Accessing gluons in the nucleon: ϕ eletroproduction on the neutron with RGB

CLAS Collaboration Meeting

18 November 2026

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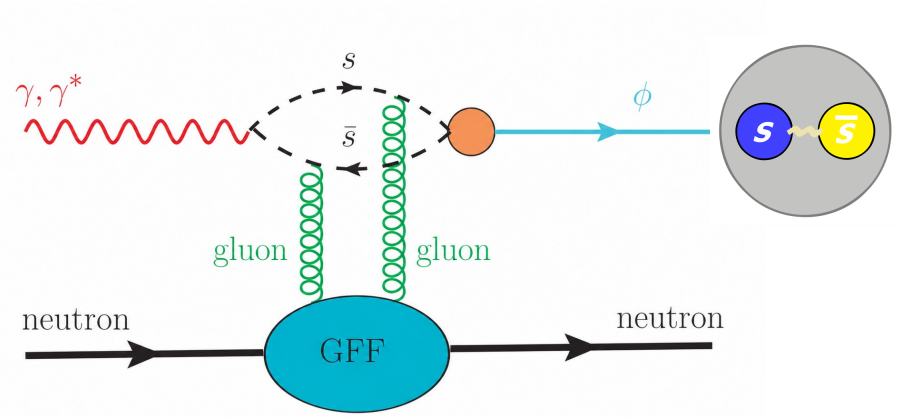
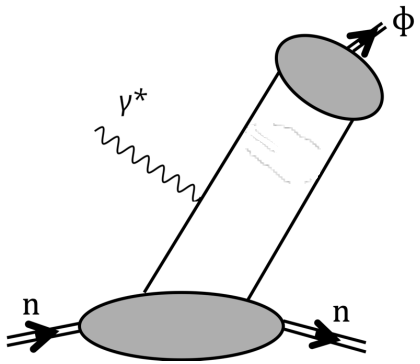
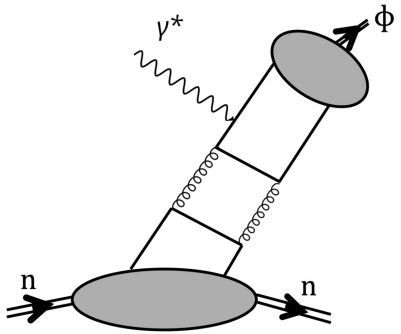


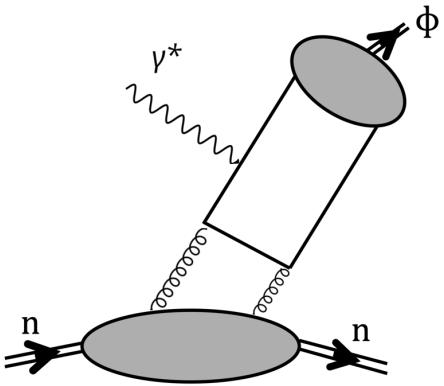
1. Motivations
2. Events selection
3. Extracted number of ϕ
4. Acceptance efficiency
5. Neutron detection efficiency correction in the FD
6. Data binning
7. Preliminary results



Contribute but $10A_s = A_g$



Contribute but at NLO



Exepted to be the main contribution

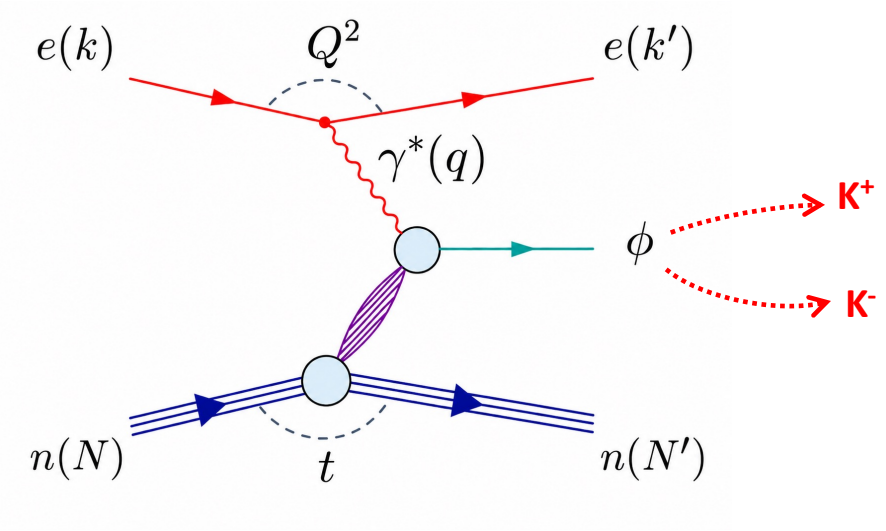
$$\frac{d\sigma_L}{dt} = \frac{2\pi^2\alpha_{em}}{(W^2-M^2)Wp_{cm}}\left((1-\xi^2)|\mathcal{H}|^2 - \left(\frac{t}{4M^2}+\xi^2\right)|\mathcal{E}|^2 - 2\xi^2\mathrm{Re}(\mathcal{H}\mathcal{E}^*)\right)$$

$$\mathcal{H}(\epsilon,t,Q^2) \propto \underbrace{C_s\cdot(A_s+\epsilon^2 D_s)}_{\text{quark s}} + \underbrace{C_q\cdot\textstyle\sum_q(A_q+\epsilon^2 D_q)}_{\text{quark u, d, c, s}} + \underbrace{C_g\cdot(A_g+\epsilon^2 D_g)}_{\text{gluons}}$$

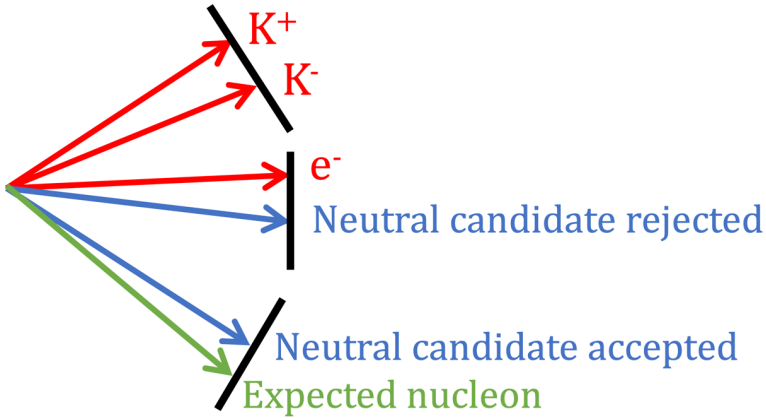
Analysis objective :

Measurement of the **cross section** of the **ϕ electroproduction** on **neutron**.

- Through $K^+ K^-$ channel : e n → e' n' $K^+ K^-$ (Br ~49.2%)
- With a liquid **deuterium** target (RGB data).
- Beam energy between **10.2 and 10.6 GeV**.



Data used *: RGB fall2019 outbending with E_b = 10.41 GeV*



Event selection :

- Exactly one K^+, one K^- and one electron
- At least one neutral candidate (PID = 2112 or 22)
- No proton detected

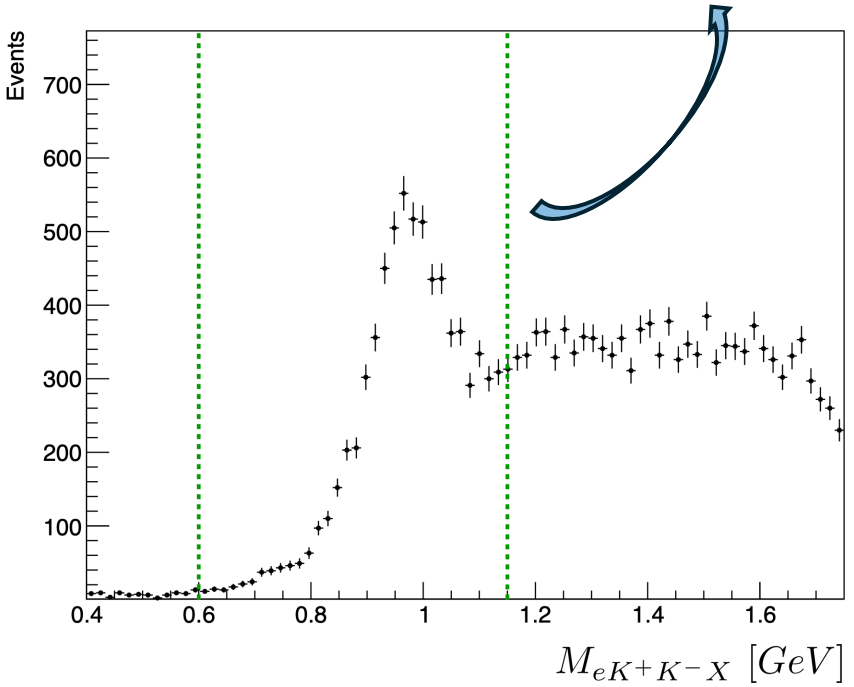
Neutral candidate :

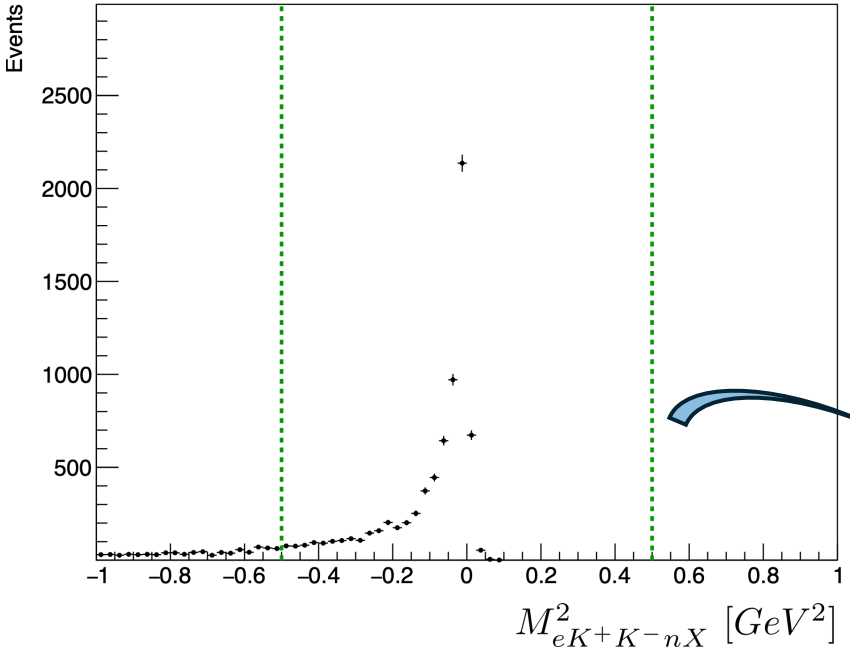
- Some fast neutron with $\beta > 0.9$ are identified as photon (especially if they depose energy in PCAL).
- Thus PID 2112 (neutron) and 22 (photon) are included.
- Selection of every neutral candidate in the cone angle (10°) of the expected nucleon. The best candidate is choosen with Δp.

Main cuts :

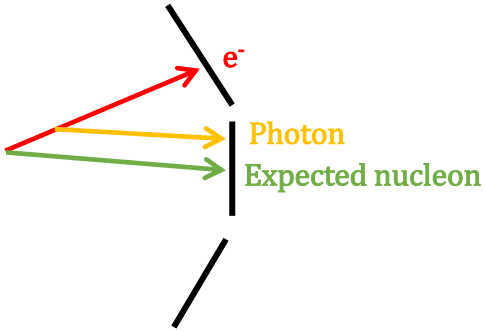
- Neutron , Kaons, and electron in the FD
- $Q^2 > 1\ GeV^2$, $W > 1.95\ GeV$ and $P_{e^-} > 2\ GeV$
- Fiducial cuts on the neutron

$0.6 < M_{eK^+K^-X} < 1.15\ GeV$

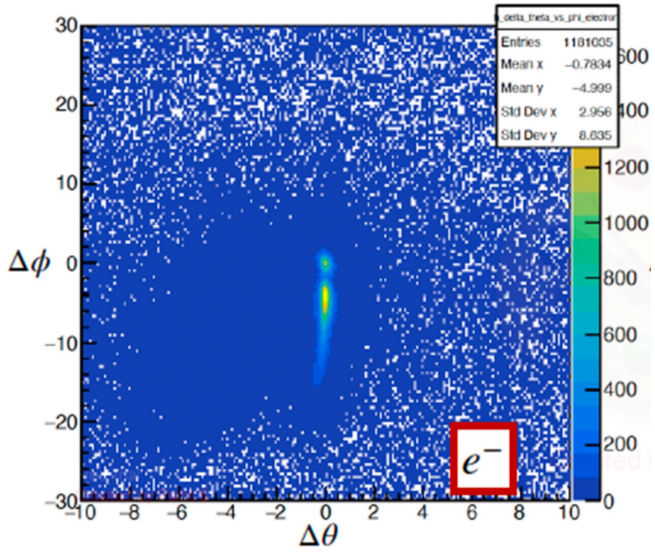




$-0.5 < M^2_{eK^+K^-nX} < 0.5\ GeV^2$



dθ electron photon FD



Plot from P. Chatagnon J/psi photoproduction analysis note.

This case can :

- Modify the momentum of the electron and thus modify the angle between the missing particle and the neutron.
- Photon contamination can happen.

