A view on the ATLAS Inner Detector Status

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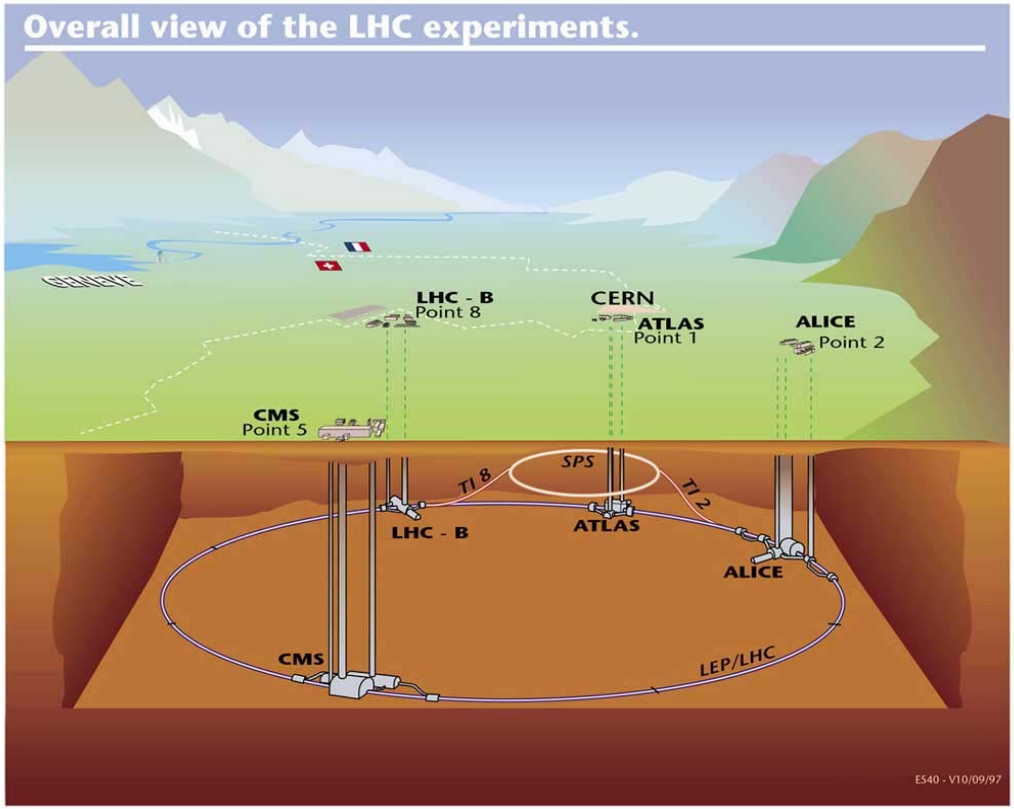
on behalf of ATLAS ID group

SiLC Satelite meeting
Vienna, Nov 2005

Large Hadron Collider

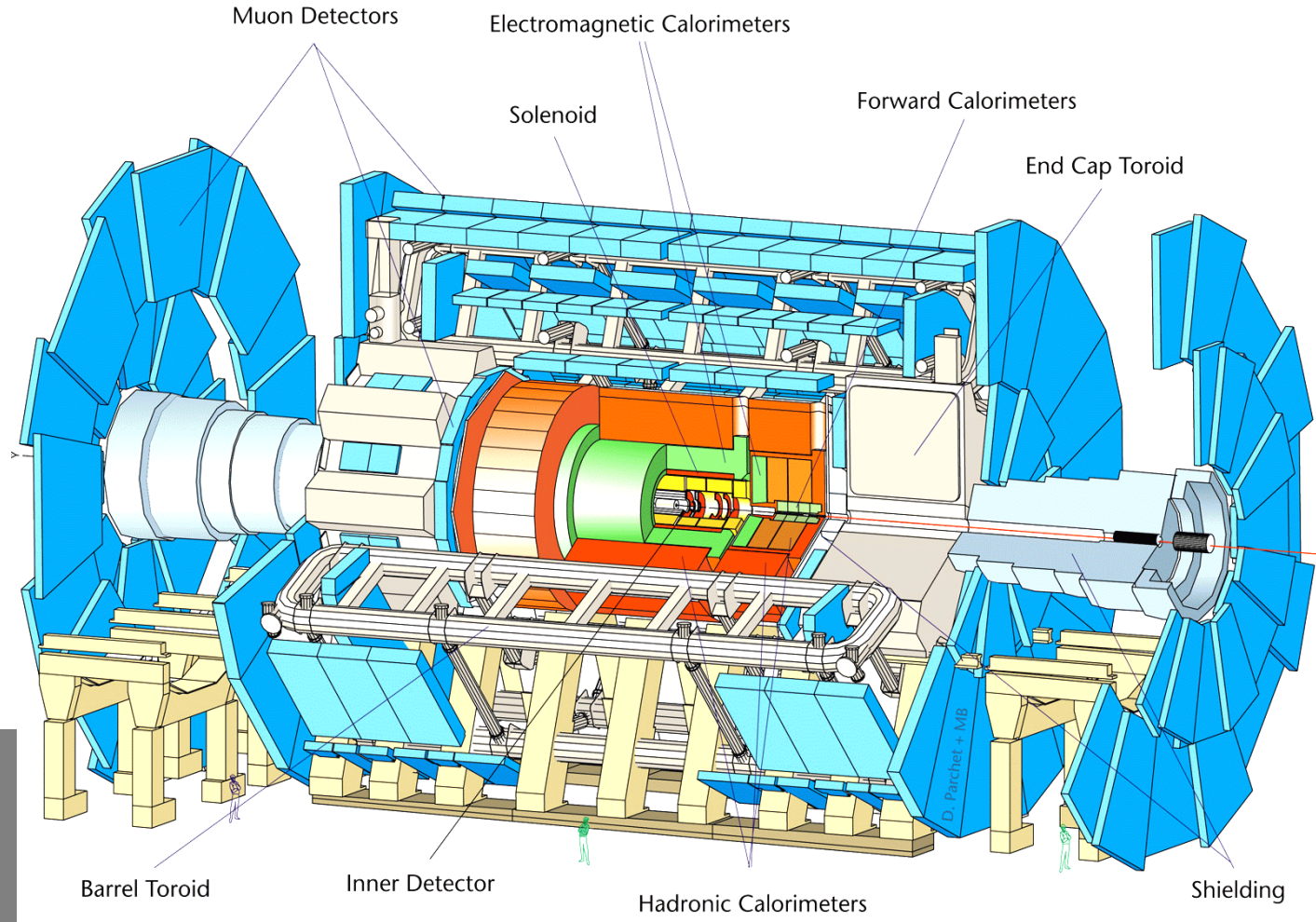
- Located at CERN
  - 27 km underground tunnel
  - $\sqrt{s}$ = 14 TeV (proton-proton)
  - Luminosity:
    - first few years: 10^{33} cm^{-2} s^{-1}
    - design luminosity: 10^{34} cm^{-2} s^{-1}
- Experiments:
  - ATLAS, CMS: general purpose
  - LHCb: devoted to B physics
  - TOTEM: total cross-section
  - ALICE: heavy ion collisions
- Startup forseen in 2007
  - More info: “LHC project passes several milestones”, CERN Courier,November 2005



More than 100 magnets already installed in the tunnel

ATLAS: A Toroidal LHC AparatuS

- General Pourpose Experiment
  - Efficient tracking (ID)
    - 2T magnetic field
    - momentum
    - impact parameter
    - b-tagging
  - Calorimetry
    - hadrons
    - electrons
    - photons
  - Muon spectrometer immersed in a magnetic field

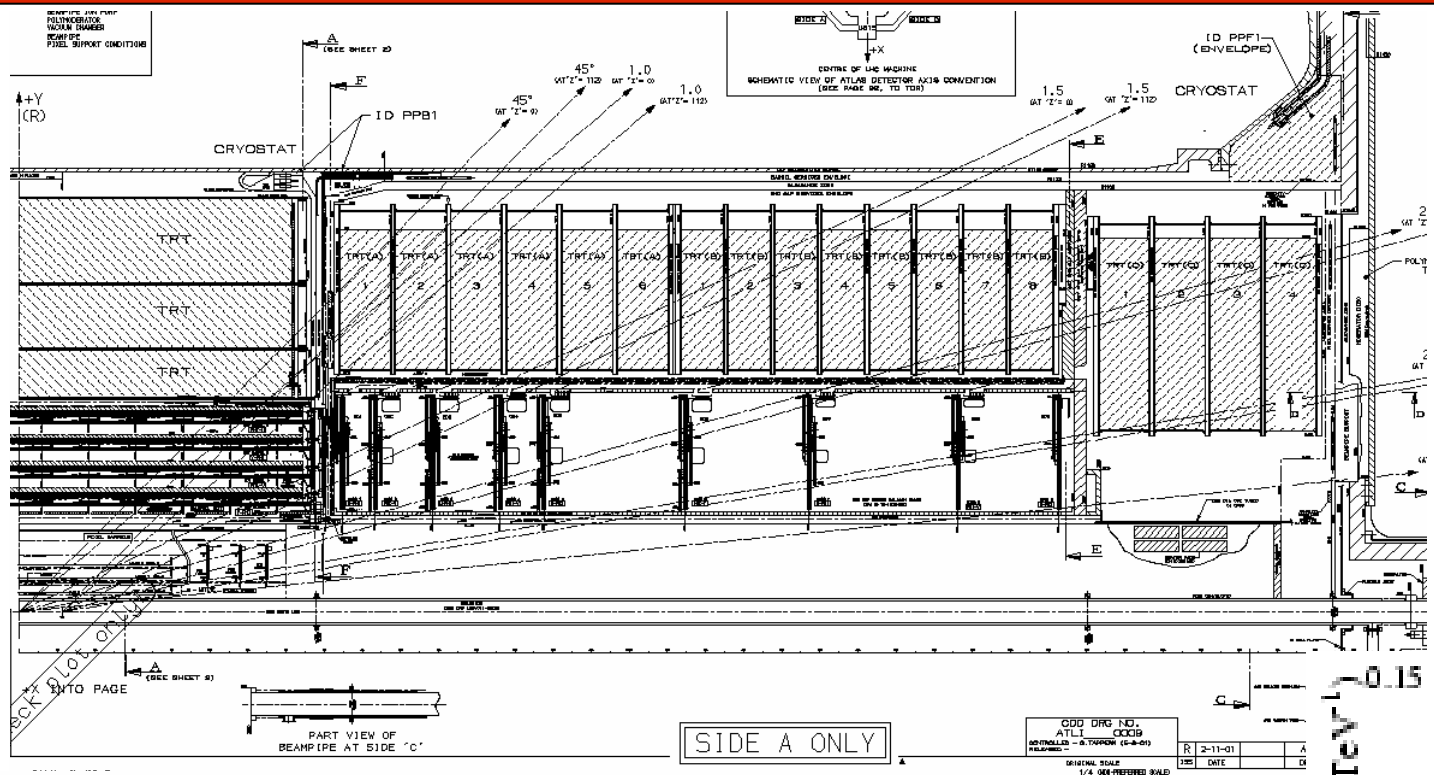


Artist's comparison of ATLAS and CERN Building 40

Tracking challenges

- Main tracking issues:
  - 25 ns bunch crossing → fast electronics
  - Occupancy: ~700 tracks/event ($|\eta| < 2.5$)
  - Minimize material → good calorimeter resolution for $H \rightarrow \gamma\gamma$
  - Radiation damage: fluence 10^{15} 1-MeV-neutrons/cm^2
- ATLAS Inner Detector (tracking system)
  - Mixture of 3 technologies: pixels , microstrips and transition rad.
    - precision space point and continuos tracking
  - Pixel detector
    - 3 barrel layers, 3 end cap disks. Resolution: 12 μm r-ϕ and 60 μm r-z
  - Semiconductor Tracker (microstrips)
    - 4 barrels and 9 disks/endcap ($|\eta| < 2.5$) → 4 points per track
    - Resolution: 22 μm r-ϕ and 500 μm r-z (40 mrad stereo angle)
  - Transition Radiation Tracker
    - Straw tube detector: axial for barrel and radial for endcaps.
    - Resolution: 160 μm
    - Electron ID through detection of transition radiation photons

