Searches for LLP's at Belle II

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Searching for long lived particles at LHC:
4th Workshop of the LHC LLP Community

Amsterdam Science Park
(remote connection)

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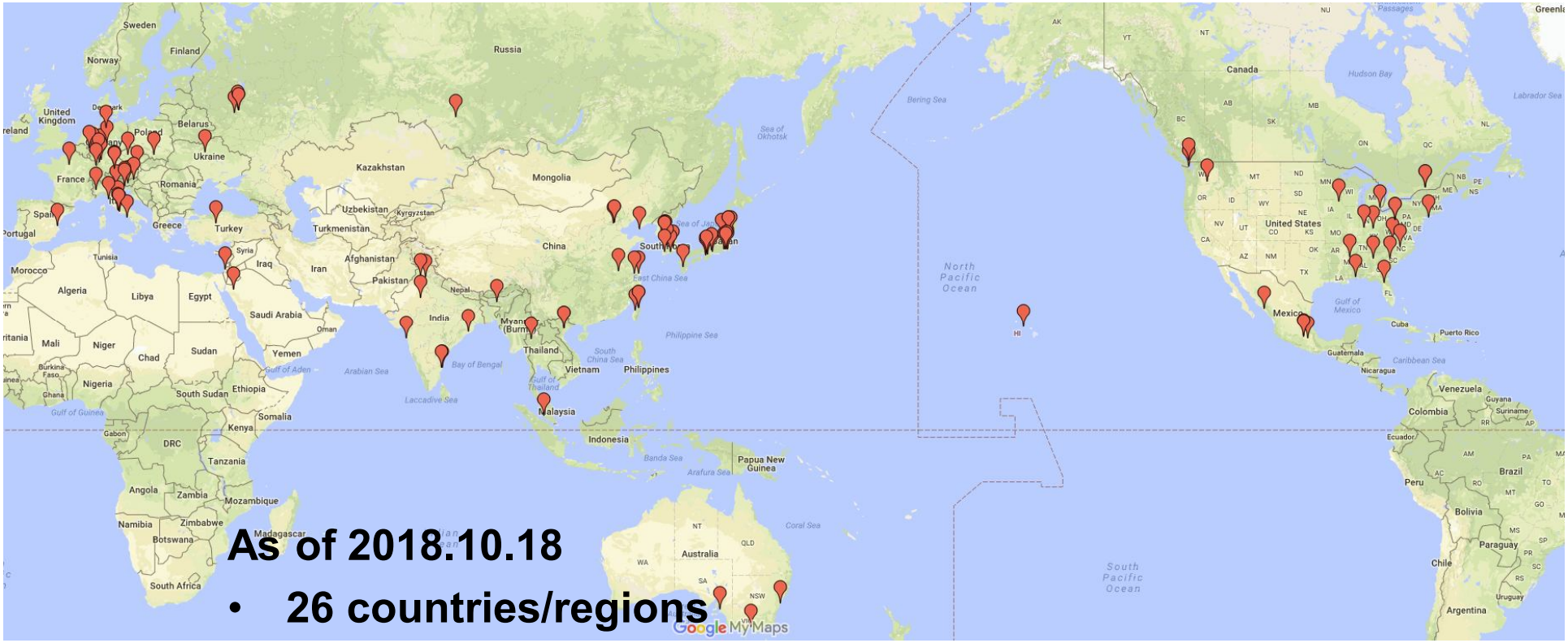
SUPERKEKB
BELLE II

Upgrade from KEK/Belle to SuperKEKB/Belle II

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

Belle II Collaboration



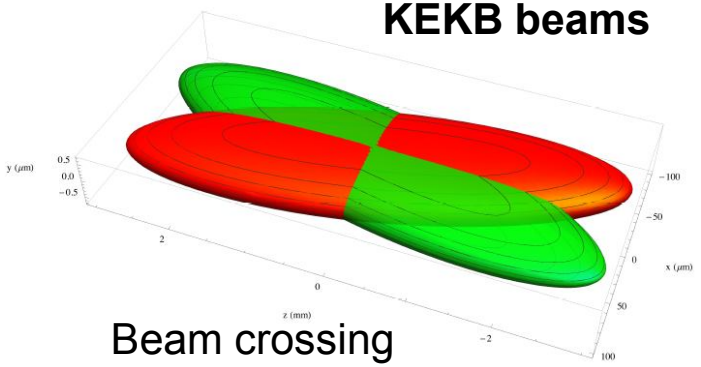
As of 2018.10.18

- **26 countries/regions**
- **113 institutions**
- **~ 850 colleagues**
- **America 17%, Asia 24%, Europe 37%, Japan 17%, Russia 5%**

SuperKEKB: Nano Beam Collision

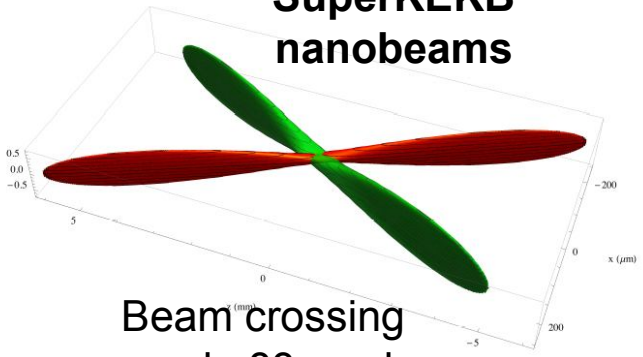
- Extremely small β_y^* at IP
- Increase beam currents $I_{e\pm}$
- Increase ξ_y

KEKB beams



Beam crossing angle 22mrad

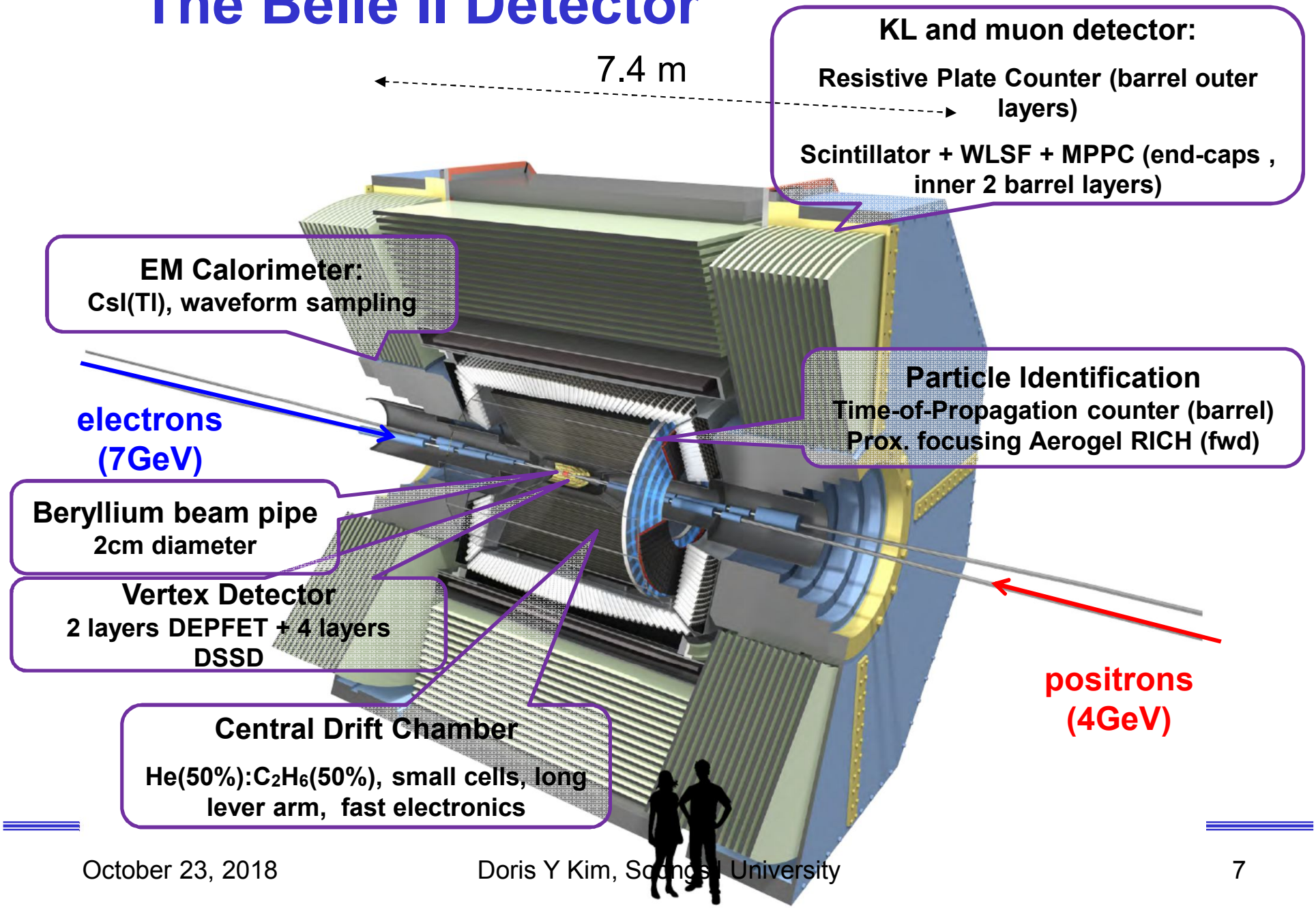
SuperKEKB nanobeams



Beam crossing angle 83mrad

$$L = \frac{\gamma_{e\pm}}{2 e r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\cdot\xi_{y,e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

The Belle II Detector

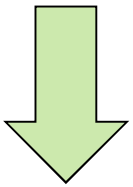


Belle II Experiment in Nutshell

- e^+e^- collisions at Y(4S), and other energies.
  - Y(4S) decays into B B meson pairs
- High tagging efficiency of B particles.
- Direct detection of neutrals such as γ, π^0, K_L.
- A hermitic detector:
  - Detection of neutrinos or invisibles as missing energy/momentum.

Beam Commissioning Phases

- BEAST Phase I in 2016.
  - Simple background measuring detector (diodes, diamonds TPCs, crystals)
  - Only single beam circulated for LER/HER.
- BEAST Phase II April 26 – July 17 2018.
  - 1/8 of vertex detector
  - Full Belle II outer detector,
  - Physics data collected ~ 0.5/fb
  - Flexible hardware trigger & pass-through software trigger
- Belle II Phase III at the end of JFY 2018.
  - The most precise silicon inner detector included. (layers 1, 3-6)
  - Physics mode with the full Belle II detector.

