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Physics Analysis Tools for Beauty Physics in ATLAS

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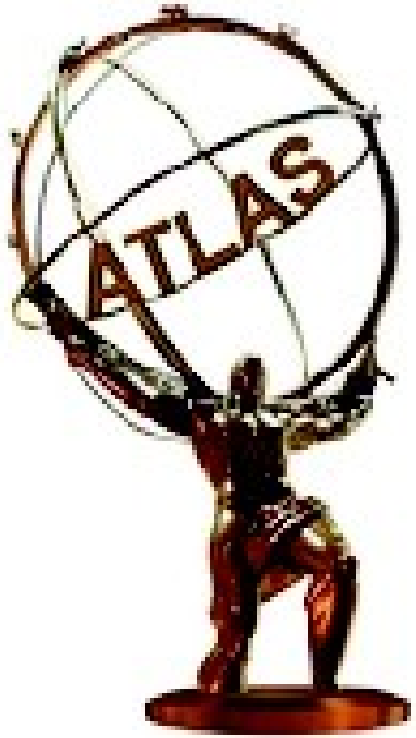
on behalf of ATLAS collaboration

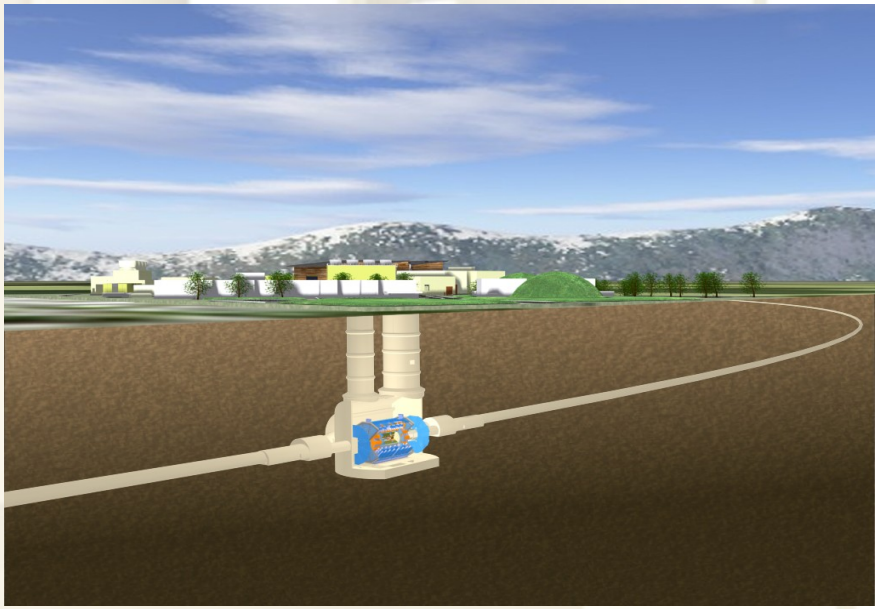


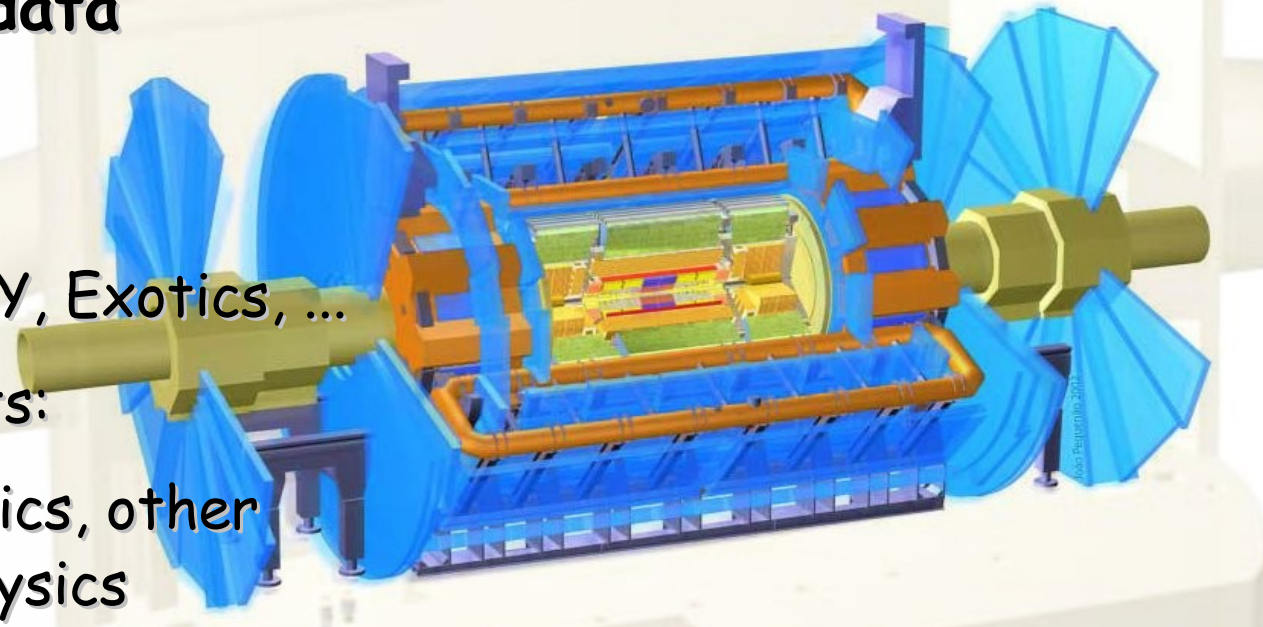
Outline

- ATLAS experiment
- B-Physics
- ATLAS data flow
- Athena software framework
- **B-Physics requirements for analysis**
- **Typical analysis procedure**
- **Analysis software overview**
- **The tools**
- **Analysis output**
- **Software releases validation**
- Summary

ATLAS Experiment

- **General purpose detector on the Large Hadron Collider at CERN**
  - E_{CMS} = 7+7 TeV
  - ultimate L = 10^{34} $cm^{-2}s^{-1}$
  - bunch rate 25 ns
- **Due to begin taking data in summer 2008**
- **Estimated annual raw data production: 3 PB**
- **Physics program:**
  - Discovery: Higgs, SUSY, Exotics, ...
  - Precision measurements:
    - B-physics, top physics, other Standard Model physics





