MATTER AND THE UNIVERSE DAYS 2022, GSI DARMSTADT, 21 OCTOBER 2022

UPDATES ON LUXE AND QUANTUM COMPUTING

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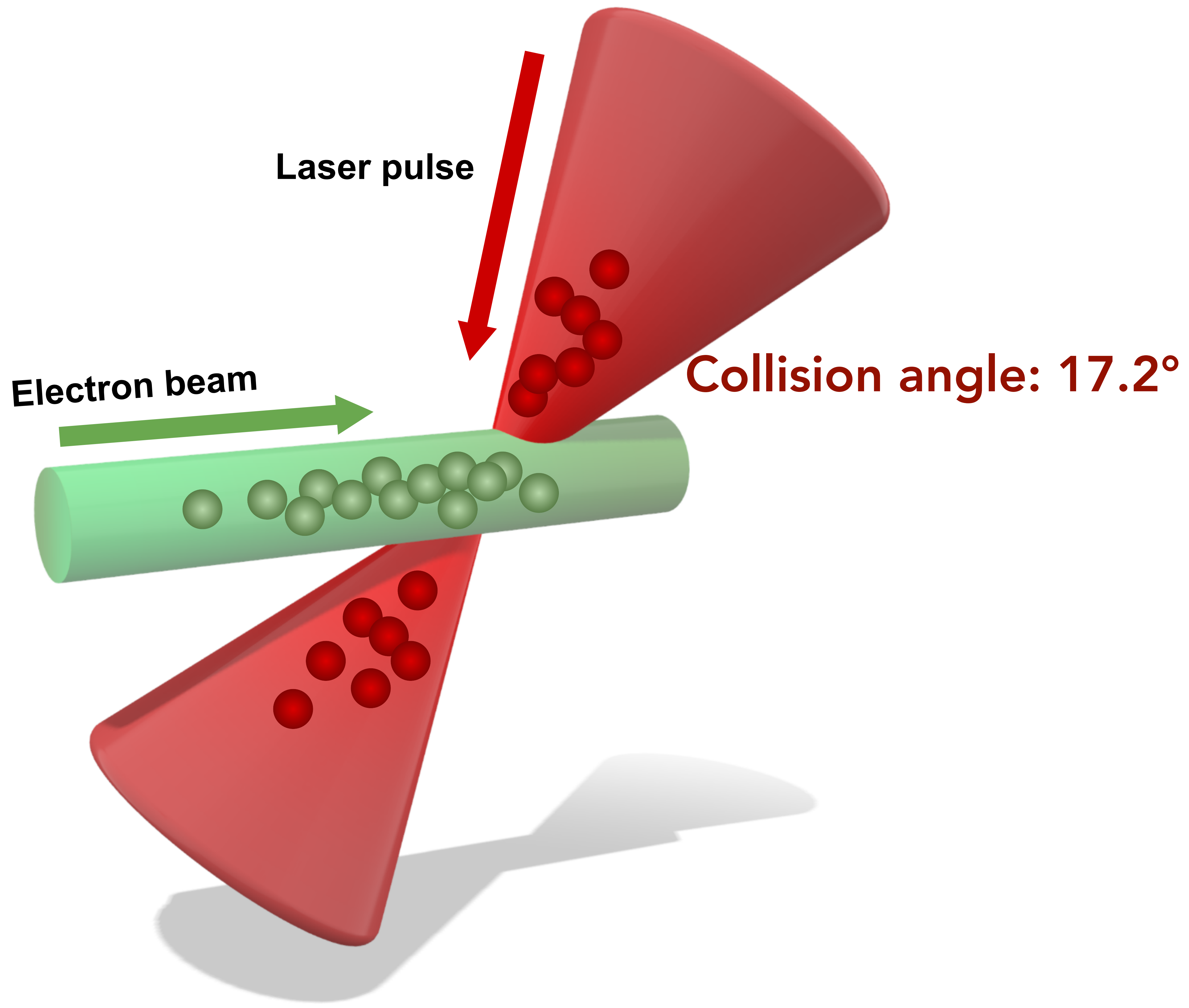
HELMHOLTZ

LUXE: LASER UND XFEL EXPERIMENT

- Experiment in planning at DESY and European XFEL to study collisions of high-energy XFEL electron beam and high-power laser.



