Universität Siegen / Naturwissenschaftlich-Technische Fakultät

Towards a Lohengrin Tracking ASIC

IHL Kickoff Meeting

Matthias Hamer, for the Lohengrin Study Group
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uni-siegen.de

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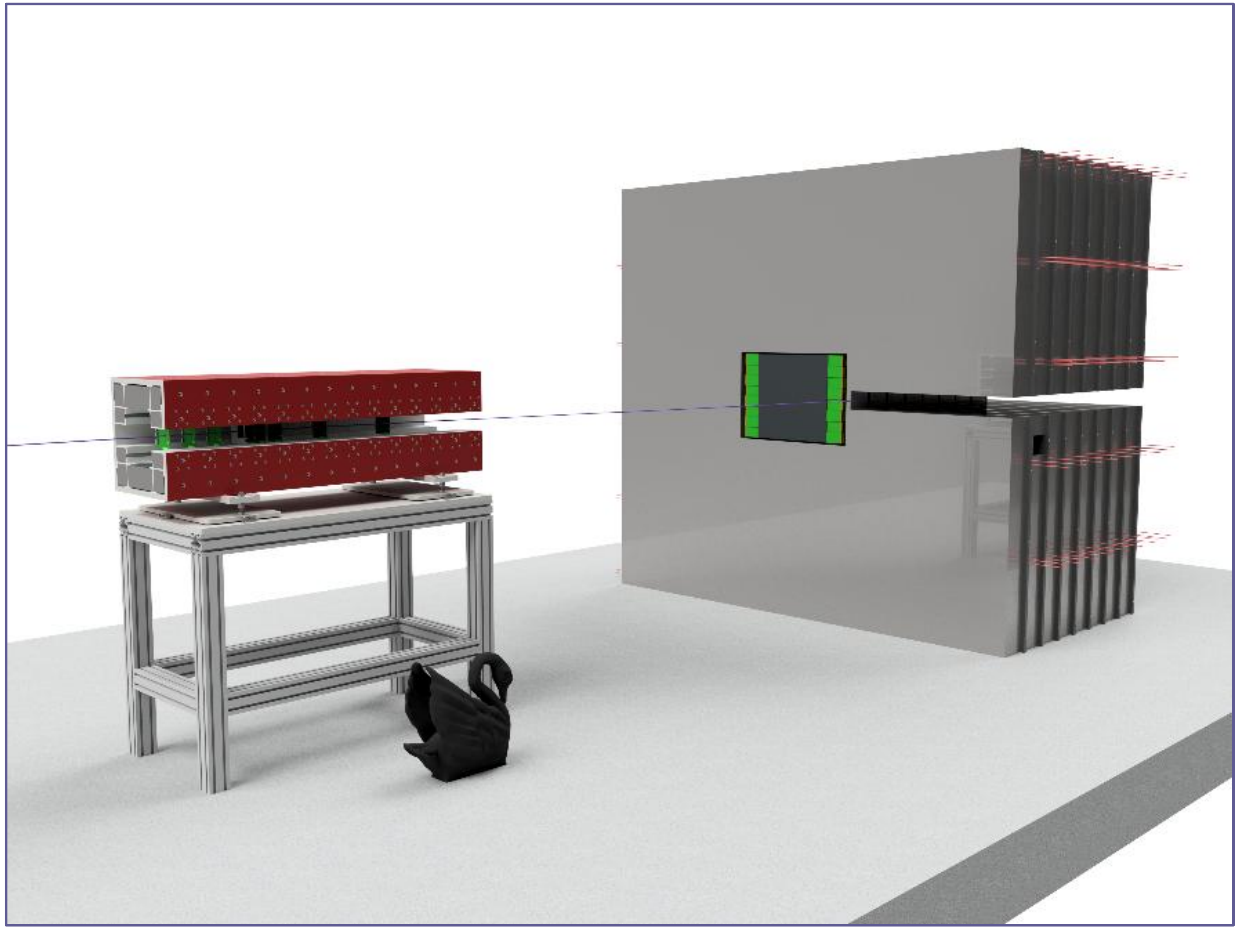
4 IFIC, Valencia | 5 DMLab, DESY/IN2P3/CNRS | 6 NTNU Norway | 7 University of Siegen

