ATLAS software for B-physics

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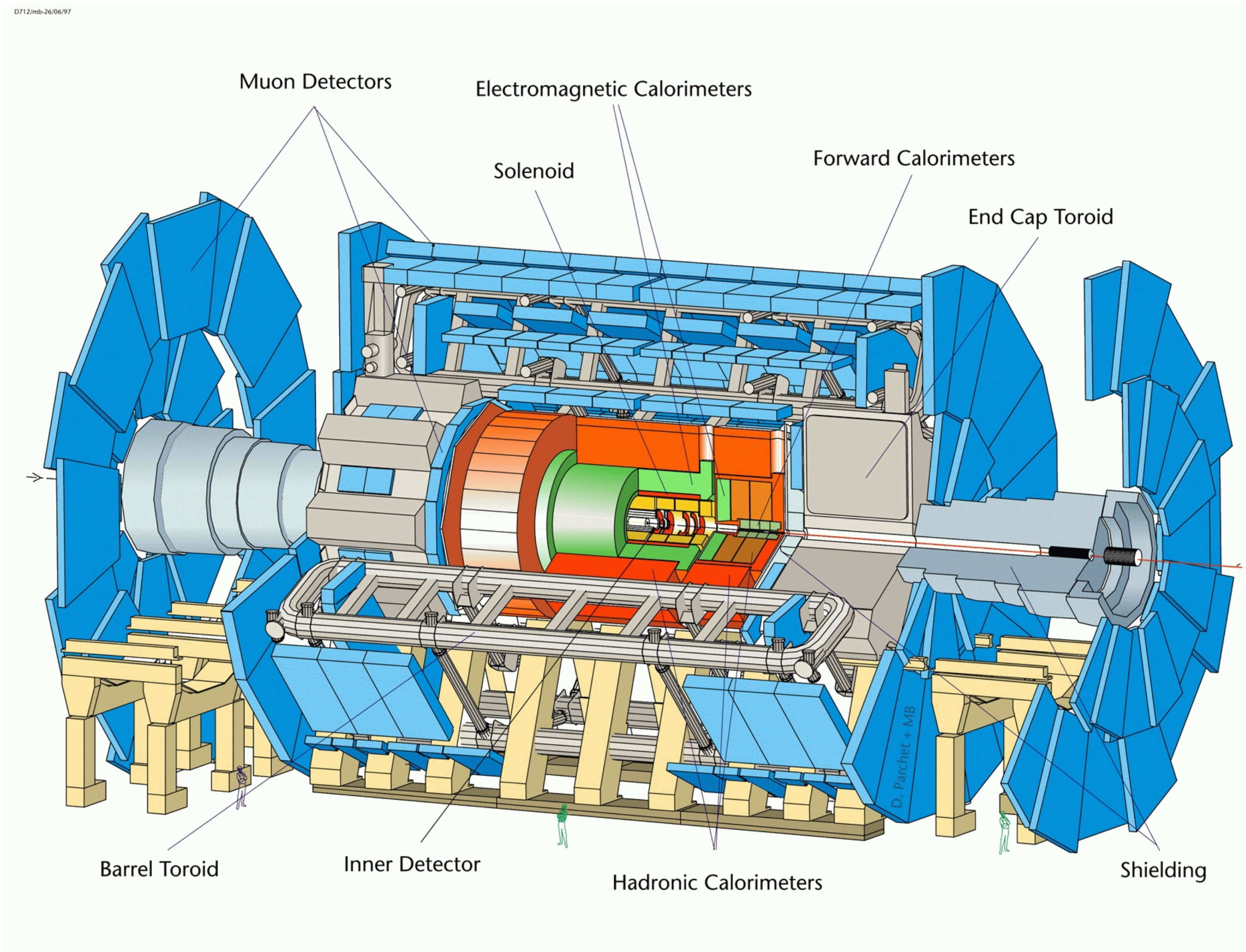
(on behalf of the ATLAS collaboration)

- Software architecture
- B-physics channels @ ATLAS
- Algorithms description and performance
- Conclusions

