

First Measurement of the energy dependet N* production Amplitudes with Partial Wave Analysis

[arXiv:1703.01978v1](https://arxiv.org/abs/1703.01978v1)

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Excellence Cluster – Origin of the Universe



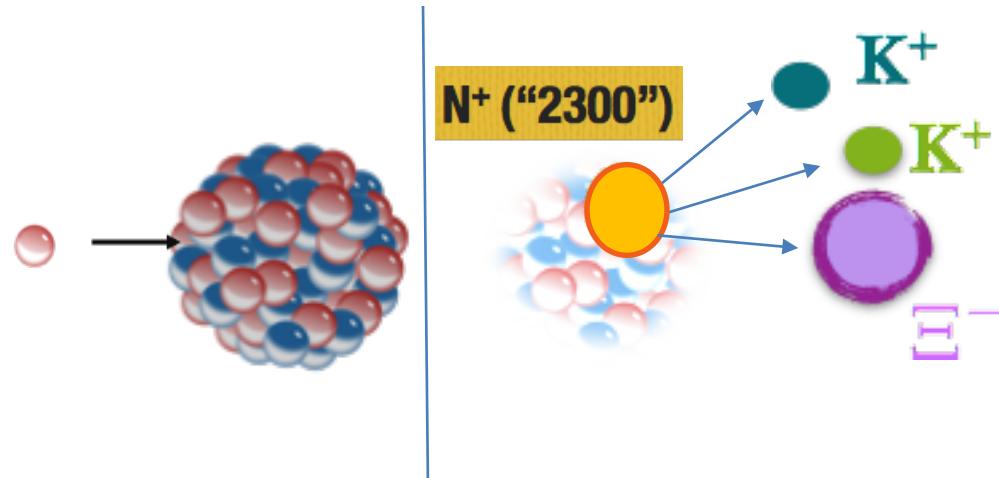
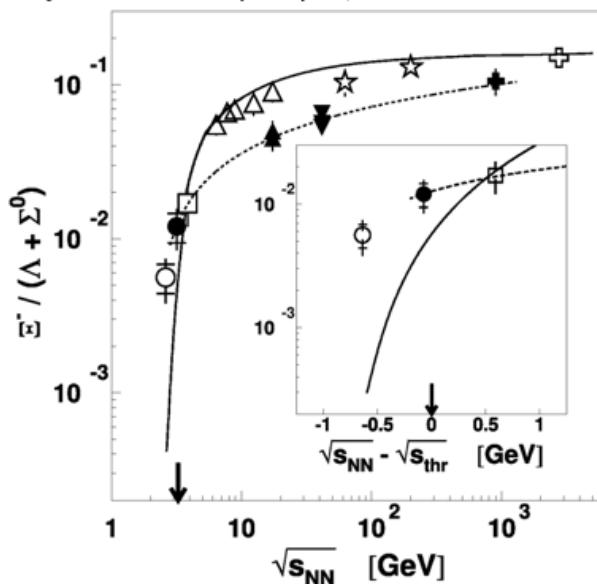
Hunting for Resonances

- In hadron collisions at GeV energies particle production proceed through the intermediate excitation of resonances
- Formation and decay rates of the resonances have to be measured