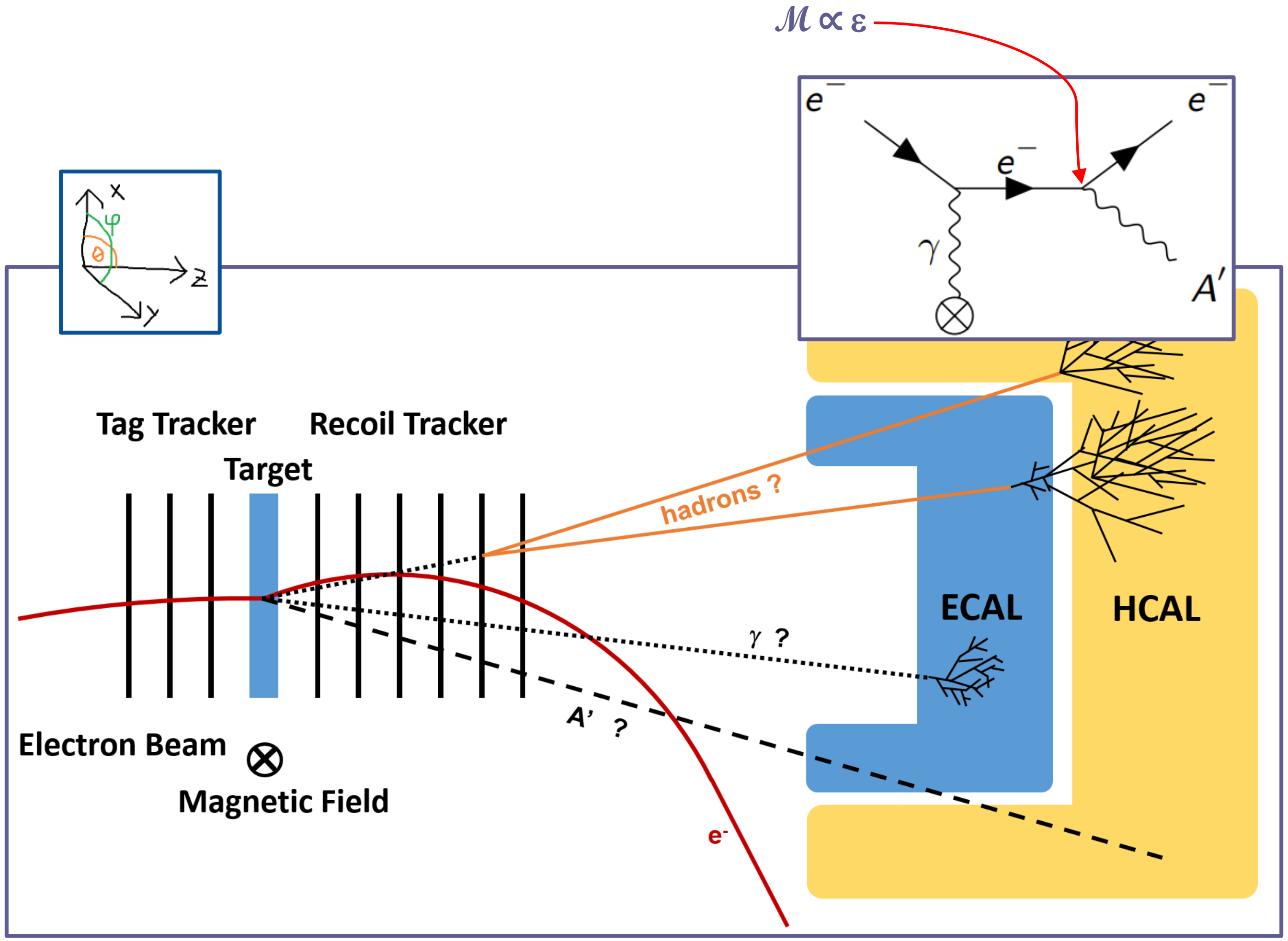
Introduction – the Lohengrin Experiment

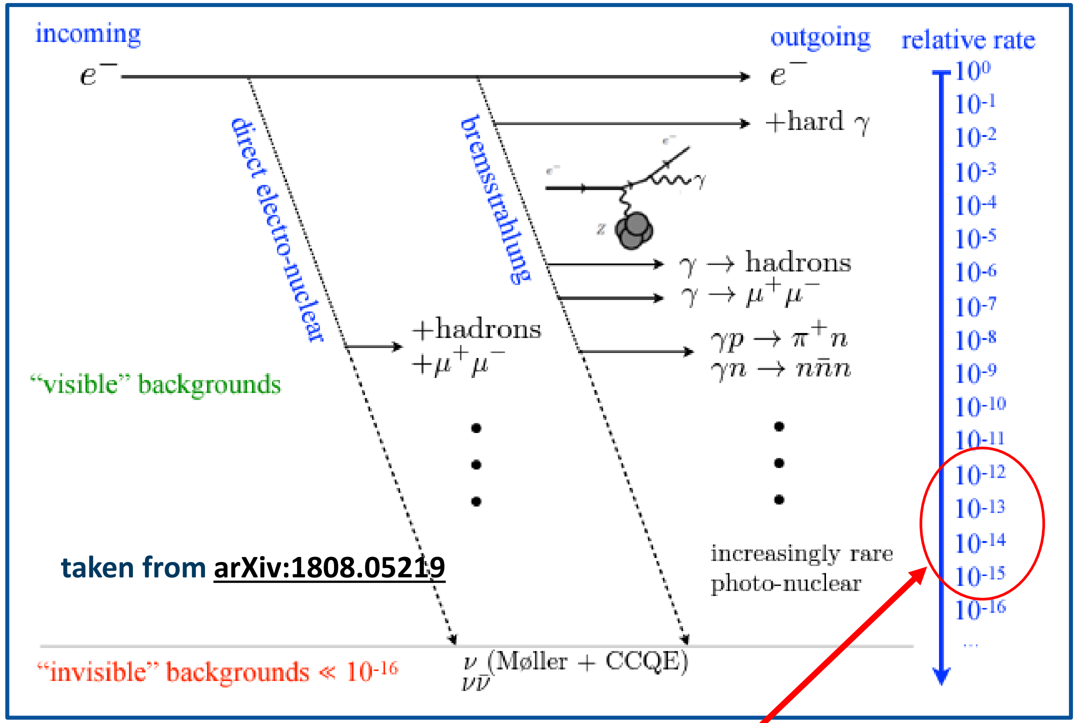


- Planned Fixed-Target, missing momentum based, dark matter experiment at ELSA
  - electrons on tungsten(?) target
  - occasional (=O(10^{-12})) production of a dark photon (or any other FIP)
  - high number of eot required for competitive sensitivity

$$\mathscr{L} \supset -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \frac{m_{A'}^2}{2}A'_\mu A'^\mu - \boxed{A'_\mu(\epsilon e J^\mu_{\mathrm{EM}}} + g_D J^\mu_D)$$