ATLAS

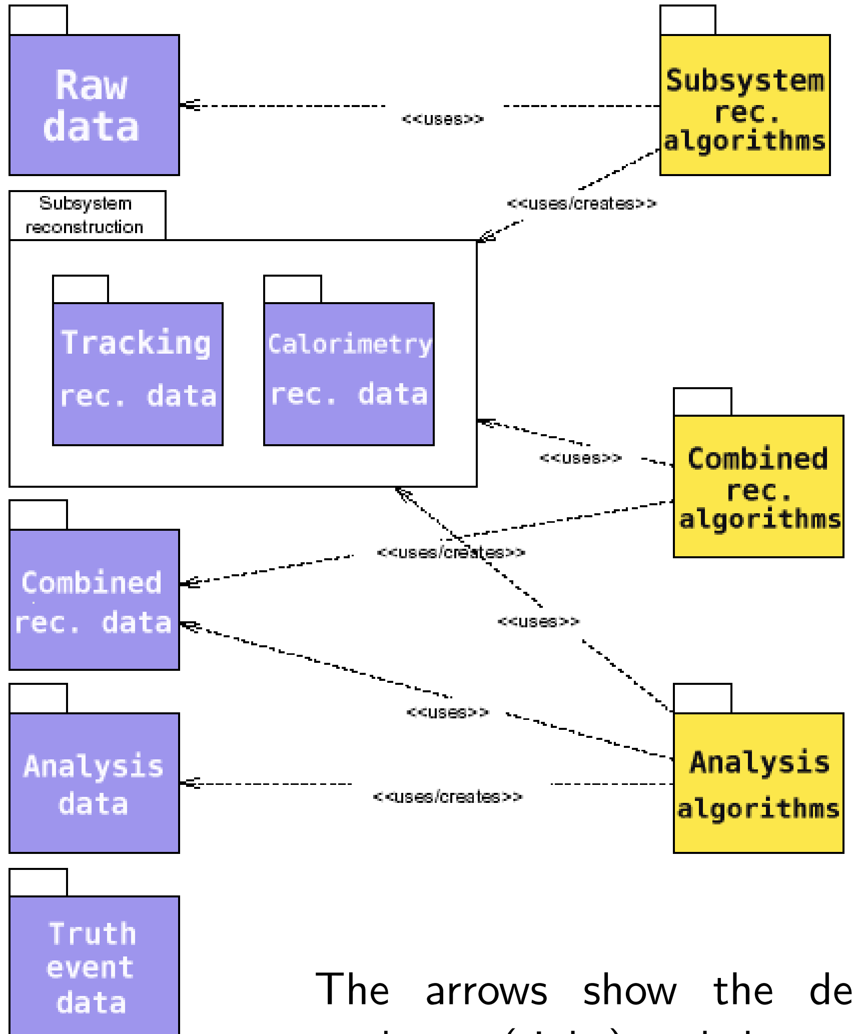
A Toroidal LHC Apparatus



Software organization

- Athena/Gaudi(with LHCB) flexible framework:
  - ▷ Separation between Data and Algorithms (coherent OO design)
  - ▷ Run-time configuration and dynamic library loading
- Athena is used for reconstruction, MC generation, simulation (Geant 4), high level trigger, fast simulation, user analysis.
- ATLAS reconstruction has evolved from feedback on detector design to evaluation of detector performance/physics reach. Recently:
  - ▷ Start using "realistic" raw data (as they will come from the detector: bytestream format)
  - ▷ migration fortran to C++ completed
  - ▷ keep improving on new algorithms
- The ATLAS reconstruction in the new framework is presently being tested with a large Data production (Data Challenge 1): several millions event simulated (Geant 3) and reconstructed world wide (tens of Terabytes of data)

Overview of the reconstruction dataflow



The arrows show the dependencies between the algorithm packages (right) and the event data packages (left).

Technical organization

- About 1500 C++ classes in 300 packages maintained and developed by more than 100 people
- Code repository (in CVS) with one directory per detector specific software (Muon, Larg calorimeter, Inner Detector), and one per activity (Reconstruction, DetectorDescription, Trigger..)
- One major release every $\sim$ 6 month (developer release every two-three weeks)
- Automatic nightly builds with the latest version of all software $\rightarrow$ crucial to spot problems in view of the following release

B-physics channels @ATLAS

ATLAS detector primarily designed to search for new particles at the highest mass scales.
Nevertheless precise B physics measurements can be performed in some channels. Examples:

$B_d \rightarrow J/\psi K^0_S$ — $sin 2\beta$

$B_s \rightarrow D_s \pi(a_1)$, $B_s \rightarrow J/\psi \phi$ — Δm_s and $\Delta\Gamma_s$

rare muonic decays $B_{d(s)} \rightarrow (X)\mu^+\mu^-$

Tools needed to perform these measurements:

(soft) e and μ identification,

precise track and vertex reconstruction.

Software for the simulation of Beauty events

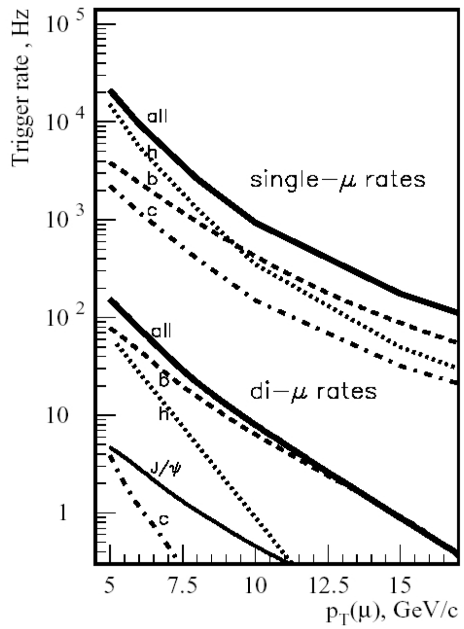
- Dedicated code for Beauty production and decays (part of the Athena/Gaudi software)
- Provides interface to external packages Pythia and EvtGen
- EvtGen: code originally developed by BaBar adapted to LHC conditions - common project of LHCB, ATLAS, CDF, BaBar. A goal: development of B-decay package allowing to proceed in terms of spin dependent complex amplitudes, polarizations and interferences.

B-physics trigger selection

Three level selection:

40MHz $\longrightarrow$ LVL1 $\longrightarrow \mathcal{O}(20KHz) \longrightarrow$ LVL2 $\longrightarrow \mathcal{O}(1KHz) \longrightarrow$ EF $\longrightarrow \mathcal{O}(200Hz)$

B-physics trigger task: reject non-$b\bar{b}$ events, select events containing the specific B-decays channels of interest



Flexible strategy at LVL1:

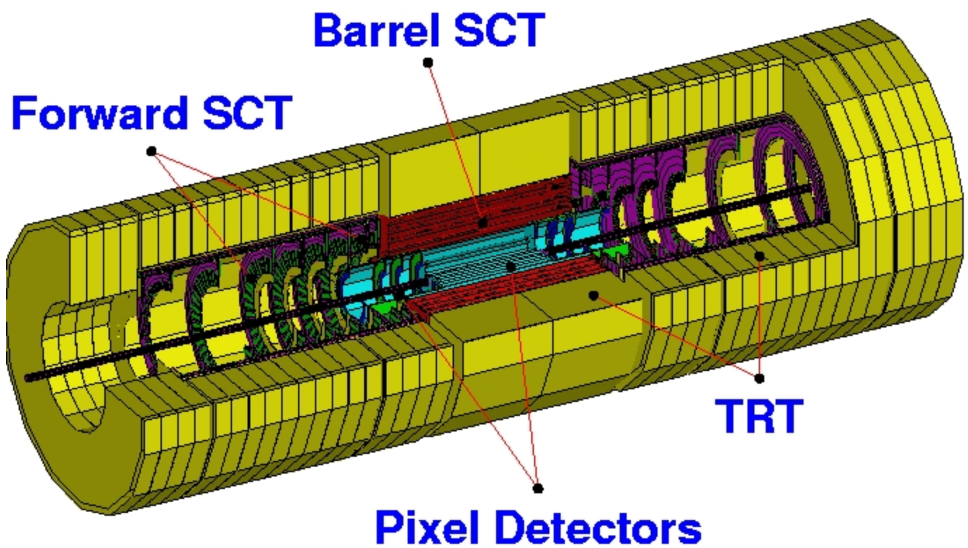
- di-muon trigger
- muon + jet or electromagnetic cluster (at low luminosity or at higher luminosity if rate is affordable)

