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Strangeness production in selected proton-induced processes at COSY-ANKE

Ph.D. Dissertation Defense

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JÜLICH
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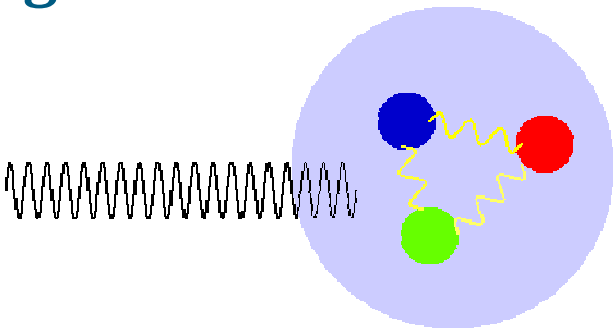
Outline

- Introduction & Motivation
- Experimental setup
- Data Analysis
- Results and Discussions
- Summary & Outlook

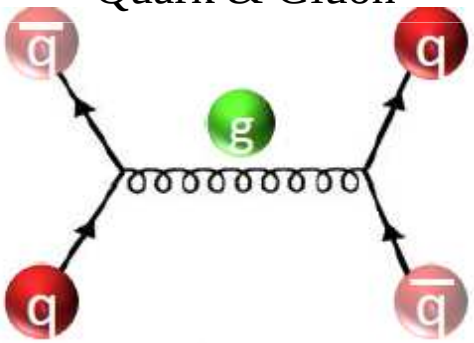
Introduction

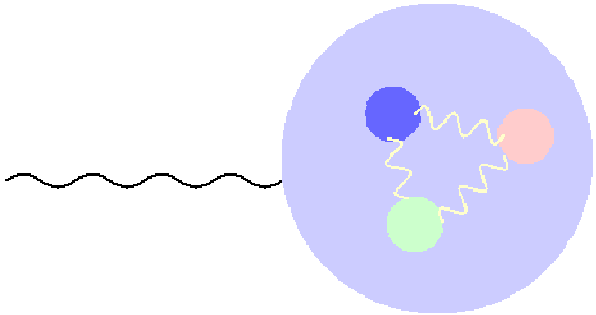
Strong interaction



$\lambda << R$

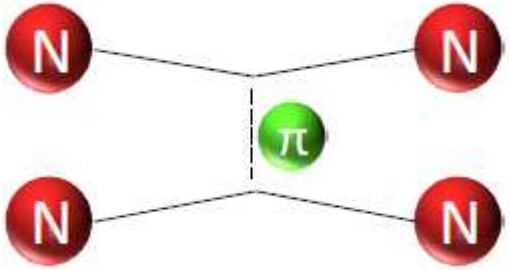
Quark & Gluon





$\lambda >> R$

Hadrons



- Interactions between quarks and gluons
- Perturbactive QCD calculation well tested at high energy.

- Interactions between hadrons
- Low energy interactions do not care about the details of high energy interactions

Hadrons：Meson and Baryon

- Only two configurations of combining quarks were found:

Quark model:

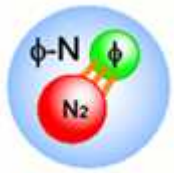
Example:

$\omega(782)$ $u\bar{u}+d\bar{d}$	Proton uud
$\phi(1020)$ $s\bar{s}$	$\Lambda(1116)$ uds

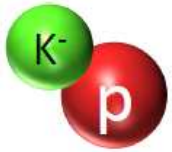
- However, QCD does not eliminate the existence of hadrons beyond simple ($q\bar{q}$) or (qqq) as a color-singlet system.

Molecule State: Bound state of more than 2 hadrons.

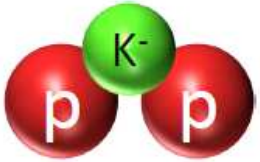
Do they exist?



ϕ-N Bound State



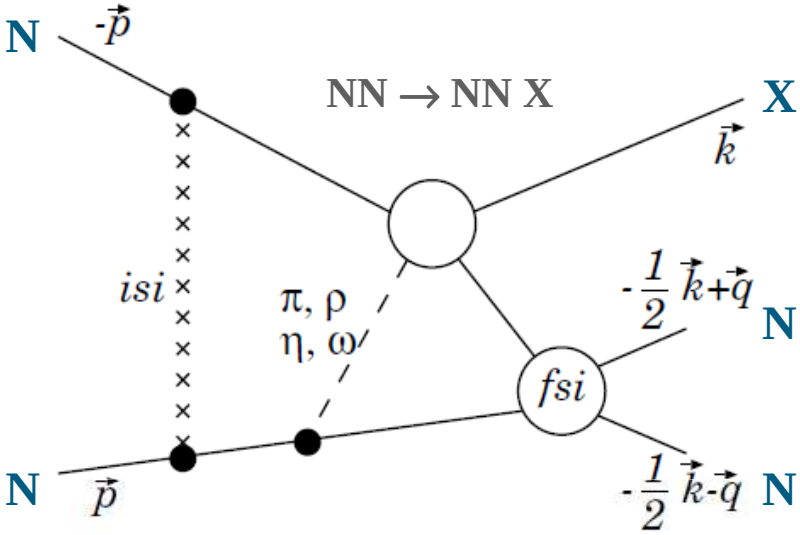
K-p Bound State



K-pp Bound State

KK molecule

Meson Production in NN collisions

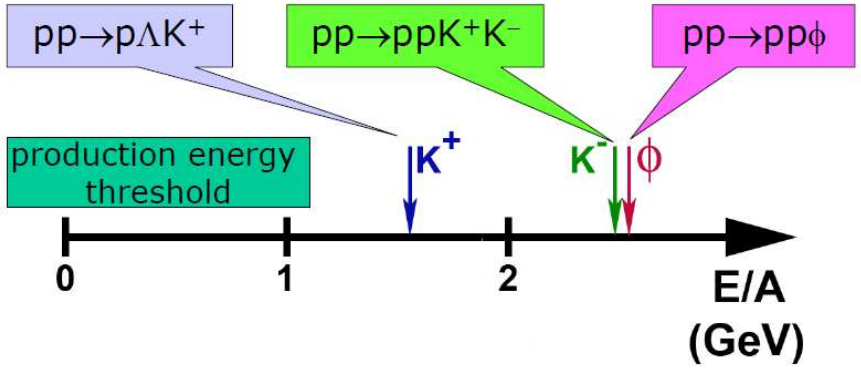


One boson exchange (OBE) model

- Final state interactions:

  meson-meson, baryon-meson interactions
- Understand production mechanisms
- Study the properties of the nucleon resonances.
- Internal strangeness inside nucleon

Selected reaction channels



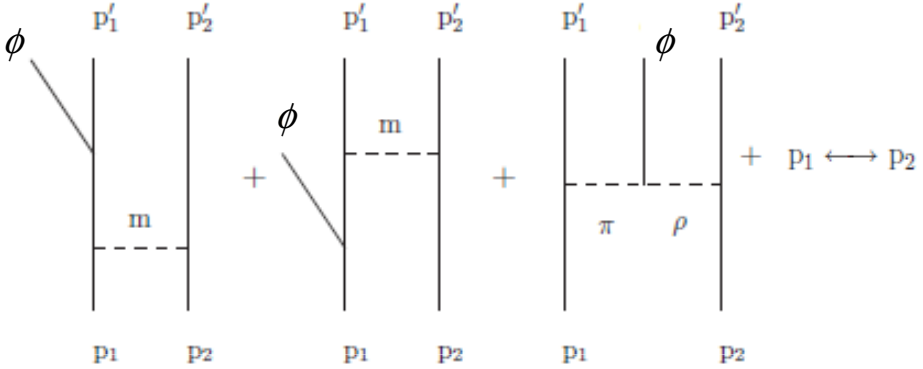
Production Thresholds:

pp →	$pK^+\Lambda$	T_p = 1.58 GeV
pp →	ppK^+K^-	T_p = 2.50 GeV
pp →	ppφ	T_p = 2.59 GeV

Physics Motivation

Motivation: ϕ meson production mechanism

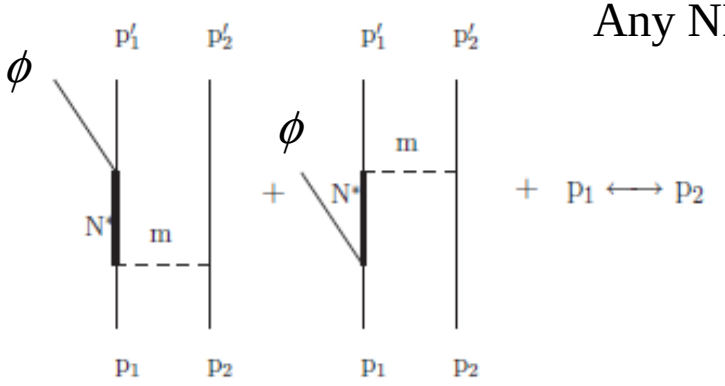
$pp \rightarrow pp\phi$



nuclenoic current *mesonic current*

- Mesonic current contribution results in an isotropic distribution in $\cos\Theta^{\phi}_{c.m.}$
- Nuclenoic current gives a $\cos^2\Theta^{\phi}_{c.m.}$ distribution.
- The angular distribution of ϕ meson is crucial in extracting the NNϕ coupling constant.

Any NNϕ coupling constant > the OZI rule prediction



N^* resonance candidate: $N^*(2090)1/2^-$

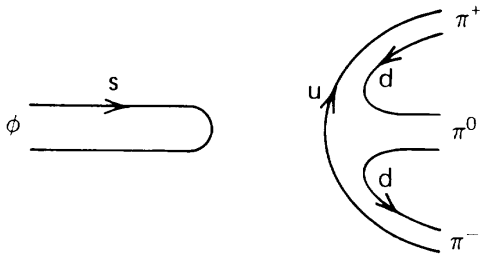
➡ **hidden strangeness** in the nucleon.

- Most of theoretical calculations predict only the total cross sections with respect to the energy.

Phys.Rev.C70:035211,2004

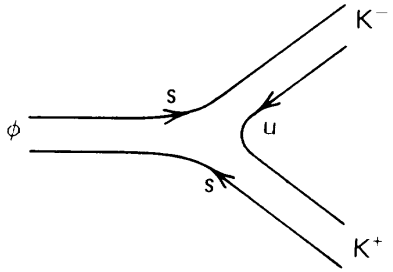
Motivation: the OZI rule

OZI suppressed



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

OZI allowed



$\phi \rightarrow K^+K^-$

The gluons are not drawn in these diagrams.

• The Okubo-Zweig-Iizuka (OZI) rule states that processes with disconnected quark lines are suppressed. Assume that such processes proceed via a multi-gluon intermediate state.

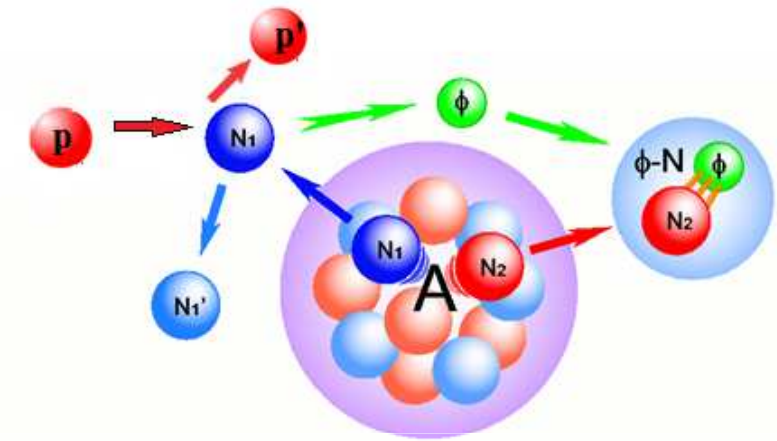
• Production of φ should be suppressed w. r. t. ω production according to
$\sigma(AB \rightarrow \phi X)/ \sigma(AB \rightarrow \omega X) = \tan^2 \delta_V = 4.2 \cdot 10^{-3}$

where A, B and X are non-strange hadrons.

•The OZI rule is generally well fulfilled, but apparent violations have been observed.
- proton-antiproton annihilations at rest
- NN collisions
- π proton induced reactions

• Apparent violations are usually interpreted as:
- Features of the meson-nucleon interaction
- **A strangeness component in the nucleon**
- a ϕN bound state or exotic baryon $B_\phi(uddss\bar{s})$

Motivation: ϕ-N Bound State in Heavy Nuclei



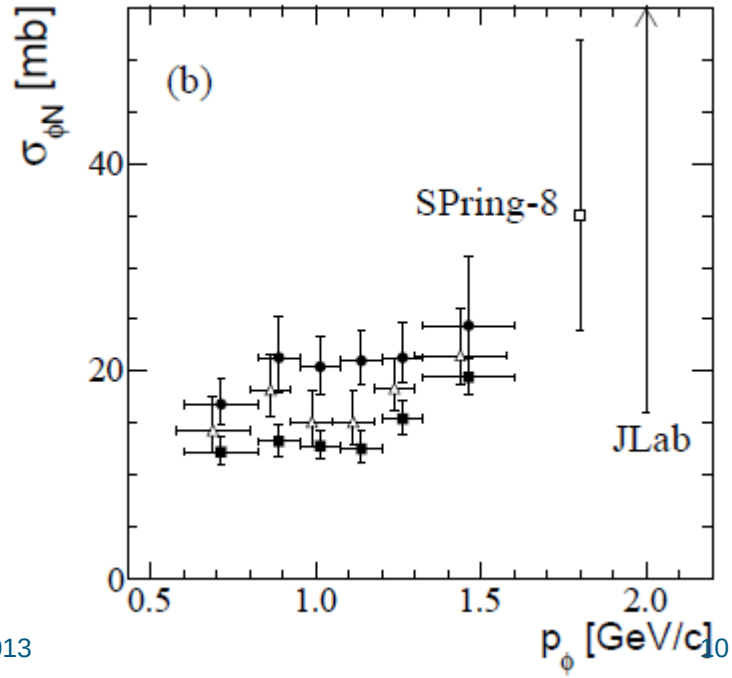
$$p + N_1 \rightarrow p' + N_1' + \phi$$
$$\phi + N_2 \rightarrow (\phi N_2)$$

➢"Sub-threshold" generated ϕ is slow enough to bound with nucleon.
➢ Near-threshold ϕ is ***possible*** to form a bound state?

➢Due to the OZI rule, multi-gluon exchanges are expected to be dominant in ϕ-N reaction.

➢QCD Van der Waals interaction mediated by multi-gluon exchanges may be strong enough to form a ϕN bound state.

An upper limit of $\sigma_{\phi N} \approx 11$mb



Sizable excesses have been observed in the numbers of φ mesons produced with momenta below 1 GeV/c.

Motivation: Kaon pair production mechanism

The original motivation was to understand the scalar mesons $a_0/f_0(980)$ as K^+K^- molecules:

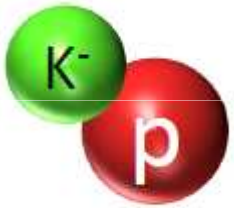
$$pp \rightarrow pp\, a_0 / f_0 \rightarrow ppK^+ K^-$$

K^+K^- molecule

It suggested that $\Lambda(1405)$ production is dominated:

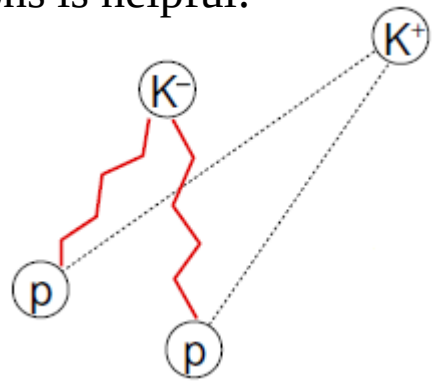
$$pp \rightarrow pK^+\Lambda(1405) \rightarrow ppK^+K^-$$

nature of Λ(1405) – K⁻p bound state?



Investigation of final state interactions is helpful:

$a_0/f_0(980)$ ~ KK fsi
$\Lambda(1405)$ ~ K^-p fsi



M(N + K) ~ 1435 MeV

- Significant discrepancy between experimental data and pure phase space calculations.
- Inclusion of the final state interactions in K^-p, pp and KK subsystems

Motivation: Kaon-antikaon final state interaction

- Elastic K^+K^- final state interaction:

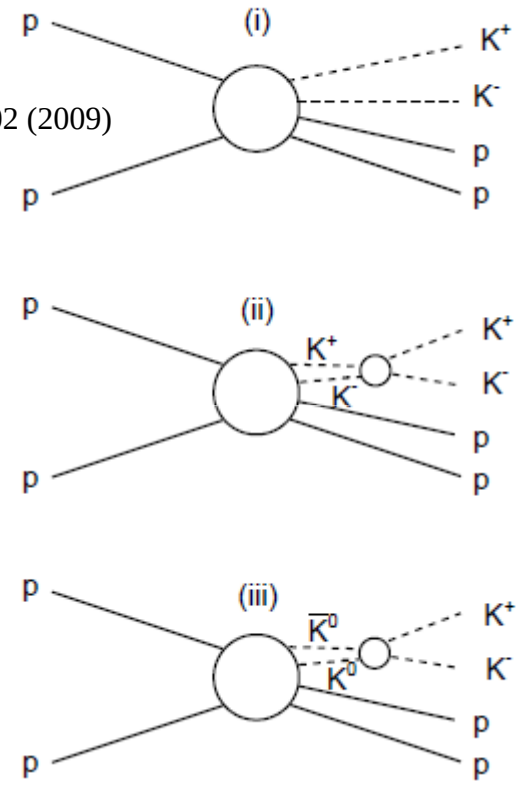
$$f_{K^+K^-}(q) = \frac{1}{1 - i\alpha_{K^+K^-} q}$$

M. Silarski *et al.*, Phys. Rev. C 80, 045202 (2009)

$$|\mathrm{Re}(\alpha_{K^+K^-})| = 0.5^{+4}_{-0.5}\ \mathrm{fm}$$

$$|\mathrm{Im}(\alpha_{K^+K^-})| = 3 \pm 3\ \mathrm{fm}$$

Based on COSY-11 results:
ε = 10 MeV,17 MeV and 28 MeV



- Coupled channel effects $K^0\bar{K}^0 \rightleftharpoons K^+K^-$

$$f_{KK}(q) = \frac{B_1/(B_0+B_1)}{(1 - i\frac{1}{2}q[A_1 - A_0])(1 - iqA_1)} + \frac{B_0/(B_1+B_0)}{(1 - i\frac{1}{2}q[A_0 - A_1])(1 - iqA_0)}$$

charge exchange scattering — elastic scattering

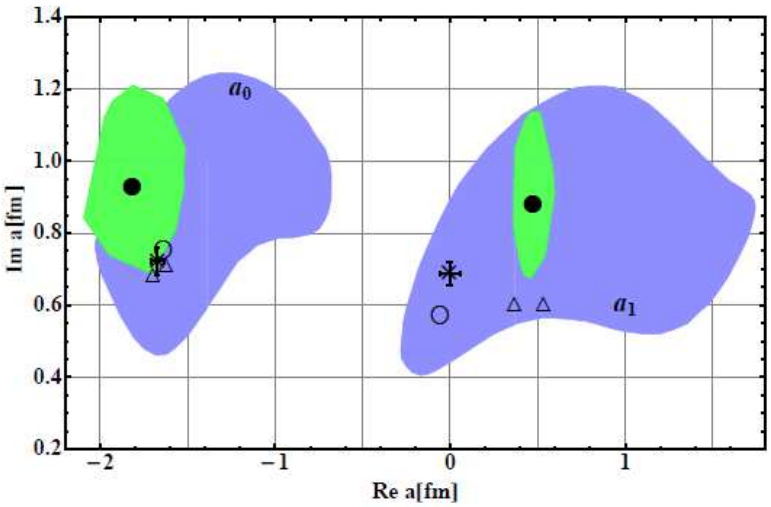
$$A_0 = (-0.45 \pm 0.2) + i(1.63 \pm 0.2),\ A_1 = (0.1 \pm 0.1) + i(0.7 \pm 0.1)$$

B_0/B_1: amplitude for $pp \rightarrow ppK\bar{K}$ in isopin-0 and 1.

A. Dzyuba et al., PLB 668, 315-318 (2008).

Motivation: Kaon-nucleon final state interaction

- $K^- p \to K^- p$: fundamental scattering process with strange quarks.
- Kaonic hydrogen + scattering data give inconsistent $a_{K\text{-}p}$ scattering lengths
- Our measurements can provide an independent contribution to this important issue



A combined analysis of antikaon-nucleon scattering cross sections gives:

$$a_{K^- p} = -0.68^{+0.18}_{-0.17} + i0.90^{+0.13}_{-0.13}\,\text{fm}$$

and the SIDDHARTA kaonic hydrogen data:

$$a_{K^- p} = (-0.65 \pm 0.15) + i(0.81 \pm 0.18)\text{fm}$$

While the DEAR kaonic hydrogen data:

$$a_{K^- p} = (-0.468 \pm 0.09) + i(0.302 + 0.140)\text{fm}$$

$$a_0 = -1.81^{+0.30}_{-0.28} + i0.92^{+0.29}_{-0.23}\,\text{fm}$$

$$a_1 = +0.48^{+0.12}_{-0.11} + i0.87^{+0.26}_{-0.20}\,\text{fm}$$

Experimental Setup

- COSY accelerator
- ANKE spectrometer
- Target systems

Forschungszentrum Jülich

COSY storage ring

COSY (COoler SYnchrotron) at Jülich, Germany

- Hadronic probes: protons, deuterons
- Polarization beam and targets
- Kinetic energy range :

  Proton: 0.045 – 2.83 GeV

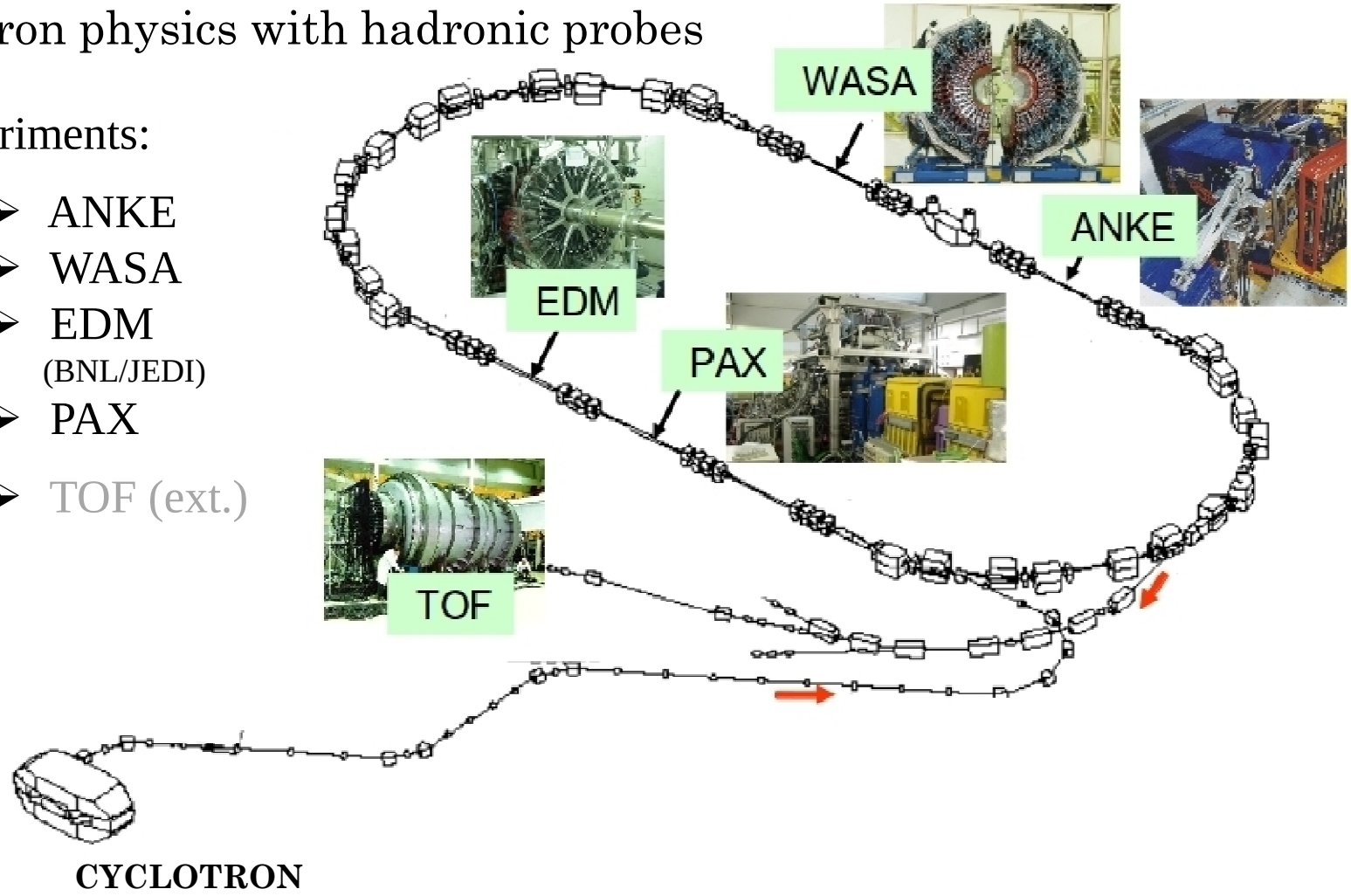
  Deuteron: 0.023 – 2.3 GeV
- Max. momentum ~ 3.65 GeV/c
- Momentum resolution $\Delta p/p \leq 10^{-4}$
- Electron and Stochastic cooling
- Internal and external experiments

COSY - experimental facilities

Hadron physics with hadronic probes

Experiments:

- ANKE
- WASA
- EDM
  (BNL/JEDI)
- PAX
- TOF (ext.)



