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Search for Low Mass Dark Photons at the Belle II Experiment

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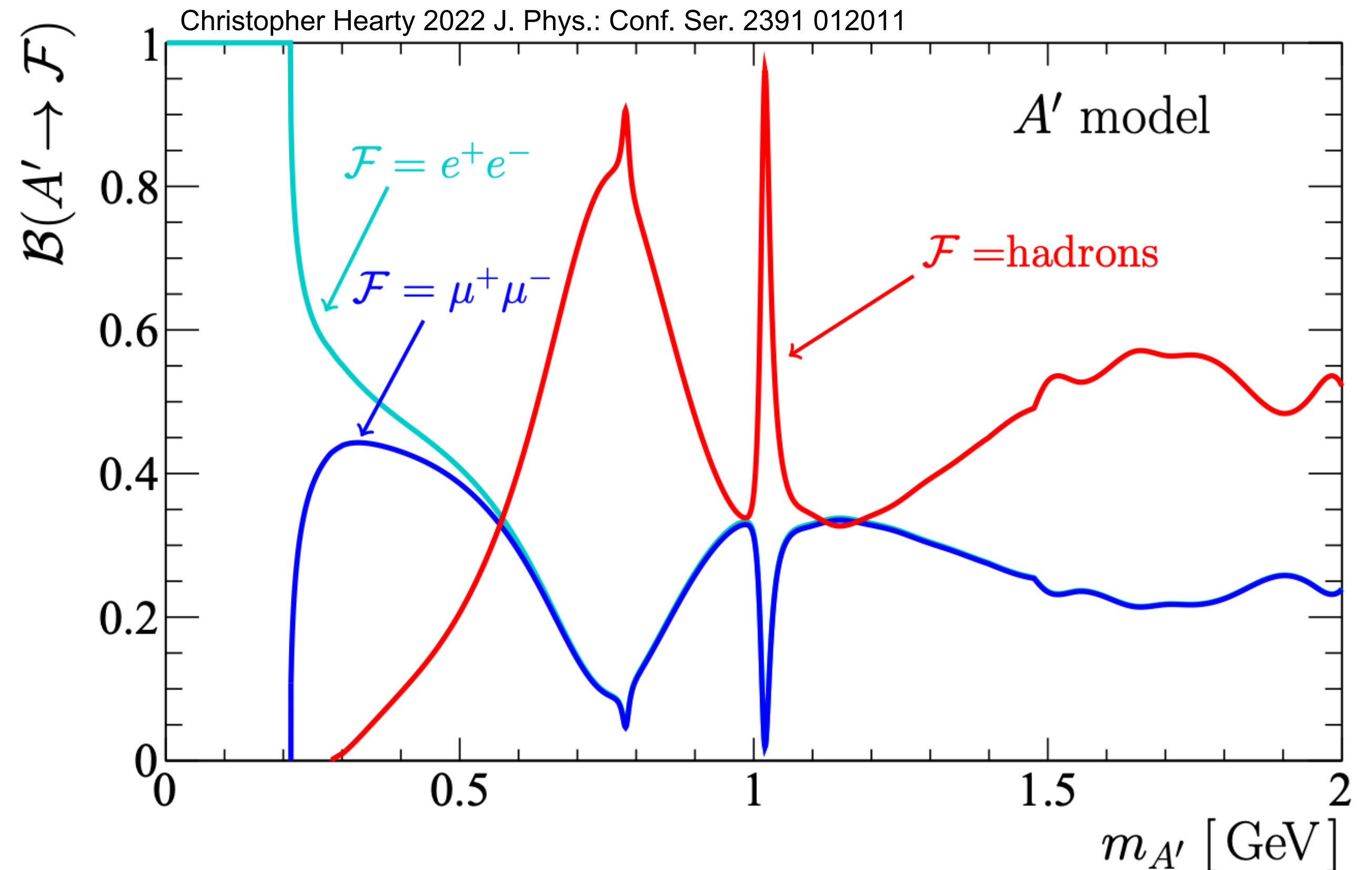
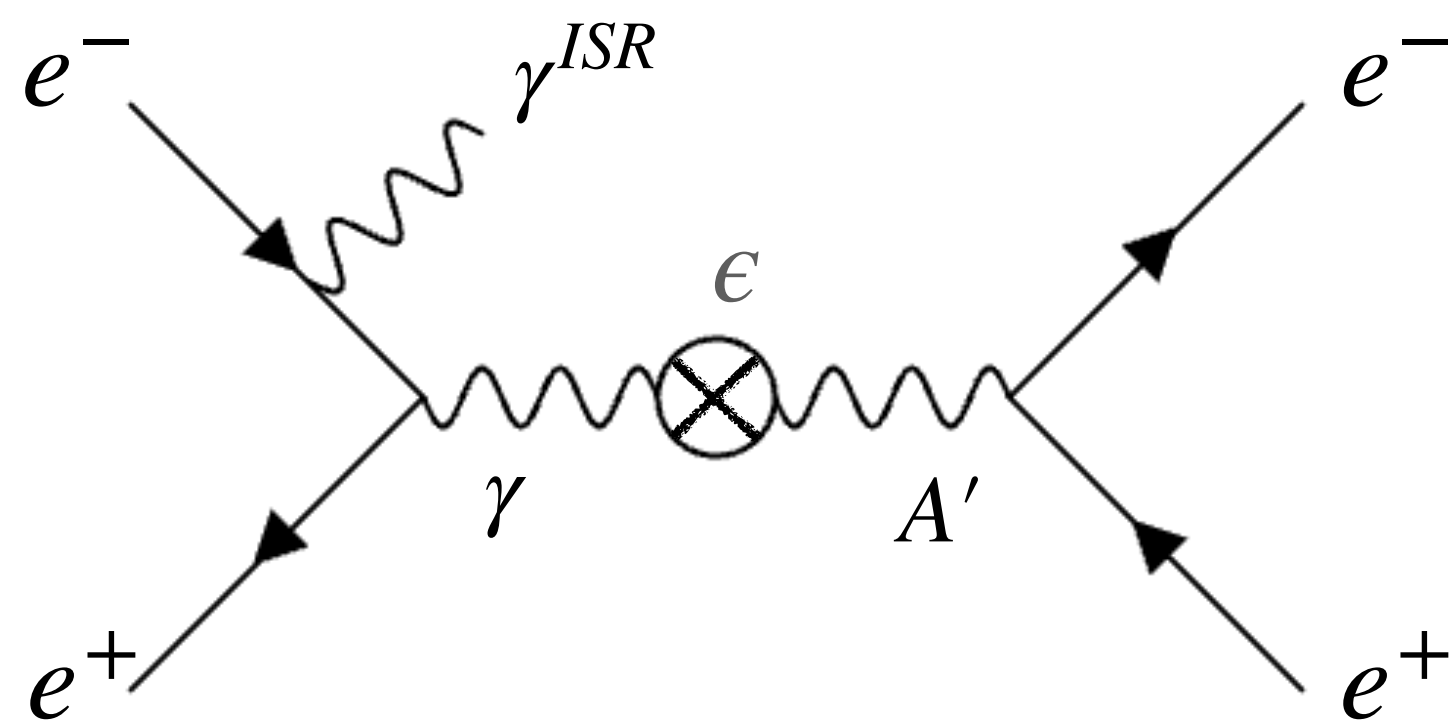
Thomas Grammatico, Michael Roney, Dhvani Sutariya

