Tracking@LHC

- Introduction and basic concepts
- The challenge of tracking at LHC.
- ATLAS and CMS.
- Where we are now
- The next challenges: the alignment, the material, the pilot run
- New ideas for the future: L1 tracker trigger.

The challenge of tracking at LHC

Repeat in the most hostile hadronic environment (high luminosity, high multiplicity of charged tracks, high radiation flux) the success obtained with the sophisticated tracking systems introduced at LEP and the Tevatron Collider.

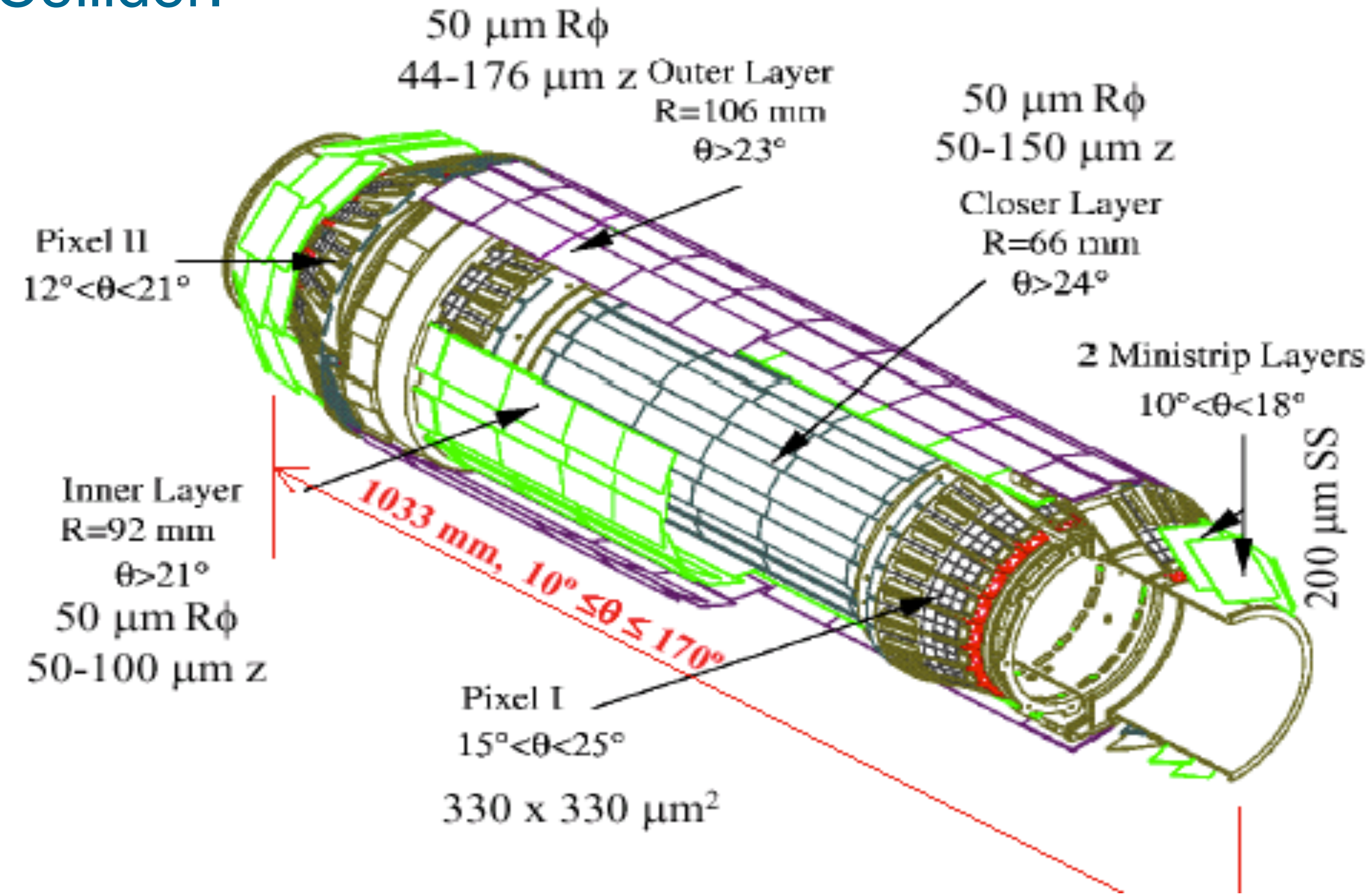
Delphi

Micro-vertex

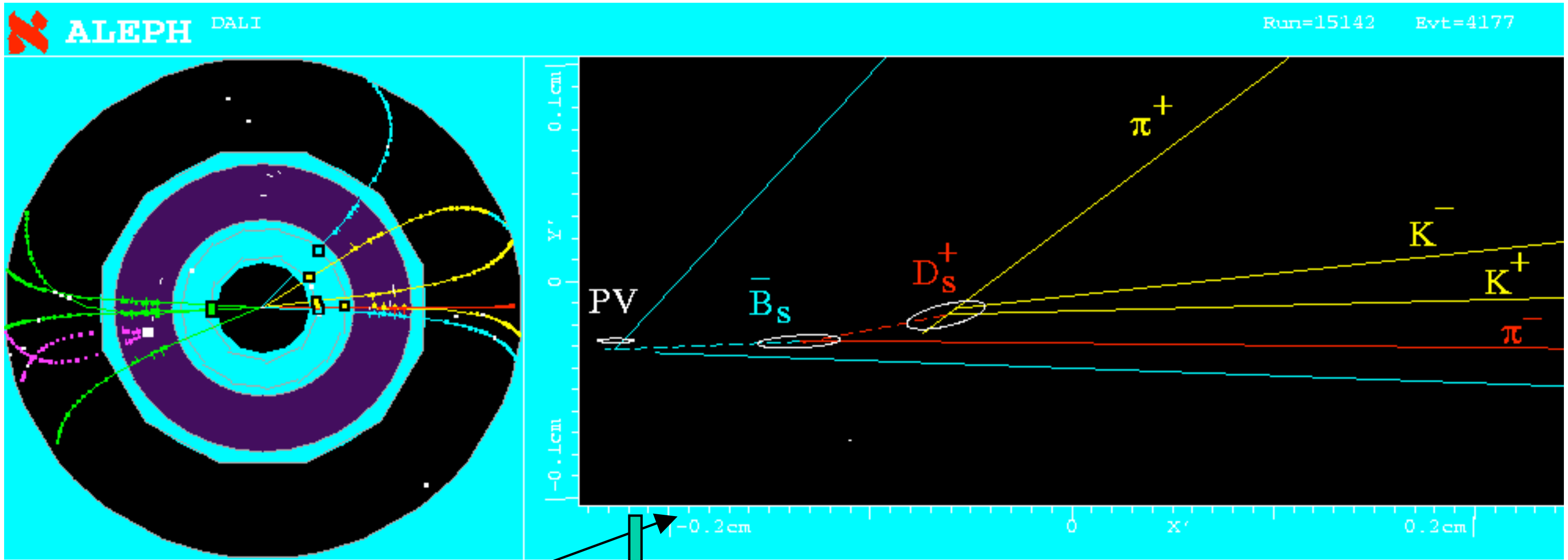
Detector

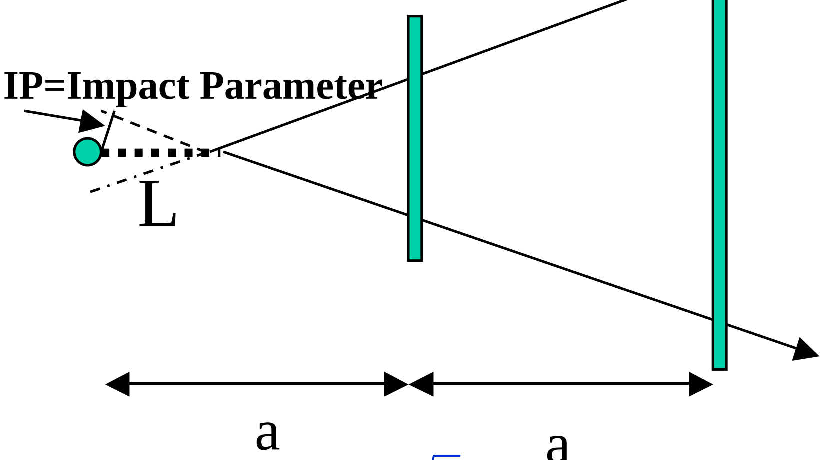
174 k μstrips

1.3 M pixel



Aleph: the importance of the impact parameter





$$\Delta IP \approx \sqrt{5}\sigma$$

$$\Delta IP << IP \Rightarrow \sigma << c\tau / \sqrt{5}$$

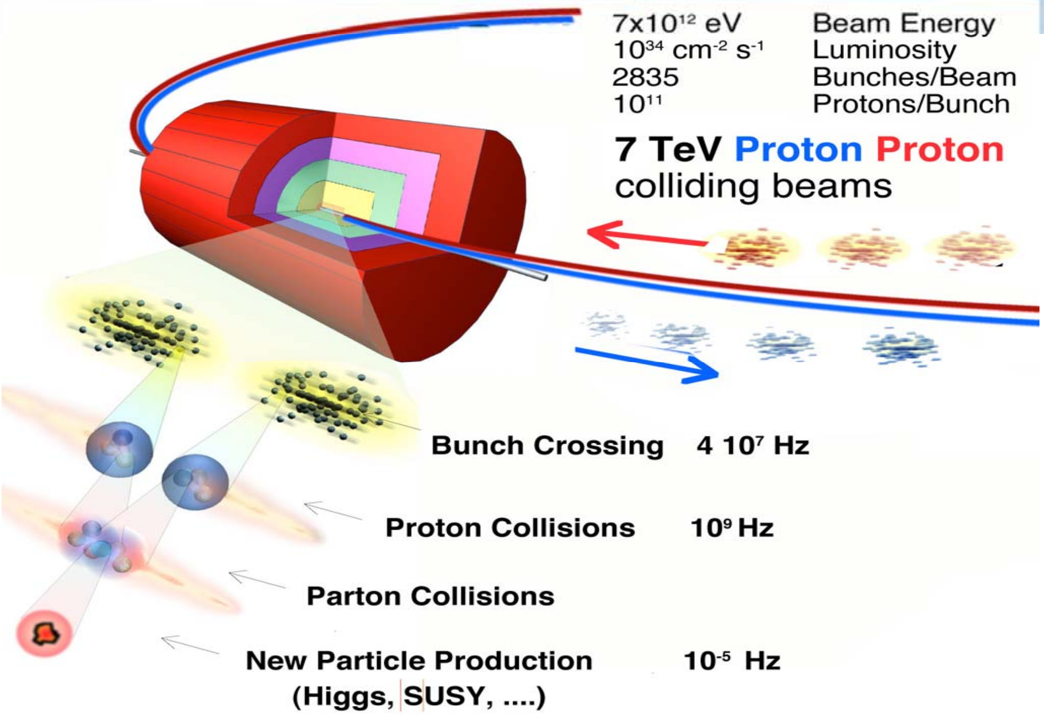
$$IP \approx L \cdot \frac{1}{\gamma} \approx c\tau\gamma \cdot \frac{1}{\gamma} = c\tau$$

σ spatial resolution

$c\tau$ (B) ~ 500 μm

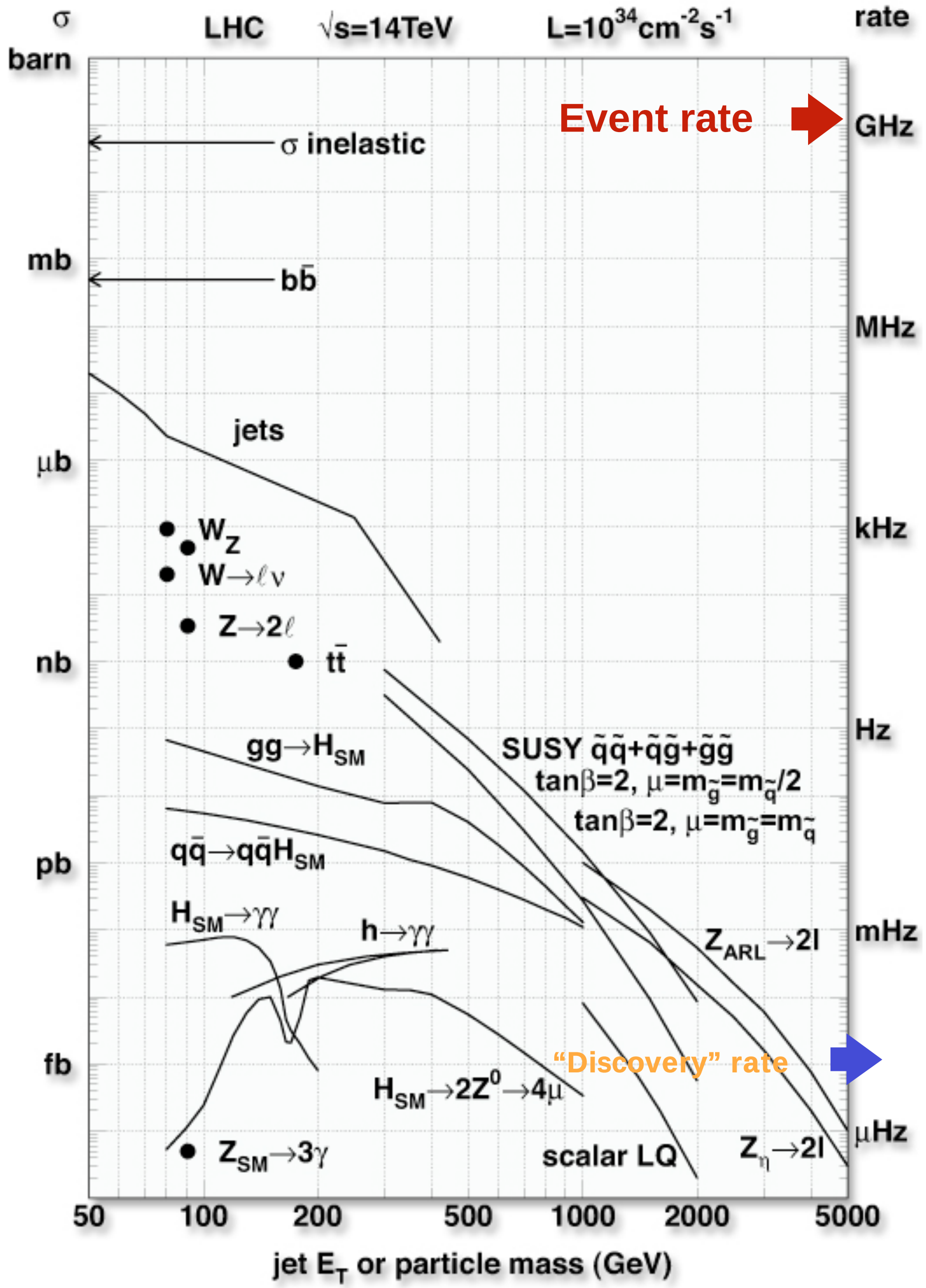
$c\tau$ (τ) ~ 100 μm

LHC main parameters



Collision frequency	40 MHz
Event frequency	~10^9 Hz
Max LV1 Trigger	100 kHz
Event size	~1 Mbyte
Readout network	1 Terabit/s
#livelli di trigger	2
Rejection factor %	99.9997% (100 Hz from 40 MHz)
Dead-time	~ %
Event selection:	~$1/10^{13}$

LHC



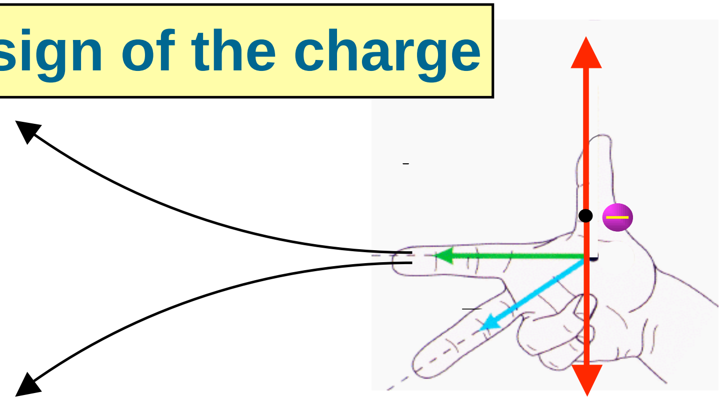
- σ_{INE}=100mb implies $R_{INE}=10^9$ ev/s;
- 25 inelastic events per crossing
  20 MB events per crossing
- About 1000 soft tracks per crossing (+loopers due to the solenoidal field)
- Very difficult pattern recognition
- Detectors and electronics capable of single bunch crossing identification (25ns) and radiation resistant.

Basic tracking concepts

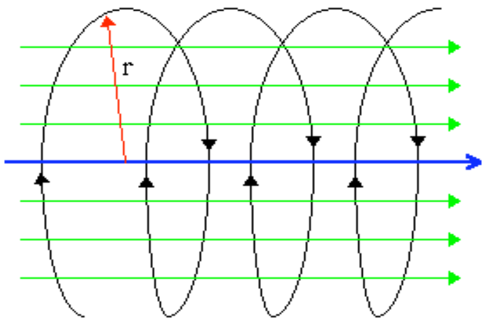
Very useful lectures by F. Ragusa
http://www.le.infn.it/lhcschool/talks/Ragusa.pdf

Tracking means reconstruction of charged particles trajectory to perform several measurements

the sign of the charge

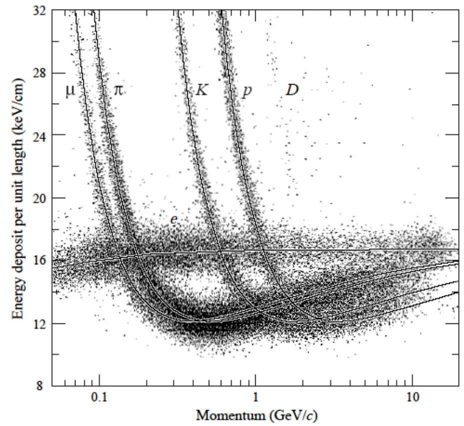


momentum (magnetic field)



$p = 0.3 \cdot B \cdot R$

particle ID (mass), not necessarily with the same detector

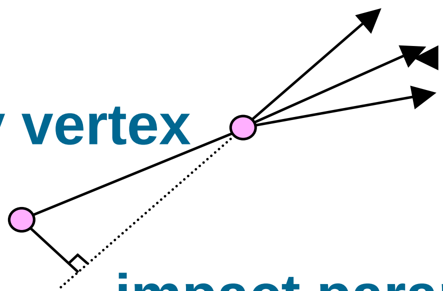


$p = m_o \gamma \beta$

vertexing

secondary vertex

primary vertex



impact parameter

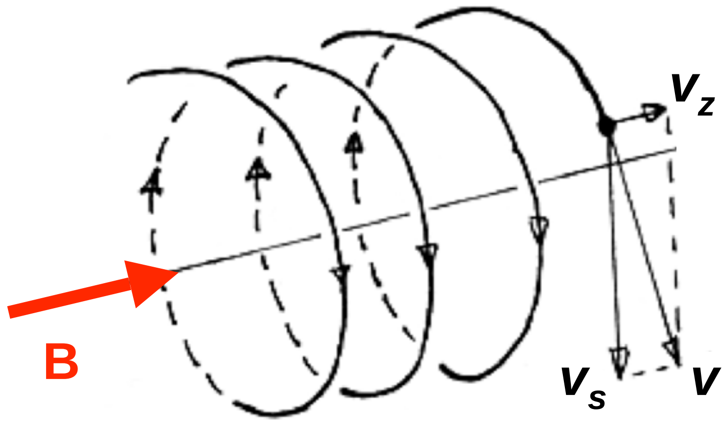
Basic concepts: motion in Magnetic Field

In a magnetic field the motion of a char-ged particle is determined by the Lorentz force. For homogenous B (solenoidal field) the trajectory is given by an helix

$$x(s) = x_o + R\left[\cos\left(\Phi_o + \frac{hs\cos\lambda}{R}\right) - \cos\Phi_o\right]$$

$$y(s) = y_o + R\left[\sin\left(\Phi_o + \frac{hs\cos\lambda}{R}\right) - \sin\Phi_o\right]$$

$$z(s) = z_o + s\sin\lambda$$

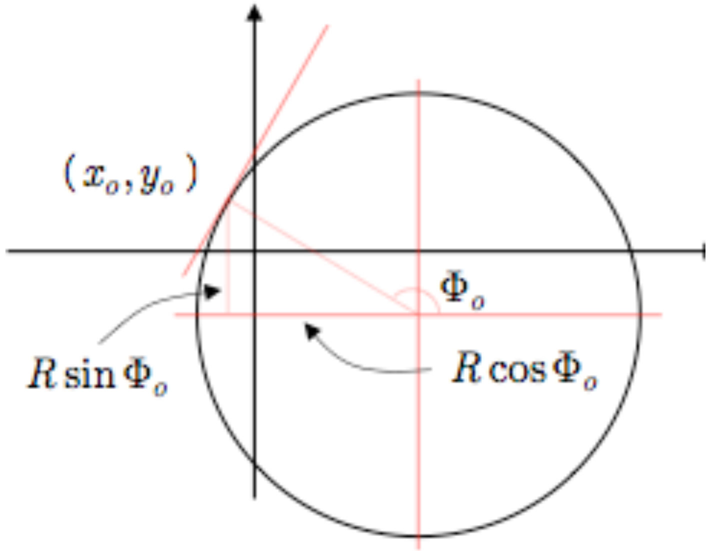


Where λ is the dip angle and h=±1 is the sense of rotation.

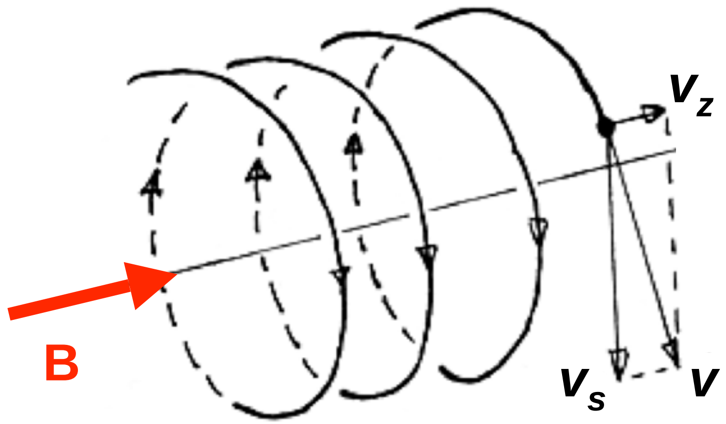
The projection of the helix

In the transverse plane (x,y) is a circle

$$(x - x_o + R\cos\Phi_o)^2 + (y - y_o + R\sin\Phi_o)^2 = R^2$$



Basic concepts: radius of curvature



$$R(m) = \frac{p_\perp(GeV)}{0.3B(T)}$$

Important to dimension the tracking system and to calculate the number of measuring points for a given transverse momentum (cut-off in pt).

Important also to calculate the average radius of the “loopers”. Low momentum particles carry no basic information on the physics of the hard processes while they might jeopardize pattern recognition by increasing the occupancy in the innermost layers.

