Belle II Software with Geant4

Doris Yangsoo Kim
Soongsil University

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8th International Geant4 Tutorial in Korea
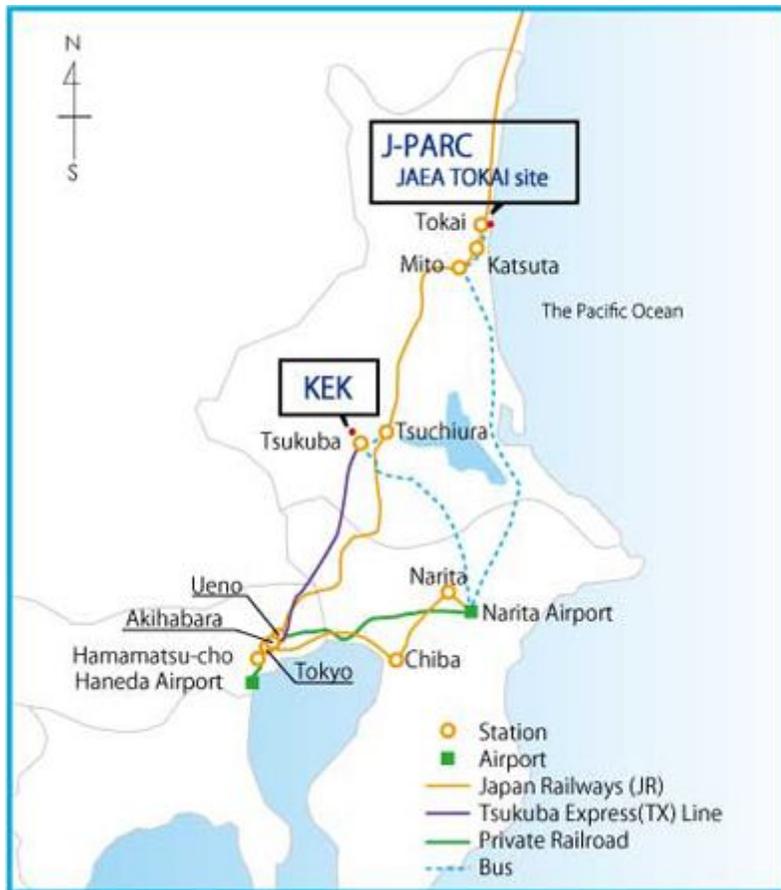
IBS, Daejeon

Belle II

Contents

- SuperKEKB and Belle II: Introduction

- Belle II Software
  - The basics of the frame structure
  - Belle II detector and events seen in virtual reality
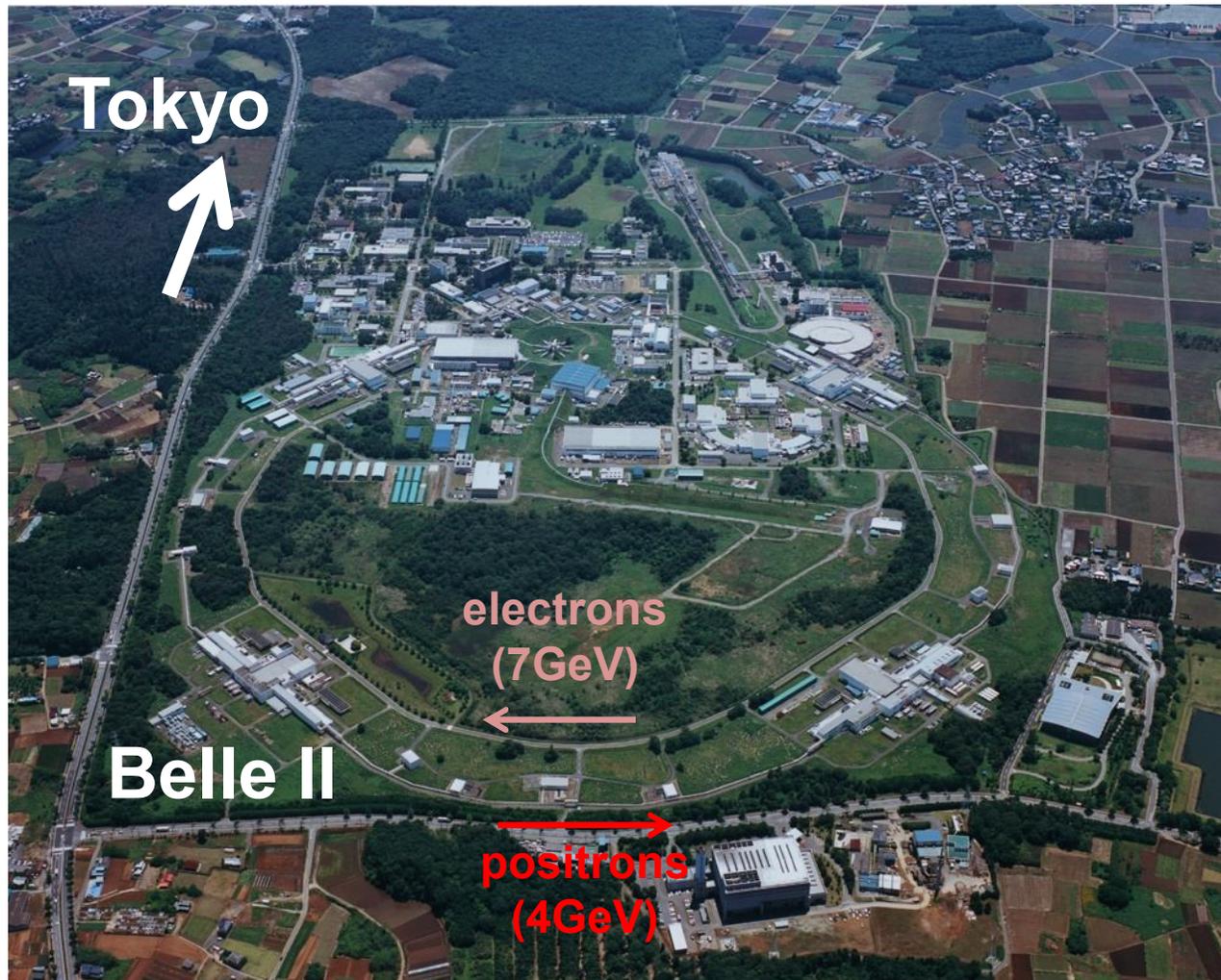
- Summary

