Belle II Experiment

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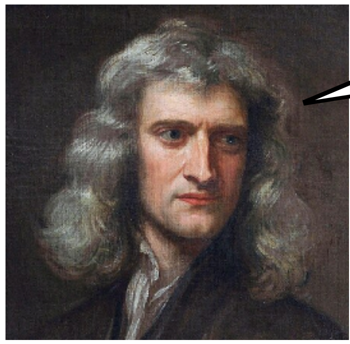
2025/6/23-27
Belle II Summer School 2025

Two sides of the same coin - Theories and Experiments



Hypotheses non fingo (I frame no hypothesis). — “Principia”

Particular propositions are inferred from the phenomena, and afterwards rendered general by induction.

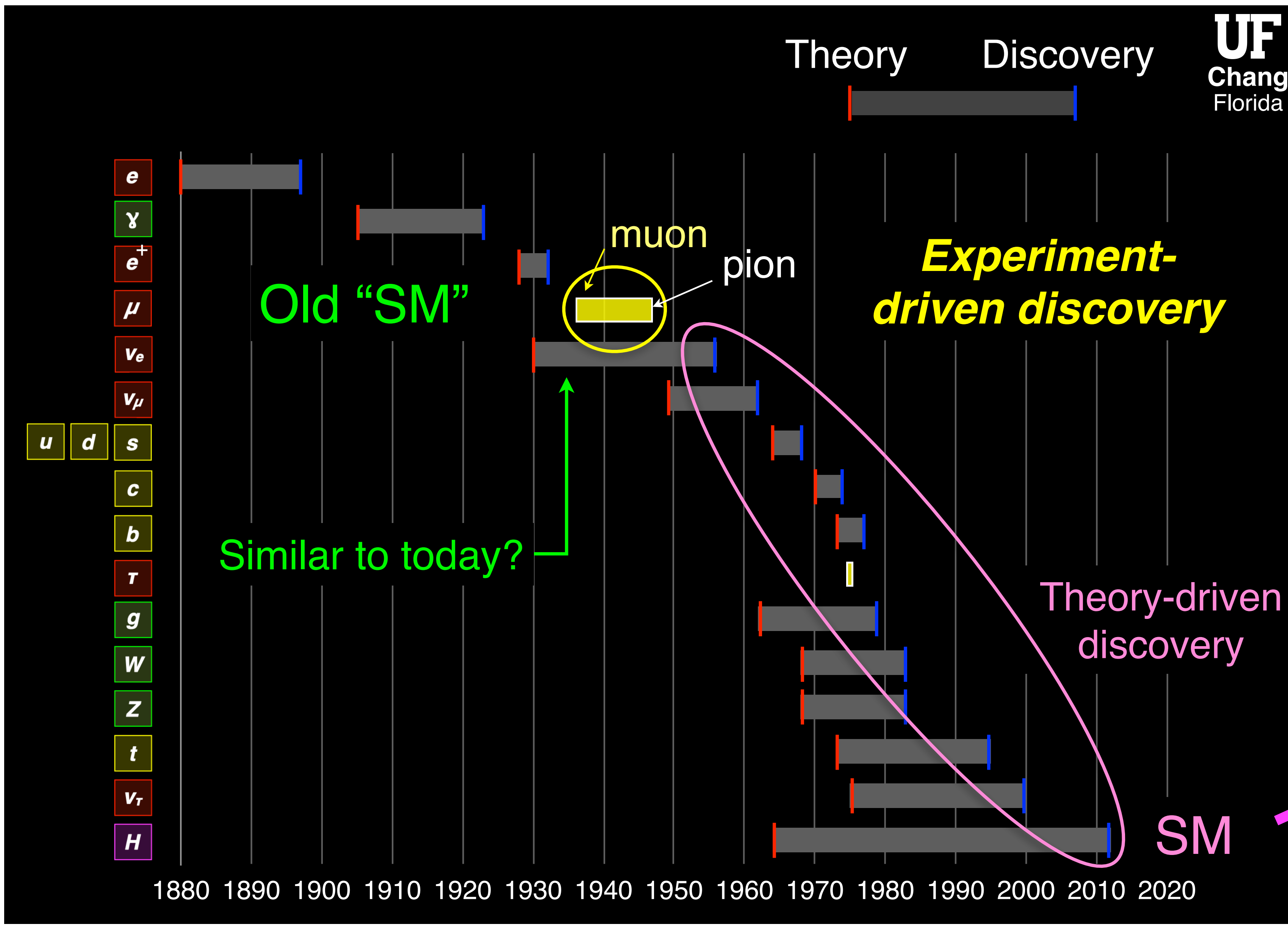
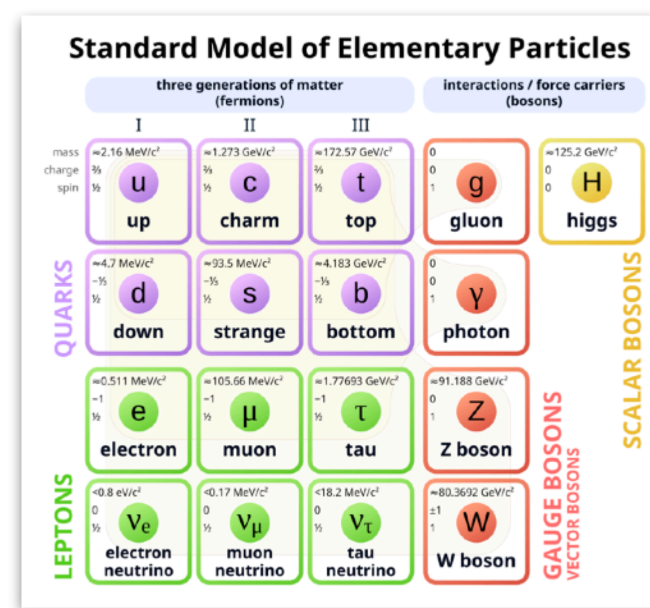


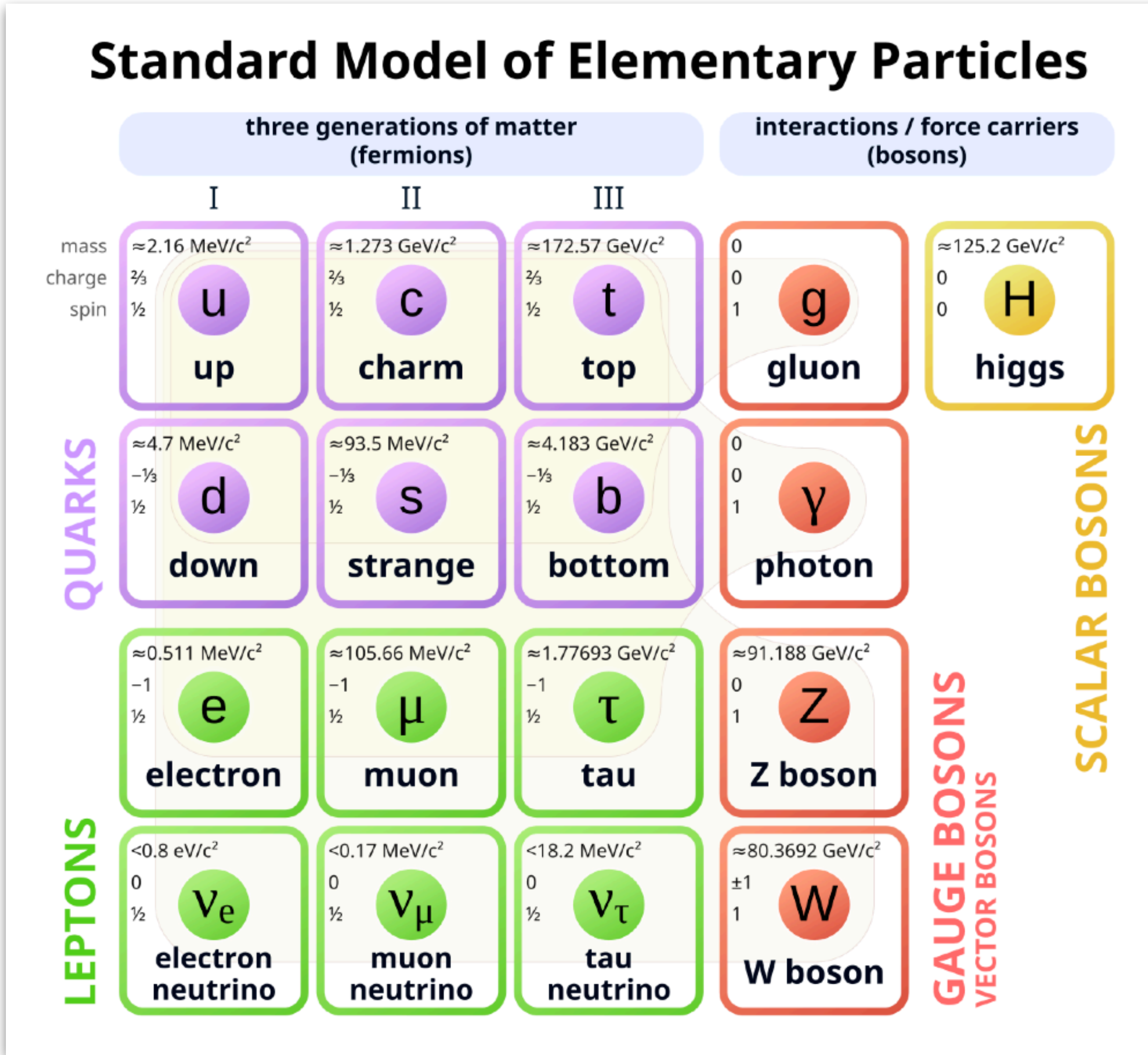
Image credit: P.Chang (PHENO2025)

How to proceed (particle) science

1. Analyze phenomena.
2. Build a theory model. (Induction)
3. Expect new phenomena.
4. Examine the expectations. (Experiments)
5. A new phenomenon is found.
6. Repeat.



The Standard Model and Beyond



The standard model is now completed.

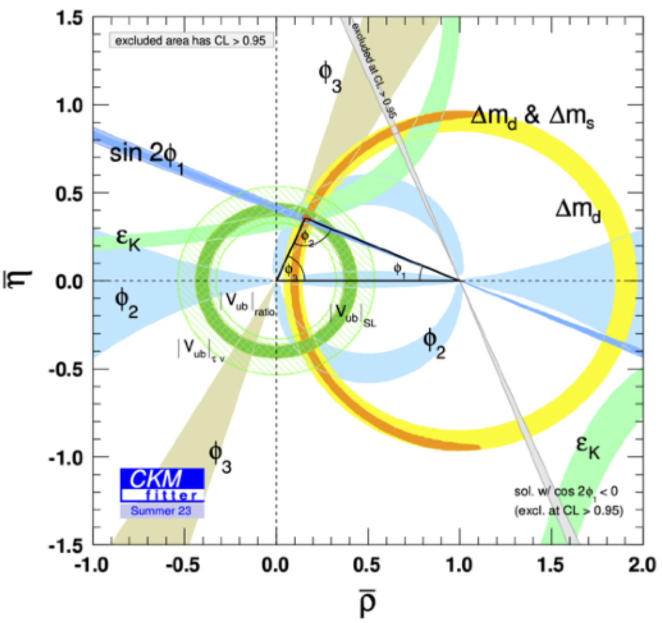
- 3 generations of quarks and leptons
- 4 interactions
- 1 Higgs particle

Q. What is the next step?

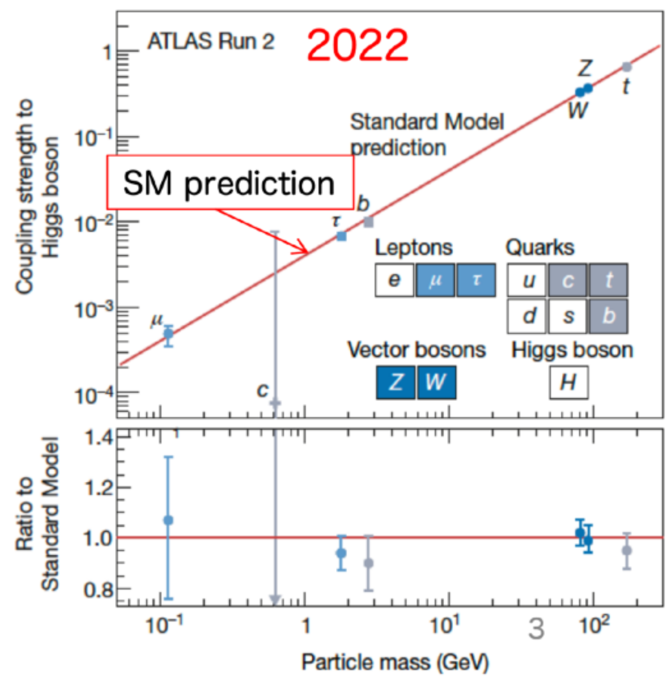
History and details can be found in Tommy's talk

The Standard Model and Beyond

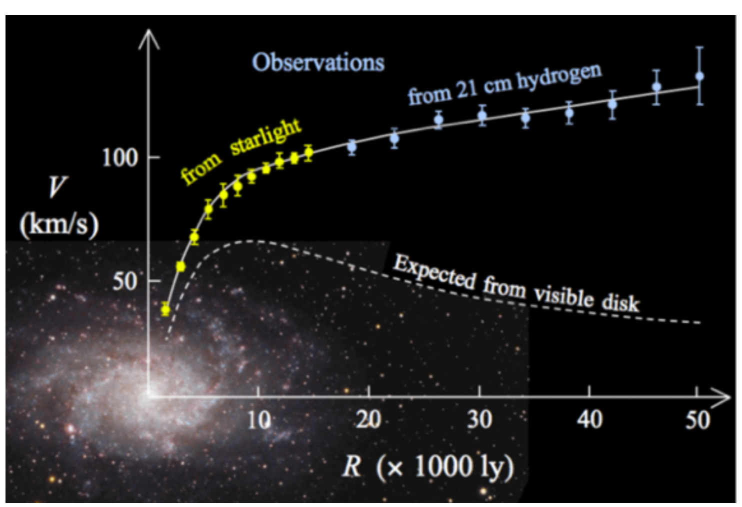
CKM parameters



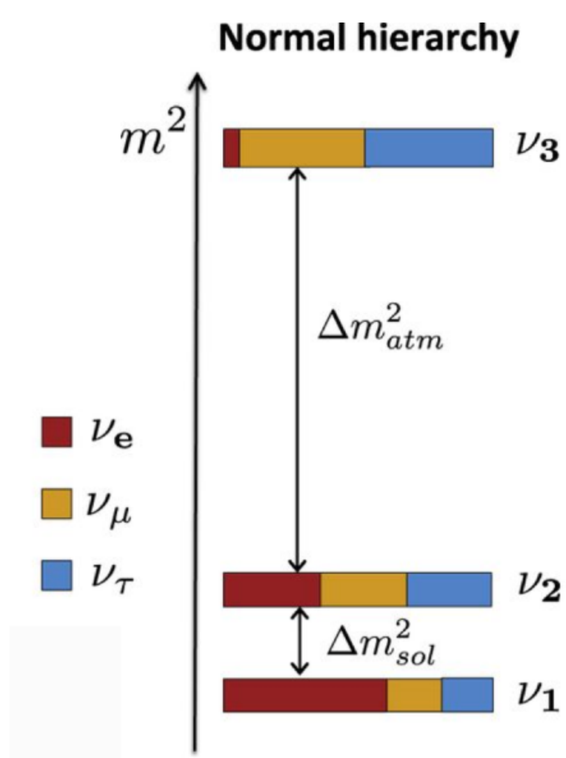
Higgs couplings



Dark matter



Neutrino hierarchy



The standard model is now completed.

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Q. What is the next step?

A. Analyze phenomena

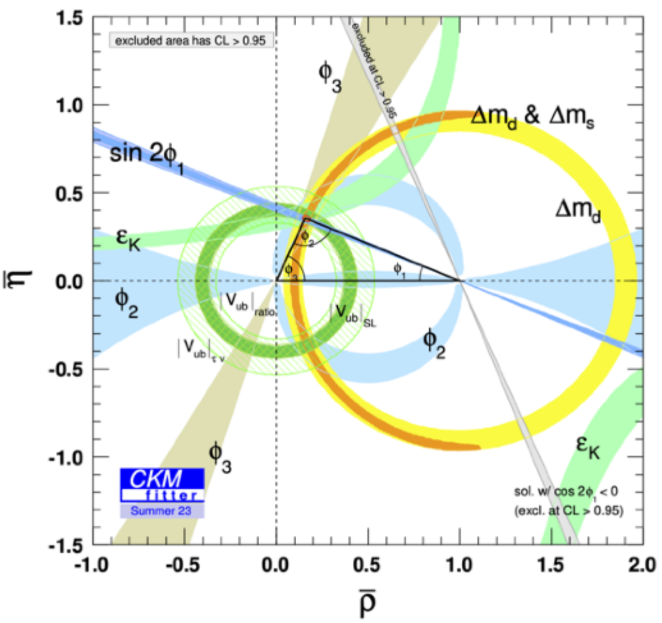
The exact parameters of the Standard Model are not fixed yet.
And, there are still “puzzles” that can not be solved by the Standard Model.

- Gravity
- Dark Matter and Dark Energy
- Neutrino mass and its hierarchy

…

The Standard Model and Beyond

CKM parameters



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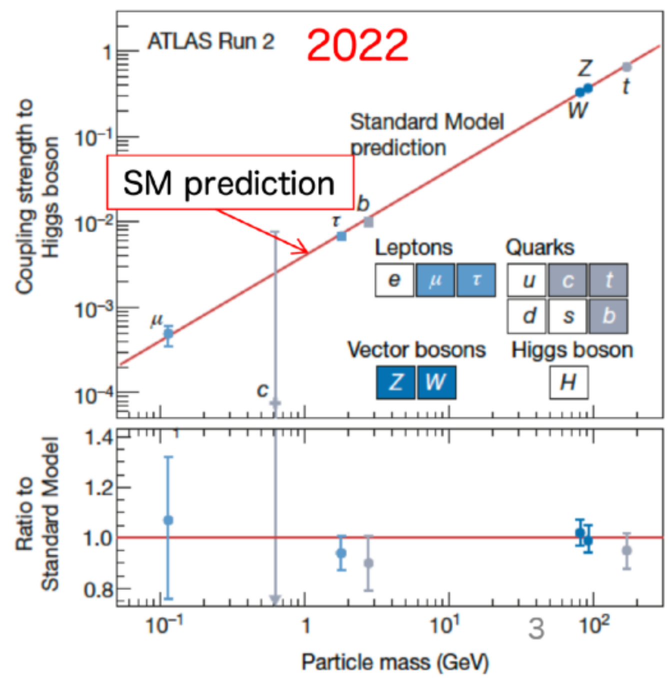
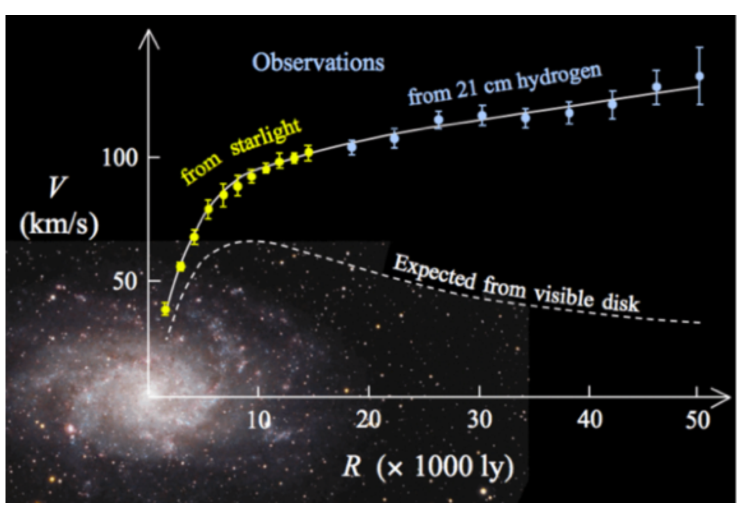


Dark matter



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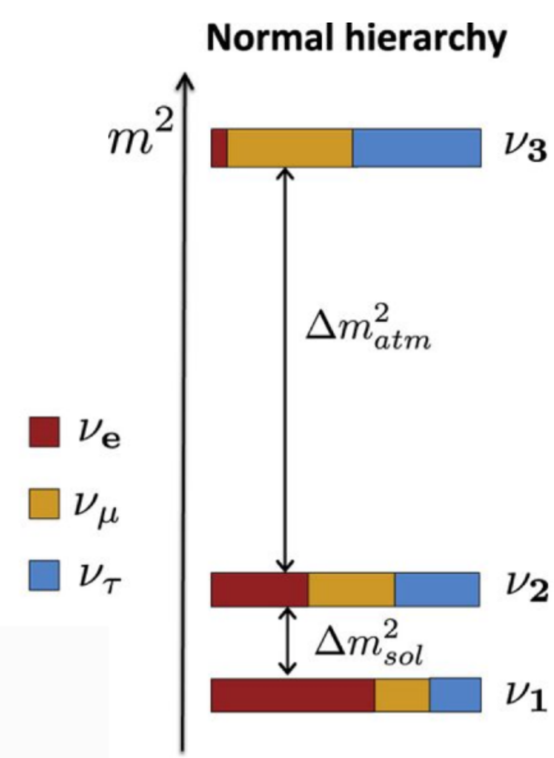

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Q. What is the next step?

A. Analyze phenomena

The exact parameters of the Standard Model are not fixed yet.
And, there are still "puzzles" that can not be solved by the Standard Model.

Then, build a model and verify it

Theorists are making hundreds of models.
But, all of them don't have any evidence.

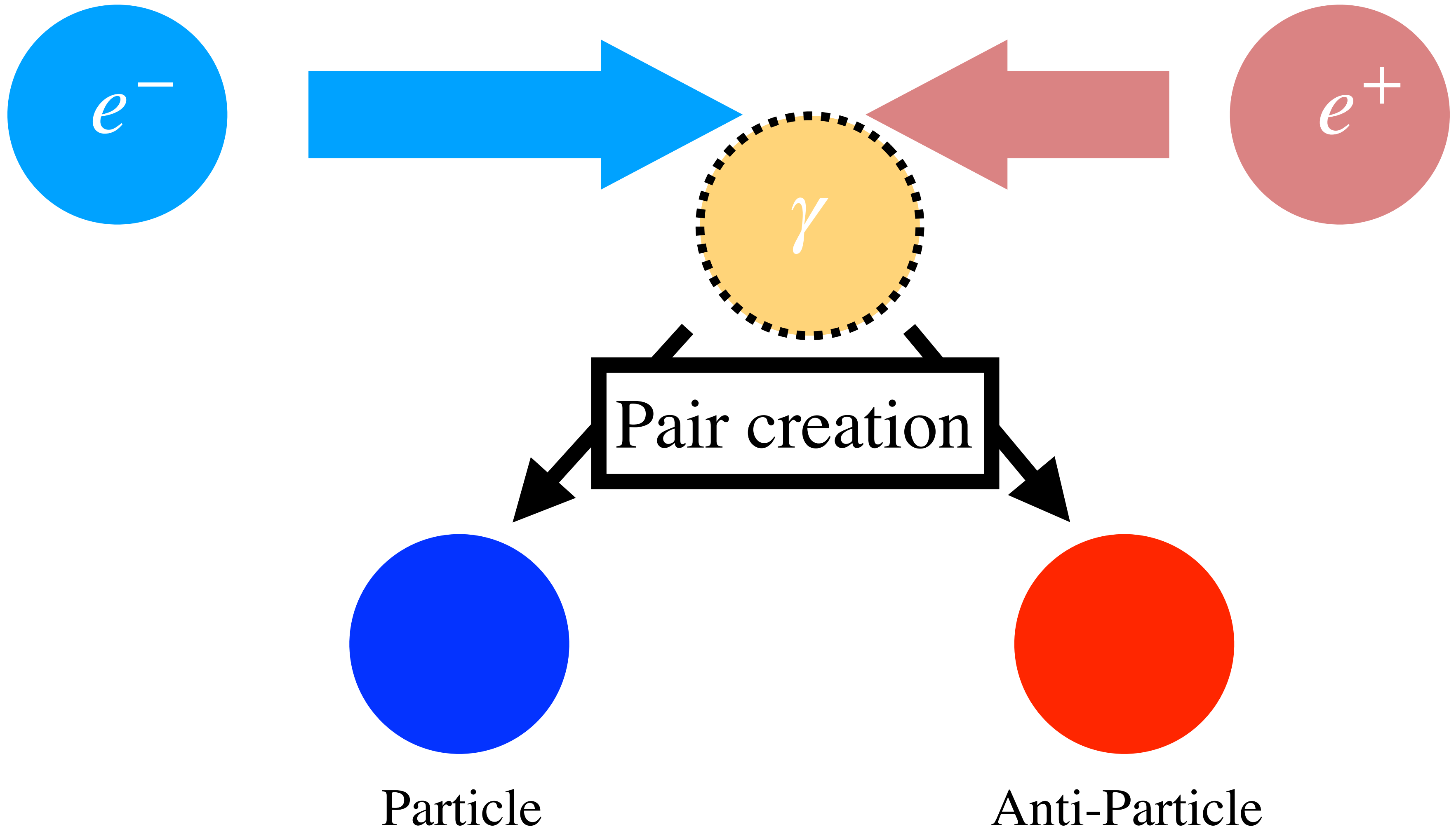
Need new experiment results!!

Belle II experiment - How it looks

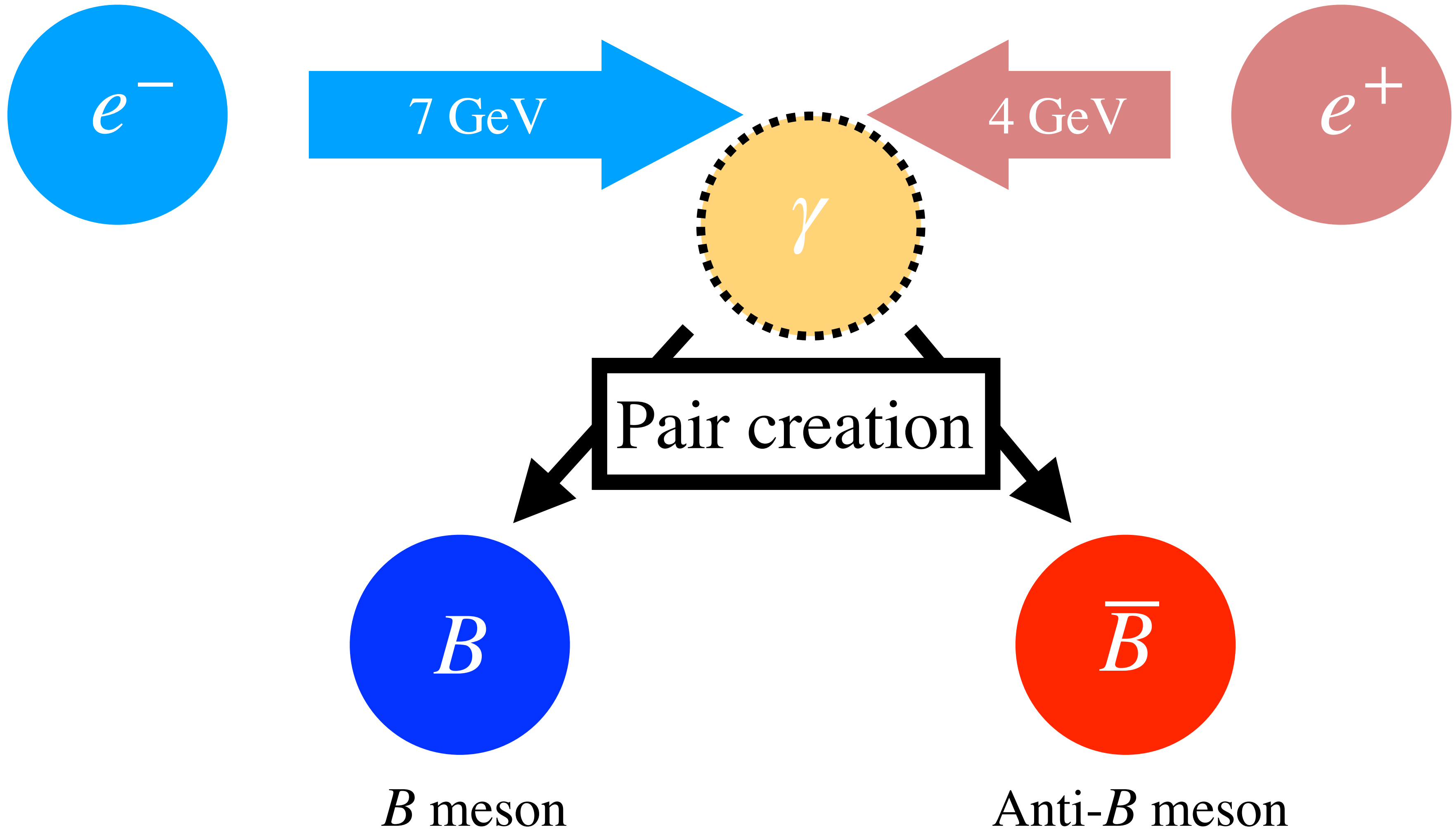
- Accelerator at KEK in Tsukuba, Japan.
- Positron and Electron are accelerated to 4 and 7 GeV respectively.
- The circle has a diameter of 1 km.

- $8 \times 8 \times 8$ m^3 detector in underground lab.
- Containing detectors and superconducting magnet.

