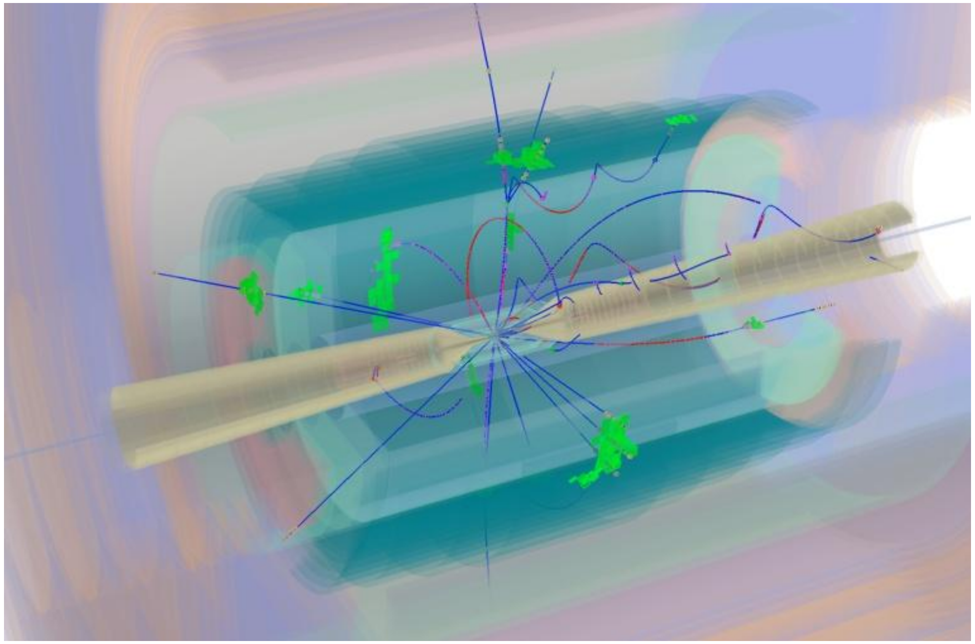
Physics tools for the Super$B$ detector

Matteo Rama
Laboratori Nazionali di Frascati



Meeting on SuperB & Flavor Physics , Jan 19-21, Benasque, Spain

Physics tools for SuperB

A detailed simulation of the SuperB detector, with its various options, with sufficient statistical precision for a relevant physics result, is beyond the capability of the current SuperB computing effort

→ development of ***FastSim***, the SuperB fast simulation

Goals of FastSim:

- evaluate the physics reach of the experiment
- optimize the detector

Requirements:

- reasonably realistic simulation
- detector layout easily configurable
- set of tools to analyze the reconstructed events
- fast

Physics tools for SuperB

- A detailed simulation (Geant4) of the SuperB detector and interaction region is also available: *Bruno*

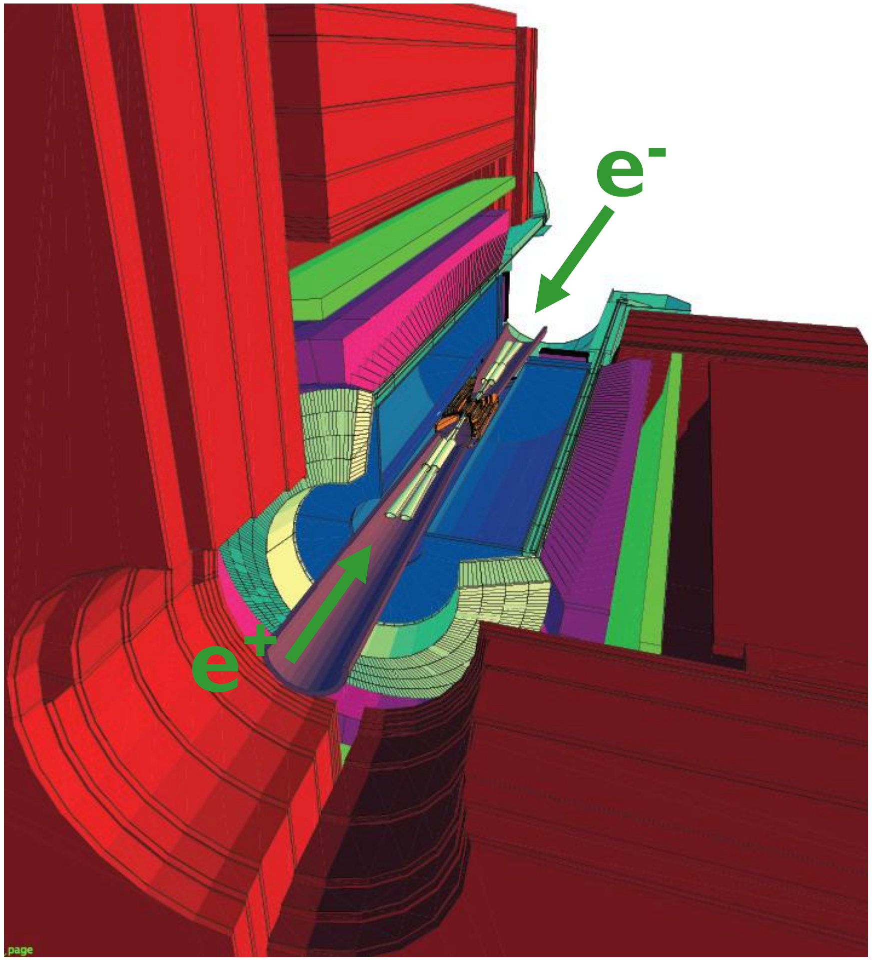
http://mailman.fe.infn.it/superbwiki/index.php/Geant4_SuperB_simulation_main_portal

  - No digitization nor reconstruction available
    ➔ Bruno cannot be used for physics analysis studies yet
- At present it is mostly used to
  - model the interaction region
  - evaluate the machine backgrounds rates at the subsystems

  Very important tasks
- The radiative Bhabha background simulated with Bruno is superimposed to the FastSim physics events (more later)

Detailed simulation with Geant4

SuperB Interaction Region and detector



The beam pipe is modeled up to 10m from the Interaction Point

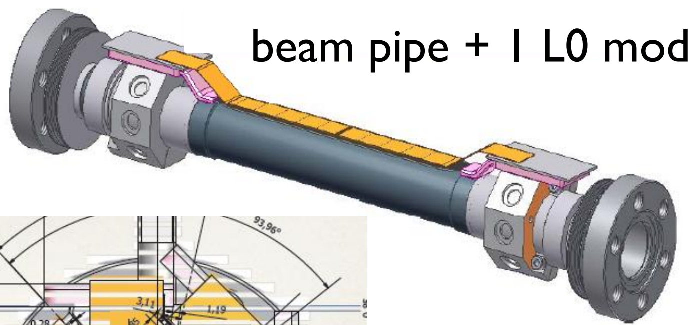
Background study only possible with detailed simulation:

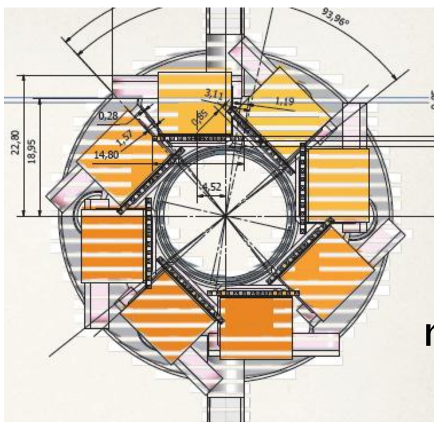
- accurate tracking of primaries through the magnetic elements of the final focus
- accurate simulation of interactions with the detector/IR material (EM/had showers, production/interaction of neutrons,…)
- accurate modeling of the detector geometry

Two examples of Geant4 studies

beam pipe and SVT L0 simulation

beam pipe + 1 L0 module





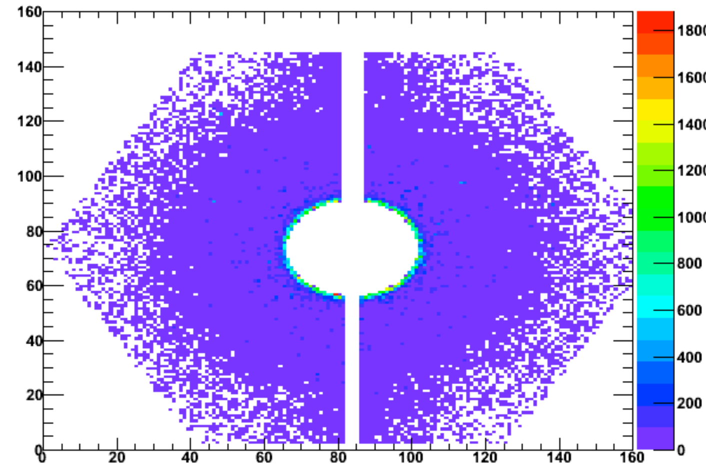
r-phi view of L0

e^+e^- pair production	~7.3 mbarn	~18	7GHz
e^+e^- pair (seen by L0 @ 1.5 cm)	~0.3 mbarn	~0.8	0.3GHz

$e^+e^- \rightarrow e^+e^-e^+e^-$ is the main background source for the L0 SVT layer

IFR simulation

background at the IFR (neutrons,γ,e)
[a layer in the forward endcap]



The amount and distribution of rad-Bhabha bkg depends on the interaction region and detector configurations (magnetic elements, tungsten shield, etc..).

