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BESIII Detector Simulation with Geant4

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IHEP, Beijing

12th Geant4 Collaboration Workshop
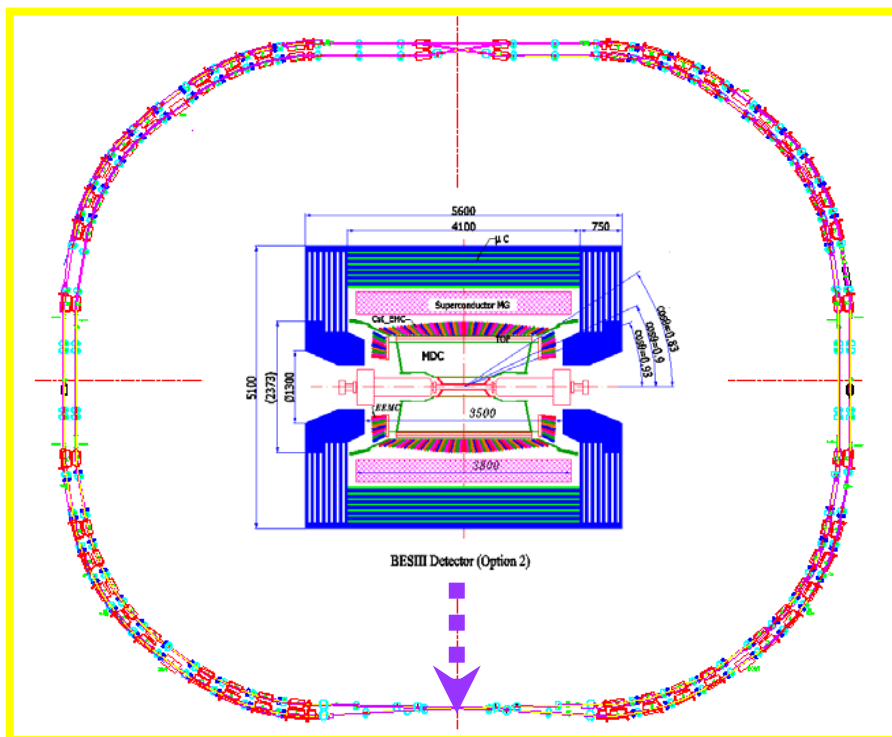Hebden Bridge (UK), 13-19 September, 2007

Contents

- The Experiment
- MC software
- Current status
- Performance
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- Summary

BEPCII Project
BEPC - Beijing Electron Positron Collider

BESIII Detector (Option 2)

- Beam energy 1~2.5 GeV

- e^+e^- multi-bunch collider

- Designed peak luminosity: 10^{33}cm^{-2} s^{-1} at Ecm=3.78GeV

- Scheduled to provide collisions in summer 2008

- Physics: tau-charm and charmonium physics

The BESIII Experiment
(BES - BEijing Spectrometer)

Main Drift Chamber (MDC)：

σ_{xy} = 130 μm

$\triangle$P/P = 0.5 %@1 GeV

$\sigma_{dE/dx}$ = 6-7 %

Super-conducting Magnet： 1.0 Tesla

TOF System：
σ_T = 90 ps barrel
110 ps endcap

Muon Chamber (MUC)：

RPC based

EM Calorimeter (EMC)： $\triangle$E/E = 2.5 % @ 1 GeV

$\sigma_{z,\phi}$ = 0.6 cm @ 1 GeV

BESIII MC Software

BOOST Project
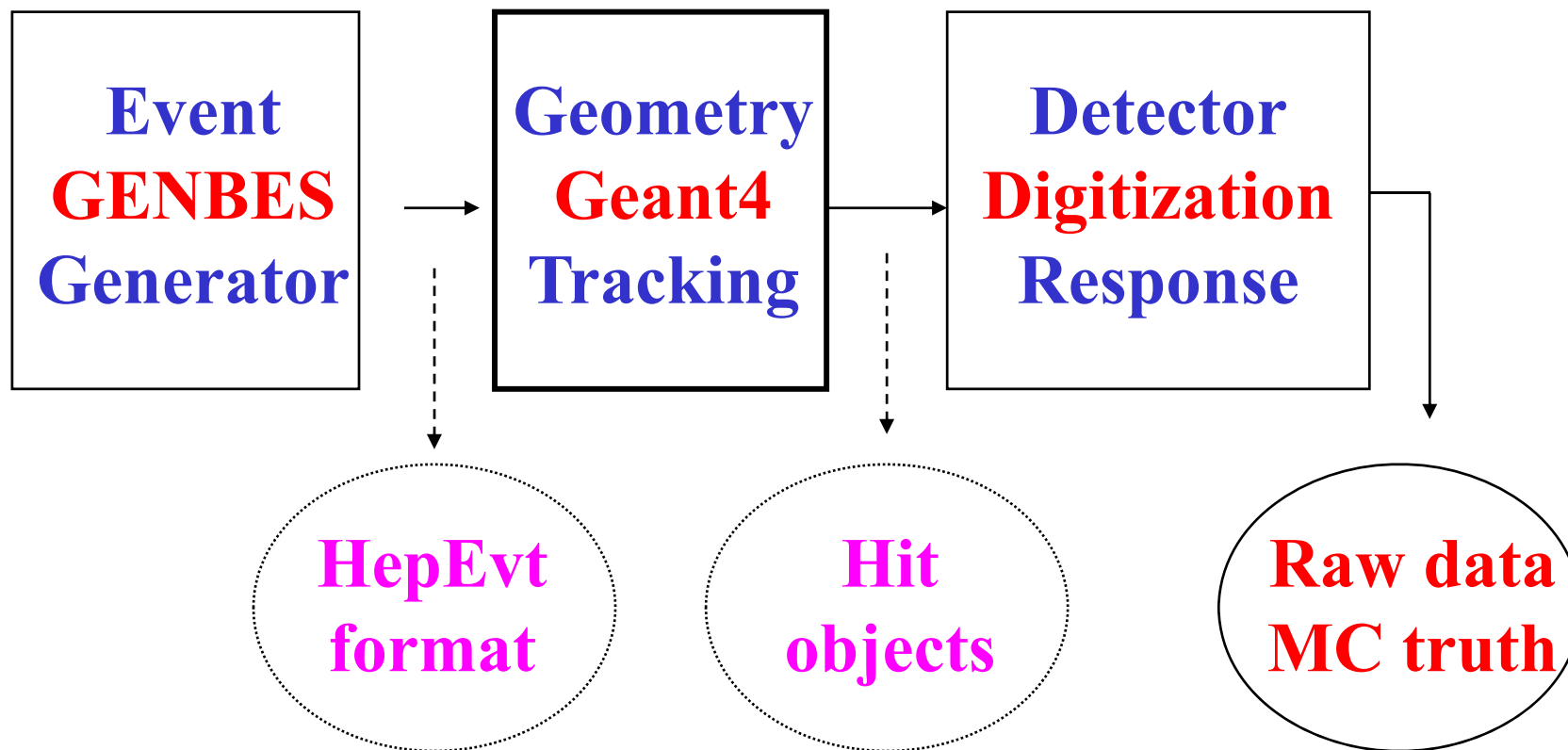
BESIII **O**bject **O**riented **S**imulation **T**ool