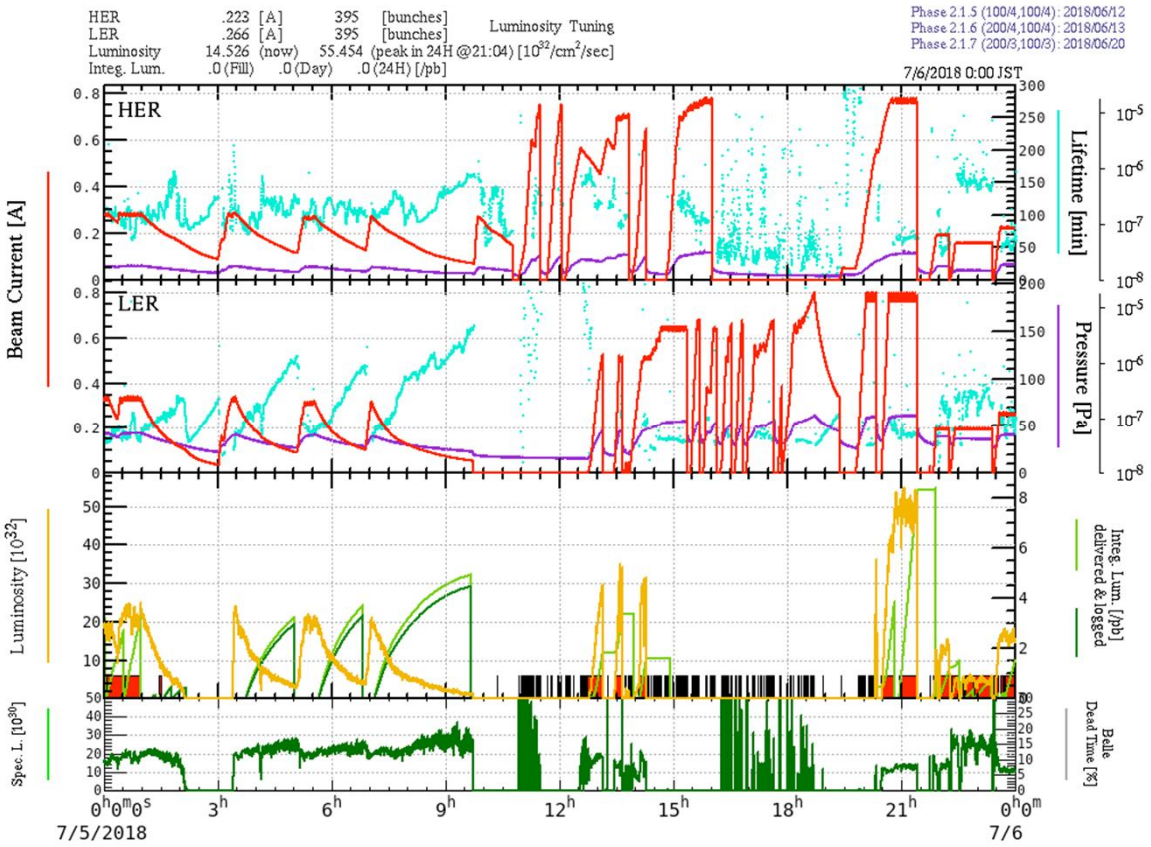


PHASE II STATUS

The BEAST Vertex Detector

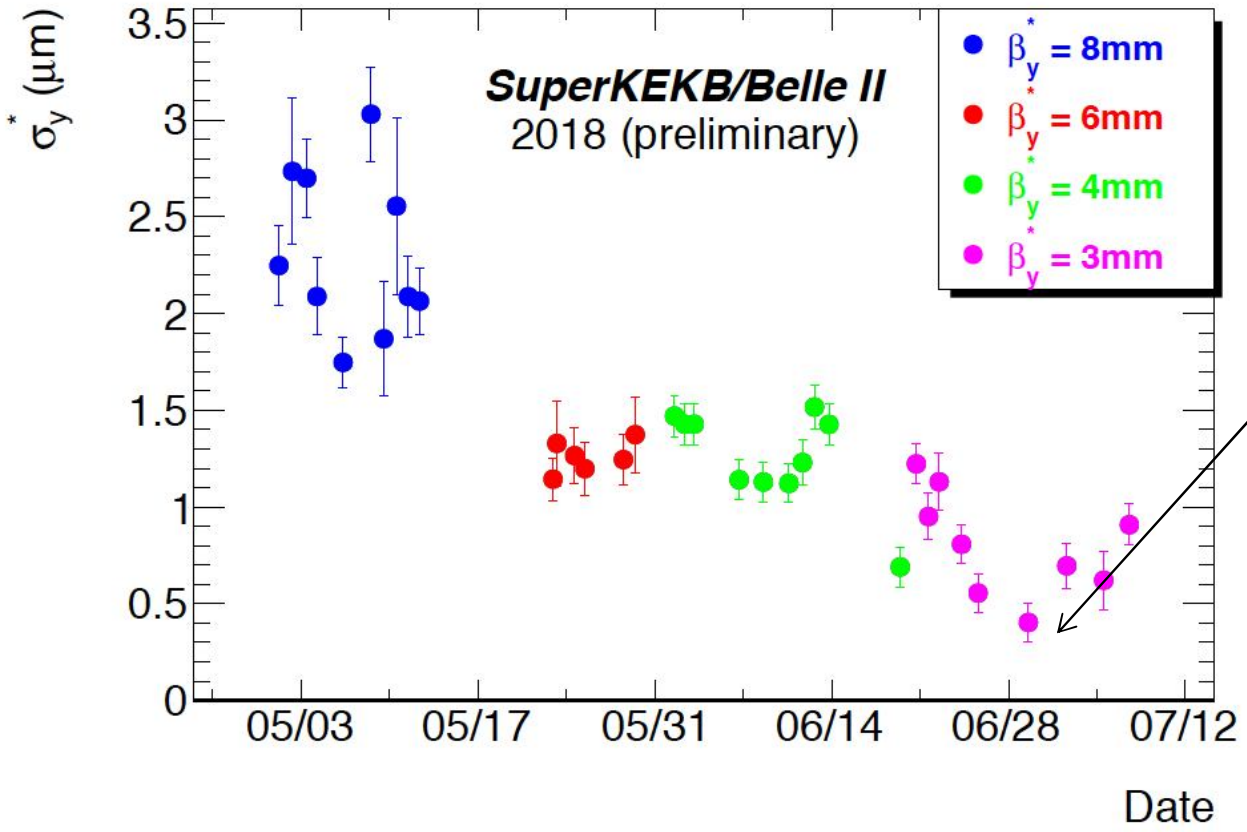
SuperKEKB R&D: July 2018

$$L_{peak} = 5.5 \times 10^{33} / cm^2 / \text{sec}$$



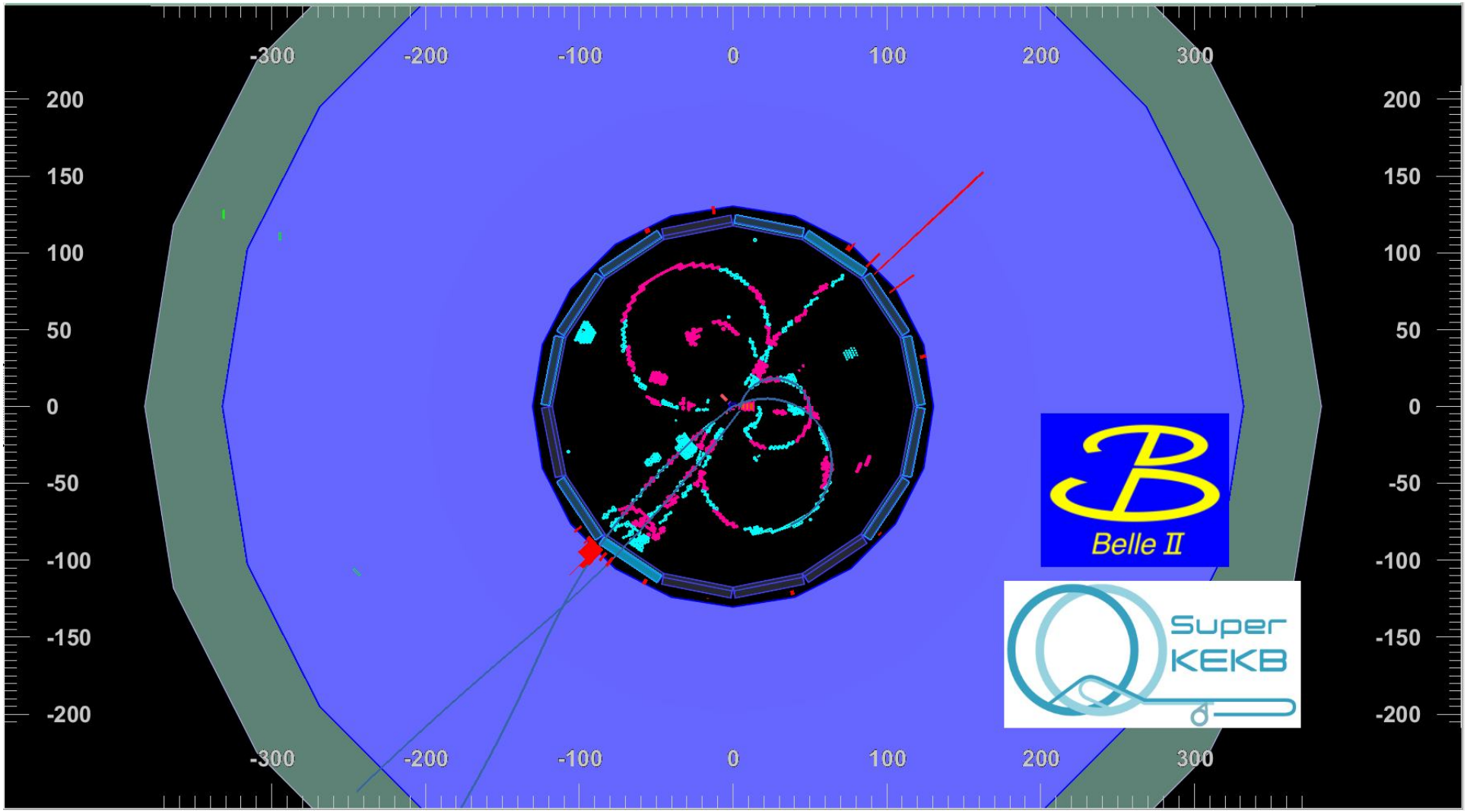
- The two beams were squeezed with the superconducting final focus down to β_y^*=3mm.
- However, instantaneous luminosity suffered as β_y^* got squeezed due to beam blowup at high current.
- Expected to reach the design luminosity in 2022.
- The physics data was taken mostly during the night when beam R&D was not done.
- **Collected ~ 0.5/fb**.

