

RGA meeting

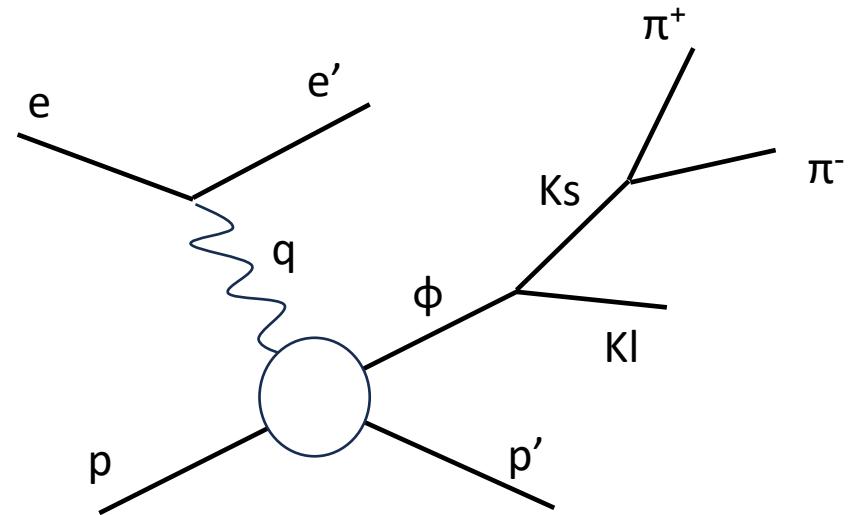
ϕ electroproduction analysis : $K_s K_L$ channel

20 Jan 2026

M. Ronayette, P. Chatagnon

Analysis objective :

- Measurement of the cross section and differential cross section of the electroproduction of ϕ in the $K_s K_L$ channel
- Datas : nSidis RG-A inbending and outbending fall 2018 + spring 2019



General informations

Data :

nSidis Rg-A datas : fall2018 inbending

Cuts :

- Selection of events with one e^- , p , π^+ and π^- in the final state. $\pi^+ \pi^-$ in FD.
- Cut on invariant mass of $\pi^+ \pi^-$ with $0.4 < M_{inv}(\pi^+ \pi^-) < 0.6 \text{ GeV}$.
- Cut on Missing Mass in the reaction $e p \rightarrow e' p' K_s X$ with $0.4 < M_{missMass} < 0.6 \text{ GeV}$.

Correction on $\pi^+ \pi^-$ vertex :

Vertex of $\pi^+ \pi^-$ are recalculated with the code of Veronique Ziegler

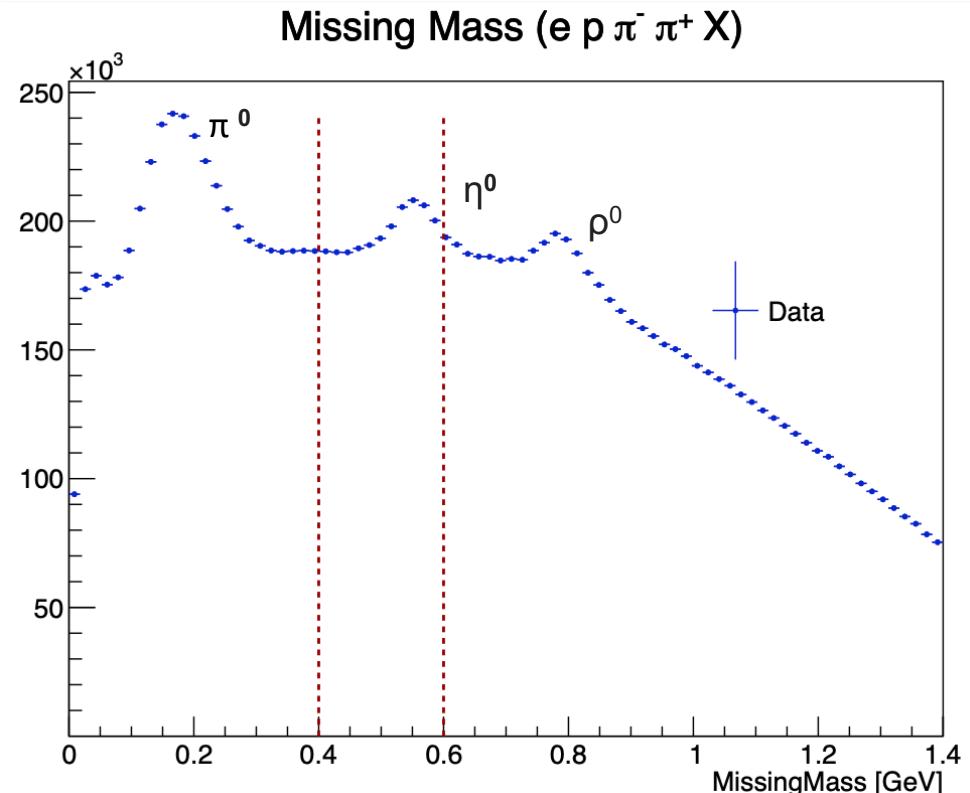
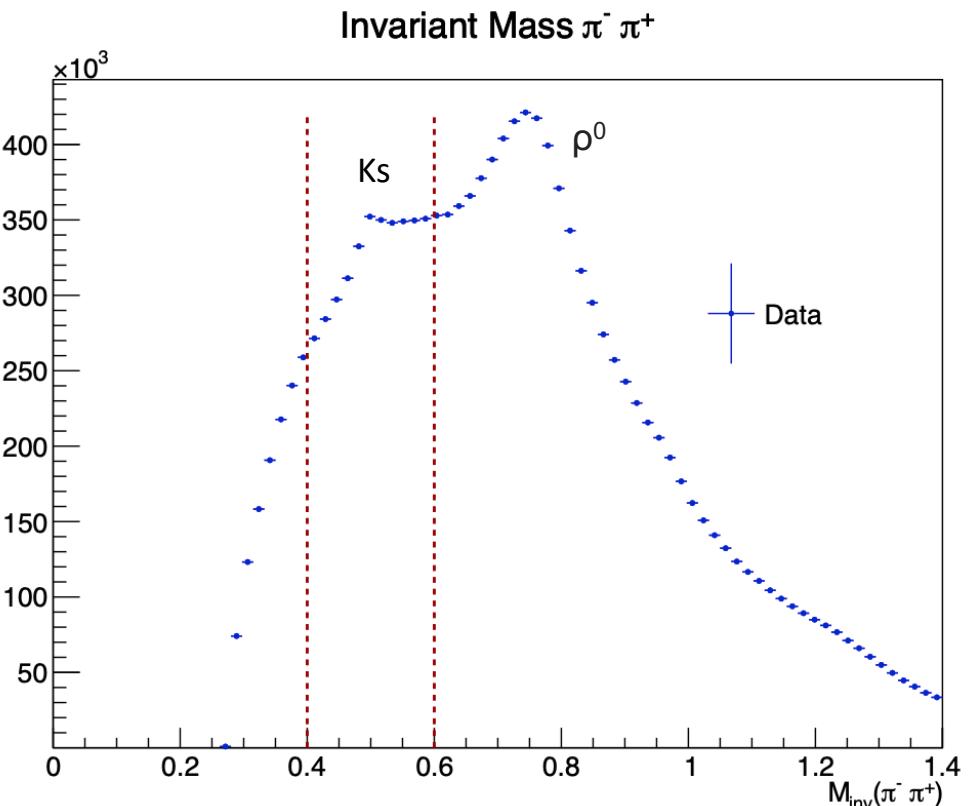
Add some cut on :

→ Distance between vertex of $\pi^+ \pi^-$ $< 3.5 \text{ cm}$

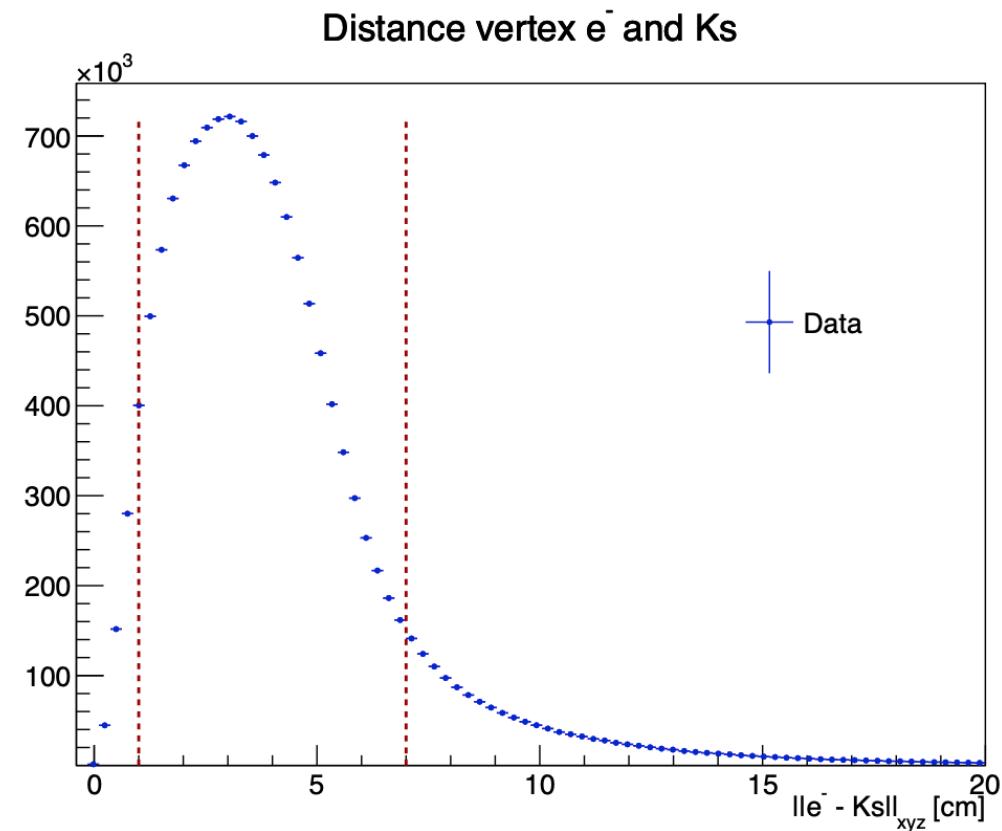
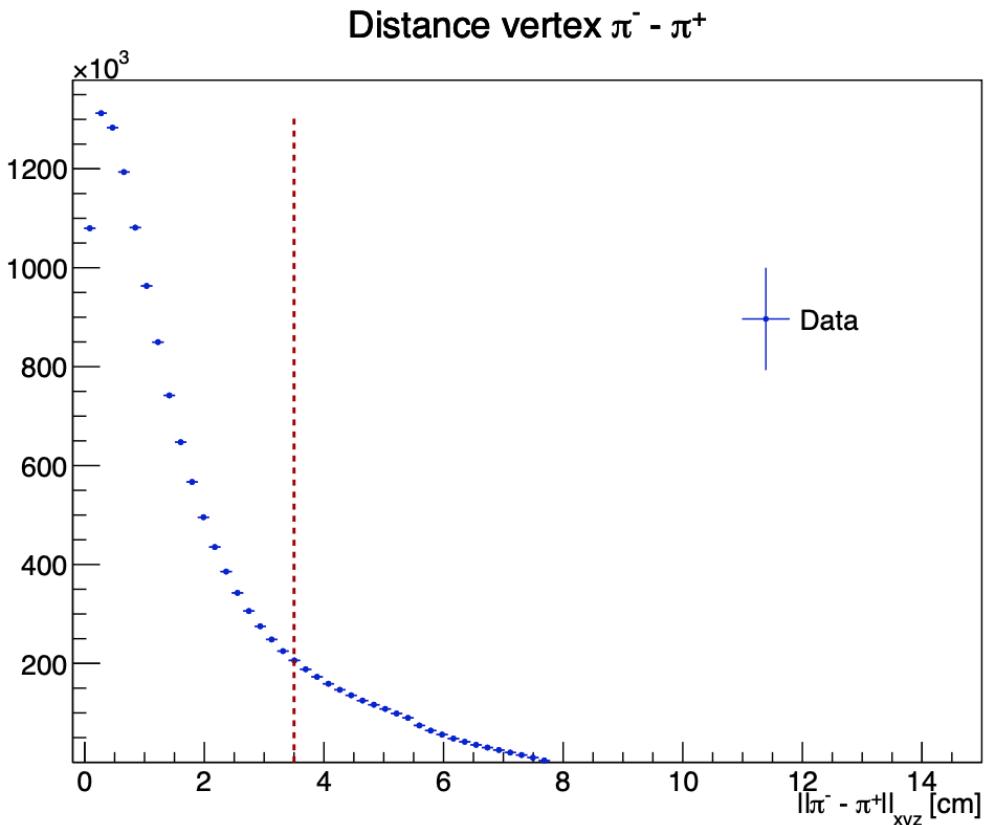
→ Distance between vertex K_s and e^- :
 $1.5 < \text{Dist} < 7.0 \text{ cm}$

because $c\tau_{K_s} = 2.68 \text{ cm}$

Details of cuts on data

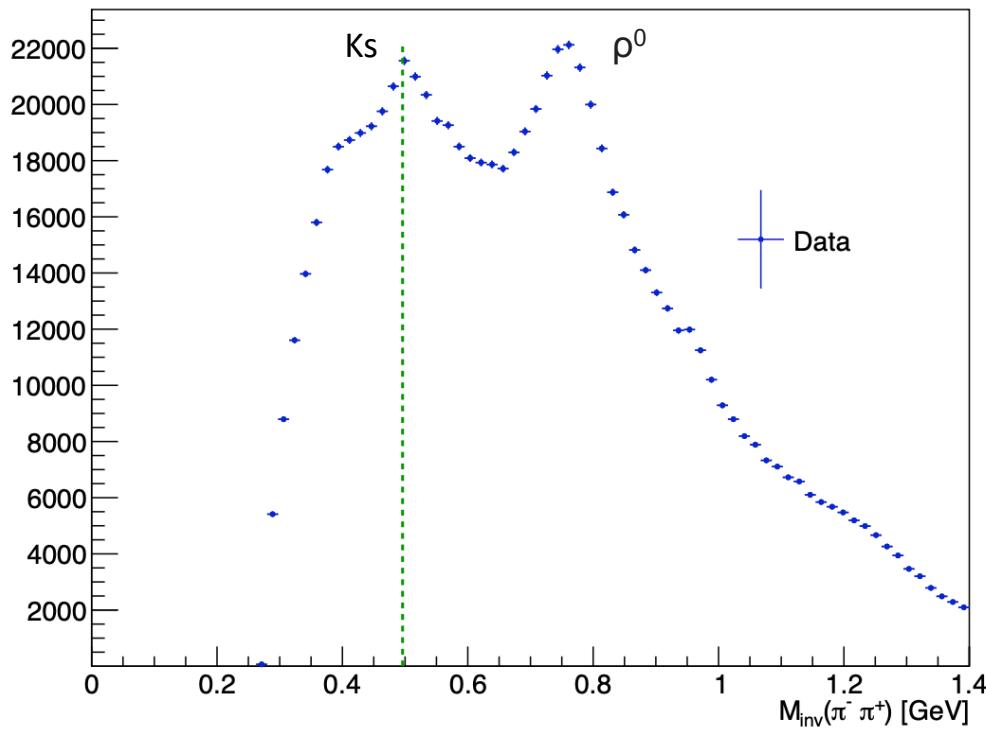


Details of cuts on data

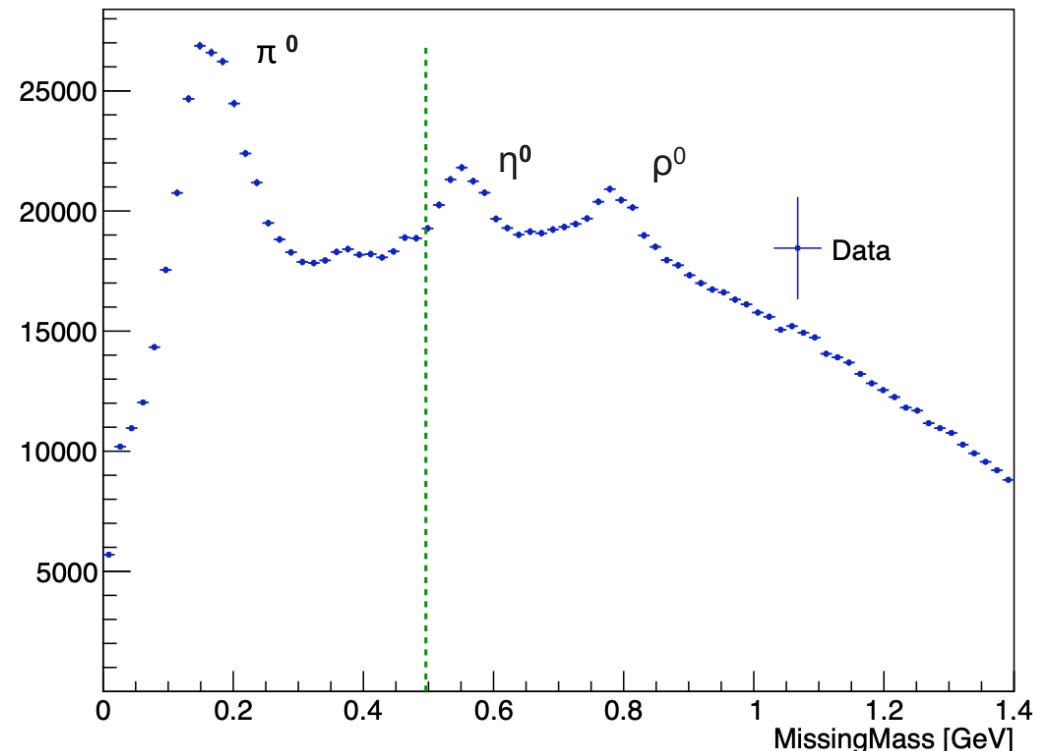


Influence of cuts on data

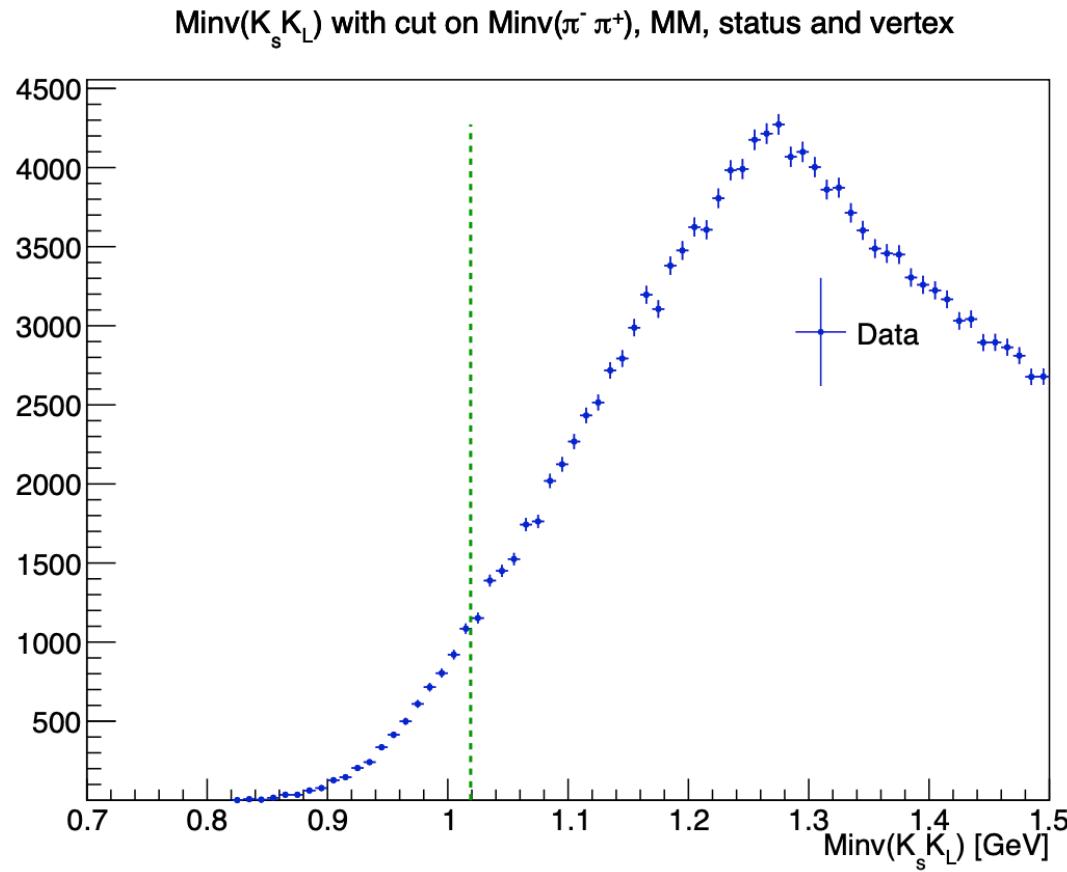
$\text{M}_{\text{inv}}(\pi^- \pi^+)$ with cut on MM, status and vertex



MM with cut on $\text{M}_{\text{inv}}(\pi^- \pi^+)$, status and vertex



Influence of cuts on data



Monte Carlo Simulation : ϕ generator

$$weight_{PhaseSpace} = |Q_{max}^2 - Q_{min}^2| * |xb_{max} - xb_{min}| * |t_{max} - t_{min}|$$

$$\frac{d^3\sigma}{dQ^2dx_Bdt}$$
 From Proposal to Jefferson Lab PAC39 Exclusive Phi Meson Electroproduction with CLAS12

