SuperKEKB/Belle II experiment

Status of GEANT4 simulation

Takanori Hara (KEK)

Contents

B-Factory aimed for

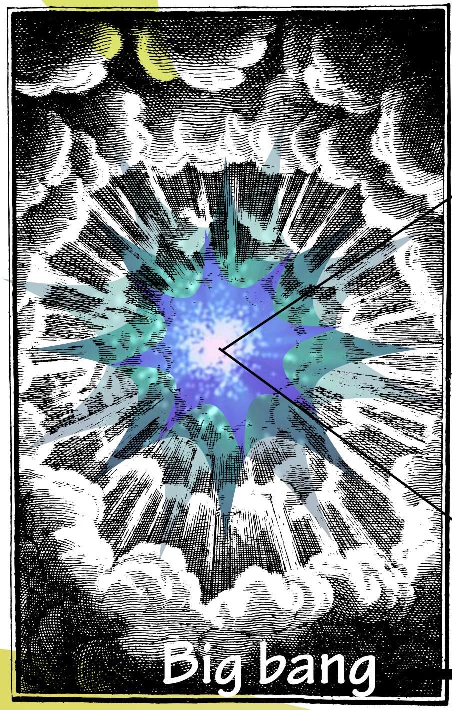
KEKB+Belle

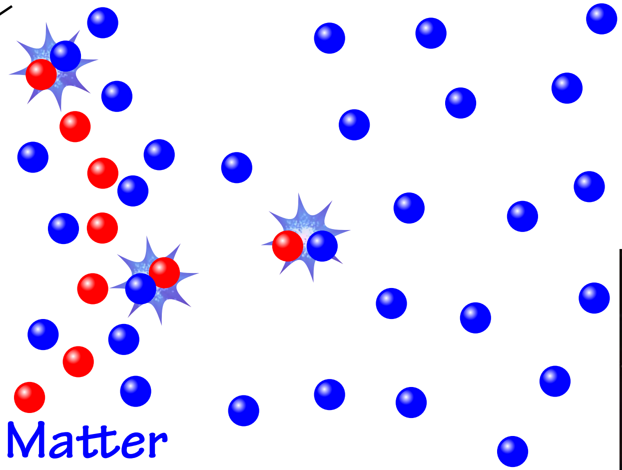
Kobayashi +Maskawa

Matter excess of Universe

Dark matter

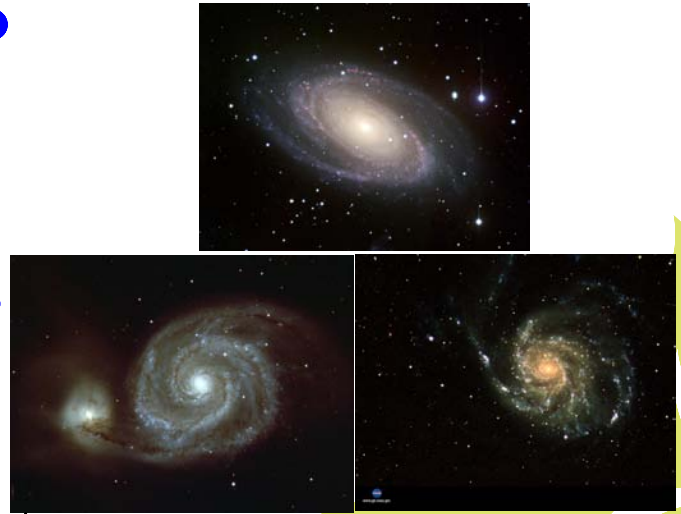
Origin of mass ...





Matter

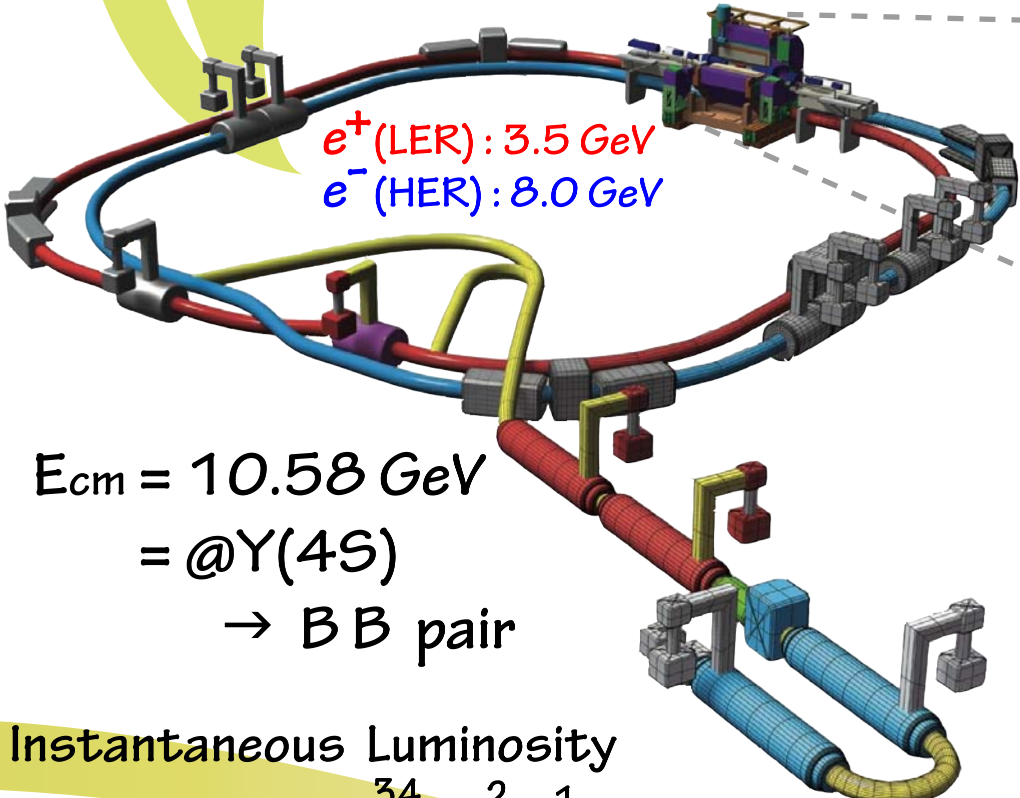
Antimatter



Now (a 13.7 billion years later)

KEKB Accelerator + Belle Detector

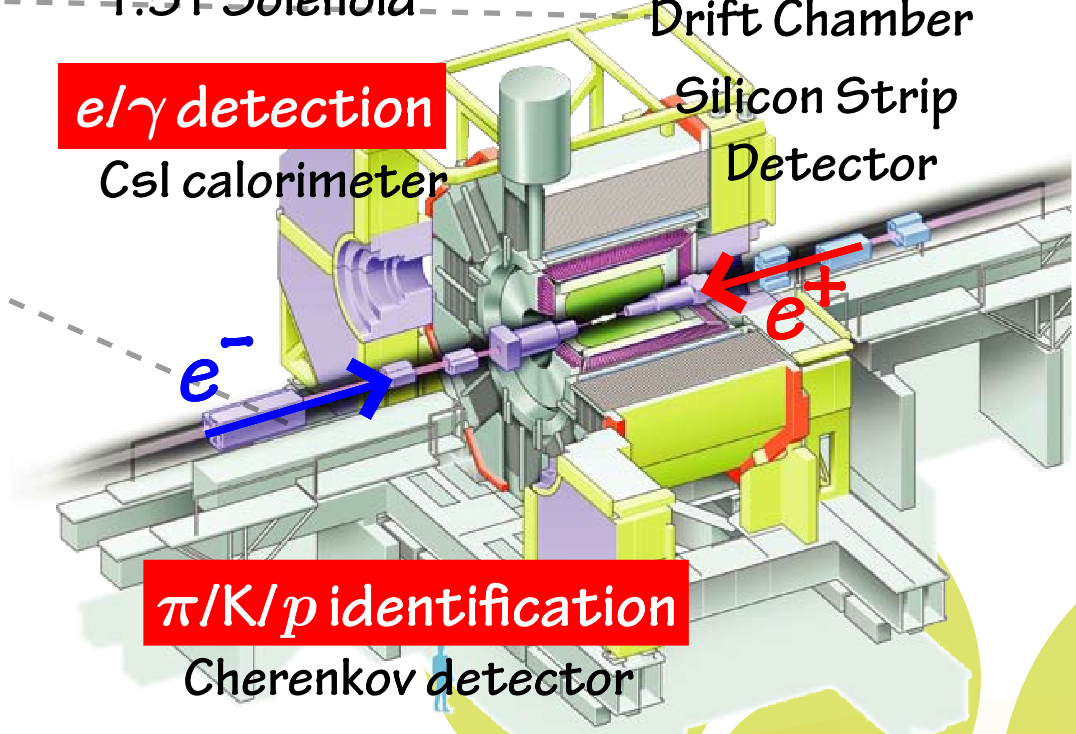
Asymmetric energy e^+e^- Collider



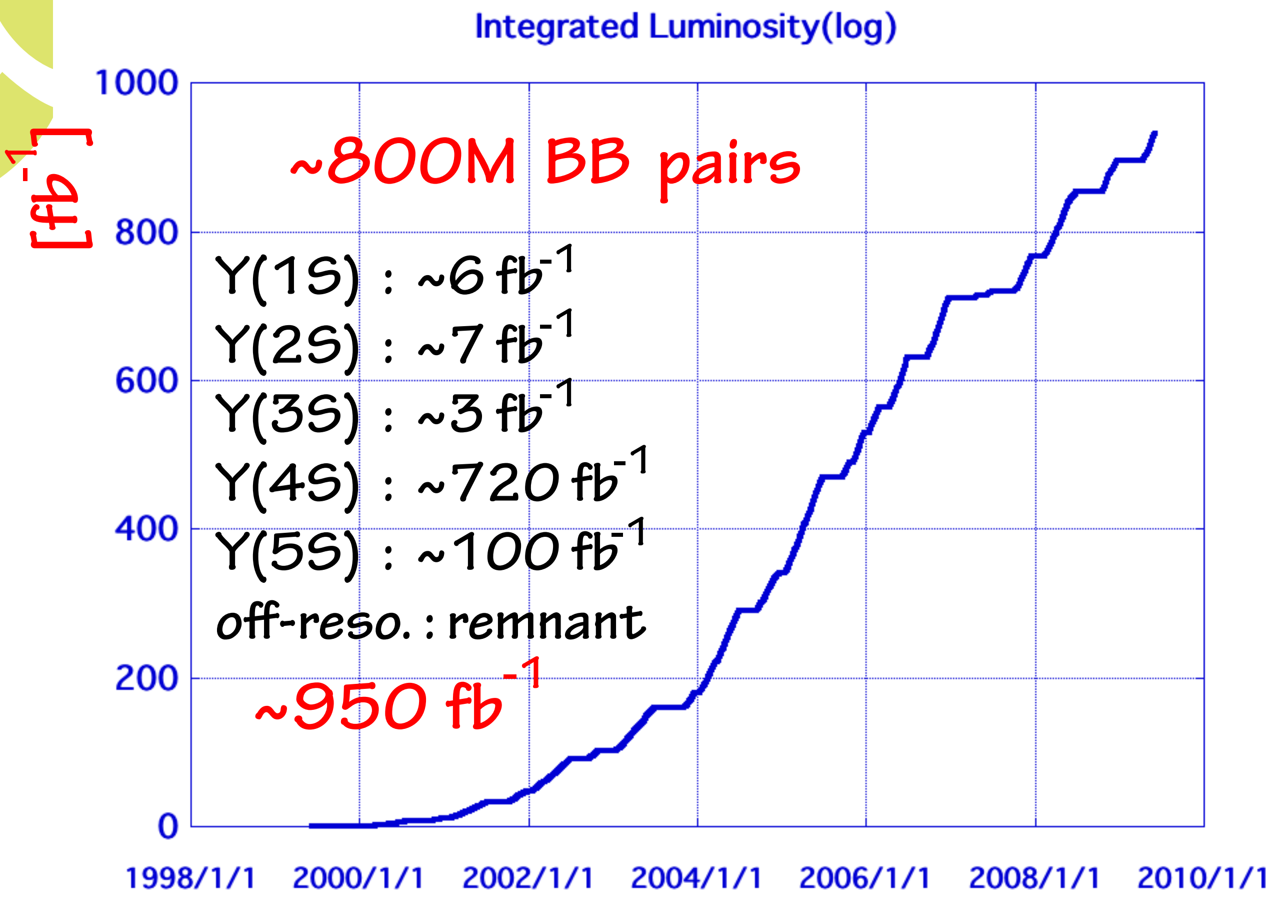
E_{cm} = 10.58 GeV
= @Υ(4S)
→ B B pair

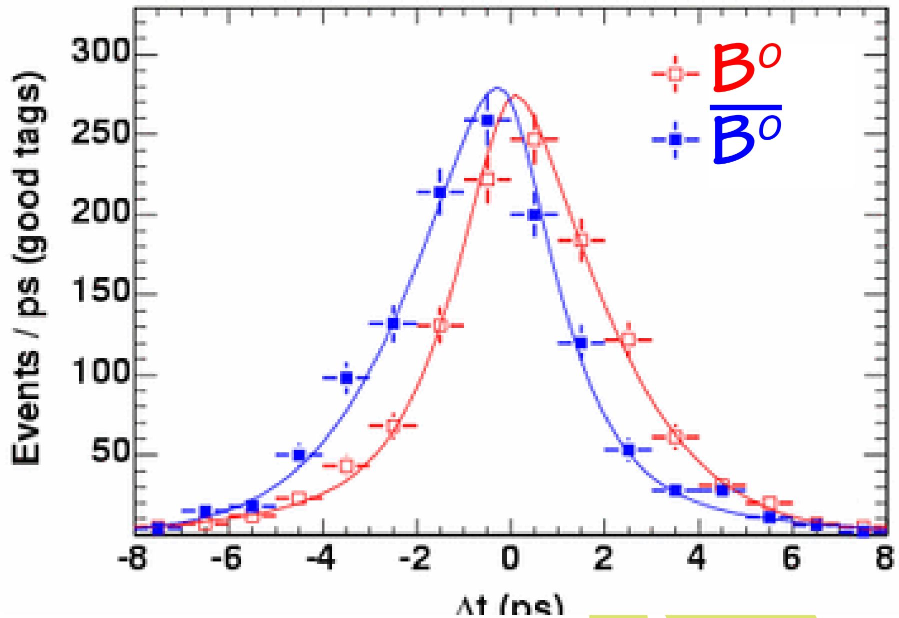
Instantaneous Luminosity
$2.108 \times 10^{34} cm^{-2} s^{-1}$
(twice of the design value)