Particle reactions - what is happening in Belle II

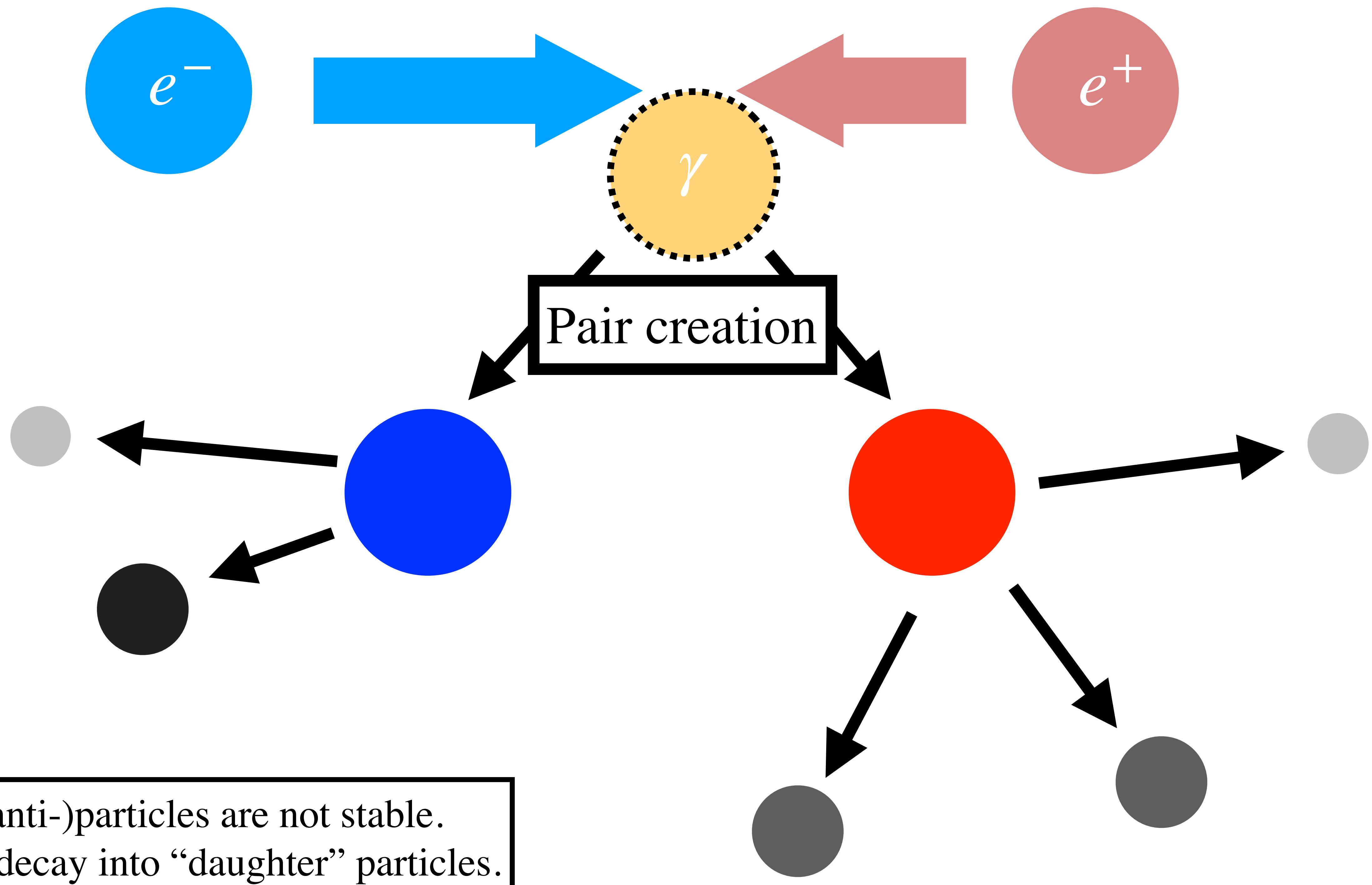


Particle reactions - what is happening in Belle II



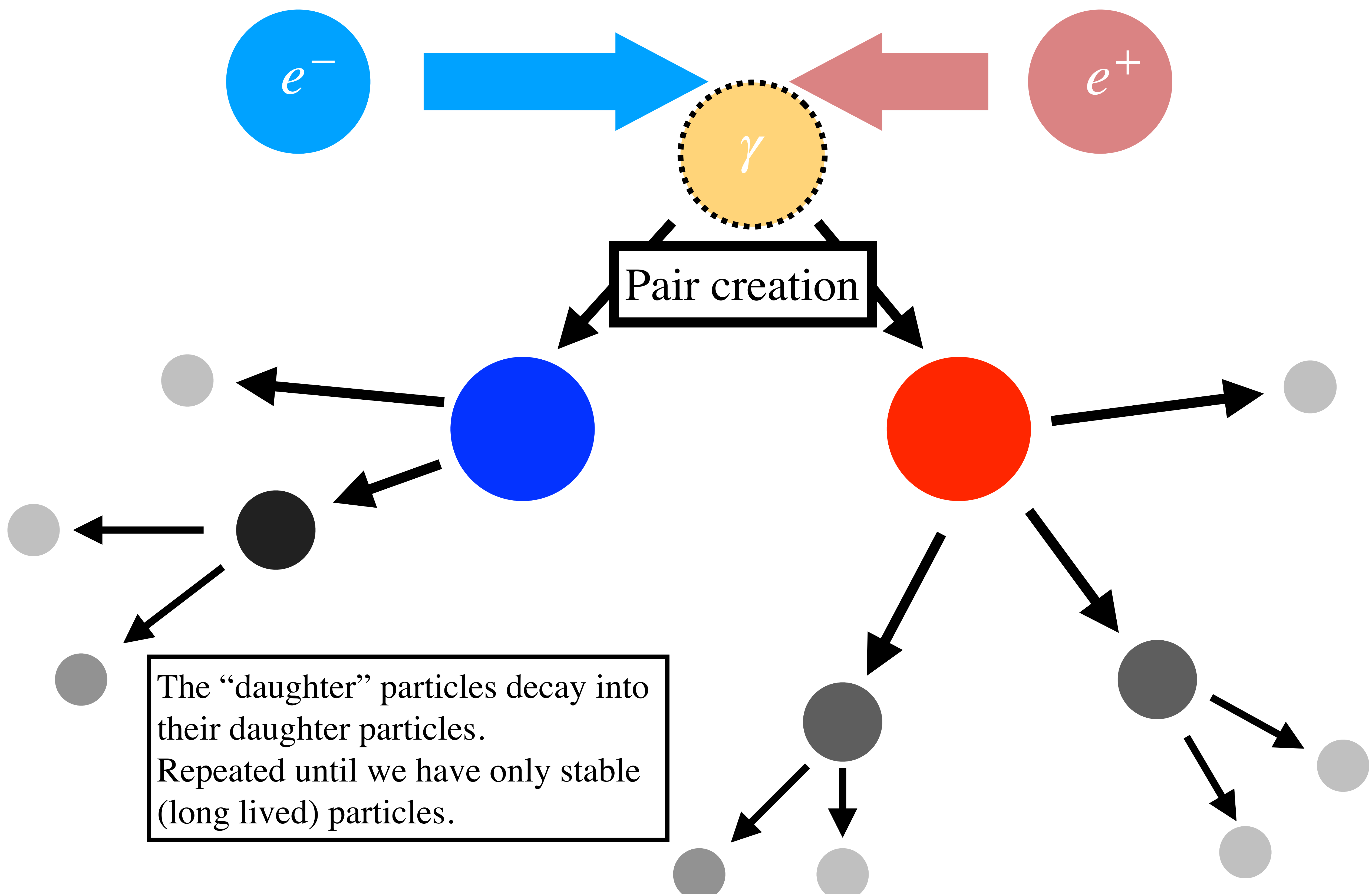
Due to the tuned energy, B meson pair creation is enhanced in Belle II

Particle reactions - what is happening in Belle II



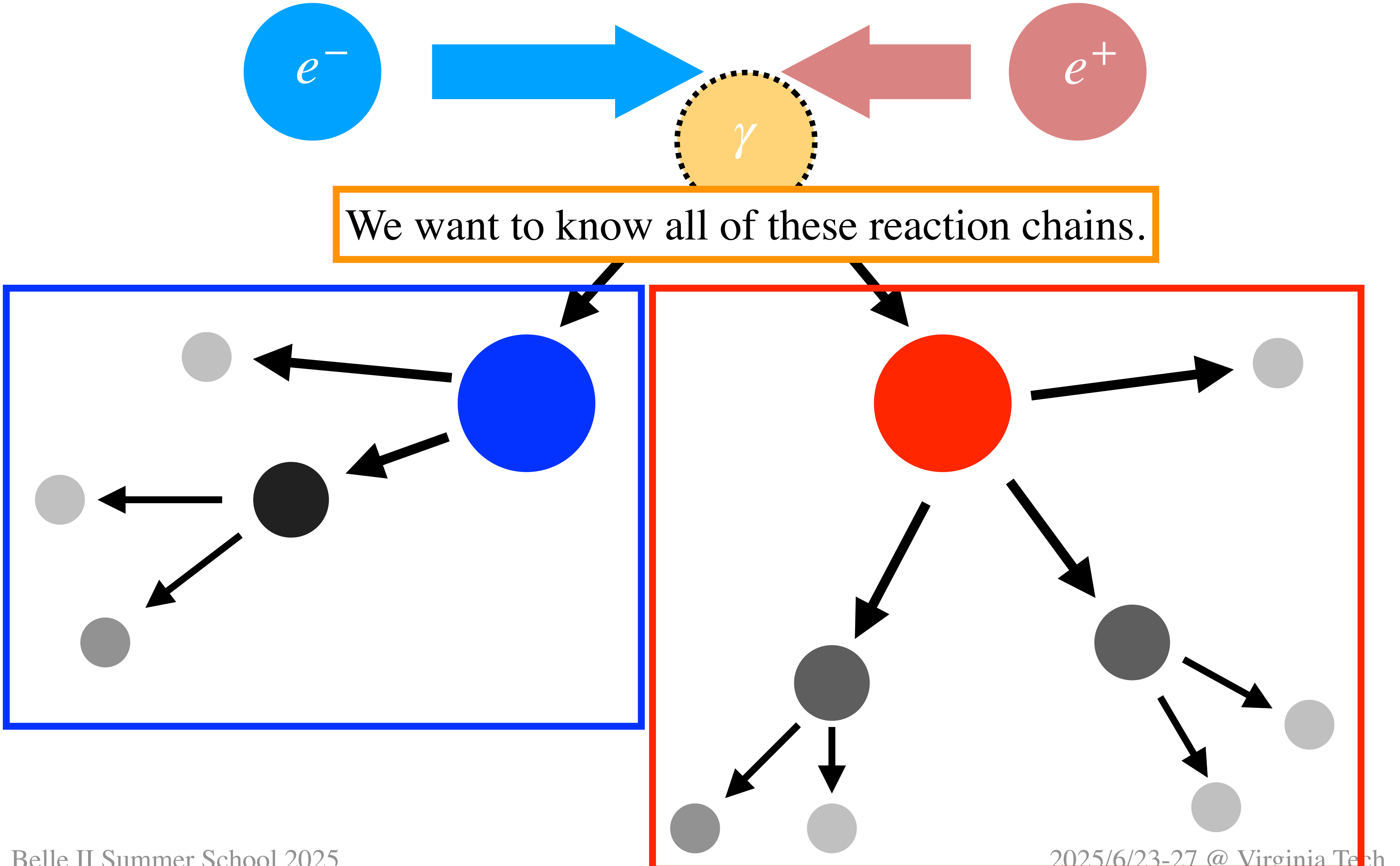
The (anti-)particles are not stable.
They decay into “daughter” particles.

Particle reactions - what is happening in Belle II



The "daughter" particles decay into their daughter particles.
Repeated until we have only stable (long lived) particles.

Detectors - what Belle II does



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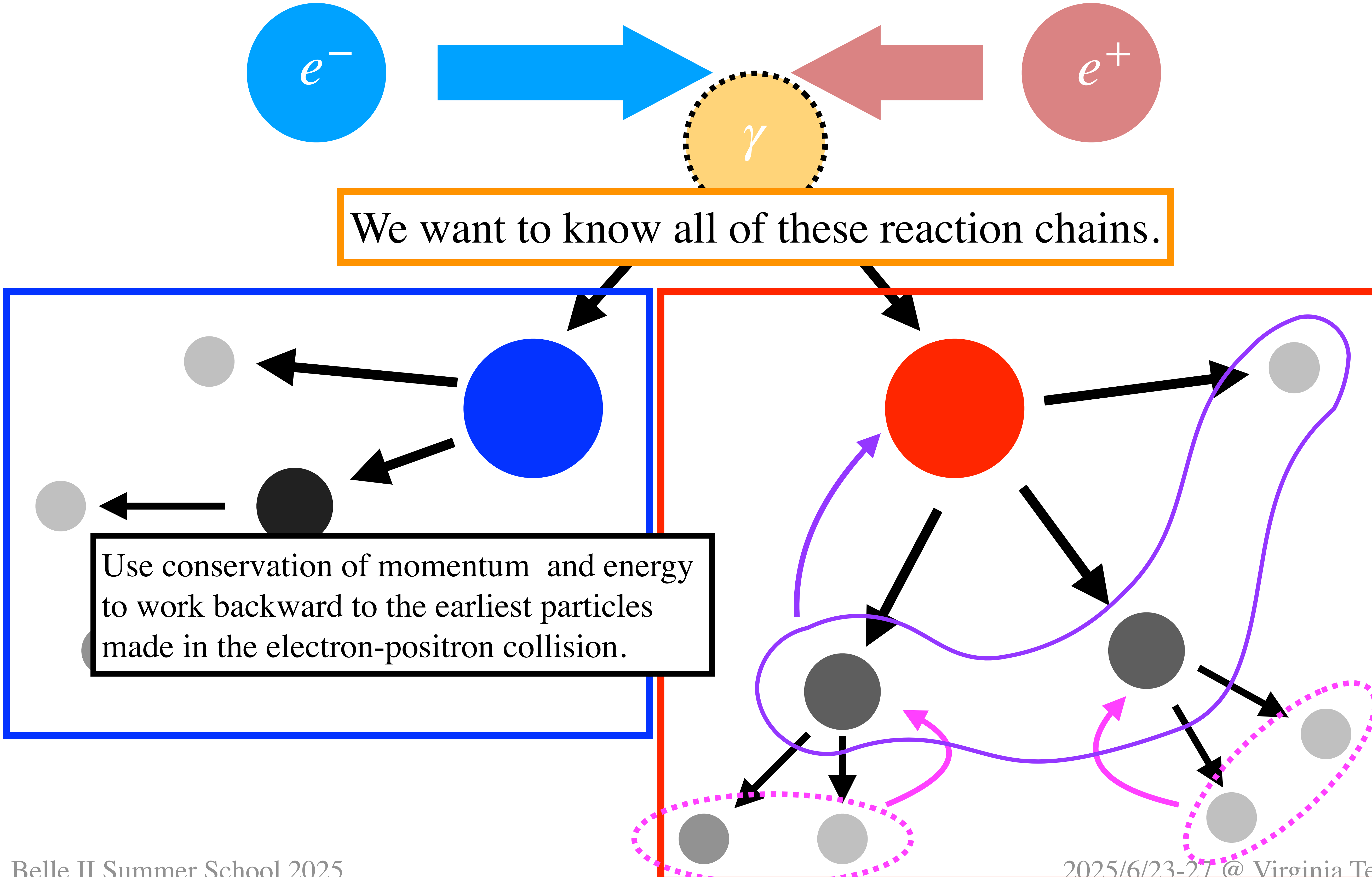

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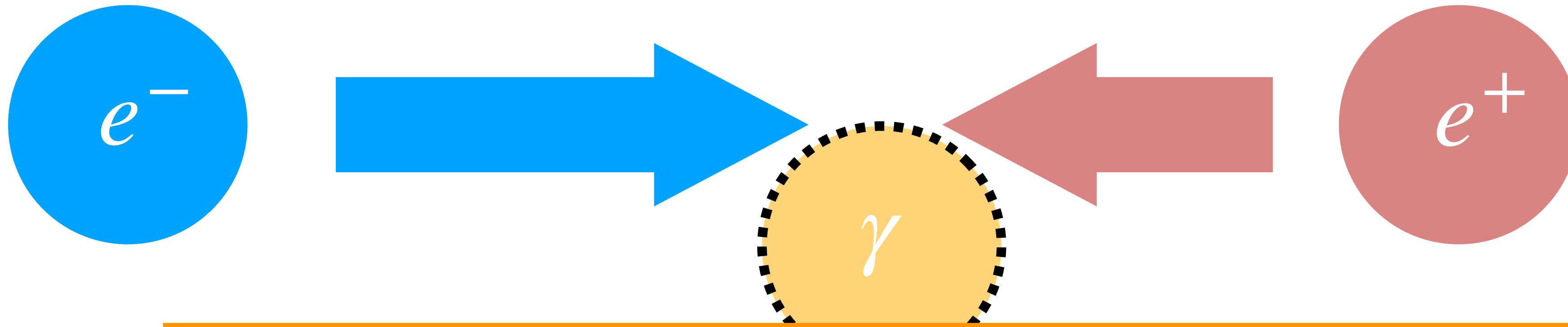
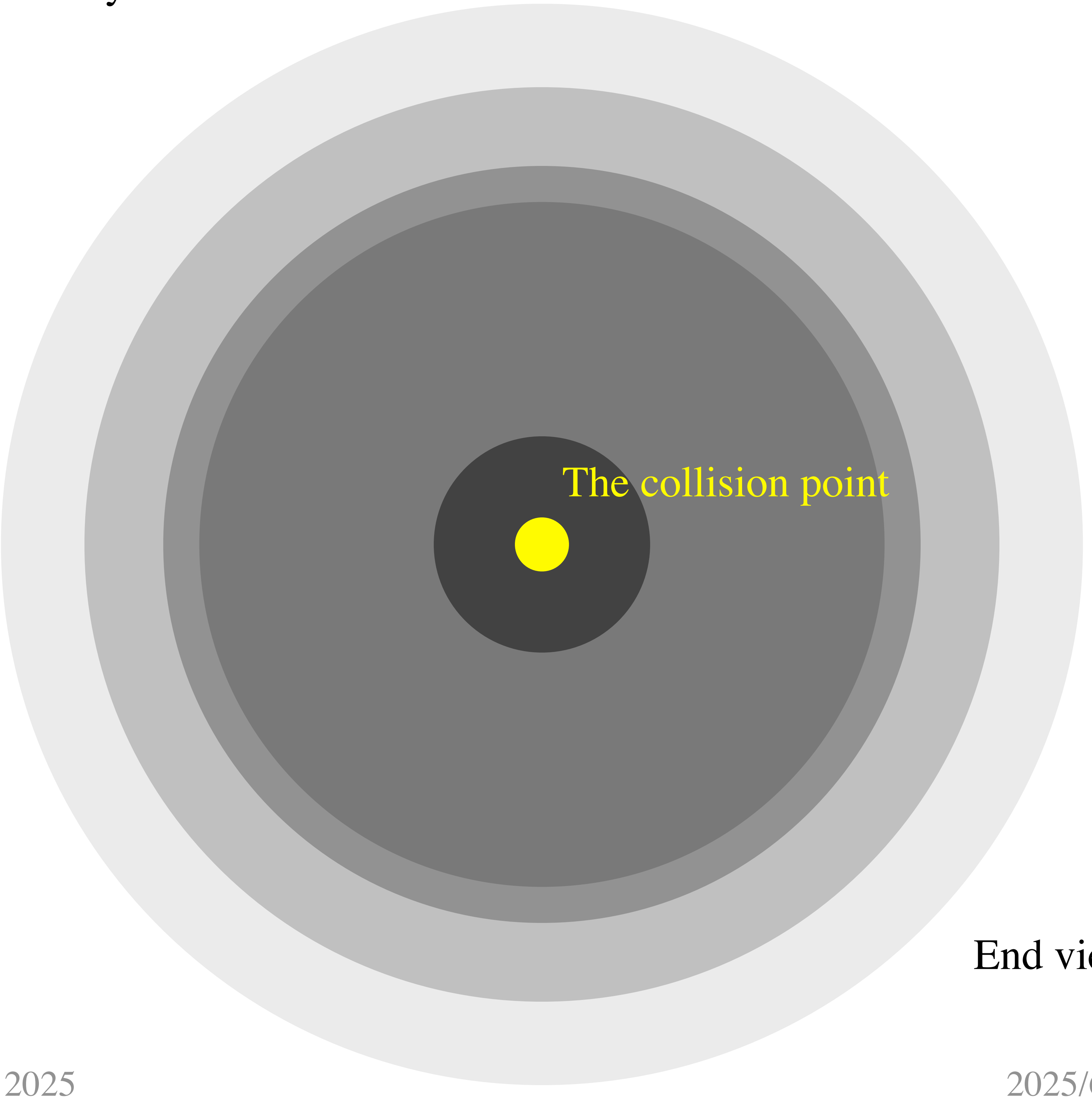


We want to know all of these reaction chains.

- Build a detector around the collision point, not to miss anything.
- No particle can be seen **by eye**, of course.
- You need to **reconstruct** them from many electronic signals.

Detectors - How to reconstruct a particle?

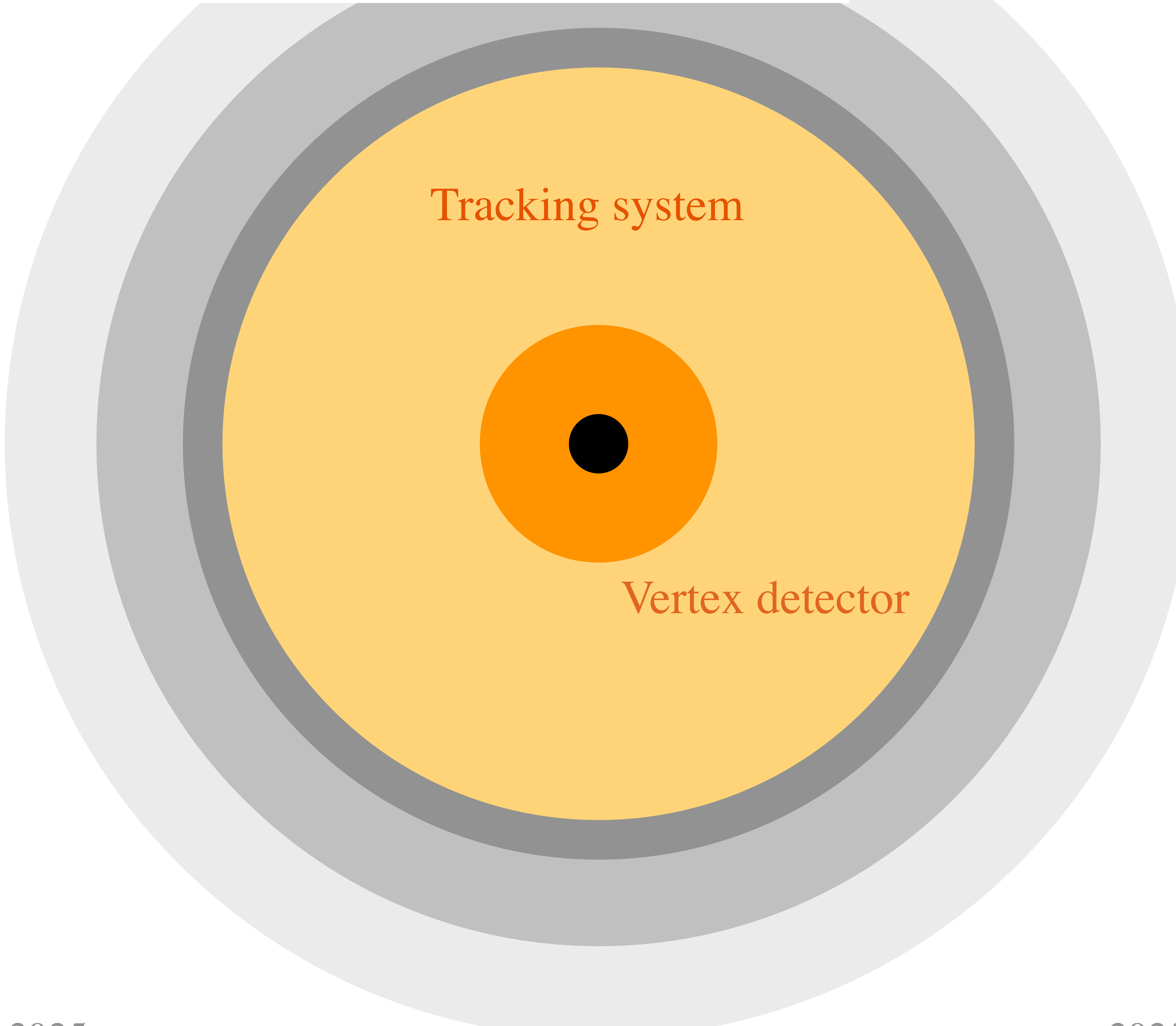
The detectors have layered structure — “One for all”.



Detectors - How to reconstruct a particle?

The detectors have layered structure — “One for all”.

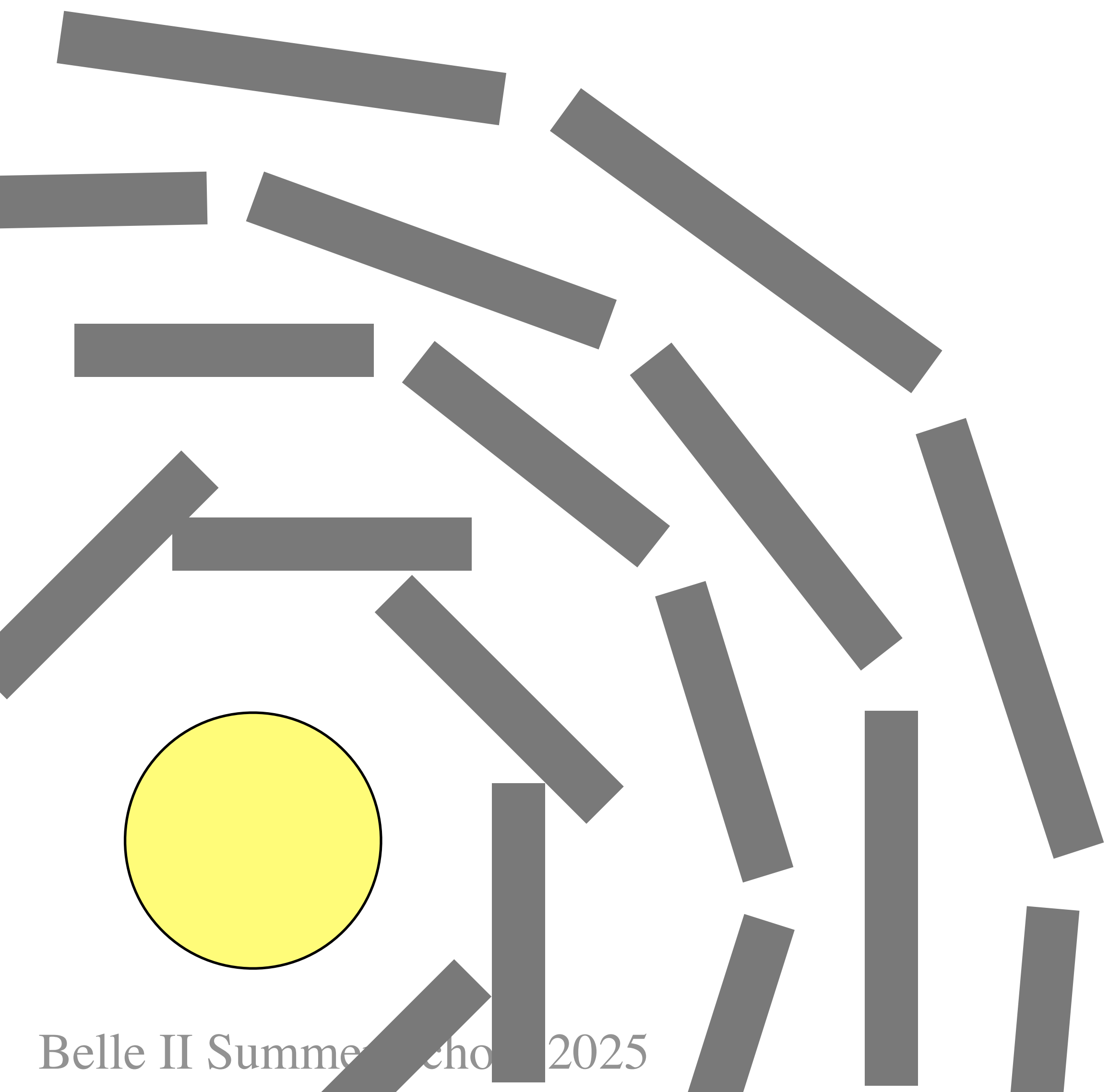
The inner part is for tracking,
where the particle passes through in the 3 dimension space.



Detectors - Chase the charged particle

A charged particle causes electronic signals in materials (i.e. gas or silicon) by ionization.
Put the detector in magnetic field (into the page) and collect the signals.

⊗ B (magnetic field)



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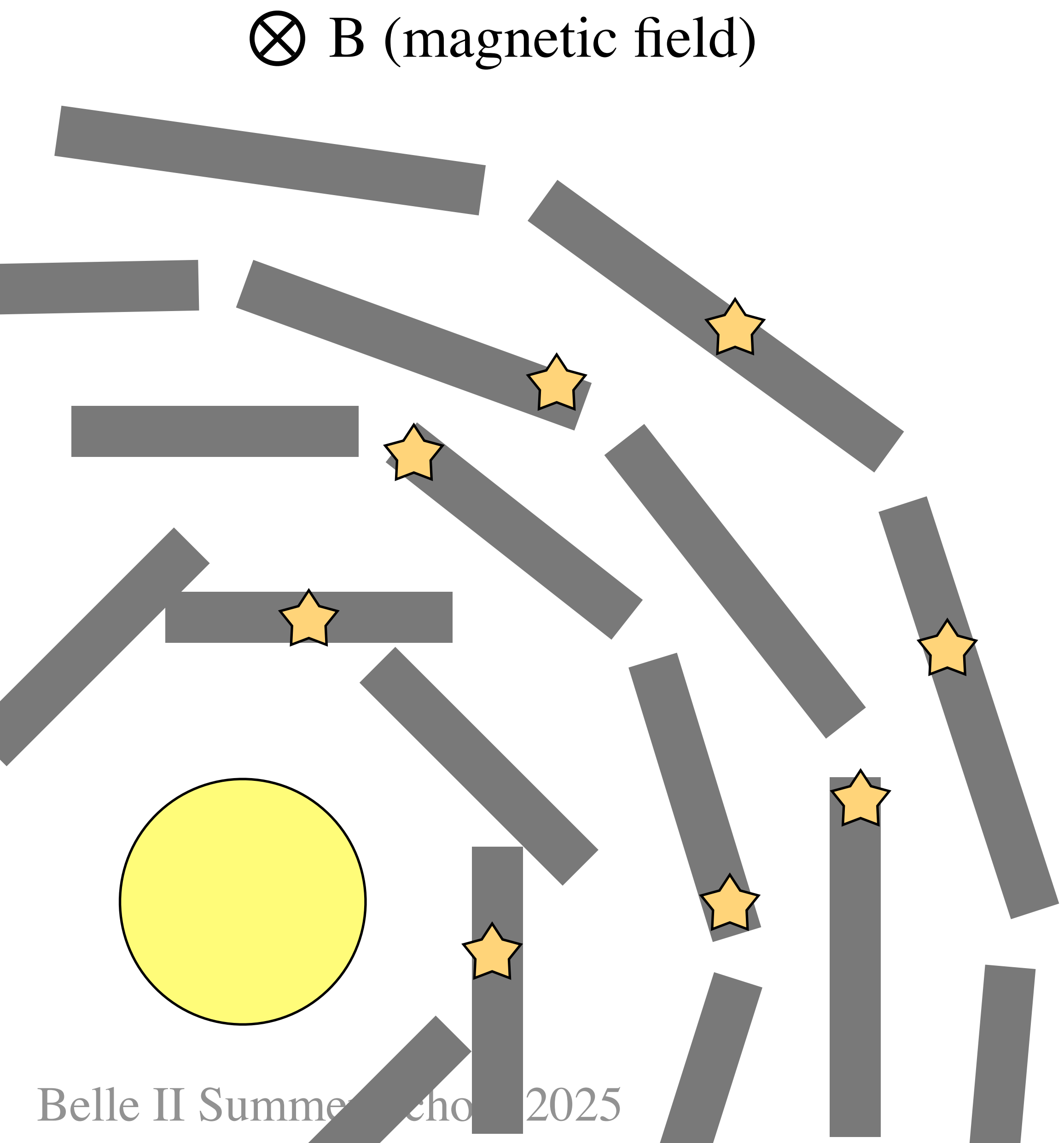
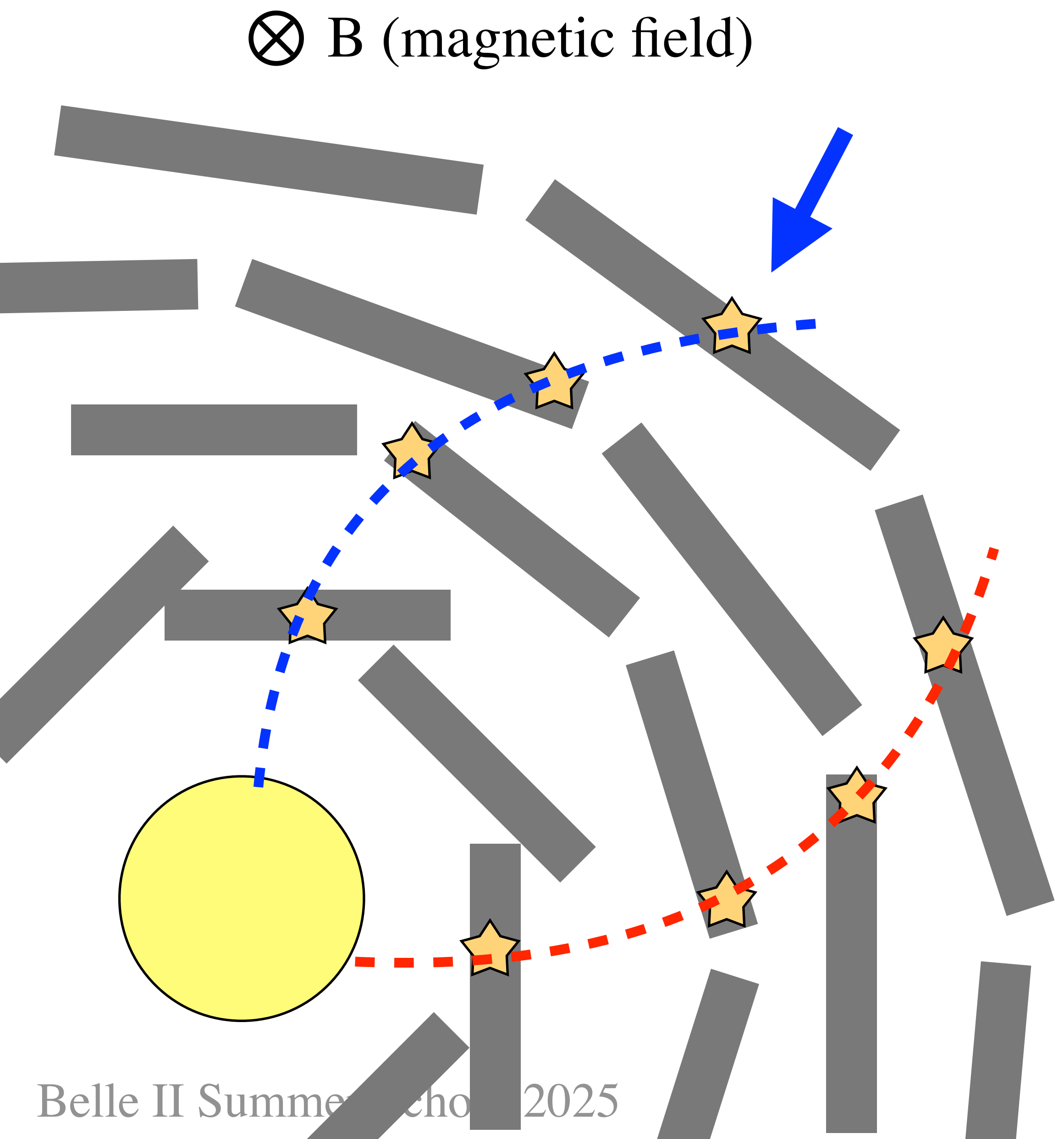


Detectors - Chase the charged particle

A charged particle causes electronic signals in materials (i.e. gas or silicon) by ionization.
Put the detector in magnetic field (into the page) and collect the signals.

