SEARCH FOR HIGHLY IONIZING PARTICLES WITH THE PIXEL DETECTOR AT BELLE II

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International Workshop on e+e- collisions from Phi to Psi
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JENNIFER

WHAT ARE HIGHLY IONIZING PARTICLES?

HIGHLY IONIZING PARTICLES

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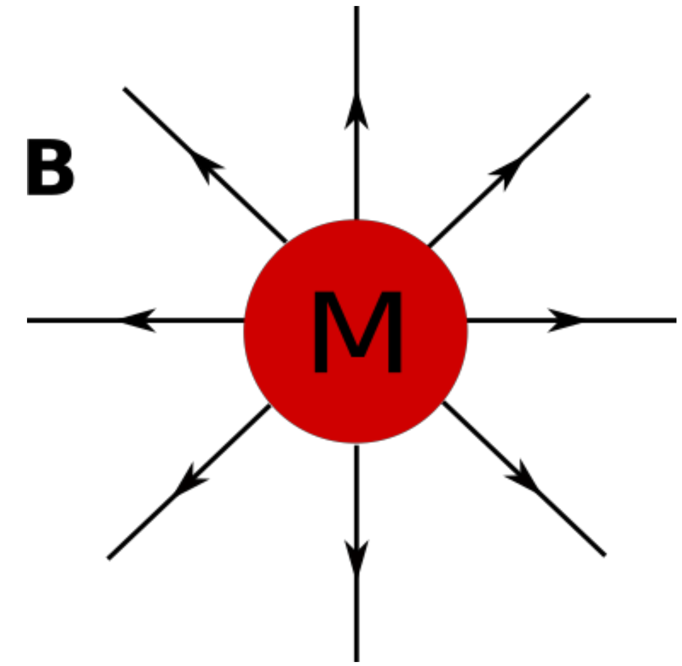
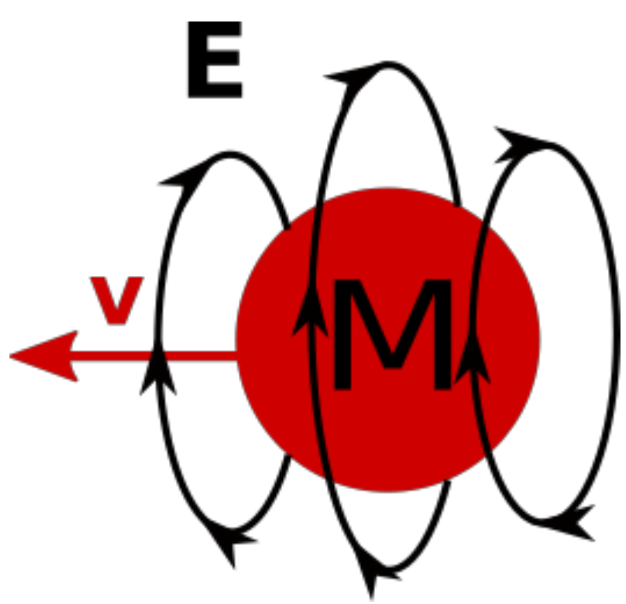
particles with a characteristically high energy loss



- Examples:
    - Anti-Deuterons
    - **Magnetic Monopoles**

- Monopoles appear in various theories ('t Hooft, GUT, String Theories etc.)



- Monopoles arising from **Dirac Quantization Theory**:

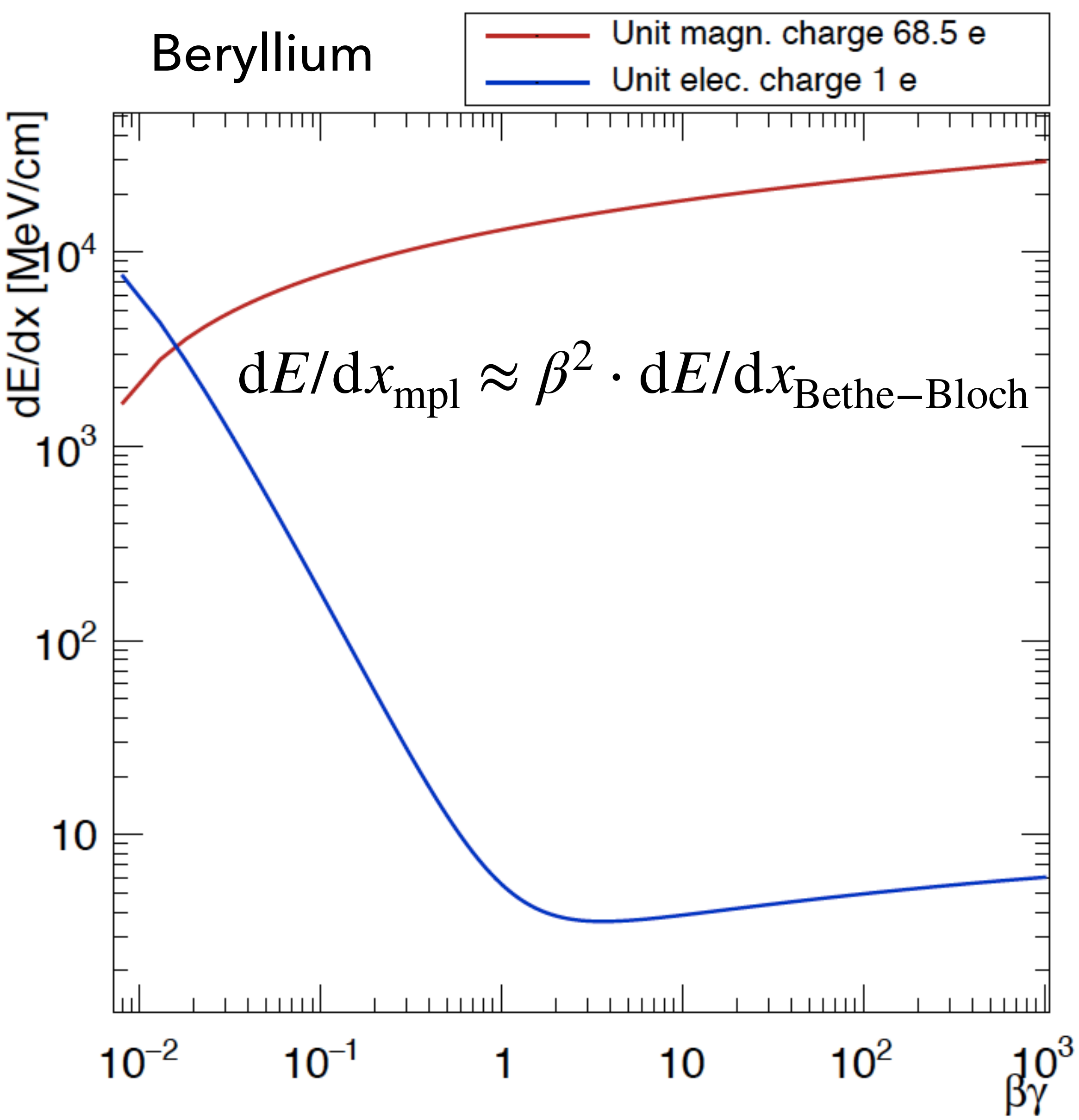
$$eg = \frac{n\hbar c}{2} \approx 68.5e \cdot n$$

Paul A. Dirac, Proc. R. Soc. Lond. A, 133, 60-72 (1931)

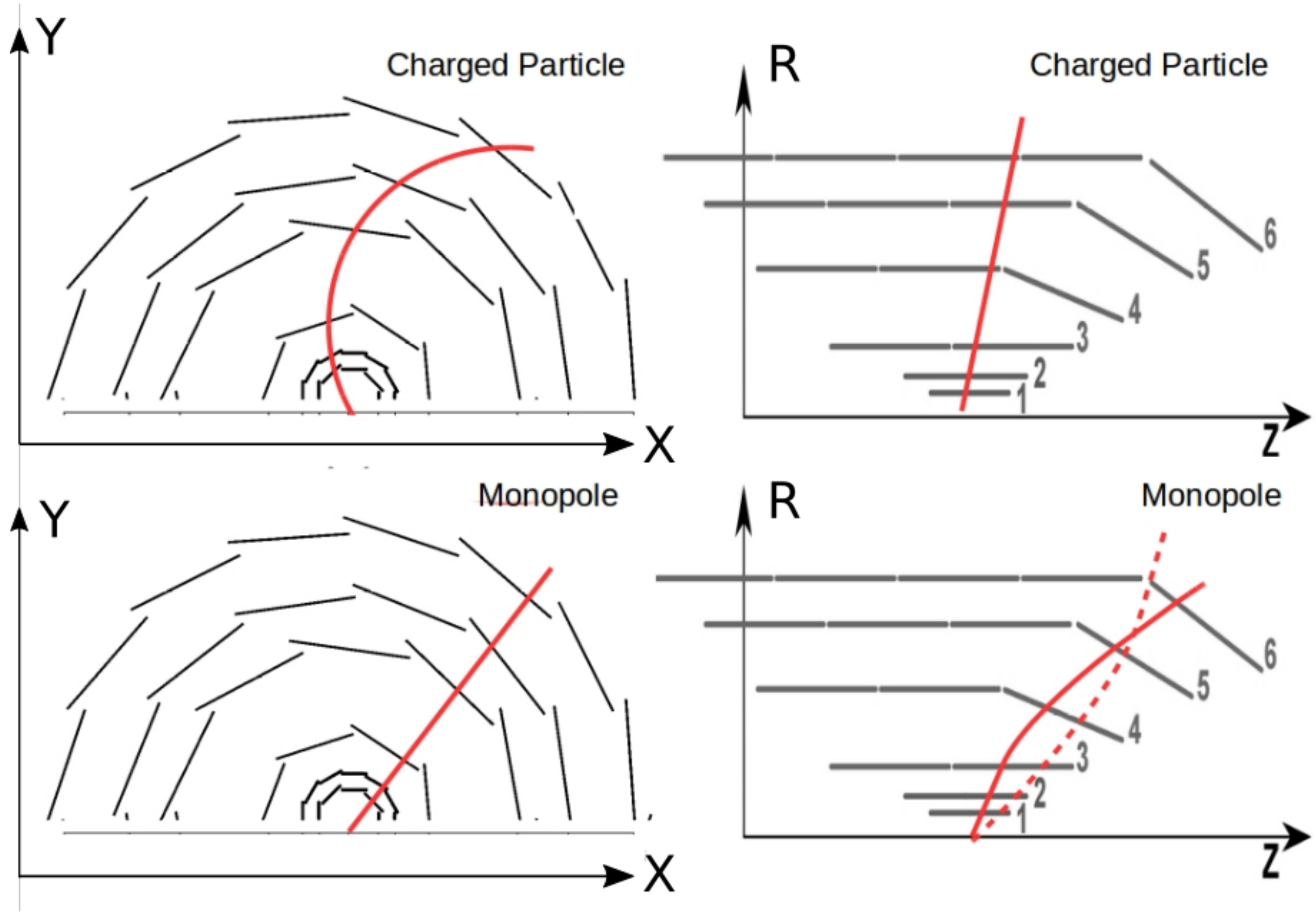
G. Lazarides et al., Phys. Rev. Lett., 49, 1756 (1982)

CHARACTERISTICS OF MAGNETIC MONOPOLES

Non-Bethe-Bloch energy loss



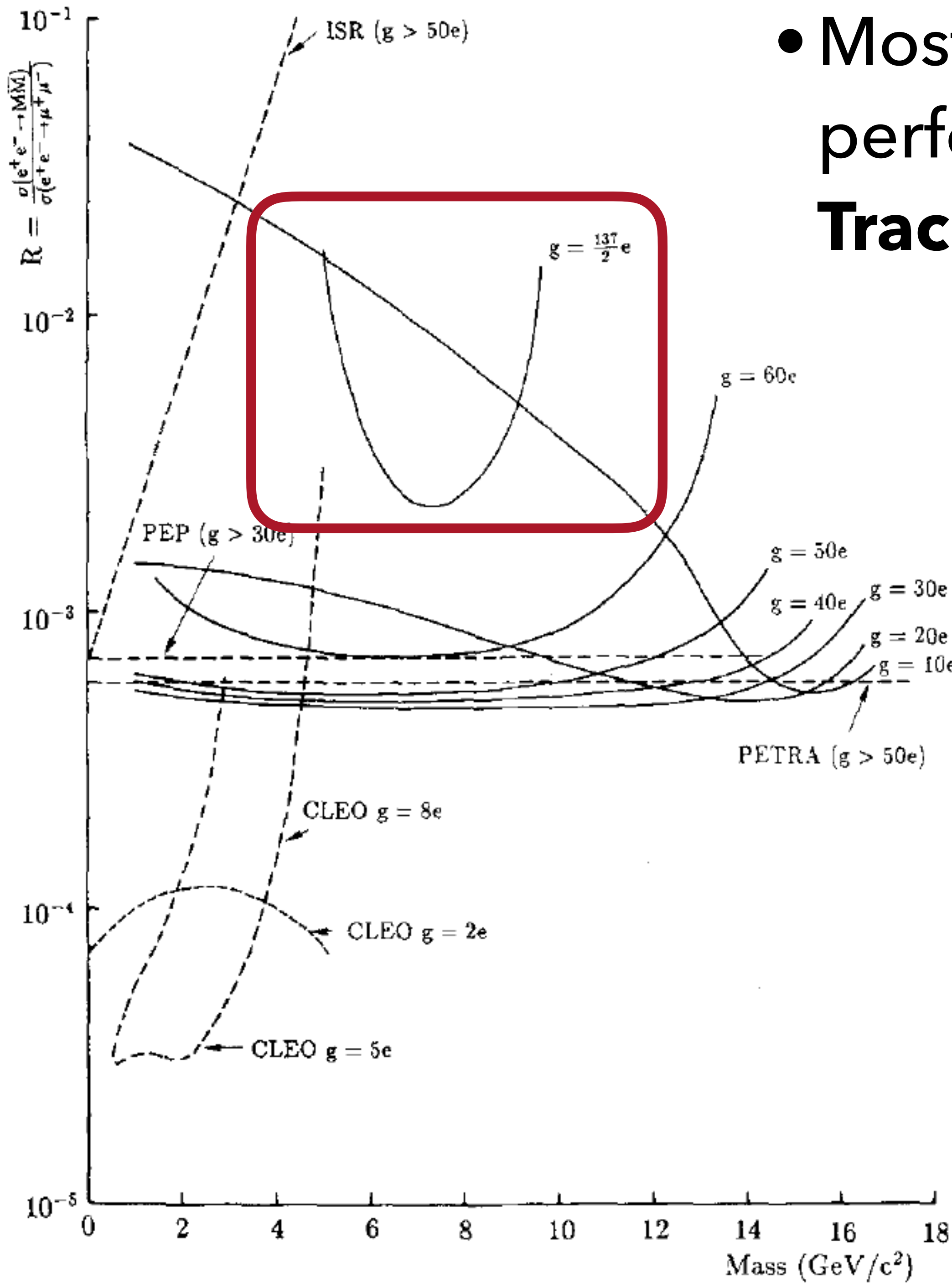
Trajectory in magnetic field



➡ See **Dark Sector physics at Belle II** at XXXIX International Conference on High Energy Physics by **Dmitrii Neverov**

