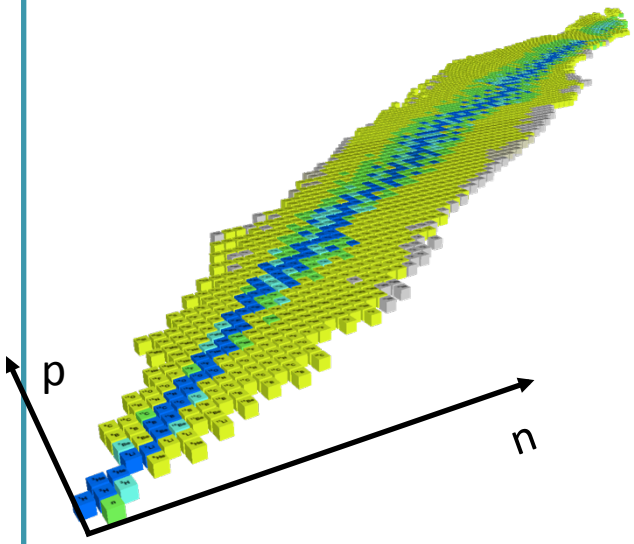
New boundaries for the "ppK-" production in p+p collisions

Eliane Epple
for the HADES collaboration

Mo., 2.6.2014

- Introduction
- Data
- Hypothesis Tests
- Conclusions

Bound Objects



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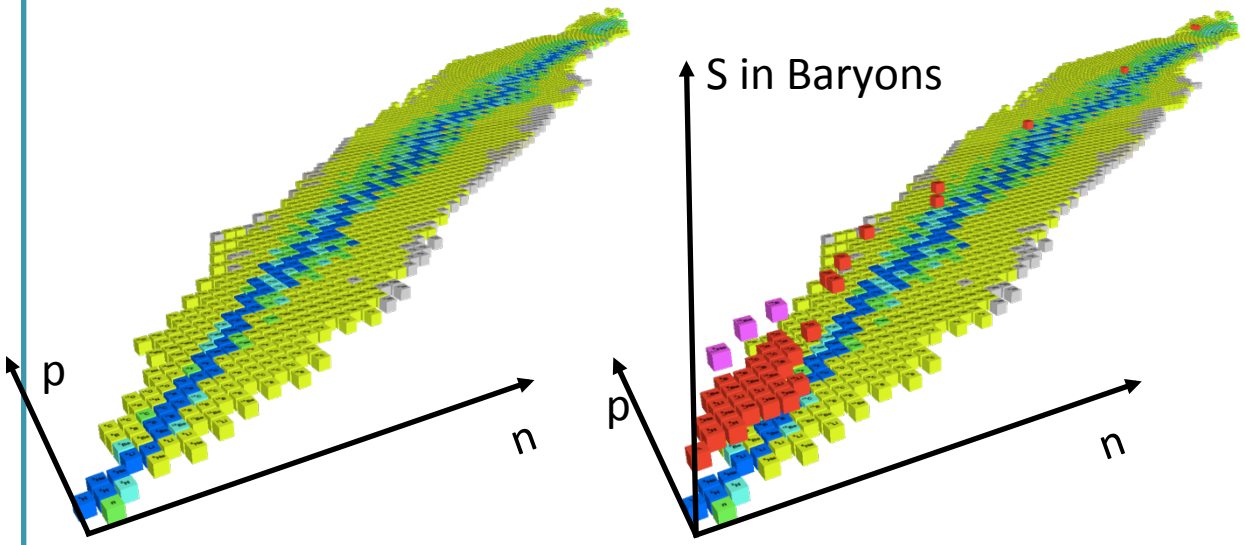
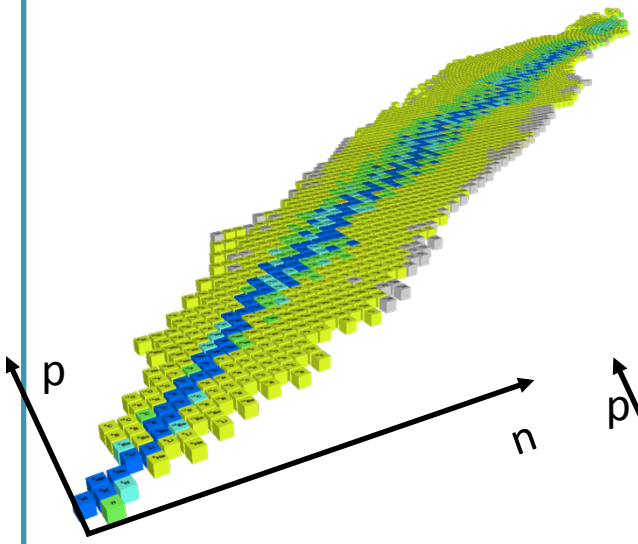
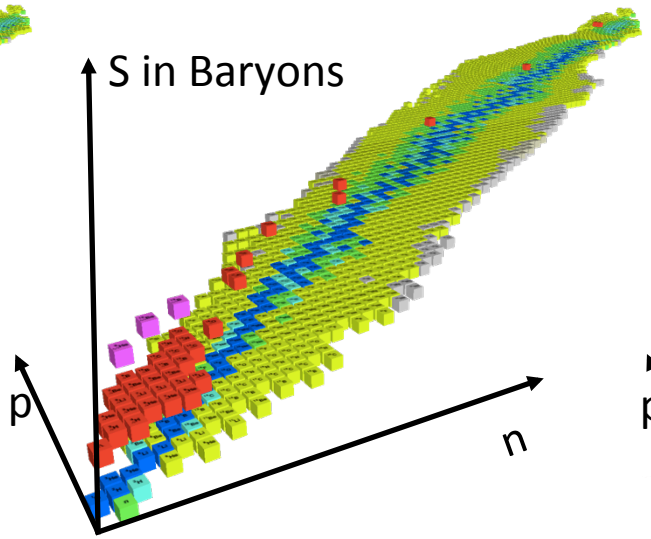


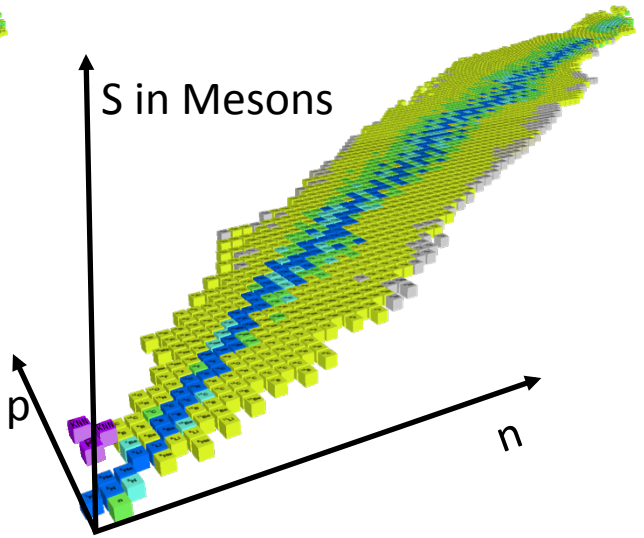
Lambda Hypernuclei

Attractive ΛN interaction

Bound Objects







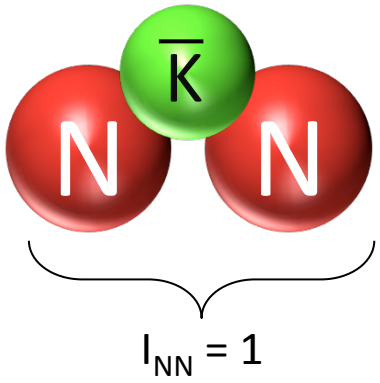
Lambda Hypernuclei

Attractive ΛN interaction

Kaonic Nuclear Cluster

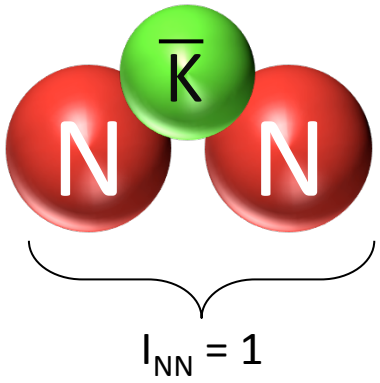
Attractive $\bar{K}$N interaction

The Smallest Cluster



Property	Value
charge	+1
strangeness	-1
participants	ppK^-, $pn\overline{K}^0$
J^P	0^-

The Smallest Cluster



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J^P	0^-

$\overline{K}NN$

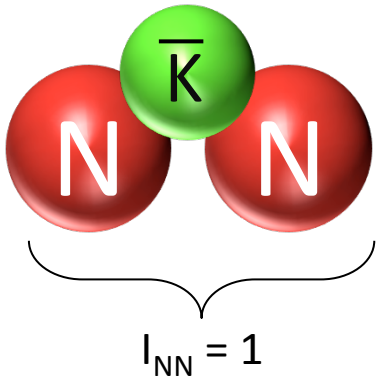
- $\Sigma + N + \pi$
- $\Lambda + N + \pi$

} Γ_m

- $\Sigma + N$
- $\Lambda + N$

} Γ_{nm}

The Smallest Cluster



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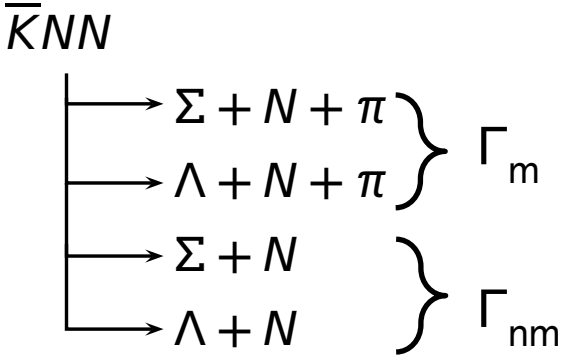


	Chiral, energy dependent				
	var. [DHW09, DHW08]	Fad. [BO12b, BO12a]	var. [BGL12]	Fad. [IKS10]	Fad. [RS14]
BE	17–23	26–35	16	9–16	32
Γ_m	40–70	50	41	34–46	49
Γ_{nm}	4–12	30			
	Non-chiral, static calculations				
	var. [YA02, AY02]	Fad. [SGM07, SGMR07]	Fad. [IS07, IS09]	var. [WG09]	var. [FIK+11]
BE	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

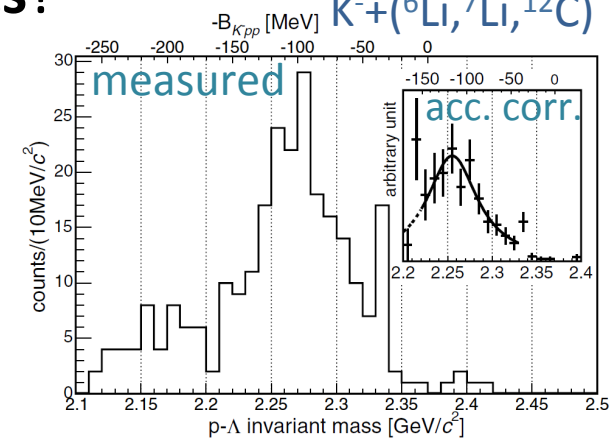
Mesonic Decay (Γ_m)
30-110 MeV

Non-Mesonic Decay (Γ_{nm})
4-30 MeV

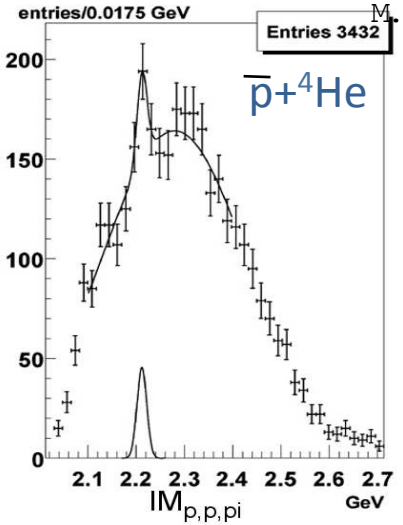
Is there a $\bar{K}$NN?

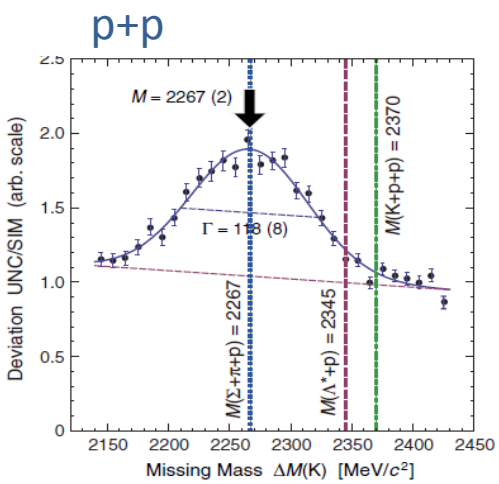
Hints?

T. Yamazaki et al. Phys. Rev. Lett. **104,** (2010)
M. Maggiora et al. Nucl. Phys. **A 835** (2010)



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





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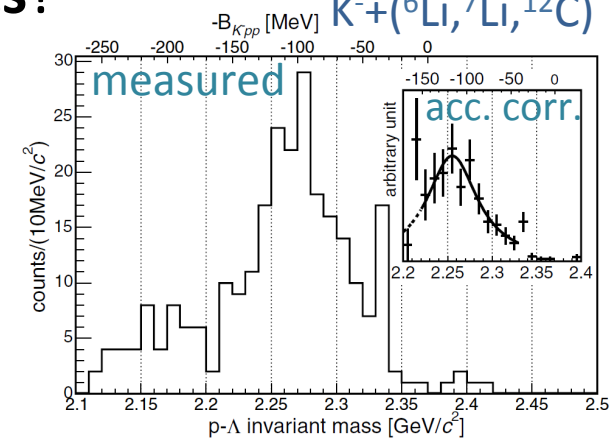

$K^-+(^6Li,^7Li,^{12}C)$

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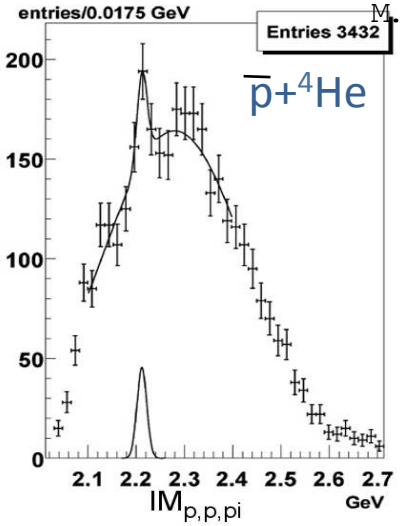

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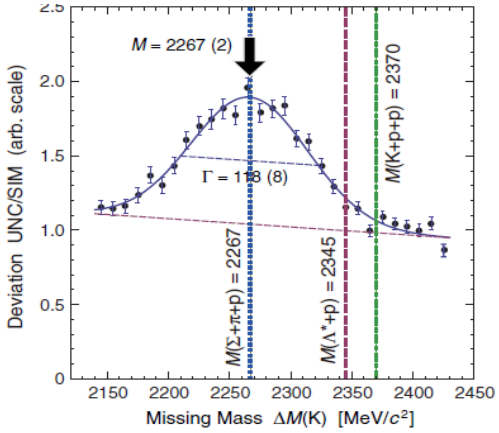
p+p



G. Bendiscioli et al. Nucl. Phys., **A 789** (2007)
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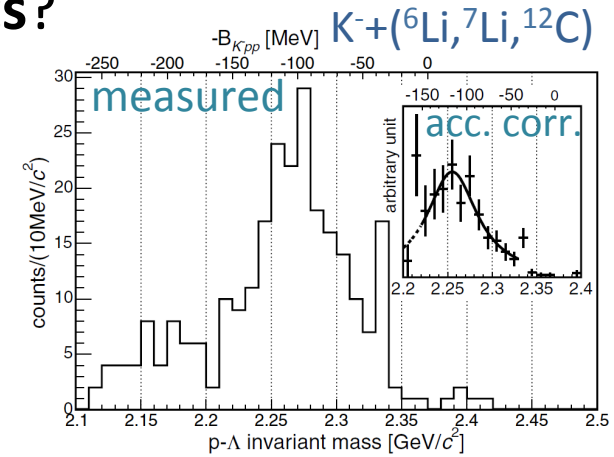
$M(ppK^-) = 2.267$ GeV/c^2
$B(ppK^-) = 103$ MeV
$\Gamma(ppK^-) = 118$ MeV/c^2

$M(ppK^-) = 2.212$ GeV/c^2
$B(ppK^-) = 158$ MeV
$\Gamma(ppK^-) = <24.4$ MeV/c^2

$M(ppK^-) = 2.255$ GeV/c^2
$B(ppK^-) = 115$ MeV
$\Gamma(ppK^-) = 67$ MeV/c^2

Is there a $\bar{K}$NN?

Hints?



