Lohengrin: A Proposed Dark Sector Particle Search Experiment at ELSA

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on behalf of the Lohengrin collaboration

Universität Bonn

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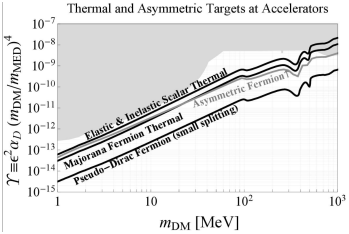
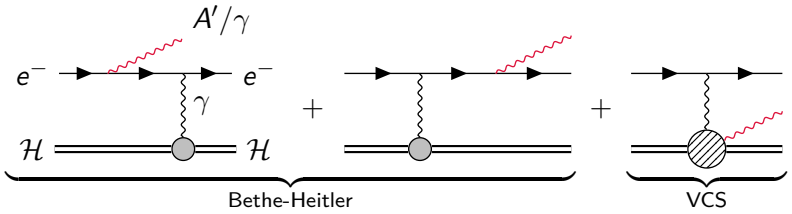
Dark Photons and Dark Sector

- Introduce model for the dark sector to potentially explain dark matter abundance in the universe:

$$\mathcal{L} \supset -\frac{1}{4} F_{\mathrm{D}\mu\nu} F_{\mathrm{D}}^{\mu\nu} + \frac{1}{2} m_{A_{\mathrm{D}}}^2 A_{\mathrm{D}\mu} A_{\mathrm{D}}^{\mu} - \frac{\sin\varepsilon_Y}{2} F_{\mathrm{D}}^{\mu\nu} B_{\mu\nu} - g_{\mathrm{D}} A_{\mathrm{D}\mu} J_{\mathrm{D}}^{\mu}$$

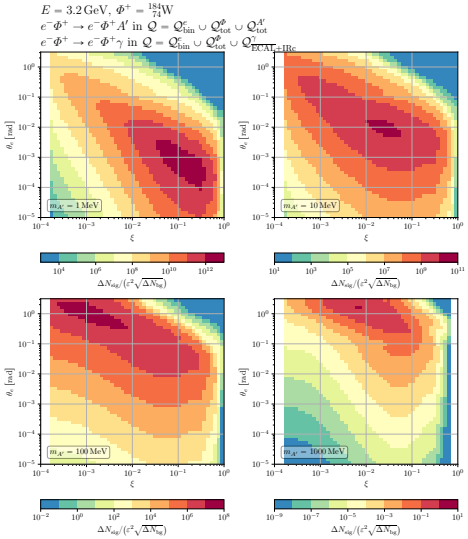




Bechtle et al. 2024; Battaglieri et al. 2017

Possible Space for Discovery (Teaser)

- Based on purely theoretical (and somewhat optimistic) considerations
- 3.2 GeV electron beam hitting $0.1\,X_0$ tungsten target
- ECal covering 0.1 rad opening angle
- Perfectly working tracking
- Only QED backgrounds to relevant order
- Components will be explained



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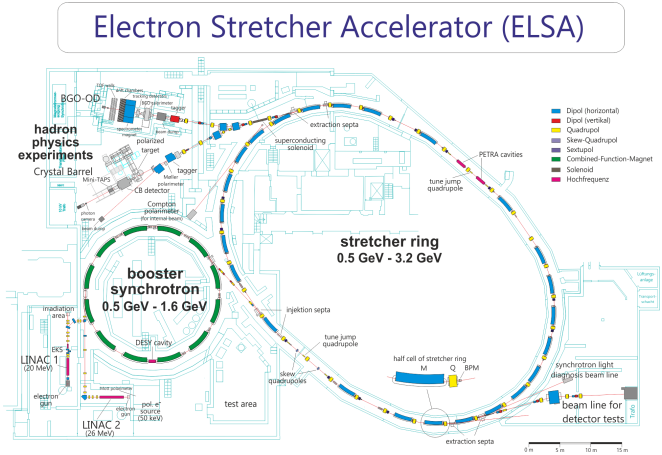
The Accelerator: ELSA