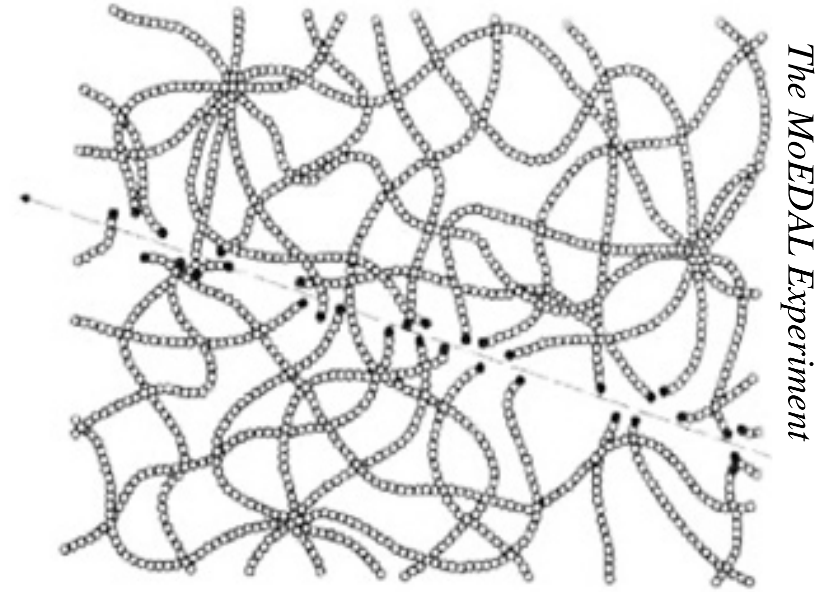
WHAT SEARCH STRATEGY IS PURSUED?

PAST SEARCHES



W. Braunschweig et al. [TASSO Collaboration], Z. Phys. C 38, 543 (1988)

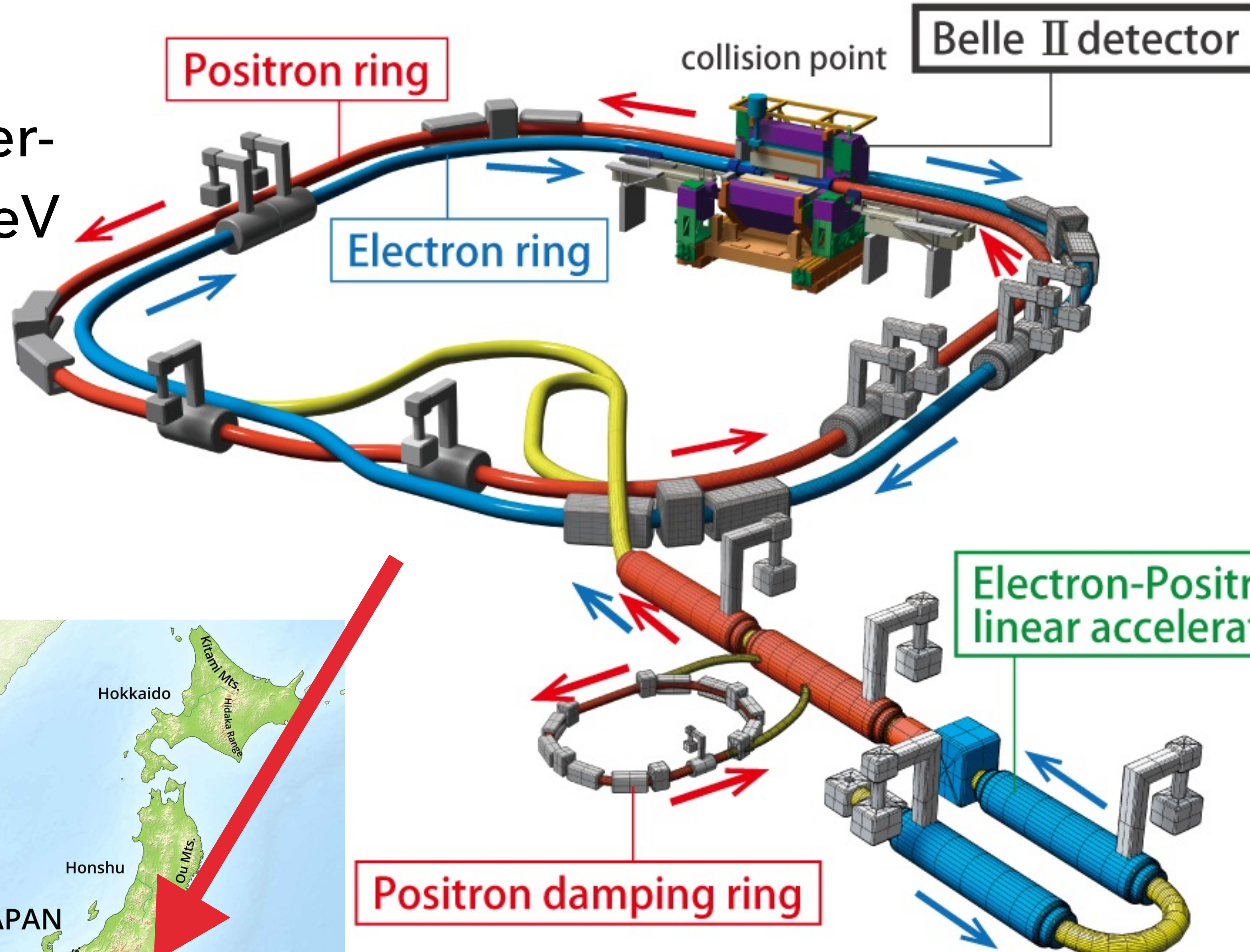
- Most searches performed with **Nuclear Track Detectors (NTDs)**



- Searches at electron-positron colliders:
  - MODAL at LEP : NTDs
    J. L. Pinfold, et al. Phys. Lett. B 316, 407 (1993)
  - TRISTAN at KEK : NTDs
    K. Kinoshita et al., Phys. Lett. B 228, 543 (1989)
  - CLEO at CESR : NTDs
    T. Gentile et al. [CLEO Collaboration], Phys. Rev. D 35, 1081 (1987).
  - PETRA at DESY : NTDs
    P. Musset, M. Price and E. Lohrmann, Phys. Lett. 128B, 333 (1983)
  - TASSO at DESY : Tracking
    W. Braunschweig et al. [TASSO Collaboration], Z. Phys. C 38, 543 (1988)
  - OPAL at LEP : Wire Chamber
    G. Abbiendi et al. [OPAL Collaboration], Phys. Lett. B 663, 37 (2008)

SUPER KEKB

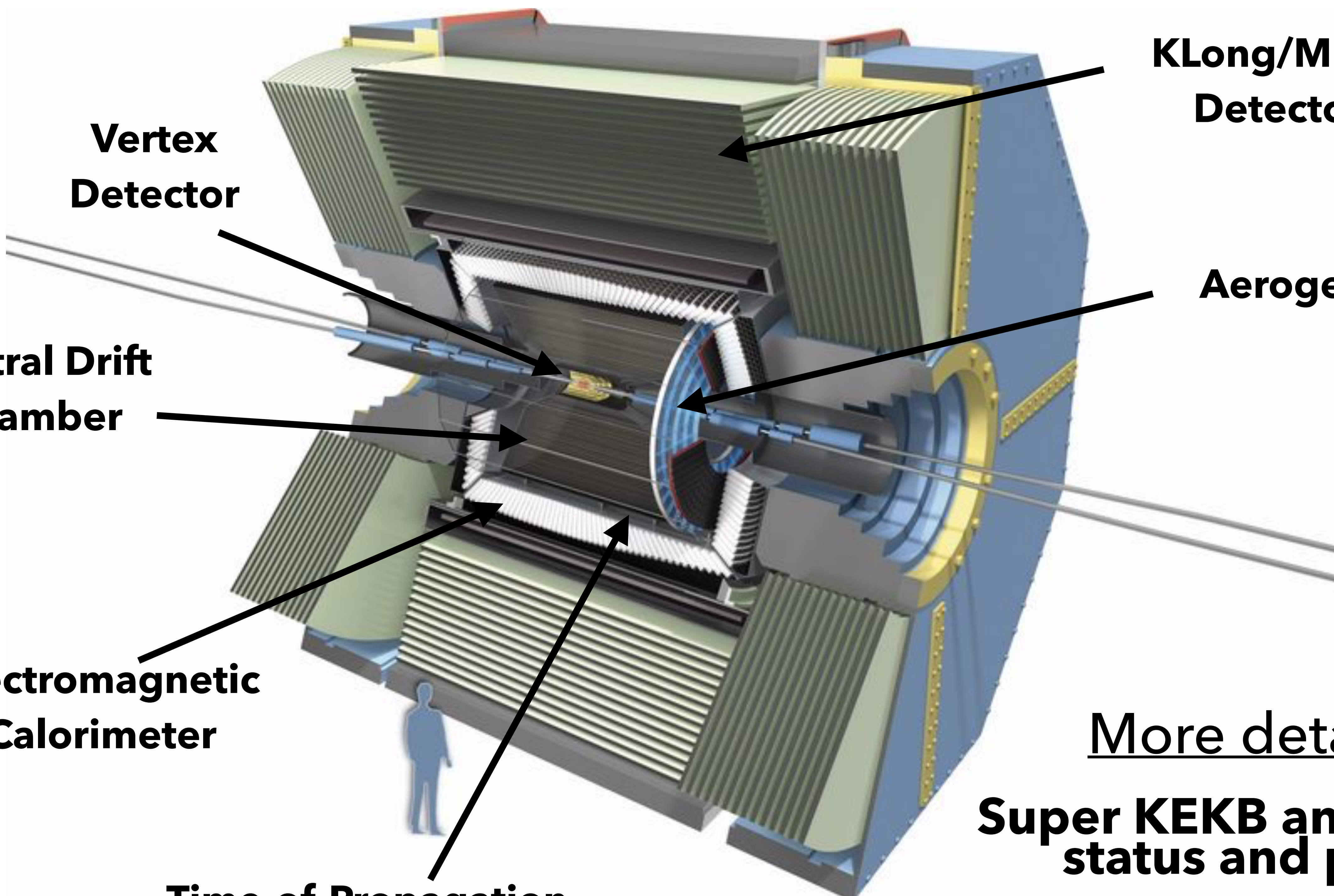
- Asymmetrical Electron-Positron Collider with center-of-mass energy of 10.58 GeV



40x KEKB peak luminosity:

$$\mathscr{L} = 8 \cdot 10^{35} \mathrm{cm}^{-2} \mathrm{s}^{-1}$$

BELLE II DETECTOR

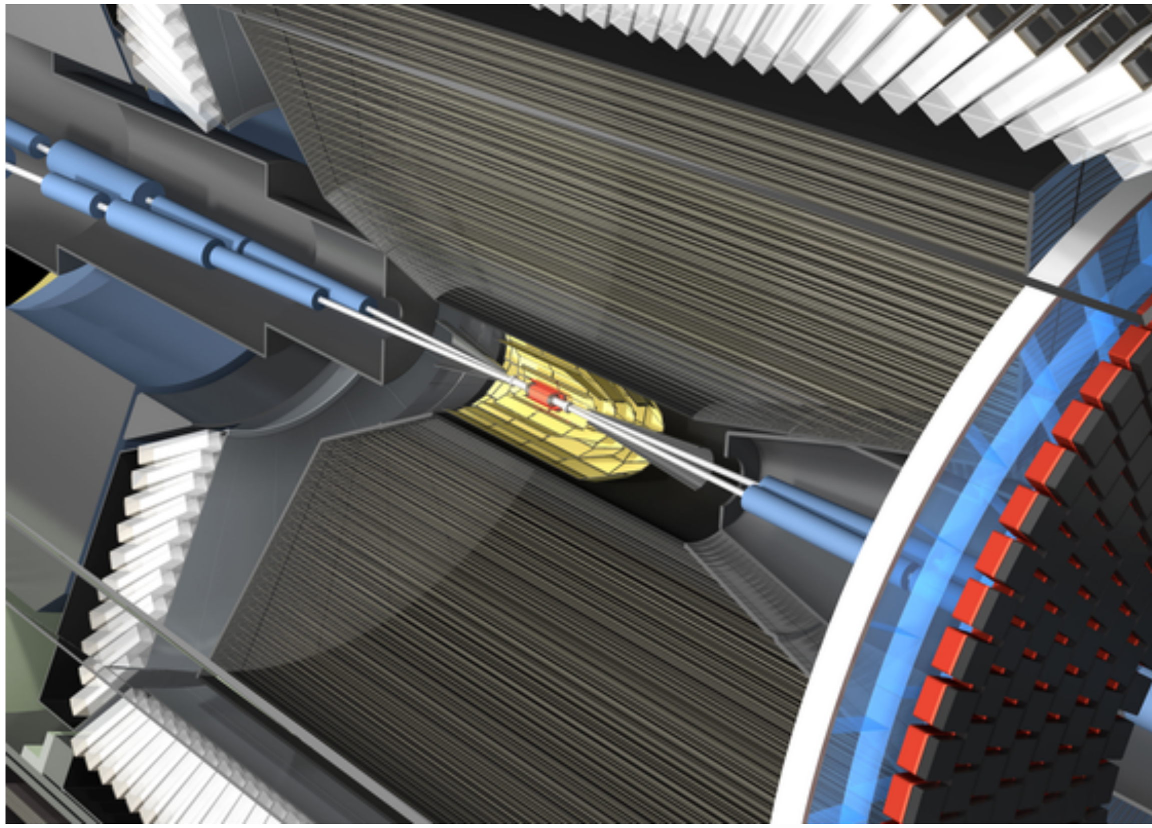


<u>More details:</u>

Super KEKB and Belle2 status and plans

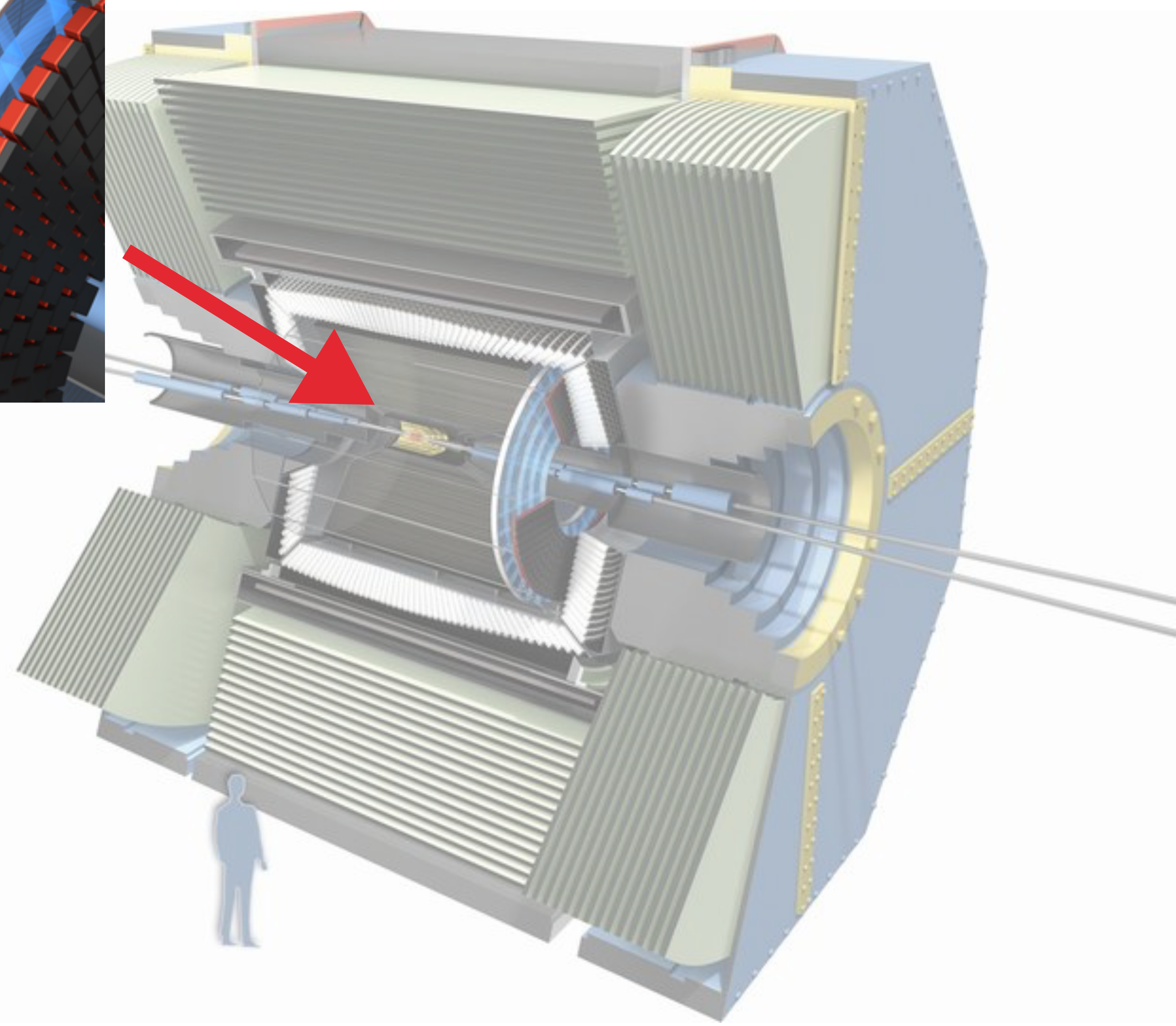
from Prof. Xiaolong Wang

PIXEL DETECTOR

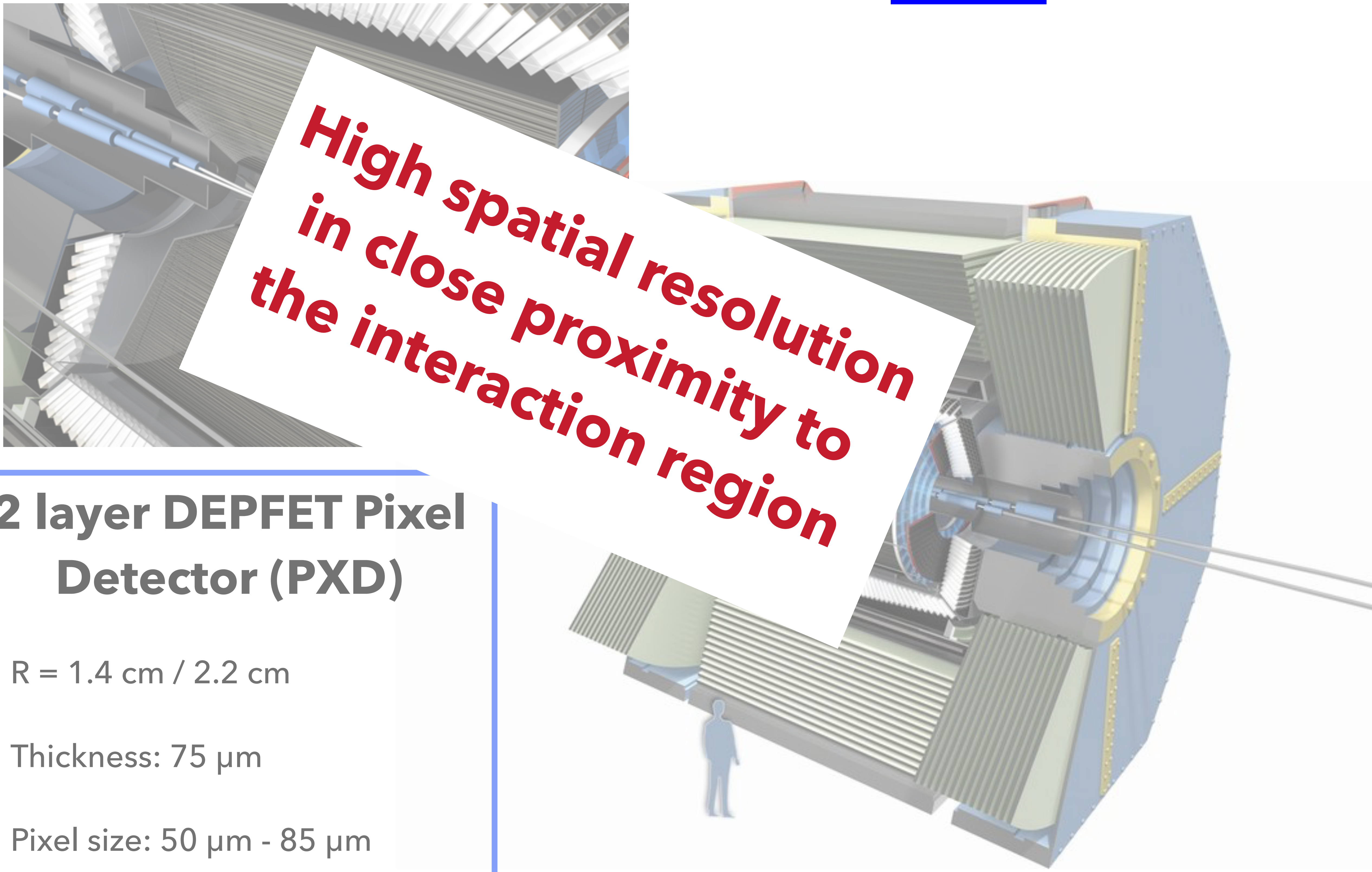


2 layer DEPFET Pixel Detector (PXD)

- R = 1.4 cm / 2.2 cm
- Thickness: 75 µm
- Pixel size: 50 µm - 85 µm



PIXEL DETECTOR



High spatial resolution in close proximity to the interaction region

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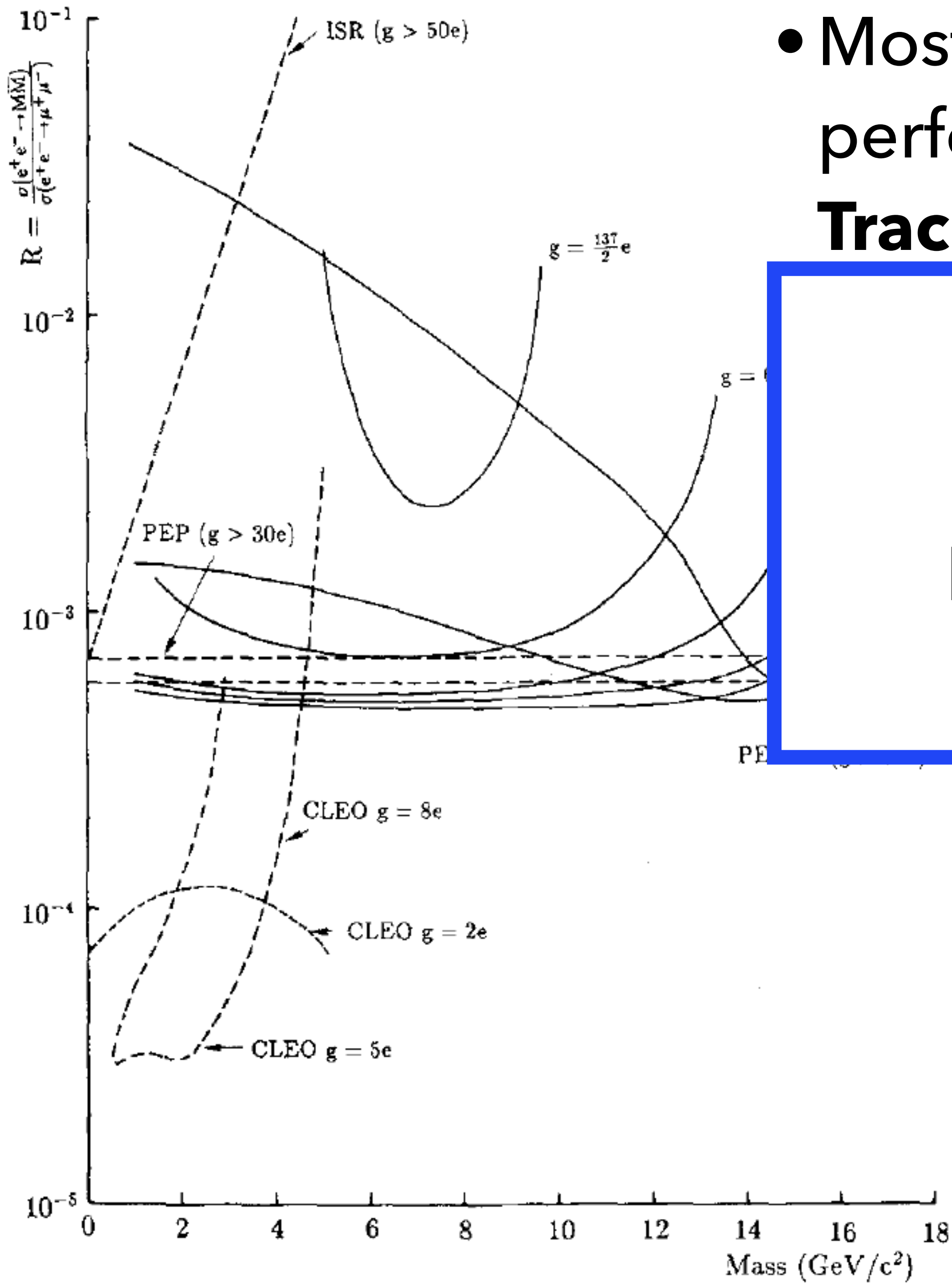

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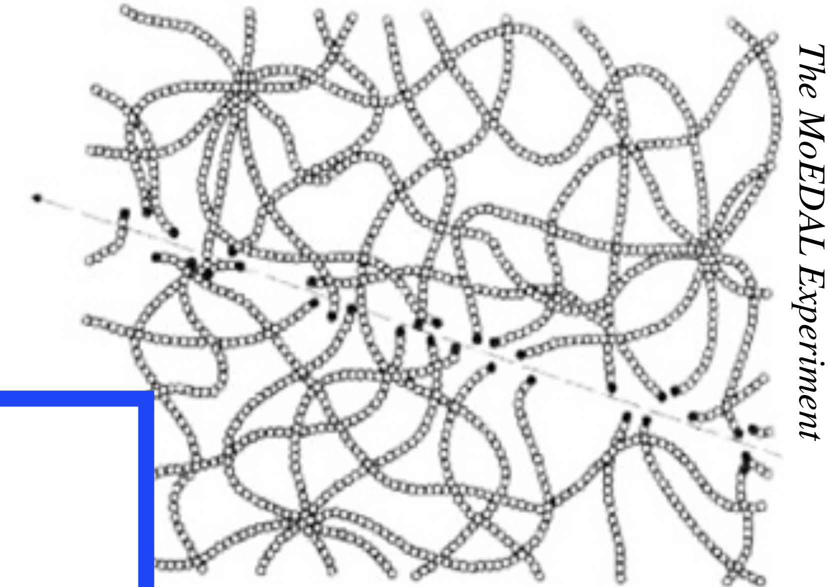