Ξ excess in A+A and p+A at low energies

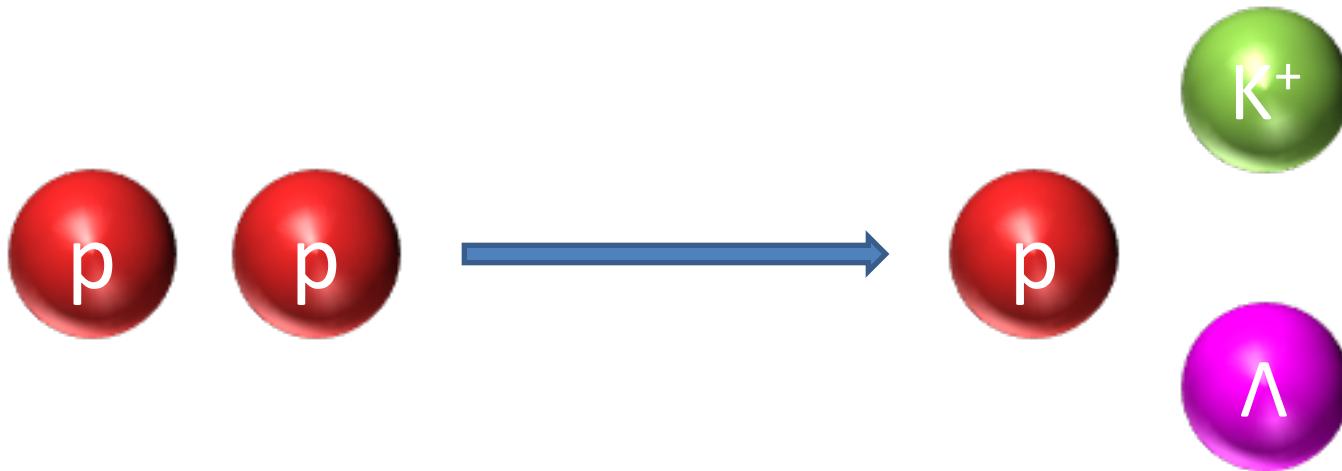
Phys.Rev.Lett. 103 (2009) 132301

Phys.Rev.Lett. 114 (2015) 21, 212301

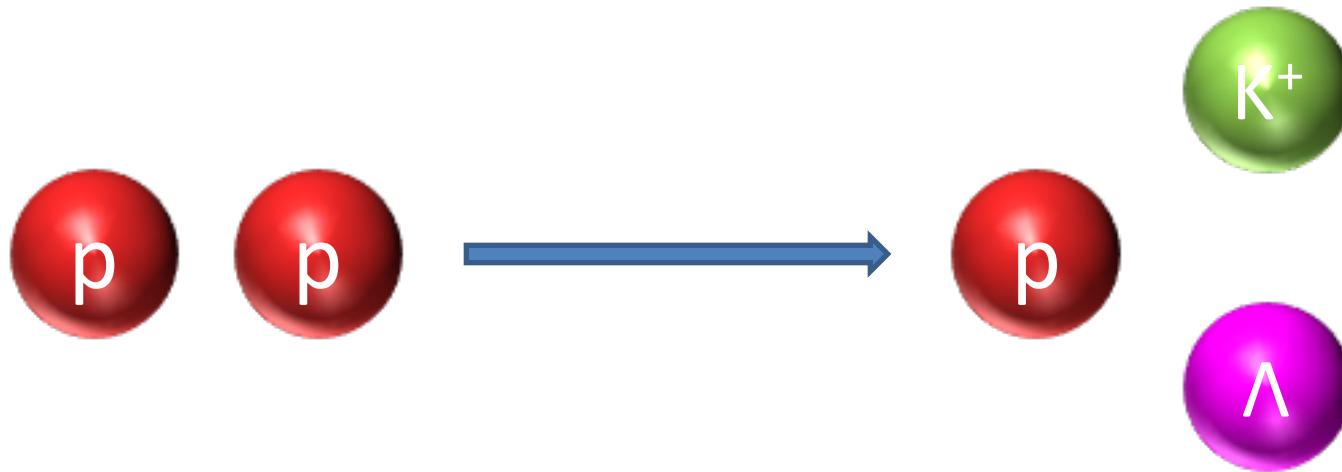


J. Steinheimer, M. Bleicher J.Phys. G43 (2016) no.1, 015104

Strangeness Production

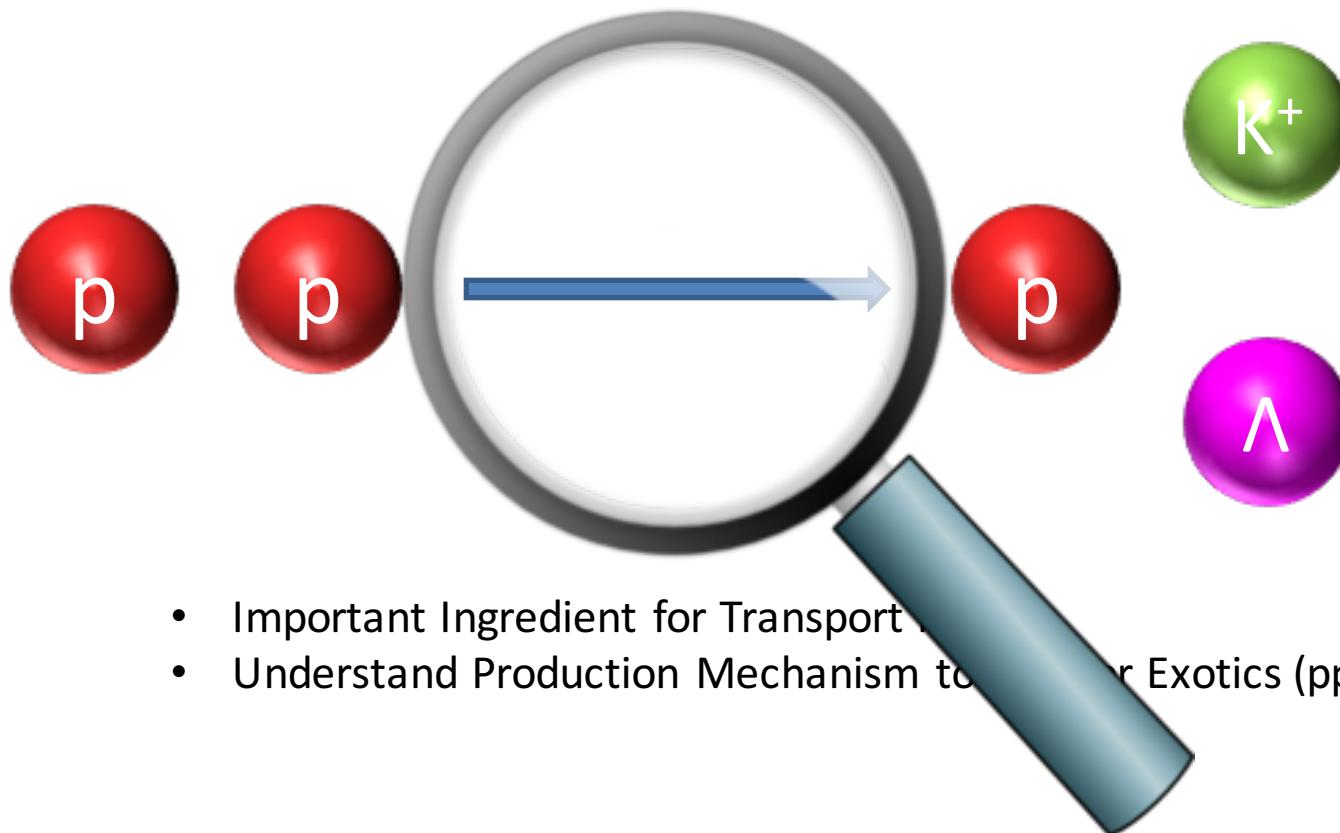


Strangeness Production



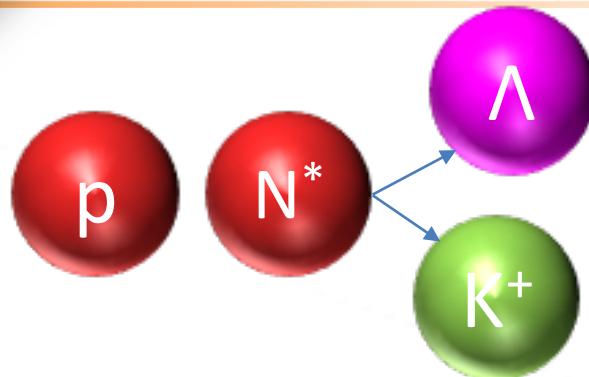
- Important Ingredient for Transport Models
- Understand Production Mechanism to look for Exotics (ppK^-)

Strangeness Production



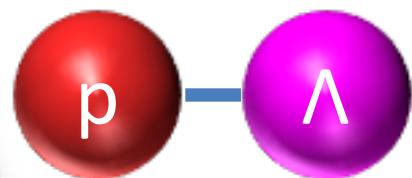
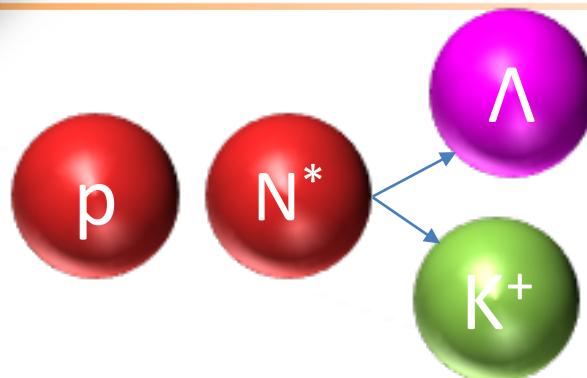
- Important Ingredient for Transport
- Understand Production Mechanism to Exotics (ppK^-)

Strangeness Production

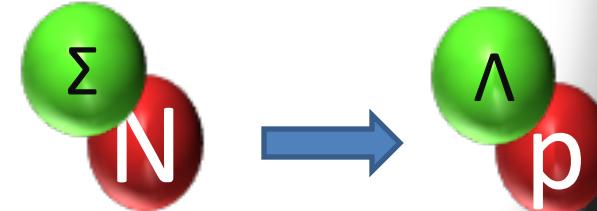


Resonance	J^P	Mass (GeV/c^2)	Γ (MeV/c^2)
$N^*(1650)$	$1/2^-$	1.655	0.150
$N^*(1710)$	$1/2^+$	1.710	0.100
$N^*(1720)$	$3/2^+$	1.720	0.250
$N^*(1875)$	$3/2^-$	1.875	0.220
$N^*(1880)$	$1/2^+$	1.870	0.235
$N^*(1895)$	$1/2^-$	2.090	0.090
$N^*(1900)$	$3/2^+$	1.900	0.0250

Strangeness Production



Final State Interaction
Aka: scattering length and
effective range



Conversion Processes

Partial Wave Analysis

Bonn-Gatchina PWA Framework

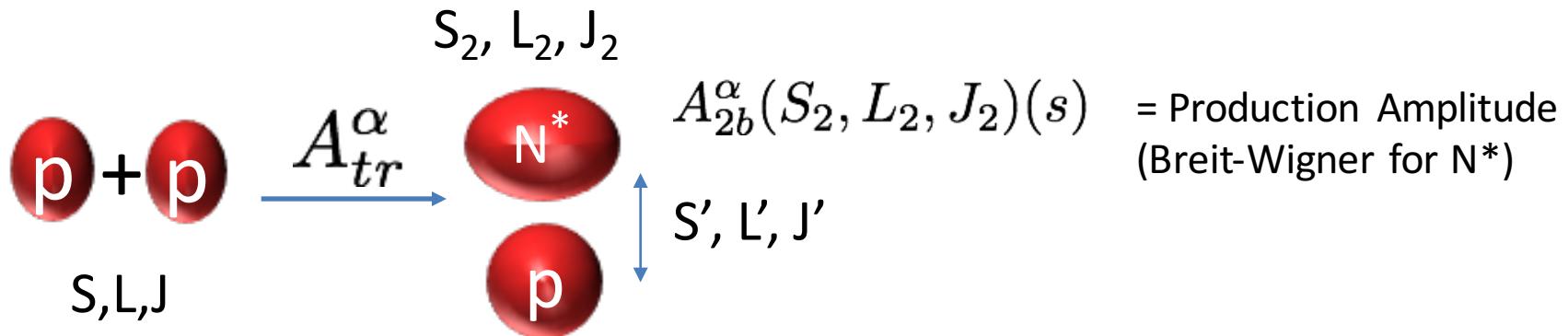
A. Sarantsev et.al., Eur.Phys J A 25 2005

Cross-section Decomposition

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

Partial Waves Decomposition:

$$A = \sum_{\alpha} A_{tr}^{\alpha} Q_{\mu_1 \dots \mu_J}^{in}(S, L, J) A_{2b}^{\alpha}(S_2, L_2, J_2)(s_j) \\ \times Q_{\mu_1 \dots \mu_J}^{fin}(j, S_2, L_2, J_2, S', L', J).$$



Partial Wave Analysis

Bonn-Gatchina PWA Framework

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

Cross-section Decomposition

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Parameterization of the Transition:

$$A_{tr}^{\alpha}(s) = (a_1^{\alpha} + a_3^{\alpha} \sqrt{s}) e^{a_2^{\alpha}}$$

a_1^{α} Constant amplitude

a_2^{α} Phase

a_3^{α} Energy dependent amp.

HADES coll. (G. Agakishiev et al.)
Phys. Lett. B742 (2015) 242–248.

[arXiv:1703.01978v1](https://arxiv.org/abs/1703.01978v1)

Data Sets

Experiment	E_B [GeV]	pK ⁺ Λ Statistics	Status
DISTO	2.15	121 k	Available
COSY-TOF	2.16	43 k	Available
COSY-TOF	2.16	~90k	In Preparation (not used in the analysis)
DISTO	2.5	304 k	Available
DISTO	2.85	424 k	Available
FOPI	3.1	0.9 k	Single PWA
HADES	3.5	21 k	Single PWA

HADES coll. (G. Agakishiev et al.)
Phys. Lett. B742 (2015) 242–248.

