A new ep generator for the OLYMPUS experiment

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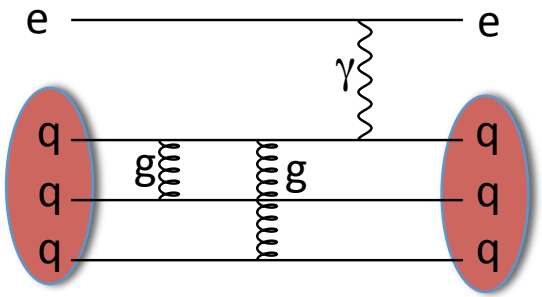
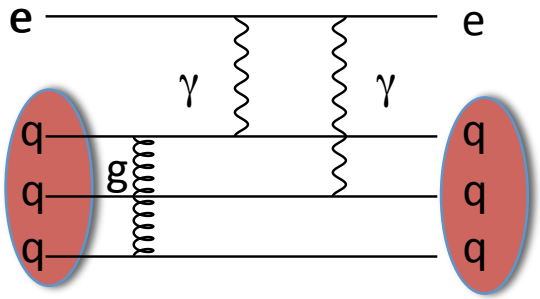
(On behalf of the OLYMPUS collaboration)

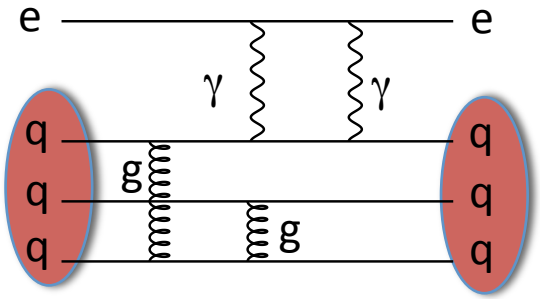
ep elastic scattering – main processes



One photon exchange (Born Approximation)



Two photon exchange (Leading order 1 hard gluon)



Two photon exchange (Subleading order 2 hard gluons)

Effects of TPE in charge asymmetry

The interference between 1-photon and 2-photon exchange amplitude has opposite sign for electron and positron scattering, leading to the charge asymmetry:

$$A^{odd} = \frac{\sigma\left(e^- p \to e^- p\right) - \left(e^+ p \to e^+ p\right)}{\sigma\left(e^- p \to e^- p\right) + \left(e^+ p \to e^+ p\right)} \approx \frac{\left|M_\gamma^{e^-}\right|^2 + 2\,\mathrm{Re}\left(M_\gamma^{e^-*} M_{\gamma\gamma}^{e^-*}\right) - \left|M_\gamma^{e^+}\right|^2 - 2\,\mathrm{Re}\left(M_\gamma^{e^+*} M_{\gamma\gamma}^{e^+*}\right)}{\left|M_\gamma^{e^-}\right|^2 + 2\,\mathrm{Re}\left(M_\gamma^{e^-*} M_{\gamma\gamma}^{e^-*}\right) + \left|M_\gamma^{e^+}\right|^2 + 2\,\mathrm{Re}\left(M_\gamma^{e^+*} M_{\gamma\gamma}^{e^+*}\right)}$$

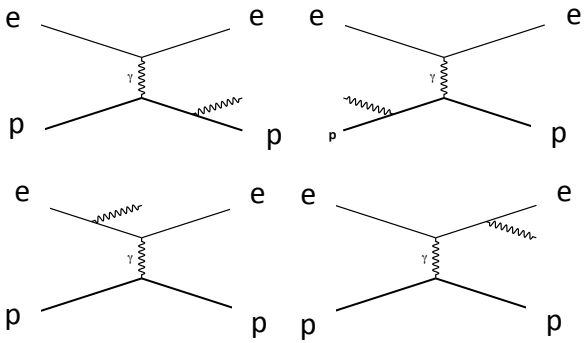
$$A^{odd} = \frac{\sigma\left(e^- p \to e^- p\right) - \left(e^+ p \to e^+ p\right)}{\sigma\left(e^- p \to e^- p\right) + \left(e^+ p \to e^+ p\right)} \approx -\frac{4\,\mathrm{Re}\left(M_\gamma^{e*} M_{\gamma\gamma}^{e}\right)}{2\left|M_\gamma^{e}\right|^2} \approx -2\frac{\mathrm{Re}\left(M_\gamma^{e*} M_{\gamma\gamma}^{e}\right)}{\left|M_\gamma^{e}\right|^2}$$

The aim of the OLYMPUS experiment of the measurement of the contribution of Two Photon Exchange in the charge asymmetry.

For details of the OLYMPUS experiment see previous OLYMPUS talks

Radiative corrections for OLYMPUS

Production of real hard photon from Bremsstrahlung affects both kinematics and cross section significantly.

