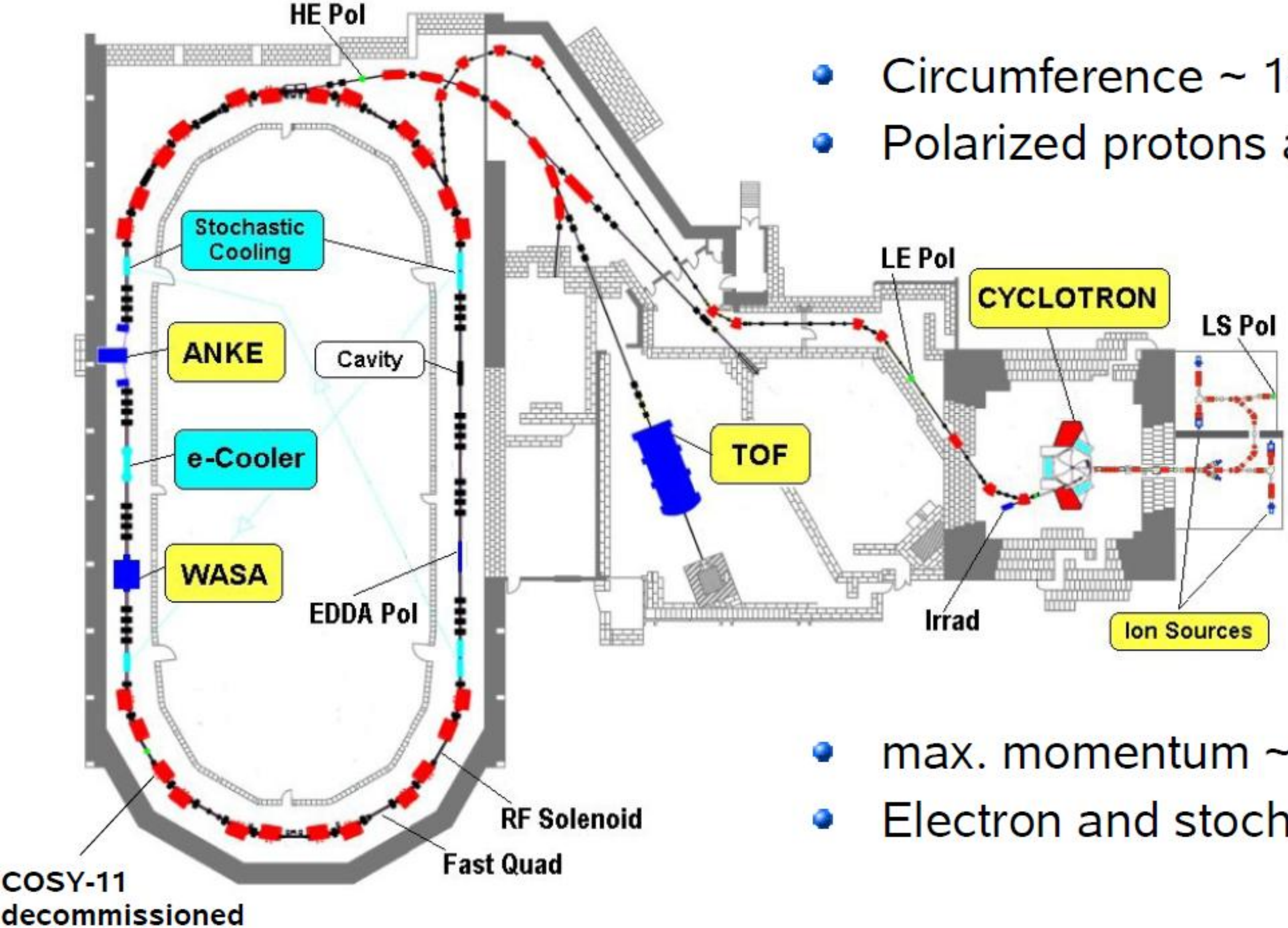
Strangeness Production at COSY

1. Experimental Facilities at COSY
2. Kaon Pair Production in pp, pd, dd Collisions
3. Near-Threshold Production of Φ Mesons
4. Hyperon Production in pp and pn Reactions (Λ, Σ^0, Σ^+, Σ^-)
5. Λp Final State Interaction in $pp \to K^+(\Lambda p)$
6. Summary

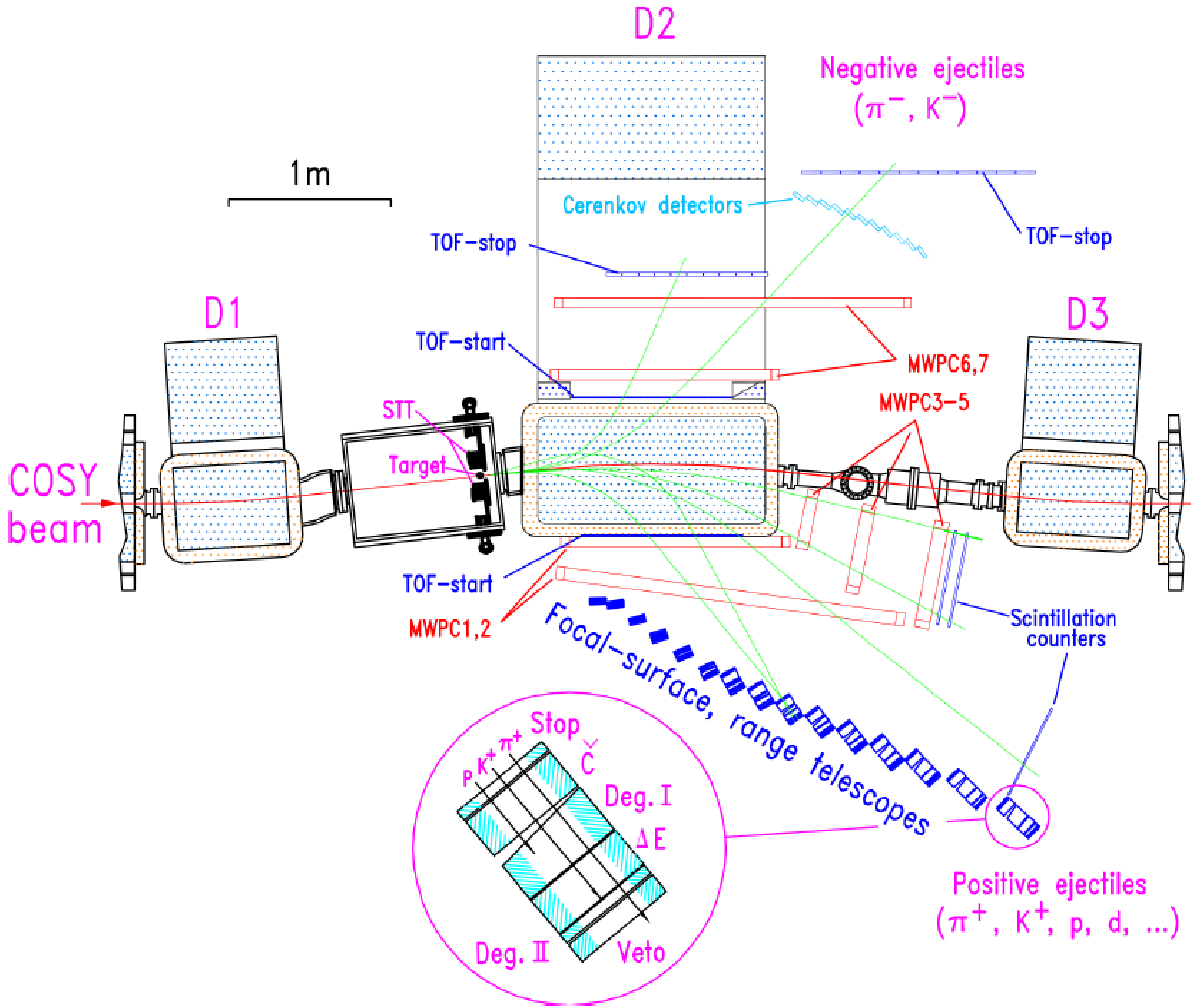
Experimental Facilities at COSY



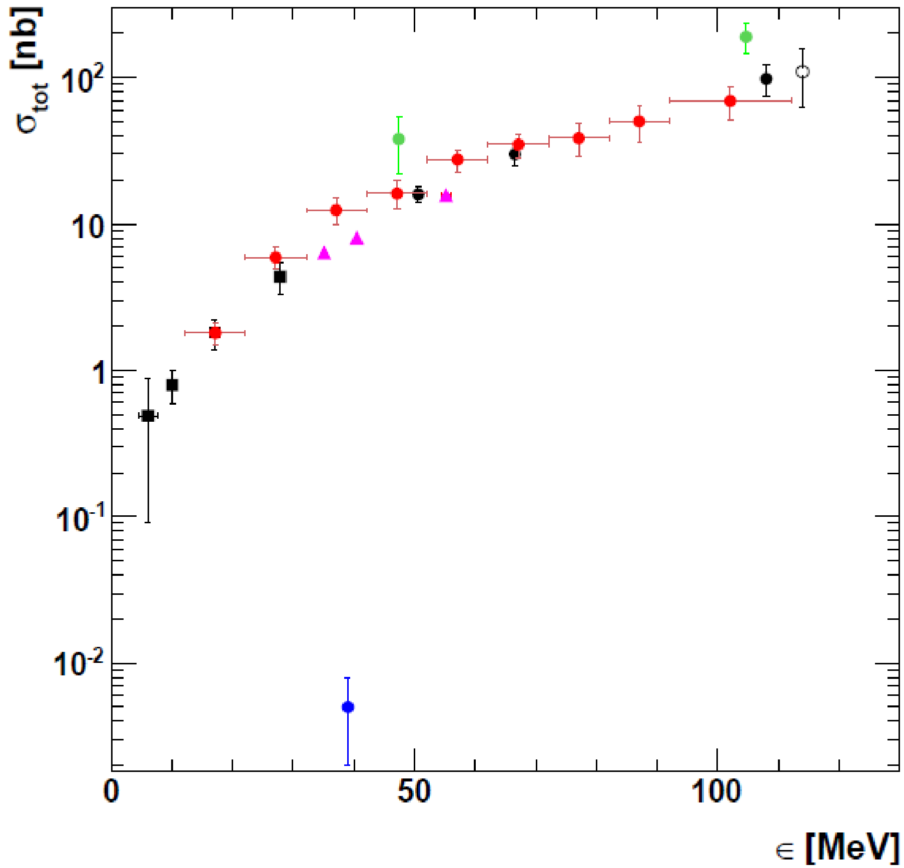
- Circumference ~ 184m
- Polarized protons and deuterons