SUPERKEKB & BELLE II

KEK
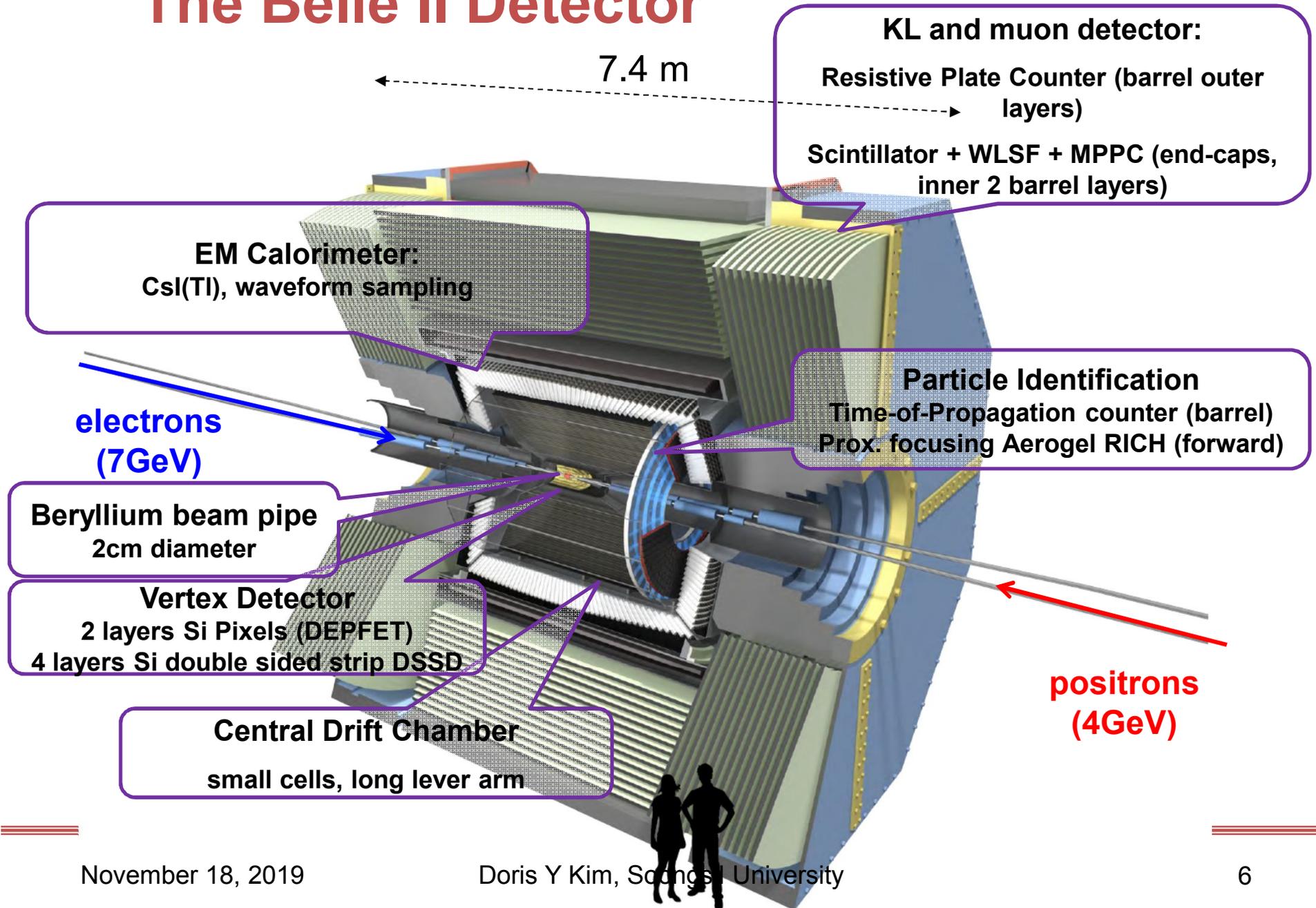# (High Energy Accelerator Research Organization)

- Established in 1997.
- This inter-university research institute consists of two campuses
  - Tsukuba Campus
    - SuperKEKB (electron positron collider)
  - Tokai Campus
    - J-PARC (proton accelerator)

SuperKEKB Collider at Tsukuba

The Belle II Detector

7.4 m

KL and muon detector:

Resistive Plate Counter (barrel outer layers)

Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling

electrons (7GeV)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers Si Pixels (DEPFET)
4 layers Si double sided strip DSSD

positrons (4GeV)

Central Drift Chamber

small cells, long lever arm

Upgrade from KEK/Belle to SuperKEKB/Belle II

	KEKB		SuperKEKB	
Luminosity:	2.1×10^{34}	$\rightarrow$	$8 \times 10^{35} \, \mathrm{cm}^{-2}\mathrm{s}^{-1}$	(x 40)
Integrated Luminosity:	$1 \, \mathrm{ab}^{-1}$	$\rightarrow$	$50 \, \mathrm{ab}^{-1}$	(x 50)
Runtime	1998 to 2010		2017 started	
Detector:	Belle	$\rightarrow$	Belle II	
Raw Data:	1 PB		100 PB	(x 100)

