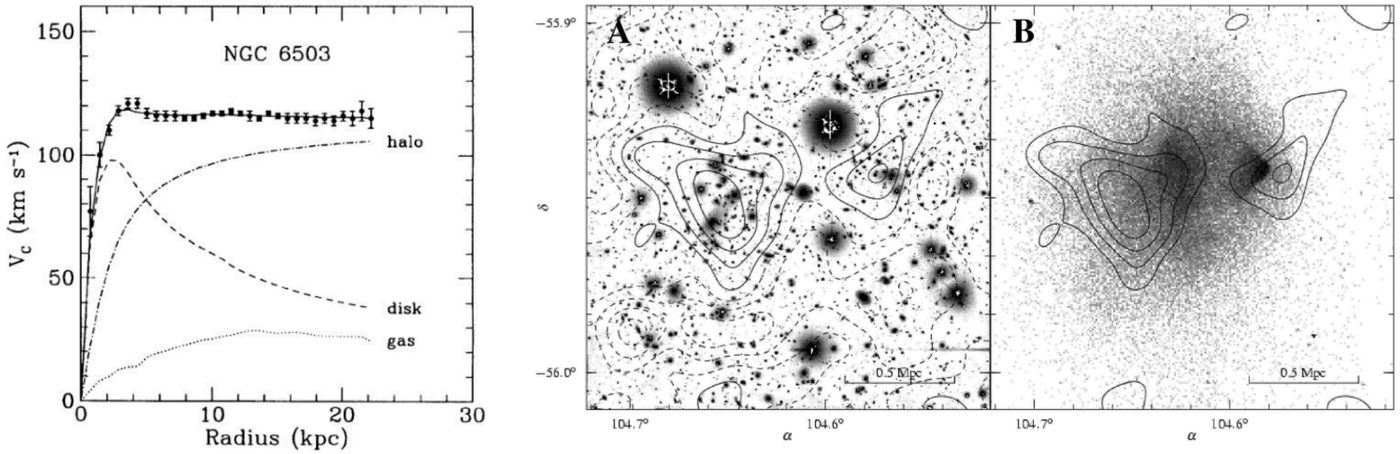
Developing a Displaced Vertex Trigger for Dark Matter Searches at the Belle II Experiment

July 12th, 2023

Elia Schmidt

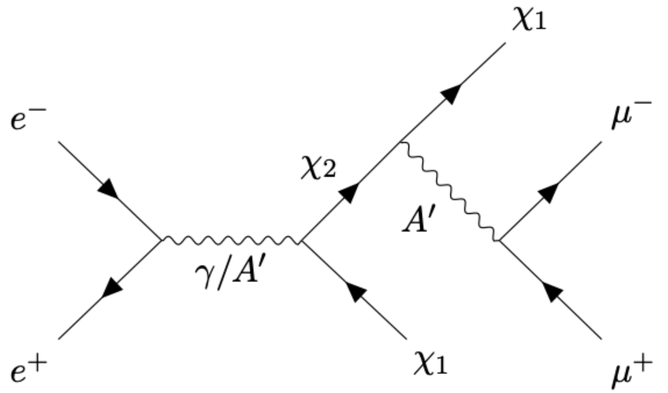
Motivation

- Evidence for dark matter (DM) is overwhelming



Evidence for dark matter from (1) and (2)

- No signal despite great experimental efforts
- New models with dark sectors
- Evade direct detection
- Discovery potential at colliders



Example vertex of inelastic dark matter

Inelastic Dark Matter (iDM)

- iDM could be produced at LHC and Belle II
- For large DM masses (~100GeV) LHC favoured (4)
- Otherwise, clean environment of lepton colliders favoured
- **Belle II** is well suited