- max. momentum ~ 3.7 GeV/c
- Electron and stochastic cooling

COSY-ANKE Spectrometer



Kaon Pair Production



$pp \to pp\ K^+K^-$ (black) COSY-11, COSY-ANKE (open circle) SATURNE

$pp \to d\ K^+K^0$ (green) COSY-ANKE

$pn \to d\ K^+K^-$ (red) COSY-ANKE

$pd \to {}^3\mathrm{He}\ K^+K^-$ (pink) COSY-MOMO

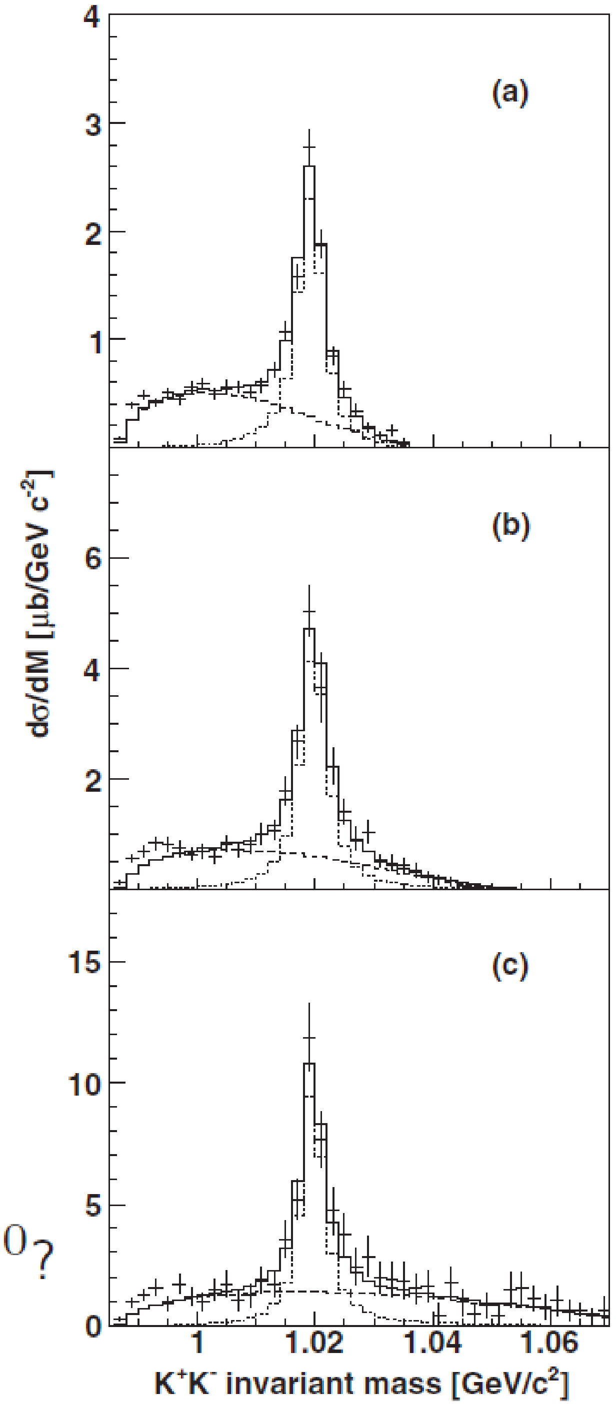
$dd \to {}^4\mathrm{He}\ K^+K^-$ (blue) COSY-ANKE

$pp \to pp\, K^+K^-$

$pp \to pp\, \phi$

COSY-ANKE

- pp FSI
- K^-p FSI
- K^+K^- FSI
- $K^+K^- \leftrightarrow K^0\bar{K}^0$?



$\epsilon_{KK} = 51$ MeV

$\sigma_{KK} = 16.0 \pm 1.4$ nb

$\sigma_\phi = 33 \pm 5$ nb

$\epsilon_{KK} = 67$ MeV

$\sigma_{KK} = 30 \pm 4$ nb

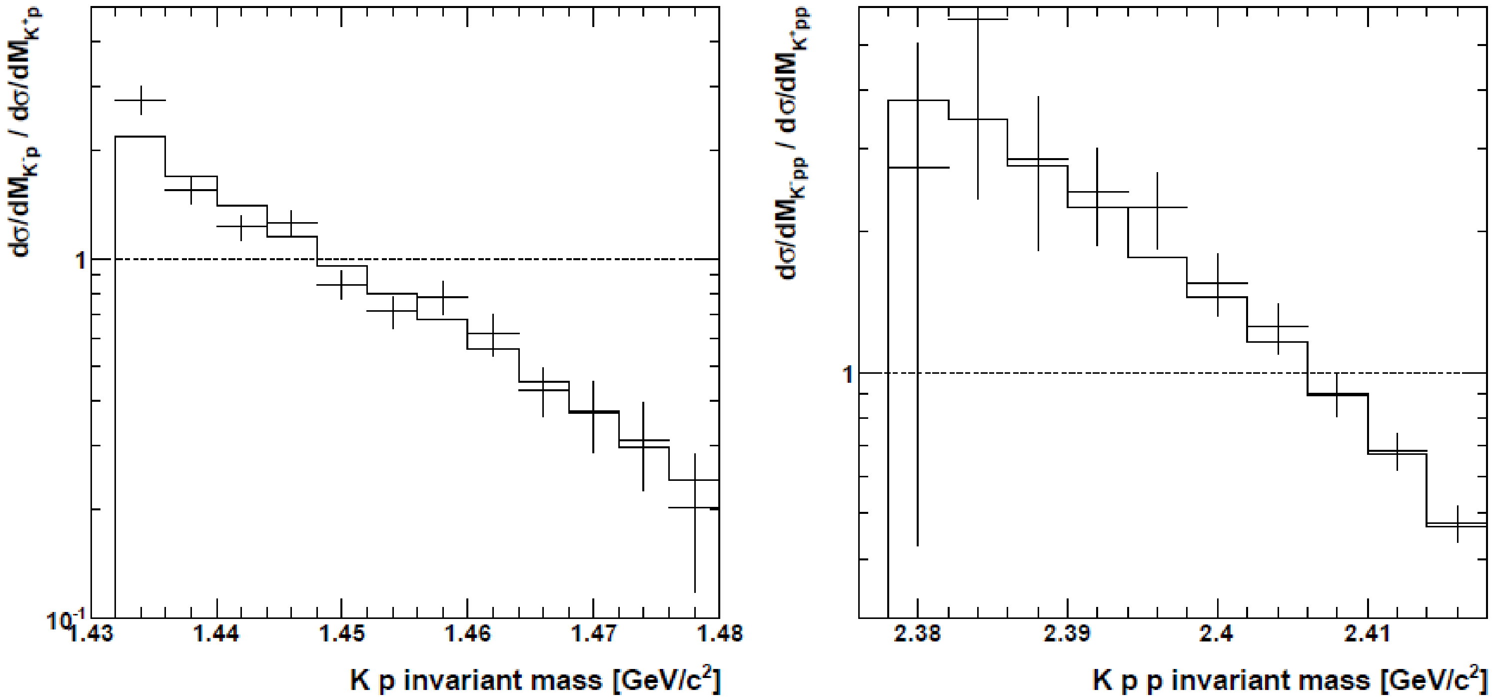
$\sigma_\phi = 64 \pm 11$ nb

$\epsilon_{KK} = 108$ MeV

$\sigma_{KK} = 98 \pm 17$ nb

$\sigma_\phi = 133 \pm 30$ nb

K^-p **FSI in** $pp \to pp\,K^+K^-$

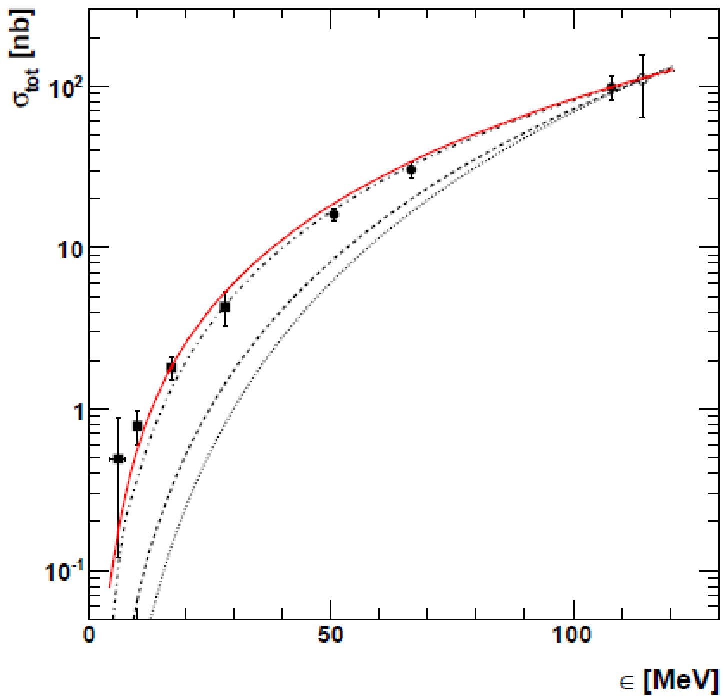


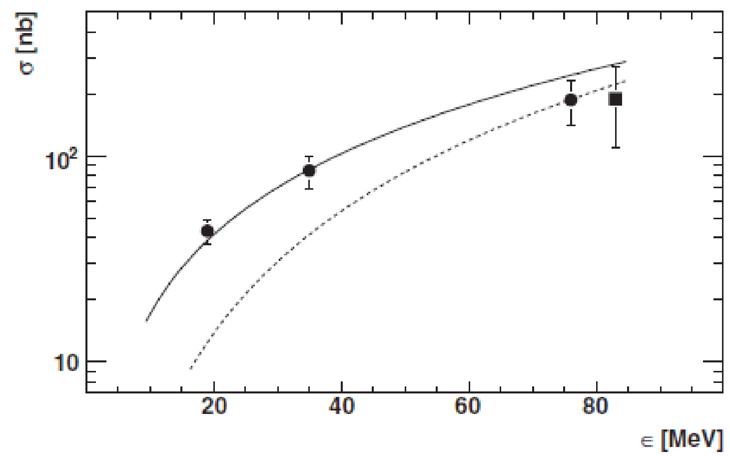
$\frac{d\sigma}{dM_{K^-p}} / \frac{d\sigma}{dM_{K^+p}}$ and $\frac{d\sigma}{dM_{K^-pp}} / \frac{d\sigma}{dM_{K^+pp}}$

Effective K^-p scattering length $a_{K^-p} = (0 + 1.5i)$ fm

$pp \to pp\, K^+ K^-$

$pp \to pp\, \phi$





dotted: four-body phase space

dashed: includes pp FSI

dot-dashed: includes $K^- p$ FSI

solid-red: includes $K^+ K^-$ FSI

dotted: three-body phase space

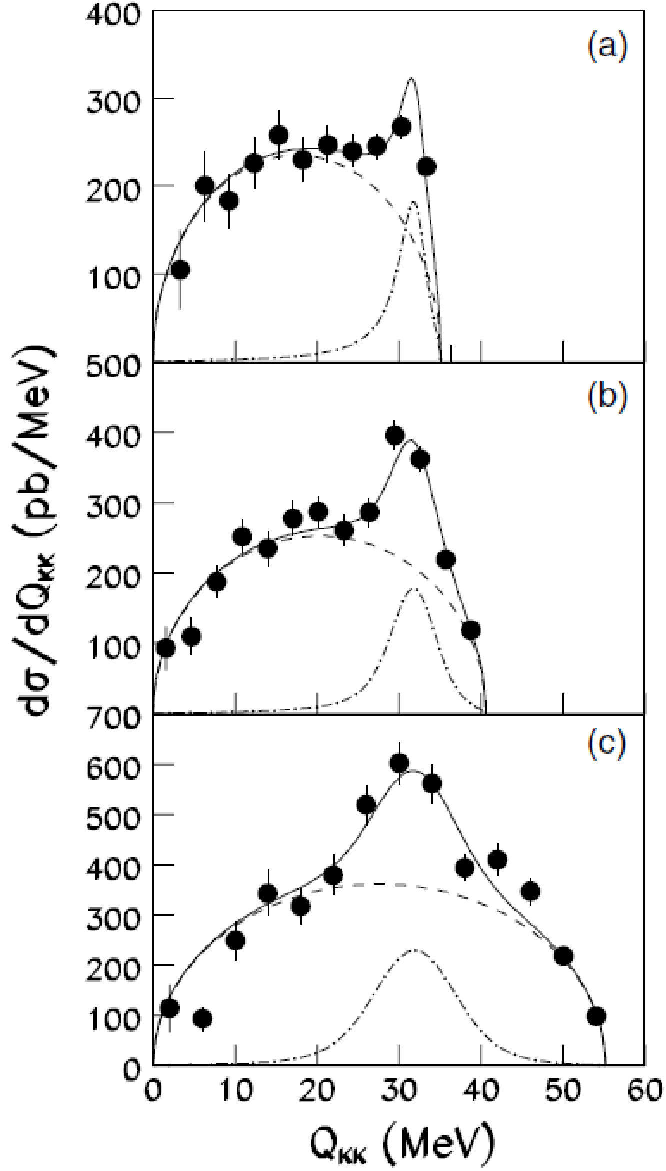
solid: includes pp FSI

$\phi \to K^+ K^- \propto \sin^2 \Theta_J \; (\rho_{00} = 0)$

ϕ is tensor polarized $(m = \pm 1)$ along $\vec{p}_{beam}$

$R_{\phi/\omega} \approx 8 \cdot R_{OZI}$

$pd \to {}^3\mathrm{He}\,K^+K^-$ **and** $pd \to {}^3\mathrm{He}\,\phi(1020)$

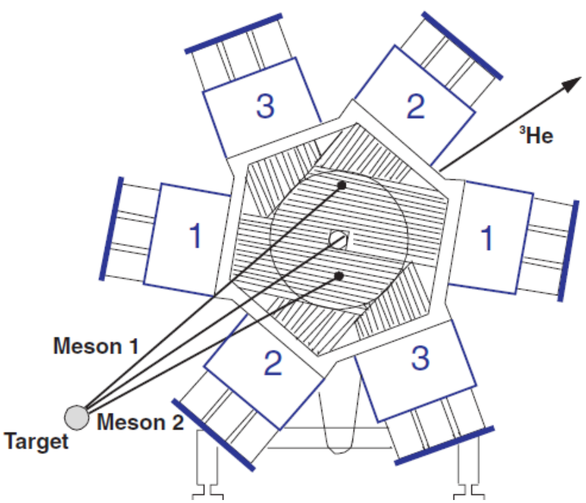


$\epsilon_{KK} = 35.1$ MeV
$\sigma_{KK} = 6.4 \pm 0.5$ nb
$\sigma_\phi = 2.0 \pm 0.4$ nb