For p_t<300MeV

<25cm in CMS (4T) pixel only

<50cm in ATLAS (2T) pixel and Si-microstrips

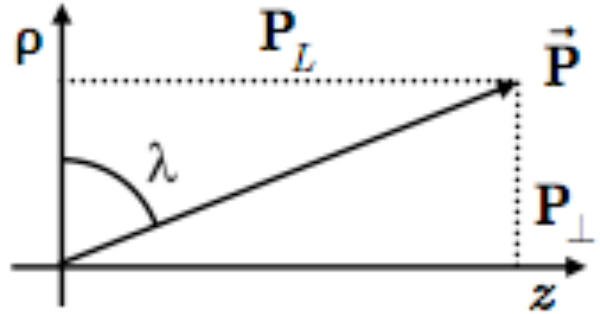
Basic concepts: momentum measurement

In hadronic colliders we want to measure mainly the transverse momentum since elementary processes happens among partons that are not at rest in the laboratory (momentum conservation only in the transverse plane)

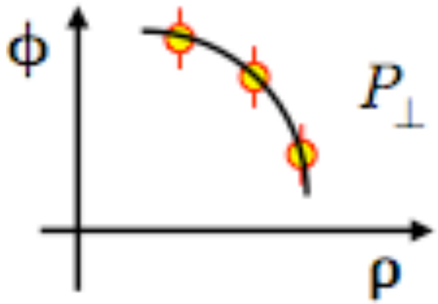
The momentum of the particle is projected along two directions

$\mathbf{P}_{\wedge}$

$$P_{\wedge} = P\cos l = 0.3\,BR$$

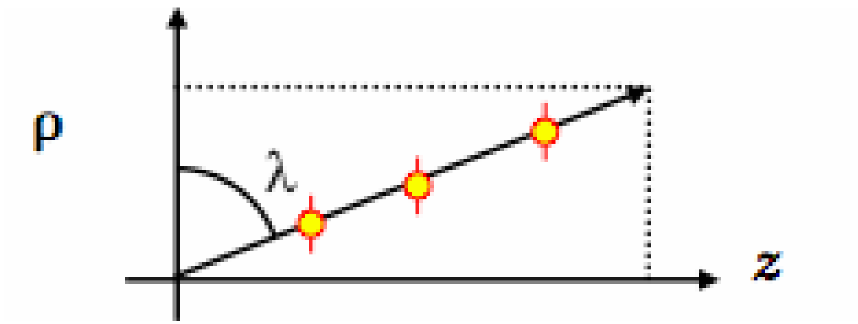


in the $\rho - \phi$ plane we measure the transverse momentum

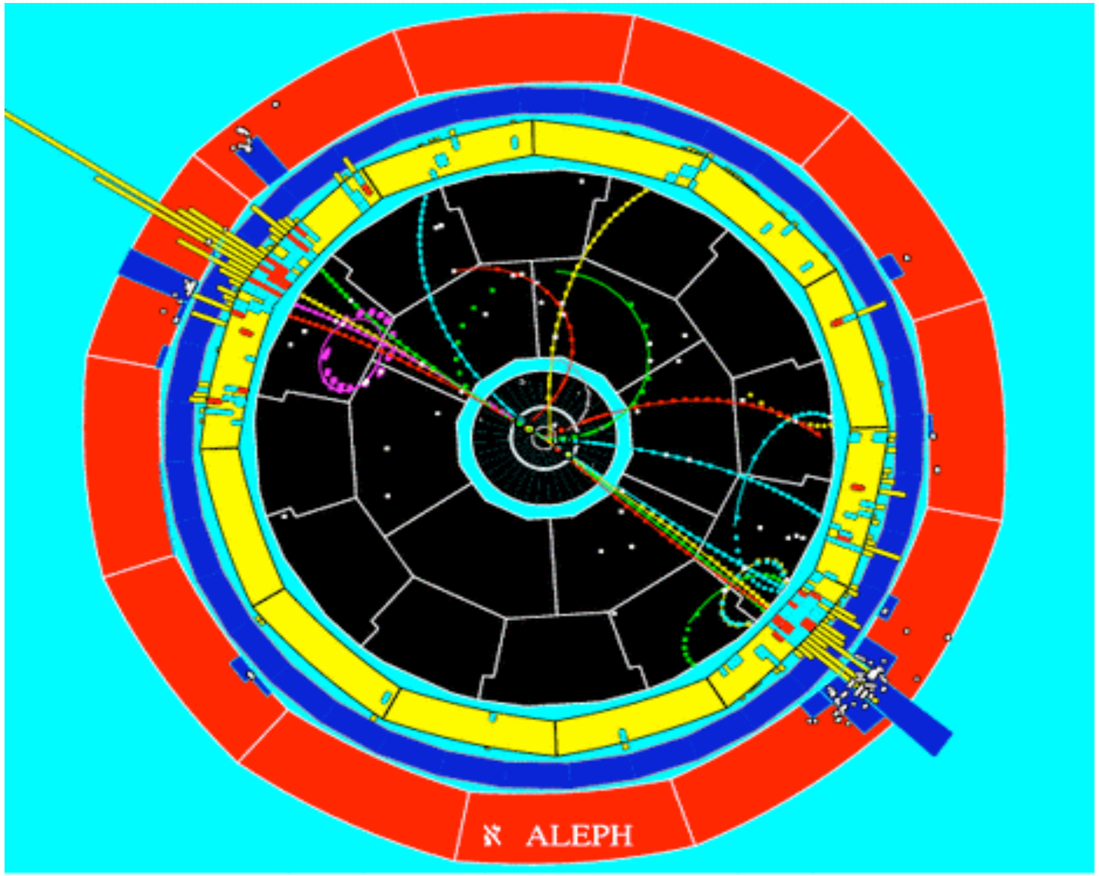


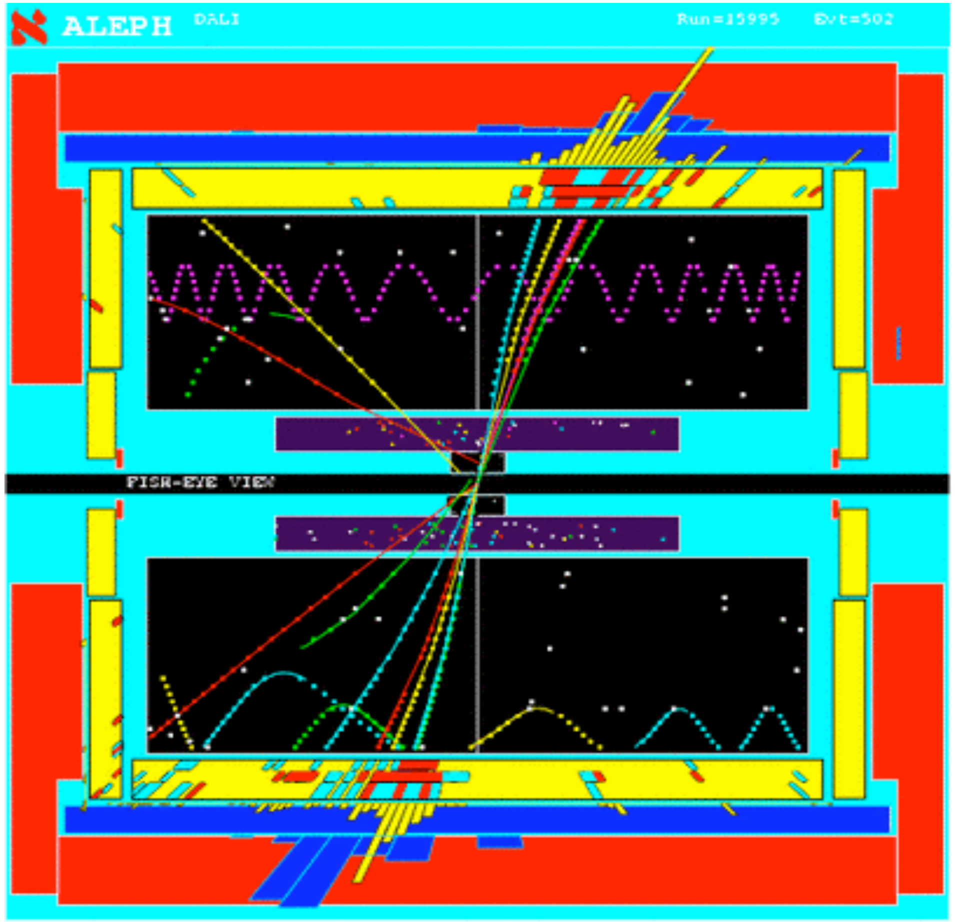
$$P_\perp = P\cos\lambda = 0.3BR$$

in the $\rho - z$ plane we measure the dip angle λ

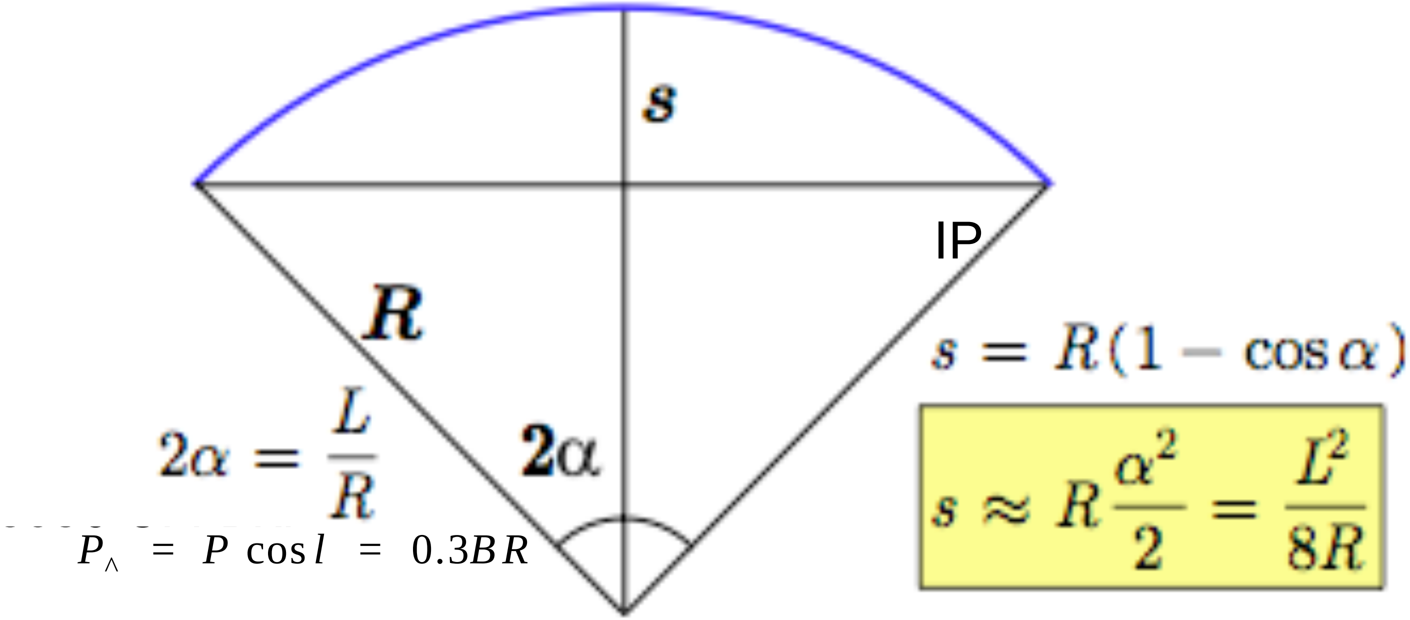


Track reconstruction in Aleph





Basic concepts: sagitta measurement



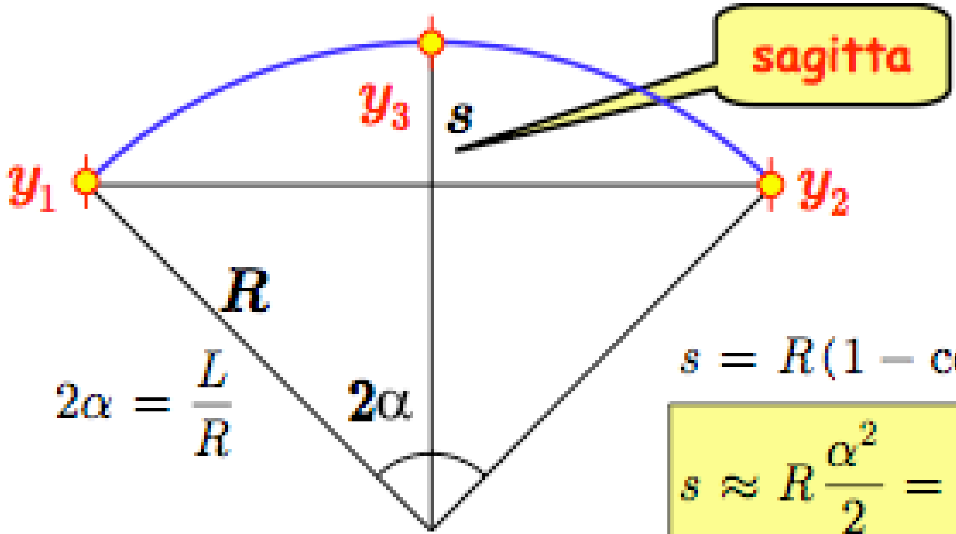
A few examples assuming a track length of 1m and magnetic fields of 2 and 4T

P_t=1 GeV	R(2T)=1,67m	R(4T)= 0,83m	s(2T)=75mm	s(4T)= 150mm
P_t=10 GeV	R(2T)=16,7m	R(4T)= 8,3m	s(2T)=7,5mm	s(4T)= 15mm
P_t=100 GeV	R(2T)=167m	R(4T)= 83m	s(2T)=0,75mm	s(4T)= 1,5mm
P_t=1 TeV	R(2T)=1670m	R(4T)= 830m	s(2T)=0,075mm	s(4T)= 0,15mm

Momentum resolution

Since the transverse momentum is proportional to the bending radius, the momentum resolution depend on the accuracy in measuring R

$$R = \frac{p}{0.3B} \qquad \frac{\delta p}{p} = \frac{\delta R}{R}$$



$$2\alpha = \frac{L}{R}$$

$$s = y_3 - \frac{y_1 + y_2}{2} \qquad \delta s = \sqrt{\frac{3}{2}}\delta y \sim \delta y$$

$$s = R(1 - \cos\alpha)$$

$$s \approx R\frac{\alpha^2}{2} = \frac{L^2}{8R}$$

$$|\delta s| = \frac{L^2}{8R}\frac{\delta R}{R} \sim \delta y \qquad \frac{L^2}{8R}\frac{\delta p}{p} = \delta y$$

$$\frac{\delta p}{p} = \frac{8R}{L^2}\delta y \qquad \frac{\delta p}{p} = \frac{8p}{0.3BL^2}\delta y$$

$$\frac{\delta p}{p^2} = \frac{8\delta y}{0.3BL^2}$$

The error in measuring momenta is proportional to momentum, decreases linearly with the accuracy of the measurements and is inversely proportional to the bending power **BL^2**. A big lever arm is the most effective tools. Beam spot and last layers are crucial.

Momentum Resolution

Useful formulas for practical purposes

$$\frac{\Delta p}{p} \approx 0.25 \left(\frac{\Delta s}{100\ \mu m}\right)^1 \left(\frac{1m}{L}\right)^2 \left(\frac{1T}{B}\right)^1 \left(\frac{p}{100\,GeV}\right)$$

When N measurement points are distributed along the trajectory.

$$\frac{\delta p}{p^2} = \frac{\sigma}{0.3BL^2}\sqrt{4C_N}$$

$$C_N = \frac{180N^3}{(N-1)(N+1)(N+2)(N+3)}$$

For N>10 C_N= 180/N+4.

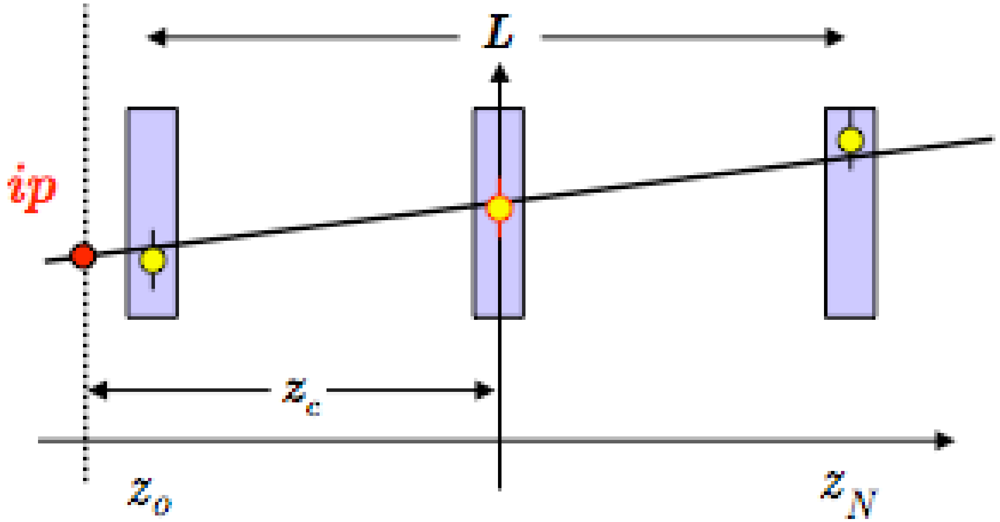
The dependance on the number of measurements is weak. Still **BL^2** dominates
Unfortunately solenoidal magnets with large B and large L are very expensive.
The cost scales with the stored energy. And also the tracking systems are not cheap.

Cost of a solenoidal magnet (M$)=0.523[(E/1 MJ)]$^{0.662}$
$E= B^2V/2\mu_o$ ($V=\pi L^2 l$) where L is the radius and l is the length of the solenoid)

The CMS solenoid stores 2.6×10^9 Joule and costs about 100M$

Impact parameter resolution and sign of the charge

Simple considerations lead to an error on the impact parameter dominated by the precisionof the first measuring layers, their distance from the interaction point and the precision on the meaurement of the slope given by the entire tracker



$$\sigma_{ip}^2 = \sigma_a^2 + z_c^2\sigma_b^2$$

Using typical resolution of about 10 μm at a few cm distance from the beam line 10-15 μm ip resolution are easily achievable

The maximum momentum which allows the identification of the charge depends again on BL^2.

$$p < \frac{0.3BL^2}{3\sqrt{4C_N}\sigma_y}$$

Basic parameter for LHC trackers

- Optimal momentum resolution (Higgs→4μ; better cuts on the Z mass and use of invariant mass in general to reduce the irreducible backgrounds).

- **$\Delta p_t/p_t$=0.2-0.4 p_t (TeV)**

- High efficiency in reconstruction of tracks both isolated (muons and electrons) and within high transverse energy jets. (muon trigger validation, isolation cuts for single photons (H→γγ) and tracks in general).

- **ε>95% for p_t>2GeV**

Basic parameters for LHC trackers

- Good impact parameter resolution (10-20μm)

Reconstruction of different primary vertices within the same high luminosity event. Tagging capability for b and tau jets.

- Radiation resistance: 10 years of running (1.5-2.4x10^{14}n/cm^2)
- Amount of material kept under control: to minimize photon conversion and secondary interactions within the tracker itself.
- Costs within the maximum available budget: 70-80MCHF.

The approach

Silicon microstrip detectors allow a very good point resolution (10-30 micron) that coupled to lever arms around 1m in solenoidal field of 2-4T would allow an adequate momentum resolution, good impact parameter resolution for b-tagging and excellent measurement of the charge up to 1TeV and beyond.

Single bunch crossing resolution is feasible in silicon (collection time <10ns) with fast read-out electronics.

The real challenge is pattern recognition for track reconstruction: the high density of tracks typical of the inner regions of high luminosity hadronic colliders can be tackled with extreme segmentations both in r-phi and r-z : pixel detectors and silicon microstrip modules.

Pattern Recognition = high granularity.

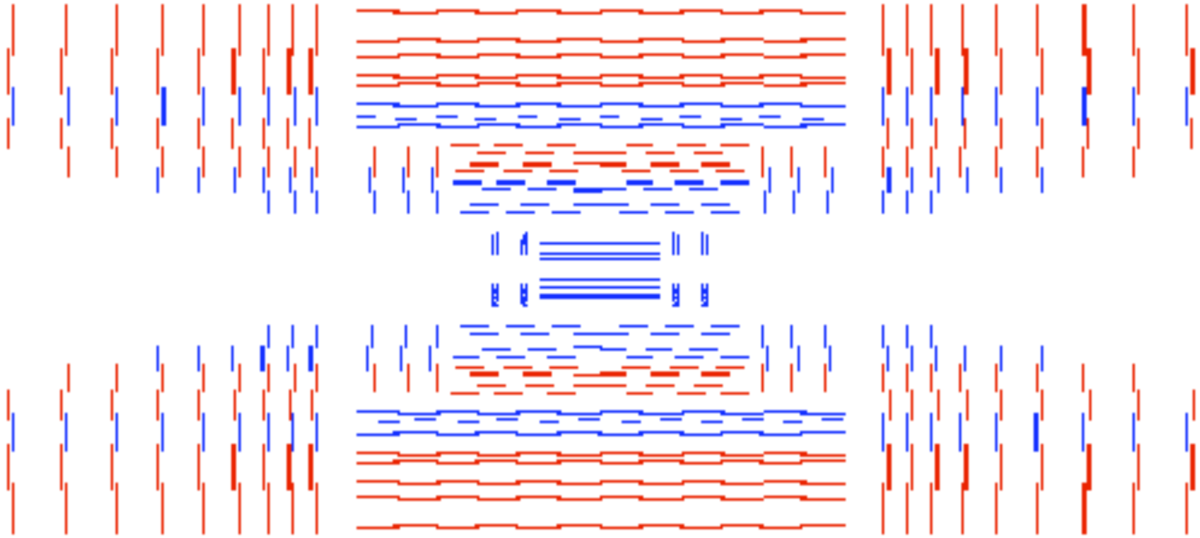
Let's consider a large drift chamber 1m radius and 6m length. Let's put a wire every 3mm (impossible to do in real life, wire tension, sagitta etc); 300k electronics channels and 300 detection planes; assume also that we have found a gas so fast to collect all charge in 25ns.

With this chamber we can reasonably afford pattern recognition problems for events producing 30 charged tracks every 25ns (Average occupancy 300layersx30 tracks/300K channels= 3%).

If now every 25ns you produce 1000 charged tracks you can maintain the same reconstruction efficiency only by SEGMENTING in Z the CHAMBER (1 chamber 6mlong→ 30 chambers 20cm each one).