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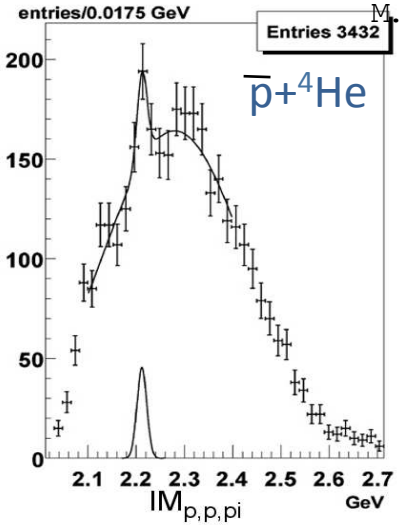
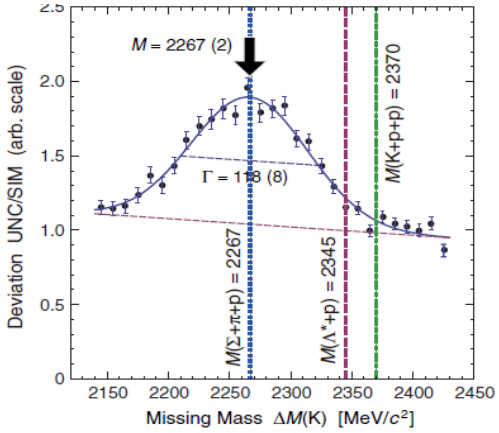


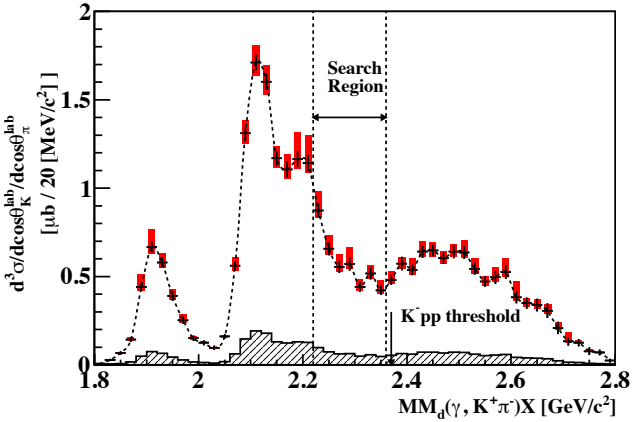
T. Yamazaki et al. Phys. Rev. Lett. **104,** (2010)
M. Maggiora et al. Nucl. Phys. **A 835** (2010)

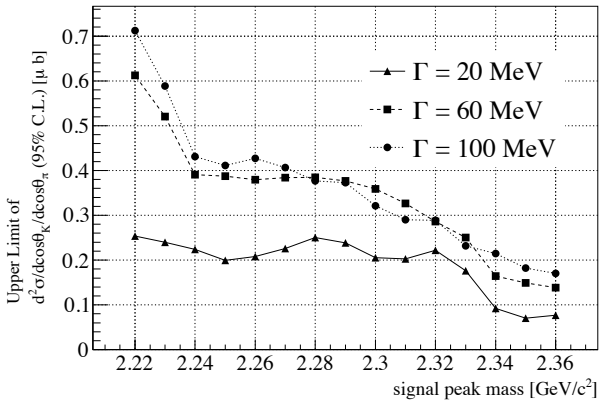
p+p



G. Bendiscioli et al. Nucl. Phys., **A 789** (2007)
G. Bendiscioli et al. Eur.Phys.J., **A 40** (2009)

Exclusions





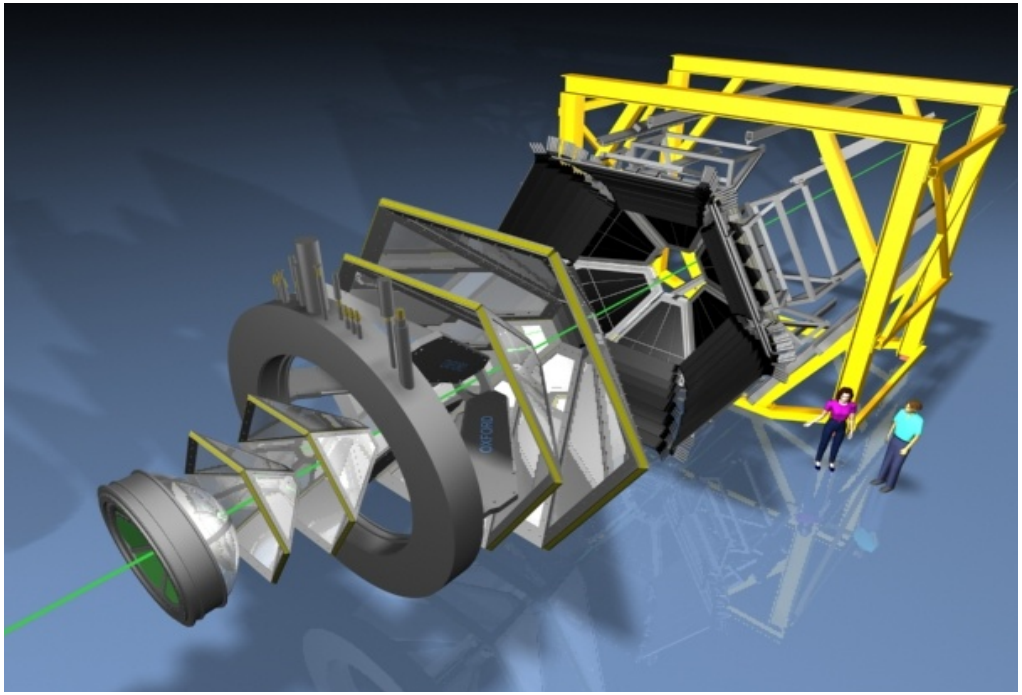
γ+d →X + K^++π

A.O. Tokiyasu et al.
Phys.Lett. B**728** 616-621 (2014)

0.5-5% of the cross section of typical hadron photo-production

The HADES experiment

High **A**cceptance **Di**-electron **S**pectrometer
GSI, Darmstadt



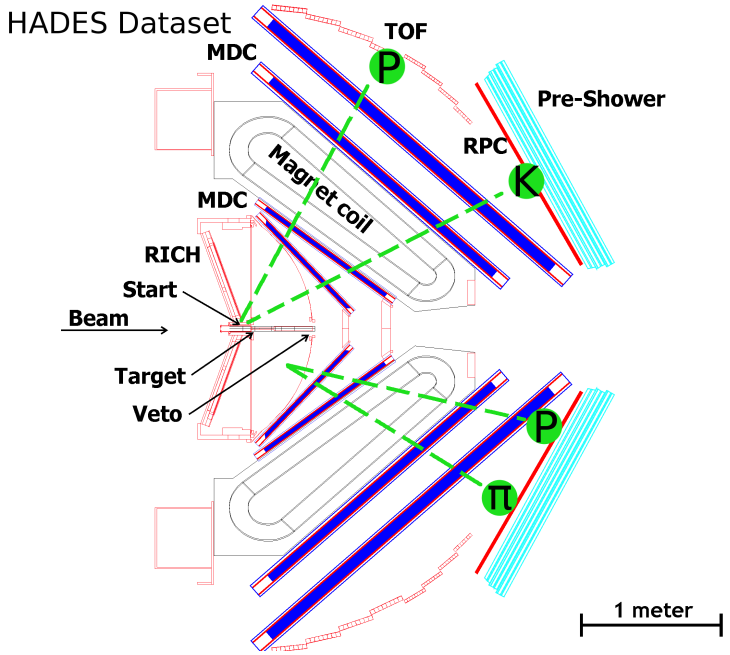
Accelerator
SIS18 at GSI
Colliding system
p+p at 3.5GeV

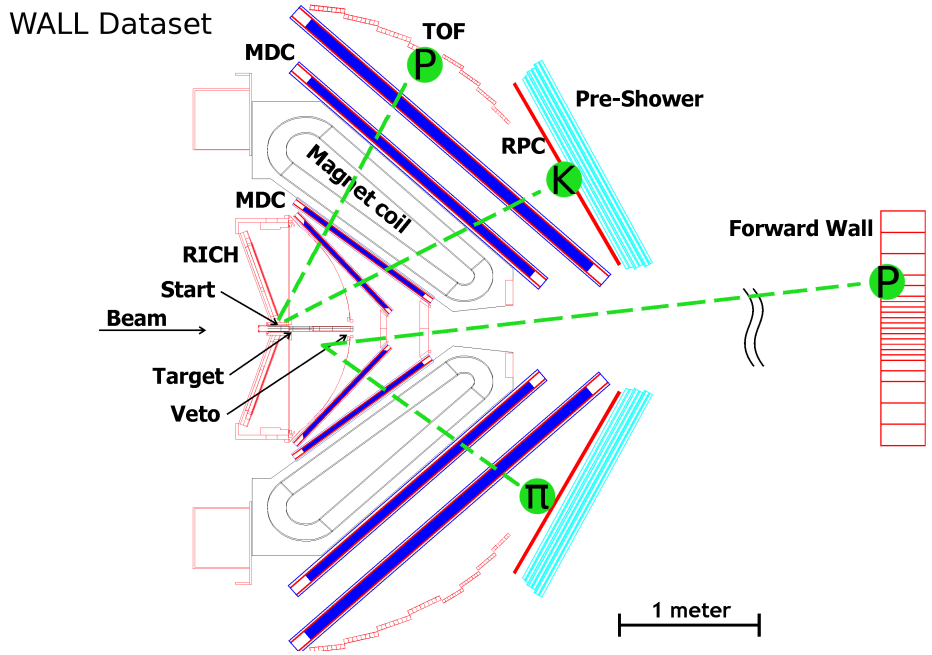
HADES Coll. (G. Agakishiev et al.),
Eur. Phys. **J. A41** (2009)

- Fixed-target experiment
- Full azimuthal coverage, 15˚- 85˚ in polar angle
- Momentum resolution ≈ 1% - 5%

The Data

Data Sample





HADES data

13,000 events of $pK^+\Lambda$

Background from wrong PID ≈6%

Background from $pK^+\Sigma^0$ ≈1%

WALL data

8000 events of $pK^+\Lambda$

Background from wrong PID ≈11.7%

Background from $pK^+\Sigma^0$ ≈ 3%

A Model for the Process

Bonn-Gatchina PWA

$$p + p \xrightarrow{3.5GeV} \boxed{N^{*+} + p \hookrightarrow \Lambda + K^+}$$

$$p + p \xrightarrow{3.5GeV} \boxed{"ppK^-" + K^+ \hookrightarrow \Lambda + p}$$

$$p + p \xrightarrow{3.5GeV} \boxed{p + K^+ + \Lambda}$$

http://pwa.hiskp.uni-bonn.de/

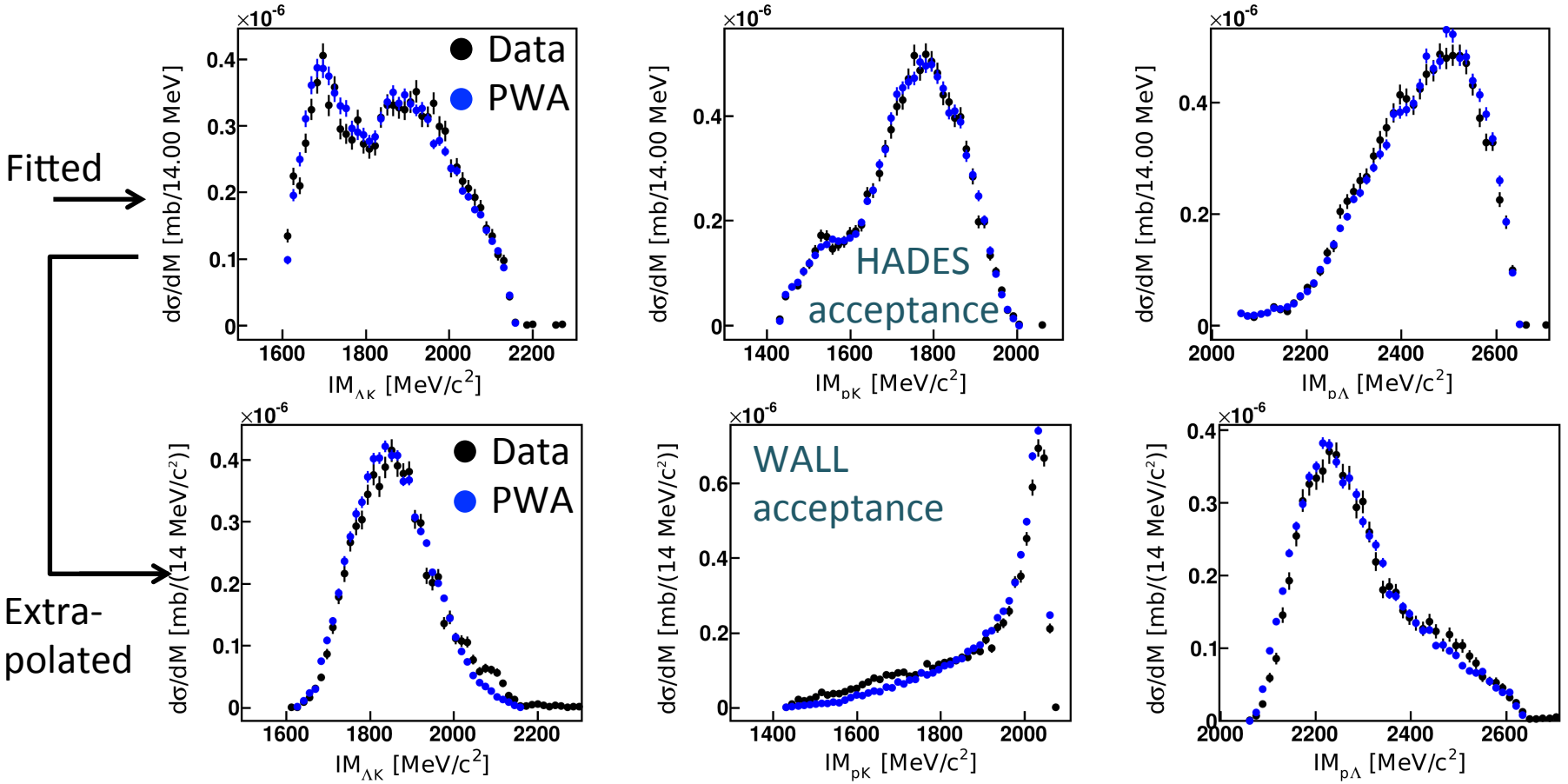
A.V. Anisovich, V.V. Anisovich, E. Klempt, V.A. Nikonov and A.V. Sarantsev
Eur. Phys. J. A 34, 129152 (2007)

What we included to model the $PK^+\Lambda$ process:

N* Resonances in the PDG with measured decay into $K^+\Lambda$

N(1650), N(1710), N(1720), N(1875), N(1880), N(1895), N(1900)
Non-resonant $PK^+\Lambda$ production waves
Interferences

The best solution

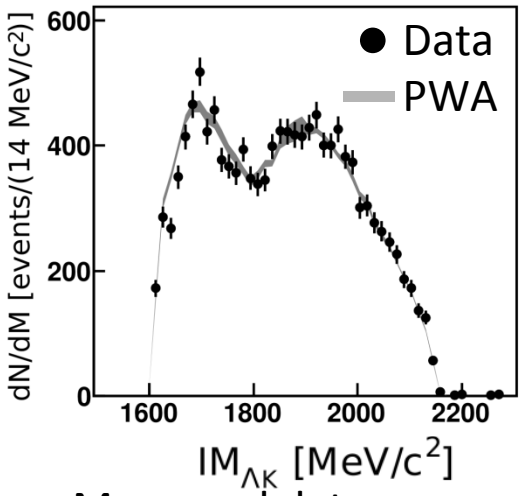


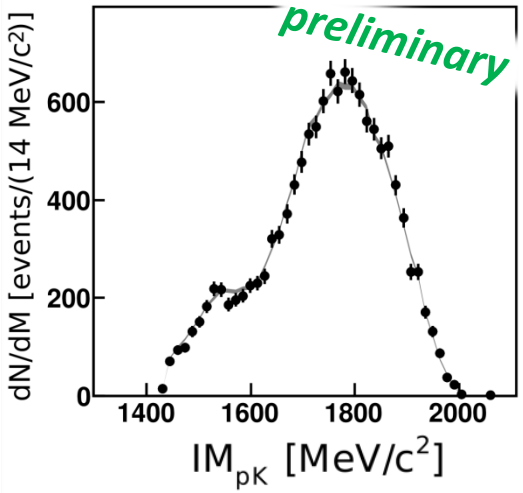
included resonances: N(1650), N(1710), N(1720), N(1900), N(1895)

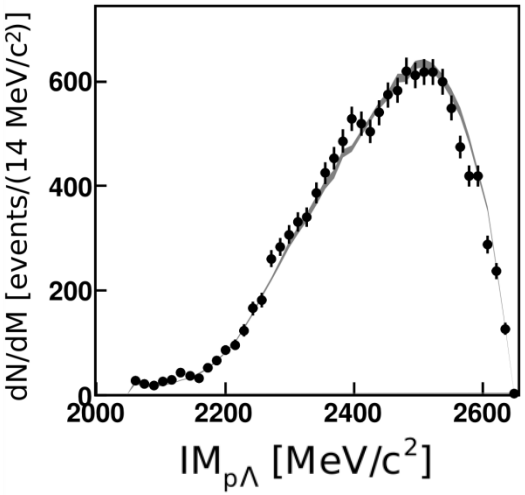
Non-resonant waves: $(pL)(^1S_0)-K$ $(pL)(^3S_1)-K$ $(pL)(^1P_1)-K$
$(pL)(^3P_0)-K$ $(pL)(^3P_2)-K$ $(pL)(^3P_1)-K$
$(pL)(^3D_1)-K$ $(pL)(^1D_2)-K$ $(pL)(^3D_2)-K$

