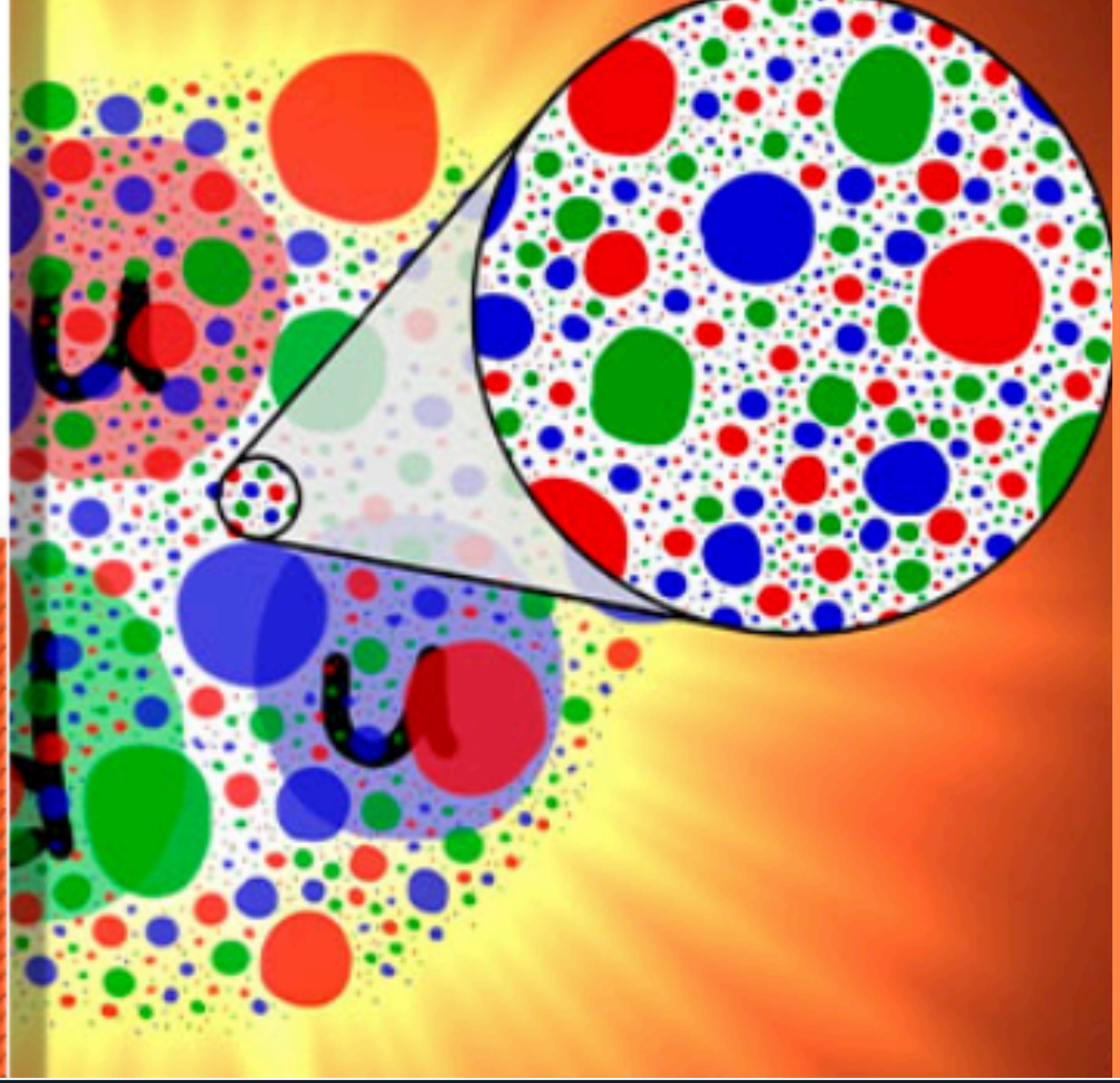
GDR Groupement de recherche
QCD Chromodynamique quantique

Chromodynamique quantique



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

Suman Deb

Laboratoire De Physique Des 2 Infinite Irène Joliot-Curie, Orsay

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Laboratoire de Physique des 2 Infinis

HADES

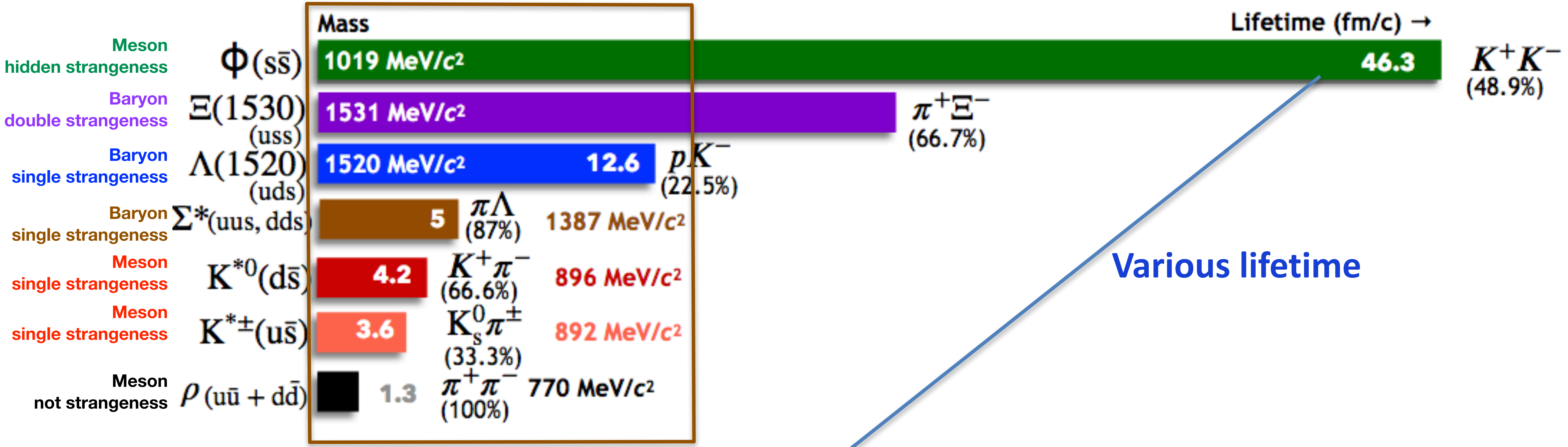
cnrs

Outline

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

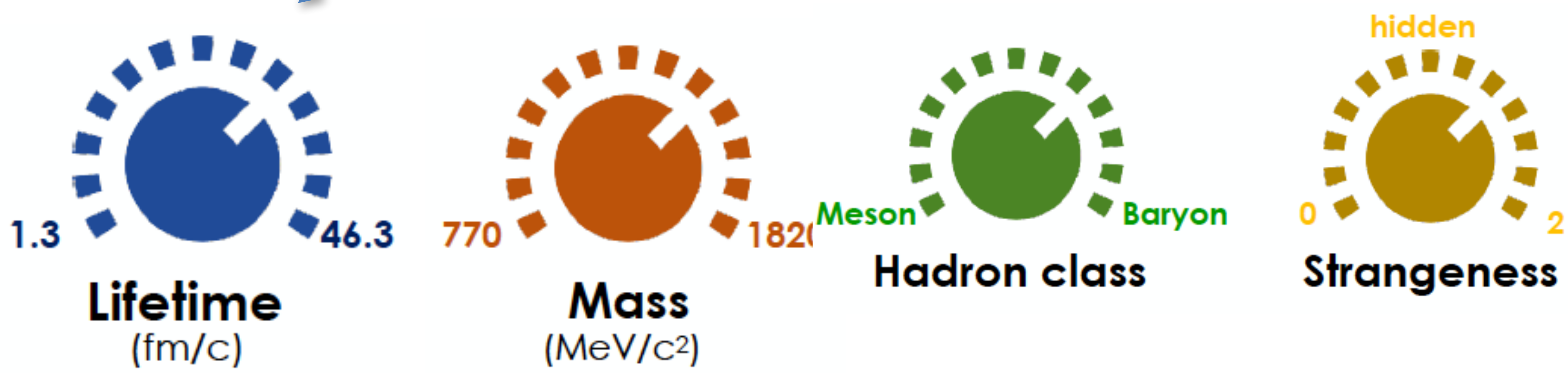
Introduction

why Resonance particle?



Different hadron class /

Strangeness



Introduction

Why is ϕ meson interesting?

		Mass (MeV/c^2)	lifetime (fm/c)
Meson hidden strangeness	$\phi\,(s\bar{s})$	1019	46.3
Meson not strangeness	$\rho(u\bar{d} + d\bar{u})$	775.3	1.3
Meson Neutral	ω	782.7	23.25

Γ = 4.3 MeV ; $\phi \rightarrow K^+K^-$ (49 %) ; $\phi \rightarrow 3\pi$ (15 %); $\phi \rightarrow e^+e^-$ ($3 \cdot 10^{-4}$)

Γ = 149 MeV ; $\rho \rightarrow 2\pi$ (~100%); $\rho \rightarrow e^+e^-$ ($4.7 \cdot 10^{-5}$)

Γ = 8.5 MeV ; $\omega \rightarrow 3\pi$ (89 %); $\omega \rightarrow e^+e^-$ ($7.3 \cdot 10^{-5}$)

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Important questions

- ϕ **production mechanism** in interactions between hadrons with u, d quarks ? Coupling to baryons ?
- **Impact for hadronic medium studies**
  - ➡Are ϕ properties modified in the nuclear medium ?
  - ➡How does ϕ contribute to in-medium strangeness and e^+e^- production ?

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- **Motivation**
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Motivation

Test of OZI rule (Okubo-Zweig-Iizuka)

Source: Phys. Rev. D 16, 2336, (1977)

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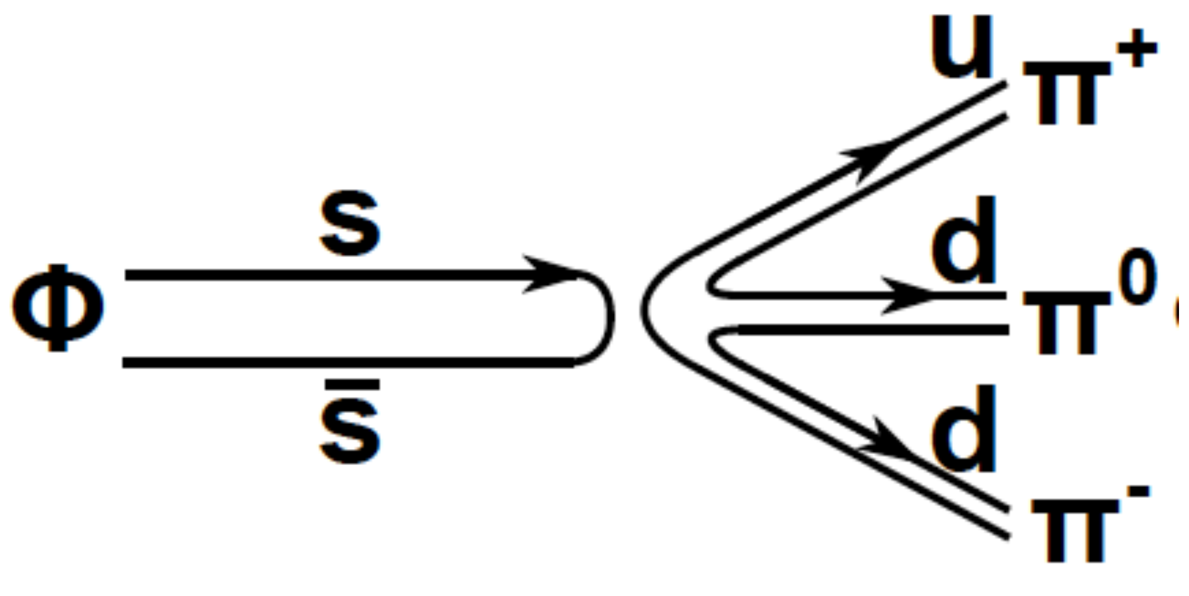
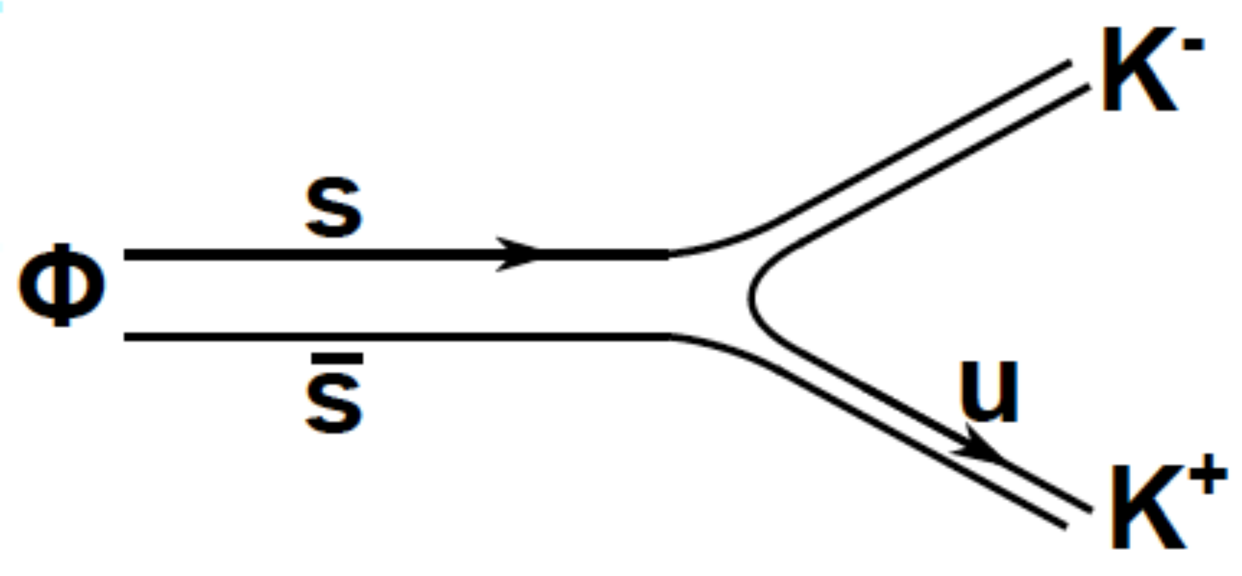


$$\phi \to \pi^+\pi^-\pi^0$$

Suppressed



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Enhanced

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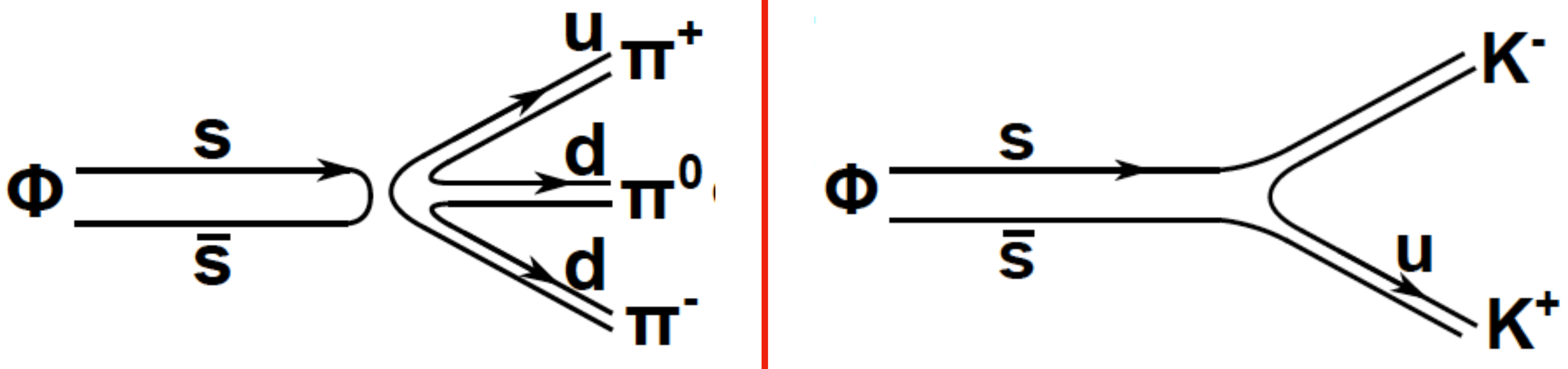

$$\phi \to \pi^+\pi^-\pi^0$$

Suppressed

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Enhanced

From OZI rule,

- **Explains the suppression of ϕ ⟶3 π w.r.t ω**
- **Predicts strong suppression of ϕ production in hadronic interactions**

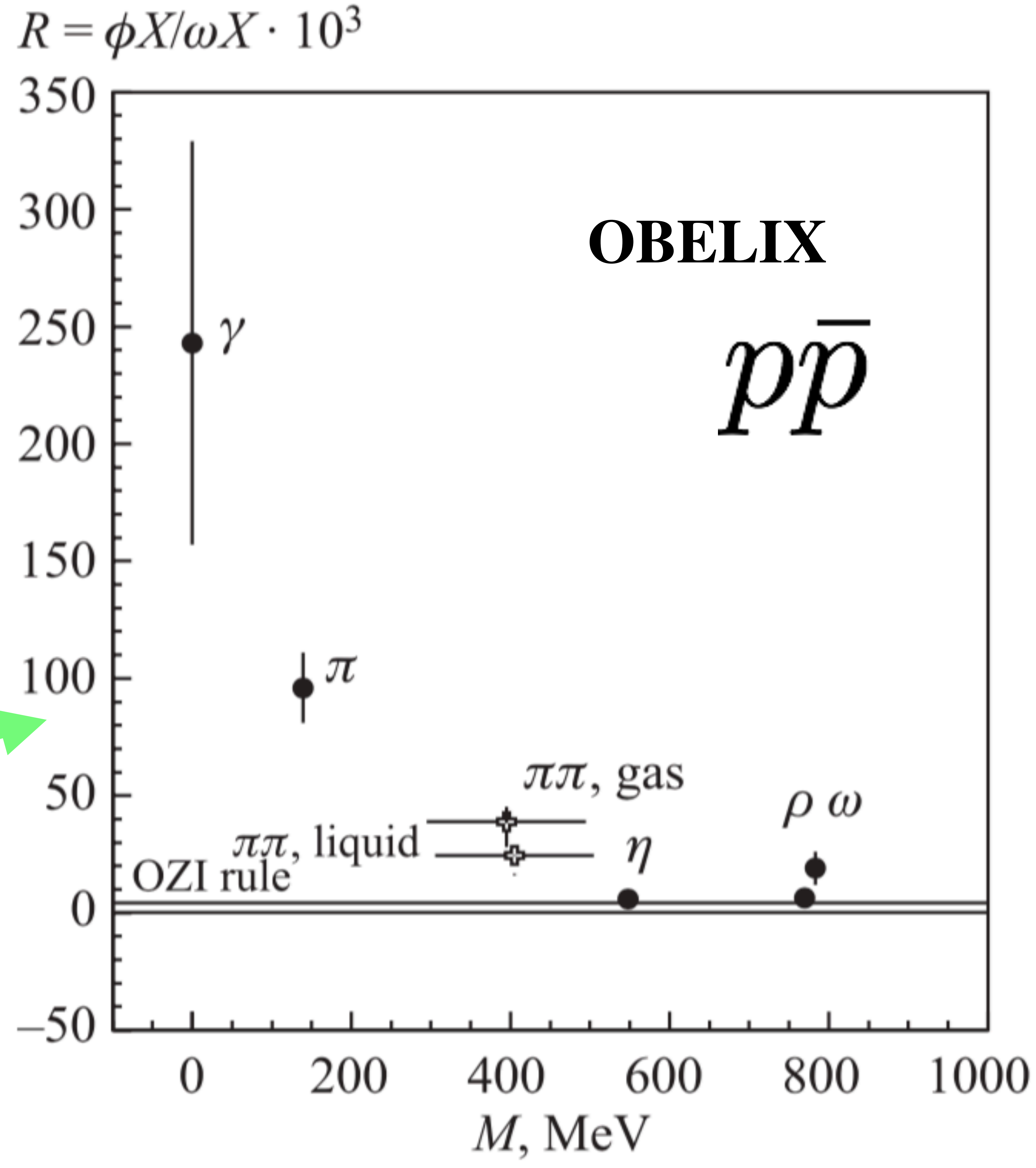
Motivation

Validity of OZI rule

- **Validity of this rule was studied by ratio of production cross section of ϕ and ω meson as**

$$R_{\phi/\omega} = \frac{A + B \to \phi X}{A + B \to \omega X}$$

- **First observation of violation of OZI rule in** $p\bar{p}$



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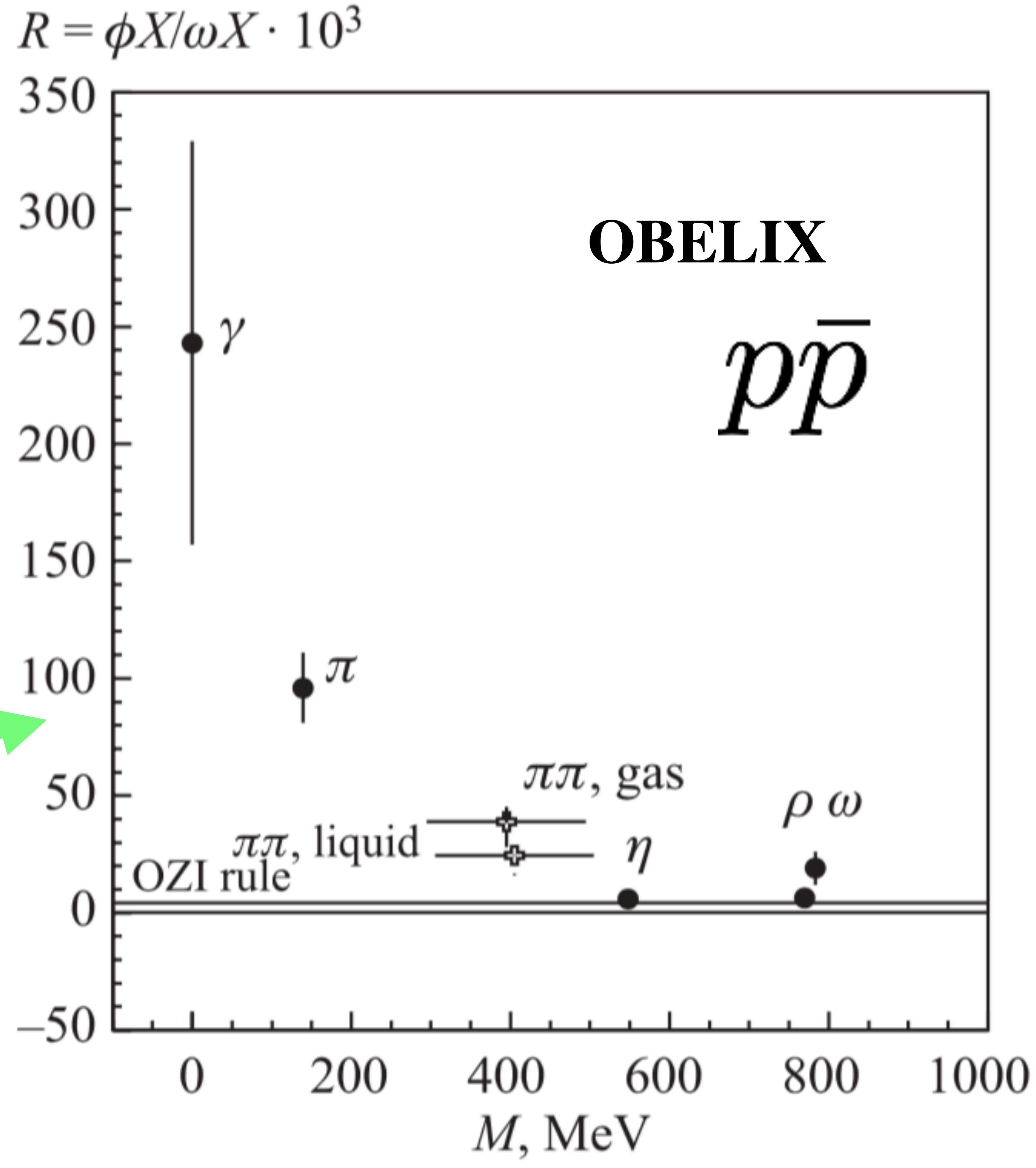


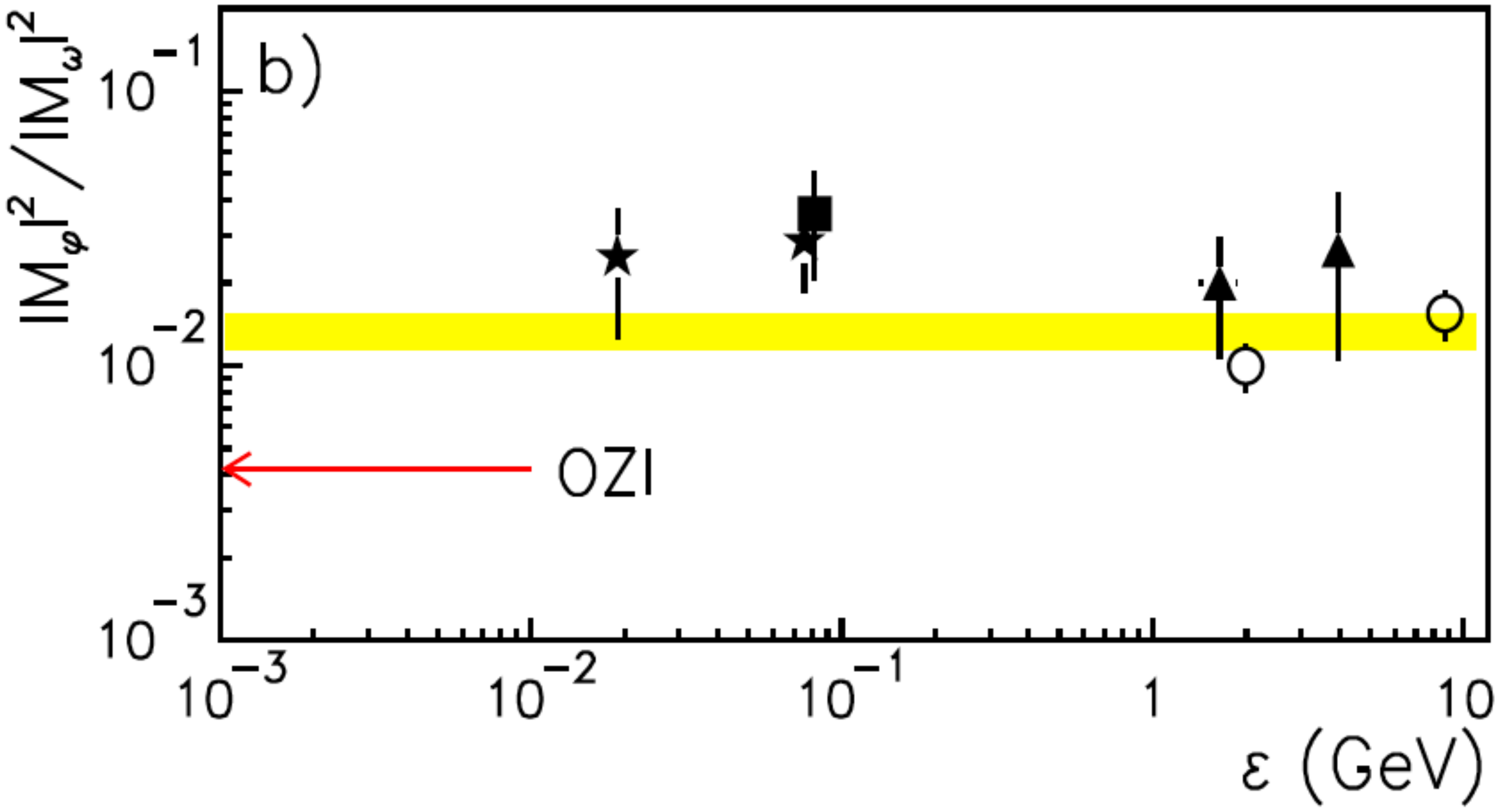
Is the enhanced cross section of ϕ related to the strange quark content of the nucleon?

Motivation

OZI rule in pp reactions

- ϕ and ω meson production matrix elements measured as a function of excess energy

- OZI rule prediction for the ω/ϕ mixing is ~$4.2 * 10^{-3}$



Motivation

OZI rule in pp reactions

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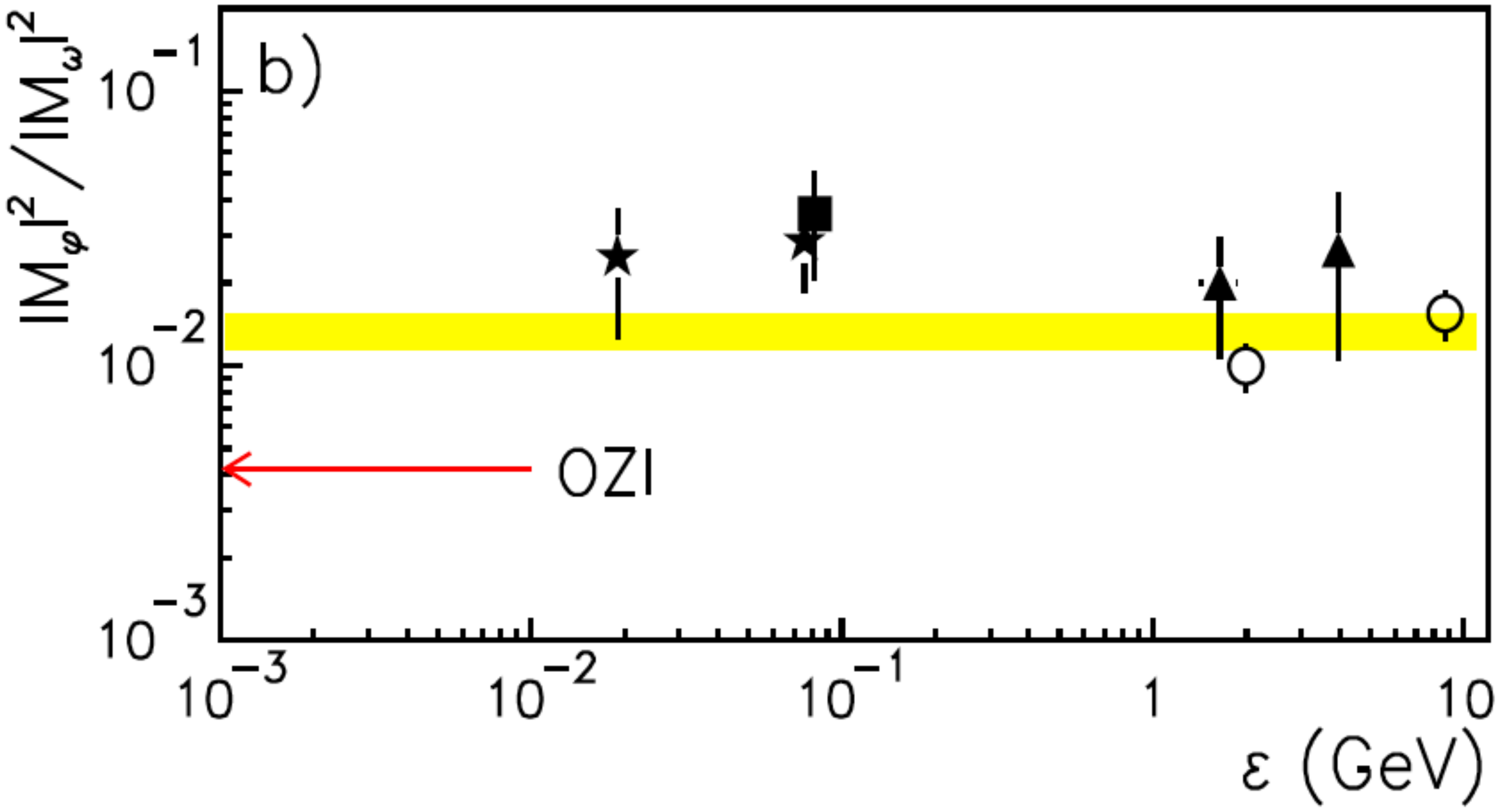

OZI rule Violation can be explained by

- **Meson exchange models + FSI e.g.** *Titov et al. Eur. Phys. J. A, 7 (2000) 543-557*
- **Or rescattering process, Kaon loops,** *Locher and Lu Z. Phys. A 351, 83 (1995)*

Motivation

OZI rule in pp reactions

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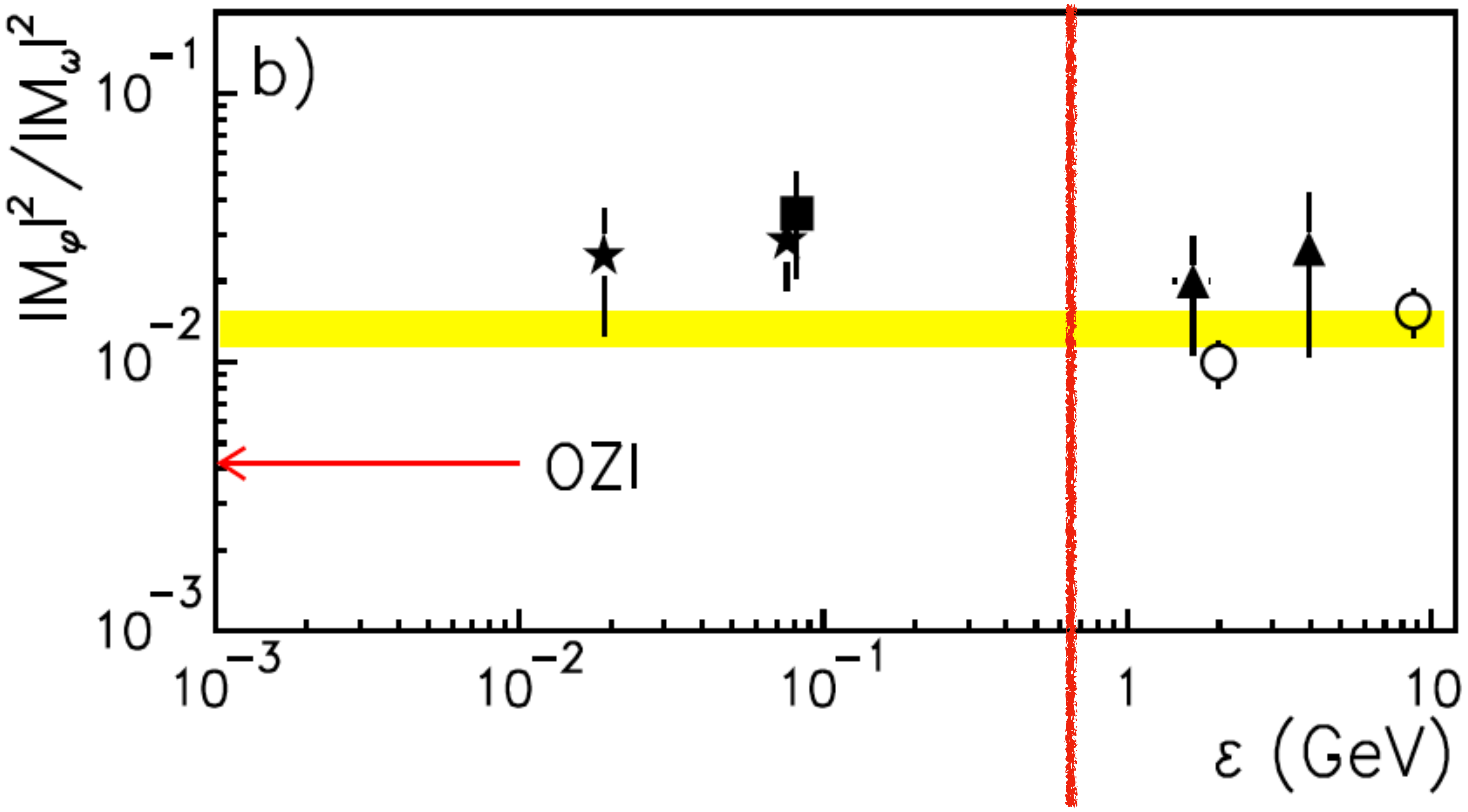
pp@4.5 GeV



