Heavy Ion Simulation Tools in ATLAS

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BNL

Motivation

Simulation Dataflow

Event Characteristics

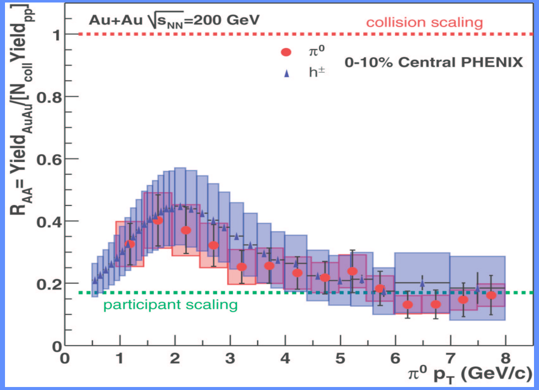
Subsystems Performance

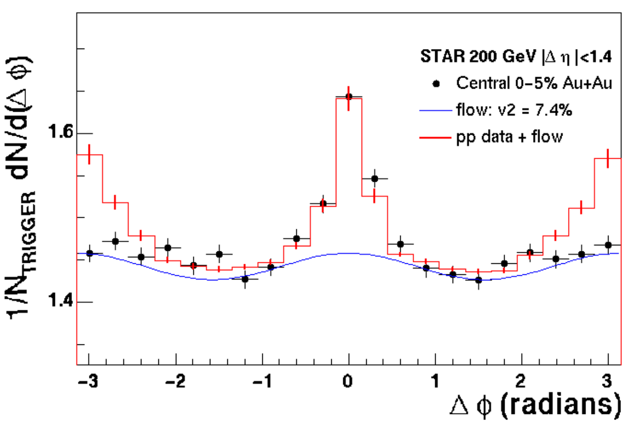
Heavy Ion Physics with ATLAS Detector

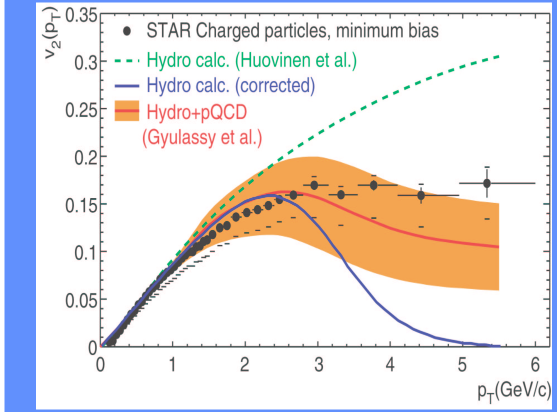
ATLAS interest in heavy ion physics was activated by highlights from RHIC experiments!

Hot/dense Nuclear Matter Diagnostics

- ☐ Suppression of high p_T particles
- ☐ Disappearance of back-to-back high p_T jet correlations
- ☐ Huge azimuthal asymmetry at high p_T







ATLAS is an excellent detector for high p_T physics and jet studies

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ATLAS as a Heavy Ion Detector

1. High Resolution Calorimeters

- Hermetic coverage up to $|\eta| < 4.9$
- Fine granularity (with longitudinal segmentation)

→ High p_T probes

2. Large Acceptance Muon Spectrometer

- Coverage up to $|\eta| < 2.7$

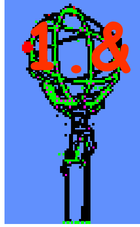
→ Muons from Υ, J/ψ, Z^0 decays

3. Si Tracker

- Large coverage up to $|\eta| < 2.5$
- Finely segmented pixel and strip detectors
- Good momentum resolution

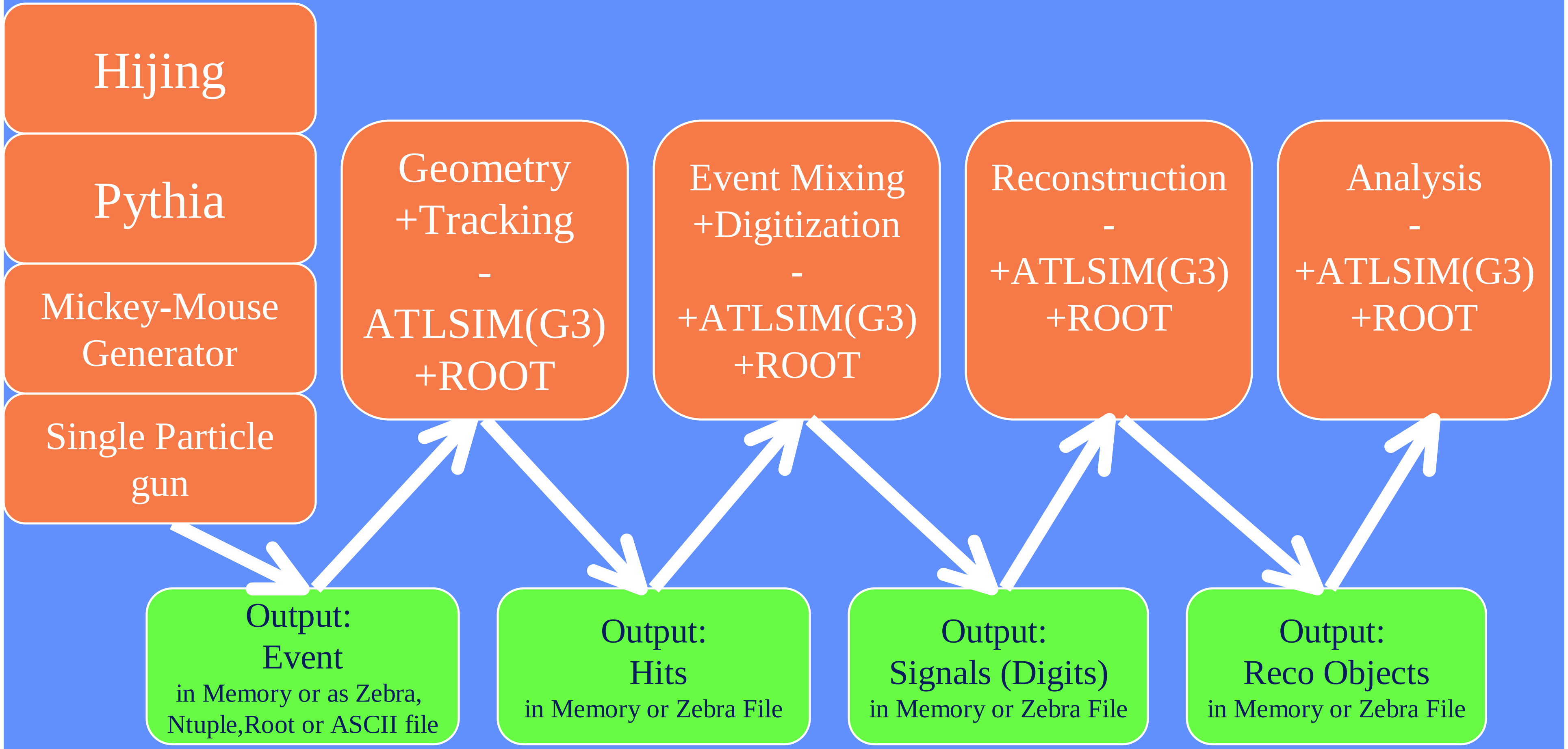
→ Tracking particles with $p_T \geq 1.0$ GeV/c

2.+ 3. → Heavy quarks(b), quarkonium suppression(Υ, Υ')



1.& 3. → Global event characterization

Simulation DataFlow



Hijing

Pythia

Mickey-Mouse Generator

Single Particle gun

Geometry
+Tracking
-
ATLSIM(G3)
+ROOT

Event Mixing
+Digitization
-
+ATLSIM(G3)
+ROOT

Reconstruction
-
+ATLSIM(G3)
+ROOT

Analysis
-
+ATLSIM(G3)
+ROOT

Output:
Event
in Memory or as Zebra,
Ntuple,Root or ASCII file

Output:
Hits
in Memory or Zebra File

Output:
Signals (Digits)
in Memory or Zebra File

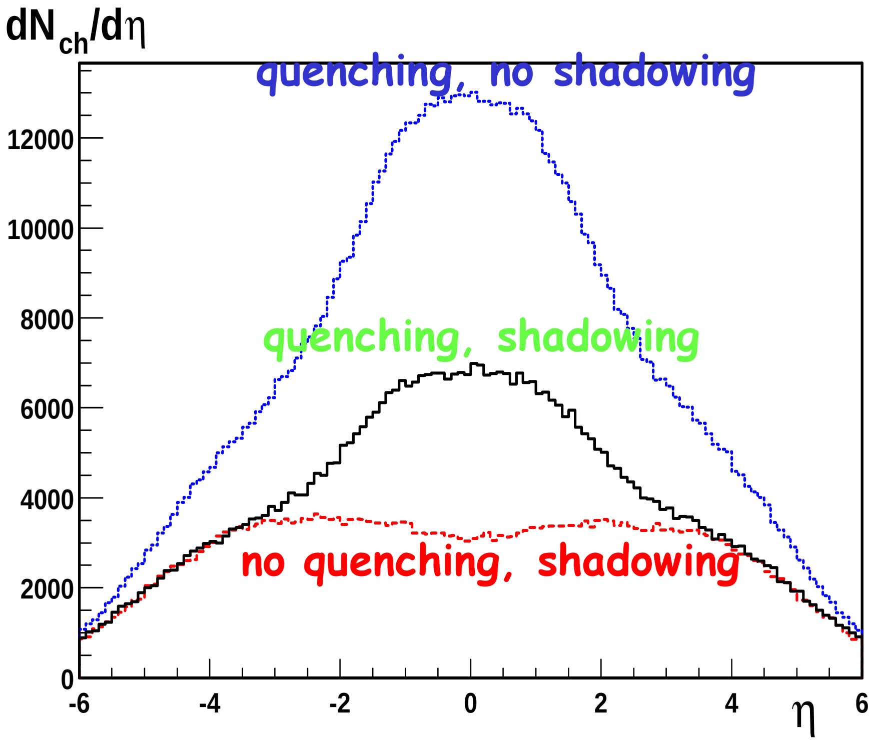
Output:
Reco Objects
in Memory or Zebra File

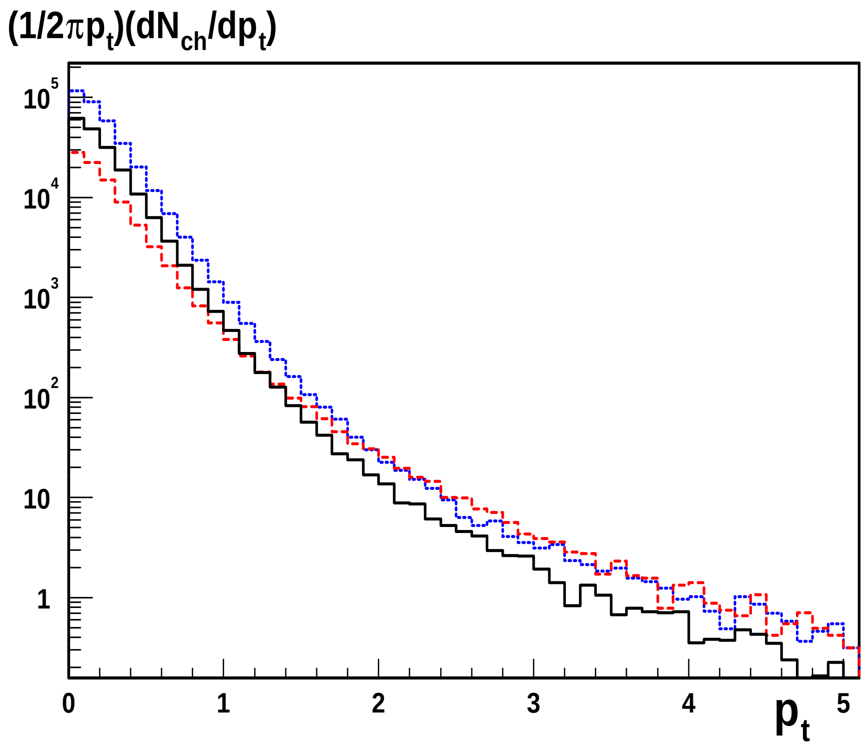
Simulation Tools: Generators

HIJING Event Generator:

Based on PYTHIA and Lund fragmentation scheme
(Soft string dynamics + hard pQCD interactions)
with nuclear effects: nuclear shadowing, jet quenching