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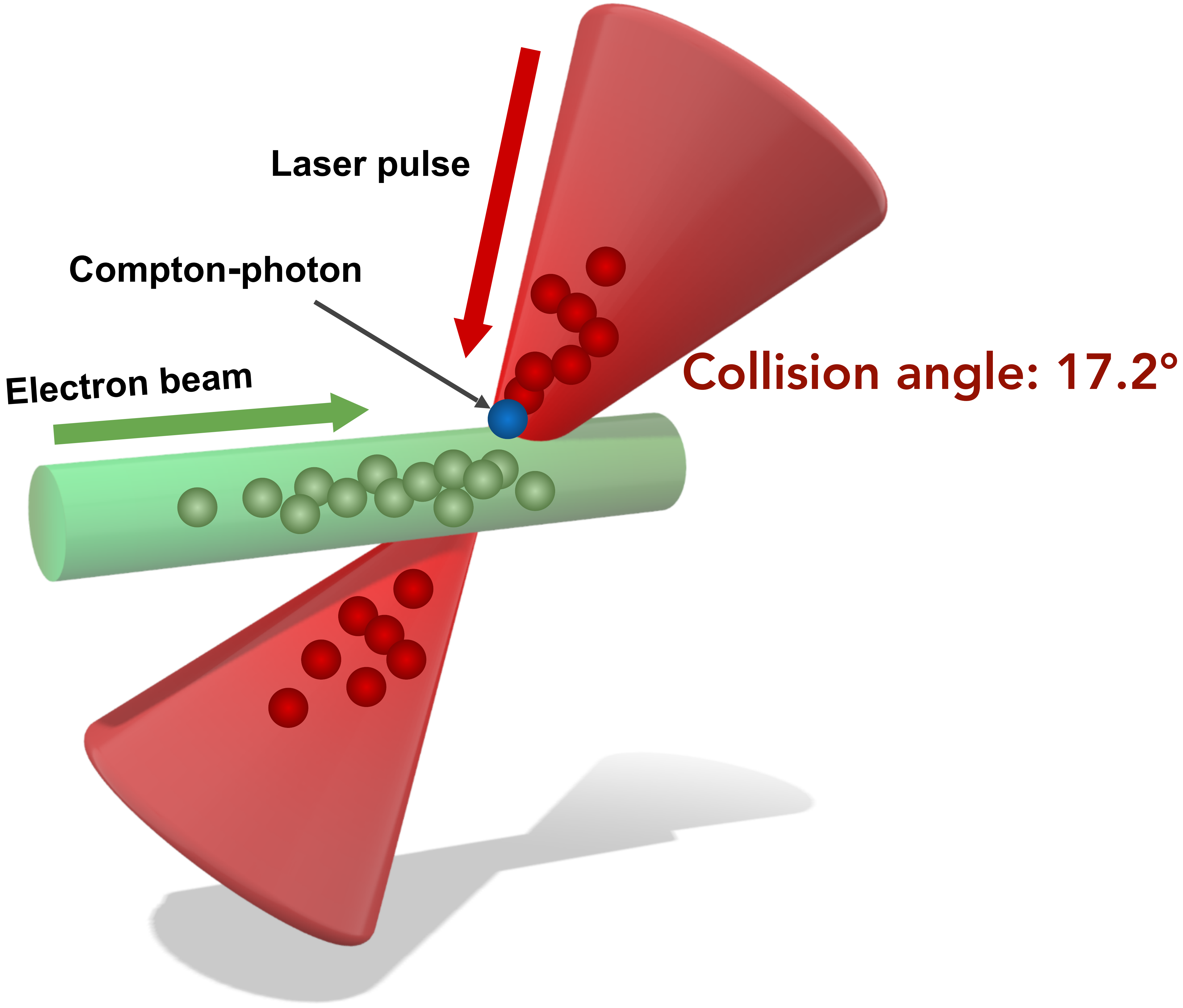
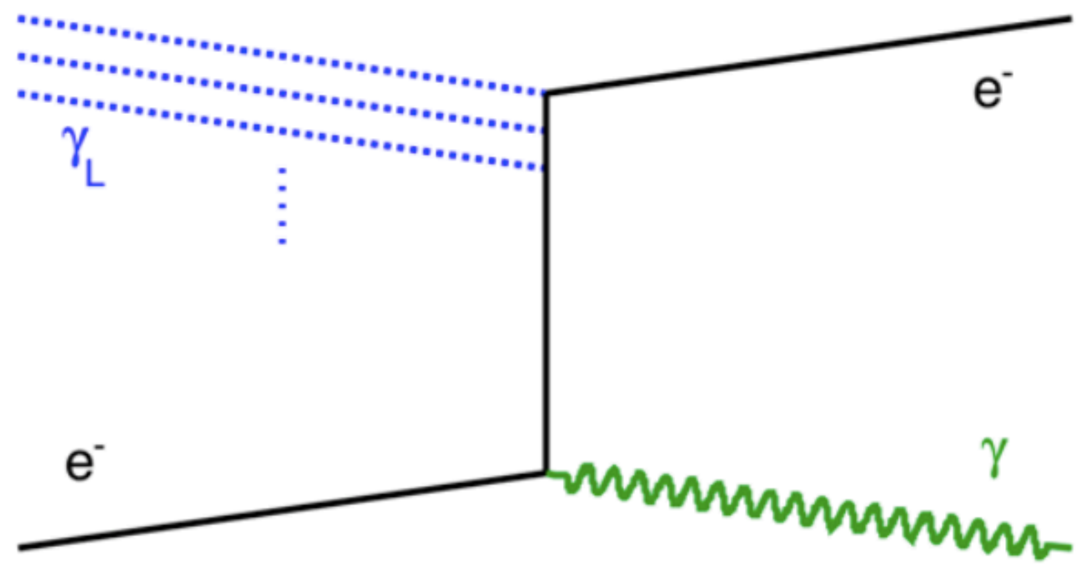


Non-linear Compton scattering:

$$e^- + n\gamma_L \rightarrow e^- + \gamma_C$$



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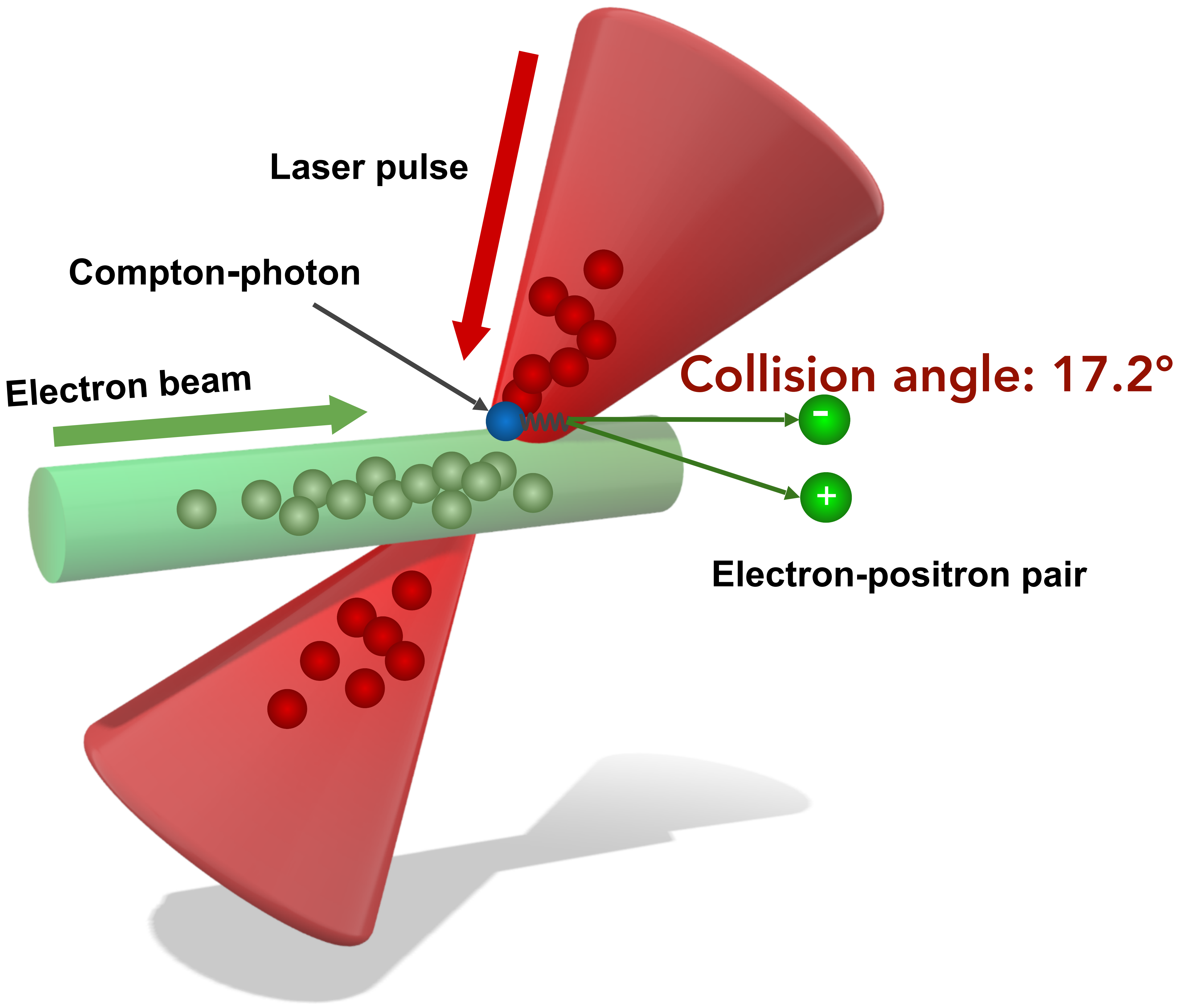