Connecting the signal points, **tracks** can be reconstructed.

What's the charge of blue particle?



Detectors - Determine the charge

A charged particle causes electronic signals in materials (i.e. gas or silicon) by ionization.
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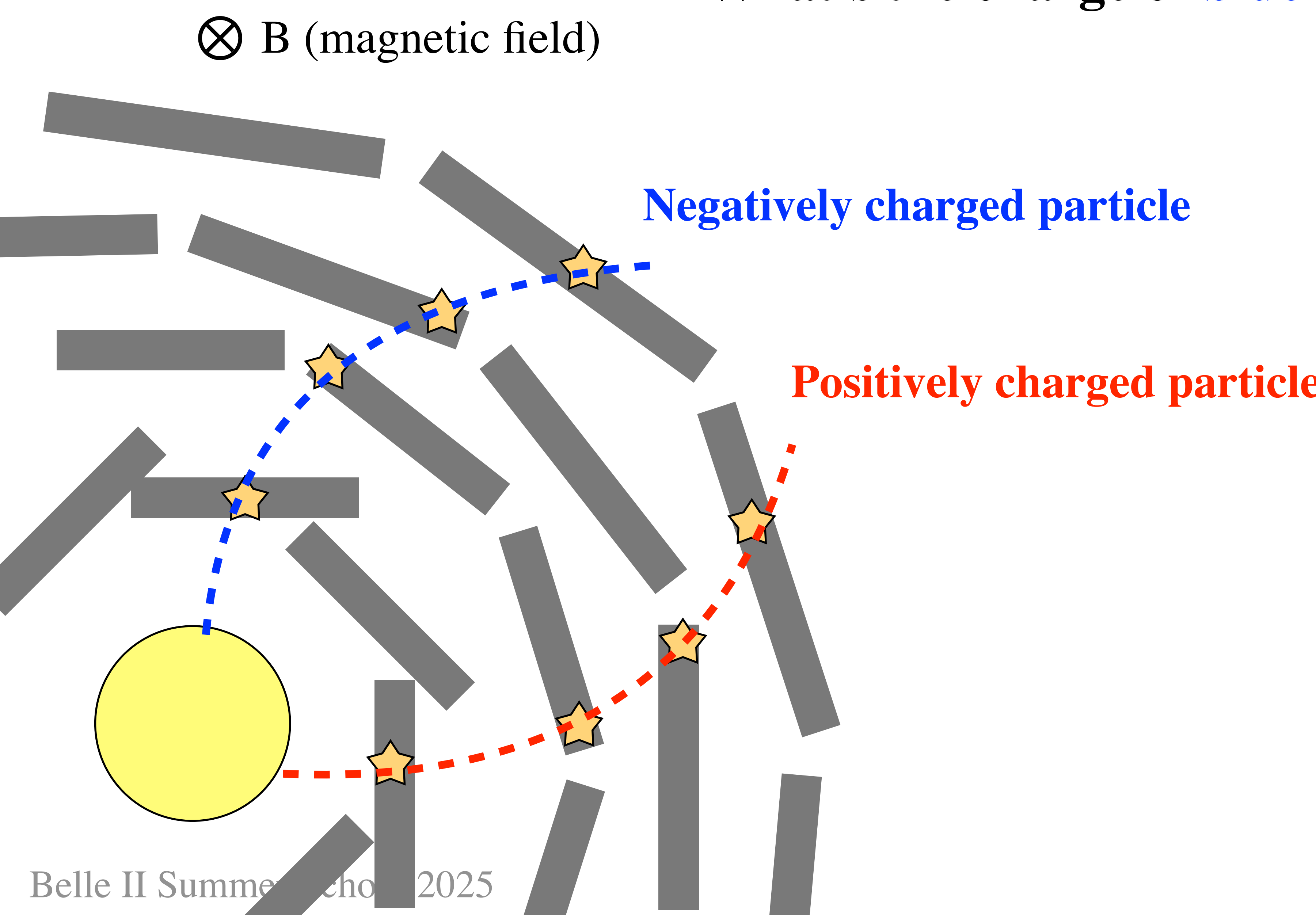

Detectors - Find the vertex

A charged particle causes electronic signals in materials (i.e. gas or silicon) by ionization.
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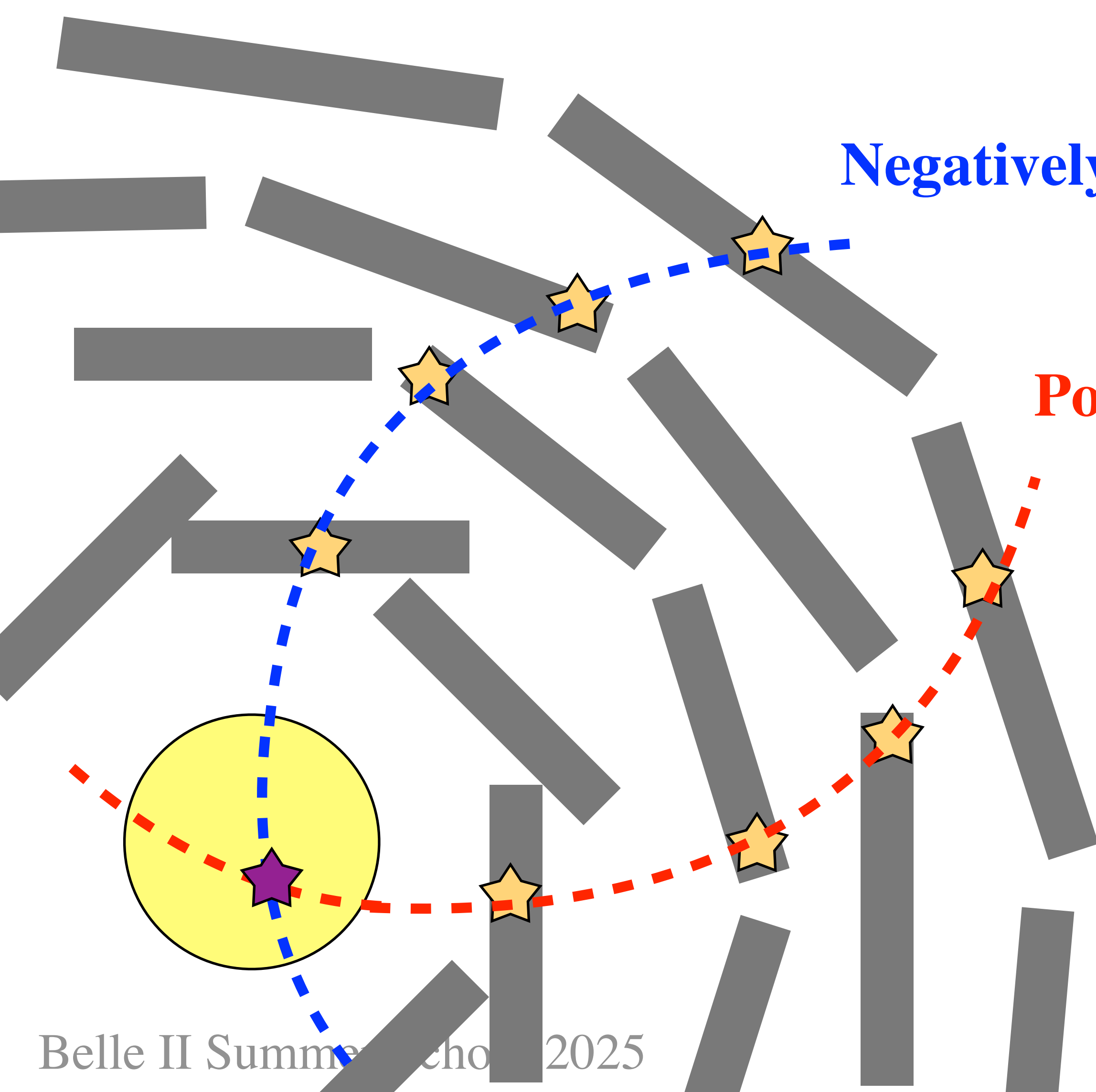
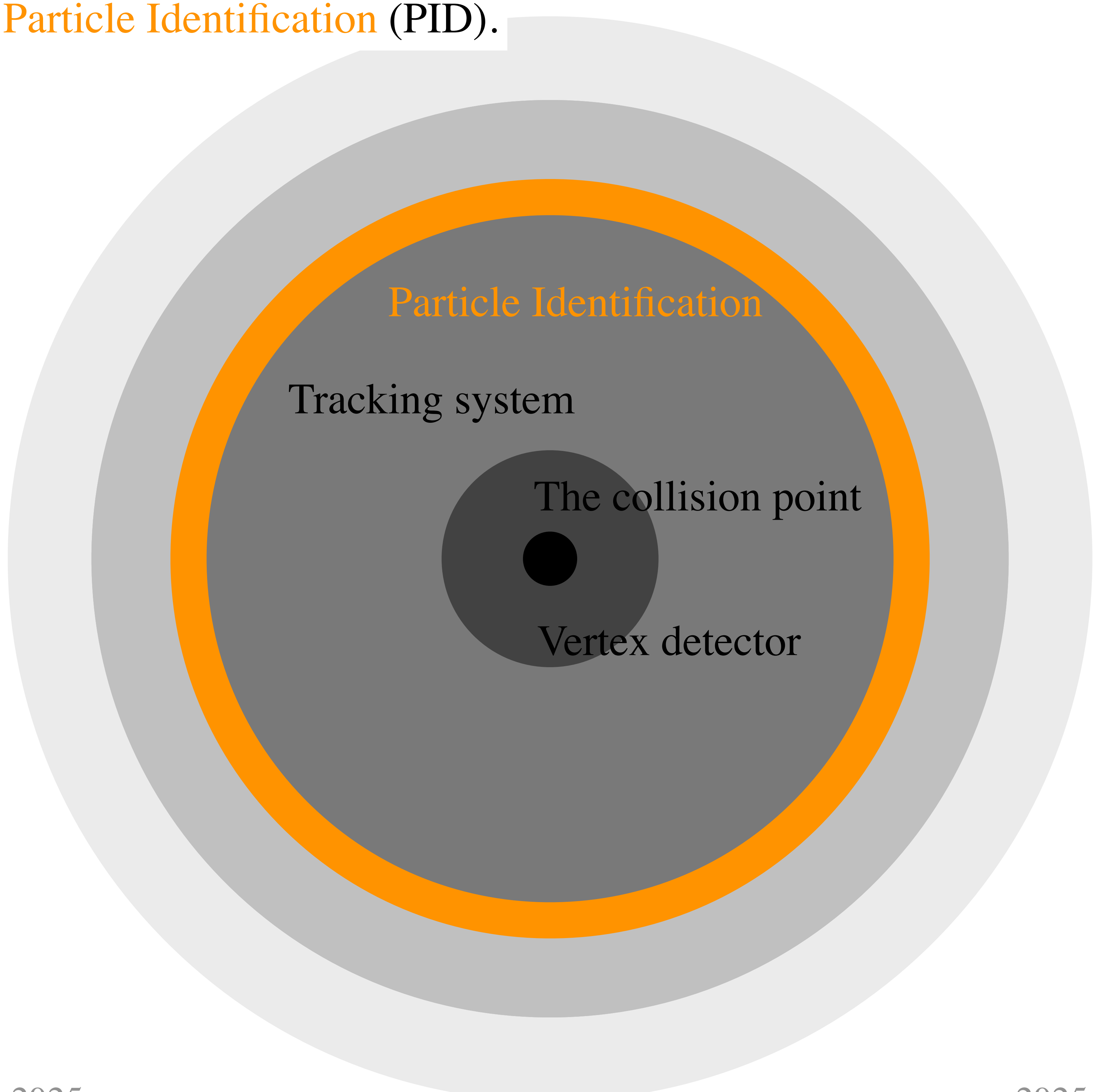
What's the charge of blue particle?



Extrapolating the tracks, the **vertex** (origin) can be determined. It is the decay point of mother particle.

Detectors - Identify particle species

The next one is Particle Identification (PID).



Detectors - Masses indicate the species

The next one is Particle Identification (PID).
Particles have different masses. (Electron = 9.1×10^{-28} g. Proton = 1.7×10^{-24} g)

For the different mass:
Same velocities lead to different momenta.
Same momenta lead to different velocities.

$$p = mv$$

Detectors - Lighter is faster

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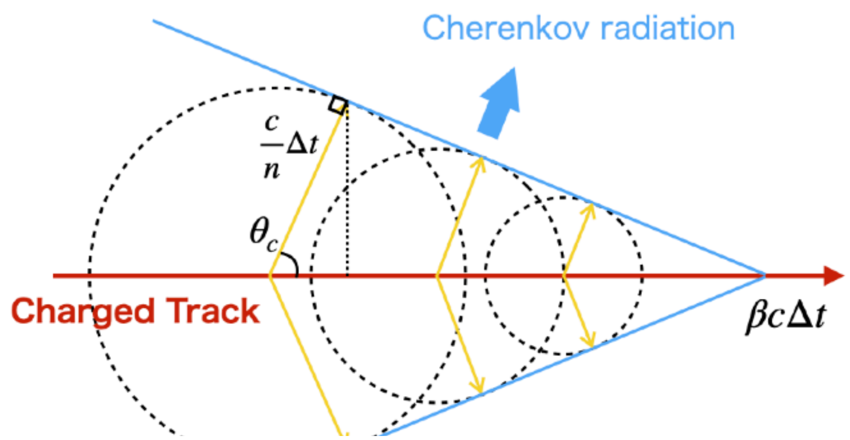
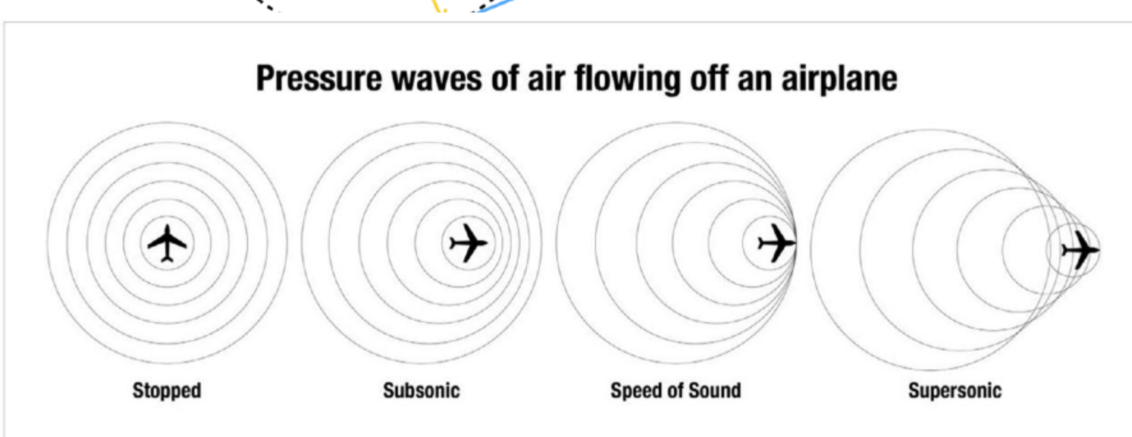
In Belle II, velocity is measured using sonic boom of light called Cherenkov radiation.





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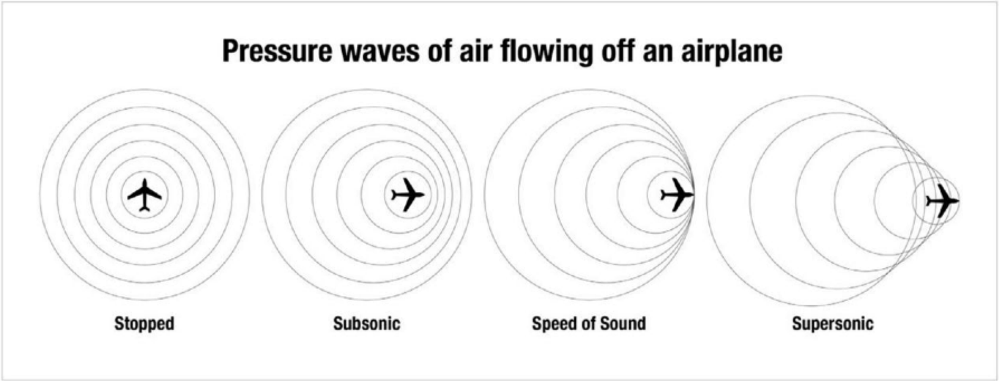

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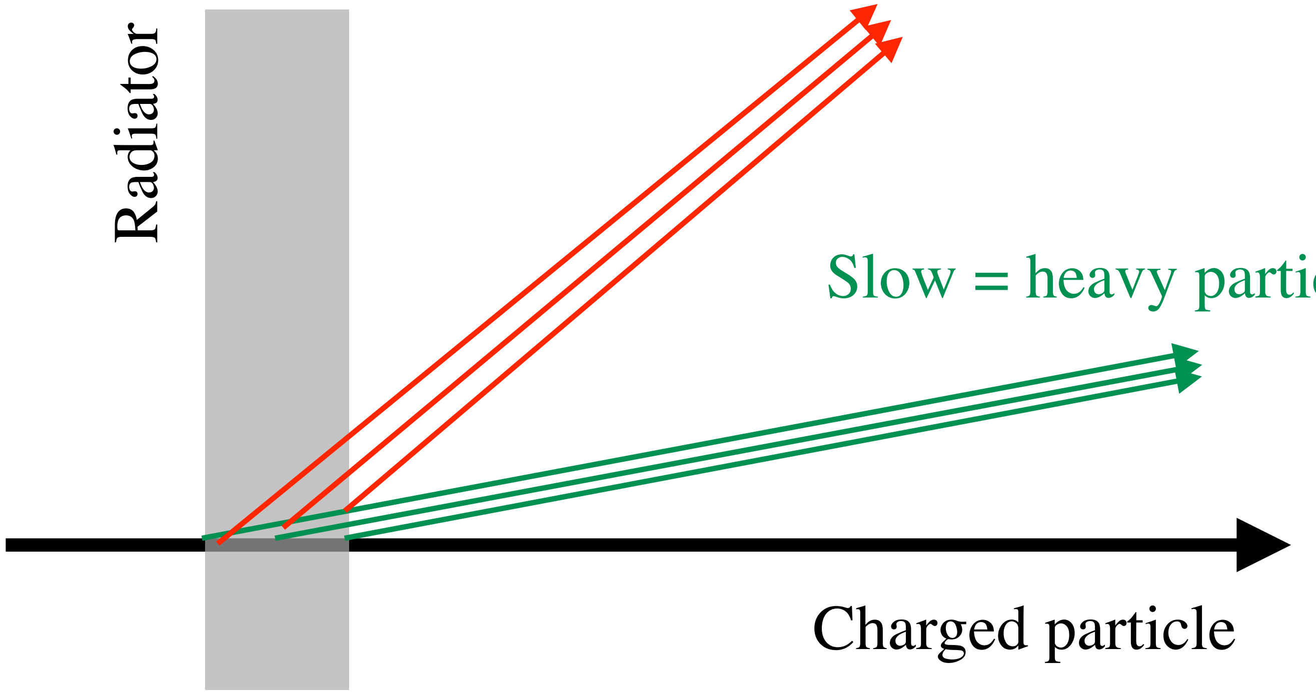

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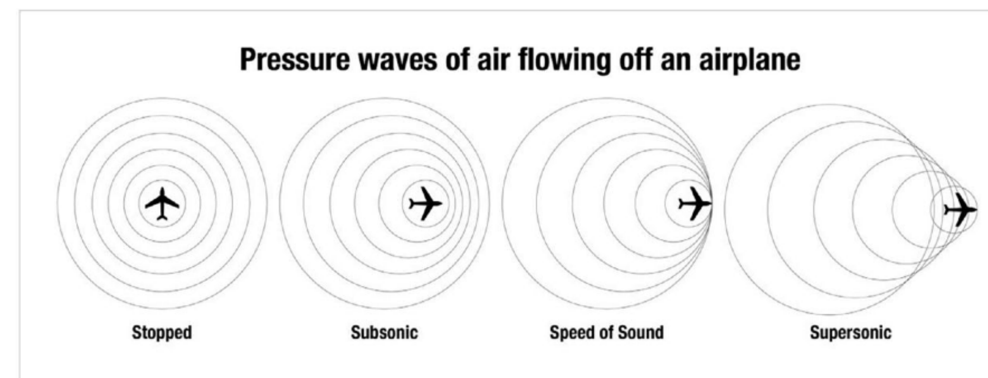

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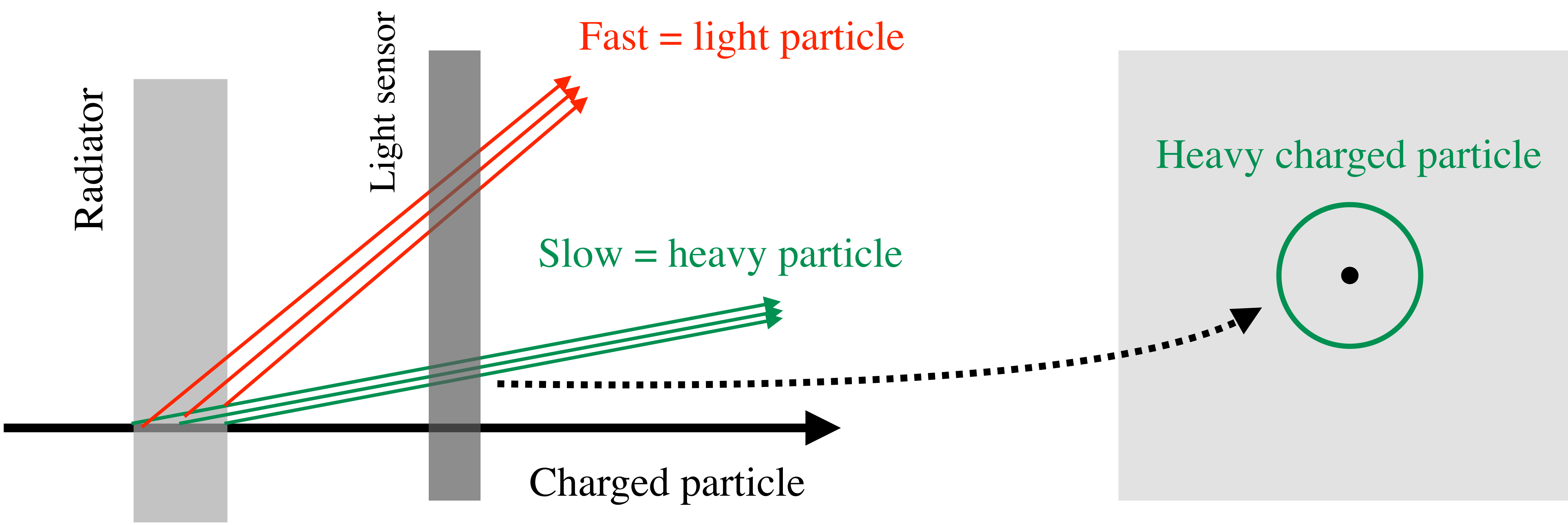

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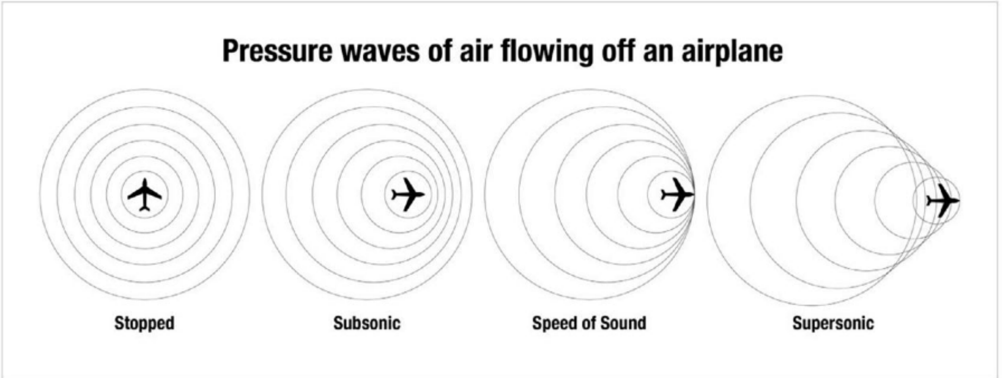

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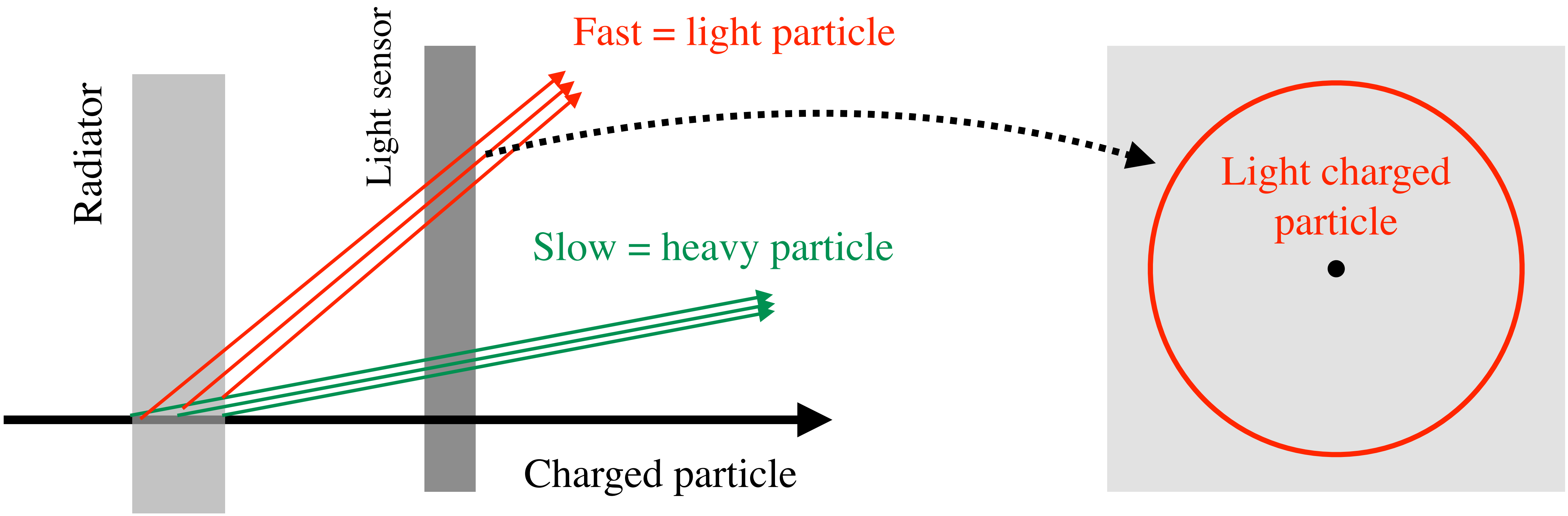
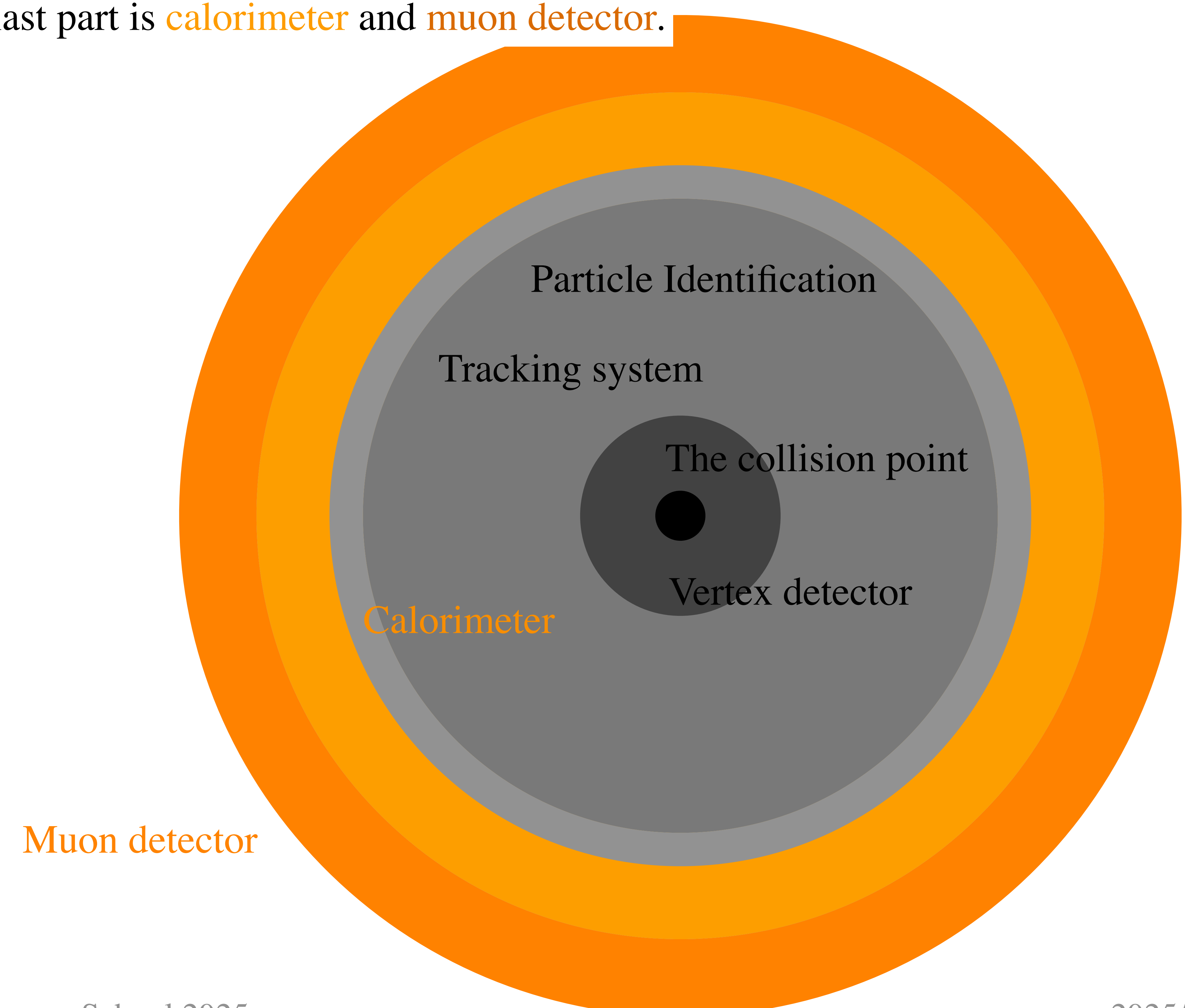


Detectors - Chase the charged particle

The last part is calorimeter and muon detector.