Correction :

$$\vec{p}_{\text{electron corr.}} = \vec{p}_{\text{electron uncorr.}} + \sum_{\gamma} \vec{p}_{\gamma} \quad \text{If } \Delta\theta < 1°$$

$$\frac{d\sigma}{dt \cdot dQ^2 \cdot dx_b} = \frac{N_\phi}{\epsilon_{corr} \cdot Acc \cdot \mathcal{L}_{\text{int}} \cdot Br \cdot \Delta t \cdot \Delta Q^2 \cdot \Delta x_b}$$

Extracted number of ϕ

Efficiency corrections

Acceptance Efficiency

Integrated Luminosity

Bin volume correction

Branching Ratio $\phi \to K^+K^- = 0.492$

$$\frac{d\sigma}{dt \cdot dQ^2 \cdot dx_b} = \frac{N_\phi}{\epsilon_{corr} \cdot Acc \cdot \mathcal{L}_{\text{int}} \cdot Br \cdot \Delta t \cdot \Delta Q^2 \cdot \Delta x_b}$$

Extracted number of ϕ

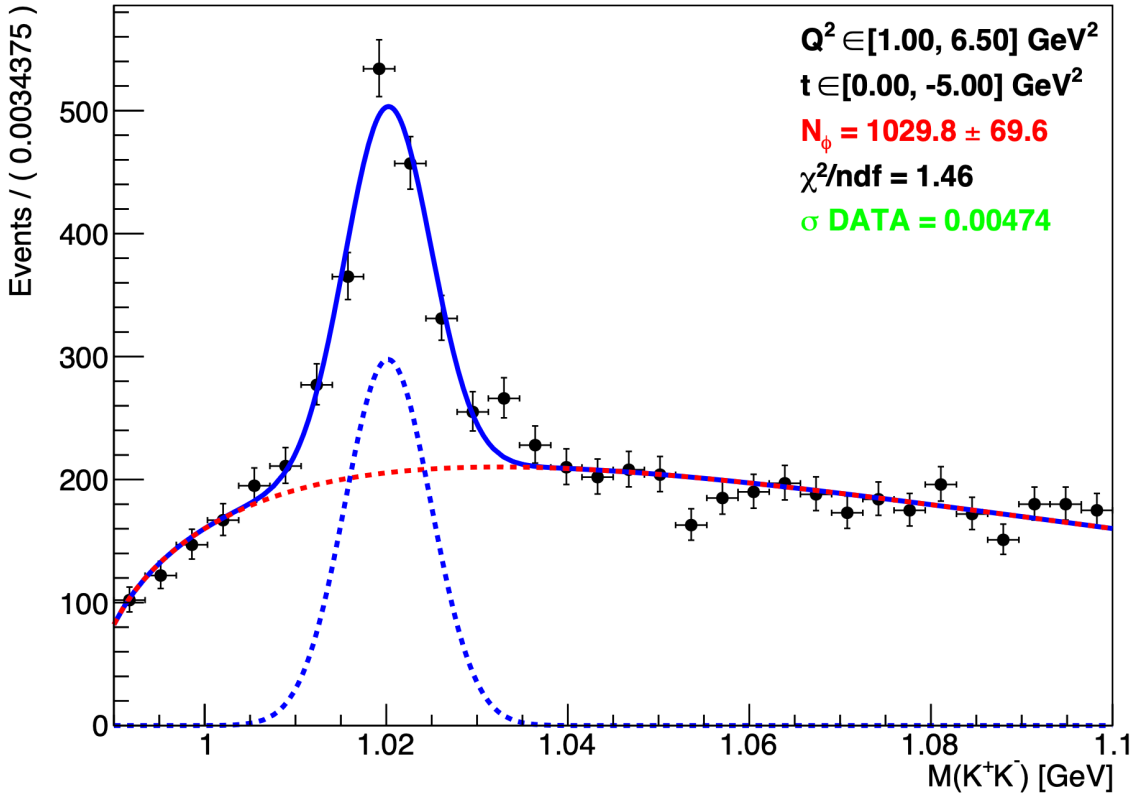
Signal model :

$$S(M_{inv}) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{(M_{inv}-\mu)^2}{2\sigma^2}\right)$$

Background model :

$$B(M_{inv}) = \sqrt{M_{inv}^2 - 4m_K^2}\ \exp\left(a_0 m + a_1 m^2\right)$$

Fits performed with RooFit.



$$\frac{d\sigma}{dt \cdot dQ^2 \cdot dx_b} = \frac{N_\phi}{\epsilon_{corr} \cdot Acc \cdot \mathcal{L}_{\text{int}} \cdot Br \cdot \Delta t \cdot \Delta Q^2 \cdot \Delta x_b}$$

Acceptance Efficiency

MC generator :

- **Cross section from :** *Proposal to Jefferson Lab PAC39*

$$\sigma_T(W,Q^2) = \frac{c_T(W)}{(1+Q^2/m_\phi^2)^{\nu_T}}, \quad \sigma_L(W,Q^2) = R(W,Q^2)\,\sigma_T(W,Q^2)$$

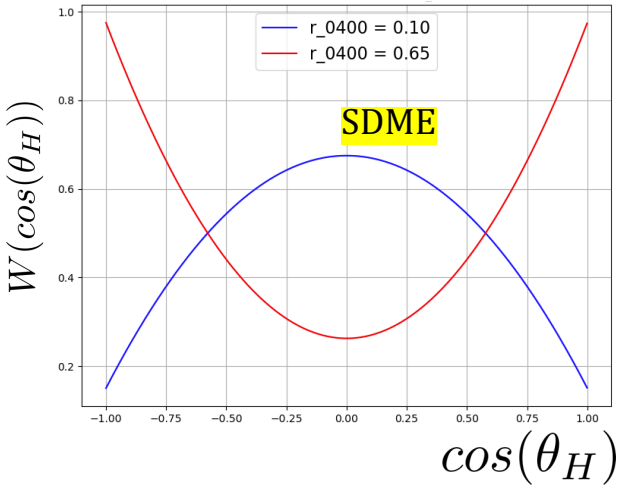
$$with \quad R(W,Q^2) = \frac{c_R Q^2}{m_\phi^2} \quad and\ a\ dipole\ \frac{m_g^8}{(m_g^2-t)^4}\ for\ the\ t-dependence$$

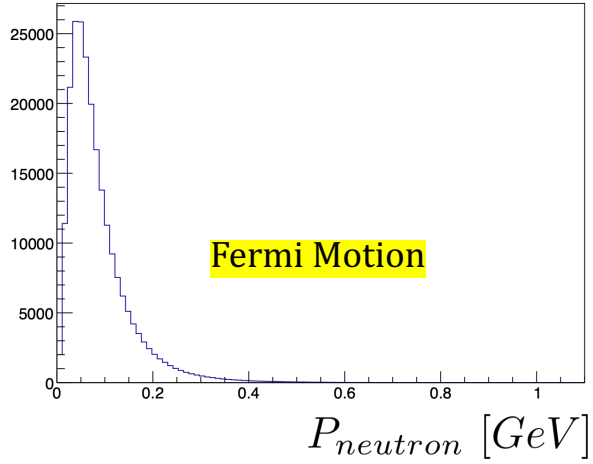
- **Fermi motion distribution from J/PSI Gen :** *https://github.com/JeffersonLab/JPsiGen/*

$$f(p_F) = \frac{p_F^2(0.26^2-0.0456^2)^2}{(p_F^2+0.0456^2)^2(p_F^2+0.26^2)^2}$$

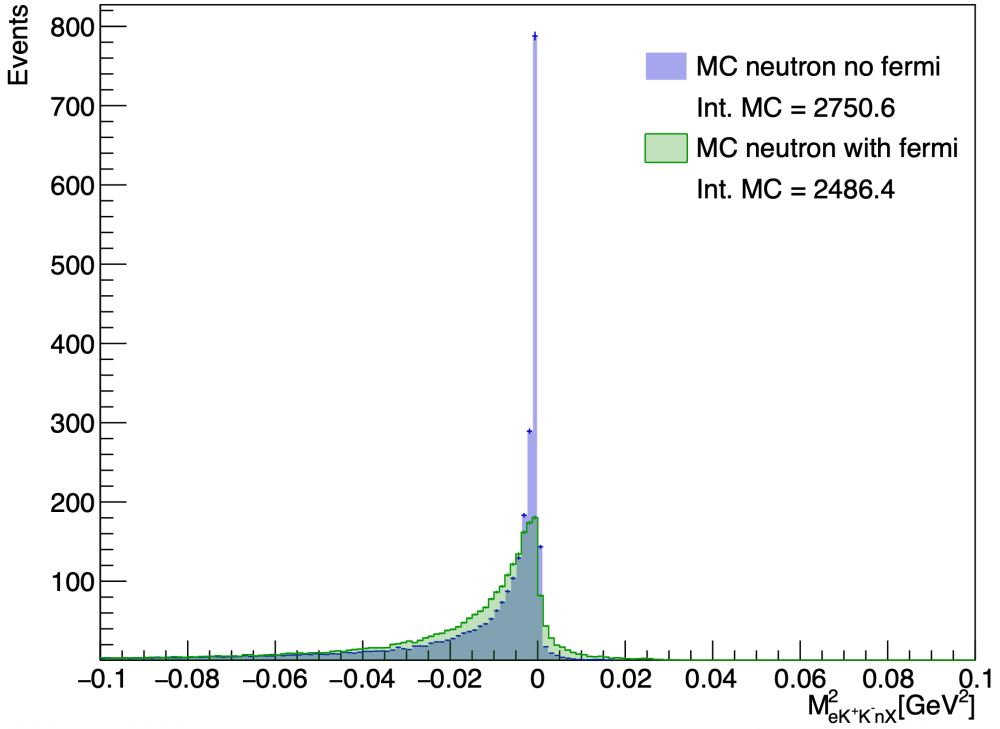
- **Simple model of SDME with only θ dependance from :** *Proposal to Jefferson Lab PAC39*

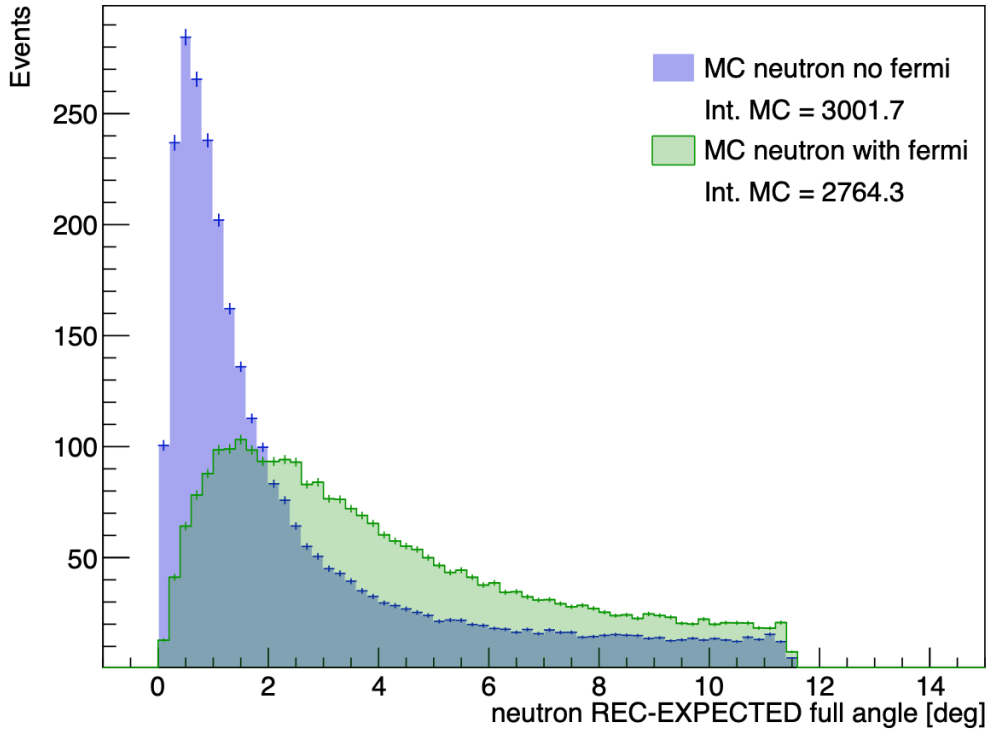
$$W(\cos\theta_H) = \frac{3}{4}\left[\left(1-r_{00}^{04}\right)+\left(3r_{00}^{04}-1\right)\cos^2\theta_H\right] \qquad R = \frac{r_{00}^{04}}{\epsilon(1-r_{00}^{04})}$$





Impact of Fermi motion :

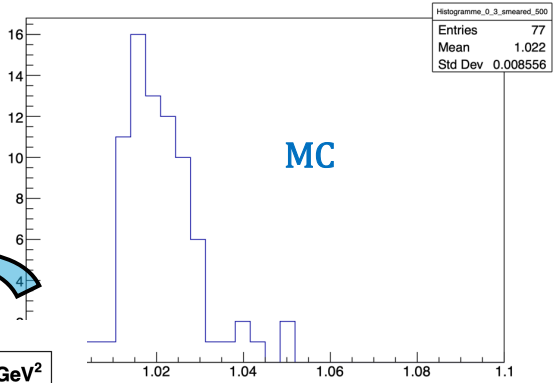


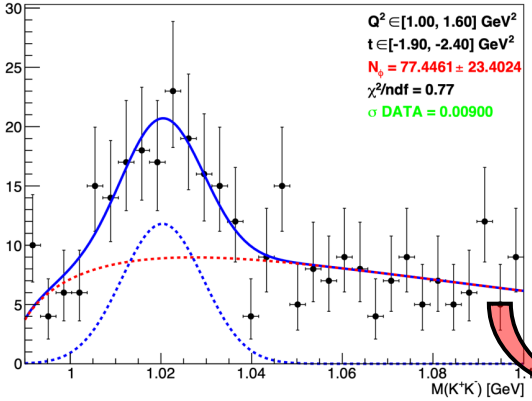


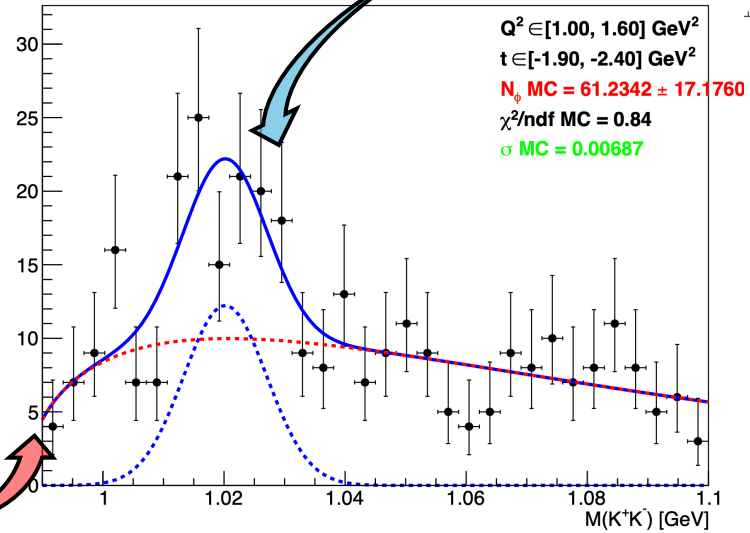
$$A = \frac{N_{rec}}{N_{gen}} * \frac{N_{fit}}{N_{random}}$$

Contribution the geometry and the efficiency.

Contribution from the resolution of the fit.