Is the basic idea we had for the CMS Tracker. The segmentation increases in the most congested regions: 20cm-10cm-1cm

Conceptual design of the CMS tracker



II radial region: 25cm<r<110cm :$10^{13}cm^{-2}<\Phi<10^{14}cm^{-2}$

Radiation resistance silicon microstrip detectors

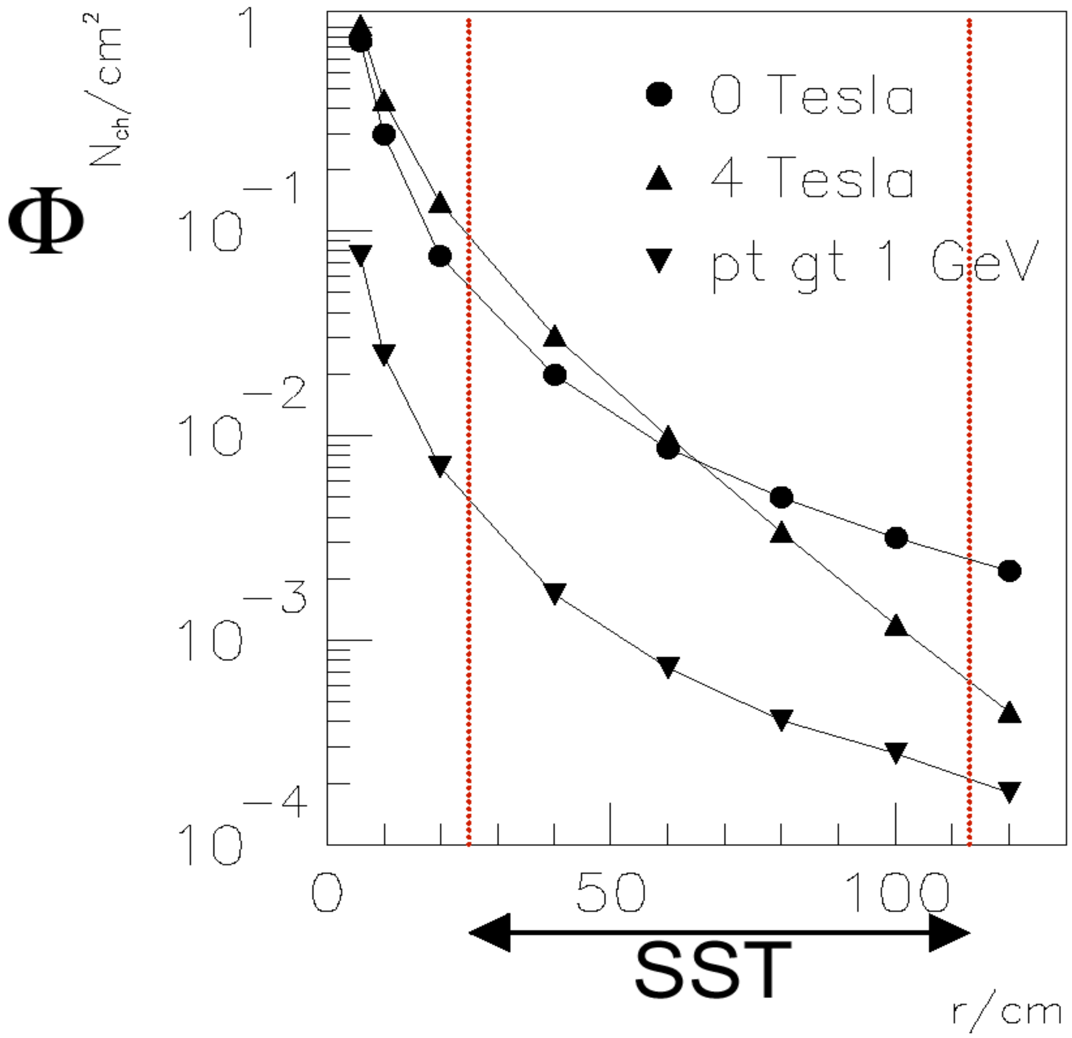
- Large scale, low cost production of rad-hard detectors ($2x10^{14}n/cm^2$)

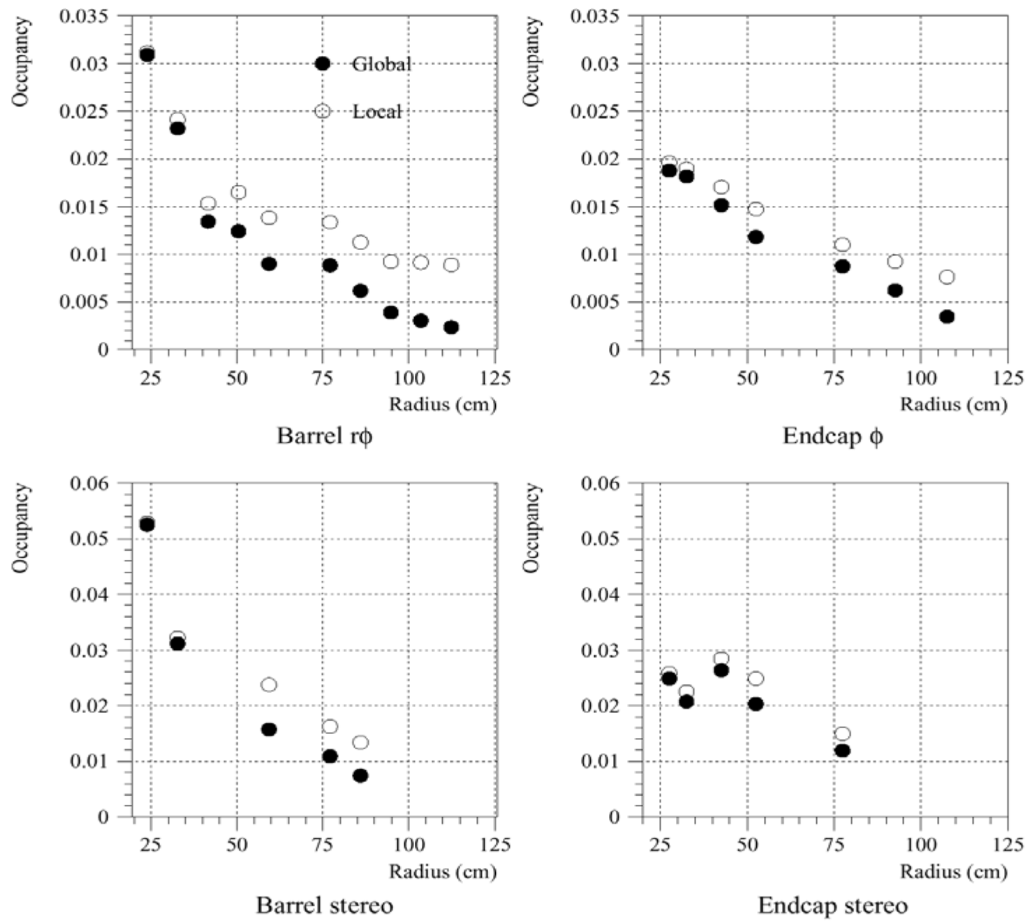
I radial region: 5cm<r<20cm :$10^{14}cm^{-2}<\Phi<10^{15}cm^{-2}$

Pixel detector in hybrid technology

- Development of a pixel detector capable to withstand $10^{15}n/cm^2$

Track occupancy





Primary charged particle densities integrating 20 minimum bias events

Very good idea…. but

•The read-out channels become 30x300K=10M. The silicon is solid and must be precisely held in place; each channel implies power and cooling →material

•Everything must be radiation resistant and detectors available in 1994 were dying after a few tens of krad.

•Cost of 25.000 detectors and 10M electronics channels.
•The cost of non rad-hard detectors was around 4000CHF/sensor; the cost for electronics was quoted between 5 and 10CHF/channel.

•How can we organize to produce 16.000 modules (100-300 modules used in previous vertex detector)

•How can be developed a pixel detector?

Two different strategies

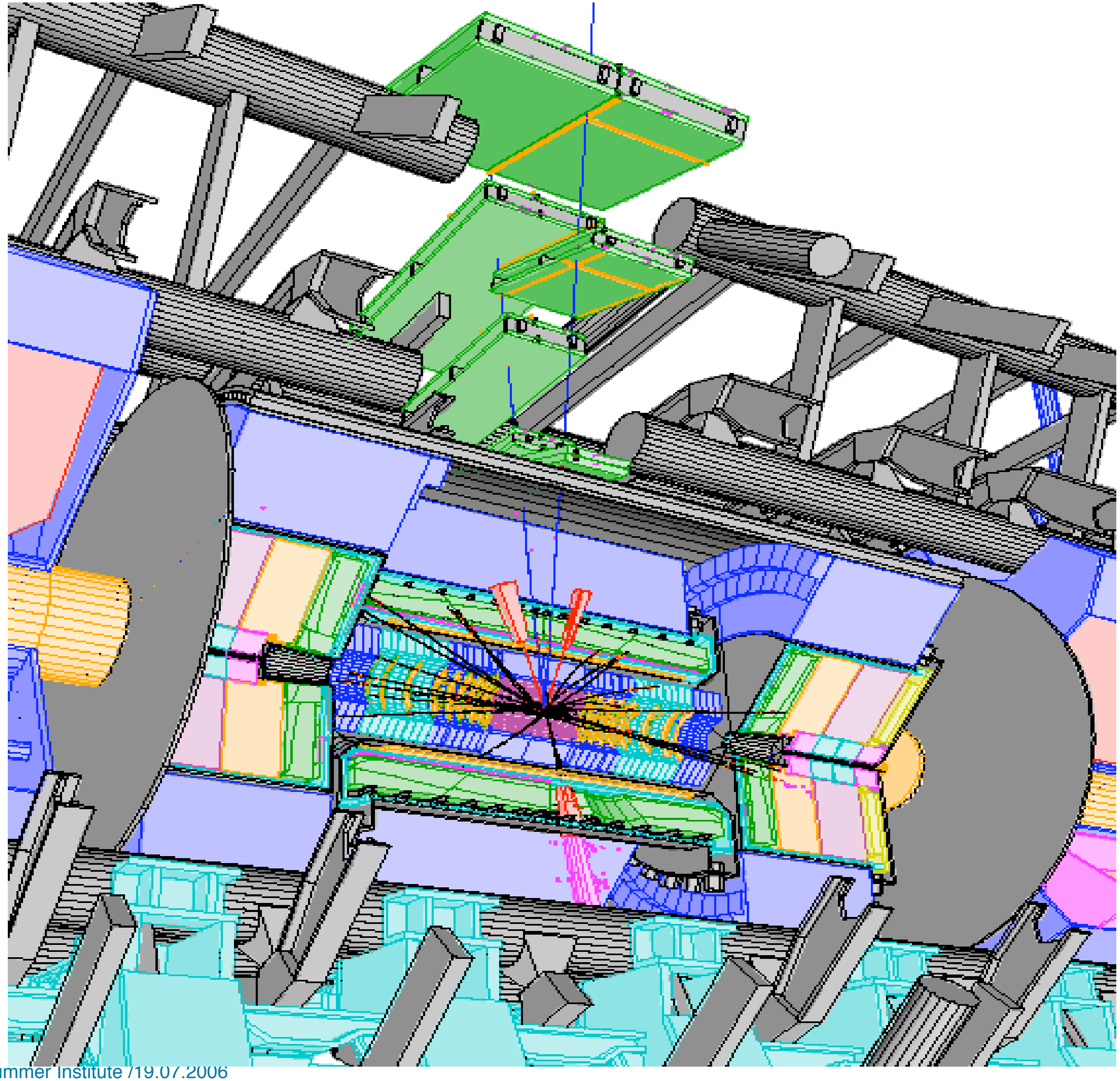
This approach has been followed very aggressively by CMS and the collaboration agreed to build the first full silicon tracker in HEP

- more challenge in terms of technology and costs
- higher performance particularly in pattern recognition

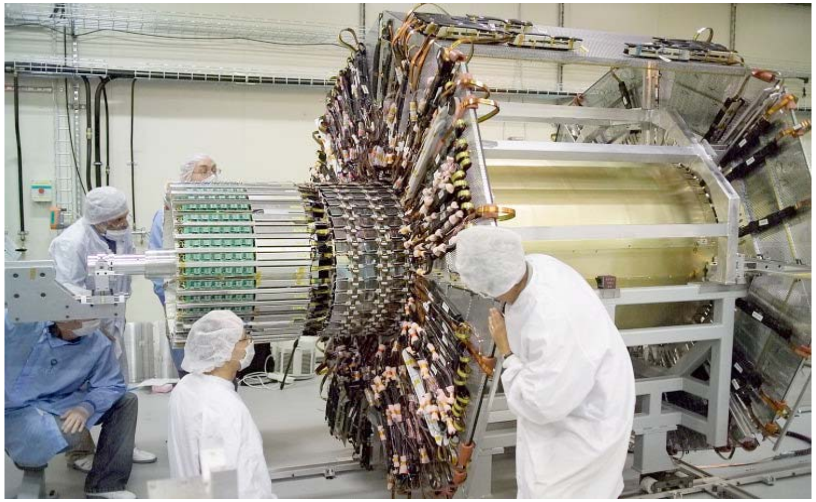
Atlas has adopted a more traditional approach based on a hybrid tracker: pixel and silicon microstrip detectors in the innermost part and a large gaseous detectors in the outer part (straw tubes).

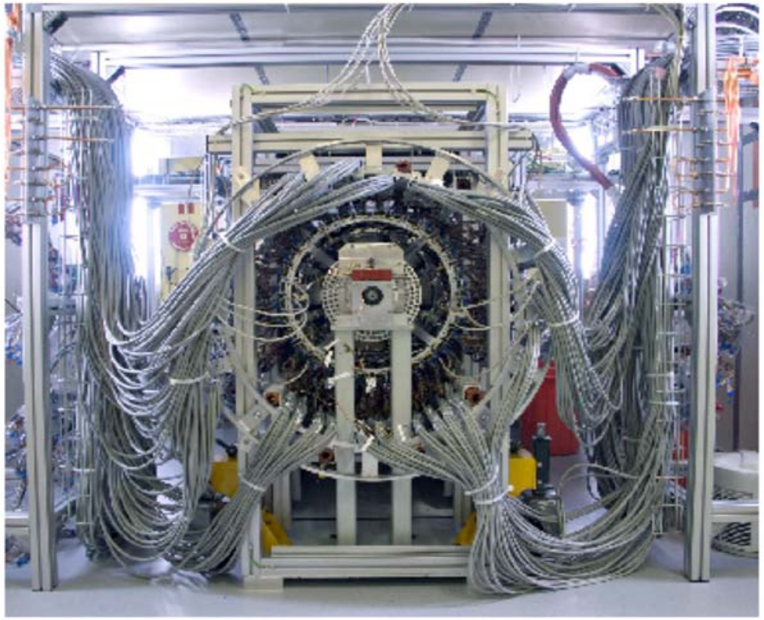
- development of new technologies limited to pixels
- higher risks in terms of performance (high occupancy foreseen in the TRT for the high luminosity run of LHC).

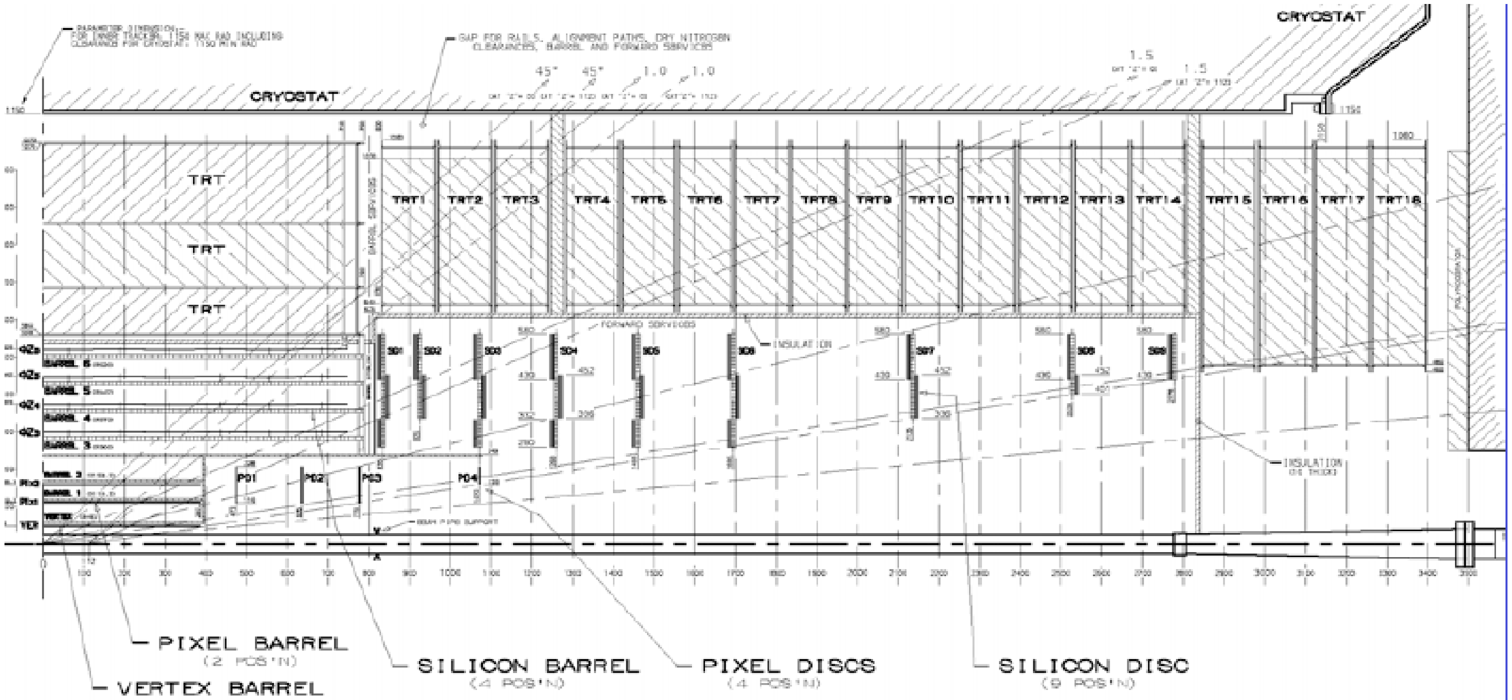
ATLAS



Atlas tracker







The ATLAS tracker

Pixel Detector

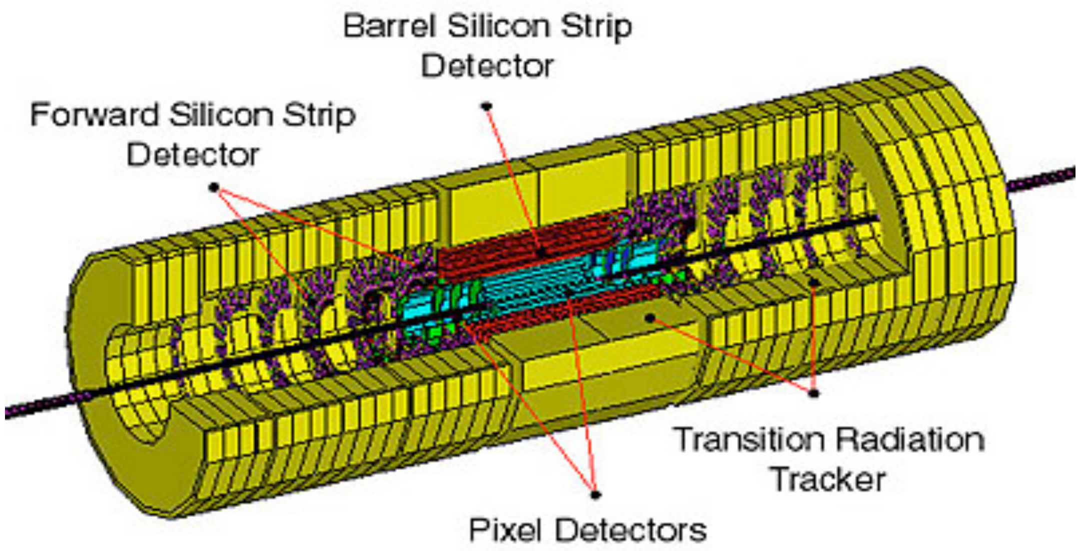
- 3 barrels, 3+3 disks: 80×10^6 pixels
- barrel radii: 4.7, 10.5, 13.5 cm
- pixel size 50×400 μm
- s_{rf}= 6-10 μm s_z = 66 μm

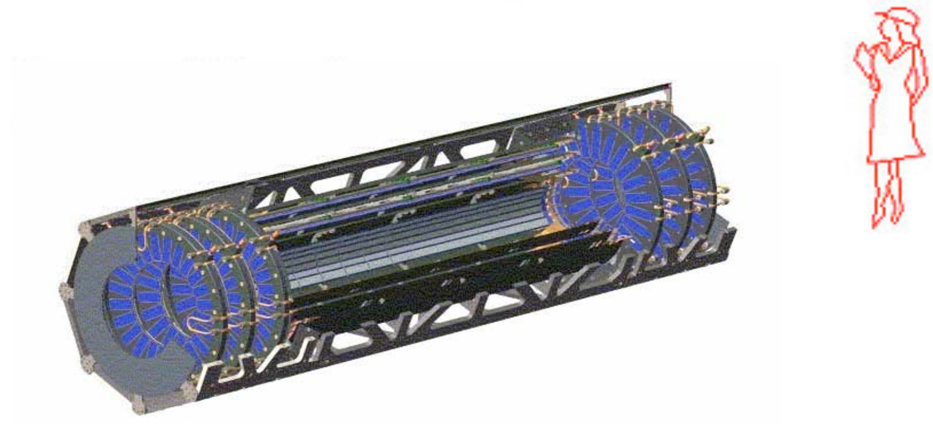
SCT

- 4 barrels, disks: 6.3×10^6 strips
- barrel radii:30, 37, 44 ,51 cm
- strip pitch 80 μm
- stereo angle ~40 mr
- s_{rf}= 16 μm s_z = 580μm

TRT

- barrel: 55 cm < R < 105 cm
- 36 layers of straw tubes
- s_{rf}= 170 μm
- 400.000 channels





Momentum resolution of ATLAS

We can now give a rough estimate of the momentum resolution of the ATLAS tracking systems

TRT: 36 point with σ = 170 μm from 55 cm to 105 cm: as a single point with σ = 28 μm at R_{max} = 80 cm

R_{min} = 4.7 cm, L = 75 cm

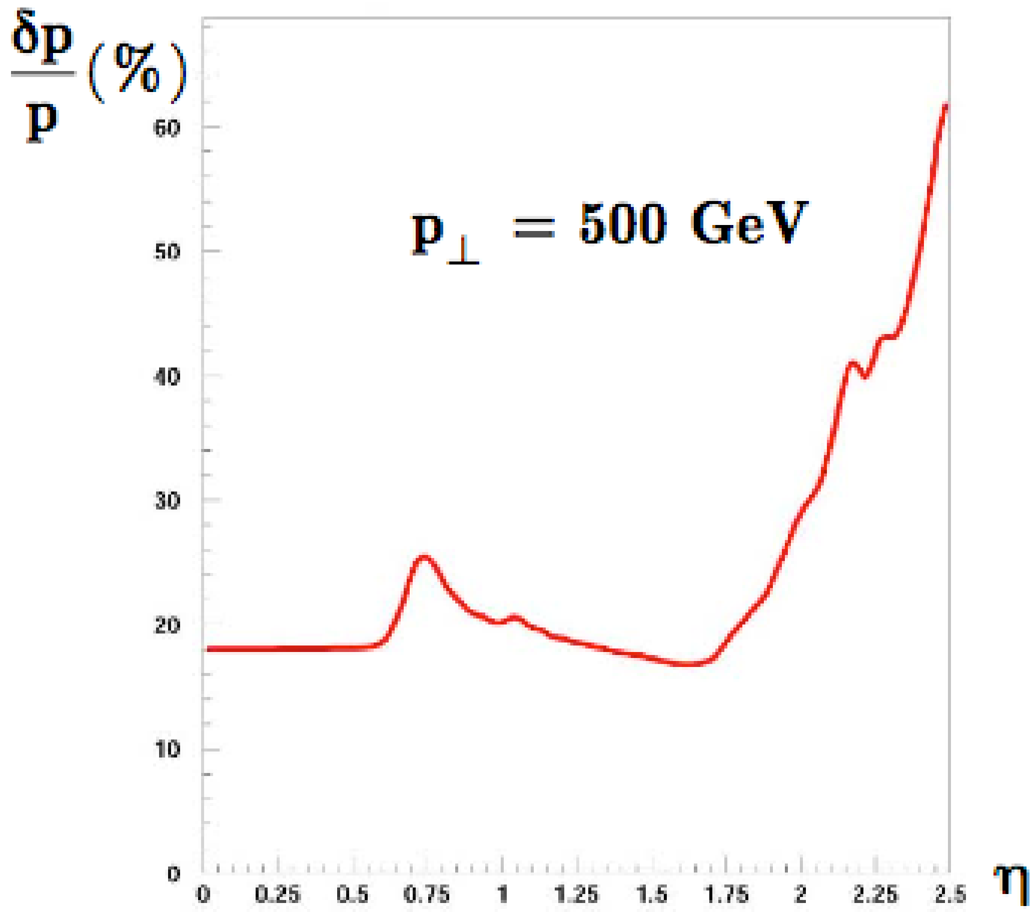
N+1= 3 + 4 + 1 = 8

σ = 12, 16, 28 ~ 20 μm

$$C_N \approx 12 \qquad \sqrt{4C_N} \approx 7$$

$$\frac{\delta p}{p^2} \sim 4 \times 10^{-4} \ GeV^{-1}$$

At 500 GeV $\qquad \frac{\delta p}{p} = 20 \times 10^{-2}$

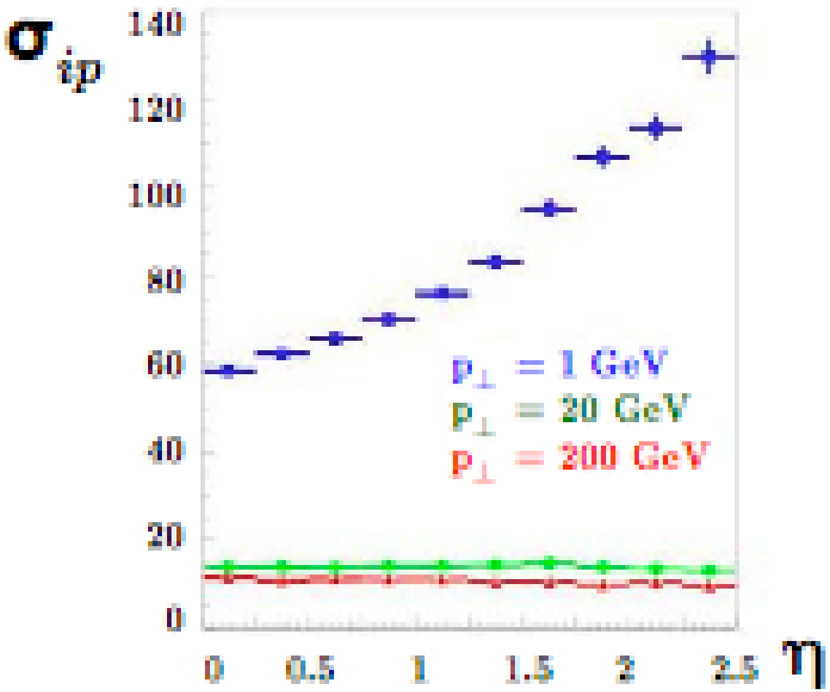


Impact parameter resolution Atlas

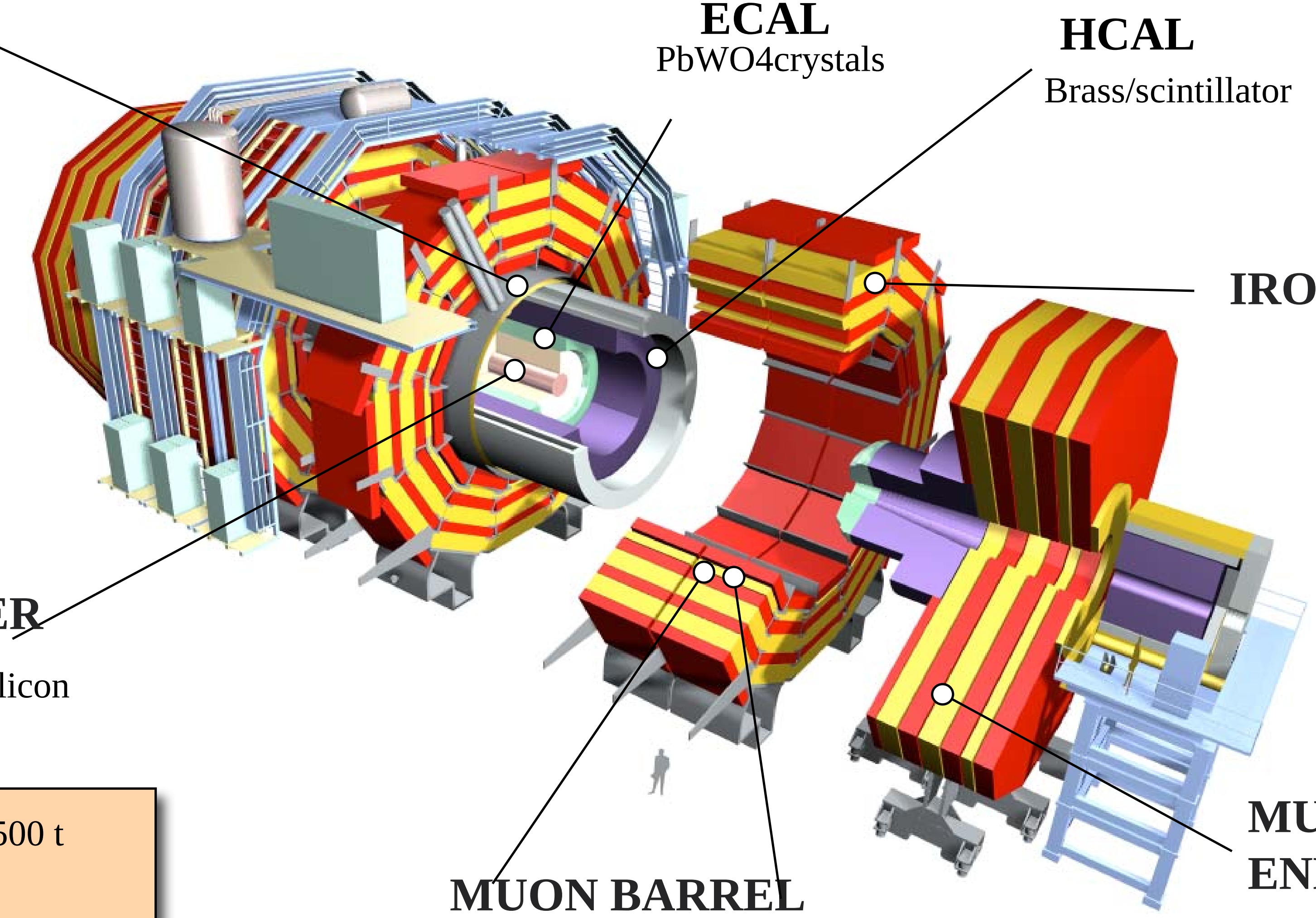
For the ATLAS detector montecarlo studies have shown that the resolutions can be parametrised as

