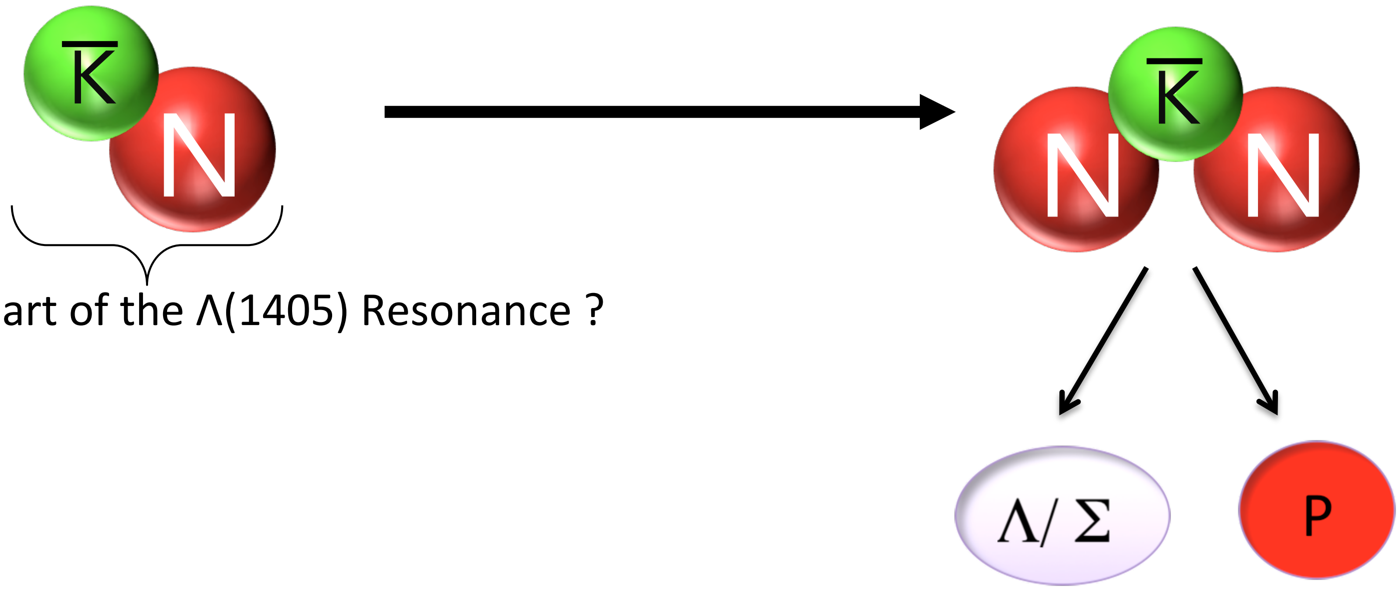
Critical overview of experimental results on kaonic clusters"

Laura Fabbietti
Technische Universitaet Muenchen

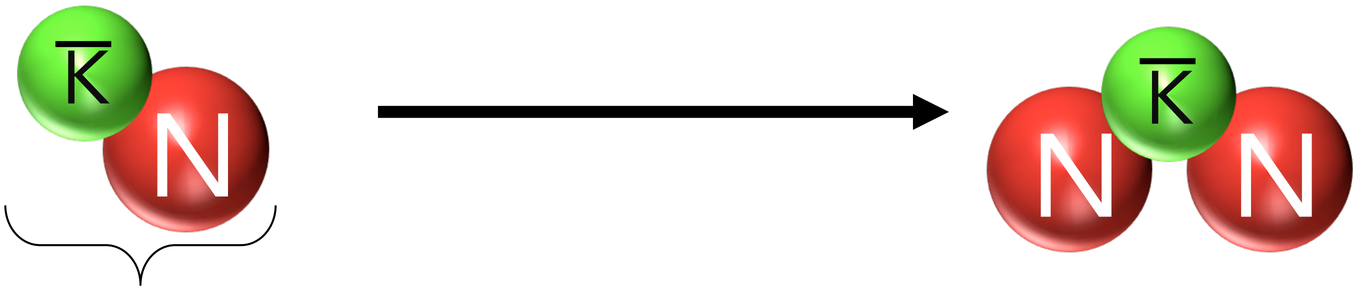
HADES and KLOE-AMADEUS collaborations

Kaonic Cluster



Part of the Λ(1405) Resonance ?

Kaonic Cluster



Part of the Λ(1405) Resonance ?

