LUXE Quantum Computing kick-off

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LUXE quantum computing meeting
17/05/2021

Intro - Miscellanea

I have created a mailing list for meeting announcements and to communicate among ourselves:

luxe-quantum-computing@desy.de (activation pending)

The meetings will live under:

https://indico.desy.de/category/851/

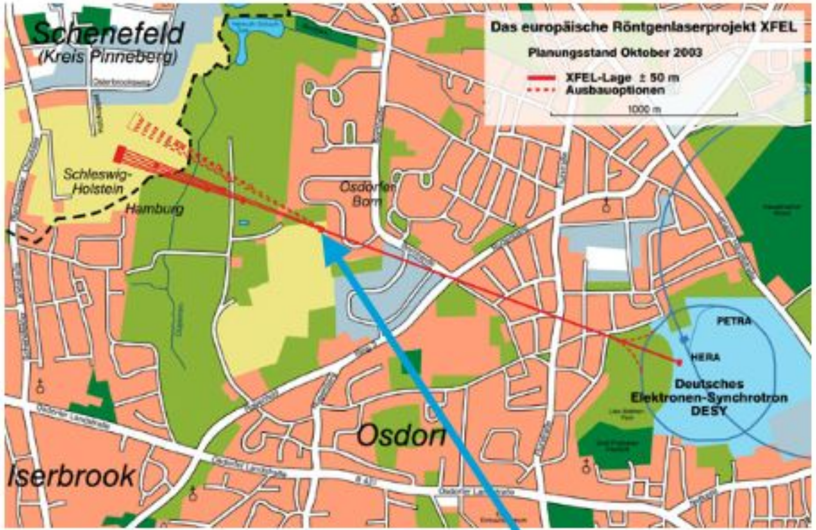
For now, bi-weekly schedule, Mondays at 14:00 (Hamburg time).

Do we need anything else?

The LUXE experiment

LUXE

LASER Und XFEL Experiment

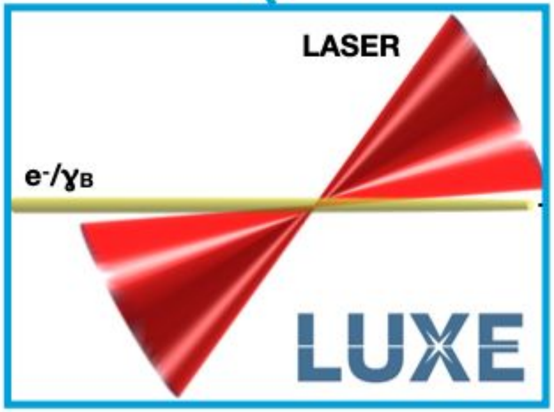


LUXE is a proposed new experiment at DESY and Eu.XFEL

- Collisions of electron beam and a high-power laser
- **Study QED in the strong field regime**

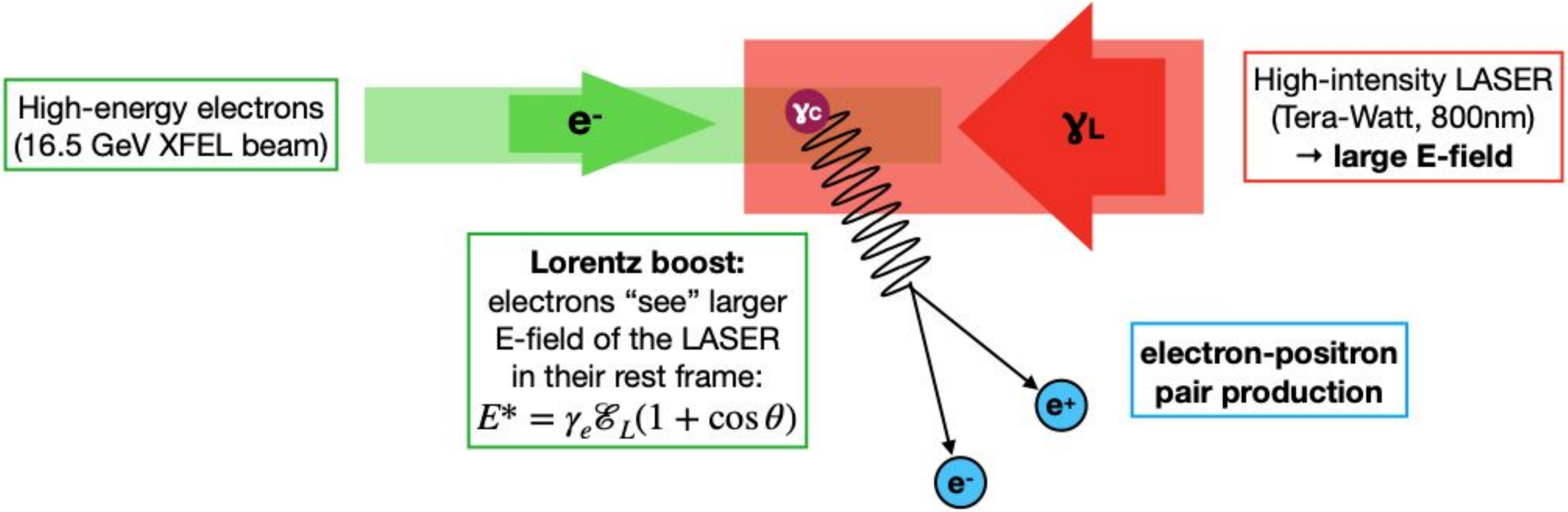
More Information at:

