Workshop at 1 GeV Scale: From Mesons to axions

“φ meson production from K^+K^- decay channel in pp@4.5 GeV using HADES”

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HADES

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Outline

- Introduction
- Motivation
- Analysis details
- Some Initial Results
- Summary
- Outlook

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- **Motivation**
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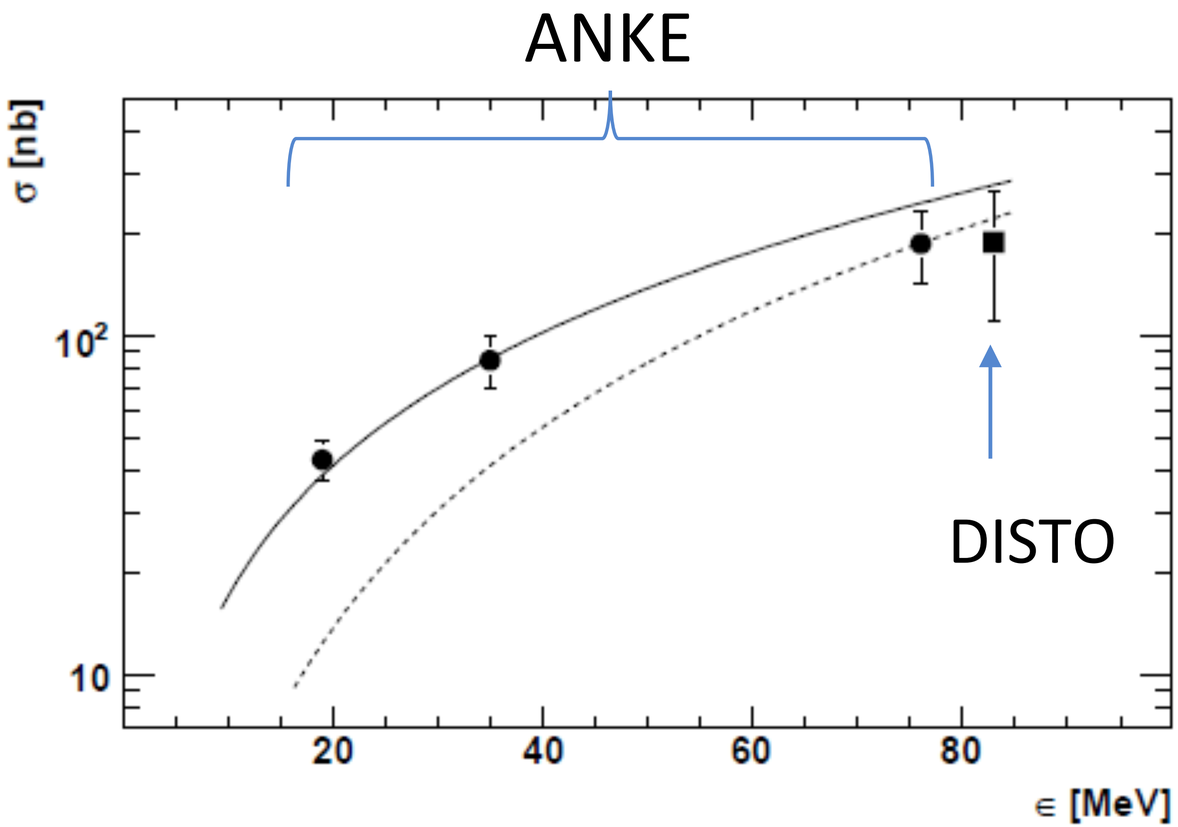
Motivation : Available data on total cross section of Φ production in pp -> ppΦ

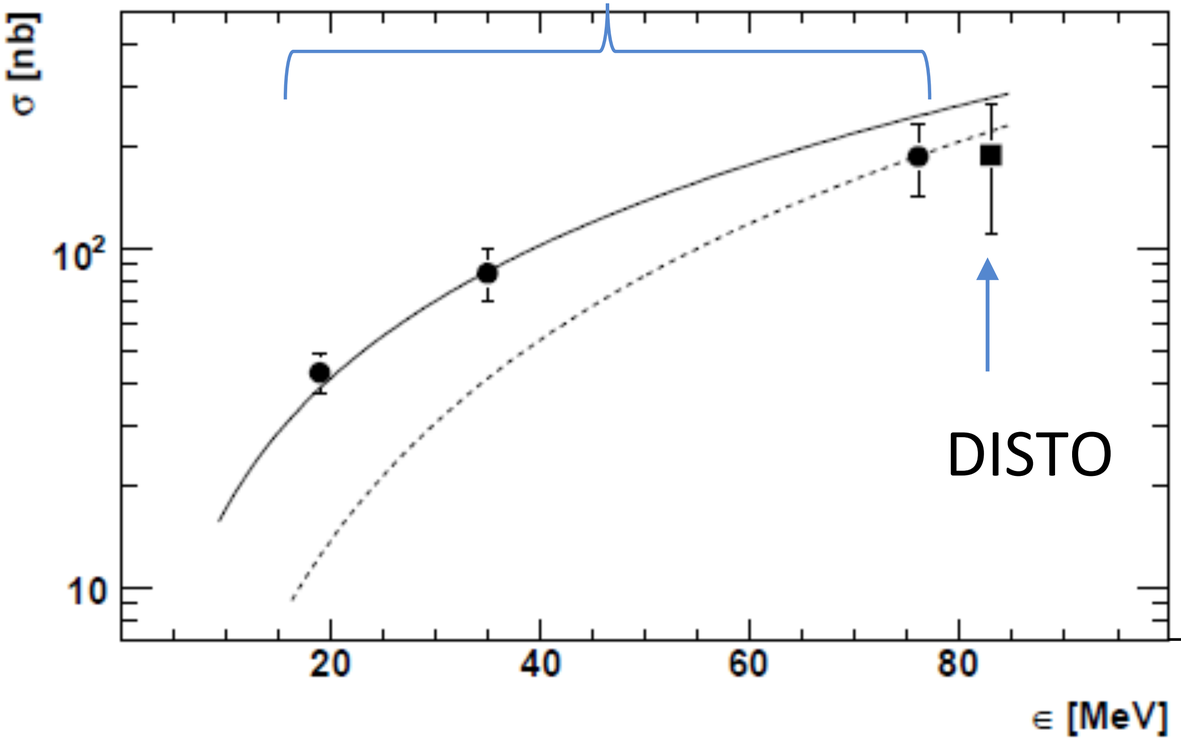


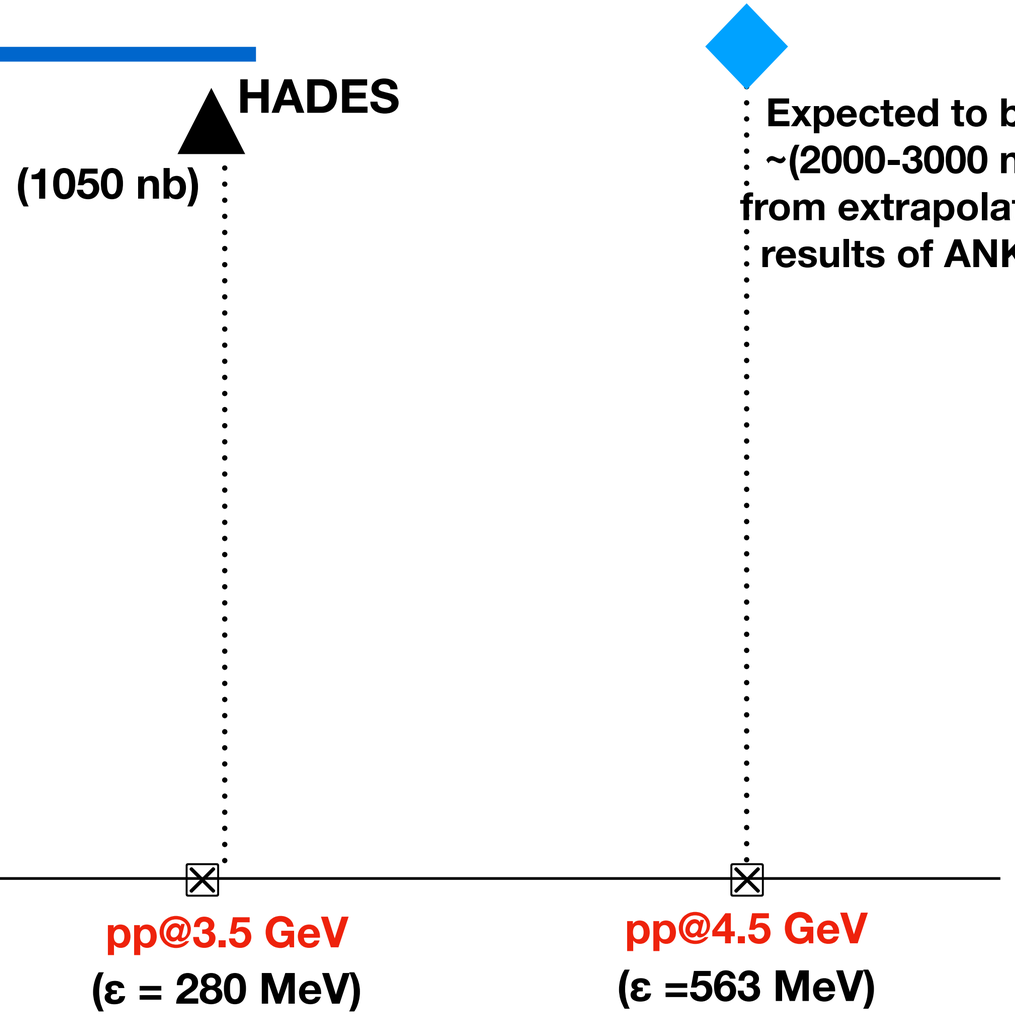
- - - - Phase space only normalised to pass through the highest energy ANKE data

— Parameterised including Final State Effect

ε = Excess Energy = $\sqrt{s}$ - $E_{threshold}$

Motivation : pp -> ppΦ : What Next?





- - - - Phase space only normalised to highest ANKE data

— Parameterised including FSI

ε = Excess Energy = $\sqrt{s}$ - $E_{threshold}$

▲ = Marek Pałka 's Thesis

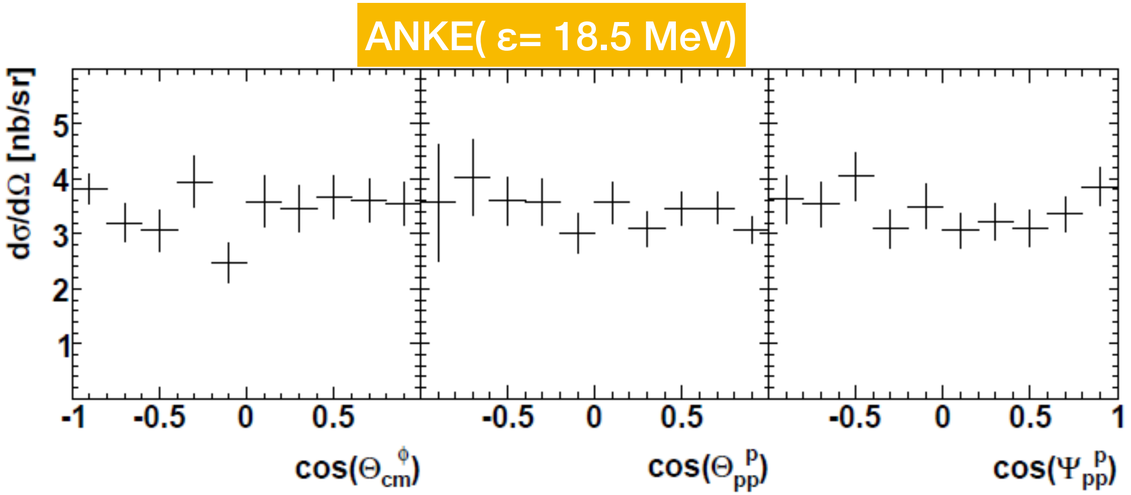
Motivation: Φ meson Angular distribution

ANKE

Close to threshold: low relative angular momenta between the two protons and between ϕ and pp system

$cos(\Theta^{p}_{pp})$ **: in the pp reference frame relative to the beam direction**

$cos(\Psi^{p}_{pp})$ **: in the pp reference frame relative to the Φ direction**



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$cos(\Theta^{p}_{pp})$ **: in the pp reference frame relative to the beam direction**

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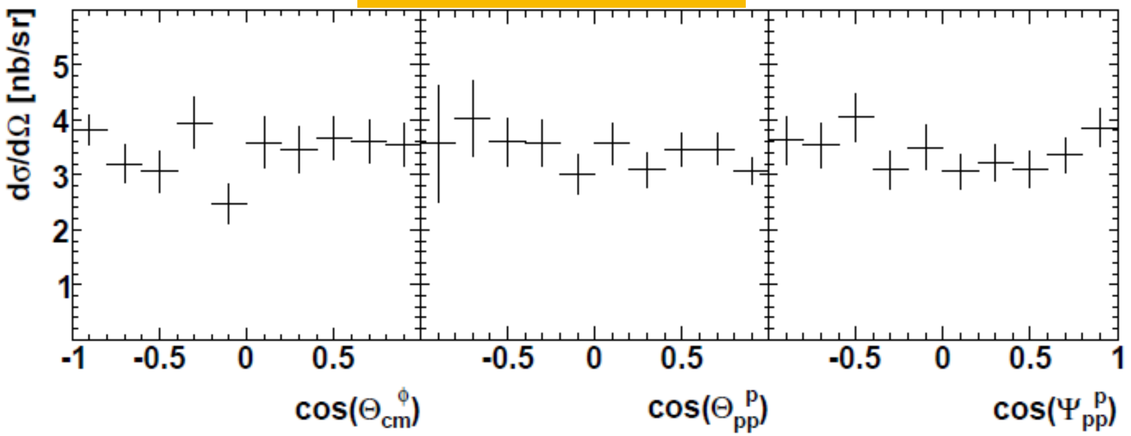
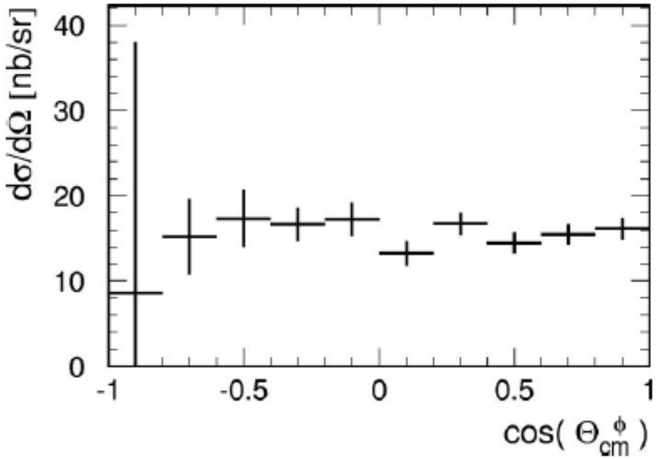
ANKE(ε= 18.5 MeV)

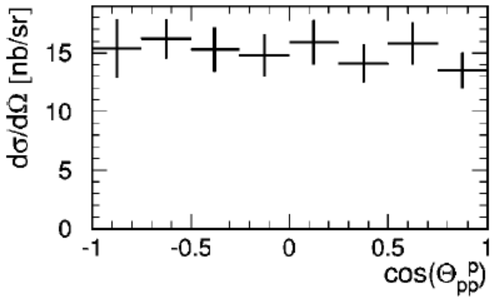


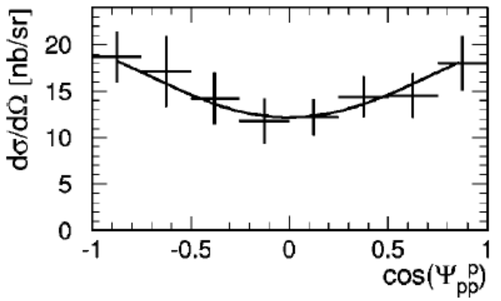
Disto results pp 2.85 GeV (3.67 GeV/c)

Balestra et al. PRC63 024004 (2001)

DISTO (ε= 83 MeV)







After acceptance corrections, ϕ angular distribution is found to be isotropic

It is expected as the measurement is close to threshold, (Q=83 MeV)

ϕ In S wave relative to the protons

We are at much higher energy (Q=563 MeV), probably higher partial waves

Motivation: Φ meson Angular distribution and production mechanisms

Meson production mechanisms mesonic/nucleonic currents
K. Nakayama et al. Phys. Rev. C, 57:1580, 1998.

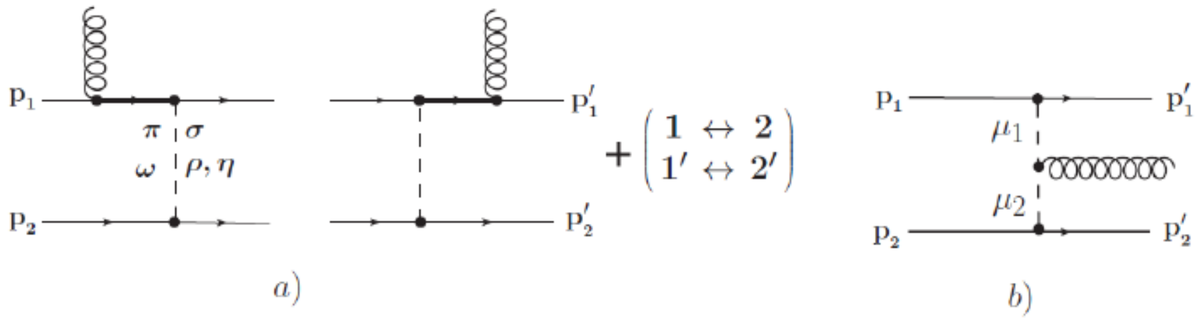
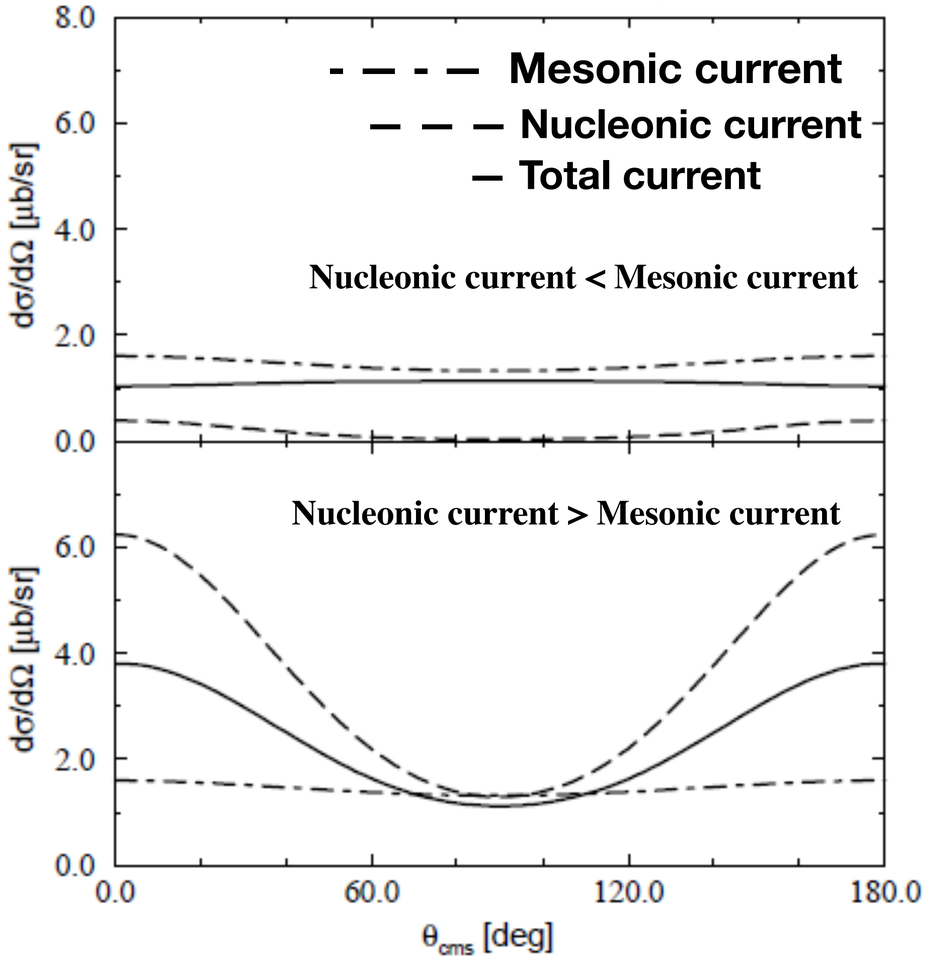


FIGURE (6.6) Feynman diagrams for the nucleonic current (a) and mesonic current (b) contributing to meson production in NN reactions.

Theoretical study



Calculation of angular distribution of ω-meson

Nucleonic current > Mesonic current : Strong Anisotropy

Nucleonic current < Mesonic current : isotropic

Possible similar qualitative behaviour for ϕ ?

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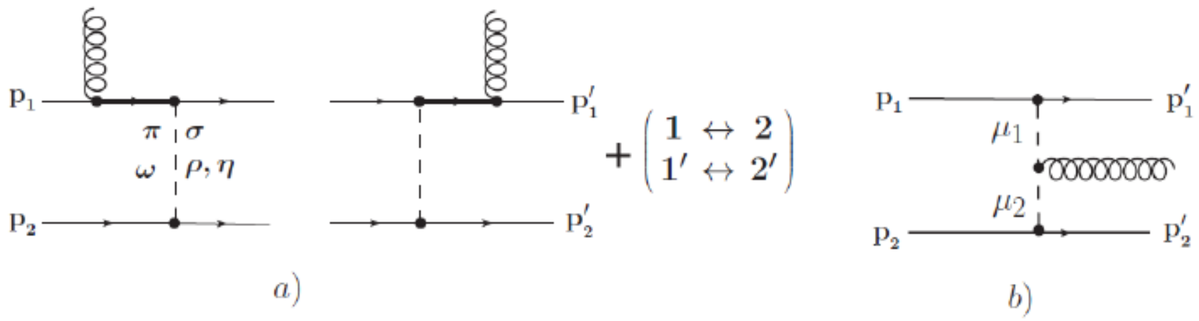

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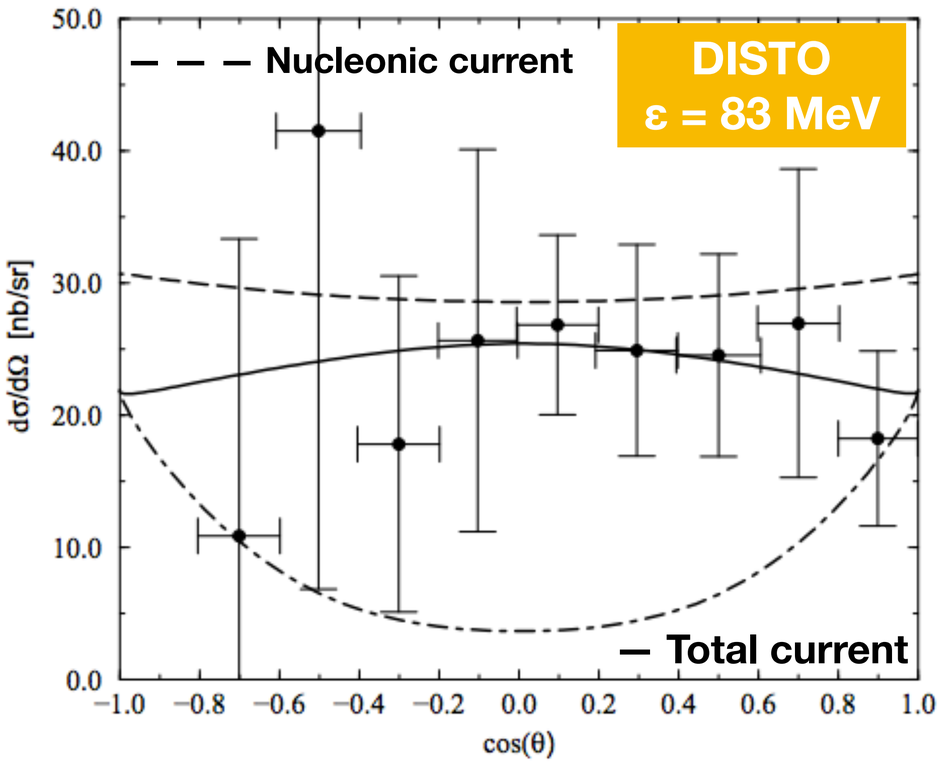
Source: Haidenbauer et.al., arXiv:nucl-th/9810069v1



- **Angular distribution of ϕ meson at T_{lab} = 2.85 GeV and ε = 83 MeV**
- **Angular distribution is fairly flat**
- **Only small contribution of nucleonic current is required if the angular distribution drops at forward and backward angles**

Motivation: Φ meson Polarisation

(1). At threshold, outgoing pp pair in $^1S_0$ state:

full alignment between spin projection of Φ and incident pp pair

(2). Alignment expected to be diluted at higher energies, due to the contribution of higher incident partial waves, K^+-> K^+/K^-

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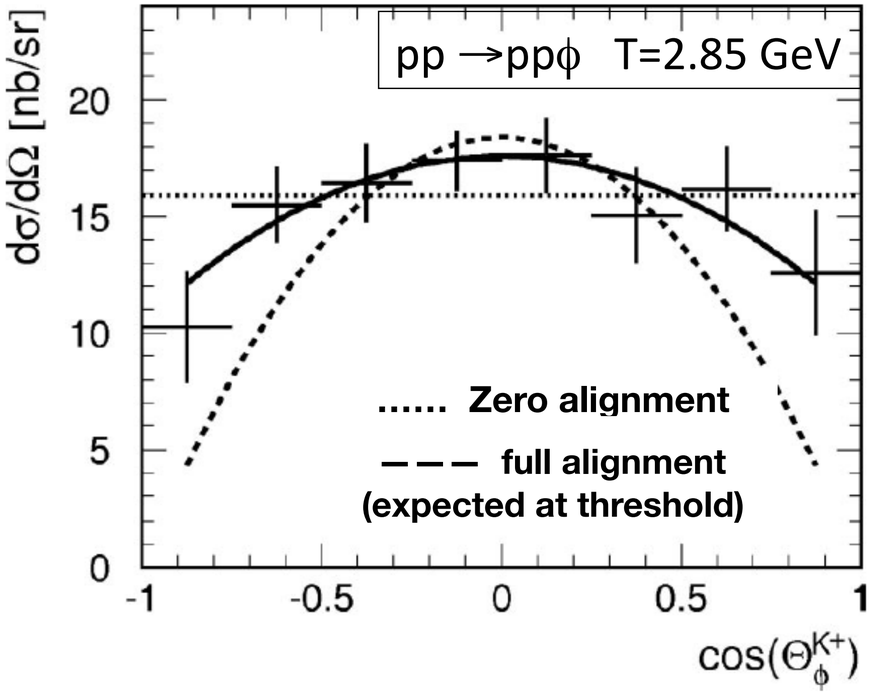
Angular distribution of K^+ in Φ reference frame:

$$W(\Theta_\phi^K) = \frac{3}{2}[\rho_{11}\ \sin^2\Theta_\phi^K + \rho_{00}\ \cos^2\Theta_\phi^K].$$

Theoretical predictions : Titov et al. Phys.Rev.C 59 (1999) 999

ρ_{00} = 0.23 +- 0.04, with mixture of $^1S_0$ and $^3P_{1,2}$



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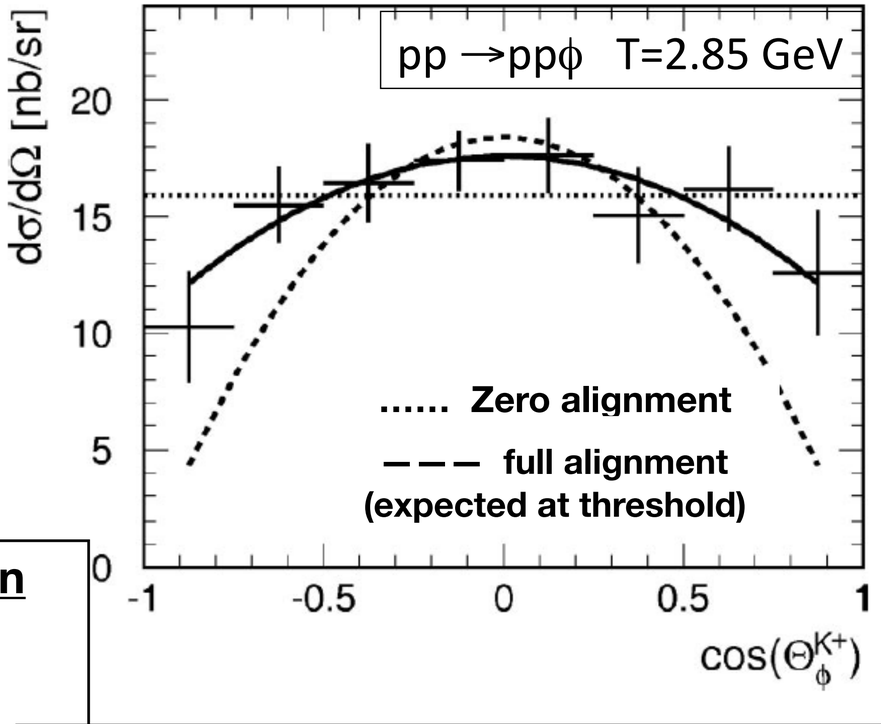
Extraction of spin density matrix elements via K+/K- angular distribution