(proposal: August, 2002)

BES MC Software Evolution

BESI	BESII	BESIII
SOBER	**SIMBES**	**BOOST**
EGS	*G3*	*G4*
1980s	*1990s*	*2000s*

BOOST architecture

Event GENBES Generator	→	Geometry Geant4 Tracking	→	Detector Digitization Response

HepEvt format

Hit objects

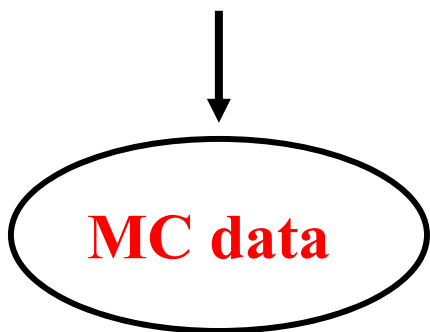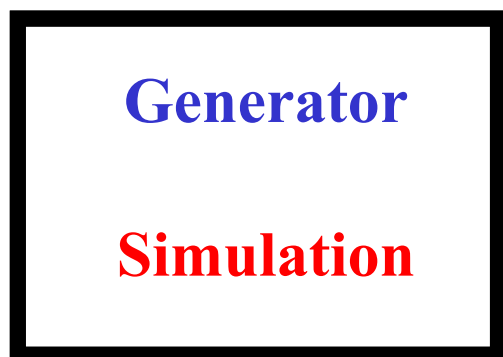Raw data MC truth

BESIII MC – main components

- Detector Description

- Event Generator

- Physics processes

- Magnetic field

- Digitization

- MC truth

- Data I/O

- Trigger simulation
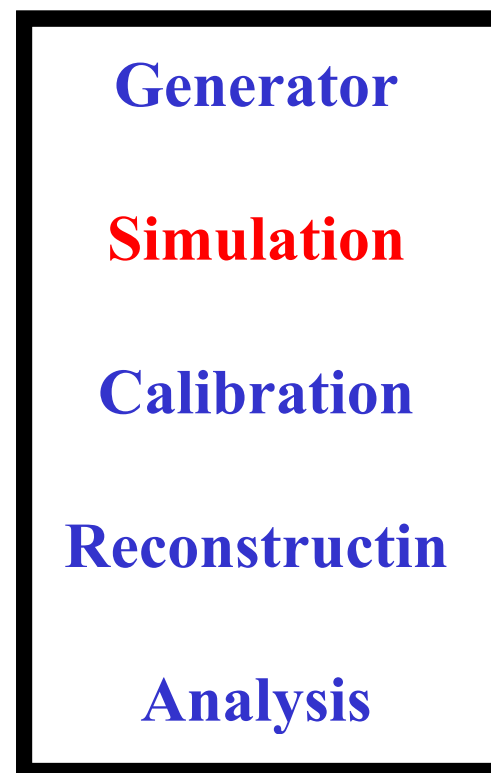
- Background mixing

BOOST working in BOSS
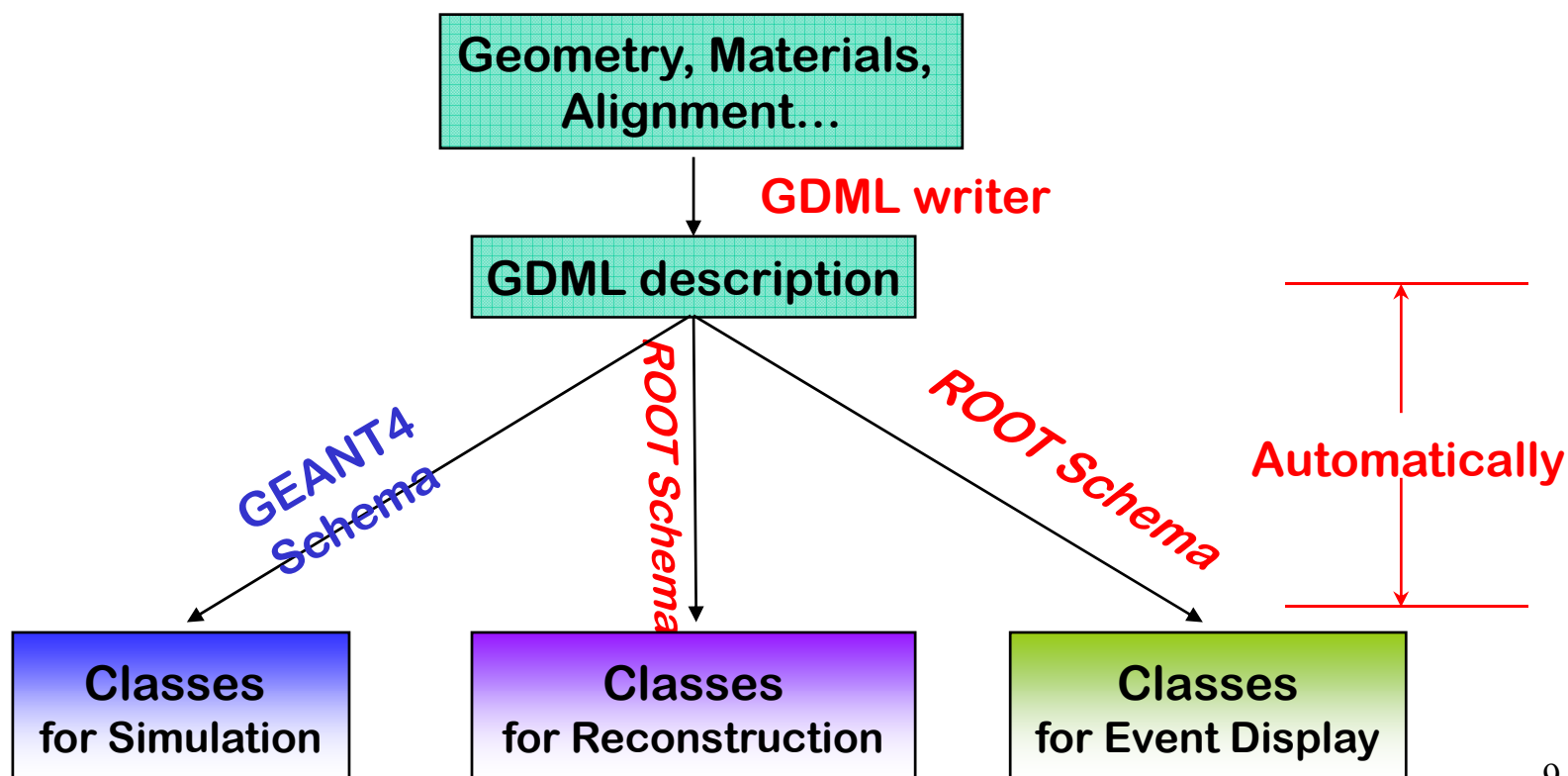# (BOSS – BESIII Offline Software System)