- CDR arXiv: 2102.02032
- Website https://luxe.desy.de



We plan to use this opportunity to test new technologies and reconstruction techniques, i.e. using **quantum computing for charged particle reconstruction.**

Electron + laser interactions



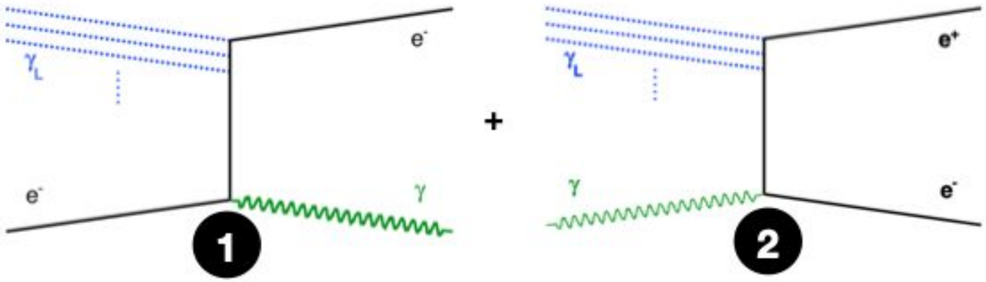
High-energy electrons
(16.5 GeV XFEL beam)

High-intensity LASER
(Tera-Watt, 800nm)
→ **large E-field**

Lorentz boost:
electrons "see" larger
E-field of the LASER
in their rest frame:
$E^* = \gamma_e \mathscr{E}_L(1+\cos\theta)$