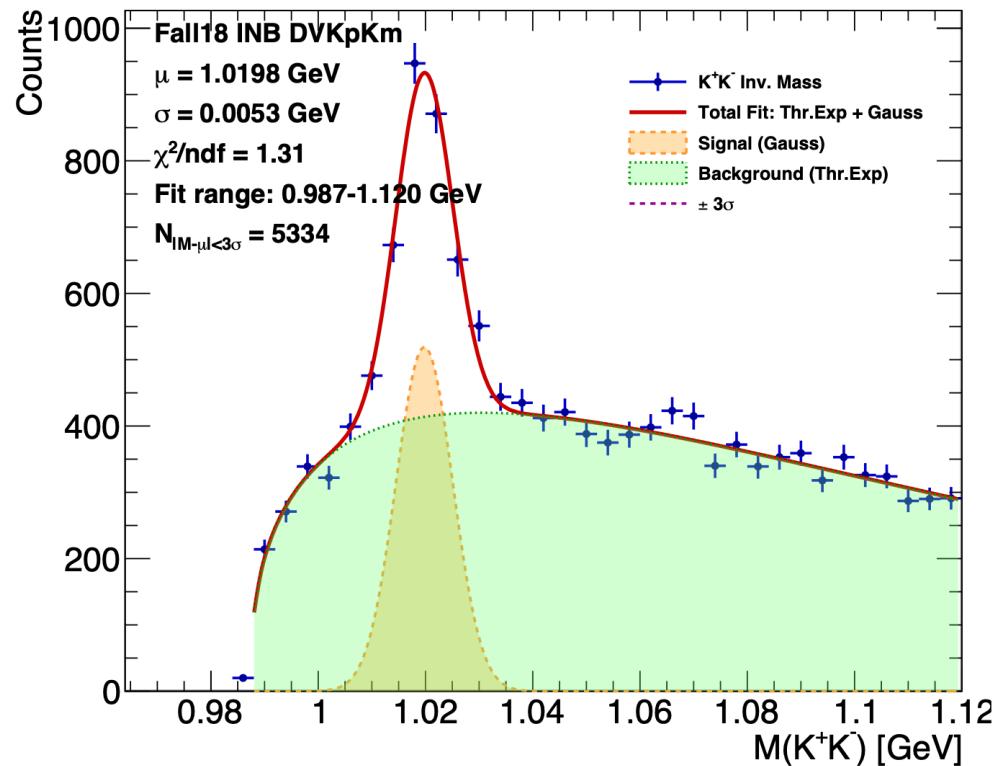
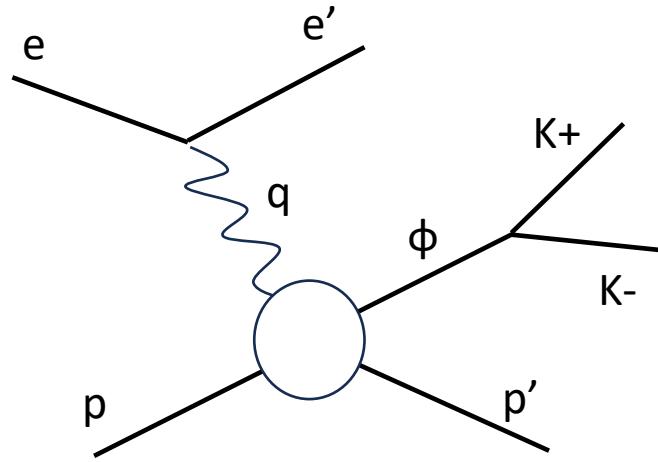
Branching ratio $\phi \rightarrow Ks Kl = 34\%$

Branching ratio $Ks \rightarrow \pi^+ \pi^- = 69\%$

$$totalweight = weight_{PhaseSpace} * weight_{crosssection} * BR_{KsKl} * BR_{\pi^+\pi^-}$$

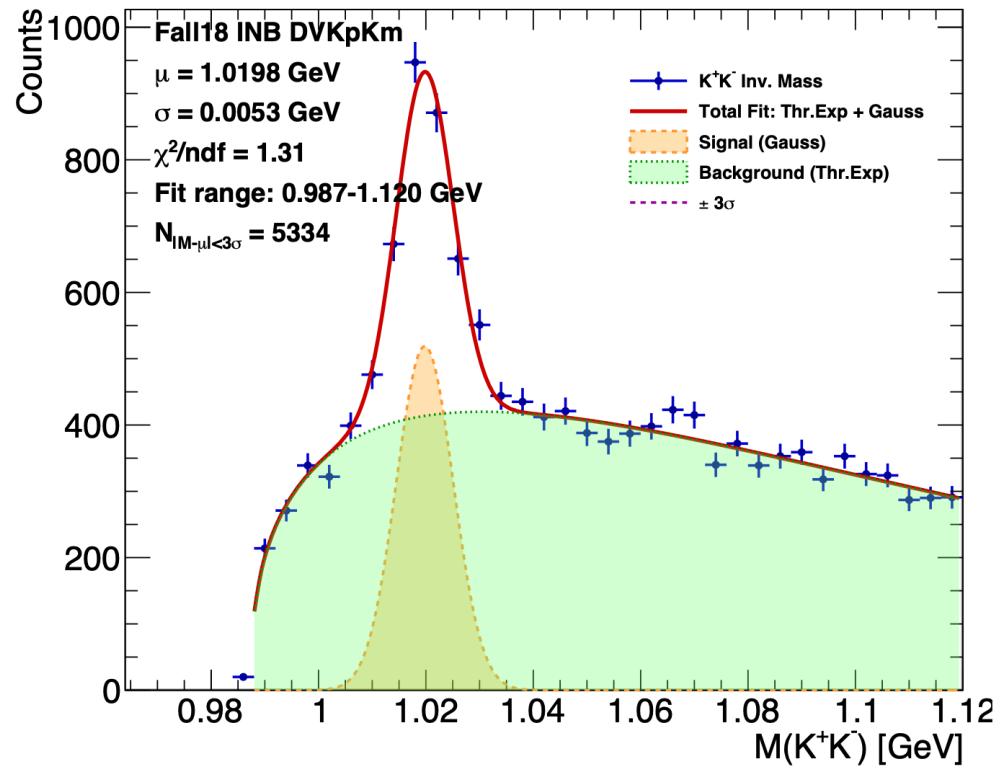
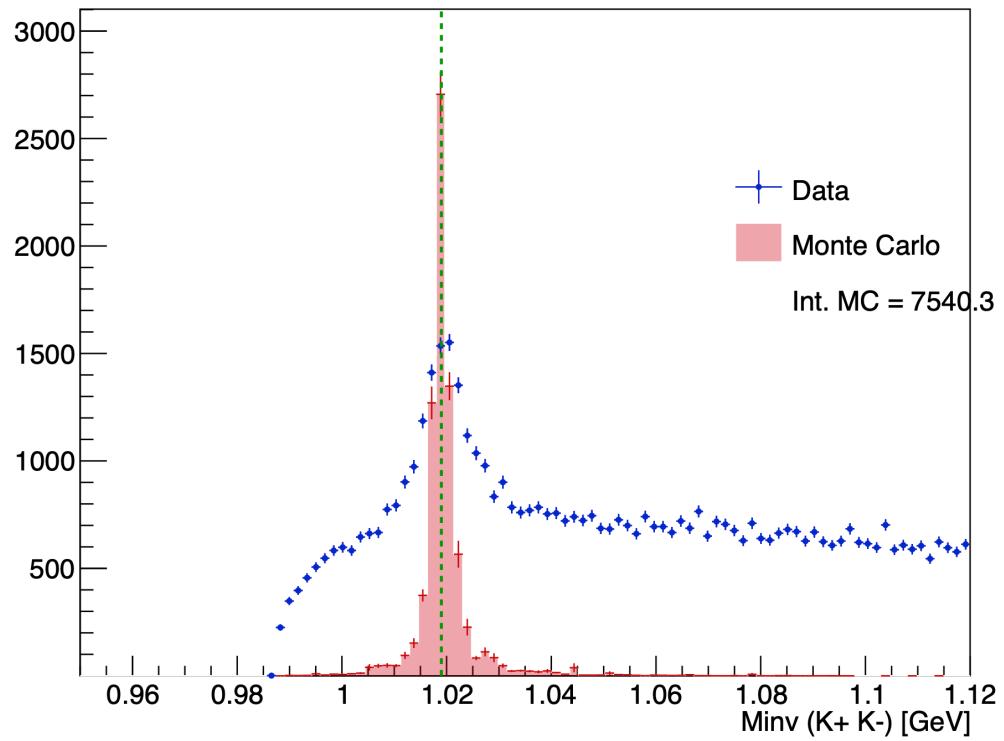
Monte Carlo Simulation : Validation with $\phi \rightarrow K^+ K^-$

→ Test my Monte Carlo with ϕ electroproduction channel $\phi \rightarrow K^+ K^-$



Monte Carlo Simulation : Validation with $\phi \rightarrow K^+ K^-$

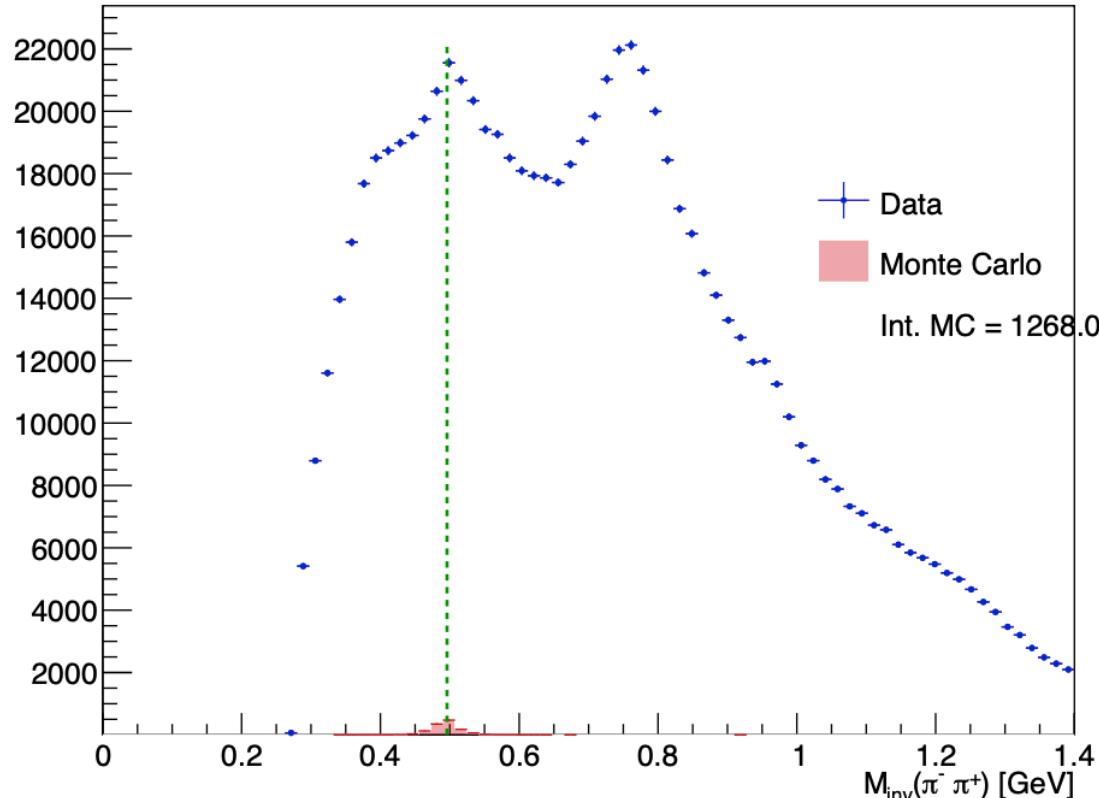
$M_{inv}(K^+ K^-)$ with cut on MM^2



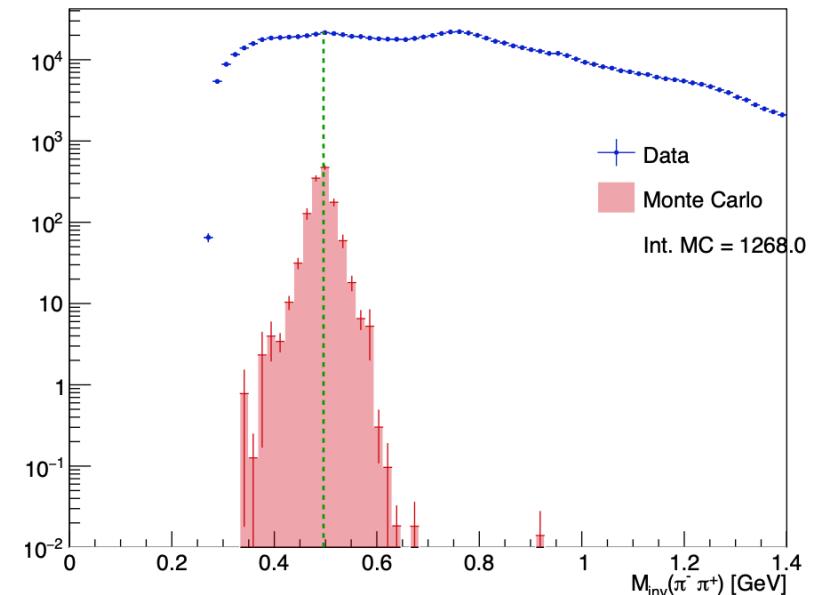
Bhawani's plot

Monte Carlo Simulation : reconstructed events in $\phi \rightarrow K_S K_L$ channel

$M_{inv}(\pi^- \pi^+)$ with cut on MM, status, and vertex

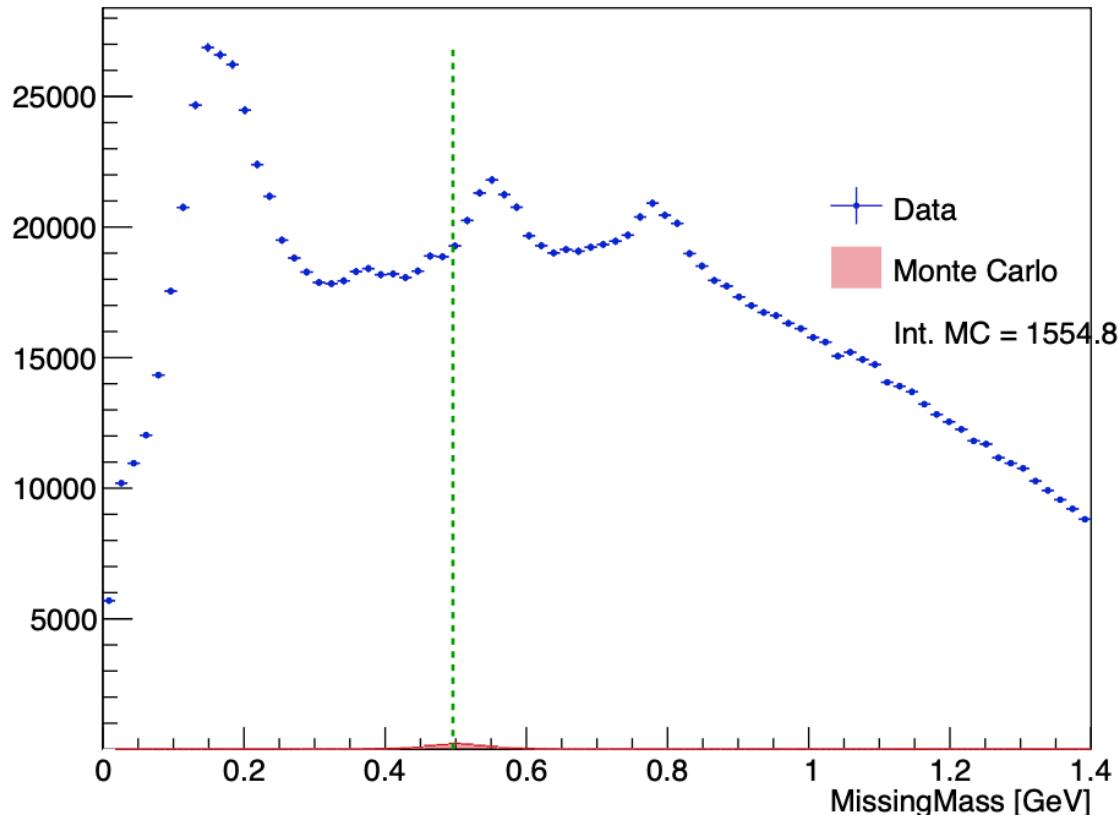


$M_{inv}(\pi^- \pi^+)$ with cut on MM, status, and vertex

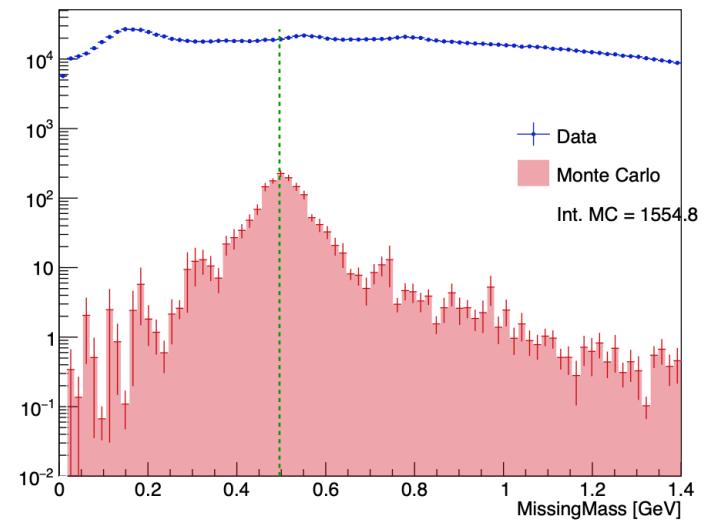


Monte Carlo Simulation : reconstructed events in $\phi \rightarrow K_s K_l$ channel

MM with cut on $\text{Minv}(\pi^- \pi^+)$, status, and vertex

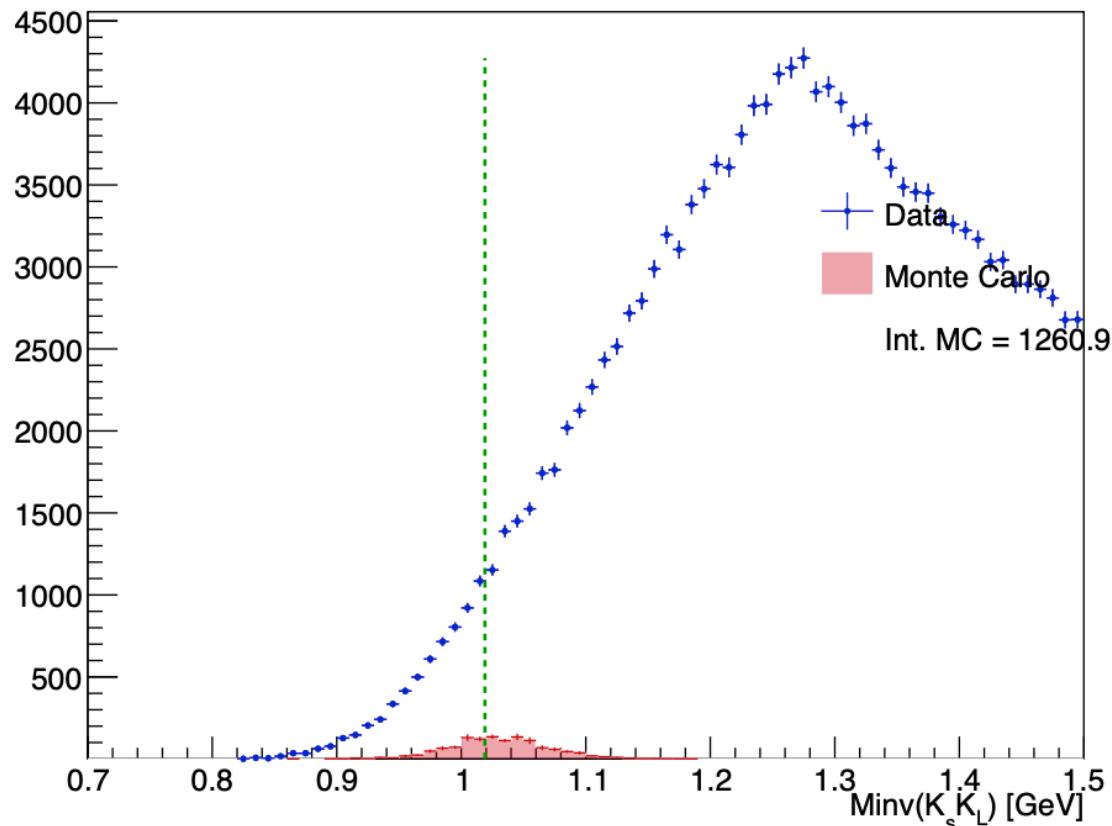


MM with cut on $\text{Minv}(\pi^- \pi^+)$, status, and vertex

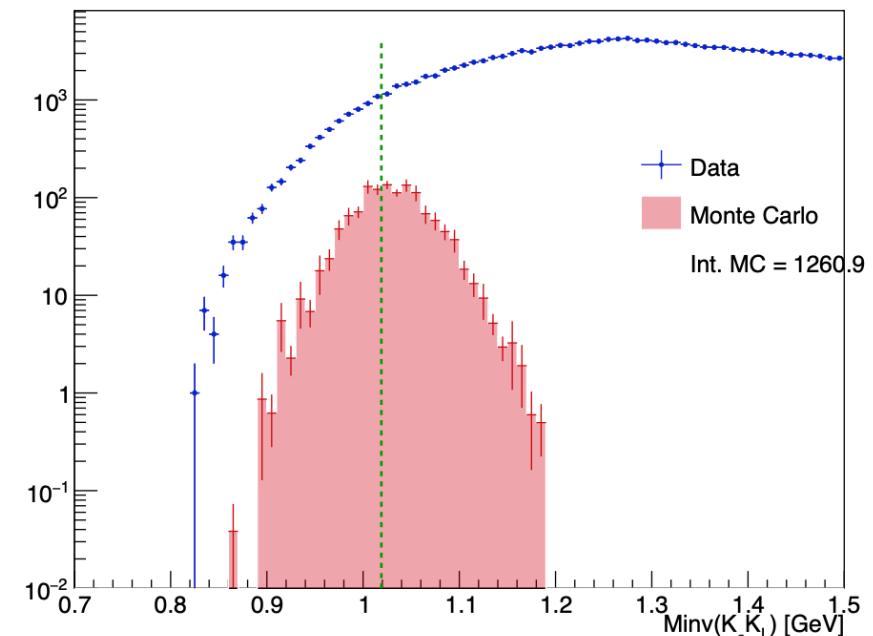


Monte Carlo Simulation : reconstructed events in $\phi \rightarrow K_s K_l$ channel