Detectors - Chase the charged particle

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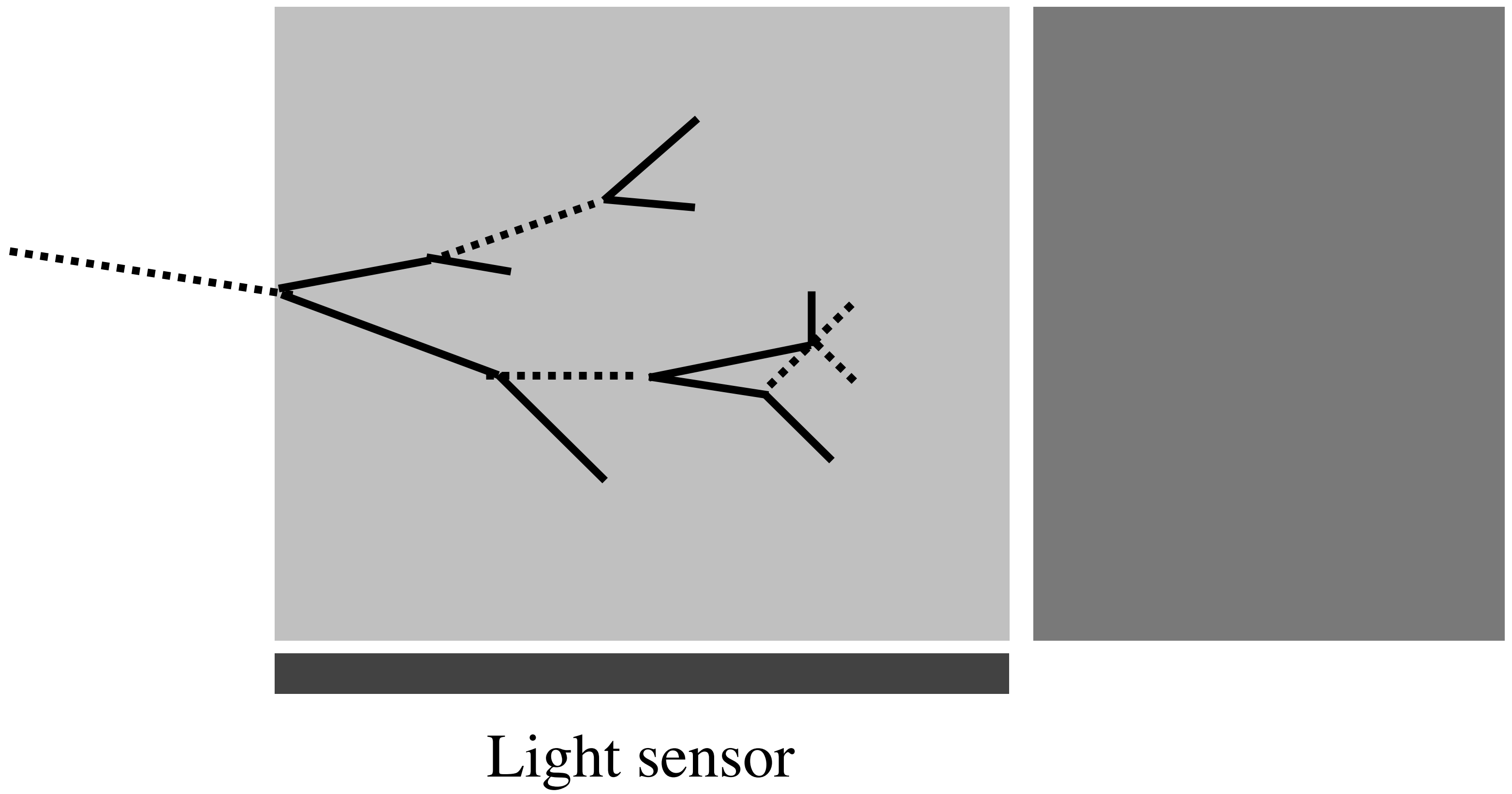
In the calorimeter, most of particles deposit their whole energy.
And they are stopped in the calorimeter.



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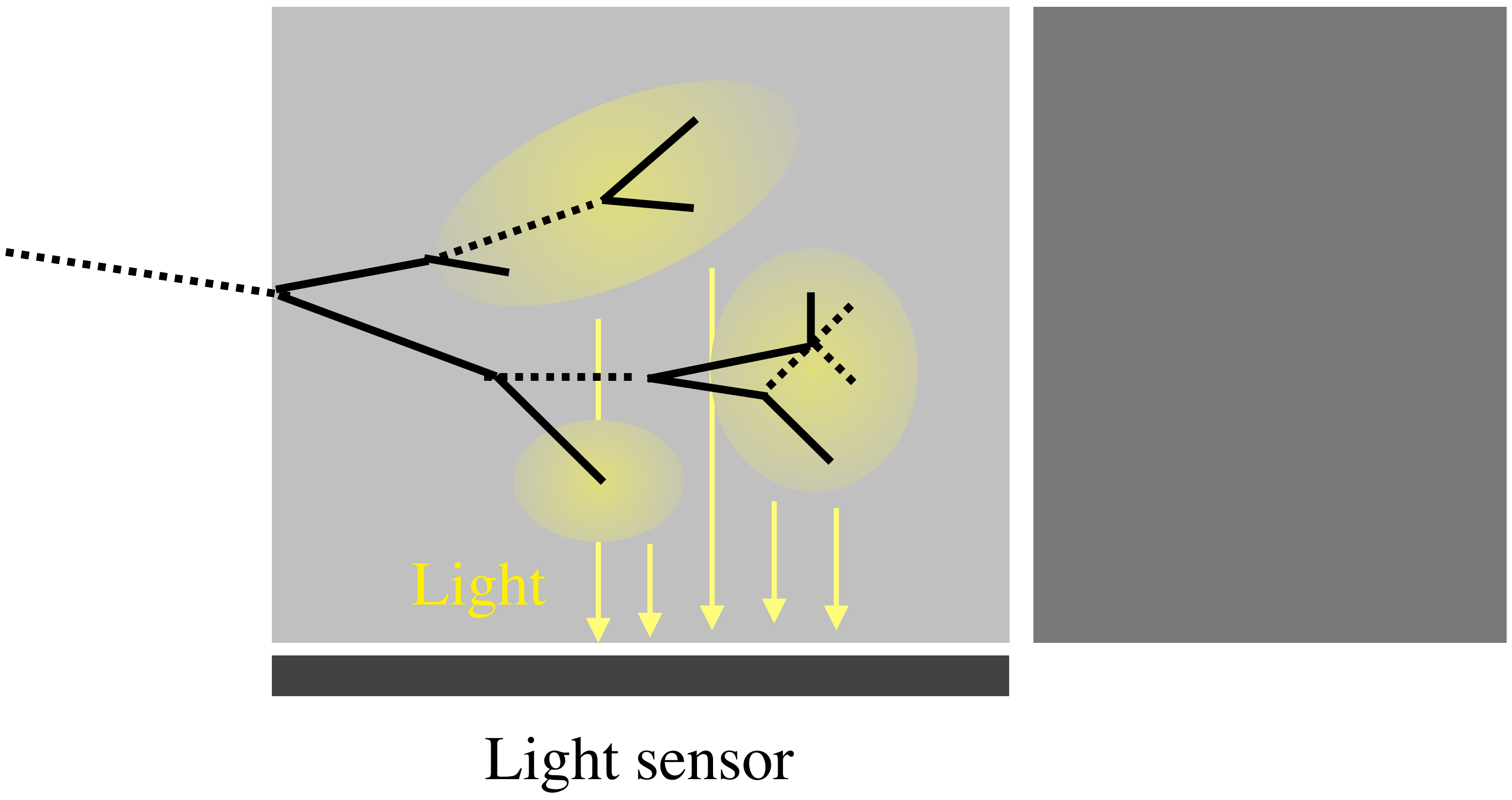
In the calorimeter, most of particles deposit their whole energy.
And they are stopped in the calorimeter.

Energy is converted to scintillation light and measured by light sensors.

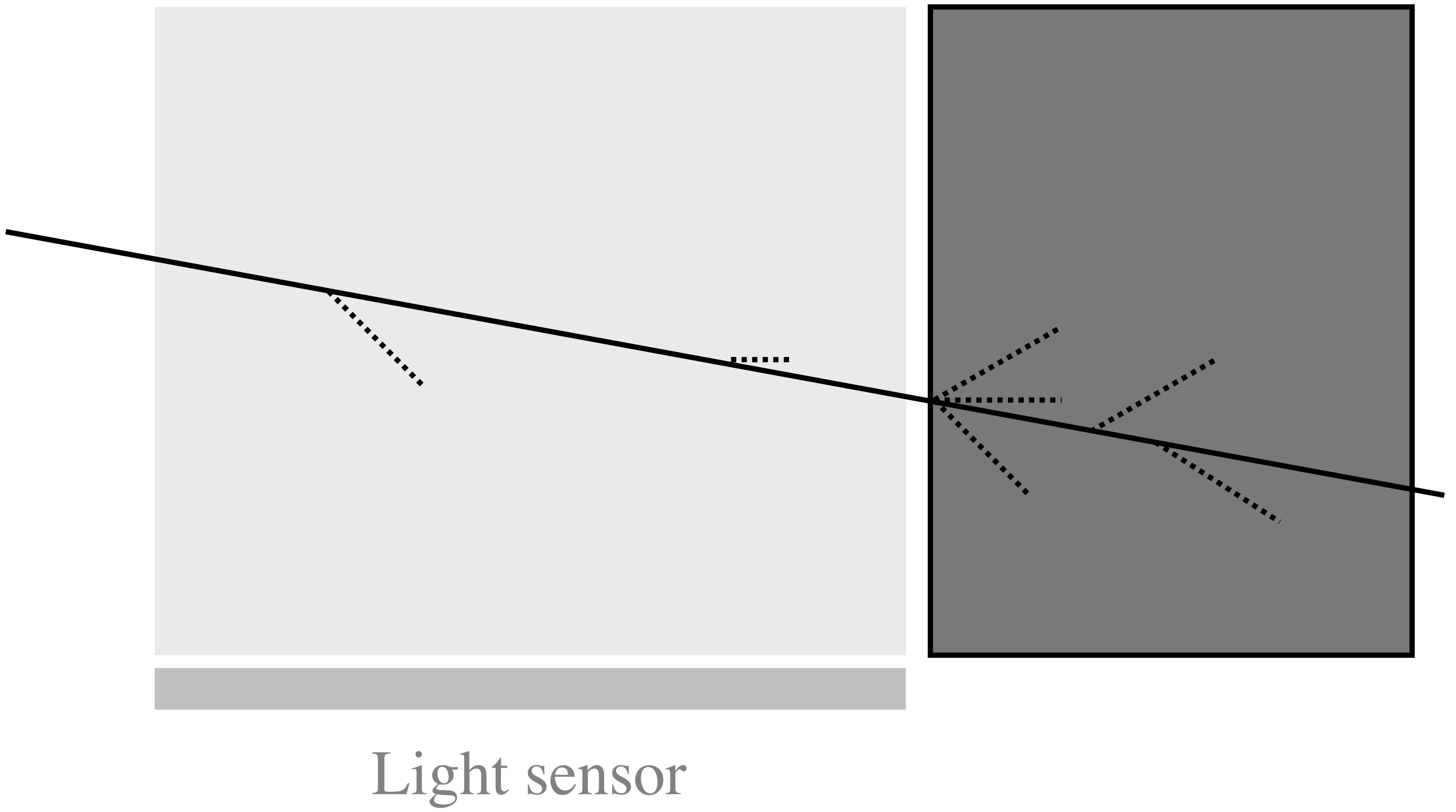


Detectors - Chase the charged particle

The last part is calorimeter and muon detector.

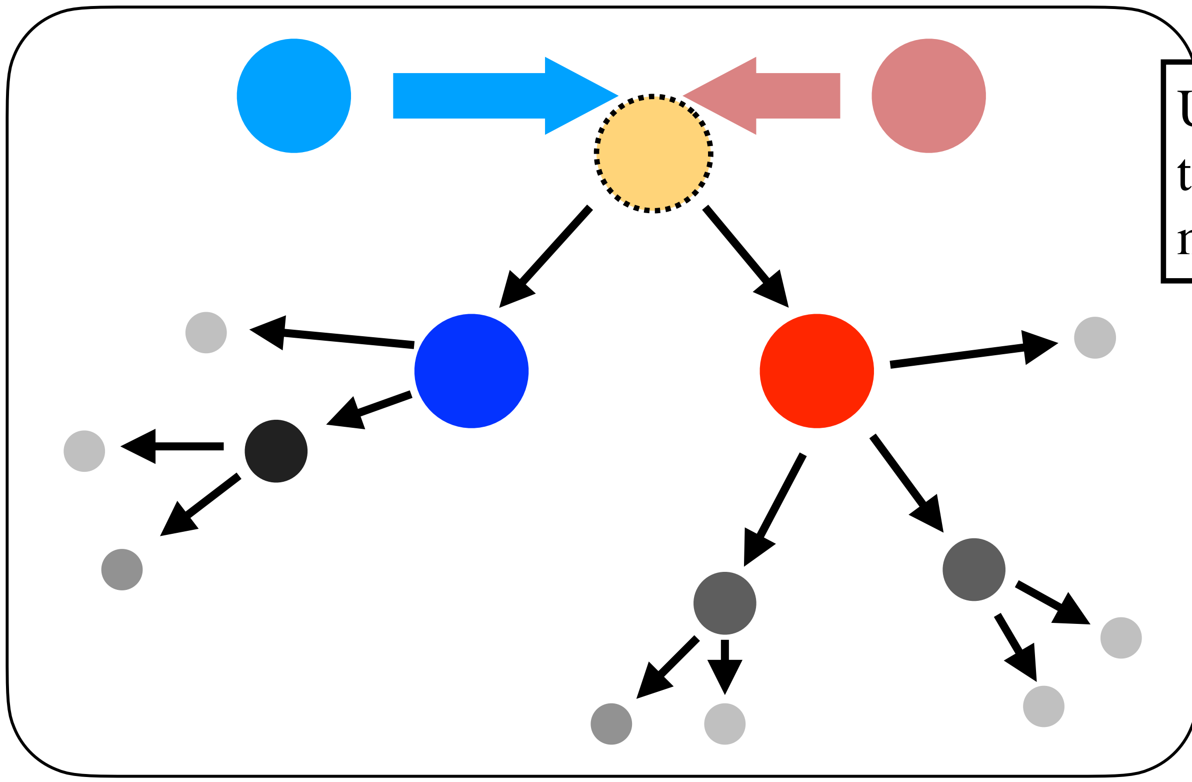
In the calorimeter, most of particles deposit their whole energy.
And they are stopped in the calorimeter.

On the other hand, muons can penetrate the calorimeter and reach the muon detector.
Muon detector is specially designed to get signal from muon.

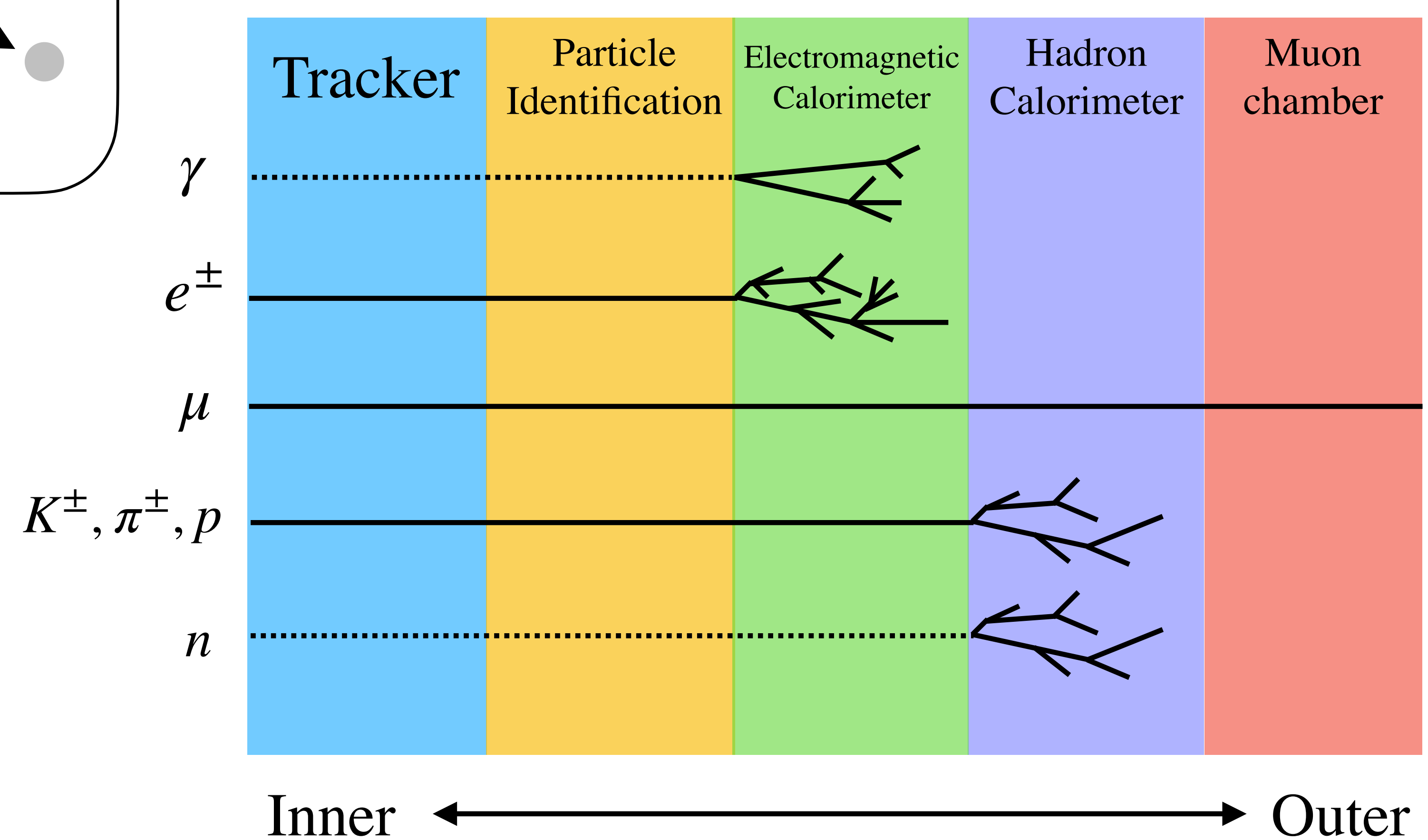


Analysis - Integrate and build a snapshot

The detectors; (1) find tracks, (2) identify particle of each track, (3) measure energies.
Finally, we get a snapshot of particle decay chains.

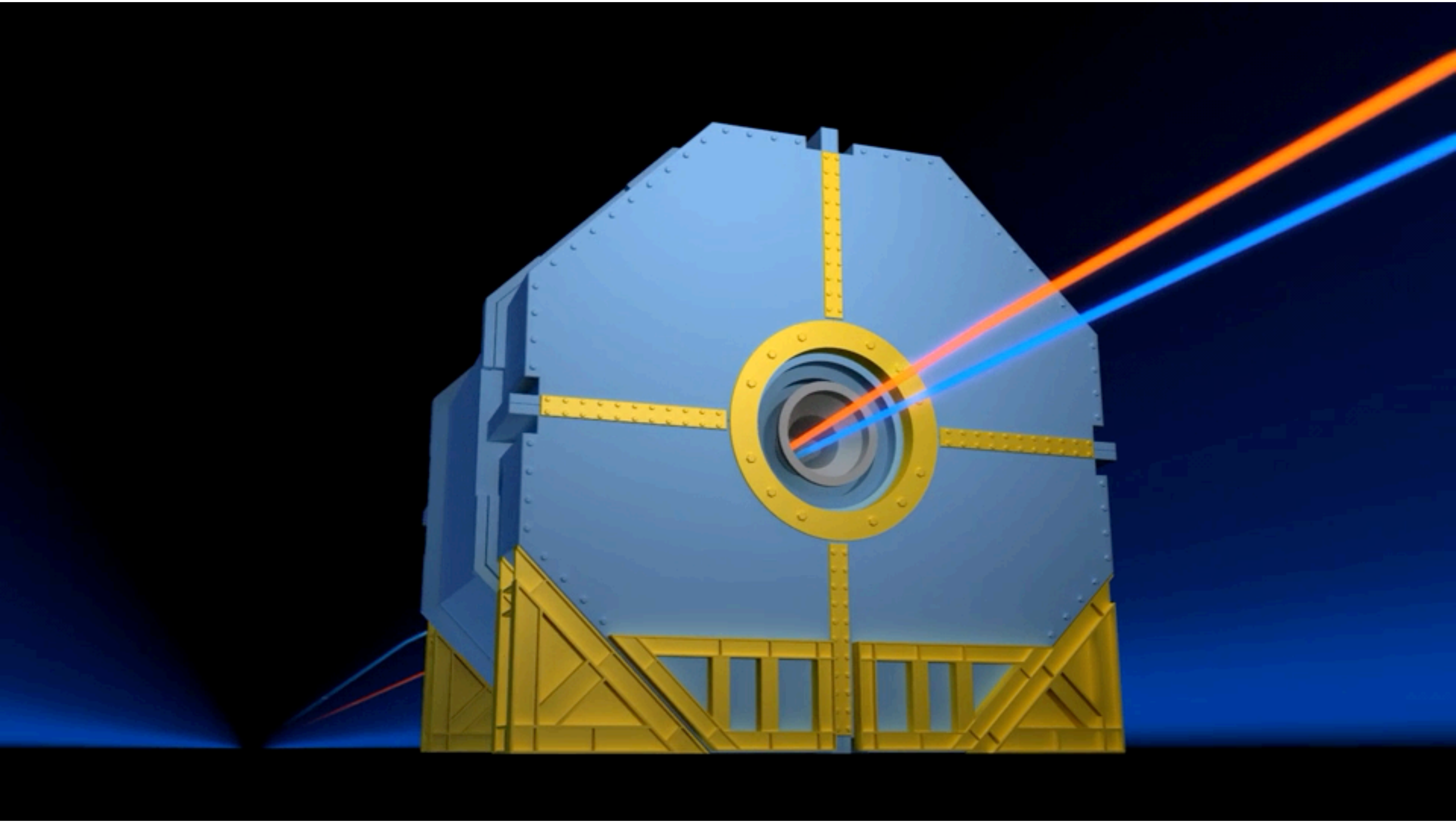


Use conservation of momentum and energy to work backward to the earliest particles made in the electron-positron collision.



Difference of reactions between particles, particles are identified.
This information is used in reconstruction.

Components of Belle II detector



Statistics - Repeat as many as possible

The detectors; (1) find tracks, (2) identify particle of each track, (3) measure energies.
Finally, we get a snapshot of particle decay chains.

And then, it is **repeated as many as possible**.
In Belle II, it will be up to 30 kHz $\times$ years = $O(10^{11})$ of snapshots.

More is better.

- There are statistical fluctuations
- Every measurement contains uncertainties and errors
- The more individual measurements the smaller uncertainty.

An example - CP violation parameters



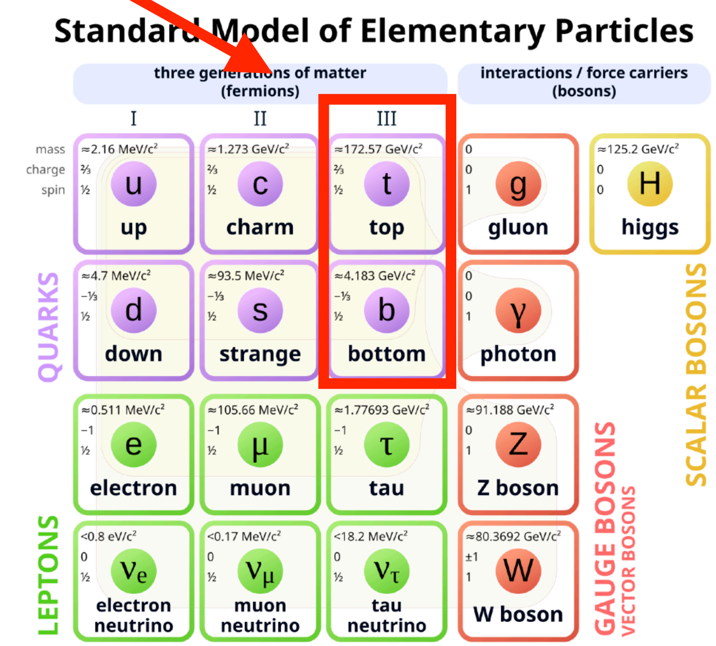
2008 Nobel Prize in physics

CP symmetry can be broken at the 3rd generation of quarks.

Charge conjugation **P**arity symmetry

The physics phenomena are exactly same when both charge and coordinate are flipped.

Need to compare the lifetimes of B meson and anti-B meson.



Details can be found in Valeria's talk

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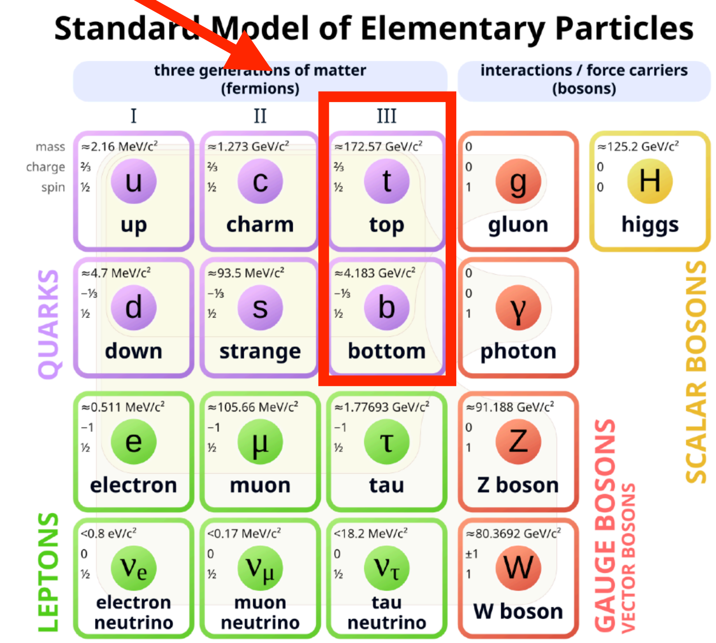
Flight length until decay



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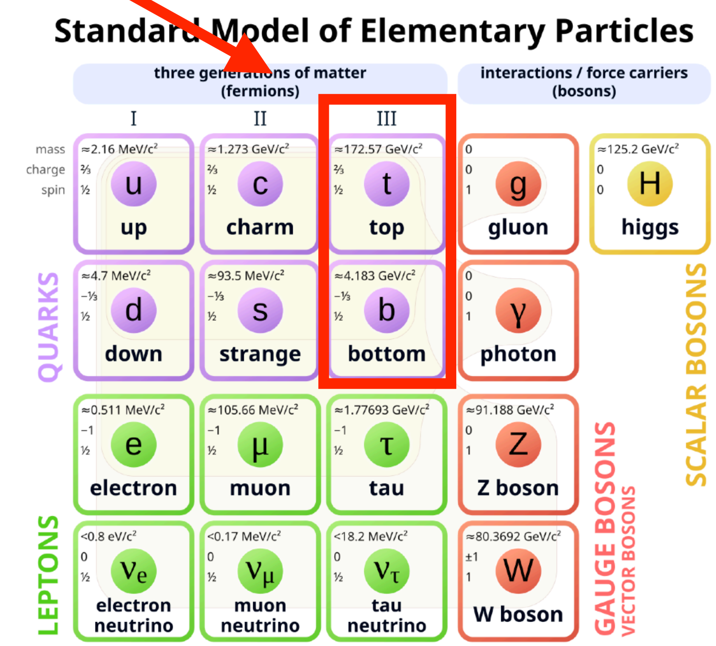


Charge conjugation **P**arity symmetry

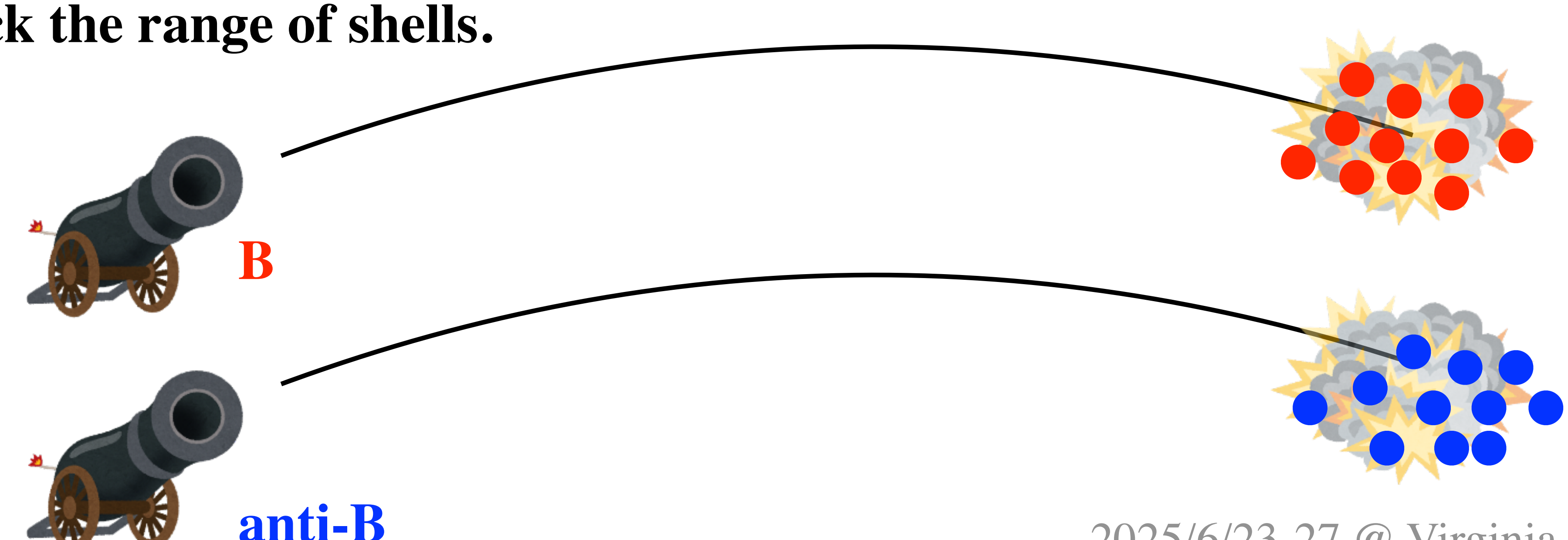
The physics phenomena are exactly same when both charge and coordinate are flipped.

Need to compare the lifetimes of B meson and anti-B meson.

Flight length until decay

Imagine:
You have two cannons which should have the same range.
How to confirm that they have exactly the same range?

-> **Shoot them. And check the range of shells.**



B

anti-B

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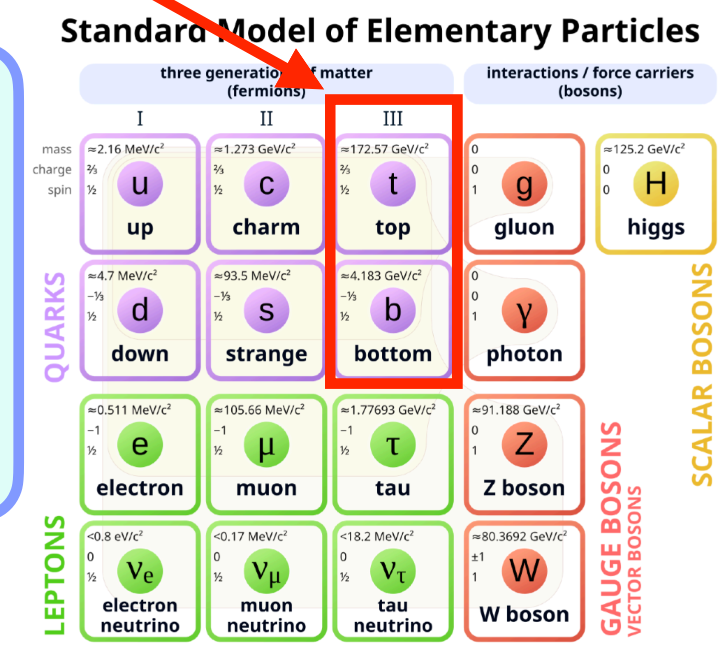

Charge conjugation **P**arity symmetry

The physics phenomena are exactly same when both charge and coordinate are flipped.