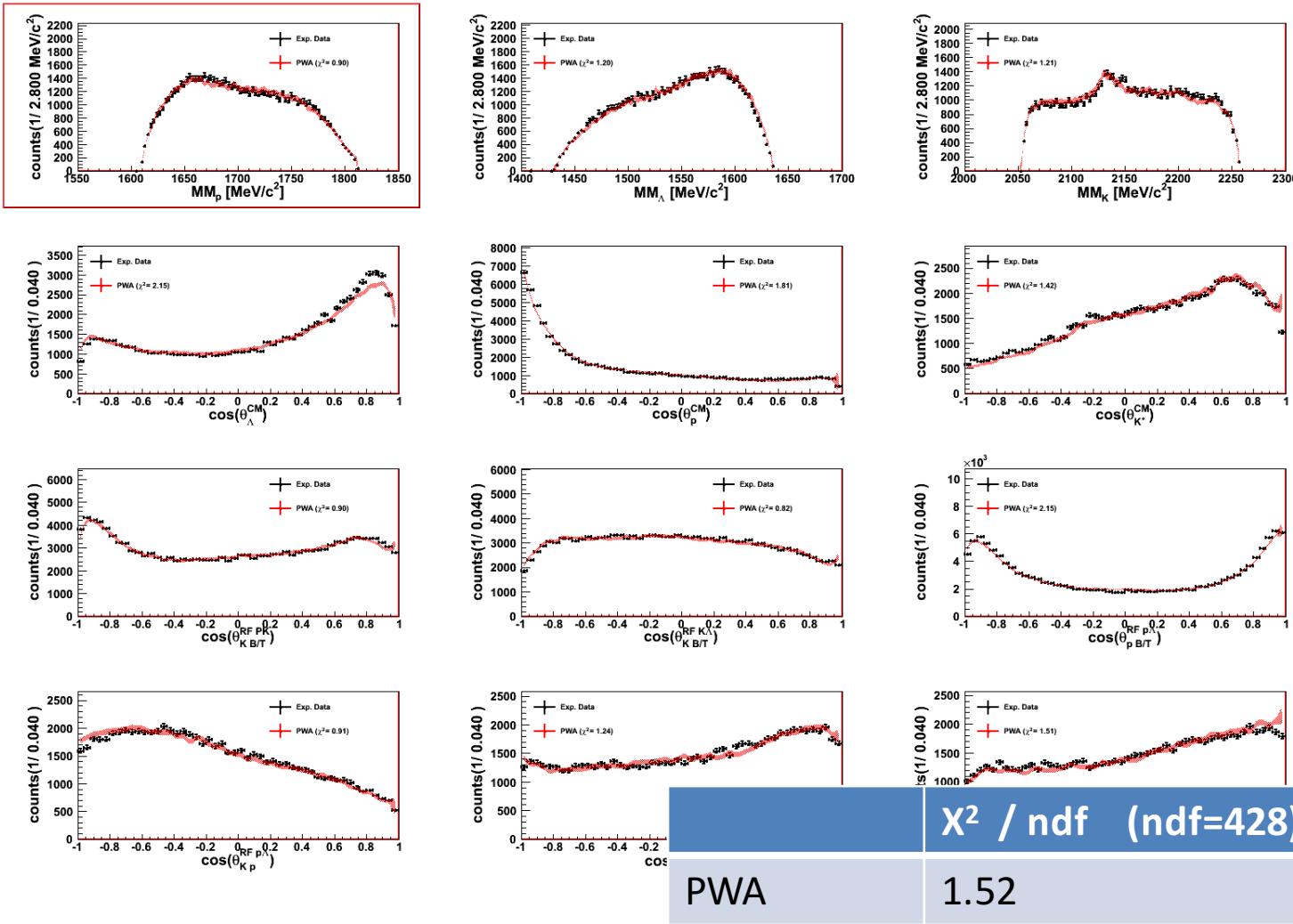
Parameter Scan

pKΛ non resonant up to F wave *

Include different N* Resonances

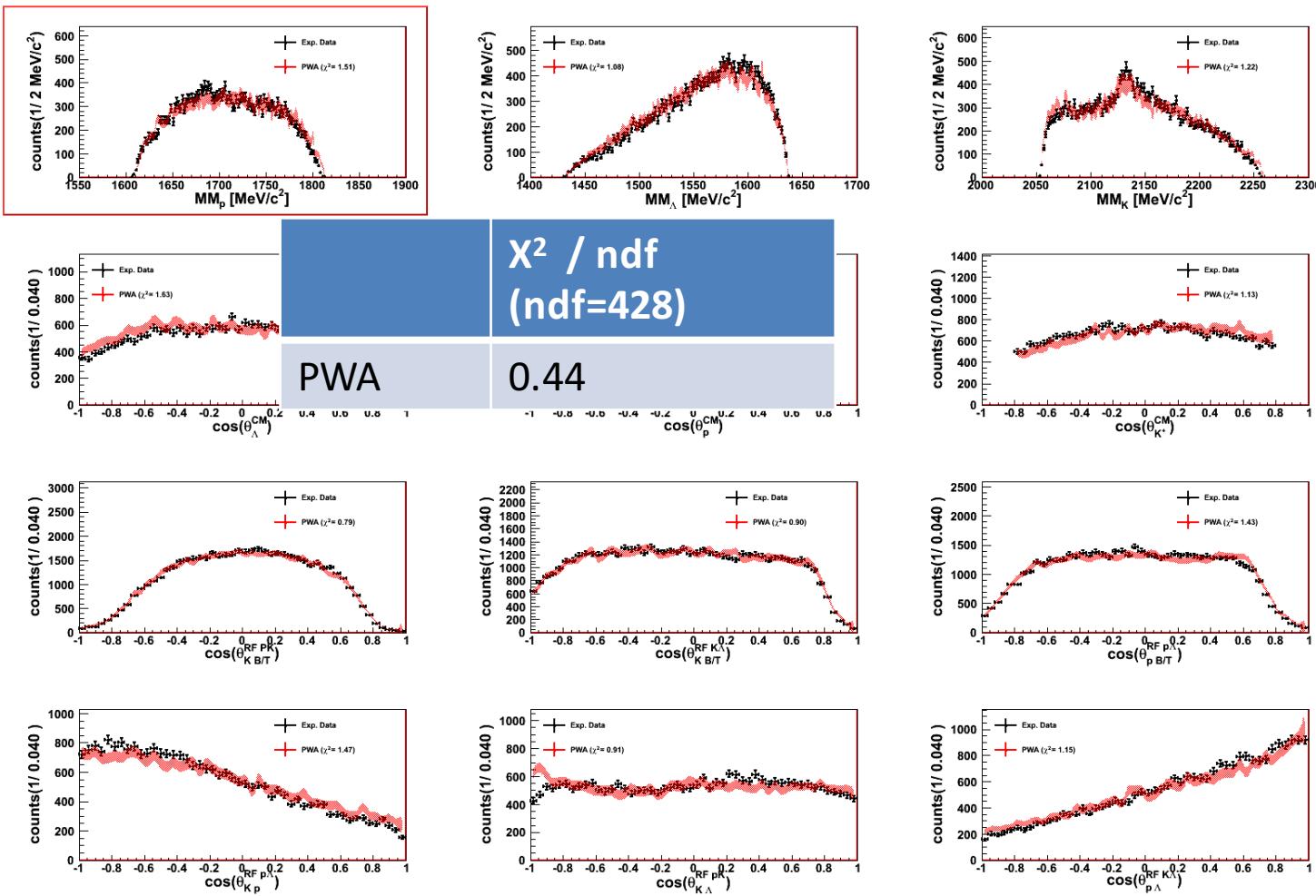
Solution	A	B	C	D	E
Loglike	-67142	-67018	-66878	-66504	-66405
N*(1650)	+	+	+	+	+
N*(1710)	+	+	+	+	+
N*(1720)	+	+	+	+	-
N*(1875)	+	+	-	-	+
N*(1880)	+	+	+	+	+
N*(1895)	+	+	+	+	+
N*(1900)	-	+	+	-	+
$\Sigma N (0^+)$	+	+	+	+	+

DISTO@2.14 GeV [arXiv:1703.01978v1](https://arxiv.org/abs/1703.01978v1)



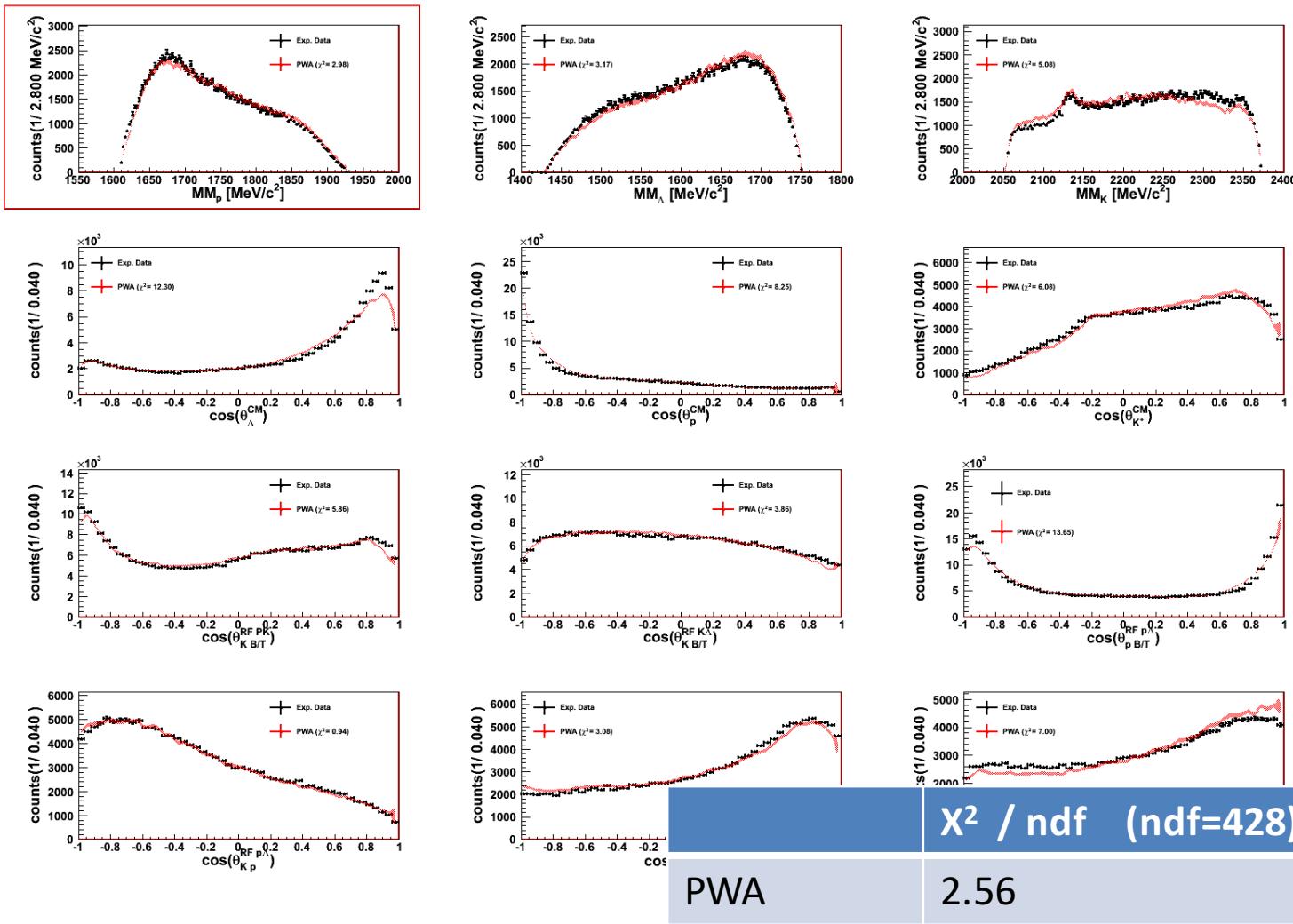
COSY-TOF@2.16 GeV

[arXiv:1703.01978v1](https://arxiv.org/abs/1703.01978v1)