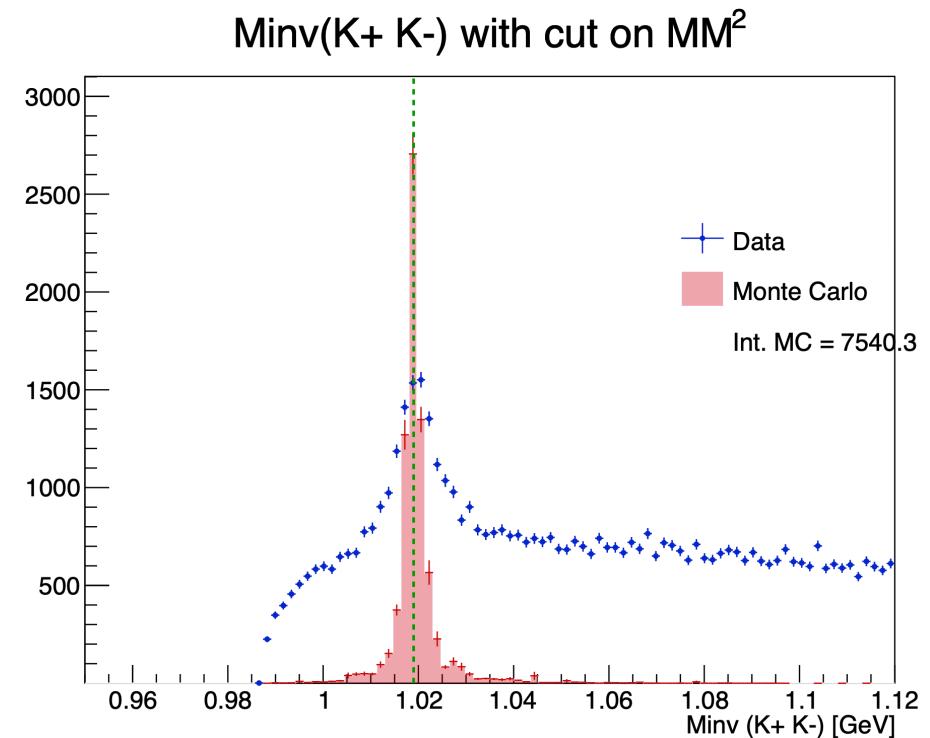
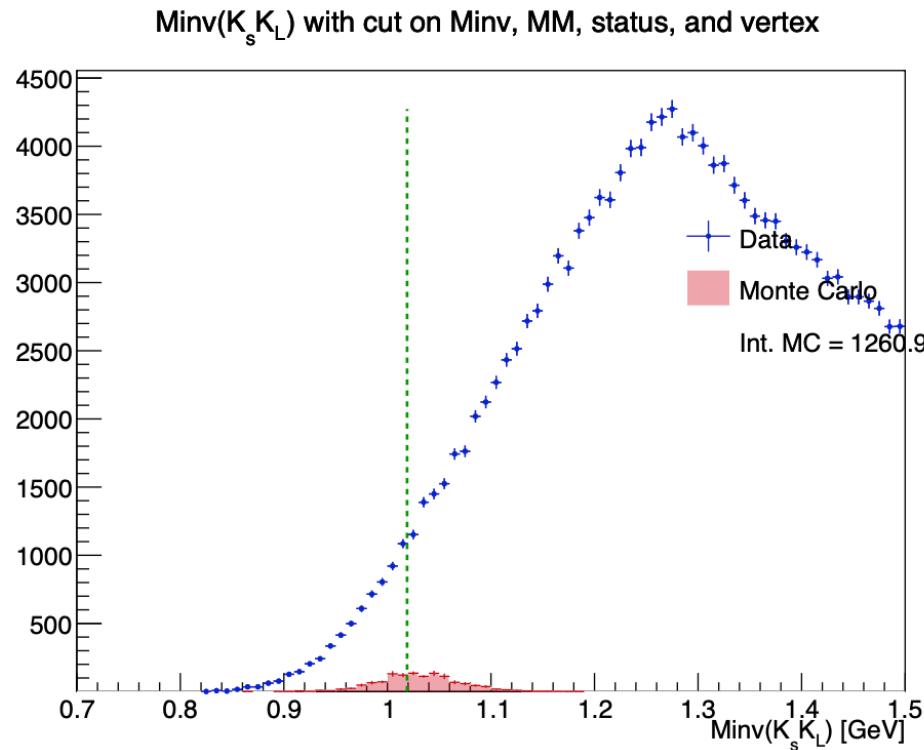
Minv($K_s K_L$) with cut on Minv, MM, status, and vertex



Minv($K_s K_L$) with cut on Minv, MM, status, and vertex



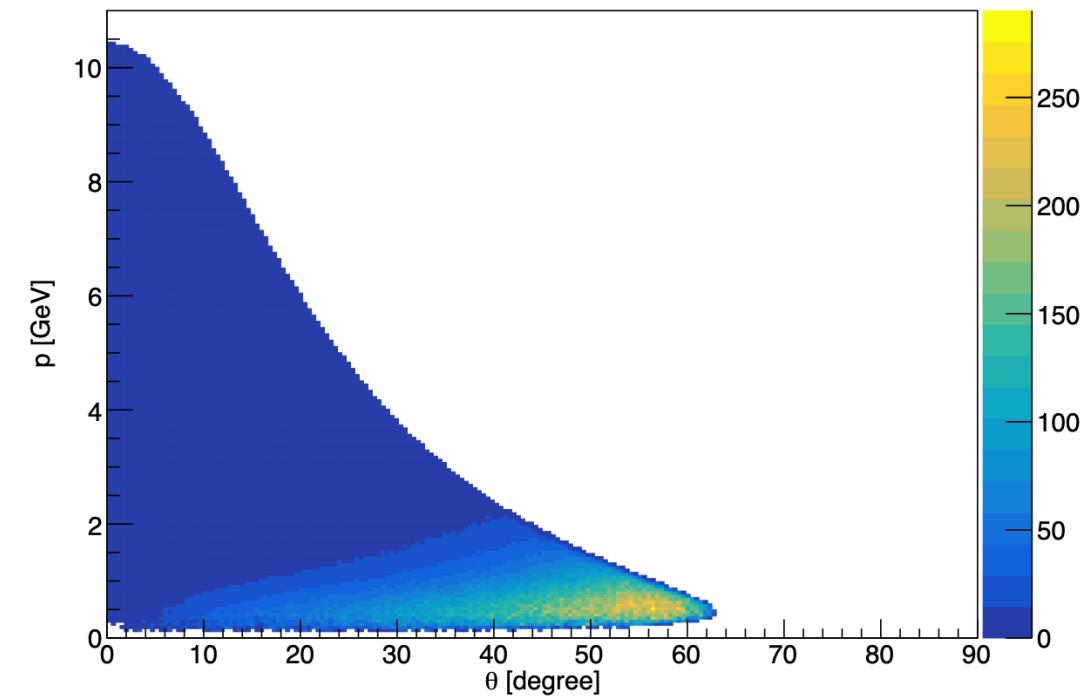
Monte Carlo Simulation : reconstructed events in $\phi \rightarrow K_s K_l$ channel



→ MC predict less events and worse resolution in $K_s K_l$ channel

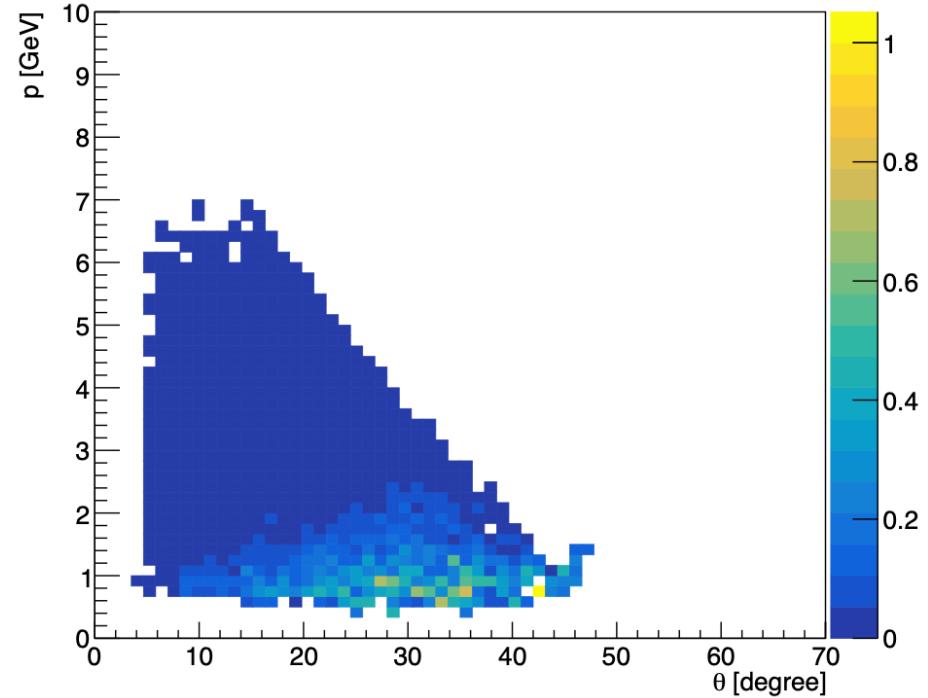
Monte Carlo simulation : comparison generated/reconstructed

p vs θ for proton



Generated events

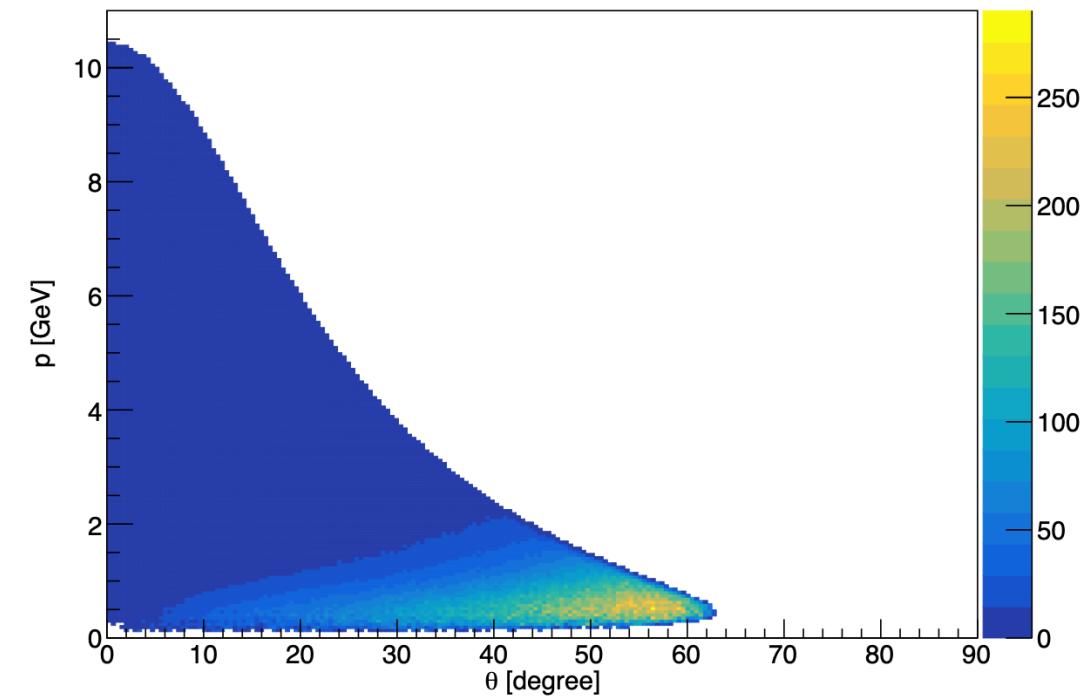
MC : p vs θ proton with cut on Minv, MM, status and vertex



Reconstructed MC Events (after cuts)

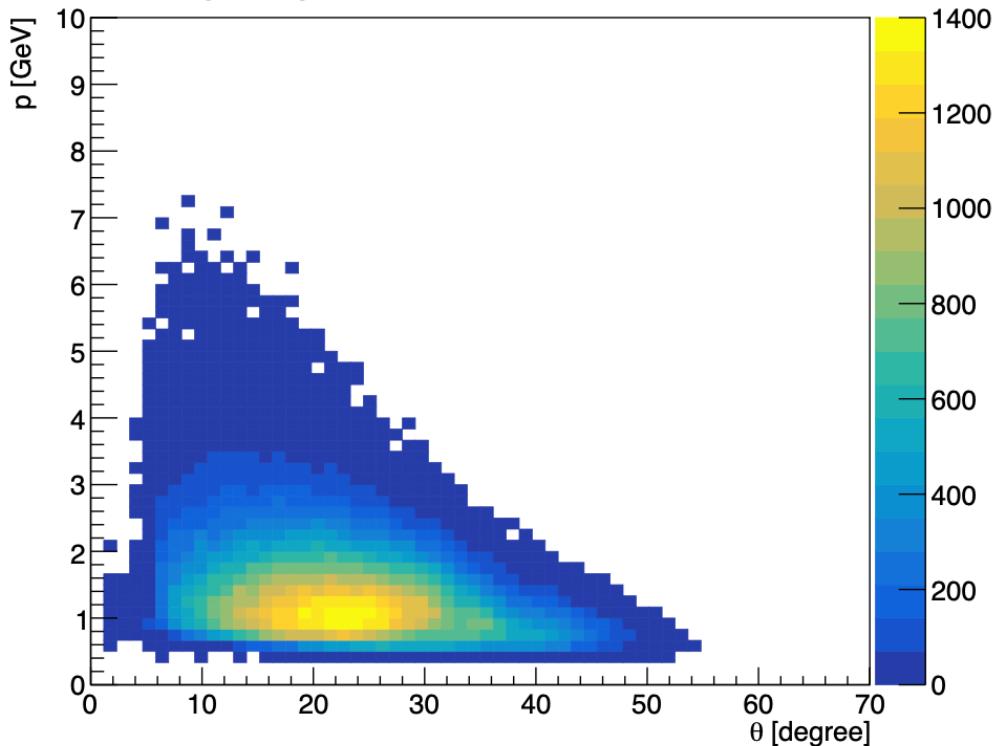
Monte Carlo simulation : comparison generated/reconstructed

p vs θ for proton



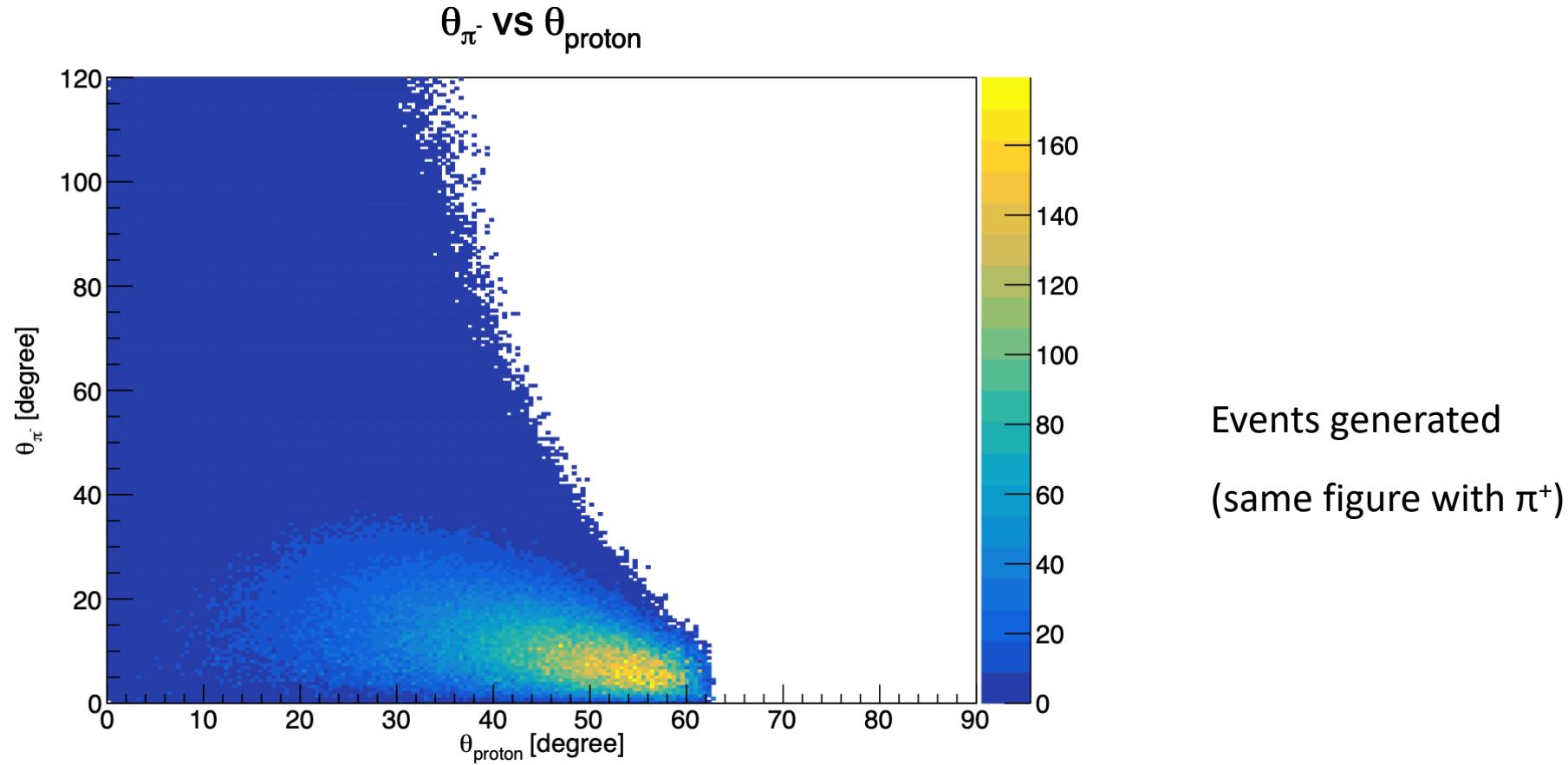
Generated events

Data : p vs θ proton with cut on Minv, MM, status and vertex



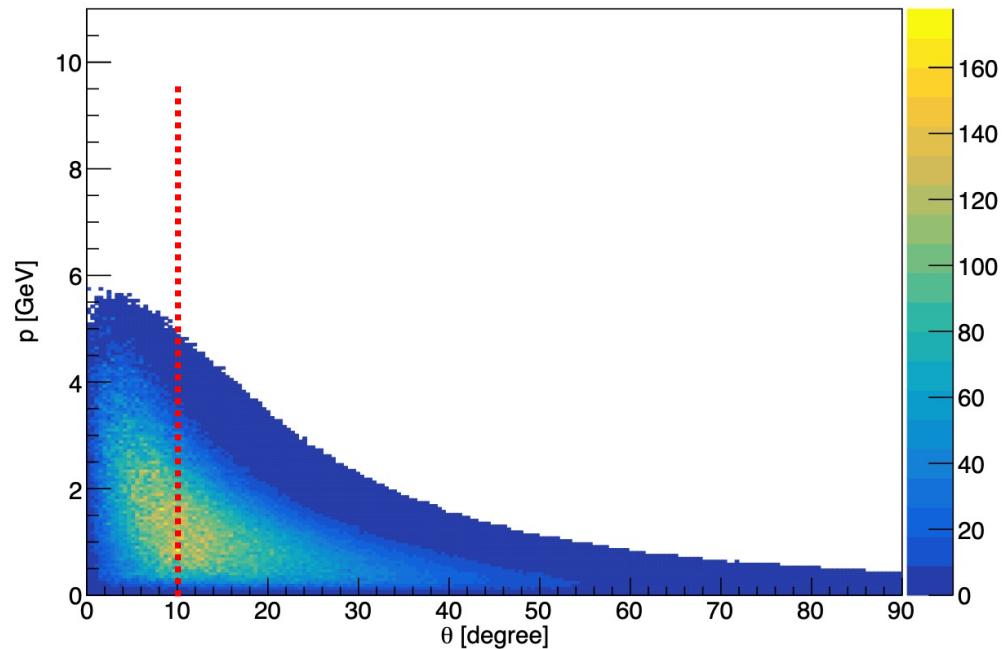
Events from data (after cuts)