$\epsilon_{KK} = 40.6$ MeV
$\sigma_{KK} = 8.1 \pm 0.5$ nb
$\sigma_\phi = 3.0 \pm 0.6$ nb

$\epsilon_{KK} = 55.2$ MeV
$\sigma_{KK} = 15.8 \pm 1.0$ nb
$\sigma_\phi = 6.4 \pm 1.8$ nb

COSY-MOMO



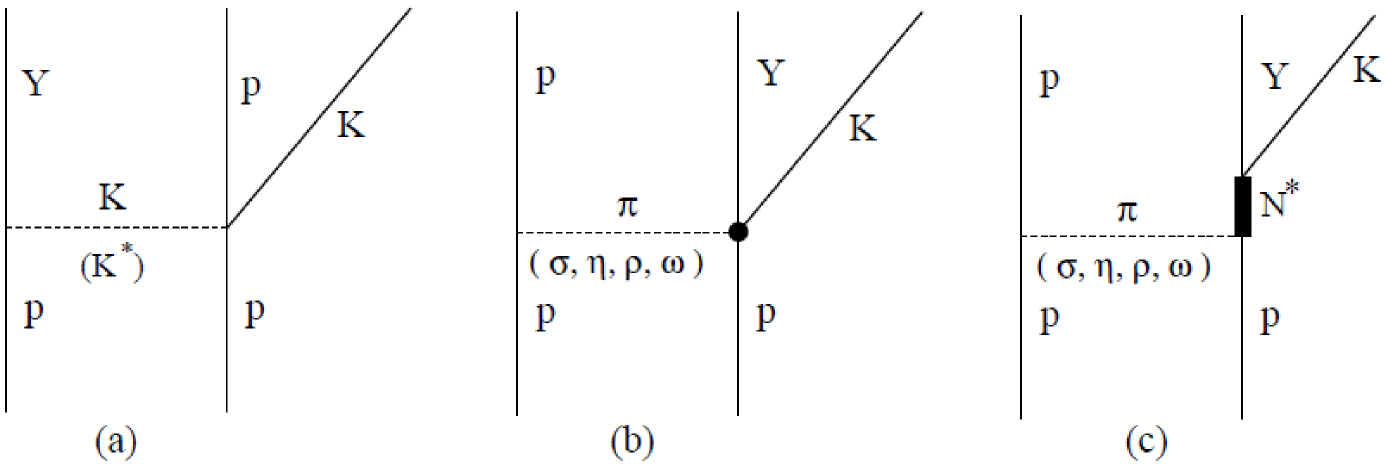
$pd \to {}^3\mathrm{He}\, K^+K^-$ and $pd \to {}^3\mathrm{He}\, \phi$

Results:

- $\sigma_\phi < \sigma_{KK}$
- $\sigma_{KK} \propto \epsilon_{KK}^2$ like phase space
- $\phi \to K^+K^- \propto \cos^2\Theta_J \ (\rho_{00} \approx 1)$
- ϕ is tensor polarized $(m = 0)$ along $\vec{p}_{beam}$
- $R_{\phi/\omega} = 20 \cdot R_{OZI}$

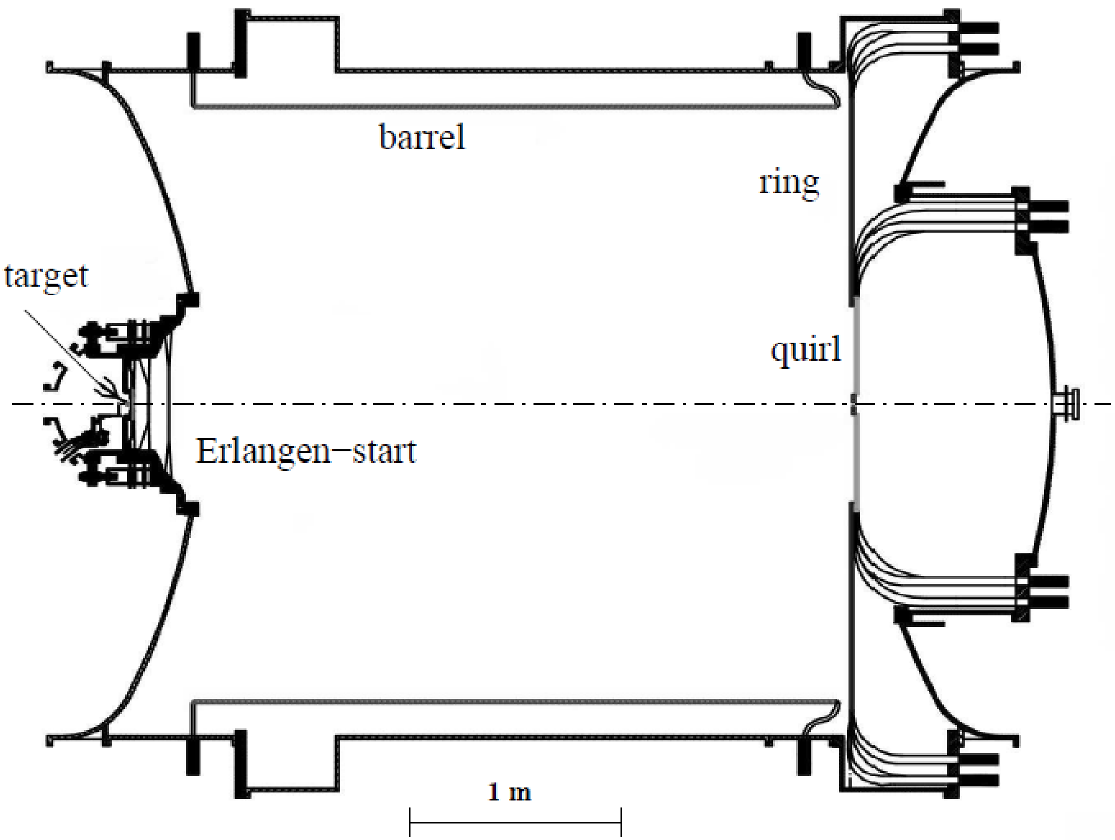
Associated Strangeness Production at COSY-TOF

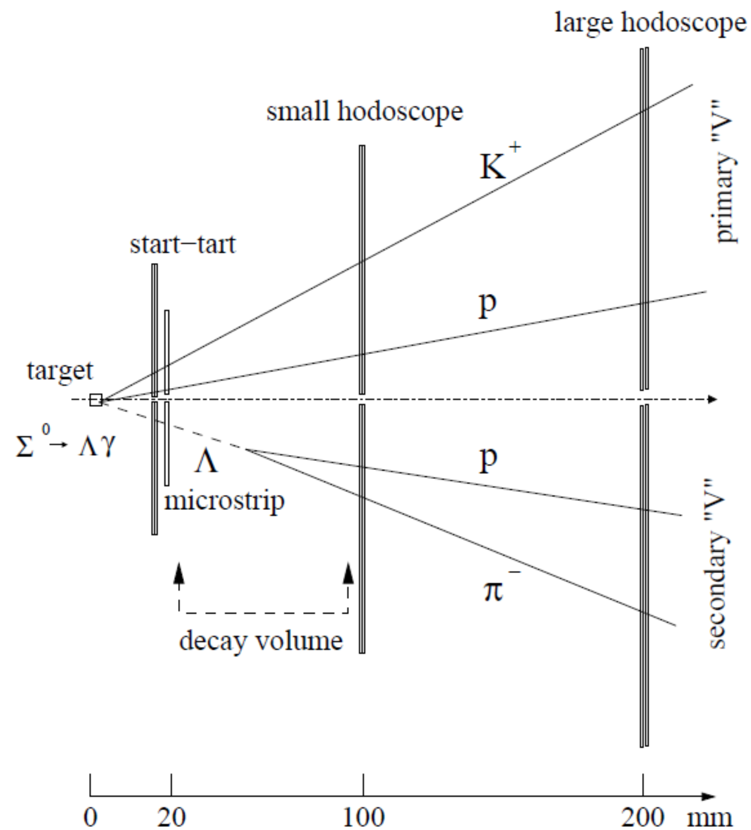
$$pp \to K^+ \Lambda p,\ pp \to K^+ \Sigma^0 p,\ pp \to K^0 \Sigma^+ p.$$



- Meson Exchange
- N^* Resonances
- FSI

COSY-TOF Detector





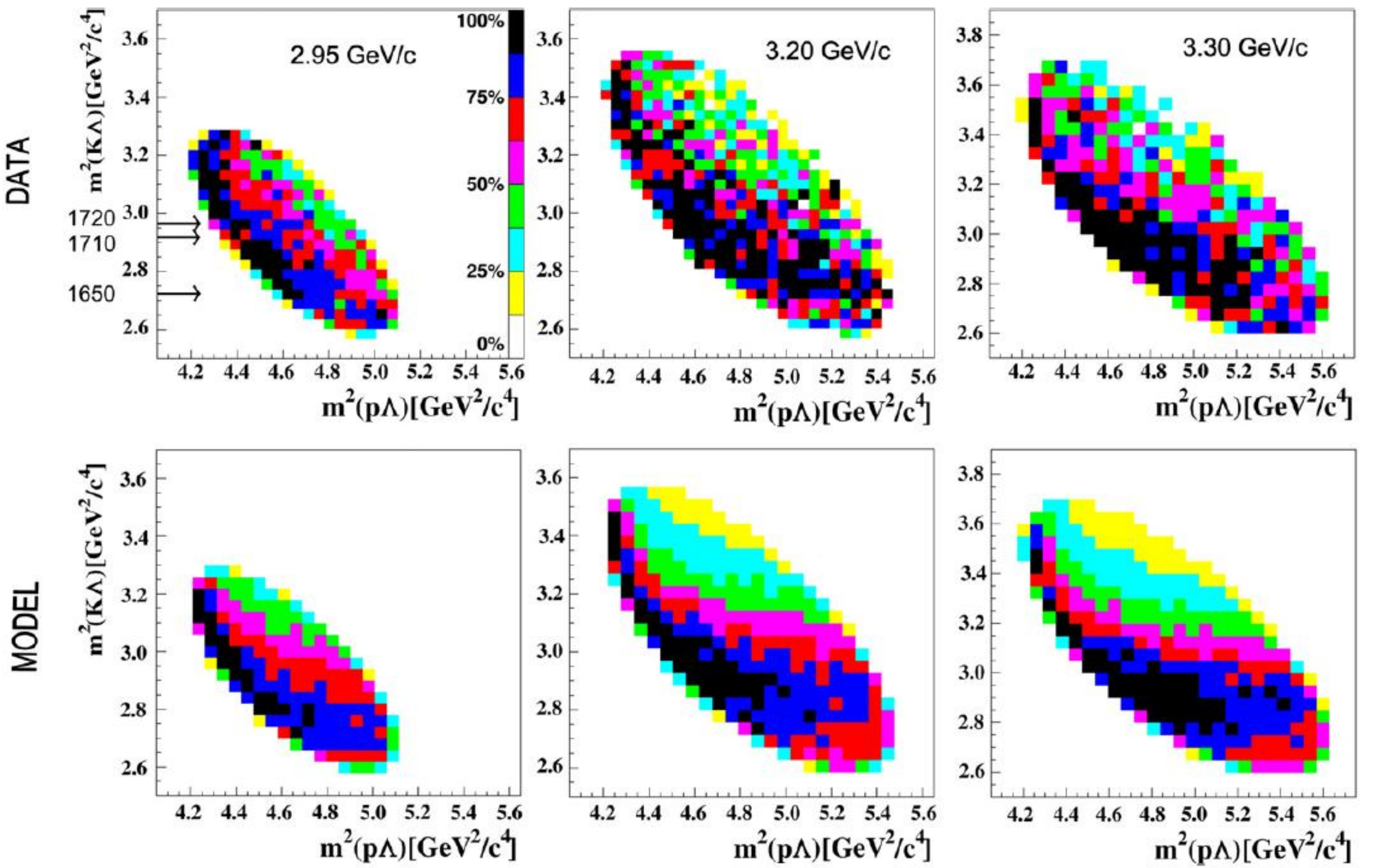
$pp \to pK^+\Lambda$, $pp \to pK^+\Sigma^0$

delayed decay of Λ (trigger)

pattern reconstruction + TOF

$pp \to K^+\Lambda p$, Dalitz Plot

Model: Λp FSI and $N(1650)$, $N(1710)$, $N(1720)$ COSY-TOF, Phys. Lett. B 688, 142 (2010)