B-Physics

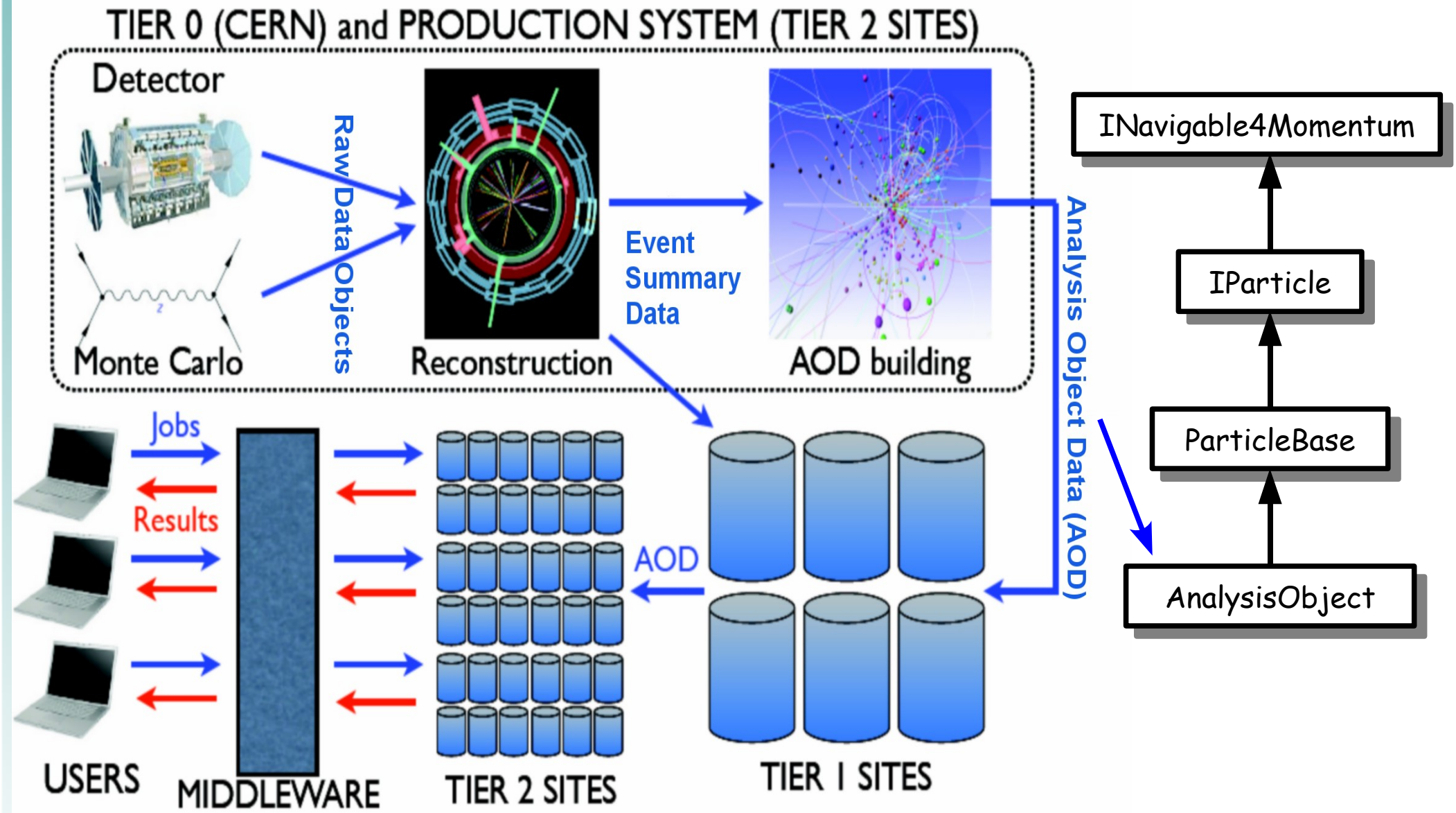
Objectives:

- Search for new physics effects in rare B-decays
- Precise measurements of known B-particles and decays
  - Mixing, CP violation
  - Aim to observe new behaviour in known processes
- At the first initial-luminosity stage, B-physics will serve as a test bed for understanding of detector properties
  - Detector commissioning with early data
  - Trigger, tracking and muon system calibrations
  - Mass and lifetime measurement of well known B-particles

1% of collisions at LHC produces 20 kHz $b\bar{b}$ pairs in ATLAS detector volume at low luminosity (10^{33} $cm^{-2}s^{-1}$) , ~ 100 Hz commited to disk for all ATLAS physics, out of which 10 Hz are devoted for B-events → Trigger challenging