Large-solid-angle magnetic spectrometer



Confirmation of CP violation



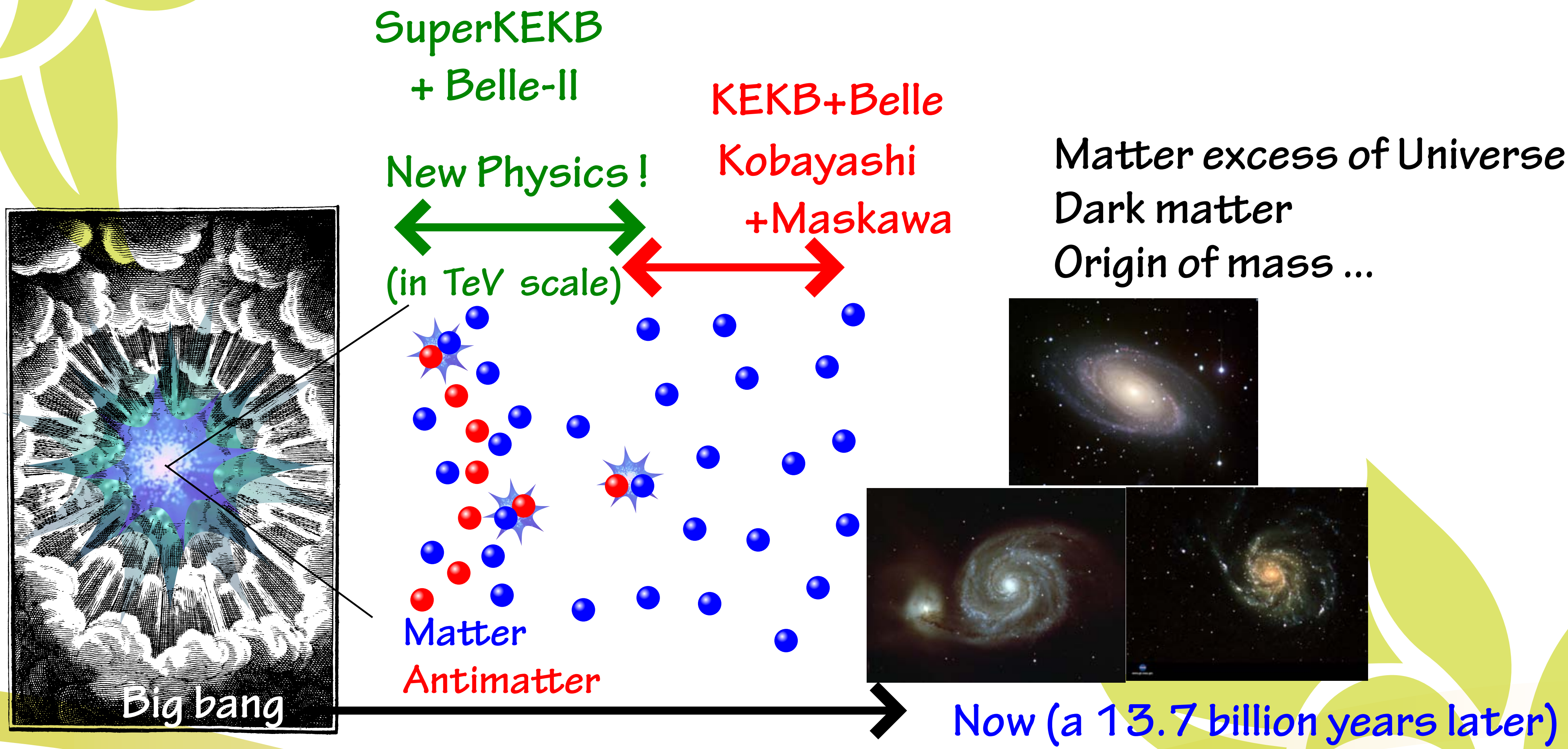


Kobayashi-Maskawa theory is confirmed.

But this is not enough to explain the Universe

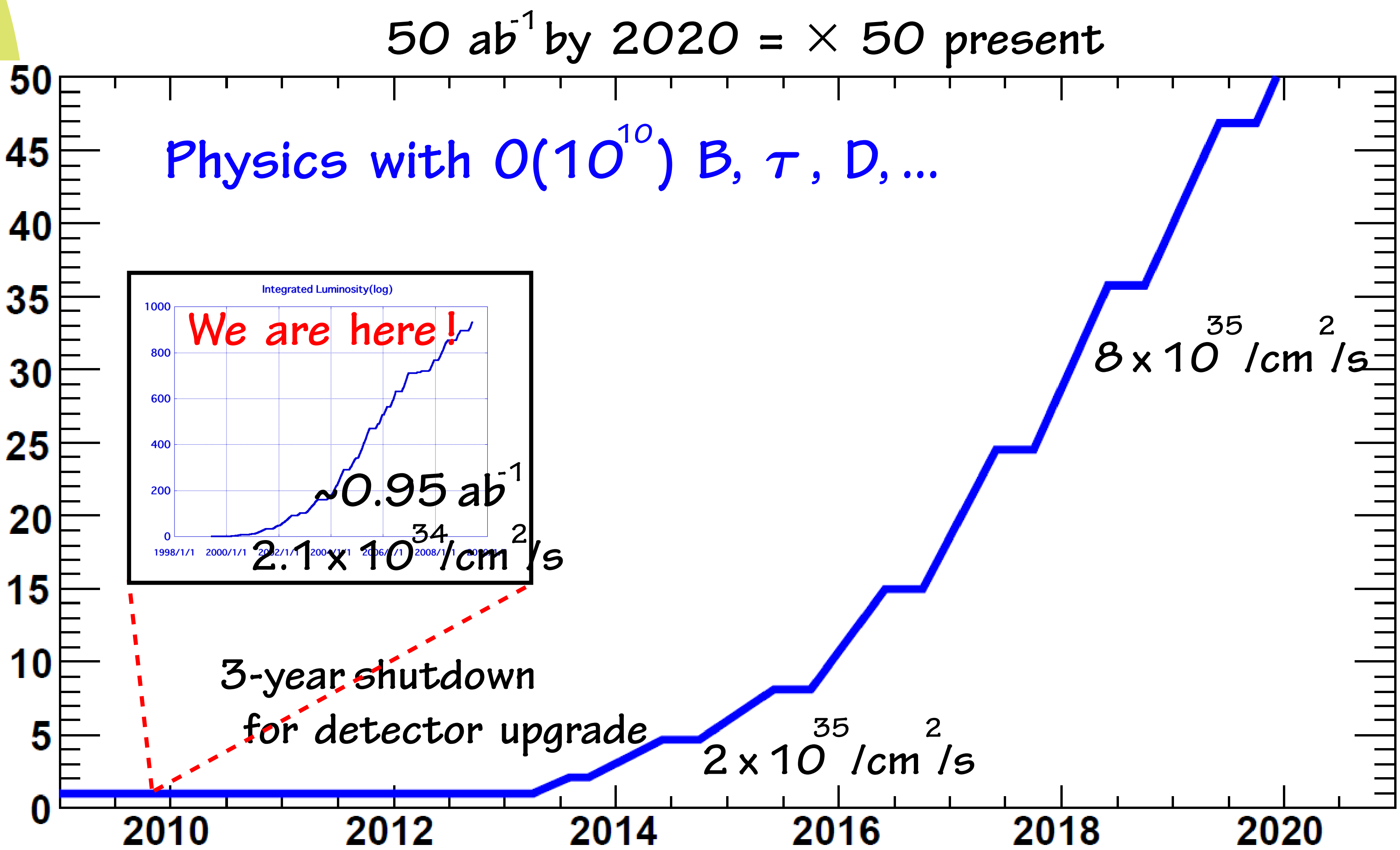
Other source of CP violation is implied ...

New B-Factory aims for



In order to see
the CP violation in the earlier stage of Universe

Luminosity Prospect



Detector Upgrade

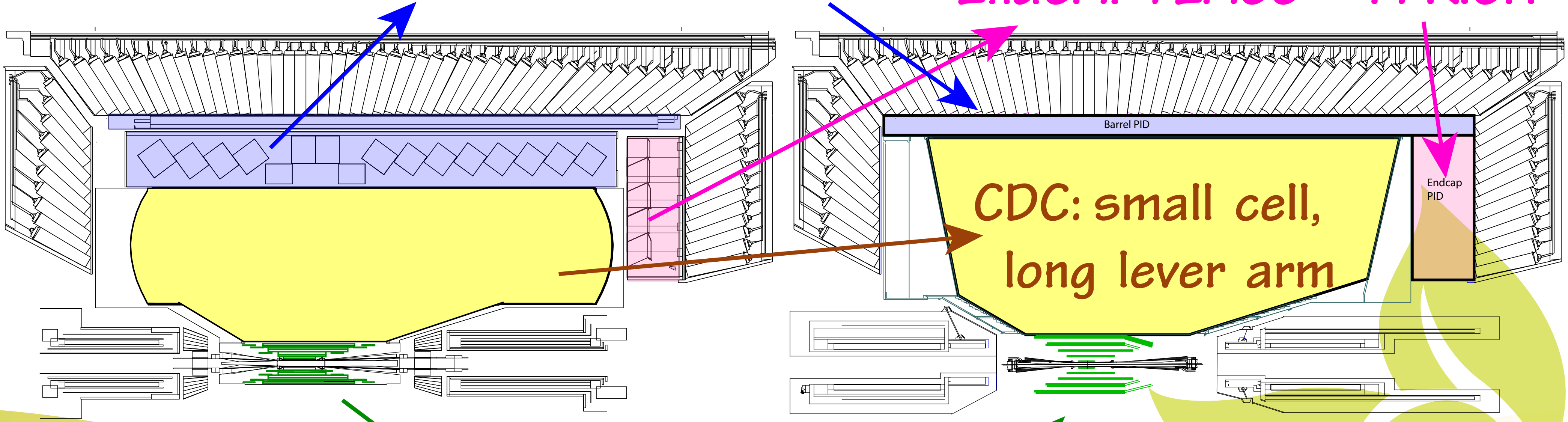
Belle

Beam BG tolerant
low material budget
better performance

Super Belle

Barrel : TOF+ACC → TOP

EndCAP : EACC → A-RICH



4-lyr SVD → 6-lyr (2-lyr PXD + 4-lyr SVD)

ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

Geant4

KEKB/Belle will continue taking data until 2010 ??
SuperKEKB/Belle II will start taking data from 2013

- IR Design (e.g. beam background simulation) : standalone G4
- Detector Optimization (e.g. PID, tracking) : w/ soft. frameworks

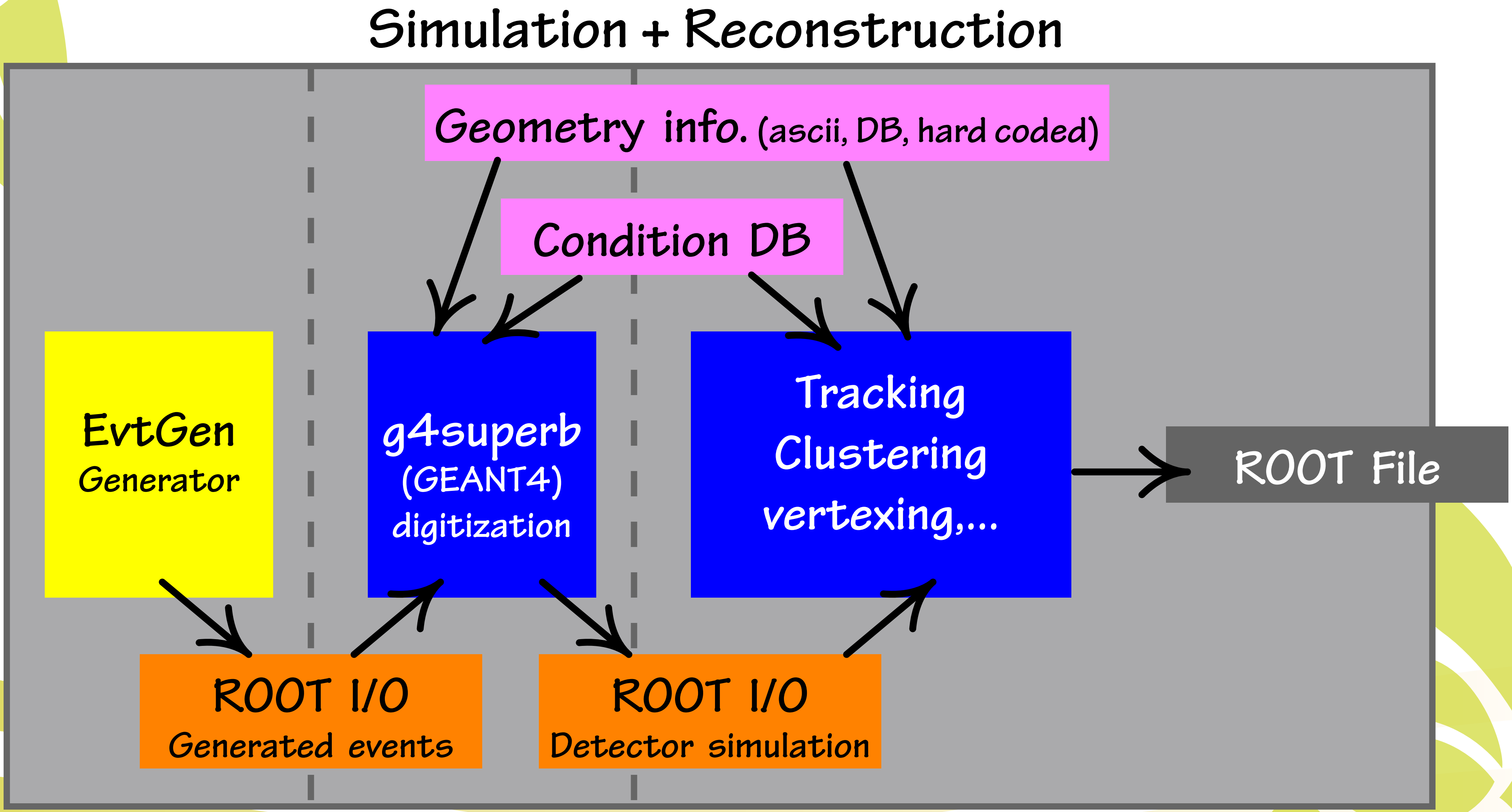
But now we have two software frameworks at this moment,

- roobasf (upgraded version of Belle Analysis Frame)
- ILC framework (Mokka/Marlin)