electron-positron
pair production

Illustration credit: Ruth Jacobs

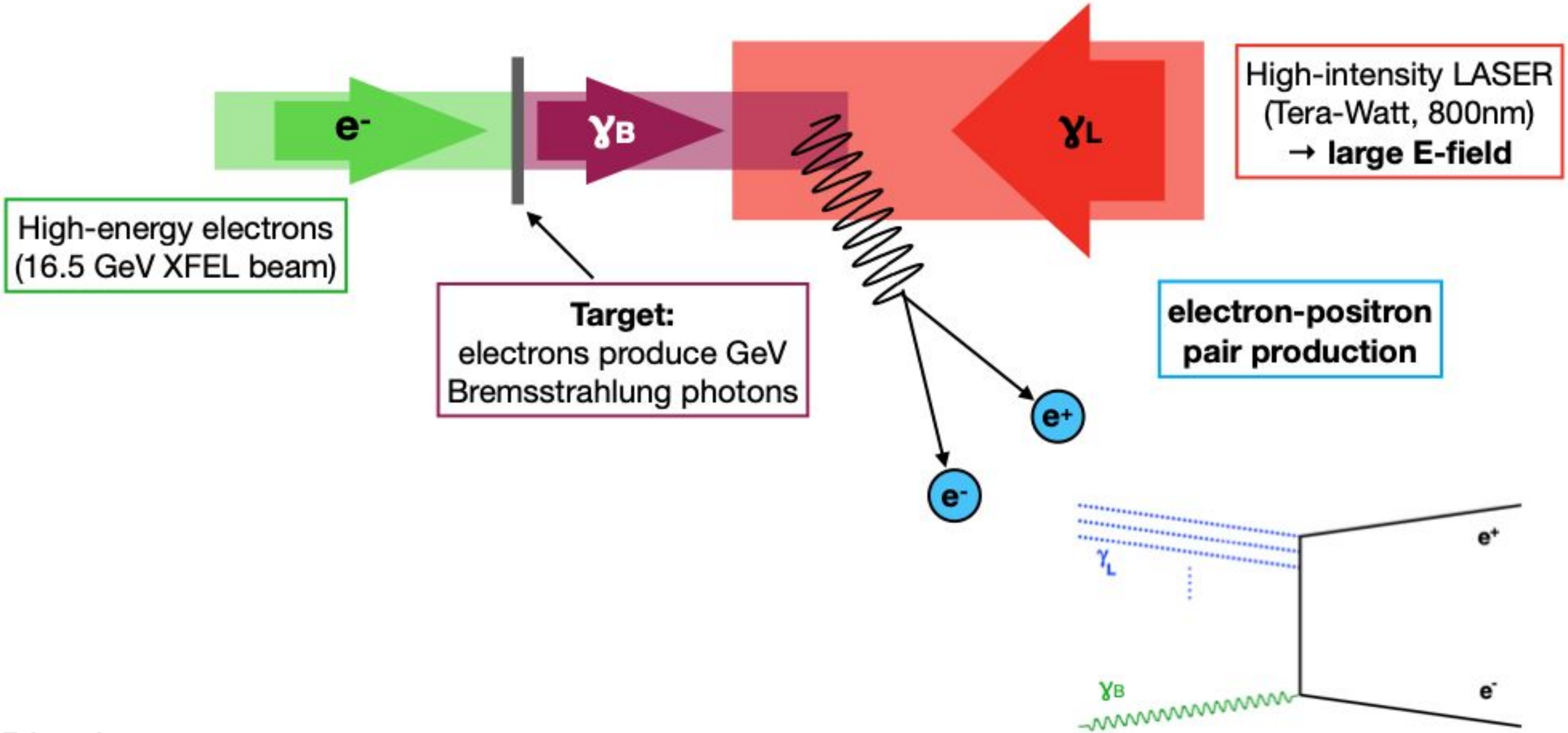


Physics processes:

1. Non-linear Compton Scattering: $e^- + n_{\gamma L} \rightarrow e^- + \gamma_C$
2. Non-linear Breit-Wheeler pair production : $\gamma_C + n_{\gamma L} \rightarrow e^+ + e^-$

Core measurement: **positron rate as function of LASER intensity.**

Electron + laser interactions



High-intensity LASER (Tera-Watt, 800nm) → **large E-field**

High-energy electrons (16.5 GeV XFEL beam)