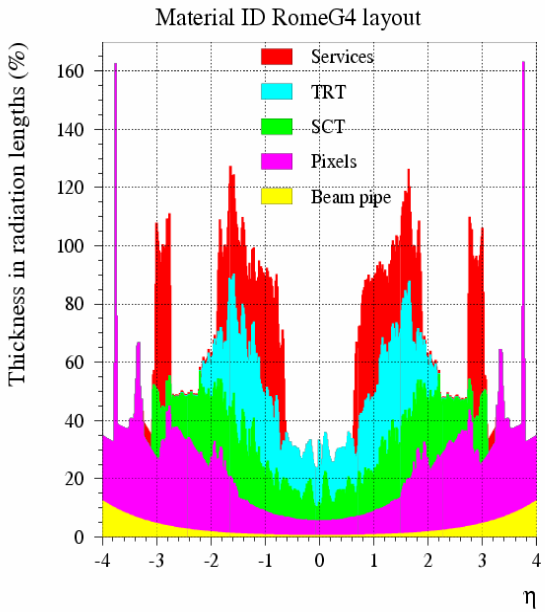
ATLAS Inner Detector (Tracker) layout



TRT
r=55-105 cm

SCT
r=25-50 cm

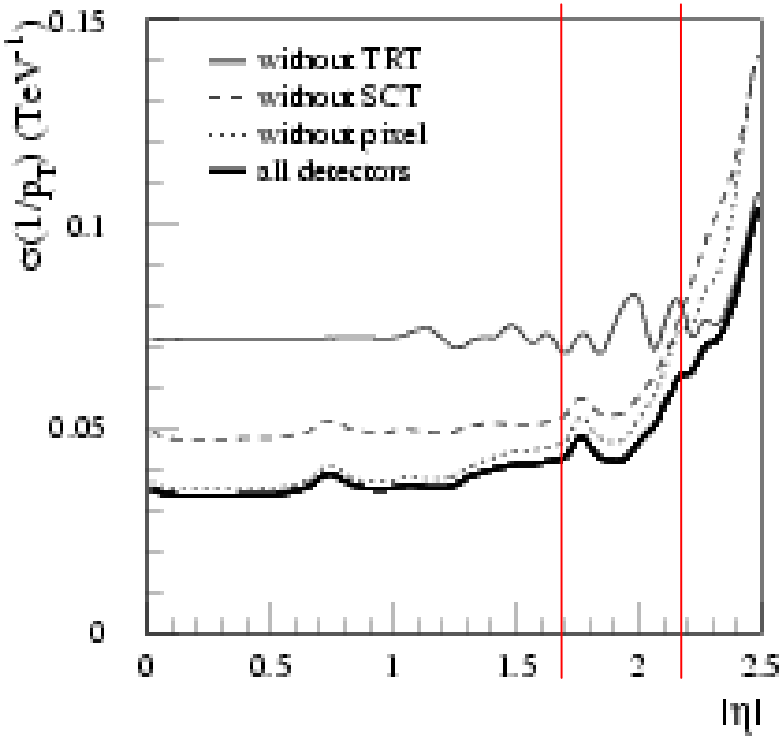
Pixels
r=5-25 cm



← Material distribution in ID

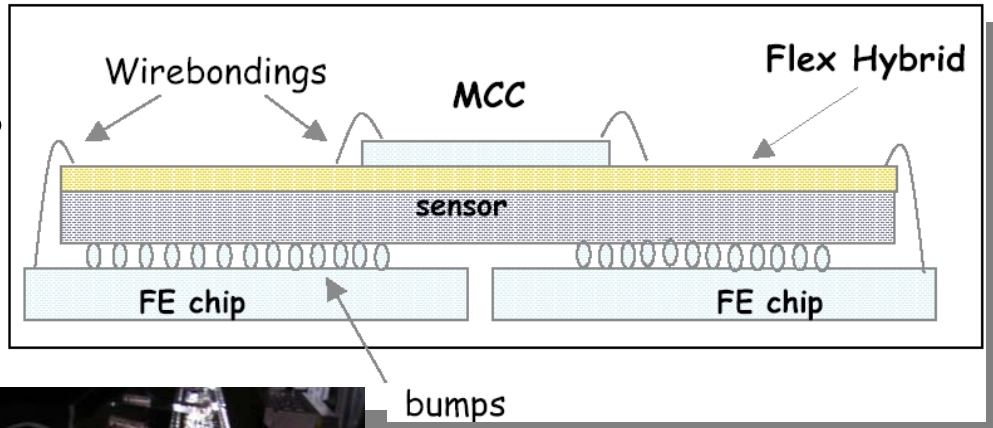
- At η=0 →0.3 X_0 rises up to > 1 X_0 at $|\eta|$=2
- Services all at high radius – minimize impact

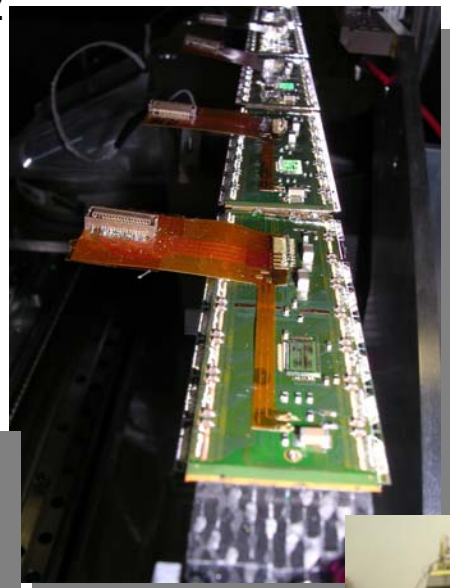
momentum resolution

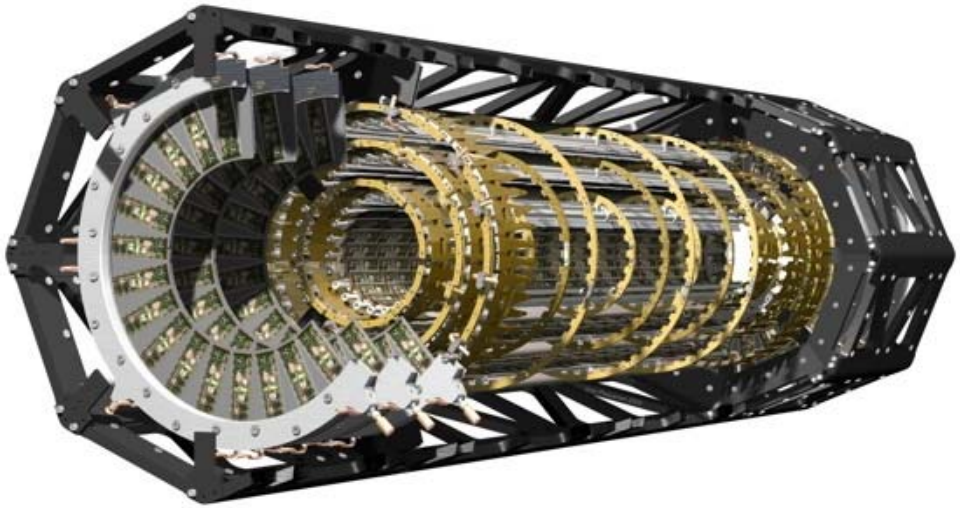


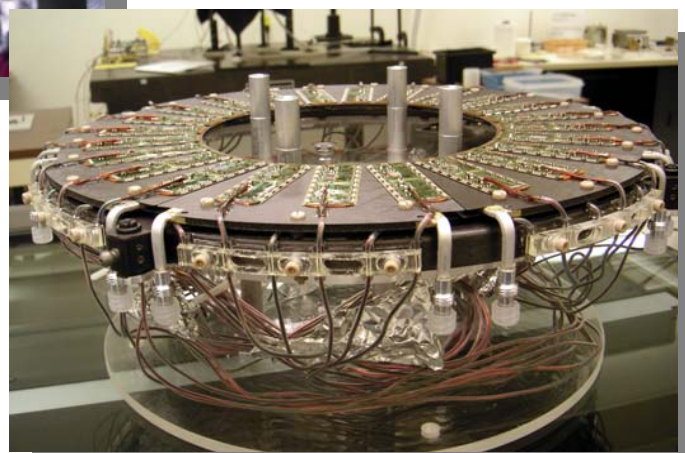
Pixel detector

- Pixel modules
  - 3 barrels and 3+3 endcap disks
    - barrels at 5, 10 at 12 cm radi
    - 70 M channels
  - n-on-n silicon sensors
  - sensor size: 16.4 x 60.8 mm^2
  - pixel size: 50 x 400 μm^2
  - 16 FE chips in 2 rows
  - Module Control Chip (MCC)
  - Carbon fibre staves



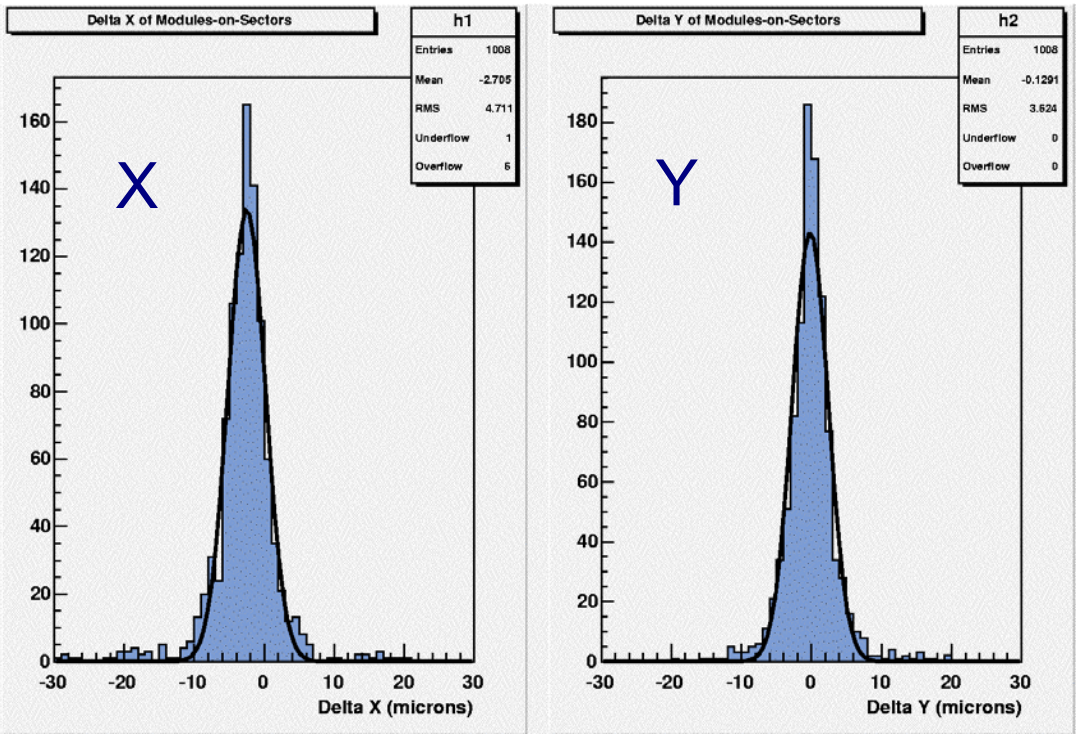


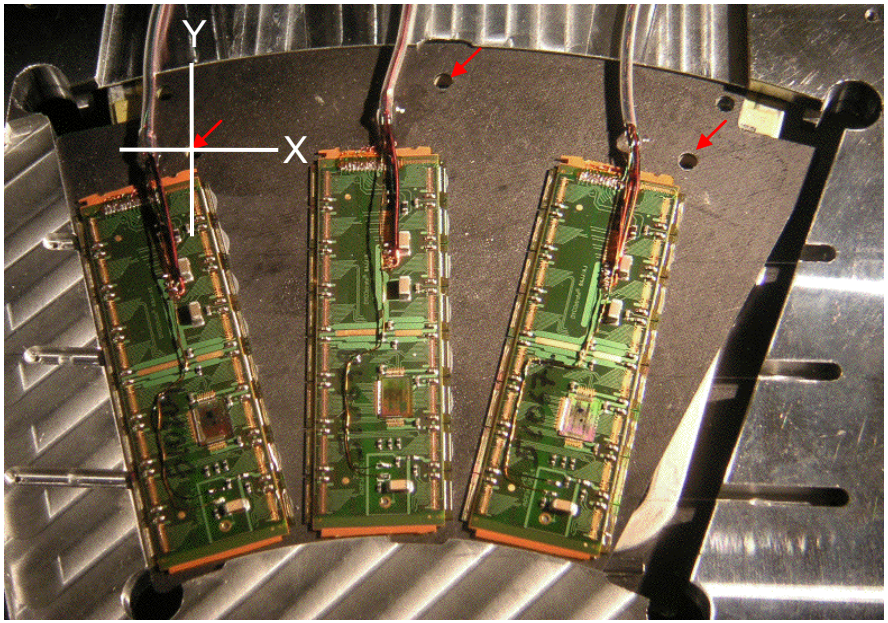




Pixel Moduls Assembly survey

- Pixel modules
  - 32 points measured (outer corners of every chip)
  - The survey data will be fed into the DB and used as initial parameters for aligment constants
  - High precision in X and Y

