CMS PRS Tracker b tau Software

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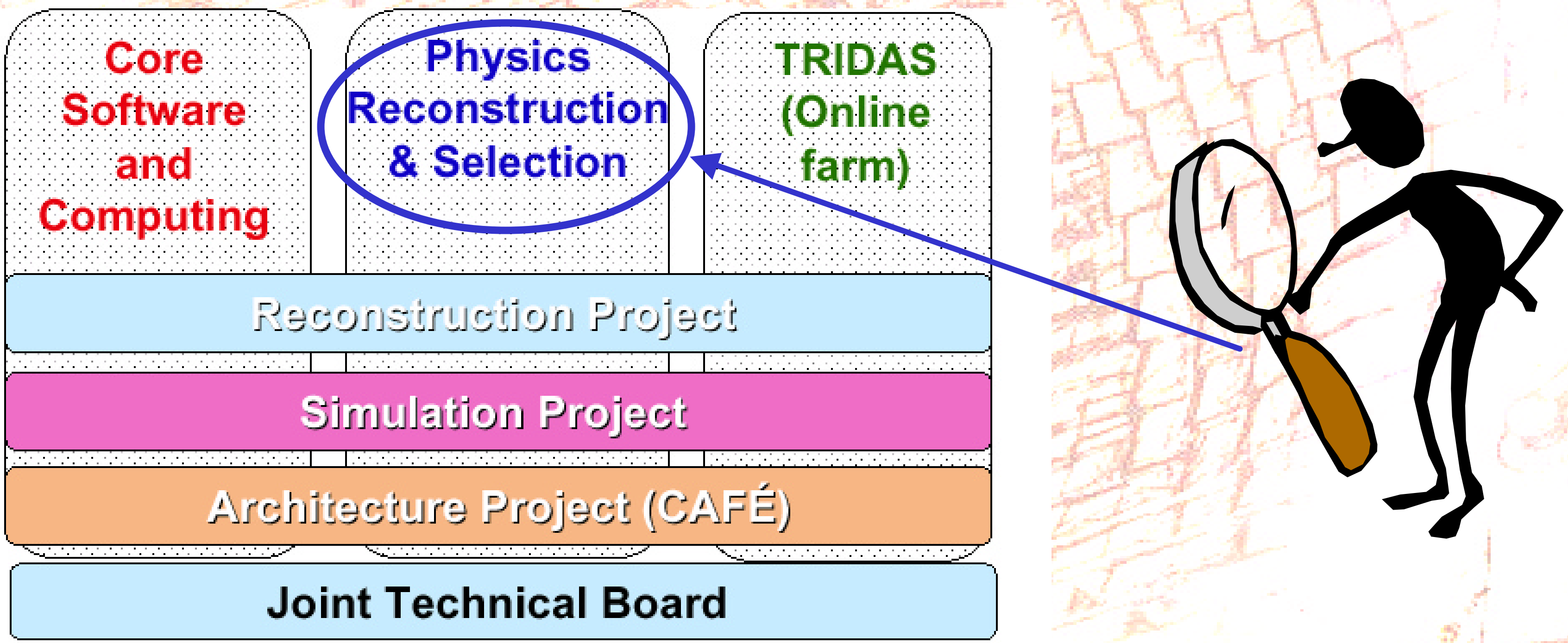
INFN Bari

Workshop on b/tau Physics at LHC
30th May 2002

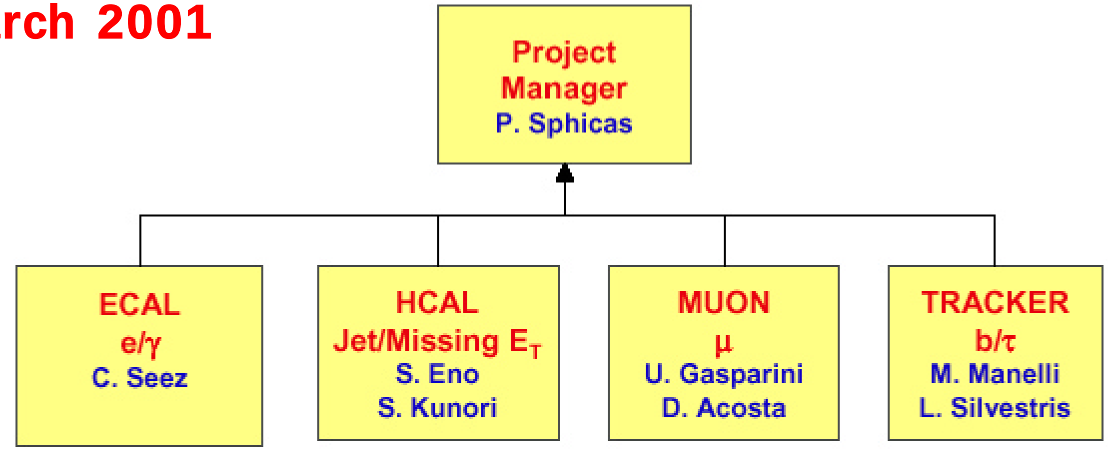
Tracker b tau Software Project

- October 2000: presentation at TIB on CMS software re-organization (CPT Project) and possible implications for Tracker in terms of software tasks, deliverables and FTE.
- December 2000: TIB approved the Tracker software Project.
- March 2001: MB approved the CPT Project



PRS Groups Organization & Mandate

MB 26 March 2001



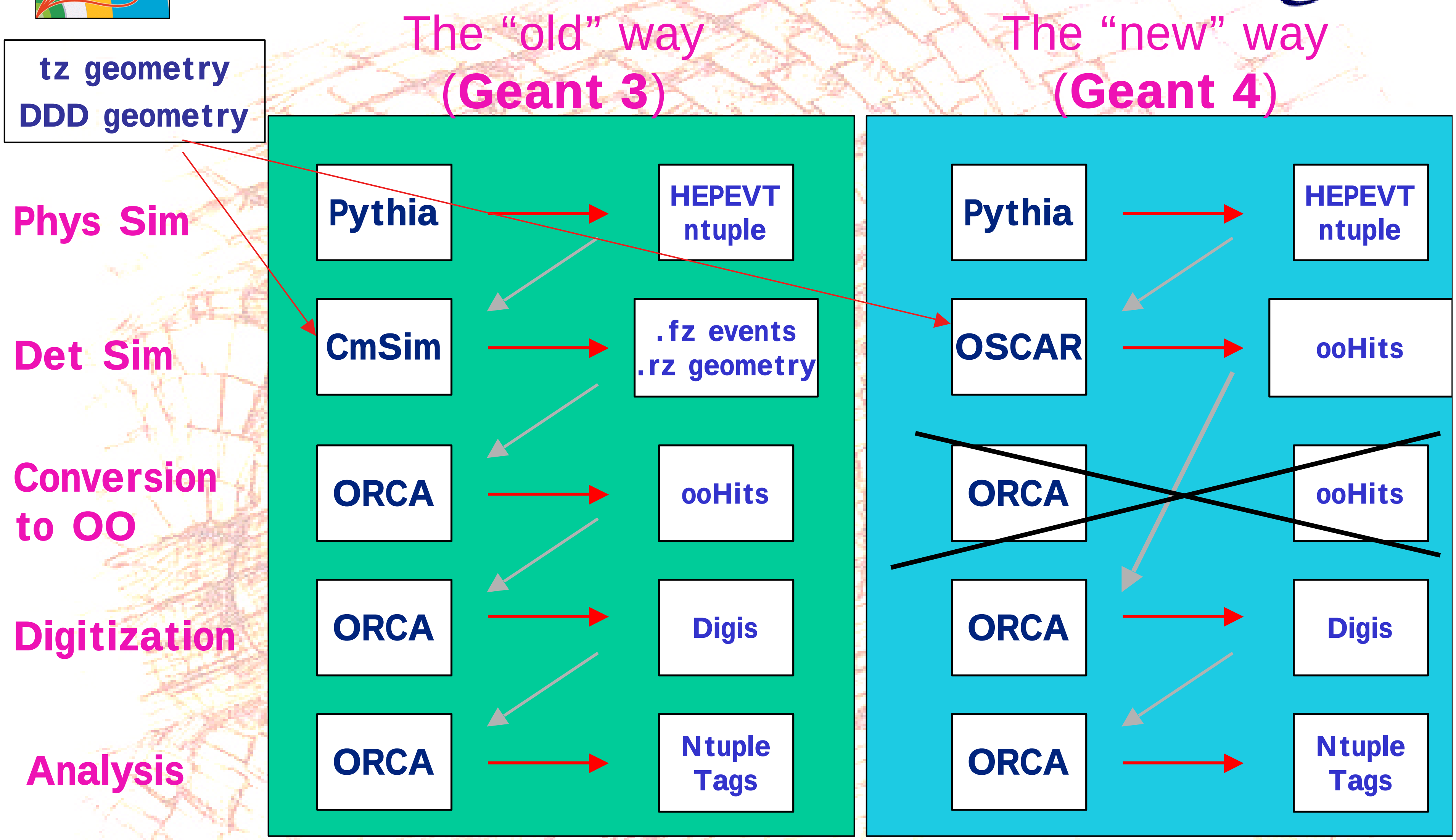
- The PRS groups work on (and also have responsibility for) the following tasks:
  - Detector simulation
  - Detector reconstruction
  - Detector calibration/alignment
  - Monitoring
  - Physics object reconstruction and selection (HLT)
  - Test beam analysis

PRS Tracker b tau Software Project

November 2001

- **Tracker b tau** — M.Mannelli, L.Silvestris
  - **Tracker Simulation** — T. Boccali
    - **Tk det Geometry** — A.Frey (SI), T.Speer(PXL)
    - **Tk det Response** — V. Ciulli (SI), D.Kotlinski (PXL)
  - **Tracker Reconstruction** — T. Todorov
    - **Track Reconstr.** — T.T
    - **Vertex Reconstr.** — P. Vanlaer
  - **Tracker Alignment** — F. Raupach
  - **Data Handling** — I. Tomalin
    - **Data Handling** — I.T. (SI), D.Kotlinski (PXL)
  - **Tools b tagging** — F. Palla
  - **Tools tau tagging** — S. Nikitenko
    - **Tau tagging** — S.N. (Calo+PXL), G.Bagliesi (SI)

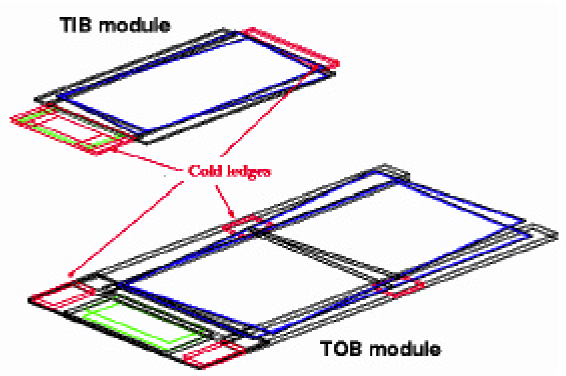
The two ways



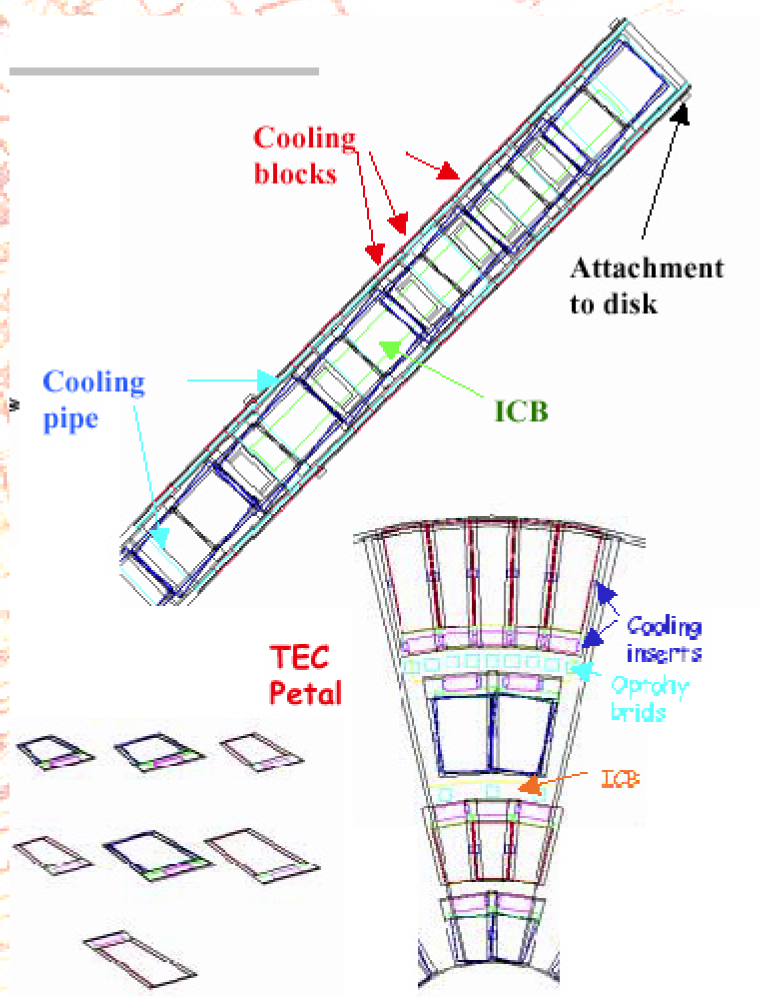
tz geometry
DDD geometry
The "old" way
(Geant 3)
The "new" way
(Geant 4)
Phys Sim
Det Sim
Conversion to OO
Digitization
Analysis
Pythia
HEPEVT ntuple
CmSim
.fz events
.rz geometry
ORCA
ooHits
ORCA
Digis
ORCA
Ntuple Tags
Pythia
HEPEVT ntuple
OSCAR
ooHits
ORCA
ooHits
ORCA
Digis
ORCA
Ntuple Tags

Detector Description (CMSIM)

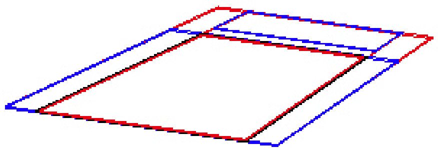
- CMSIM 122 : complete update of TIB and TOB
- CMSIM 123: no changes for the tracker
- CMSIM 124: complete TEC update, changes in TIB geometry, pixel barrel update
- CMSIM 125: pixel forward update



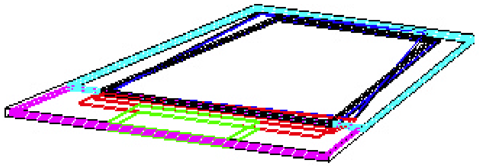
TID next cmsim 126



Old Layout

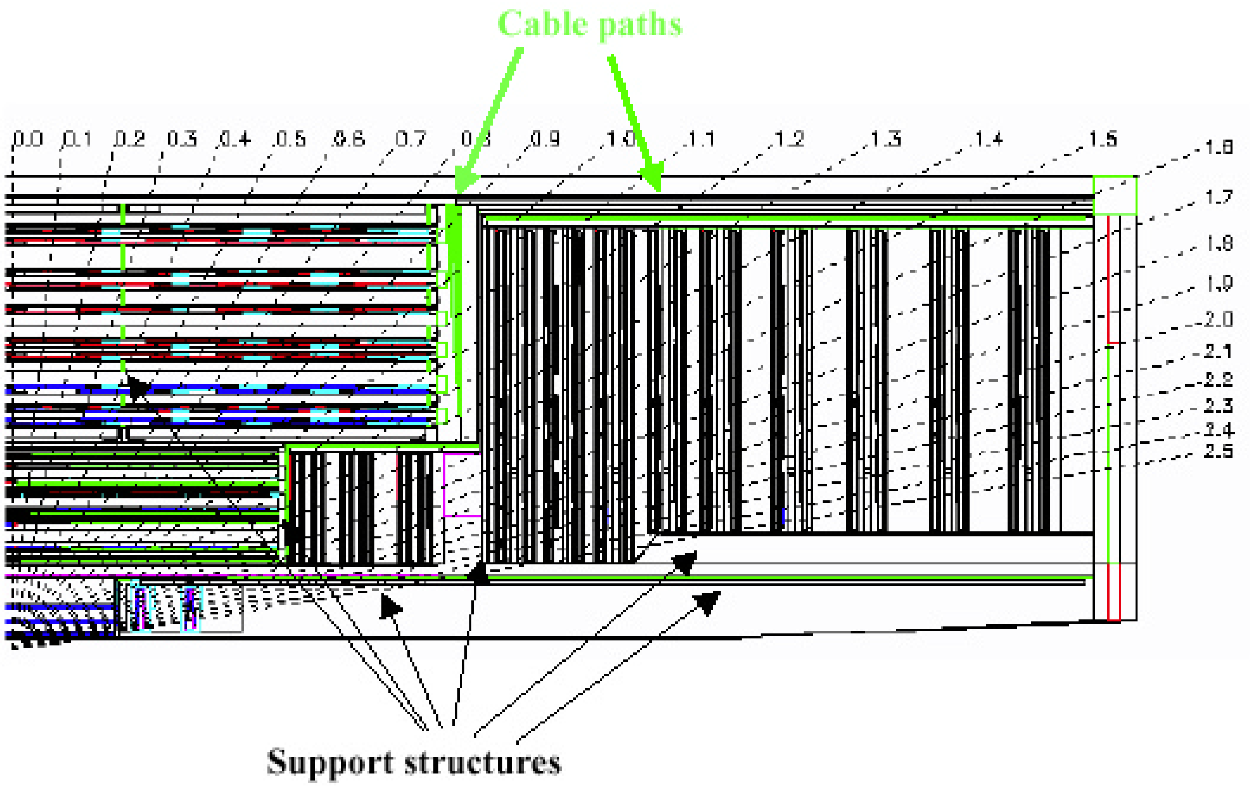


New Layout



Detector Description

- The Material budget is estimated from are from detailed GEANT simulation which includes latest engineering design