Pb+Pb b=0 fm $\sqrt{s_{NN}}=5.5$ TeV

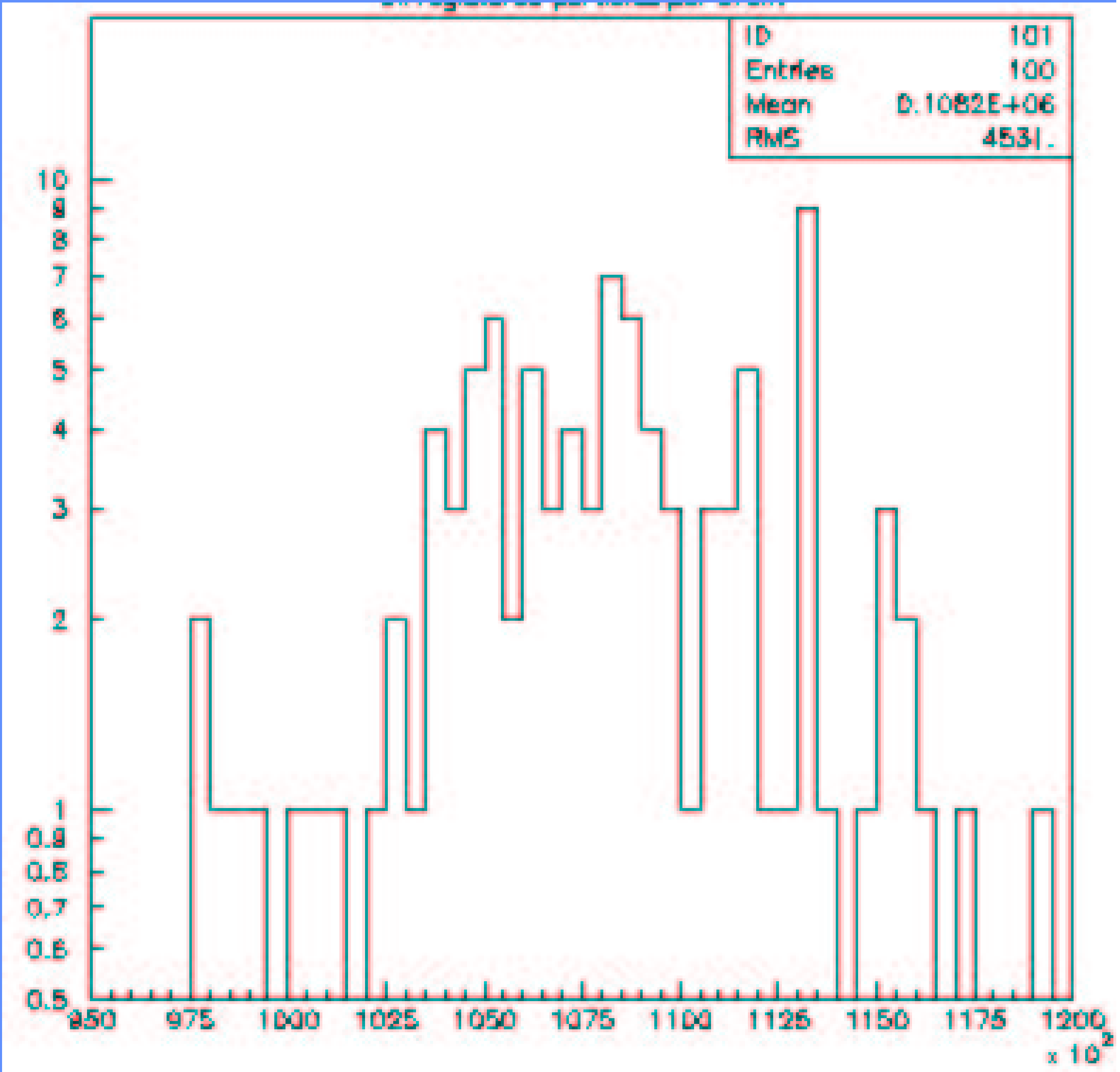




Central Event Multiplicity

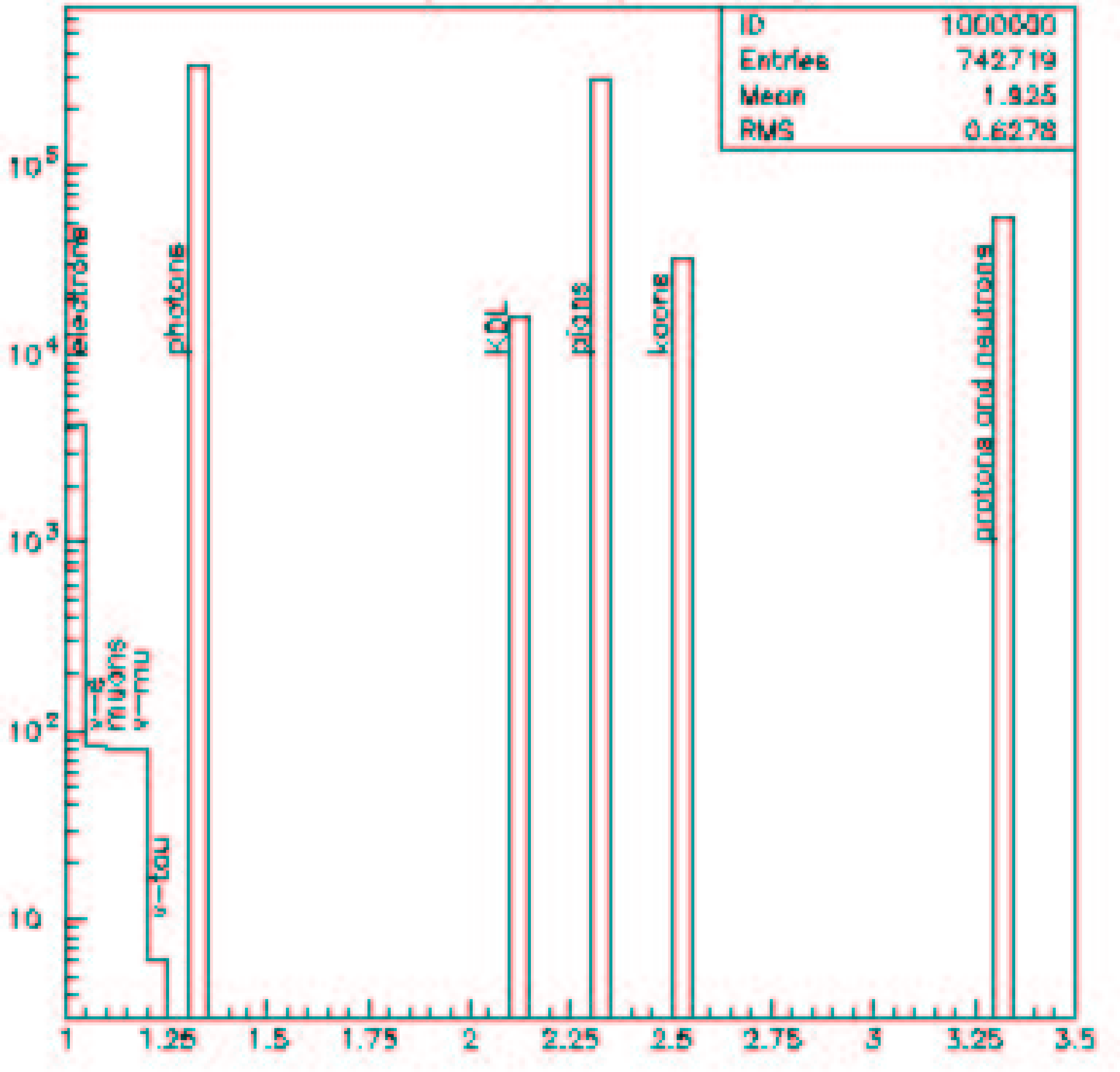
All particles output by HIJING event generator – stable plus their parents

100 events generated



Stable Particles after HIJING

Per 10 Events

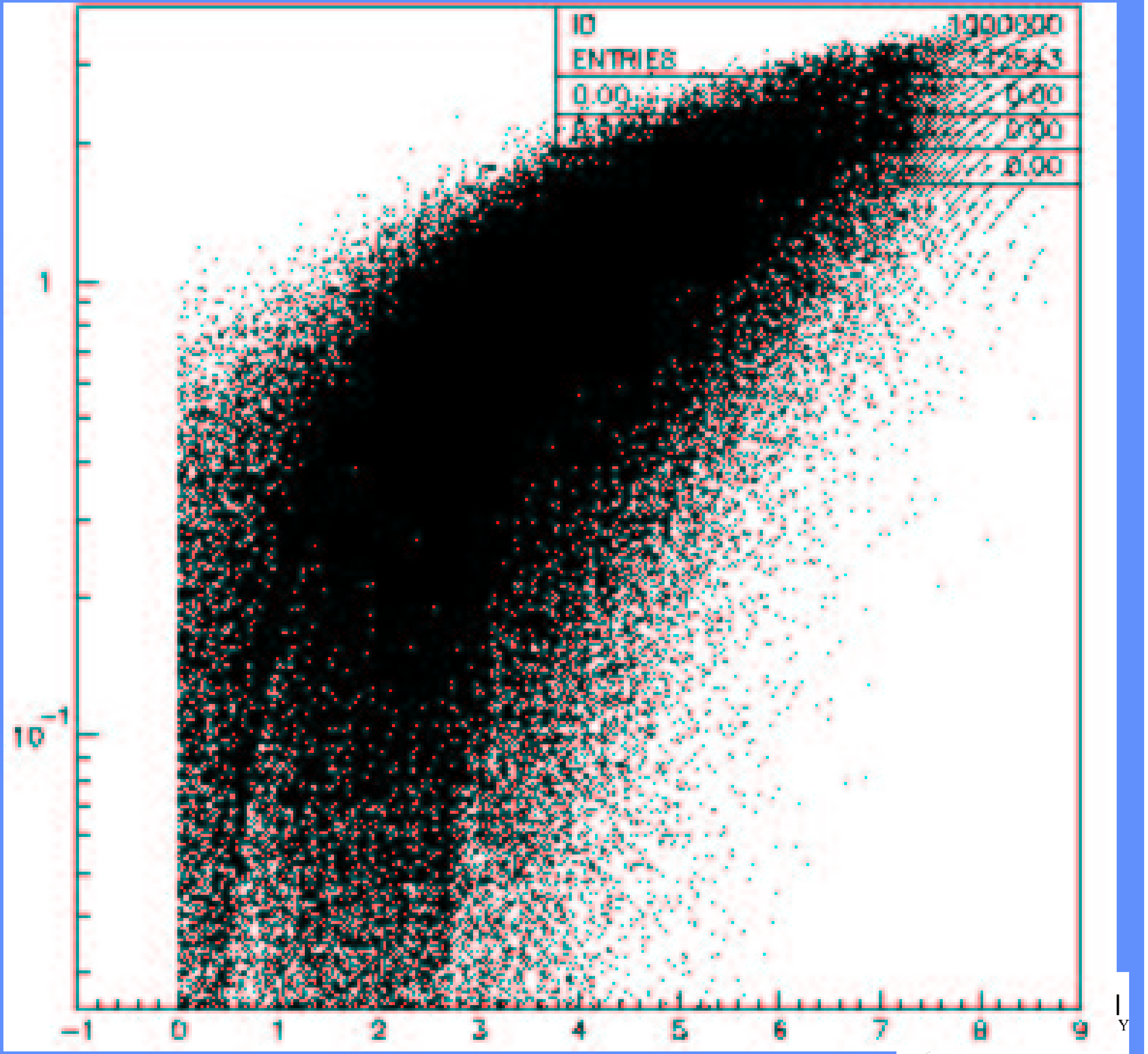


All decays faster then pi0 are now done by hijing,
But you can switch some of them off

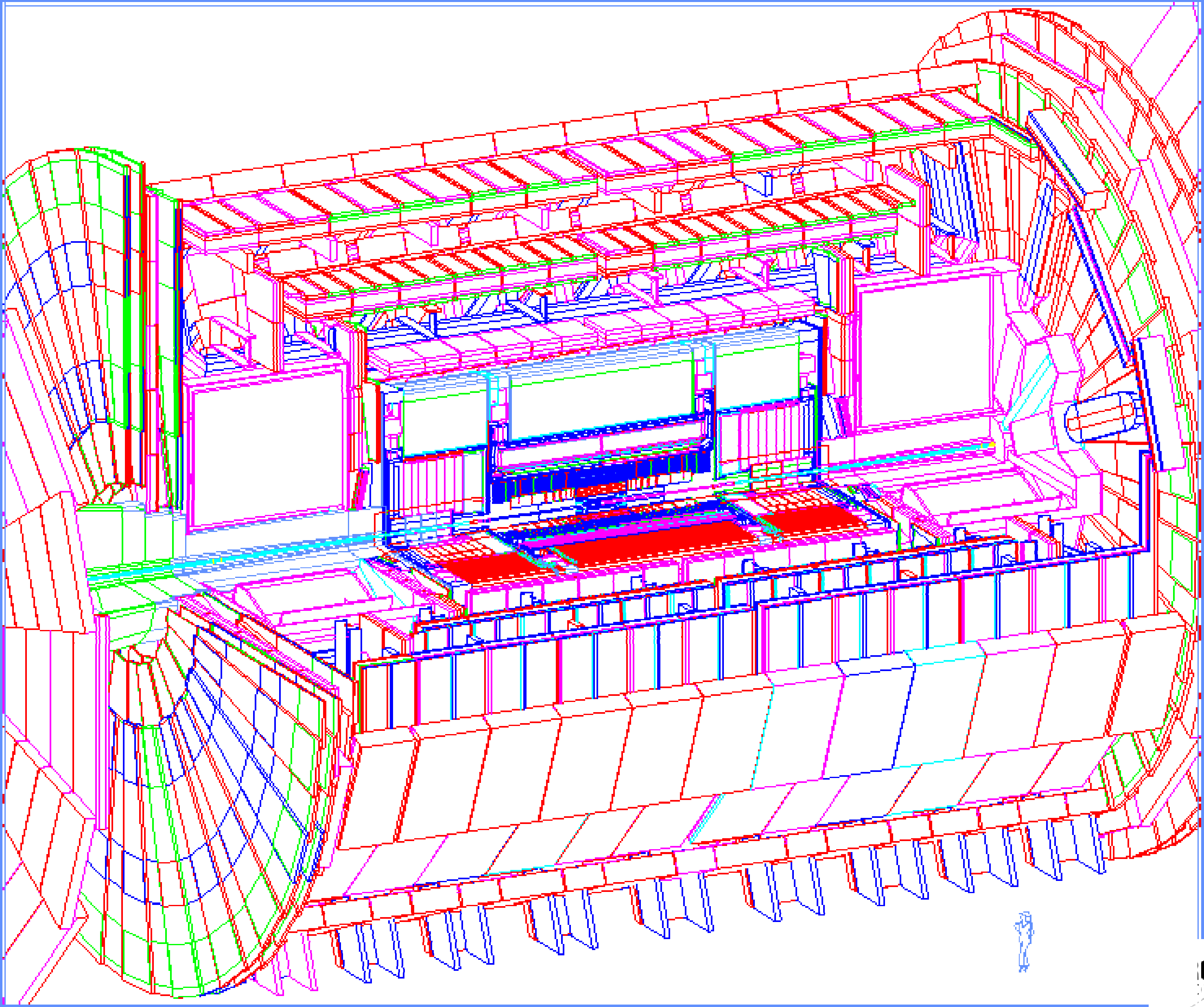
Simulation view- E vs Rapidity

Particles at high rapidities transport enormous energies but have little impact on detector

We use rapidity cut at +/- 3 units in this simulations



ATLAS Detector View With G3



Few Numbers at a Glance

- More then 30 millions distinct volume copies
- 25 thousand different volume objects
- 7 thousand different volume types
- Only 33 K lines of code (with digitization!)
- No step routine is needed for most of the detectors, no “if statement” problem
- Few hundred pile-up events possible
- About 1 million hits per event on average

Software Challenge

- Few basic numbers in an engineering description (about 1200 in ATLAS).
- Complicate relationship between input numbers and geometry objects (drawings).
- More “readers” than “writers”, not all of them are software engineers.
- A lot of geometry objects in the final model (30M in ATLAS), a lot of code at the end.
- Maintenance over dozens of years.