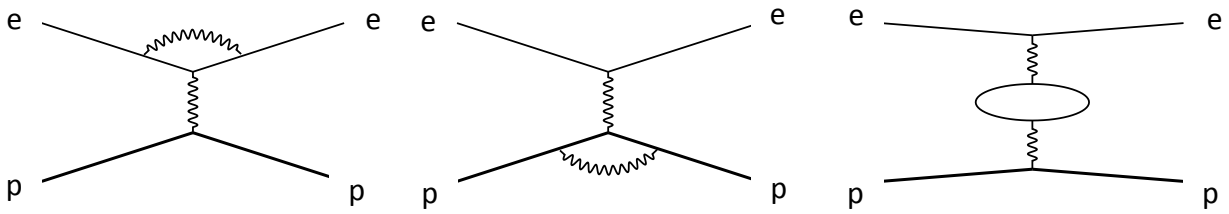


Dependence of angular distribution of emitted photon.

Such processes affect the charge asymmetry as:

$$A^{odd} = \frac{\sigma\left(e^- p \to e^- p\right) - \left(e^+ p \to e^+ p\right)}{\sigma\left(e^- p \to e^- p\right) + \left(e^+ p \to e^+ p\right)} \approx -\frac{2\mathrm{Re}\left(M_\gamma^{e*} M_{\gamma\gamma}^{e}\right)}{\left|M_\gamma^{e^-}\right|^2} - \frac{2\mathrm{Re}\left(M_{brem}^{l*} M_{brem}^{p}\right)}{\left|M_\gamma^{e^-}\right|^2}$$

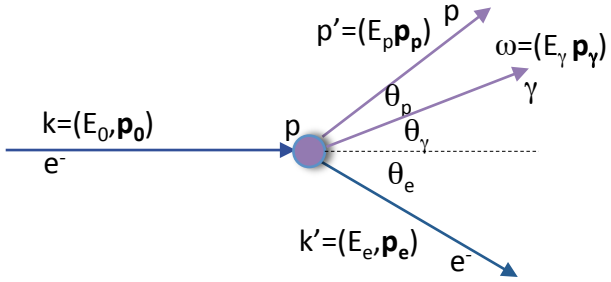
Virtual correction to the cross section remove infrared divergences:



Generator for the OLYMPUS experiment

- Inclusion of ep elastic scattering, bremsstrahlung and virtual corrections
- Specific conditions of the OLYMPUS experiment
- Interface with **GEANT4** simulation for realistic estimation of radiative corrections in the experimental data treatment
- Statistical analysis of generator data embedded within the analysis of experimental data on the basis of **ROOFIT**

Kinematics



- Initial $e^{\pm}$ energy: 2 GeV
- Kinematic obsevables: final 4-momentum of electron, proton and photon
- Events are considered to follow the kinematics of ep elastic scattering when the energy of the radiated photon is less than 10 MeV

Some kinematic variables:

$$Q^2 = 4E_e E_0 \sin^2\frac{\theta_e}{2}$$

$$\tau = \frac{Q^2}{4M^2}$$

$$\frac{1}{\varepsilon} = 1 + 2(1+\tau)\tan^2\frac{\theta_e}{2}$$

1-photon cross section

The differential cross-section of ep elastic scattering is included at the one-photon exchange Born approximation with the Rosenbluth formula (T is the electron kinetic energy):

$$\left.\frac{d\sigma}{d\Omega}\right|_R = \frac{\alpha^2}{4T^2}\frac{1}{1+2\frac{T}{M_p}\sin^2\frac{\theta_e}{2}}\frac{\tau}{\varepsilon(1+\tau)}\left[G_M^2(Q^2)+\frac{\varepsilon}{\tau}G_E^2(Q^2)\right]\frac{\cos^2\frac{\theta_e}{2}}{\sin^4\frac{\theta_e}{2}}$$

The proton form factors are defined within the dipole approximation:

$$G_E(Q^2) = \frac{1}{\left(1+Q^2/0.71\right)}$$

$$G_M(Q^2) = \mu G_E(Q^2)$$

Internal Bremsstrahlung

The cross section of internal bremsstrahlung is included according to the calculation in Ent (PRC 64 054610)**, Maximon&Tjon (**PRC 62 054320**):**

$$\left.\frac{d\sigma}{d\Omega_e d\Omega_\gamma dE_\gamma}\right|_{brem} = \frac{\alpha E_\gamma}{4\pi^2}\left[\frac{p'}{\omega\cdot p'}+\frac{k}{\omega\cdot k}-\frac{k'}{\omega\cdot k'}-\frac{p}{\omega\cdot p}\right]^2 \left.\frac{d\sigma}{d\Omega_e}\right|_R$$

And including the virtual photon corrections:

$$\left.\frac{d\sigma}{d\Omega_e}(E_\gamma < E_{cut})\right|_{brem} = \left(1-\delta_{soft}(E_{cut})-\delta_{hard}\right)\left.\frac{d\sigma}{d\Omega_e}\right|_R$$