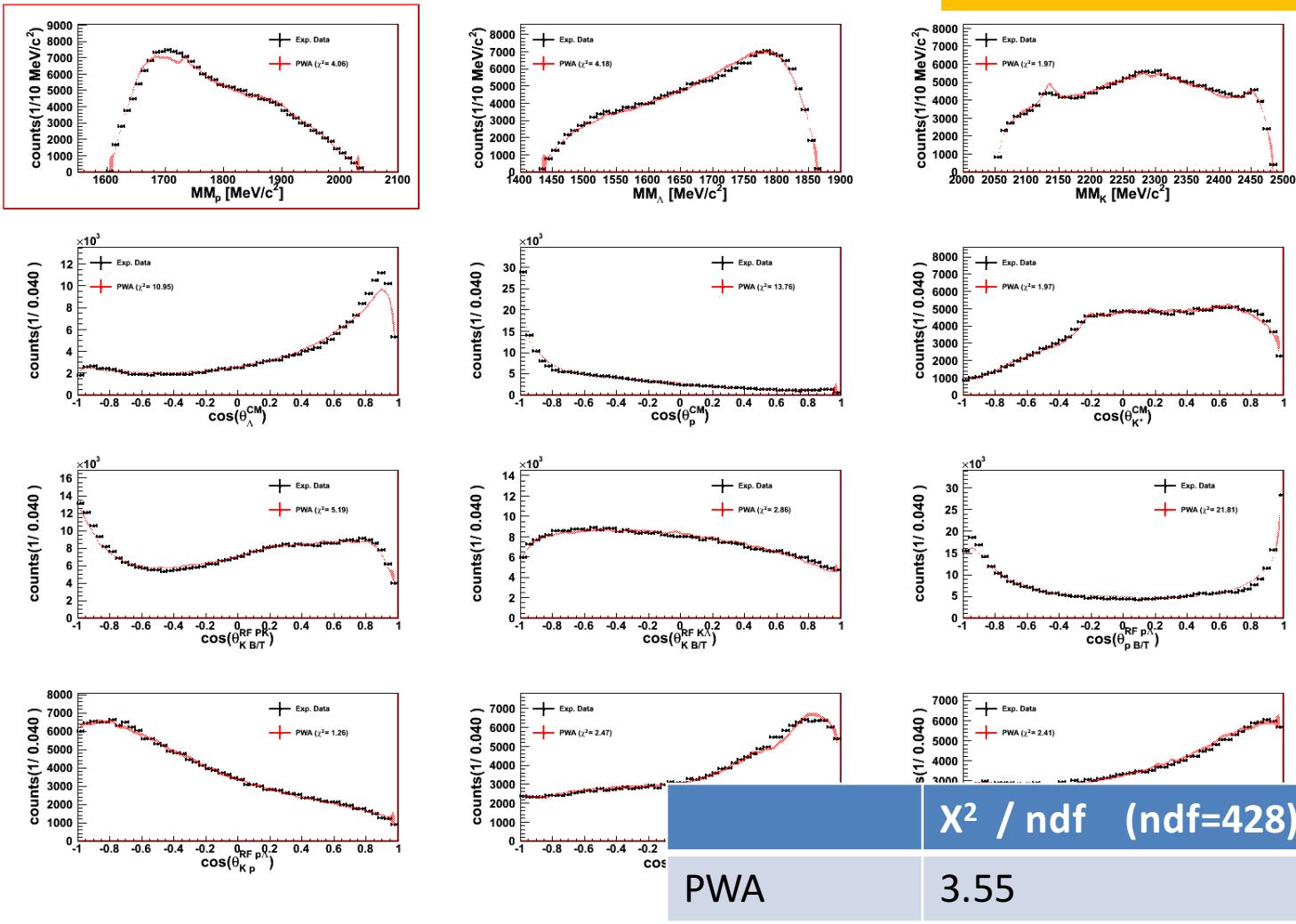
DISTO@2.5 GeV

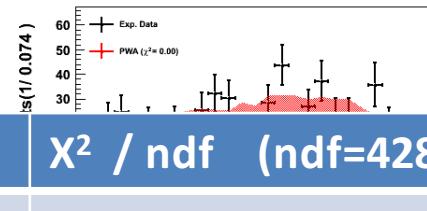
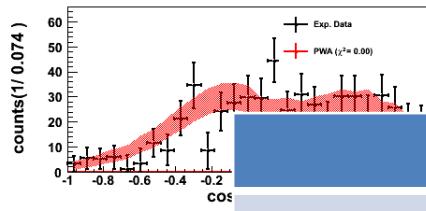
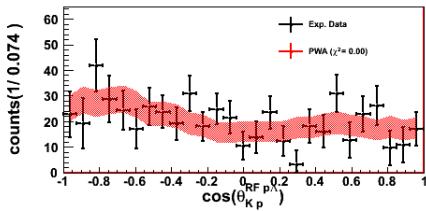
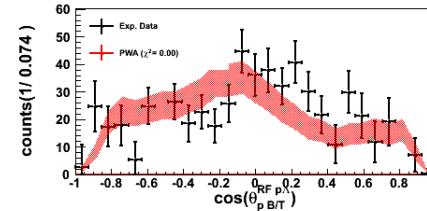
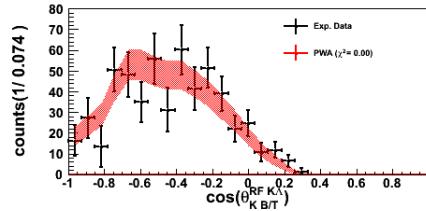
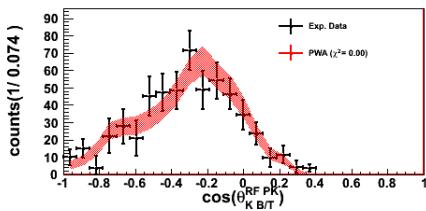
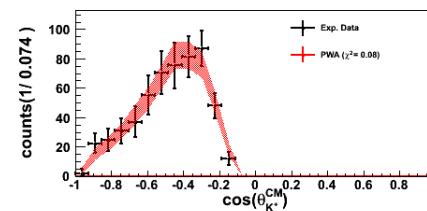
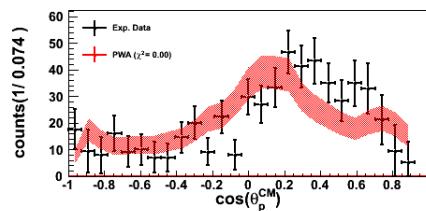
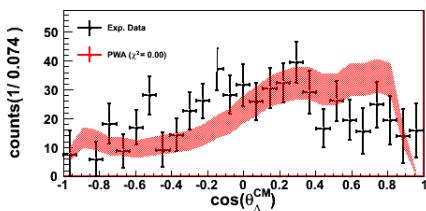
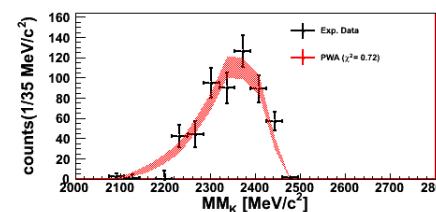
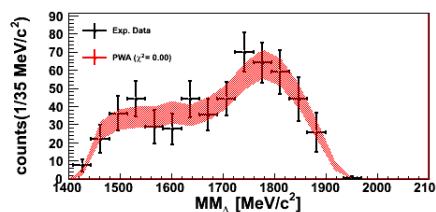
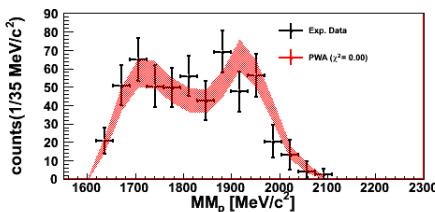
[arXiv:1703.01978v1](https://arxiv.org/abs/1703.01978v1)



DISTO@2.85 GeV [arXiv:1703.01978v1](https://arxiv.org/abs/1703.01978v1)

