Search for ppK^- in exclusive $pp \rightarrow pK^+\Lambda$ reaction using Partial Wave Analysis

Robert Münzer
for the FOPI and HADES Collaboration

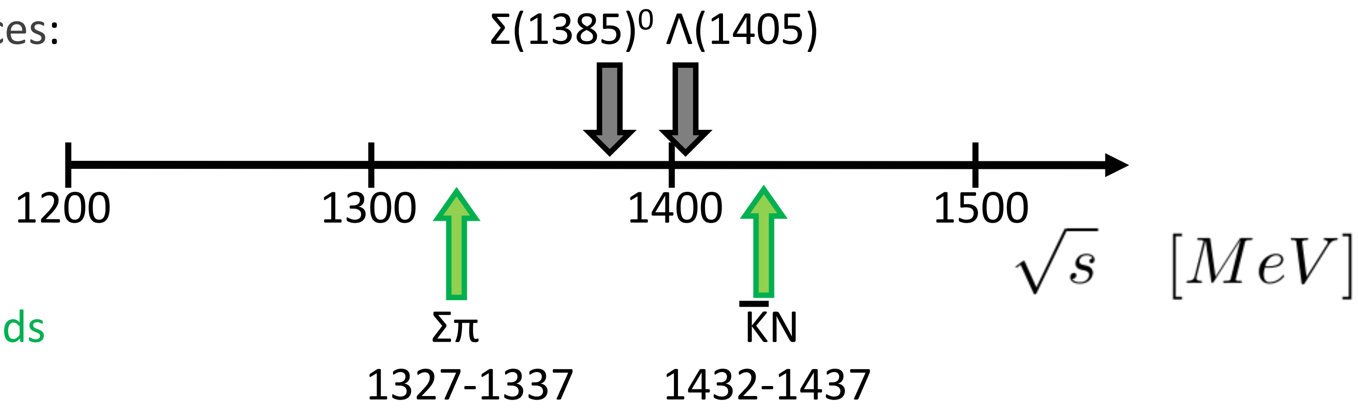
Excellence Cluster Universe, Technical University of Munich

Outline

- Introduction: Kaonic Cluster in theory and experiment
- Results for exclusive measurement in p + p from HADES + FOPI
  - Partial Wave Analysis approach
- Combined Data Analysis Data samples
  - Parallel Analysis different exclusive data samples.
- Summary
- Outlook

Resonance near $\bar{K}$N Threshold

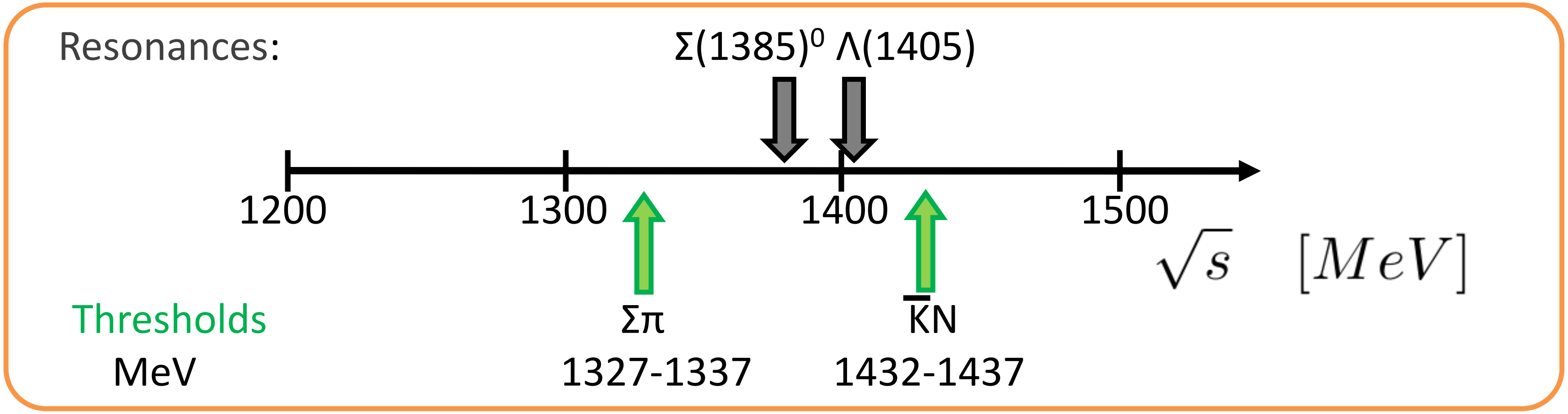
Resonances:



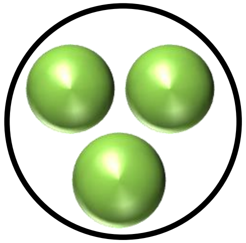
Thresholds

MeV

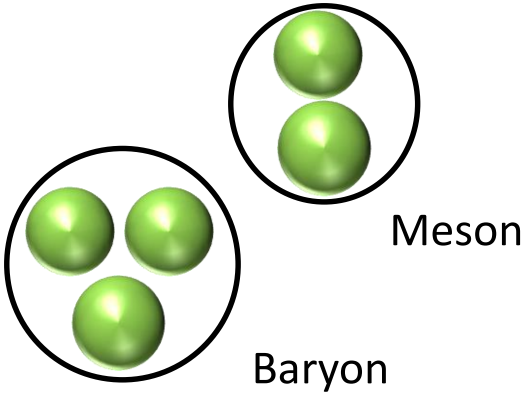
Resonance near $\bar{K}$N Threshold



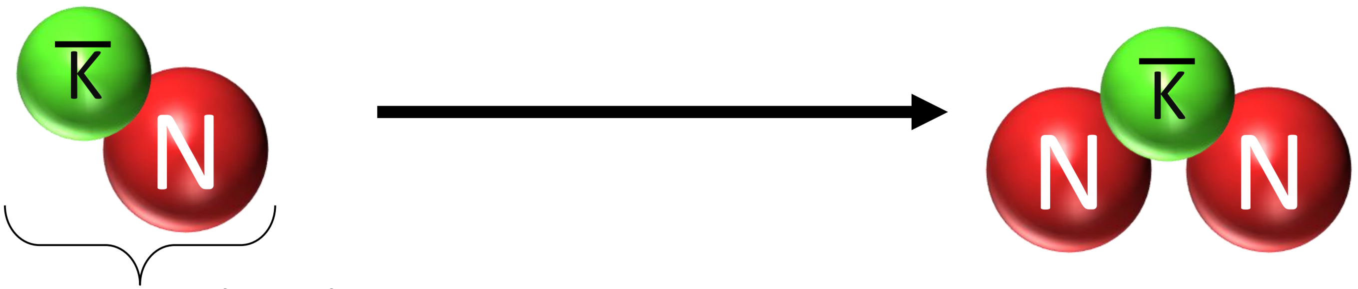
Σ(1385)



Λ(1405)



Kaonic Cluster



Part of the Λ(1405) Resonance

Theoretical Predictions

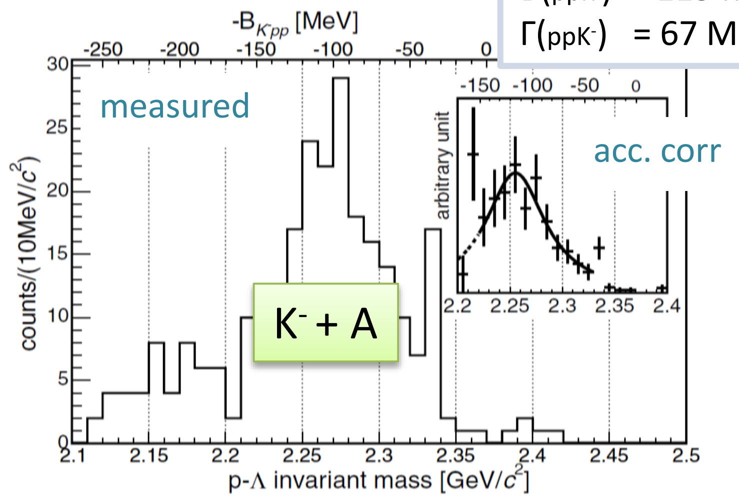
	Chiral, energy dependent				
	var. [DHW09, DHW08]	Fad. [BO12b, BO12a]	var. [BGL12]	Fad. [IKS10]	Fad. [RS14]
BE	17–23	26–35	16	9–16	32
Γ_m	40–70	50	41	34–46	49
Γ_{nm}	4–12	30			
	Non-chiral, static calculations				
	var. [YA02, AY02]	Fad. [SGM07, SGMR07]	Fad. [IS07, IS09]	var. [WG09]	var. [FIK+ 11]
BE	48	50–70	60–95	40–80	40
Γ_m	61	90–110	45–80	40–85	64–86
Γ_{nm}	12			~20	~21

Binding Energy (BE):
10-100 MeV
Mesonic Decay (Γ_m)
30-110 MeV
Non-Mesonic Decay (Γ_{nm})
4-30 MeV

Experimental Results on ppK⁻

FINUDA

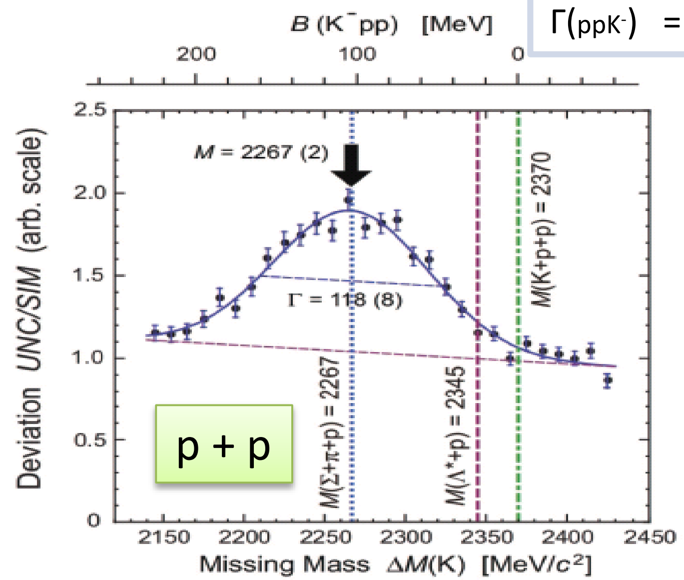
$M(ppK^-)$ = 2.255 $GeVc^{-2}$
$B(ppK^-)$ = 115 MeV
$\Gamma(ppK^-)$ = 67 $MeVc^{-2}$