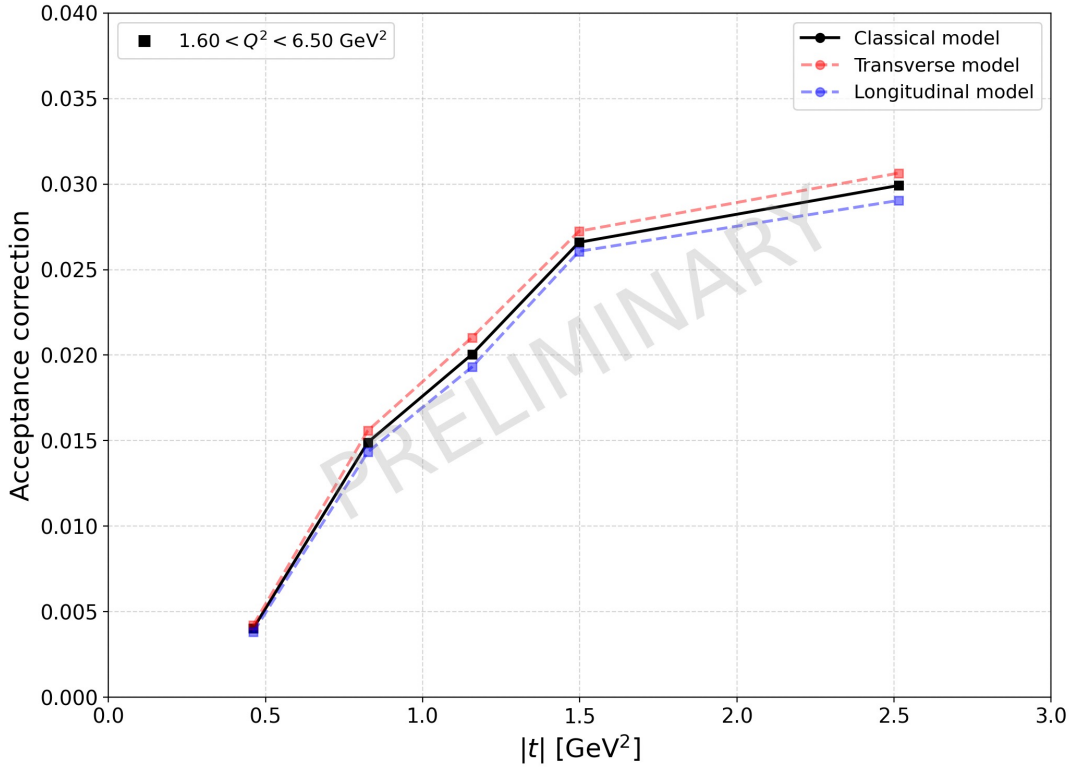


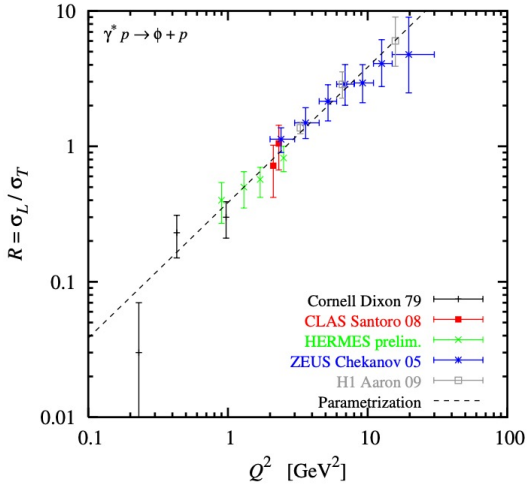


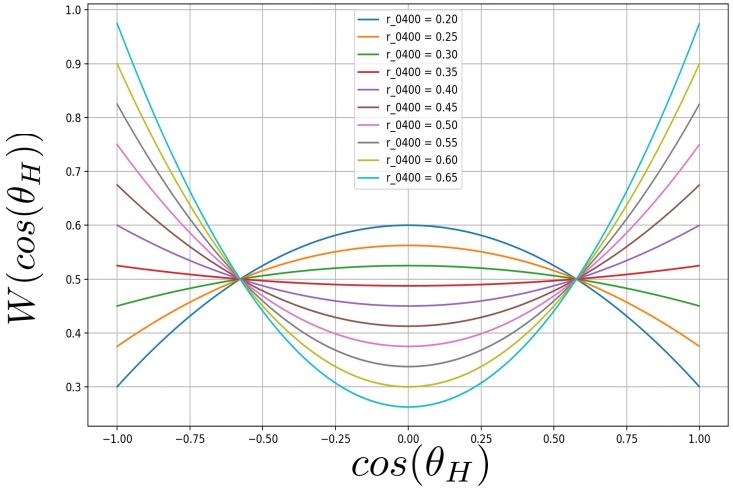


Impact of the SMDE :

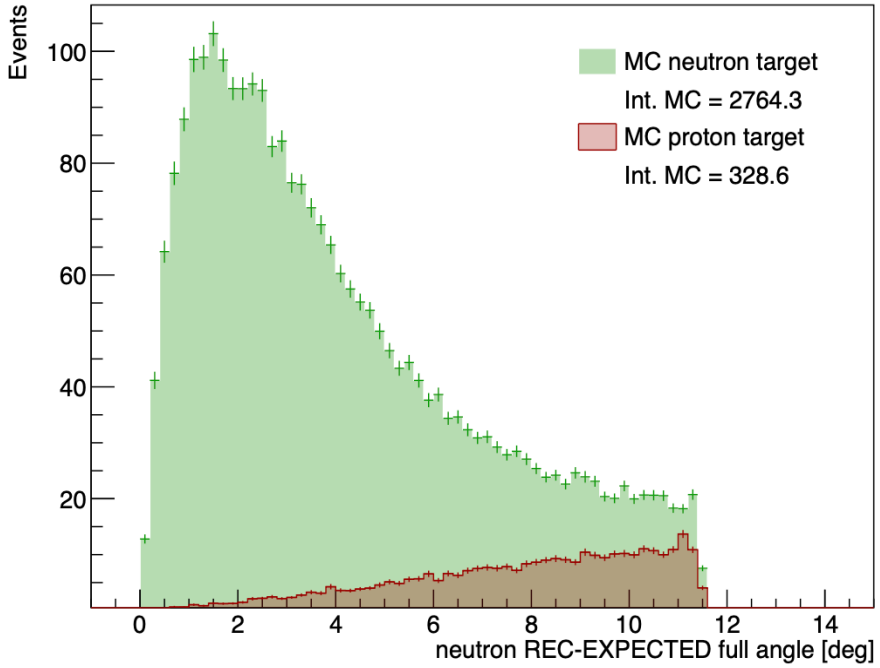
$$W(\cos\theta_H) = \frac{3}{4}\left[\left(1 - r_{00}^{04}\right) + \left(3r_{00}^{04} - 1\right)\cos^2\theta_H\right] \qquad R = \frac{r_{00}^{04}}{\epsilon(1 - r_{00}^{04})}. \qquad R(W, Q^2) = \frac{c_R Q^2}{m_\phi^2}$$

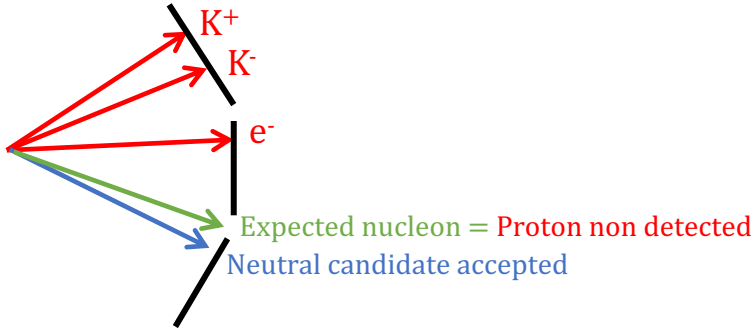


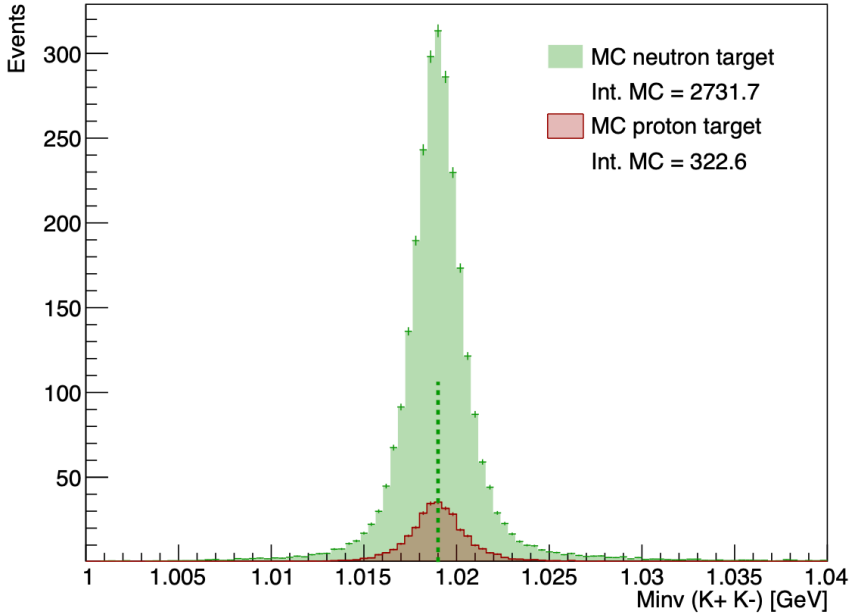




Estimation of the proton contamination in MC :







$$\frac{d\sigma}{dt \cdot dQ^2 \cdot dx_b} = \frac{N_\phi}{\epsilon_{corr} \cdot Acc \cdot \mathcal{L}_{\text{int}} \cdot Br \cdot \Delta t \cdot \Delta Q^2 \cdot \Delta x_b}$$

Efficiency corrections

$$\epsilon_{DATA} = \frac{N_{detected\ DATA}}{N_{expected\ DATA}}$$

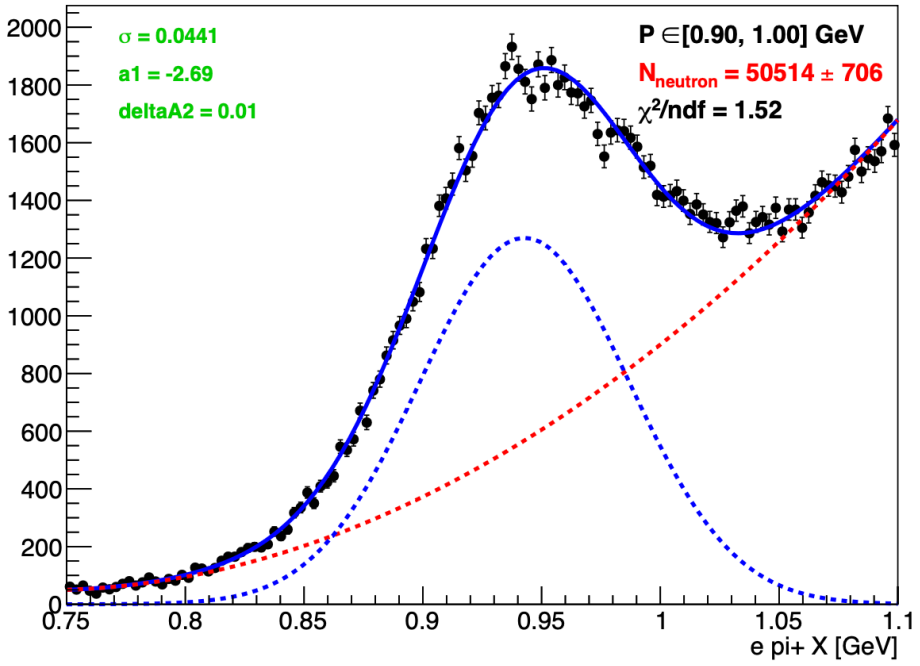
$$\epsilon_{MC} = \frac{N_{detected\ MC}}{N_{expected\ MC}}$$

The MC correction facor is : $R = \frac{\epsilon_{DATA}}{\epsilon_{MC}}$

Method :

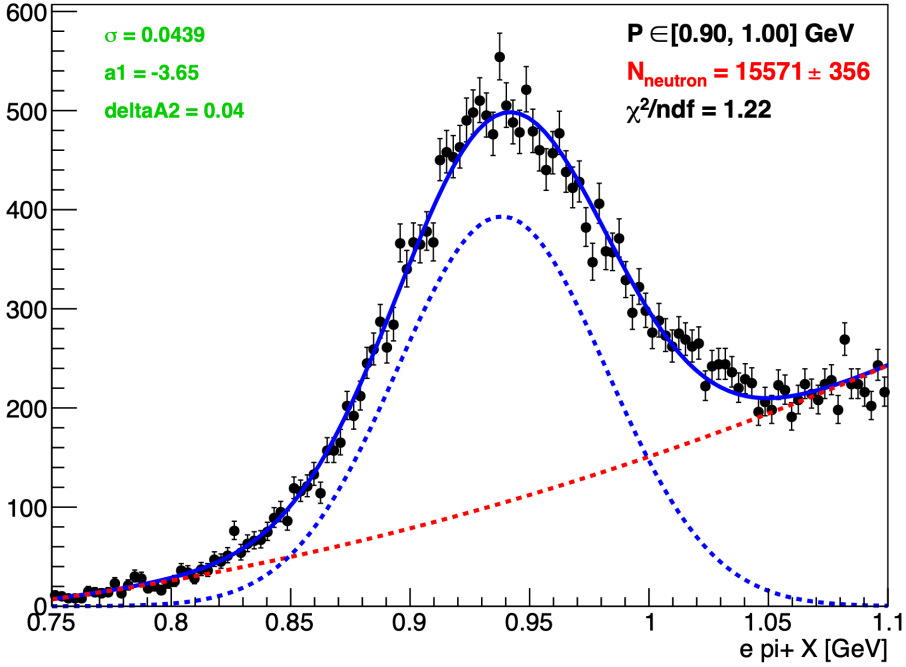
- Efficiency in DATA : use RGA Data with the channel ep → e π+ n
- Efficiency in MC : Generator adapted the phi electroproduction for ep → e π+ n with a cross section implemented from : *Basnet, S., Huber, G. et al. Exclusive π+ electroproduction off the proton from low to high −t. Physical Review C, 100(6). https://doi.org/10.1103/physrevc.100.065204*

Efficiency in DATA :



