EIEIOO — The Belle II Experiment

Alexandre Beaubien, PhD candidate

University of Victoria

The Belle II collaboration

2024-05-15

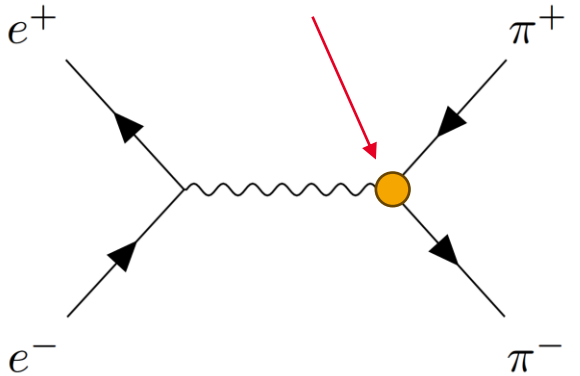
About Myself

Holding a CsI(Tl) crystal.
Belle II has 8736.

PhD student — UVic

Research:

- Software tools
- Data analysis:
  - Measuring strong nuclear force



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The Belle II International Collaboration

~1200 collaborators
- ~600 authors, ~500 students,

125 Institutions
28 Countries

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Previously: *Belle* & *BaBar*

Previous generation of **experiments** gave the experimental results that led to the 2008 Nobel prize.

-> Experimental observation of CP violation in B-mesons.

© The Nobel Foundation Photo: U. Montan

Makoto Kobayashi

Prize share: 1/4

© The Nobel Foundation Photo: U. Montan

Toshihide Maskawa

Prize share: 1/4

That's the "K" and "M" in "CKM Matrix"..!

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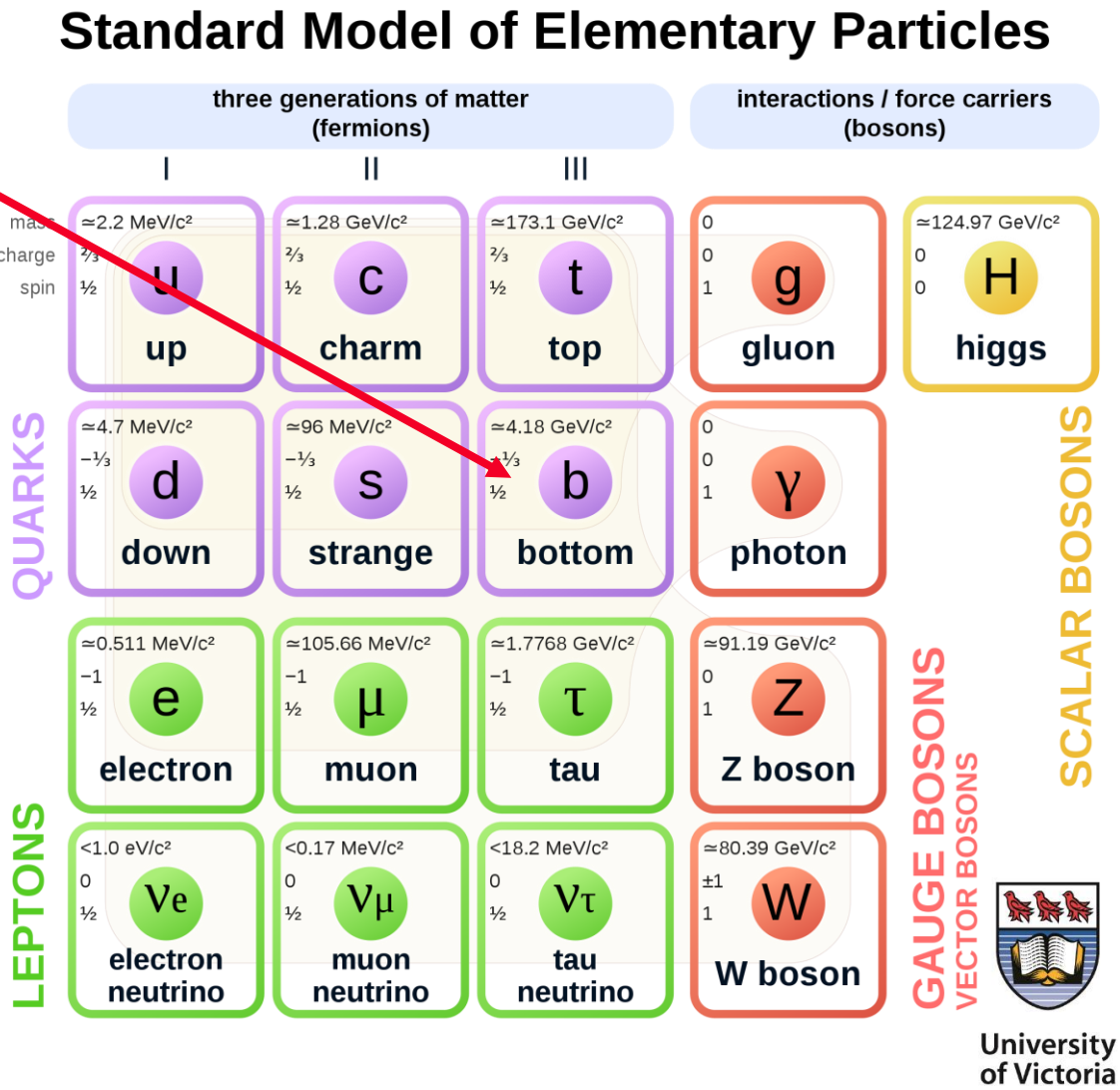
Belle II — a B-Factory

Produce B-mesons:

- $B^+ : u\bar{b}$
- $B^- : \bar{u}b$
- $B^0 : d\bar{b}\,, \bar{d}b$

$$e^+e^- \rightarrow \underset{10.58\ GeV}{\Upsilon(4s)} \rightarrow B^+B^-$$

$(b\bar{b})$



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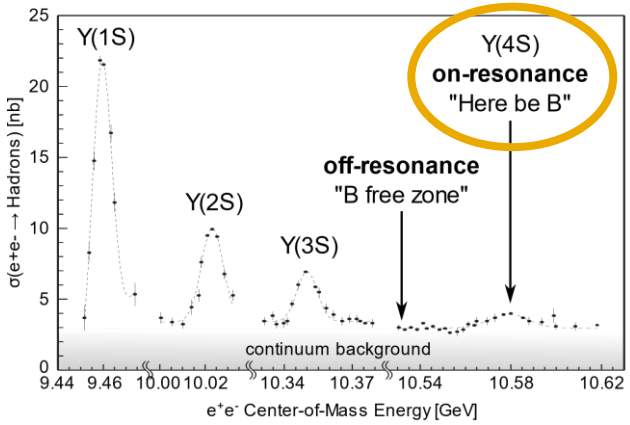

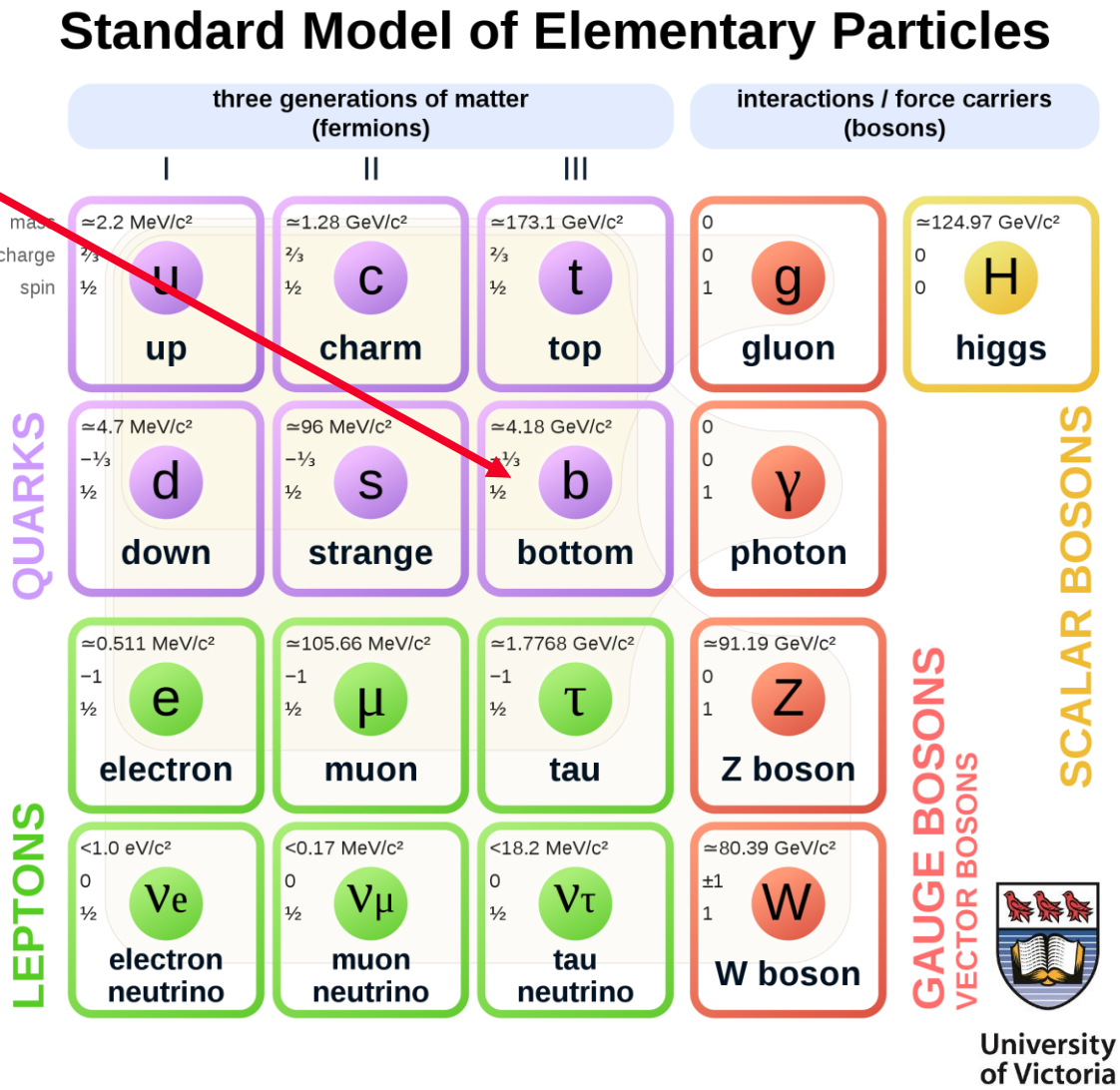

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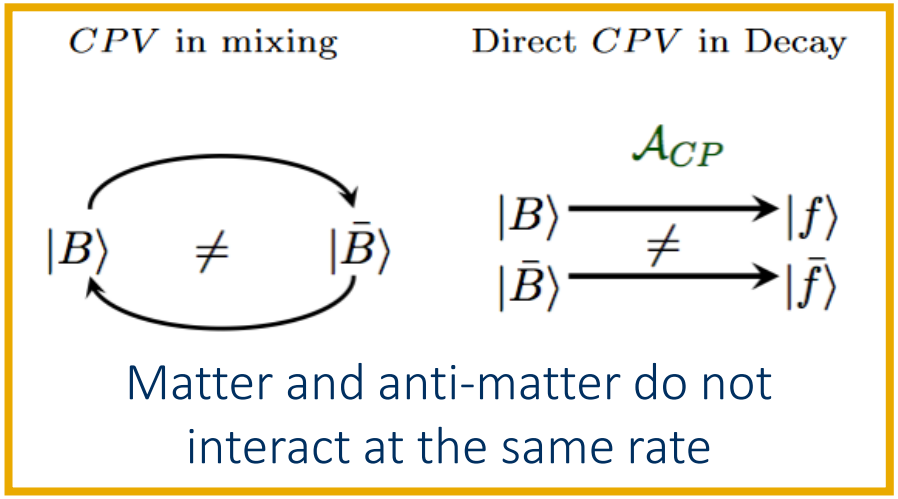
Why B-mesons?