Apparatus for Studies of Nucleon and Kaon Ejectiles

Magnets

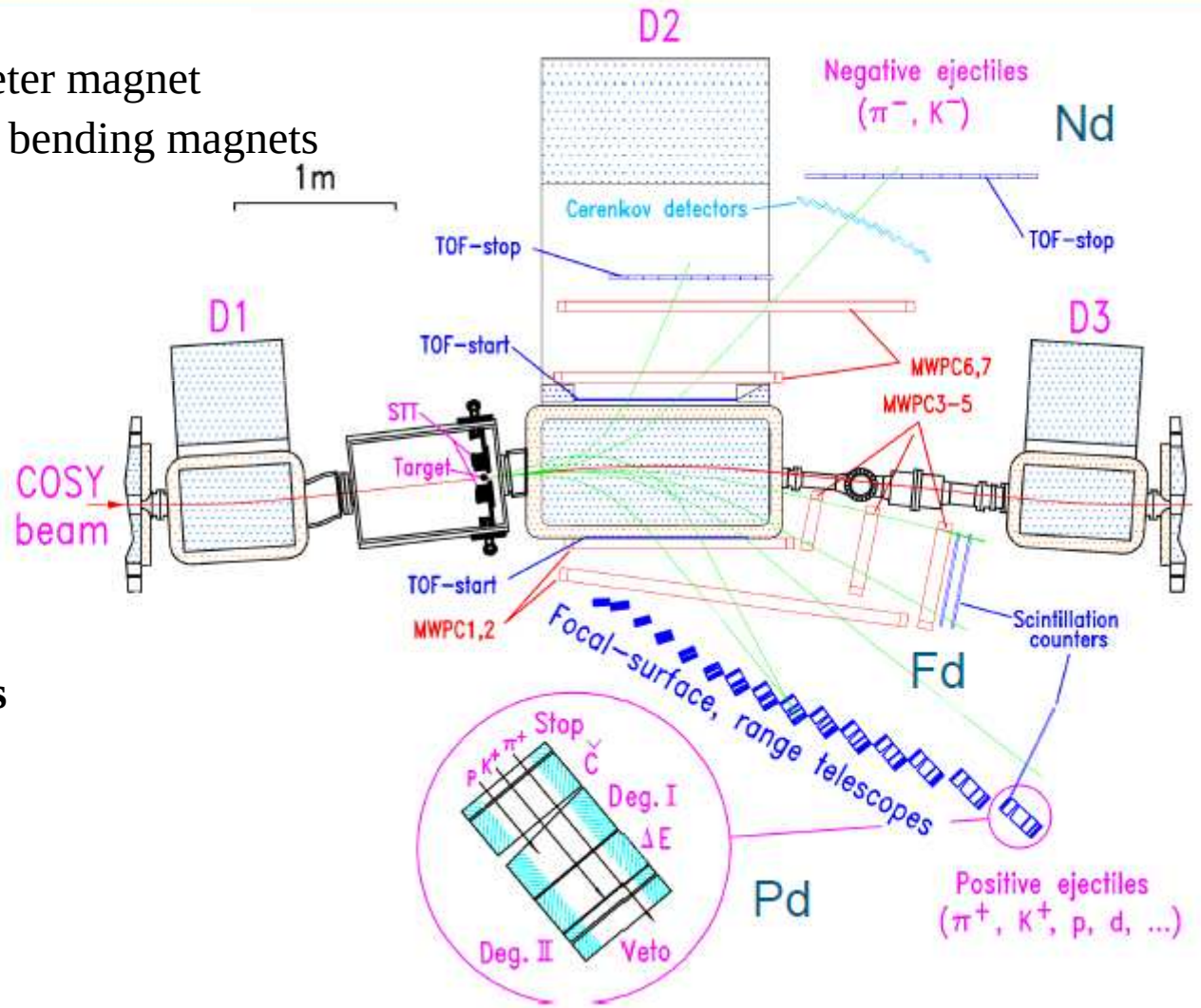
- D2 – spectrometer magnet
- D1, D3 – beam bending magnets

Targets

- Solid strips
- Cluster jet

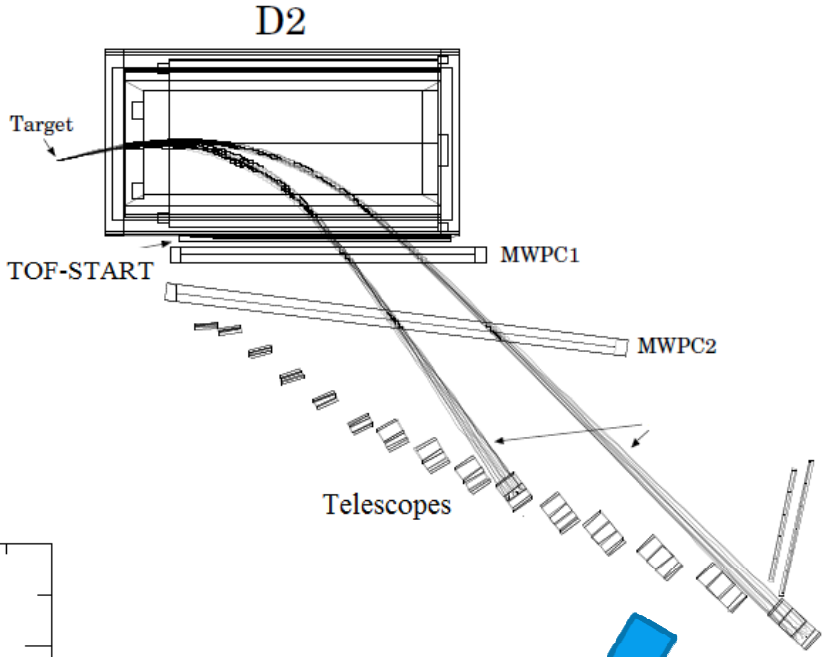
Detector systems

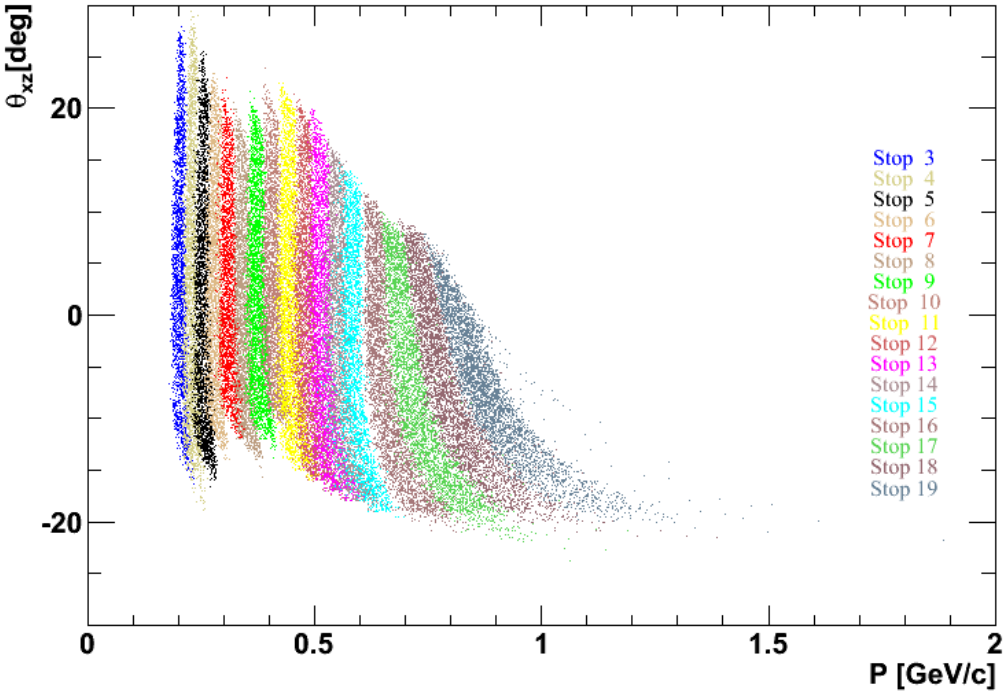
- Positive - Pd
- Negative - Nd
- Forward - Fd

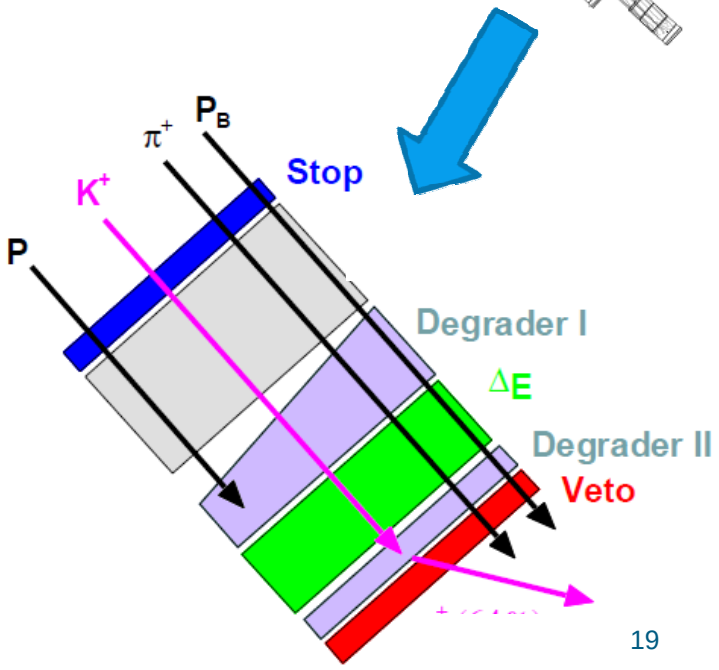


Positive Detection system

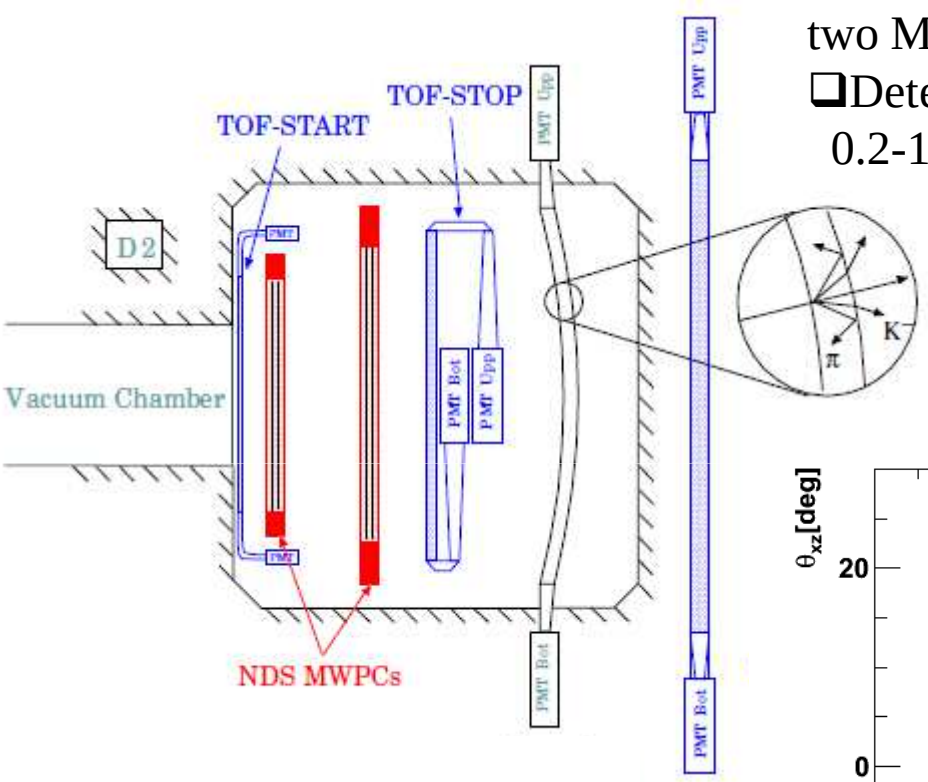
- Consists of 23 START and 21 STOP counters (15 telescopes) and two MWPCs.
- Detected positive particles momentum range: 0.2-1.3 GeV/c.
- Momentum resolution: 2~3%.



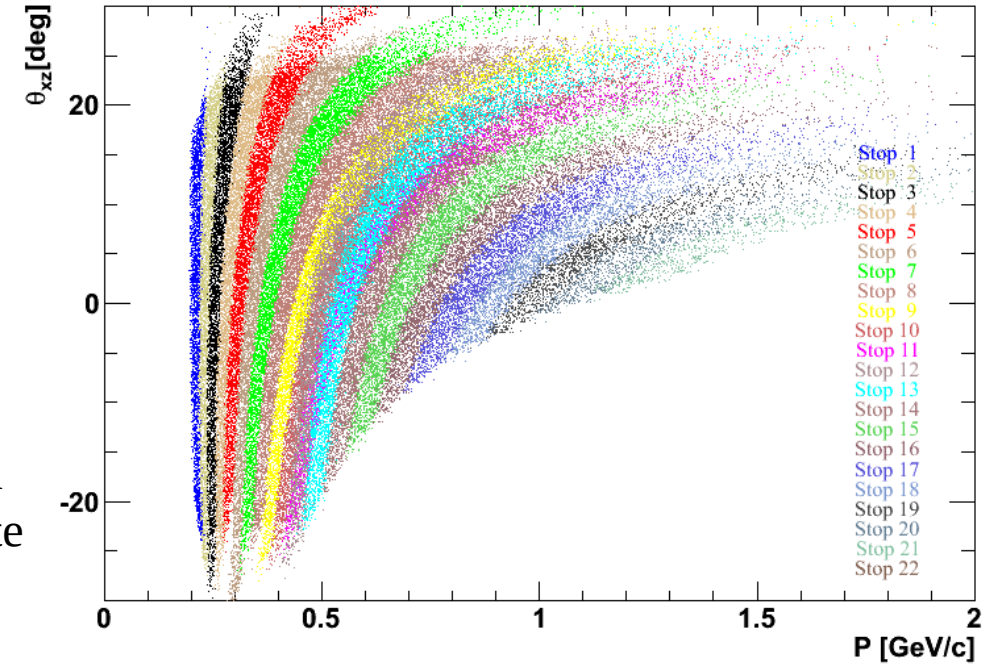




Negative Detection system

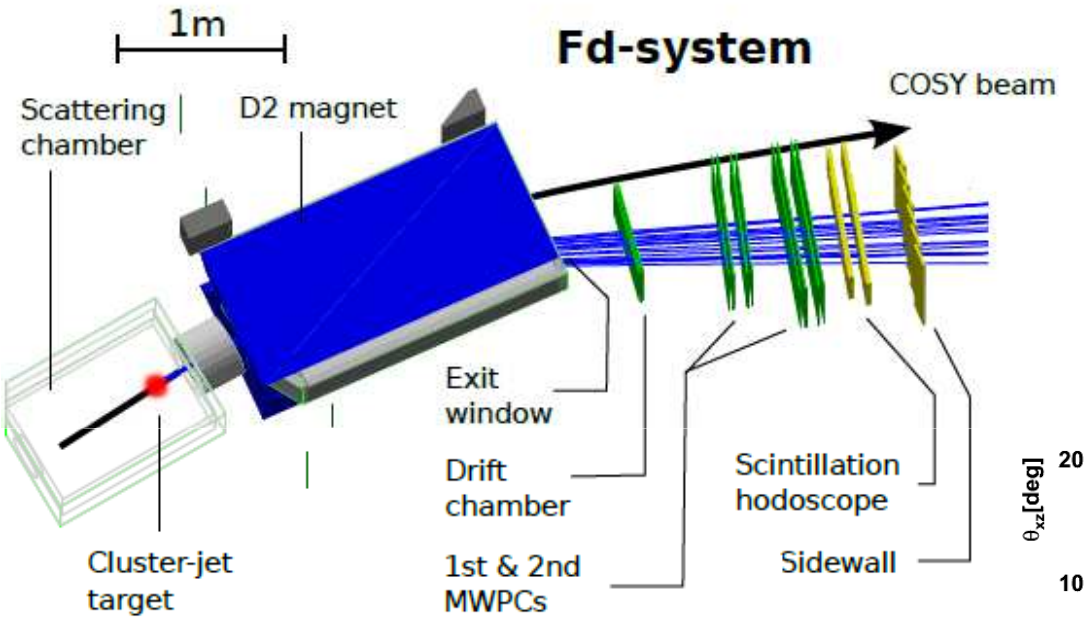


- Consists of 20 START, 22 STOP counters and two MWPCs .
- Detected negative particles momentum: 0.2-1.8 GeV/c.
- Momentum resolution: 2~3%

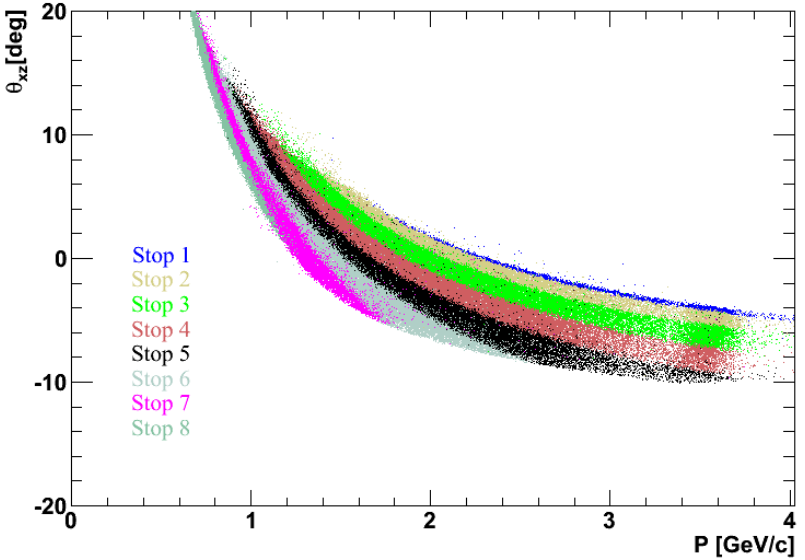


- The time difference between START and STOP Counter is insufficient to differentiate K^- and π^-.

Forward Detection System



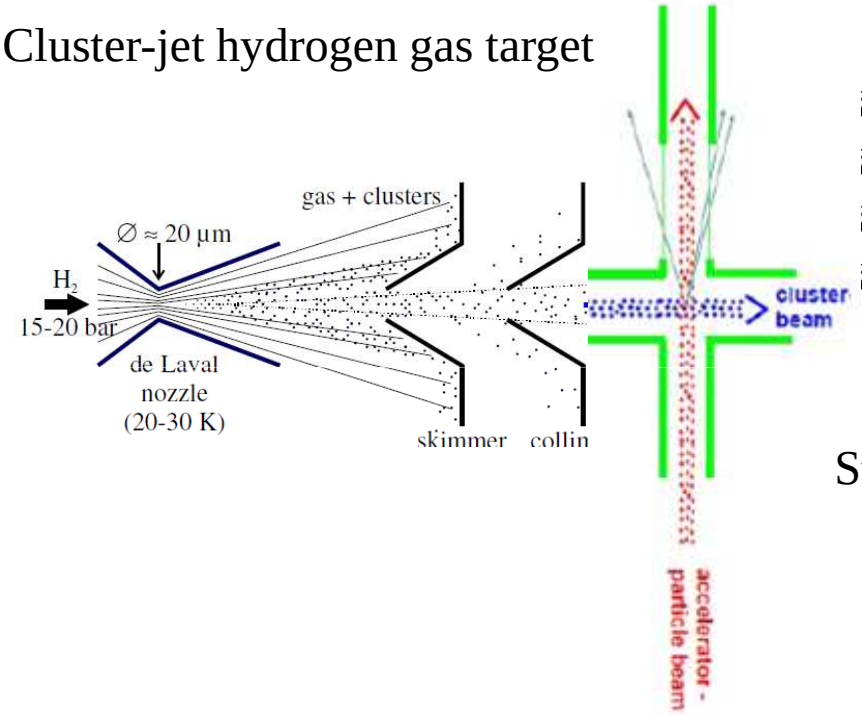
- High spatial resolution 1mm
- Momentum Resolution ~1%
- Measure pp elastic scattering for luminosity determination



- Consists of three MWPCs and 17 counters
- Detected positive particles momentum range: 0.8-4.0 GeV/c.

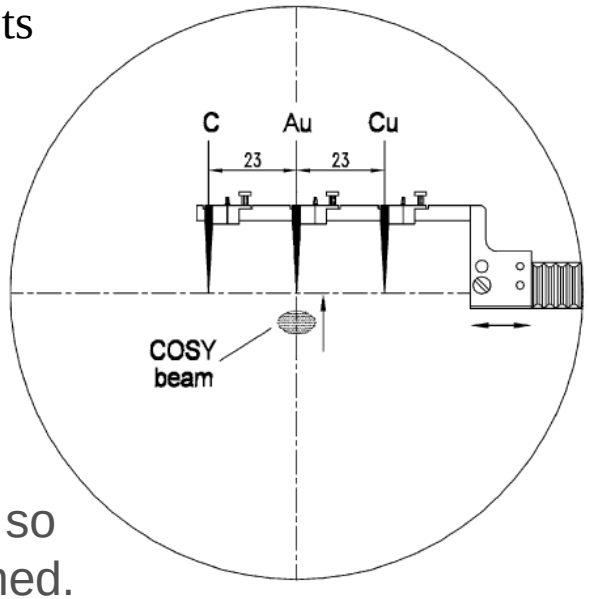
Targets

Cluster-jet hydrogen gas target



- H_2 gas passes a de Laval nozzle
- Form clusters surrounded by gas
- Effective target thickness ~ 10^{-14} cm^{-2}
- Windowless target

Strip Targets



Target: ^{12}C, ^{63}Cu, ^{107}Ag, ^{197}Au.
Thickness: 10-30 µm.

different targets can be inserted simultaneously so that comparative measurements can be performed.

Experimental details

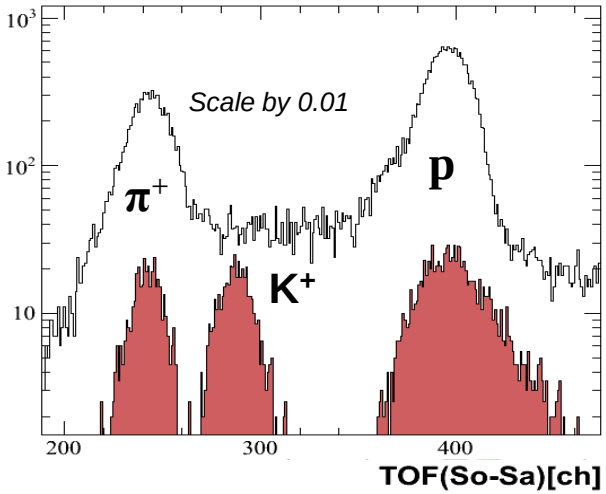
Parameter	Value
Beam Particle	Unpolarized Proton
Beam Energy	2.57GeV, 2.83 GeV
Beam Resolution $\Delta p/p$	10^{-4}-10^{-5}
Beam flux	~10^{10} nucleon/s
Target	H, C, Cu, Ag, Au
D2 Magnetic field	1.57 T
Detection System	Pd, Nd & Fd
Trigger	Pd(K+) & Fd & Nd Fd

Data Analysis

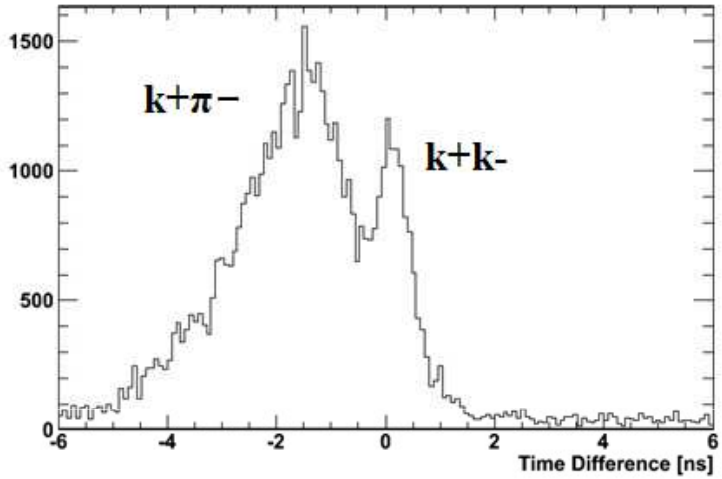
- Particle Identification
- Efficiency Determination
- Luminosity
- Acceptance Correction