With only e^-, π^+ detected

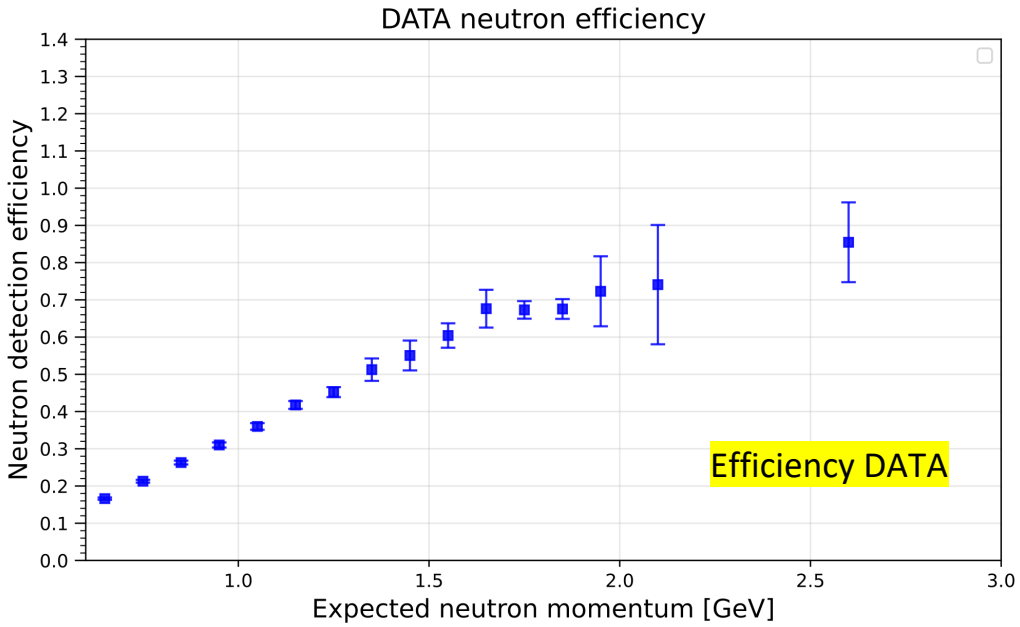
$\rightarrow$ $N_{expected}$

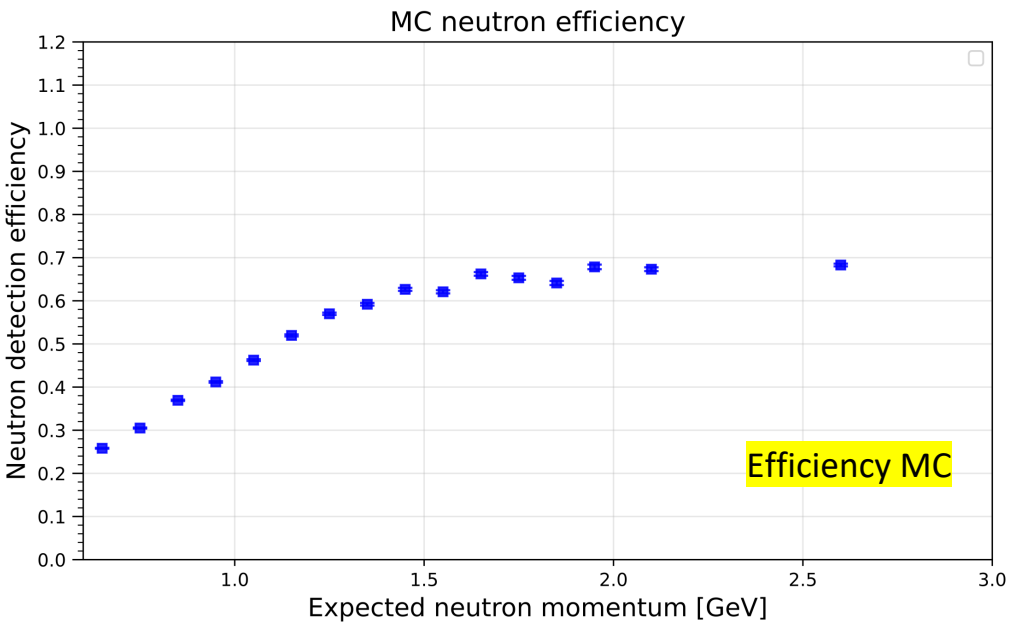


With e^-, π^+ and neutron detected

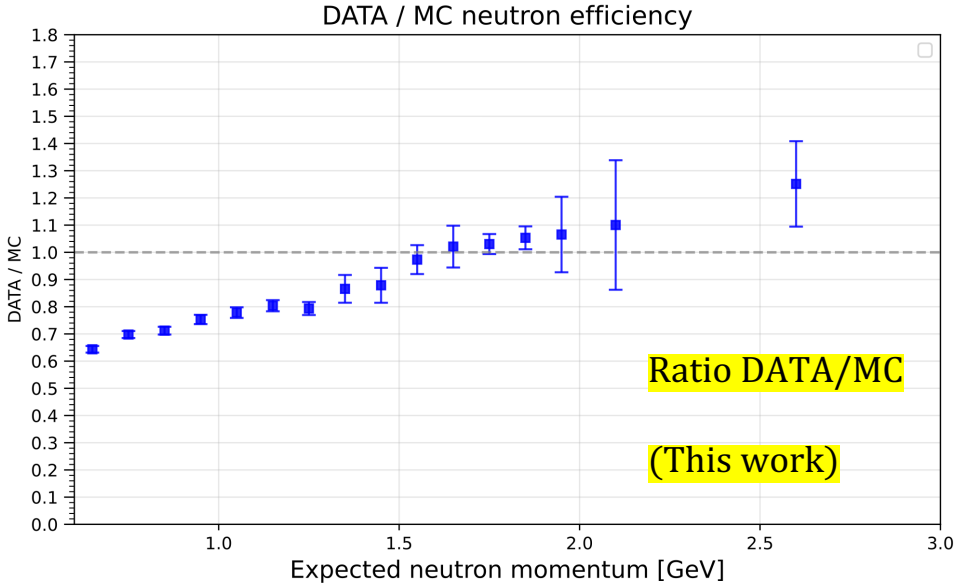
$\rightarrow$ $N_{detected}$

Neutron detection efficiency corrections

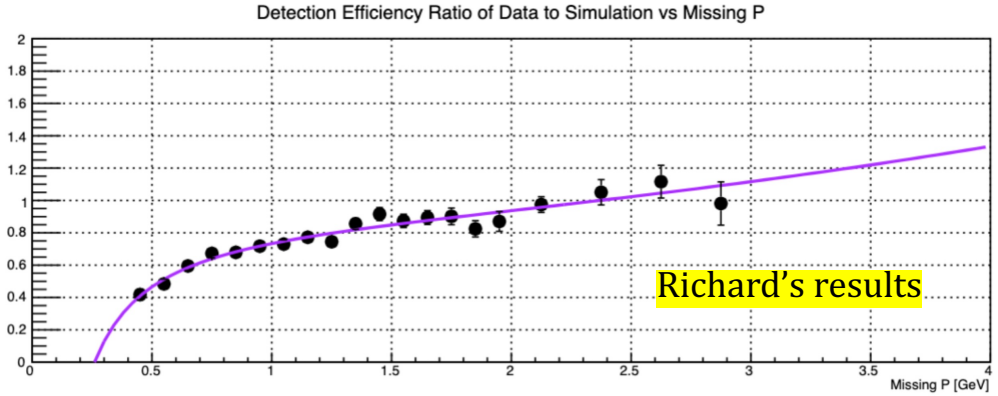




Neutron detection efficiency corrections



→ Then the acceptance is corrected by this ratio per bin of expected neutron momentum.



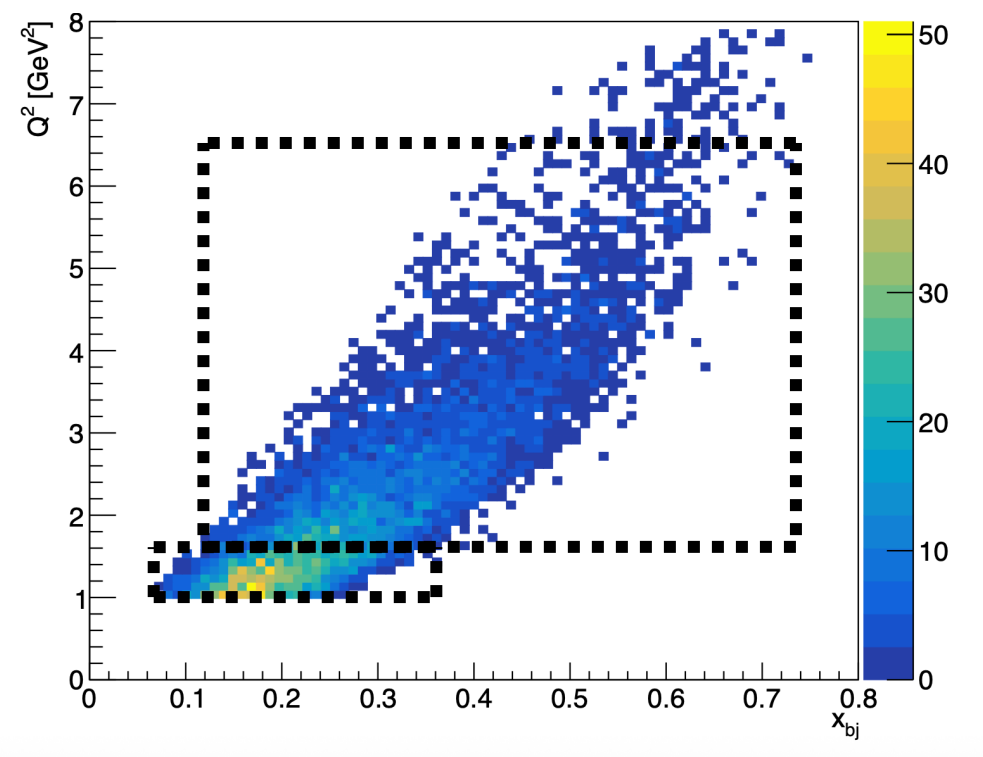
Source of differences :

- More stats from Richard.
- I have to add π+ momentum correction.
- We don't exactly select the neutron in exactly same way.

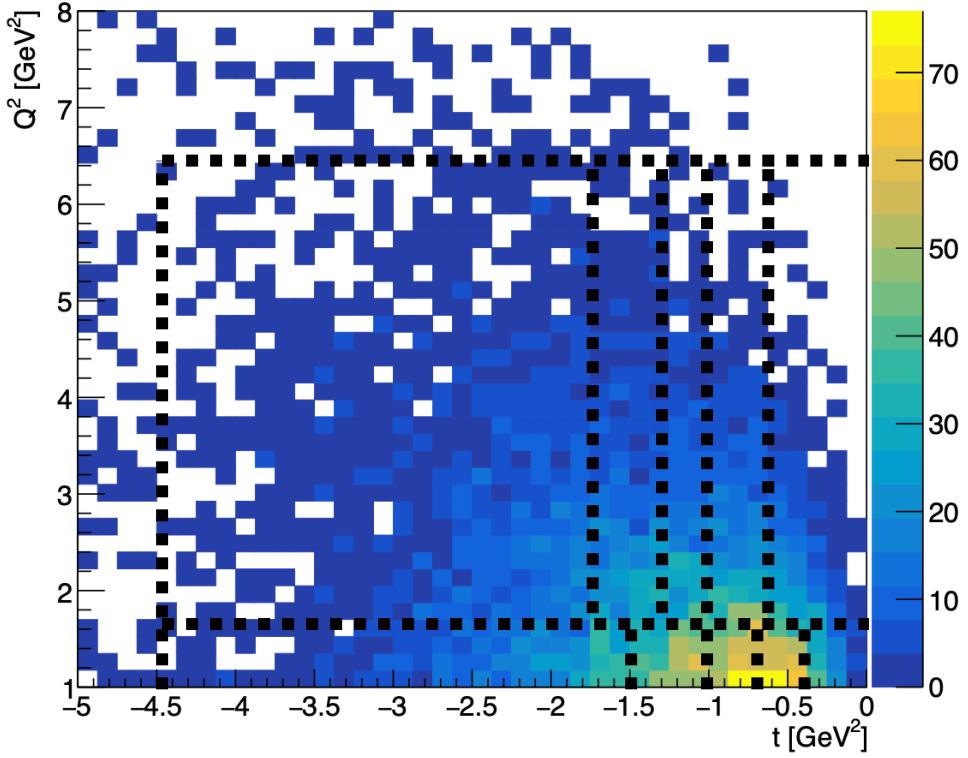
$$\frac{d\sigma}{dt \cdot dQ^2 \cdot dx_b} = \frac{N_\phi}{\epsilon_{corr} \cdot Acc \cdot \mathcal{L}_{\text{int}} \cdot Br \cdot \Delta t \cdot \Delta Q^2 \cdot \Delta x_b}$$

Bin volume correction

Data binning



- x_b vs Q^2 binning



- t vs Q^2 binning

Preliminary results of the reduced differential cross section

The differential cross section of this reaction $e\,n \rightarrow e'\,n'\phi$ is :

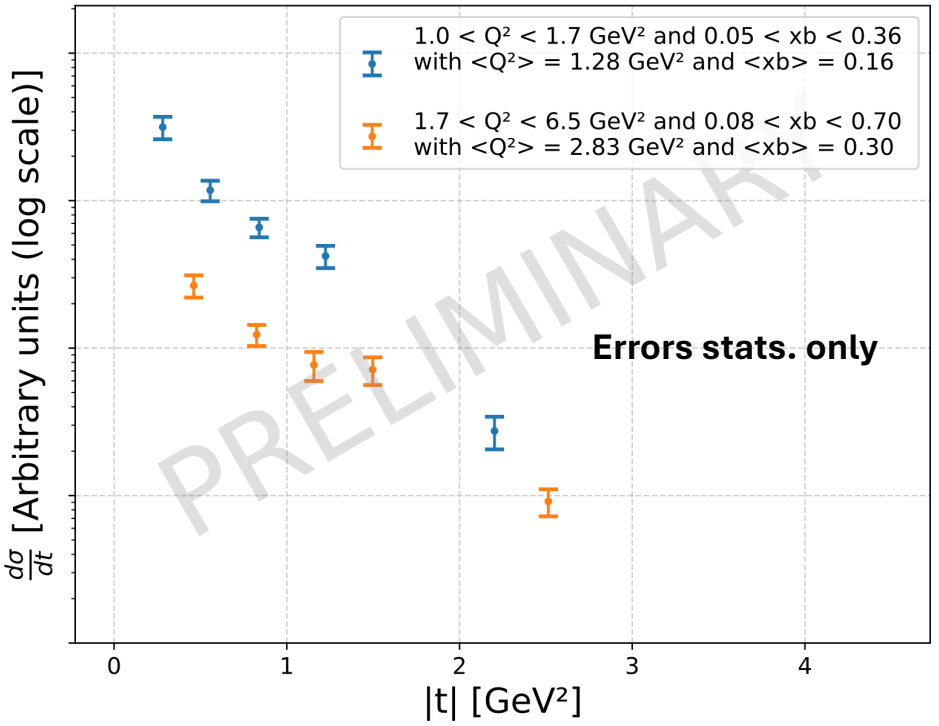
$$\frac{d^3\sigma}{dQ^2 dx_B dt} = \Gamma(Q^2, x_B, E)\left[\frac{d\sigma_T}{dt}(Q^2, x_B, t) + \epsilon\frac{d\sigma_L}{dt}(Q^2, x_B, t)\right]$$

with $\Gamma \equiv \frac{\alpha}{8\pi m_N^2 E^2}\frac{Q^2(1-x_B)}{x_B^3}\frac{1}{1-\epsilon}$ the virtual photon flux factor.

