Determination of the Proton Energy Loss MC Study

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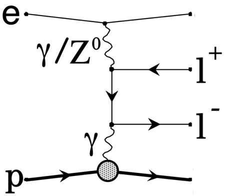
Motivation

A process to study is exclusive two-photon production of the lepton pairs, $\gamma\gamma \rightarrow l^+l^-$.



- Background to the exclusive VM production (main source at HERA)
- Window to $\tau\tau$ physics;
- Handle on the proton's charge radius and proton (ion) form-factors.

EIC offers:

- large statistics data: thanks to $>$ 100 times bigger ep luminosity;
- low pile-up;
- high momentum resolution; data streaming $\rightarrow$ high efficiency of the (semi)exclusive event selection;
- proton/ion beams;
- polarisation.

Aim:

- original and very interesting research;
- energy calibrations of very forward detectors.

Tool: GRAPE Event Generator

- GRAPE MC generator by T. Abe (arXiv:hep-ph/0012029):
  - * lepton pair production in ep interactions via $\gamma\gamma$, γZ and ZZ exchanges, and by the internal photon conversions;
  - * includes effects of the on-/off-shell Z production and those of the ISR/FSR.
  - * generated state passed to Pythia 6.4 for fragmentation/hadronisation.
- Here, only the exclusive ("elastic") case is looked at;
- $p - p - \gamma$ vertex calculated using the standard Sachs ("dipole") EM form-factors as a function of the four-momentum transfer squared t, μ_p is the proton magnetic moment:

$$G_E(t) = (1 - t/0.71\ \mathrm{GeV}^2)^{-2},\ G_M(t) = \mu_p G_E(t)$$

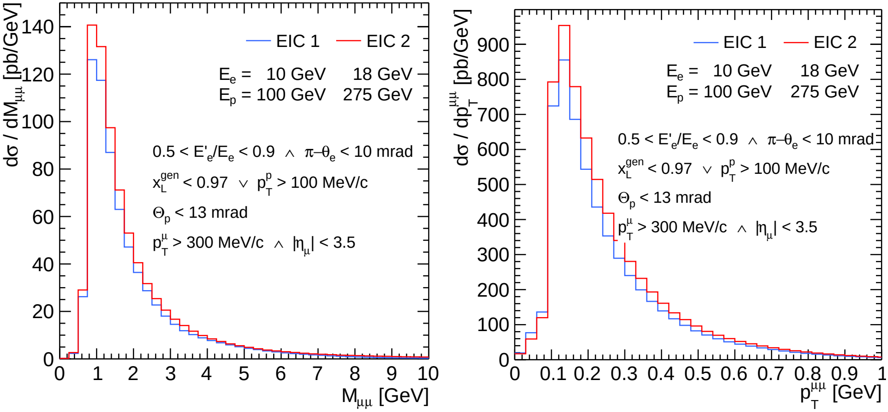
- Generation kinematic cuts:
  - * $E'_e > 0.44 \cdot E_{e,beam}$ and $\theta_e > 179^\circ$
  - * $\Theta_p < 0.75^\circ$ (13 mrad);
  - * $p_{T,\mu} > 300$ MeV/c and $|\eta_\mu| < 4$.

$\sigma_{gen.}(10\ \mathrm{GeV}) = 3182\ \mathrm{pb}$
$\sigma_{gen.}(18\ \mathrm{GeV}) = 1680\ \mathrm{pb}$

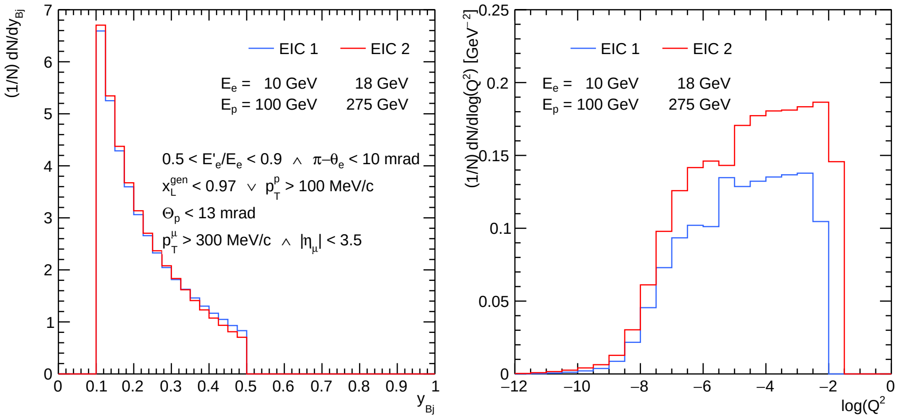
- Analysis cuts:
  - * $0.1 < y_{Bj} < 0.5$ and $\theta_e < \pi - 0.010$
  - * $|\eta_\mu| < 3.5$