Belle II at KEK :

PXD (+ Tracking)

…ositron colliders:

- …TDs

  …, 407 (1993)

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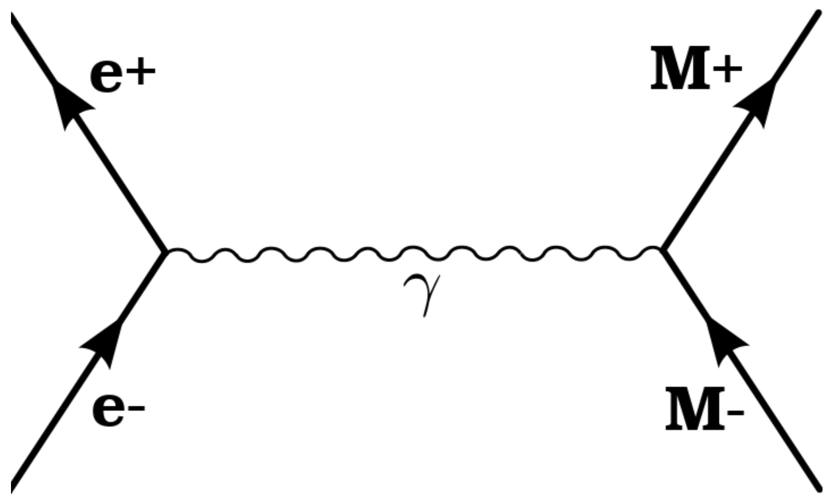

- Dirac monopoles **do not** reach outer sub-detectors
- Principal **purpose** of PXD: Tracking in close proximity to interaction region
- Our **objective**: Check if particle identification with PXD is feasible

Neural Networks

Feed-Forward Networks

Unsupervised Training:

Self - Organizing Maps

Input Variables

Cluster size properties

+ Charge distribution in cluster

____

6-dim input vector

or

5x5 pixel matrix around cluster

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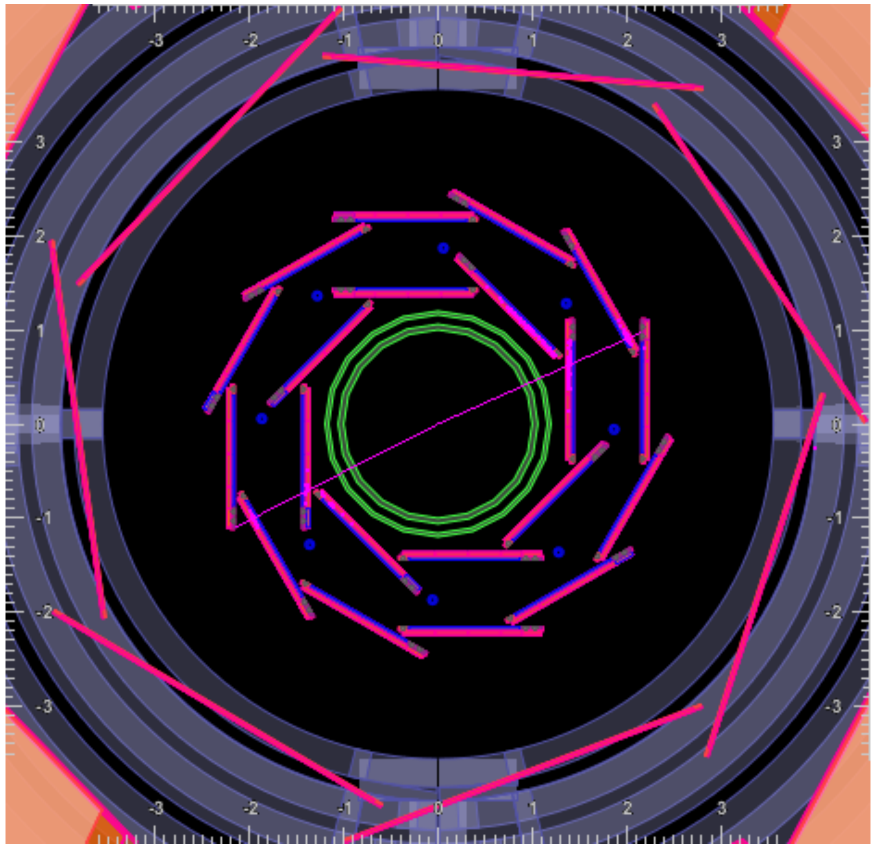

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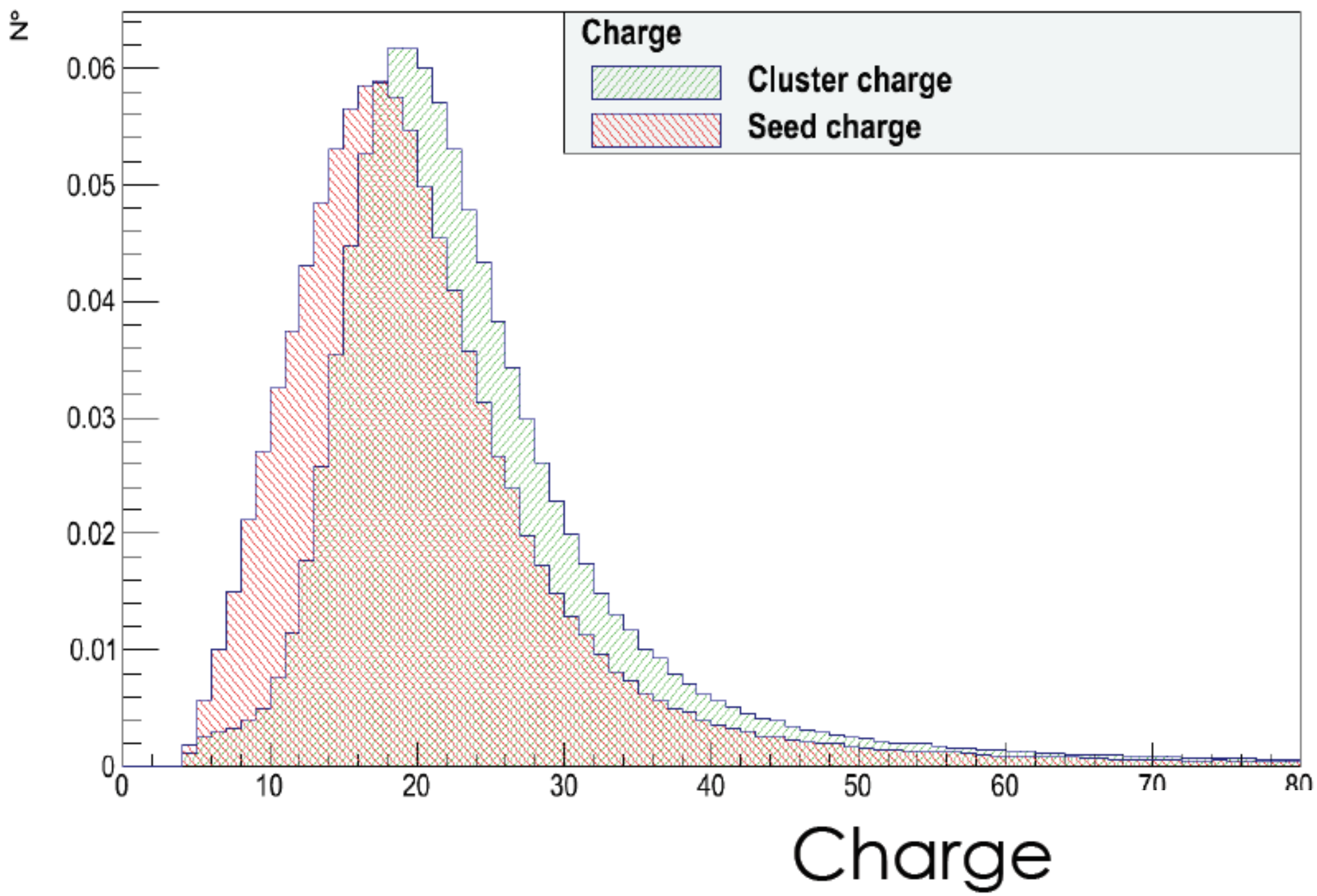
WHAT'S THE STATUS?

STATUS - MONOPOLE SIMULATION

Testbeam at DESY and CERN

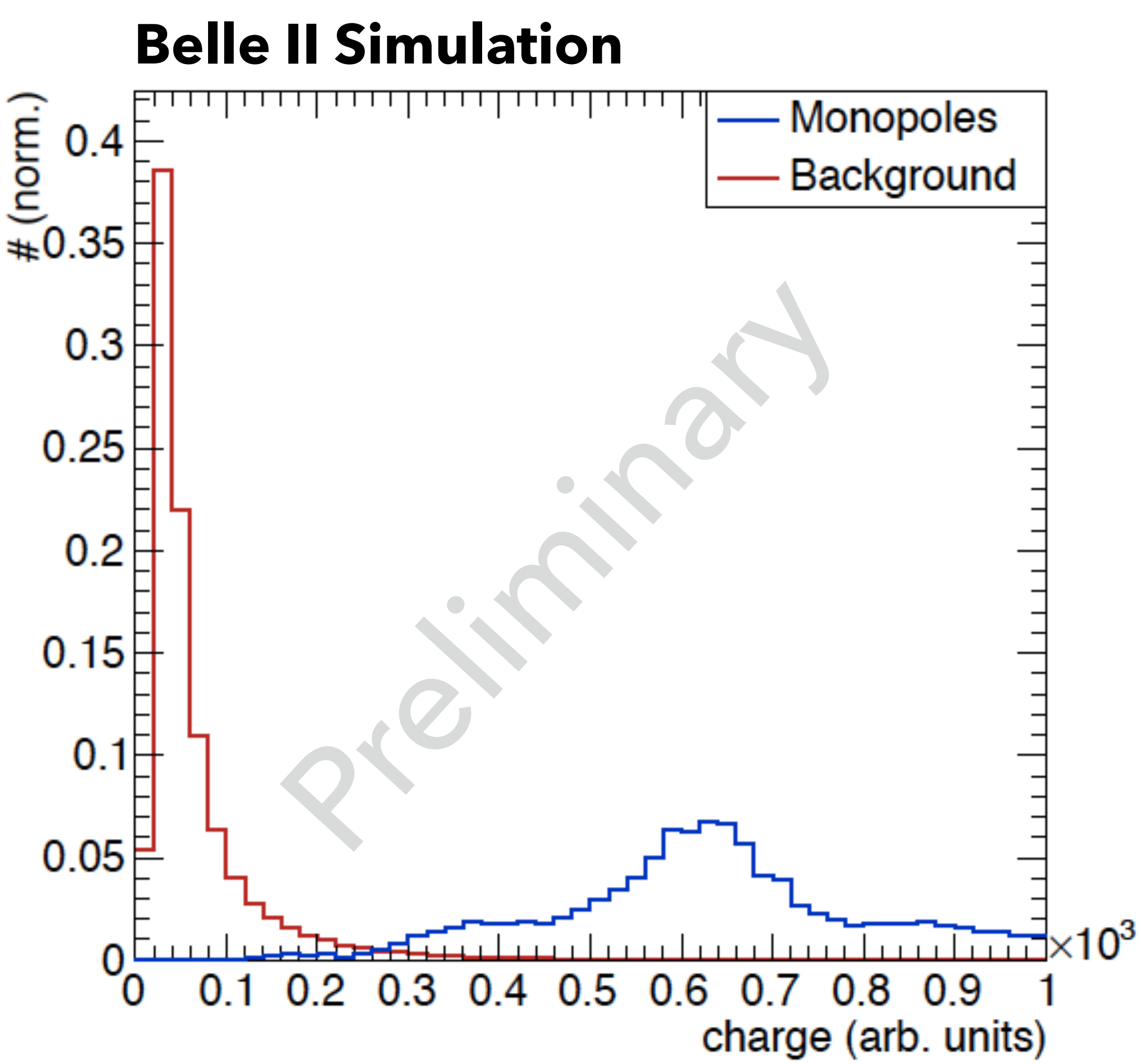
Minimum ionizing particles

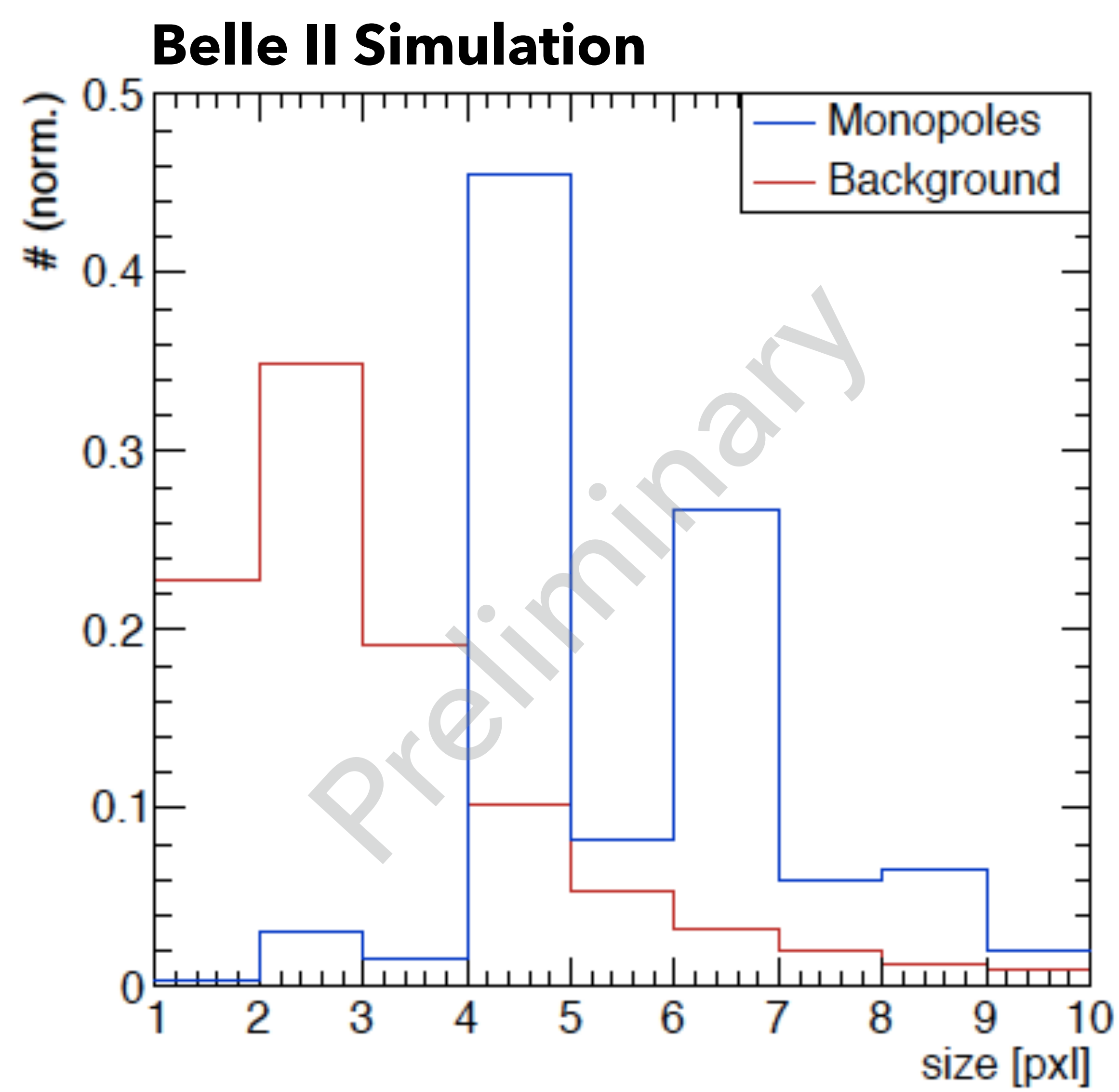


DEPFET Technology, Test Beam Performance *at Taller de Altas Energías 2013 by Boronat et al.*