SuperB detector and data sample

$L = 1 \times 10^{36} \mathrm{cm}^{-2} \mathrm{s}^{-1}$

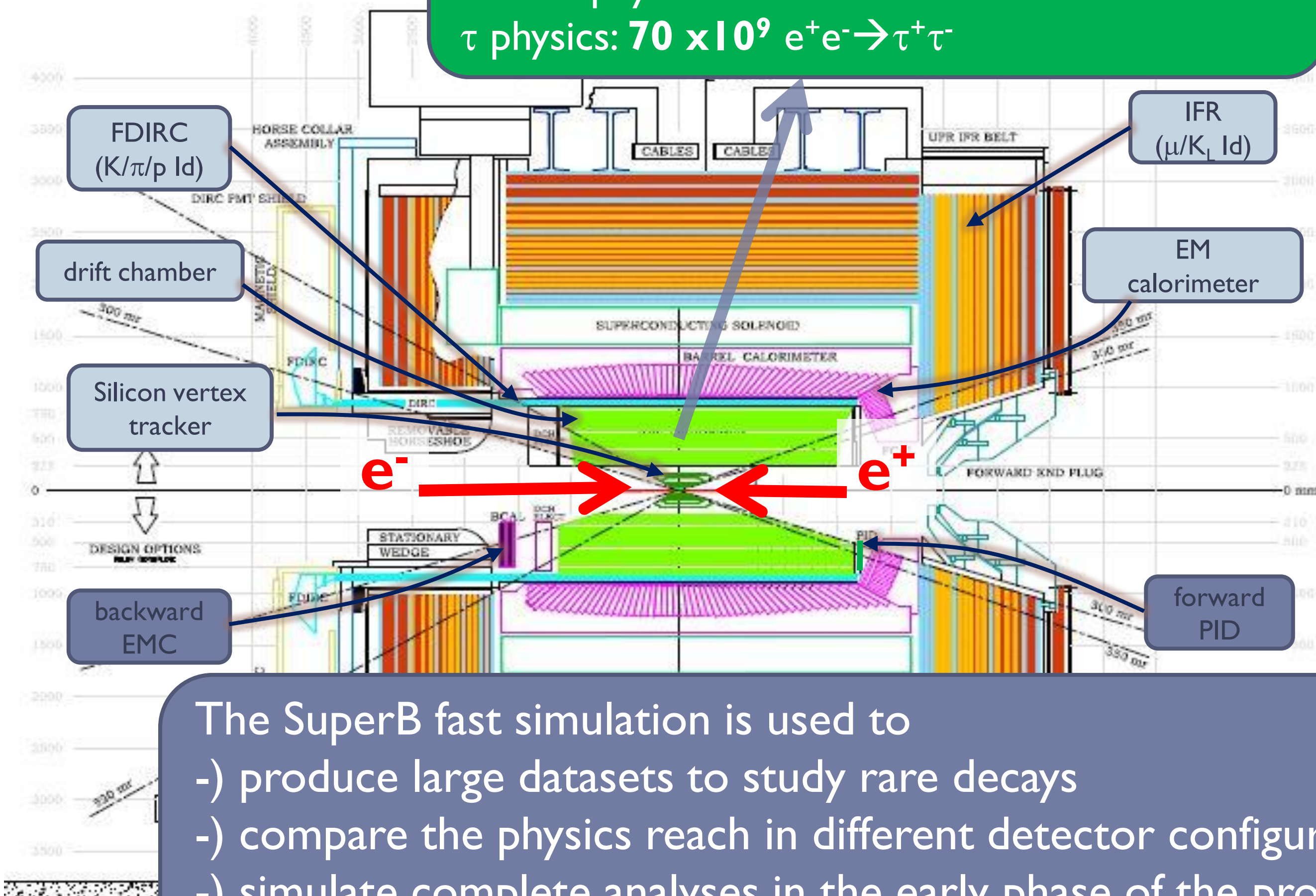
$75\ ab^{-1}$ in 5y of baseline L

dataset

$B_{u/d}$ physics: **>80 x10⁹** $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B_q \bar{B}_q$ (q=u,d)

Charm physics: **100 x 10⁹** $e^+e^- \rightarrow c\bar{c}$

τ physics: **70 x10⁹** $e^+e^- \rightarrow \tau^+\tau^-$



baseline concept

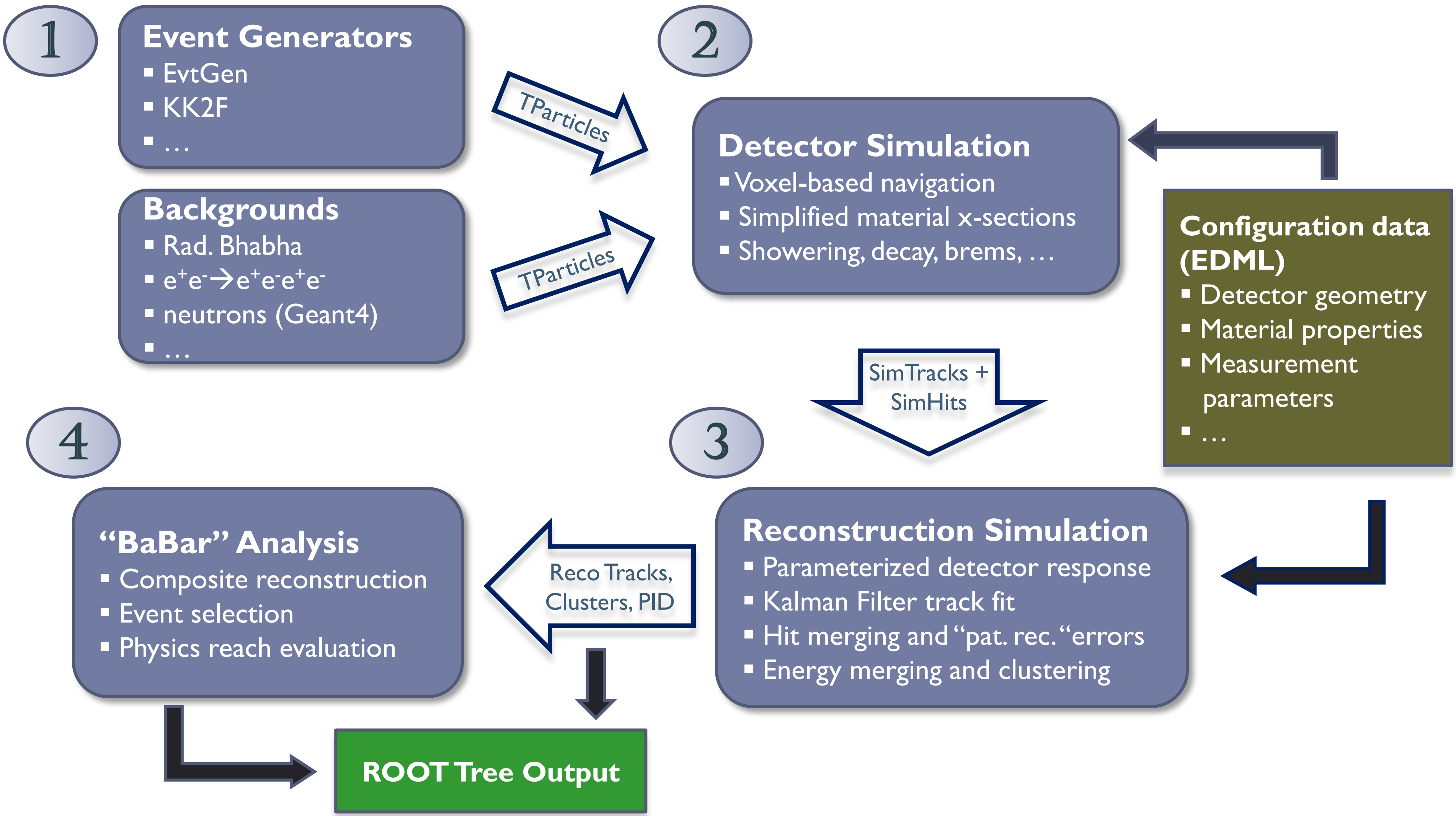
design options

The SuperB fast simulation is used to
-) produce large datasets to study rare decays
-) compare the physics reach in different detector configurations
-) simulate complete analyses in the early phase of the project when the full simulation chain is not yet in place

FastSim design overview

- Simplified detector element description
  - cylinders, rings, cones, planes
- Particle passage through detector fully modeled
  - ionization energy loss, multiple scattering, bremsstrahlung, photon conversion, EM/hadronic showering, …
- Parameterized detector response
  - track hit resolution and efficiency, Cherenkov ring resolution, shower shape,…
- Reconstruction of tracks, clusters, Cherenkov rings, …
- Output compatible with BaBar analysis tools
  - vertexing, B-flavor tagging, B recoil technique, …

