Collider Detectors II

Taking useful data

Identifying physics objects

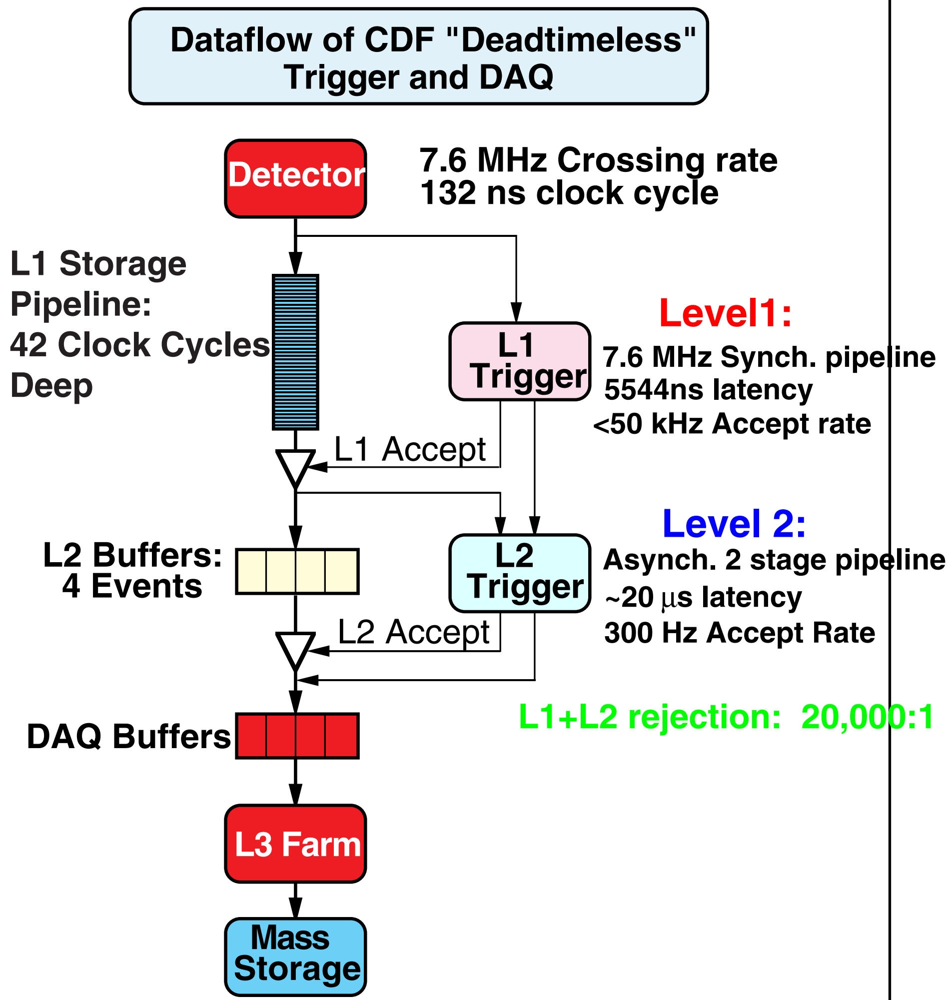
Performing measurements

CDF Trigger

Designed in early '80 (of the last century) as a three stage system:

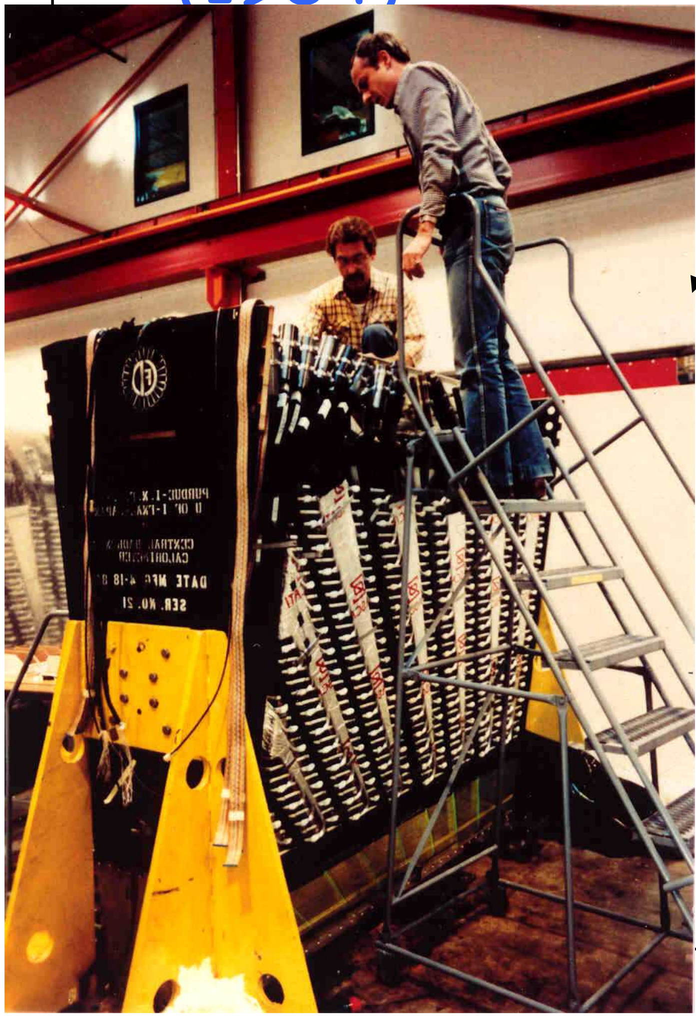
- ☞ L1 (hw), synchronous with bunch crossing
- ☞ L2 (hw processors)
  - ⇨ Over time added more programming capability to gain in flexibility
- ☞ L3 (commercial processors capable to run a simplified version of the offline)
  - ⇨ First run on VAX cluster processors, now linux boxes

The Run II version



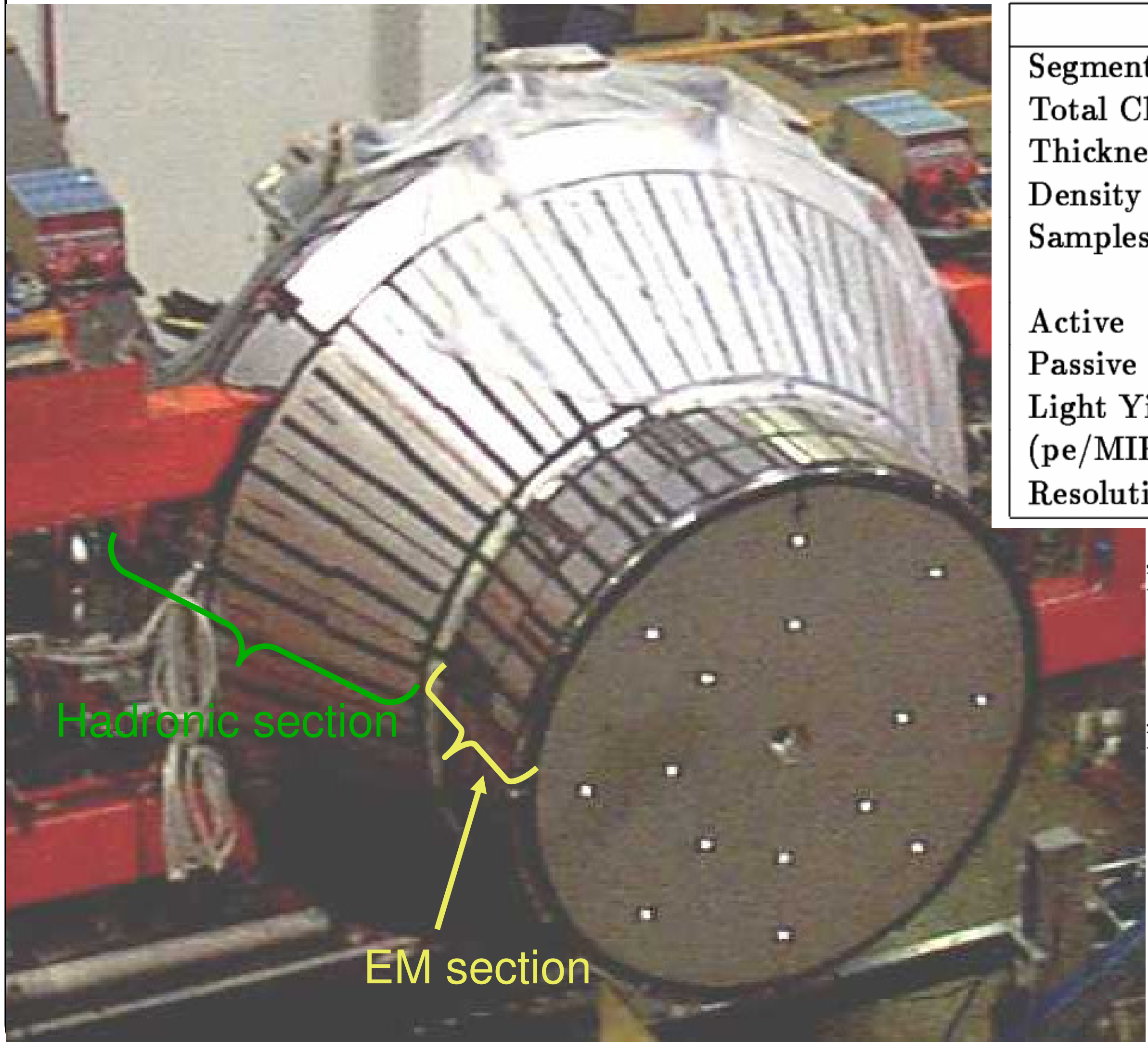
Central Calorimeter

Assembly and test of Central Calorimeter (1984)

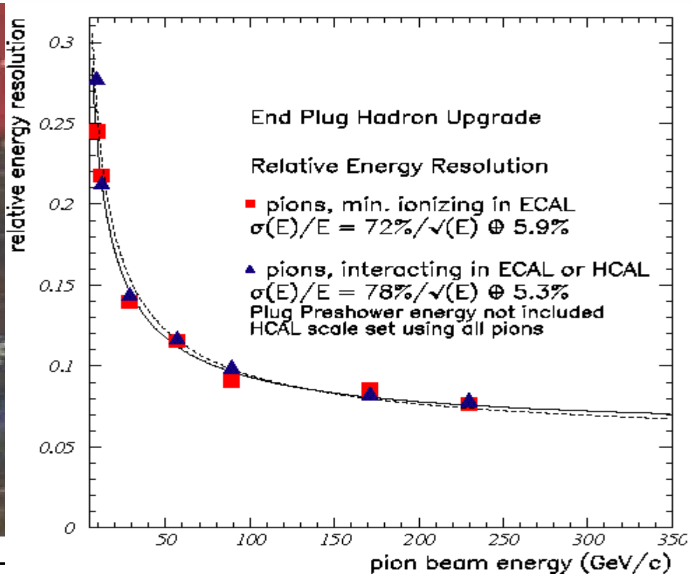


	EM	HAD
Segmentation	~ 50 cm $\times$ 20 cm	~ 70 cm $\times$ 35 cm
Total channels	956	1344 (with endwall)
Thickness	18 X_0, 1 λ_0	4.7 λ_0
Samples	21-30	32
Active	5 mm Scint.	1.0 cm Scint.
Passive	3.2 mm lead	2.5 cm steel
Resolution	$13.5\%/\sqrt{E} + 1\%$	$75\%/\sqrt{E} + 3\%$

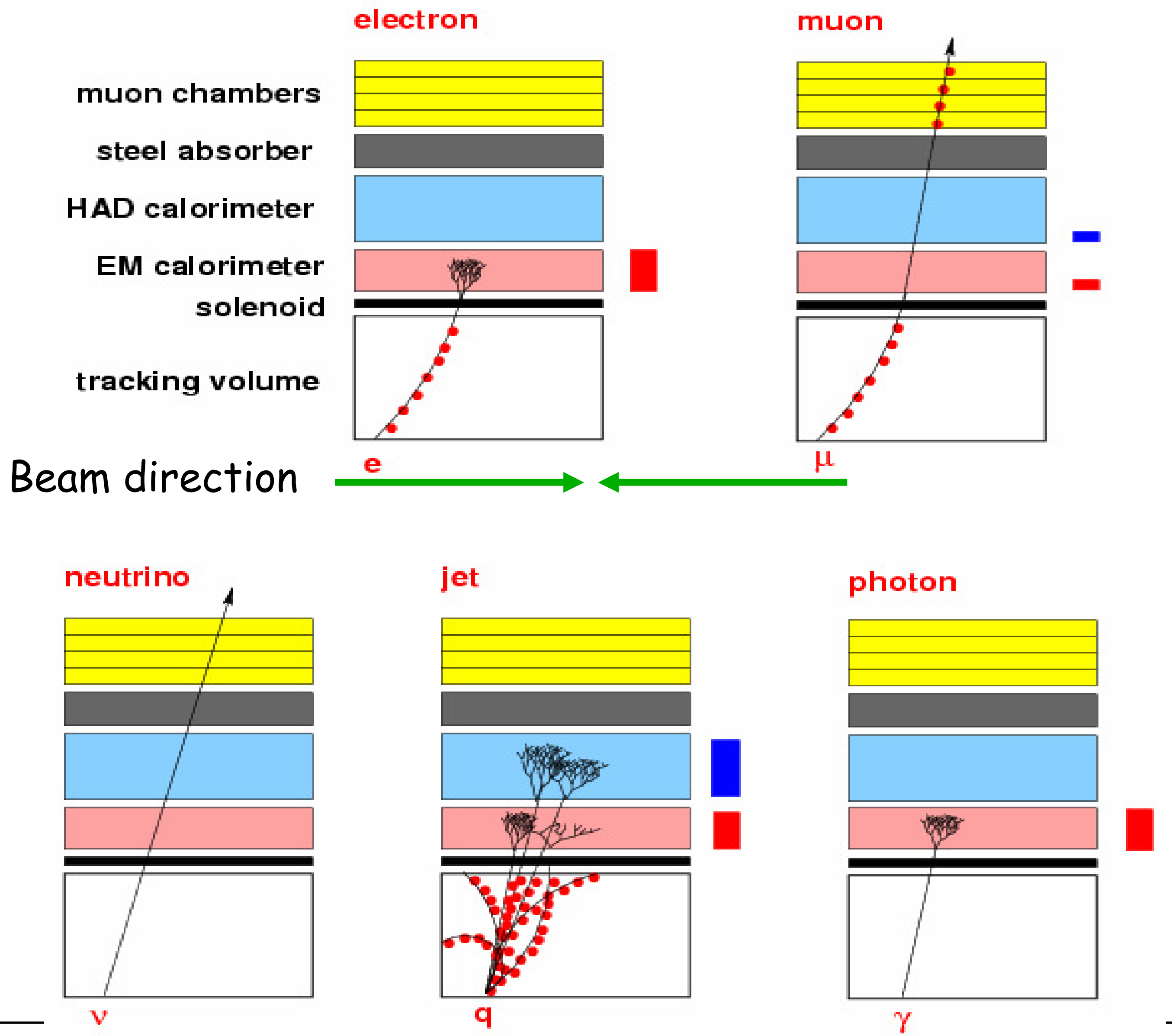
"Plug" Calorimeters



	EM	HAD
Segmentation	$\sim 8 \times 8cm^2$	$\sim 24 \times 24cm^2$
Total Channels	960	864
Thickness	$21\ X_0$, $1\ \lambda_0$	$7\ \lambda_0$
Density	$0.36\rho_{Pb}$	$0.75\rho_{Fe}$
Samples	22 + Preshower	23
Active	4 mm Scint	6 mm Scint
Passive	4.5 mm Pb	2 inch Fe
Light Yield (pe/MIP/tile)	$\geq$3.5	$\geq$2
Resolution	$16\%/\sqrt{E} \oplus 1\%$	$80\%/\sqrt{E} \oplus 5\%$

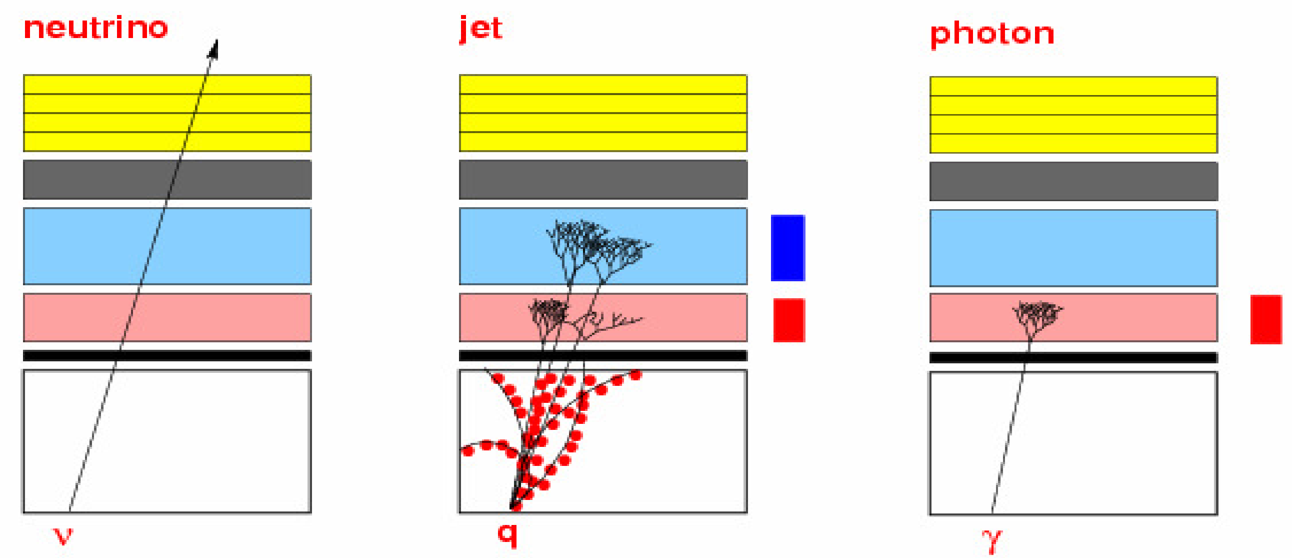


How do we identify a particle?