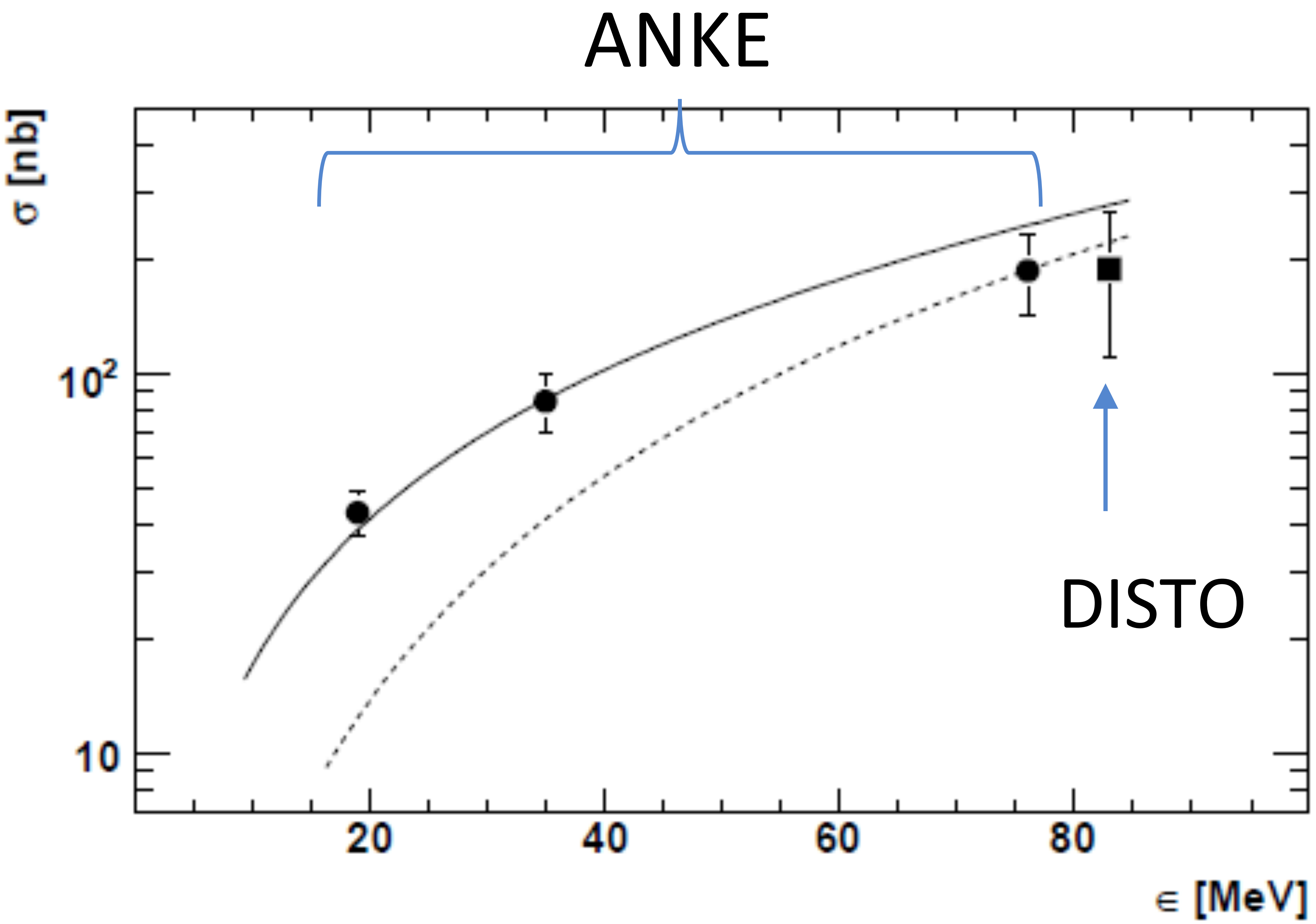
This analysis is here

For this analysis

Available data : close to threshold or at high energies:

Important to fill the gap : new HADES data at 4.5 GeV

Motivation : pp -> ppΦ : Available data



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

— **Parameterised including FSI**

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- **Important to fill the gap : new HADES data at 4.5 GeV**

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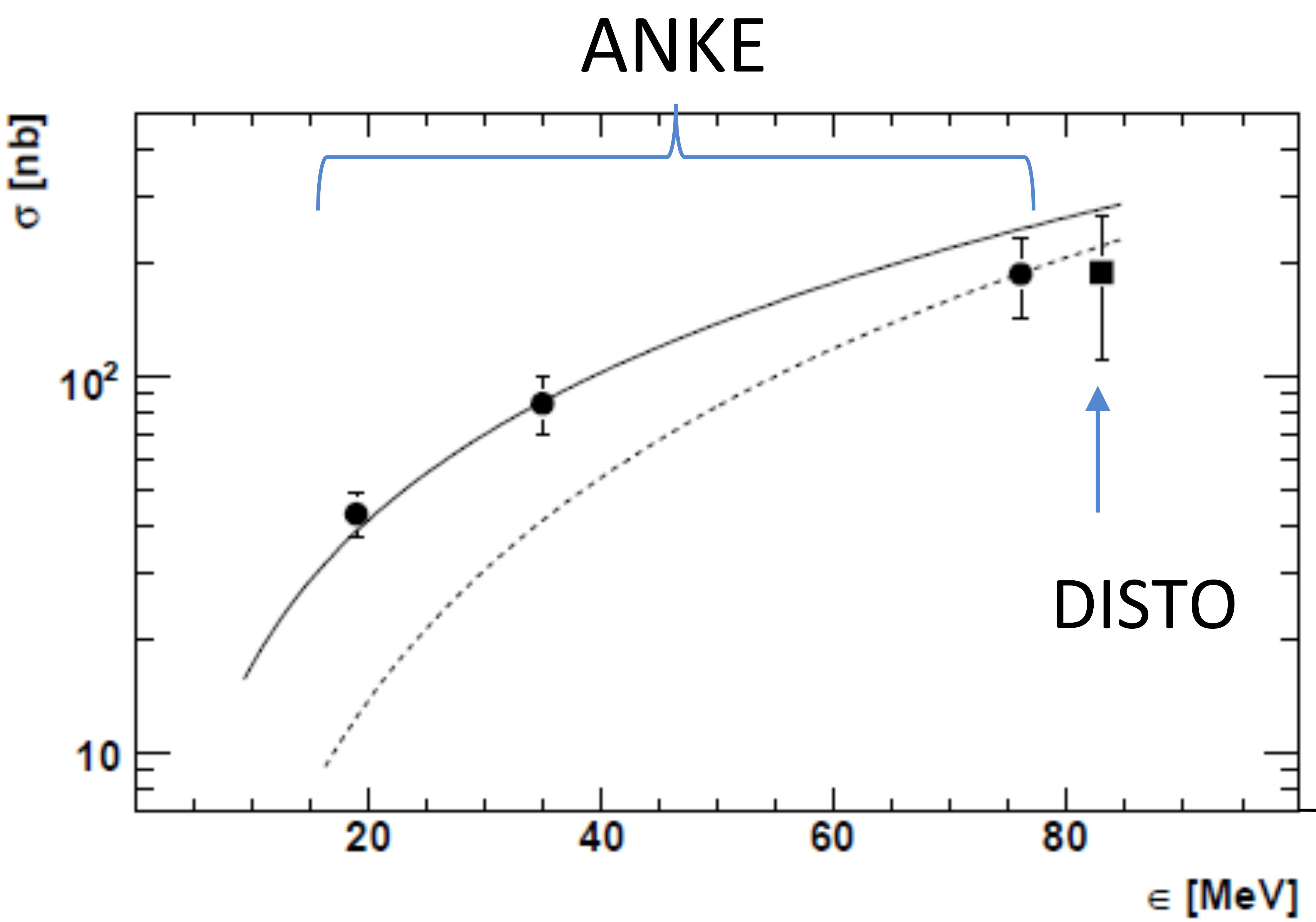

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— Parameterised including FSI

pp@4.5 GeV

Our measurement ε = 563 MeV

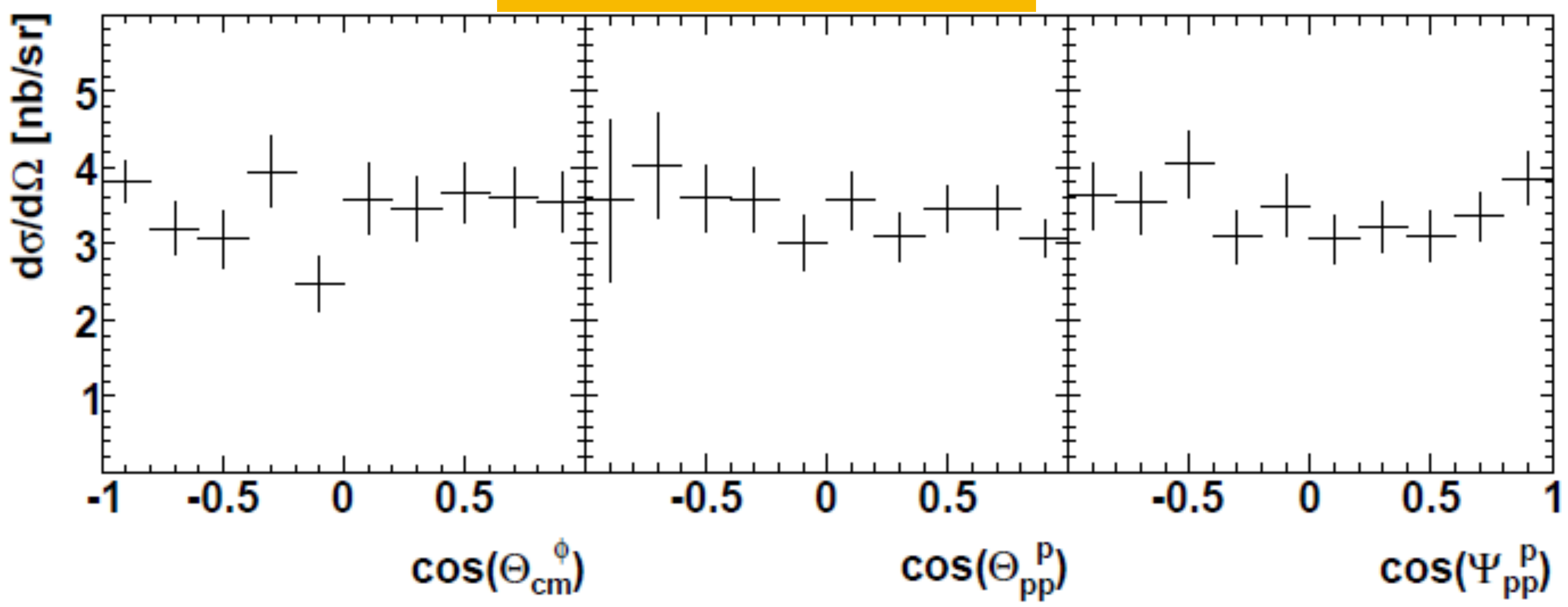
Motivation: Φ meson Angular distribution

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**

ANKE(ε= 18.5 MeV)



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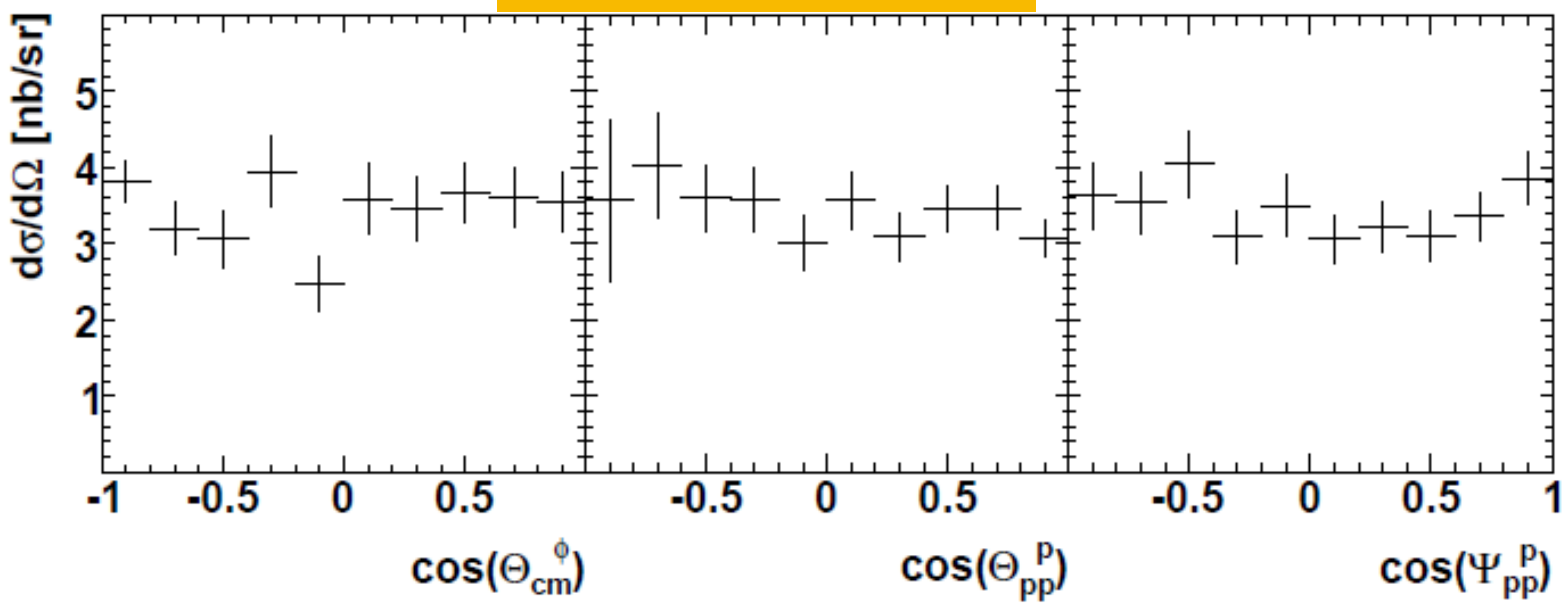
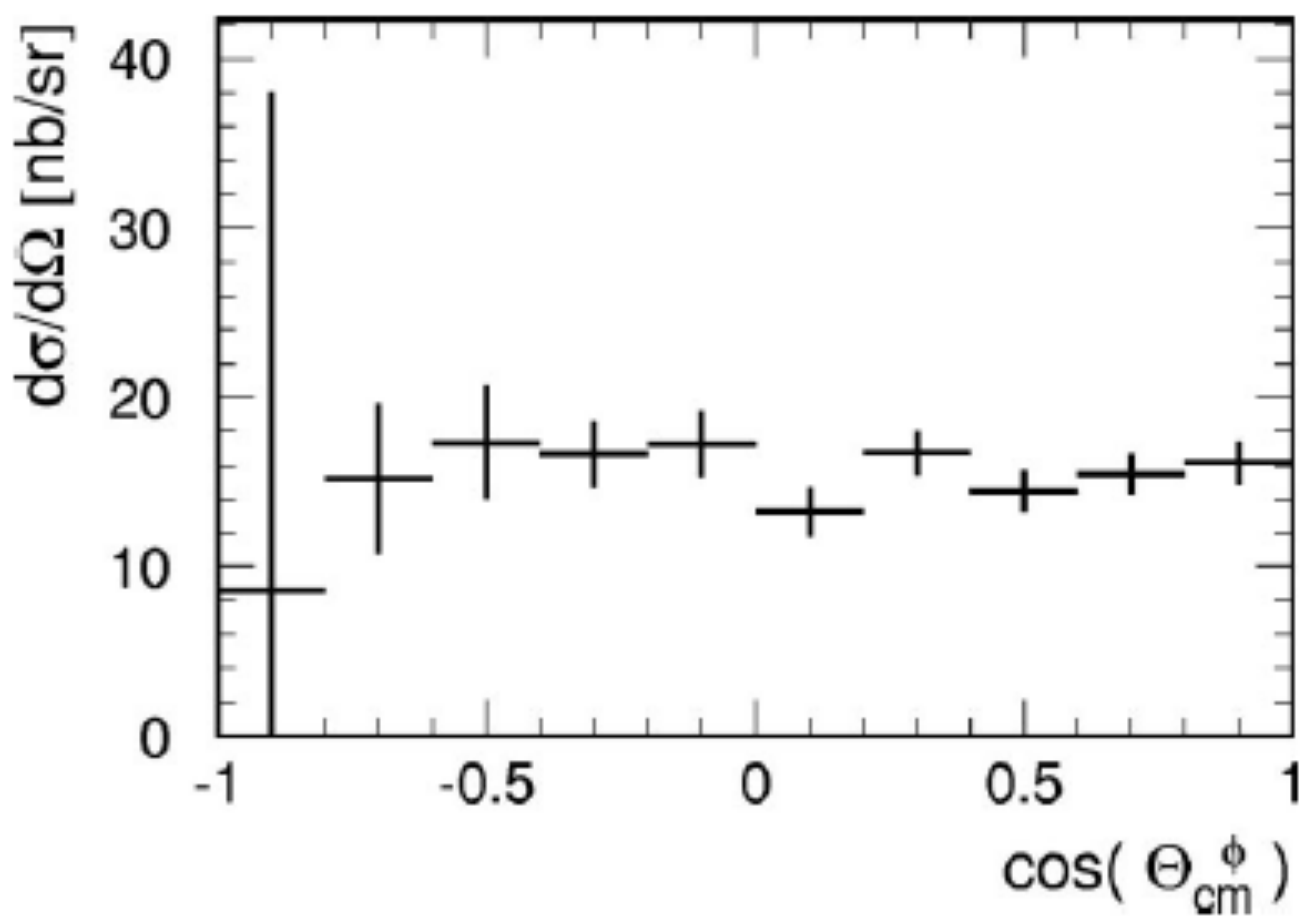
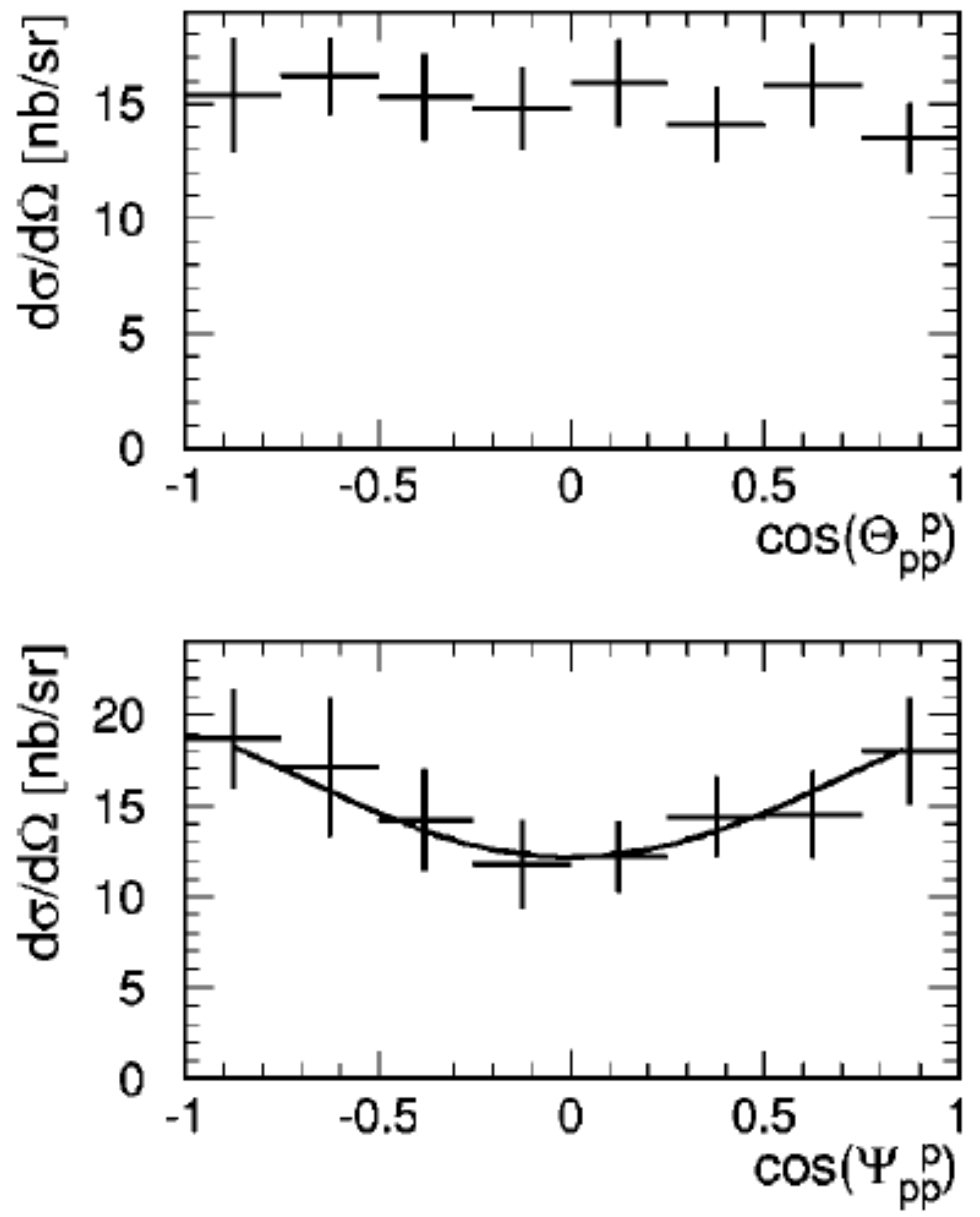


Disto results pp 2.85 GeV (3.67 GeV/c)

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.

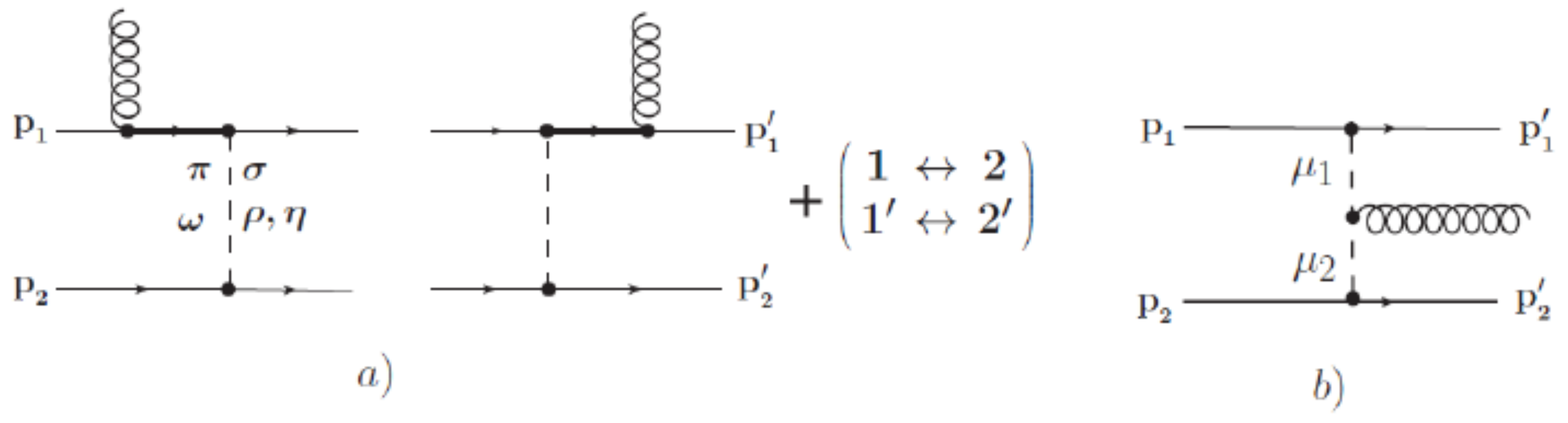
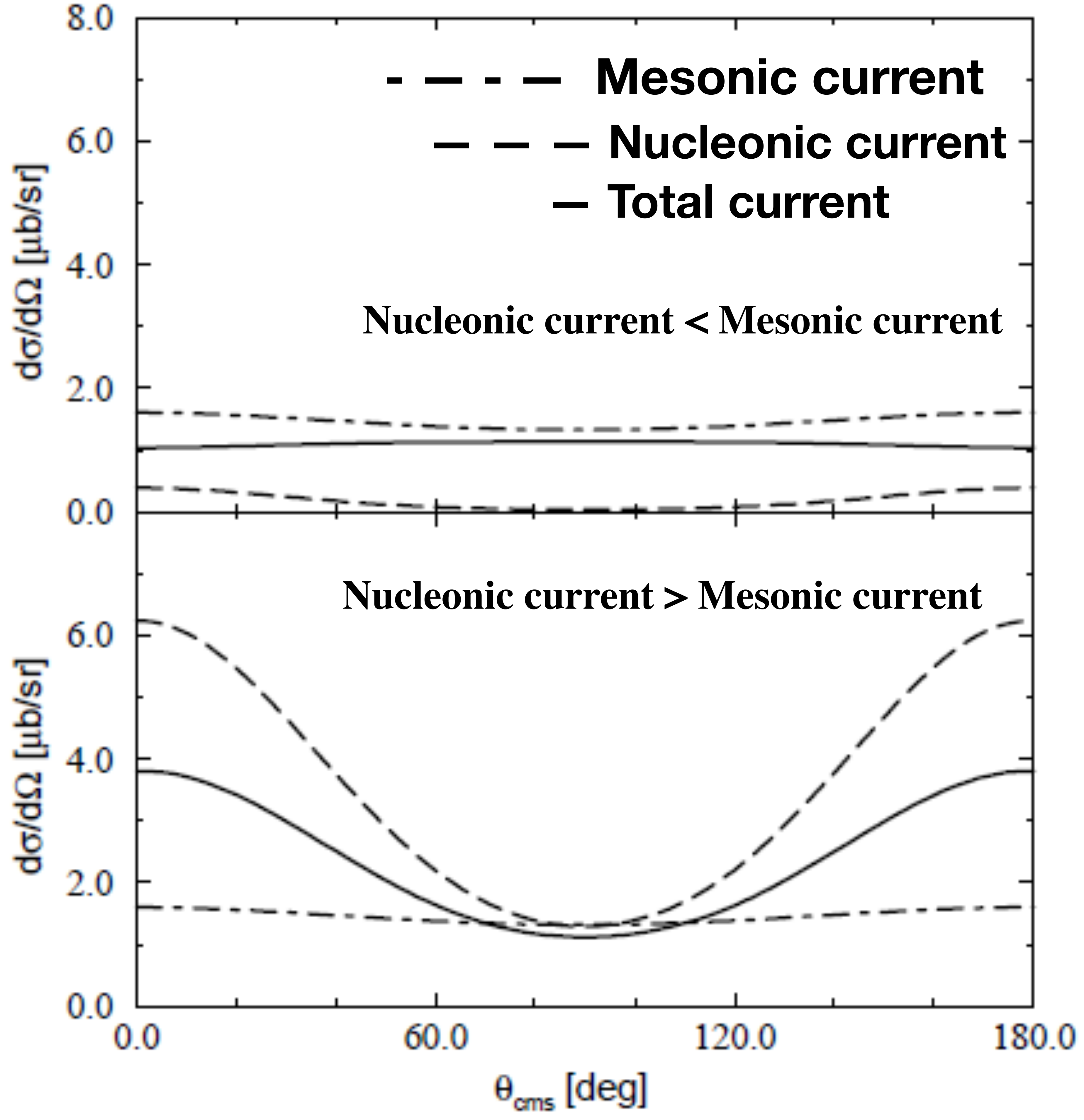


FIGURE (6.6) Feynman diagrams for the nucleonic current (a) and mesonic current (b) contributing to meson production in NN reactions.

Theoretical study



<u>**Calculation of angular distribution of ω-meson**</u>

Nucleonic current > Mesonic current : Strong Anisotropy

Nucleonic current < Mesonic current : isotropic

Possible similar qualitative behaviour for ϕ ?

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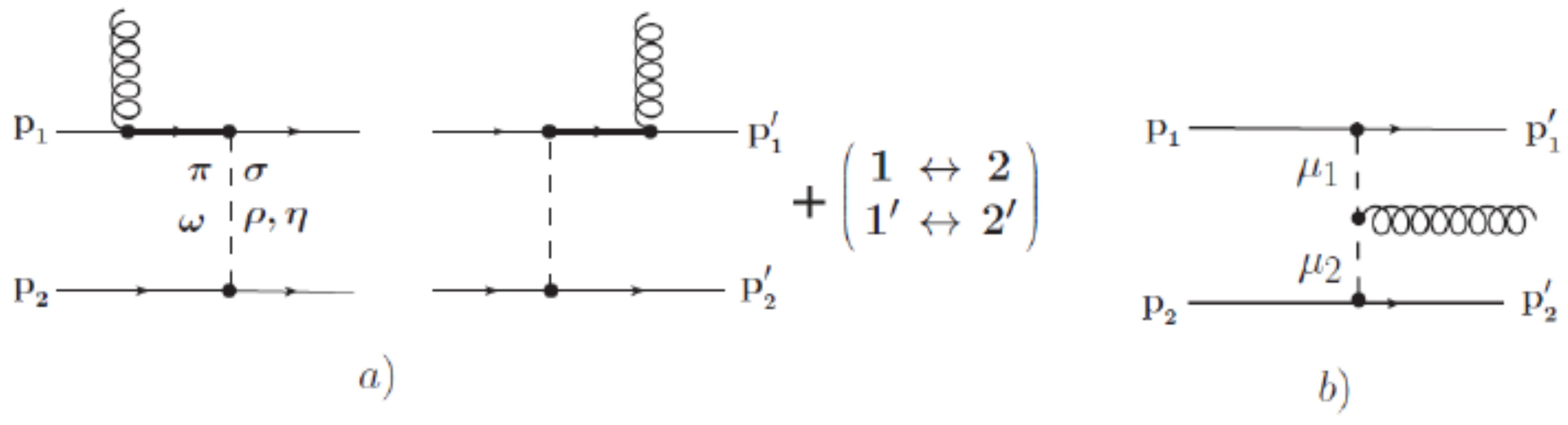

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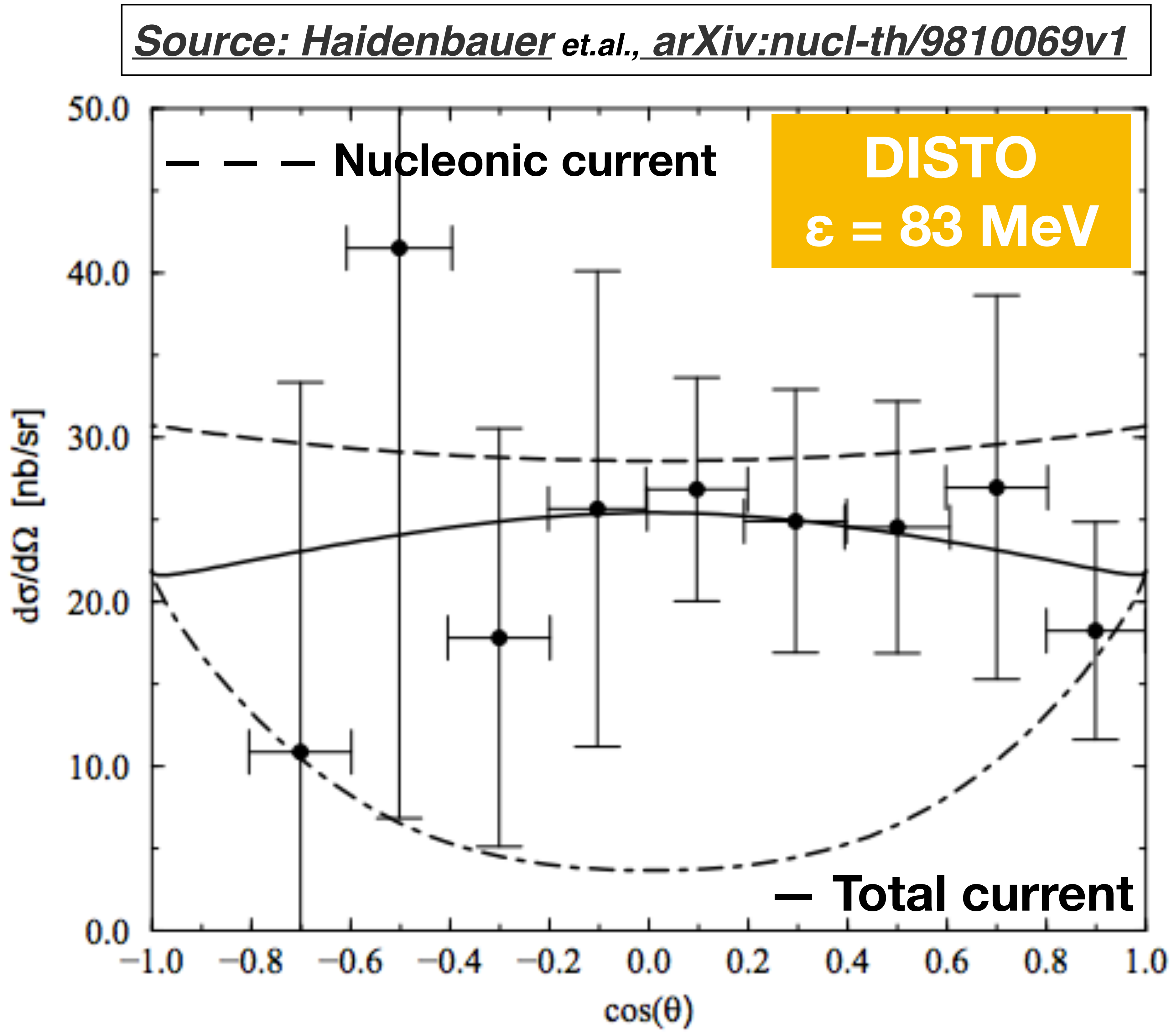

Calculation of angular distribution of ω-meson

Nucleonic current > Mesonic current : Strong Anisotropy

Nucleonic current < Mesonic current : isotropic

Possible similar qualitative behaviour for ϕ ?