CP violation!



Looking for new and unknown sources of CP violation in B-Physics

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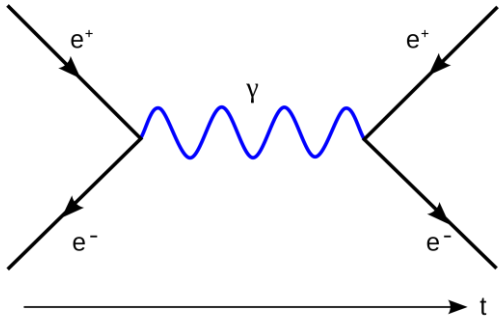
CP Violation

Ignoring dark matter…

Question: How is the universe ~100% matter?



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CP Violation

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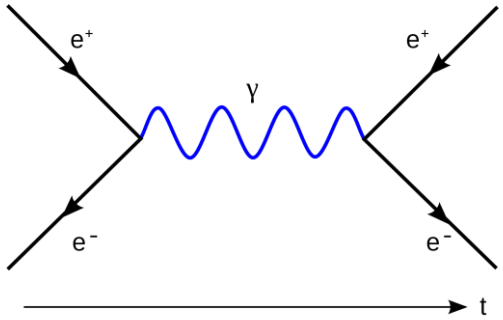

1. Violate baryon/lepton number
   - matter ⇄ anti-matter
2. Need CP violation
   - matter ⇄ anti-matter
3. Something about thermodynamics…
   - See Sakharov conditions

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CP Violation

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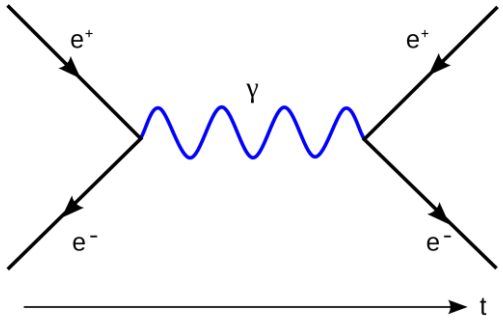

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   - matter ⇄ anti-matter
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Currently, CP violation is much too small.

Need more precision!

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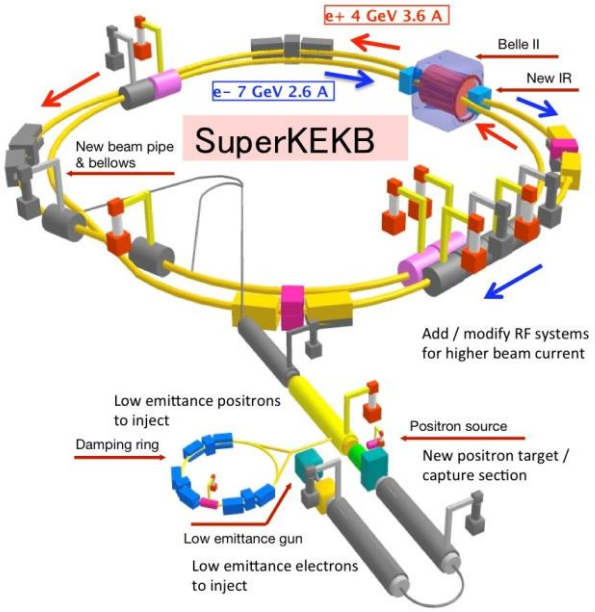
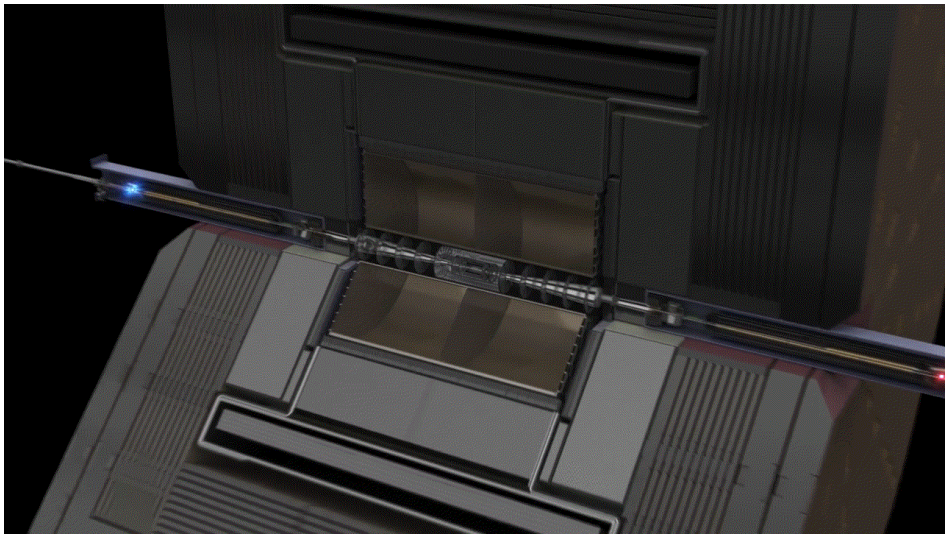
Matter, anti-Matter Collisions

SuperKEKB (10.58 GeV) collides electrons & anti-electrons





What comes out of the collision, we can study the Physics

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What's so « Super » about SuperKEKB?

As of 2020, SuperKEKB is the highest luminosity collider ***ever***! Target is ~10 to 20 times the cumulative luminosity of HL-LHC

Luminosity ∝ intensity of beam.

$$N = \sigma L$$

N = Number of collisions
σ = Cross section (probability)
L = Luminosity

→ # of potential collisions

More luminosity = more events = more precision

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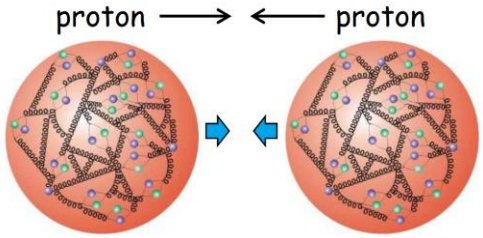
What's so « Super » about SuperKEKB?

2 advantages of electron, anti-electron colliders:

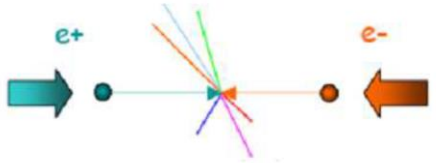
1. "One event at a time"
2. "Known initial state"

« clean » collisions

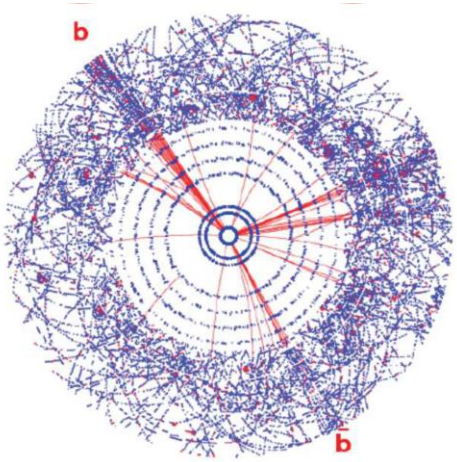
More Precise Physics

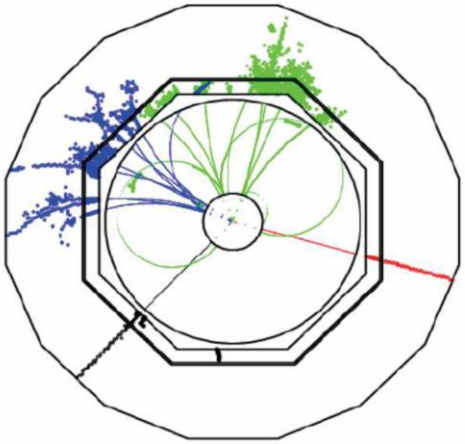


pp Collision



e^+e^- Collision





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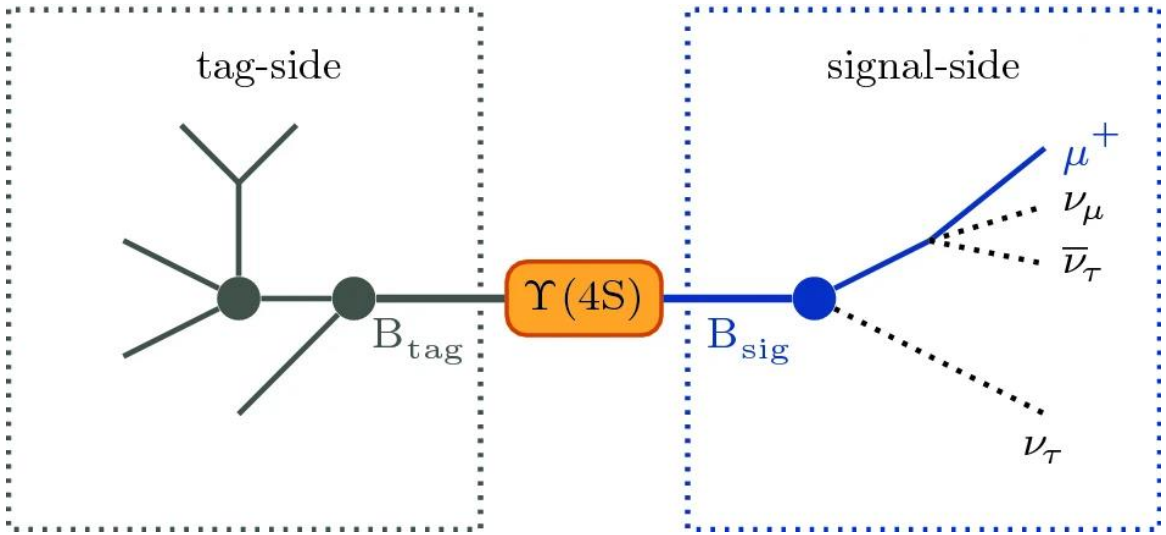
What is the Advantage of Belle II?