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

DISTO

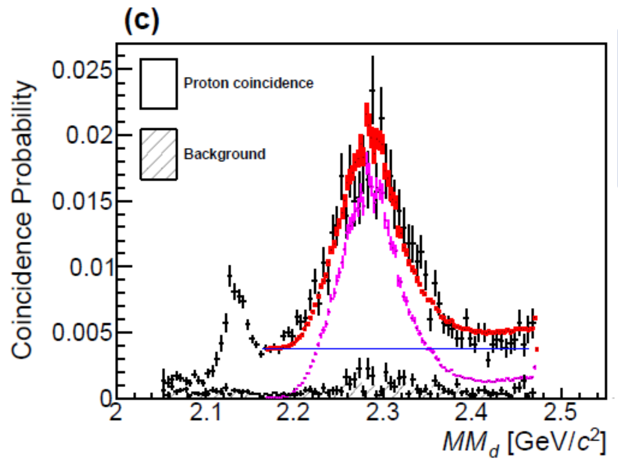
$M(ppK^-)$ = 2.267 $GeVc^{-2}$
$B(ppK^-)$ = 103 MeV
$\Gamma(ppK^-)$ = 118 $MeVc^{-2}$



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

Experimental Results on ppK$^-$

E-27 JParc

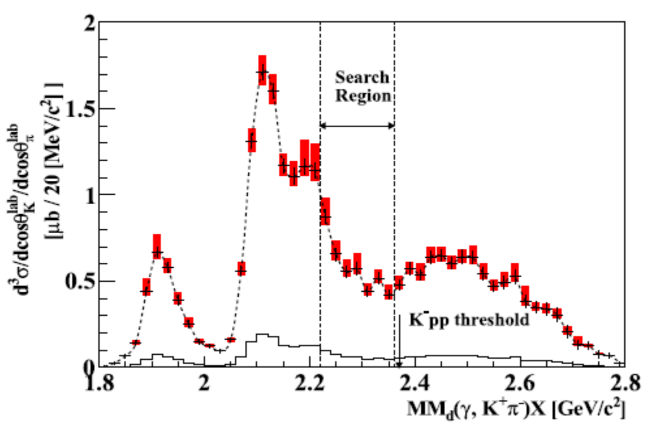


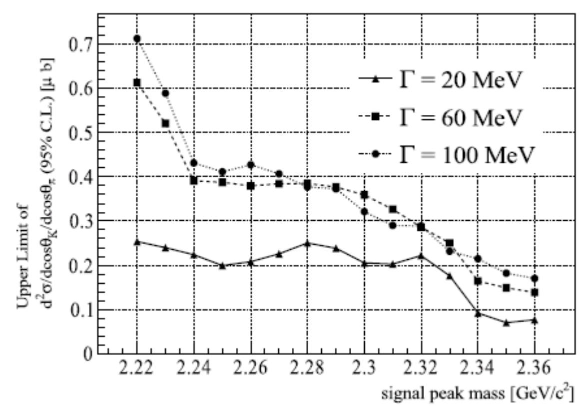
M(ppK$^-$) = 2.27 GeVc^{-2}
B(ppK$^-$) = 95 MeV
Γ(ppK$^-$) = 162 MeVc^{-2}

Y. Ichikawa et al.
Prog. Theor. Exp. Phys. 2013

LEPS/ SPRING8

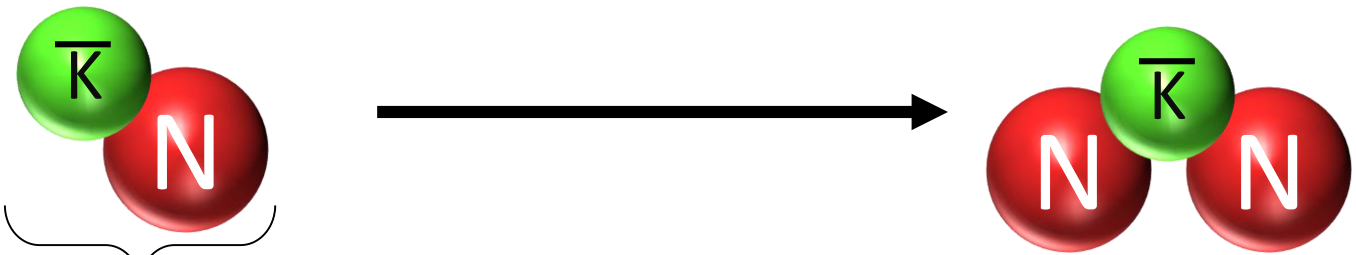
γ + d





A.O. Tokayasu et al.
Phys.Lett. B728, (2014)

Kaonic Cluster



Part of the Λ(1405) Resonance

$$p + p \longrightarrow \underbrace{\Lambda(1405) + p}_{} + K^+$$

$$ppK^- + K^+$$

$$\hookrightarrow \Lambda + p$$

Physical Background:

$$p + p \longrightarrow \Lambda + p + K^+$$

$$p + p \longrightarrow N^{*+} + p$$

$$\hookrightarrow \Lambda + K^+$$

N^{*+} - Resonances

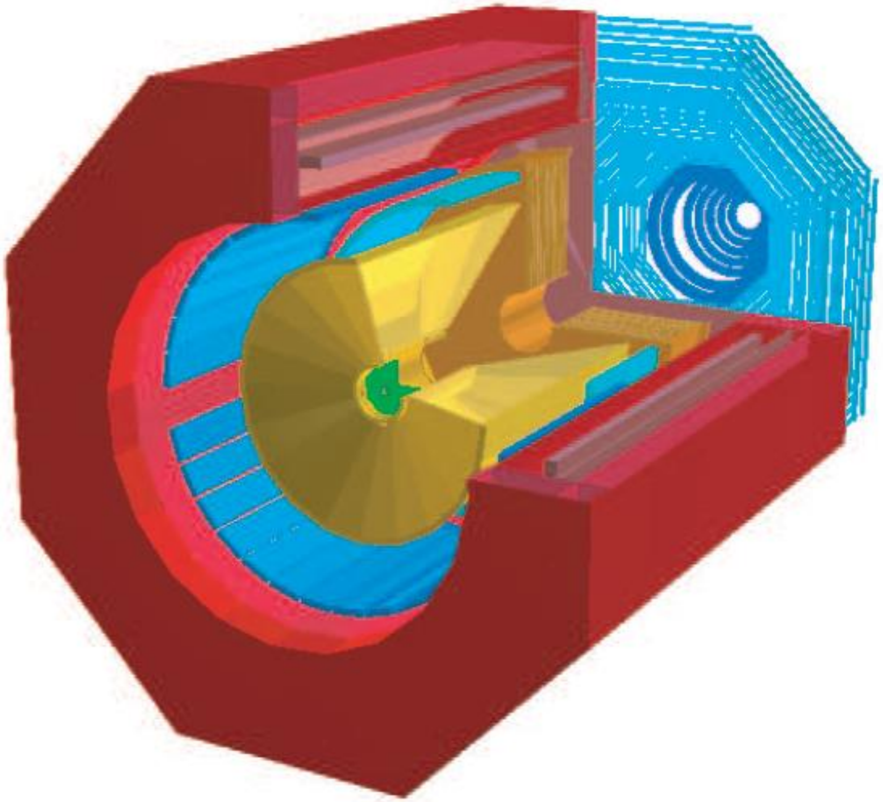
	Mass [GeV/c^2]	Width [GeV/c^2]	$\Gamma_{\Lambda K}/\Gamma_{All}$ %
$N(1650)S_{11}$	1.655	0.150	3-11
$N(1710)P_{11}$	1.710	0.200	5-25
$N(1720)D_{13}$	1.720	0.250	1-15
$N(1875)D_{13}$	1.875	0.220	4± 2
$N(1880)P_{11}$	1.870	0.235	2± 1
$N(1895)S_{11}$	1.895	0.090	18± 5
$N(1900)P_{13}$	1.900	0.250	0-10

J. Beringer
Phys.Rev. D86 (2012)

Experimental Data

The FOPI Experiment

SIS18 GSI Darmstadt



Beam Energy: 3.1 GeV

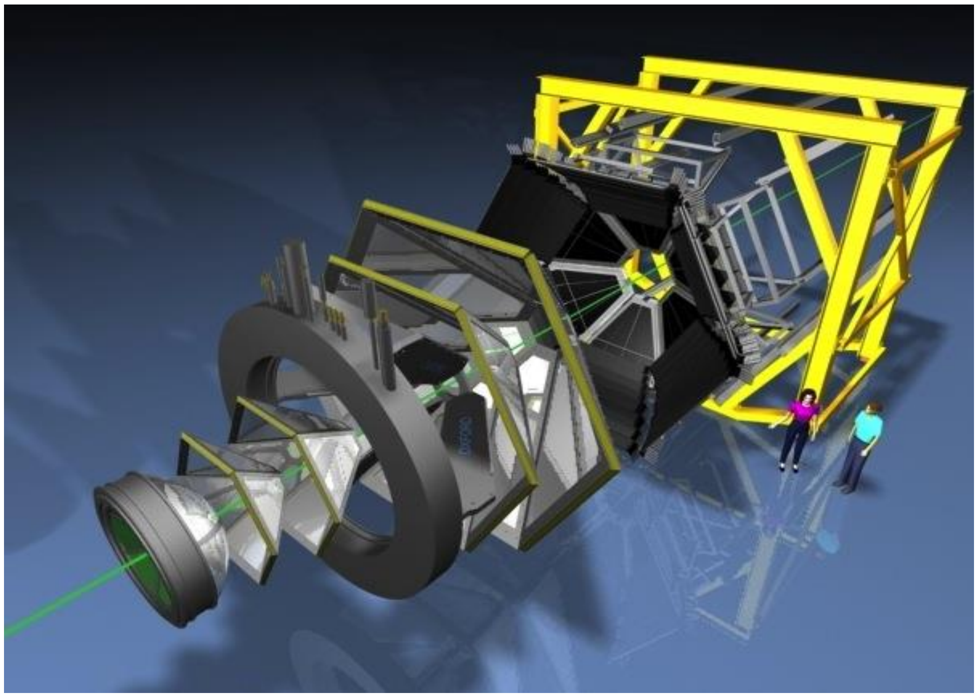
- Fixed-target Setup
- Full azimuthal coverage, 5°- 110° in polar angle
- Momentum resolution ≈ 7% - 15 %
- Particle identification via dE/dx & ToF

Trigger Detector – SiΛViO:

Λ – Enhancement: $14.1 \pm 7.9(stat)^{+4.3}_{-0.6}$

The HADES experiment

High **A**cceptance **D**i-electron **S**pectrometer
GSI, Darmstadt



HADES Coll. (G. Agakishiev et al.),
Eur. Phys. **J. A41** (2009)

Beam Energy: 3.5 GeV

- Fixed-target Setup
- Full azimuthal coverage, 15˚- 185˚ in polar angle
- Momentum resolution ≈ 1% - 5 %
- Particle identification via dE/dx & ToF

Total Data Set

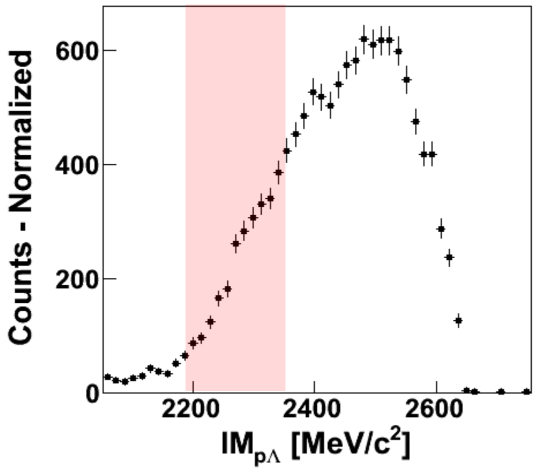
Hades Data E_{beam}=3.5 GeV

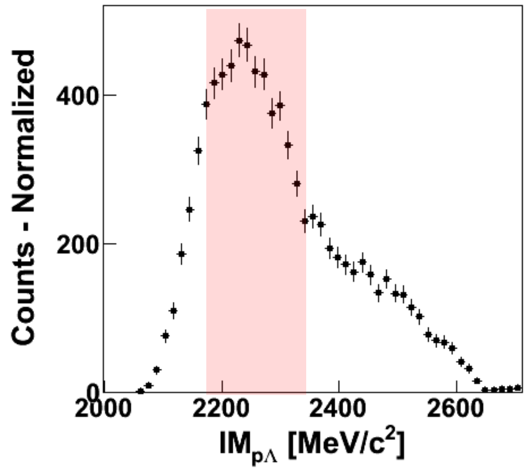
Had. Wall Data E_{beam}=3.5 GeV

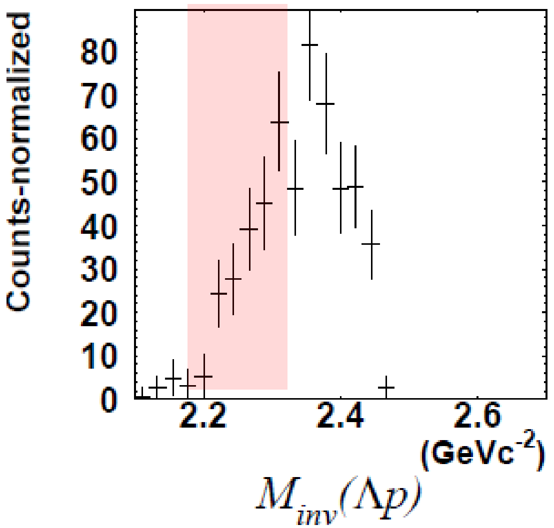
FOPI Data E_{beam}=3.1 GeV

Total Number of exclusive Events: 21000

Total Number of exclusive Events: 903







No Peak Visible
No Signal?

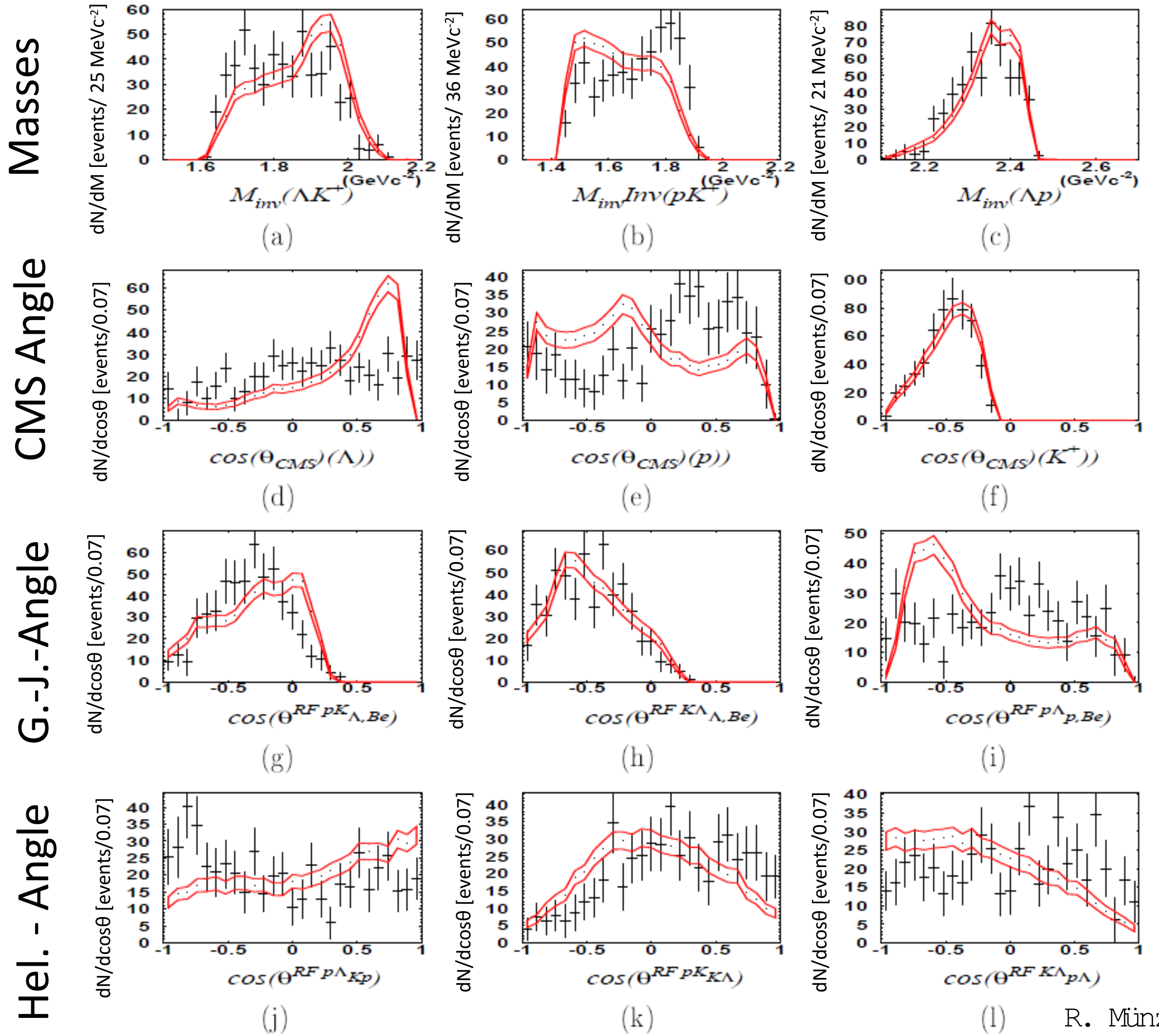
R. Münzer, Hyperfine Interaction, in print
G. Agakishiev,Phys.Lett. B742 (2015) 242-248

Model Comparison

Phase Space Simulation

Partial Wave Analysis

Phase Space Simulation

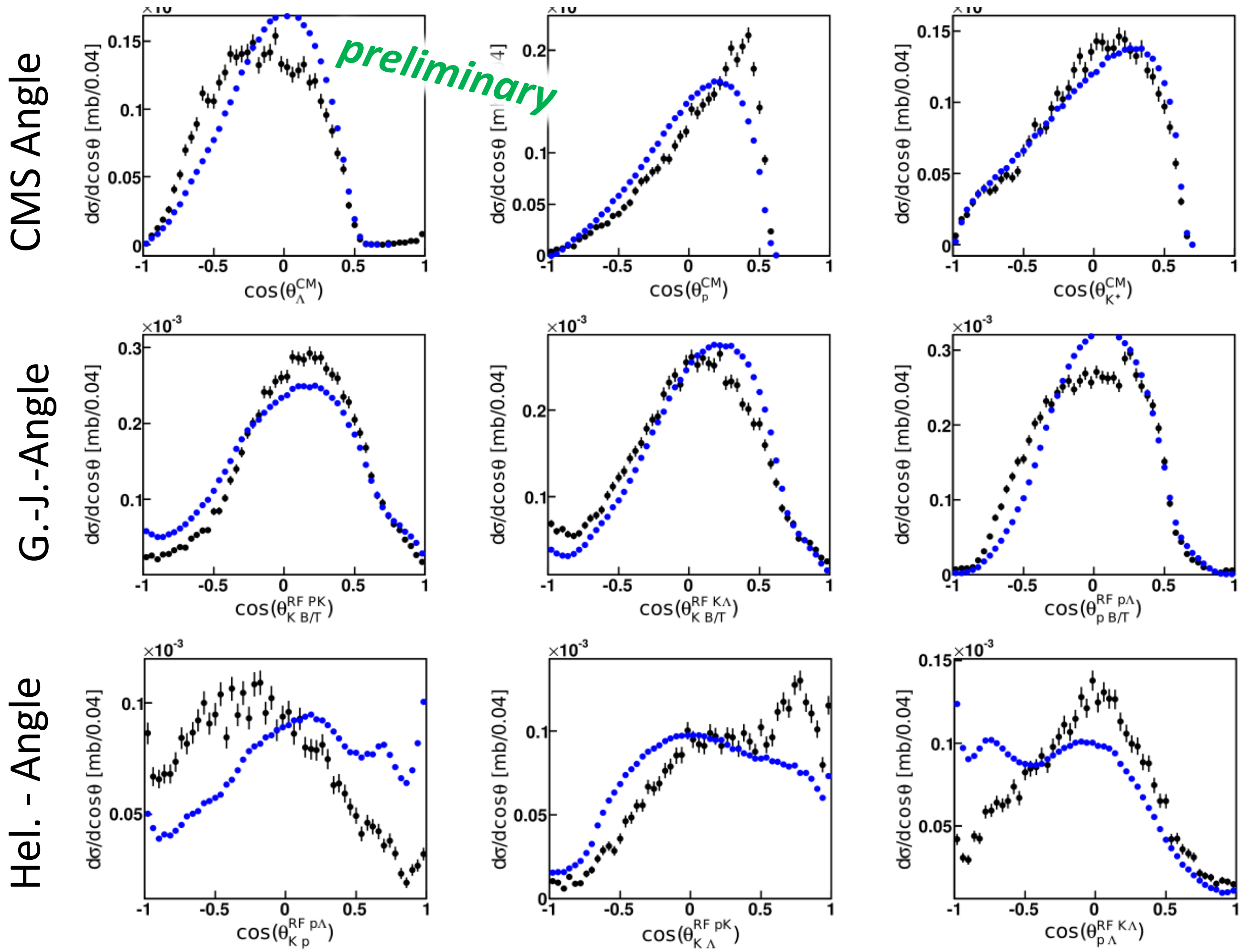


✚ Experimental Data

pp→ p K⁺ Λ Phase Space

R. Münzer, Hyp. Int., 233,1-3,159-166 (2015)

Phase Space Model



G. Agakishiev,Phys.Lett. B742 (2015) 242-248

Inside HADES acceptance

- Experimental Data
- pp→p+K^++Λ Phase Space

Partial Wave Analysis

Bonn-Gatchina PWA Framework

A. Sarantsev et.al., Eur.Phys J A 25 2005

Cross-section Decomposition

$$d\sigma = \frac{(2\pi)^4 |A|^2}{4|k|\sqrt{s}} d\phi(P, q_1, q_2, q_3), \qquad P = k_1 + k_2$$