STATUS - MONOPOLE SIMULATION

- Preliminary simulation of **1 GeV** magnetic monopoles with **unit charge**:





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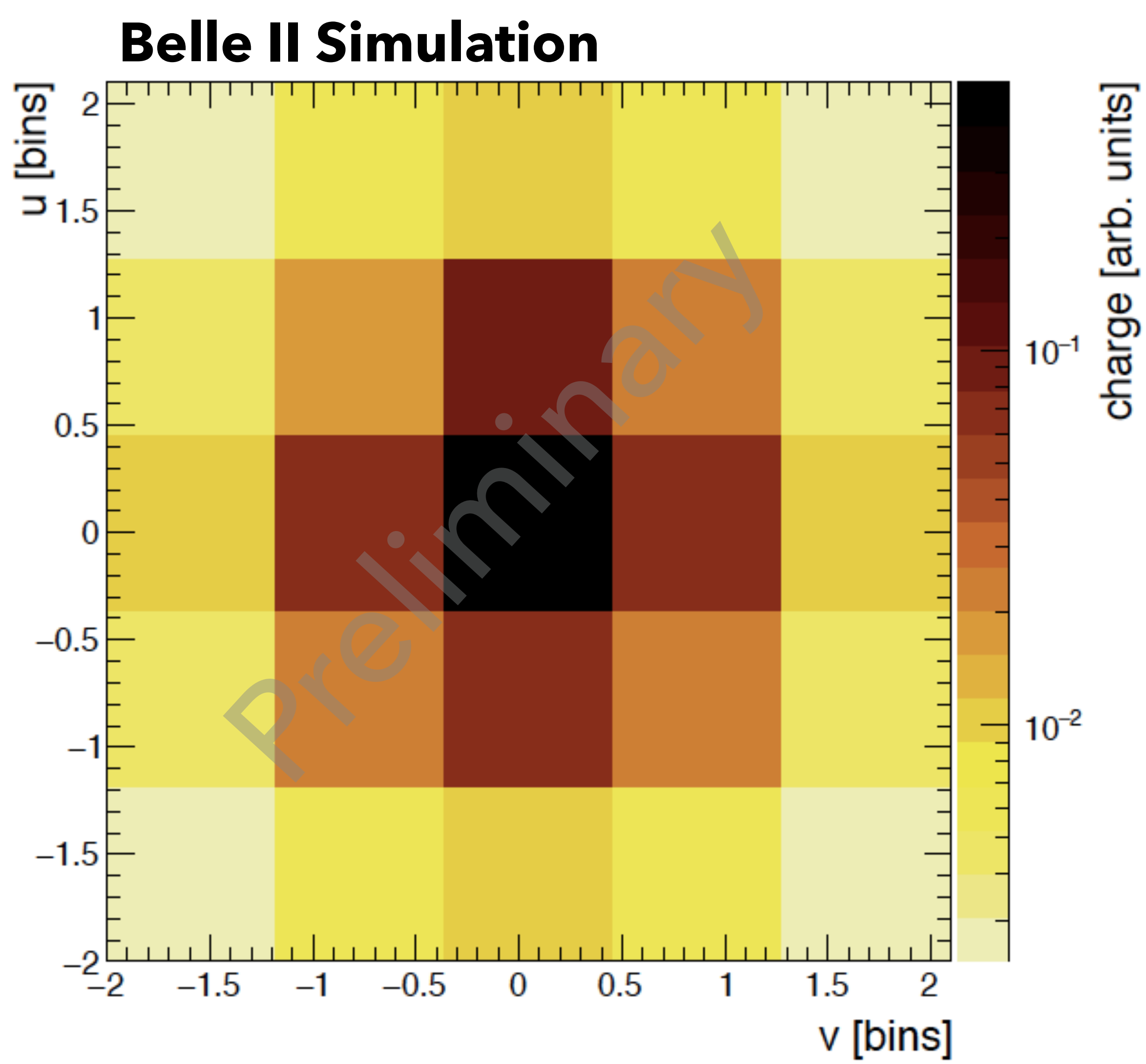
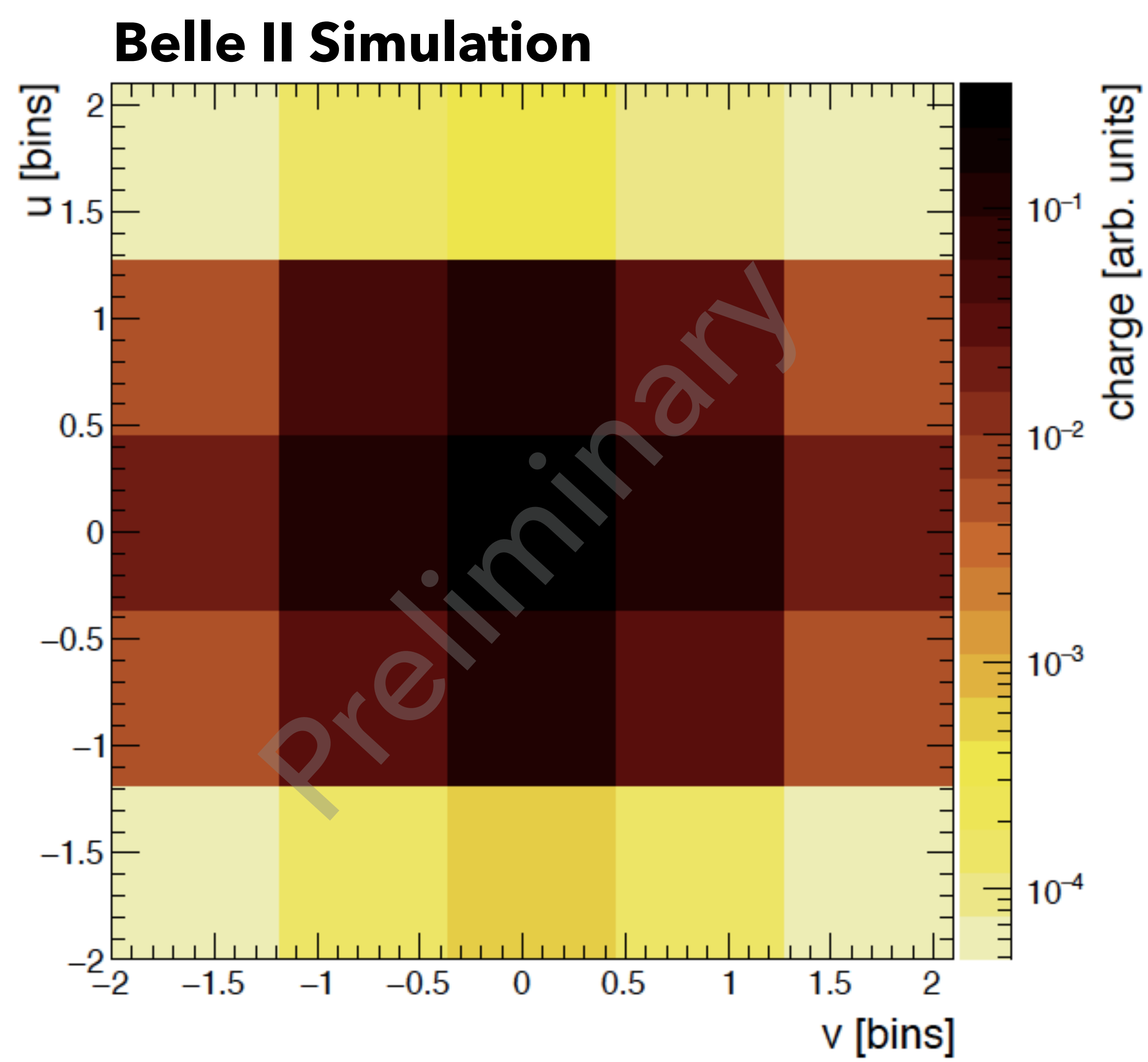
Background



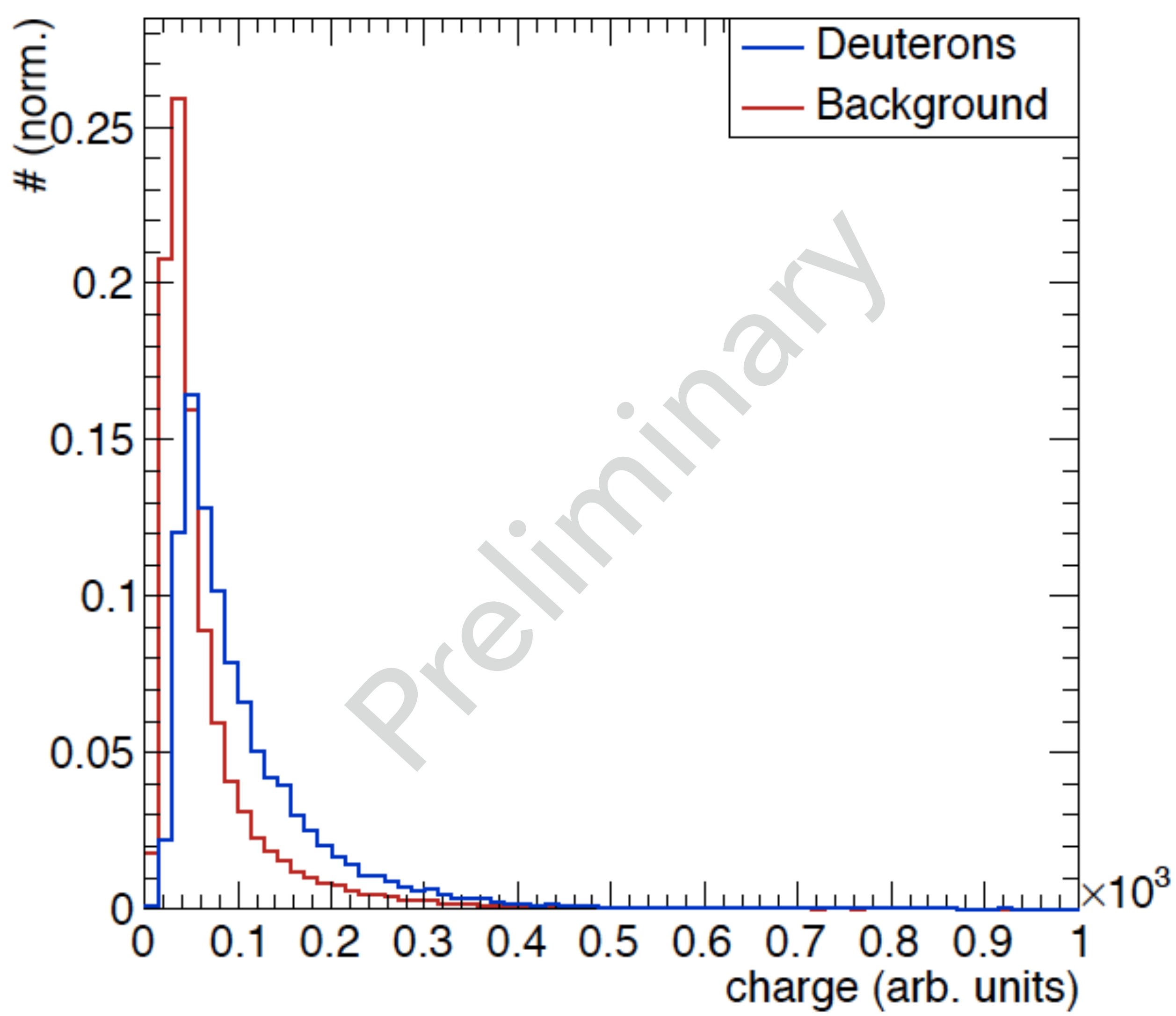
Monopoles



STATUS - IDENTIFICATION OF ANTI-DEUTERONS

- Branching fraction in $\Upsilon(4S)$ decay: $\Gamma_i/\Gamma < 1.3 \cdot 10^{-5}$