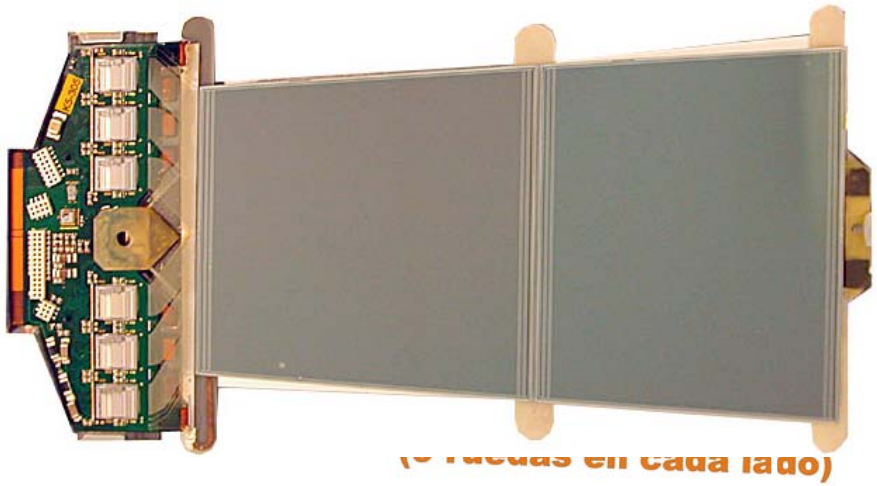


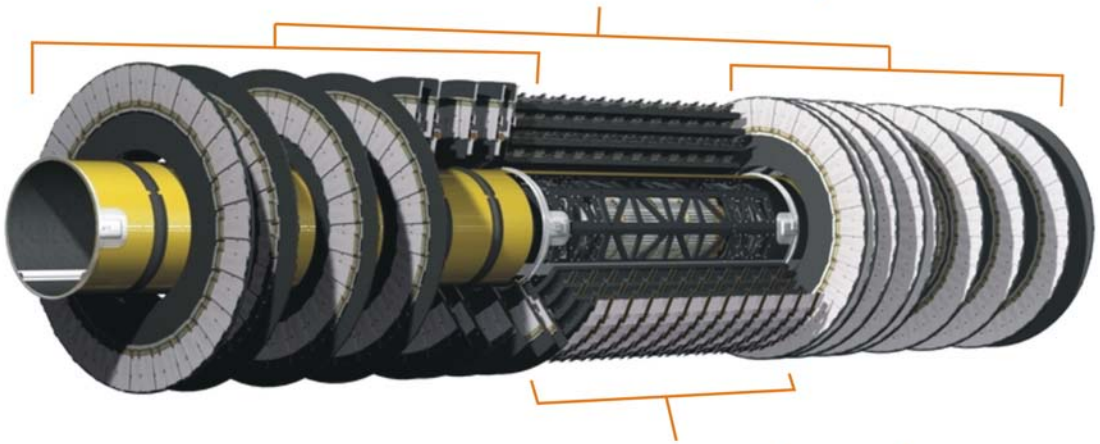


From fits: Mean: -2.5 microns Mean: -0.2 microns
Sigma: 2.7 microns Sigma: 2.6 microns

Silicon Tracker SCT

- SCT modules (microstrips)
  - 4 p-on-n sensors
    - 2 + 2 : 40 mrad stereo angle
  - ABCD digital chip
  - 4 barrels and 9+9 disks





Barrel

- 34.4 m^2 of silicon
- ~3.2 x 10^6 channels
- 2112 barrel modules (1 type)
- Coverage: $|\eta| < 1.1$ to 1.4

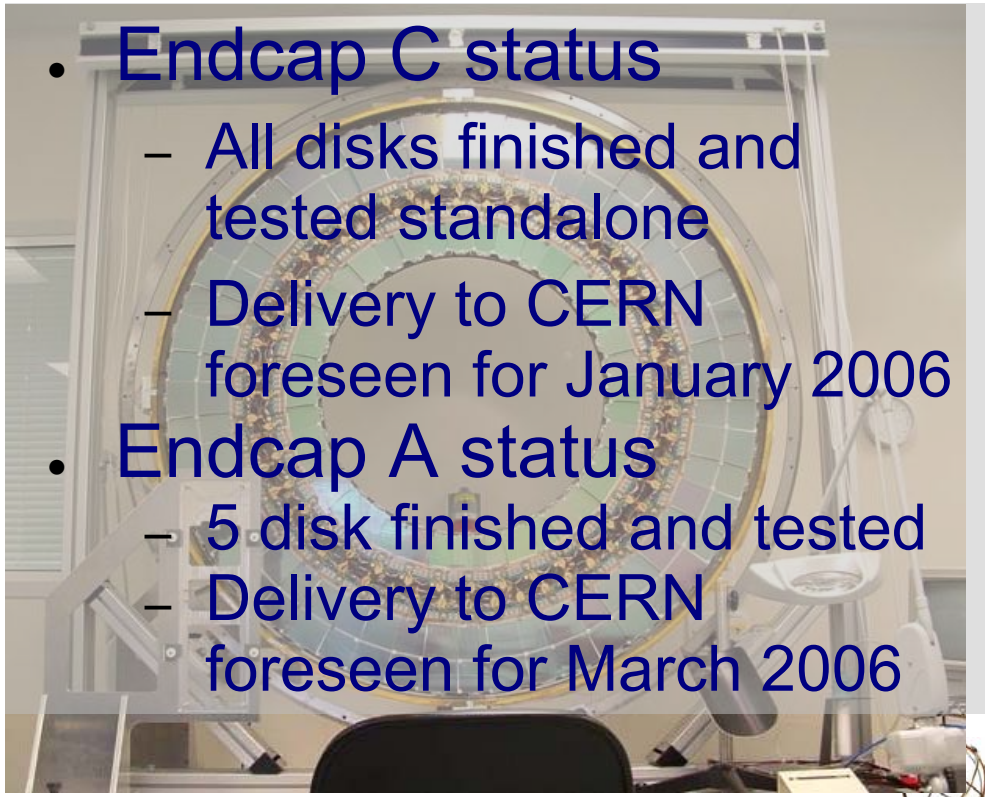
Forward (2)

- ~26.7 m^2 of silicon
- ~3.0 x 10^6 channels
- 1976 modules (4 types)
- Coverage: $1.1 - 1.4 < |\eta| < 2.5$

SCT Module assembly

- Assembly sites:
  - Module assembly, bonding & QA assesing at many sites
    - Barrel: Japan, Scandinavia, UK and USA
    - Endcap: UK (Manchester, Liverpool, Glasgow), Valencia, Geneva, CERN, Freiburg, Munich, NIKHEF, Melbourne)
  - Barrel and disk assembly:
    - barrel: robotic automation
    - endcap: manually operated tooling

- Barrels arrived at CERN January-August 2005.
- July-September: 4-barrel + thermal enclosure integration
- Fully tested (>99.9% working channels)
- SCT barrel to be inserted into TRT during November

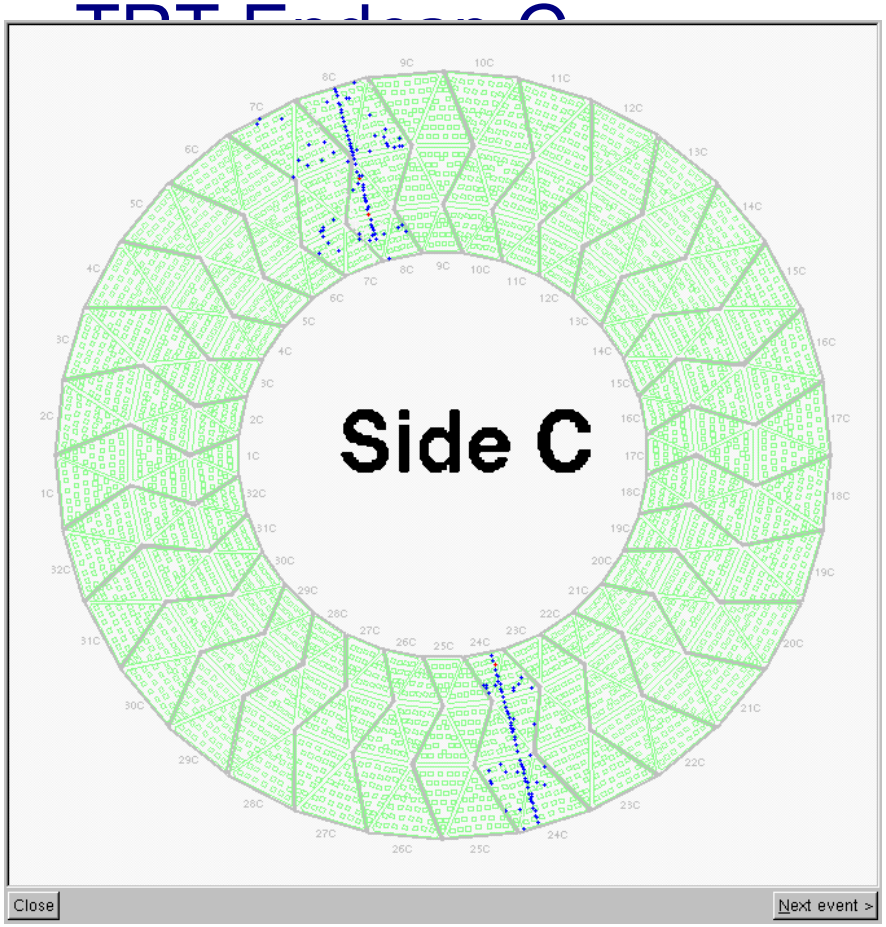


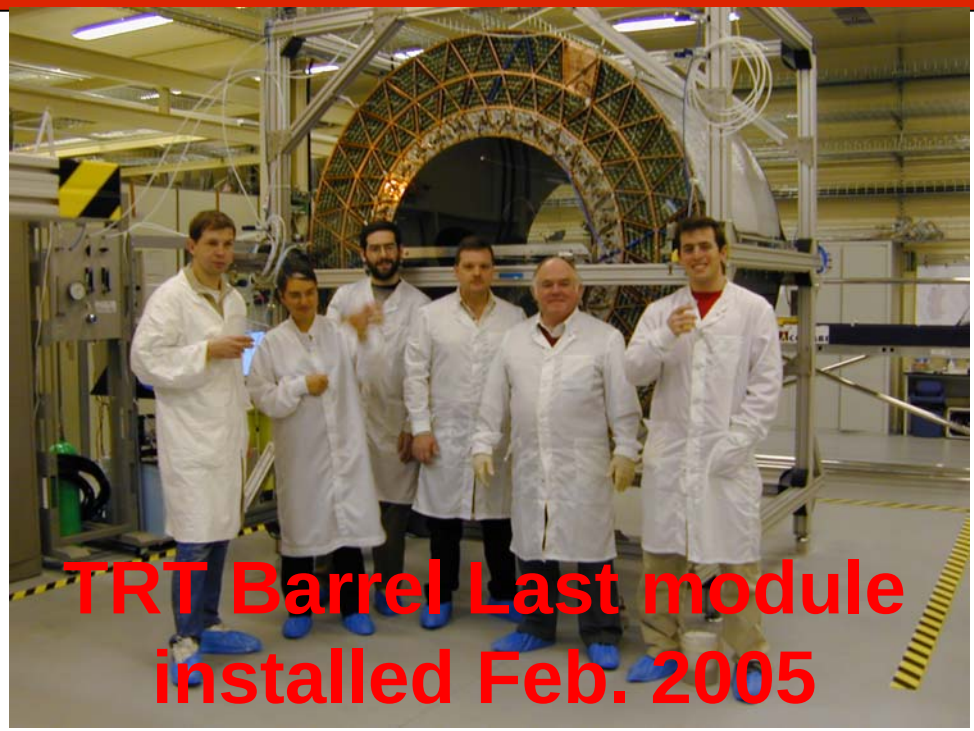
- Endcap C status
  - All disks finished and tested standalone
  - Delivery to CERN foreseen for January 2006
- Endcap A status
  - 5 disk finished and tested
  - Delivery to CERN foreseen for March 2006