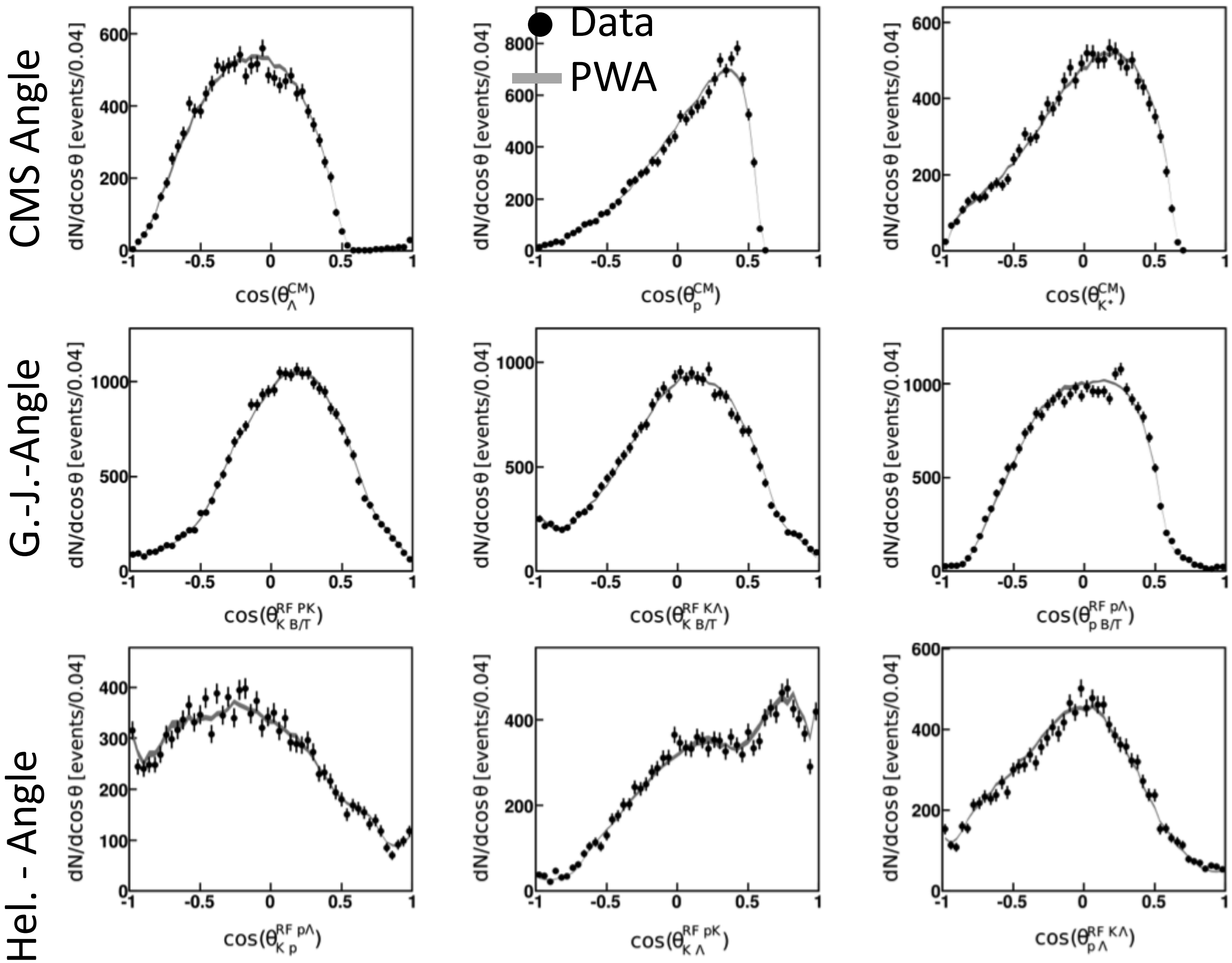
A : reaction amplitude A ∝ $A \propto A^{\alpha}_{tr}$ (s) (Transition amplitude of wave α)
k : 3-momentum of the initial particle in the CM
$s - P^2 : (k_1 + k_2)^2$
$d\phi(P, q_1, q_2, q_3)$: invariant three-particle phase space

Parameterization of the Transition

$$A^{\alpha}_{tr}(s) = (a^{\alpha}_1 + a^{\alpha}_3 \sqrt{s}) e^{i a^{\alpha}_2}$$

a^{α}_1 Constant amplitude
a^{α}_2 Phase
a^{α}_3 Energy dependent amp.