- ✓ **Φ polarisation**
- ✓ **additionnal information on production mechanism**



Source: Balestra et al., PHYSICAL REVIEW C 63 024004

With this motivation, We Proceed Further

Objectives of this work :

1) Inclusive production cross section of φ meson
2) Angular distribution of φ meson
3) φ Polarisation via kaon angular distribution
4) Production Mechanism of φ meson

Complimentary to Valentin's work

1) which involves neural network selection of decay products, whereas here we use hard cuts
2) Exclusive

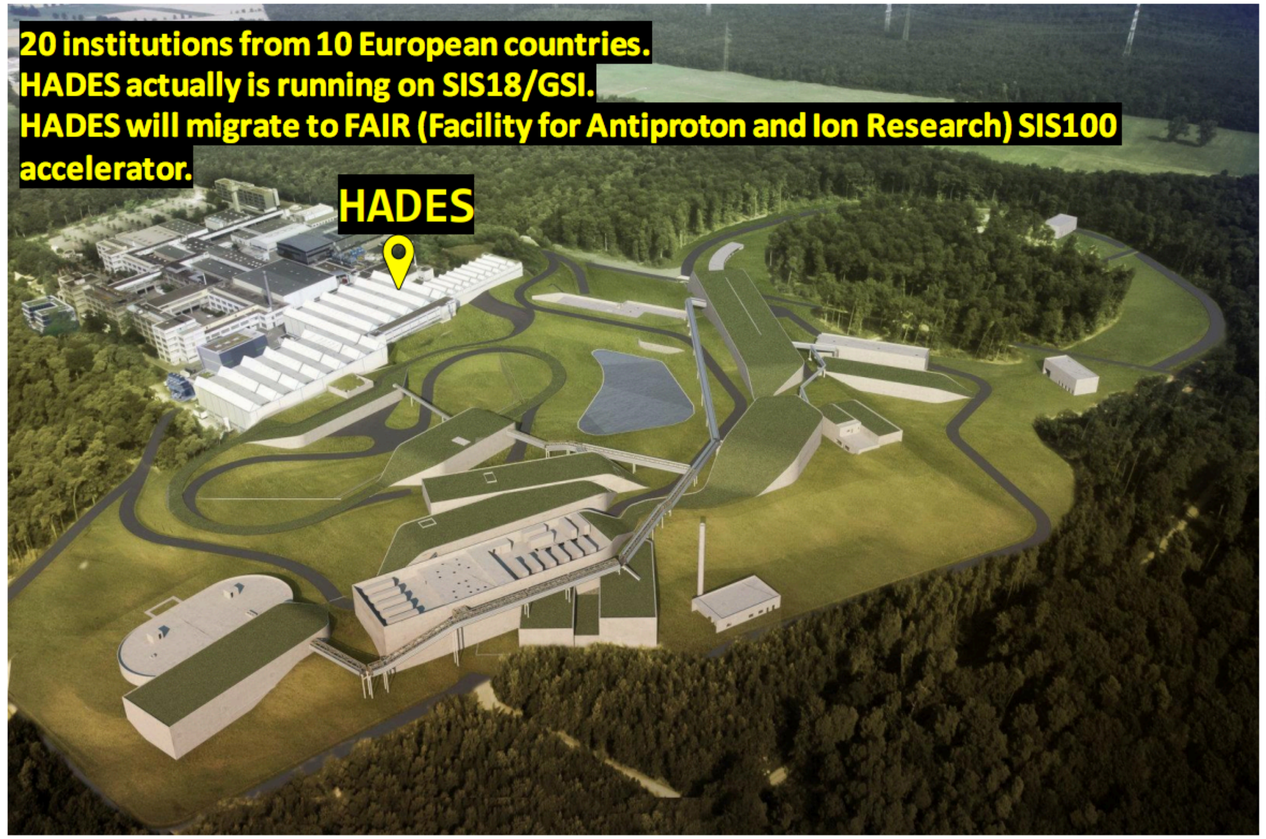
Objectives of this work : p(4.5 GeV)+p -> ppφ[K^+K^-]

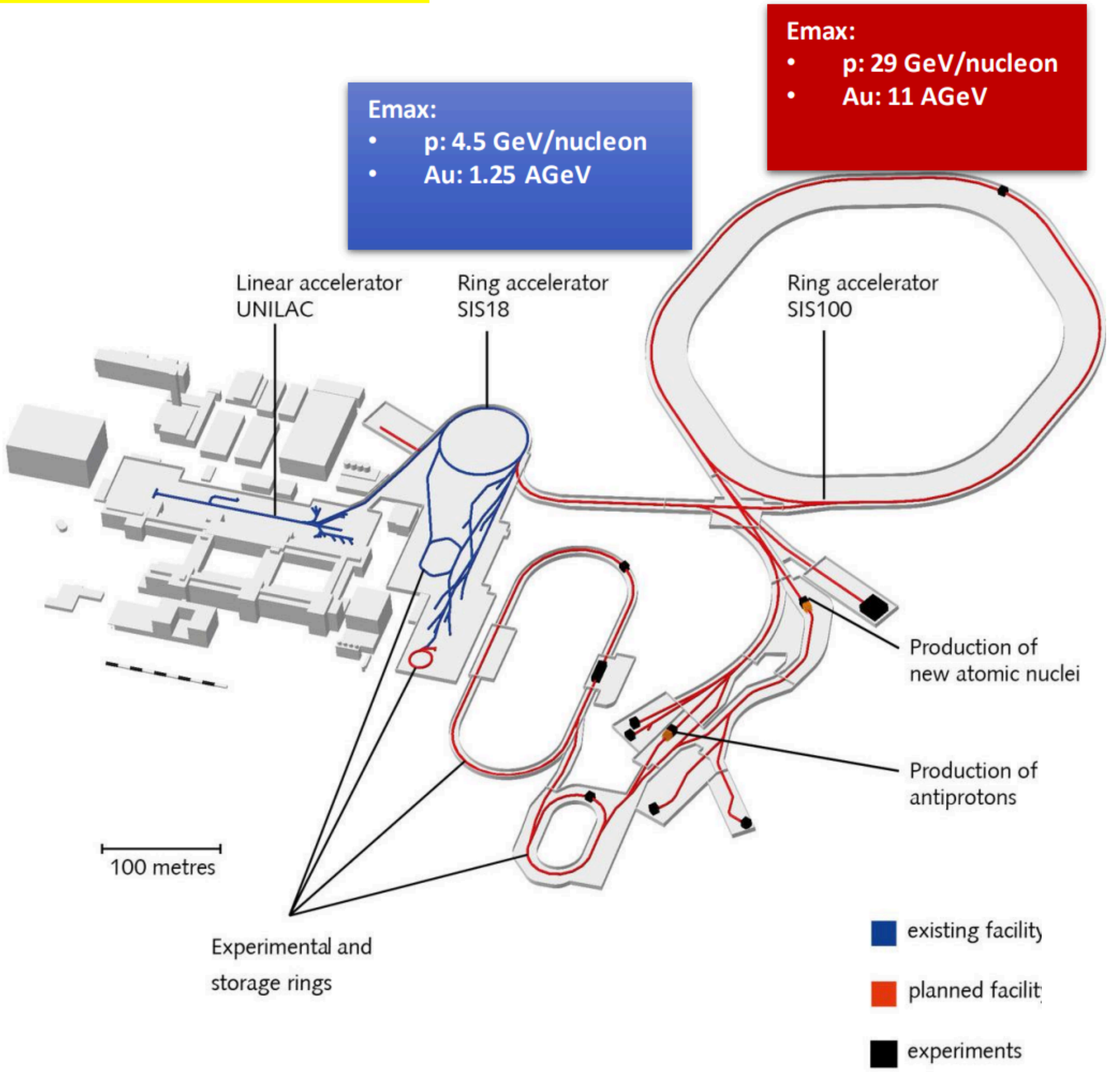
1) Inclusive production cross section of φ meson
2) Angular distribution of φ meson
3) φ Polarisation via kaon angular distribution
4) Production Mechanism of φ meson

We are using HADES and Forward detector @ GSI to achieve this objectives

The HADES Detector @GSI

HADES collaboration and FAIR @ GSI

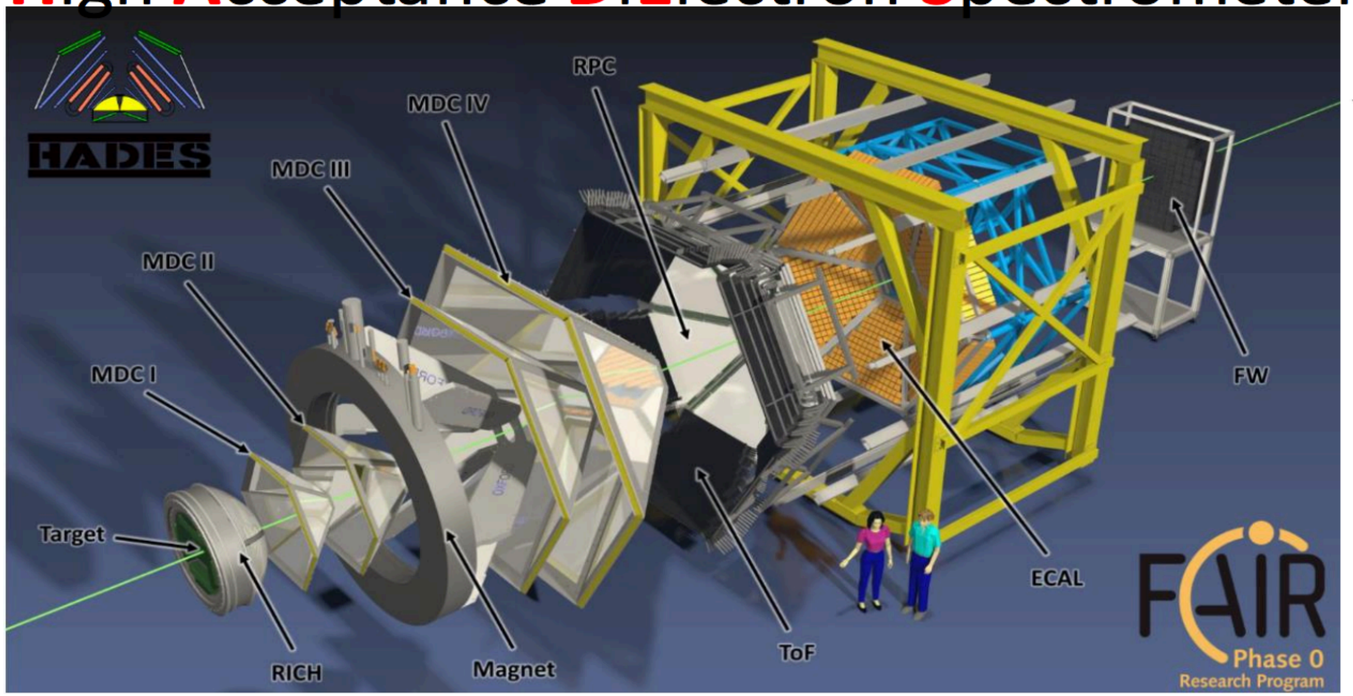


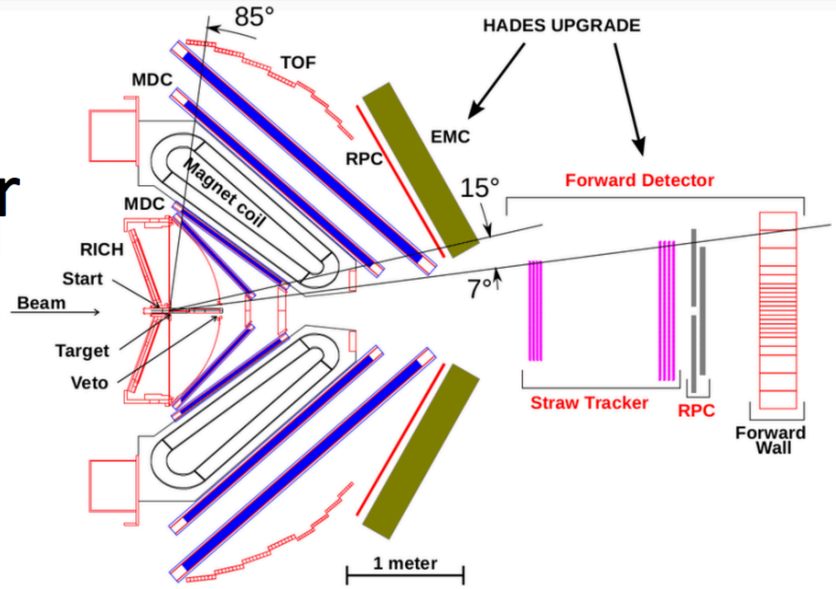


The HADES Detector - in detail

HADES experimental setup

High Acceptance DiElectron Spectrometer



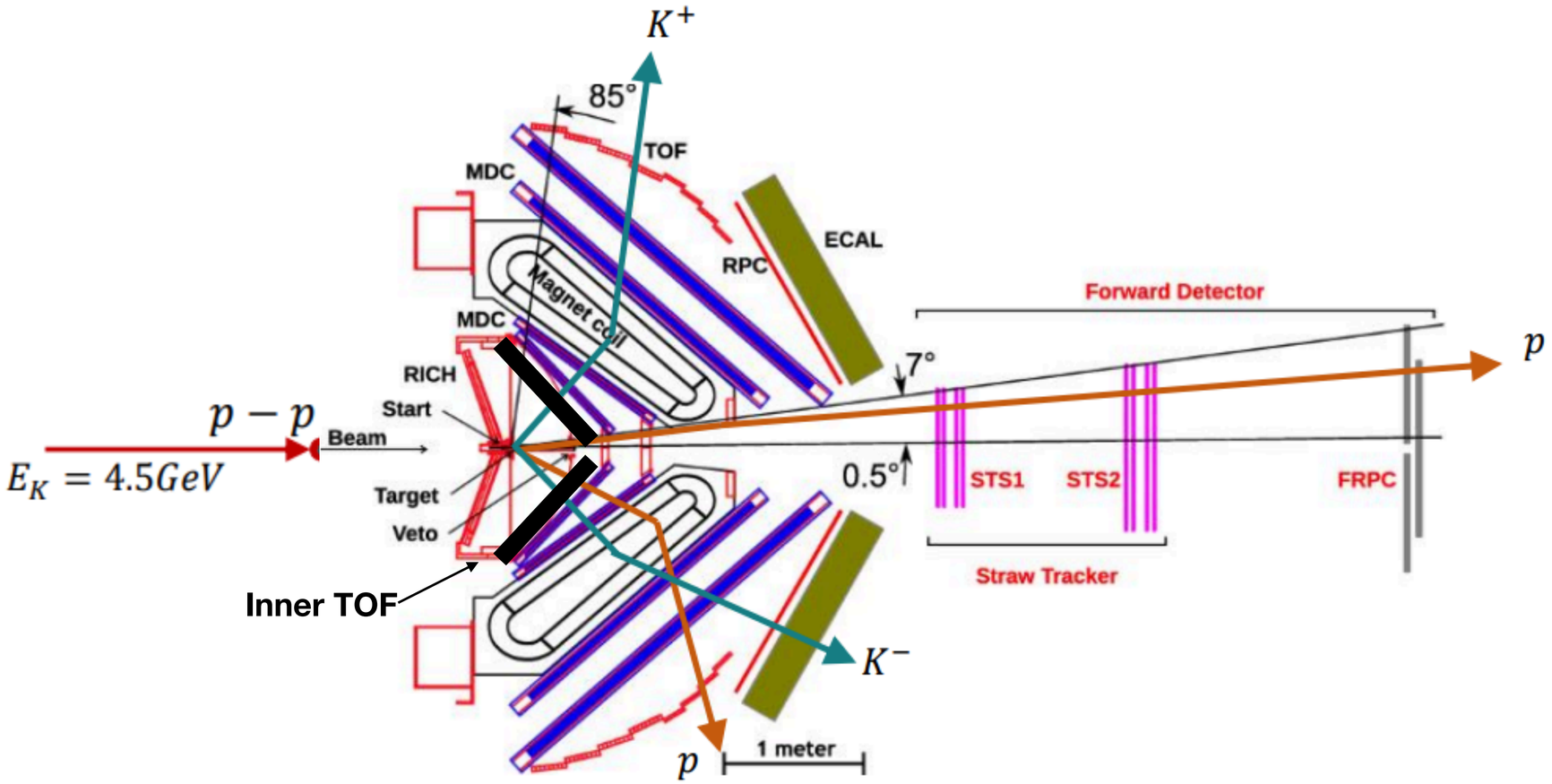


- Fixed target experiment.
- Large geometrical acceptance: full azimuthal range and polar angles 18° and 85°.
- Efficient track reconstruction and momentum determination (MDC+Magnet) and particle identification (RICH, TOF, RPC and ECal).
- FWD: polar angles [0.5°-7°].

Experiments (2004-2022)

- Dense and hot hadronic matter studies: **C+C** (1 and 2 AGeV), **Ar+KCl** (1.75 AGeV), **Au+Au** (1.25 AGeV), **Ag+Ag** (1.65 AGeV).
- Cold matter studies : **p+Nb** (3.5 GeV), **π^-+C/W** (1.7 GeV/c), **π^- + CH2/C** (0.7 GeV/c).
- Elementary reactions: **p+p** (1.25, 2.2, 3.5 and recently 4.5 GeV), **d+p** (1.25 GeV/nucleon).

The HADES Detector - Particle identification for my work



Beam Proton with Kinetic energy 4.5 GeV made to collide with Target Proton

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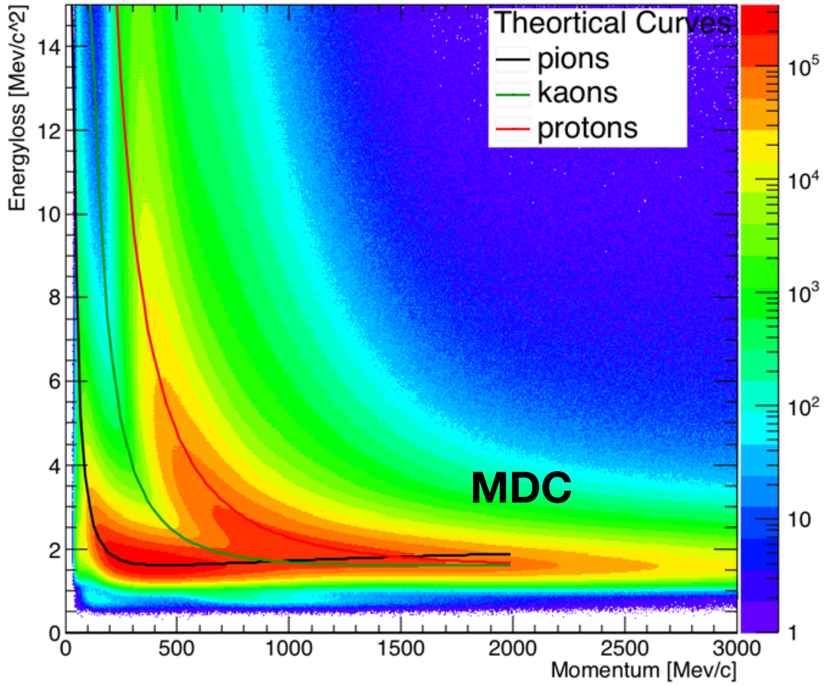
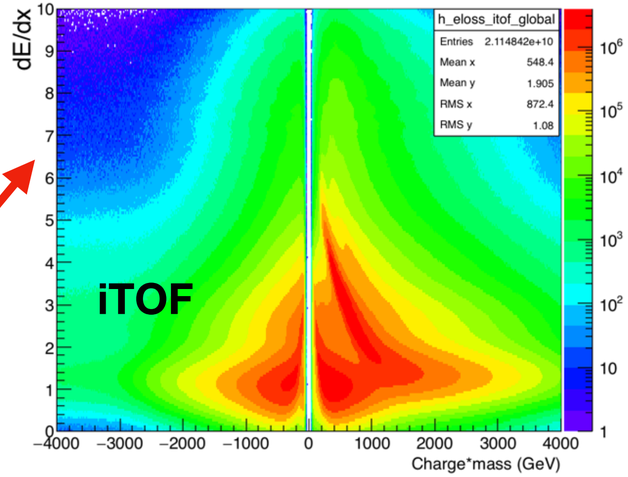
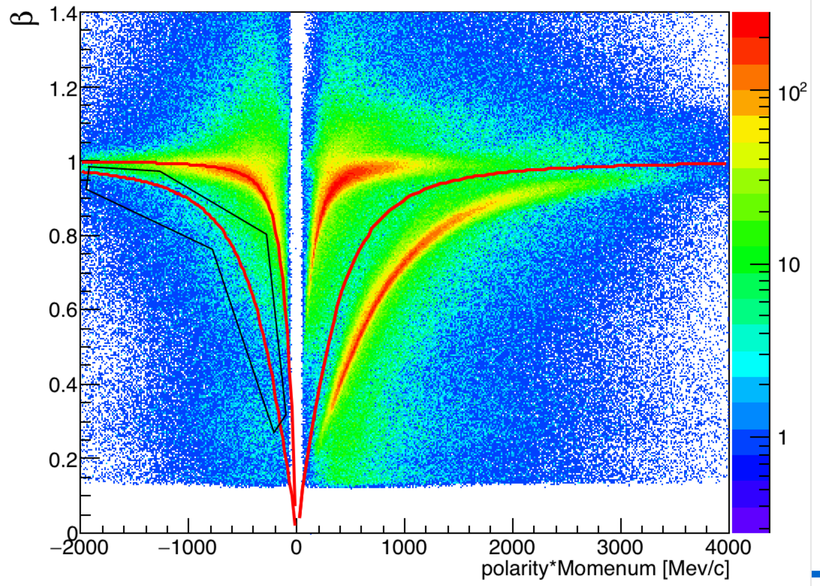
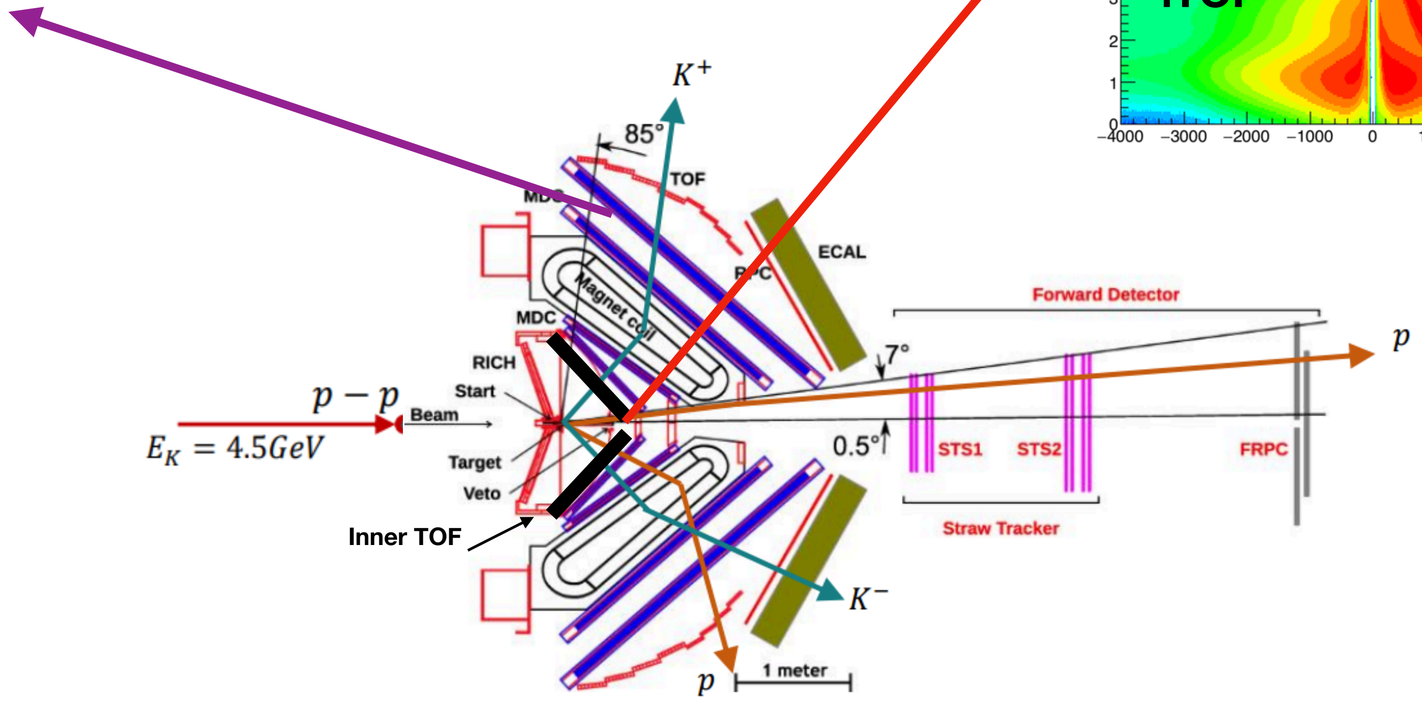


- MDC used for (1).Tracking, (2) PID of particles
- Use energy loss technique







- TOF also used for (1).Tracking, (2) PID of particles
- Mass calculated from β and momentum

$$m = \sqrt{\frac{(1-\beta^2)p^2}{\beta^2}}$$

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- **Analysis Strategy**
- Some Initial Results
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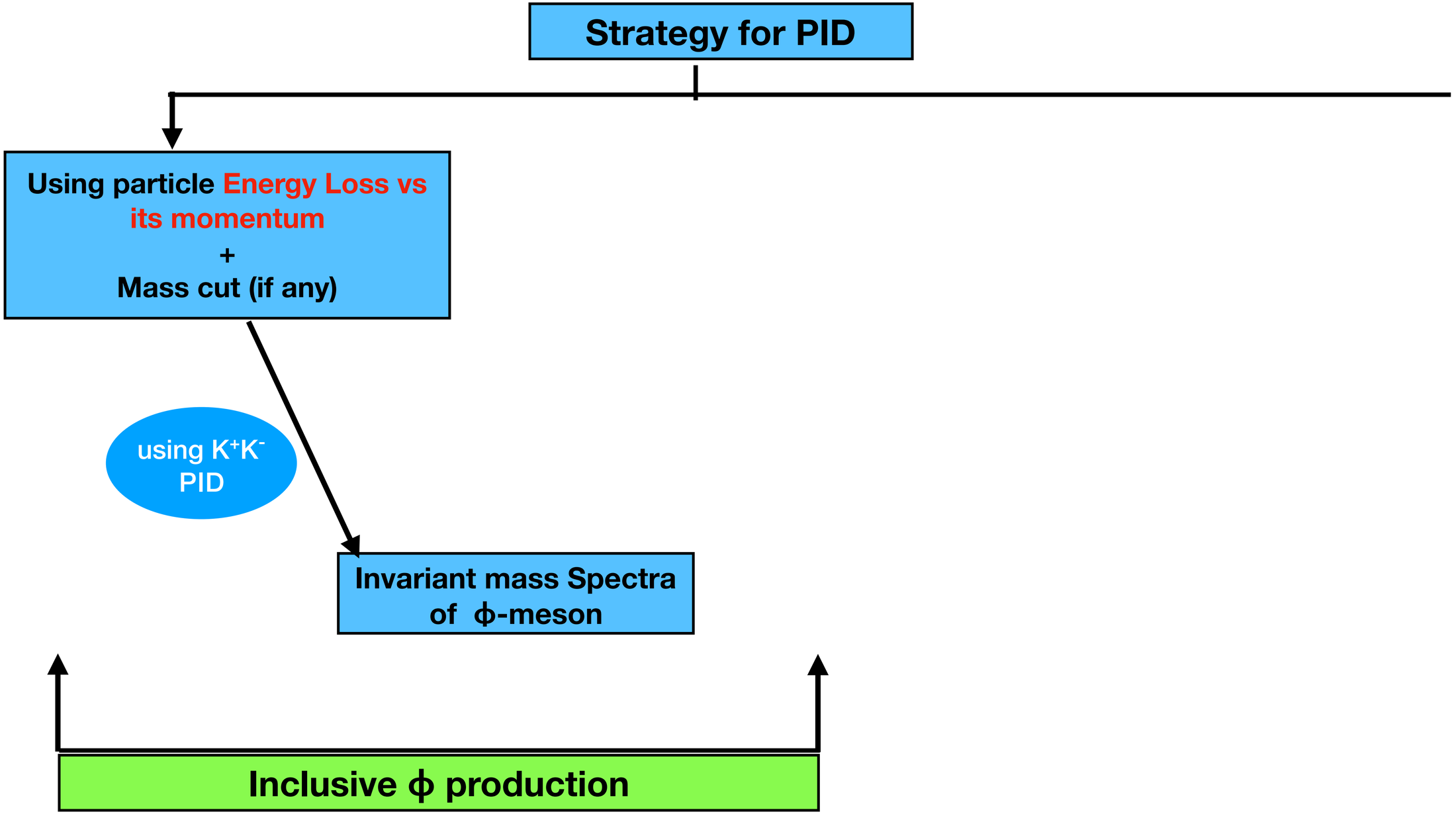
Analysis Strategy