Introduction – the Lohengrin Experiment

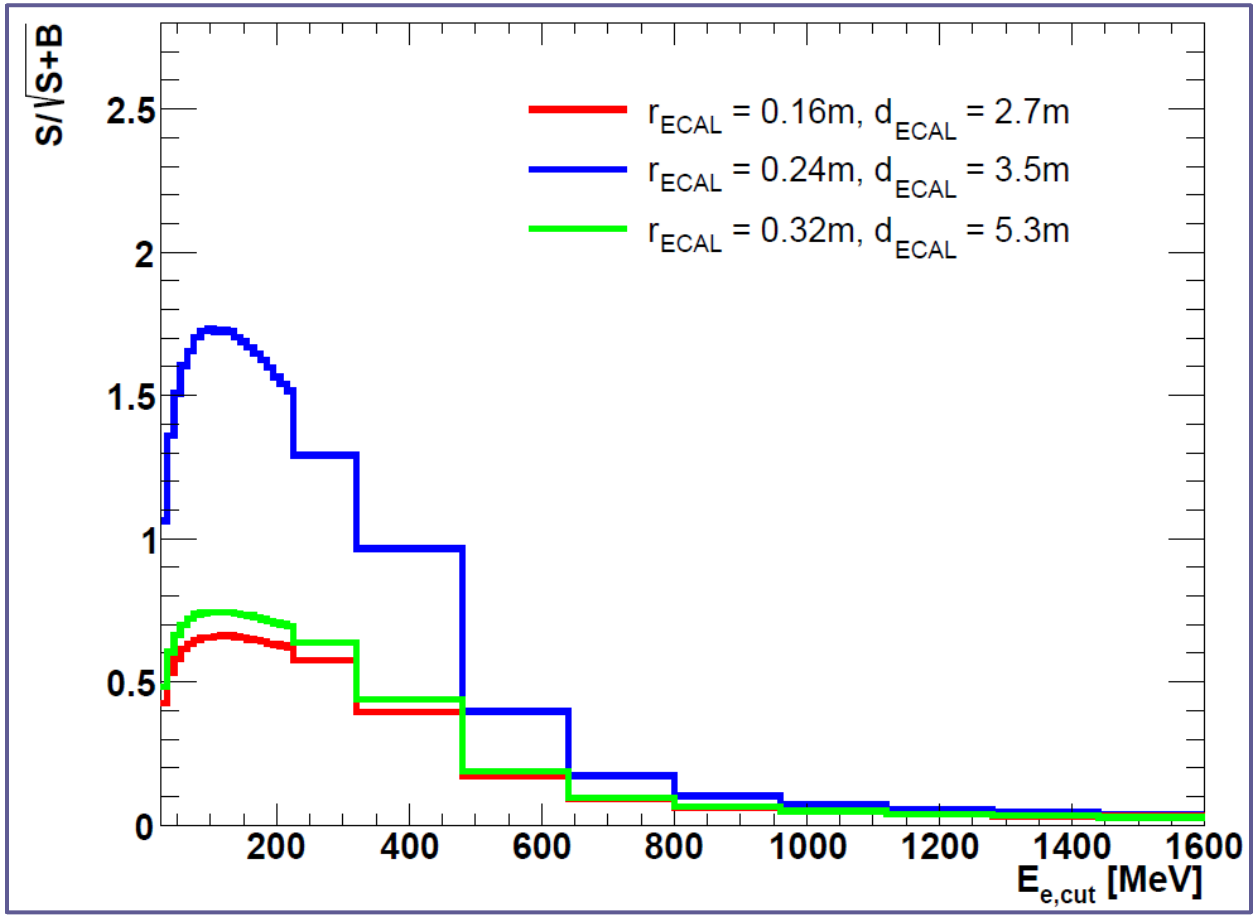




this is where the music plays

→ name of the game is background suppression

Introduction – sensitivity considerations

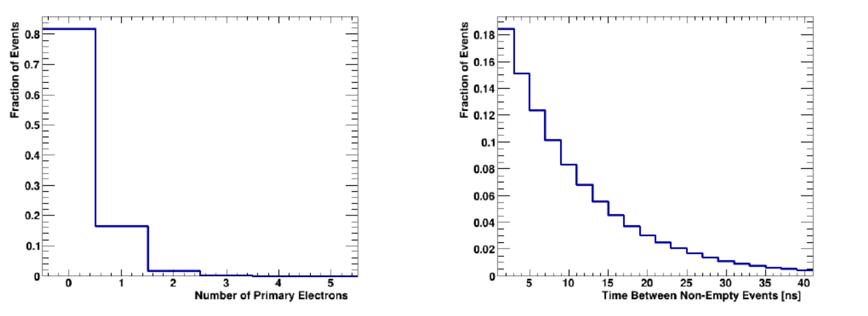


- skipping a lot of steps here, obviously
- we achieve the best sensitivity in a signal region where we require the **recoil electron to have an energy of O(100) MeV** or less
    - we need high tracking efficiency for electrons with as low energies as imaginable
- that cut alone still leaves us with overwhelming amount of SM bremsstrahlung and hadronic activity in the final state
    - rely on calorimeters as veto detectors

ELSA as the ideal electron source for Lohengrin

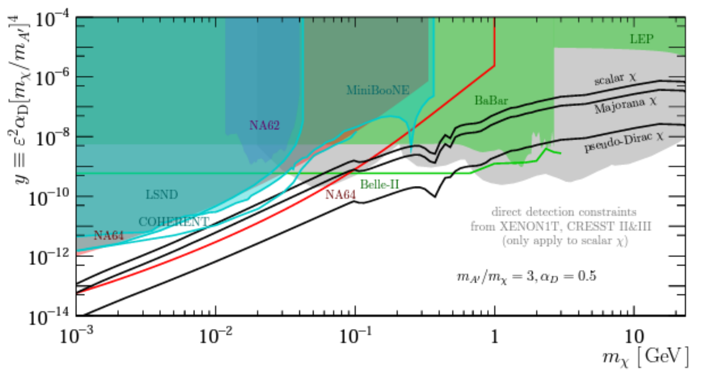
- ELSA can produce (on average) single electrons that hit our target
- 1 extraction cycle every 2ns
  - IF we can resolve single events, this experiment provides a unique environment to search for feably interacting particles
  - achieving scientifically valuable sensitivity within a reasonable amount of runtime requires a high extraction rate

    → 100 MHz as preliminary target. can work with μ = 0.2 extracted electrons per cycle to reach an average rate of 100 MHz eot, while keeping the amount of di-eot or tri-eot events at a reasonably low rate