- B-trigger based on single muon, di-muon, or muon+calorimeter cluster

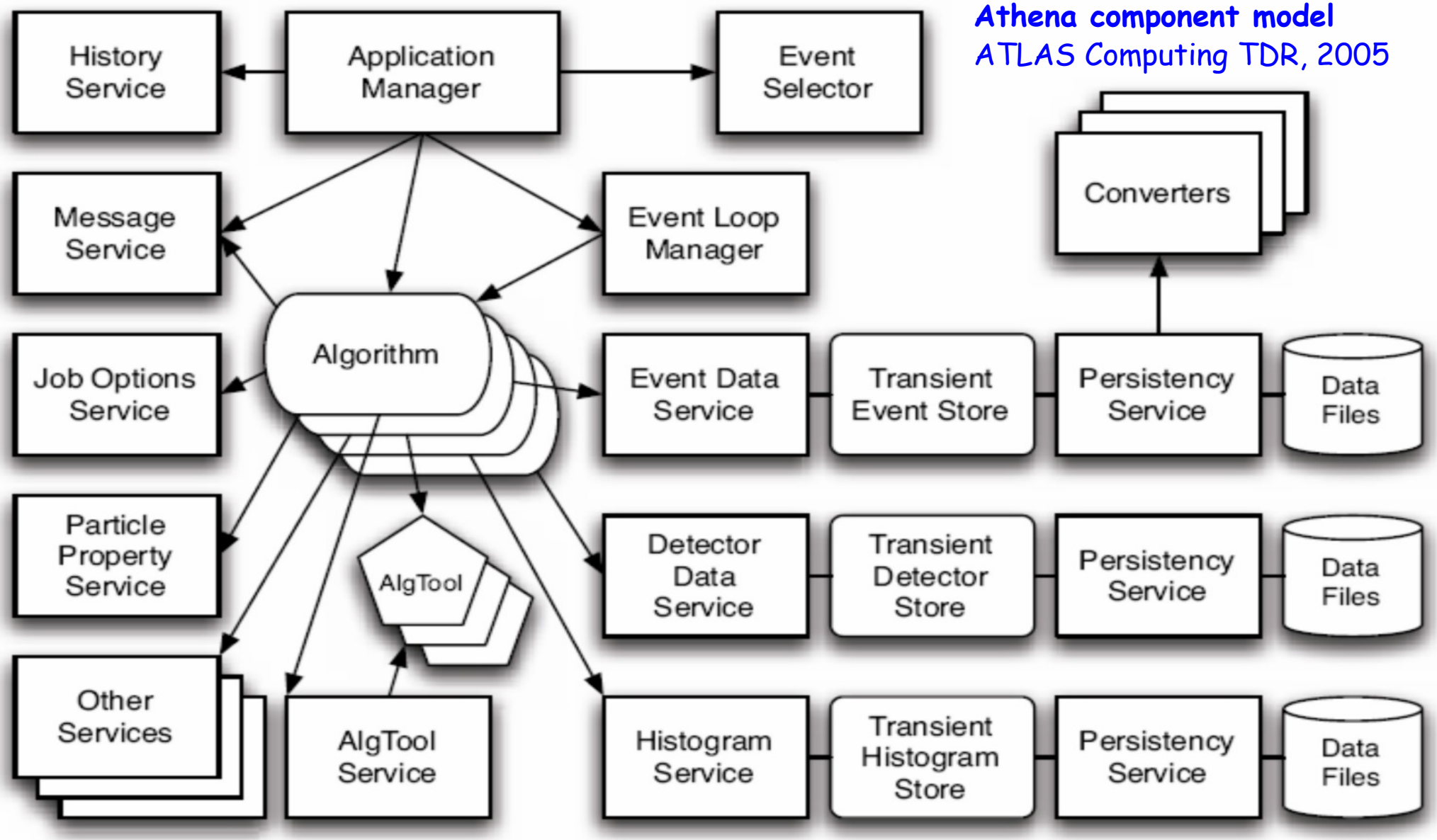
ATLAS Data Flow



- Jobs go to data using Ganga GRID interface

Athena Software Framework

B-Physics analyses are algorithms within Athena SW framework



Athena Software Framework

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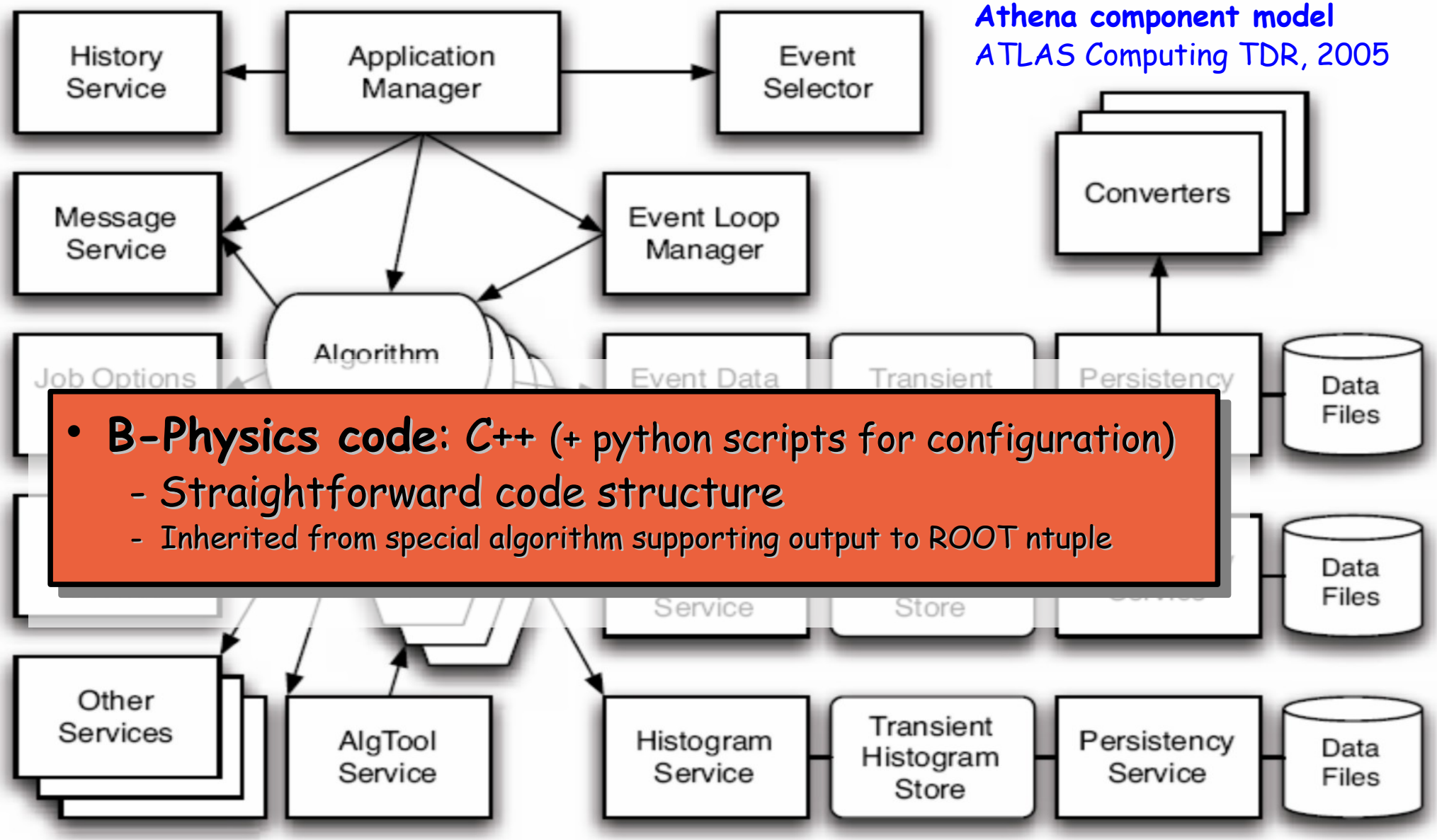
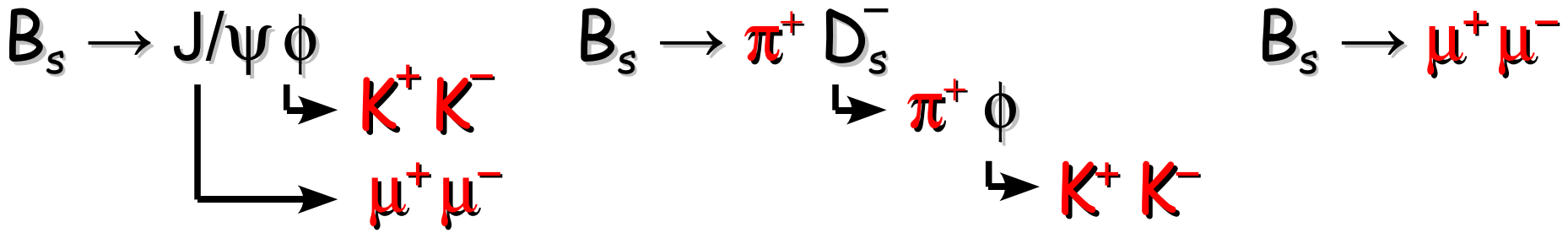


- **B-Physics code**: C++ (+ python scripts for configuration)
  - Straightforward code structure
  - Inherited from special algorithm supporting output to ROOT ntuple

B-Physics Requirements for Analysis

- B-physics sector is characterized by many different topologies and constraints
  - Tools for performing common operation and calculations have been written by B-physics group and stored in a single Athena package
  - The main task is to identify B-decay chain, typically consisting of cascade of several vertices, e.g.: => use offline vertex finder



- Access to analysis objects used by B-physics:
  - reconstructed inner detector tracks
  - combined muon and electron objects
  - trigger decision information, reconstructed primary vertex, jets
- MC truth information and its association to reconstructed objects to check the efficiencies, ideal performance, sources of background, etc.
- Output to format readable with simple tools (ROOT ntuple)

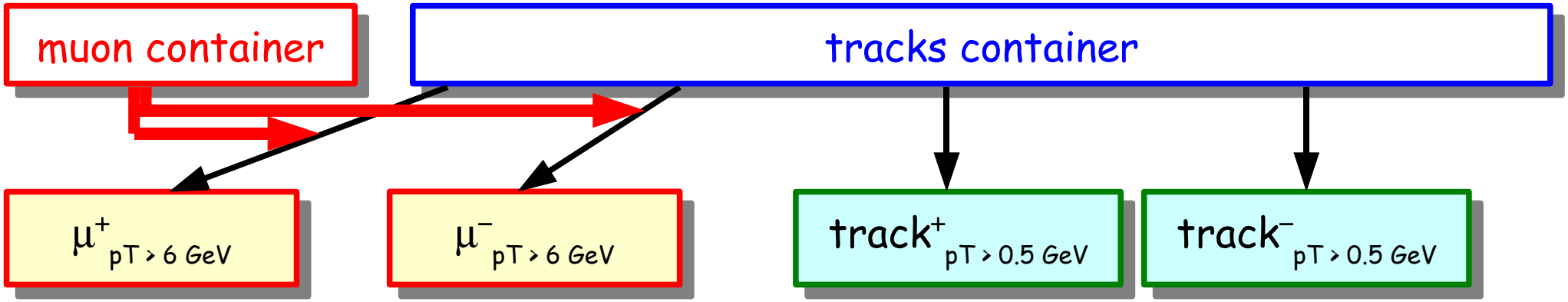
Typical Analysis Procedure (B_s > $\phi_{>KK}$ $J/\psi_{>\mu\mu}$)