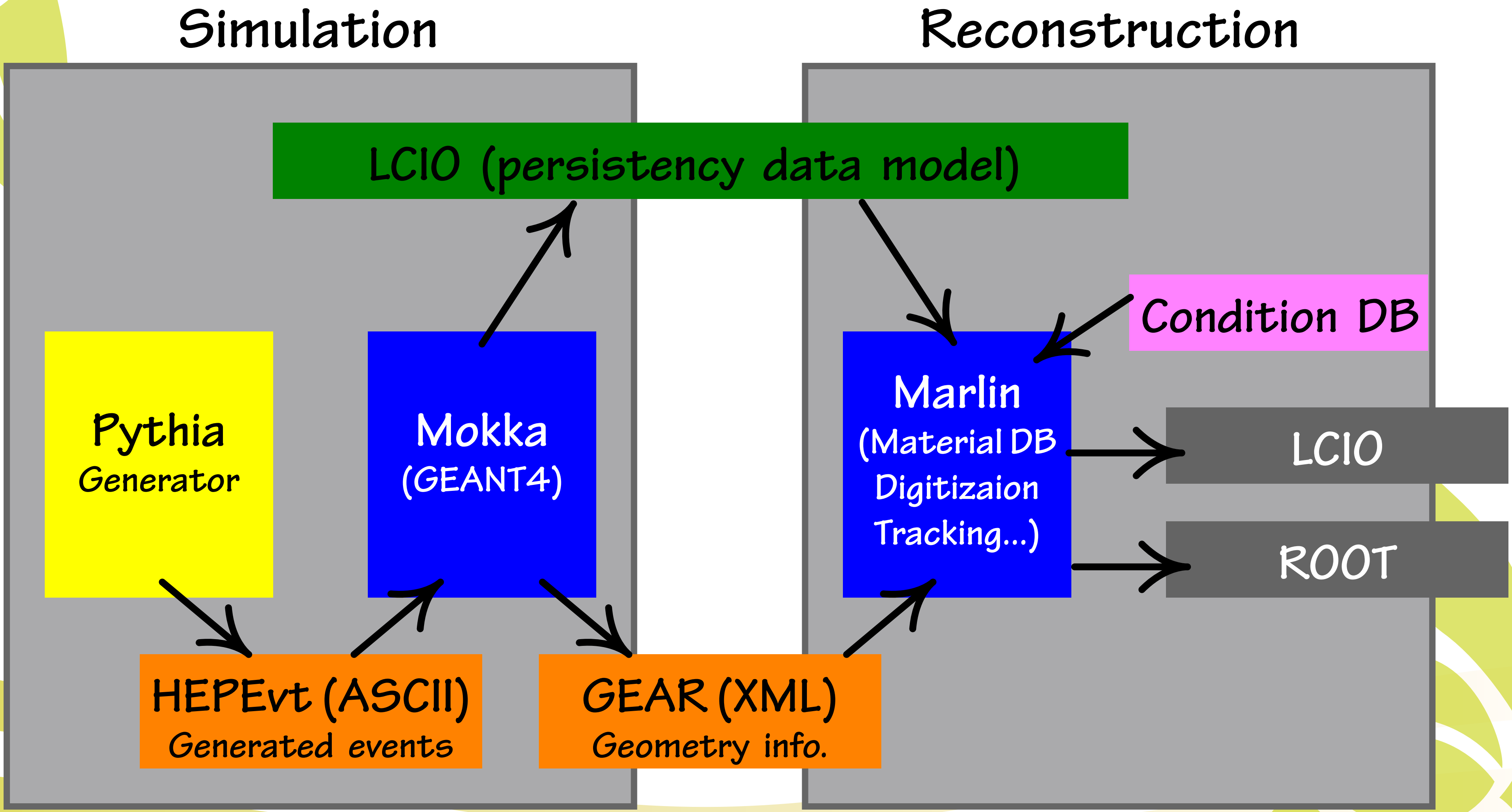
Geant4 is implemented in each framework,
but there is no campatibility

→ combining good features from both sides ...

roobasf Framework



ILC Software Framework



Standalone Geant4 simulation or Geant4 with roobasf

Detector Background Component

Background component	w.r.t current Belle
Synchrotron Radiation (upstream)	Lower ? Higher ? Smaller beam size at Q but large bending magnet
Synchrotron Radiation (back-scatter)	Much lower → 1/800 No QCS bending
Radiative Bhabha	Much lower → 1/40 Larger crossing angle but no QCS bending
Touschek (intra-beam)	Much higher → x 20-30 Very small beam size
Beam-gas interaction	Higher Vacuum around IP will be worse Higher current (x 10-100)

Beam-gas simulation

Beam-gas scattering : Bremsstrahkung $eN \rightarrow \gamma eN$ and Coulomb $eN \rightarrow eN$

1) Upstream Beam-gas scattering

Upstream beam-gas scattering causes beam energy loss.
Then such beams may hit the beam-line component near IP
and produce particle showers → Affects to many (~all) detectors

This BG depends on the upstream vacuum level, beam-current, beamline optics, and beampipe apertures

2) Beam-gas scattering near IP

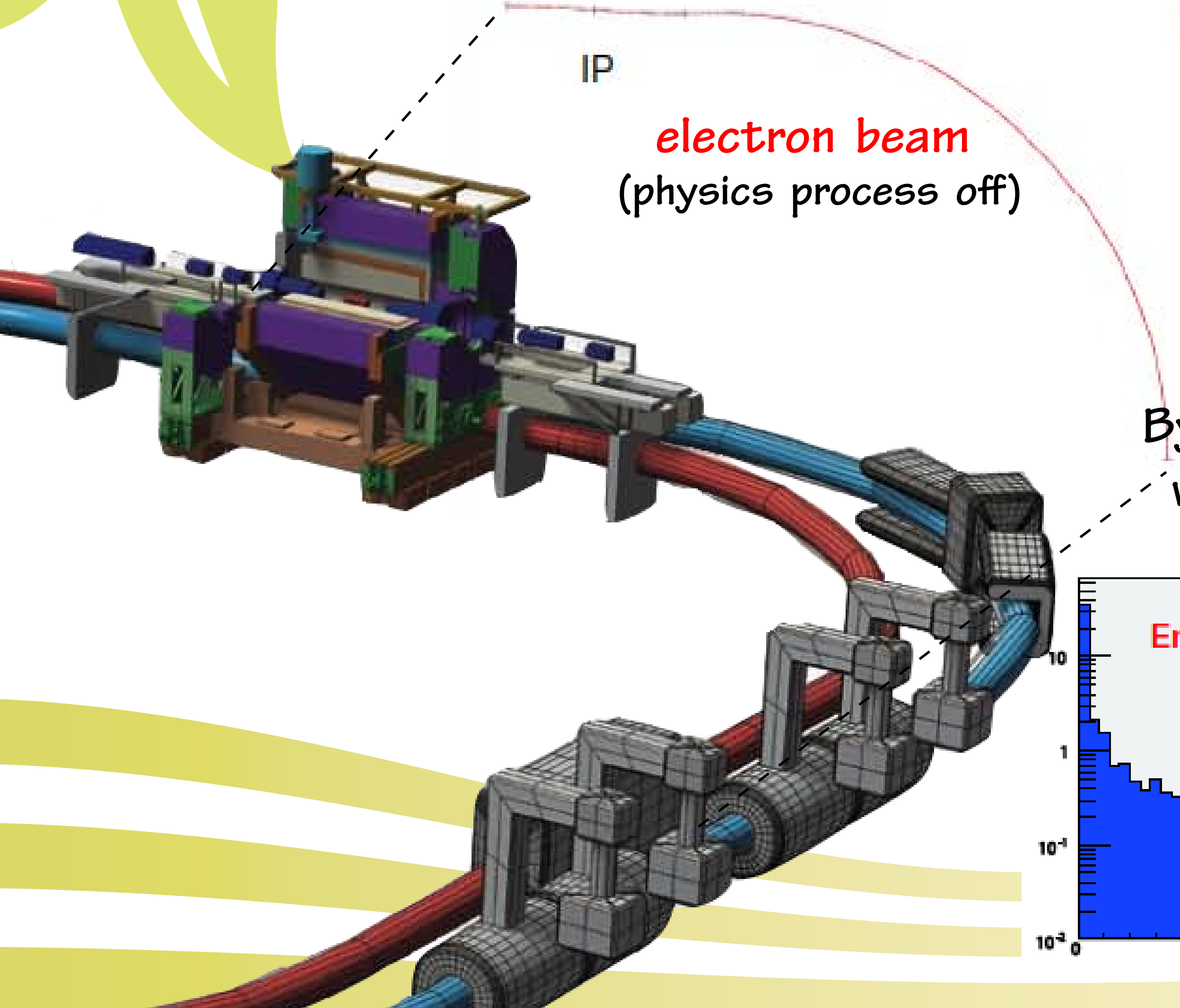
Beam-gas scattering near IP produces particles,
and it may hit the detectors → Affects to PXD, SVD, CDC, ...

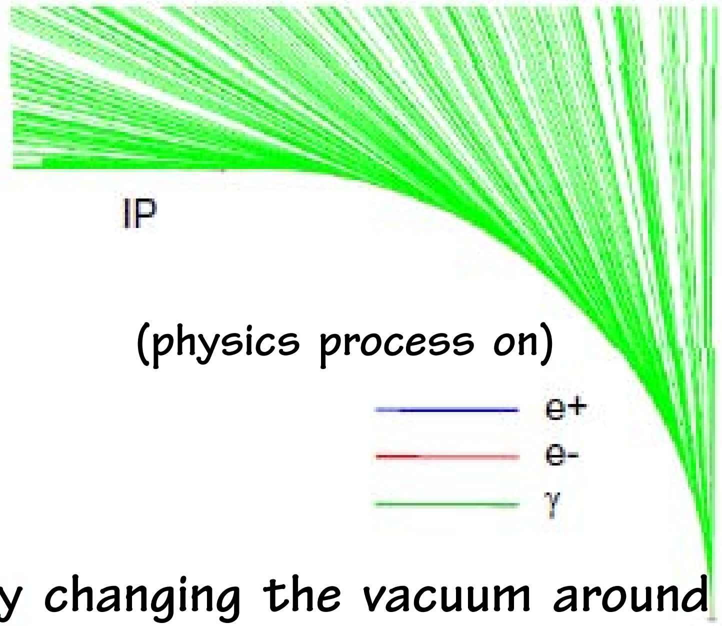
This BG depends on the vacuum level around IP (x10~100 worse)

Important to fix the IR design

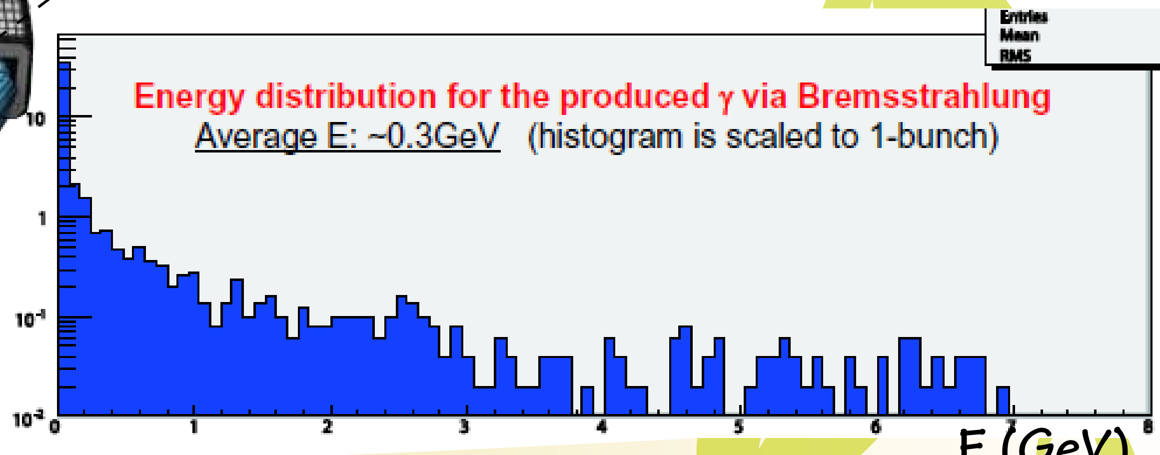
Beam-gas simulation

1/4 of the whole beamline is constructed in G4 simulation



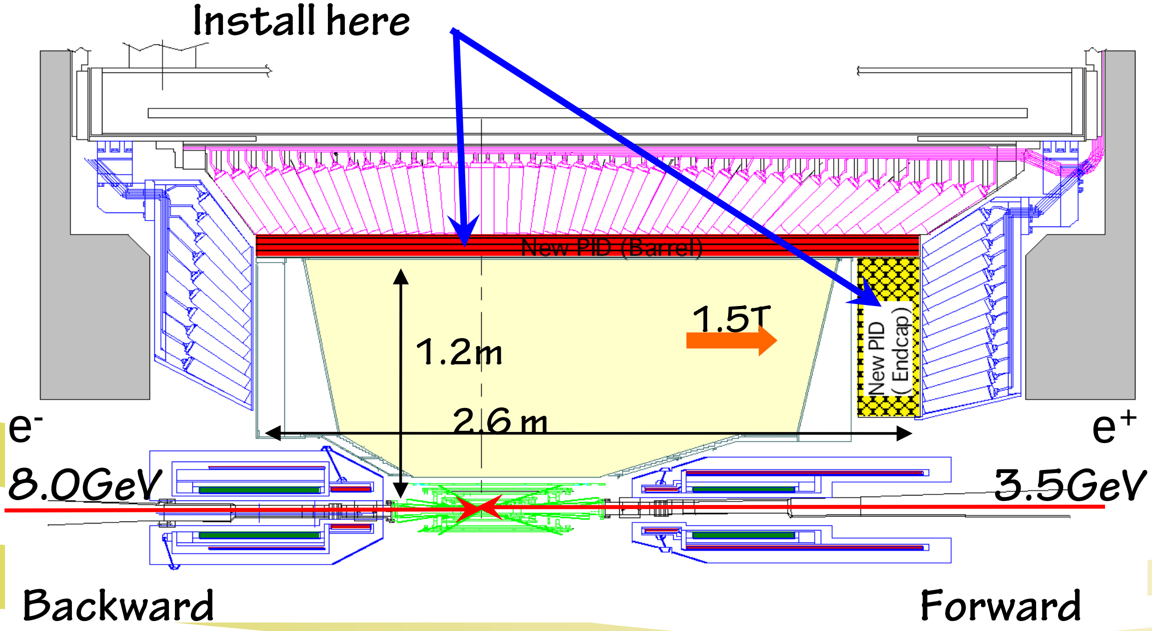


By changing the vacuum around IP, we'll estimate the beam-gas BG



Particle Identification (PID)

- Upgrade of Belle PID system
  - Current PID system of Belle
    - K/π - separation power : 3σ
- Target Performance
  - $3\sigma \rightarrow 4\sigma$ $(0.6 < p < 4\ \mathrm{GeV}/c)$



Belle

Barrel : TOF + ACC

End cap : ACC

ACC : Aerogel Cherenkov Counter (Threshold type)