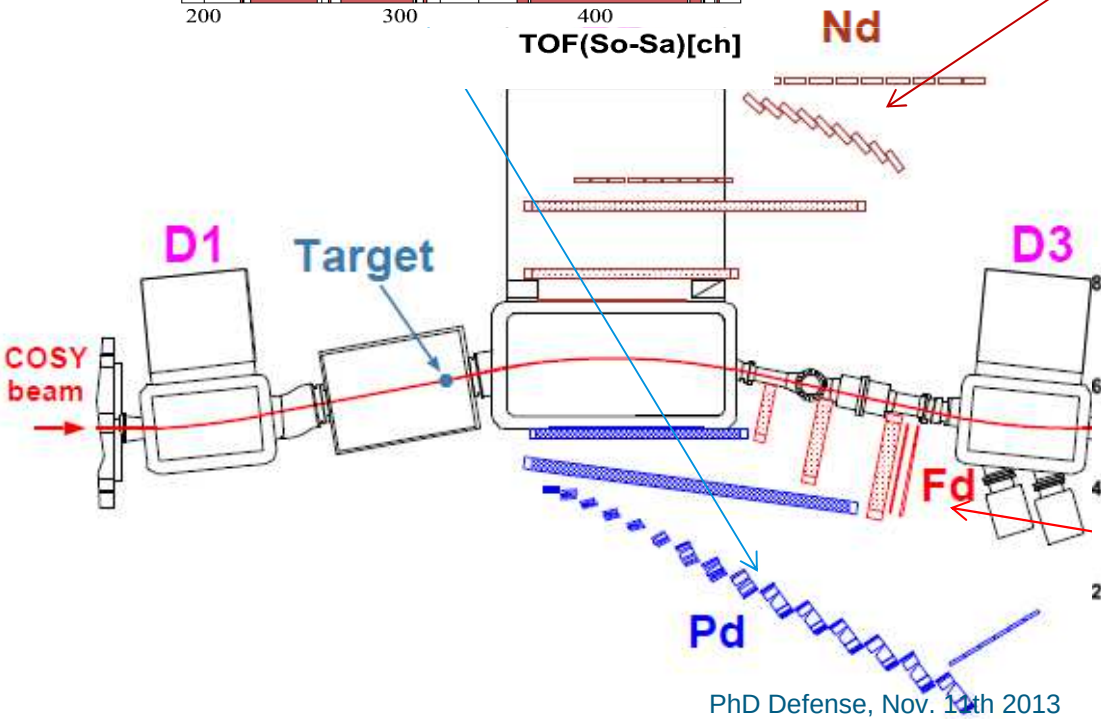
Particle Identification: overview

K^+ Selection

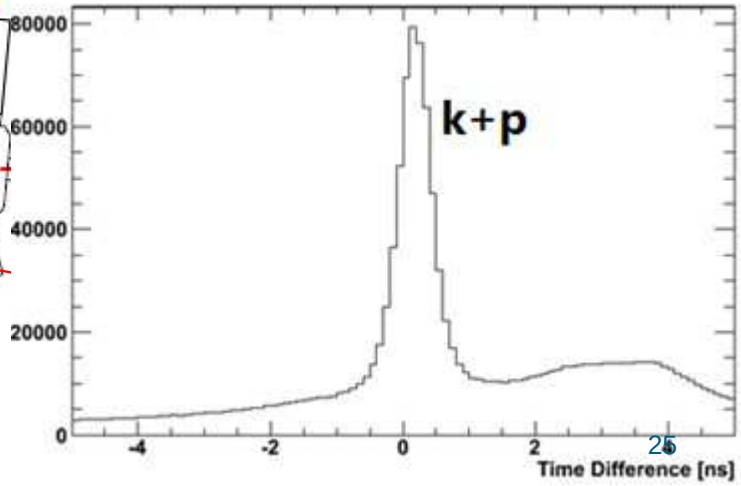


K^+K^- Selection



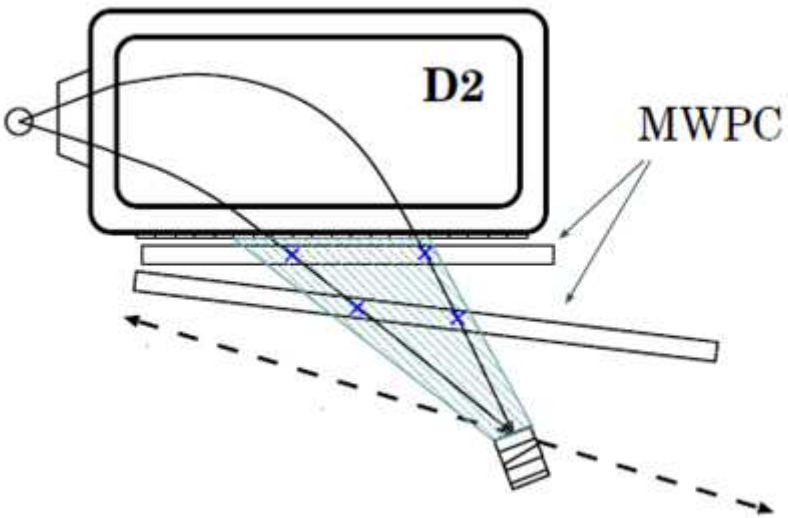


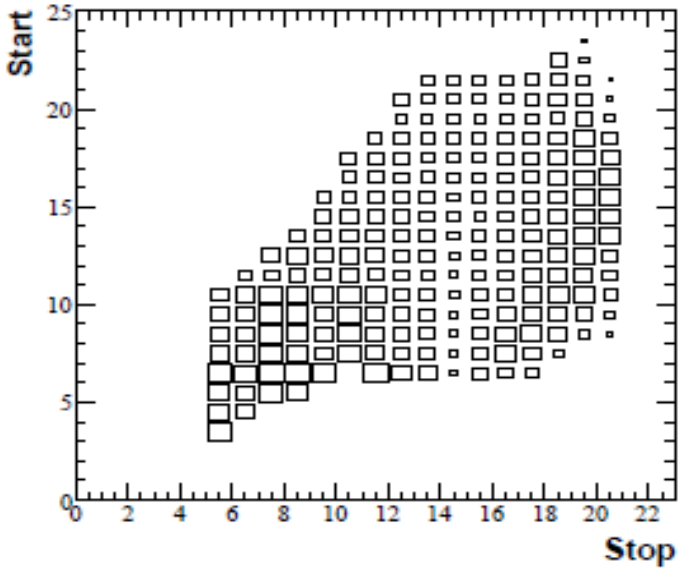
K^+p Selection



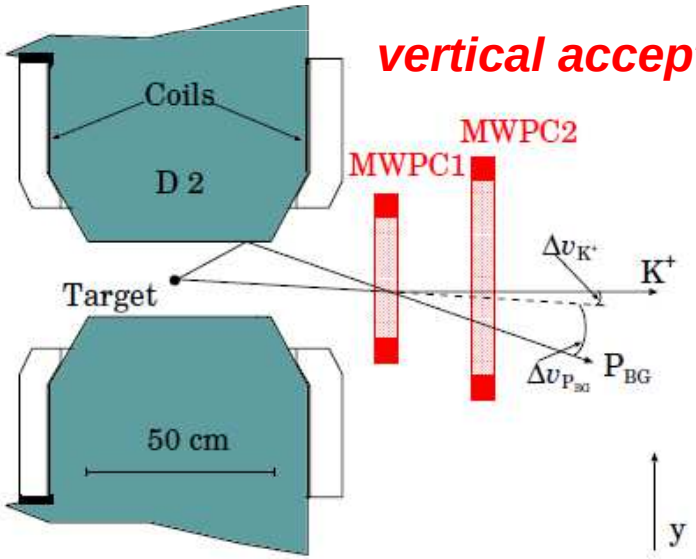
Background suppression

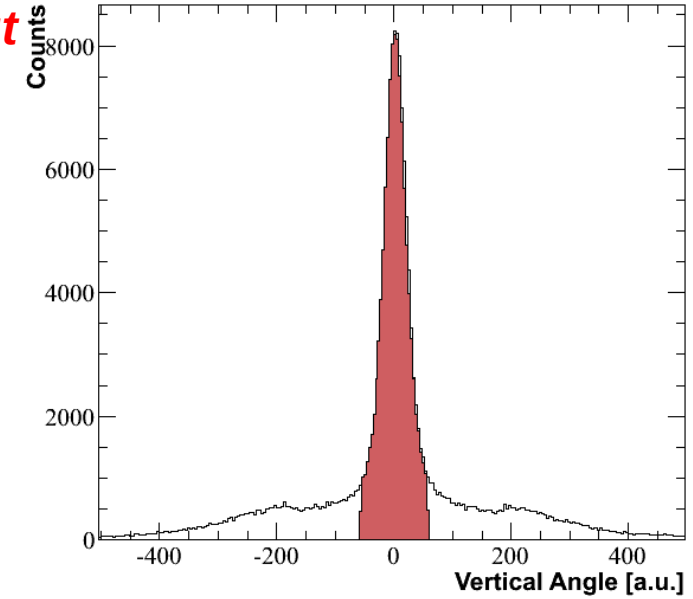
horizontal acceptance cut



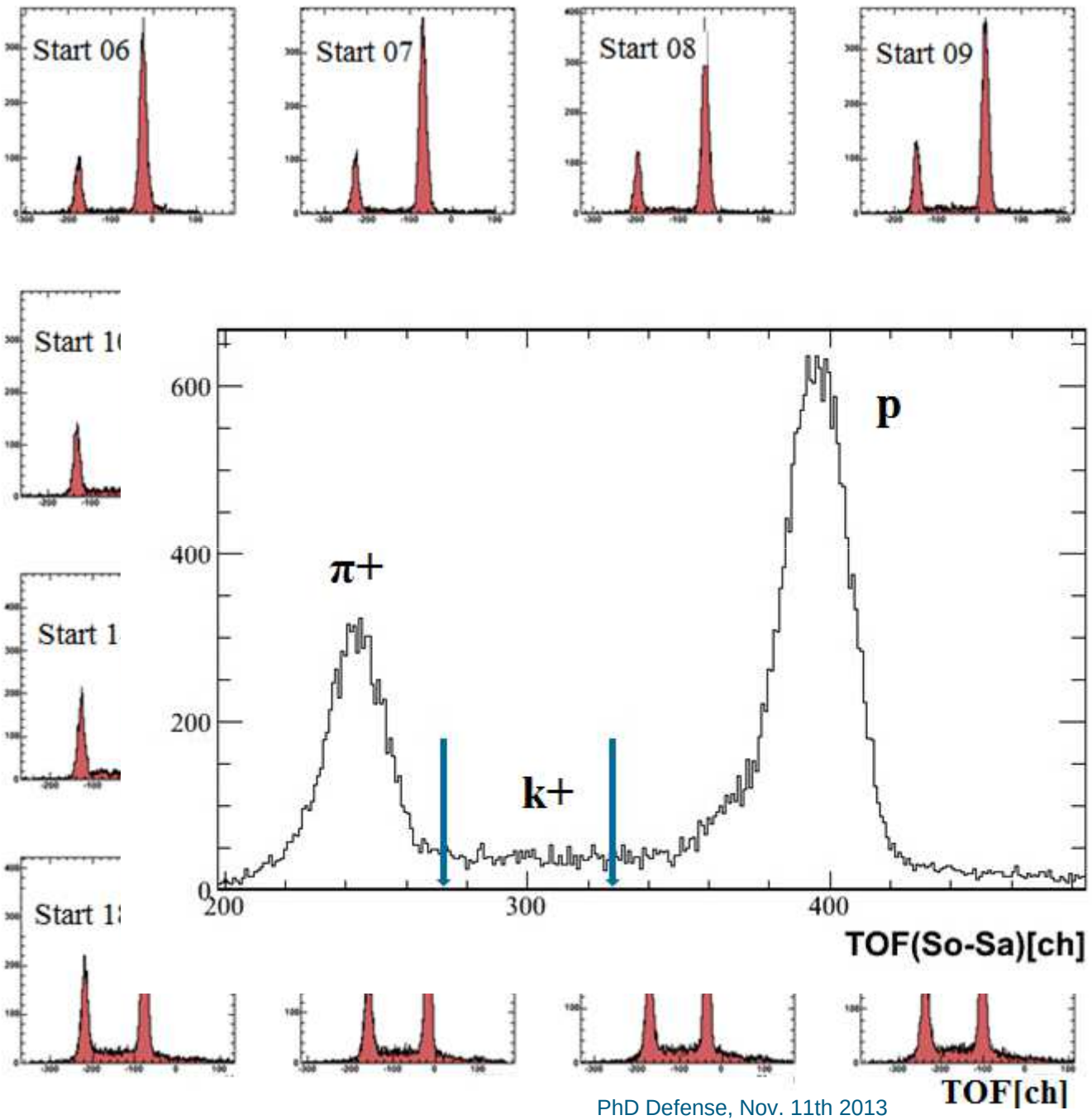


vertical acceptance cut





Principle: ejectiles from the target and scattered background have different vertical angles.



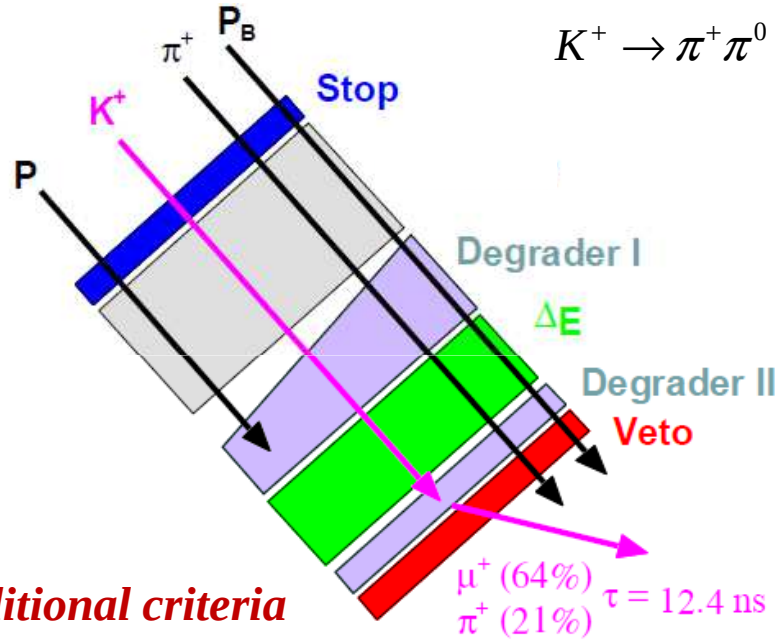
Raw TOF Spectra Positive Detector

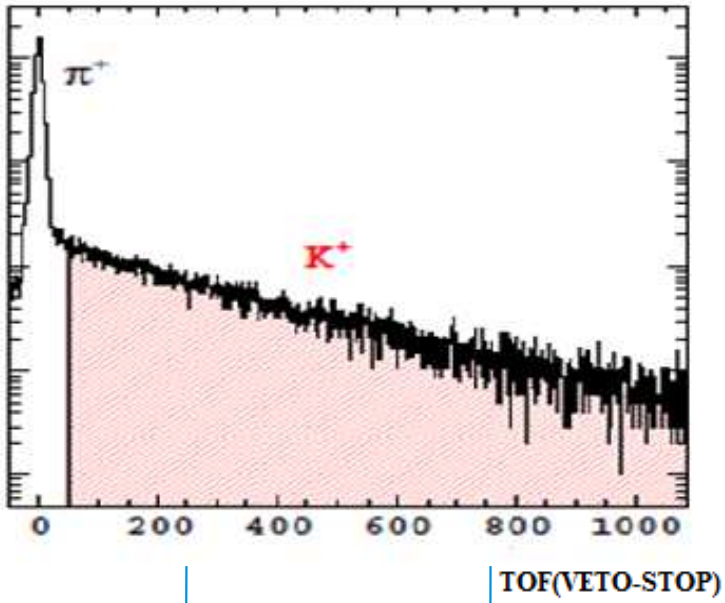
Positive Side #12: TDC(STOP-START)

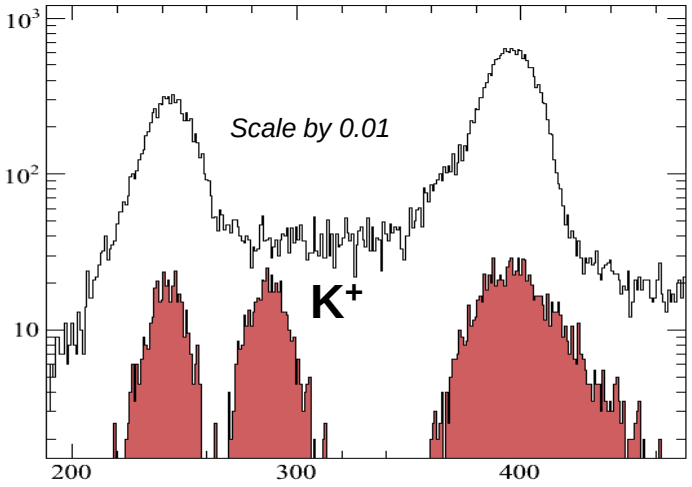
K^+ Selection Method(I)

$$K^+ \rightarrow \mu^+ + \upsilon_\mu$$

$$K^+ \rightarrow \pi^+ \pi^0$$



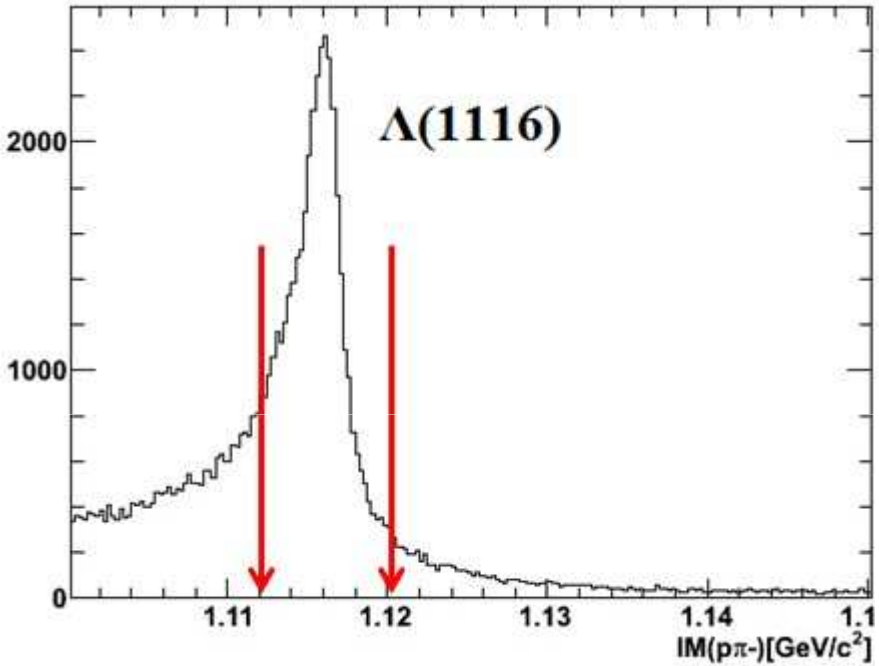




Additional criteria

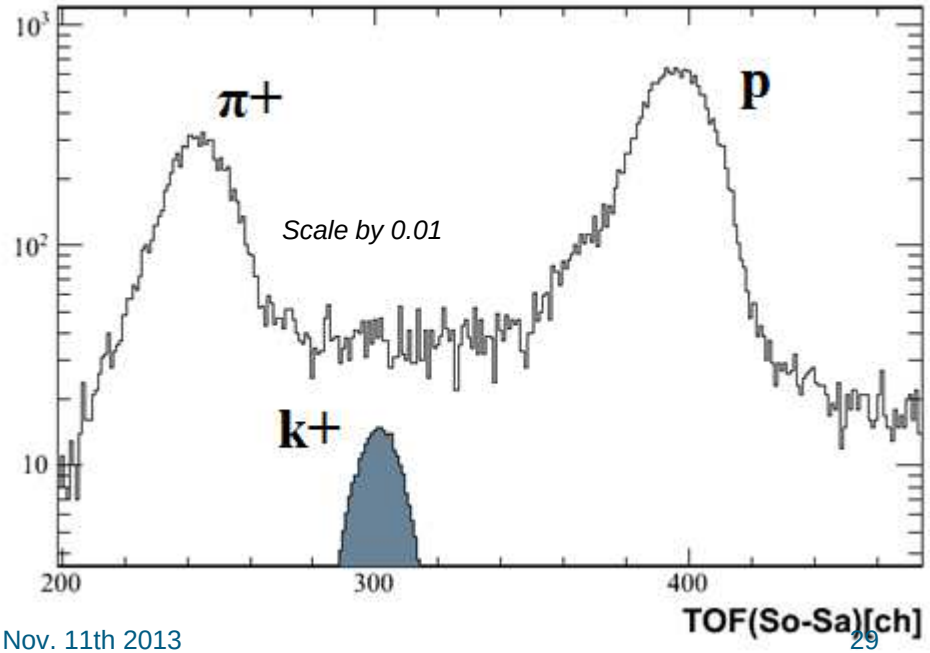
- With delayed VETO the signal of the K^+ peak is clearly seen.
- Inside this time corridor, some amount of π^+ and proton are expected.

K^+ Selection Method (II)



- Select particle in TOF region of π^- in Nd and proton in Fd.
- Most particles in Nd are π-.
- Cut on invariant mass of pπ− to select proton in Fd.

- Via PdFd time calibration (discussed later), one can identify the K^+ in Pd.
- Advantage compared the Delayed VETO:
  - Keep most kaons.
  - do not to perform efficiency corrections.



K^- & P Selection Method

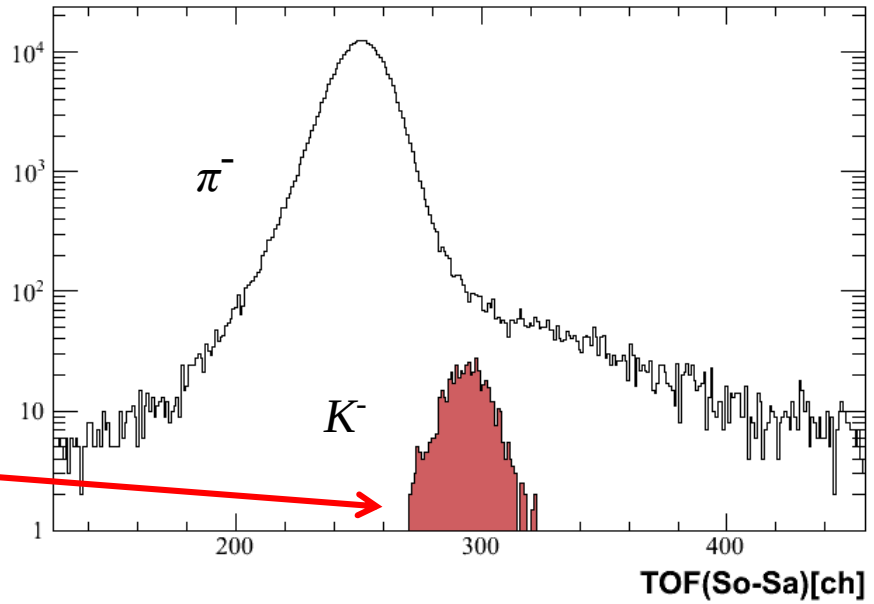
- For Negative Detector.
  - Time Resolution between START-STOP Counters in Nd is ~ 1ns.
  - Insufficient to separate π^- *and* K^-.
- Using Time Calibration between Pd STOP counters and Nd STOP counters, sufficient absolute time resolution can be achieved.
- Based on TDC information and calibration parameters:

$$\Delta TOF(X^- - K^+)_{TDC}$$

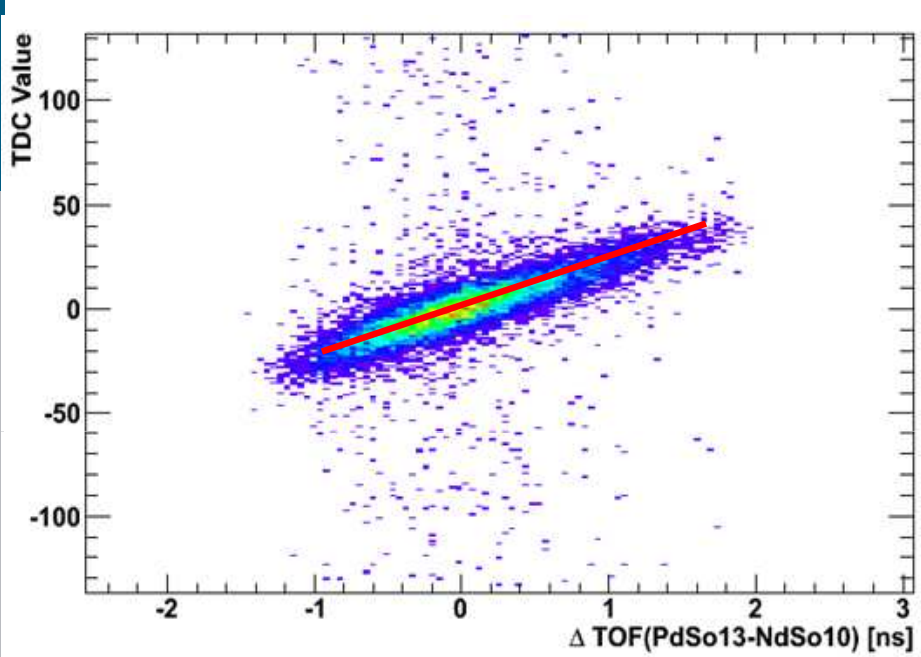
- Based on track length and particle momentum.

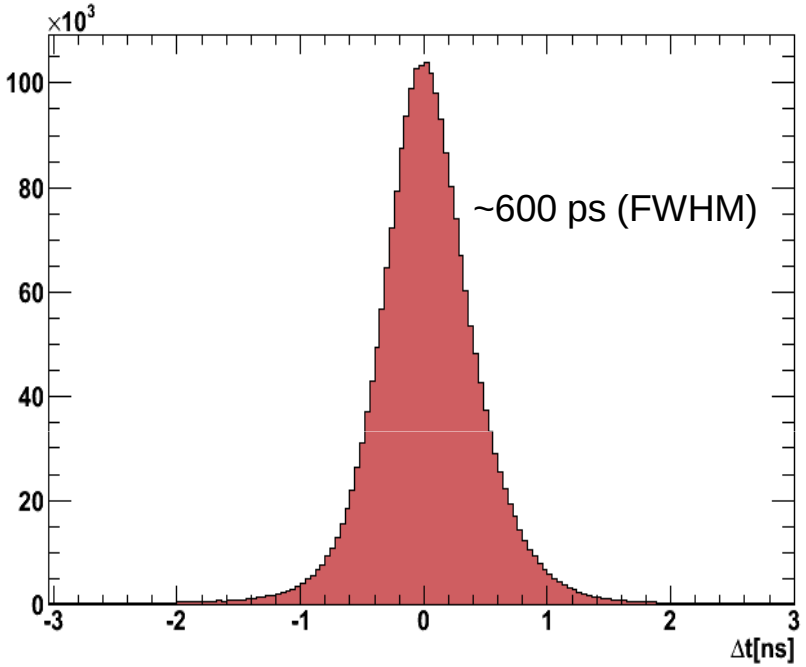
$$TOF(K^-) - TOF(K^+)$$

K^- Selection by using absolute time calibration.