muon container

tracks container

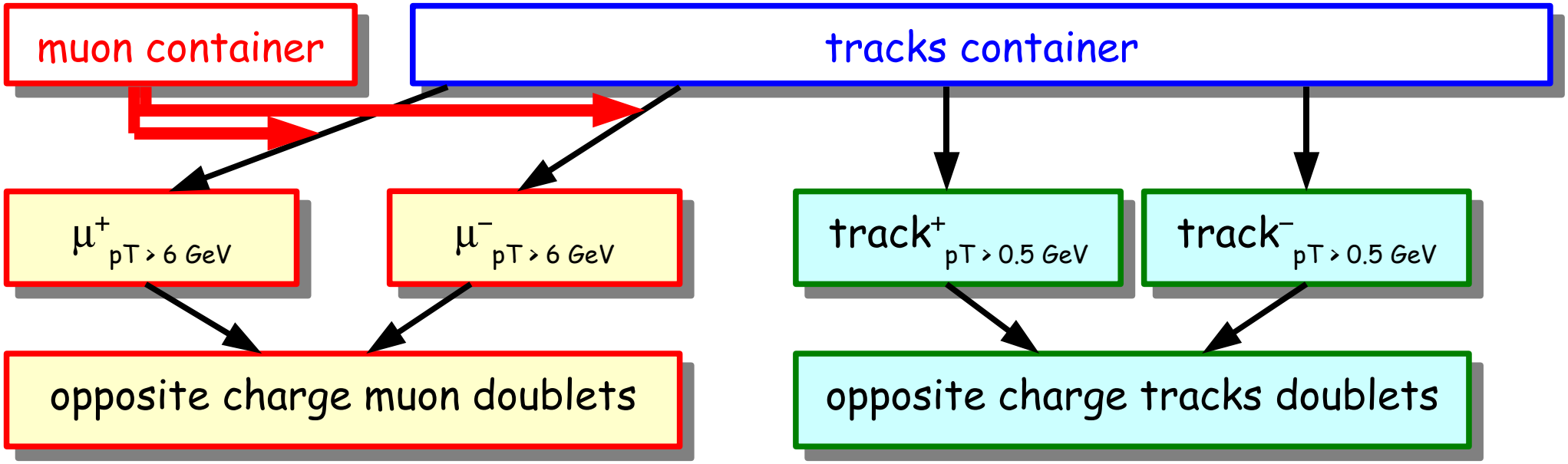
- Start with the collection of analysis objects (collections) in the event

Typical Analysis Procedure ($B_s > \phi_{>KK}\ J/\psi_{>\mu\mu}$)



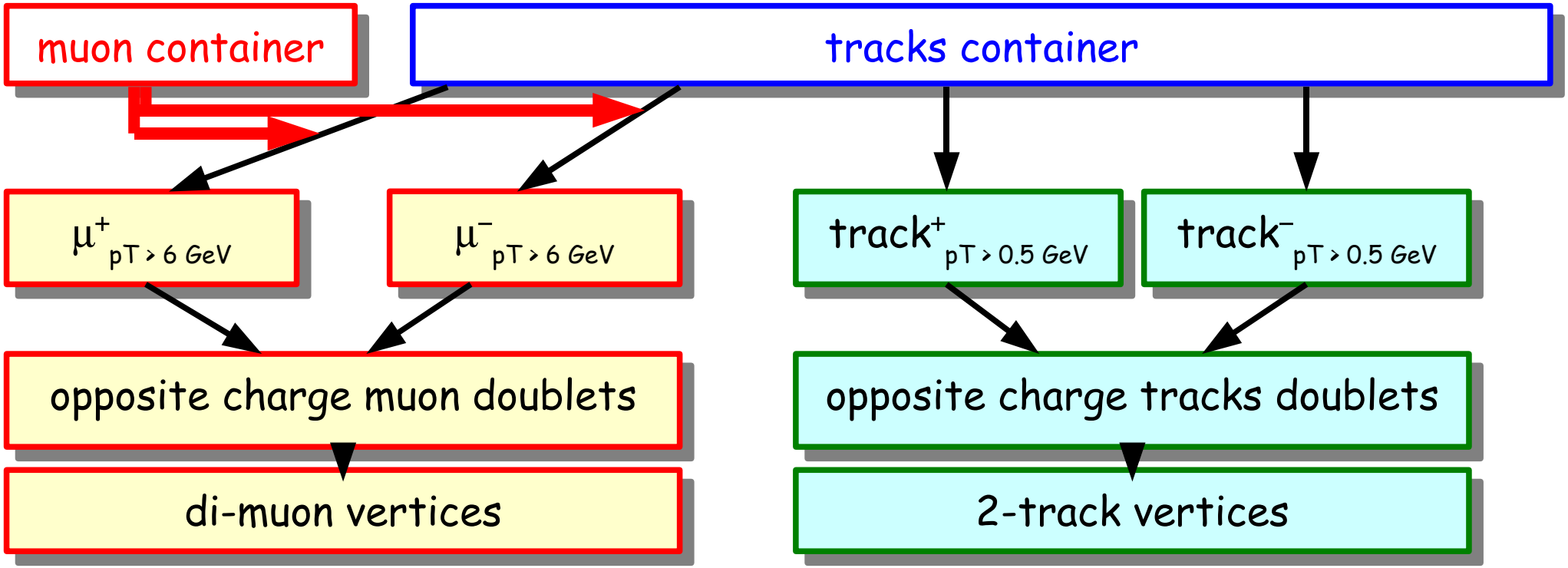
- Select tracks passing kinematic and identification criteria

Typical Analysis Procedure ($B_s > \phi_{>KK}\, J/\psi_{>\mu\mu}$)



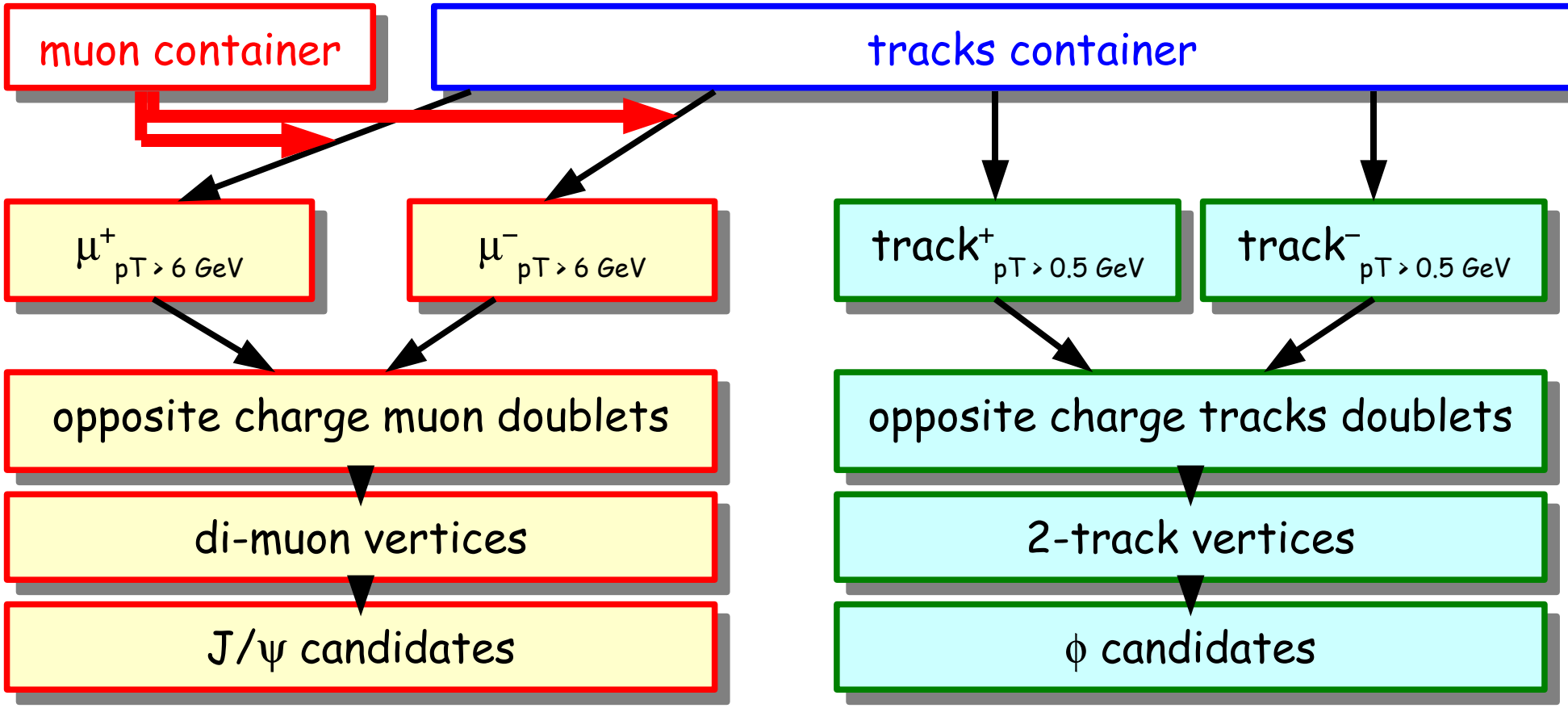
- Combine the tracks into doublets, triplets etc. to form candidates of the composite (decayed) particles (ϕ, J/ψ)
- Apply some preselection cuts (e.g. invariant mass)