↓ Upgrade

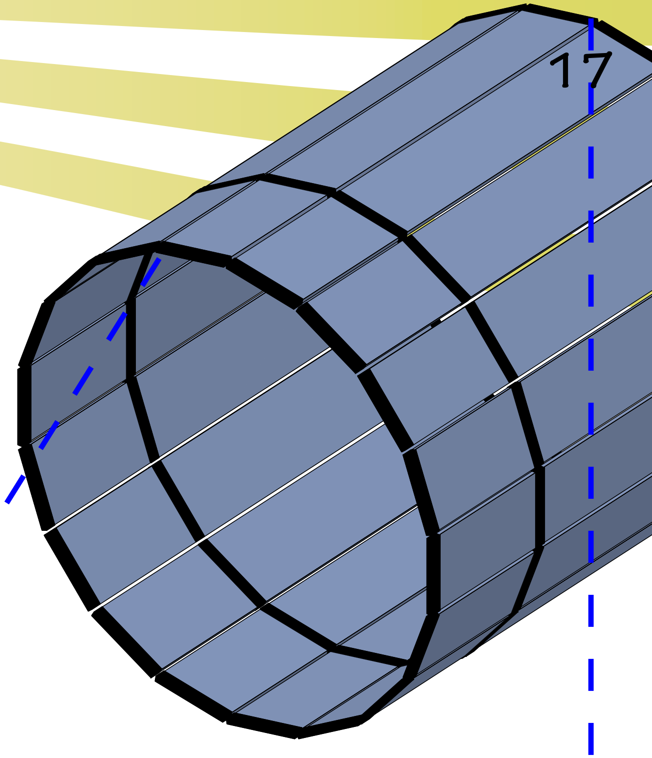
Belle II

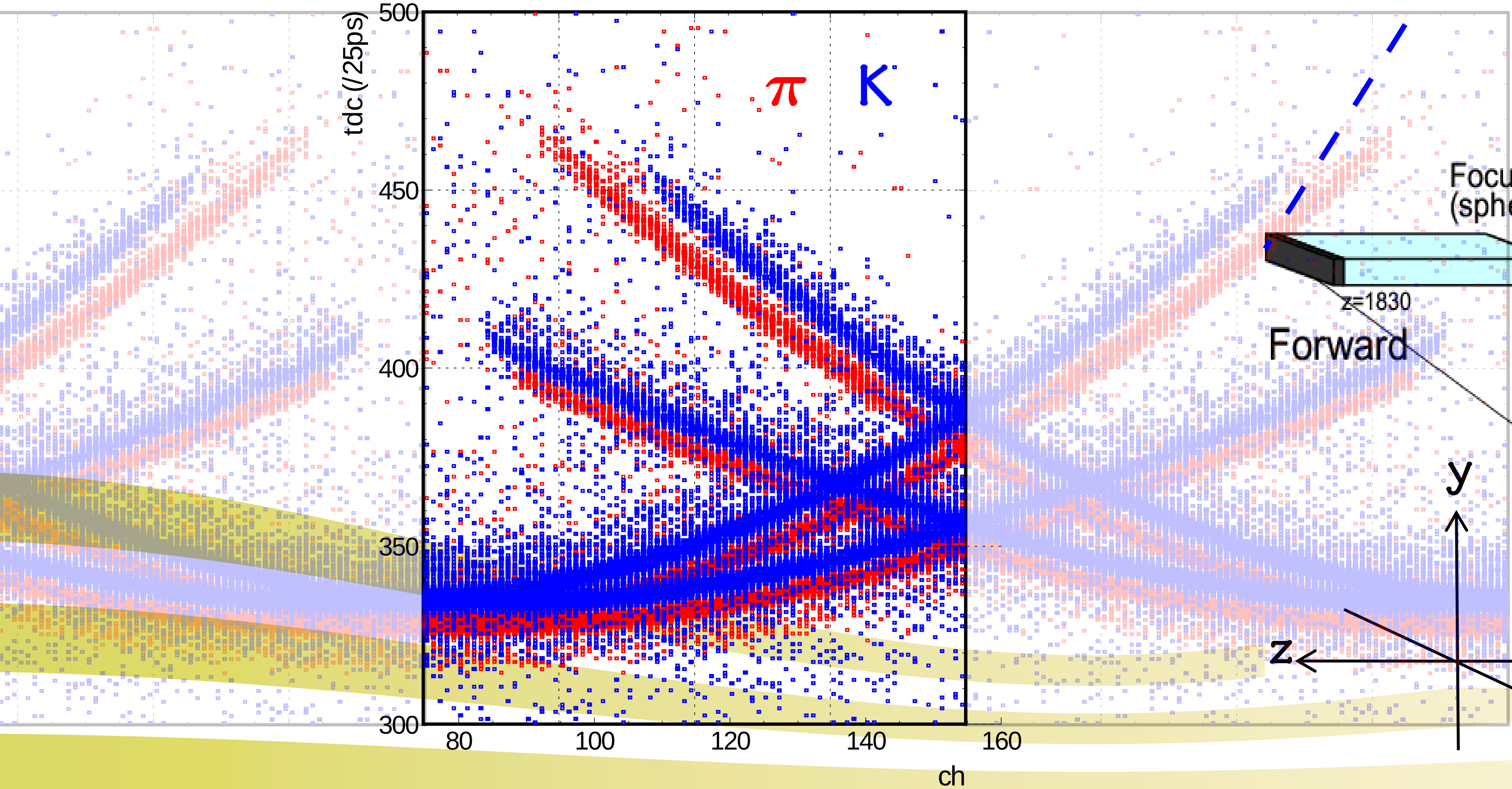
Barrel : TOP

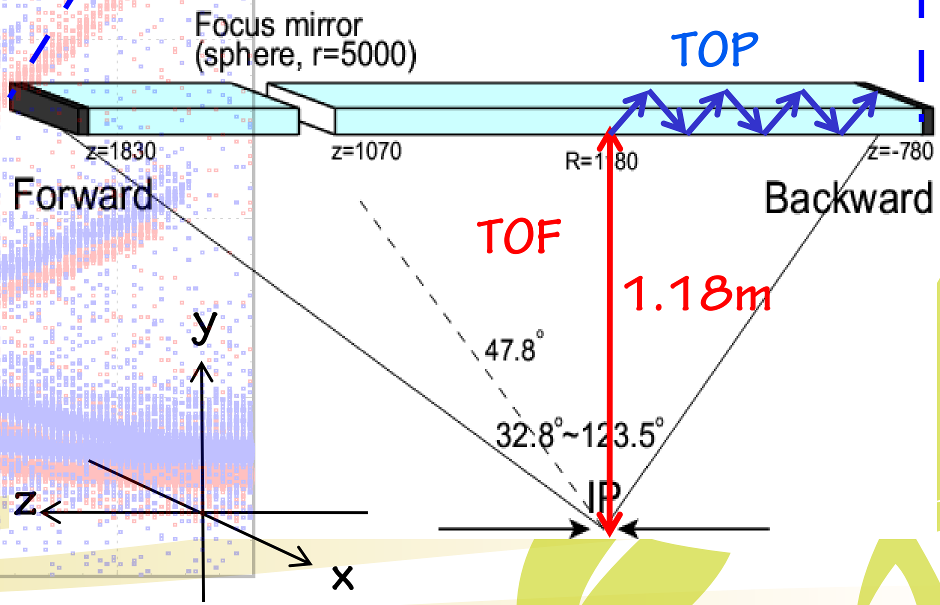
End cap : Aerogel RICH

TOP counter

- TOP (Time of Propagation)
  - A kind of RICH counter
  - Cherenkov radiator + time sensitive screen
  - Position (x, y) → Position + time (x, y)
  - very compact & simple



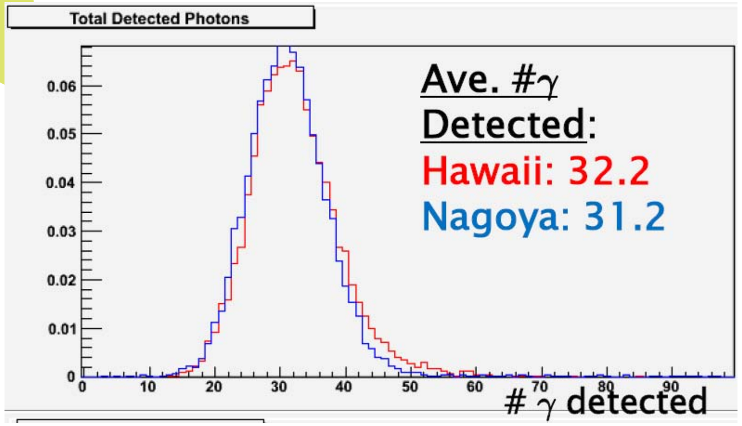


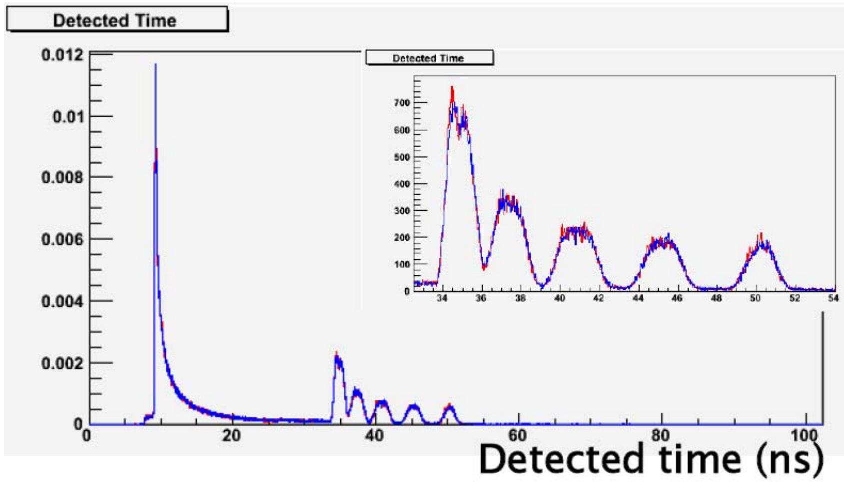


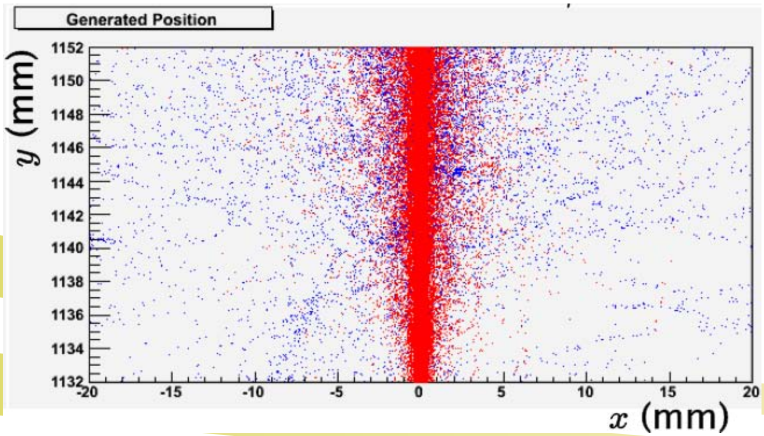
TOP counter

Completely Geant4 based

- Multiple scattering
- d-ray
- Electromagnetic/Hadronic shower
- Generation/Propagation of Cherenkov ph.







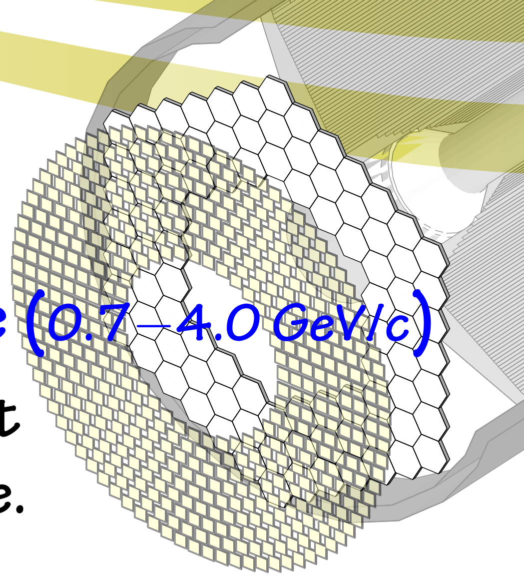
Good agreement in:

- Number of detected photons
- Detected time distribution

Disagreement in:

- Spread of generated photon positions

g4superb A-RICH



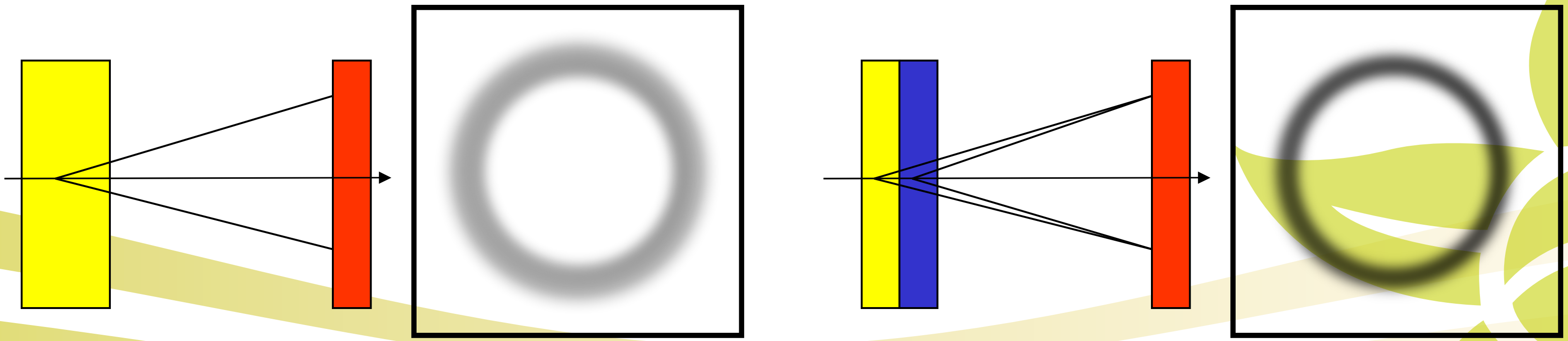
. A better π/K separation for a wider mom. range (0.7 – 4.0 GeV/c)

threshold-type Cherenkov detector (Belle) does not provide sufficient separation for high-P particle.