University of Victoria

Low mass dark photons

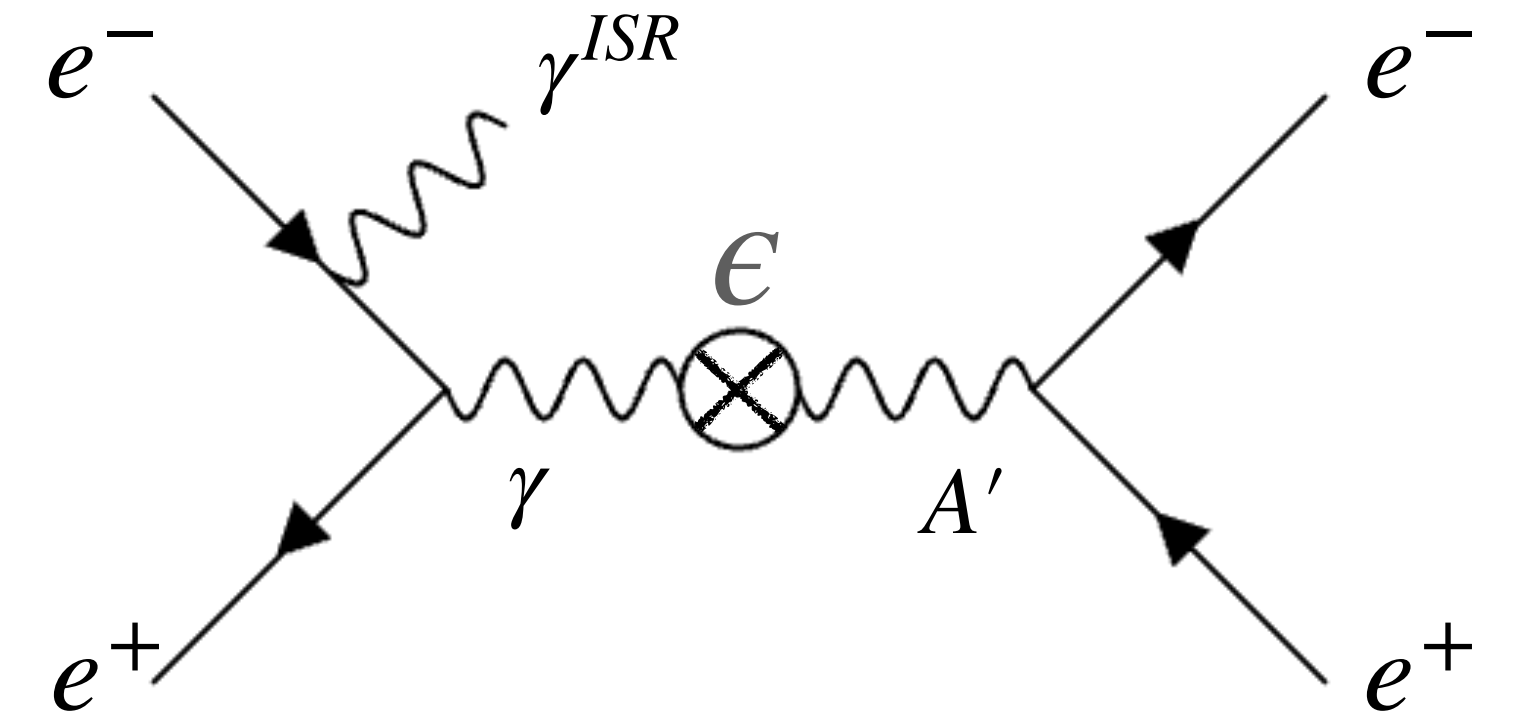
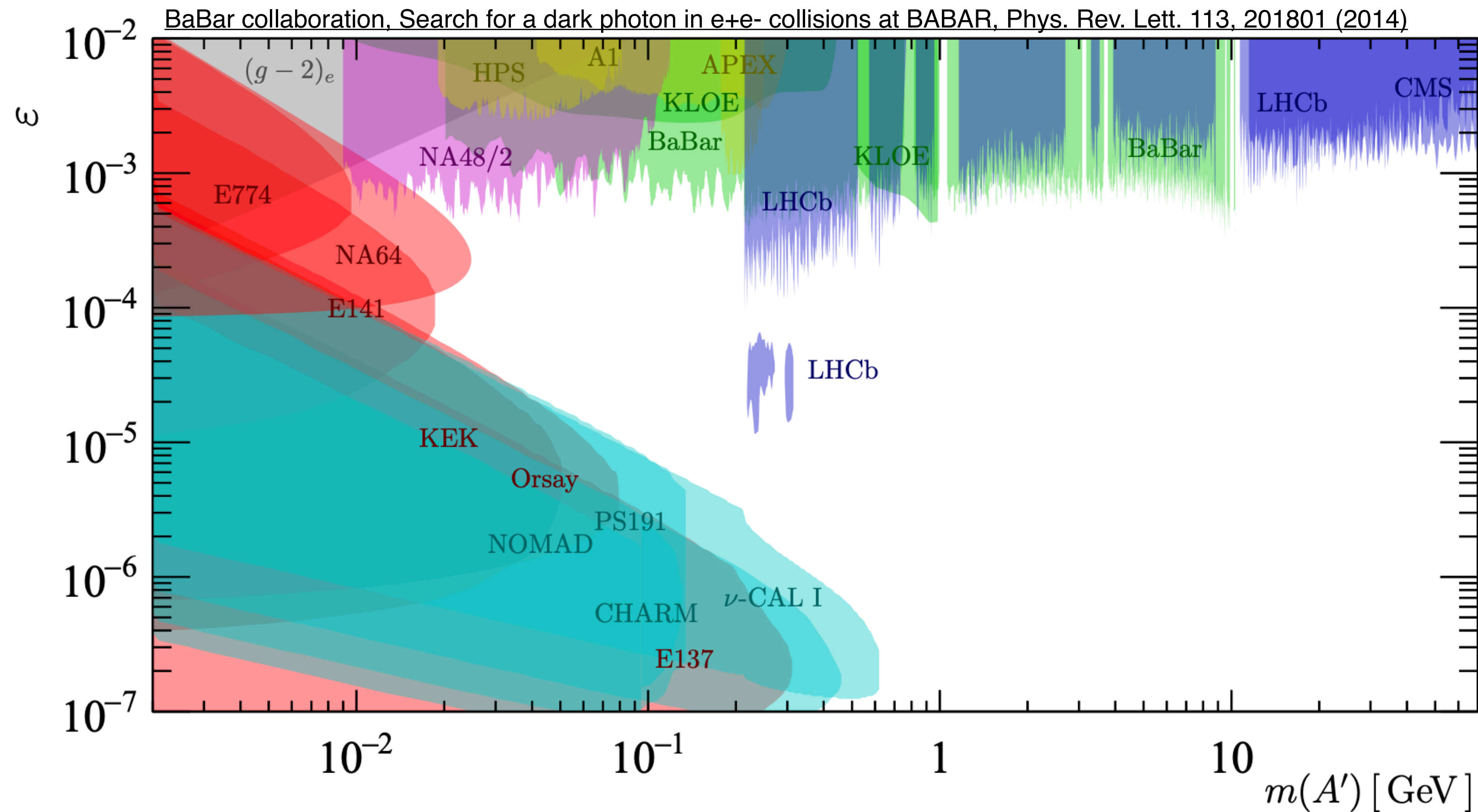
- Hypothesis : Dark photon A' interacts with Standard Model by kinematic mixing, with mixing strength ϵ
- It's mass $m_{A'}$ and ϵ are free parameters
- It $m_{A'} \leq 2m_\chi$ it must decay into Standard Model particles and the branching fraction depends on $m_{A'}$
 m_χ : dark matter mass

- Below muon pair production threshold, A' only decays into electron pair



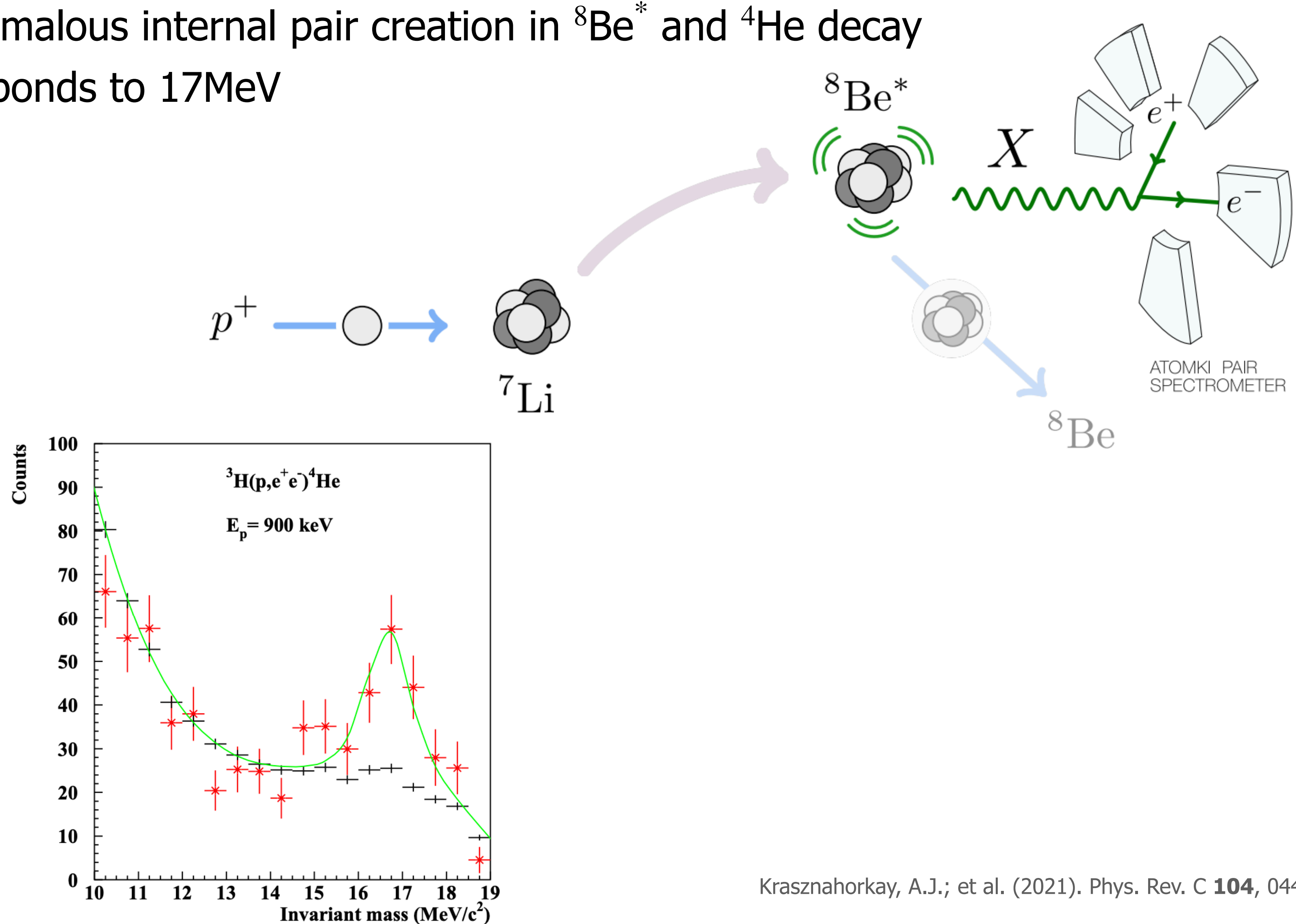
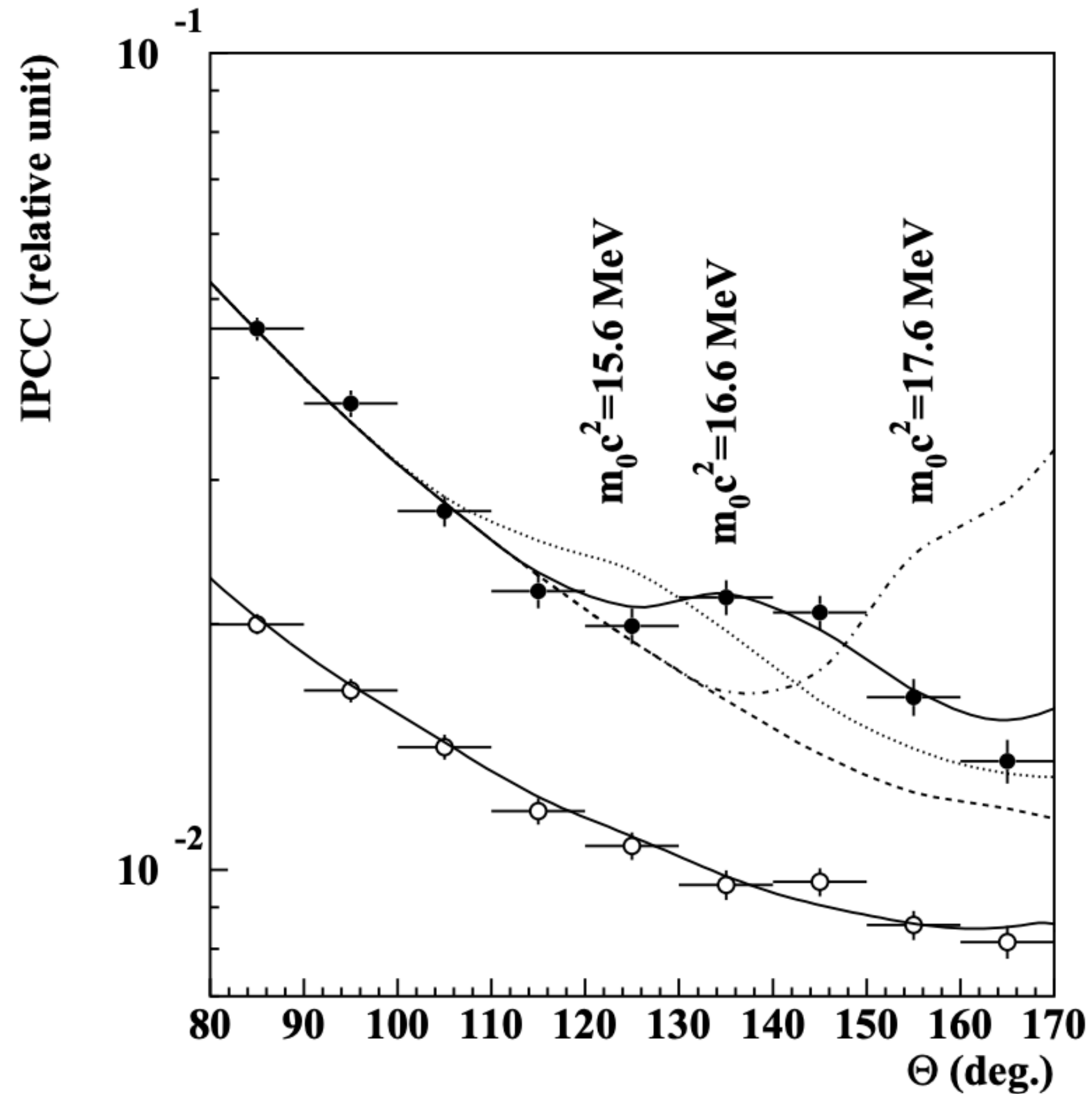
Low mass dark photons