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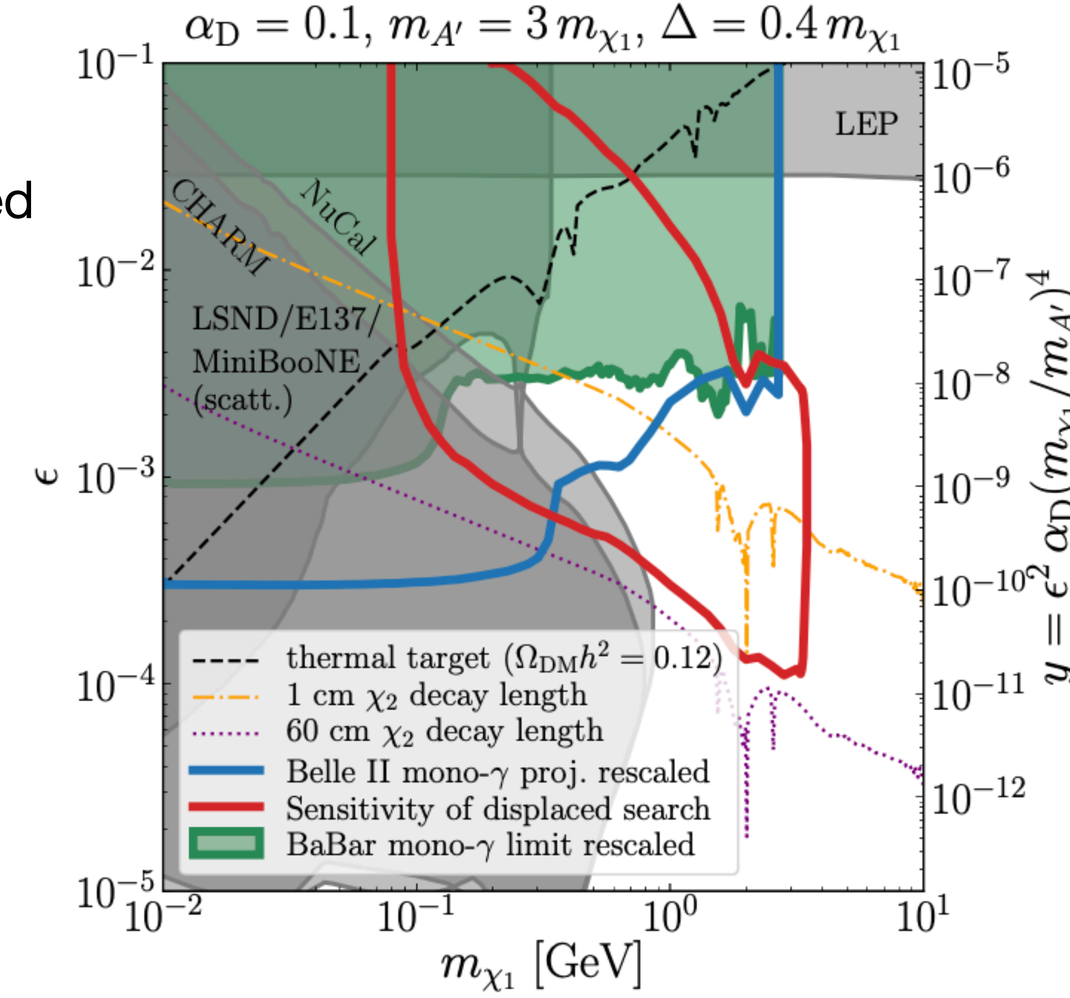
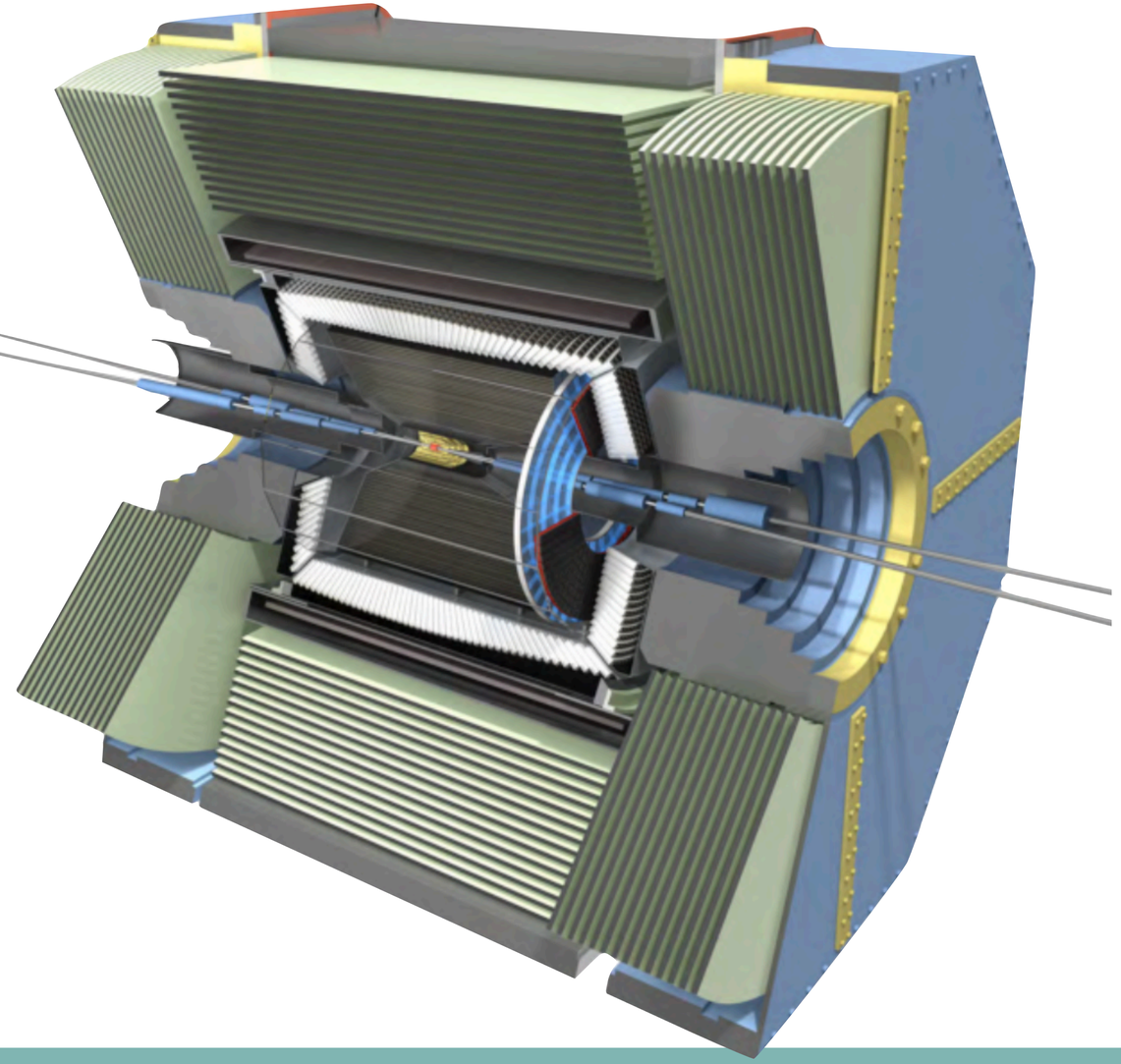
Why is iDM challenging?

- Search limited by trigger efficiency
- Long-lived neutral particle
- Belle II built to detect tracks from collision point
- Displaced Vertex Trigger (DVT) needed