Simulation diagram



Particle generators

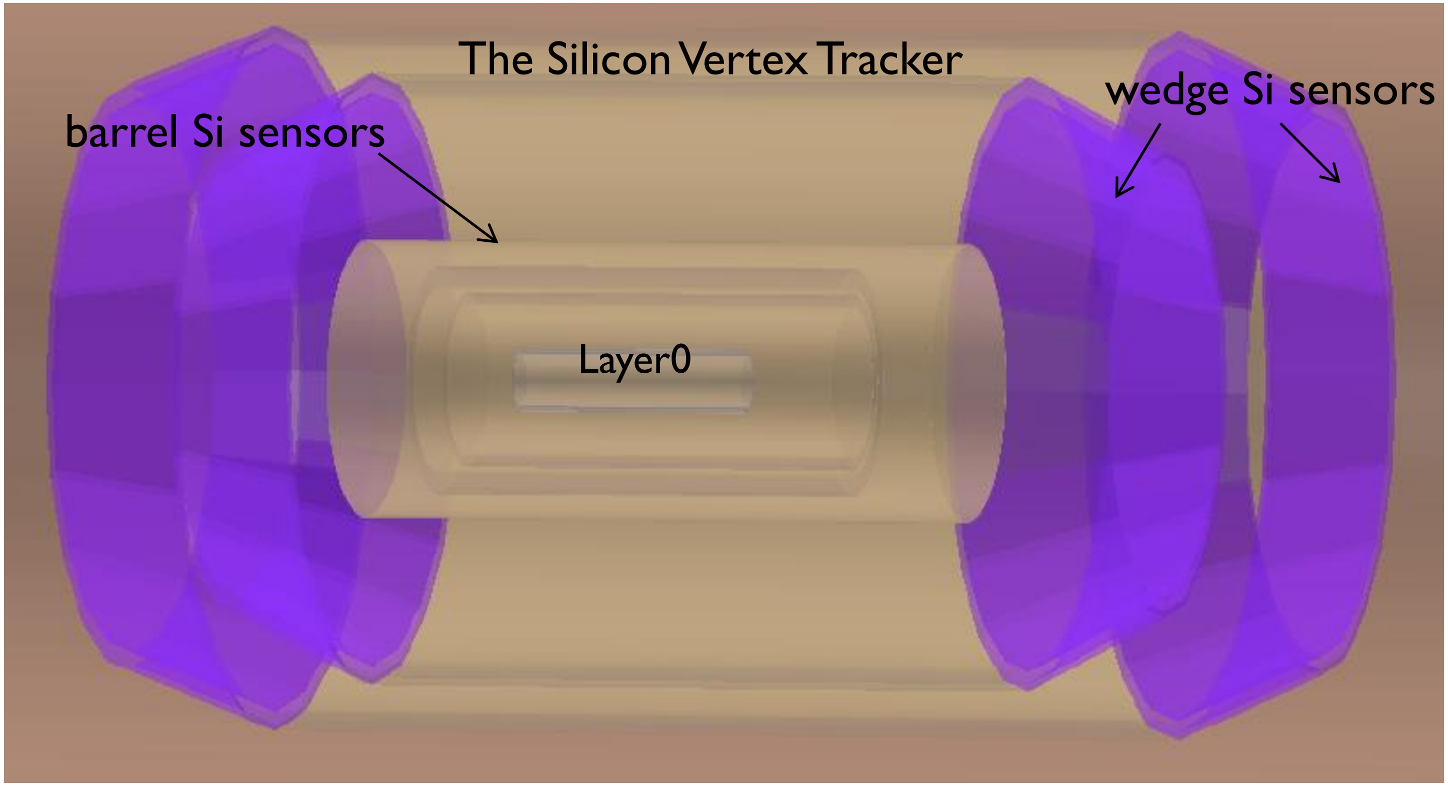
- *Physics events* generated by:
  - EvtGen+JETSET ($e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ and subsequent B decays)
  - EvtGen+JETSET ($e^+e^- \rightarrow q\bar{q}$)
  - EvtGen+JETSET ($e^+e^- \rightarrow \Psi(3770) \rightarrow D^{(*)}D^{(*)}$ and subsequent $D^{(*)}$ decays)
  - KK+TAUOLA ($e^+e^- \rightarrow \tau^+\tau^-$ and subsequent τ decays)
    - with possibility of polarized e beams
- Also possible to generate other classes of events:
  - single particles
  - large-angle Bhabha events
  - $e^+e^- \rightarrow \mu^+\mu^-$

Particle generators

- Machine backgrounds assumed to be dominated by luminosity-based sources
  - *Radiative Bhabhas:* generated in dedicated Geant4 runs (Bruno)
  - $e^+e^- \rightarrow e^+e^-e^+e^-$: generated (diag36) in dedicated FastSim runs
- stored in ROOT files as collections of TParticles
- background events from all sources are overlaid on top of each generated physics event
  - particles from background events are simulated exactly as those from the physics event
  - only background particles inside the time-sensitive windows of the detectors generate a signal

Detector element description

The detector elements are modeled as cylinders, cones, disks and planes
Example: the SVT described as collections of cylinders and cones



Detector element description

- The geometry and properties of the detector elements and associated measurements are defined through XML files

Example: drift chamber shaped as cylindrical layers of wires and gas

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<edml>
  <included>
    <define>
    <constant name="wirezmin" value="-101.5"></constant>
    <constant name="wirezmax" value="154.9"></constant>
    </define>
    <detector>
      <volume name="Drift_Tracking">
        <cyl name="DchInnerCyl" id="101" zmin="wirezmin" zmax="wirezmax" radius="23.60" thick="0.1000" mat="dch-CFiber" />
        <cyl name="dch-Wires" id="151" zmin="wirezmin" zmax="wirezmax" radius="26.05" thick="0.0120" mat="dch-Wires" gap="0.985" />
        <cyl name="dch-He-Ibu" id="152" zmin="wirezmin" zmax="wirezmax" radius="26.06" thick="1.4300" mat="dch-He-Ibu" meas="Axial" />
        <cyl name="dch-Wires" id="153" zmin="wirezmin" zmax="wirezmax" radius="27.24" thick="0.0120" mat="dch-Wires" gap="0.986" />
        <cyl name="dch-He-Ibu" id="154" zmin="wirezmin" zmax="wirezmax" radius="27.25" thick="1.4300" mat="dch-He-Ibu" meas="Axial" />
        <cyl name="dch-Wires" id="155" zmin="wirezmin" zmax="wirezmax" radius="28.43" thick="0.0120" mat="dch-Wires" gap="0.987" />
        …
```

inner wall

gas

wires

geometry type
(cylinder in this case)

z min and z max
of the cylinder

radius

thickness

material
(mat. properties
defined in a database)

the wires fills a fraction
1-gap of the cylinder
lateral surface

Detector element description

Parameters defining the drift chamber cells