The reduced differential cross section of this reaction $\gamma^* n \rightarrow n'\phi$ is given by :

$$\frac{d\sigma}{dt}(Q^2, x_B) = \frac{1}{\Gamma(Q^2, x_B, E)} \cdot \frac{d^3\sigma}{dQ^2 dx_B dt}$$

$$\frac{d\sigma}{dt}(Q^2, x_B) = \frac{\Delta N}{\Gamma \cdot \Delta x_B \cdot \Delta Q^2 \cdot \Delta t \cdot L \cdot Acc \cdot \epsilon_{corr} \cdot Br}$$

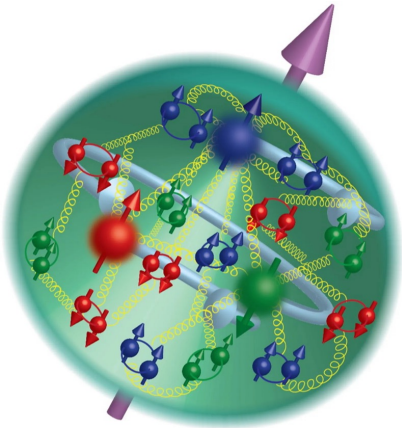


Outlook :

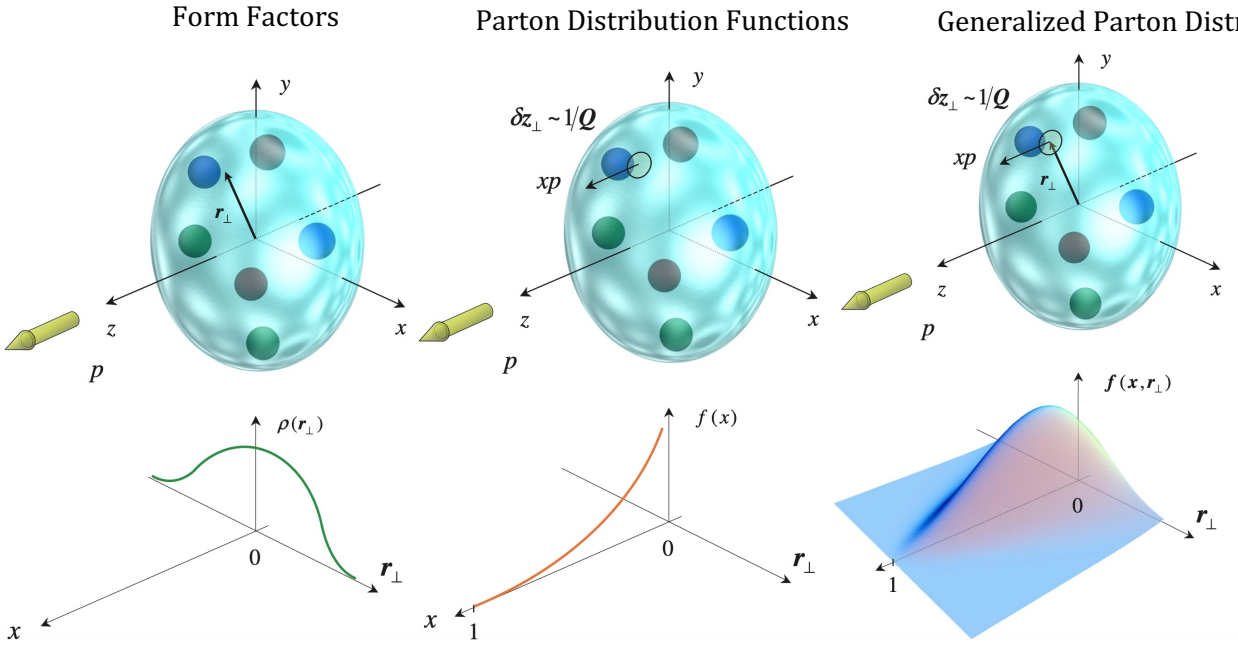
- Add momentum corrections for neutron, kaons.
- Kaons detection efficiency correction.
- Look for neutrons in the CND.
- Study the background with mixing events.
- Estimation of radiative corrections.

- Stay tuned for the final results, the analysis is progressing toward the first measurement of exclusive ϕ electroproduction on the neutron with CLAS12.

Thanks!



Backup slides



The interpretation of GPDs as a tomography of the nucleon

Figure from A.V. Belitsky and A. V. Radyushkin. Unraveling hadron structure with GPDs.

Density of gluons carrying momentum fraction x :

$$H_g(x, \xi = 0, t = 0) \quad = \quad xg(x)$$

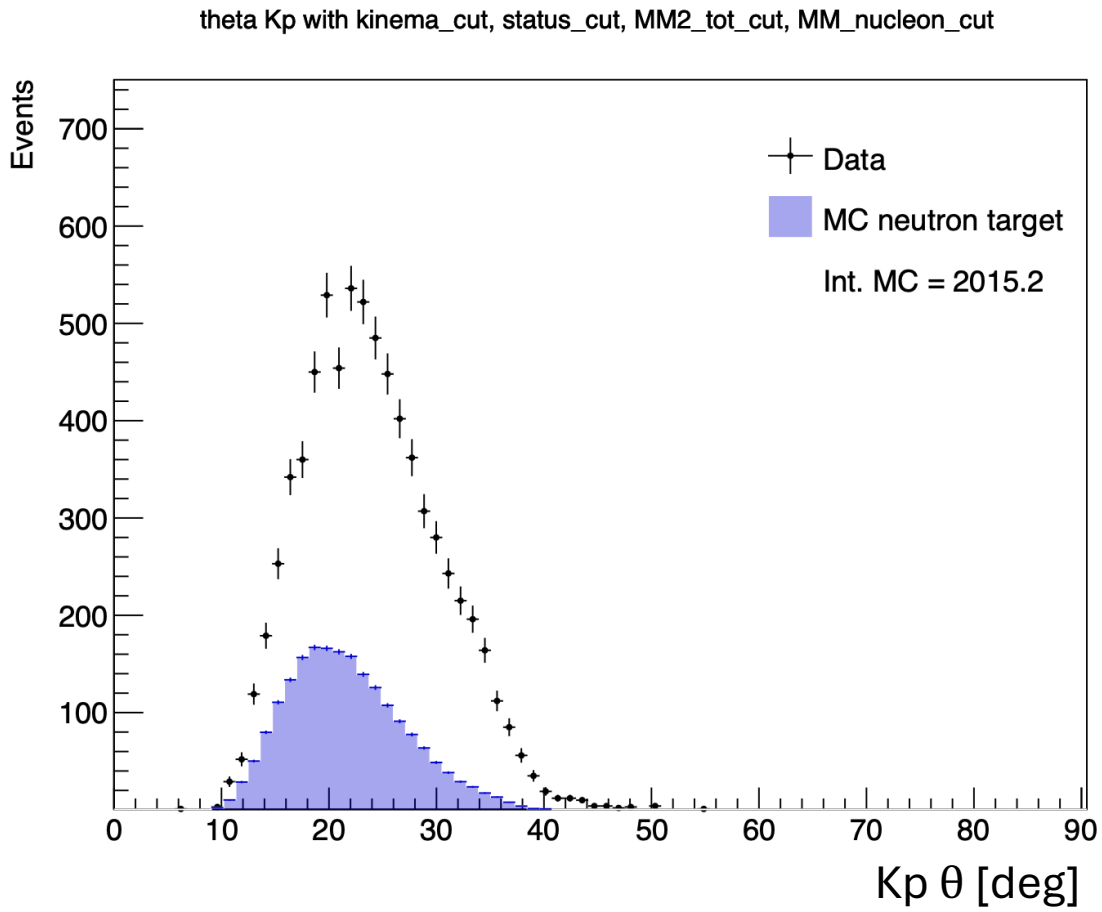
Spatial profile of the distribution of gluons at given x :

$$xg(x, b) \equiv \int \frac{d^2\Delta_T}{(2\pi)^2} e^{i\boldsymbol{\Delta}_T \boldsymbol{b}} H_g(x, \xi = 0, t = -\boldsymbol{\Delta}_T^2)$$

Exclusivity cuts and kinematics cuts

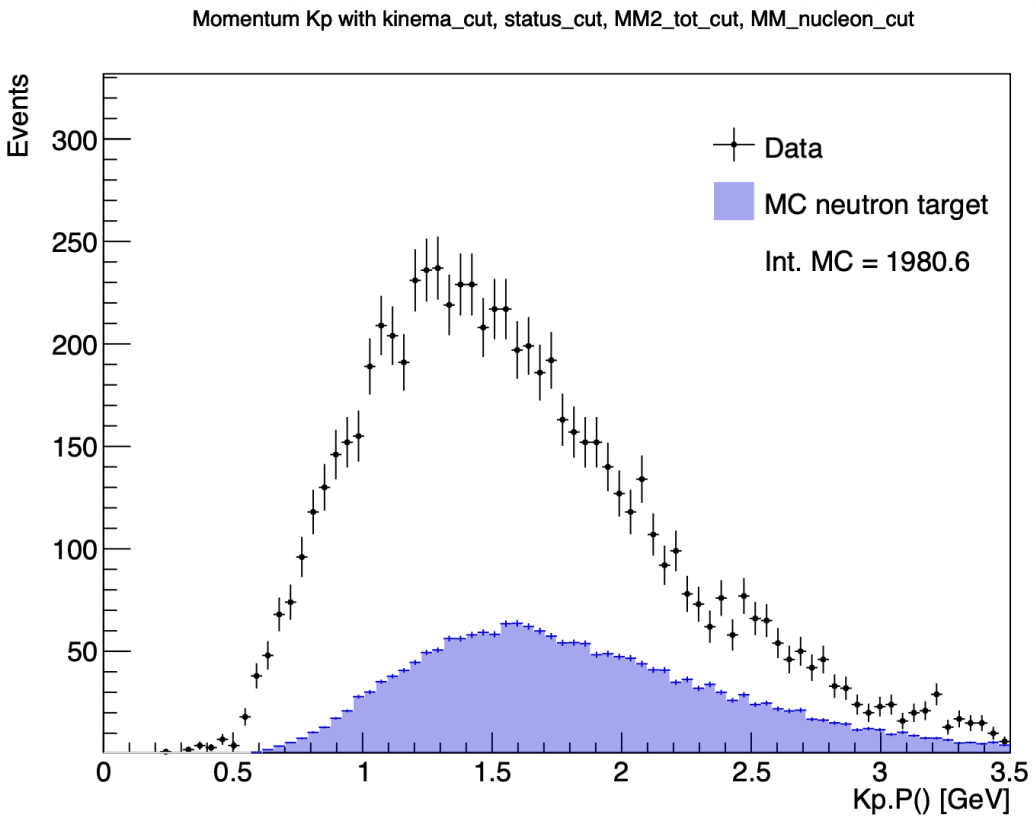
Two justifications to cut K+ K- in CD :

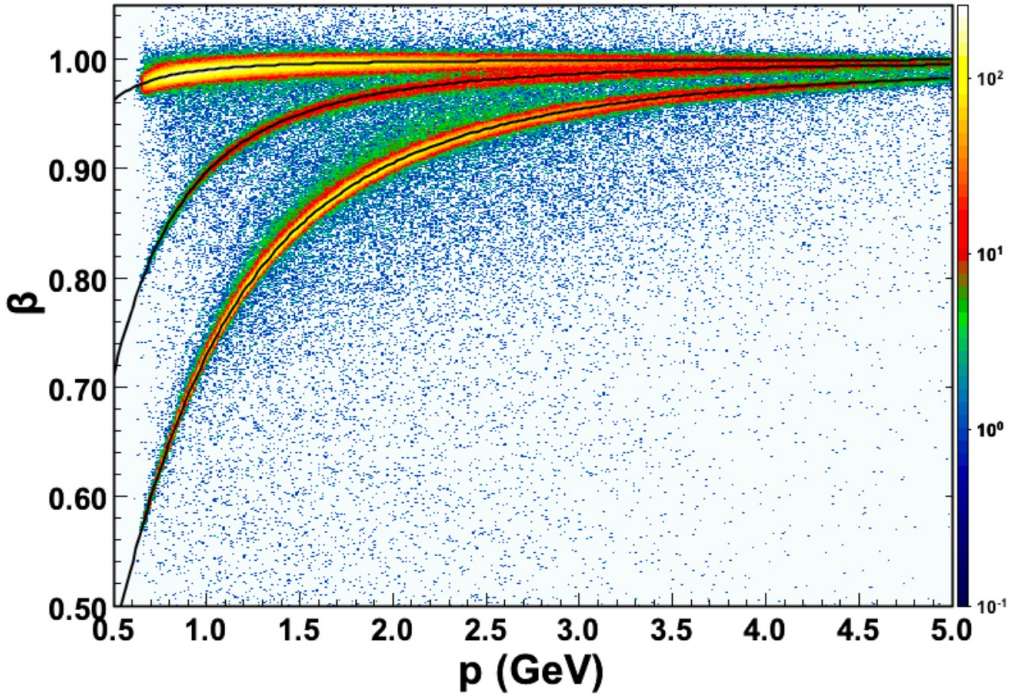
- Reconstruction of kaons in the CD is less good than in the FD
- The MC predict few events in the CD