- e^+e^- collider experiments probe A' produced from $e^+e^- \rightarrow A'\gamma \rightarrow \ell^+\ell^-\gamma$ reaction.
- Previously BaBar set up an upper limits (90% CL) of the mixing strength in $M_{A'}$ [0.02GeV , 10GeV]



Low mass dark photons and ATOMKI anomaly

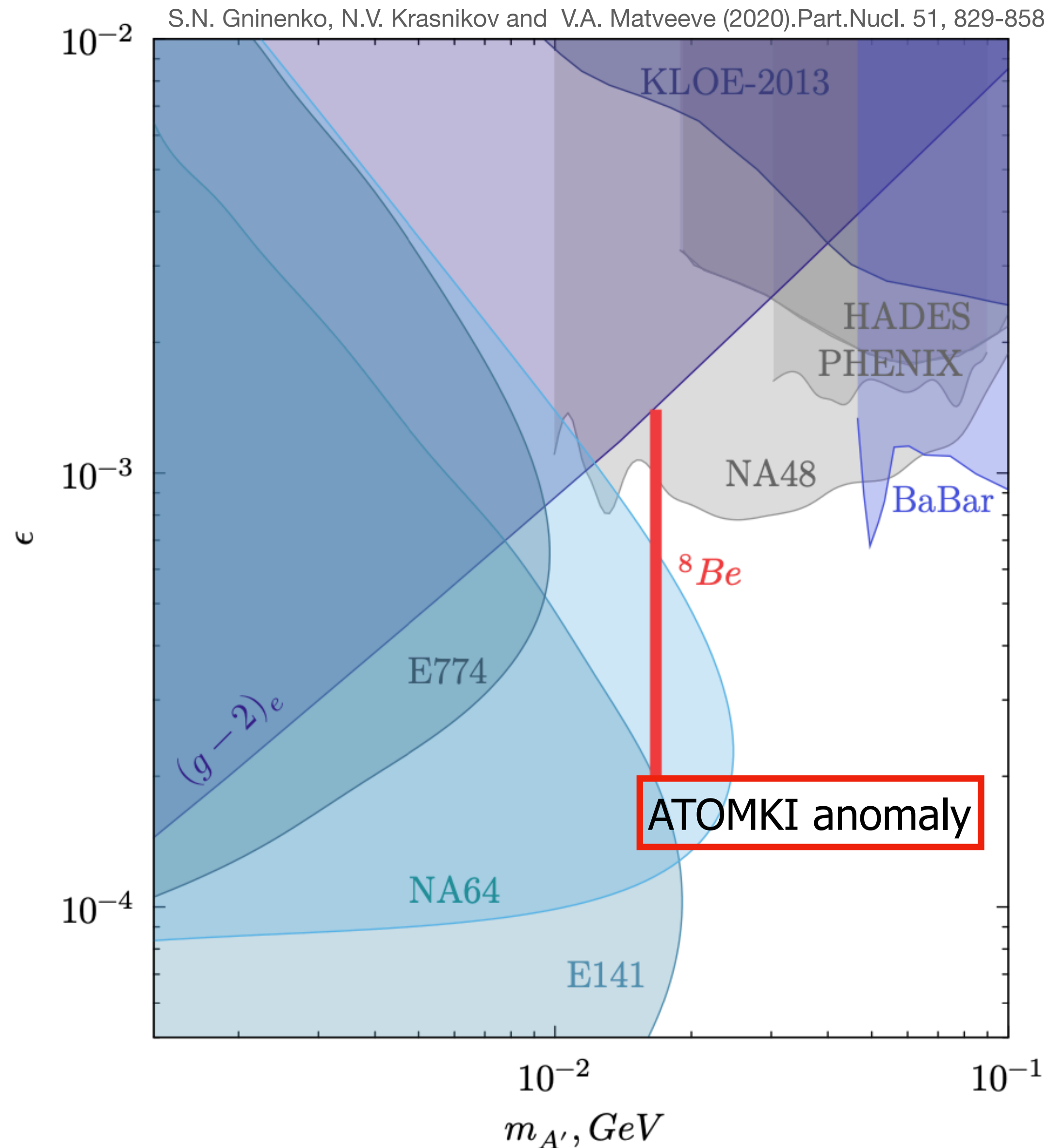
- ATOMKI collaboration studied anomalous internal pair creation in ${}^8\text{Be}^*$ and ${}^4\text{He}$ decay
- The Invariant mass of pair corresponds to 17MeV
- X17 ? unknown nuclear effect?



Krasznahorkay, A.J.; et al. (2021). Phys. Rev. C **104**, 044003

A. J. Krasznahorkay et al., Phys. Rev. Lett. **116**, 042501 (2016)

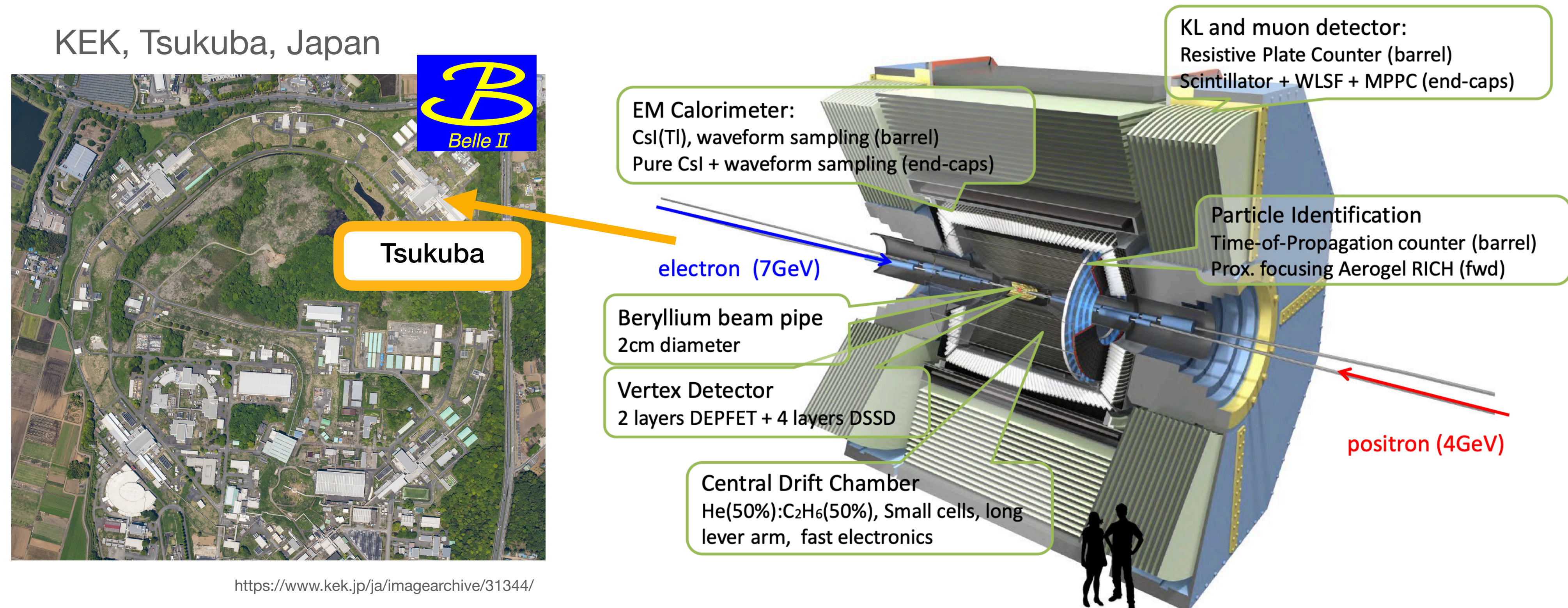
Low mass dark photons and ATOMKI anomaly