Target: electrons produce GeV Bremsstrahlung photons

electron-positron pair production

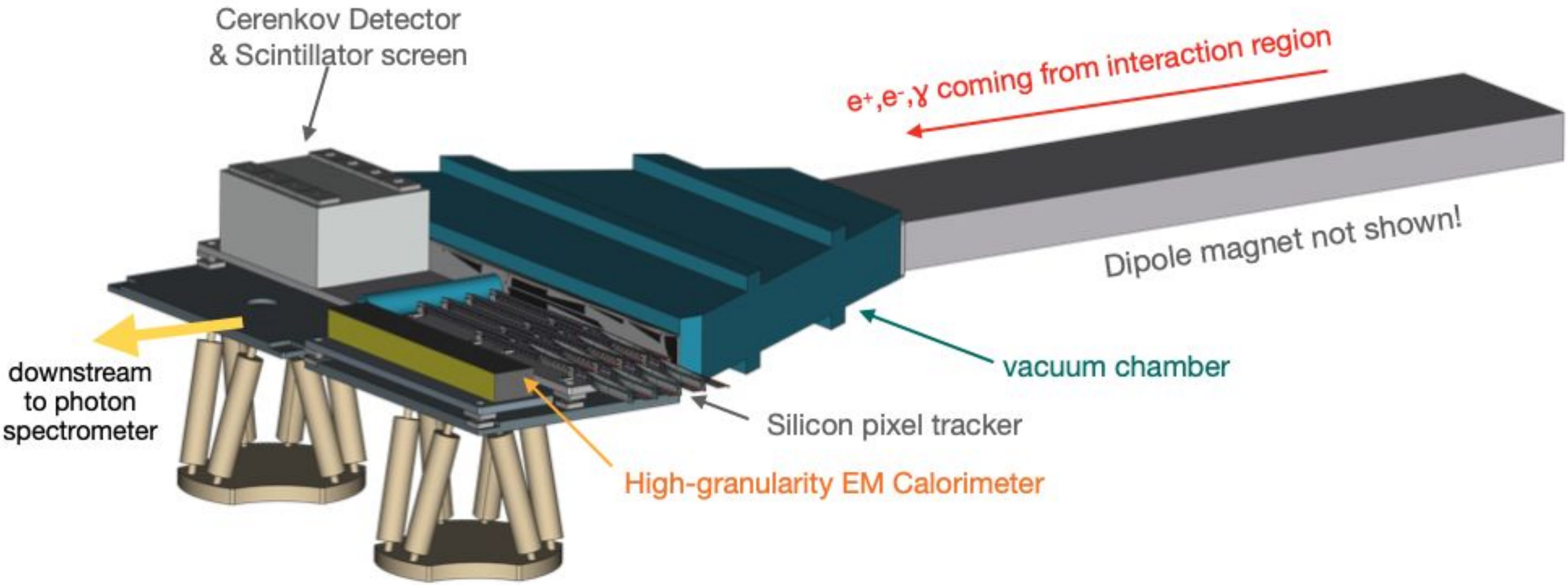
Illustration credit: Ruth Jacobs

Physics processes:

1. Non-linear Breit-Wheeler pair production : $\gamma_B + n_{\gamma L} \rightarrow e^+ + e^-$

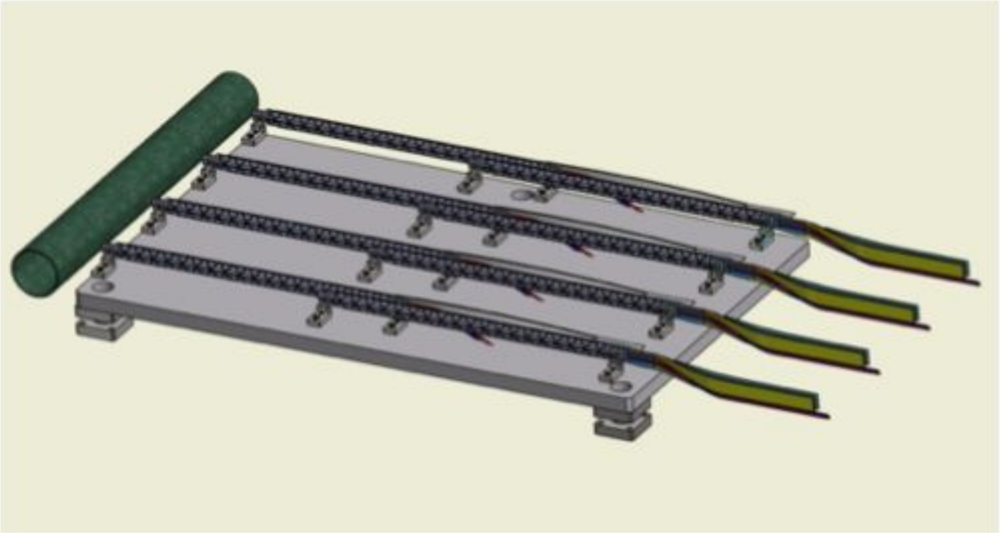
Core measurement: **positron rate as function of LASER intensity.**

Electron and positron detection



The inputs for our track reconstruction algorithm are the energy deposits (hits, or better hit clusters) measured by the silicon pixel tracker.

The tracker



The technology based on monolithic active pixel sensors.