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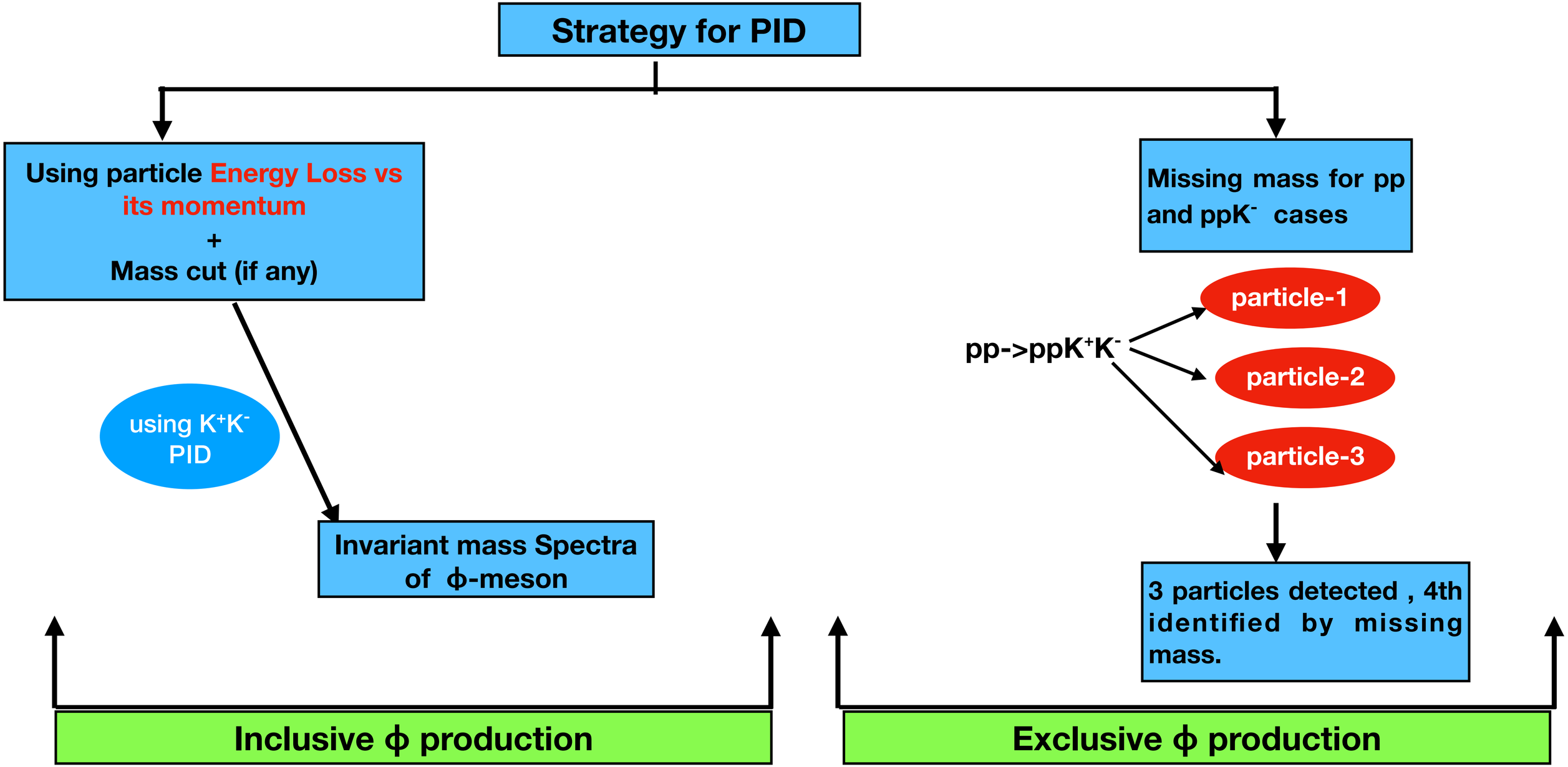


This analysis

- ✓ focuses on both inclusive + exclusive channel
- ✓ uses both HADES and Forward detector

But this talk

- ✓ focuses on only ***Inclusive*** K+/K- using Energy loss (ITOF and MDC) and momentum dependent mass

Analysis details

- Data Analysis ~ 15 x 10^9 events
- Integrated Luminosity = 6.46 pb^{-1}

Methodology

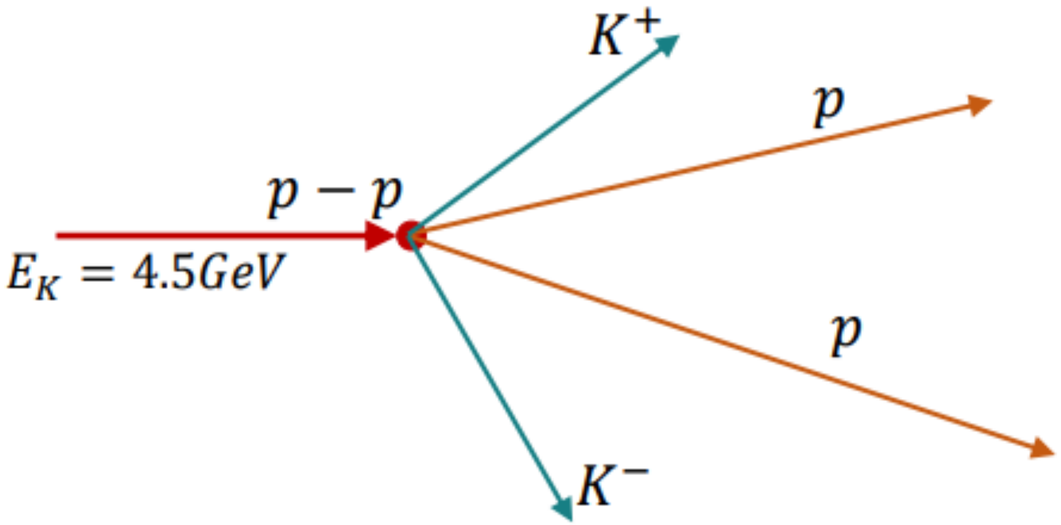
- Start with optimising kaon PID cuts
- Criterium: Significance of the Φ reconstruction
- First look into the Φ inclusive angular distribution

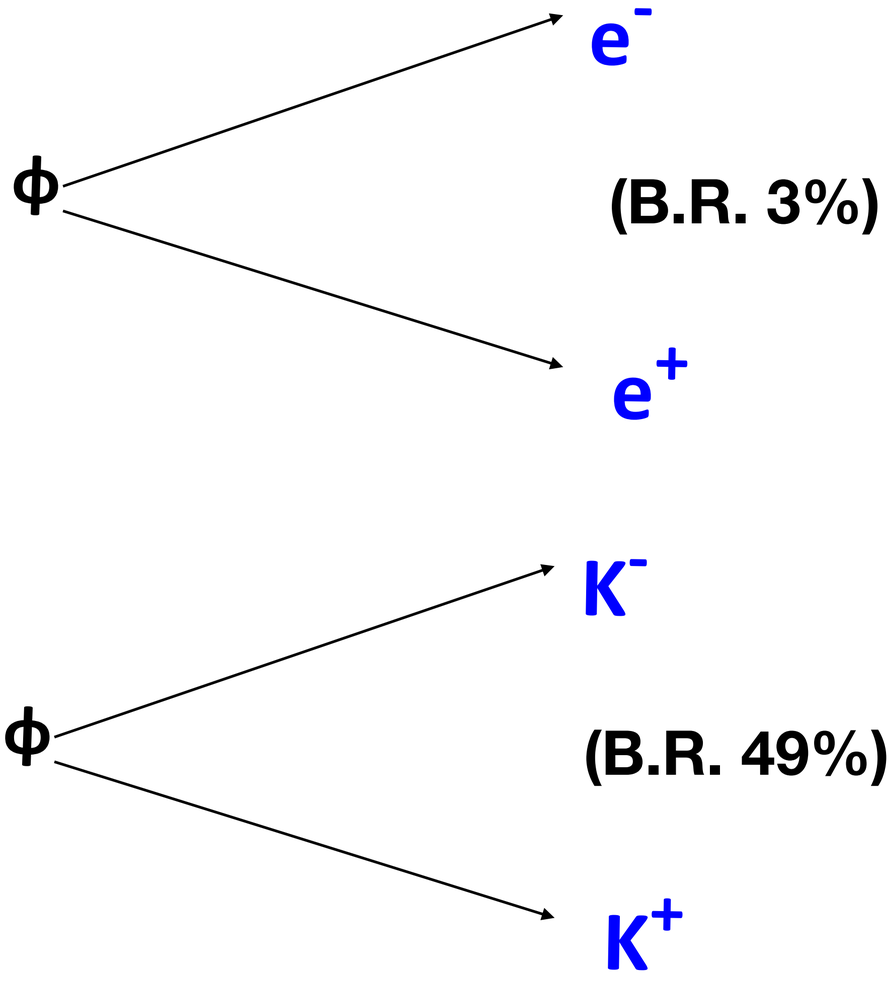
Simulations

- PLUTO + Geant for exclusive channel [pp->pp Φ(K+K-)]

PLUTO: event generator developed by the HADES collaboration

ϕ meson identification





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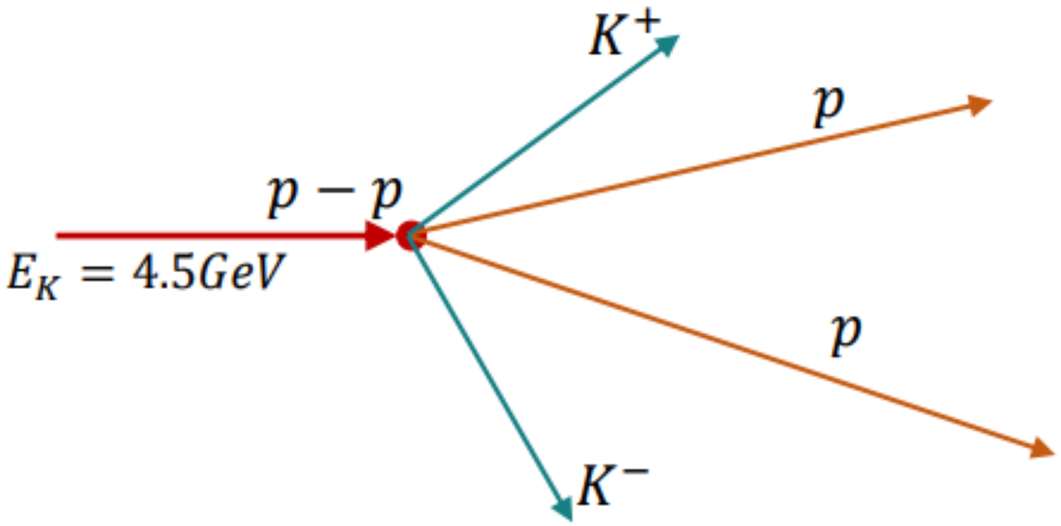
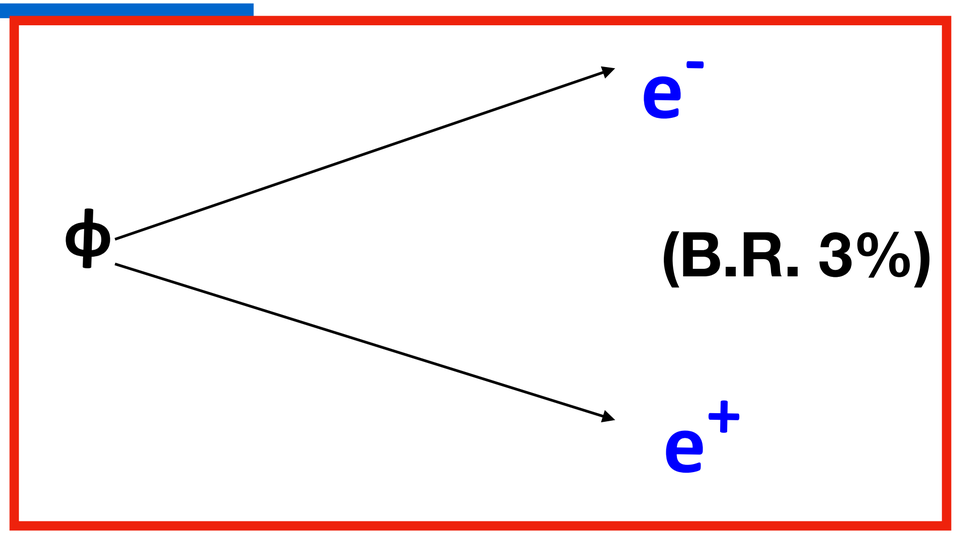
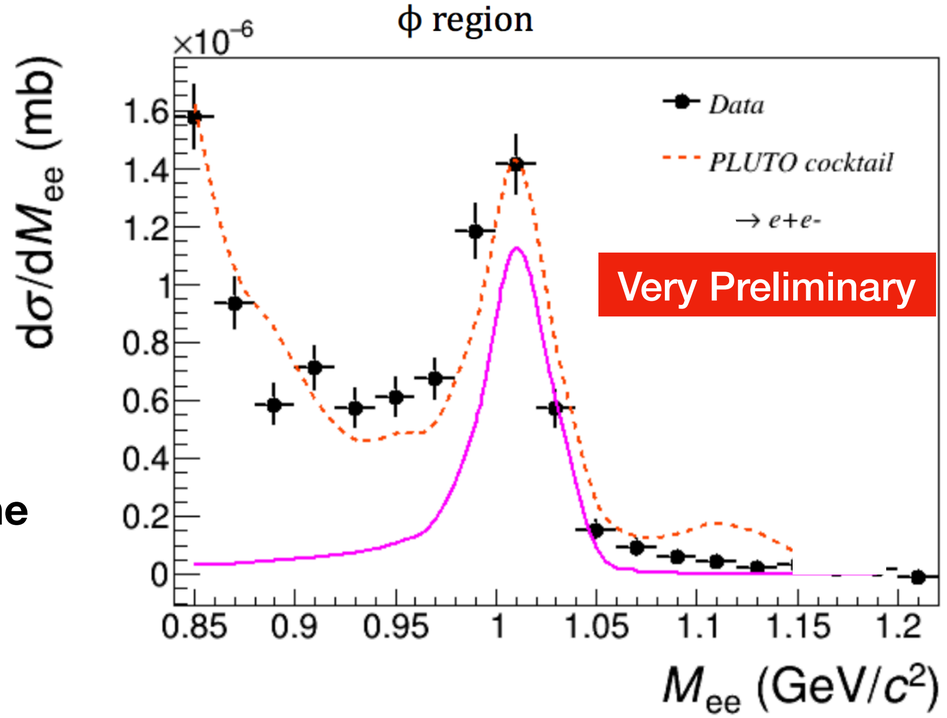
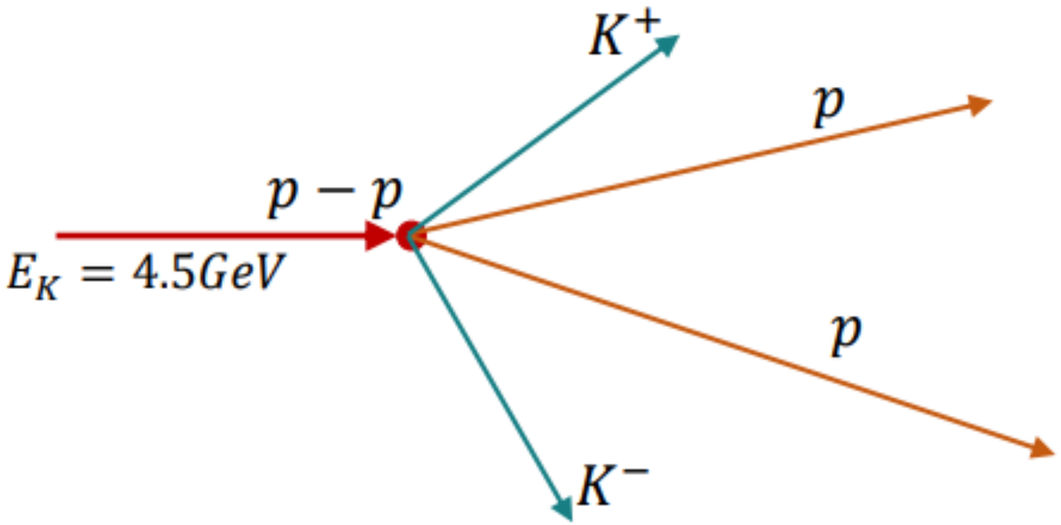


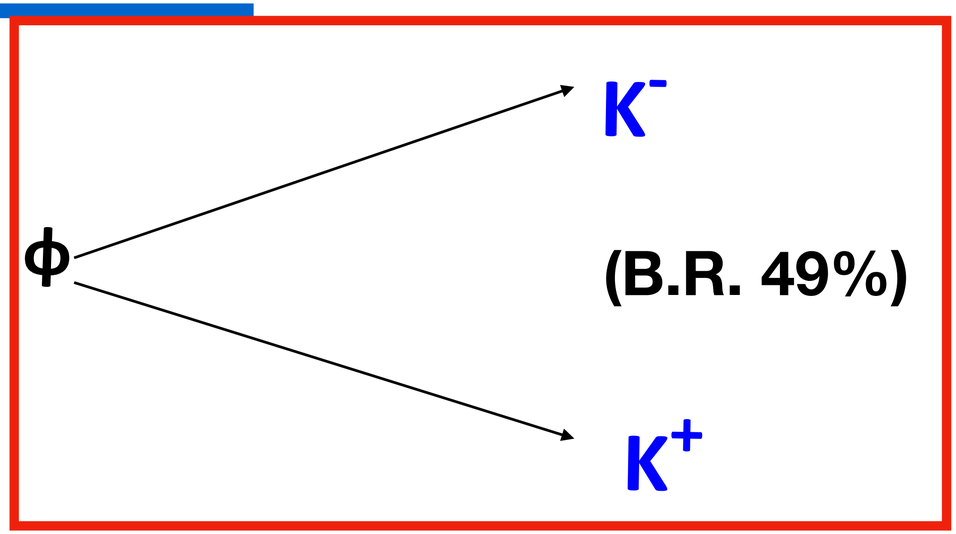




Analysis by Rayane Abou Yassine

ϕ meson identification

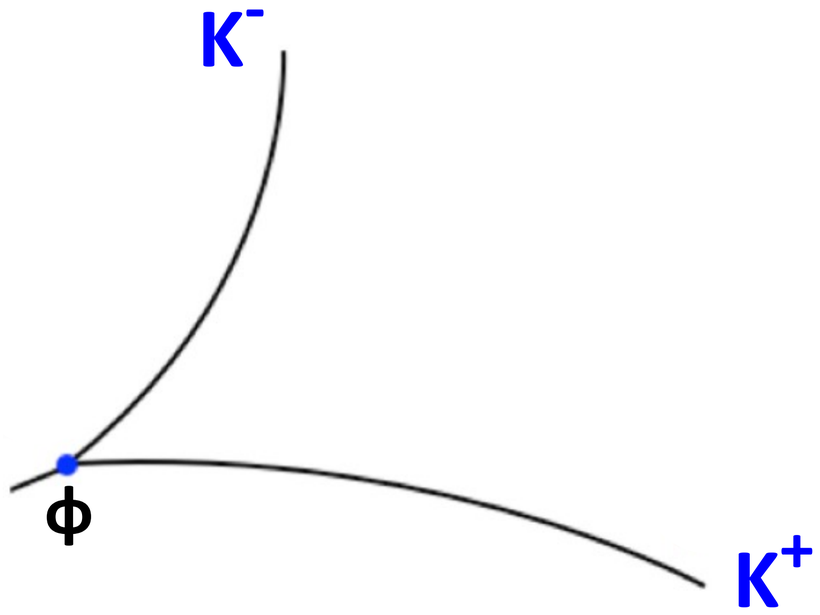




This analysis

ϕ meson identification

ϕ identified via hadronic decay channel: $\phi \rightarrow K^{+} + K^{-}$ (B.R. 49%)



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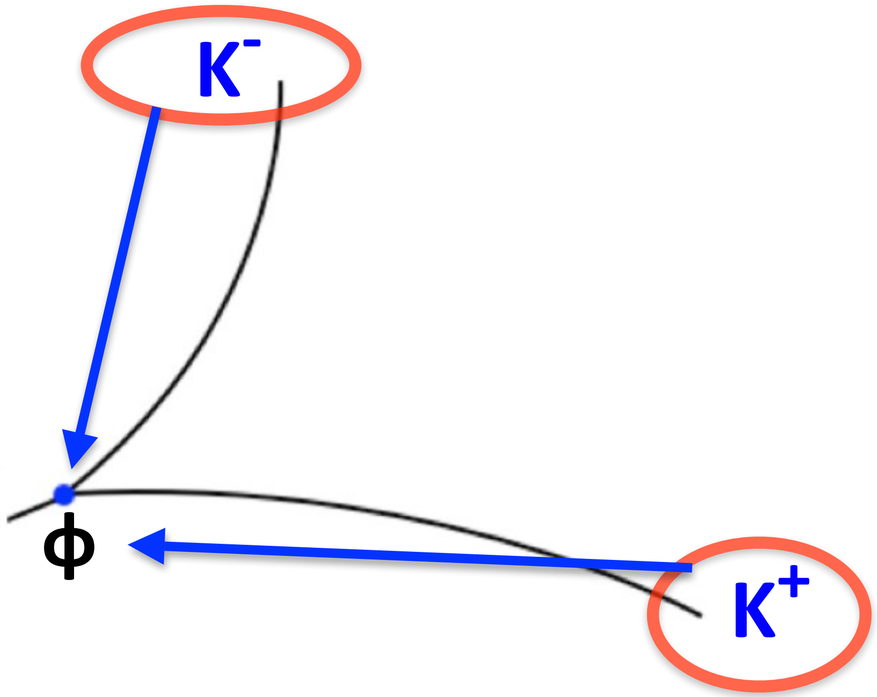
Reconstructed by invariant mass distribution of daughter particles:

$$M_{K^+K^-} = \sqrt{((E_{K^+} + E_{K^-}) - (\vec{p}_{K^+} + \vec{p}_{K^-}))}$$



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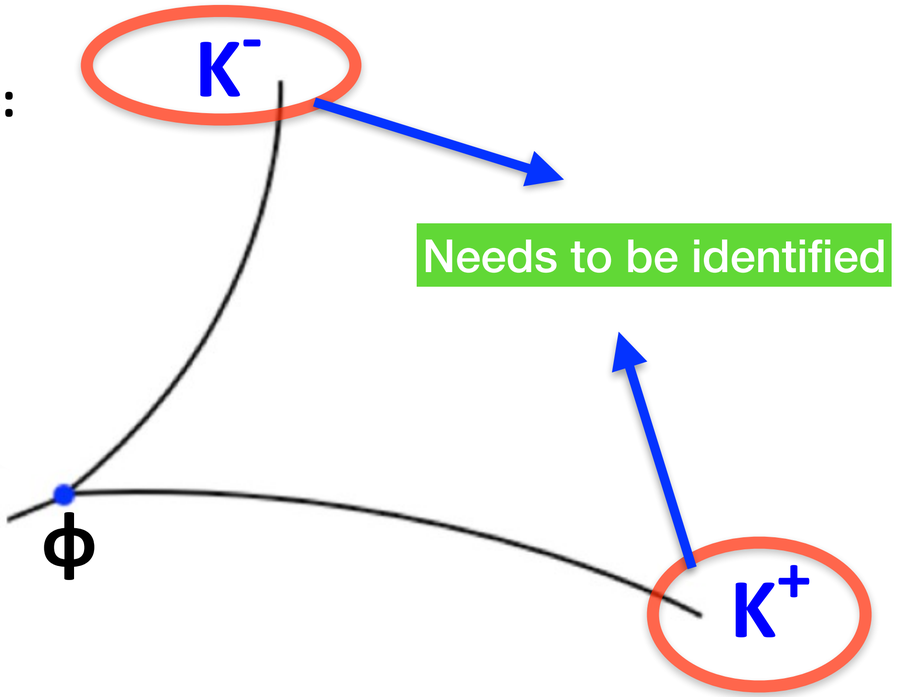
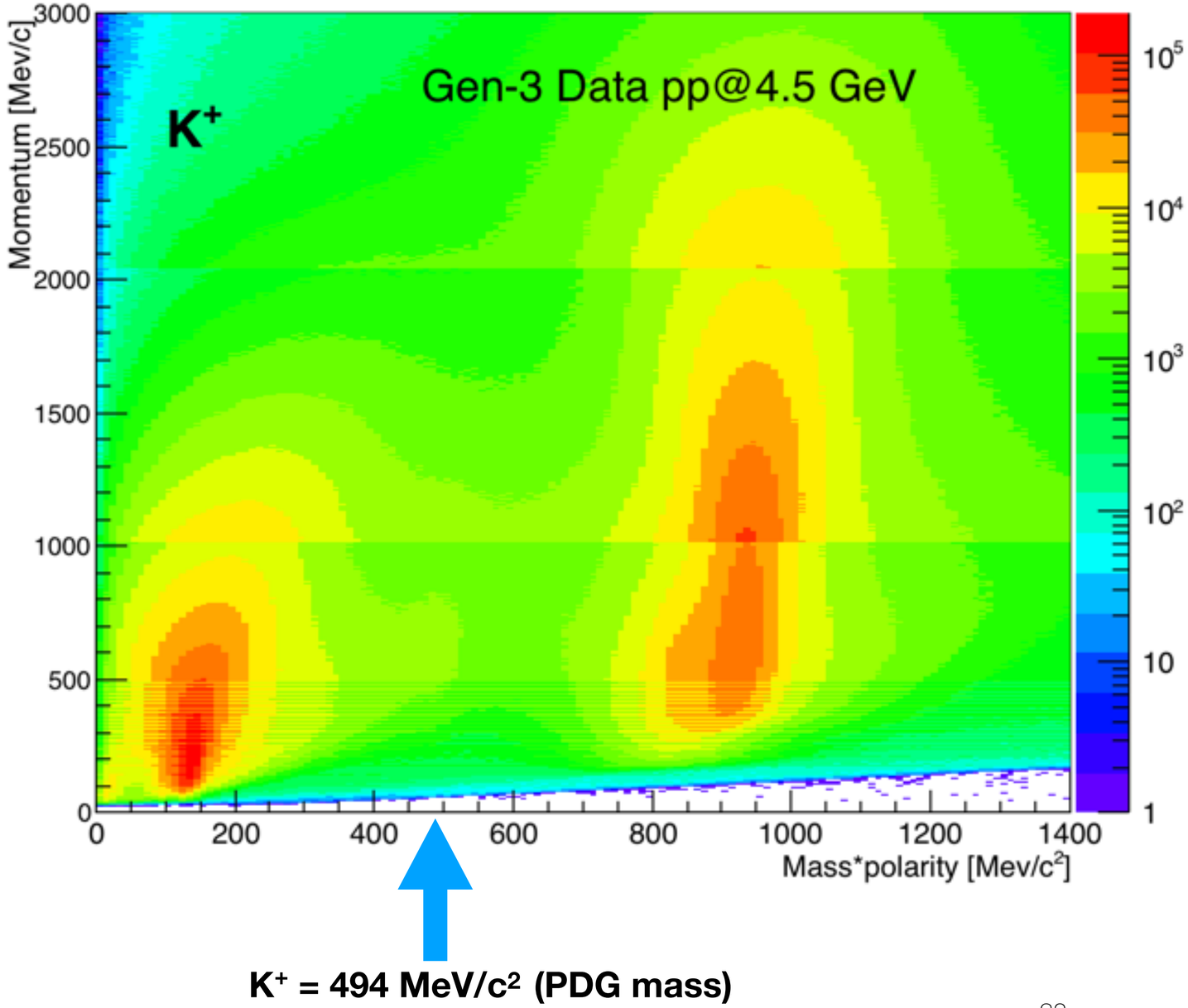