All the LVL1 (LVL2) objects will guide the reconstruction at LVL2 (EF) $\longrightarrow$ performing the reconstruction in a limited region of the inner detector reduces considerably the processing power w.r.t. the previous strategy (full scan of ID at LVL2).

More details in the S. George talk

The ATLAS Inner Detector

Sub-Detector	r(cm)	geometry	element
Pixel	5-12.5	3 cylinder + 3 disks	$50\mu m$ x $400\mu m$ (3D)
SCT (Si Strips)	30-52	4 cylinder + 9 disks	$80\mu m$ x $12cm$ (stereo)
TRT (Straw Tubes)	56-107		40mm x 74cm (projective)

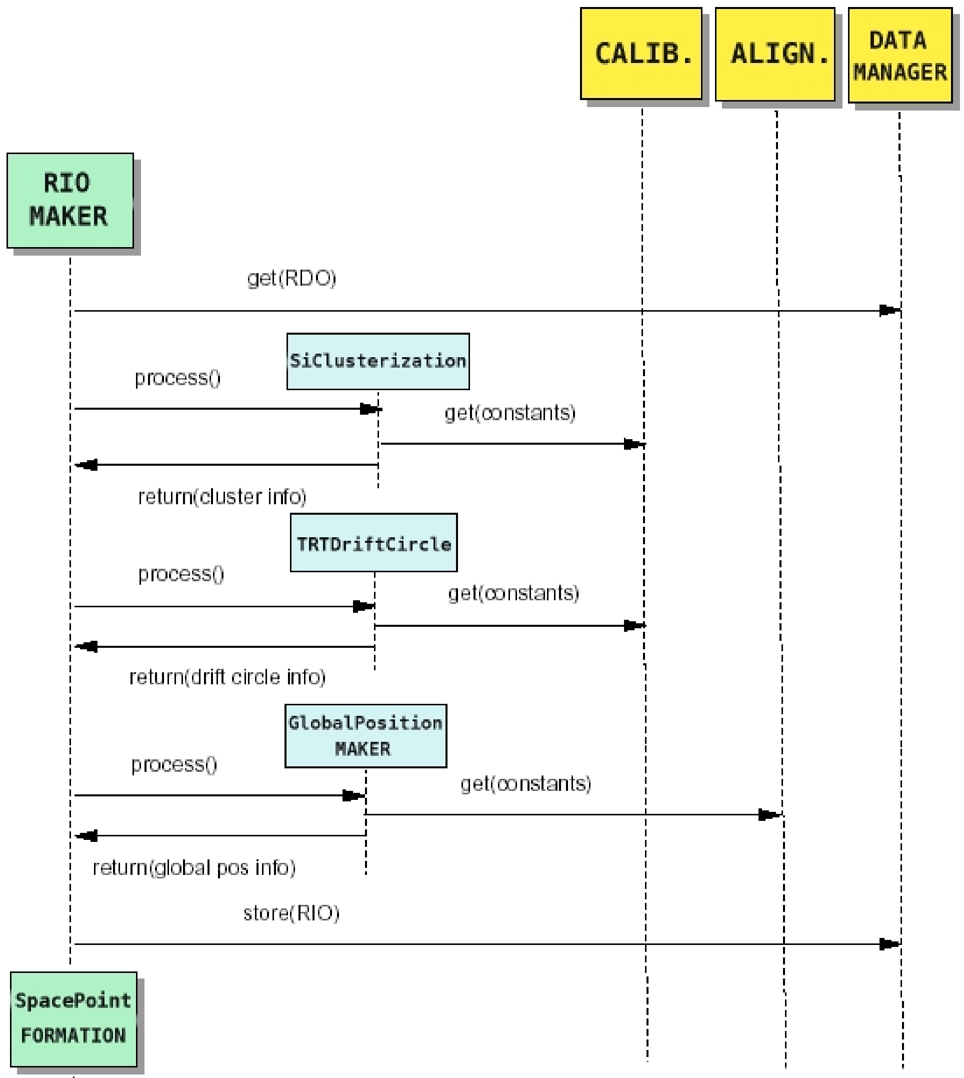


Detector layouts:

	Complete	Initial	TDR 1999
R of 1st Pixel layer	5 cm	5 cm	4.3 cm
pixel z-length (1st layer)	400 μm	400 μm	300 μm
2nd pixel layer	yes	no	yes
2nd pixel disk, TRT C-wheels	yes	no	yes