- Existing experiments could not cover this region
 - Babar mass scan starts from 20MeV
 - NA48 is not sensitive to protophobic X17
 - NA64 covered most of the region, but $6.8 \times 10^{-4} \lesssim \epsilon \lesssim 1.4 \times 10^{-3}$ is remaining unexplored

SuperKEKB and Belle II

- Belle II detector is located at the SuperKEKB asymmetric electron-positron collider operating at 10.58GeV
- Started first physics run in 2019, 427/fb data readied for the analysis
 - Well known initial state e^+e^-
 - Specialized triggers for dark sector signatures
 - Improved vertex resolution and tracking performance

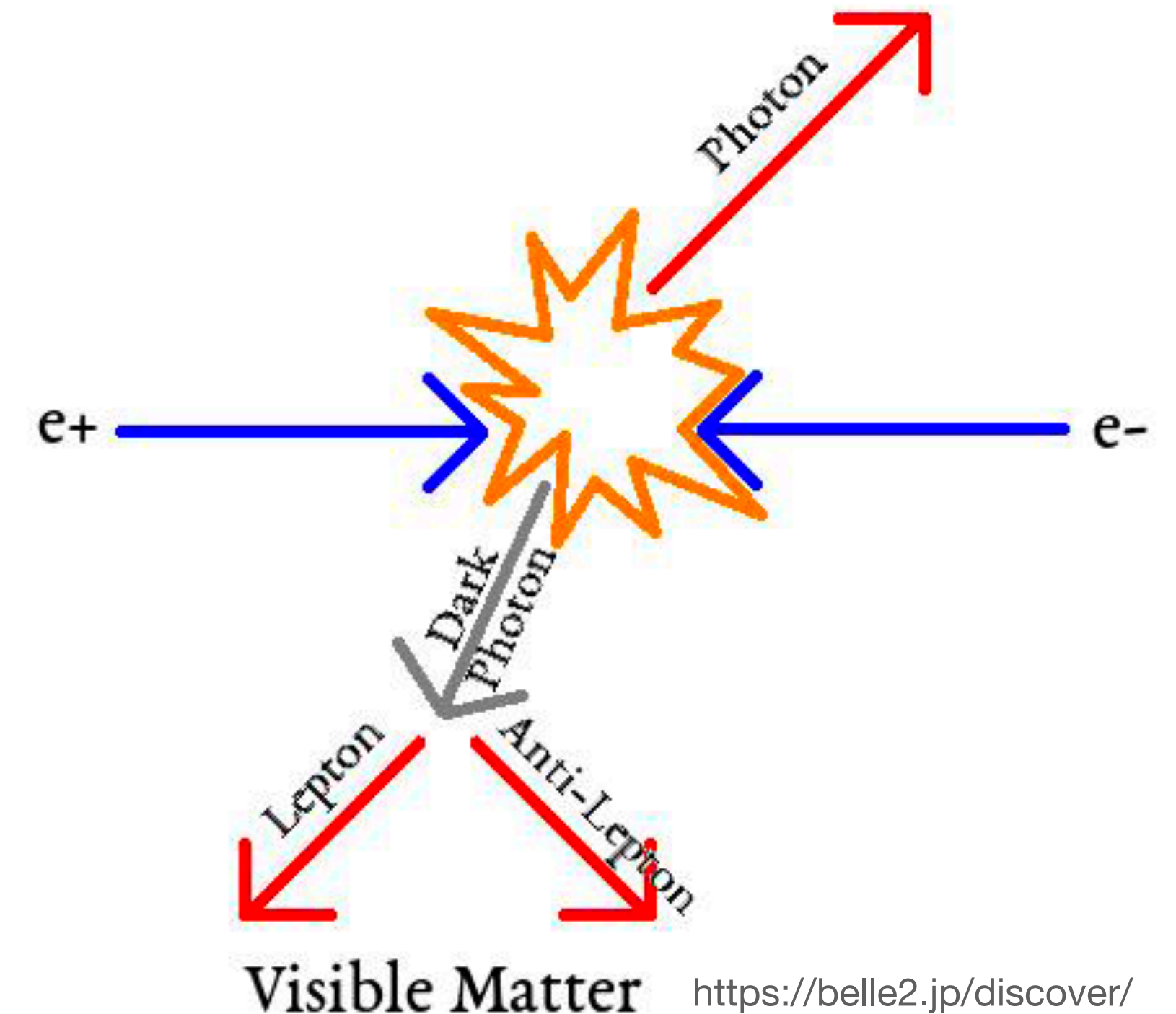


Search for low mass dark photons at Belle II

- Search for $e^+e^- \rightarrow A'\gamma \rightarrow e^+e^-\gamma$
- Signature : localized excess in Invariant mass ($M_{e^+e^-}$) distribution

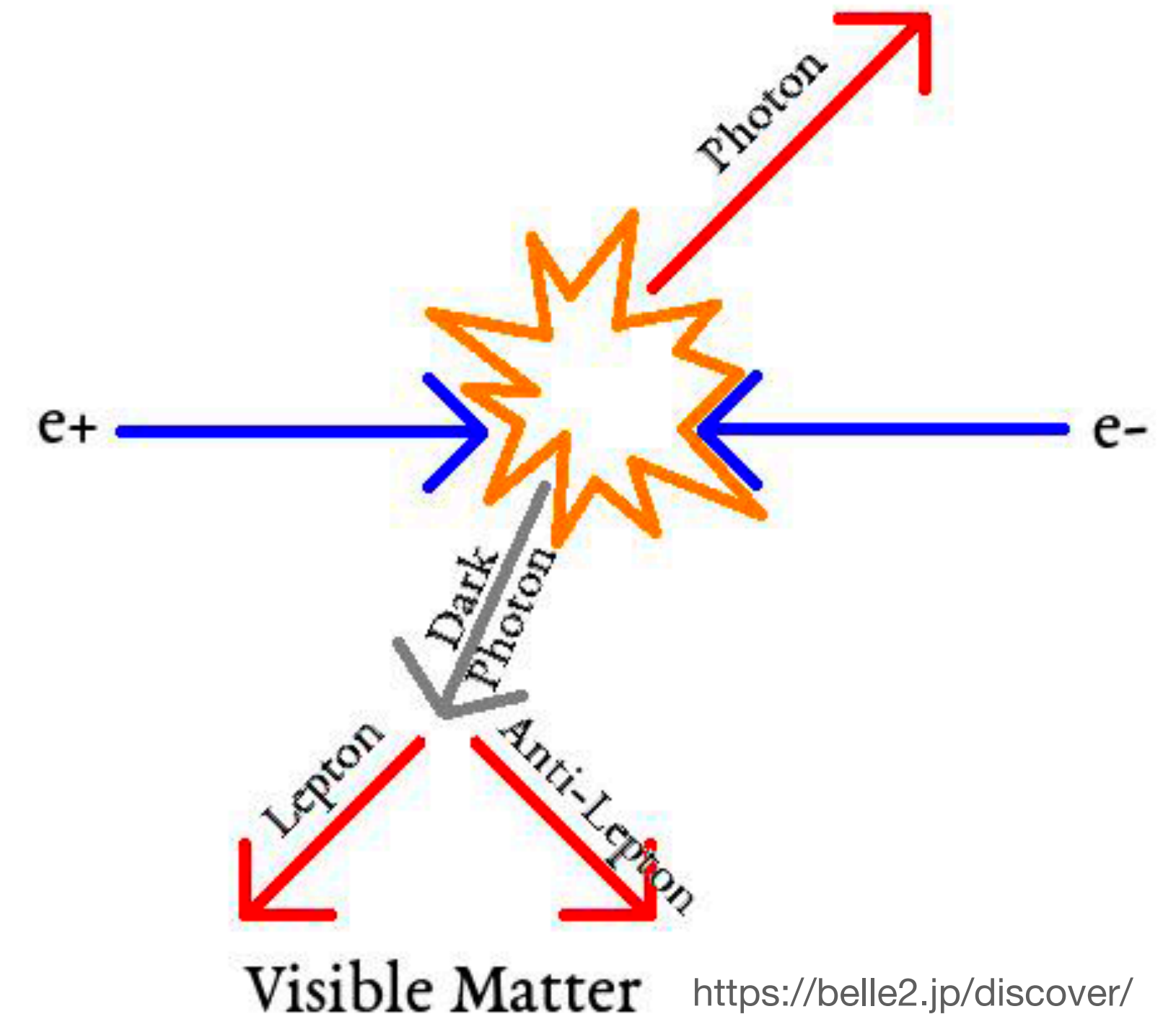
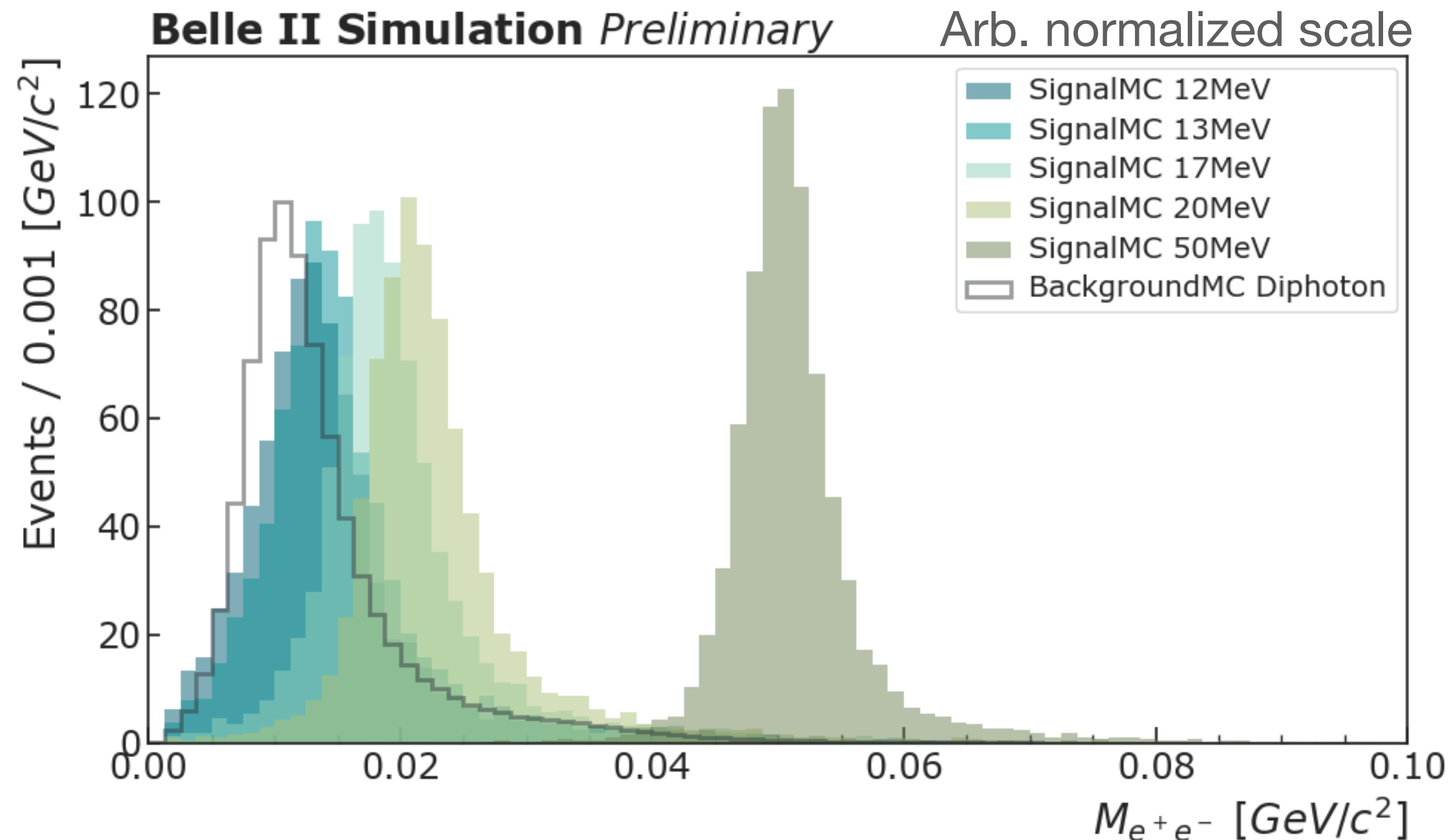
Reconstruction