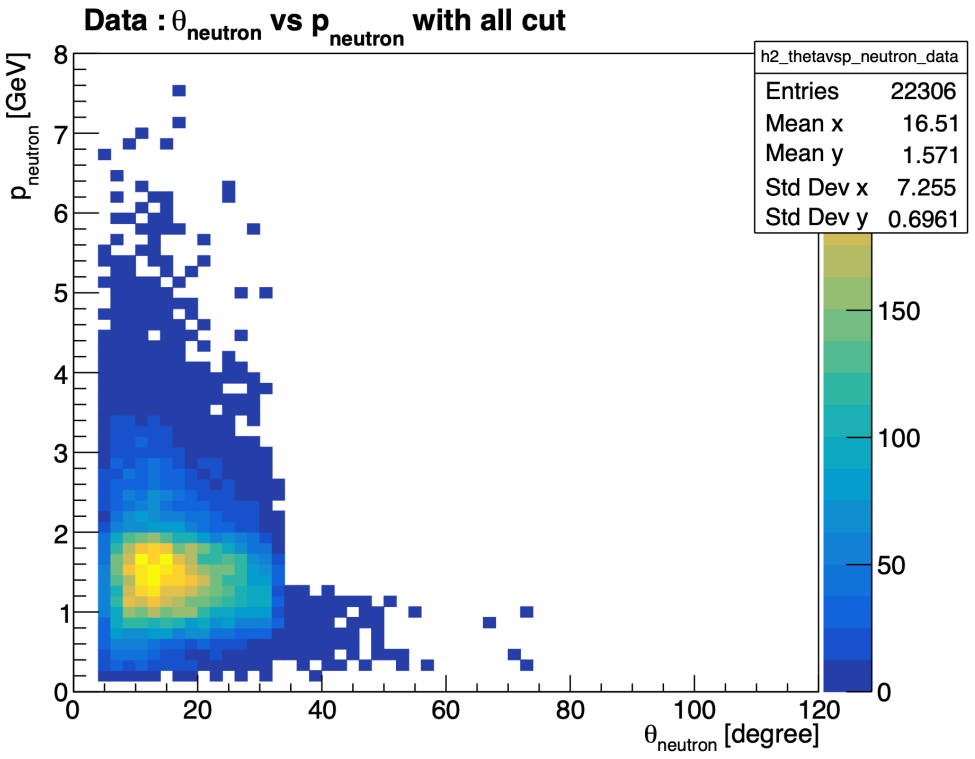
Exclusivity cuts and kinematics cuts

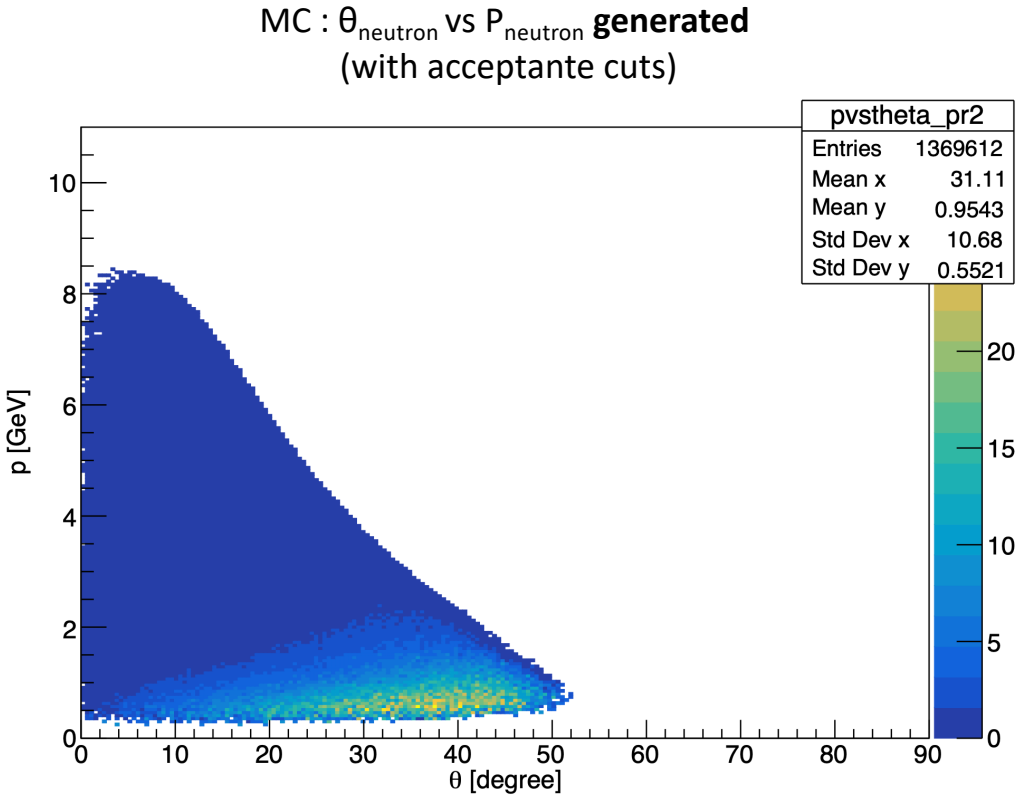
Miss identification K pions



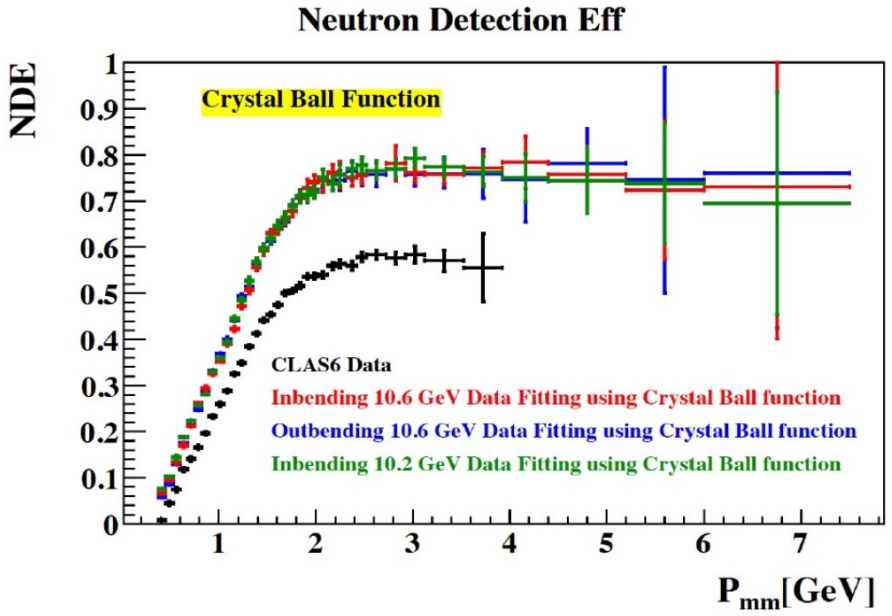


Exclusivity cuts and kinematics cuts

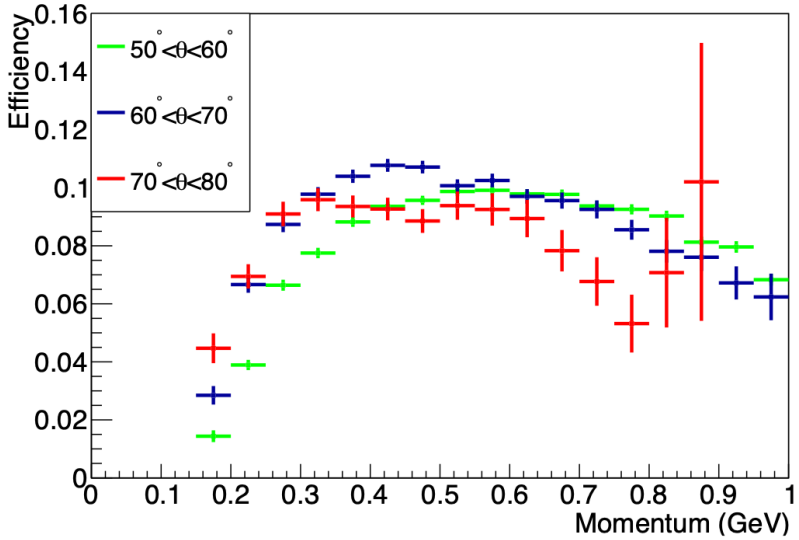




Exclusivity cuts and kinematics cuts



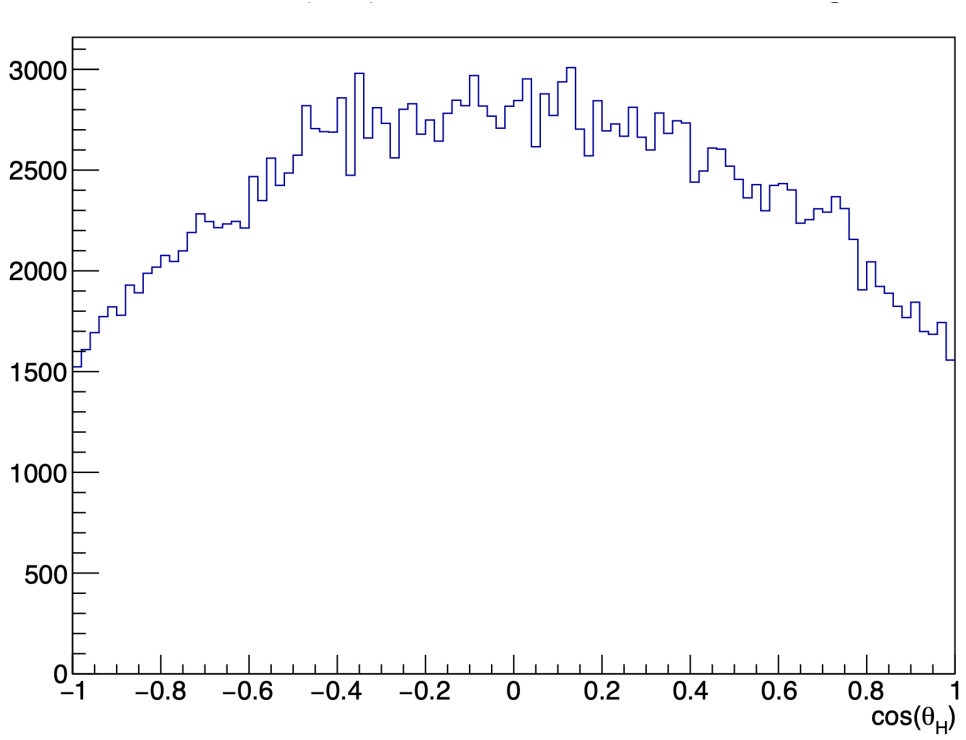
Neutron detection efficiency in the FD



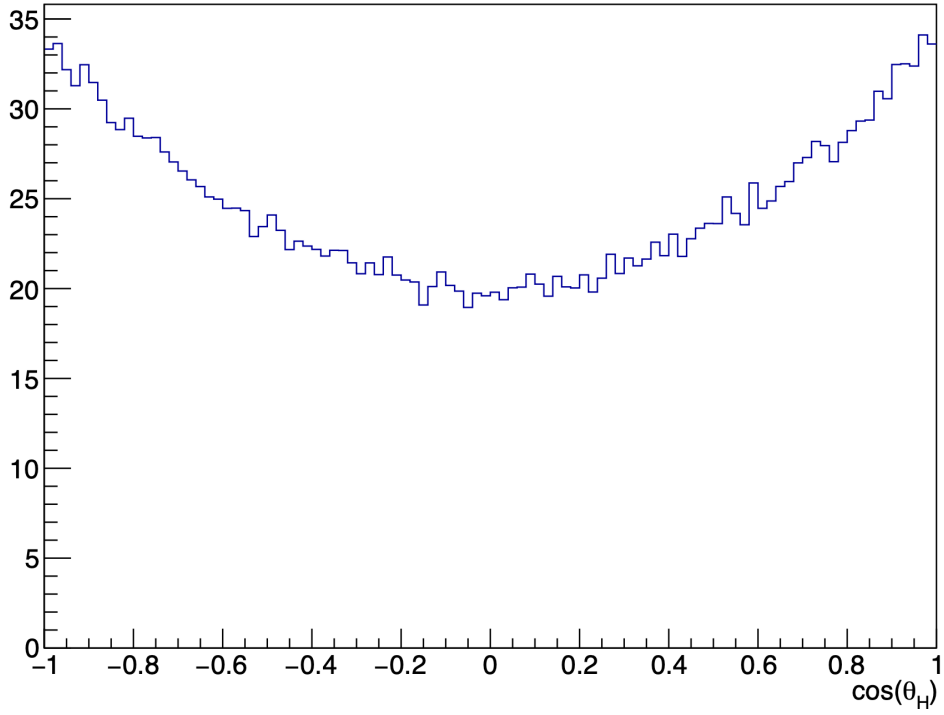
P. Chatagnon's plot

Neutron detection efficiency in the CND

Generator for MC simulation (SDME generated plots)