- We can do e.g. tagging, missing mass measurements
  - Use known initial state to understand missing particles



Recoil mass:
How much energy/momentum is "taken" by invisible particles

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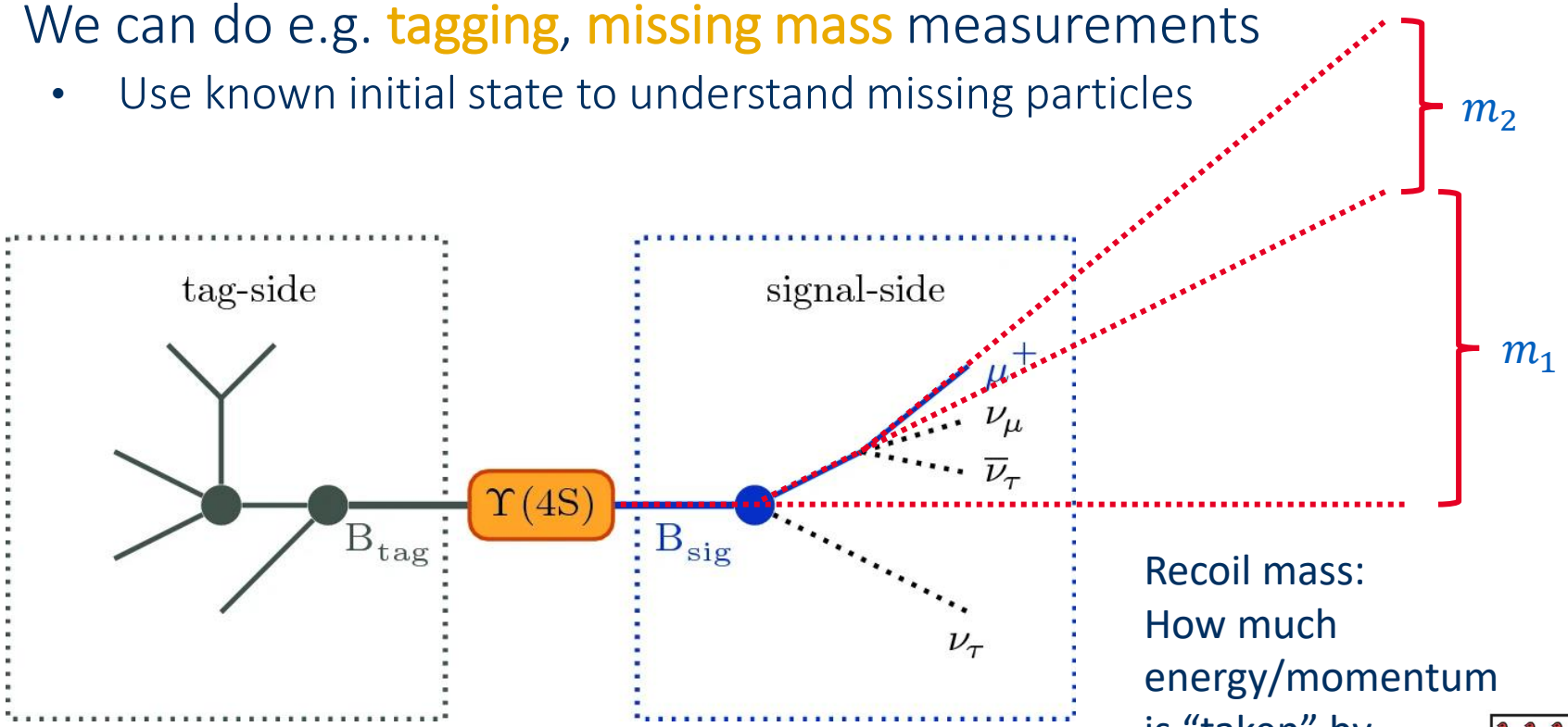

Recoil mass:
How much energy/momentum is "taken" by invisible particles

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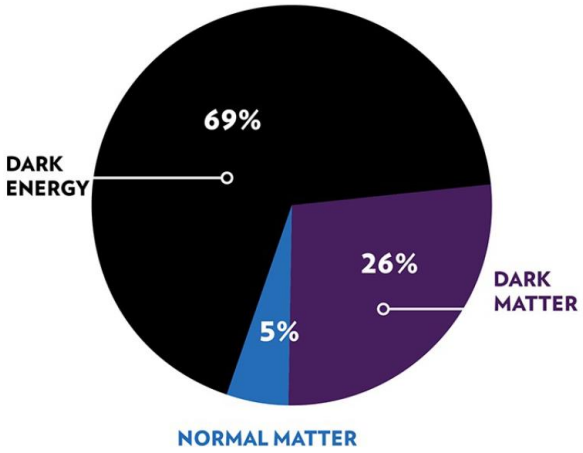
Dark Sector

Standard Model (SM)

Dark Sector (DS)

- Dark matter
- Dark forces
- Other dark particles



Dark Sector is a dark matter theory.

The dark sector parallels the SM (particles, forces, etc.).

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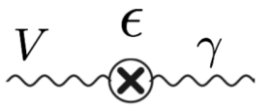
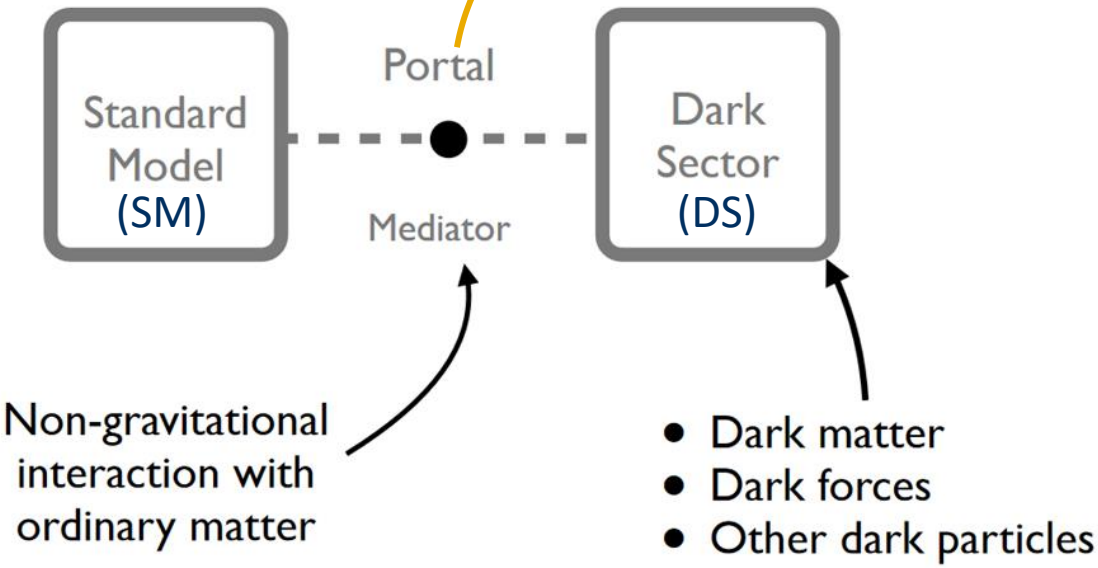
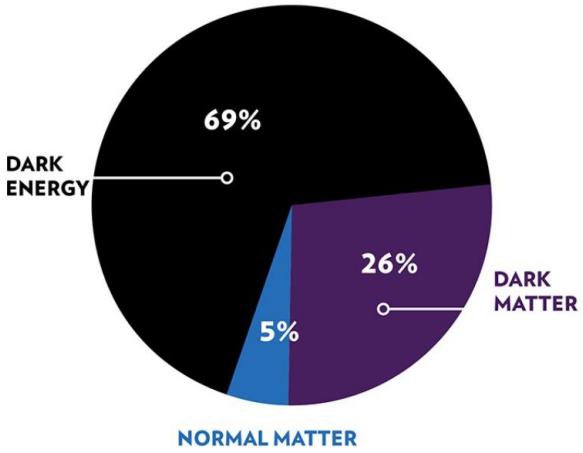
Dark Sector







Dark Sector is a dark matter theory.

The dark sector parallels the SM (particles, forces, etc.).

It interacts through mixing of mediators.

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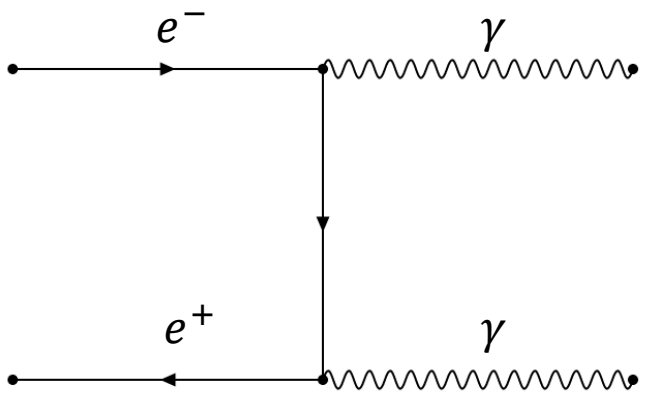
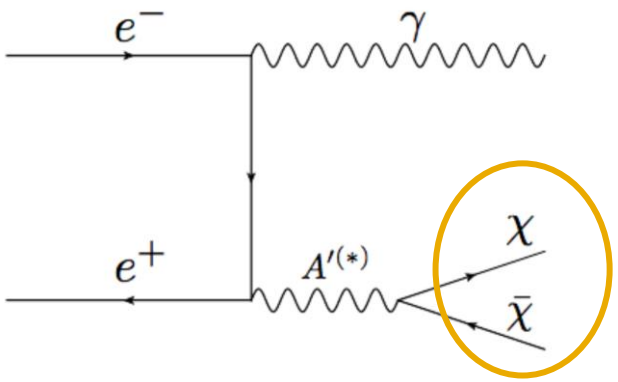
Dark Sector Searches w/ Missing Mass

Dark Sector processes look quite **similar** to Standard Model processes

SM process: annihilation into **2 photons**



DS process: one of the **photons mixes** with a DS particle (e.g. **dark photon**)



DM particles Invisible

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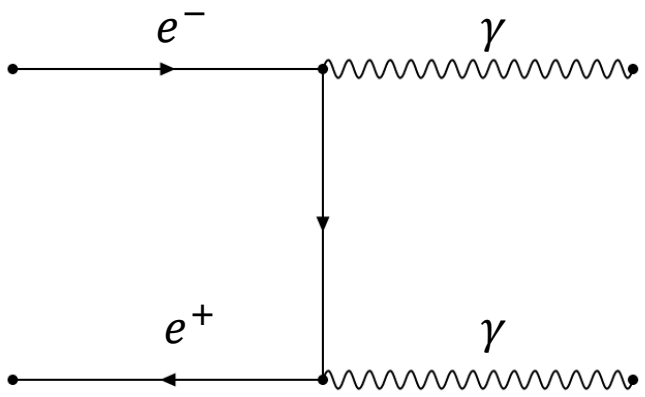

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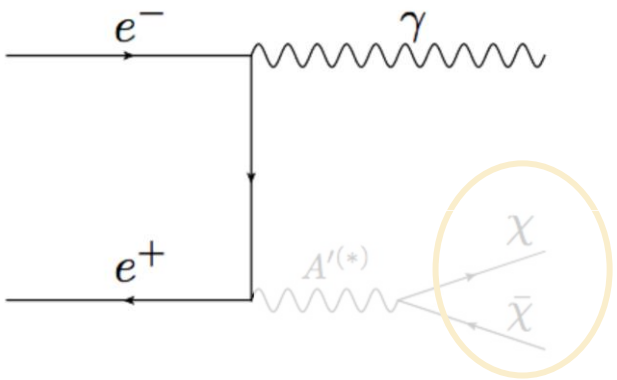

