NAGOYA UNIVERSITY

Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe

Dark sector physics with Belle II

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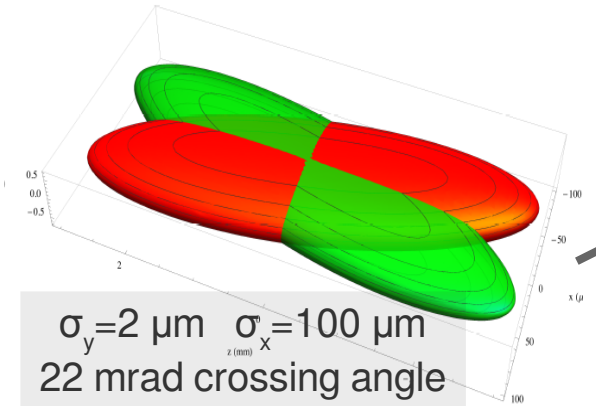
for the Belle II collaboration

XXXIX International Conference on High Energy Physics
5th July 2018, Seoul, Korea

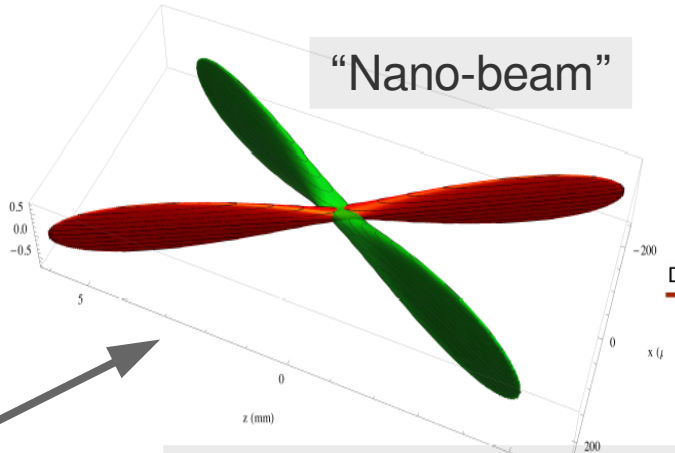
Accelerator and detector

SuperKEKB collider

- Super B-factory in KEK (Tsukuba, Japan)
- Asymmetric e^+e^- collider operating around 10.58 GeV c.o.m. energy
- Successor of KEKB with Belle
  - Higher currents
  - Smaller beams

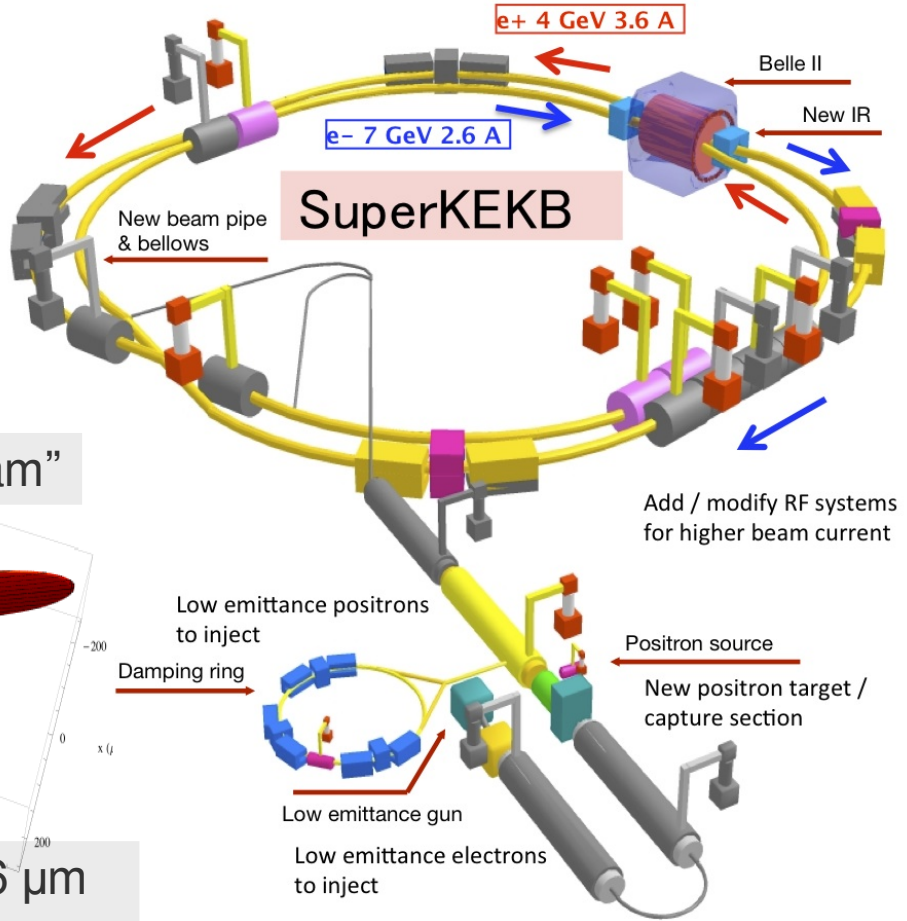


σ_y=2 μm σ_x=100 μm
22 mrad crossing angle

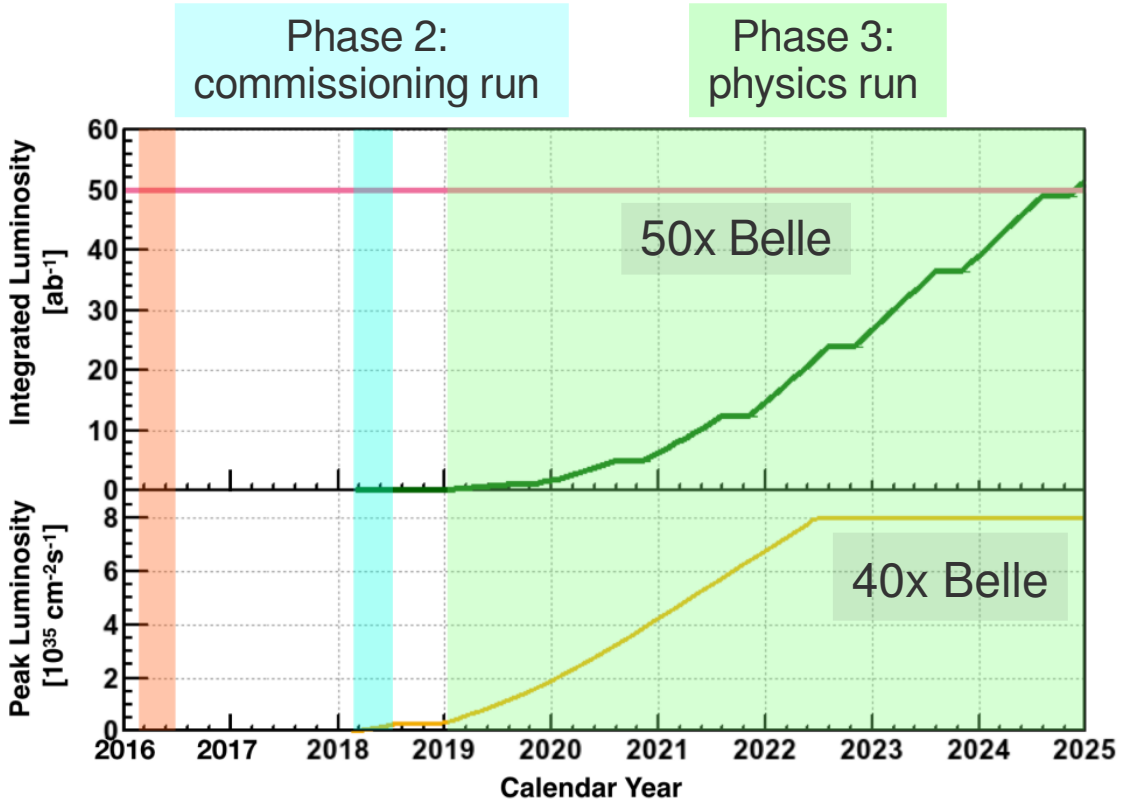


"Nano-beam"