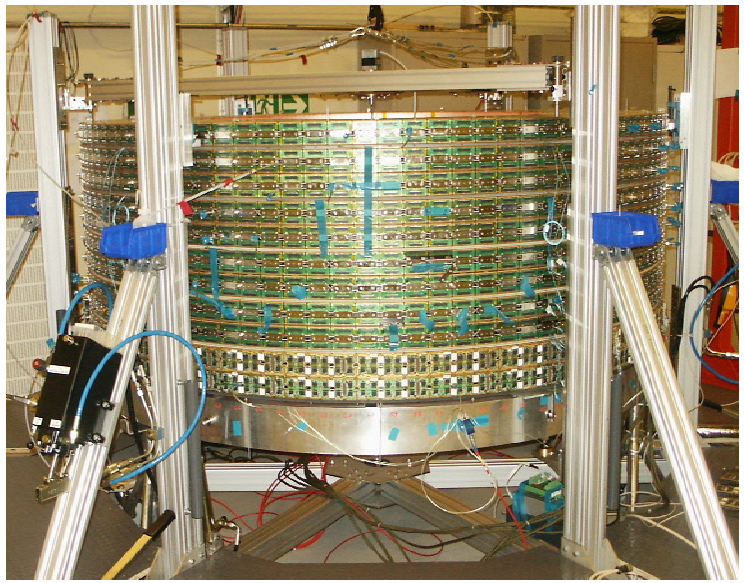
TRT integration

- TRT Barrel
  - assembly completed
  - ready to SCT insertion
  - cosmic test

TRT Endcap C



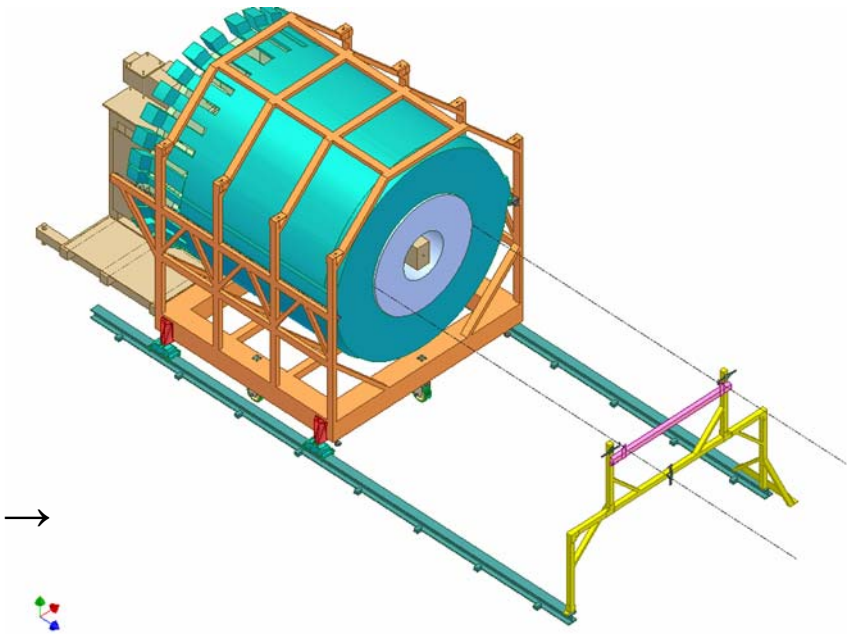




SR1 Integration

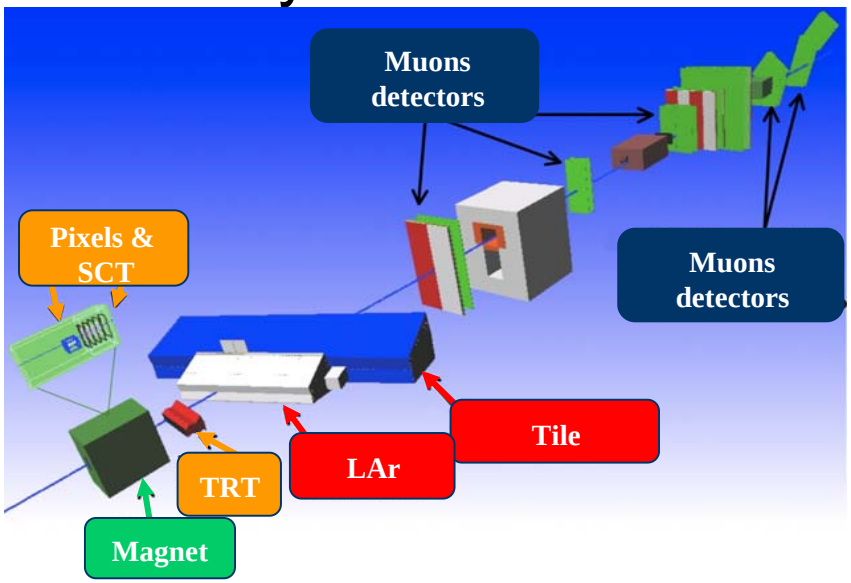
- Inner detector being integrated at the surface building SR1
  - TRT Barrel completed
  - SCT Barrel completed

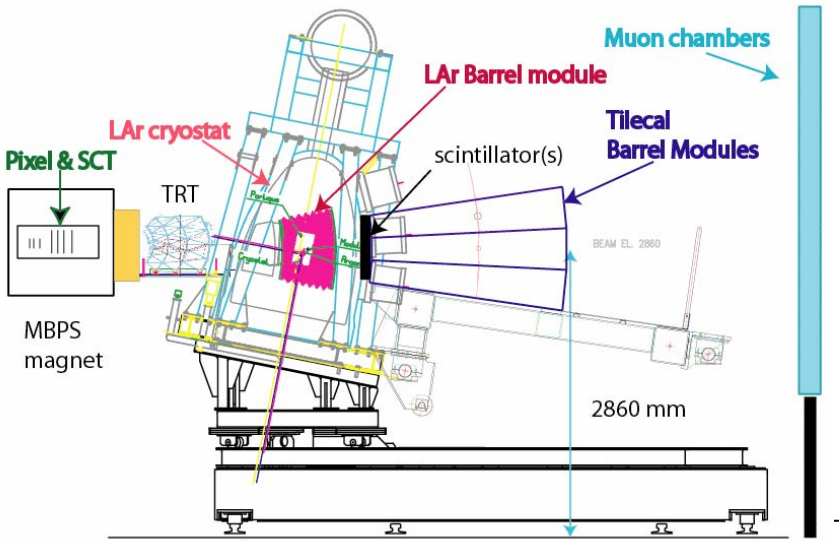
SCT Barrel into TRT Barrel →



Combined Test Beam 2004

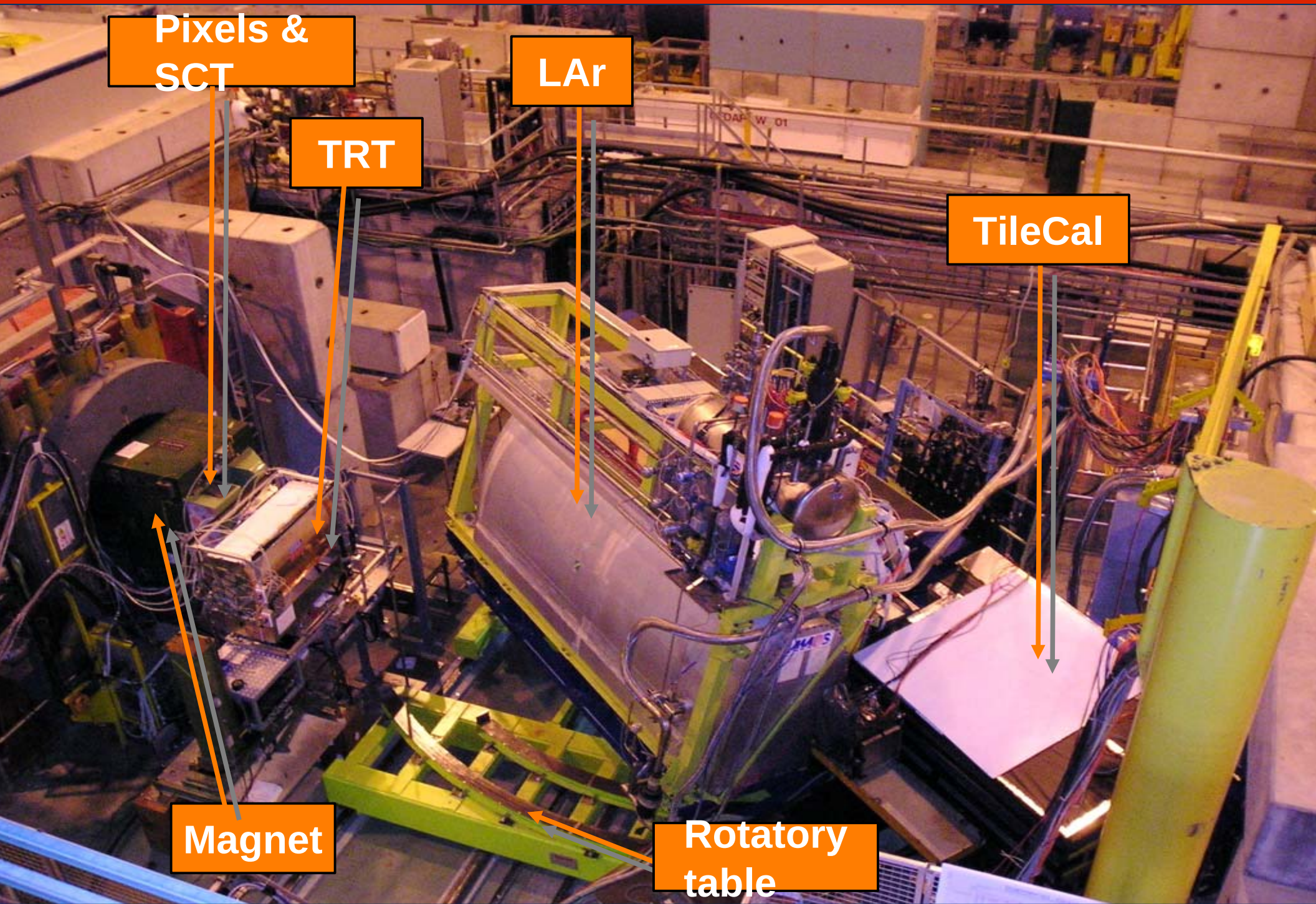
- Combined test beam: March to November 2004
  - full ATLAS barrel slice at η=0 with all the subsystems
    - Inner Detector: Pixels, SCT & TRT
    - Calorimetry: LAr, TileCal
    - Muon Spectrometer
- Primary objectives and motivations:
  - Combined data taking with all detectors
  - Testing of the whole DataFlow
  - Final prototypes of the electronics (RODs)
  - Combined calorimetry studies
  - Combined studies of the ID
  - Combined studies ID + muons





- ***Inner Detector:***
  - Pixels + SCT inside MBPS magnet (gap ~230mm)
  - Horizontal field (along the strip orientation); B_{max} ~1.4T
  - TRT: 1/16th of the barrel

CTB04 setup



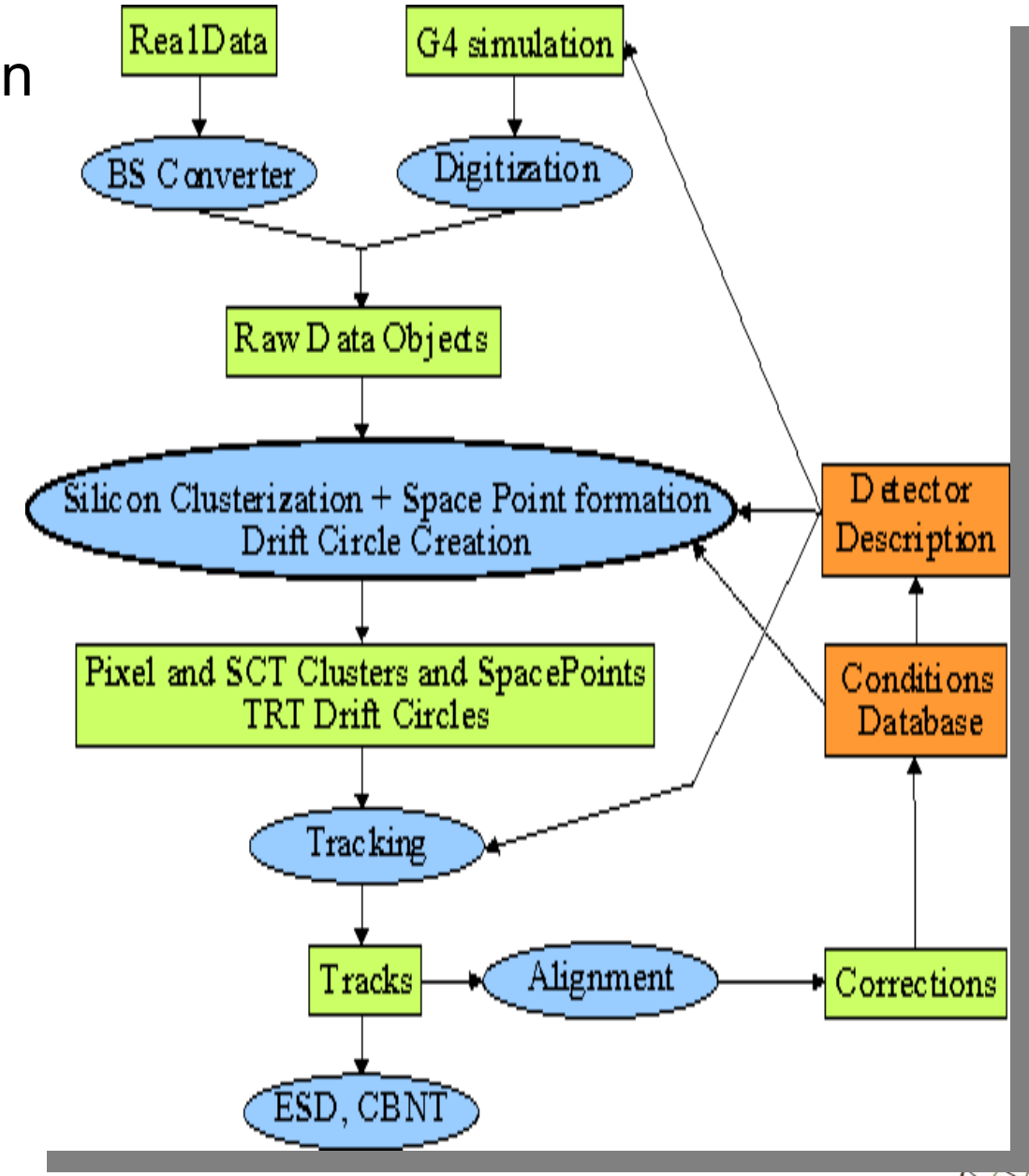
CTB04: Data Taking

- Reconstruction software challenge:
  - Make use of the full reconstruction chain
  - 22 Mevents validated
  - Use Geom. and Conditions DB
  - Pixel and SCT
    - Test bytestream converters
    - Standalone reconstruction
    - Tuning of simulation
    - Alignment
  - TRT
    - Reconstruction
    - Aligment: standalone and vs silicon
    - electron id.
  - Inner Detector
    - Track parameters, momentum resolution, B field, Material studies
  - Combined reconstruction
    - Matching ID-calorimetry: e-π id.
    - Muons: combined tracking ID – muon chambers