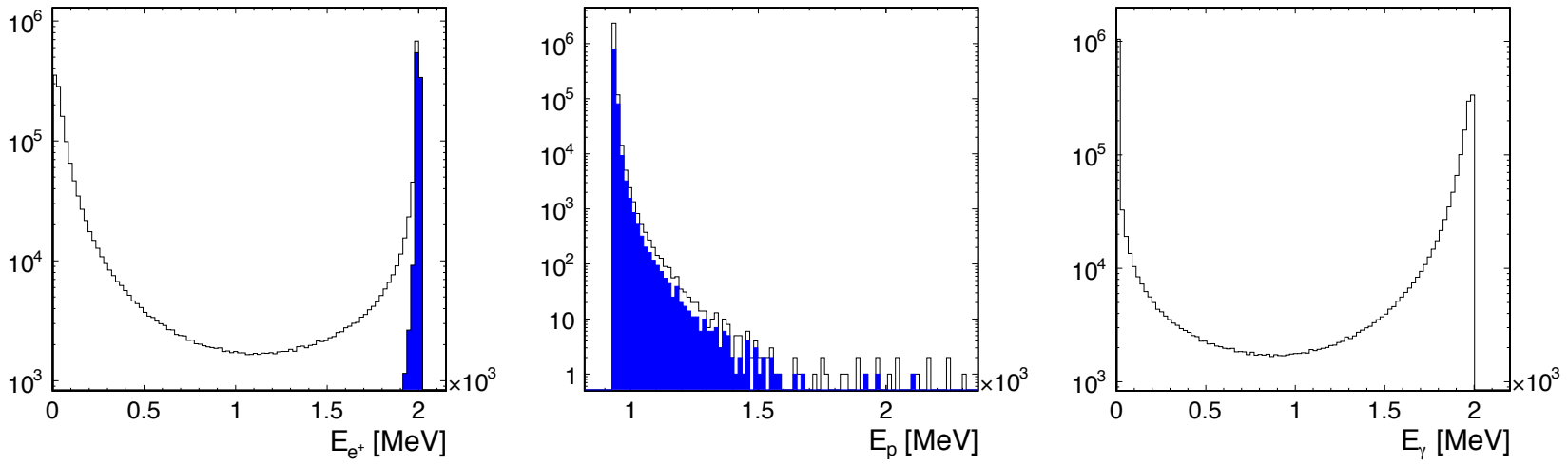
$$\delta_{soft}(E_{cut}) = \int_0^{E_{cut}} \left.\frac{d\sigma}{d\Omega_e d\Omega_\gamma dE_\gamma}\right|_{brem} d\Omega_\gamma dE_\gamma$$

$$\delta_{hard} = 2\alpha\left(-\frac{3}{4\pi}\ln\frac{Q^2}{m^2}+\frac{1}{\pi}-\frac{1}{3\pi}\left(-\frac{5}{3}+\ln\frac{Q^2}{m^2}\right)\right)$$