Monte Carlo simulation : comparison generated/reconstructed

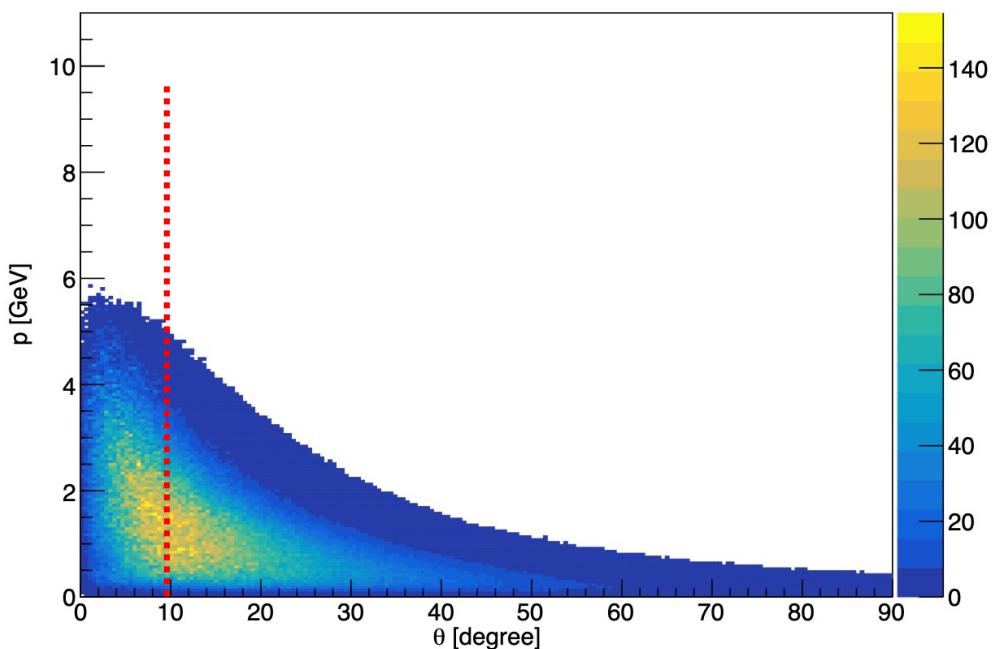


Monte Carlo simulation : comparison generated/reconstructed

p vs θ for π^-

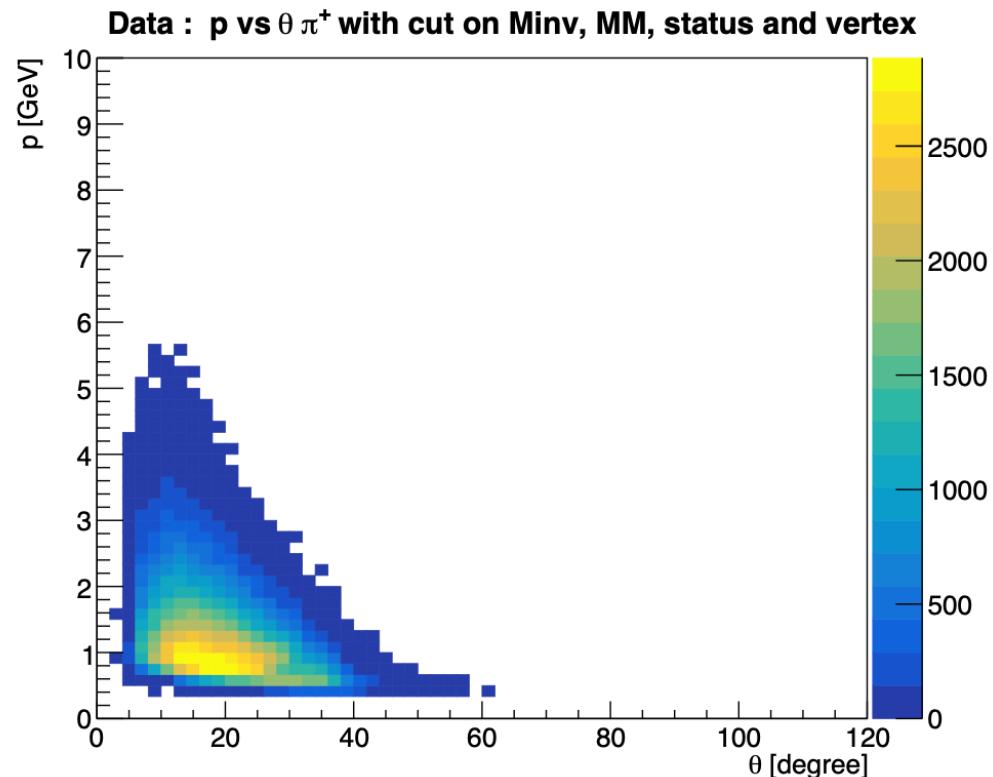
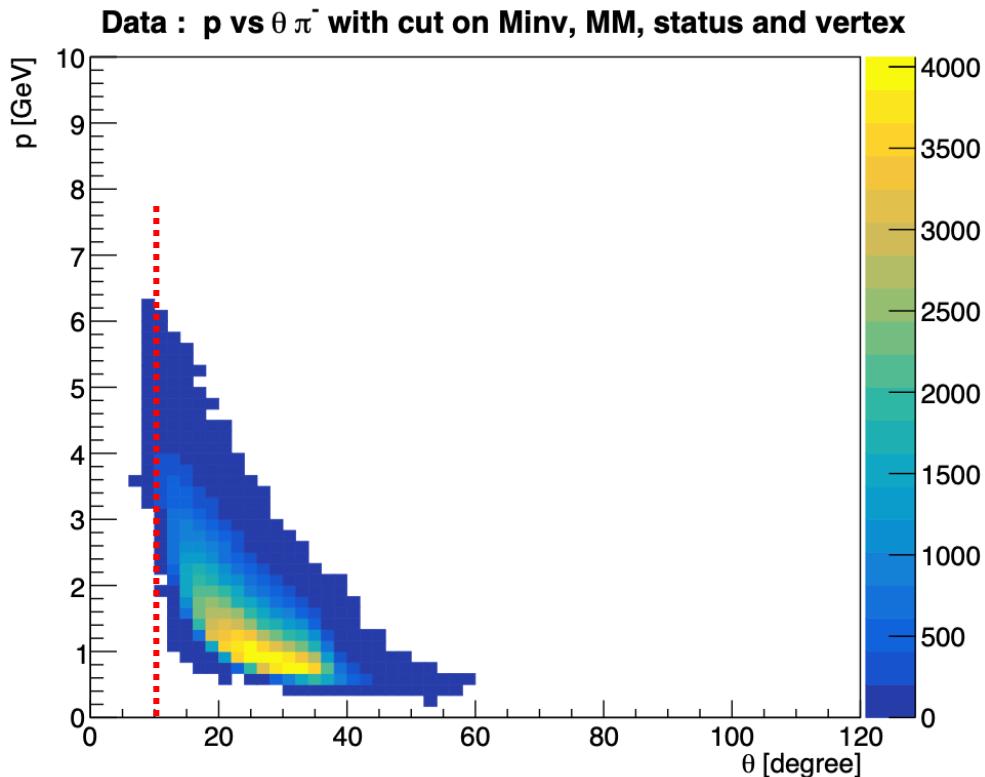


p vs θ for π^+



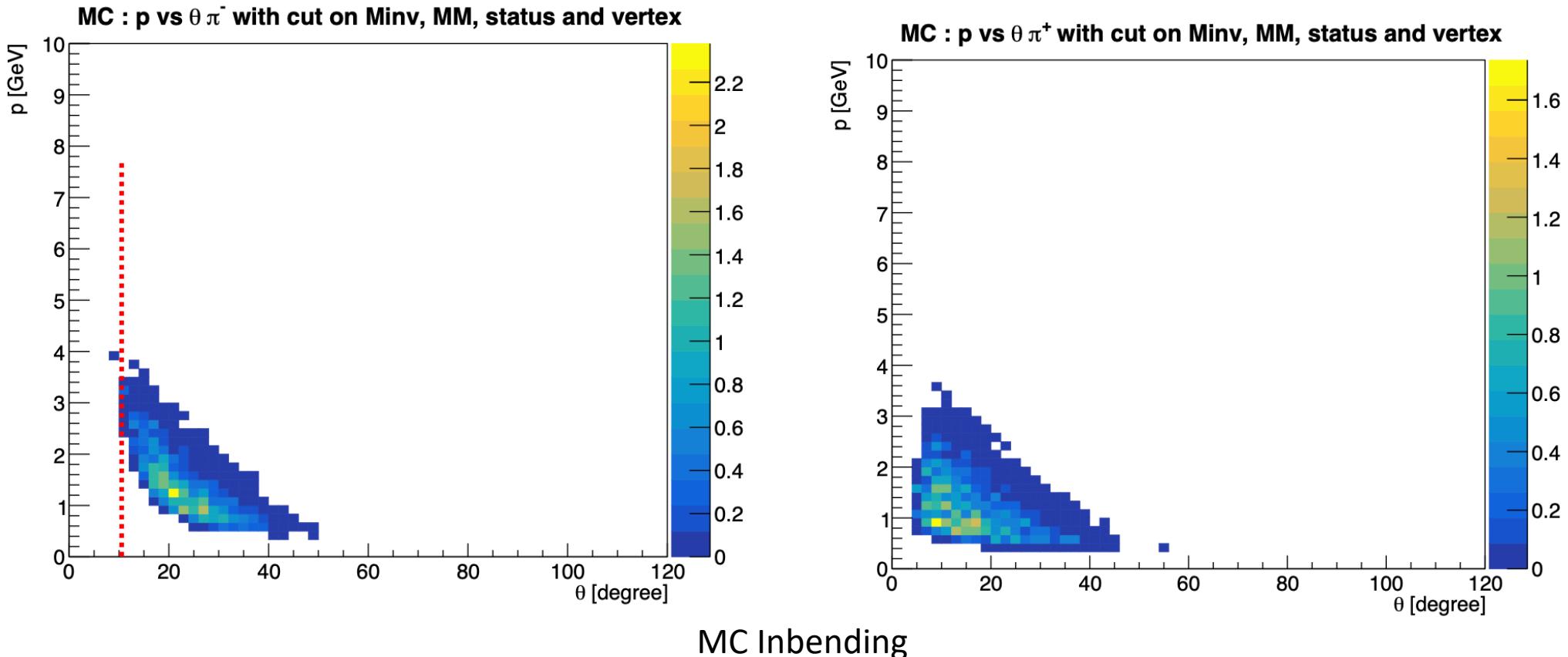
Generated events

Monte Carlo simulation : comparison generated/reconstructed



DATA Inbending

Monte Carlo Simulation : comparison generated/reconstructed



Pions in the FT ?

For inbending : events with 1 proton 1 π^+ and 2 e^-

- one e^- in the FD (real e^-)
- one e^- in the FT (π^- identified like an e^-)

For outbending : events with 1 proton 1 π^- and 2 e^-

- one e^- in the FD (real e^-)
- one e^- in the FT (π^+ identified like an e^-)

No correction with Veronique Ziegler code

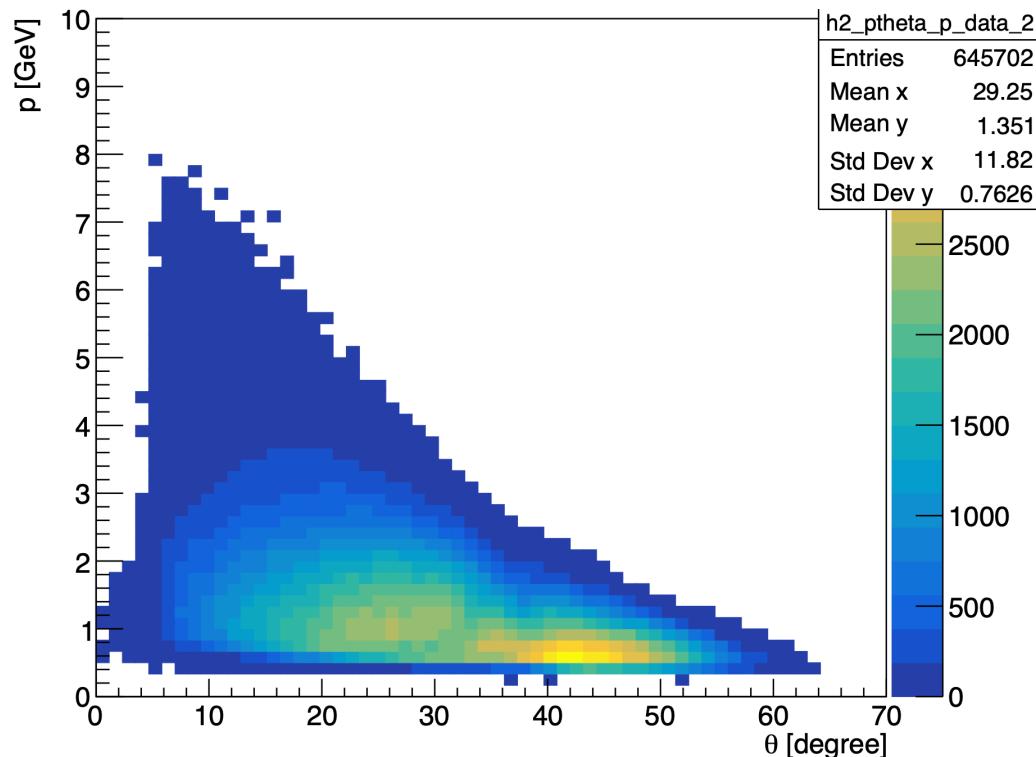
- no cuts on vertex

We do not expect a good reconstruction because
theses cut have to be satisfied in the calorimeter
of the FT :

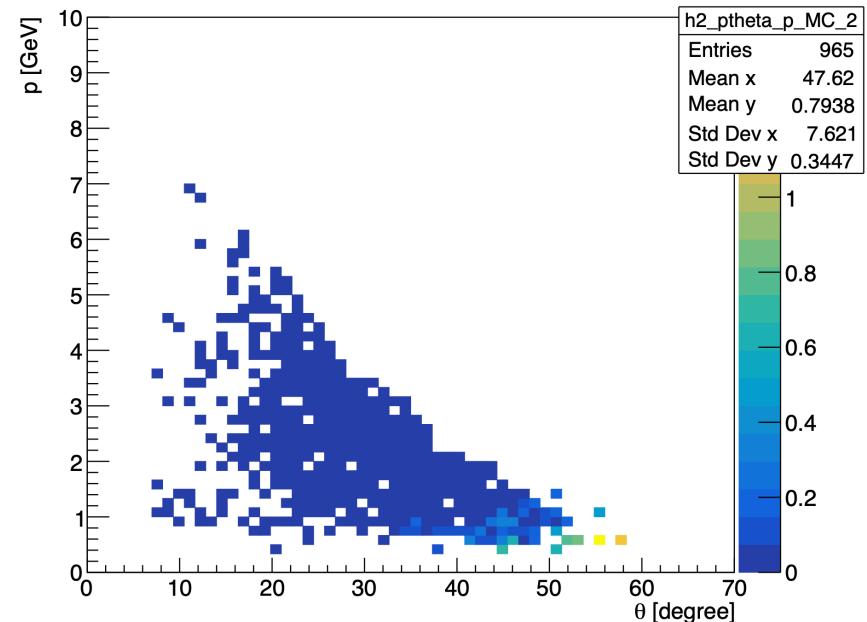
- At least two crystal with energy > 30 MeV
- At least one crystal with energy > 50 MeV
- Total energy > 200 MeV

Pions in the FT ?

Data : p vs θ proton with cut on M_{inv} , MM

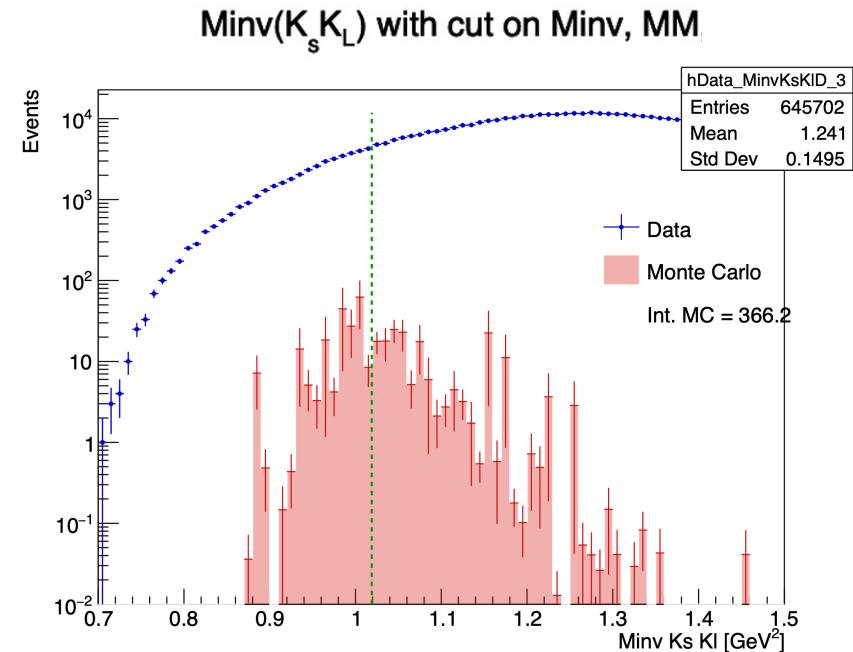
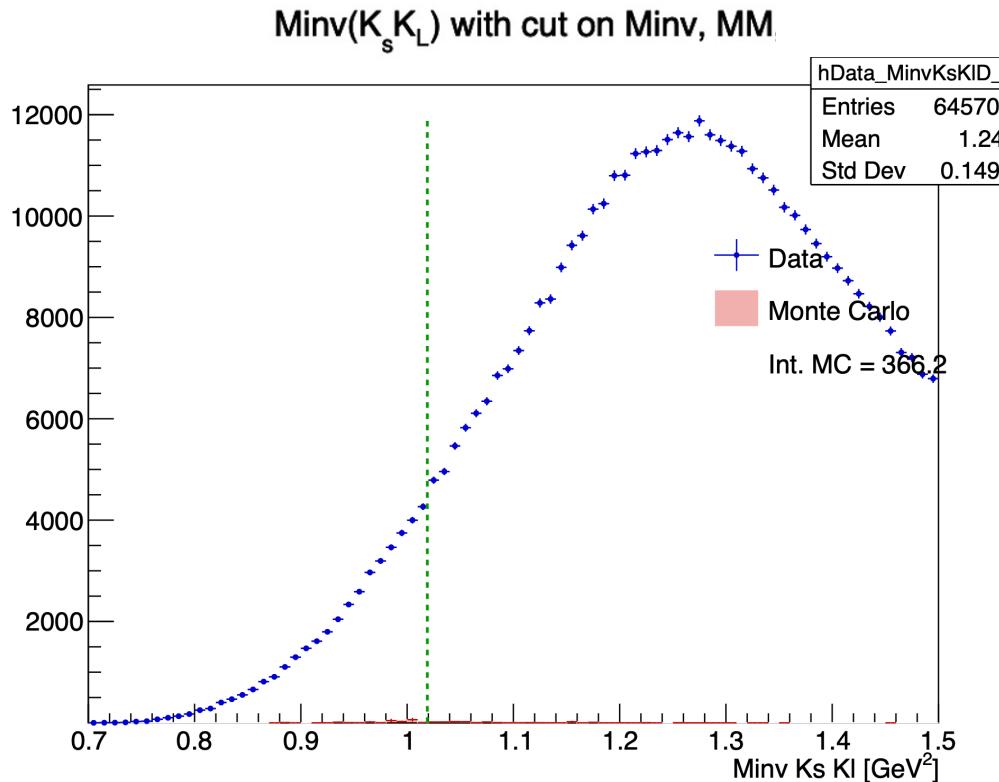


MC : p vs θ proton with cut on M_{inv} , MM



inbending

Pions in the FT ?



inbending

Conclusion

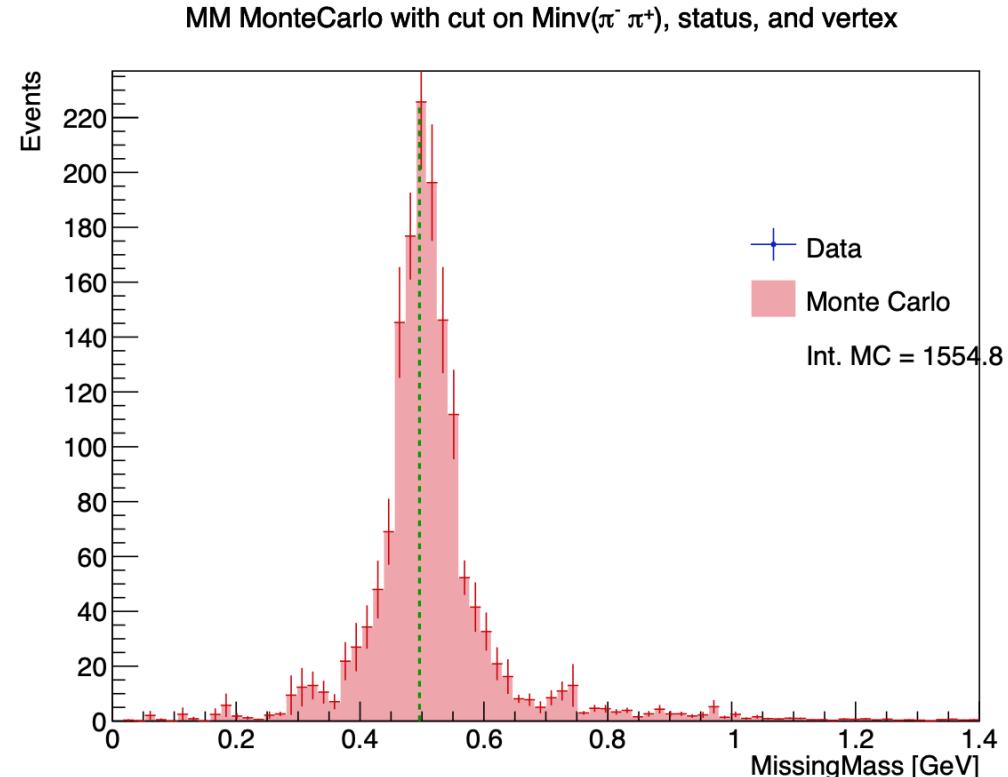
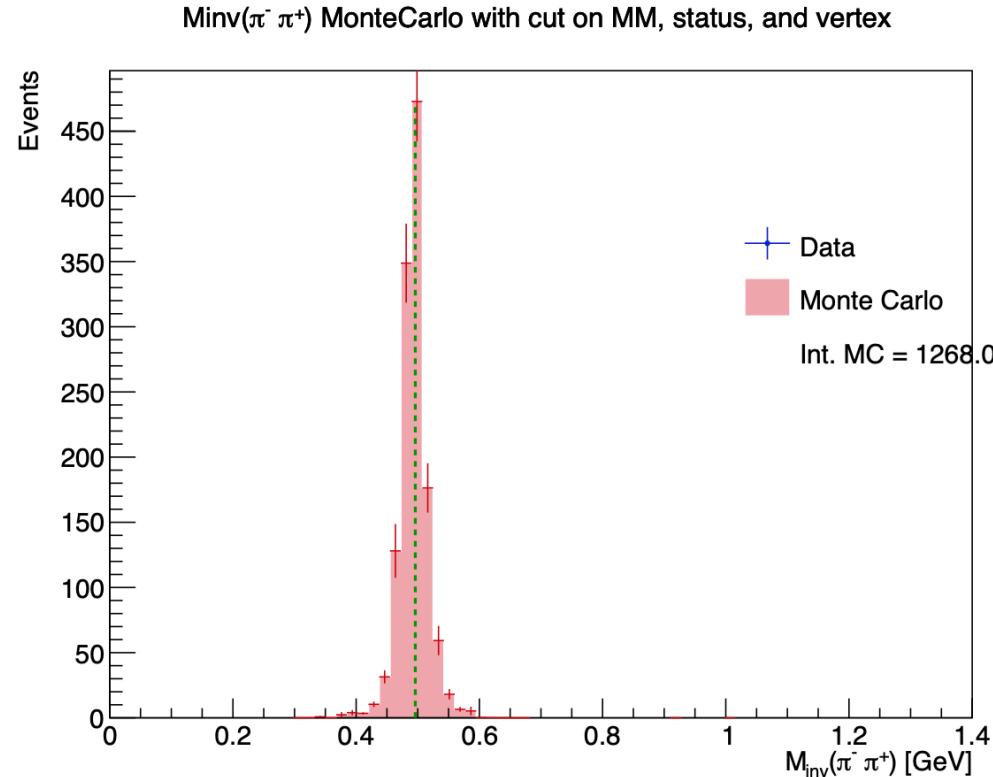
Conclusion :

We do not see a signal in the Ks Kl channel because of pions acceptance and the peak resolution .