Particles	*e, π, μ, γ*
Energy	*2 – 180 GeV*
Material study	*12% X_0 between Pixels-SCT* *24% X_0 between SCT-TRT*
Magnetic field	*0 – 1.4 T (TRT outside)*

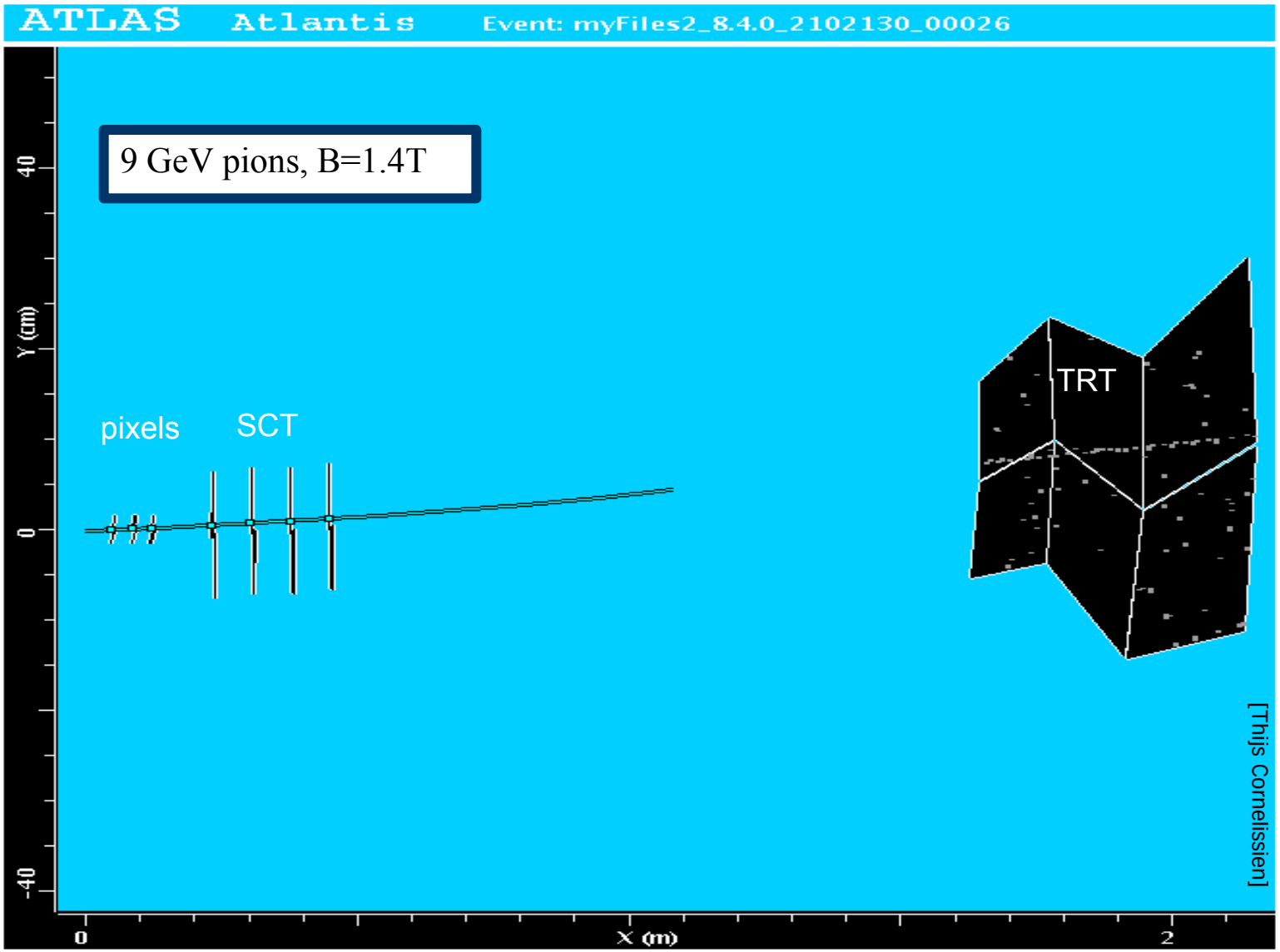
CTB04 Reconstruction

- Reconstruction chain
  - same for data and simulation
  - Data preparation
    - ByteStream Converters
    - Raw data (pixel, strip)
    - clustering
    - SpacePoint formation
    - Drift Circle (TRT)
  - Track Reconstruction
    - pattern recognition
    - track fitting
      - CTBTracking
        - specific for CTB
      - xKalman
        - ATLAS designed



CTB04 Event Display

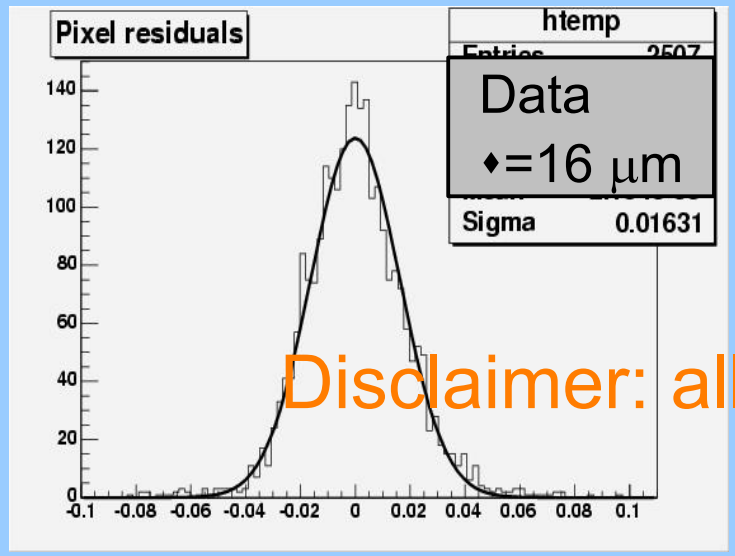
- Real Data

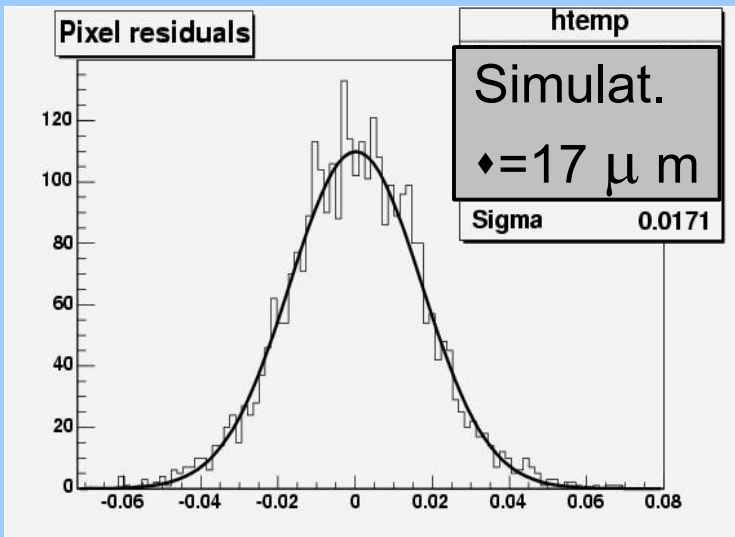


CTB04 Silicon Residuals

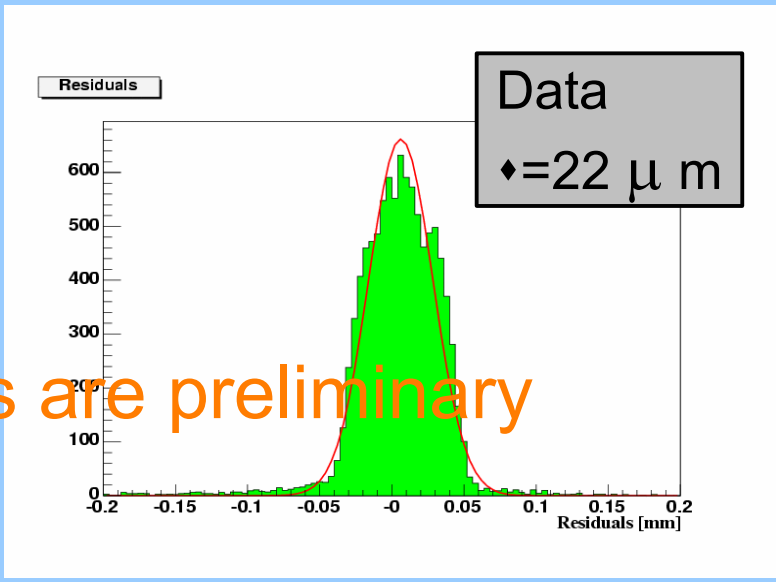
- Real Data vs MC (high momentum π beam) after alignment