Need to compare the lifetimes of B meson and anti-B meson.

If no violation, $\Delta t = 0$ and no difference between the distributions.

$$\Gamma_{B^0\to f_{CP}} \propto \exp\left[-\frac{|\Delta t|}{\tau_{B^0}}\right] \times (1 - A\cos\Delta m_d\Delta t - S\sin\Delta m_d\Delta t)$$

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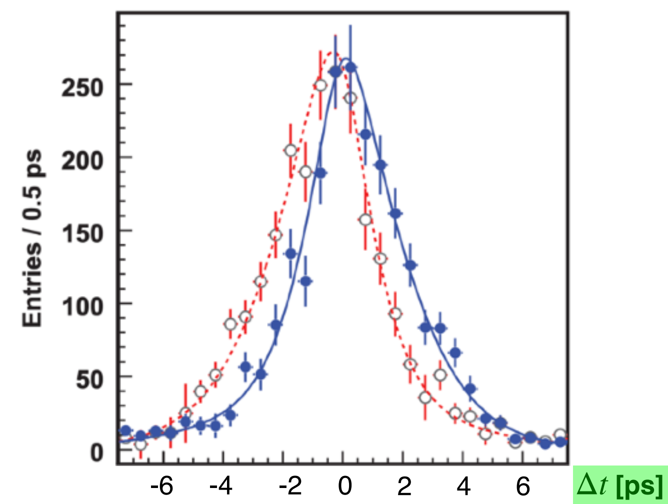
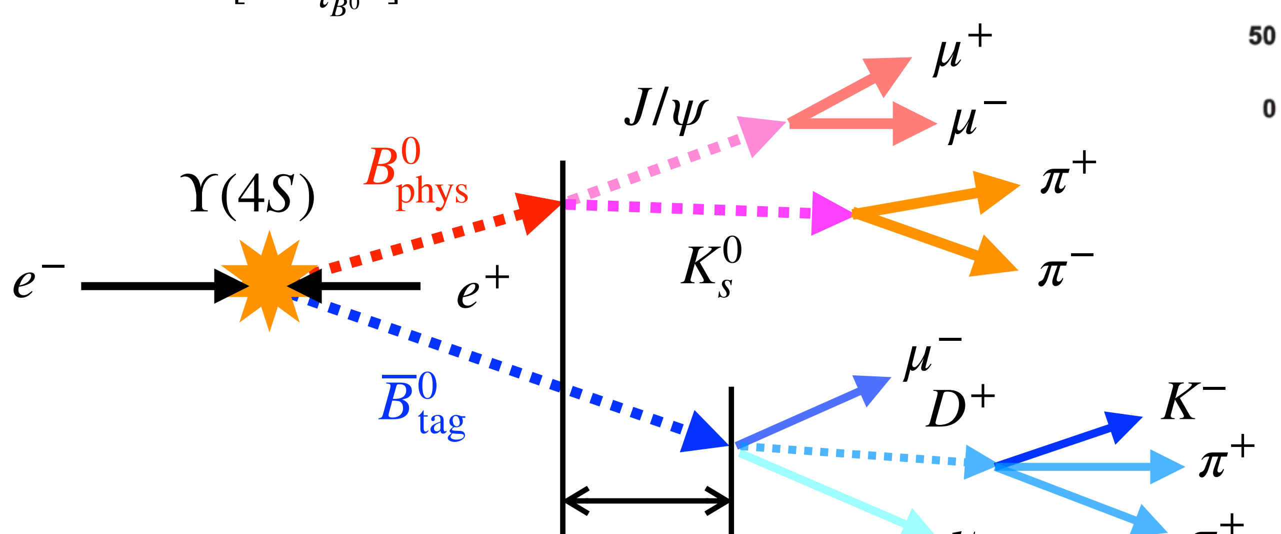
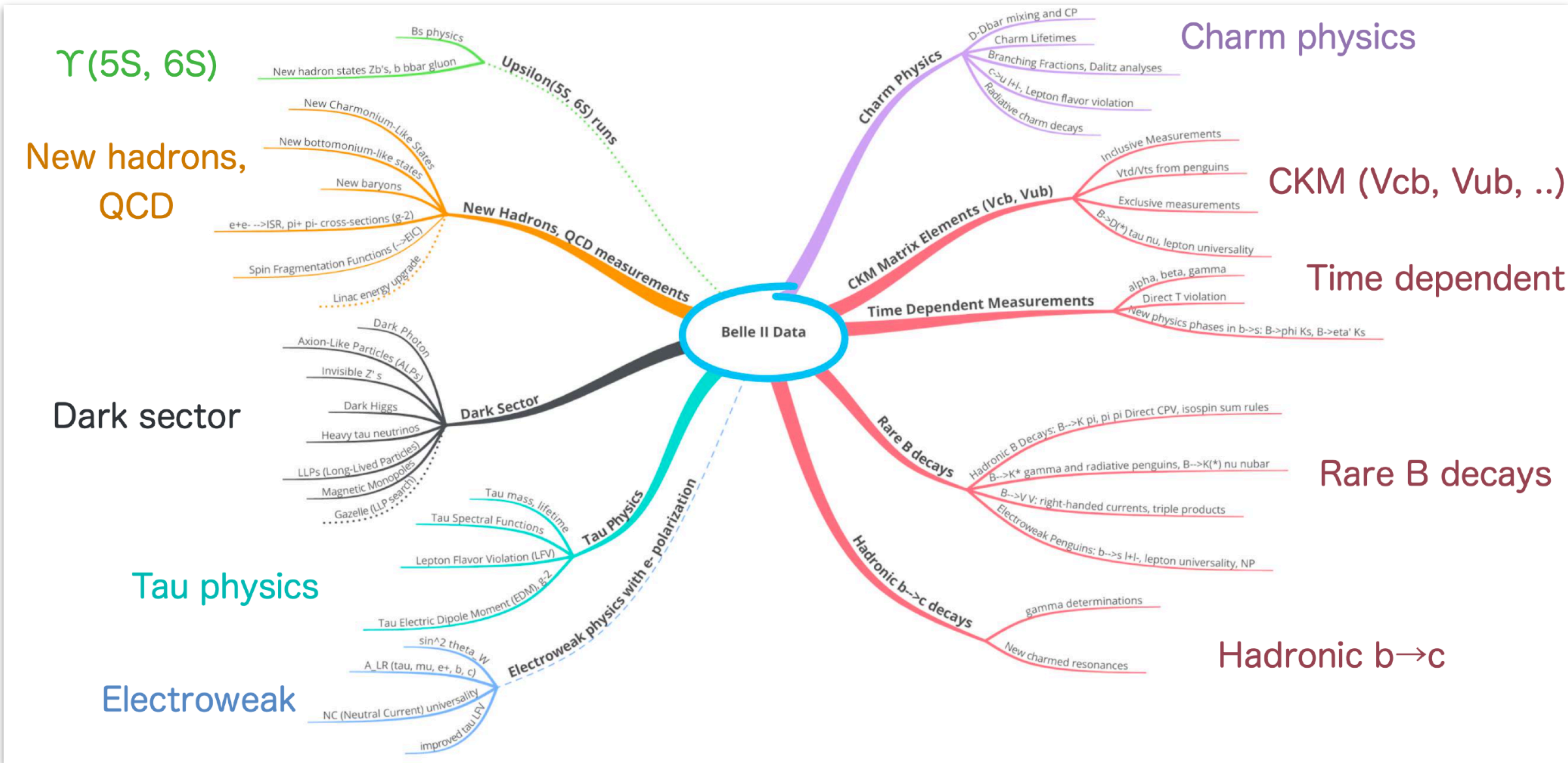




Flight length $\Delta z \sim \beta\gamma\Delta t$

The lifetime of B^0 is about 1.5 ps that is impossible to measure directly.
Using Lorentz boost, it is converted to the flight distance = vertex position of daughters.

More things to discover in Belle II



Summary

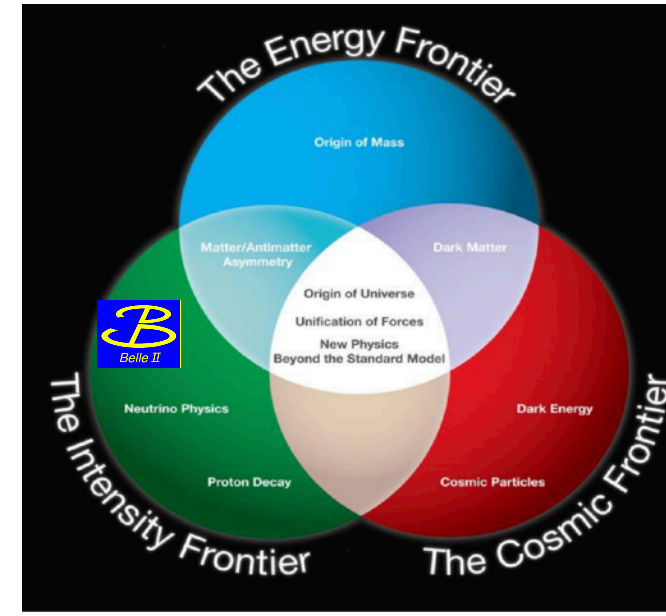
- Particle physics has many frontiers to be discovered.
- Belle II is one of experiments trying to find physics beyond the Standard Model.
- If you are interested in, you are welcomed!!

For students seeking advanced information:

- Belle II Technical Design Report - KEK Report 2010-1 (2010), arXiv.org :1011.0352 - provides details of each system; IR design, detectors, trigger, and DAQ.
- For more, Belle II Physics Book - PTEP 2019, 123C01 (2019) provides a wealth of detail on the machine, detector, analysis tools, and physics.

BackUp

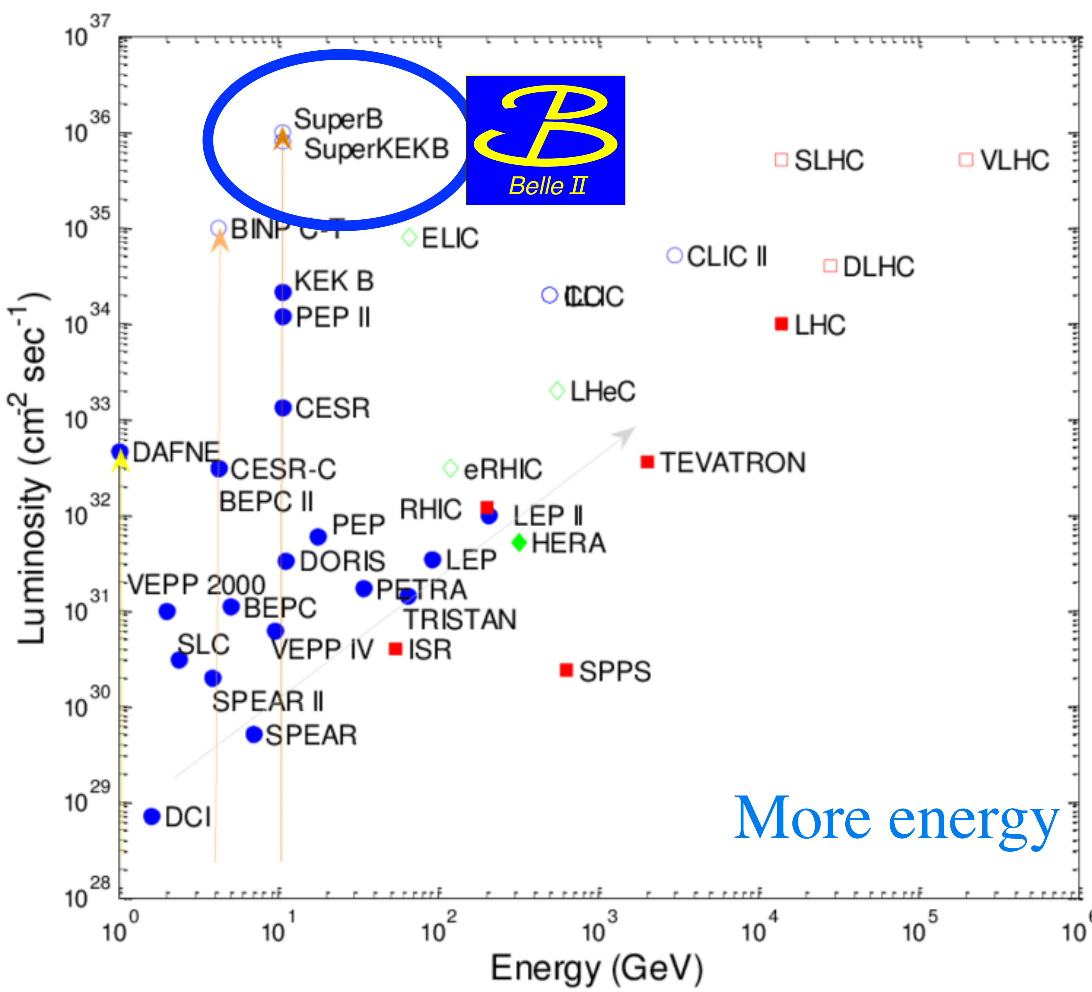
Two directions of physics experiments



1. Challenge for More Luminosity

Try to get **more events**.
Rare event search, precise measurements.
Require low systematics and precise theory predictions, since the difference from the theories are the issue.
(Can set upper limits even nothing is found.)

More luminosity



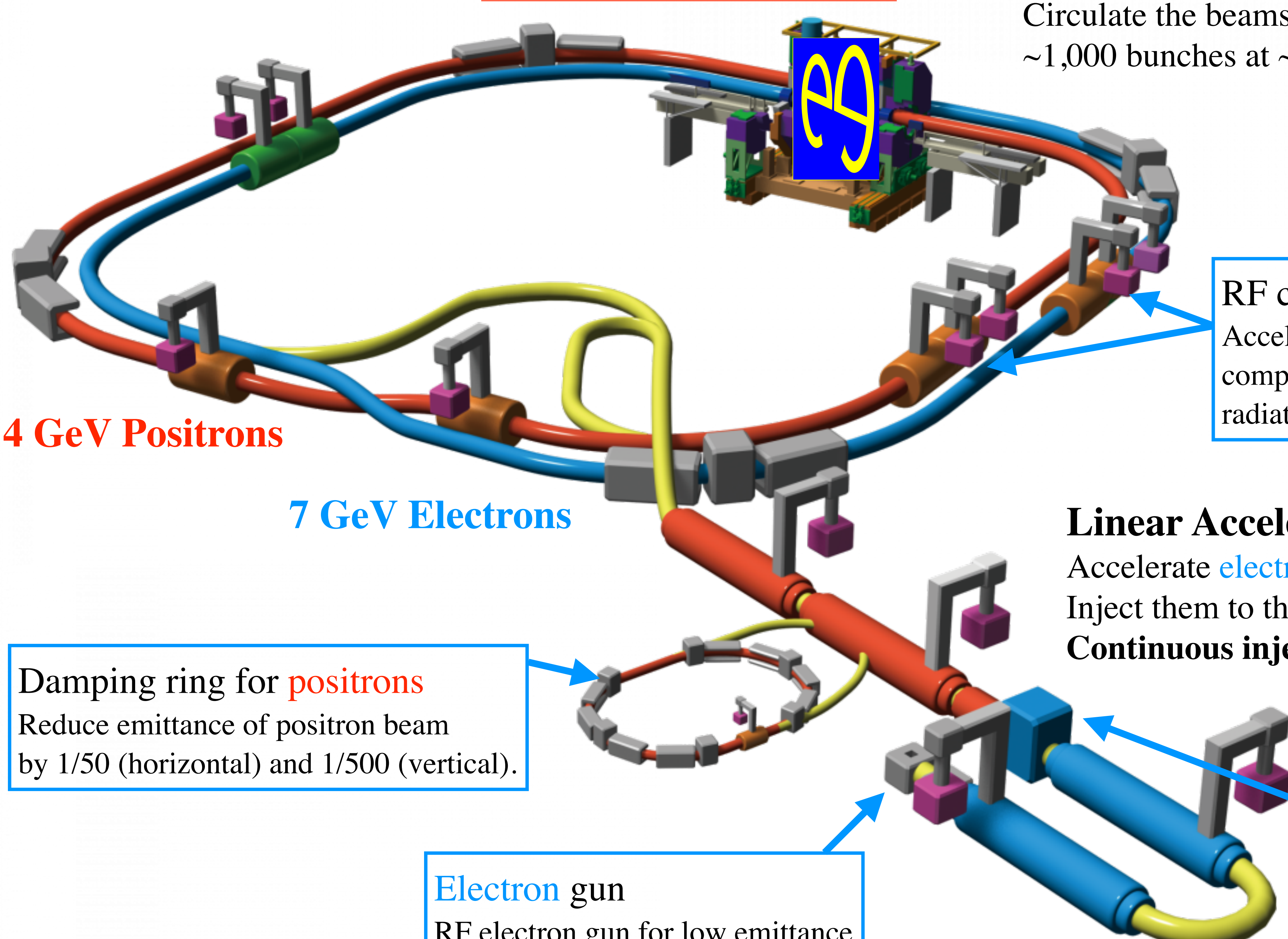
2. Challenge for More Energy

Try to produce **new heavier particles**.
Direct new particle search in unexplored area.
Require low systematics, but the result is always clear = an explicit peak on mass distribution.
(Can expand excluded region in case of no result.)

B factory experiment ~ SuperKEKB accelerator

$e^+e^- \to \Upsilon(4S) \to BB$

Storage Rings
Circulate the beams keeping their energies.
~1,000 bunches at ~100,000 RPS.



RF cavities
Accelerate electrons/positrons to compensate for loss of synchrotron radiation.

Linear Accelerator (LINAC)
Accelerate electrons and positrons.
Inject them to the storage rings.
Continuous injection can be performed.

Damping ring for positrons
Reduce emittance of positron beam by 1/50 (horizontal) and 1/500 (vertical).

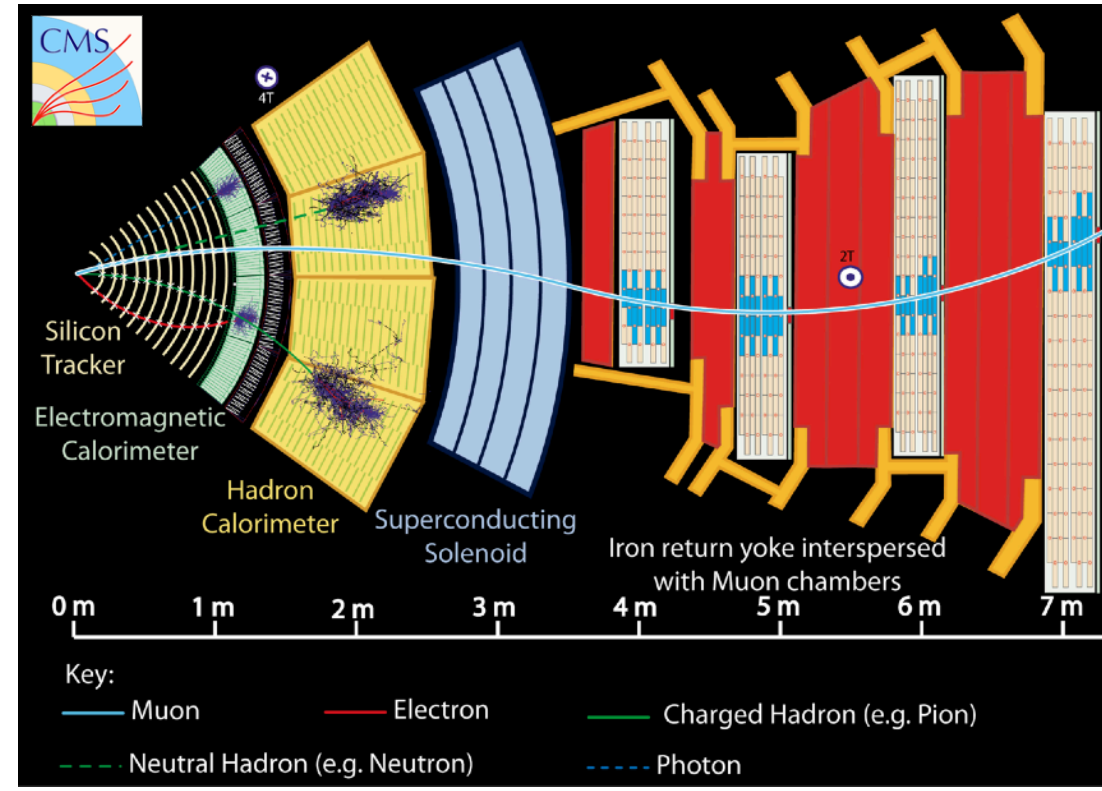
Electron gun
RF electron gun for low emittance and bright injection.

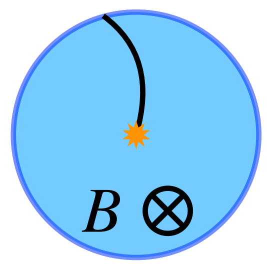
Positron source
Tungsten target to produce positrons by EM shower.

Details

(Common) Fundamental components of detector

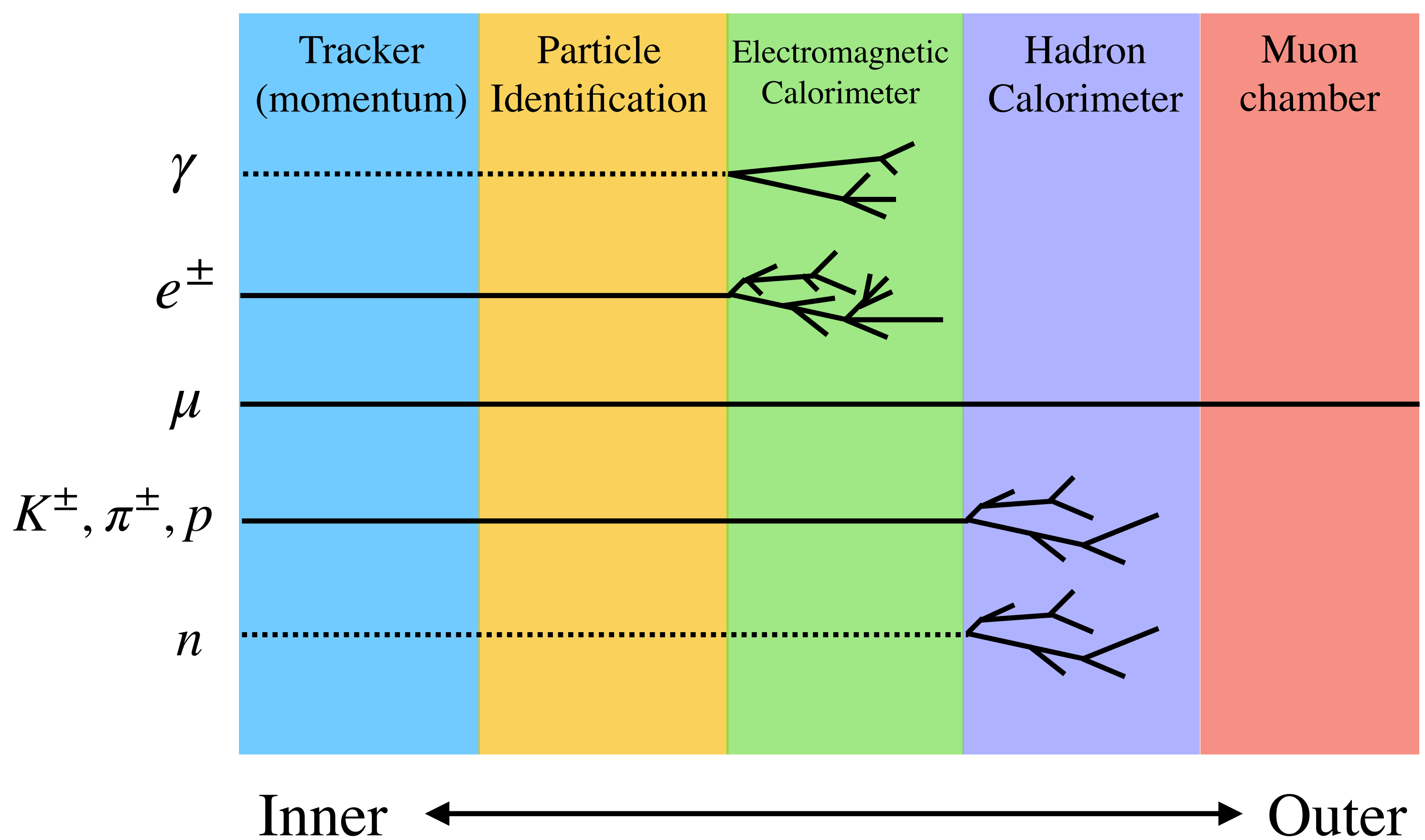
- Detect final state particles ($l^{\pm}$, $K^{\pm}$, $\pi^{\pm}$, and γ)
  - 3D tracking
  - Momentum measurement
  - (3D tracking and momentum measurement:) } Done by same detectors
  - Energy measurement
  - Particle identification → Combination of detectors

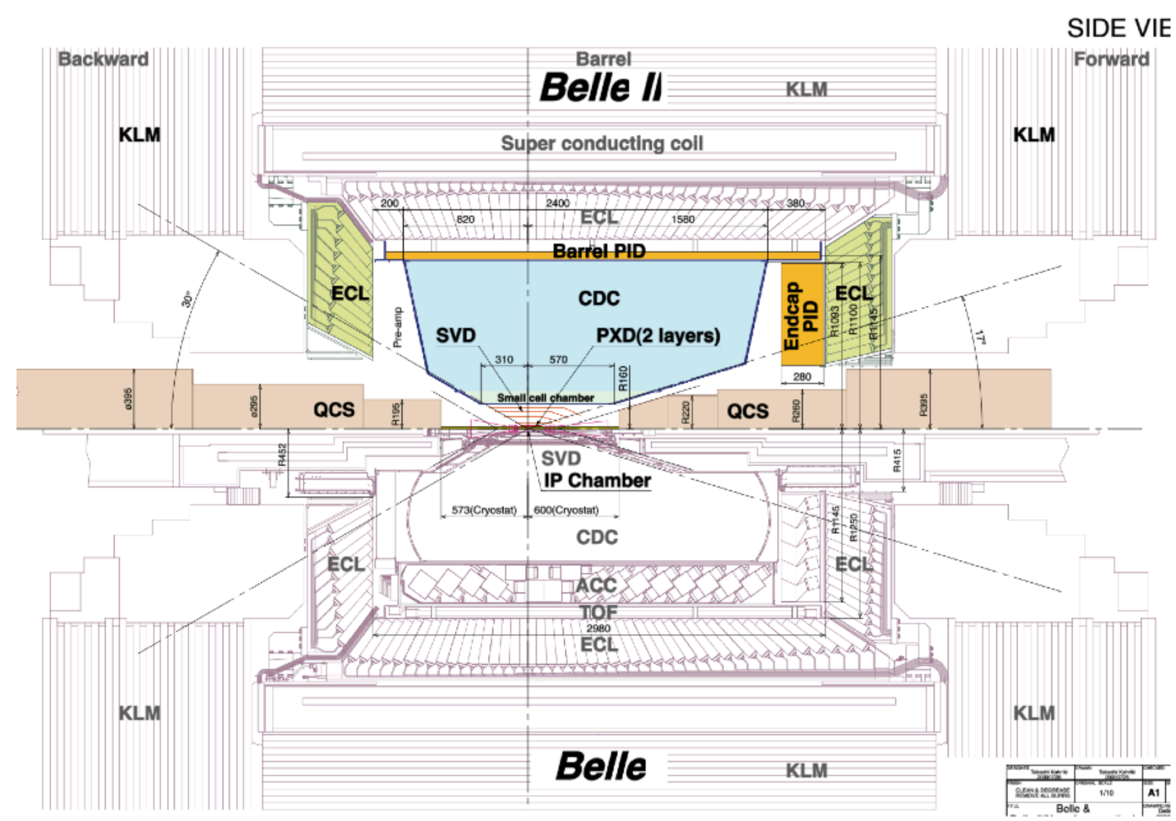




$p_T = 0.3Br$

(r : curvature)

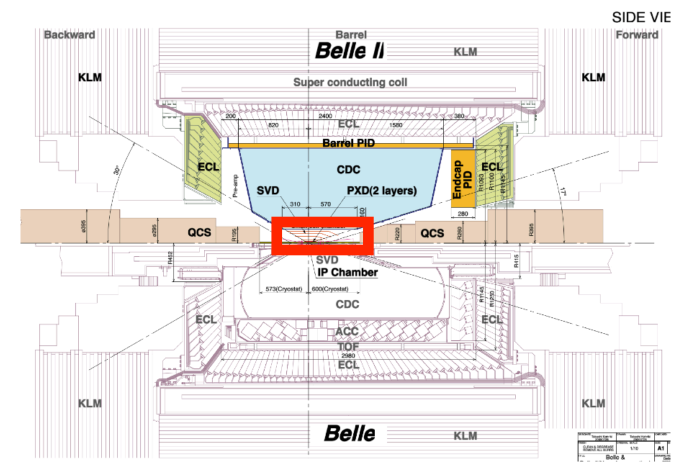




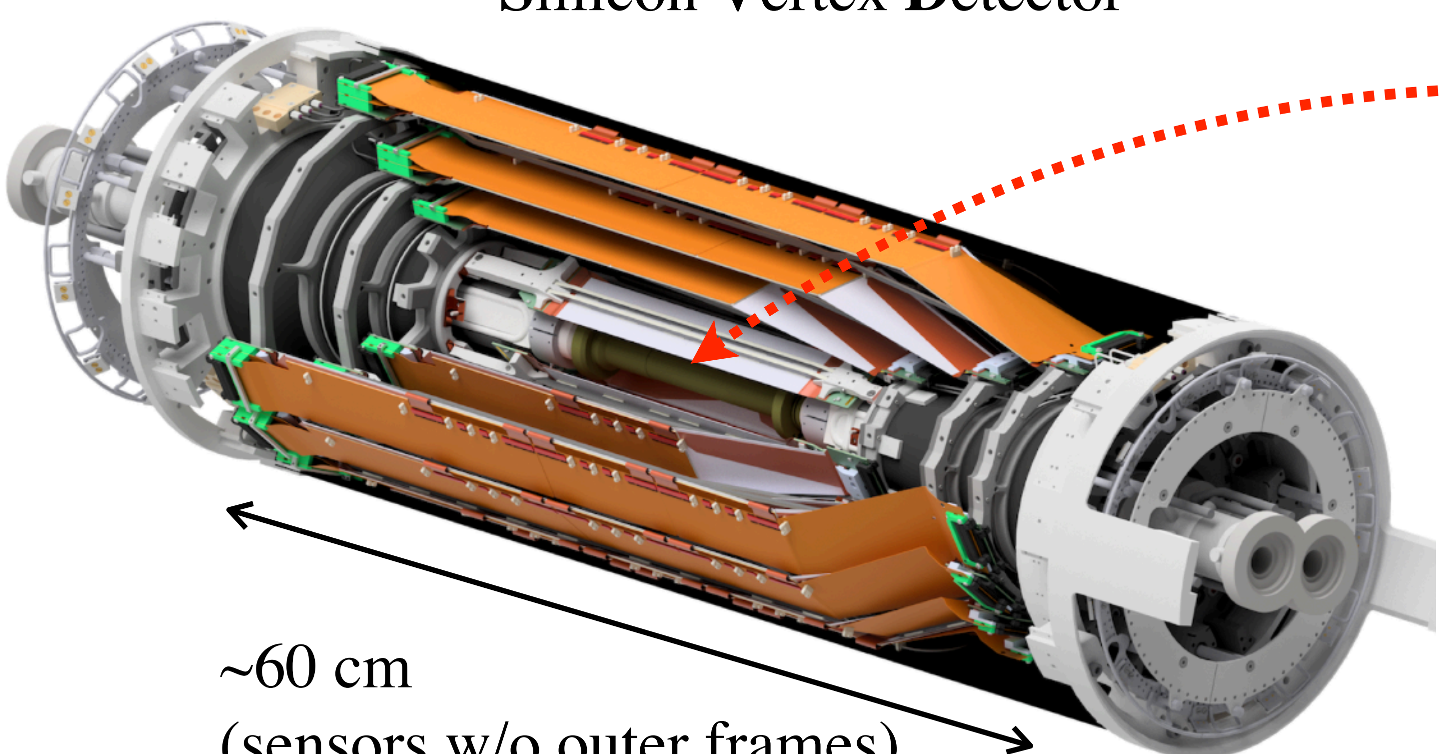
Vertex Detector (PXD, SVD)

- The innermost part of Belle II spectrometer.
- Tracking in combination with CDC, but more precise.