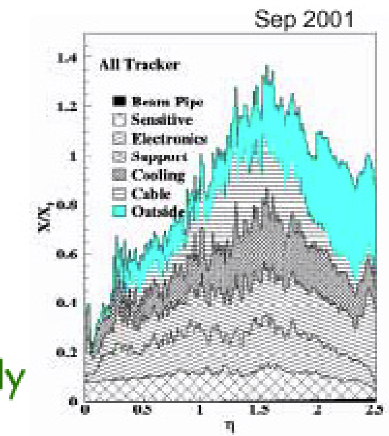
Tracker Material Budget (cmsim)

Material Budget

- or the price to pay for a large, high precision tracker with stringent cooling requirements

A lot of effort went into reducing the material budget of the tracker:

- Light support structures (mainly Carbon fiber with Honeycomb)
    - holes and slots wherever possible
- Cables inside the tracker have Aluminium as conductors
- For the smaller inner barrel (where the material hurts the most) the "mother cable" distributing power and signals will be Cu on Kapton
- Cooling pipes of inner detector are Aluminium, all cooling pipe radii and wall thickness have been minimized



Nothing sticks out particularly

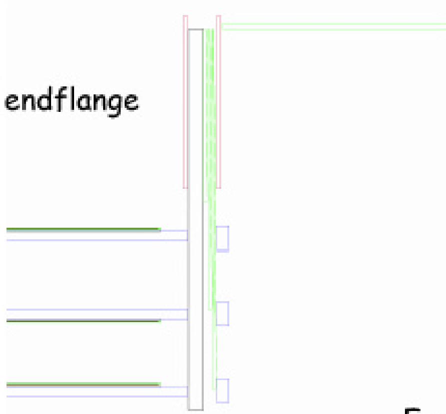
Ariane Frey, CERN

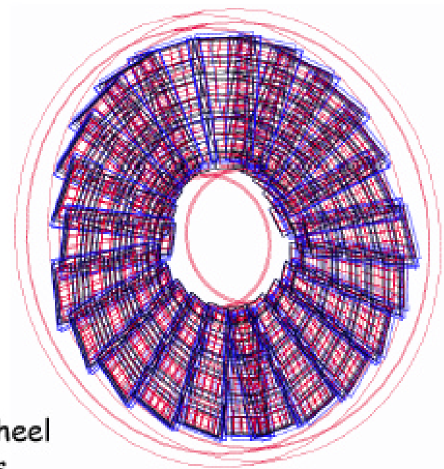
Tracker Material Budget (cmsim)

➢ **Pixel detector !**

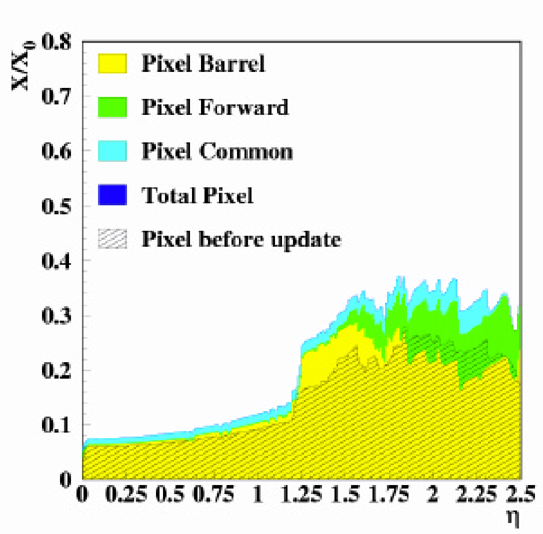
- Complete update of geometry and materials for both barrel and forward pixels

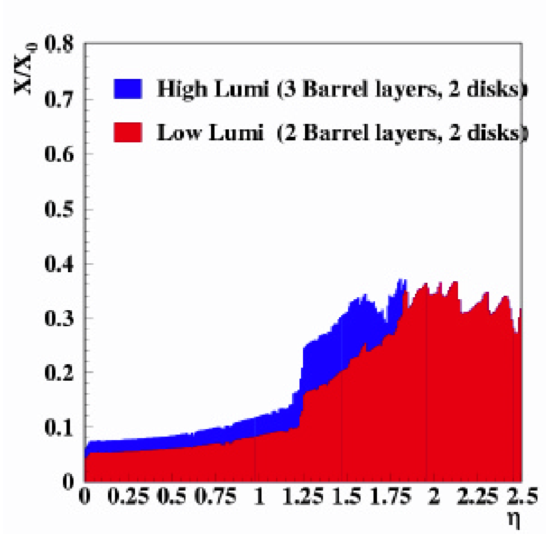
Barrel endflange





Forward wheel
with blades





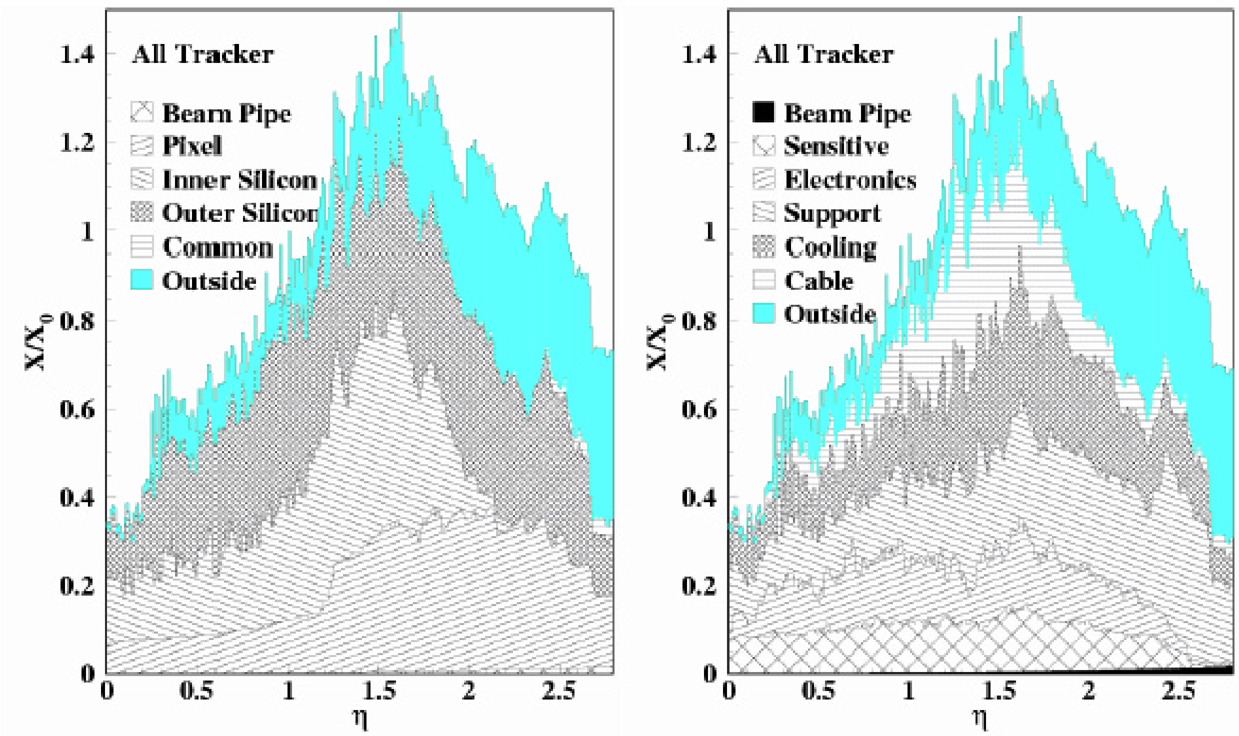
For low lumi configuration almost no increase compared to Sep 2001 up to $\eta \approx 1.75$

are

Tracker Material Budget (cmsim)

Radiation Length in the Tracker

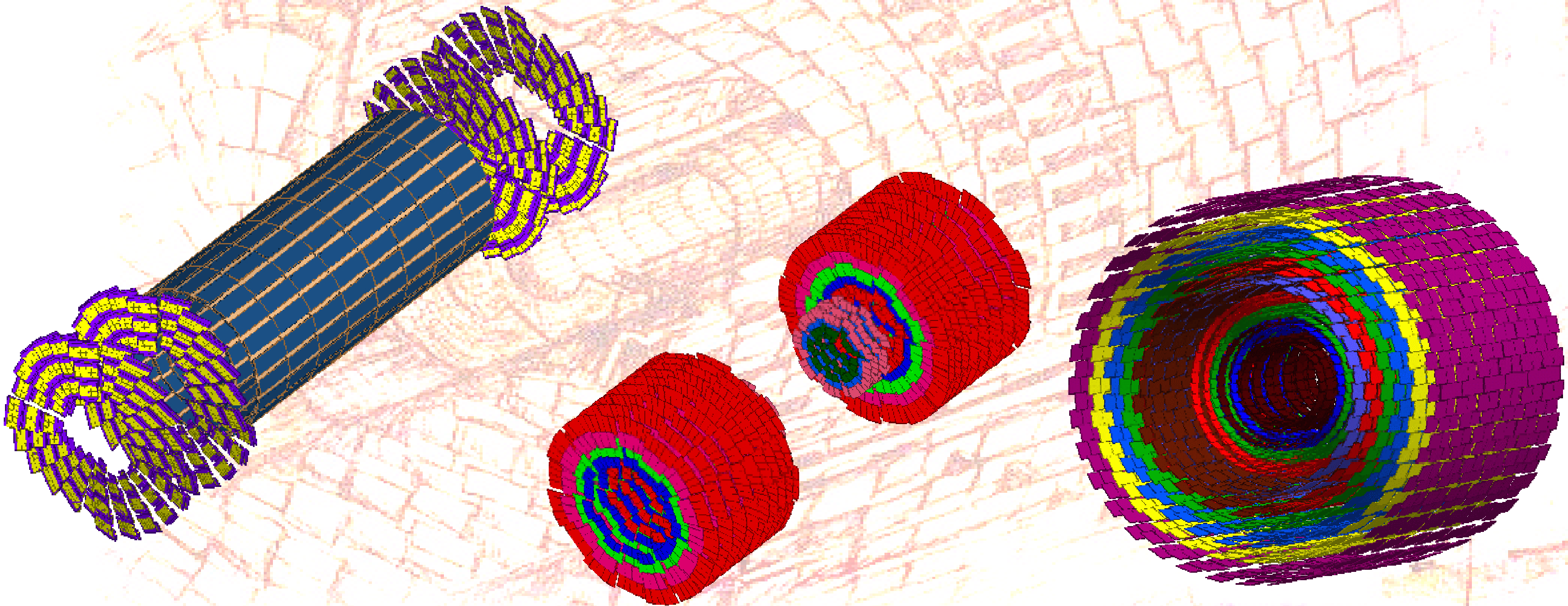
High lumi !



All components updated except : TID and bulkhead

OSCAR Detector Geometry

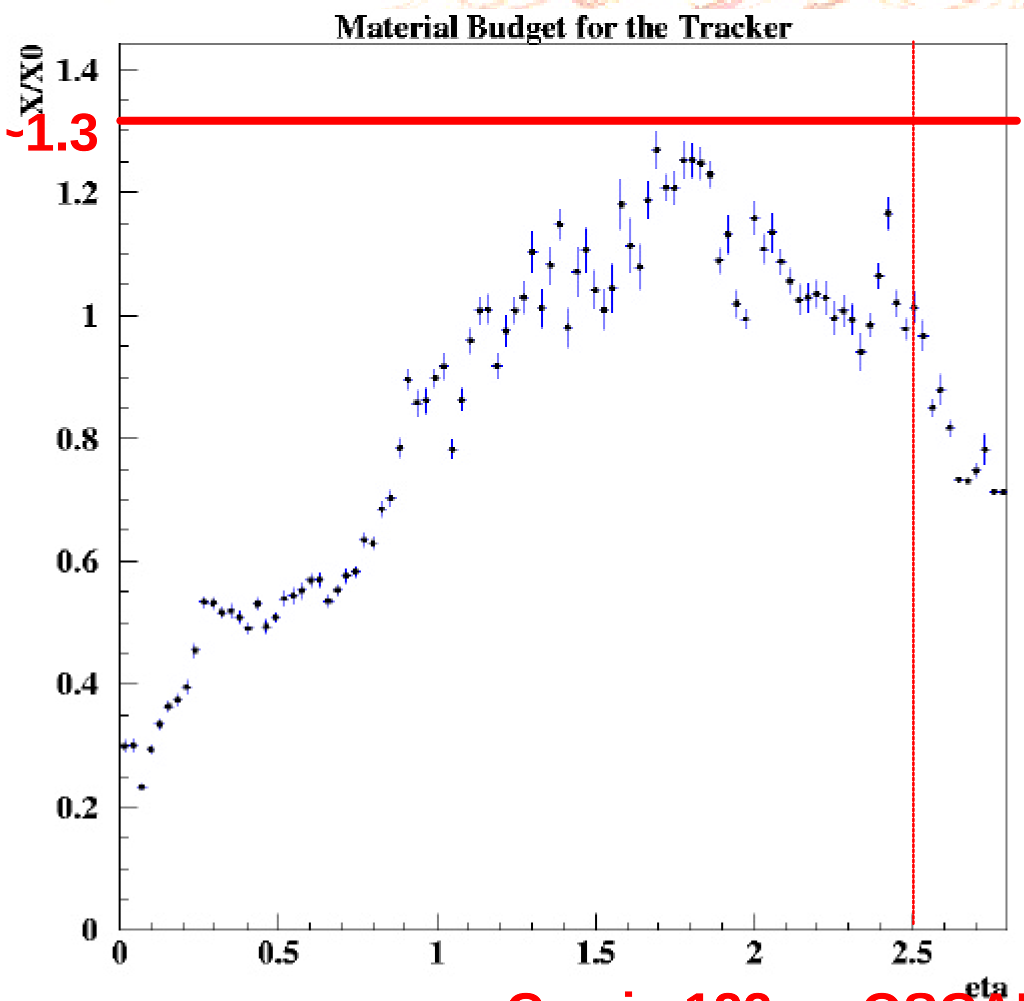
Automatic tool to compare Cmsim/OSCAR geometry implemented. All the detectors (20280) are <u>now</u> within 5 μm and also the orientation is fine. First DDD version for Tracker Geometry (OSCAR) is available

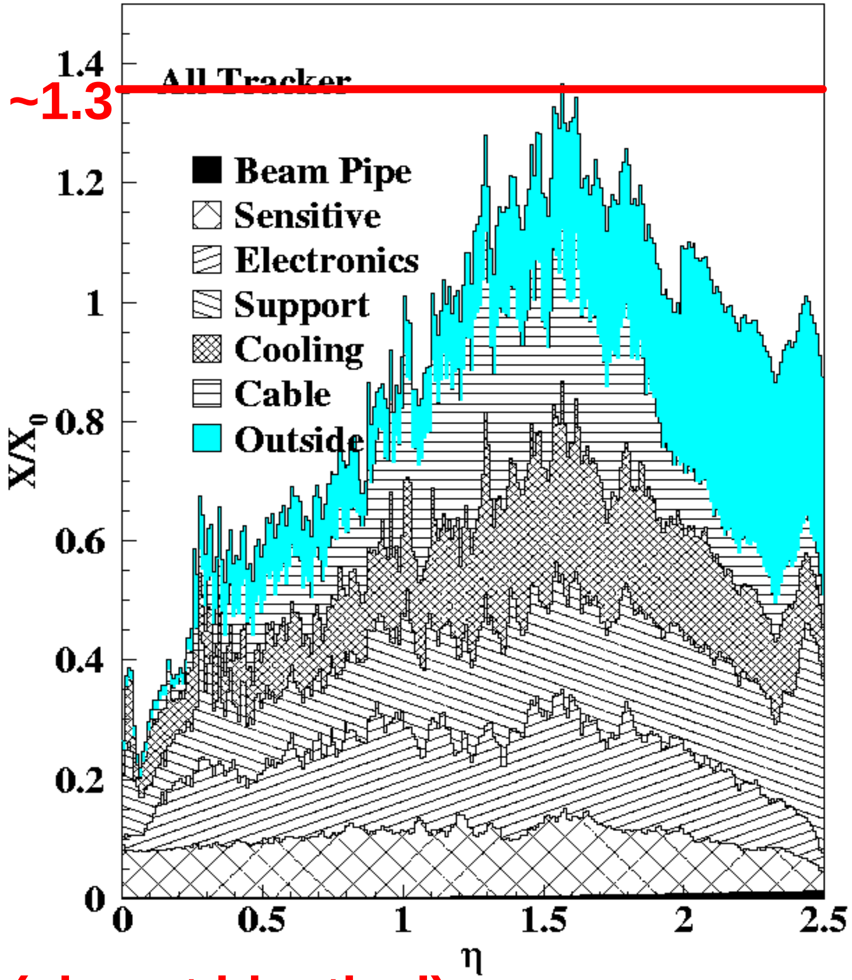


Material Budget in OSCAR

OSCAR

Cmsim 122





Cmsim122 vs OSCAR (almost identical)

Tracker Detector Response

- A **SimHit** only knows about its **entry** and **exit** point in a detector (+ tof and energy deposit…)
- The energy released is spread into the detector volume along the line connecting these into a number of **smaller deposits**, whose signals are drifted to the strip plane. **Landau fluctuations** are allowed for the deposits.
- During the drift, **Lorentz angle** and **diffusion** are taken into account.
- Charge is injected into the **strips,** taking into account the inter-strip **capacitive couplings**. **We have the so called Digis!!!**
- **Digis** are clusterized and **RecHits** are made.
- **Different zero suppression** algorithms can be applied. (Data-rates studies)

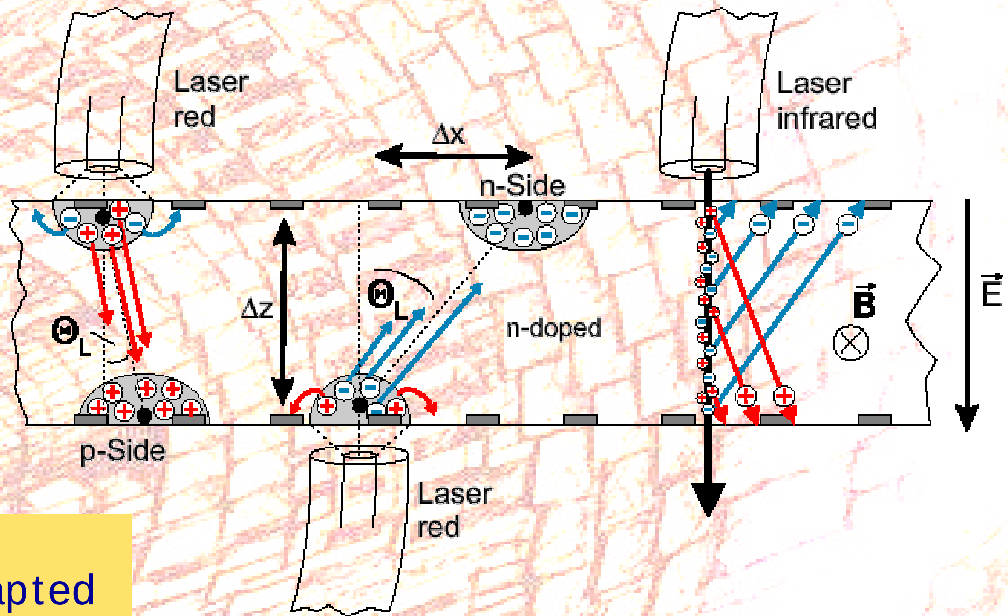
Tracker Detector Response

•New and more reliable (from real tests in Karlsruhe) treatment of the Lorentz angle in silicon, as a function of bias, irradiation etc.