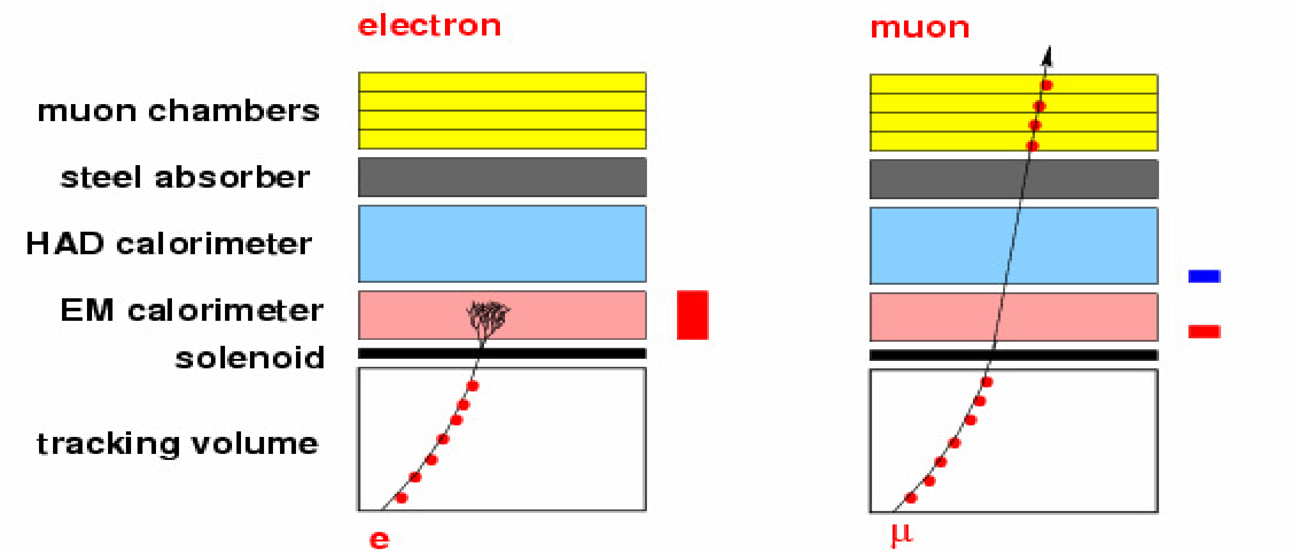


PID- I

Neutrino:	Jet:	Photon:
Non interacting	Release of energy in EM and Had compartment	Energy deposited in EM compartment of calorimeter
Missing Transverse energy: $\vec{E}_T = \Sigma_i E_{Ti} \bullet \vec{n}_i$ $\vec{\not{E}}_T = - \vec{E}_T$	Projective geometry, Fixed cone algo in $\eta-\phi$, $\Delta R = 0.4$	No associated track



PID II



Electrons: (|η| < 2.8)	Muons: (|η| < 1)
Track in COT (offline require COT-SVX)	Track in COT
Energy reconstructed in EM compartment, small Had/EM Shower profile consistent with an electron	Energy deposition: MIP Extrapolated track combined with stub in mu chamber

Neutrinos

Measurements:

- ☞ Energy from individual calorimetric towers

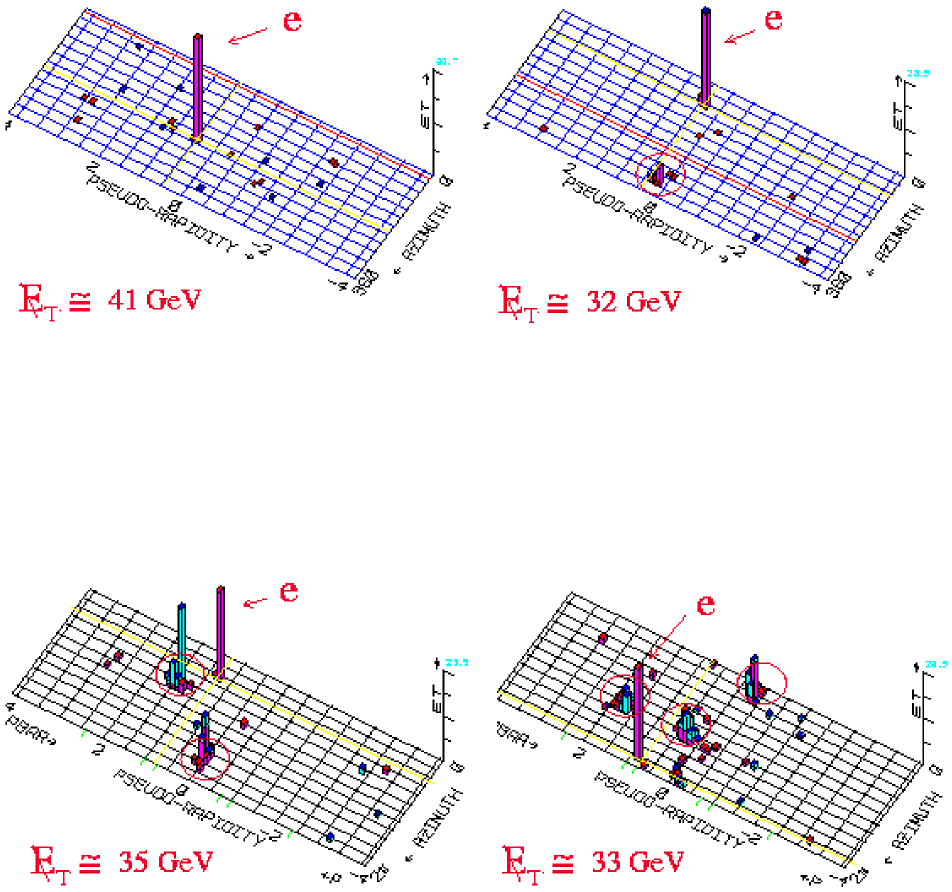
Requirement:

- ☞ Imbalance of tranverse energy (above threshold)
  - ⇨ Computation of tower energy

Background:

- ☞ Leaks in non instrumented regions (*cracks*)
- ☞ Cosmic rays
- ☞ Hardware problems

CDF:
W + 0,1,2,3 jet(s) Events



Electron

Measurement:

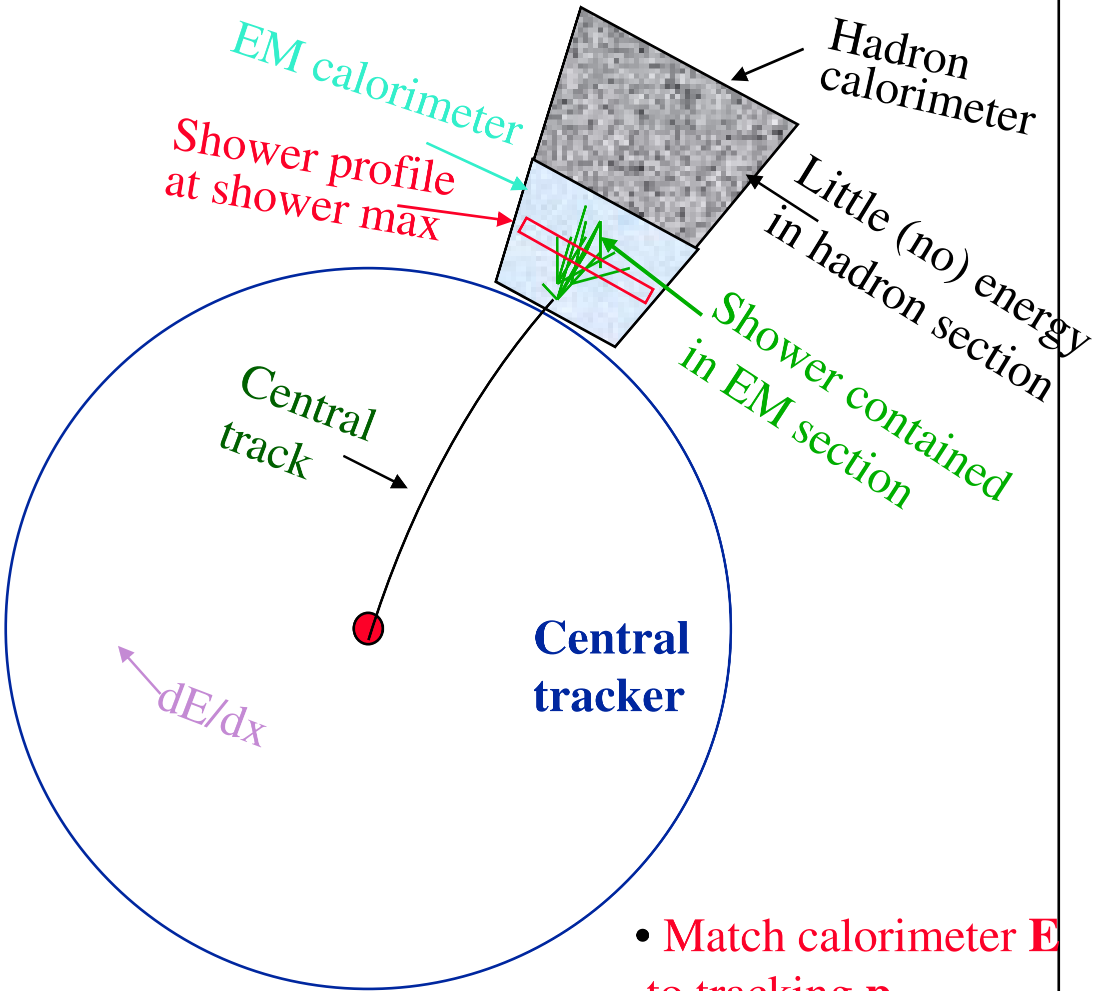
- Central tracker:
  - ⇨ Momentum
  - ⇨ Trajectory
  - ⇨ dE/dx
- Calorimeter:
  - ⇨ Energy in EM e HAD section (EM/HAD)
- Shower max chambers:
  - ⇨ Shower profile

Requirements:

- Cluster EM
- Small energy in Had compartment
- Track-cluster match
- Energy momentum match
- dE/dx and shower profile

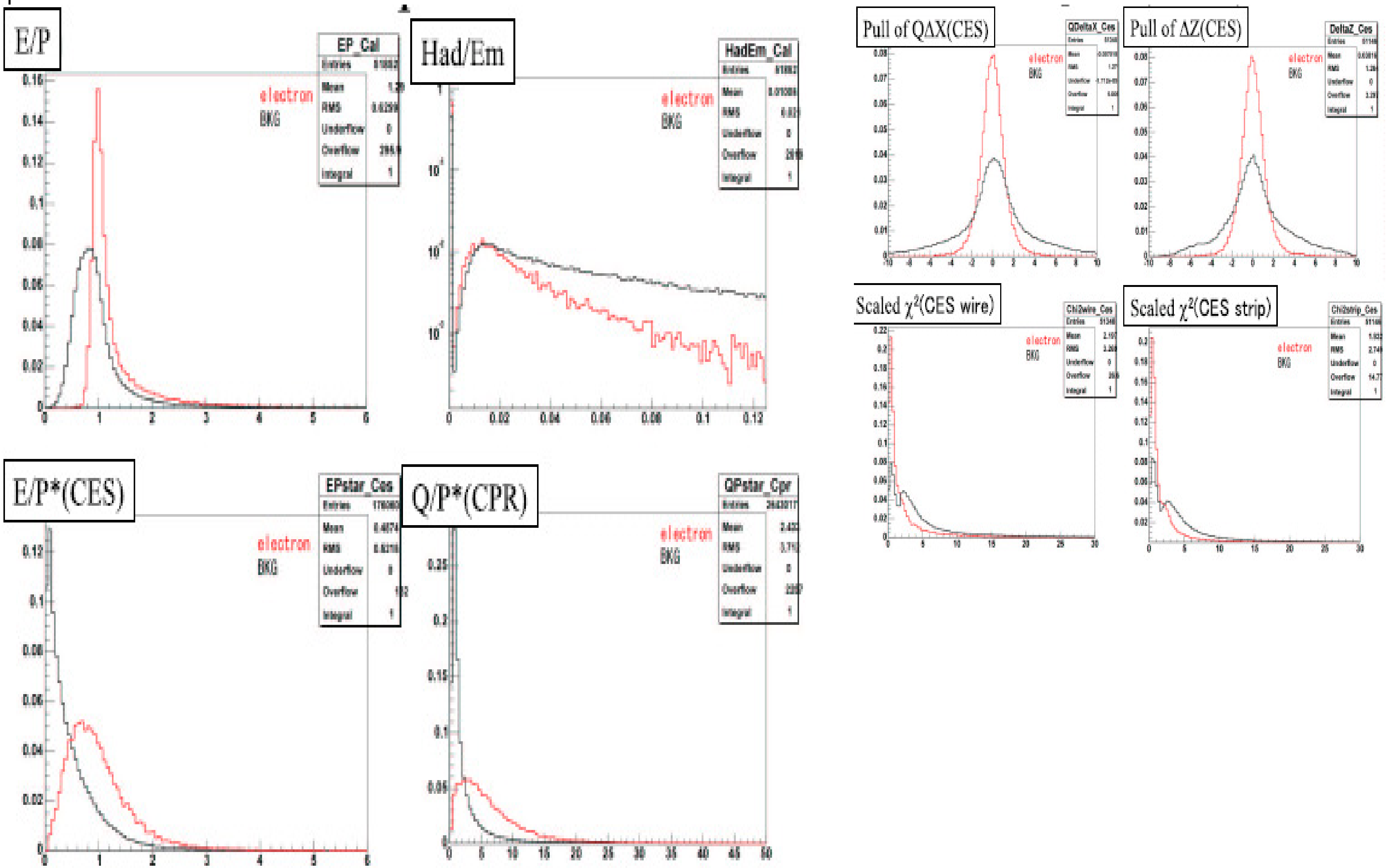
Background:

- π_0, hadrons, early interactions, γ conversions



• Match calorimeter **E** to tracking **p**

$e^{\pm}$ definition cuts



What is a muon?