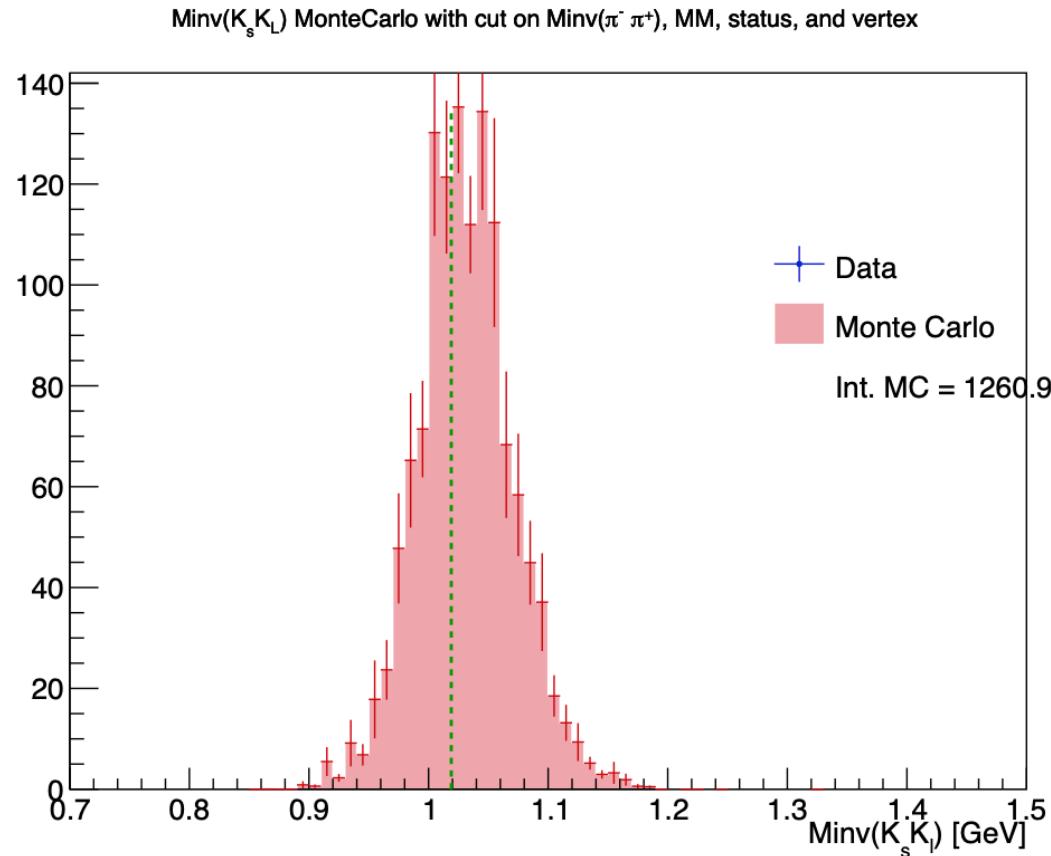
- For the peak resolution : a kinematic fitter could be a solution
- For the acceptance limitation : we could try to implement pions ID in the FT

Thanks!

Monte Carlo Simulation : reconstructed events in $\phi \rightarrow K_s K_l$ channel



Monte Carlo Simulation : reconstructed events in $\phi \rightarrow K_s K_l$ channel



Update on ϕ generator

Backup ϕ generator

Update on ϕ generator

Simulation objectives :

- Estimate the expected number of ϕ with

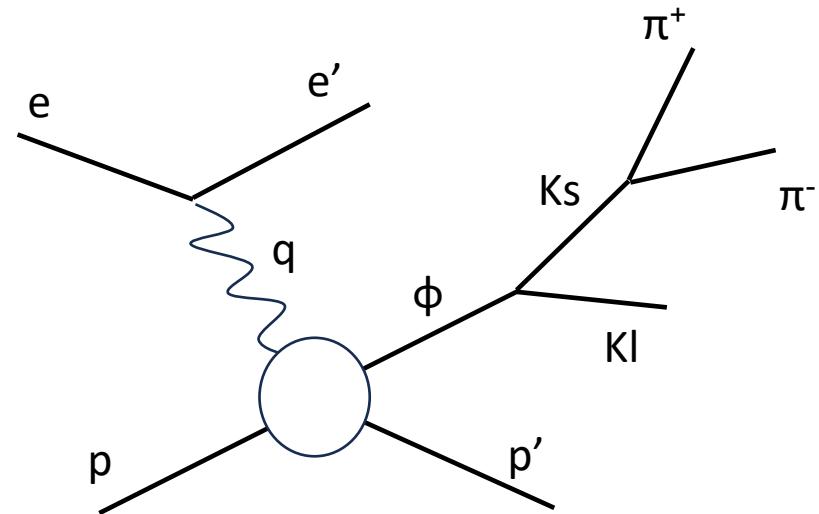
$$N_{expected} = \frac{\sum w_{rec}}{N_{gen}} * \mathcal{L}$$

- Find interesting cuts

Previously with TGenPhasespace (root module) :

- Generate automatically quadri-impulsion in the phasespace
- But problems with the weight associated with the phasespace

→ In the next slides the generator that we implemented without TGenPhaseSpace



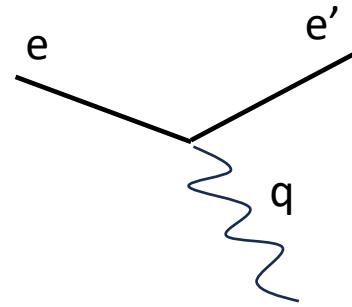
Update on ϕ generator

1. Initially :

Target = $(0, 0, 0, Mp)$

Beam = $(0, 0, Eb, Eb)$

Q^2 generated in $[1, 6.5]$ GeV



2. Scattering electron kinematics :

- Find W_{min}^2 and W_{max}^2 . Formula in *Byckling, E., and Kajantie, K. (1973b). Particle kinematics. Wiley-Interscience.*
- Find xb_{min} and xb_{max} (which depend on $W_{min/max}^2$ and Q^2)
- Generate xb in $[xb_{min}, xb_{max}]$
- Find $E' = E - \nu$ with $\nu = \frac{Q^2}{2*Mp*xb}$
- Find $\theta_{e'} = 2 * \arcsin(\sqrt{\frac{Q^2}{4EE'}})$
- Generate $\phi_{e'}$ in $[0, 2\pi]$

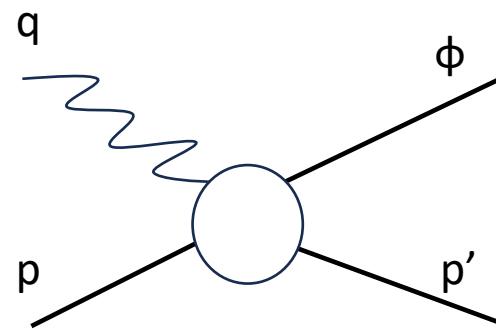
Update on ϕ generator

3. Virtual photon kinematics :

$$q = e - e'$$

4. Scattering proton kinematics :

- Find t_{min} and t_{max}
 - Generate t in $[t_{min}, t_{max}]$
 - Find $E_{p'} = \frac{-t+2*Mp^2}{2Mp}$
 - Find $\theta_{\gamma p}$ between proton and photon
 - Generate ϕ_p (relative to the photon axis) in $[0, 2\pi]$
- Formula for $t_{min/max}$ and $\theta_{\gamma p}$ in *Byckling, E., and Kajantie, K. (1973b). Particle kinematics. Wiley-Interscience.*



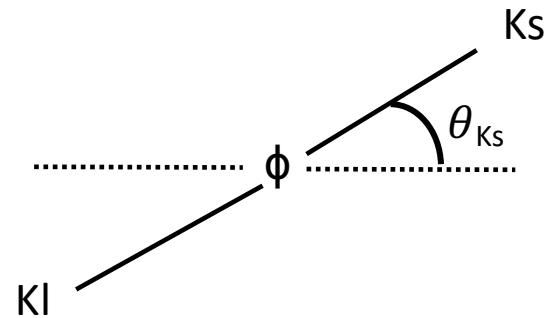
5. Meson ϕ kinematics :

$$\phi = p + q - p'$$

Update on ϕ generator

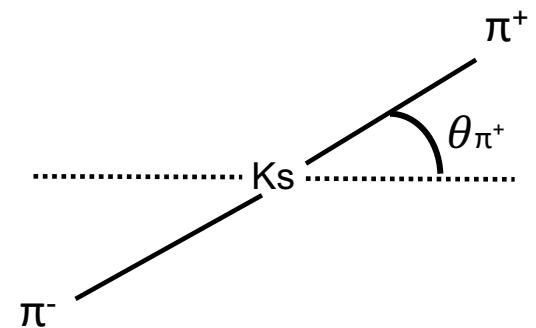
6. Kinematics of second decay $\phi \rightarrow K_s K_l$:

- Uniform decay in θ (and ϕ) in first approximation (in CM)
- Generate $\cos(\theta_{K_s})$ in $[-1, 1]$
- Generate ϕ_{K_s} in $[0, 2\pi]$
- Find $E_{K_s} = m_\phi/2$ and $p_{K_s} = \sqrt{E_{K_s}^2 - m_{K_s}^2}$
- $p_{K_l} = -p_{K_s}$ in CM
- Boost in order to find K_s and K_l in the lab



7. Kinematics of thrid decay $K_s \rightarrow \pi^+ \pi^-$:

- Same method than in step 6.
- V_x V_y V_z shifted by 2.8 cm in the direction of K_s emmision to simulate the flight of K_s



Update on ϕ generator

$$weight_{PhaseSpace} = |Q_{max}^2 - Q_{min}^2| * |xb_{max} - xb_{min}| * |t_{max} - t_{min}|$$

$$\frac{d^3\sigma}{dQ^2dx_Bdt}$$
 From Proposal to Jefferson Lab PAC39 Exclusive Phi Meson Electroproduction with CLAS12

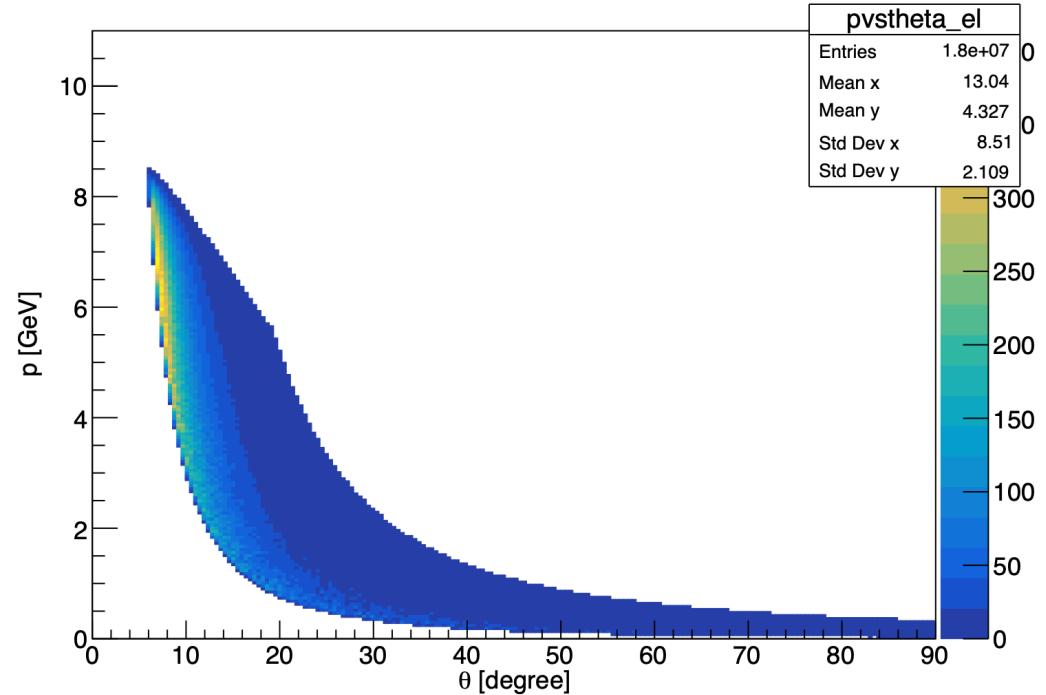
Branching ratio $Ks \rightarrow \pi^+ \pi^-$ = 69%

Branching ratio $\phi \rightarrow Ks Kl$ = 34%

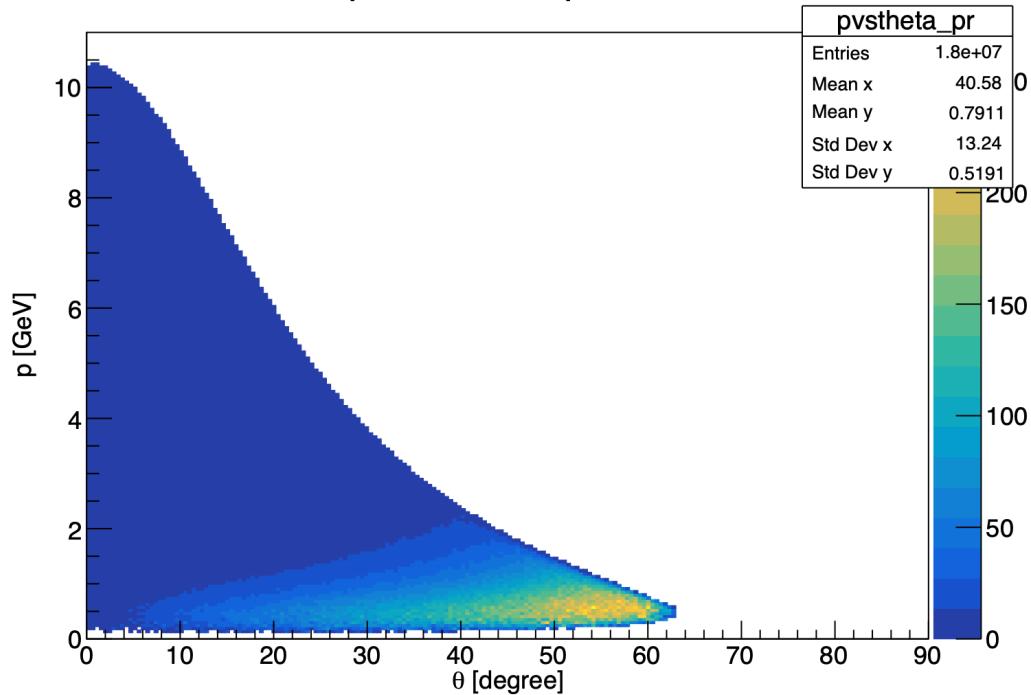
$$totalweight = weight_{PhaseSpace} * weight_{crosssection} * BR_{KsKl} * BR_{\pi^+\pi^-}$$

