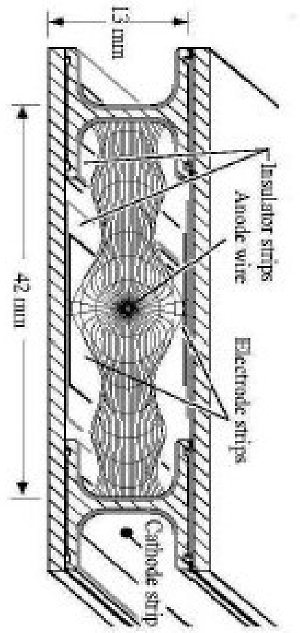


Figure 2: Schematic view of a drift cell with electric field lines.

t/rϕ linear

Global Muon Trigger Overview

[redacted]

calo

252 MIP bits
252 Quiet bits

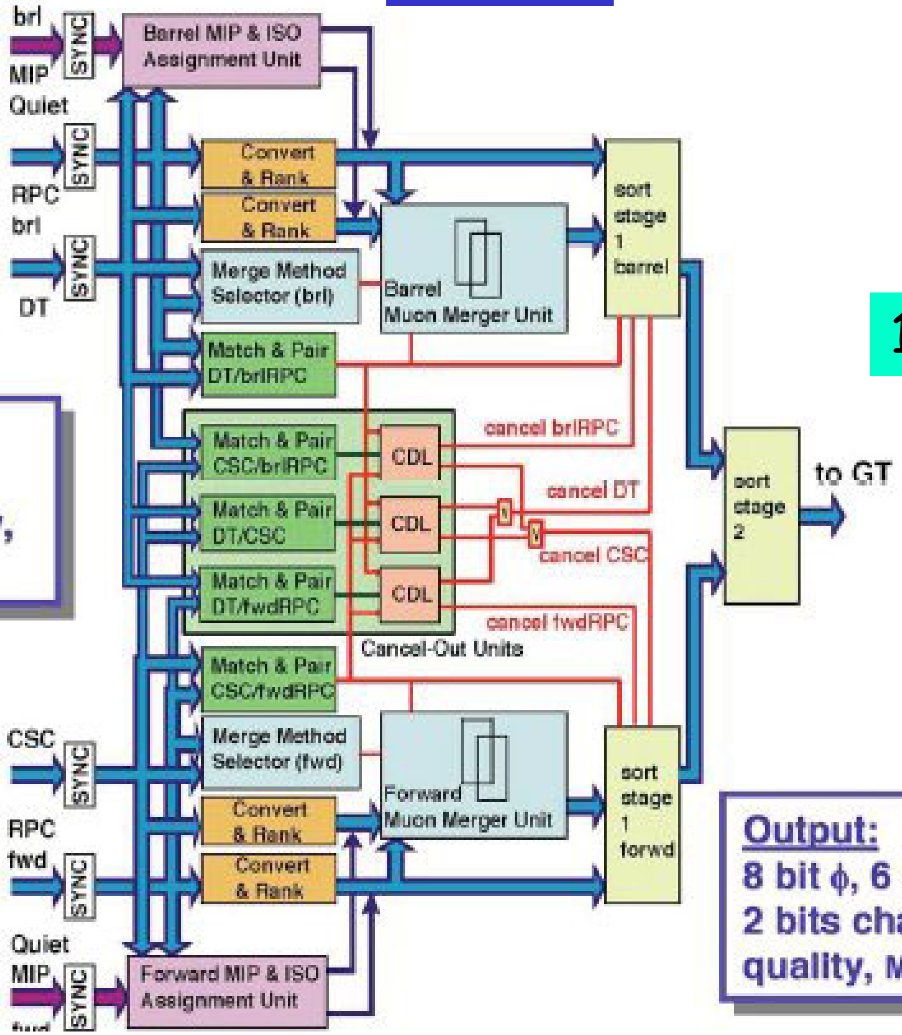
4 μ RPC brl