Four Best PWA Solutions

Inside HADES acceptance







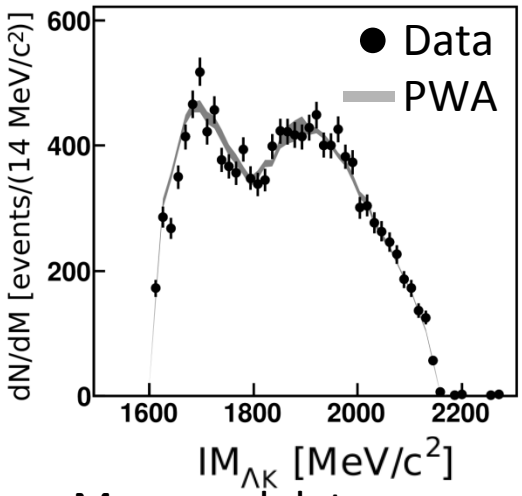
Measured data

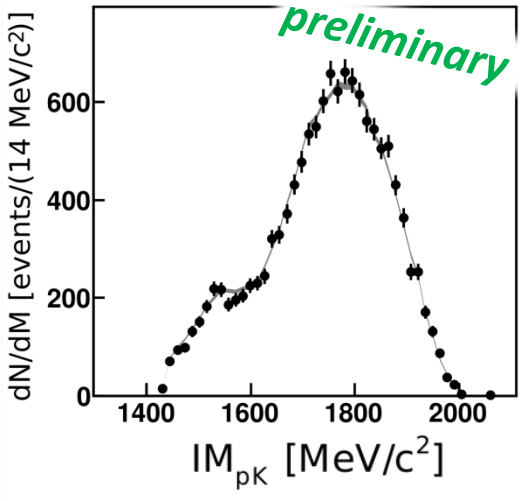
PWA solutions

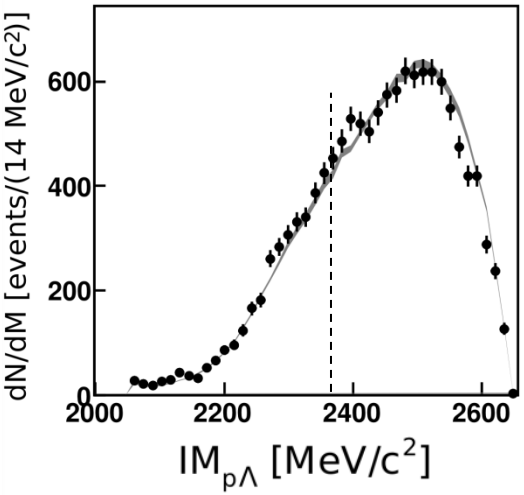
Name	N* combination
1/8	N(1650), N(1710), N(1720), N(1900)
3/8	N(1650), N(1710), N(1720), N(1880)
6/9	N(1650), N(1710), N(1720), N(1900), N(1895)
8/8	N(1650), N(1710), N(1720), N(1895), N(1880)

Four Best PWA Solutions

Inside HADES acceptance







Measured data

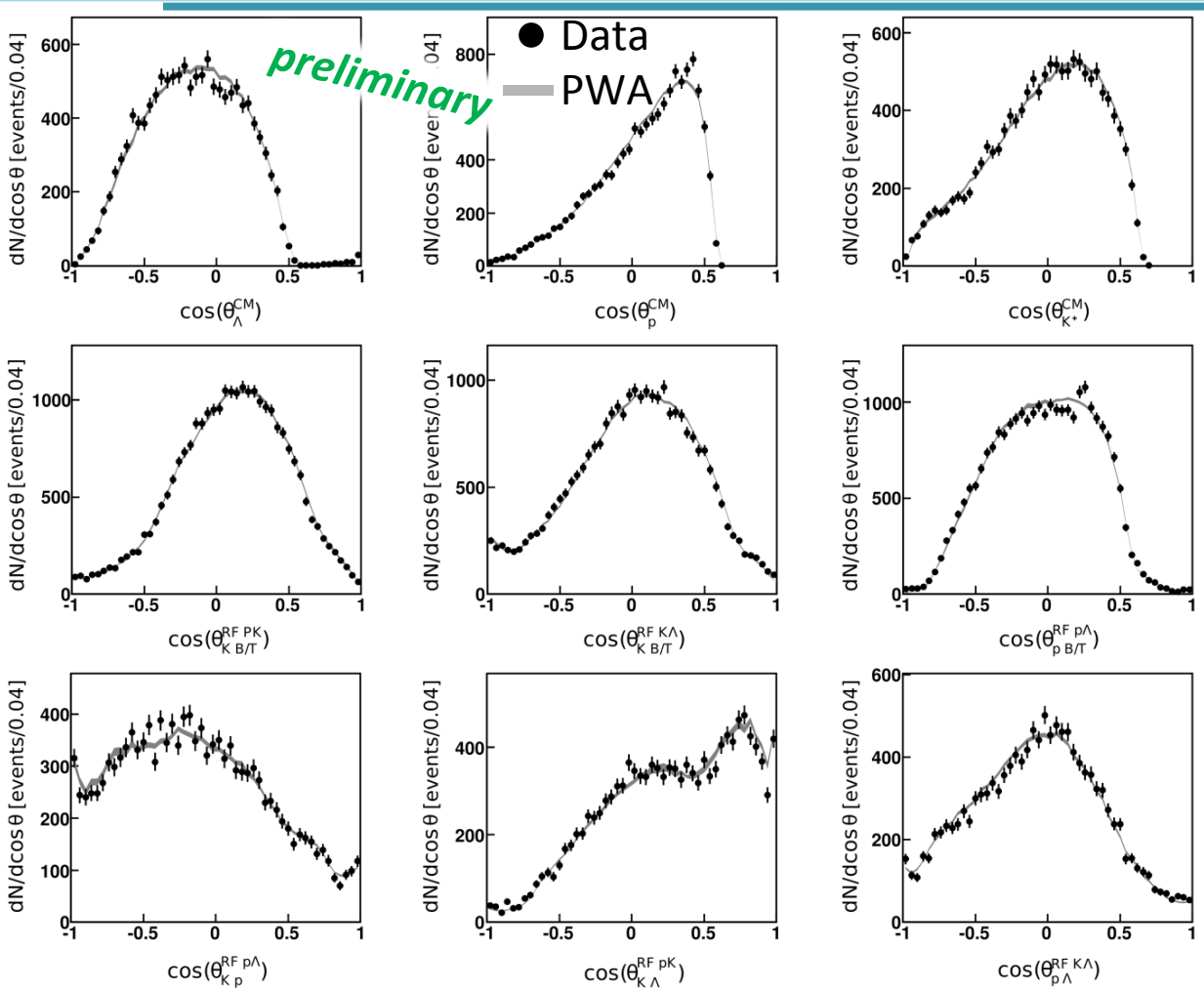
PWA solutions

mass of Λ+p = 2053.96 MeV/c^2

mass of Σ^0+p = 2130.82 MeV/c^2

mass of p+p+K^- = 2370.22 MeV/c^2

Four Best PWA Solutions



CM Angle

Jackson Angle

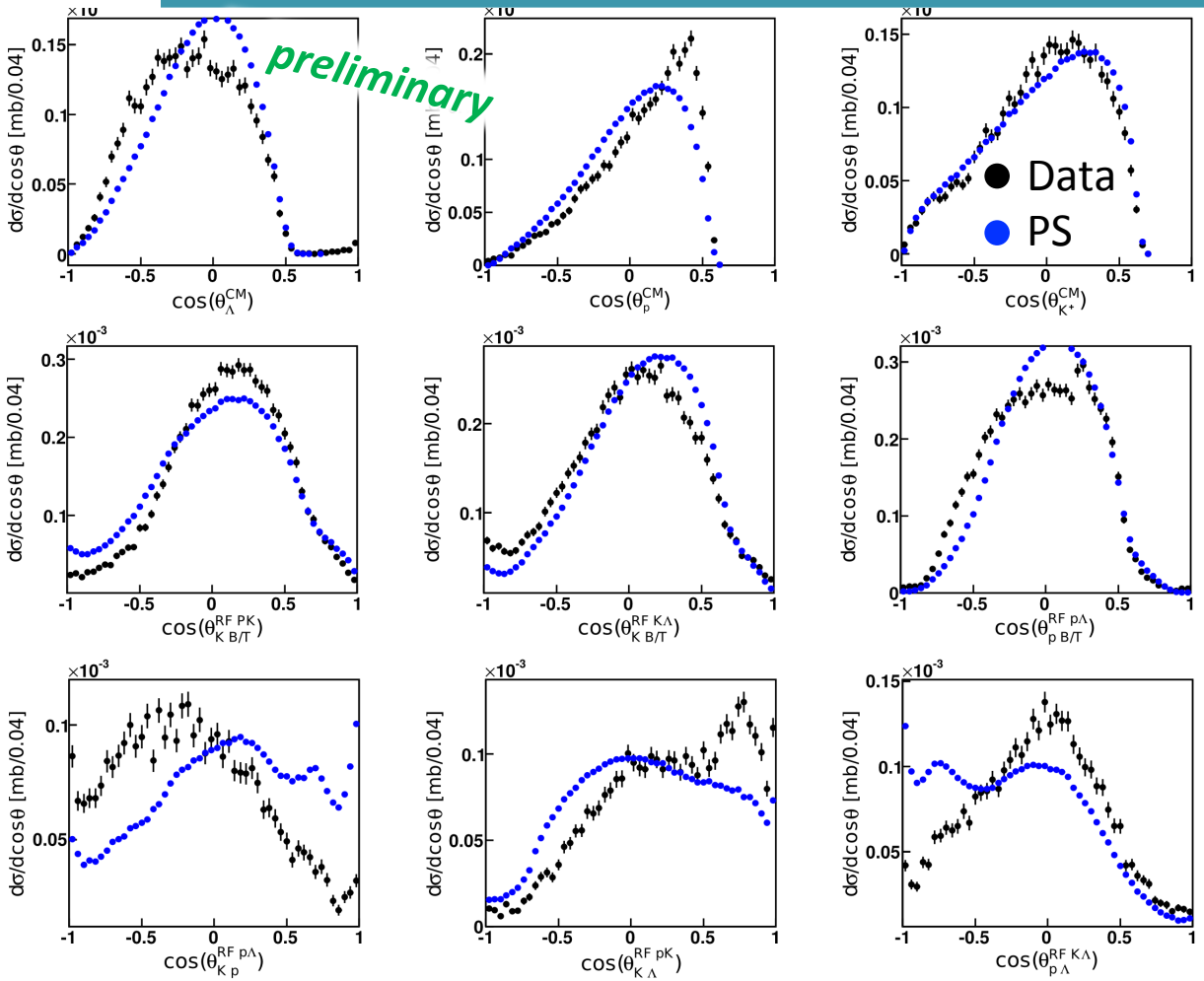
Helicity Angle

Measured Data

PWA solutions

Inside HADES acceptance

Phase Space Model



CM Angle

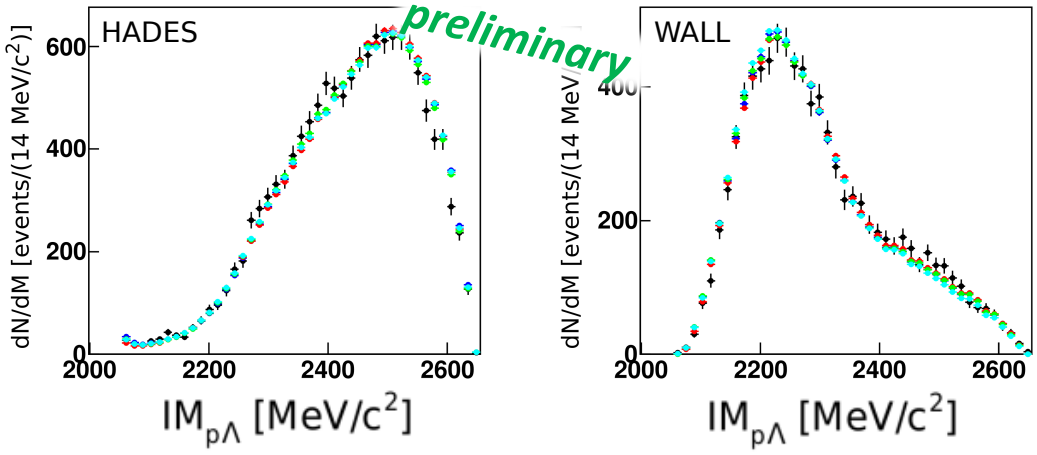
Inside HADES acceptance

Jackson Angle

Helicity Angle

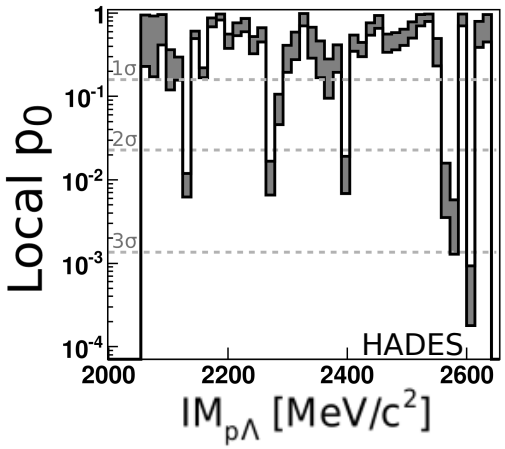
Test of the Null Hypothesis

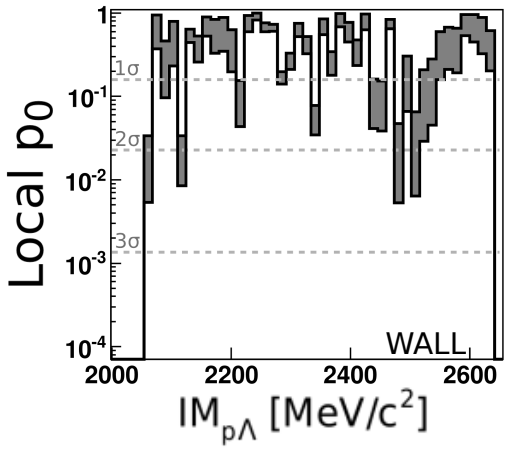
Test of the Null Hypothesis



$$\chi^2_P = \frac{(m\ -\lambda\ )^2}{\lambda}$$

$$p - value = \int_{\chi^2_{P,d}}^{\infty} P(\chi^2, Ndf)d\chi^2$$

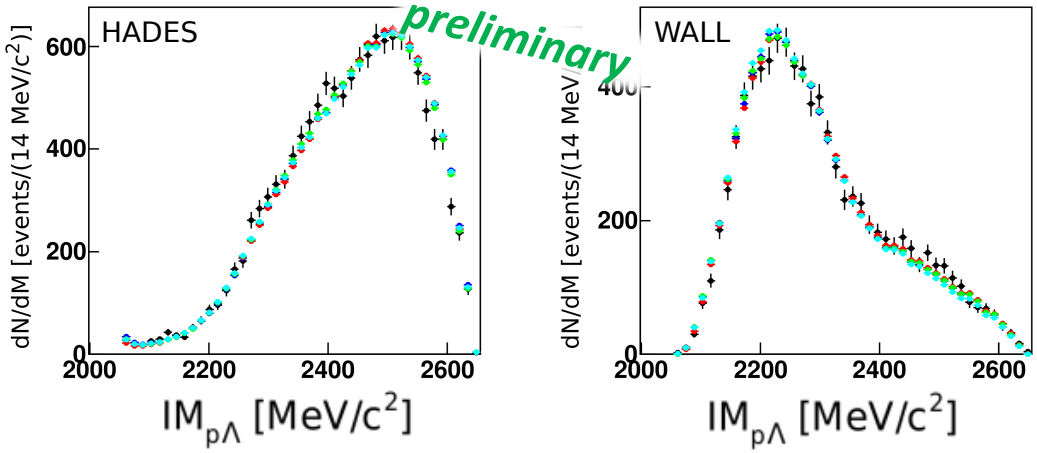


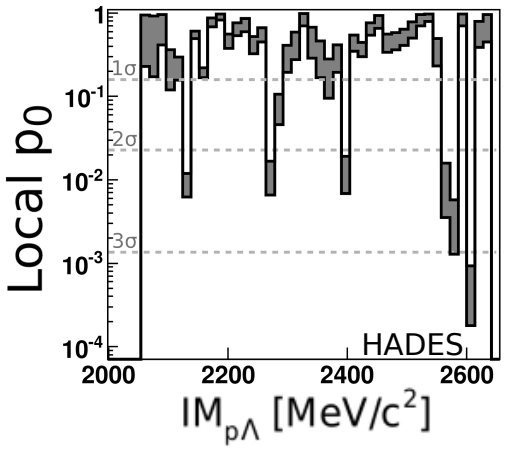


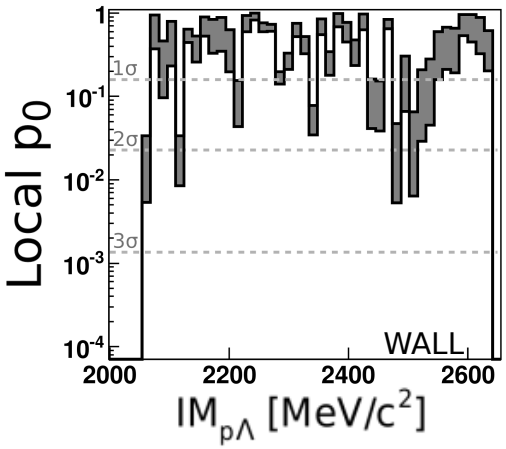
m_i measured events in bin i

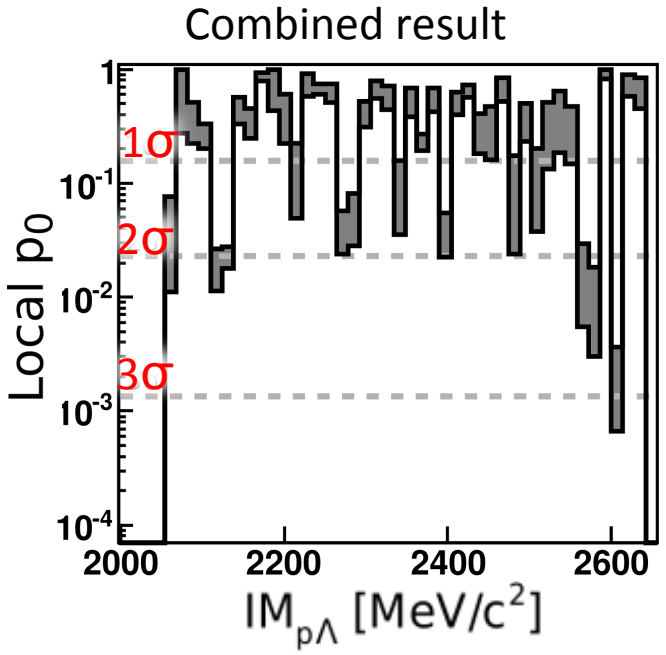
λ_i expected events in bin i according to the model