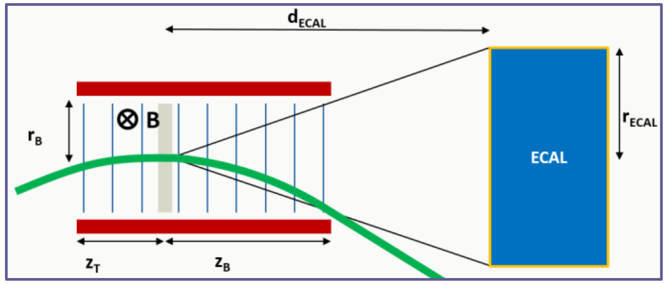


(a) Number of Electrons per Event (b) Time between subsequent non-empty Events

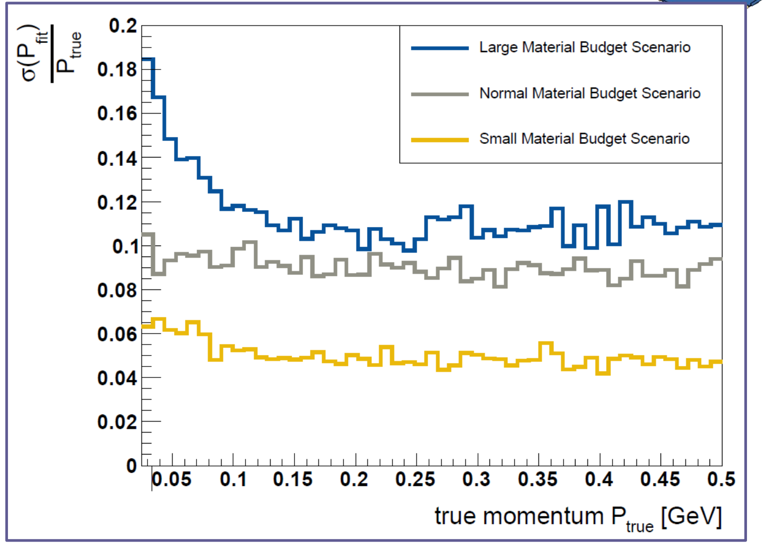
	Scalar			Majorana			Pseudo-Dirac		
mA [Mev]	ε^2	EoT_1	$t_{100}2$ [days]	ε^2	EoT_1	$t_{100}2$ [days]	ε^2	EoT_1	$t_{100}2$ [days]
4.5	4.3E-11	**4.9E+12**	112	2.2E-11	**9.6E+12**	221	2.9E-12	**7.4E+13**	1709
10	2.0E-10	**4.7E+12**	110	9.8E-11	**9.7E+12**	225	1.3E-11	**7.5E+13**	1729
100	2.6E-08	**1.0E+13**	238	1.2E-08	**2.1E+13**	495	1.2E-09	**2.2E+14**	5205
1000	5.4E-07	**1.0E+19**	238388060	2.7E-07	**2.0E+19**	472519191	2.5E-08	**2.2E+20**	5188446020

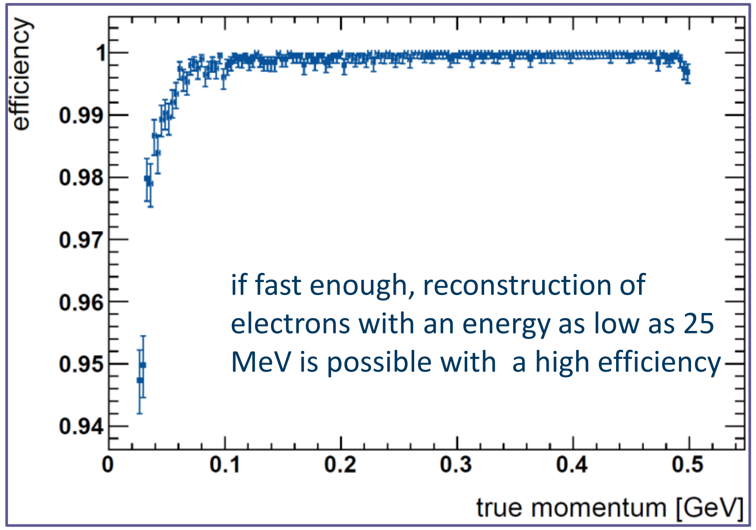


The Lohengrin Tracker



- tracker will play a crucial rule for Lohengrin
- idea is to make use of O(10) tracking planes in a O(1) T magnetic field
  - tag tracker: 3 layers in front of target in order to estimate the number of electrons in the initial state
  - recoil tracker: 6 layers behind the target in order to
    - measure the momentum of recoil electron
    - identify additional tracks in the final state
    - use recoil tracker as key detector for 2-level trigger system
  - candidate design based on 100µm thick TJ Monopix2 like ASICs
    - 33.04µm x 33.04µm pixels
    - 2x2 ASICs per layer



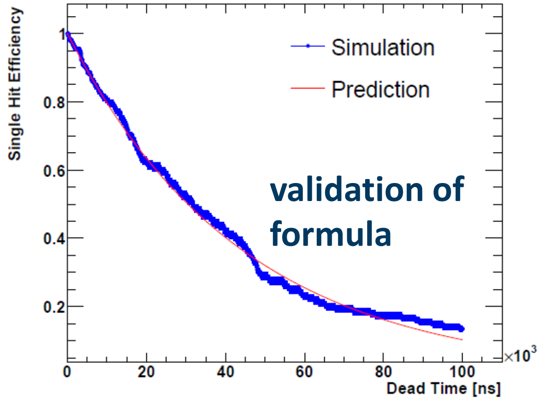


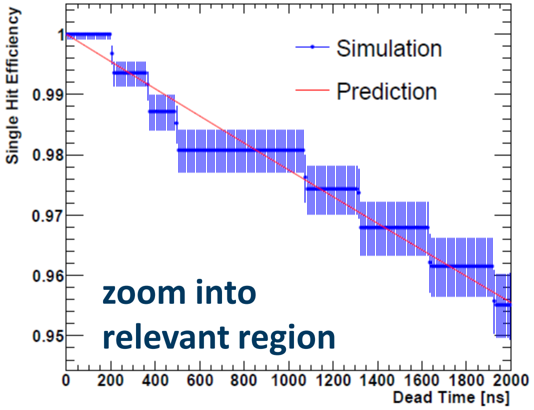
Layer	Target	1	2	3	4	5	6	7	8	9
z Position [mm]	2000	1810	1840	1900	2010	2030	2045	2070	2100	2130