Measurements:

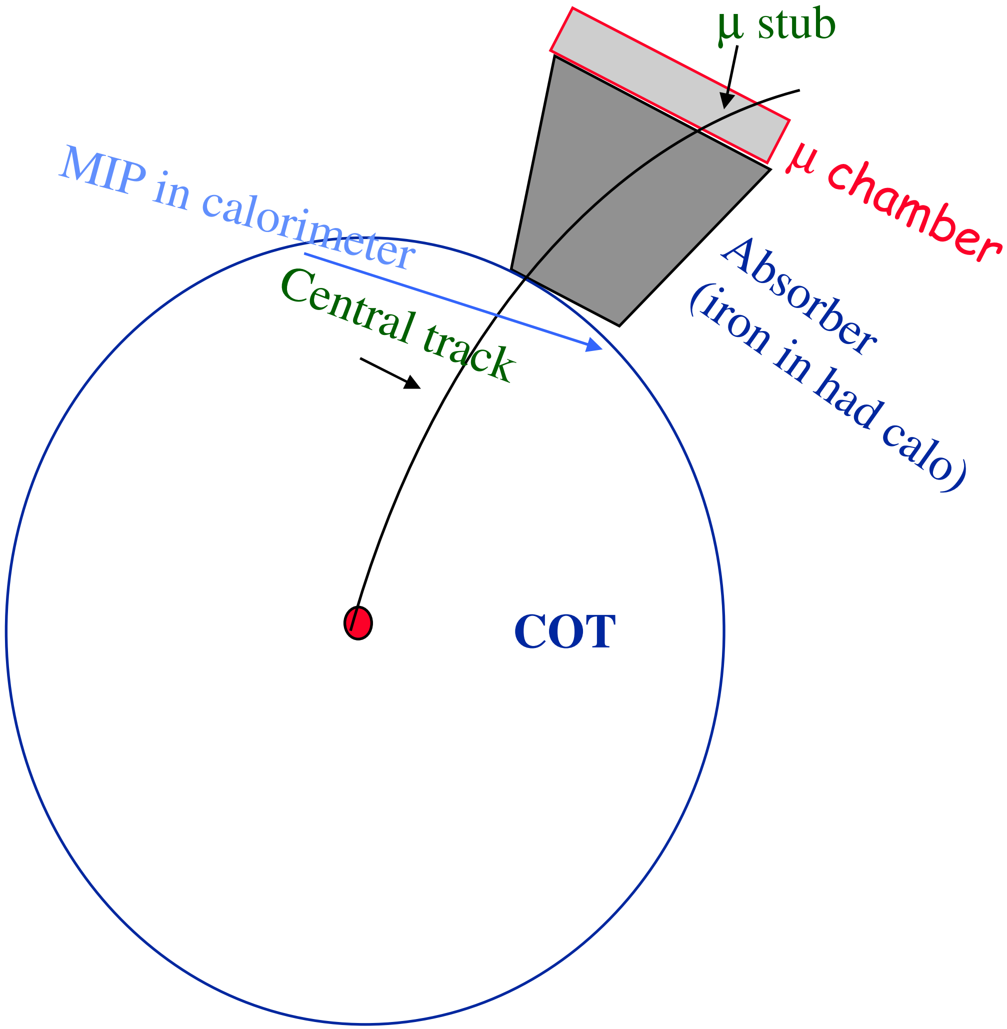
- ☞ Central tracking chamber:
  - ⇨ Trajectory and momentum
- ☞ Calorimeter
  - ⇨ Energy (m.i.p.)
- ☞ Muon chamber
  - ⇨ Trajectory (stub)

Requirement:

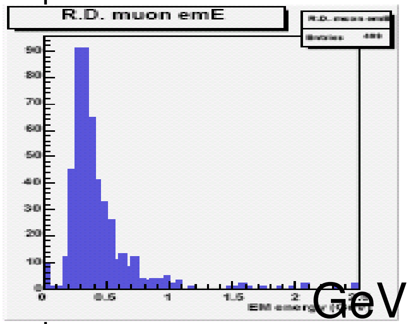
- ☞ MIP in calorimetric towers crossed by a candisate
- ☞ Track angle and position matching with the stub

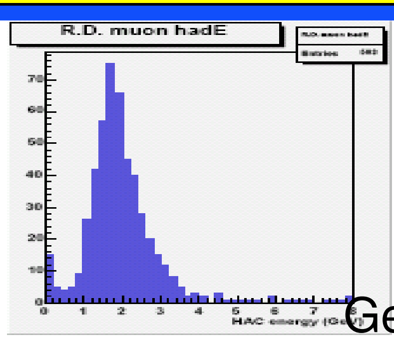
Backgrounds:

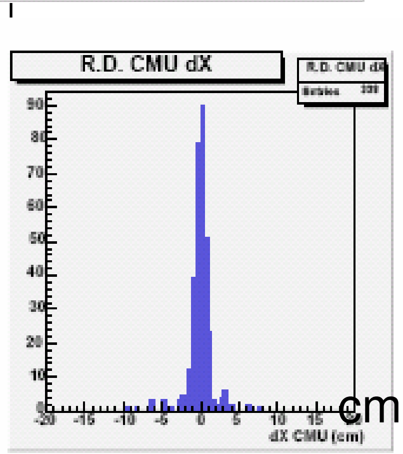
- ☞ Decady I n flight, non-interacting particles (K, π a.ka. punch-trough)

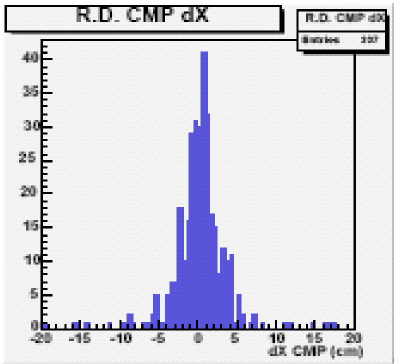


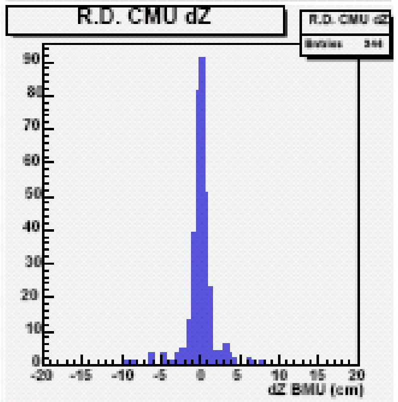
μ definition cuts

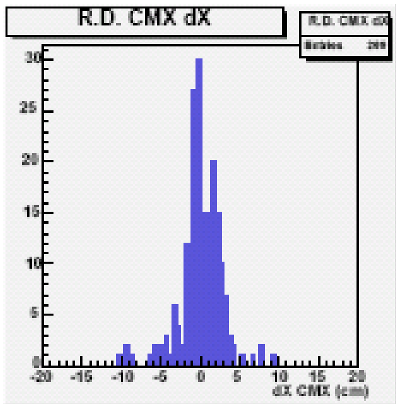




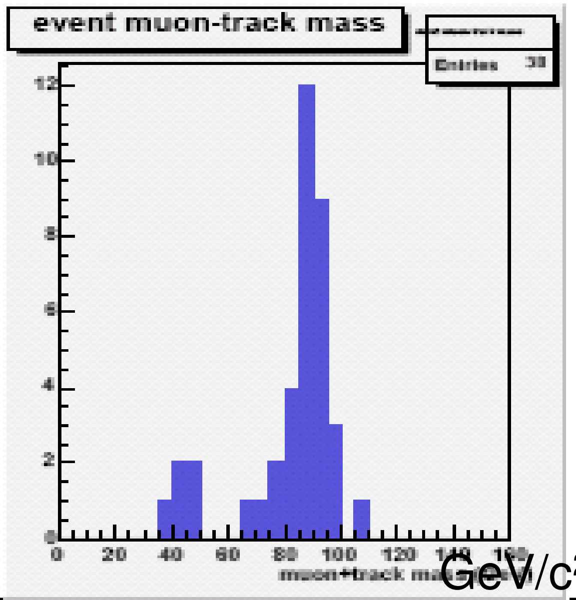




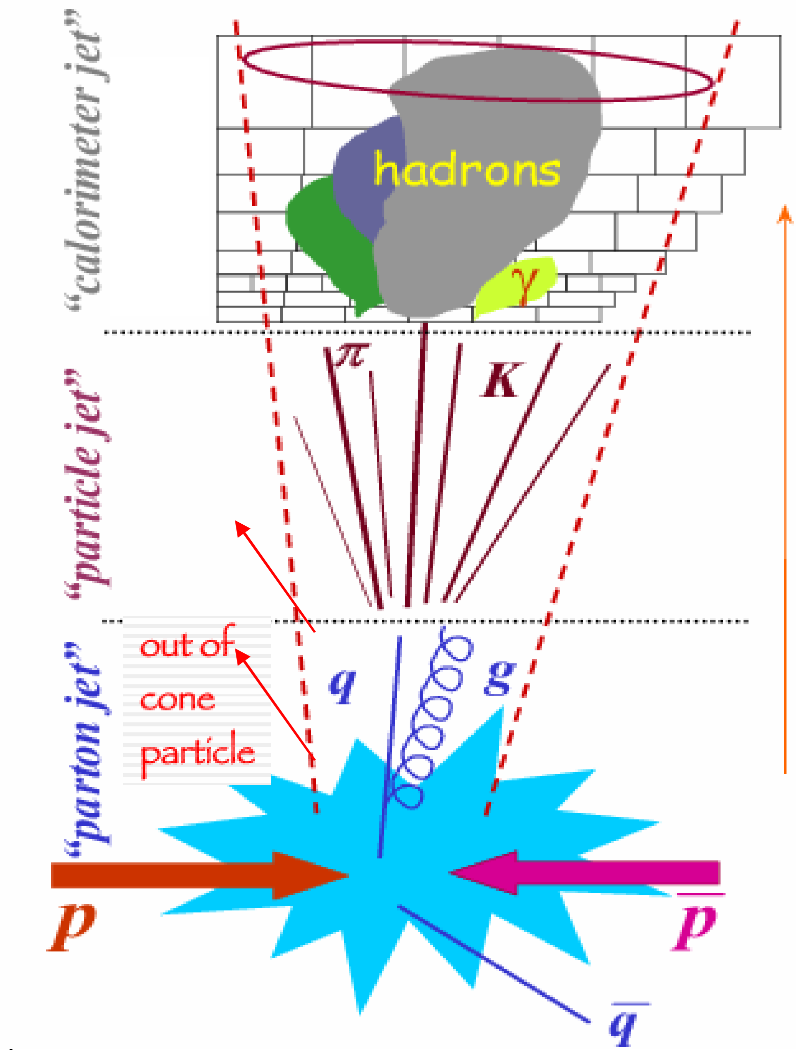




Check:
Z→μ+track



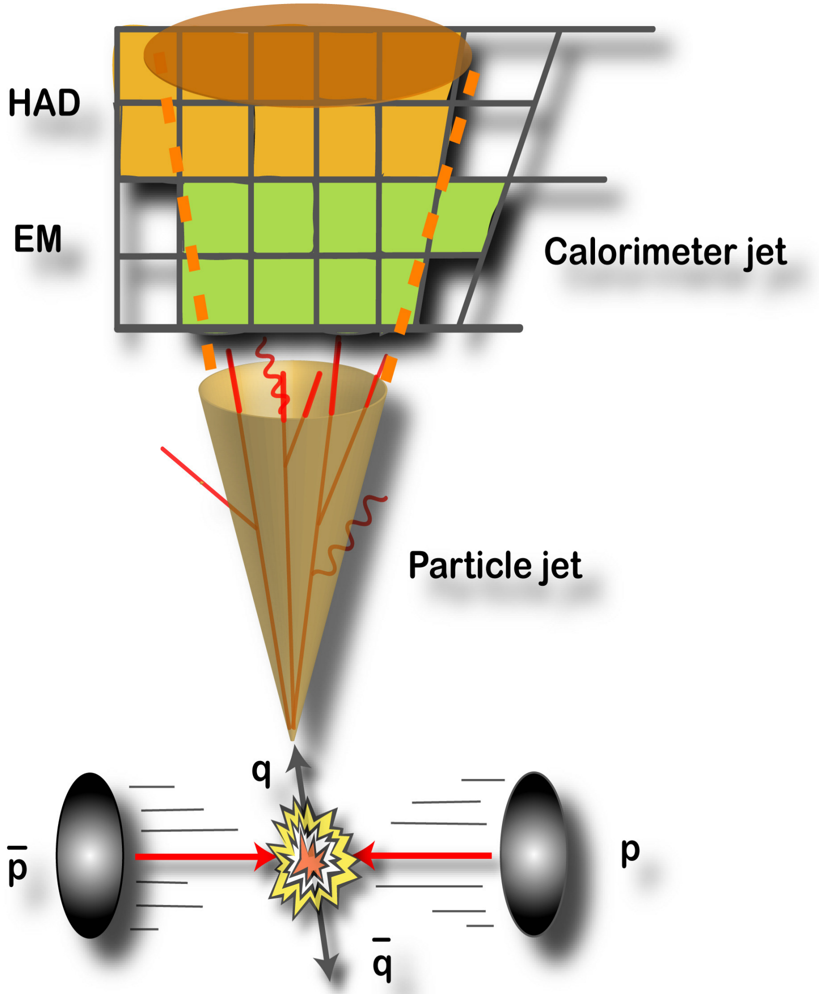
Reconstructing quarks -I



A jet is a fairly complicated object:

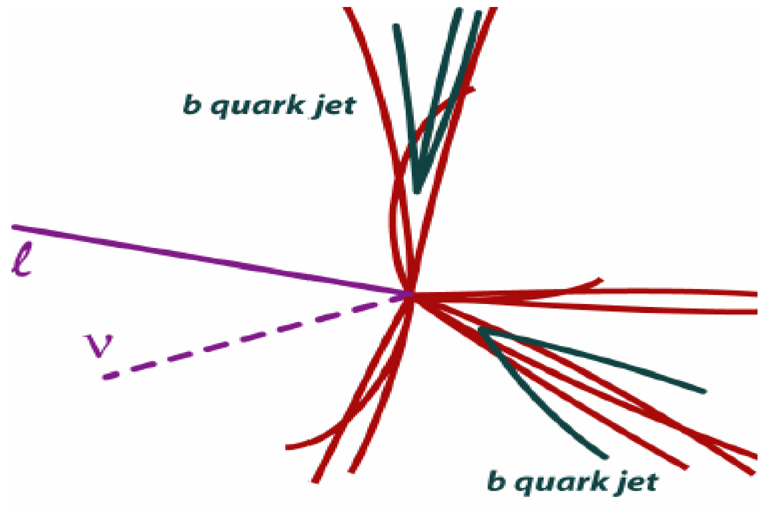
- Measured by: calorimetric towers
- Defined by a clustering algorithm
- Physics measurements with jets imply to convert *observed* energy into parton energy
- To convert jet energies into parton energies we must correct for:
  - Instrumental effects
  - Physics effects
  - Jet Algorithm effects
- Dubbed: Jet Energy Scale (JES)

Reconstructing quarks -II



You need to correct Jet Energy Scale (JES) to reconstruct the initial energy of the primary parton

b-jets have an exceptional value you can use a vertex tracker to reonctruct secondary vertices generated in b-hadrons decays



What is a jet at CDF?