Dice95 (Atlsim)

- Third generation of the ATLAS simulations tools
- Strictly hierarchical design to separate detector specific code from the infrastructure
- Stable GEANT3 simulation framework since 95
- Improved memory management
  - » Elastic ZEBRA (using malloc)
  - » No limits on number of tracks, vertices, hits etc (apart from physical memory limits)
- Interfaces to existing and future services
  - » Geant3/paw, MySQL … ROOT and even more

Dice-95: Functionality in Term of Layers

- Layers *a la* Open System Interconnection (OSI) model:
  - “External – parameter database
  - “User” – generic geometry description
  - “System” – object generation interface
  - “Application” – Geant 3/4, reconstruction, root
  - “Low” (logical) layer – ZEBRA, root, LHC++
  - “Basic” (physical) layer - platform dependant code, system libraries,graphics etc

Geometry Description

- For geometry description a **specification language** is a must !
  - – Detectors have parameters which may describe geometry evolution.
  - – Most of the geometry dimensions has to be calculated using parameters.
  - – Both input parameters and calculation results should be available to the reconstruction.
  - – A mechanism of keeping both parameters and calculation results is needed.
- What should it be if we don’t want to write a new language ? *any existing* …+ *more !*

Geometry Specification

- Role of the geometry specification.
  - Use simplest possible tools to pass user’s perception of geometry objects to an **executable code**.
  - Creates instances of a “user request” objects and invokes a generic object constructor (material, volume, rotation matrix etc).
  - Actual object creation is completely decoupled from the geometry description language and done by the **generic constructor.**

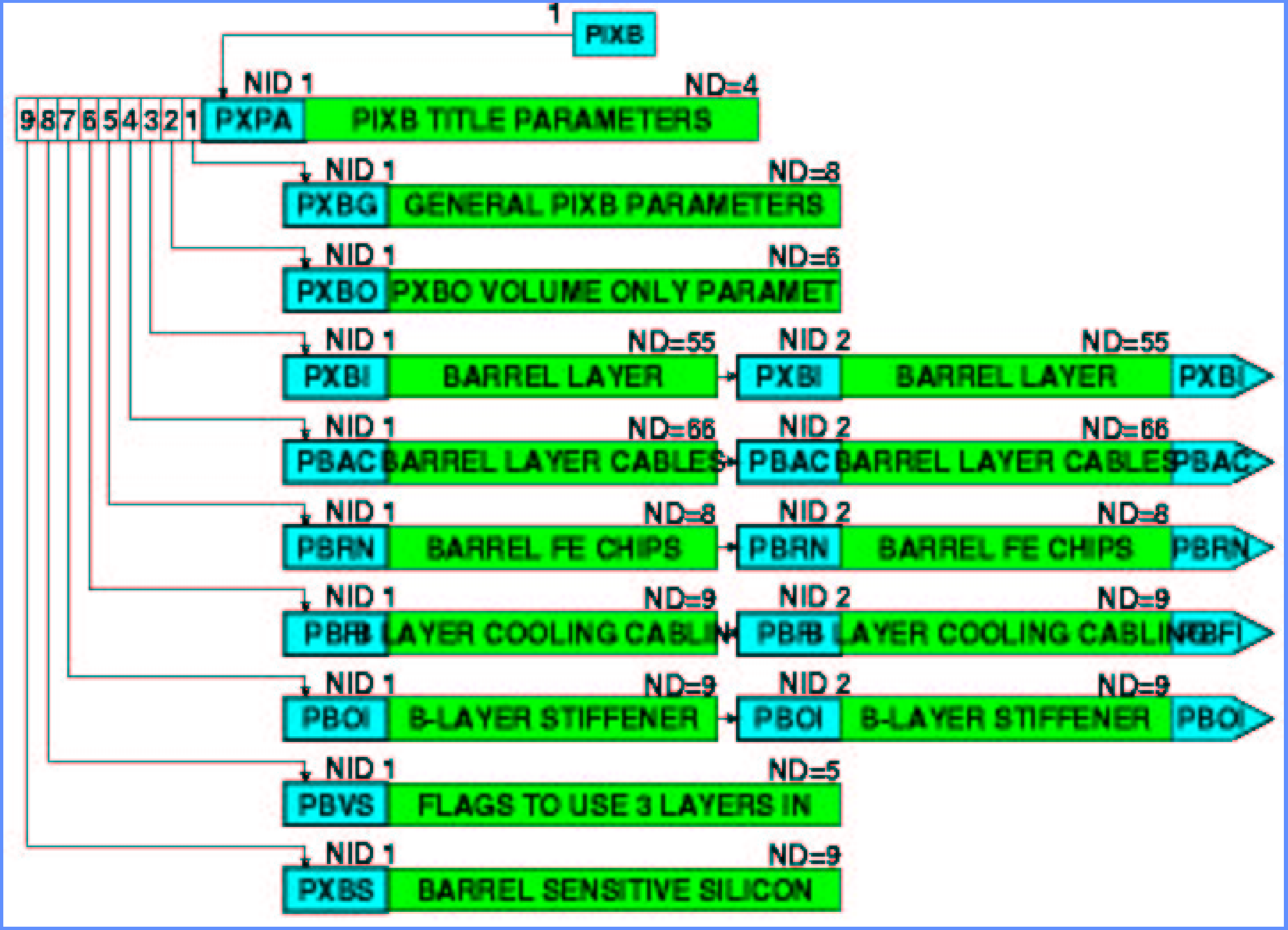
Generic Constructor

- It gets and executes a single “user request.”
- It takes care of bookkeeping:
  - If an object with requested attributes already exists, return pointer to it.
  - If object attributes are different from all previously existing objects, a new object is created and its pointer is returned.
- Output is similar to “flat XML” apart from
    - » maintenability
    - » Generic and symmetry memory
- This is where the most of the coding happens.

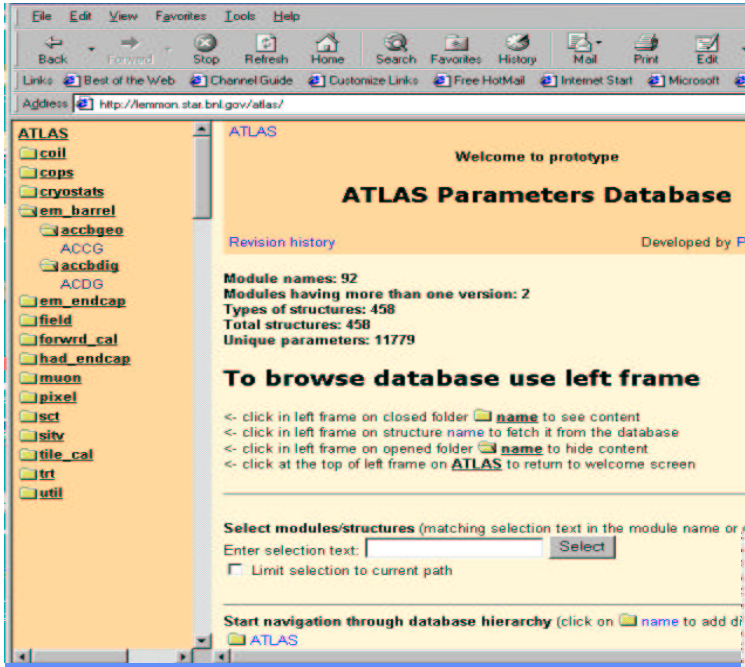
Database Interface

- Loading geometry data or opening an existing configuration creates a relational database in memory - a subset of the full database.
- Selection of an actual copy of each structure (instantiation) is done by the ***<u>use</u>*** statements.
- Any variable from the structure can be used as a selection key – within selected configuration.
- USE processor in AGI makes dynamic brokerage in case the structures in the code differs from DB.

How This DB Looks Like ?



ATLAS Parameter Database



http://lemmon.star.bnl.gov/atlas/

Welcome to prototype

ATLAS Parameters Database

Revision history

Developed by PN, AV and TW

Module names: 92
Modules having more than one version: 2
Types of structures: 458
Total structures: 458
Unique parameters: 11779

To browse database use left frame

<- click in left frame on closed folder **name** to see content
<- click in left frame on structure name to fetch it from the database
<- click in left frame on opened folder **name** to hide content
<- click at the top of left frame on **ATLAS** to return to welcome screen

Select modules/structures (matching selection text in the module name or comment)

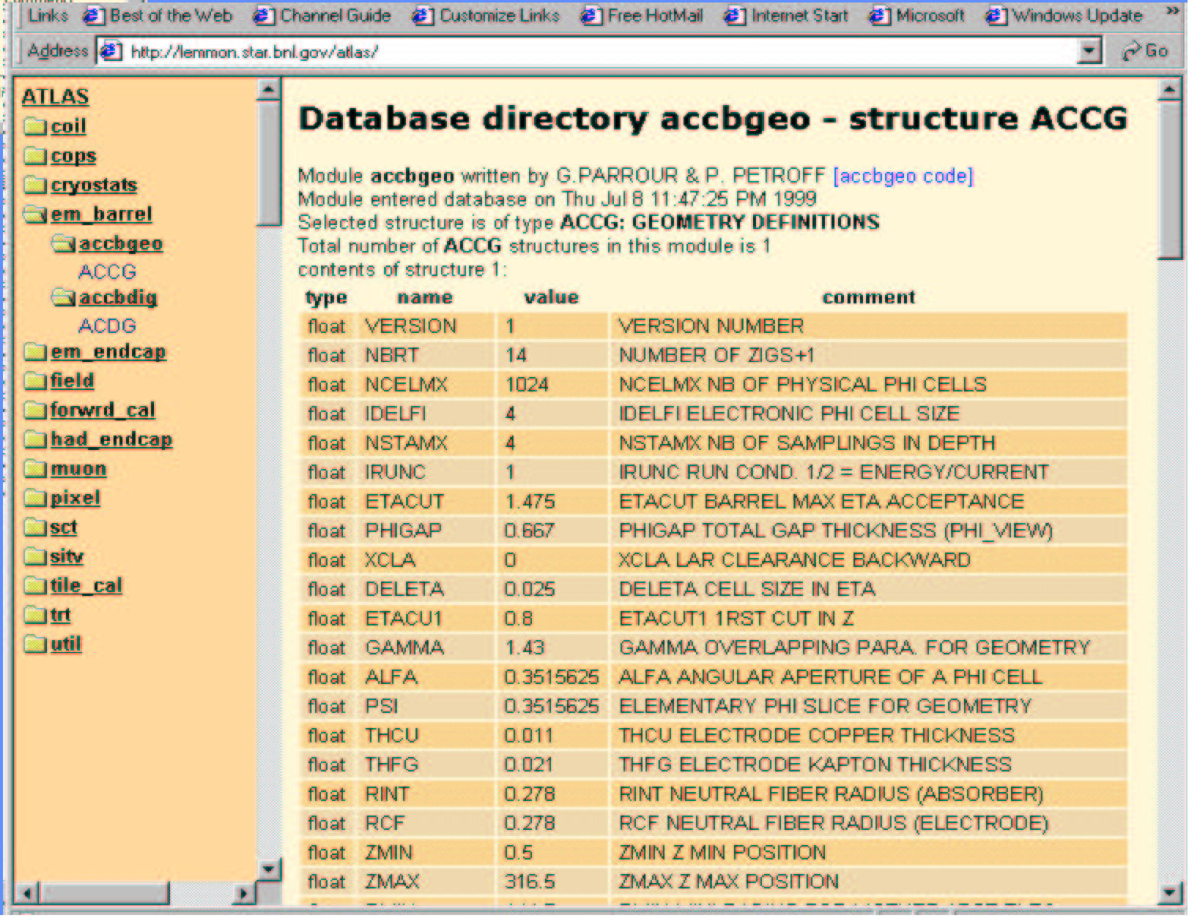
Enter selection text:

☐ Limit selection to current path

Start navigation through database hierarchy (click on name to add di

ATLAS

- Contains only independent (basic) parameters
- Parameter values: ~14,000
- Dimensions and positions are calculated in the code



http://lemmon.star.bnl.gov/atlas/

Database directory accbgeo - structure ACCG

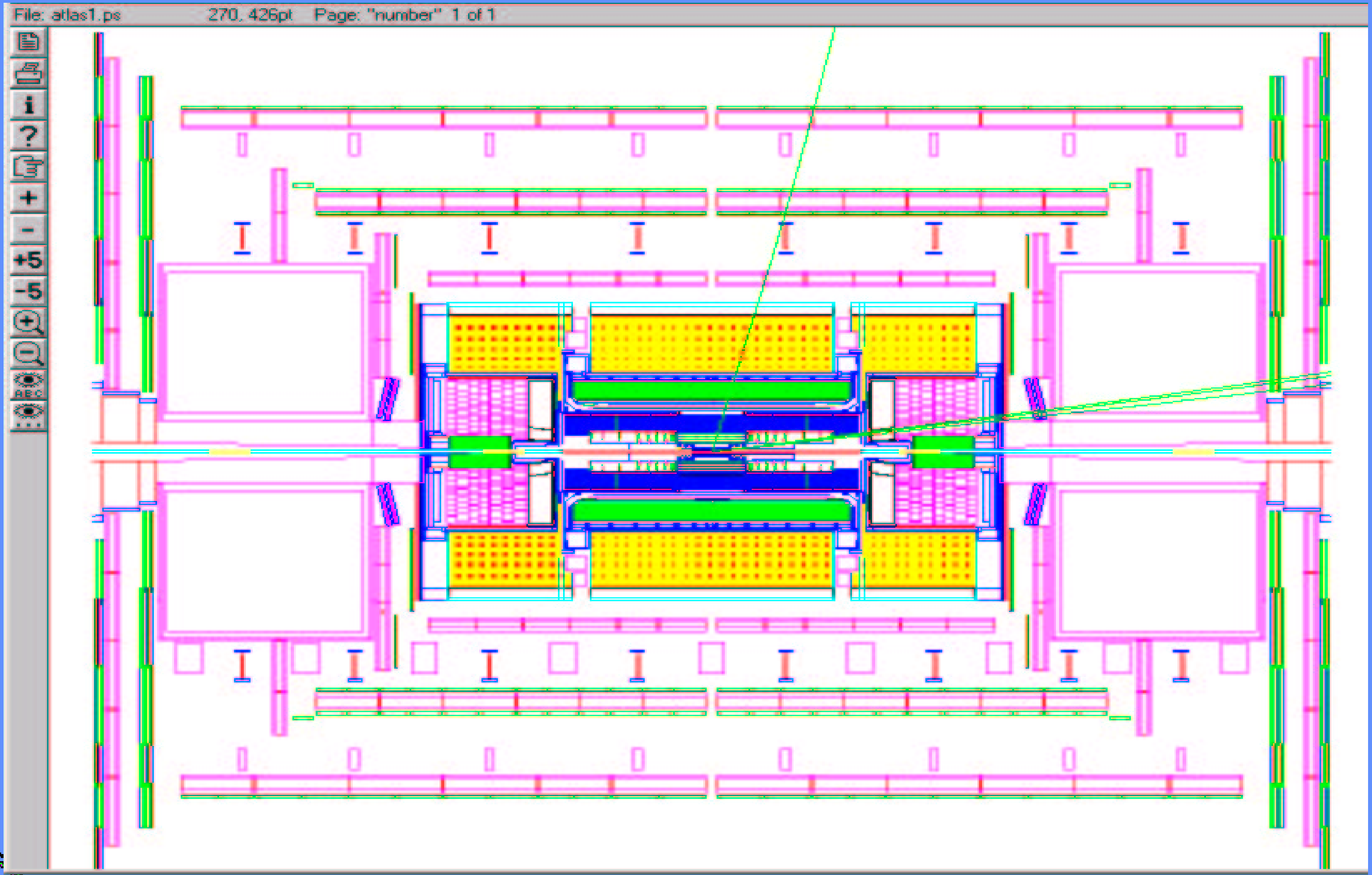
Module **accbgeo** written by G.PARROUR & P. PETROFF [accbgeo code]
Module entered database on Thu Jul 8 11:47:25 PM 1999
Selected structure is of type **ACCG: GEOMETRY DEFINITIONS**
Total number of **ACCG** structures in this module is 1
contents of structure 1:

type	name	value	comment
float	VERSION	1	VERSION NUMBER
float	NBRT	14	NUMBER OF ZIGS+1
float	NCELMX	1024	NCELMX NB OF PHYSICAL PHI CELLS
float	IDELFI	4	IDELFI ELECTRONIC PHI CELL SIZE
float	NSTAMX	4	NSTAMX NB OF SAMPLINGS IN DEPTH
float	IRUNC	1	IRUNC RUN COND. 1/2 = ENERGY/CURRENT
float	ETACUT	1.475	ETACUT BARREL MAX ETA ACCEPTANCE
float	PHIGAP	0.667	PHIGAP TOTAL GAP THICKNESS (PHI_VIEW)
float	XCLA	0	XCLA LAR CLEARANCE BACKWARD
float	DELETA	0.025	DELETA CELL SIZE IN ETA
float	ETACU1	0.8	ETACUT1 1RST CUT IN Z
float	GAMMA	1.43	GAMMA OVERLAPPING PARA. FOR GEOMETRY
float	ALFA	0.3515625	ALFA ANGULAR APERTURE OF A PHI CELL
float	PSI	0.3515625	ELEMENTARY PHI SLICE FOR GEOMETRY
float	THCU	0.011	THCU ELECTRODE COPPER THICKNESS
float	THFG	0.021	THFG ELECTRODE KAPTON THICKNESS
float	RINT	0.278	RINT NEUTRAL FIBER RADIUS (ABSORBER)
float	RCF	0.278	RCF NEUTRAL FIBER RADIUS (ELECTRODE)
float	ZMIN	0.5	ZMIN Z MIN POSITION
float	ZMAX	316.5	ZMAX Z MAX POSITION

Resulting G3 Geometry Model

- Complete geometry model is created only in the computer memory as a result of code execution with a set of input parameters coming from:
    - Default code versions
    - Database (MySQL supported)
    - Data card parameters and version input
- Selection is done at run-time (user controlled)
- Resulting geometry is ***persistent***, as well as all selected input parameter structures

Same Geometry Everywhere ?!



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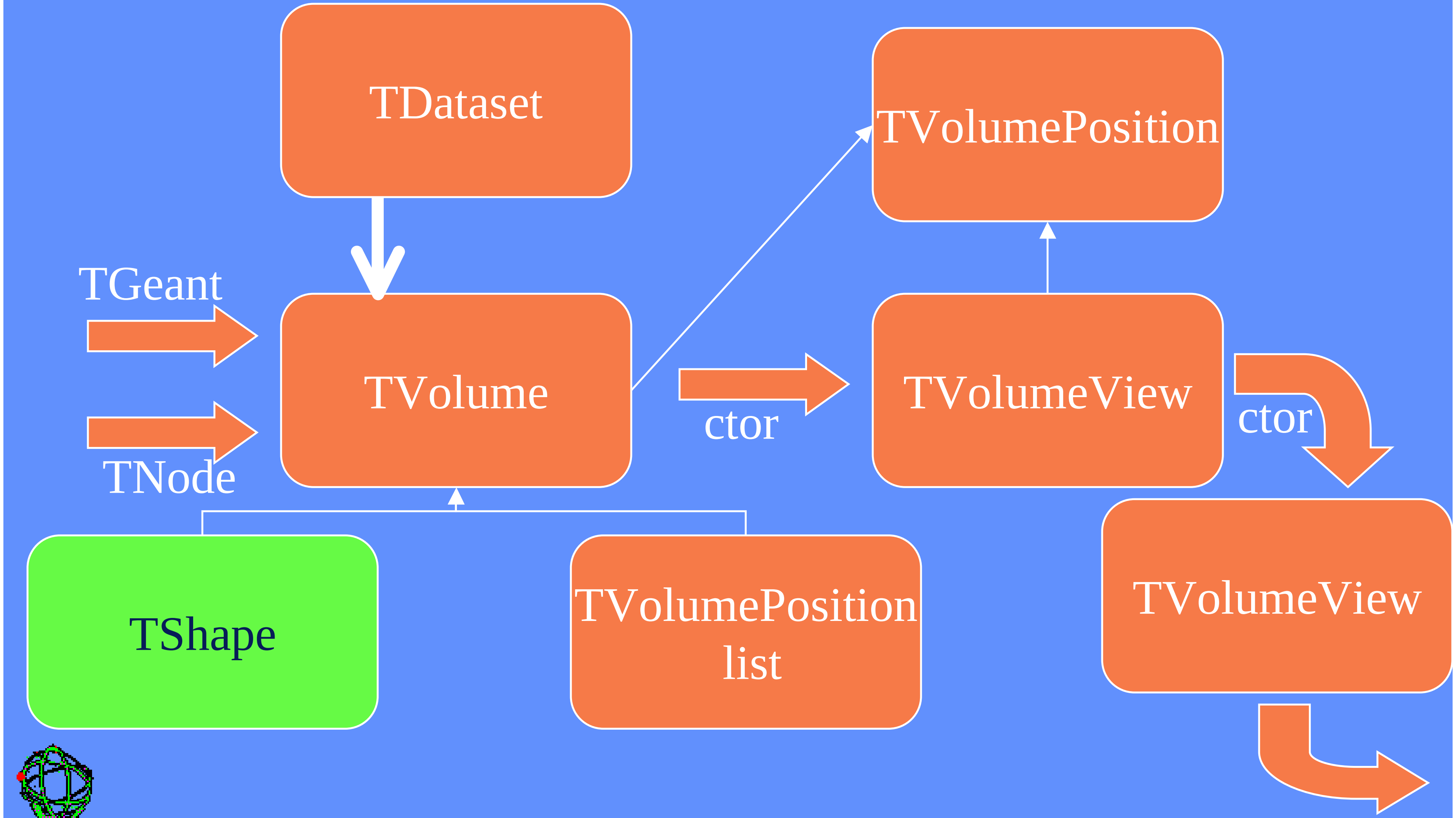
Generic Geometry Via ROOT



TDataset

TVolumePosition

TGeant

TVolume

ctor

TVolumeView

ctor

TNode

TShape

TVolumePosition list

TVolumeView

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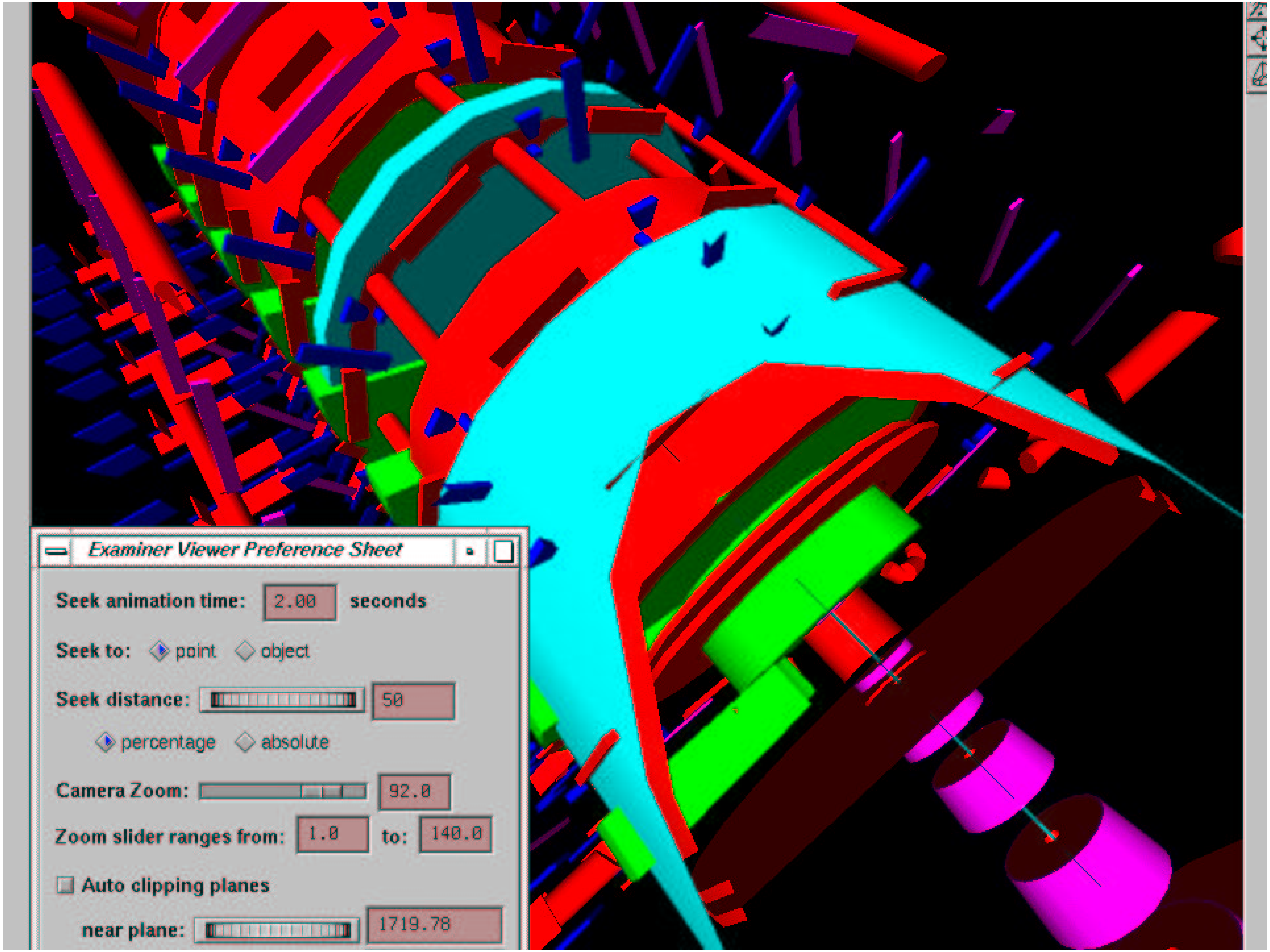


Examiner Viewer Preference Sheet

Seek animation time: 2.00 seconds

Seek to: ● point ○ object

Seek distance: 50

● percentage ○ absolute

Camera Zoom: 92.0

Zoom slider ranges from: 1.0 to: 140.0

☐ Auto clipping planes

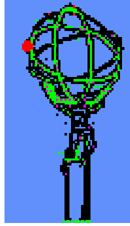
near plane: 1719.78

Hit Service: Definitions

Universal hit definition:

HITS volume measurement:bin_or_bits:(a,b)...