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



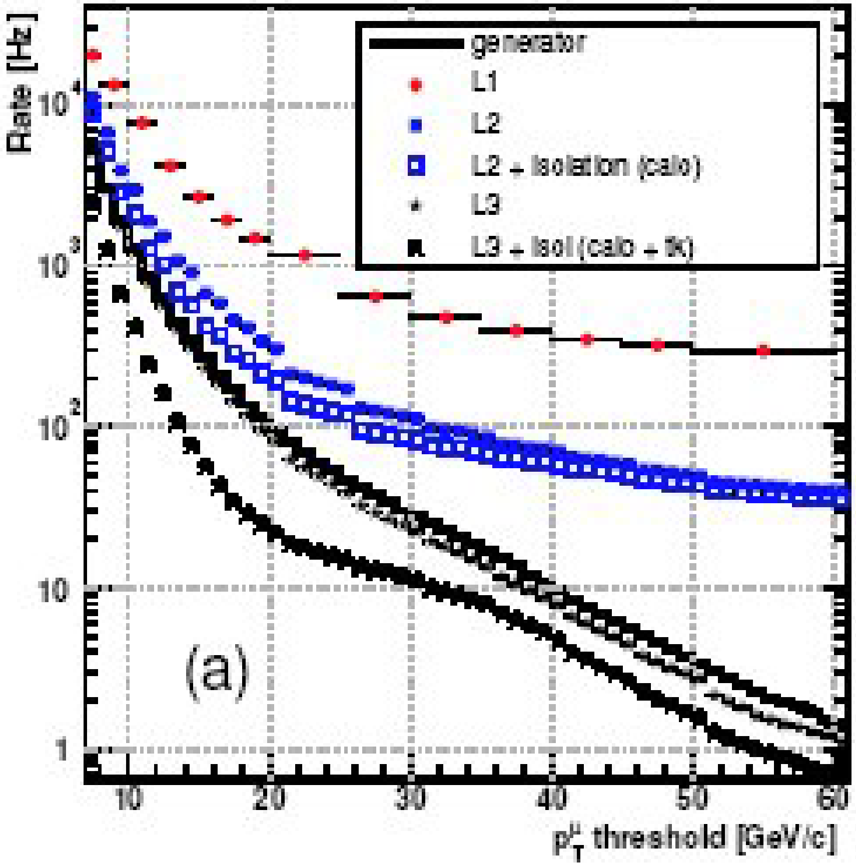
16→4 candidates

Best 4 μ

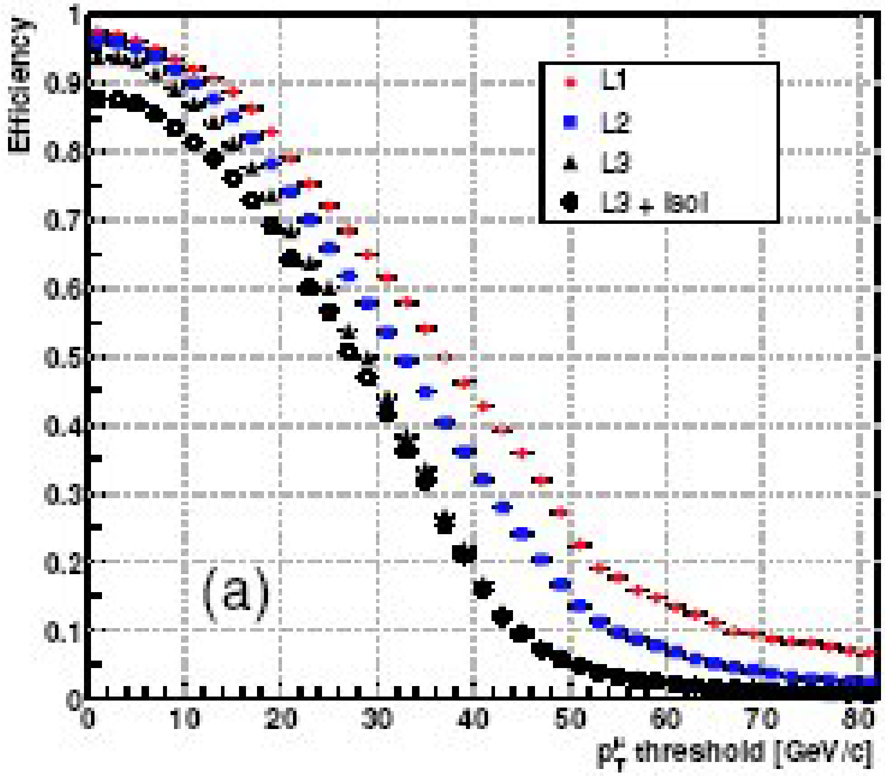
Output:
8 bit ϕ, 6 bit η, 5 bit p_T,
2 bits charge/synch, 3 bit
quality, MIP bit, Isolation bit