tentative distribution of tracker planes

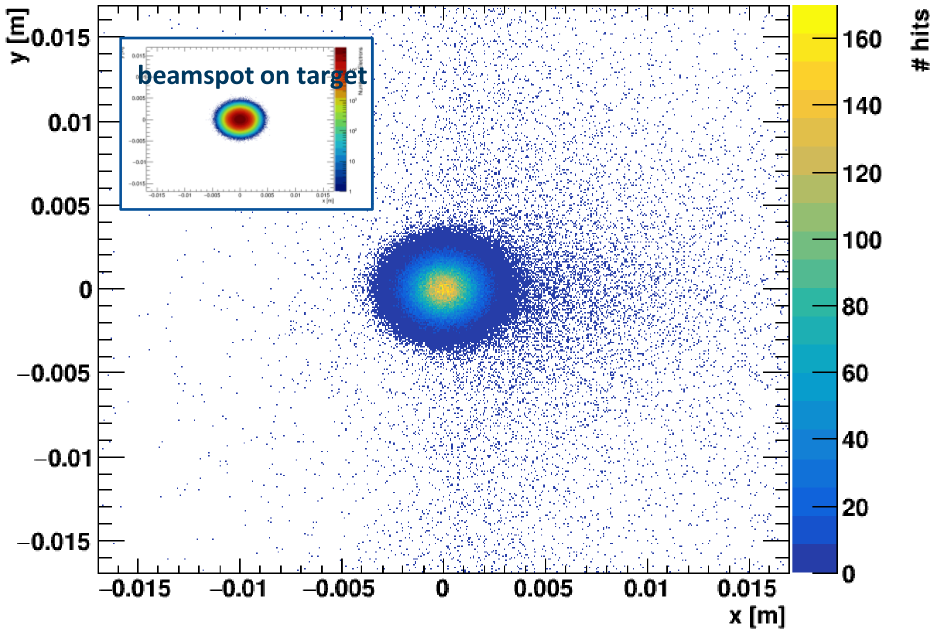
The Lohengrin Tracker

- some basic requirements:
  - as thin as possible (see previous slide)
  - pixel pitch of modern detectors is adequate
  - with "baseline" beam parameters: expect maximum single pixel hitrate of approximately 25kHz to 50 kHz





hitmap of 2nd plane of recoil tracker for 800.000 electrons on target, O(6) ms



$$P(\Delta t = m \cdot t_{\text{cycle}}) = \sum_{n=0}^{\infty} P_\lambda(n) \cdot (1 - P^n_{\text{no hit}}) \cdot \left(\sum_{n=0}^{\infty} P_\lambda(n) \cdot P^n_{\text{no hit}} \right)^{m-1}$$

probability that in the m^{th} cycle at least one electron hits the pixel

probability that in the m-1 cycles before that no electron hits that pixel

$$\varepsilon(t_{\text{dead}}) = 1 - \sum_{m=1}^{M} P(\Delta t = m \cdot t_{\text{cycle}}).$$

in order to get a 99% single hit efficiency from timing in the busiest pixels, should have a deadtime of less than ~400ns – that doesn't seem to be completely out of the world...

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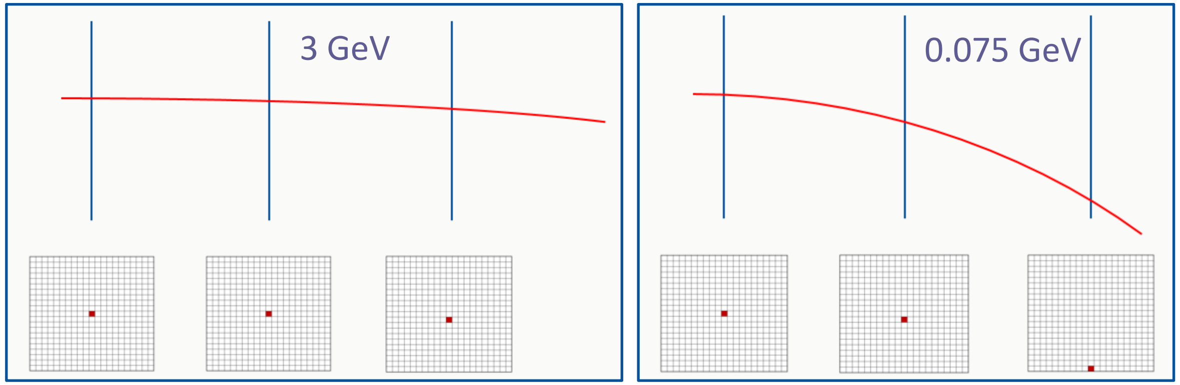
  - with “baseline” beam parameters: expect maximum single pixel hitrate of approximately 25kHz to 50 kHz
  - usage of tracker for triggering purposes
    - first stage: hit-or to tag events with low energy electrons, 100 MHz → 1MHz to 10 MHz