Particle identification

Particle Identification in HADES : Mass vs Momentum



K^+ = 494 MeV/c^2 (PDG mass)

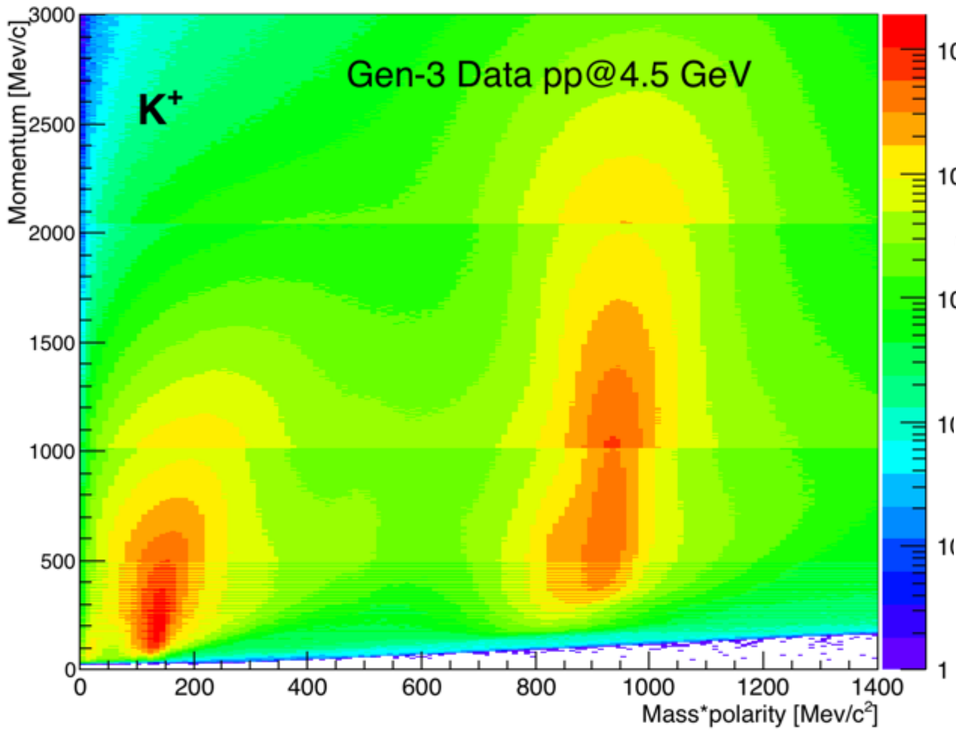
Mass calculated from beta and momentum relation as

$$m = \sqrt{\frac{(1-\beta^2)p^2}{\beta^2}}$$

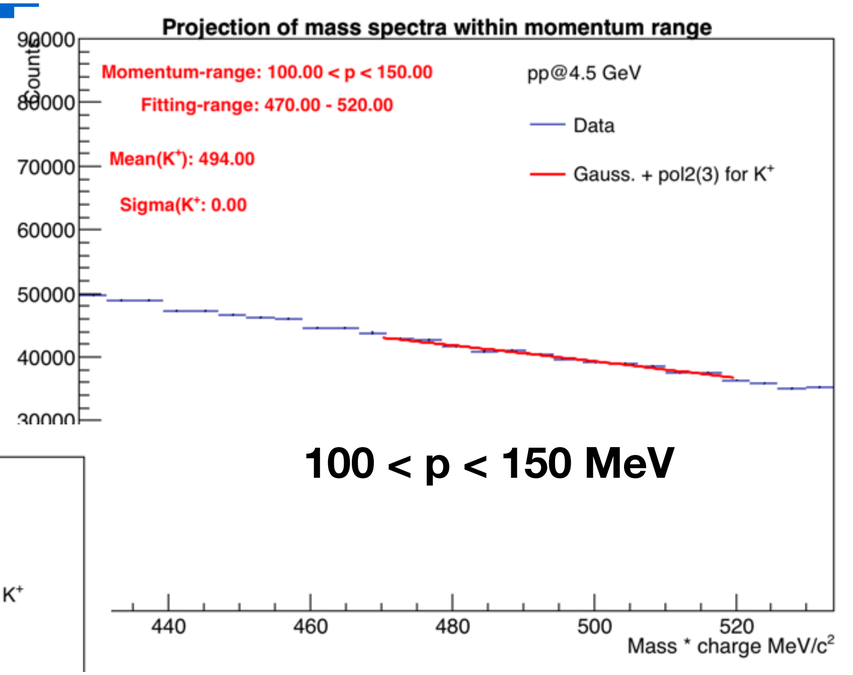
here, β = particle velocity/speed of light
p = particle momentum

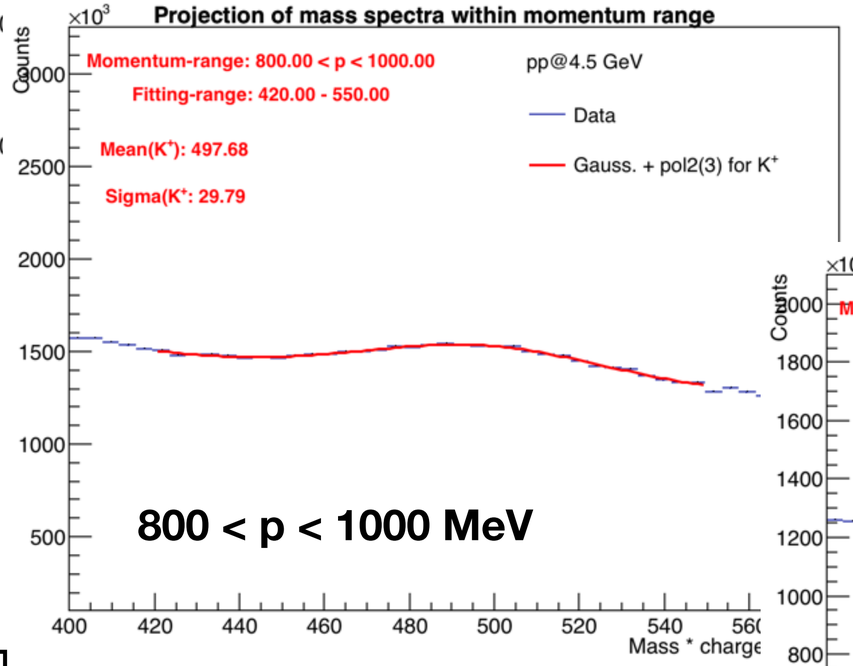
No Clear Kaon Signal in experiment is observed

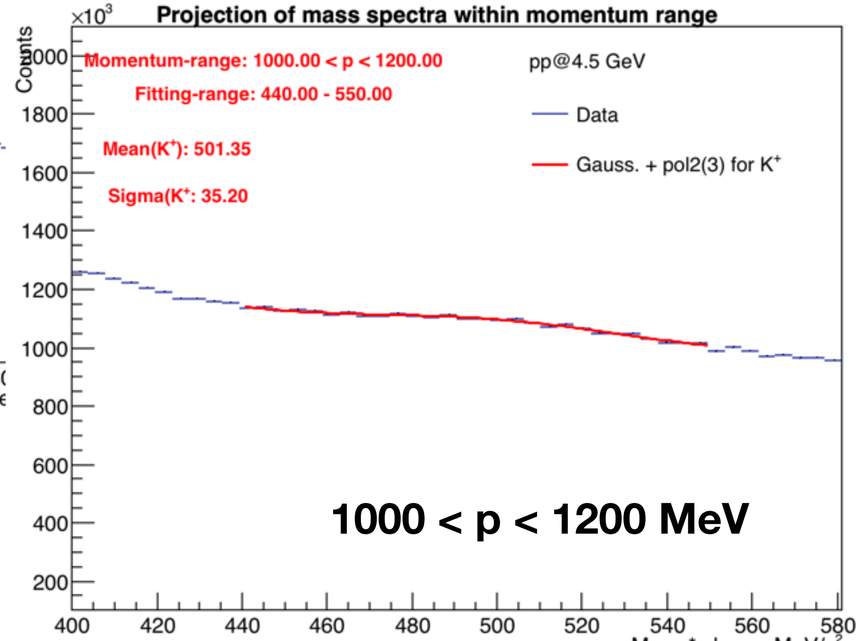
Particle Identification in HADES : Mass vs Momentum: K+ signal



Projections

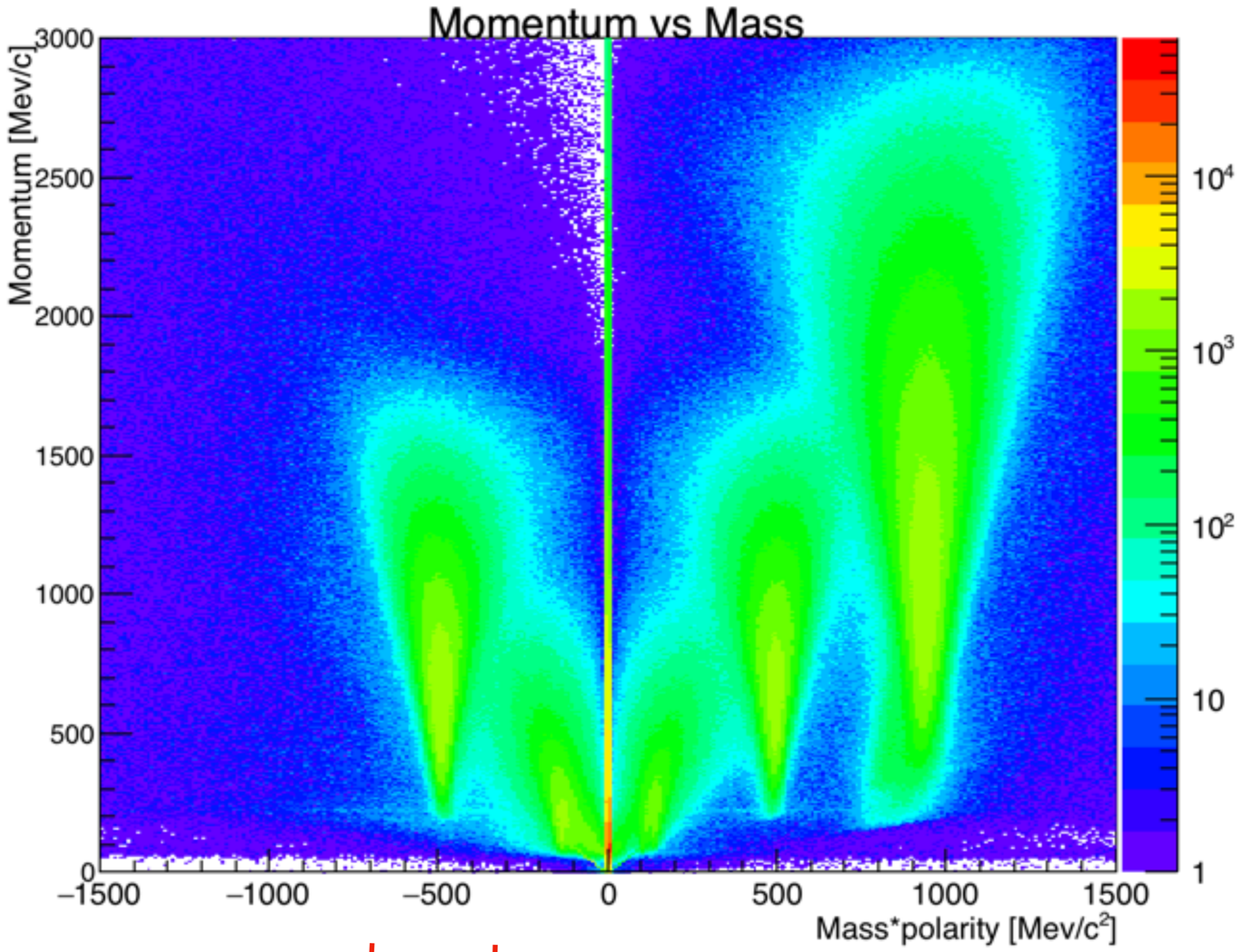






Starts to loss K+ signal at higher momentum

Particle identification: Step-1: Mass vs momentum from Simulation



K⁻ = 494 MeV/c² **K⁺ = 494 MeV/c²**

Using PLUTO + Geant
for exclusive channel [pp->pp Φ(K+K-)]

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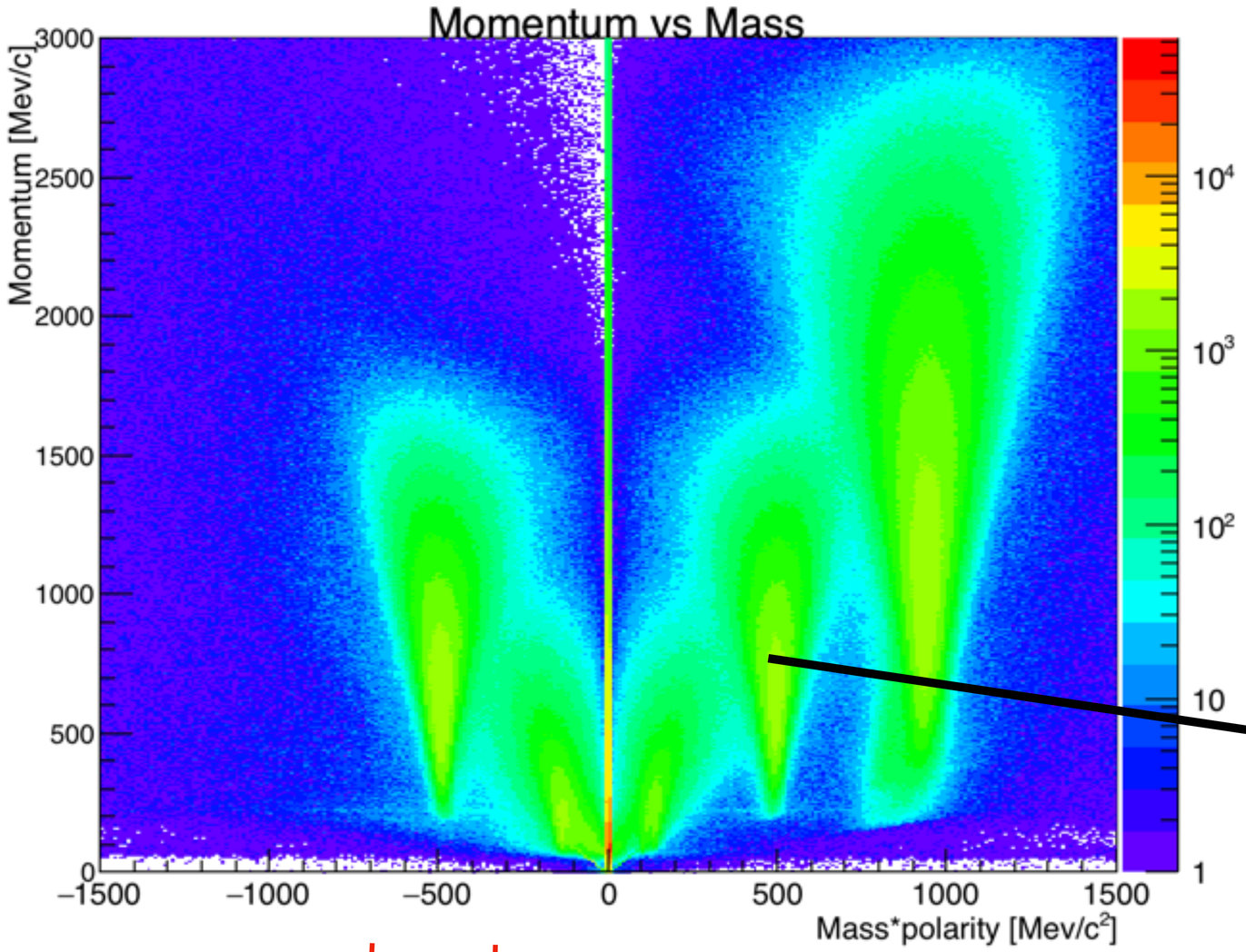
p = particle momentum

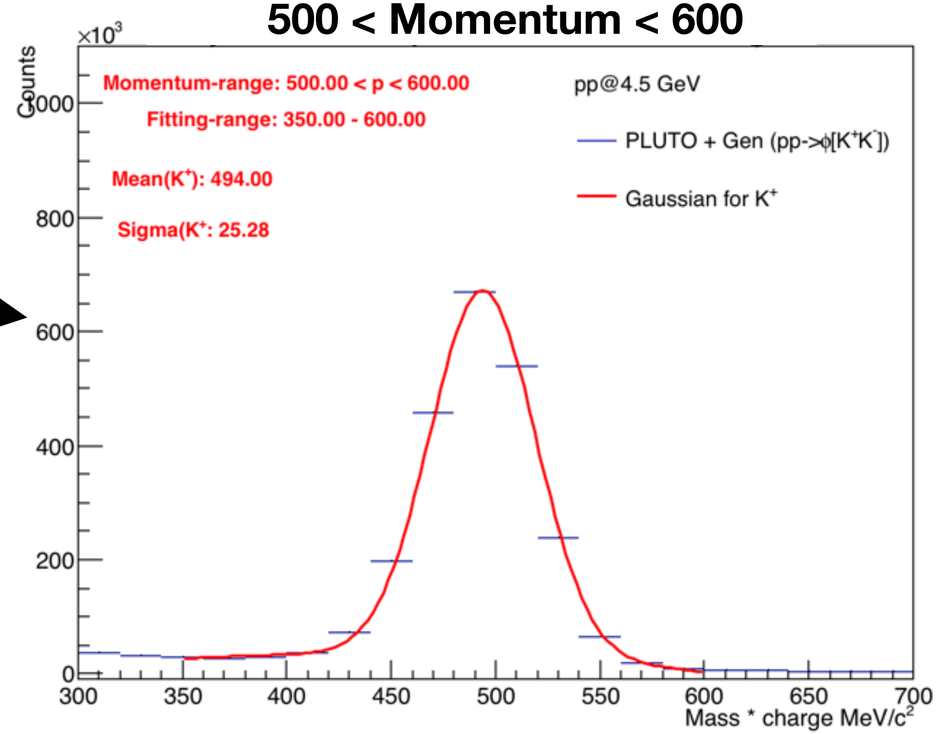
Particle identification: Step-1: Mass vs momentum from Simulation



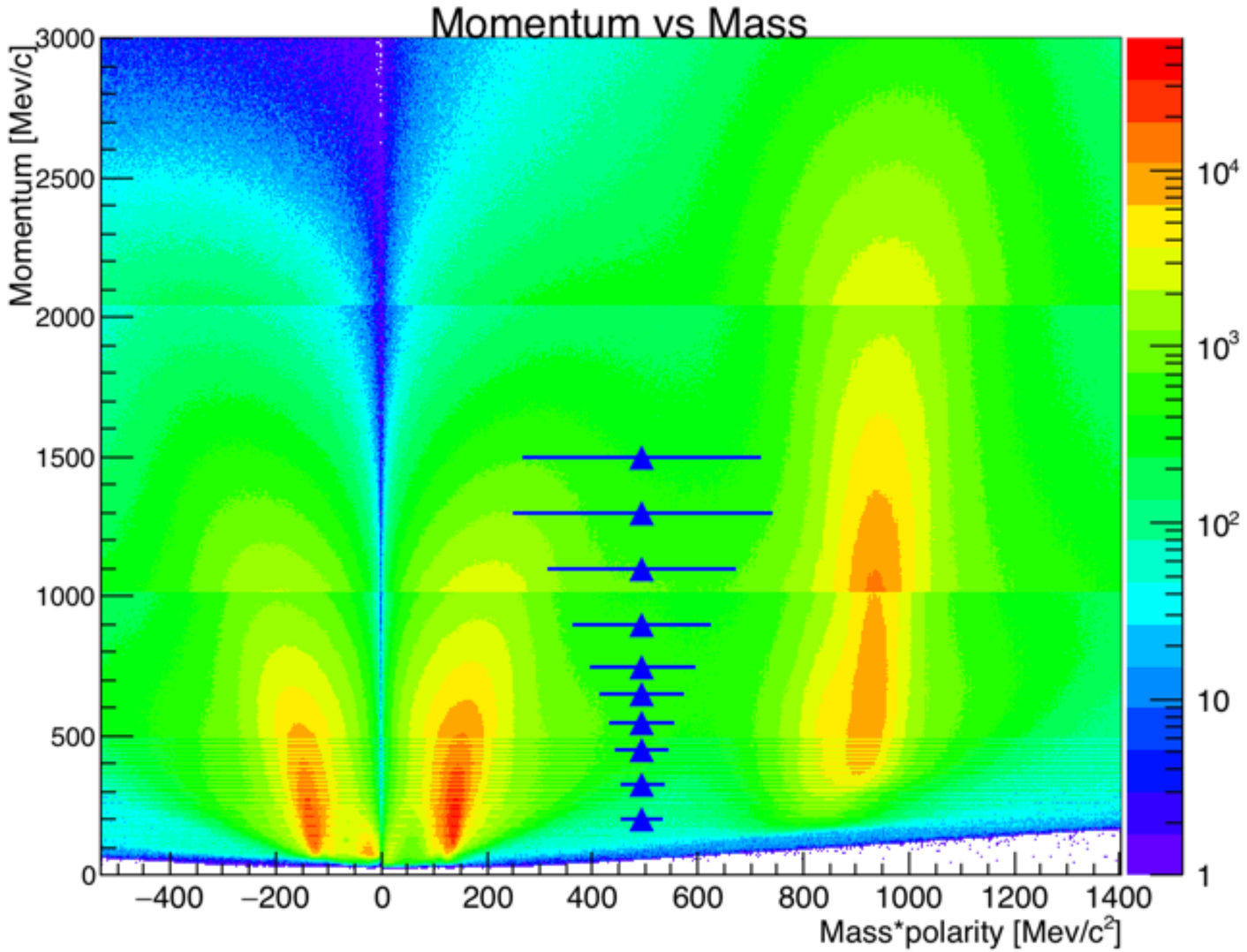
K⁻ = 494 MeV/c² **K⁺ = 494 MeV/c²**

Using PLUTO + Geant
for exclusive channel [pp->pp Φ(K+K-)]

Step-2: Projection of Mass for diff. momentum range



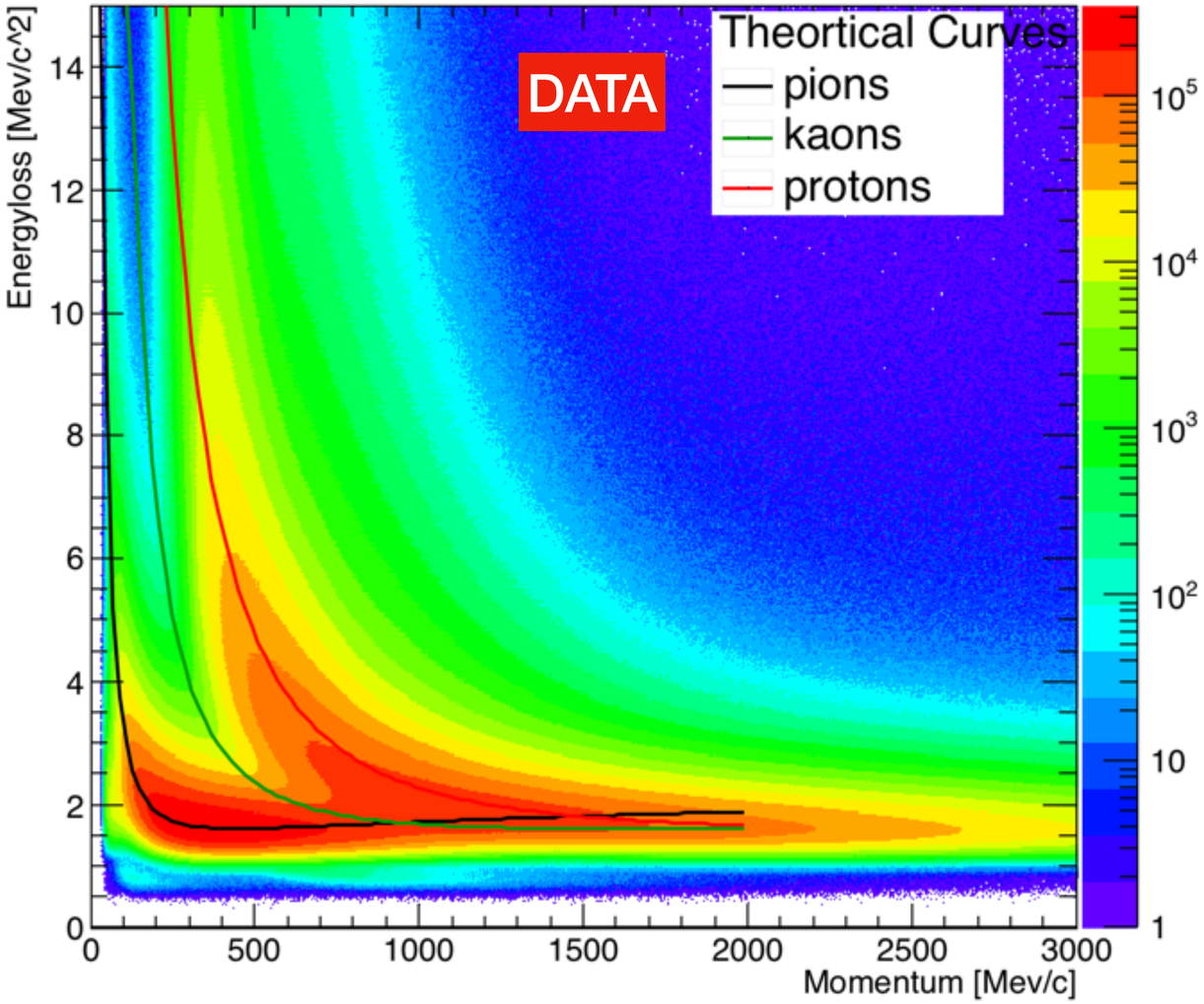
Particle Identification in HADES : Step:3-> Using K^+ Width on DATA



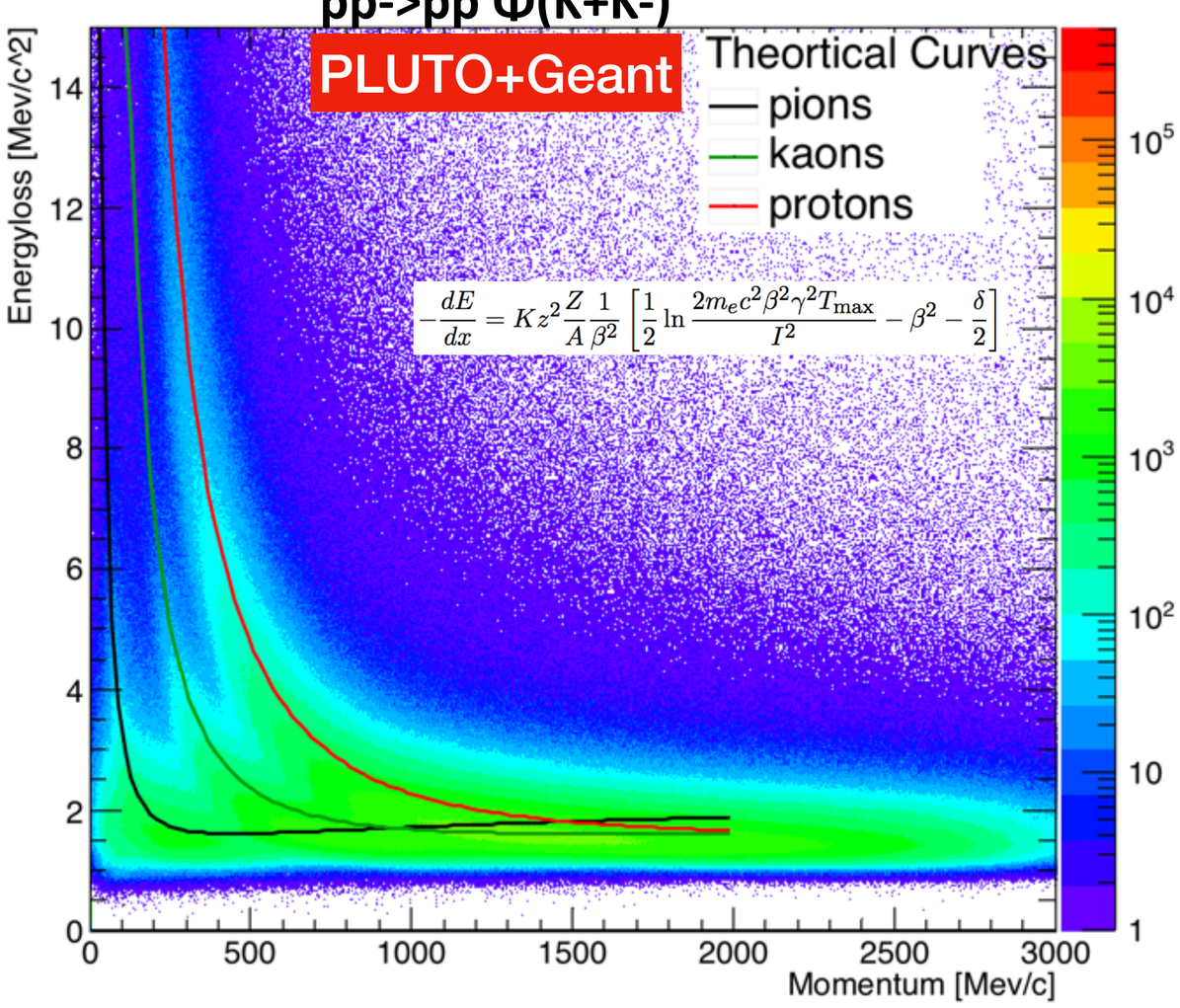
K^+ = 494 MeV/c^2 (PDG mass)