Measurements:

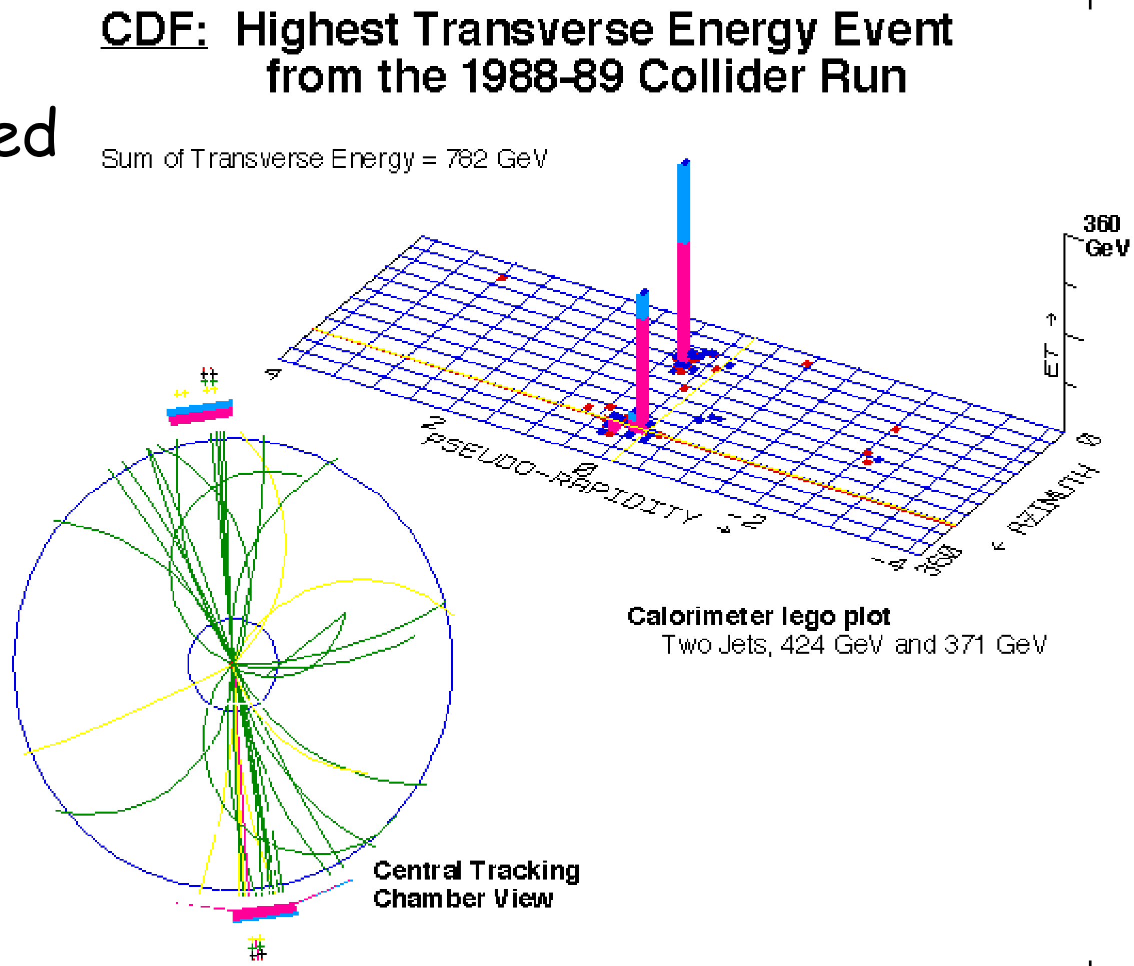
☞ Energy reconstructed in calorimeter

Requirement

☞ Cluster of adjacent towers above threshold

Background

☞ Problems related to adjacent jets and *underlying event* clusterized as jets (most important at high L)



B jets-tagging

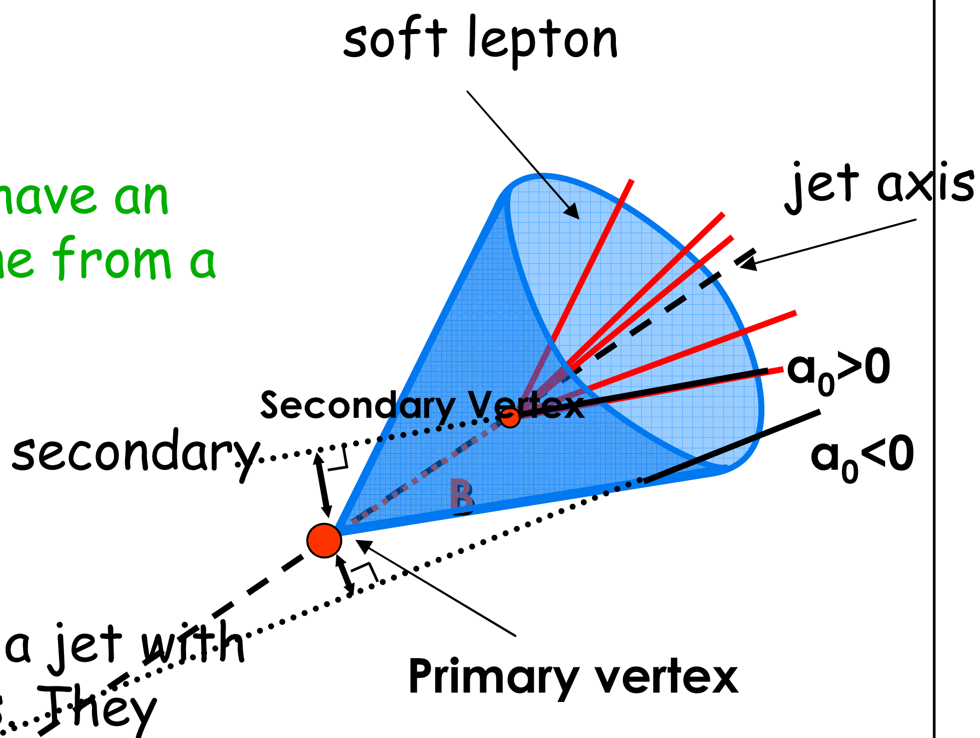
B decays provide high Pt tracks and secondary vertices (τ_b ~ 1.5 ps $c\tau$= 450μm)

Main methods:

1. Tracks originating from a b-jet have an higher impact parameter than one from a u,d,g jets.

2. Mass and energy associated to a secondary vertex are different for a b-jet

3. Identification of soft leptons in a jet with a relatively high pt from jet axis. They originate from b quarks semileptonic decay



Secondary vertices -I

Measurement:

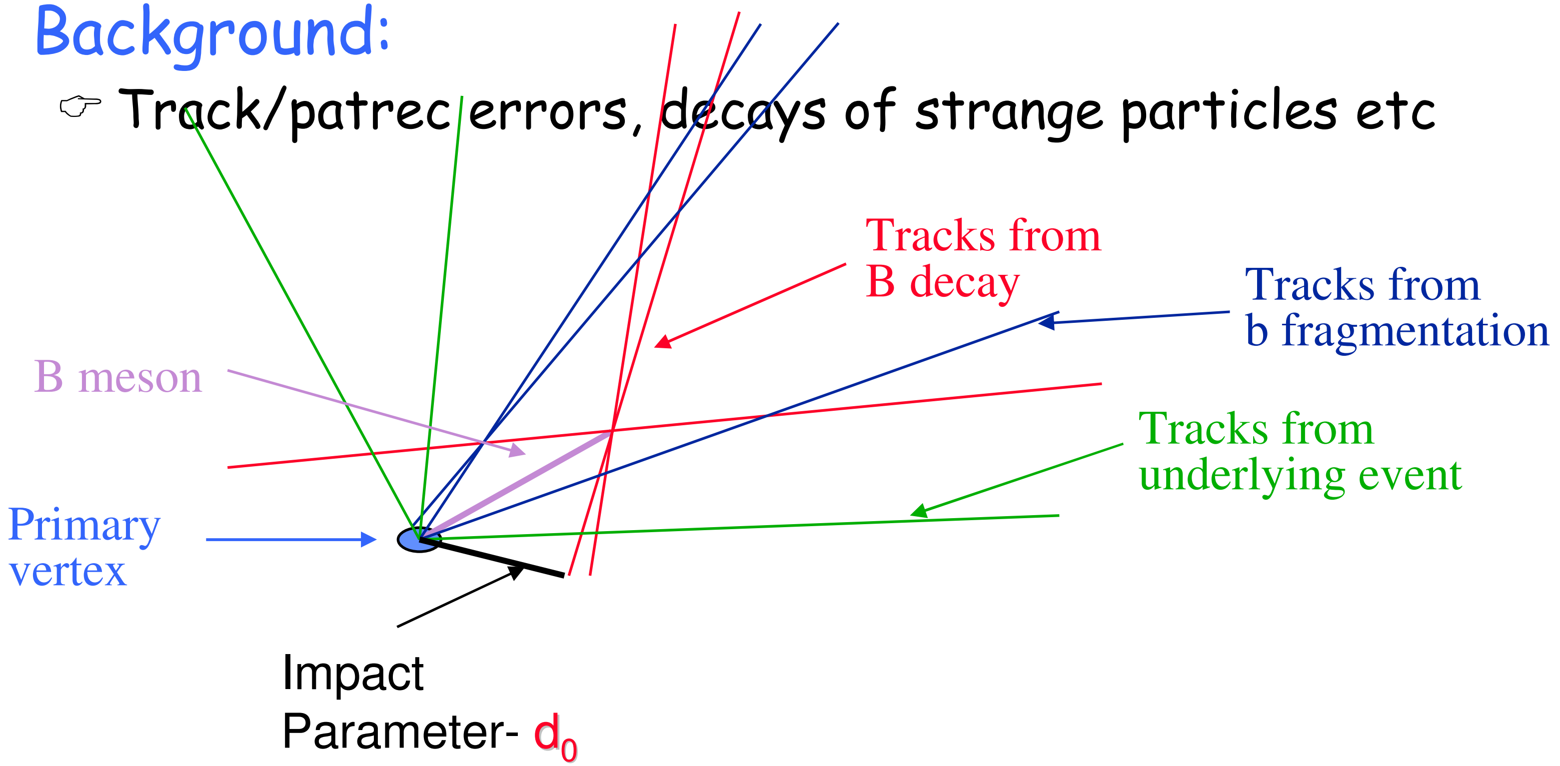
- ☞ Measure track impact parameter with great accuracy

Requirement:

- ☞ Find track with non-zero impact parameters reconstructing a vertex

Background:

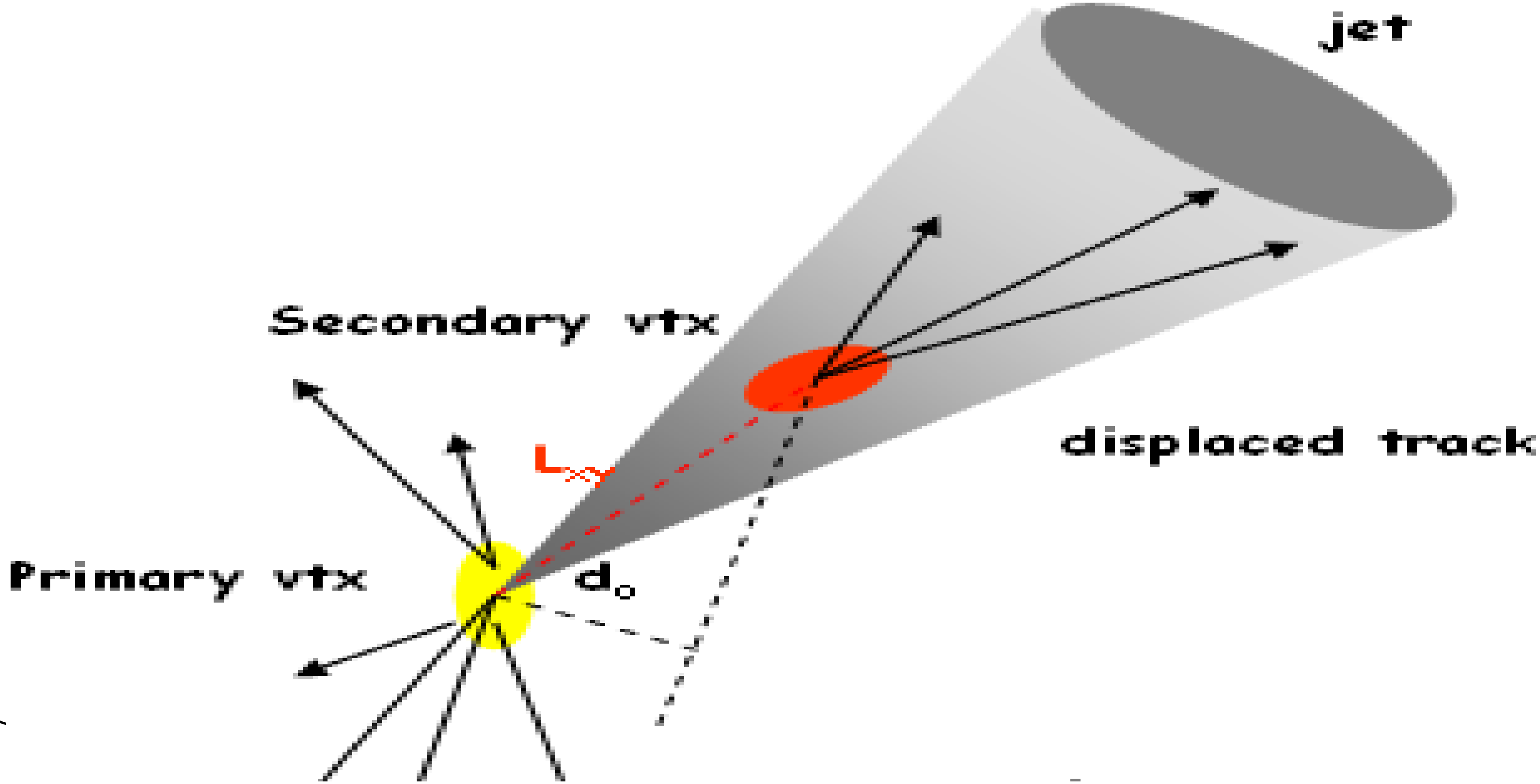
- ☞ Track/patrec errors, decays of strange particles etc