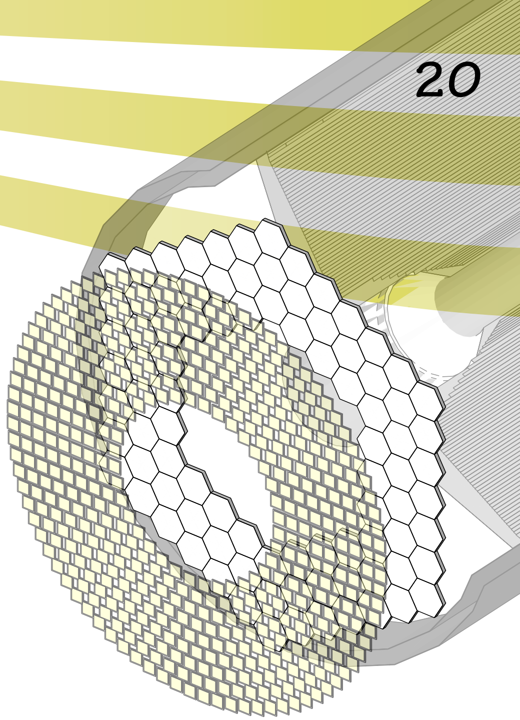
esp. high-P(~4GeV/c) region for B → ππ, Kπ

. limited available space (Forward region)

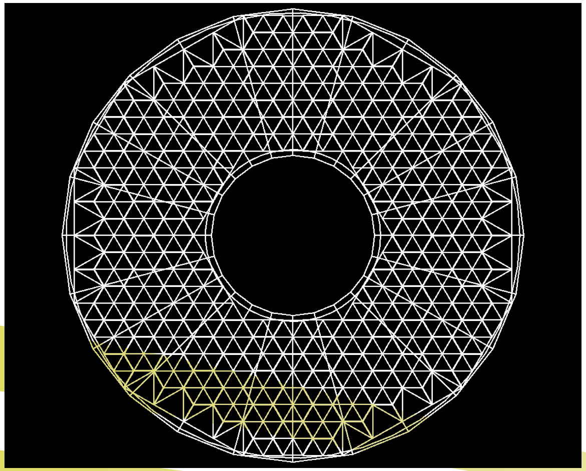
Proximity focusing ring-imaging Cherenkov counter (RICH)



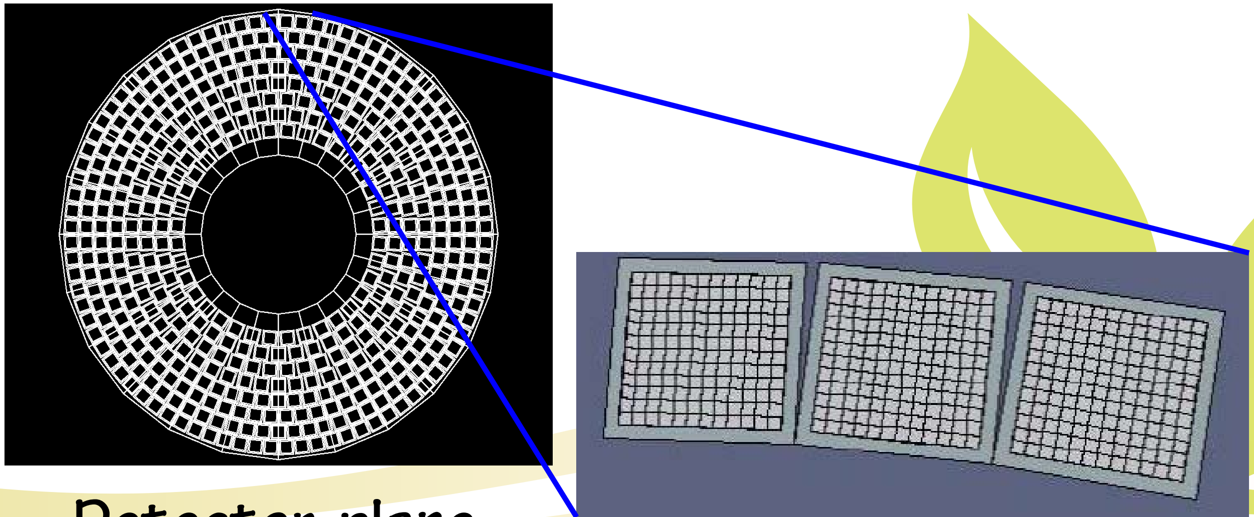
g4superb A-RICH



. Geometry description
. Particle tracking through A-RICH
. Cherenkov ph. generation in the aerogel
  and the quarz window of the ph. detector
. Rayleigh scattering of the photons in the aerogel
. Photons tracking through the quartz windown of the photon detector
. Photon detectiion in the active area

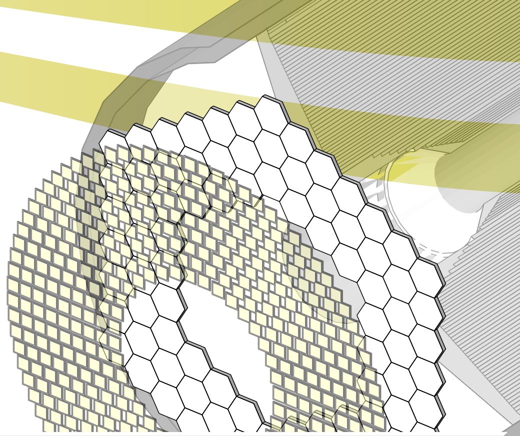


Aerogel plane

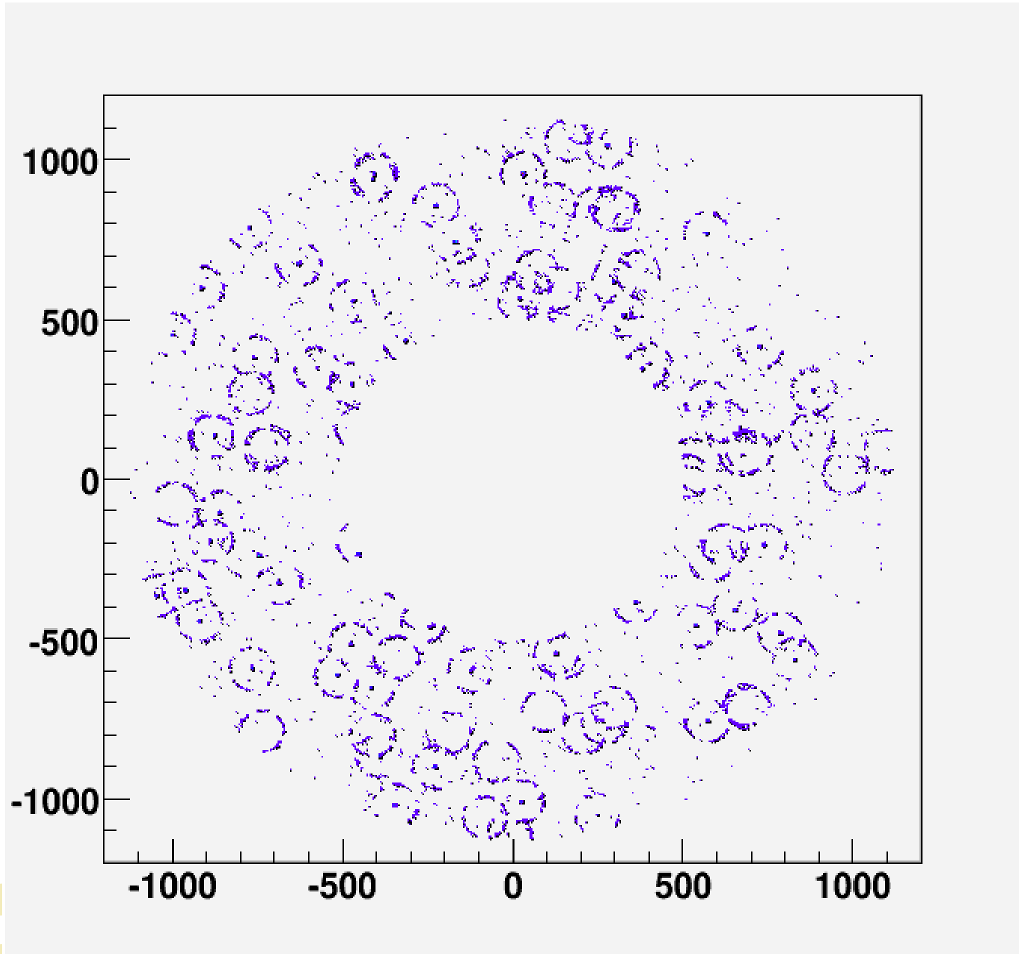


Detector plane

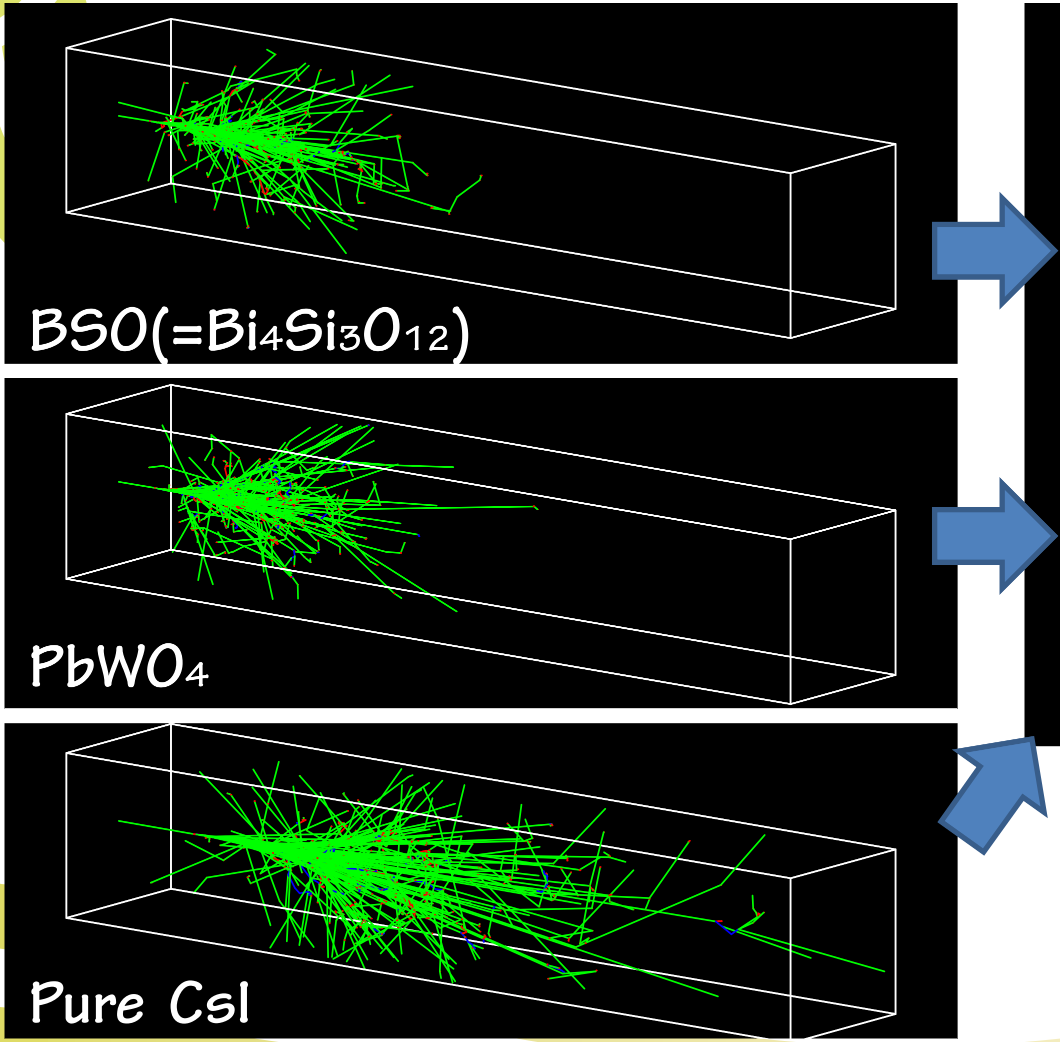
g4superb A-RICH

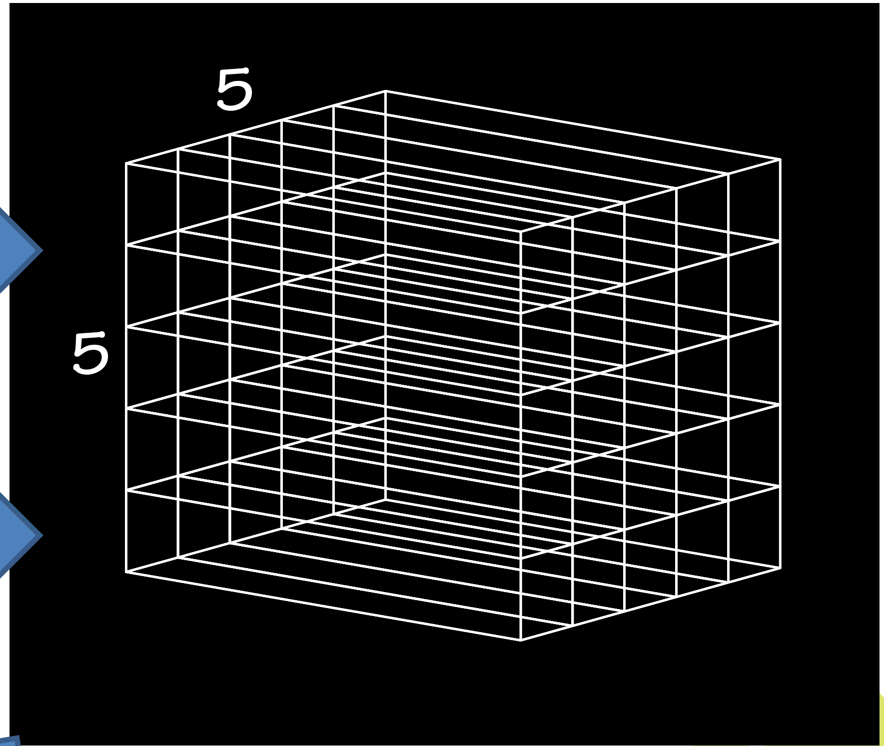


- Geometry at the moment hardcoded with the main parameters read from the text file
- Currently optimizing the geometry and materials



ECL (Electromagnetic Calorimeter)