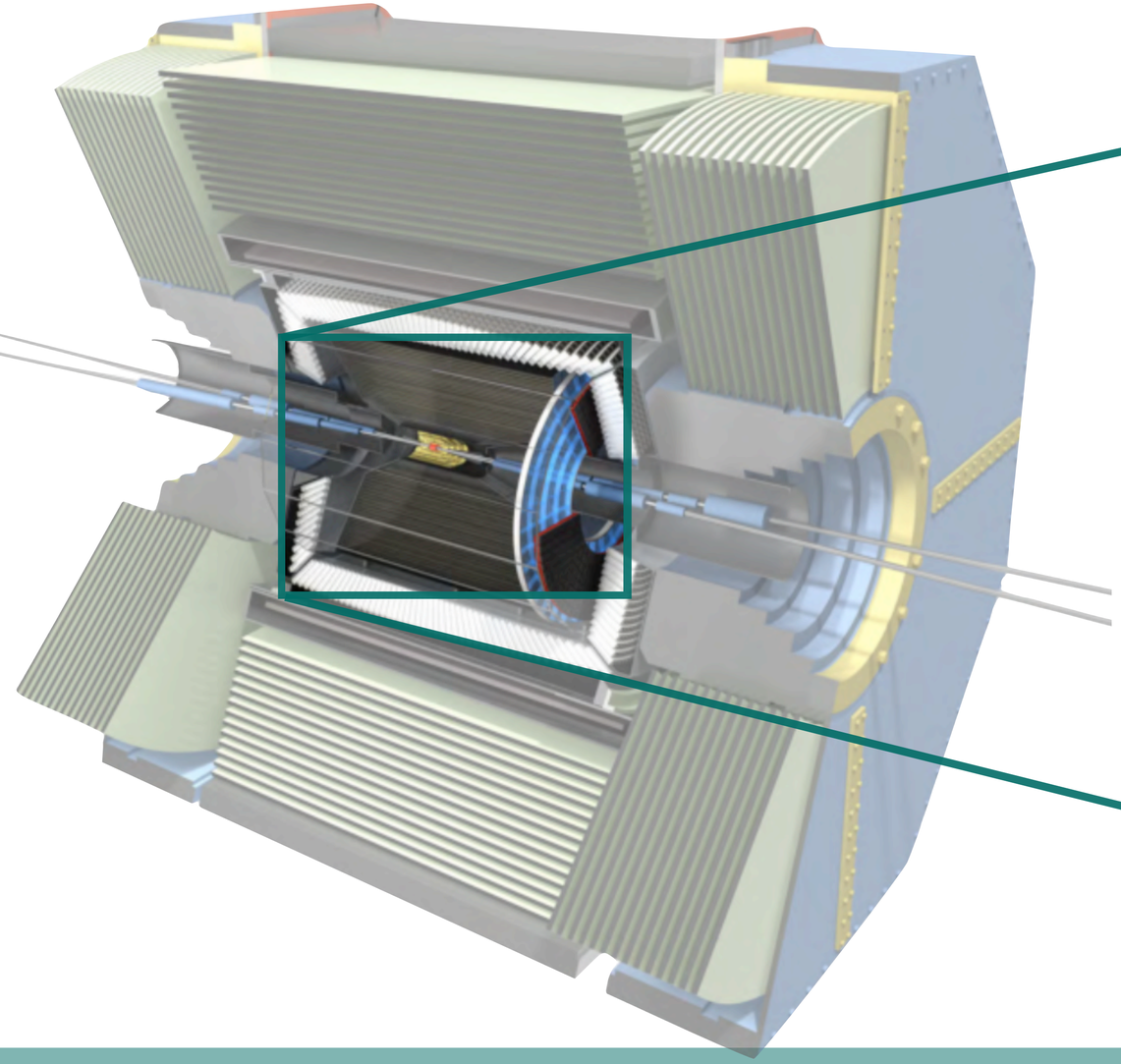


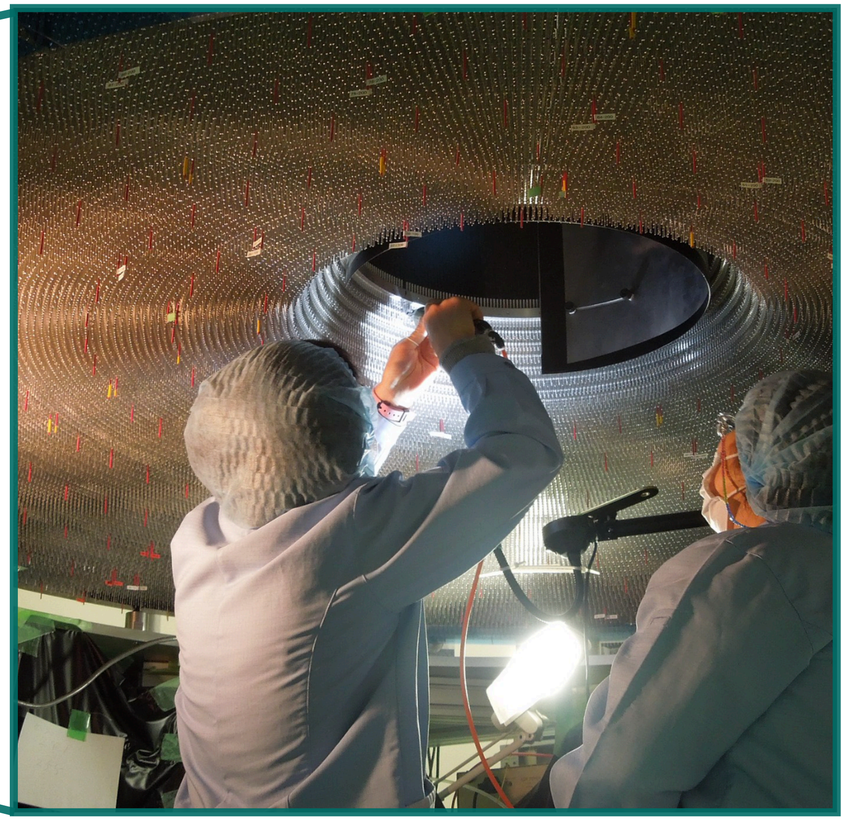
Projected sensitivity of Belle II to iDM (4)