PdNd Time Calibration via $\pi^+\pi^-$





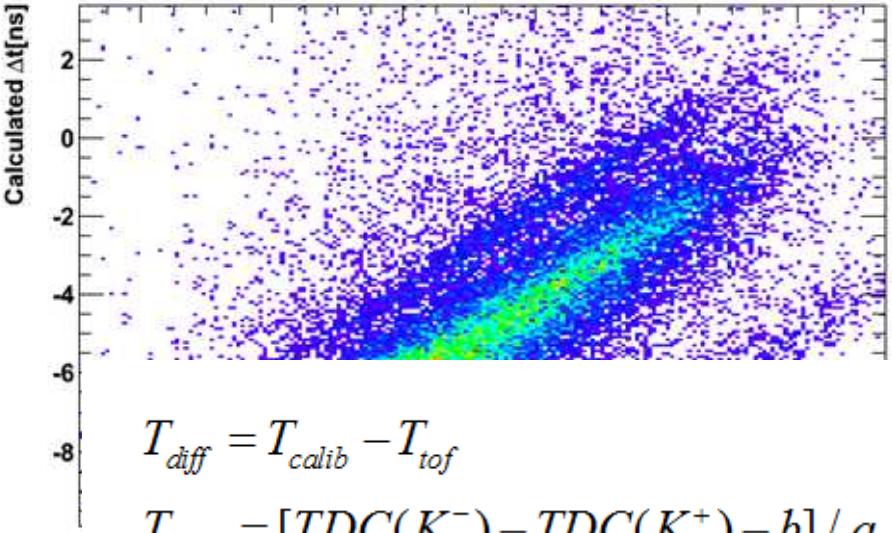
- an open X+X− trigger accepts π+π− events measured during the experiment.
- the start signal for the TDC derived from the STOP counters in Pd.
- allows an absolute time calibration using the track length and momentum information.

$$\Delta TDC = a \times \Delta TOF + b$$

$$\Delta TDC = TDC(\pi^-) - TDC(\pi^+)$$

$$\Delta TOF = TOF(\pi^-) - TOF(\pi^+)$$

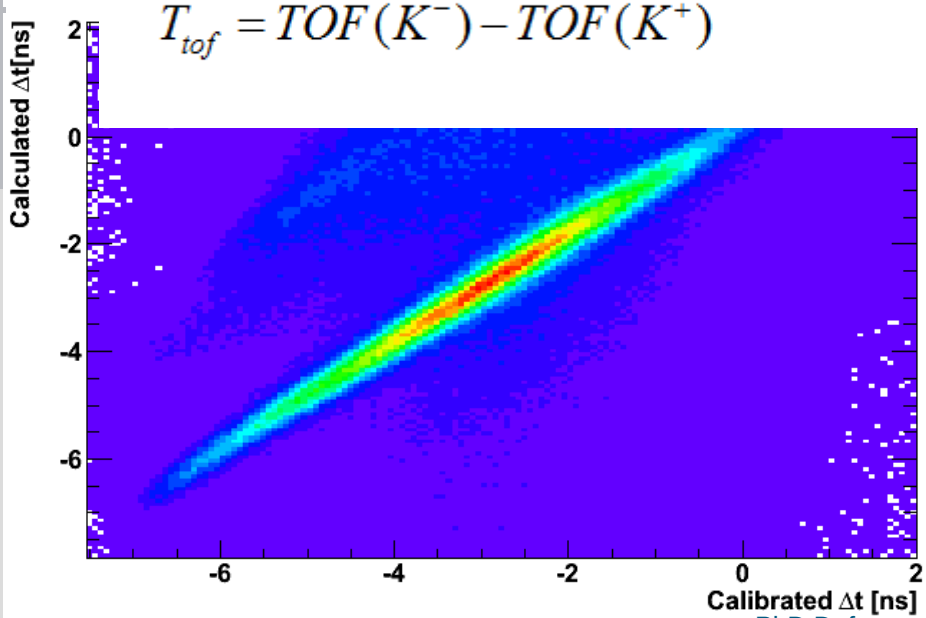
K^+K^- and K^+P Time Correlation

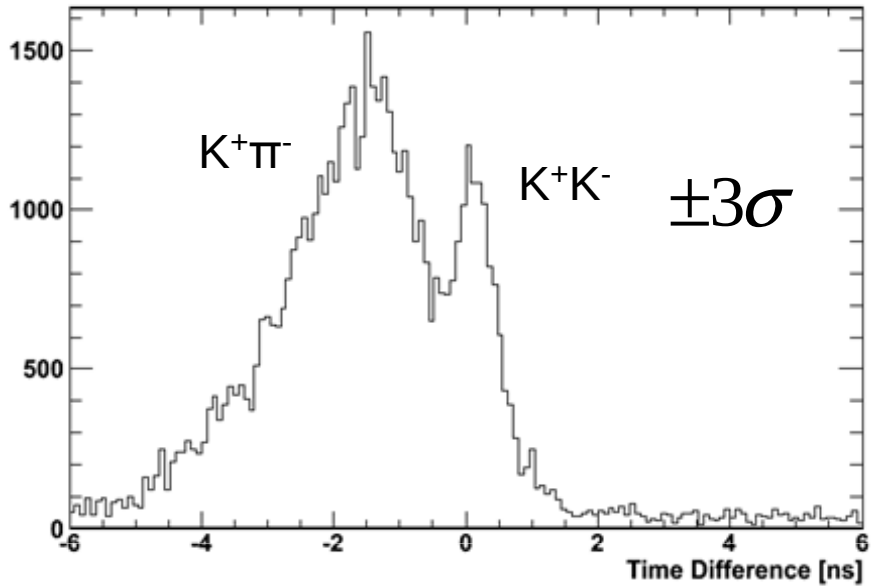


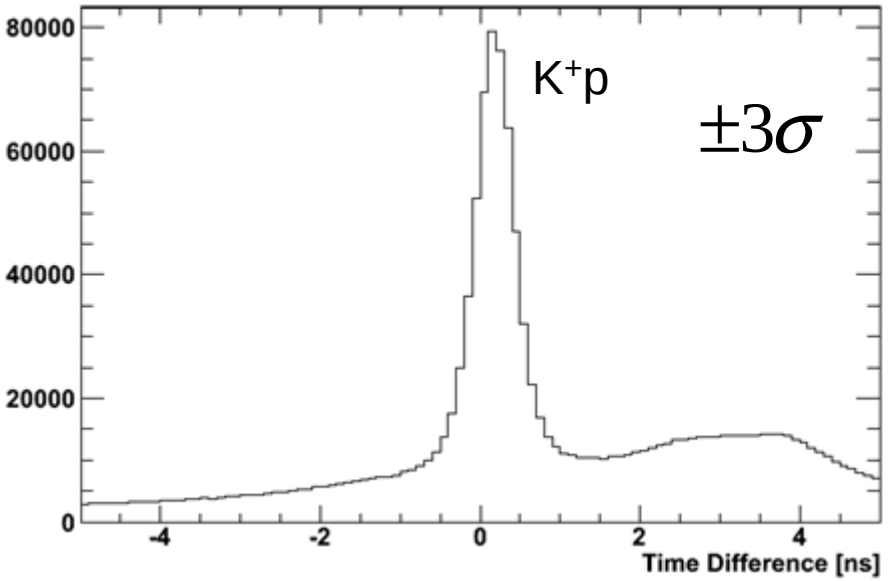
$$T_{diff} = T_{calib} - T_{tof}$$

$$T_{calib} = [TDC(K^-) - TDC(K^+) - b] / a$$

$$T_{tof} = TOF(K^-) - TOF(K^+)$$



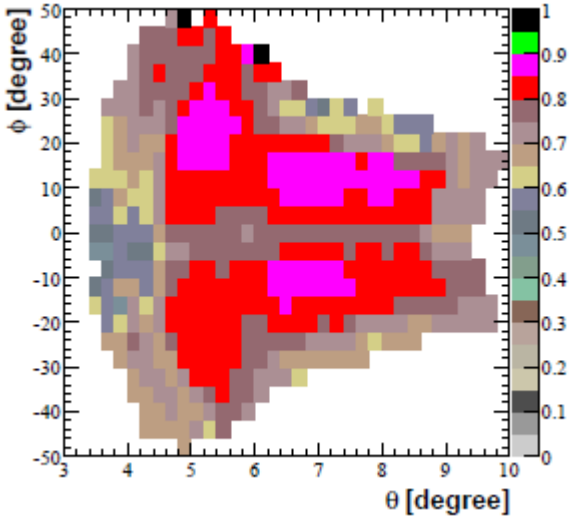


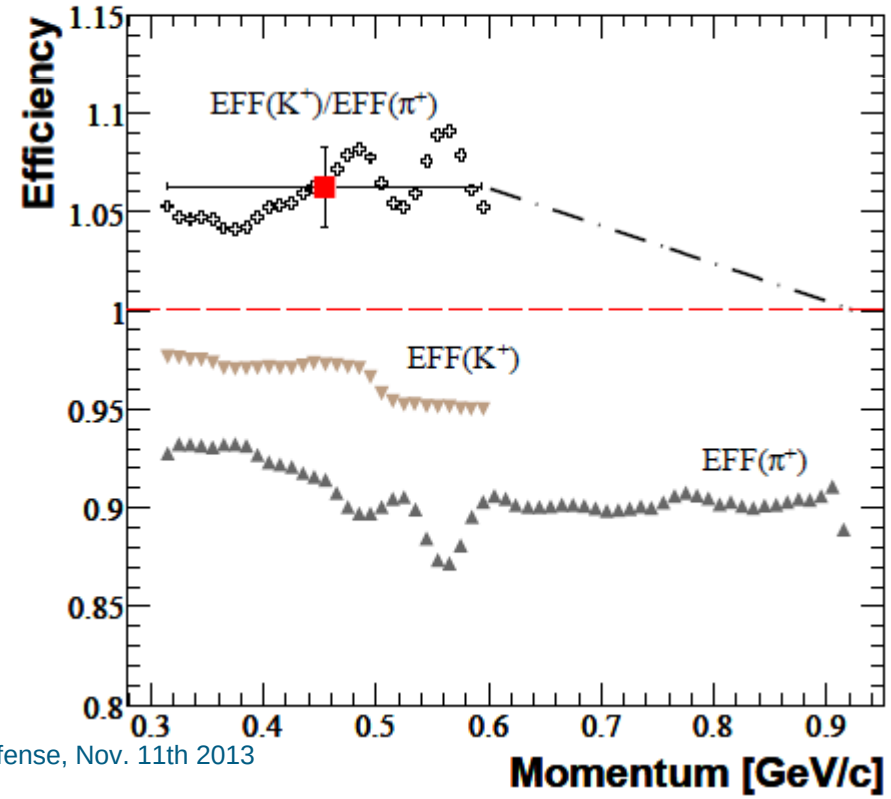


Efficiency Determination

- The detection efficiency of scintillation counters ~ 100%.
- The efficiency of Multi-Wire Proportional Chambers:
  - Depend on the type and momentum of the particle.
  - The ratio of K^+/π^+ is used to deduce the K^- efficiency.
  - 2D efficiency map in Fd
- Trigger efficiency.

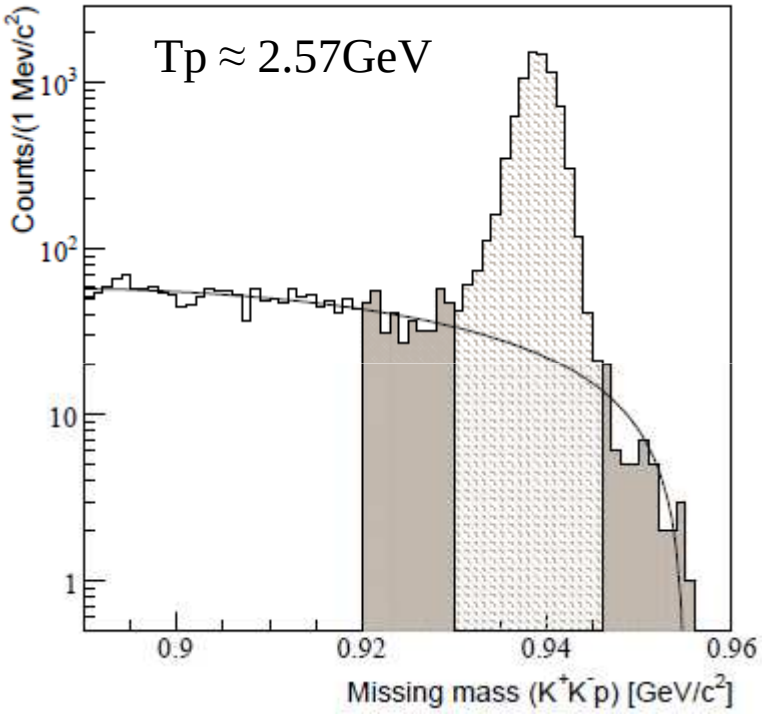
$$\varepsilon = \frac{T_{out}}{T_{in}}$$

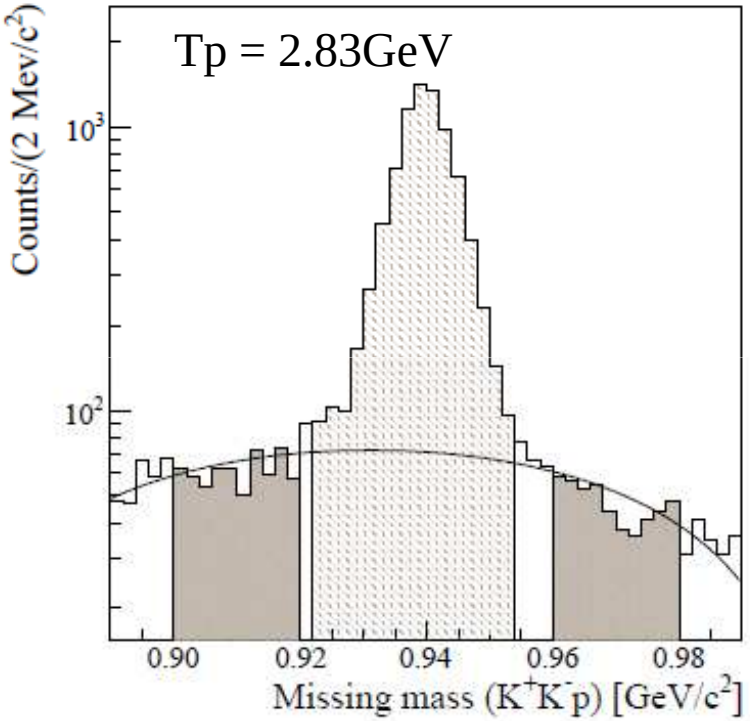




Missing mass distribution of K^+K^-p

$$pp \rightarrow K^+K^-pX$$





~ 5% background

~ 11.5% background

- a 3σ cut applied on the missing mass distribution.
- background subtraction based on side-band events.

Luminosity determination

pp elastic scattering

$$L = \frac{N_{tot}}{\int_{\Omega_{det}} \frac{d\sigma}{d\Omega} d\Omega}$$

N_{tot} - total number of elastically protons

$\frac{d\sigma}{d\Omega}$ - differential cross section for pp elastic scattering

$d\Omega$ - solid angle of the detector

Cross sections are based on predictions of SAID database

Energy Loss Measurement (Schottky method)

$$L = n_{\text{beam}} \cdot n_{\text{target}}$$

n_{beam} - beam flux

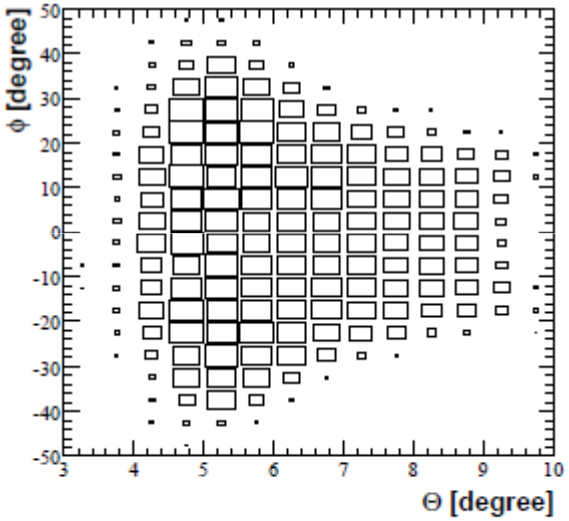
n_{target} - effective target thickness

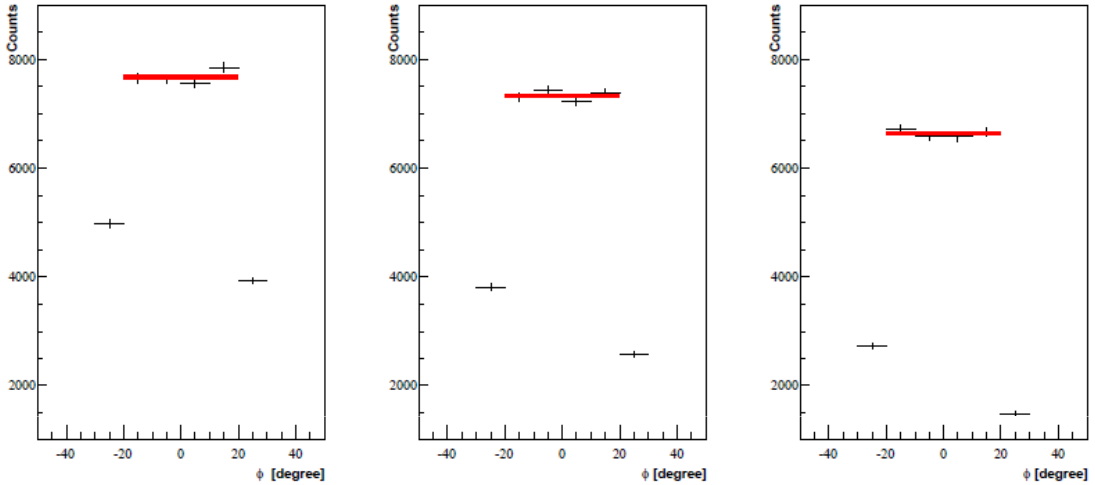
$$n_{\text{target}} = \frac{dT}{(dE/dx) \cdot m}$$

dT- energy loss
dE/dX – stopping power of protons in hydrogen gas
m – proton mass

Luminosity via pp elastic scattering

Angular acceptance of pp elastic scattering

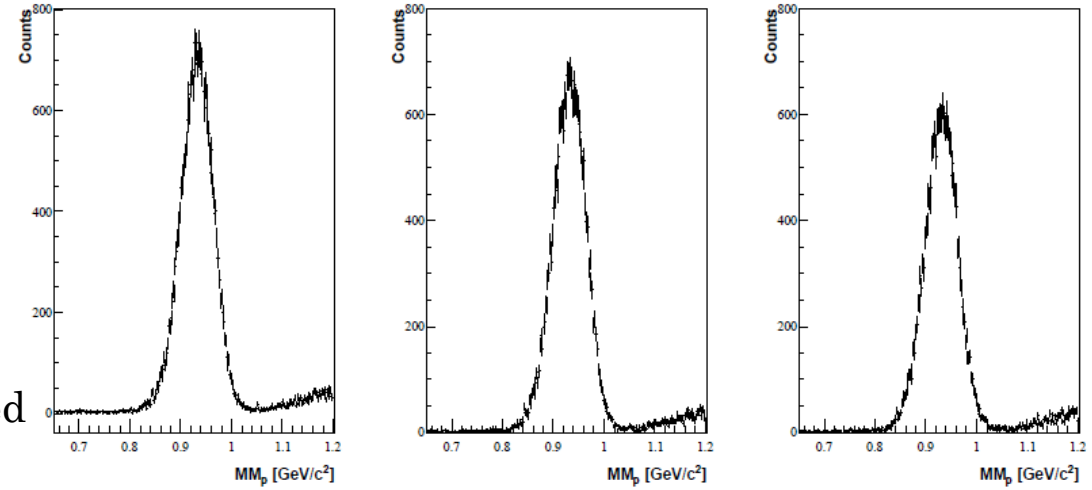




azimuthal angle distribution

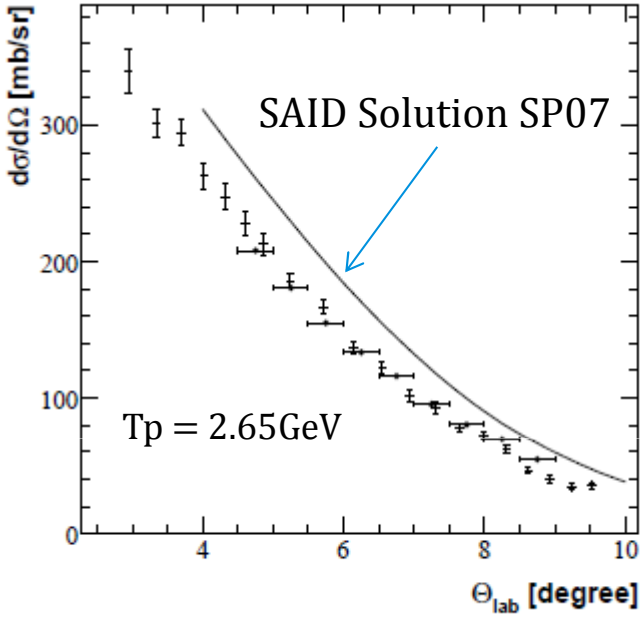
$$N_{tot} = \frac{N_{det} \cdot f}{\varepsilon_{trigger} \cdot \varepsilon_{det}}$$

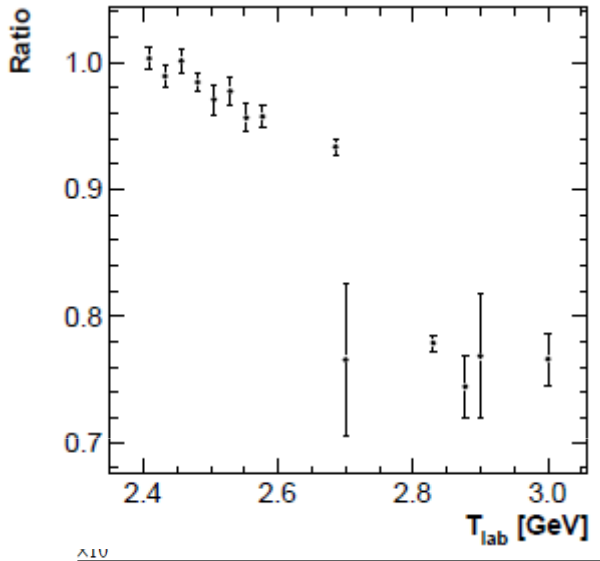
- N_{det} is number of reconstructed events
- f is the prescaling factor



missing mass distributions

Luminosity via pp elastic scattering: fitting

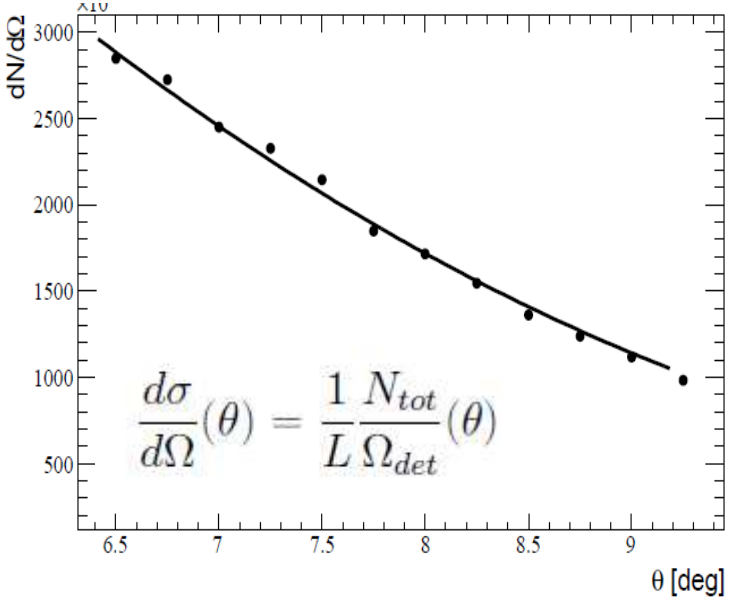




scaling factor

- SAID Solution overestimates the values in small angles
- Scaling factors were applied.

Uncertainty	2.57 GeV	2.83 GeV
Track reconstruction efficiency	5%	5%
Acceptance correction	6%	7%
Momentum reconstruction	1%	1%
Background subtraction	3%	3%
$\Delta L=(L_\theta - L_{Mean})$	2%	2.4%
Total	8.6%	9.5%



Luminosity via Schottky method: Overview

Luminosity can also be calculated as:

$$L = n_{\text{beam}} \cdot n_{\text{target}}$$

❖ Accurate measurement of beam intensity I_{beam} *is possible via* the high precision Beam Current Transformer (BCT) device.