Lorentz angle very important for hit resolution:

•Silicon: $\tan(\theta_L)$ = 0.12 (6° at 4T)

•Pixel: $\tan(\theta_L)$ = 0.53 (28° at 4T)



Code in ORCA can be adapted via configurables to any

•Irradiation conditions

•Temperature

•V bias

•Etc...

Silicon

Pixel Inefficiencies

❖ Pixel detector will have substantial readout losses.

❖ These losses are due to highly stochastic nature of our events, the direct causes are : buffer overflows and dead times.

❖ Some type of losses affect single pixels, others whole pixel columns or even whole readout chips

❖ The inefficiency value depends on the occupancy (luminosity & radius) and the 1st level trigger rate.

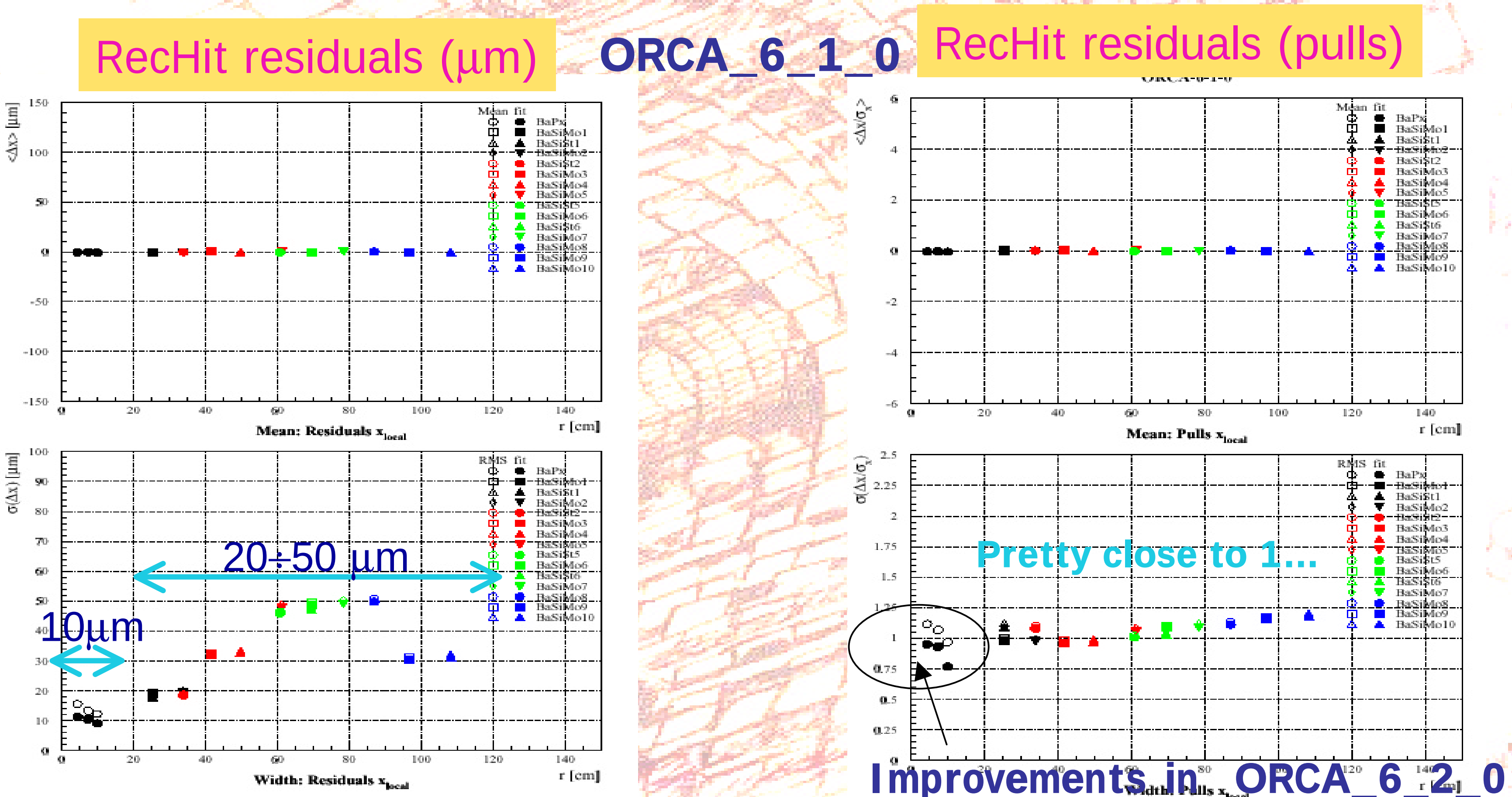
Remember: pixel rechits are at the base of tracking!

Pixel inefficiencies are properly treated in the official Tracker b tau production

See Danek Talk

Tracker Detector Simulation

Given a set of Digitization parameters, the simulation is adjusted to parameterize correctly the errors.



Data Handling...

- The idea is to stress the Tracker code to handle test-beam data and also the simulation of realistic FEDs (front-end drivers)
- We have to simulate realistic pedestals and noise and problems (dead/noisy strips...) in the Tracker, and then use ApvAnalysis to subtract/correct; then the rest of the reconstruction must follow.
- All the tools available (ORCA_6_1_0)

Data-Handling: Expected Tracker data Rates

Results updates
Respect Data-Handling
Mini-workshop dec 01

Study exist ORCA_6_1_0

http://hepwww.rl.ac.uk/CMSTracker/b_tau_DataHandling/readout.pdf

Results depends on :

Tracker strip occupancy

- Pythia simulation, heavy Ion collisions, detector simulation, clustering cuts

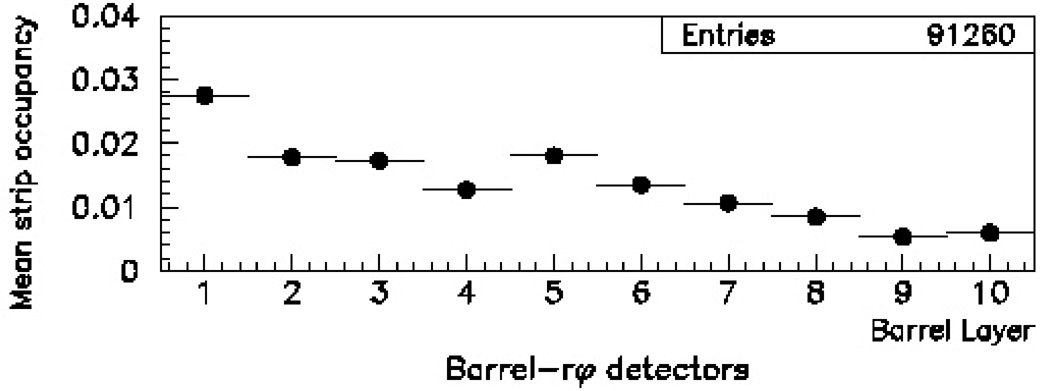
Knowledge of readout-electronics

- Detector FED cabling

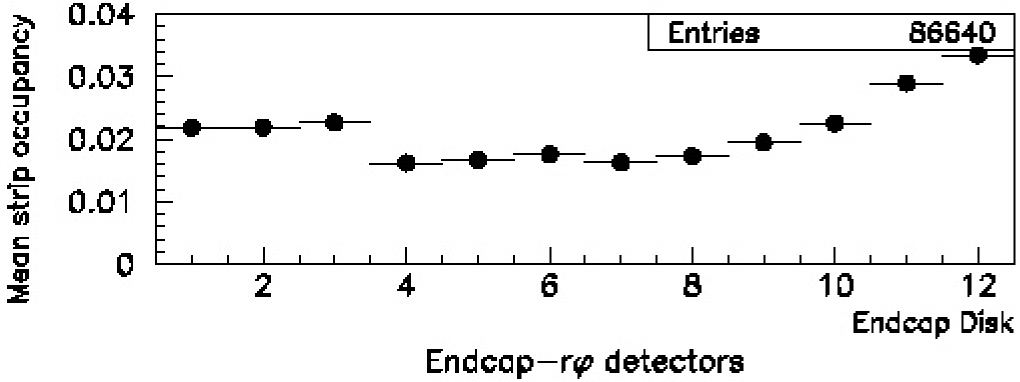
Tracker Strip occupancy

Strip occupancy: fraction of strip associate with clusters by FED (on-line) cluster

High lumi



barrel



endcap

Tracker Strip occupancy

- Pythia simulation
  - MSEL =1 or MSEL=2 (inclusion of diffractive events) Data rates increase 15%.
- Detector simulation
  - Increase the capacitive-coupling -> Data rate increase 11%.
  - Material out-side tracker fully simulated -> data rates in the last three endcap disks increased 3 times.
- New detector-FED cabling

Tracker Data Rates per FED

Layer	FEDs			Mean Occupancy			Data Rate/FED (MB/s)		
	N	f	x	p–p (high lumi)	p–p (low lumi)	Pb–Pb	p–p (high lumi)	p–p (low lumi)	Pb–Pb
TIB1	12	0.88	0.80	0.028	0.009	0.20	103	41	51
TIB2	16	0.84	0.80	0.018	0.006	0.14	69	31	34
TIB3	6	0.94	0.82	0.017	0.006	0.08	73	34	24
TIB4	8	0.84	0.82	0.013	0.005	0.06	52	26	16
TOB1	11	0.95	0.80	0.019	0.006	0.11	79	34	31
TOB2	12	1.00	0.81	0.014	0.005	0.09	63	31	25
TOB3	7	0.96	0.81	0.011	0.004	0.05	50	26	15
TOB4	8	0.94	0.82	0.008	0.003	0.04	41	23	12
TOB5	14	0.88	0.83	0.005	0.002	0.04	29	20	12
TOB6	15	0.93	0.88	0.006	0.003	0.03	33	21	10

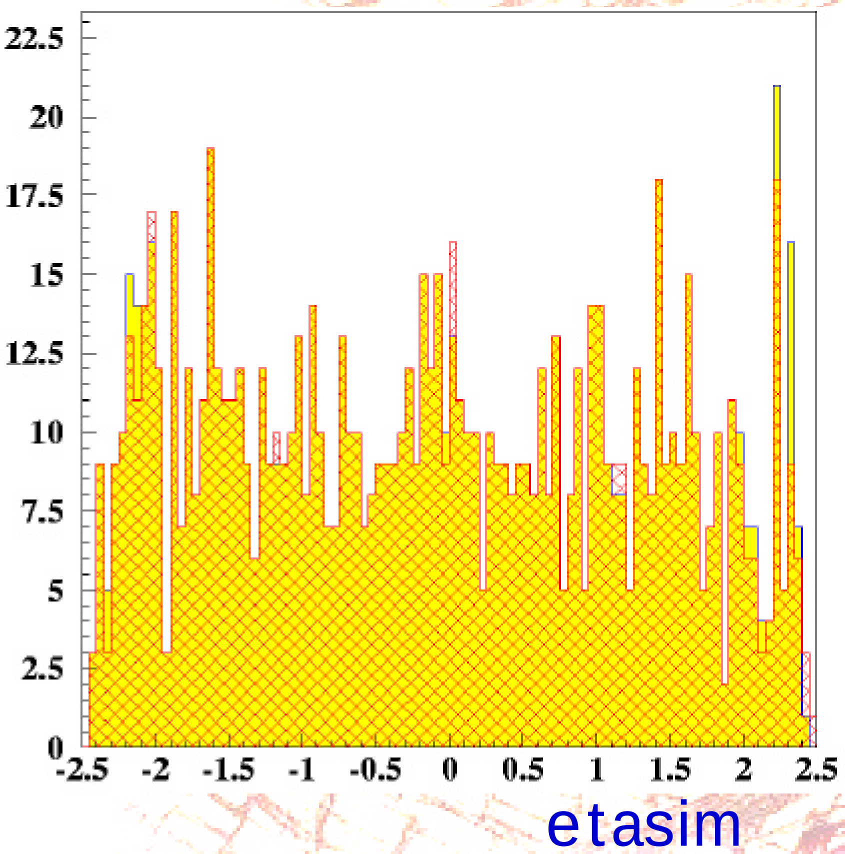
max data rate in each DAQ switch is 138+-41 MB/s at High lumi. #FED 440 and #DAQ FED builder switch 272

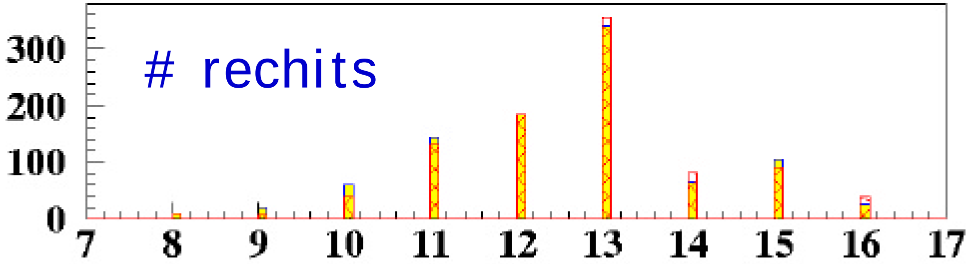
Disk	FEDs			Mean Occupancy			Data Rate/FED (MB/s)		
	N	f	x	p–p (high lumi)	p–p (low lumi)	Pb–Pb	p–p (high lumi)	p–p (low lumi)	Pb–Pb
TID1	5	0.77	0.88	0.022	0.008	0.13	81	35	31
TID2	5	0.77	0.88	0.022	0.008	0.13	81	35	31
TID3	5	0.77	0.88	0.022	0.008	0.13	81	35	31
TEC1–3	40	0.78	0.88	0.018	0.005	0.09	66	30	22
TEC4–6	32	0.83	0.88	0.018	0.006	0.08	72	32	21
TEC7–8	16	0.92	0.88	0.024	0.008	0.07	101	40	20
TEC9	8	0.81	0.88	0.028	0.010	0.06	104	44	17

