

Lohengrin: A Proposed Dark Sector Particle Search Experiment at ELSA

Jan - Eric Heinrichs
on behalf of the Lohengrin collaboration

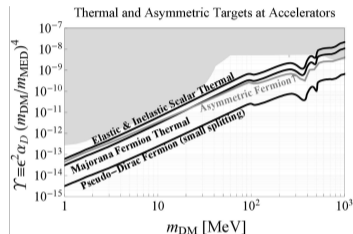
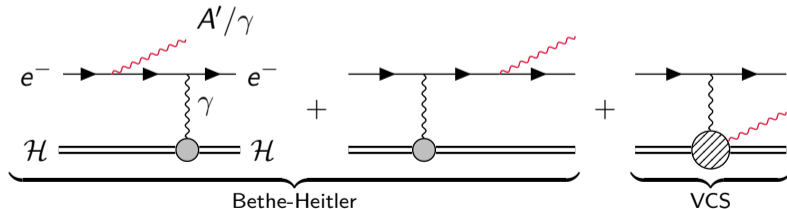
Universität Bonn

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Dark Photons and Dark Sector

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

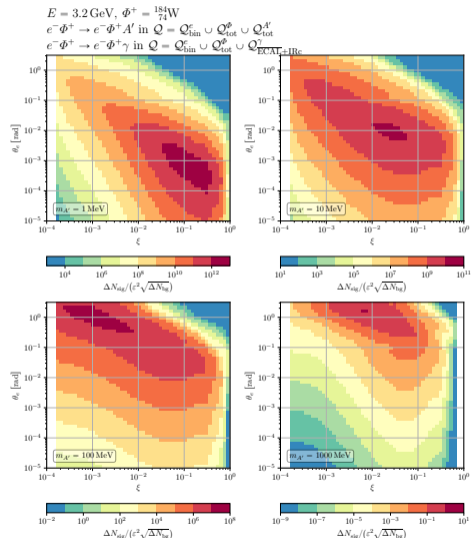
$$\mathcal{L} \supset -\frac{1}{4} F_{D\mu\nu} F_D^{\mu\nu} + \frac{1}{2} m_{A_D}^2 A_{D\mu} A_D^\mu - \frac{\sin \varepsilon \gamma}{2} F_D^{\mu\nu} B_{\mu\nu} - g_D A_{D\mu} J_D^\mu$$



Bechtle et al. 2024; Battaglieri et al. 2017

Possible Space for Discovery (Teaser)

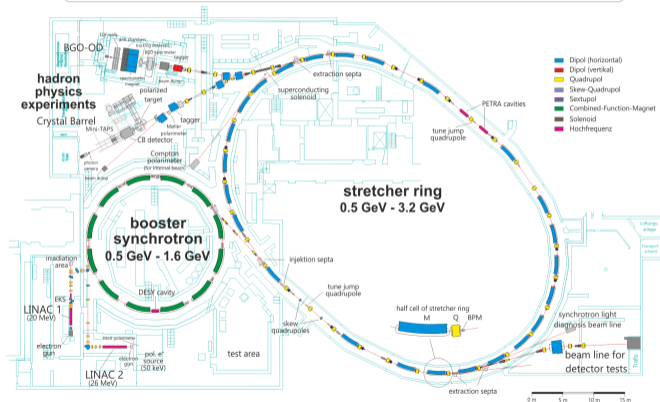
- Based on purely theoretical (and somewhat optimistic) considerations
- 3.2 GeV electron beam hitting 0.1 X_0 tungsten target
- ECal covering 0.1 rad opening angle
- Perfectly working tracking
- Only QED backgrounds to relevant order
- Components will be explained



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 → 100 MHz electron rate
- Huge advantage: Precisely known initial state

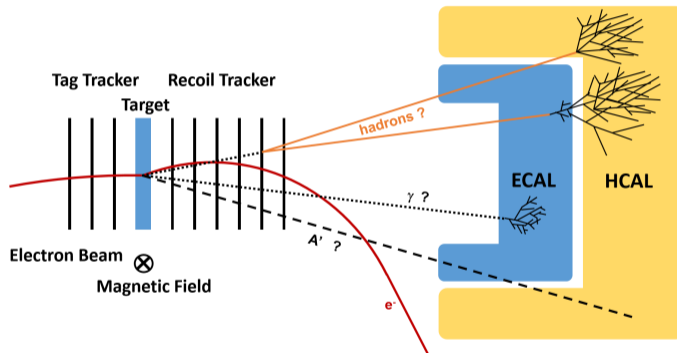
Electron Stretcher Accelerator (ELSA)