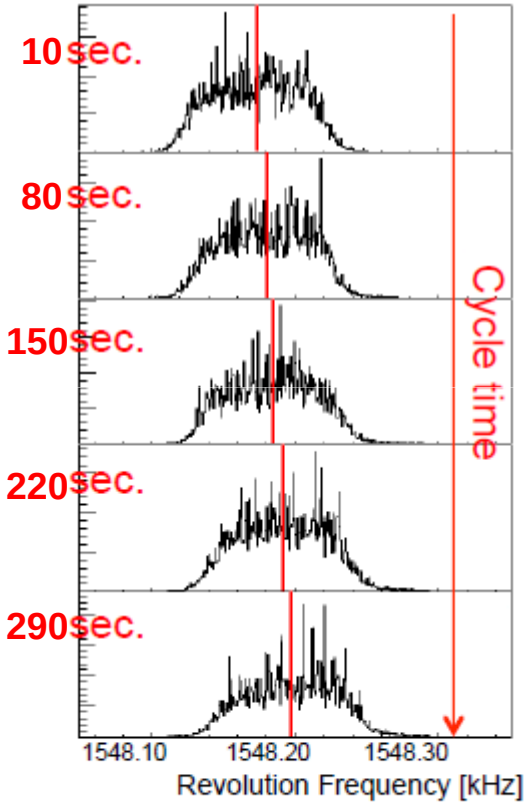
$$n_{\text{beam}} = I_{\text{beam}} / q_{\text{beam}}$$

❖ Effective target thickness n_{target} can be obtained via the measurement of the frequency shift of the beam using the Schottky device.

$$n_T = \left(\frac{1+\gamma}{\gamma}\right) \frac{1}{(dE/dx)m} \frac{T_0}{f_0^2} \frac{1}{\eta} \frac{df}{dt}$$

f_0 - revolution frequency
T_0 - beam kinetic energy
γ - Lorentz factor
p_0 - beam momentum
η - frequency-slip parameter
df/dt - frequency shift

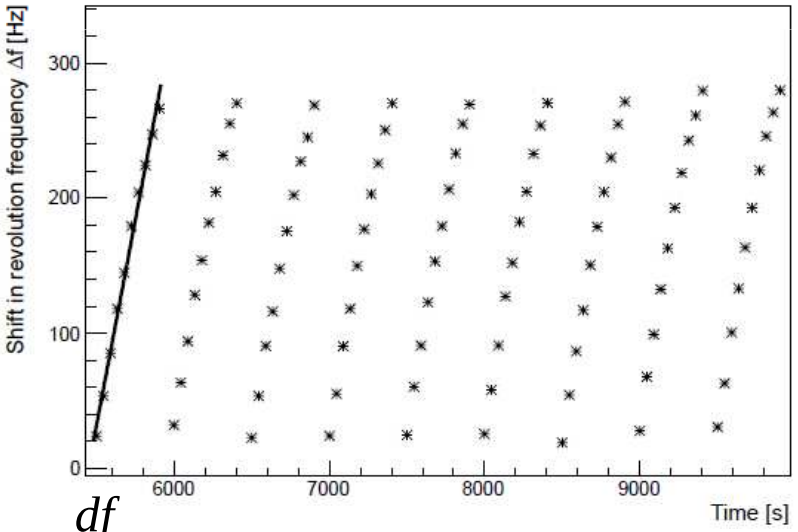
Luminosity via Schottky method: Frequency shift



Beam frequency changes due to energy loss

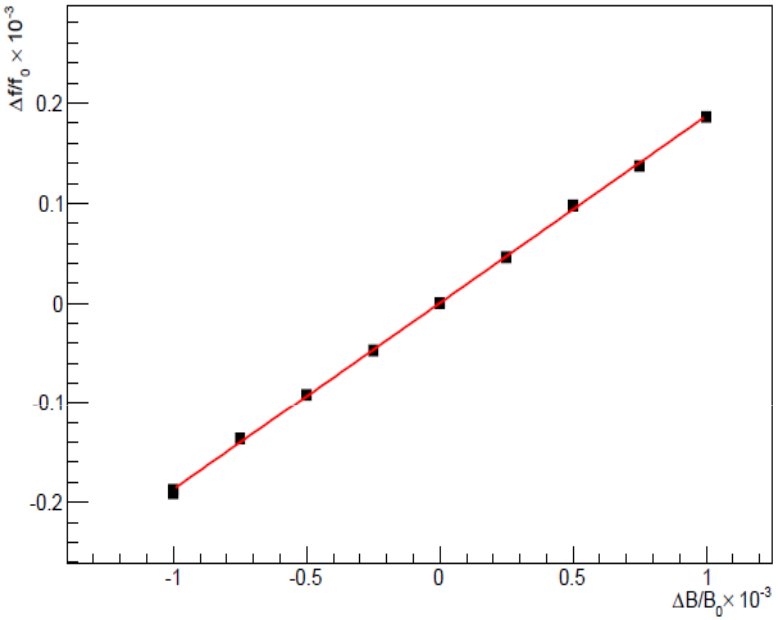
$$n_T = \left(\frac{1+\gamma}{\gamma}\right)\frac{1}{(dE/dx)m}\frac{T_0}{f_0^2}\,\frac{1}{\eta}\,\frac{df}{dt}$$

$$\left(\frac{df}{dt}\right)_{target} = \left(\frac{df}{dt}\right)_{total} - \left(\frac{df}{dt}\right)_{bg}$$



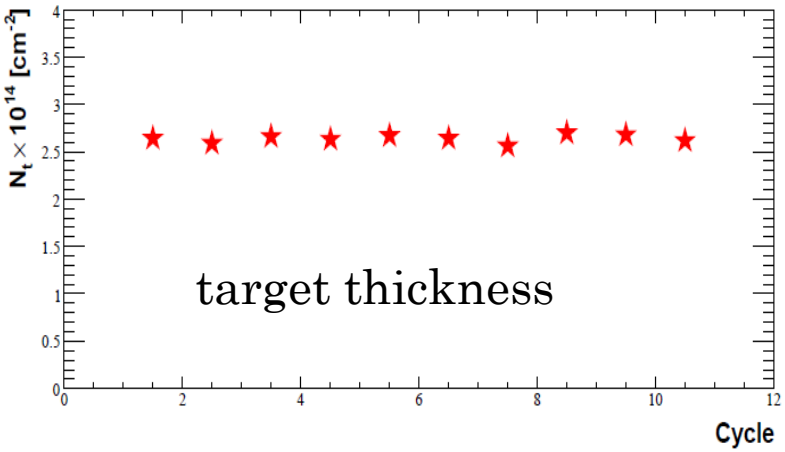
$\frac{df}{dt}$ extracted in each beam cycle

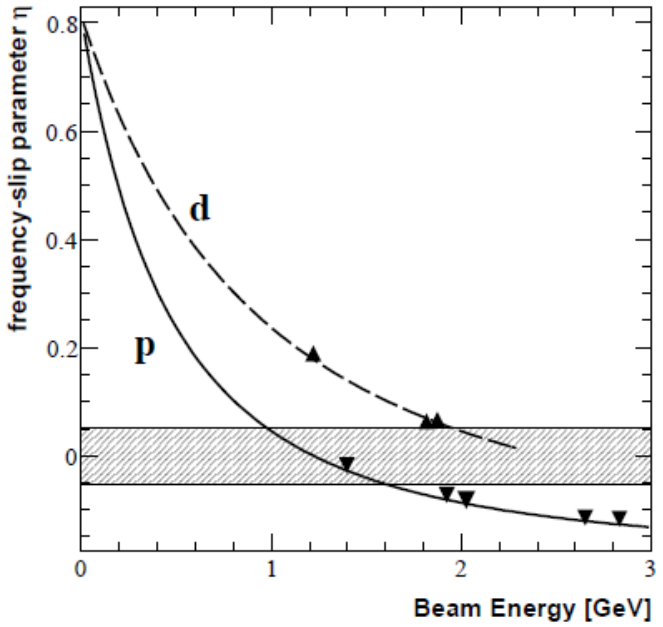
Luminosity via Schottky method: frequency-slip parameter



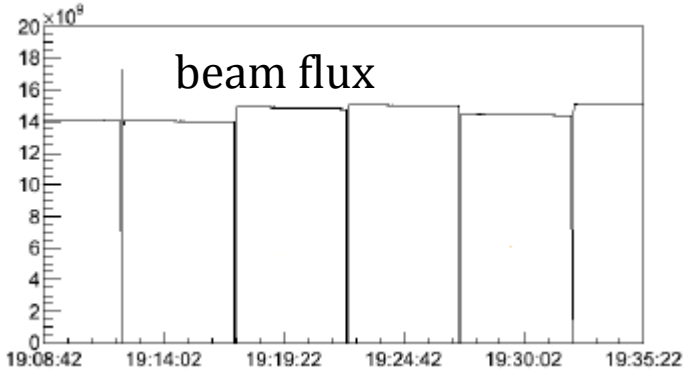
$$n_T = \left(\frac{1+\gamma}{\gamma}\right)\frac{1}{(dE/dx)m}\frac{T_0}{f_0^2}\frac{1}{\eta}\frac{df}{dt}$$

$$\eta = \frac{1}{\gamma^2} - \alpha \qquad \frac{\Delta f}{f_0} = \alpha\frac{\Delta B}{B_0} \qquad \frac{\Delta f}{f_0} = \eta\frac{\Delta p}{p}$$

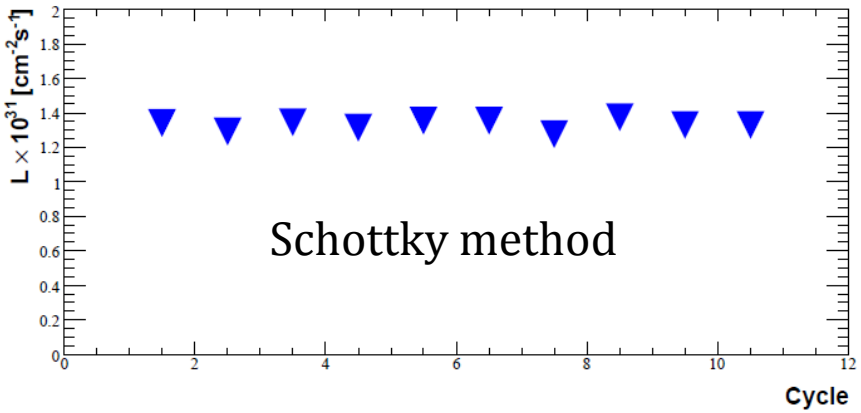




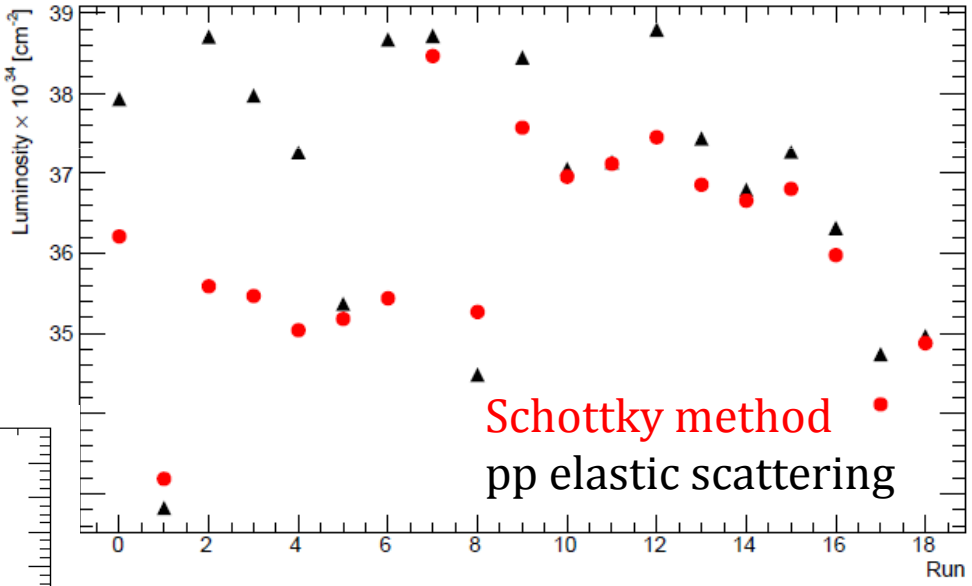
Luminosity via Schottky method: Comparison



Uncertainty	[%]
Corrected frequency shift rate	4
Frequency-slip parameter (η)	3
Total	5

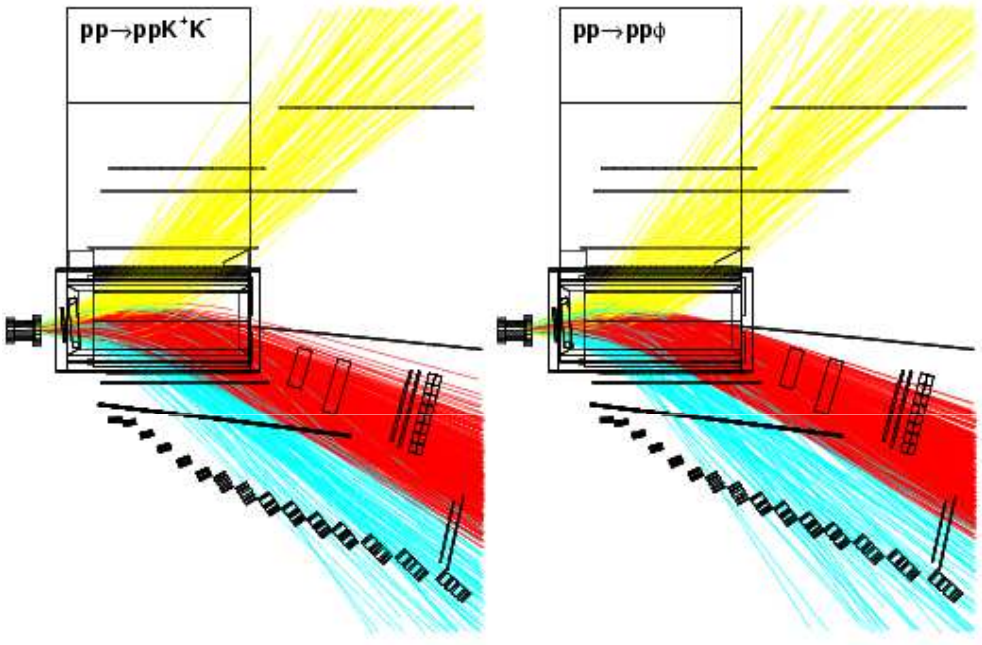


pp elastic scattering will cancel out the systematic uncertainties caused by the accelerator, target, Fd detector, DAQ system and …



Luminosity is ~ 10^{31} $cm^{-2}s^{-1}$

Acceptance correction: Geant4 Simulation

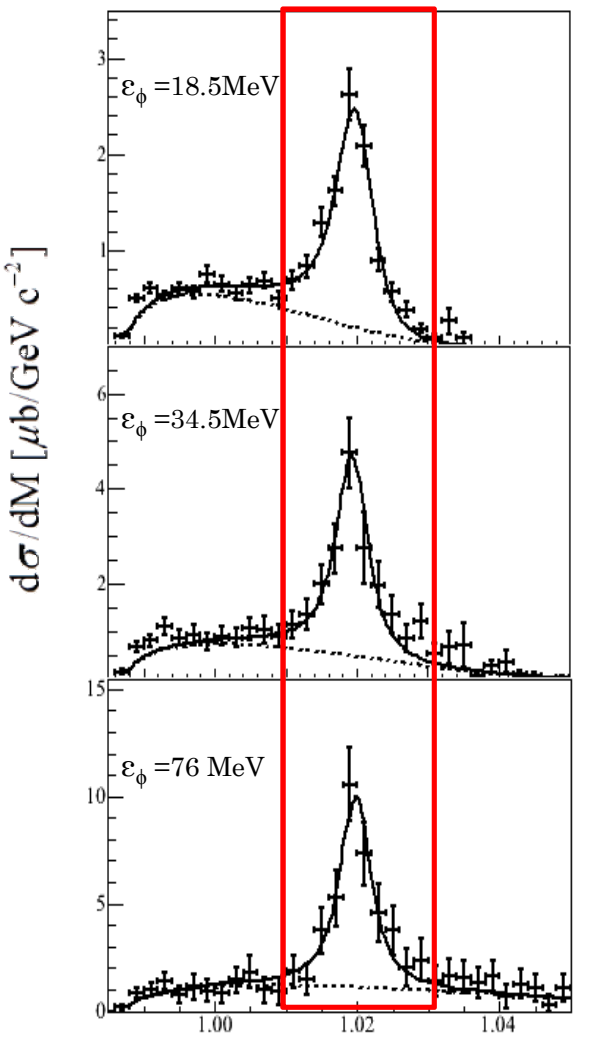


- Geant4 Simulation takes into account of the geometrical acceptance, detector efficiency, and kaon decay probability.
- The detector acceptance is not uniform over the phase space.
- Phenomenological parametrizations are required for different reactions.

Phenomenological models:

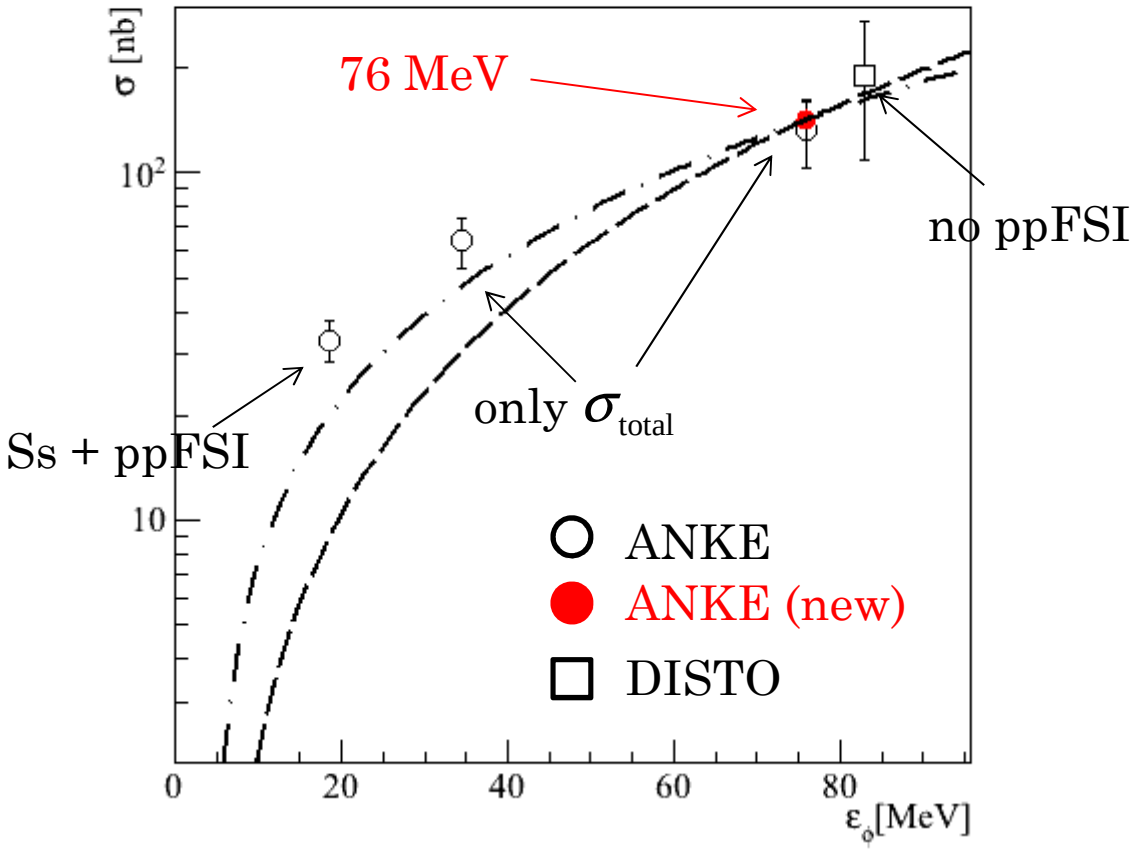
- ϕ meson production: truncated partial wave decomposition.
- Kaon pair production: phase space + final state interactions.

Acceptance correction: ϕ meson production



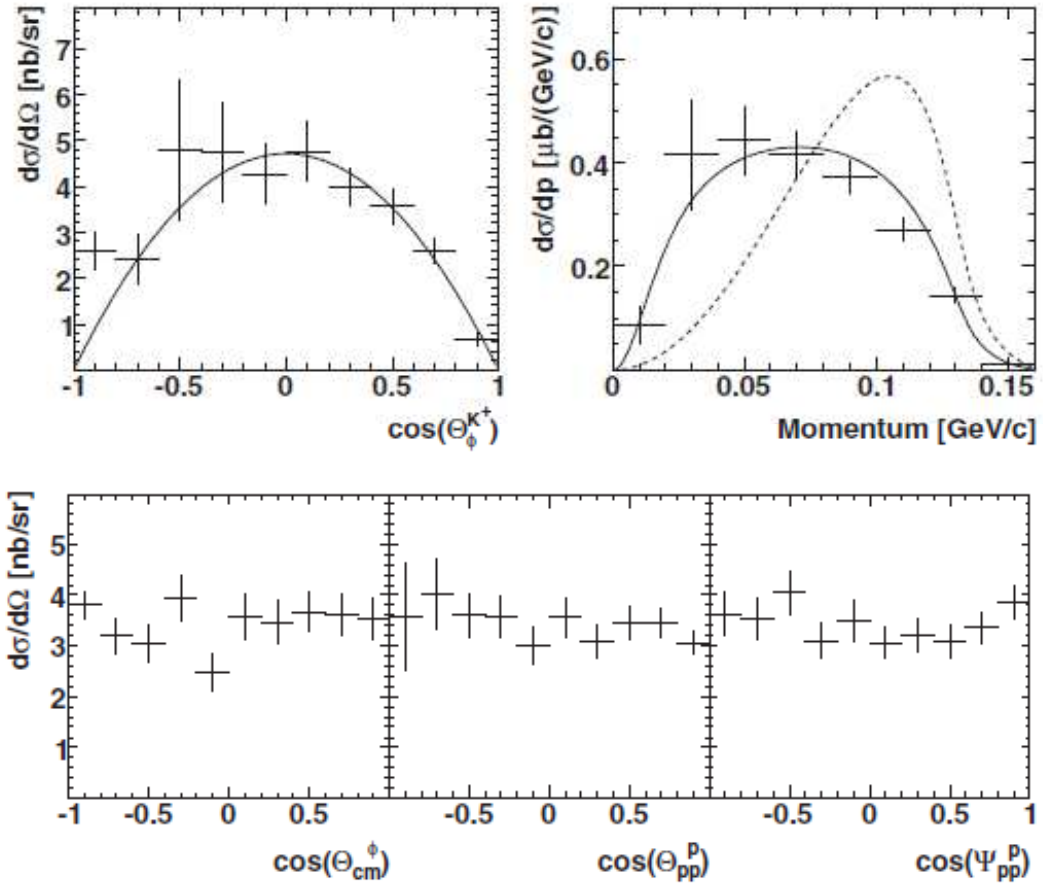
K^+K^- invariant mass [GeV c^{-2}]

$pp \rightarrow pp\phi$ $(\phi \rightarrow K^+K^-)$ BR: ~50%



Acceptance correction: ϕ meson production at ε = 18.5 MeV

ANKE results @ ε = 18.5 MeV



M. Hartmann et al. PRL. 96, 242301 (2006)

- close to threshold, the kaon decay angular distribution should display ~ $\sin^2\theta$.

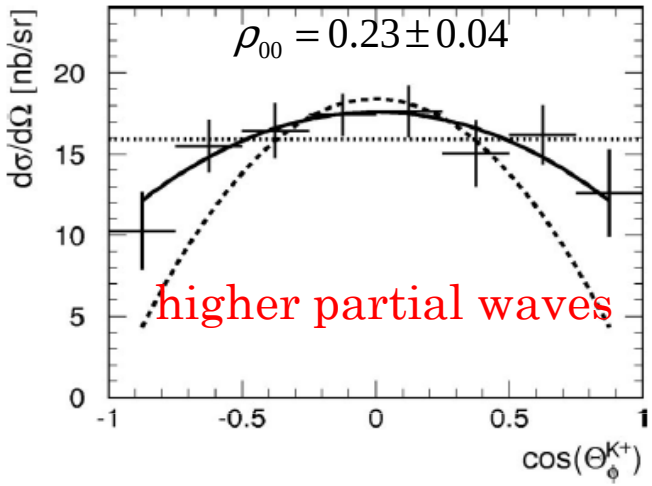
$$\frac{d\sigma}{d\Omega} \propto \left[(1-\rho_{00})\sin^2\theta_\phi^K + 2\rho_{00}\cos^2\theta_\phi^K\right],$$

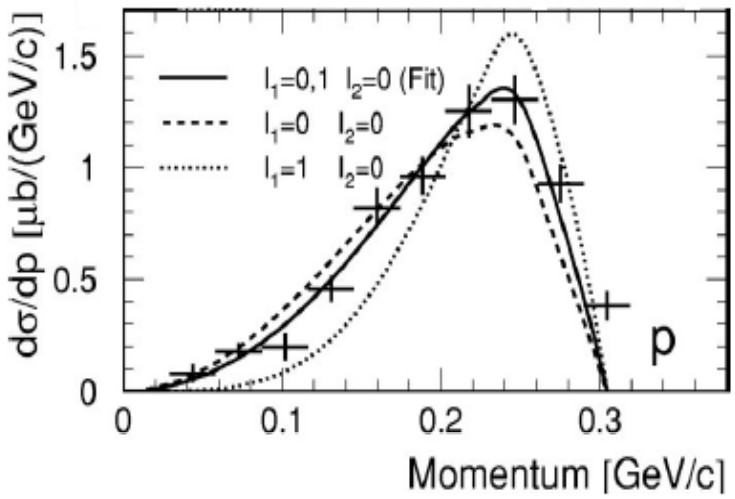
- ϕ in relative s-wave
- transition from $^3P_1$ (pp)-entrance channel to $^1S_0$ (pp) final-state *link*
- clear effect of ppFSI

$$f(q_{pp}) = \frac{q+i\beta}{q-i\alpha} \quad |\alpha| = 0.1\,\mathrm{fm}^{-1} \quad |\beta| = 0.5\,\mathrm{fm}^{-1}$$

Acceptance correction: ϕ meson production at ε = 83 MeV

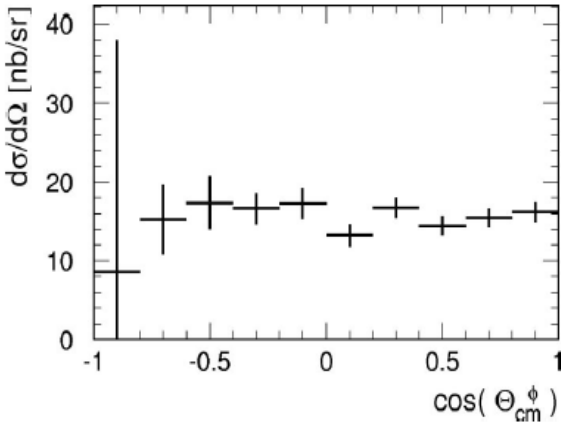
DISTO results @ ε = 83 MeV

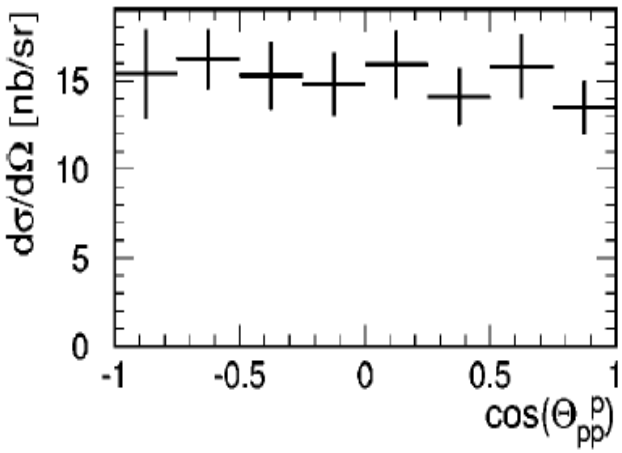


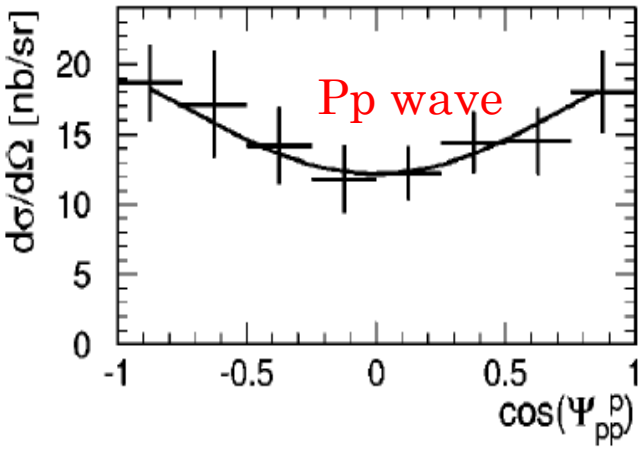


Ps wave
no ppFSI

$$\overline{|M|^2} = A_{Ss}(\hat{k}\times\hat{K})^2 + A_{Ps}\vec{p}^{\,2} + A_{Pp}(\vec{q}\cdot\vec{p})^2 + A_{Sp}[3(\vec{q}\cdot\hat{K})^2 - \vec{q}^{\,2}]$$