For our detector:
Looks like a SM process with a **missing particle**

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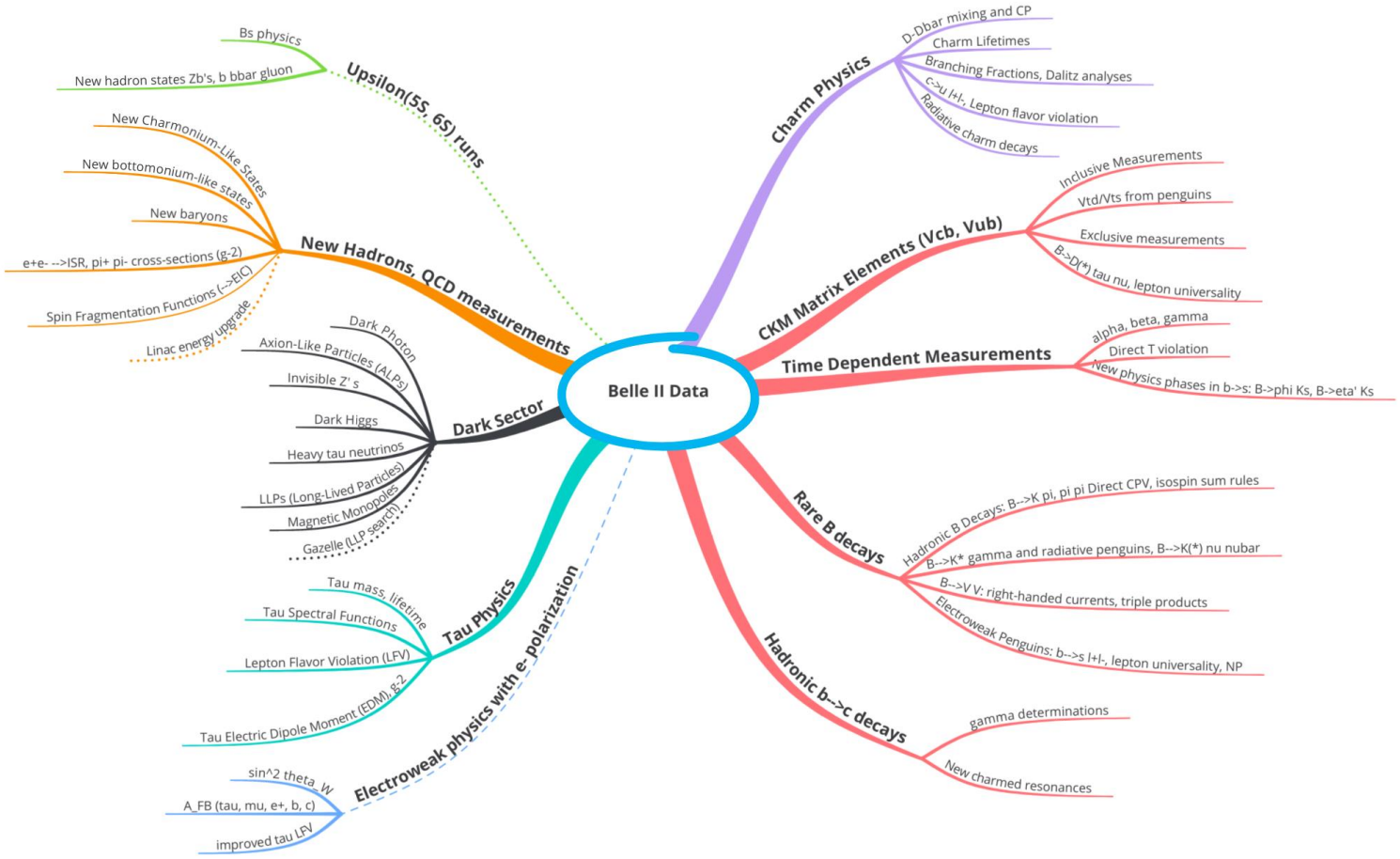
Belle II Physics Program

1. Probe the limit of Standard Model (SM) with high precision
2. Search for new Physics



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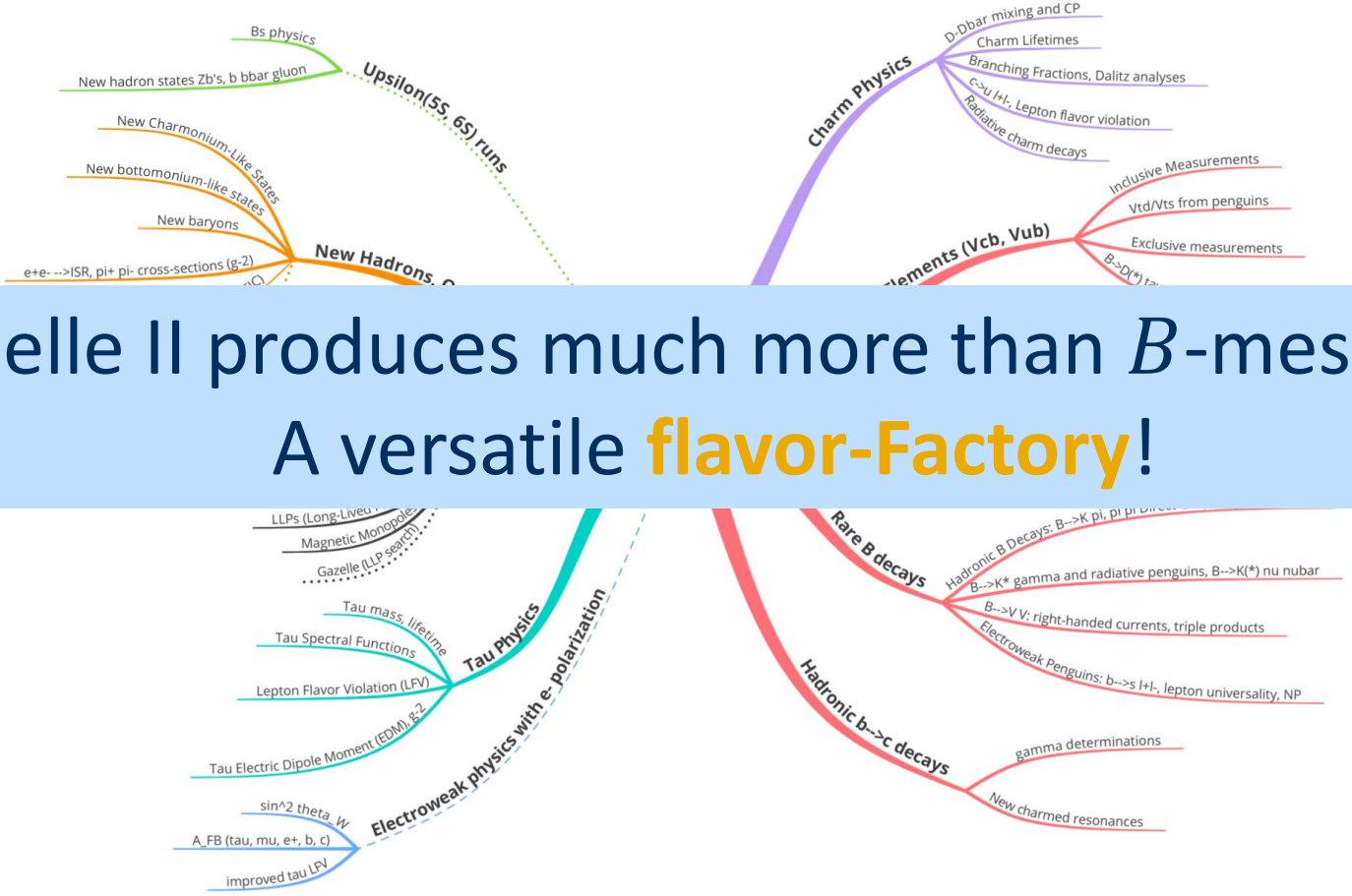

Belle II produces much more than B-mesons
A versatile flavor-Factory!

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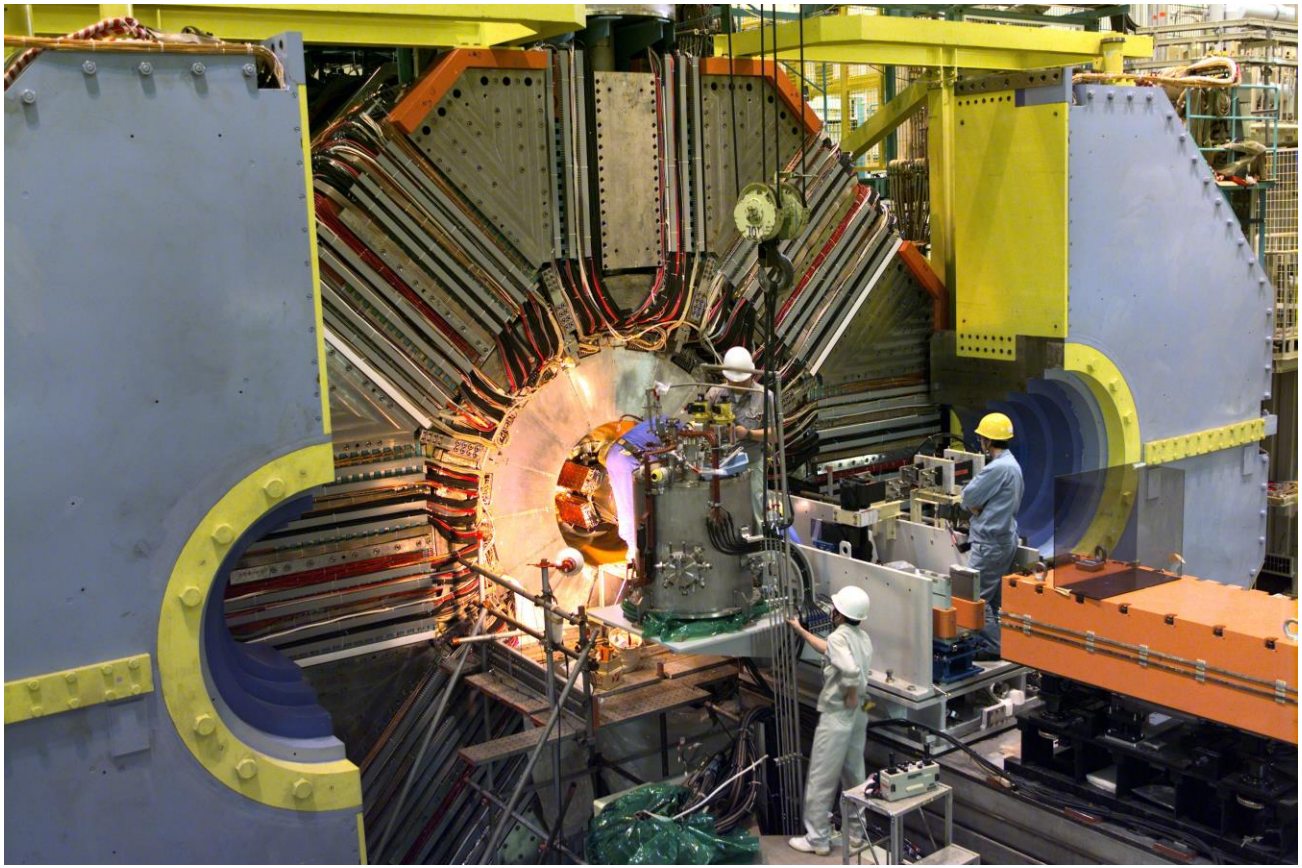
The Belle II Detector



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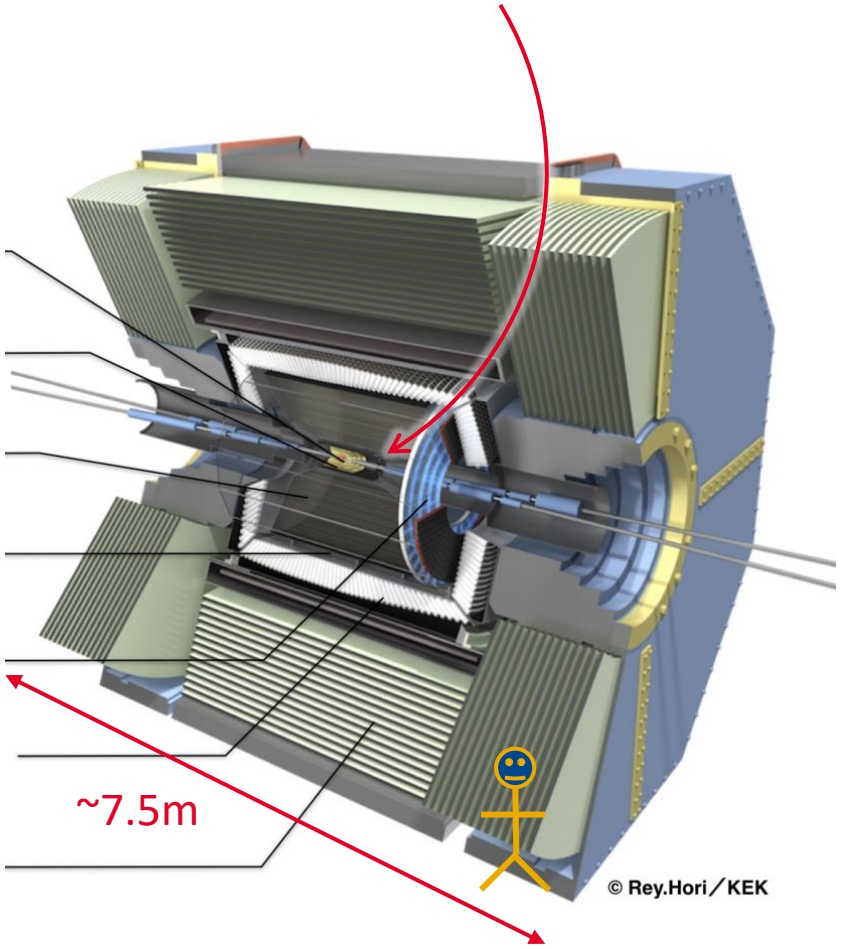
The Belle II Detector