Test of the Null Hypothesis









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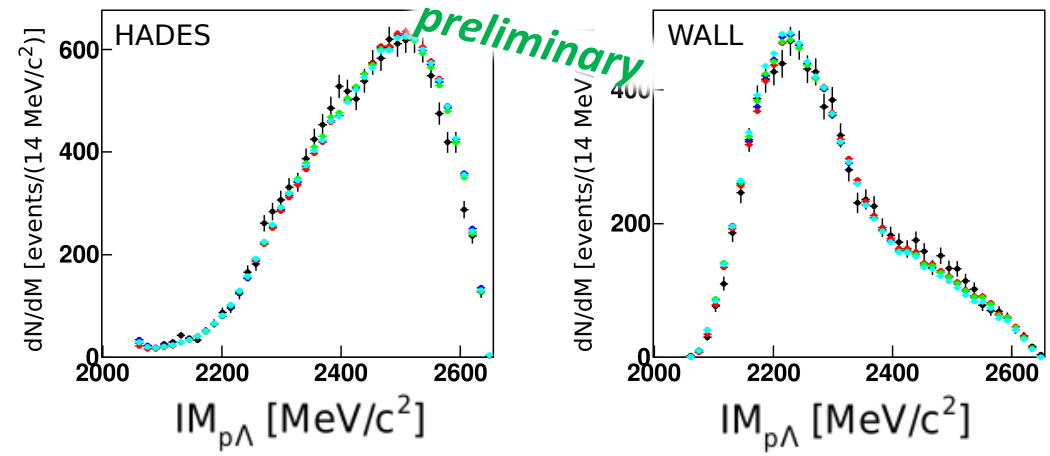
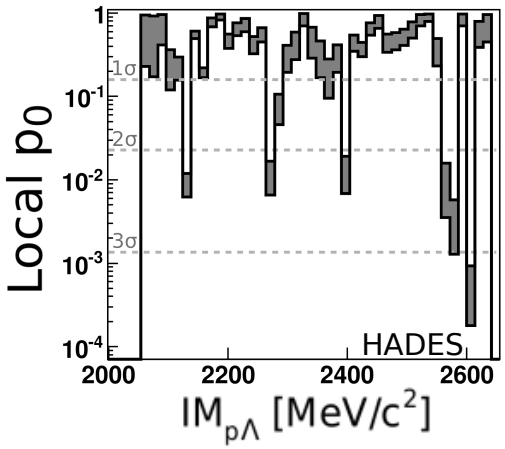
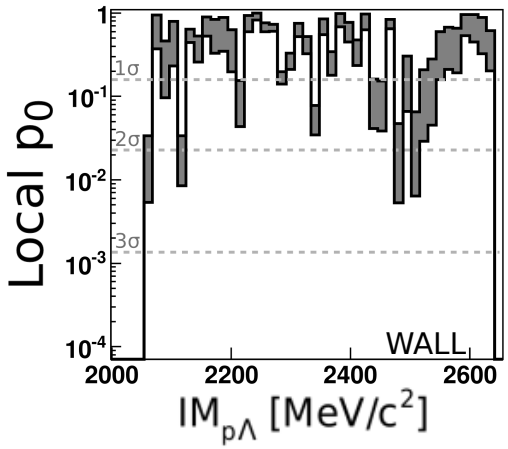
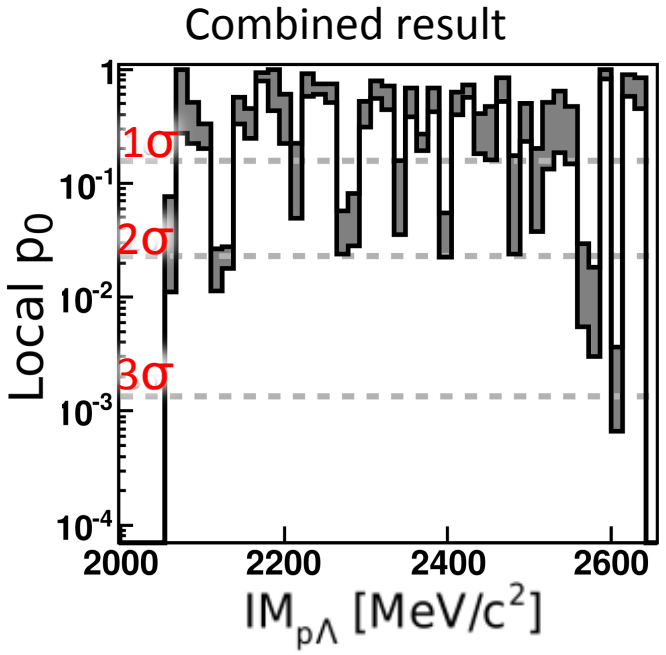




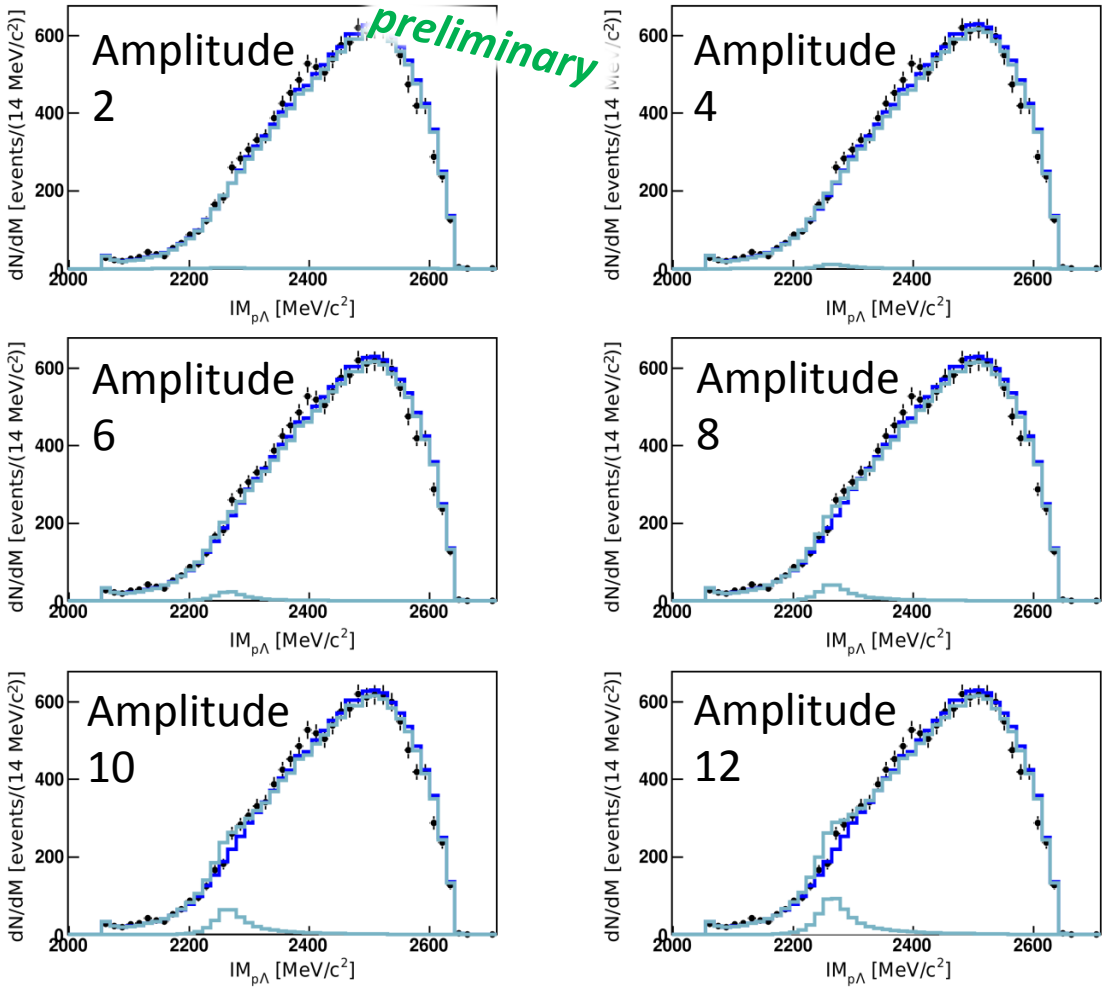




We found no new signal in the data

Test of the Signal Hypothesis

Inclusion of a new State



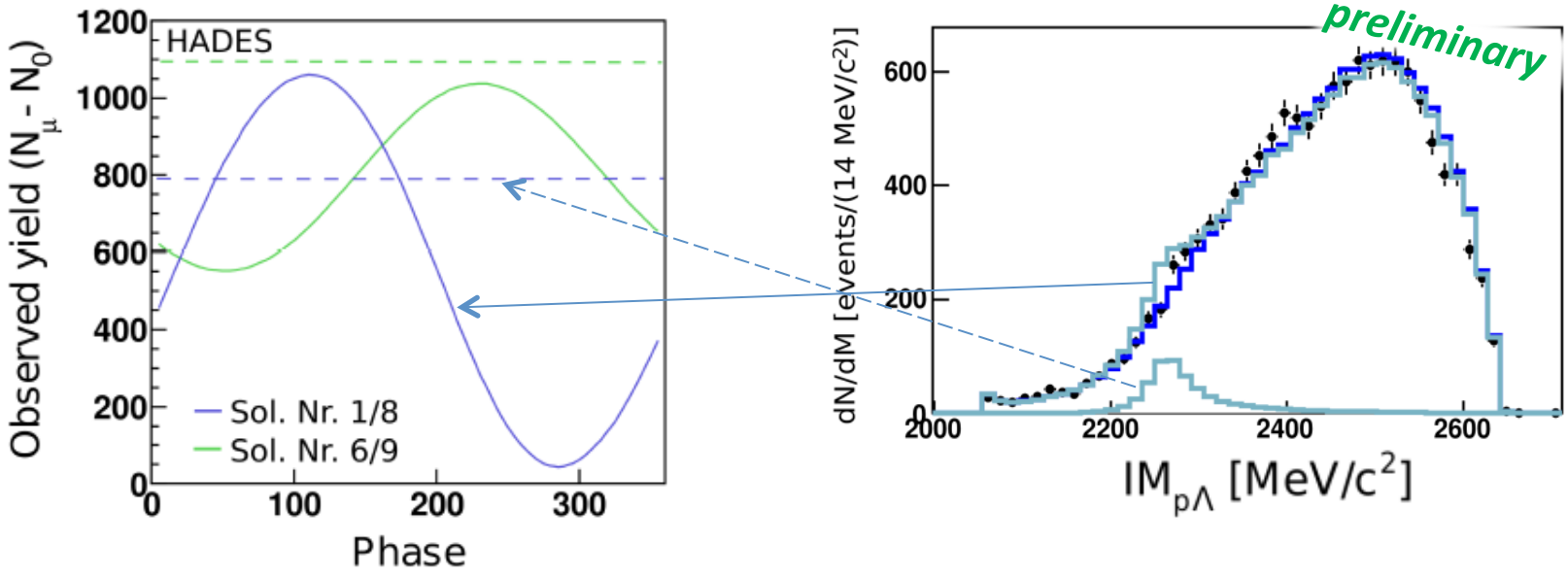
Data Points

Null Hypothesis

Hypothesis with ppK-

Feature of a PWA…

… Interferences



The minimum has to be found by the fit

Upper limit at CL_s 95%

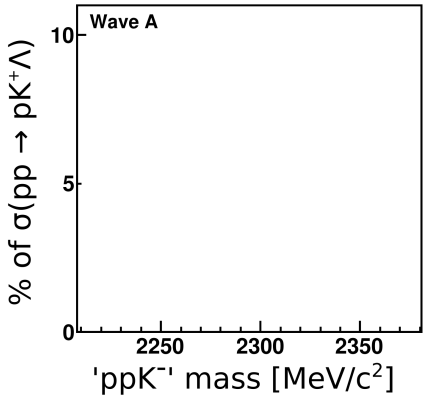
These waves are included into the four best solutions of the PWA

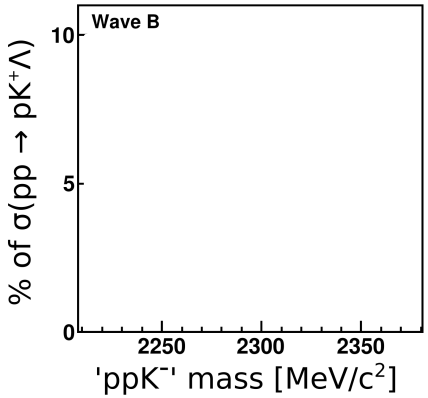
$^{2S+1}L_J$

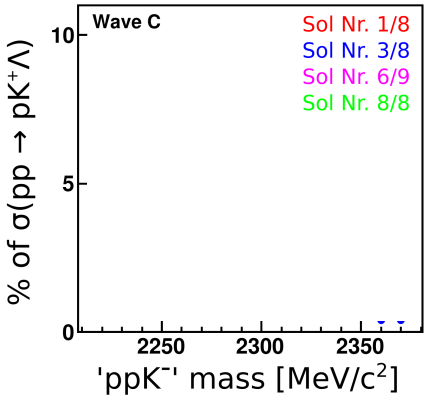
$$WaveA: \ 'p+p' \ {}^1S_0 \rightarrow \ 'ppK(2250)-K' \ {}^1S_0$$
$$WaveB: \ 'p+p' \ {}^3P_1 \rightarrow \ 'ppK(2250)-K' \ {}^1P_1$$
$$WaveC: \ 'p+p' \ {}^1D_2 \rightarrow \ 'ppK(2250)-K' \ {}^1D_2$$

Scanned masses:
2220 – 2370 MeV/c^2 (in steps of 10 MeV/c^2)
Scanned widths:
30 MeV, 50 MeV, and 70 MeV