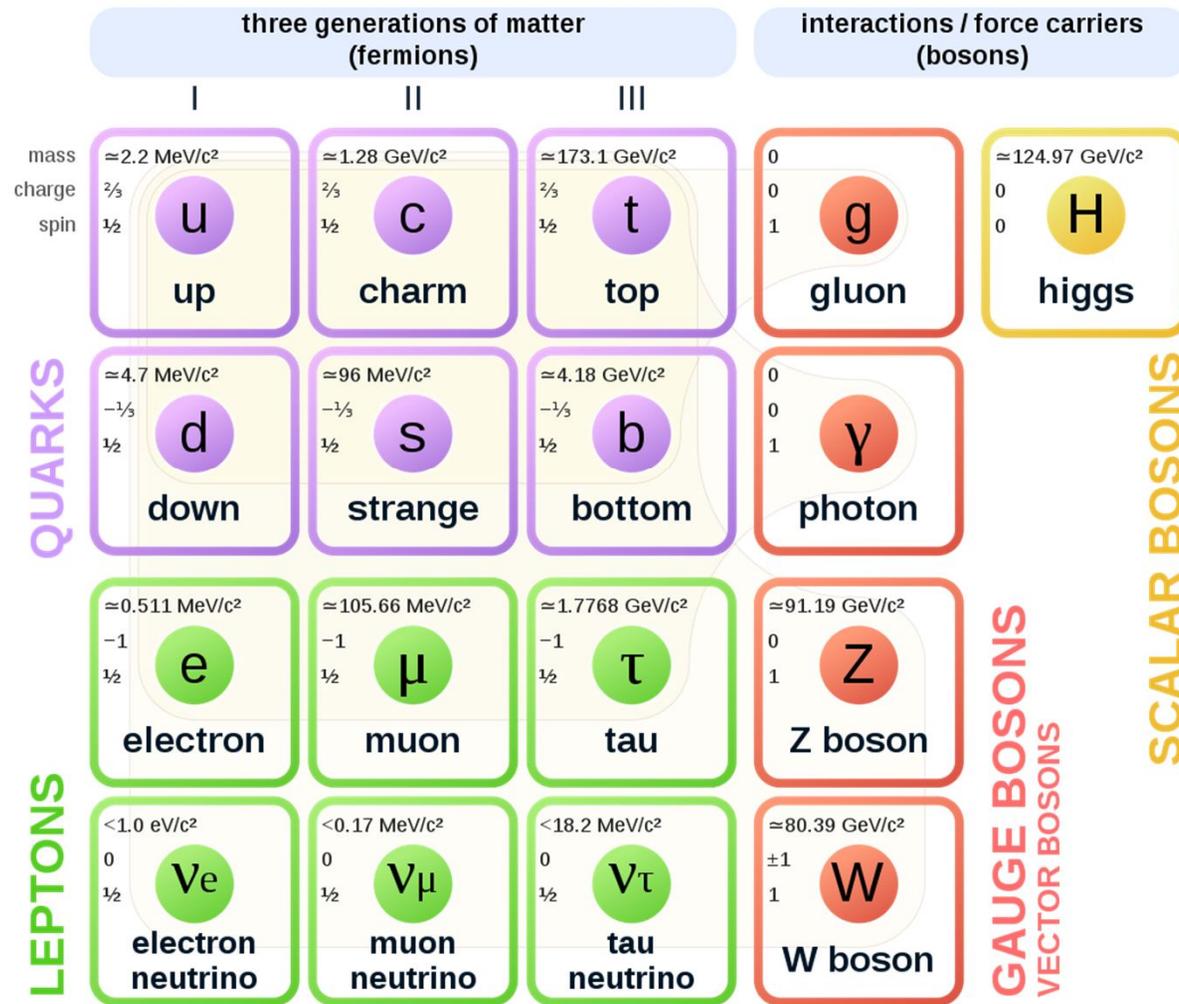Doris Y Kim, Soongsil University

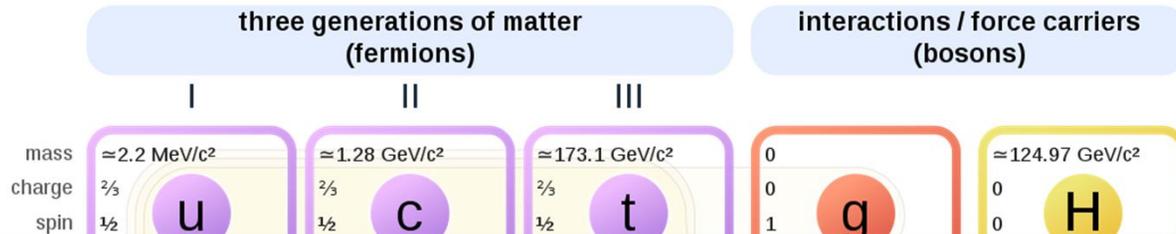# Belle II Collaboration

As of 2019.8.7
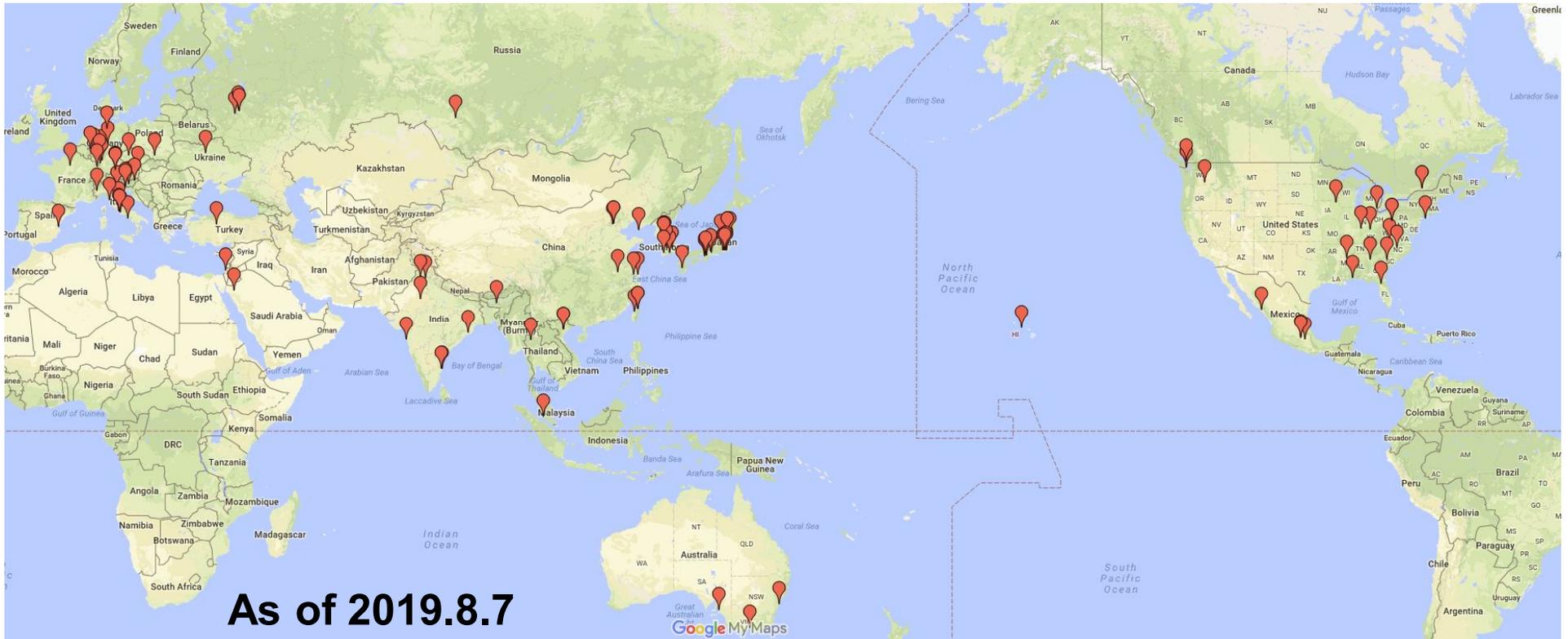
- **26 countries/regions**
- **114 institutions**
- **~ 950 colleagues (45 from South Korea)**
- **America 16%, Asia 23%, Europe 39%, Japan 17%, Russia 5%**
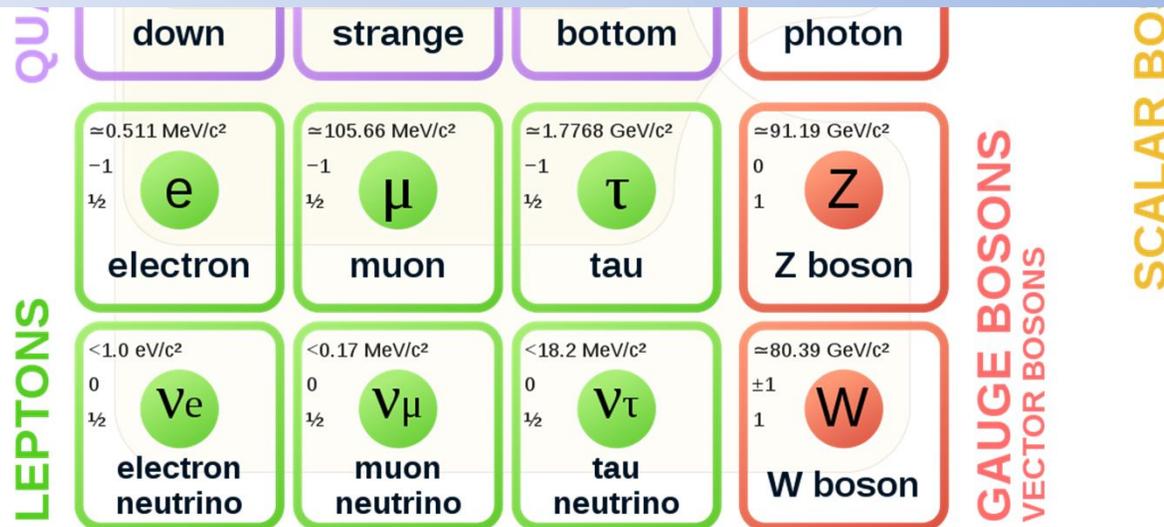
Standard Model of Elementary Particles
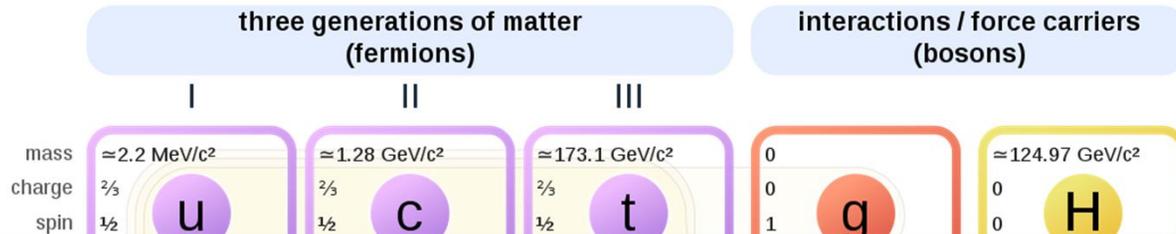
Standard Model of Elementary Particles