- **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 coupling to baryon resonances

ϕ resonance production via baryon resonance

Source: Bleicher and Steinheimer J.Phys.G 43 (2016) 1,015104

Mass range around 2 GeV

$pp \rightarrow pB_{\phi} \rightarrow pp\phi$

branching ratio of 2% added to URQMD to describe sub-threshold ϕ-production in heavy ion reactions

In this analysis, we would also be exploring this baryon resonance "by investigating ϕ proton invariant mass in the exclusive pp->ppϕ channel"

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, $K^+ \rightarrow K^+/K^-$

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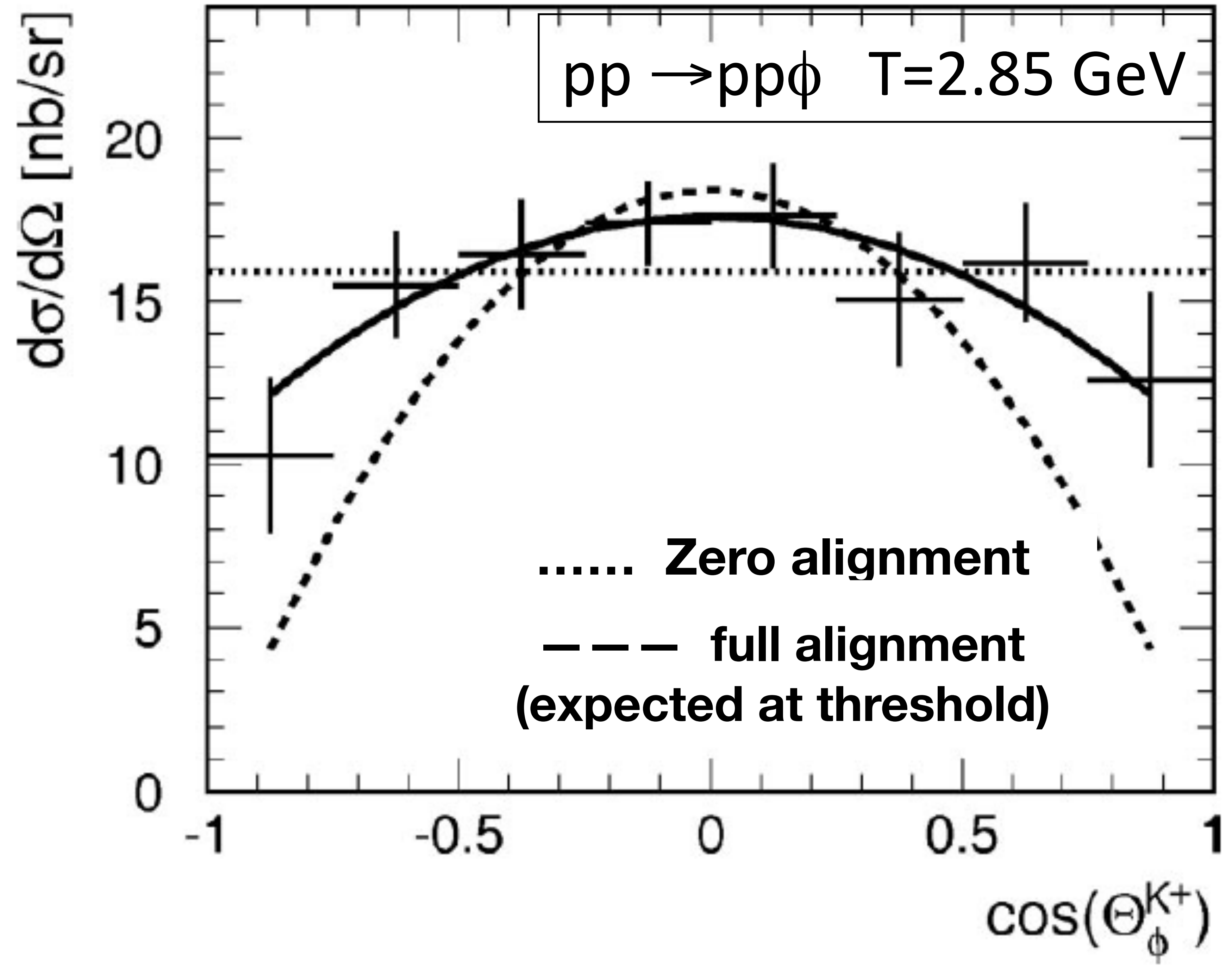
Angular distribution of K^+ in Φ reference frame:

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

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

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



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

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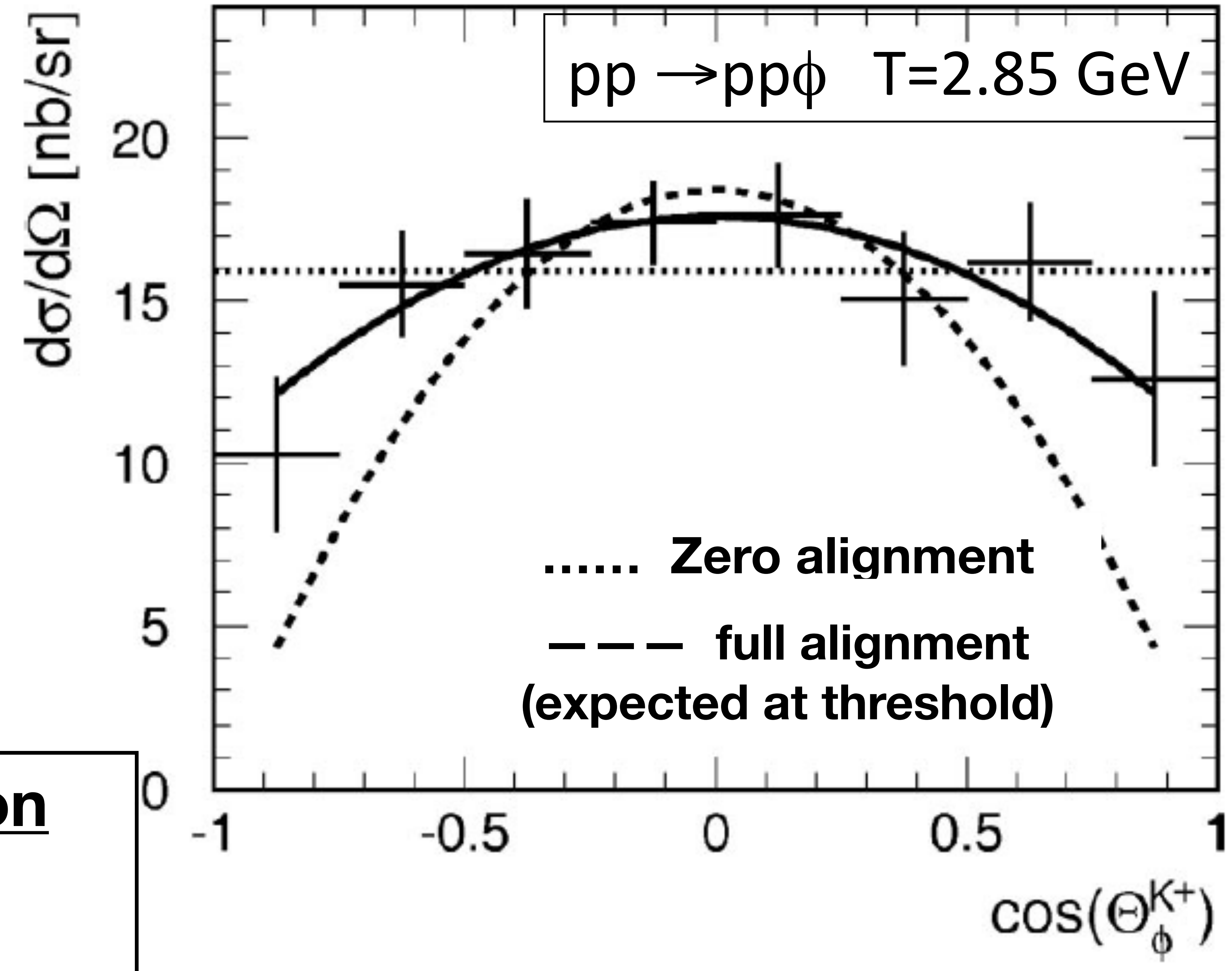
<u>Extraction of spin density matrix elements via K+/K- angular distribution</u>

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



<u>Source: Balestra et al., PHYSICAL REVIEW C 63 024004</u>

With this motivation, We Proceed Further

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

1) Inclusive/exclusive 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
5) Baryon resonance (φ,N)

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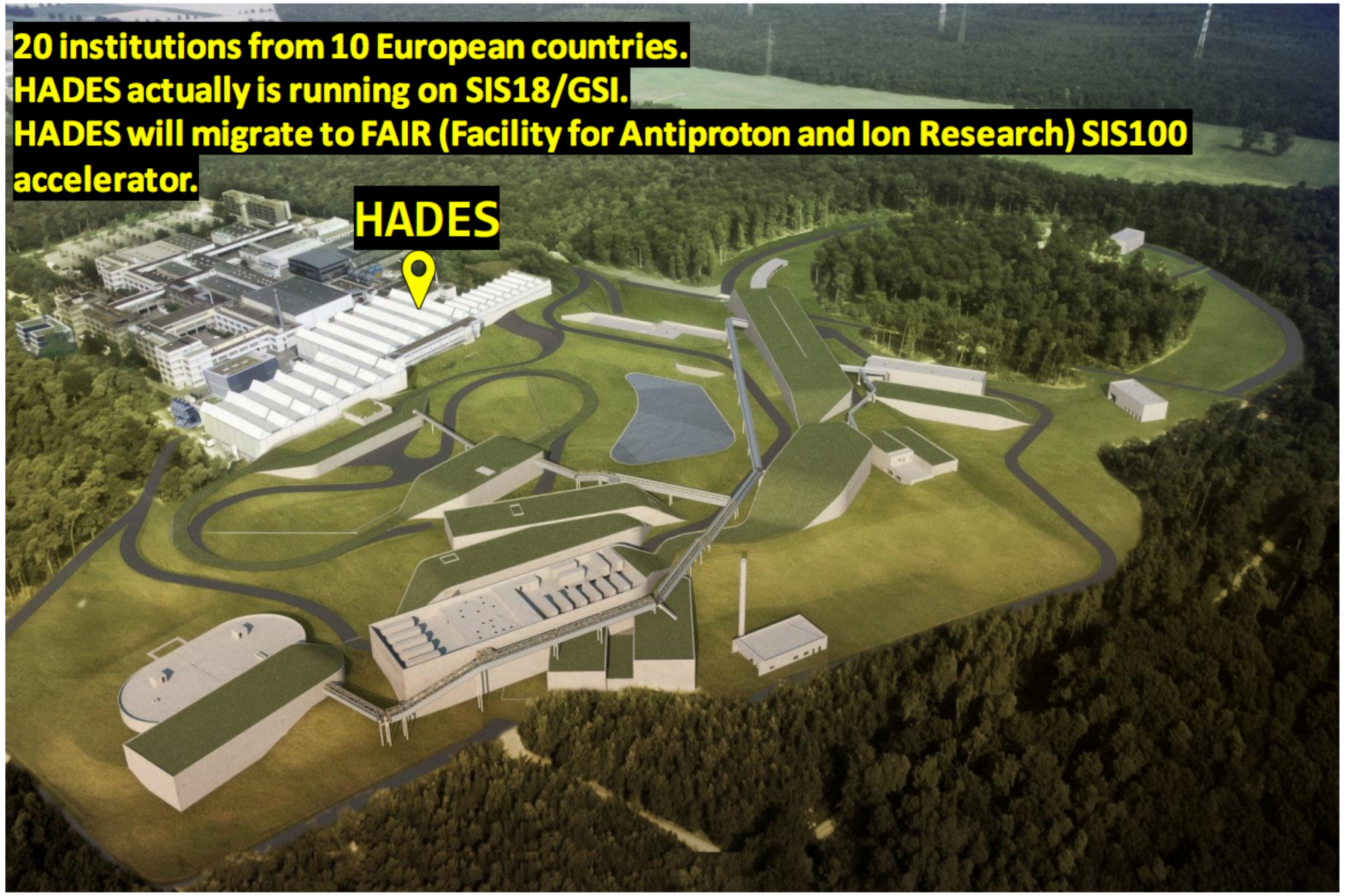
We will be using HADES and Forward detector @ GSI to achieve this objectives

The HADES Detector @GSI

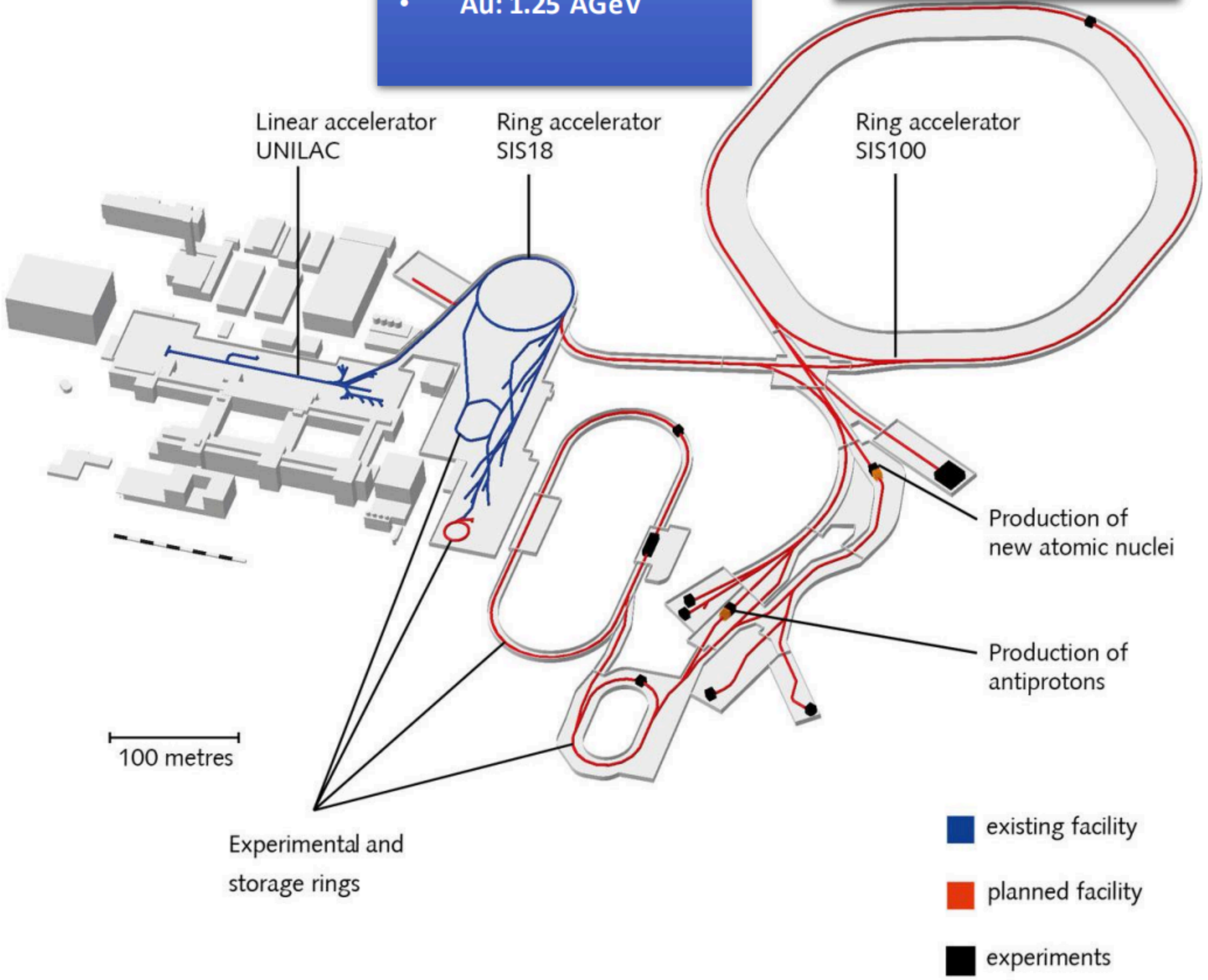
HADES collaboration and FAIR @ GSI

20 institutions from 10 European countries.
HADES actually is running on SIS18/GSI.
HADES will migrate to FAIR (Facility for Antiproton and Ion Research) SIS100 accelerator.



Emax:
- p: 4.5 GeV/nucleon
- Au: 1.25 AGeV

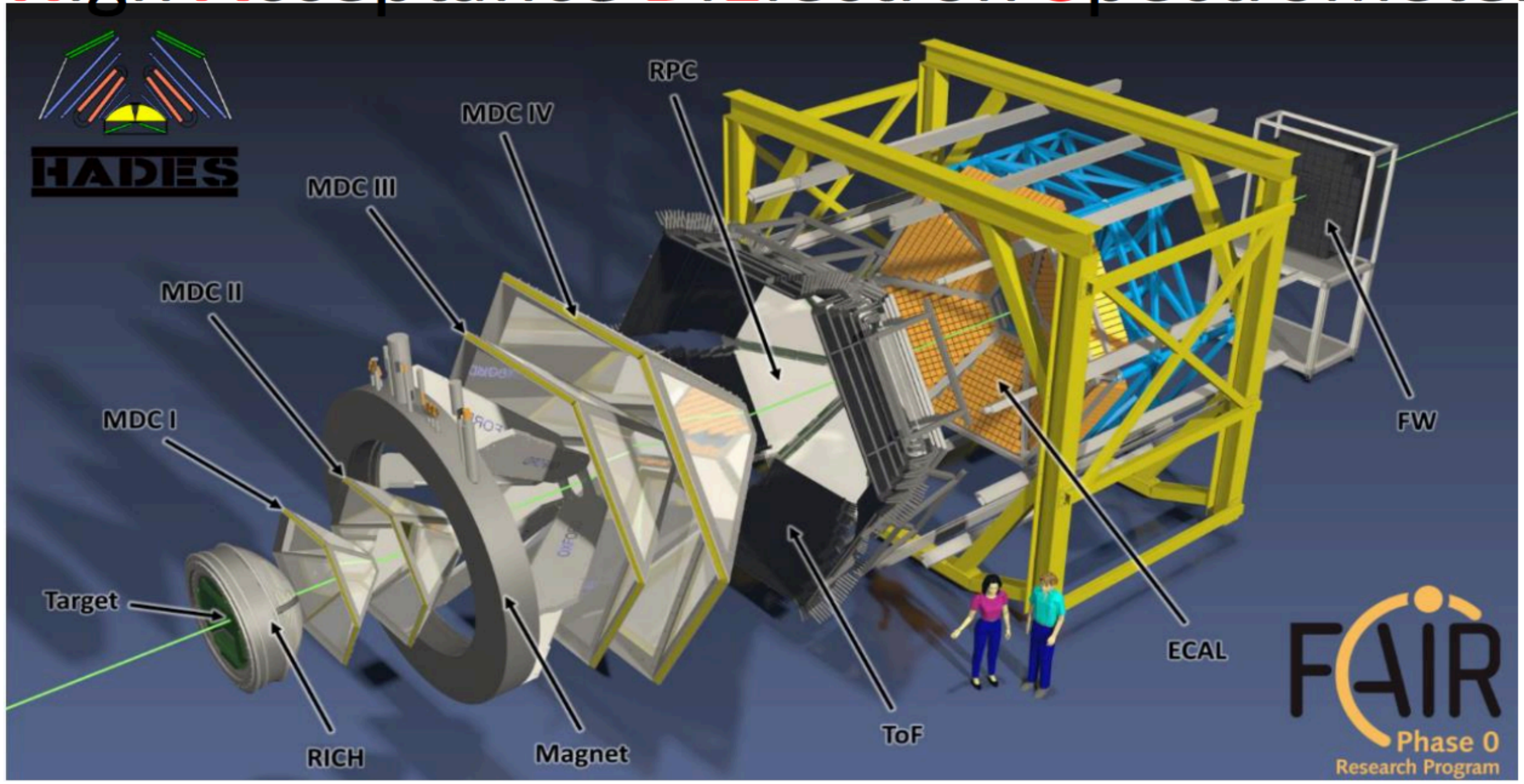
Emax:
- p: 29 GeV/nucleon
- Au: 11 AGeV

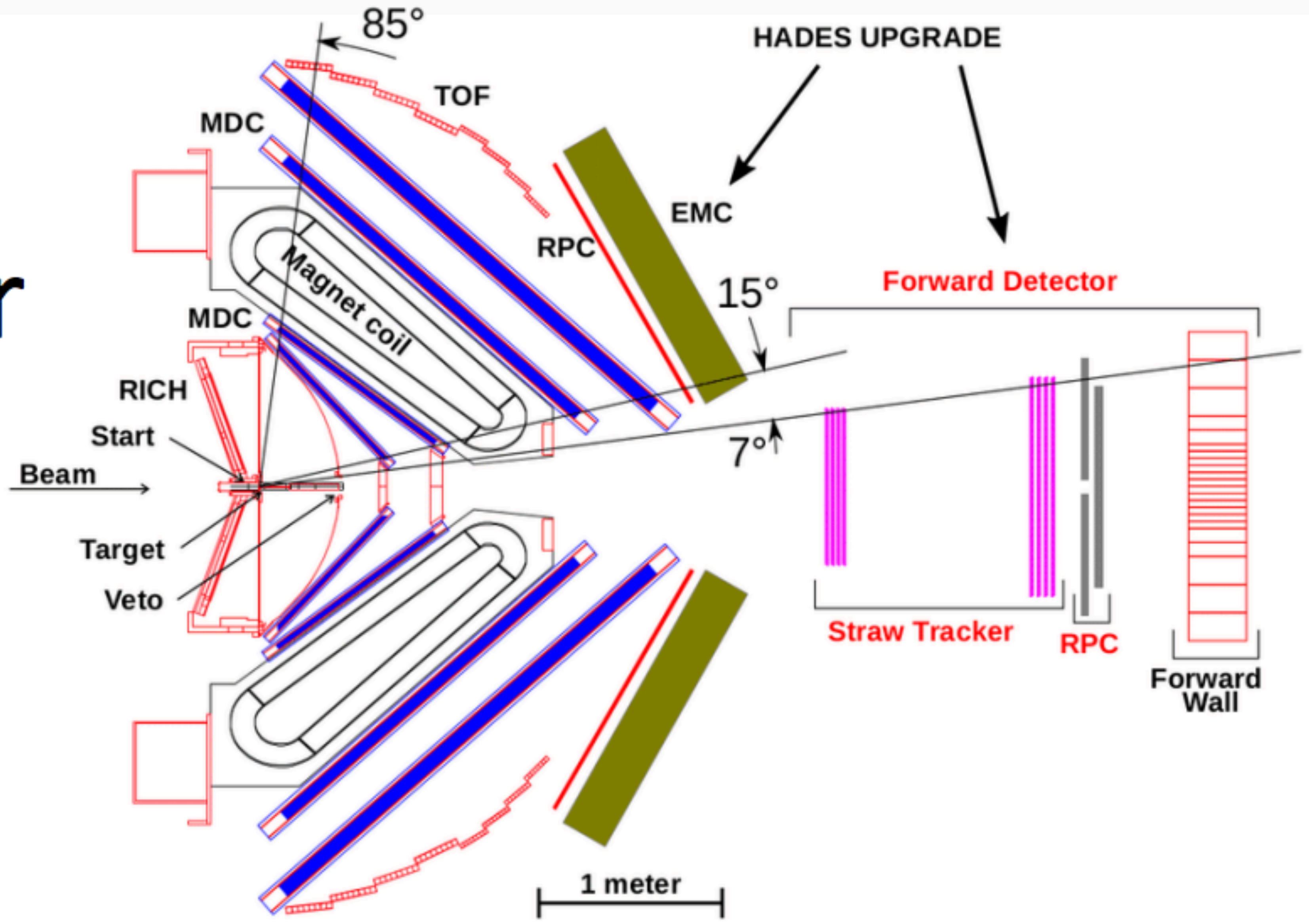


The HADES Detector - in detail

HADES experimental setup

High Acceptance DiElectron Spectrometer



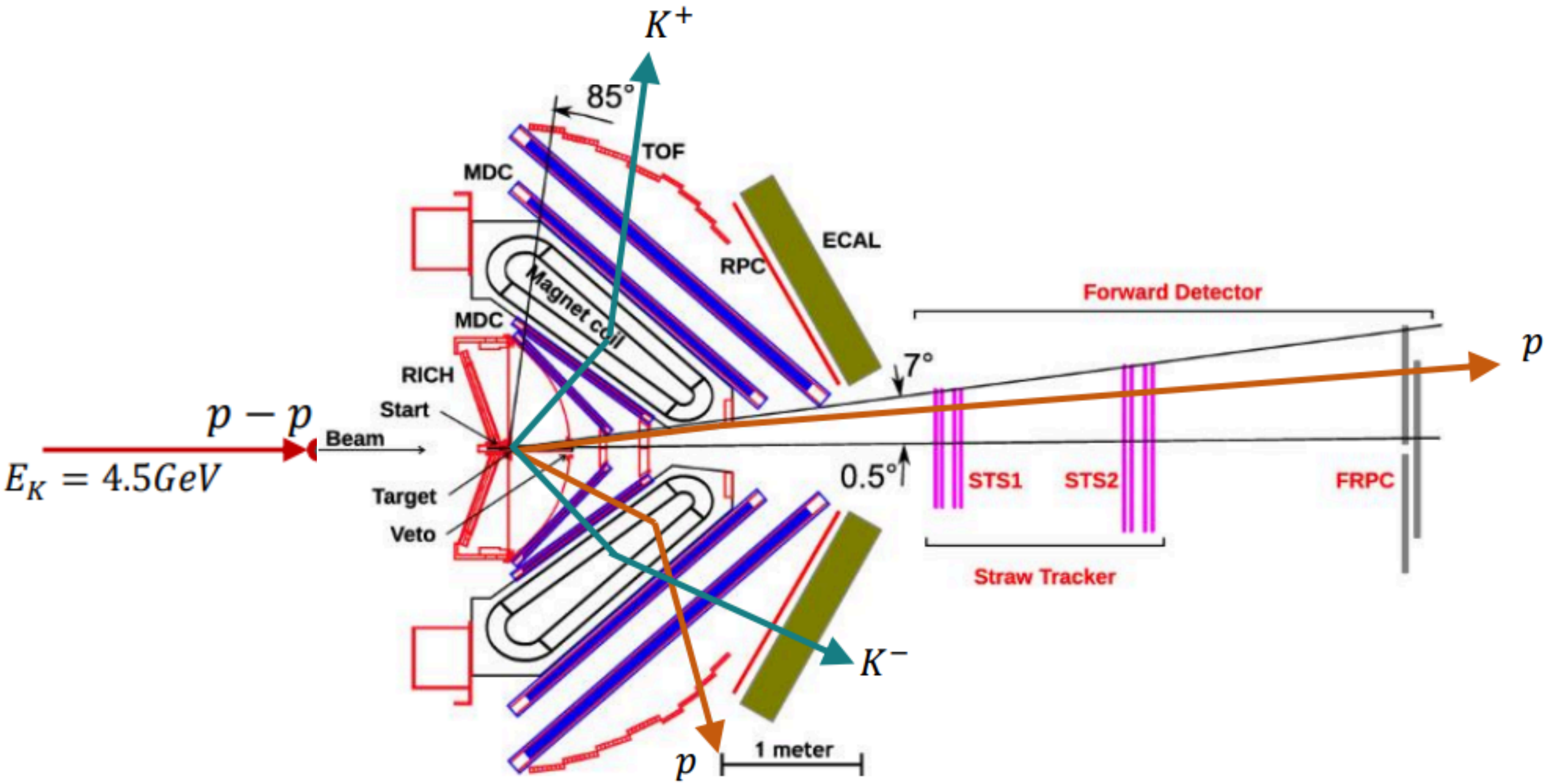


- Fixed target experiment.
- Large geometrical acceptance: full azimuthal range and polar angles 18° and 85°.
- Efficient track reconstruction and momentum determination (MDC+Magnet) and particle identification (RICH, TOF, RPC and ECal).
- FWD: polar angles [0.5°-7°].

Experiments (2004-2022)

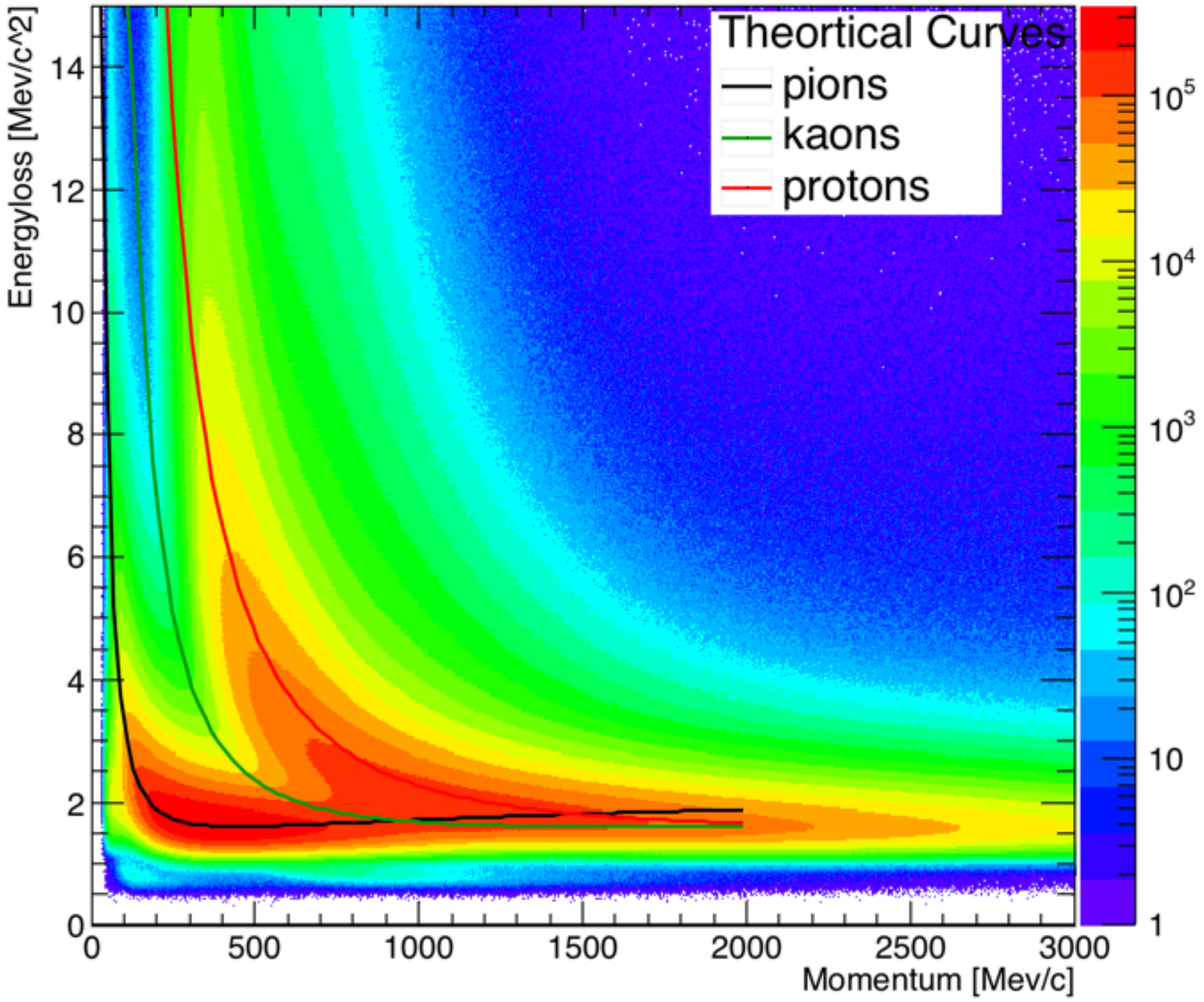
- Dense and hot hadronic matter studies: **C+C** (1 and 2 AGeV), **Ar+KCl** (1.75 AGeV), **Au+Au** (1.25 AGeV), **Ag+Ag** (1.65 AGeV).
- Cold matter studies : **p+Nb** (3.5 GeV), **π^-+C/W** (1.7 GeV/c), **π^- + CH2/C** (0.7 GeV/c).
- Elementary reactions: **p+p** (1.25, 2.2, 3.5 and recently 4.5 GeV),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

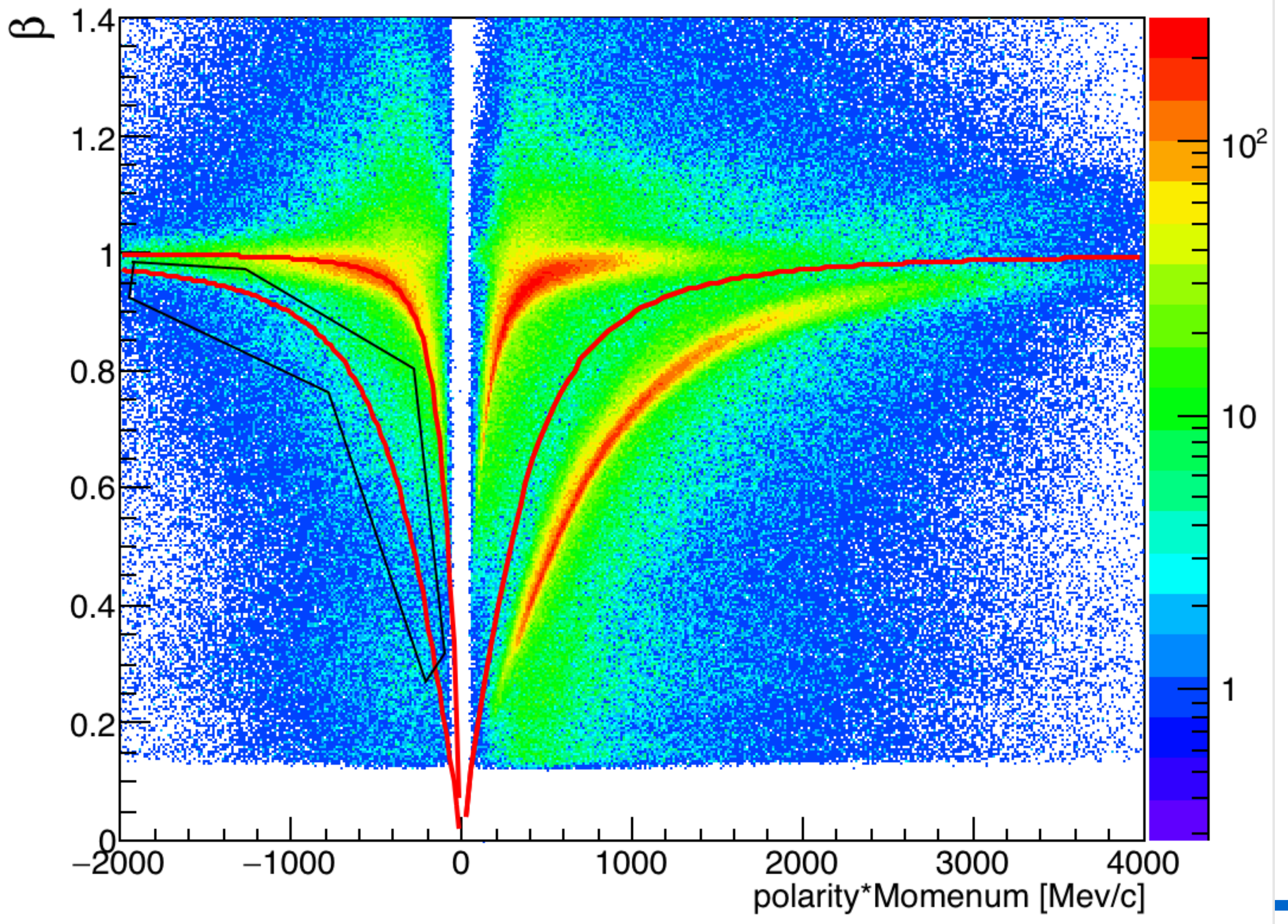
The HADES Detector - Particle identification for my work



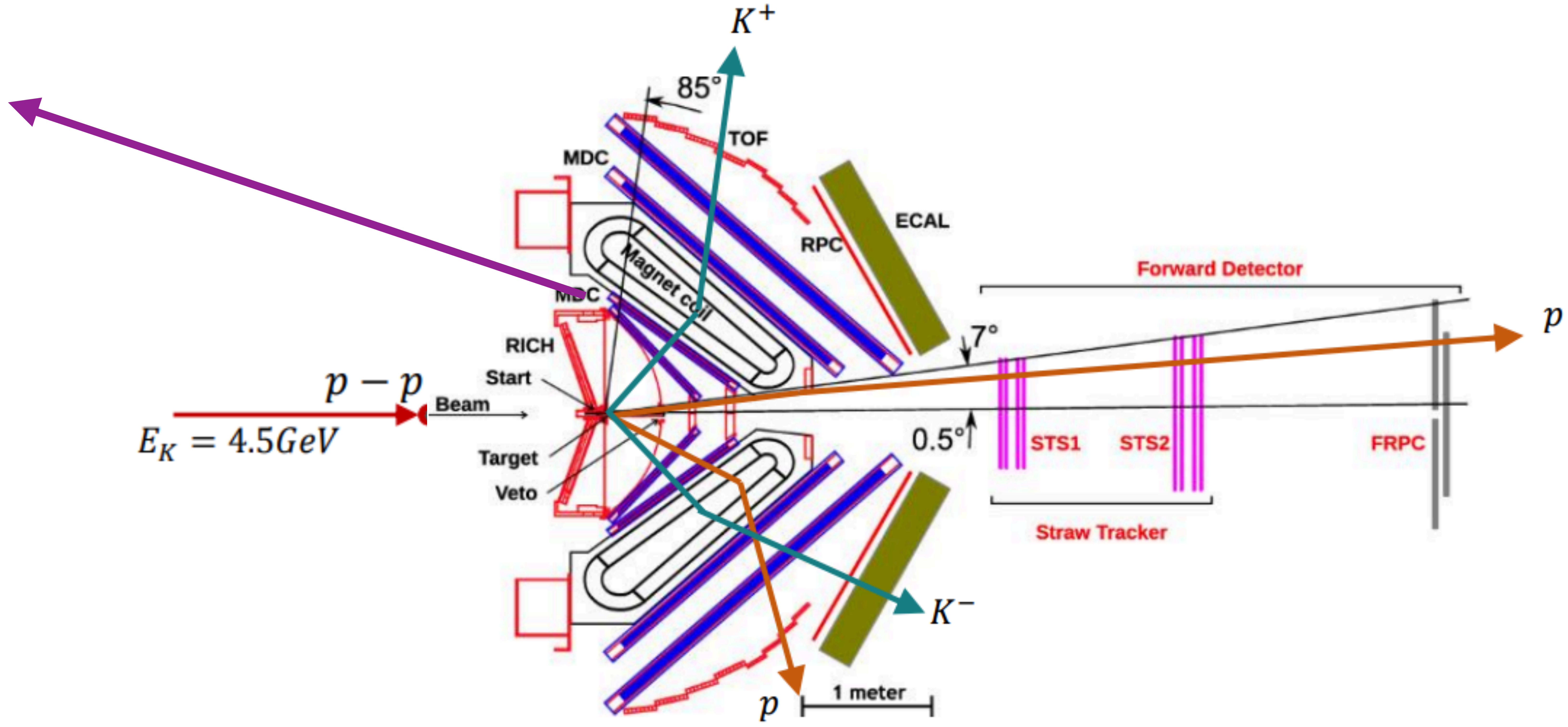
Beam Proton with Kinetic energy 4.5 GeV made to collide with Target Proton