```
<device name="Axial"
        type="DriftChamber"
         sensitiveTimeWindow="0.5e-6"
         rms_par0="0.0178977"
         rms_par1="0"
         rms_par2="-0.161932"
         rms_par3="0.357955"
         rms_par4="-0.238636"
         rms_par5="0.0409091"
         eff_par0="0.98"
         eff_par1="0.83"
         cell_size="1.8"
         trunc_frac="0.7"
         dedx_par1="0.00154"
         dedx_par2="1"
         dedx_par3="-0.34"
         angle="0"  />
```

spatial resolution, hit efficiency, phi size, dE/dx parameters, stereo angle

- The physical properties of materials stored are stored in a database
  - density, A, Z, radiation/interaction lengths, …
  - composite materials can be modeled as admixtures of simpler materials

		ρ	Z	A		X_0	λ_I				
gas mixture	dch-He-Ibu	6.408E-04	23.8	46.1	0	51.16	75.65	-30	20.0	1.0	gas
wires metal mixture	dch-Wires	6.237E+00	29.0	62.4	0	15.31	118.56	-30	20.0	1.0	solid

Interaction of particles with the detector material

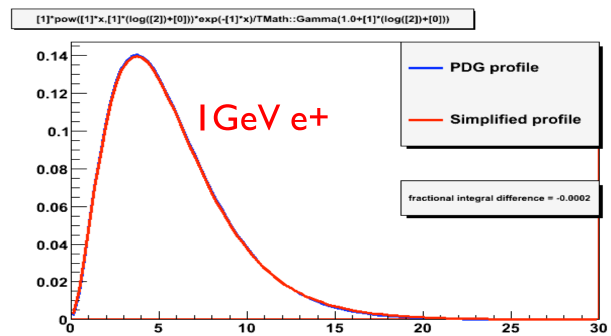
- Unstable particles allowed to decay in flight
  - Decay rates and modes are simulated using the BaBar EvtGen code and parameters

- Ionization energy loss and multiple scattering modeled using standard parameterizations
  - Landau and Moliere tails included
- Interaction probability given by rad (int) length
  - γ conversion, $e^{\pm}$ bremsstrahlung, had interaction in "thin" materials
  - EM (had) showers for e, γ (π,…) in "thick" materials

Interaction of particles with the detector material

- EM showers
  - longitudinal profile is simplified PDG gamma distribution
  - lateral distribution modeled with Grindhammer et al

} PDG ch. 27



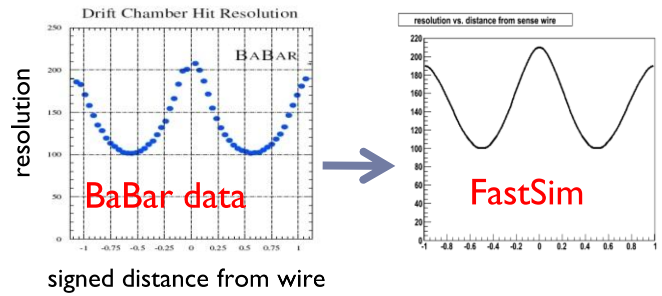
longitudinal profile

- HAD showers
  - Longitudinal and transversal profiles of the **hadronic shower** for pions are parameterized from: NIM 186 (1981) 533 and CERN-PPE/91-223 (1993)

Tracking simulation

- Multiple measurement types supported
  - double-sided Si strips, Si pixels, wires, ...
  - Can be associated to any geometry
    - cylinder, cone, ring, plane
  - dE/dx hit measurement
- Hit positions smeared by an analytic function
  - double-Gaussian for Svt, 'T2D' function for Dch
- Electronic inefficiency, geometric overlaps and gaps modeled statistically
  - For example: drift chamber wires are modeled as cylindrical layers of metal with very large gaps