σ_y=42 **nm** σ_x=6 μm
83 mrad crossing angle

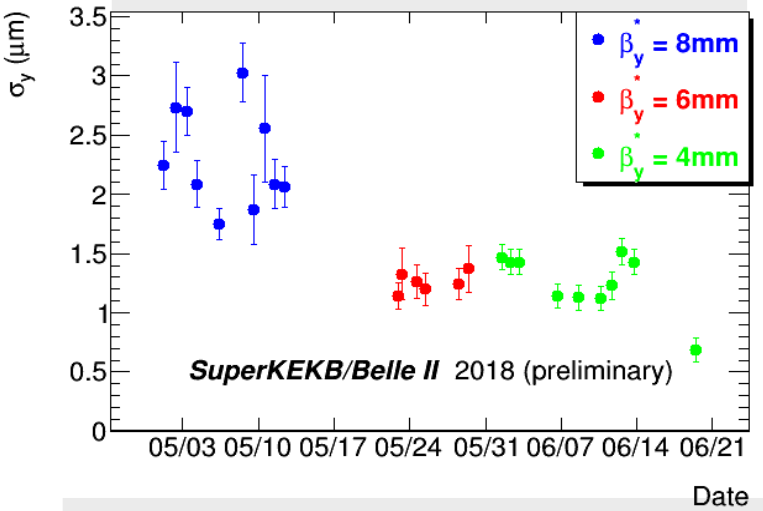


SuperKEKB collider plans

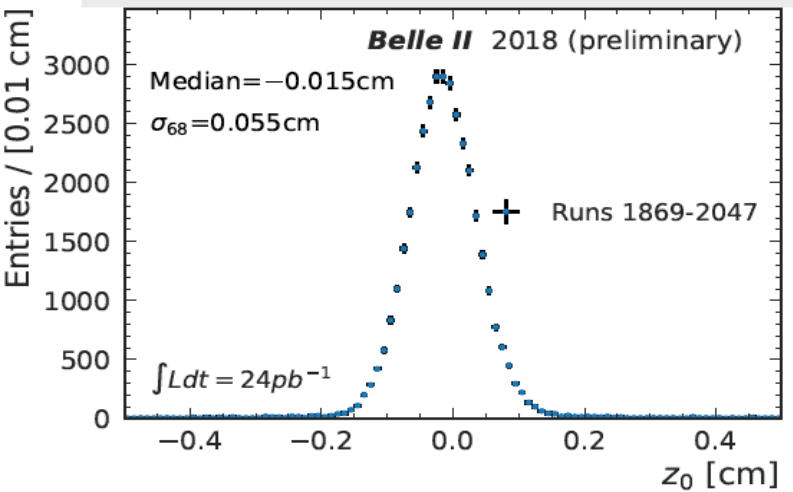


- Currently collected $\approx 0.5 fb^{-1}$

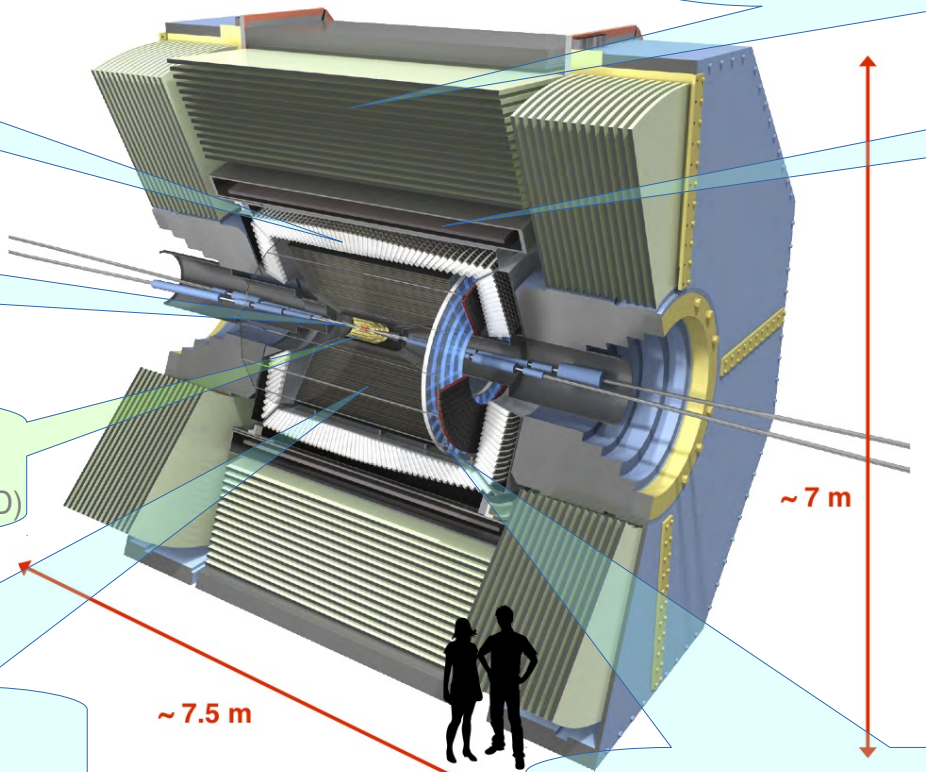
Measured vertical beam size



Measured longitudinal IP position



The Belle II detector



K_L and muon calorimeter (KLM):
Resistive Plate Counters (RPC) (outer barrel)
Scintillator + WLSF + MPPC (endcaps, inner barrel)

Electromagnetic calorimeter (ECL):
CsI(Tl) crystals, waveform sampling to measure time and energy

Magnet
1.5 T, superconducting

Beryllium beam pipe
2cm diameter

Vertex detectors (VXD):
2 layer DEPFET pixel detectors (PXD)
4 layer double-sided silicon strip detectors (SVD)

7 GeV electrons

4 GeV positrons

Central drift chamber (CDC):
He (50%) : C2H6 (50%),
small cells, fast electronics

Particle Identification (PID):
Time-Of-Propagation counter (TOP) (barrel)
Aerogel Ring-Imaging Cherenkov Counter (ARICH) (FWD)

Phase 2 (26 April – 17 July 2018)

- 1/8 of vertex detector
- Lower backgrounds
- Flexible hardware triggers
- Pass-through software trigger

Good for dark sector searches

Hardware trigger:

- Tracking and clustering
- QED pre-scale, bhabha veto

Software trigger: (3000 cores)