$$\sigma_{ip} = 11 \oplus \frac{73}{p_\perp \sqrt{\sin\theta}} \quad [\mu m]$$

$$\frac{\delta p_\perp}{p_\perp^2} = 0.00036 \oplus \frac{0.013}{p_\perp \sqrt{\sin\theta}} \quad [GeV^{-1}]$$



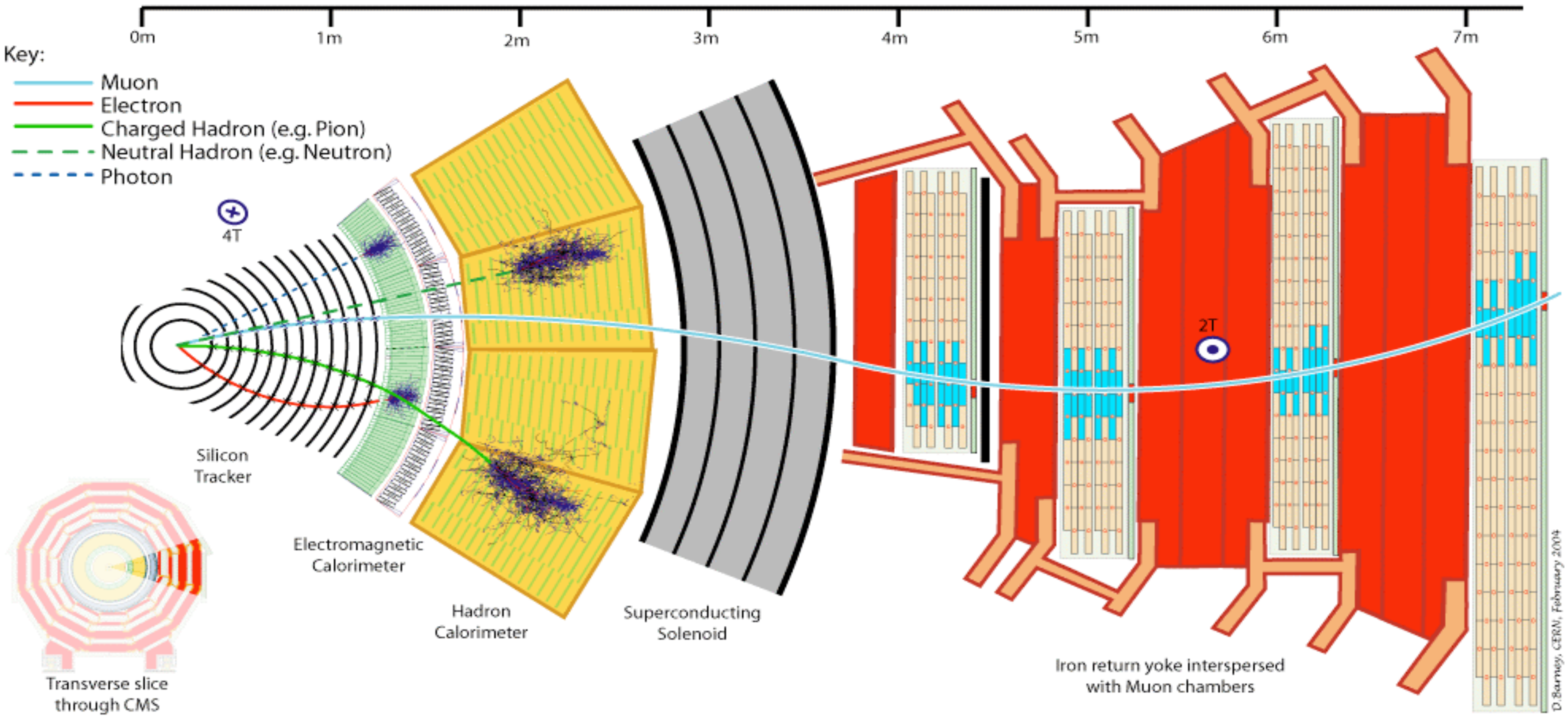
The CMS detector



Total weight : 12,500 t
Diameter : 15 m
Length: 21.6 m
Magnetic field : 4 Tesla

Tracking in CMS

>13 precision measuring points per track + 4T solenoidal field



The CMS Full Silicon Tracker

Pixel Detector

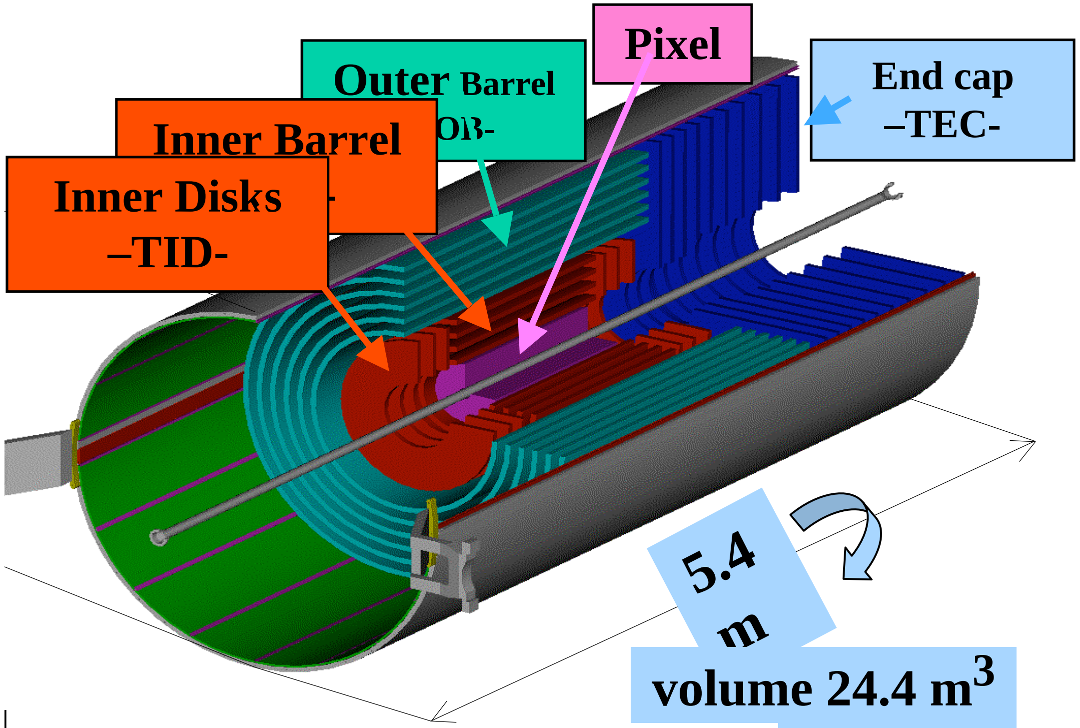
- 2 barrels, 2 disks: 40×10^6 pixels
- barrel radii: 4.1, ~10. cm
- pixel size 100×150 μm
- $\sigma_{r\phi}$= 10 μm σ_z = 10 μm

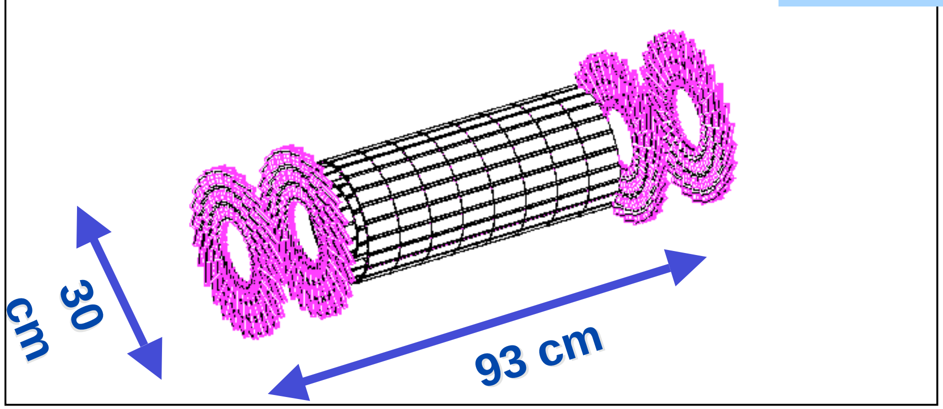
Internal Silicon Strip Tracker

- 4 barrels, many disks: 2×10^6 strips
- barrel radii:
- strip pitch 80,120 μm
- $\sigma_{r\phi}$= 20 μm σ_z = 20 μm

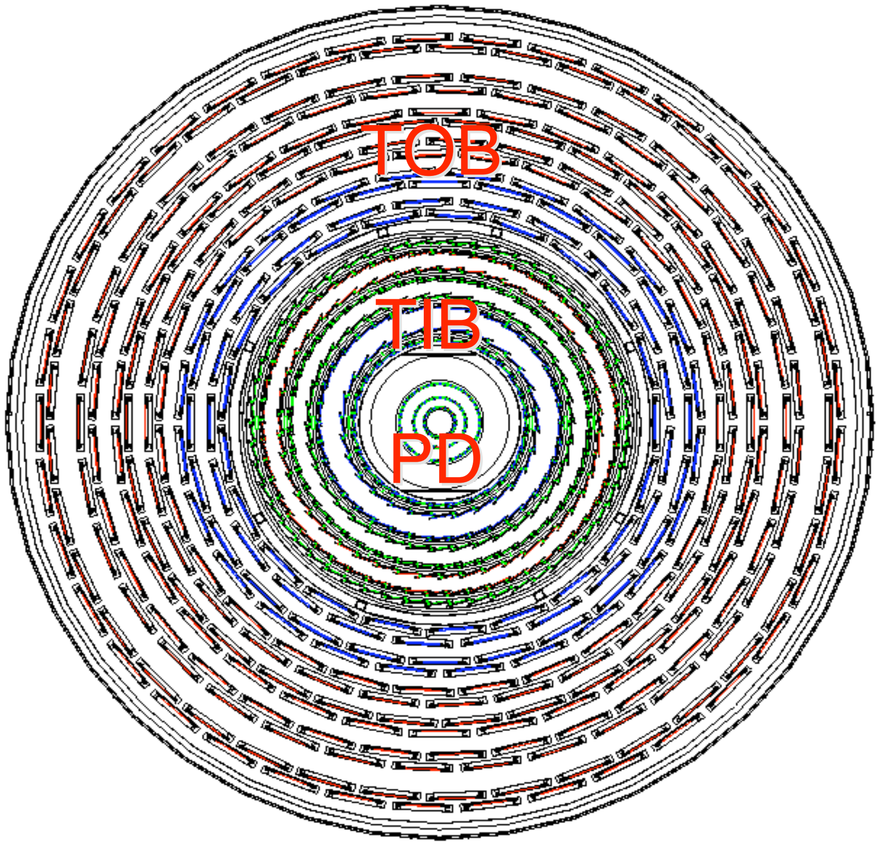
External Silicon Strip Tracker

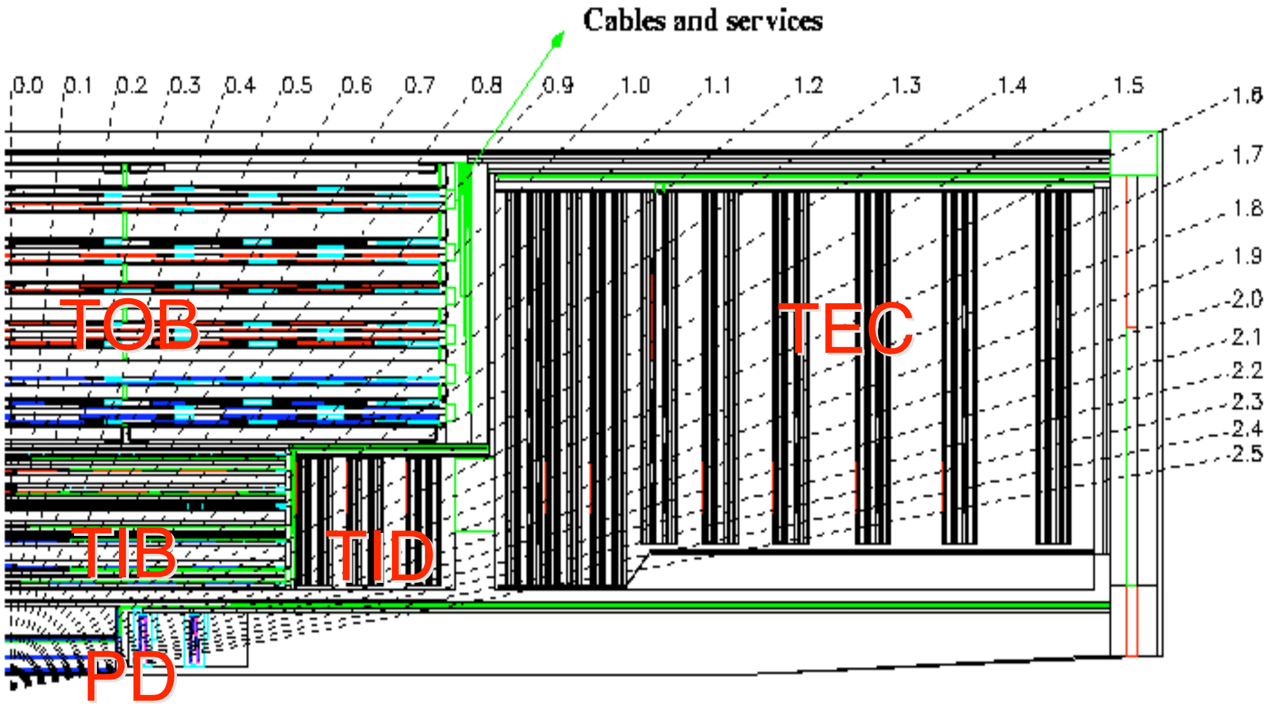
- 6 barrels, many disks: 8×10^6 strips
- barrel radii: max 110 cm
- strip pitch 80, 120 μm
- $\sigma_{r\phi}$= 30 μm σ_z = 30 μm





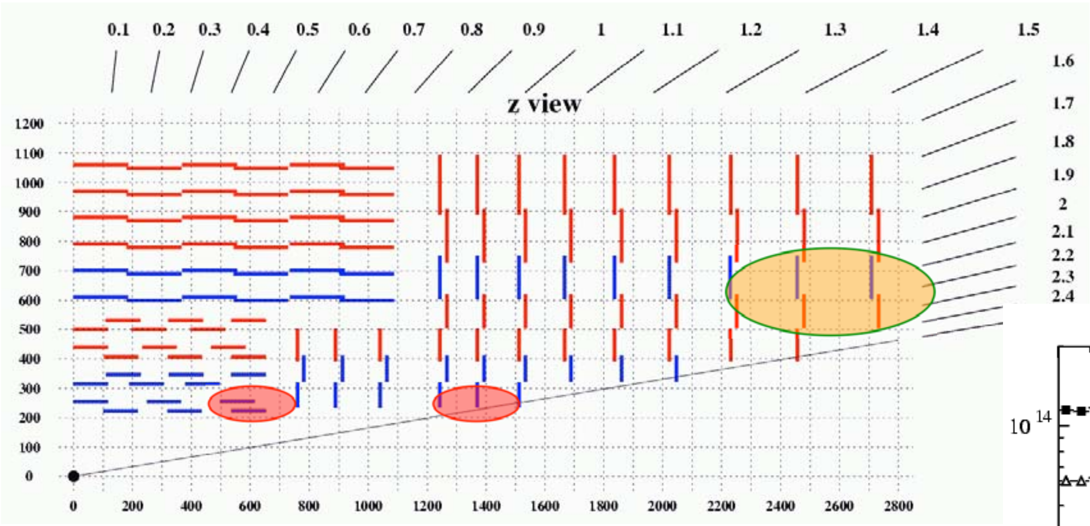
The CMS Full Silicon Tracker



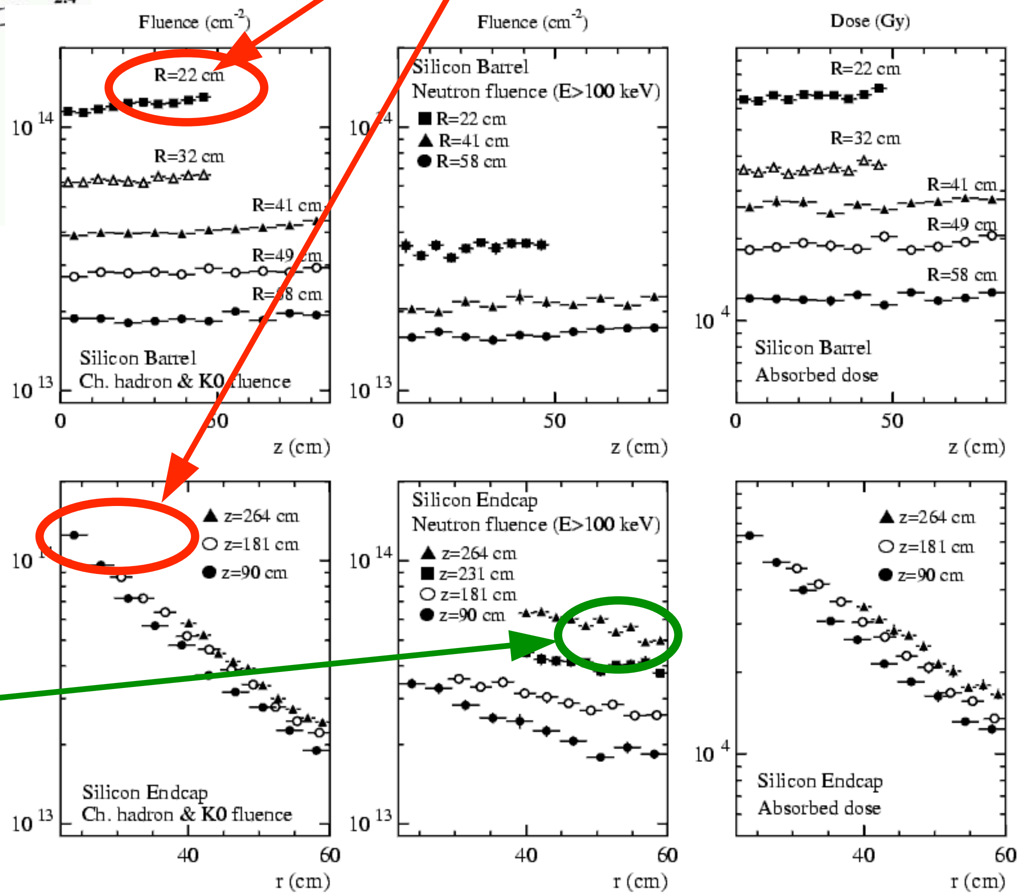


- 207m² of microstrip silicon detectors 15.232 modules
- 6136 thin sensors, 320μm (HPK) and19292, thick sensors 500μm (HPK + STM) all produced on 6" wafers.
- 60M channels pixel detector.