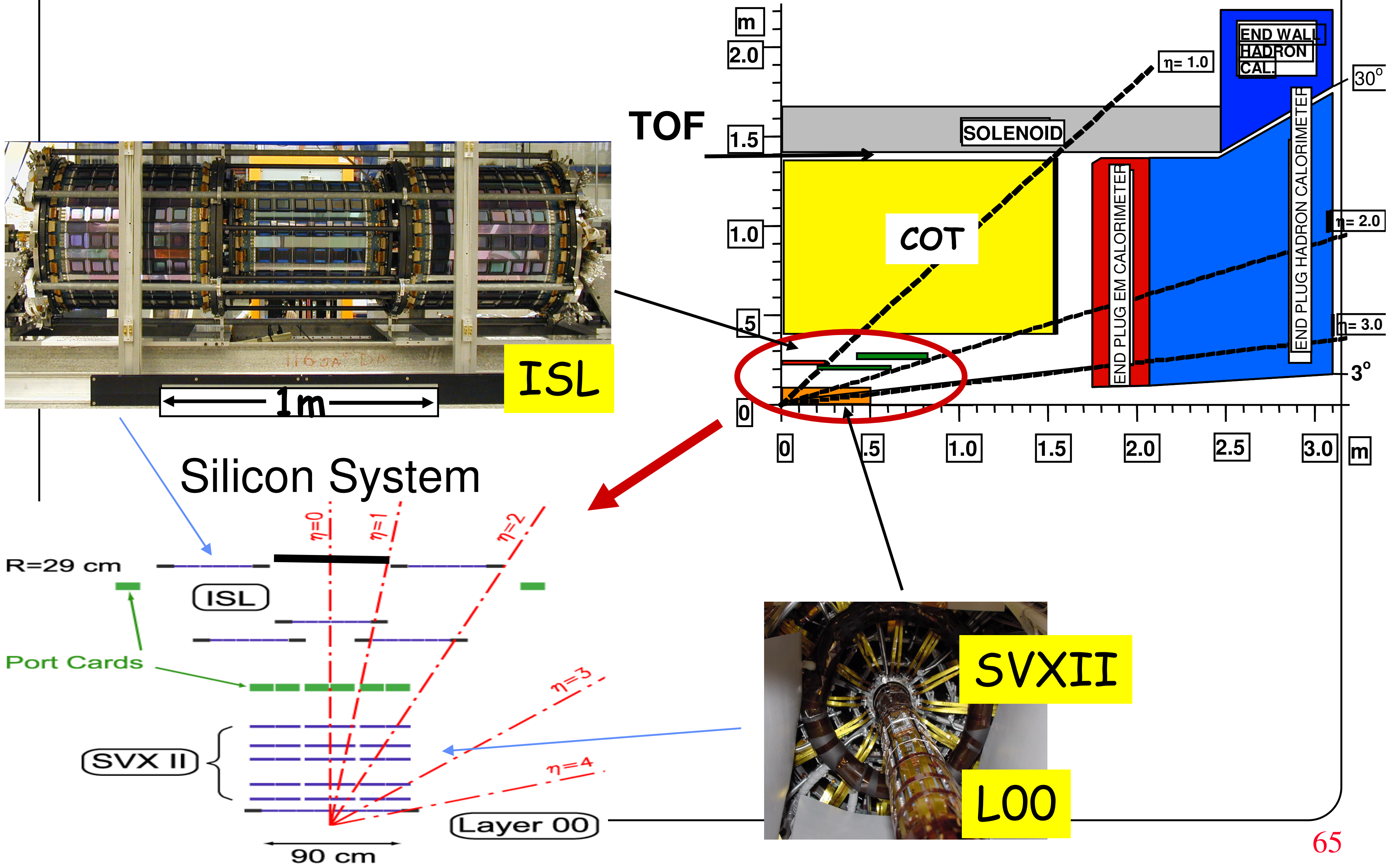
Secondary vertices -II

More schematic, try to identify with a *lifetime based* tagger

Relevant quantity: impact parameter and Lxy



Tracking system

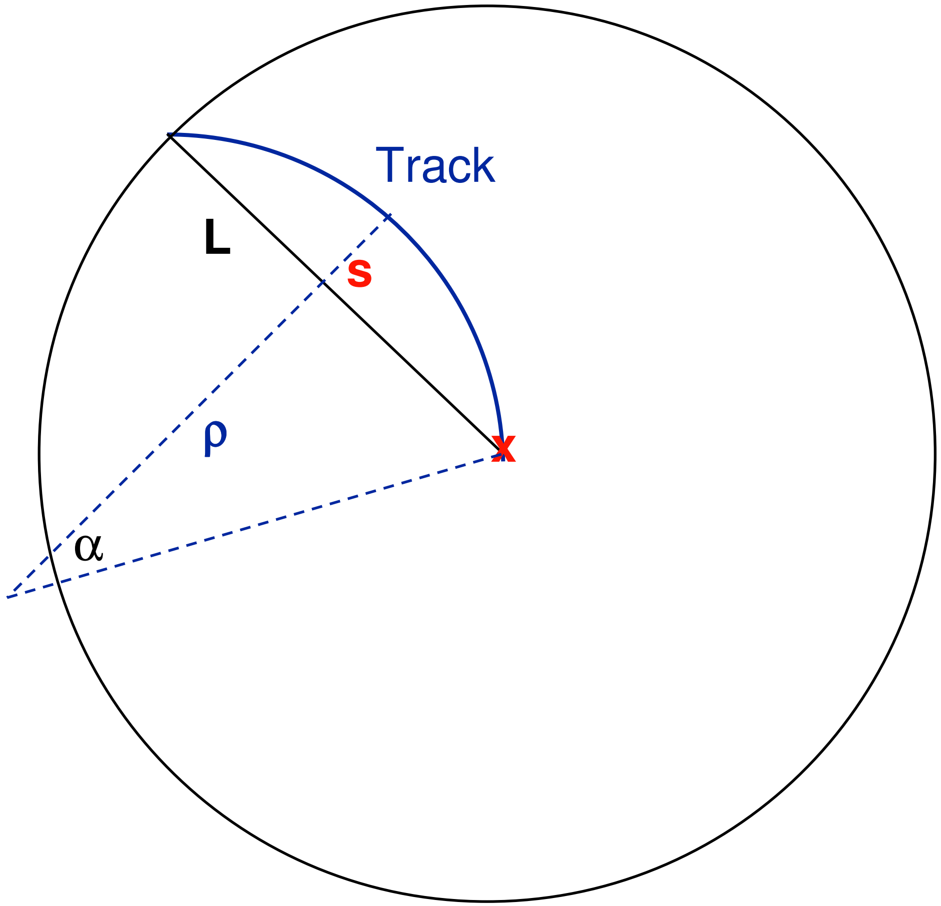


Momentum measurement

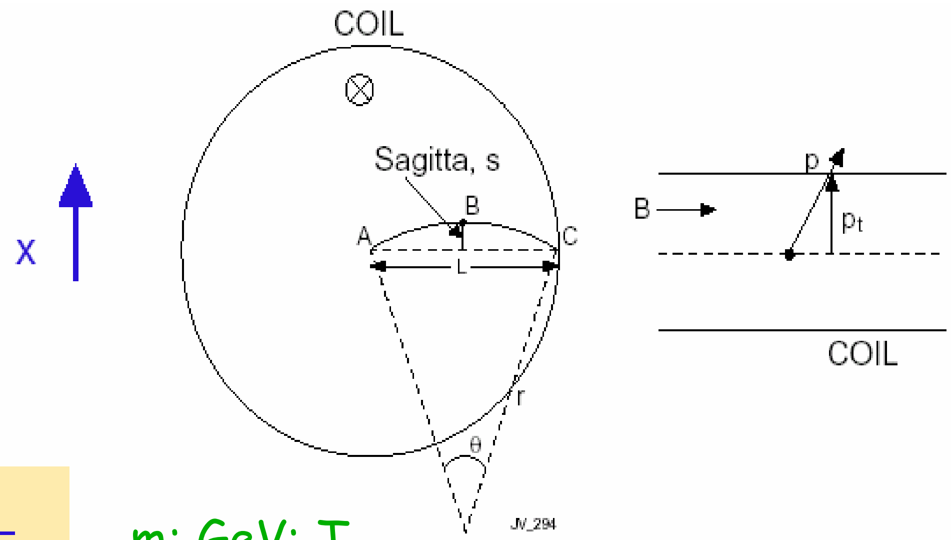
Momentum resolution

- Measure sagitta with constant resolution
  - $s = \rho\,(1-\cos\alpha)$
  - $\cos\alpha \sim 1-\alpha^2/2 \sim 1-(L/2\rho)^2/2$
  - $s = L^2/(8\rho)$
- $\rho \propto p_T/B$
- $s \propto L^2 * B/p_T$
- $\sigma_s \propto [L^2 * B/\ p_T] * \sigma_{p_T}\ /\ p_T$

$\sigma_{pT}/p_T^2 \propto \sigma_s\ /\ BL^2 =$ cost.



Momentum Measurement



Radius of curvature $r = \dfrac{p_T}{0.3B}$ m; GeV; T

If r>>L then $\sin\dfrac{\theta}{2} = \dfrac{L}{2r} \Rightarrow \dfrac{\theta}{2} \approx \dfrac{L}{2r} \Rightarrow \theta \approx \dfrac{0.3BL}{p_T}$

Sagitta

$$s = r - r\cos(\theta/2)$$

$$\approx r\left[1 - \left(1 - \frac{1}{2}\frac{\theta^2}{4}\right)\right]$$

$$= \frac{r\theta^2}{8} \approx \frac{0.3BL^2}{8p_T}$$

e.g. s ≈ 3.75 cm
for p_T=1 GeV/c, L=1m and B=1T

Momentum Measurement -II

At low P_t MS becomes important and dominant:

$$\theta_{rms} = \frac{13.6\,MeV\ \sqrt{L/X_0}}{\beta p}$$

This contributes to the uncertainty on the sagitta ~ L θ_{rms} ~ $L^{3/2}$ and decreases as 1/p. But the sagitta goes as 1/p and L^2. The result is:

$$\left.\frac{dp}{p}\right)_{ms} = \frac{0.045}{B\sqrt{LX_0}}$$

constant with P.

Conclusion: at low P MS is the dominant effect

Momentum measurement III

since: $$\frac{ds}{s} = \frac{dp_t}{p_t}$$

if one measures N points uniformly distributed along the track with an error σ_x

$$\frac{dp_t}{p_t} = \frac{1}{0.3BL^2}\sigma_x P_t \sqrt{720/N+5} = cP_t$$

which decreases linearly with B, quadratically with L and increases linearly with Pt

Ex: B=1.5T ; L=1m N= 96; σ_s= 180 μm

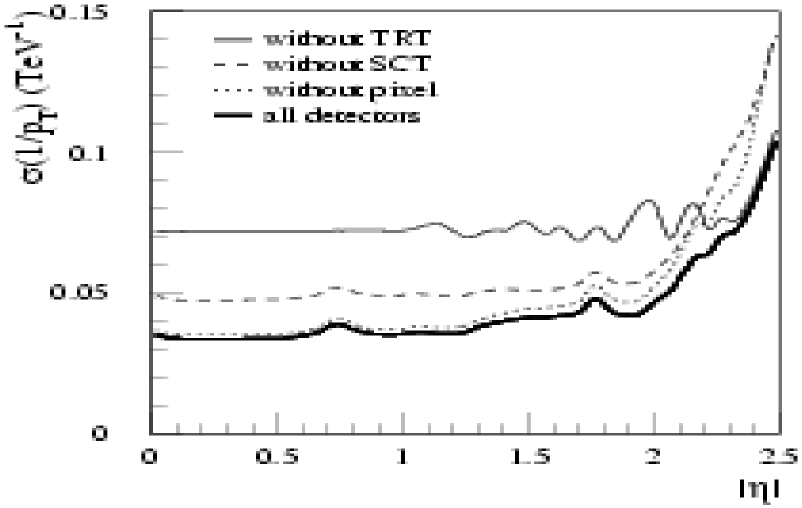
c = 10^{-3}

The Max measurable P_t would be:

Pt= 0.3/c = 0.33 TeV

For ATLAS c=$6\times10^{-4}$and Pmax=1 TeV

Detailed simulations give 2% of 1 TeV muons with wrong charge (η=0)



Uncertainties on track parameters

Paper: R.L.Gluckstern, NIM 24 (1963) 381-389

curvature:

$$\langle c^2 \rangle = \frac{\varepsilon^2}{L^4} A_N$$

$$A_N = \frac{720\, N^3}{(N-1)(N+1)(N+2)(N+3)}$$

Valid for equally spaced measuremnt points

- ⇨Non optimal choice

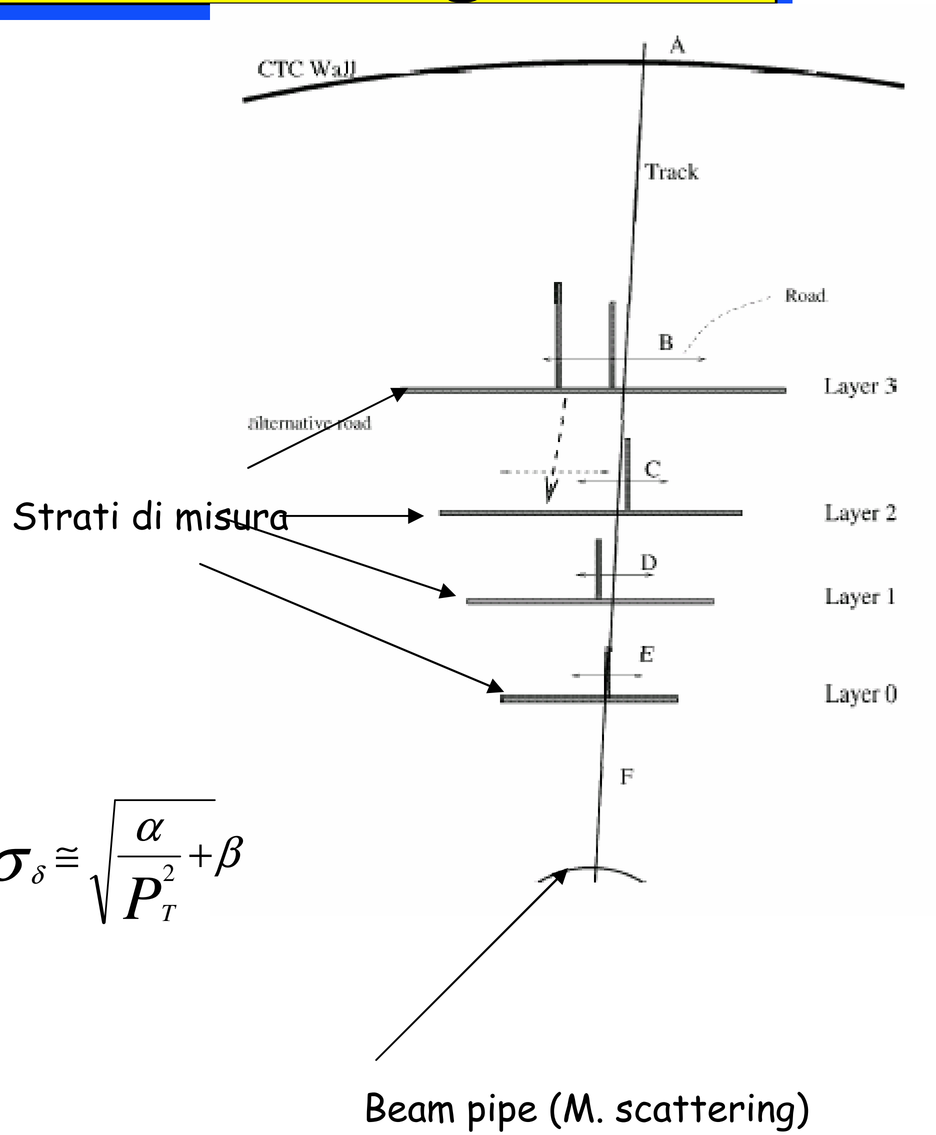
☞Its approximation (used in previous page) only valid for large N

- ⇨latter abused (and sometimes used with wrong coeffcients)

Vertexing and tracking -I

In Run I at tracks were not reconstructed by silicon vertex

- Track parameteters (5) reconstructed by an external (gas) detector
- Points measured in SVX are then attached to the track
  - Minimize role of M.S
  - Fast (only fitting)
  - Dominant role played in measuring impact parameter
- First measurement point and its distance from first scattering layer dominant in impact parameter accuracy
  - Need to maintain this layer efficienct



$$\sigma_{\delta} \cong \sqrt{\frac{\alpha}{P_T^2} + \beta}$$

Vertexing and tracking -II

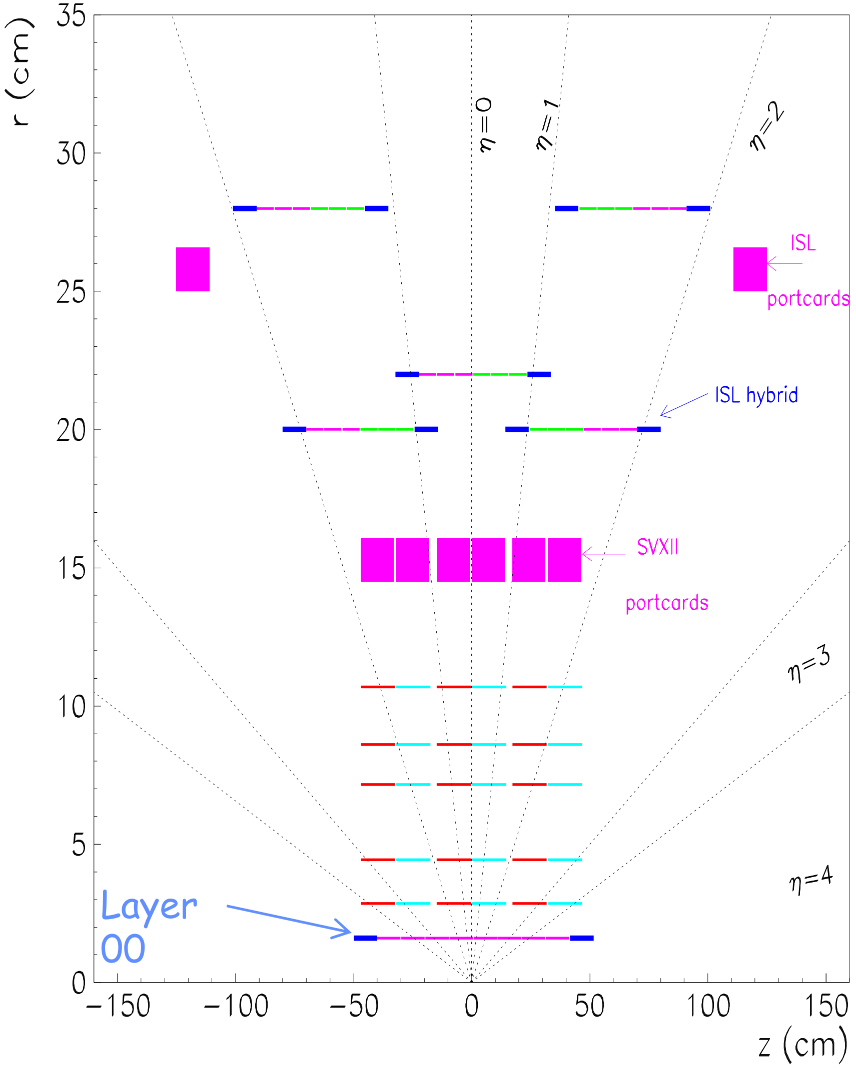
In a system in which a vertex detector has a role in tracking (CMS, CDF at $|\eta|>1$),you need enough point to guarantee redundancy and pattern recognition capability.

There is no independent system reconstructing the track.

- ☞ Delicate issue: material budget (γ-conversions)
- ☞ Another issue: radiation damage
  - ⇨ noise generates spurious hits, combinatorics can severely affects the pattern recognition capability
  - ⇨ Change in efficiency of a single layer can seriously affect the overall system efficiency

Always recall that a track has 5 parameters..