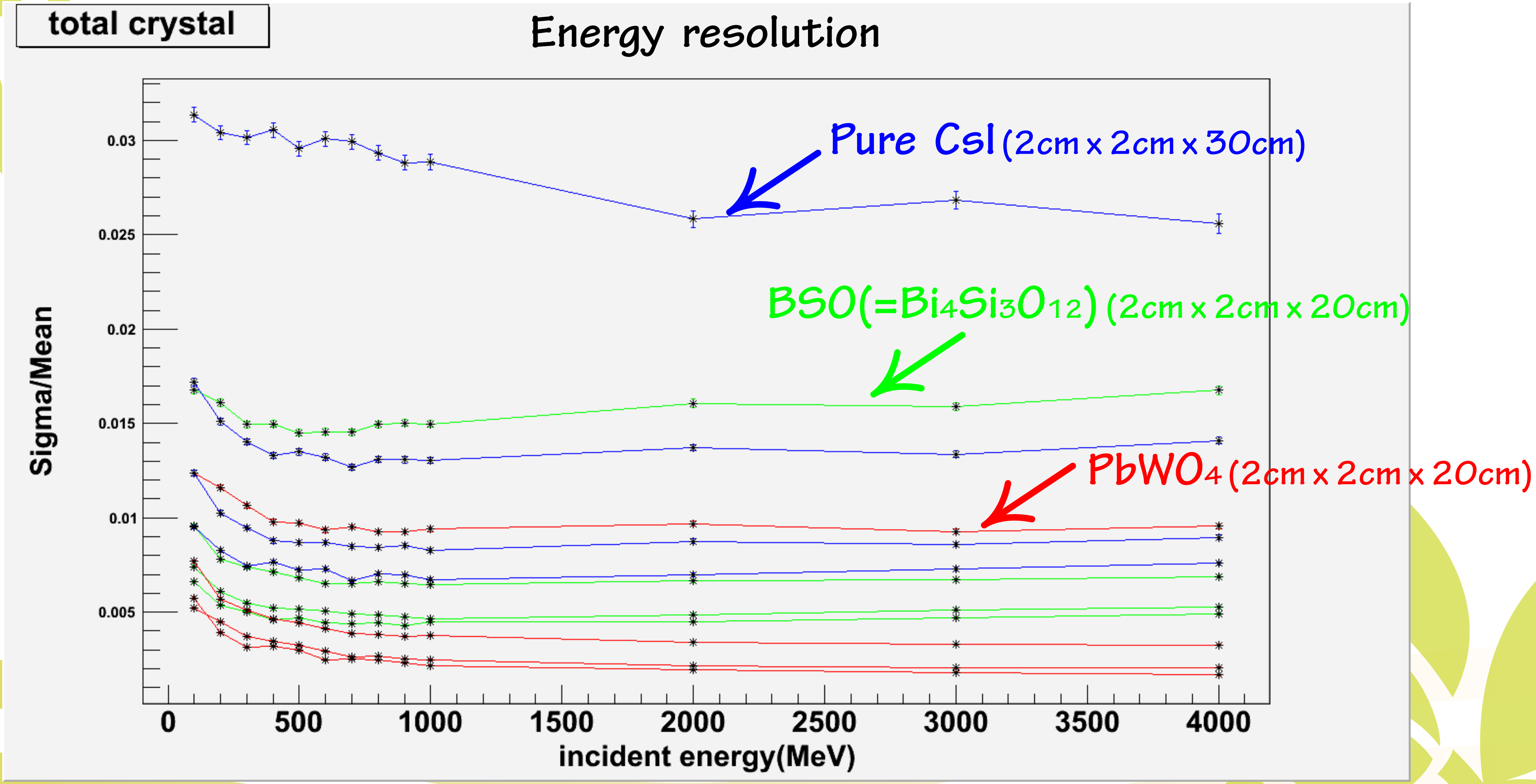




Incident particle : γ (0.1 ~4GeV)

random position & insident angle (<30°)

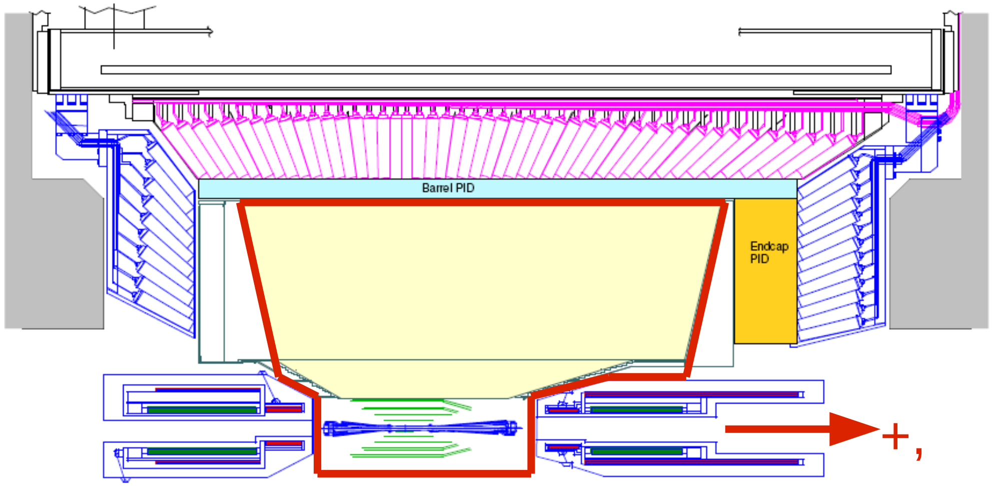
ECL (Electromagnetic Calorimeter)



Geant4 with ILC framework

Mokka - BelleExp Geometry

- ***BelleExp geometry*** currently, only a tracker implemented
  - ***TubeBelle, TubeBelleII*** – geometry driver of a beam pipe
  - ***SVDBelle, VXDBelleII*** – geometry driver of a vertex detector (for BelleII: PXD and SVD detectors defined together)
  - ***CDCBelle, CDCBelleII*** – geometry driver of a central drift chamber
  - ***Sensitives:***
    - *SVDSens* (Belle), *VXDSens* (BelleII)
    - *MaterialSens* (for mat. budget studies)
    - *CDCSD02* (both)
  - ***Hits:***
    - *VXDHit* (Belle, BelleII), *TRKHit* (CDC)
  - ***Mag. field*** **:**
    - *Field00* (both) – 1.5 T in z



Mokka - Beam Pipe Geometry

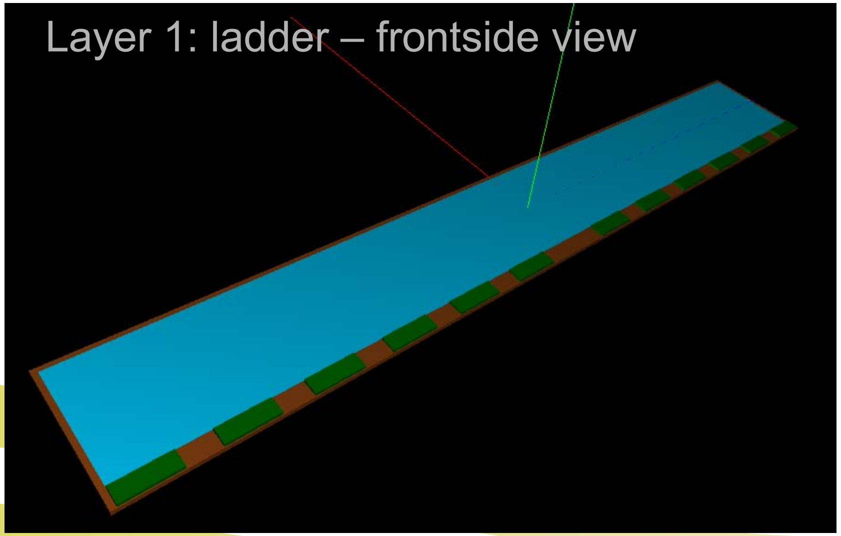
- ***TubeBelle & TubeBelleII*** geometry drivers that describe a beam pipe for Belle & BelleII
  - Cylindrical, onion-like structure , with option to be rotated around Y axis:
    - “vacuum”
    - inner gold layer (shielding against soft SR): 10 μm
    - inner beryllium wall: 0.6 mm
    - cooling gap (filled with paraffin): 0.5 mm
    - outer beryllium wall: 0.35

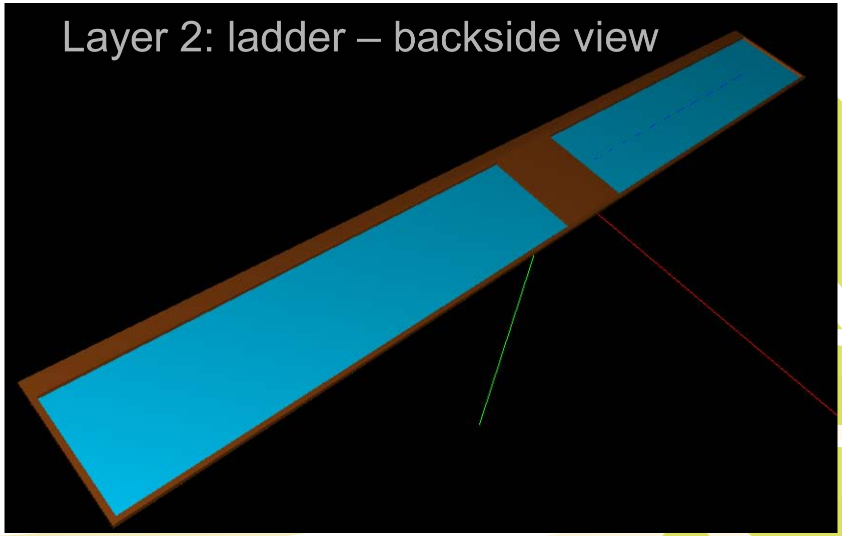
	R_{min} [mm]	R_{max} [mm]
Belle	14.99	16.45
BelleII	9.99	11.45

Mokka - Belle II PXD Geometry

- ***VXDBelleII:*** geometry driver for BelleII VXD (pixel part: PXD + strip part: SVD)
  - Description: 2 layers → ladders → Si sensors (50 μm) + rims (450 μm) + support (400 μm) + 12 switchers

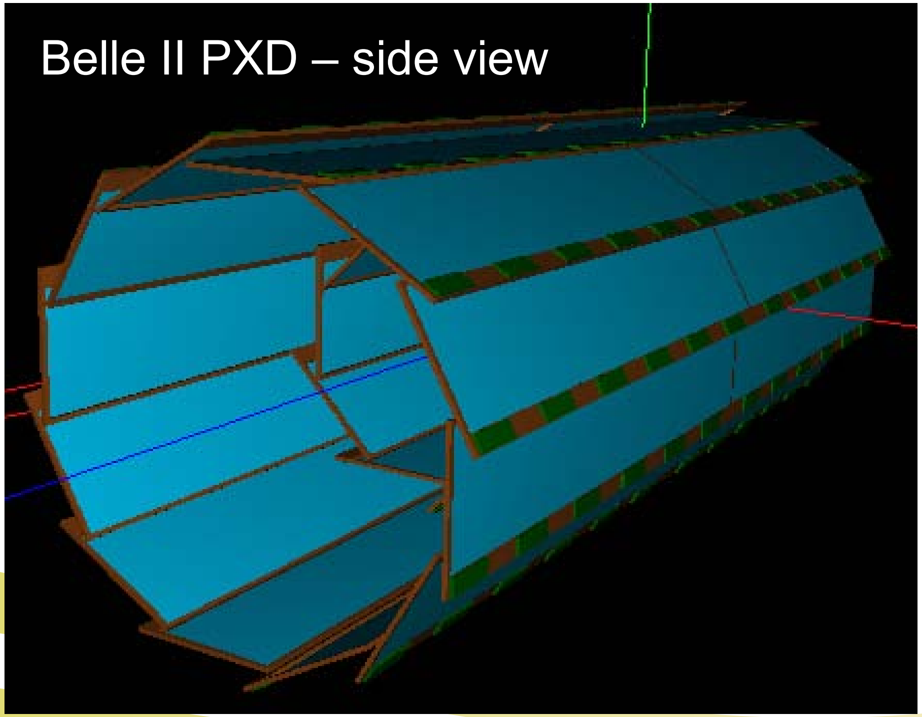
	R [mm]	***# ladders***	***support***
Pxl layer 1	13.00	8	no
Pxl layer 2	22.00	12	yes

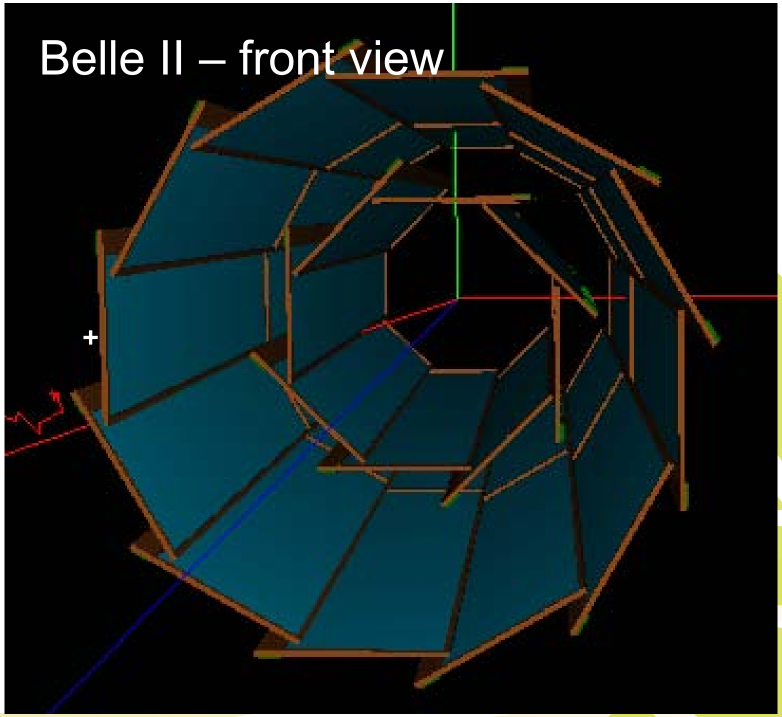




Mokka - Belle II PXD Geometry

- ***VXDBelleII:*** detail of pixel part of VXD detector
  - Layers arranged in wind-mill structure
  - Option: rotate pixel layers together with beam pipe

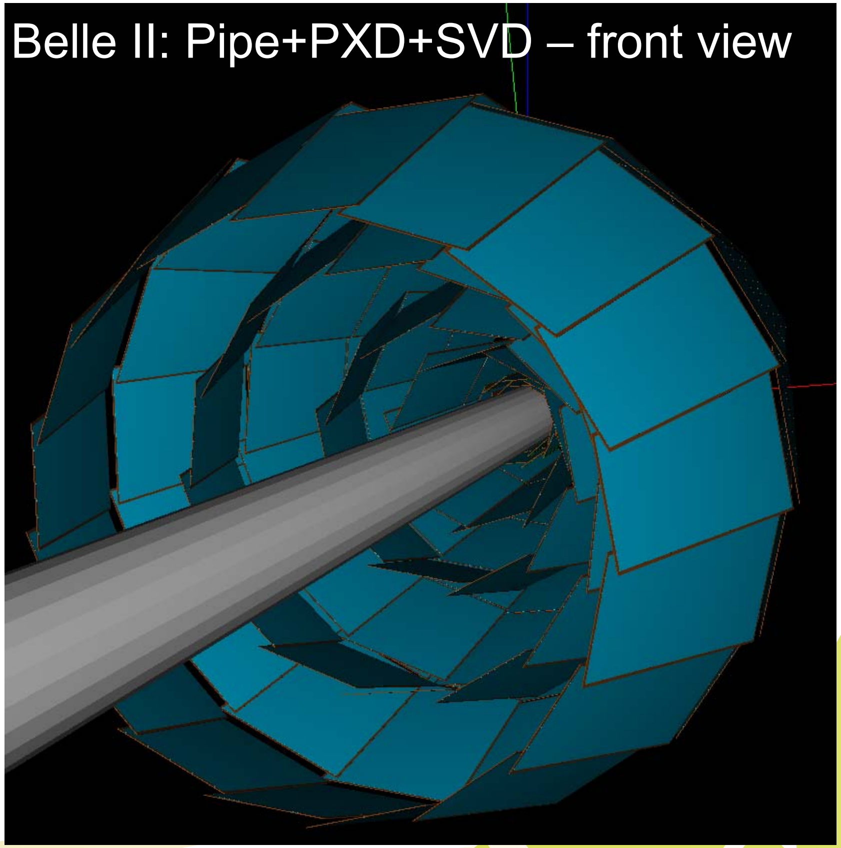




Mokka - Belle II SVD Geometry

- ***VXDBelleII:*** geometry driver for VXD of Belle II (pixel part: PXD & strip part: SVD)
  - Description of SVD: 4 layers in barrel part + 3 layers in "forward" region; all arranged in wind-mill structure; only silicon implemented now!
    - Active part: Si layers → Si ladders → Si sensors – DSSDs (300μm thick)
    - Passive part: Si rims around sensors (300μm thick)