- Select two electron tracks, construct A' candidate
- Perform vertex fit
- Combine A' with an energetic photon
- Perform energy constrained kinematic fit

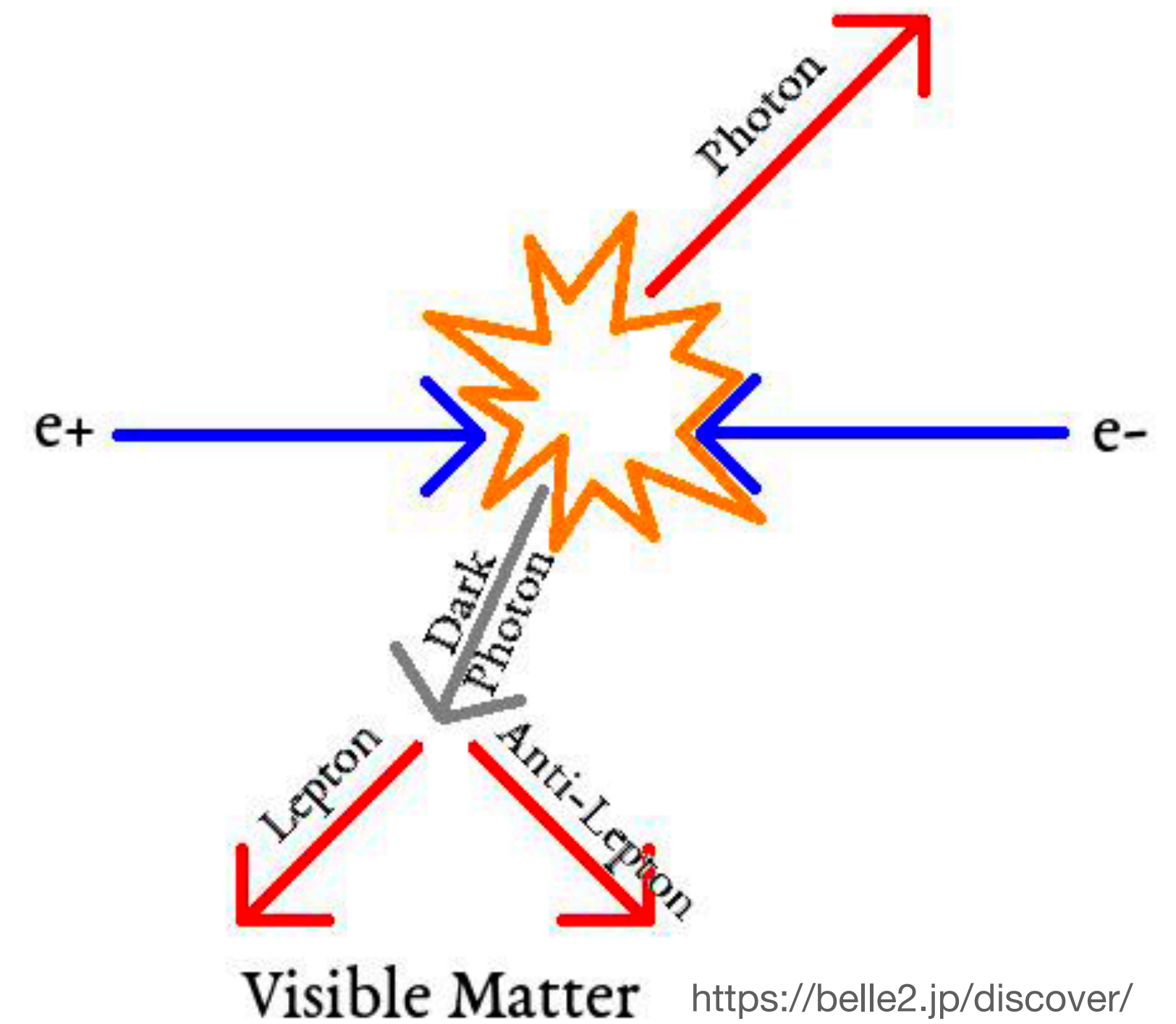
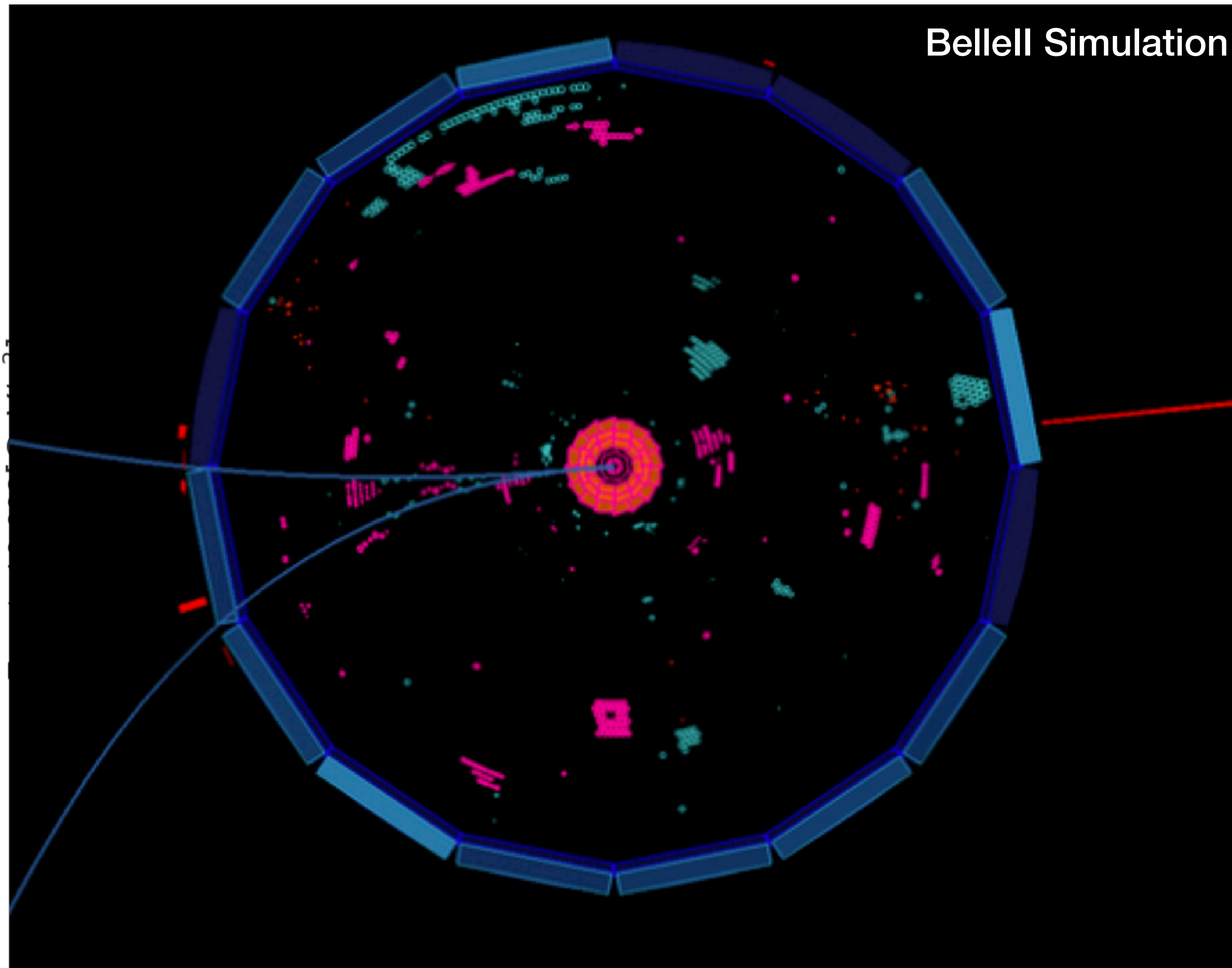