- Kalman filter track fit
- No pattern recognition. But "pattern recognition confusion" effect:
  - Hits from two tracks that are within their spatial resolution will be merged into one hit with a position between the two original hits, and assigned to one track
  - Hits that give large contributions to the track χ^2 are removed from the track

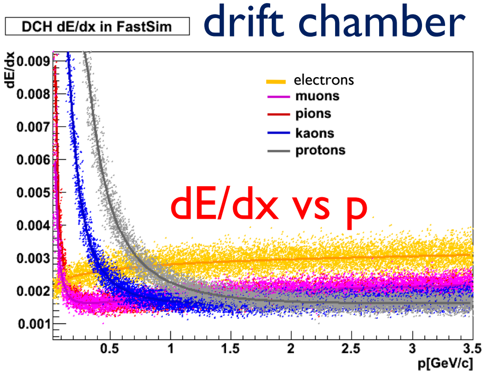
drift chamber T2D



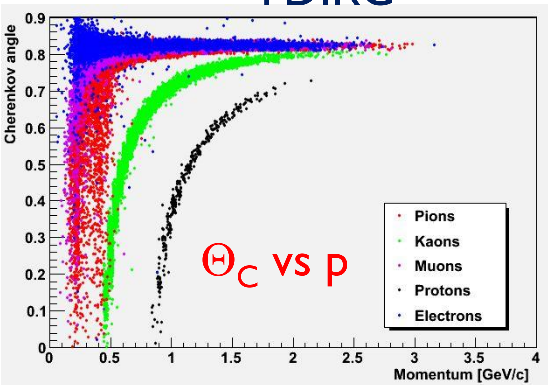
Particle identification

- dE/dx measurement in silicon vertex detector and drift chamber
  - truncated-mean of the ionization measurements from the track hits
- Cherenkov detector (FDIRC)
  - photons generated according to ring dictionary
  - Θ_C smeared according to intrinsic resolution and track p error at the radiator
- Time of flight detector
  - time measurement depending on charged particle trajectory and intrinsic time resolution

drift chamber



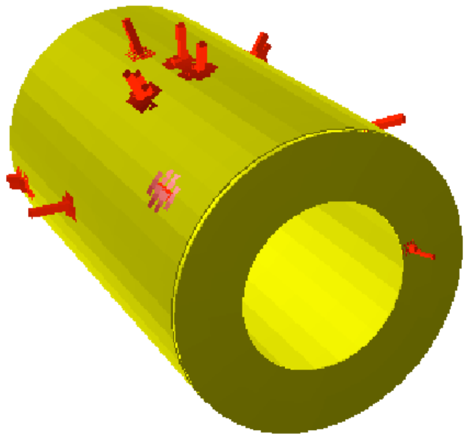
FDIRC



Adding a new type of measurement is simple

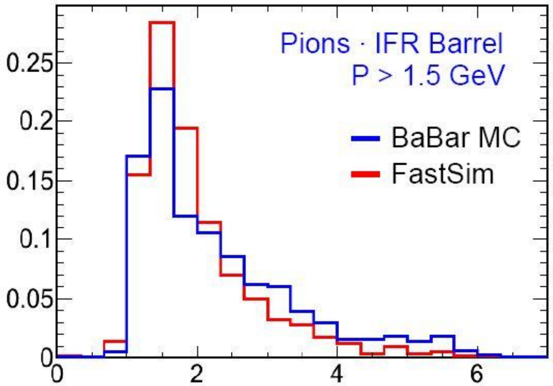
Calorimeters

- EM calorimeter
  - If >1 discrete interactions (conversion, brems) in detector element ➔ EM shower
  - Energy loss distributed according to the shower profile over a grid representing the crystal segmentation Fluctuations included
  - Cluster reconstruction, cluster-track matching

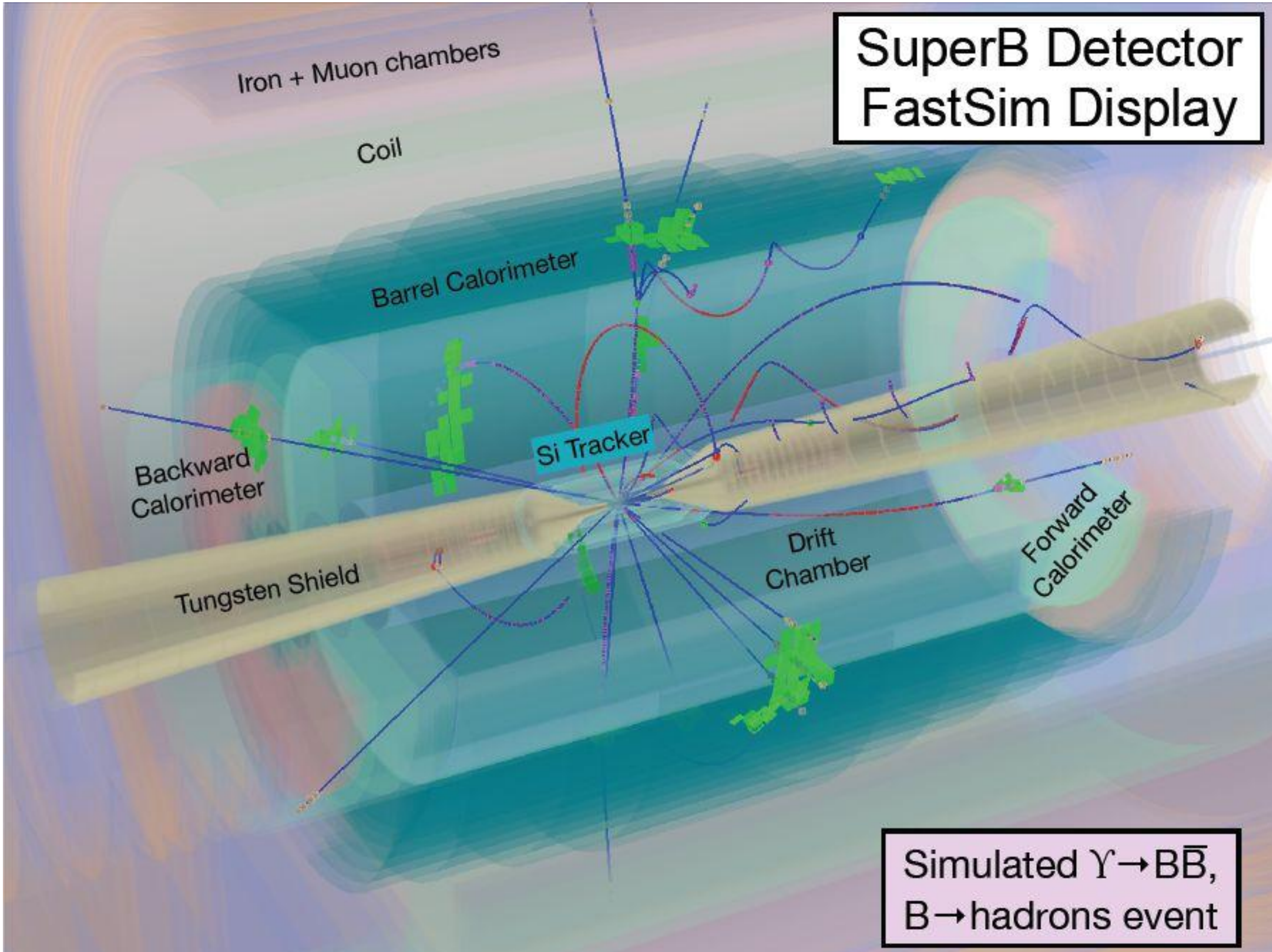


EM calorimeter

- IFR detector (muon/pion discrimination)
  - Hits generated according to hadronic shower model (hadrons) or ionization (muons).
  - Hits digitized and clustered. Statistical fluctuations in hits generation included.
  - Reconstruction of detector response



# of measured interaction lengths


SuperB Detector
FastSim Display
Iron + Muon chambers
Coil
Barrel Calorimeter
Si Tracker
Backward Calorimeter
Tungsten Shield
Drift Chamber
Forward Calorimeter
Simulated ϒ→BB̄,
B→hadrons event

Analysis tools

- FastSim is compatible with the BaBar analysis framework
- Well tested tools borrowed from BaBar experience
  - vertexing
  - composition tools
  - B flavor tagging
- Output stored in ROOT files
- Possible to run complex physics analyses
  - FastSim validation (comparison with BaBar MC and data)
  - estimate of SuperB physics reach
  - optimization of the detector design