- Combination of 2 + 4 layers of 2D silicon sensors
  - 2 layers of DEPFET pixel sensors
  - 4 layers of double-sided orthogonal silicon-strip sensors



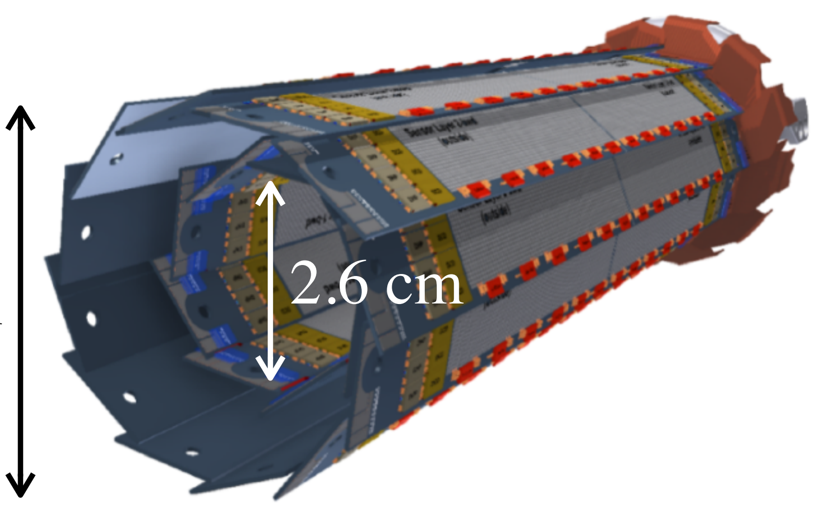
Sillicon **V**ertex **D**etector



~60 cm
(sensors w/o outer frames)

27 cm

6.6 cm



Pi**X**el **D**etector

More details: Belle II Technical Design Report

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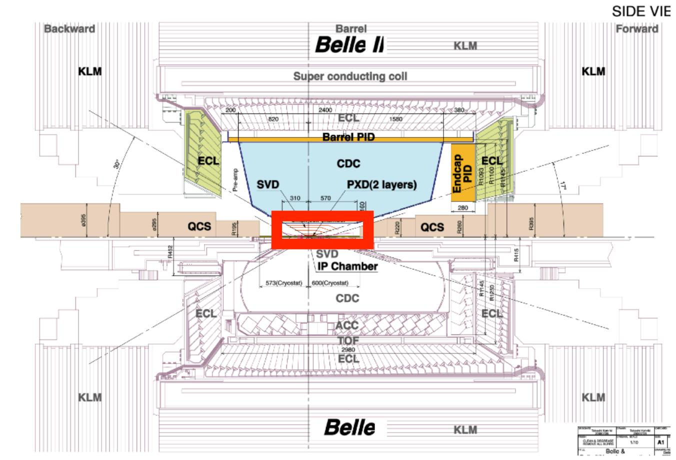
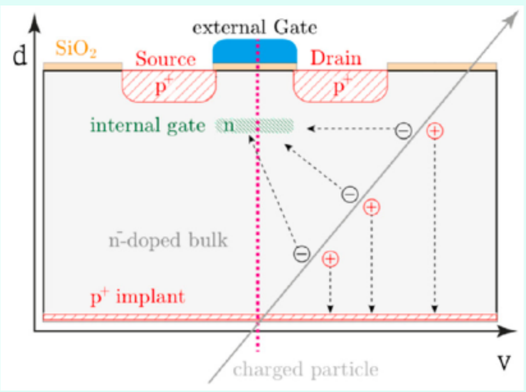


- Semiconductor detector. Reverse-biased PN-junction semiconductor creates a depletion layer, and the holes and electrons generated by charged particles are drifted to the electrode for detection.

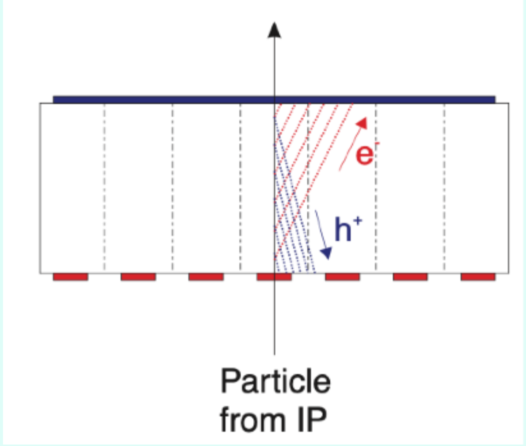
- The position resolution is about 15 μm.

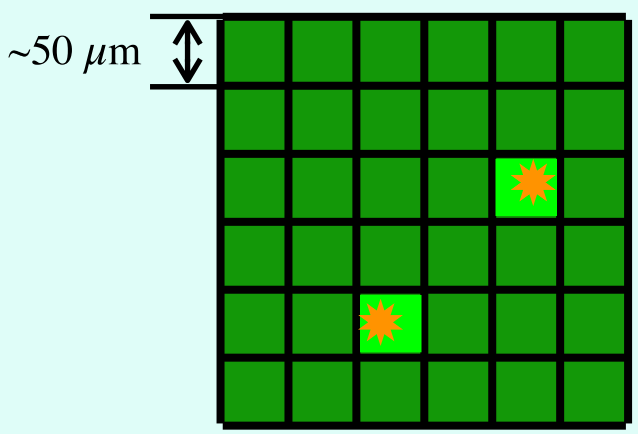
- PXD is a pixel detector and SVD is a 2D strip detector.
  - PXD is more precise and resistant to pile-ups.
  - SVD is faster and its data size is smaller.
  - The inner part is PXD for more resolution.
  - Outer region is SVD to cover larger volume with small data flow.

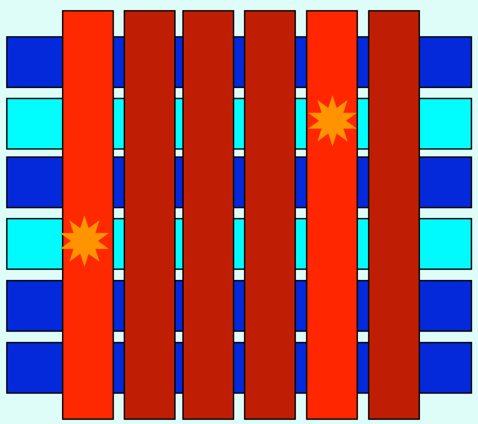
PXD



SVD

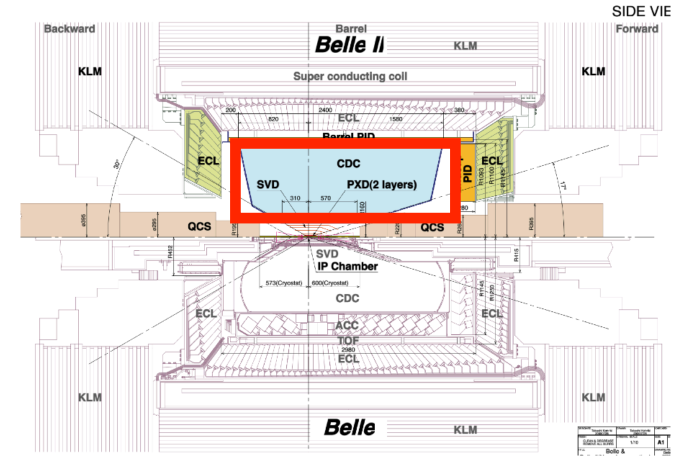


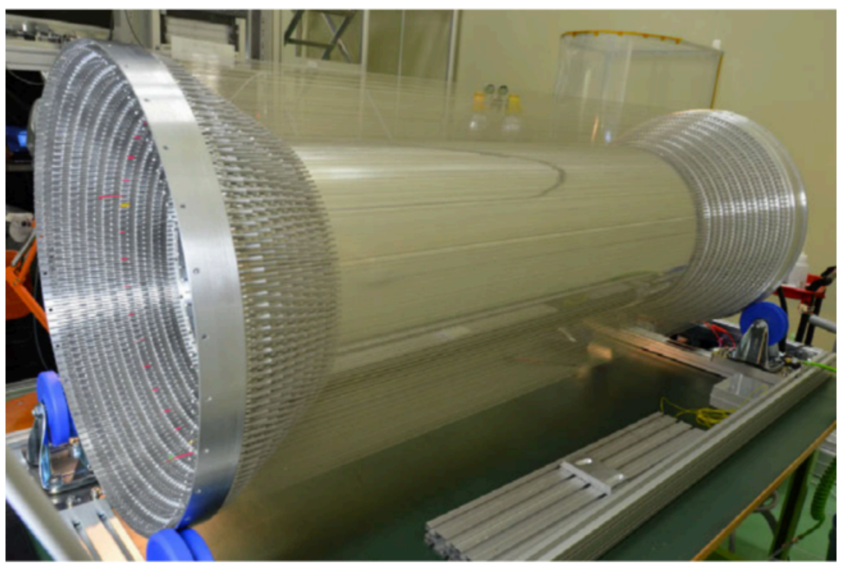




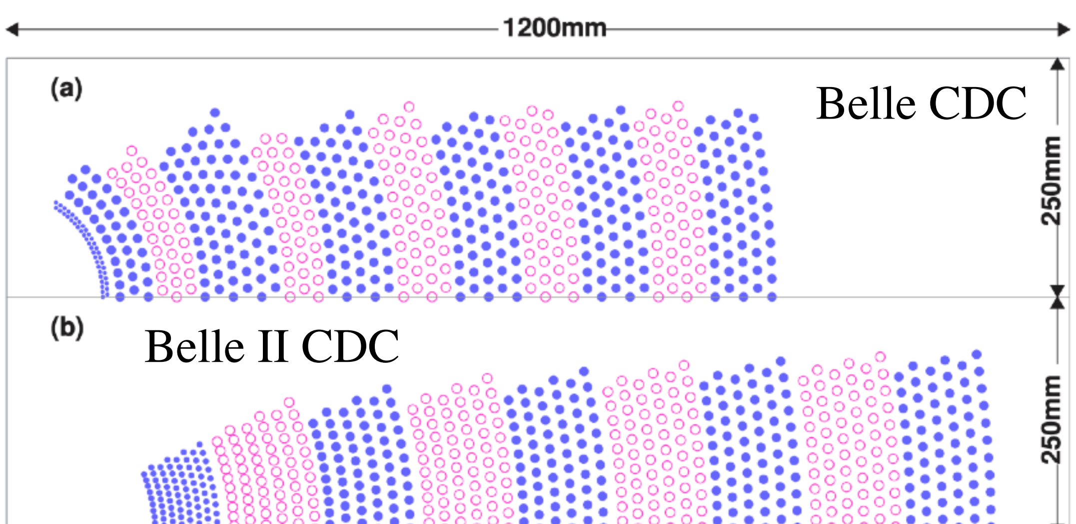
Central Drift Chamber (CDC)

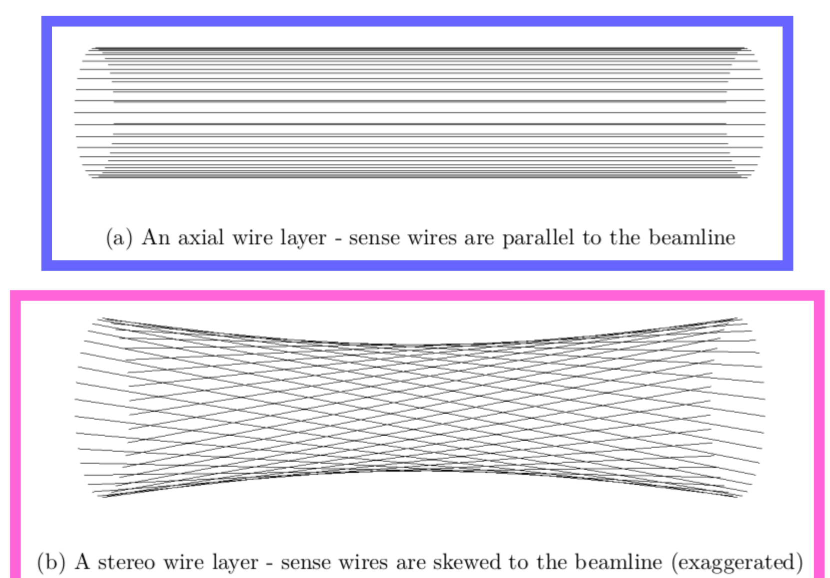
- Gas-filled cylinder in 1.5 T solenoidal magnetic field.
- The main tracking device.
- Additionally, a part of particle identification and momentum measurement
- Data without CDC must be useless…the heart of Belle II.





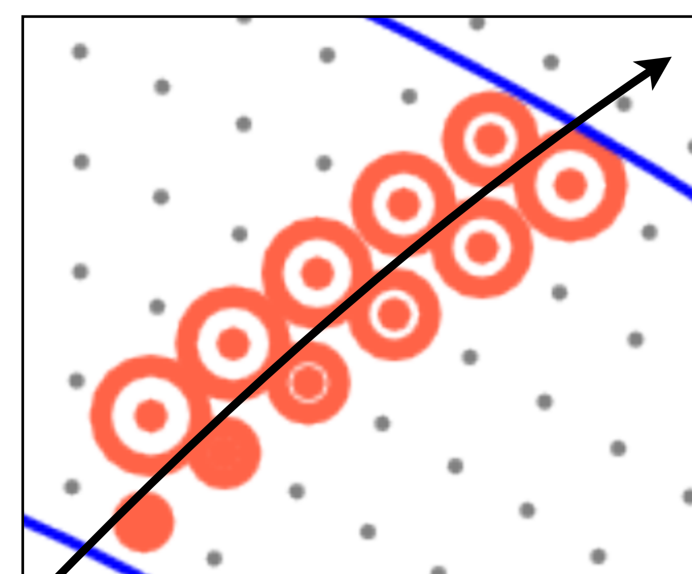
- Drift time for earliest hit on a sense wire gives radius of the tangent circle for that wire.
- Some of layers have wires tilted slightly to measure z position.
- Helical trajectory reconstructed from the circles is converted to 3D momentum using known magnetic field.





(a) An axial wire layer - sense wires are parallel to the beamline

(b) A stereo wire layer - sense wires are skewed to the beamline (exaggerated)



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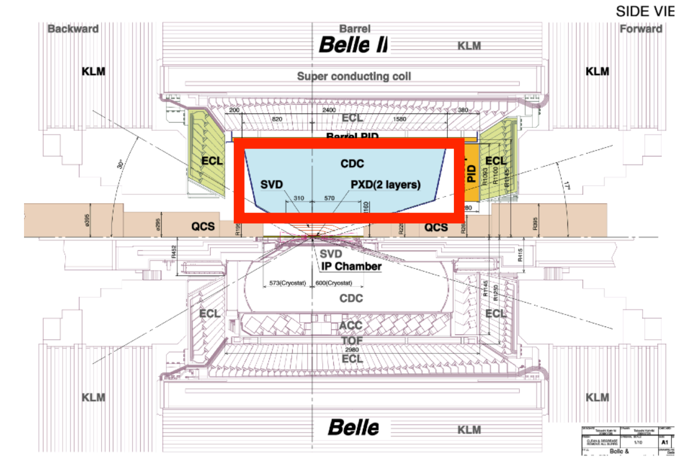
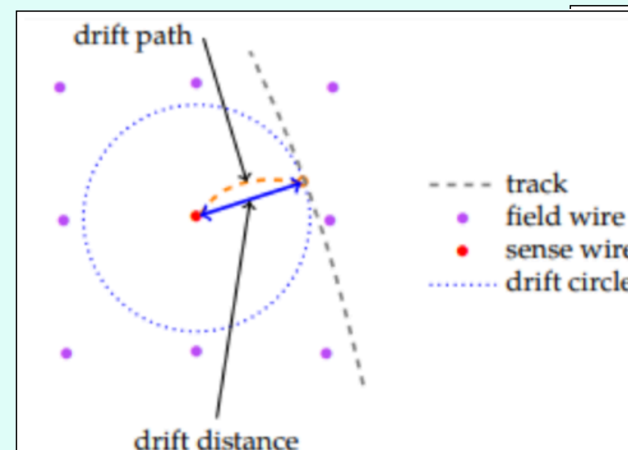
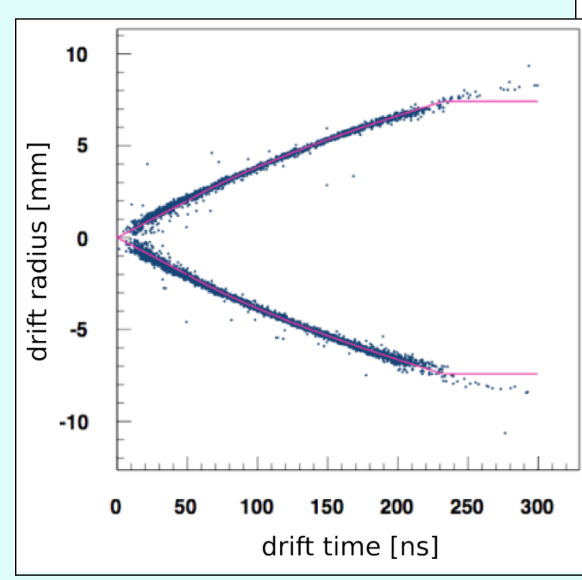
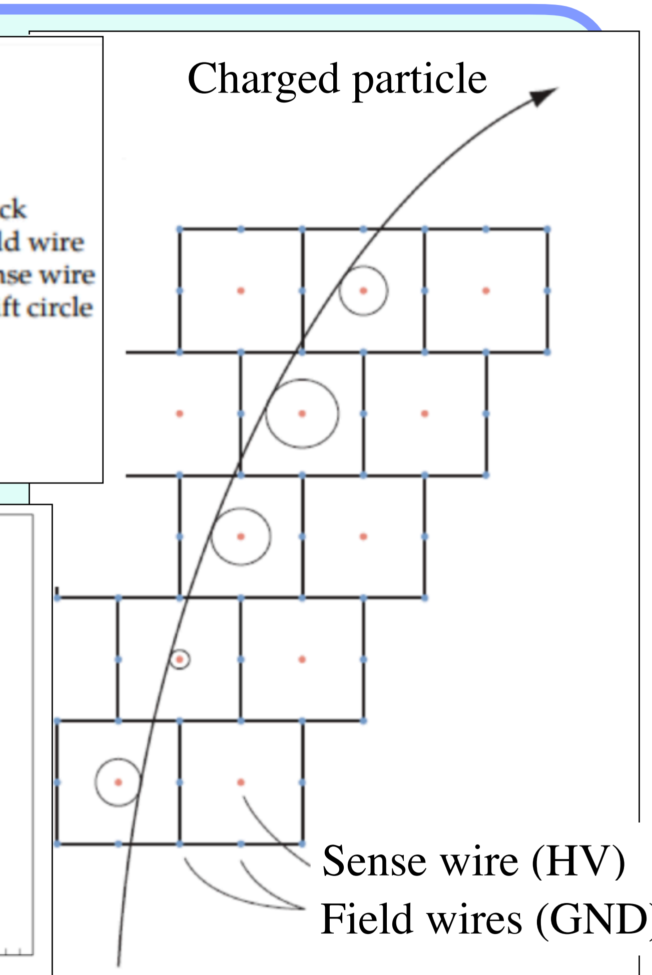


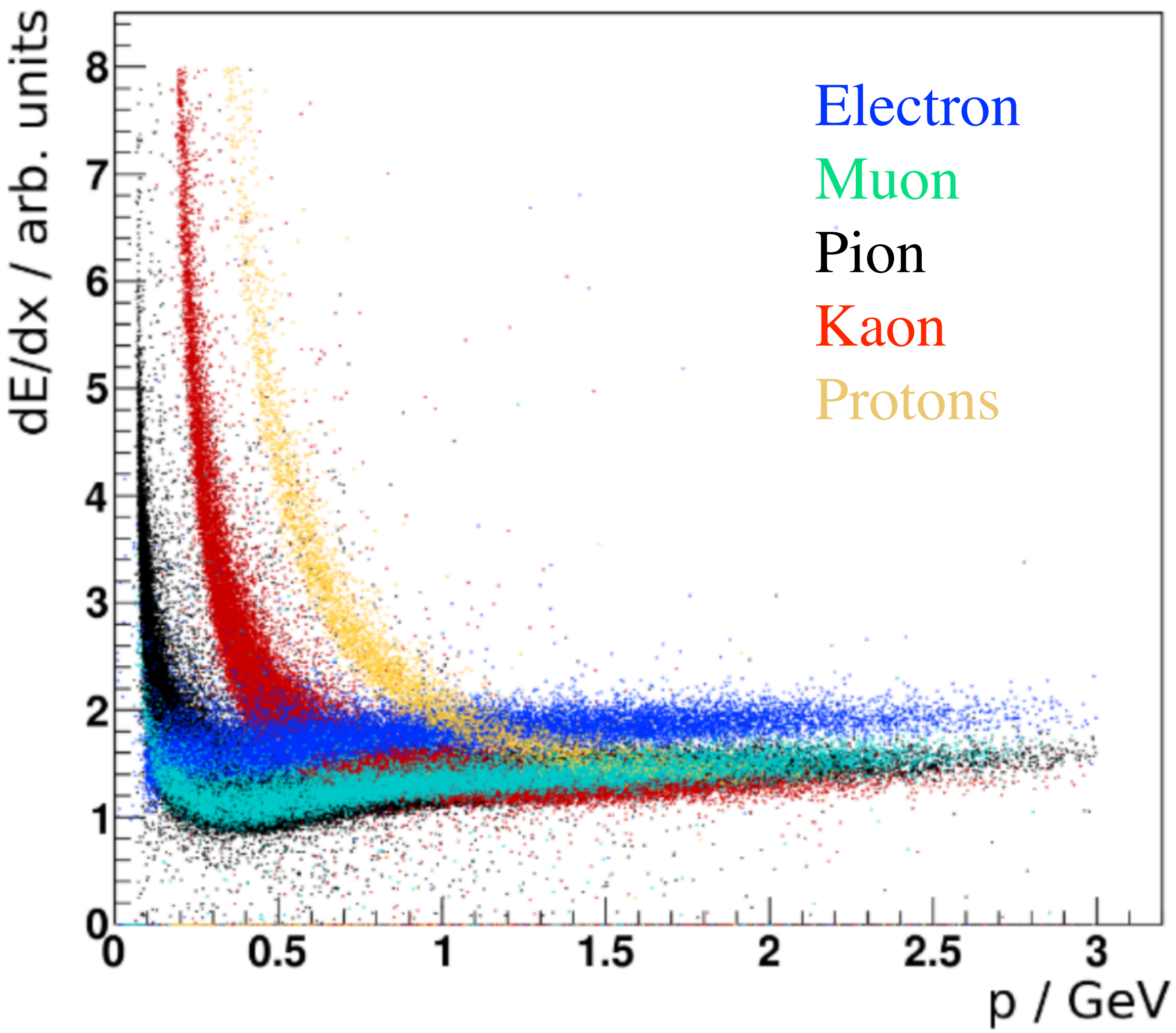
- Consists of "cells" of drift chamber.
  - Each sense wire (HV) is surrounded by field wires (GND). 1 cell = 1 sense wire + 8 field wires.
  - Charged particle ionizes gas and produce electrons.
  - Electrons drift to the sense wire.
  - By electron avalanche, the signal is amplified.
- Based on the relation between the drift radius and time, trajectory is determined.
  - CDC resolution is too coarse to separate two B mesons vertices.
  - CDC track is extrapolated to VXD and vertices are determined in combination with VXD.
- Energy deposit on each wire is the key of PID function.







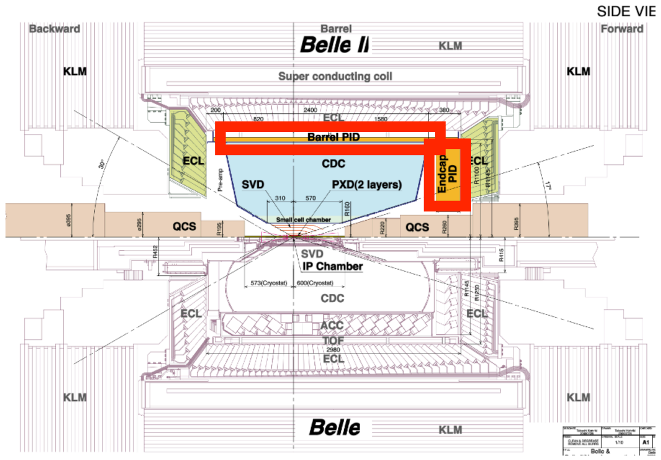
Particle identification in CDC



- CDC also contributes to identify the particle.
- Slight energy loss in gas (dE/dx) for a given momentum differs for each particle.
- dE/dx in this gas depends only on $\beta\gamma = p/m$.
- One of strongest tools for PID in $p < 1$ GeV region

Particle identification detectors (TOP, ARICH)

- Placed in barrel region (TOP) and forward end cap (ARICH).
- Designed to separate kaons and pions in 0.5 - 4.0 GeV.
- Measure velocity of particles and calculate mass using momentum provided by CDC.

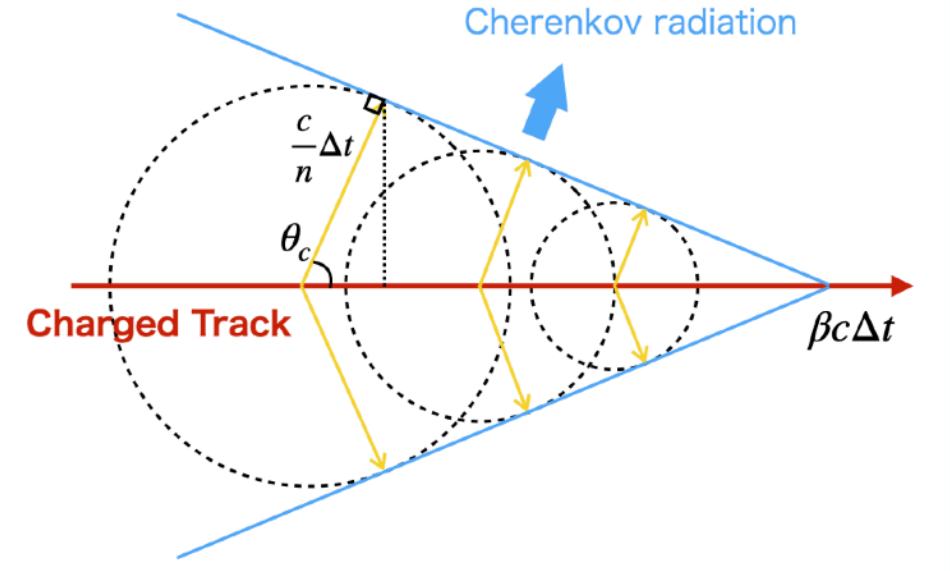


Time **O**f **P**ropagation / **A**erogel **R**ing **I**maging **CH**erenkov

$$\cos\theta_c = \frac{c/n}{\beta c} = \frac{1}{n\beta}$$

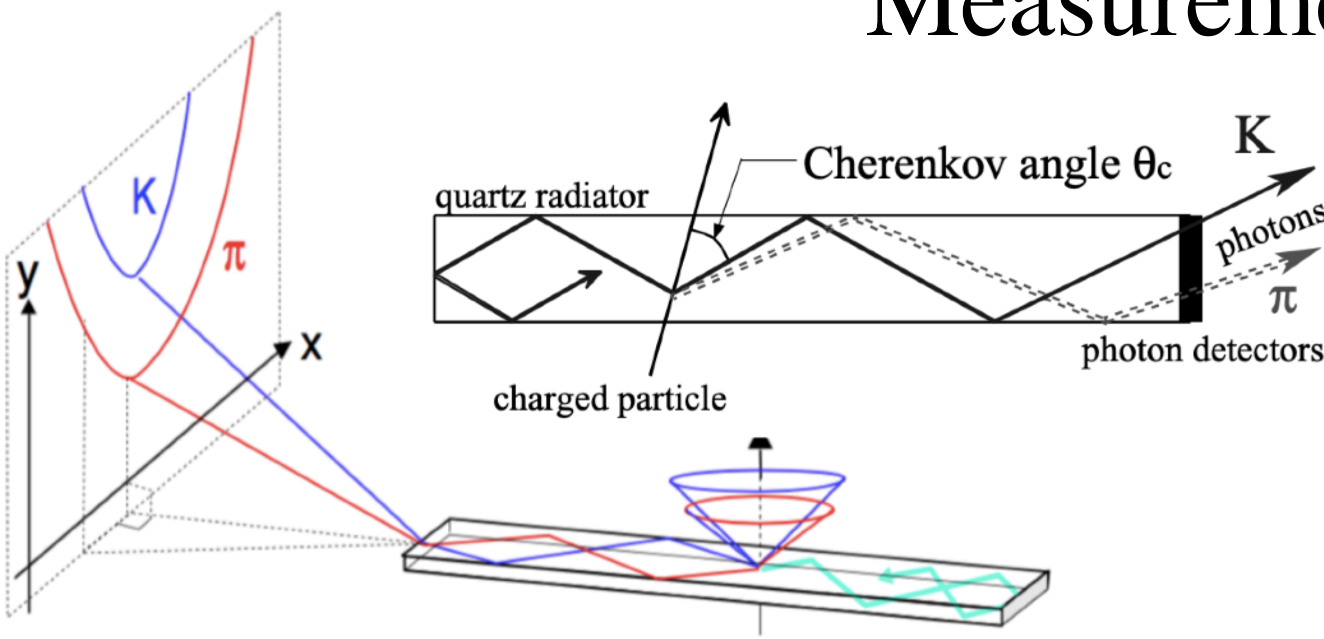
$$p_{\min} = \frac{m}{\sqrt{n^2\cos^2\theta_c - 1}} > \frac{m}{\sqrt{n^2 - 1}}$$

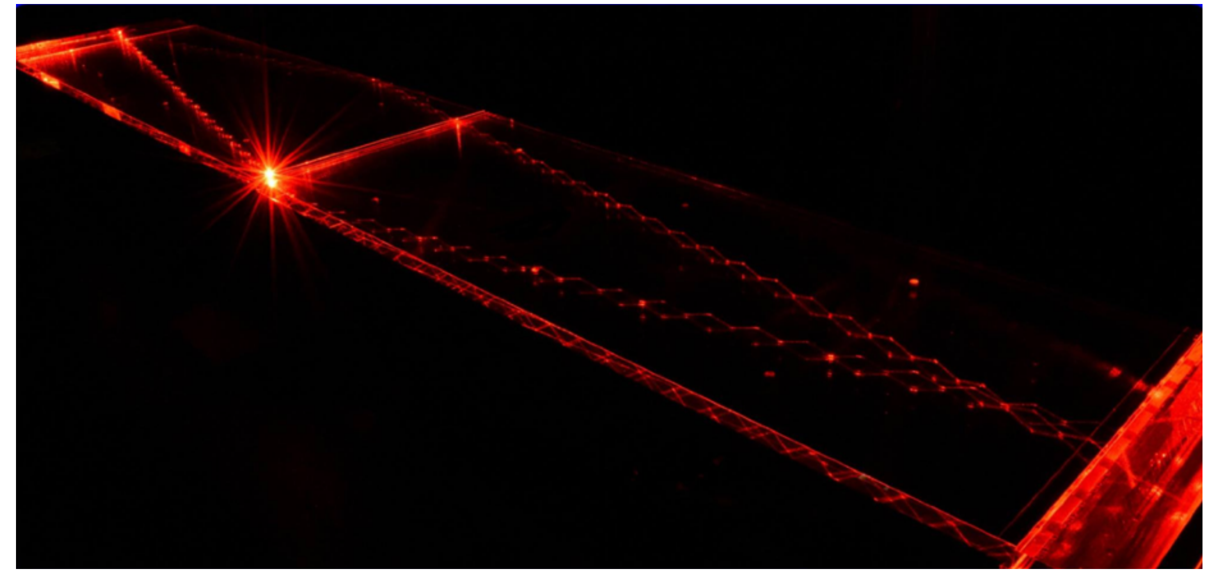
- Cherenkov radiation - “Light shock wave”
  - When a charged particle moves faster than the speed of light in a certain material ($v = \beta c > c/n$), a light shock wave called Cherenkov radiation is generated.
  - The angle of radiation depends on the velocity and refractive index.
  - Larger angle = faster velocity = lighter particle.