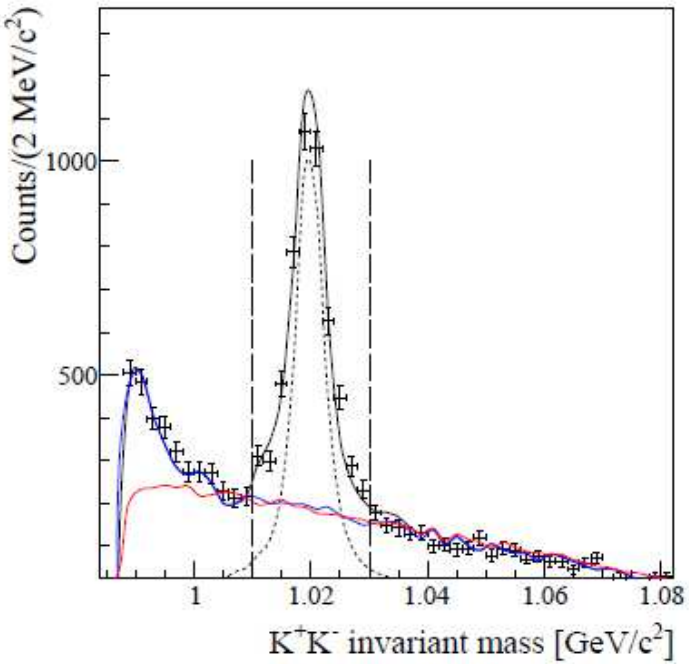


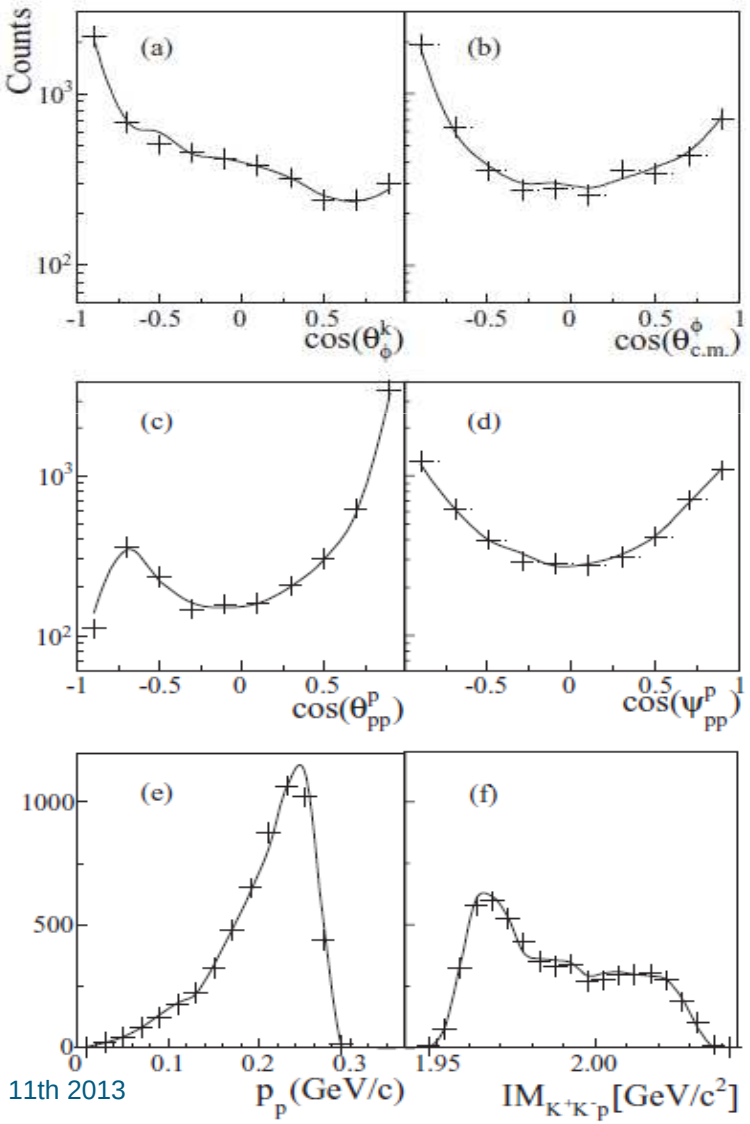
F. Balestra et al., Phys. Rev. C 63, 024004 (2001)

Acceptance correction: ϕ meson production

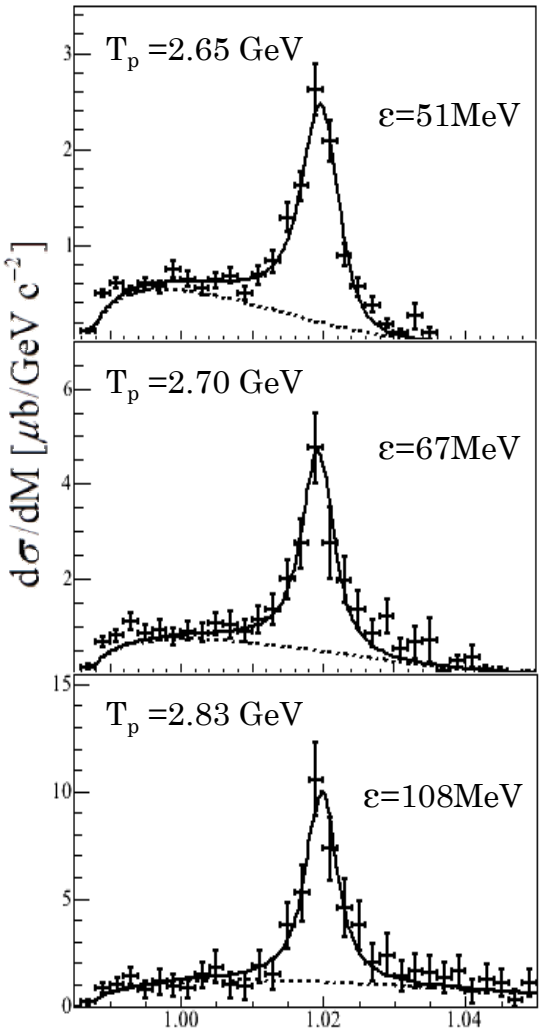
$$\overline{|M|^2} = A_{Ss}(\hat{k}\times\hat{K})^2 + A_{Ps}\vec{p}^{\,2} + A_{Pp}(\vec{q}\cdot\vec{p})^2$$
$$+A_{Sp}[3(\vec{q}\cdot\hat{K})^2 - \vec{q}^{\,2}]$$

Parameter	Fit value
A_{Ss}	1.0
A_{Sp}	9.9 ± 1.8
A_{Ps}	143 ± 4
A_{Pp}	293 ± 21





Acceptance correction: Non-ϕ kaon pair production



Y. Maeda et al., PRC77, 015204 (2008)

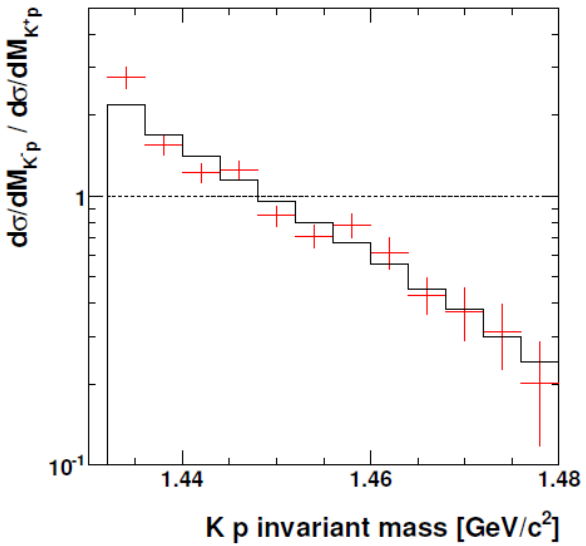
Assumption: K-p FSI effect

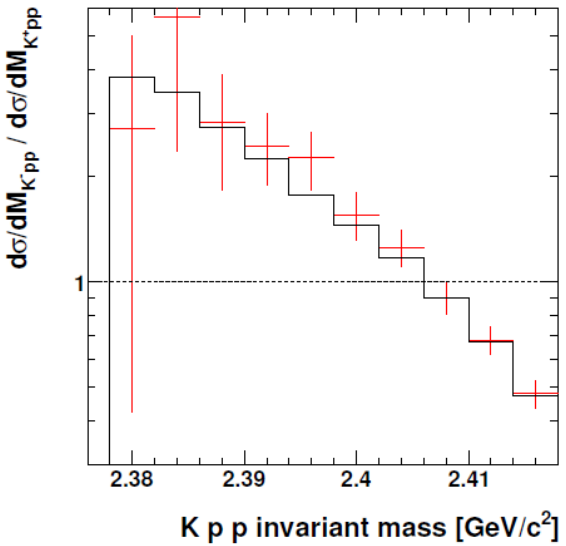
$$f(q) = \frac{1}{1 - iaq}$$

q: relative momentum
a: scattering length

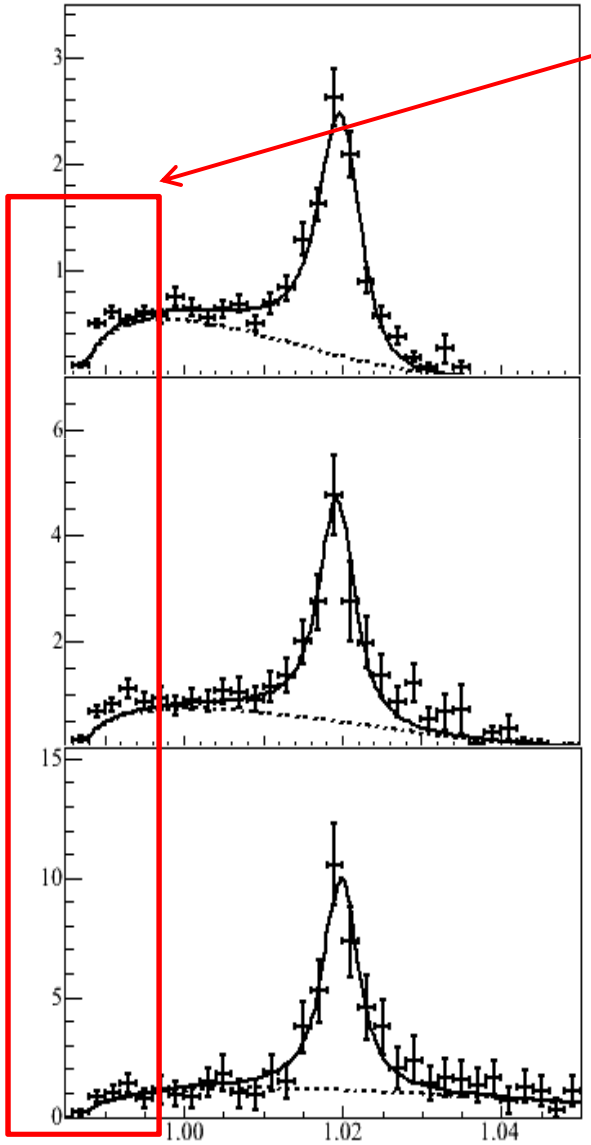
3-body FSI

$$f(q_{pp}) \times f(q_{K^- p_1}) \times f(q_{K^- p_2}) \text{ with } a_{K^- p} = 1.5i \text{ fm}$$





Acceptance correction: Non-ϕ kaon pair production



coupled channel effect $K^0\bar{K}^0 \rightleftharpoons K^+K^-$

Final state interactions:

$$|M_{pp\to ppK^+K^-}|^2 \approx |M_0|^2 |F_{FSI}|^2$$

$$F_{FSI} = f(q_{pp}) \times f(q_{K^-p_1}) \times f(q_{K^-p_2}) \times f(q_{KK})$$

Through iterative fitting the minimum χ^2 can be found.

- The effective scattering length of K-p was extracted:

$$\alpha_{K^-p} = (0.115 \pm 0.121) + (2.45 \pm 1.07)i \text{ fm}$$

The parameters for charge exchange effect:

$$B_1 / B_0 = Ce^{i\phi_c} \quad C = 0.50 \pm 0.05 \quad \phi_c = 76.2 \pm 6$$

ε_{kk}=25MeV

- Previous measurement at ε_{kk}=51MeV

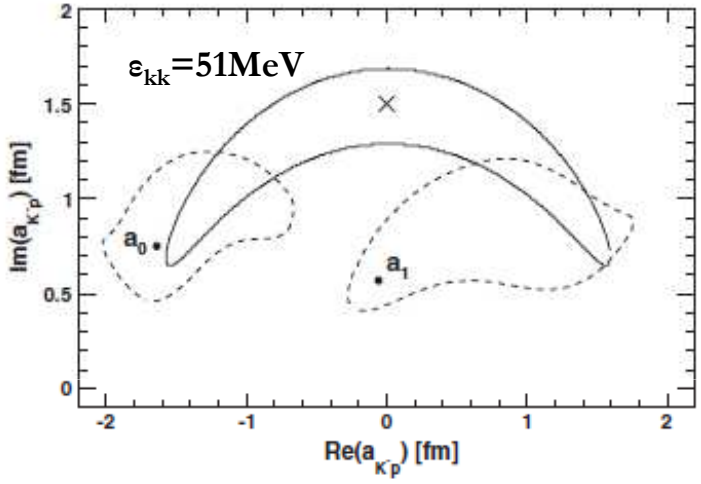
The effective scattering length: $\alpha_{K^-p} = 1.5i$ fm

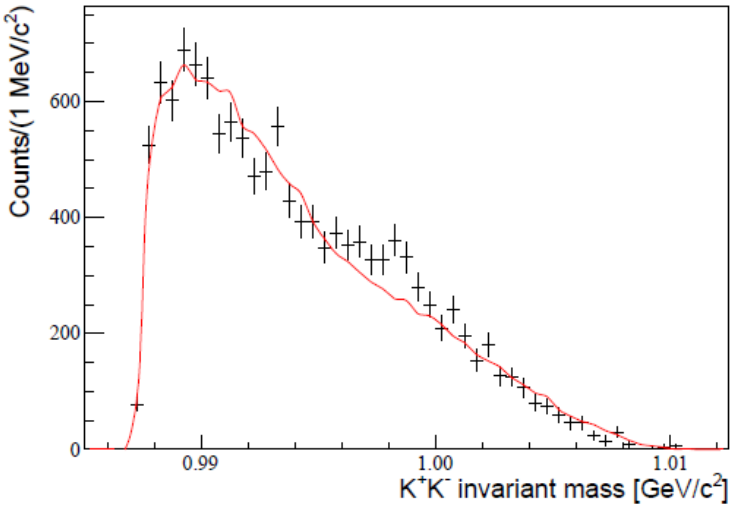
Charge exchange effect: $C = 0.62^{+0.16+0.07}_{-0.11-0.07}$

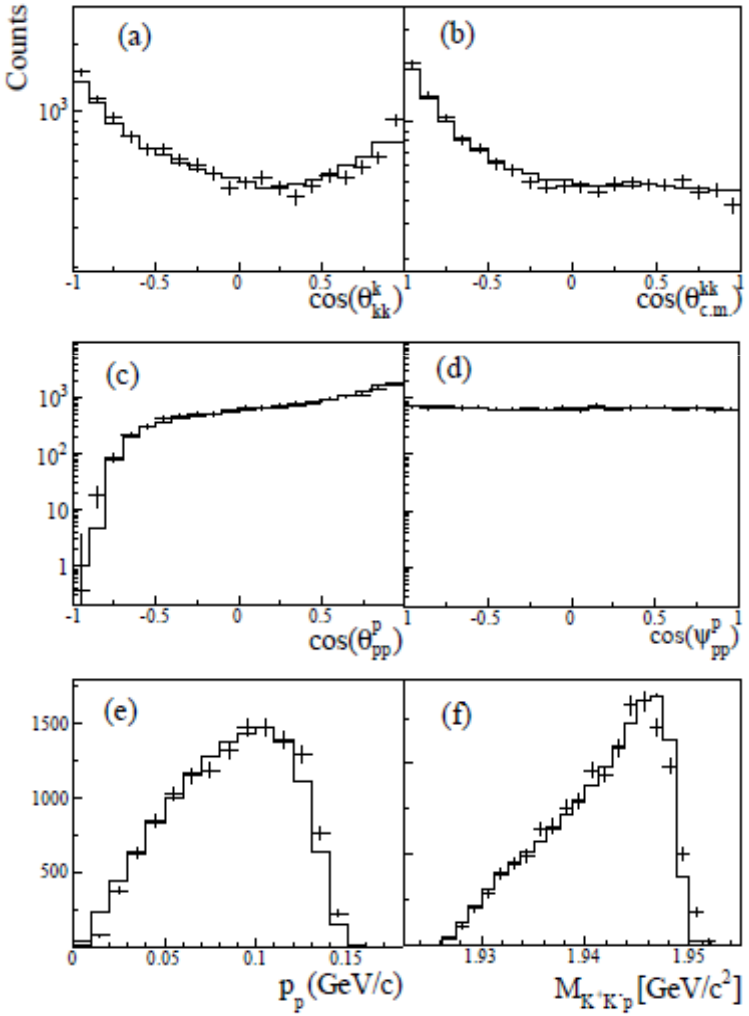
$$\phi_c = 81^{+36+13}_{-25-13}$$

Acceptance correction: kaon pair production

T_p=2.57 GeV







Systematic uncertainty

- Luminosity determination: 8~9%

  - Major source: efficiency corrections in the Fd system, acceptance corrections for pp elastic reaction, and momentum reconstructions.

  - Using the pp elastic method cancel out the systematic uncertainties from the accelerator, target system and Fd.

- Background subtraction: ~ 3%

  - Estimated by varying the range of the side-band around the missing-mass peak when fitting the background .

- Acceptance correction:

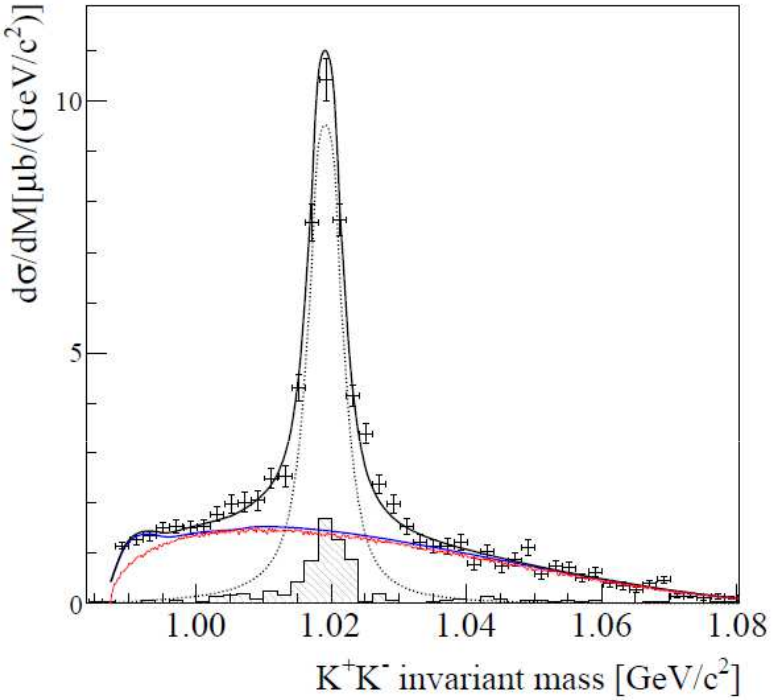
  - Estimated as the differences between the distributions corrected by the models and those corrected by the phase space.

- Efficiency measurement: ~3%

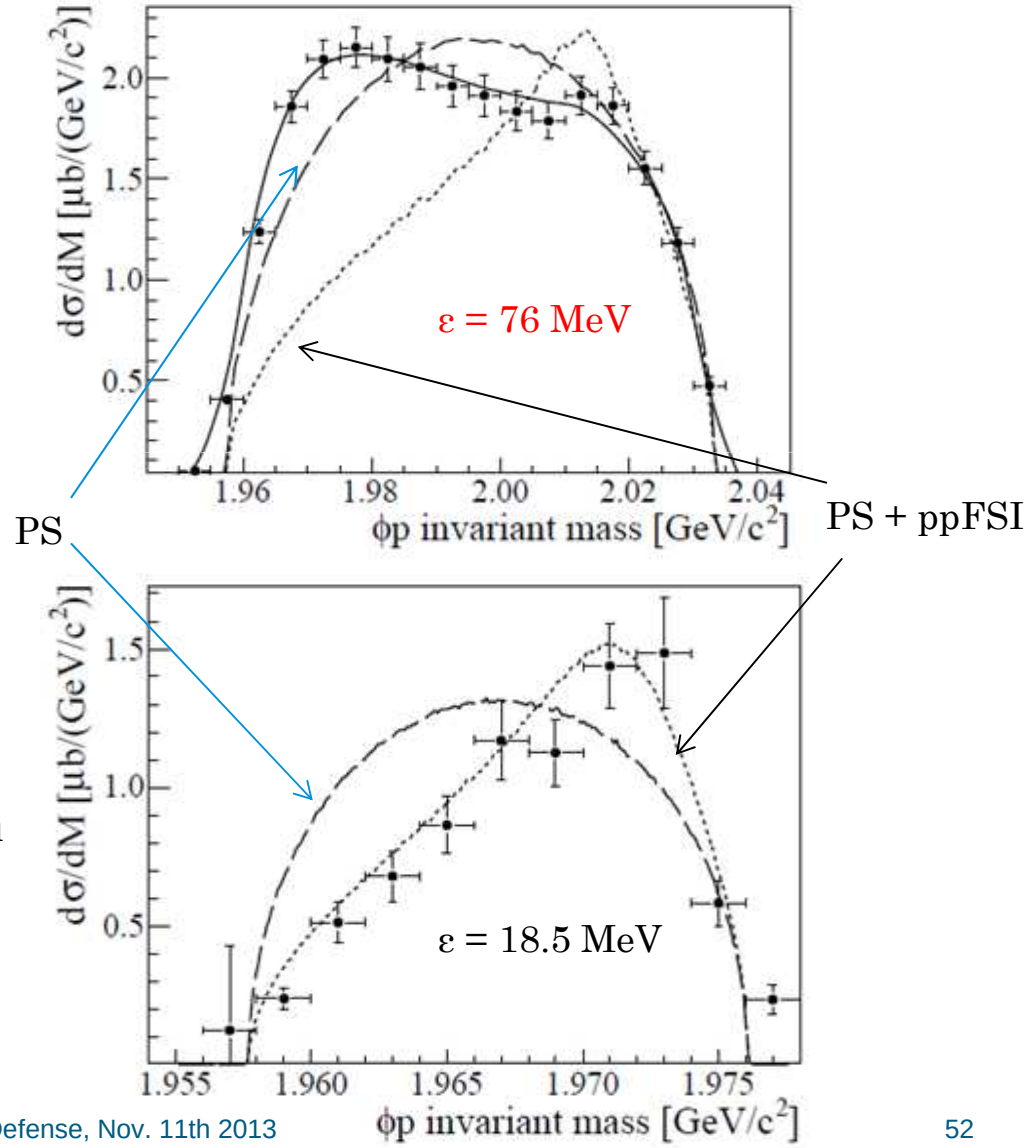
  - From the momenta spread inside each of the STOP counters

ϕ production in pp collisions @ Tp=2.83 GeV

Invariant mass distribution



The distribution is given by the ϕ meson folded with a Gaussian to account for detector resolution.



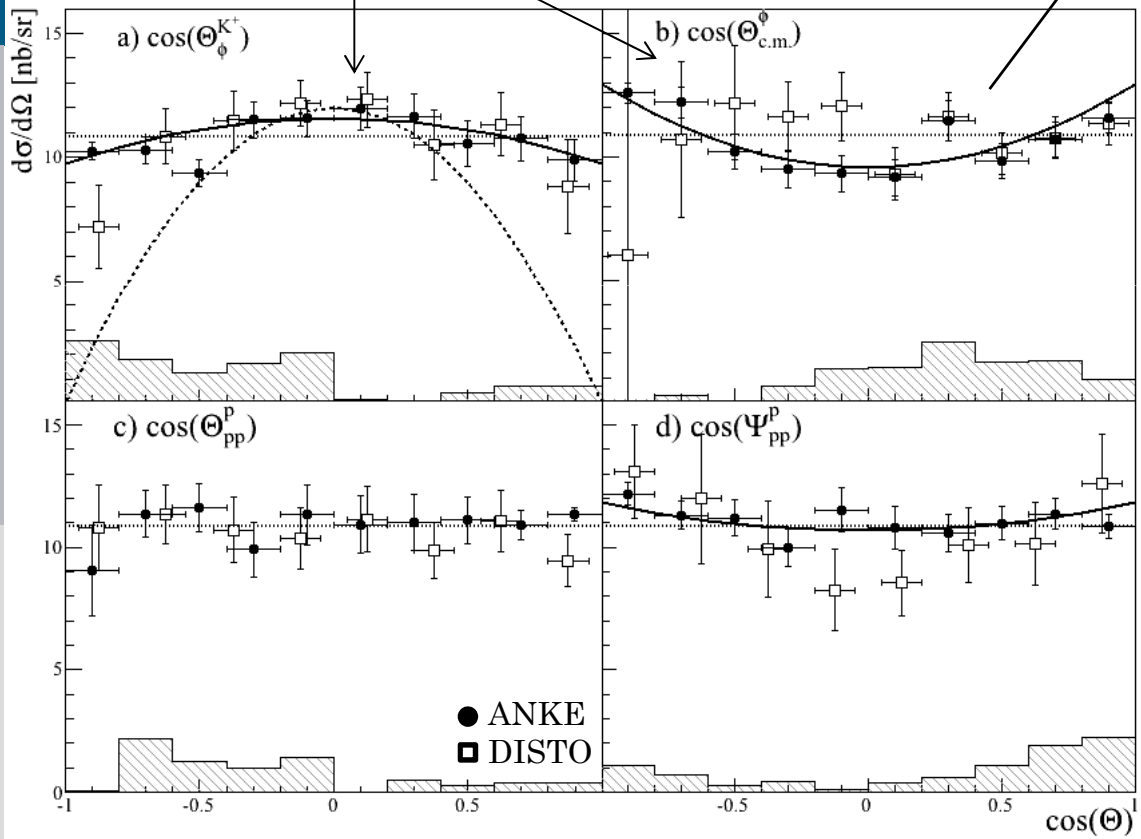
Angular distribution at ε = 76 MeV

$$\frac{d\sigma}{d\Omega} \propto \left[(1-\rho_{00})\sin^2\theta_\phi^K + 2\rho_{00}\cos^2\theta_\phi^K\right] \quad \rho_{00} = 0.30 \pm 0.01$$

(DISTO) $\rho_{00} = 0.23 \pm 0.04$

High partial waves

nucleonic current contribution and ϕNN coupling constant



$$\frac{d\sigma}{d\Omega} = a\left[1 + b\,P_2(\cos\theta)\right]$$

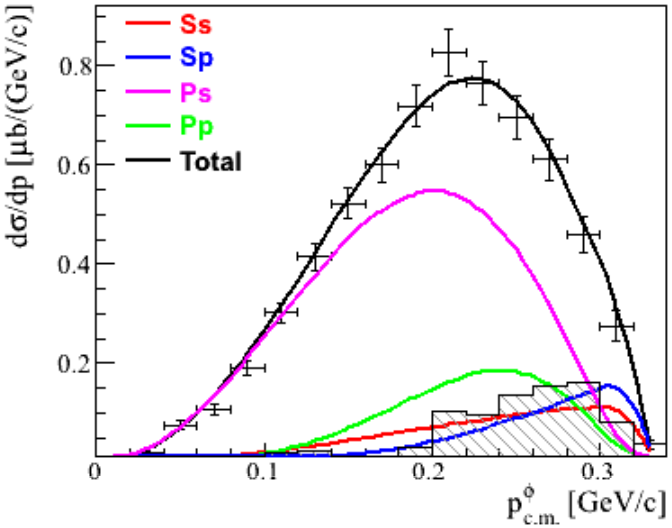
	a [nb/sr]	b
$\cos\Theta^K_\phi$	10.96±0.23	-0.11±0.04
$\cos\Theta^\phi_{c.m.}$	10.71±0.21	0.21±0.04
$\cos\Psi^p_{pp}$	11.06±0.22	0.07±0.04

angular distribution should be symmetric with respect to cosθ =0

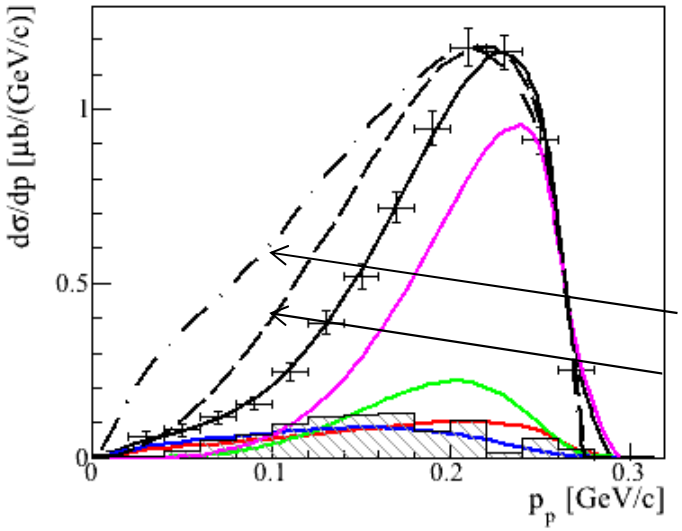
K. Nakayama et al., PRC 60, 055209 (1999).
K. Tsushima and K. Nakayama, PRC 68, 034612 (2003).
Q. J Ye et al., PRC 85, 035211 (2012).