General-purpose detector — Layers built around collision point

7 sub-detectors



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The Belle II Detector

General-purpose detector — Layers built around collision point

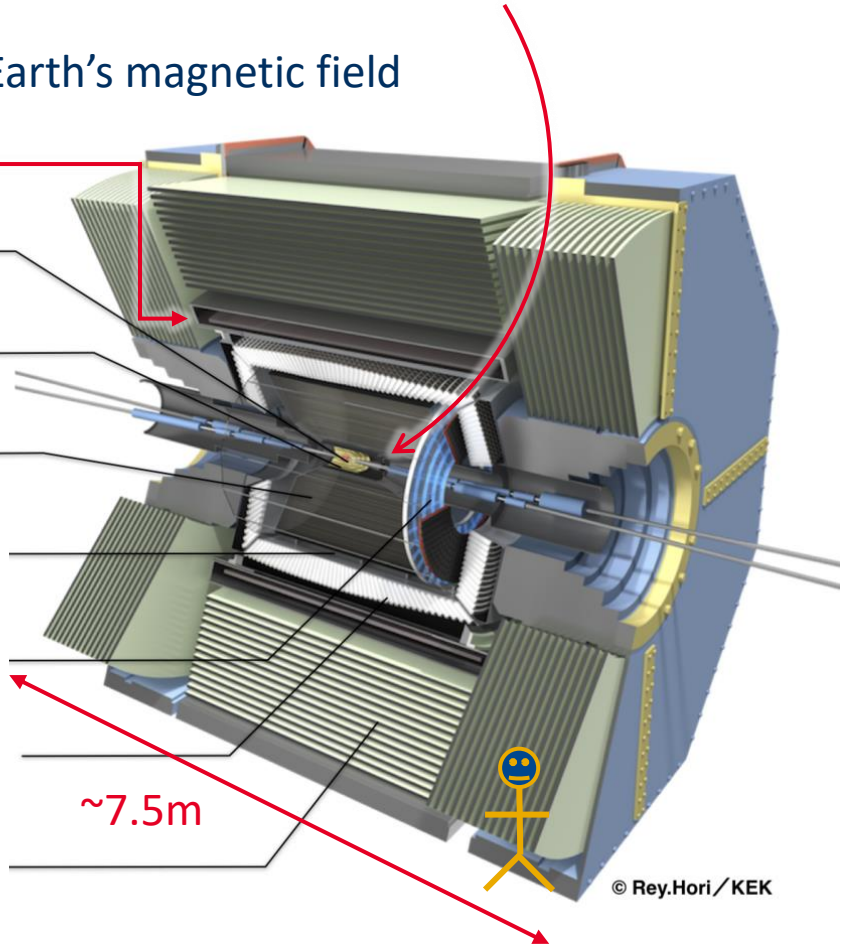
7 sub-detectors

~30 000x the Earth's magnetic field

Also, a 1.5T magnet!

Particle Position & Tracks

- Pixel Detector (PXD)
- Silicon Vertex Detector (SVD)
- Central Drift Chamber (CDC)



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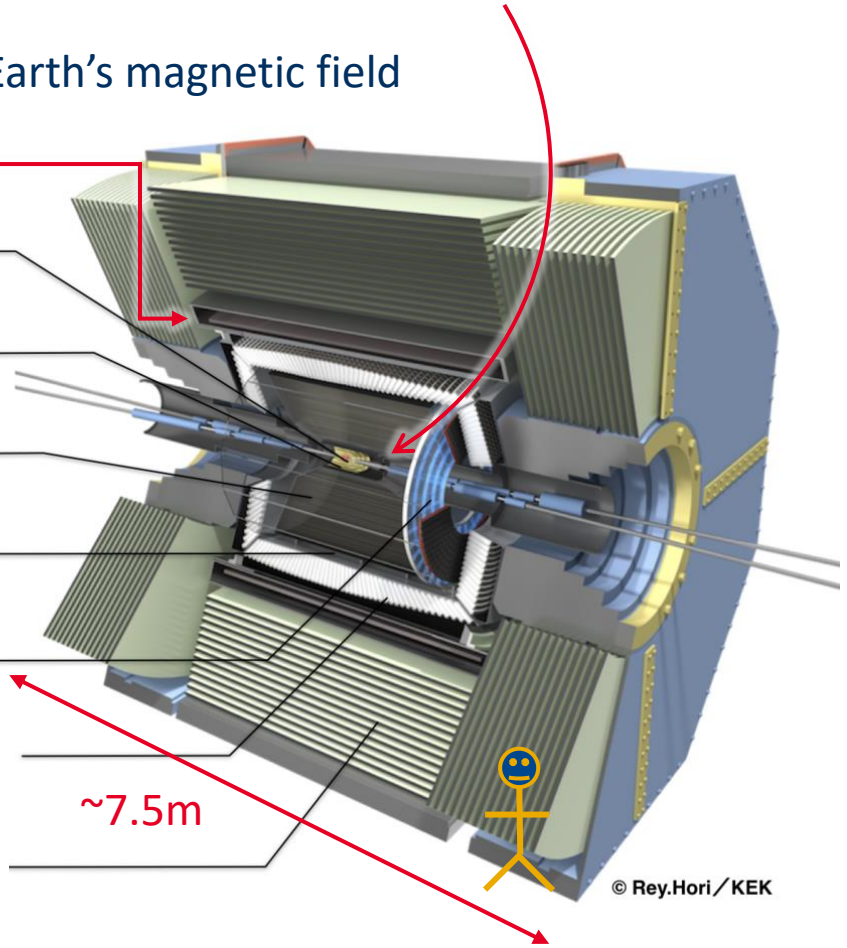
Particle ID

- TOP counter (TOP)
- Aerogel RICH counter (ARICH)



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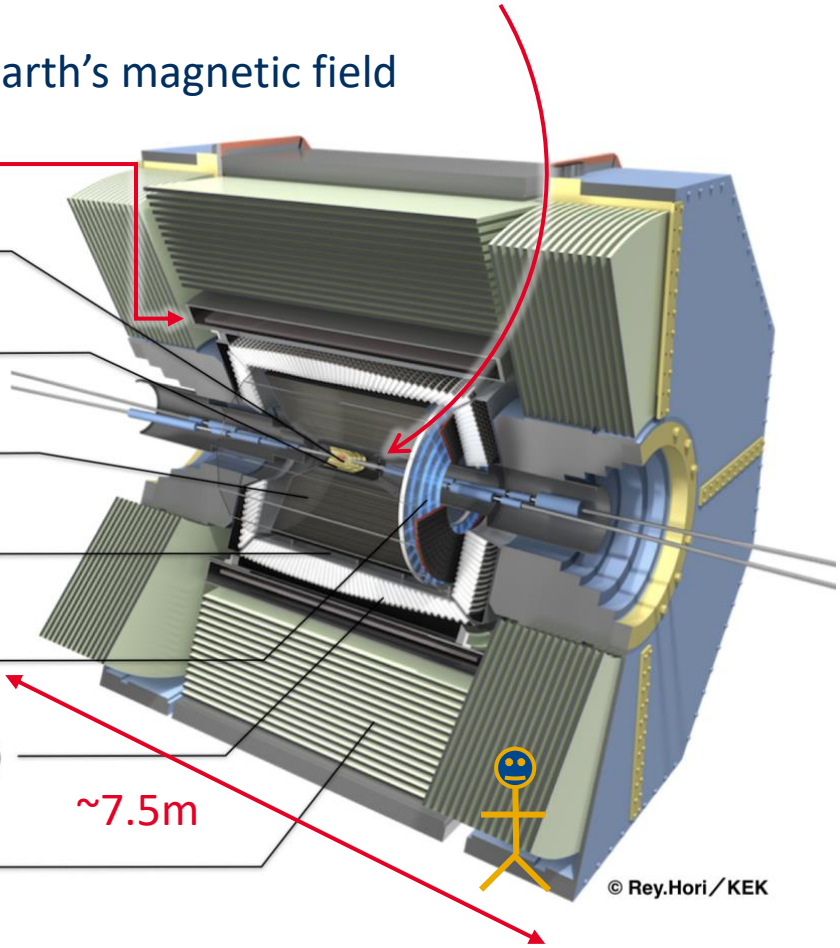
Particle Energy

- Electromagnetic Carolimeter (ECL)
- K^0_L/Muon Detector (KLM)



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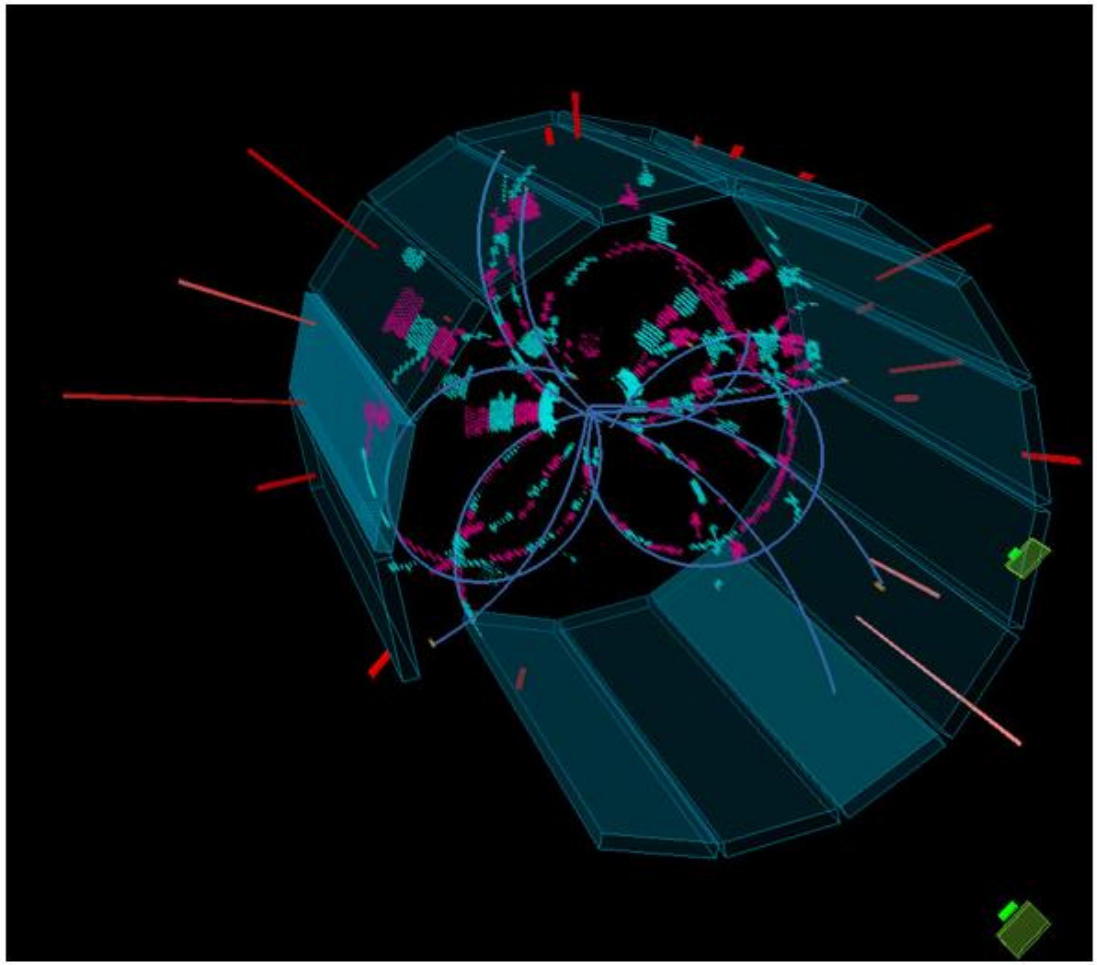
Event Viewer —Collisions

3D **visualization** of Belle II **collision**.