Search for low mass dark photons at Belle II

- Search for $e^+e^- \rightarrow A'\gamma \rightarrow e^+e^-\gamma$
- Signature : localized excess in Invariant mass ($M_{e^+e^-}$) distribution
- Dominant background : $e^+e^- \rightarrow \gamma\gamma \rightarrow e^+e^-\gamma$ (Diphoton event with photon conversion)



Search for low mass dark photons at Belle II



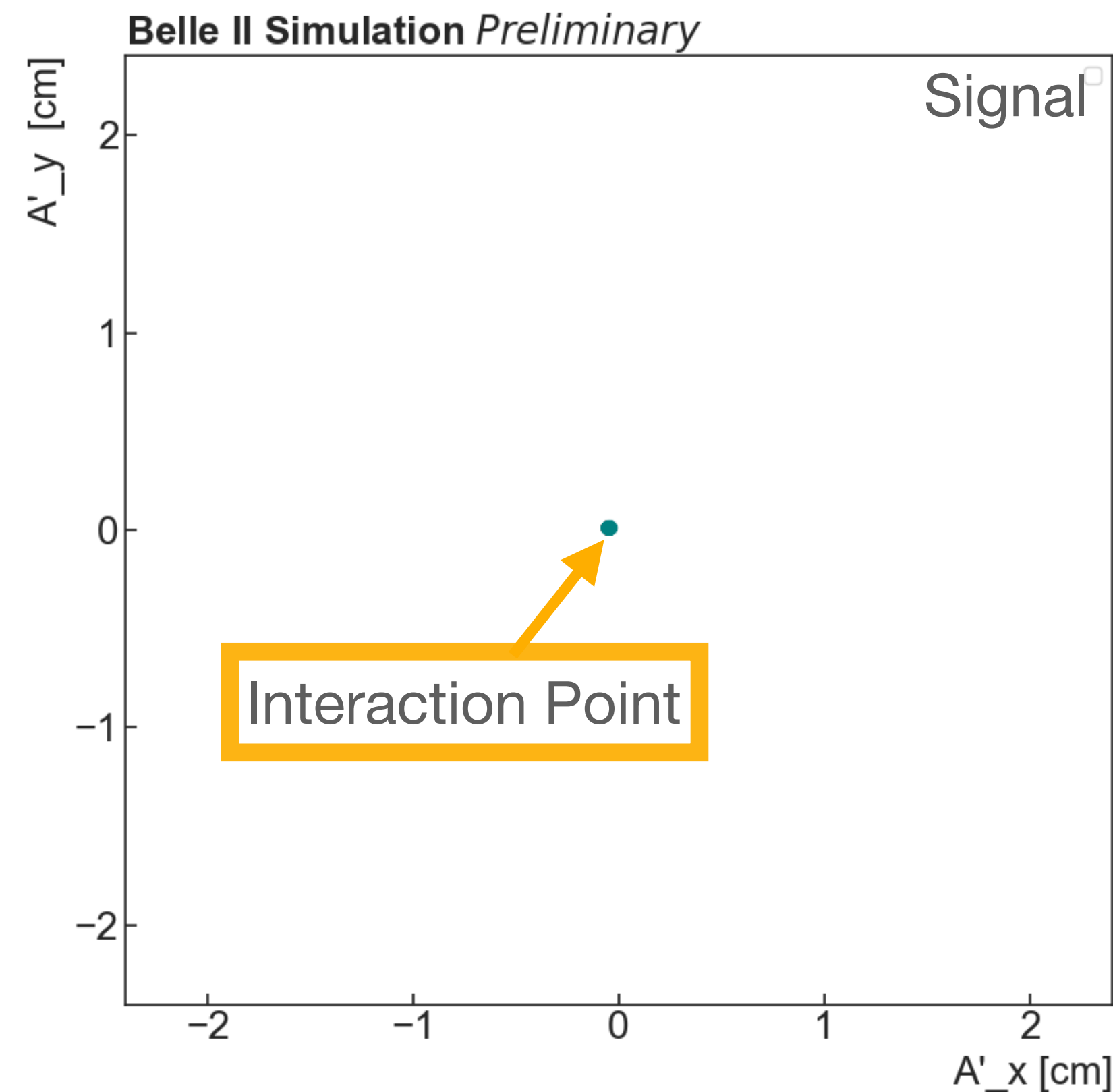
Converted photon background

- Converted photon background mimics signal
- Sideband is important to validate this background

Converted photon background

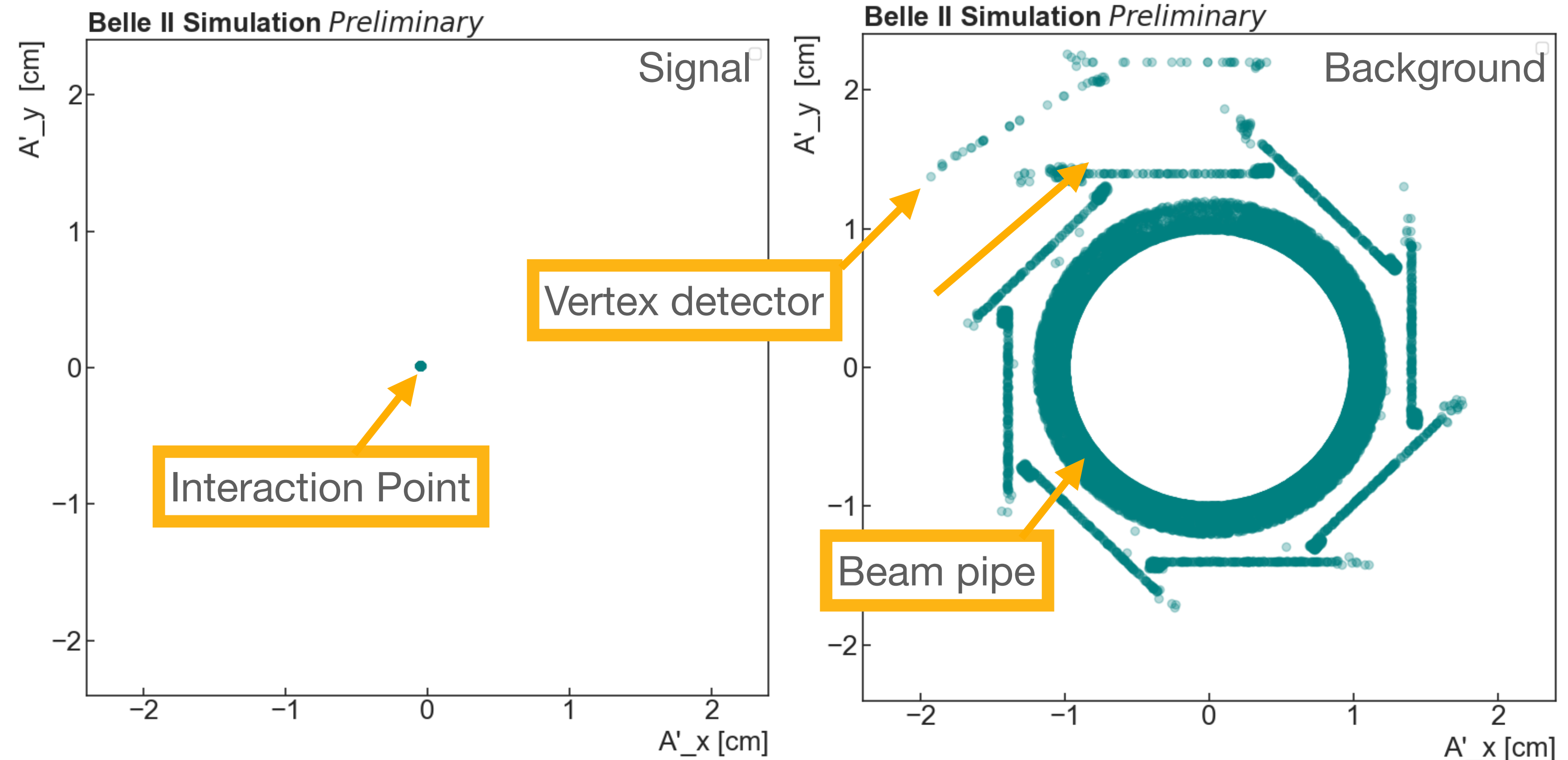
- Converted photon background mimics signal
- Sideband is important to validate this background
 - Dark photons decay promptly \rightarrow Signal events distribute at transverse distance ~ 0 cm.