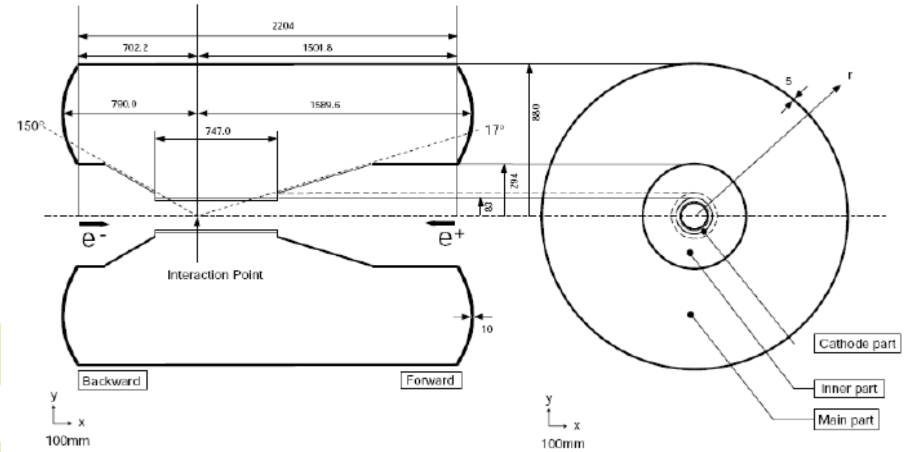
	R [mm]	***# ladders***	***# DSSDs***
Strip layer 31 – barrel	38	8	2
Strip layer 41 – barrel	80	10	2
Strip layer 42 – barrel-slanted	66	14	3
Strip layer 51 – barrel	115	17	4
Strip layer 52 – barrel-slanted	95.5	10	1
Strip layer 61 – barrel	140	14	1
Strip layer 62 – barrel-slanted	114	17	1

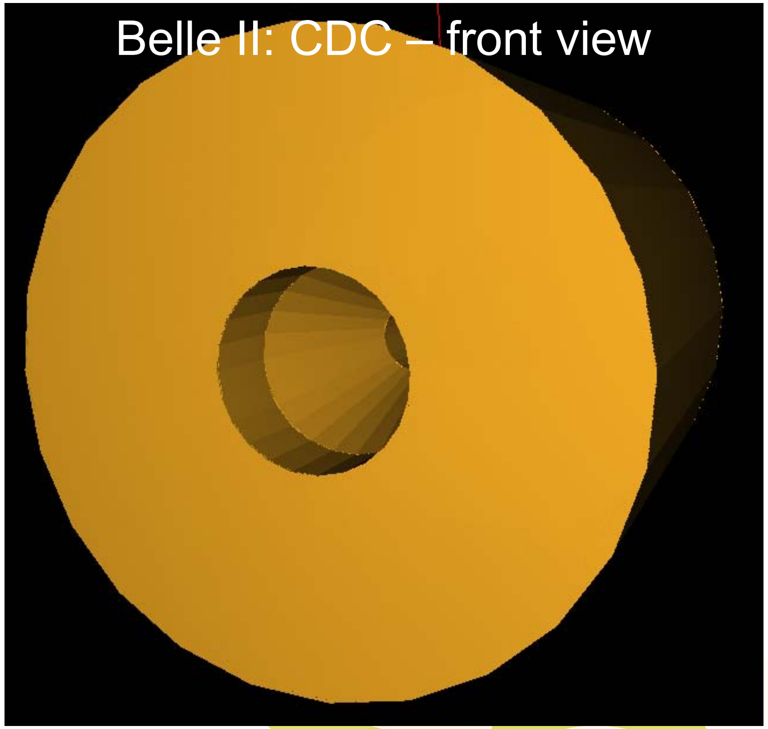


Mokka - Belle II CDC Geometry

- ***CDCBelleII:*** geometry driver describing central drift chamber
  - Aluminium cylinder with cone-shaped inner parts filled with gas He/C_2H_6 (50:50)

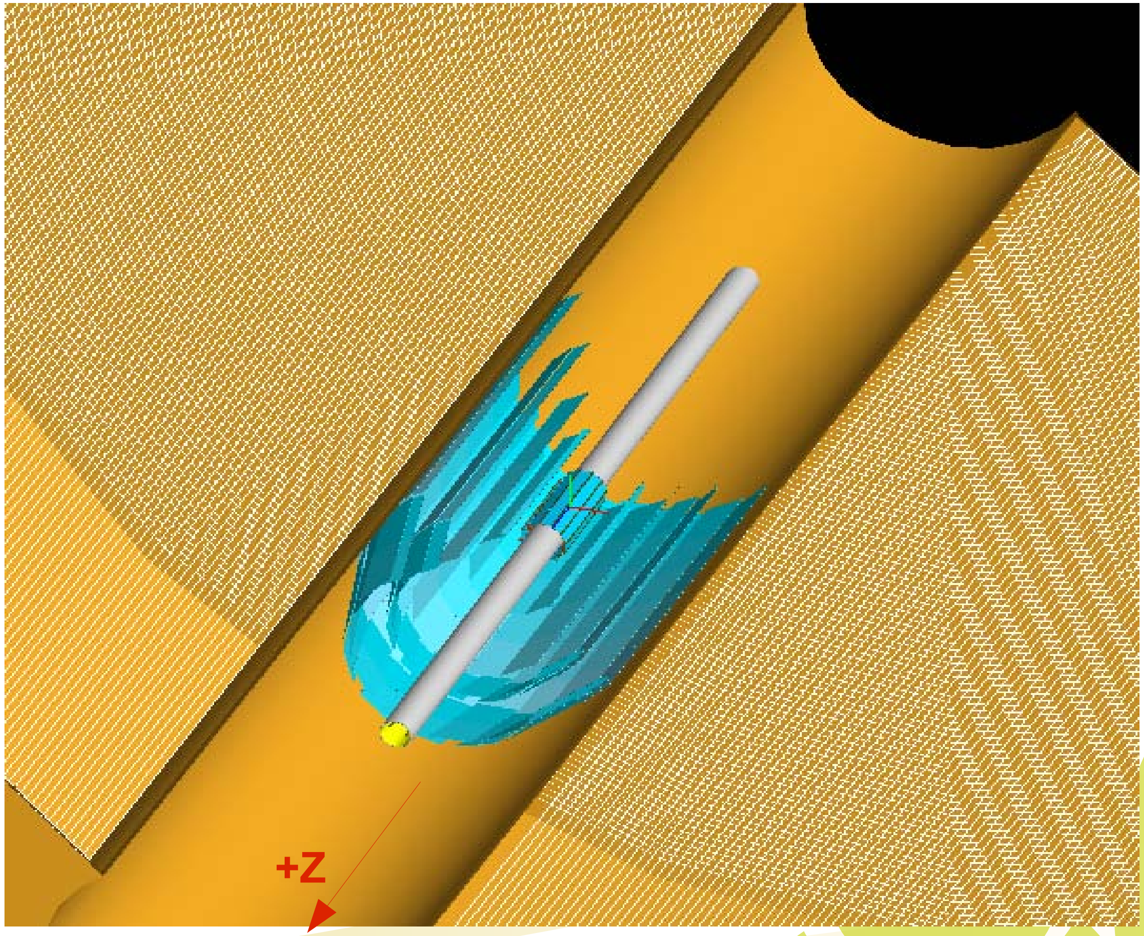
Radius – inner boundary	361 mm
Radius – inner-middle boundary	150 mm
Radius – outer boundary	1150 mm
Radius – innermost sens. wire	172 mm
Radius – outermost sens. wire	1120 mm
Number of sensitive layers	4H





Mokka - Tracker Implementation

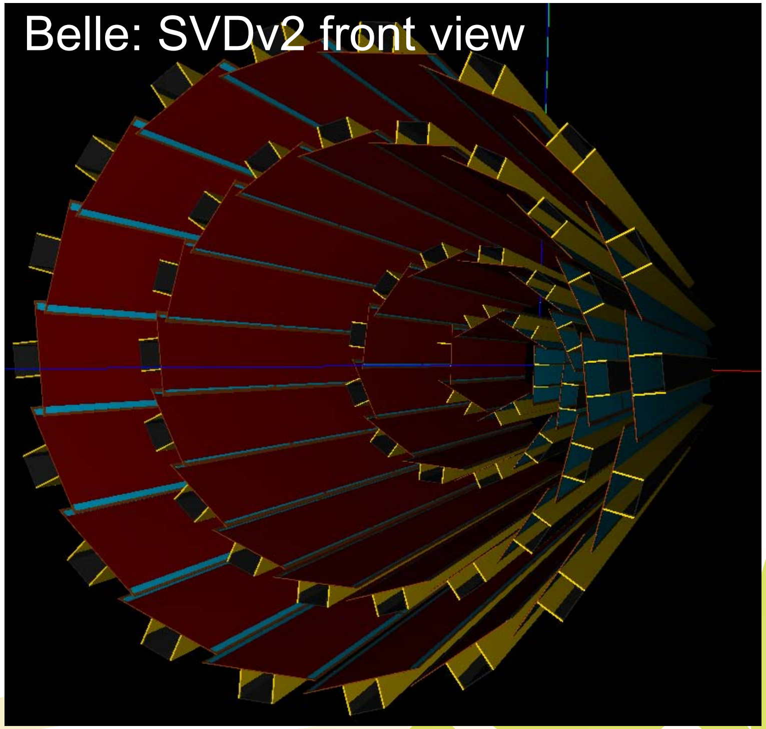
- ***Tracker geometry:***
  - Pixel layers (PXD)
  - Strip layers (SVD)
  - CDC
- Mokka – simulation only
  - incident particles → tracks produced → hits generated → hit collections (+ true MC information) created & saved in LCIO
  - digitization (simulation of detector response) realized at the level of Marlin toolkit (see next slides)



Mokka - Belle SVD Geometry

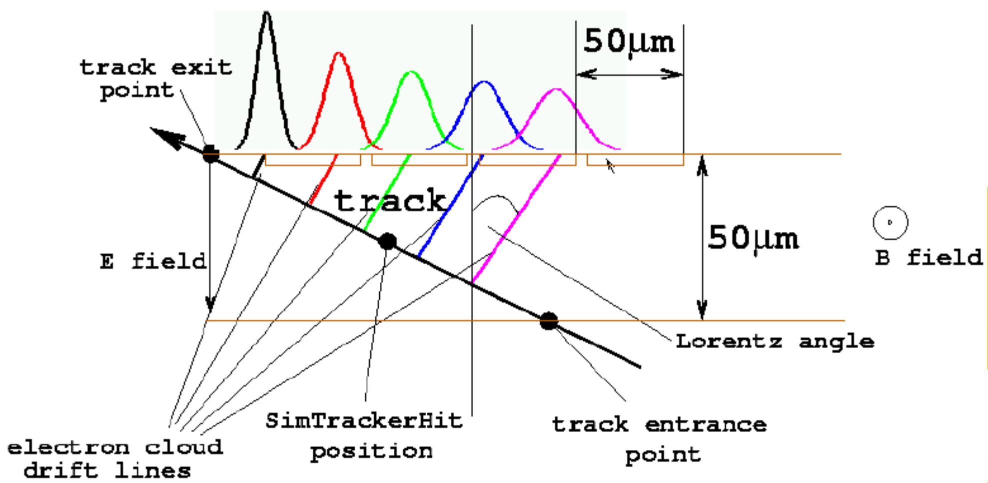
- ***SVDBelle:*** driver used for current Belle vertex detector (SVD version 2)
  - Description: 4 layers in barrel part arranged in wind-mill structure
  - Active part: Si layers → Si ladders → Si sensors - DSSDs (300μm thick)
  - Passive part:
    - Si rims around sensors, i.e. passive Si part (300μm thick)
    - Kaptons (polyimide + copper)
    - Zylon ribs
    - CRFP bridge & rims

	R [mm]	***# ladders***	***# DSSDs***
Strip layer 1 – barrel	20	6	2
Strip layer 2 – barrel	43.5	12	3
Strip layer 3 – barrel	70	18	5
Strip layer 4 – barrel	88	18	6



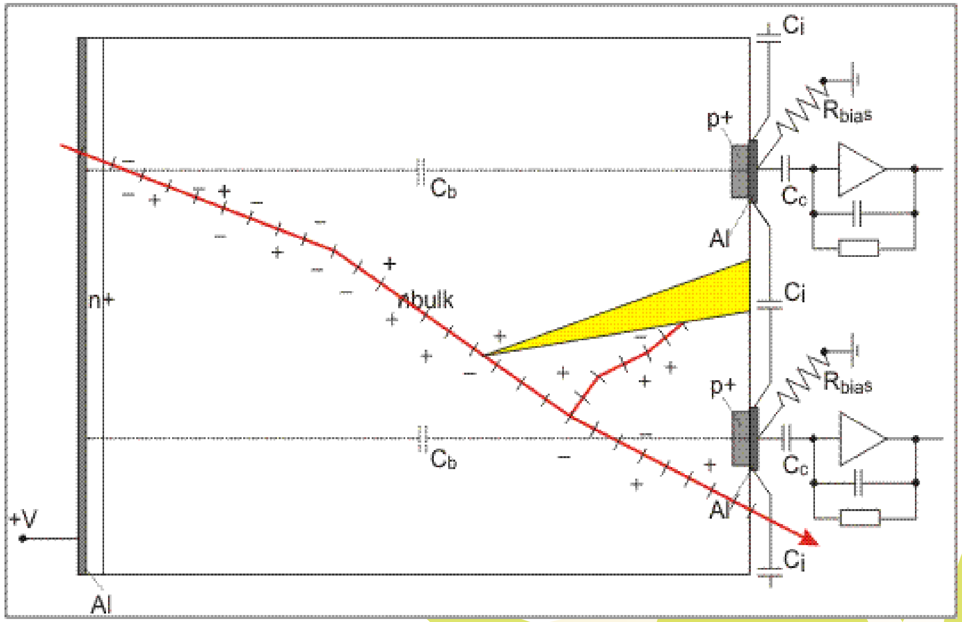
Marlin - PXD Digitizer

- ***SiPxlDigi:*** MarlinReco pixel digitizer – based on A. Raspereza's VTXDigitizer
  - Input: LCIO SimTrackerHits → Output: LCIO TrackerHits
  - Processes:
    - Global to local ref. system transformation
    - Ionization points generated: energy loss fluctuation added → e-h pairs along the path created
    - Signal points generated: e^{7} drift performed → e^{7} Lorentz shift in mag. field of 1.5 T calculated → e^{7} diffusion calculated
    - Digits produced: pixels with signal bigger than threshold (2 x noise) found
      - noise for pixels set = 100 e
      - noise for strips set = 1200 e
    - Local to global ref. system transformation
    - Hits produced + resolution calculated
    - Background generated



Marlin - SVD Digitizer

- ***SiStripDigi:*** MarlinReco strip digitizer
  - Input: LCIO SimTrackerHits → Output: LCIO TrackerHits
  - Geometry: Mokka hits transformation – from global to local reference system
  - Physical processes:
    - Generation of e-h pairs (E_{eh}=3.65 eV)
    - Drift of e-h pairs in electric field
    - Diffusion of e-h due to multiple collisions
    - Lorentz shift of e-h pairs in magnetic field
    - Mutual microstrip cross talks (wrt. AC or DC)
    - Noise: sensor, electronics ...
  - Clustering: (based on COG algorithm)
    - Cluster finding (seed strips + their neighbours)
    - Cluster transformation back to global ref. s.