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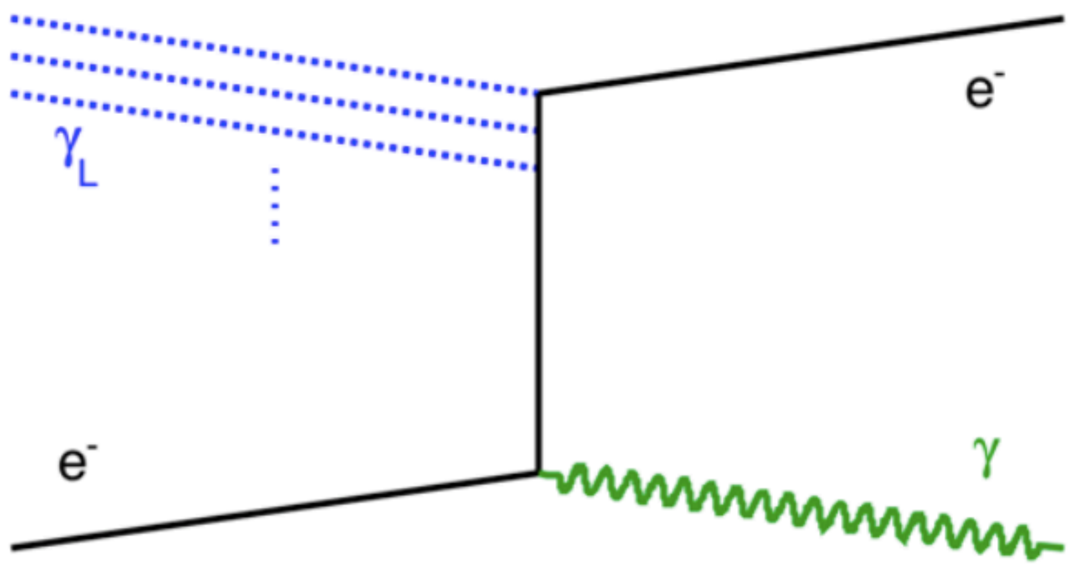
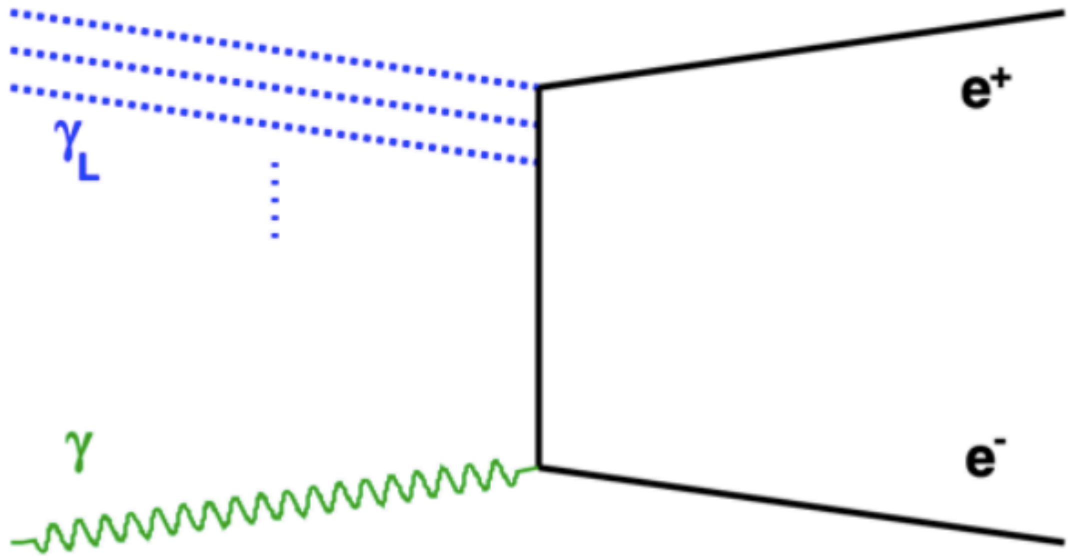


Non-linear Breit Wheeler:

$$\gamma_C + n'\gamma_L \rightarrow e^+ + e^-$$



MEASUREMENT

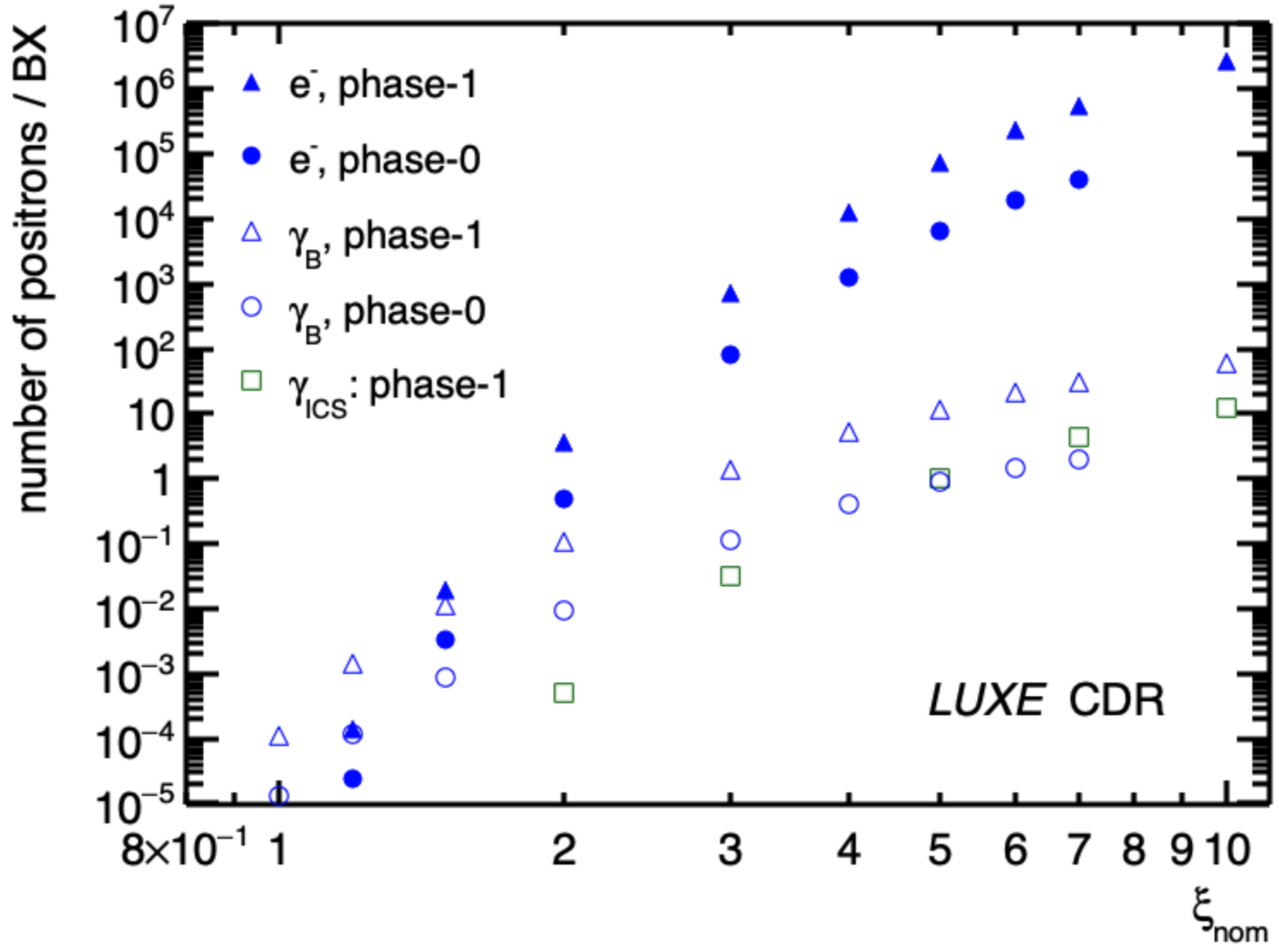
- LUXE aims to make precise measurements of these QED interactions to investigate the transition into non-perturbative regime.