Tracks are left by **charged particles** traveling through the detector.



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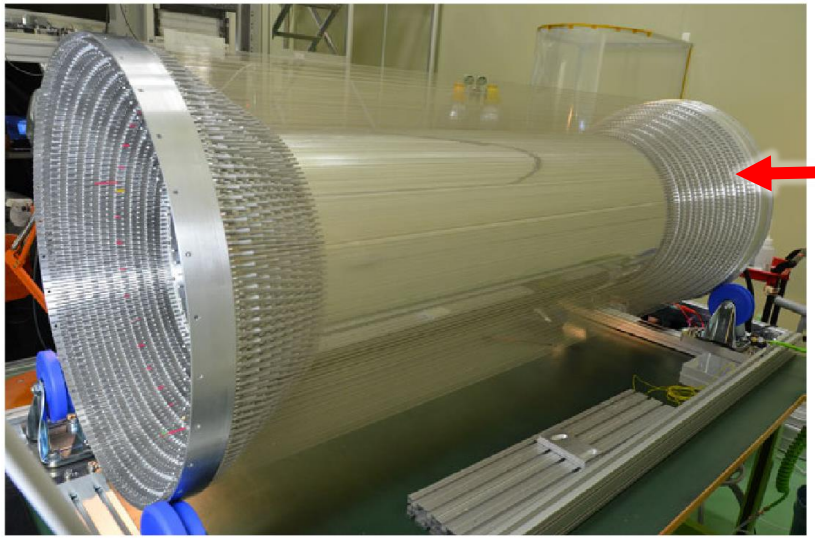
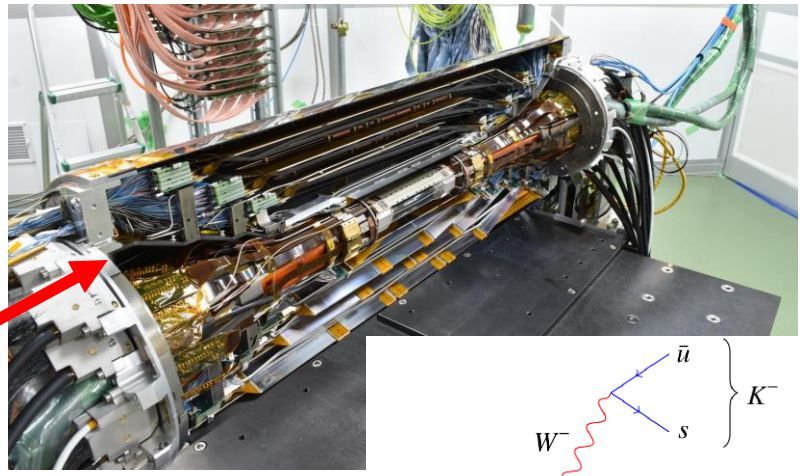
Belle II Tracking & Vertexing



The **drift chamber** tracks the trajectory of charged particles.

14336 wires of diameter 30 μm track charged particles through space.



The **vertex detector** find where particles decay.
Each shell is made of **« pixels »** with resolution on the order of 10 μm

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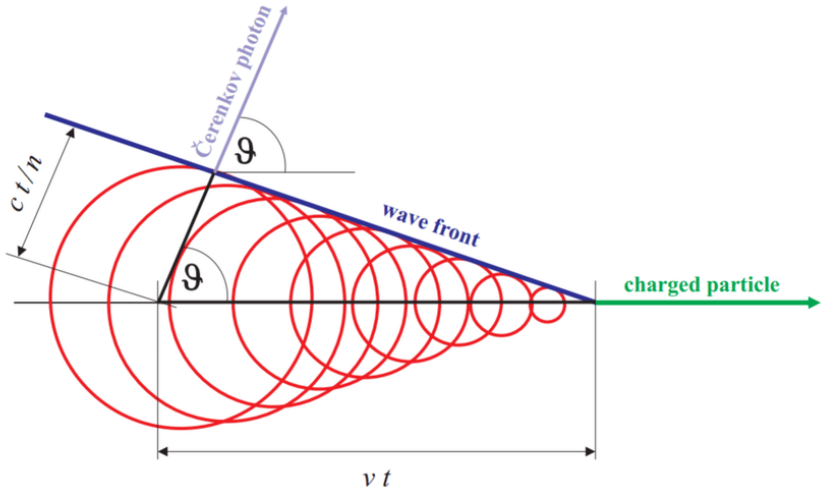
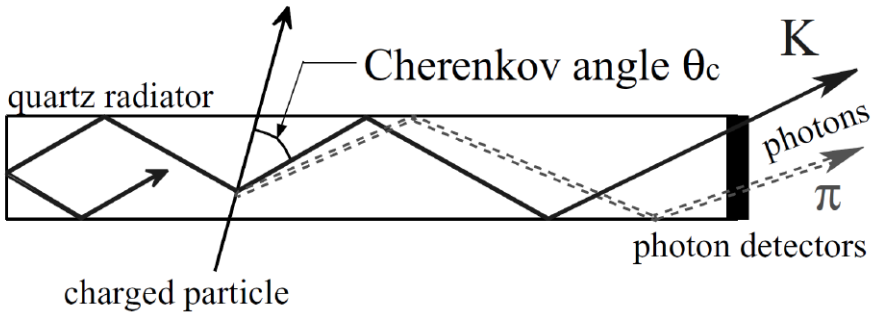
ARICH and TOP

The **TOP** and **ARICH** identifies charged particles using **Cherenkov radiation** (sonic boom for light).

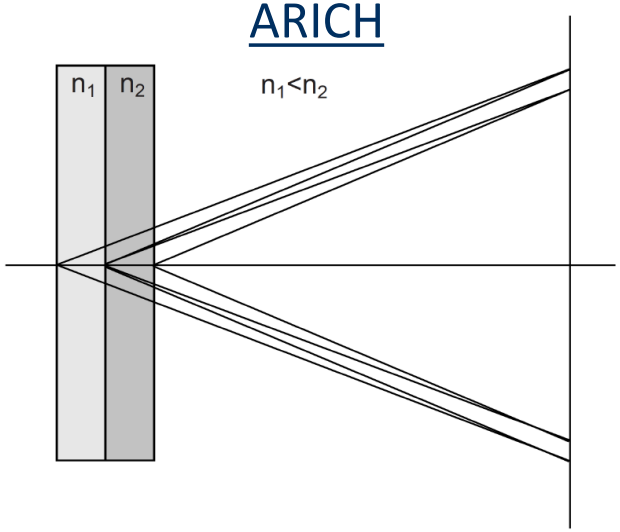


Cherenkov radiation tells you what your particle **velocity** is. Mix with **momentum** and you get **mass**!

TOP



ARICH



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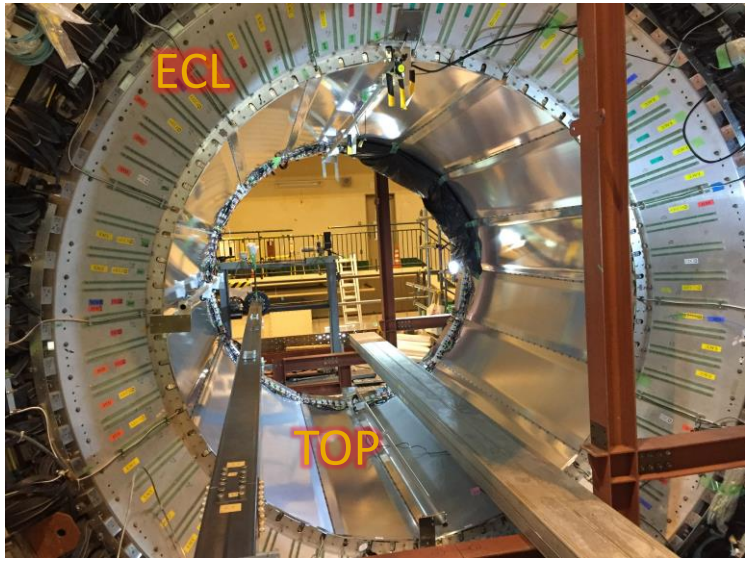
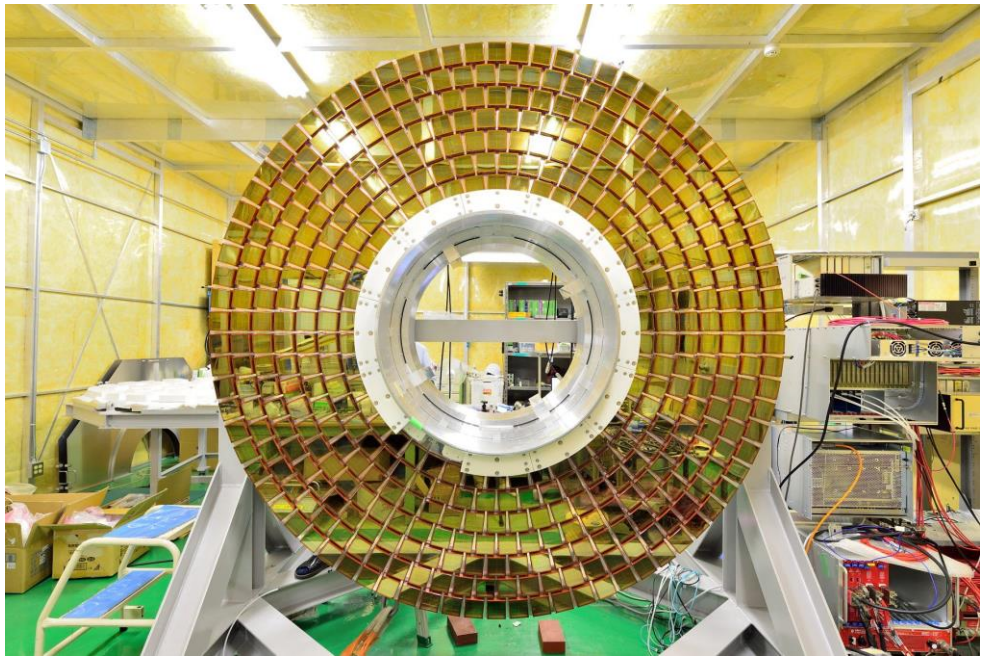
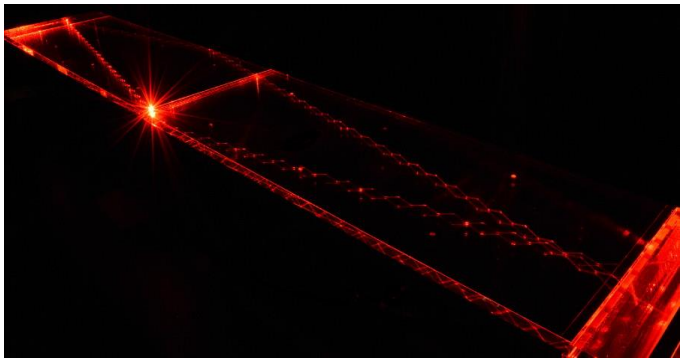
ARICH and TOP