The HADES Detector - Particle identification for my work





- 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**
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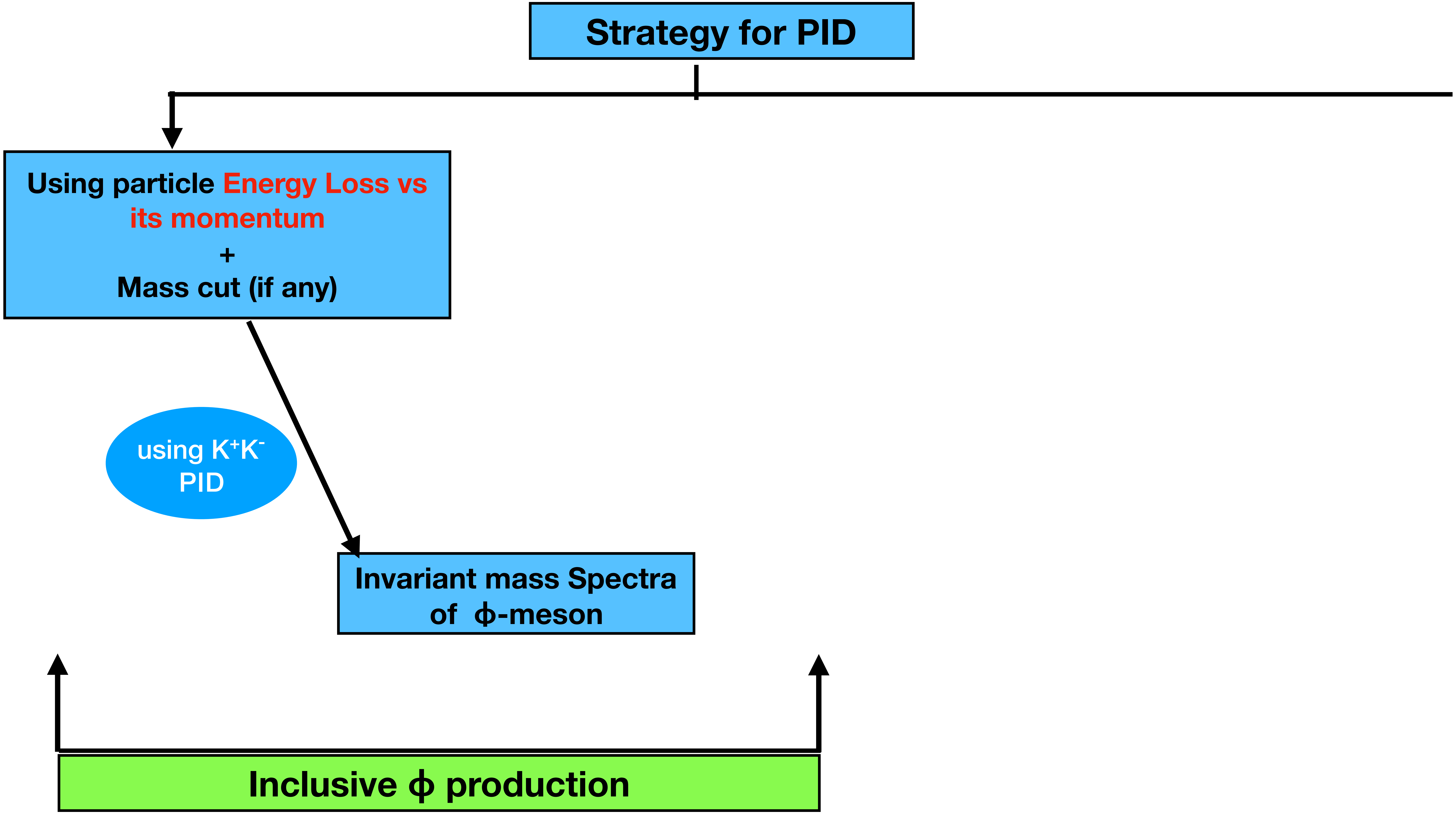
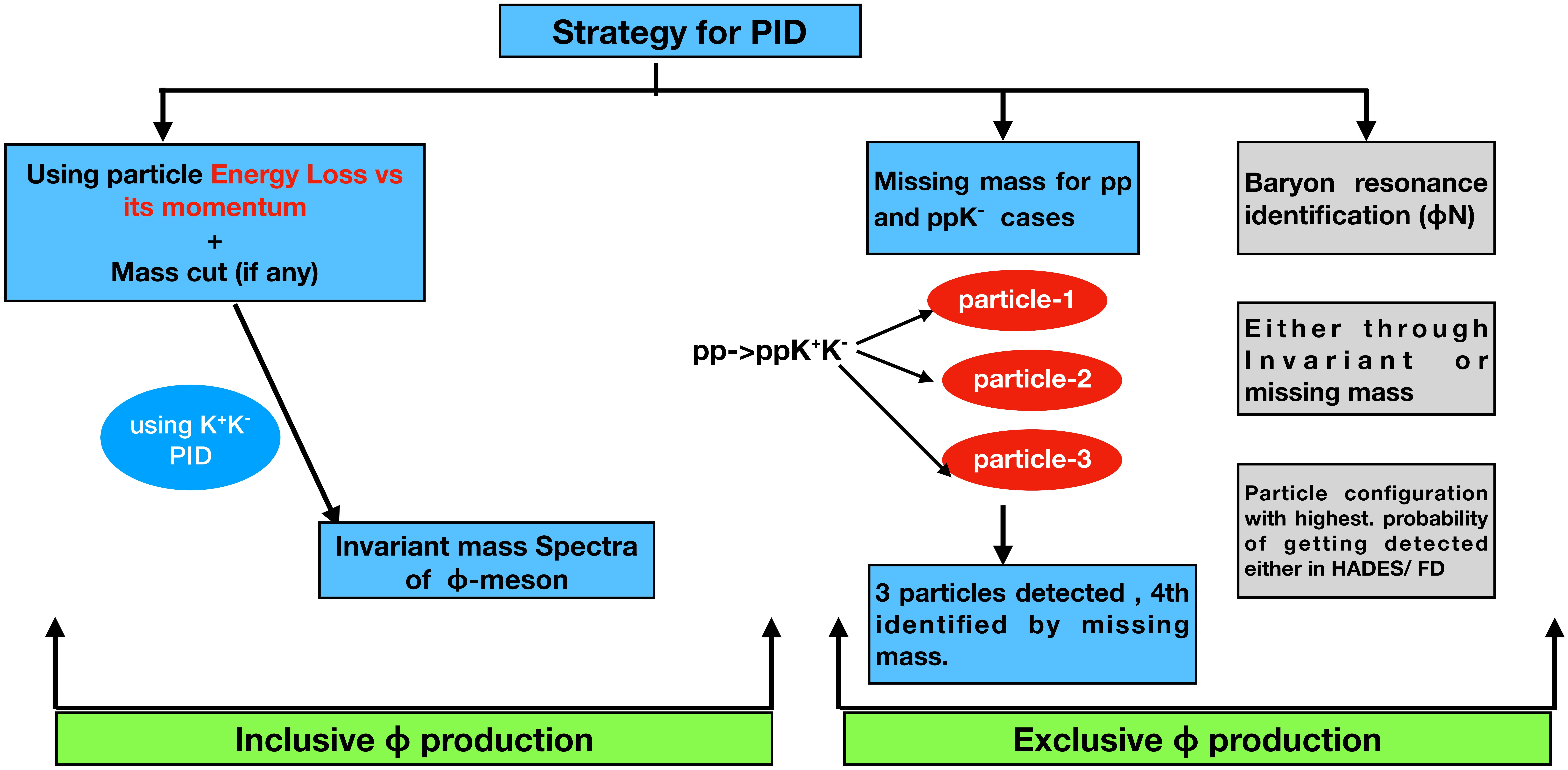
Analysis Strategy



Analysis Strategy



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 and momentum dependent mass

Analysis details

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

Methodology

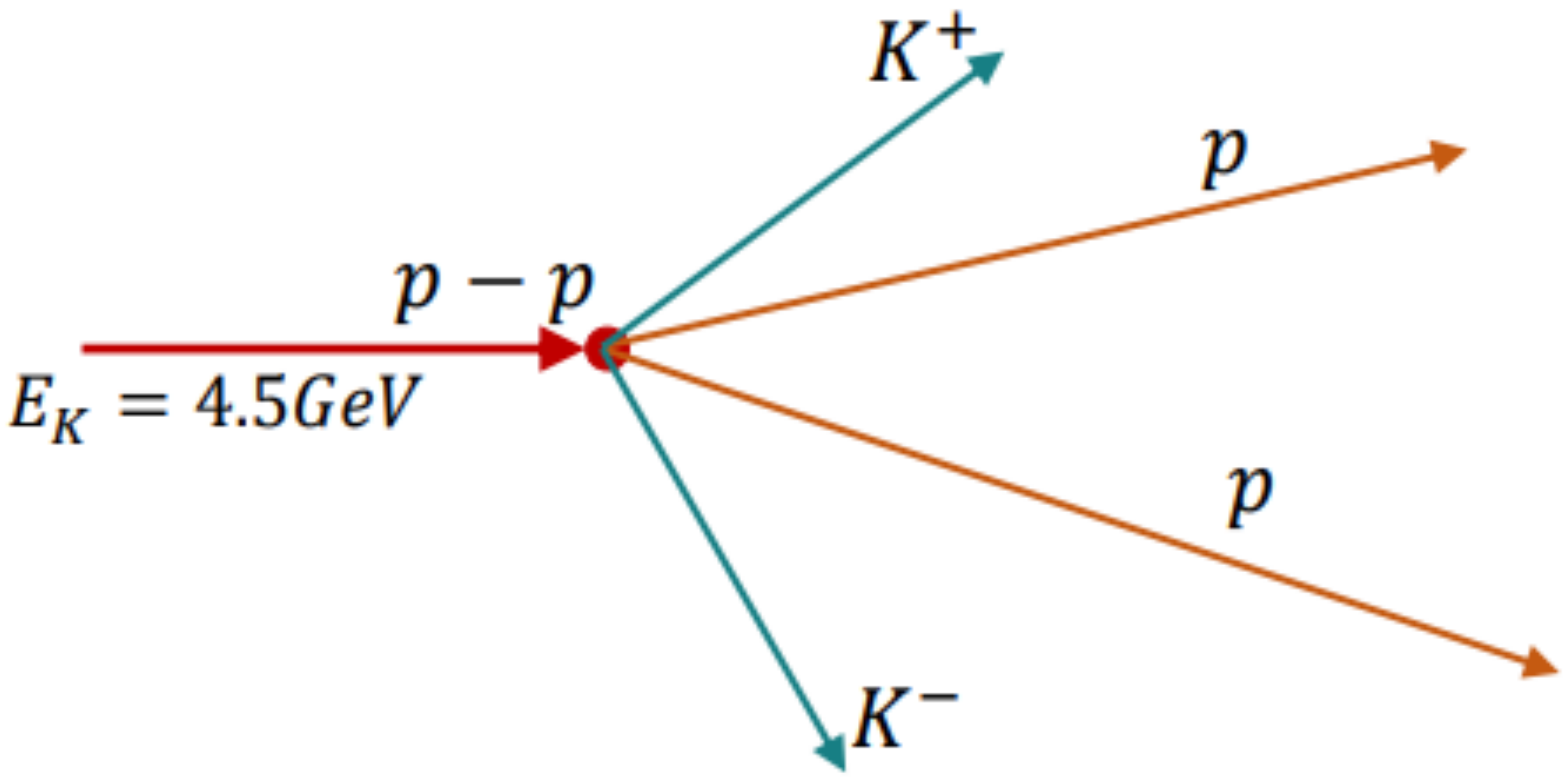
- ❖ Start with optimising kaon PID cuts
- ❖ Criterium: Significance of the Φ reconstruction
- ❖ First look into the Φ inclusive angular distribution