Theoretical Predictions

Binding Energy (BE): 10-100 MeV

Mesonic Decay (Γ_m): 30-110 MeV

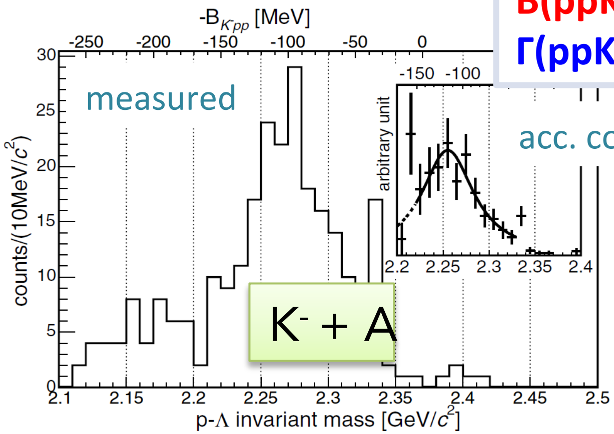
Non-Mesonic Decay (Γ_{nm}): 4-30 MeV

	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

Experimental Results on ppK^-

FINUDA

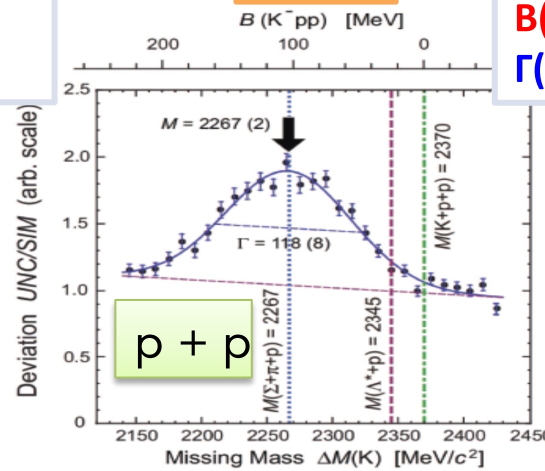
$M(ppK^-)$ = 2.255 $GeVc^{-2}$
$B(ppK^-)$ = 115 MeV
$\Gamma(ppK^-)$ = 67 $MeVc^{-2}$



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

DISTO

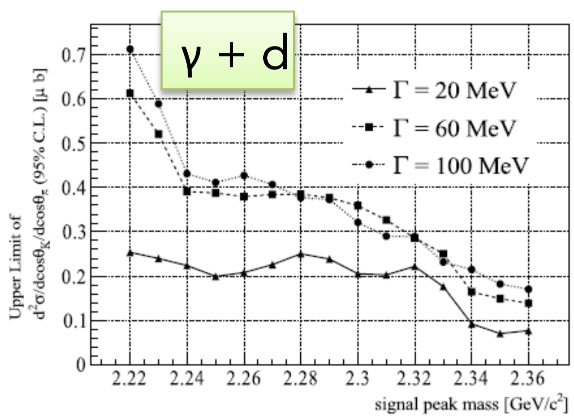
$M(ppK^-)$ = 2.267 $GeVc^{-2}$
$B(ppK^-)$ = 103 MeV
$\Gamma(ppK^-)$ = 118 $MeVc^{-2}$



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

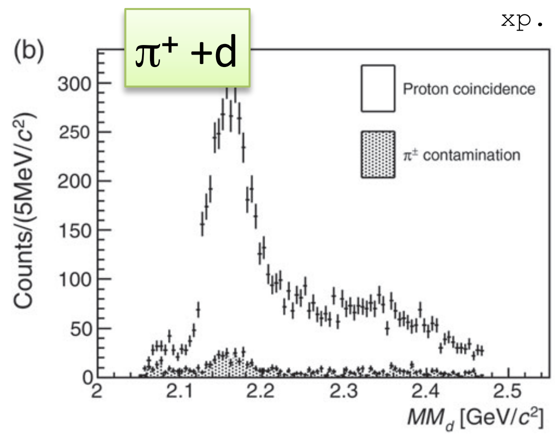
LEPS/ SPRING8

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



J-PARC E27

Y. Ichikawa et al. Prog. Theor. Exp. Phys. 2015, 021DOI



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

Criticism nr. 1: Deviation Spectra

Example: DISTO analysis

Experimental data divided by Phase Space simulation
Or a data sample divided by another

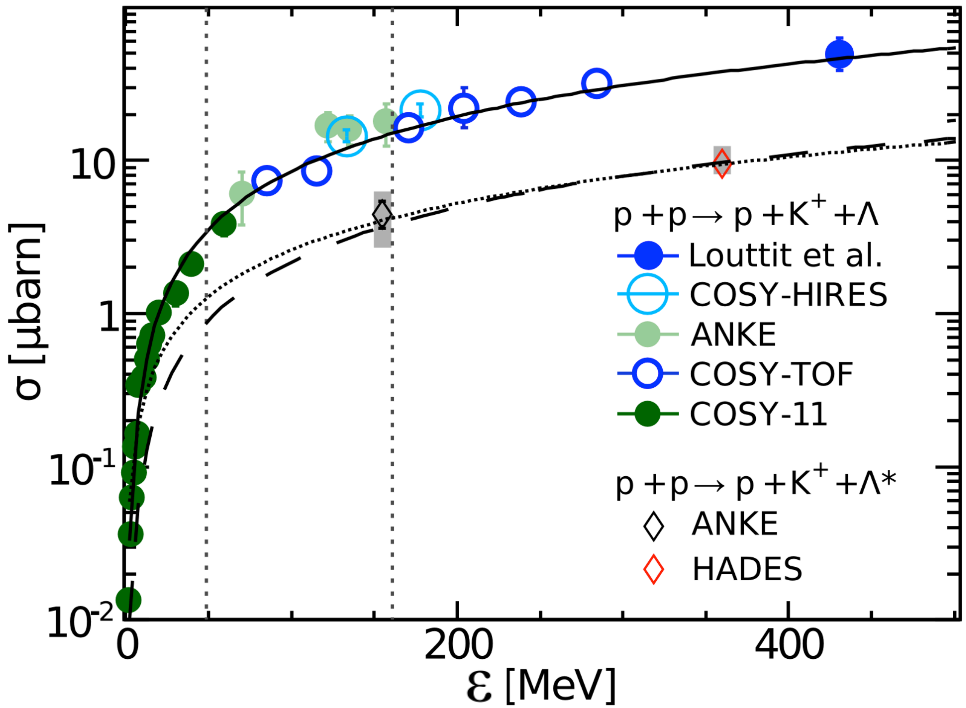
Eliane Epple, Laura Fabbietti. Apr 8, 2015. 9 pp.
e-Print: **arXiv:1504.02060 [nucl-ex]**