Belle II Simulation



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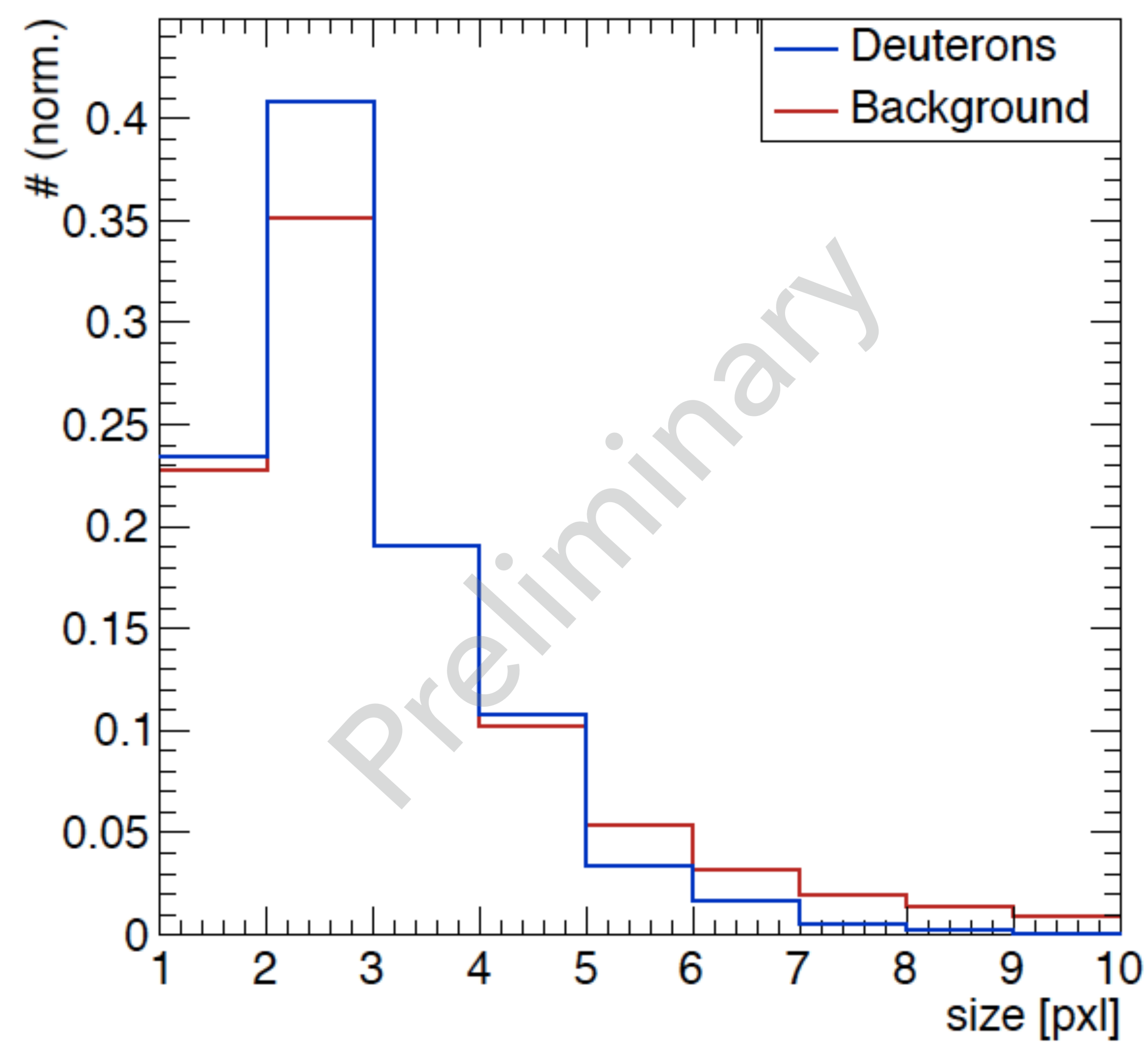
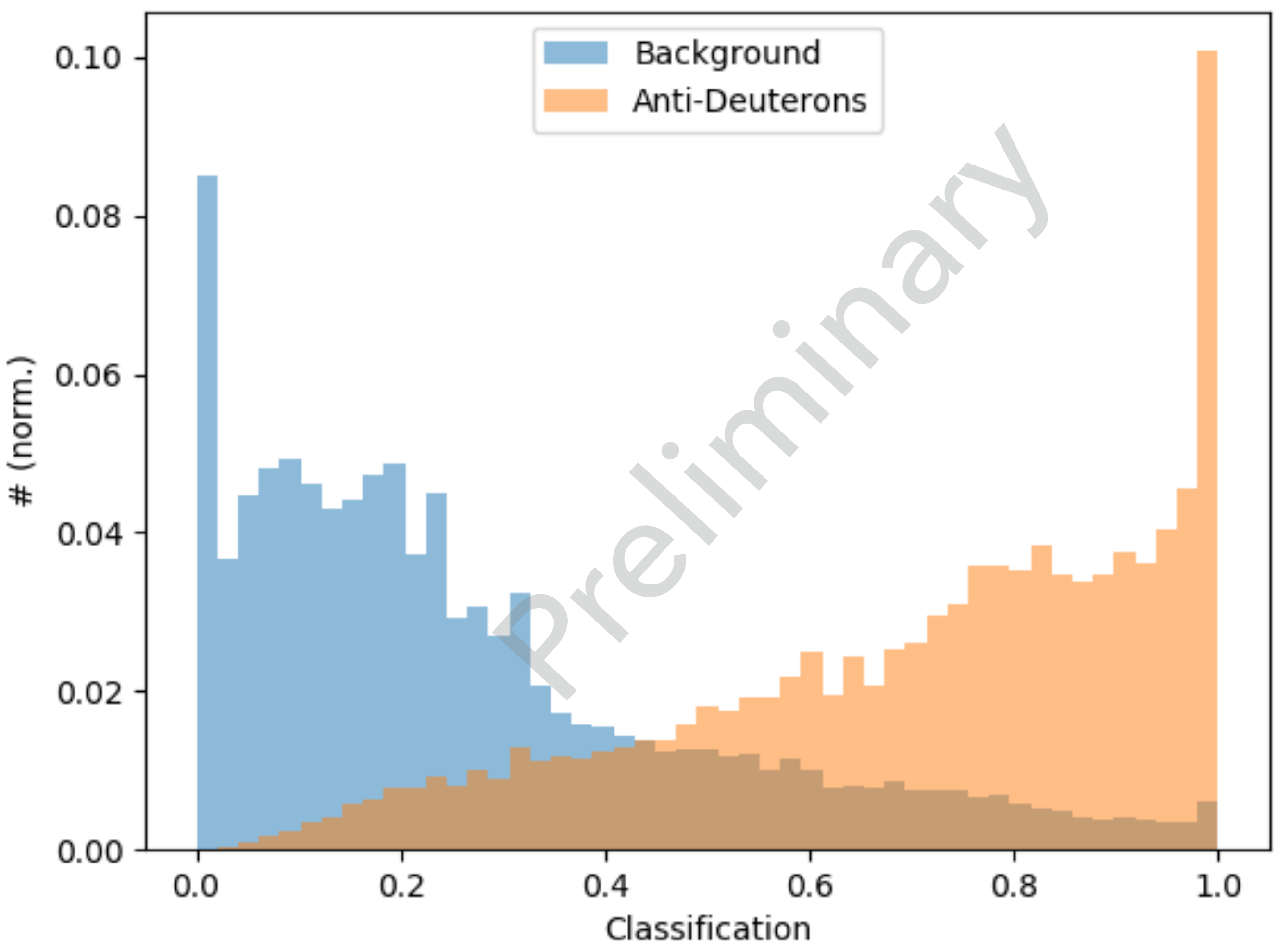
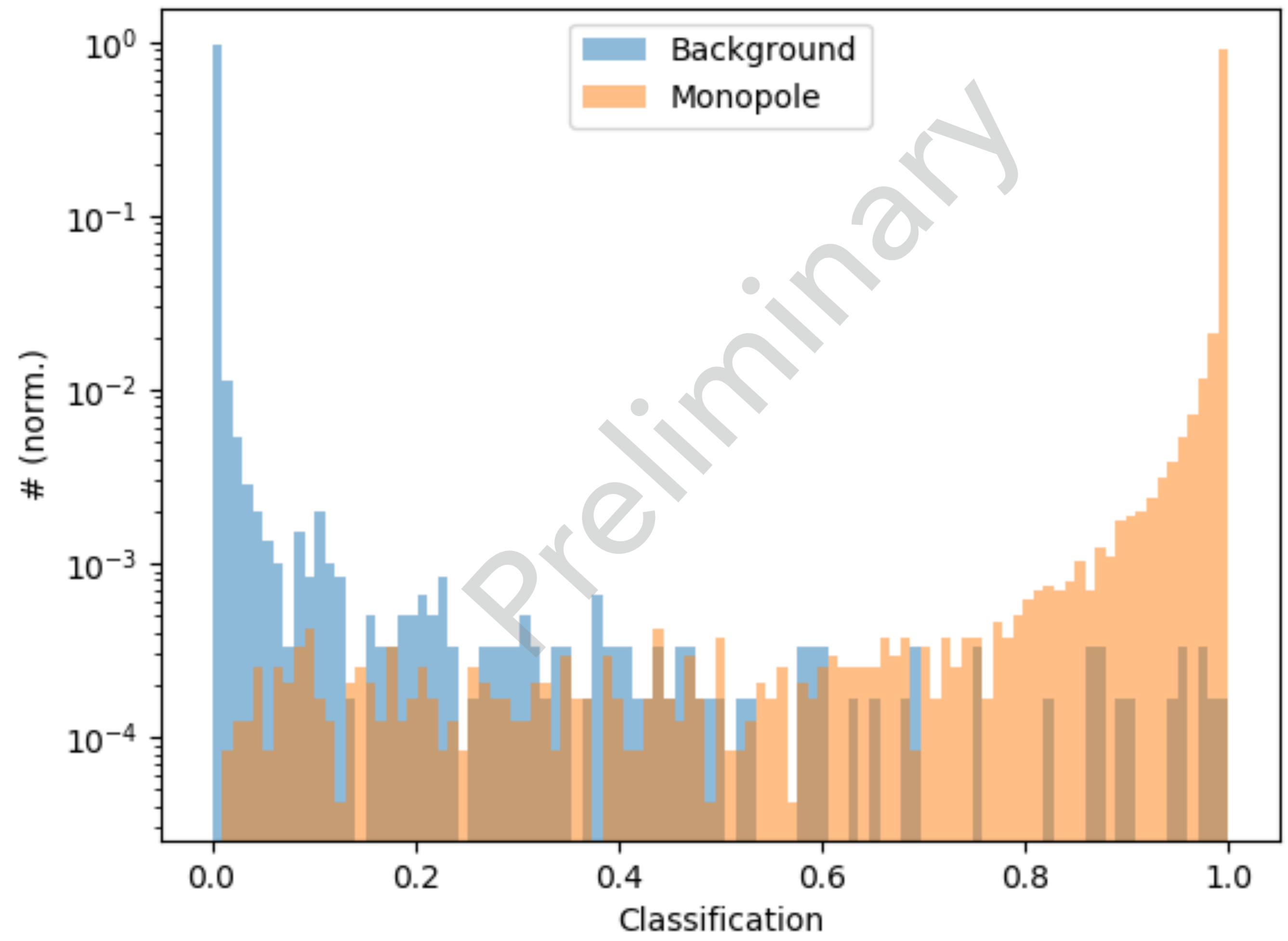


STATUS - CLASSIFICATION WITH NEURAL NETWORK





- <u>Motivation:</u> **Online** identification with PXD to prevent loss of HIP events

- <u>Challenge:</u> Background at least four orders of magnitude higher

OUTLOOK AND CONCLUSION

- **Challenge:** Identification of HIPs complicated due to short range in detector
- **Strategy:** HIP identification with the Belle II Pixel Detector
- **Status:** Feasibility study underway / implementation of monopole simulation currently evaluated
- **Future Objective :** HIP identification on hardware level

OUTLOOK AND CONCLUSION

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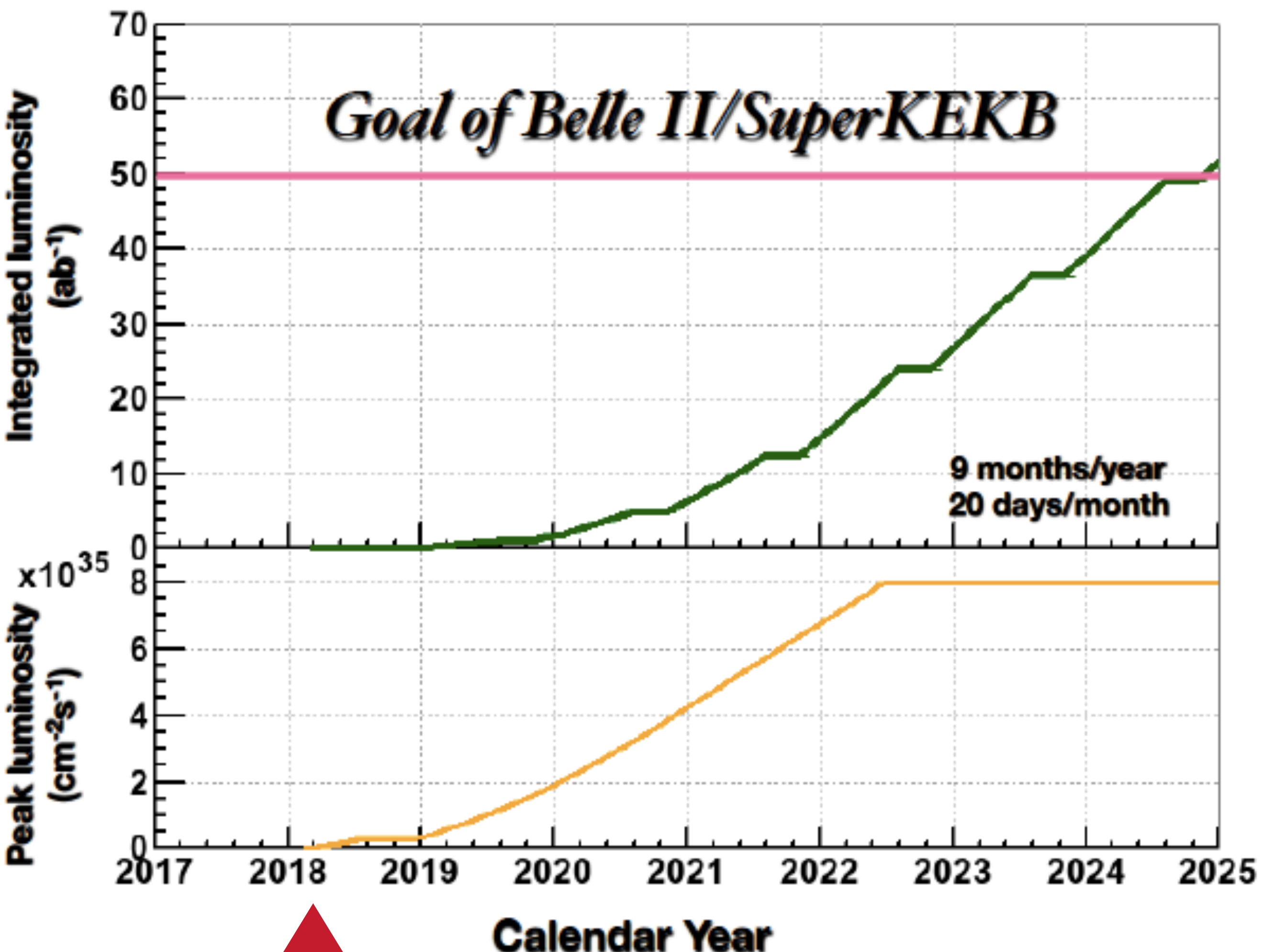
Thank you for your attention!