- Complete reconstruction
- Multi-variate BG rejection

- Commissioning phase
  - Collider
  - Detector
  - Software

Phase 2:
Hardware < 8 kHz
Software n/a

Design (phase 3):
Hardware < 30 kHz
Software < 10 kHz

Dark photons

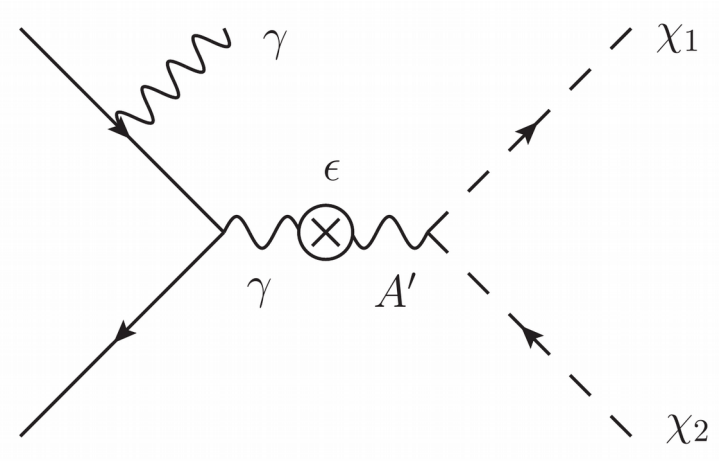
Dark photons

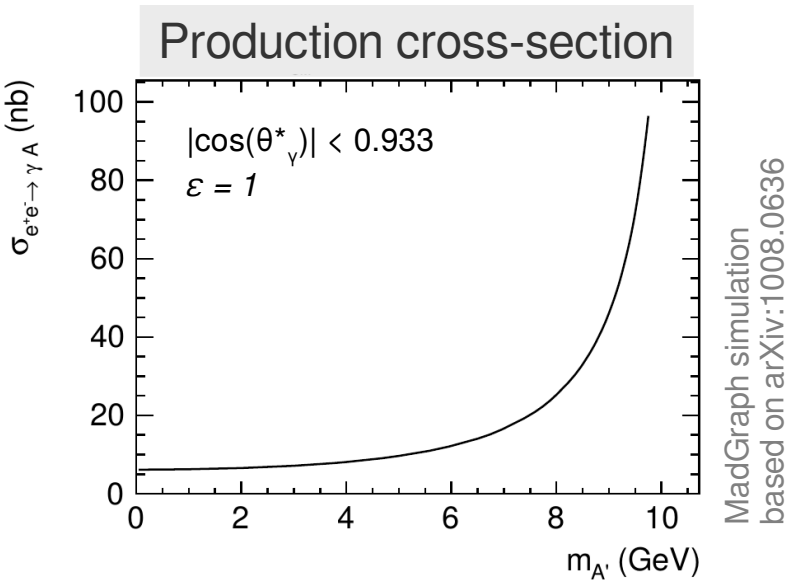
- Massive dark photon A' that mixes with SM with strength ε

$$\mathcal{L} \subset \epsilon V_\mu J^\mu_{SM}$$

- Depending on DM mass, decays into:
  - Dark matter – invisible ($e^+ e^- \to \gamma + inv$)
  - Fermions – visible ($e^+ e^- \to \gamma\, l^+ l^-$)
- ISR photon with energy

$$E_\gamma = \frac{(E^2_{CM} - E^2_{A\prime})}{2E_{CM}}$$

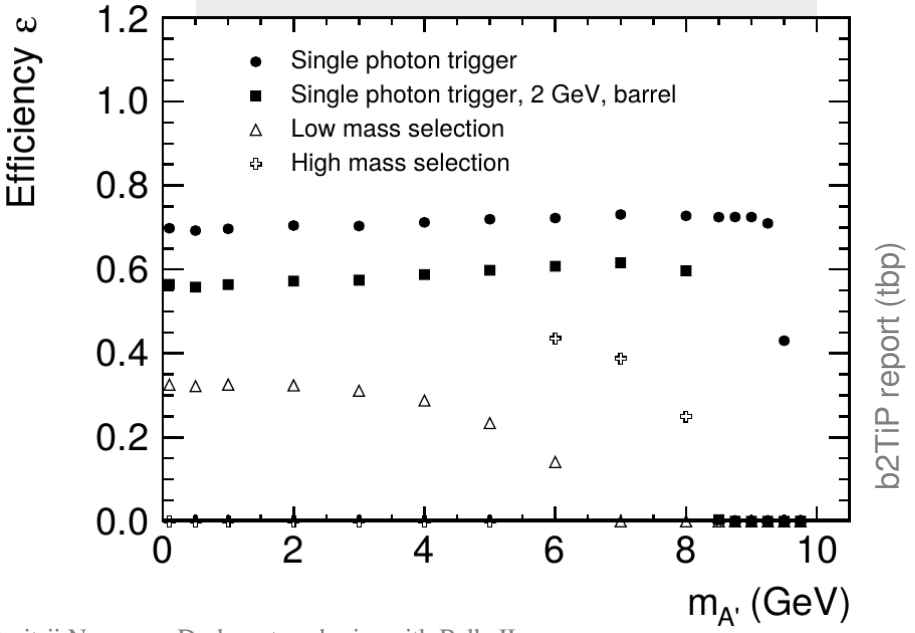




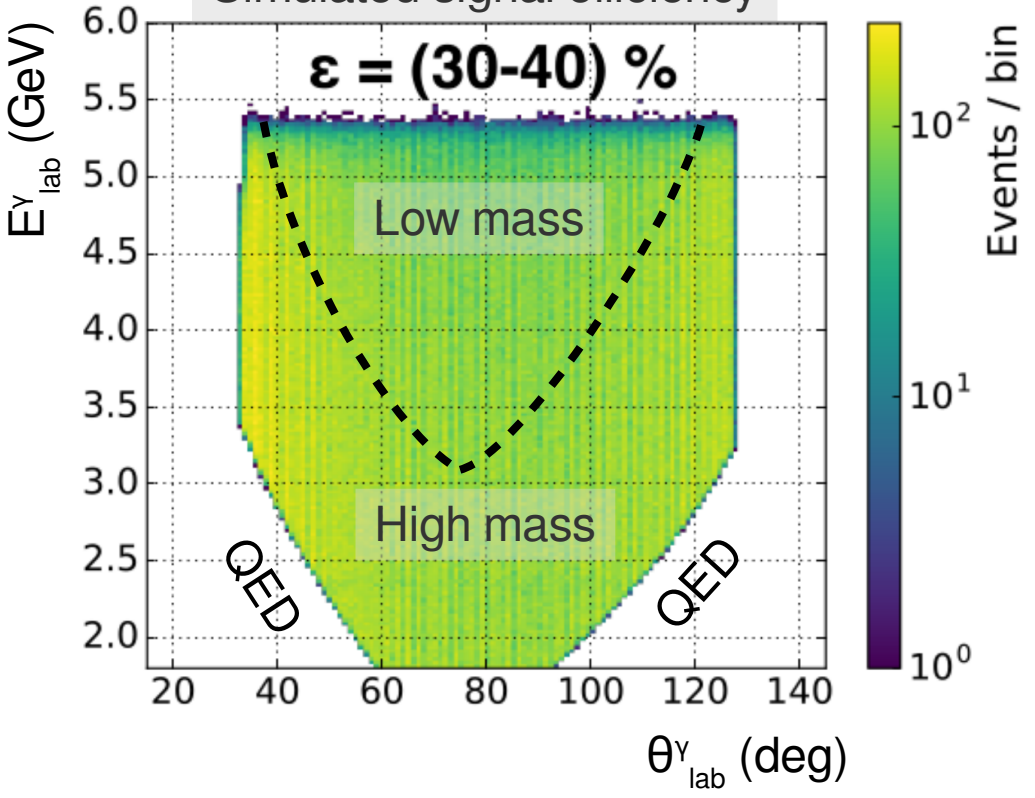
Dark photon to invisible

- Single photon final state
- Cascaded single photon trigger with 1 GeV energy threshold