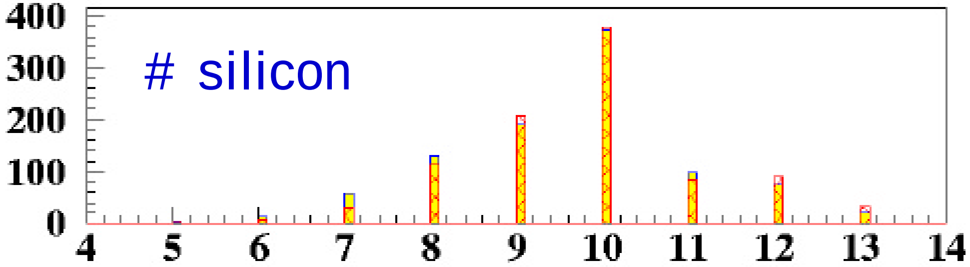
OSCAR/CMSIM comparison using ORCA

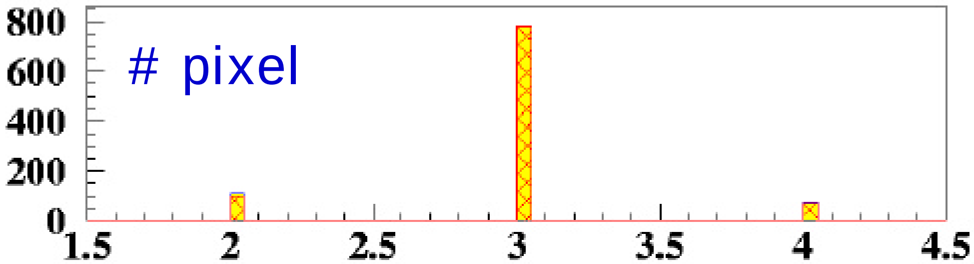
OSCAR

CMSIM







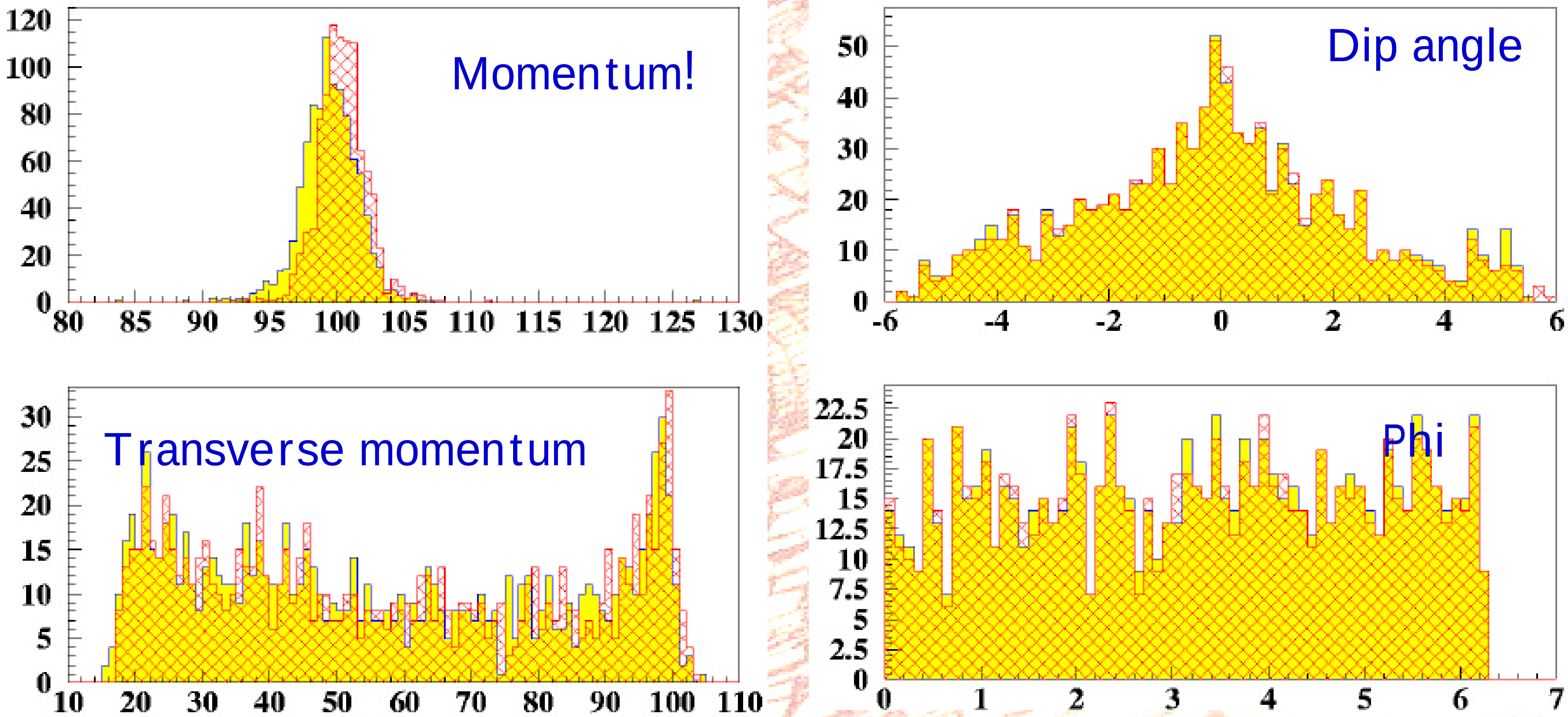


OSCAR/CMSIM comparison using ORCA

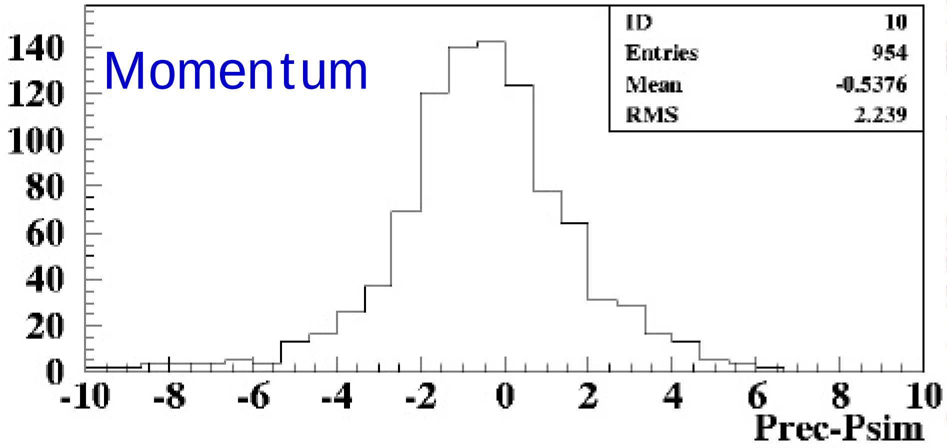
OSCAR

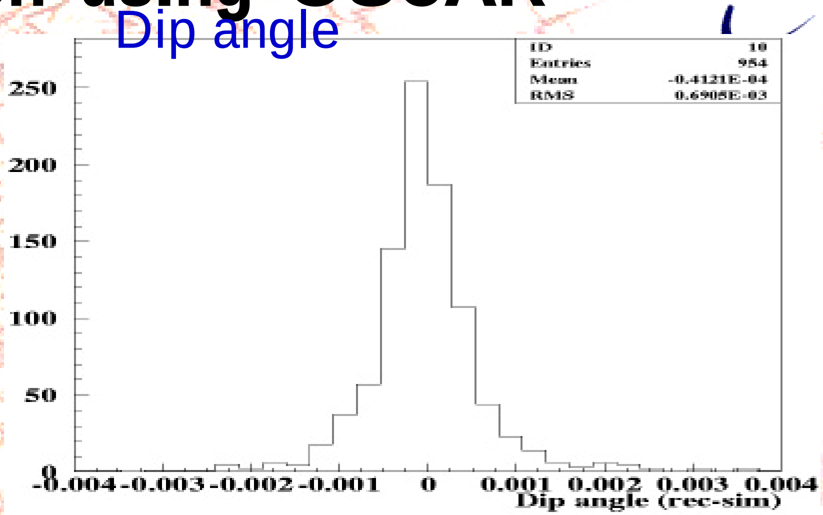
CMSIM

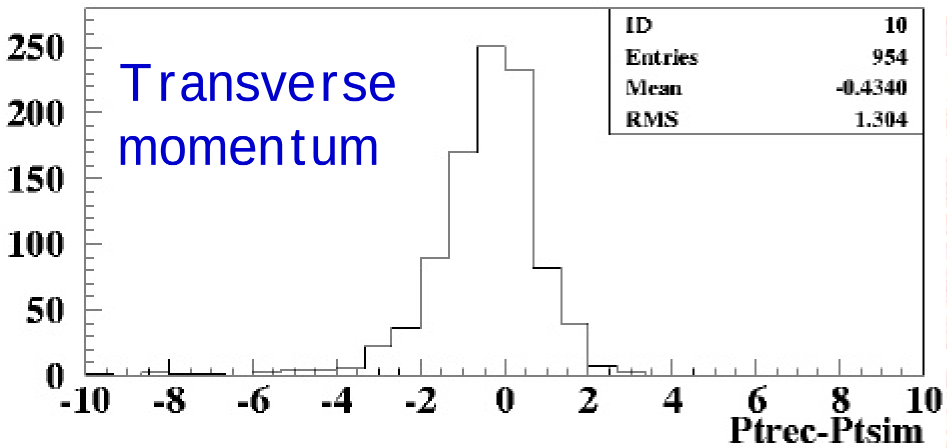
All quantities are reconstructed ones

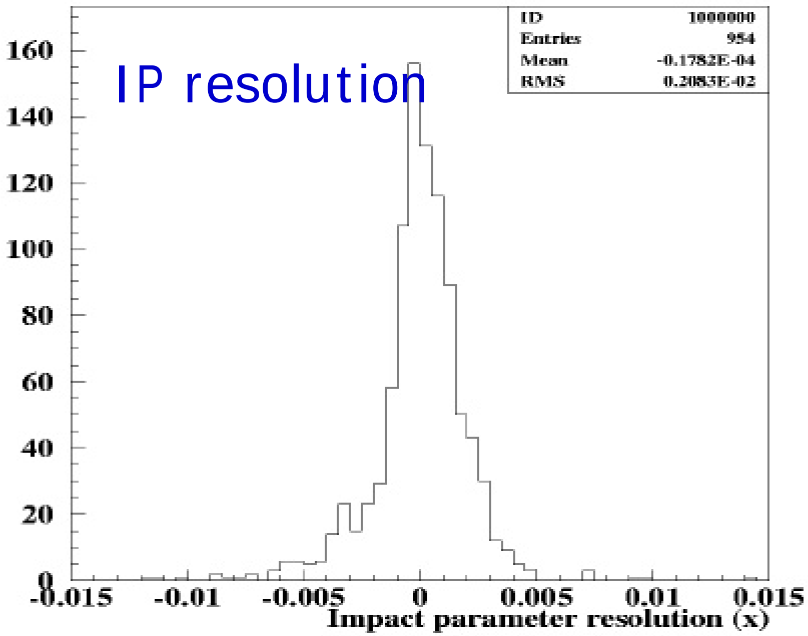


Track Resolution using OSCAR





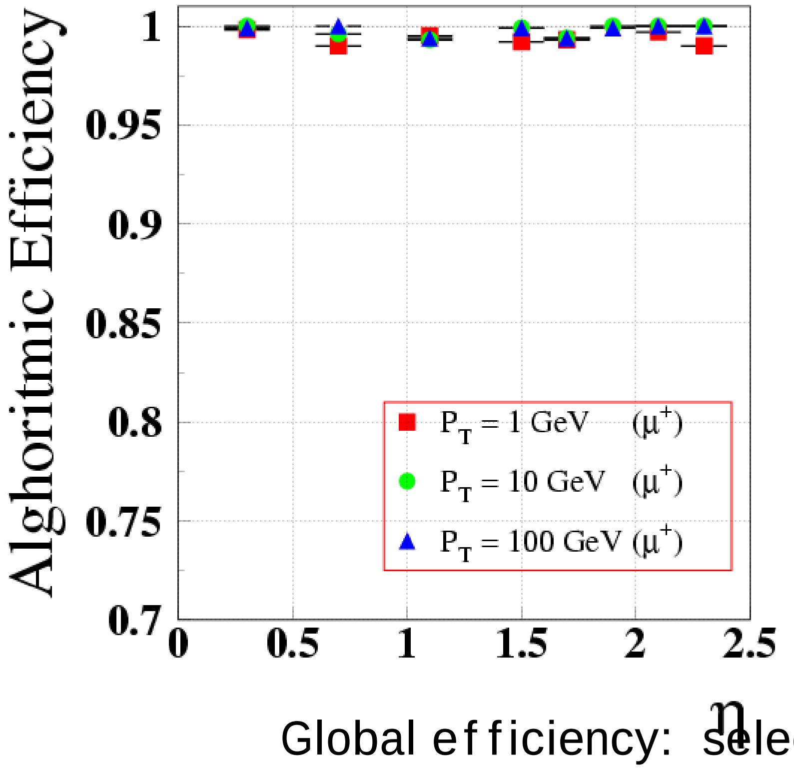


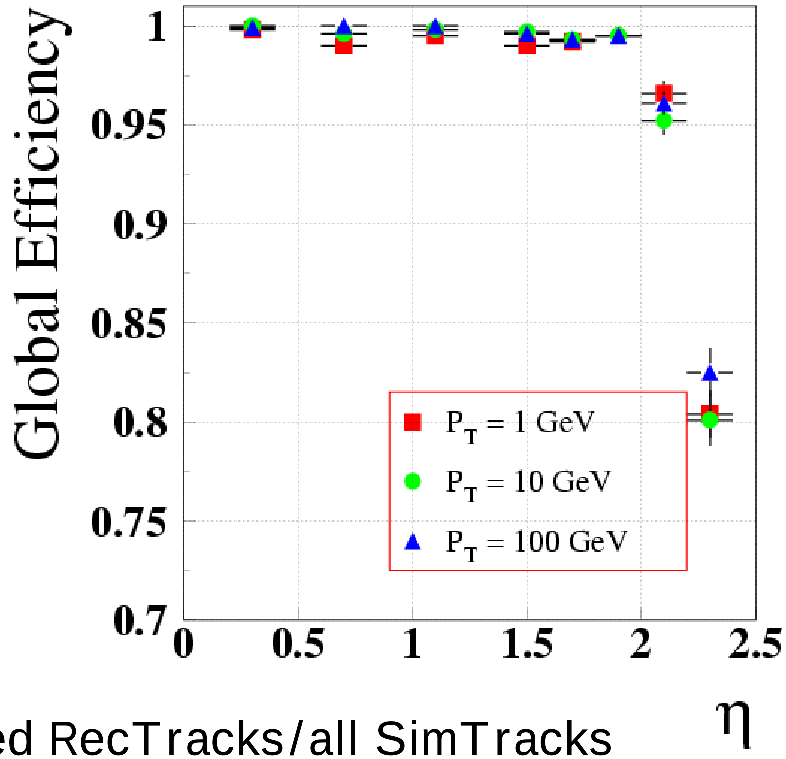


Everything is produced using standard btau code.

Tracker: Track Finding Efficiency Single m

Starting from pixel seeds, combinatorial Kalman filter





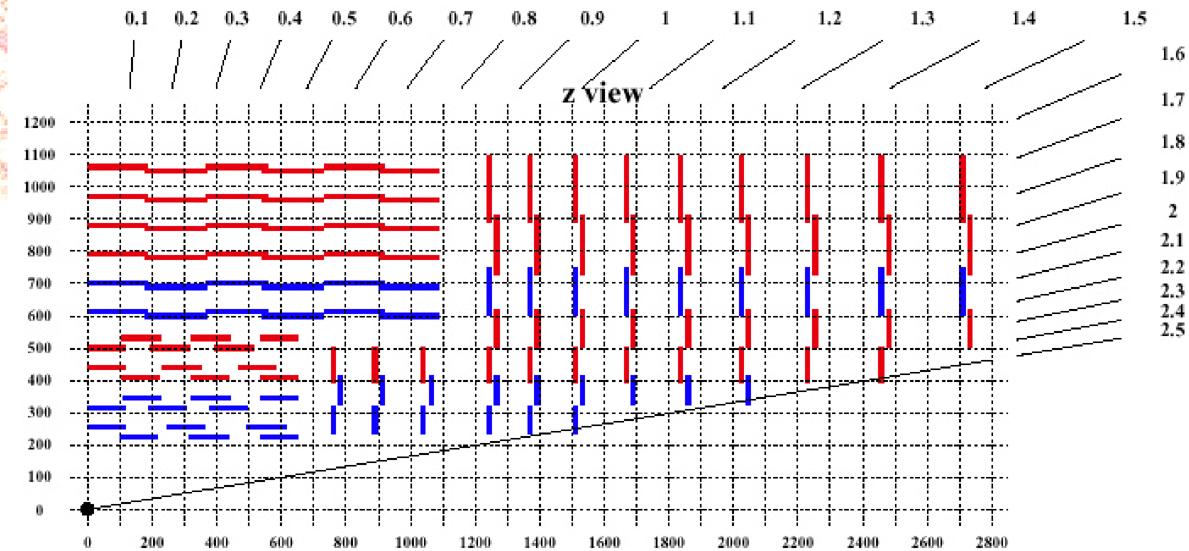
Global efficiency: selected RecTracks/all SimTracks

Algorithmic efficiency: selected RecTracks/selected SimTracks

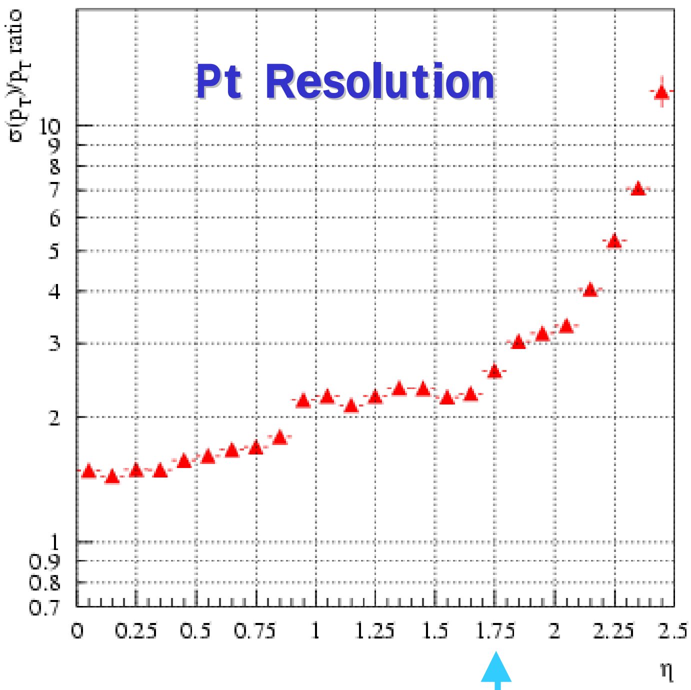
SimTrack selection: at least 8 hits, at least 2 in pixel