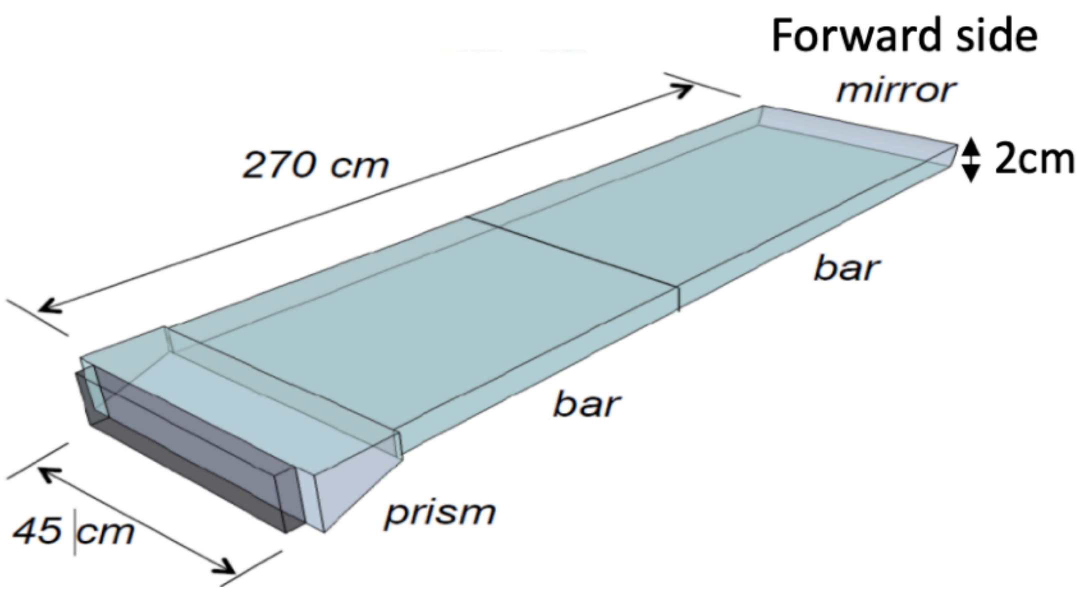


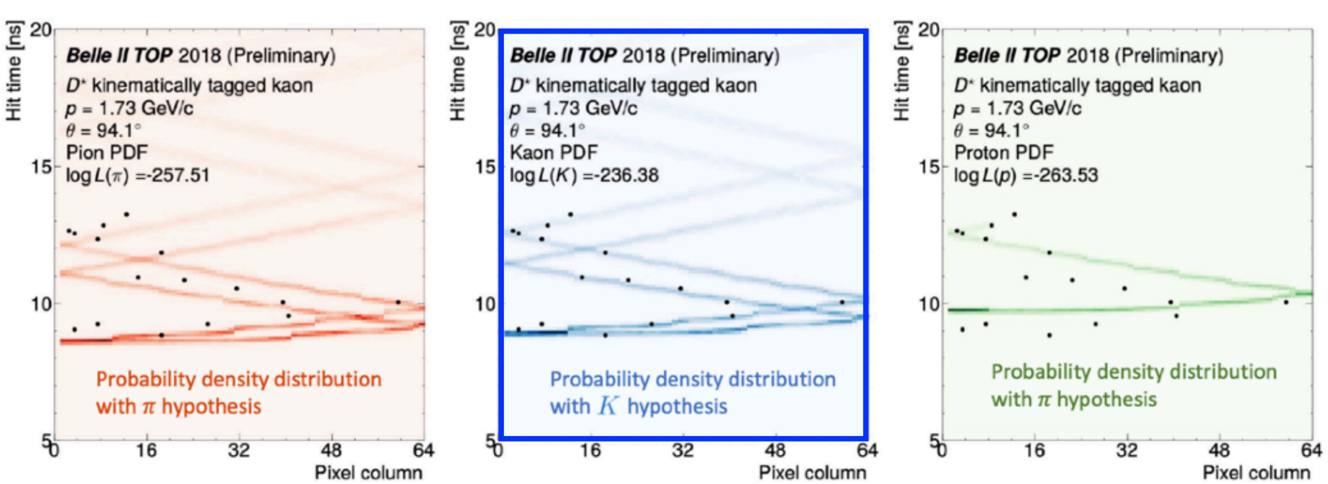
- Because momentum is known by CDC, mass can be calculated from the velocity.
  - TOP calculate the angle from propagation time.
  - ARICH calculate the angle from ring image.
  - The refractive indices are tuned for K/π separation.

Measurement of TOP



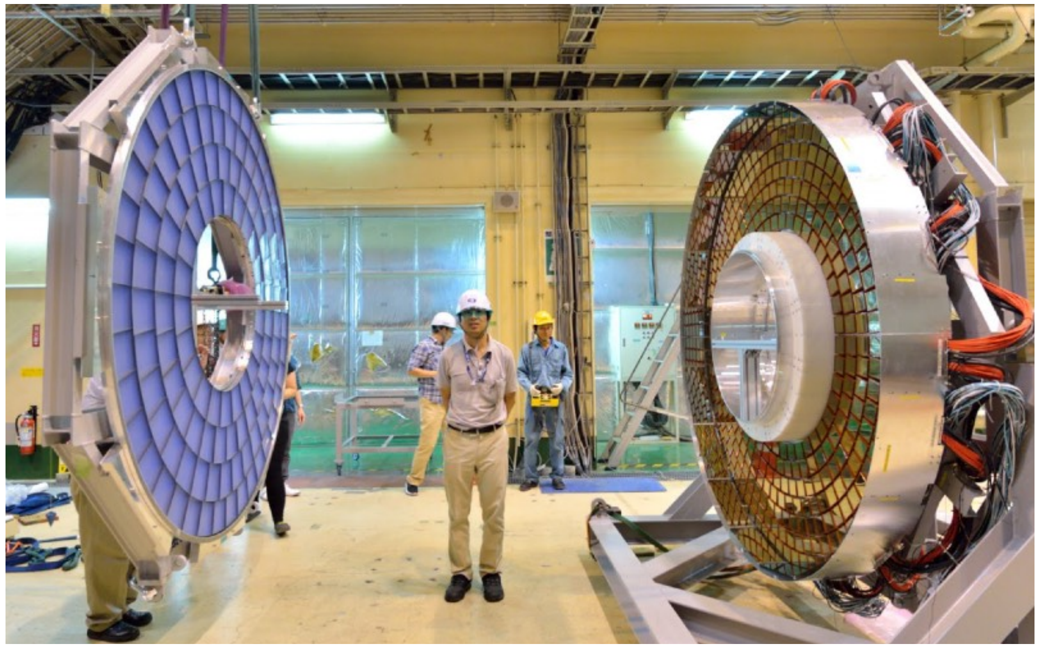


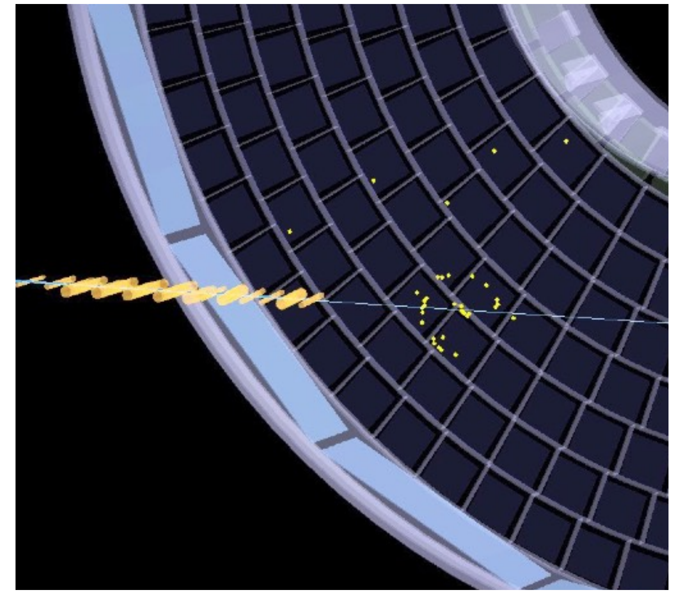


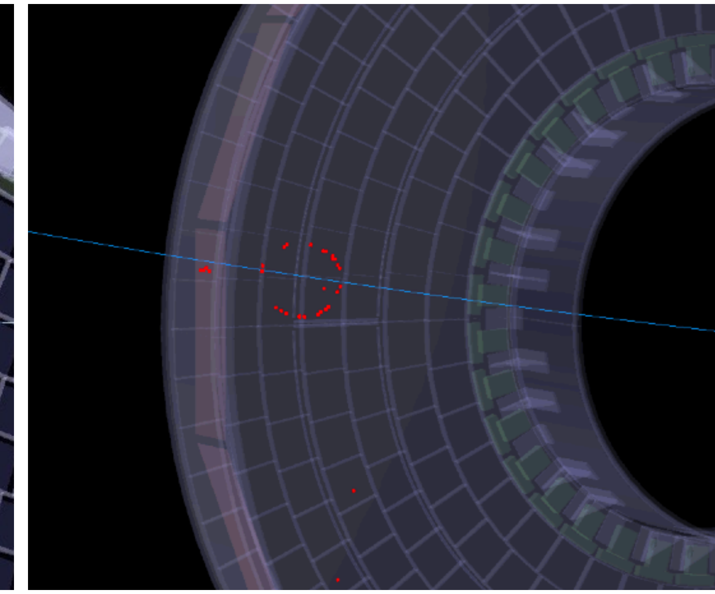


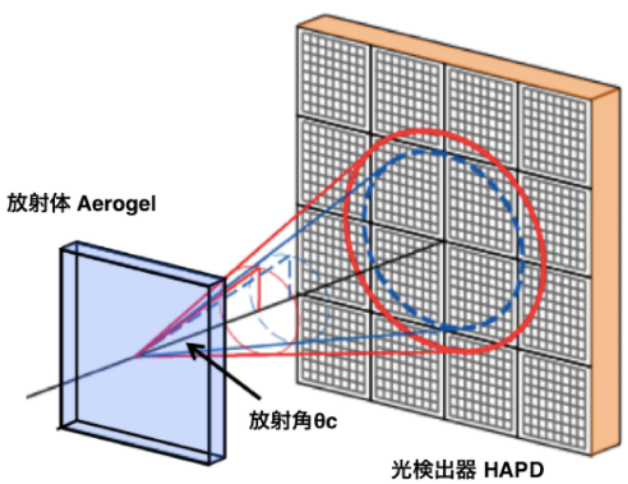
- Cherenkov light is generated in a quartz bar.
- Photons propagates to the sensor while reflecting inside the quartz bar.
- Photons arrive at sensors at different time and location.
- Fitting the hits by each hypothesis and most suitable one is taken.
  (In the example, the particle looks like a kaon.)

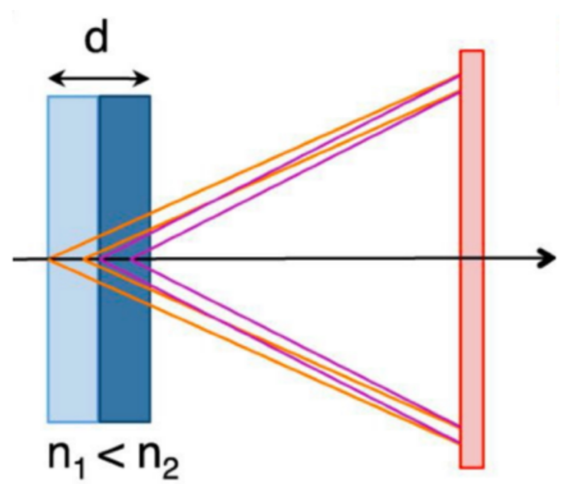
Measurement of ARICH









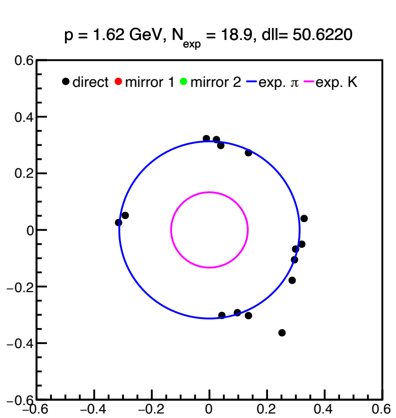


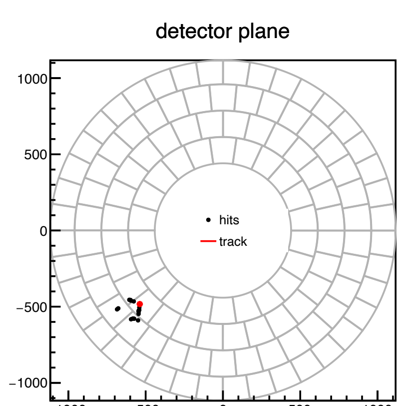
Dual-layer system

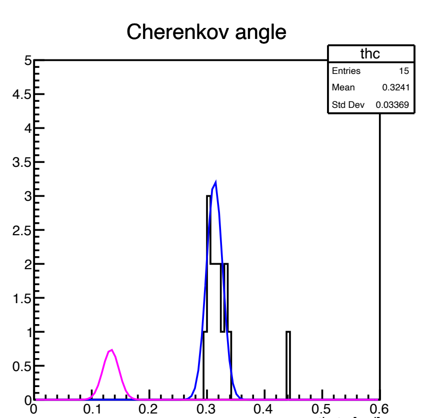
- Cherenkov light is generated in aerogel tiles and directly incident on the sensors.

- Dual layer of aerogel focuses light onto sensors: double the light without a blurry image.

- Fitting the angle distribution by each hypothesis and most suitable one is taken. (In the example, the particle looks like a pion.)



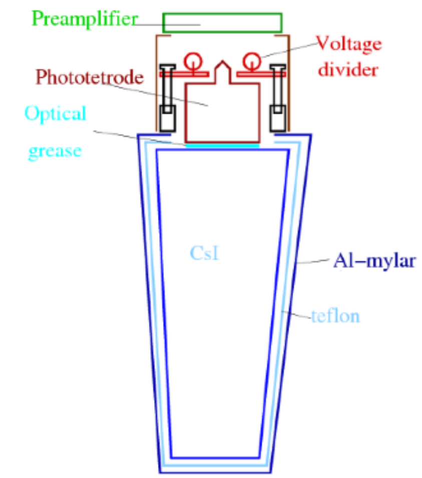


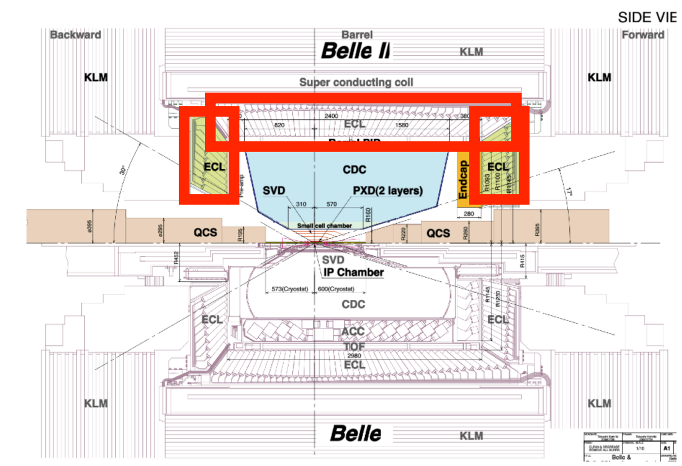


Electromagnetic Calorimeter (ECL)

- Outside of PID detectors, covering all directions.

- The most important role is photon detection. Trigger generation, e/K_L identification, and luminosity measurement.



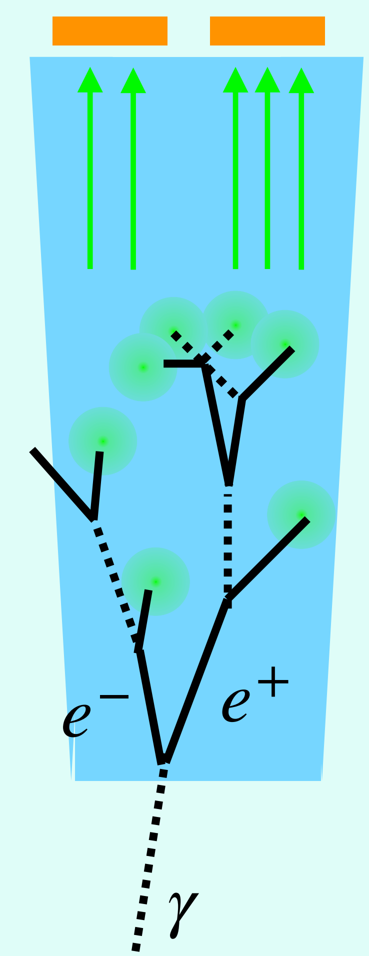


- Consists of CsI (TI) Cristal bars (scintillator) and photon sensors.
  - Incident particle generates an electromagnetic shower: loops of bremsstrahlung (γ production) and e^+e^- pair production.
  - Finally, all deposit energy is used for excitation and emitted as scintillation.
  - The energy deposit is well proportional to the particle energy. (The ratio depends on the type of particle.)

- The “shower shape” = width and depth varies depending on the incident particles.
  - Because of directions of initial bremsstrahlung photons.
  - In general, hadrons show wider showers.

- **Only ECL can detect photons.** ISR, FSR, and π^0 detection depend on ECL.
  - Required energy range is 20 MeV - 7 GeV.
  - To reconstruct π^0, energy resolution need to be < 5 MeV and position resolution need to be <10 mm.

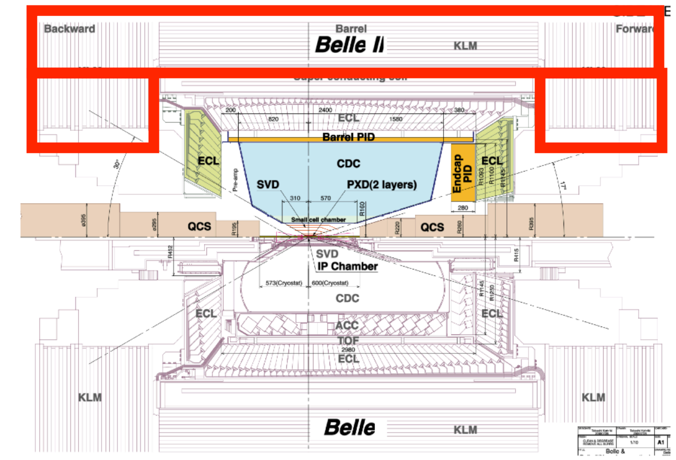
Loop of pair production and bremsstrahlung.



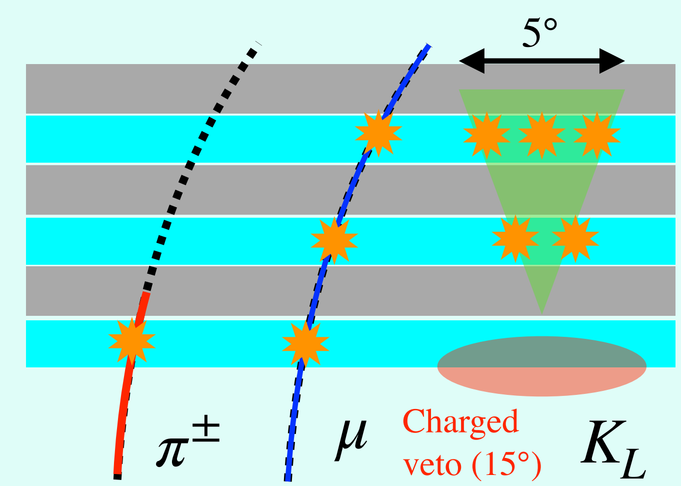
K_L^0 and μ (K-Long and Muon) detector

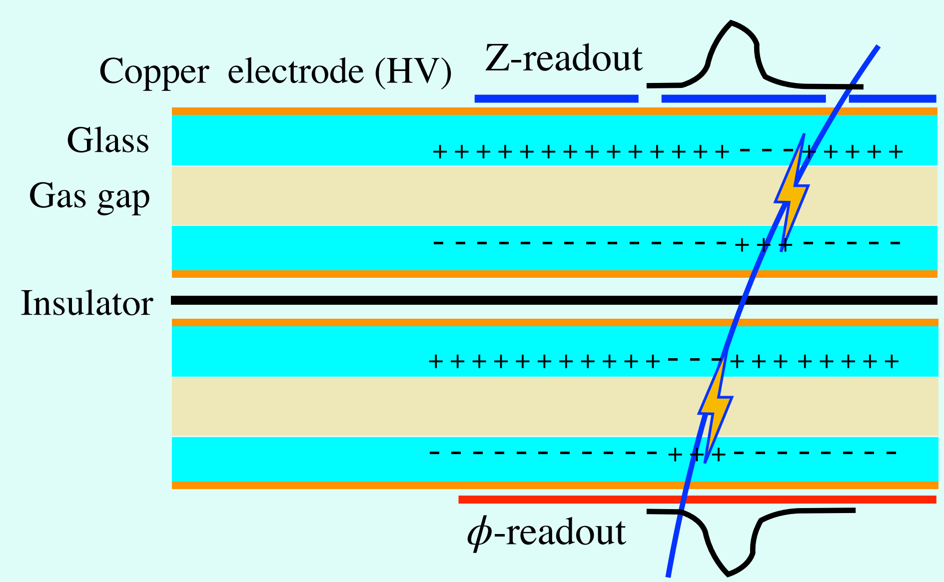
Koninklijke Luchtvaart Maatschappij

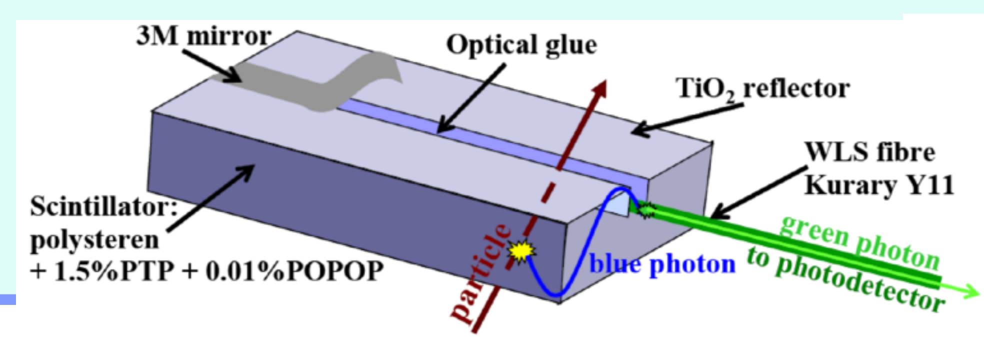
- Outermost layer of Belle II. For long-lived particle detection.
- Layered structure of steel plates and RPC / Scintillator.
- Detect secondary particles from a shower generated in a steel plate
- Originally built in Belle. Big, sturdy, and less expensive per volume.



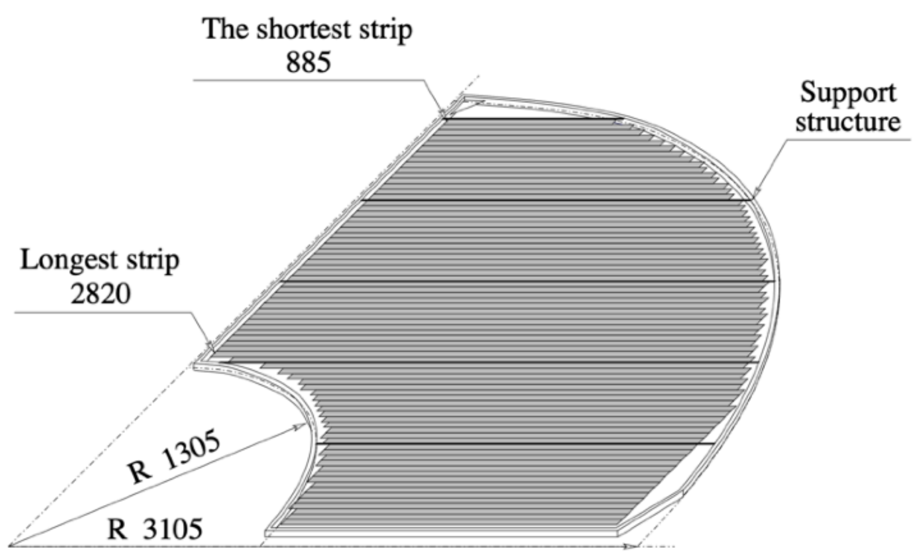
- Typically, only muons can penetrate steel plates and leave signals on detectors.
  - Muons can be easily distinguished, since other particles stop in inner layers.
  - Need track information from CDC.
- For K_L, secondary particles are used, since neutral particles give no signal.
  - Clustering hits in a specific region, vetoing charged tracks.
  - In combination with ECL clusters, identify K_L.
- The detector layers consist of RPC (barrel) and scintillators (end caps.)
  - In Belle era, all of them were RPCs.
  - Because of backgrounds, end caps were replaced by scintillators.



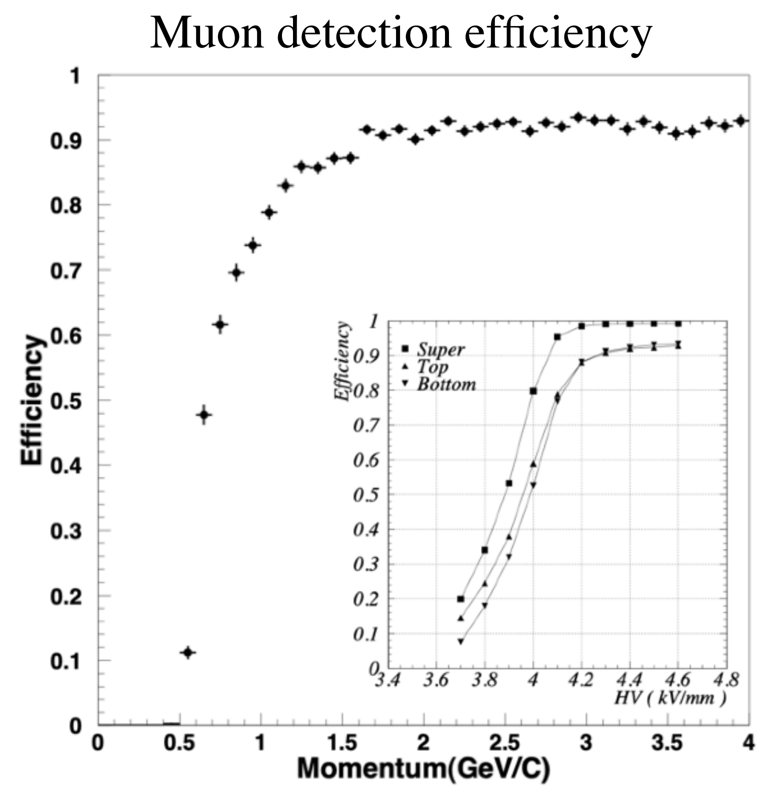




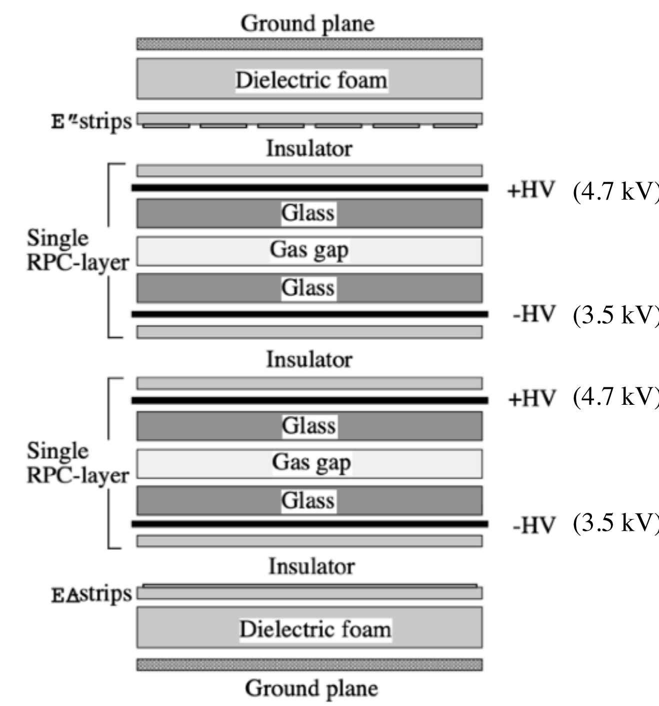
長寿命粒子検出 (KLM)



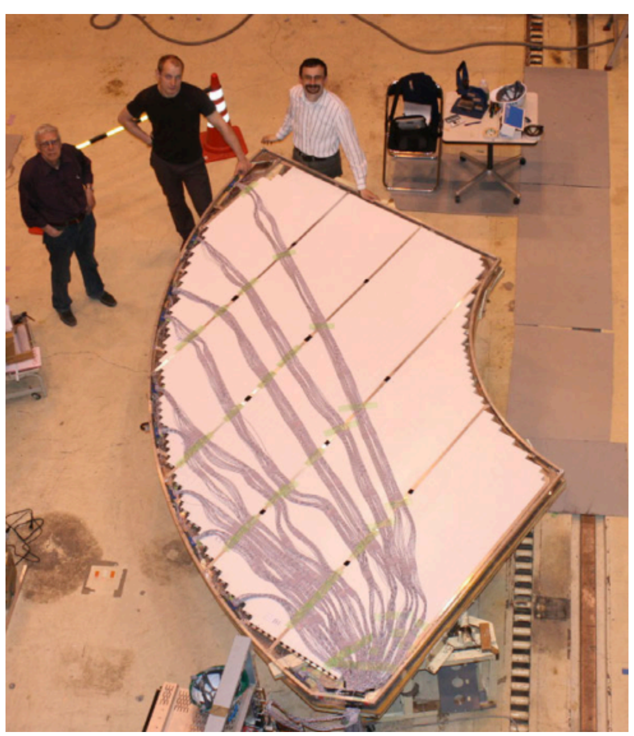
The shortest strip
885
Support
structure
Longest strip
2820
R 1305
R 3105

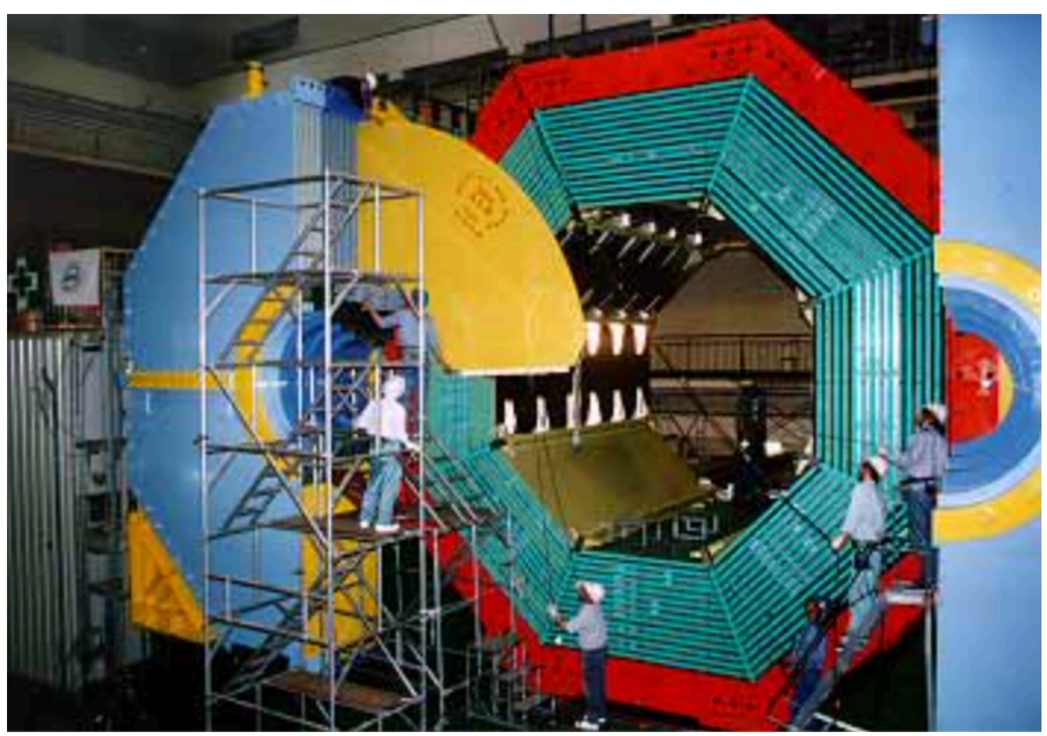


Muon detection efficiency
Efficiency
Momentum(GeV/C)
Super
Top
Bottom
HV (kV/mm)



Ground plane
Dielectric foam
Insulator
+HV (4.7 kV)
Glass
Single
RPC-layer
Gas gap
Glass
-HV (3.5 kV)
Insulator
+HV (4.7 kV)
Glass
Single
RPC-layer
Gas gap
Glass
-HV (3.5 kV)
Insulator
Dielectric foam
Ground plane

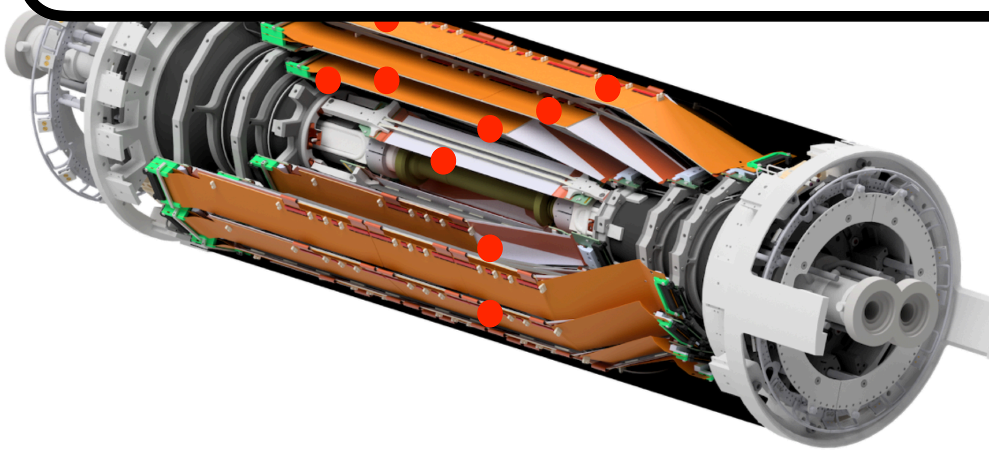


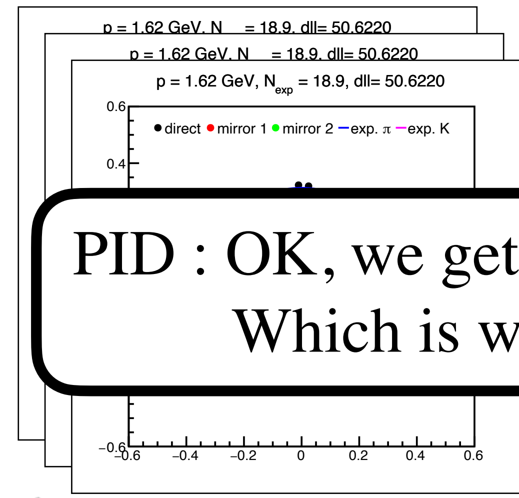


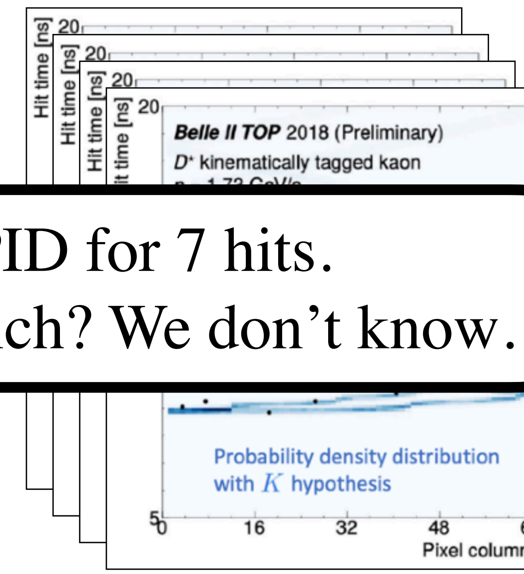
Data Acquisition and Trigger (DAQ & TRG)

- **Integrate information from all detectors and build an "event".**
- Select valuable events excluding "useless" (= well known and too many) events such as Bhabha.

