QM19 Highlights
Measurements of γγ→e^+e^- Process

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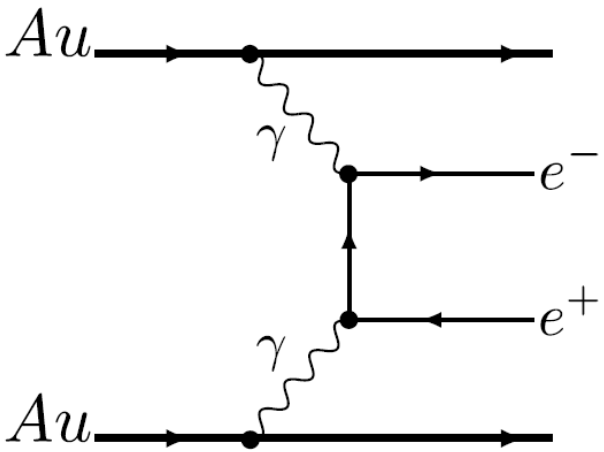
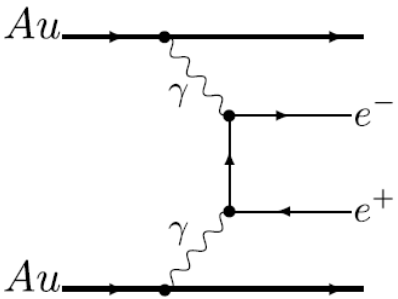


γγ→e⁺e⁻ Process

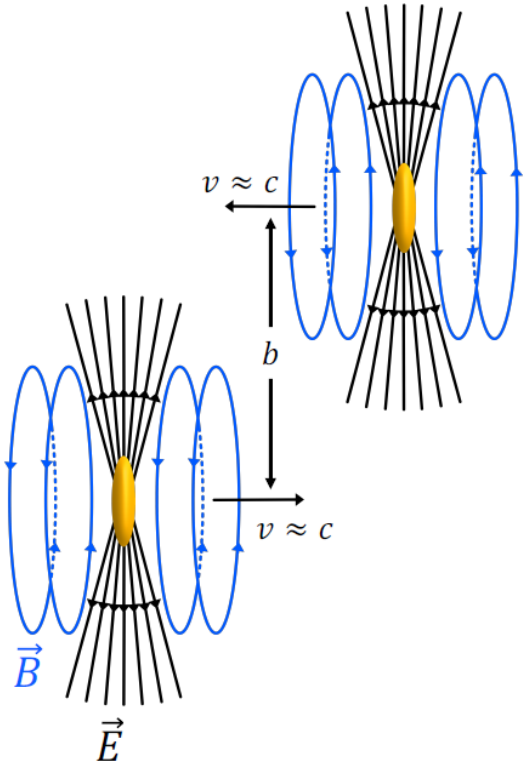
rather than exact relations. It is also hopeless to try to observe the pair formation in laboratory experiments with two beams of x-rays or γ-rays meeting each other on account of the smallness of σ and the insufficiently large available densities of quanta. In the considerations of Williams, however, the large nuclear electric fields lead to large densities of quanta in moving frames of reference. This, together with the large number

Breit, Wheeler: Phys. Rev. 46 (1934) 1087



- 1934: Breit & Wheeler
  - "Collision of two Light Quanta" to produce matter
  - Fundamental process in astrophysics
    - Ultra-high energy cosmic photon interacting with phtons from the CMB
    - Study the sources and acceleration mechanisms of cosmic rays
- Breit & Wheeler realized near impossibility of achieving γ ray collisions in Earth-based experiments
- Proposed alternative approach
  - Highly charged nuclei passing each other

Ultra-Peripheral Collisions



- Ultra-relativistic charged nuclei produce highly Lorentz-contracted electromagnetic fields
  - Weizäcker-Williams Equivalent Photon Approximation (EPA)
  - in a specific phase space EM fields can be quantized as a flux of **real photons**