CDF Silicon Tracking System



System made of three different detectors(!)

- L00
- SVXII
- ISL

L00 arrived as last (added), single sided detector, rad-hard

SVXII was the first:

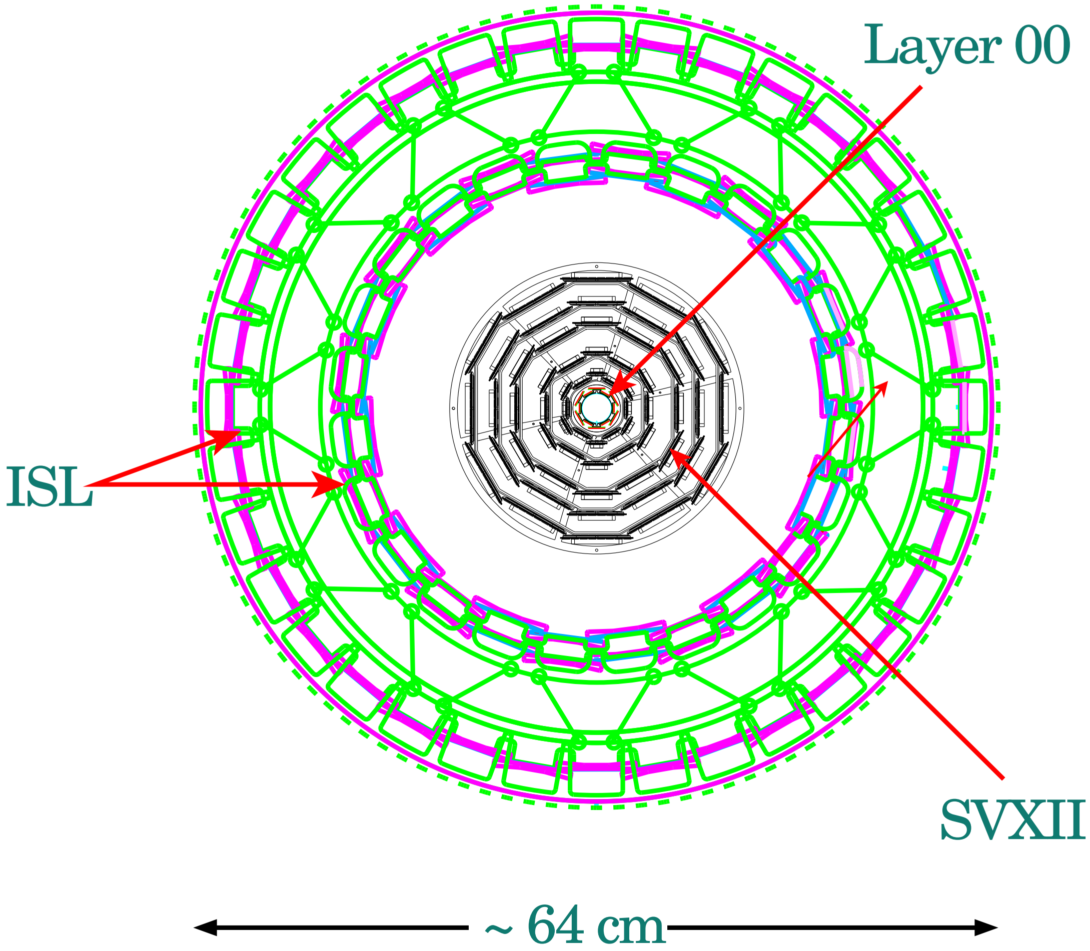
- 5 layers double sided (2 r-z stereo and 3 with 90° strips)

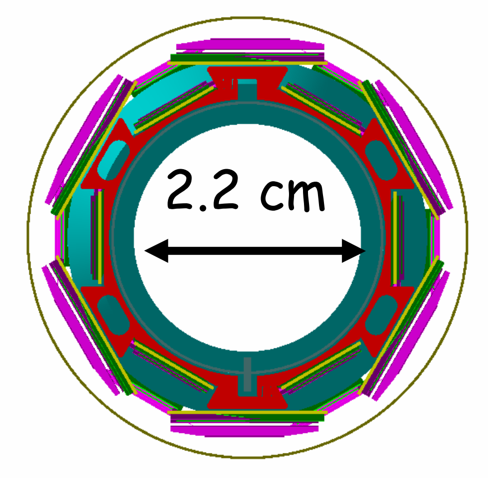
ISL is the first large radius tracker:

- 2 double sided (r-z) layers at 2<|η|<1 and 1 in central region

Mixed system

CDF Silicon T

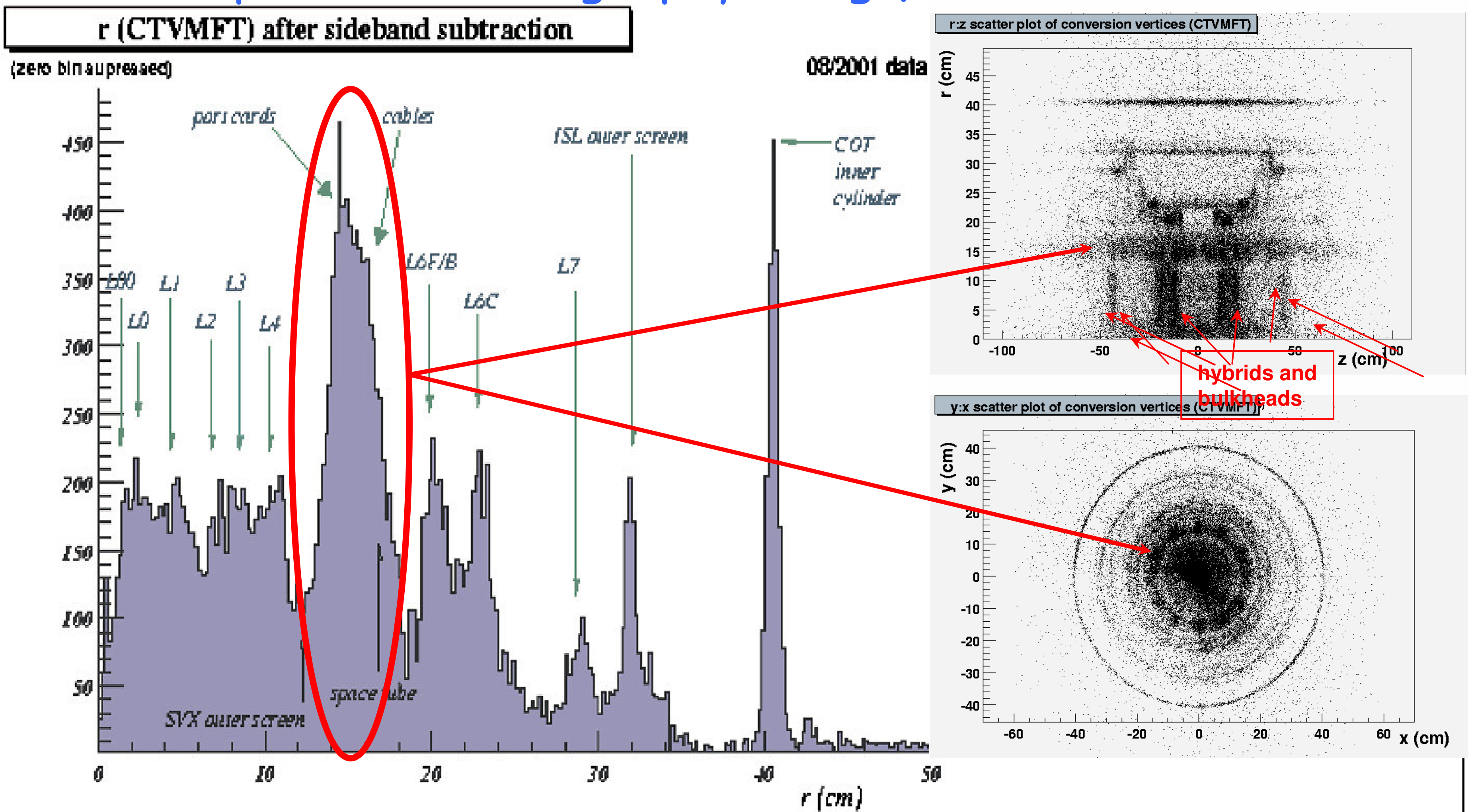




L00

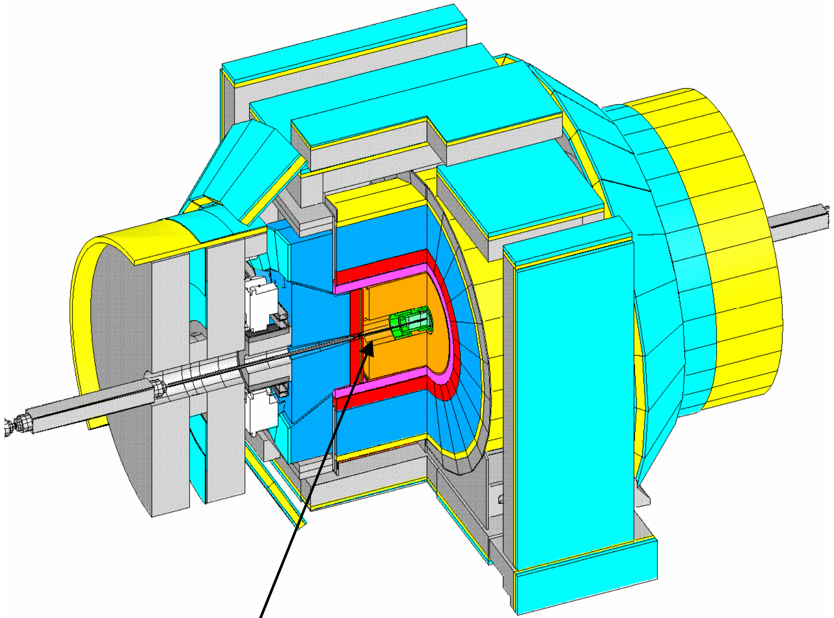
Material budget: not only silicon

Experiment radiography using γ conversions

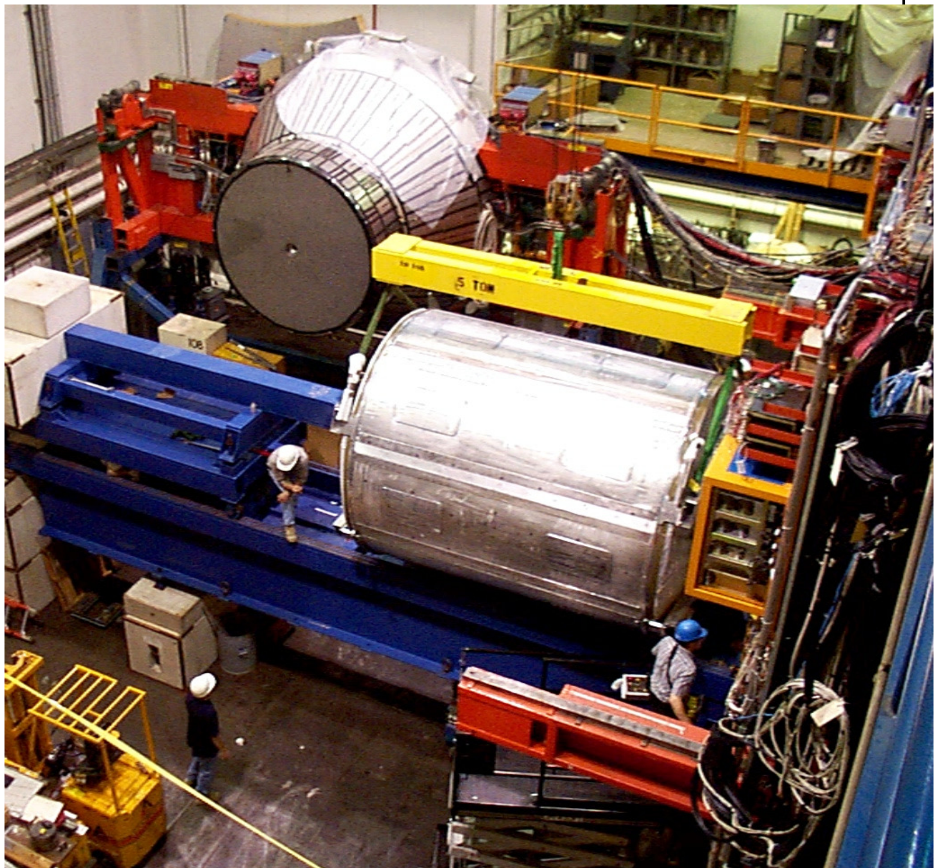


Electronics become *noise* source for pattern recognition!

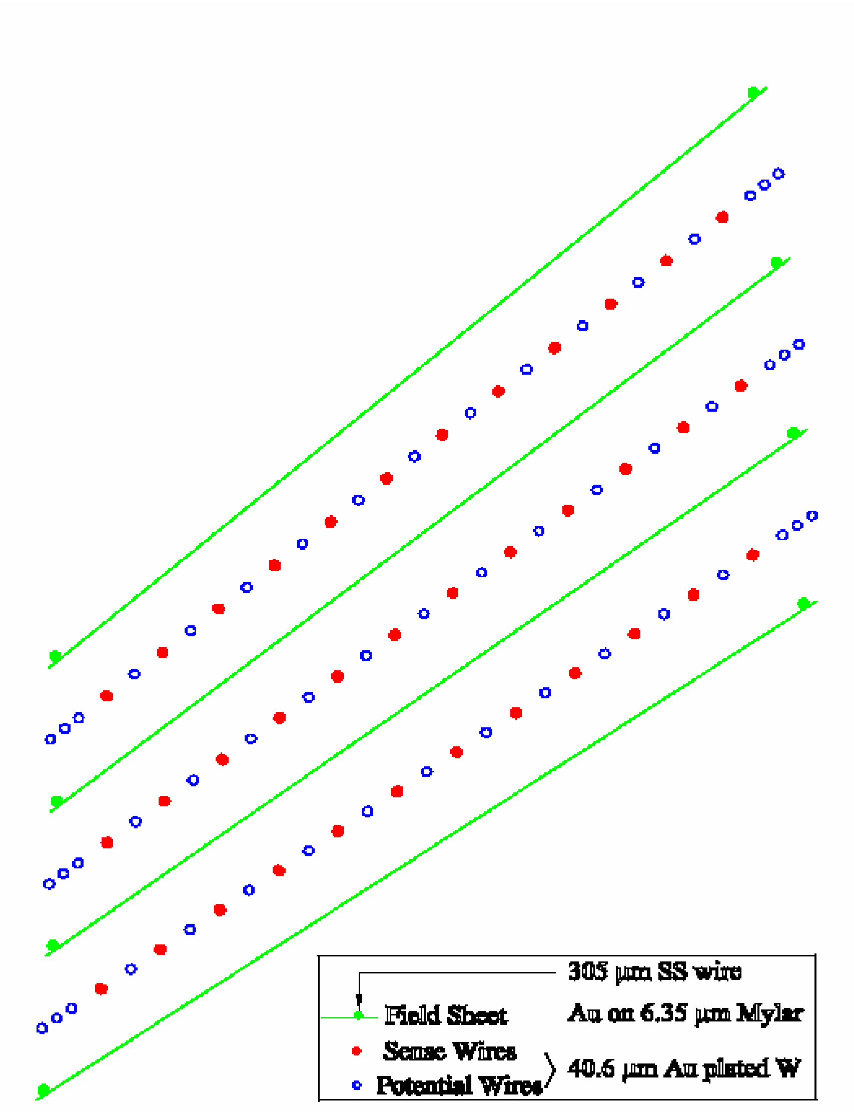
Geometry and construction of the COT



COT



Cell geometry



Cathos

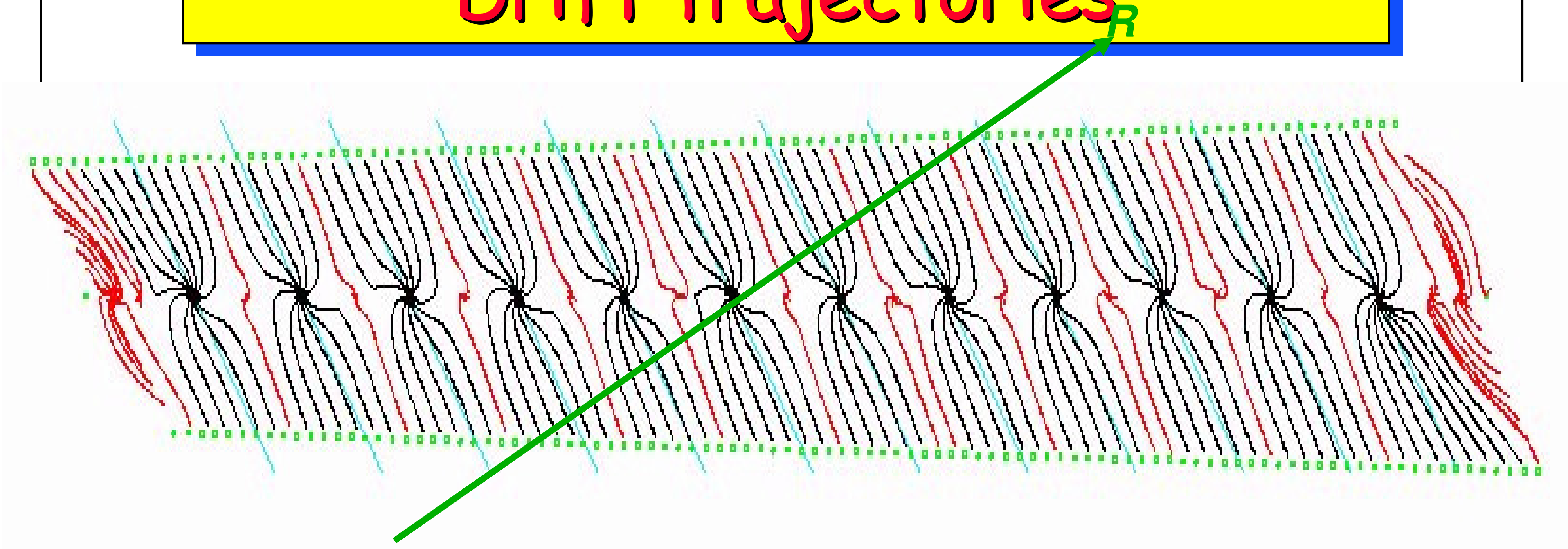
- ☞ Gold on Mylar
- ☞ Mylar thickness 6.4 μm
- ☞ Gold ~350 Å each side