Progress on Beam Size

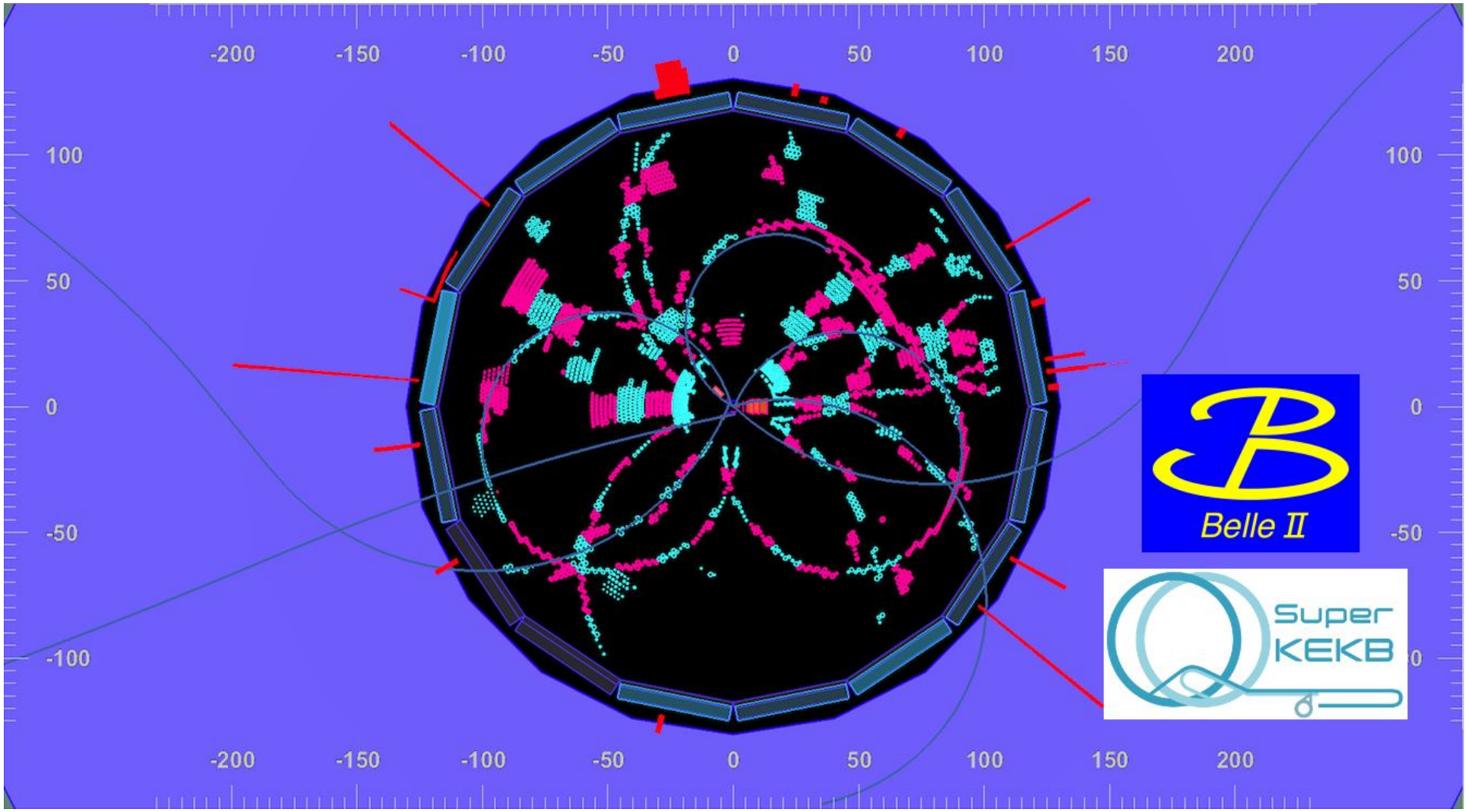


- For Phase 3, we will start with β_y^* = 3mm.
- The record is 400 nm at beam currents of only ~15mA.
- The vertical height of the nano beams was measured using vertical luminosity scanning of the diamond detectors.