Λ(1405) Doorway for the DISTO energies

arXiv:1504.02060

X claim by DISTO for p+p at 2.85 GeV but not for 2.5 GeV
Reason: small Λ(1405) cross-section at 2.5 GeV??

P. Kienle et al., Eur. Phys. J. A 48, 183 (2012).

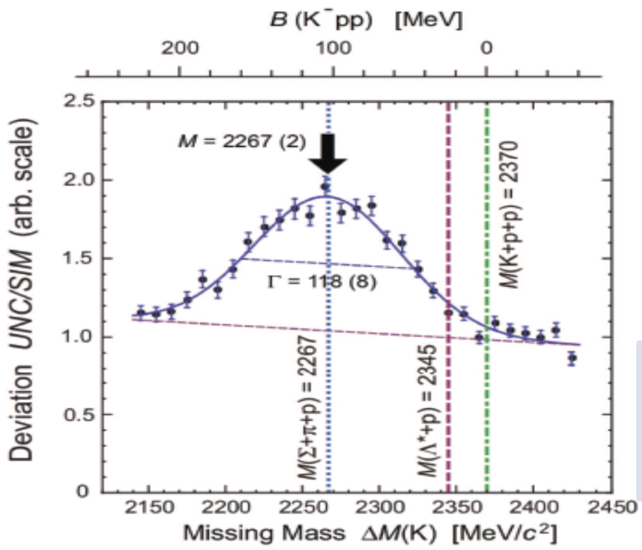


$$\sigma_{pK^+\Lambda(1405)}(2.5GeV)/\sigma_{pK^+\Lambda(1405)}(2.85GeV) = 0.23$$

If the Λ(1405) argument holds true, one should see the X also at 2.5 GeV
Even more than 23%, because of smaller phase-space!!

Deviation Spectra: the HADES Data

DISTO



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

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

Selections:

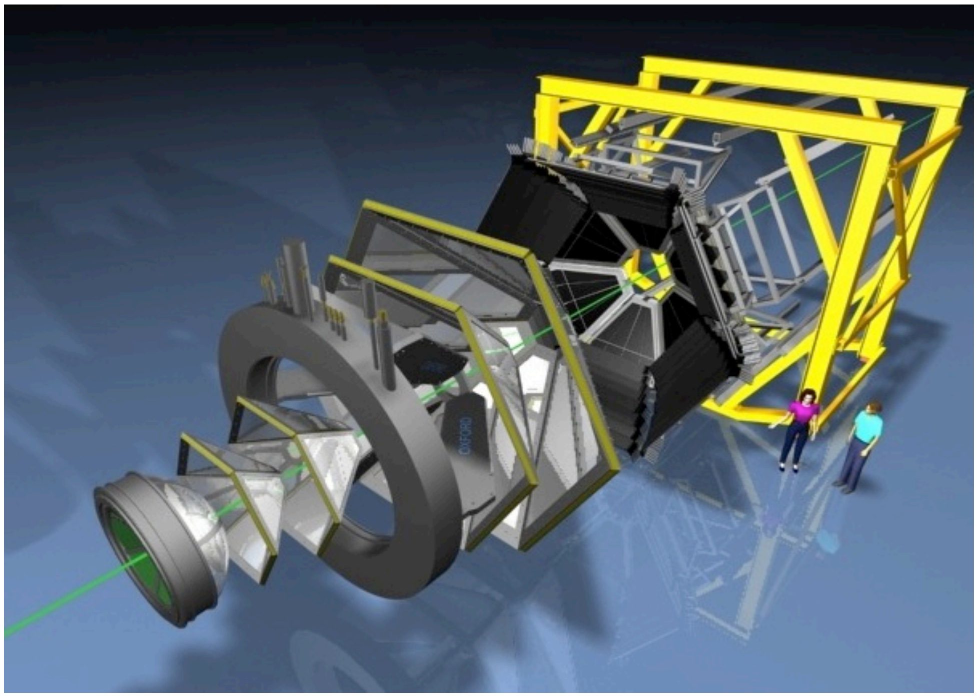
$$|cos\theta_p| < 0.6$$

$$-0.2 < cos\theta_{K^+} < 0.4$$

The HADES experiment

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

HADES



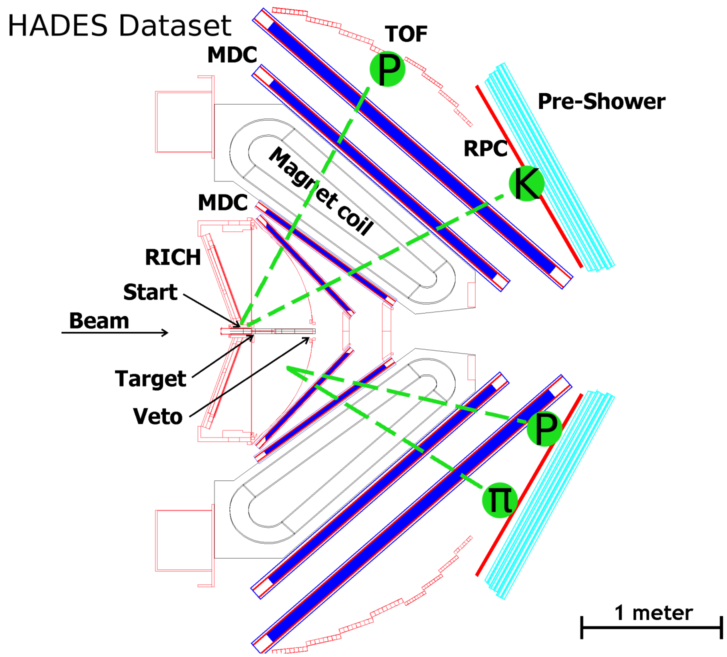
Beam Energy: 3.5 GeV

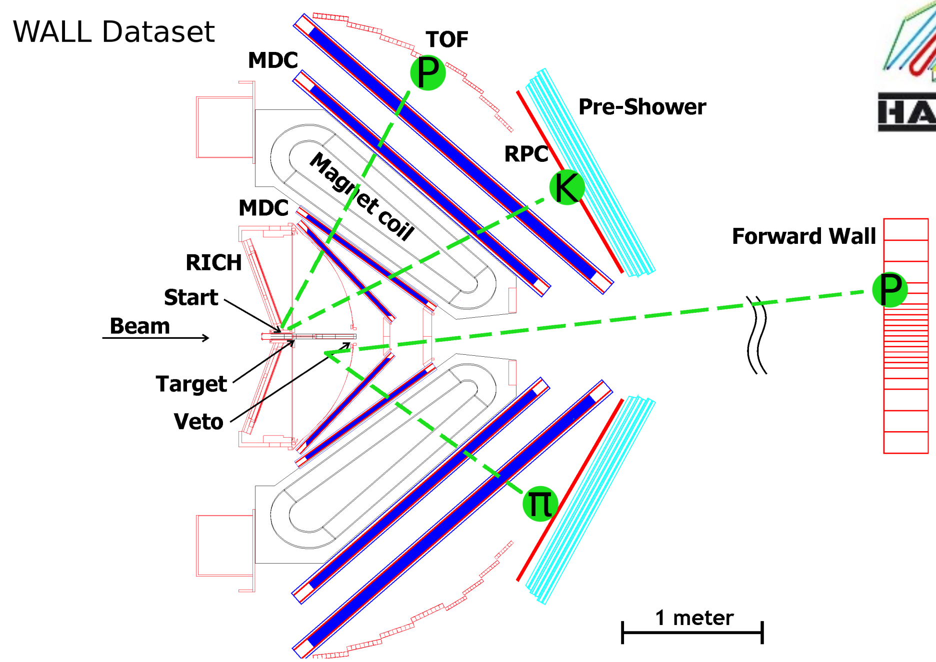
- Fixed-target Setup
- Full azimuthal coverage, 15˚- 185˚ in polar angle
- Momentum resolution ≈ 1% - 5 %
- Particle identification via dE/dx & ToF