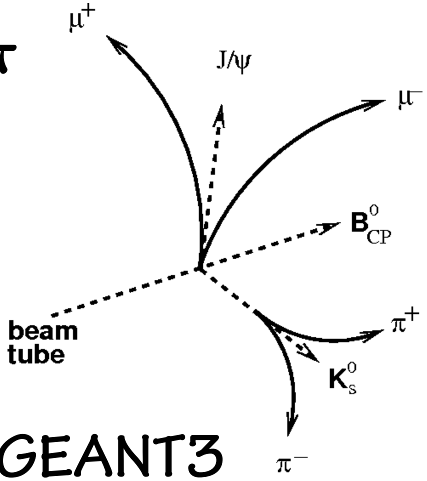


Tracking : Reconstructed Decay

CP side:

$B \to J/\psi\, Ks$

$\to \mu\, \mu\, \pi\, \pi$

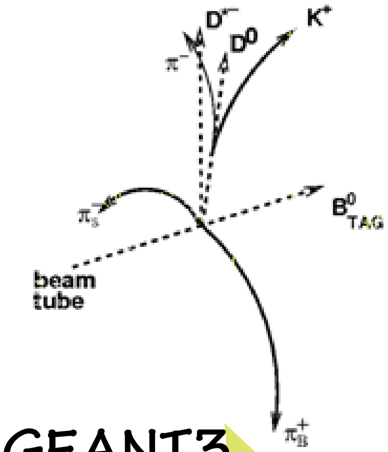


Tag side (+c.c.):

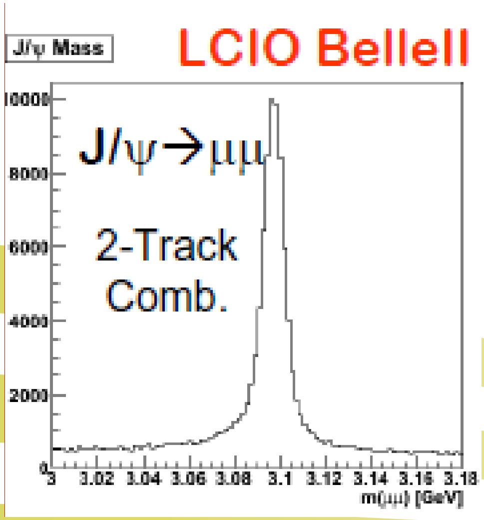
$B \to D^*\, \pi$

$\to D\, \pi\, \pi$

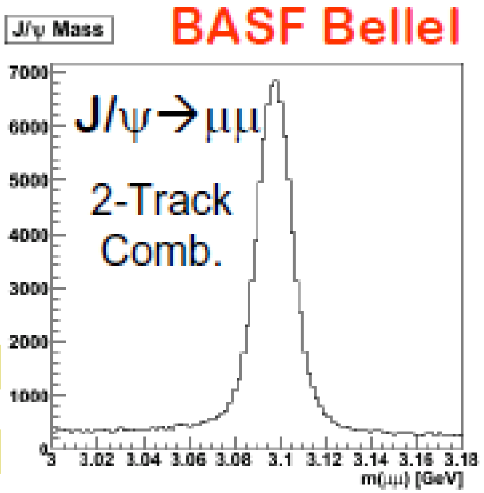
$\to K\, \pi\, \pi\, \pi$



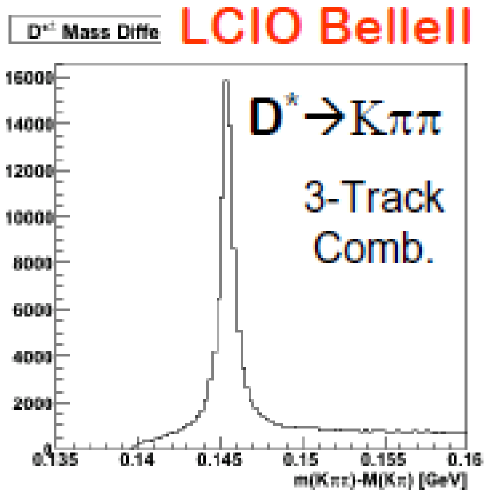
GEANT4



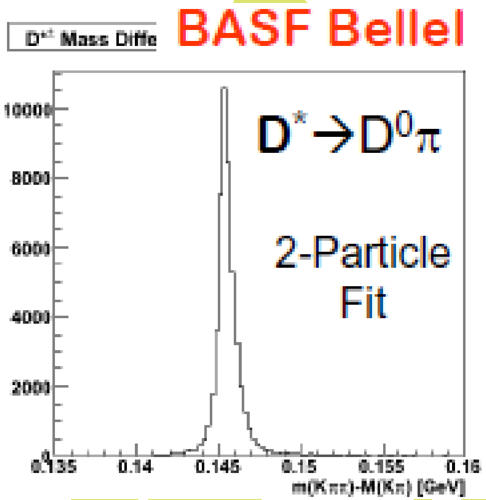
GEANT3



GEANT4

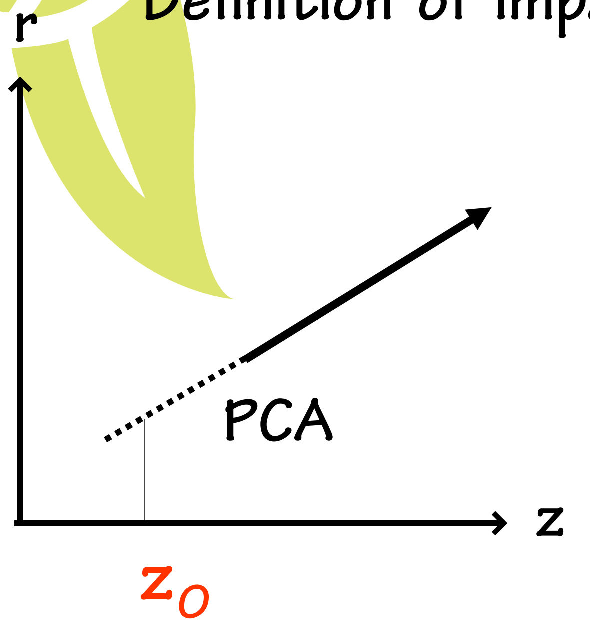


GEANT3

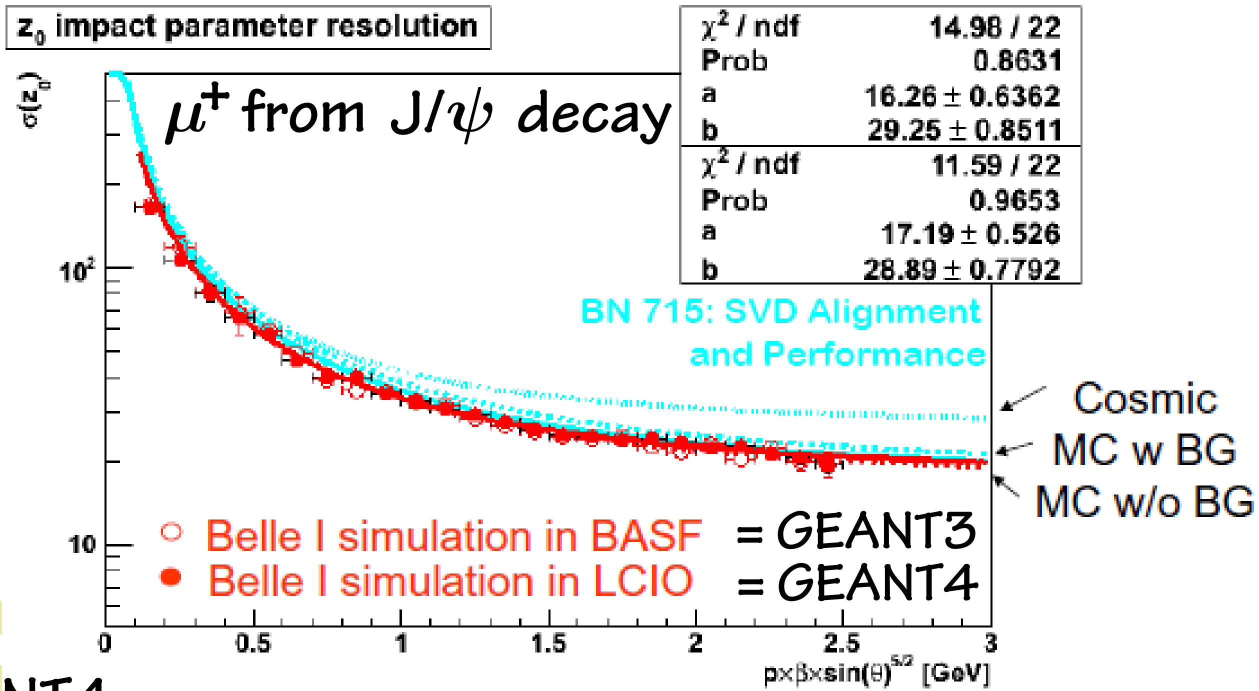


Tracking : Impact Parameter Resolution

Definition of impact parameter d_0 & z_0

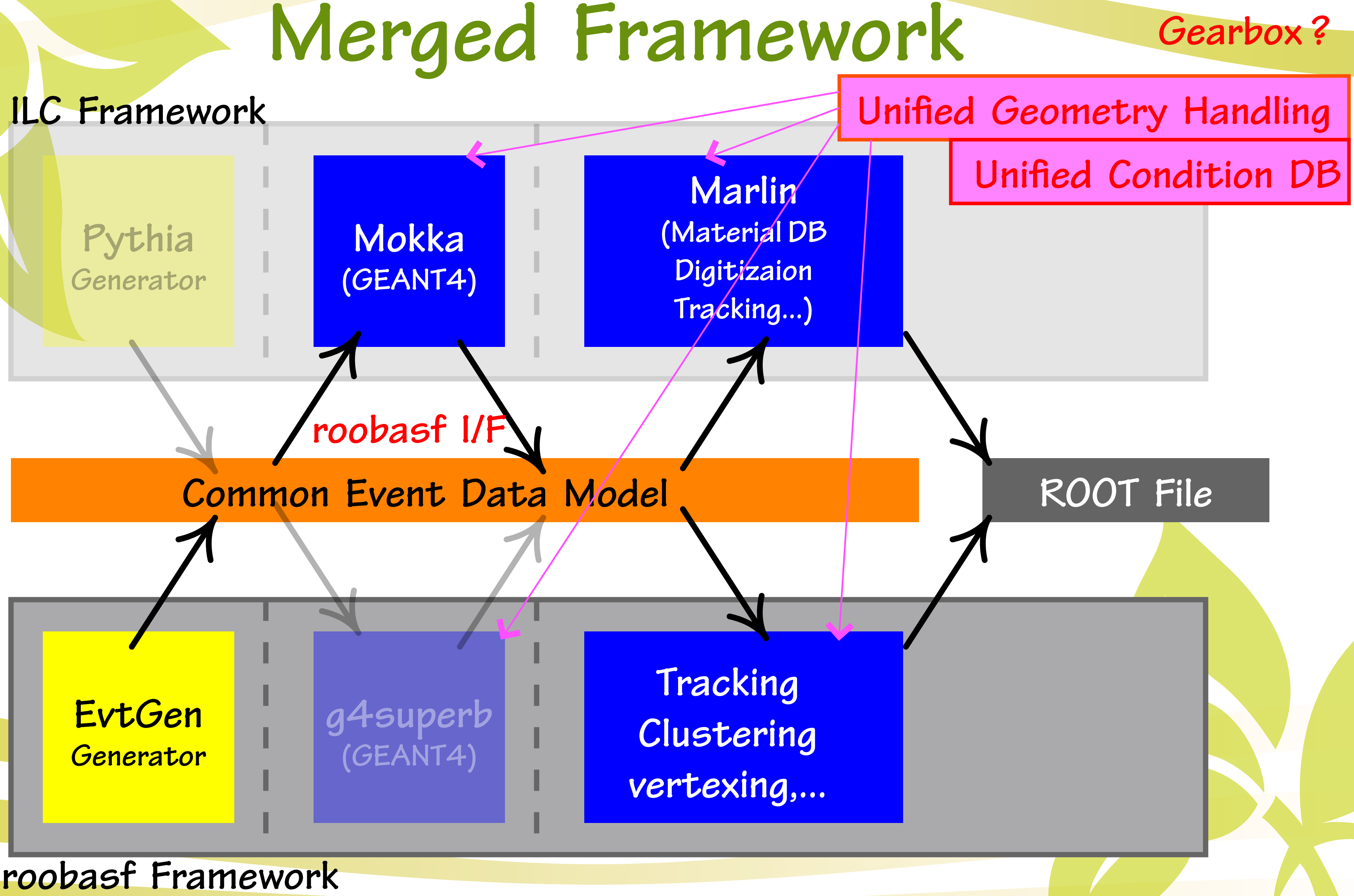


PCA = point of closest approach
defined in x-y plane



Perfect agreement
between GEANT3 and GEANT4

Merged Framework



Summary

- Geant4 is the basic and practical tool for
  - Beam background simulation for IR design
  - Performance study for Particle ID detectors
  - Detector optimization

  in Belle-II experiment

- Geant4 works well with roobasf/ILC framework
  - unified framework is proposed and
    Geant4 module has to be fit to this framework
  - Common event data model, Mokka I/F,
    Geometry handling (Gearbox ?), ... have to be prepared
  - Geometry handling is a good start point for Geant4

  We have already start this.