Candidate: e^+e^- to $q\,\bar{q}$

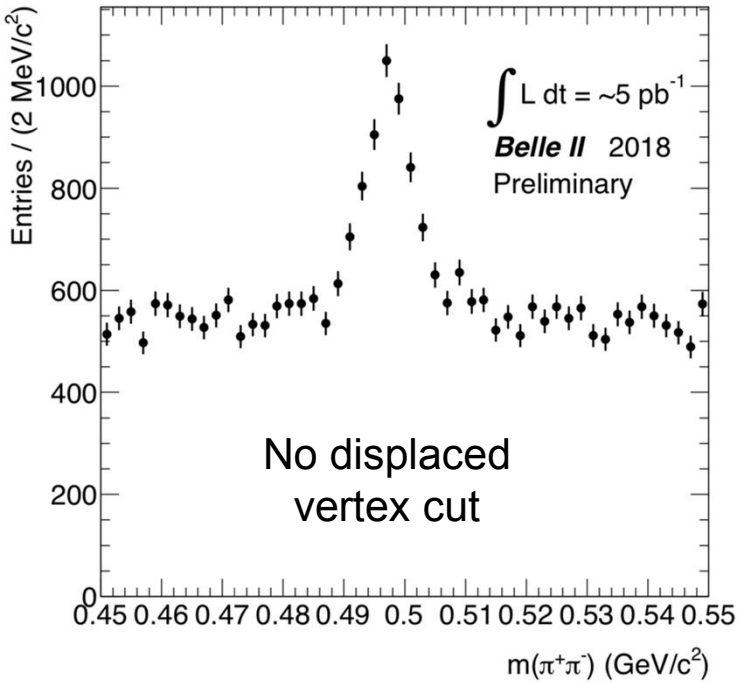


Candidate: e^+e^- to $B\,\overline{B}$

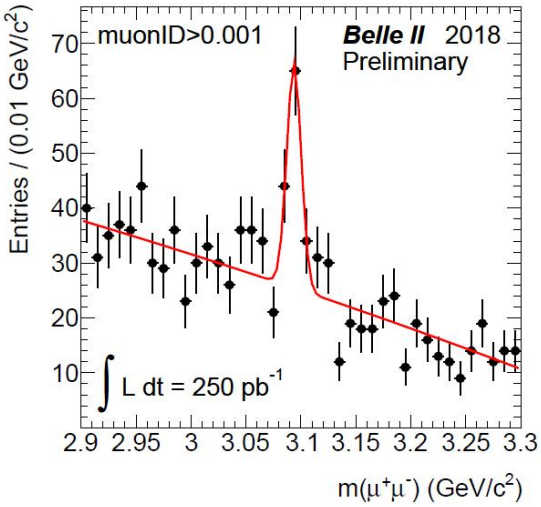


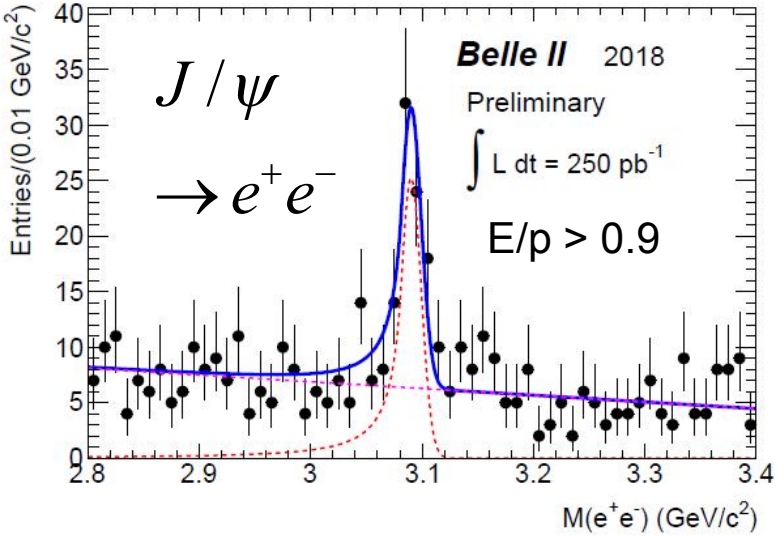
Phase II Particles as Charged Tracks

$K_s \to \pi^+\pi^-$



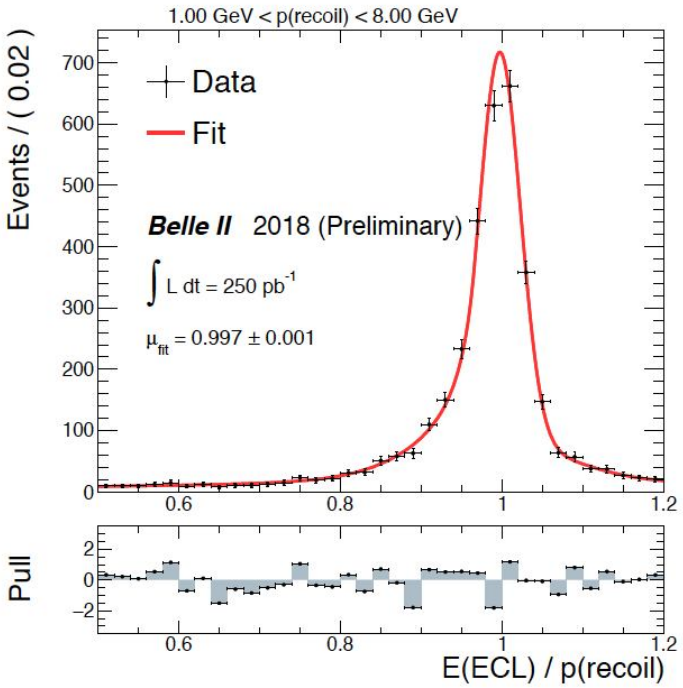
$J/\psi \to \mu^+\mu^-$

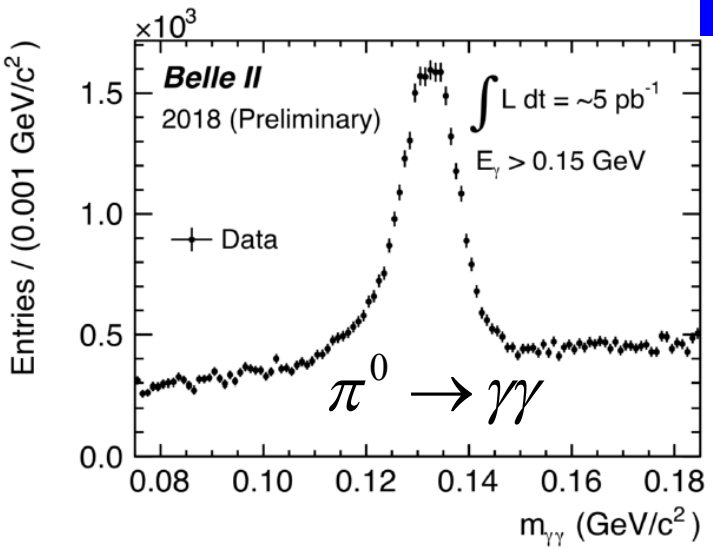


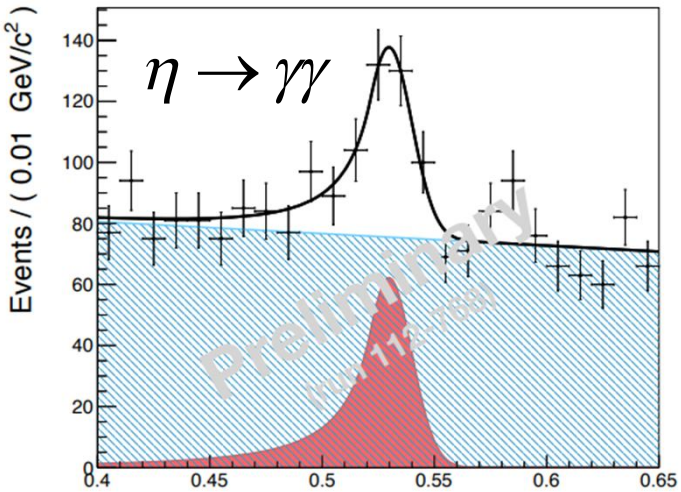


Phase II Events with Photons

$e^+e^- \to \mu^+\mu^-\gamma$



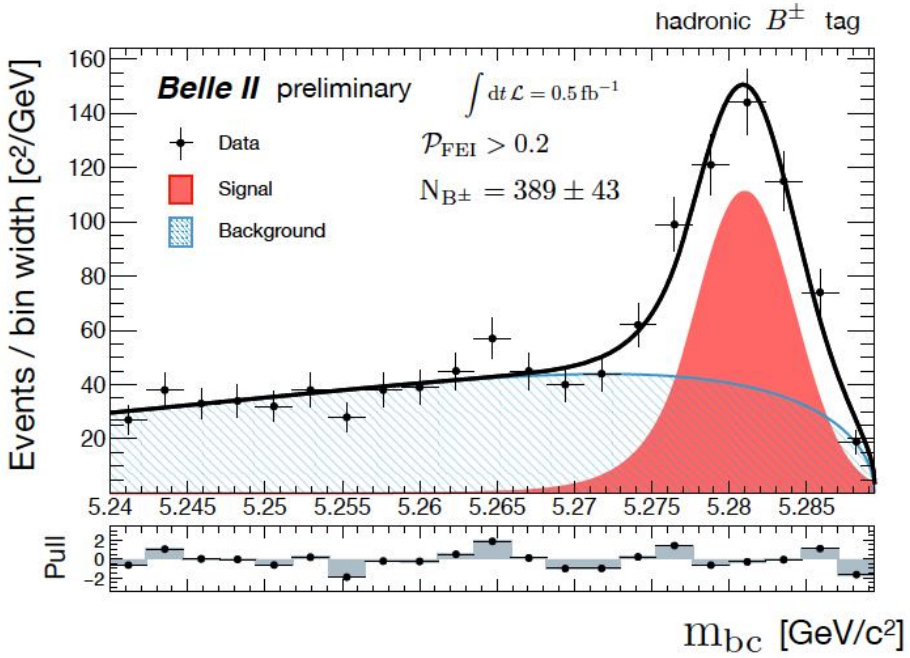


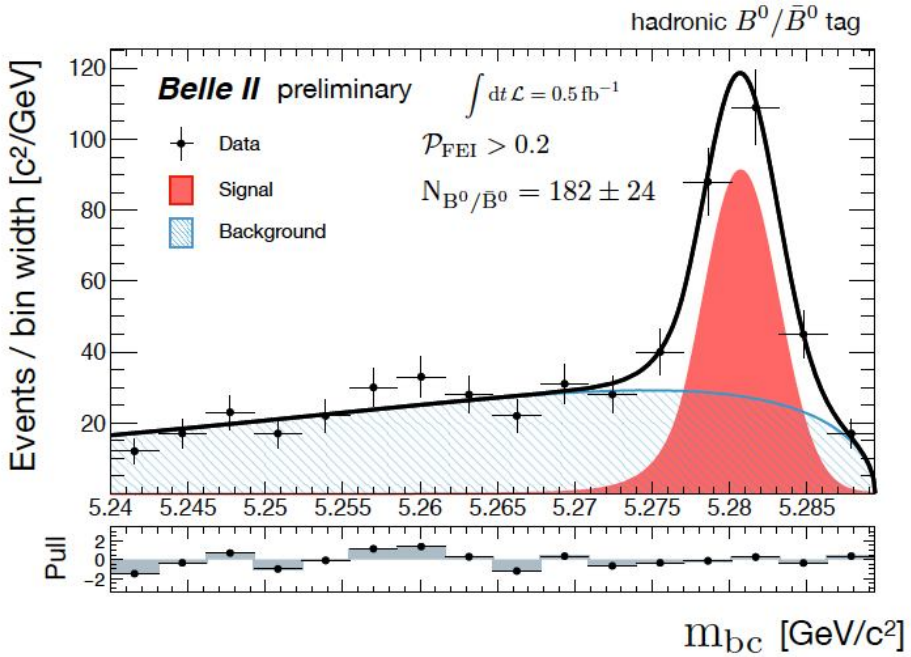


Note: Dark sector search

- $e^+e^- \to \gamma A'$
- $e^+e^- \to \gamma ALPS \to \gamma(\gamma\gamma)$
- $e^+e^- \to \ldots$

B Mesons
by Full Event Interpretation





~571 (= 389 charged + 182 neutral) fully reconstructed B mesons from the full Phase II data set

Some Ideas on LLP Signature

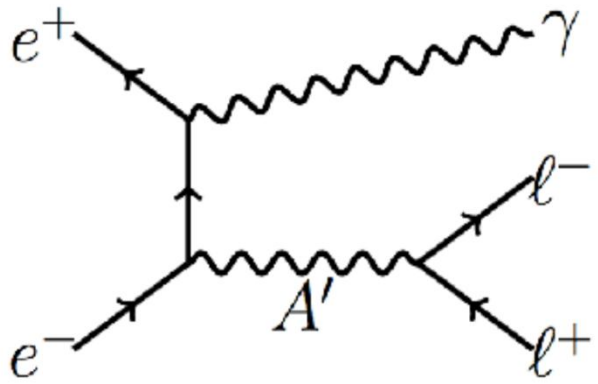
- In the LLP field, the current Belle II search signatures include
  - particles decaying outside the detector, i.e., invisible modes.
  - displaced vertices in tracker or outer detectors
  - magnetic monopoles
  - …
- These signatures have topologies different from the SM particles. Hence, dedicated reconstruction strategies are needed.

(LLP) or (LLP+Prompt)

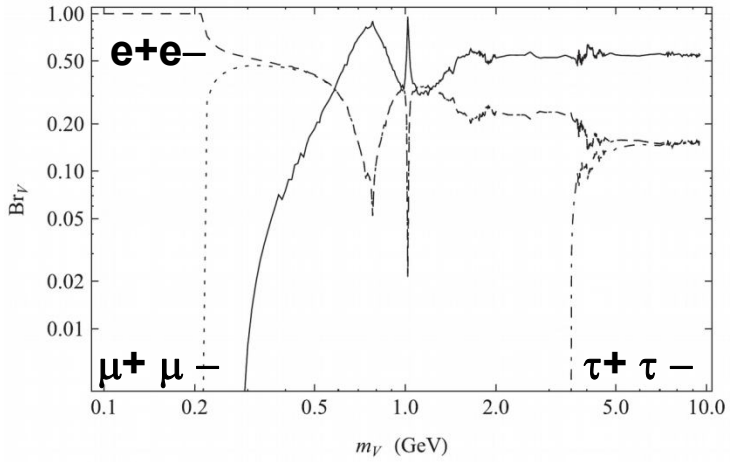
DARK PHOTON

Dark Photon to Leptons

Visible mode



Branching Ratio for lepton pairs by flavor



PRD79: 1115008 (2009)

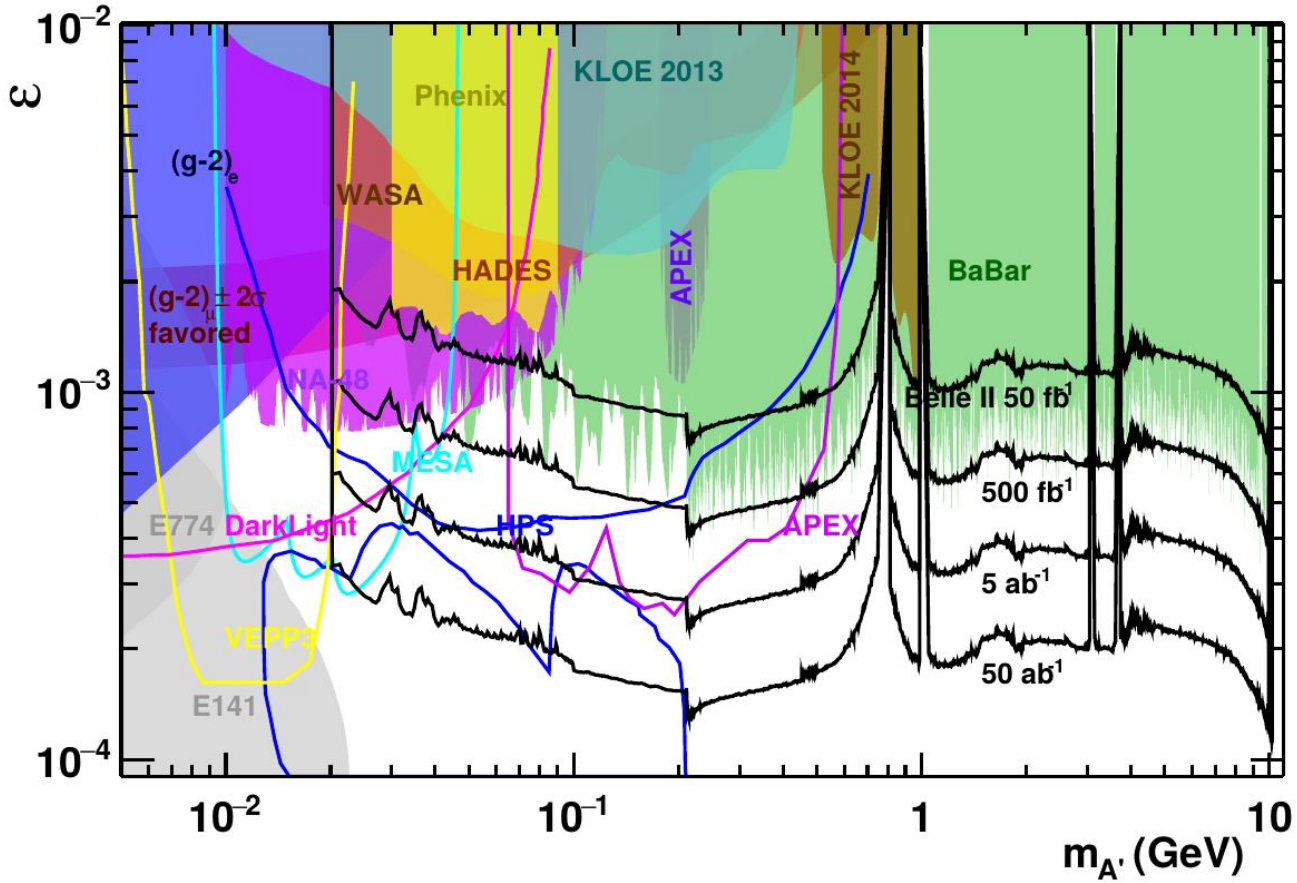
- Case: Dark Photon A' mixes with the SM.
- Depending on its mass, it decays into a pair of fermions (visible mode)

$$e^+e^- \rightarrow \gamma\, l^+\, l^-$$

- Signature:
  An energetic single photon with a pair of leptons.