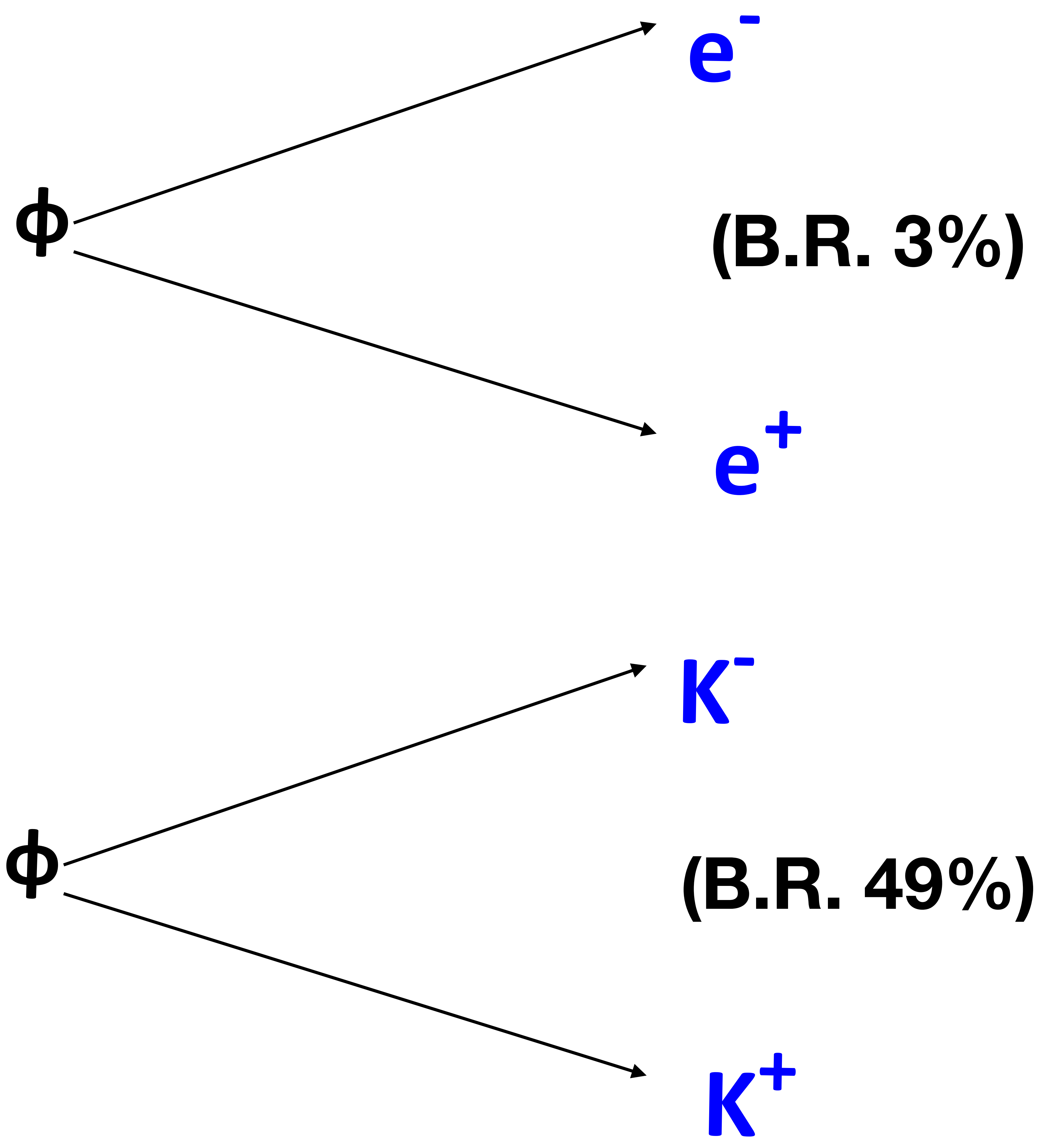
Simulations

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

PLUTO: event generator developed by the HADES collaboration

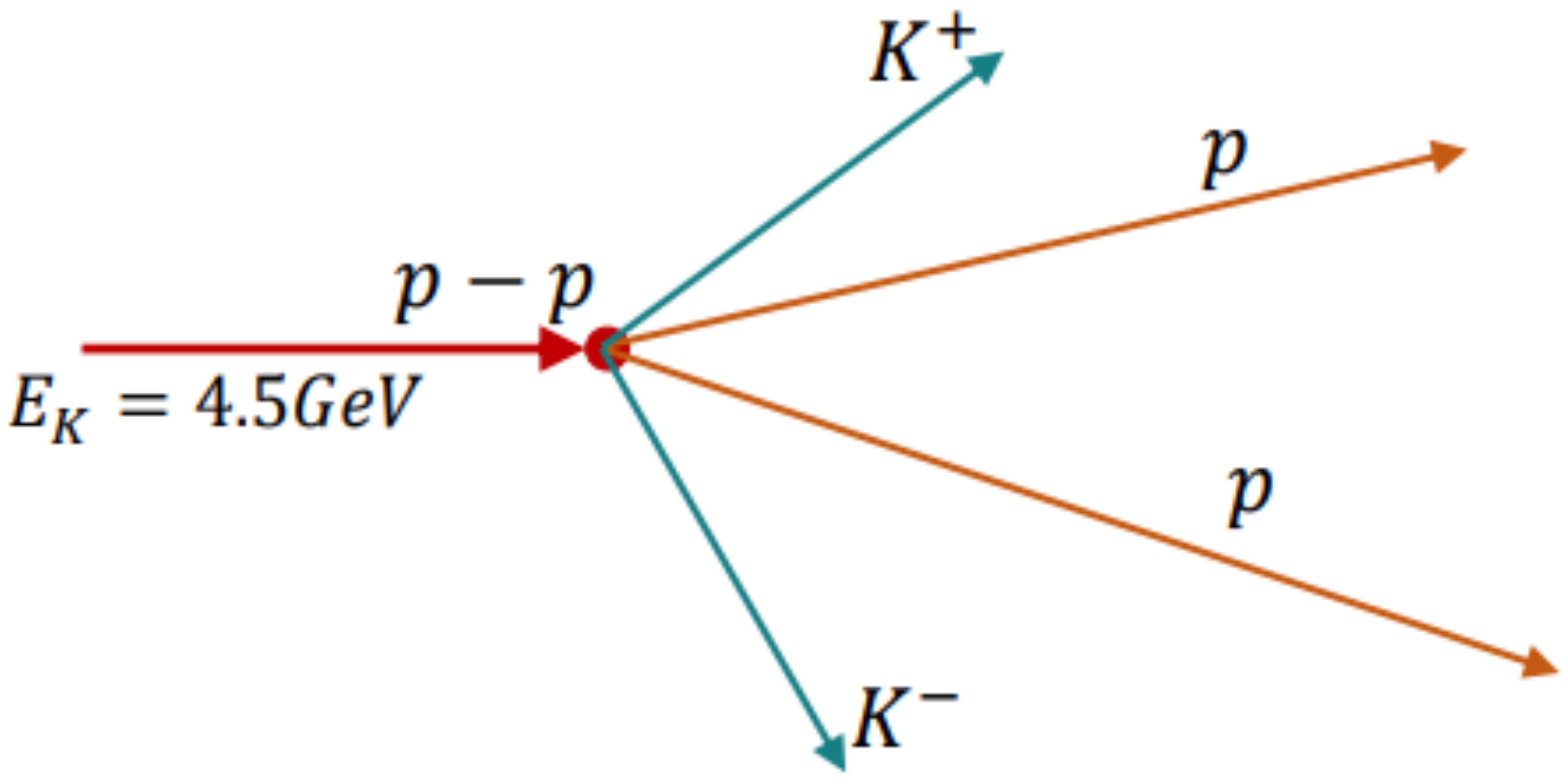
ϕ meson identification

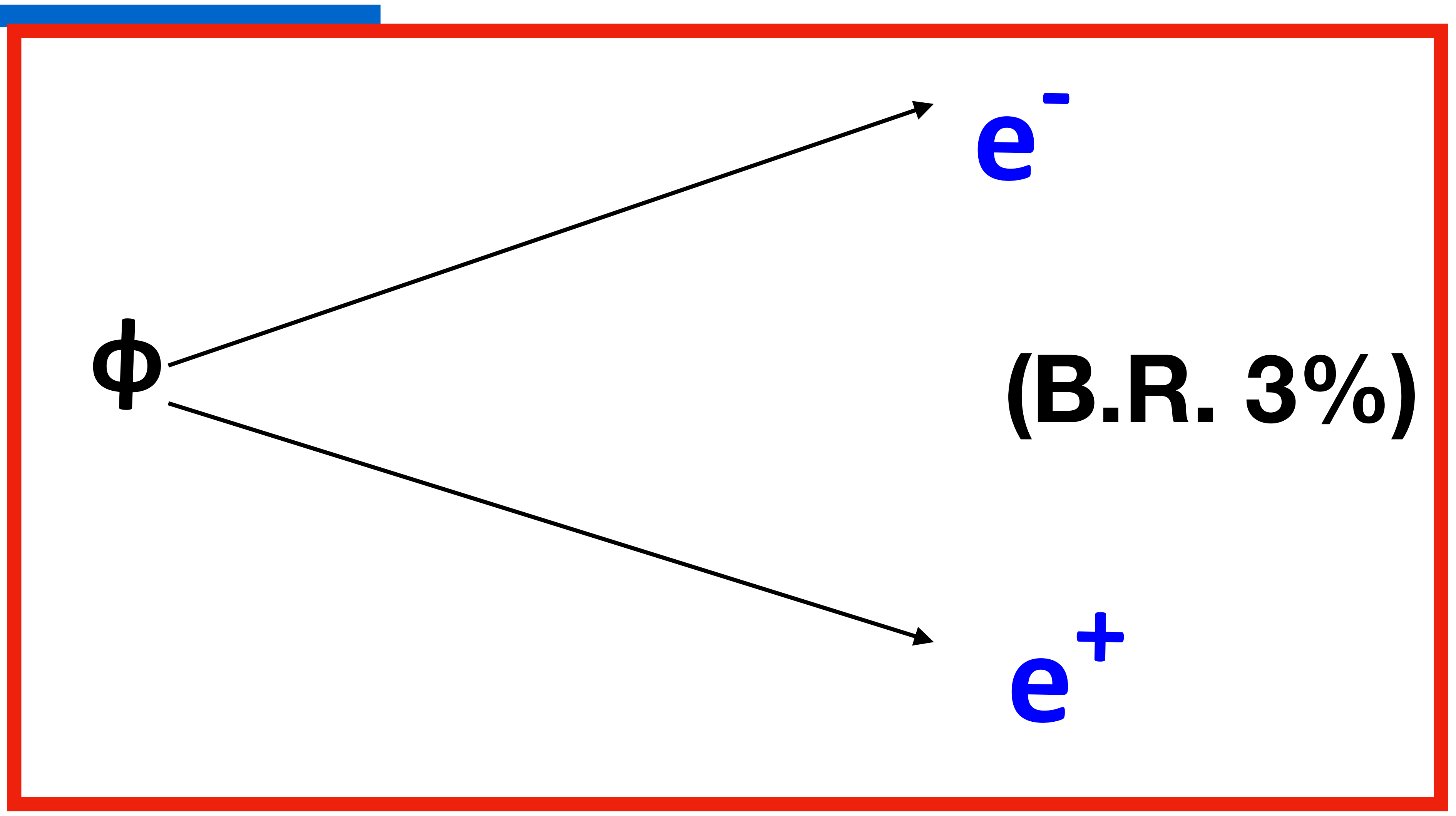


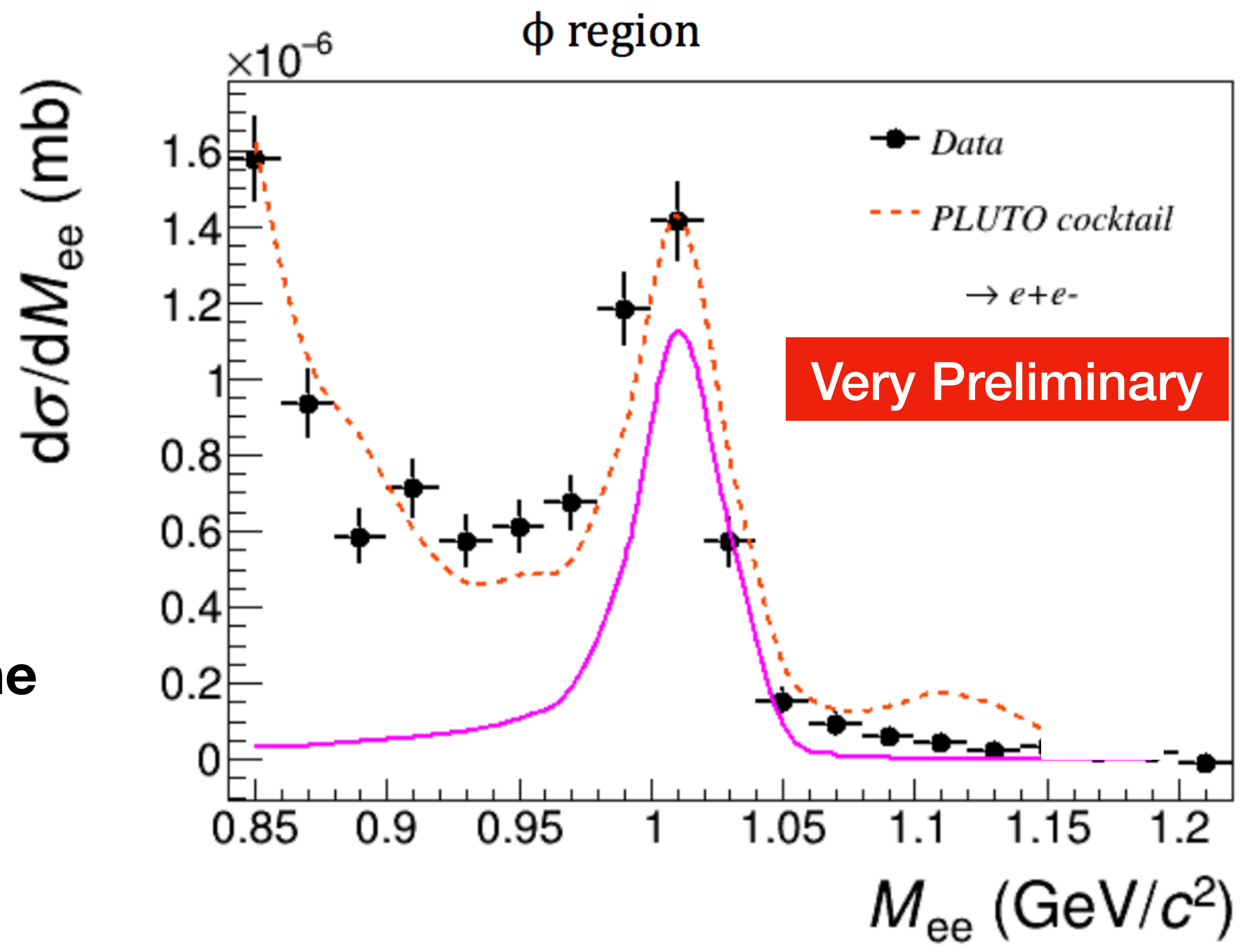


etc

ϕ meson identification

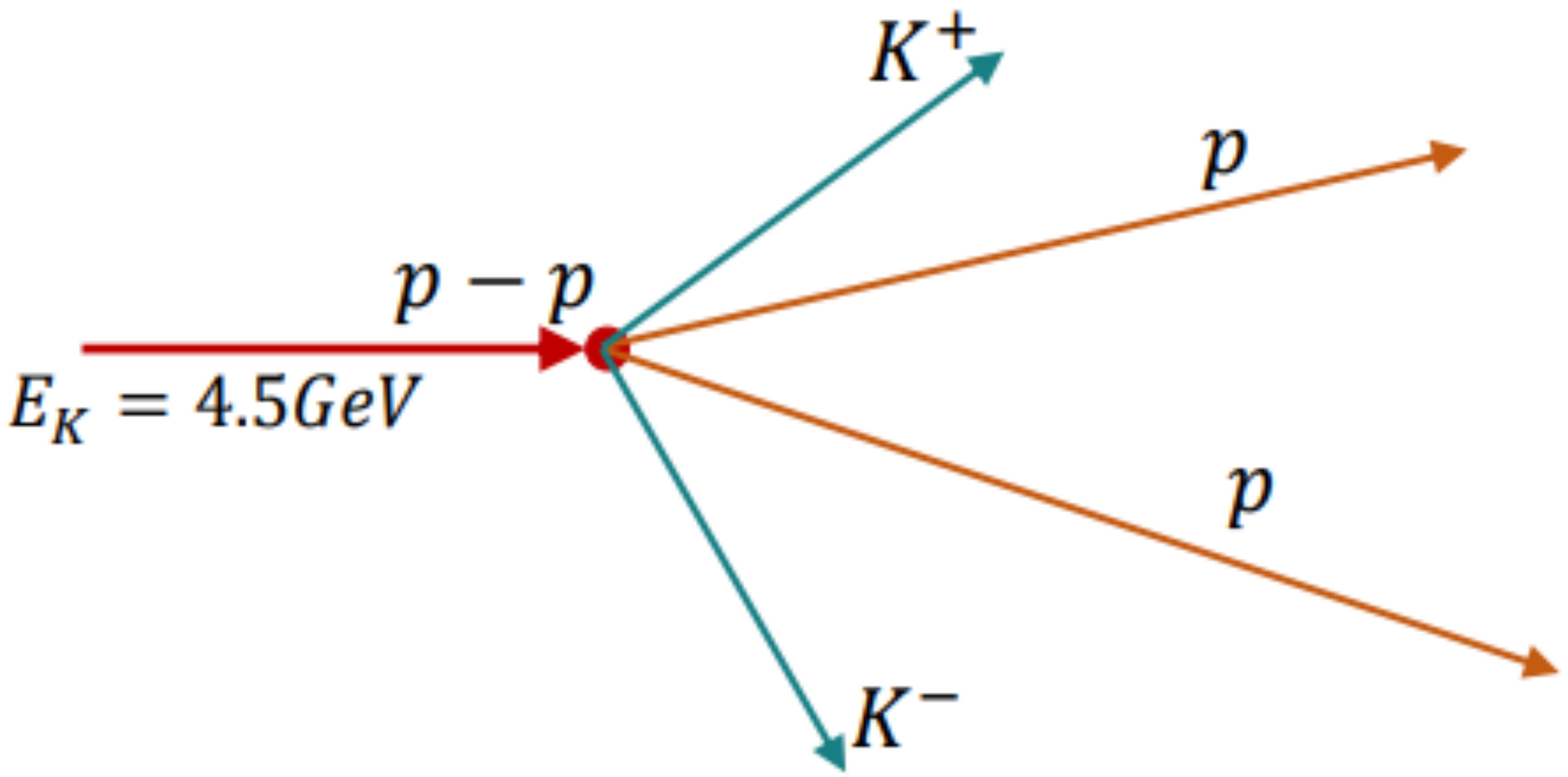


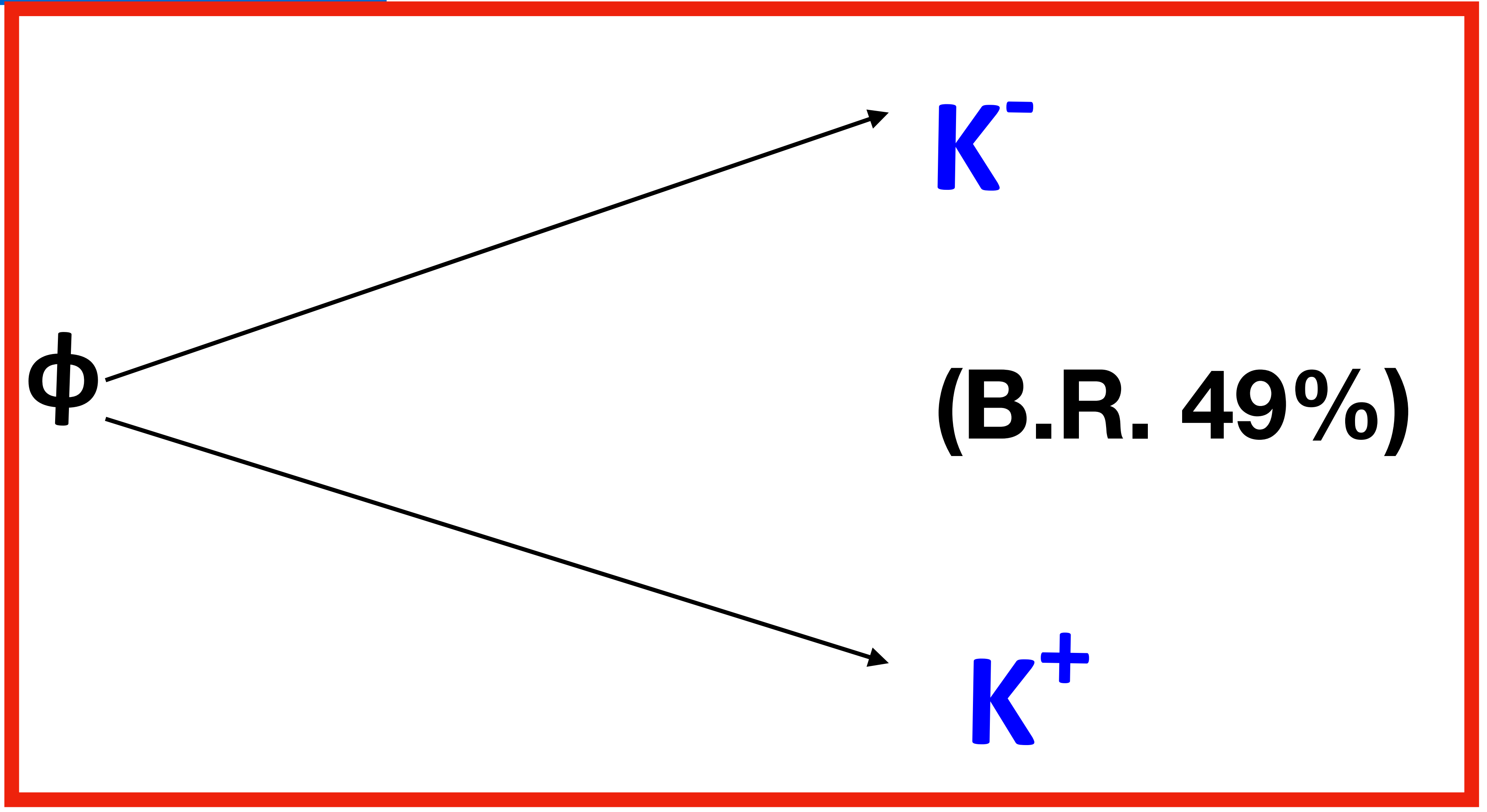




Analysis by Rayane Abou Yassine

ϕ meson identification

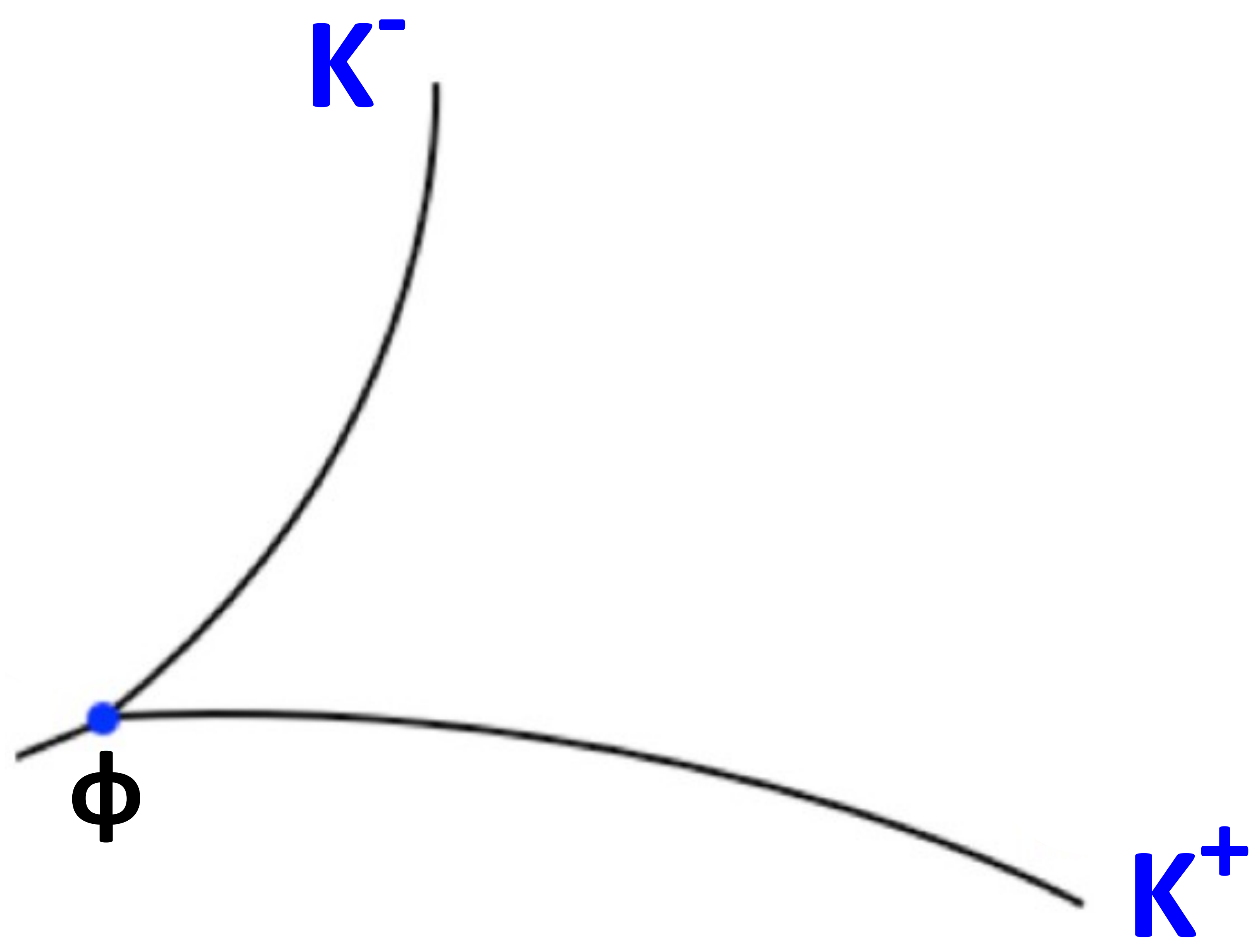




This analysis

ϕ meson identification

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

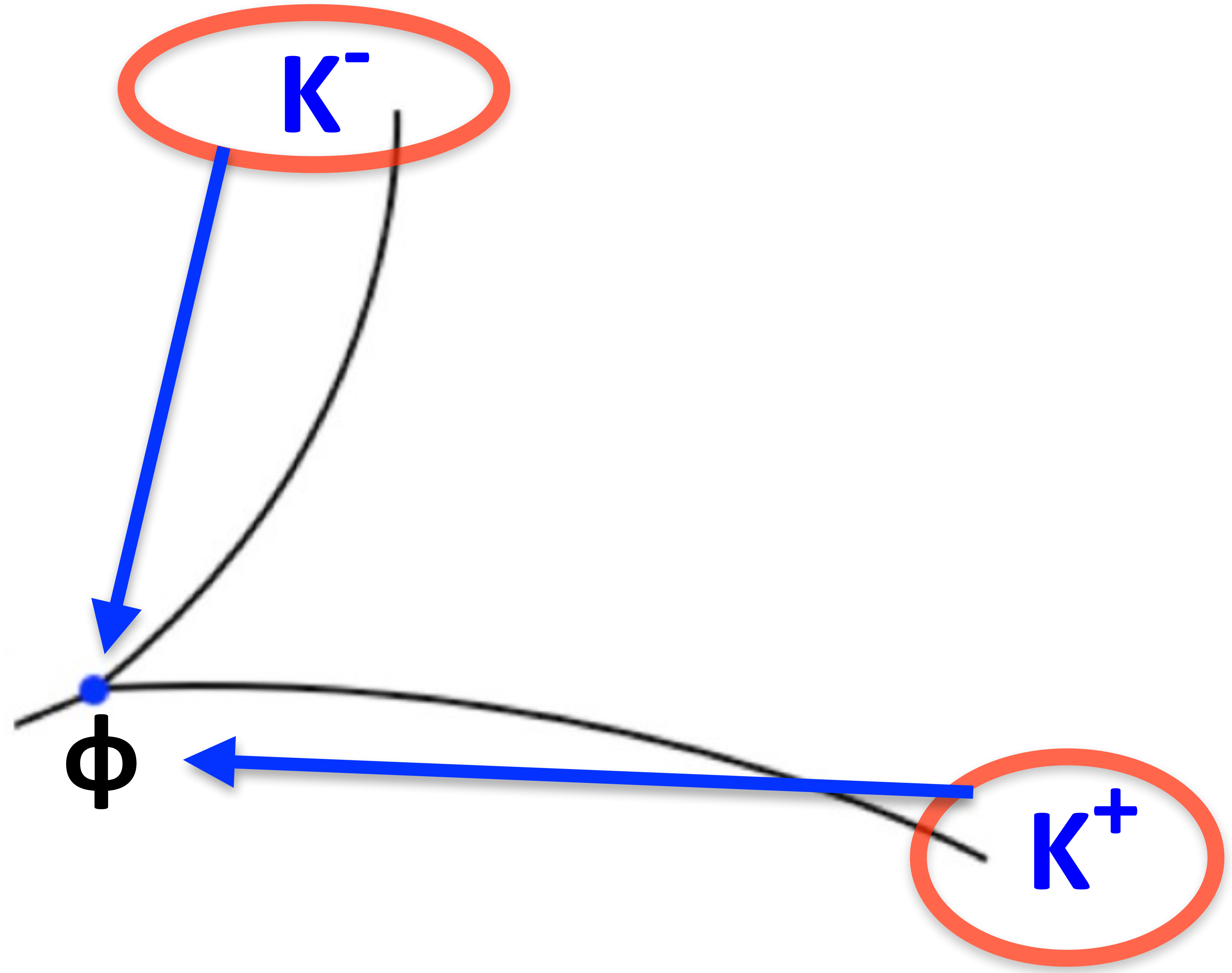


ϕ meson identification

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

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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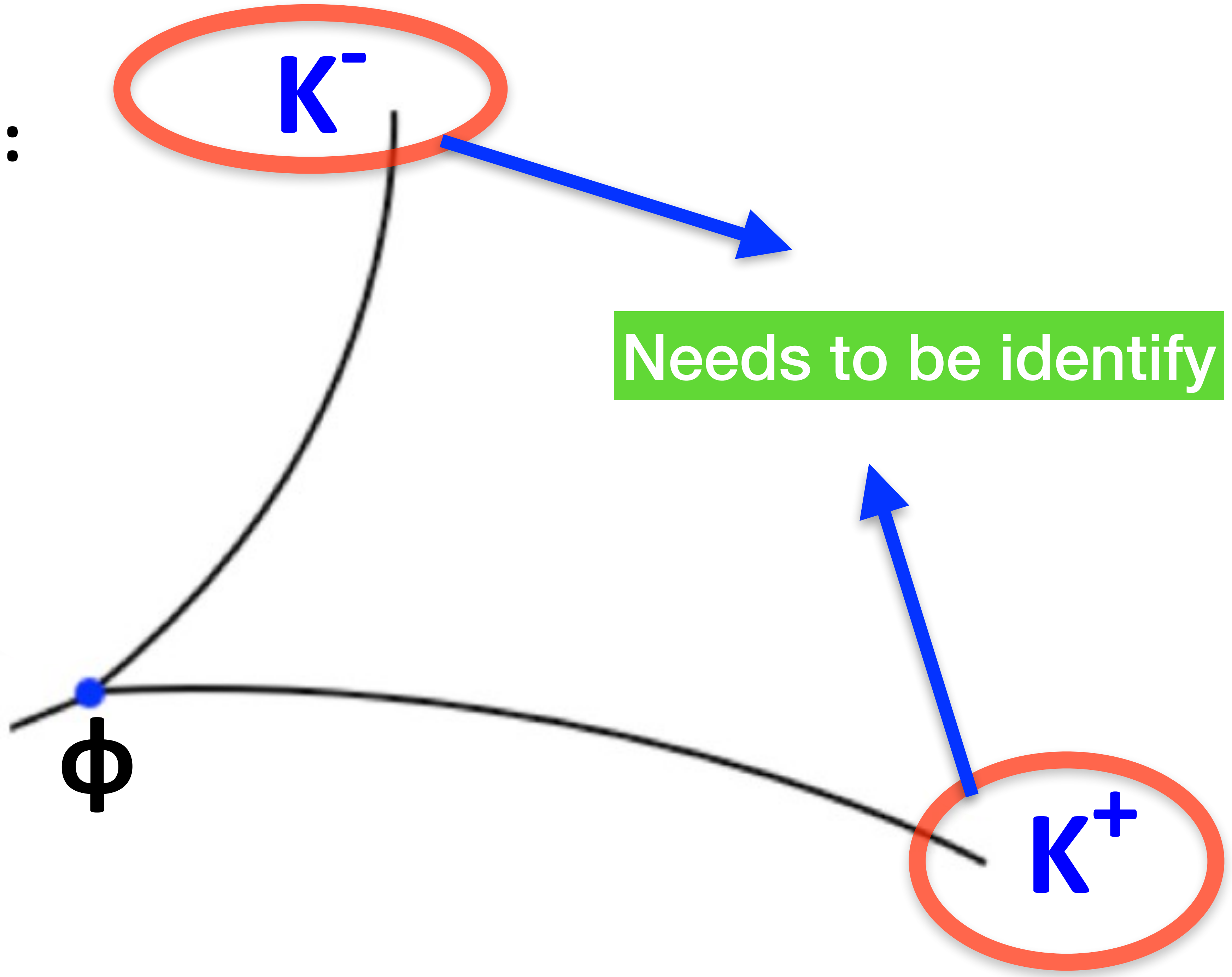
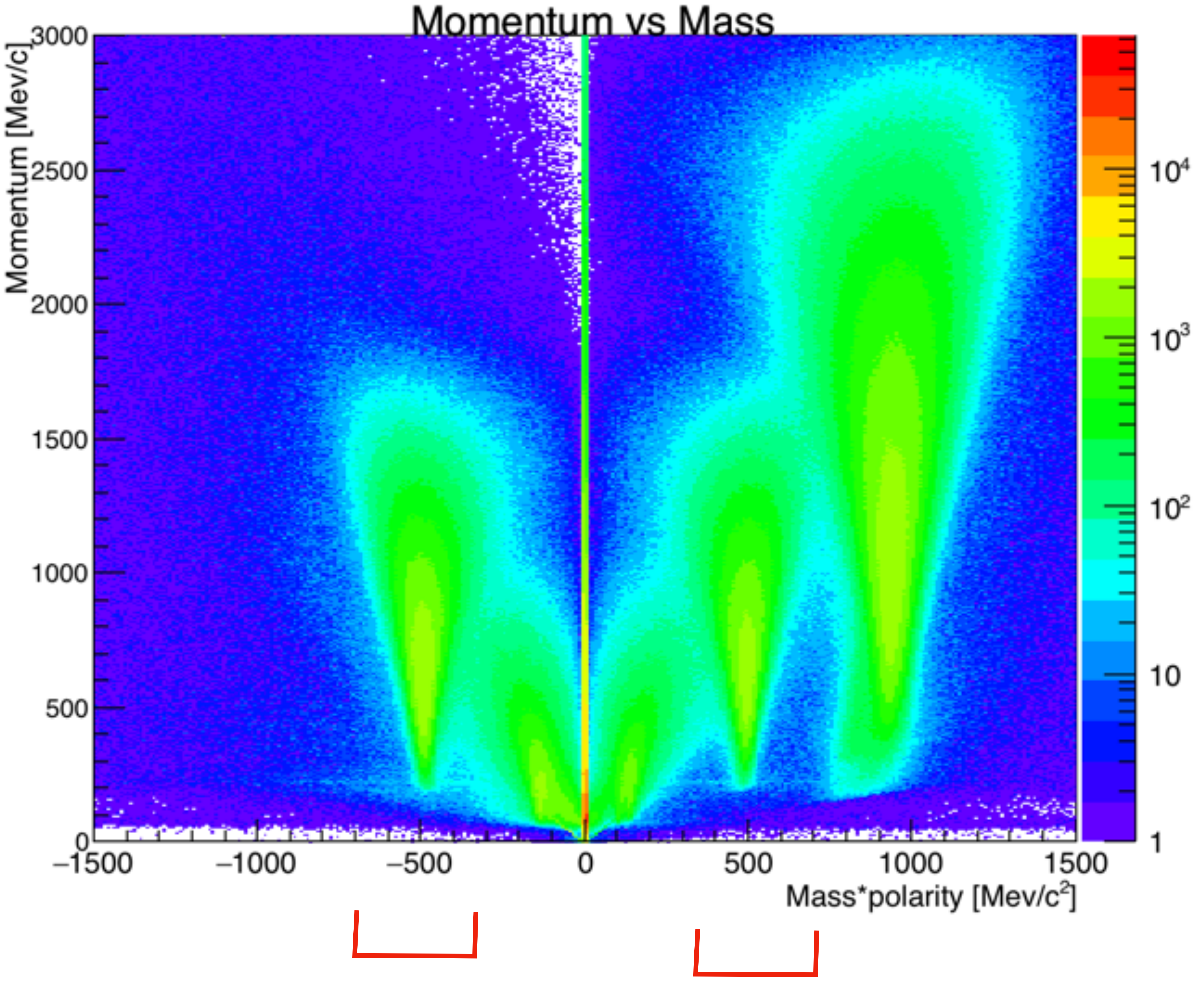


Particle identification

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



K^- = 494 MeV/c² K^+ = 494 MeV/c²

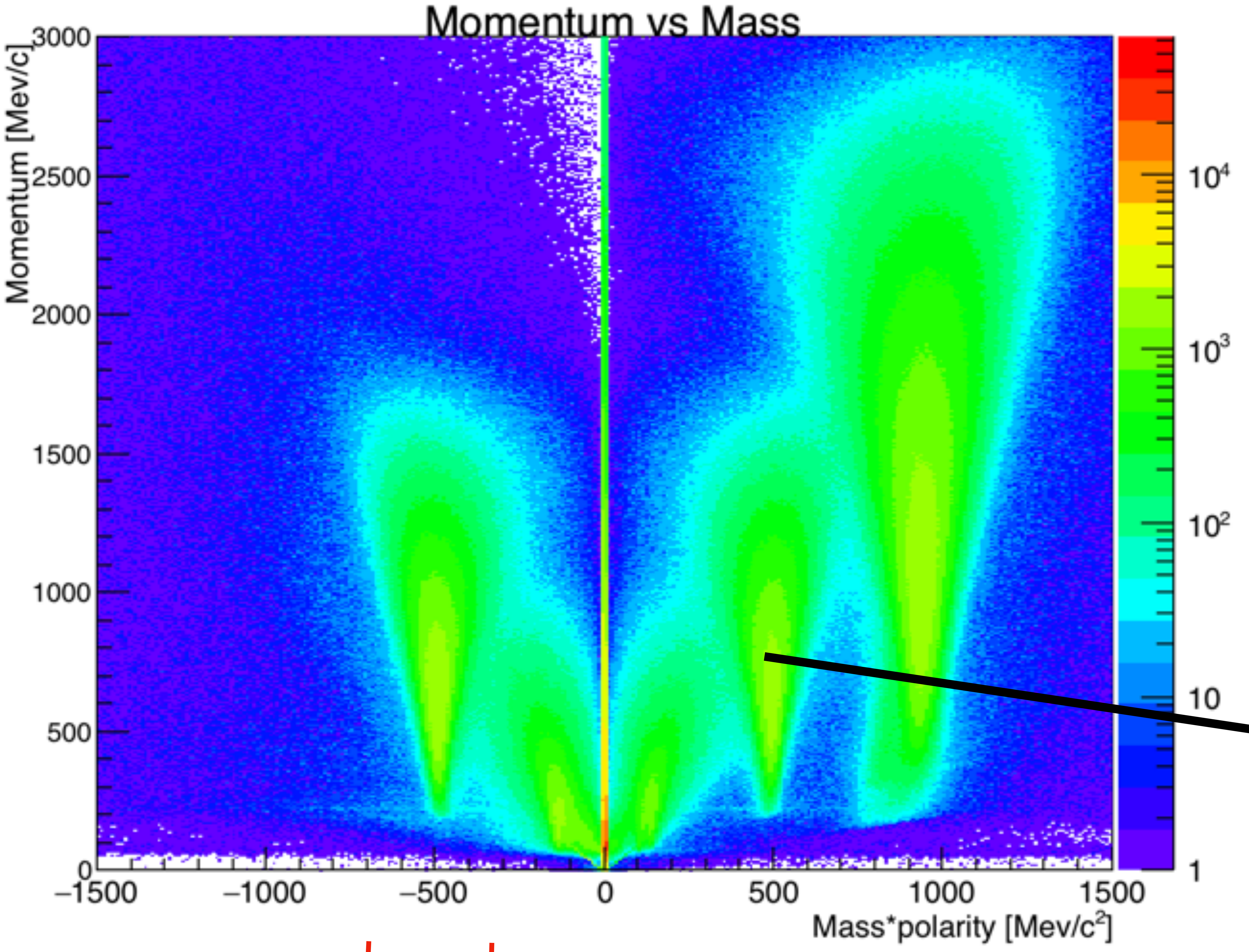
Using PLUTO + Geant
for exclusive channel [pp->pp Φ(K+K-)]

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

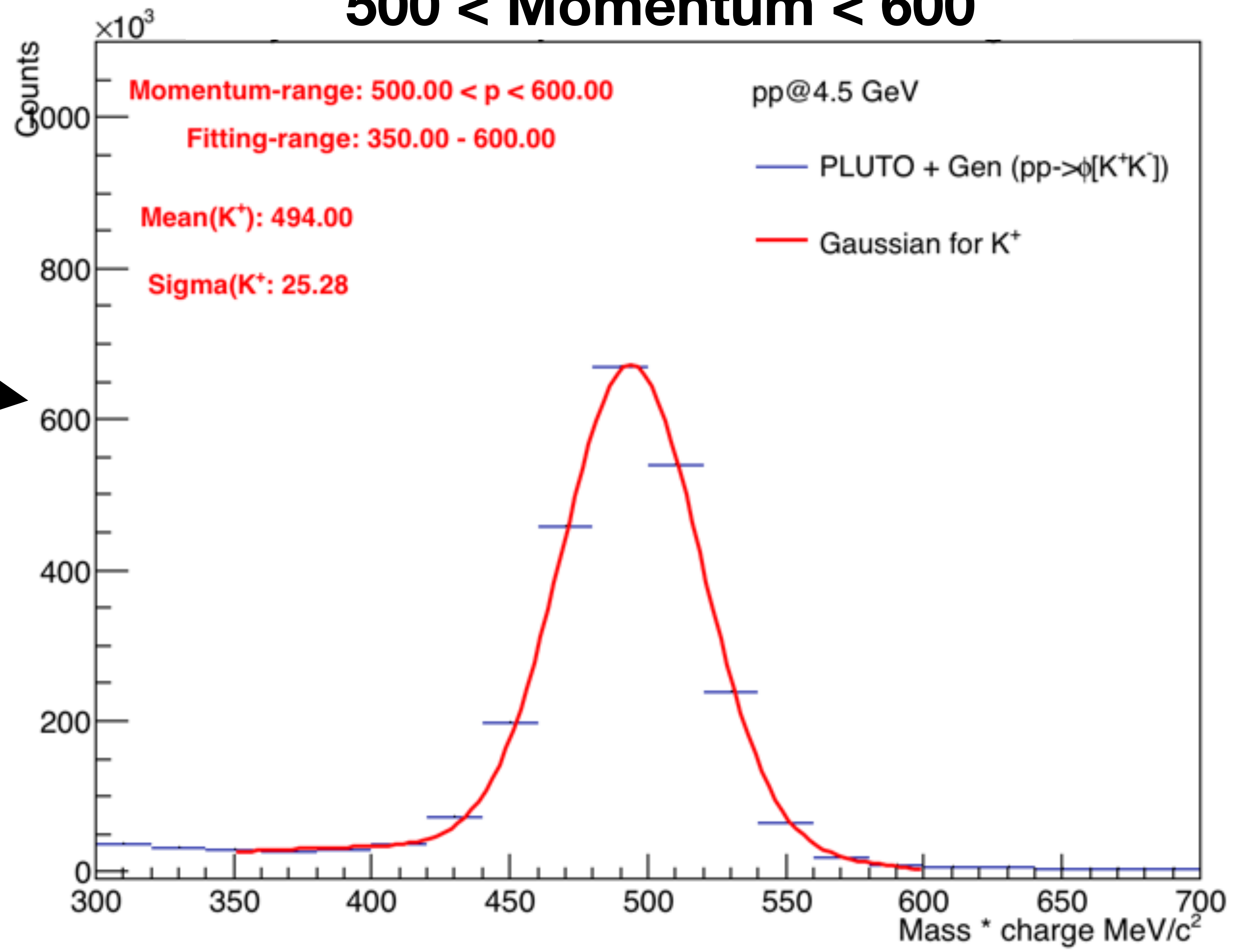
Particle identification: Step-1: Mass vs momentum from Simulation



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



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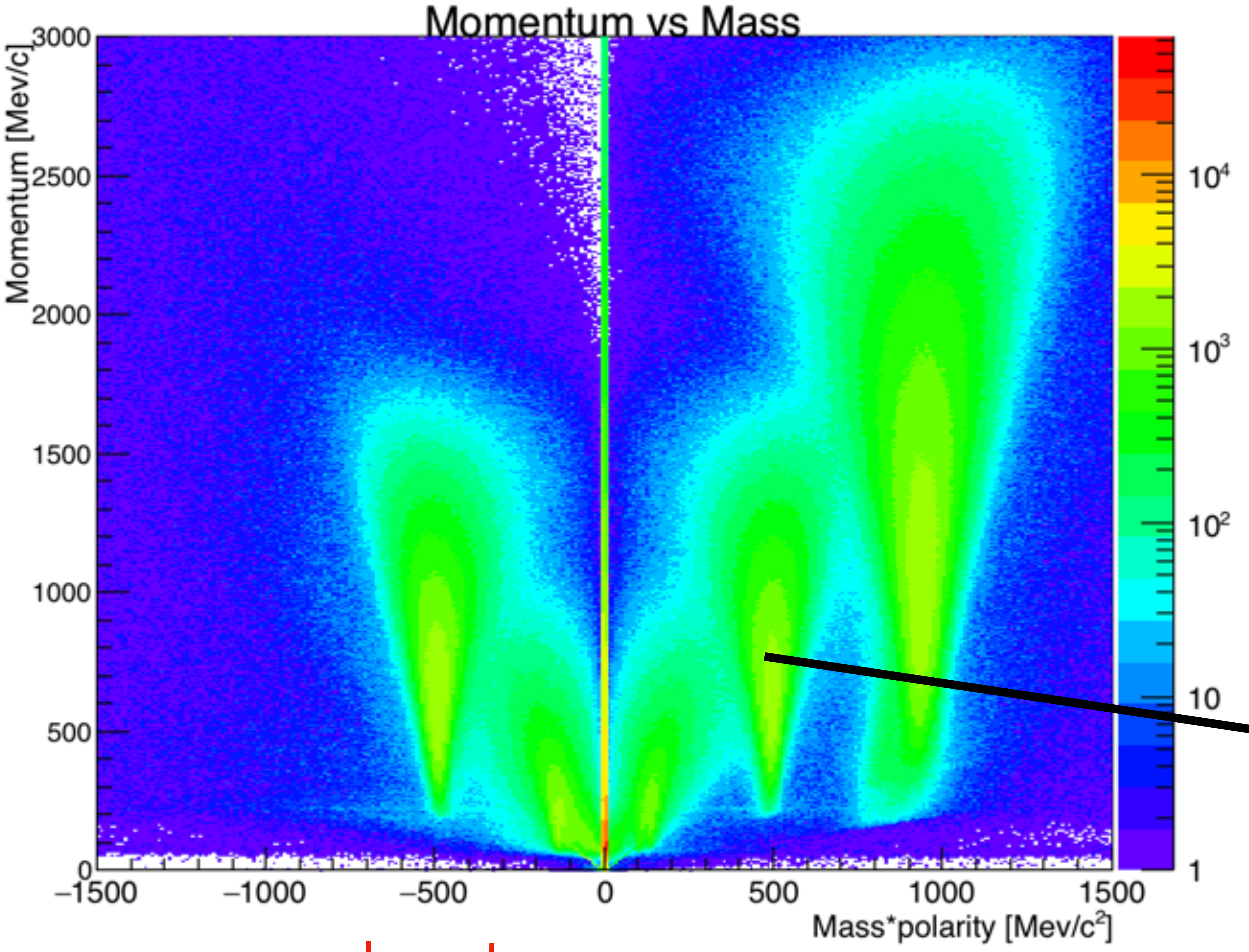

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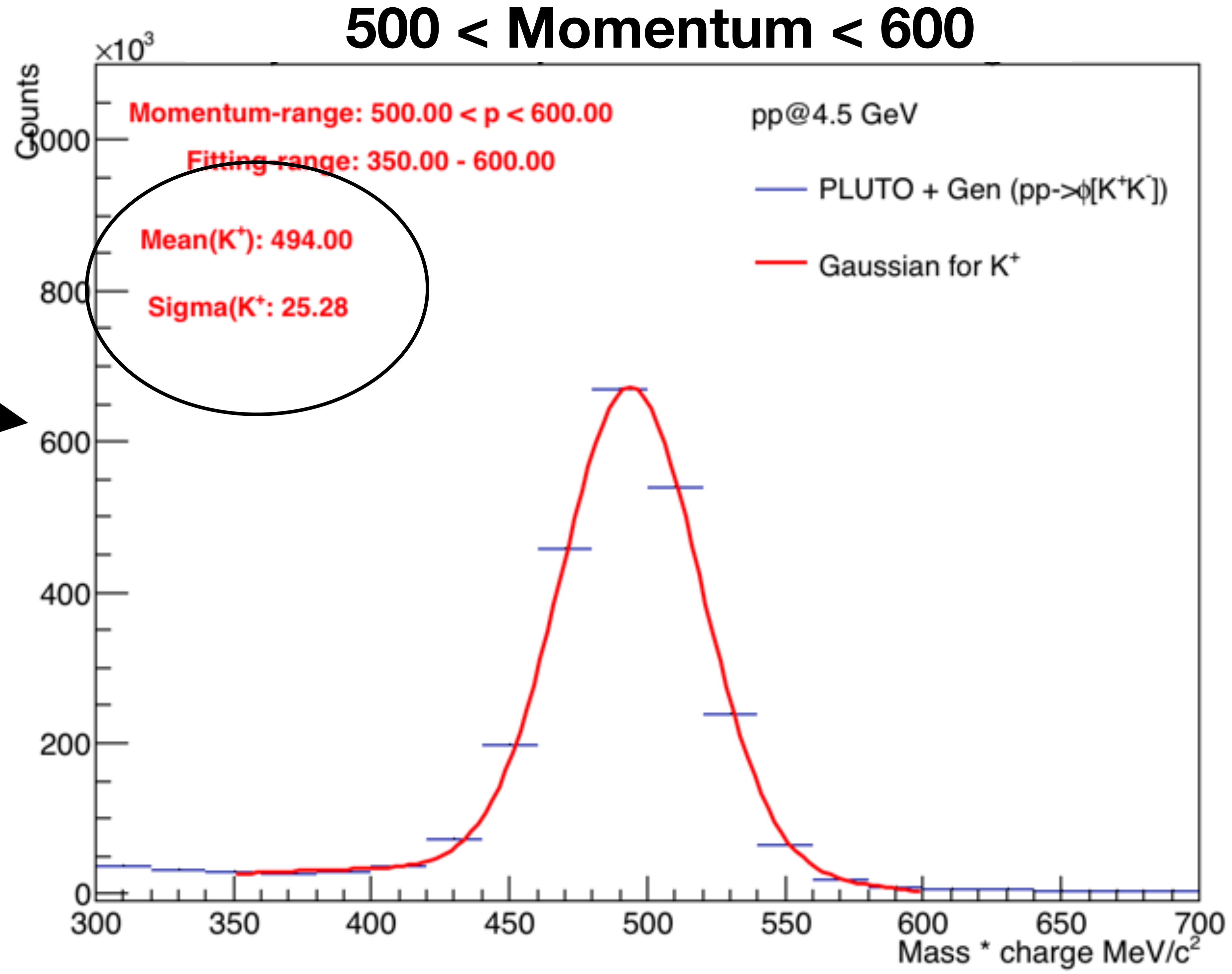
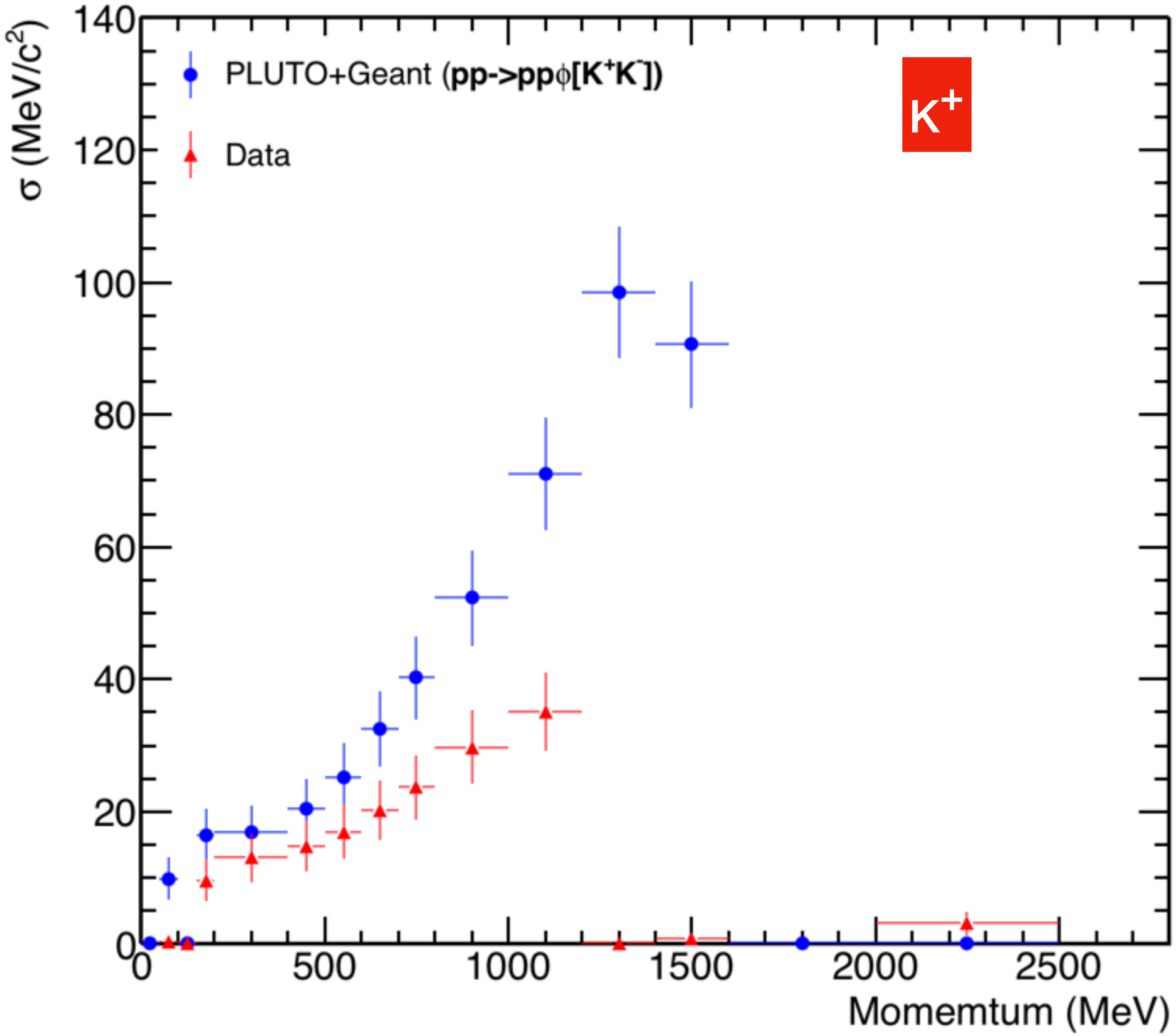


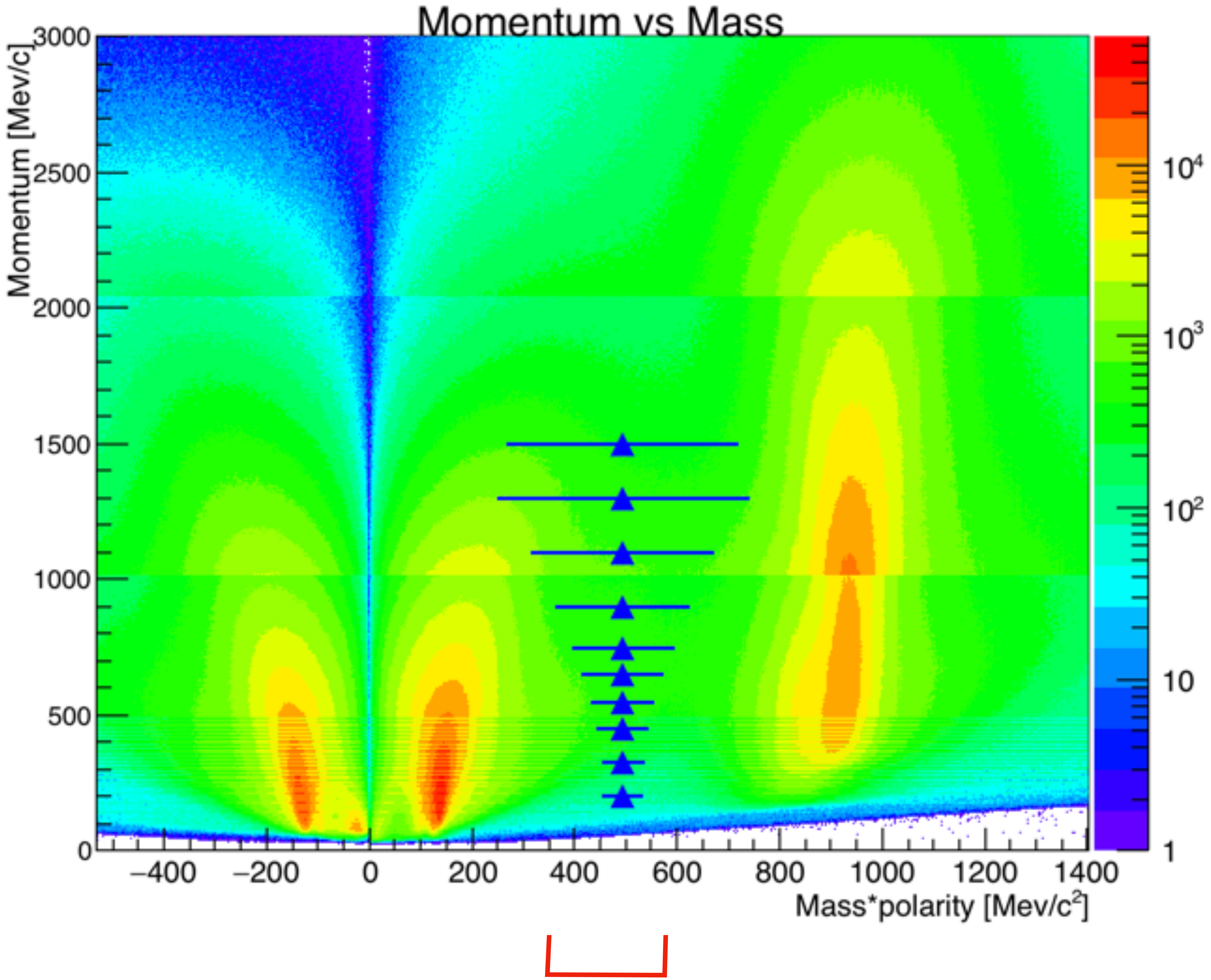
Width from the fit vs Momentum: Simulation Vs Data



- **Stopped kaons are not seen in data at low momentum and at high momemtum, consistent kaons yield are not seen.**
- **However, kaon yield from data seems to be reasonable w.r.t simulation for 125 < mometum < 1200 MeV**

So, Mass cut is restricted for momentum range [150 ,1400] MeV

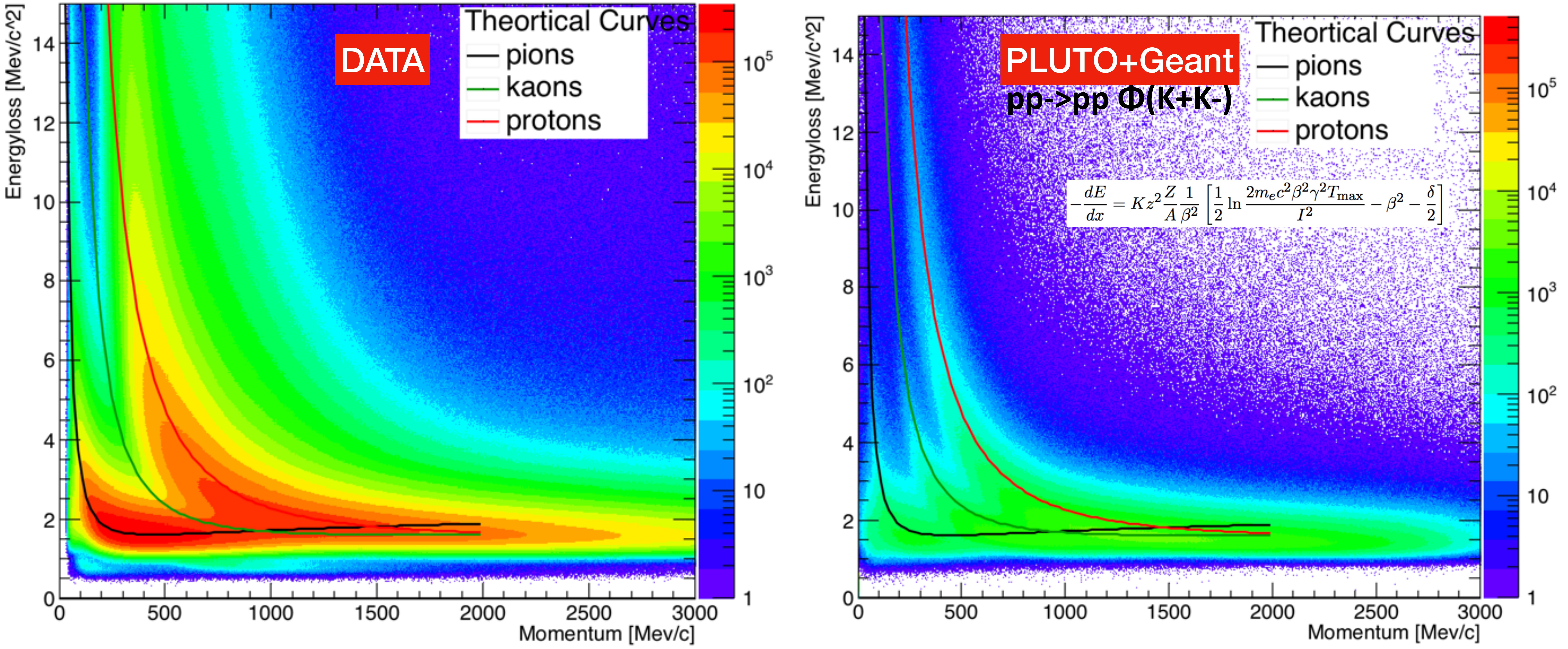
Particle Identification in HADES : Step:3-> Using K^+ Width on DATA