ARICH



TOP



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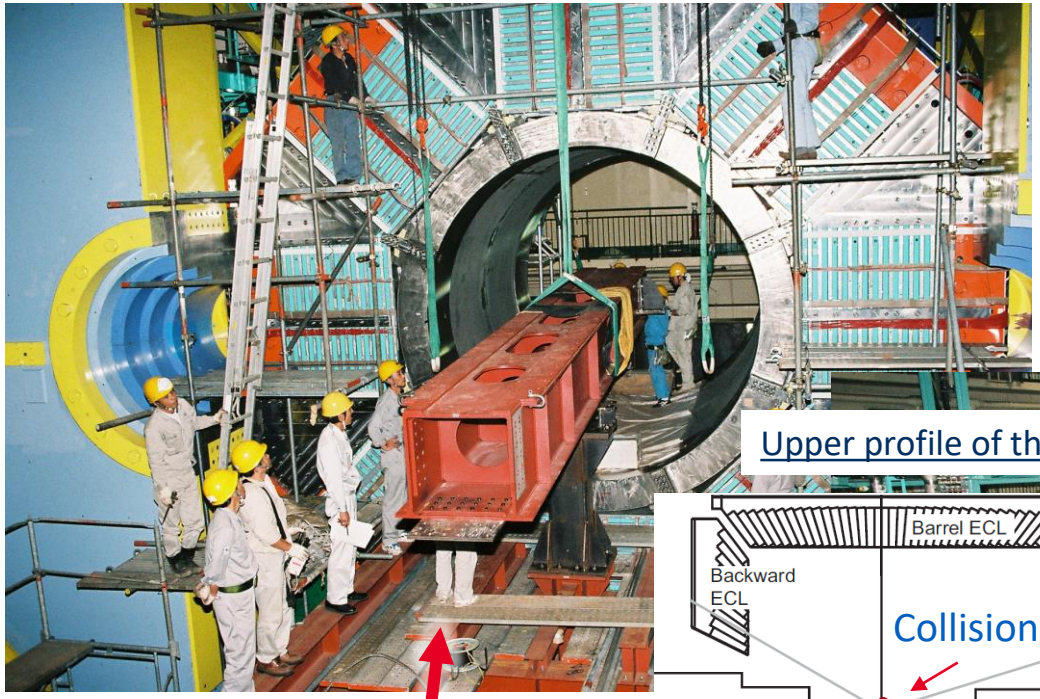
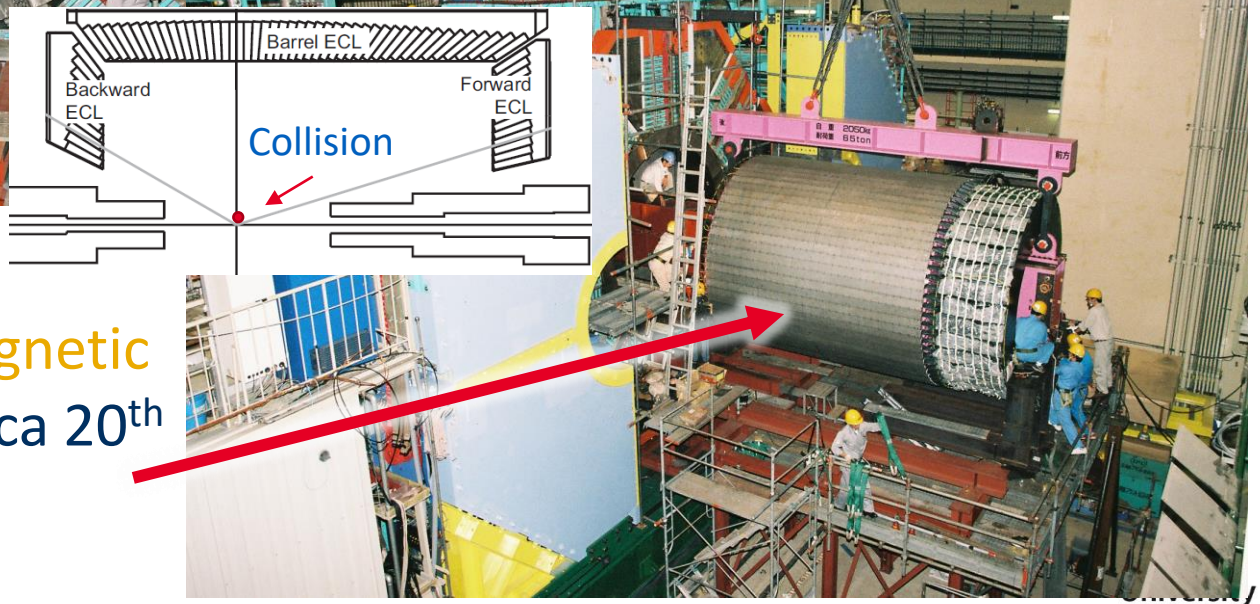
ECL Installation (old)

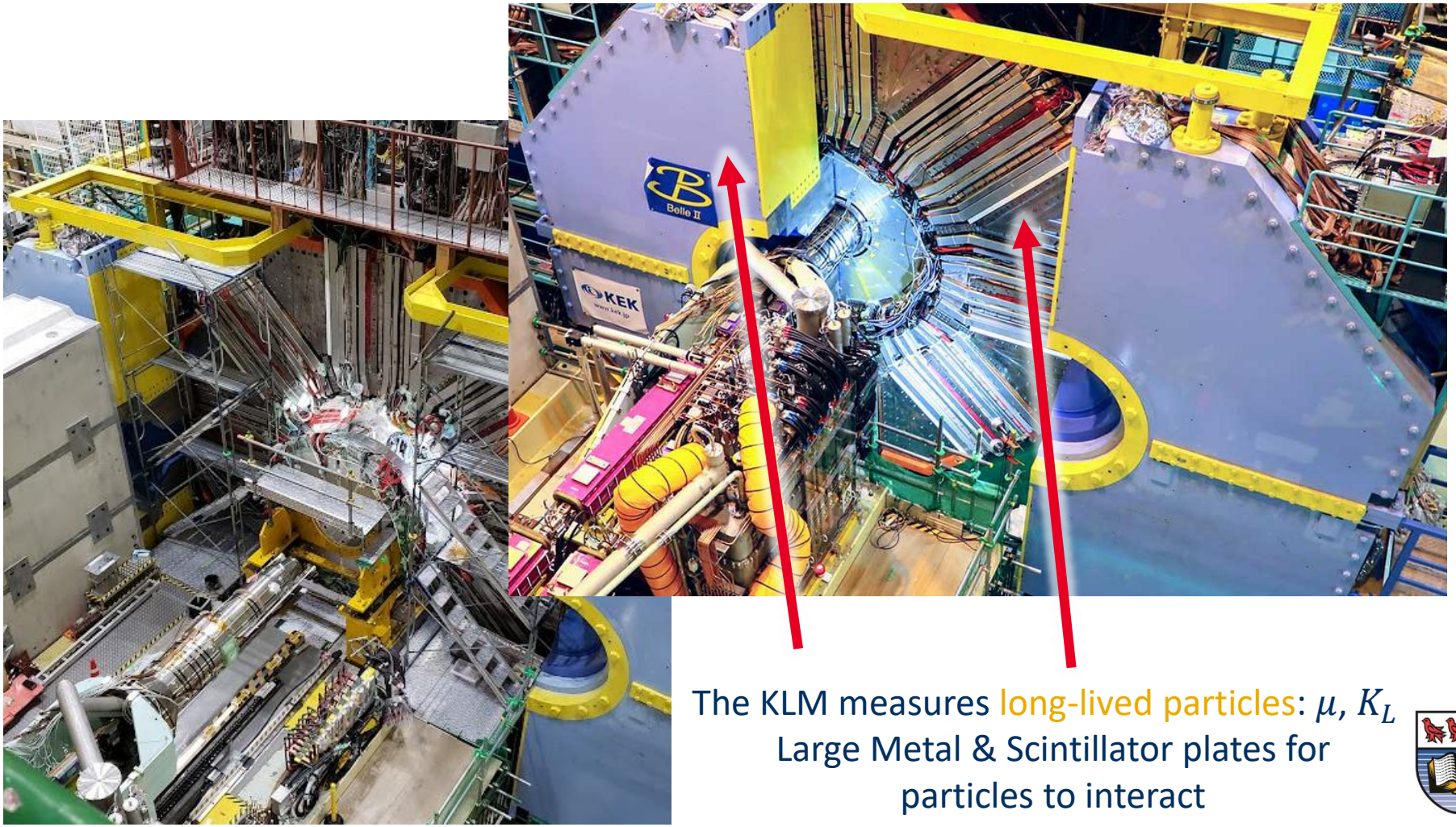
The **Electromagnetic Calorimeter** measures particle's energies deposited in 8736 **CsI(Tl)** crystals





Installing the Electromagnetic Calorimeter (Belle) – circa 20th century.

K-Long and Muon detector (KLM)



The KLM measures long-lived particles: μ, K_L
Large Metal & Scintillator plates for particles to interact

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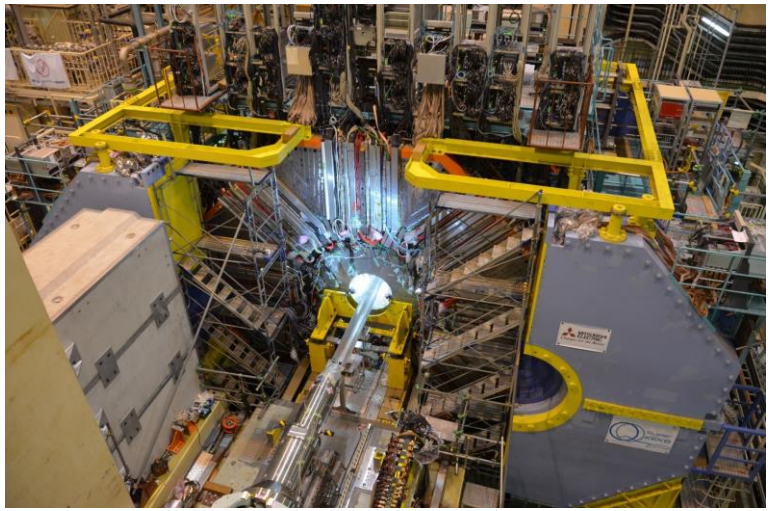
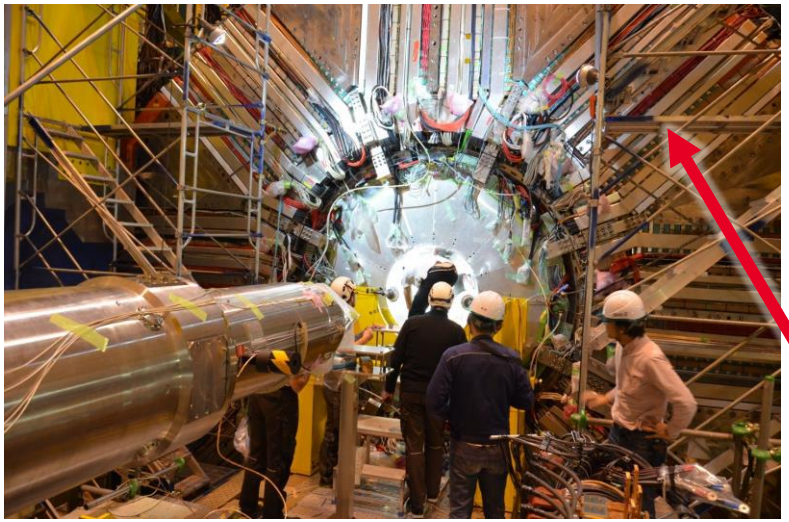
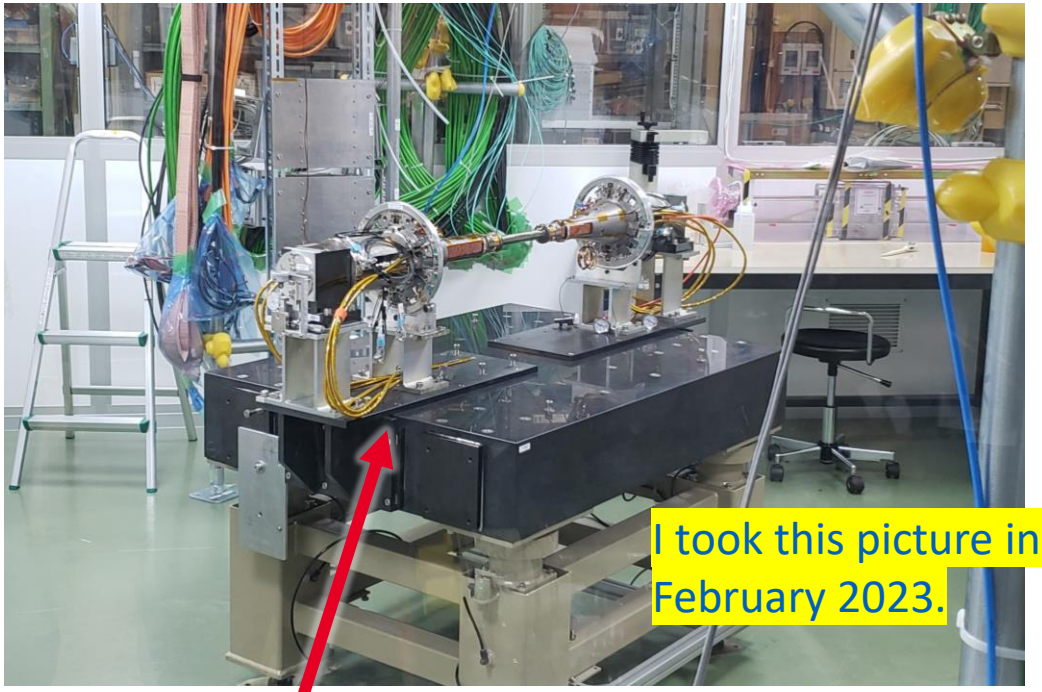
Installing the Belle II Vertex Detector