Vertex

Vacuum

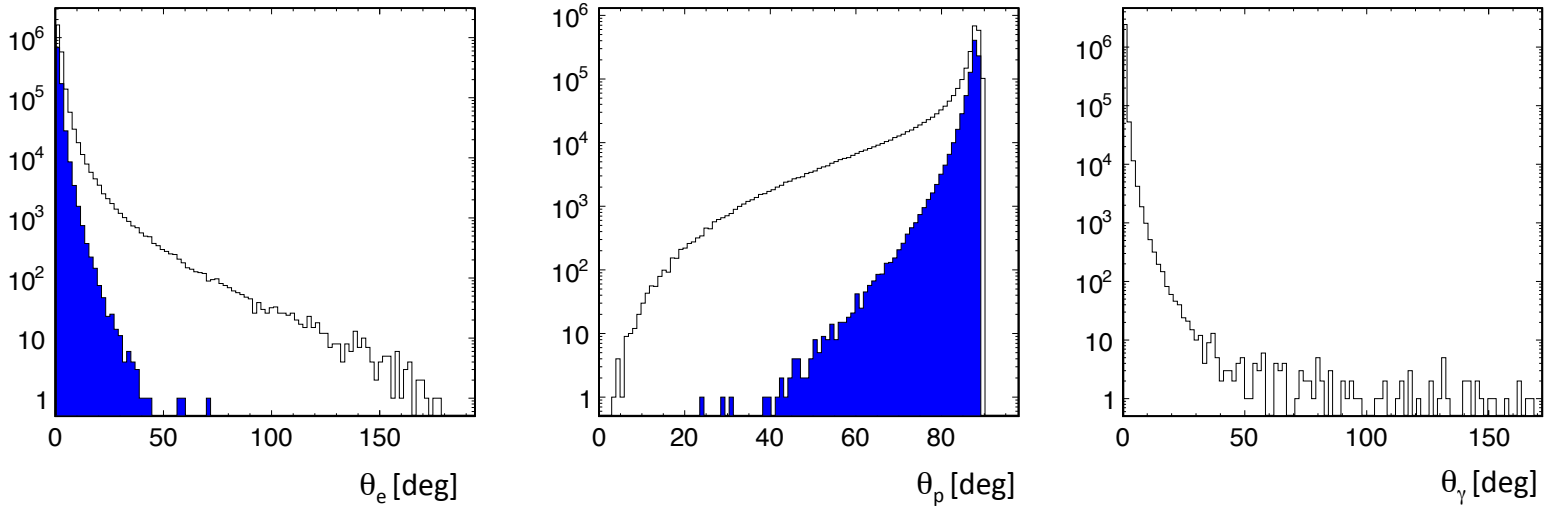
Example of event generation



Energy of generated particles in the final state

In black full generated statistics, in blue events with only elastic scattering

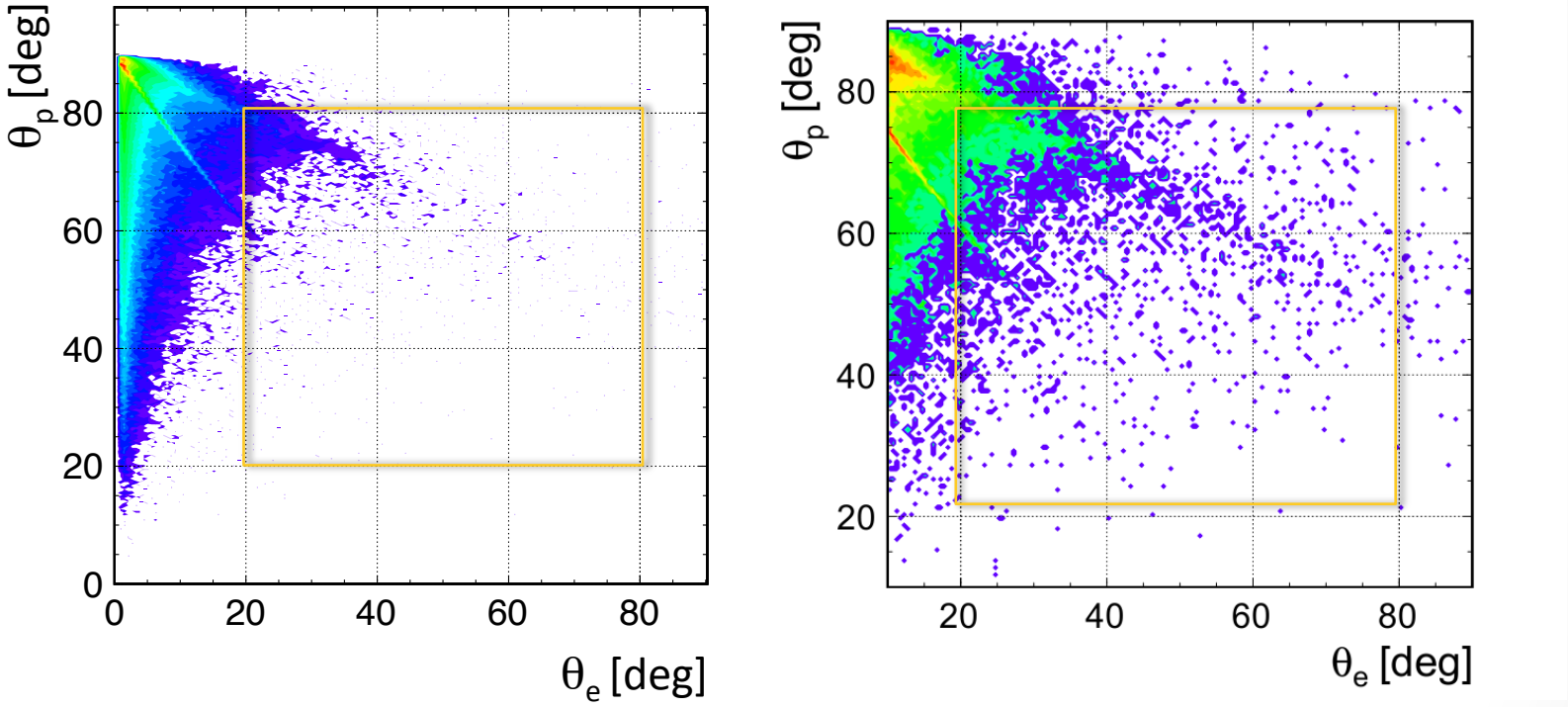
Example of event generation