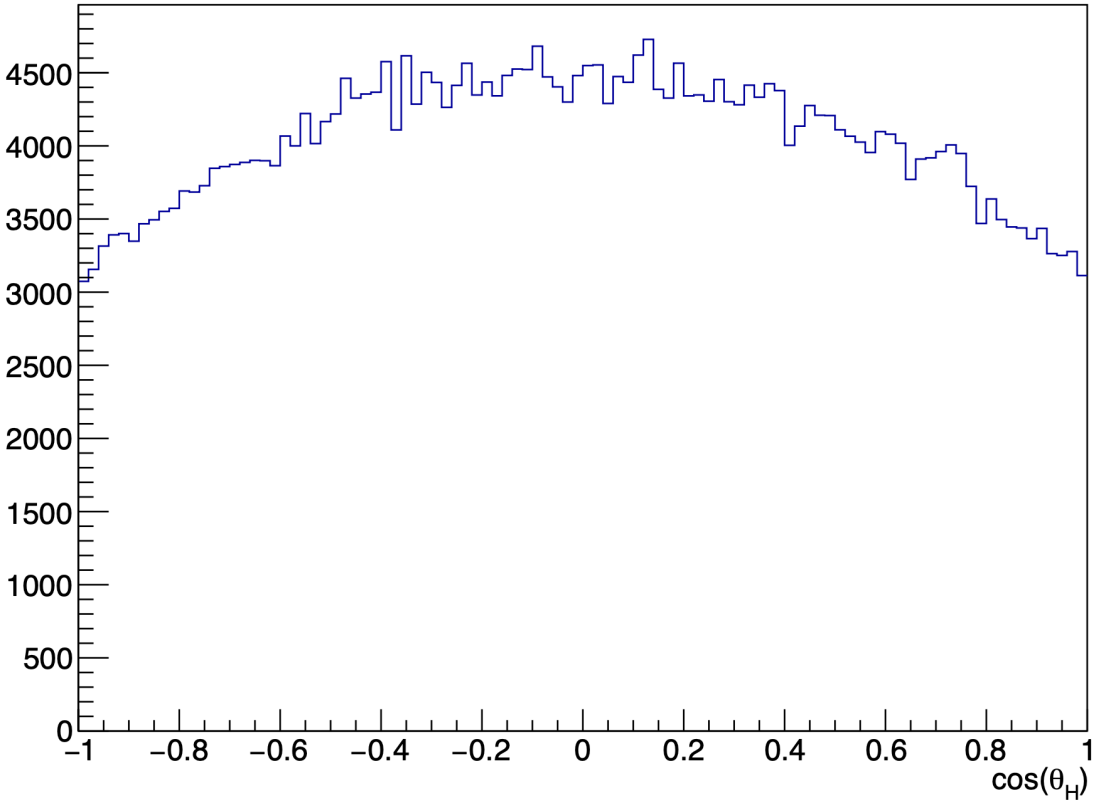


With Q^2 in [1.0 – 1.5] GeV^2



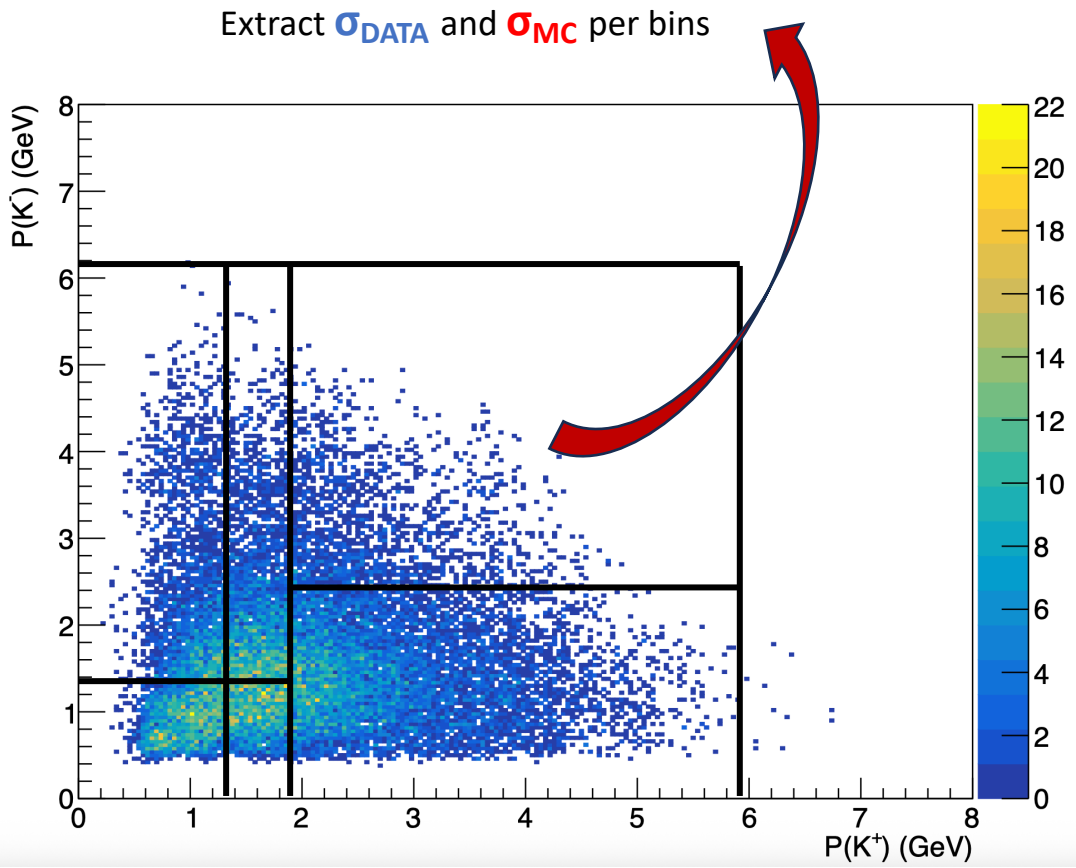
With Q^2 in [5.0 – 6.5] GeV^2

Generator for MC simulation (SDME generated plots)



With no cut on Q^2

Smearing of the kaons



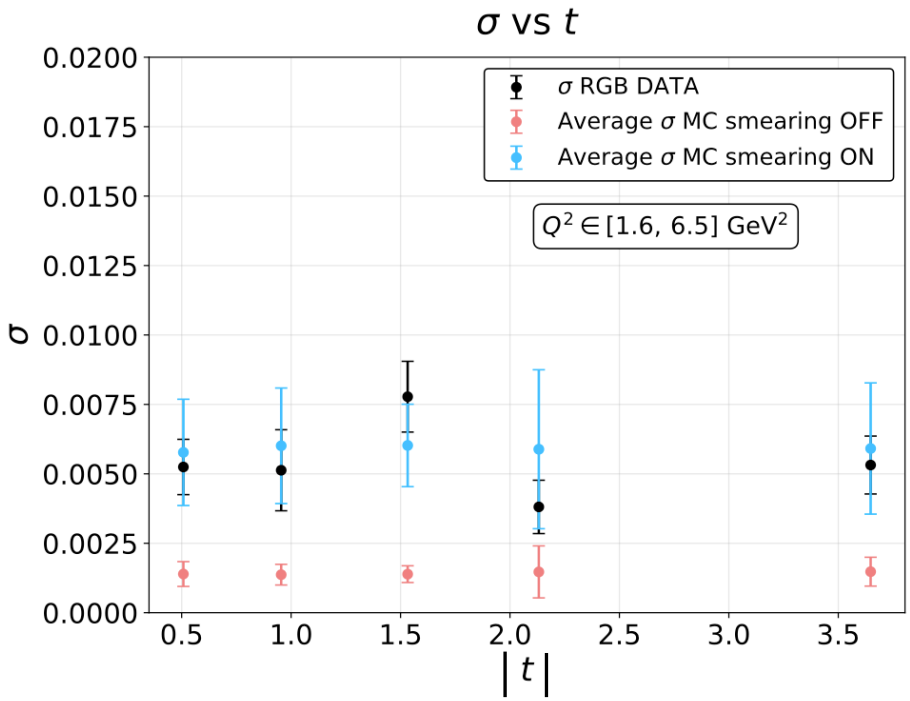
- To extract σ_{DATA} the invariant mass of data in the correponding bin is just fitted and σ_{DATA} correspond to the width of the Gaussian.
- To extract σ_{MC} several pseudos-experiments (like explained before) are permormed. Thus, σ_{MC} correpond to the average of Gaussian width.

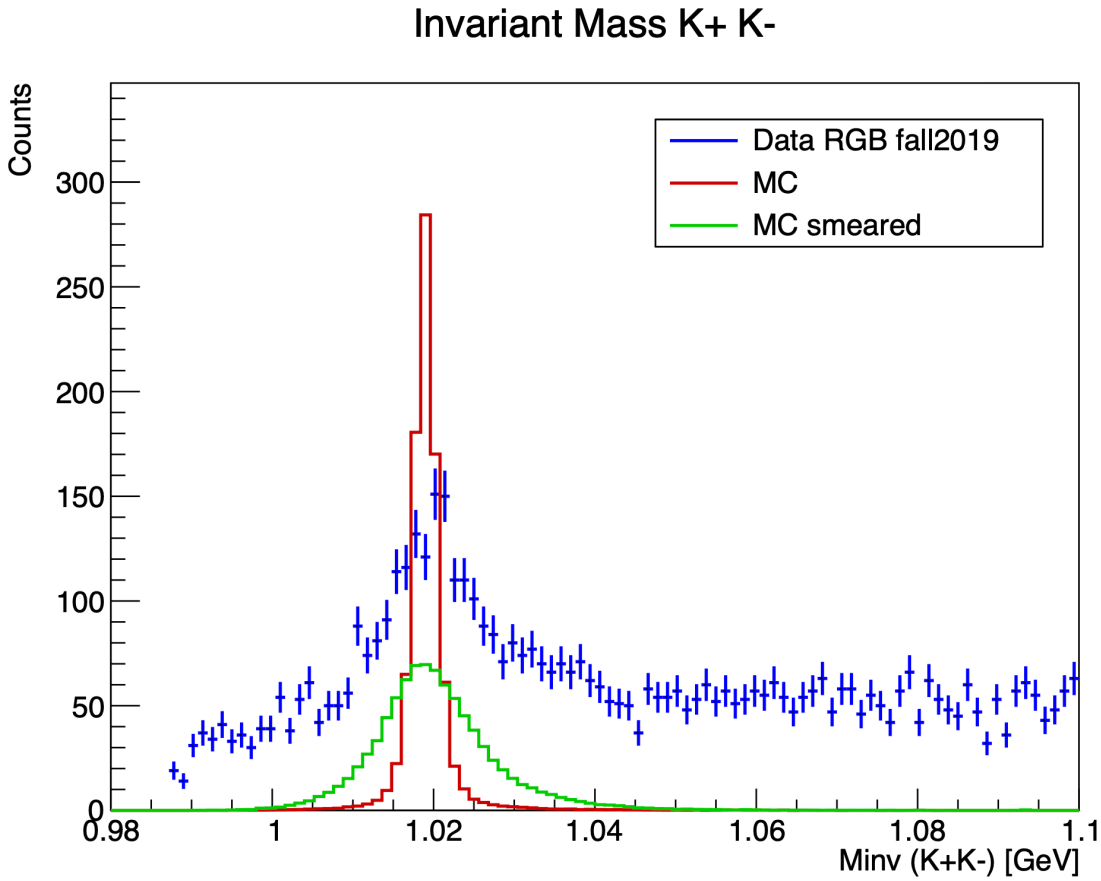
$$\chi^2 = \sum_{bins} \frac{\sigma^2_{data} - \sigma^2_{MC}}{err^2_{\sigma_{data}}}$$

→ Minimise X^2 with Minuit2 or simply with a grid lead to :

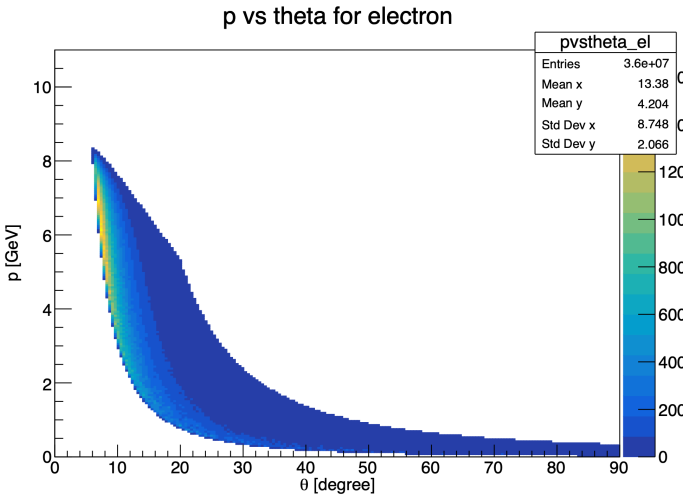
- $\delta_{K^+} = 0.077$
- $\delta_{K^-} = 0.057$