- K^+ region in data
- **Blue lines**: Width of K+ obtained from simulation (PLUTO + Geant) with $\sigma = \pm 2.0$

Particle Identification in HADES : Step:4-> particle from (p,dE/dx) of MDC

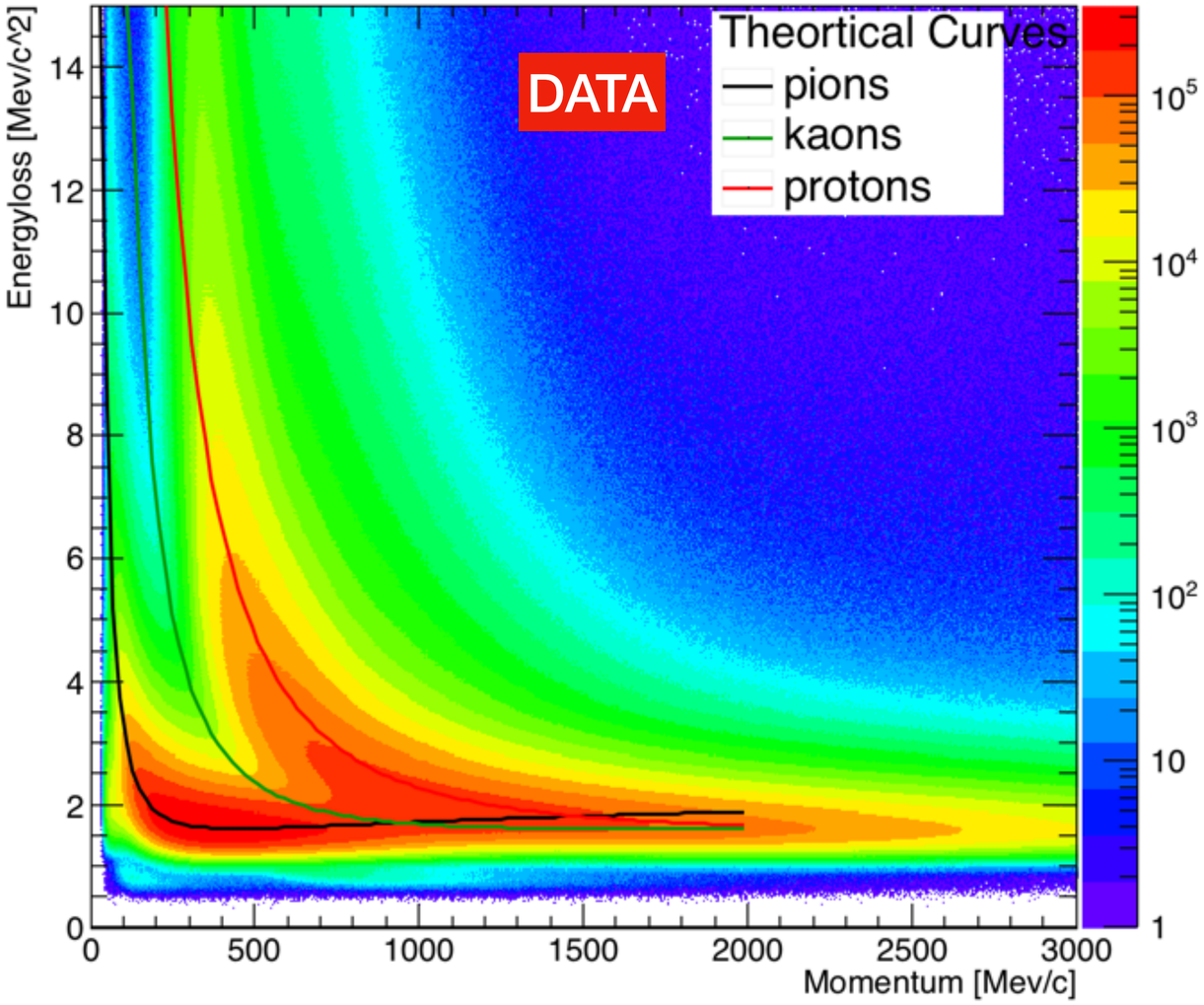


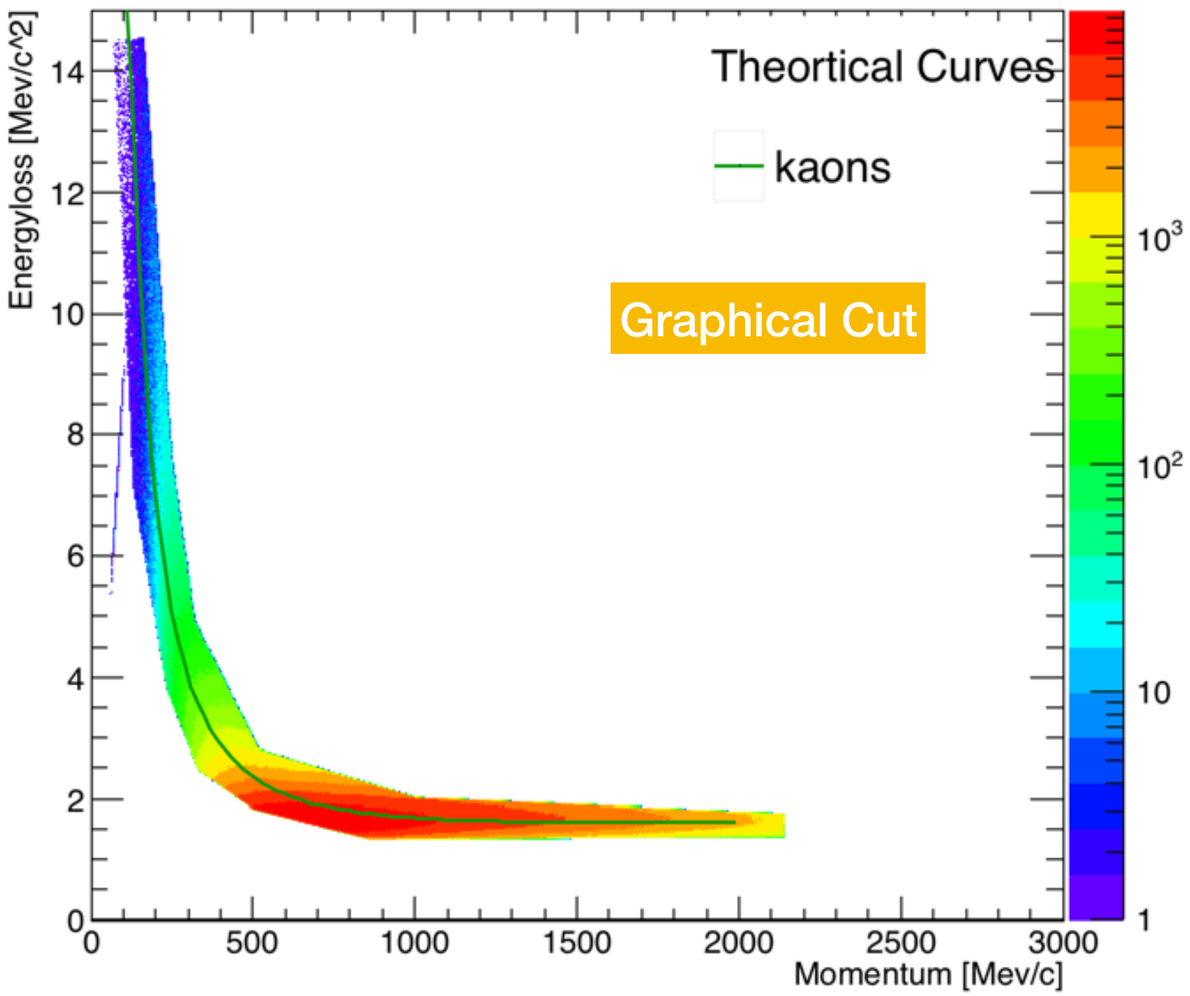
pp->pp Φ(K+K-)



- Comparison of Energy loss distribution between data and simulation (PLUTO + Geant)

Particle Identification in HADES : Kaon from (p,dE/dx) of MDC

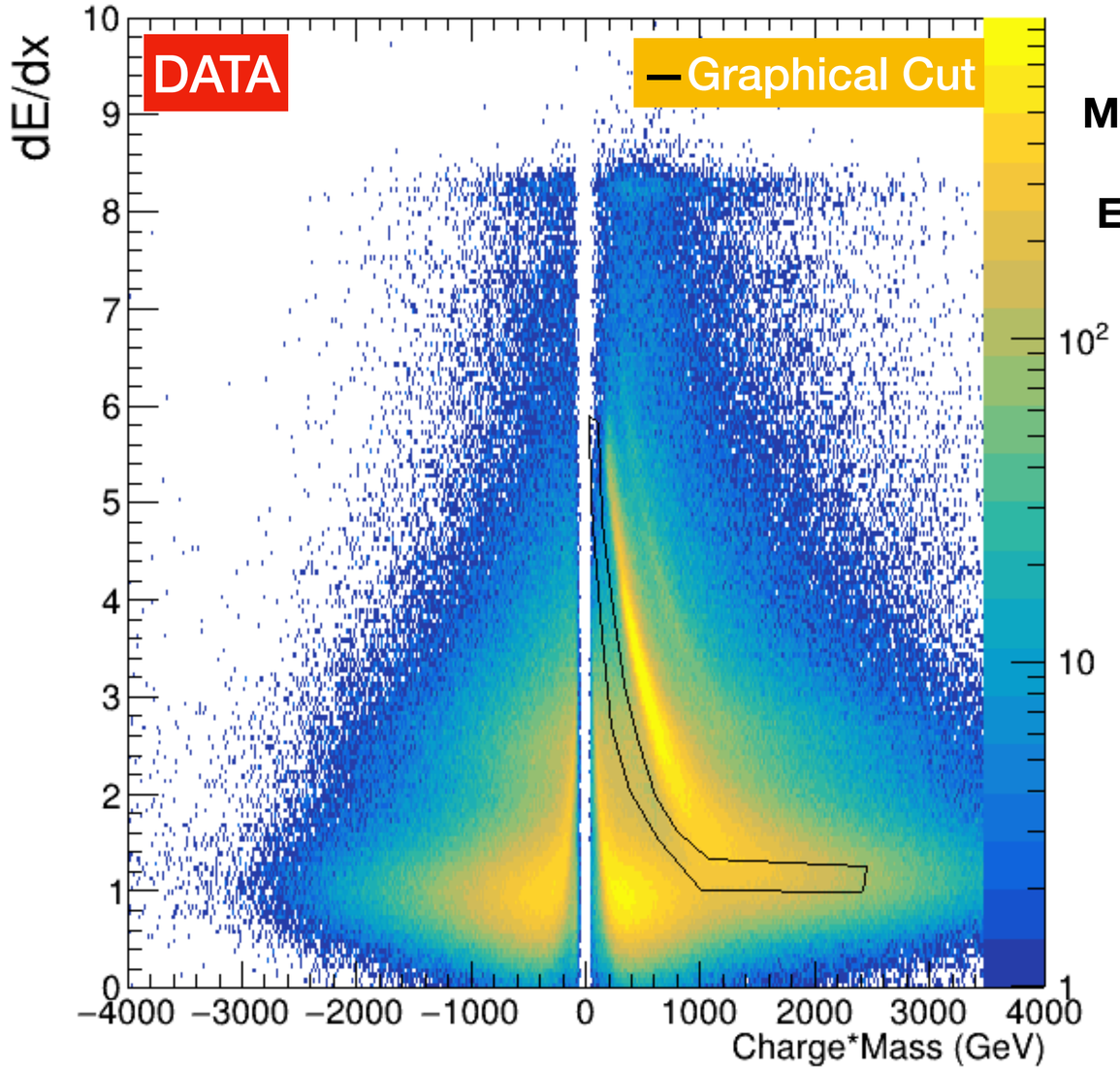




K^+ region of Energy loss distribution is identified from Bethe-Block relation

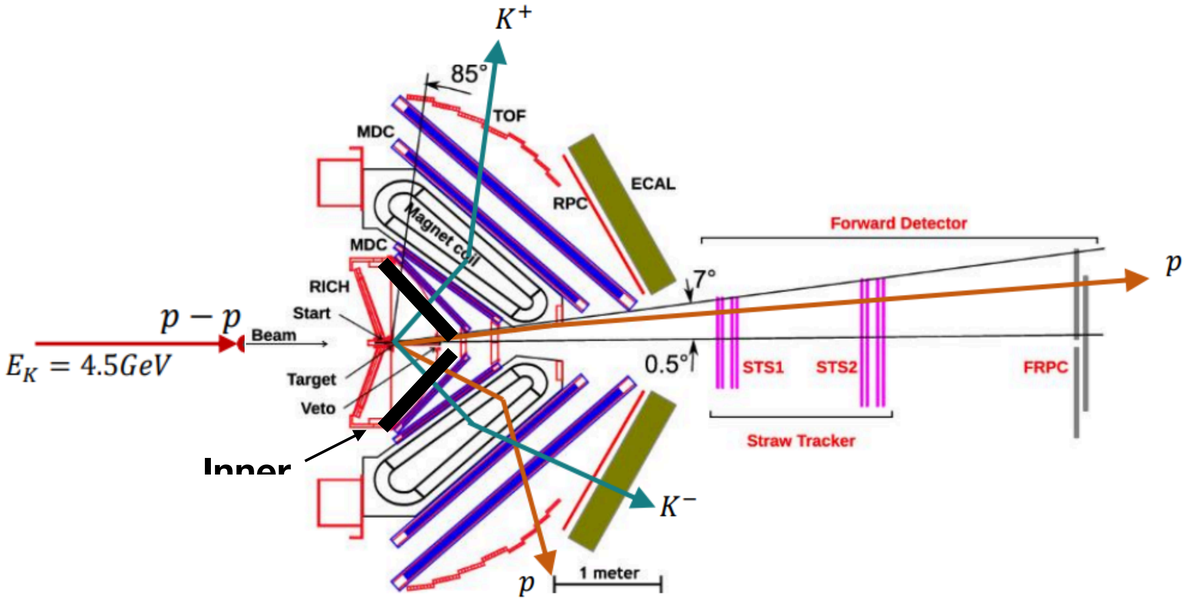
$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2}\right]$$

Particle Identification in HADES : Kaon from (p,dE/dx) of iTOF

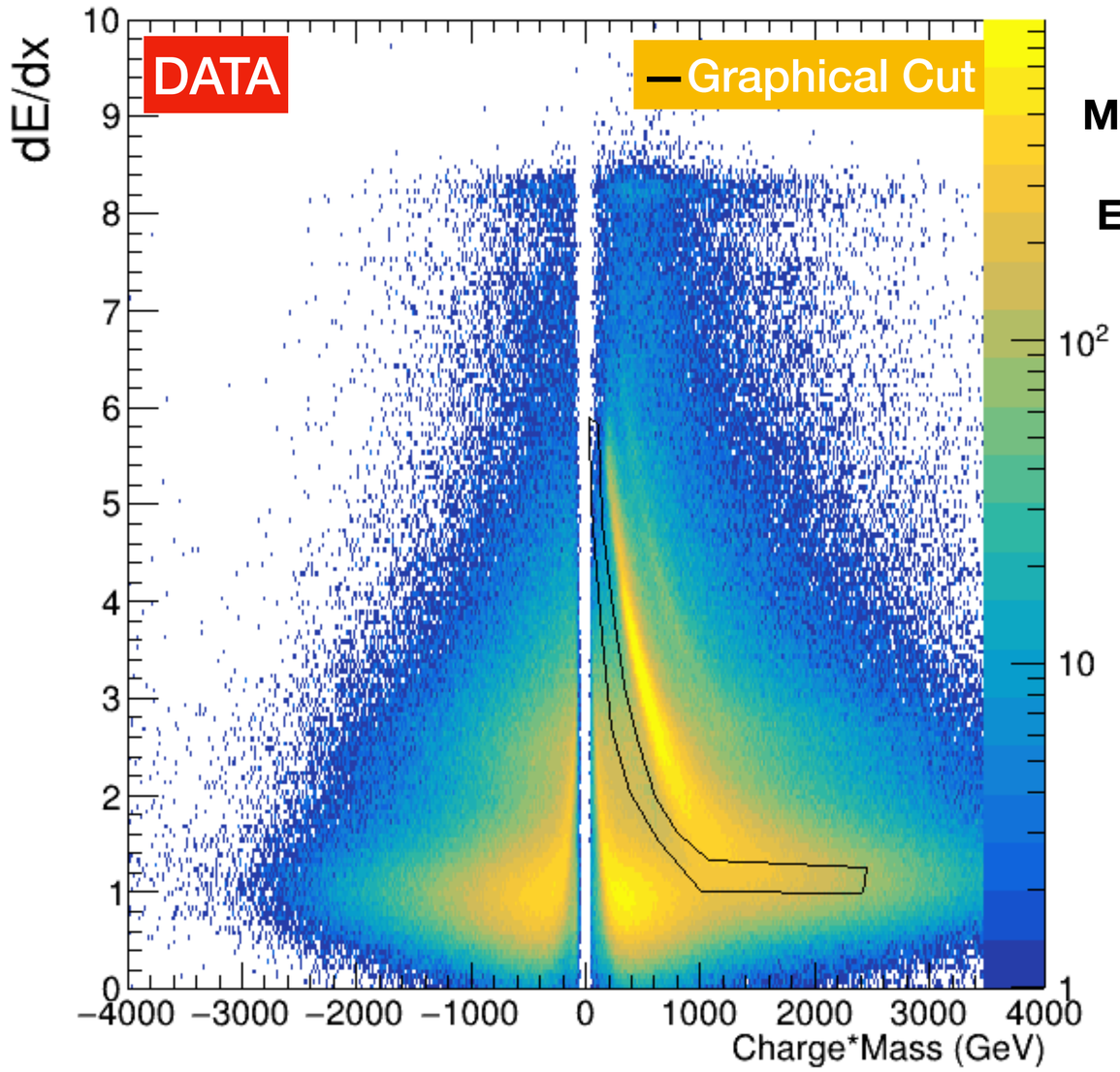


Matching of iTOF with tracks based of azimuthal angle of the tracks

Energy loss in iTOF = Additional PID

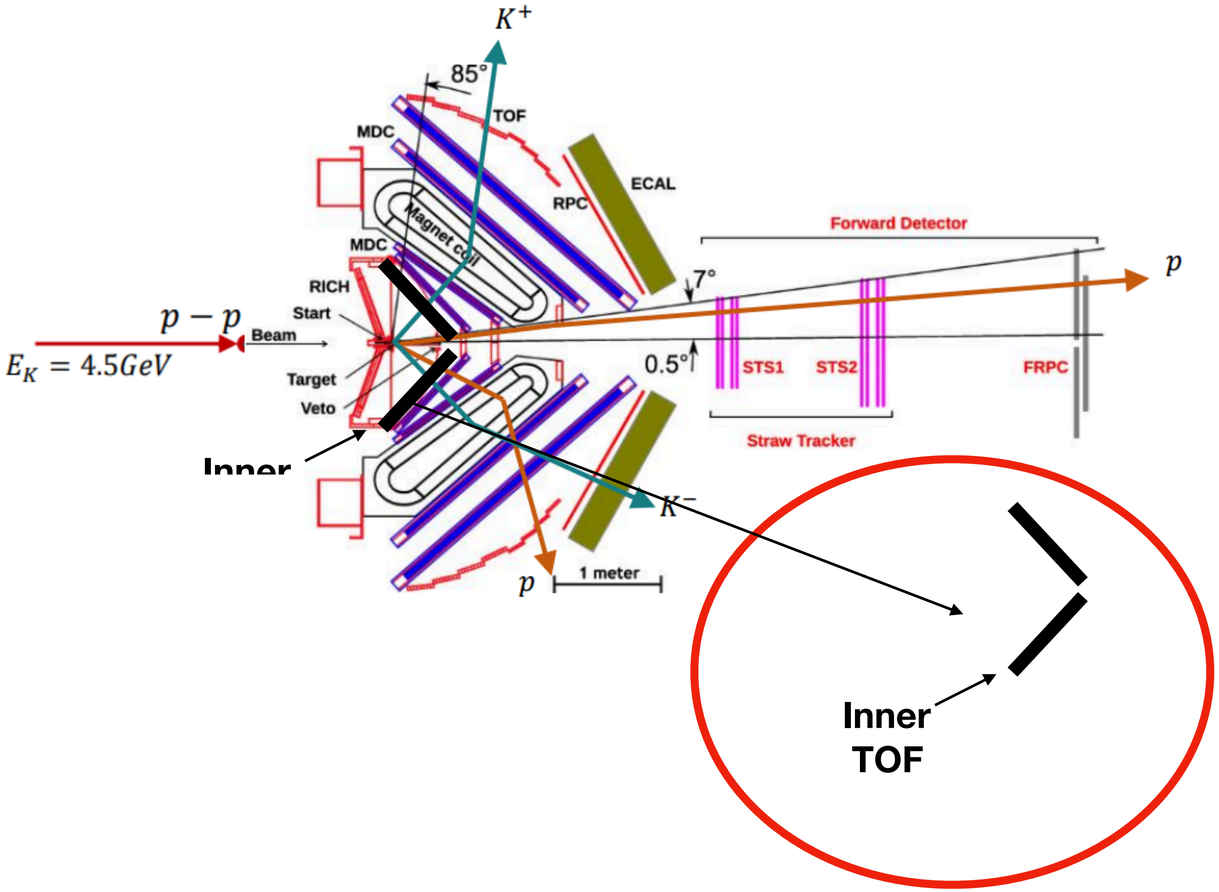


Particle Identification in HADES : Kaon from (p,dE/dx) of iTOF



Matching of iTOF with tracks based of azimuthal angle of the tracks

Energy loss in iTOF = Additional PID



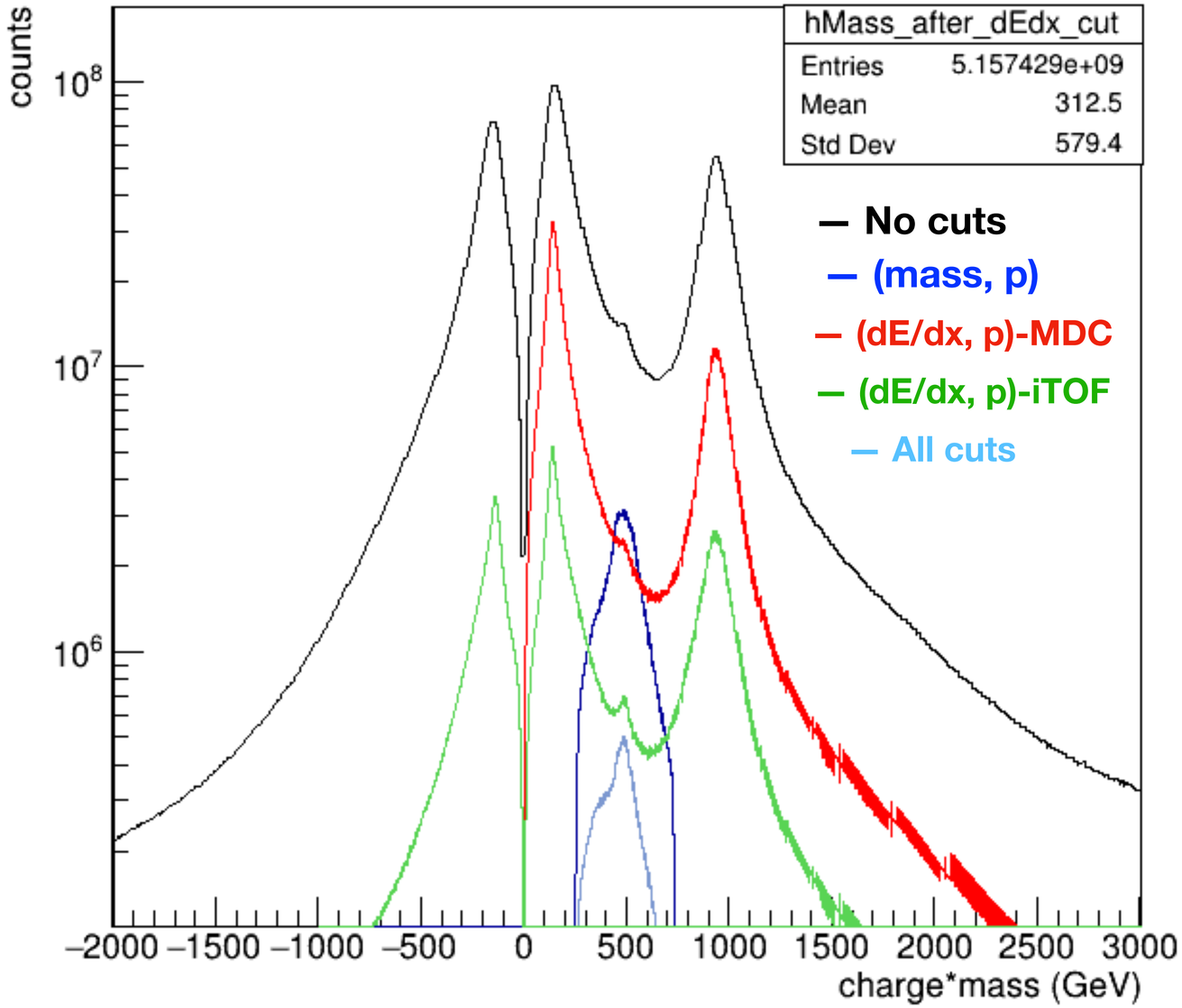
Particle Identification in HADES (In Summary)

PID for K^+ in the analysis

- K^+ region cut on (p, dE/dx) from MDC and iTOF
- charge > 0
- Mass cut with $\sigma = \pm 2.0$ from simulation

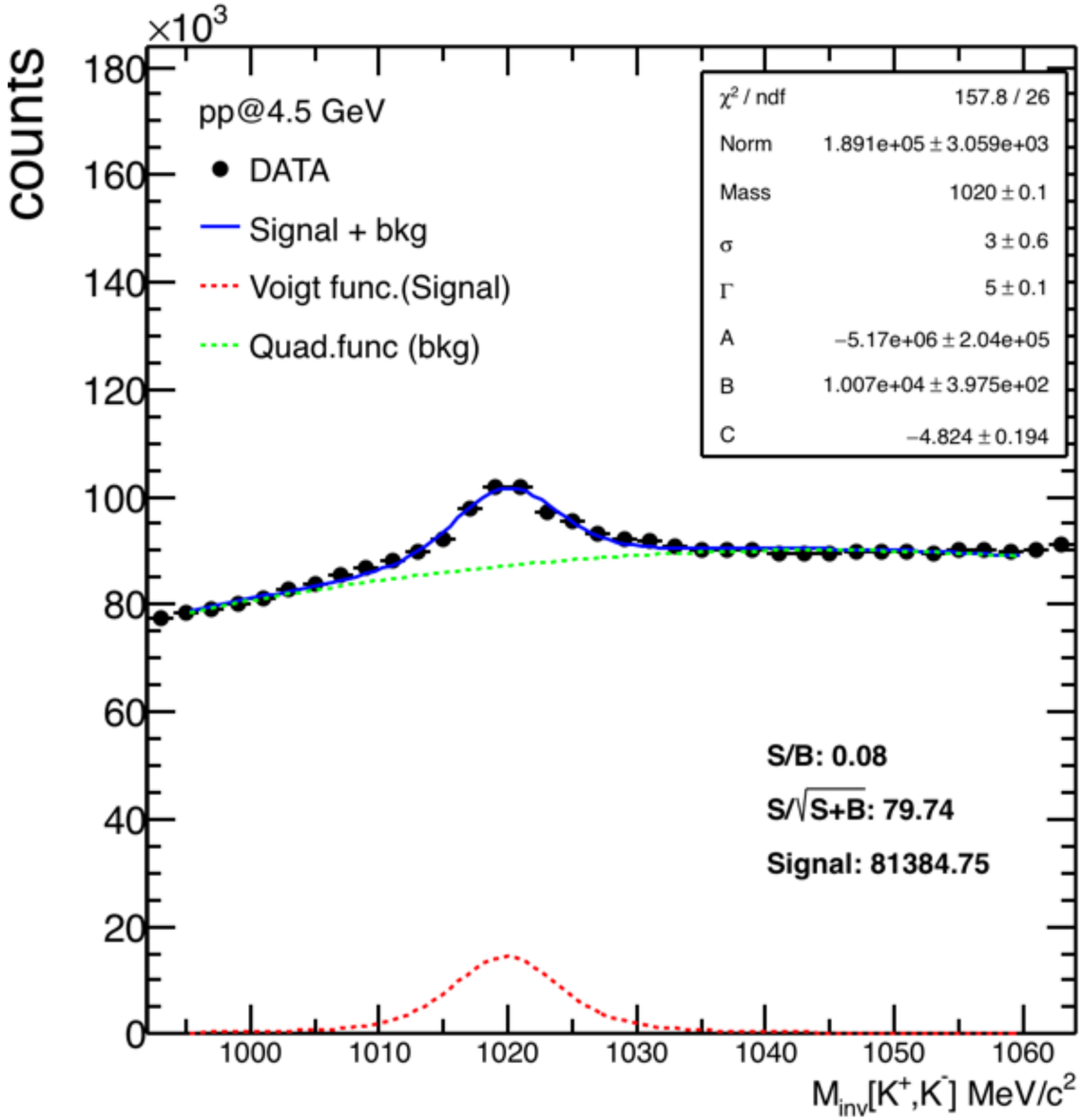
And, PID for K^- in the analysis

- Similar to K^+
- Charge < 0



Invariant Mass

Invariant mass Spectra ($M_{inv}[K^+K^-]$):