Particle Id selectors

- PID selectors provide lists of identified particles ($\pi^{\pm}$, $K^{\pm}$, $e^{\pm}$…)
- "realistic" Kaon/pion selectors
  - do not use any truth-related information
  - combine into a likelihood the dE/dx (SVT and DCH), n_{γ} and Θ_C (FDIRC) and if available the info from the fwd TOF detector
- First version of muon and electron selectors
- Truth-based selectors also available (users set the efficiency and mis-Id levels for various particle types)

Brecoil anaysis

To reduce the bkg, reconstruct a tag B meson in a hadronic or semileptonic decay channel and search for the signal B in the remaining part of the event.

- Hadronic B tag

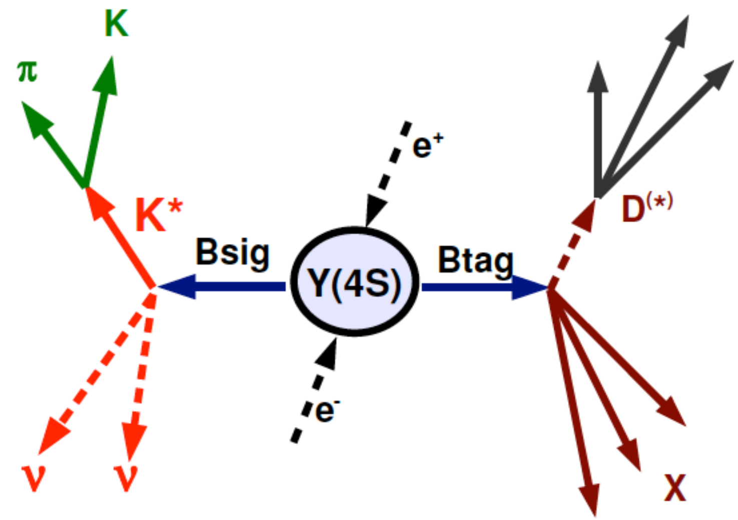
  B→D(*)X

  $$X = n\pi + mK + rK^0_S + q\pi^0$$

  $$n+m+r+q<6$$

- Semileptonic B tag

  B→D(*)lν   l=e,μ



with:

$D^{*+} \to D^0\pi^+$

$D^{*0} \to D^0\pi^0$

$D^{*0} \to D^0\gamma$ (HAD only)

$D^0 \to K^-\pi^+$

$D^0 \to K^-\pi^+\pi^0(\gamma\gamma)$

$D^0 \to K^-\pi^+\pi^+\pi^-$

$D^0 \to K^0_S\pi^+\pi^-$

$D^+ \to K^-\pi^+\pi^-$

$D^+ \to K^-\pi^+\pi^-\pi^0$ (HAD only)

$D^+ \to K^0_S\pi^+$

$D^+ \to K^0_S\pi^+\pi^-\pi^+$ (HAD only)

$D^+ \to K^0_S\pi^+\pi^0$ (HAD only)

FastSim performance

- Time/event*
  - Particle generation: ~1ms
  - Propagation of particles through the detector: ~ 10 ms
  - Reconstruction: ~ 100 ms
  - Analysis of the event: 100÷1000 ms

* on a dual quad core Intel(R) Xeon(R) CPU E5520 @ 2.27GHz architecture

"Tricks" to speed up the simulation

- Include pairs background only if necessary
  - its inclusion increases the combinatorics time quite significantly
  - or apply anti-electron cuts to the low-p tracks
- Use "B cocktails"
  - Study the bkg composition and identify a subset of decays covering 'most of' the selected events. Generate that subset instead of everything.
  - Note: need to be very careful of possible biases

B cocktails used in the 'September 2009 production'

List of breco cocktail files and their properties

breco sample (HAD/SL)	generator	dec file name	number of modes	fraction of BBbar decay'*'
HAD	B+B-_Btag-HD_Cocktail	B+B-_Btag-HD_Cocktail.dec	31	0.2176
HAD	B0B0bar_Btag-HD_Cocktail	B0B0bar_Btag-HD_Cocktail.dec	38	0.1806
SL	B+B-_Btag-SL_e_mu_tau_Bsig-HD_SL_Cocktail	B+B-_Btag-SL_e_mu_tau_Bsig-HD_SL_Cocktail.dec	247	0.157