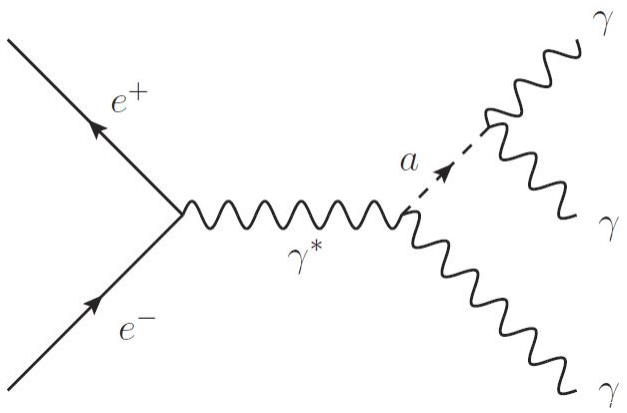
Projected Sensitivity

Note: These numbers are for the prompt case for the visible mode.



AXION LIKE PARTICLES

Axion-like Particles (ALP)



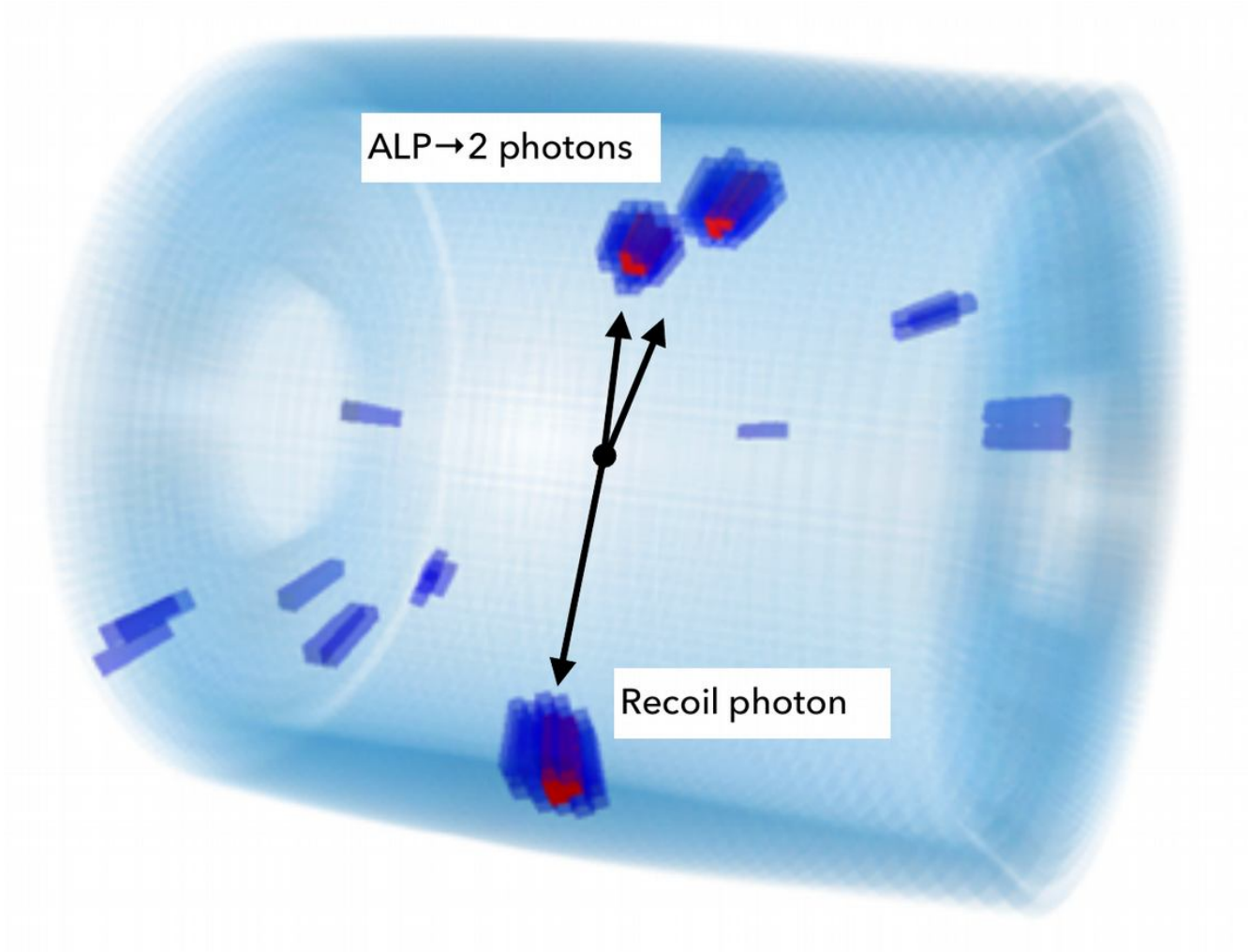
ALP strahlung

- ALP: pseudo-scalar particles from the extensions of SM

$$L \sim -\frac{g_{a\gamma\gamma}}{4} aF_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{g_{a\gamma Z}}{4} aF_{\mu\nu}\tilde{Z}^{\mu\nu} - \frac{g_{aZZ}}{4} aZ_{\mu\nu}\tilde{Z}^{\mu\nu} - \frac{g_{aWW}}{4} aW_{\mu\nu}\tilde{W}^{\mu\nu}$$

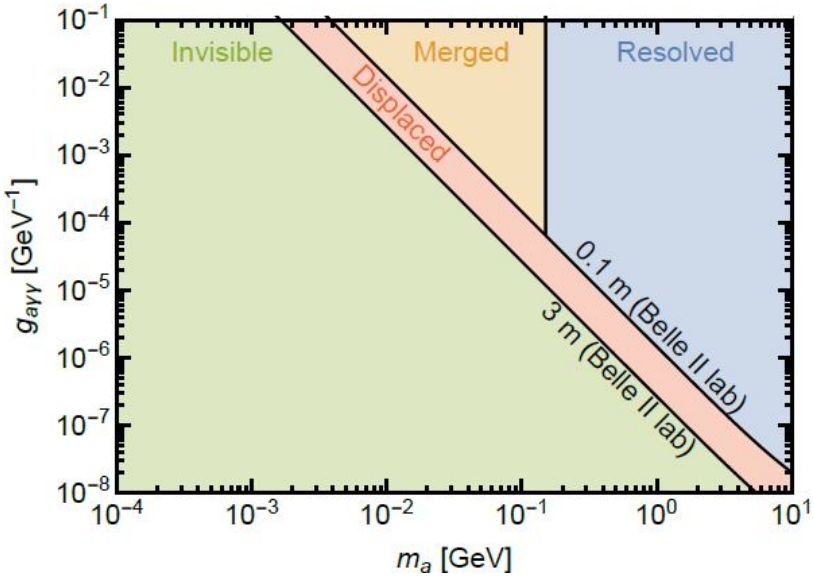
- Look for ALP's decaying into
  - Nothing (invisible mode)
  - a couple of photons. i.e., ALP strahlung, in the detector (visible mode).

Simulated Example of ALP

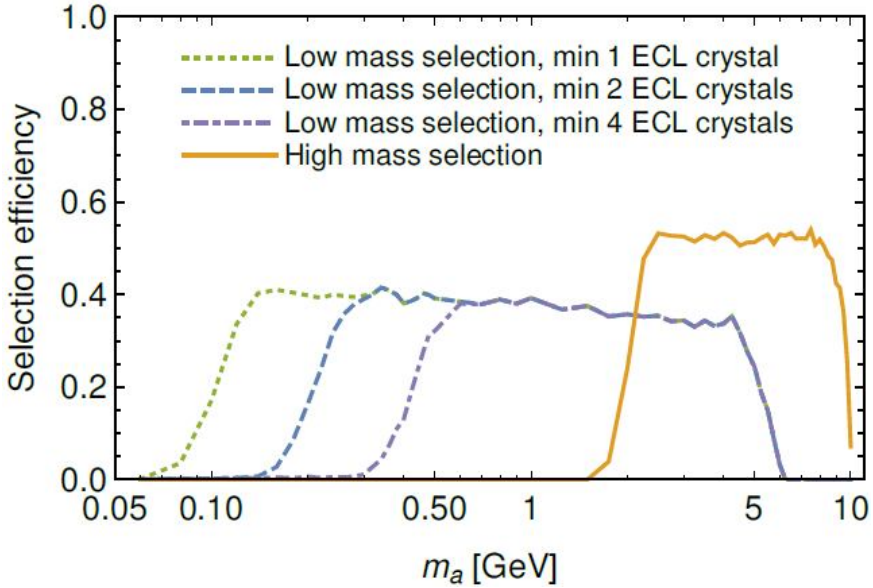


Selection Regime and Efficiency

Selection Regime of
ALP→ 2 photons



Selection efficiency of
(recoil photon +
ALP→ 2 resolved photons)

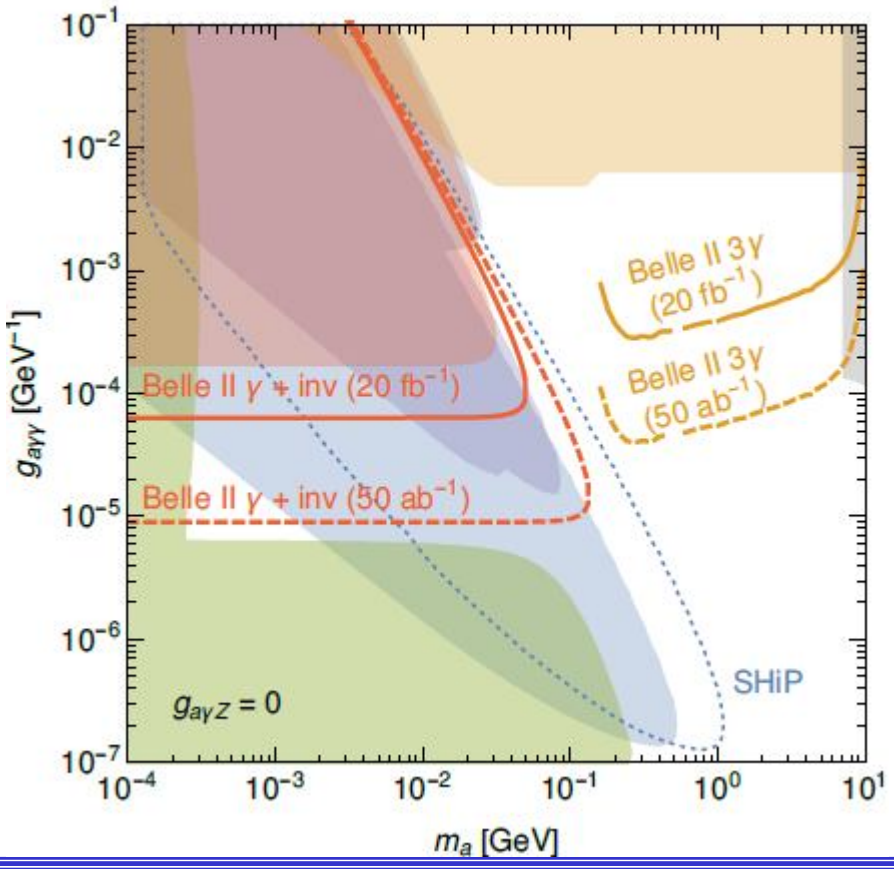


JHEP 1712, 094 (2017)