Спасибо за внимание!

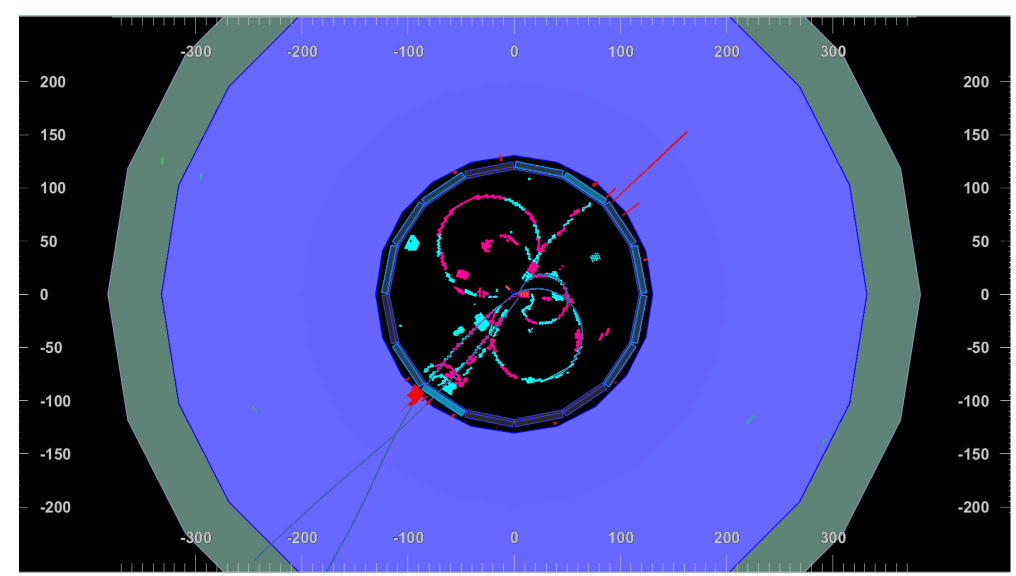
BACK-UP

SUPER-KEKB



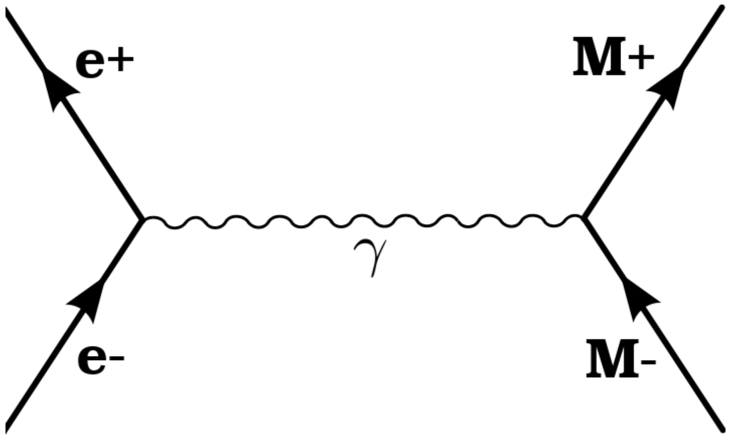
First collision: April 2018

Phase II: $\sim 0.5\ \mathrm{fb}^{-1}$



MONOPOLE PRODUCTION

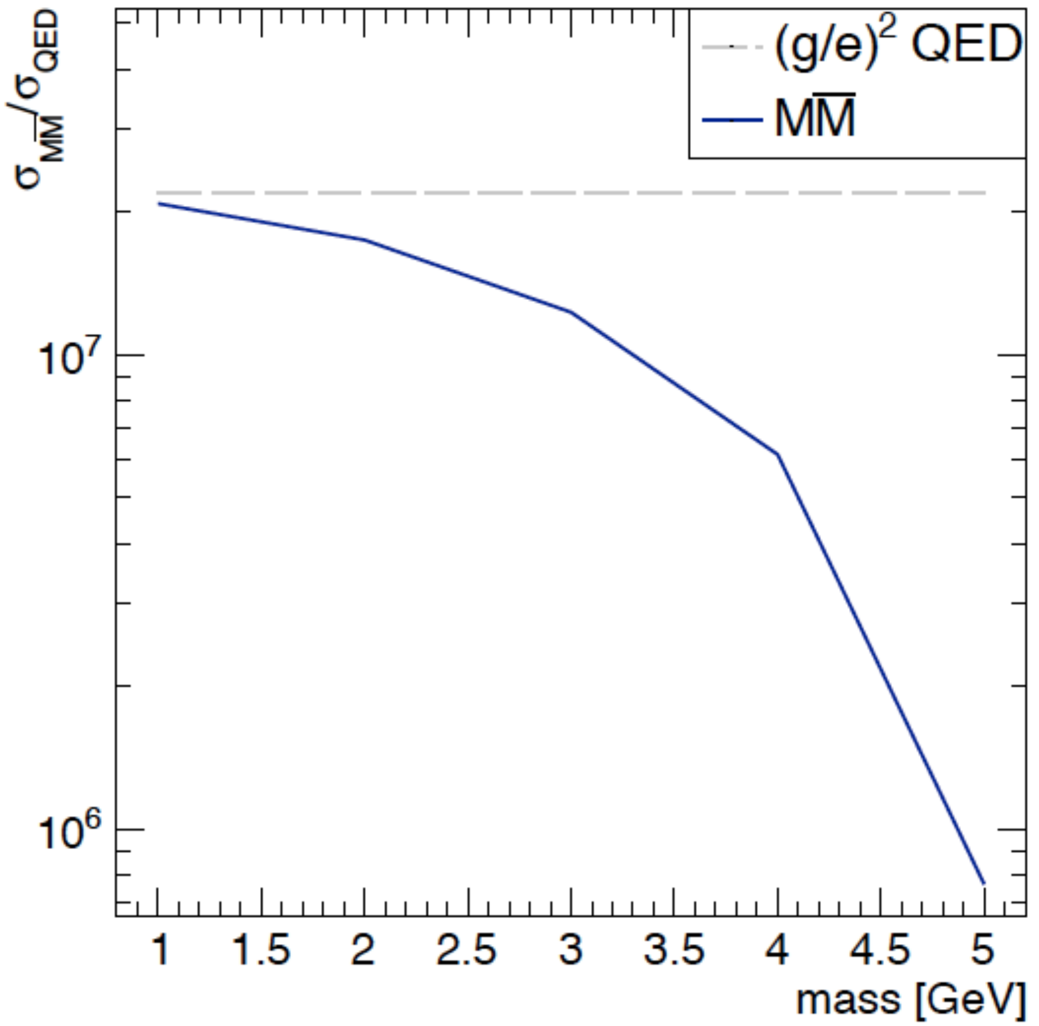
- Monopole pair production:
  $e^+e^- \rightarrow \gamma^* \rightarrow M^+M^-$



- No perturbative treatment possible due to large coupling constant $\alpha_m \approx 34n^2$

- Based on QED pair production:

$$\sigma(e^+e^- \rightarrow M^+M^-)/\sigma(e^+e^- \rightarrow \mu^+\mu^-) \propto \beta^3(\frac{ng}{e})^2$$



WHY NOT DETECTED YET?

- General-purpose detectors in today's particle physics experiments not suitable for HIPs

Characterize detector with HIP source (e.g. alpha emitter)

- Short range prevents activation of trigger

Provide (partial) particle identification with inner detectors

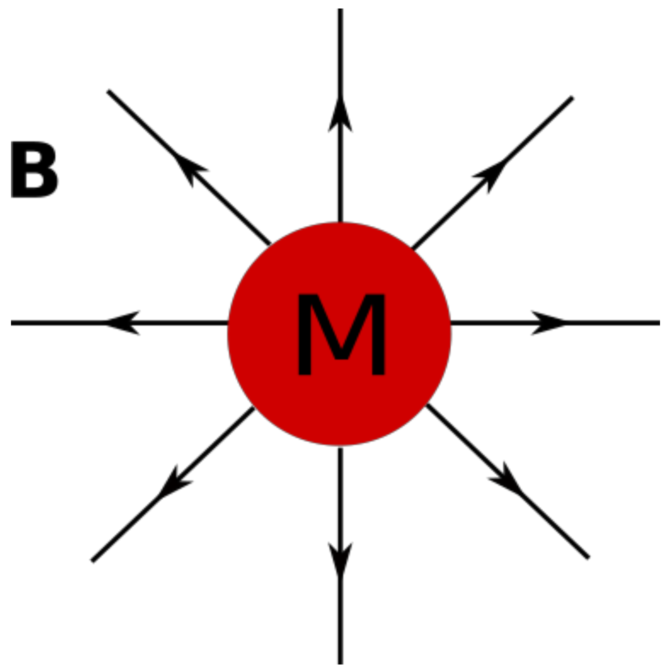
- Conventional tracking algorithms do not recognize trajectory

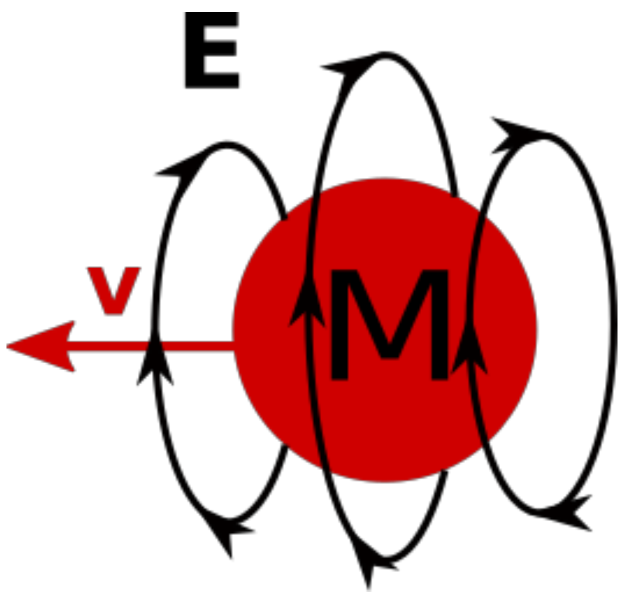
Implement *Monopole-tracking*

MAGNETIC MONOPOLES

- Modified Maxwell equations:

$$
\begin{aligned}
\nabla \mathbf{D} &= 4\pi\rho_e \\
\nabla \mathbf{B} &= 4\pi\rho_m \\
-\nabla \times \mathbf{E} &= \frac{1}{c}\frac{\partial}{\partial t}\mathbf{B} + \frac{4\pi}{c}\mathbf{j}_m \\
\nabla \times \mathbf{H} &= \frac{1}{c}\frac{\partial}{\partial t}\mathbf{D} + \frac{4\pi}{c}\mathbf{j}_e \,.
\end{aligned}
$$