Anodes

- ☞ Tungsten gold plated
- ☞ Diameter 40 μm
- ☞ Same wire used for sense and field shaping

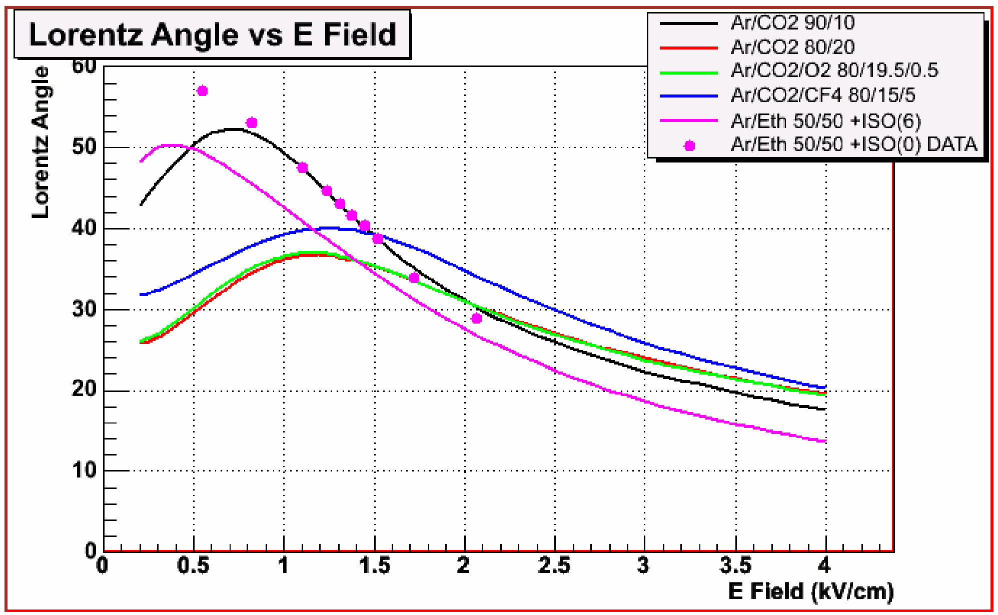
Cell are tilted by 35° to correct for $E \times B$ (e do not drift along E field but ~along φ)

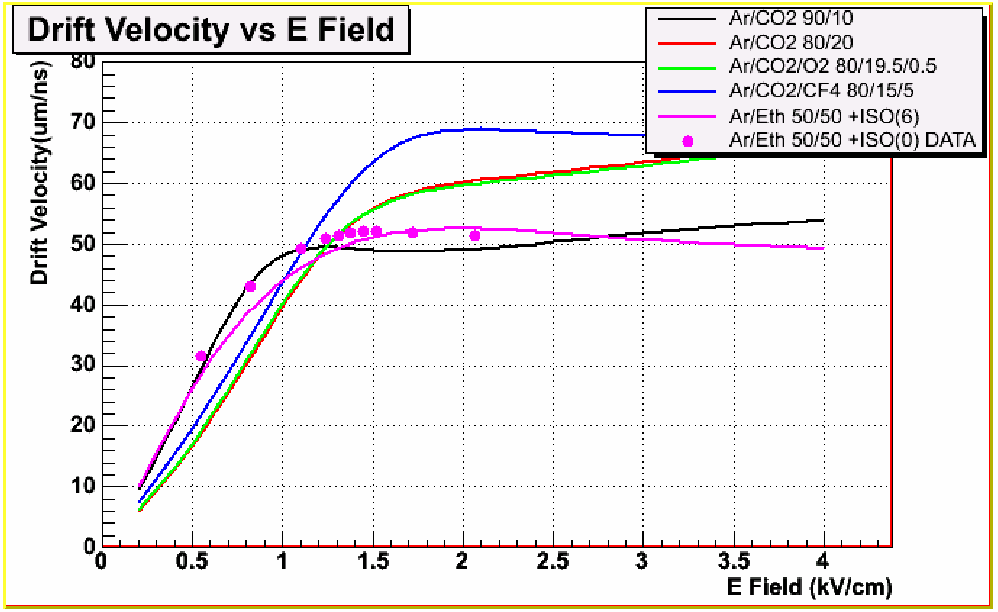
Drift trajectories



Gas choice (Ar:Et 50:50)
Set charge (↔ surface electric field) on sense wires to control gain
Set charge on potential wiresto control drift field

Drift trajectories

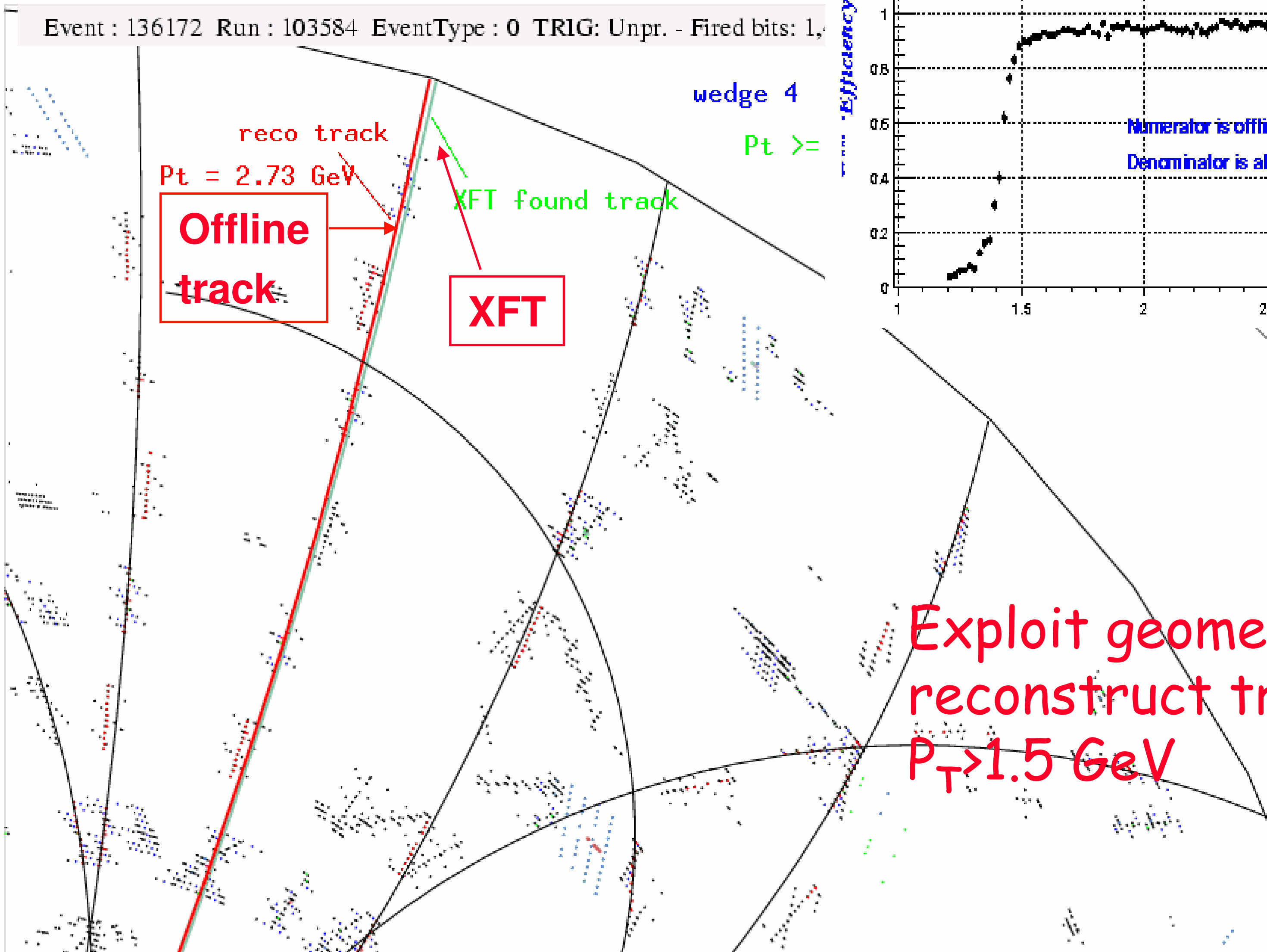


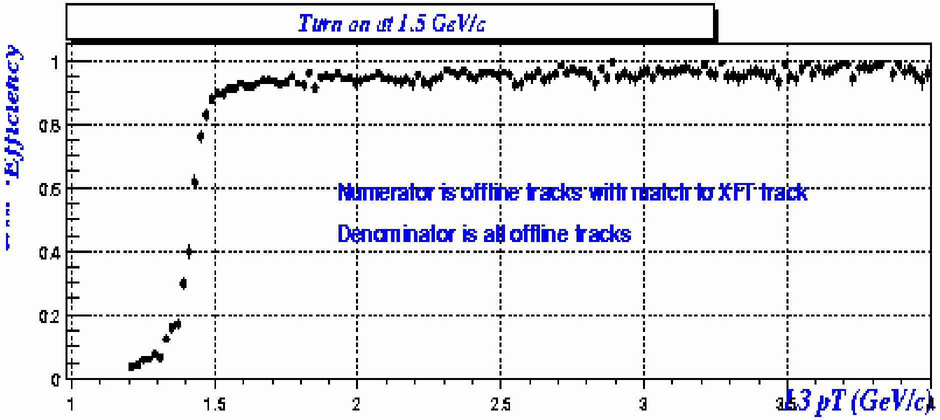


Based on a 396 ns interbunch and cell dimensions we want

- ~50 μm/nsec drift velocity
- Strong drift field to minimize space charge (sweeping ions quickly)
- ~35° drift angle (based on cell tilting)

Track trigger at L1

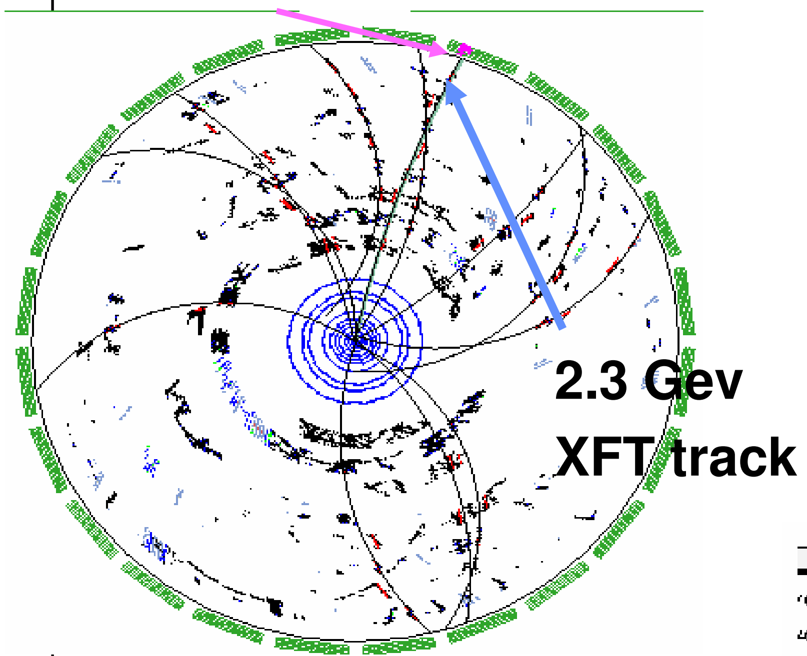


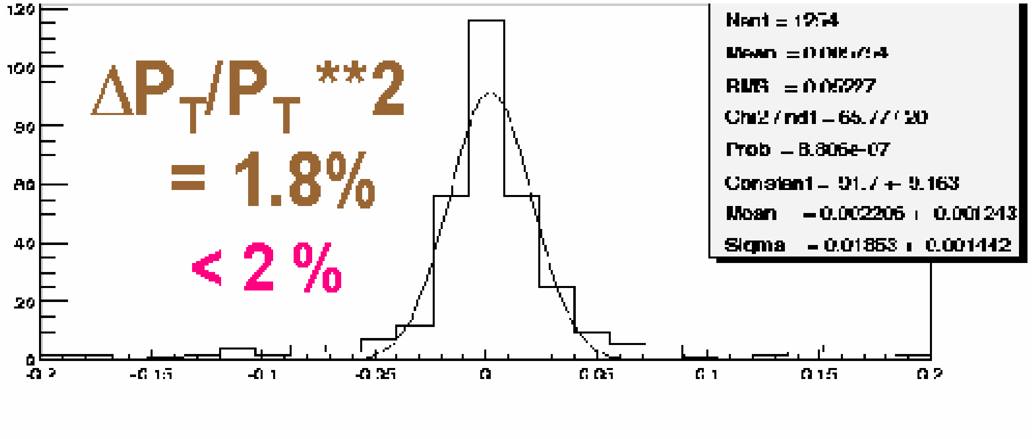


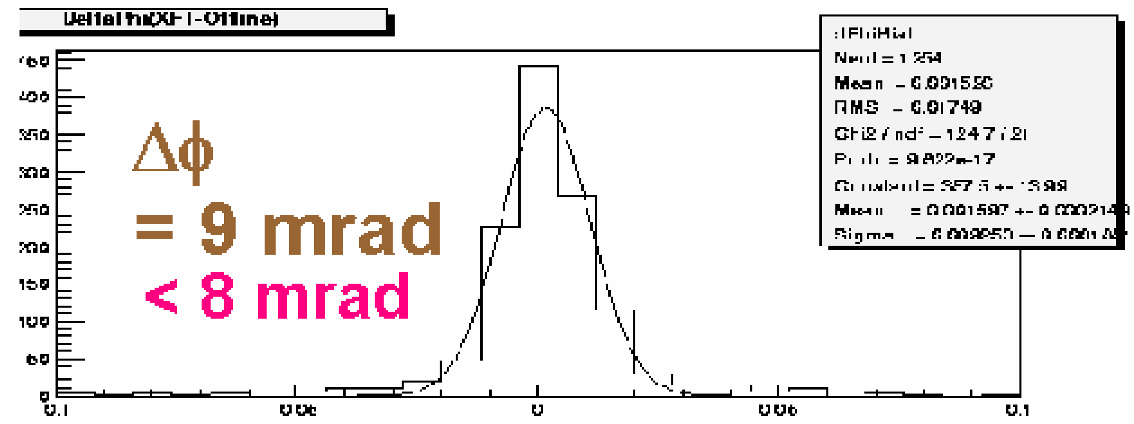
Efficiency curve:
XFT cut at
P_T = 1.5 GeV/c