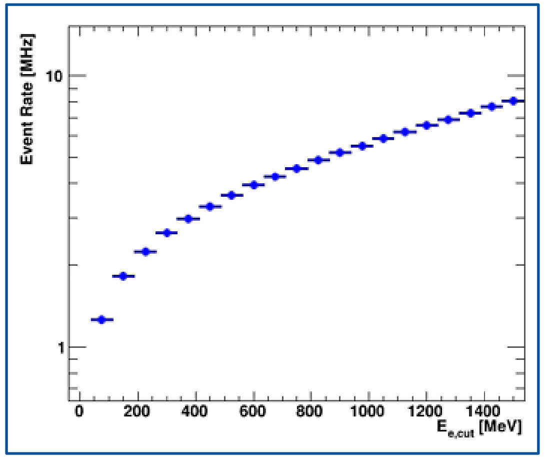


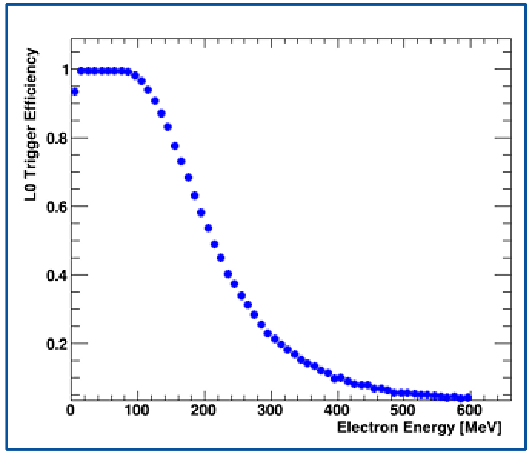
- hit in plane at z=1cm

  AND
  - hit in plane at z=7cm with x > 3.1mm

    OR
  - hit in plane at z=4.5cm with x > 2.3mm

    OR
  - hit in plane at z=3cm with x > 1.99 mm
- Total Rate: 1.7 MHz





need to correlate these signals in time

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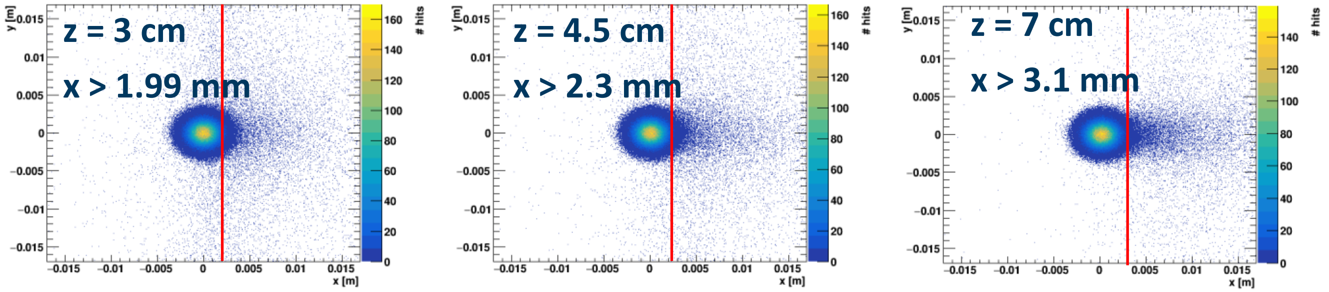

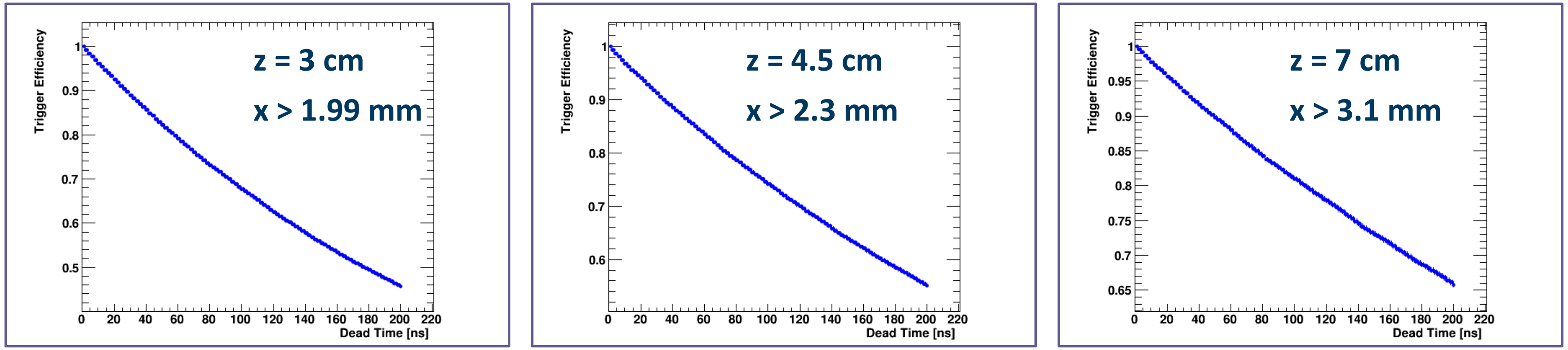

the hit-or signal would have to return to baseline within a few ns in order to achieve reasonable trigger efficiencies . . .

single pixel deadtime is not so relevant here → entire regions that can make our trigger fire

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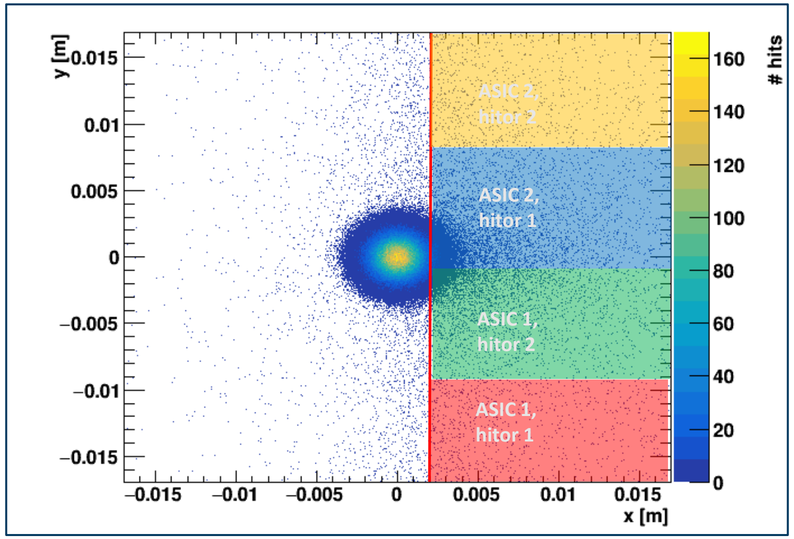