Fitting function:

Signal: Voigtian function (Convolution of Breit-Wigner and Gaussian function)

$$\frac{dN}{dm_{KK}} = \frac{A\Gamma}{(2\pi)^{3/2}\sigma}\int_{-\infty}^{\infty} \exp\left[-\frac{(m_{KK}-m')^2}{2\sigma^2}\right]\frac{1}{(m'-M)^2+\Gamma^2/4}dm'.$$

where,
A -> Normalisation factor; M-> Mass; σ -> detector resolution

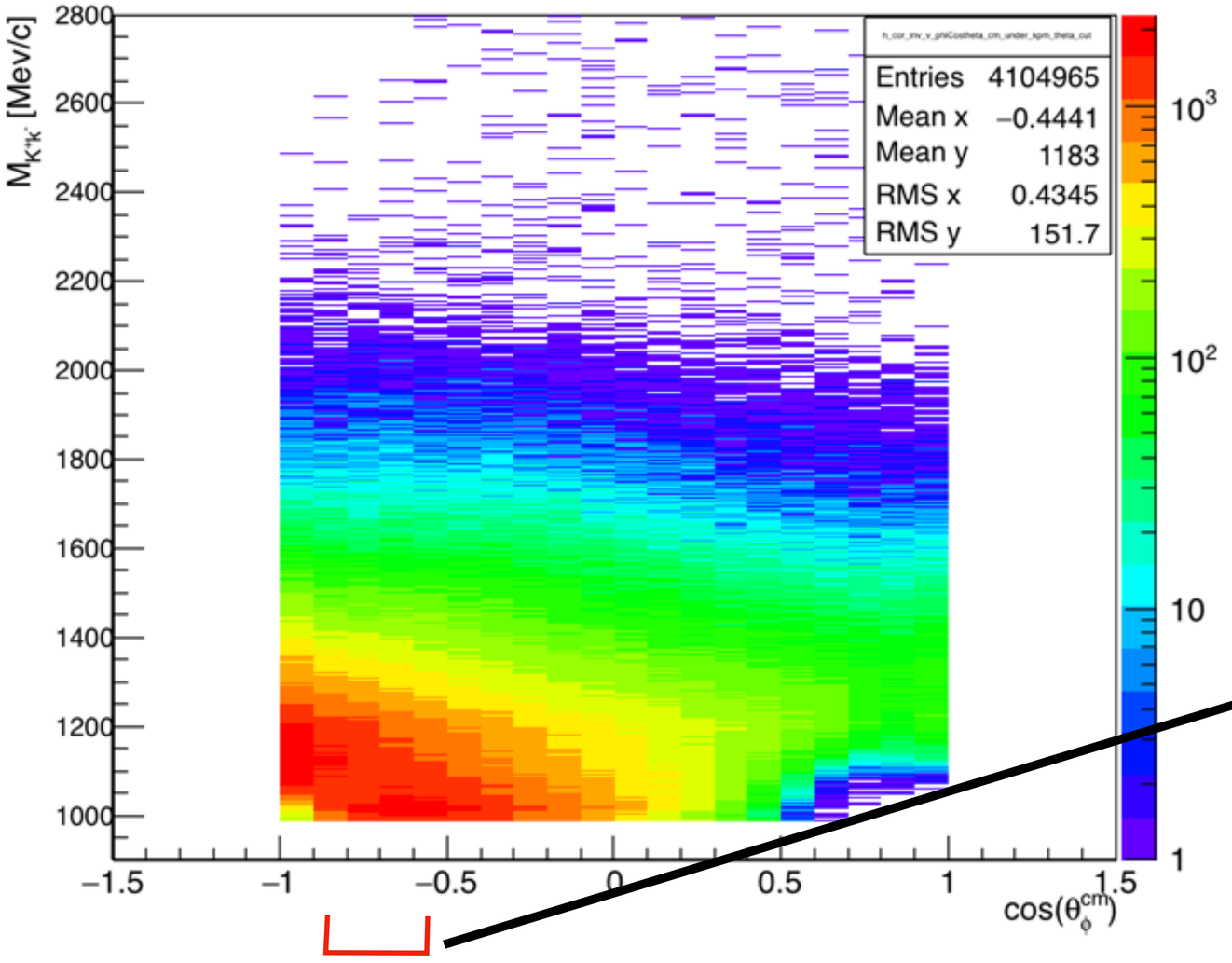
Background: Quadratic polynomial

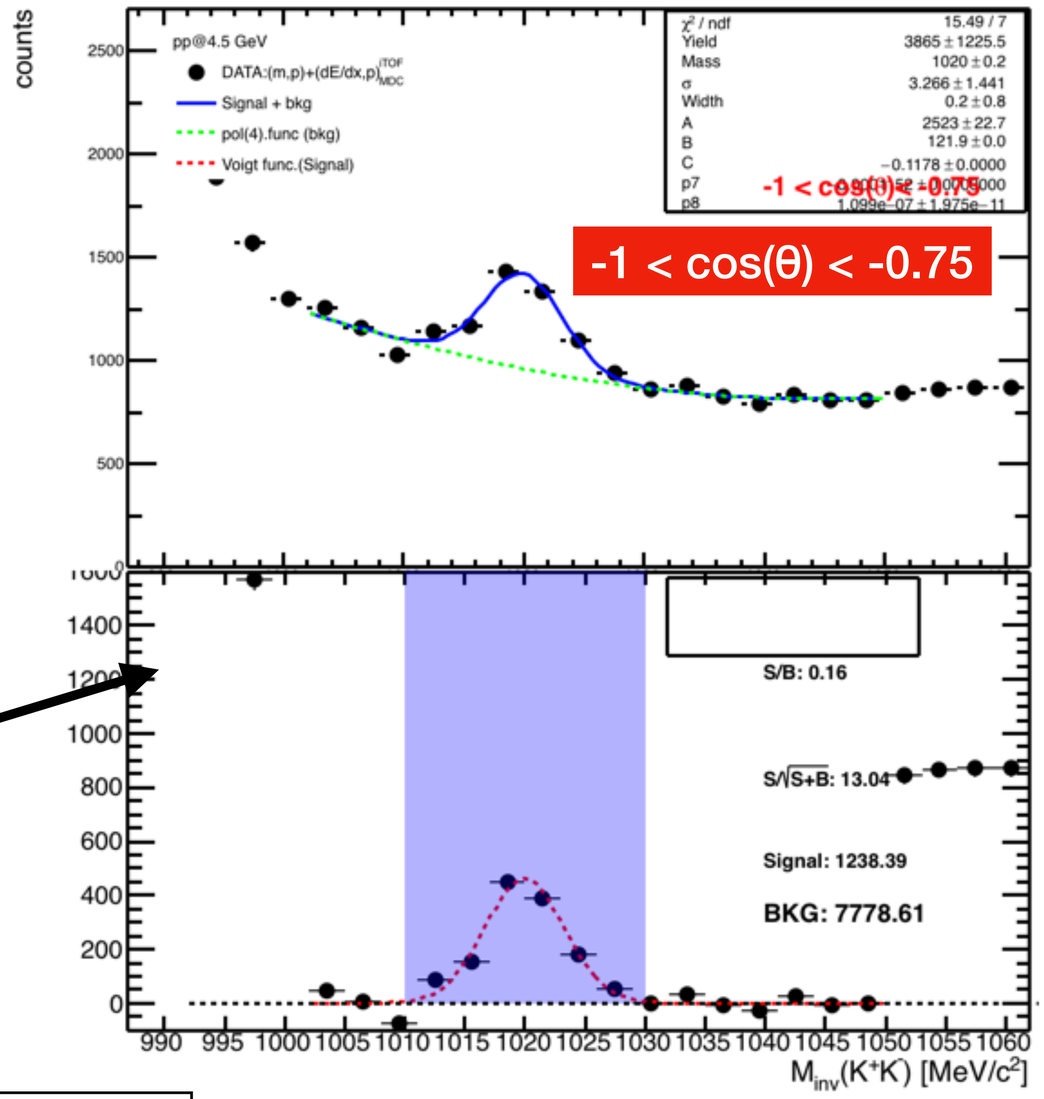
We observe a very good significance
And number of Φ produced

$M_{PDG}(\varphi) = 1019.461 \pm 0.020$ MeV/c²

Angular Distribution of Φ meson using PID from (p, dE/dx)-MDC + mass cut

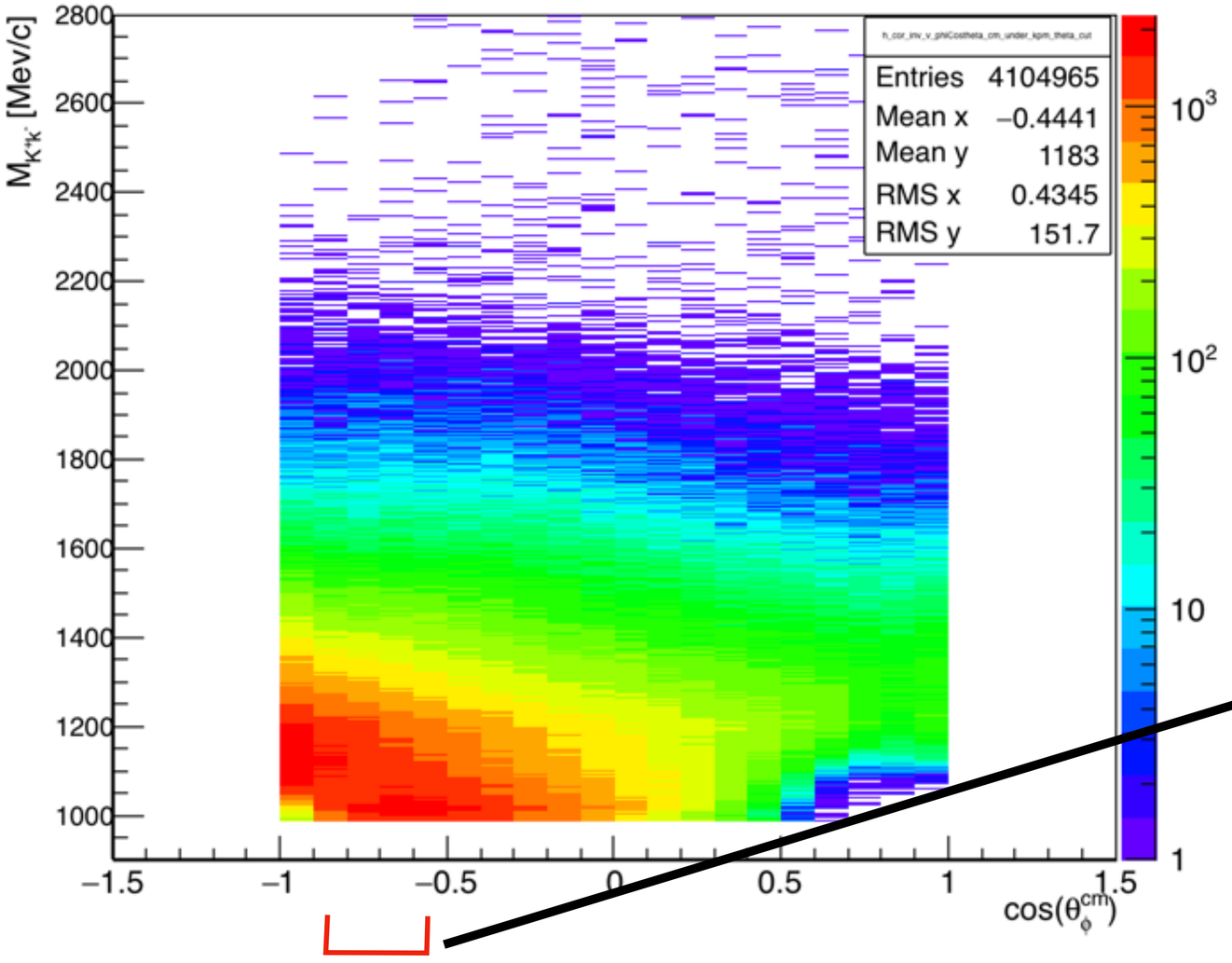
Invariant mass [K+K-] under different cosine range: Method

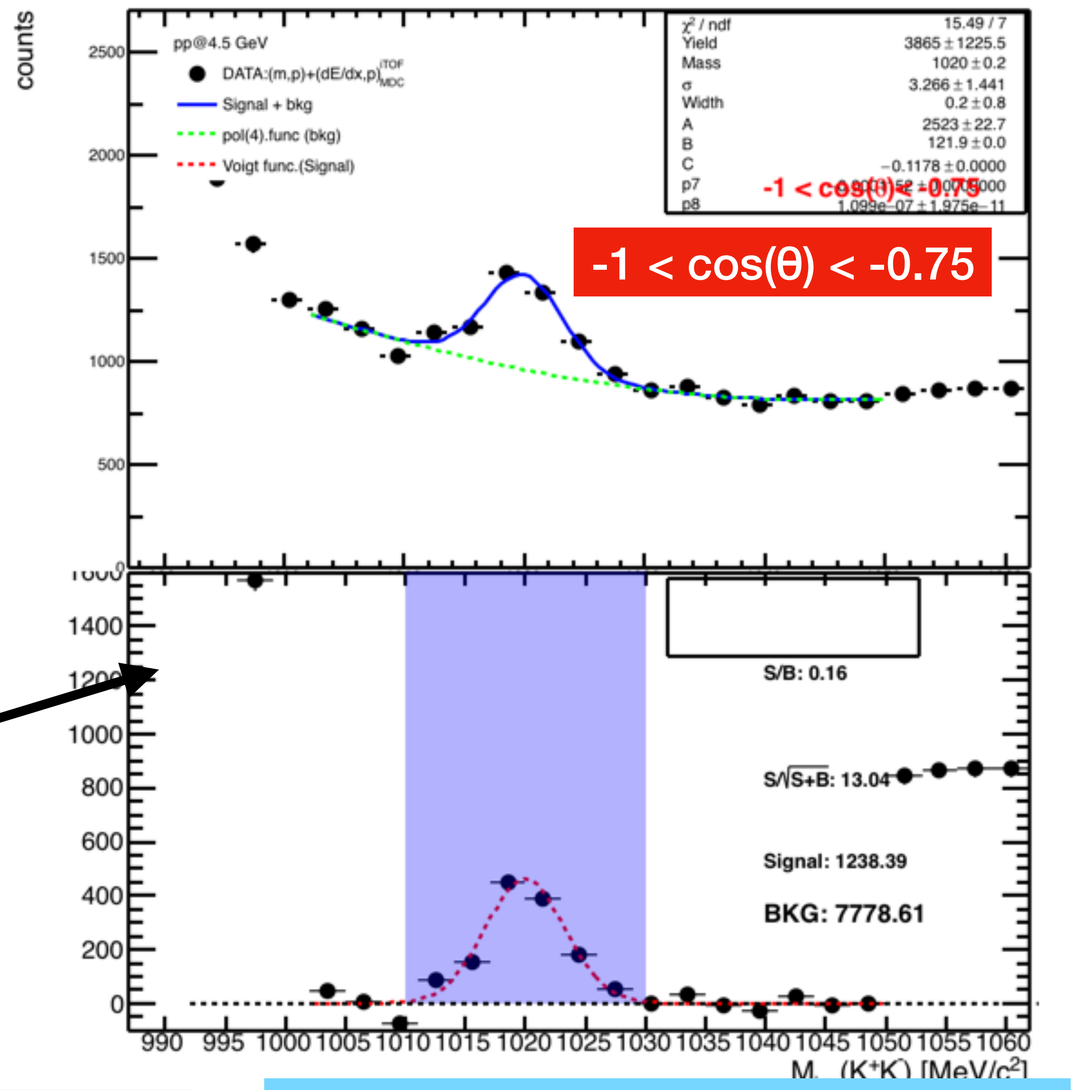




- **Reconstructed Φ meson obtained for -1 < cosθ <-0.75**

Invariant mass [K+K-] under different cosine range: Method

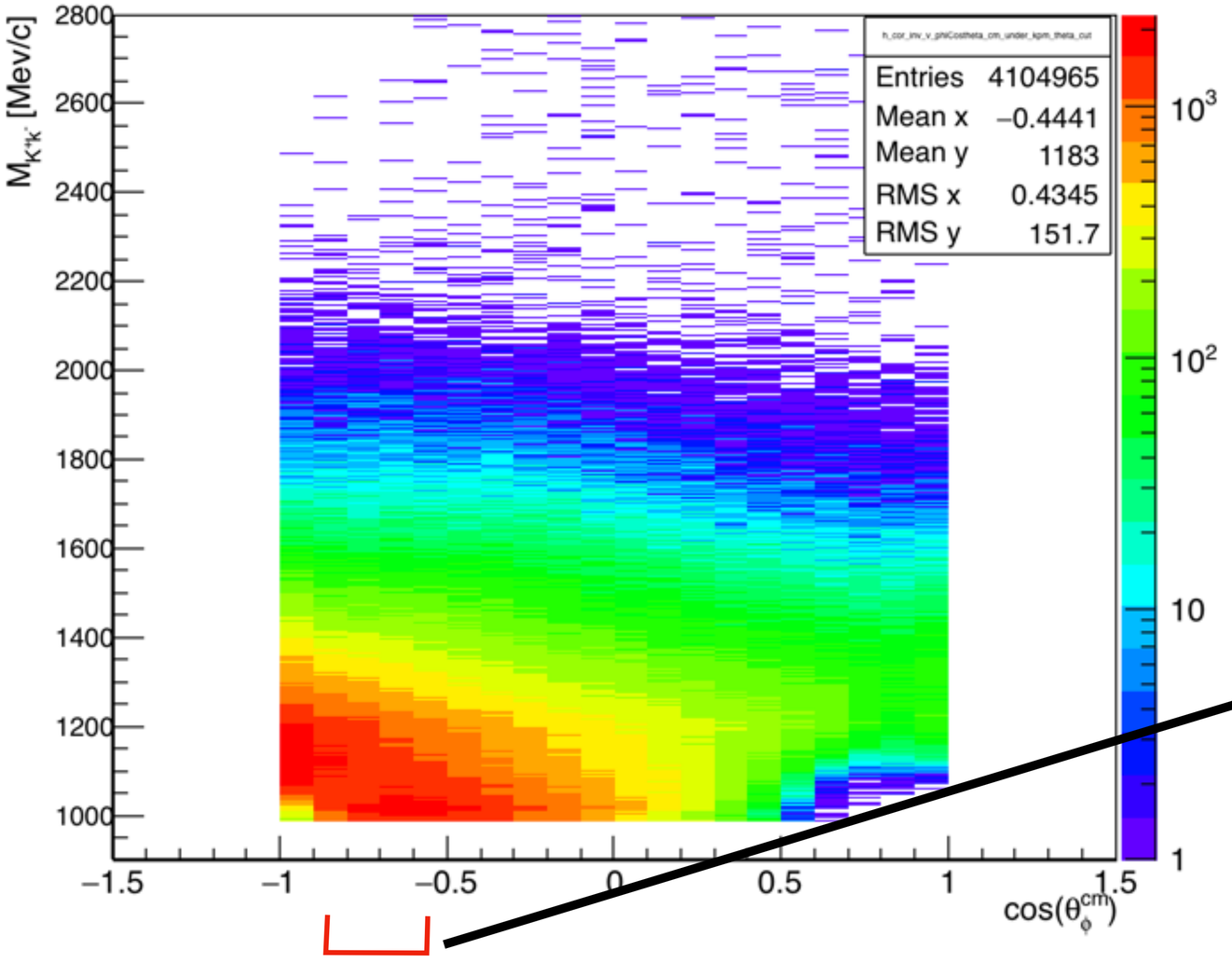


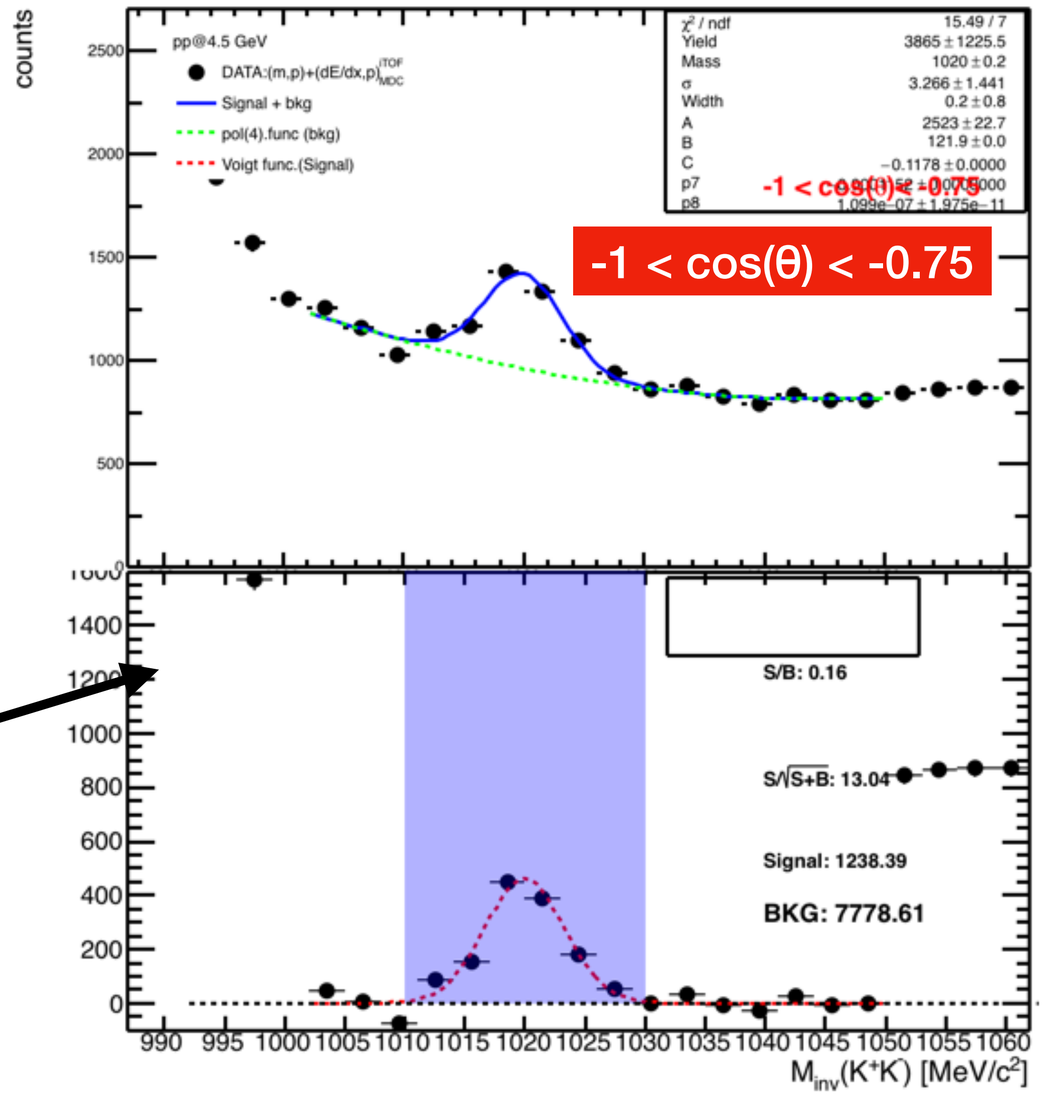


- Reconstructed Φ meson obtained for -1 < cosθ <-0.75

This is repeated for other cosθ intervals and simulation

Invariant mass [K+K-] under different cosine range: Method

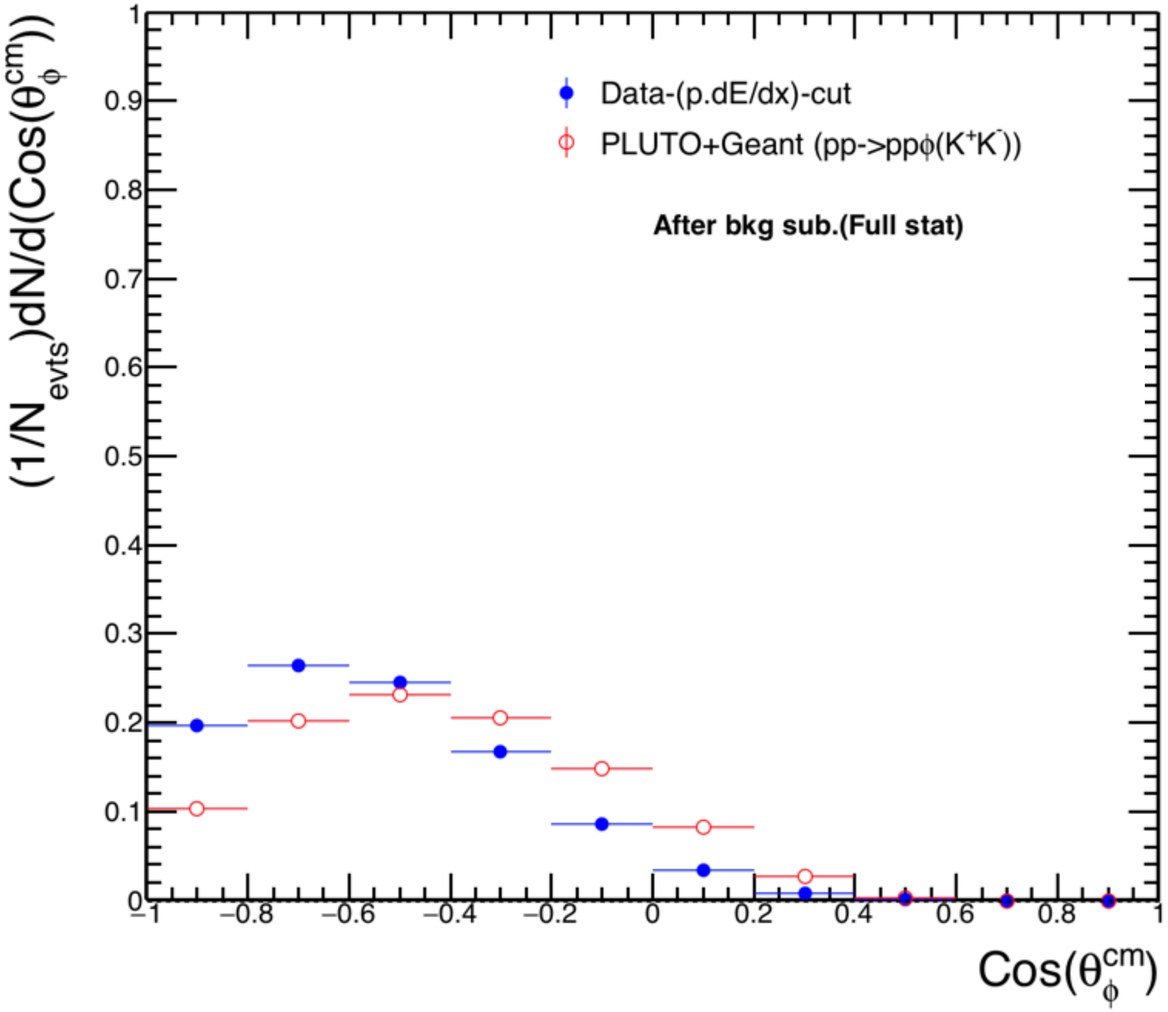


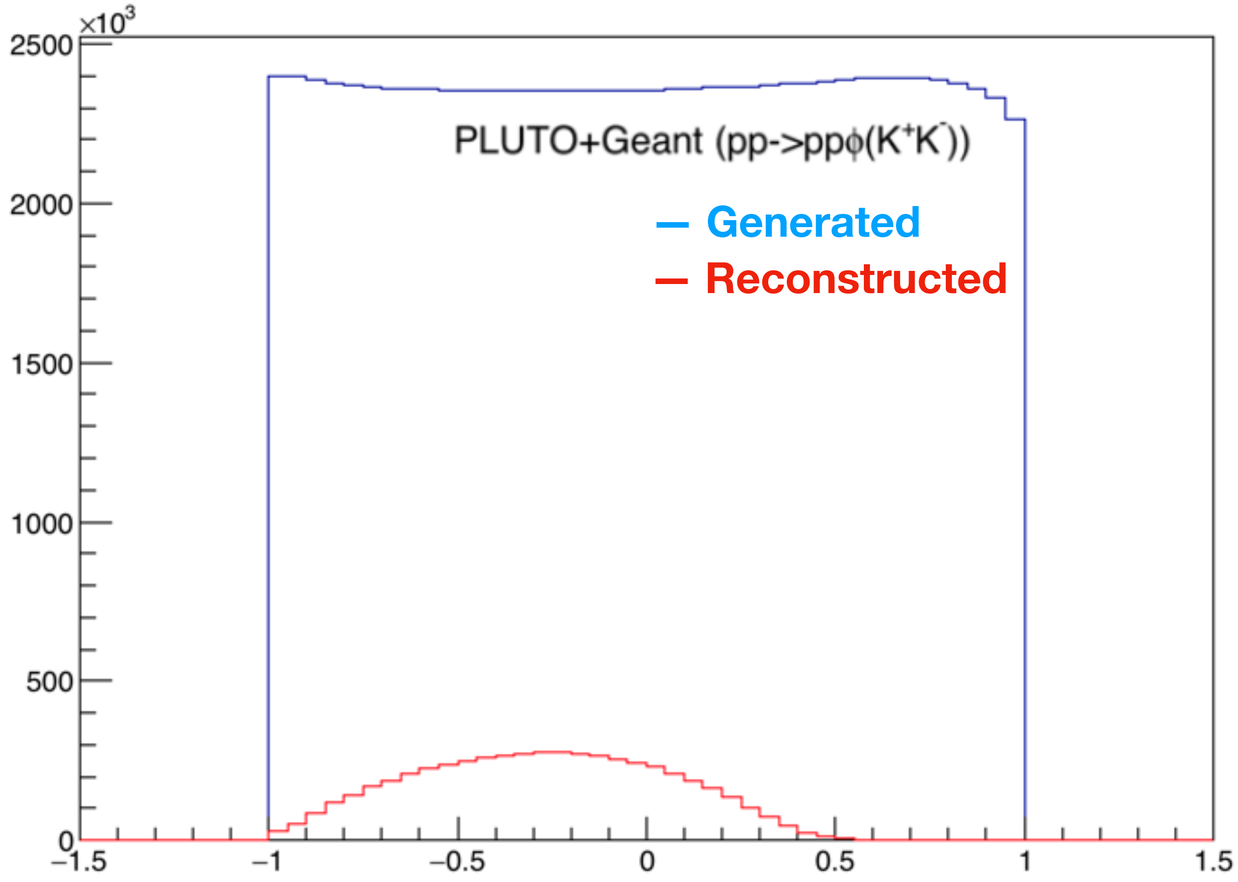


CosΘ: [-1.0, -0.75, -0.5, -0.25, 0, 0.75, 0.5, 0.25,1]