SL	B0B0bar_Btag-SL_e_mu_tau_Bsig-HD_SL_Cocktail	B0B0bar_Btag-SL_e_mu_tau_Bsig-HD_SL_Cocktail.dec	271	0.138

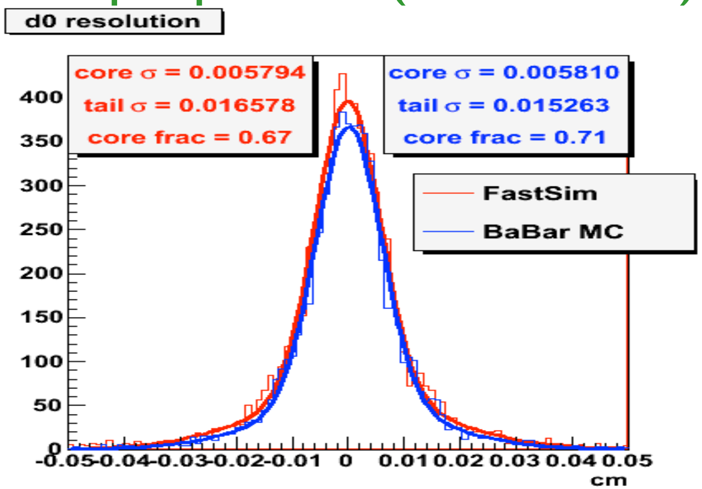
'*' 100% means B->everything, Bbar->everything

Software

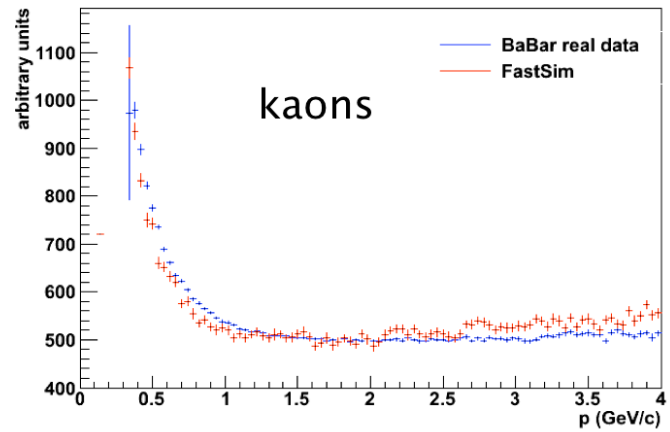
- C++ class library in SVN repository (21 packages)
- XML-based configuration language (EDML)
- Dependencies: CLHEP, BOOST, ROOT, BaBar (PDT, Kalman track fit, EvtGen, …)
- Supported platforms: SL4, SL5 (32+64 bit), MacOSX 10.6

Detector performance comparisons

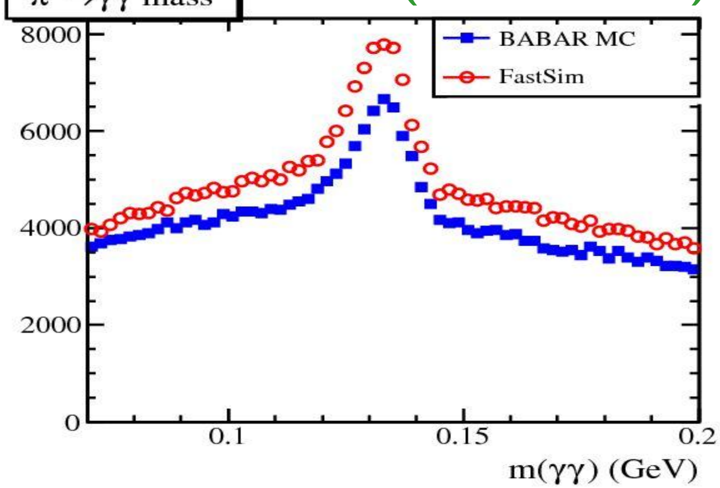
track impact parameter (vertex detector)



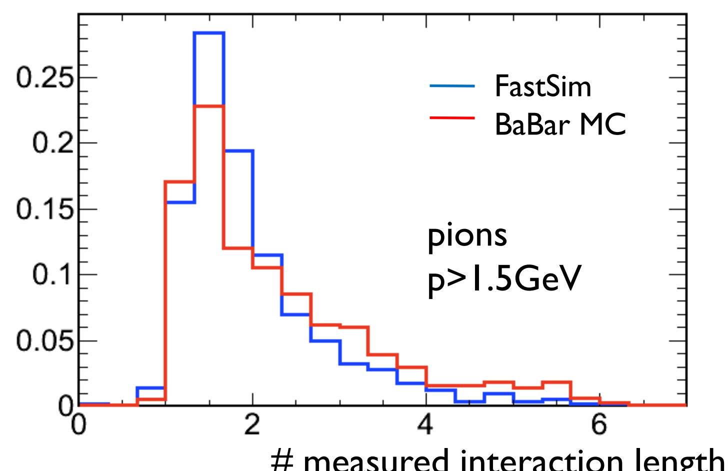
kaon dE/dx vs p (drift chamber)



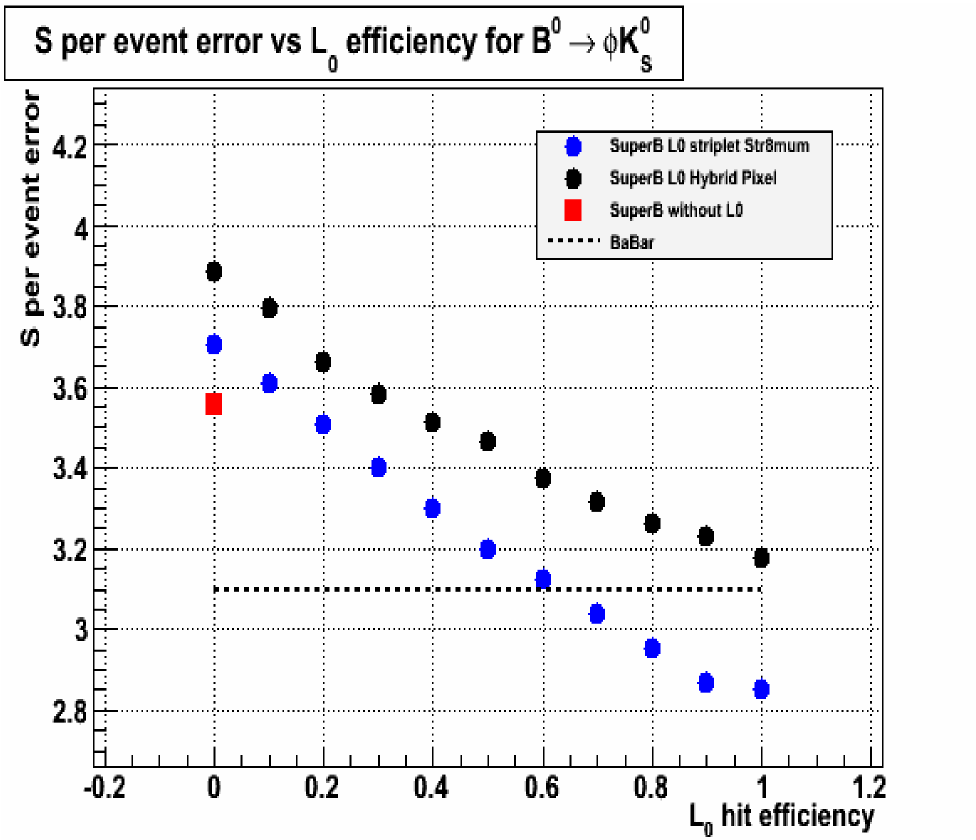
π^0 mass (EM calorimeter)



 # interaction length – pions (muon detector)



Detector optimization studies



$\sin 2\beta_{eff}$ ($B \to \phi Ks$) per event error as a function of:

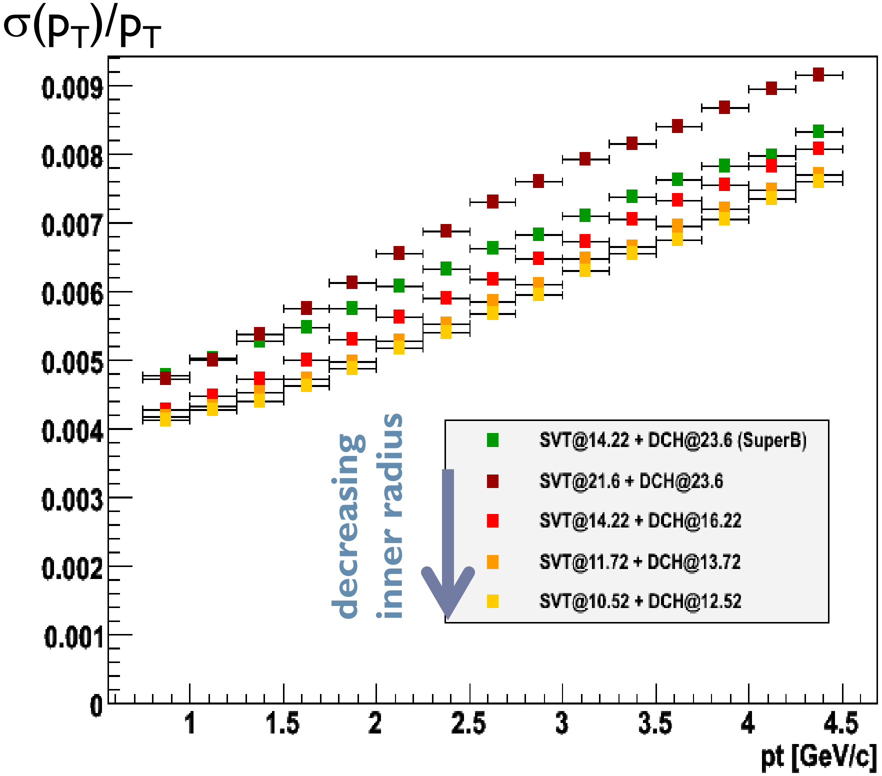
1) **L0 hit efficiency**
2) **technology (striplets, pixels)**

L0 = inner vertex tracker layer

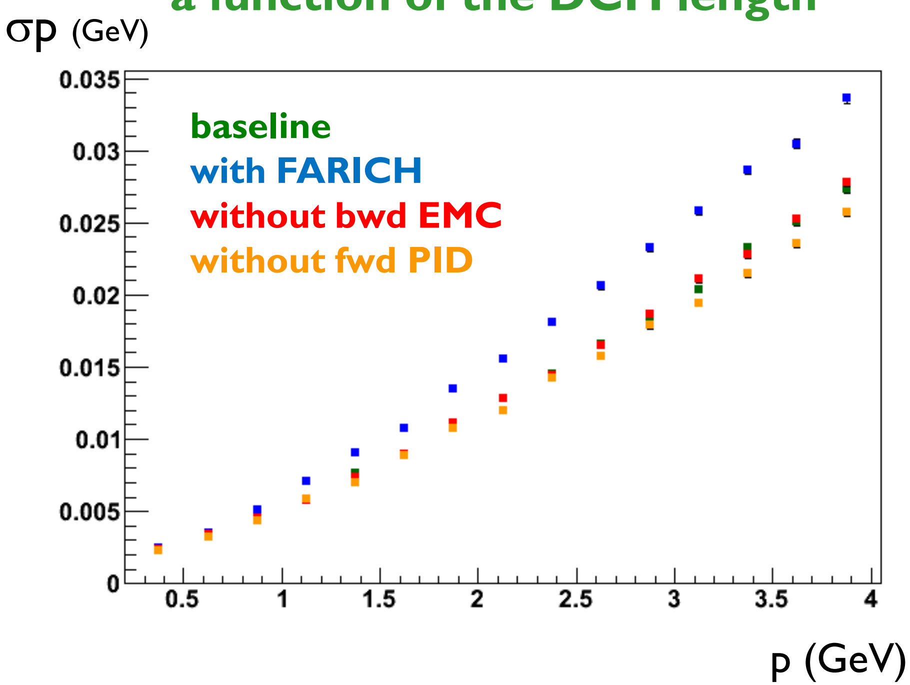
In this study:
Striplets: 0.40% X_0
Hybrid pixels: 1.08% X_0

Detector optimization studies

p_T rel. error as a function of the SVT-DCH transition radius

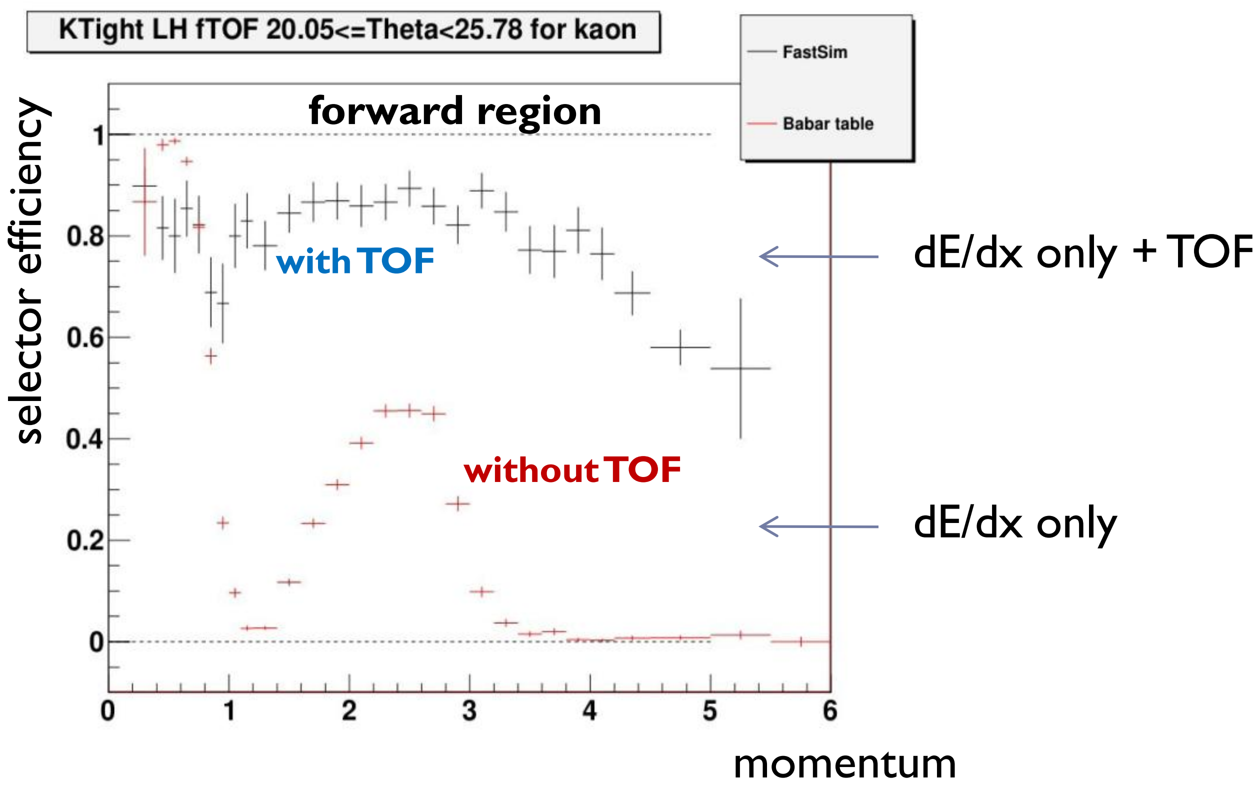


p error in the forward region as a function of the DCH length



Detector optimization studies

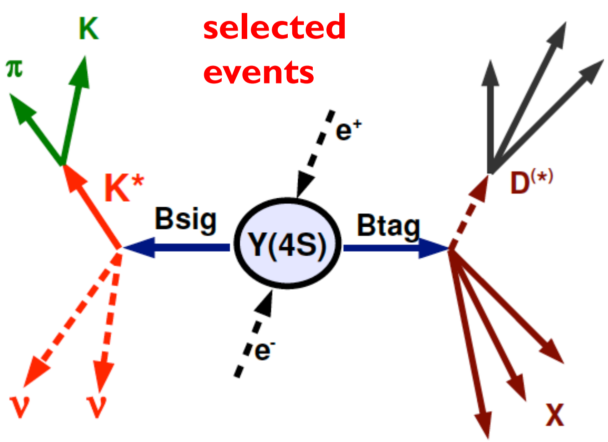
$K^{\pm}$ detection efficiency in the forward region with or without the TOF detector (keeping the pion mis-Id unchanged)



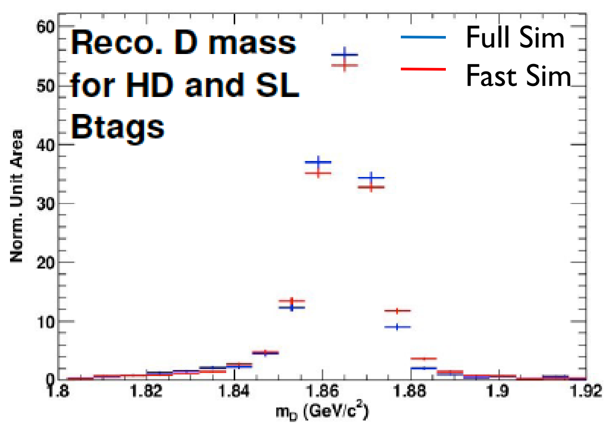
Sensitivity estimate of complex measurements

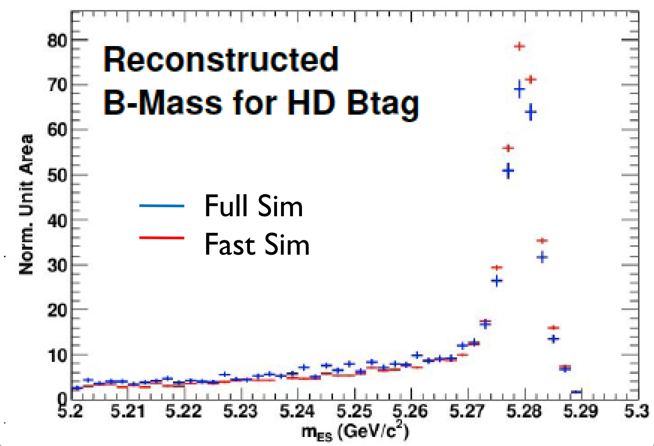
Example of a complete physics analysis: BF($B \to K^{(*)}\nu\nu$)

Study S/sqrt(S+B) vs data with baseline SuperB and with fwd PID + bwd EMC



-) Brecoil analysis: reconstruct the tag B (HAD or SL) and search the signal on the other side

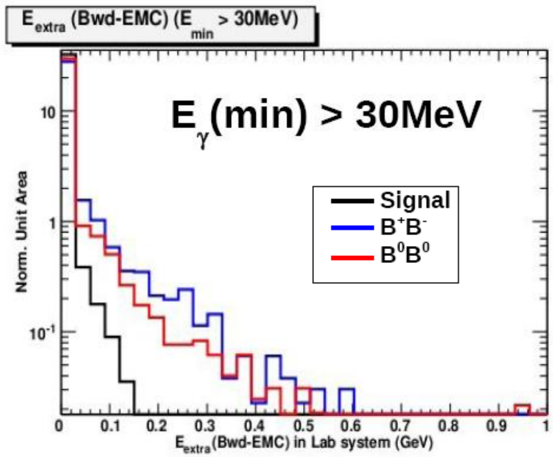


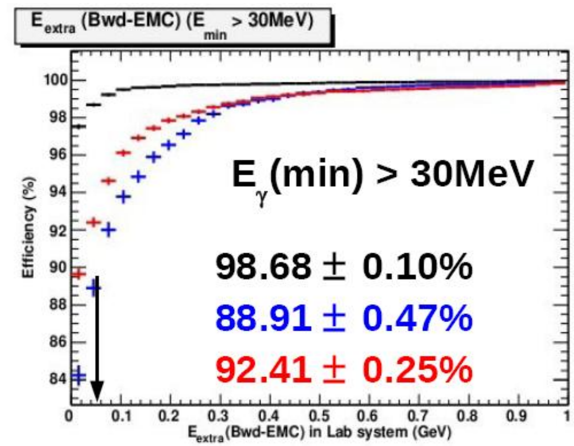


Example of a complete physics analysis: BF($B \to K^{(*)}\nu\nu$)

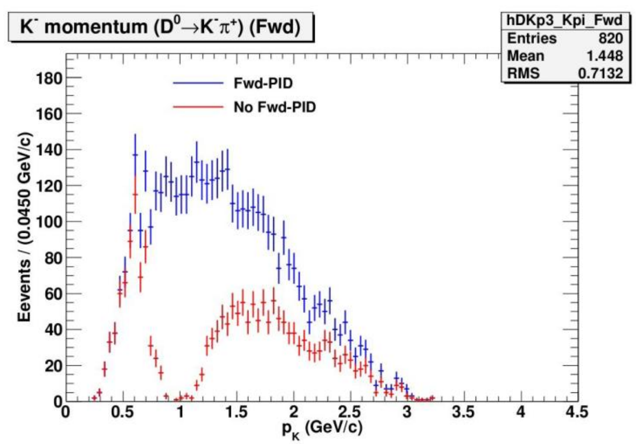
After all selection cuts, measure S and B using E_{extra}
(E_{extra}: EMC energy not associated to the reconstructed B candidates in the event)

if there is the bwd EMC, cut on the additional E_{extra}(bwd)





if there is a fwd TOF, gain efficiency in the fwd region