Four Best PWA Solutions

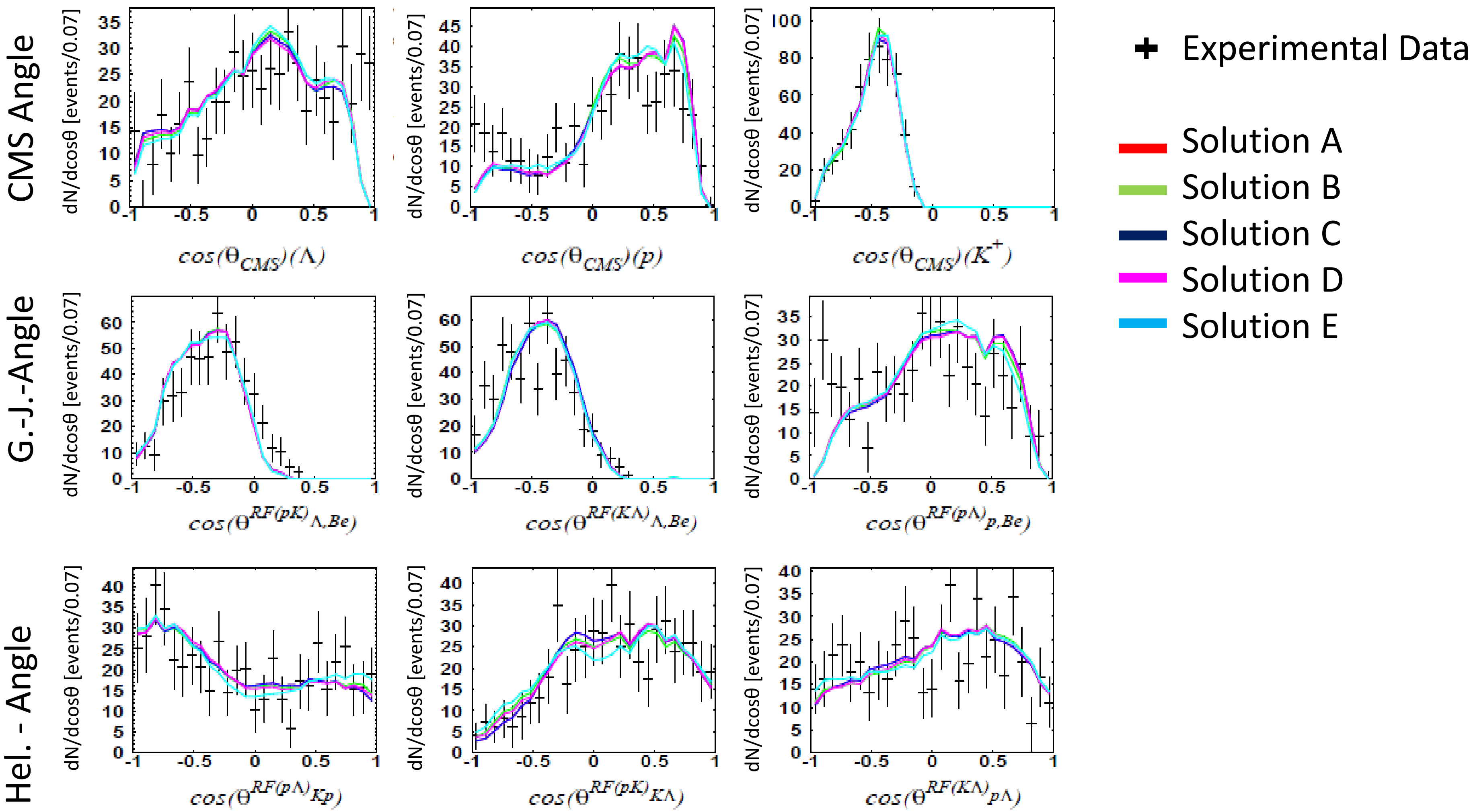


G. Agakishiev,Phys.Lett. B742 (2015) 242-248

Inside HADES acceptance

Measured Data
PWA solutions

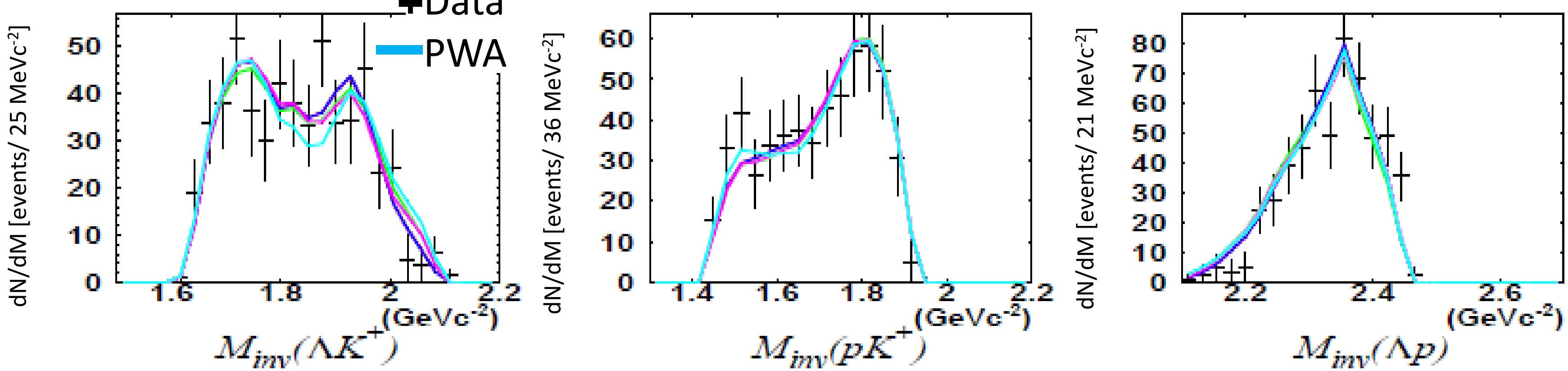
PWA Results



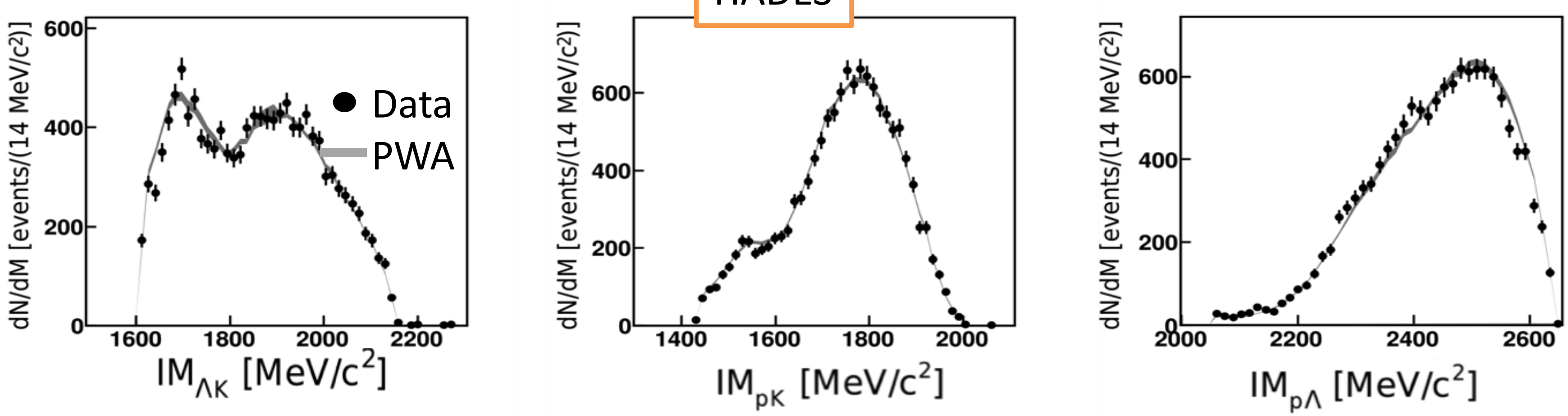
R. Münzer, Hyp. Int., 233,1-3,159-166 (2015)

Four Best PWA Solutions

FOPI



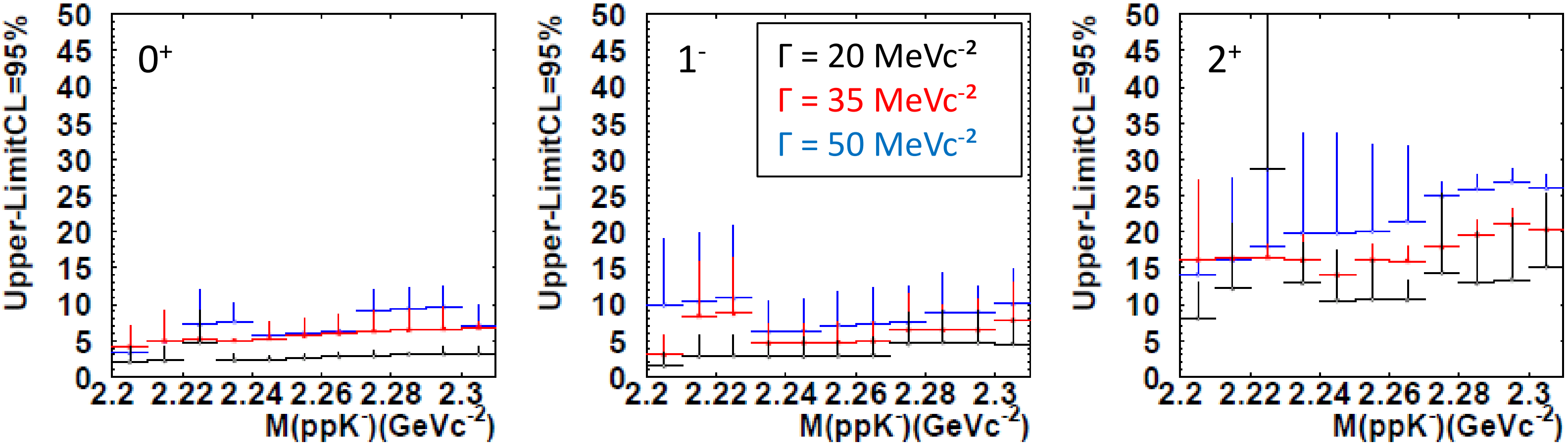
HADES



R. Münzer, Hyp. Int., 233,1-3,159-166 (2015) / G. Agakishiev, Phys.Lett. B742 (2015) 242-248

Upper Limit of ppK^- Contribution

ppK$^-$ Upper Limit Determination



p + p -> p + K$^+$ + Λ
Total Cross Section

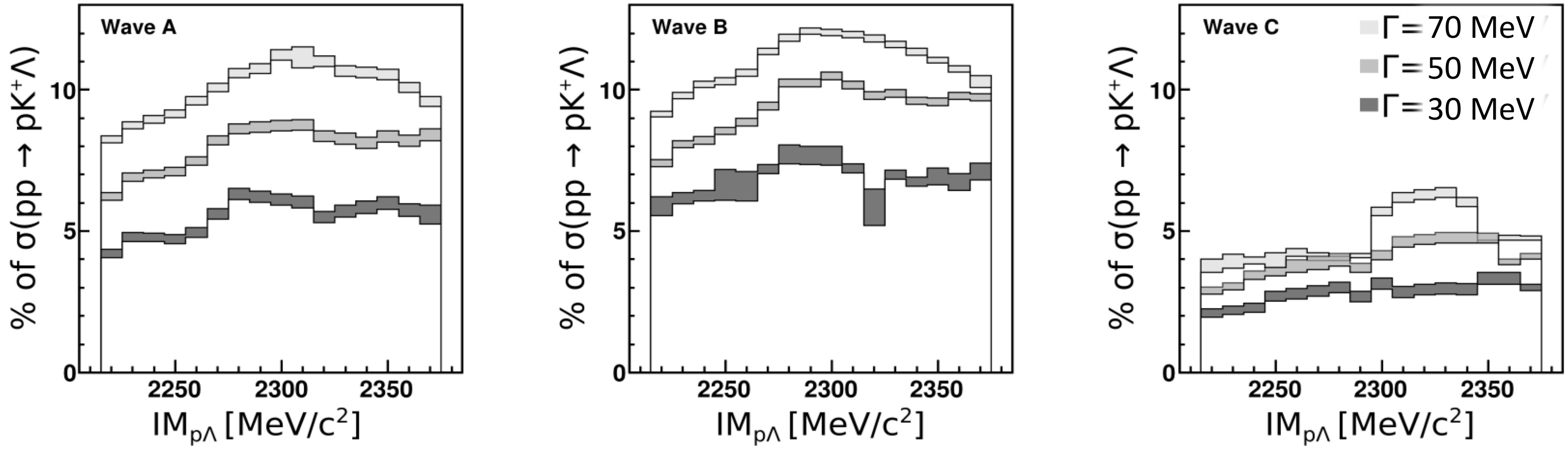
$$\sigma_{pK^+\Lambda} = 41.0 \pm 12.8 \mu b$$

Interpolated from literature

Upper Limit Cross Section

Γ (MeVc^{-2})	Cross Section (µb)
20	$7.6 \pm 1.2^{-3.5}$ - $22.4 \pm 3.6^{-10.7}$
35	$6.3 \pm 1.7^{-0.6}$ - $9.5 \pm 2.6^{-0.9}$
50	$10.2 \pm 1.8^{-4.5}$ - $11.6 \pm 3.4^{-0.6}$
60	$11.2 \pm 1.9^{-5.0}$ - $33.8 \pm 5.2^{-16.9}$
80	$11.4 \pm 2.7^{-3.8}$ - $35.9 \pm 5.7^{-17.4}$

Upper Limit



Measured total cross-section: $\sigma_{pK^+\Lambda} = 38.12 \pm 0.43^{+3.55}_{-2.83} \pm 2.67(p+p\text{-}error) - 2.9(background)\ \mu b$

Upper limit of ppK⁻ Cross Section:

Γ (MeVc^{-2})	Cross Section (μb)
0^+	1.9 – 3.9
1^-	2.1 – 4.2
2^+	0.7 – 2.1

G. Agakishiev,Phys.Lett. B742 (2015) 242-248

Production Cross Section Λ(1405)

$9.2 \pm 0.9 \pm 0.7\ ^{+3.3}_{-1.0}\ \mu b$

HADES coll. (G. Agakishiev et al.)
Phys. Rev. **C 87**, 025201 (2013)