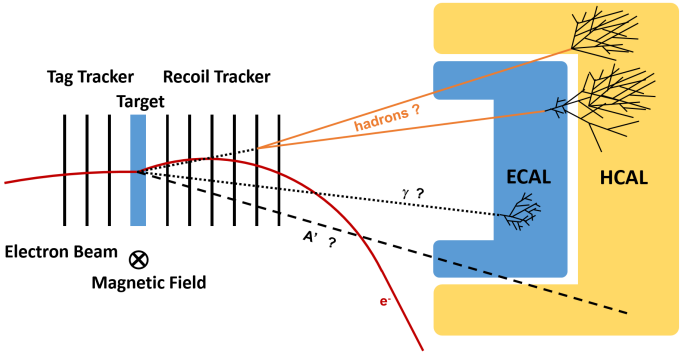
- 3.2 GeV electron beam
- 0.8 ‰ energy resolution
- Beamspot: Gaussian profile with 1 mm size in both directions, divergence< 0.8 mrad
- 2 ns bunch spacing with 0.2 electrons on average $\rightarrow$ 100 MHz electron rate
- Huge advantage: Precisely known initial state



Bechtle et al. 2024; Frommberger 2019

Proposed Concept → Necessary Detector Requirements

- Trackers for electron momentum measurement
- Calorimeters for vetoing



- Next: Implications for detector requirements

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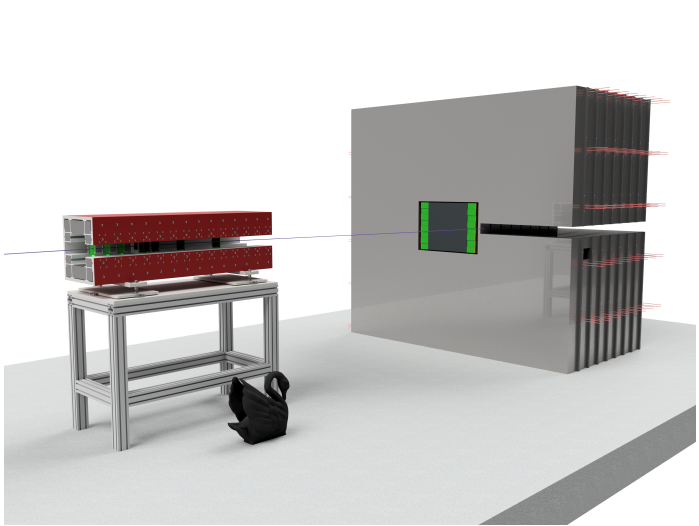
Current Proposed Setup



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You see:

- C-shaped magnet
- Tagging and recoil tracker inside the magnet
- Tungsten target in between both trackers
- ECal
- HCal surrounding ECal
- Cygnus atratus (to scale)

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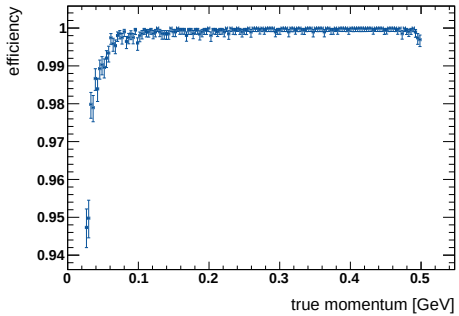
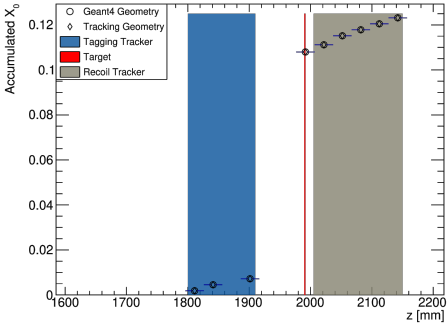
Tracking

Layer	Target	1	2	3	4	5	6	7	8	9
z Position [mm]	2000	1810	1840	1900	2010	2030	2045	2070	2100	2130





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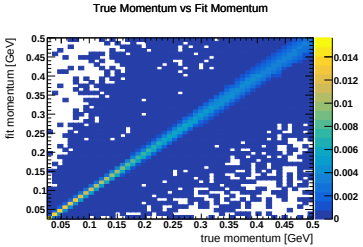
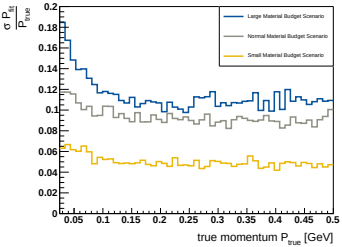
Tracking