- A hit is a container of **measurements**, representing a piece of particle trajectory.
- Most of the measurements are similar for all detectors and rather trivial:
  - » X,y,z – local or global, momentum and directions.
  - » eta or phi, time of flight, deposited energy.
  - » Distance of the closest approach to a wire.
- Repeating their coding was error-prone.

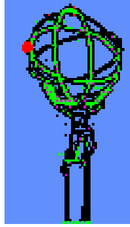


Hit Service: Mixing and Sorting

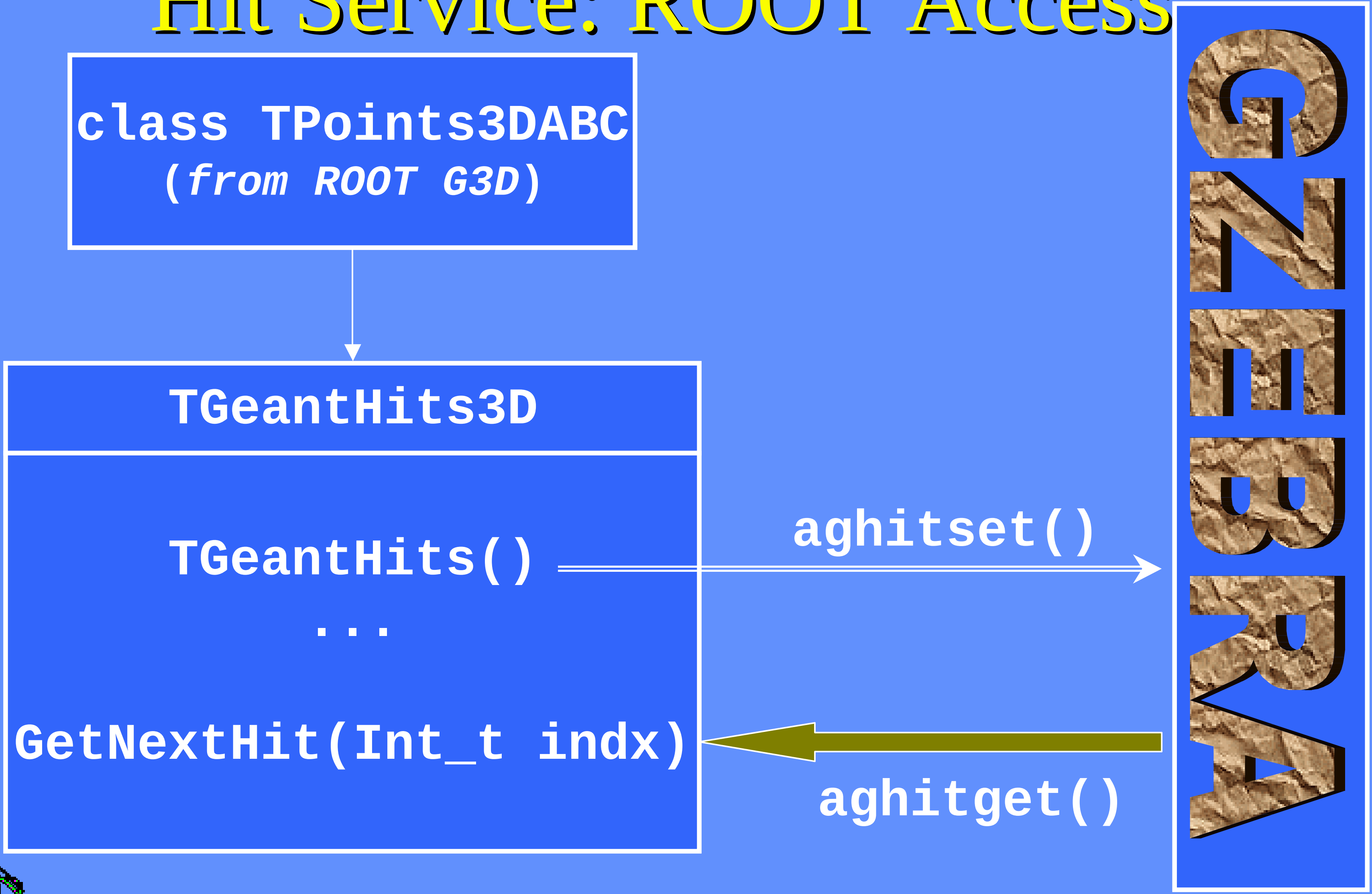
- Universal hit sorting => see demo at three.
  - Hits are produced along a particle trajectory, but most often are analyzed together in a detector element.
  - Hits are often produced in different events, but still analyzed together in the same detector element.
  - A flexible hit navigation may solve both tasks.
  - It also can be detector independent.

Hit Service: History

- It is often desirable to determine the origin of a hits from secondary tracks, produced during simulations. However in practice it is hard to save all secondary tracks.
- DICE can save only those secondaries, which have produced a hit in specified detectors or made a specified interaction.
- The vertex entry of secondary tracks keeps their closest ancestor as well as the originating process and volume where it happened.



Hit Service: ROOT Access



class TPoints3DABC
(from ROOT G3D)

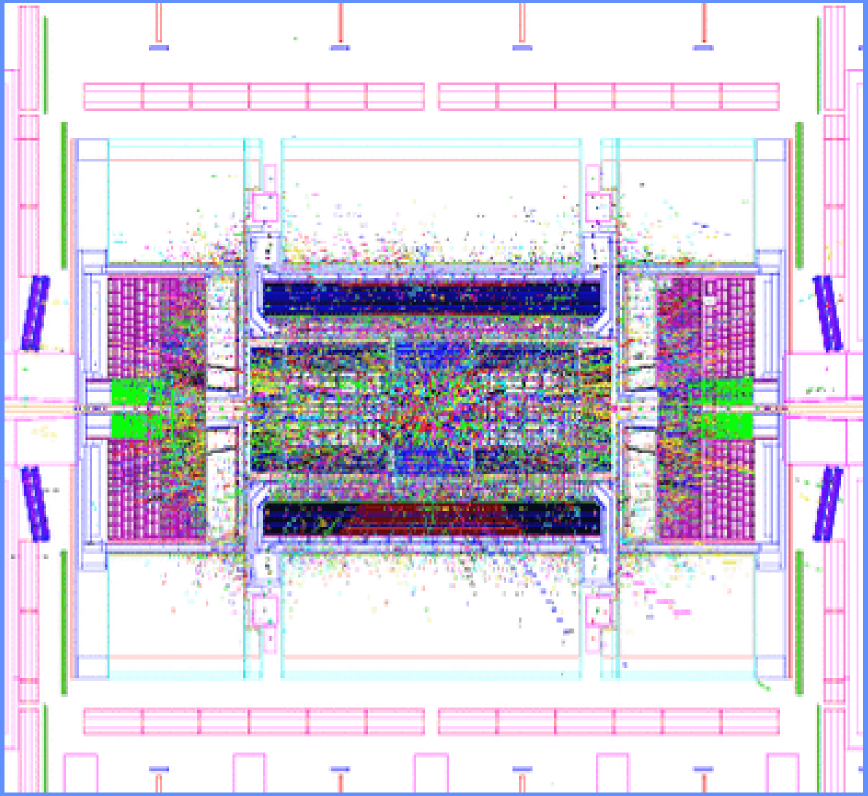
TGeantHits3D

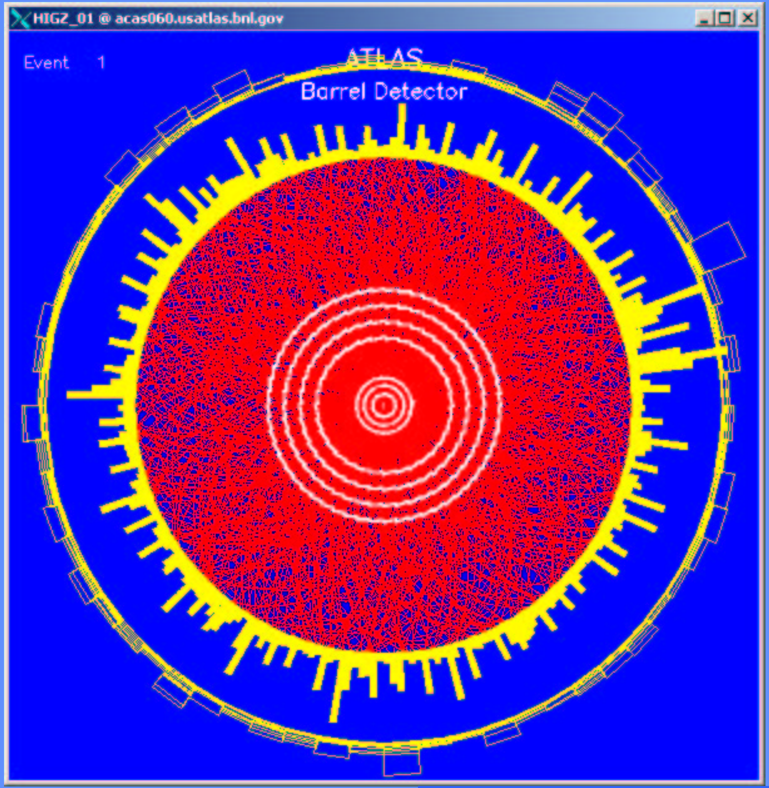
TGeantHits()
...
GetNextHit(Int_t indx)

aghitset()

aghitget()

Central Pb+Pb Collision





$N_{ch}(|y| \leq 0.5)$

- About 75,000 stable particles
- ~ 40,000 particles in $|\eta| \leq 3$
- CPU – 6 h per central event (800MHz)
- Event size 50MB (without TRT)

Simulated Event Samples

HIJING + full GEANT3 ATLAS detector simulations
Only particles within |y| < 3.2

- ☐ High Geant thresholds
  1 MeV tracking/10 MeV production
  - 5,000 events in each of 5 impact parameter bins:
    b = 0-1, 1-3, 3-6, 6-10, 10-15 fm
- ☐ Standard ATLAS thresholds
  100 keV tracking/1 MeV production
  - 1,000 central events, b = 0-1fm
- ☐ Initial layout – 2 pixel barrel layers
  - 1,000 central events, b = 0-1fm

Event Reconstruction

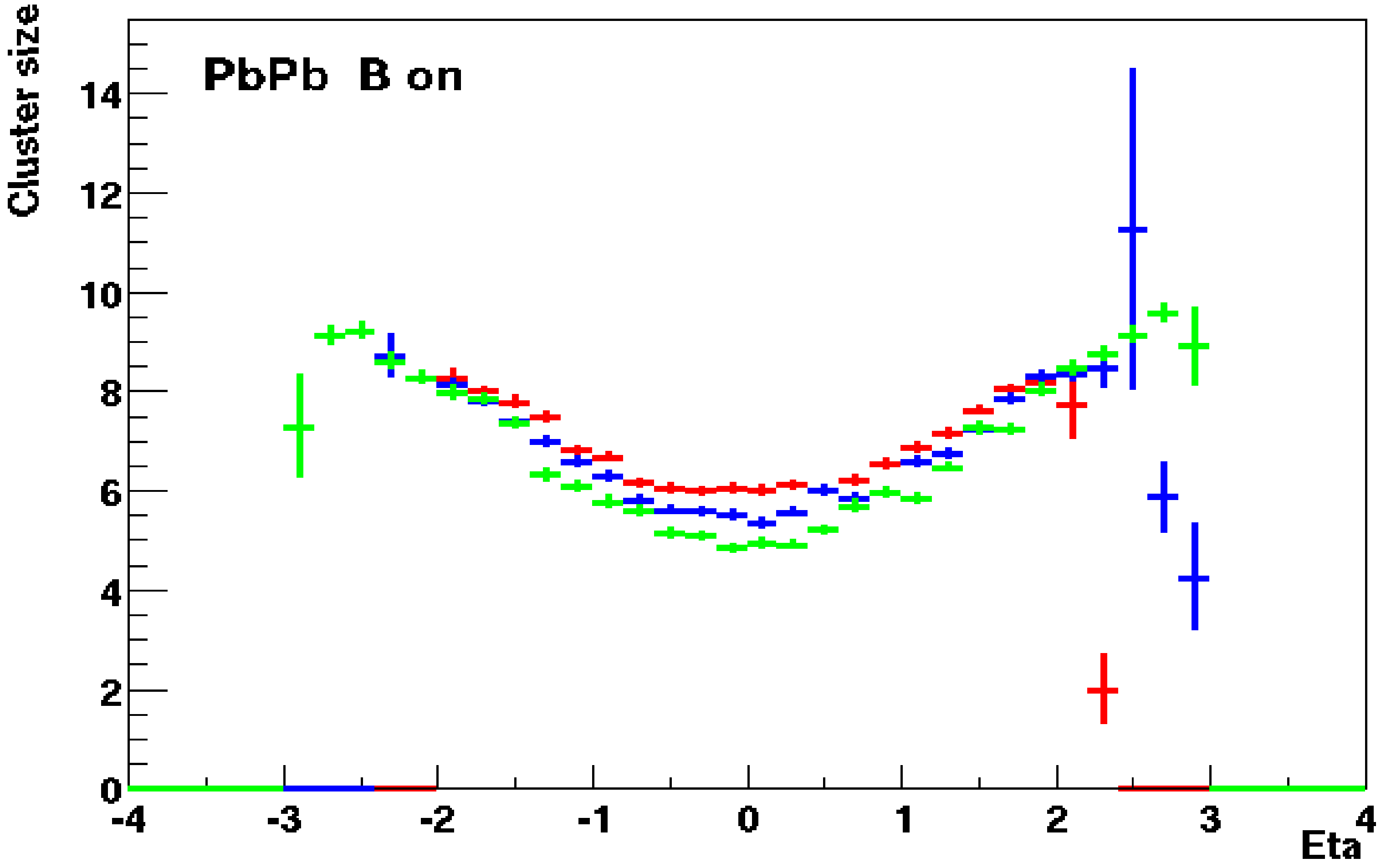
- Most of the standard ATLAS reconstruction packages are working on HI events after minimal parameter tuning
- We have successfully exercised all calorimeter reconstruction - photons, jets, missing energy.