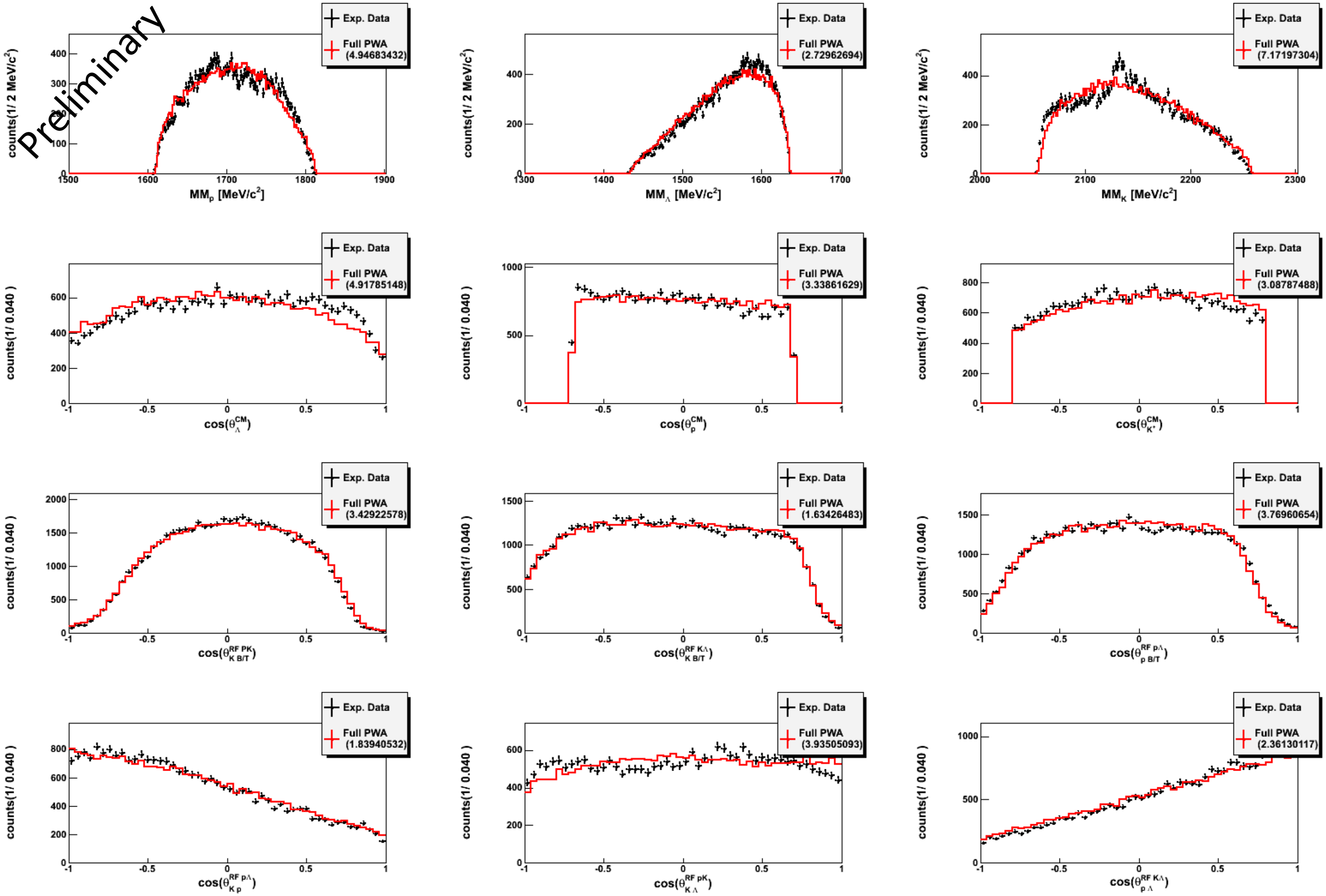
Combined Analysis

Outlook

- Improvement of background description
- Combined Analysis

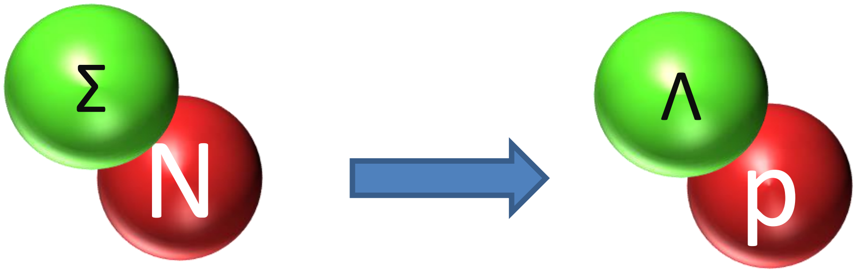
Experiment	E_B [GeV]	$pK^+\Lambda$ Statistics	ε_{ppK^-} [MeV]	Status
COSY-TOF	1.96	~160k	-104	In Preparation
DISTO	2.15	120 k	-114	Available
COSY-TOF	2.16	3.6 k	-104	Available
COSY-TOF	2.16	40 k	-104	Available
COSY-TOF	2.16	~90k	-104	In Preparation
COSY-TOF	2.25	36 k	-83	Available
COSY-TOF	2.40	1.6 k	-24	Available
DISTO	2.5	304 k	26	Available
DISTO	2.85	424 k	116	Available
FOPI	3.1	0.9 k	196	Single PWA
HADES	3.5	21 k	315	Single PWA

PWA Results – COSY-TOF@2.16 GeV



The ΣN Cusp Effect

Coupled Channel:



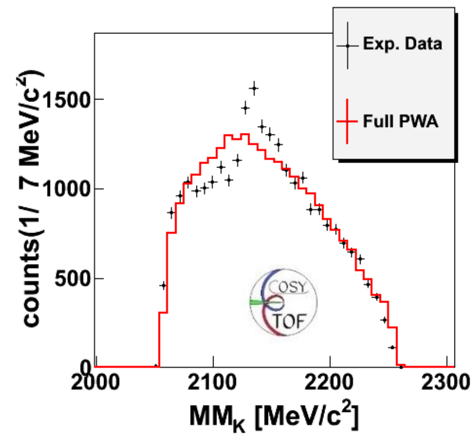
At Threshold : 2130 $MeVc^{-2}$

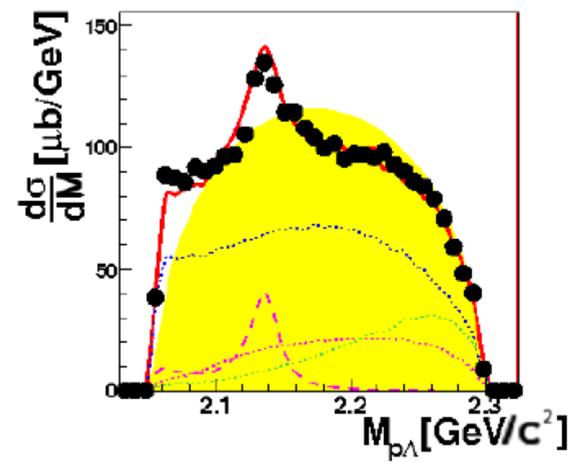
Quantum Number of Cusp: 0^+ / 1^+ (L=0,2)

Spectral Function:

Breit Wigner

Flatté





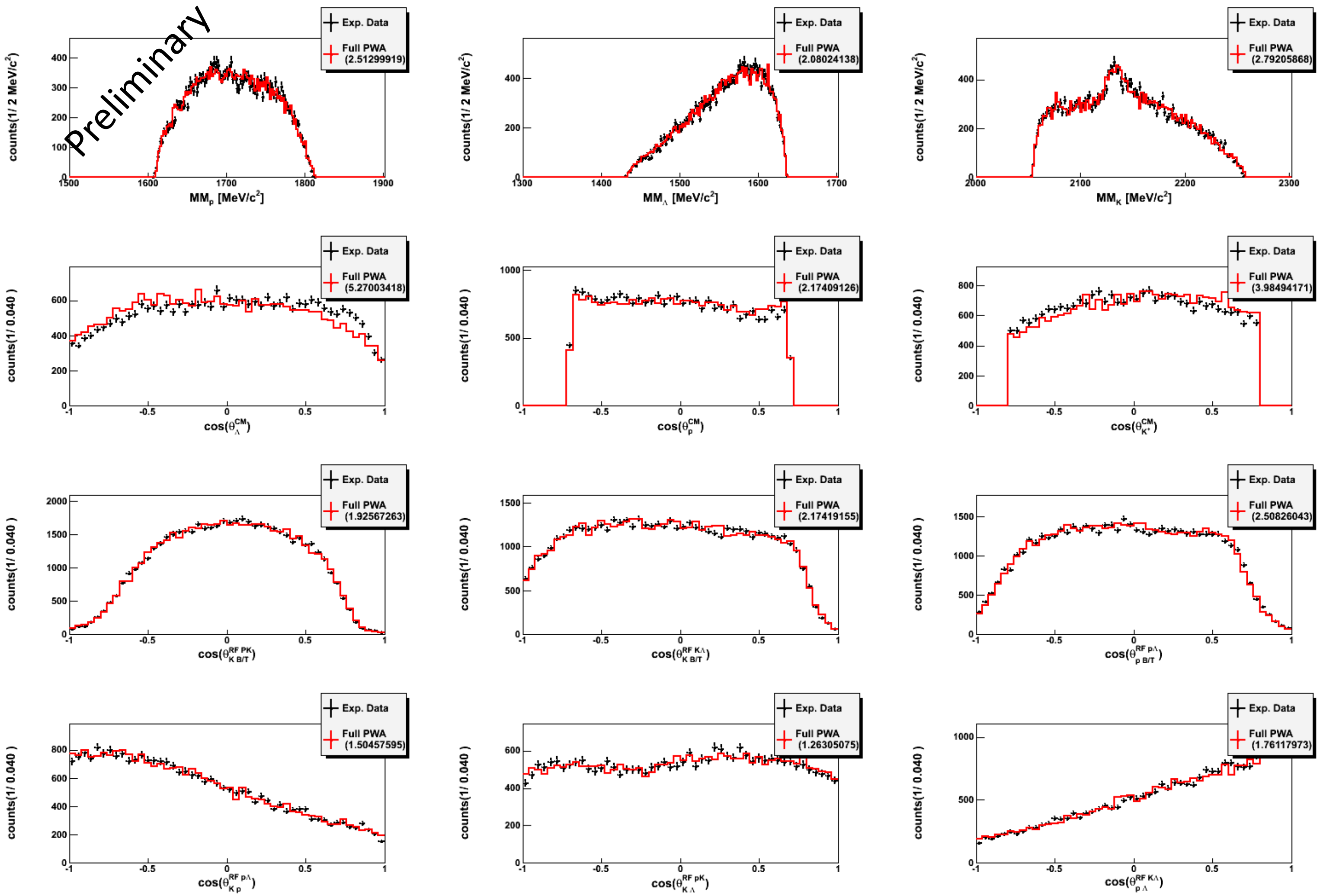
S.Abd El-Samad, Eur.Phys.J A49(2013)