Update on ϕ generator

p vs theta for electron

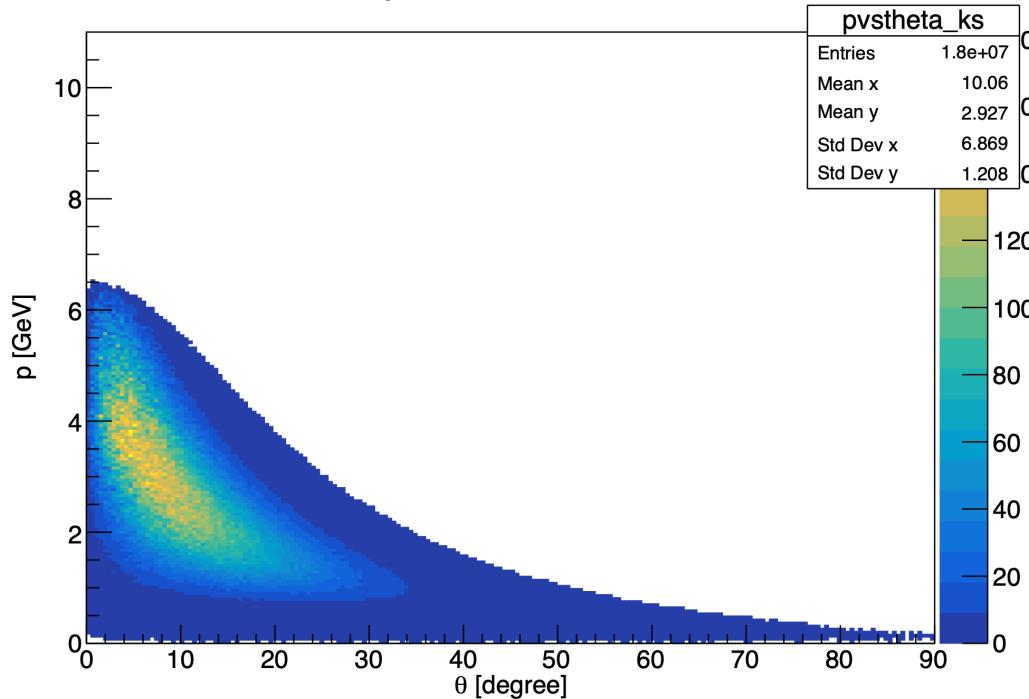


p vs theta for proton

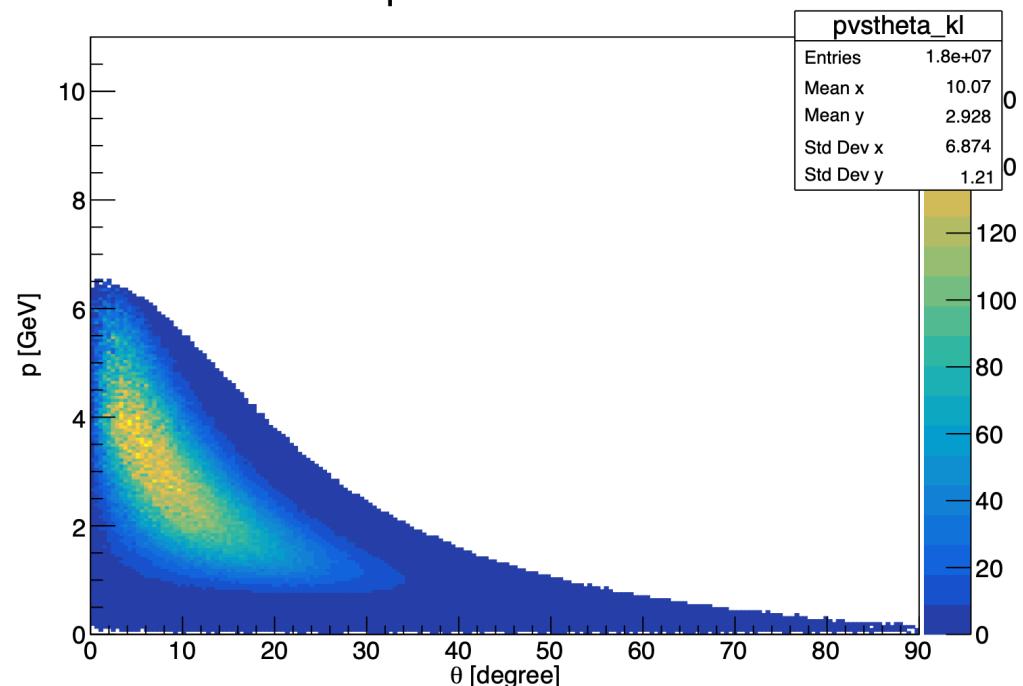


Update on ϕ generator

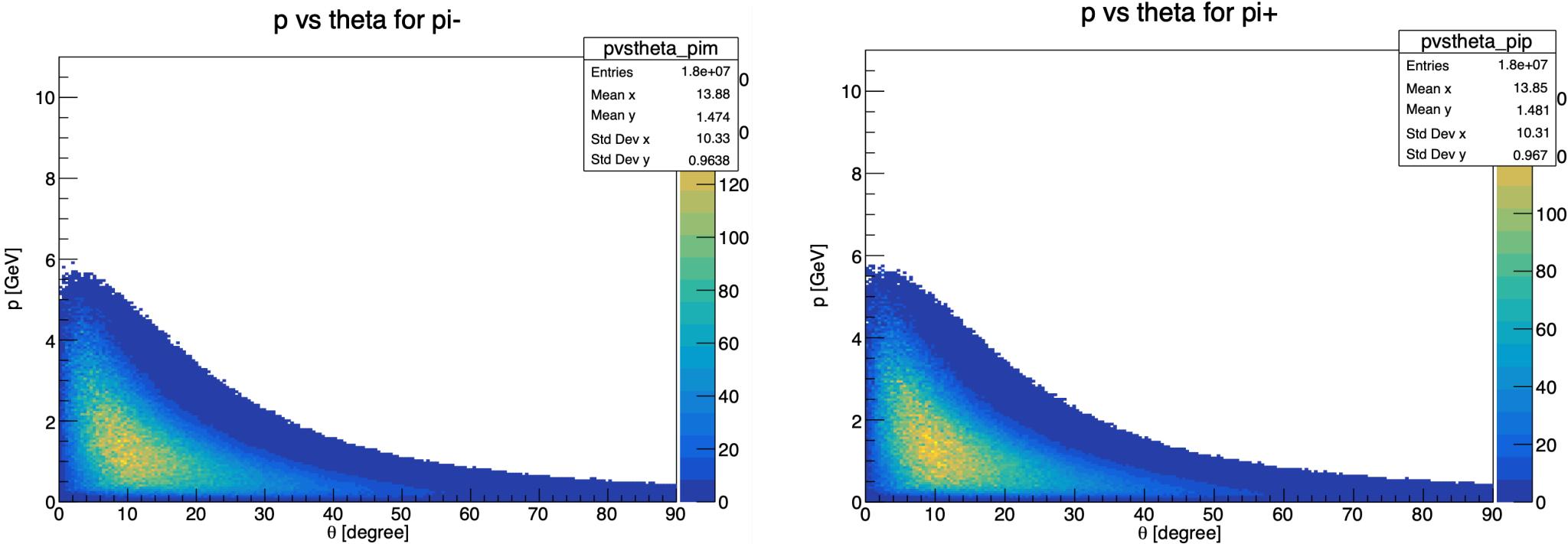
p vs theta for ks



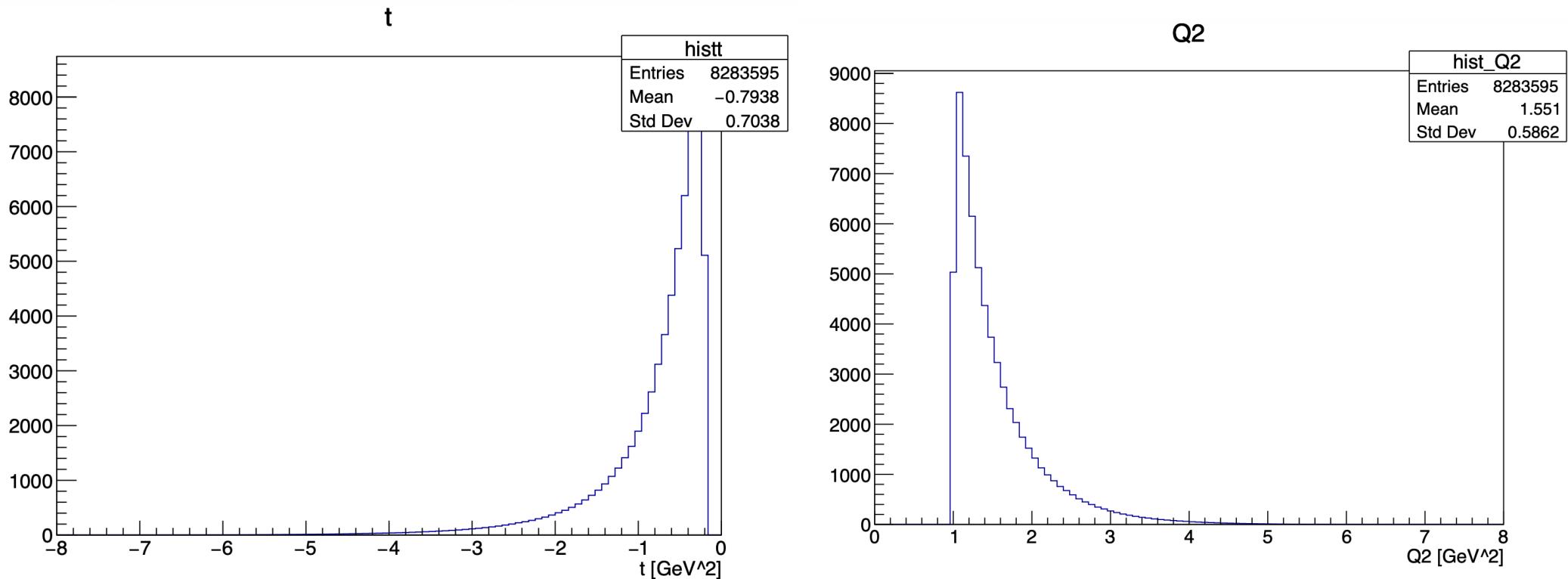
p vs theta for kl



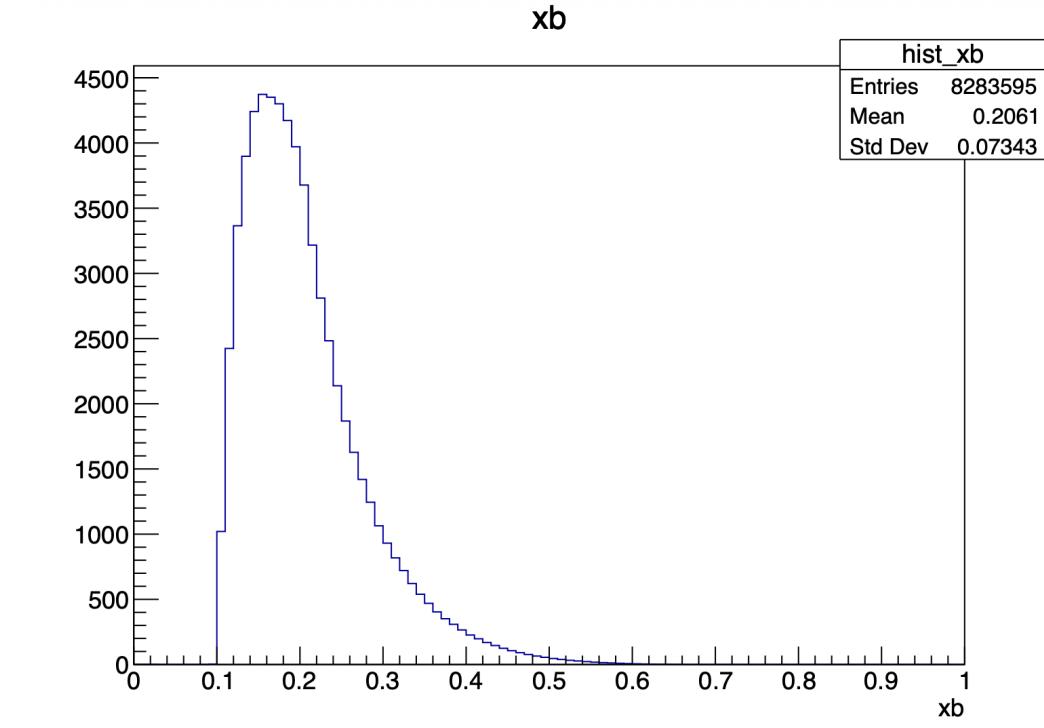
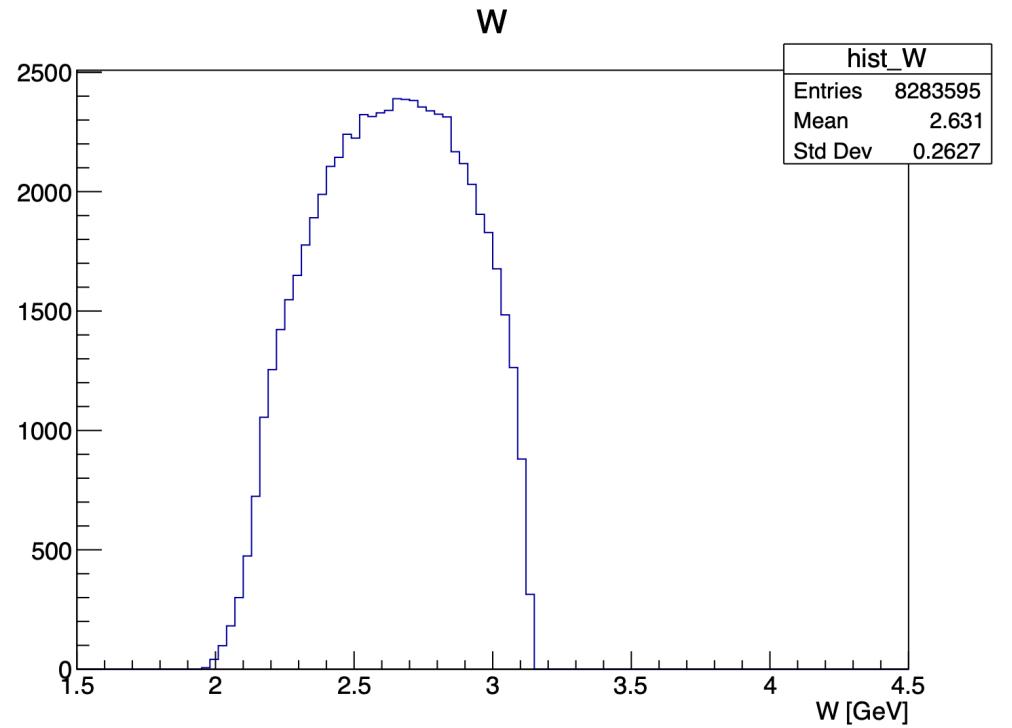
Update on ϕ generator



Update on ϕ generator

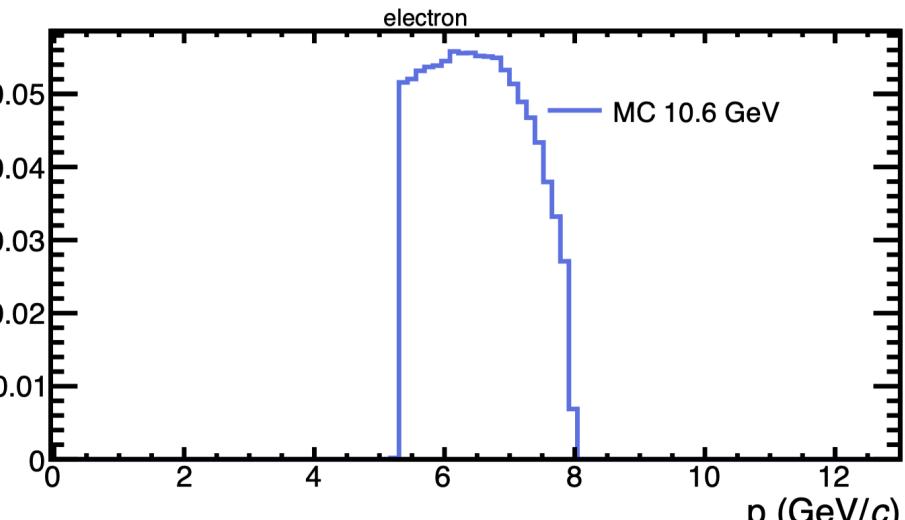
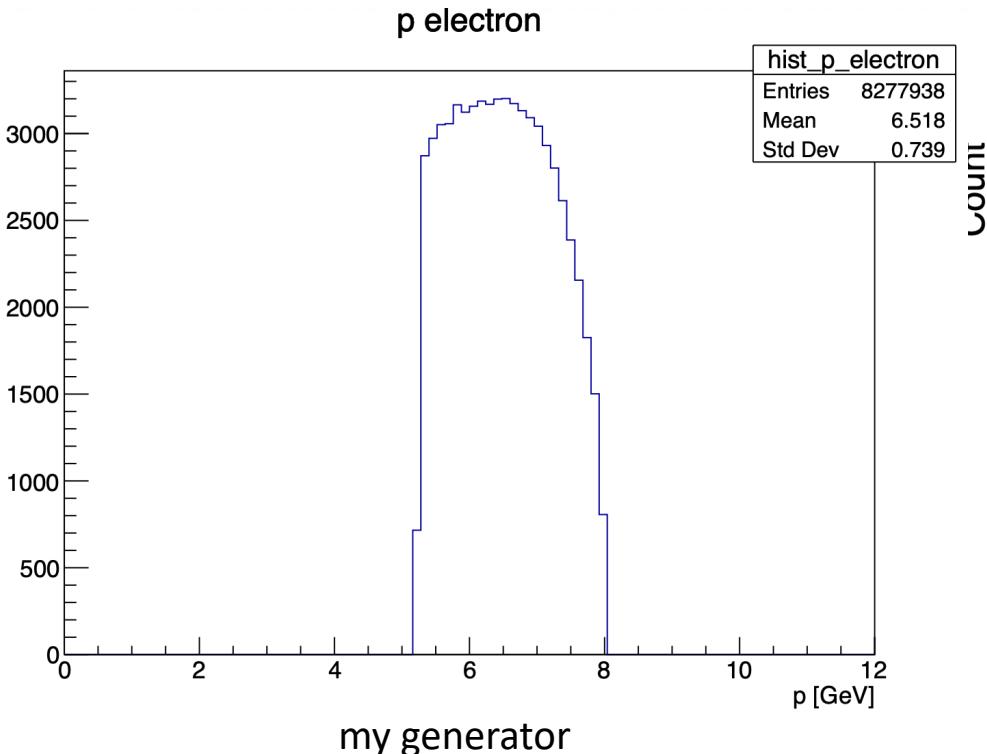


Update on ϕ generator



Update on ϕ generator

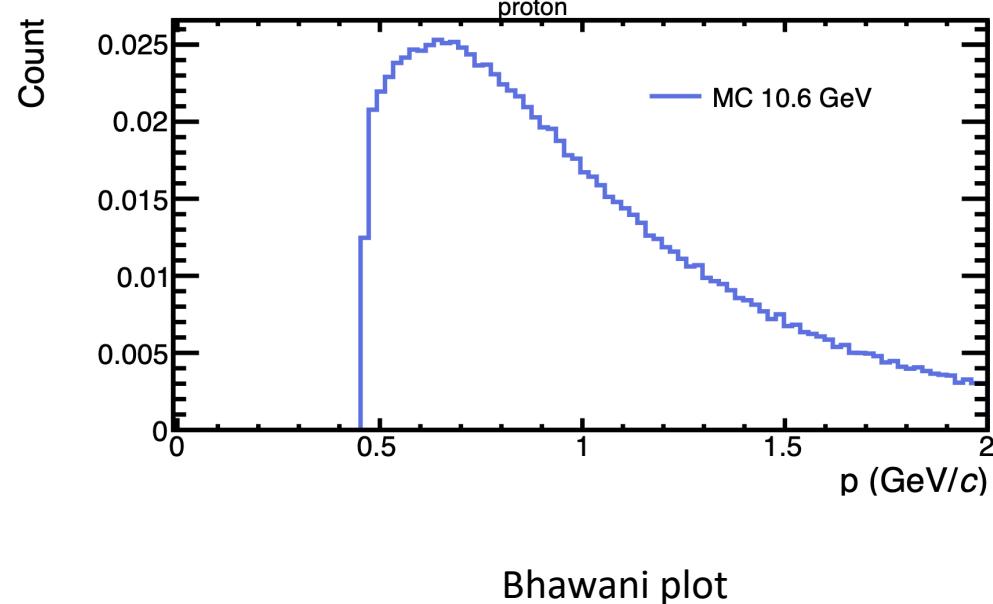
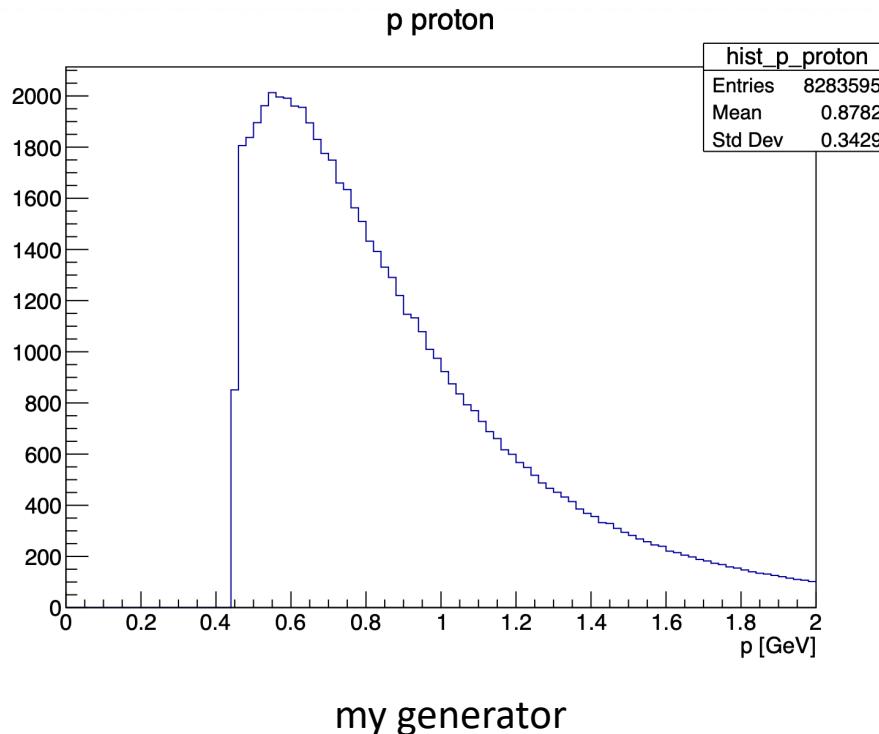
With this cuts : $5.25 < P_{\text{electron}} < 8 \text{ GeV}$ and $P_{\text{proton}} > 0.45 \text{ GeV}$



Bhawani plot

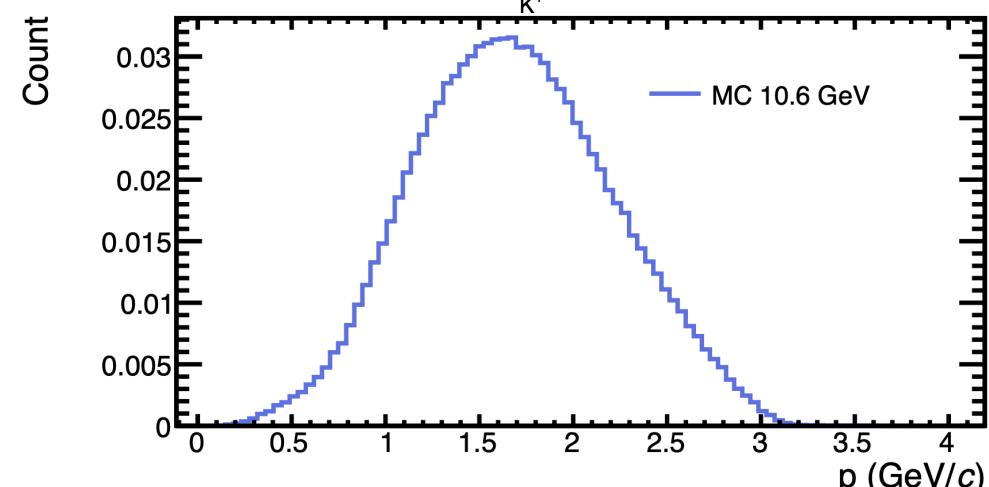
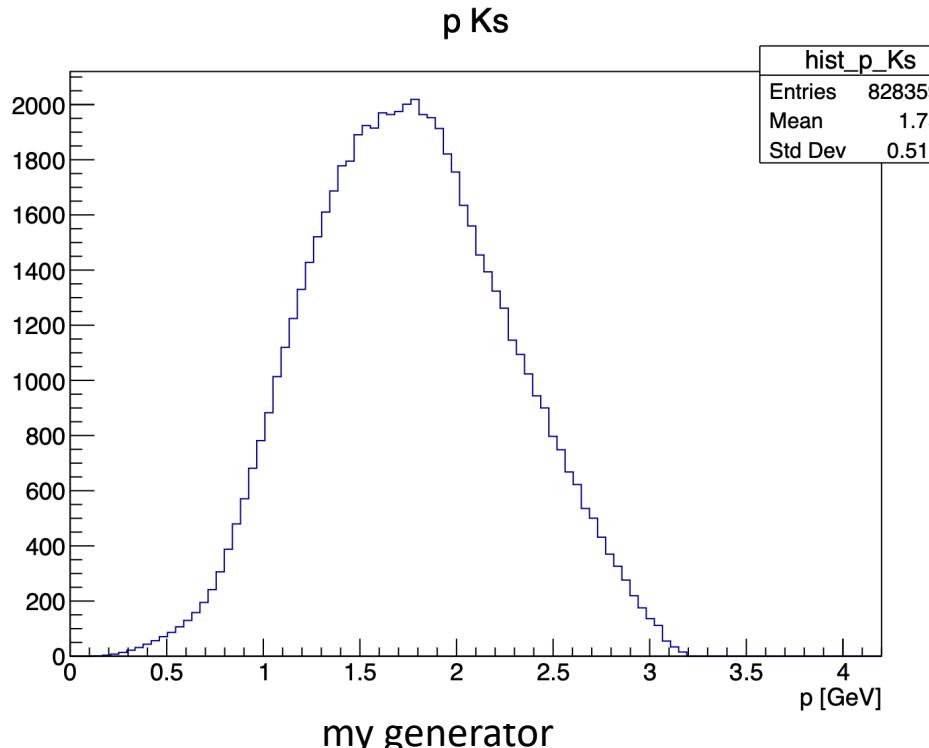
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Update on ϕ generator