Belle II & SuperKEKB

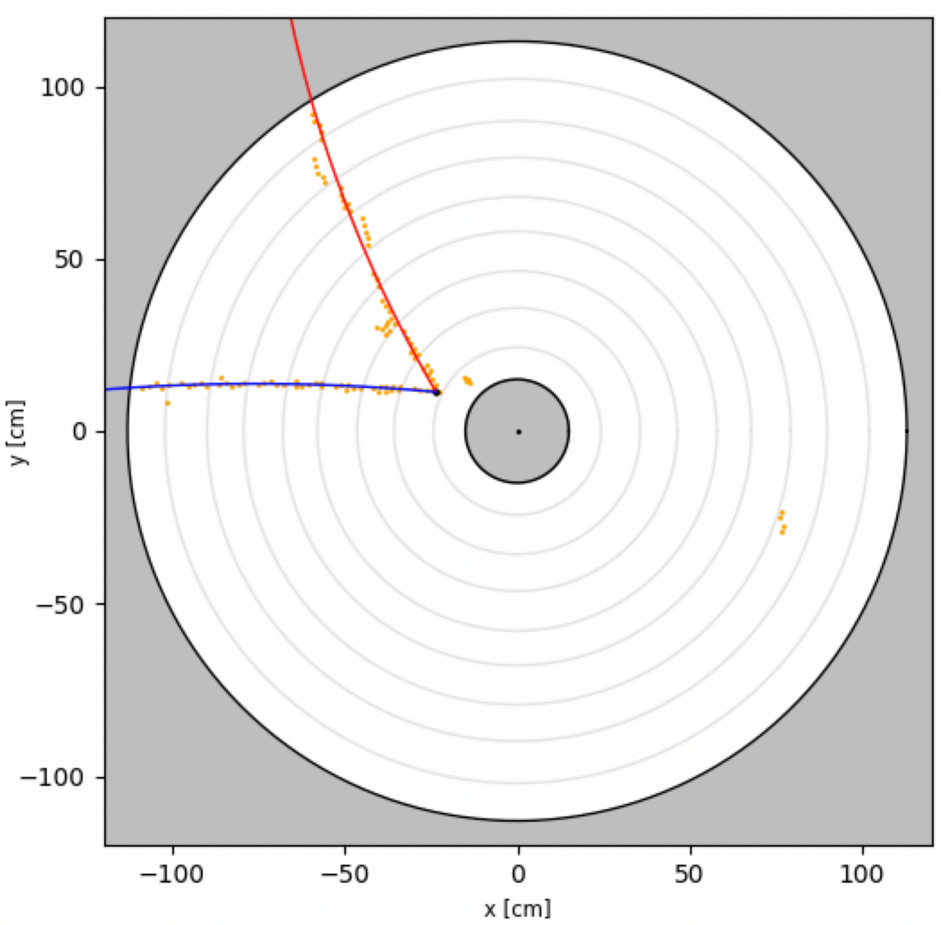


Belle II & SuperKEKB





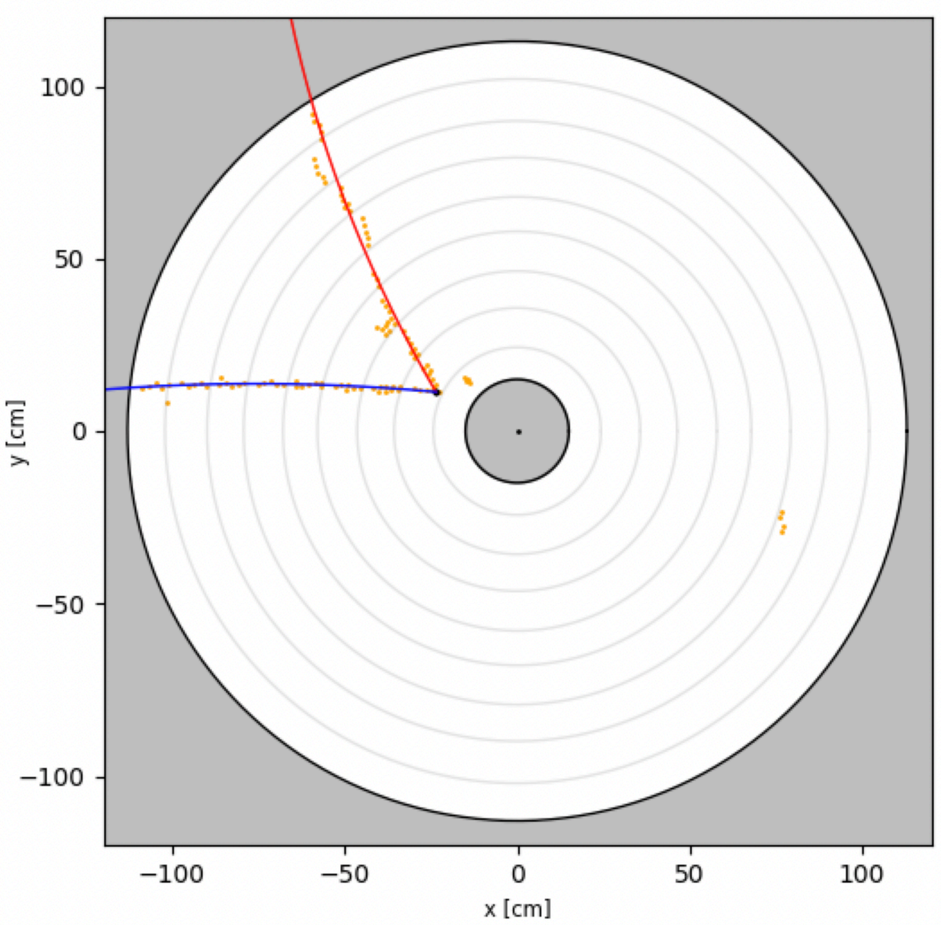
Central Drift Chamber (CDC)



iDM example event (simulated)

- Wires fire when charged particle passes
- CDC triggers are track finders
- Using the Hough transform
- Main track trigger of Belle II: Single Track Trigger

Central Drift Chamber (CDC)



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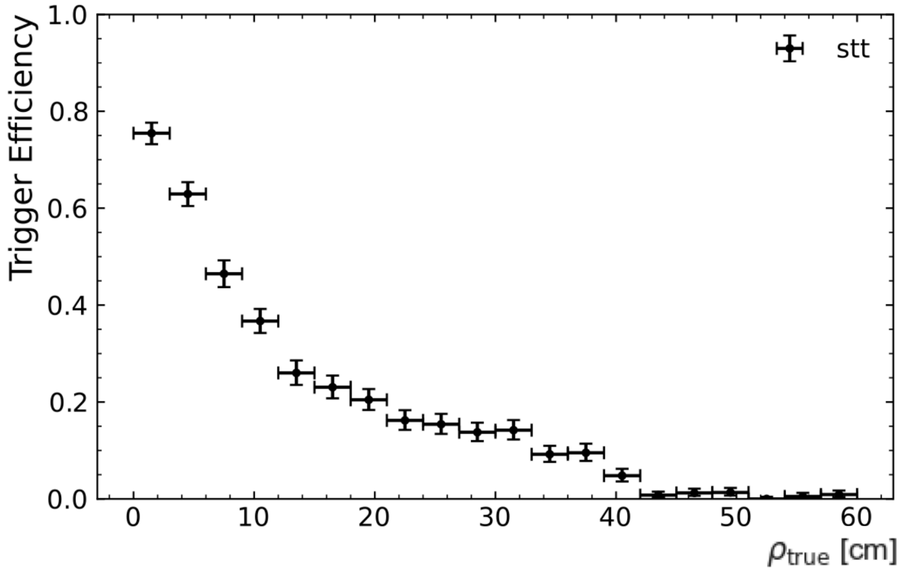
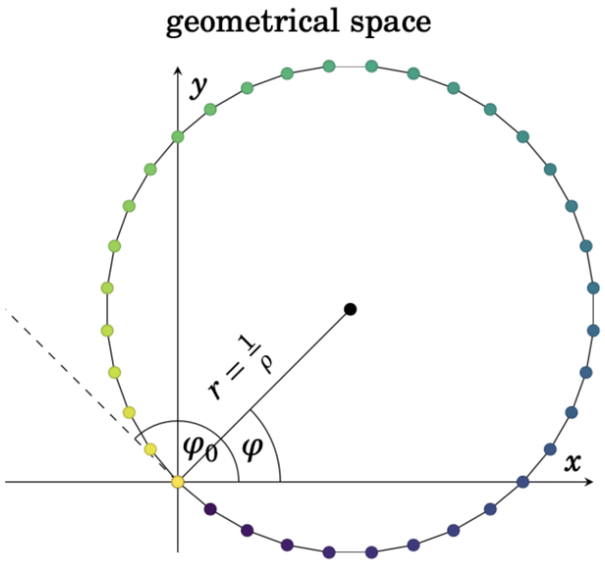