Upper Limit

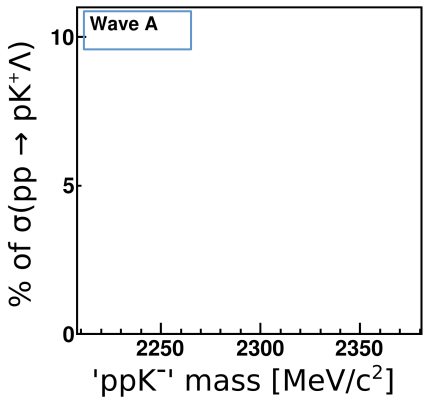


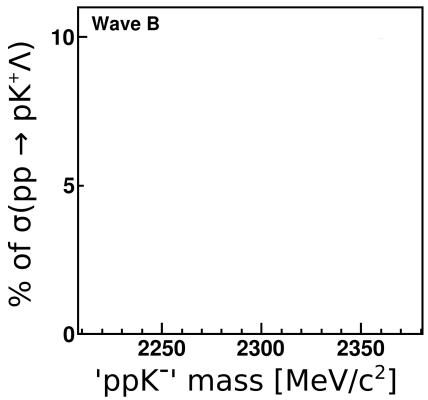


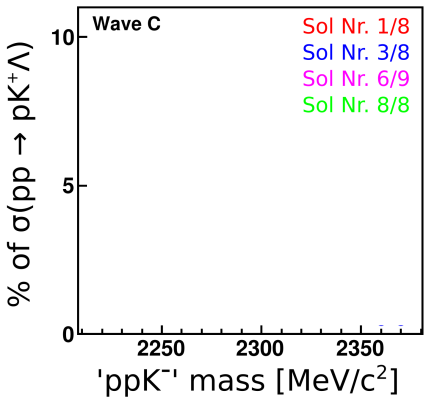


Γ(ppK⁻)=50 MeV

Upper Limit

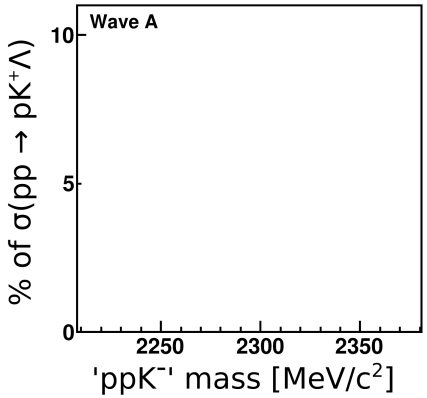


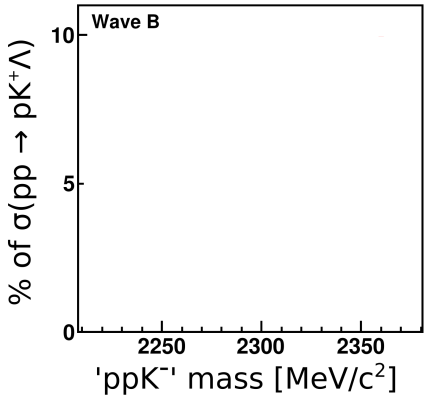


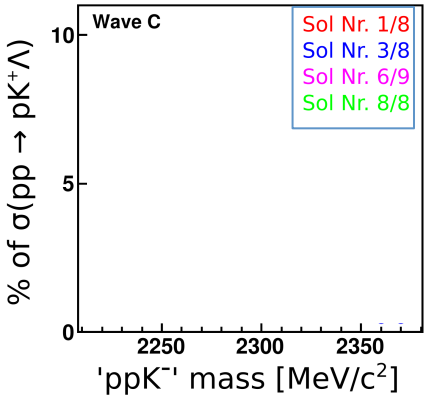


Γ(ppK$^-$)=50 MeV

Upper Limit

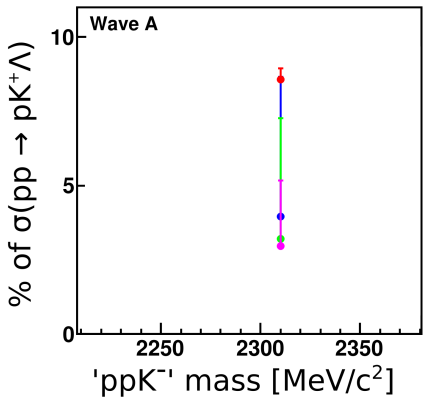


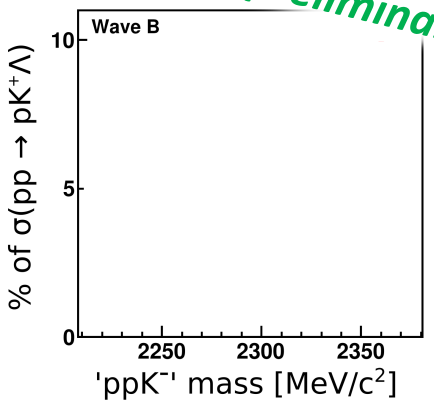


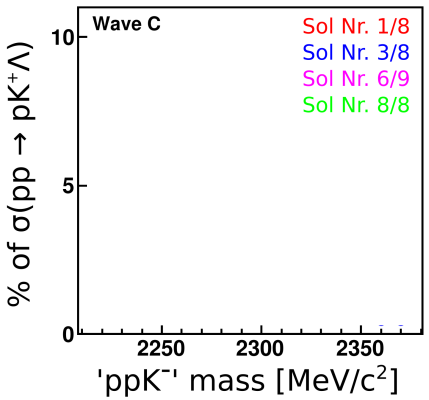


Γ(ppK⁻)=50 MeV

Upper Limit



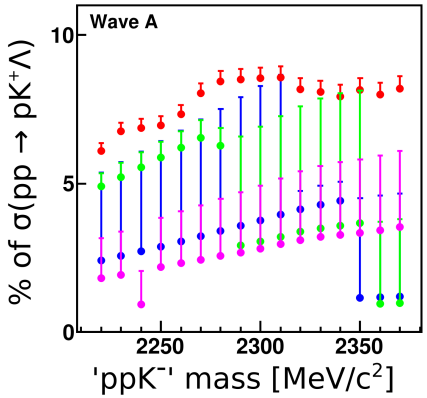


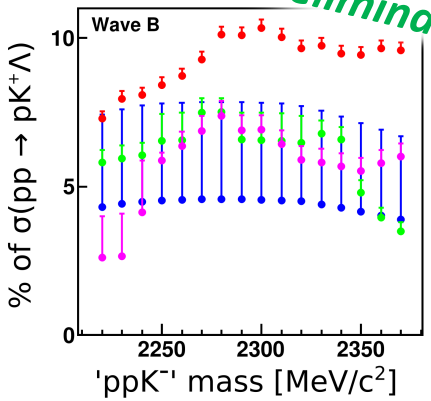


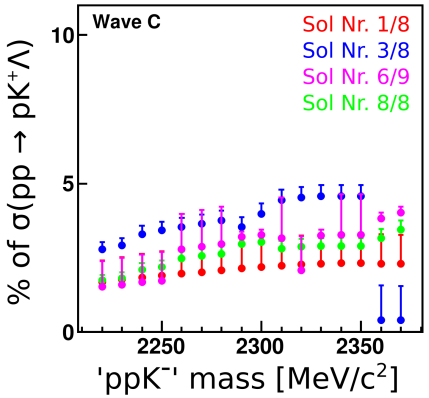
Γ(ppK⁻)=50 MeV

Mass:
2310 MeV/c²

Upper Limit

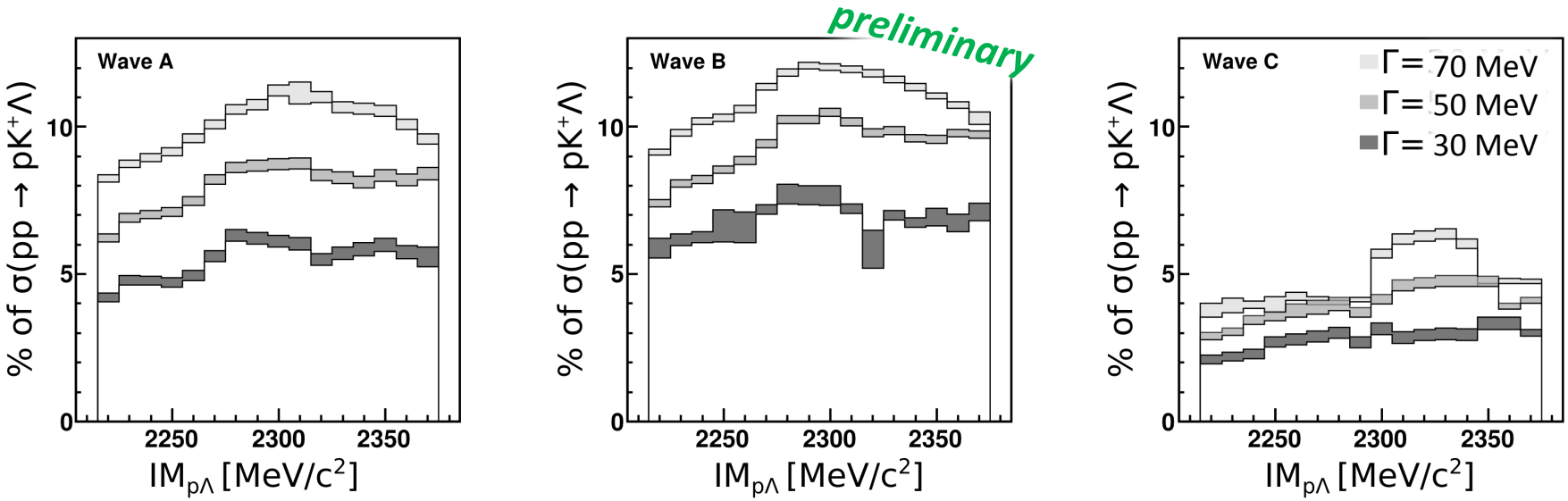






$\Gamma(ppK^-)$=50 MeV

Upper Limit



Exclusion of a 'ppK$^-$' at a sensitivity level of 95% (CL_s)
This means in 95% of the experiments we would be sensitive to a kaonic cluster of that strength

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

→ 12% ≈ 4µb

Summary and Outlook

First PWA of $pK^+\Lambda$ production with Bonn-Gatchina-PWA
First coherent description of a "ppK^-" production

The PWA fit yields an excellent description of the data
→ no new signal needed

The Upper limit for a broad KNN is in the order
of <12% (Γ = 70MeV) of the total $pK^+\Lambda$ cross section ≈ 4µb

Outlook:
More experimental data at J-Parc, KLOE, LEPS and BELLEII coming up
A combined PWA of several $pK^+\Lambda$ data is currently prepared
(different energies, Experiments, polarization)

DFG Proposal: "Partialwellenanalyse von Ereignissen in Proton-Proton Reaktionen für Energien zwischen 1.9 und 3.5 GeV." FA 898/2-1

Thanks to the HADES Collaboration

Jörn Adamczewski-Musch, Geydar Agakishiev, Claudia Behnke, Alexander Belyaev, **Jia-Chii Berger-Chen**, Alberto Blanco, Christoph Blume, Michael Böhmer, Pablo Cabanelas, Nuno Carolino, Sergey Chernenko, Jose Díaz, Adrian Dybczak, **Eliane Epple**, **Laura Fabbietti**, Oleg Fateev, Paulo Fonte, Jürgen Friese, Ingo Fröhlich, Tetyana Galatyuk, Juan A. Garzón, Roman Gernhäuser, Alejandro Gil, Marina Golubeva, Fedor Guber, Malgorzata Gumberidze, Szymon Harabasz, Klaus Heidel, Thorsten Heinz, Thierry Hennino, Romain Holzmann, Jochen Hutsch, Claudia Höhne, Alexander Ierusalimov, Alexander Ivashkin, Burkhard Kämpfer, Marcin Kajetanowicz, Tatiana Karavicheva, Vladimir Khomyakov, Ilse Koenig, Wolfgang Koenig, Burkhard W. Kolb, Vladimir Kolganov, Grzegorz Korcyl, Georgy Kornakov, Roland Kotte, Erik Krebs, Hubert Kuc, Wolfgang Kühn, Andrej Kugler, Alexei Kurepin, Alexei Kurilkin, Pavel Kurilkin, Vladimir Ladygin, **Rafal Lalik**, **Kirill Lapidus**, Alexander Lebedev, Ming Liu, Luís Lopes, Manuel Lorenz, Gennady Lykasov, Ludwig Maier, Alexander Malakhov, Alessio Mangiarotti, Jochen Markert, Volker Metag, Jan Michel, Christian Müntz, **Rober Münzer**, Lothar Naumann, Marek Palka, Vladimir Pechenov, Olga Pechenova, Americo Pereira, Jerzy Pietraszko, Witold Przygoda, Nicolay Rabin, Béatrice Ramstein, Andrei Reshetin, Laura Rehnisch, Philippe Rosier, Anar Rustamov, Alexander Sadovsky, Piotr Salabura, Timo Scheib, Alexander Schmah, Heidi Schuldes, Erwin Schwab, **Johannes Siebenson**, Vladimir Smolyankin, Manfred Sobiella, Yuri Sobolev, Stefano Spataro, Herbert Ströbele, Joachim Stroth, Christian Sturm, Khaled Teilab, Vladimir Tiflov, Pavel Tlusty, Michael Traxler, Alexander Troyan, Haralabos Tsertos, Evgeny Usenko, Taras Vasiliev, Vladimir Wagner, Christian Wendisch, Jörn Wüstenfeld, Yuri Zanevsky

Backup

References for the Calculations

[AY02] Yoshinori Akaishi and Toshimitsu Yamazaki. Nuclear anti-K bound states in light nuclei. *Phys.Rev.*, C65:044005, 2002.

[BGL12] N. Barnea, A. Gal, and E.Z. Liverts. Realistic calculations of $\bar{K}NN$, $\bar{K}NNN$, and $\bar{K}\bar{K}NN$ quasibound states. *Phys.Lett.*, B712:132–137, 2012.

[BO12a] M. Bayar and E. Oset. $\bar{K}NN$ Absorption within the Framework of the Fixed Center Approximation to Faddeev equations. 2012.

[BO12b] M. Bayar and E. Oset. Improved Fixed Center Approximation of the Faddeev equations for the $\bar{K}NN$ system with S=0. *Nucl.Phys.*, A883:57–68, 2012.

[DHW08] Akinobu Dote, Tetsuo Hyodo, and Wolfram Weise. K^-pp system with chiral SU(3) effective interaction. *Nucl.Phys.*, A804:197–206, 2008.

[DHW09] Akinobu Dote, Tetsuo Hyodo, and Wolfram Weise. Variational calculation of the ppK^-system based on chiral SU(3) dynamics. *Phys.Rev.*, C79:014003, 2009.

[FIK+11] M. Faber, A.N. Ivanov, P. Kienle, J. Marton, and M. Pitschmann. Molecule model for kaonic nuclear cluster $\bar{K}NN$. *Int.J.Mod.Phys.*, E20:1477–1490, 2011.

[IKS10] Yoichi Ikeda, Hiroyuki Kamano, and Toru Sato. Energy dependence of $\bar{K}N$ interactions and resonance pole of strange dibaryons. *Prog.Theor.Phys.*, 124:533–539, 2010.

[IS07] Y. Ikeda and T. Sato. Strange dibaryon resonance in the $\bar{K}$NN - πYN system. *Phys.Rev.*, C76:035203, 2007.

[IS09] Yoichi Ikeda and Toru Sato. On the resonance energy of the $\bar{K}$NN - πYN system. *Phys.Rev.*, C79:035201, 2009.

[RS14] J. Revai and N.V. Shevchenko. Faddeev calculations of the $\bar{K}NN$ system with chirally-motivated $\bar{K}N$ interaction. II. The K^-pp quasi-bound state. 2014.

[SGM07] N.V. Shevchenko, A. Gal, and J. Mares. Faddeev calculation of a K^-pp quasi-bound state. *Phys.Rev.Lett.*, 98:082301, 2007.

[SGMR07] N.V. Shevchenko, A. Gal, J. Mares, and J. Revai. $\overline{K}NN$ quasi-bound state and the $\overline{K}N$ interaction: Coupled-channel Faddeev calculations of the $\overline{K}NN$-$\pi\Sigma N$ system. *Phys.Rev.*, C76:044004, 2007.

[WG09] S. Wycech and A. M. Green. Variational calculations for $\overline{K}$–few-nucleon systems. *Phys. Rev. C*, 79:014001, 2009.

[YA02] T. Yamazaki and Y. Akaishi. (K^-,π^-) production of nuclear $\bar{K}$ bound states in proton-rich systems via Λ^* doorways. *Phys.Lett.*, B535:70–76, 2002.

N* resonances

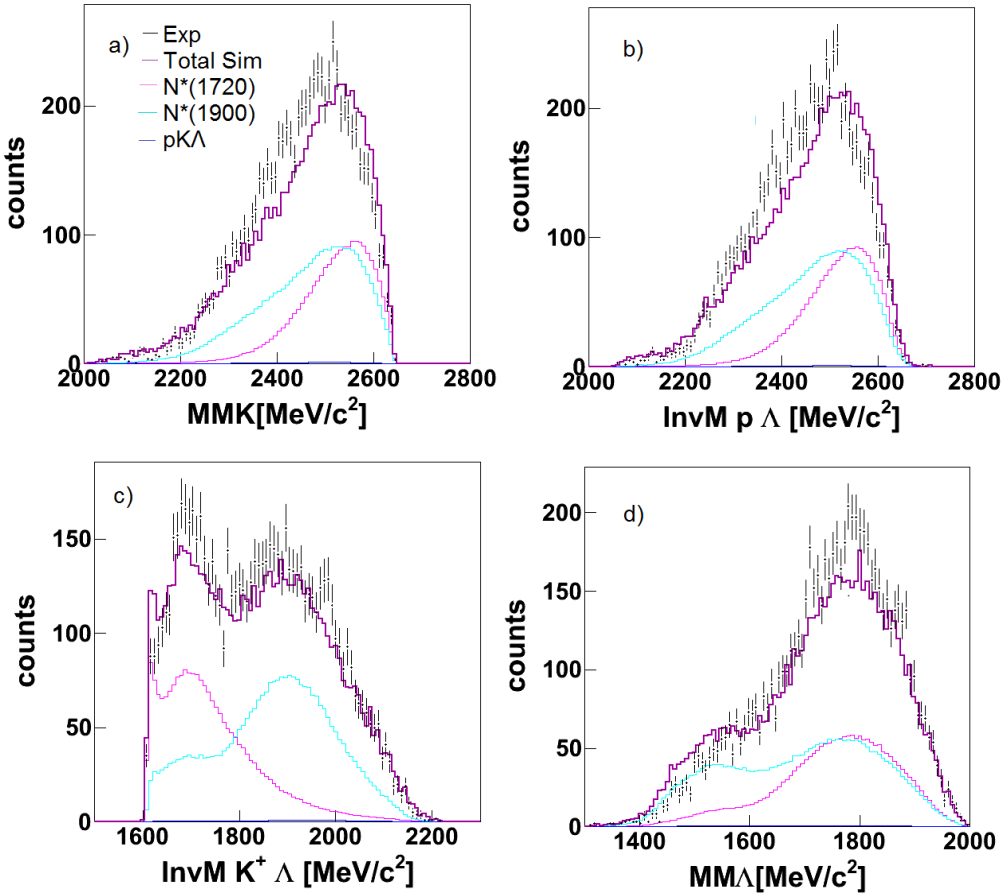


Figure 6.10: a) $IM_{K^+\Lambda}$, b) $IM_{p\Lambda}$,c) MM_{K^+} and d) MM_{Λ} fitted with the sum of the four N^{*+}-resonances from table 6.2 and the simulation of a direct $pK^+\Lambda$ production.