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- Fit is done using a GSF with 6 components
- Pattern matching using truth info (single electron bunches)
- Works well even down to 25 MeV
- Comparison to Gluckstern formula theoretical value:
  - Small scenario: $\approx 3\,\%$ to $5\,\%$
  - Normal scenario: $\approx 8\,\%$ to $10\,\%$
  - Large scenario: $\approx 11\,\%$ to $17\,\%$

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Sensitivity Estimate: Backgrounds

Acceptance backgrounds

- Dominant process
- Main contributor SM Bremsstrahlung
- Studied and can be simulated in detail → Included in all you have seen so far

Neutral hadrons

- Hard to estimate theoretically
- Made rough estimated based on Geant4 simulations
- Included a generous amount as irreducible background

Neutrinos

- Small cross section →
- Not as relevant for current number of EOT
- Is ignored in first approximation for now

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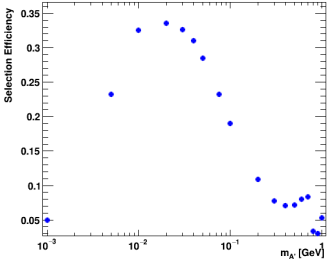
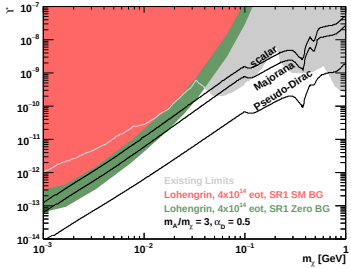
Sensitivity Estimate

- Define signal region:
  - At least one beam electron, one signal electron:
    - ★ 25 MeV$<E_{\text{electron}}<$75 MeV
    - ★ $\theta_e<0.25$
  - $E_{\text{ECal}} < 640$ MeV
  - No veto in HCal
  - Absence of other charged tracks
- Go through analysis chain
- Combine into sensitivity plot with confidence level 90 %





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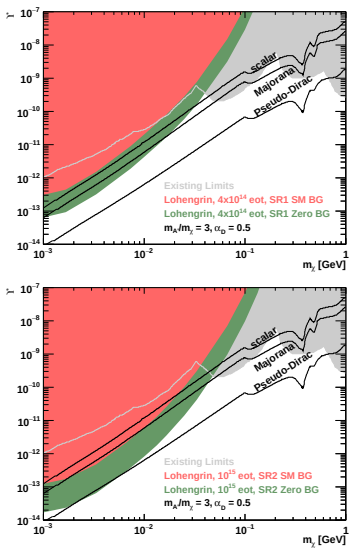
Conclusion and Outlook



- Walk through some detector components
- Showing tracking as vital part for sensitivity estimate
- Phased approach: Build components necessary for measurements going into more accurate sensitivitiy estimate first
- Can increase sensitivity by extending signal region
- More luminosity is also always an option
- More info see: `https://arxiv.org/abs/2410.10956`

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Battaglieri, M. et al. (July 2017). "US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report". In: *U.S. Cosmic Visions: New Ideas in Dark Matter*. arXiv: 1707.04591 [hep-ph].

Bechtle, P. et al. (2024). *A Proposal for the Lohengrin Experiment to Search for Dark Sector Particles at the ELSA Accelerator*. arXiv: 2410.10956 [hep-ex]. URL: https://arxiv.org/abs/2410.10956.

Frommberger, F. (2019). *ELSA Homepage*. URL: https://www-elsa.physik.uni-bonn.de/index_en.html (visited on 26/02/2020).

Lohengrin, Oper Oslo (2024). URL: https://en.wikipedia.org/wiki/Lohengrin_(opera)#/media/File:Lohengrin_8420-Peralta.jpg (visited on 11/09/2024).