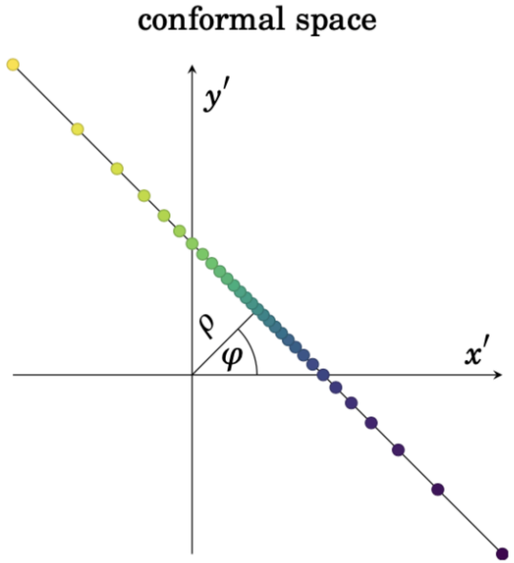
Efficiency of the single track trigger (5)

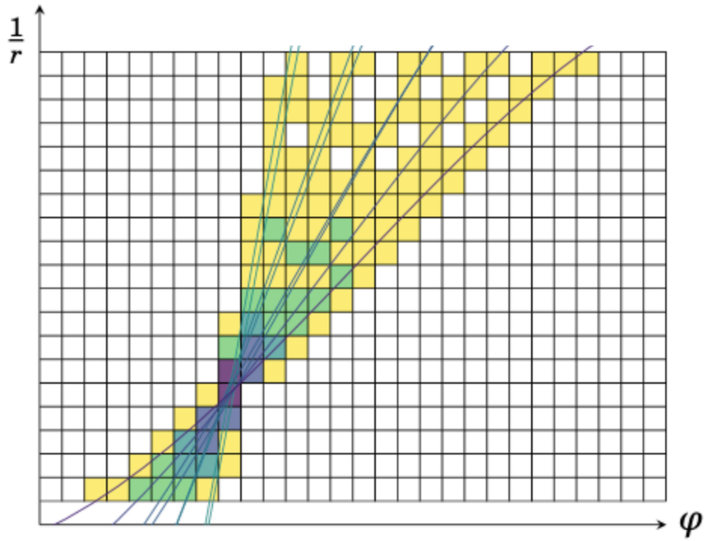
Hough Transform

- Geometrical space (x, y) → Parameter space (r^{-1}, φ)
- Track finding → Peak finding
- Conformal mapping: 2D circles → Straight lines
- Requires setting of reference vertex, normally (0,0)