* “True” vertex location in transverse plane



Converted photon background

- Converted photon background mimics signal
 - Sideband is important to validate this background
 - Dark photons decay promptly \rightarrow Signal events distribute at transverse distance ~ 0 cm.
 - Photon conversion happens at the material
- ➔ Use transverse distance?**



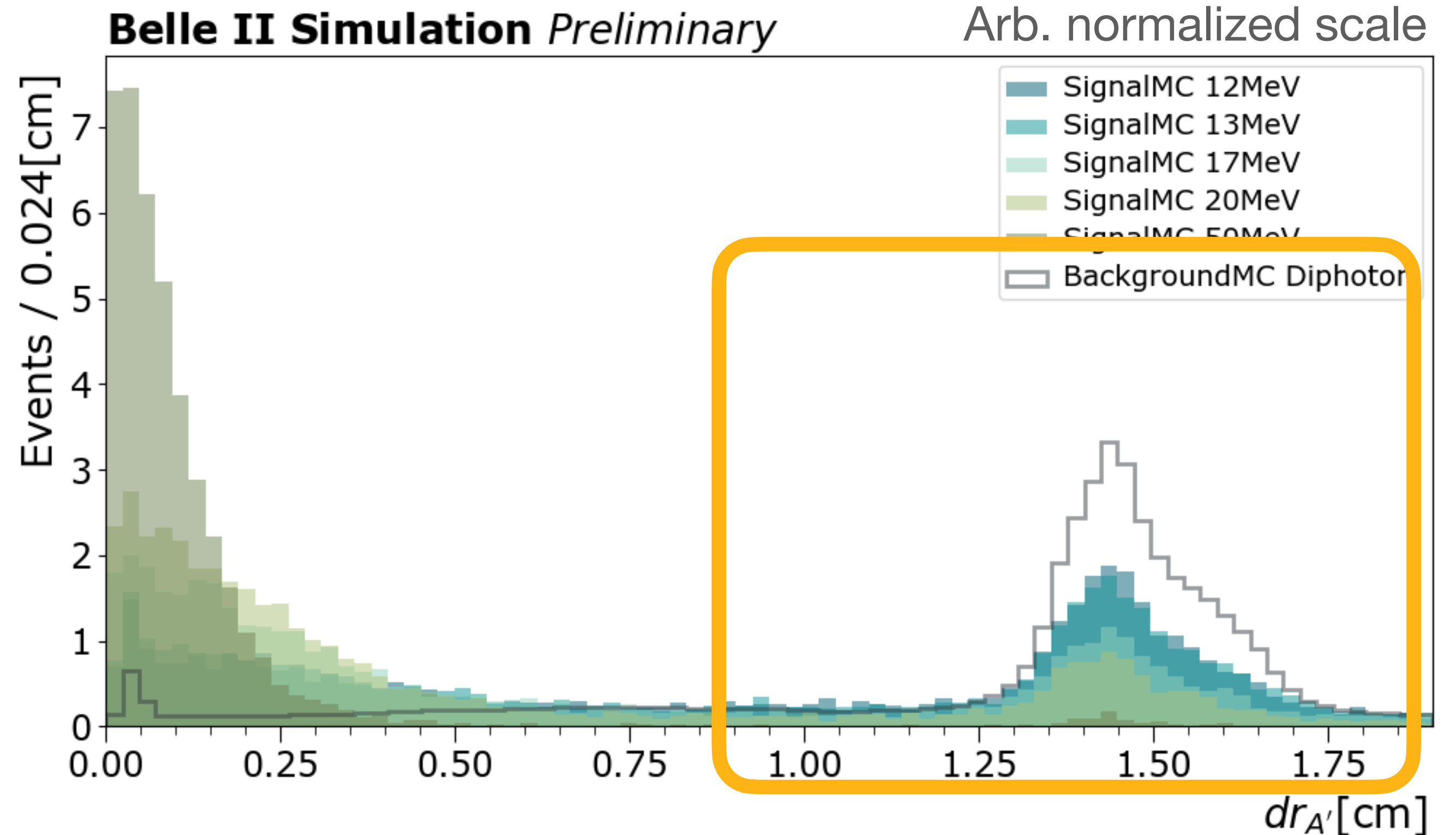
Converted photon background

- Converted photon background mimics signal
- Sideband is important to validate this background
 - Dark photons decay promptly \rightarrow Signal events distribute at transverse distance ~ 0 cm.
 - Photon conversion happens at the detector material

➔ Use transverse distance?

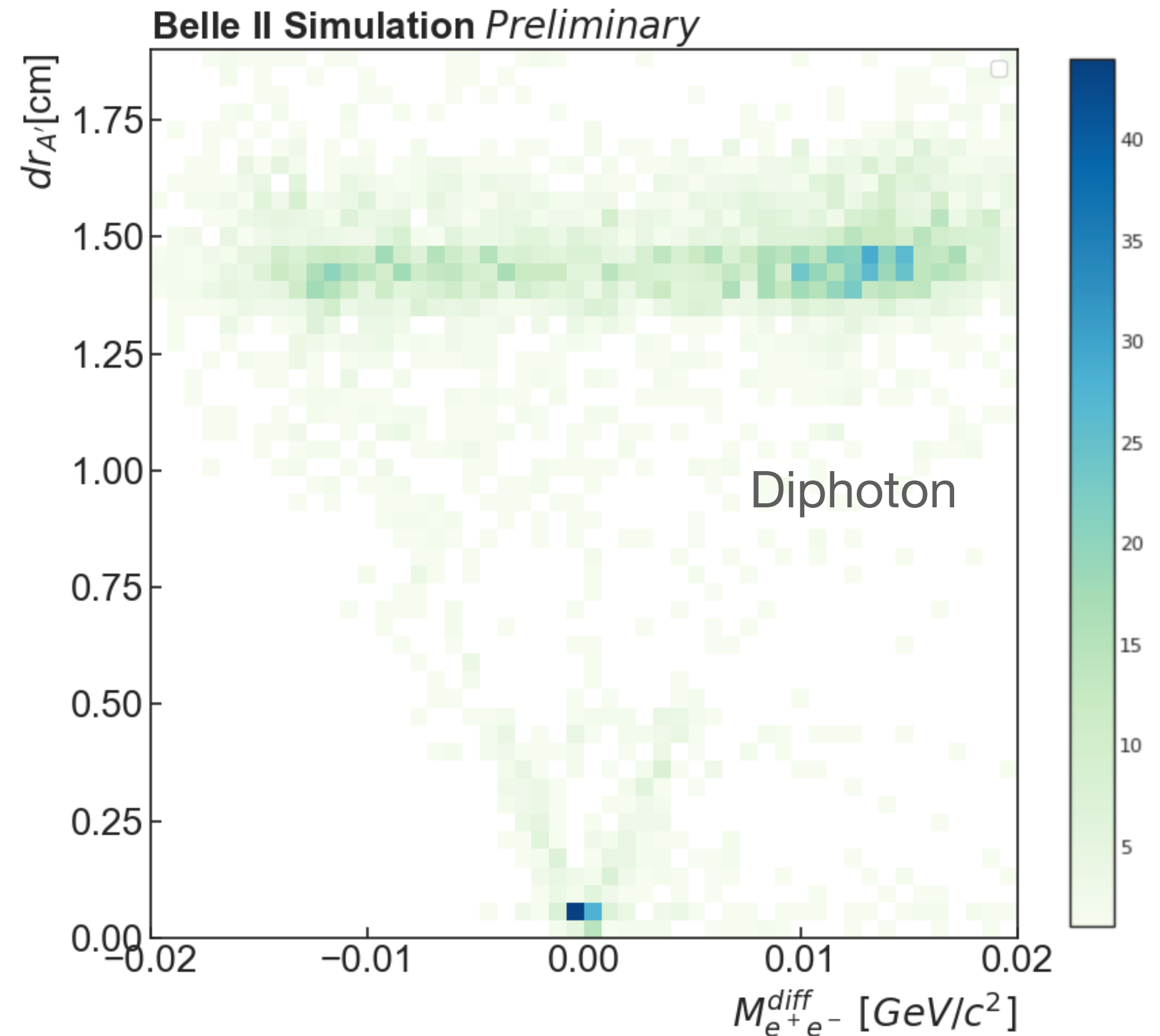
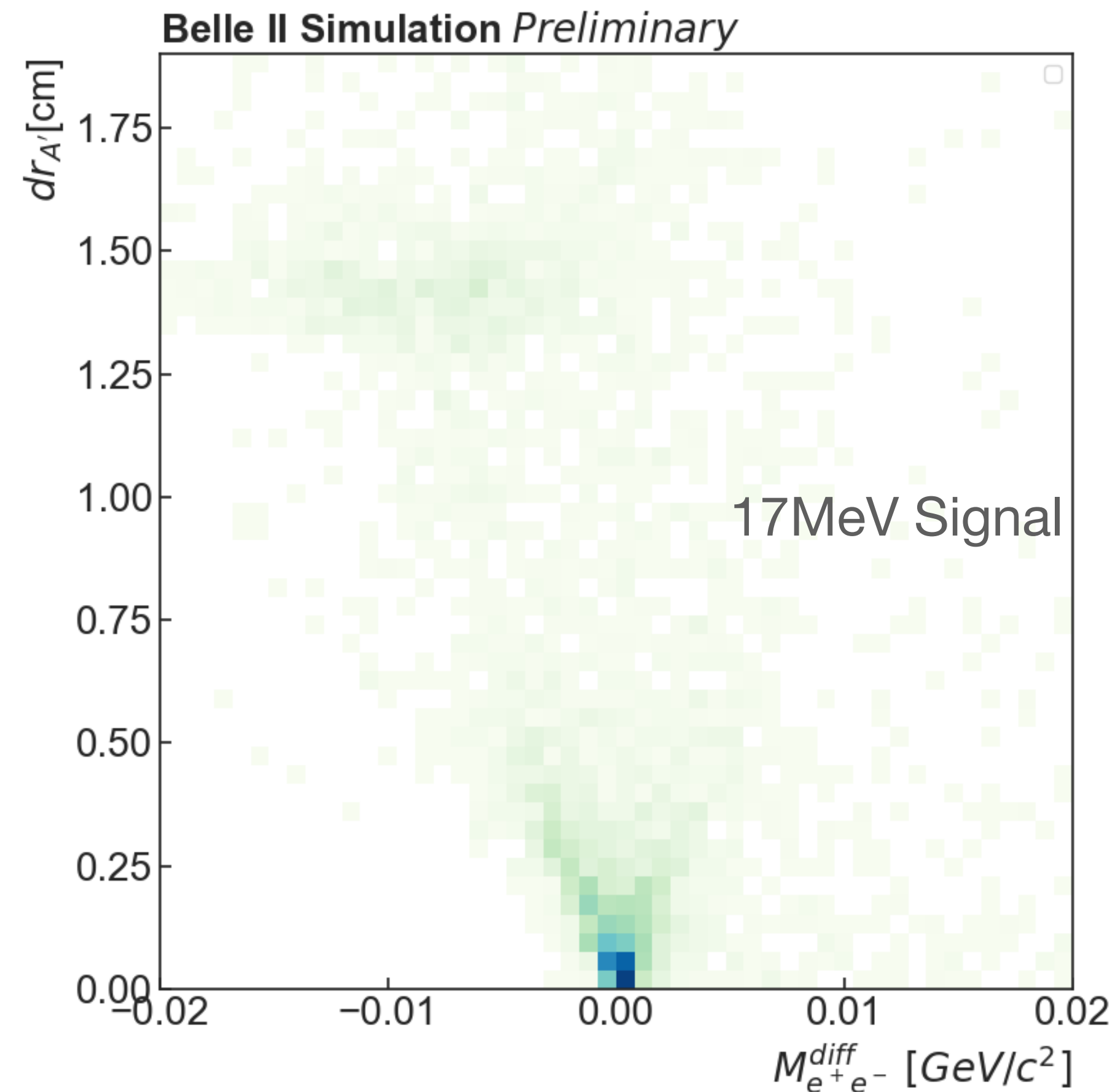
➔ Misreconstructed low mass signals also have peak at conversion peak ..
Cannot be used by itself