Radiation levels foreseen for the CMS tracker



~1.5x10^{14}cm^{-2}

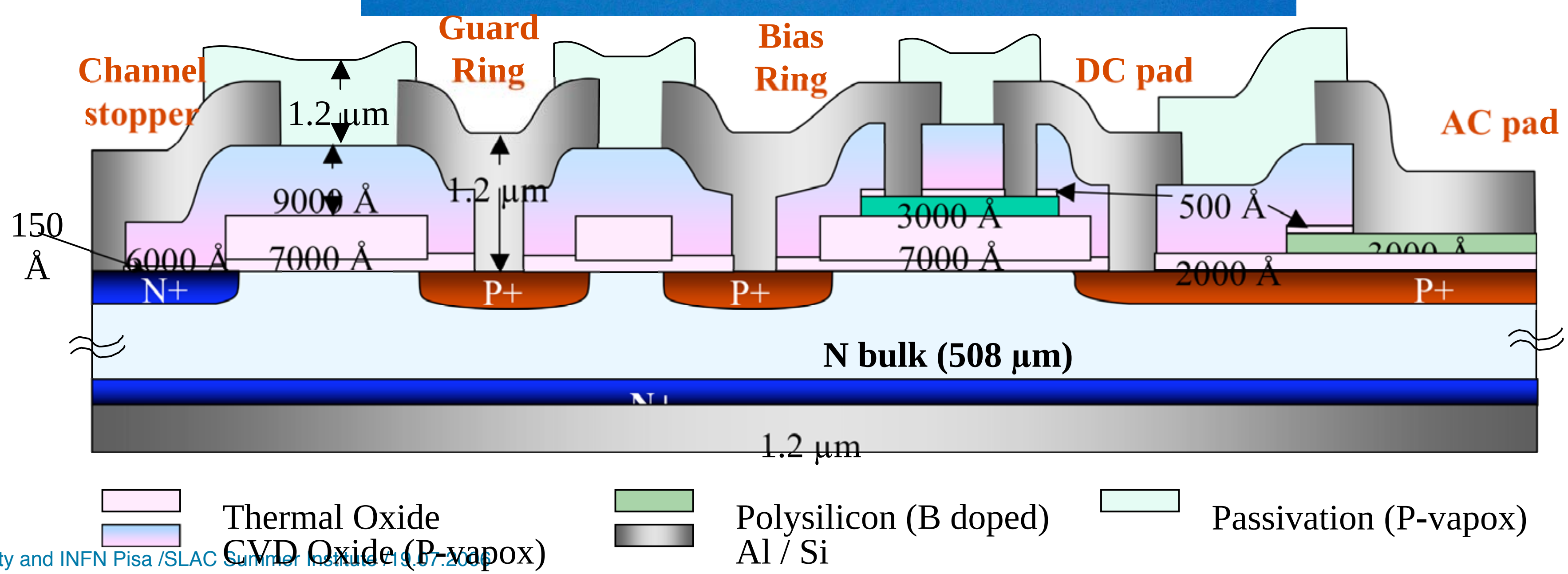


~0.5x10^{14} n/cm^{-2}

Sensors: radiation resistant technology

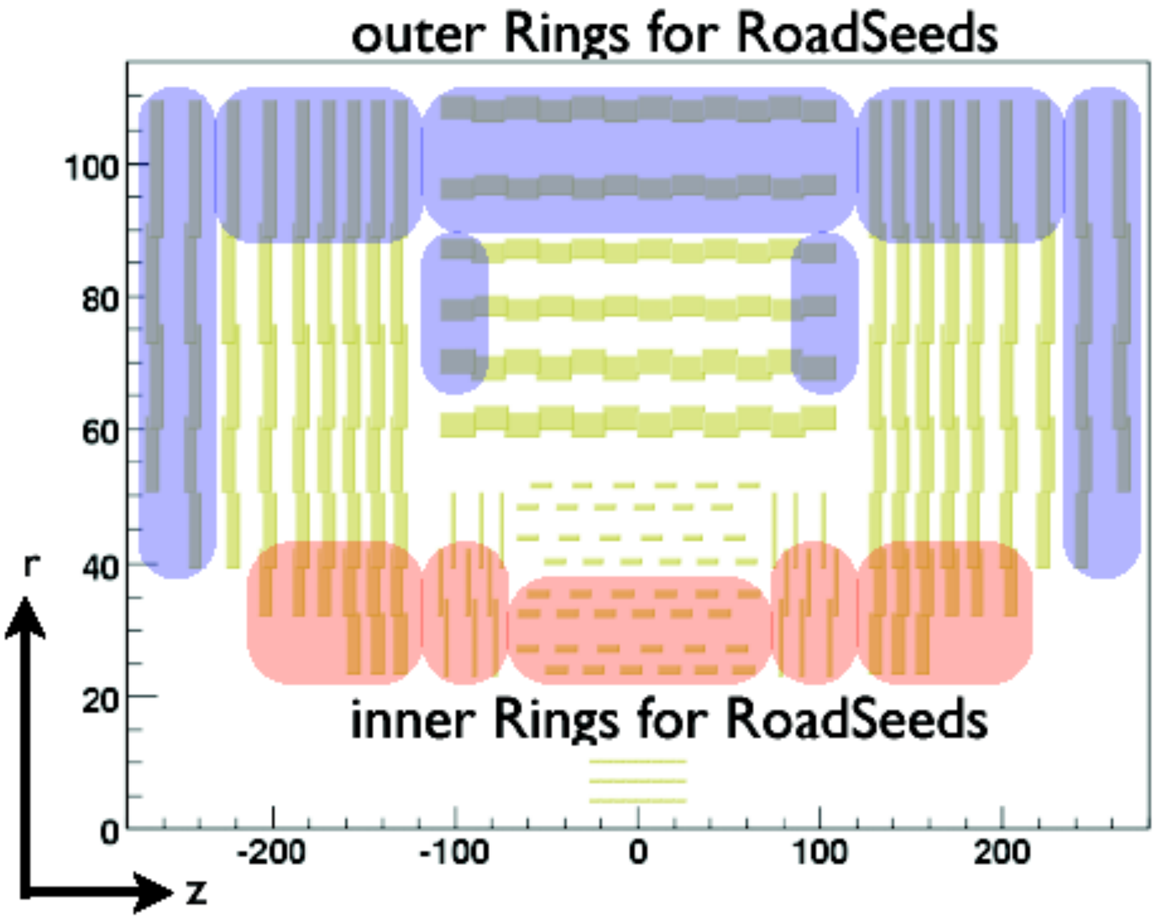
- Single-sided detectors p+ on n.
- Double-sided layers produced coupling two detectors back-to-back.
- AC coupling (no effect due to the increase of the leakage current)
- Polysilicon bias resistor integrated in the sensor (highly stable)
- High breakdown >500V (technology+careful design of the edge regions: asymmetric guard ring , n+ implant at the edge, distance between the active area and the edges d= 2* thickness + 150μm; 15% metal overhang per side; rounded edges).
- The width of the p+ implant is 0.15-0.20 of the readout pitch (minimal capacity).
- Crystal orientation <100> no sensitivity of the capacitance to irradiation
- Increasing resistivity from inside to outside 2-4KΩcm.
- Increasing thickness 320-500μm for modules length 12 to 18 cm.
- Low costs (6” wafers and high throughput production lines).

A CMS detector on 6” wafer



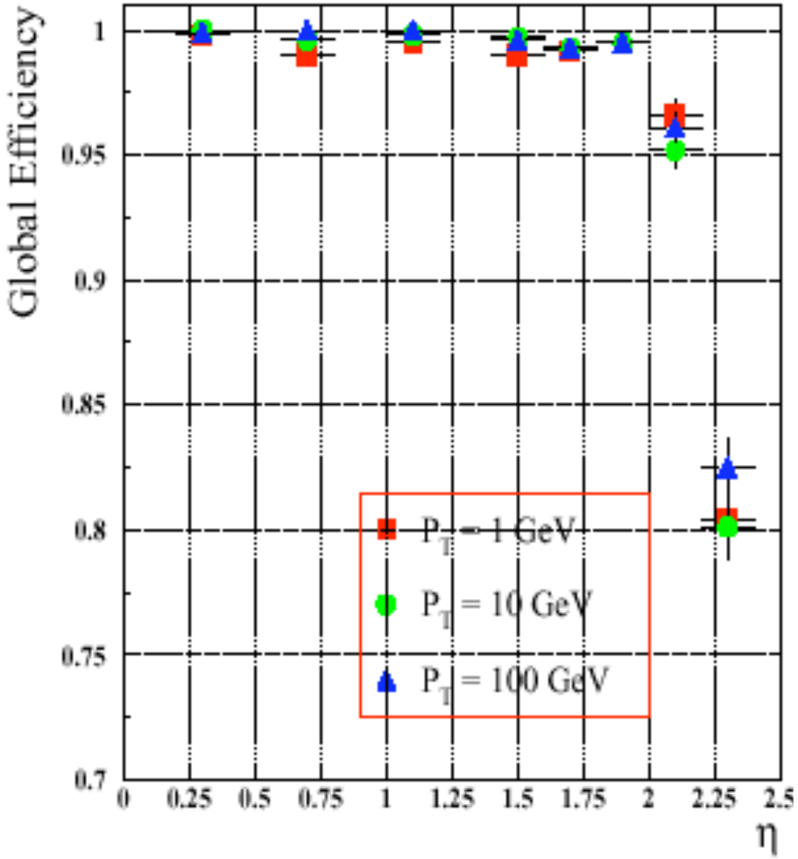
Track reconstruction

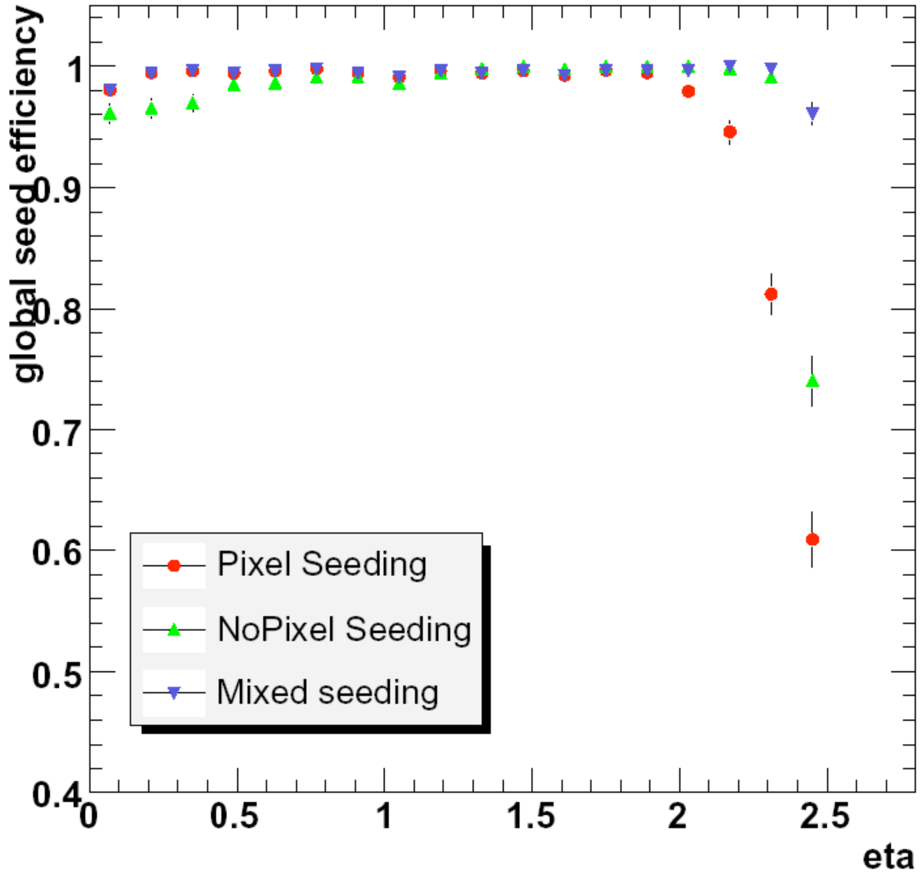
1. Kalman Filter
   - Pixel seeds
   - Cosmic seed (no-pixel seed, but non-pointing geometry)
   - Pixel only
2. Road Search
   - w/ or w/o pixels



Tracking performance: isolated tracks

- Tracking efficiency (Kalman filter) for isolated muons
- > 99% for $\eta<2.4$



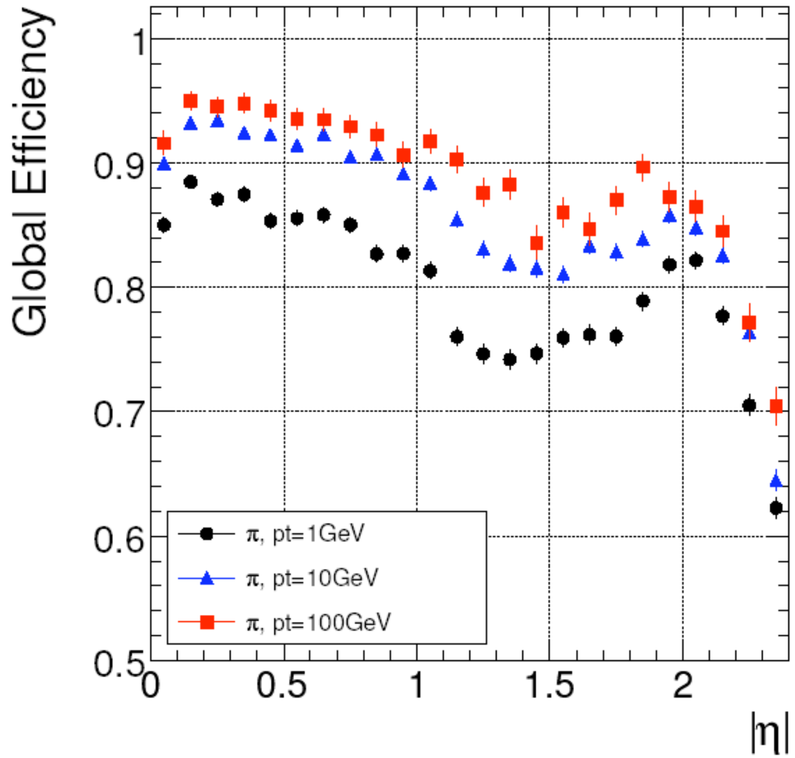


Track reconstruction in high pt jets

Track finding efficiency in 200 GeV E_T Jets; $p_T > 0.9$ GeV

		$\|\eta\| < 0.7$	$1.2 < \|\eta\| < 1.6$
≥ 6 hits	(eff.)	93.7 ± 0.6	91.6 ± 0.6
	(ghosts)	0.26 ± 0.09	0.10 ± 0.07
≥ 8 hits	(eff.)	88.3 ± 0.9	86.8 ± 0.8
	(ghosts)	0.10 ± 0.07	0.10 ± 0.07

Reconstruction efficiency for low momentum pions

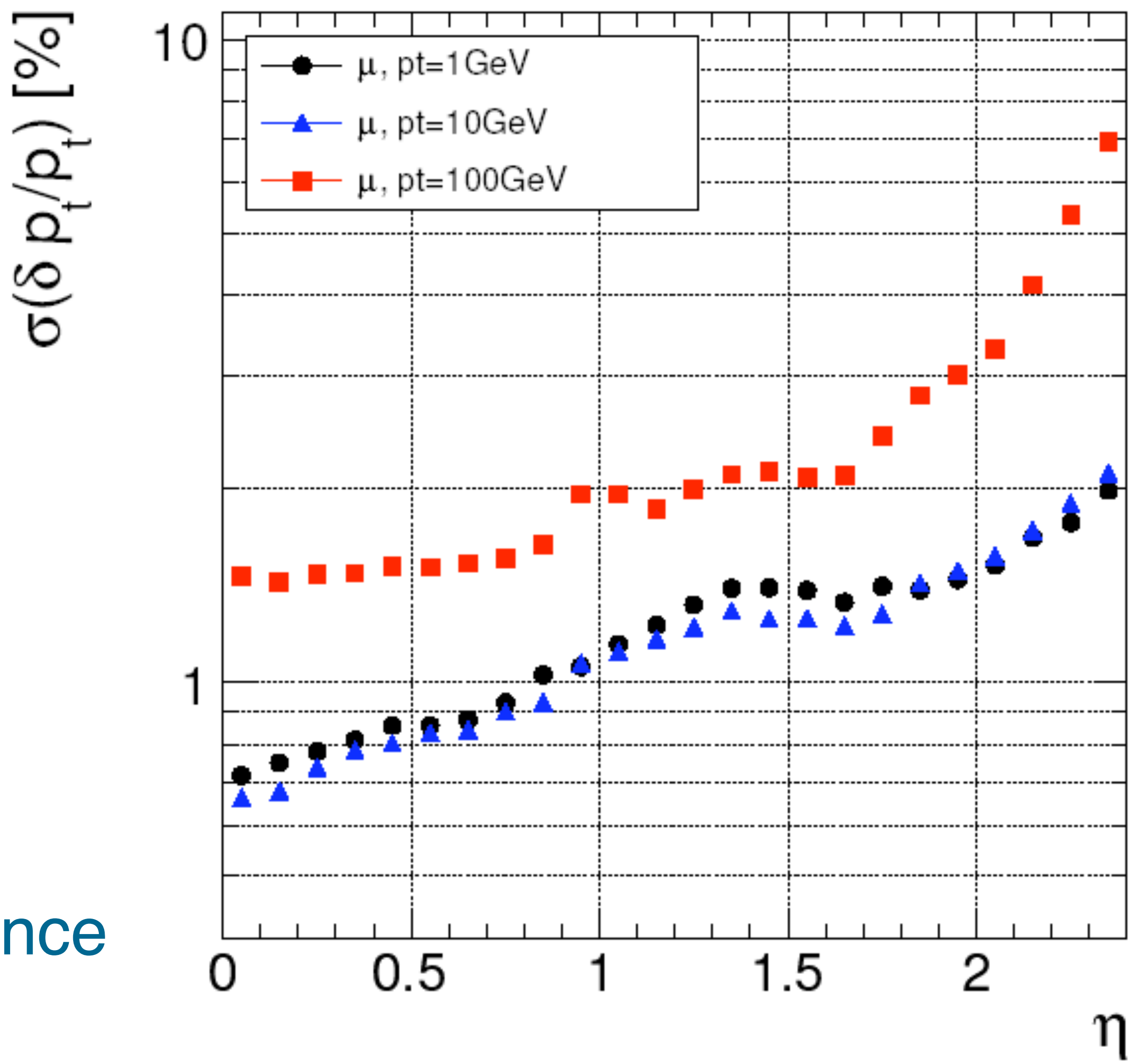


Momentum resolution

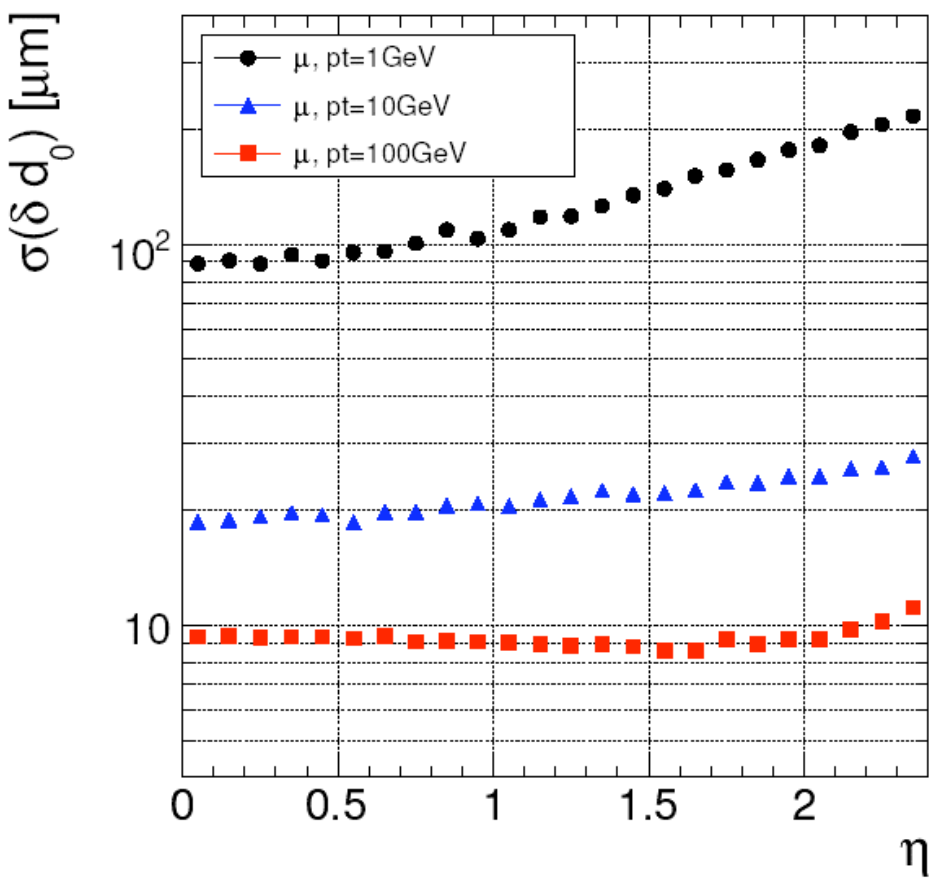
$\Delta p_t/p_t=0.15\ p_t$ (TeV)
for high pt tracks

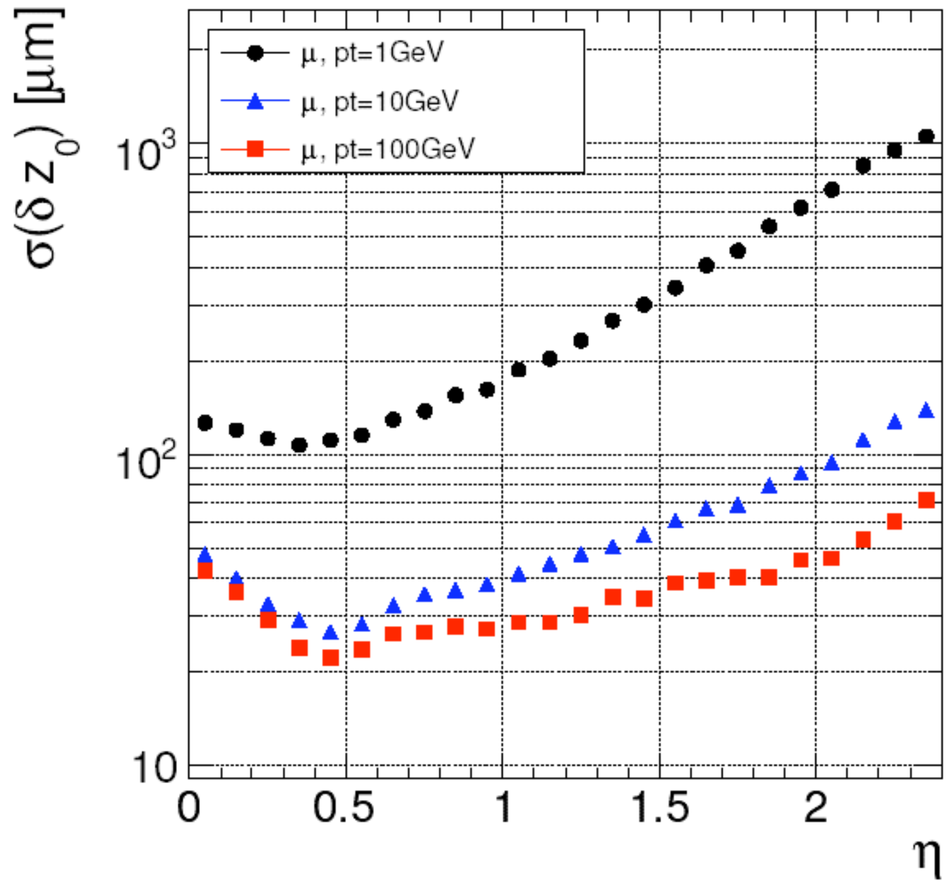
$\Delta p_t/p_t=1.5\%$ for $p_t=100$GeV
$\Delta p_t/p_t=7.5\%$ for $p_t=500$GeV

Spectacular invariant mass distributions.
Precision measurements and positive effects on significance of elusive channels



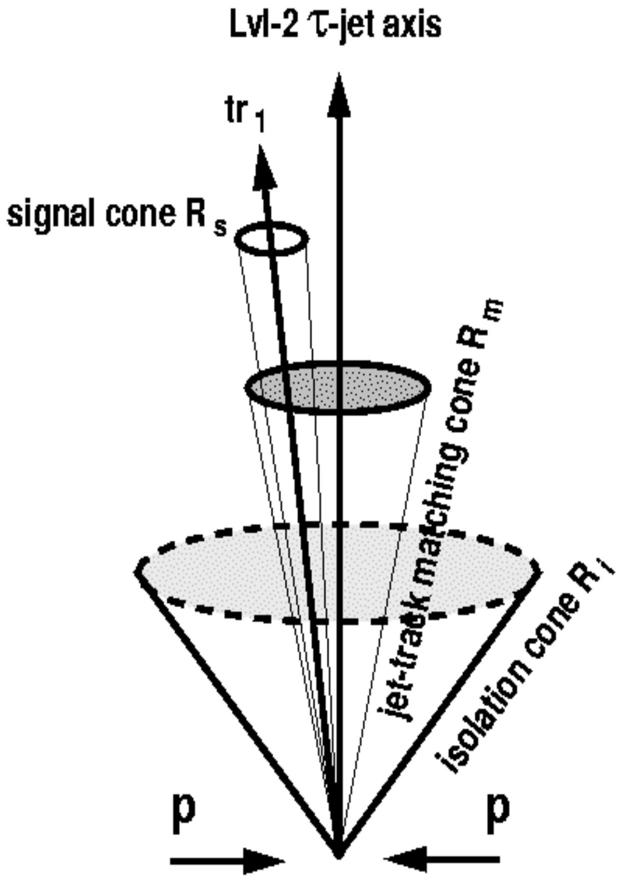
Impact parameter resolution

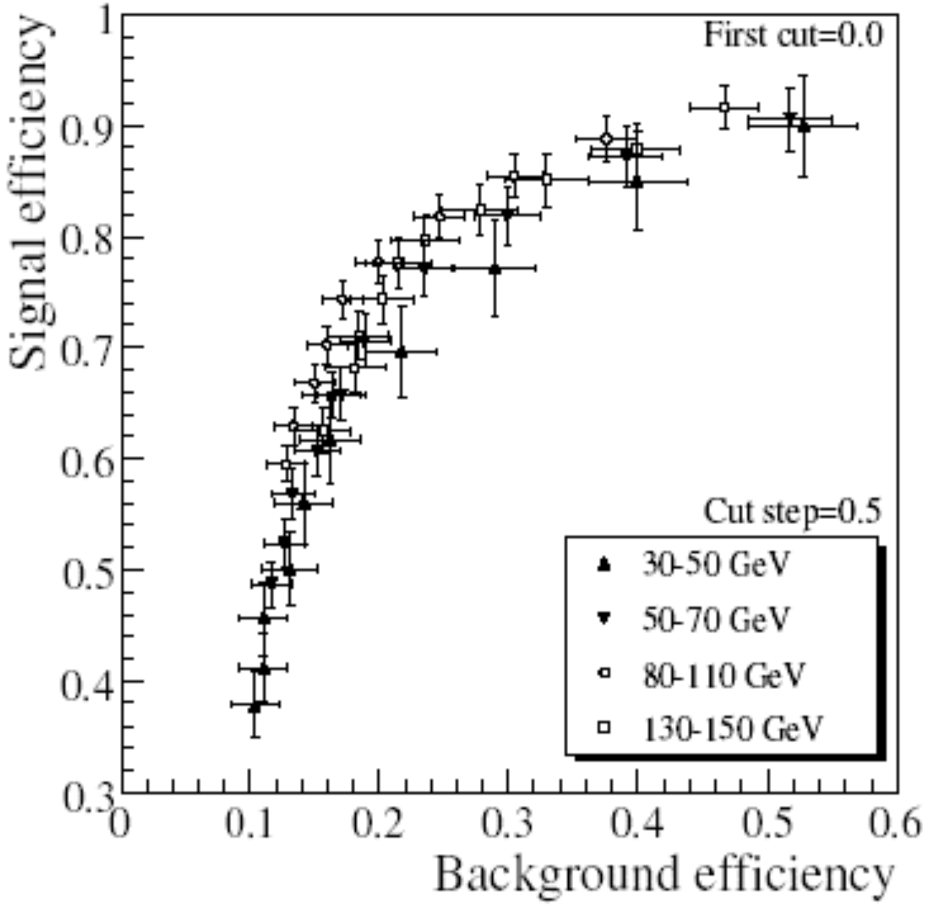




Excellent results both in the transverse plane (10-20μm) and the r-z plane (20-40μm) (several tagging techniques available)

Tau Tagging efficiency





Several tagging techniques that exploit the isolation of the decay products:

mass tag, secondary vertex, impact parameter

Developed for HLT, have been refined for offline.