Polar angles of generated particles in the final state

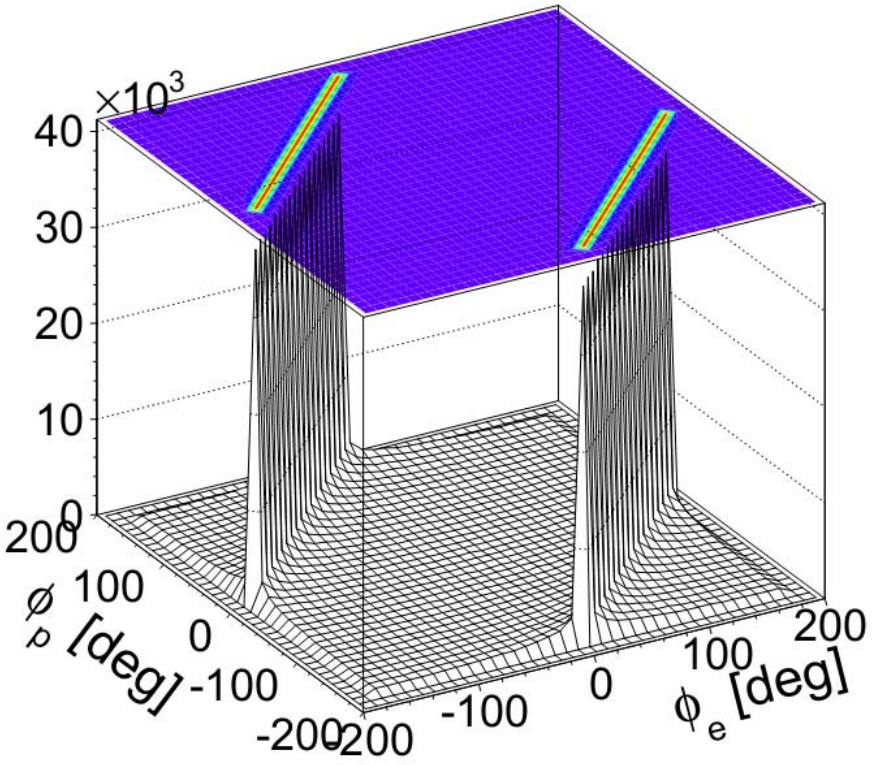
In black full generated statistics, in blue events with only elastic scattering

Example of event generation



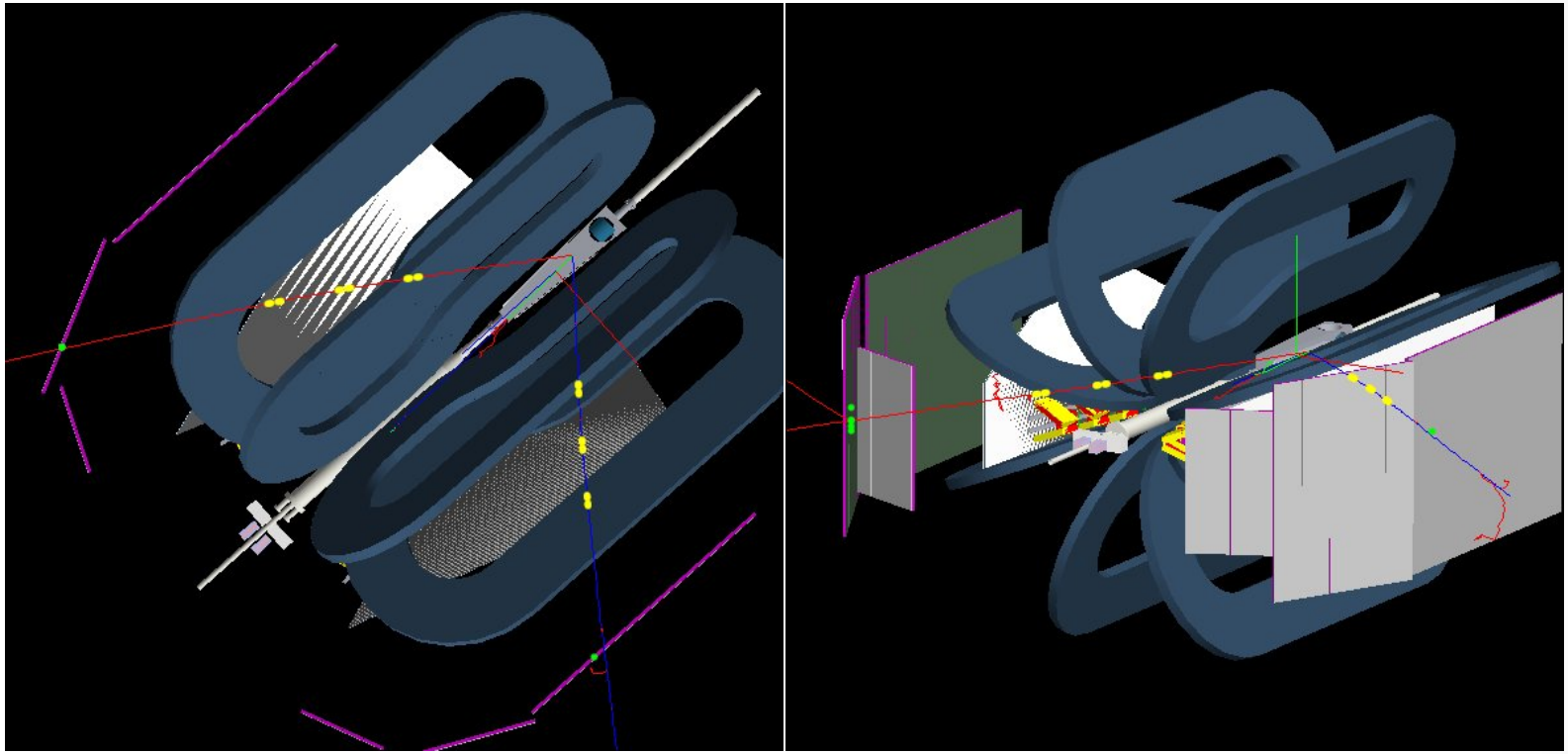
Correlation between polar angles of electrons and protons