Simulated trigger and signal selection efficiencies

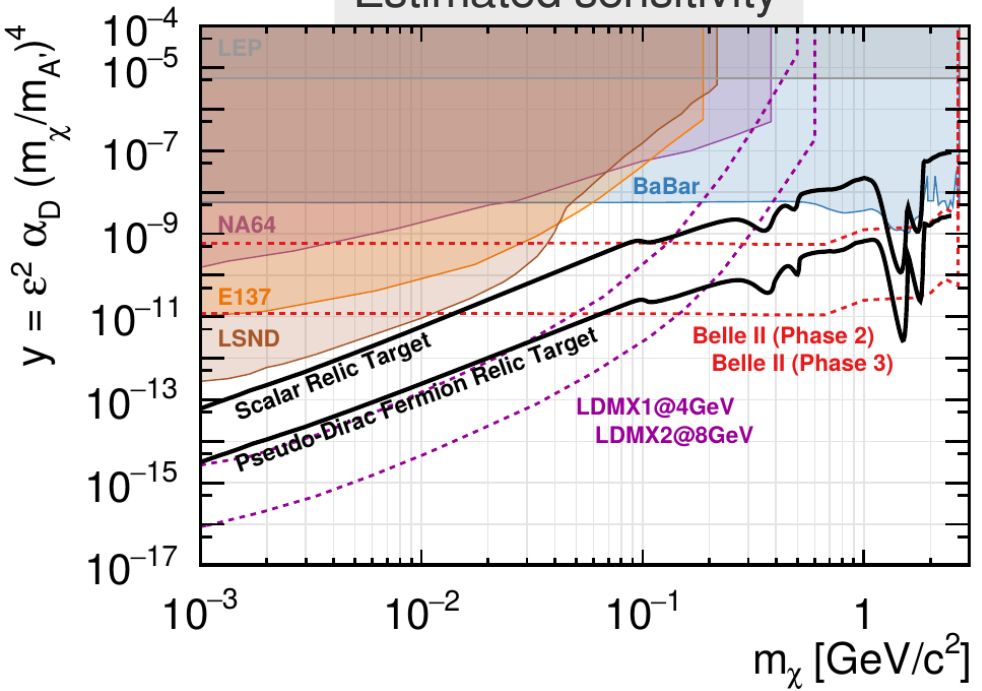


Simulated signal efficiency

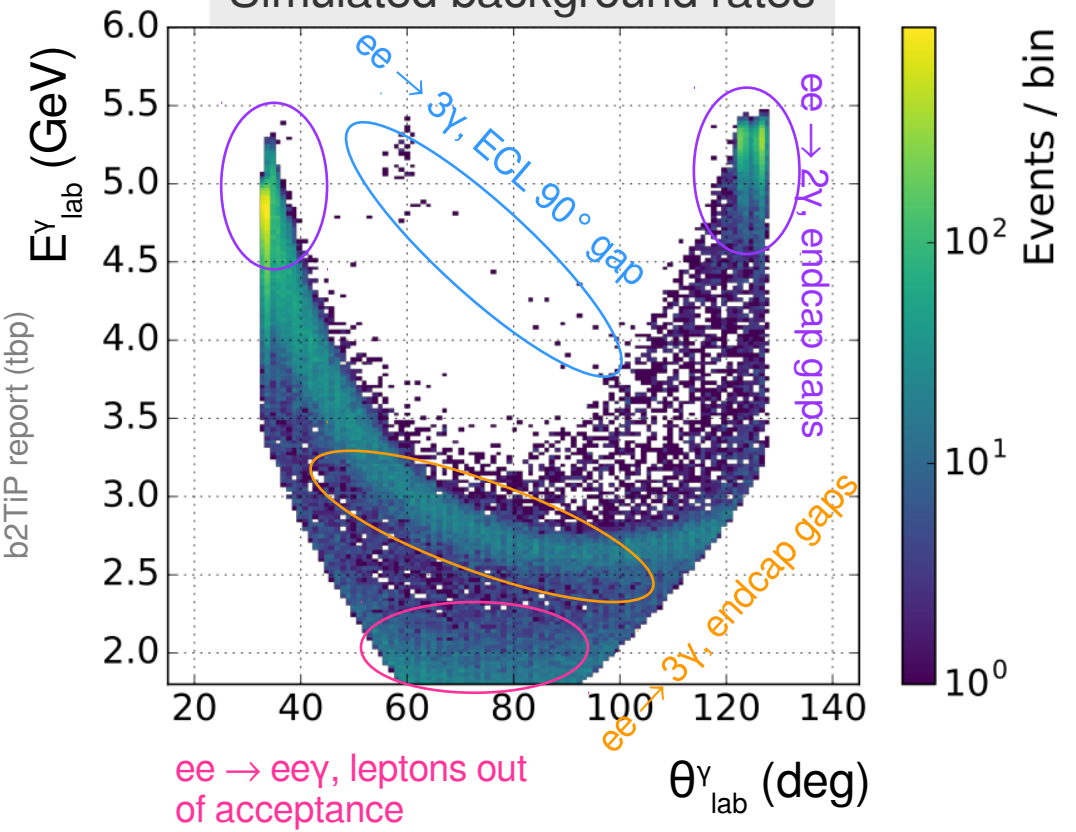


Dark photon to invisible searches sensitivity

Estimated sensitivity

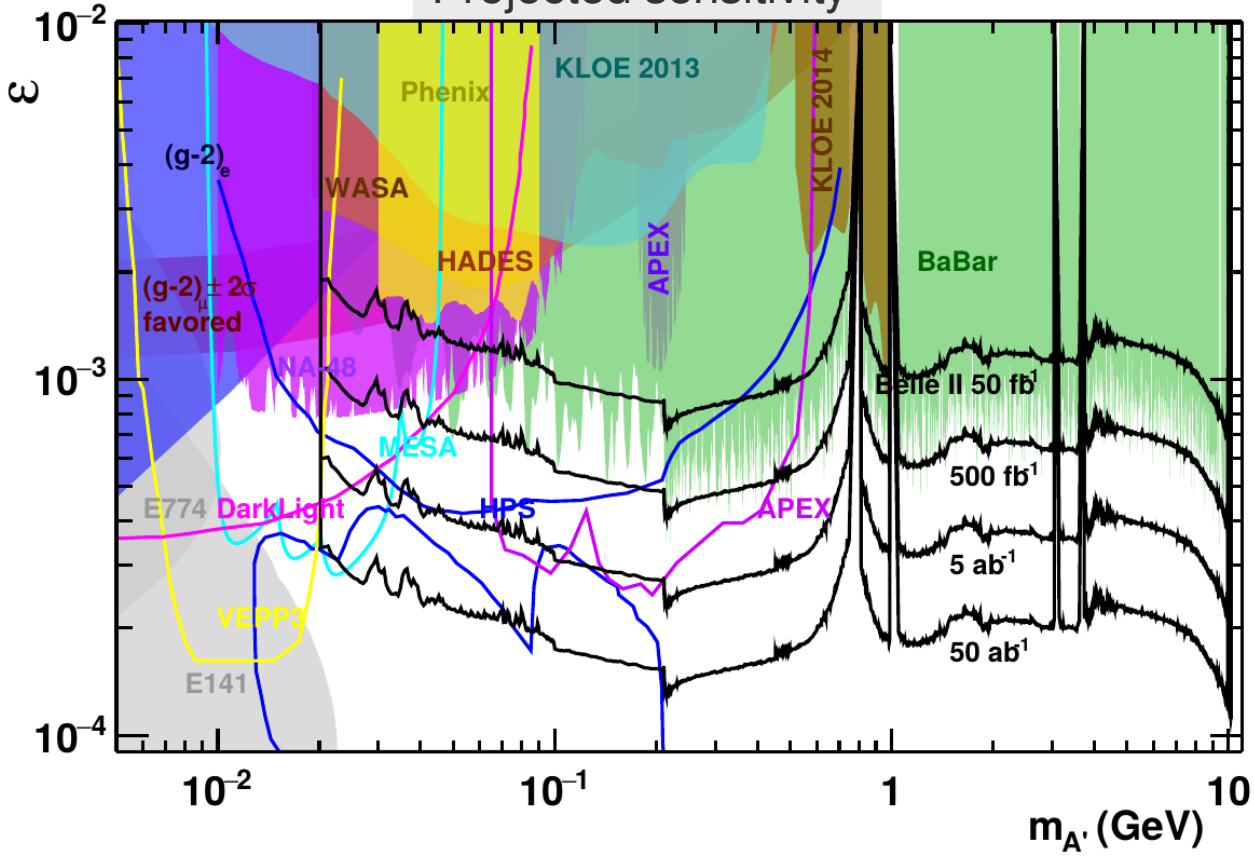


Simulated background rates

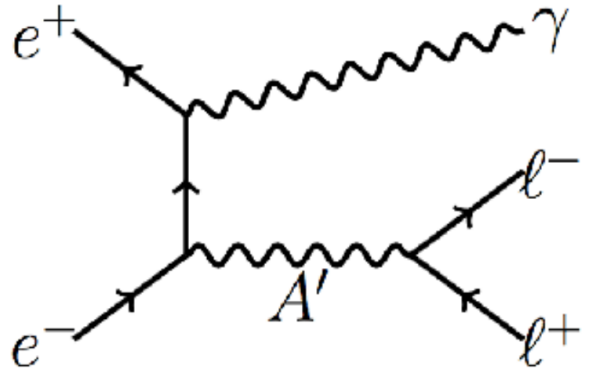


Dark photon to visible searches sensitivity

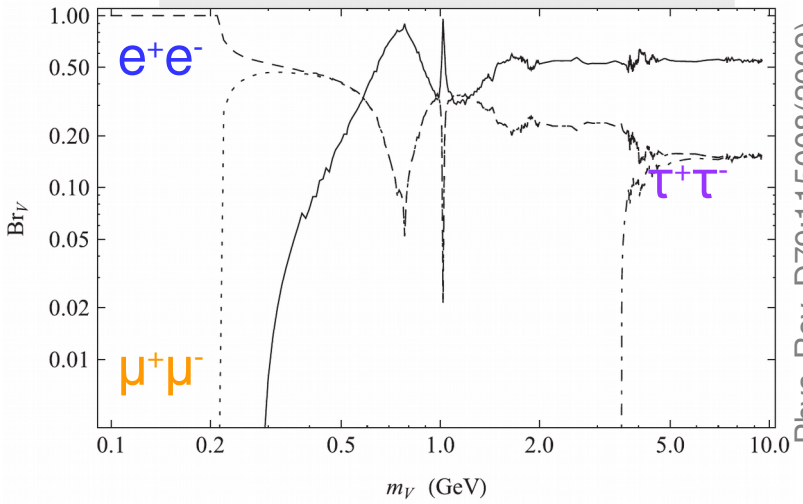
Projected sensitivity



b2TiP report (tbp)