Bechtle et al. 2024; Frommberger 2019

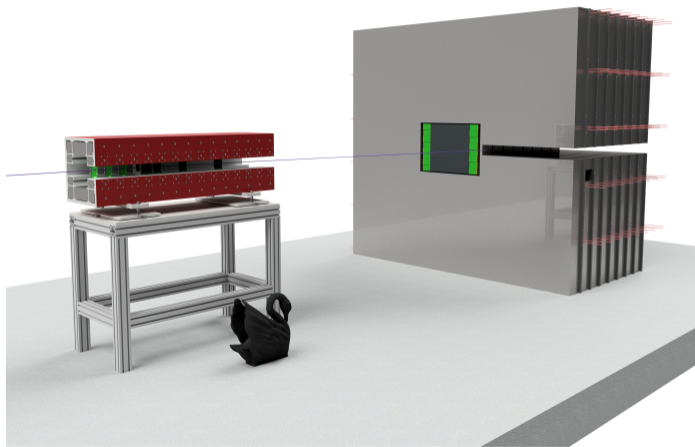
Proposed Concept → Necessary Detector Requirements

- Trackers for electron momentum measurement
- Calorimeters for vetoing



- Next: Implications for detector requirements

Current Proposed Setup

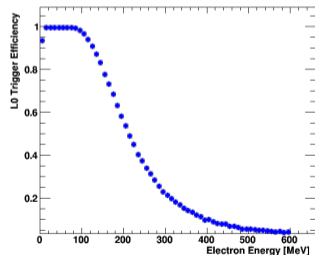
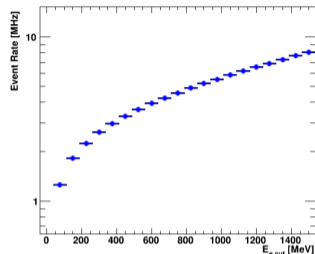


You see:

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

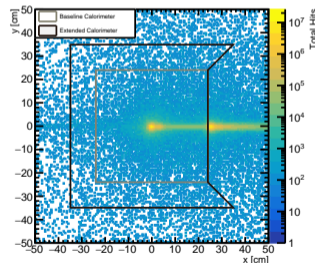
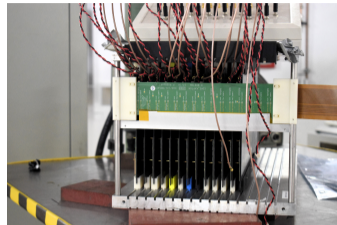
Bechtle et al. 2024

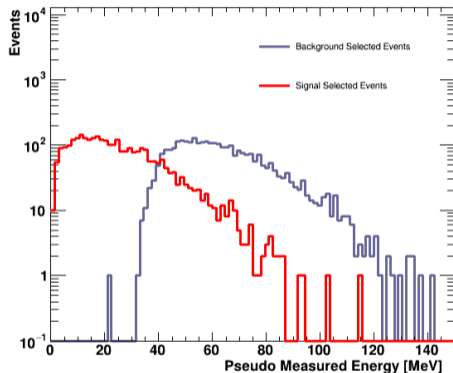
- For previous considerations to work, trigger needs to reduce event rates by factor $\approx 10 - 20$
- Needs to be fast \rightarrow very simple, relies on hit or signal
 - ▶ Hit in first plane (1 cm distance) AND
 - ▶ at least 1.99 mm off center in 2nd (3 cm distance)
OR
 - ▶ at least 2.3 mm off center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



ECal Considerations

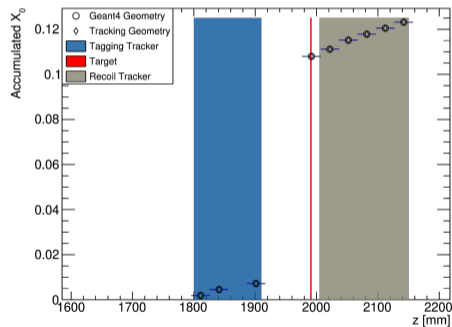
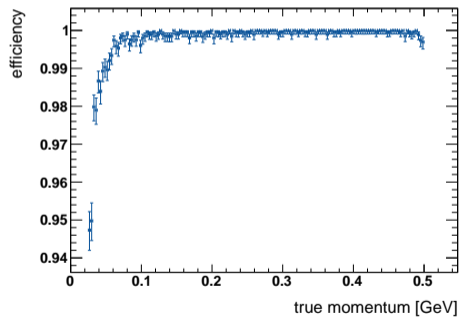
- Crystal calorimeters: Not radiation hard enough
- Currently SiW sampling calorimeter on CALICE prototype
- Main challenge: Coping with hitrate (plot shows total hits after 0.5 s of runtime \rightarrow 10 MHz in central modules)
- Steer main electron beam away from ECal
- Upper end of what electronics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