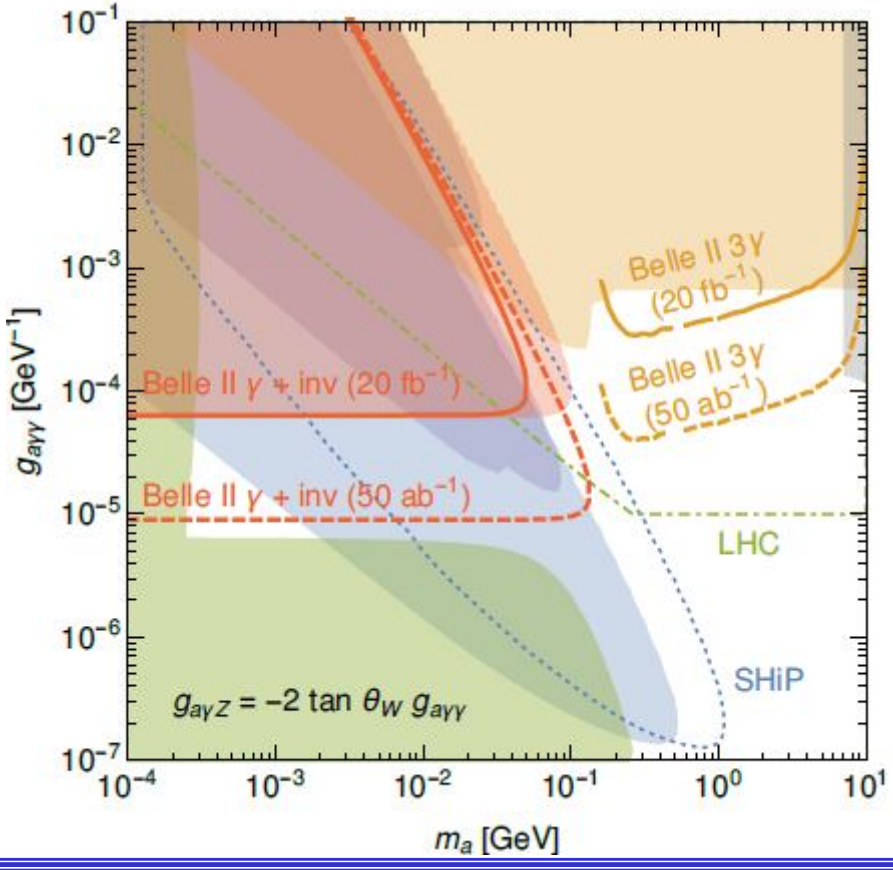
Expected Sensitivity

3γ : 3 resolved photons
$\gamma + \text{inv}$: 1 resolved recoil photon + ALP decaying to 2 photons outside Belle II

Photon coupling $g_{a\gamma\gamma} \ll g_{aZZ}$



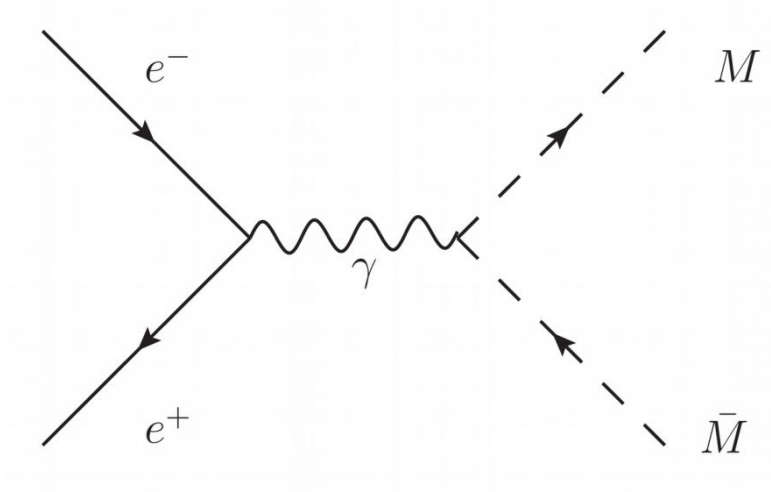
Hypercharge coupling $g_{a\gamma\gamma} \approx -g_{aZZ}$



JHEP 1712, 094 (2017)

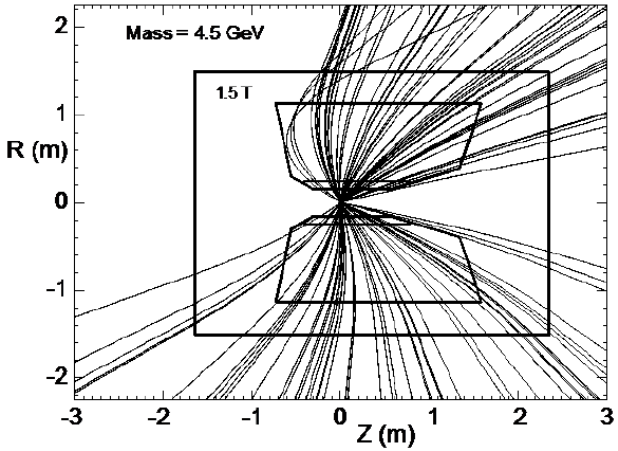
MAGNETIC MONOPOLE

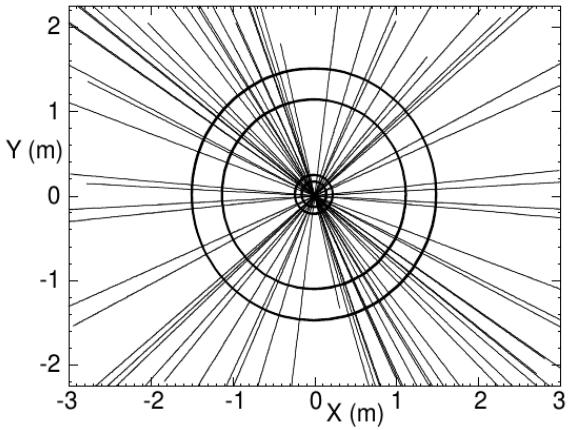
(small charge) Magnetic Monopole



- MoEDAL 2017 searched g > 68.5e.
- ATLAS 2016 searched 34e < g < 137e.
- Low magnetic charges g <10e have not been excluded yet.

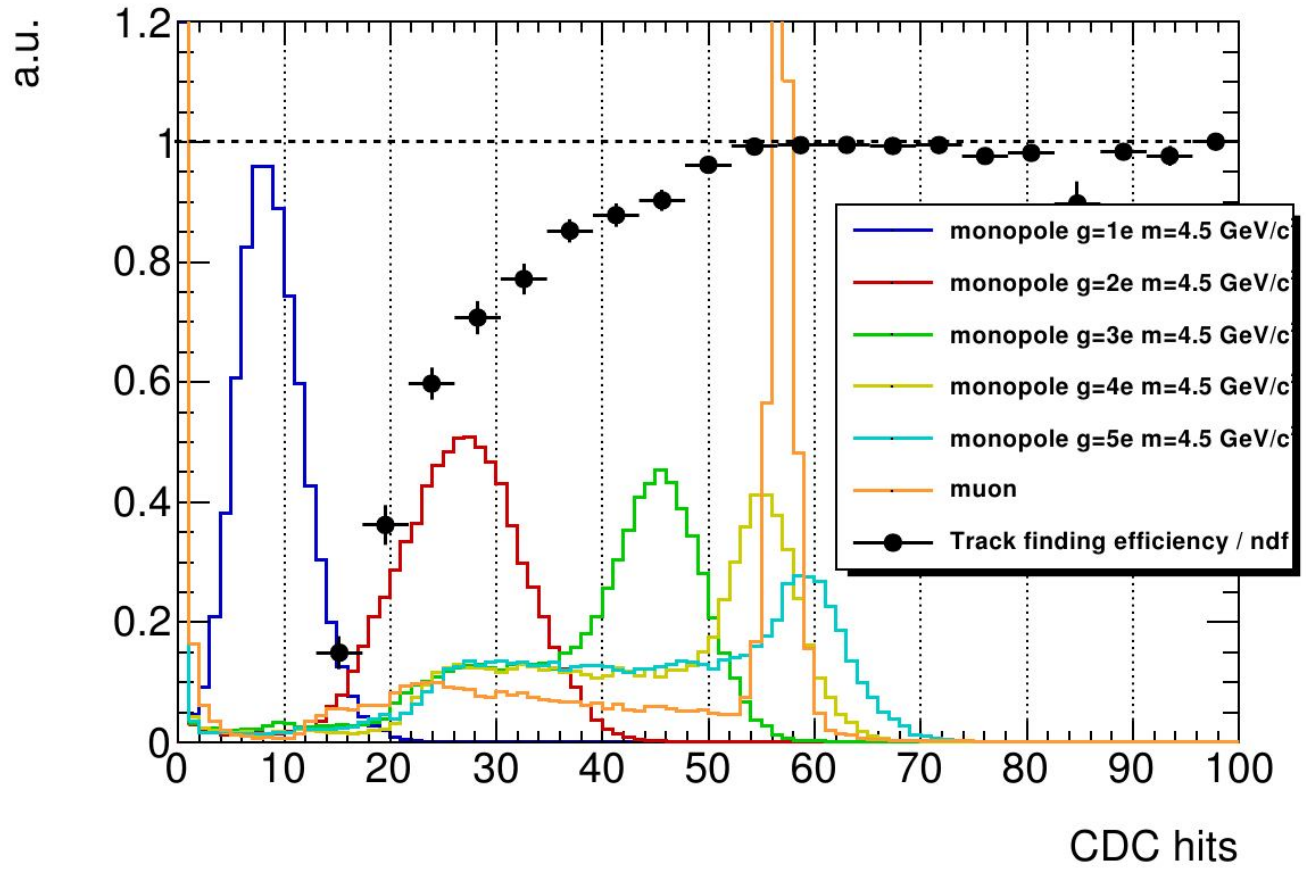
- Signature: a pair of tracks straight in XY, curved in RZ planes.