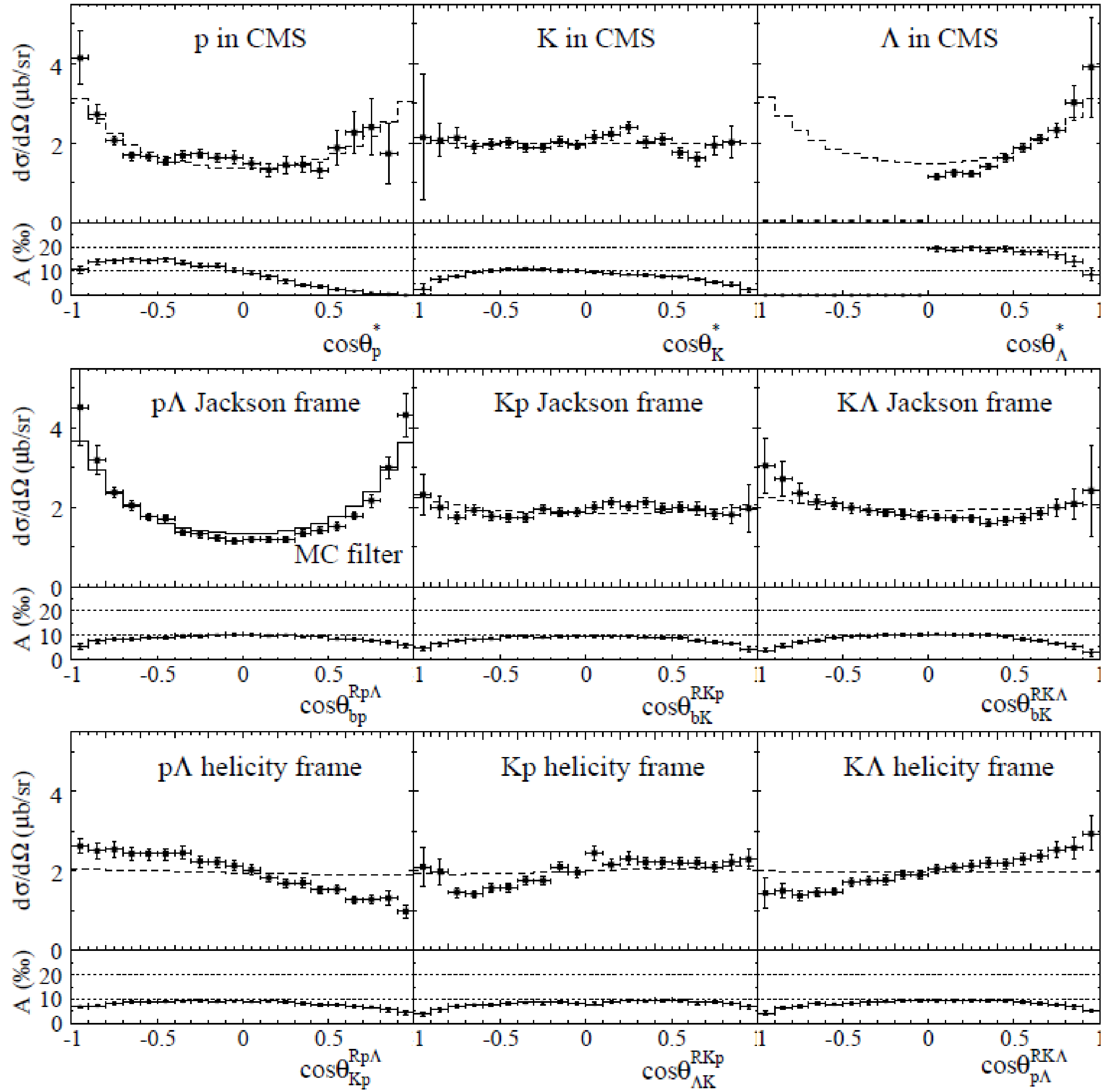
$d\sigma/d\Omega$ in CMS, Jackson- and Helicity-Frame

$pp \rightarrow pK^+\Lambda$

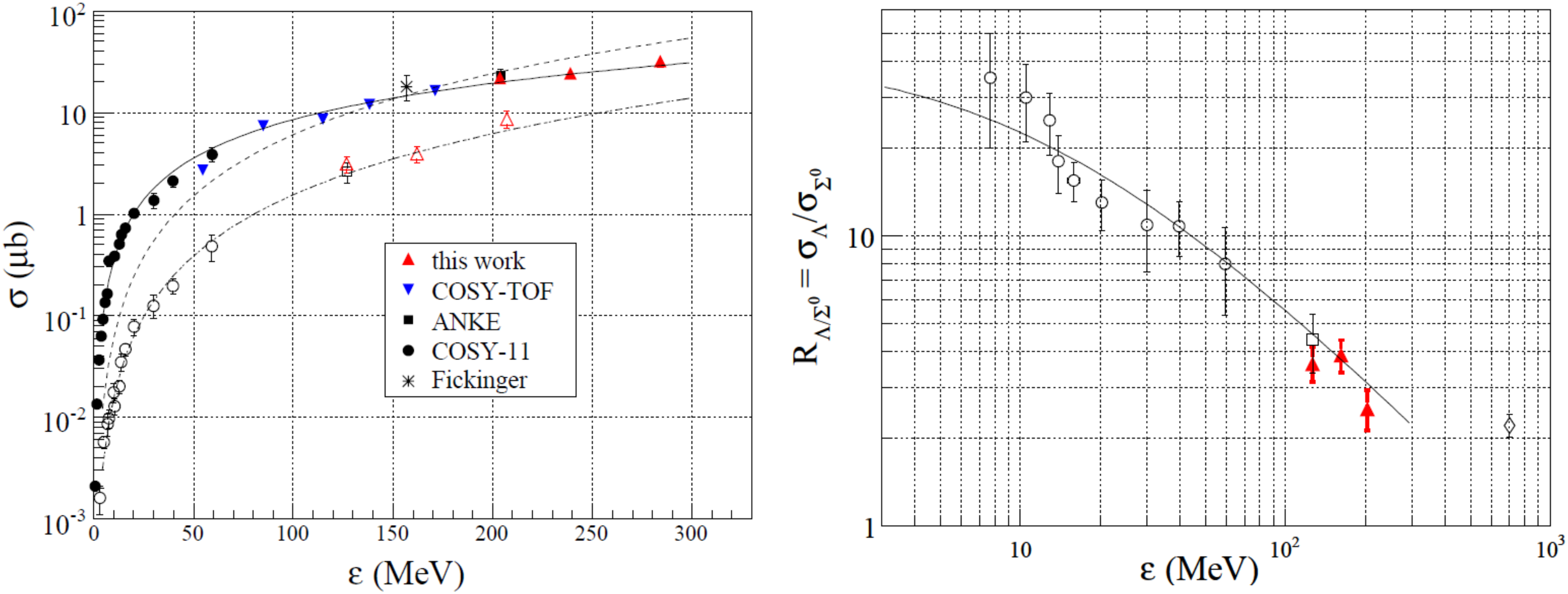
$\epsilon = 239$ MeV

(COSY-TOF)

Eur. Phys. J. A



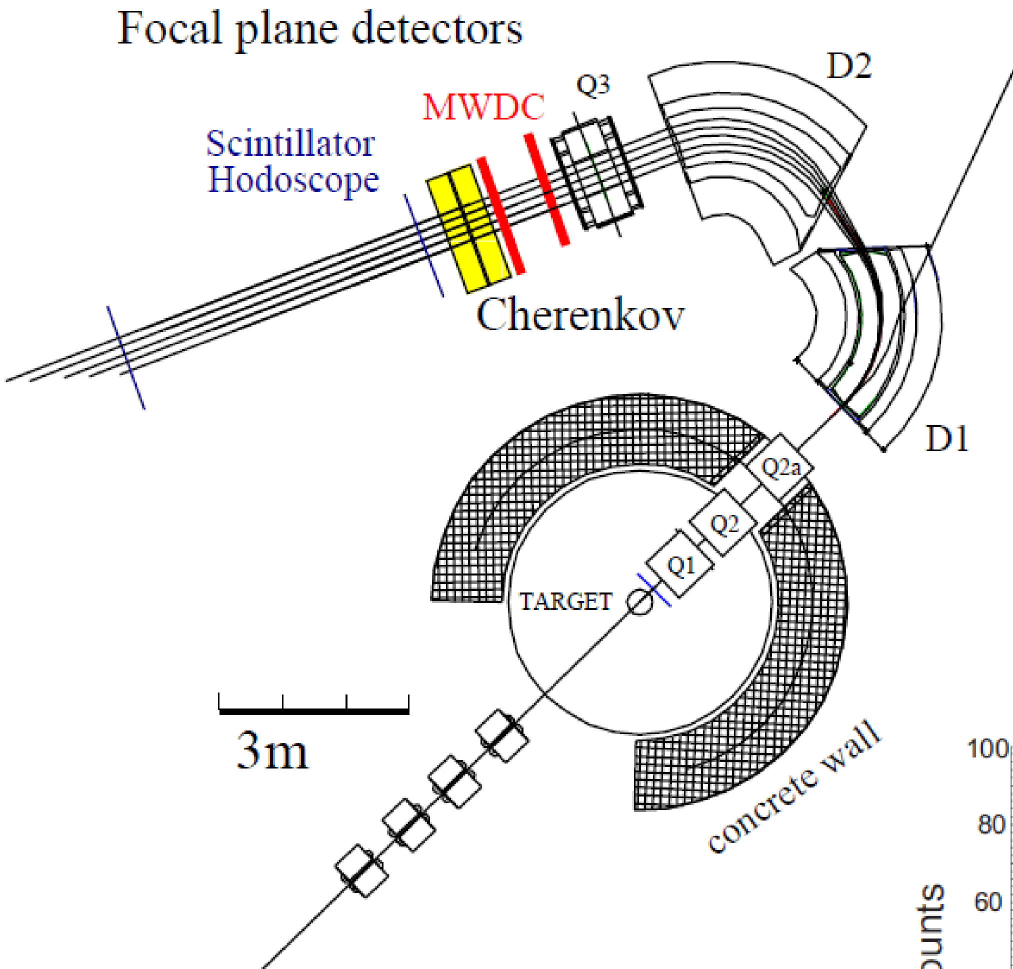
$pp \rightarrow K^+\Lambda p$ **vs.** $pp \rightarrow K^+\Sigma^0 p$