- 30 × 15 mm^2 with $5 \cdot 10^5$ pixels
- 512 rows and 1024 columns

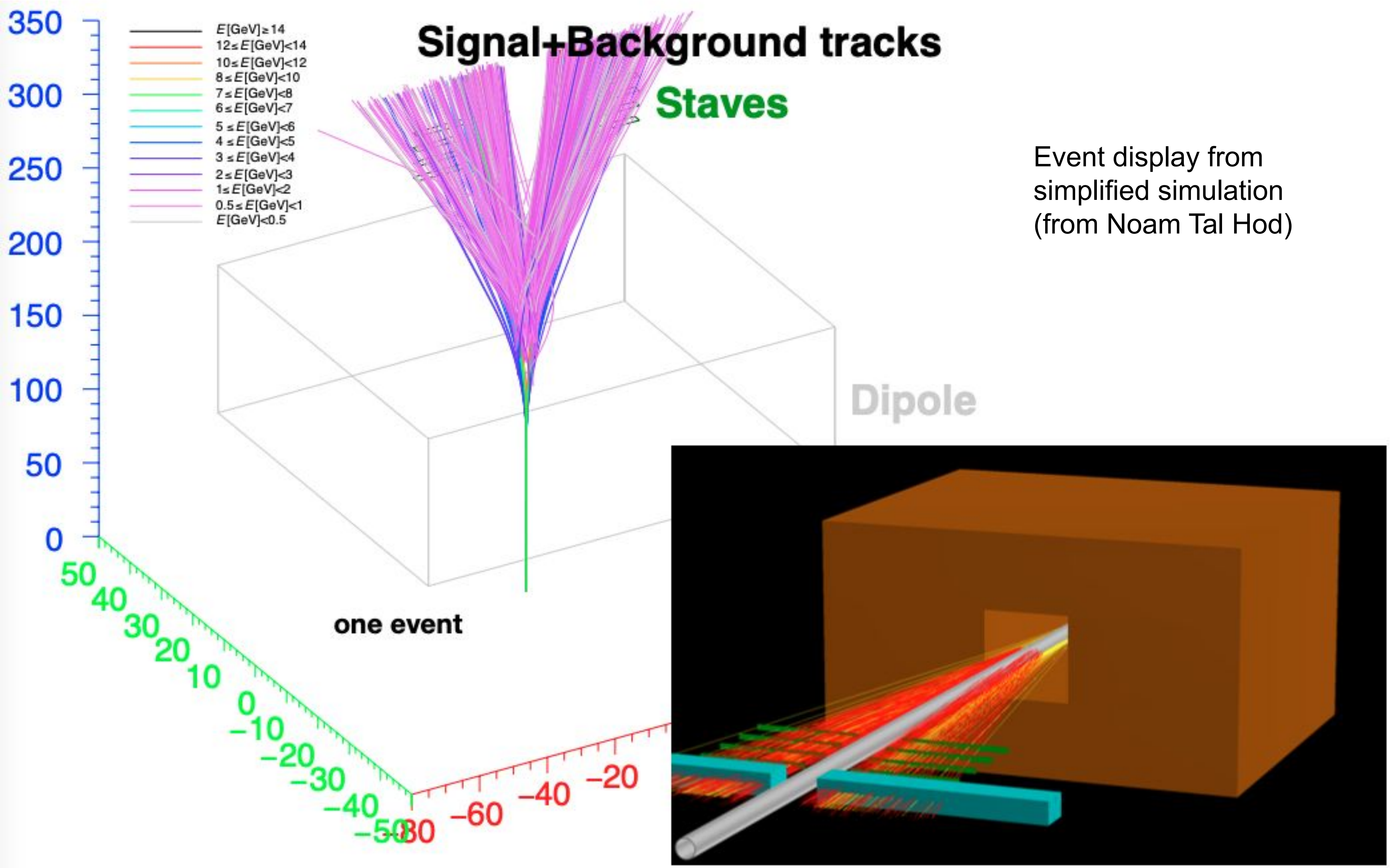
Detection efficiency above 99% and a noise hit rate much below 10^{-5}.

Spatial resolution of around ~5μm, time resolution of ~2μs.