Example of event generation



Coplanarity between azimuthal angles of electrons and protons

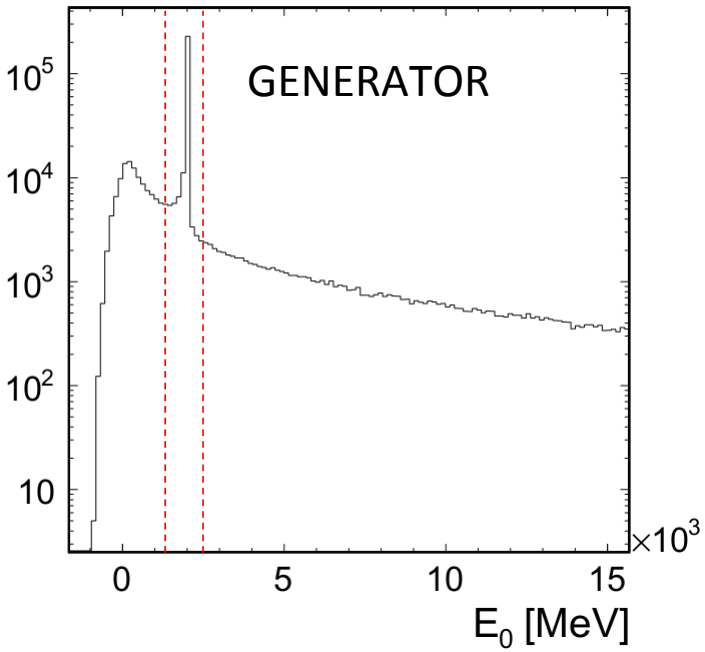
Example of generated events

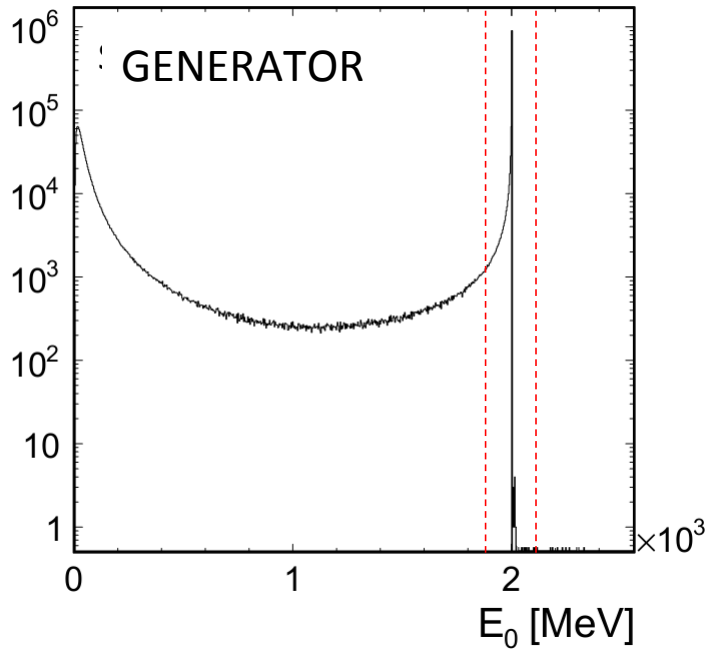


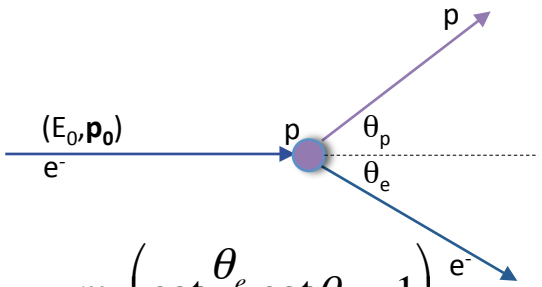
- Example of Generated event through the OLYMPUS Monte Carlo (GEANT4 detector simulation)
- Color code tracks: blue proton, red electron, green photon
- Color code hits: yellow wire chamber, green TOF