No Kaonic Cluster included



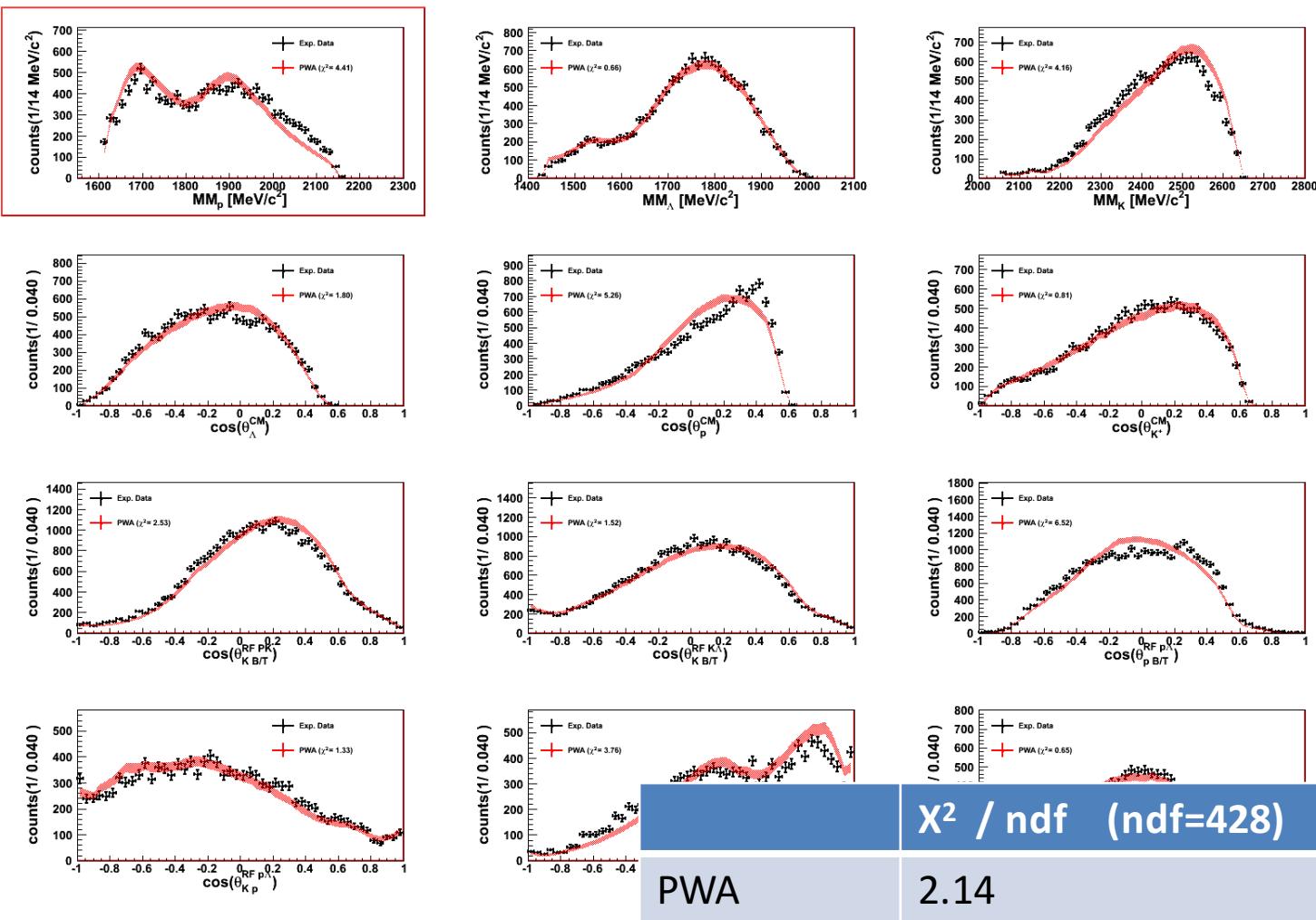


χ^2 / ndf (ndf=428)

PWA

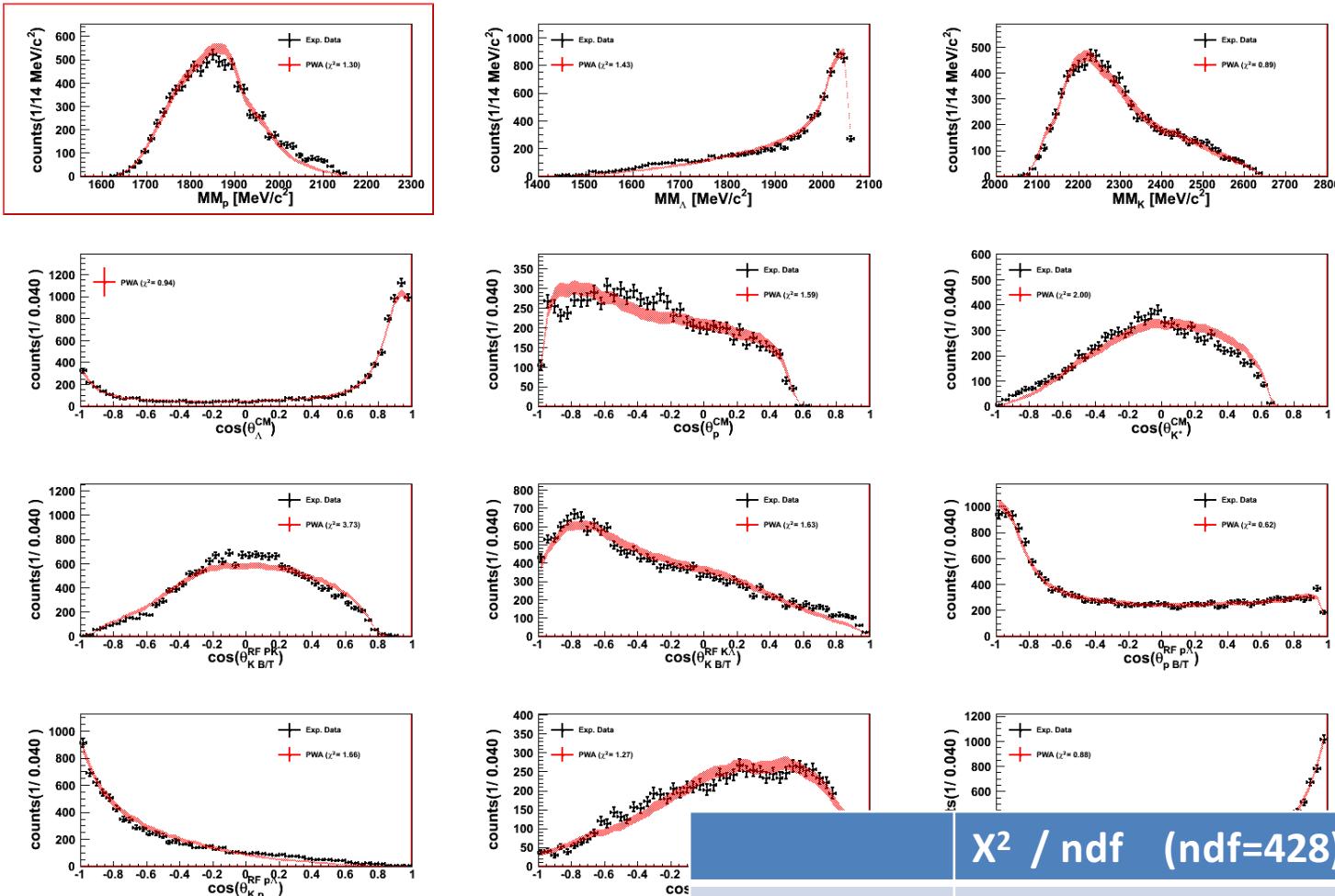
0.91





HADES - WALL

[arXiv:1703.01978v1](https://arxiv.org/abs/1703.01978v1)



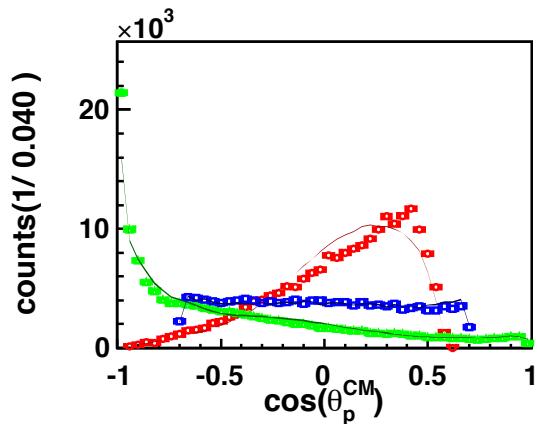
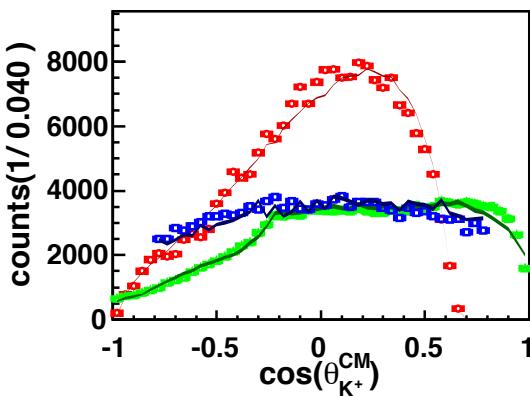
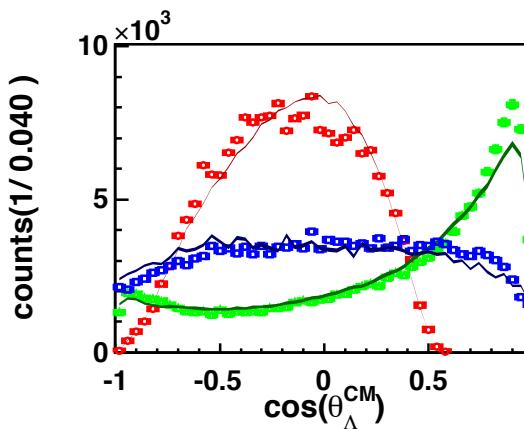
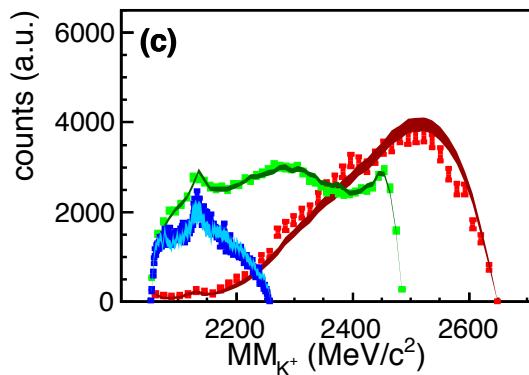
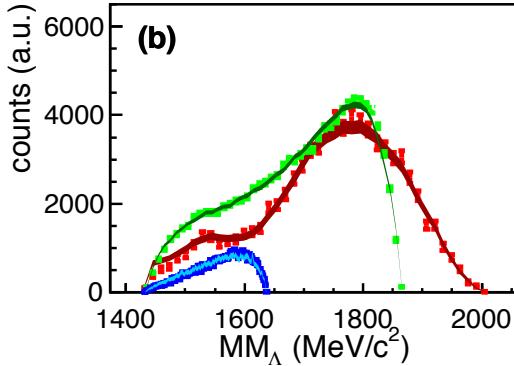
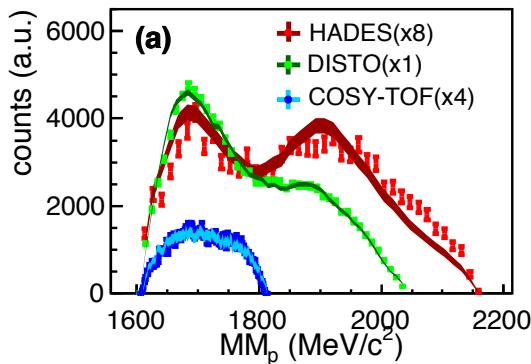
χ^2 / ndf (ndf=428)