Vertexing

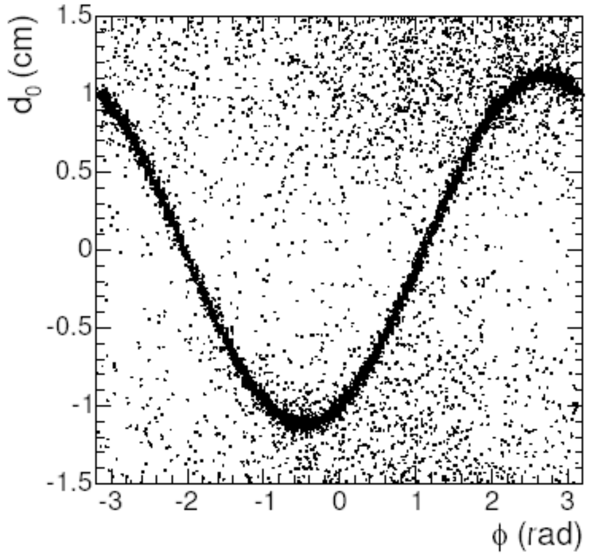
Online pixel primary vertex finding

Offline Vertex reconstruction:
efficiency to find primary vertex in
High luminosity run >95%

Recent developments

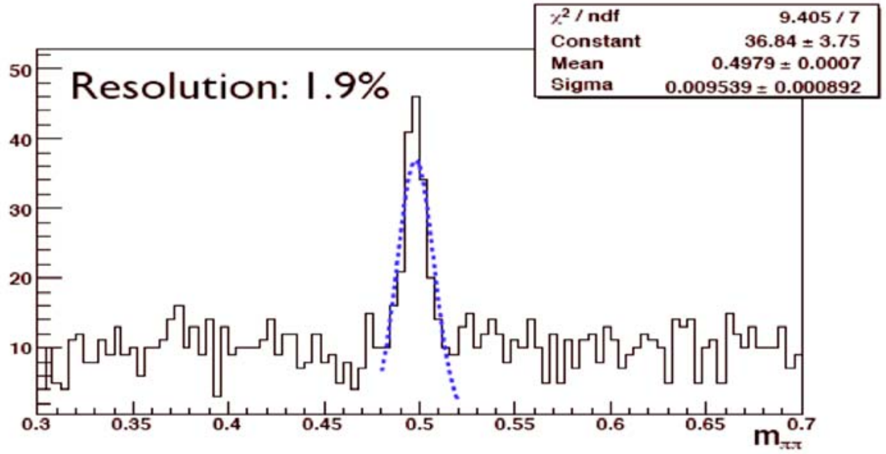
- V^0 and Λ^0 reconstruction
- Tertiary vertex finder for B-jets

Beam spot with ~ 1000 MB events



Offline P.V. resolution

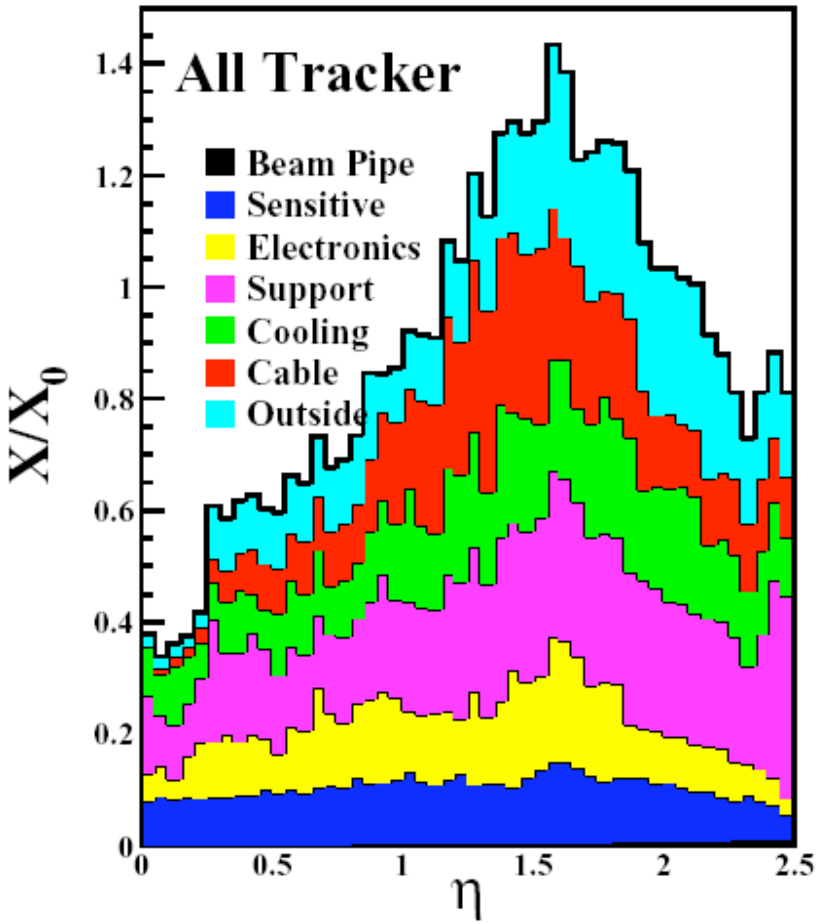
	σ_x (μm)	σ_z (μm)
$H(150GeV/c^2) \rightarrow ZZ \rightarrow 4e$	17	21
$H(115GeV/c^2) \rightarrow \gamma\gamma$, g fusion	25	32
$H(115GeV/c^2) \rightarrow \gamma\gamma$, VB fusion	20	31
$B_s^0 \rightarrow J/\psi\ \phi$, primary vertex	44	65
b-jets; $30 < E_T < 50GeV$	24	31
$t\bar{t}$	13	18
Drell-Yan 2μ	13	25
$t\bar{t}H$	10	14

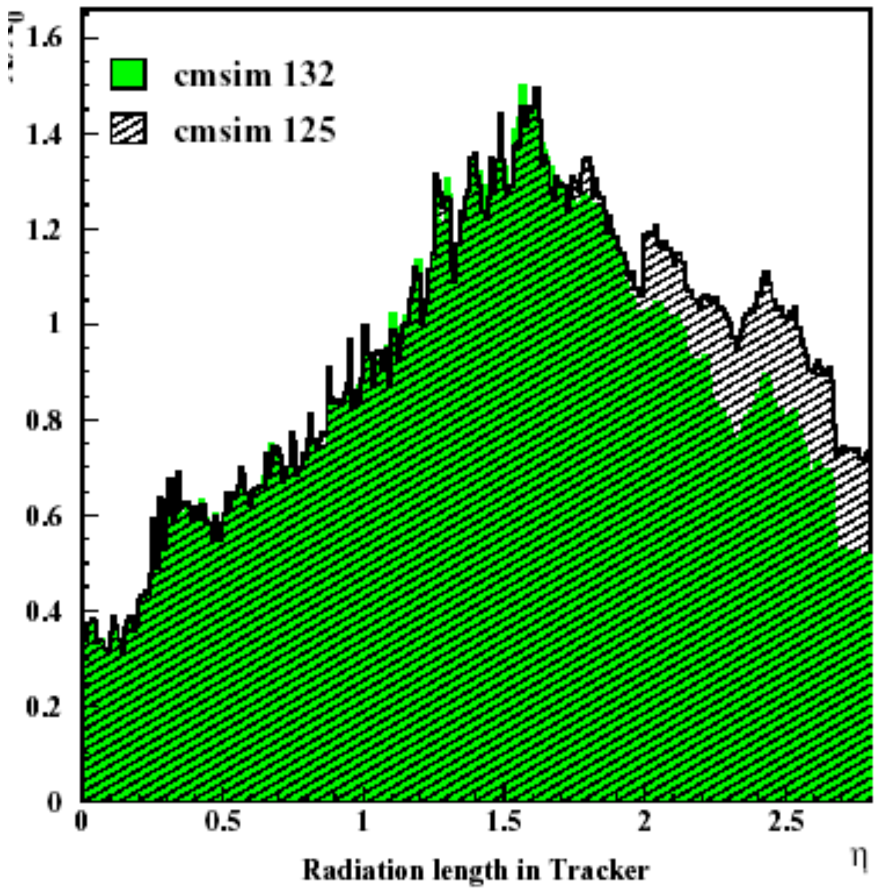


M(π+π−)

Big worries: material budget

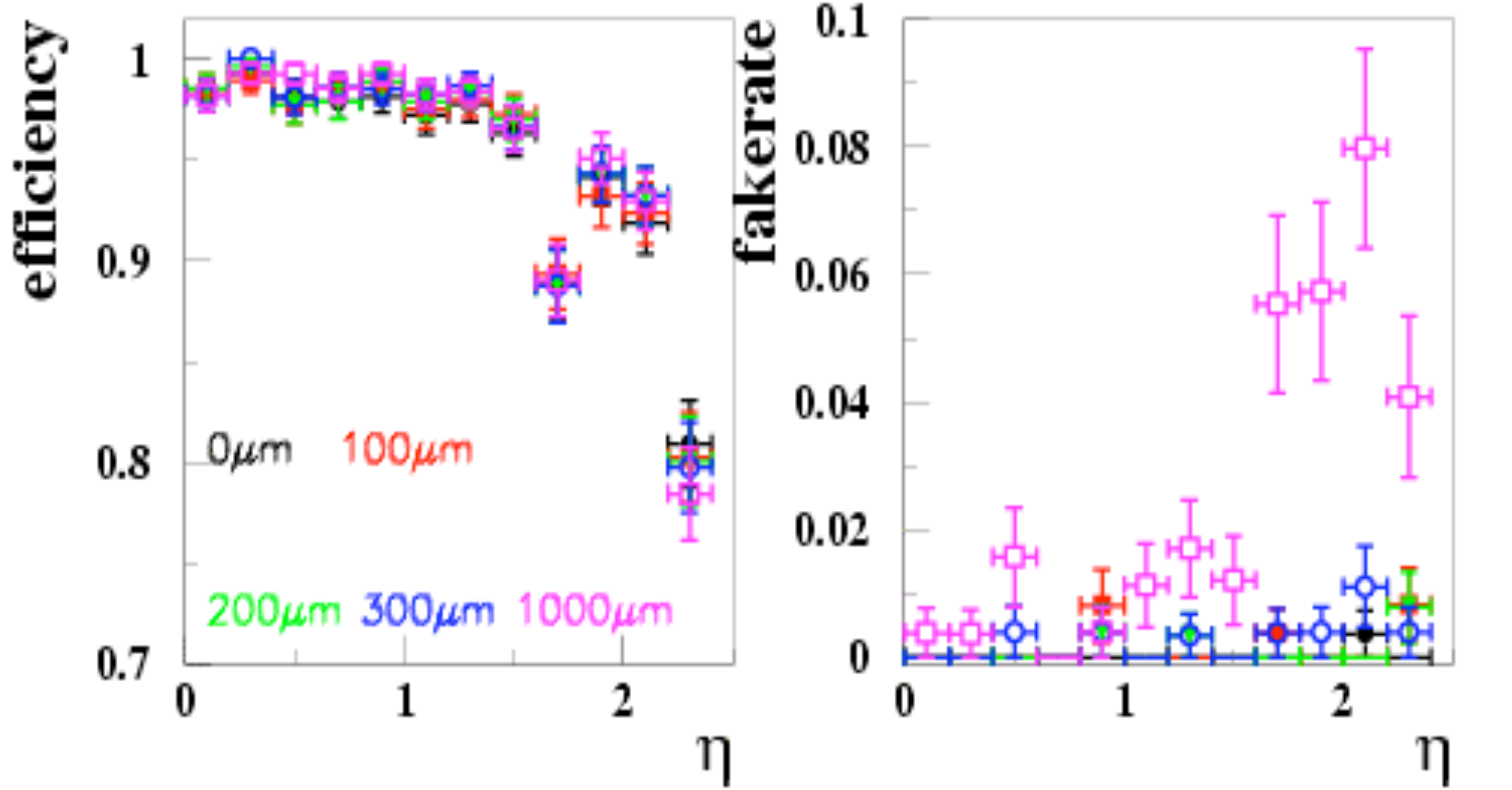
During construction all components are measured and weighted to update the description of the material budget. Detailed simulations are continuously improved. Incredible care is put in choosing low mass materials everywhere….. but ….





Big worry: the alignment

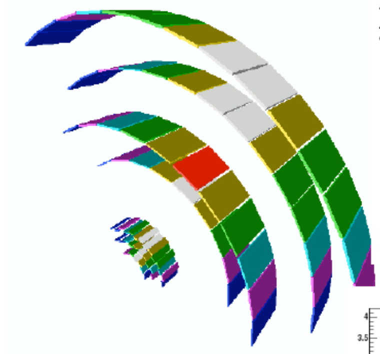
Pattern recognition algorithms work still very well with initial misalignments up to 1mm and 1 mrad for events W->$\mu\nu$ a 2*10^{33}



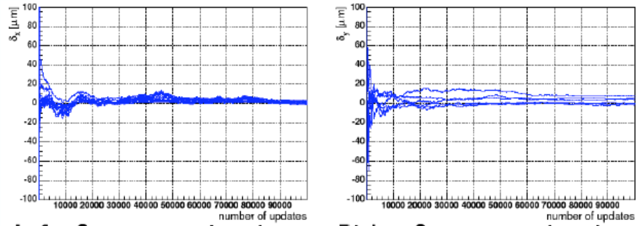
Alignment tools

Three different algorithms in CMS

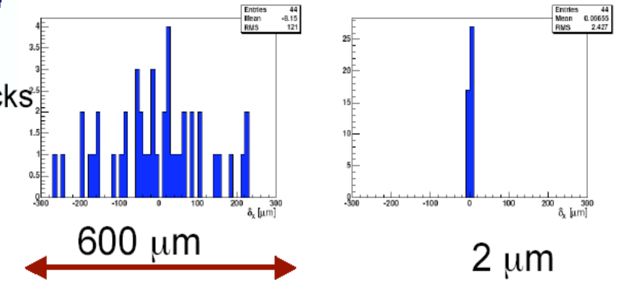
- HIP
  - Iterative method – no correlations between sensors considered
- Kalman Filter
  - Full correlation among sensors
- Millipede II
  - Residual minimization – evolution of Millipede (CDF, H1)

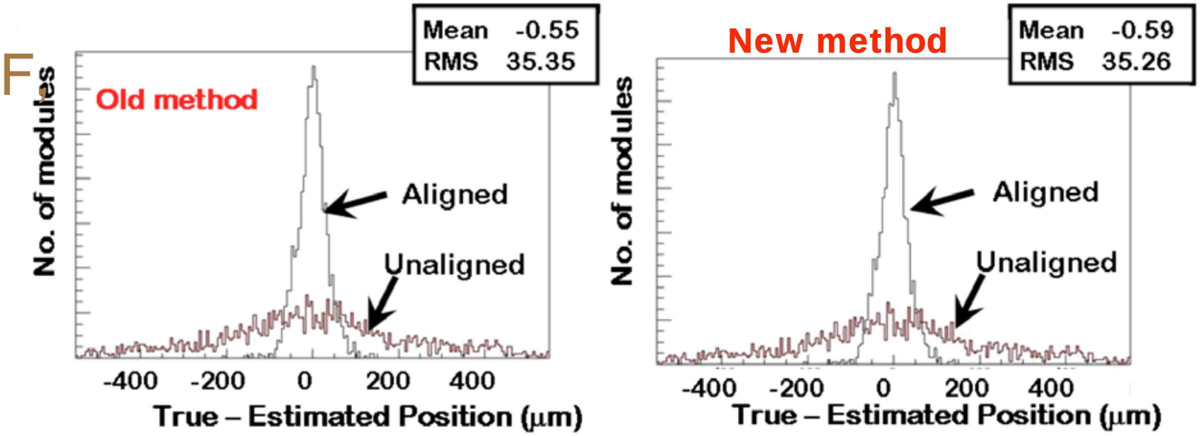


After 100K single muon tracks



Left: Convergence in x in μm, Right: Convergence in y in μm

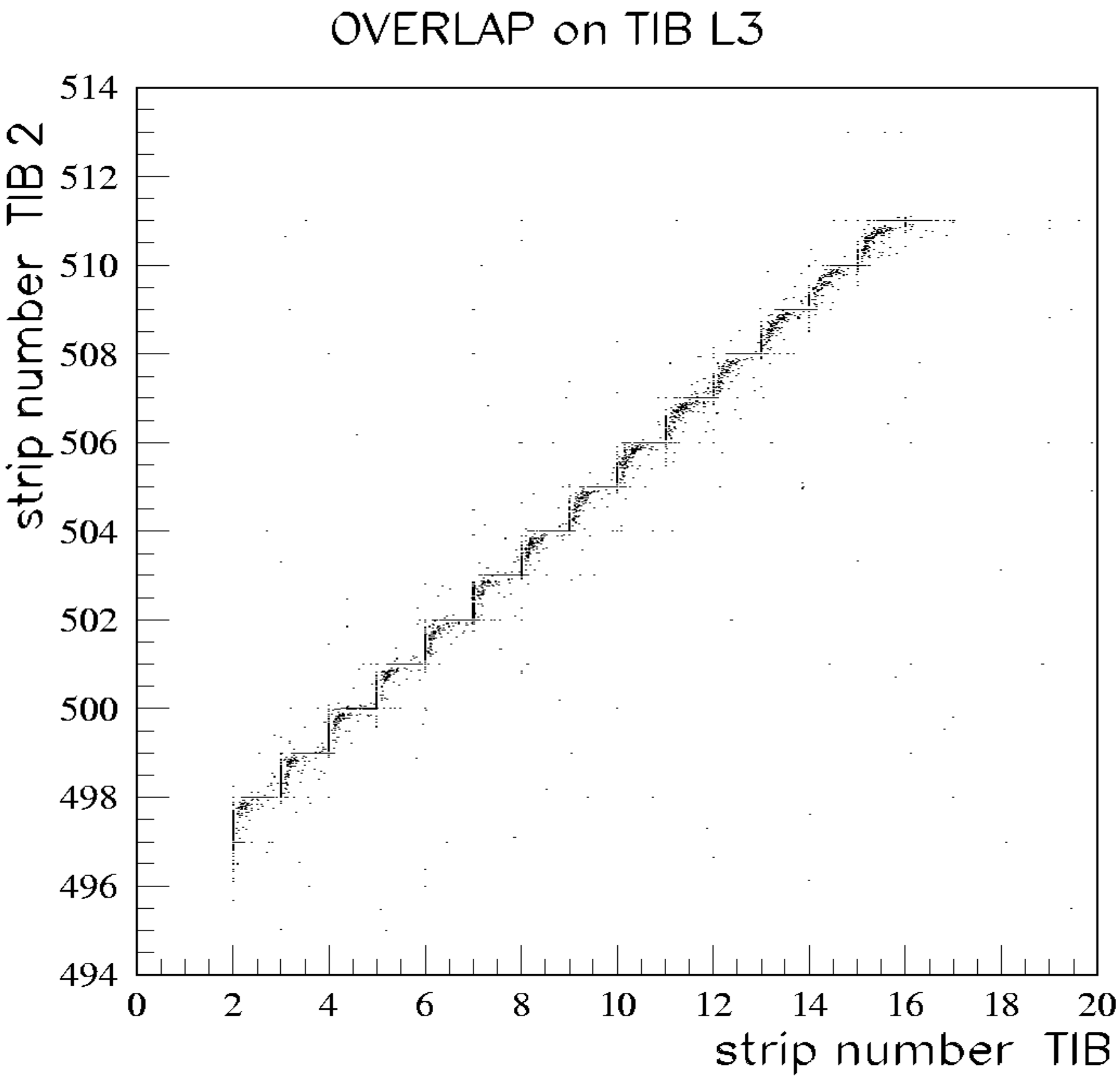




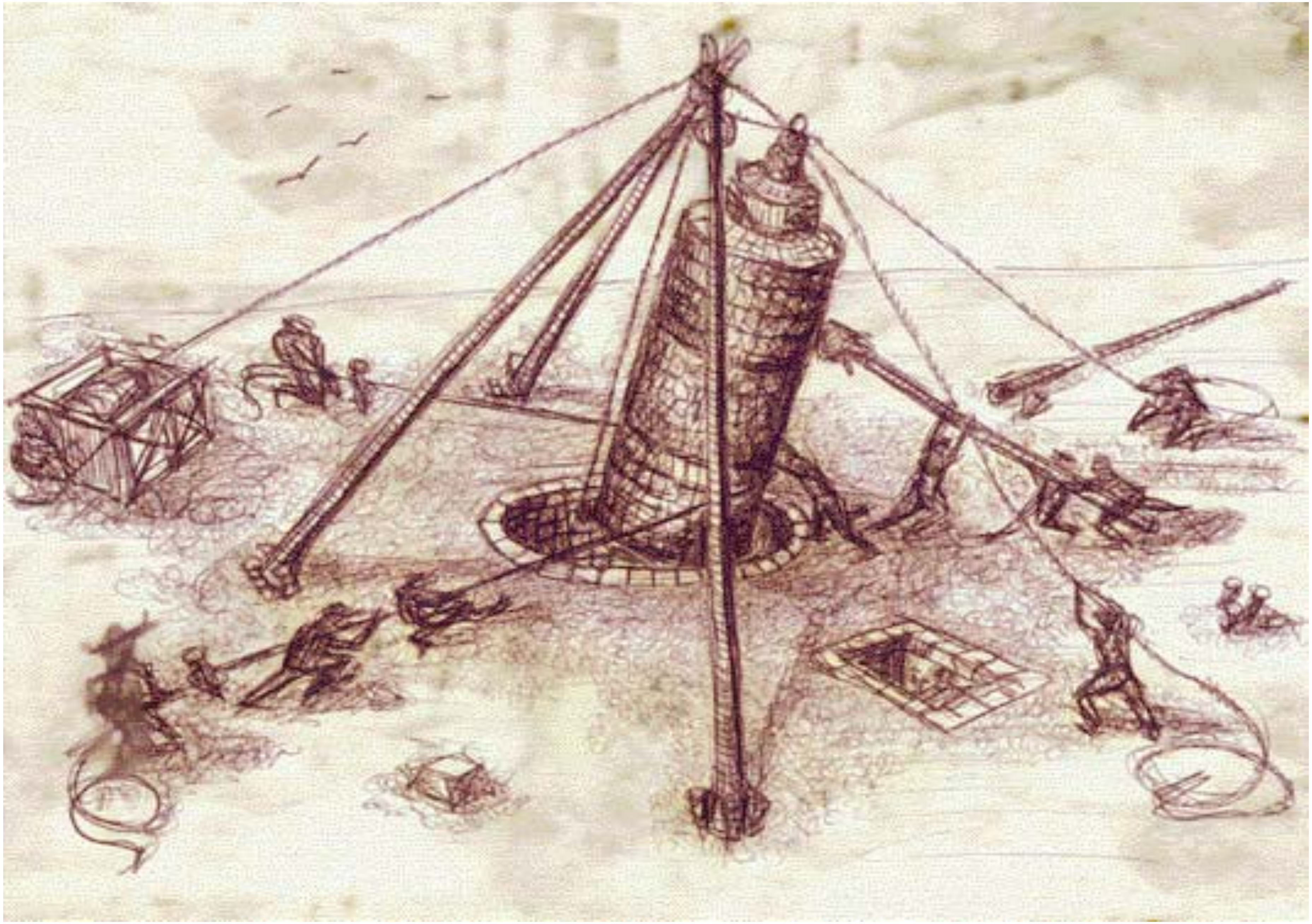
TIB overlap (alignment)