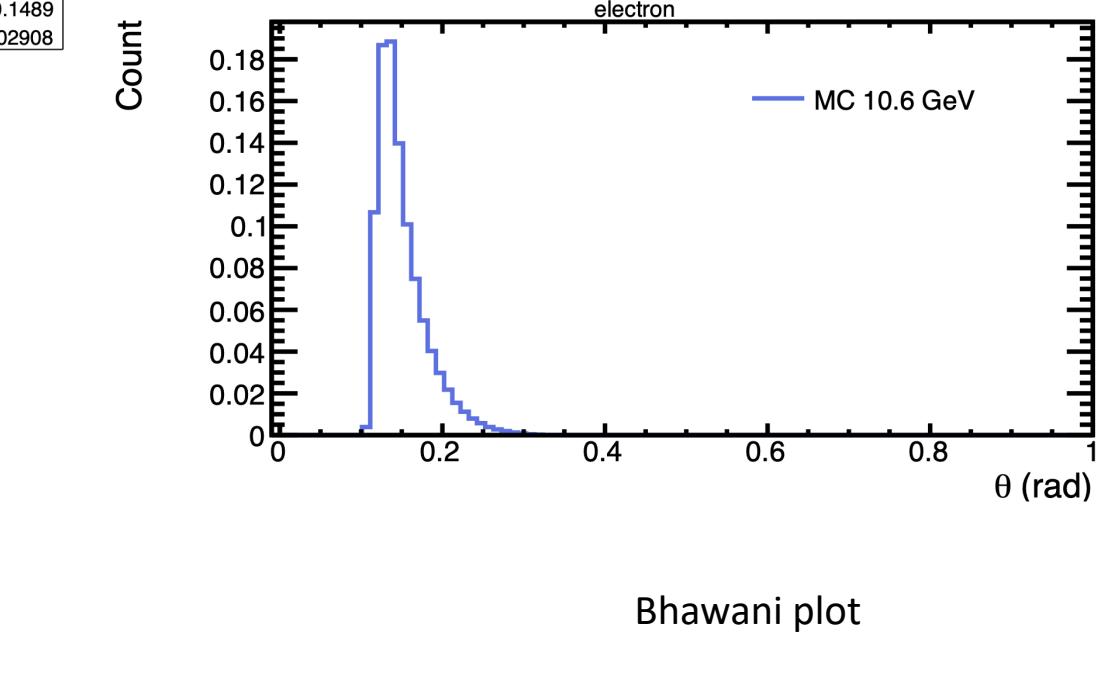
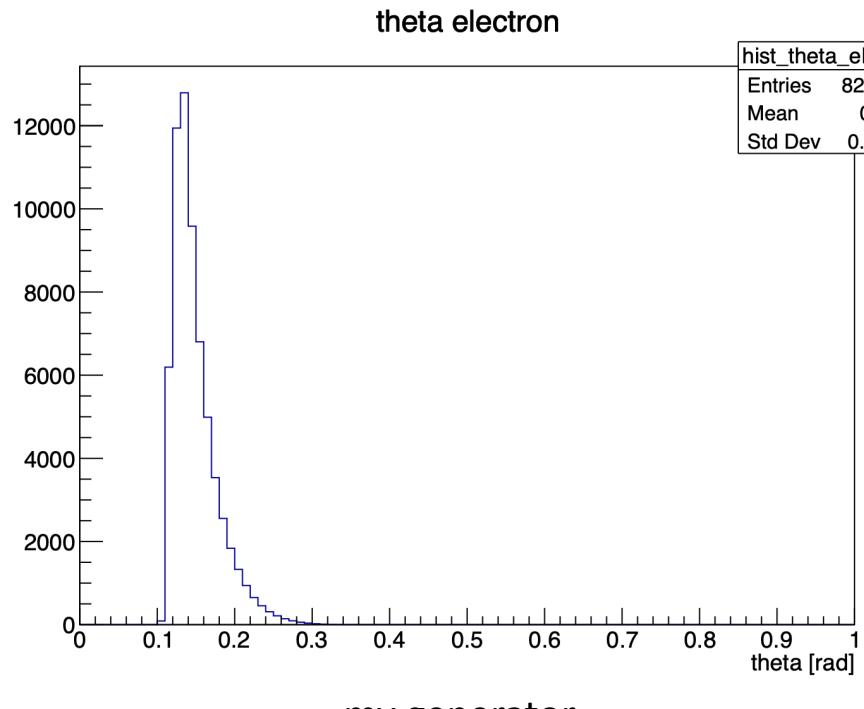
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Bhawani plot

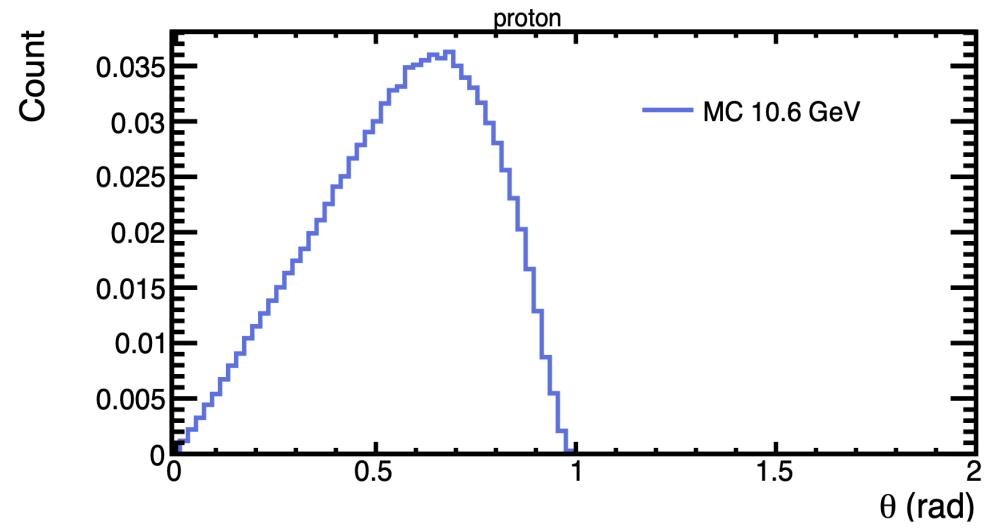
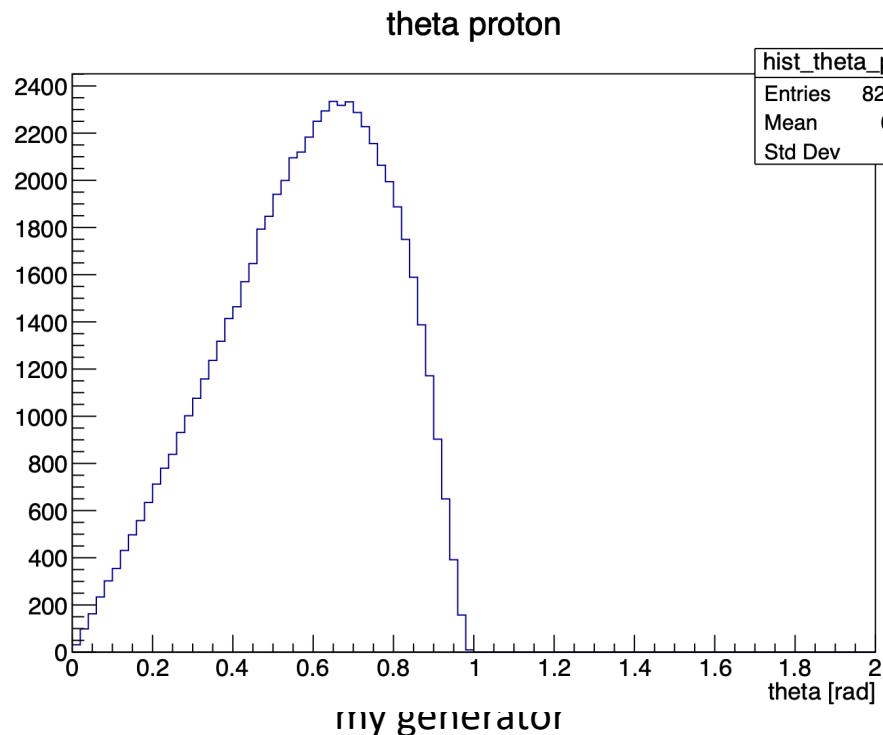
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Update on ϕ generator

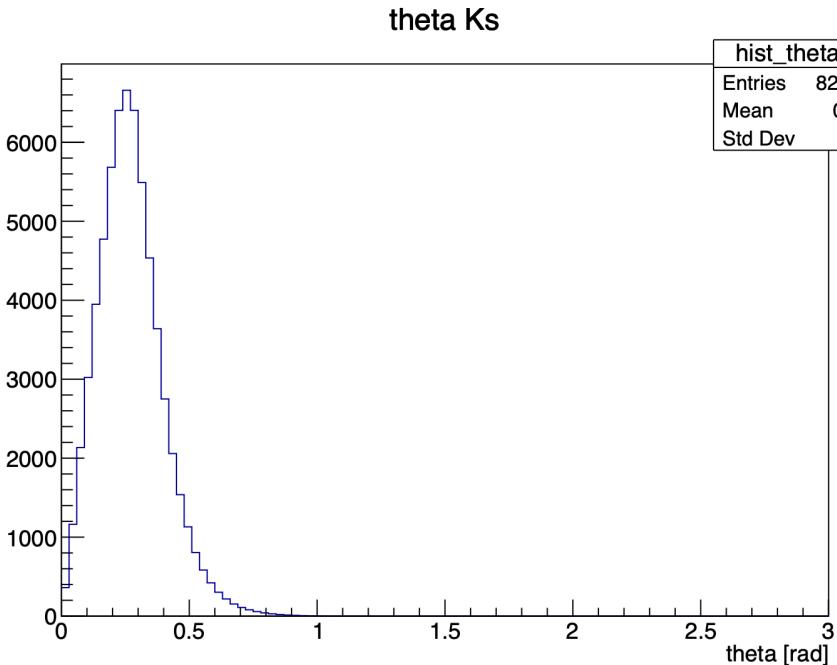
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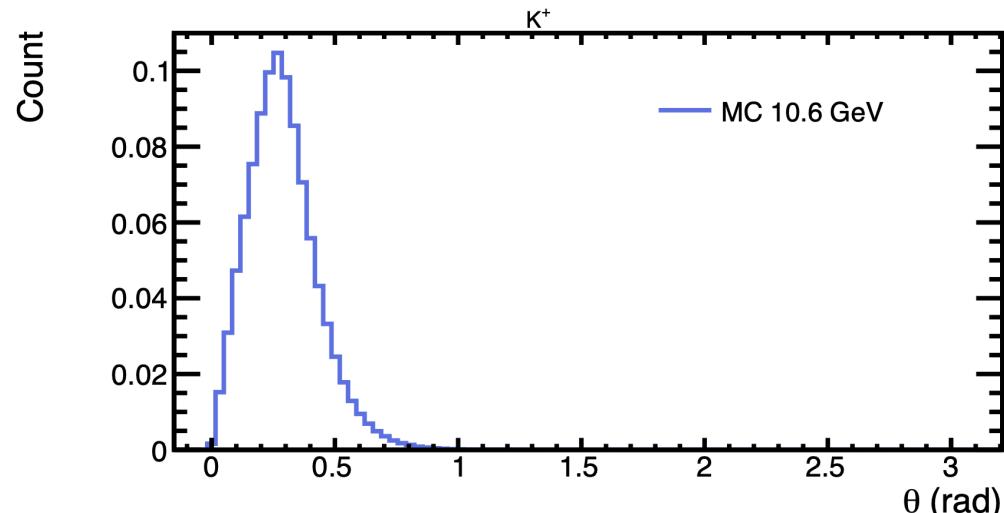
Bhawani plot

Update on ϕ generator

With this cuts : $5.25 < P_{\text{electron}} < 8 \text{ GeV}$ and $P_{\text{proton}} > 0.45 \text{ GeV}$



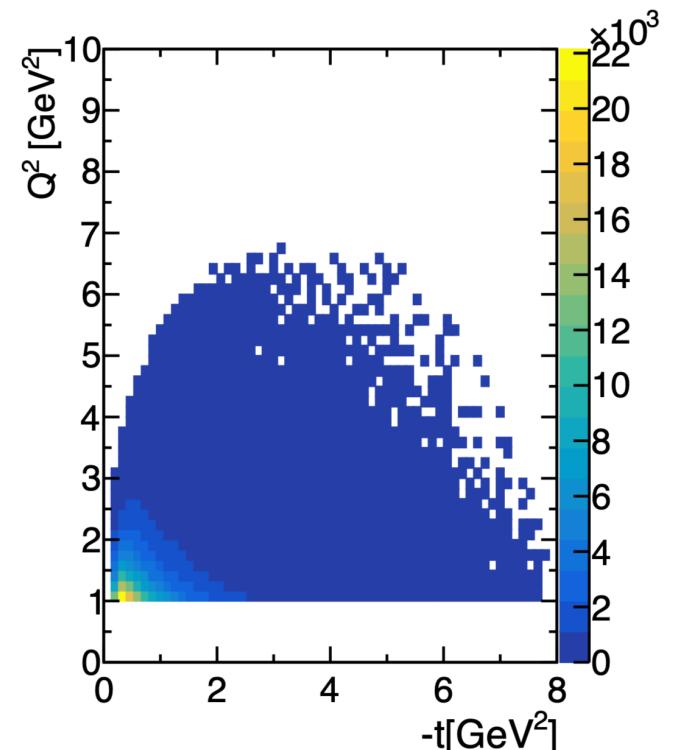
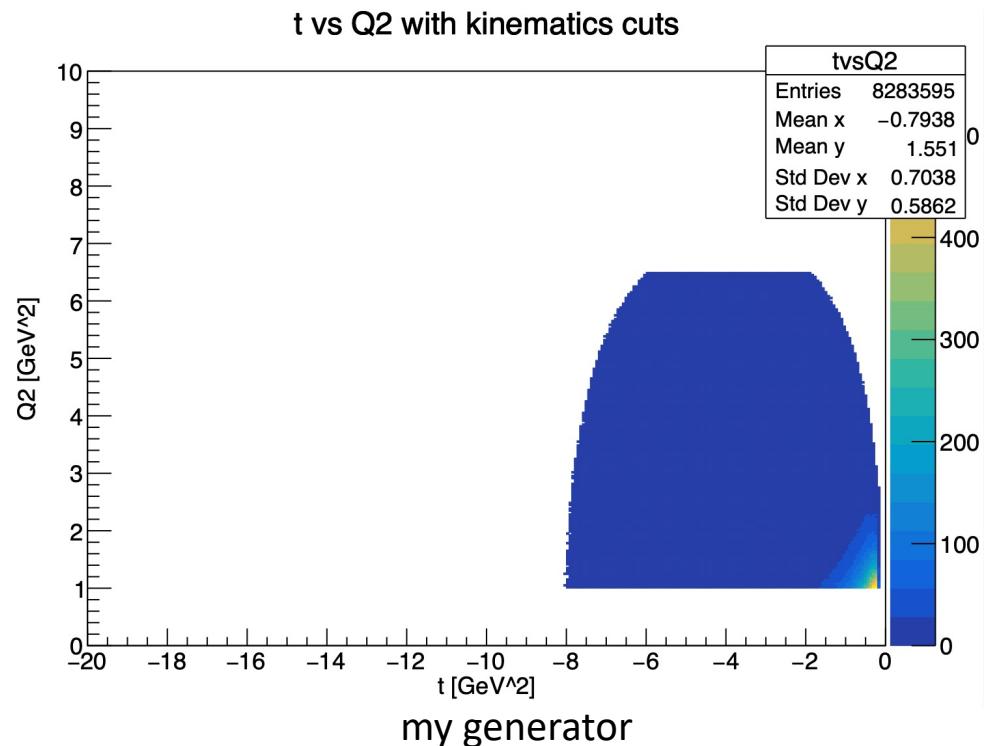
my generator



Bhawani plot

Update on ϕ generator

With this cuts : $5.25 < P_{\text{electron}} < 8 \text{ GeV}$ and $P_{\text{proton}} > 0.45 \text{ GeV}$



Bhawani plot

Update on ϕ generator

Backup cross section

Update on ϕ generator

Details on cross section :

σ_T and $\sigma_L(\gamma^* p \rightarrow \phi p)$:

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

$$R = \sigma_L(W, Q^2)/\sigma_T(W, Q^2)$$

$$R(W, Q^2) = \frac{c_R Q^2}{m_\phi^2}$$

t-dependence (dipole) :

$$\frac{d\sigma_{L,T}}{dt} = \frac{\sigma_{L,T} F(t)}{F_{\text{int}}}$$

$$F(t) = \frac{m_g^8}{(m_g^2 - t)^4}$$

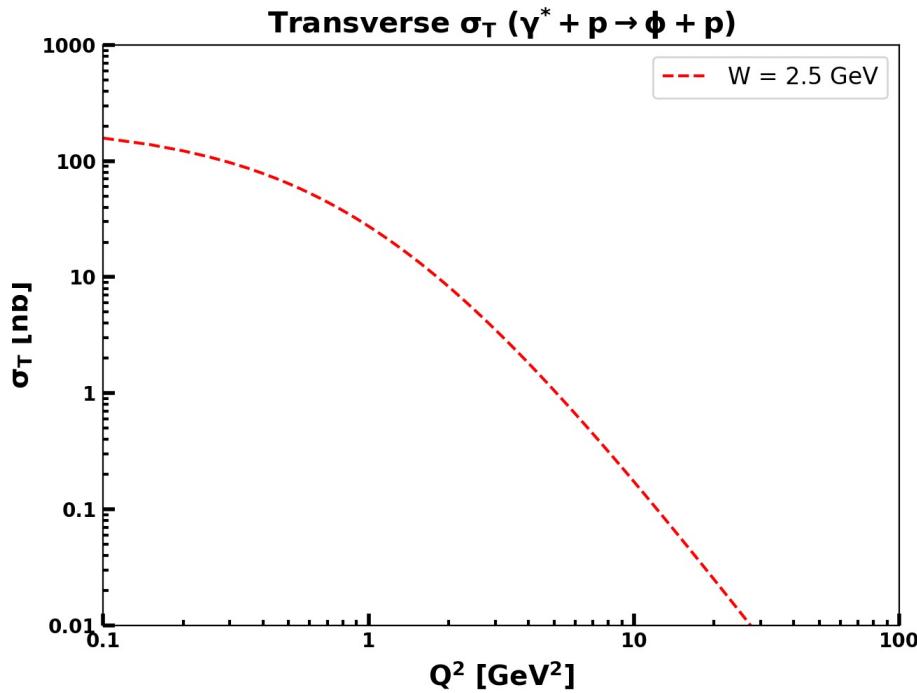
Update on ϕ generator

Cross section ($e p \rightarrow \phi p$) :

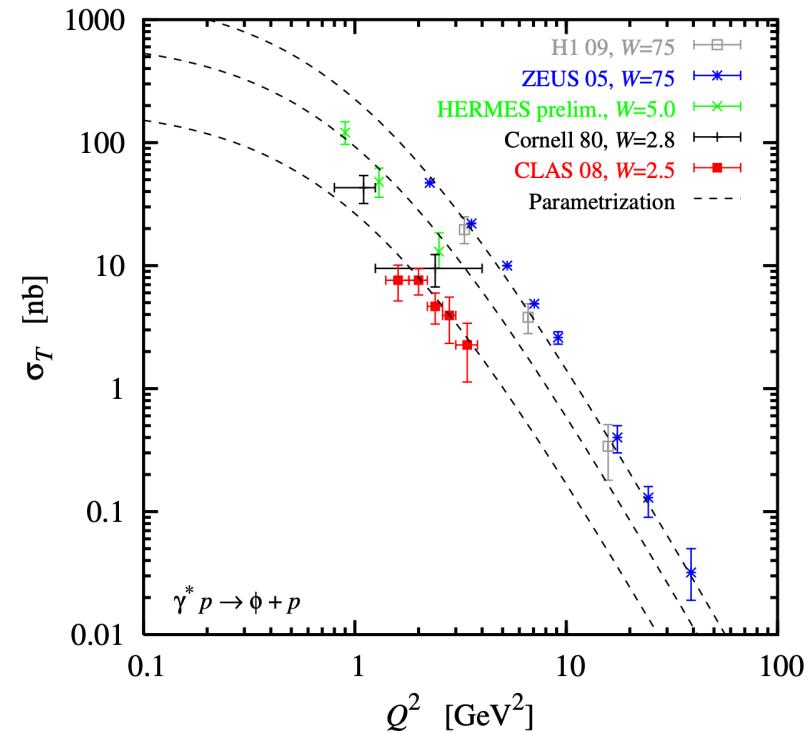
$$\frac{d^3\sigma}{dQ^2 dx_B dt} = \Gamma(Q^2, x_B, E) \left[\frac{d\sigma_T}{dt}(Q^2, x_B, t) + \epsilon \frac{d\sigma_L}{dt}(Q^2, x_B, t) \right]$$

The virtual photon flux : $\Gamma \equiv \frac{\alpha}{8\pi} \frac{Q^2}{m_N^2 E^2} \frac{1-x_B}{x_B^3} \frac{1}{1-\epsilon}$