Differential angular distribution of Φ meson for different Cos (θ_{Φ}^{cm})

$\cos(\theta_{\Phi}^{cm})$ distribution- after bkg sub. + Normalised by events

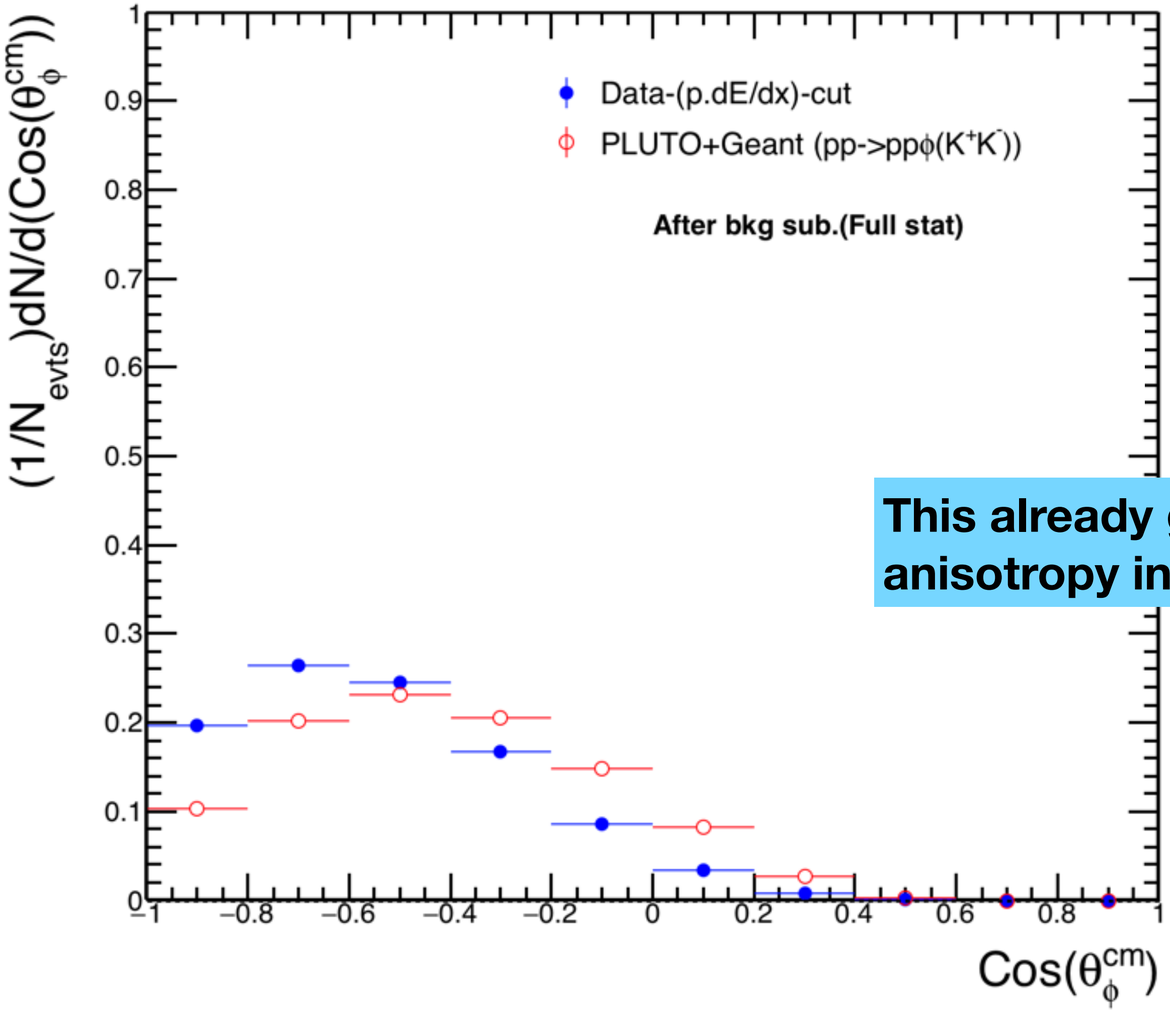


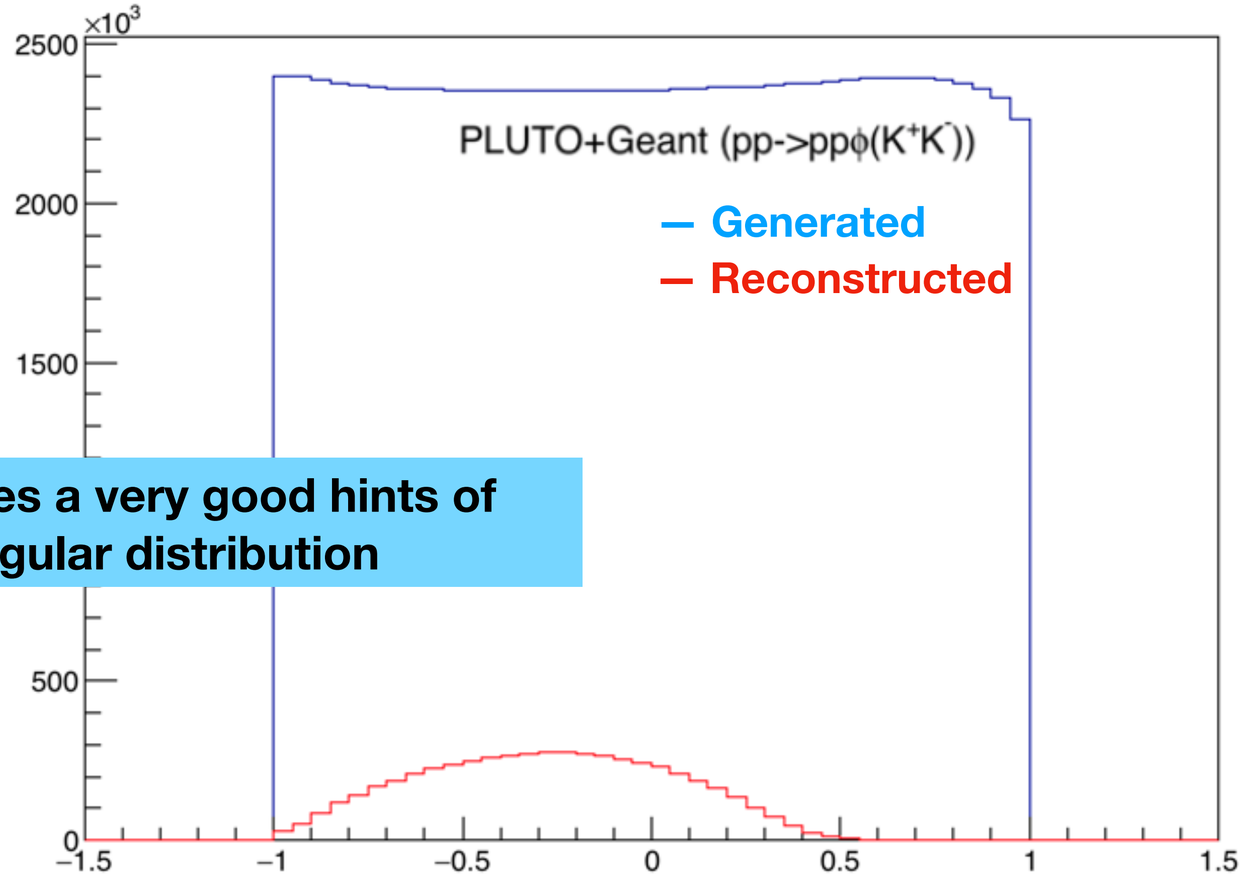


- Here we clearly observed an anisotropic behaviour
- Also, experimental data seems to be more backward than Simulation

- It is to be noted that Generated events are Isotropic
- Strong distortion after reconstructed

$\cos(\theta_{\Phi}^{cm})$ distribution- after bkg sub. + Normalised by events





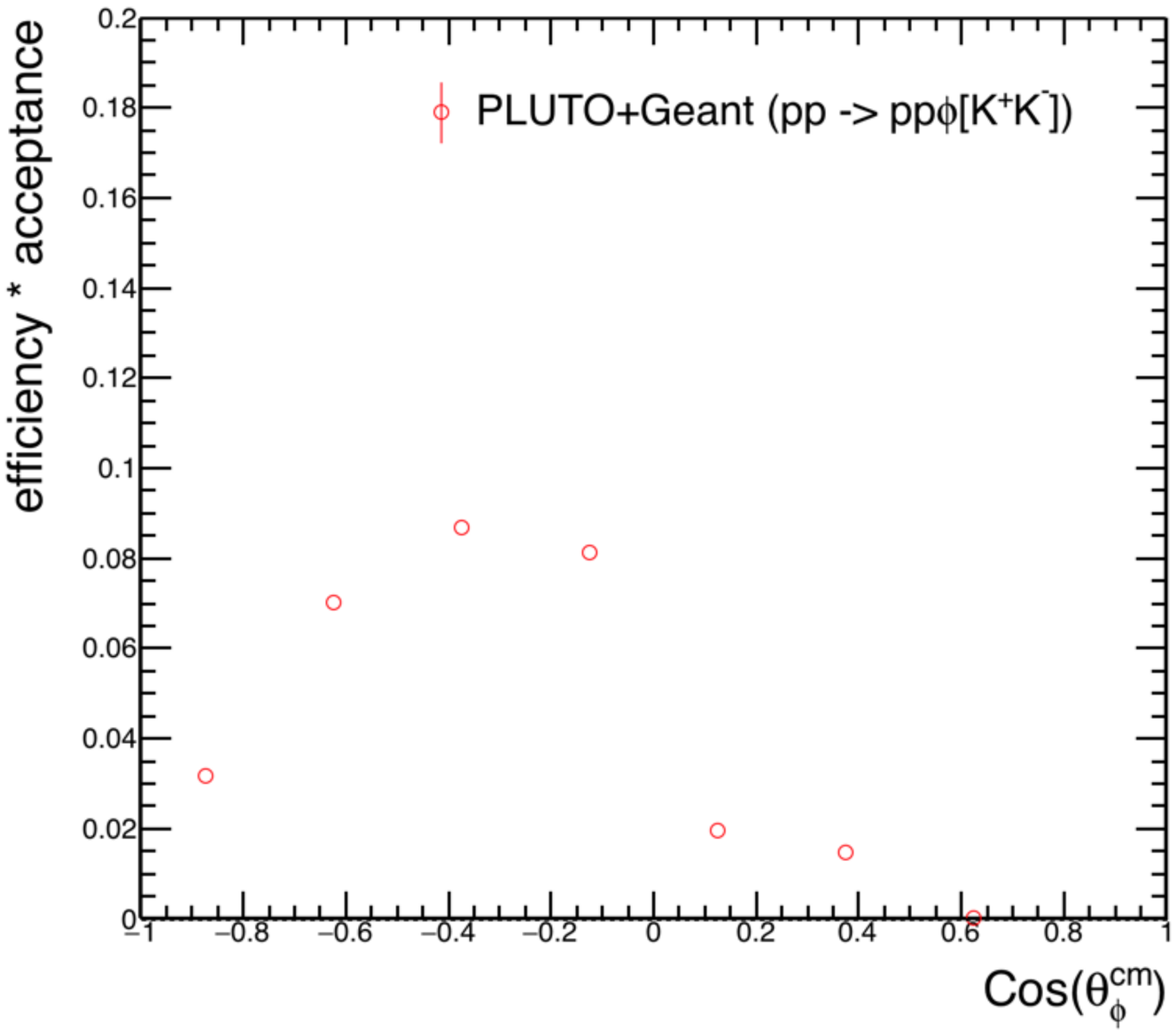
This already gives a very good hints of anisotropy in angular distribution

- Here we clearly observed an anisotropic behaviour
- Also, experimental data seems to be more backward than Simulation

- It is to be noted that Generated events are Isotropic
- Strong distortion after reconstructed

Efficiency * Acceptance using PLUTO+ Geant

Efficiency*acceptance vs cos(θ_{Φ}^{cm}) distribution



Efficiency is obtained for each cosθ bins using following

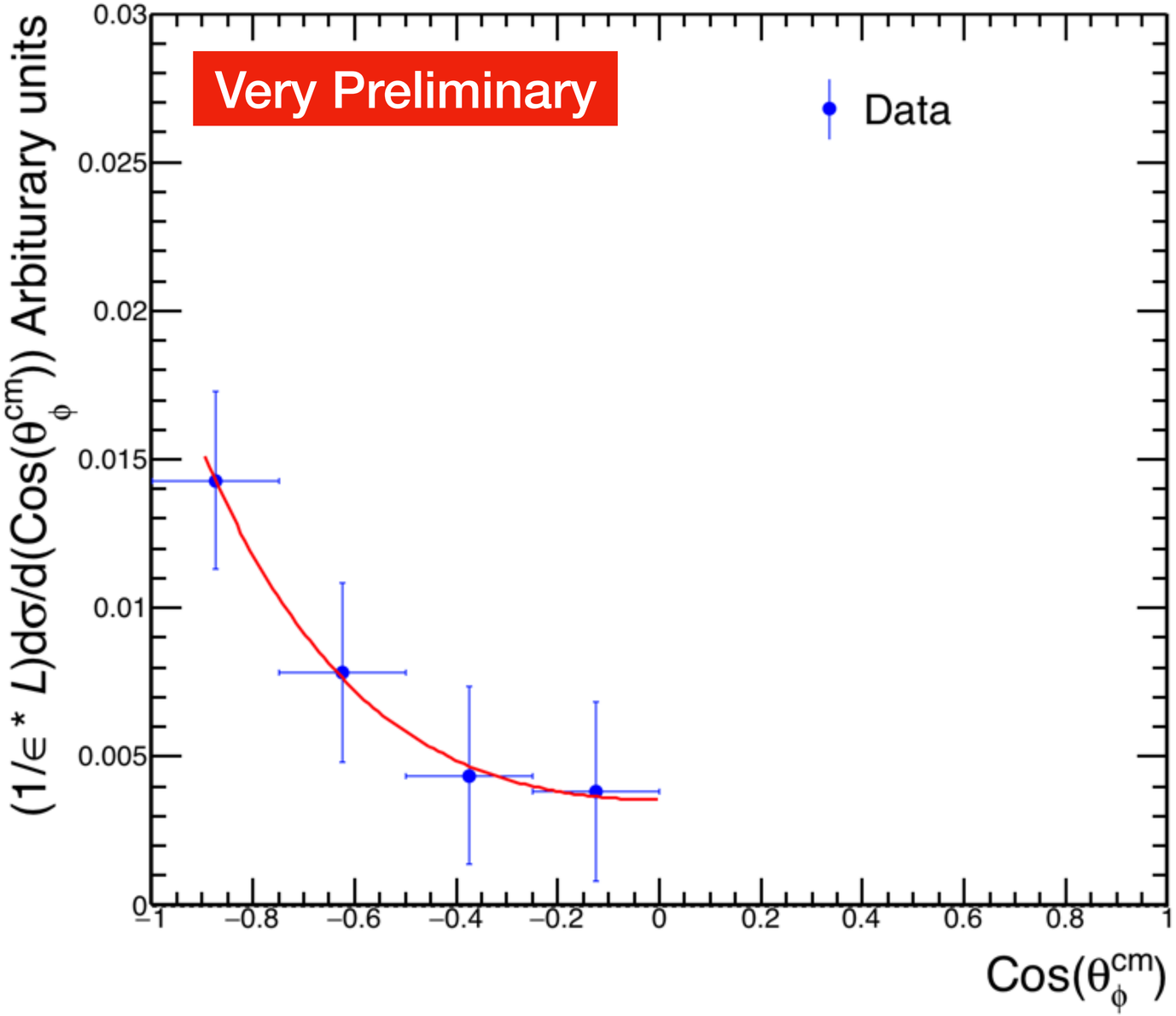
CosΘ: [-1.0, -0.75, -0.5, -0.25, 0, 0.75, 0.5, 0.25,1]

$$\epsilon = \frac{Number\ of\ reconstructed\ \phi\ meson}{Number\ of\ generated\ \phi\ meson}$$

Number of reconstructed Φ are obtained by the method described in slide -51

Only negative part is used for correction further

Differential Cross-section Vs $\cos(\theta_{\Phi}^{cm})$ distribution



- **Luminosity is obtained from known pp elastic cross section and number of elastic events**

- **Only negative part is considered**
- **Stat. Error are negligible**
- **Systematic error yet to investigate**

Very preliminary result shows a strong anisotropy of Φ production in pp@4.5 GeV

Summary

- Very preliminary analysis of ϕ production in pp reaction at 4.5 GeV via K+K- decay (HADES data): signal extraction and production angular distribution

- Using the complementaries of HADES detectors like tracking, time of flight and dE/dx technique

Next Step

- Large pionic background PID selection needs to be improved.
- Model dependence of efficiency * acceptance to be checked.
- Analysis of kaon angular distribution in reference frame to measure polarisation

Outlook

- Large ϕ yield ⟶ very good perspective for extraction of cross section, angular distribution and polarization (via angular distribution of kaons) ⟶ information on production mechanism (OZI rule)

- Complementary to HADES data for ϕ ⟶ e^+e^- measured simultaneously

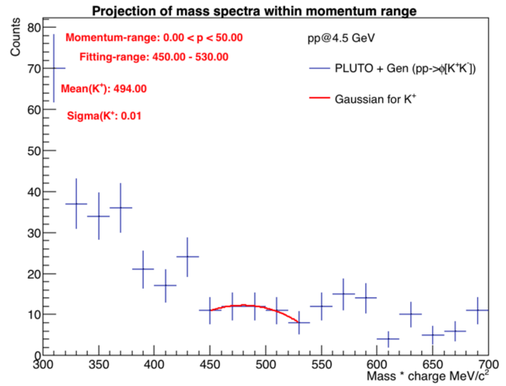
Thank you for your kind attention

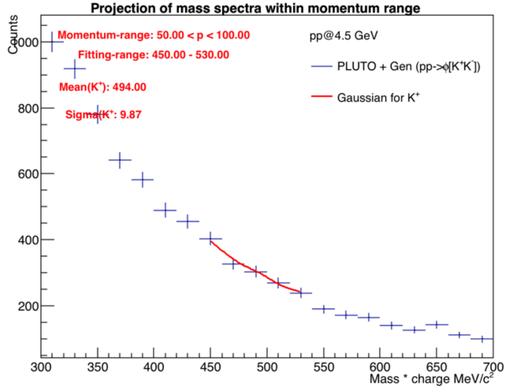
backup

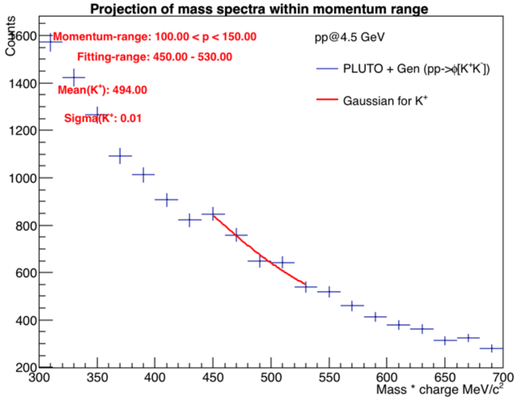
Particle identification: Step-2: Projection of Mass for diff. momentum range