Master Thesis A. Solaguren-Beascoa Negre

Bonn-Gatchina PWA

Cross Section for the production of three particles out of a collision of two particle

$$d\sigma = \frac{(2\pi)^4 |A|^2}{4|\boldsymbol{k}|\sqrt{s}}\, d\Phi_3(P, q_1, q_2, q_3)\ , \qquad P = k_1 + k_2$$

A - reaction amplitude
k – 3-momentum of the initial particle in the CM
s – $P^2=(k_1+k_2)^2$
$d\Phi_3(P,q_1,q_2,q_3)$ – invariant three-particles phase space

The decomposition of the scattering amplitude into partial waves can be written as follows:

$$A = \sum A^{\alpha}_{tr}(s) Q^{in}_{\mu_1 \ldots \mu_J}(SLJ) A_{2b}(i, S_2 L_2 J_2)(s_i) \times\ Q^{fin}_{\mu_1 \ldots \mu_J}(i, S_2 L_2 J_2 S' L' J)\ . \quad (2)$$

S,L,J – spin, orbital mom. and total angular momentum of the pp system
S_2,L_2,J_2 – spin, orbital mom. and total angular momentum of the two particle system in fin. state
S',L' – spin, orbital mom. between the two particle system and the third particle with four mom. q_i
multiindex α – possible combinations of the S, L,J, S_2, L_2, J_2, S', L' and i
A_{tr}^{α} (s) - transition Amplitude
A_{2b}^{α} (i,S_2,L_2,J_2) – rescattering process in he final two-particle channel (e.g. production of Δ)

http://pwa.hiskp.uni-bonn.de/
A.V. Anisovich, V.V. Anisovich, E. Klempt, V.A. Nikonov and A.V. Sarantsev
Eur. Phys. J. A 34, 129152 (2007)

Fitting Procedure

The transition Amplitude is parameterized as follows

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

This is a log-likelihood minimization on an event-by-event base

What we included to model the $pK^+\Lambda$ process:

N* Resonances in the PDG with measured decay into $K^+\Lambda$

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

And the production of $pK^+\Lambda$ via non resonant waves

Systematic

N* content

No.	Combination
0	N(1650), N(1710), N(1720)
1	N(1650), N(1710), N(1720), N(1900)
2	N(1650), N(1710), N(1720), N(1895)
3	N(1650), N(1710), N(1720), N(1880)
4	N(1650), N(1710), N(1720), N(1875)
5	N(1650), N(1710), N(1720), N(1900), N(1880)
6	N(1650), N(1710), N(1720), N(1900), N(1895)
7	N(1650), N(1710), N(1720), N(1900), N(1875)
8	N(1650), N(1710), N(1720), N(1895), N(1880)
9	N(1650), N(1710), N(1720), N(1895), N(1875)
10	N(1650), N(1710), N(1720), N(1880), N(1875)

non-resonant content

No.	Combination
0	no non-resonant waves
1	$(pL)(^1S_0) - K$
2	previous wave + $(pL)(^3S_1) - K$
3	previous waves + $(pL)(^1P_1) - K$
4	previous waves + $(pL)(^3P_0) - K$
5	previous waves + $(pL)(^3P_1) - K$
6	previous waves + $(pL)(^3P_2) - K$
7	previous waves + $(pL)(^1D_2) - K$
8	previous waves + $(pL)(^3D_1) - K$
9	previous waves + $(pL)(^3D_2) - K$

Best Solutions

No. of N* combination	No. of non-res. waves	Log-likelih.
0	7	-2415.74
1	**8**	**-2708.49**
2	8	-2524.59
3	**8**	**-2712.49**
4	4	-2671.05
5	8	-2310.4
6	**9**	**-2754.37**
7	8	-2657.77
8	**8**	**-2734.97**
9	6	-2698.86
10	4	-2642.58

Solution inside WALL acceptance

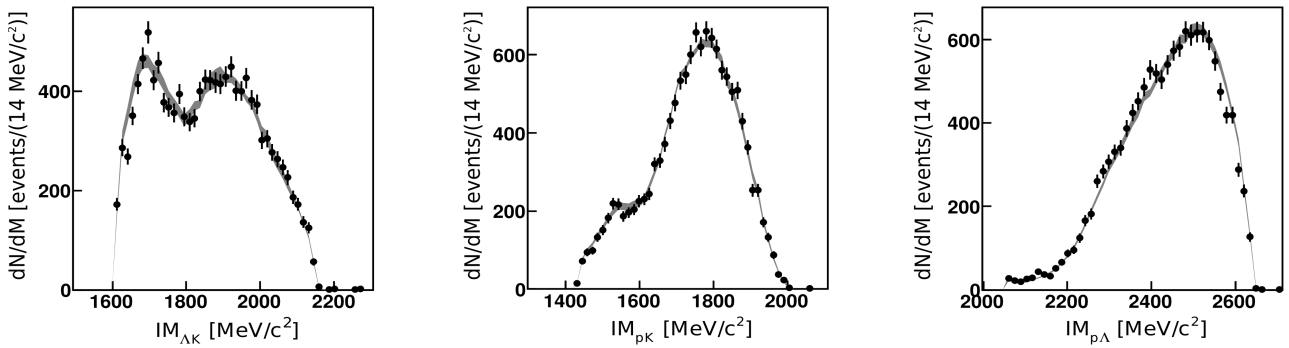


Figure 2.18: Two-particle masses for the **HADES data set** (black points) shown with the **four best PWA solutions** (gray band), obtained by a fit to the HADES and WALL data.

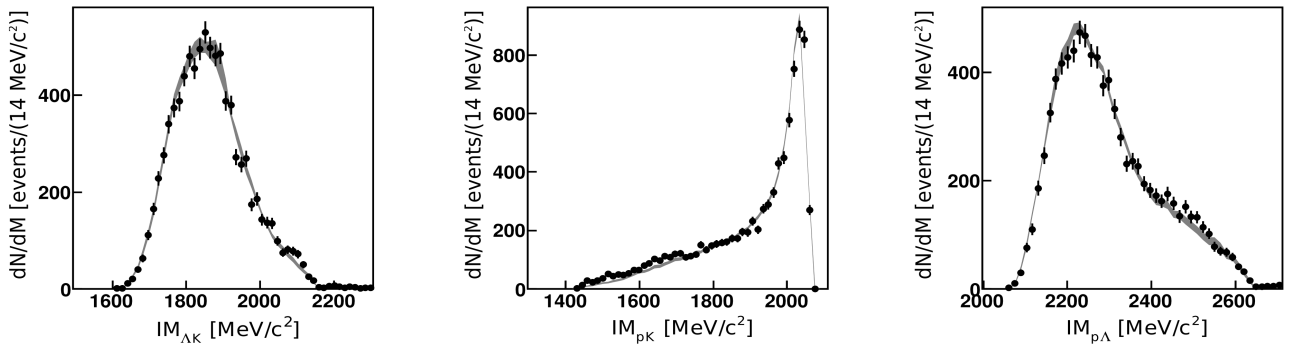
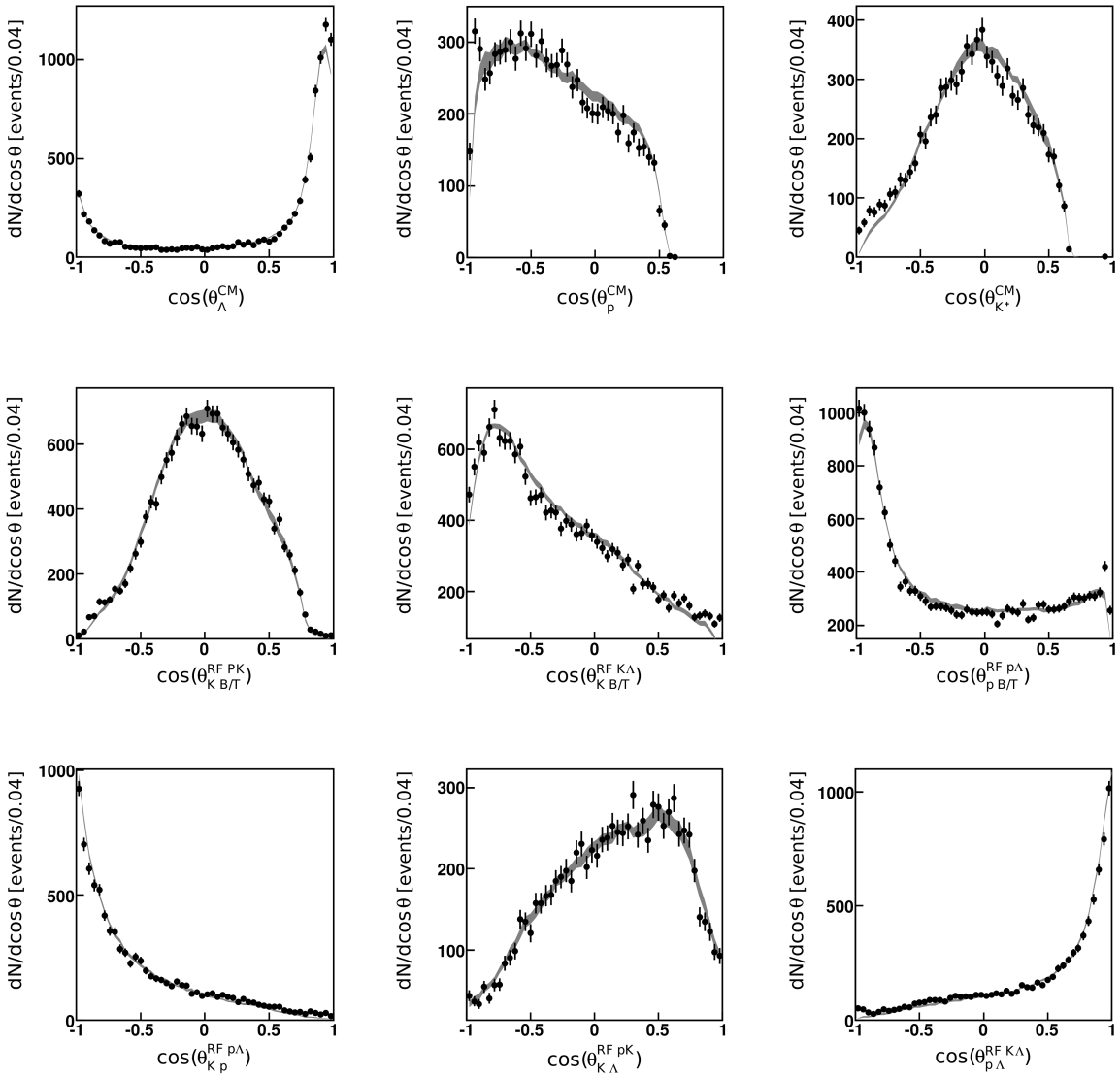
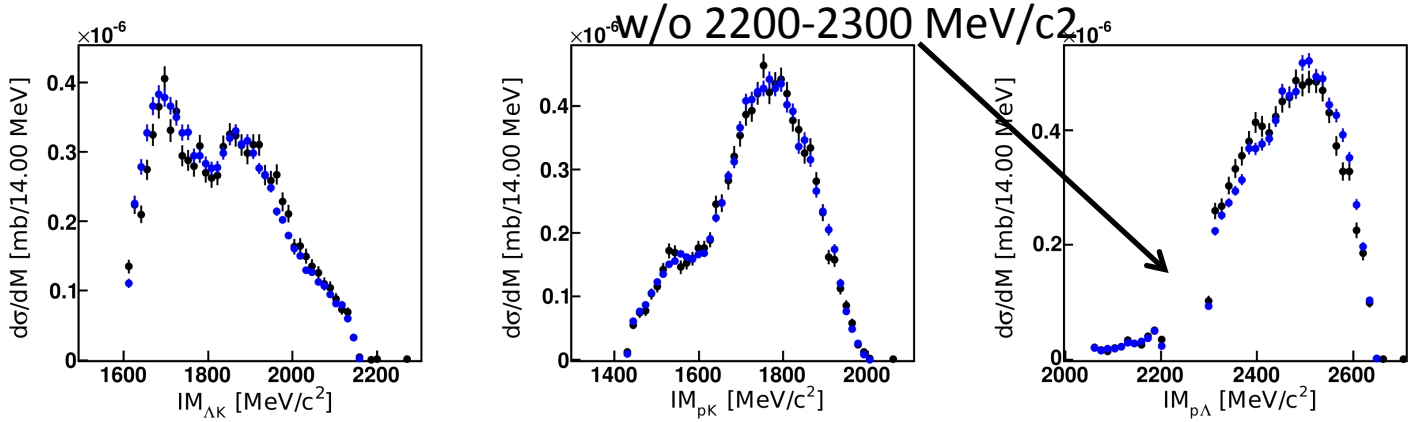


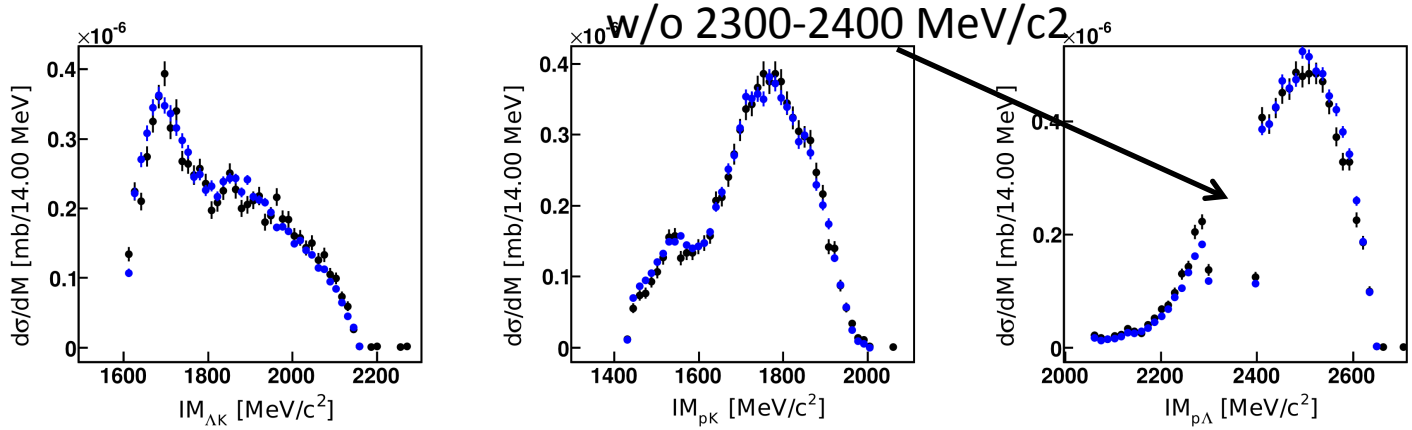
Figure 2.19: Two-particle masses for the **WALL data set** (black points) shown with the **four best PWA solutions** (gray band), obtained by a fit to the HADES and WALL data.