Update on ϕ generator

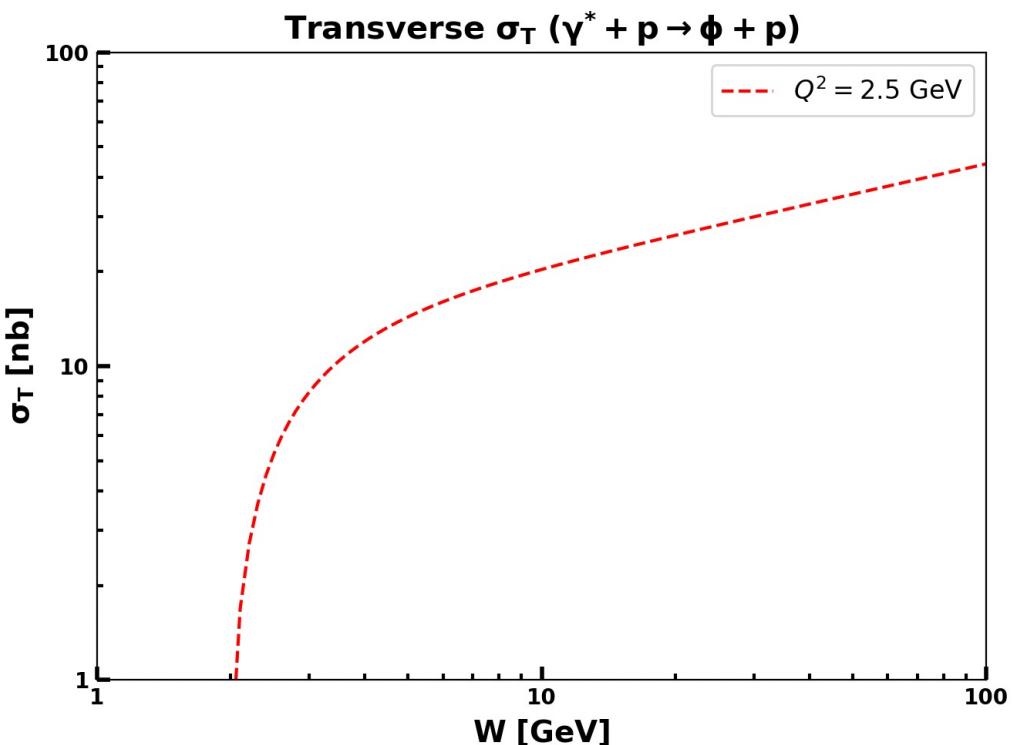


Implemented in the generator

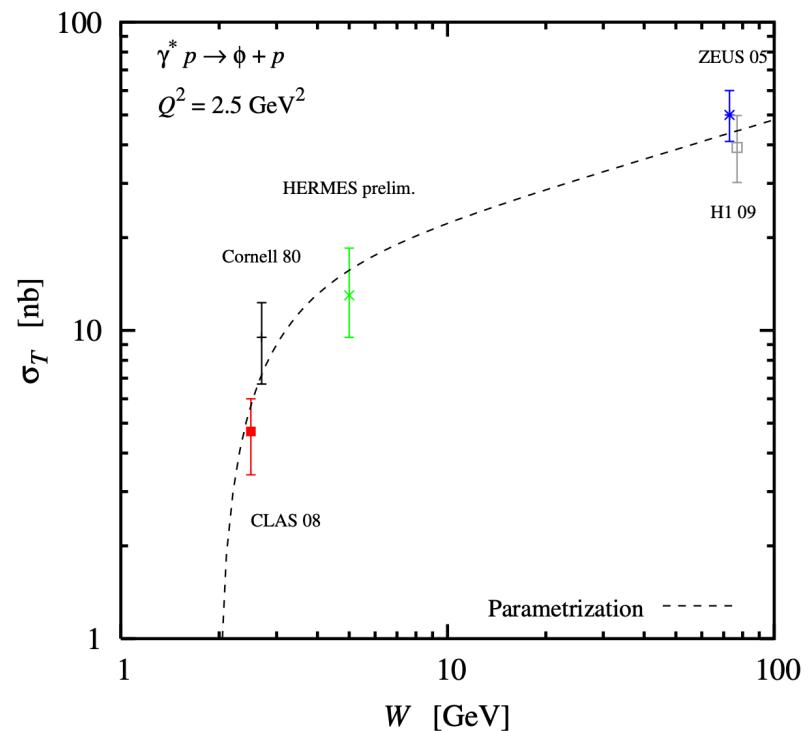


From Proposal to Jefferson Lab PAC39

Update on ϕ generator

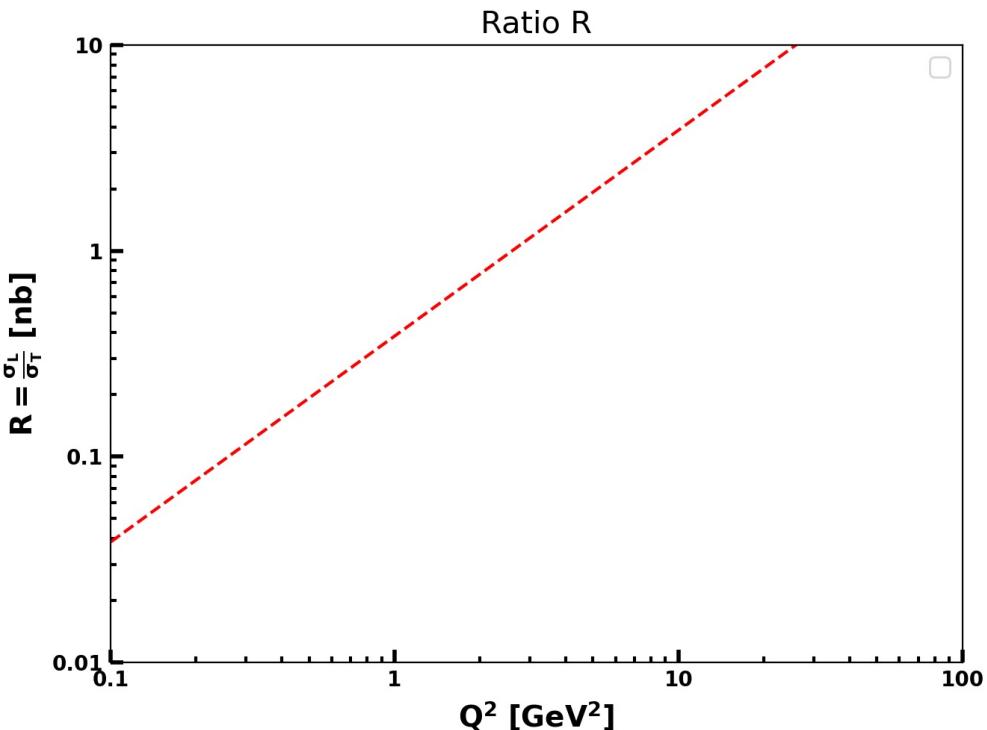


Implemented in the generator

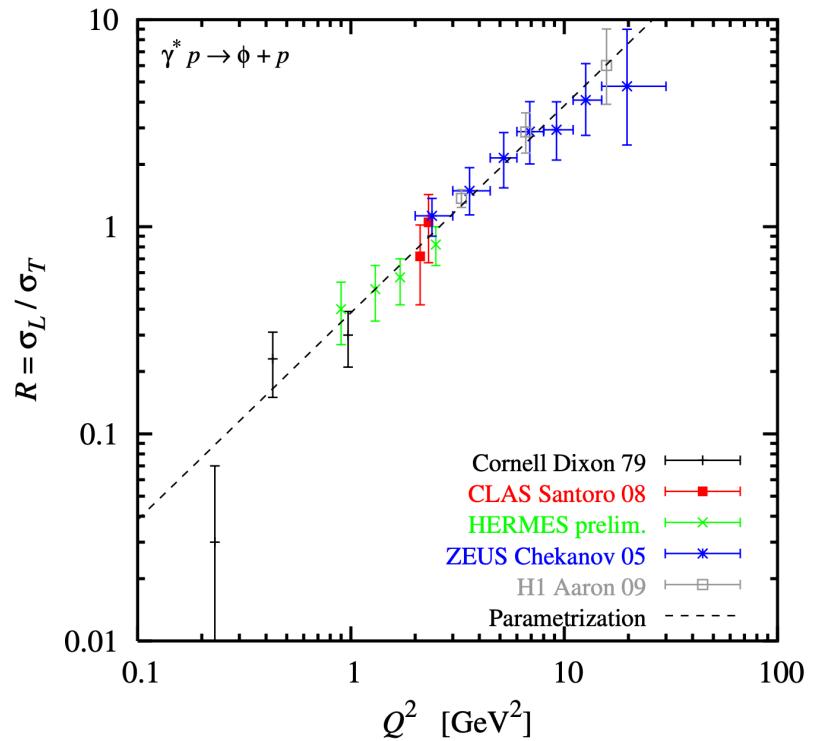


From Proposal to Jefferson Lab PAC39

Update on ϕ generator

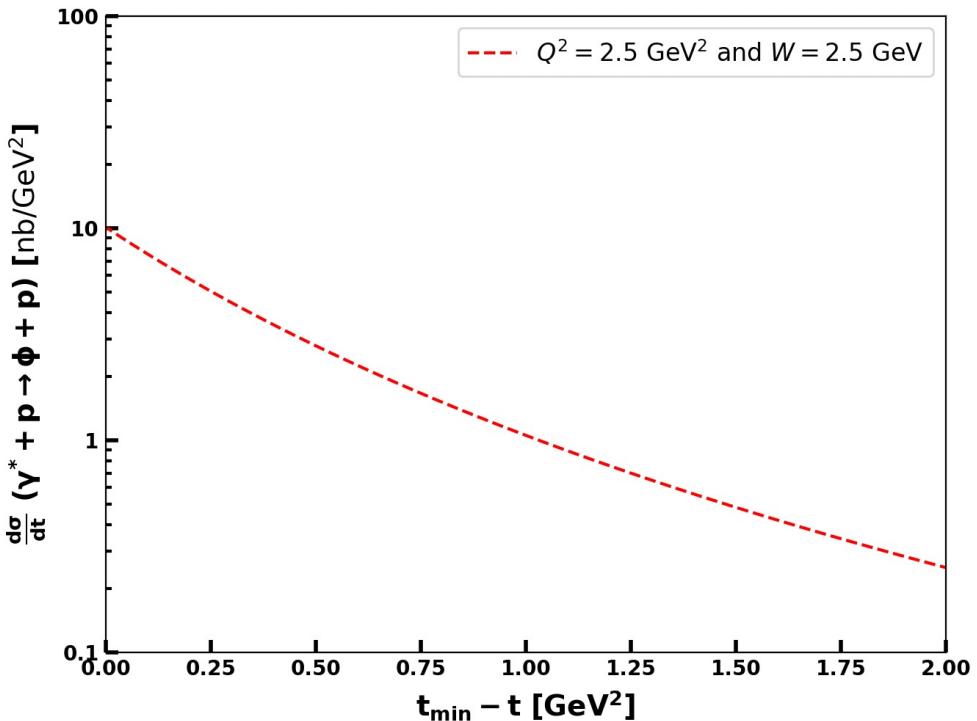


Implemented in the generator

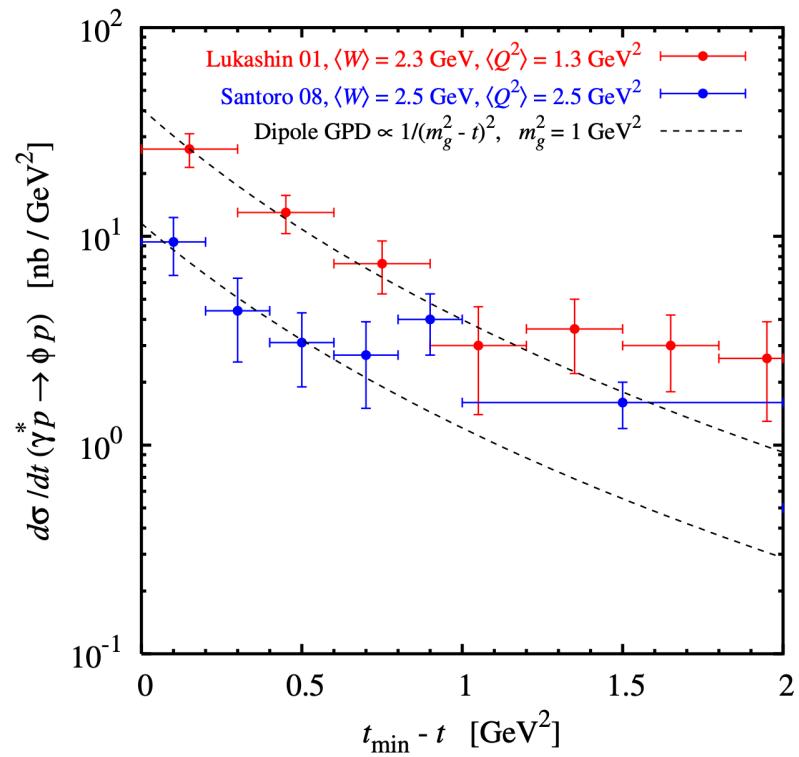


From Proposal to Jefferson Lab PAC39

Update on ϕ generator



Implemented in the generator



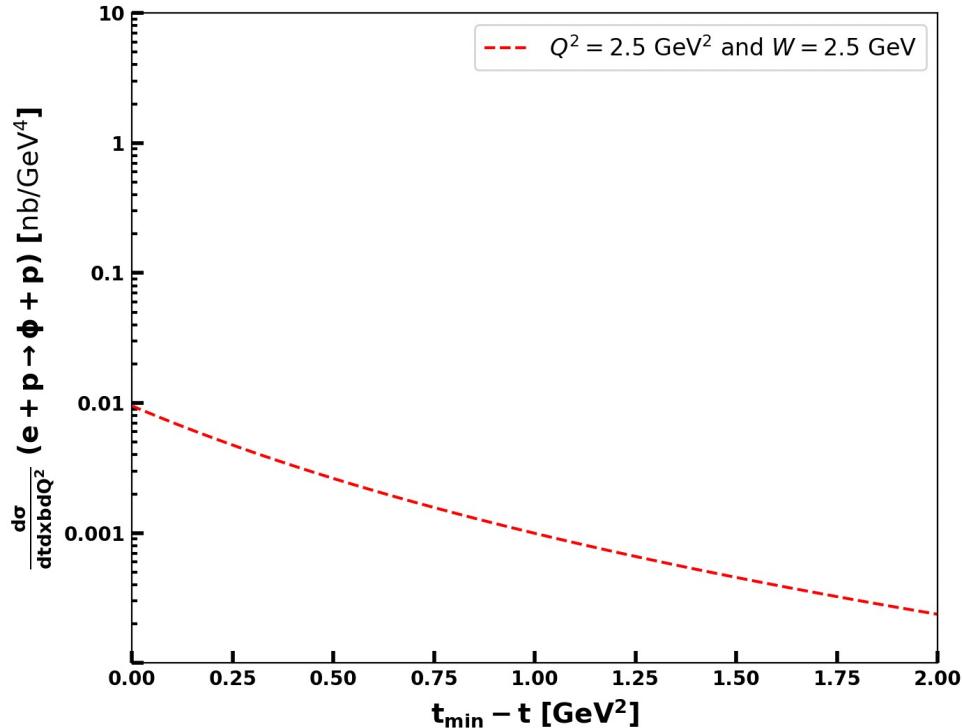
From Proposal to Jefferson Lab PAC39

Update on ϕ generator

Cross section ($e p \rightarrow \phi p$) (with the virtual photon flux) :

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

$$\Gamma \equiv \frac{\alpha}{8\pi} \frac{Q^2}{m_N^2 E^2} \frac{1-x_B}{x_B^3} \frac{1}{1-\epsilon}$$

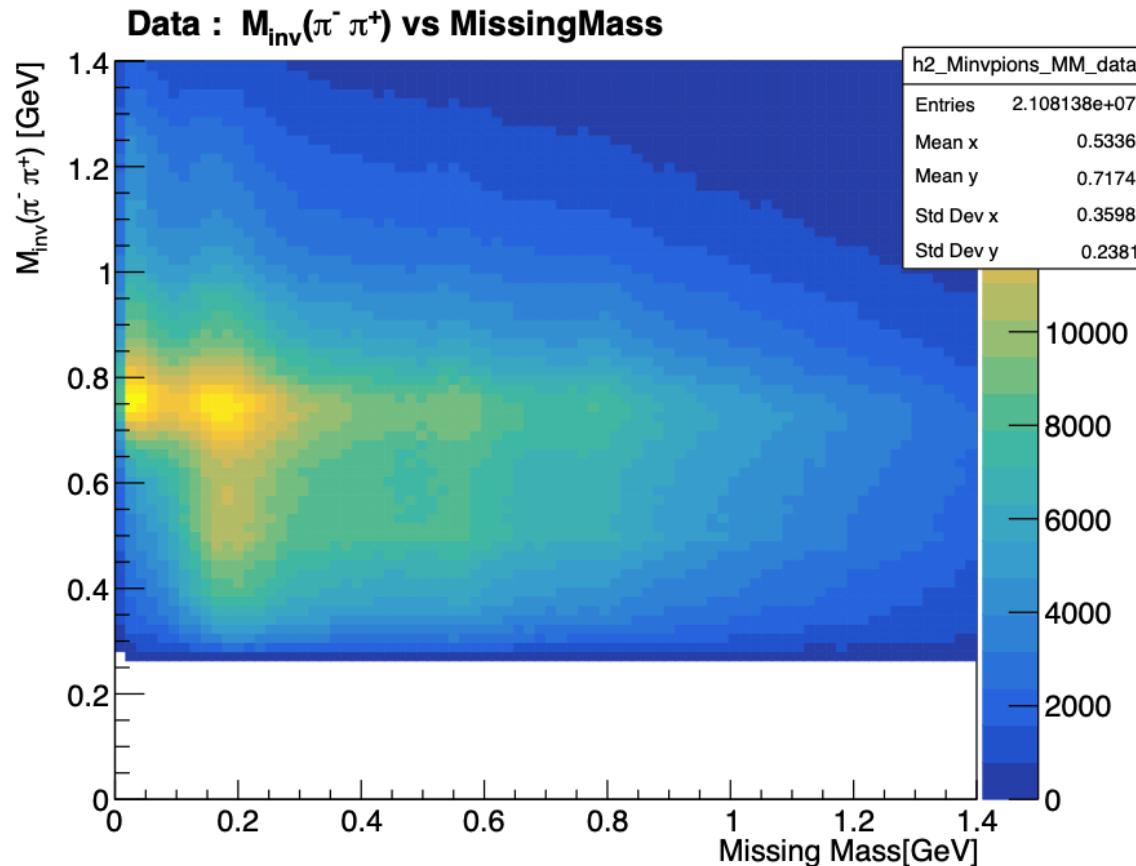


Implemented in the generator

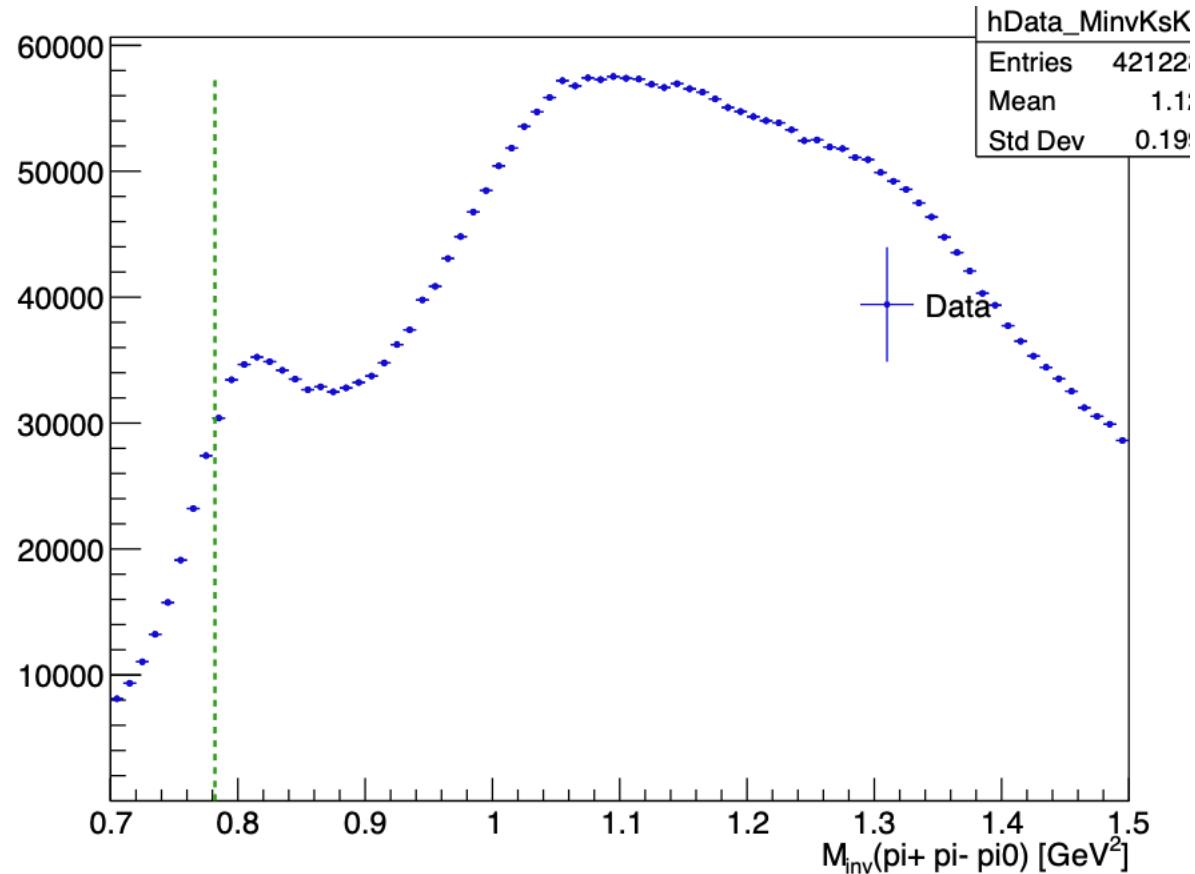
Update on ϕ generator

Backup other plots

Update on ϕ generator



Update on ϕ generator



Test meson w
with cut on MM at the mass of pi0

Update on ϕ generator