- One key measurement is the positron rate (i.e. Breit-Wheeler rate) as a function of laser intensity ξ.

Field intensity parameter (charge-field coupling)

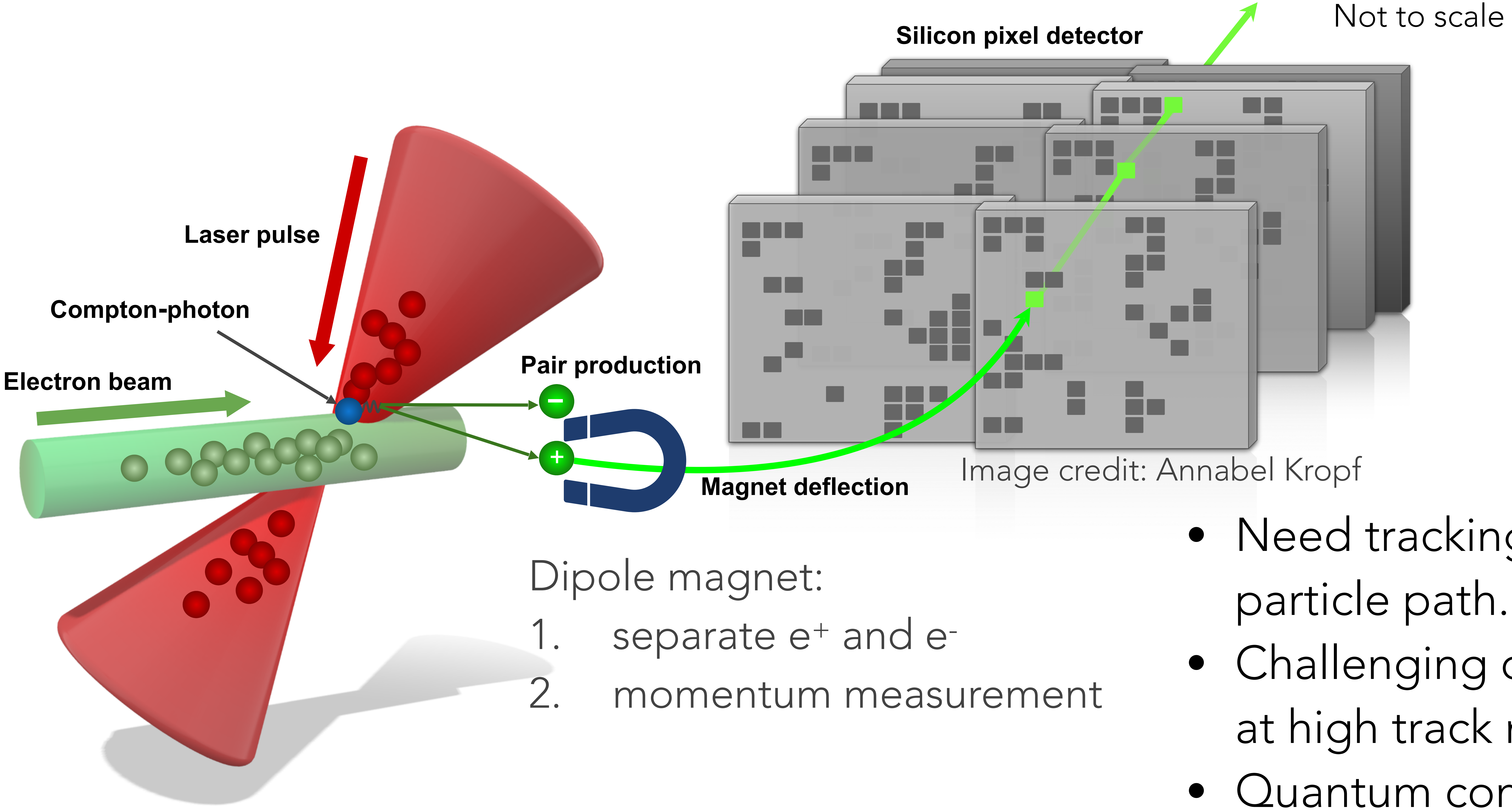
$$\xi = \frac{m_e}{\omega_L}\frac{E_L}{E_{cr}}$$

- Need excellent background rejection at low ξ and good linearity at high ξ.



The positrons have typically 1-10 GeV energy.