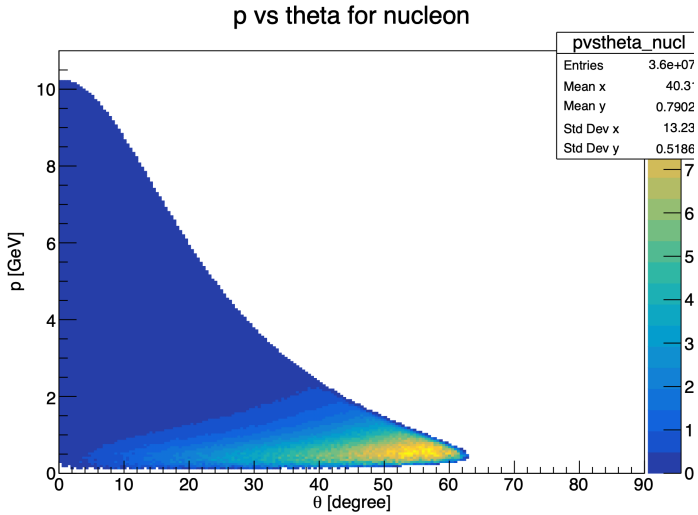
Smearing of the kaons

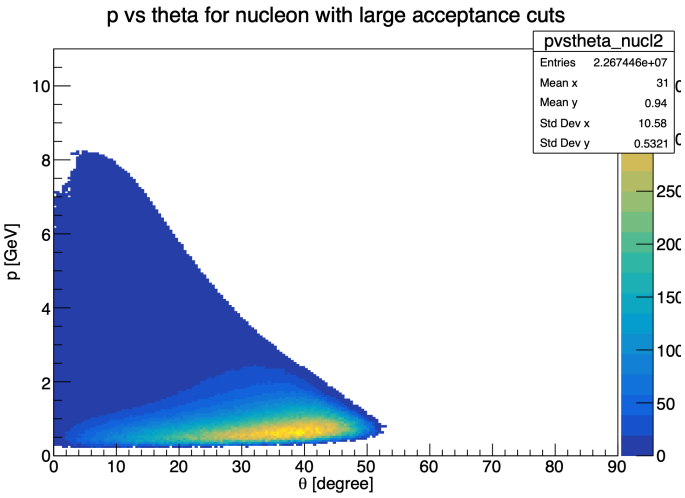




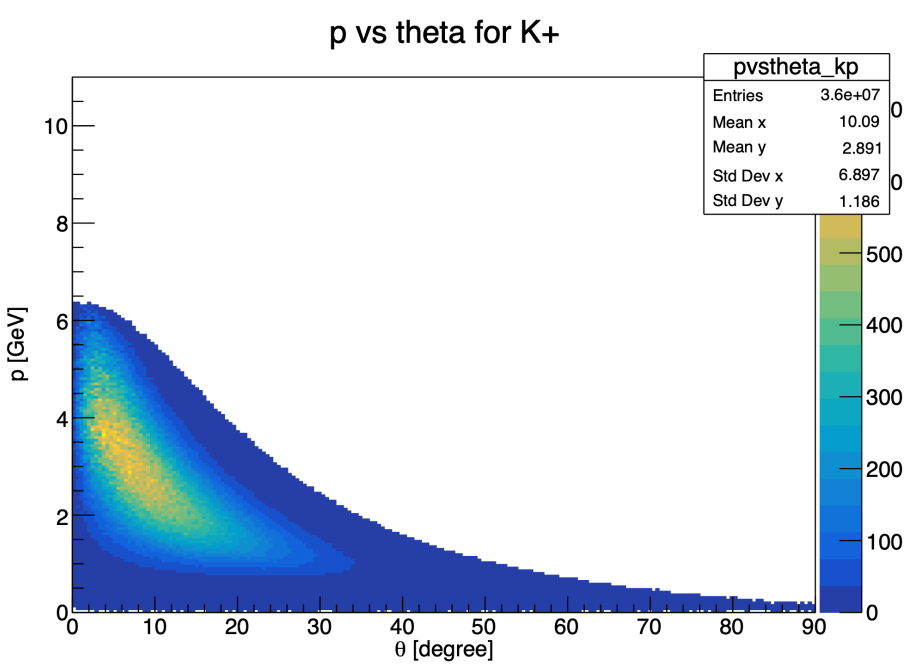
ϕ generator additionals plots 1

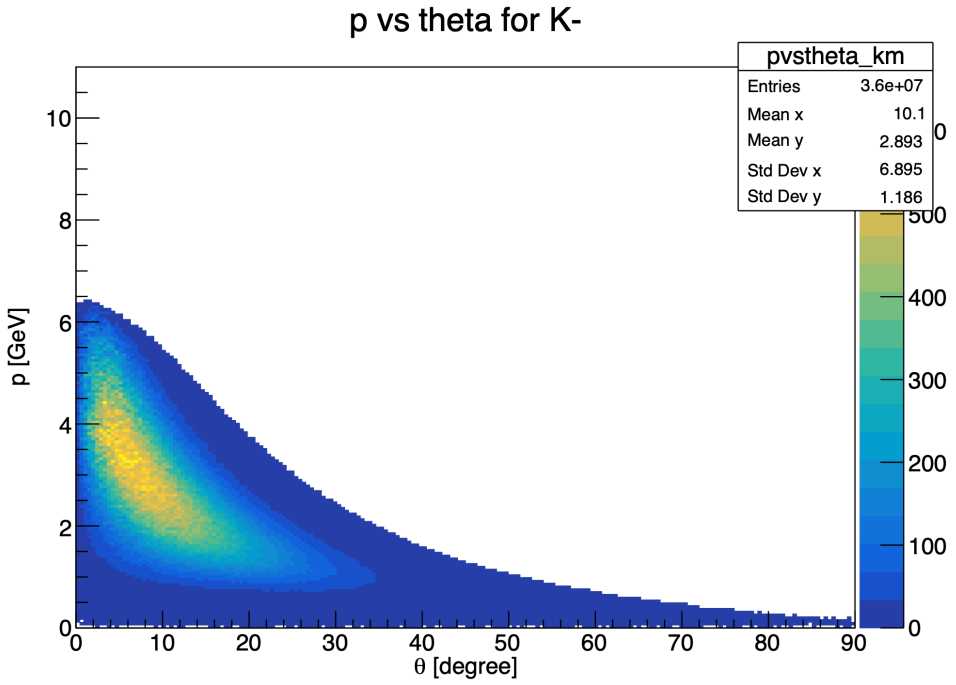




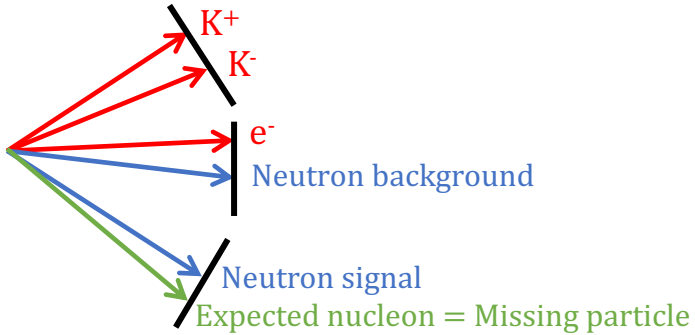


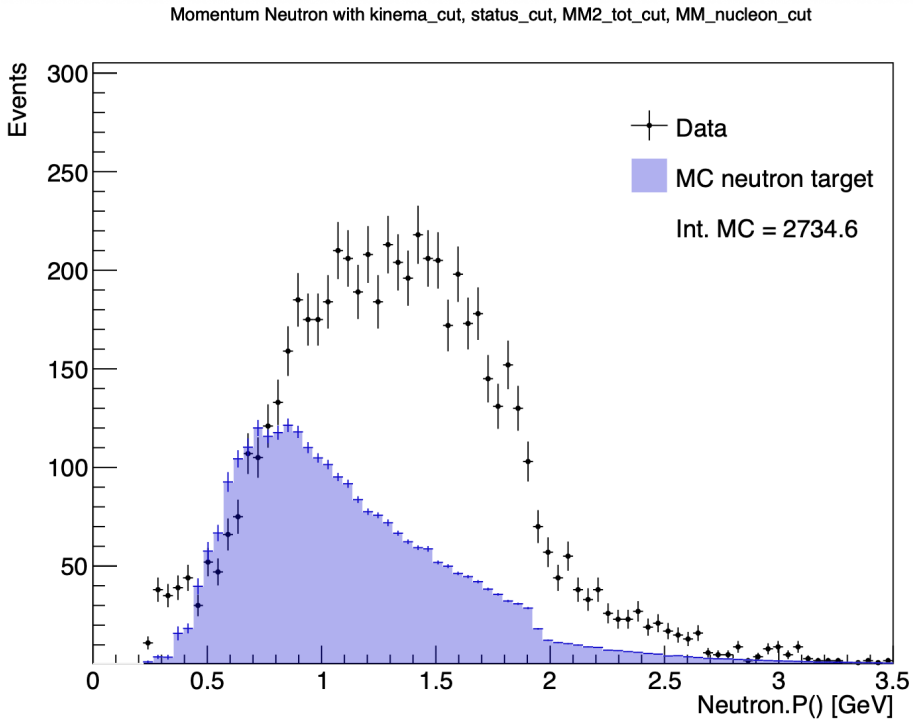
ϕ generator additionals plots 2





Update on the events selection :

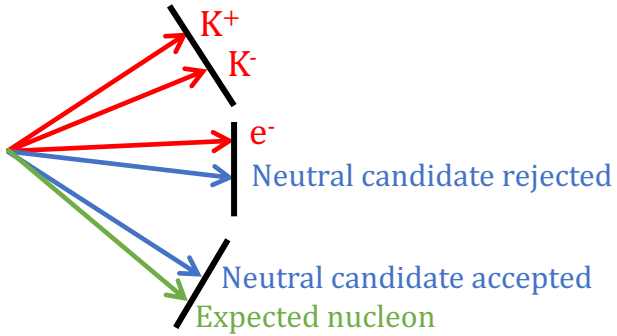




Previous selection

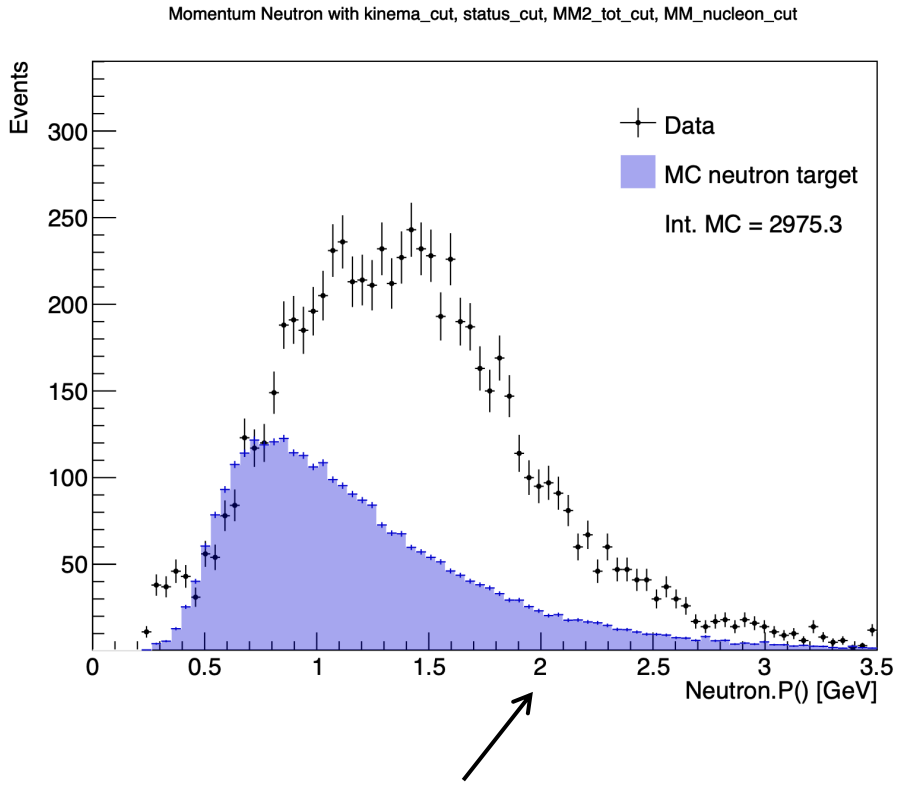
- Select the best neutron wich minimize the angle between the expected nucleon and the neutron. Also, the number of proton detected have to be equal to 0 to reduce proton contamination.
- Use the neutron PID.
- Problem if Beta > 0.9 neutron wich depose energy in the PCAL are identified as photon. This correpond to P ~ 2 GeV.

Update on the events selection :



New method selection

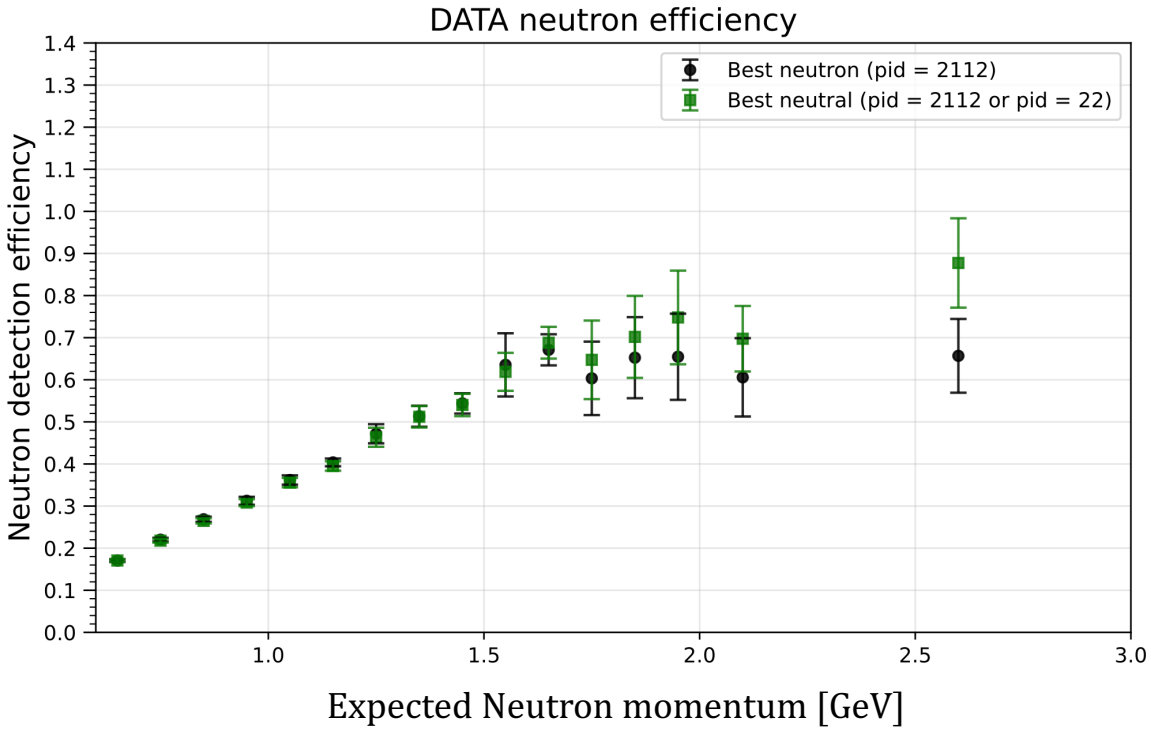
- Select every neutral candidate in the cone angle (10°) of the expected nucleon. Choose the best candidate with Δp.
- Neutral candidate PID : 2112 (neutron) and 22 (photon).
- Possible radiative photon contamination (see following slides).



now, it's continious at 2 GeV

Update on the neutron detection efficiency correction

Efficiency in DATA :

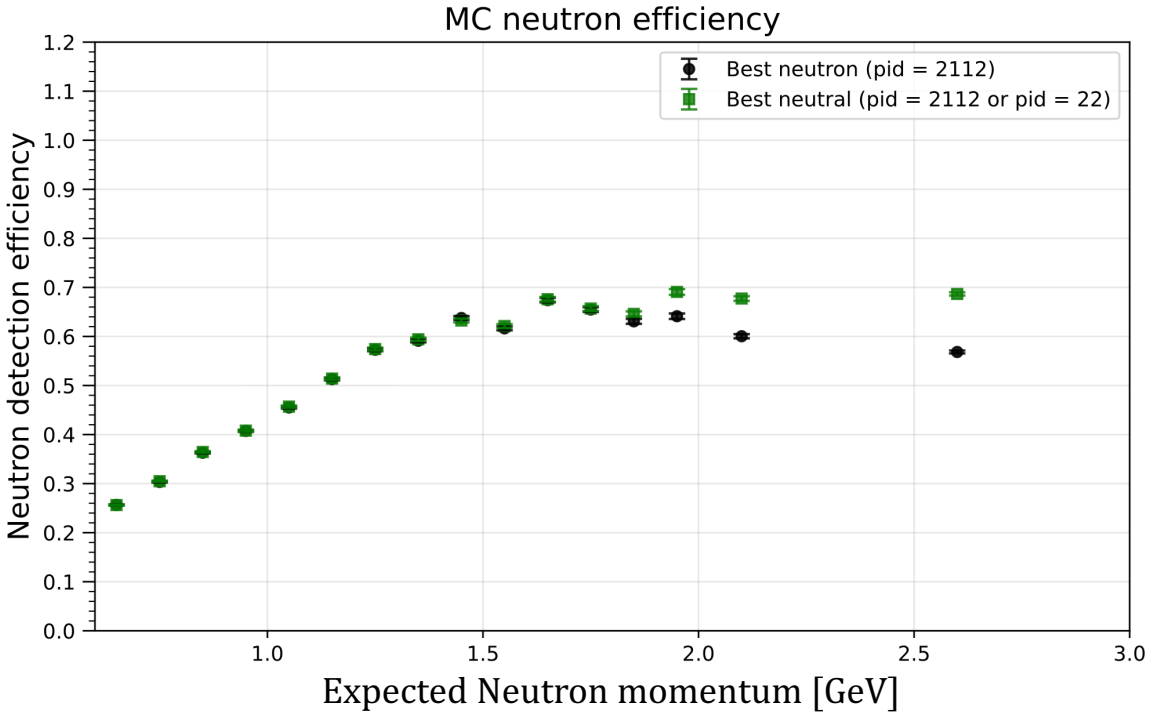


Two methods were compared to detect the neutron :

- **Best Neutron** among **PID = 2112**
- Best Neutral among PID = 2112 and 22 (as presented in the first slides)

Update on the neutron detection efficiency correction

Efficiency in MC :



Two methods were compared to detect the neutron :

- **Best Neutron** among **PID = 2112**
- Best Neutral among PID = 2112 and 22 (as presented in the first slides)