Global efficiency limited by pixel geometrical acceptance

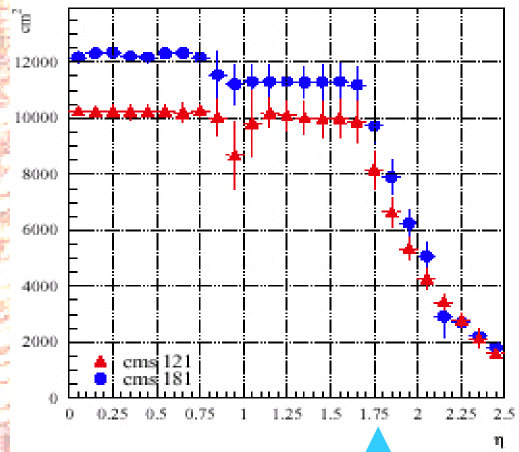
Tracker: Pt Resolution



Single muons 100 GeV



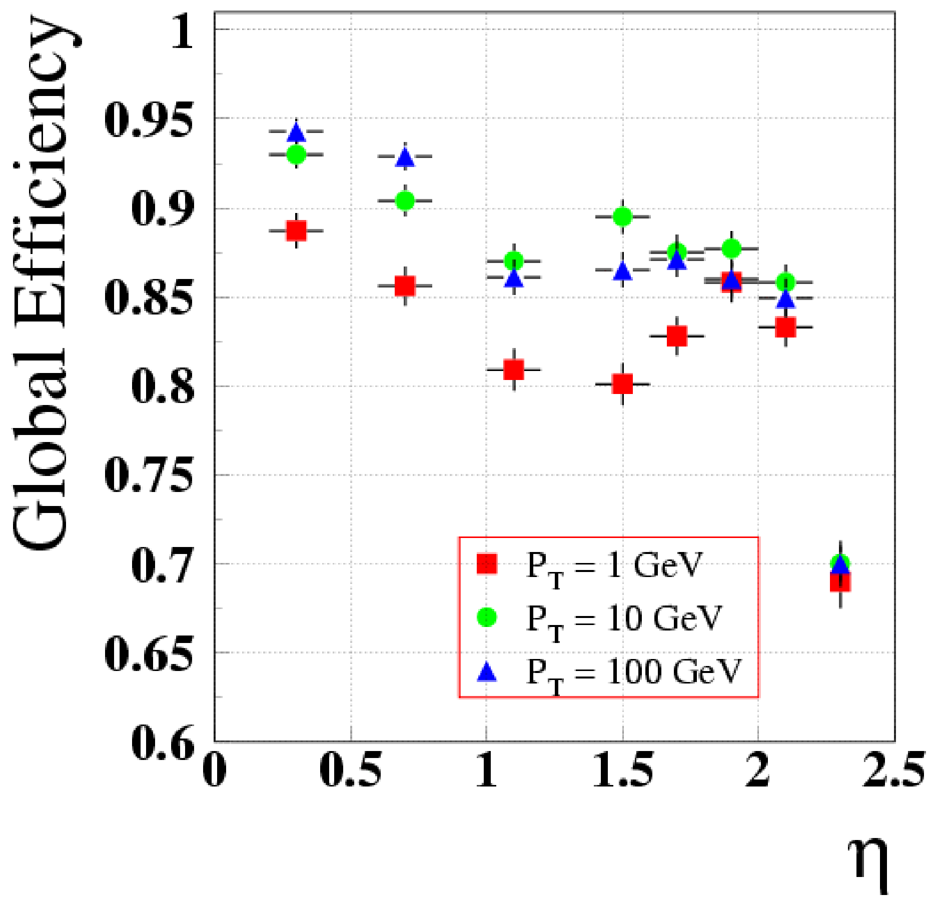
1.75



1.75

Level arm

Tracker: Track Finding Efficiency Single p



Efficiency for p is lower compared to m due to secondary interactions in the Tracker

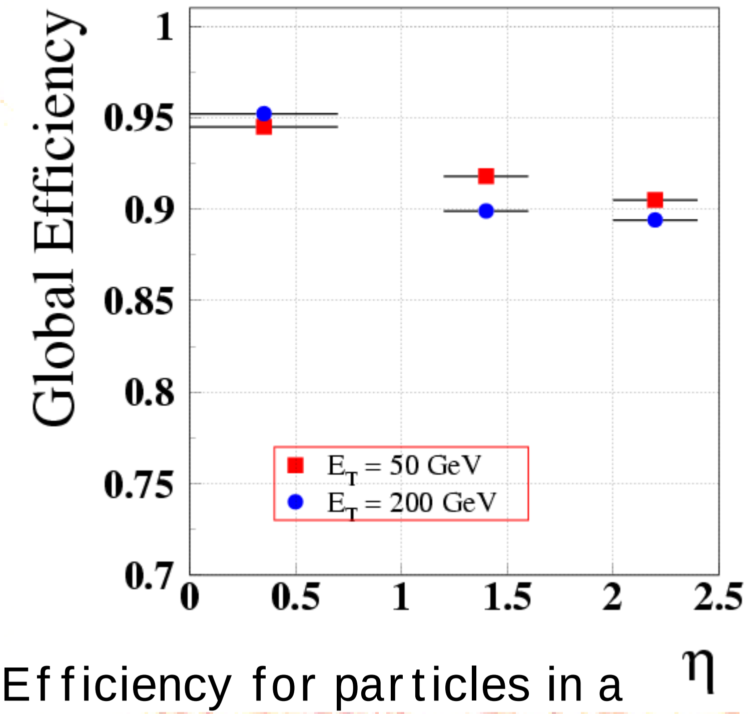
Efficiency can be increased by relaxing track selection

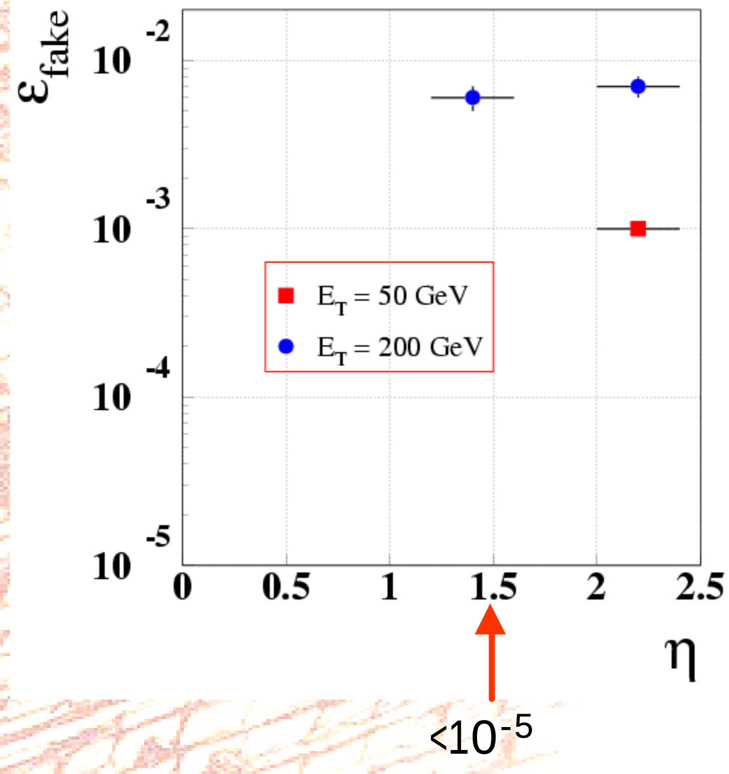
Tracker: Track Finding Efficiency in Jets

See Teddy Talk

e_{fake} = % rectrack associated to simtrack

Track associated when shared >= 50% of rechits





Efficiency for particles in a 0.4 cone around jet axis

No significant degradation compared to single pions

ET = 200 GeV Fake Rate < 8 *10^-3

ET = 50 GeV Fake Rate < 10*10 ^ -3

See Pascal Talk

Tracker: Vertex Reconstruction

Primary Vertices: several methods are availables:

- **Using only the Pixels**: fast, resolution < 40 μm in z
- **Using full Tracker**: slower, better resolution ~15 μm in z (uu events)

Secondary Vertex: Exclusive Vertices

The basic tool for the vertexing classes is a general purpose fitter. Test on $B^0_s \to J/\psi\ \phi$, with $J/\psi \to \mu\mu$ and $\phi \to KK$

Secondary Vertex: Inclusive Vertices

✓Useful for B and τ tagging.

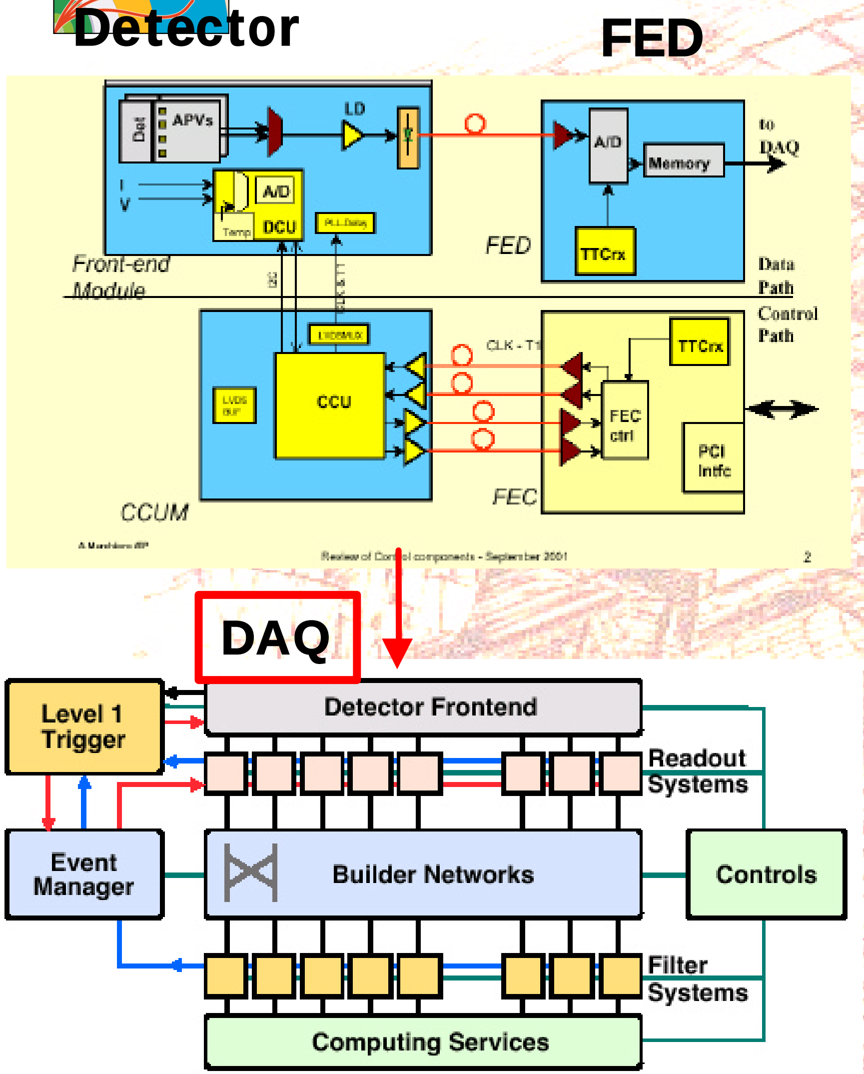
✓Two methods available and tested (Combinatorial method, D0/Φ method)

✓ Others methods will be available in future (Trimmed vertex fitting, least median of squares)

✓Analysis Tools: vertex selection and association, vertex finding efficiency and fake rate estimators.

✓ Generation of controlled event kinematics (VertexGun) will be interfaced to Track Fast Simulation (in Famos)

Tracker @ HLT



- **When the Tracker could be used in the High Level Trigger Chain??**
  - **None! The current DAQ design provides fully assembled events in the builder units after Level1**
  - **All tracker Digis available**
  - **The only constraint is CPU time**
- **Why we would use the Tracker as soon as possible!!**

Partial reconstruction

- Basic idea: do the absolute minimum of reconstruction needed to answer a specific question
- Use the same reconstruction components as the full reconstruction
  - No need for writing, debugging, maintaining several tools for same task
  - No compromise on efficiency or accuracy except from limit on number of hits

Btrigger algorithm

<u>Input: L1 jet</u>

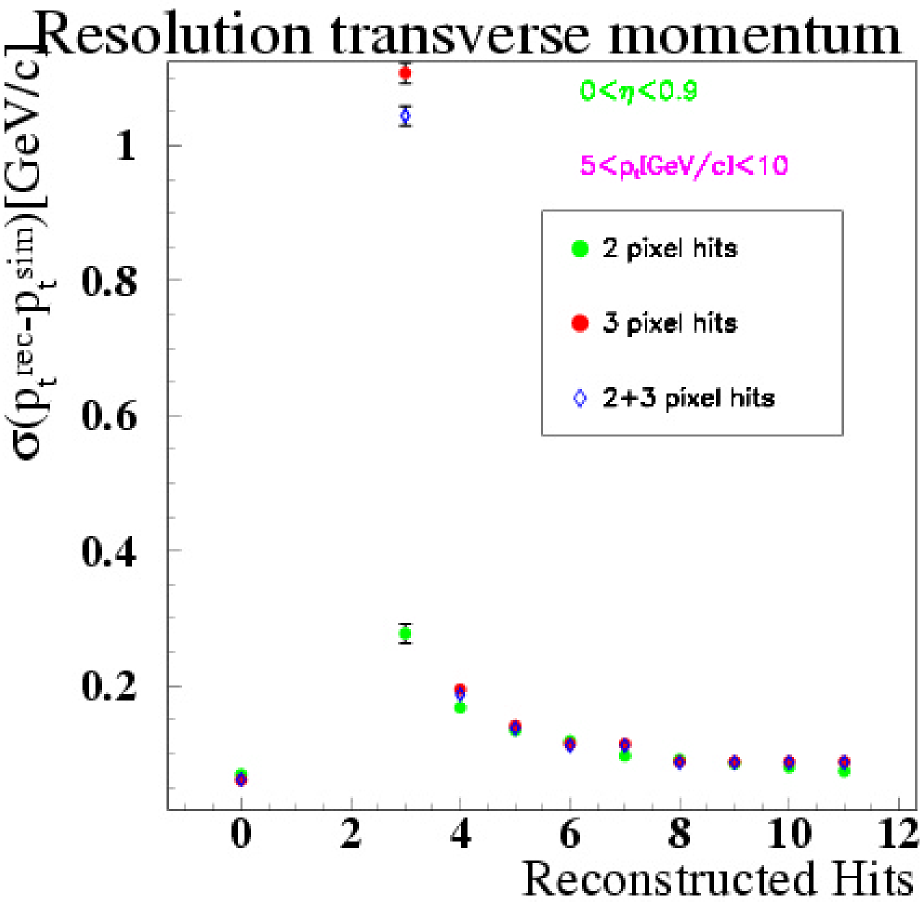
PixelSelectiveSeeds

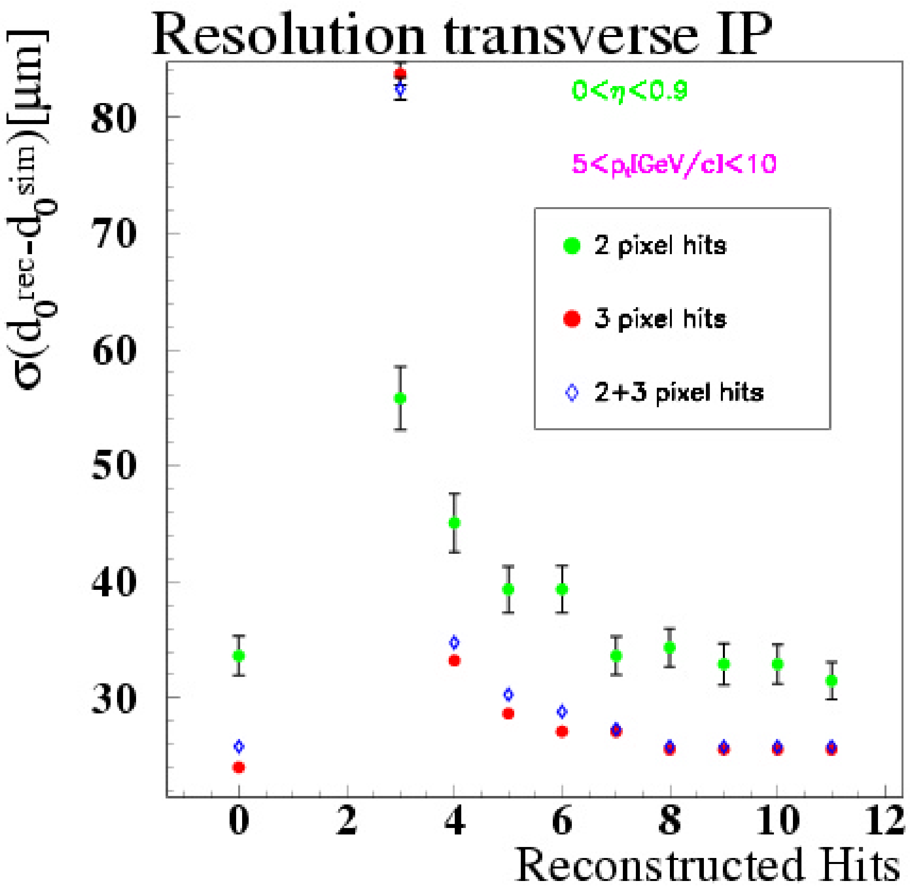
- **PixelLines** [*Danek*]
- Minitracks with pixel hits
- **PV** from pixel
- **? R** around jet directions

CombinatorialTrajectoryBuilder

- Stopping condition at **n** hits

Partial Track reconstruction

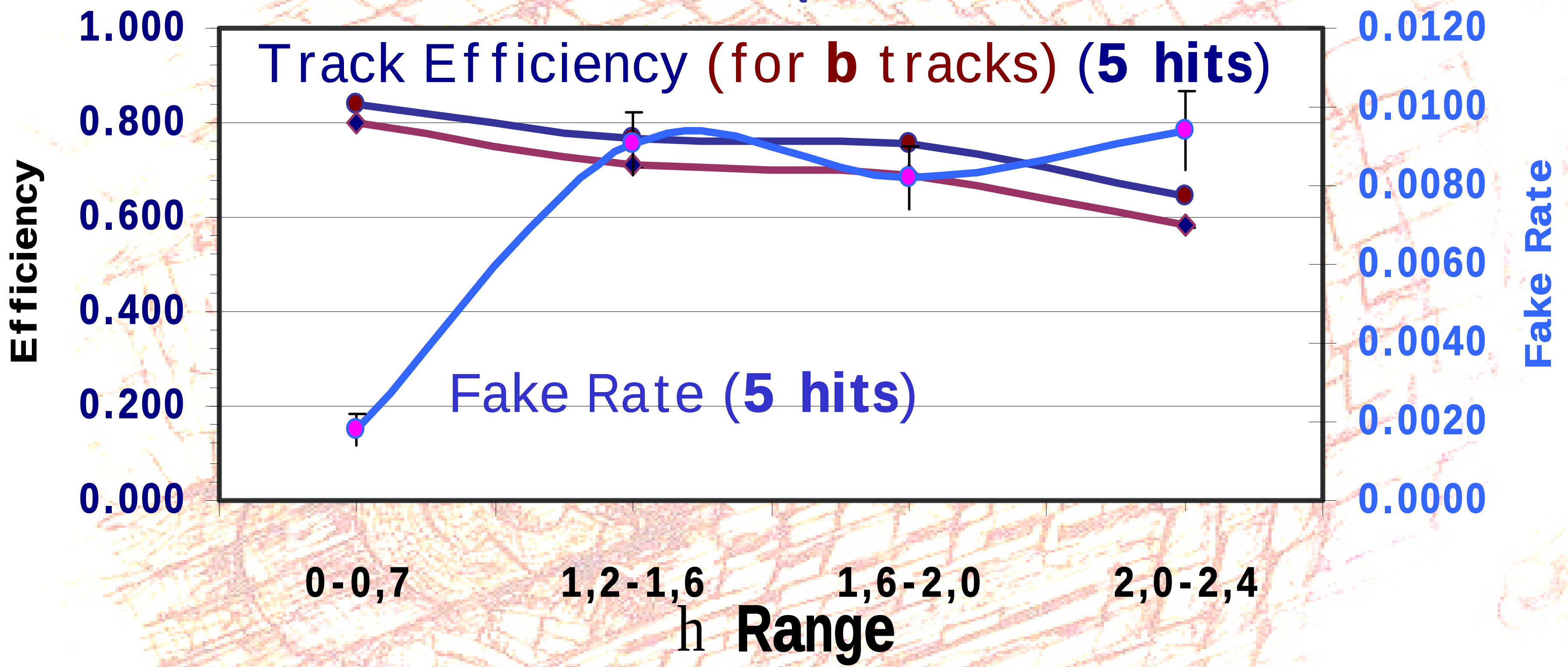




Good resolution with only **5 hits** [*Riccardo*]