But only 5% of Universe is visible to us!

Who/what is the remaining 95%?

Standard Model of Elementary Particles

three generations of matter (fermions)			interactions / force carriers (bosons)	
I	II	III		

	≈2.2 MeV/c²	≈1.28 GeV/c²	≈173.1 GeV/c²	0	≈124.97 GeV/c²
mass	⅔	⅔	⅔	0	0
charge					
spin	½ u	½ c	½ t	1 g	0 H

But only 5% of Universe is visible to us!

Who/what is the remaining 95%?

down	strange	bottom	photon

Let's find New Physics!

electron	muon	tau	Z boson

<1.0 eV/c²	<0.17 MeV/c²	<18.2 MeV/c²	≈80.39 GeV/c²
0	0	0	±1
½ νe	½ νμ	½ ντ	1 W
electron neutrino	muon neutrino	tau neutrino	W boson

QUARKS

LEPTONS

GAUGE BOSONS / VECTOR BOSONS

SCALAR BO...

Belle II Experiment in Nutshell

- e^+ and e^- beams collide at the mass of Y(4S), and other energies.
  - Y(4S) particles decay into B and anti-B meson pairs promptly.
  - B meson consists of a b quark and a lighter quark.
  - Other mesons and leptons are being studied, too.

- In the Belle II detector, tagging (i.e., reconstruction with correct ID) efficiency of B mesons is high. This is very useful when studying B meson decays.
  - Many theories expect B decays are an excellent place to look for new physics phenomena.