Visible dark photon decay branching ratios



Phys. Rev. D79:115008(2009)

Axion-like particles

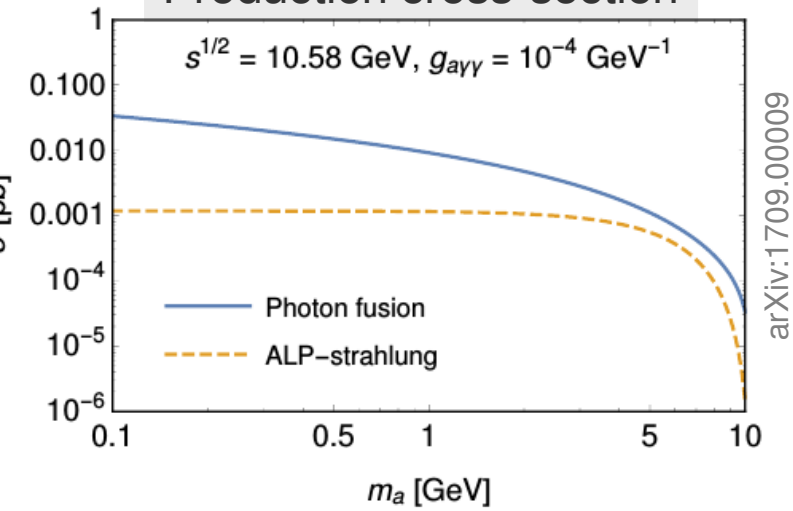
Axion-like particles

- ALPs are pseudo-scalars appearing in many extensions of SM

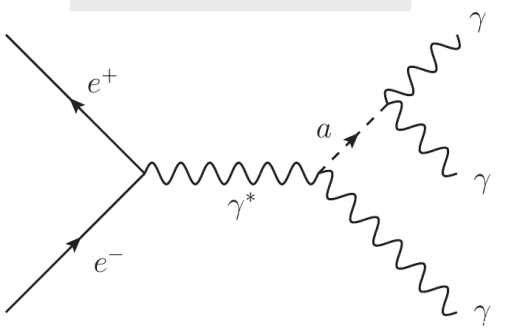
$$\mathcal{L} \supset -\frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{g_{a\gamma Z}}{4} a F_{\mu\nu}\tilde{Z}^{\mu\nu} - \frac{g_{aZZ}}{4} a Z_{\mu\nu}\tilde{Z}^{\mu\nu} - \frac{g_{aWW}}{4} a W_{\mu\nu}\tilde{W}^{\mu\nu}$$

- Two regimes
  - Photon coupling ($g_{a\gamma\gamma} << g_{aZZ}$)
  - Hypercharge coupling ($g_{a\gamma\gamma} \approx - g_{aZZ}$)
- Two production processes possible
  - Focus on ALP-strahlung
    - $e^+ e^- \to \gamma + inv$
    - $e^+ e^- \to 3\gamma$

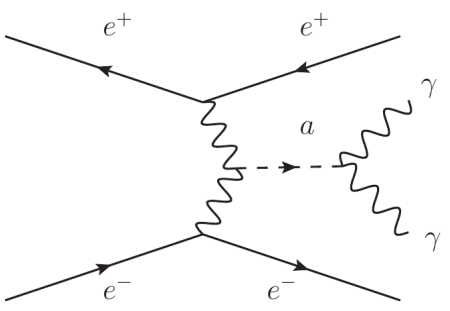
Production cross-section



ALP-strahlung



Photon fusion

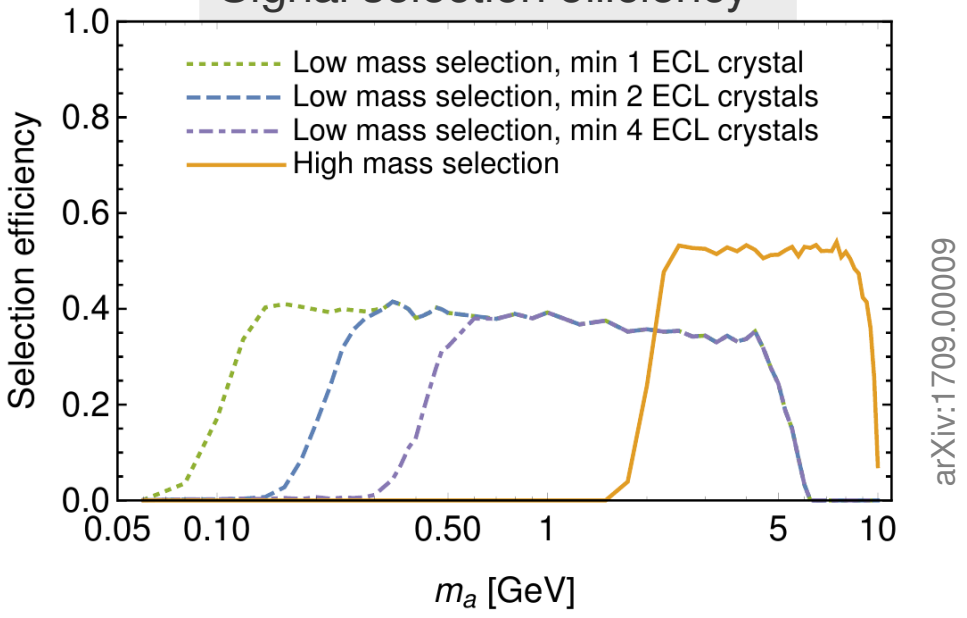


* ALPs can also decay to DM

Axion-like particles search

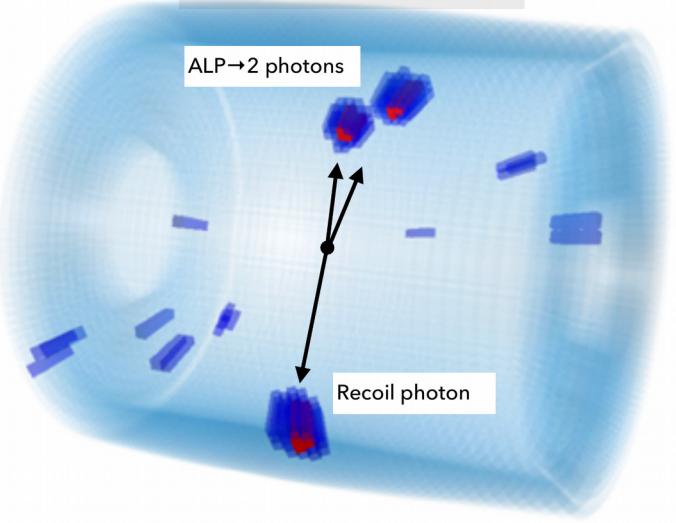
- Single photon final state ($a \rightarrow$ DM)
- Bump in two-photon mass ($a \rightarrow \gamma\gamma$)