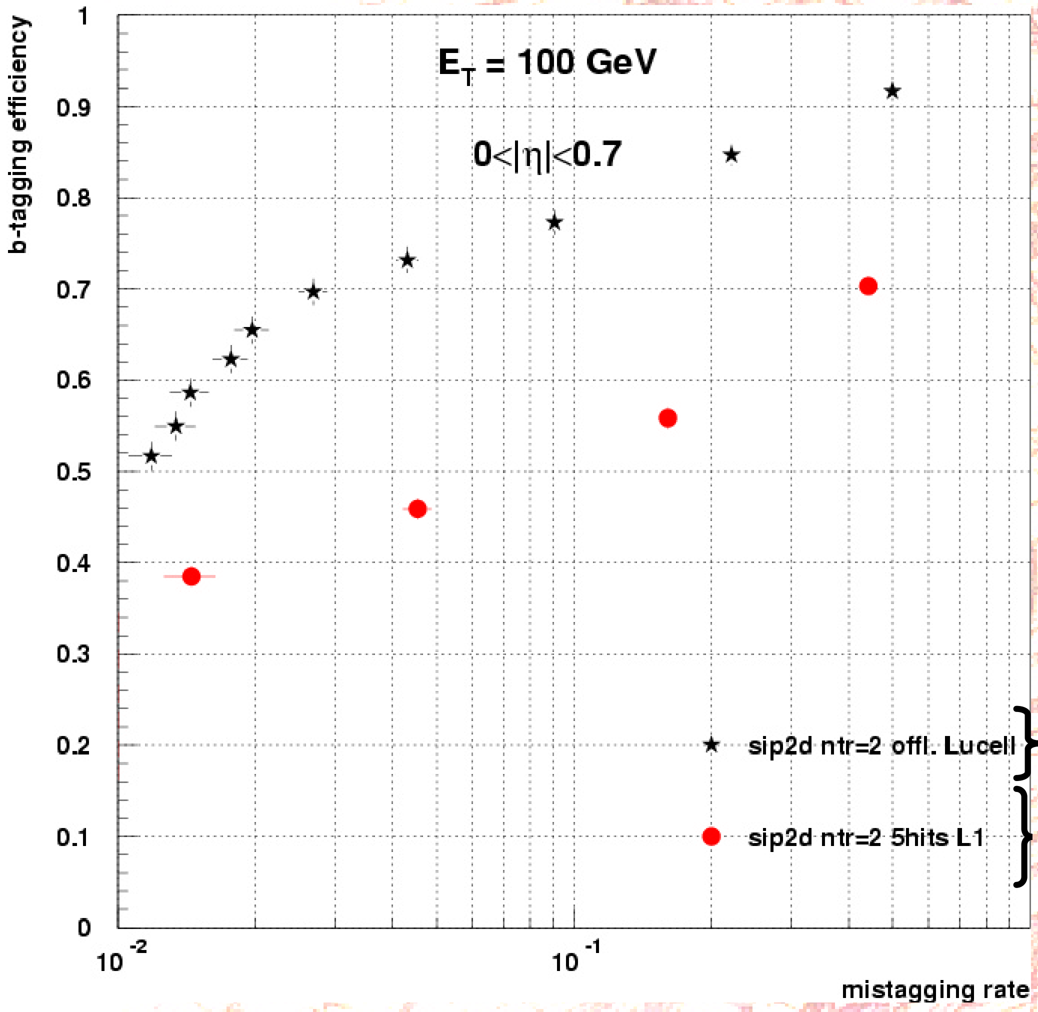
Efficiency bb jets

Jet info from Lucell E_t=100 GeV ? R<0.4



Fake Rate below 1% [*Riccardo*]

B-tag performance



} OFFLINE [*Gabriele*]

} HLT

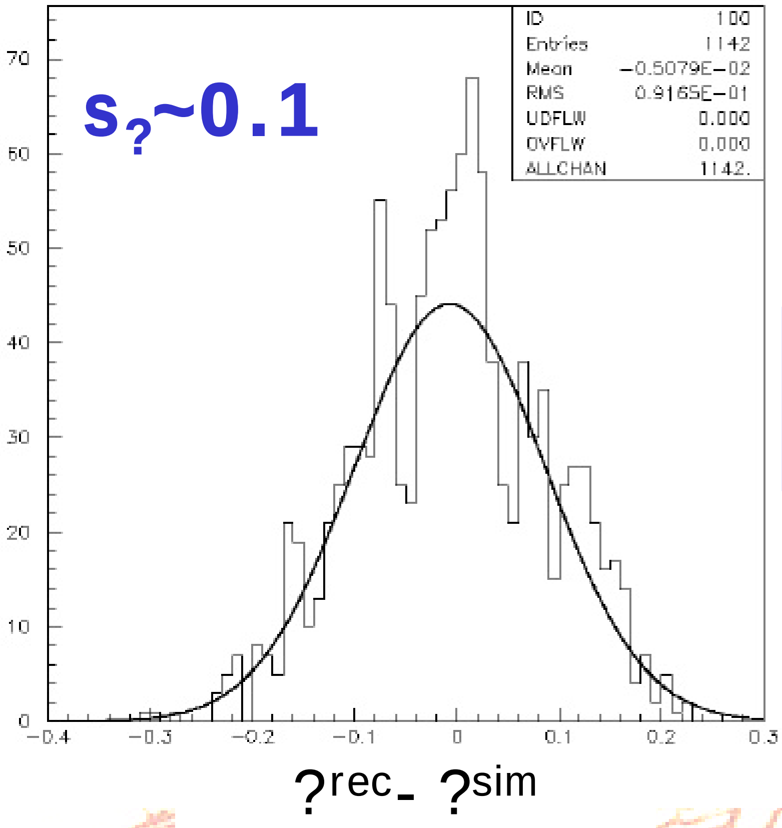
E_t=100 GeV jets

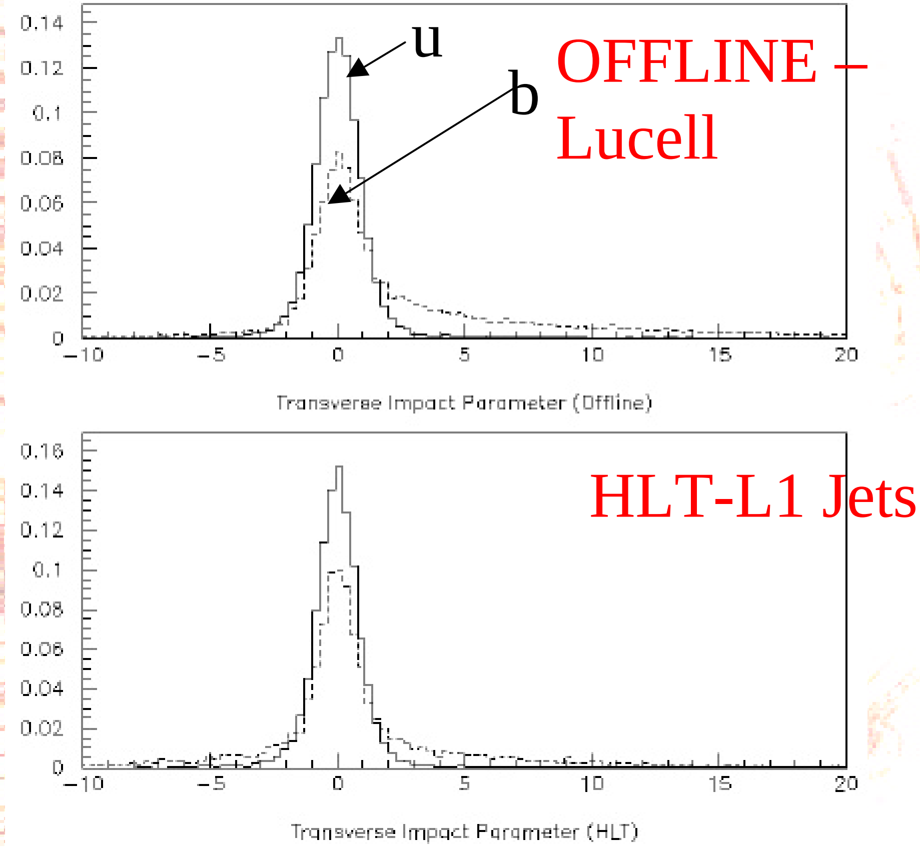
barrel 0.<|?|<0.7

Rejection factor **u** jets **~10** with **b** jets efficiency **<80%** (online)

Jet-tag: 2 tracks with S_{IP}>0.5,1.,1.5,2.,2.5,3.,3.5,4.

Sign flip of IP





L1 jet (poor) resolution in ? and f (s~0.1) [*Livio*]

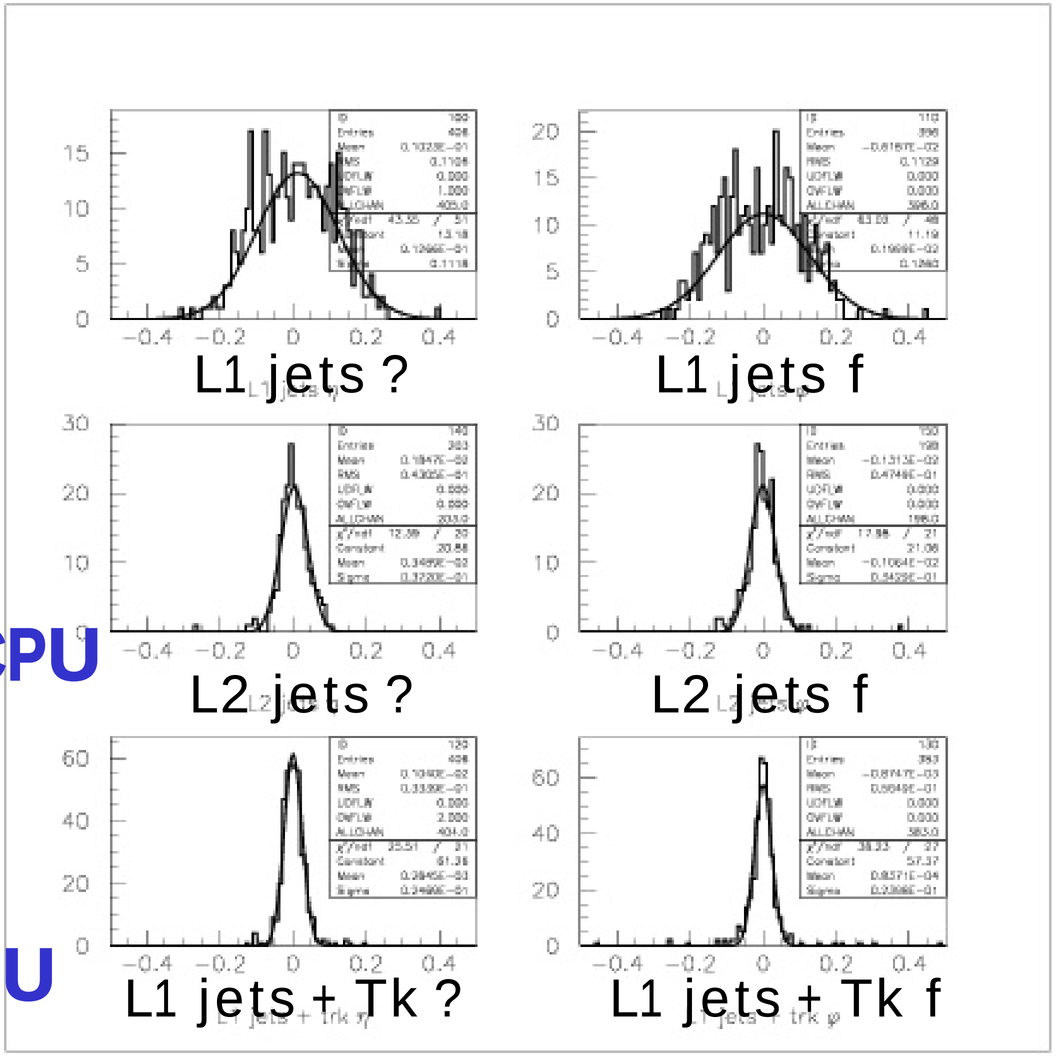
2d transverse IP sign flip [*Gabriele*]

Jet axis measurements

$s_{?}=0.112$

$s_{?}\sim 0.037$
+70 ms CPU

$s_{?}\sim 0.025$
+2 ms CPU



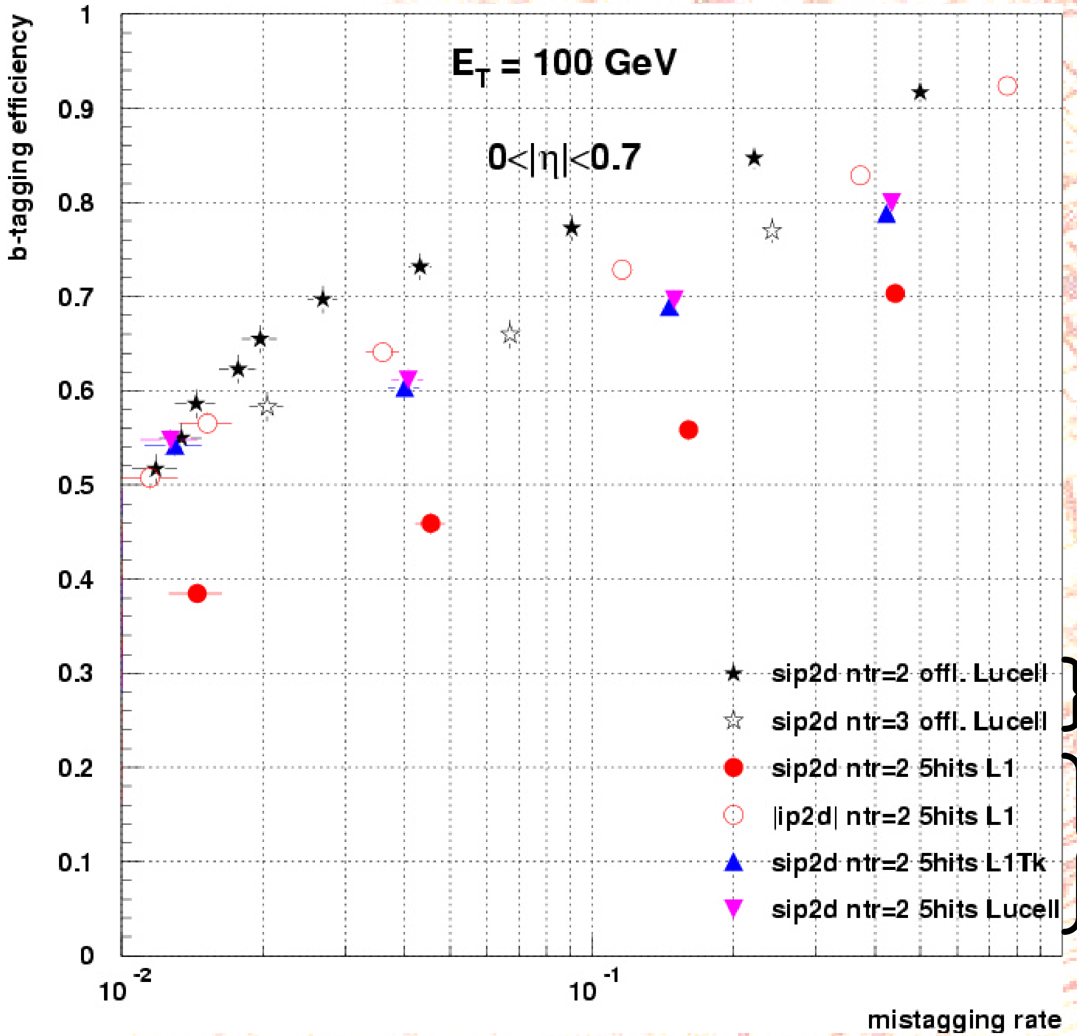
$s_{f}=0.126$

$s_{f}\sim 0.034$

$s_{f}\sim 0.024$

[*Livio*]