BELLE II SOFTWARE

# Belle II Data Flow
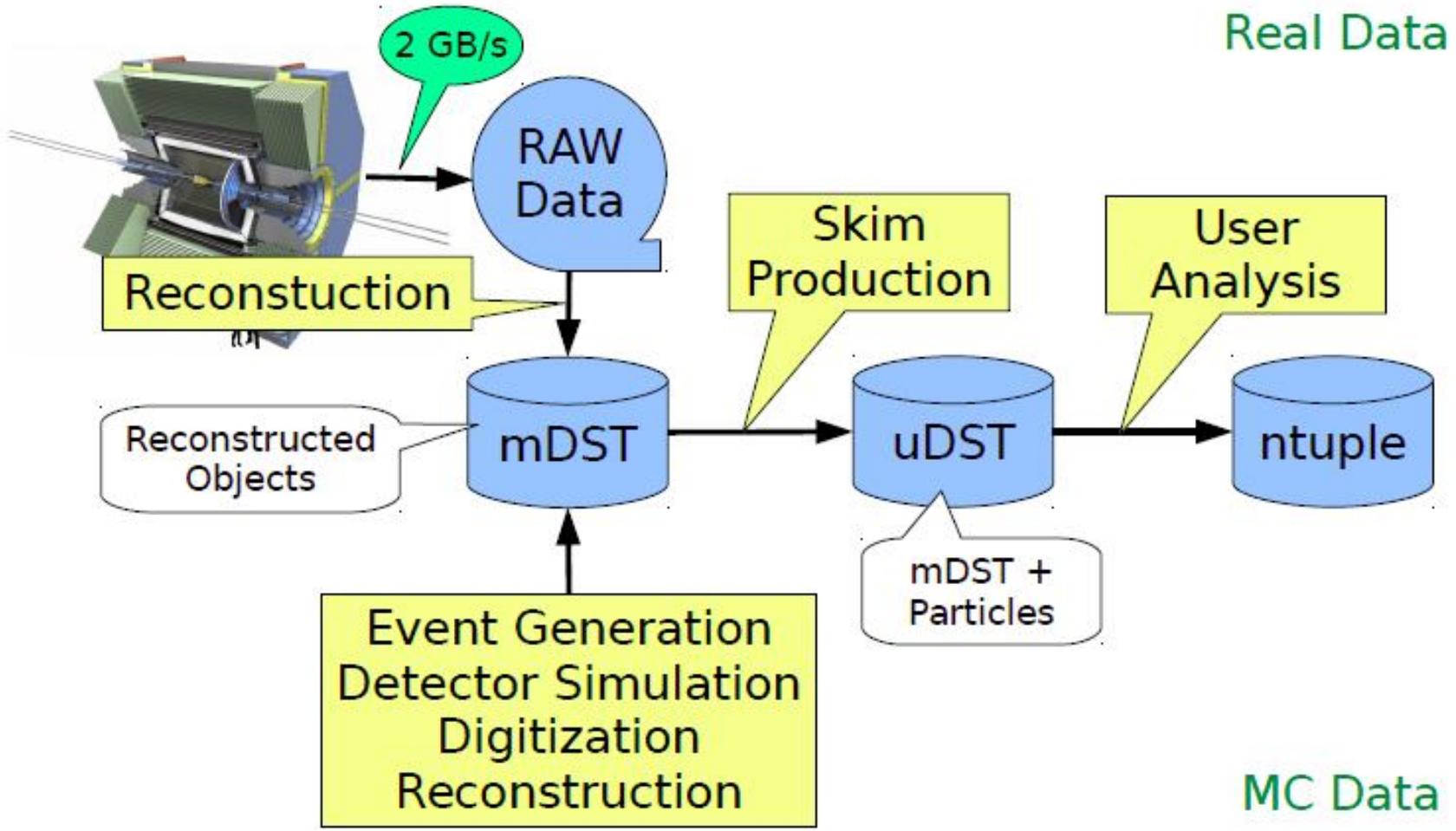
basf2: Software Framework for Belle II

- basf2 is used for both online and offline computing works.

- Python scripts are used to run a basf2 execution job.
- A basf2 job is a chain of C++ modules, which are loaded by the job script dynamically.
- Parallel processing is handled by event fork.

- External software libraries are incorporated into basf2.
- Input/output software for data exchange is done by ROOT.
- Detector geometry and event simulation is handled by Geant4.

- Collaborative tools (Bitbutcket, Confluence, Jira, Indico, Invenio, Askbot, etc.) are used to manage the codes, processes, and results at the central repository (Git based) at DESY.

Example: Processing of One Event

The Belle II software is written in C++ mostly. The scripts are handled by Python.
- A basf2 event is created by a user defined chain of modules on a path.
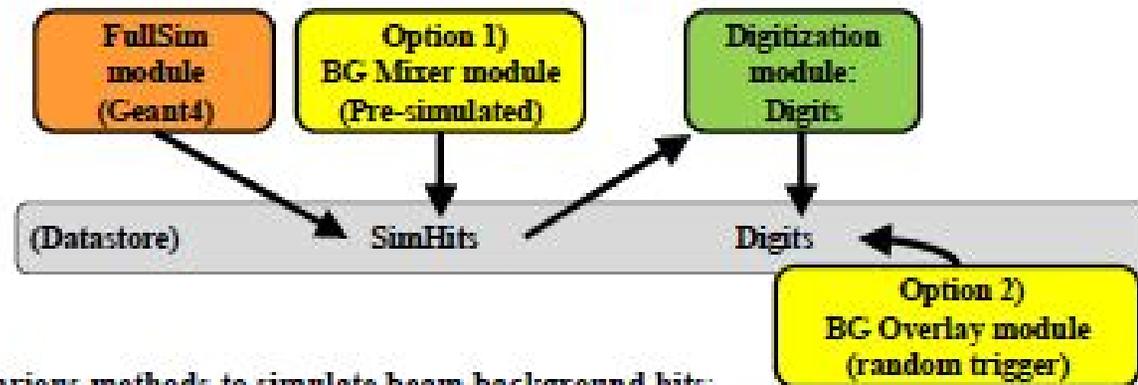- The core simulation module, *FullSim*, is an interface to Geant4 v 10.1.2.

Example: Order of basf2 Modules per Event
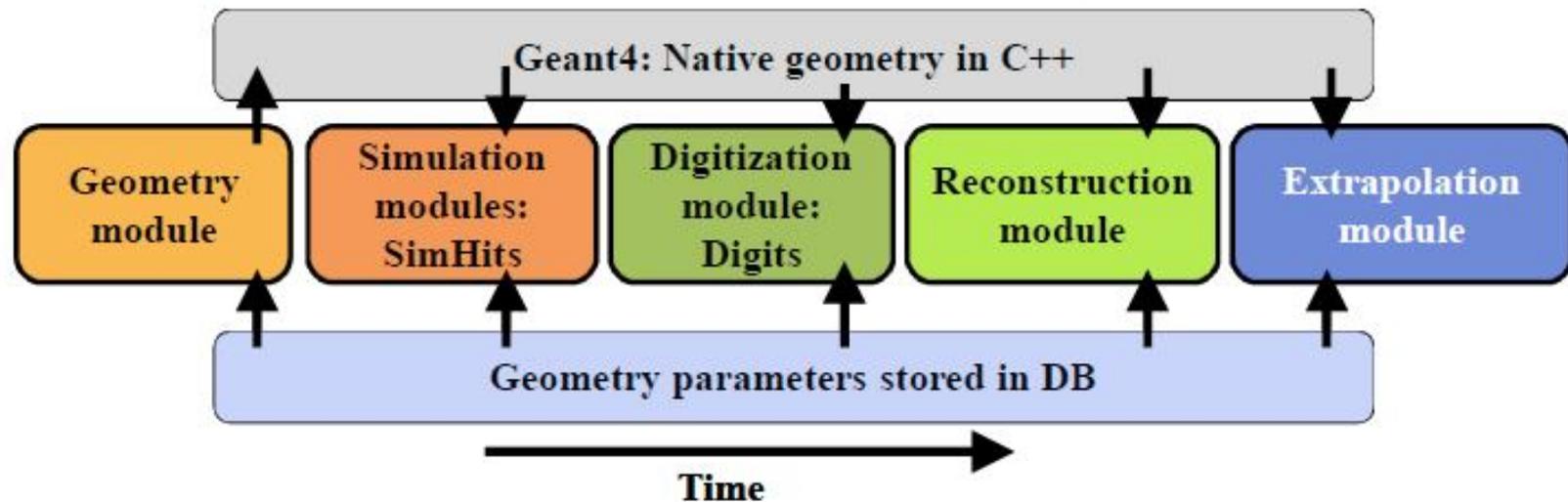
Simulation

- To generate a MC event, EvtGen, KKMC, BABAYAGA.NLO, AAFH generators are used

- The detector geometry is created in Geant4, during basf2 execution.