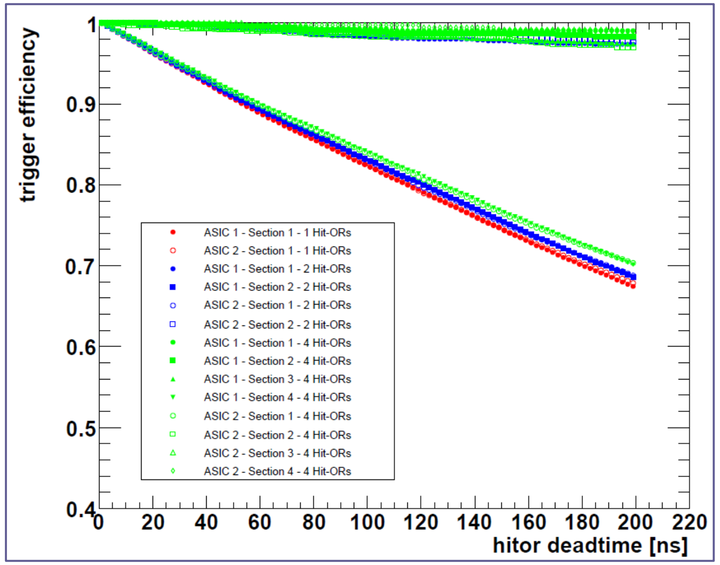

implementation of "regional" hit-or on ASICs does not help much

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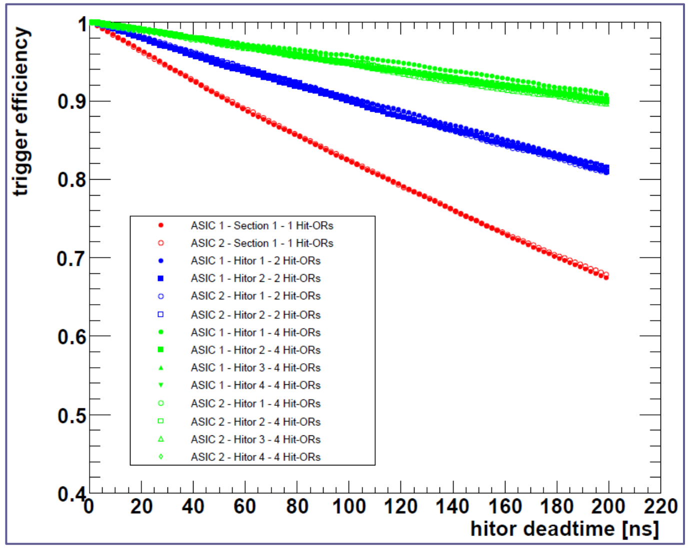

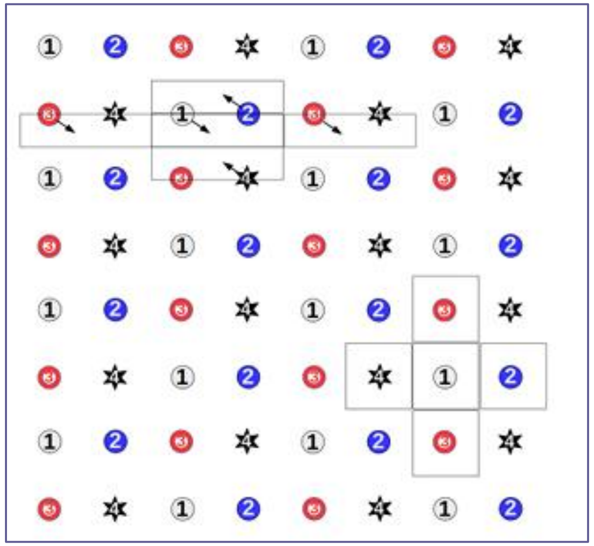

an RD53-like distribution of hit-or busses would help substantially!

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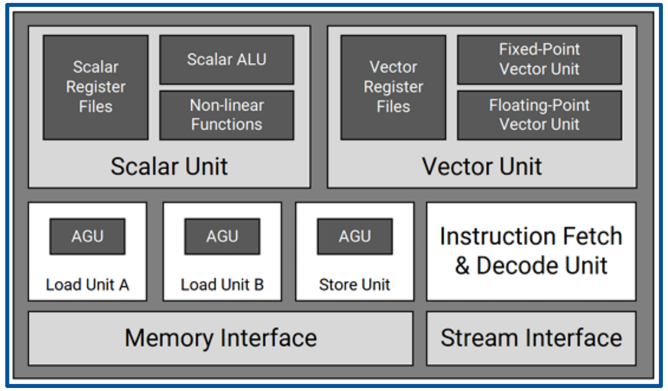
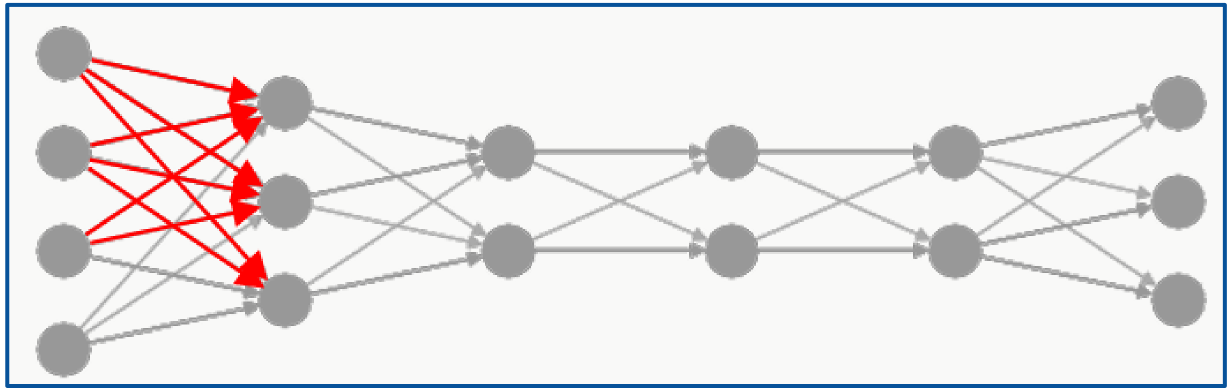
    - second stage: AI engine powered FPGAs to reduce the data rate even further