Signal selection efficiency

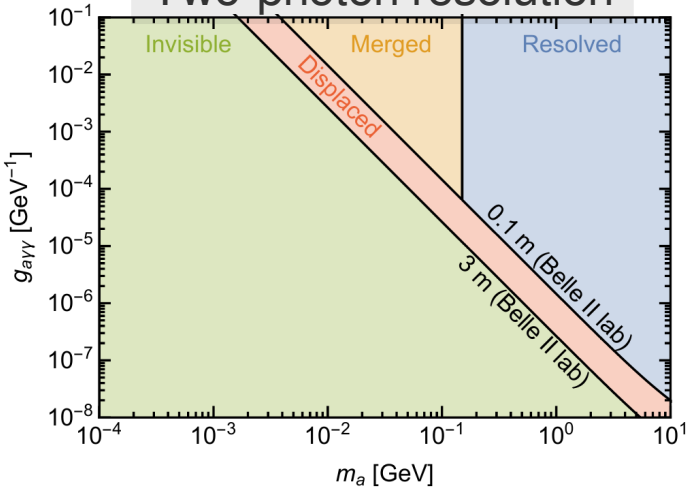


arXiv:1709.00009

Example event

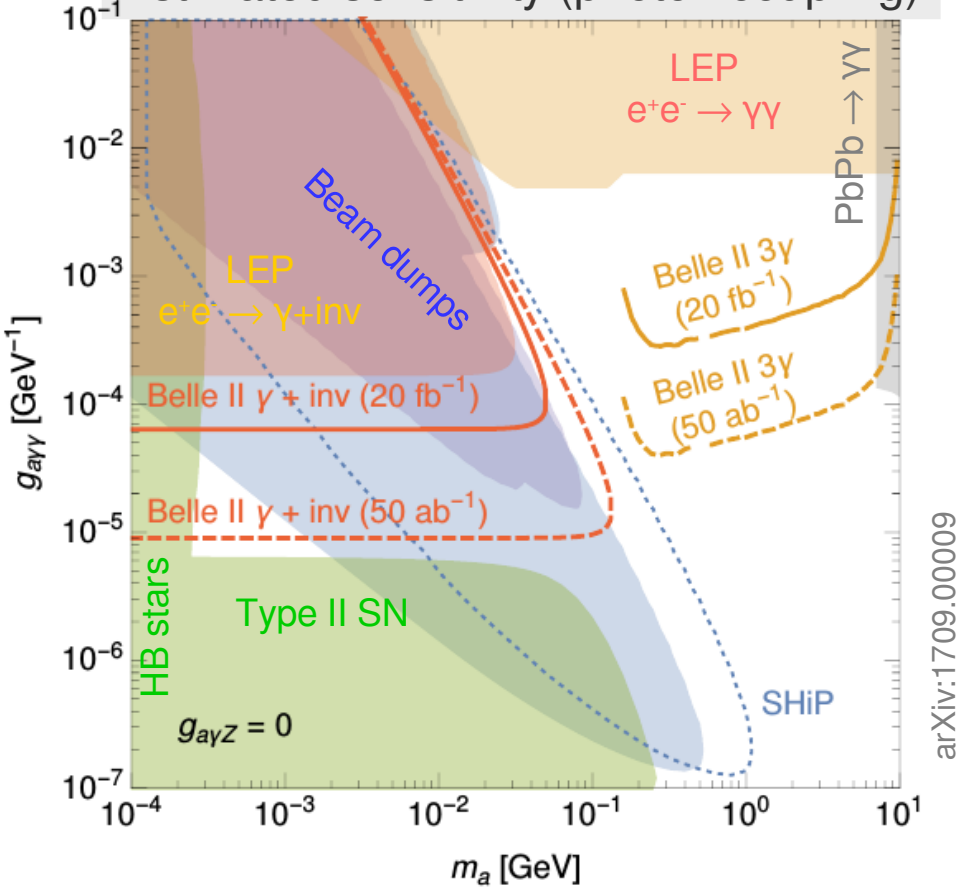


Two-photon resolution

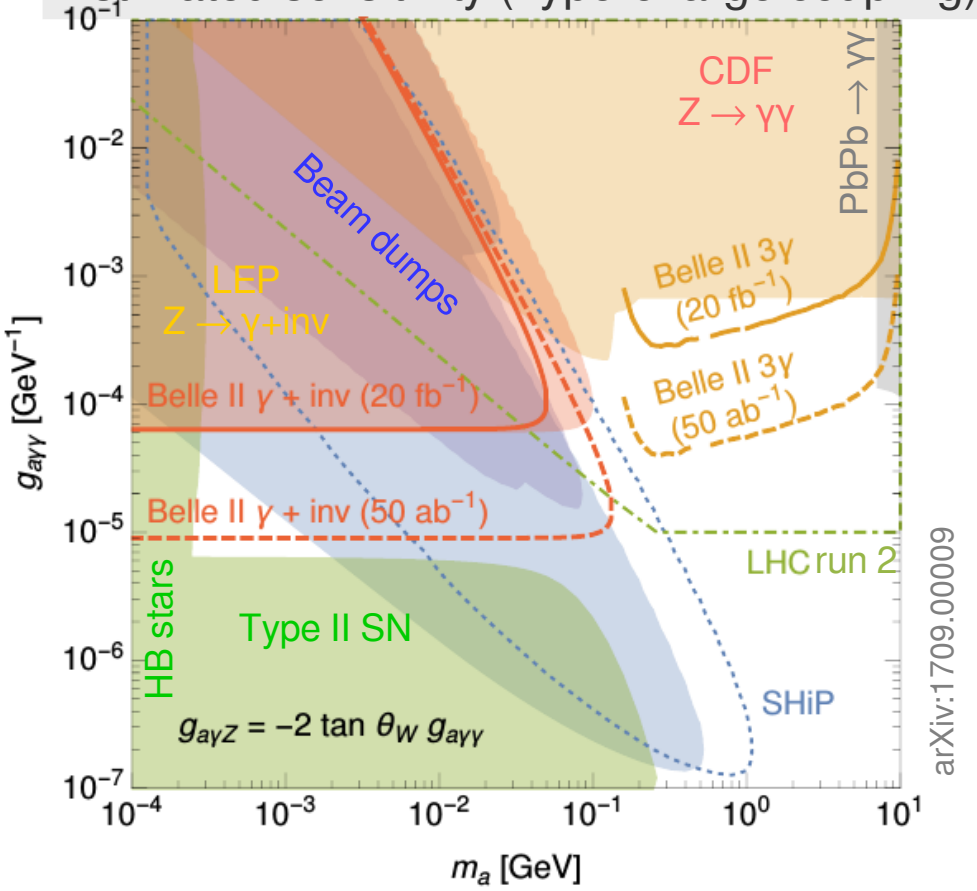


Axion-like particle search sensitivity

Estimated sensitivity (photon coupling)



Estimated sensitivity (hypercharge coupling)