Cusp Spectral Function

Relativistic Breit-Wigner Distribution:

$$\frac{d\sigma}{dm} \approx \frac{1}{(M^2 - s - i\Gamma M)}$$

PWA Results with Cusp – COSY-TOF@2.16 GeV

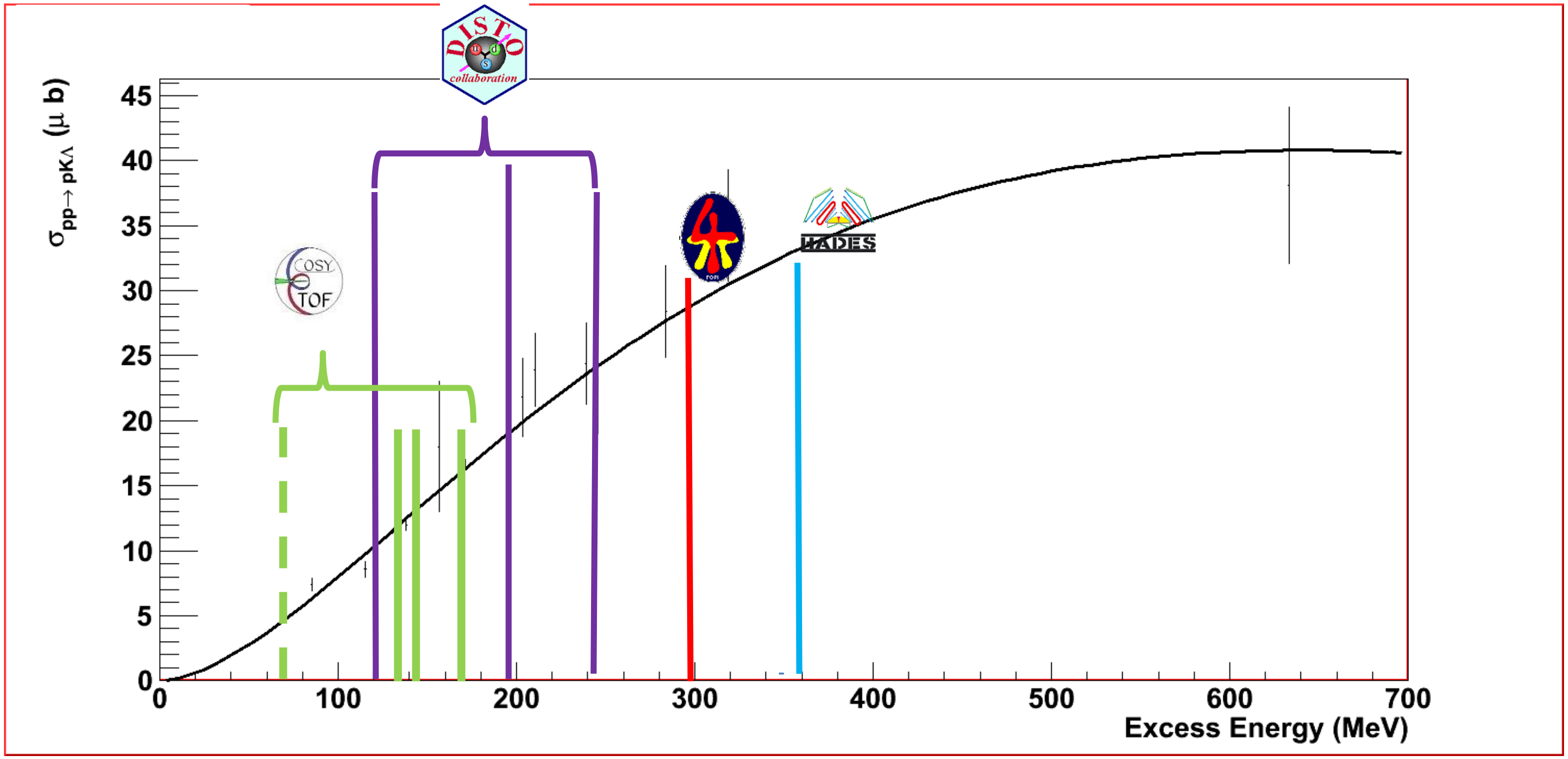


Data Sets

Experiment	E_B [GeV]	$pK^+\Lambda$ Statistics	ε_{ppK^-} [MeV]	Status
COSY-TOF	1.96	~160k	-104	In Preparation
DISTO	2.15	120 k	-114	Combined PWA
COSY-TOF	2.16	3.6 k	-104	Combined PWA
COSY-TOF	2.16	40 k	-104	Combined PWA
COSY-TOF	2.16	~90k	-104	In Preparation
COSY-TOF	2.25	36 k	-83	Combined PWA
COSY-TOF	2.40	1.6 k	-24	Combined PWA
DISTO	2.5	304 k	26	Combined PWA
DISTO	2.85	424 k	116	Combined PWA
FOPI	3.1	0.9 k	196	Combined PWA
HADES	3.5	21 k	315	Combined PWA