Correlation between adiacent detectors

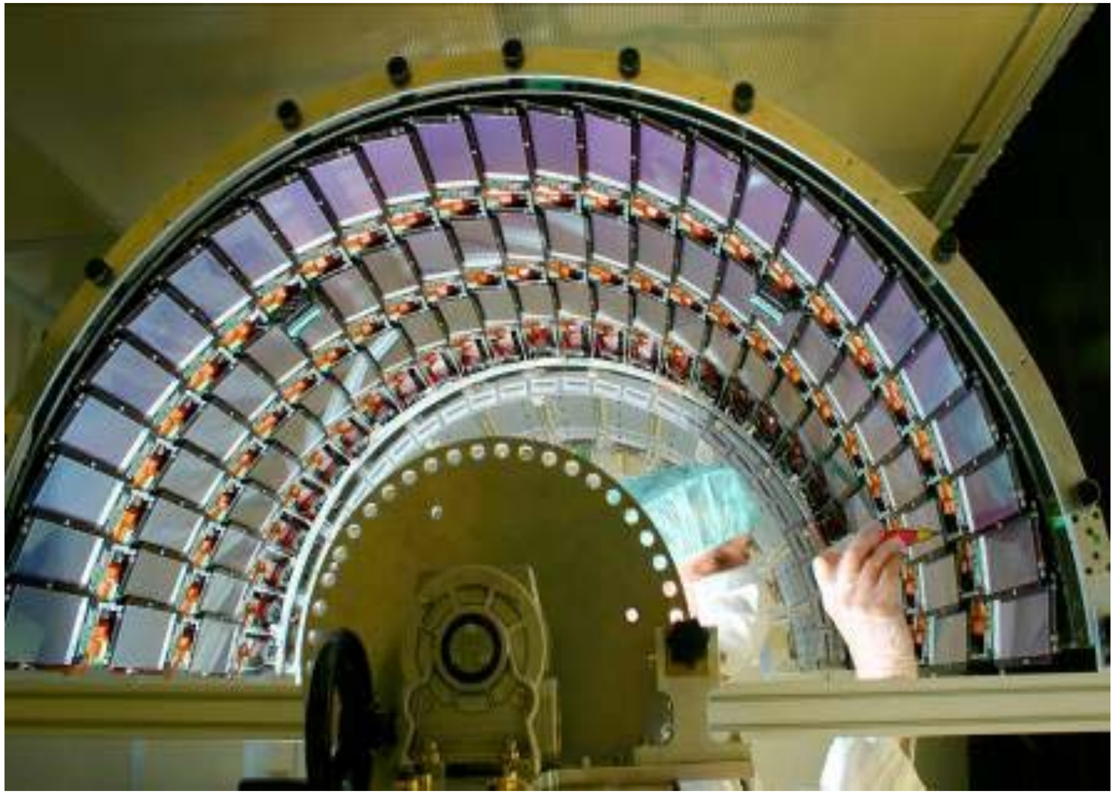
~15-20 channels in the overlap~2mm

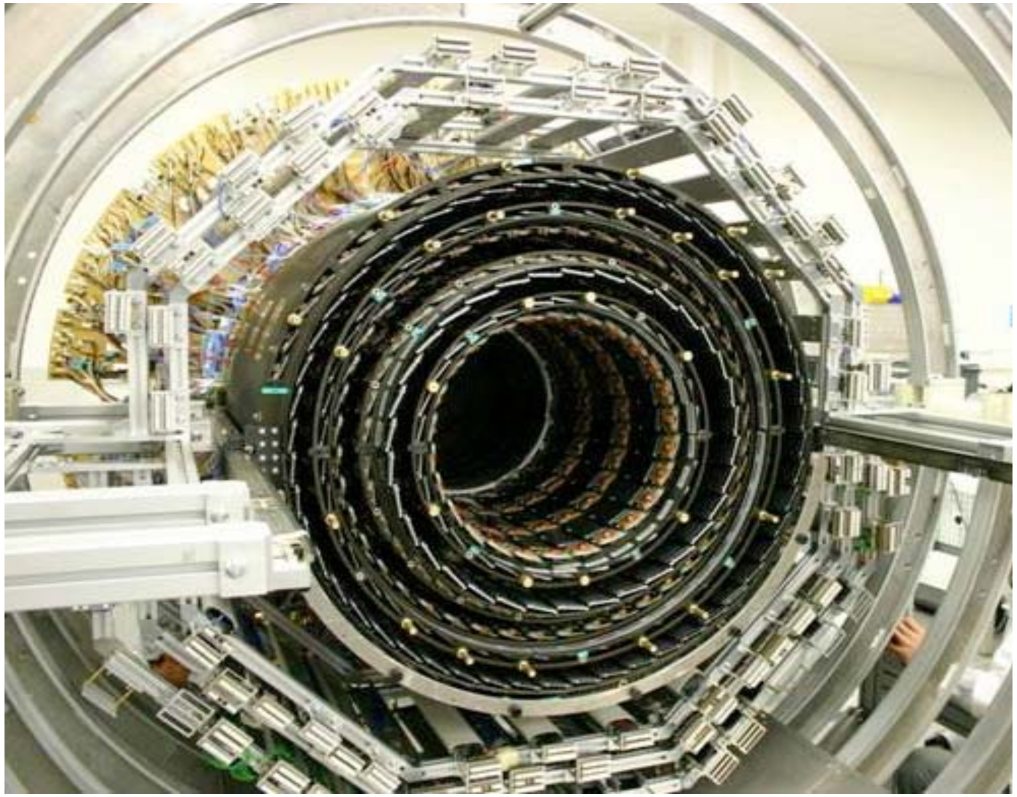


Where we are now

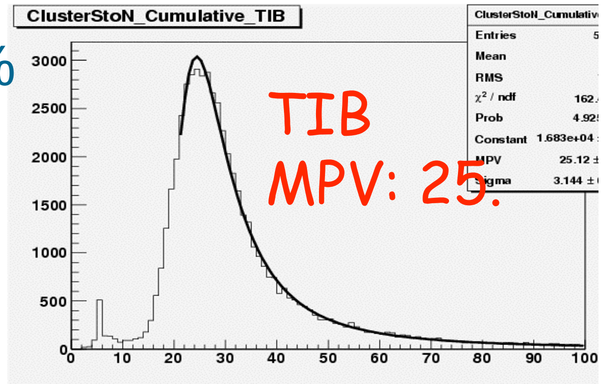


TIB/TID (Italy): 90% completed

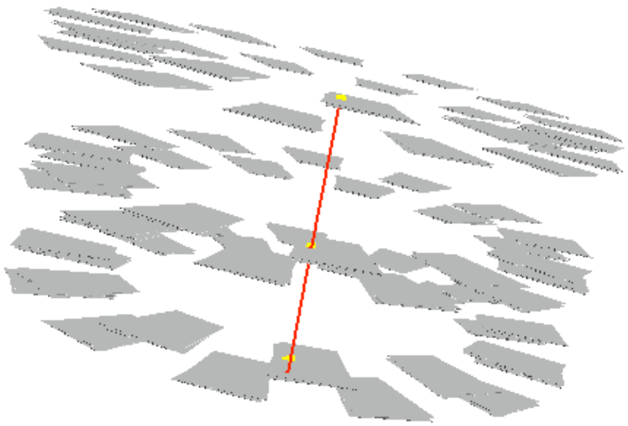




Excellent quality: bad channels <0.1%
Pre-commissioning in cold already done.
Cosmic ray test: pre-alignment constants and excellent S/N ratio.

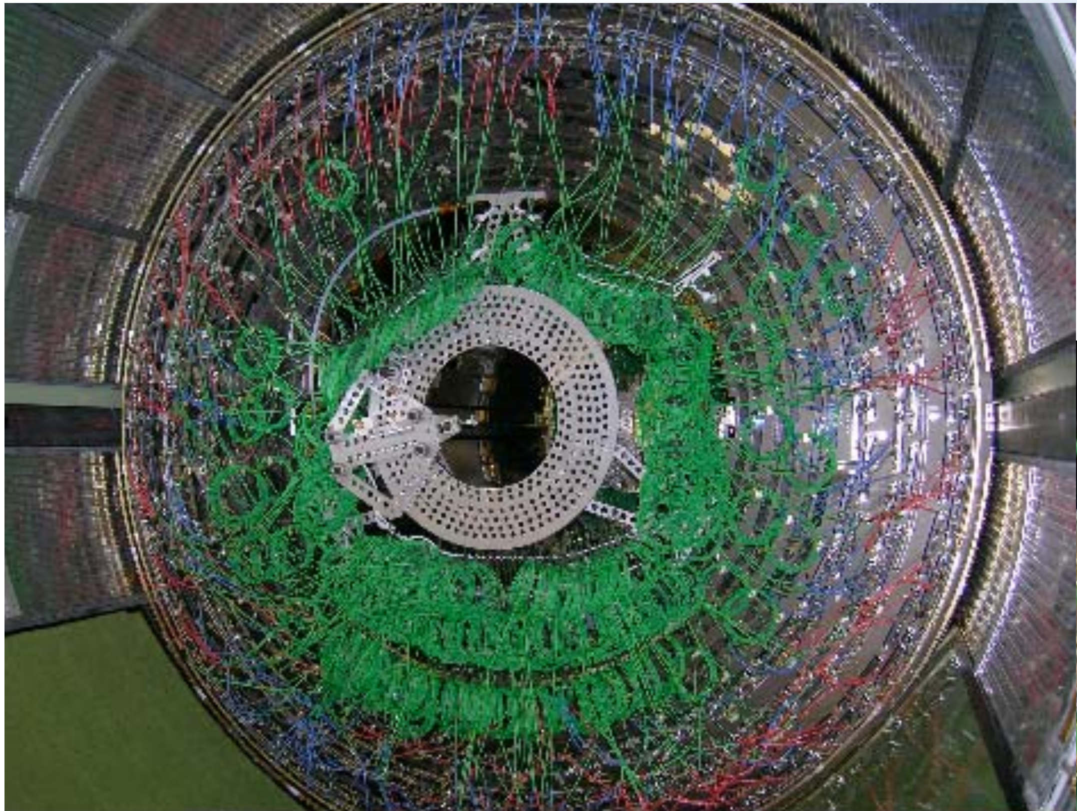


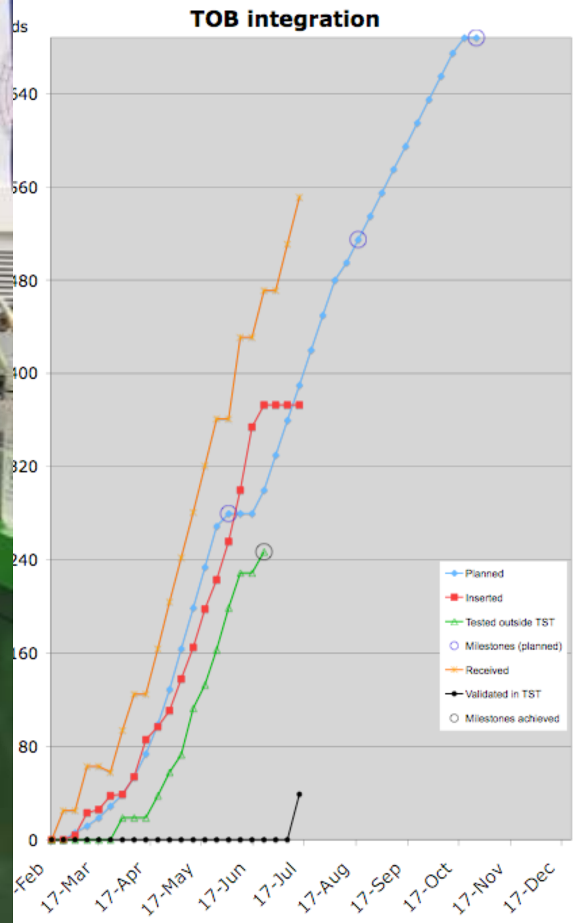
S/N

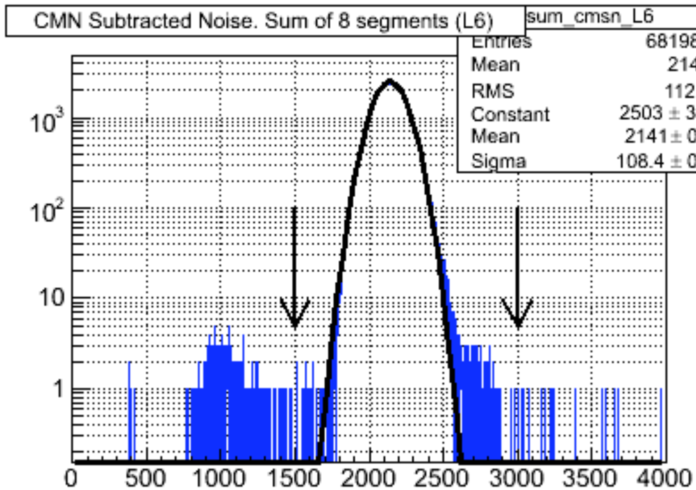


TOB (USA&CERN) = 50% completed

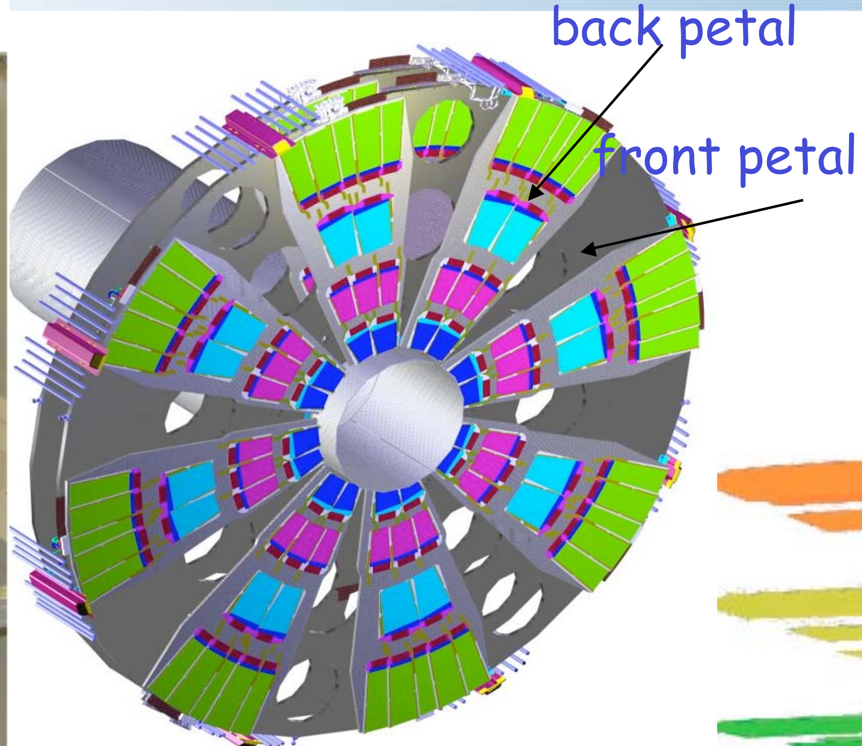
Excellent quality so far: dead or noisy strips<0.1%.

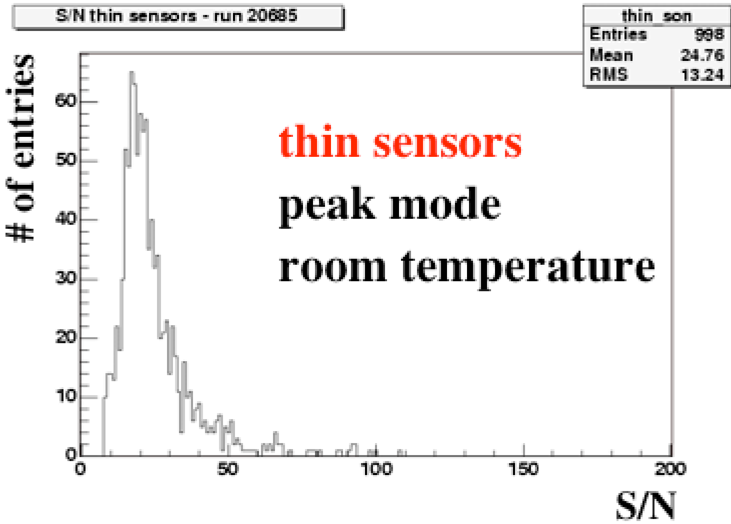


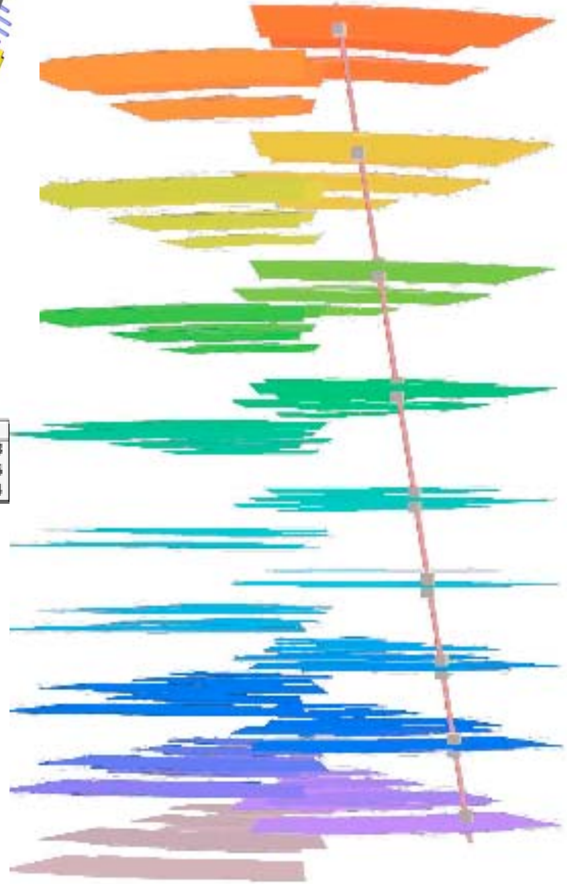




TEC (Aachen&Lyon): 40% completed







Very good quality (bad channels<0.3%).
Very nice cosmic ray data
S/N>25 for thin sensors in peak mode. Pre-alignment constants.

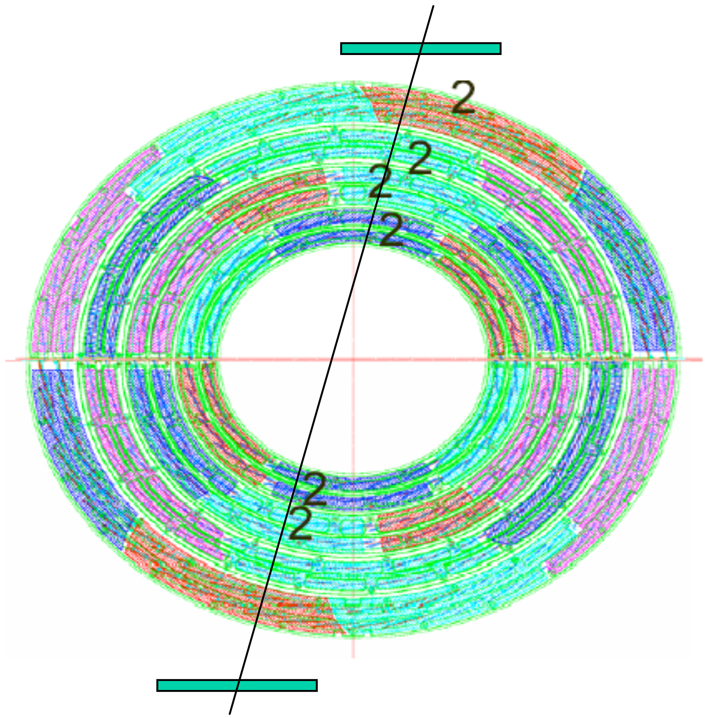
First ideas for the pilot run 900GeV (11/07)

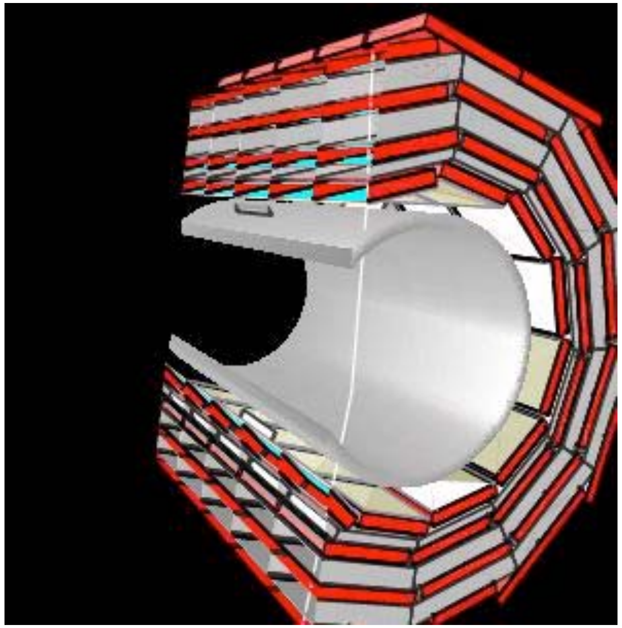
Pre-align with cosmics

Test 25% at the Tracker Integration Facilities (no B)

Cosmic run (in cold and with B)

Rate for muons> 10GeV reaching the tracker : 60Hz



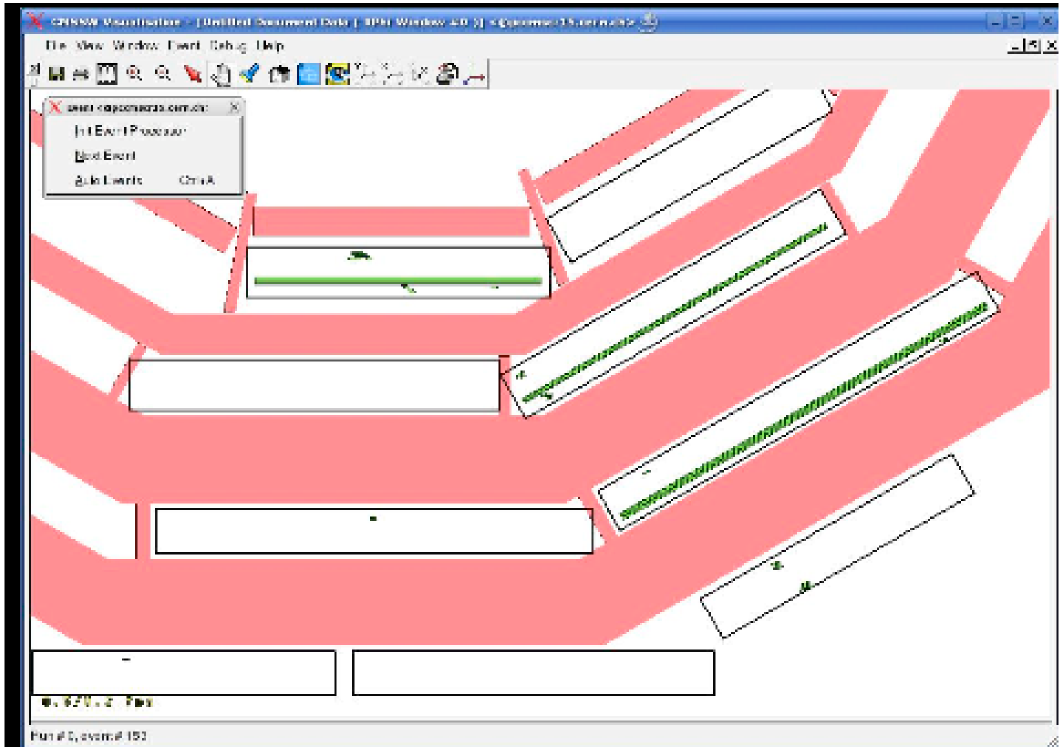


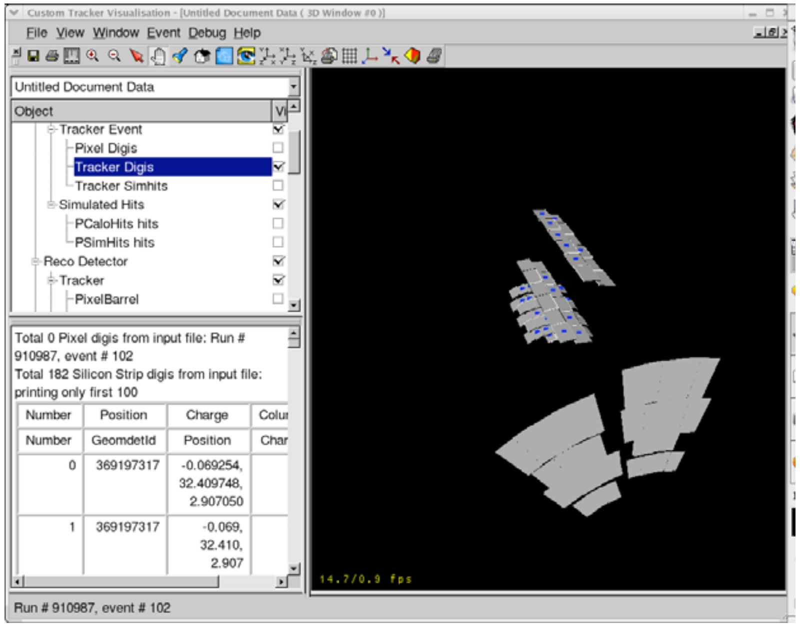
The goal is to reach a pre-aligned tracker (better than 100μm) prior to collisions. Using minimum bias events from the first collisions (700k tracks>2GeV) it seems possible to align in the range of ~20μm.