Typical Analysis Procedure ($B_s > \phi_{>KK}\ J/\psi_{>\mu\mu}$)



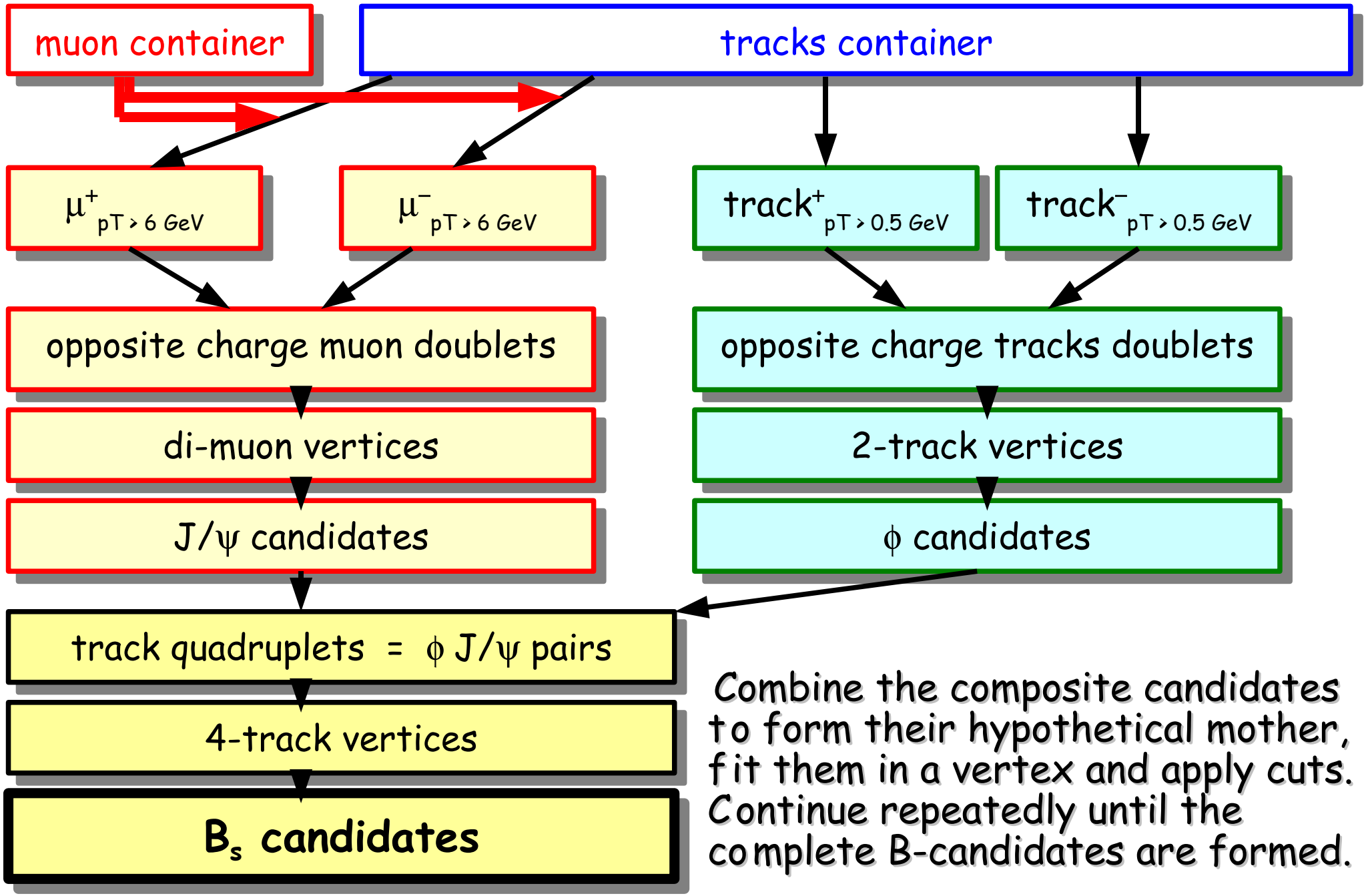
- Attempt to perform a vertex fit for each composite particle

Typical Analysis Procedure (B_s > $\phi_{>KK}$ $J/\psi_{>\mu\mu}$)



- Apply vertex quality and properties (e.g. invariant mass, transverse radius, ...) cuts and form list of composite candidates

Typical Analysis Procedure ($B_s > \phi_{>KK}\, J/\psi_{>\mu\mu}$)



Combine the composite candidates to form their hypothetical mother, fit them in a vertex and apply cuts. Continue repeatedly until the complete B-candidates are formed.

Analysis Software Overview

- **Specific analysis data structures (`BPhysAnalysisObjects`)**
- **Tools for building decay identification algorithm (`BPhysAnalysisTools`)**
  - Tracks combinatorics, kinematic cuts
  - Secondary vertex fitting
  - Truth finding and associations
  - Helper routines to calculate proper time, transverse decay length, etc.
  - B-flavour tagging
- **Set of predefined algorithms (`BPhysExamples`) producing ROOT ntuples**
  - one algorithm per one decay process, presently implemented:
    - $B^+ \rightarrow J/\psi(\mu^+\mu^-)\, K^+$ $B^0_s \rightarrow J/\psi(\mu^+\mu^-)\, \phi(K^+K^-)$ $B^0_s \rightarrow D^-_s(\phi(K+K-)\pi^-)\, \pi^+$
      $B^0_s \rightarrow D^-_s(\phi(K+K-)\pi^-)\, a_1$ $\Lambda^0_b \rightarrow \Lambda^0(p,\pi^-)\, \mu^+\mu^-$
  - skeletons
- **ROOT scripts to analyze the output ntuples**
- **Held in Atlas offline CVS repository:**
  - path `PhysicsAnalysis/BPhys/BPhys`(`Examples`,`AnalysisTools`,`AnalysisObjects`)

The Tools: Basic Data Structures

- **Vertex** class
  - **holds results of the vertex fit in the form for physics analysis, e.g.:**
    - error flags, covariance matrix
    - vertex position
    - refitted track parameters
    - invariant mass, distance to
  - **uses CLHEP objects**
- **VertexAndTracks** class
  - **designed to represent a co**
    - fitted vertex
    - original tracks of the stable daughters
    - reference to composite mother and children candidates
    - MC truth particles associated with the daughter tracks
    - variables like invariant mass, etc. on which selection cuts are headed
- **BFlavourParticle** class
  - **holds tagging muon candiates from lepton flavour tagging procedure**
    - kinematic of the muon
    - relation to the nearest jet and B-hadron

Designed to represent particle-like objects in the analysis, in contrast to e.g. reconstructed tracks and vertices without mass hypotheses as the ouput of reconstruction process.