Total Cross Section

Relative Contribution scaled by total cross section

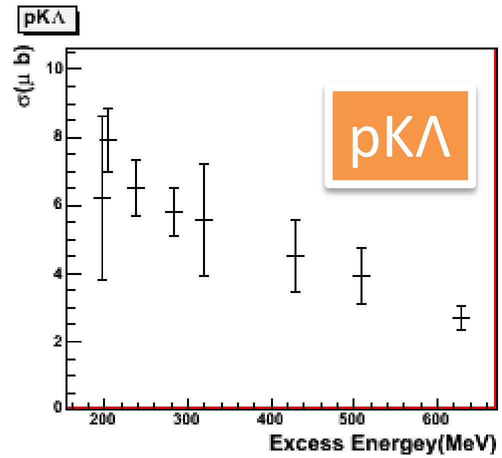


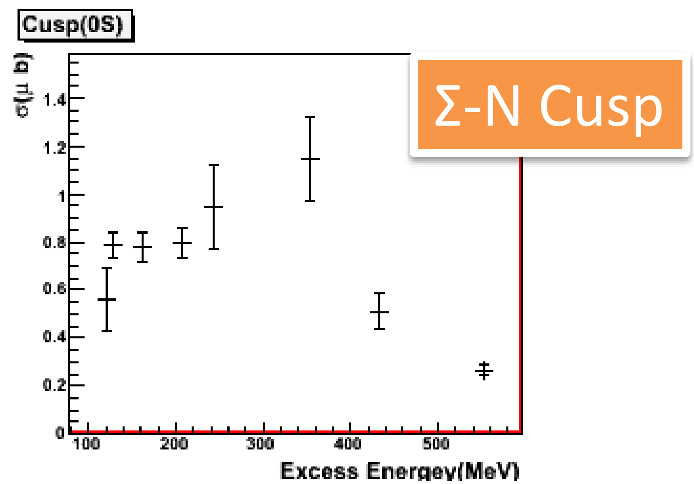
Cross Section

$$\sigma(\,p + p) \rightarrow Channel \rightarrow p + K^{+} + \Lambda$$

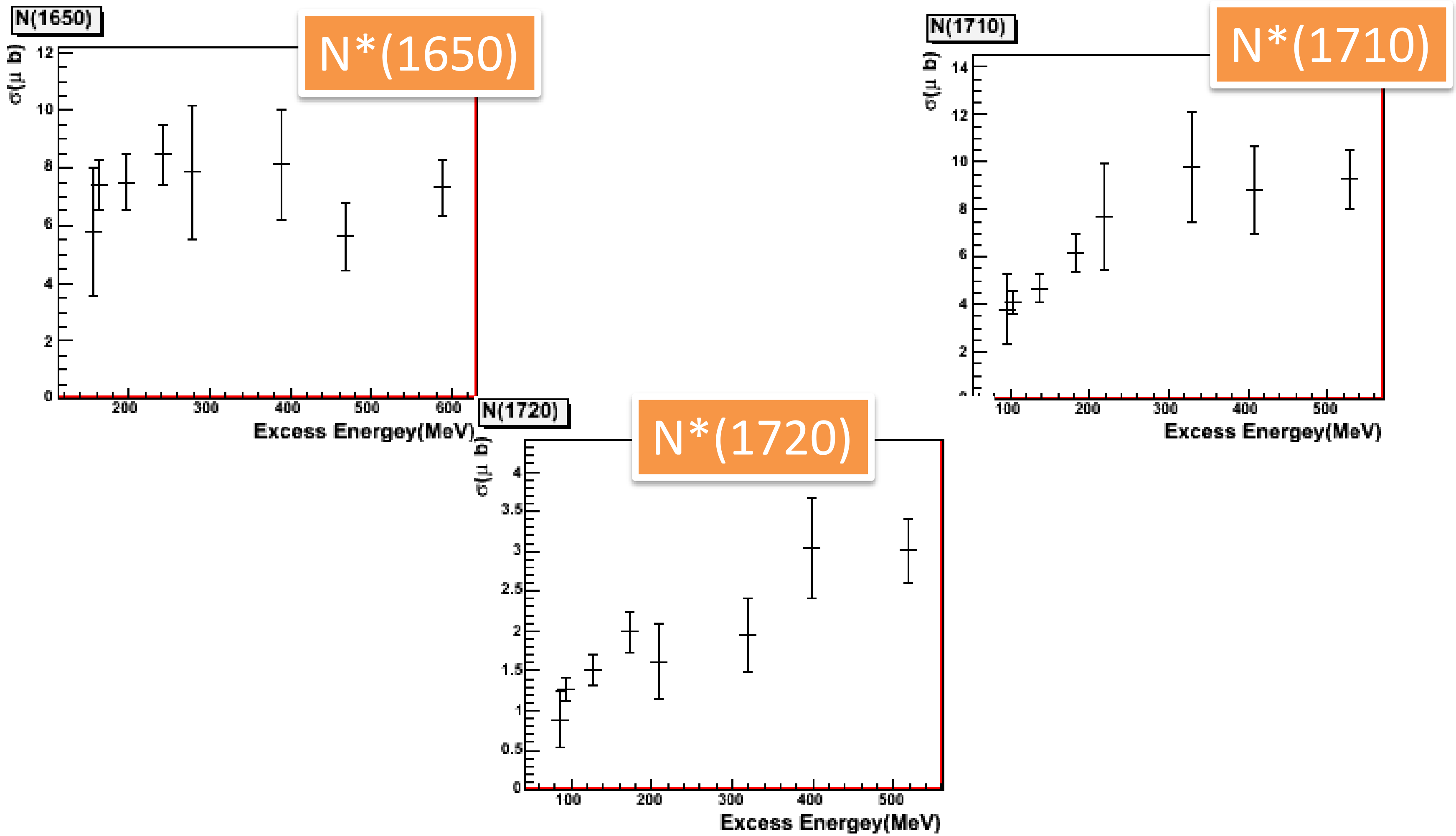
Convoluted Cross Section

Production + Branching Ratio

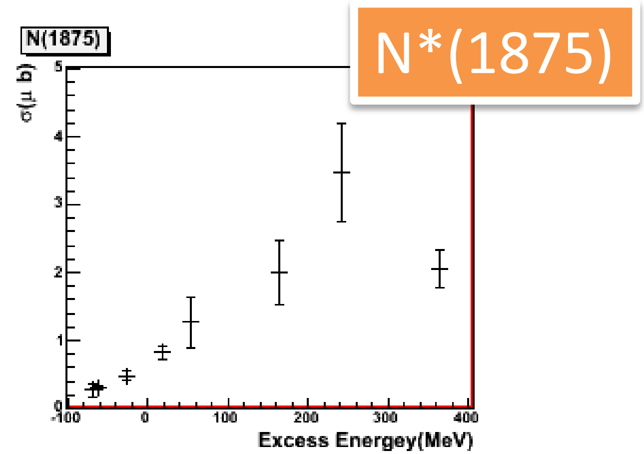


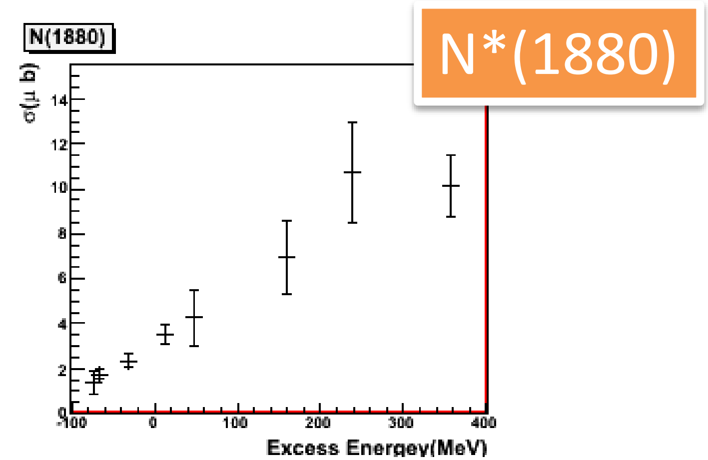


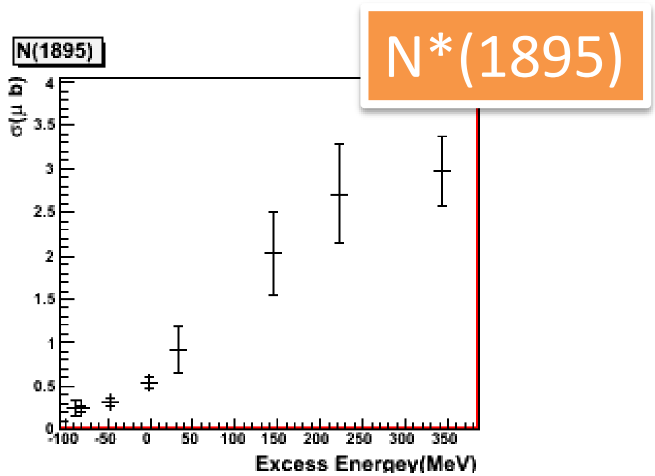
Cross Section

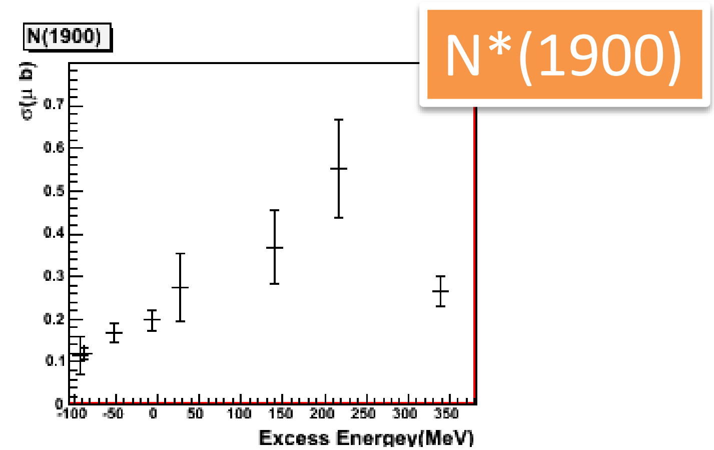


Cross Section









Cusp Spectral Function

Relativistic Breit-Wigner Distribution:

$$\frac{d\sigma}{dm} \approx \frac{1}{(M^2 - s - i\Gamma M)}$$

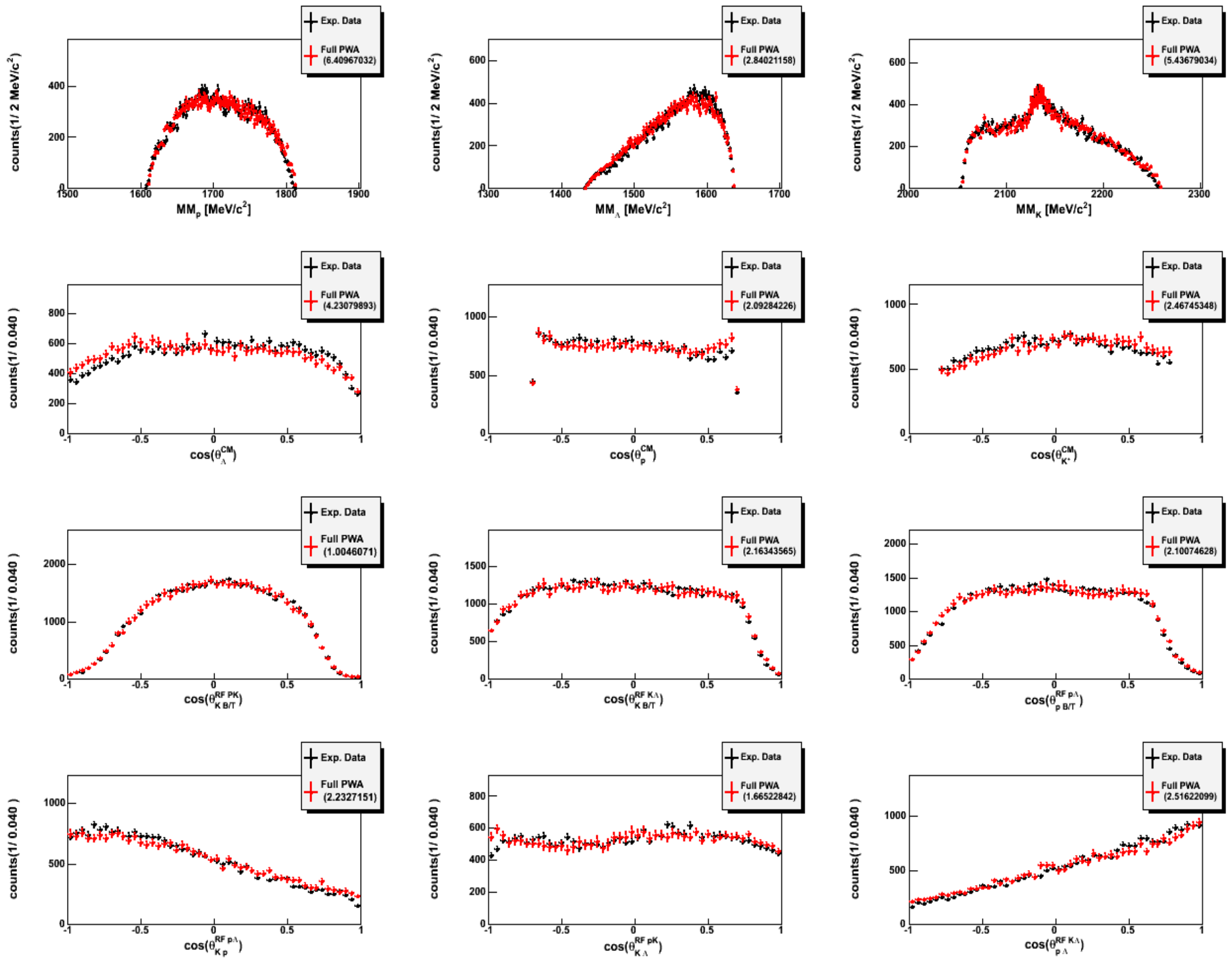
Flatte Distribution:

$$\frac{d\sigma}{dm} \approx \frac{\sqrt{\Gamma_{\Lambda p}}}{\left(M^2 - s - i\left(\Gamma_{\Lambda p} + \Gamma_{\Sigma N}\right)M\right)}$$

$$\Gamma_{\Lambda p} = g_{p\Lambda} q_{p\Lambda} \quad \Gamma_{\Sigma p} = g_{p\Sigma} q_{p\Sigma}$$

$q_{p\Lambda}, q_{p\Sigma}$: *Relative Momentum*
$g_{p\Lambda}, g_{p\Sigma}$: *Couplong Constants*
$g_{p\Lambda} \ll g_{p\Sigma}$: *Asymetric Structure*
$g_{p\Lambda} \gg g_{p\Sigma}$: *Symetric Structure*

COSY-TOF@2.16GeV



Error bars for cusp are a bit high.

Black dots: Exp data
Red dots with error bars: PWA results

Resulting value:

$g_{p\Lambda}$: $(0.143)^2$

$g_{p\Sigma}$: $(0.001)^2$

Summary

- Kaonic Bound State
  - Kaon Nucleon Bound States -> Predicted by Theory but not conclusive Properties
  - Experimental Results show different behavior
  - No Signal Visible in p + p Reaction data measured at FOPI and HADES
  - Production Mechanism has to be described by Partial Wave Analysis including Interference
  - Extraction of Upper Limit: 0.7 - 4.1 μb (HADES) 7.1 - 35.7 μb (FOPI)

- Combined Analysis
  - Set of 9 different data sample can be fitted in parallel with BG-PWA analysis
  - Extraction of excitation function → Strong contribution of N*
  - Contribution of ppK^- very small → No further channel required
  - Σ-N can be reproduced by BG-PWA: symmetric shape -> Coupling p-Λ > Σ-N

Thank You

HADES Collaboration

FOPI Collaboration

DISTO Collaboration
M. Maggiora

COSY-TOF Collaboration
J. Ritman, E. Roderburg
F. Hauenstein, D. Gronzka

Petersburg Nuclear Physics Institute

Bonn Gatchina Group
A. Sarantsev

K-Cluster – Excellence Cluster Universe – TU Munich
L. Fabbietti, E. Epple, P. Klose, S.Lu, J. Siebenson, D. Soliman