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

Total Number of exclusive Events: 21000

The HADES Data Sample





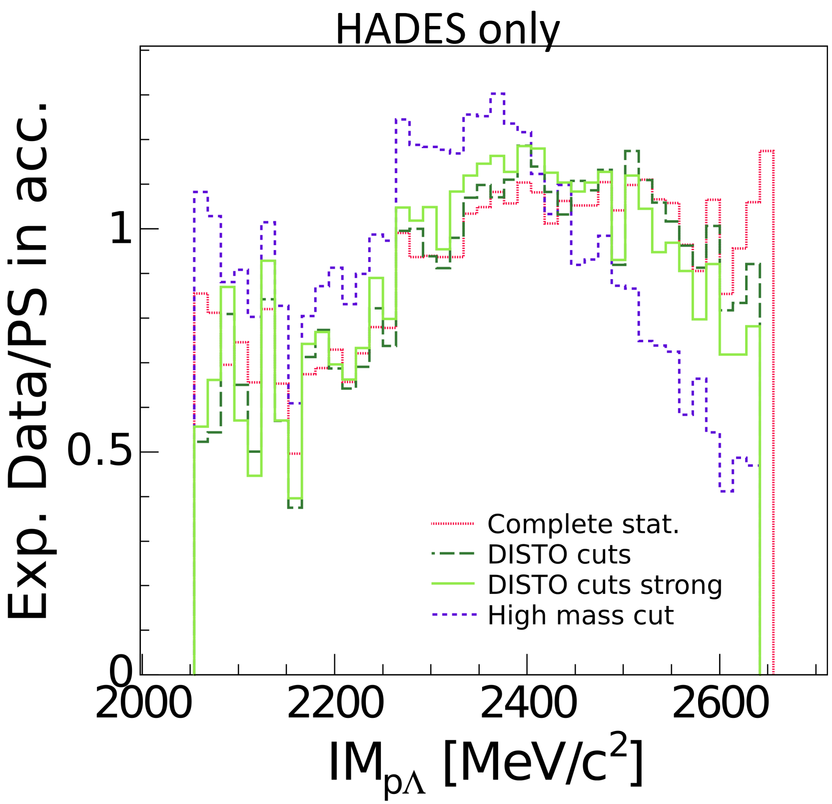
HADES data
13,000 events of $pK^+\Lambda$
Background from wrong PID ≈6%
Background from $pK^+\Sigma^0$ ≈1%

WALL data
8000 events of $pK^+\Lambda$
Background from wrong PID ≈11.7%
Background from $pK^+\Sigma^0$ ≈ 3%

Deviation Spectra: the HADES Data

Exzellenzcluster Universe

arXiv:1504.02060



Selections:

$$|cos\theta_p| < 0.6$$
$$-0.2 < cos\theta_{K^+} < 0.4$$

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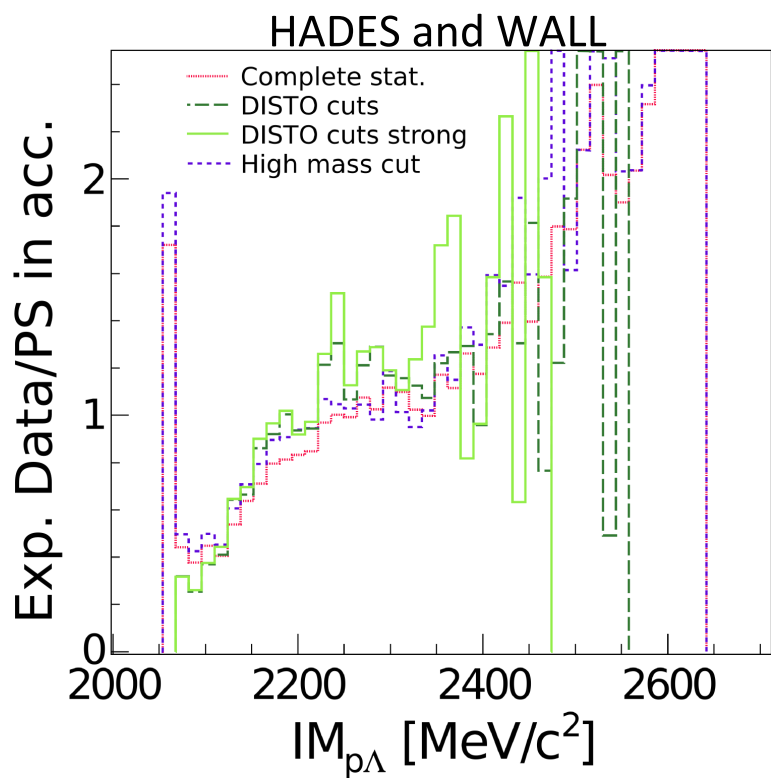
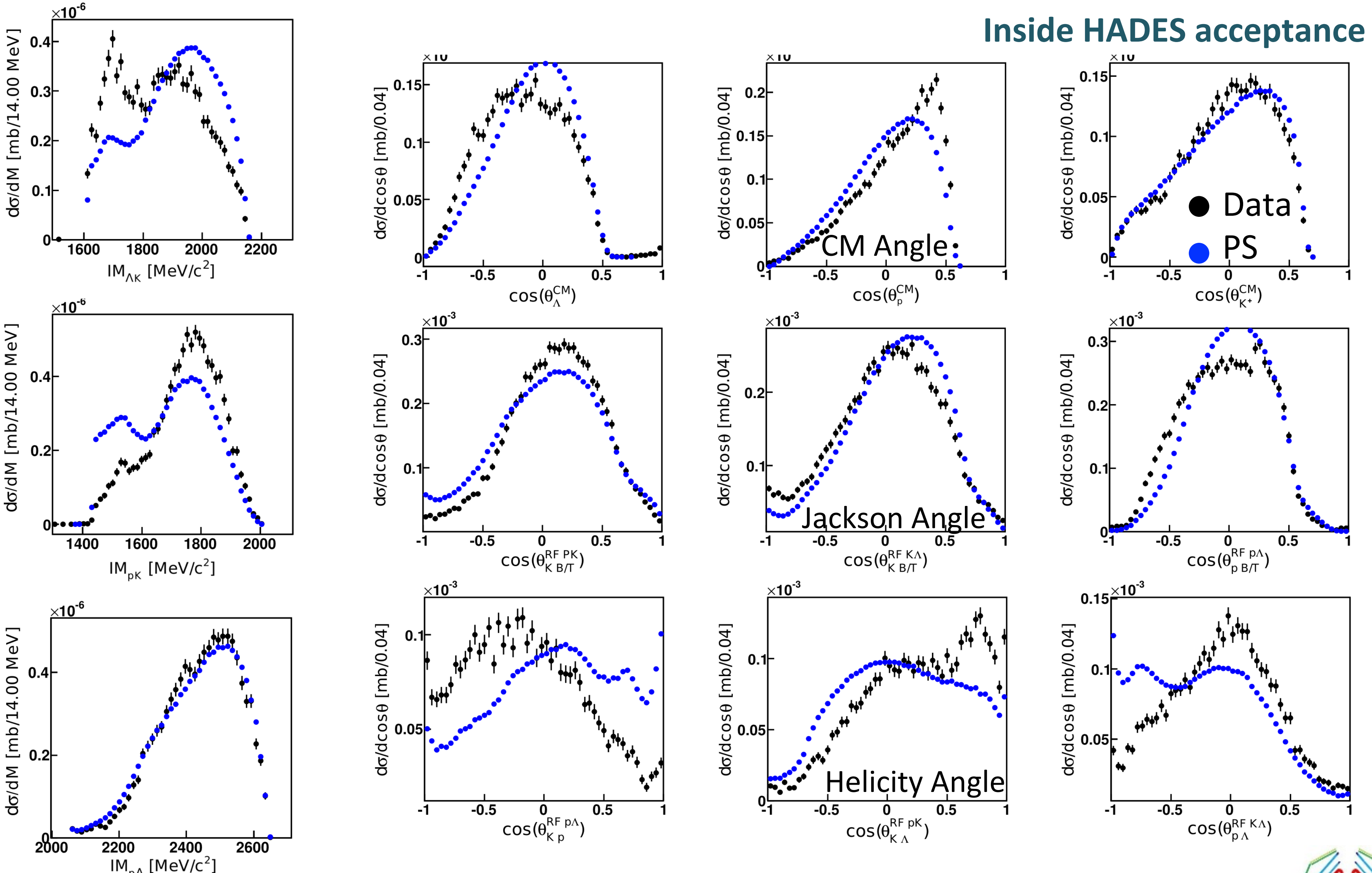
$$|cos\theta_p| < 0.4$$
$$-0.2 < cos\theta_{K^+} < 0.4$$
$$M_{K^+\Lambda} > 1810 MeV/c^2$$