$$\frac{1}{r} = x \cdot \cos\varphi + y \cdot \sin\varphi$$

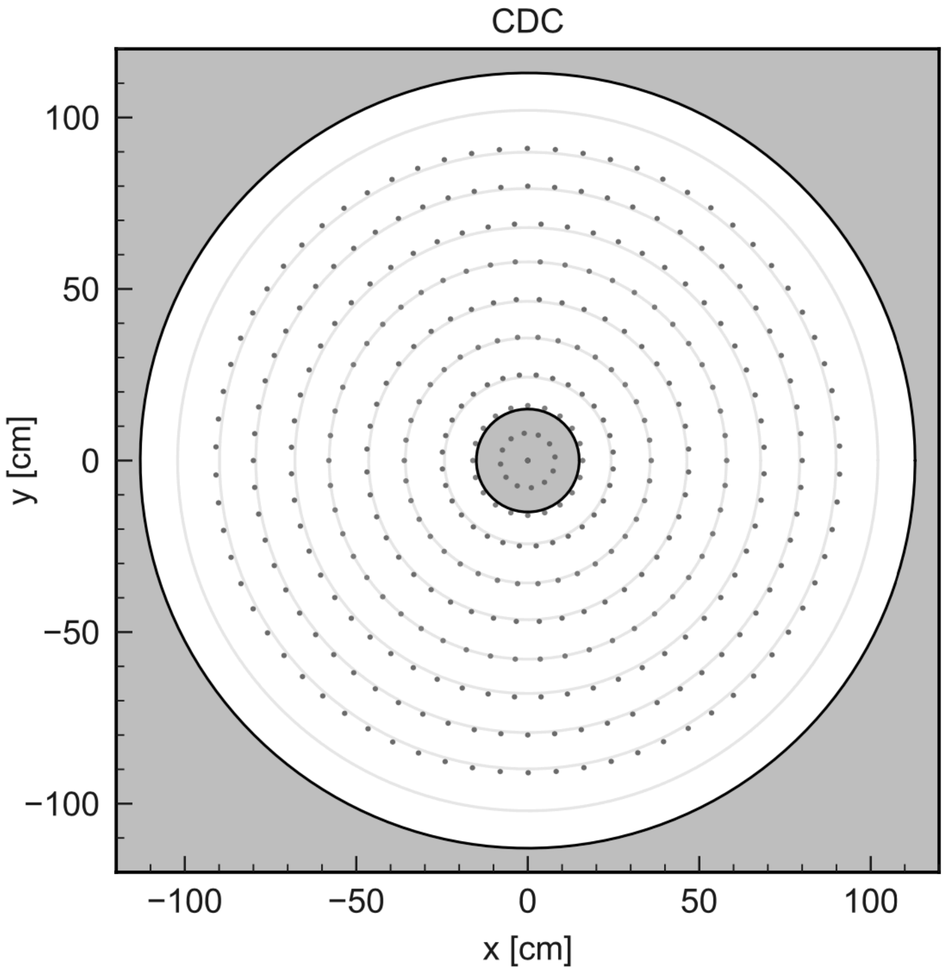






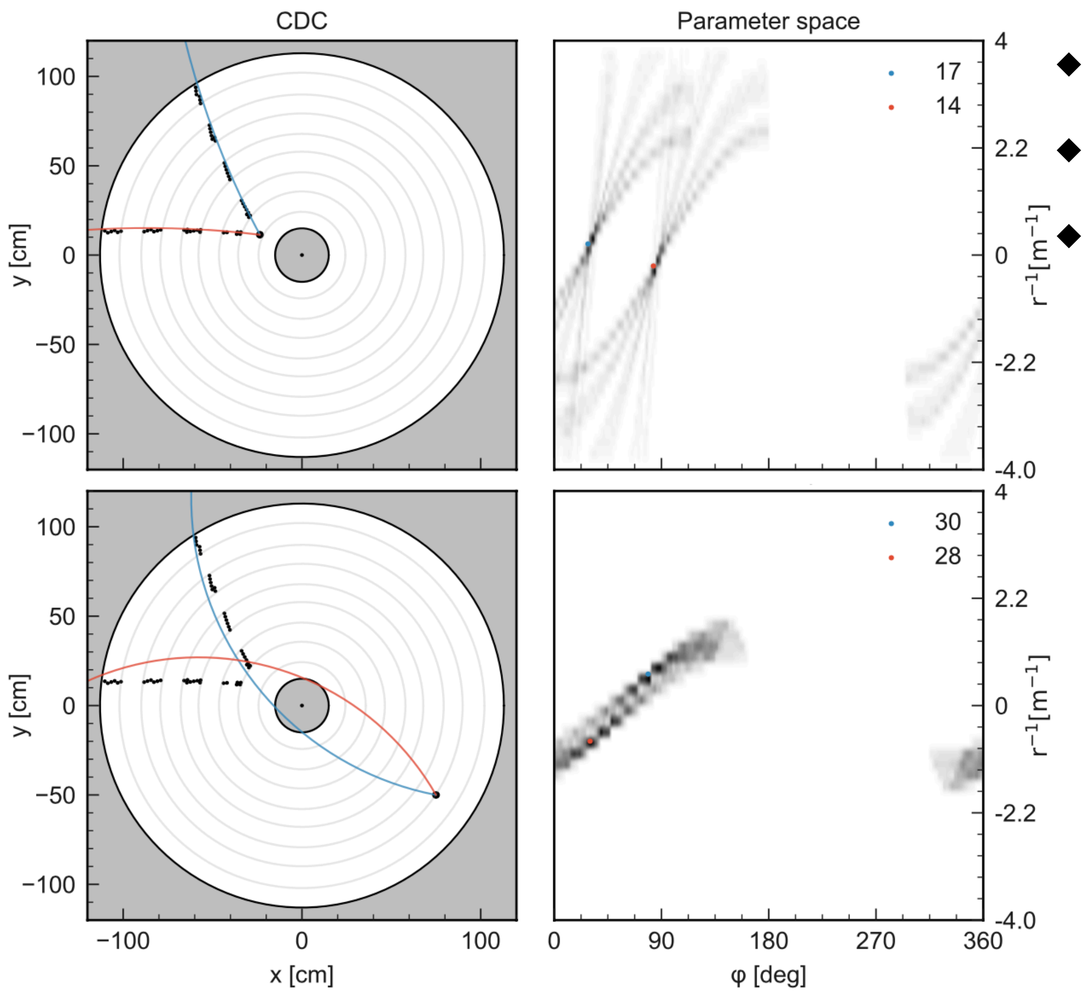
Basic idea of the Hough transform (6)

MacroCells



- ~400 reference vertices (MacroCells)
- Hough transforms in parallel, assuming MacroCell as vertex
- Select promising vertex candidate

MacroCells



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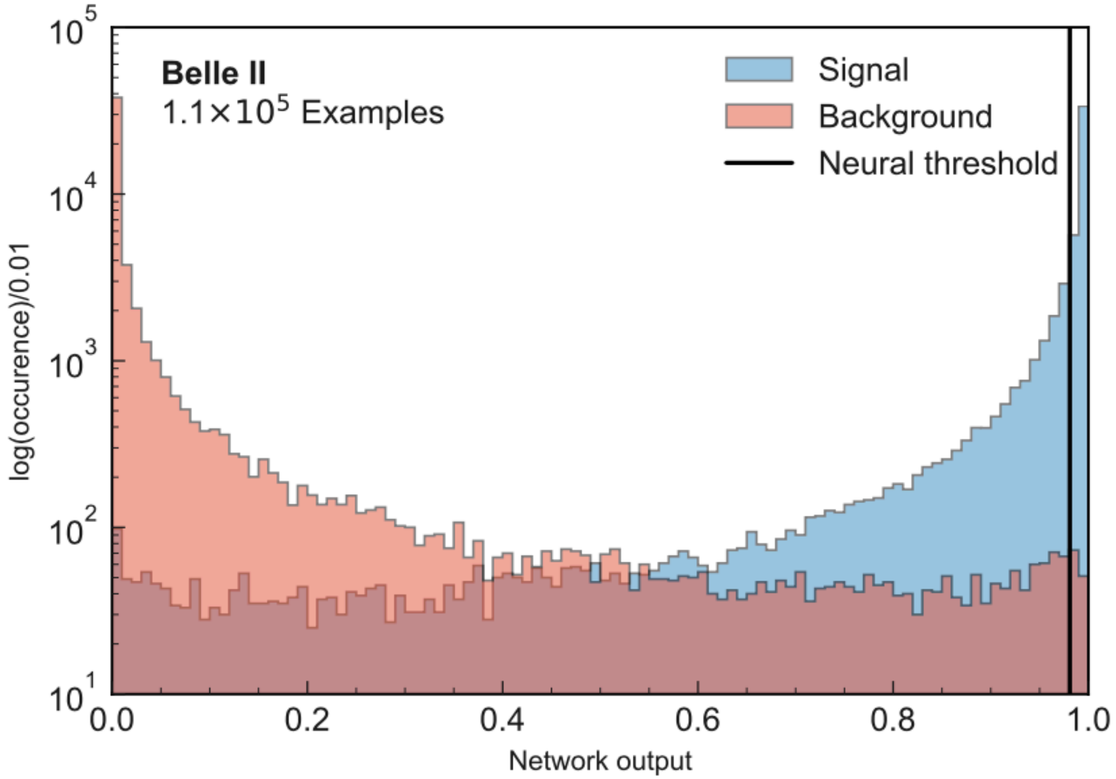
Problem