POSITRON TRACKER

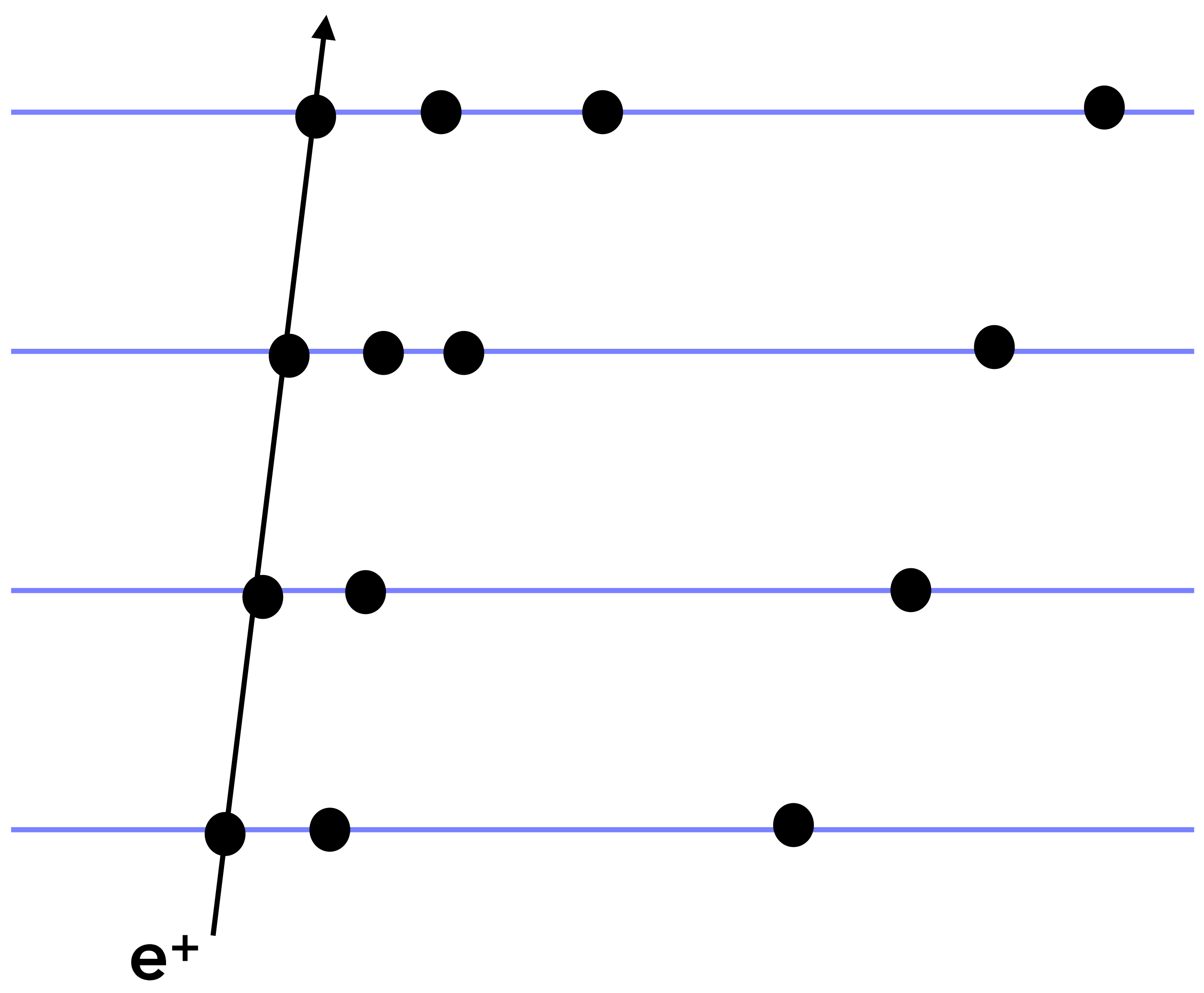


Dipole magnet:

1. separate e^+ and e^-
2. momentum measurement

- Need tracking to reconstruct particle path.
- Challenging due to combinatorics at high track multiplicities.
- Quantum computing may offer an advantage.