The Tools: Basic Data Structures

- **Vertex** class
  - **holds results of the vertex fit in the form for physics analysis, e.g.:**
    - error flags, covariance matrix
    - vertex position
    - refitted track parameters (4-momenta including mass hypothesis)
    - invariant mass, distance to mother (primary) vertex etc.
  - **uses CLHEP objects**
- **VertexAndTracks** class
  - **designed to represent a composite particle candidate, contents:**
    - fitted vertex
    - original tracks of the stable daughters
    - reference to composite mother and children candidates
    - MC truth particles associated with the daughter tracks
    - variables like invariant mass, etc. on which selection cuts are headed
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The Tools: Vertexing

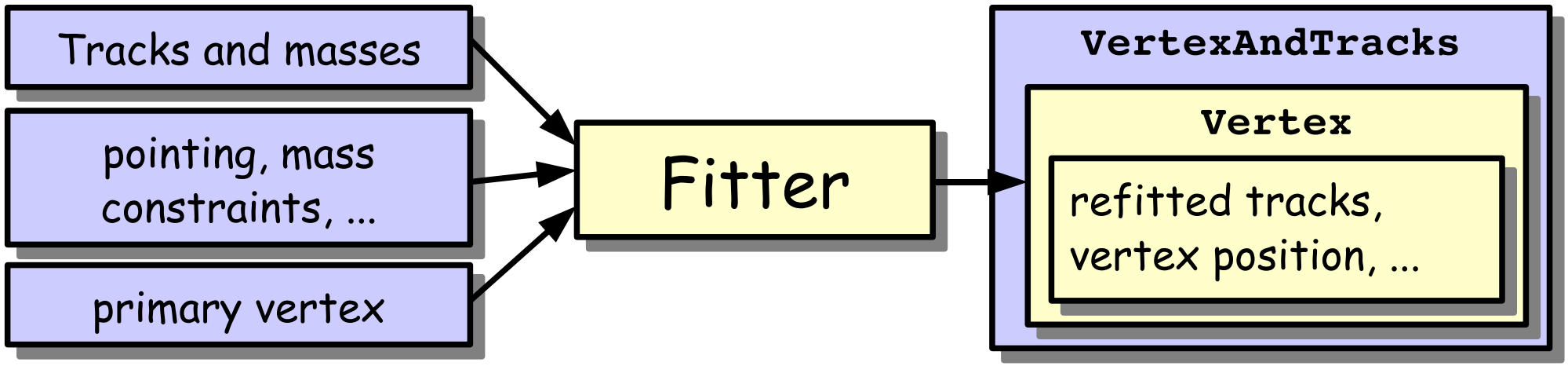
Presently having interfaces to two fitters:

- VKalVrt fitter
  - using Kalman filter method for vertexing
- CTVMFT vertexer
  - CDF fortran code (with interface to ATLAS software)
  - fits whole topology of several vertices in one turn

→ XtoYZFinder (inherited from Athena `AlgTool`)

  - unified interface to the previous fitters for simple vertex fit

Easily configurable to any topology. In principle can connect to any other fitter.



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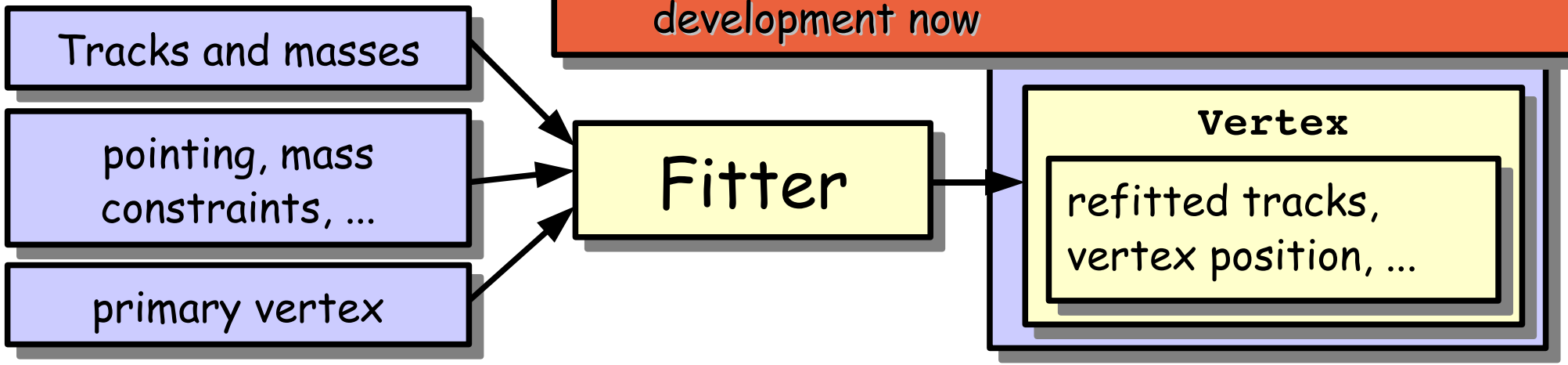
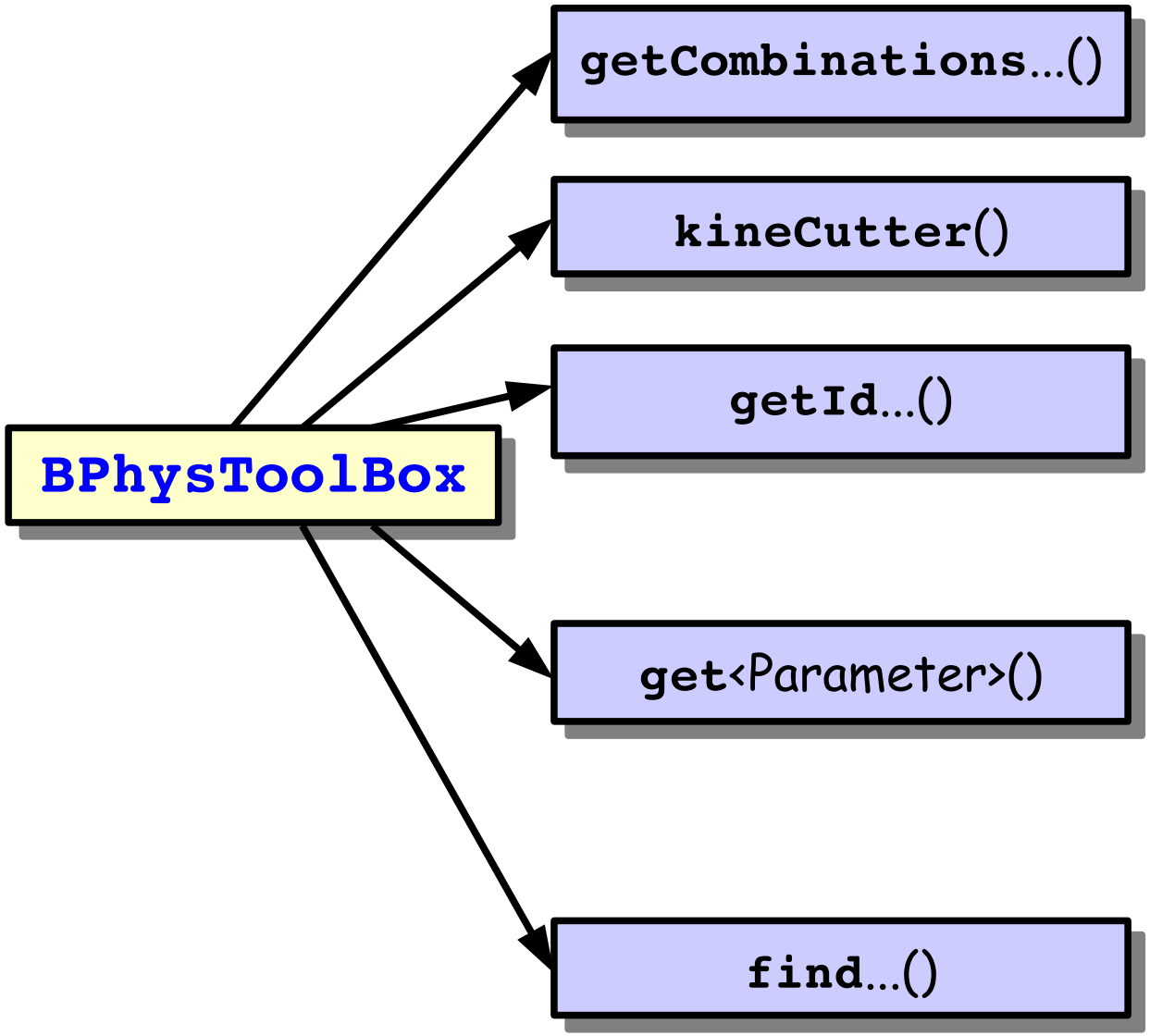
Easily configurable to any top