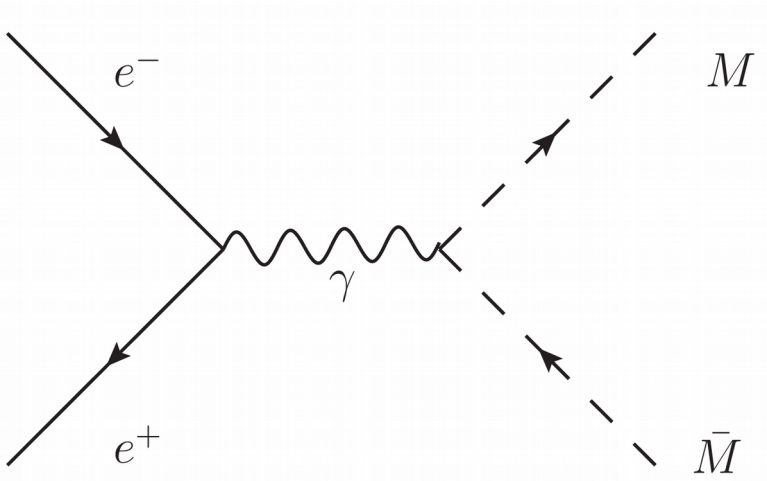


Magnetic monopoles

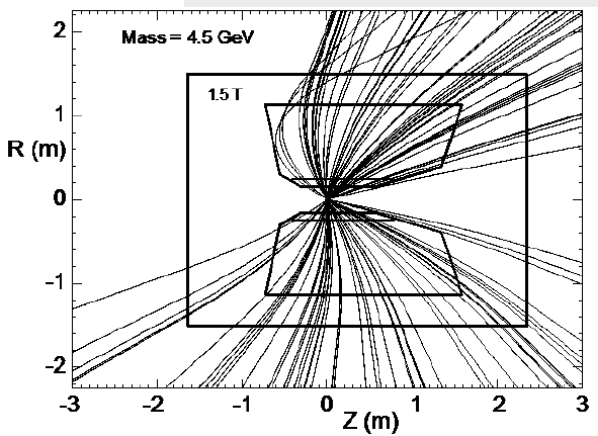
(small charge) Monopoles

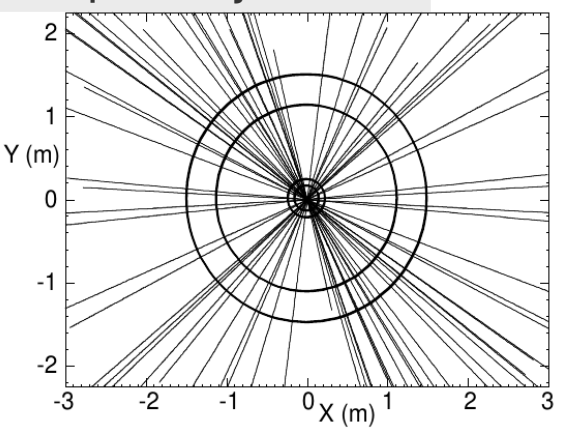
- Particle carrying magnetic charge
- Recent searches for magnetic charges $g > 68.5e$
  - Small charges $g < 10e$ are not excluded
- Signature tracks:
  - Straight in XY
  - Curved in RZ