More details in the H-G. Moser Talk

Tracking software scheme

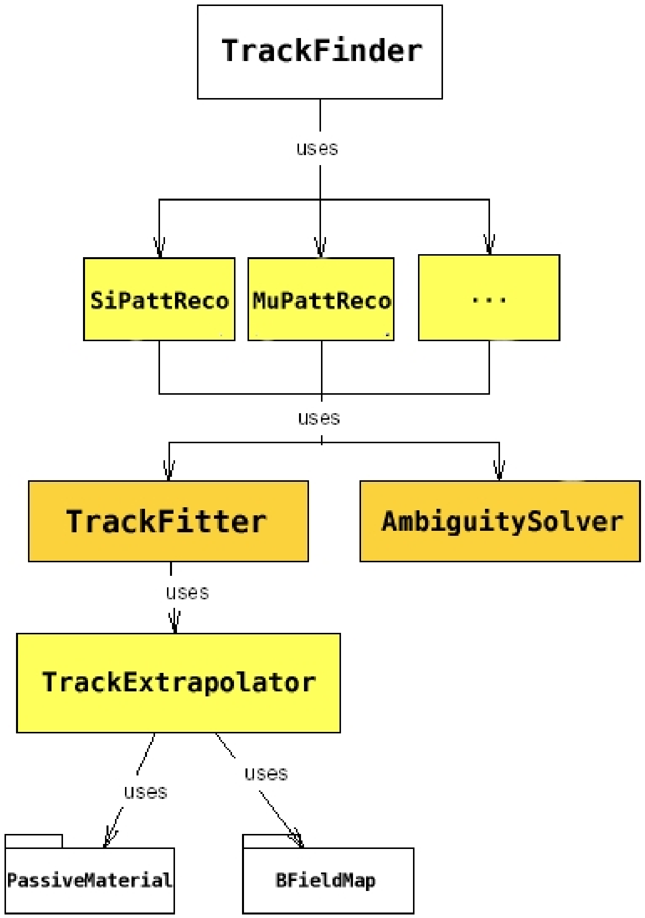


- From the Raw Data Objects (RDO) to the Reconstruction Input Objects (RIO):

  The detector raw information is converted using calibration constants and alignment information in reconstruction objects (clusters in Pixel, drift circles in TRT) and, eventually, in three dimensional points (SpacePoints).

  The RIOs are common to LVL2, EF and Offline but they can have different implementations depending on the specific requirements.

Tracking software scheme (cont'd)



- From SP to Tracks:

  SPs are combined in TrackSegments and then merged together by the Track Fitter

  In order to avoid huge combinatorics the number of candidates can be reduced using AmbiguitySolver (checking shared hits and track quality).

Fitting algorithms

Two algorithms have been used for the track reconstruction in ATLAS (they are being ported in the new framework):

- iPatRec search for tracks using the SPs in the Pixels and SCT. Candidates are extrapolated to the TRT and drift time hits added using a χ^2 fit.
- xKalman search for tracks in TRT using fast histogramming of straw hits. Candidates are extrapolated to the SCT and Pixel and fitted using a Kalman filter, the improved tracks are then extrapolated back into TRT and drift-time hits added.

The various algorithms have different advantages: xKalman is fast because it benefits from the histogramming in the TRT; iPatRec is less sensitive to interactions or bremsstrahlung.

Good features of different programs can be combined after an appropriate modularization of the algorithms (as the design of the new software impose).

Tracking performance

Efficiency:

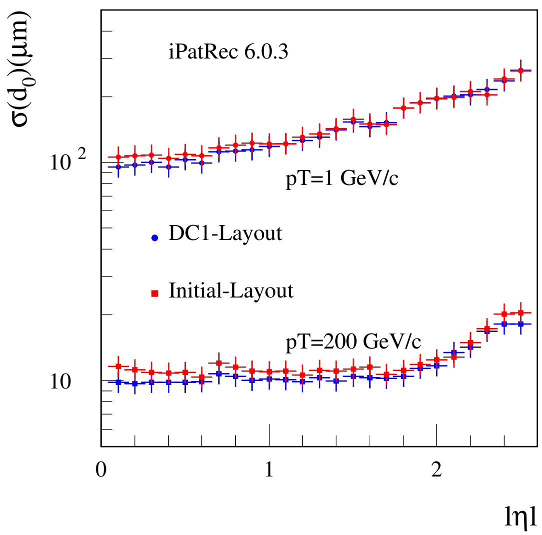
single track ~ 0.95, track in jet ~ 0.90 (fake rate ~ 0.003)

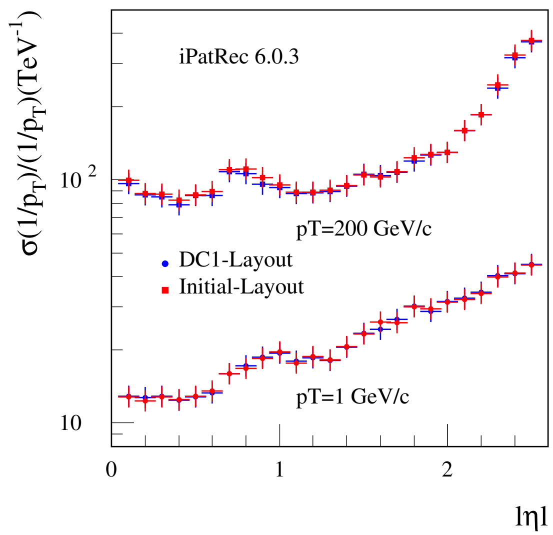
Track parameters resolution:

$$\sigma(d_0) = 12 \oplus \left(\frac{107}{p_T}\right) \mu m \qquad \sigma\left(\frac{1}{p_T}\right) = 0.6 \oplus \left(\frac{18}{p_T}\right) TeV^{-1}$$

These resolutions depend strongly on: radius of innermost pixel layer, thickness of pixel layers, radius and thickness of the beam pipe. Example: in the complete layout of ID the radius of first pixel layer is larger than in the TDR layout $\longrightarrow$ slight degradation of d_0 resolution ($\sigma(d_0)_{TDR} = 11 \oplus (68/p_T)\mu m$)

The d_0 and p_T resolutions are almost identical in the initial and complete layout





Vertices reconstruction

Primary vertex (z coordinate):