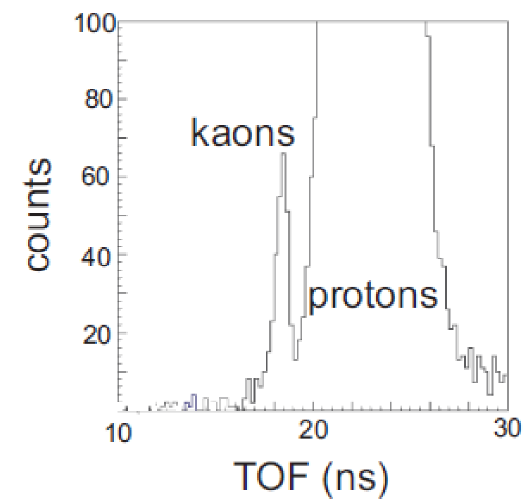


$pp \rightarrow K^+\Lambda p$ (solid symbols), $pp \rightarrow K^+\Sigma^0 p$ (open symbols)

COSY-TOF, submitted to Eur. Phys. J. A

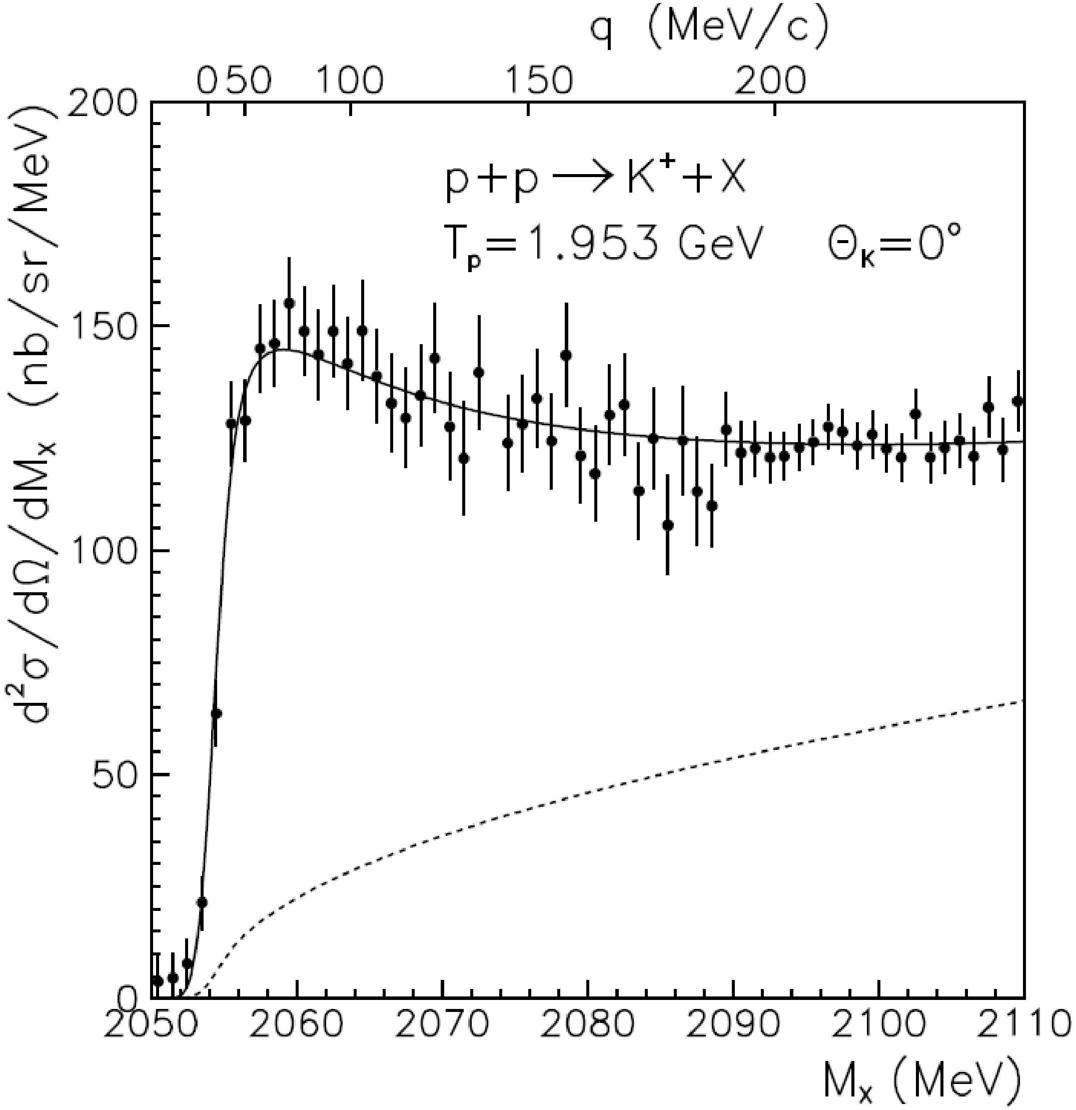
BIG KARL Spectrograph

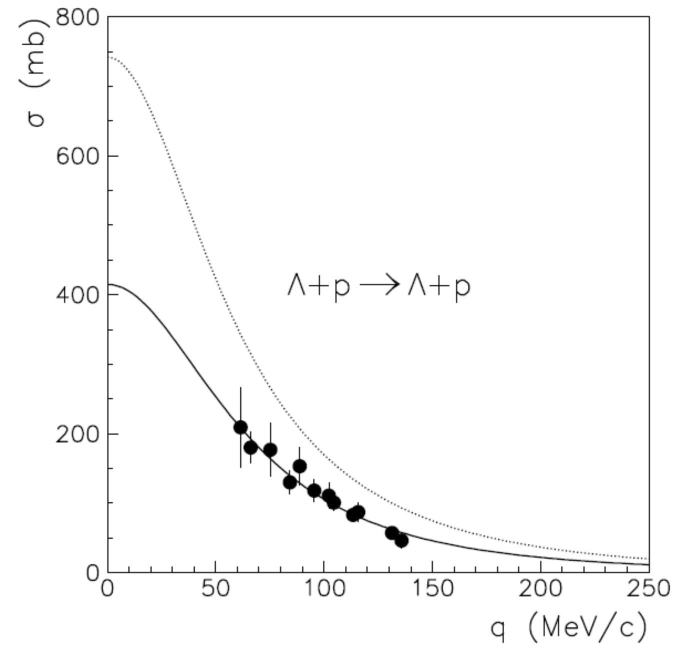




COSY-HIRES: $pp \to K^+ (\Lambda p)$

Λp FSI in $pp \to K^+ (\Lambda p)$





FSI enhancement $\propto$ (Jost Function)$^{-2}$

$\bar{a} = -2.43^{+0.16}_{-0.17}$ fm, $\bar{r} = 2.21^{+0.16}_{-0.16}$ fm.

G. Alexander et al., Phys. Rev. 173 (1968) 1452

B. Sechi-Zorn et al., Phys. Rev. 175 (1968) 1735

Λp FSI Analysis: Results

	a_s (fm)	r_s (fm)	a_t (fm)	r_t (fm)
COSY-HIRES	$-2.43^{+0.16}_{-0.25}$	$2.21^{+0.16}_{-0.36}$	$-1.56^{+0.19}_{-0.22}$	$3.7^{+0.6}_{-0.6}$
NSC97f	-2.51	3.03	-1.75	3.32
J04	-2.56	2.75	-1.66	2.93
J04c	-2.66	2.67	-1.57	3.08

COSY-HIRES, Phys. Lett. B **687**, 31 (2010)

Nijmegen NSC97f: V.G. Stoks, Th.A. Rijken, Phys. Rev. C **59**, 3009 (1999)

Juelich J04: J. Haidenbauer, U.G. Meißner, Phys. Rev. C **72**, 044005 (2005)

Caveat: A possible theoretical uncertainty of the Jost-function approach may be in the order of 0.4 fm for the scattering length and even more for the effective range (A. Gasparyan et al., Phys. Rev. C **72**, 034006 (2005)).

New Analysis using Dispersion-Integral Method of A. Gasparian et al., Phys. Rev. C **69**, 034006 (2004)

Planned Experiment: $\vec{p}p \rightarrow K^+(\Lambda p)$ using COSY-TOF

Summary

- Experimental Facilities: (COSY-11), COSY-ANKE, (COSY-HIRES), (COSY-MOMO), COSY-TOF, COSY-WASA

- Kaon pair production in pp, pn, pd and dd collisions

- K^-p FSI important in $pp \to ppK^+K^-$

- Tensor polarized ϕ in $pp \to pp\phi$ and $pd \to {}^3He\phi$

- $R_{\phi/\omega} \approx 8R_{OZI}$ and $R_{\phi/\omega} \approx 20R_{OZI}$, respectively

- $pp \to K^+\Lambda p$: Dalitz Plots: Λp FSI, dominant contributions of $N(1650)$, $N(1710)$ and $N(1720)$

- $pp \to K^+\Lambda p$ and $pp \to K^+\Sigma^0 p$: $\mathrm{d}\sigma/\mathrm{d}\Omega$ in CMS-, Jackson- and Helicity-Frame

- Partial Wave Analysis of $pp \to K^+\Lambda p$ and $pp \to K^+\Sigma^0 p$

- FSI enhancement in $pp \to K^+(\Lambda p)$ at $\Theta = 0^\circ$

Polarized Beam for Spin Triplet Scattering Length

- $\vec{p}p \rightarrow K^+(\Lambda p)$ near Threshold using COSY-TOF
- $\frac{\mathrm{d}^2\sigma^\uparrow}{\mathrm{d}m_{\Lambda p}\mathrm{d}\Omega_{cm}} - \frac{\mathrm{d}^2\sigma^\downarrow}{\mathrm{d}m_{\Lambda p}\mathrm{d}\Omega_{cm}} = 2A_y\frac{\mathrm{d}^2\sigma}{\mathrm{d}m_{\Lambda p}\mathrm{d}\Omega_{cm}}$
- $A_y\frac{\mathrm{d}^2\sigma}{\mathrm{d}m_{\Lambda p}\mathrm{d}\Omega_{cm}}$ at $\Theta_{cm} = 90^\circ$ only spin triplet

  (A. Gasparian et al., Phys. Rev. C **69**, 034006 (2004))

- Previous Experiment

  $K^- + d \rightarrow \pi^- + (\Lambda p)$

  $a_t = (-2.0 \pm 0.5)$ fm, $r_t = (3.0 \pm 1.0)$ fm.

  (Tai Ho Tan, Phys. Rev. Lett. **23**, 395 (1969))