K^+ = 494 MeV/c² (PDG mass)

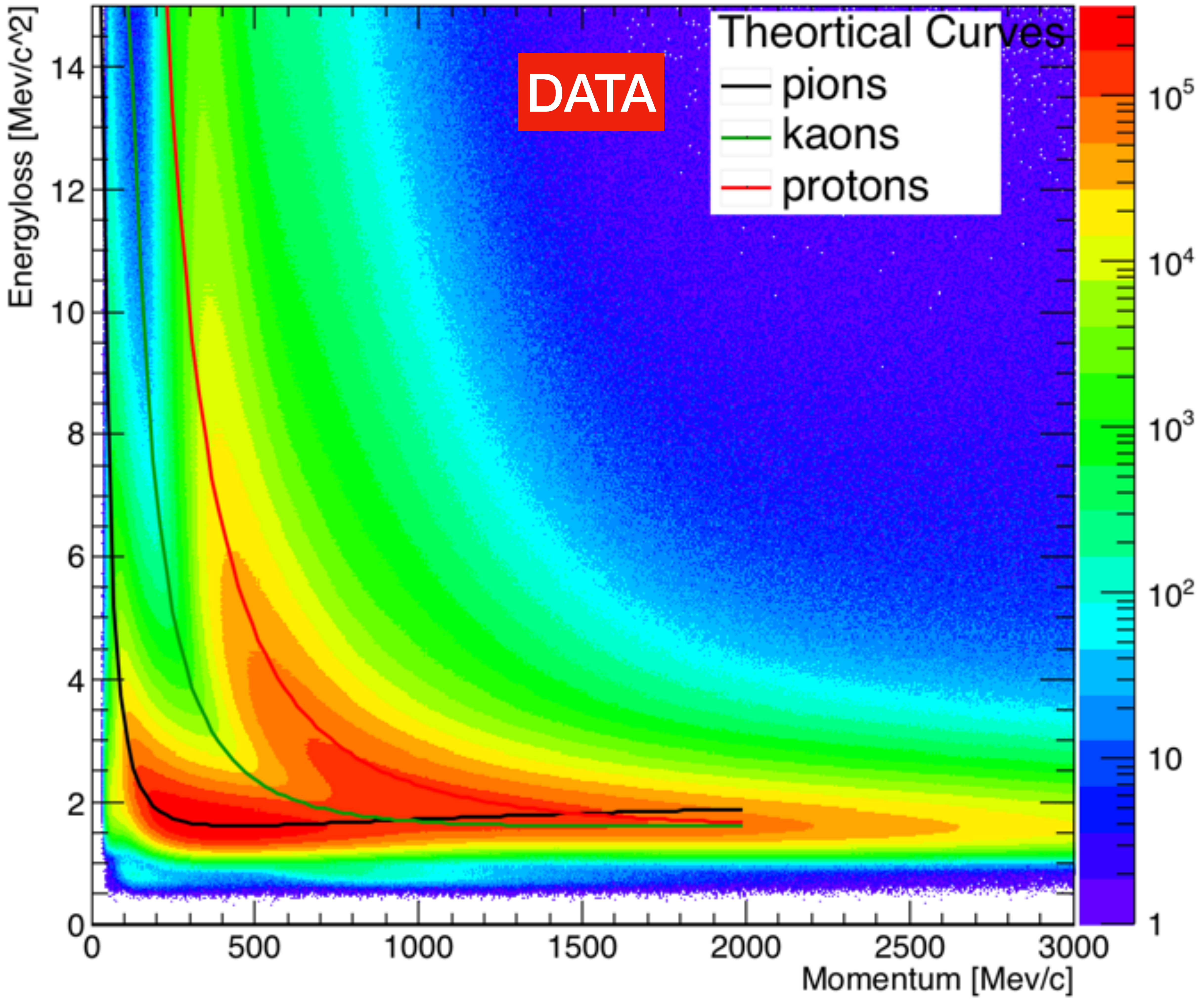
- K^+ region in data
- **Blue lines**: Width of K+ obtained from simulation (PLUTO + Geant) <u>with **σ** = ± 2.5</u>

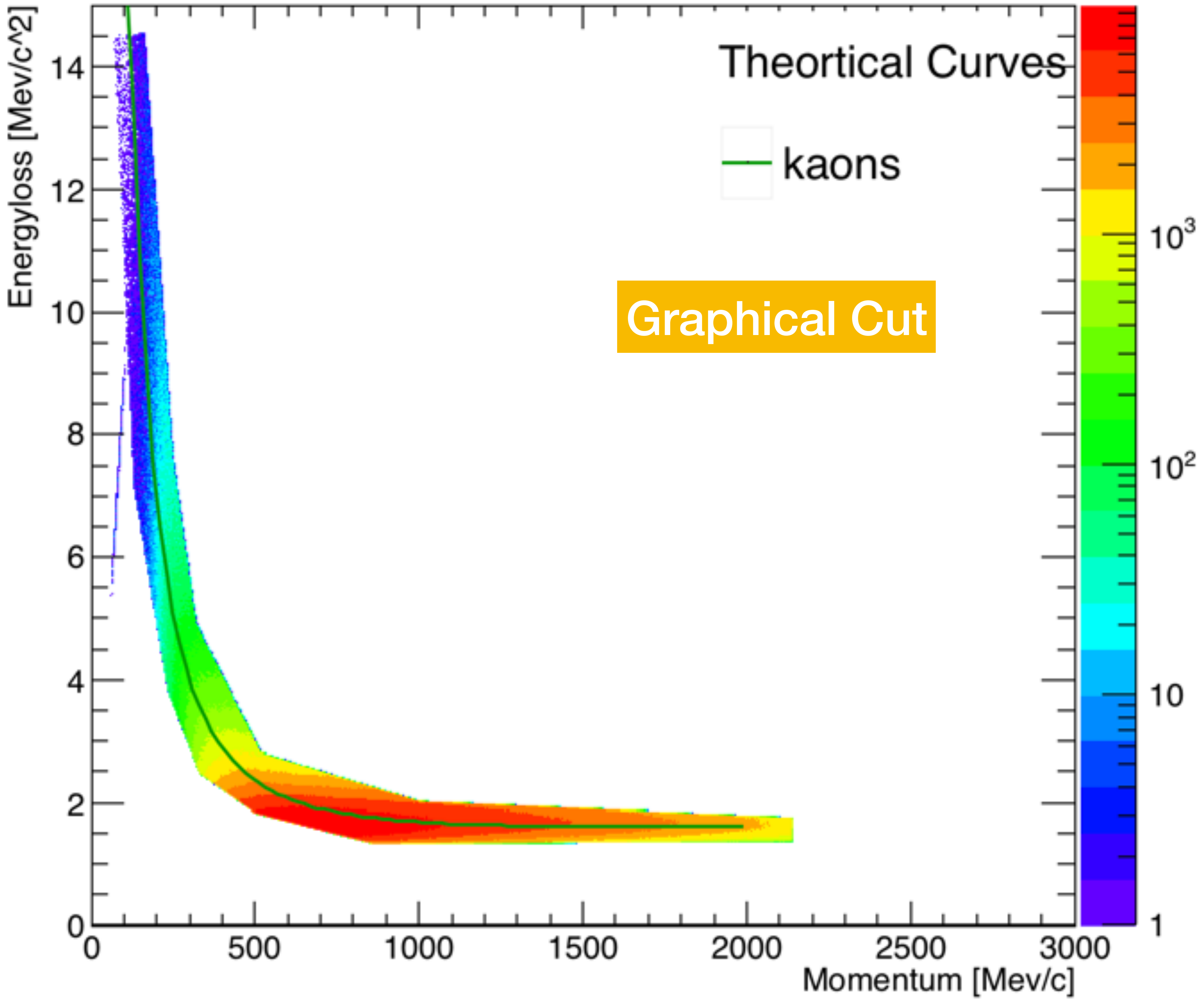
Particle Identification in HADES : Step:4-> particle from (p,dE/dx) of MDC



- Comparison of Energy loss distribution between data and simulation (PLUTO + Geant)
- Energy loss for proton seems bit lower than the theoretical curve in case of data

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





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

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

Particle Identification in HADES (In Summary)

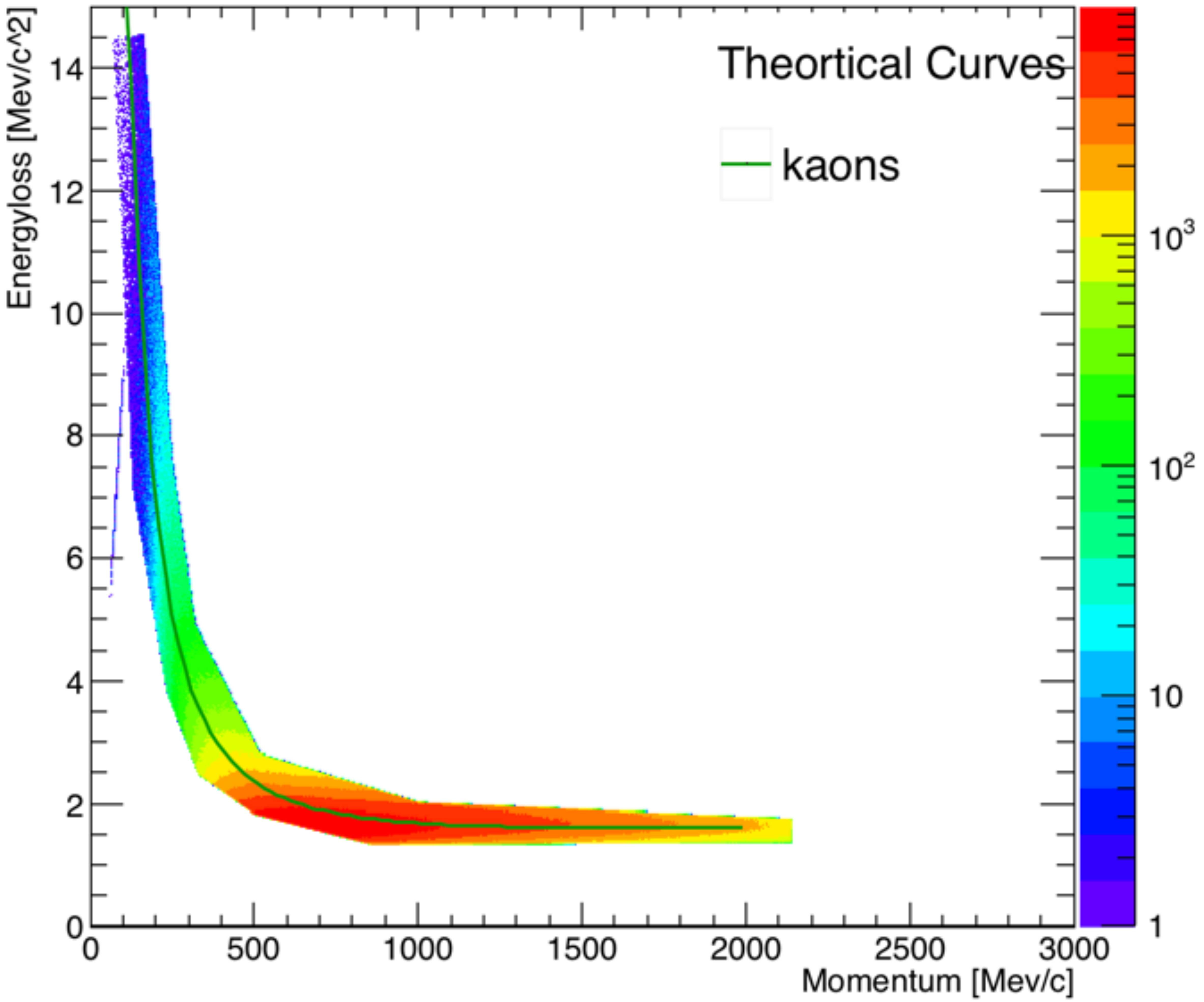
PID for K^+ in the analysis

- K^+ region cut on (p, dE/dx)
- charge > 0
- Mass cut with $\sigma = \pm 2.5$ from simulation

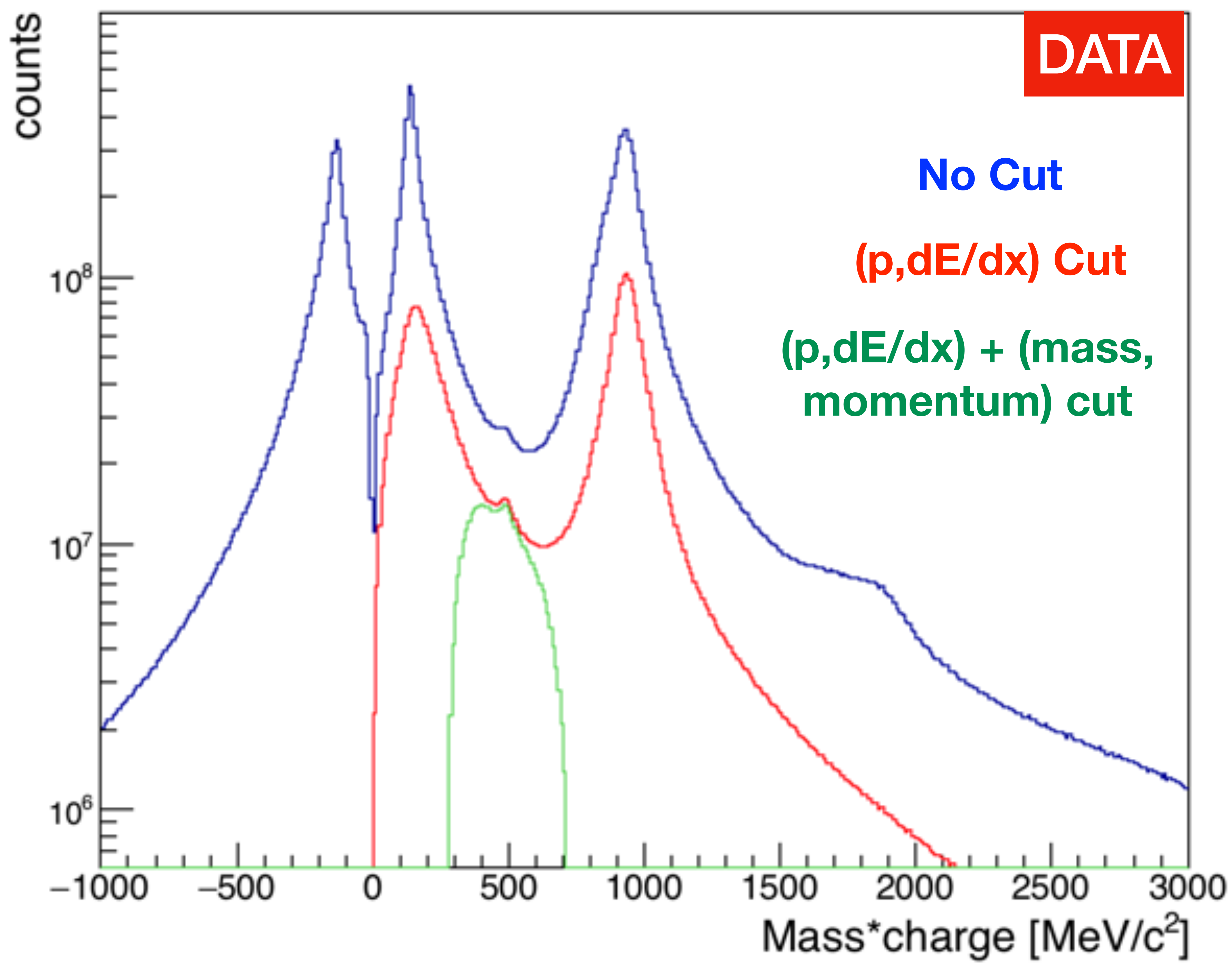
And, PID for K^- in the analysis

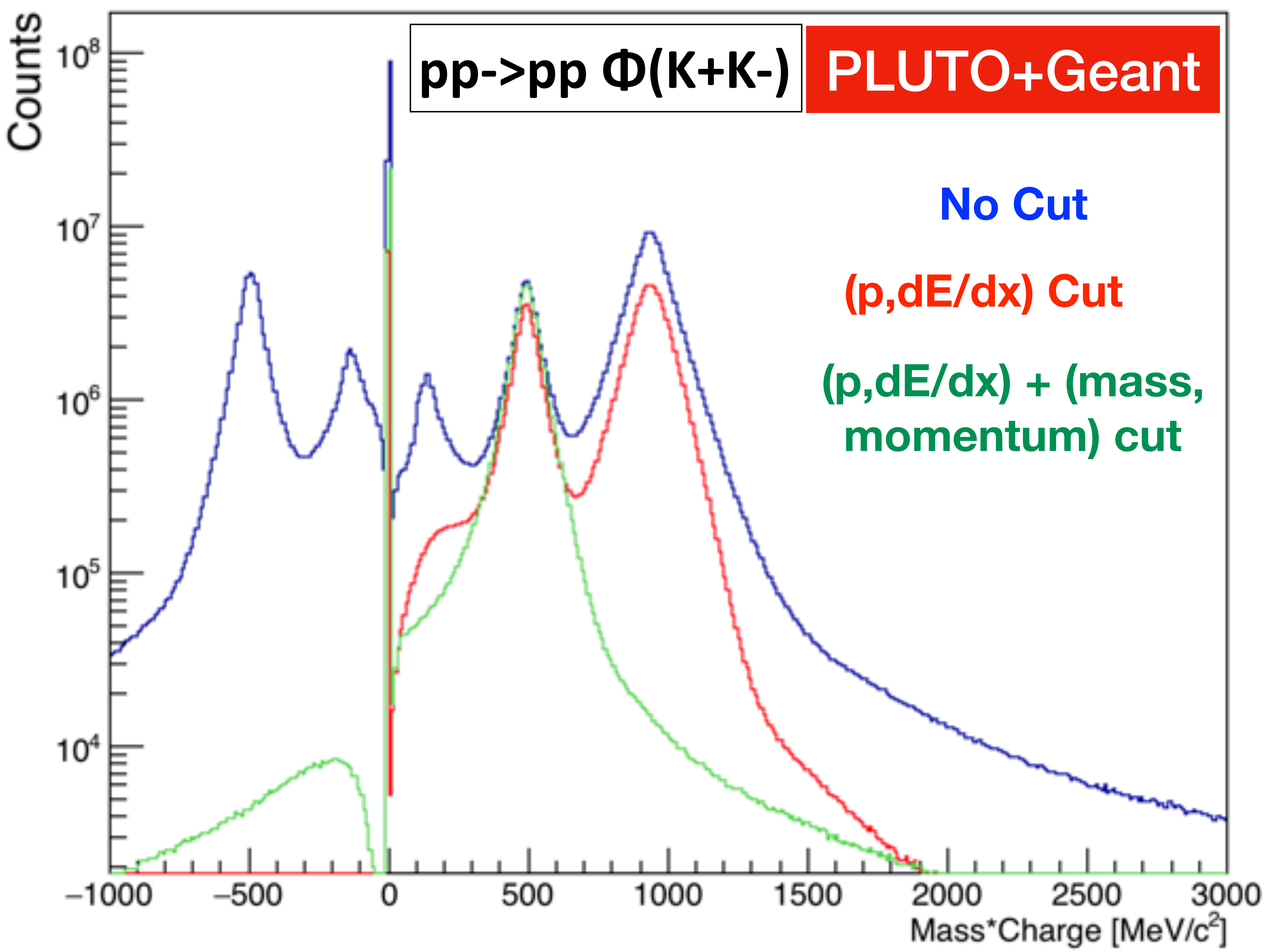
- Similar to K^+ (it will not change much)
- Charge < 0

Region for K+



Affect of cuts on selection of K+: Data vs Simulation

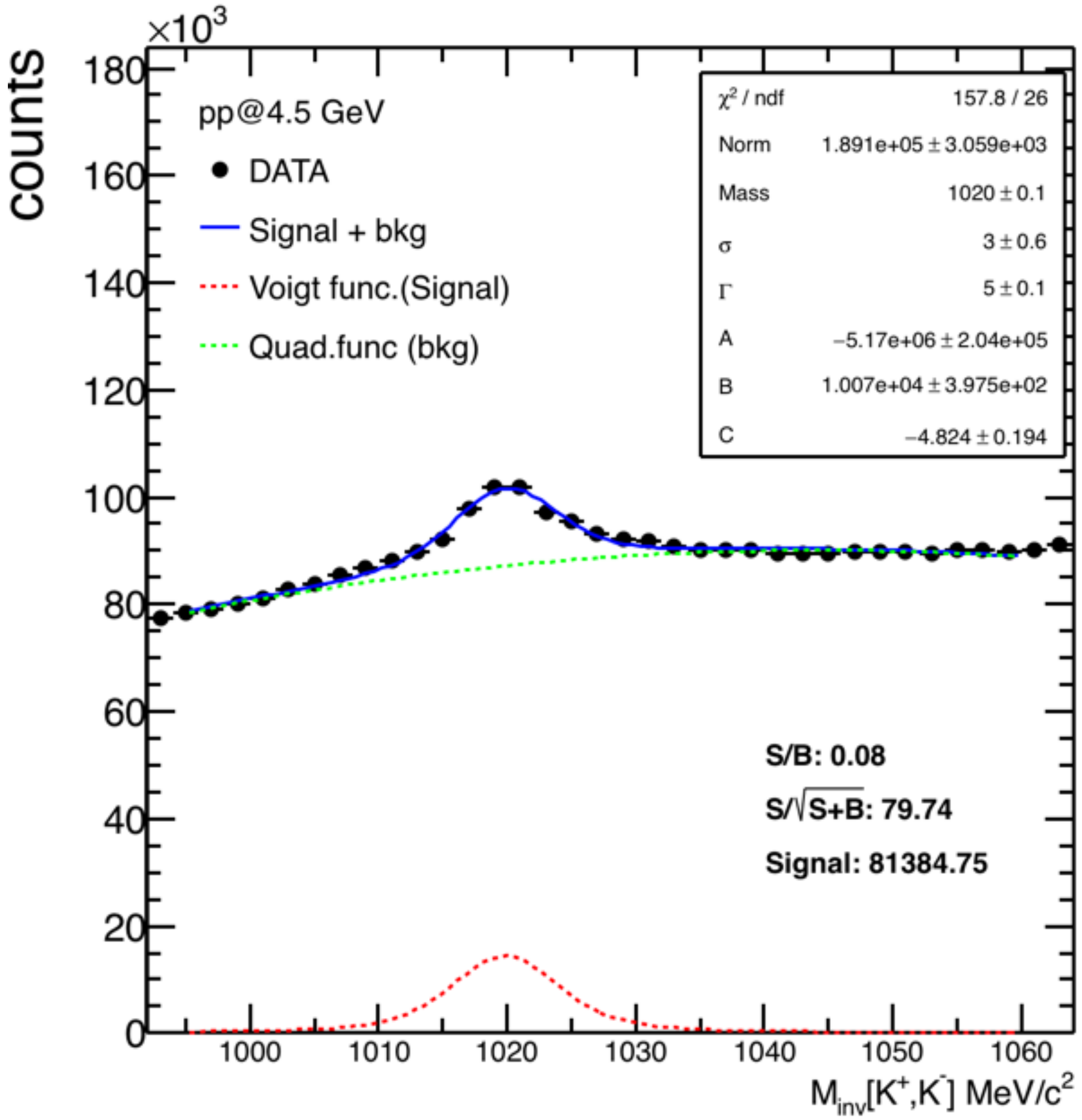




- In simulation, with cuts, we have almost no primary pions, only a low yield of secondary pions
- Cuts remove approx. the same proportion of pions in sim and data, just you have many more pions in data.

Invariant Mass

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



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

Fitting function:

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

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

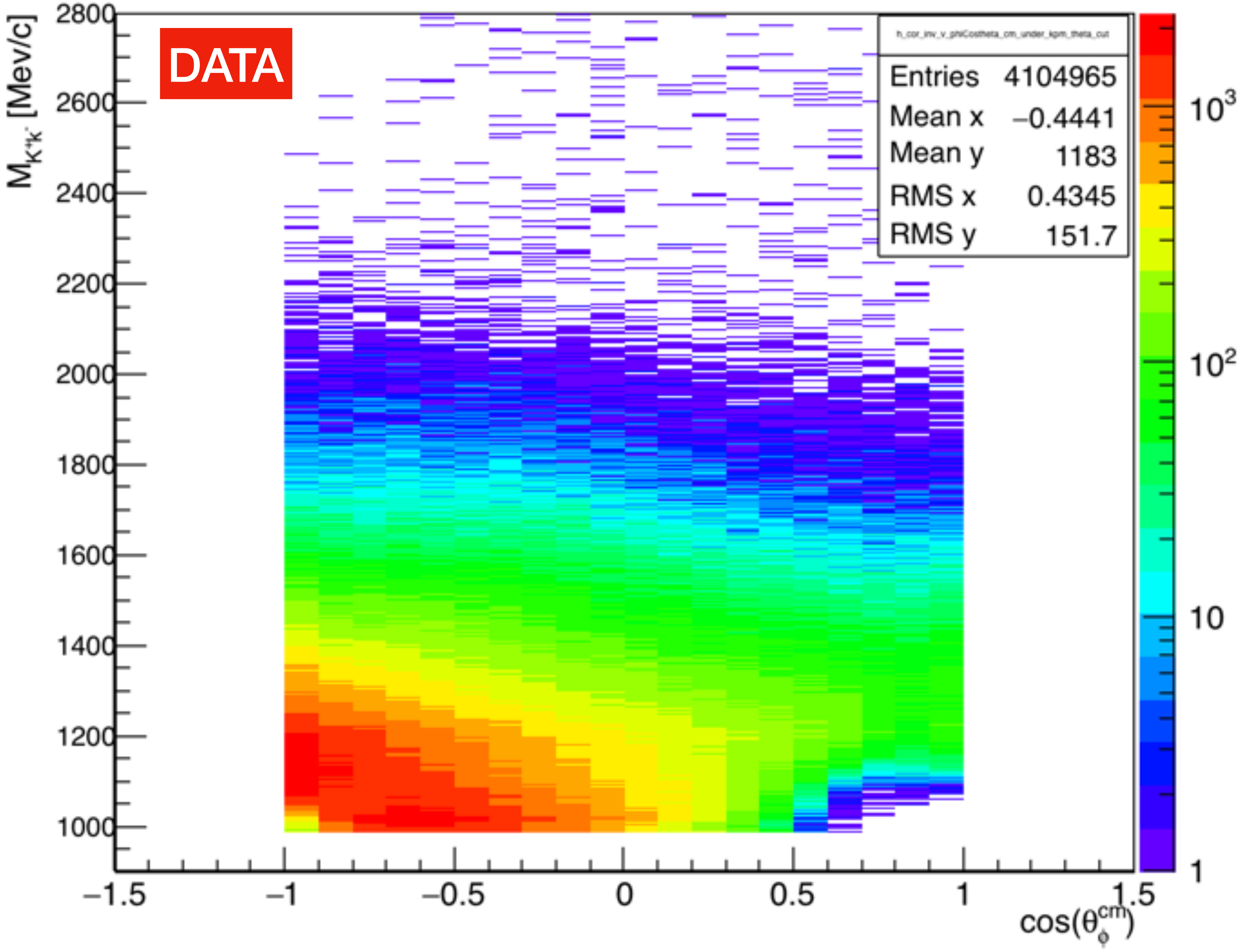
where,
A -> Normalisation factor; M-> Mass; σ -> detector resolution

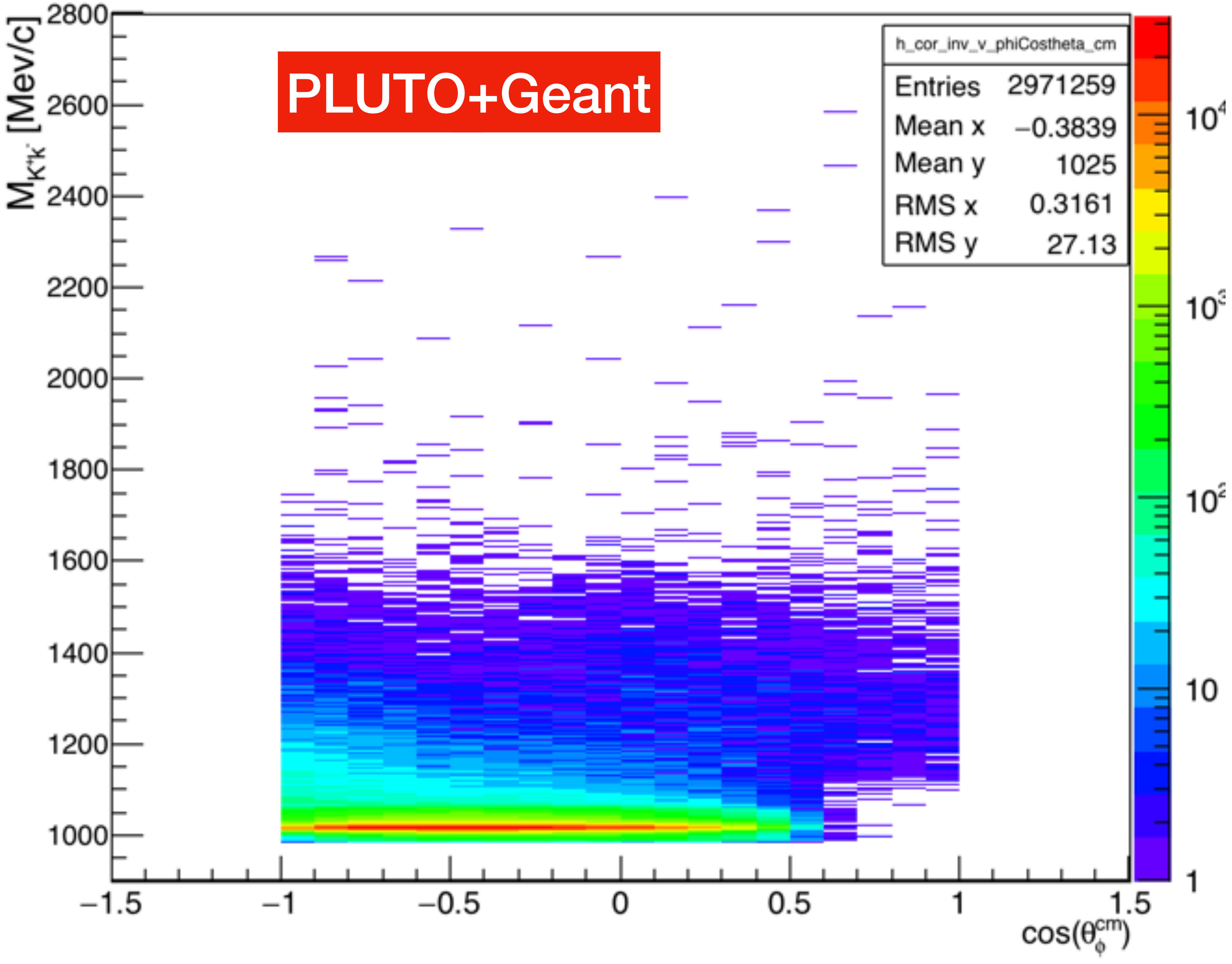
Background: Quadratic polynomial

We observe a very good significance of ~80
And number of Φ produced ~80k

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

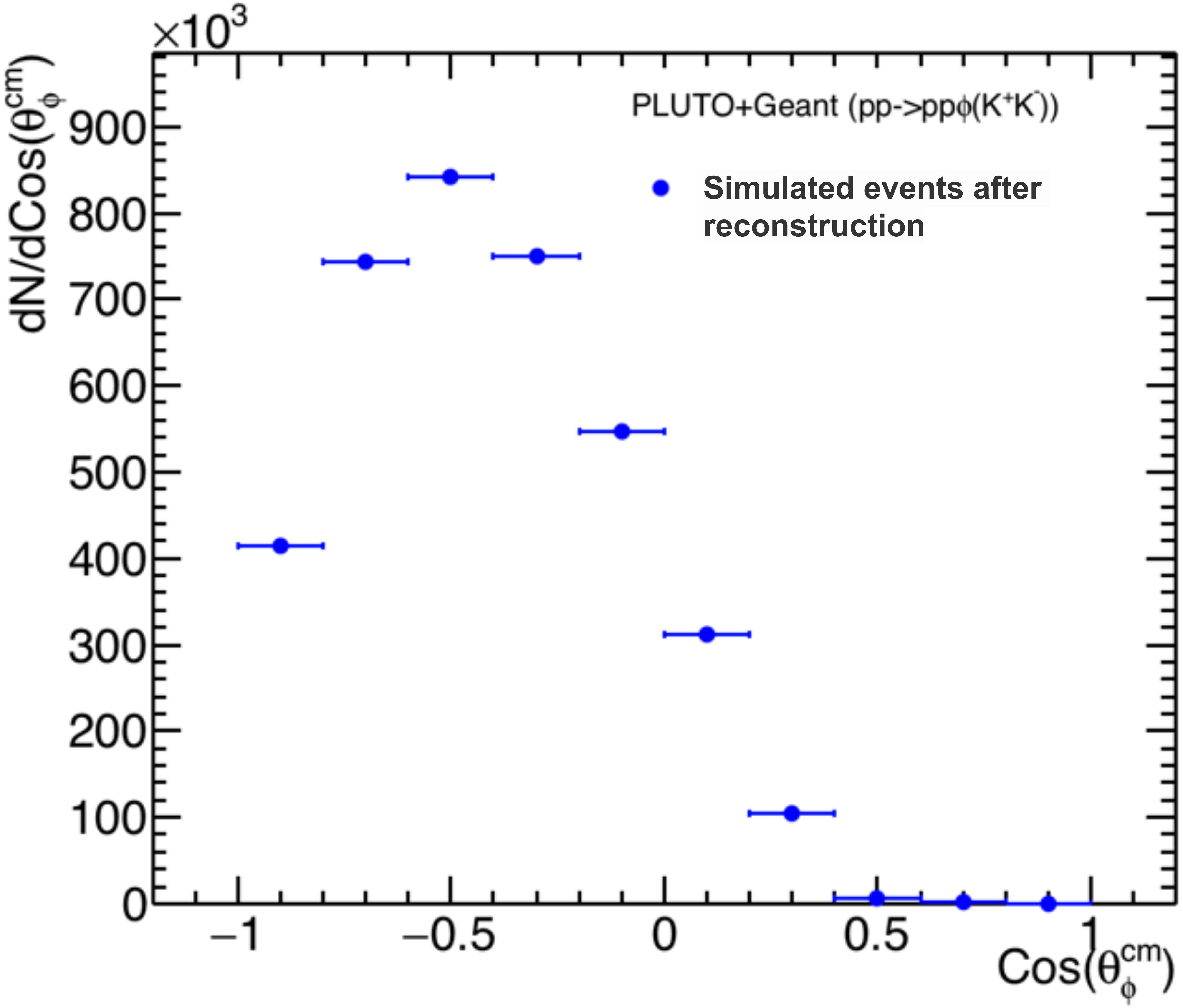
$M_{inv}[K^+K^-]$) vs $\cos(\theta_\Phi^{cm})$: Data vs Simulation