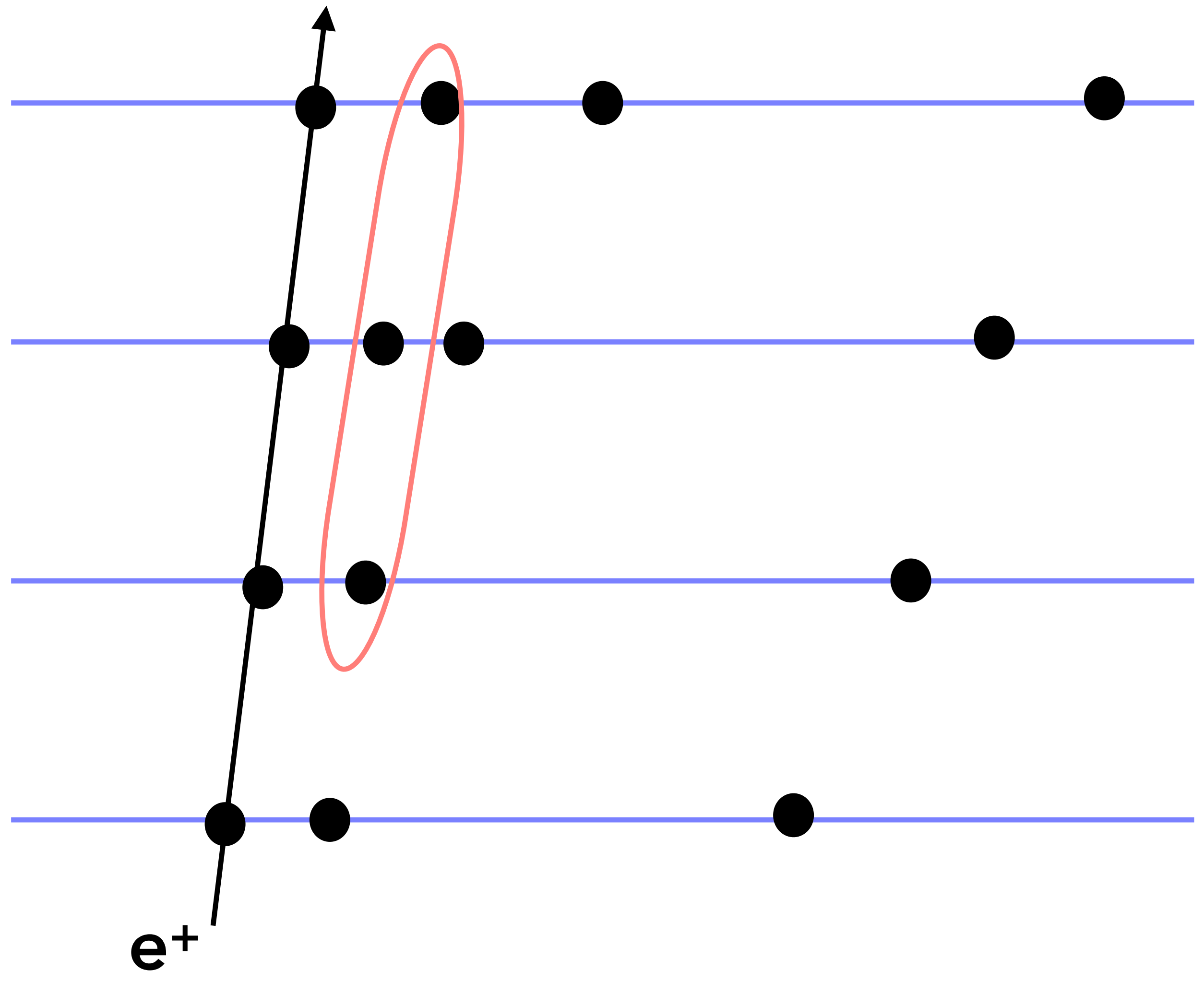
TRACKING USING QUANTUM COMPUTING



TRACKING USING QUANTUM COMPUTING

Step 1: form triplets

Example triplets



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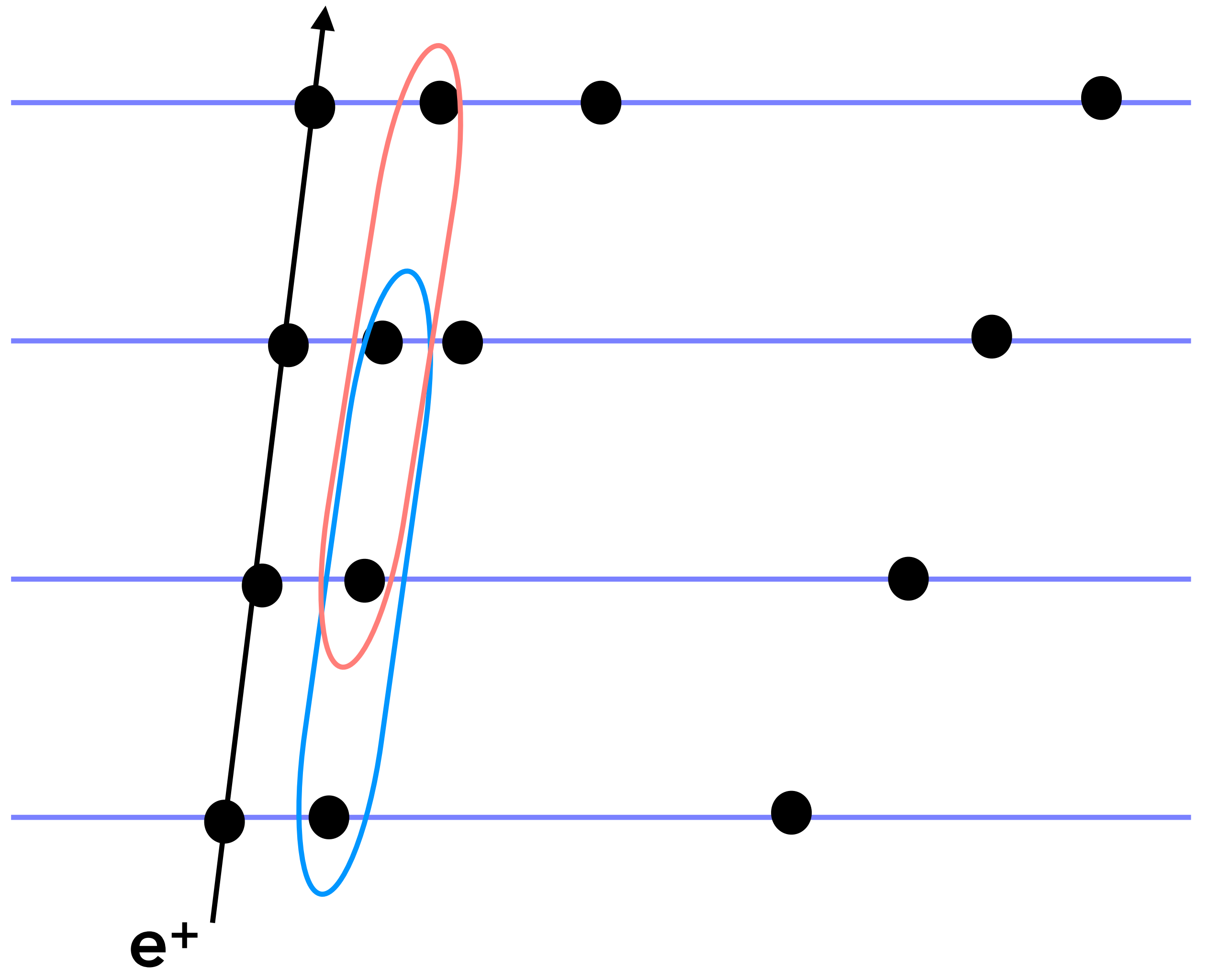

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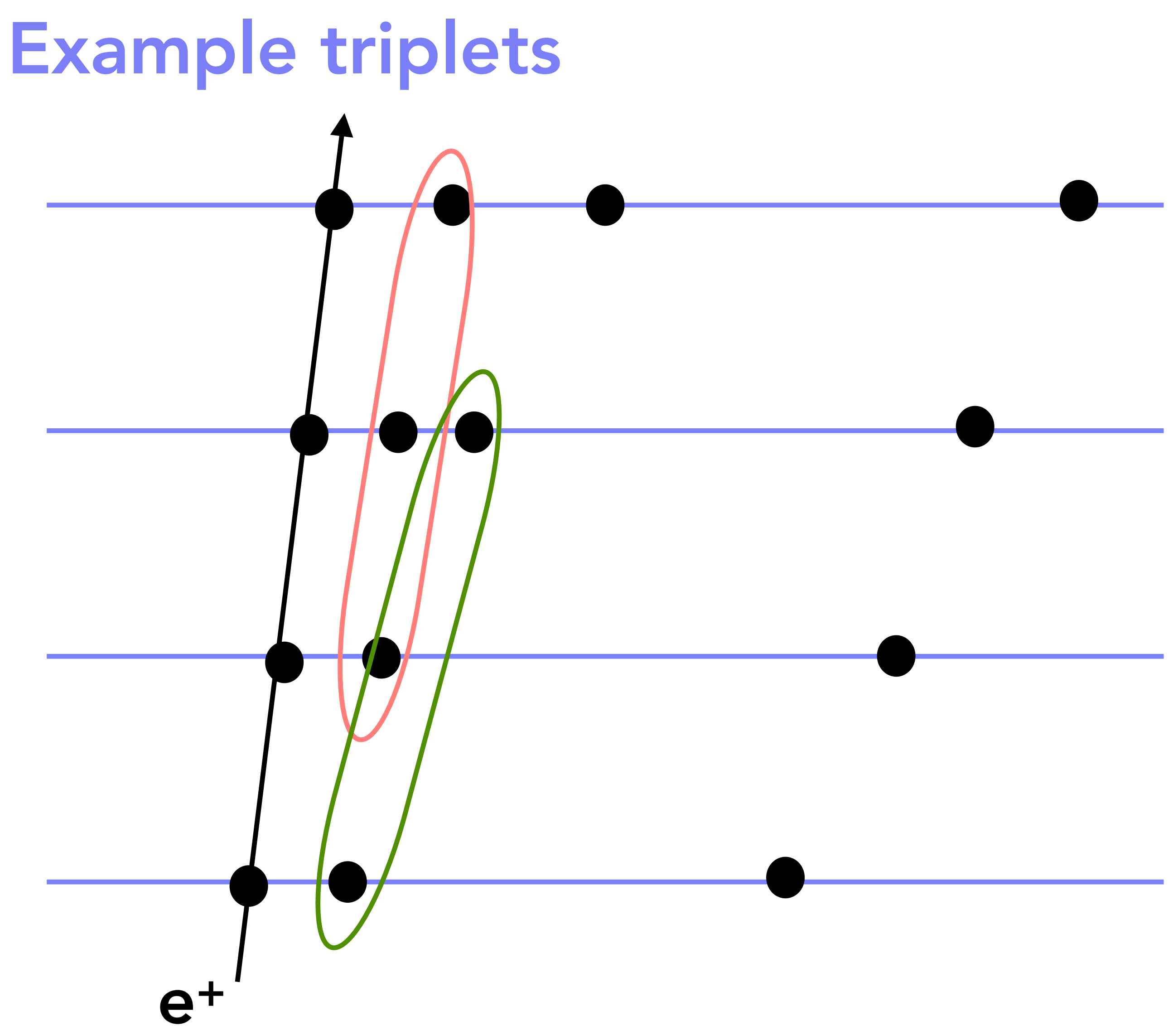