Alternative FSI Analysis

Dispersion-Integral Method

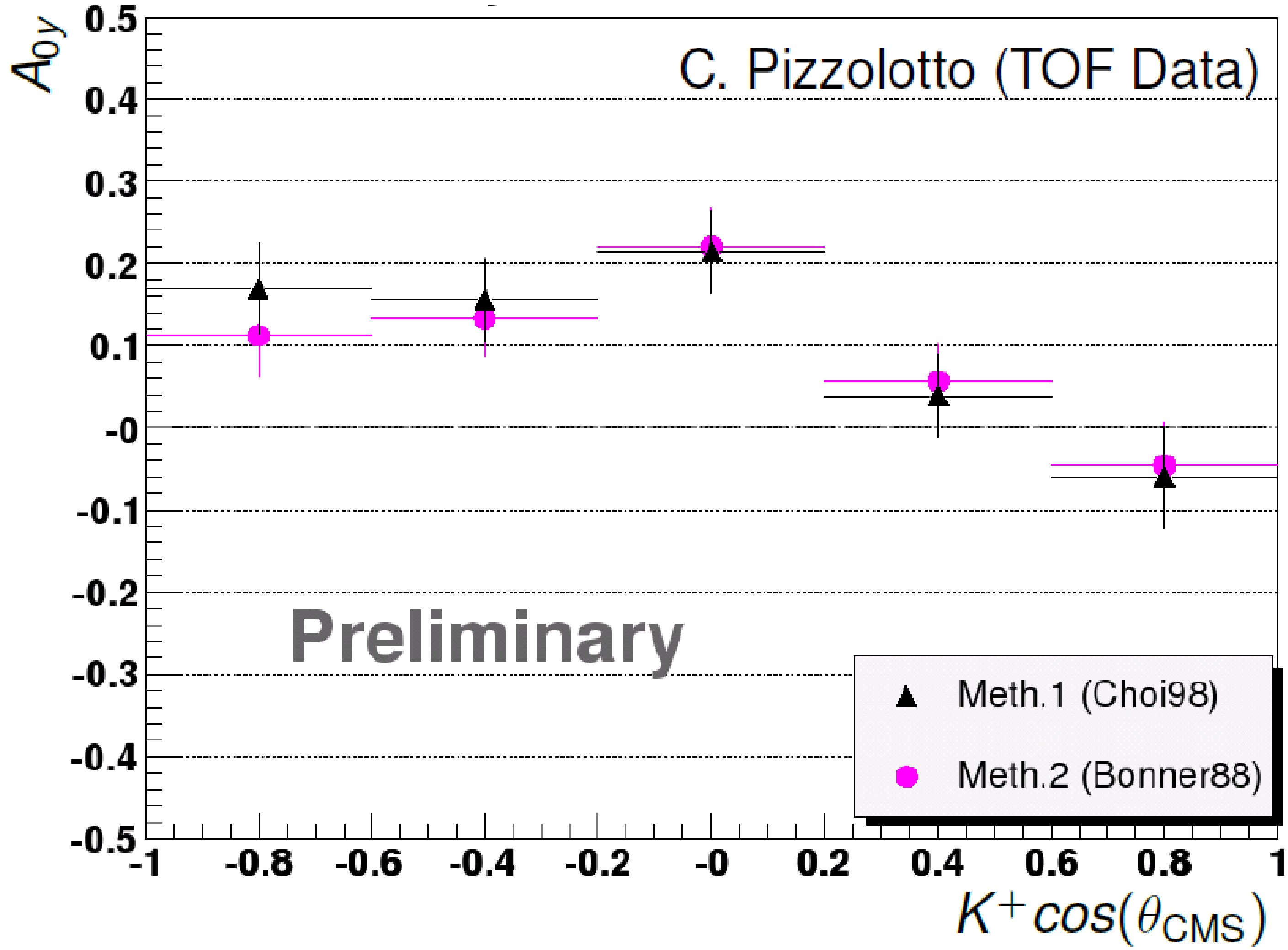
$$a_{s,t} = \lim_{m^2 \to m_0^2} \frac{1}{2\pi} \frac{m_\Lambda + m_p}{\sqrt{m_\Lambda m_p}} \, \mathrm{P} \int_{m_0^2}^{m_{max}^2} \mathrm{d}m'^2 \sqrt{\frac{m_{max}^2 - m^2}{m_{max}^2 - m'^2}}$$

$$\cdot \sqrt{\frac{1}{m'^2 - m_0^2}} \frac{1}{m'^2 - m^2} \ln \left(\frac{1}{q} \frac{\mathrm{d}^2 \sigma_{s,t}}{\mathrm{d}m'^2 \mathrm{d}t} \right)$$

(A. Gasparyan et al., Phys. Rev. C **69**, 034006 (2004))

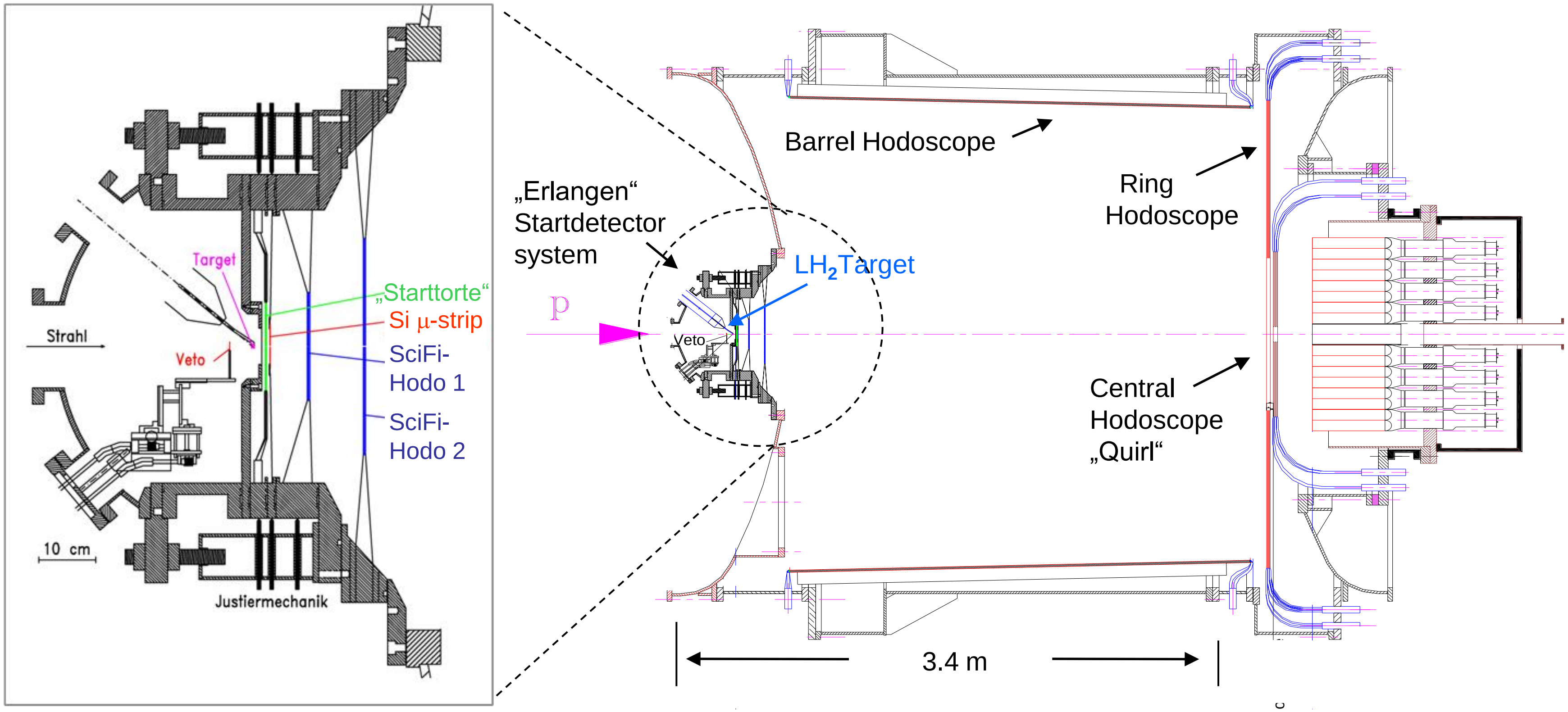
Theoretical Error of Scattering Length: 0.3 fm

K^+ Analysing Power



- $\approx$ 20% analysing power at 2.75 GeV/c beam momentum

Large-angle Time-of-Flight spectrometer (modular vacuum vessel)

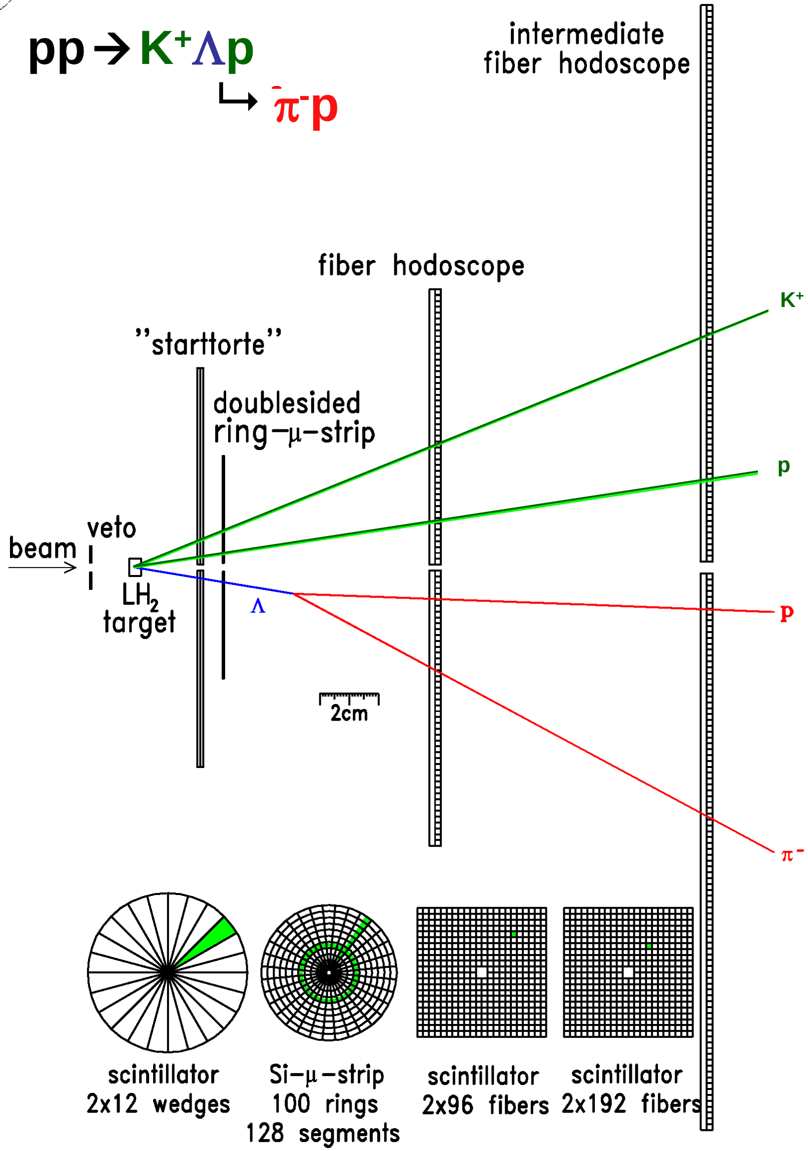


Start detector system: designed for strangeness production

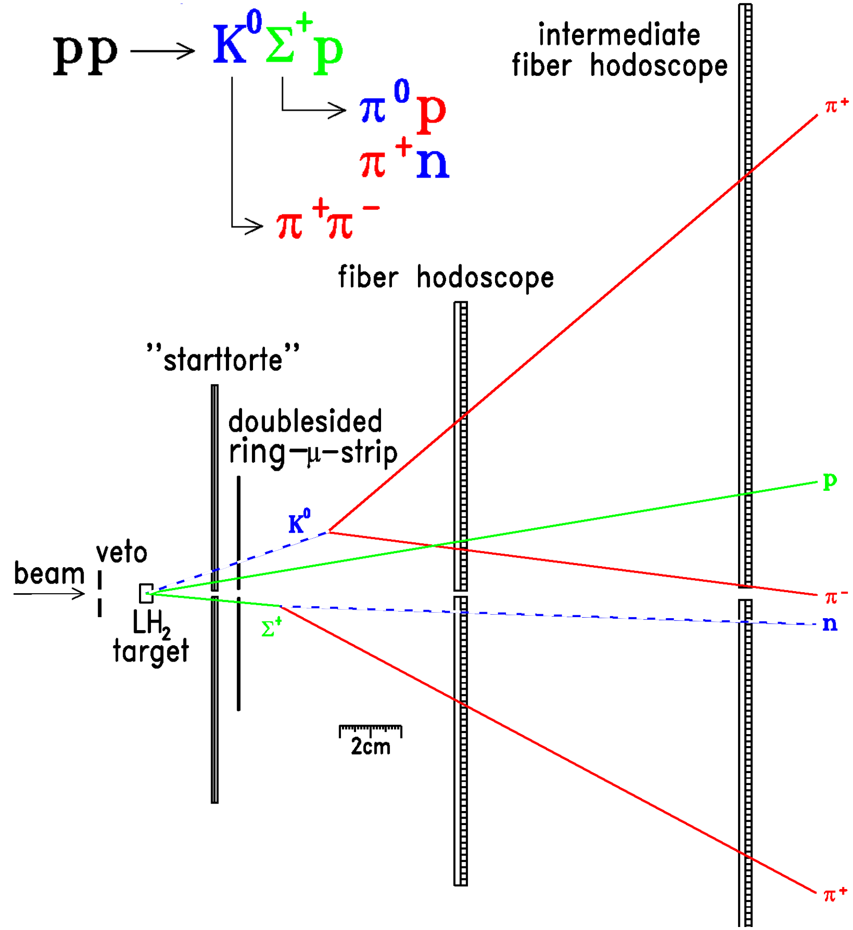
$pp \to \Lambda K^+p$, Σ^+K^0p, Σ^0K^+p, Σ^+K^+n, $pn \to \Lambda K^0p$, ... **„4π“ coverage**