- Invariant mass in data is more inclined towards negative part

$\cos(\theta_{\Phi}^{cm})$ distribution- Simulated events after reconstruction



Using Simulation (PLUTO+Geant),

Following $\cos(\theta_{\Phi}^{cm})$ are used for the current analysis

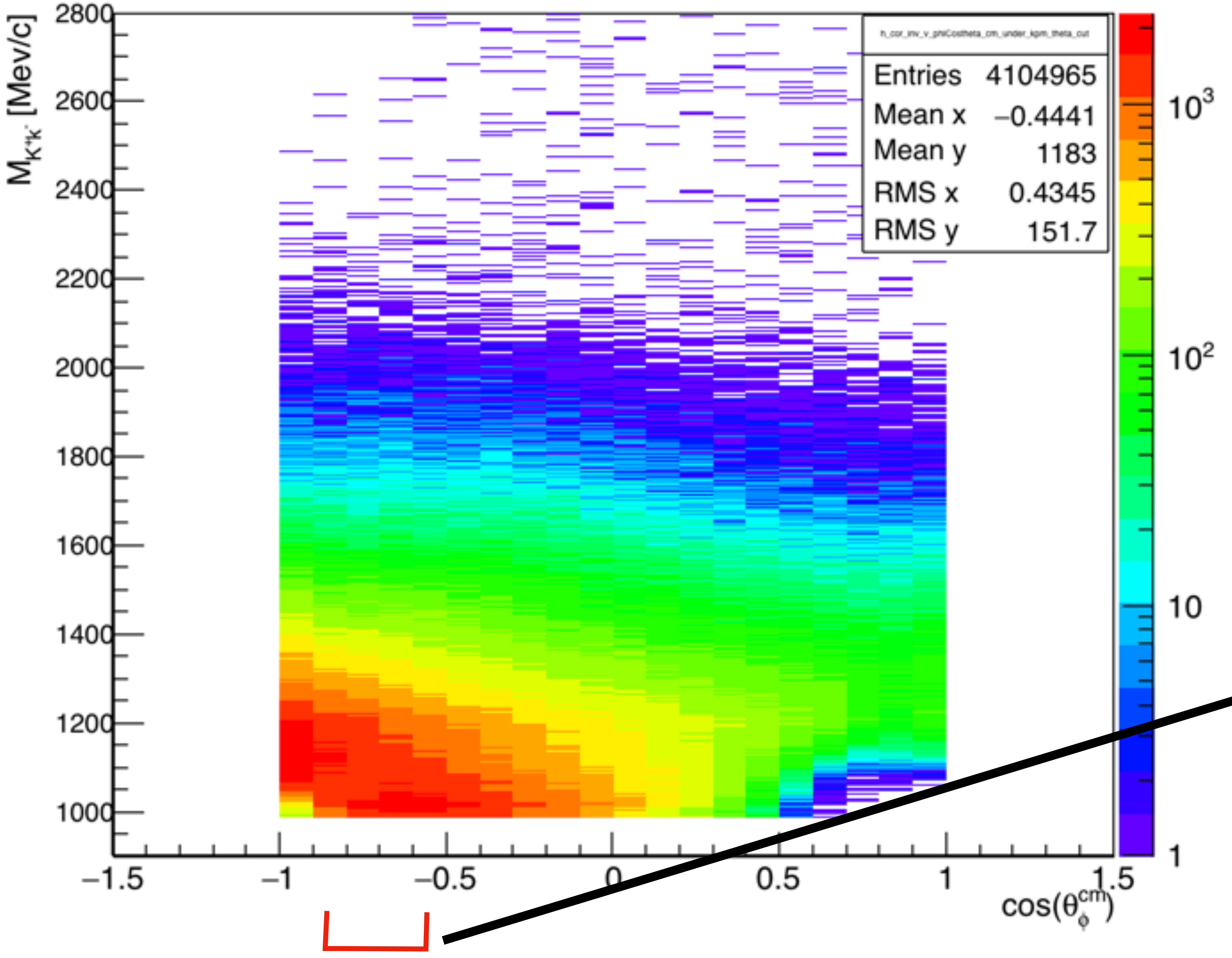
Cosine intervals: **[-1.0,-0.8,-0.6,-0.4,-0.2,0,0.2,0.4,0.6,0.8,1]**

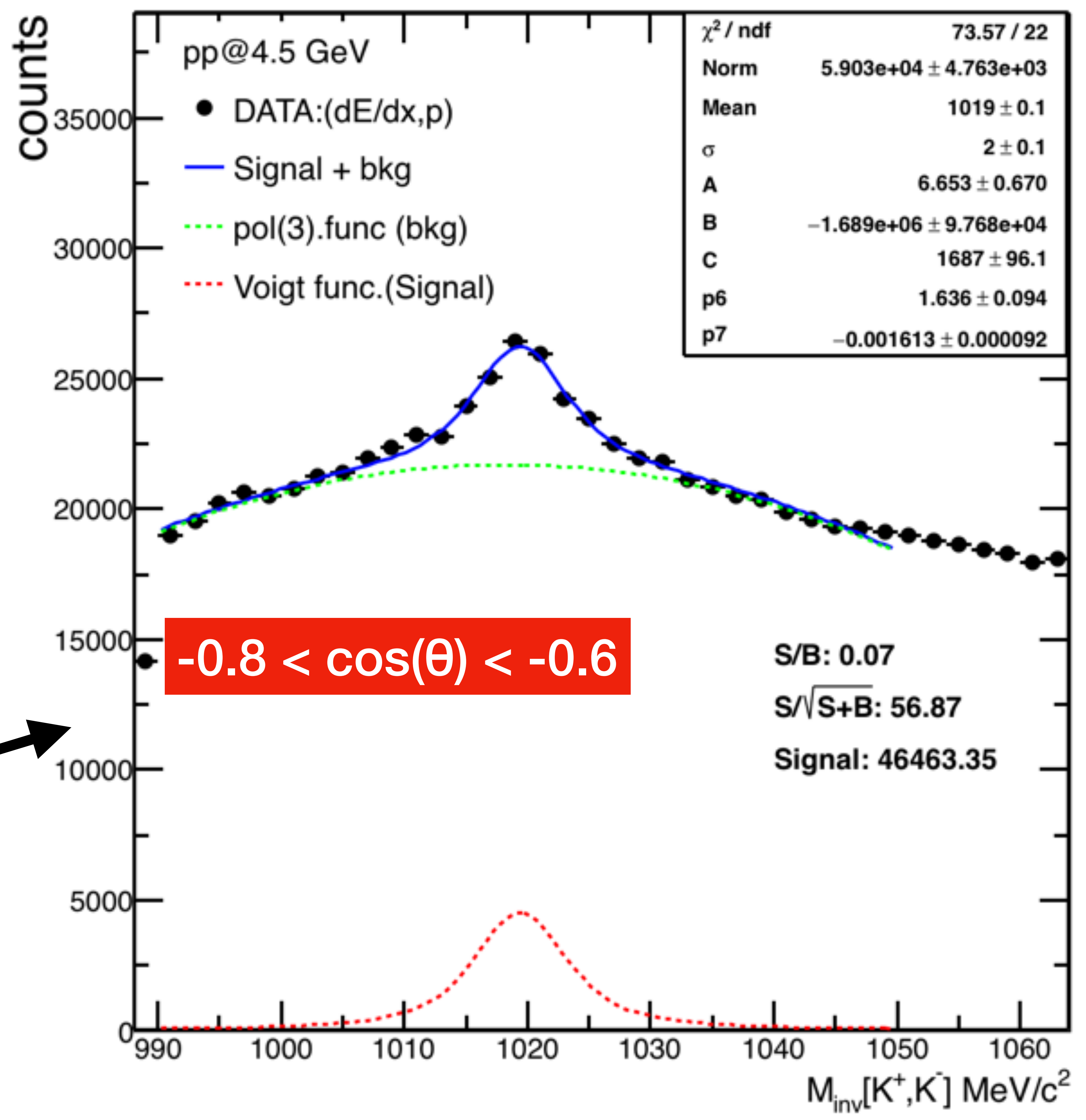
- **We see that the angular distribution is generated isotropically and strongly distorted after reconstruction**

As observed from Simulation, we are restricting this analysis to only negative part of distribution

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

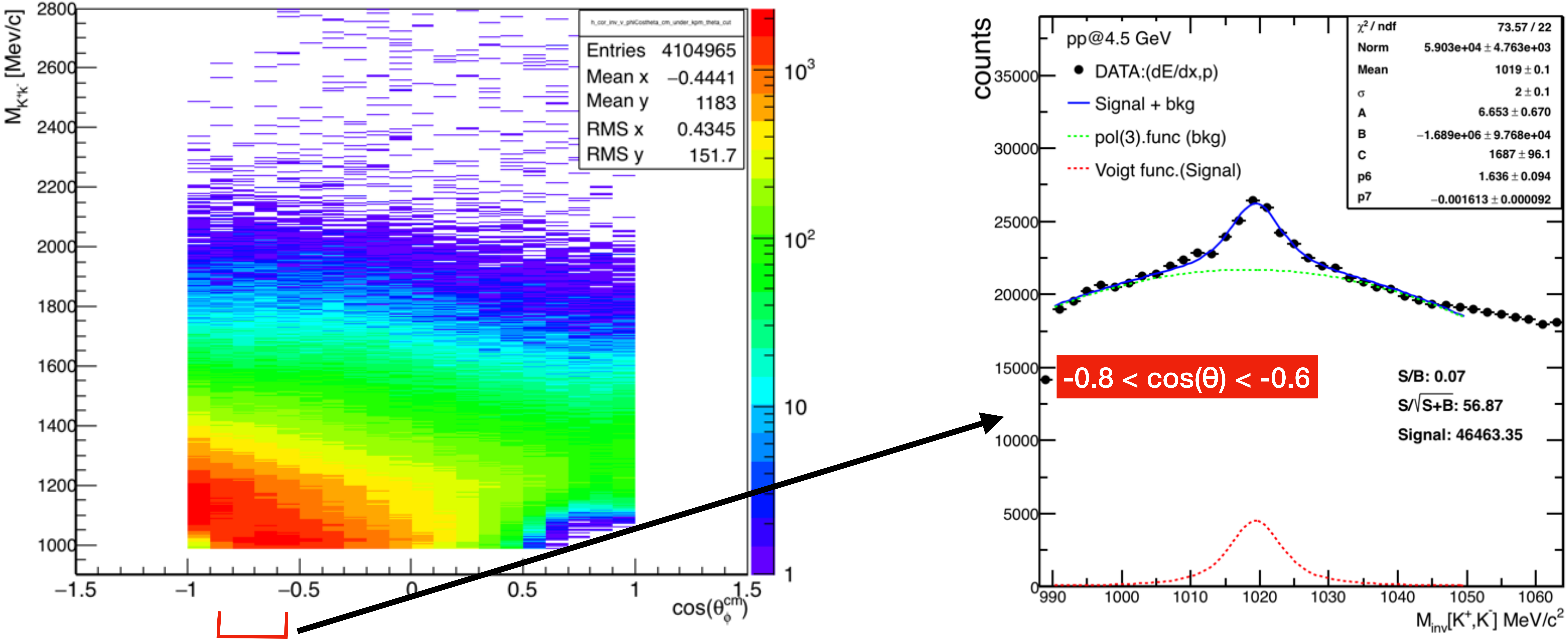
Invariant mass [K+K-] under different cosine range: Method





- **Reconstructed Φ meson obtained for -0.8 < cosθ <-0.6**
- **A very clear signal is obtained with number of Φ produced ~40k**

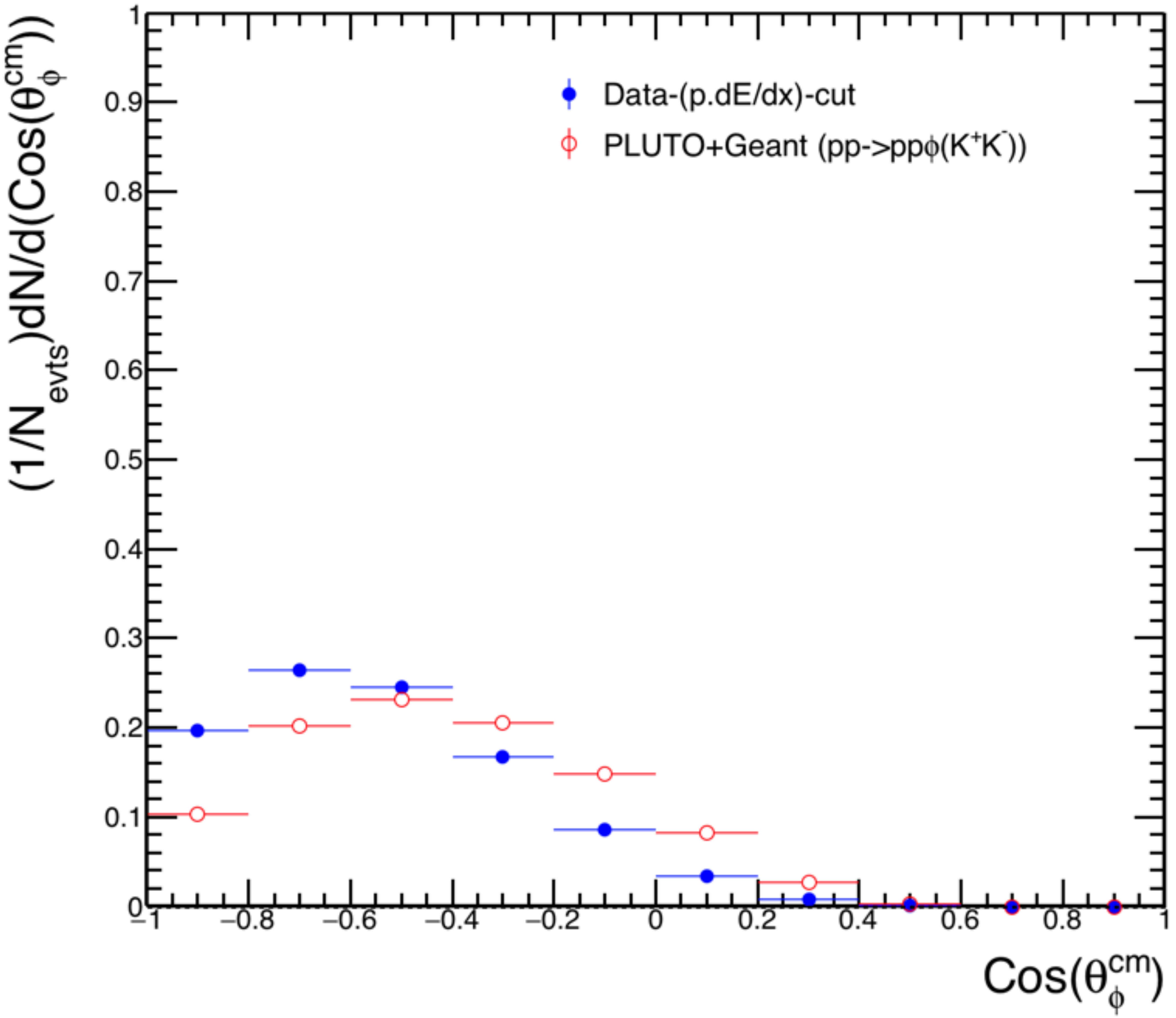
Invariant mass [K+K-] under different cosine range: Method



- **Reconstructed Φ meson obtained for -0.8 < cosθ <-0.6**
- **A very clear signal is obtained with number of Φ produced ~40k**

This is repeated for other cosθ intervals and simulation

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

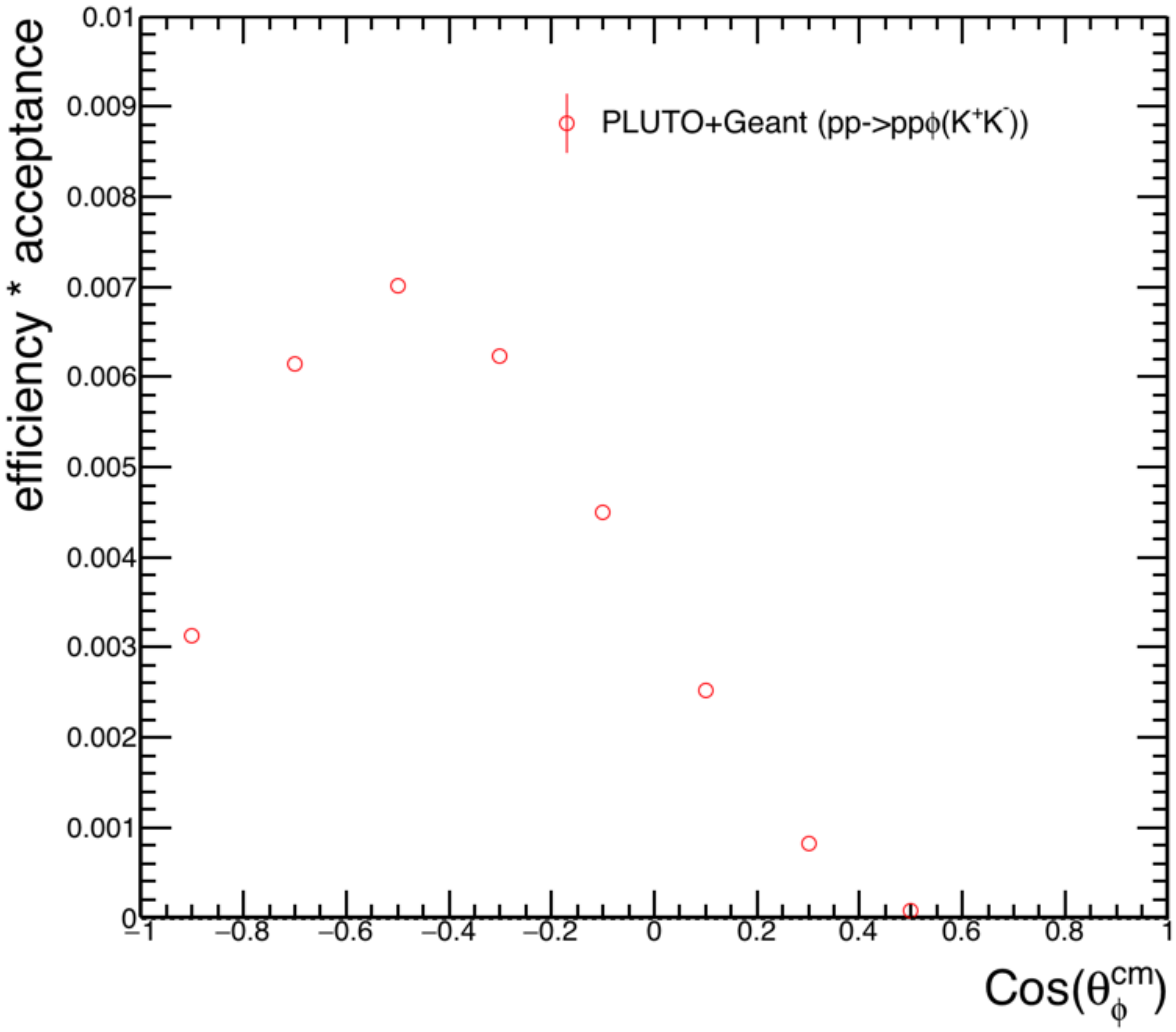


- **It is to be noted that Generated events are Isotropic**
- **Here we clearly observed an anisotropic behaviour**
- **Also, experimental data seems to be more backward than Simulation**

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

Efficiency * Acceptance using PLUTO+ Geant

Efficiency*acceptance vs $\cos(\theta_{\Phi}^{cm})$ distribution



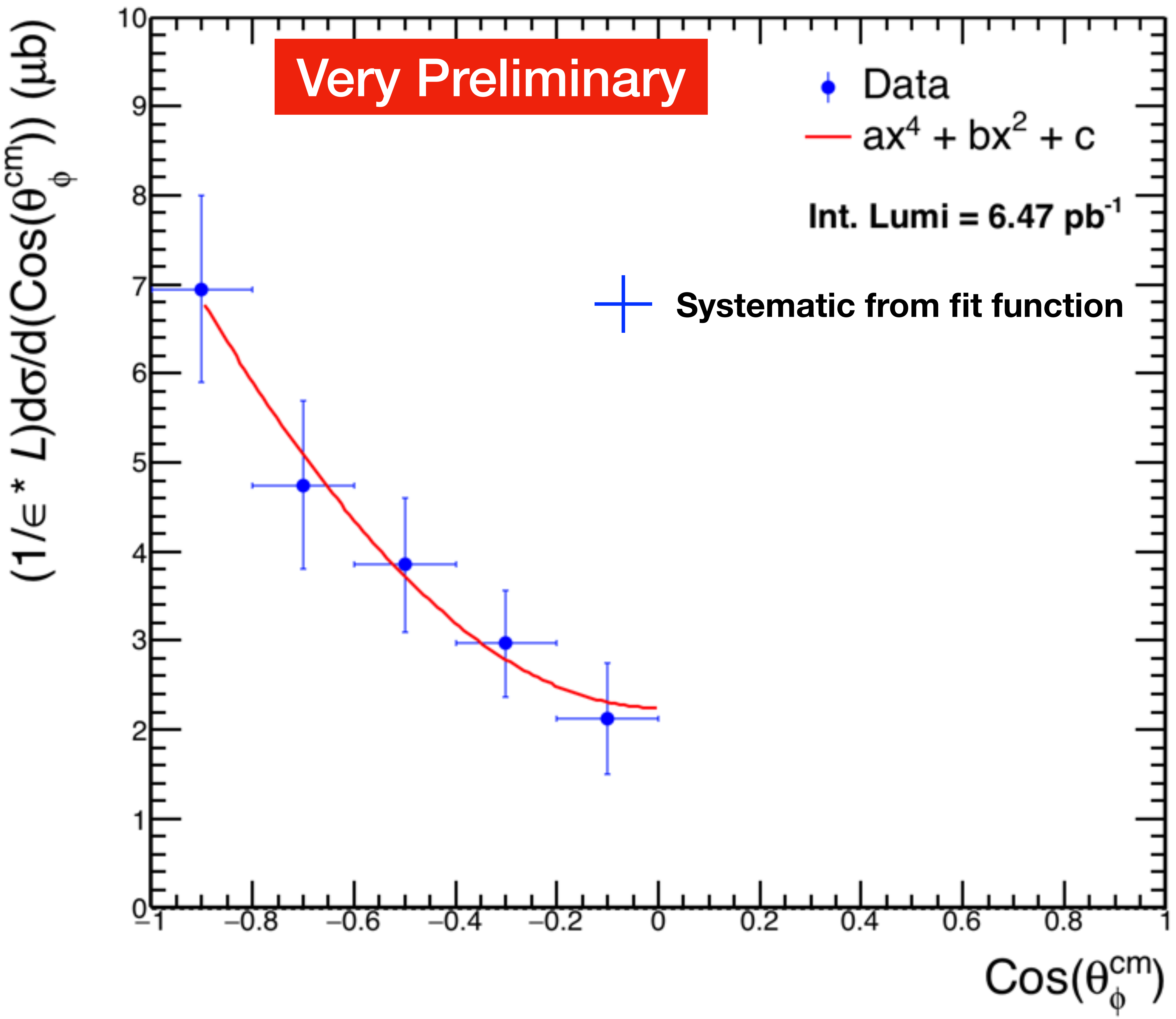
Efficiency is obtained for each cosθ bins using following

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

Number of reconstructed Φ are obtained by the method described in slide -58

Only negative part is used for correction further

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



Only negative part is considered

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

Next Step

- Large pionic background PID selection needs to be improved (add Inner TOF energy loss information, use Neural Network,…)

- Analysis of kaon angular distribution in reference frame

Outlook

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

- Complementary to HADES data for $\phi \longrightarrow e^+e^-$ measured simultaneously