arxiv.org: 1707.05295

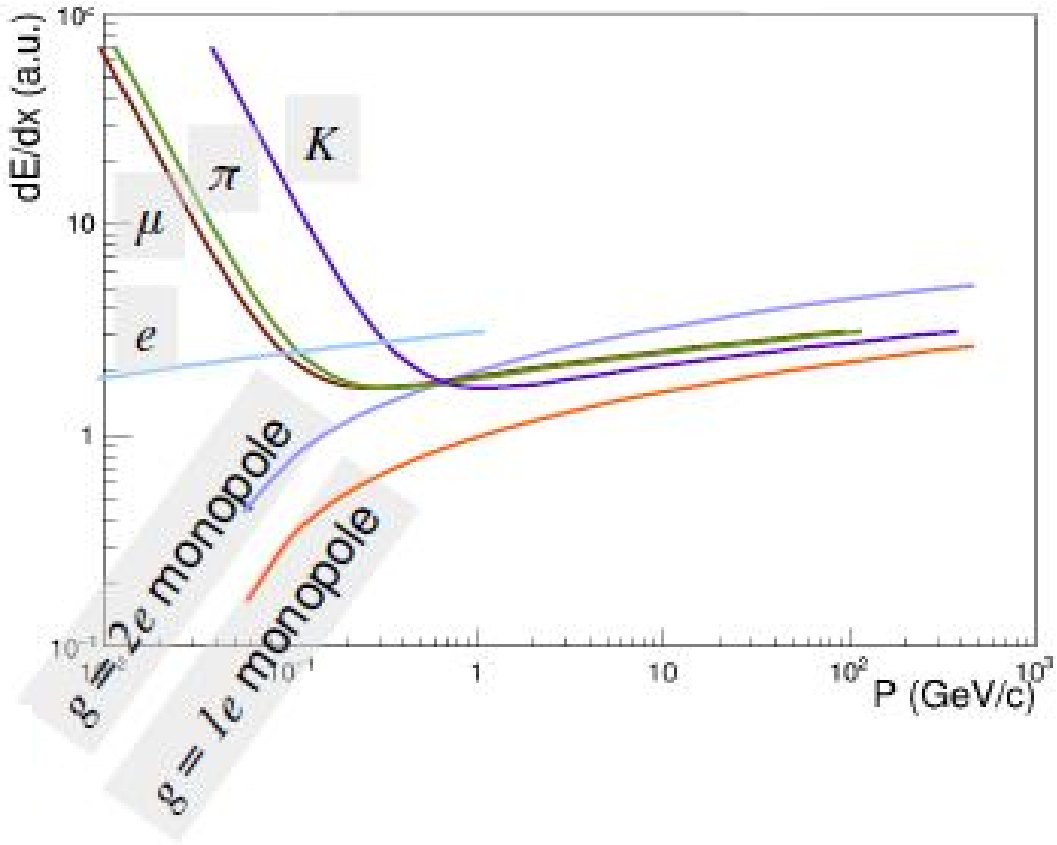
Monopole Tracks



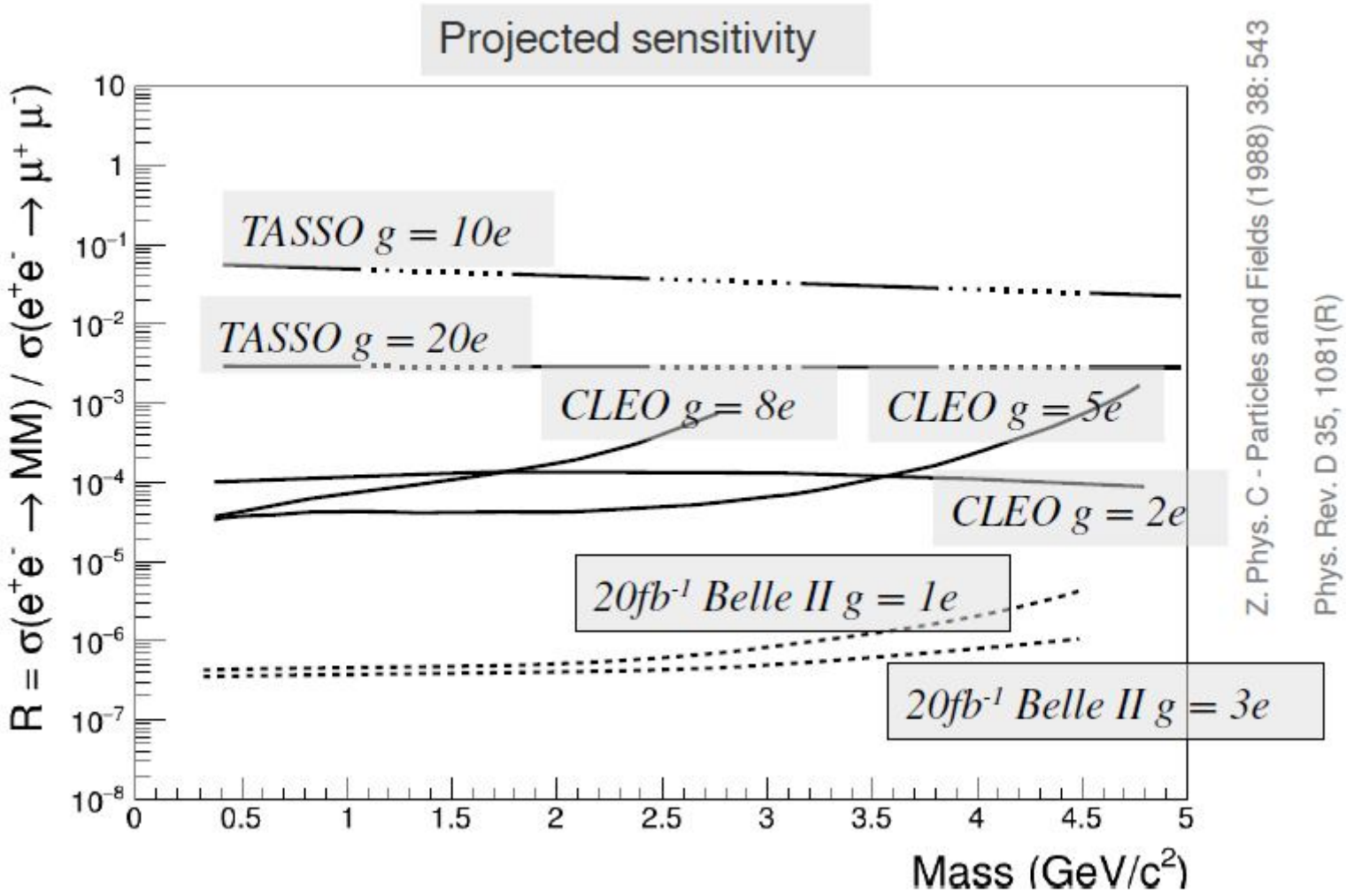
- Number of hits in CDC for different magnetic charges (unit e).
- We need a dedicated tracking algorithm!

dE/dx vs Particle Type

- Monopole tracks show weaker dE/dx curves, since the $1/\beta^2$ term is missing from Bethe-Bloch equation for ionization.



Monopoles: Sensitivity

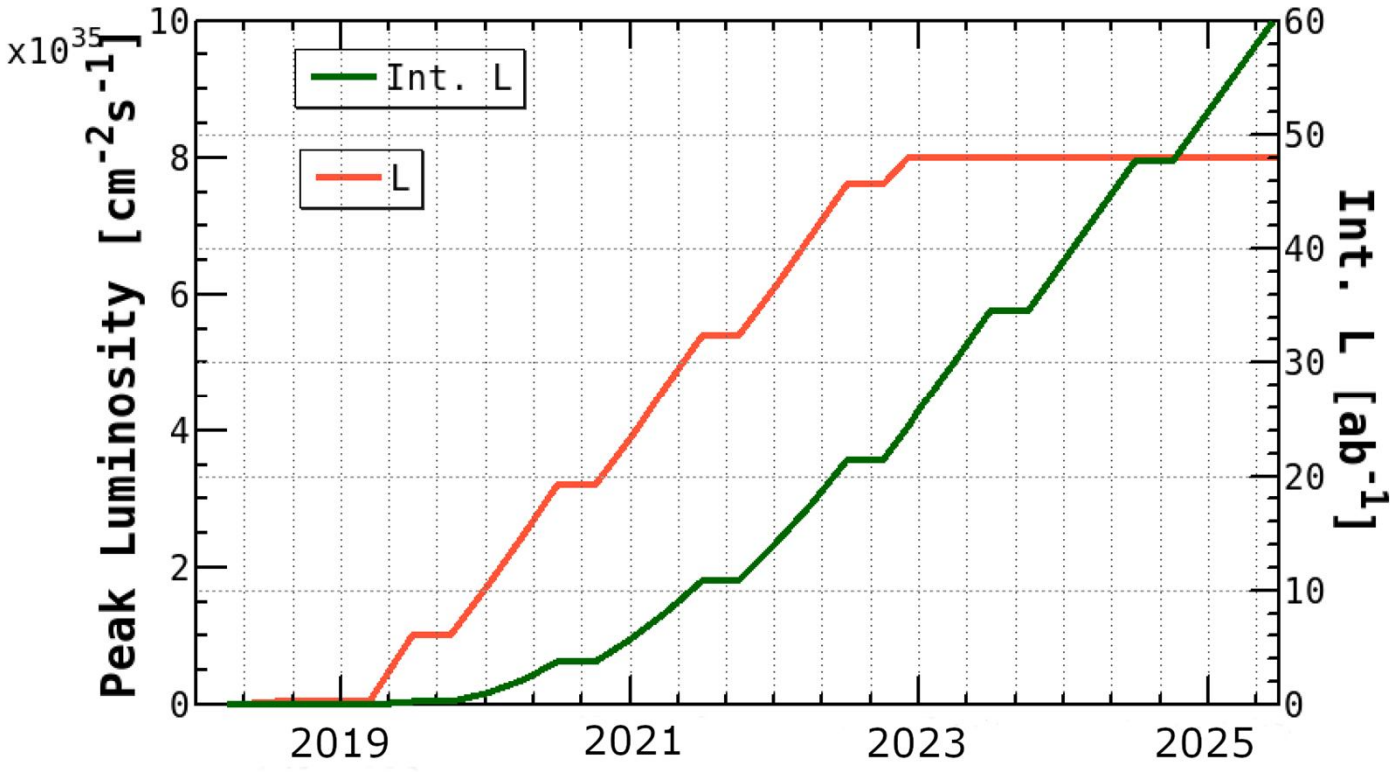


PHASE III: PREPARATION

The Full Vertex Detector

One layer of PXD in 2019.
Two PXD layers after.