Scheme of start detector

$pp \rightarrow K^+ \Lambda p$, $\Lambda \rightarrow \pi^- p$



$pp \rightarrow K^0 \Sigma^+ p$, $\Sigma^+ \rightarrow \pi^0 p$, $\pi^+ n$; $K^0 \rightarrow \pi^+ \pi^-$



unique signature: delayed decay of Λ, K^0_s

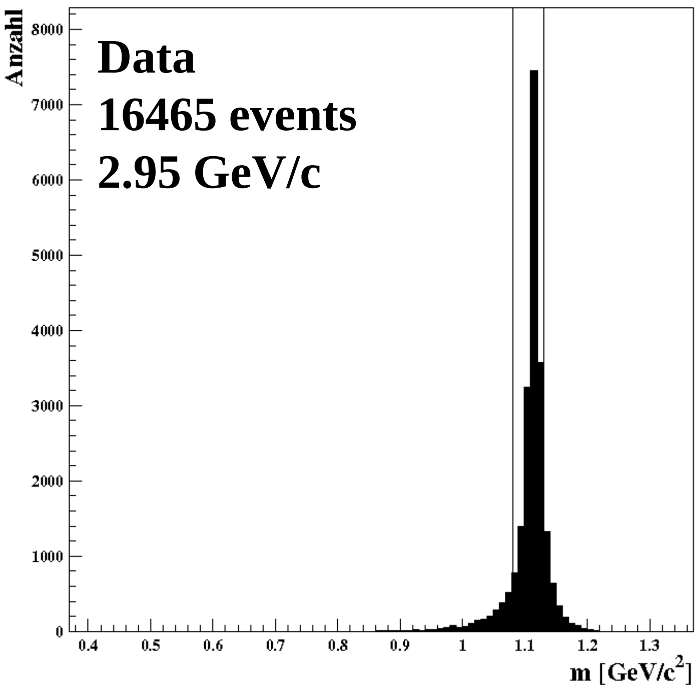
→ charged multiplicity 2 → 4 → trigger

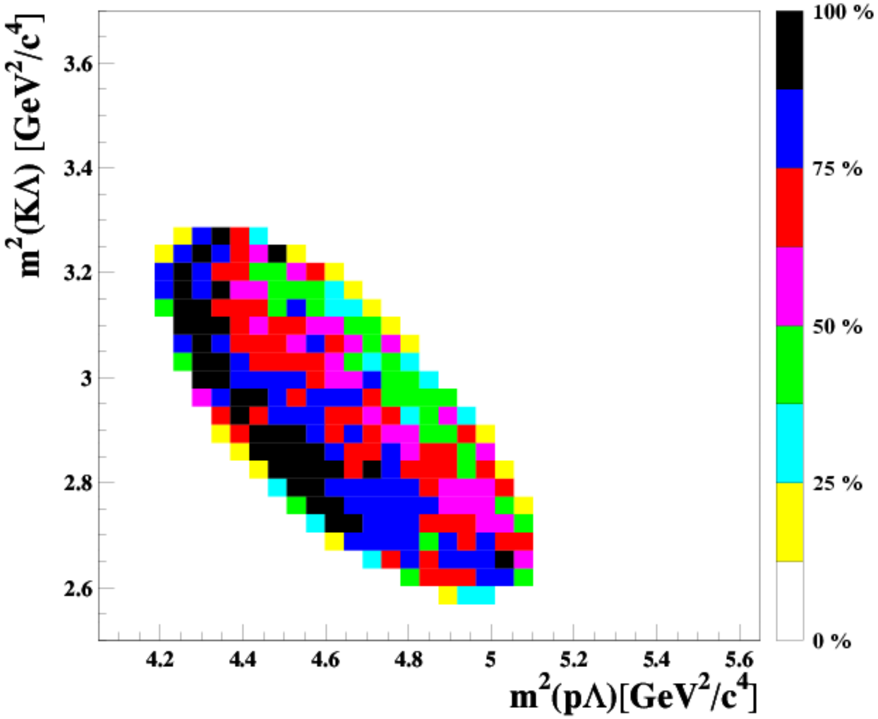
vertex reconstruction → Λ, K^0_s

pp → $K^+\Lambda p$: Reconstruction of Λ events

Unpolarized measurements at beam momentum:
2.50/2.59/2.68/2.75/2.85/2.95/3.06/3.20/3.30 GeV/c
Polarized measurements at beam momentum:
2.75/2.95 GeV/c

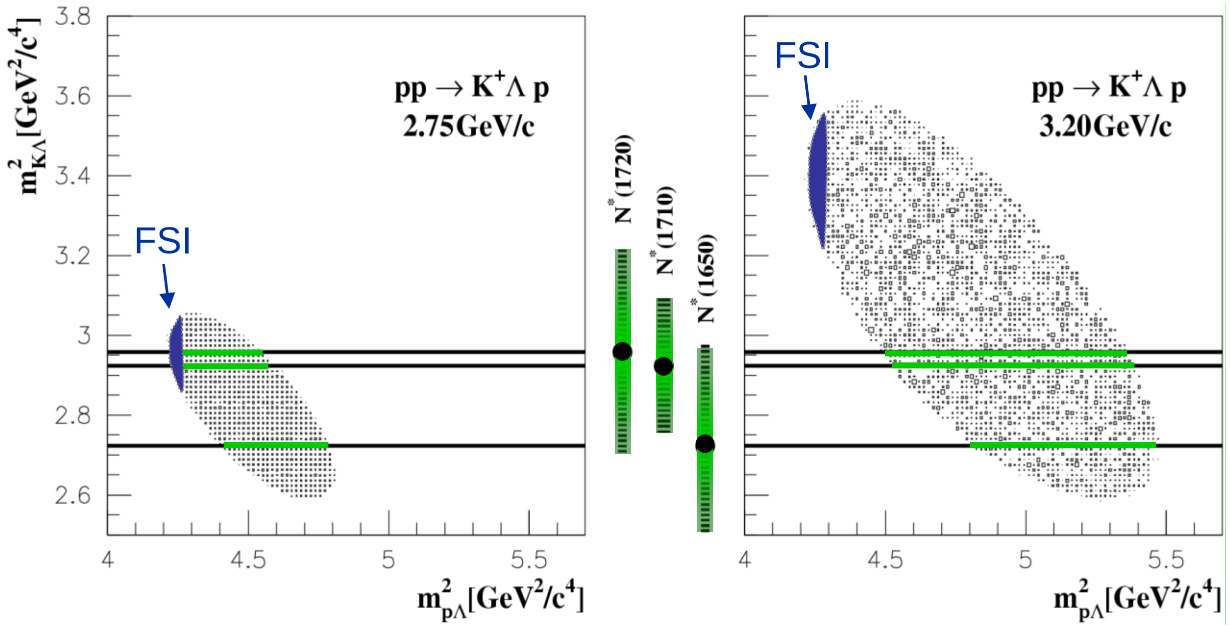
Clean event sample covering the full phase space





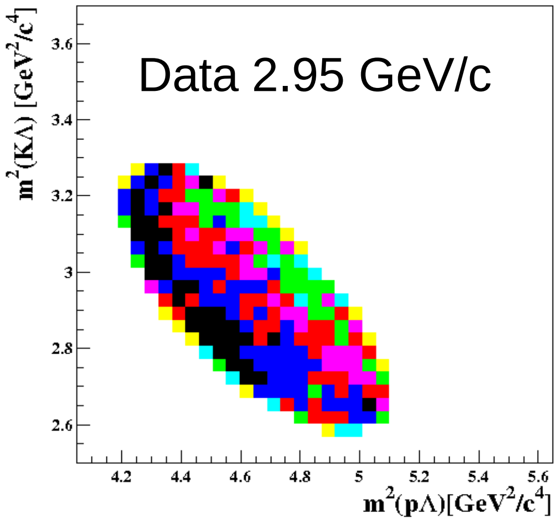
Strangeness production at COSY-TOF:

- **exclusive observables**
- **full phase-space → Dalitz Plots**
- **polarization**: Hyperon-polarization, polarized beam, (polarized target)
- threshold region → only few partial waves, no Y*



MC

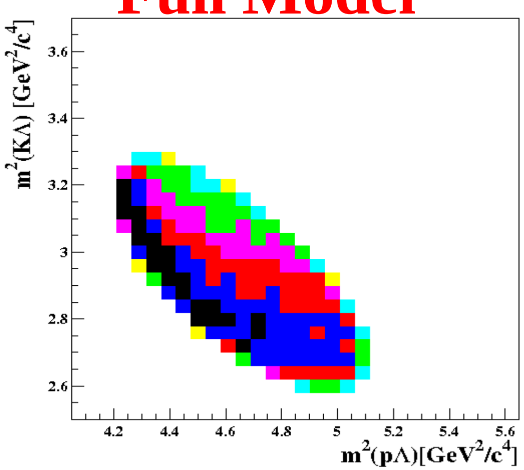
pp → $K^+\Lambda p$: Dalitz plot analysis



Model calculation of Sibirtsev

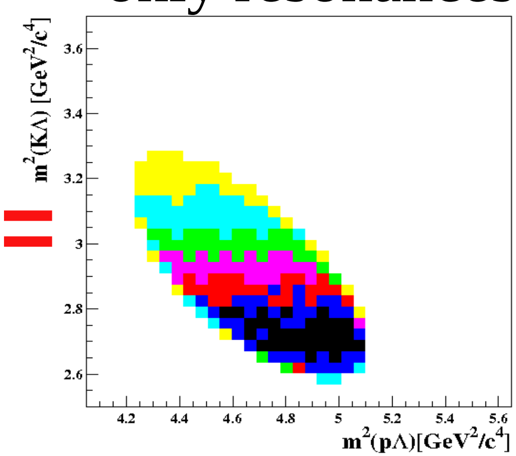
$$\frac{d^2\sigma}{dm_{K\Lambda}^2 dm_{p\Lambda}^2} = (flux) \cdot \left| \left(\sum_R (C_R \cdot A_R) + C_N \right) \cdot (1 + C_{FSI} \cdot A_{FSI}) \right|^2$$