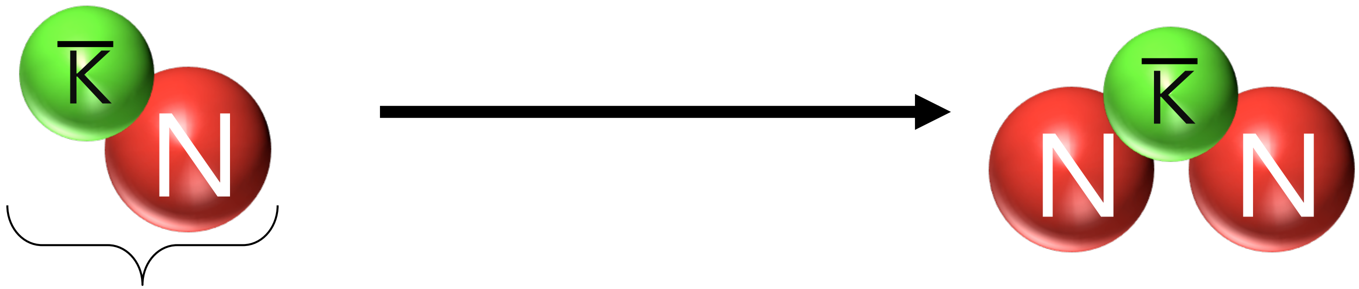


Phase Space Model

Inside HADES acceptance



Kaonic Cluster



Part of the Λ(1405) Resonance

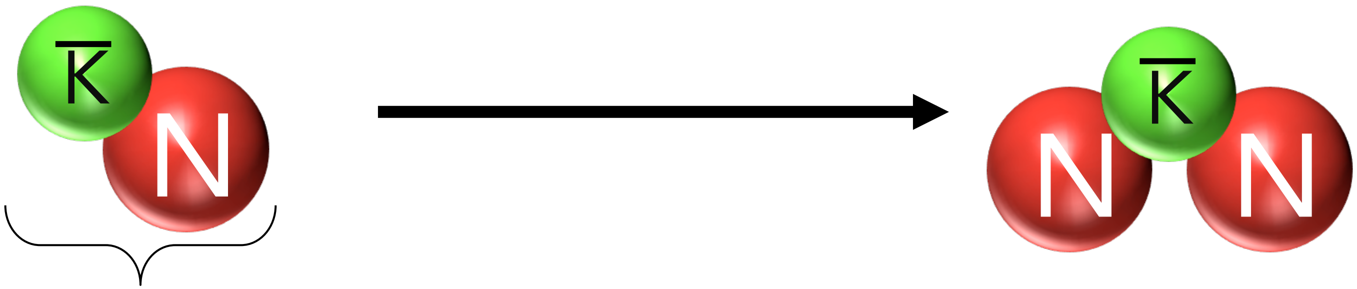
$$p + p \longrightarrow \underbrace{\Lambda(1405) + p}_{ppK^-} + K^+$$