Solution inside WALL acceptance



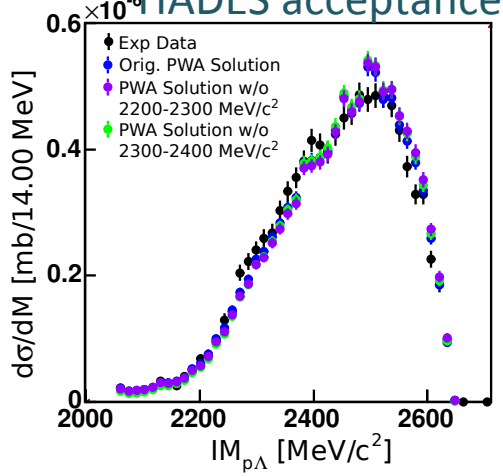
Cross Check

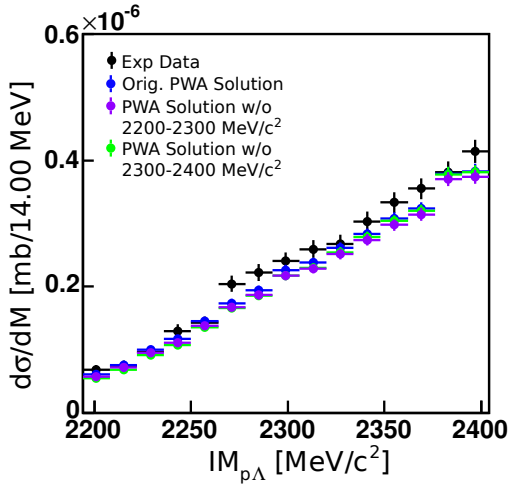

w/o 2200-2300 MeV/c2
×10⁻⁶
dσ/dM [mb/14.00 MeV]
IM_ΛK [MeV/c²]
IM_pK [MeV/c²]
IM_pΛ [MeV/c²]


w/o 2300-2400 MeV/c2
×10⁻⁶
dσ/dM [mb/14.00 MeV]
IM_ΛK [MeV/c²]
IM_pK [MeV/c²]
IM_pΛ [MeV/c²]

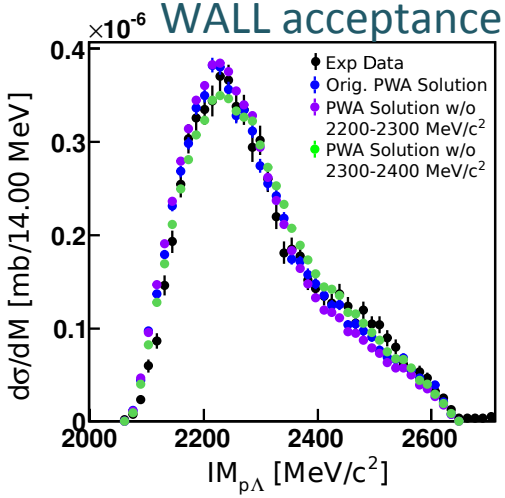
Cross Check

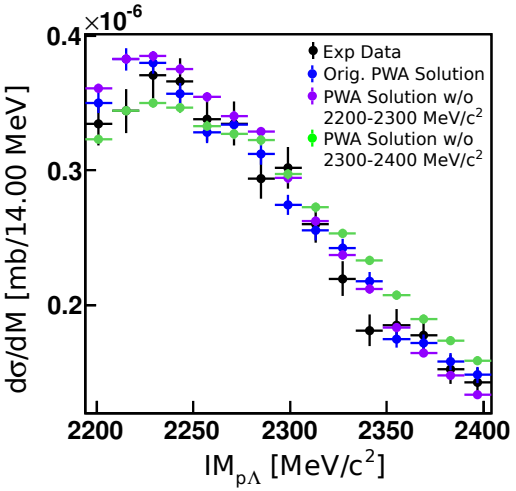
HADES acceptance





WALL acceptance

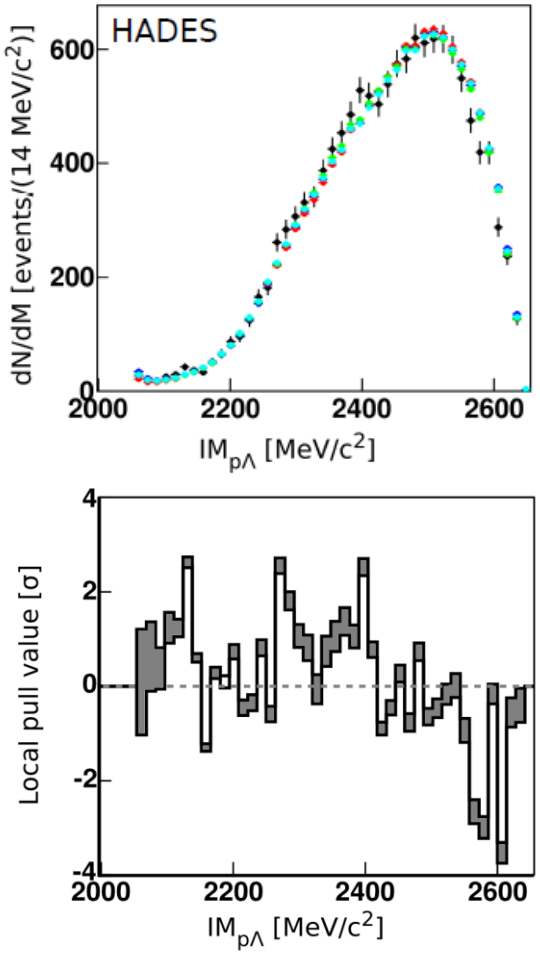




Good consistency among the results.

The solution is not biased by a possible signal in the excluded mass range

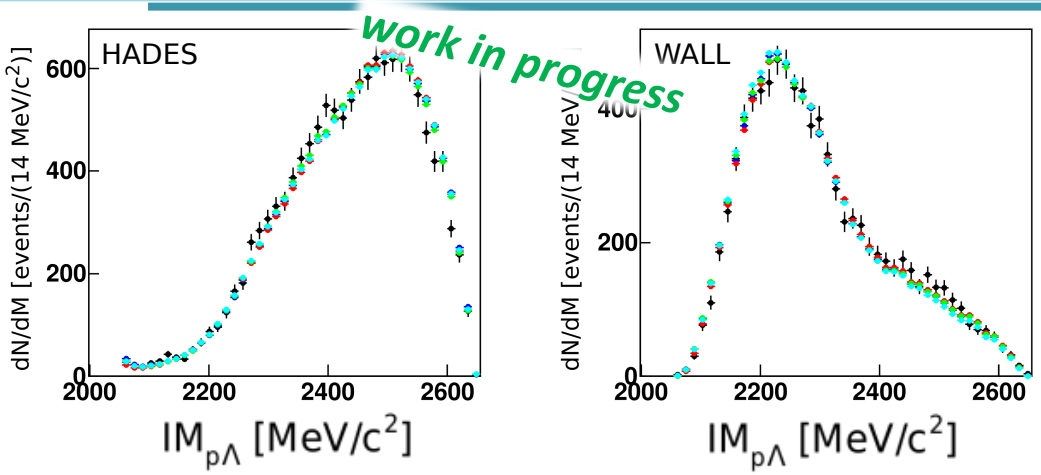
Result



$$pull = \sum_{i=1}^{N_b} \frac{(m_i - \lambda_i)}{\lambda_i}$$

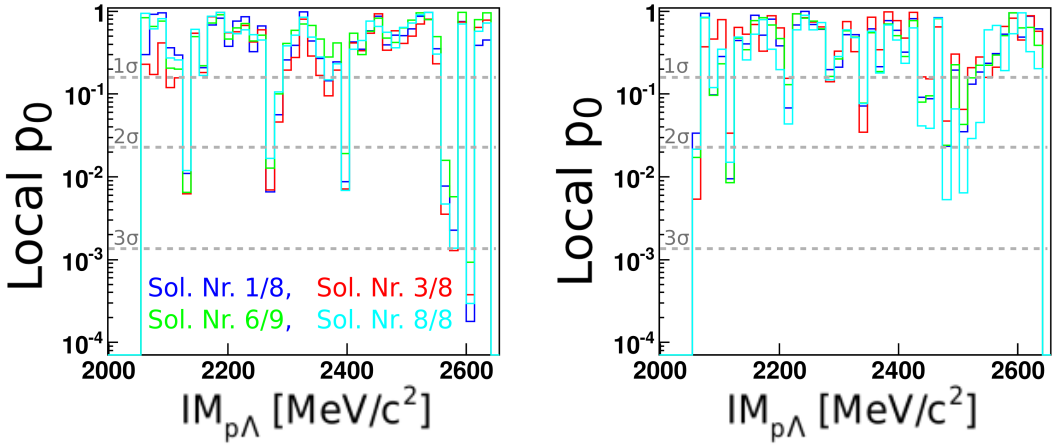
m_i are the number of measured events in the bin i
λ_i number of expected events in the bin according to the model
N_b is the number of bins

Test of the Null Hypothesis



$$\chi^2_P = \frac{(m - \lambda)^2}{\lambda}$$

$$p - value = \int_{\chi^2_{P,d}}^{\infty} P(\chi^2, Ndf) d\chi^2$$

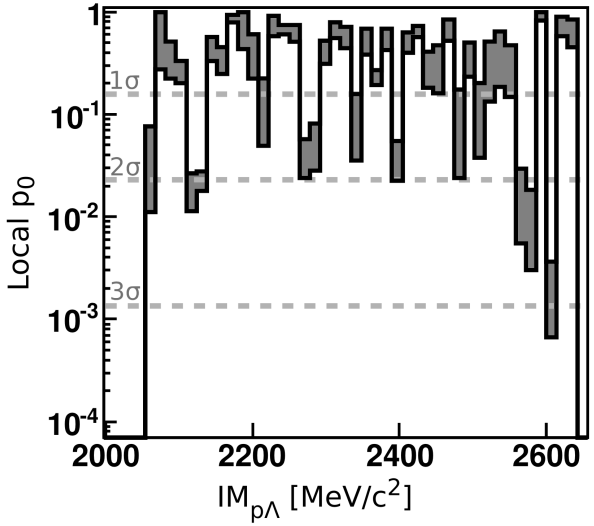


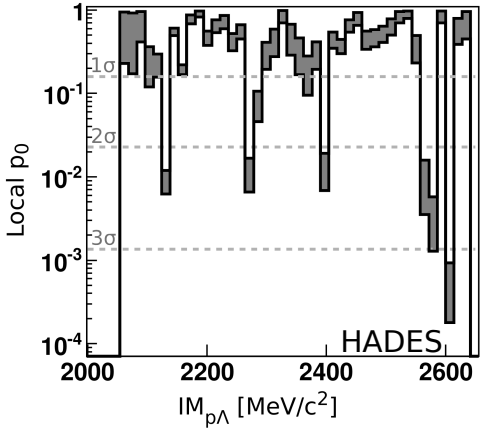
m_i measured events in bin i

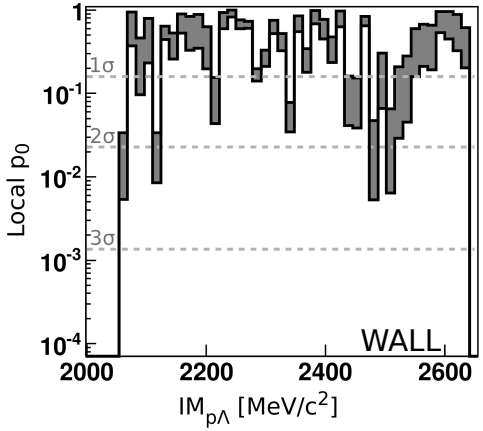
λ_i expected events in bin i according to the model

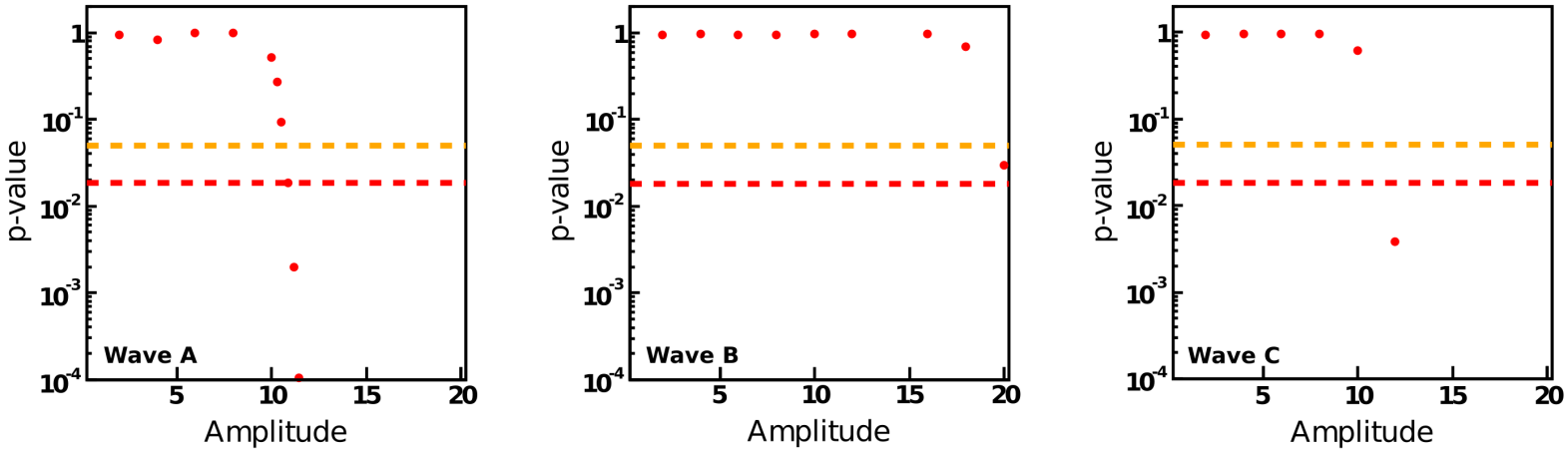
$$\chi^2_P = \frac{(m\ -\lambda\ )^2}{\lambda} \Rightarrow \chi^2_P = \sum_{i=1}^{N_b} \frac{(m_i - \lambda_i)^2}{\lambda_i}$$

Combined result







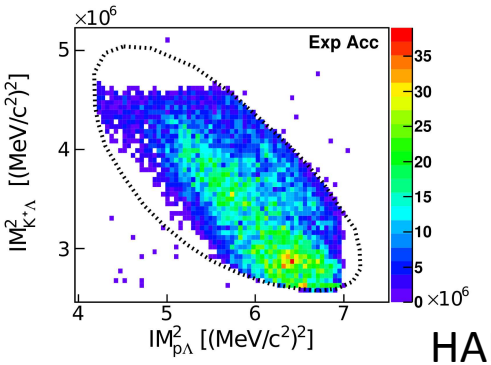


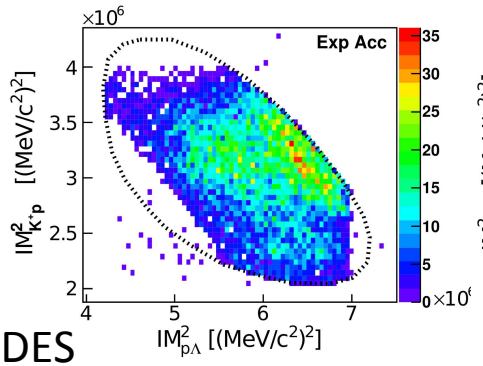
$$CL_s = \frac{p_\mu}{1 - p_0}.$$

Values are rejected in a test if $CL_s \leq \alpha$.