BOOST based on GEANT4

BOSS based on GAUDI

Generator

Simulation

MC data

Generator

Simulation

Calibration

Reconstructin

Analysis

BESIII Detector Description based on GDML

➢ GDML (Geometry Description Markup Language) is a kind of XML, developed by GEANT4 group.

➢ We expanded GEANT4 Schema and developed a new ROOT Schema (CPPGDML) for BESIII applications.

Geometry, Materials, Alignment…

GDML writer

GDML description

GEANT4 Schema

ROOT Schema

ROOT Schema

Automatically

Classes for Simulation

Classes for Reconstruction

Classes for Event Display

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Current status

- A stable full simulation program with Gean4.8.1.p1 finally works after a long test and bug fix

- Large MC data samples (~100M events) have been produced for reconstruction software tuning and physics reach study

- Physics results from simulation are quite reasonable and consistent with the design report

- We are trying hard to compare with some test beam results

The BEIII Detector
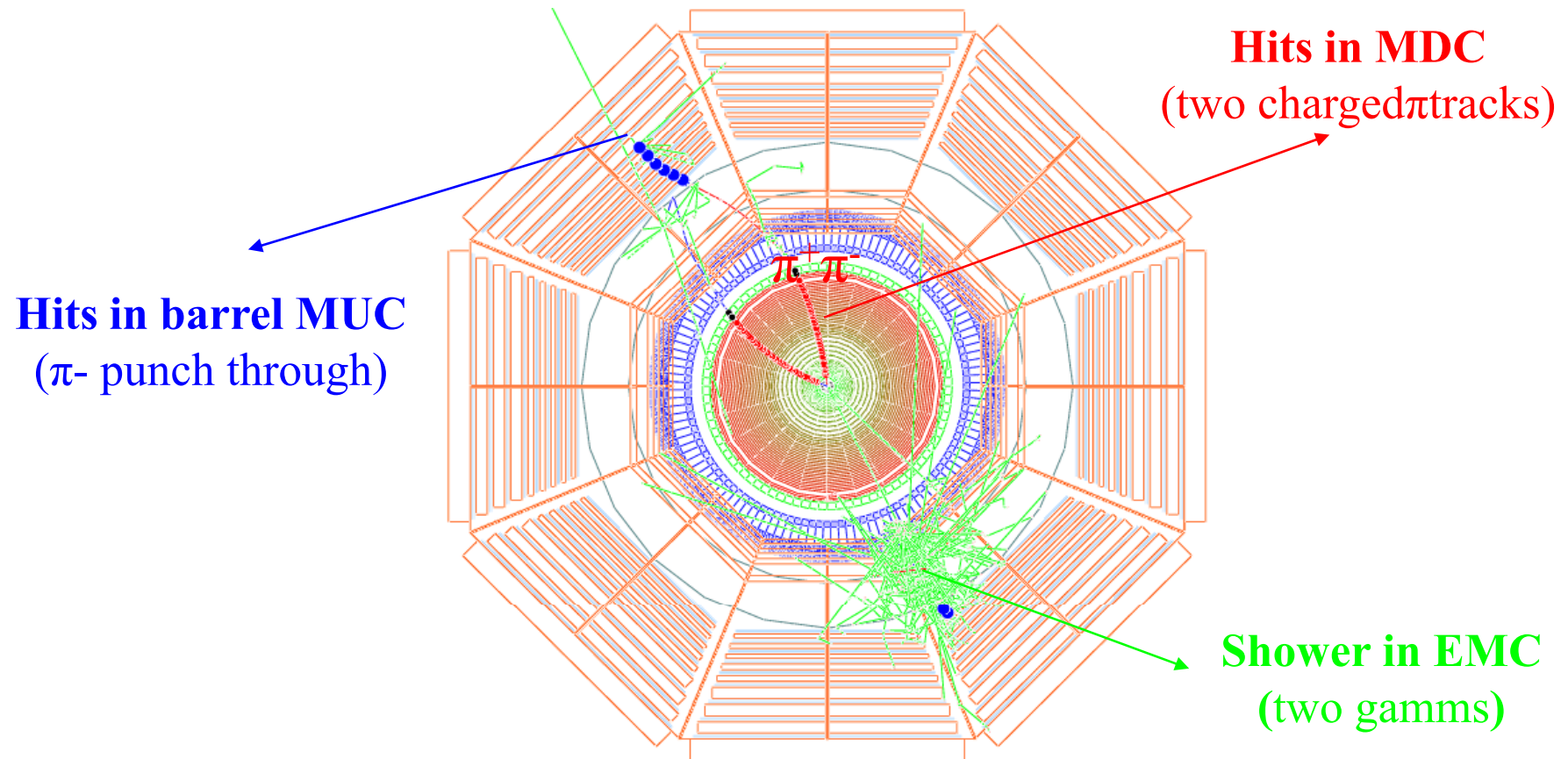## (constructed by Geant4)
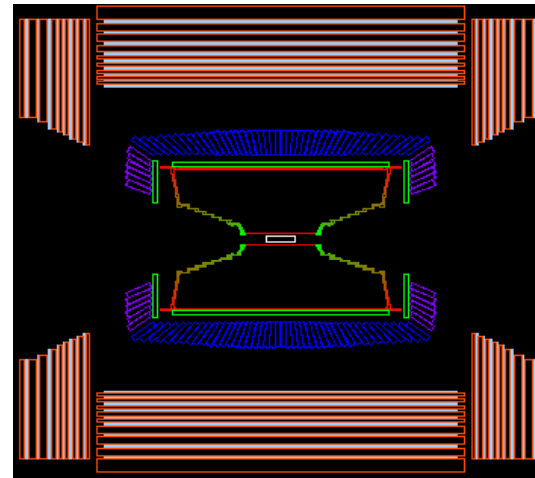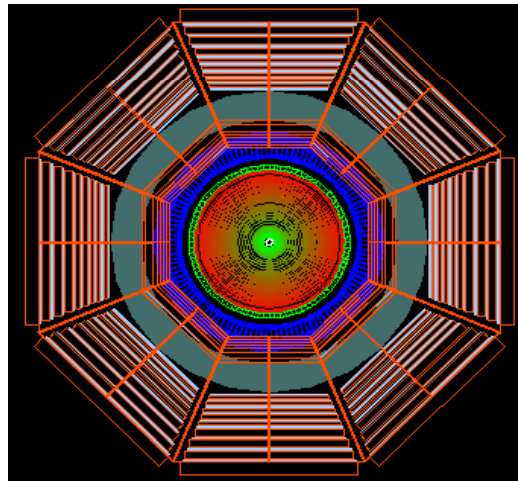
Barrel (from inner to outer):