PWA

1.86

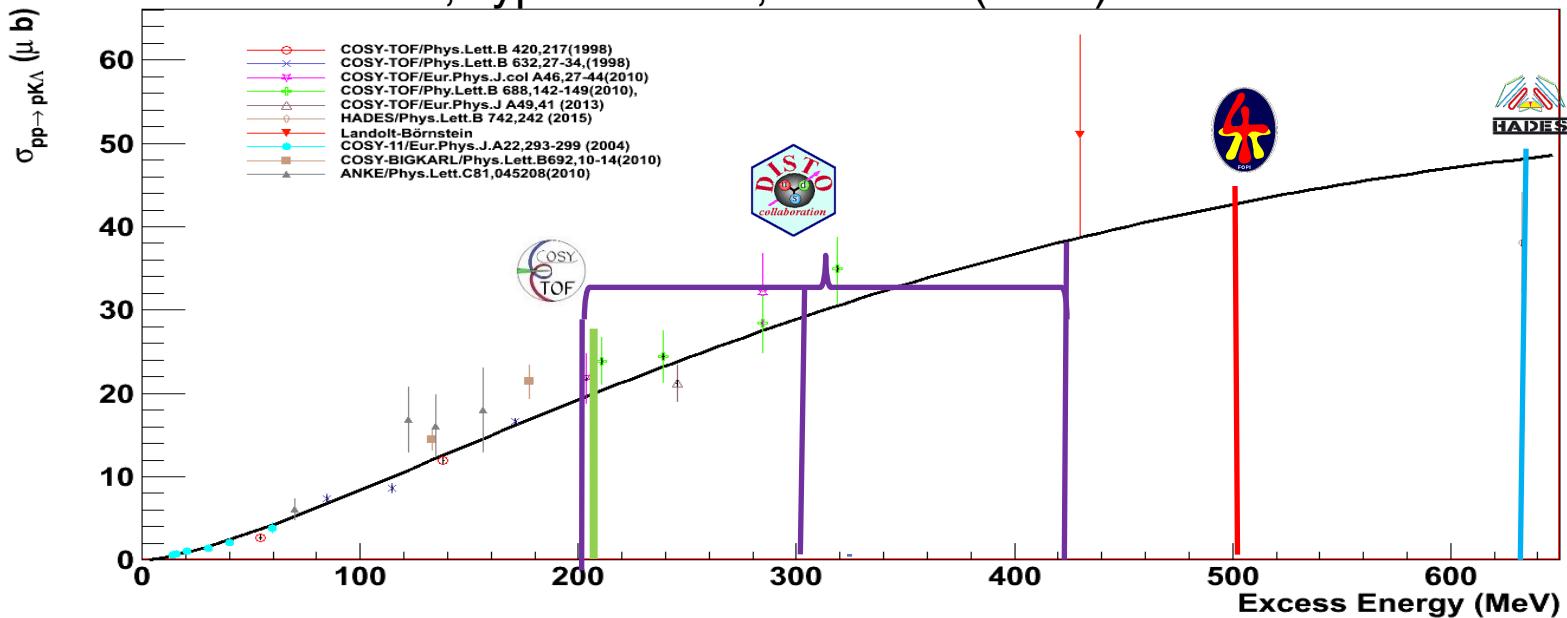


Different Acceptances



Total Cross Section

R.Muenzer et al., Hyperfine 233, 159-166 (2016)



Value:

$$\sigma_{pK\Lambda} = C_1 \left(1 - \frac{s_0}{(\sqrt{s_0} + \epsilon)^2} \right)^{C_2} \left(\frac{s_0}{(\sqrt{s_0} + \epsilon)^2} \right)^{C_3}$$

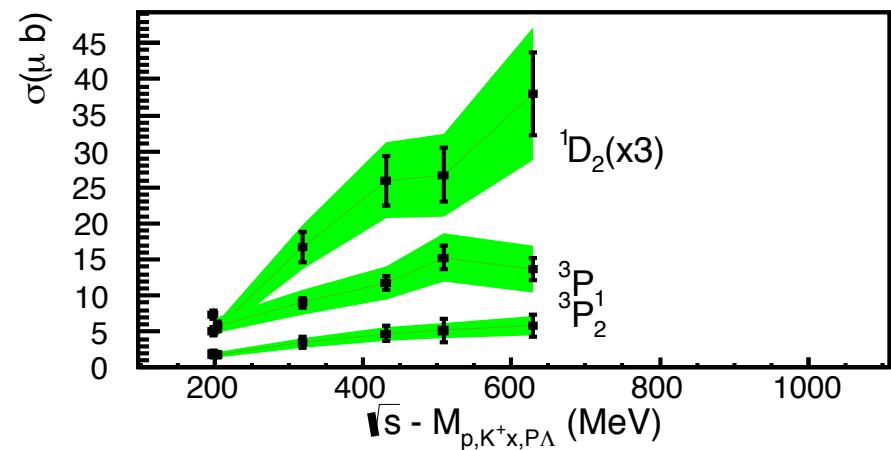
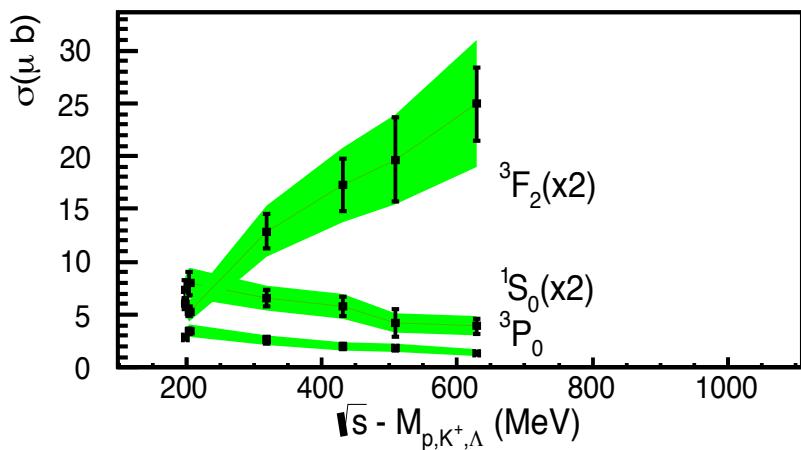
$$C_1 = 4.03 \pm 0.57 \cdot 10^2$$

$$C_2 = 1.49 \pm 0.04$$

$$C_3 = 1.43 \pm 0.39$$

Initial States

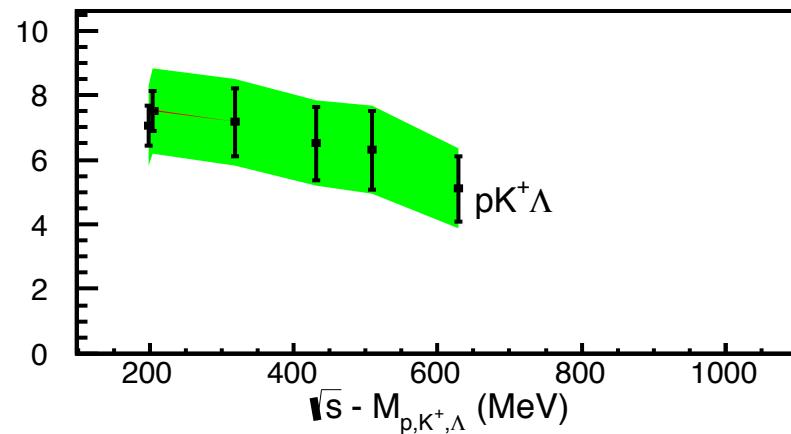
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Resulting N* Excitation Function

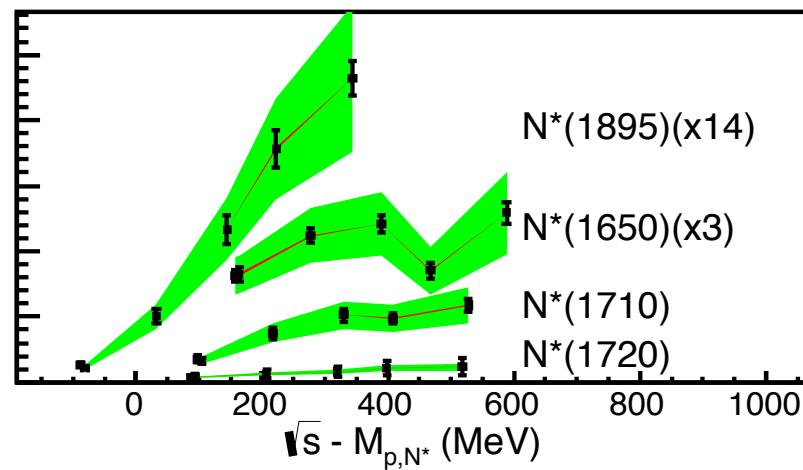
[arXiv:1703.01978v1](https://arxiv.org/abs/1703.01978v1)