L1+Tracks B-tag



OFFLINE

HLT

E_t=100 GeV jets

barrel 0.<|?|<0.7

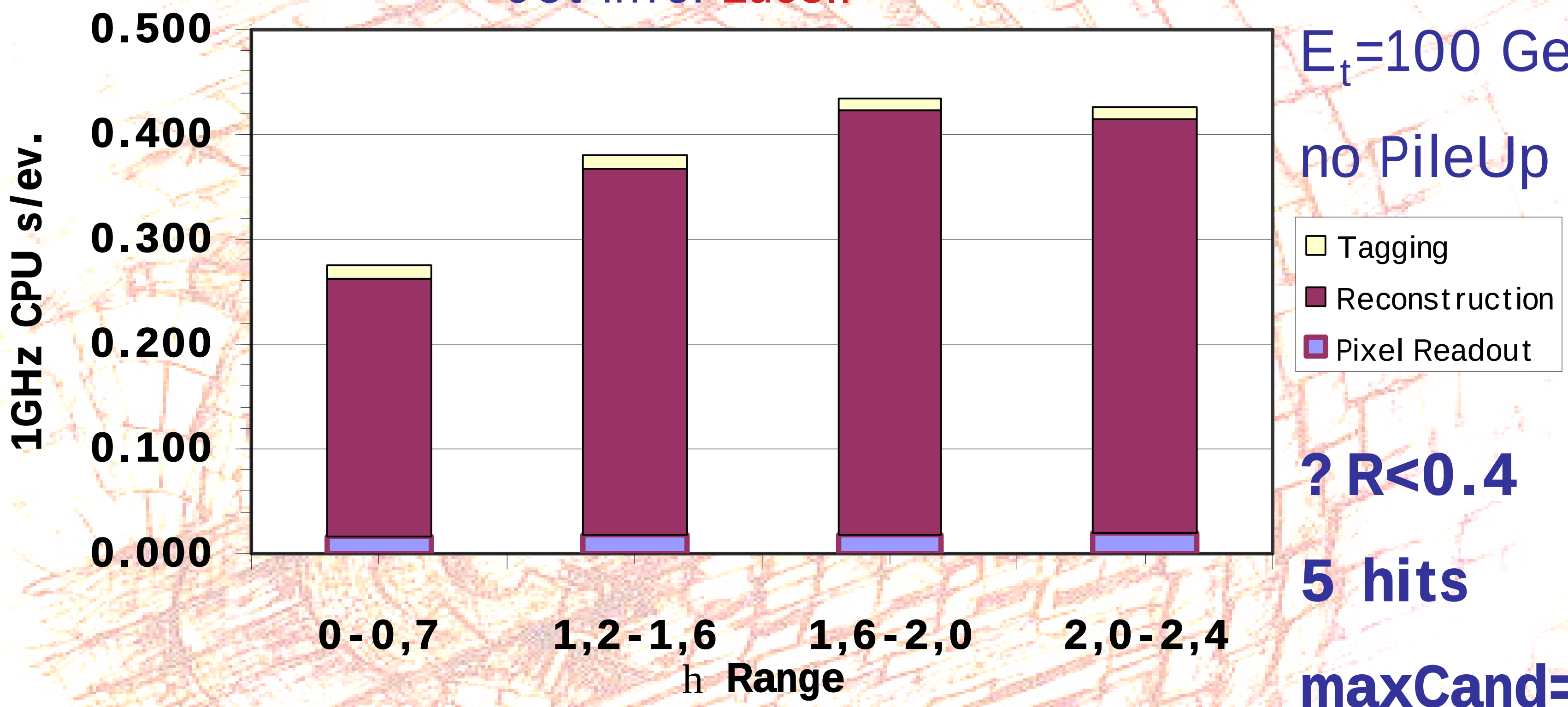
Online performance is better with **L1+Tk** jets!!

See Fabrizio Talk

Jet-tag: 2 tracks with S_{IP}>0.5,1.,1.5,2.,2.5,3.,3.5,4.

Timing bb jets

Jet info: Lucell



E_t=100 GeV

no PileUp

? R<0.4

5 hits

maxCand=3

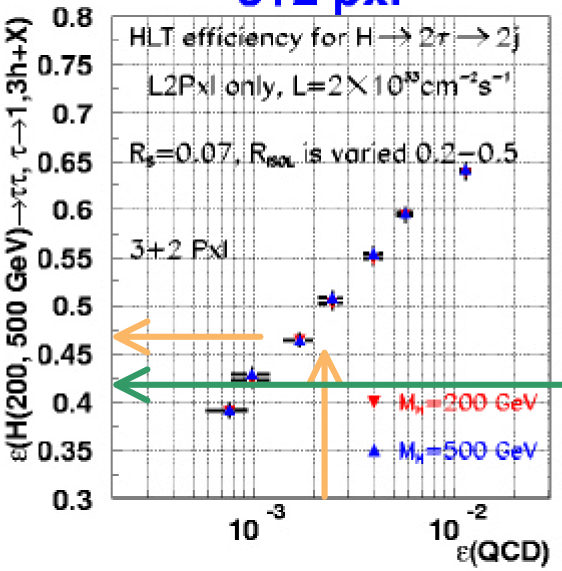
Increasing of reco time towards forward regions

Tagging algorithm: <10 ms/ev !!!

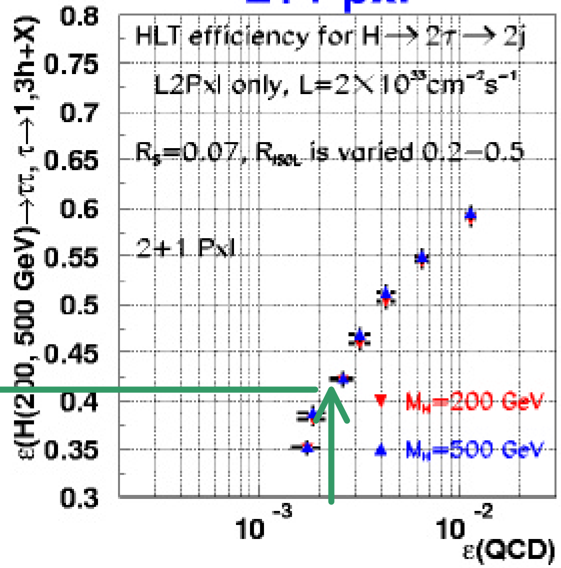
See Sasha Talk

H->2τ -> 2j selections at HLT with Pixel data only.

3+2 pxl



2+1 pxl



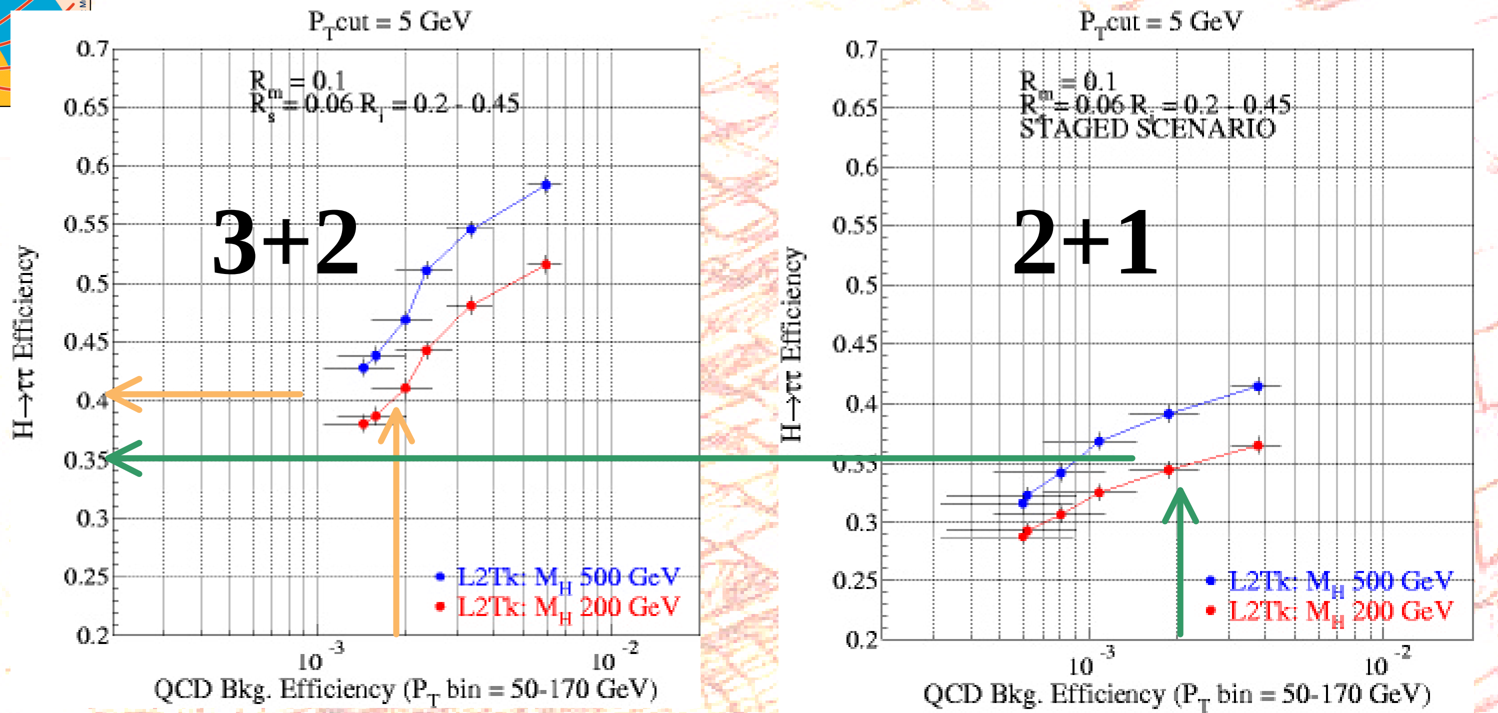
CPU estimates with Pentium III (Coppermine); cpu MHz : 600.

Pxl Tau ID steps ; Time (sec) 3+2 vs 2+1 pxl	qcd 50-80	qcd 120-170	H 200 GeV	H 500 GeV
Pixel RHits reco (getData)	0.0580 / 0.0420	0.0570 / 0.0400	0.0550 / 0.0400	0.0530 / 0.0390
Reco pxl lines and vrtx (doIt)	0.0590 / 0.0390	0.0570 / 0.0370	0.0490 / 0.0320	0.0450 / 0.0290
Pxl Tau ID for 1-st jet Pxl Tau ID for 2-nd jet	~ 0.001	~ 0.001	~ 0.001	~ 0.001
Total time (sec) 3+2 vs 2+1 pxl	0.1180 / 0.0820	0.1150 / 0.0780	0.105 / 0.0726	0.0990 / 0.068
Total time (sec) 3+2 vs 2+1 pxl for 1GHz CPU	0.0710 / 0.0490	0.0690 / 0.0470	0.063 / 0.0440	0.0590 / 0.041

H ® 2t ® 2 Jets Selection with Tra

See Giuseppe Talk

INFN



Tracker Reconstruction steps (for single jet) :Time (sec) 3+2/2+1 (1 GHz cpu)

	Bkg	mH 200	mH 500
Pxl Reco	0.070/0.050	0.060/0.044	0.061/0.044
Trk Reco 1st Jet	0.215/0.300	0.063/0.106	0.062/0.100
Isolation for 1st jet	<0.005	<0.005	<0.005
Total Time	0.290/0.351	0.124/0.152	0.127/0.145

Tracker @ HLT

- **Today …**
  - **We achieved close to 150-200 ms CPU times (or better) for complex HLT tracker algorithms** (if we consider the fast detlayer implementation)
  - **The tracker can be used at the first stage in the High Level Trigger on all events**
  - **Regional Seeding speed up in case of PileUp and High Luminosity**

Tracker @ HLT (Next Steps)

– Now almost all samples request from btau are available..

– … more and more realistic environment (Staged pixels, PileUp, High Luminosity, Mis-alignment)
  - Tau studies with high luminosity (see Sasha, Lauri, Giuseppe talks)
  - B inclusive and exclusive studies with low and high luminosity (see Fabrizio talk)
  - Muon and electron studies (with PRS Muon and ECAL) at low and high luminosity. (see Kati talk)

Tracker Alignment

Two different approaches for Alignment

- Laser System :
  → outside physics → different conditions (Voltages,temperature)
  once per day
  → during physics → real conditions
  on demand, fast reaction

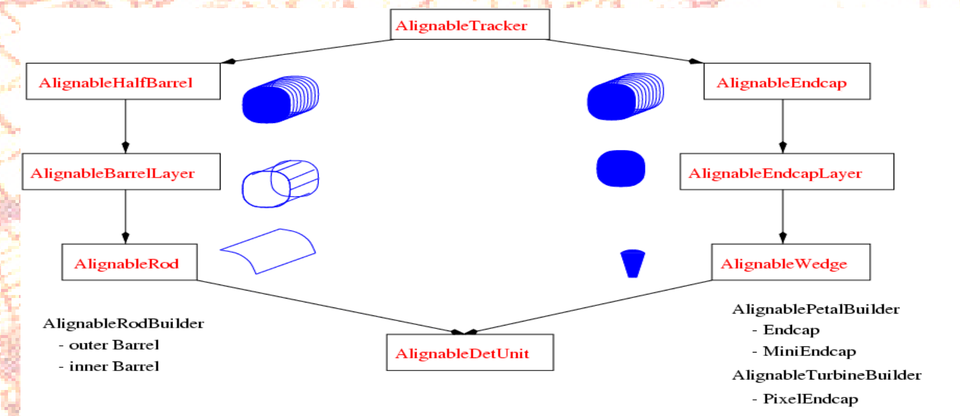
- Alignment with tracks :
  → starts from other measurements : Poli, Laser System etc.
  → offline, reaction time depends on procedures developed
  how fast , how often ? (Laser System)

Some tools for Alignment studies available

See Saturday Session dedicated to Tracker Alignment

Alignment Tools

- ORCA Alignment Tools
  - MC generation with perfect geometry
  - simulate arbitrary misalignment at reconstruction level
    - study track reconstruction (efficiency/resolution)
    - test alignment procedures
    - apply alignment procedures

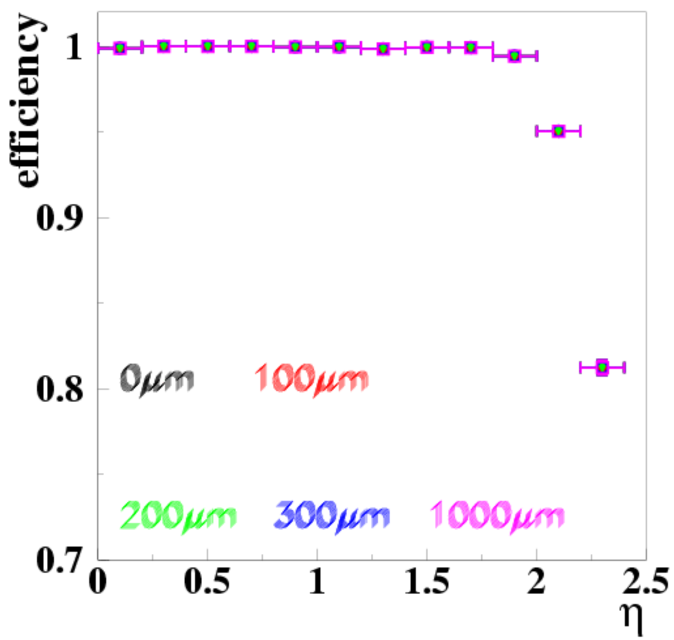


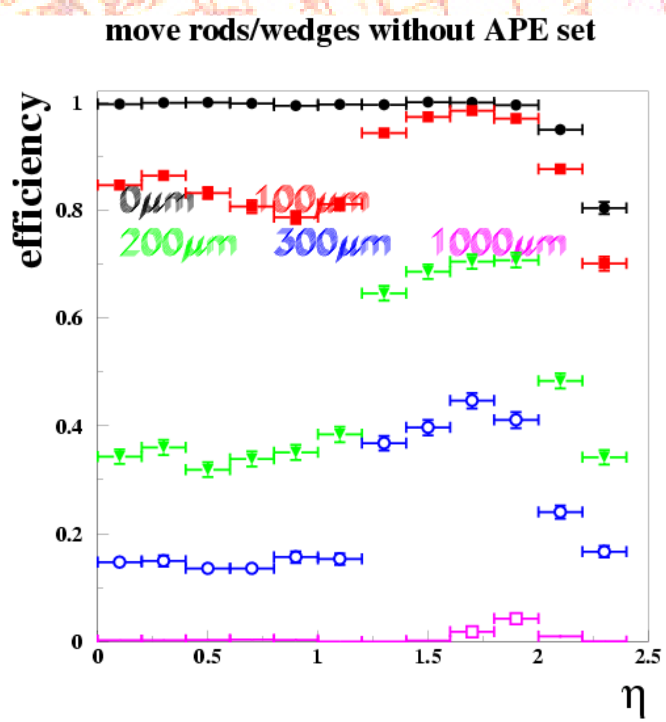
All objects can be moved and rotated individually or as composites

- reflect structure of physical components:
  - realistic misalignment scenarios
  - minimizes later alignment parameters
- Now the same tools are used also from PRS Muon

Misalignment Studies (single-m)

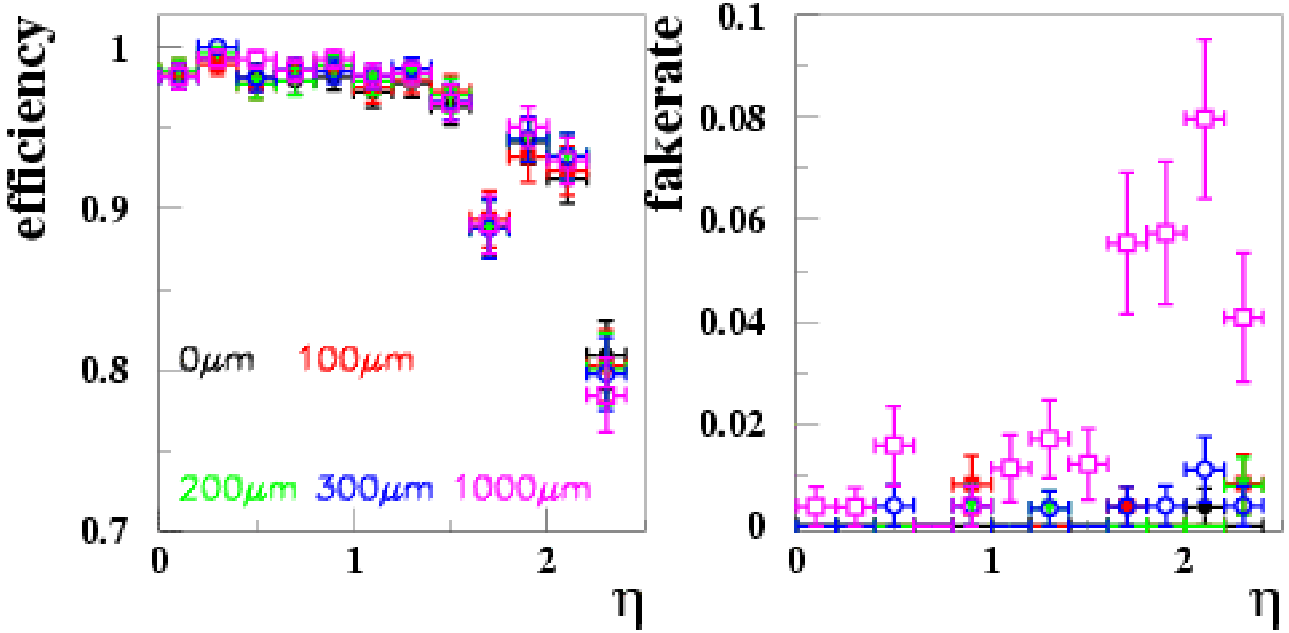
- track reconstruction (single-μ, P_t =100GeV)
- random movements of rods / wedges + setting the Ali.Pos.Err. accordingly





More realistic: W®mn events with pileup (low lumi)

- random movements of rods / wedges
- reconstruct tracks with P_t > 20GeV



Alignment Conclusions

- Alignment Tools: work ✓
  - We need still add functionality
- Alignment studies:
  - reconstruction is uncritical up to even 1mm/1mrad misalignment (10 times more than survey/laser-alignment accuracy)
- How the mis-alignment affect the Tracker at HLT...