SuperKEKB/Belle II Luminosity Plan



Yukiyoshi Ohnishi @ KEK

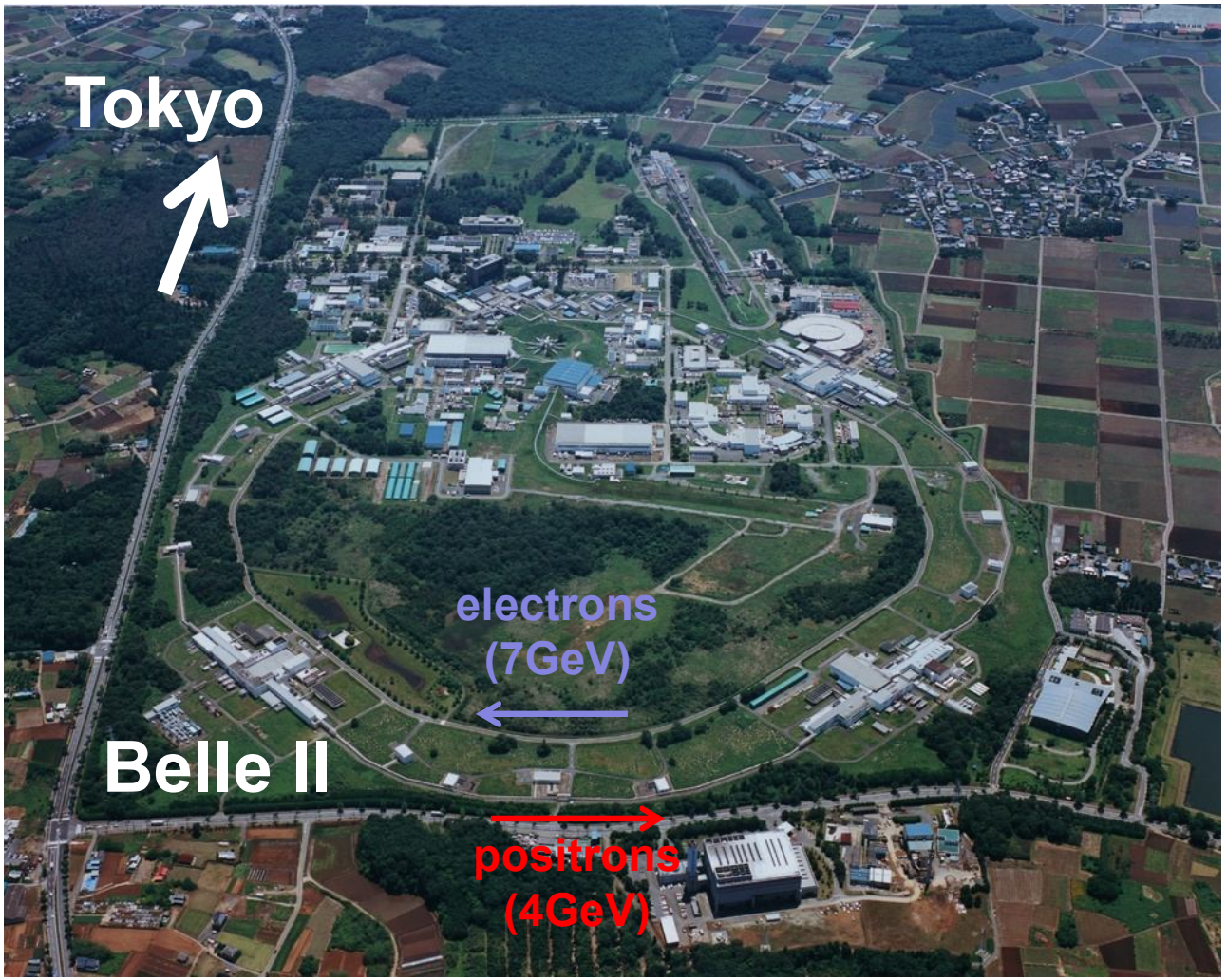
Summary

- Phase II mode of the Belle II Experiment has been executed successfully.
  - This is an excellent opportunity to search for new physics such as dark matter or ALP.
  - Preparing for dark sector papers.

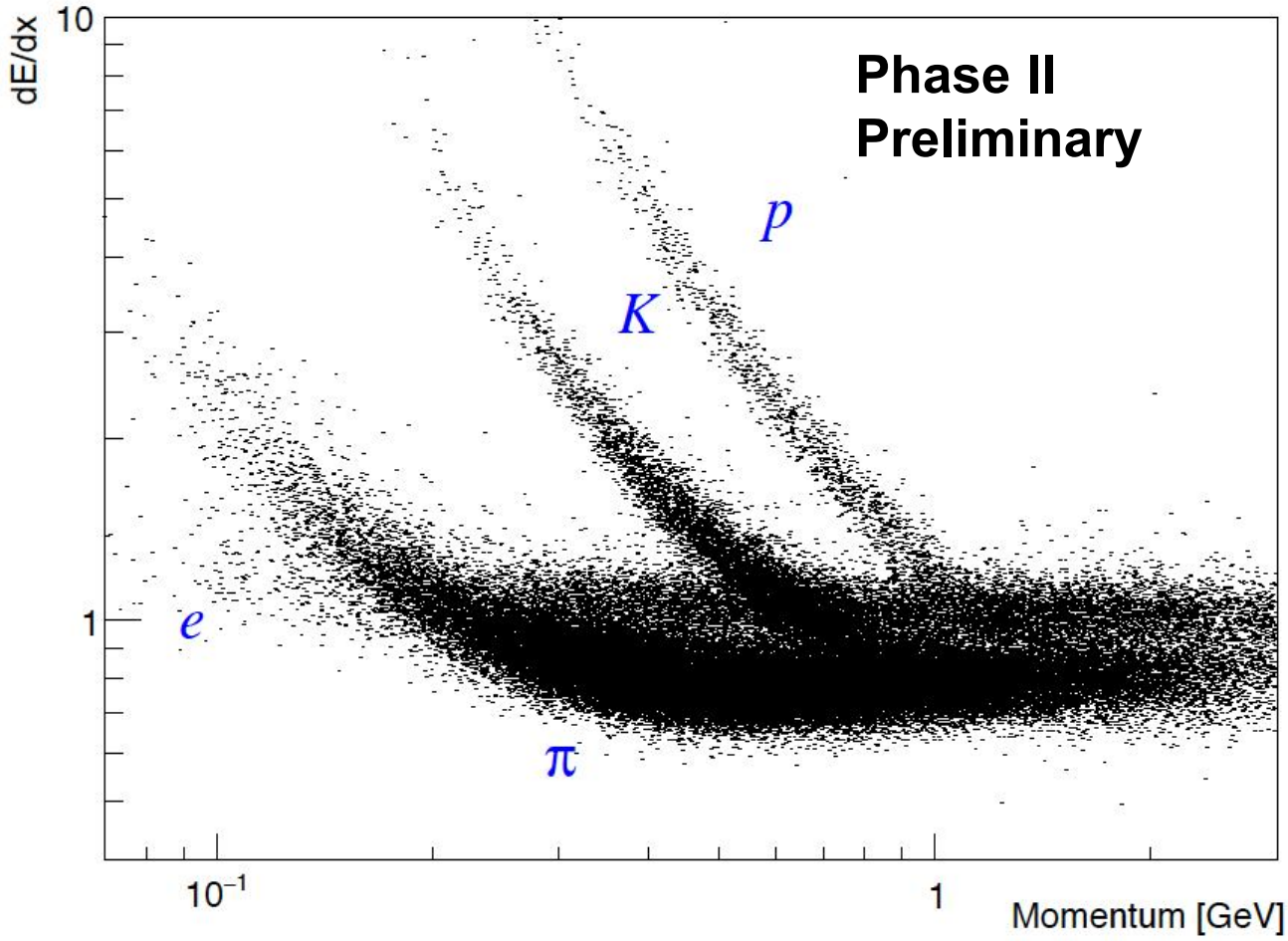
- Phase III of Belle II will start early 2019.
  - Competing and complementary to LHCb.
  - SuperKEKB will become the highest luminosity machine in the World.
  - Stay tuned for the exciting physics!

EXTRA

SuperKEKB Collider



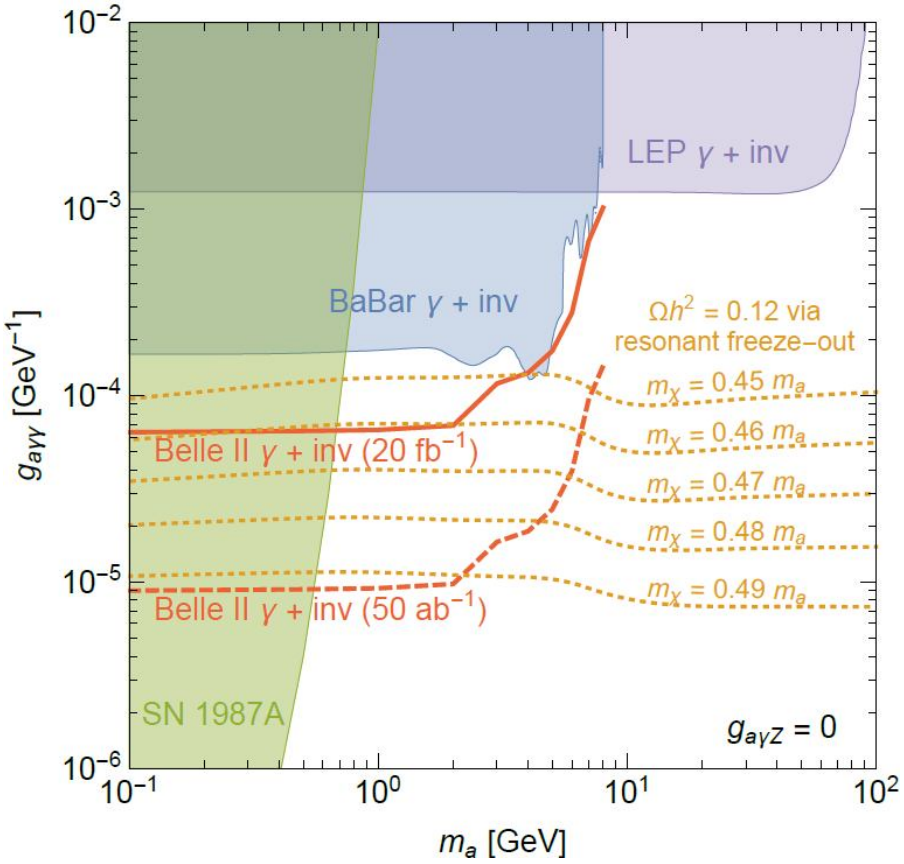
dE/dx in CDC



- Separation power is expected to be improved with further alignment and calibration efforts.

Expected Sensitivity for ALP decays to Dark Matter

$\gamma + \text{inv}$: 1 resolved recoil photon + ALP decaying to dark matter



$$e^+e^- \to \gamma a, \quad a \to \chi\chi$$

$$E_\gamma = \frac{s - m_a^2}{2\sqrt{s}}$$

JHEP 1712, 094 (2017)