    BMP, MDC, TOF, EMC, SCM, MUC

End-cap: TOF, EMC, MUC

An MC event in BESIII

$$J/\psi \rightarrow \rho^0 \pi^0 \rightarrow \pi^+ \pi^- \gamma\gamma$$

Hits in MDC
(two charged π tracks)

Hits in barrel MUC
(π- punch through)

Shower in EMC
(two gamms)

Performance – Memory usage

- ~ 80 MB memory needed for simulation

- For electromagnetic interaction, the memory growth is small in long runs

- For hadronic event simulation, using the hadronic physics list (for example LHEP/QGSP), the memory growth rate is about 3 MB / 10000 events

- No memory leak detected in our application
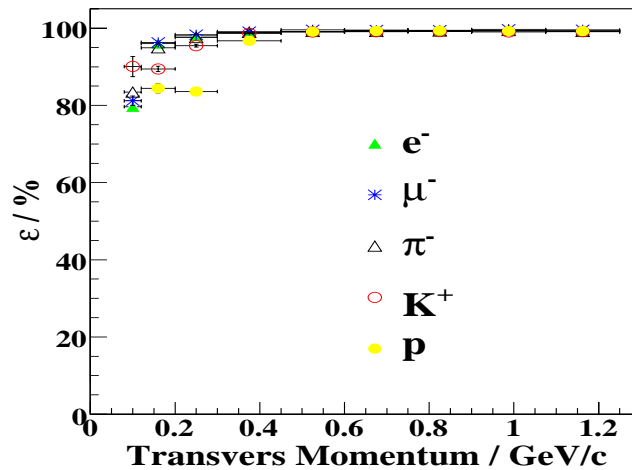
Performance – speed and stability

CPU time (s) for one event on Besfarm7 (PIII/933MHz)		
Event type	SIMBES (BESII+G3)	BOOST (BESIII+G4)
ee -> $\mu\mu$ (at J/ψ)	0.122	0.189
J/ψ->$\rho\pi$	0.471	0.763
ee -> ee (at J/ψ)	0.736	1.224

- BESIII+G4 is slower (by 1.5) than BESII+G3

  Not direct comparison of G4 and G3! Detectors are different
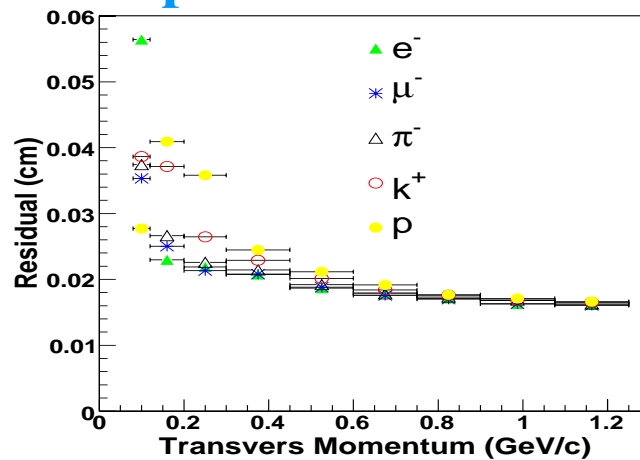
- Stable run for 1M events of each type, no crash or dead-loop
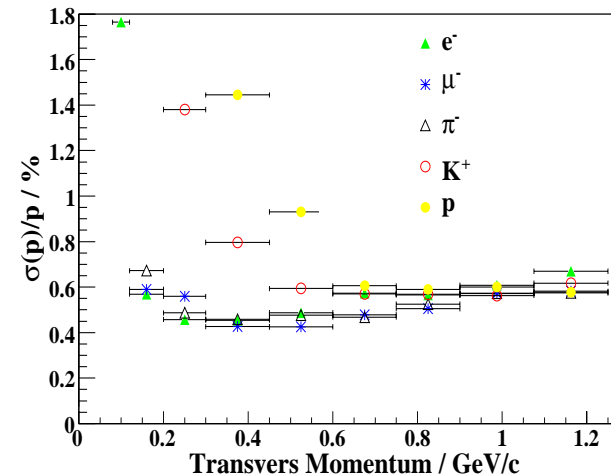
Tracking efficiency

Single particle Pt:

50MeV/c~1.25GeV/c

No momentum
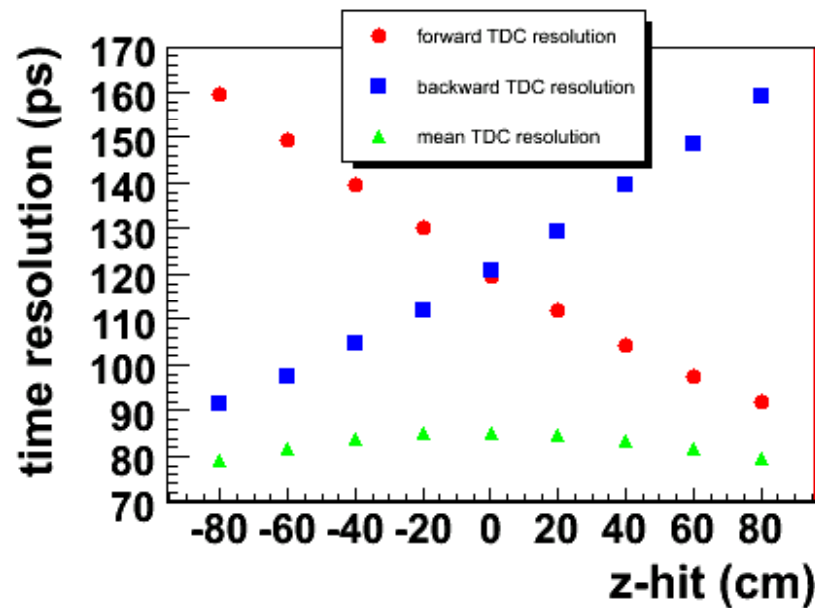   correction on dE/dx

Spatial resolution

Momentum resolution

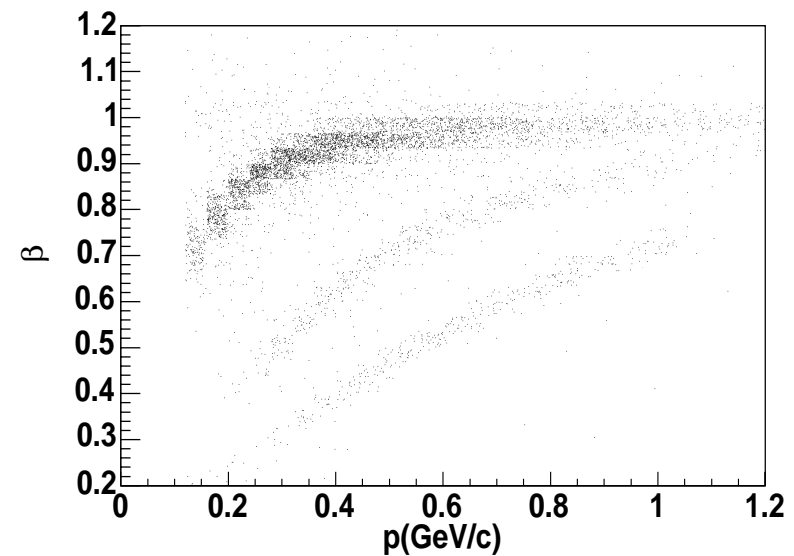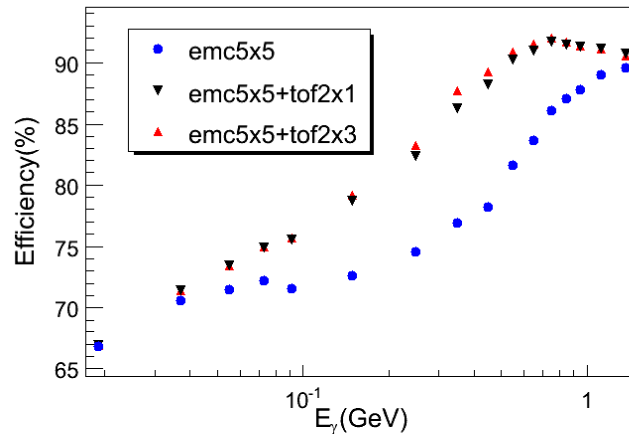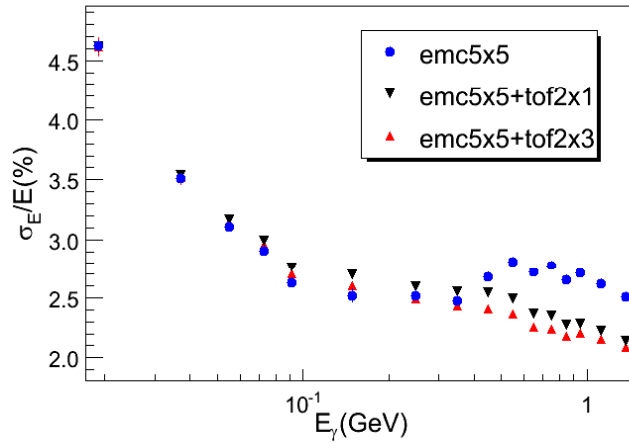

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TOF performance check (Sim+Rec)

time resolution at z=0: 85ps

(1GeV electron)

beta vs momentum

(e, μ, π, K, p)

$$J/\Psi \to \gamma\eta, \eta \to \gamma\gamma$$

Emc5x5: **15.1**MeV
Emc5x5+Tof2x1: **13.2**MeV

$$E_{peak} - 4\sigma_E < E_{rec} < E_{peak} + 2\sigma_E,$$
$$|\theta_{rec} - \theta_{init}| < 3\sigma_\theta,$$
$$|\phi_{rec} - \phi_{init}| < 3\sigma_\phi.$$
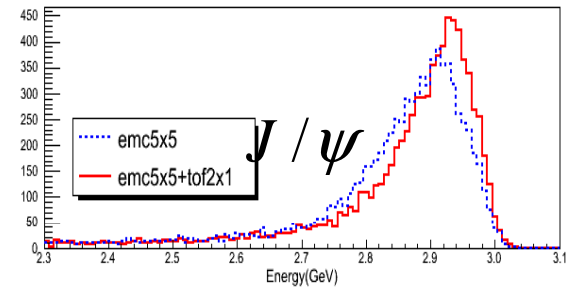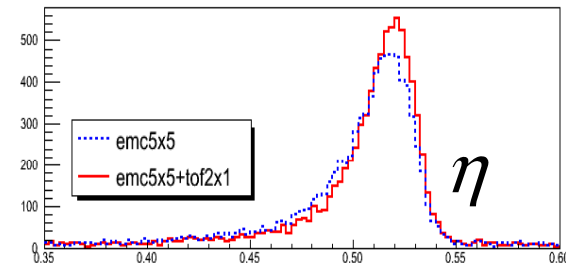
Emc5x5: **63.7**MeV
Emc5x5+Tof2x1: **52.9**MeV

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BESIII MC performance

Sub-detector		Designed	MC
MDC	spatial	130um	130μm(smeared as designed)
			110μm(smeared based on beam test)
	momentum	0.46%@1GeV	0.45%(σ_{xy}=130μm)
			0.41%(σ_{xy}=110μm)
	dE/dx	6-7%	6%
TOF	time	80-90ps	85ps
EMC	energy	2.5%@1GeV	2.3%
	spatial	6mm@1GeV	5.8mm
MUC	μ ID	95%	96%
	π miss_ID	6%	6.2%

J/Ψ->$K_S K_L$ with BESII and BESIII

BESII 58M J/ψ data

signal

MC Bkg
$K^{*0}K_S$+c.c.