- Beam/Machine background events are included either by mixing the simulated hits or by overlaying the measured data events.
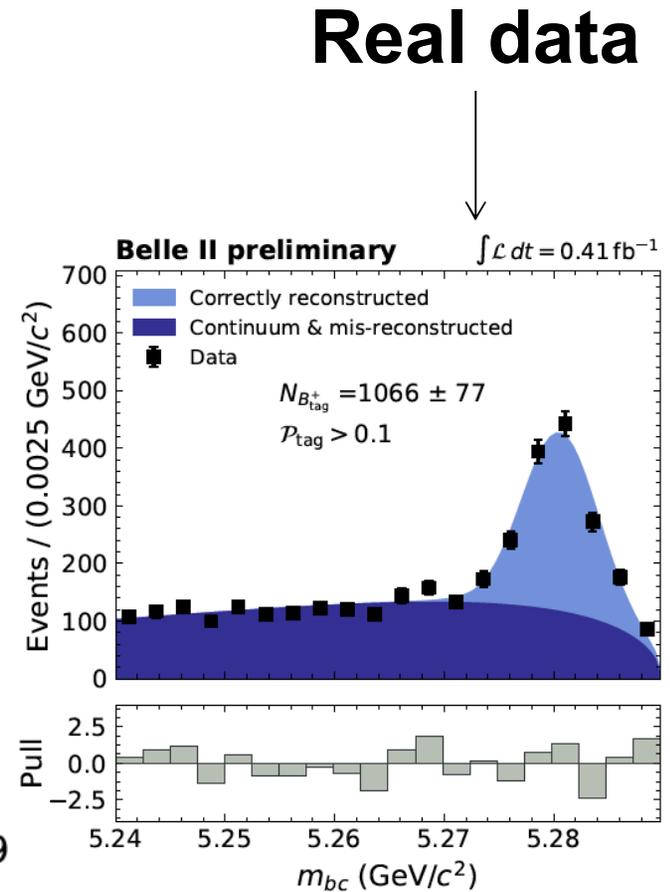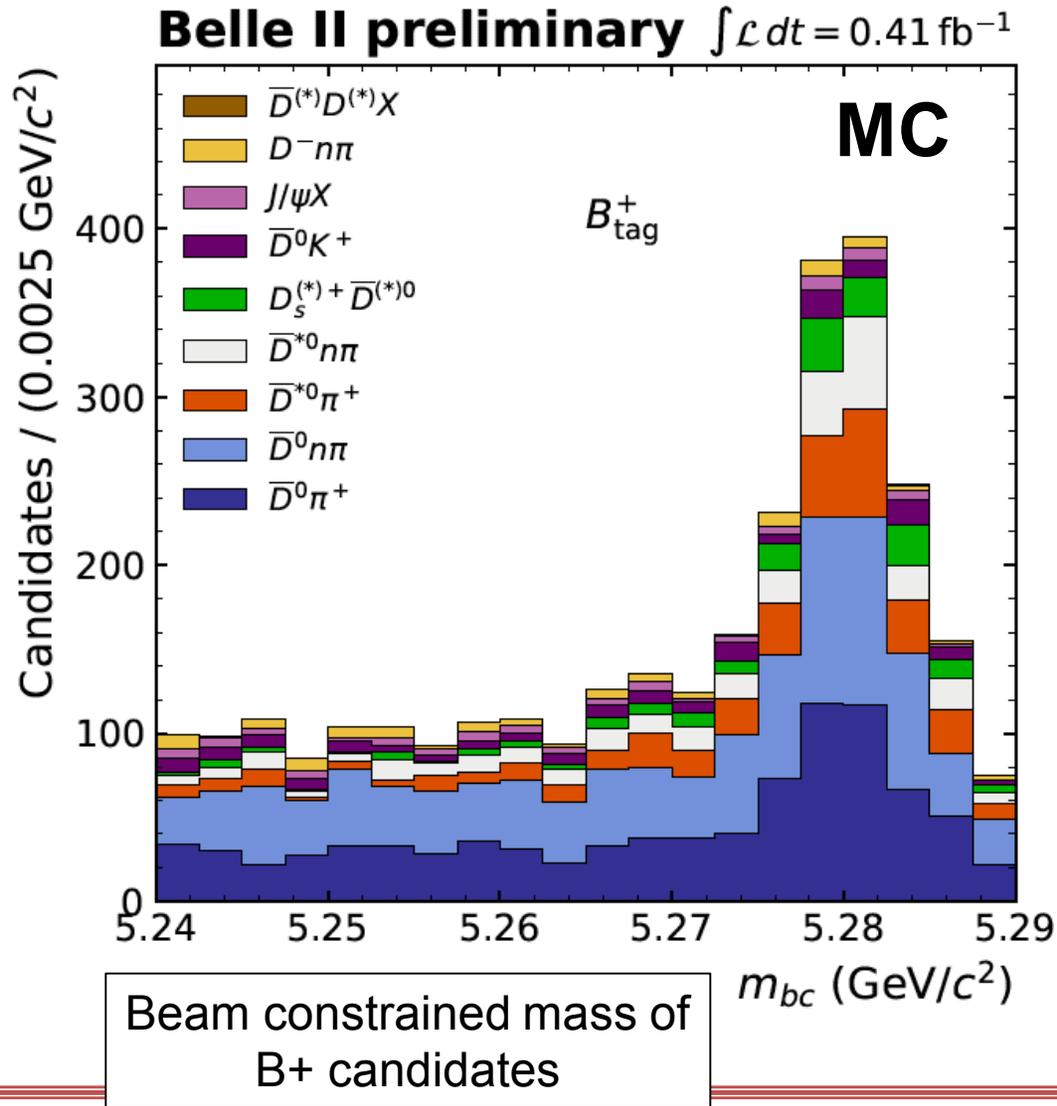
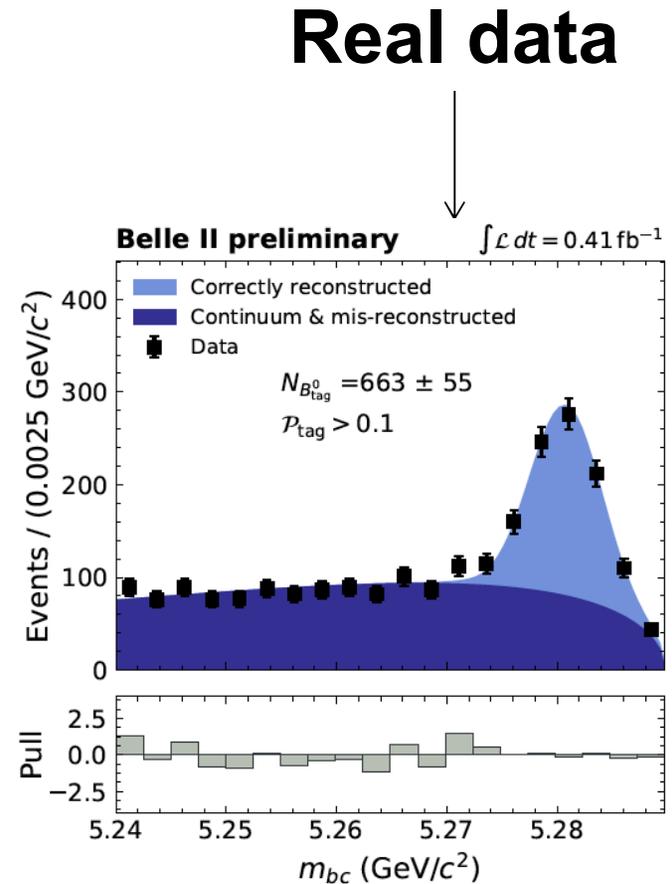## Mixing of Beam Background Hits