Xilinx Versal / VCK 190

400 AI engines





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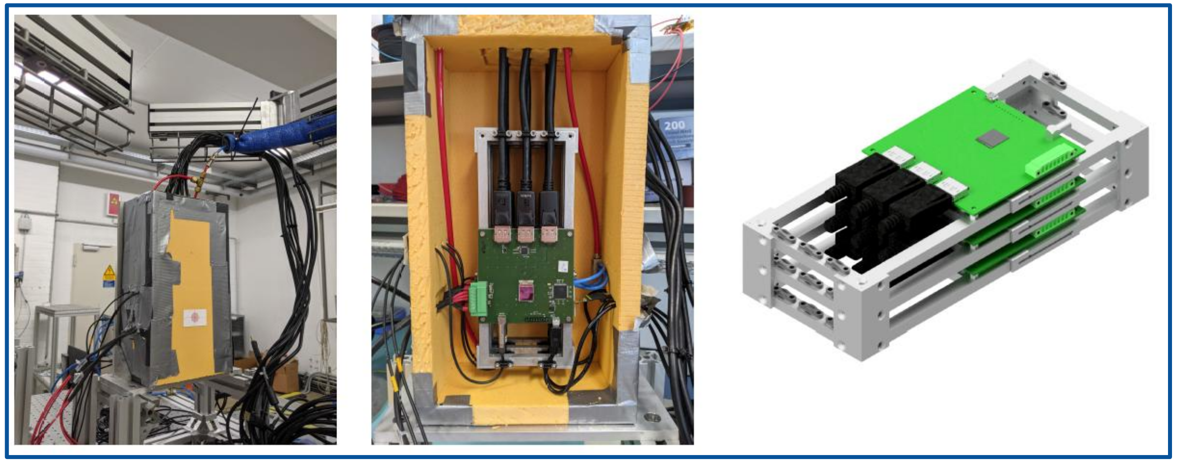
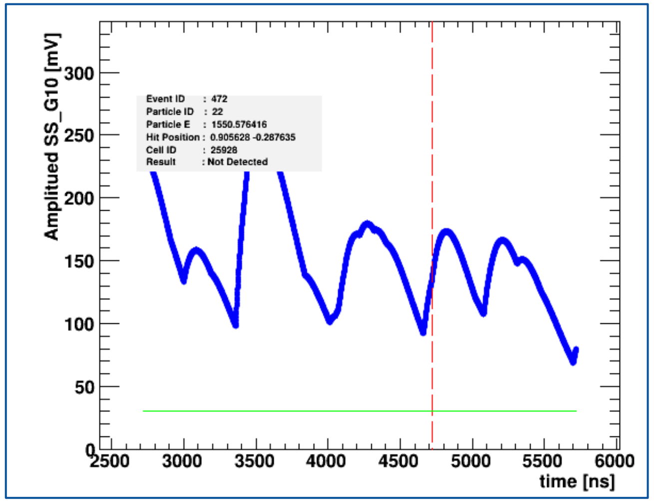
  - usage of tracker for triggering purposes
    - first stage: hit-or to tag events with low energy electrons, 100 MHz → 1MHz to 10 MHz
    - second stage: AI engine powered FPGAs to reduce the data rate even further
  - telescope-like detector: ideally no cooling material around/in the active area
  - expect relatively low radiation levels

  - timing resolution: not perfectly clear yet
    - ideally, 2ns…
    - we can probably live with less
      - implementation of timing layers?
      - snychronisation, pattern recognition, etc. has not been evaluated yet



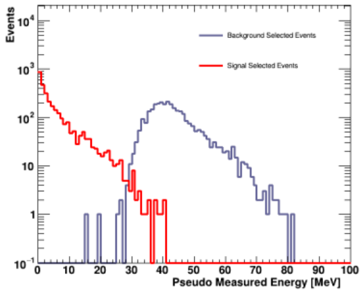
reaodut ASICs for a SiW ECAL



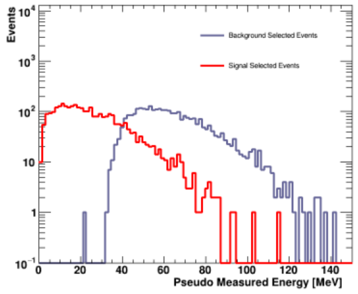
- as a side note here
  - require ASICs with fast shaping times for the readout of our calorimeter
  - we did look into using SiW ECAL with a cell size of O(5mm x 5mm)
  - example for readout architecture: SKIROC2a ASIC with CRRC shaper
    - assuming infinitely fast discharge of pre-amplifier
  - purpose of the calorimeter is to detect photons
    - act as veto in events with high energy QED bremsstrahlung

  - electronics afterglow from previous events should not veto our dark matter signal events!

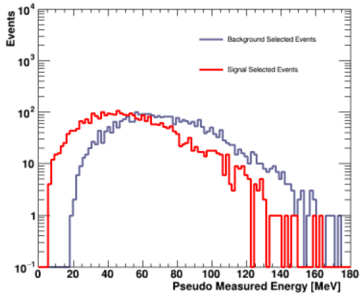
  - need very fast shaping time in order to achieve that



- τ = 10 ns
- th = 18 MeV
- ε = 81%



- τ = 30 ns
- th = 18 MeV
- ε = 68%



- τ = 60 ns
- th = 18 MeV
- ε = 5%

summary

- Lohengrin tracker ASIC:
  - electron rate at the order of 100 MHz
  - efficient reconstruction of electrons down to <25 MeV
  - single pixel deadtime should be O(400 ns) or lower
  - for implementation of first trigger stage: hit-or deadtime O(10 ns) required
    - we are studying a scintillator based trigger that could take the hit-or based trigger's place
  - monolithic ASICs with reasonably small pixel pitch

- Lohengrin ECAL:
  - if SiW ECAL is used, require fast shaping in readout ASICs