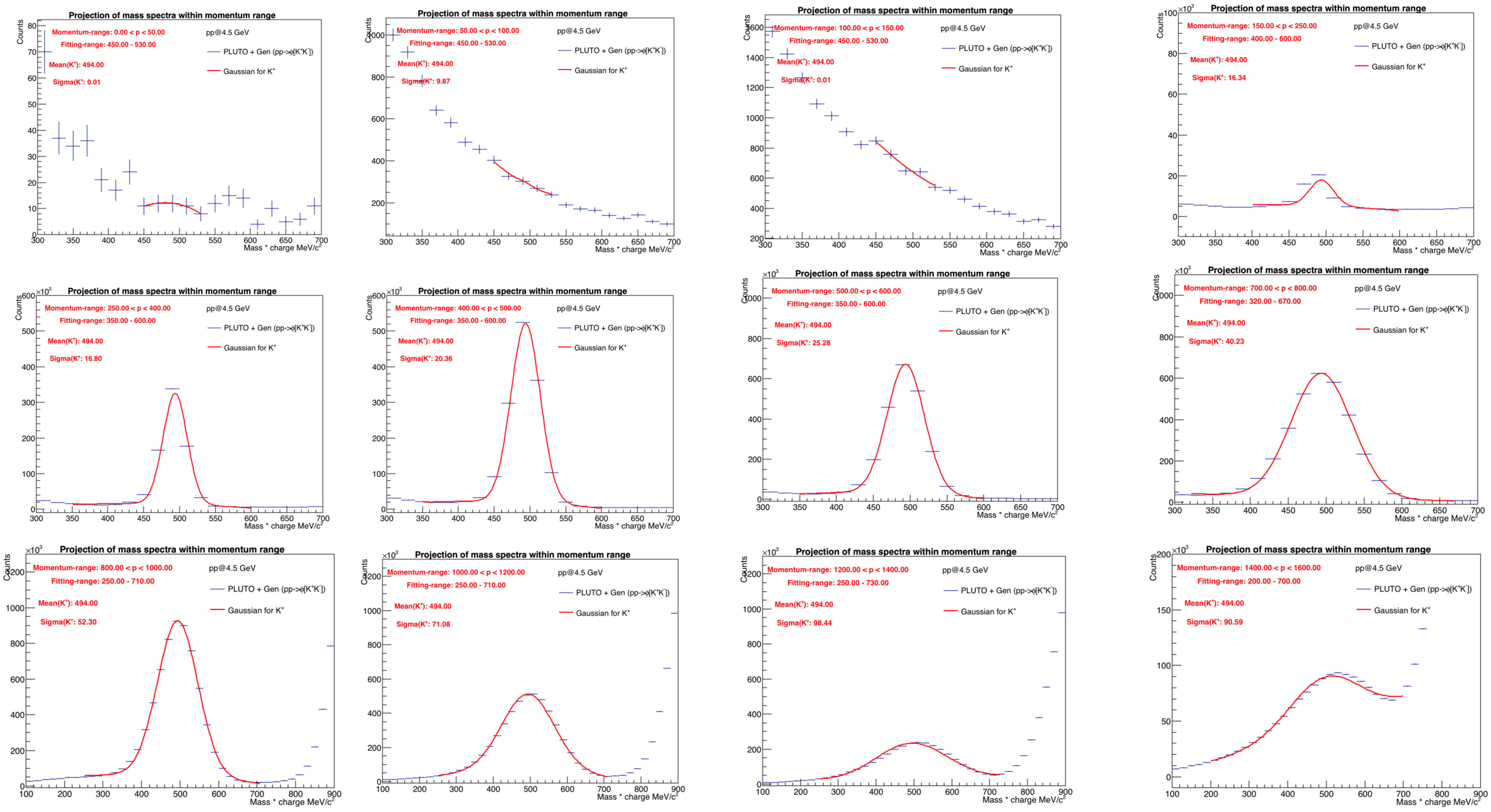
Thank you for your kind attention

backup

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

PLUTO+Geant

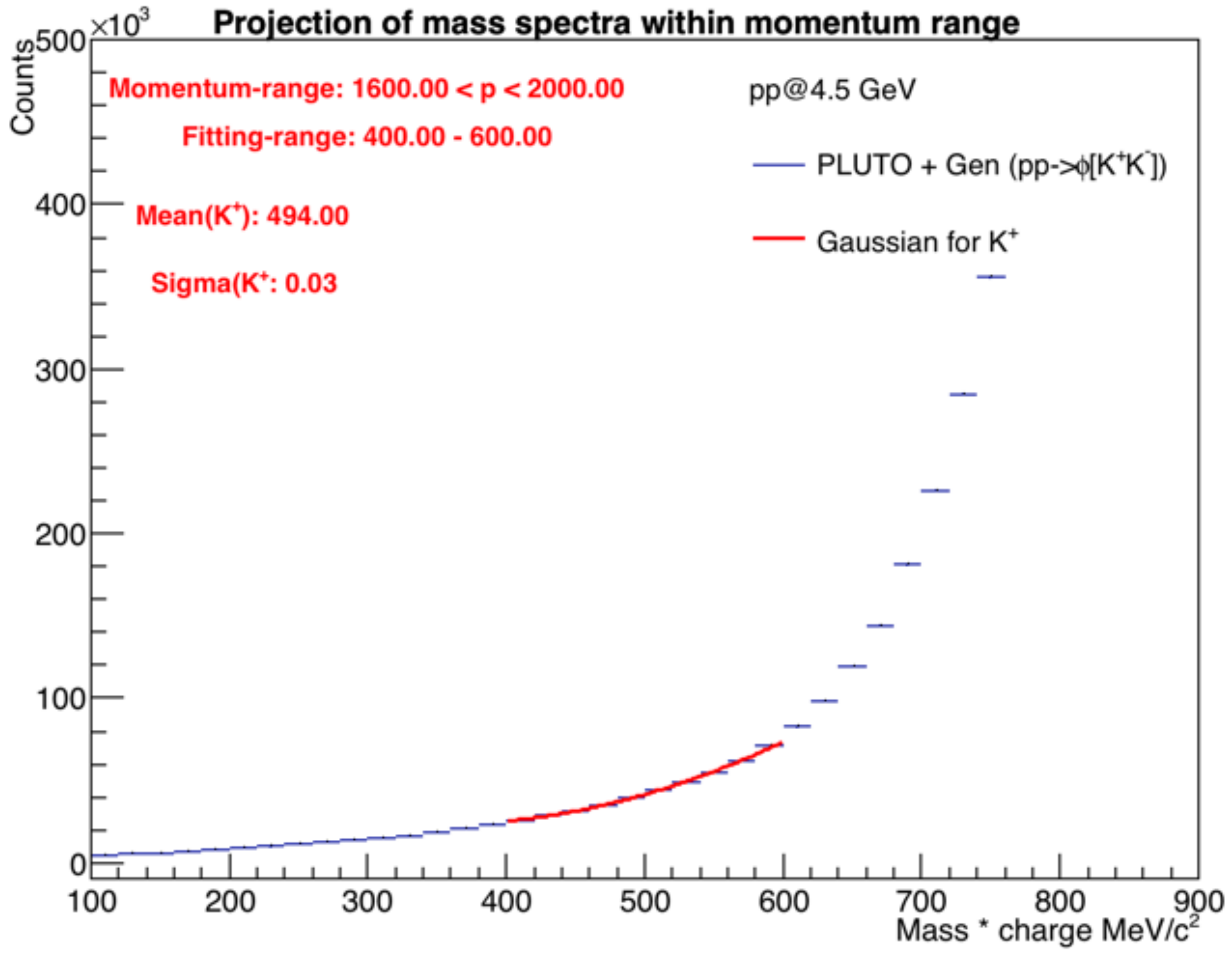
K^+

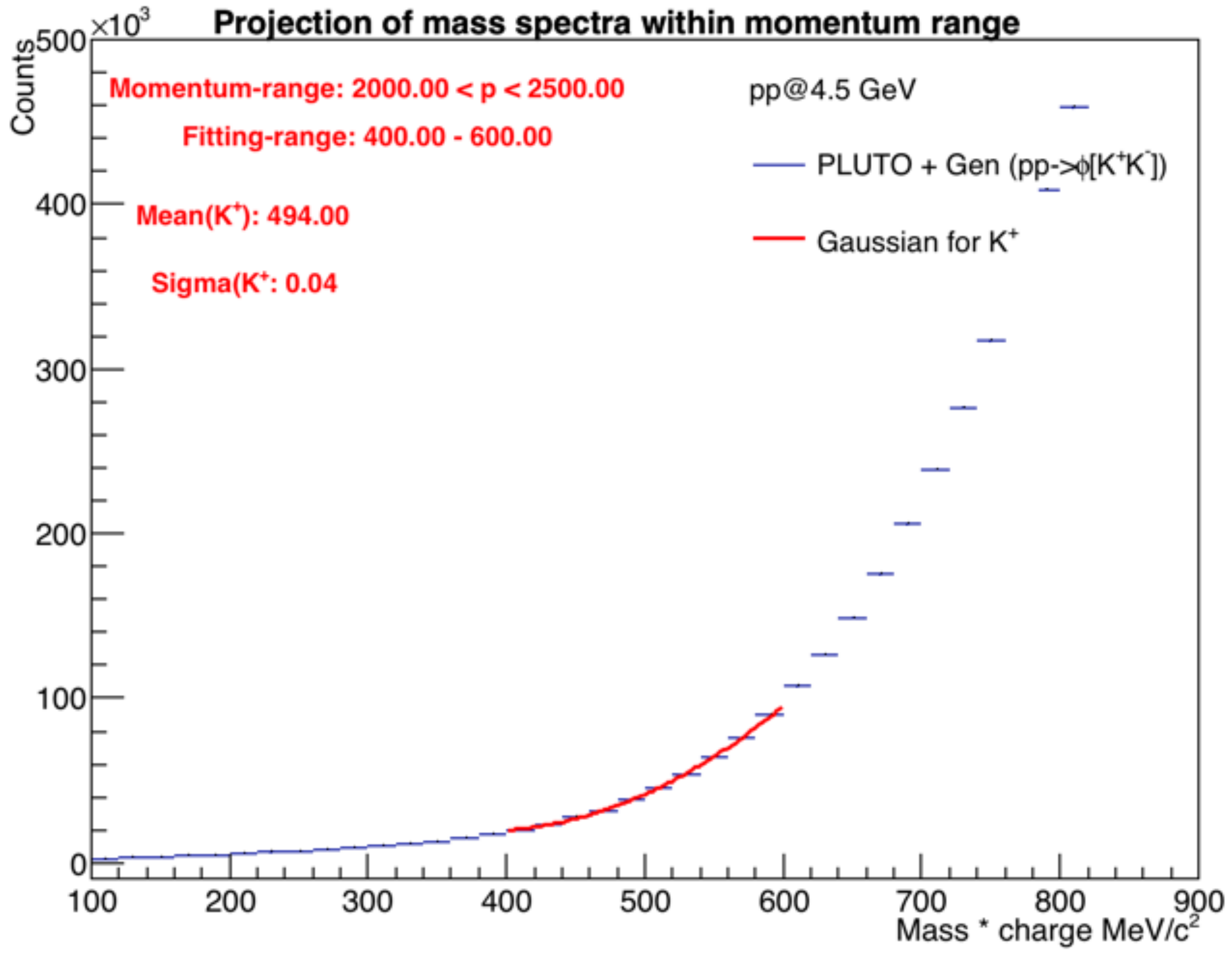


Particle identification: Step-2: Projection of Mass for diff. momentum range

PLUTO+Geant

K^+

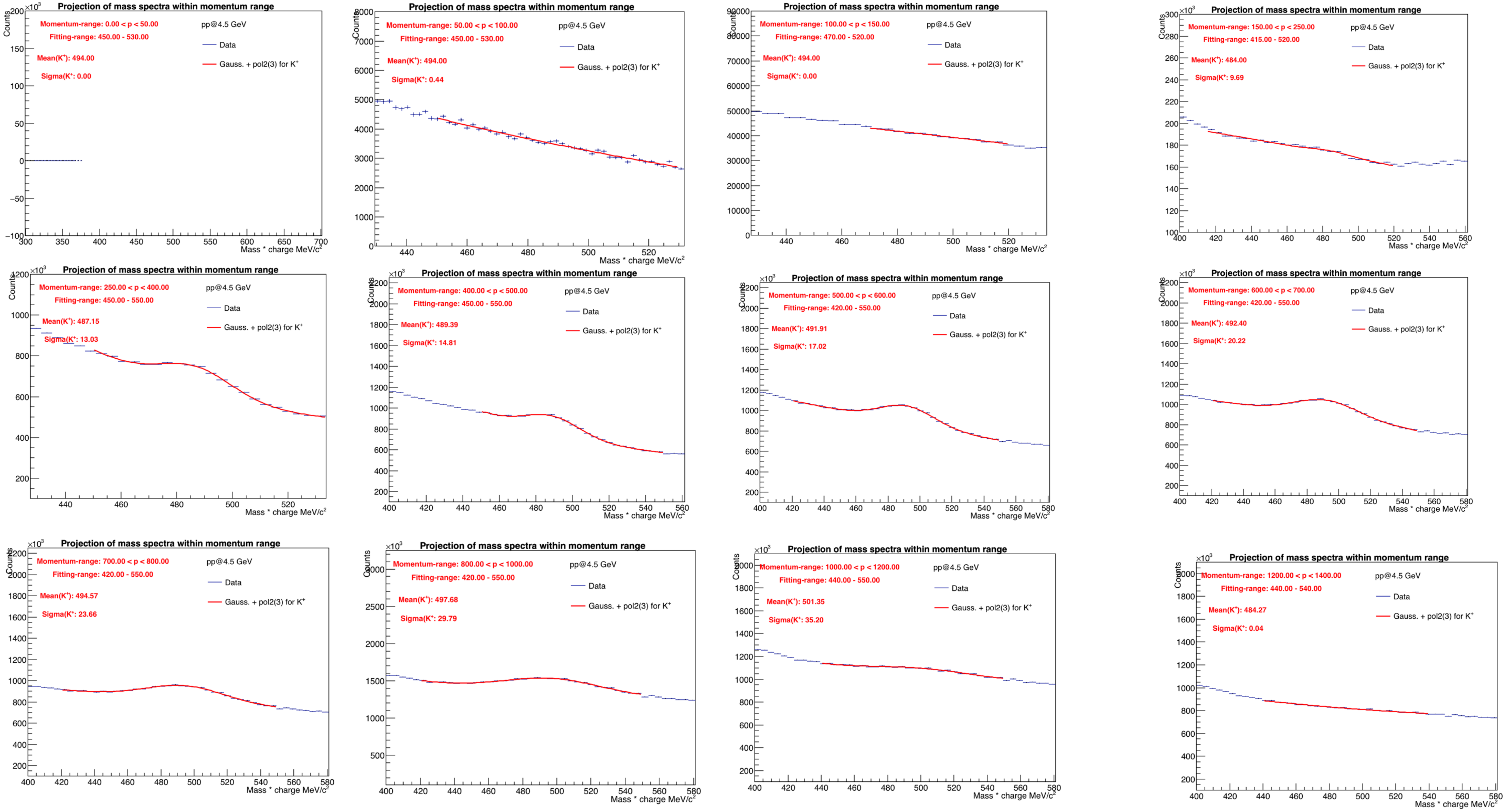




Particle identification: Step-2: Projection of Mass for diff. momentum range

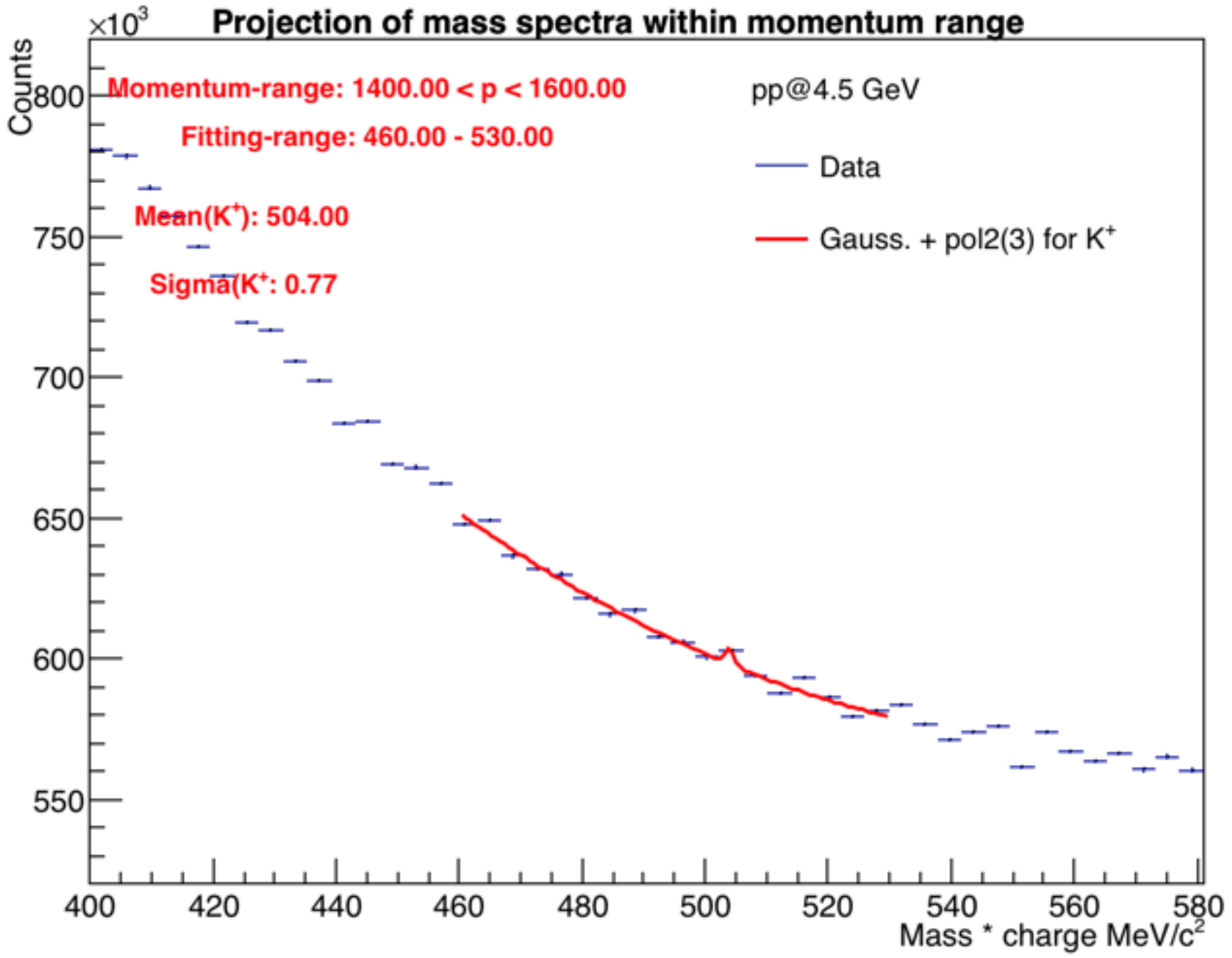
Data

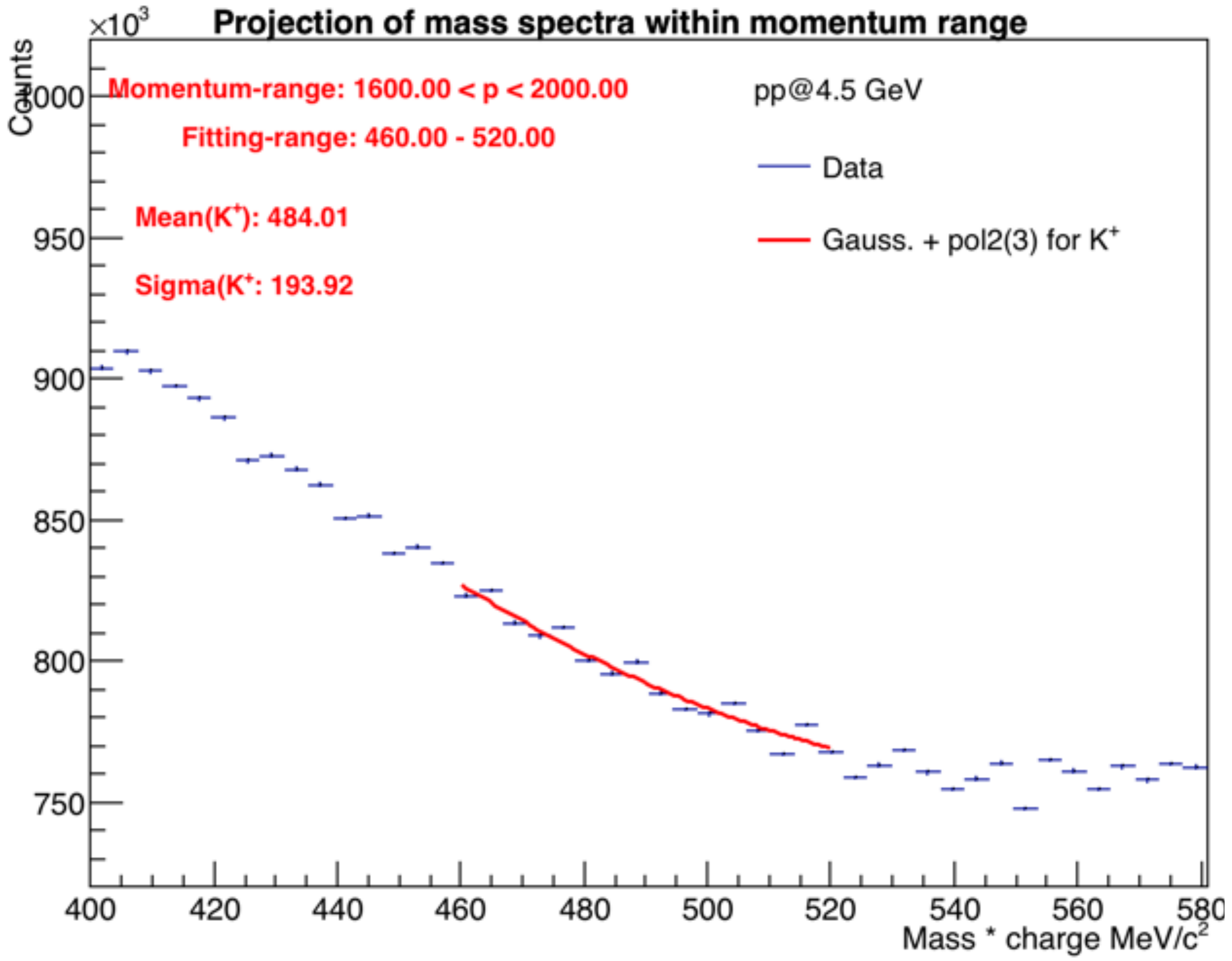
K^+

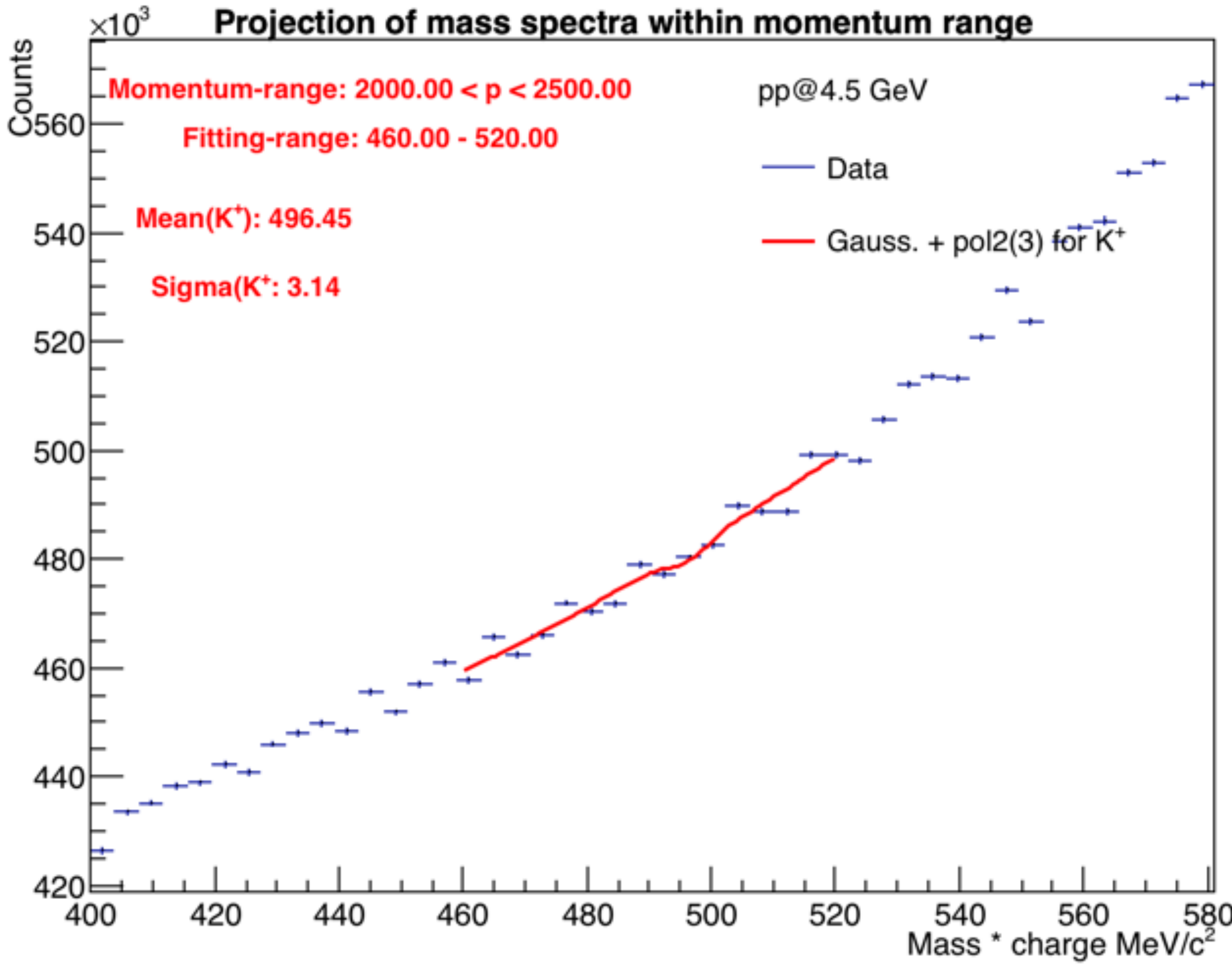


Particle identification: Step-2: Projection of Mass for diff. momentum range

K^+

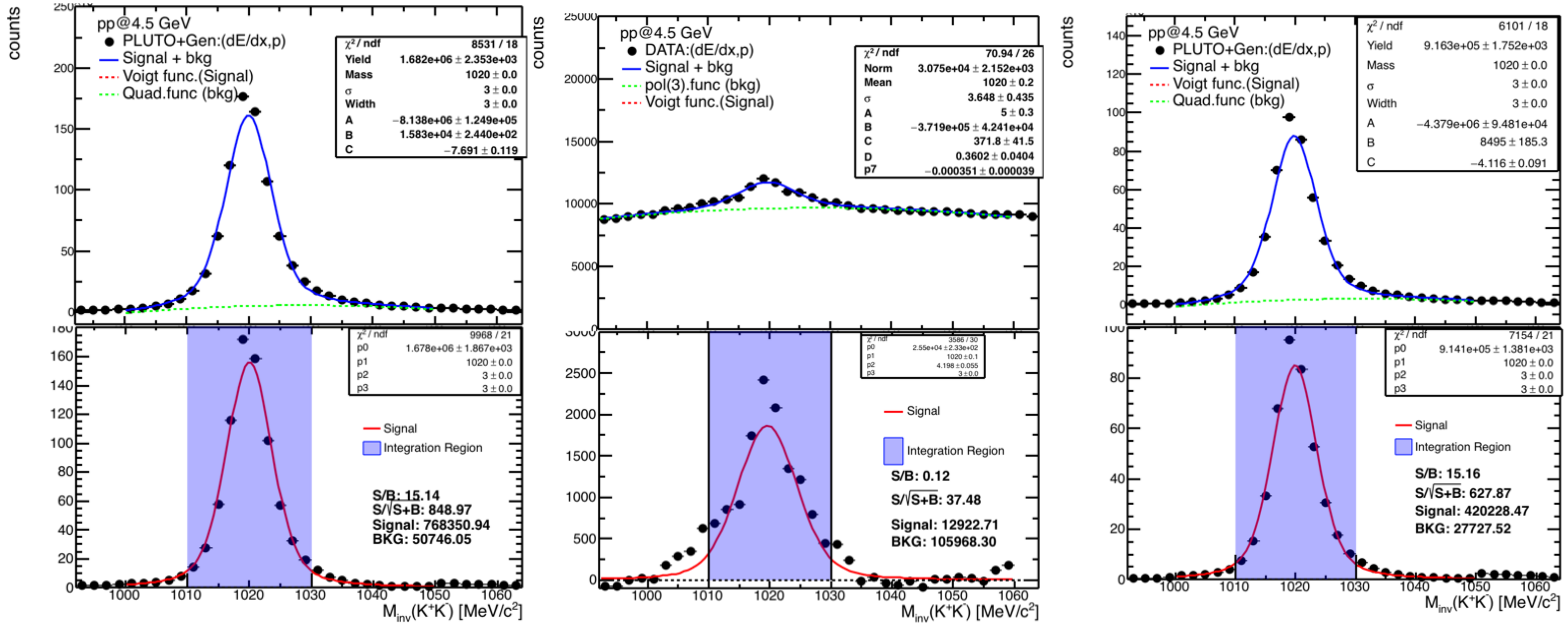






DATA

Invariant mass [K+K-] under different cosine range (dE/dx cut)



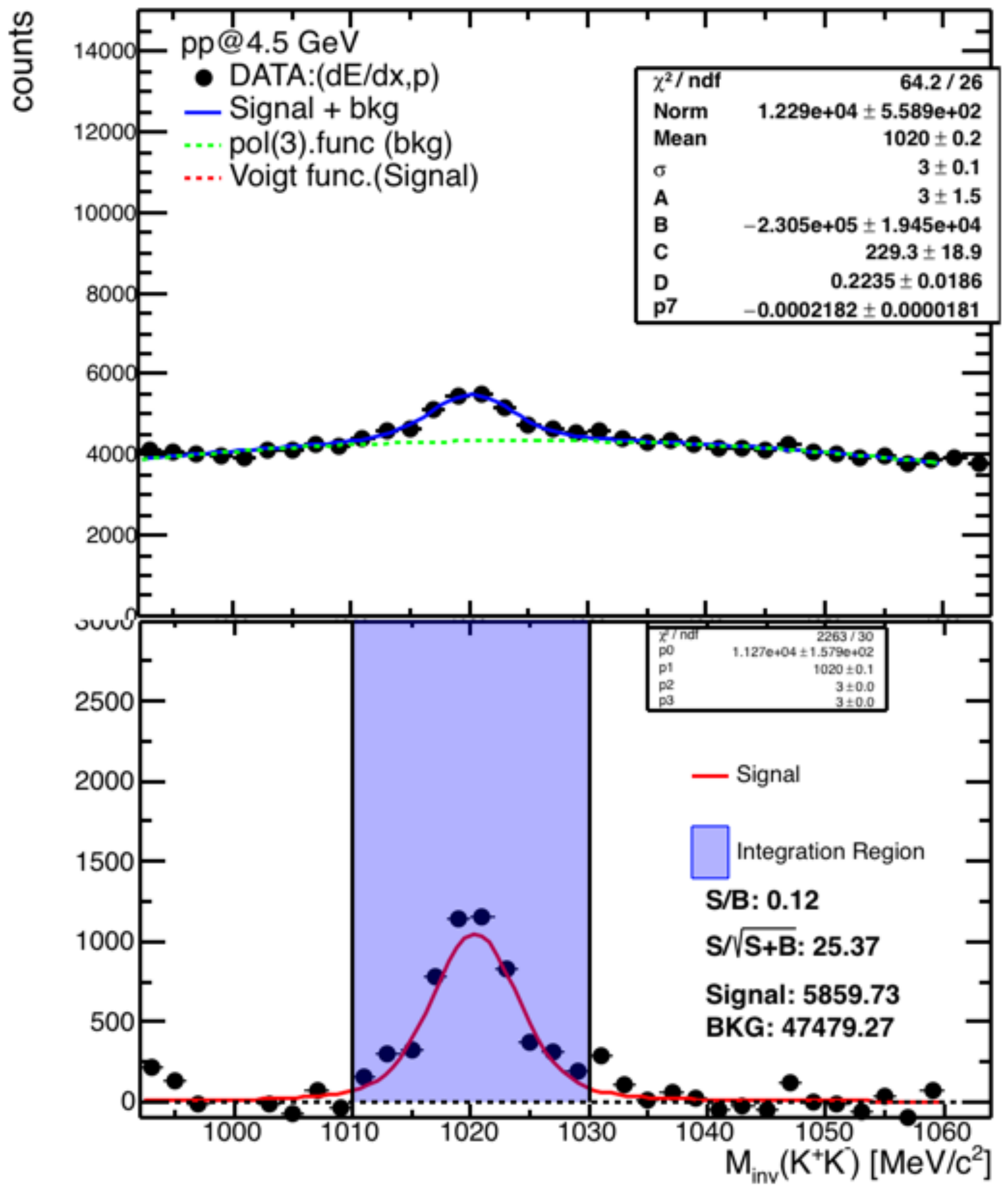
-1 < cos(θ) < -0.75

-0.75 < cos(θ) < -0.50

-0.50 < cos(θ) < -0.25

Invariant mass [K+K-] under different cosine range (dE/dx cut)

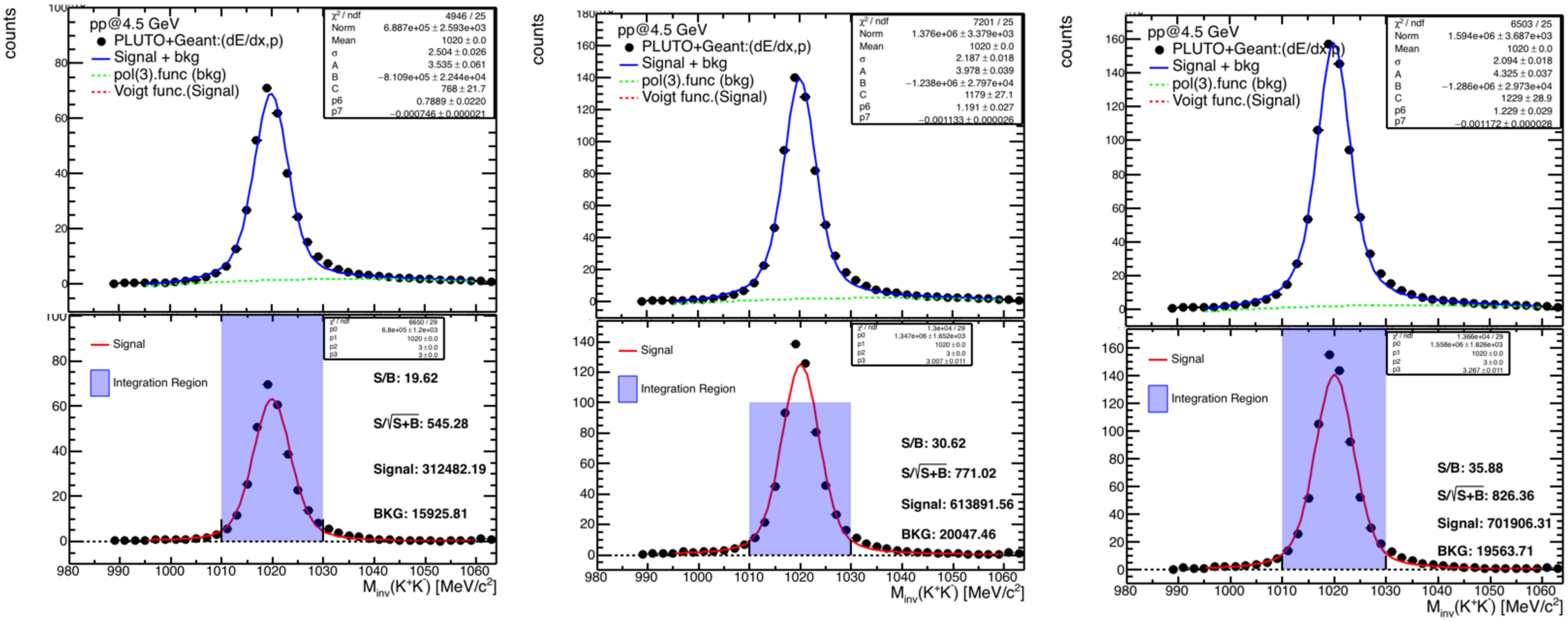
DATA



-0.25 < cos(θ) < 0

Invariant mass [K+K-] under different cosine range (dE/dx cut)

SImulation



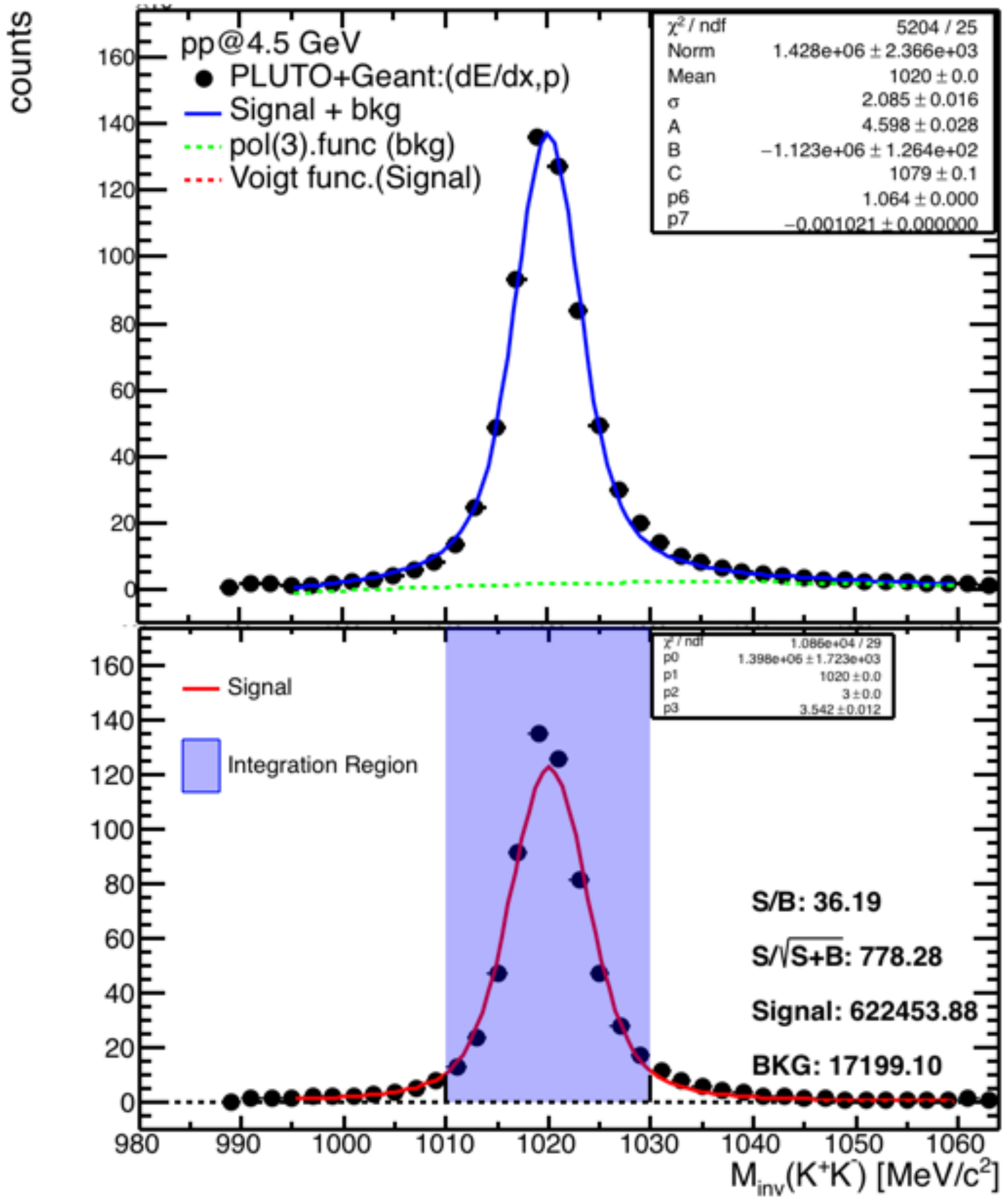
-1 < cos(θ) < -0.8

-0.8 < cos(θ) < -0.6

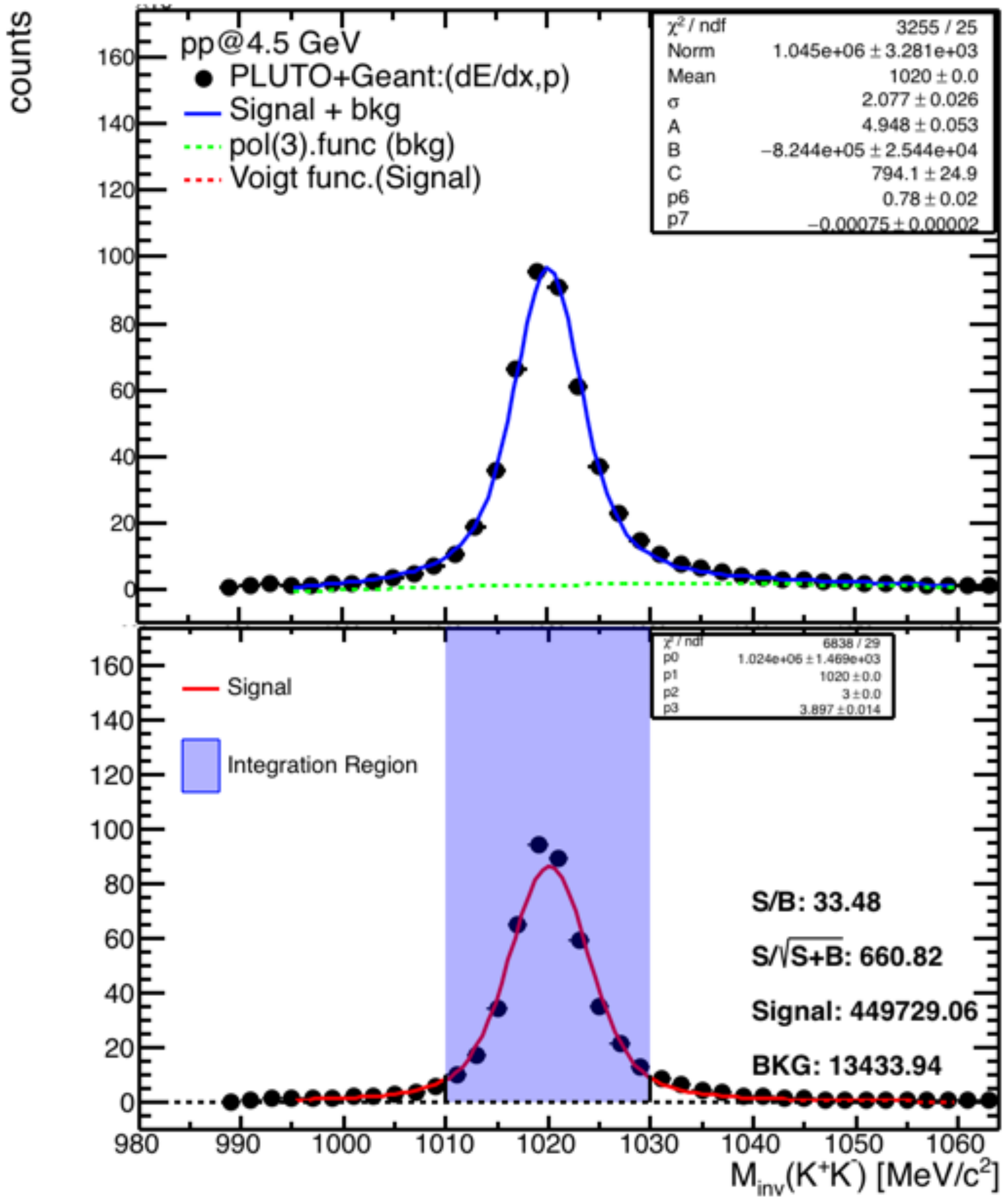
-0.6 < cos(θ) < -0.4

Invariant mass [K+K-] under different cosine range (dE/dx cut)

SIM

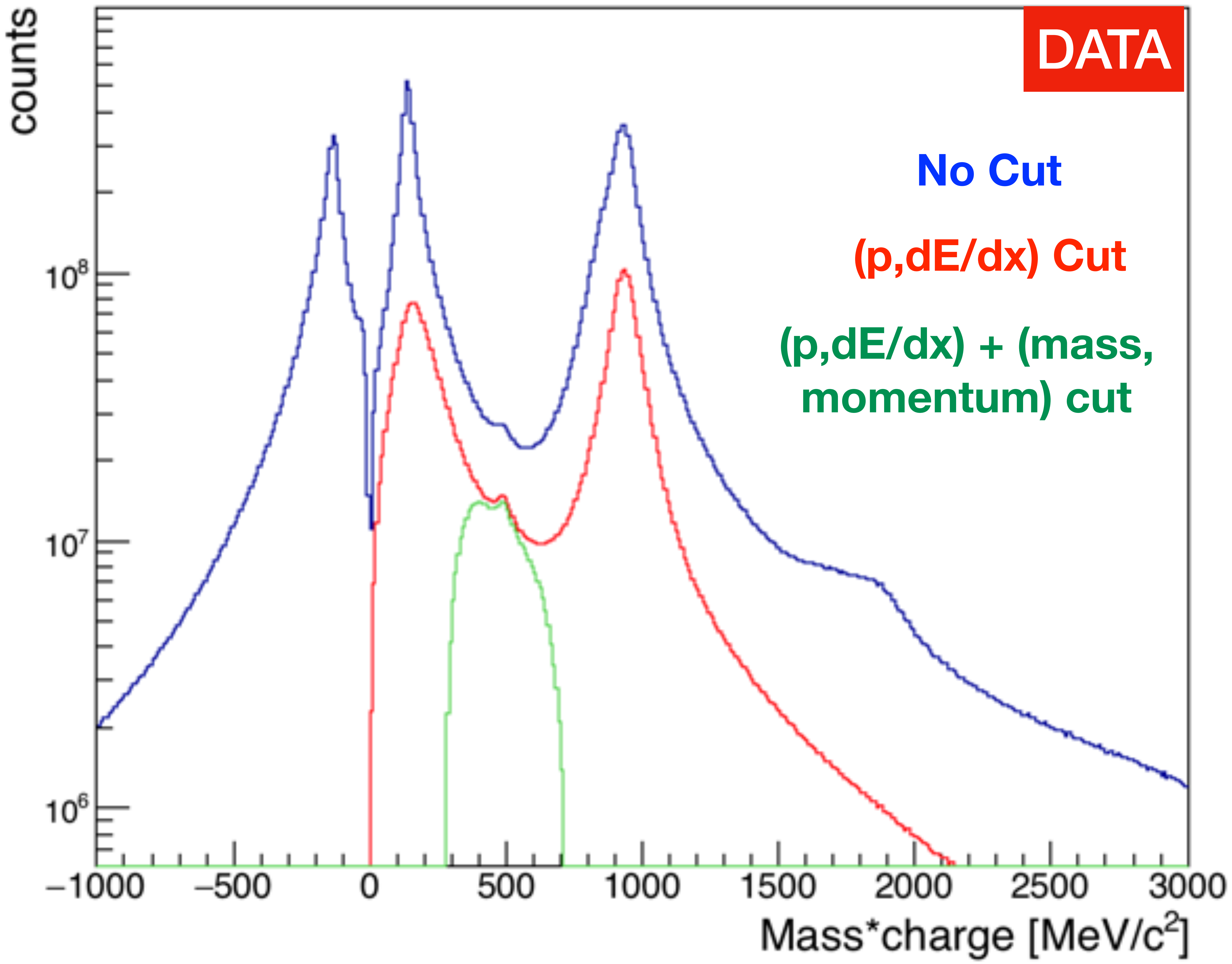


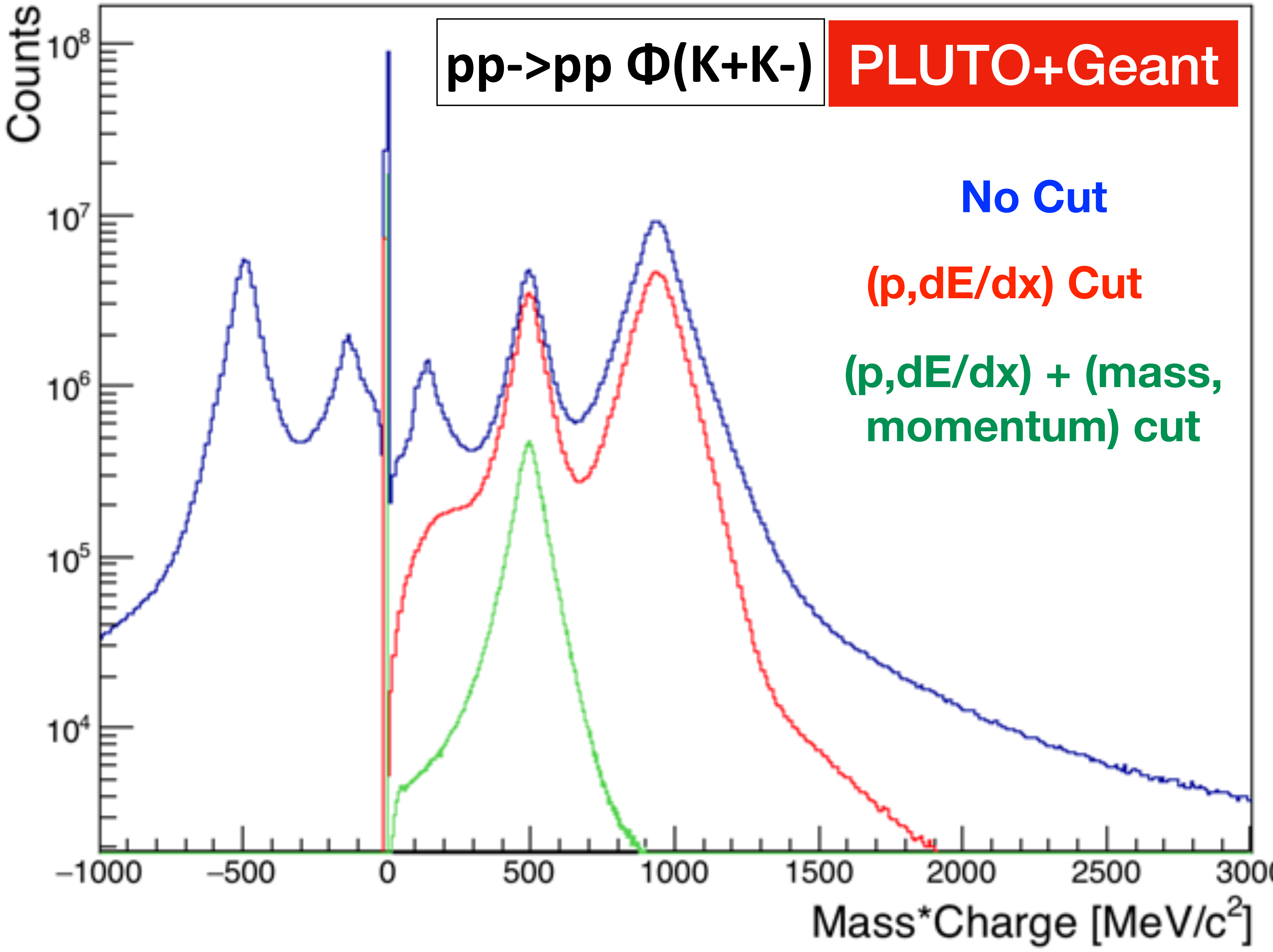
-0.4 < cos(θ) < -0.2



-0.2 < cos(θ) < 0

Affect of cuts on selection of K+: Data vs Simulation





- In simulation, with cuts, we have almost no primary pions, only a low yield of secondary pions
- Cuts remove approx. the same proportion of pions in sim and data, just you have many more pions in data.

z-vertex vs Missing mass