  Of course, jet reconstruction is a tricky issue -

  work is ongoing to develop an appropriate code
- Silicon Pixel and Strip detectors have reasonable occupancy and can provide track reconstruction
- Muon reconstruction is even simpler in HI events

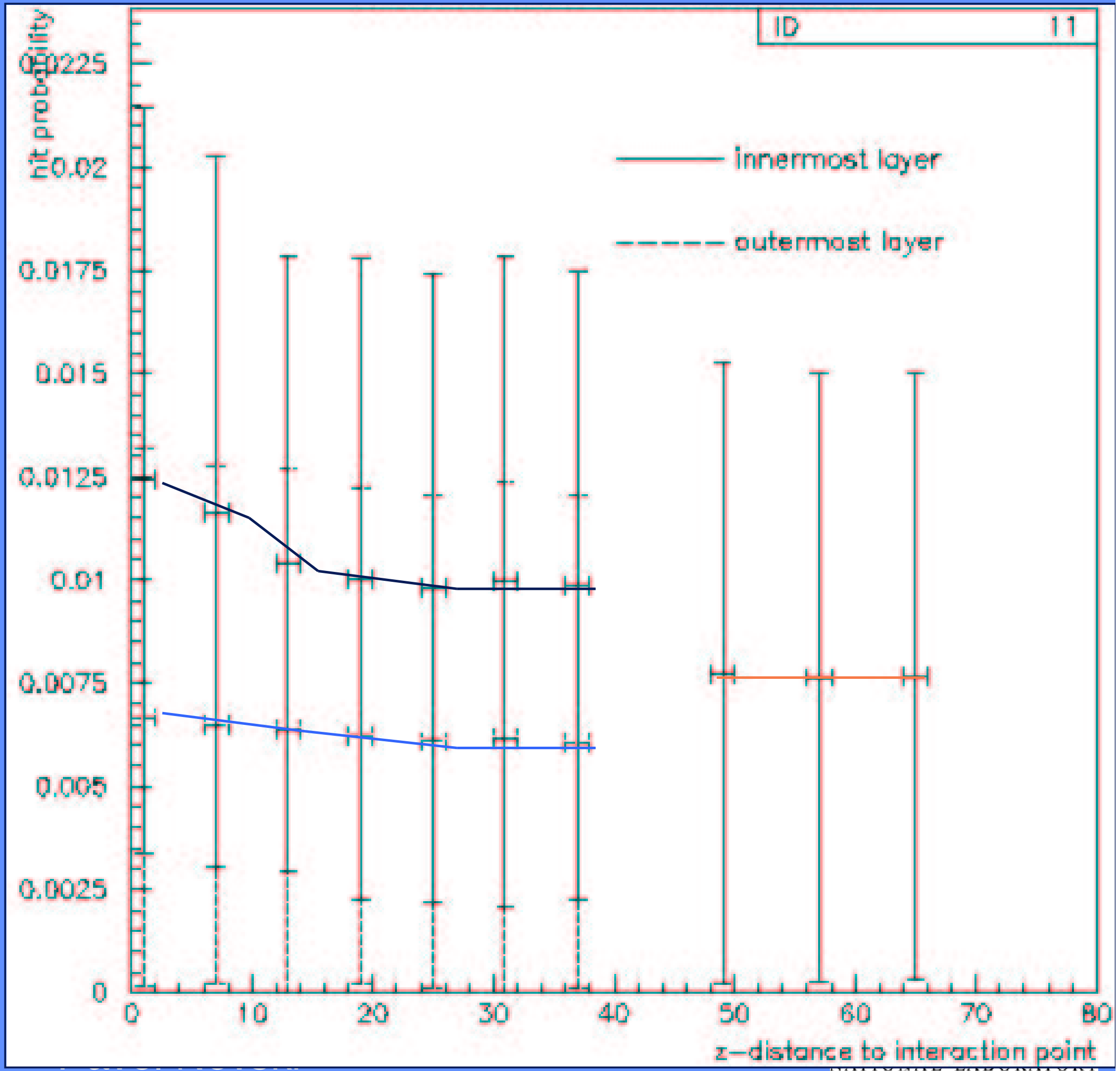
  - provided the muon energy is above 6 GeV

Cluster Size - η dependence



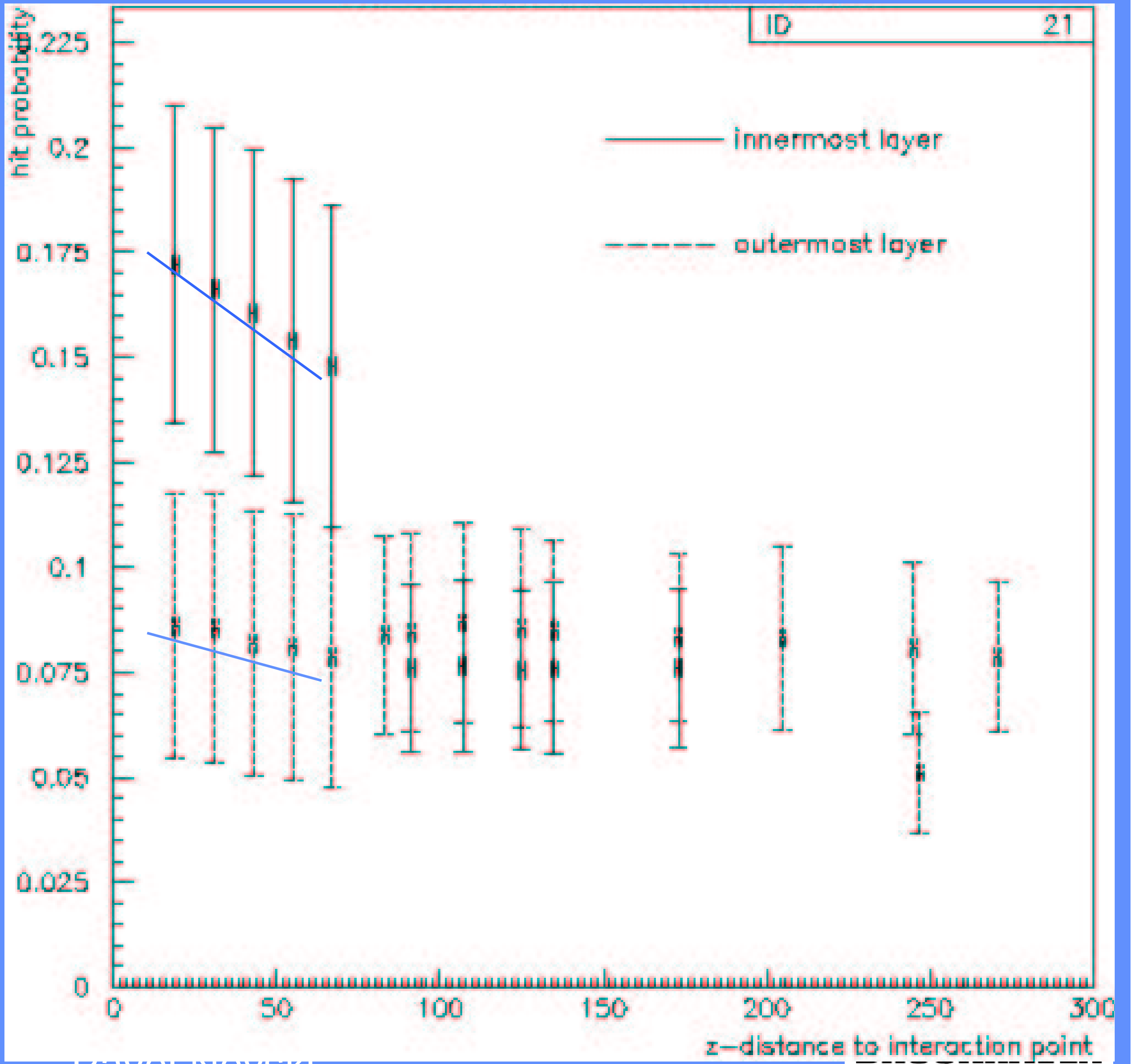
Pixel occupancy vs. rapidity

- Average occupancy close to one per cent
- Strong local fluctuations
- Outermost layers are in a better condition
- 4096 pixel limit in the readout system - corresponds to 4% maximum occupancy



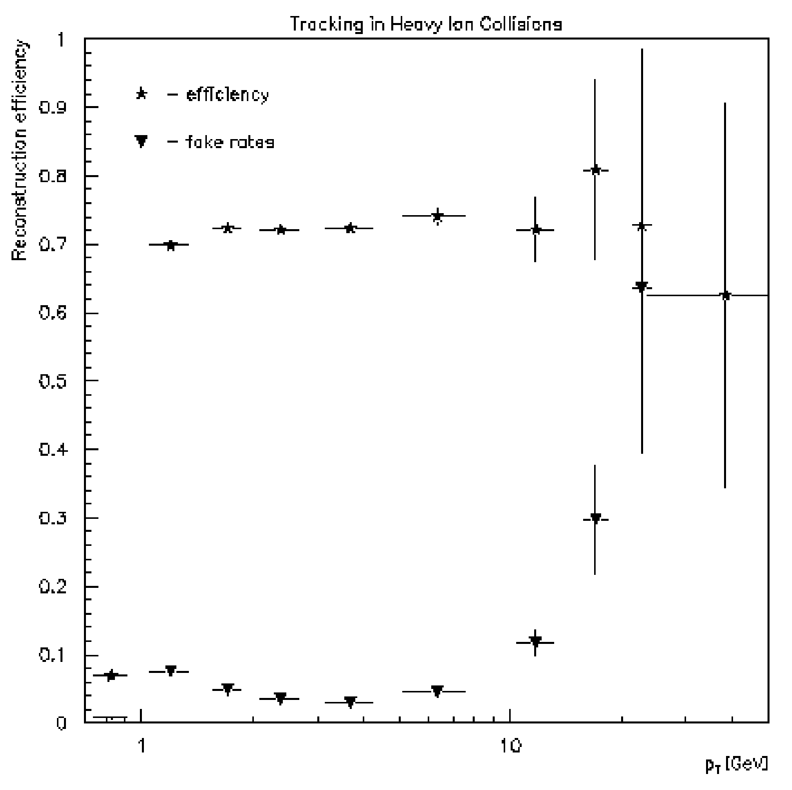
Strip occupancy vs. rapidity

- Occupancy is significantly lower in the outermost layer
- Even in worse case still below 20 per cent



Track Reconstruction

Track reconstruction performed with ATLAS pp tracking code using the Pixel and SCT detectors (xKalman++).



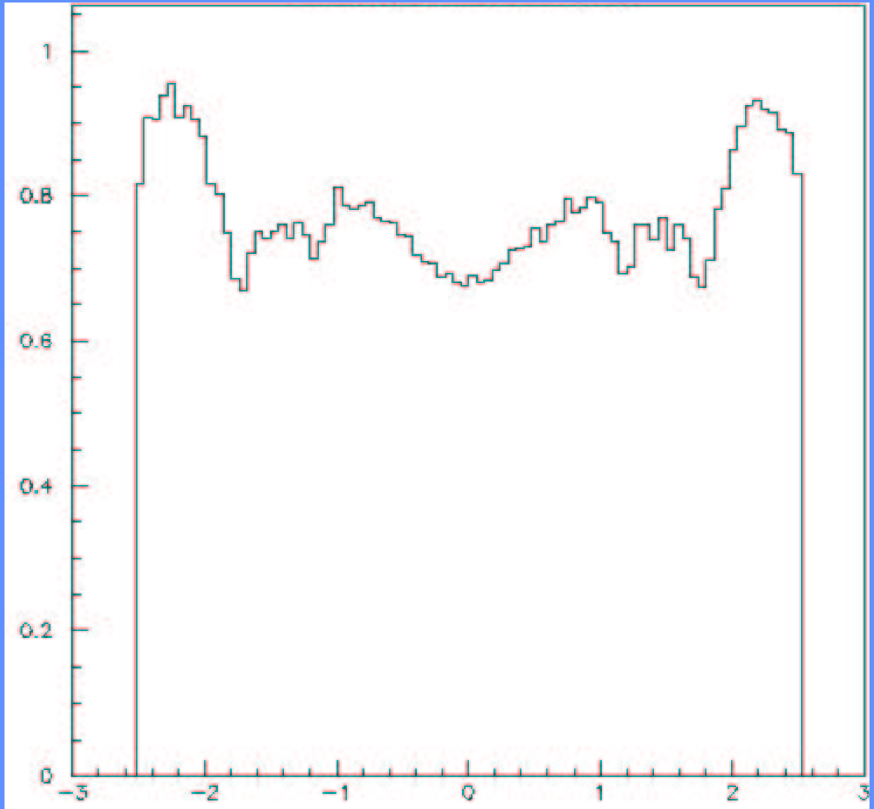
- p_T threshold for reconstructable tracks is 1 GeV.
- Tracking cuts are optimized to get a decent efficiency and low rate of fake tracks.