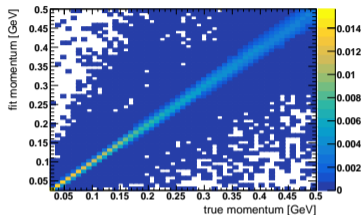


- Simulate calorimeter response with fast peaking times for shaper
- Look at events which pass L0 trigger
- Generate "signal" by removing high energy photon
- Able to sufficiently distinguish both cases

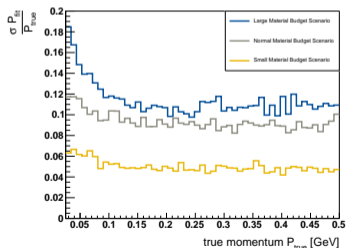
Layer	Target	1	2	3	4	5	6	7	8	9
z Position [mm]	2000	1810	1840	1900	2010	2030	2045	2070	2100	2130



True Momentum vs Fit Momentum



- 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%



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

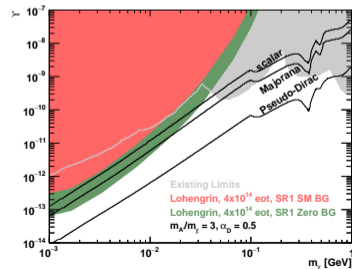
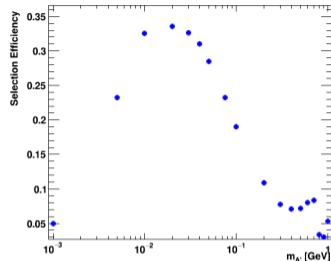
- Hard to estimate theoretically
- Made rough estimated based on Geant4 simulations
- Included a generous amount as irreducible background

Neutrinos

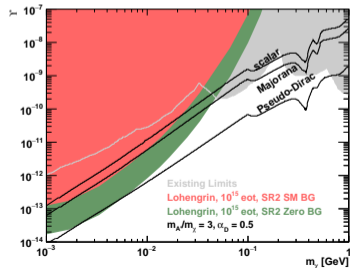
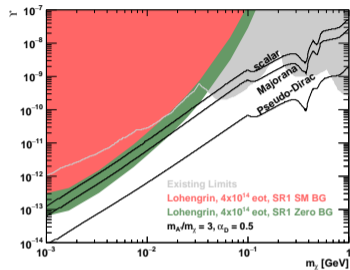
- Small cross section →
- Not as relevant for current number of EOT
- Is ignored in first approximation for now

Sensitivity Estimate





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



Conclusion and Outlook

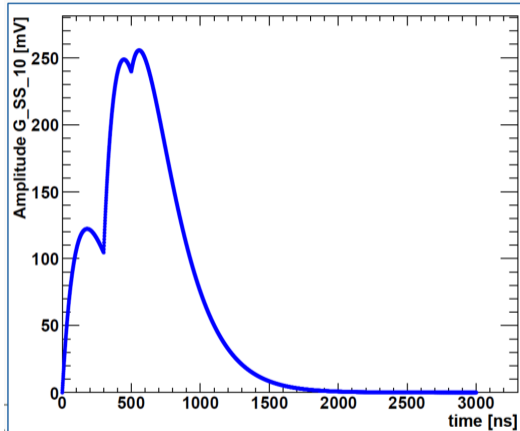
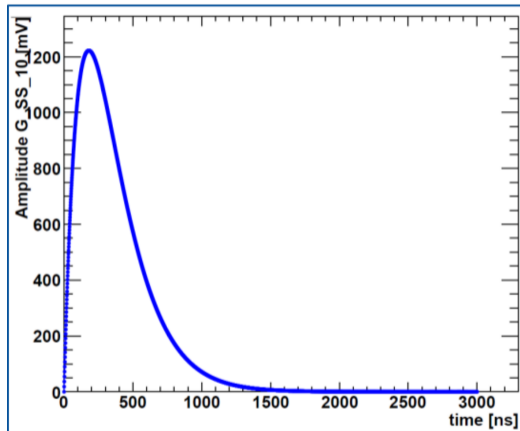


- Walk through detector components
- Slowly build up necessary info for sensitivity estimate
- Address problems one at a time
- Phased approach: Build components necessary for measurements going into more accurate sensitivity estimate first
- Can increase sensitivity by extending signal region
- More luminosity is also always an option
- More info see:
<https://arxiv.org/abs/2410.10956>

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

Additional Material

Simulated signal shaping in the ECal



Courtesy of Matthias Hamer

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