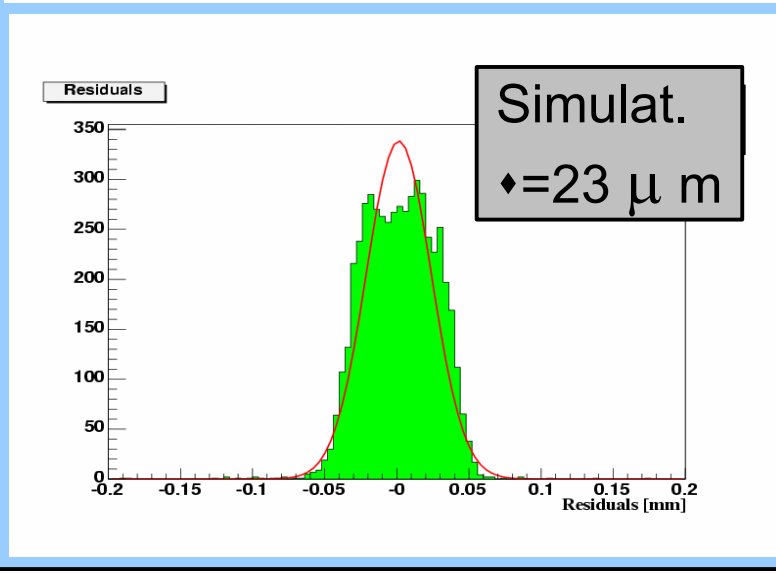
Pixels





SCT

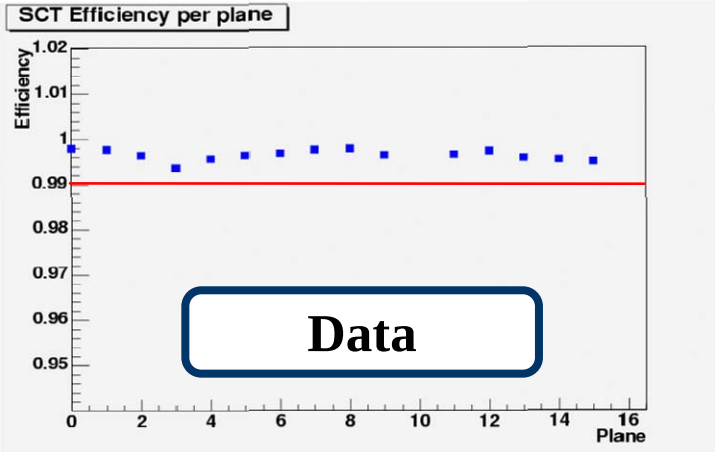


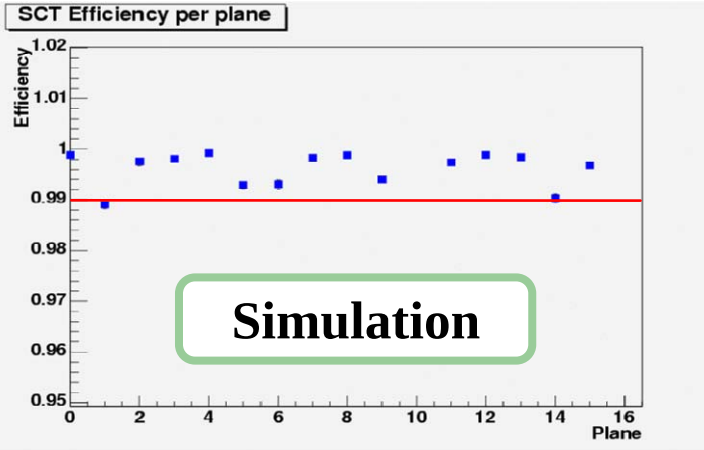


Disclaimer: all results are preliminary

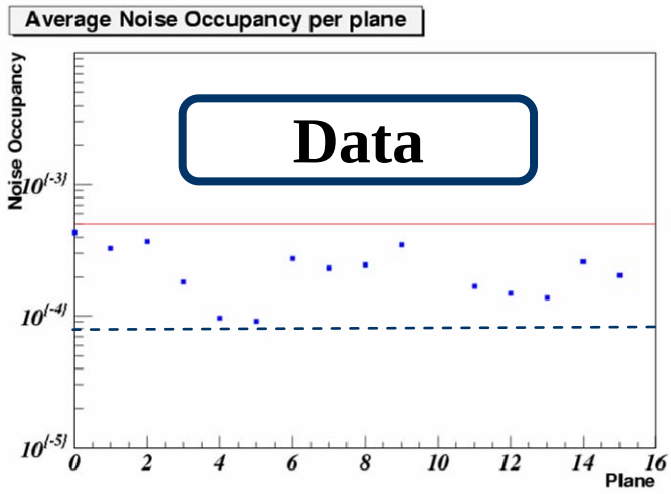
CTB04 SCT

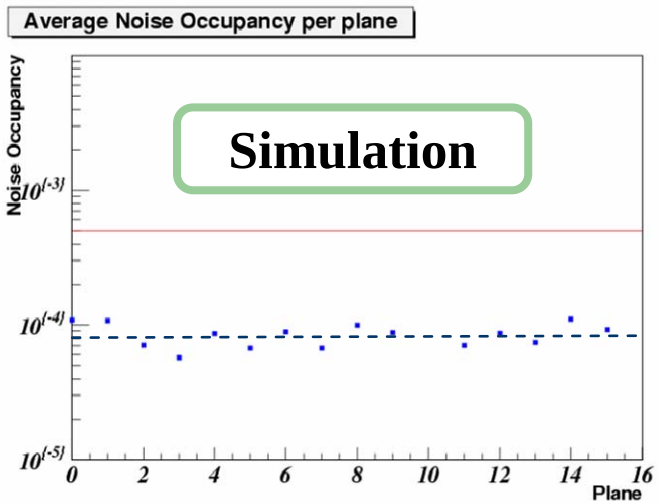
- ***SCT study of the efficiency and noise occupancy***
  - ***Tracking efficiency. ATLAS spec. > 99% @ 1fC***





  - ***Noise occupancy:***
    - ***spec NO < $5x10^{-4}$ @ 1fC***
    - ***Lab noise measurement: 1650 ENC ⇨ NO $8x10^{-5}$***

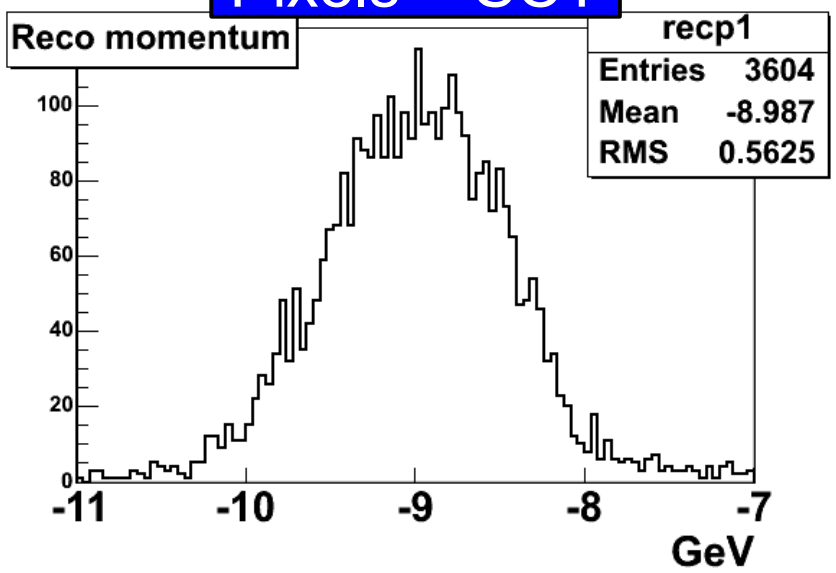




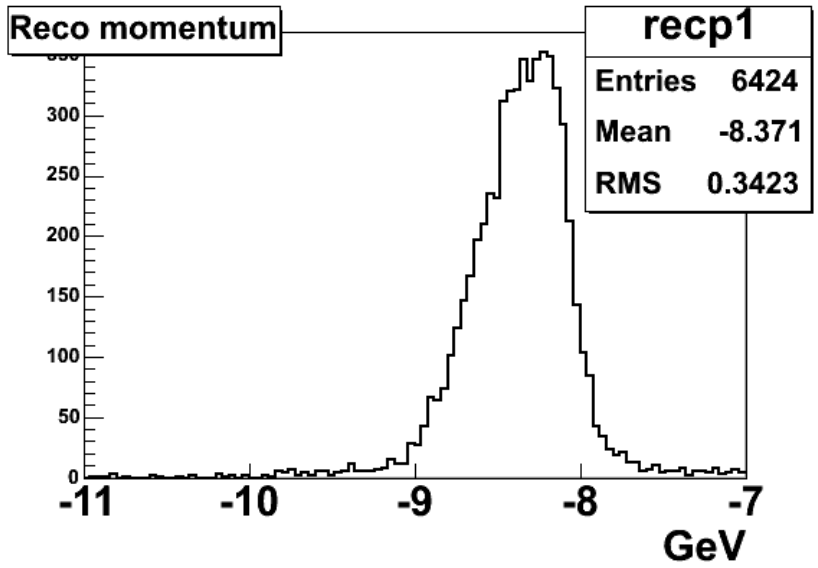
CTB04 Reconstructed Momentum

- Momentum reconstructed for runs with B field (Preliminary)

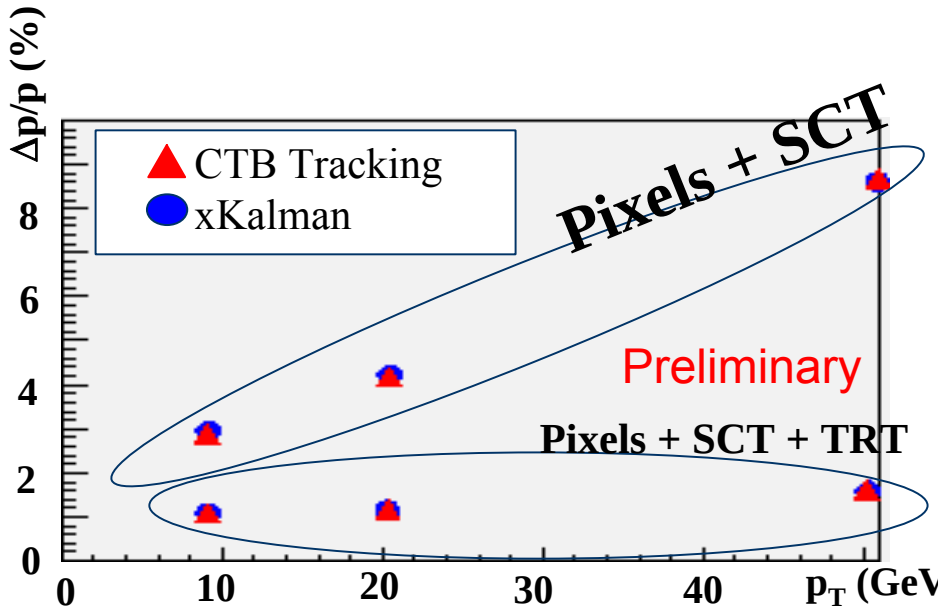
Pixels + SCT



Pixels + SCT+TRT

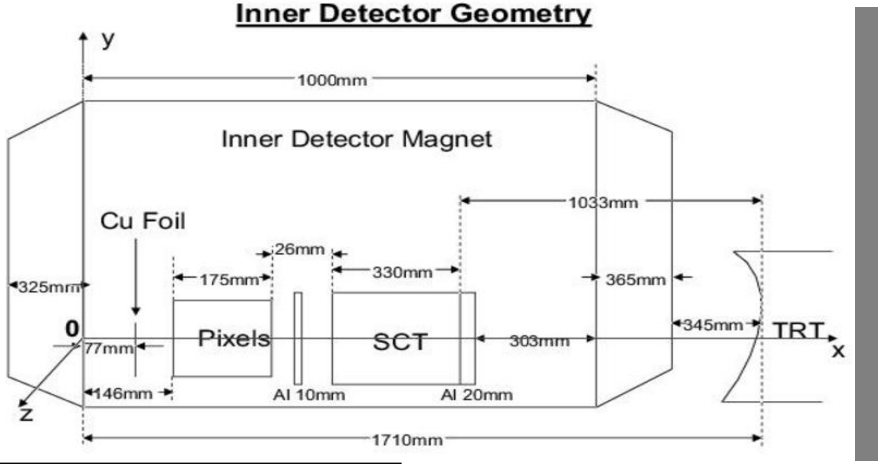


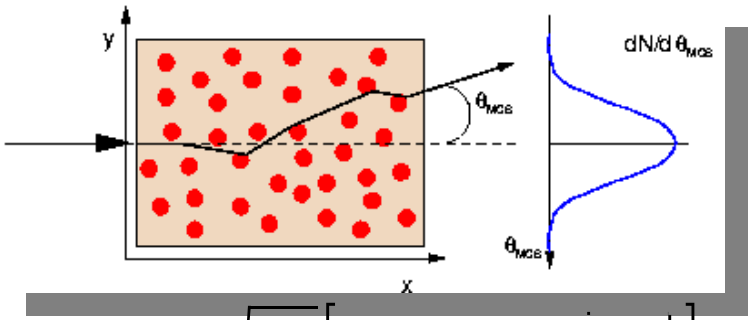
- TRT improves P resolution.
  - of course !
  - Systematic effects
    - not yet considered
    - Alignment uncertainties
    - Magnetic field map



