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

Katharina Dort, Soeren Lange, Klemens Lautenbach
(katharina.dort@physik.uni-giessen.de)

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WHAT ARE HIGHLY IONIZING PARTICLES?
HIGHLY IONIZING PARTICLES

= 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)*

CHARACTERISTICS OF MAGNETIC MONOPOLES

Non-Bethe-Bloch energy loss

\[ \frac{dE}{dx}_{mpl} \approx \beta^2 \cdot \frac{dE}{dx}_{\text{Bethe–Bloch}} \]

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

**Searches at electron-positron colliders:**

- **MODAL at LEP**: NTDs  

- **TRISTAN at KEK**: NTDs  

- **CLEO at CESR**: NTDs  

- **PETRA at DESY**: NTDs  

- **TASSO at DESY**: Tracking  

- **OPAL at LEP**: Wire Chamber  
SUPER KEKB

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

40x KEKB peak luminosity:
\[ \mathcal{L} = 8 \cdot 10^{35} \text{cm}^{-2}\text{s}^{-1} \]
More details:
Super KEKB and Belle2 status and plans
from Prof. Xiaolong Wang
**PIXEL DETECTOR**

2 layer DEPFET Pixel Detector (PXD)

- $R = 1.4 \text{ cm} / 2.2 \text{ cm}$
- Thickness: $75 \mu \text{m}$
- Pixel size: $50 \mu \text{m} - 85 \mu \text{m}$
High spatial resolution in close proximity to the interaction region

2 layer DEPFET Pixel Detector (PXD)

- $R = 1.4 \text{ cm} / 2.2 \text{ cm}$
- Thickness: 75 $\mu\text{m}$
- Pixel size: 50 $\mu\text{m} - 85 \mu\text{m}$
PAST SEARCHES

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

**Belle II at KEK:**

PXD (+ Tracking)

- **CLEO at CESR:** NTDs

- **PETRA at DESY:** NTDs

- **TASSO at DESY:** Tracking

- **OPAL at LEP:** Wire Chamber
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• Our **objective**: Check if particle identification with PXD is feasible

• Dirac monopoles **do not** reach outer sub-detectors

**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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WHAT’S THE STATUS?
Testbeam at DESY and CERN

Minimum ionizing particles

DEPFET Technology, Test Beam Performance at Taller de Altas Energías 2013 by Boronat et al.
Preliminary simulation of 1 GeV magnetic monopoles with unit charge:
STATUS - MONOPOLE SIMULATION

- Preliminary simulation of 1 GeV magnetic monopoles with unit charge:
STATUS - IDENTIFICATION OF ANTI-DEUTERONS

• Branching fraction in $\Upsilon(4S)$ decay: $\Gamma_i/\Gamma < 1.3 \times 10^{-5}$
**Motivation:** Online identification with PXD to prevent loss of HIP events

**Challenge:** 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
• **Challenge:** Identification of HIPs complicated due to short range in detector

• **Strategy:** HIP identification with the Belle II Pixel Detector

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**Thank you for your attention!**

**Спасибо за внимание!**
BACK-UP
SUPER-KEKB

Goal of Belle II/SuperKEKB

First collision: April 2018

Phase II: \( \sim 0.5 \text{ fb}^{-1} \)
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:
  \[ \frac{\sigma(e^+e^- \rightarrow M^+M^-)}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)} \propto \beta^3\left(\frac{ng}{e}\right)^2 \]
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:

\[
\nabla D = 4\pi \rho_e \\
\nabla B = 4\pi \rho_m \\
- \nabla \times E = \frac{1}{c} \frac{\partial}{\partial t} B + \frac{4\pi}{c} j_m \\
\nabla \times H = \frac{1}{c} \frac{\partial}{\partial t} D + \frac{4\pi}{c} j_e .
\n\]
STATUS - MONOPOLE SIMULATION

• Preliminary simulation of 1 GeV magnetic monopoles with unit charge:
NEURAL NETWORKS

Unsupervised Learning

Input → Neural Network → Output → Interpretation

Supervised Learning

Input → Neural Network → Output → Label
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