Conclusions

- PRS Tracker b tau Software is in good-shape.
- Tracker geometry and detector simulation
  - in Cmsim (Geant3) and OSCAR (Geant4)
  - Geant4 Physics validation will start (I.e. comparison between test-beam PSI data and simulation)
- Tracker Data-Handling Tracker data rates & test-beam analysis
- Track Reconstruction flexible & robust tool
- Vertex Reconstruction Primary & Secondary
  - Tracker Performances (pattern recognition, momentum resolution, vertex capability etc)
  - The Tracker (micro-strip and pixel) reconstruction is a powerful and fundamental tool for Tracker @ HLT

Conclusions

- **Tracker @ HLT**
  - Tau High Level Trigger (Calorimeters, Pixel, Silicon) and Tau offline (tau decay vertex, mass, impact parameter)
  - b High Level Trigger (Impact Parameter, secondary vertices, Regional track finding) and b Offline (inclusive & exclusive)
  - Muon High Level Trigger
  - Electron High Level Trigger
- **Tracker Alignment (tools available…)**

Next steps:

Complete tau & b Analysis at 2* 10^33 and at 10^34 CMS Week (10 June 2002)

DAQ TDR CMS Week (September 2002)

……

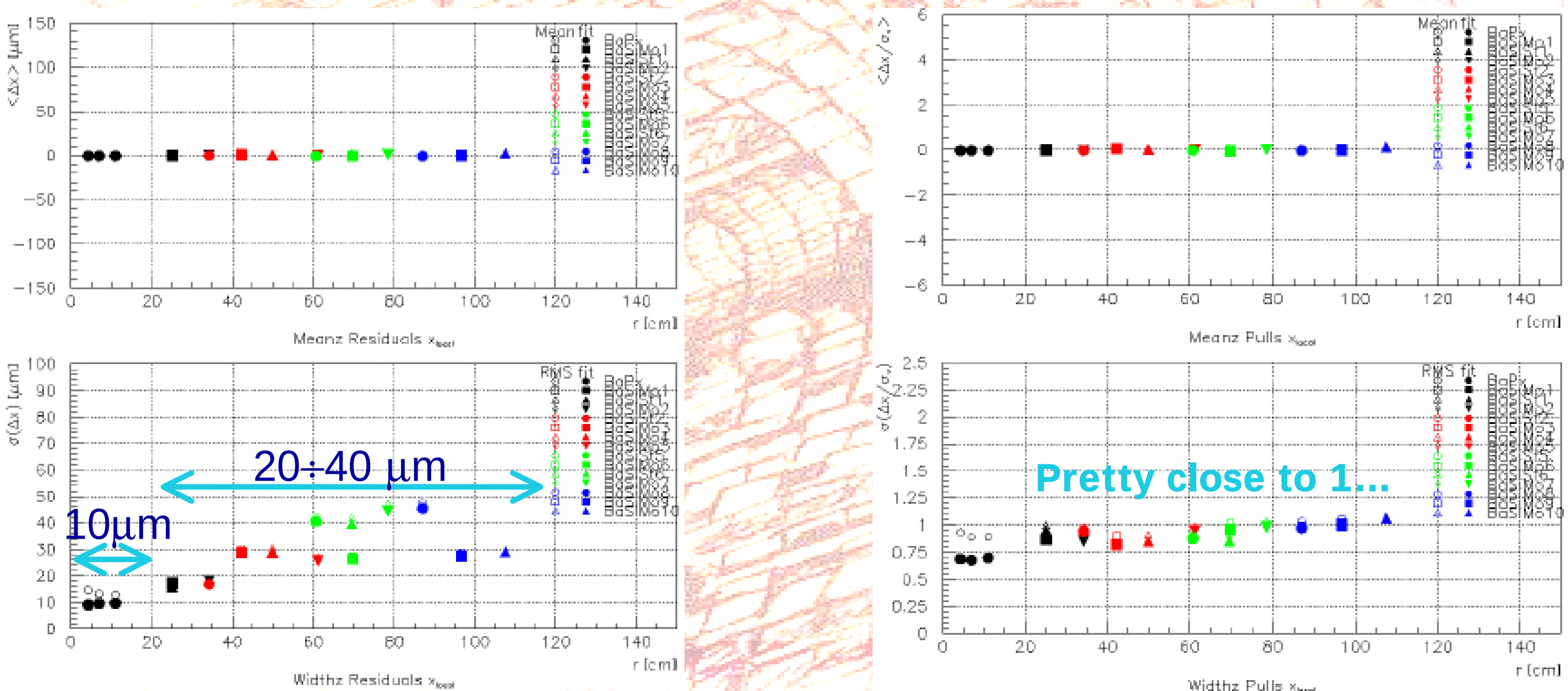
Back - up

Tracker Detector Simulation

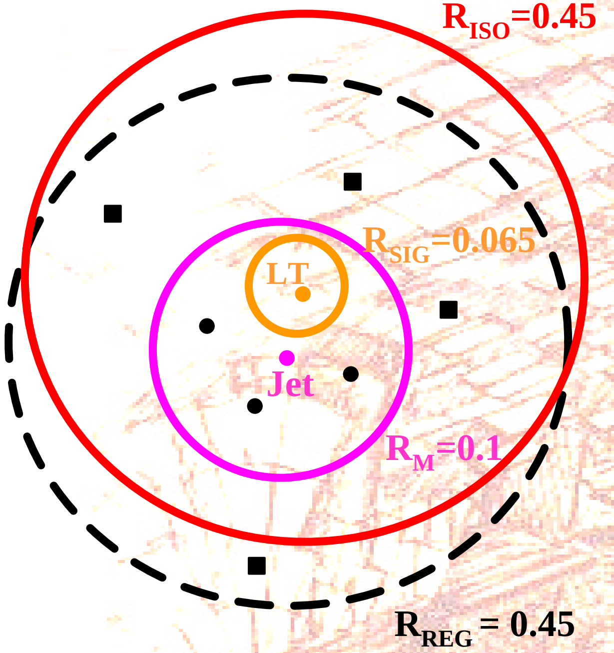
Given a set of Digitization parameters, the simulation is adjusted to parameterize correctly the errors.

ORCA_5_4_x

RecHit residuals (µm) RecHit residuals (pulls)



How to reduce tracking time

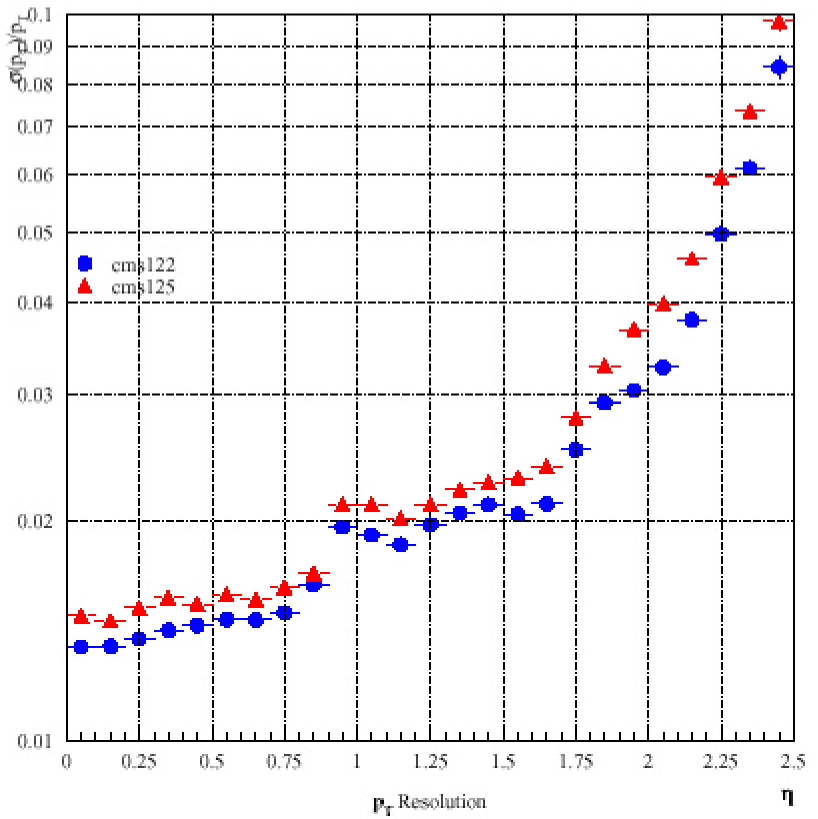


- Reconstruct tracks inside R_M only
- Find LT:
  - If LT doesn't exists stop everything
  - If LT exists apply isolation on rec Tk, if it is not isolated stop everything
- If event is isolated go on reconstructing also tracks inside region between R_M and R_{REG}
- Apply isolation to all tracks.

Tracker Reconstruction steps (for single jet) :Time (sec) 2+1 (1 GHz cpu)

Staged scenario	Bkg	mH 200	mH 500
Total Time (pxl + Tk + iso)	0.351 -> 0.216	0.152 -> 0.136	0.145 -> 0.126

Tracker: Pt Resolution

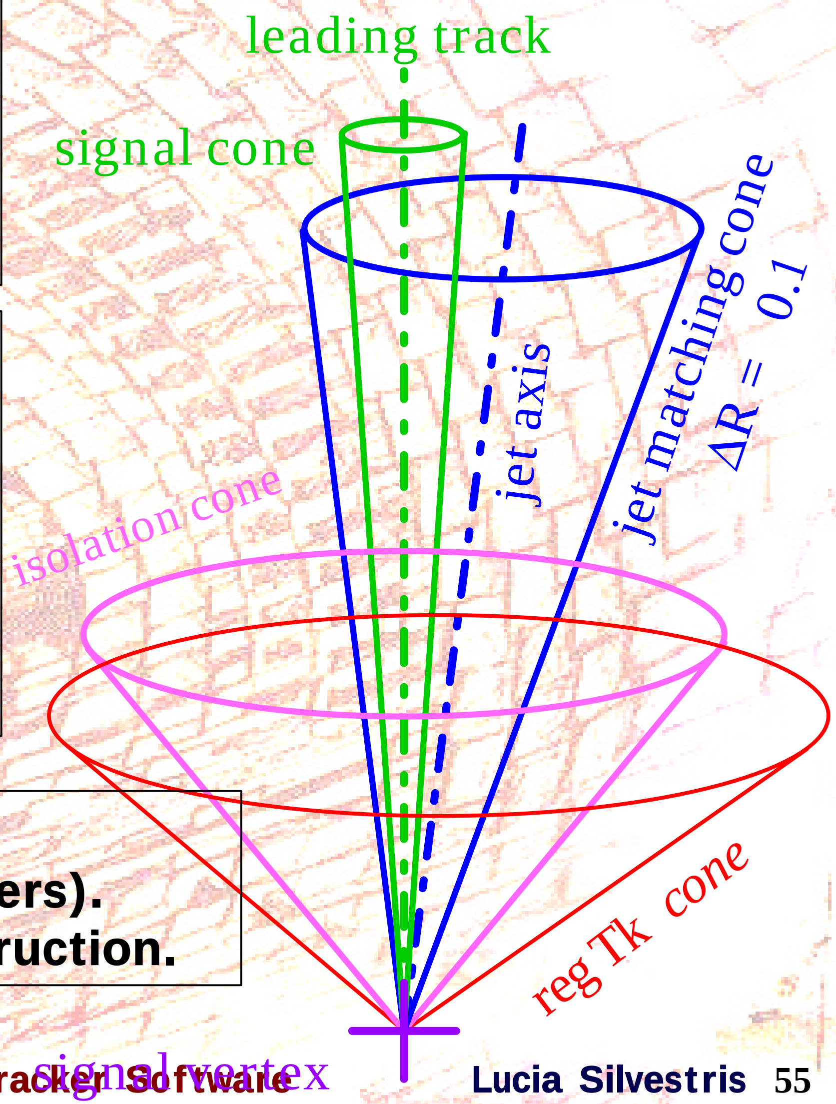


Tau case: Isolation Algorithms

Signal vertex identified by:
Pxl: leading track (P_T>3GeV)
Trk: best signal vertex candidate from pixel Reconstruction.

Both algorithms count number of tracks inside signal (N_{SIG}) cone and isolation cone (N_{ISO}).
Events is accepted if leading track
exists and $N_{SIG} = N_{ISO}$

Pxl: use pixel lines (i.e. tracks reconstructed only with pixel layers).
Trk: use regional tracker reconstruction.



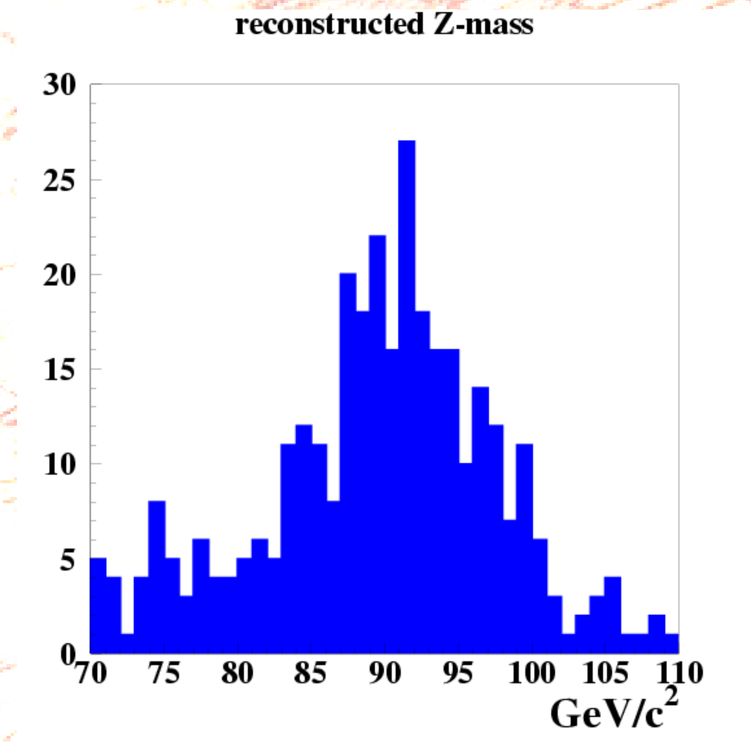
Example: Tracker L2 muon trigger

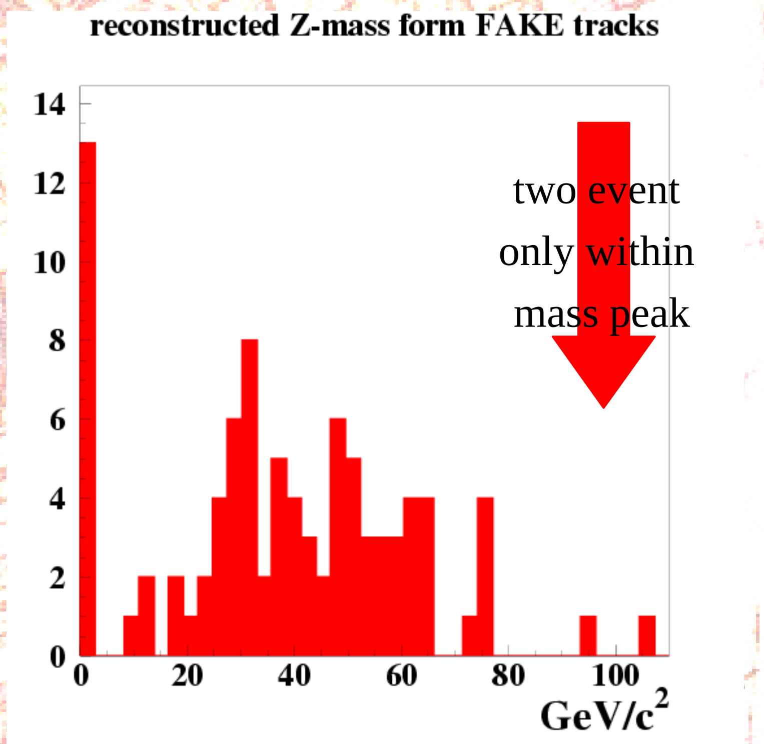
- Conditions:
  - High Pt threshold – around 15 GeV
  - Primary muon: transverse impact parameter below 30 microns
  - Direction known from L1 with 0.5 rad accuracy
- Tracker information needed: confirm existence of track with the selection criteria above
- Using regional seeding and Pt cut in trajectory building, it takes about 10 ms to reject L1 muon candidate

Tracker can be used at Level 2!

Alignment with Tracks Þ Fake-rate ?

- reconstruct Z-mass in $Z \rightarrow \mu\mu$ events
  - movement rods/wedges $\sigma_x = \sigma_y = \sigma_z = 1000\ \mu m$





Tracker Data Rates per FED

Data rate variation event by event

High lumi