$\sigma(\mu b)$

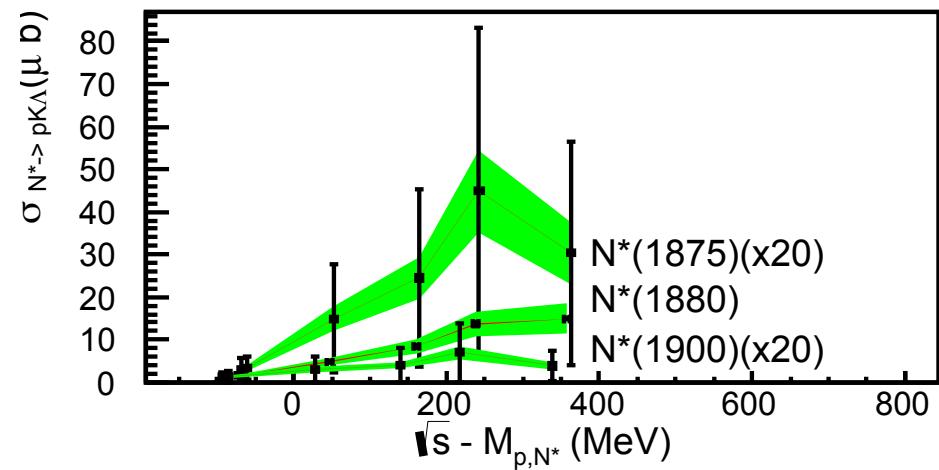


Phase Space contribution varies from 40% to 10% of the resonance contributions when going from 2.14 GeV to 3.5 GeV proton kinetic energy

$\sigma_{N^* \rightarrow pK\Lambda}(\mu b)$



$\sigma_{N^* \rightarrow pK\Lambda}(\mu b)$



Final State Interaction in PWA

[arXiv:1703.01978v1](https://arxiv.org/abs/1703.01978v1)

$$A_{2b}^{\beta} = \frac{\sqrt{s_i}}{1 + \frac{1}{2}r^{\beta}q^2a_{p\Lambda}^{\beta} + iq a_{p\Lambda}^{\beta} q^{2L}/F(q, r^{\beta}, L)}$$

$a_{p\Lambda}^{\beta}$ Scattering Length

r^{β} Effective Range of System

Source	1S_0 $a_{\Lambda-p}$ [fm]	1S_0 $r_{\Lambda-p}$ [fm]	3S_1 $a_{\Lambda-p}$ [fm]	3S_1 $r_{\Lambda-p}$ [fm]
This work	$-1.43 \pm 0.36 \pm 0.09$	$1.31 \pm 0.24 \pm 0.16$	$-1.88 \pm 0.38 \pm 0.10$	$1.04 \pm 0.78 \pm 0.15$
[28]	$-1.8^{+2.3}_{-4.2}$	-	$-1.6^{+1.1}_{-0.8}$	-
[37]	$-2.43^{+0.16}_{-0.25}$	$2.21^{+0.16}_{-0.36}$	$-1.56^{+0.19}_{-0.22}$	$3.7^{+0.6}_{-0.6}$
[29]	-	-	$-2.55^{+0.72}_{-1.39} \pm 0.6 \pm 0.3$	-

Comparison to theory:

NLO ² [15]	-2.91	2.78	-1.54	2.72
LO ² [15]	-1.91	1.40	-1.23	2.13

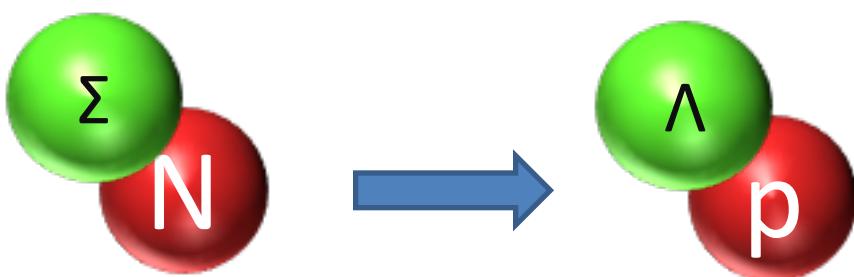
[15] Haidenbauer et al. Nuclear Physics A, 915, 24-58 (2013), $^2\Lambda$ cut off of 500 MeV/c

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

[17] M. Roeder et al., Eur. Phys. J. A49, 157 (2013)

[18] Hauenstein 2014

The ΣN Cusp Effect



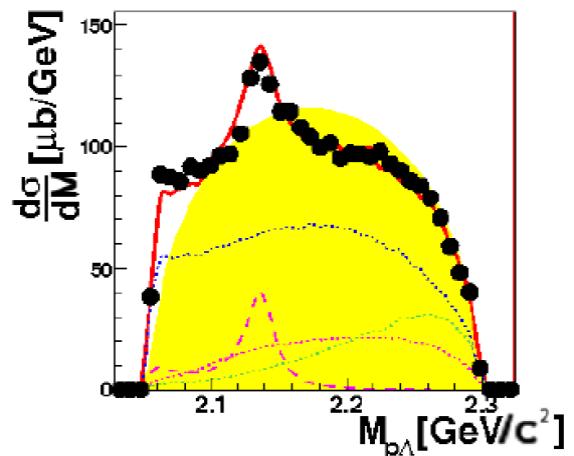
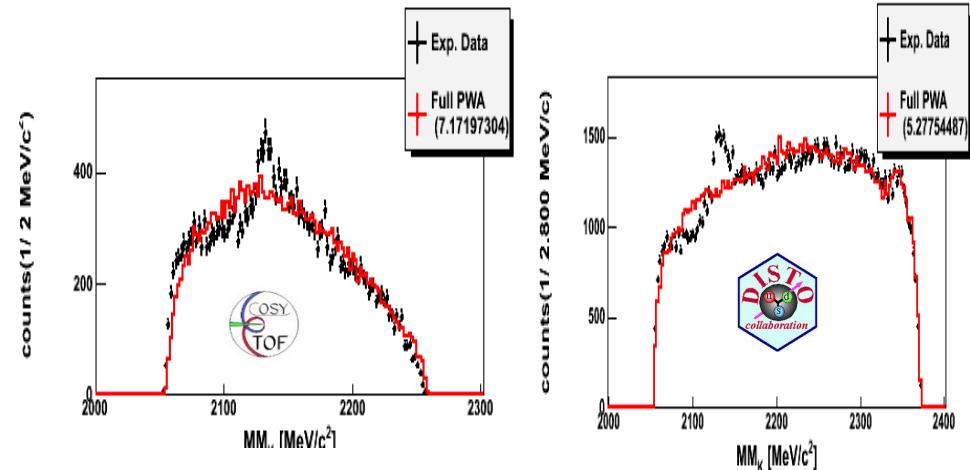
At Threshold : $2130 \text{ MeV}c^{-2}$

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

Spectral Function:

Breit Wigner

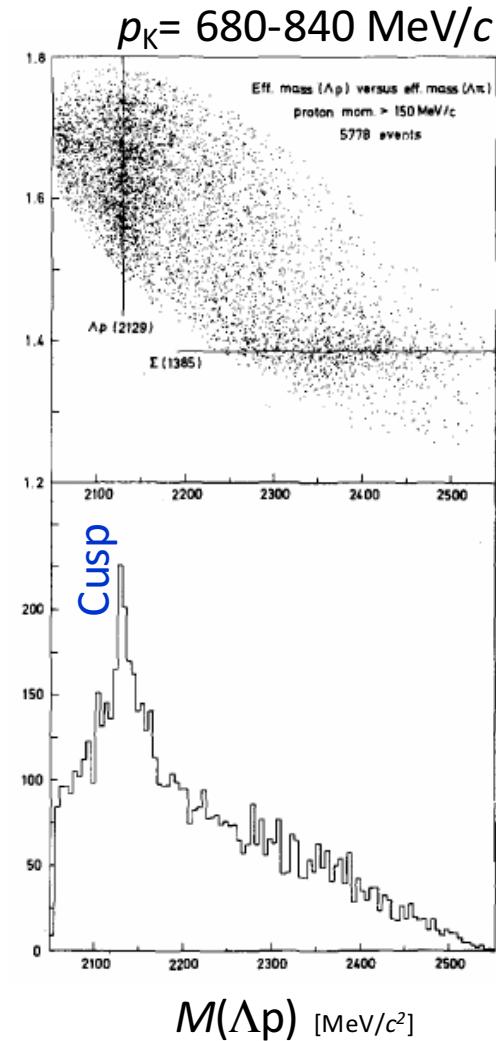
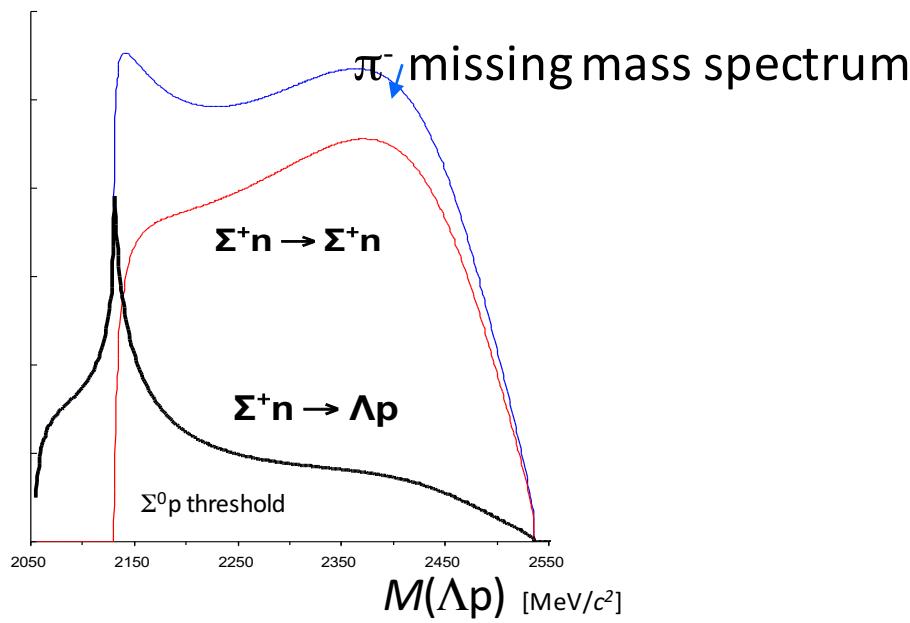
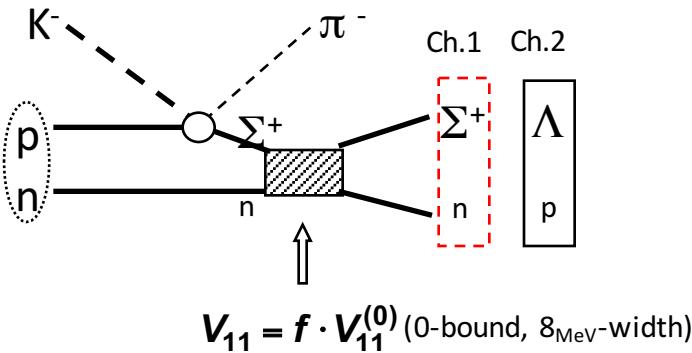
Flatté