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Additional Material

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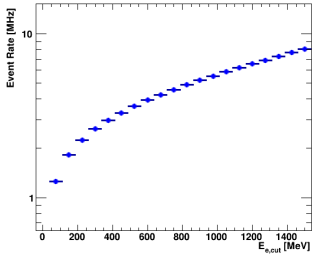
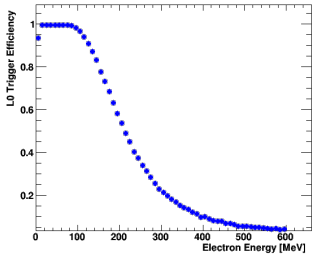
Trigger

- For previous considerations to work, trigger needs to reduce event rates by factor $\approx 10 - 20$
- Needs to be fast $\rightarrow$ very simple, relies on hit or signal
  - Hit in first plane (1 cm distance) AND
  - at least 1.99 mm off center in 2nd (3 cm distance) OR
  - at least 2.3 mm off center in 3rd (4.5 cm distance) OR
  - at least 3.1 mm off center in 4th (7 cm distance)





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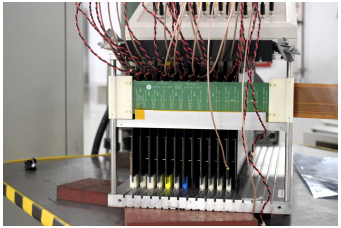
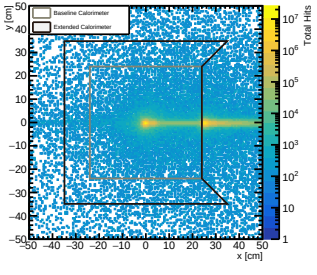
ECal Considerations

- Crystal calorimeters: Not radiation hard enough
- Currently SiW sampling calorimeter on CALICE prototype
- Main challenge: Coping with hitrate (plot shows total hits after 0.5 s of runtime $\rightarrow$ 10 MHz in central modules)
- Steer main electron beam away from ECal
- Upper end of what electronics can handle





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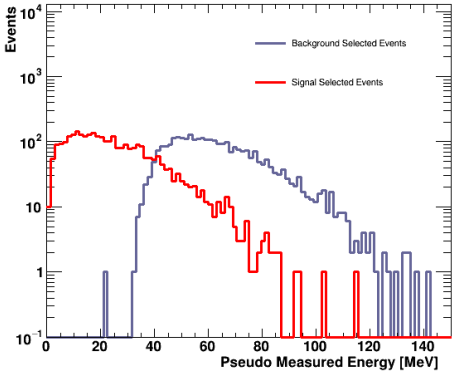
ECal Considerations



- Simulate calorimeter response with fast peaking times for shaper
- Look at events which pass L0 trigger
- Generate "signal" by removing high energy photon
- Able to sufficiently distinguish both cases

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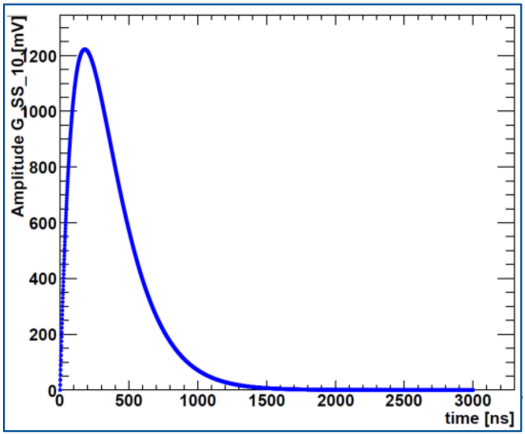
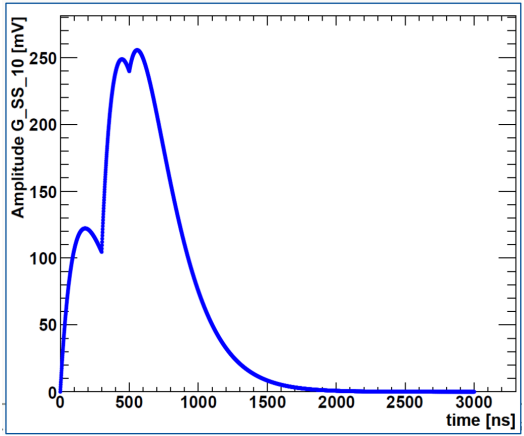
Simulated signal shaping in the ECal





Courtesy of Matthias Hamer

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Lohengrin: Why the name?

- Princess Elsa needs help for trial by combat
- Mysterious knight Lohengrin helps out → One rule: His identity has to remain unknown
- Elsa asks about it after the wedding ceremony
- He has to leave

> Nie sollst du mich befragen,
> noch Wissens Sorge tragen,
> woher ich kam der Fahrt,
> noch wie mein Nam' und Art.
>
> — *Richard Wagner*

Lohengrin, Oper Oslo 2024

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