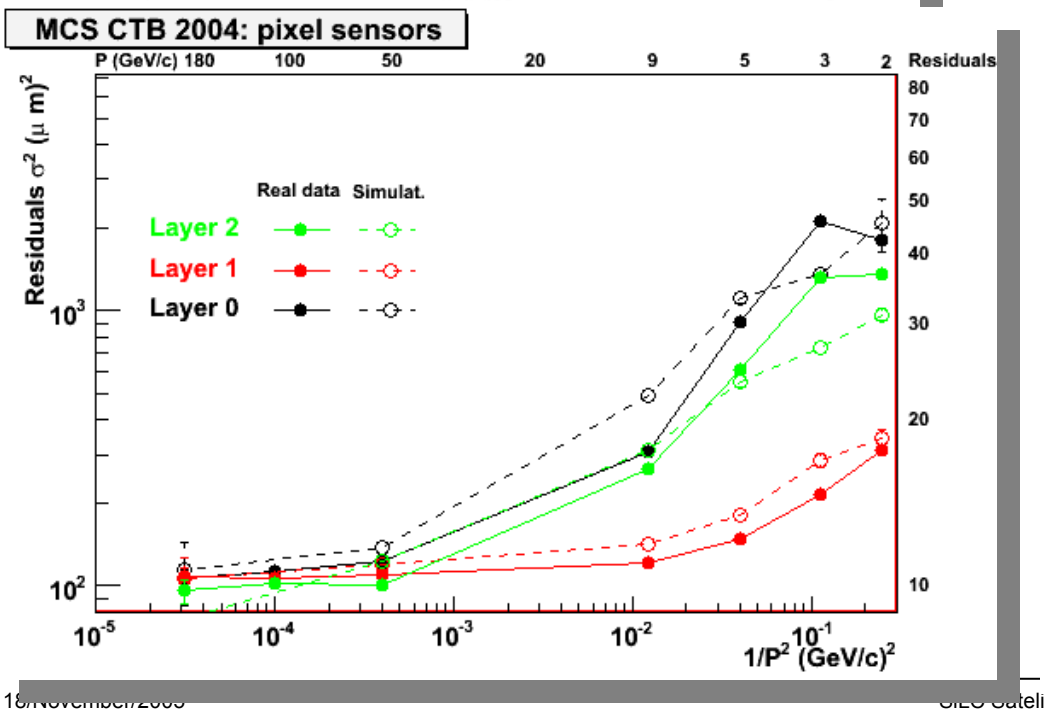
CTB04 Material Studies

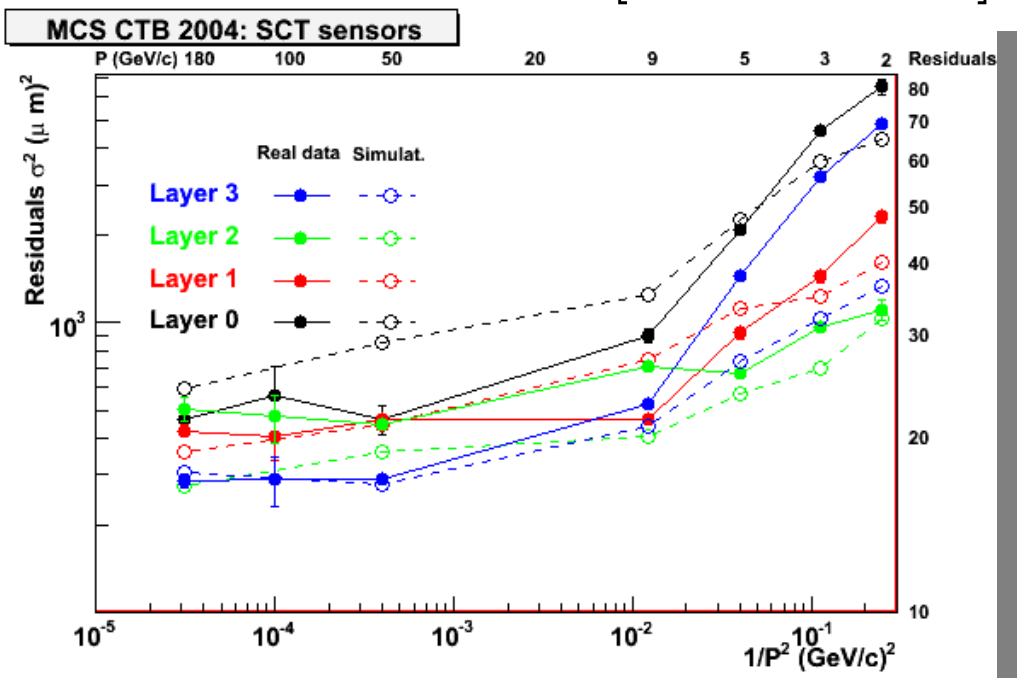
- Study of Multiple Coulomb Scattering
  - During CTB 2004 material was inserted between pixel and SCT in order to simulate the services X_0 at η=1.6





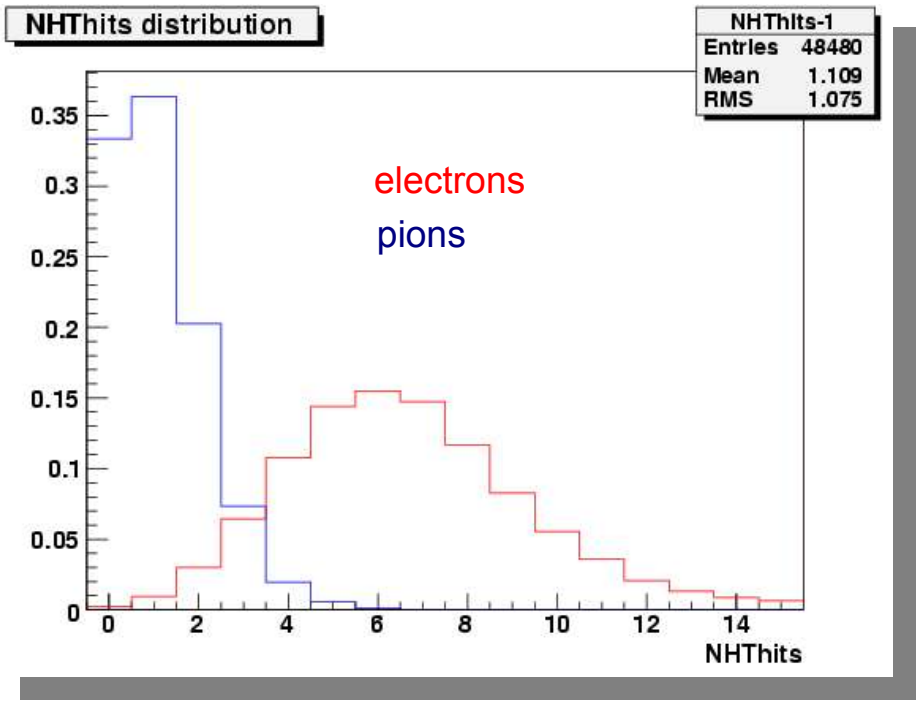
$$\theta_{MCS} = \theta^{rms} = \frac{13.6\,MeV}{\beta cp} z \sqrt{\frac{x}{X_0}} \left[1 + 0.038 \ln \left(\frac{x}{X_0} \right) \right]$$

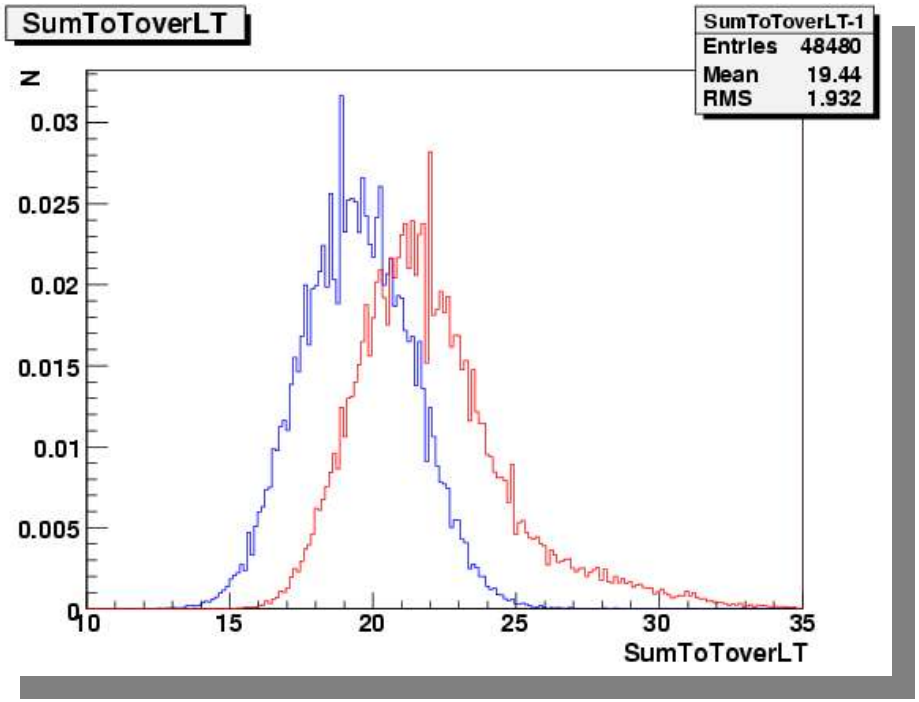




CTB04: TRT particle ID

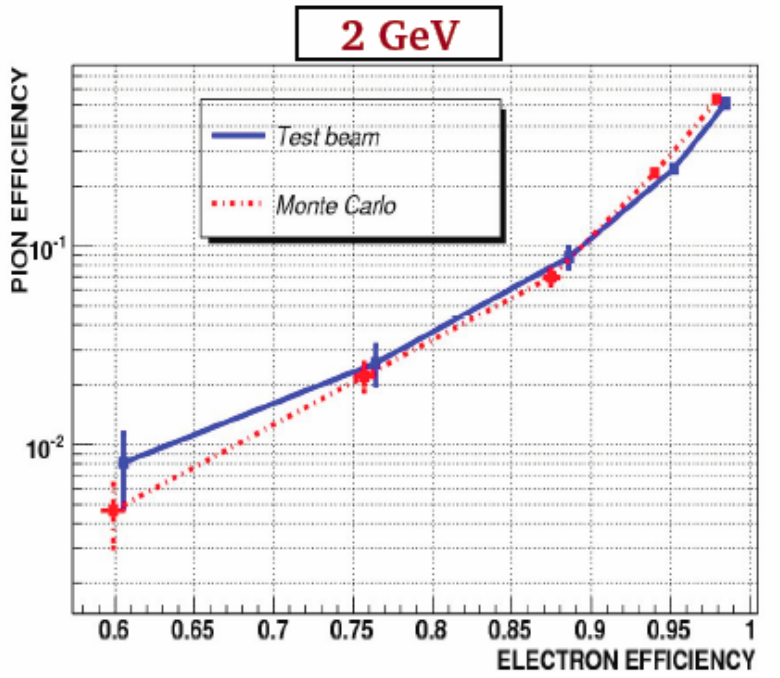
- TRT electron and pion id
  - Operation
    - Real Data and simulation consider dead and noisy channels
    - conditions data base
  - Info available for particle ID
    - High-Threshold hits (transition radiation, electrons only)
    - Time-over-Threshold (Energy loss: dE/dX)
    - combined both methods in a probabilistic approach

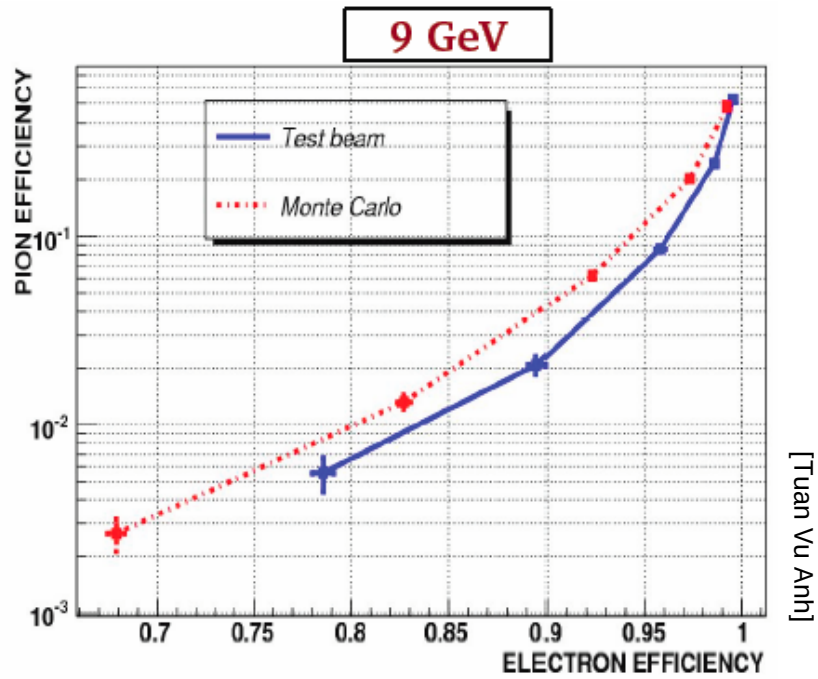




CTB04: TRT particle ID

- Real data sample
  - Use of CTB Cerenkov counter and LAr to enrich the samples
  - systematic: different straw by straw response
    - take individual HT hit per straw
- Data vs Simulation

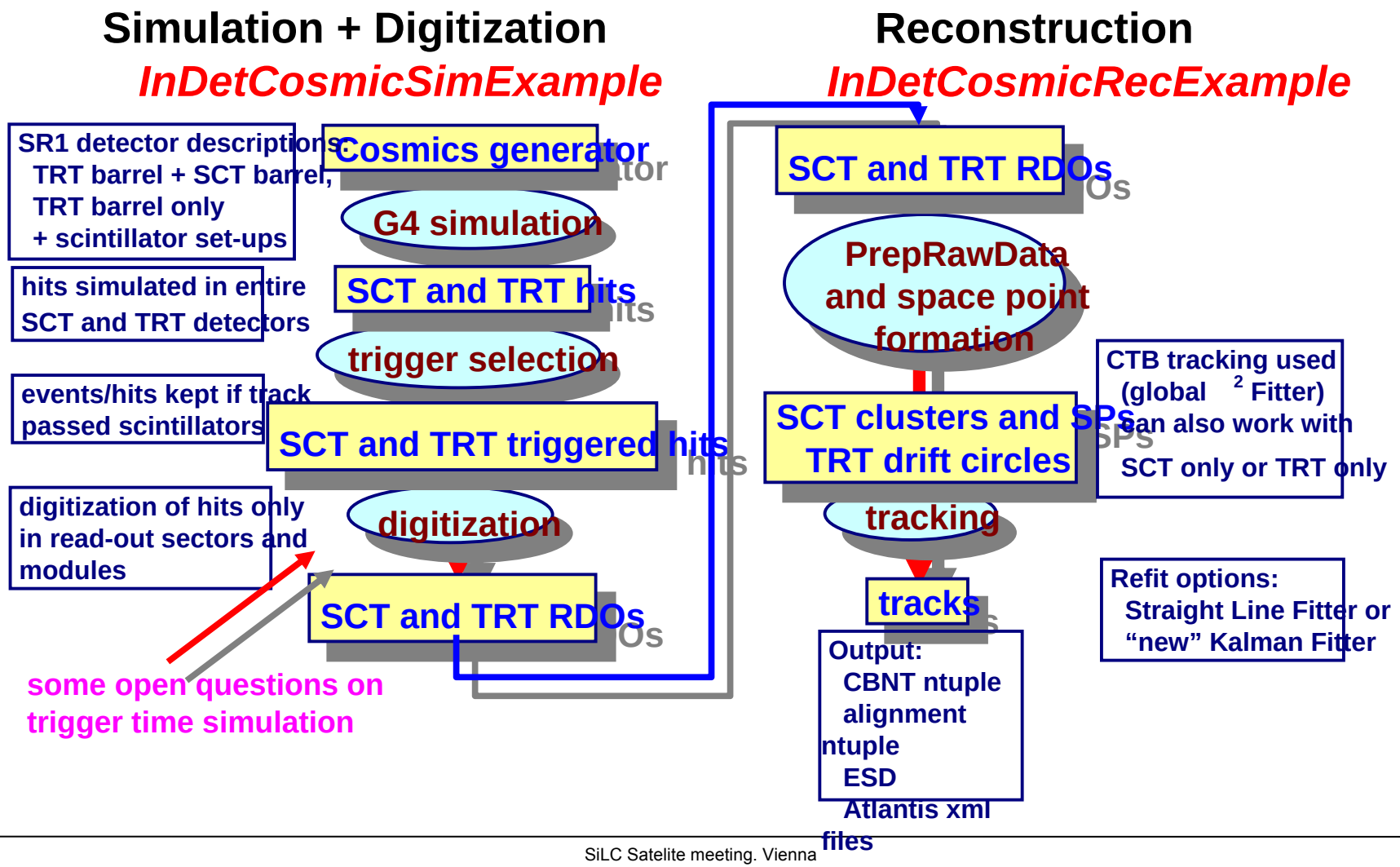




[Tuan Vu Anh]