Rad. Corrections and analysis variables

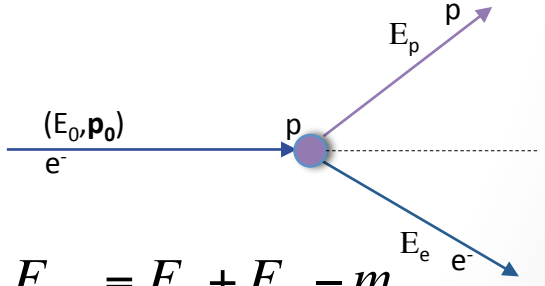
In the two arms experiment the kinematics is over constrained





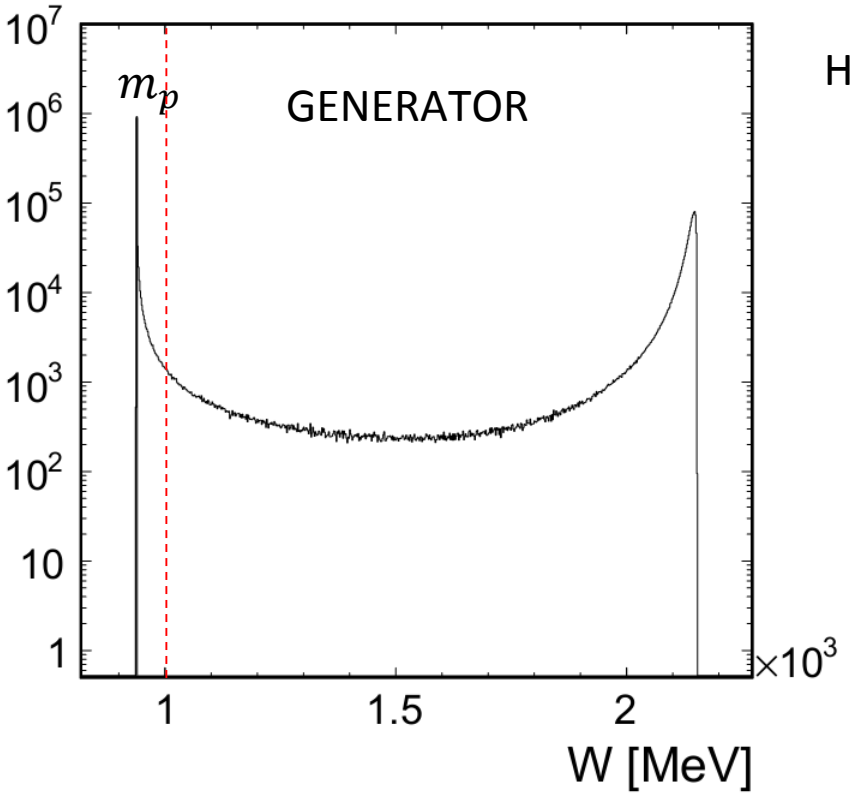


$$E_{0,1} = m_p\left(\cot\frac{\theta_e}{2}\cot\theta_p - 1\right)$$

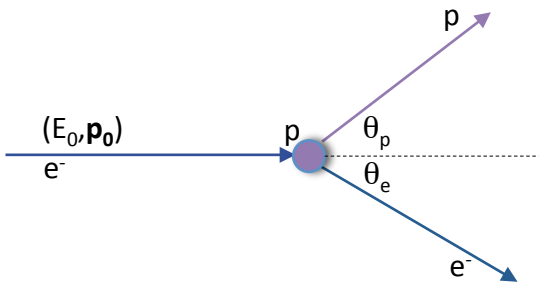


$$E_{0,2} = E_e + E_p - m_p$$

Rad. Corrections and analysis variables

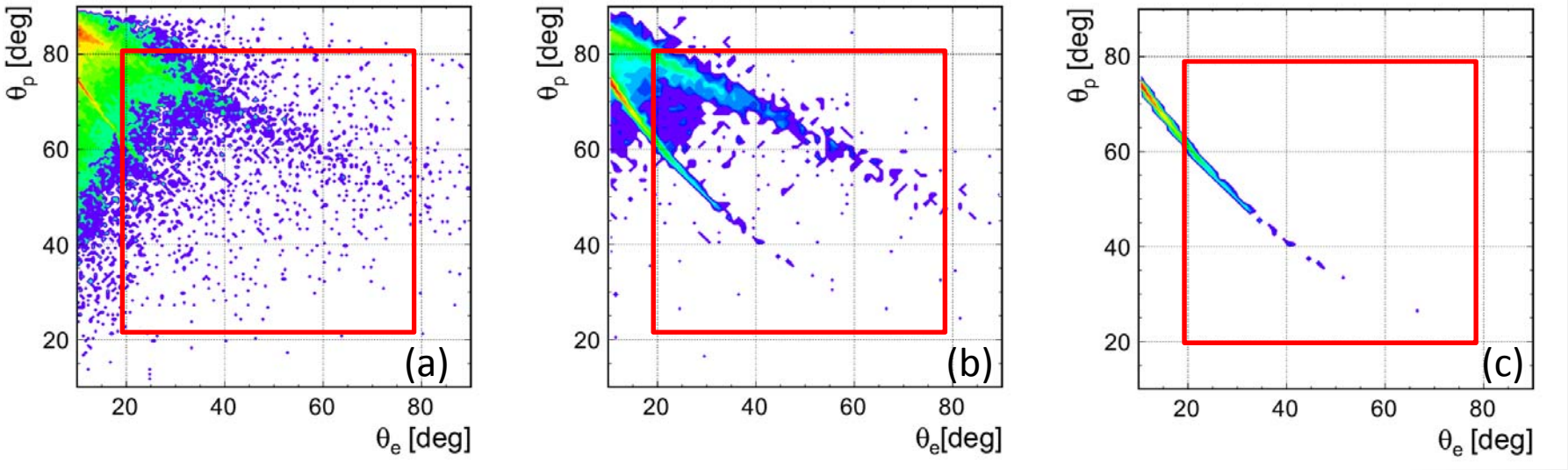


Hadronic Invariant Mass



$$W = \sqrt{m_p^2 + 2m_p\left(E_0 - E_e\right) - 4E_0E_e\sin^2\frac{\theta_e}{2}}$$

Rad. Corrections Generator and analysis

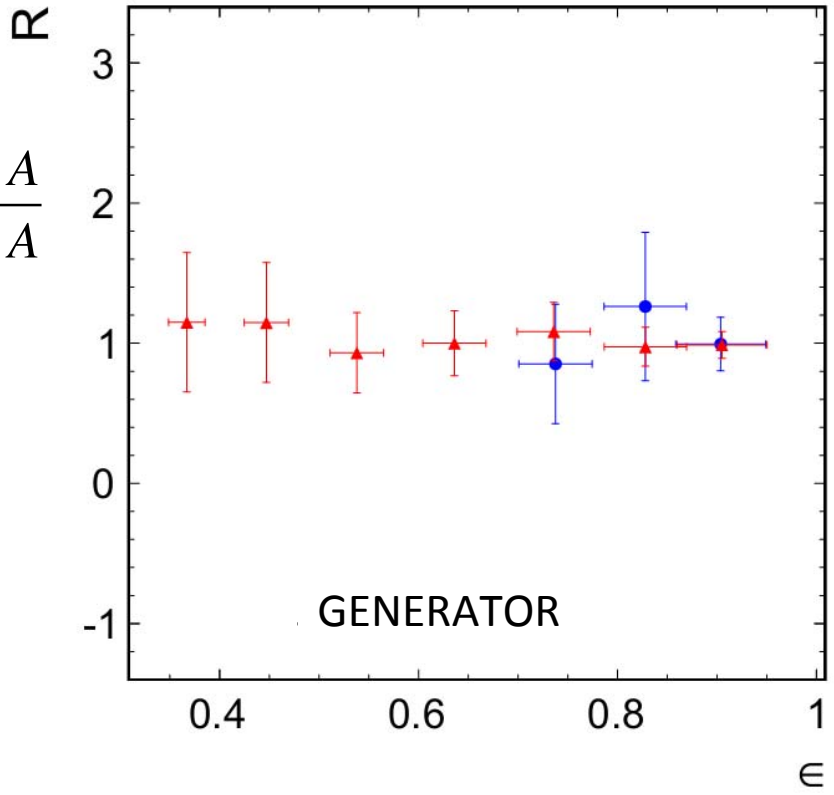


- Study in the region of the acceptance of OLYMPUS
- (a) No cuts
- (b) $179<\Delta\phi<181$
- (c) $1900<E_0<2100$ MeV and $W<1000$ MeV

Elastic kinematic band as a result of the cuts. Width dependent on radiative corrections

Determination of the ratio in generator

$$R_{e^+e^-} = \frac{\sigma\left(e^+ p\right)}{\sigma\left(e^- p\right)} = \frac{1-A}{1+A}$$



Radiative corrections are sensitive to the selection cuts

Preliminary estimation based on low statistics test sample

Outlook

- New generator for the OLYMPUS experiment under development and test
- Preliminary results in agreement with theoretical expectation
- Interface with **GEANT4** simulation
- Statistical analysis of generator data on the basis of **ROOFIT**

- Inclusion of model for TPE process (Maximon and Tjon…)
- Inclusion of higher order bremsstrahlung
- Inclusion of external bremsstrahlung
- Inclusion of intermediate resonances