FullSim module (Geant4)	Option 1) BG Mixer module (Pre-simulated)	Digitization module: Digits

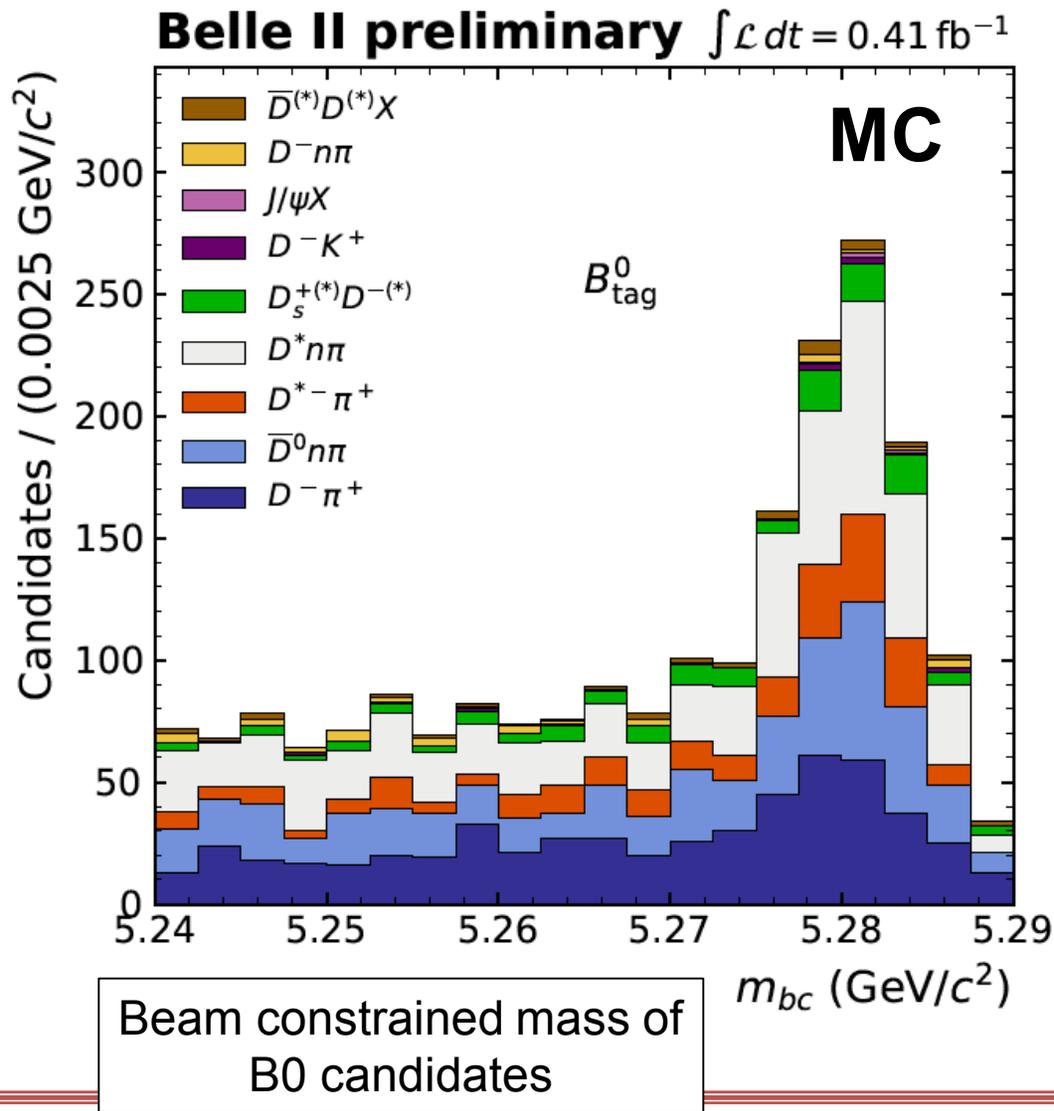(Datastore) → SimHits → Digits

Option 2) BG Overlay module (random trigger)

Various methods to simulate beam background hits:
- High luminosity operation creates substantial background hits inside the detector.

GEANT4
A SIMULATION TOOLKIT

Early 2019 Belle II Results: B+ tag

Beam constrained mass of B+ candidates

Early 2019 Belle II Results: B0 tag

Beam constrained mass of B0 candidates

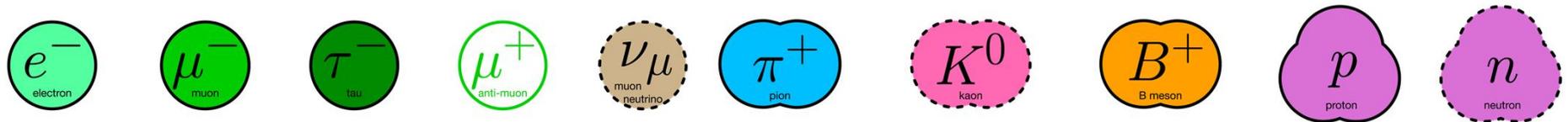# VIRTUAL REALITY

Belle II Virtual Reality

- Developed by the Virginia Tech University team led by Prof. Leo Piilonen.

- Unity (unity3d.com) was used as the VR software development platform.