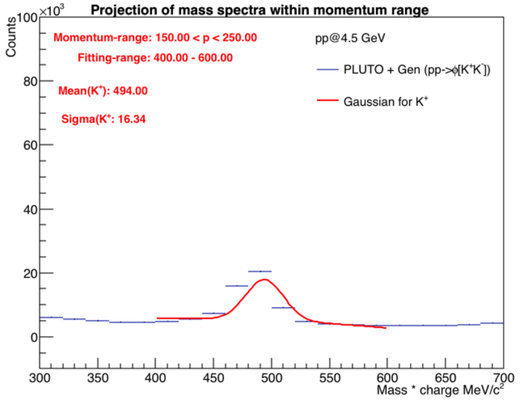
PLUTO+Geant

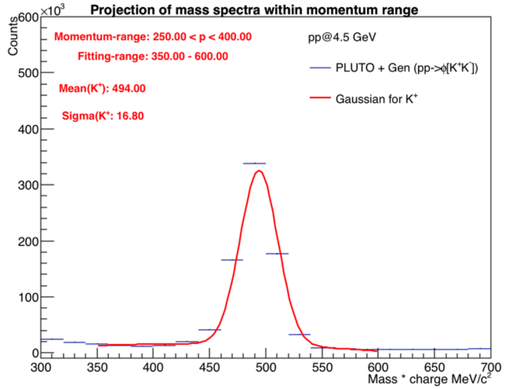
K^+

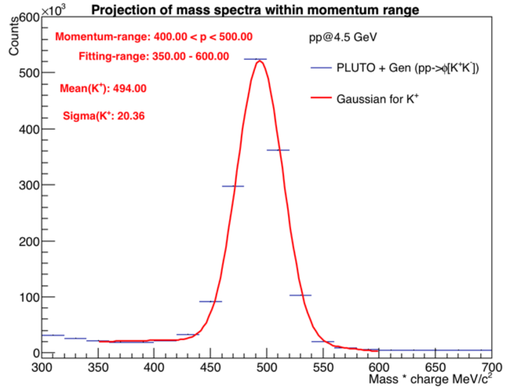


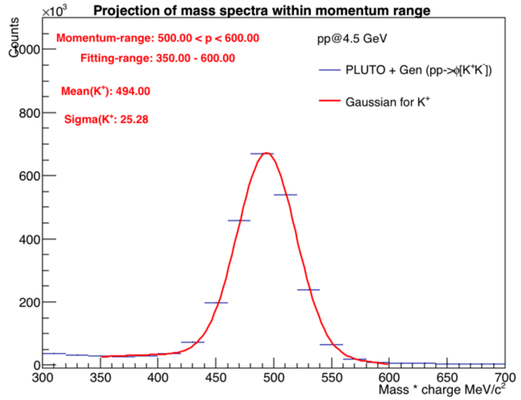


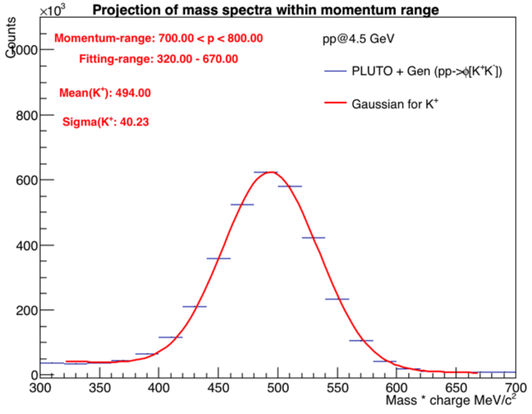


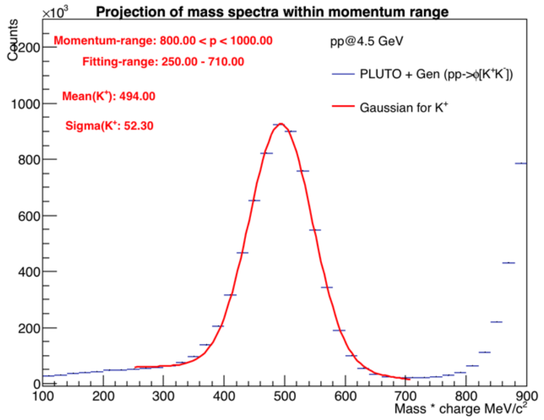


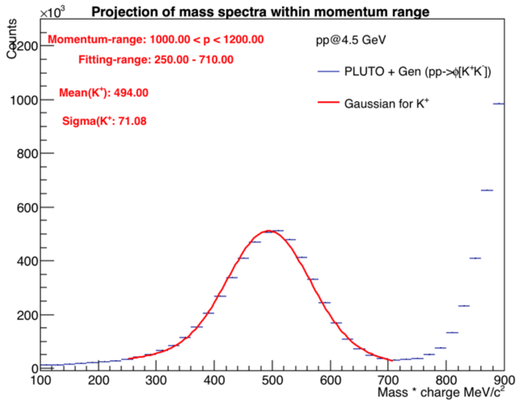


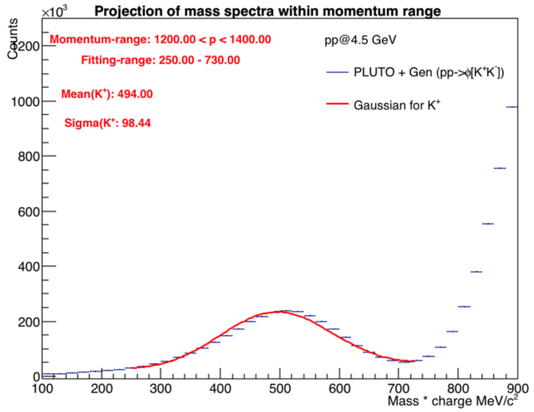


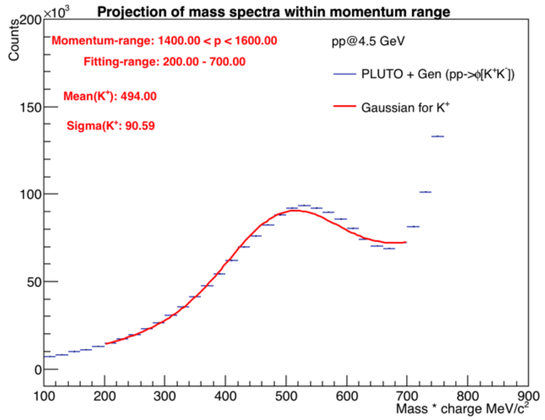








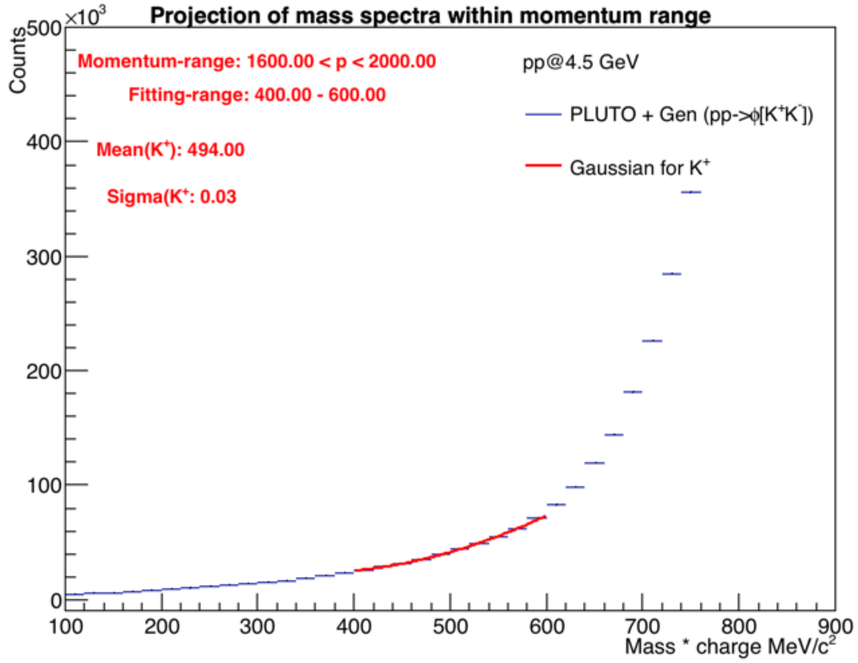


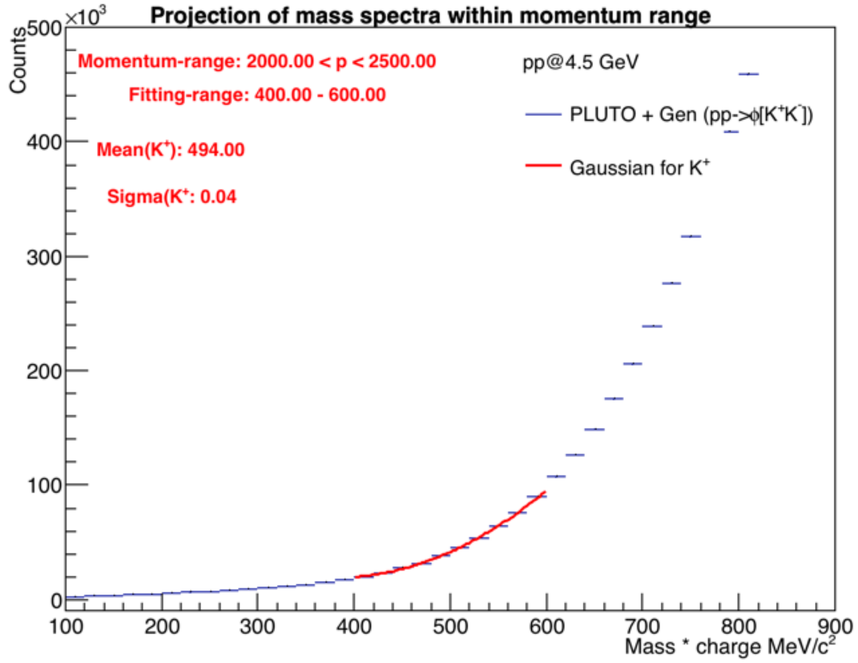


Particle identification: Step-2: Projection of Mass for diff. momentum range

PLUTO+Geant

K^+

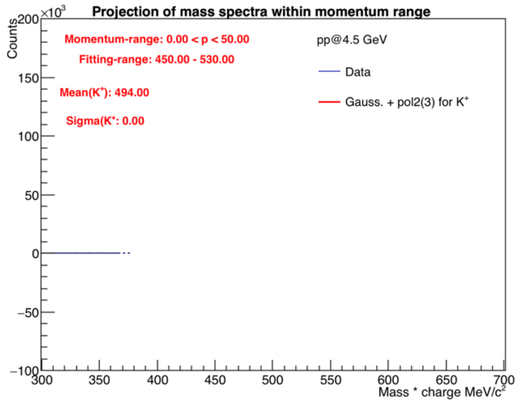


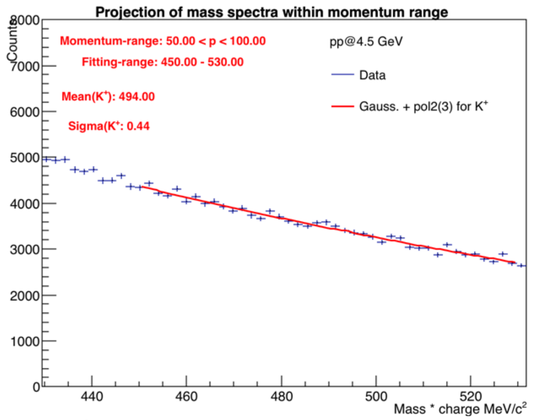


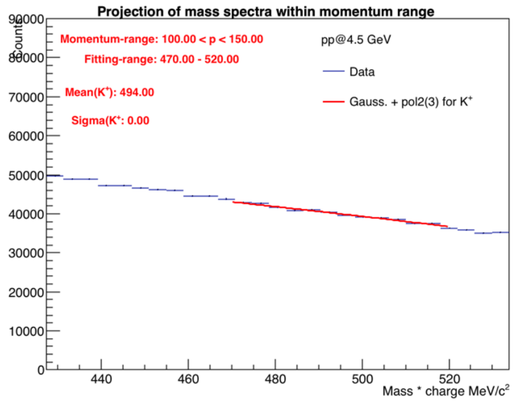
Particle identification: Step-2: Projection of Mass for diff. momentum range

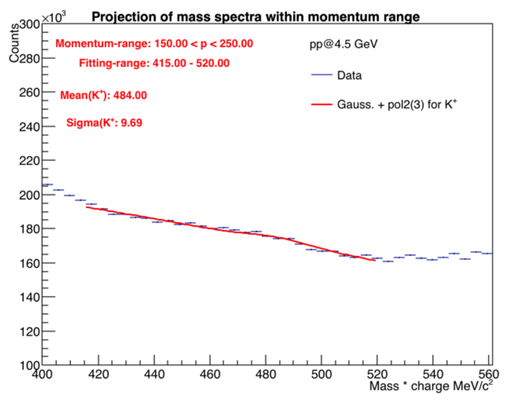
Data

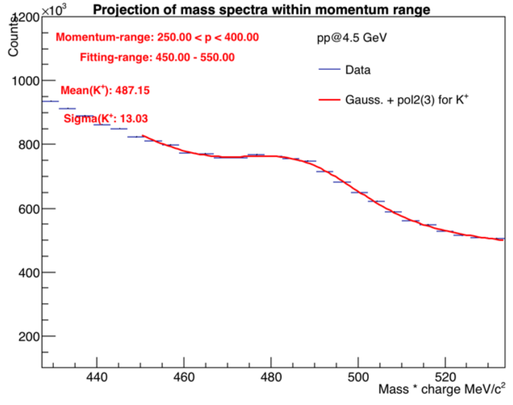
K^+

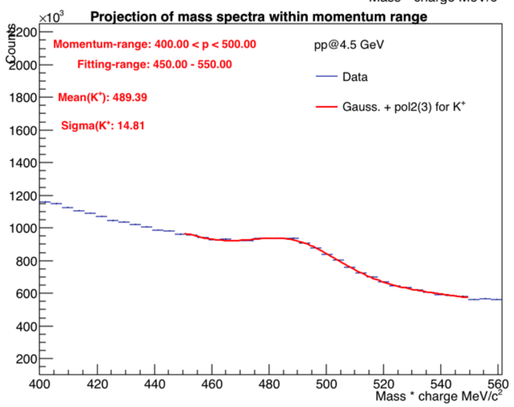


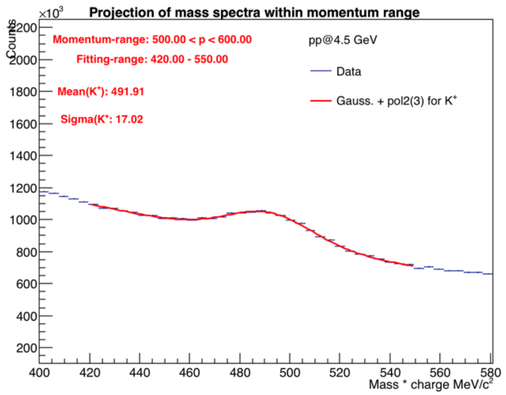


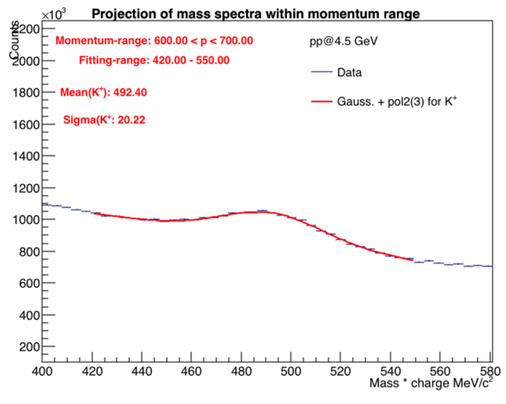


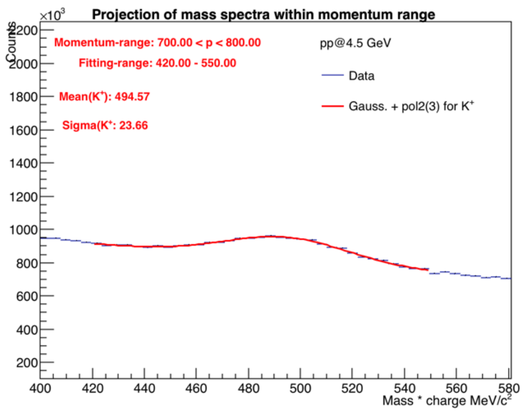


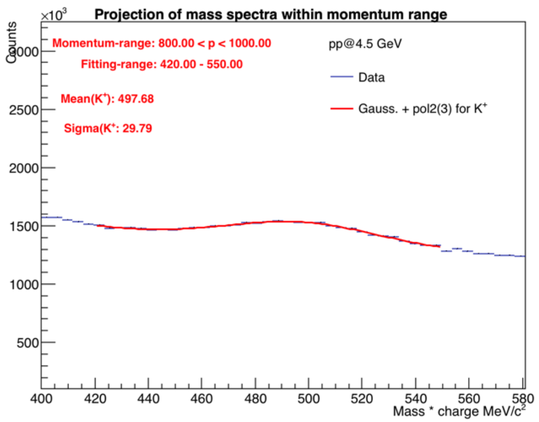


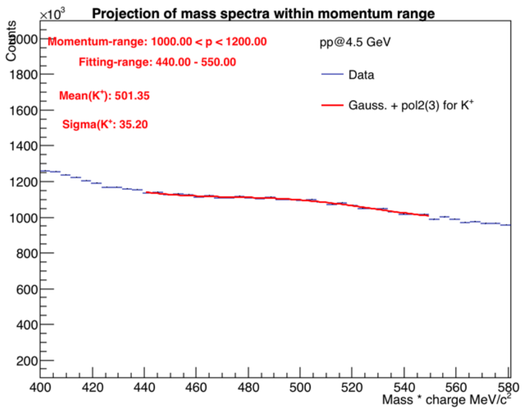


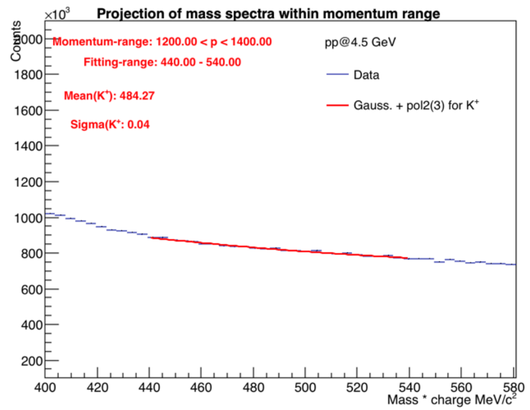








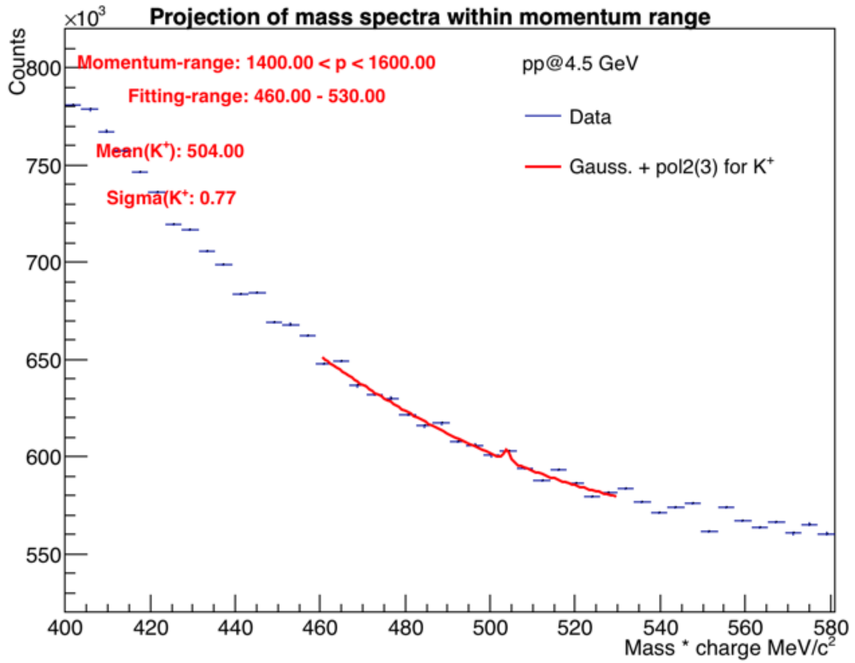


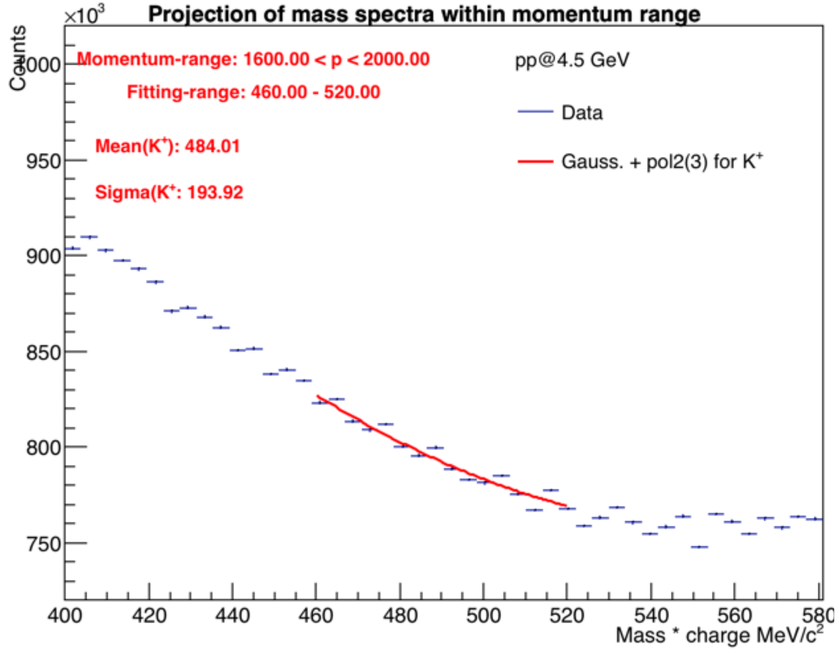


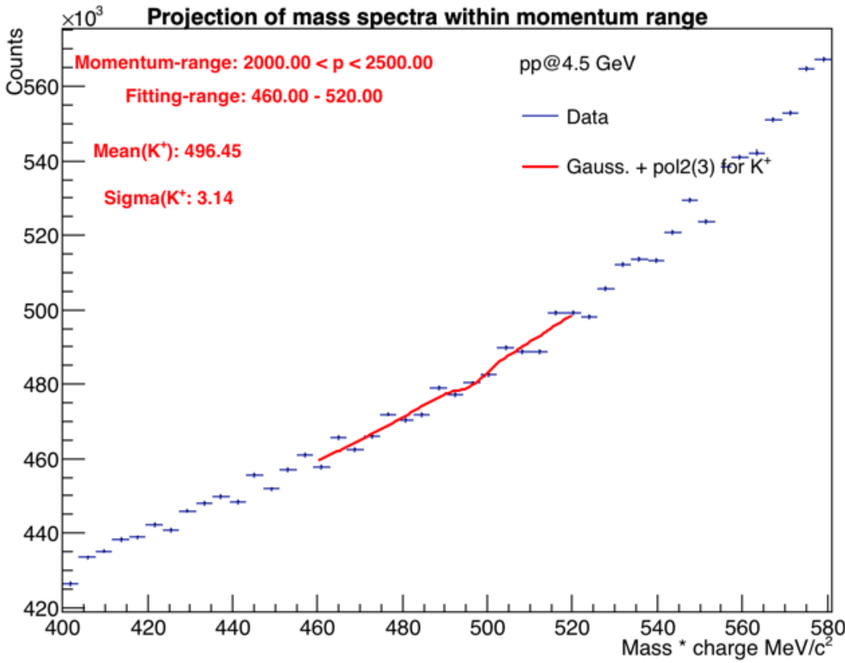
Particle identification: Step-2: Projection of Mass for diff. momentum range

Data

K^+



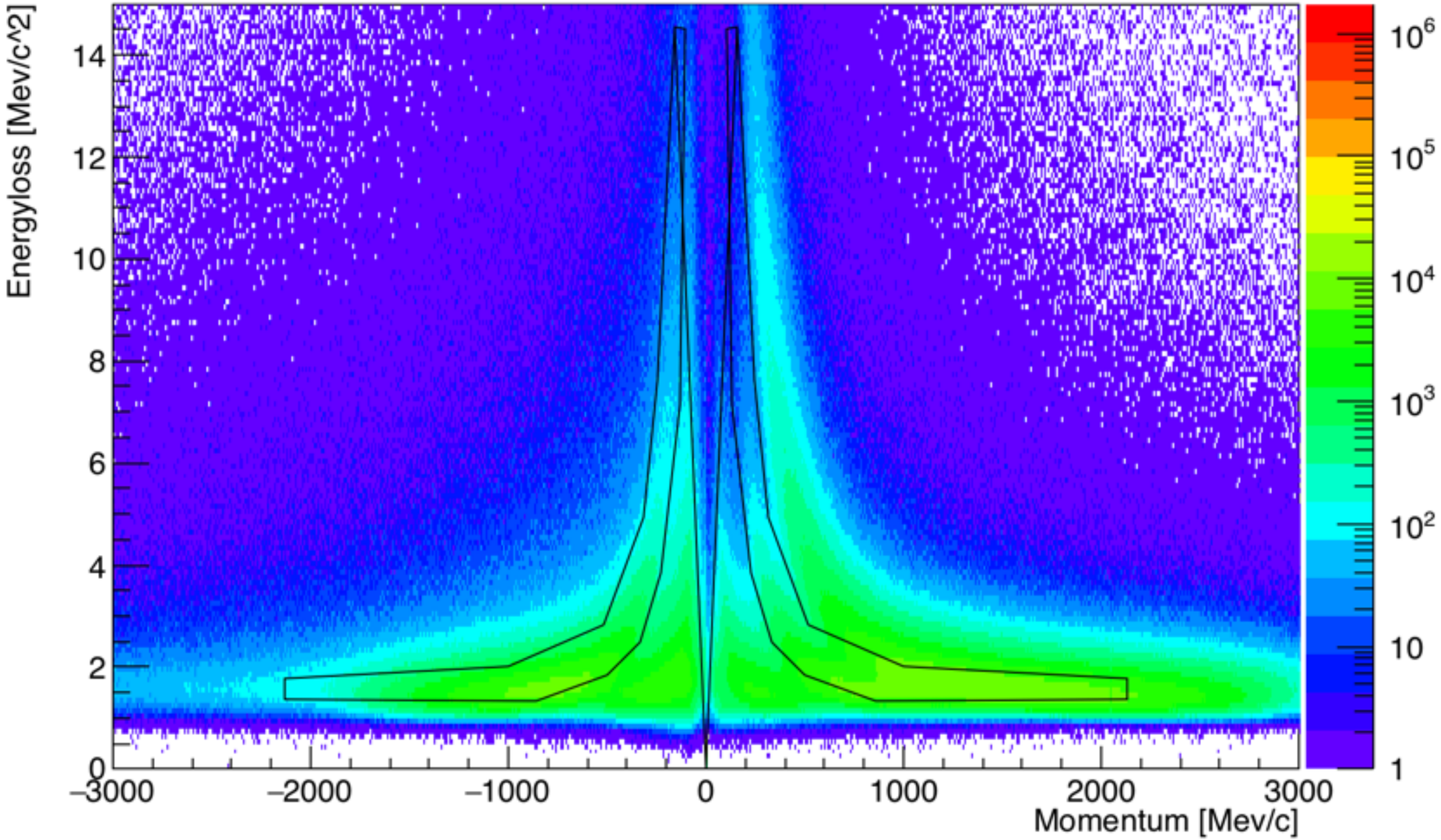




Affect of Graphical cut (p,dE/dx) on Simulations

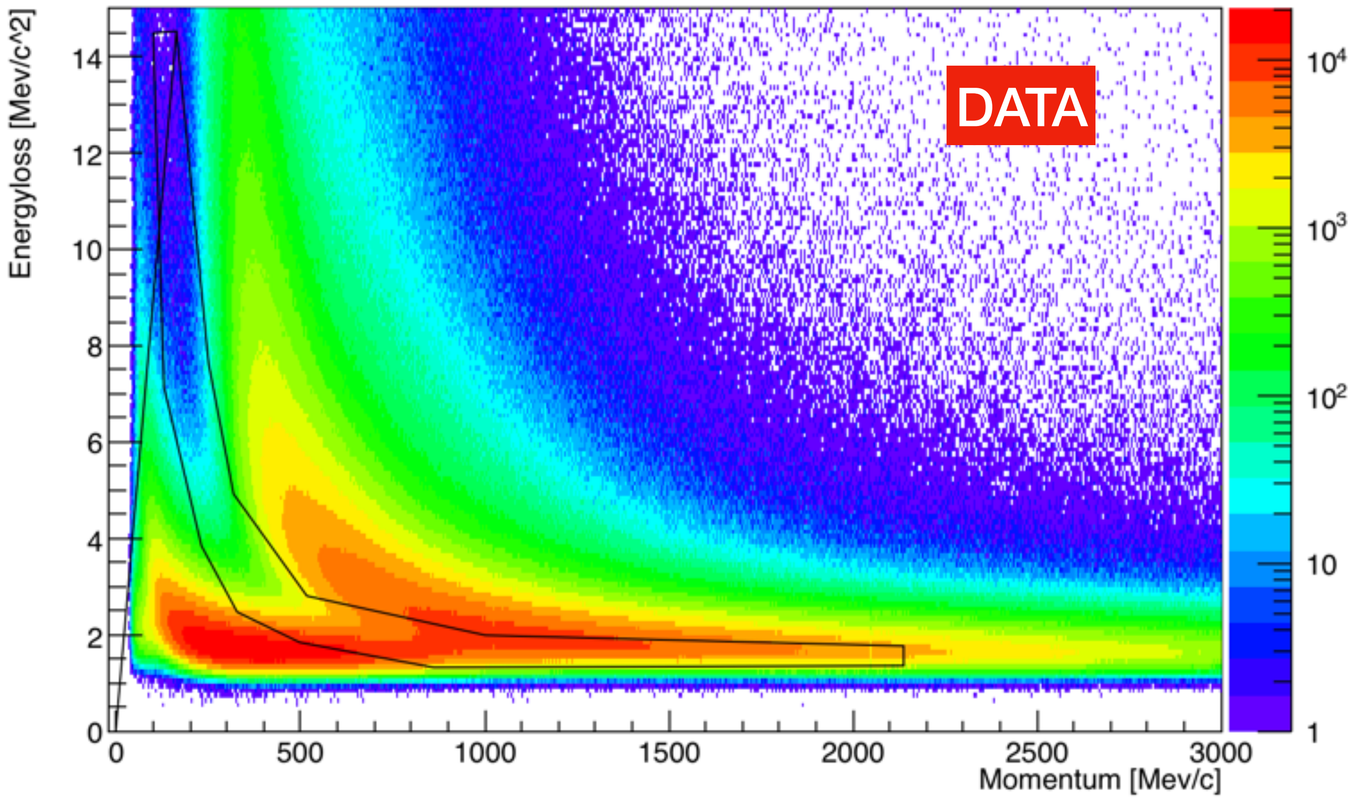
PLUTO+Geant

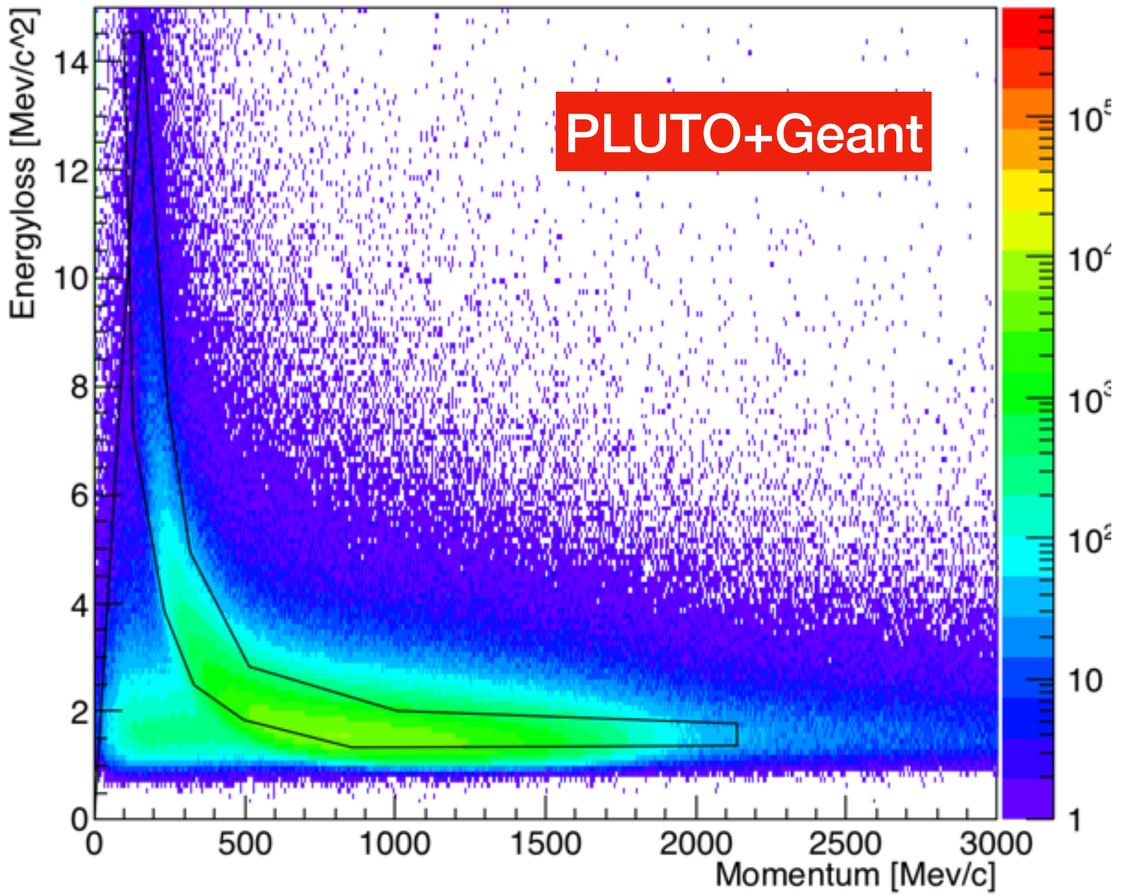
pp->pp Φ(K+K-)



Affect of Graphical cut (p,dE/dx) on Simulations

K+





Affect of Graphical cut (p,dE/dx) on Simulations

K-