Ks mass sidebands

BESIII MC sample
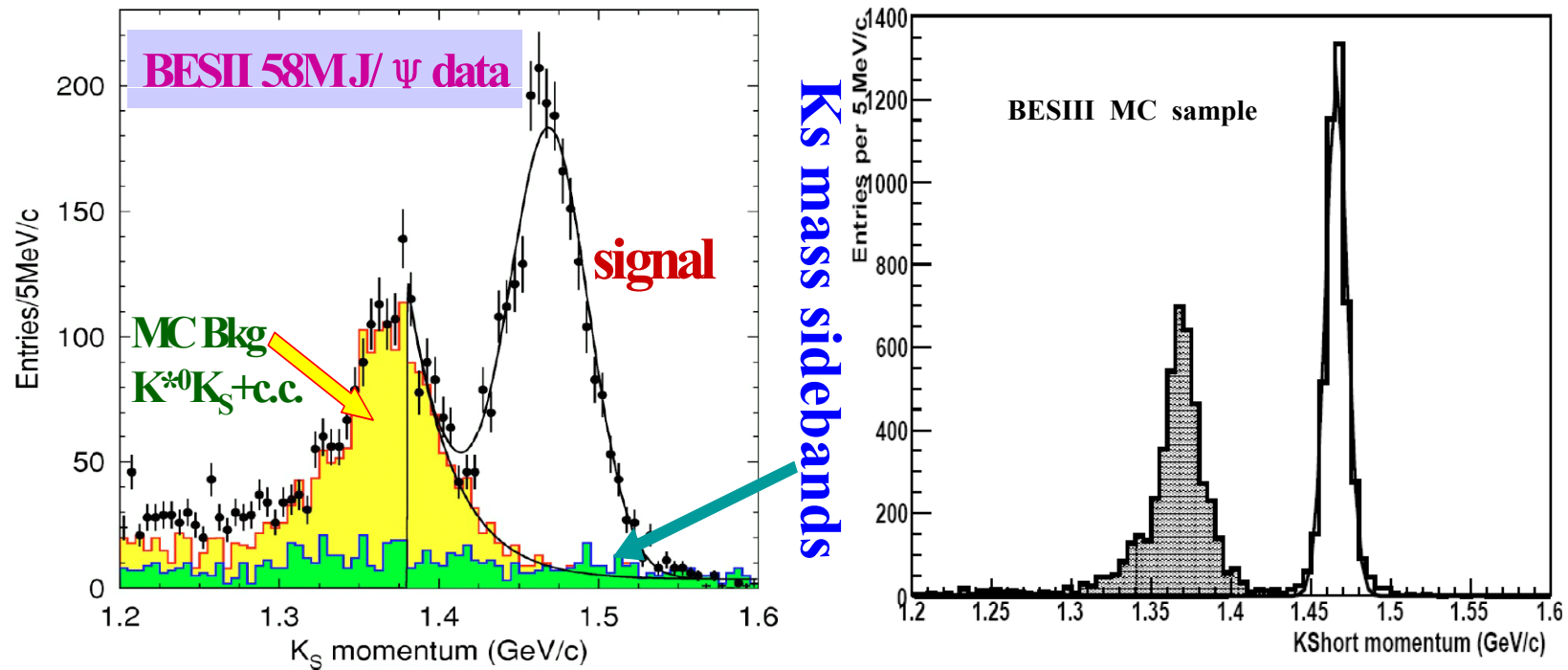
Ψ(3770) -> D0 D0bar
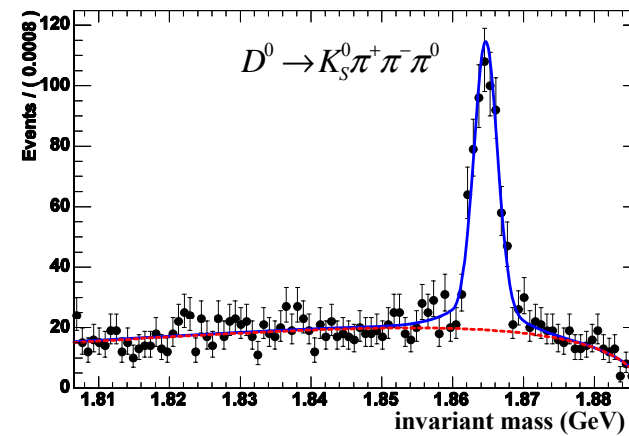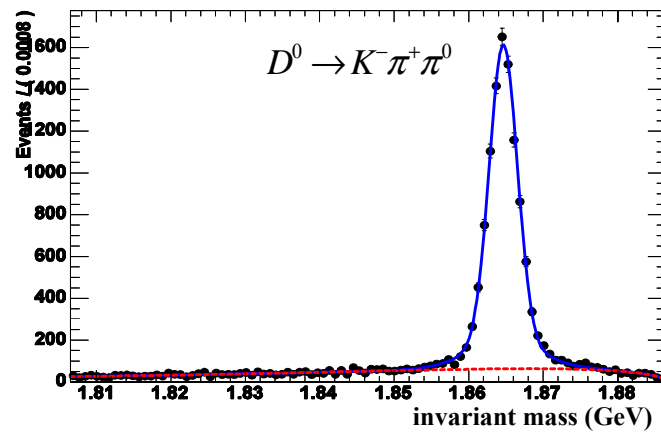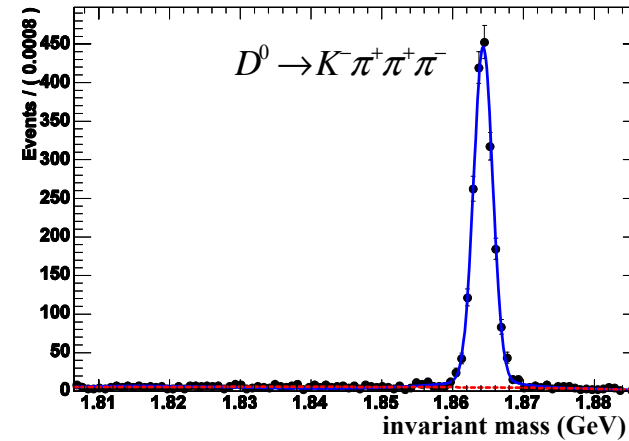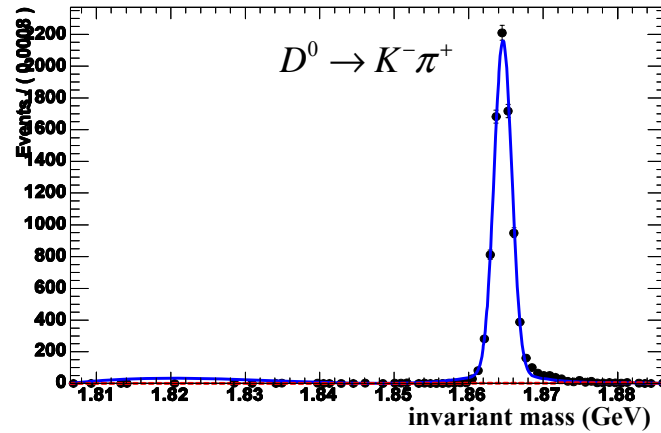
Singly tagged channels

Physics study at BESIII (MC)