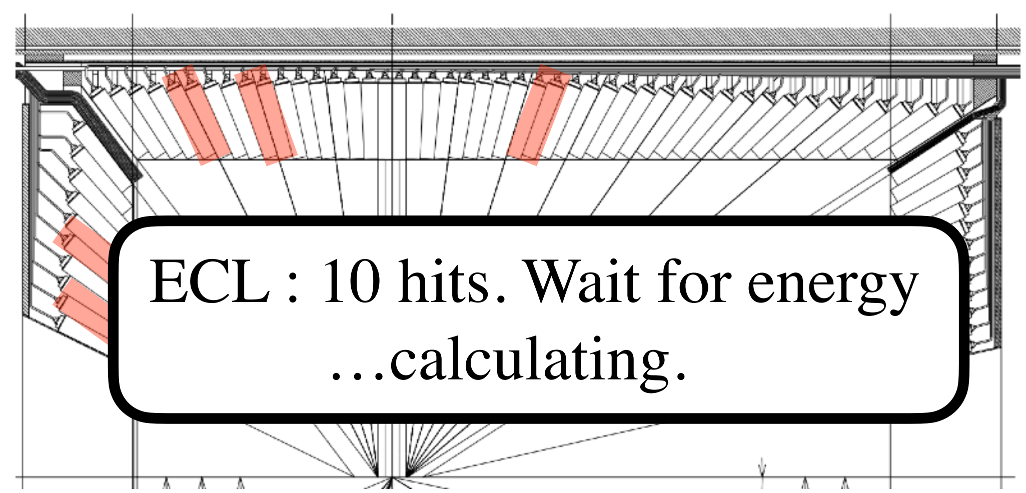
VXD: Wait. Too many raw data…
OK, 9 hits. The coordinates are…



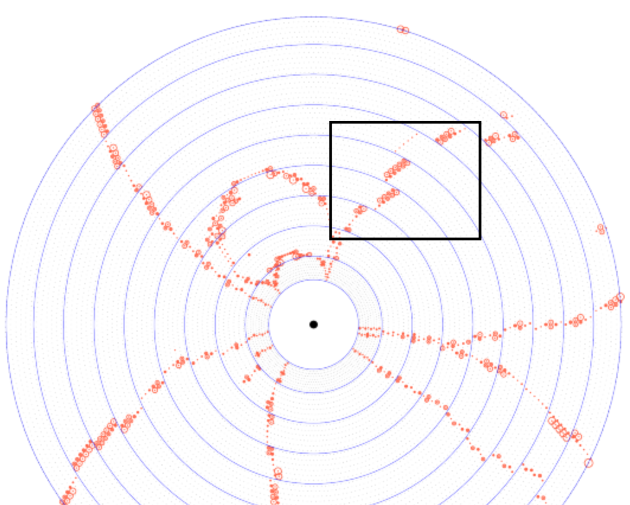




PID : OK, we get PID for 7 hits.
Which is which? We don't know…



ECL : 10 hits. Wait for energy
…calculating.



CDC : Here is the hit map.
There seems to be 8 tracks.

KLM

2 muon-like hits.
Give me track information.
Then, I will check other hits…

Data Acquisition and Trigger (DAQ & TRG)

- Integrating information from all detectors and build an "event".
- **Select valuable events excluding "useless" (= well known and too many) events.**

- The rate and data size of each "event" is a big issue.
  - [PXD (1 MB) + Others (100 kB)] × 30 kHz = 33 GB/sec (raw data)
  - For reference; USB 3.2 Gen 2 = 10 Gbps. = 1.25 GB/sec. HDD writing < 200 MB/sec.

(1) Event selection is essential **(2) Selection speed must be 30 kHz (= 33 μsec/event)**

- The rate of important physics events are much less than others (Bhabha, $\gamma\gamma$, etc…)

Cross sections and event rates at the target luminosity ($8 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
Hadron production from continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\mathrm{lab}} \geq 17°$)	44	350 $^{(a)}$
$\gamma\gamma$ ($\theta_{\mathrm{lab}} \geq 17°$)	2.4	19 $^{(a)}$
2γ processes ($\theta_{\mathrm{lab}} \geq 17°$, $p_t \geq 0.1\,\mathrm{GeV}/c$)	~ 80	~ 15000
Total	~ 130	~ 20000

$^{(a)}$ rate is pre-scaled by a factor of 1/100

Structure of DAQ & TRG - Three layers

- **No dead time is allowed.** However, maximum rate can exceed 30 kHz.
- Necessary to “wait” for processing at each stage.
  - Collision information from the accelerator, synchronization of signals among detectors, L1 trigger generation…

① **Level 1 trigger**

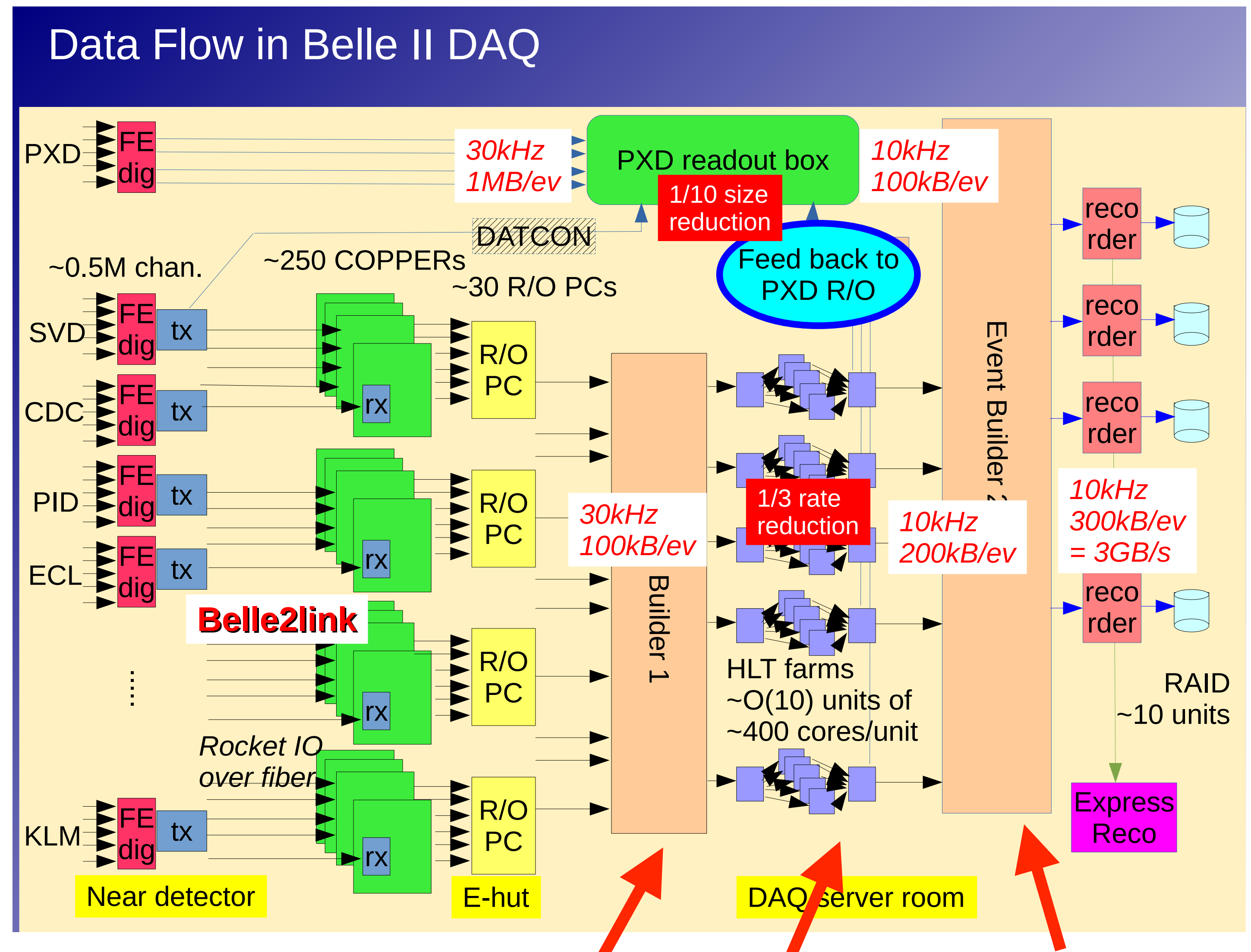
FPGA based trigger ~5 μsec response.

② **High Level Trigger (HLT)**

CPU based. Event building.
Check if “physical” events or not.
Event-by-Event parallel processing.

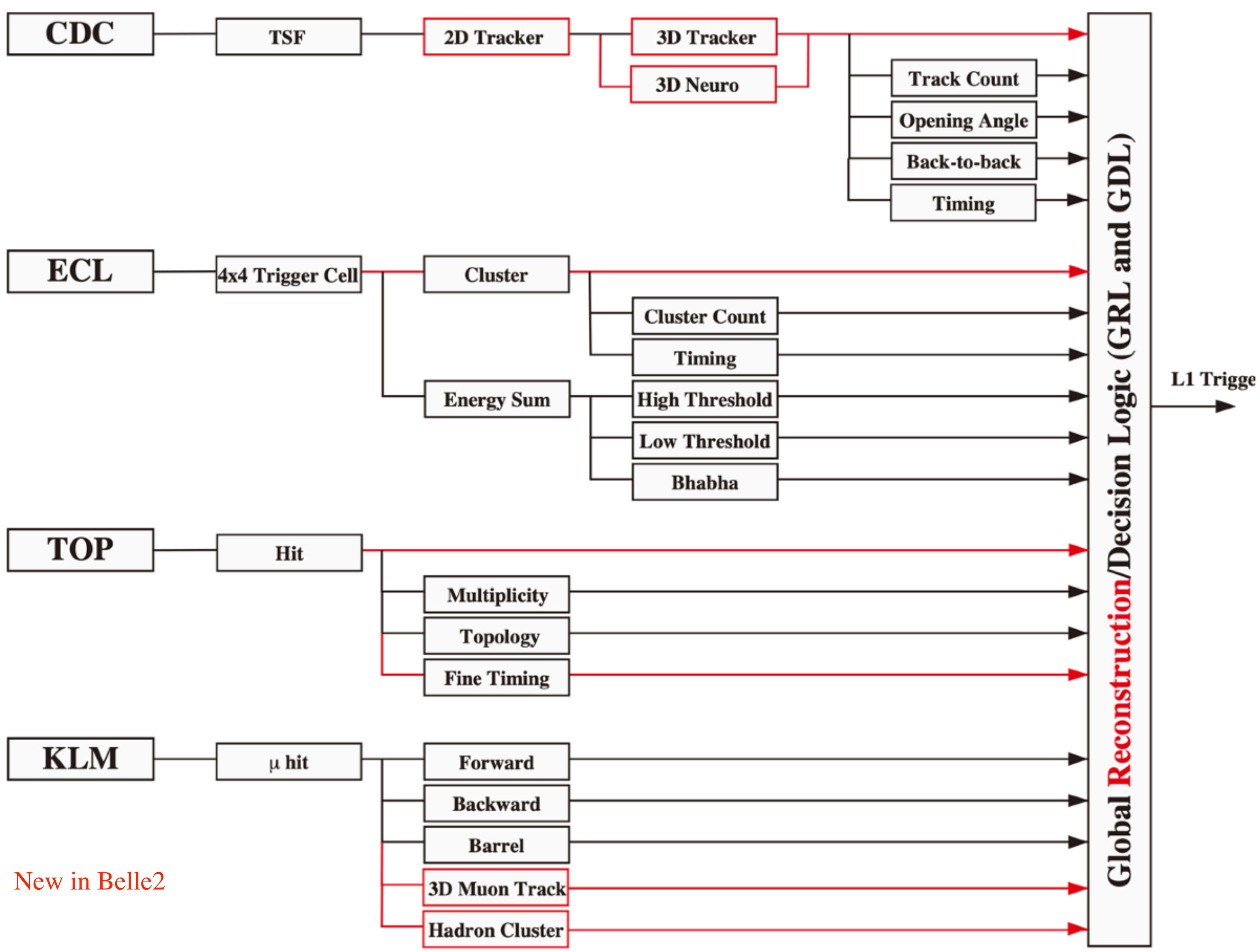
③ **Event builder**

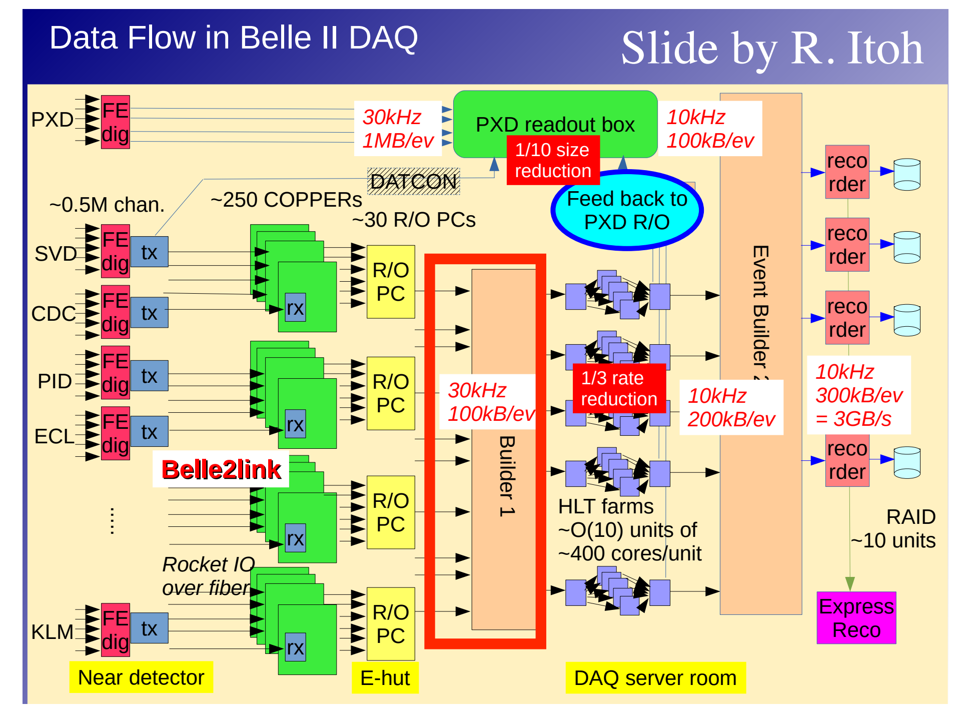
Integrate PXD information.
Event building is finalized.



① **L1 trigger** ② **HLT** ③ **Event builder**

Level 1 Trigger - selection by logic circuits





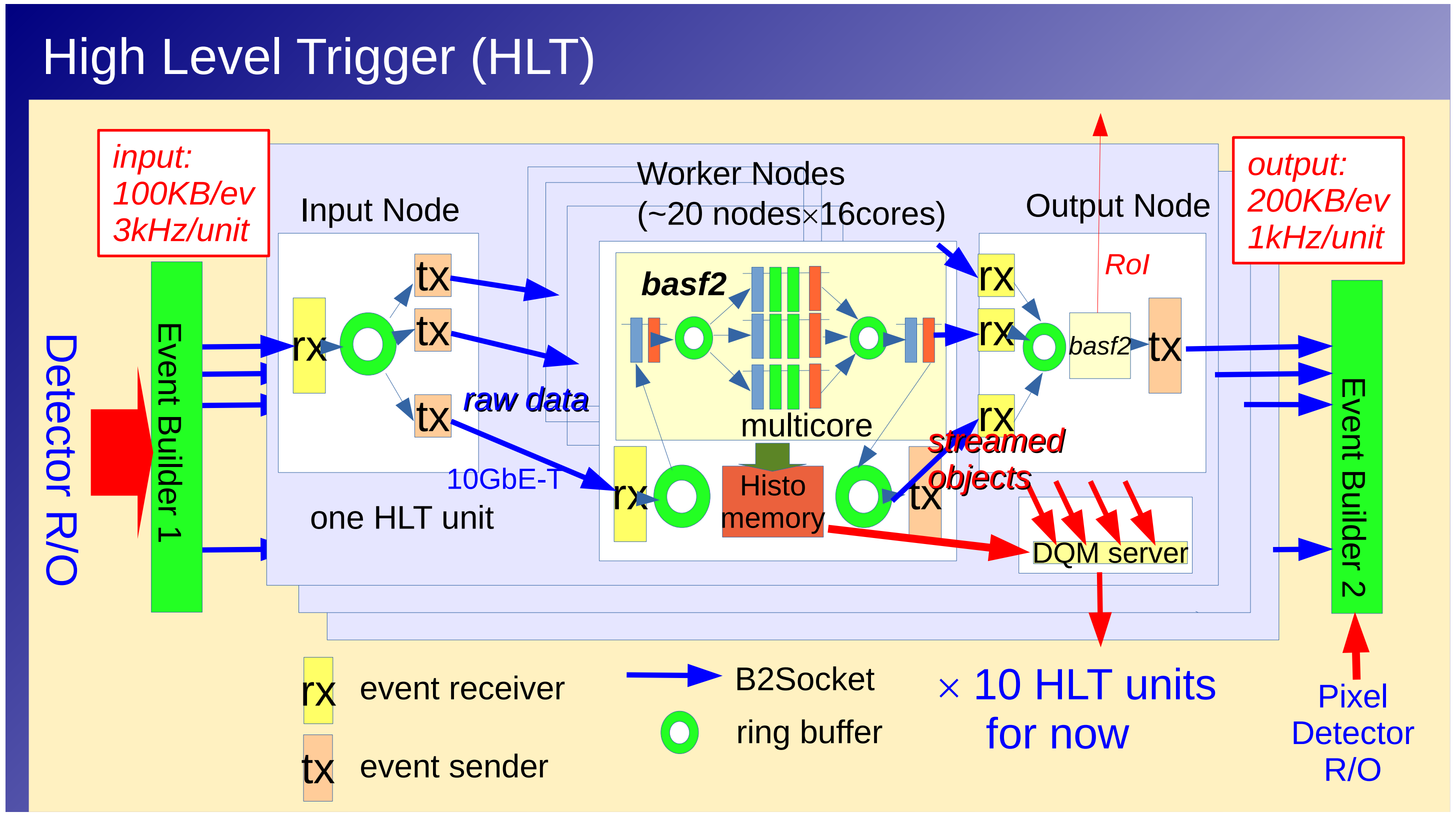
① L1 trigger

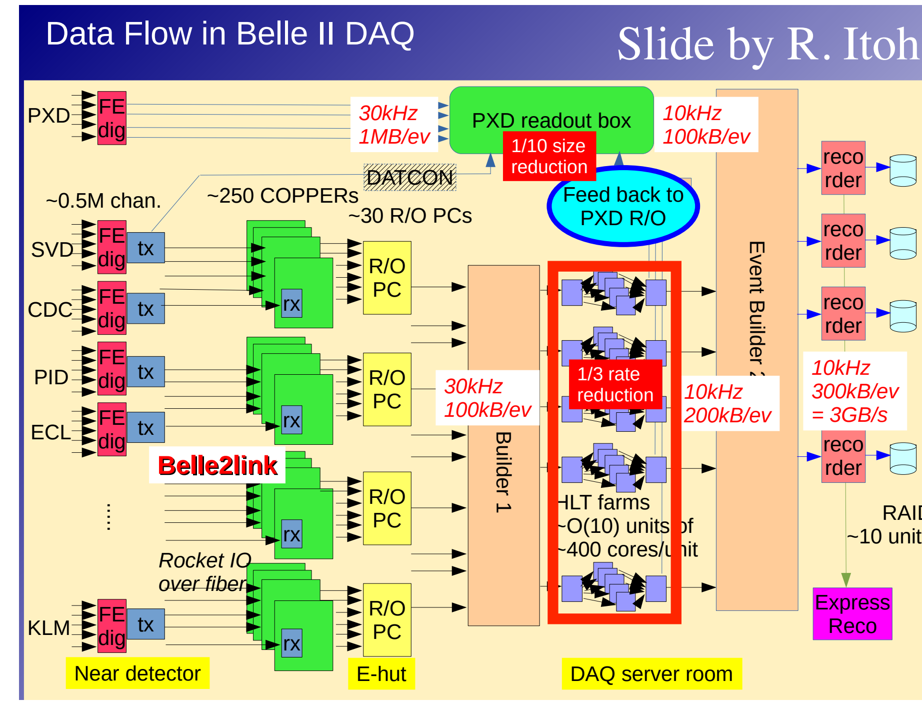
- Input the number of tracks, angles, energy, and timing to Global Decision Logic (GDL).
- Only when one of criteria is fulfilled, trigger is generated.

- **Physics (PS=1)**
  - **ffo : 2D track > 1 & opening angle > 90° & !Bhabha**
  - **fff : 2D track > 2**
  - **hie : energy > 1 GeV & !Bhabha**
  - **c4 : isolated cluster > 3 & !Bhabha**
- **Calibrations (PS>1)**
  - **ff(PS=20), c2(PS=150), bhabha(PS=1), 3D bhabha(PS=1), many others**
- **MC background overlay**
  - **Pseudo random(1Hz), revolution(1Hz)**
  - **Delayed bhabha logic had a bug (PS=0)**
- **Triggers for the dark sector**
  - **c1 & hie/lum, c3 & hie/lum, n1 & hie/lum, n3 & hie/lum**
- **Timing decision**
  - **ECL timing only**

Slide by A. Ishikawa

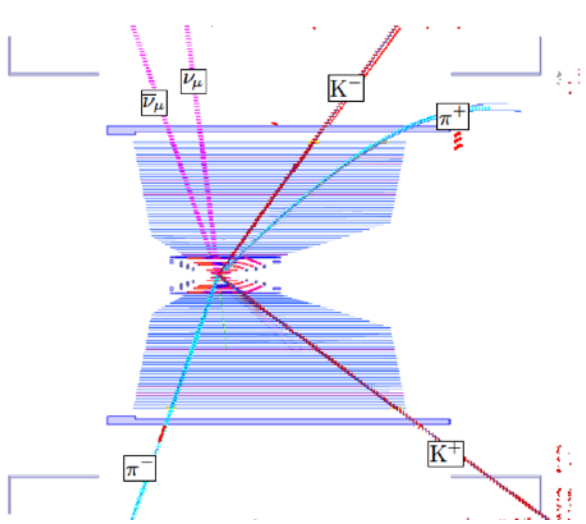
High Level Trigger - Event building

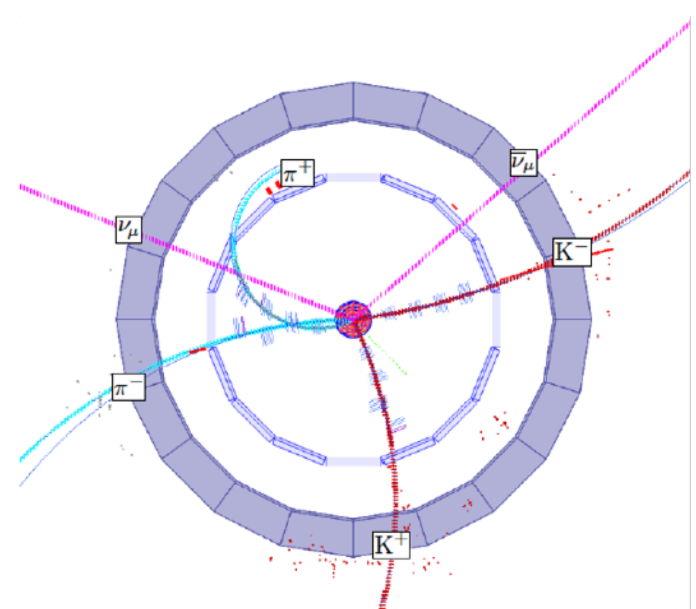


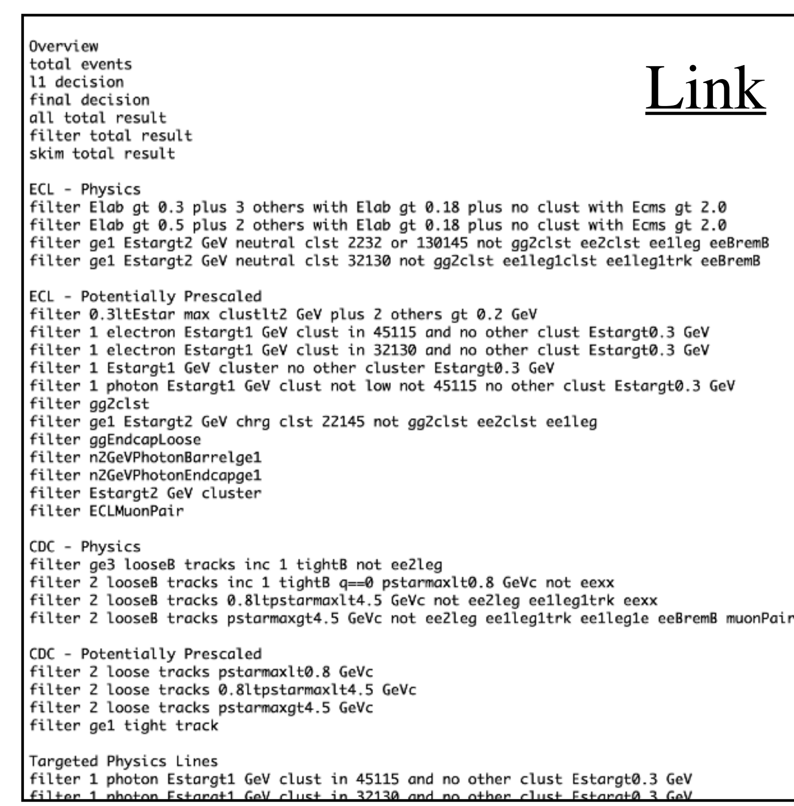


② High level trigger

- Event-by-Event reconstruction
- Track quality and PID information are connected to each track.
- There is a list of target events and corresponding trigger conditions
- "Event display" is completed here.






Overview
total events
l1 decision
final decision
all total result
filter total result
skim total result

ECL - Physics
filter Elab gt 0.3 plus 3 others with Elab gt 0.18 plus no clust with Ecms gt 2.0
filter Elab gt 0.5 plus 2 others with Elab gt 0.18 plus no clust with Ecms gt 2.0
filter ge1 Estargt2 GeV neutral clst 2232 or 130145 not gg2clst ee2clst ee1leg eeBremB
filter ge1 Estargt2 GeV neutral clst 32130 not gg2clst ee1leg1clst ee1leg1trk eeBremB

ECL - Potentially Prescaled
filter 0.3ltEstar max clustlt2 GeV plus 2 others gt 0.2 GeV
filter 1 electron Estargt1 GeV clust in 45115 and no other clust Estargt0.3 GeV
filter 1 electron Estargt1 GeV clust in 32130 and no other clust Estargt0.3 GeV
filter 1 Estargt1 GeV cluster no other cluster Estargt0.3 GeV
filter 1 photon Estargt1 GeV clust not low not 45115 no other clust Estargt0.3 GeV
filter gg2clst
filter ge1 Estargt2 GeV chrg clst 22145 not gg2clst ee2clst ee1leg
filter ggEndcapLoose
filter n2GeVPhotonBarrelge1
filter n2GeVPhotonEndcapge1
filter Estargt2 GeV cluster
filter ECLMuonPair

CDC - Physics
filter ge3 looseB tracks inc 1 tightB not ee2leg
filter 2 looseB tracks inc 1 tightB q==0 pstarmaxlt0.8 GeVc not eexx
filter 2 looseB tracks 0.8ltpstarmaxlt4.5 GeVc not ee2leg ee1leg1trk eexx
filter 2 looseB tracks pstarmaxgt4.5 GeVc not ee2leg ee1leg1trk ee1leg1e eeBremB muonPairVB

CDC - Potentially Prescaled
filter 2 loose tracks pstarmaxlt0.8 GeVc
filter 2 loose tracks 0.8ltpstarmaxlt4.5 GeVc
filter 2 loose tracks pstarmaxgt4.5 GeVc
filter ge1 tight track

Targeted Physics Lines
filter 1 photon Estargt1 GeV clust in 45115 and no other clust Estargt0.3 GeV
filter 1 photon Estargt1 GeV clust in 32130 and no other clust Estargt0.3 GeV

Link