Full Model



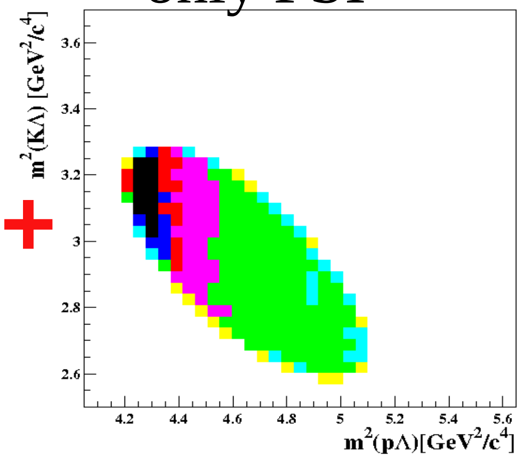
=

only resonances

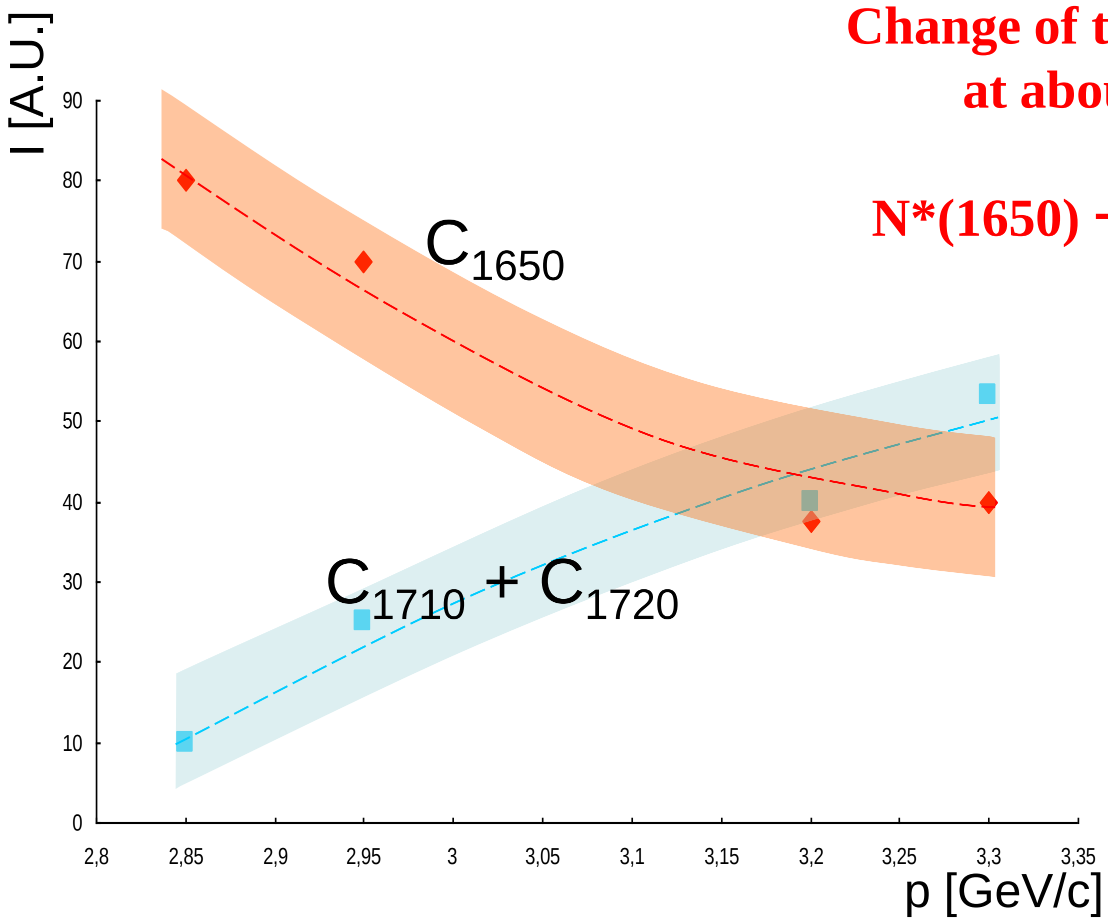


+

only FSI



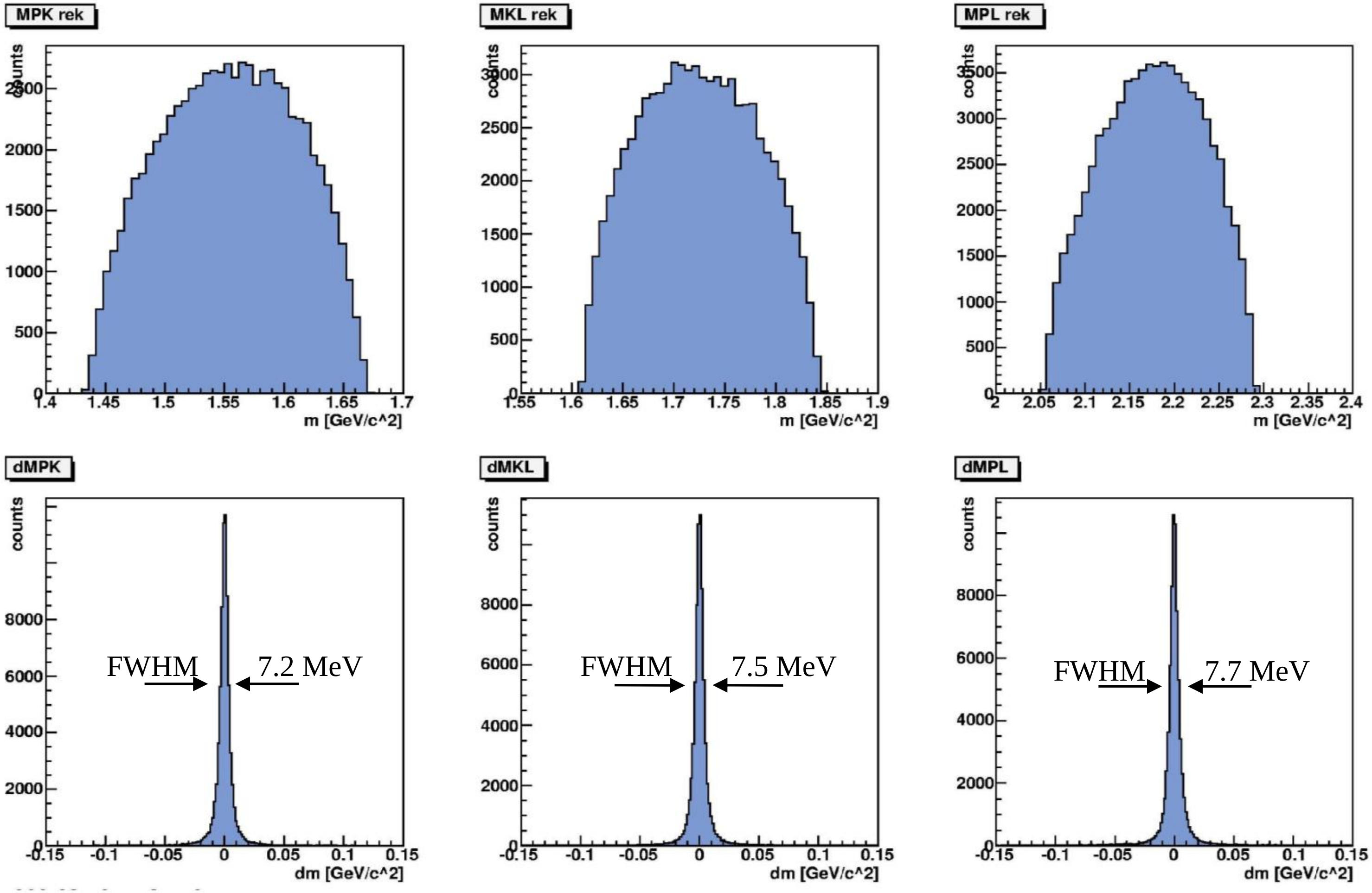
pp → $K^+\Lambda p$: Results of analysis



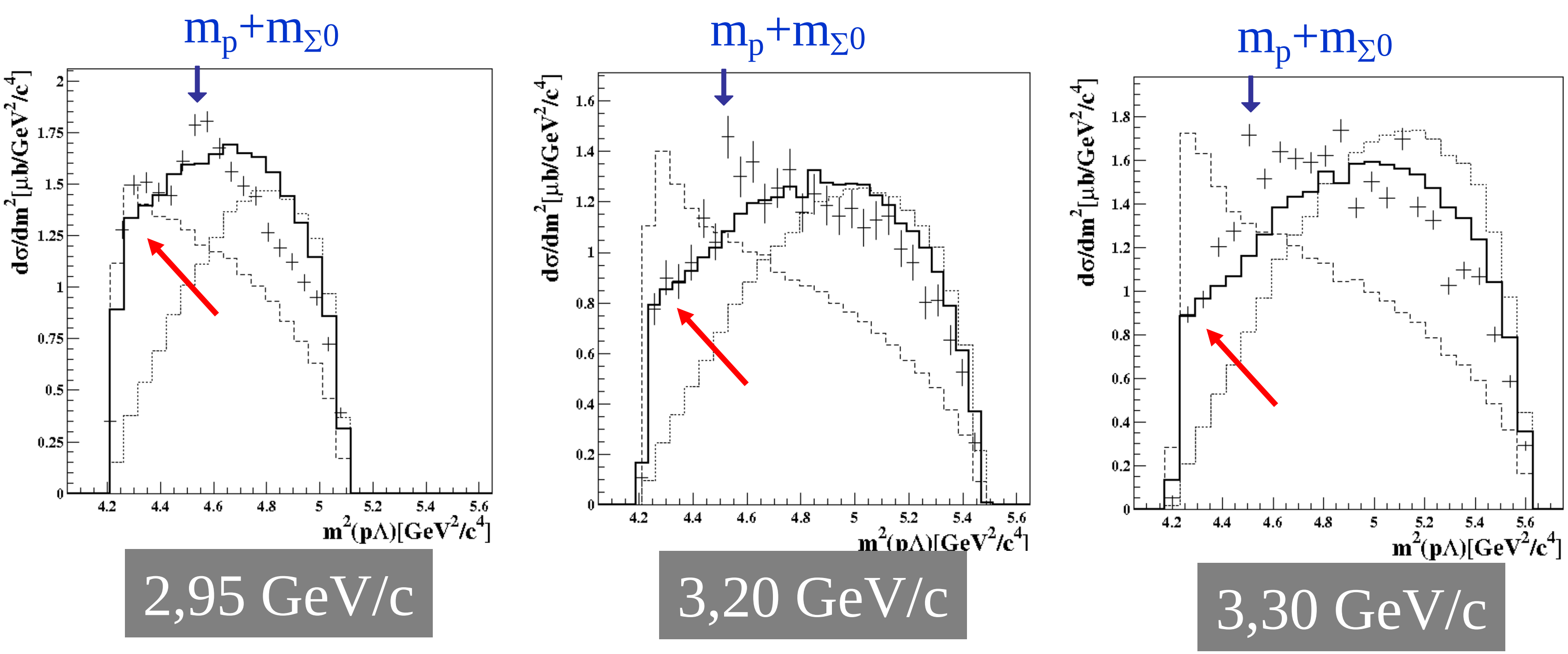
Change of the <u>dominant resonance</u>
at about p_{beam}=3 GeV/c :

N*(1650) → N*(1710) / N*(1720)

$pK^{+}\Lambda$ - MC : Resolution of invariant masses (kin. fit included



pp → $K^+\Lambda p$: Results of analysis

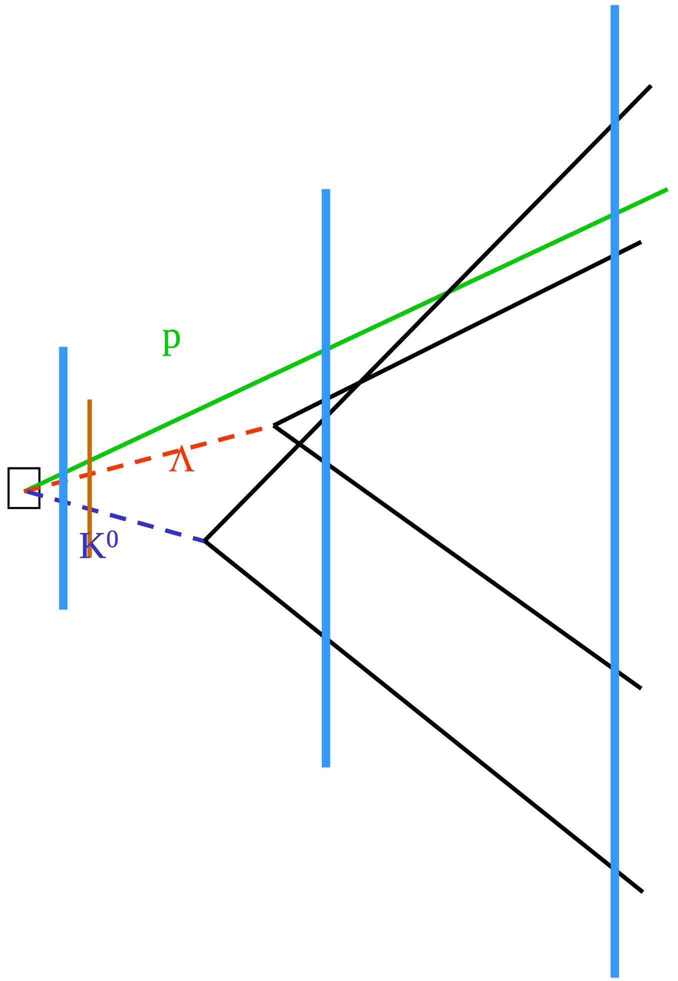


Description of the Data with **N*- Resonances** **and** **FSI**

→ **pΛ-scattering length** (using pol. Beam)

Improvement of resolution by straw tracker!

pn(p) → pK^{0}Λ(p)



Unique signature:

2 „V's" corresponding to the delayed decays of Λ and K^0

Event candidate

pn(p) ⟶ pK^{0}Λ(p)

from test run