Momentum distribution

ANKE



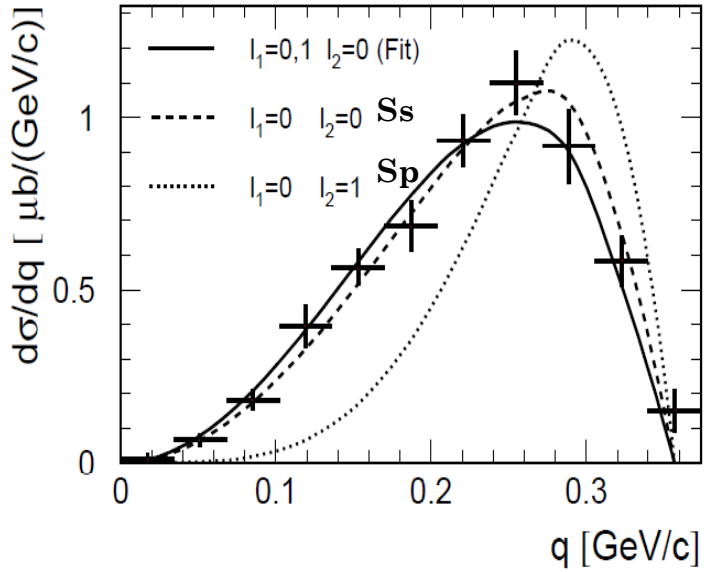
P waves dominate

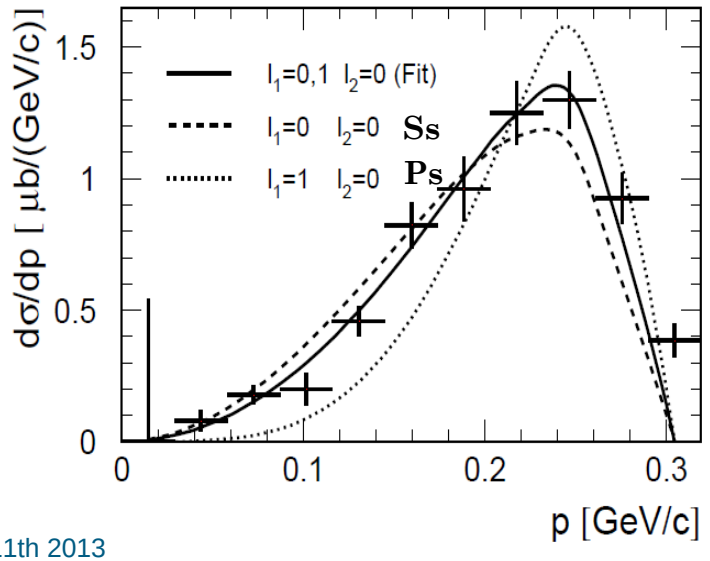


PS + ppFSI

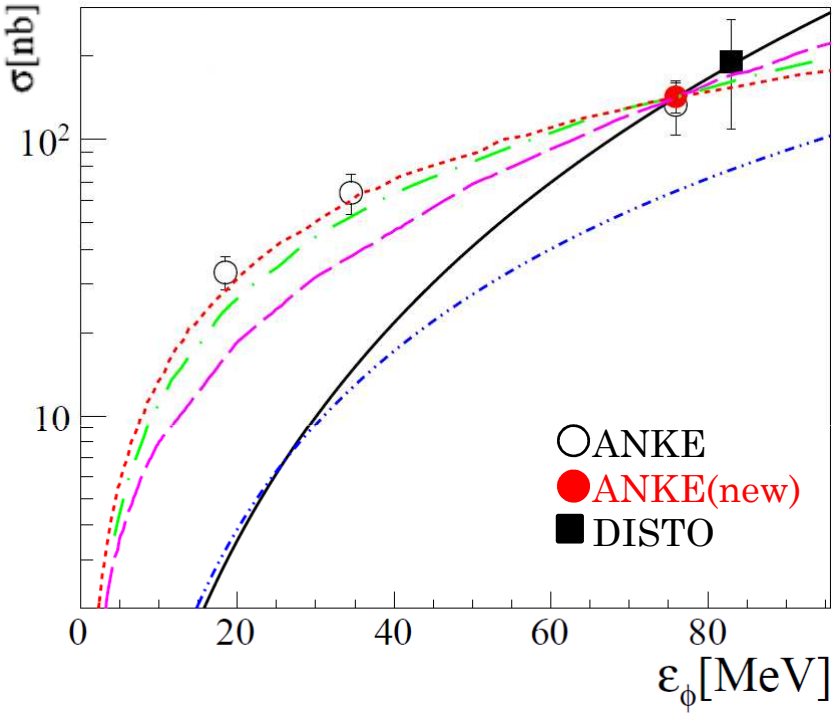
PS

DISTO





ppϕ total cross section



Xie *et al.*, resonant model; Sibirtsev, one pion exchange+ exotic baryons

Kaptari and Kampfer, mesonic and nucleonic current

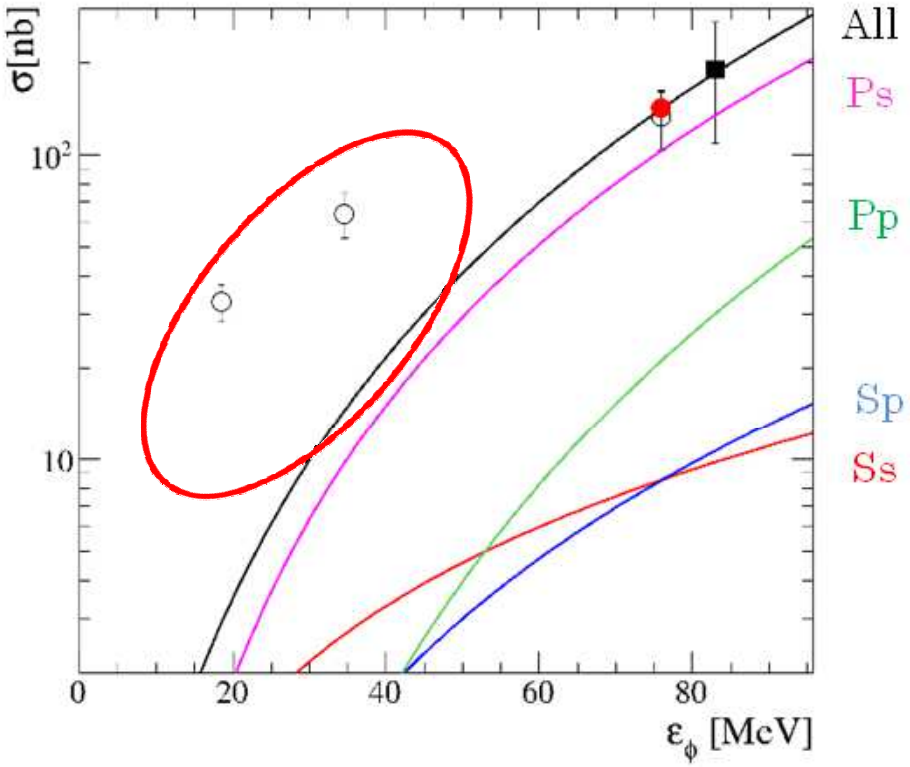
Sibirtsev, one pion exchange

Tsushima and Nakayama, mesonic and nucleonic current

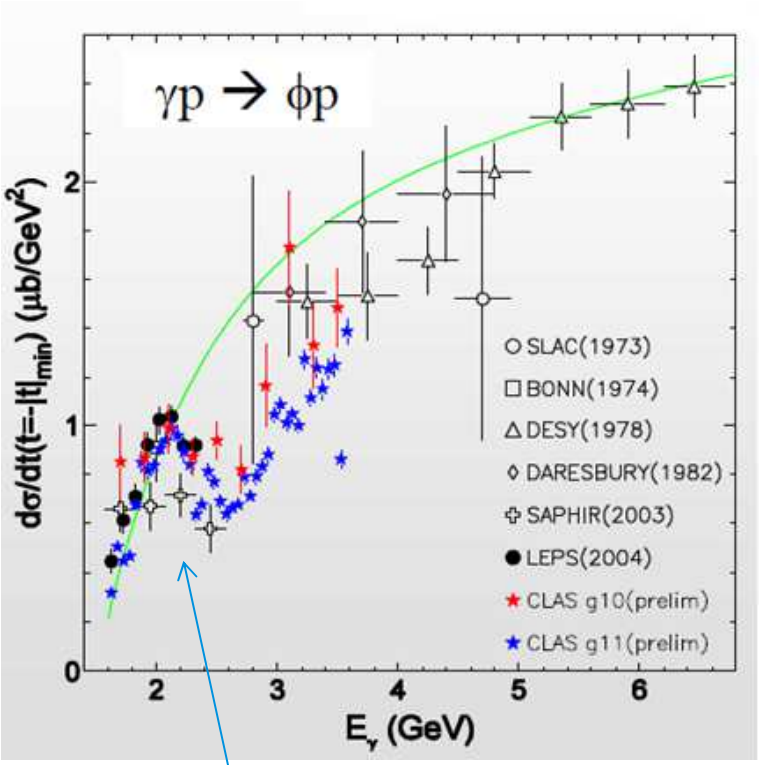
More differential distributions needed to distinguish different models.

Q. J Ye et al., PRC 85, 035211 (2012).

ppϕ total cross section



ϕp enhancement in photoproduction

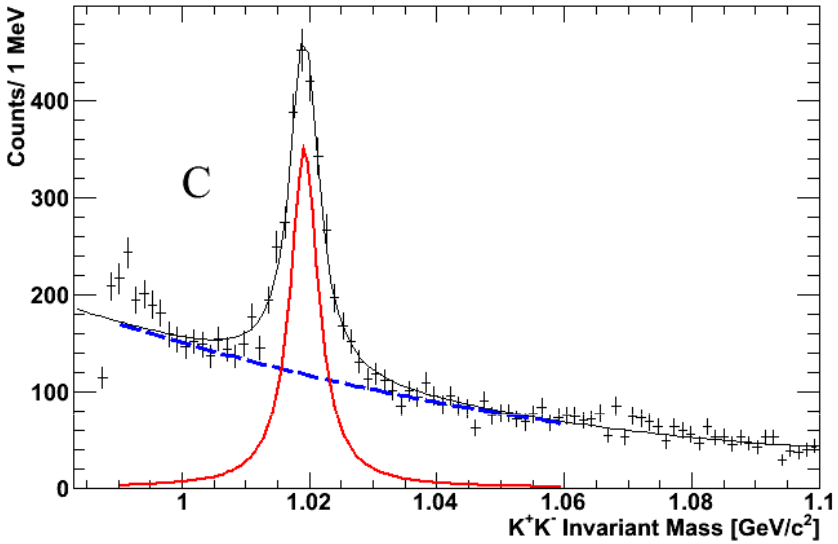


Simplest way out: A ϕp near threshold enhancement leads to a significant energy dependence of some A_{Ll} coefficients.

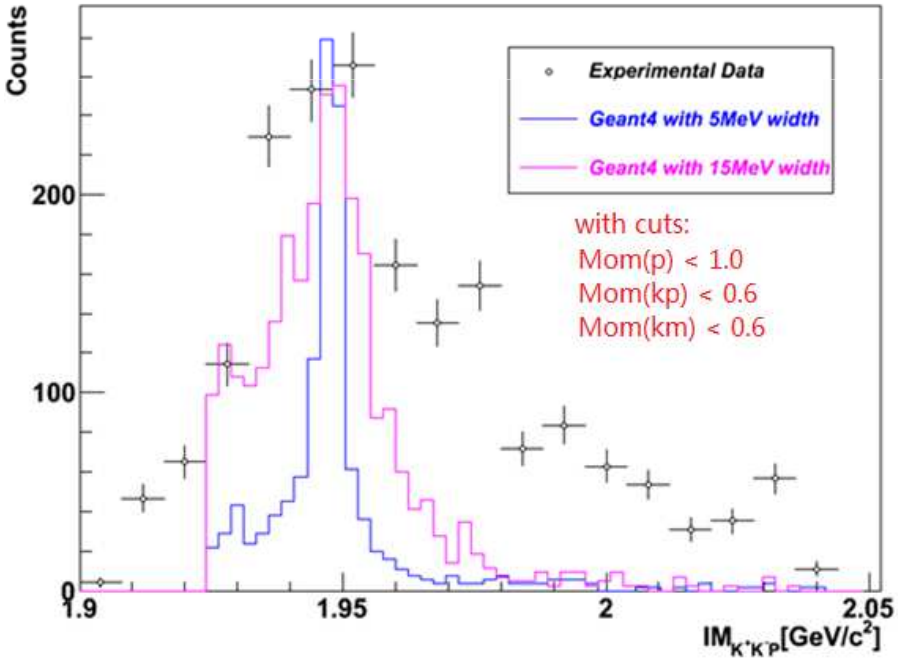
Q. J Ye et al., PRC 85, 035211 (2012).

Bump!

pA Results at T_p= 2.83 GeV



Target: ^{12}C, ^{63}Cu, ^{107}Ag, ^{197}Au.

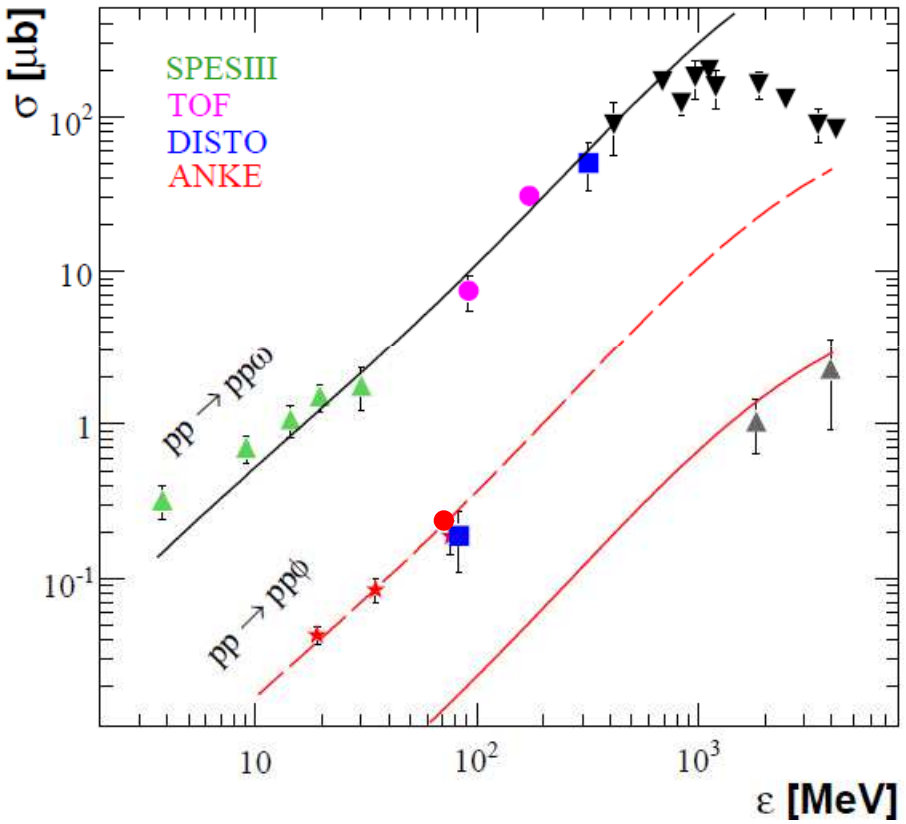


No conclusive evidence of a ϕ-N bound state, it might be due to:

- high proton energy, expected below threshold.
- the final state interactions.

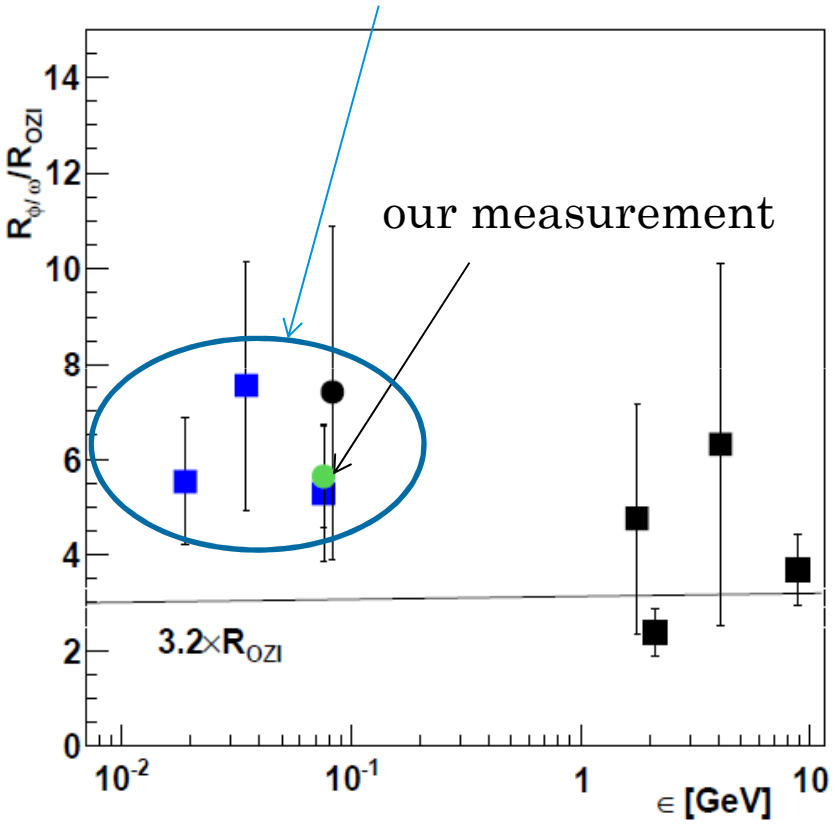
Two different widths were assumed: 5MeV and 15MeV.

ϕ/ω ratio



$$R_{\phi/\omega} = \frac{\sigma(pp \to pp\phi)}{\sigma(pp \to pp\omega)}$$

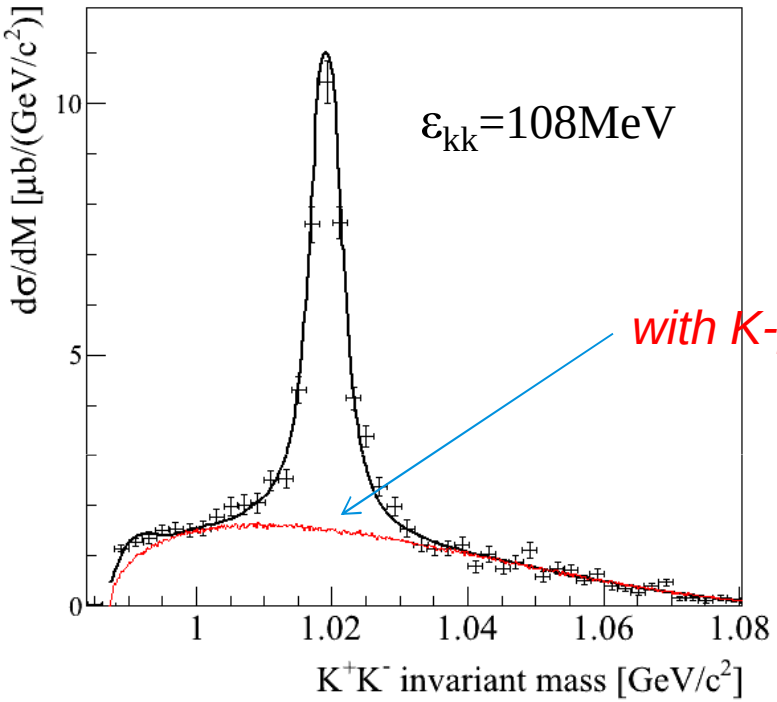
additional production mechanism



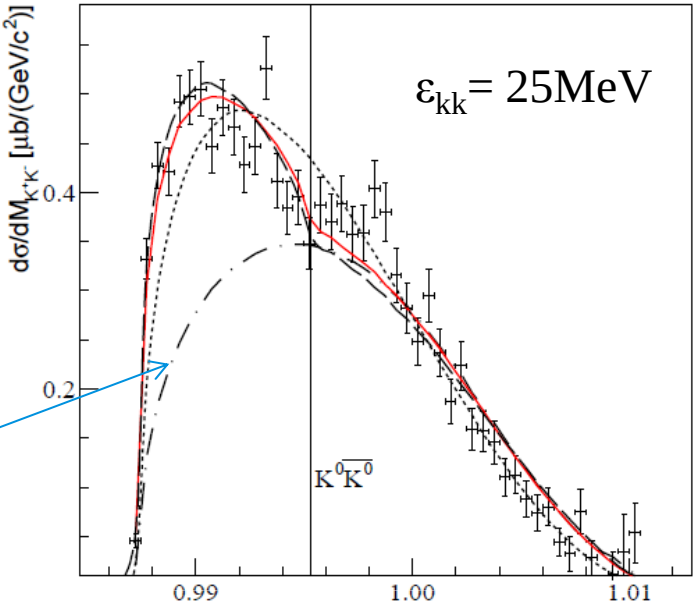
Experimental results show that $\phi\rho\pi$ coupling itself violates OZI rule

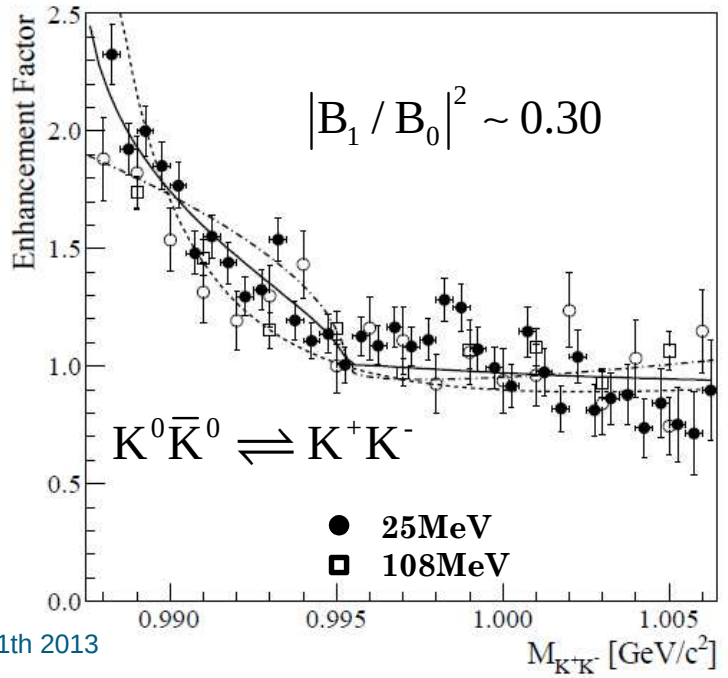
Non-Φ kaon-pair production in pp @ Tp=2.83 & 2.57 GeV

Invariant mass distributions



with K-p fsi

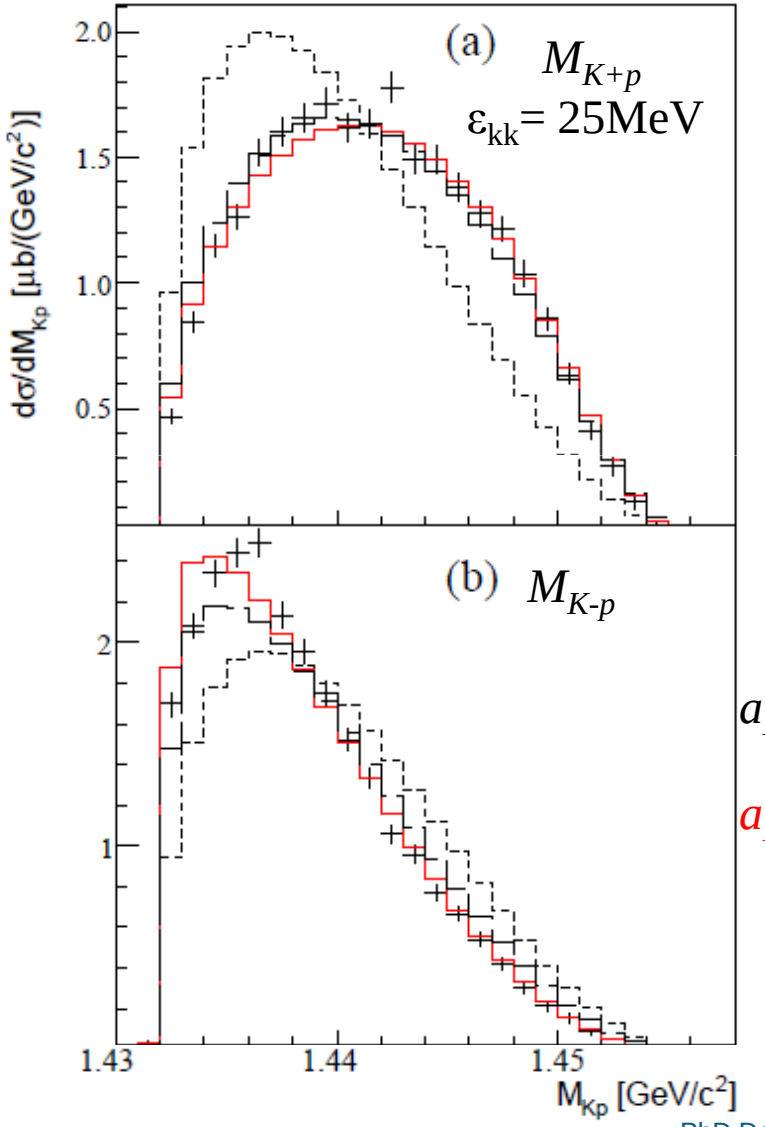




Isospin-0 $K\bar{K}$ pairs in the near threshold region that is about three times stronger than that for Isospin-1.