Semileptonic Decays

$D^0 \to K^- e^+ \nu$

$U_{miss}=E_{miss}-P_{miss}$

$D^0 \to \pi^- e^+ \nu$

$D^0 \to K^- e^+ \nu$

$U_{miss}=E_{miss}-P_{miss}$
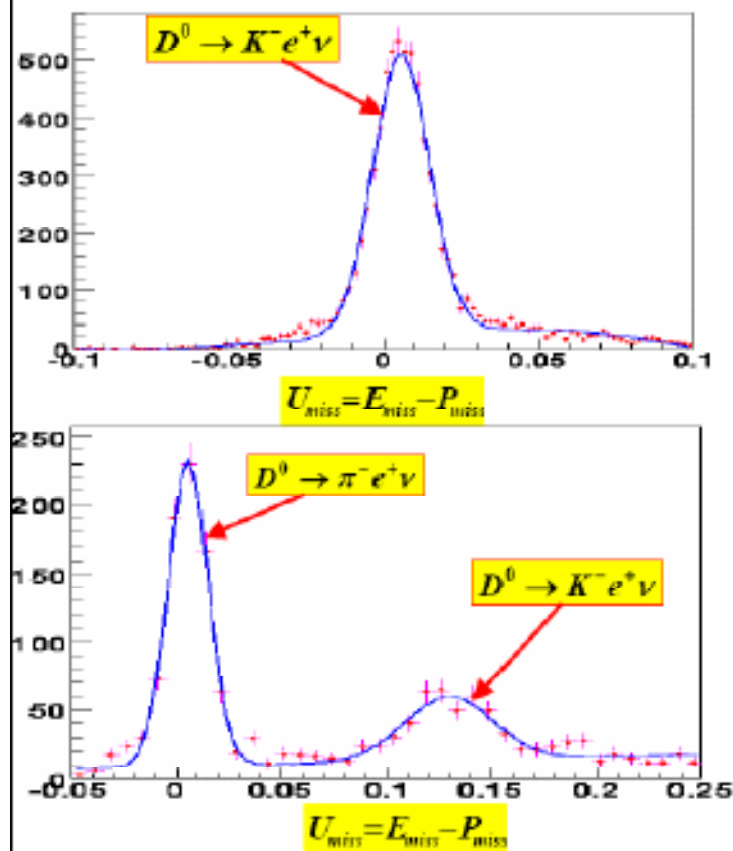
BOSS Version 6.0.2

$4.9 \times 10^6 \quad e^+ e^- \to DD$

$(L \approx 800 \text{ pb}^{-1})$

$N_{tag} = 359884 \pm 600$

$N(D^0 \to K^- e^+ \nu) = 5528 \pm 80$

$\varepsilon = 45 \%$

$Br(D^0 \to K^- e^+ \nu) = (3.41 \pm 0.05)\%$

$\delta B / B = 1.5\%$ **Input: 3.58%**

$N(D^0 \to \pi^- e^+ \nu) = 707 \pm 29$

$\varepsilon = 48 \%$

$Br(D^0 \to \pi^- e^+ \nu) = (0.41 \pm 0.02)\%$

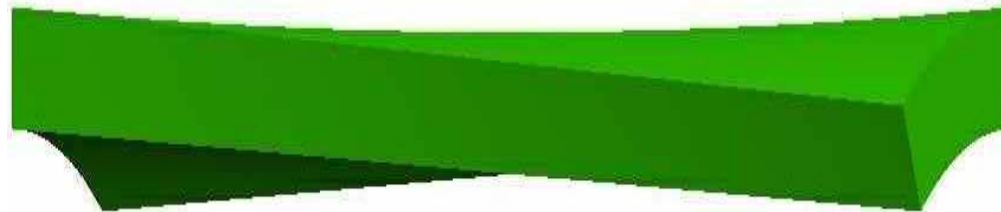$\delta B / B = 4.1\%$ **Input: 0.36%**

Some issues

G4TwistedTubs

We use it to describe the stereo cell structure of the drift chamber

At some points inside the volume, the calculated
DistantanceToOut is infinite,
which cause the program to crash!!!

Temporary solution: simply discard the problematic tracks

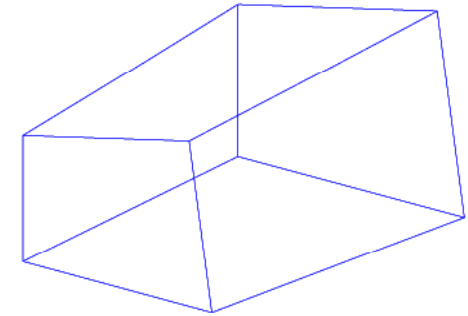Bug reported to G4 group, Problem# 899,
unsolved

Irregular Box

Developed in G4 standard by Keven L. Ates.
Not a G4 Solid now!
Very useful to construct irregular boxes.
Some G4 users are using it!

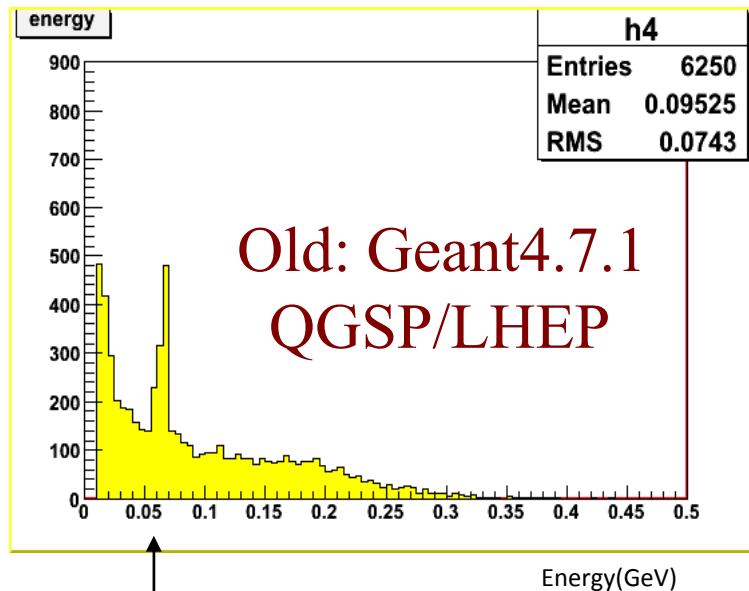We use it to describe irregular shapes of crystals

Sometimes, it needs modification with new G4 release

Question: Is it possible to import the solid to G4?