efficiency gain
All K^{*+} modes

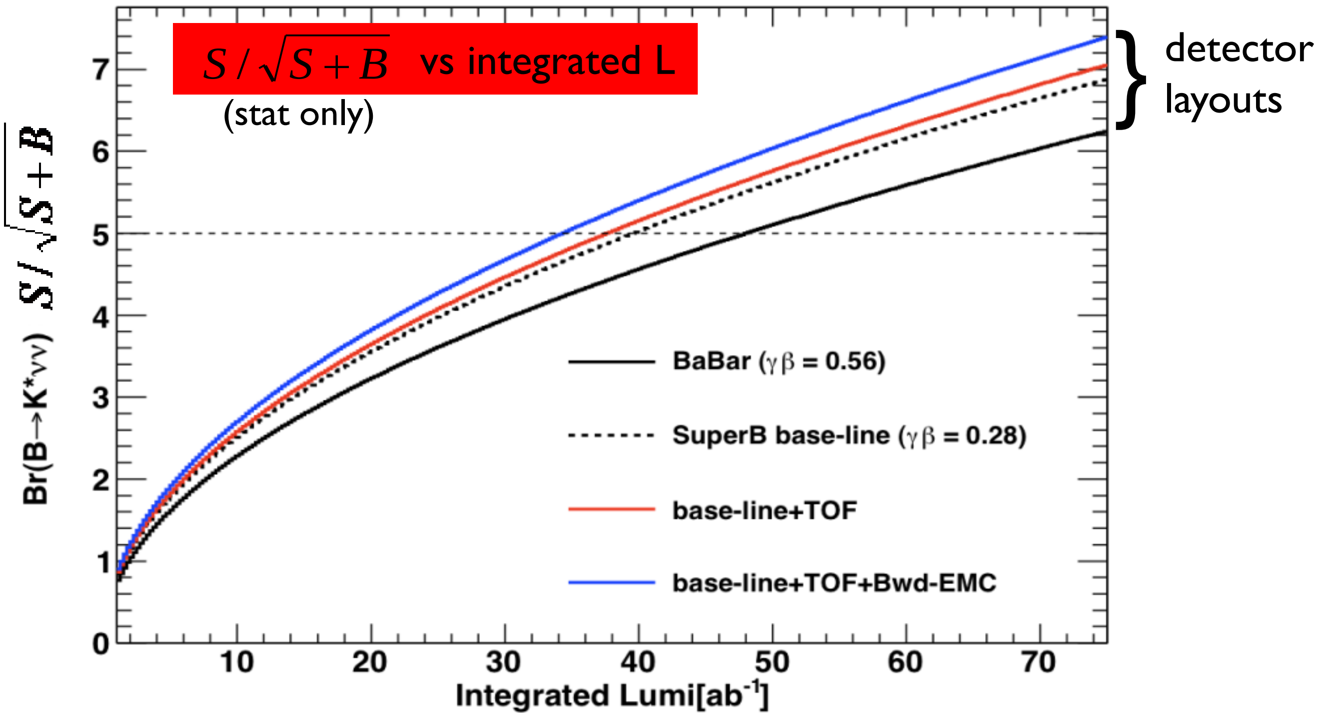
- **Signal:** - Tag-side: 2.3 %
  - Sig-side: 1.4 ± 0.3%
- **B^+B^-:** - Tag-side: 2.1 %
  - Sig-side: 0.2 ± 0.2%
- **B^0B^0:** - Tag-side: 2.0 %
  - Sig-side: 0.2 ± 0.1%

Example of a complete physics analysis: BF($B \rightarrow K^{(*)}\nu\nu$)

summary of the study:

with the fwd TOF: S/sqrt(S+B) increases 1-4% (depending on the mode)
with the bwd EMC: S/sqrt(S+B) increases ~5%

result in terms of S/sqrt(S+B) as a function of the integrated luminosity



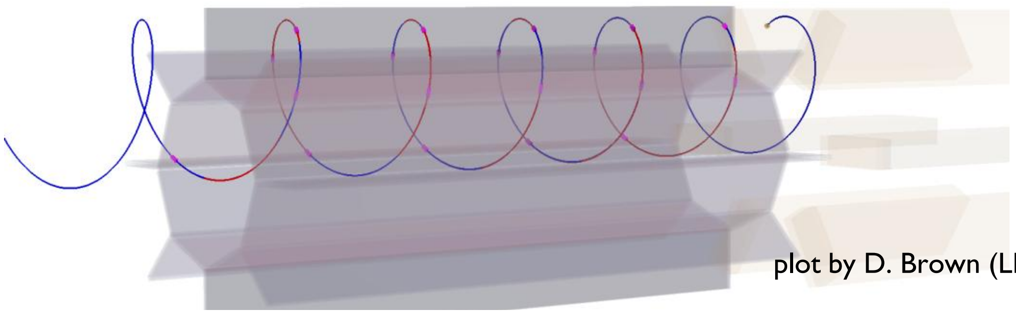
S is the number of expected $B \rightarrow K^*\nu\nu$ signal events assuming the SM prediction

public release of FastSim

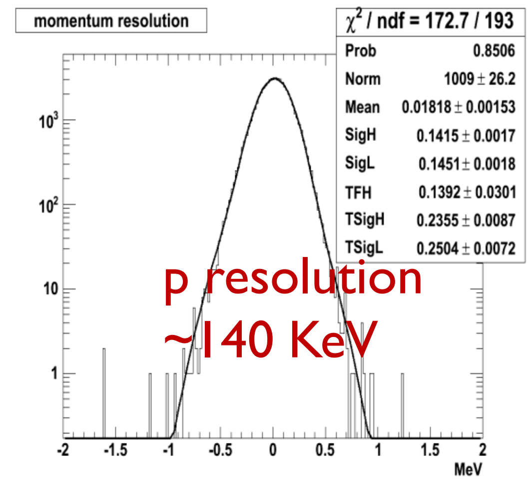
- FastSim is flexible. Potentially useful in other HEP experiments
- Plan to release a public release of FastSim in 2011
- The SuperB specific code and configurations will stay in protected repositories

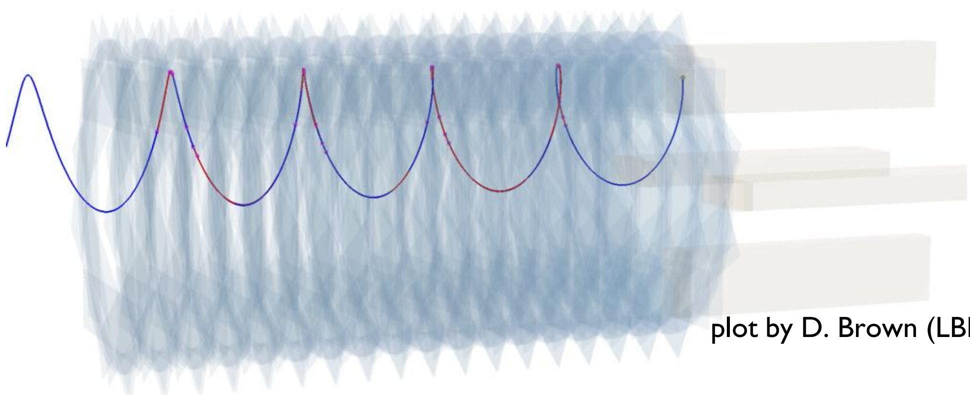
Not only SuperB

mu2e experiment at FNAL

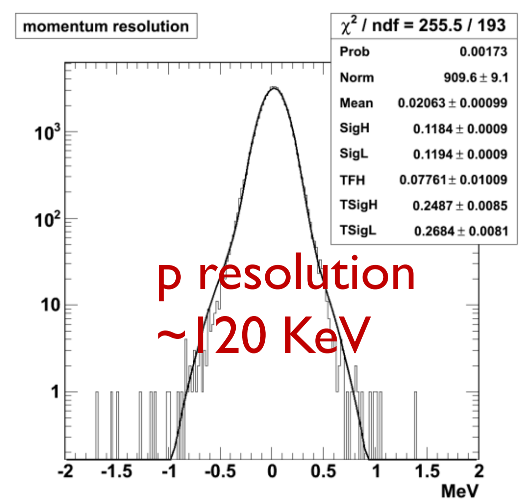


plot by D. Brown (LBNL)

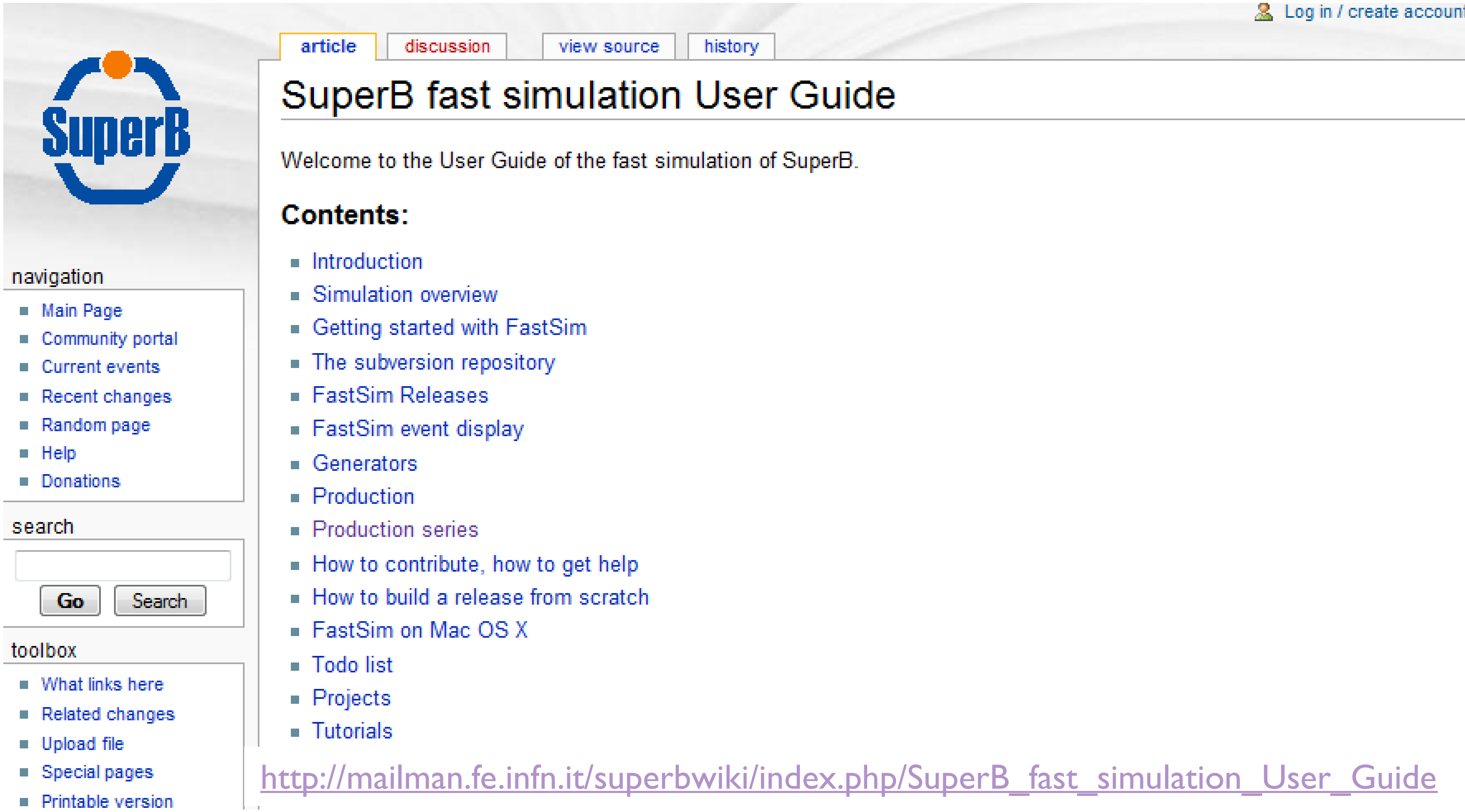




plot by D. Brown (LBNL)



Documentation



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SuperB fast simulation User Guide

Welcome to the User Guide of the fast simulation of SuperB.

Contents:

- Introduction
- Simulation overview
- Getting started with FastSim
- The subversion repository
- FastSim Releases
- FastSim event display
- Generators
- Production
- Production series
- How to contribute, how to get help
- How to build a release from scratch
- FastSim on Mac OS X
- Todo list
- Projects
- Tutorials

http://mailman.fe.infn.it/superbwiki/index.php/SuperB_fast_simulation_User_Guide

Summary

- New fast simulation developed within the SuperB project
  - main tool to perform physics studies at this stage of the SuperB experiment
  - the Geant4 simulation is crucial to quantify the machine backgrounds
- Complete simulation chain
  - from particles generation to the analysis of reconstructed events
- XML interface to define the detector configuration
- Validated with the BaBar Geant simulation
  - very satisfactory results overall
- Flexible tool
  - easy to configure the detector and add new measurements
  - not limited to SuperB detector simulation