- Display targets are
  - VR headsets such as Oculus Rift, Oculus GO, HTC Vive
  - Windows, Mac OSX, Linux
  - Web browser
  - iPhone, Android (limited interaction)
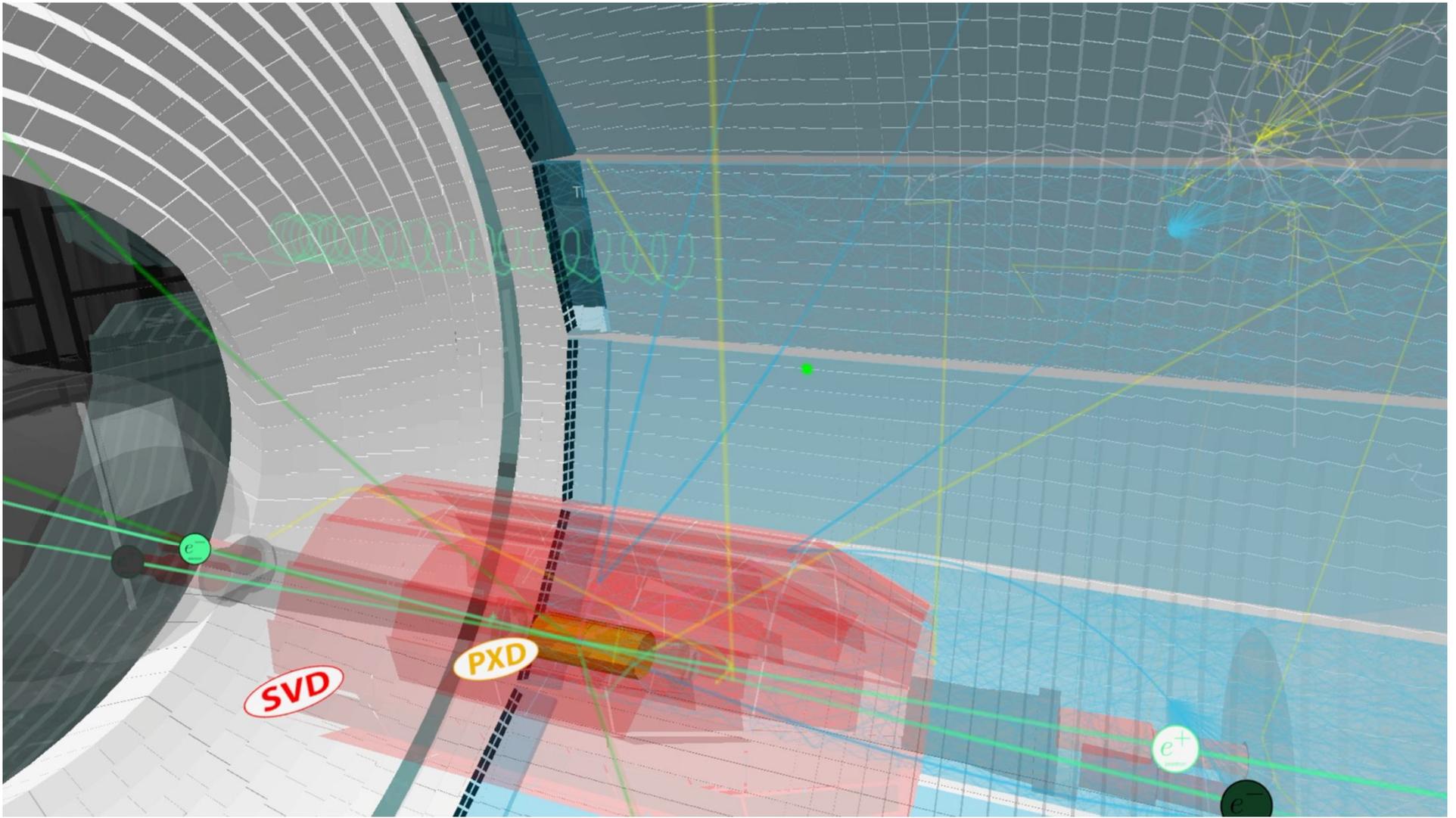
Belle II Virtual Reality: Details

- Belle II Detector geometry
    - Created by Geant4
    - Next, the geometry volumes are extracted to either FBX files or VRML2 files using *GetPolygon()* function.
    - FBX text file is imported by Unity.

- Belle II event info
    - History of each particle is simulated by basf2/Geant4
    - The event info (location, energy, momentum, particle ID, etc.) is extracted at (almost) each step using *G4UserSteppingAction()*.
    - The result is stored in a csv file.
    - Then sent to Unity.

Belle II Virtual Reality: Details

- C# scripts are used by Unity to read the csv files.

- Animate the event history using
  - Faint lines represent particle trajectory
  - The active part of the lines are highlighted.
  - Sprite represent each particle
    - Leptons are represented by circles
    - Mesons by a combination of two circles
    - Baryons by a combination of three circles
  - Note) 90fps is required for VR headsets

Geant4 Event History: Animation Example

Public Examples

- https://store.steampowered.com/app/810020/Belle_II_in_Virtual_Reality/

- https://vimeo.com/220004044 (voice)

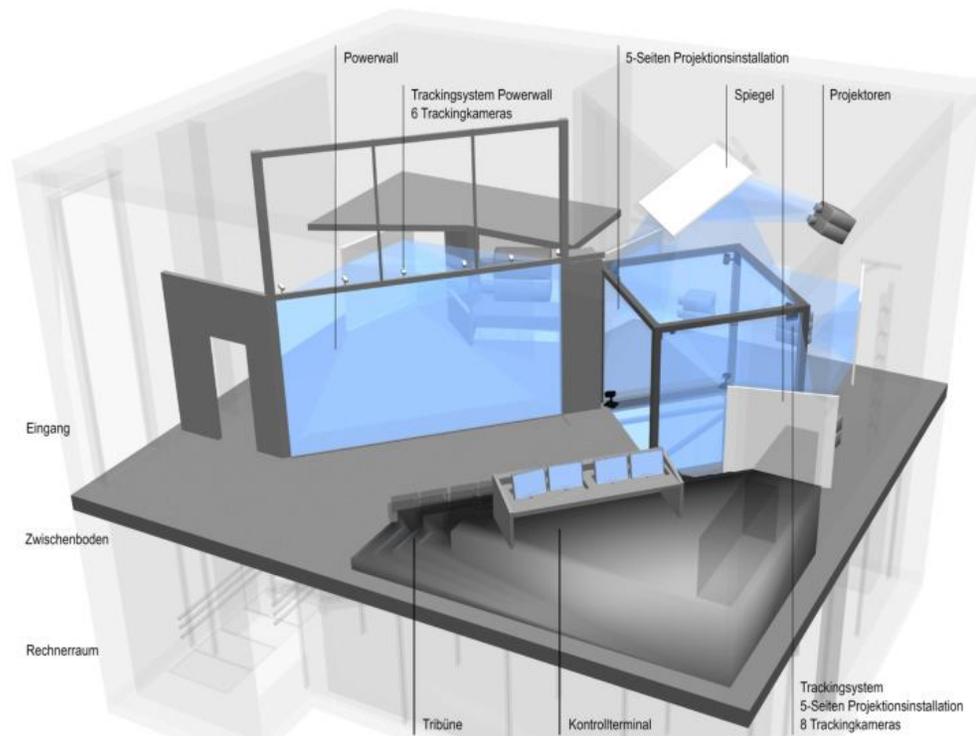- https://vimeo.com/214899668 (caption)

Various Presentation Mode

- Standalone mode using Oculus devices.

- The CUBE facility at Virginia Tech
  – Multiple people in the room, represented by avatars in the VR world.

Various Presentation Mode

- The CAVE facility at LMU, Munich

SUMMARY

Summary and Future Plan

- After several years of collider testing, physics phase of Belle II started 2019
  - Geant4 is the core software used to create detector geometry and event simulation.
  - Geant4 is also used to create Belle II virtual reality applications.

- To optimize the Geant4 performance for high luminosity runs of SuperKEKB, we are planning to
  - Test the Belle II costume physics list instead of FTFP_BERT
  - Upgrade version from 10.1.2 to 10.5.1