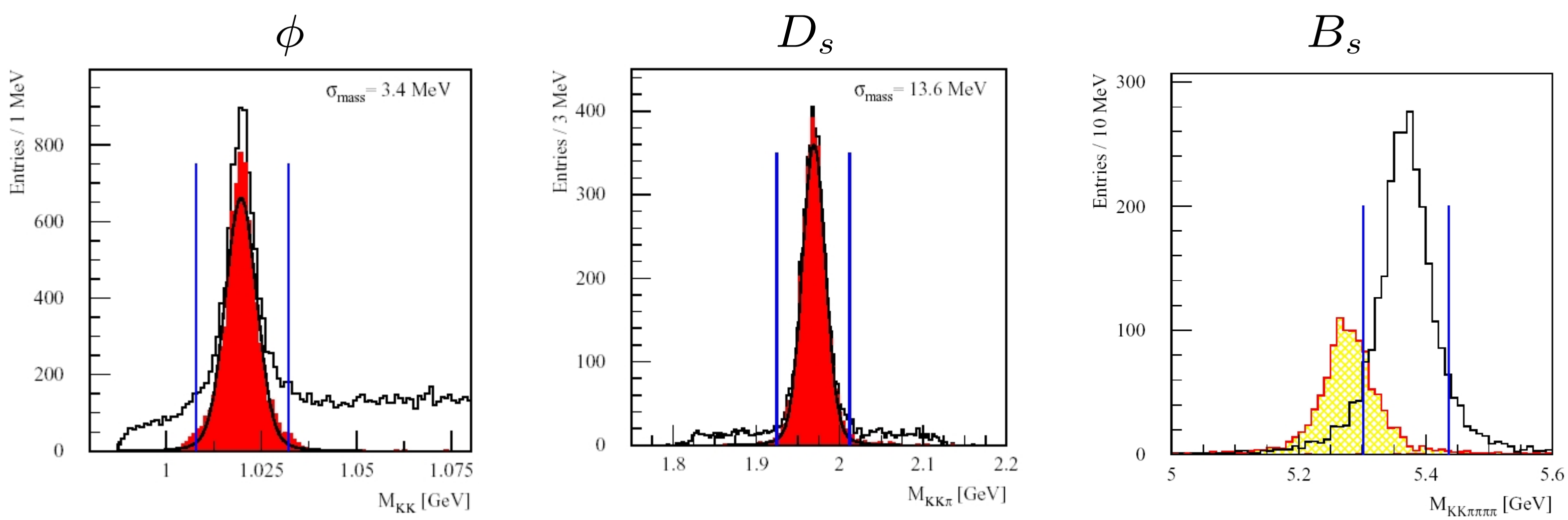
At LHC design luminosity ~ 25 interaction per beam crossing spread out by $\sigma(z) = 5.6\ cm$. z_{PV} determination:

- assume that all tracks come from the beam line in the transverse plane and determine z_0
- istogram z_0 and identify clusters of tracks
- fit the z_{beam} for each clusters, retain more than one vertex for the following reconstruction

Average resolution: $48\ \mu m$.

Exclusively reconstructed B vertices (es. $B_s \to D_s(\phi\pi)\pi$):

The four charged tracks in the final state $(KK\pi\pi)$ are fitted together imposing all the intermediate mass hypotheses.



Proper time resolution in $B_s \to D_s\pi$:

$$\sigma_t = \sqrt{\sigma_L^2 + (\sigma_P/P)^2 t^2}$$

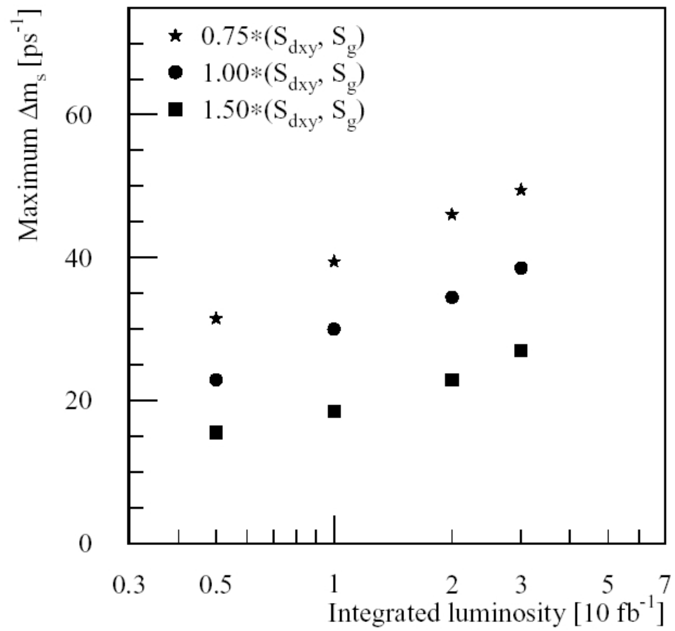
$= 0.052ps$ $(0.107ps)$ in 60%(40%) of the events dominated by the flight lenght resolution

$$\sigma(P)/P = 0.6\%$$

The Δm_s reach depends strongly on σ_t.

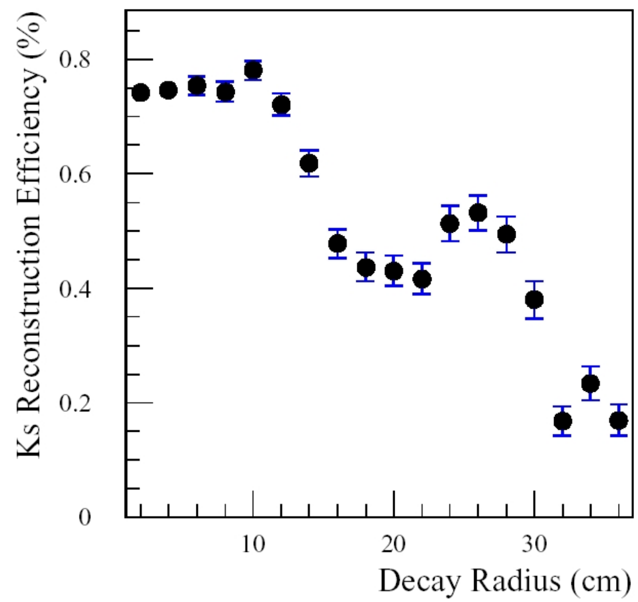
Exp: $\Delta m_s > 14.4\ ps^{-1}$ at 95% C.L.