Detector had final **upgrade** in 2023.

Installation in 2019.

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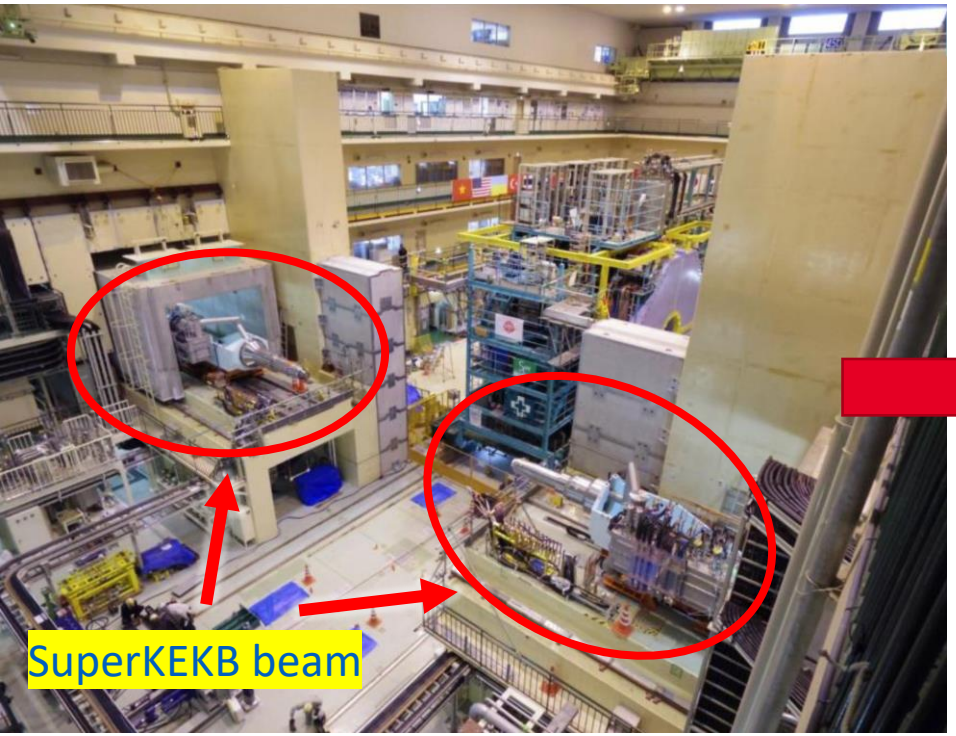
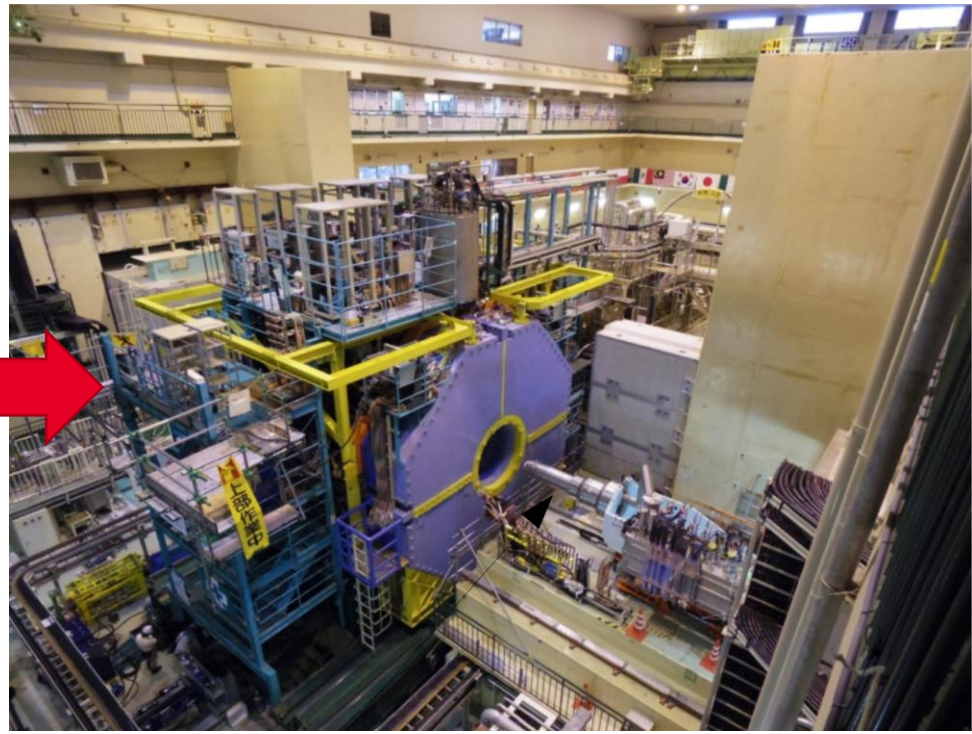
Rolling-in the Detector





We **roll-in** the detector to the **collision area** after it is fully built.

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Control Room

Belle II control room →

← SuperKEKB control room

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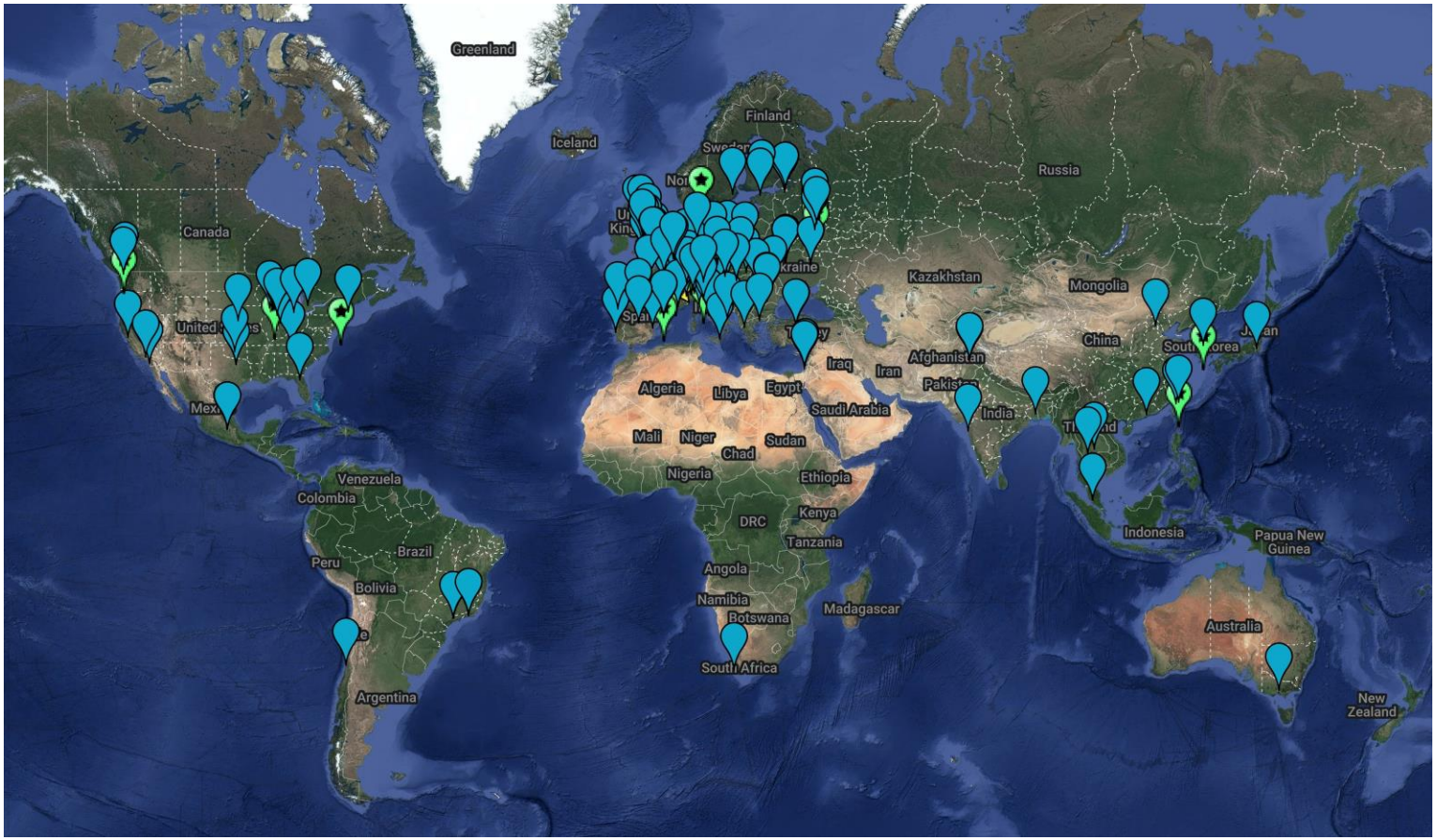
Much More Than That…

Computing infrastructure: data processing, analysis and simulations. 40+ countries, 170+ computing centers.



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Much More Than That…

Advanced software is needed to run the experiment.
Hundreds of collaborators contribute to the open-source software in one capacity or another:

https://github.com/belle2/basf2

It includes many advanced computing techniques
e.g. A.I., machine learning, etc.
Used for Physics tools, computing tools, …

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Conclusion

Belle II is a highly international effort to push understanding of Physics beyond the Standard Model.

It utilizes the highest luminosity collider ever, SuperKEKB, to obtain the ~50 billion B-meson events it targets.

Its world class detector is complemented by a world class software and computing infrastructure.

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