$\sigma_{obs.}(10\ \mathrm{GeV}) = 170\ \mathrm{pb}$
$\sigma_{obs.}(18\ \mathrm{GeV}) = 194\ \mathrm{pb}$

Muon pairs

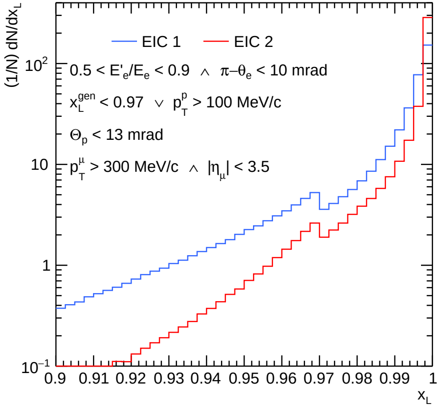


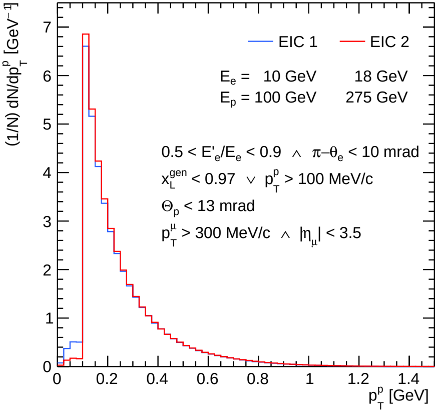
Note: Threshold effects are due to acceptances of the central tracker and far forward proton detectors, respectively



Kinematic ranges in y_{Bj} and the photon virtuality Q^2, at the electron vertex, are due to acceptances of the far backward electron detectors

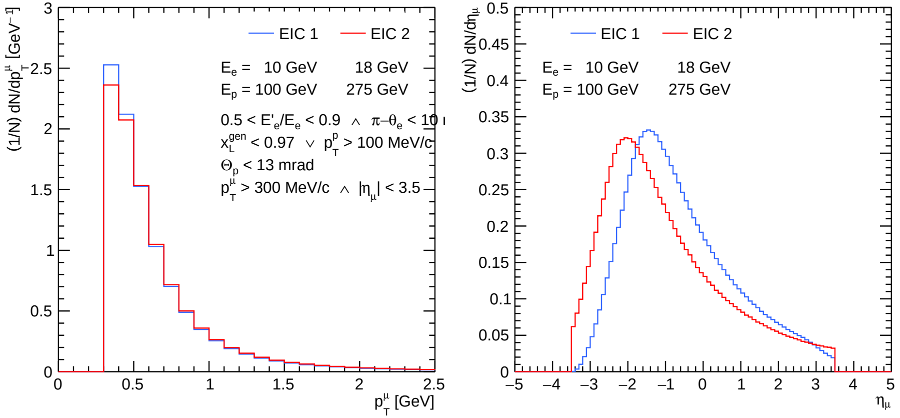
Acceptance windows: protons





Kinematic ranges in x_L and p_T^p are due to acceptances of the far forward proton detectors