$$z(s) = z_0 + \frac{p_z}{p_T}s + \frac{gBm}{2p_T^2}s^2$$



Examples of monopole pair trajectories



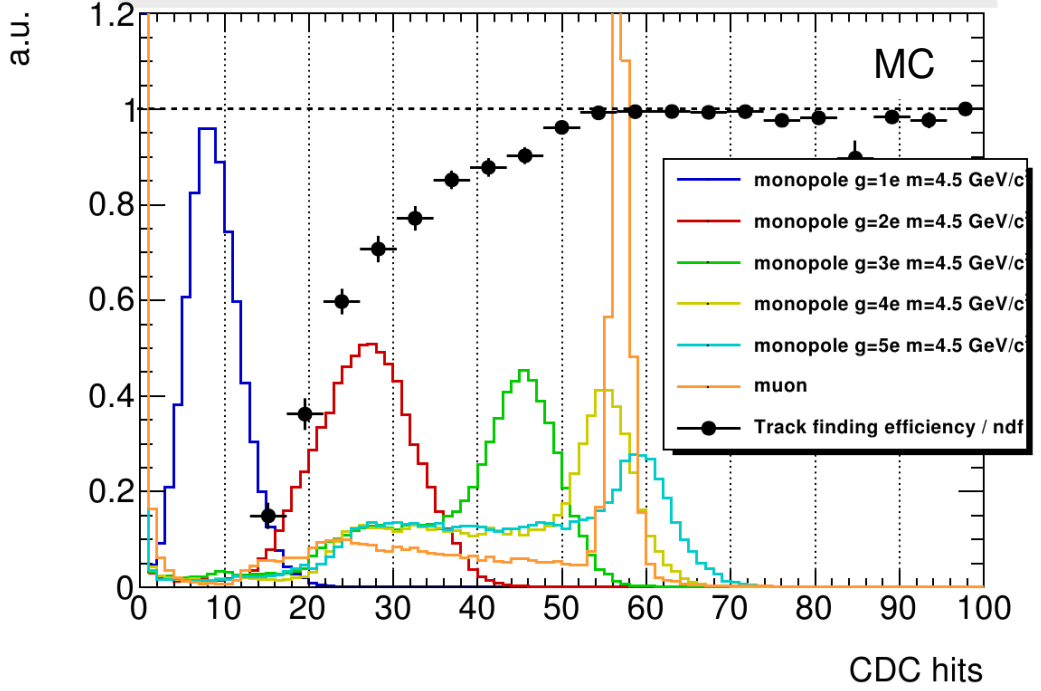


arXiv:1707.05295

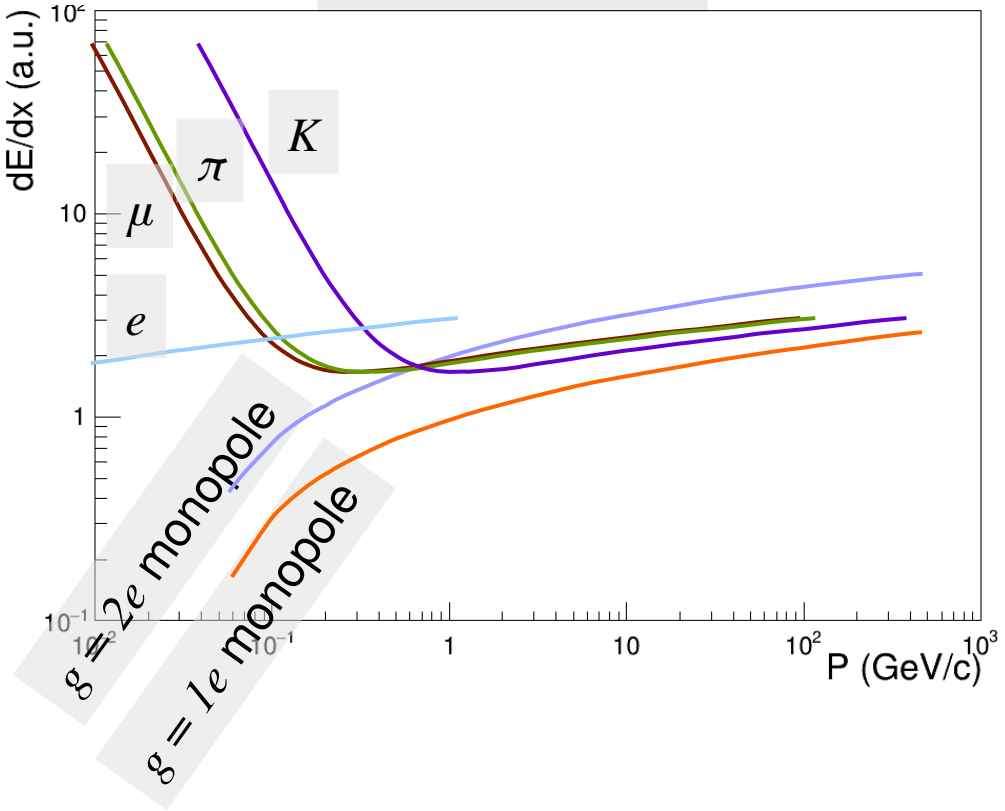
Monopole ionisation

- Weaker ionisation due to absence of $1/\beta^2$ factor for magnetic charges

Expected number of hits in drift chamber



Ionisation curves

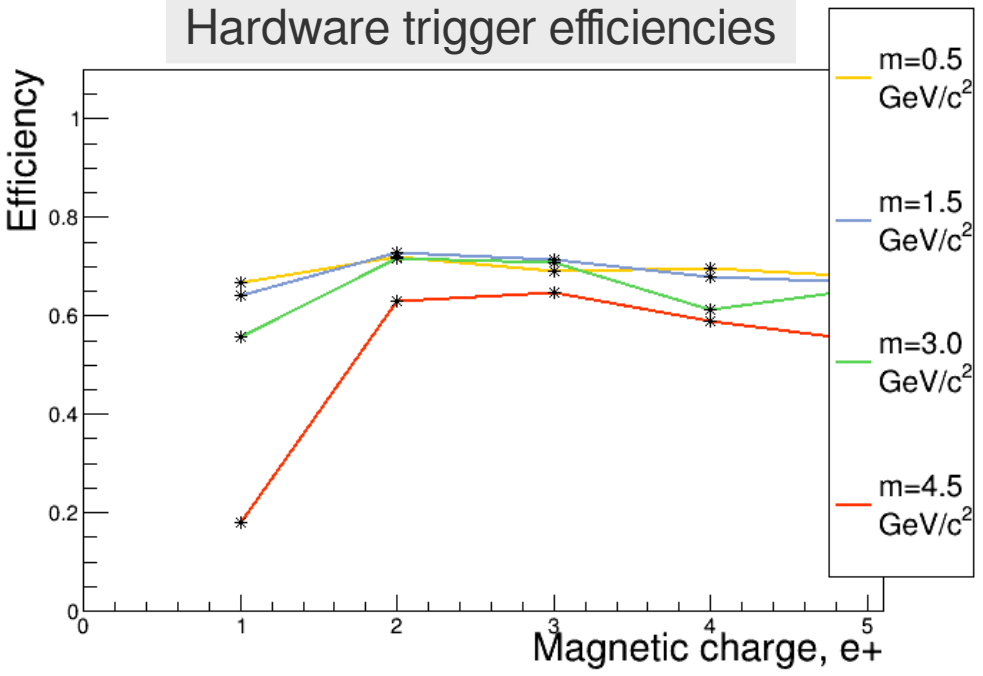


- Can be improved with dedicated tracking

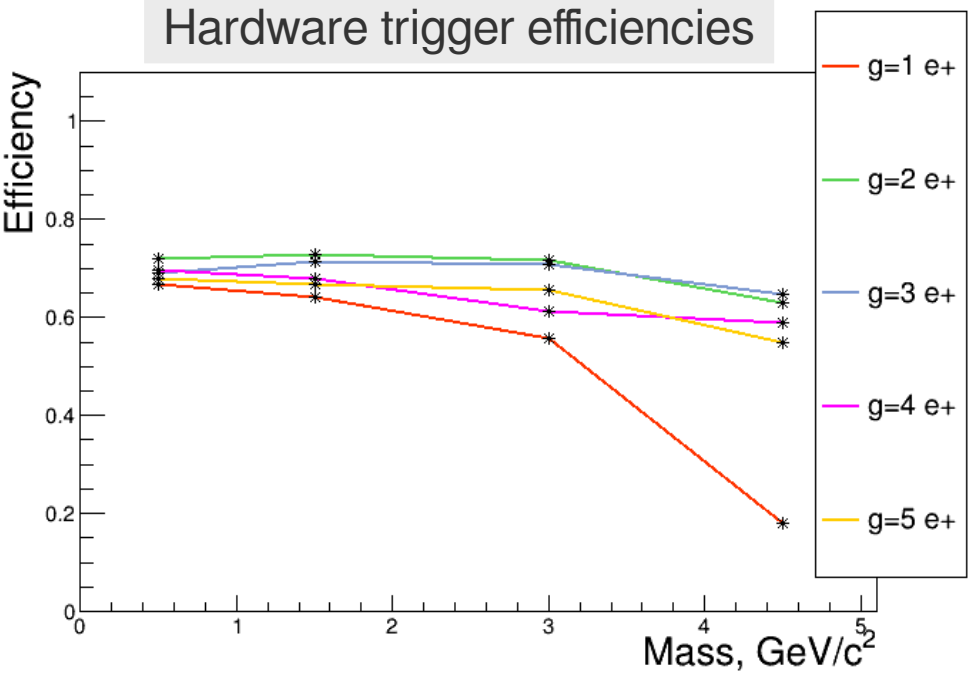
Monopole search

- Tracks are not properly reconstructed on hardware level
  - Trigger on back-to-back calorimeter clusters (low charges)
  - Trigger on >2 tracks in event (high charges)

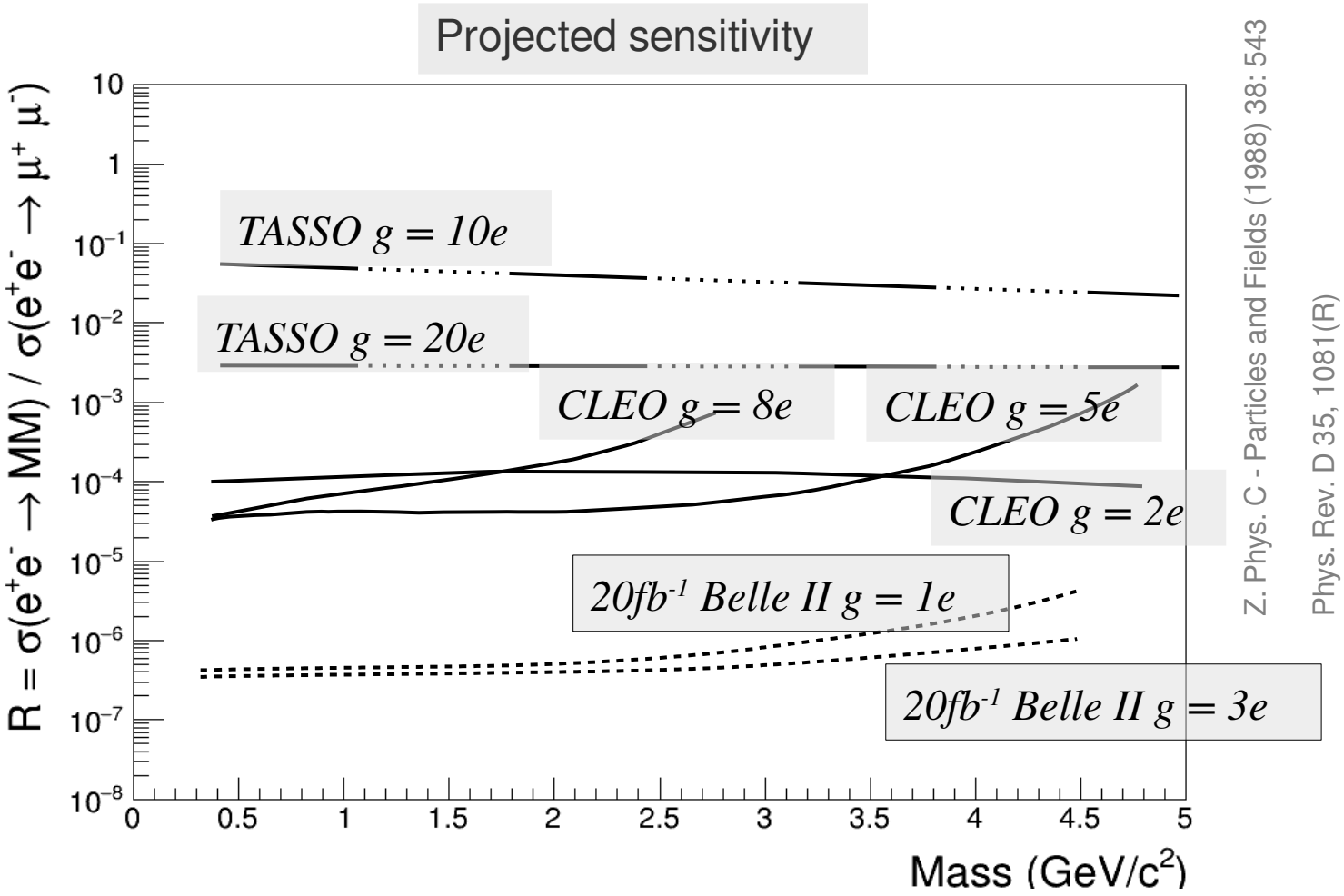
Hardware trigger efficiencies



Hardware trigger efficiencies



Monopole searches sensitivity



Summary

Summary

- Belle II is in the middle of early data taking (phase 2)
- Flexible triggers and efficient background rejection allow obtaining results even with small datasets
  - Dark photons (m < *10 GeV/c²*)
  - Axion-like particles (m < *10 GeV/c²*)
  - Magnetic monopoles (g < *5 e*)
- Even more from 2019 (phase 3)

Not mentioned:

- Invisible Z' decays
- Z' LFV decays
- Muonic dark force
- Dark Higgs
- Higgs-strahlung
- (Magnetic) inelastic dark matter
- . . .