CMS Muon ID(3)

10^{33}



Combined mu-ID at LVL3



Rate against Efficiency (W decay)

Muon trigger and ID summary

- Instrumental BG : showers debris, random (n-induced) hits

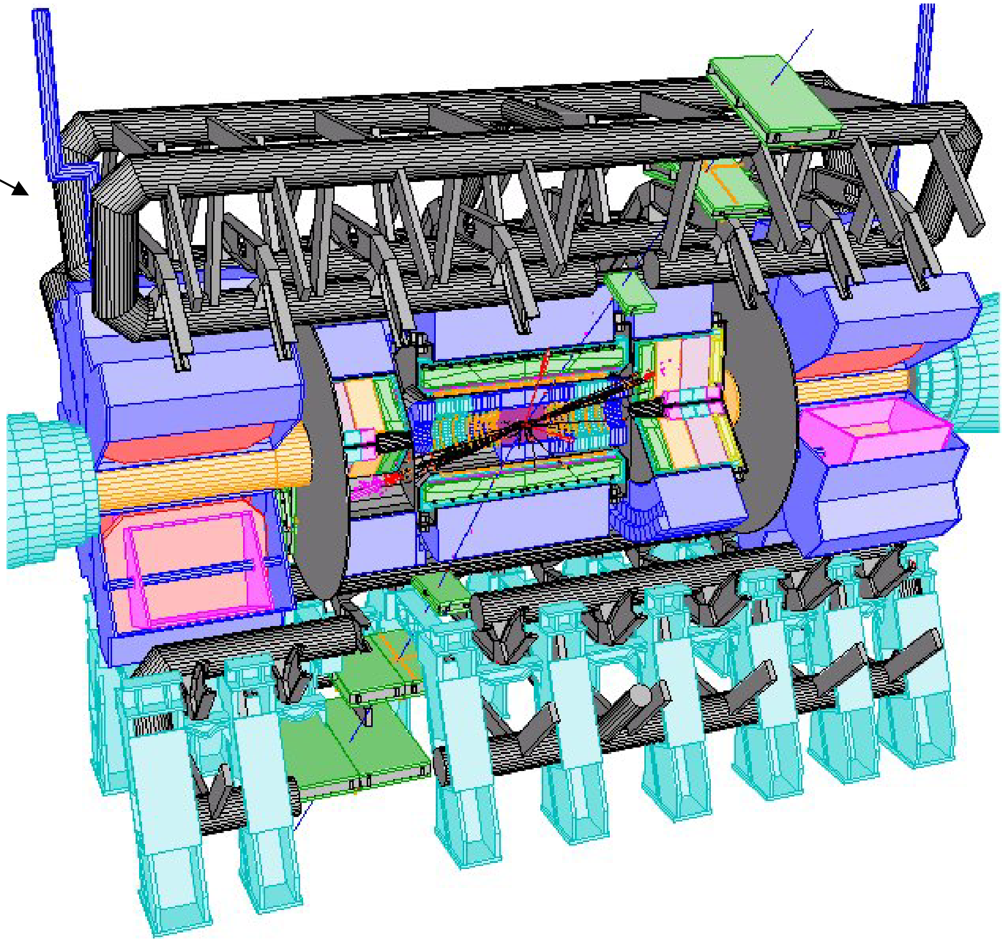
- LVL1 rate dominated by real muons

- Fast pattern recognition needed

- Final rate strongly linked to threshold

- Final Strategy depends on Luminosity/Physics
  - low L (B physics threshold down to ~6 GeV/c desirable)
  - high L threshold down to 20 GeV/c p_T needed