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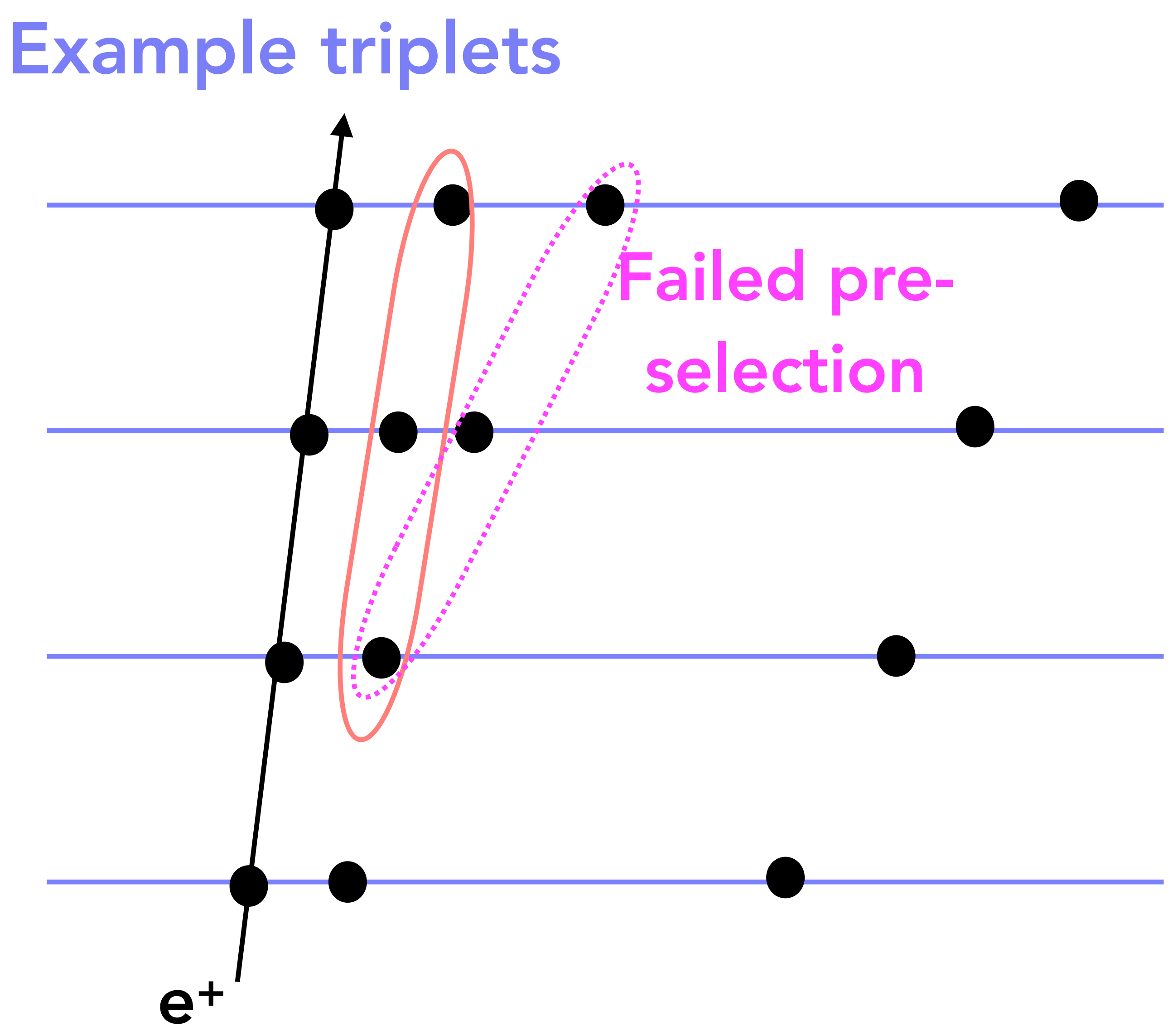
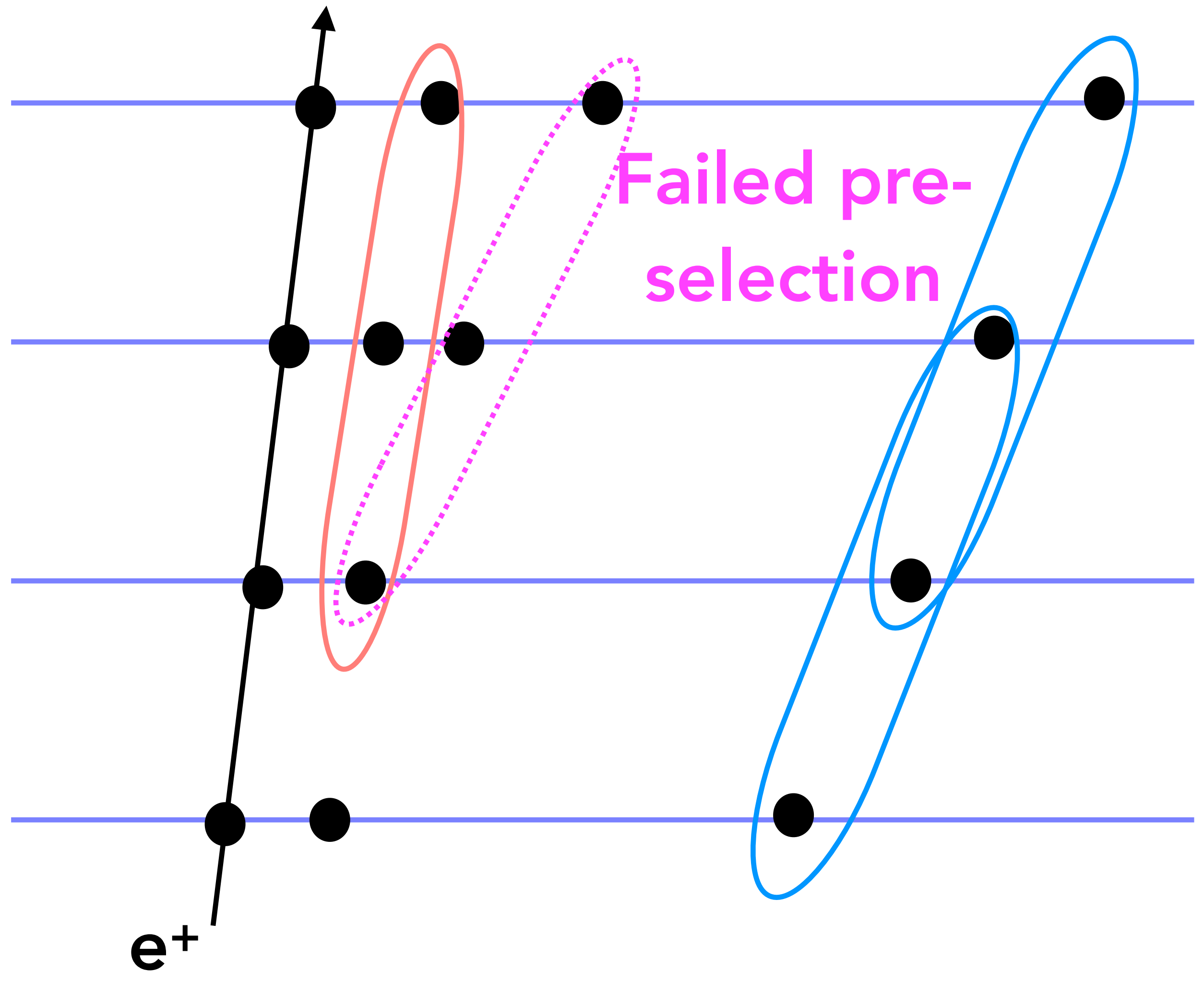