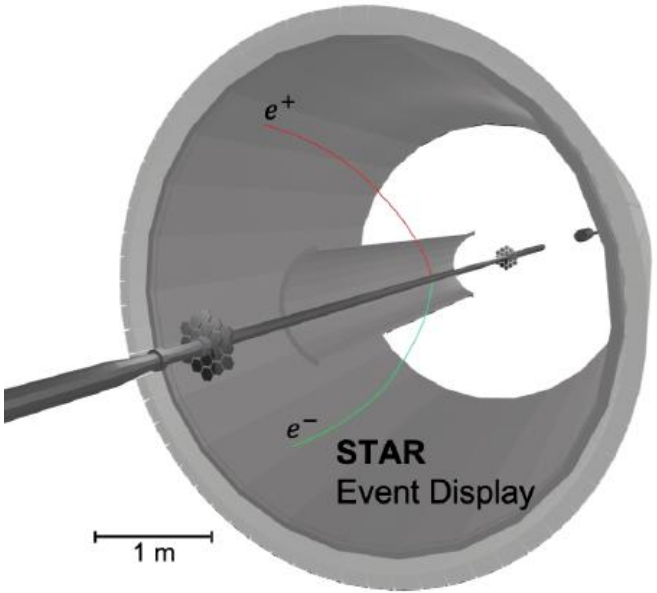
Weizäcker: Zeitschrift für Physik 88 (1934) 612

- $Z\alpha \sim 1 \rightarrow$ High photon density
- Magnetic field strength B ~ 10^{14} – 10^{16} T

Skokov et al.: Int. J. Mod. Phys. A 24 (2009) 5925

Test QED under extreme conditions

Signatures of the γγ→e⁺e⁻ Process (1)



- To identify the Breit-Wheeler process
  - Exclusive production of e+e- pair
    - No accompanying background particles
  - Smooth invariant mass spectrum
    - Quantum numbers of two real photons forbid the formation of vector mesons
    - Slope consistent with QED 2-body scattering
  - Individual e+/e- preferentially aligned in beam direction
    - Lorentz-boost of colliding photons leads to distinct distribution wrt. polar angle θ

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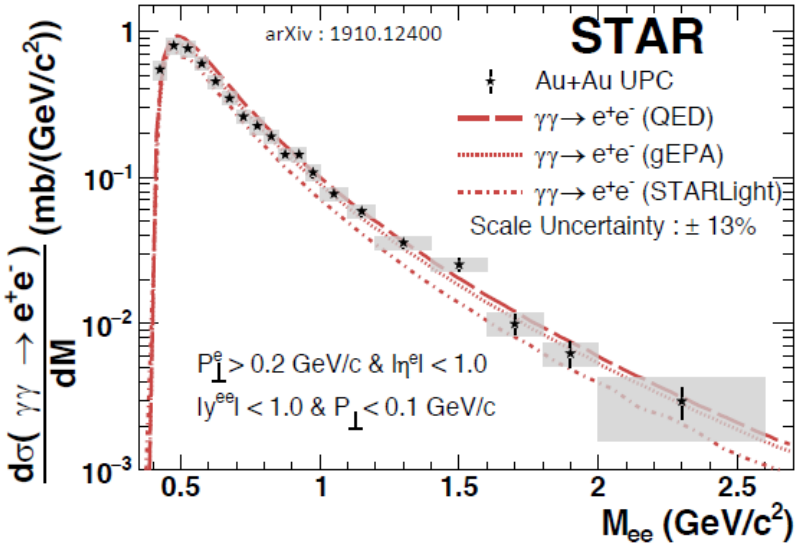

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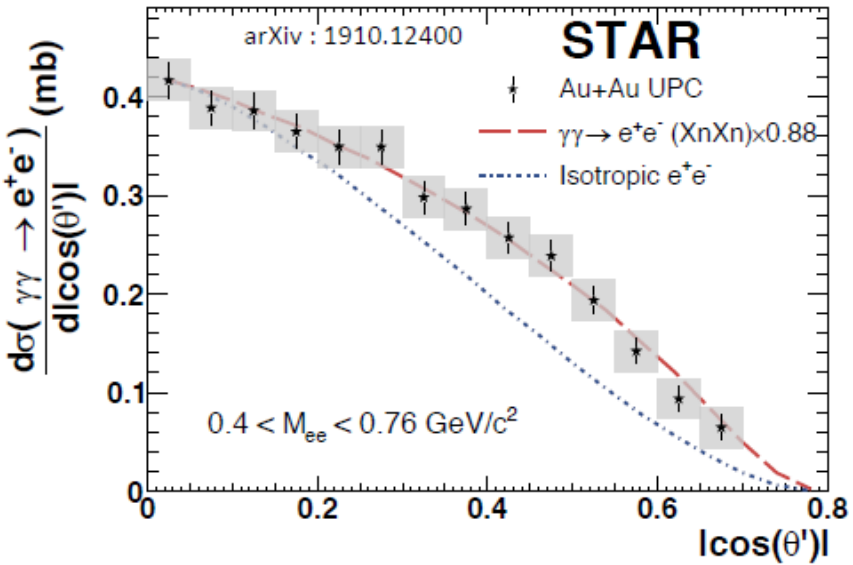