* Reconstructed transverse distance
Arb. normalized scale



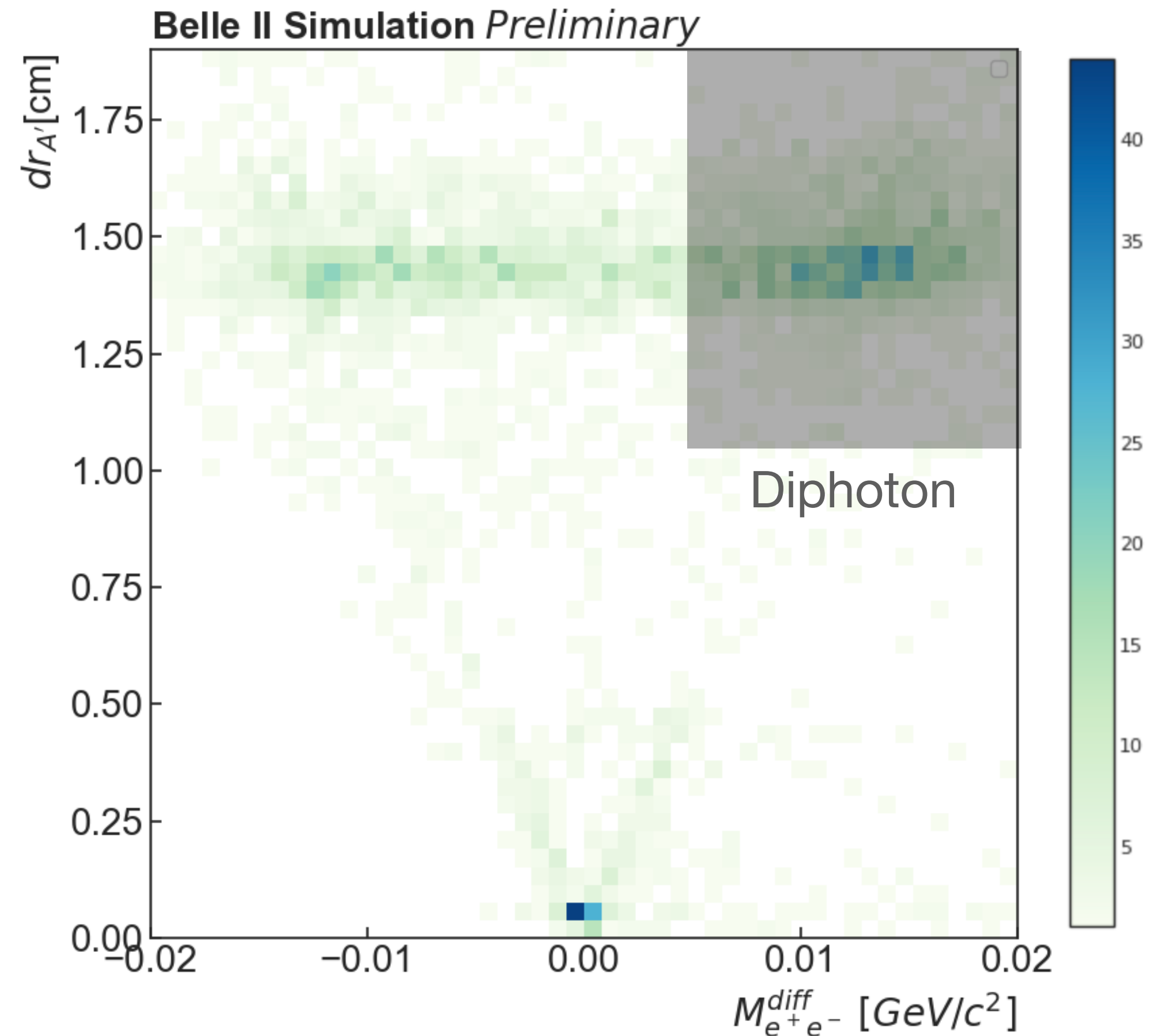
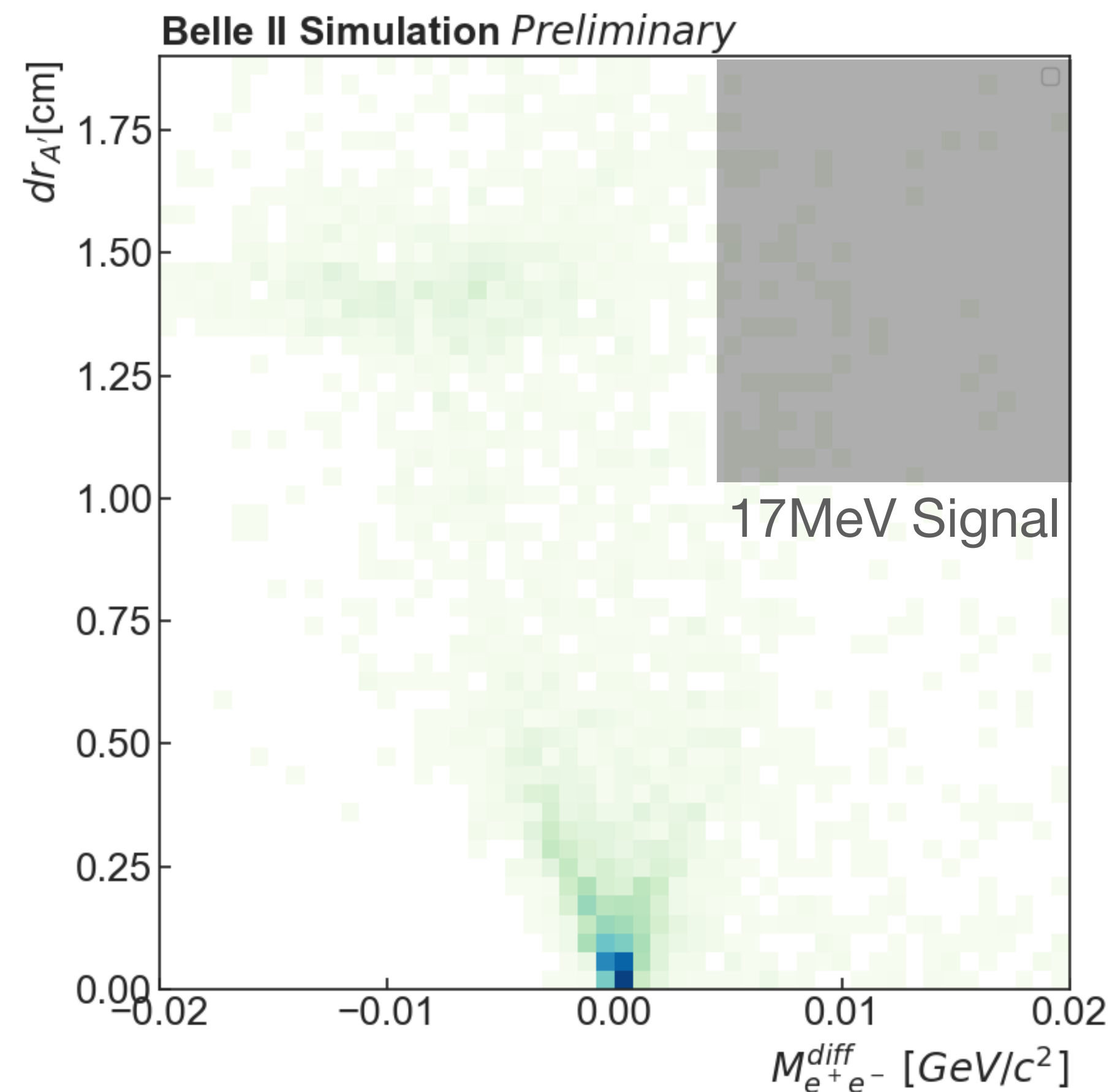
Sideband proposal

- Vertex fit shifts Invariant mass of A' candidate
- The Invariant mass shift $M_{e^+e^-}^{diff} = M_{e^+e^-}^{After\ Fit} - M_{e^+e^-}^{Before\ Fit}$ can separate signal and background events concentrated at transverse distance peak



Sideband proposal

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- The Invariant mass shift $M_{e^+e^-}^{diff} = M_{e^+e^-}^{After Flt} - M_{e^+e^-}^{Before Flt}$ can separate signal and background events concentrated at transverse distance peak -> Define 2D sideband



Summary & Projection

- ATOMKI anomaly suggests 17MeV dark photon, e^+e^- collider experiments search for it's visible decay
- Below 20MeV is remaining unexplored due to the uncertainty from converted photon background
- Belle II analysis on $e^+e^- \rightarrow A'\gamma \rightarrow e^+e^-\gamma$ is ongoing to probe this region
 - Sideband study to validate converted photon background is presented
 - Planning to apply on 427/fb data