CKM fits: $\Delta m_s \in [15.6, 22.2]\ ps^{-1}$ (Ciuchini et al., hep-ph/0307195)



K_S^0 decay vertices:

Challenging because of the long lifetime which leads tracks with a limited number of silicon hits. The total K_S^0 efficiency in $B_d \to J/\psi K_S^0$ is 41%.



(Soft) e reconstruction

The identification of soft electrons (with p_T as low as 0.5) is based mainly based on TRT. Rejection against pion is achieved by counting the fraction of TRT straws which have a high-threshold (TR) hit.

Additional identification power come from e.m. calorimeter and the inner detector.

Full set of tagging variables (distributions shown for e and π):

fraction of E in 1st sampling

fraction of E in 3rd sampling

shower isolation

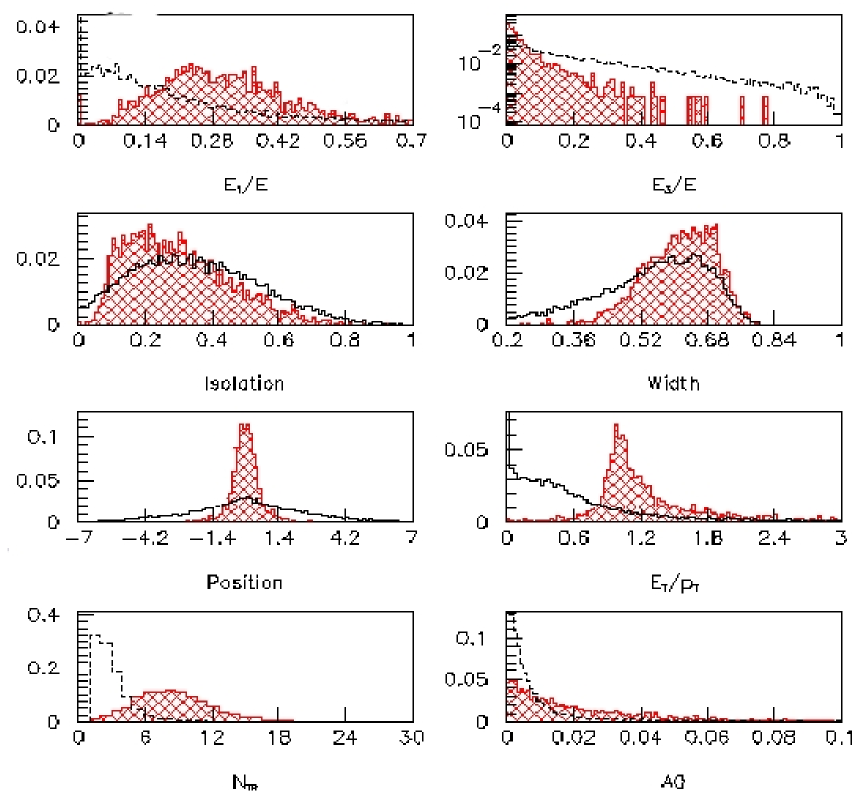
energy weighted width

diff between shower and impact position

E_T(calo)$/p_T$

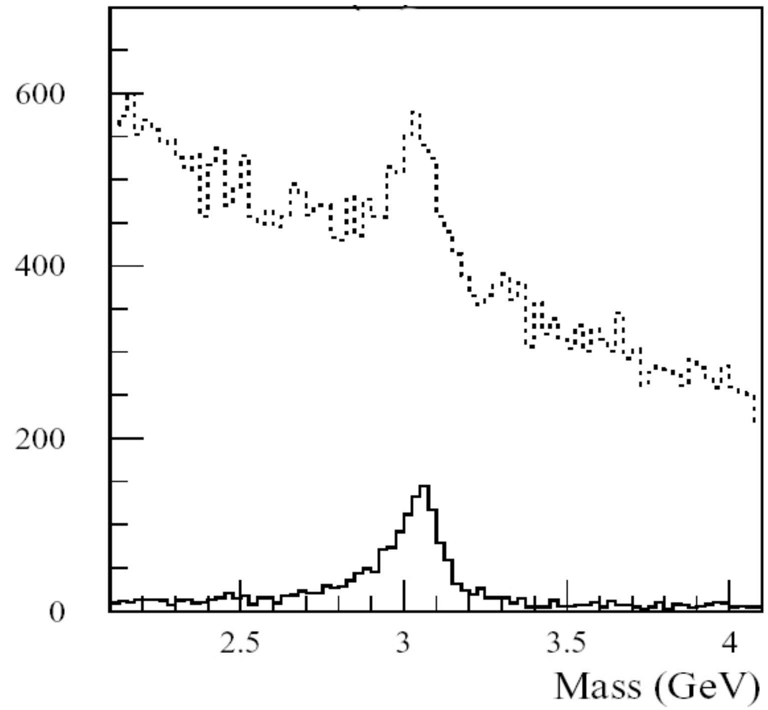
# of TR hits

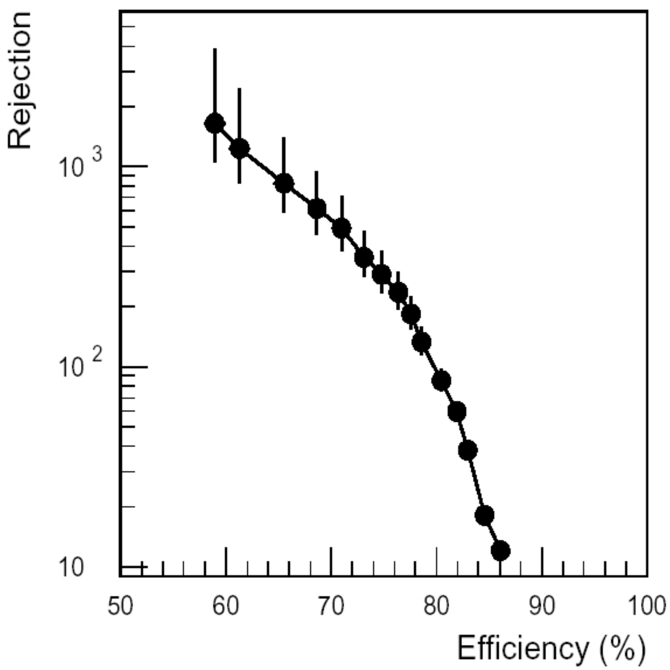
transverse i.p.



(Soft) e reconstruction

Example of the combinatorial rejection using electron identification from TRT pn the $J/\psi(ee)$ invariant mass plot.



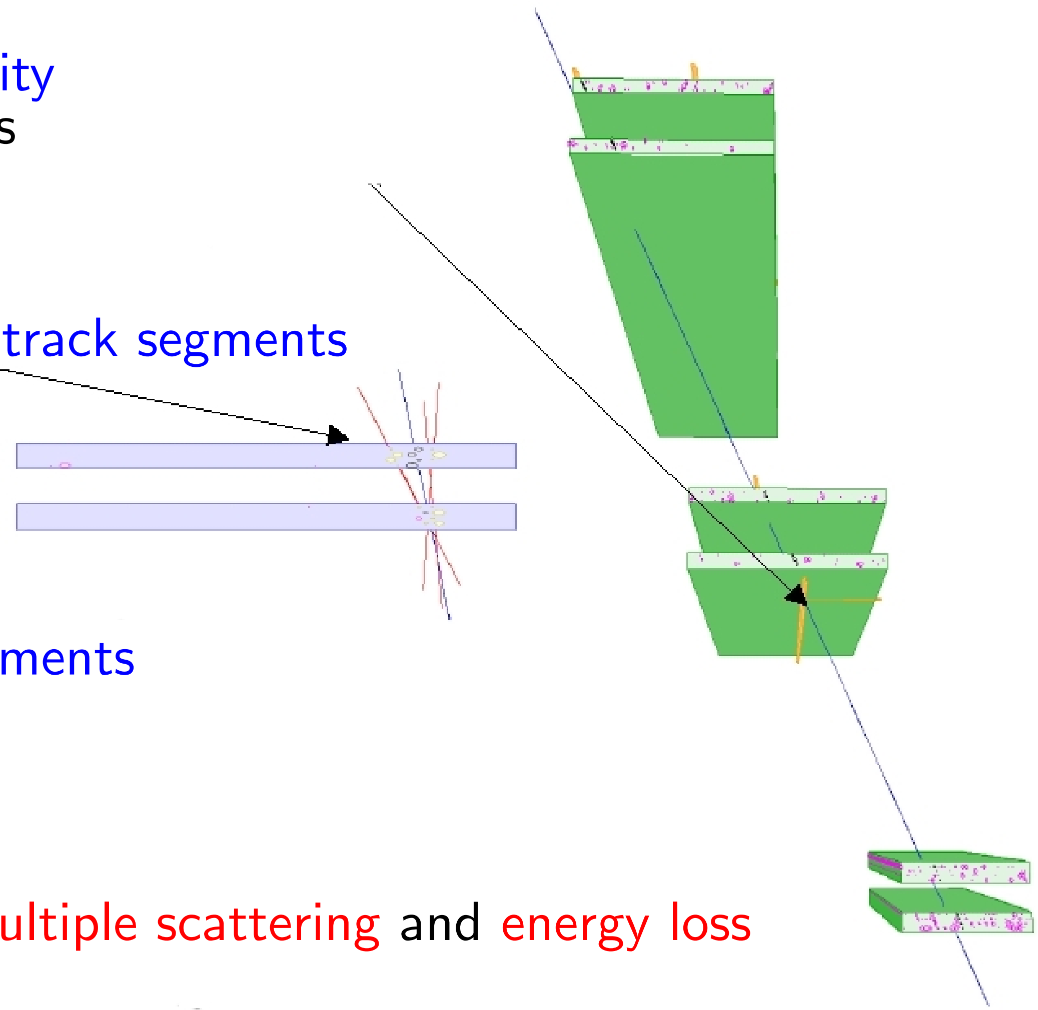


Using combined identification of the inner detector and the calorimeter the inclusive $b\bar{b} \to \mu e X$ events can be selected with 70% efficiency with a rejection toward $b\bar{b} \to \mu X$ of about 600.