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

Λp Cusp Formation Mechanism

O. Braun et al., Nucl. Phys. B 124 (1977) 45



Cusp Spectral Function

The Breit-Wigner:

$$\frac{d\sigma_{p\Lambda}}{dm_{p\Lambda}} \approx \frac{1}{|m_R^2 - m_{p\Lambda}^2 - i m_{p\Lambda} \Gamma|^2}$$

Mass $M_{cusp} = 2.13 \text{ GeV}$, With $\Gamma = 0.02 \text{ GeV}$

$g_{p\Sigma} \ll g_{p\Lambda}$ Symmetric

$g_{p\Sigma} \gg g_{p\Lambda}$ Antisymmetric

The Flatté parametrization:

$$\frac{d\sigma_{p\Lambda}}{dm_{p\Lambda}} \approx \frac{\Gamma_{p\Lambda}}{|m_R^2 - m_{p\Lambda}^2 - i m_{p\Lambda} (\Gamma_{p\Lambda} + \Gamma_{p\Sigma})|^2}$$

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

$$q_{p\Sigma} = \frac{\sqrt{(m_{p\Sigma}^2 - (m_\Sigma + m_p)^2) * (m_{p\Sigma}^2 - (m_p - m_\Sigma)^2)}}{2 m_{p\Sigma}}$$

$$q_{p\Sigma} = i * \frac{\sqrt{((m_\Sigma + m_p)^2 - m_{p\Sigma}^2) * (m_{p\Sigma}^2 - (m_p - m_\Sigma)^2)}}{2 m_{p\Sigma}}$$

Above the threshold
Below the threshold

PWA fits including Cusp resonance

$p\Sigma$ Coupling = 0.001
 $p\Lambda$ Coupling = 0.004

Scattering parameters compatible with previous fit except for the triplet effective range

	Analysis
scattering length for 1S0	-1.34733
effective range for 1S0 r_s	0.8593
scattering length for 3S1	-1.78129
effective range for 3S1	0.08960

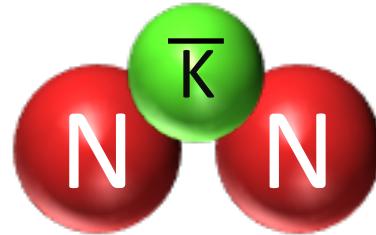
	Reduced Chi2 for invariance mass pL	Chi2 only for cusp (2120,2160)	Reduced Chi2 Total (ndf)	P value
DISTO2.5GeV	2.56	1.63	$2688.95 / 766 = 3.51038$	0.060985
DISTO2.14GeV	1.08	2.59	$1287.3 / 643 = 2.00202$	0.15709
DISTO2.8GeV	2.55	7.28	$3157.07 / 555 = 5.68842$	0.017077
COSY-TOF2.16GeV	0.79	1.35	$506.149 / 712 = 0.710883$	0.399151
HADES3.5GeV	7.54	6.25	$2706.2 / 527 = 0.023447$	0.021477
WALL3.5GeV	0.93	2.27	$1653.73 / 535 = 3.09108$	0.07872
FOPI3.1GeV	1.87	0.73	$287.109 / 226 = 1.27039$	0.259693

Summary and Outlook

- Combined Analysis for COSY & DISTO & HADES & FOPI completed
- Systematical Analysis performed
- Excitation Function for N^* and $p\bar{\Lambda}$ extracted
- Scattering Length $p\bar{\Lambda}$ separate for Singlet and Triplet
- Cusp Wave included too and coupling coefficients were determined
- Common upper limit for Kaonic Bound states to come soon

N^* better constraint to model Heavy Ion collisions

Kaonic Cluster



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

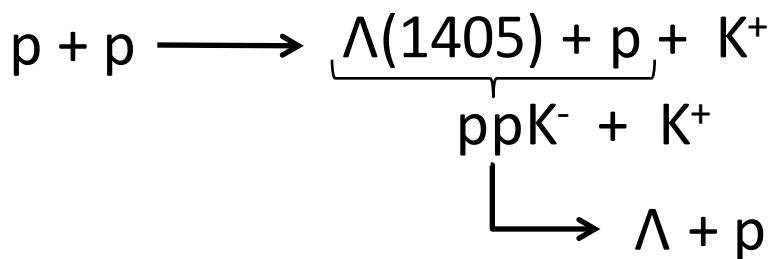
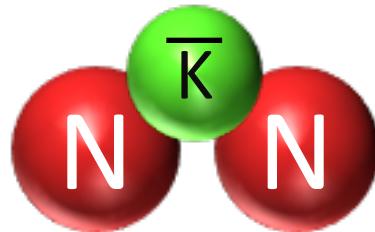
Mesonic Decay (Γ_m):

30–110 MeV

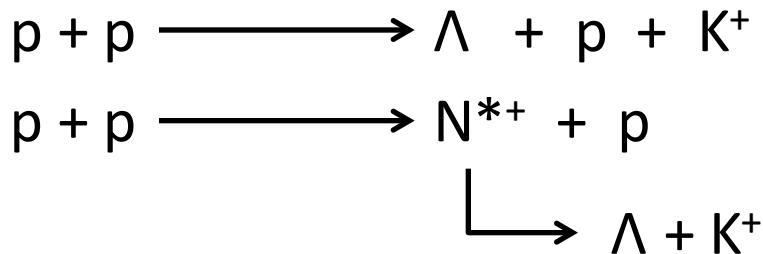
Non-Mesonic Decay (Γ_{nm}):

4–30 MeV

Kaonic Cluster



Physical Background:

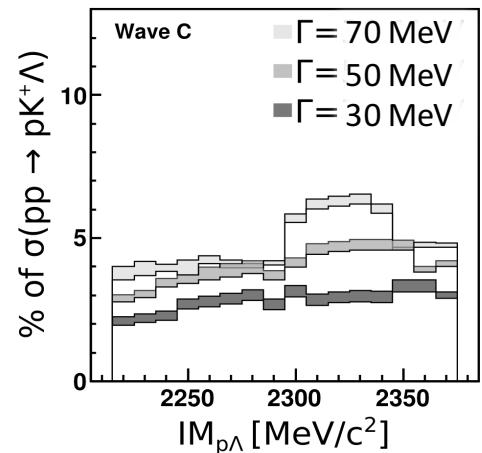
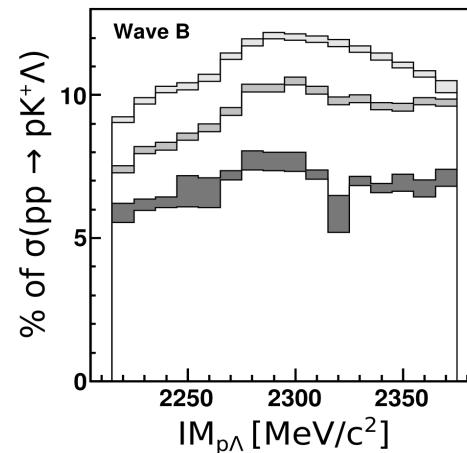
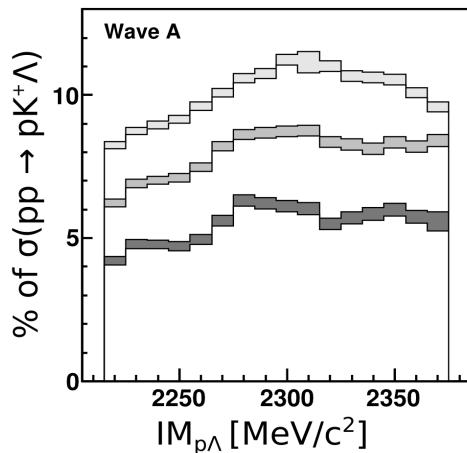


N^{*+} - Resonances

J. Beringer
Phys. Rev. D86 (2012)

Resonance	J ^P	Mass (GeV/c ²)	Γ (MeV/c ²)
N*(1650)	1/2 ⁻	1.655	0.150
N*(1710)	1/2 ⁺	1.710	0.100
N*(1720)	3/2 ⁺	1.720	0.250
N*(1875)	3/2 ⁻	1.875	0.220
N*(1880)	1/2 ⁺	1.870	0.235
N*(1895)	1/2 ⁻	2.090	0.090
N*(1900)	3/2 ⁺	1.900	0.0250

Upper Limit



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

Upper limit of ppK⁻ Cross Section:

$\Gamma (\text{MeVc}^{-2})$	Cross Section (μb)
0 ⁺	1.9 – 3.9
1 ⁻	2.1 – 4.2
2 ⁺	0.7 – 2.1

Production Cross Section $\Lambda(1405)$

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

HADES coll. (G. Agakishiev et al.)
Phys. Lett. B742 (2015) 242–248.