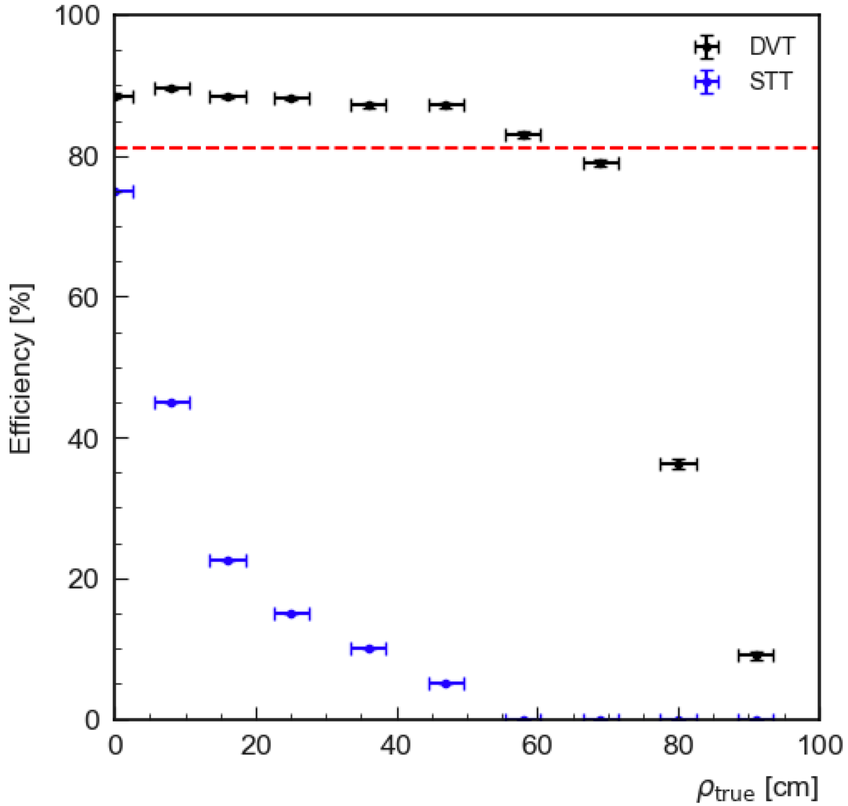
- Hough transform meant to fit two parameters
- Four parameters need to be fitted, two from vertex
- Strong bias towards far-away vertices
- Smarter algorithm needed
- **Neural cluster analysis**

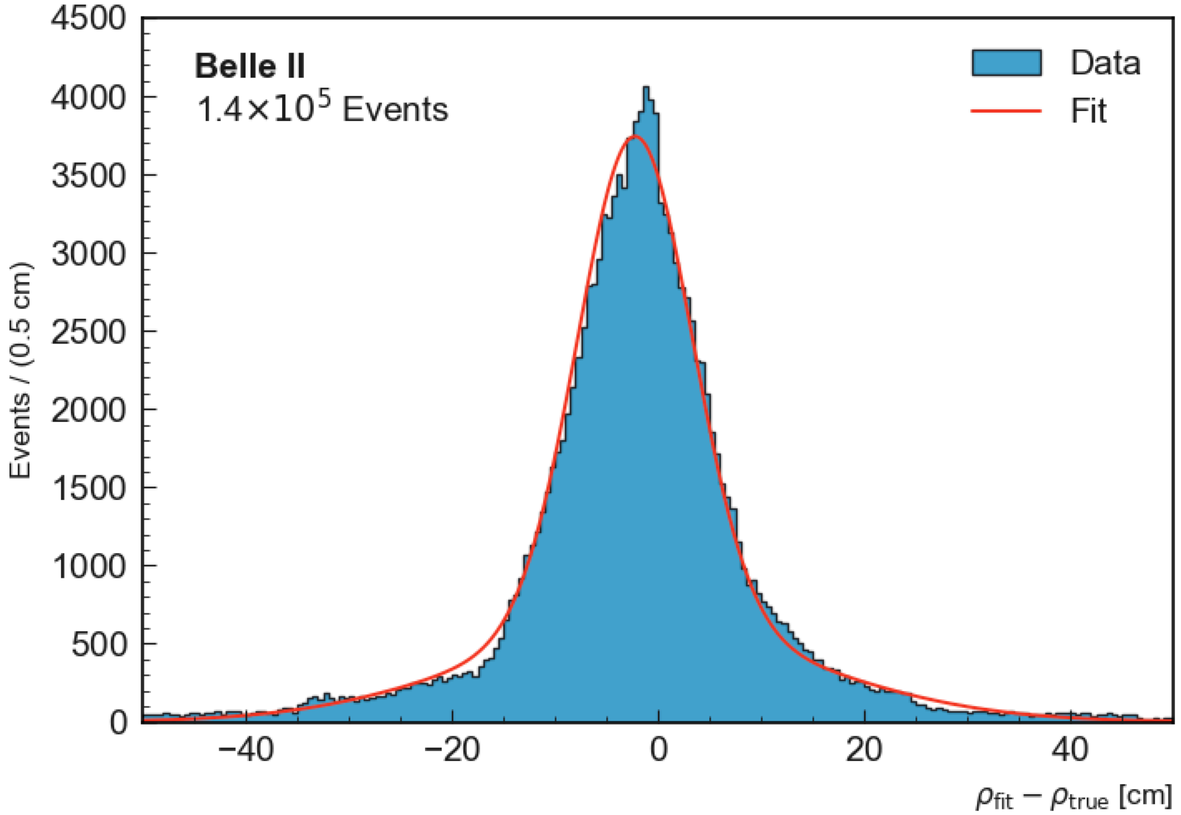
Neural Cluster Analysis



- Network runs on cluster parameters (size, σ, peak height, etc…)
- Classifies clusters [tracks, fakes]
- Requires two tracks
- Training data: iDM + background