MTCC

A complete wedge of CMS (Muon Detectors, HCAL, ECAL and Tracker) is currently taking data at P5.

4 days ago first successful run: 0.5 M muon events collected in 1 night.



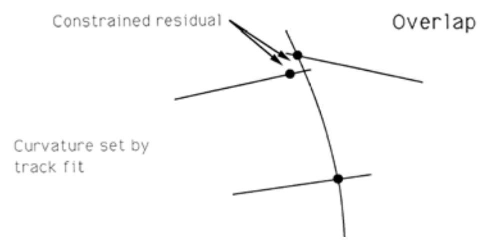


Study of the material budget (Pilot Run)

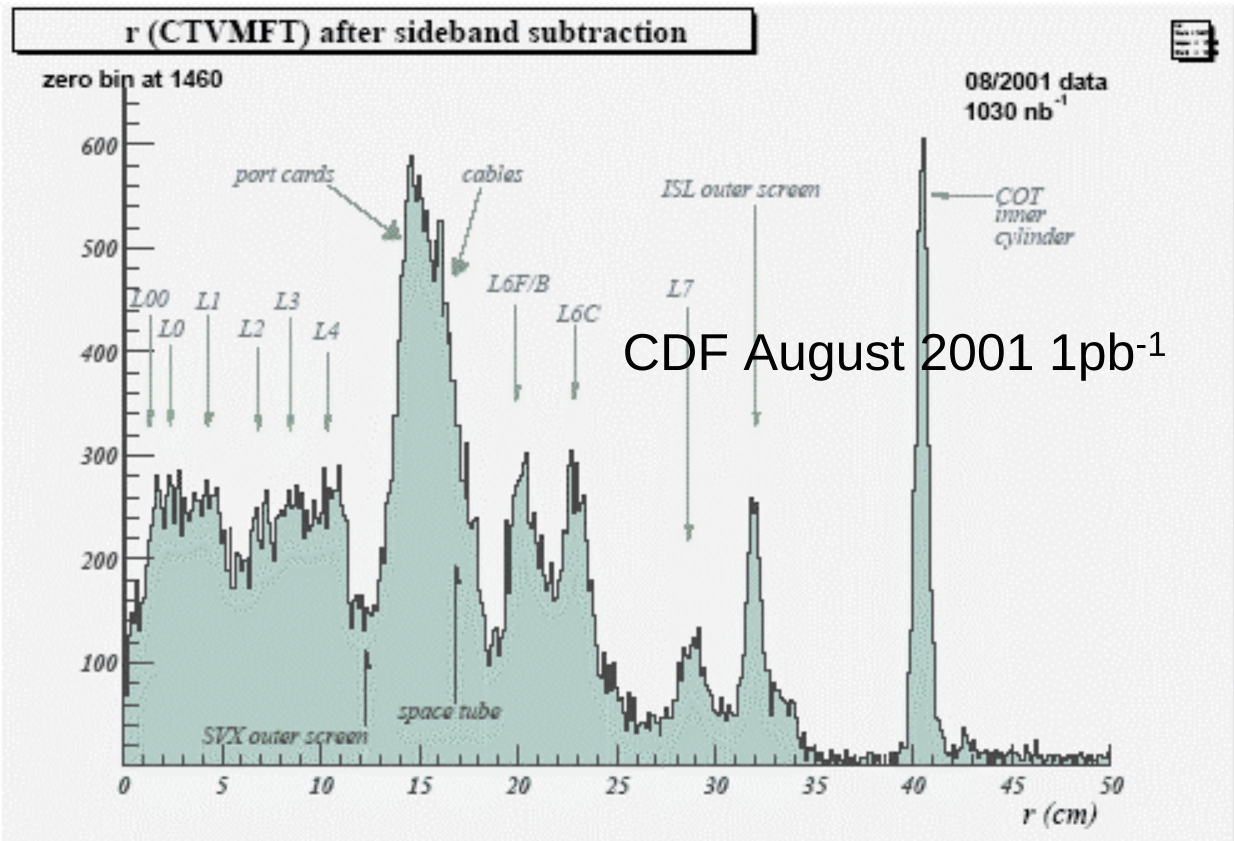
Align detector better than ~ 20 μm (80/√12)

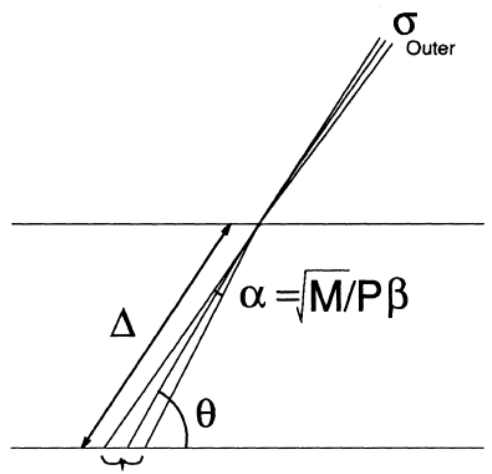
Use overlaps to determine the hit resolution

Use residuals wrt 1/p to measure material budget



$$\sigma_{res} = 2 \otimes \sigma_{vdet} \oplus \sigma_{outer} \oplus \sigma_{MS}$$





$$\sigma_{residual} = \alpha\, \Delta \cos(\theta) \oplus 2\, \sigma_{VDET} \oplus \sigma_{Outer}$$

J/psi tool for material and B (Pilot run)

Need to define a new J/Psi trigger

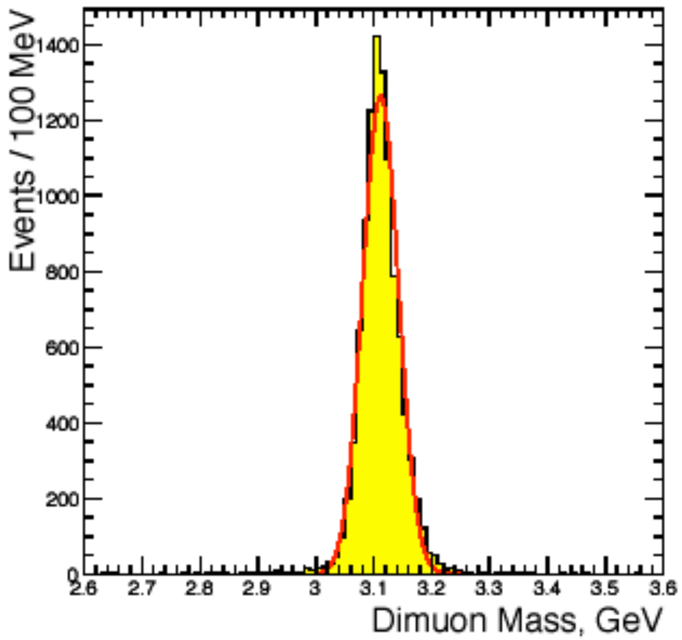
L1

- 2 muons with p_T>3 GeV

L2

- Primary vertex reconstruction (in z)
  - Currently done using pixel
  - No experience w/o pixels so far
  - In each region identified by the two muons reconstruct tracks with up to 5 hits

Need to be re-evaluated taking into account the new running conditions

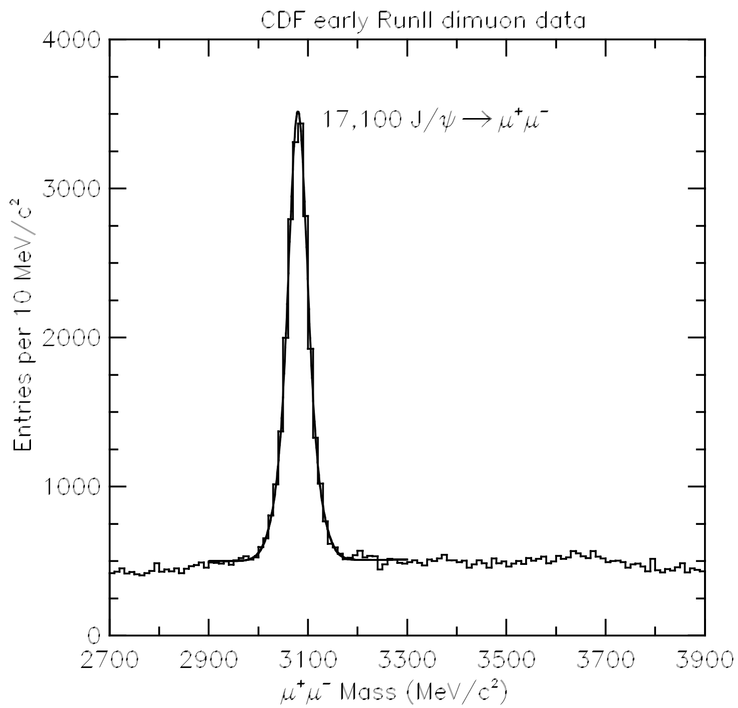


J/ψ mass residuals
Mean = 3.112 GeV
σ = 31 MeV

J/psi tool for material and B (Pilot run)

CDF Very early J/ψ data (few pb^{-1})

- **Established basic momentum scale for tracking**
- **Used to measure muon chamber efficiencies**
- **Used to measure vertex resolution of SVX**
- **Used to measure energy scale of hadron calorimeter**

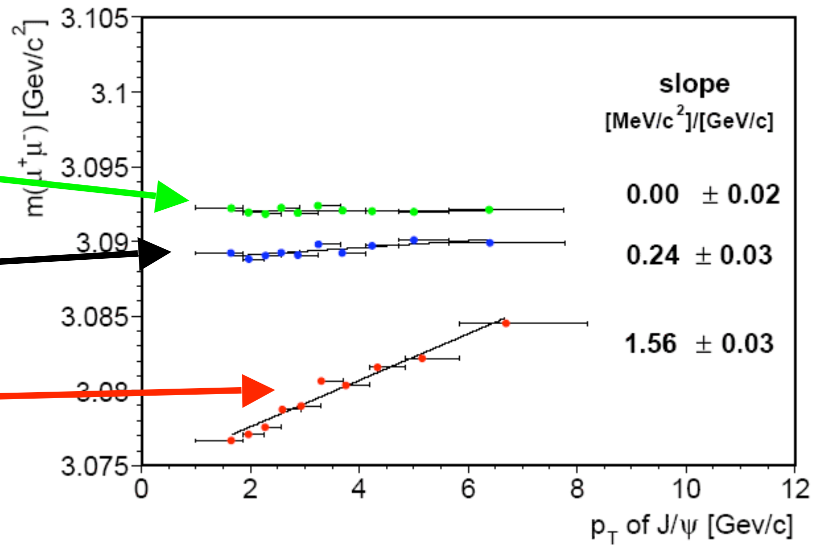


Similar tools using the mass of reconstructed J/psi, Upsilon and Z's can be used to study the Magnetic Field effects (physics run)

Additional 0.455 g/cm^2

Corrected for nominal material in simulation

No corrections



New ideas for the future: SLHC

Basic assumptions

•Luminosity $10^{35}cm^{-2}\ s^{-1}$
•Bunch spacing 12.5ns (10ns)

•Program of new physics with an integrated luminosity of $2500fb^{-1}$
•Start-up around 2015

•Need of maintaining B-tagging capability
•Momentum resolution
•Pattern recognition

•Fast (10ns) and low power (1-2mW/ch) electronics assumed to be available

New ideas for the future: SLHC

The CMS concept can be maintained for S-LHC

•Radial region: 50-60cm<r<110cm ;

$1x10^{14}cm^{-2}<\Phi<2.5x10^{14}cm^{-2}$

No basic new development. Optimization of existing technologies.

•Radial region: 20cm<r<50-60cm;

$2.5x10^{14}cm^{-2}<\Phi<8x10^{14}cm^{-2}$

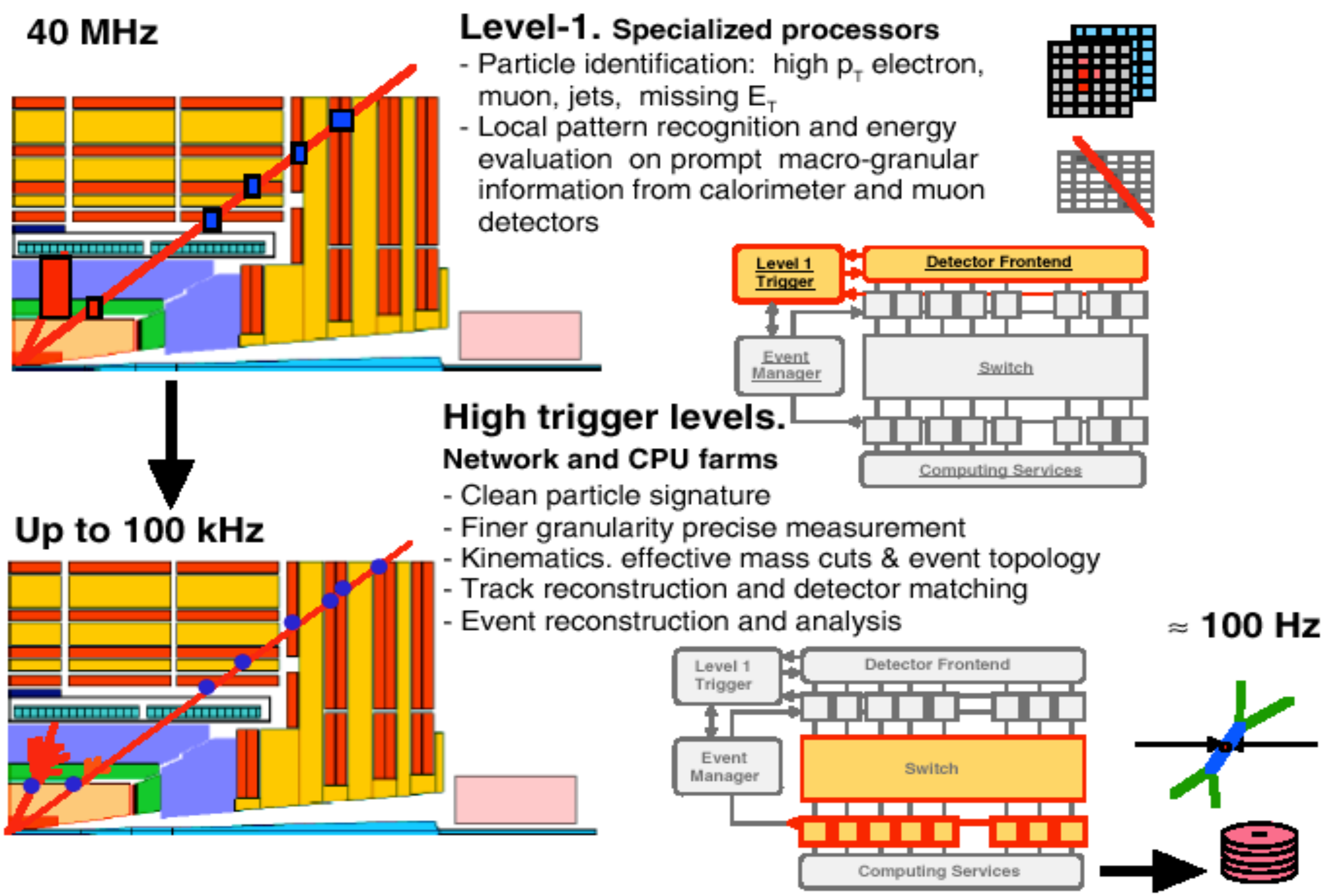
Extension of the actual pixel technology, low cost and triggering capability

•Radial region: 5cm<r<20cm :

$10^{15}cm^{-2}<\Phi<10^{16}cm^{-2}$

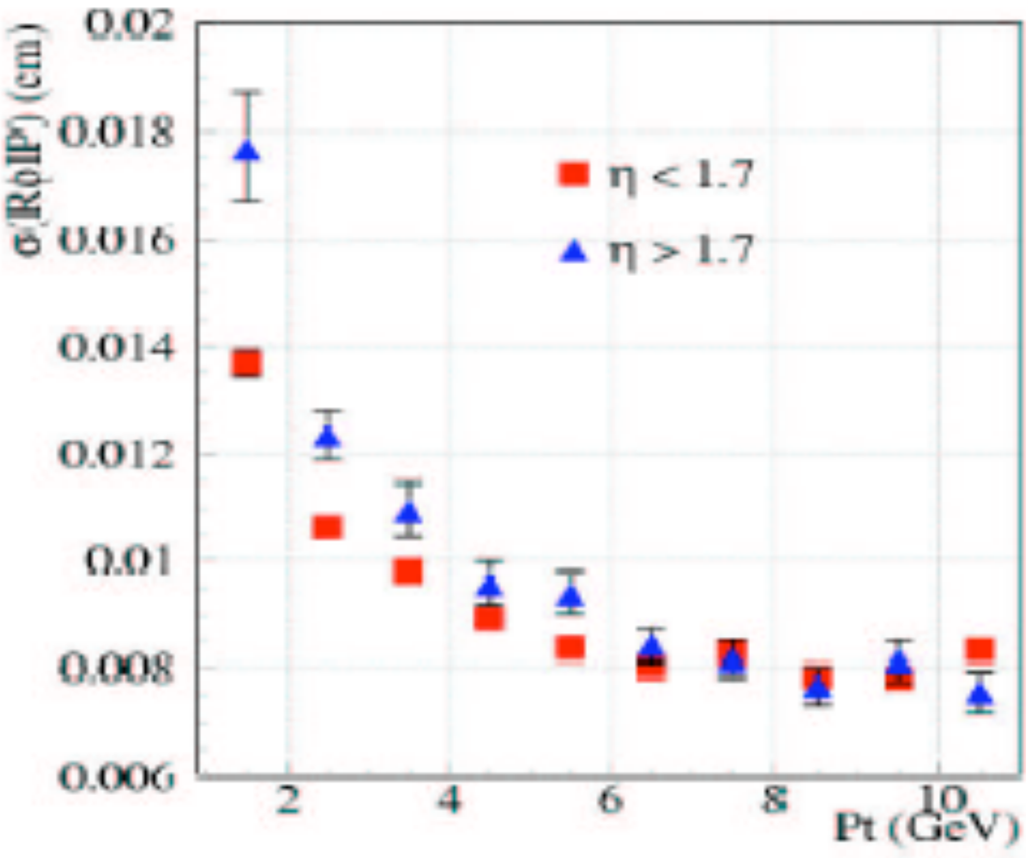
New ideas, new materials.

New ideas for the future: tracking@L1

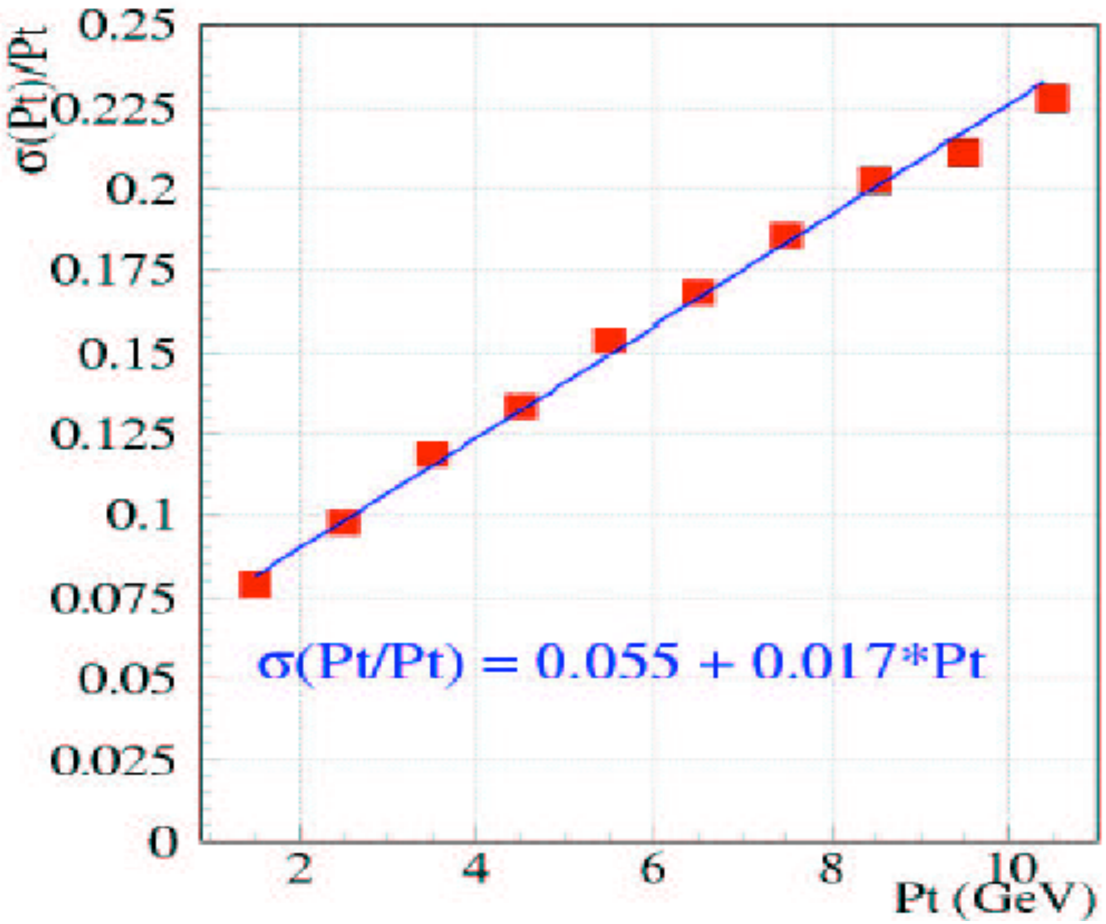


@L1 very high thresholds are needed: 250GeV for single jet, 110GeV for three jets; pt>20GeV/c for muons and E>34 GeV for electrons

What can be achieved with 3 pixel points only



σ(high Pt) ~ 80 μm



With a dedicated read-out for the pixel detector (SUPER-LHC upgrade) we plan to include the tracker in L1 trigger (a lot of physics potential of the new technique; improved S/N ratio in many difficult channels)

Conclusion

Join us!
We'll have a lot of fun !