μ reconstruction

Identification of Region of Activity
guided by the trigger chambers

Reconstruction of local straight track segments



Combination of three tracks segments
to form the muon track

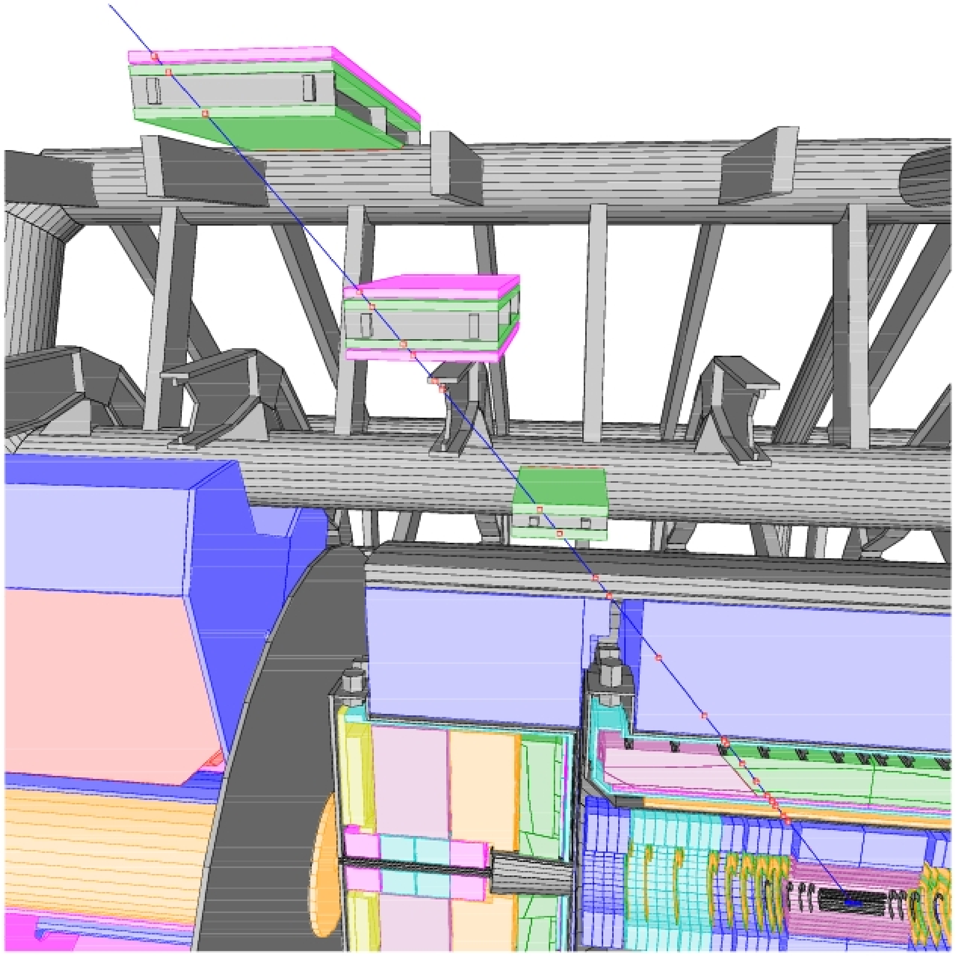
Global fit taking into account multiple scattering and energy loss

μ backtracking

- Backtracking from Muon System down to the beam region through calorimeters taking into account E loss, multiple scattering and E loss fluctuations

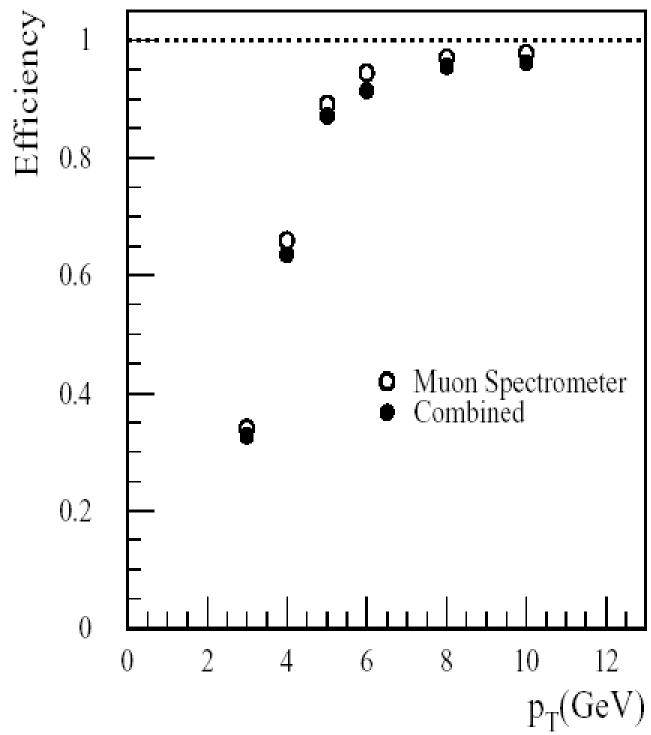
- E loss from parametrization

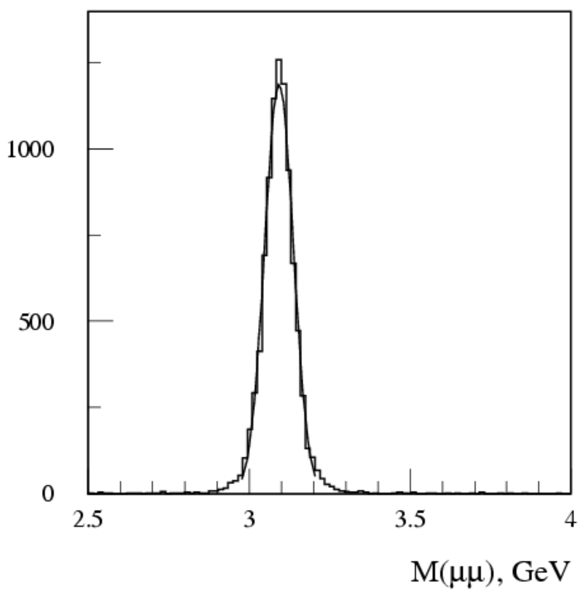
- Combination with an inner detector track



μ reconstruction

Good performance achieved by combining information from the precision muon chambers and from the inner detector





Good mass resolution on the $J/\psi(\mu^+\mu^-)$ (44 MeV)

Conclusions

- Complete and coherent OO framework for all the ATLAS software
- Most of the existing ATLAS software is now available in this framework
- Relevant B-physics analyses have already been repeated in the new framework
- Ongoing developments:
  - ▷ Improve modularization
  - ▷ Explore robustness (misalignment, inefficiency)
  - ▷ New algorithms