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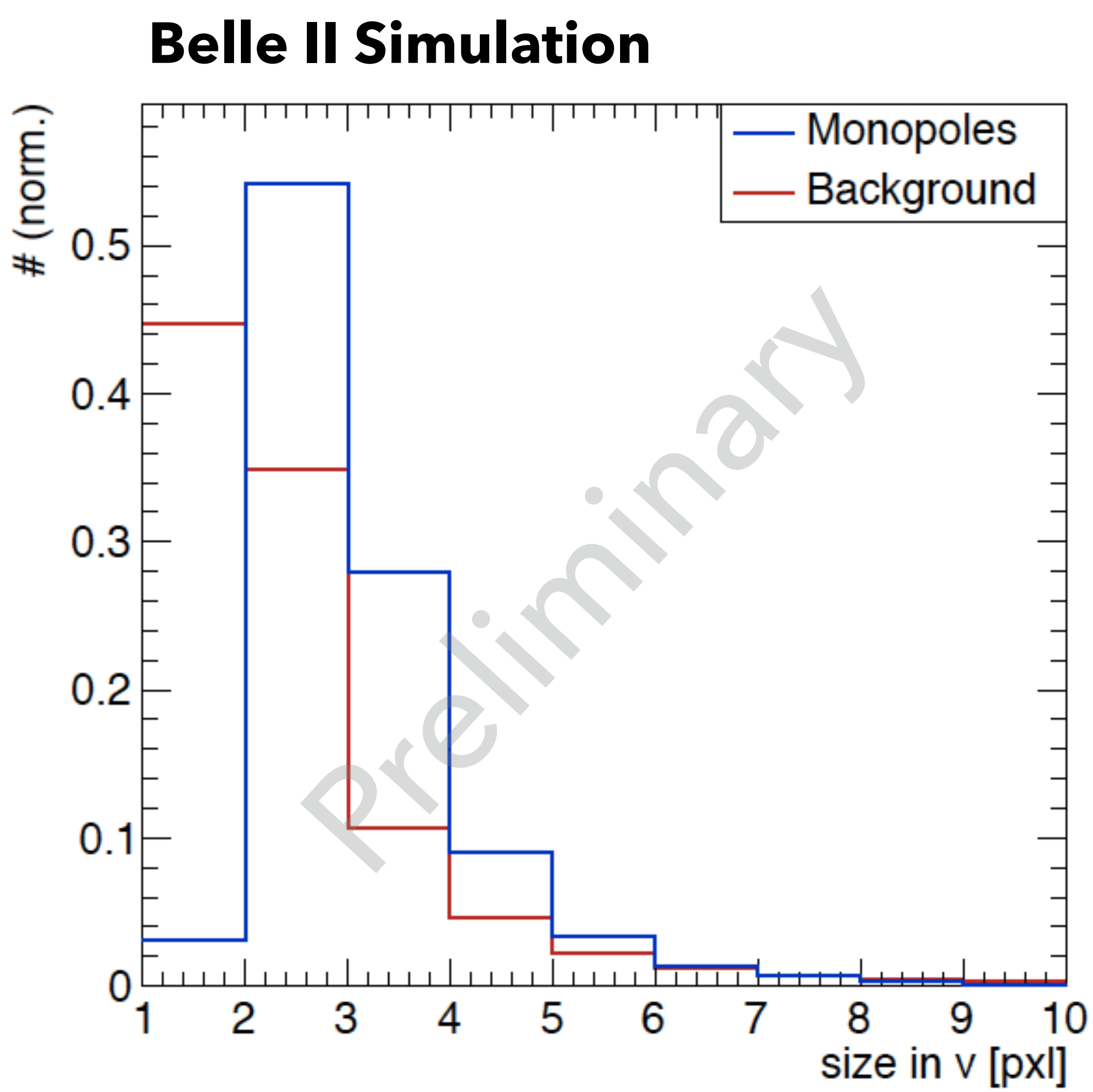
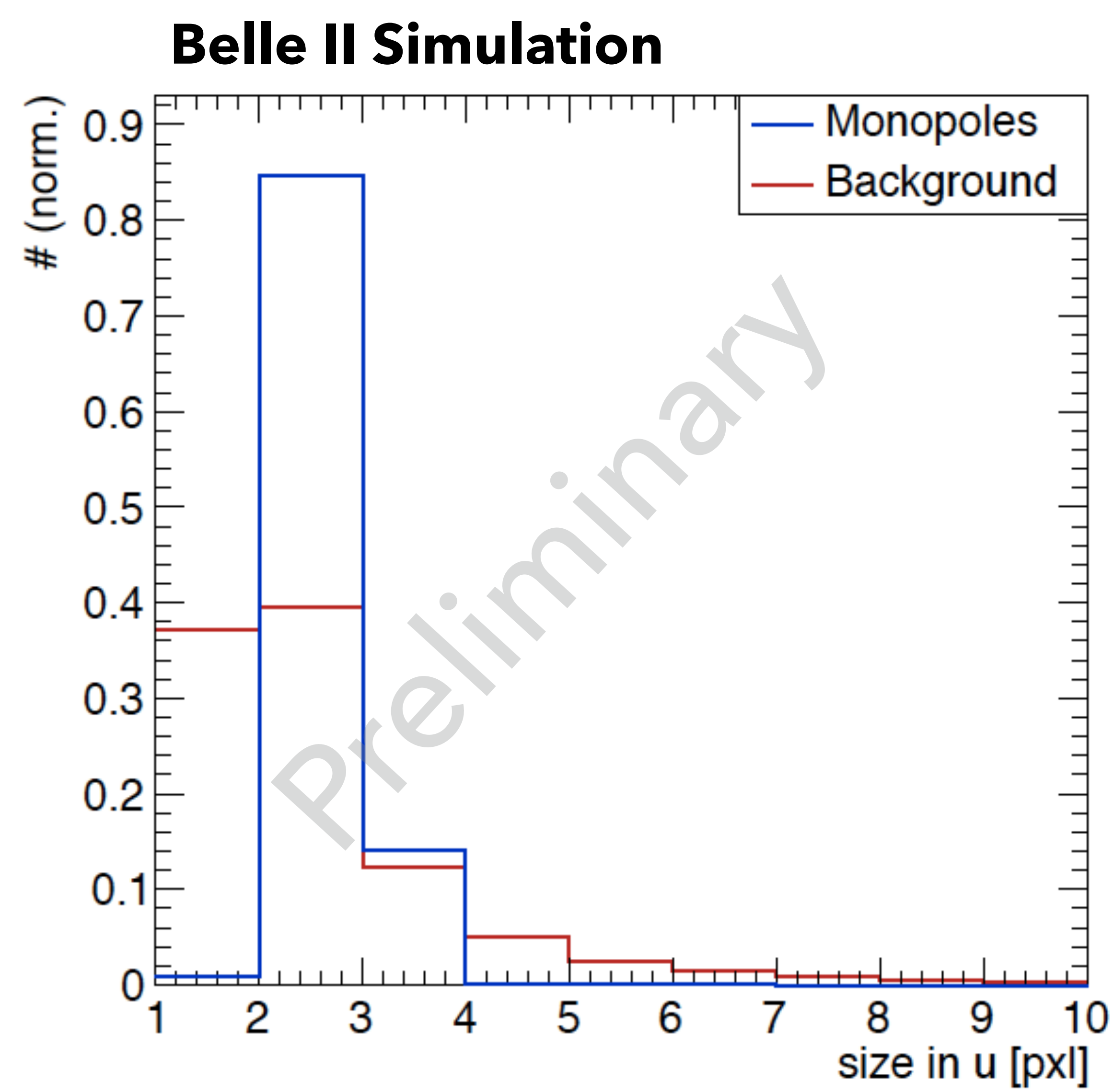
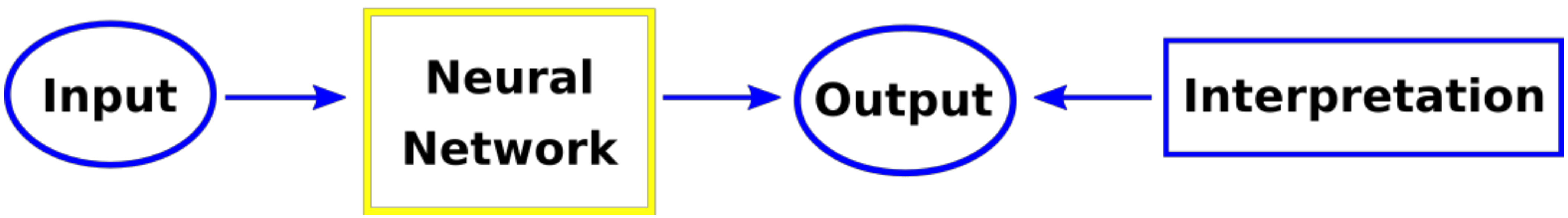


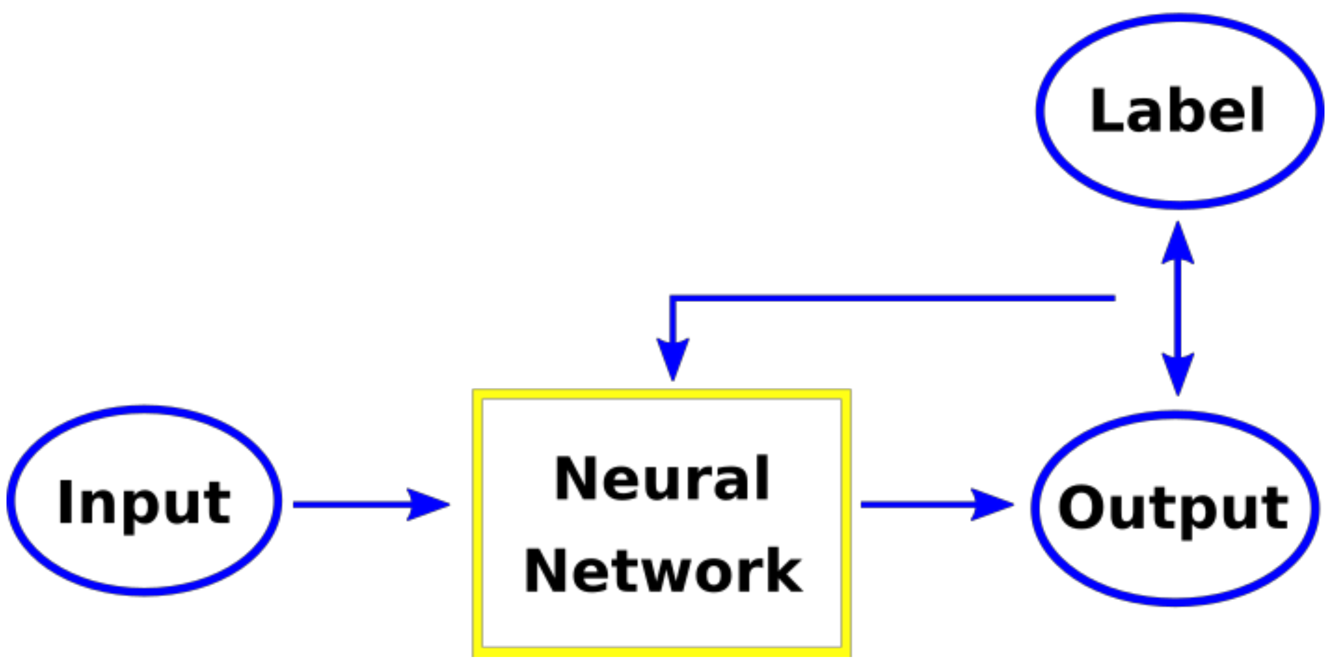


NEURAL NETWORKS

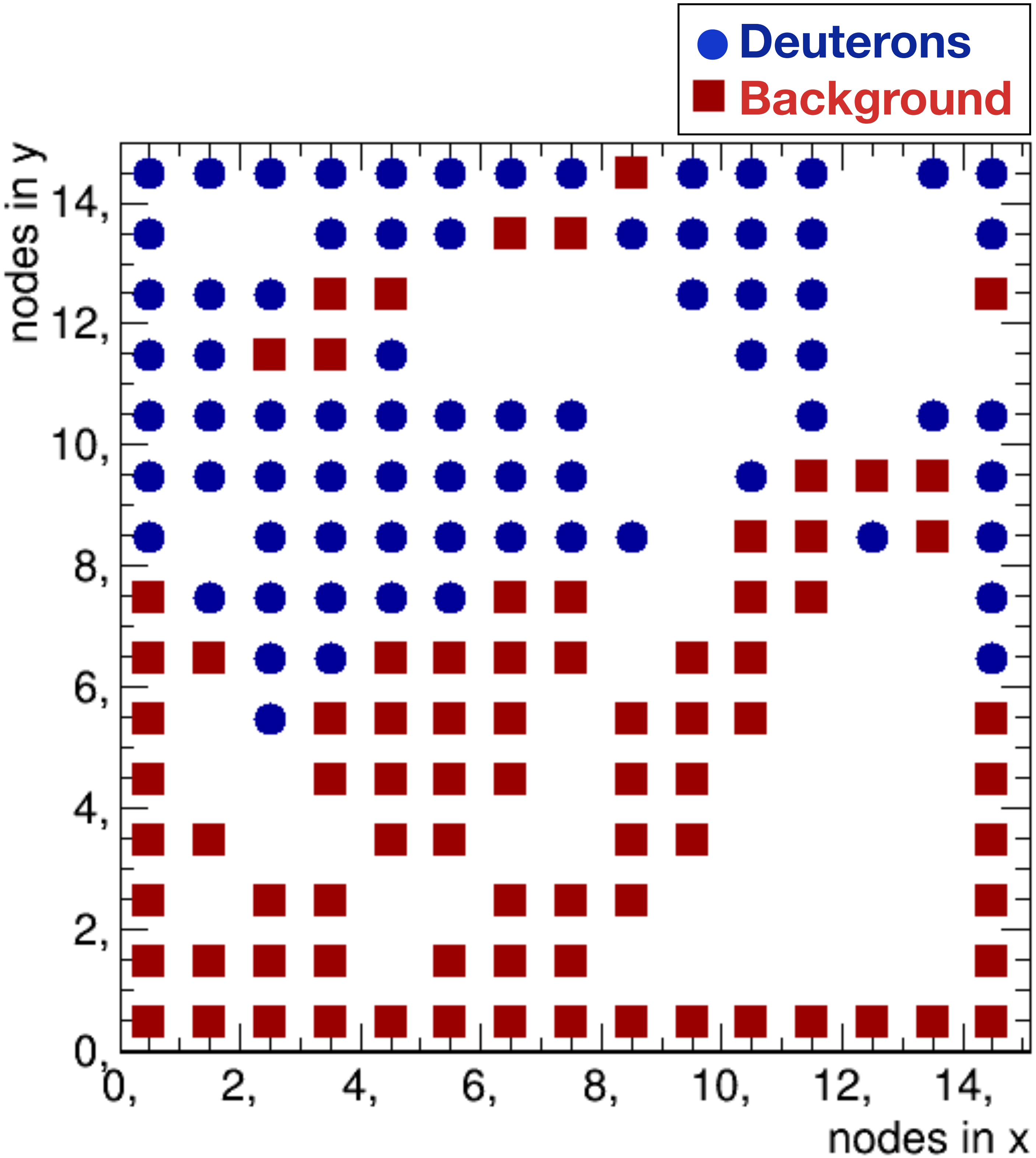
Unsupervised Learning



Supervised Learning



SELF-ORGANIZING MAPS



Self organizing maps

- Node space: 15 x 15
- Size of input vector: 6
- 40,000 input vectors (50% anti-deuterons, 50% background)
- Gaussian learning function
- 400,000 iterations (1 vector per iteration)
- Test with 3,000 vectors