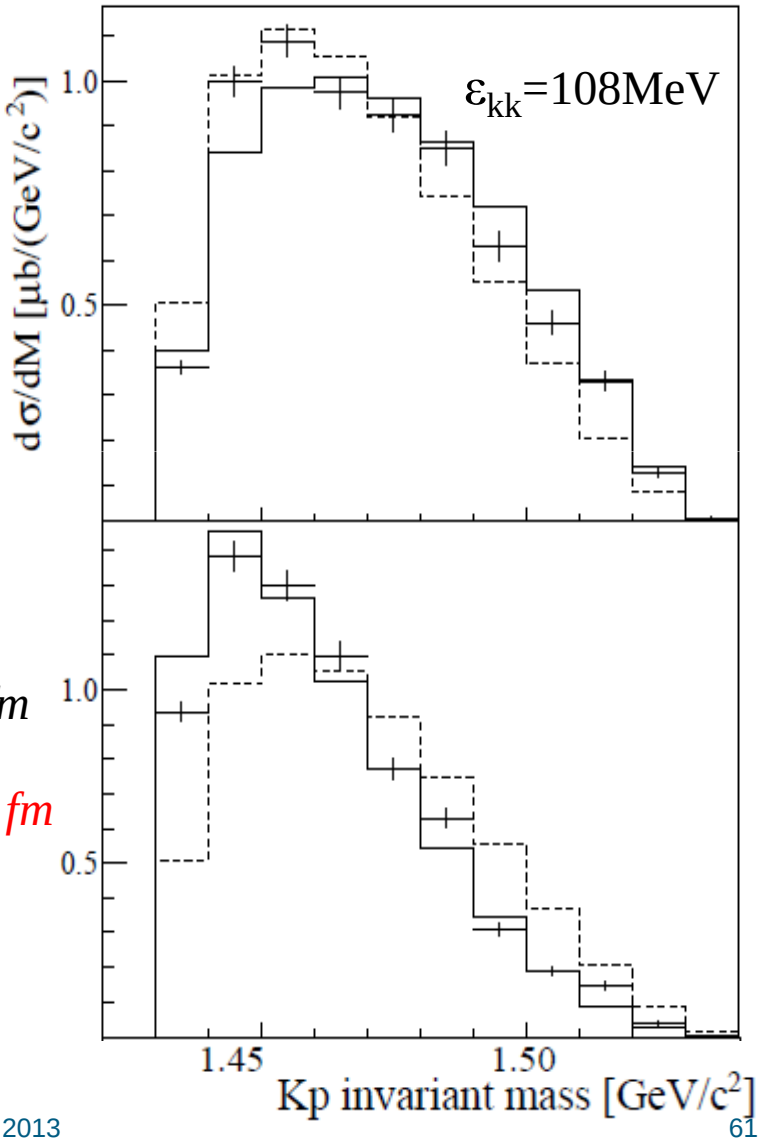
Q. J Ye et al., PRC 85, 035211 (2012).
Q.J Ye et al, PRC 86, 065203 (2013).

Invariant mass distributions

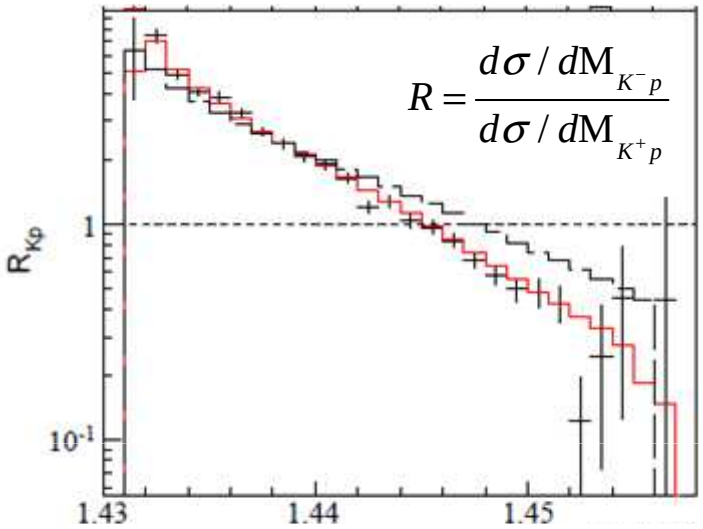


a_{K-p} = 1.5*i* fm

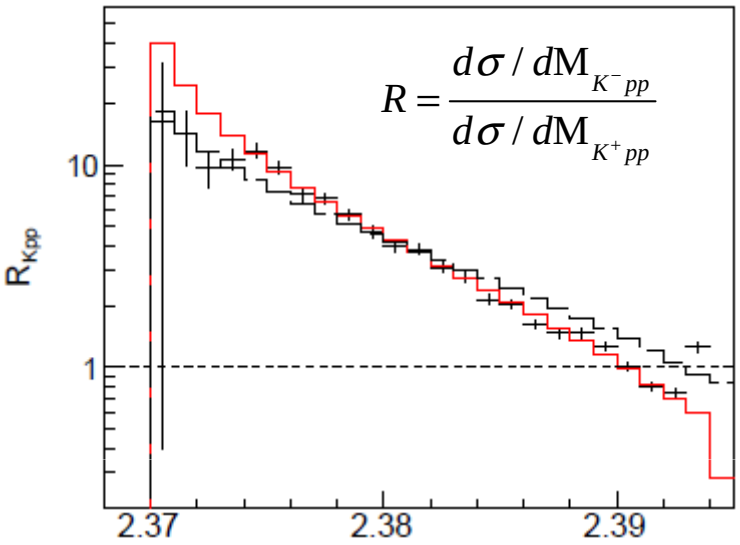
a_{K-p} = 2.45*i* fm

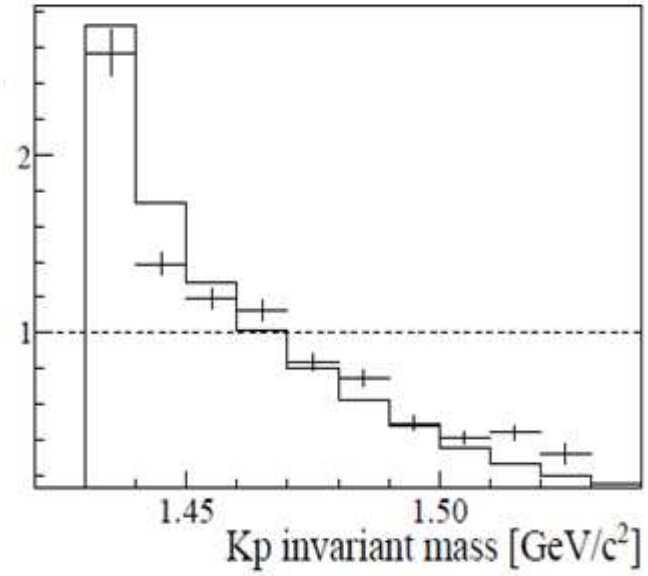


Ratio with respect to M_{kp} and M_{kpp}

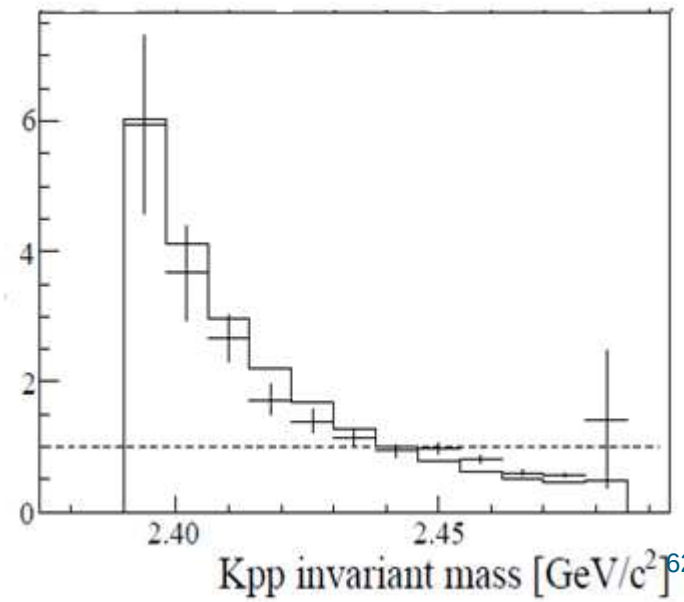


ε_{kk}= 25MeV

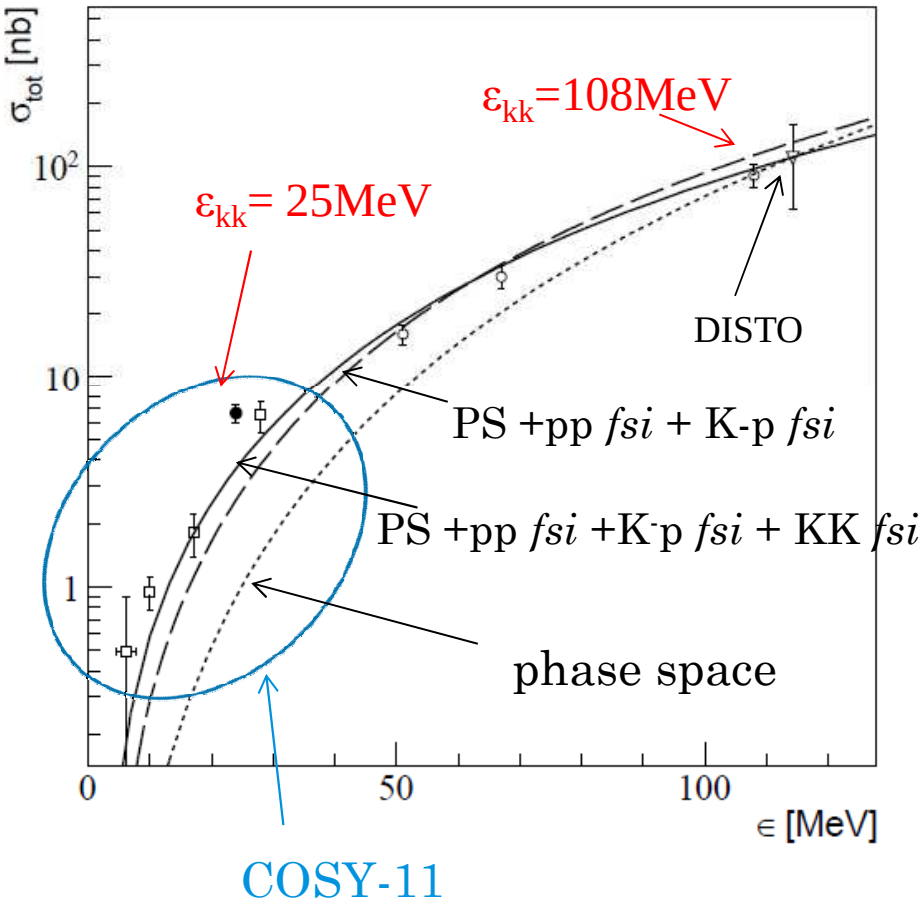




ε_{kk}=108MeV



Total cross section



- Low statistics in COSY-11 data:

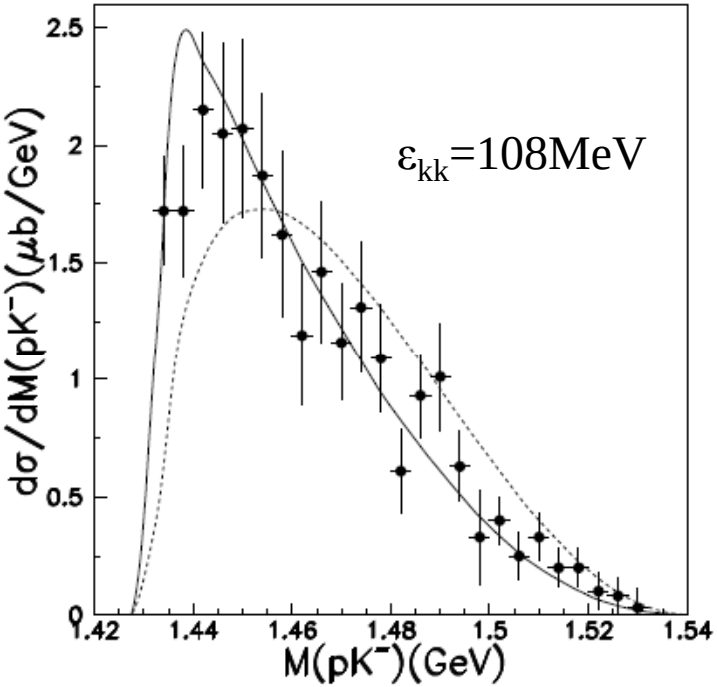
  ε = 10 MeV (27 events)
  ε = 17 MeV (~60 events)
  ε = 28 MeV (30 events)

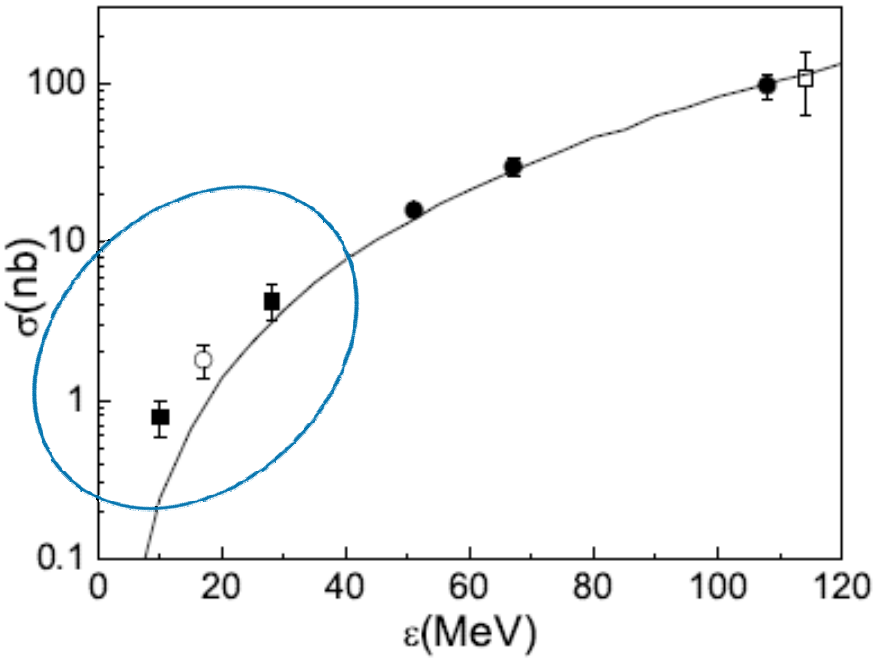
- Total cross sections from COSY-11 increase by 20~50% after considering final state interaction.

- DISTO cross sections are based on phase space simulation.

- K-p with the effective scattering length 1.5i *fm* is shown.

pp → ppΛ(1405)





$pp \rightarrow pN^{*}(1535) \Rightarrow N^{*}(1535) \rightarrow \Lambda(1405)K^{+}$

- Suggests that Λ(1405) is the main doorway state for $ppK^{+}K^{-}$
- Contribution of a_0/f_0 is rather small.

Similar conclusion by Xie & Wilkin Phys. Rev. C 82, 025210 (2010);

Summary and …

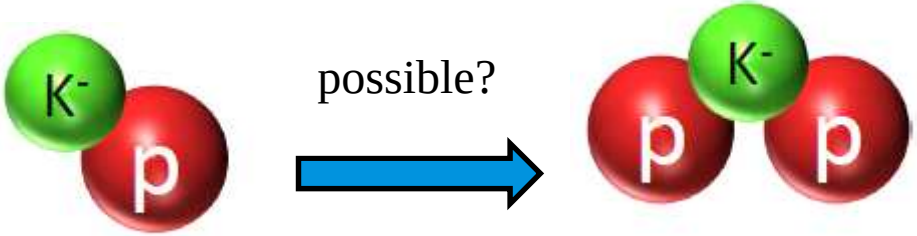
- The contribution from purely S-wave final states represents only a small fraction of the total cross section at ε=76 MeV
  - ➢ explains why there is no S-wave pp-FSI in ANKE & DISTO data
  - ➢ a low mass ϕp enhancement is required.
- The investigation of ϕNN coupling constant is crucial for the OZI rule violation and the intrinsic strangeness inside proton.
- No evidence is found for a possible ϕN bound state.

ϕ meson

- The studies of ppK^+K^- show strong K^-p FSI.
- Coupled channel effect was observed at low invariant mass of K^+K^-
- The reaction cannot be dominated by the a_0/f_0 production.
- It is possible via the Λ(1405) production.

non-ϕ kaon pair

Outlook: Search for the K⁻pp bound state



Λ(1405) K⁻p strongly attractive

Λ(1405) I=0 $J^p = 1/2^-$

- FINUDA @ $K^- + A \rightarrow p + \Lambda + X$

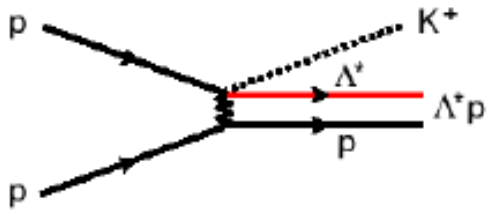
$M_{K\text{-}pp}$=2255 MeV/c²

$\Gamma = 67^{+14}_{-11}(sta)^{+2}_{-3}(sys)$MeV

- DISTO @ $p + p \rightarrow p + \Lambda + K^+$

$M_{K\text{-}pp}$=2267MeV/c²

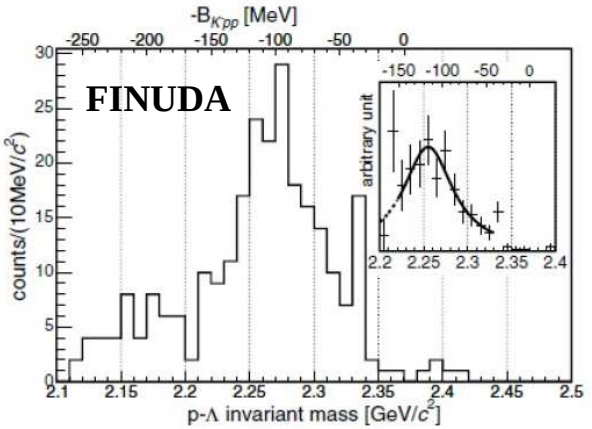
$\Gamma = 118 \pm 8 \pm 10$MeV



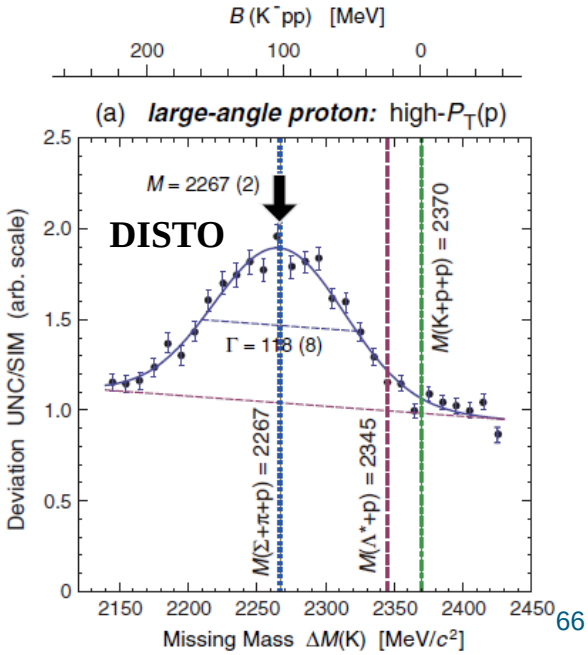
ANKE

$$p + p \longrightarrow ppK^- + K^+$$
$$\hookrightarrow \boxed{\Lambda + p}$$
$$\hookrightarrow p + \pi^-$$

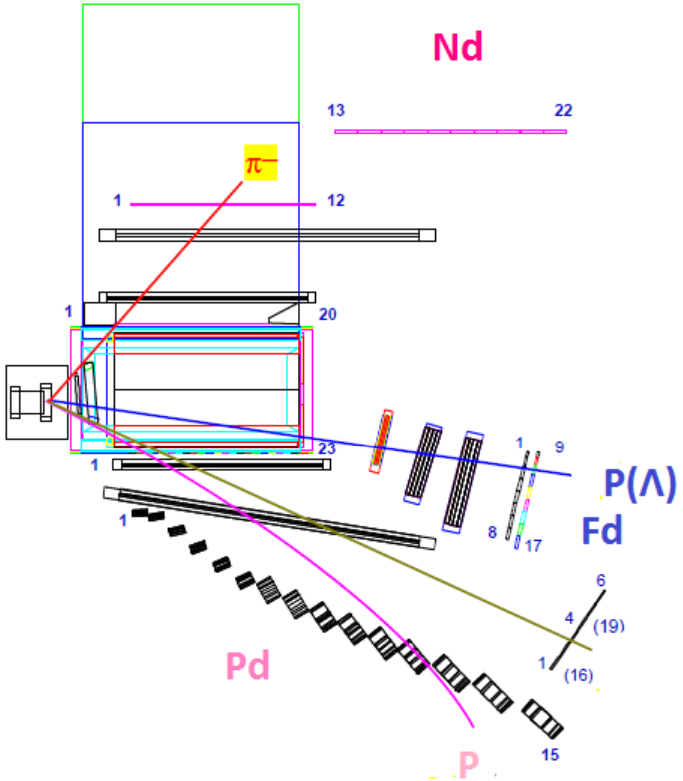
M. Agnello et al. Phys. Rev. Lett. **94 (2005)**



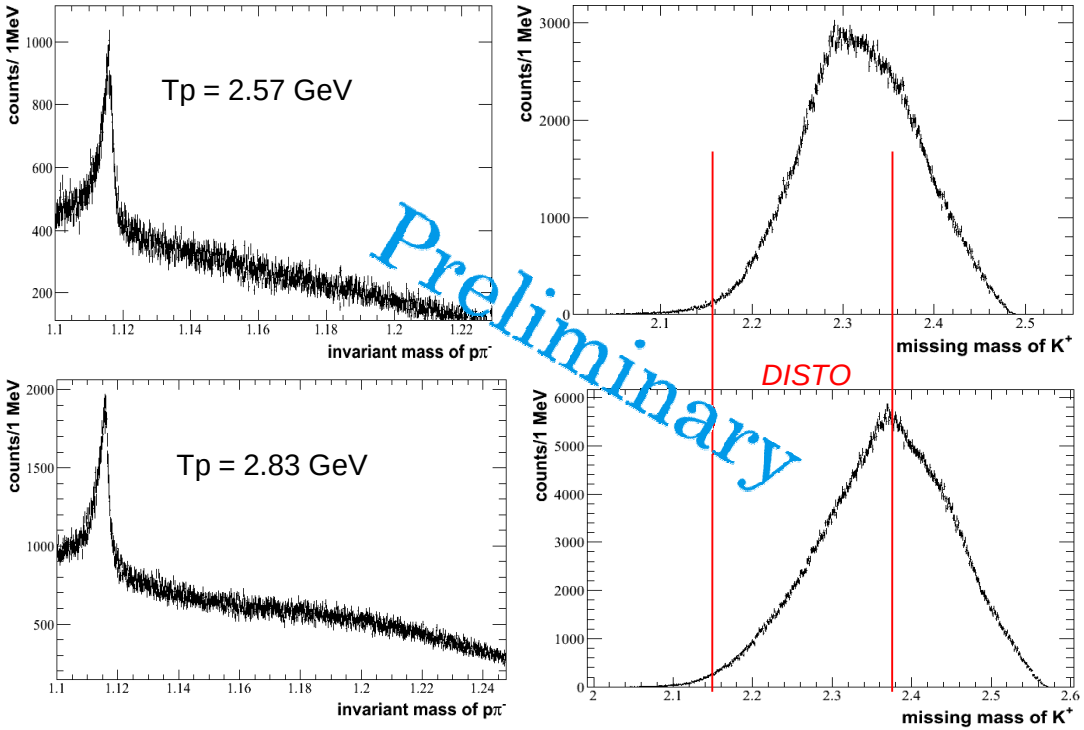
T. Yamazaki et al. Phys. Rev. Lett. **104, (2010)**



Outlook: Search for K⁻pp at COSY-ANKE



$p + p \rightarrow K^+ + X$

$X \rightarrow \Lambda + p$

Data have been collected for two energy Tp = 2.57 and 2.83 GeV.