TRACKING USING QUANTUM COMPUTING

Step 1: form triplets

Example triplets

Two selected triplets form a track candidate



Step 2: find the best sets of triplets

Quadratic
Unconstrained
Binary
Optimisation

$$O(a,b,T) = \sum_{i=1}^{N} a_i T_i + \sum_{i}^{N} \sum_{j<i}^{N} b_{ij} T_i T_j \qquad T_i, T_j \in \{0,1\}$$

Weighting triplet T_i with quality a_i

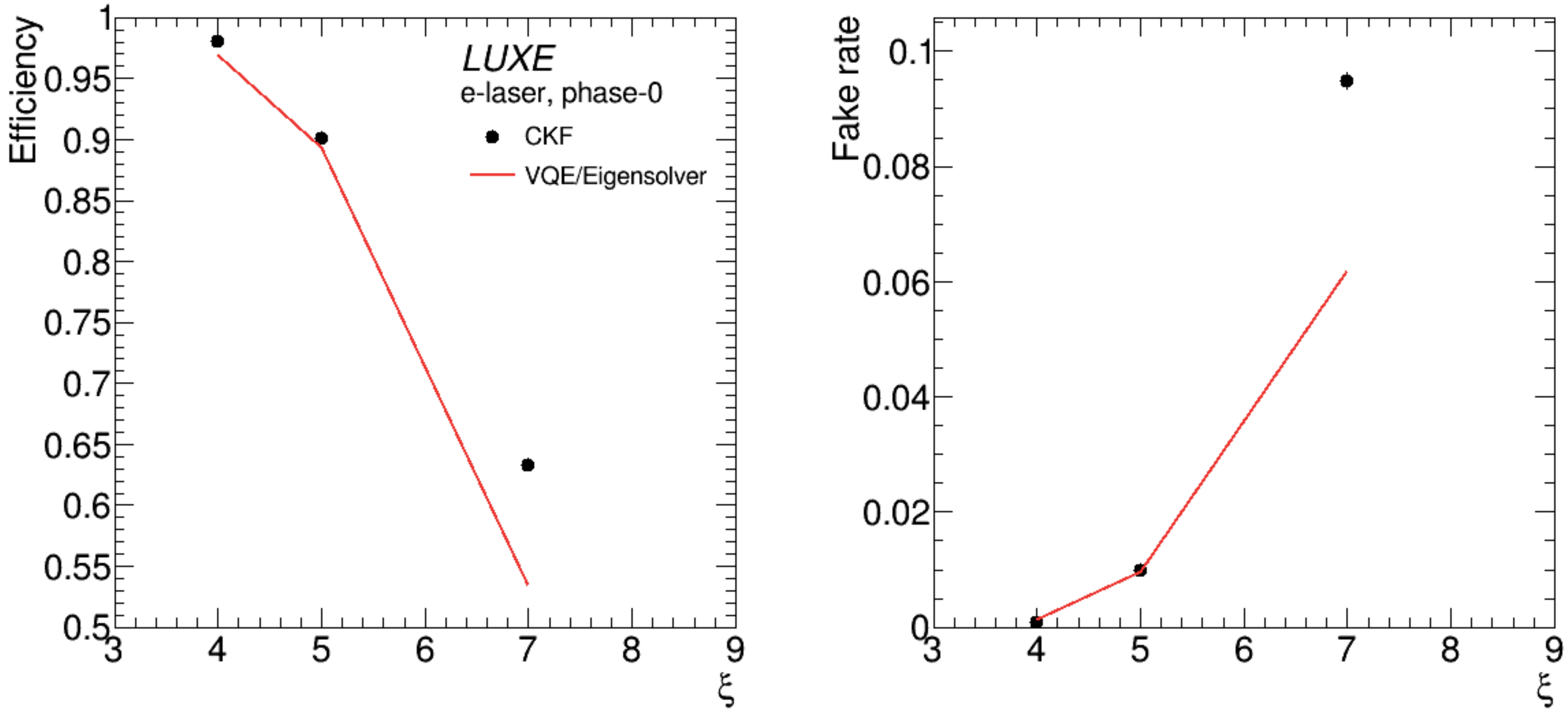
Compatibility b_{ij} between two triplets

$$b_{ij} = \begin{cases} -S(Ti,Tj), & \text{if } (T_i,T_j) \text{ form a quadruplet,} \\ \zeta & \text{if } (T_i,T_j) \text{ are in conflict,} \\ 0 & \text{otherwise.} \end{cases}$$

The QUBO is mapped onto a quantum computer (here: simulator) and minimised using the Variational Quantum Eigensolver (VQE).

PERFORMANCE

- Benchmark performance against conventional Combinatorial Kalman Filter (CKF) for ξ=4,5,7 where number of positrons are between 2,000 and 67,000.



For xi=7, Eigensolver results is shown instead of VQE.

A track is considered matched if an absolute majority of its hits belong to the same particle (i.e. at least 3 out of 4 hits).

SUMMARY AND OUTLOOK

- Demonstrated the feasibility of tracking using a quantum approach.
  - Achieved similar performance as classical tracking.
- Next:
  - Move from quantum computer simulator to real device. Need noise mitigation.
  - Study even more extreme environments and explore regions where quantum computing could outperform traditional methods.