- Wrappers to ATLAS vertexer interfaces
  K. Prokofiev – primary vertex reconstruction in the ATLAS experiment at LHC
  G. Piacquadio – A new inclusive secondary vertex algorithm for b-jet tagging in ATLAS
- Physics-like input – e.g. decay topology to be fitted: `fitter->getJpsiPhiVertexCDF()`
- Convert ouput format of all the vertexers to the `Vertex` class
  - unified output of all ATLAS vertexers is in development now



The Tools: ToolBox

- Class containing variety of tools for building analysis algorithms



make tracks pairs, triplets, etc.

select tracks based on kinematic cuts

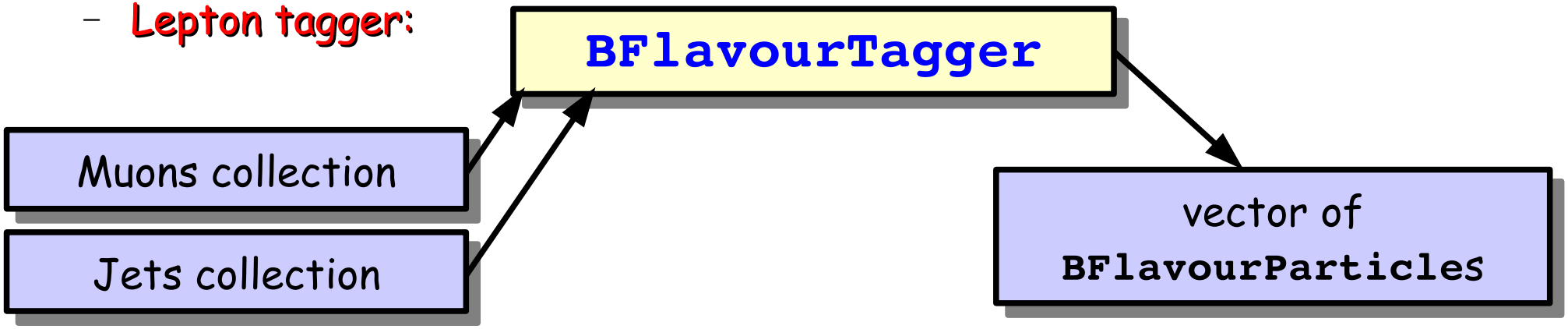
get tracks corresponding to identified muon, etc.

get parameter like p_T, η, mass, proper time, impact parameter, Forward backward asymmetry, etc.

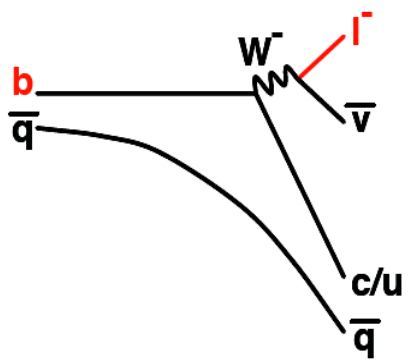
Tracks and MC particles association, get tracks from complete signal tree

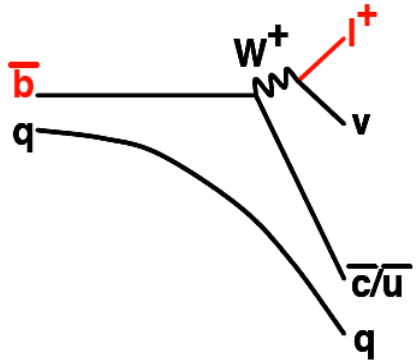
The Tools: Flavour Tagging

- Have to distinguish flavour of the B-meson at t=0 especially for mixing and CP-violation studies
- **2 methods implemented (inherited from Athena `AlgTool`):**
  - **Lepton tagger:**



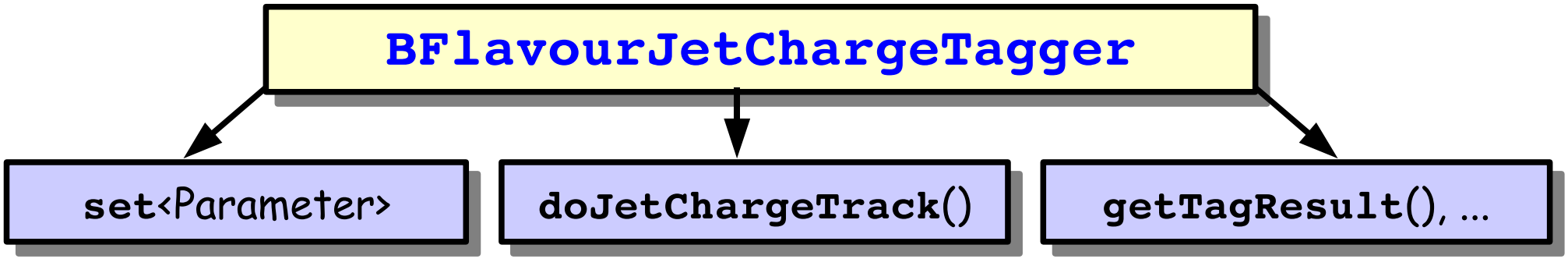
  - **gets muon collection, associates muons with jets and returns sorted tagging muons by transverse momenta**
  - **internal histogramming for wrong tag fraction calculation**





The Tools: Flavour Tagging

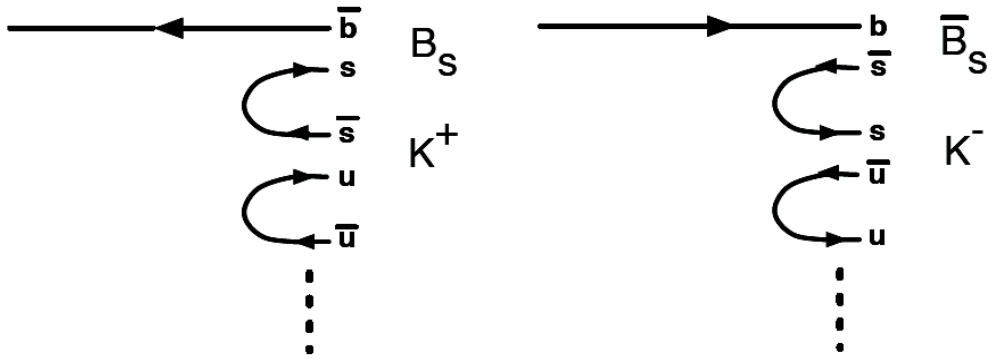
- Have to distinguish flavour of the B-meson at t=0 especially for mixing and CP-violation studies
- **2 methods implemented (inherited from Athena `AlgTool`):**
  - Jet charge tagger:



parameters driving tagging methods, jet building and tag discrimination, input tracks collection settings