The detector has four detection layers:

- The basic unit of the detector is a 27 cm long stave with nine pixel chips (active area 270.8 × 15 mm^2)
- Two staves per layer, with a central overlap of about 1 cm

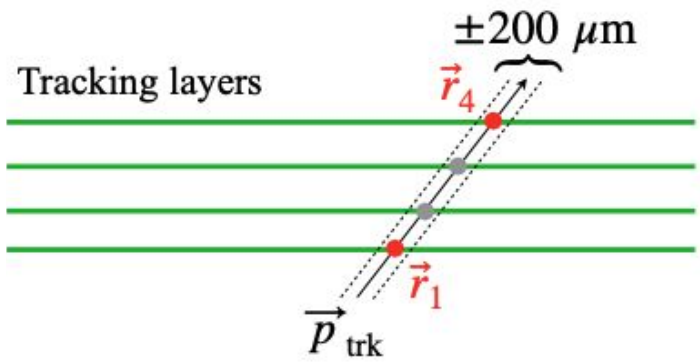
Simulated event



Event display from simplified simulation (from Noam Tal Hod)

Standard tracking

Current (preliminary) implementation

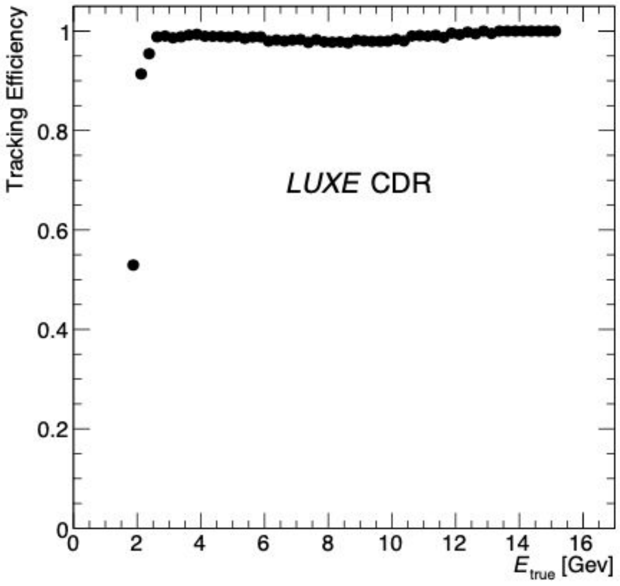


Based on seeding + Kalman filter.

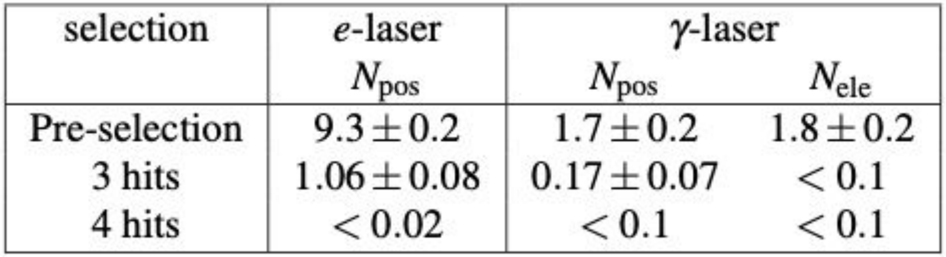
1. Start with one cluster measured at layer 4 (L4 -outermost) and loop on all clusters in L1 (innermost)
2. Reject all obviously wrong cluster pairs (e.g. combinations pointing towards the beam or combinations missing hits in a “road” defined by the L4 and L1)
3. All surviving seed pairs are passed to the Kalman Filter, assuming $r_{\mathrm{vertex}} = (0,0,0)$
    a. Require tracks with at least 4 clusters, good χ^2/N_{DoF}, vertex-to-IP match
4. Remove all clusters associated to the selected track
5. Consider the next cluster at L4 and repeat

Performance

Good efficiency across the expected momentum range (efficiency loss at low momentum due to geometrical acceptance).