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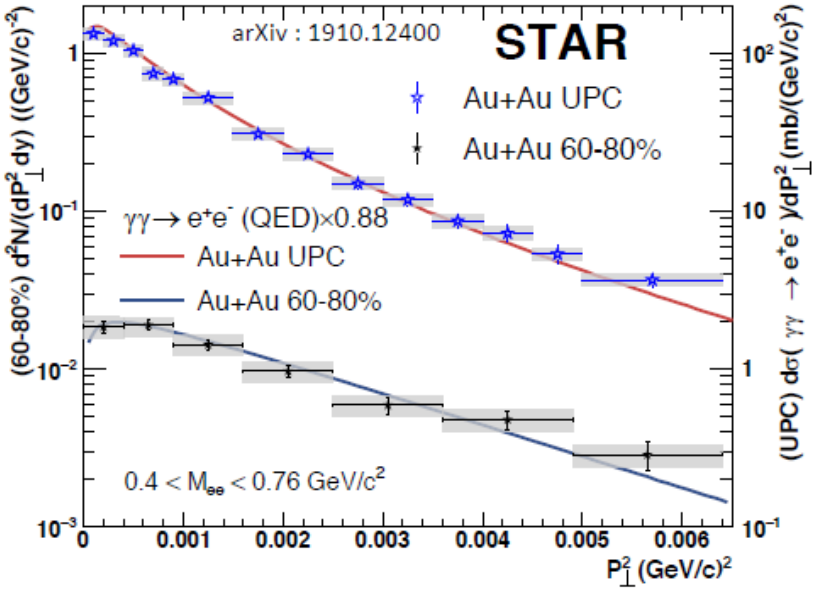
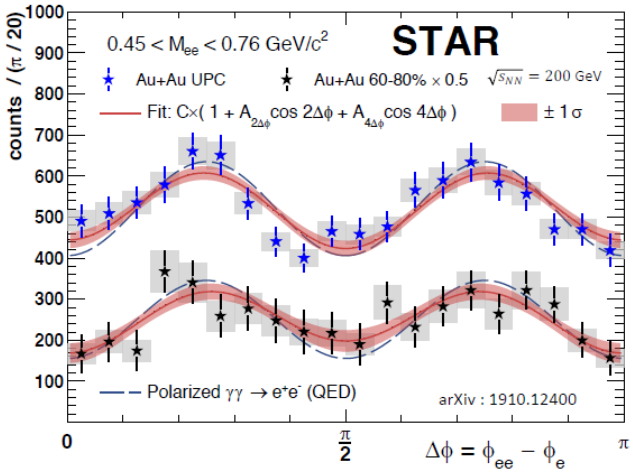
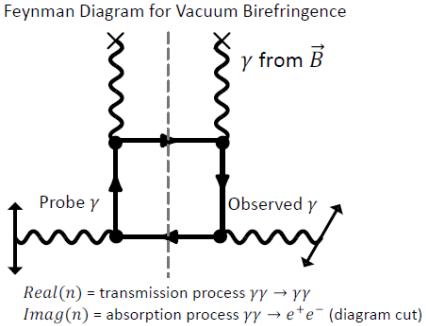


- To identify the Breit-Wheeler process
  - Cross-section peaks at low pair p_T as expected for real photons
  - Leading order QED calculation of γγ→e⁺e⁻ describes spectra in UPC and peripheral (60-80%) collisions
  - Best fit in 60-80% collisions found by QED shape plus additional 14MeV/c momentum broadening
    - Probe of the trapped magnetic field or Coulomb scattering in the QGP?

Birefringence of the QED Vacuum





- Vaccum birefringence predicted in 1936 by Heisenberg and Euler
  - Index of refraction for γ interaction with magnetic field depends on relative polarization angle
  - Lorenz-contracted EM fields → linearly polarized of quasi-real photons
- Experimental signature: Δϕ modulation
  - Absorption of a linearly polarized photon by the circular magnetic field generated by the other nucleus
  - Absorption rate (imaginary part of the refraction index) depends on angle between photon polarization and the magnetic field

Summary

- Colliding photons originate from highly contracted Coulomb fields
  - Map the extreme fields produced in the collision of ultra-relativistic heavy ions
- Creation of matter and antimatter from the fusion of two real photons
- Realization of this process in a controllable way
  - New tool for studying QED and QCD under extreme conditions