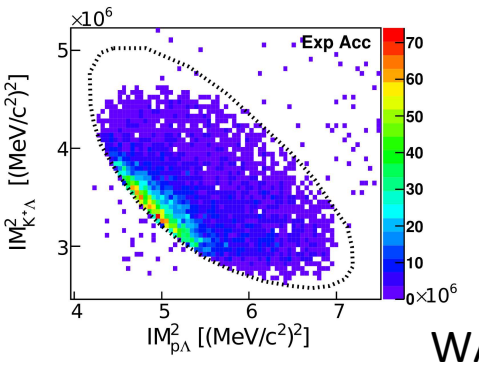
$$p_\mu \leq \alpha \cdot (1 - p_0).$$

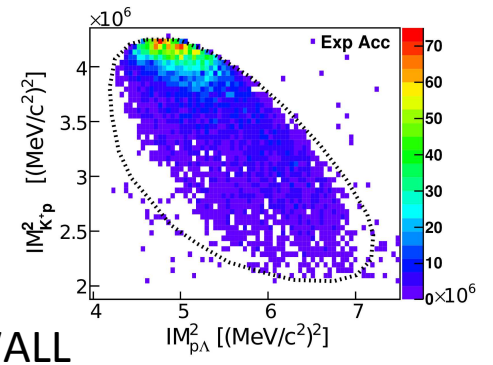
Dalitz Plots



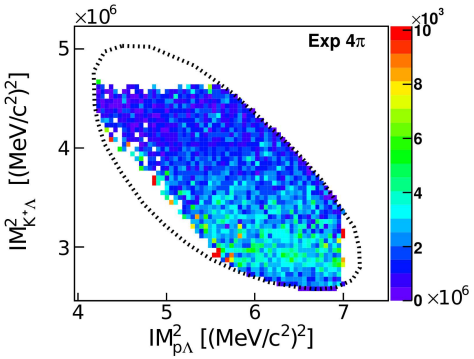


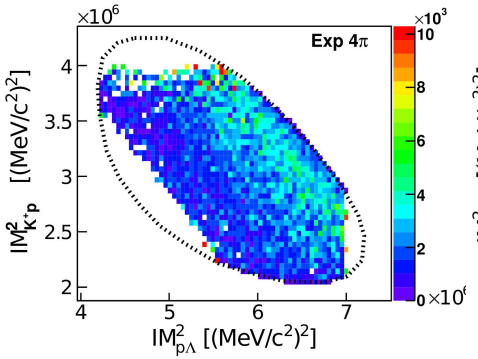
HADES

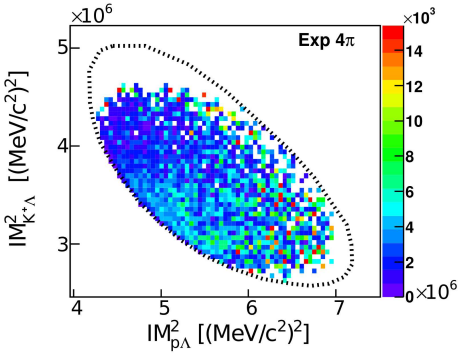


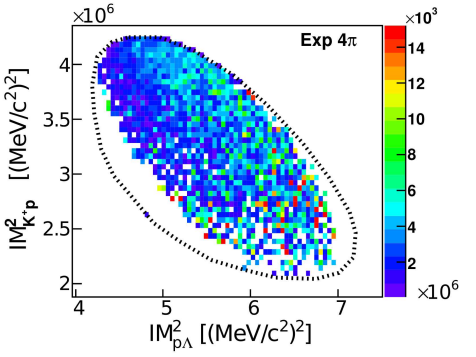


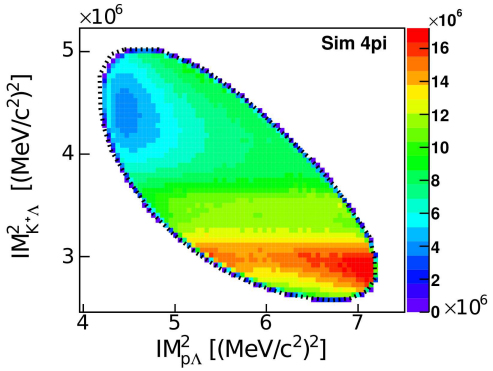
WALL

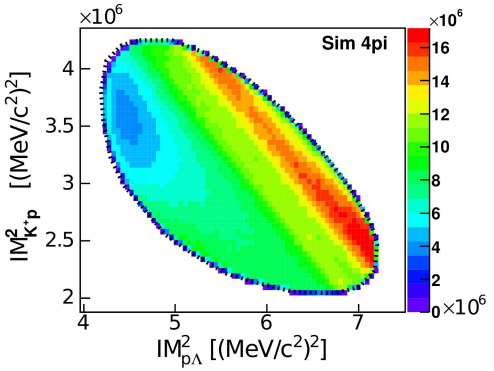




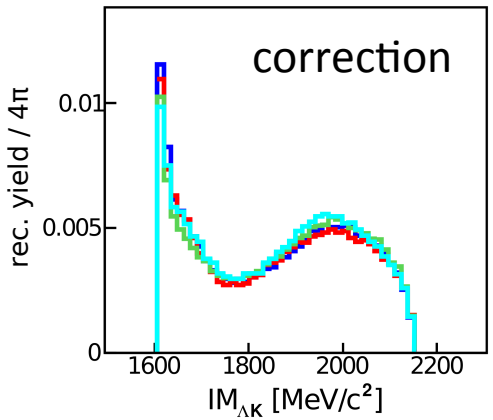


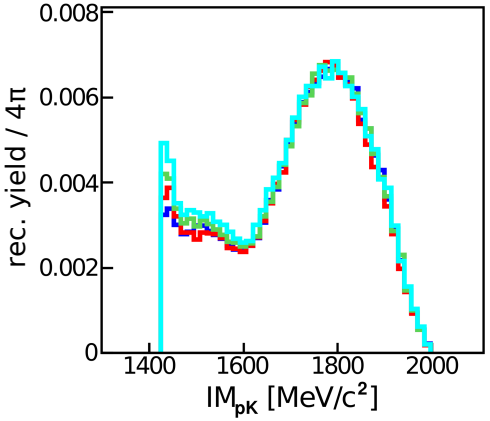


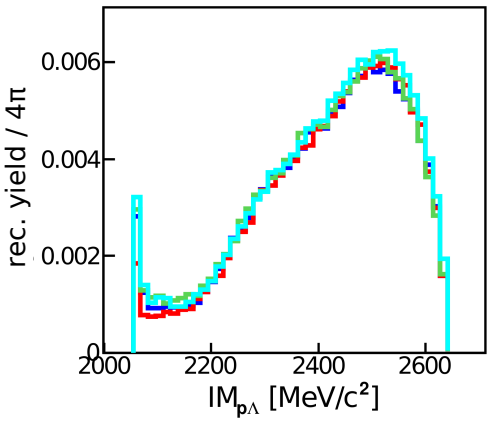


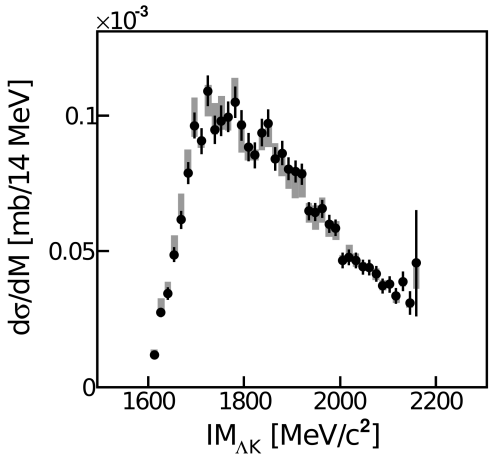


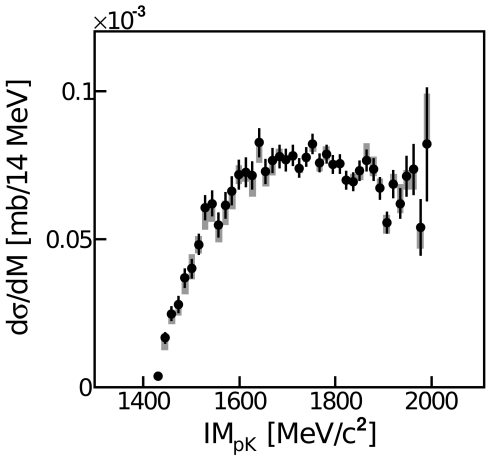
Cross Section

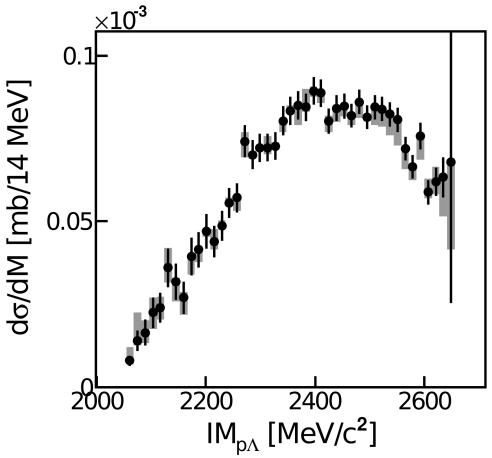


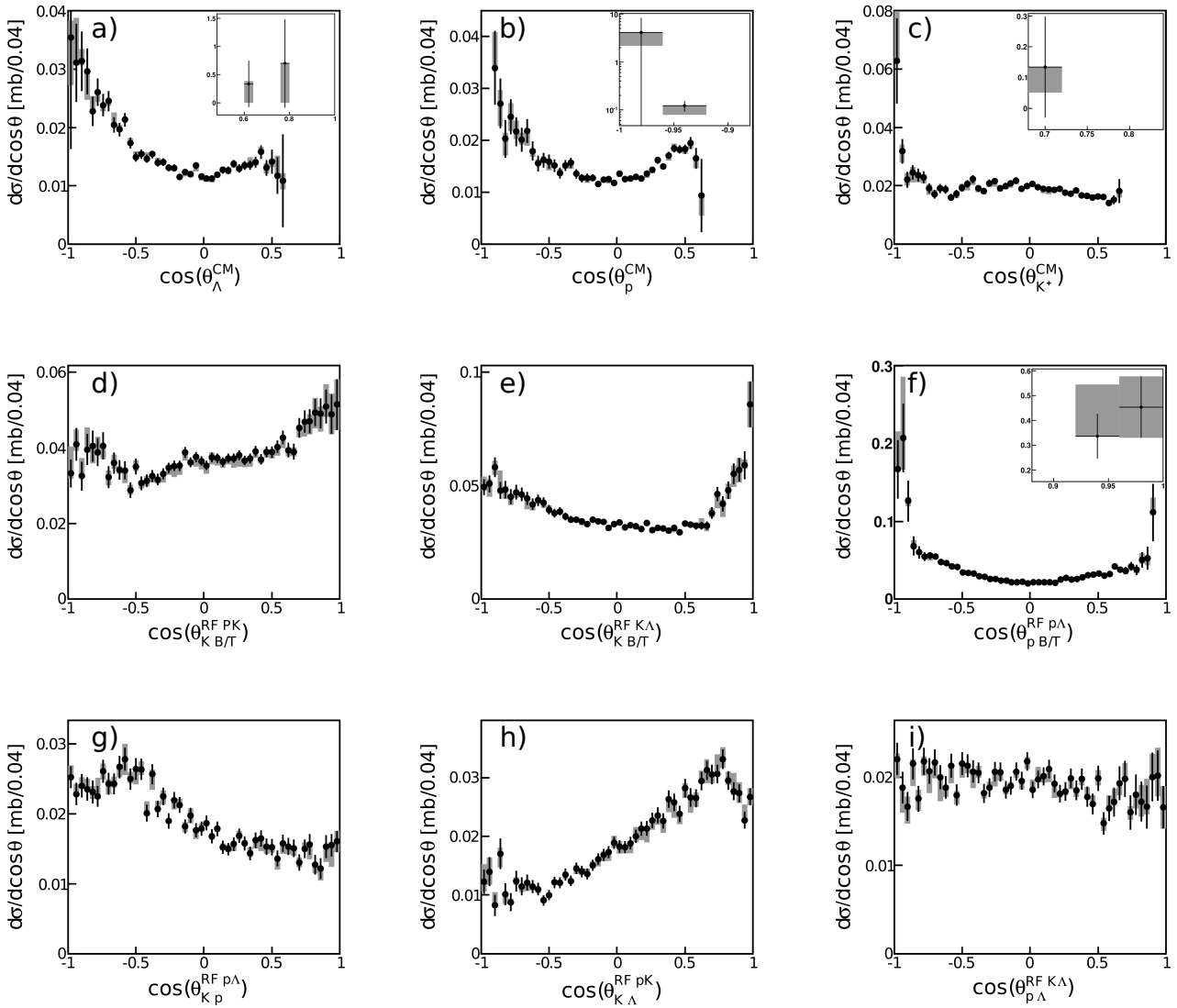






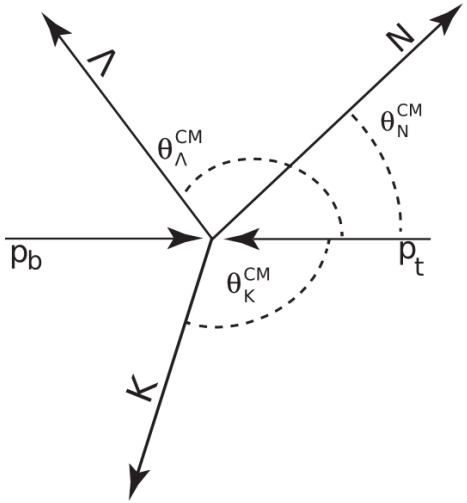




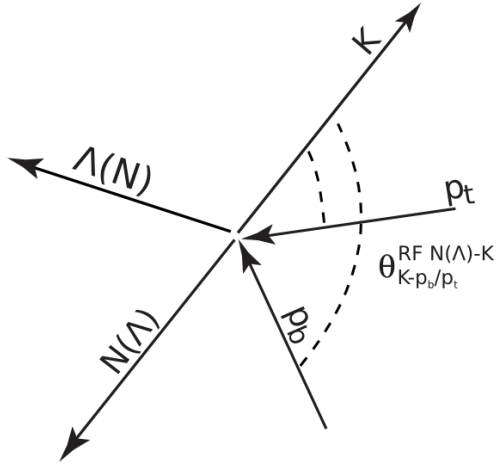

a)
b)
c)
d)
e)
f)
g)
h)
i)
dσ/dcosθ [mb/0.04]
cos(θ^CM_Λ)
cos(θ^CM_p)
cos(θ^CM_K+)
cos(θ^RF PK_K B/T)
cos(θ^RF KΛ_K B/T)
cos(θ^RF pΛ_p B/T)
cos(θ^RF pΛ_K p)
cos(θ^RF pK_K Λ)
cos(θ^RF KΛ_p Λ)

Definition of Angles

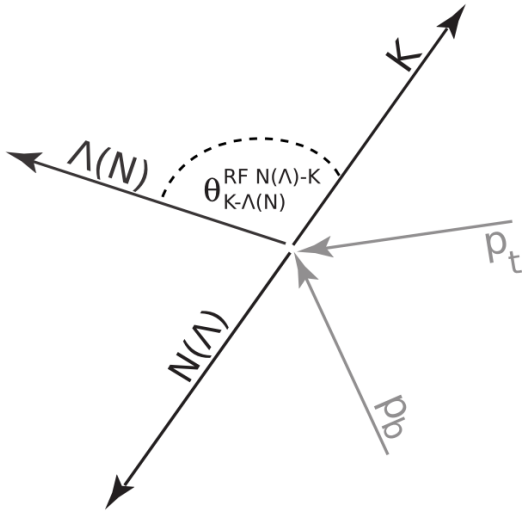
I) CM Angle



II) Jackson Angle



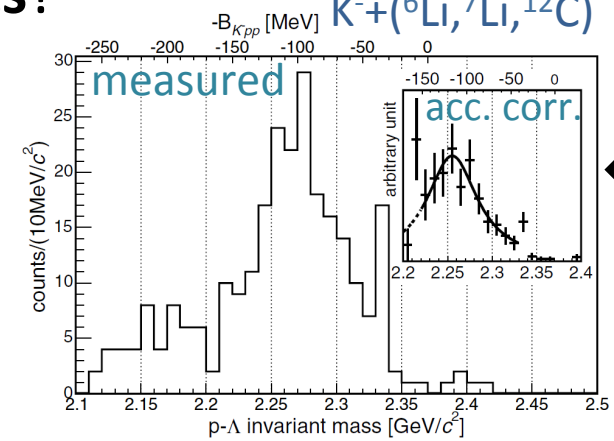
III) Helicity Angle



Is there a $\bar{K}$NN?

Hints?

$K^-+(^6Li,^7Li,^{12}C)$

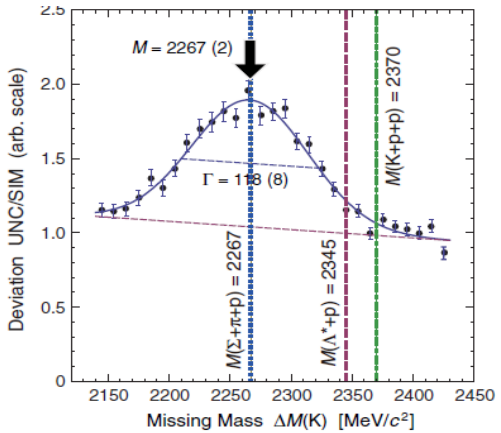


M. Agnello et al. Phys. Rev. Lett. **94** (2005)

$M(ppK^-) = 2.255$ GeV/c^2
$B(ppK^-) = 115$ MeV
$\Gamma(ppK^-) = 67$ MeV/c^2

$M(ppK^-) = 2.267$ GeV/c
$B(ppK^-) = 103$ MeV
$\Gamma(ppK^-) = 118$ MeV/c^2

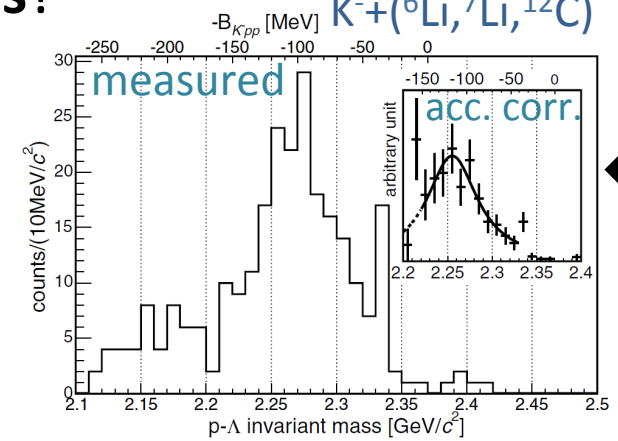
p+p



T. Yamazaki et al. Phys. Rev. Lett. **104,** (2010)
M. Maggiora et al. Nucl. Phys. **A 835** (2010)

Is there a $\bar{K}NN$?

Hints?



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

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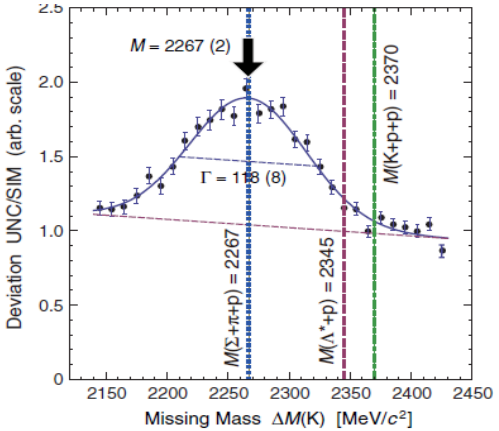
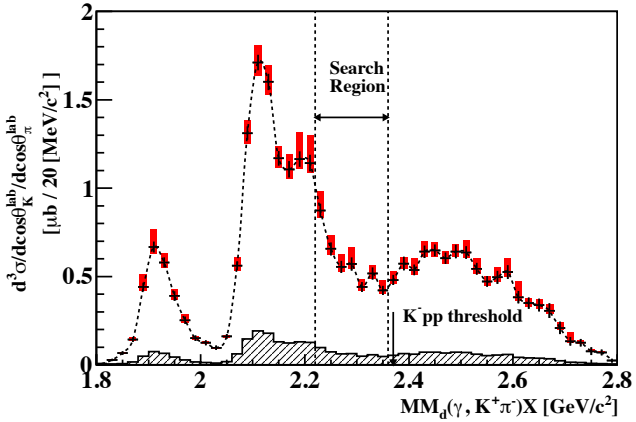
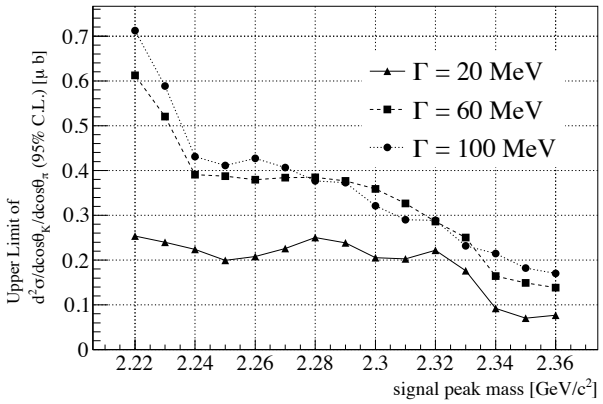
p+p



T. Yamazaki et al. Phys. Rev. Lett. **104,** (2010)
M. Maggiora et al. Nucl. Phys. **A 835** (2010)

Exclusions





γ+d →X + K^++π

A.O. Tokiyasu et al.
Phys.Lett. B**728** 616-621 (2014)

0.5-5% of the cross section of typical hadron photo-production