G4PionMinusAbsorbtionAtRest

Reconstructed energy in EMC for π^- (p= 100~500MeV)

Old: Geant4.7.1
QGSP/LHEP

New: Geant4.8.1.p1
QGSP/LHEP

a peak around 70 MeV
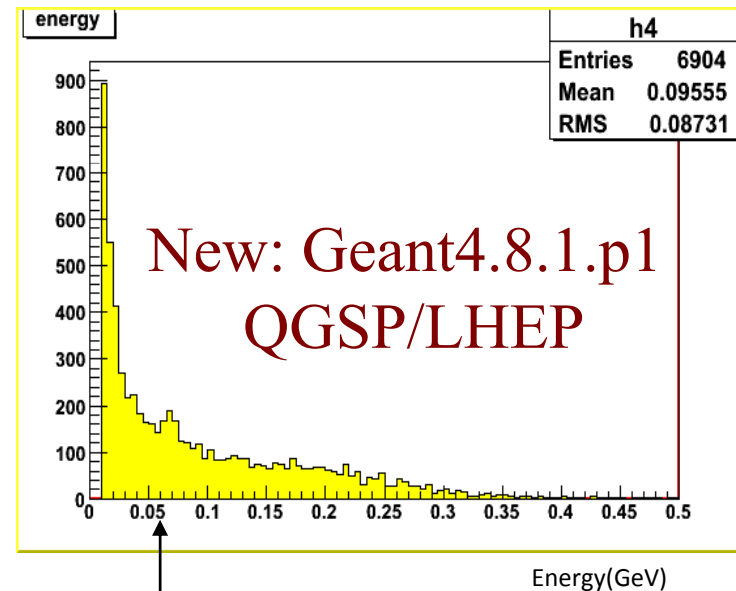
still a bump at 70 MeV
fake photons increase:~10%

$$\pi^- + p \rightarrow \pi^0 + n ?$$
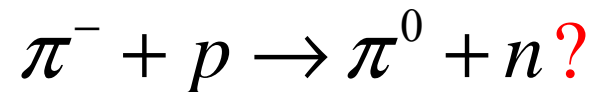
No peak or bump for G4PiMinusAbsorbtionAtRest!

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Inclusive ψ(2S) decays
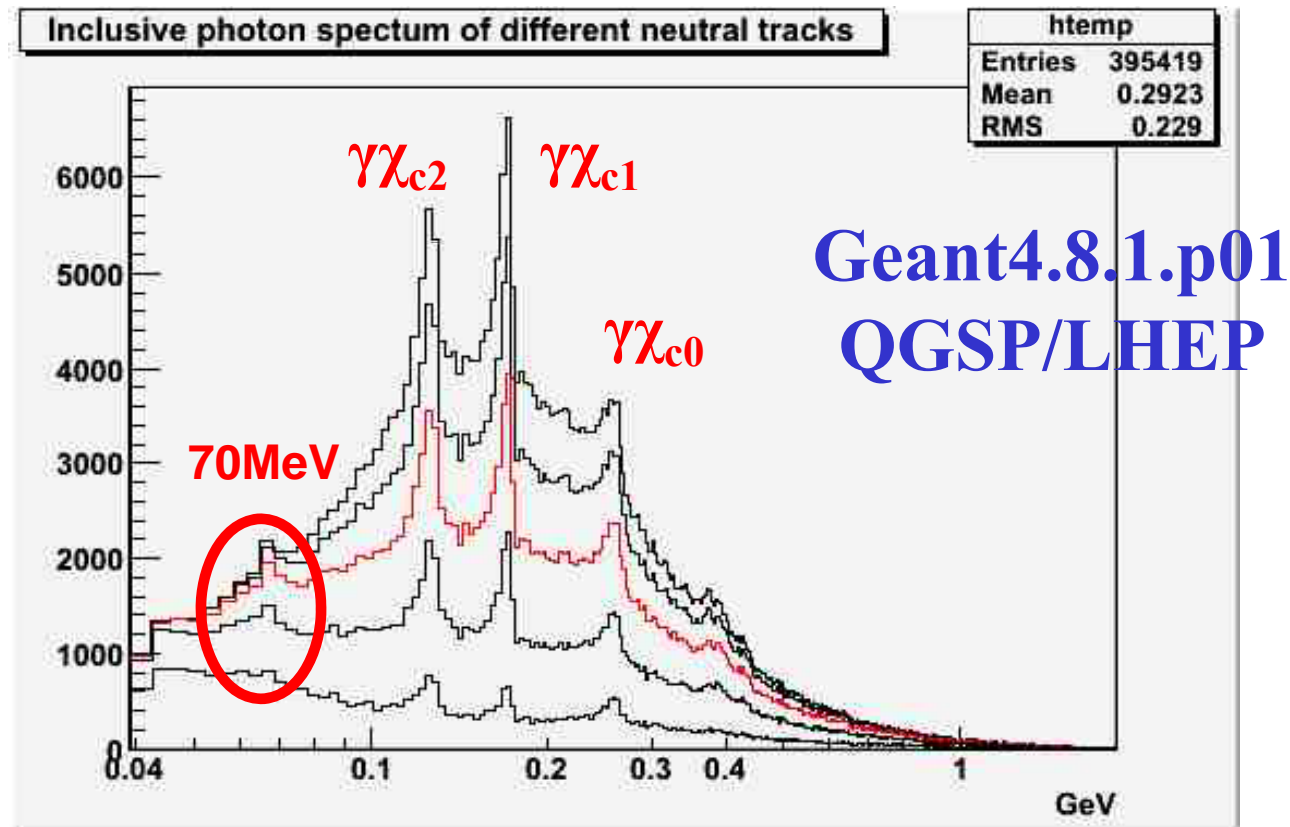
From the upper to the lower : good neutral track < 10,5,4,3,2

G4MuMinusCaptureAtRest

The simulation goes to infinite loop due to wrong momentum calculation –Modified.

Bug reported to G4 group, Problem# 891 solved in Gean4.8.2

NaN problems from:
G4HadronElastic
G4UHadronElasticProcess
G4LEAntiProtonInelastic
protected

Physics list - QGSP

Problem: (you can verify it from novice example N03)

RUN1 (500 evts) +using saved random status RUN2 (500 evts))
RUN3 (1000 evts) with same initial random status as RUN1

1000 evts in RUN1+RUN2 is not identical to 1000 evts in RUN3

No such kind problem is observed in standard EM

Problem found in Geant4.8.1
But still exists in Geant4.9.0

Problems with GDML2.8.0

- Only G4Box and G4Tubs can be parameterized in GDML, we add G4Trap parameterization

- Fix a bug in Writer for G4TwistedTubs, which is not compatible with Subscriber

- Fix a bug for G4UnionSolid, active and passive methods are mixed for Subscriber and Writer

Future considerations

- Move to recent G4 release – Geant4.9.0.p1/GDML2.9.0, we have about one year behind Geant4 development

- Compare different hadronic packages, physics validation below 2 GeV, we will try Babar's hadronic package first

- Improve simulation speed, BESIII event rate is about 3KHz , this depends heavily on Geant4 improvement

- Study digitization process, this is also very important to have good agreement between data and MC

Summary

- **The BESIII Simulation with Geant4 works successfully**

- **Mass production starts for software and physics study**

- **Some bugs found and reported to Geant4 group**