Exploit geometry to reconstruct tracks with P_T>1.5 GeV

Used by many triggers







Trigger: XFT-μ

SVT- tracks with large d_0 at L2

Reconstruction of tracks at L1 allows …

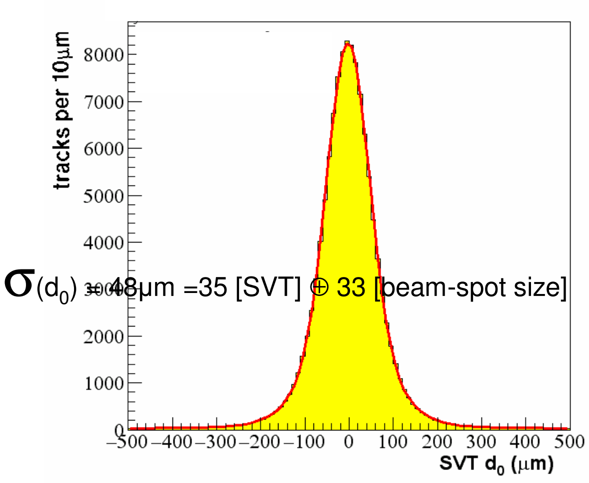
- ☞Silicon Vertex Tracker (SVT) you can
  - ⇨Trigger (L2) on tracks not coming from the primary

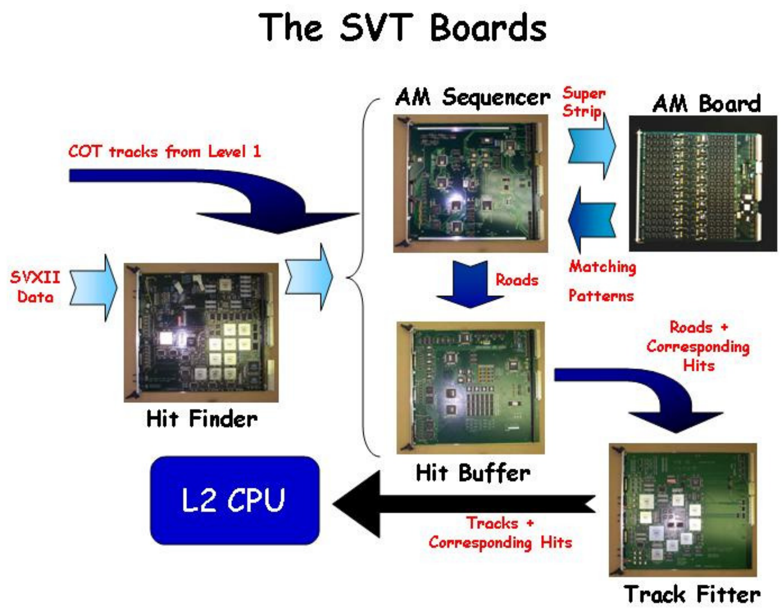
Fundamental for

- ☞B Physics (low P_T)

Can be important for

- ☞high P_T events with B
  - ⇨Top, Higgs
    - →Select rare processes



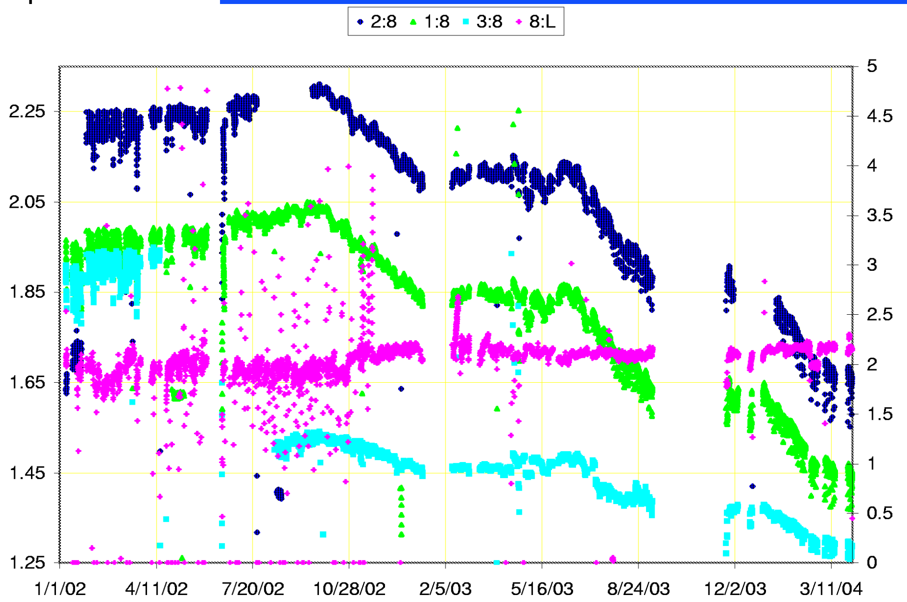


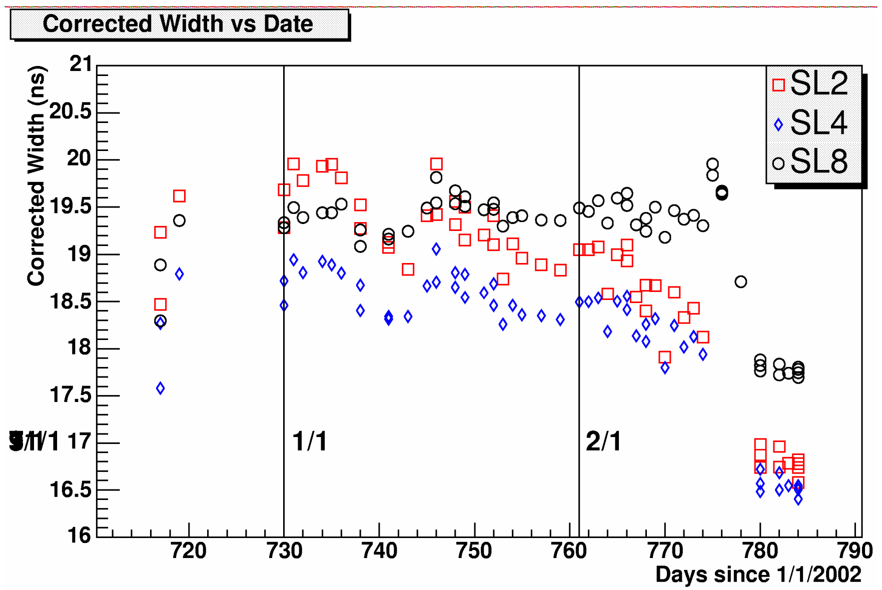
Operational challenges

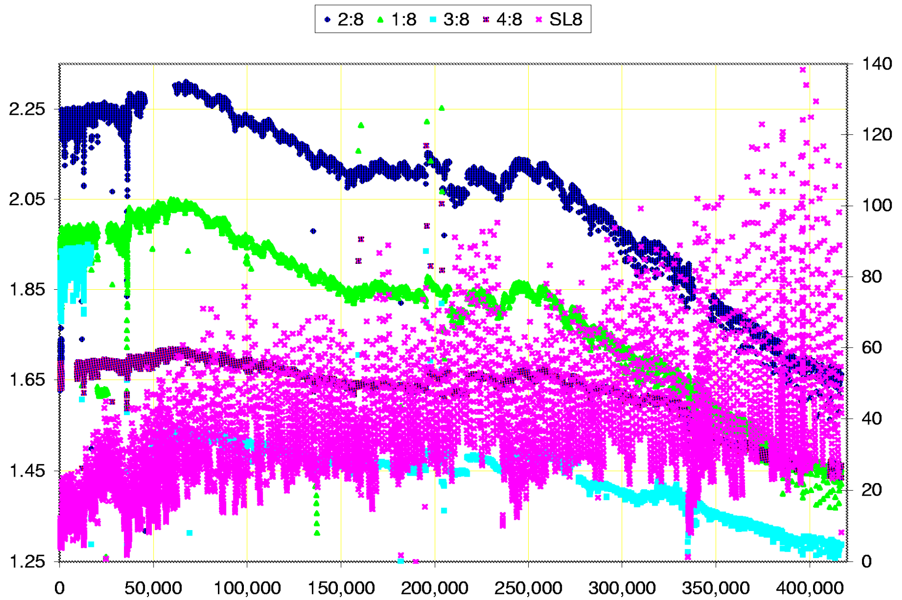
Unknown effects are (usually) unrelated to new physics

- ☞Rather new problems
- ☞Pick up problems as soon as they arise is fundamental
  - ⇨Solving can be difficult
- ☞I will show two examples

COT- Aging





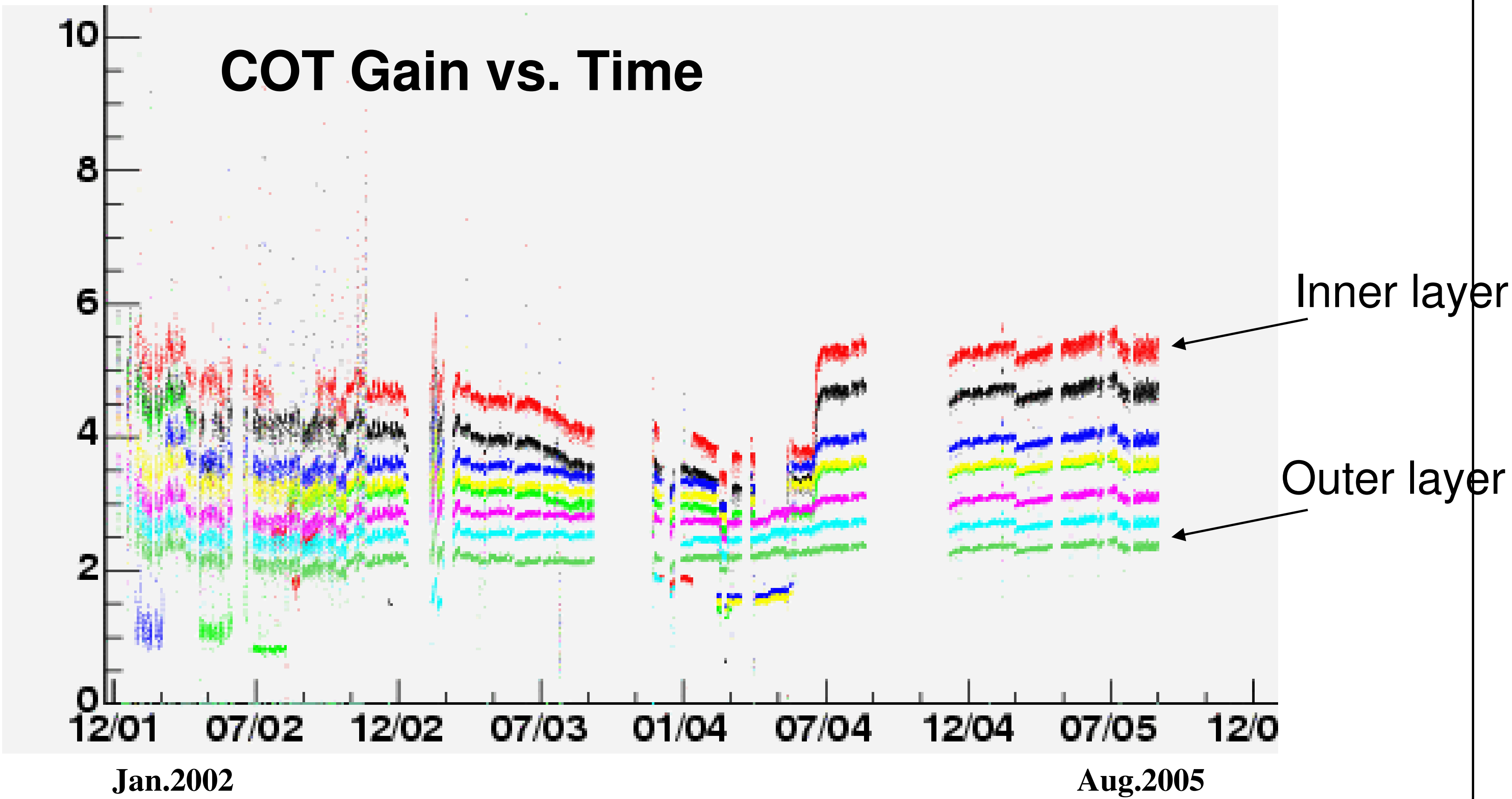


- Gain lowers over time
- Directly connected to integrated luminosity
- NOT observed in monitoring chambers
- ~~Hydrocarbons growth~~

COT Stability

Since we inserted oxygen

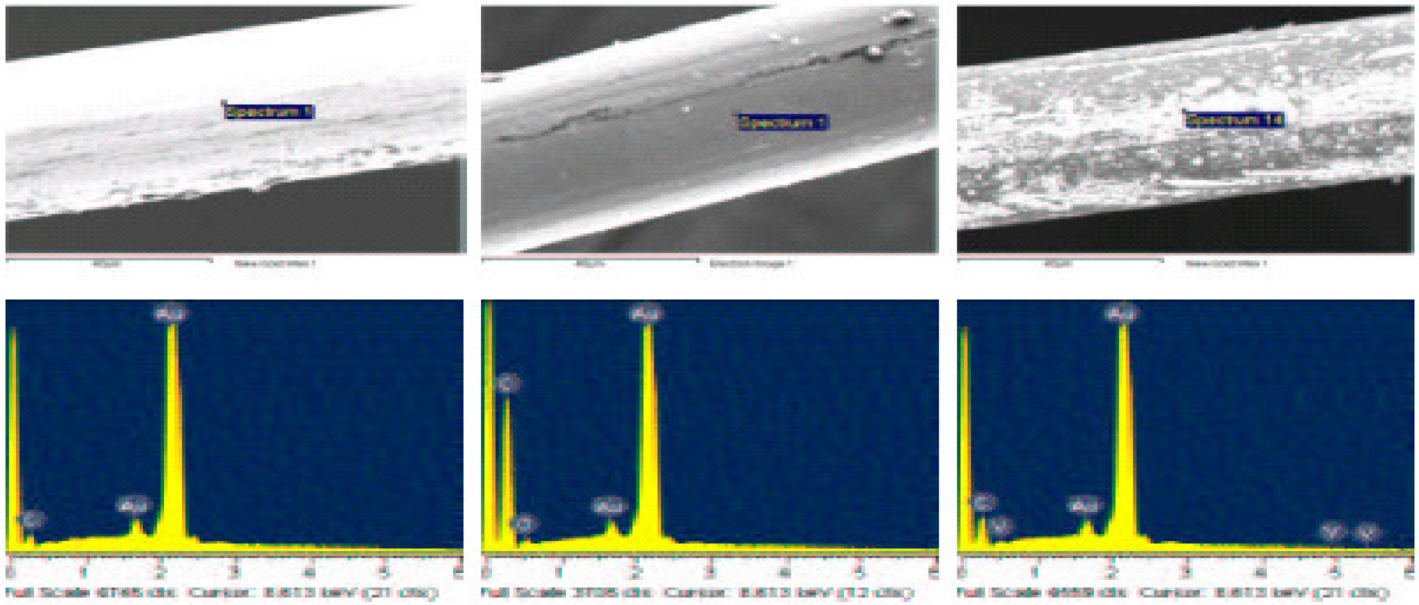
☞COT stable



Is the problem still there ?

Results from SEM Analysis of Wire Samples

NEW WIRE AGED WIRE REVERSE AGED



Sample	% gold	% carbon	% oxygen
New Wire	57	43	-
Aged Wire	11	85	4
Reverse Aged Wire	35	65	-

Microbonds breaking

Symptom: power lost on digital section of the chips (Z side) for 13/360 SVXII

Hypothesis: breaking due to Lorentz force

- ☞ Bonding(I) orthogonal to B
- ☞ $I \propto$ occupancy
- ☞ L1A rate $\Rightarrow$ Resonance?
- ☞ Convincing tests
  - ⇨ movie
- ☞ Changed operational settings
- ☞ Now under control

Keep monitoring the problem