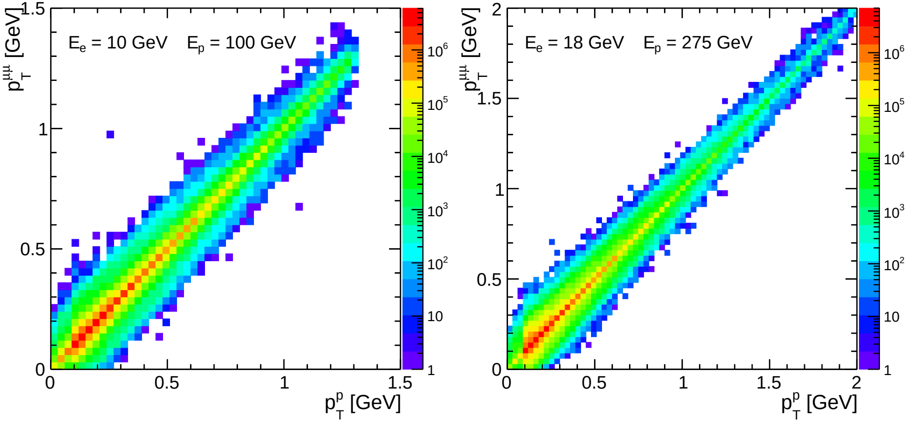
Acceptance windows: muons



Muon distributions within the acceptance of the central tracker

Correlations: proton p_T vs. pair p_T

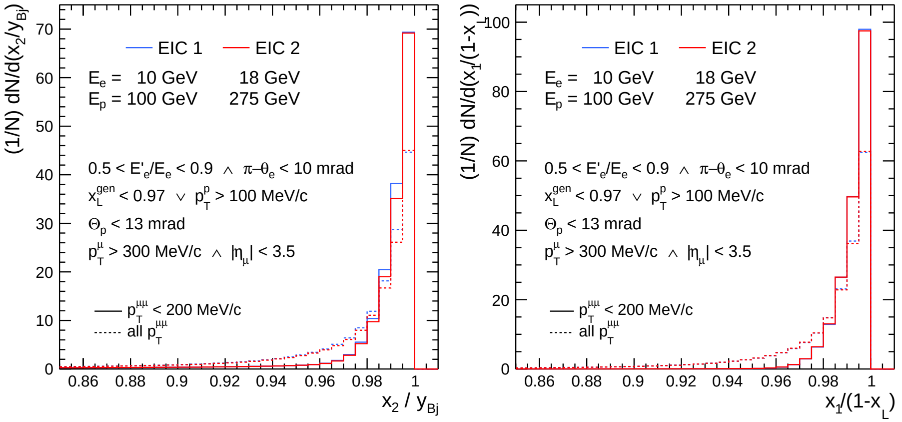
Photon veto: remove events with $E_\gamma > 200$ MeV and $|\eta_\gamma| < 4$.



Muon (and electron) pair p_T will provide an excellent calibration tool for the direct proton p_T measurement; possibly, also the proton acceptance can be well calibrated using the exclusive muon pairs.

Energy calibration of far forward and far backward detectors

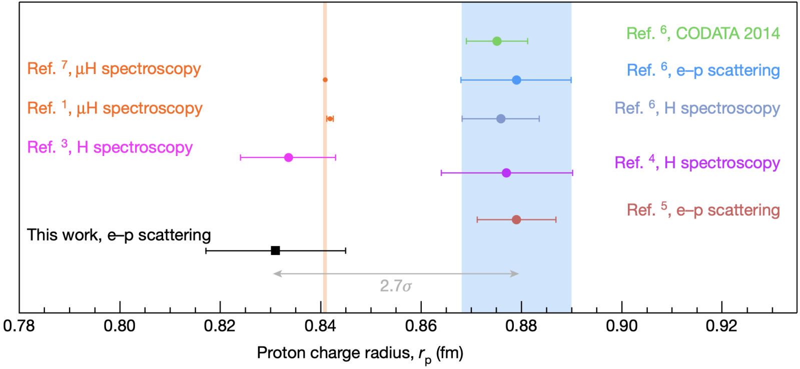
Use "DY formulae", assuming collinear photons: $x_{1,2} = \frac{M_{ll}}{\sqrt{s}} \sqrt{\frac{(E \pm p_z)}{(E \mp p_z)}} \exp\left(\mp Y^*\right)$



Narrow "kinematic peaks" are clearly visible allowing for regular and precise data-driven calibrations of the far detectors

Proton charge radius puzzle: Introduction

There are continuing discrepancies among measurements of the proton charge radius, in particular among "classic" measurements using electron-proton *elastic* scattering:



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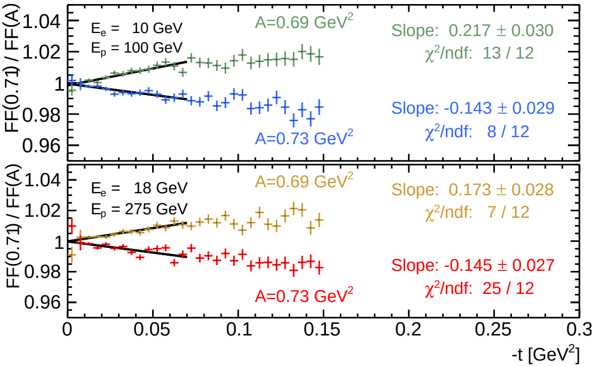
where the charge radius is determined from the elastic form-factor G_E at $t = 0$,

$$R_p^2 = 6\frac{\mathrm{d}G_E}{\mathrm{d}t}(0)/G_E(0), \text{hence } R_p^2 = 12/0.71\ \mathrm{GeV}^2 \text{ for the standard } G_E$$

Proton charge radius: Sensitivity at the EIC

We estimated an "ultimate" sensitivity to R_p at the EIC using the "elastic"' muon pairs, true kinematic variables and statistical errors only:

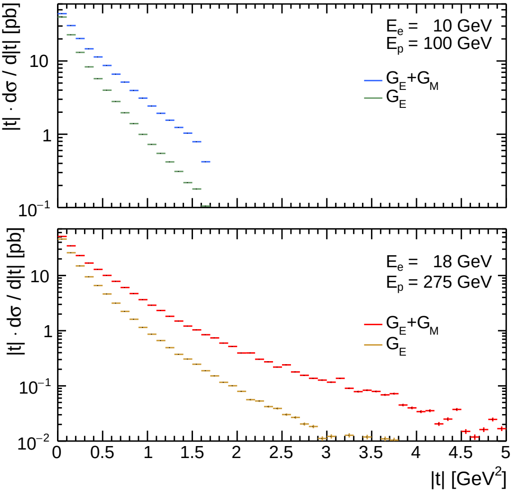


- t distributions of the selected events were made for three values of R_p
- ratios of these distributions were fitted next to $t = 0$ with straight lines
- fitted slopes are directly sensitive to the changes of R_p, as

$$\Delta(R_p^2) \propto \mathrm{d}(\frac{d\sigma_1}{dt} / \frac{d\sigma_2}{dt})/\mathrm{d}t|_{t=0}$$

Statistics of the GRAPE samples correspond to the integrated luminosities of about 33 fb^{-1}, what demonstrates that for the full EIC luminosity of 1 ab^{-1} one can expect statistical uncertainties, on the measured R_p, significantly below 1%

Separation of the form-factors G_E and G_M

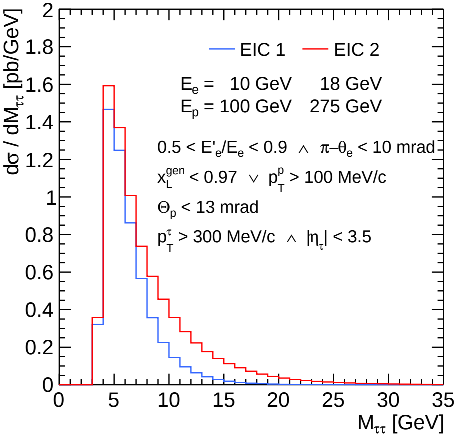


- Recently, there has been renewed interest in the proton electromagnetic form-factors in the region close to $-t = 1\ \mathrm{GeV}^2$ and beyond, in particular for testing the relation $G_M = \mu_p G_E$
- Here we show the "observed" cross-sections for fully exclusive production of muon pairs – only at high energy EIC 2 such a region can be studied
- Large cross-sections will allow for precise measurements of the G_E and G_M contributions

Note: High proton polarization and azimuthal $p - \mu\mu$ correlations will enhance the separation power for the G_E and G_M contributions

Tau lepton pairs

Two-photon production of pairs of τ leptons in the UPC became recently a very active field of research as $\gamma\gamma \to \tau^+\tau^-$ is particularly sensitive to the τ lepton anomalous magnetic dipole moment a_τ, and its electric dipole moment d_τ



- At the EIC, the detection of forward scattered protons and electrons will allow for a good event-by-event control of $\gamma\gamma$ kinematics
- Detection of the forward scattered protons will allow to build $p - \tau\tau$ azimuthal correlations, **amplified** by high polarization of incident protons
- Large "observed" cross-sections are expected at the EIC:
  - EIC 1: $\sigma = 5.5$ pb
  - EIC 2: $\sigma = 8$ pb

Excellent conditions will be available at the EIC for the τ lepton studies with very high $\tau\tau$ event statistics – about two orders of magnitude larger than at the HL-LHC

Summary and Outlook

EIC will provide perfect conditions for studying exclusive processes:

- Very high luminosity will ensure high statistics even for relatively rare processes,
- data streaming will result in no trigger losses and in lack of efficiency corrections,
- negligible event pileup and excellent particle momentum resolutions/PID (at low and medium p_T) will strongly enhance full final state reconstruction,
- in addition, far forward and far backward high resolution detectors of protons and electrons, respectively, might even provide "over-constrained reconstruction" allowing for precise data-driven inter-calibrations and testing understanding of acceptances and reconstructions.

These first exploratory studies show that two-photon exclusive production of lepton pairs can be used at the EIC for stringent and original tests of Standard Model:

- Precise studies of elastic production of muon and electron pairs will result in competitive measurements of the proton charge radius as well the elastic G_E and G_M form-factors;
- high statistics of exclusive τ pairs will provide unique access to the magnetic and electric moments of τ leptons.

Future studies will be yet extended to include the impact of beam polarizations as well as the electron-ion case, apart from introduction of various detector effects.