For p_T 1 to 15 GeV/c:
efficiency ~ 70 %
fake rate ≤ 10%

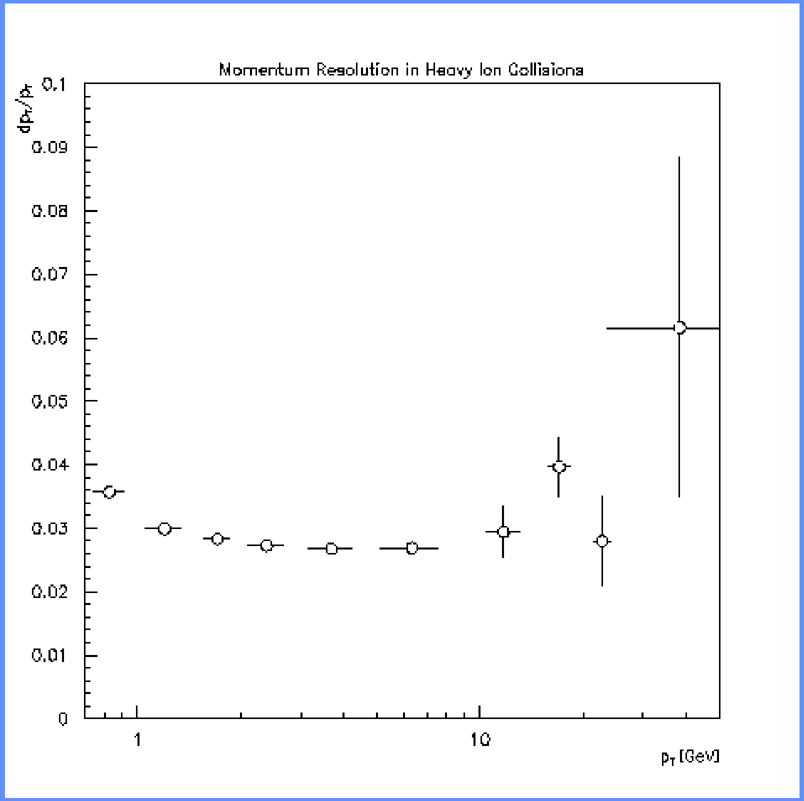
Eff. ~80% , fake rate 15-20%
Eff. ~65%, fake rate ~5%

Track Reconstruction

Efficiency versus rapidity



Momentum resolution



Flat dependency for |y| < 2

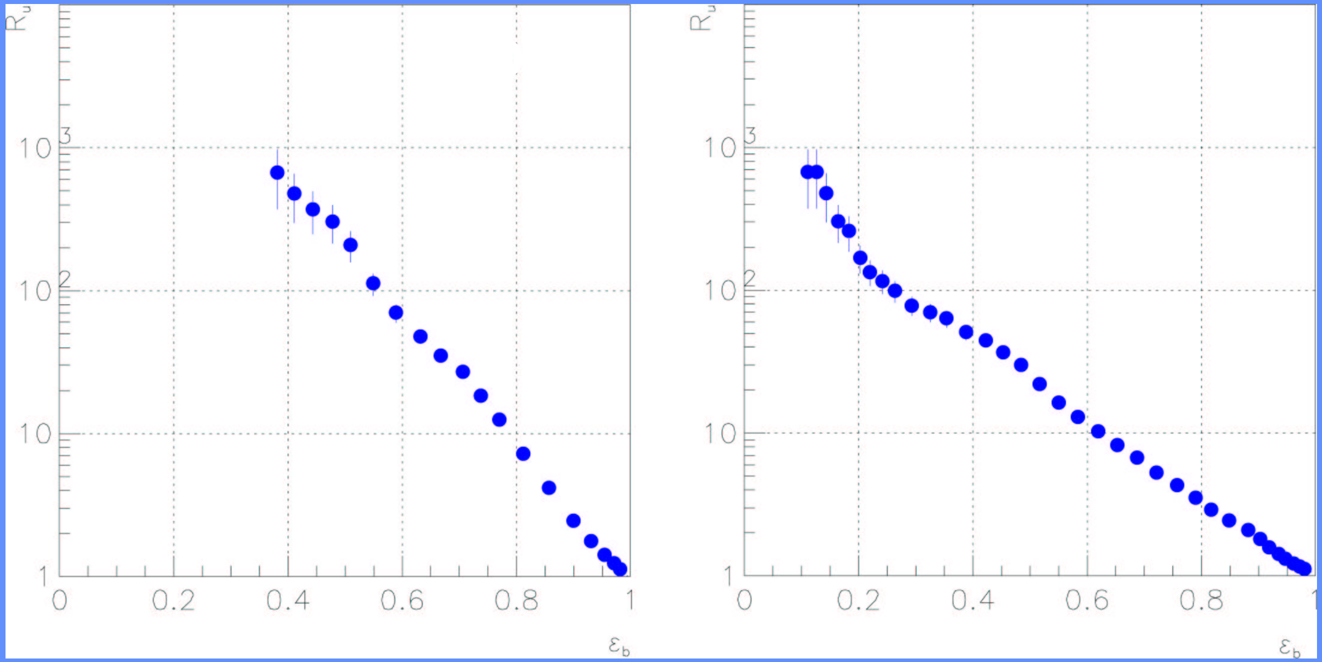
~3% for p_T up to 20 GeV/c

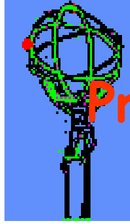
B-jet Tagging

Preliminary study:

- —Standard ATLAS algorithm for pp
- —Higgs events embedded into pp or Pb-Pb event
- —Cuts on the vertex impact parameter in the Pixel and SCT

Rejection factors against light quarks versus b-tagging efficiency





Promising, should be improved when combined with muon tagging!

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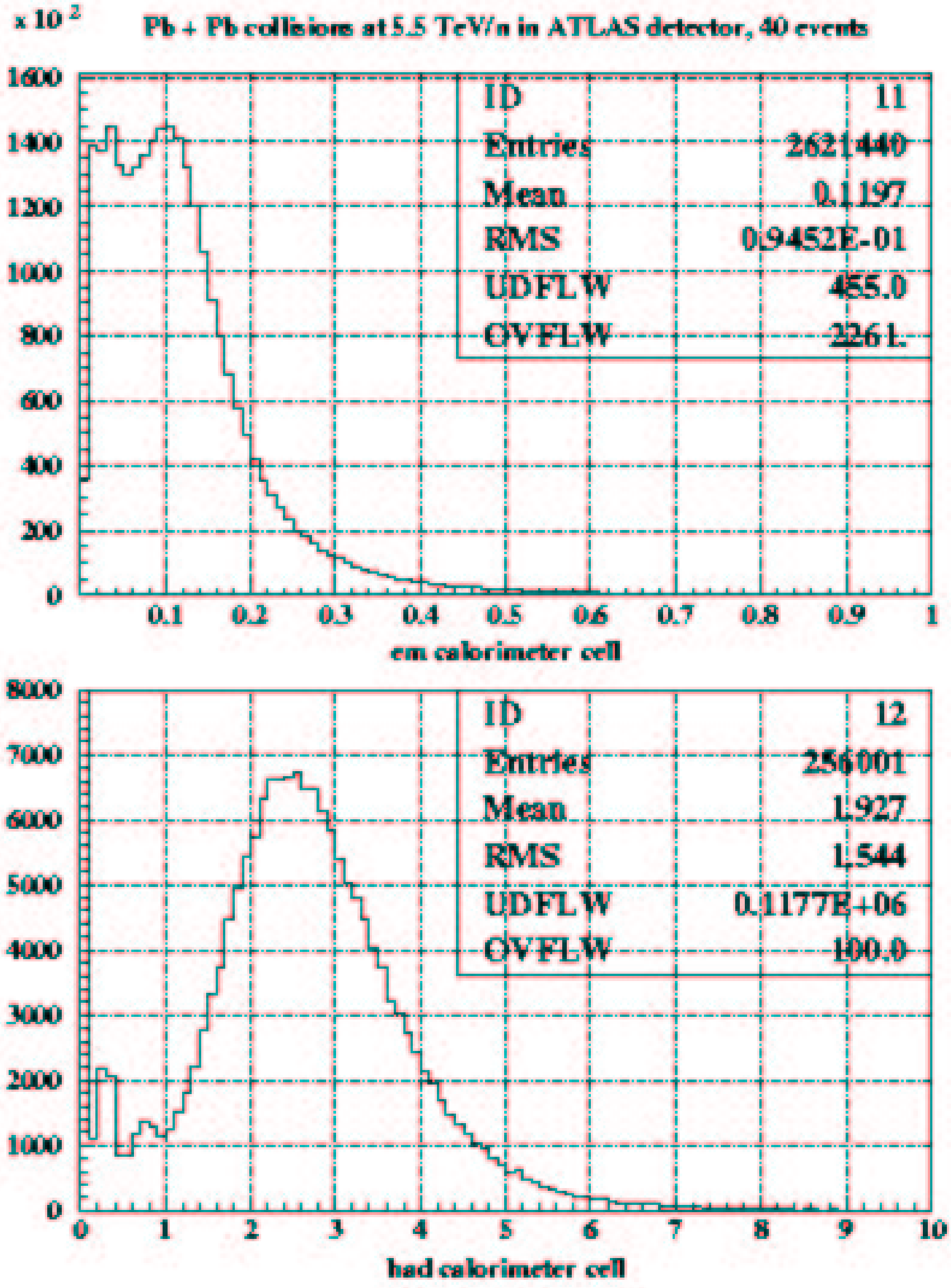
Calorimetry

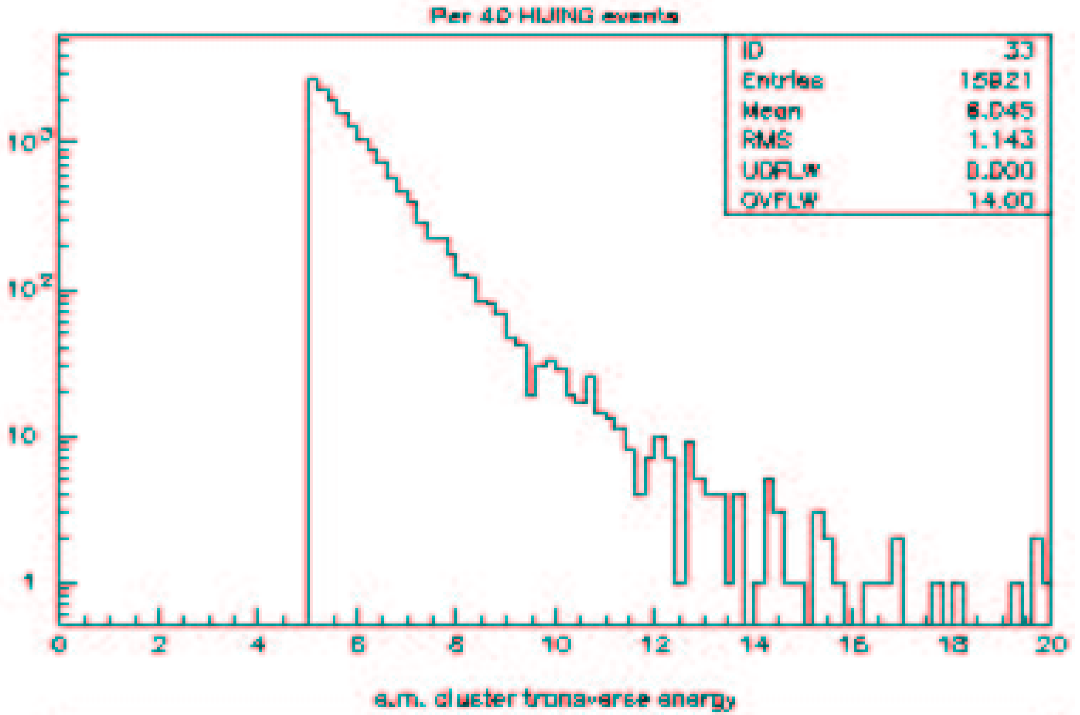
Energy Per Cell:

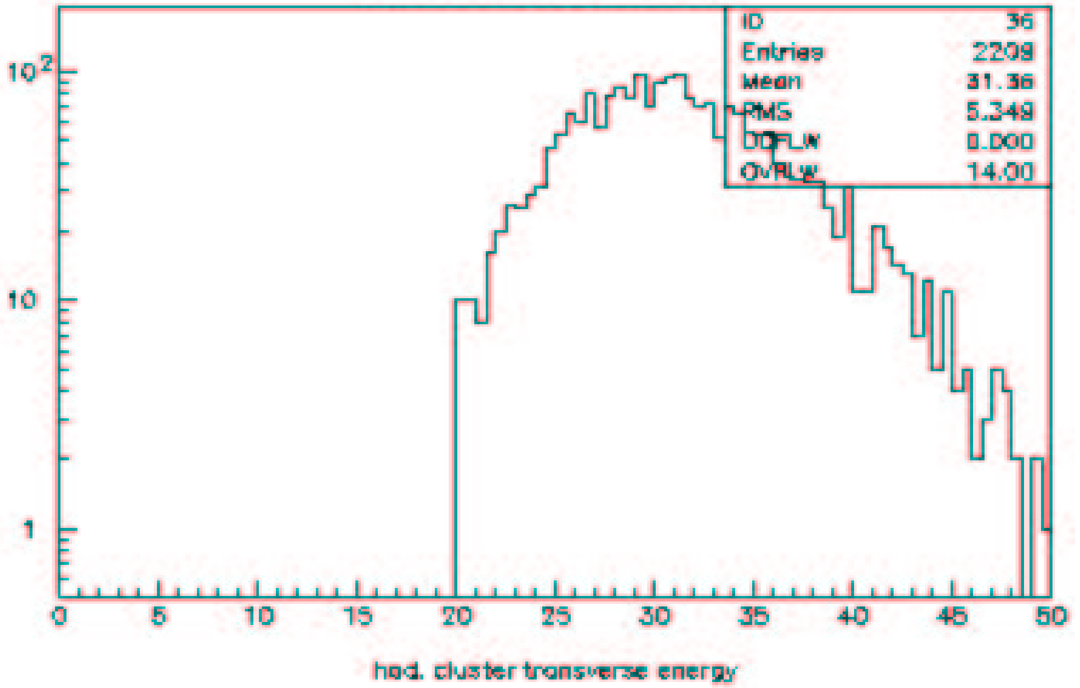
- 0.025 x 0.025 cell in e.m. calorimeter
- 0.10 x 0.10 cell in hadron calorimeter



Jets and Clusters

- Reconstructed e.m. clusters – exotic processes can be observed with cluster energy more than ~15 GeV (?)
- Reconstructed hadronic jets – jet signature can be used with Pt above 50 GeV (?)