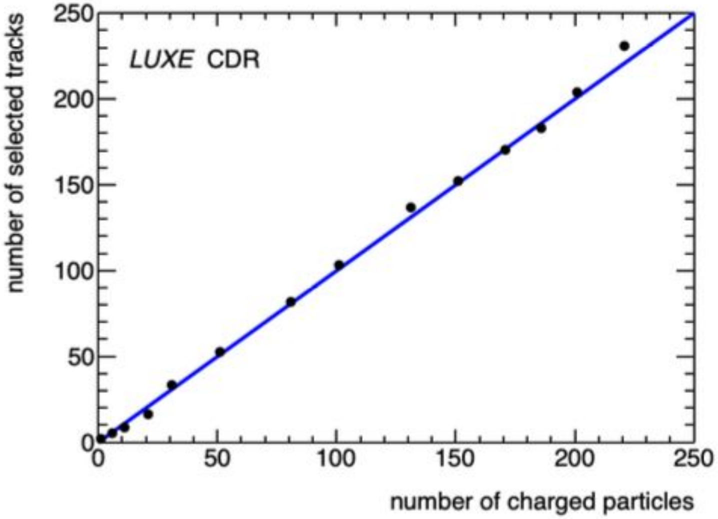
Small beam-background expected



selection	e-laser	γ-laser	
	N_{pos}	N_{pos}	N_{ele}
Pre-selection	9.3 ± 0.2	1.7 ± 0.2	1.8 ± 0.2
3 hits	1.06 ± 0.08	0.17 ± 0.07	< 0.1
4 hits	< 0.02	< 0.1	< 0.1

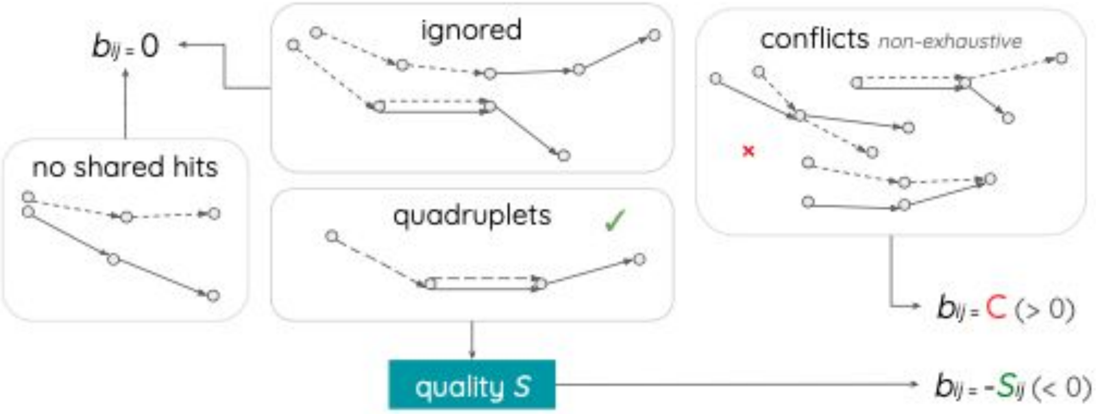
Signal multiplicity can however become large: up to ~10000 particles per event.

- Under study, but expected to be ok



The quantum approach

Following arXiv: 1902.08324



Studying the tracking problem at the HL-LHC using a quantum annealer.

- Use triplets of hits T^{abc} and attempt to combine them in quadruplets
- Triplet characteristics are the **number of holes H_i**, the **curvature q/p** and the **angle δθ between the doublets** and can be used to build compatibility measure

$$S(T_i, T_j) = z_1 \frac{z_2\left(1 - |\delta(q/p_{Ti}, q/p_{Tj})|\right)^{z_3} + (1 - z_2)\left(1 - \max(\delta\theta_i, \delta\theta_j)\right)^{z_4}}{(1 + H_i + H_j)^{z_5}},$$

- The best grouping of hits can be found by minimising a global function

$$O(a, b, T) = \sum_{i=1}^{N} a_i T_i + \sum_{i}^{N} \sum_{j<i}^{N} b_{ij} T_i T_j$$

Our case

Our tracker is shorter and the particle multiplicity is not as large:

- Use doublets directly instead of triplets (and combine into triplets)

No magnetic field in the detector region:

- The particle trajectories are straight (ignoring multiple scattering and resolutions)!
  - Doublet curvature could be swapped out for IP pointing (also if we use doublets, “curvature” is not defined)
  - Curvature of triplet (or delta theta) can be used too

Keep number of holes, allowing doublets to be formed by non-consecutive detector layers

Rough tentative plans

From simple to complex

Each step should characterise the algorithm as a function of the number of particles and see if the errors of the resulting system can be mitigated.

1. Toy experiment with N (=4) layers, straight lines from (0,0,0)
2. Toy experiment with N layers, straight lines from (0,0,0), gaussian multiple scattering
3. Toy experiment with realistic beamspot size
4. Full detector simulation (including detector inefficiencies)
5. Full detector simulation with beam backgrounds
6. Test algorithms on real data from test-beam campaign

Thank you!