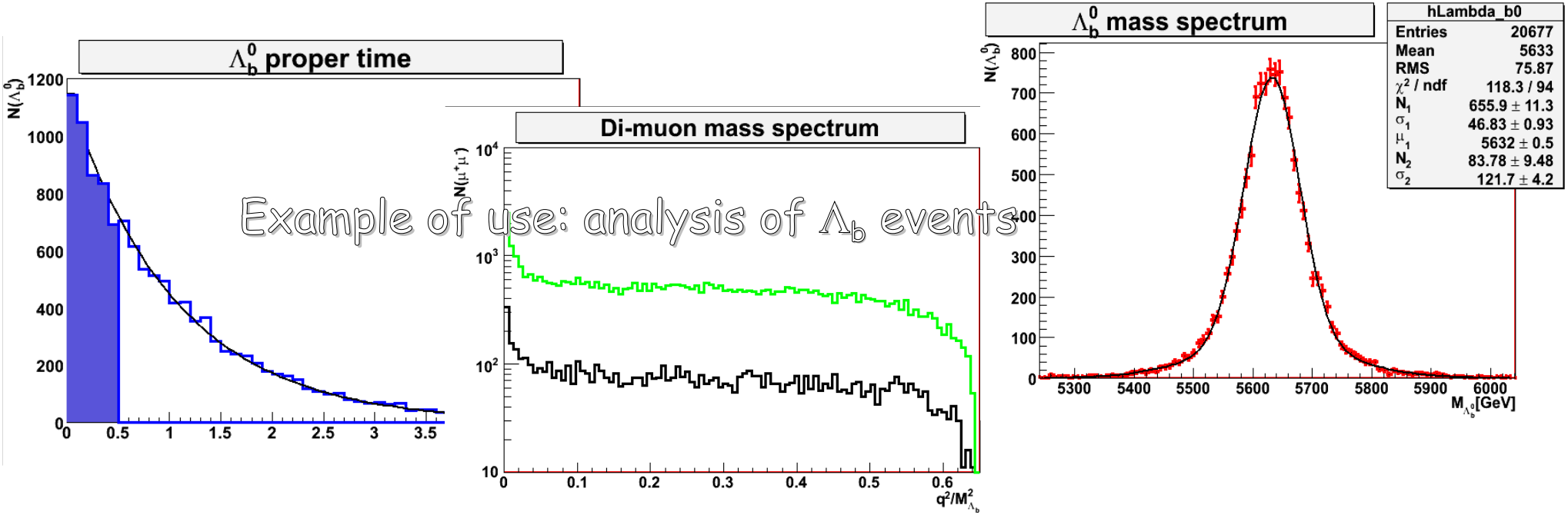
main procedure searching for the tagging jets

get the tagging result:
- sucess, jet charge, number of tracks in jet



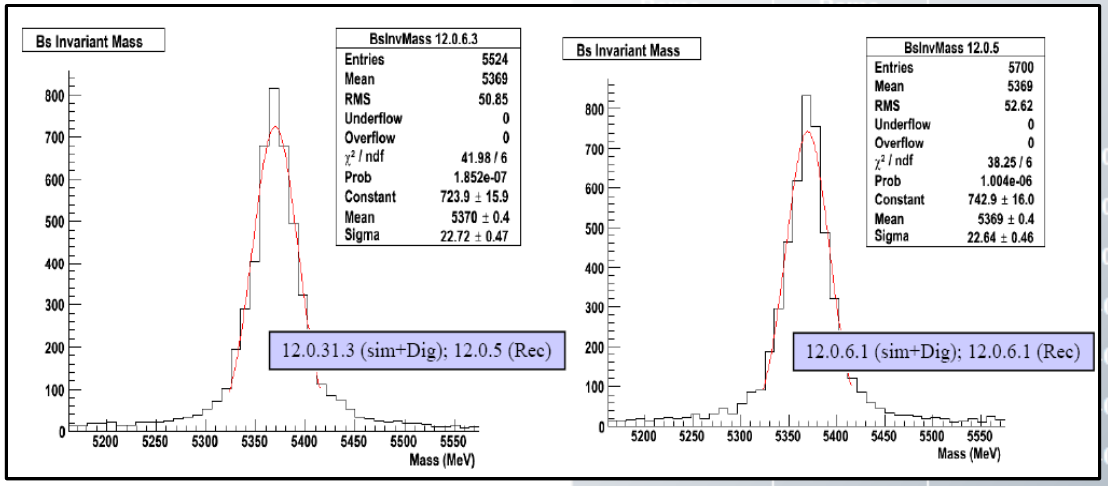
Analysis Output

- **Produces ROOT histograms and ntuple (Athena Aware)**
  - Easy to make more analysis without requiring Athena framework
  - Draw on existing statistical and mathematical tools included in ROOT
- **Apply loose cuts on the analysis level, tune the cuts on ntuple level**
  - not need to rerun analysis over Grid when changing simple cut



Software Releases Validations

- **Developed several standard tests of the Athena releases performance using B-physics analysis tools (`BPhysValidation`)**
  - set of python scripts driving the validation job and ROOT scripts producing plots
  - repeated analysis (with fixed cuts) on predefined set of signal events
- **used by Run Time Tester running on each nightlies** (daily builds)
  - results available online on **cern.ch/atlas-project-rtt-results**



Steve Dallison

Sim+Dig Version	Rec Version	Geometry	No. Events	Mean Mass (MeV)	Sigma	Propper Time Resolution (fs)
			4300	5369 +- 0.4	16.17 +- 0.40	81-83
			3600	5369 +- 0.6	16.02 +- 0.57	92
			5600	5370 +- 0.4	18.47 +- 0.43	86
		02	8000	5370 +- 0.4	20.48 +- 0.45	96
		02	8000	5371 +- 0.3	17.69 +- 0.31	95
		07	8000	5370 +- 0.5	23.59 +- 0.49	104
		00-00	1500	5370 +- 1.0	20.88 +- 1.23	100
		01-00	1500	5370 +- 1.0	19.16 +- 1.04	97
		01-00	1200	5370 +- 1.1	22.02 +- 1.27	100
		02-00	1500	5370 +- 1.1	22.15 +- 1.27	98
12.0.31.8	12.0.5	ATLAS-CSC-01-02-00	9500	5369 +- 0.4	22.64 +- 0.46	102.5 +- 1.6
12.0.31	12.0.6.3	ATLAS-CSC-01-02-00	9500	5370 +- 0.4	22.72 +- 0.47	100.6 +- 1.6
12.0.6.1	12.0.6.1	ATLAS-CSC-01-02-00	8000	5369 +- 0.4	22.01 +- 0.48	99.6 +- 1.7
12.0.6.1	12.0.6.3	ATLAS-CSC-01-02-00	9500	5370 +- 0.4	22.72 +- 0.47	100.6 +- 1.6
12.0.6.1	12.0.6.4	ATLAS-CSC-01-02-00	9700	5370 +- 0.4	22.38 +- 0.45	99.9 +- 1.6
12.0.6.5	12.0.6.5	ATLAS-CSC-01-02-00	2250	5371 +- 0.9	22.98 +- 1.00	101.1 +- 3.4

Summary

- The B-physics group has a range of Athena and ROOT tools for building physics analysis code
- The code structure is straightforward and is therefore easy to understand
- The code was firstly used during large production ATLAS studies in 2005 and is being currently used for Computing System Commissioning studies, run on the Grid via job management system Ganga
- Plans:
  - Complete the set of B-decay channel algoriths
  - Collect and develop the ROOT scripts used for analysis of the output ntuples (many of them yet in private users areas)
  - Further development and unification of the tools based on new requirements