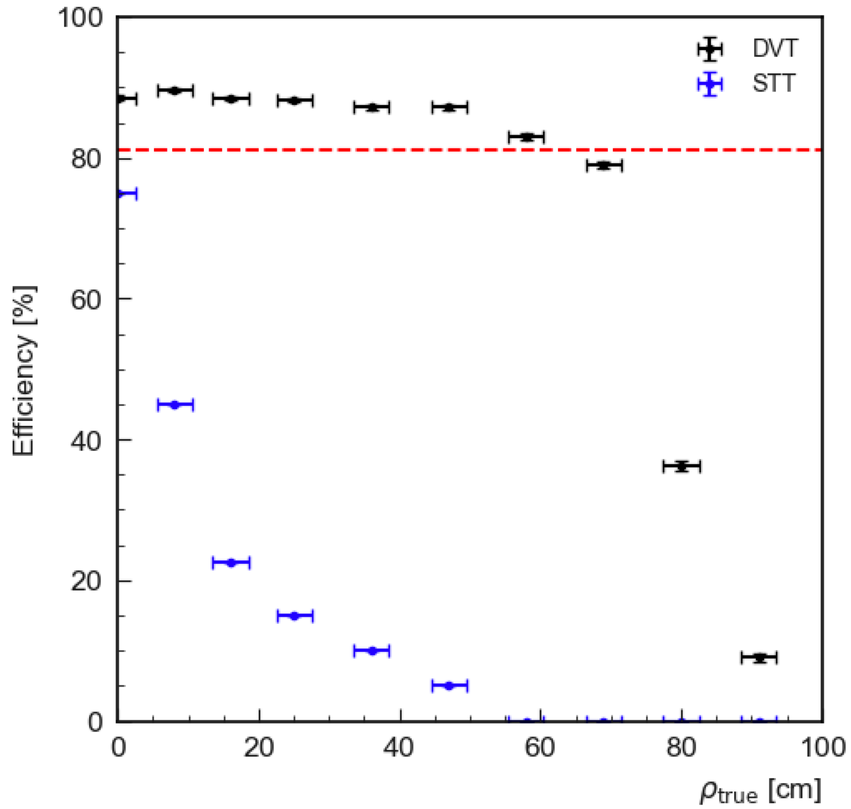
Results

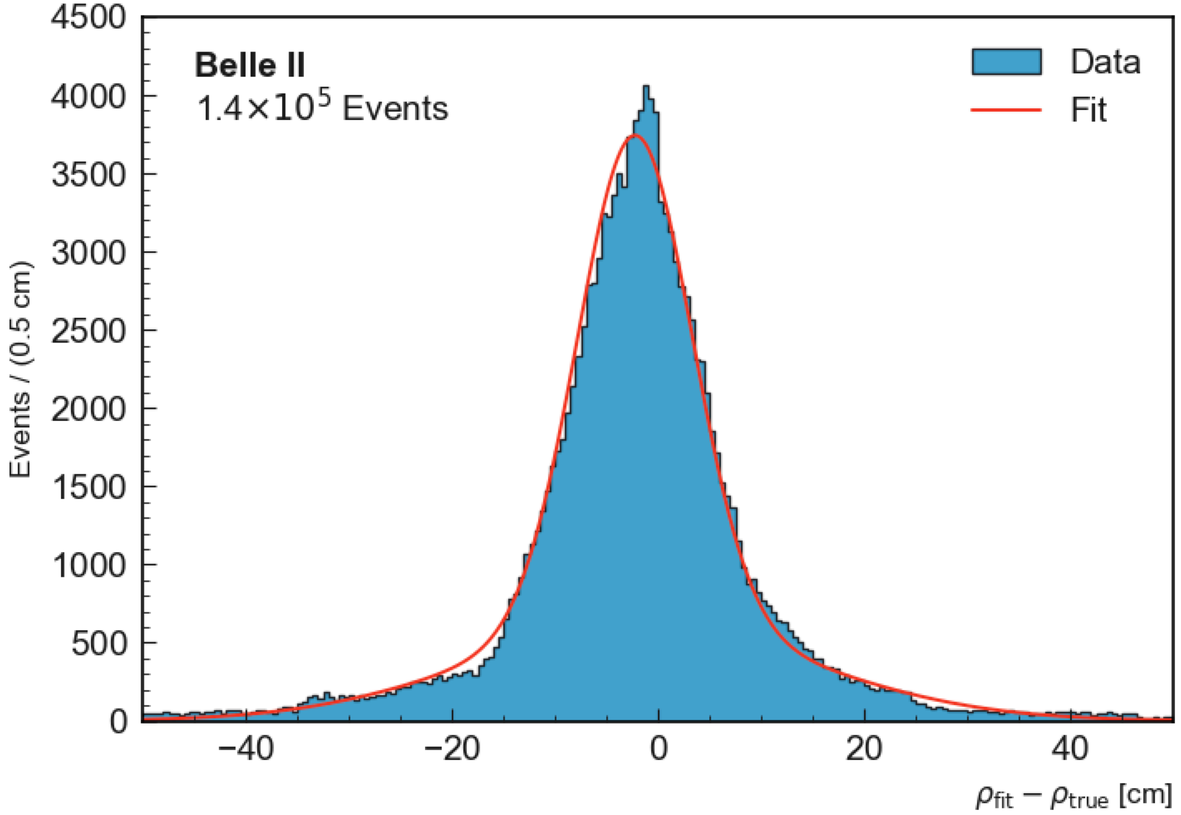




- Signal efficiency: ~80%
- Fake rate should not exceed 1kHz
- Vertex resolution: ~5cm

Results & Implementation





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- Implementation of FPGAs
- In collaboration with KIT-ITIV
- DVT planned to be ready for next running period

References

(1): G. Helou, B. F. Madore, M. Schmitz, M. D. Bicay, X. Wu, and J. Bennett. The NASA/IPAC extragalactic database. In M. A. Albrecht and D. Egret, editors, *Databases and On-line Data in Astronomy*, volume 171 of *Astrophysics and Space Science Library*, pages 89–106, 1991

(2): D. Clowe, A. Gonzales, and M. Markevitch. Weak lensing mass reconstruction of the interacting cluster 1e0657-558: Direct evidence for the existence of dark matter. *The Astrophysical Journal*, 604:596–603, 2008

(3): Asher Berlin and Felix Kling. Inelastic Dark Matter at the LHC Lifetime Frontier: ATLAS, CMS, LHCb, CODEX-b, FASER, and MATHUSLA. *American Physical Society APS,* 99:1, 2019

(4): Torben Ferber, Camilo Garcia-Cely, and Kai Schmidt-Hoberg. Belle II sensitivity to long–lived dark photons. *Physics Letters B*, 833:137373, 2022

(5): Plot used with permission from Patrick Ecker, KIT.

(6): Sara Pohl. Track Reconstruction at the First Level Trigger of the Belle II Experiment. PhD thesis, Ludwig-Maximilians-Universität, Munich, 2018

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