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

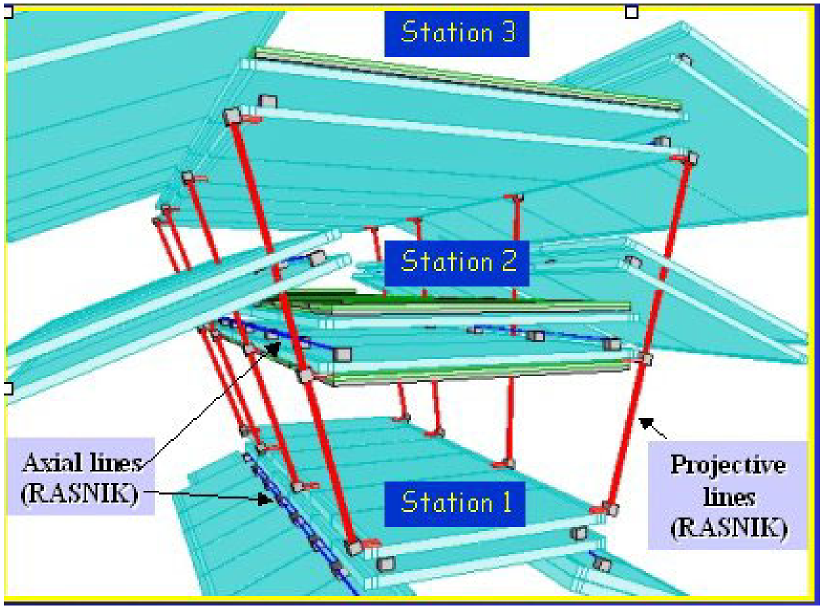
- cold test first coil just started
- All 8 coils assembled in pit march 05

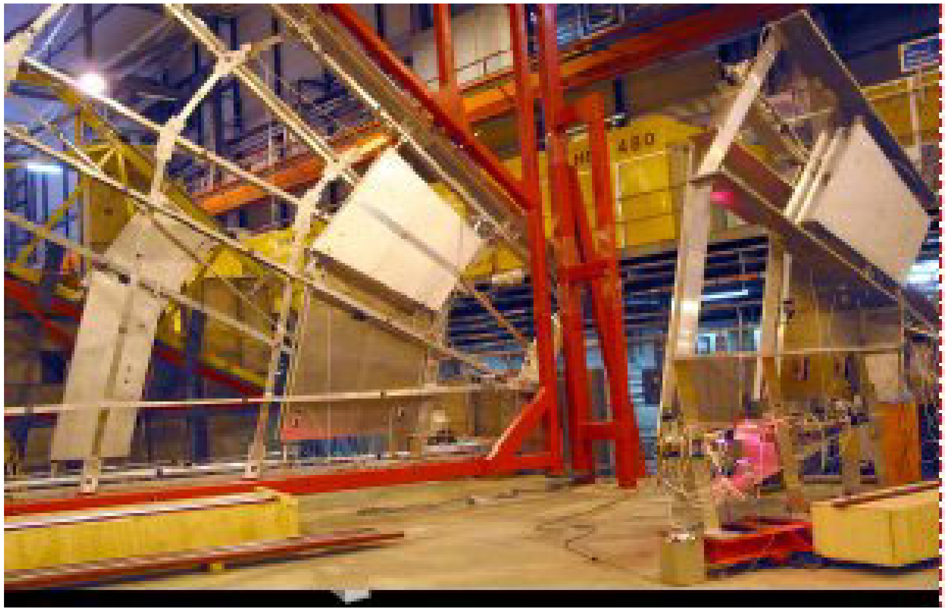
16 double pancake ready

Cryostat vacuum vessel,

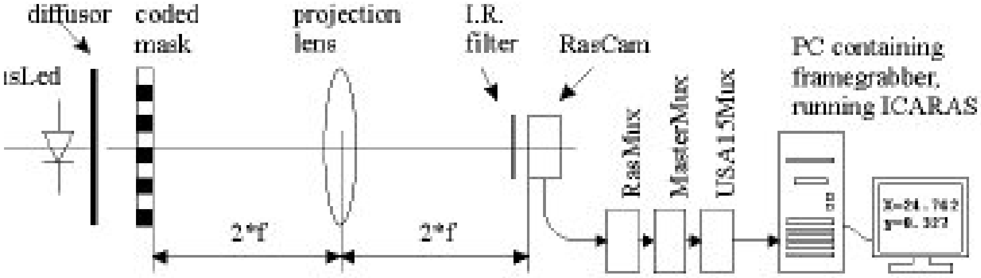
all delivered

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 with tracks and sensors

CMS solenoid

- Main parameters: 4 Teslas, 7m diameter, 15 m length, 2.5 GJ stored
- Coil is made of 5 modules (CB-2 →CB+2),each with 4 layers
- Cold test of complete coil on surface : mid 05

Winding of CB -2

CMS : DT module insertion