$$ppK^- + K^+$$

$$ppK^- \rightarrow \Lambda + p$$

J. Beringer
Phys.Rev. D86 (2012)

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

Resonance	J^P	Mass (GeV/c^2)	Width (GeV/c^2)
$N^*(1650)$	$\frac{1}{2}^-$	1.655	0.150
$N^*(1710)$	$\frac{1}{2}^+$	1.170	0.100
$N^*(1720)$	$\frac{3}{2}^+$	1.720	0.250
$N^*(1875)$	$\frac{3}{2}^-$	1.875	0.220
$N^*(1880)$	$\frac{1}{2}^+$	1.870	0.235
$N^*(1895)$	$\frac{1}{2}^-$	2.090	0.090
$N^*(1900)$	$\frac{3}{2}^+$	1.900	0.250

J. Beringer
Phys.Rev. D86 (2012)

The PWA Framework

p K+ Λ

N*

$$A^{\beta}_{2b}(s_{K^+\Lambda}) = \frac{M\Gamma_{K^+\Lambda}}{M^2 - s_{K^+\Lambda} - iM\Gamma_{tot}}$$

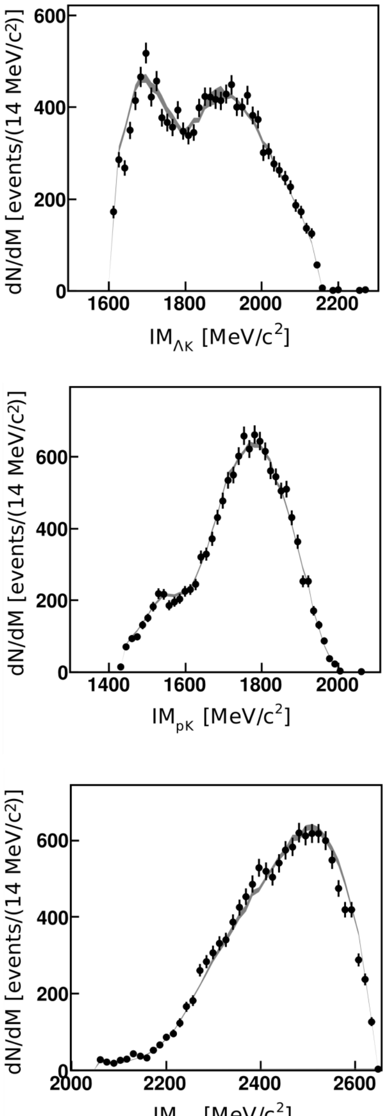
Bonn Gatchina PWA
http://pwa.hiskp.uni-bonn.de/