SR1 cosmics

- SR1 cosmic run forseen early 2006
  - TRT and SCT barrels
  - Scintillator triggers
  - ongoing work on: reconstruction, simulation, alignment

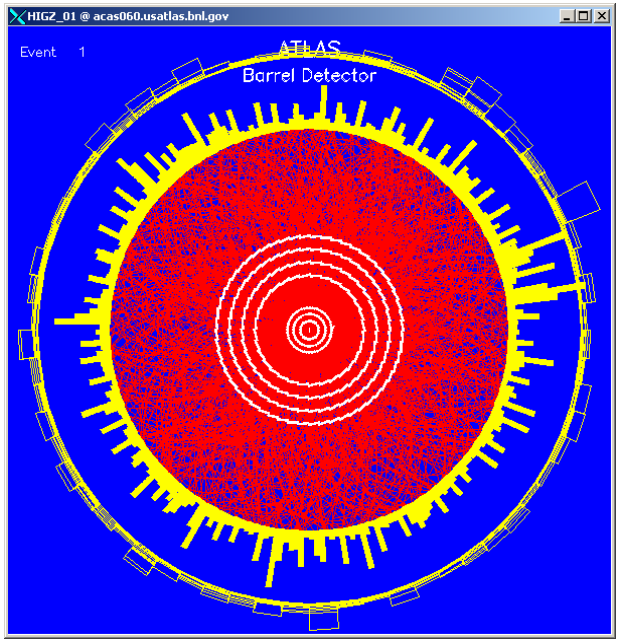


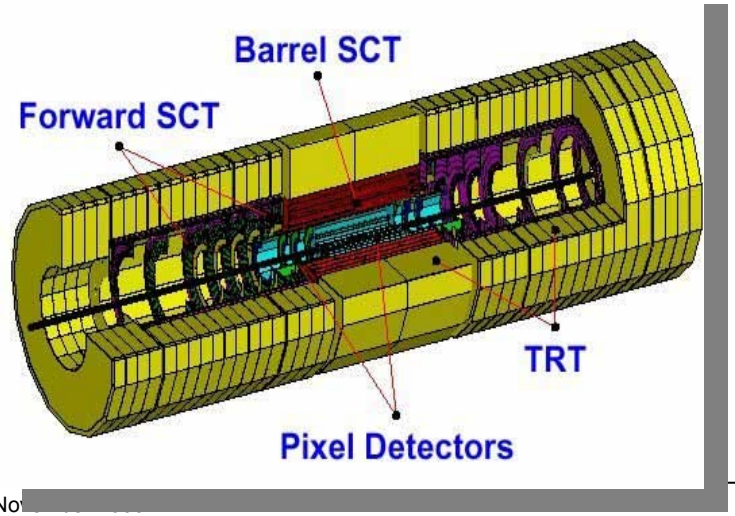
A word on the SuperLHC

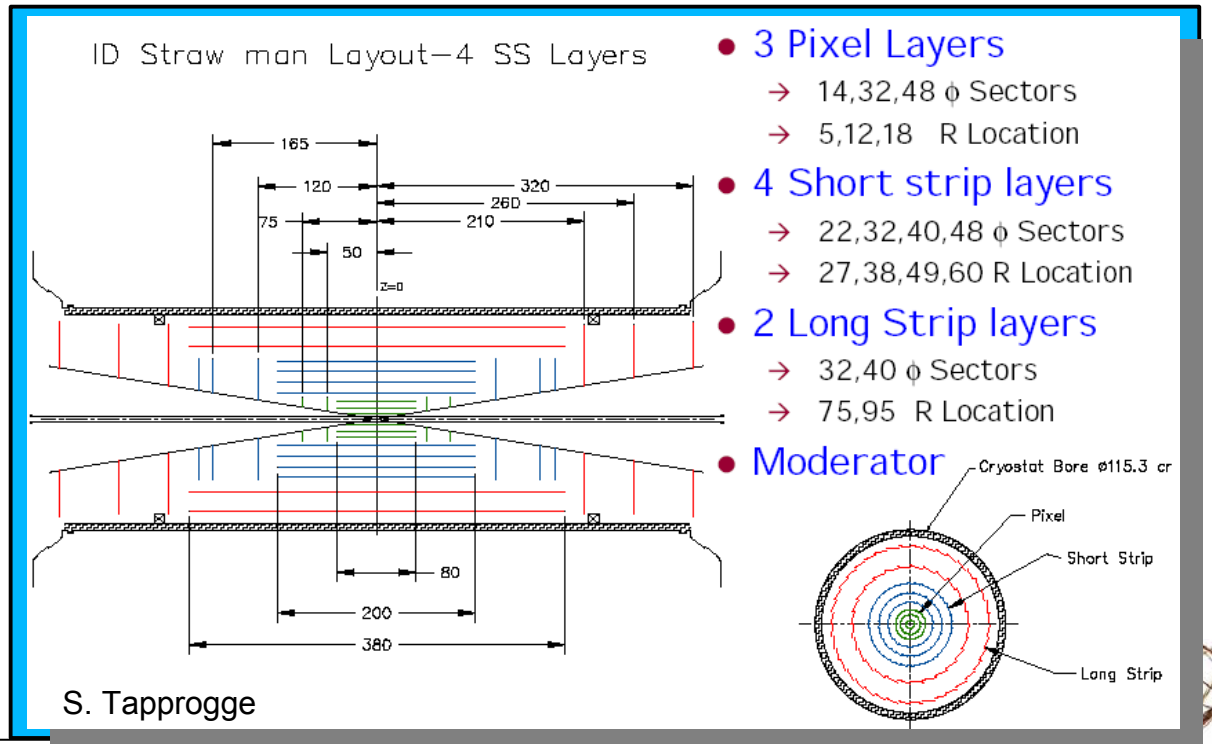
- Goal: squeeze the physics potential of LHC
  - Increase $\sqrt{S}$ would be ideal but unafordable
  - Luminosity increase
    - 10^{34} $cm^{-2}s^{-1}$ $\rightarrow$ 10^{35} $cm^{-2}s^{-1}$
    - precise measurements in those channels statistically limited
    - in some cases (e.g. SUSY) allows increasing the mass searching range
    - Performance of experiments must be kept ~ constant
    - Multiple interactions
      - from 20 to 80/500 (depending on configuration)
      - many tracks to record (~10000 tracks/event)
    - Increased radiation damage
      - effects on detectors and opertaing conditions
        - ID: to be operated ~ 30C below current temperature
      - effects on experimental area
    - Bunch crossing
      - reduced to 10 or 15 ns
  - In summary: new tracking system needed

New Inner Detector for SuperLHC

- Wish list for the tracking system
  - high tracking efficiency and low fake rate
  - Good resolution (p & IP)
  - Highly segmented
  - Radiation hard
    - LHC: 10^{15} cm^{-2}
    - SLHC: 10^{16} cm^{-2}
- Preliminary design
  - All silicon
  - 3 pixel layers
  - short and long strip







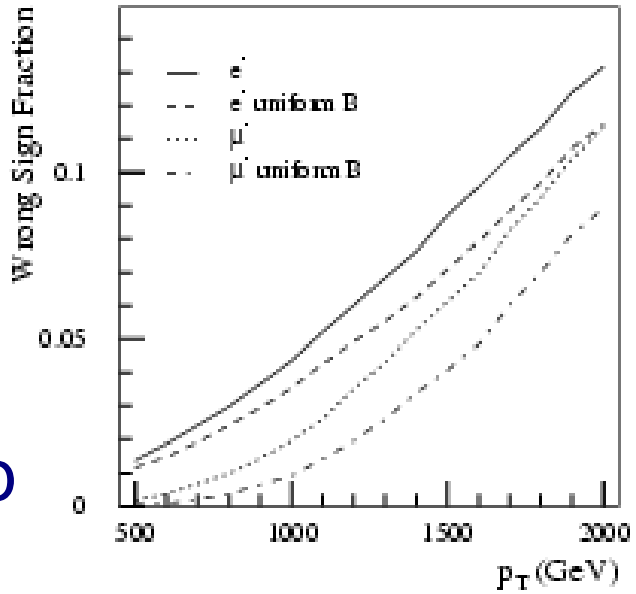
Summary

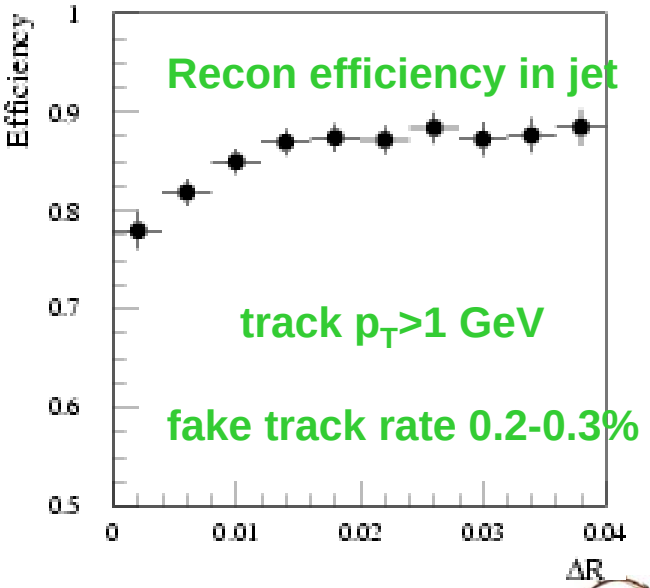
- ATLAS Inner Detector
  - modules production almost finished
    - SCT completed and TRT completed,
    - undergoing assembly into barrel and endcaps
  - Integration underway in SR1
  - Tests in SR1
    - TRT barrel has taken cosmics
    - SCT barrel works at 99.9%
    - Assembly of TRT endcaps
  - Preparations for SR1 full integration in progress
    - channel and services testing
    - cosmic run
  - Commissioning of full detector foreseen for sumer 2006
  - Combined TB 04
    - nice preliminary results
    - Experience gained

Acknowledgment: thanks to all the people whose help served to prepare this talk (either comments or source slides). Sorry not to mention all of them.

Design parametes

- ID inside barrel cryostat including solenoid and LAr calorimeter
  - 2T solenoid field, non uniform at high z
    - Reduces to 1.0T at z=2.7m
  - p_T resolution: charge det. at ~500 GeV
  - Full coverage to $|\eta|$=2.5 for all detectors
- Pattern recognition inside jets / with pileup
  - Challenging: high track density
  - 7 precision points/track (3 pixel+4 SCT)
    - Each r-ϕ and z (40 mrad stereo in SCT)
  - Up to 36 TRT straw hits
    - Continuous tracking optimised for tracking performance not TR e-ID
    - π rejection up to 100 for 80% e-ID efi.
  - cotθ resl. <10^{-3}, V^0 finding, b-tagging
  - Results from Physics TDR





Tracking software

- Two major pattern recognition and trackfitting programs:
  - xKalman – Kalman filter based approach, seeded from TRT or SCT/pixels
  - iPatRec – combinatoric space point search in SCT/pixels, extrapolate to TRT
    - Similar results on simulated data – best final approach will depend on real-life detector performance.
    - Mixed Fortran/C^{++} versions used for PhysicsTDR, now major effort in migrating to OO analysis framework (Athena) and common elements where possible.
  - Major effort on 'event data model' for inner detector
    - Flow of information: digitisation $\Rightarrow$ 'byte stream' data $\Rightarrow$ clusters $\Rightarrow$ space points$\Rightarrow$tracks
    - Work starting on including proper alignment and calibration information in chain.
- Data challenges:
  - Simulating and reconstructing ATLAS events is a major operation
  - Data challenges DC0/DC1 – 1000s CPUs used for weeks,worldwide –