Quarkonium Suppression

Direct probe of the QGP:
Color screening of the binding potential leads to the dissociation of the quarkonium states.

Upsilon family	$\Upsilon(1s)$	$\Upsilon(2s)$	$\Upsilon(3s)$
Binding energies (GeV)	1.1	0.54	0.2
Dissociation at the temperature	$\sim 2.5T_c$	$\sim 0.9T_c$	$\sim 0.7T_c$

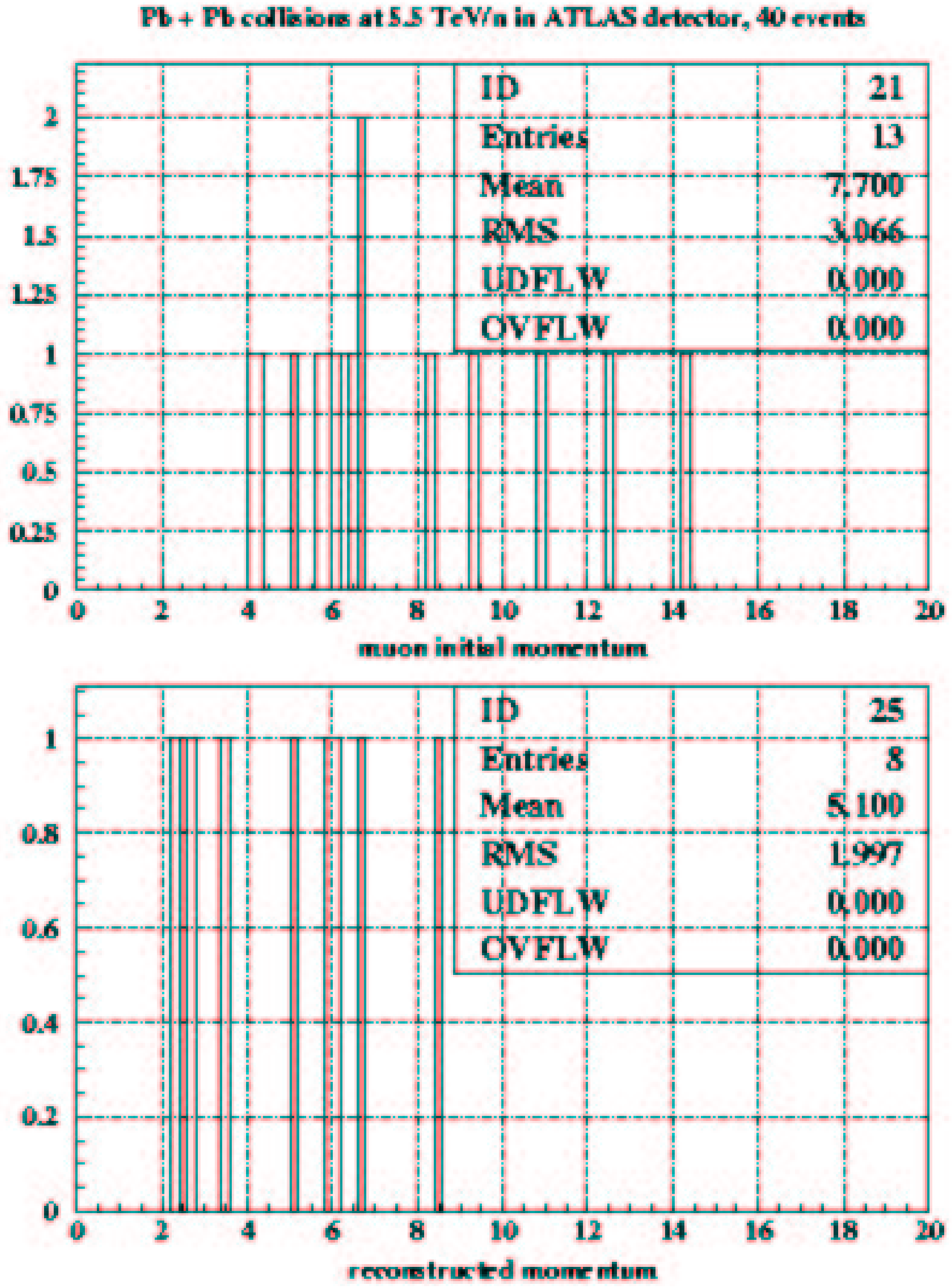
→ **Important to separate $\Upsilon(1s)$ and $\Upsilon(2s)$**

Upsilon mass reconstruction using the Muon Spectrometer, Silicon Tracker and the Pixel Detector. →

Muons

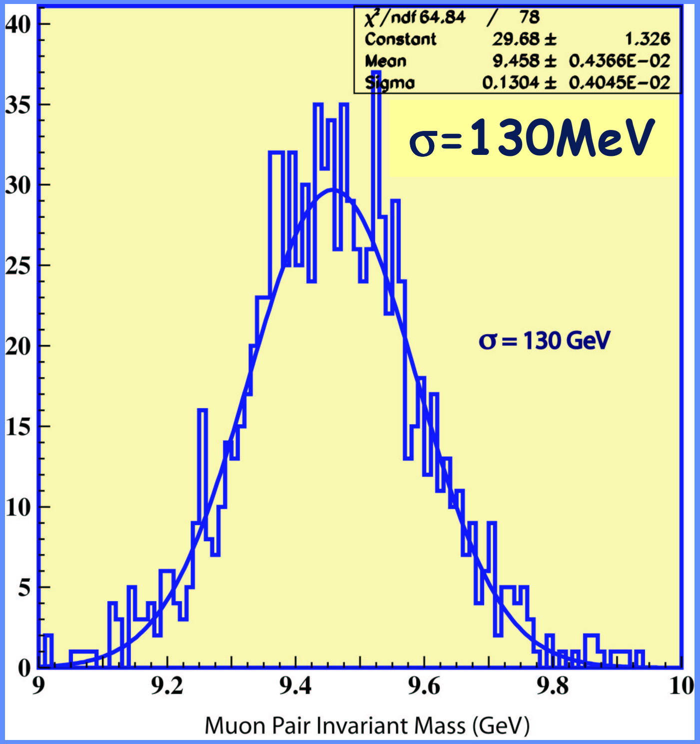
- Energy of muons which have reached the muon system (about 5-6 GeV are lost in the calorimeter)

- Reconstructed muon energy (not corrected for energy loss in calorimeter)

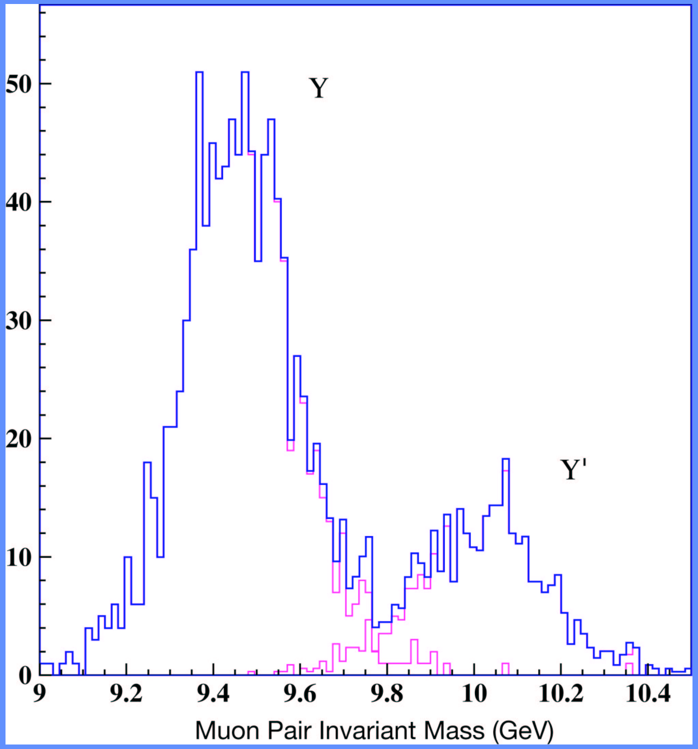

Pb + Pb collisions at 5.5 TeV/n in ATLAS detector, 40 events

Quarkonium Suppression

- GEANT3 simulations of pure $\Upsilon(1s)$ and $\Upsilon(2s)$ states → $\mu^+\mu^-$
- Muons with $p_T > 3$GeV are tracked backwards to the ID
- Invariant mass is calculated from the overall fit.

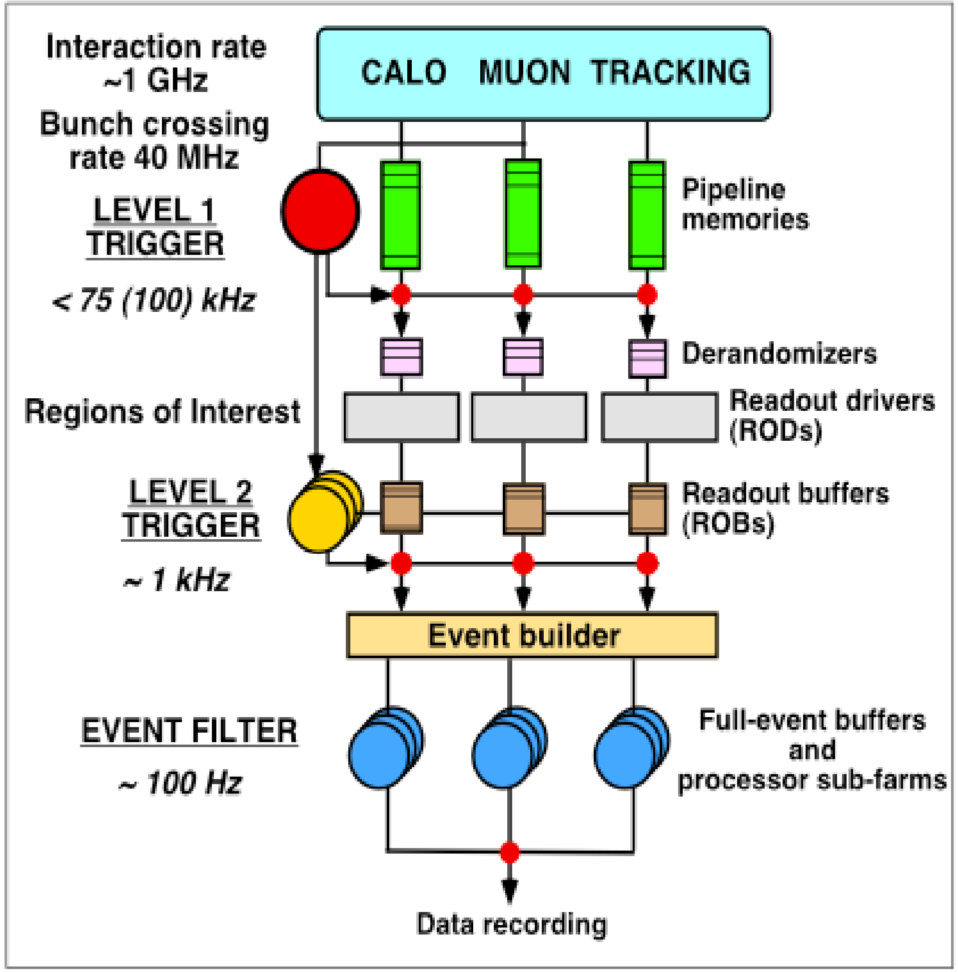


σ=130MeV



- Background estimate (HIJING+G3) → S/B ~ 0.6
- Acceptance 10-15% providing 100% efficient dimuon trigger
- Overlay with HIJING Event is under study!

Trigger DAQ



For Pb+Pb collisions the interaction rate is 8kHz, a factor of 10 smaller than LVL 1 bandwidth.

We expect further reduction to 1kHz by requiring central collisions and pre-scaled minimum bias events (or high p_T jets or muons).

The event size for a central collision is ~ 5 Mbytes.

Similar bandwidth to storage as pp at design L implies that we can afford ~ 50 Hz data recording.

Conclusion

- **ATLAS detector will be capable of measuring many aspects of relatively low pT heavy-ion physics**
- **Simulation, Reconstruction and Analysis tools exist to evaluate the detector performance**
- **Work is in progress to understand the detector performance for studying the truly high pT phenomena**