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

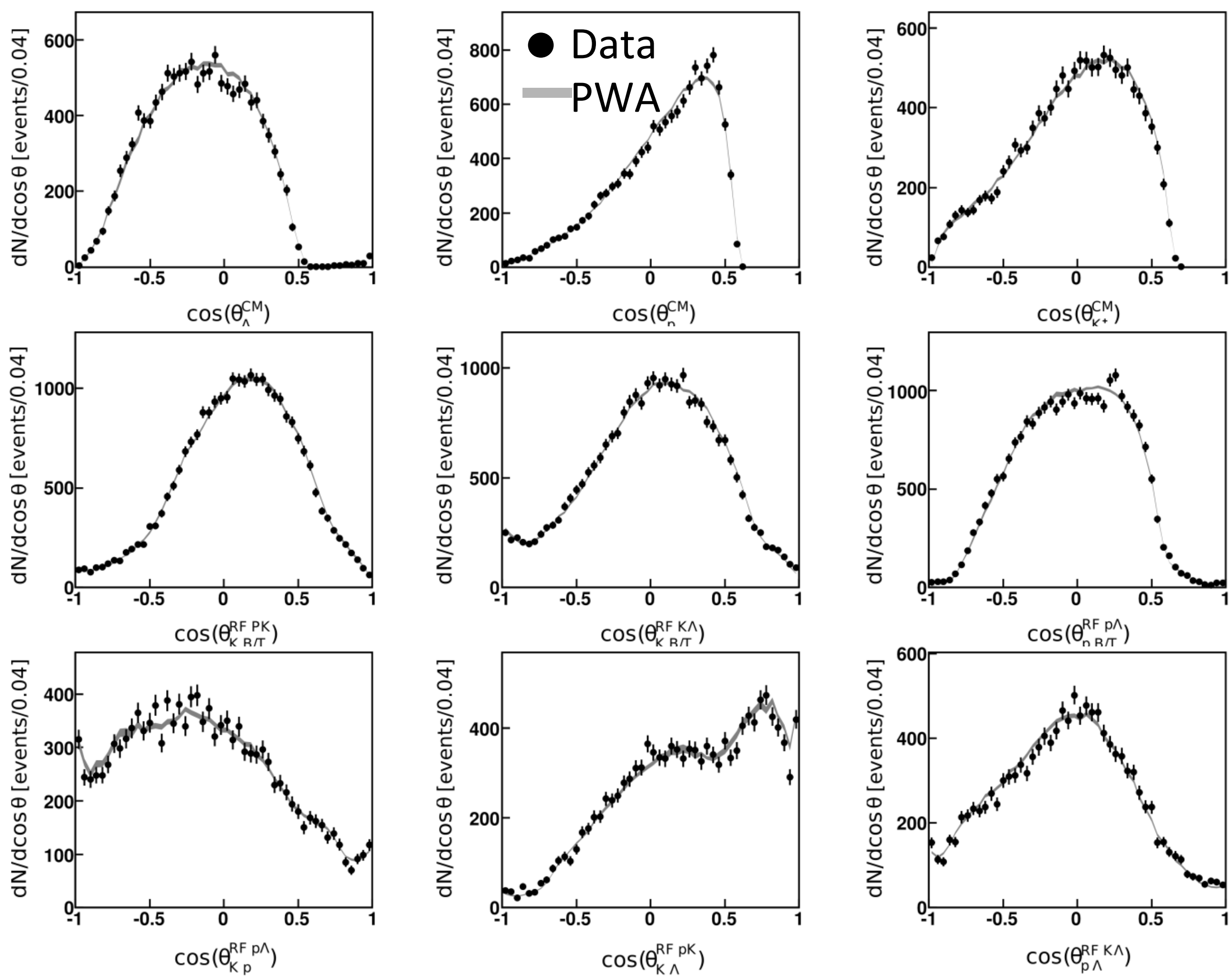
Notation in PDG	Old notation	Mass [GeV/c^2]	Width [GeV/c^2]	$\Gamma_{\Lambda K}/\Gamma_{All}$ %
N(1650) $\frac{1}{2}^-$	N(1650)S_{11}	1.655	0.150	3-11
N(1710) $\frac{1}{2}^+$	N(1710)P_{11}	1.710	0.200	5-25
N(1720) $\frac{3}{2}^+$	N(1720)D_{13}	1.720	0.250	1-15
N(1875) $\frac{3}{2}^-$	N(1875)D_{13}	1.875	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

Systematic variation of different N* waves in the input of the PWA fit

PWA Model



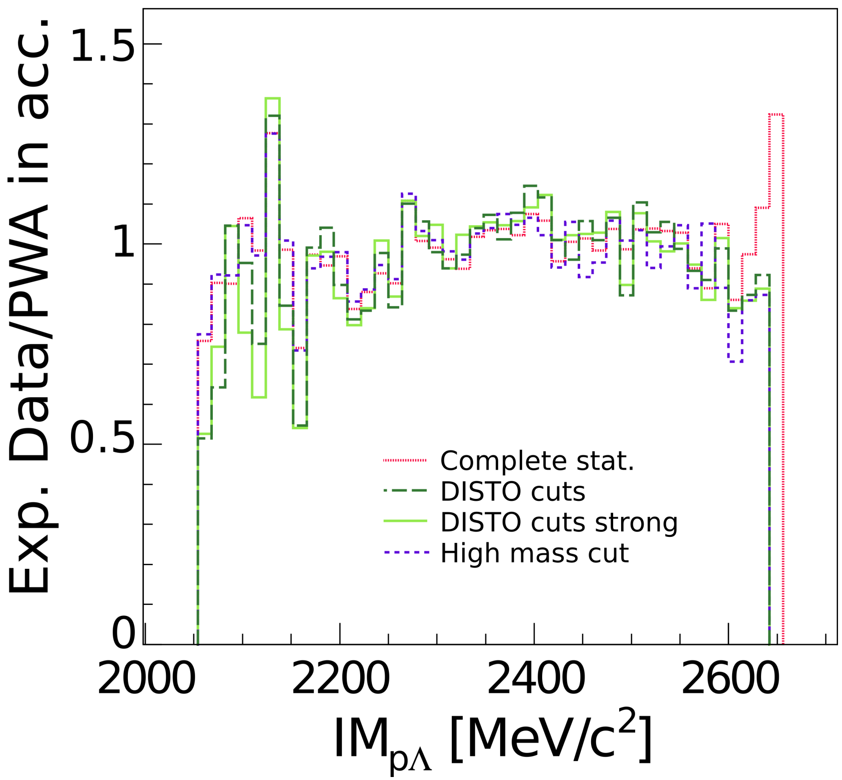
HADES coll. Phys.Lett. B742 (2015) 242-248 arXiv:1410.8188 [nucl-ex]



Deviation Spectra reloaded

arXiv:1504.02060

HADES only



$$|cos\theta_p| < 0.4$$
$$-0.2 < cos\theta_{K^+} < 0.4$$
$$M_{K^+\Lambda} > 1810 MeV/c^2$$

Selections:

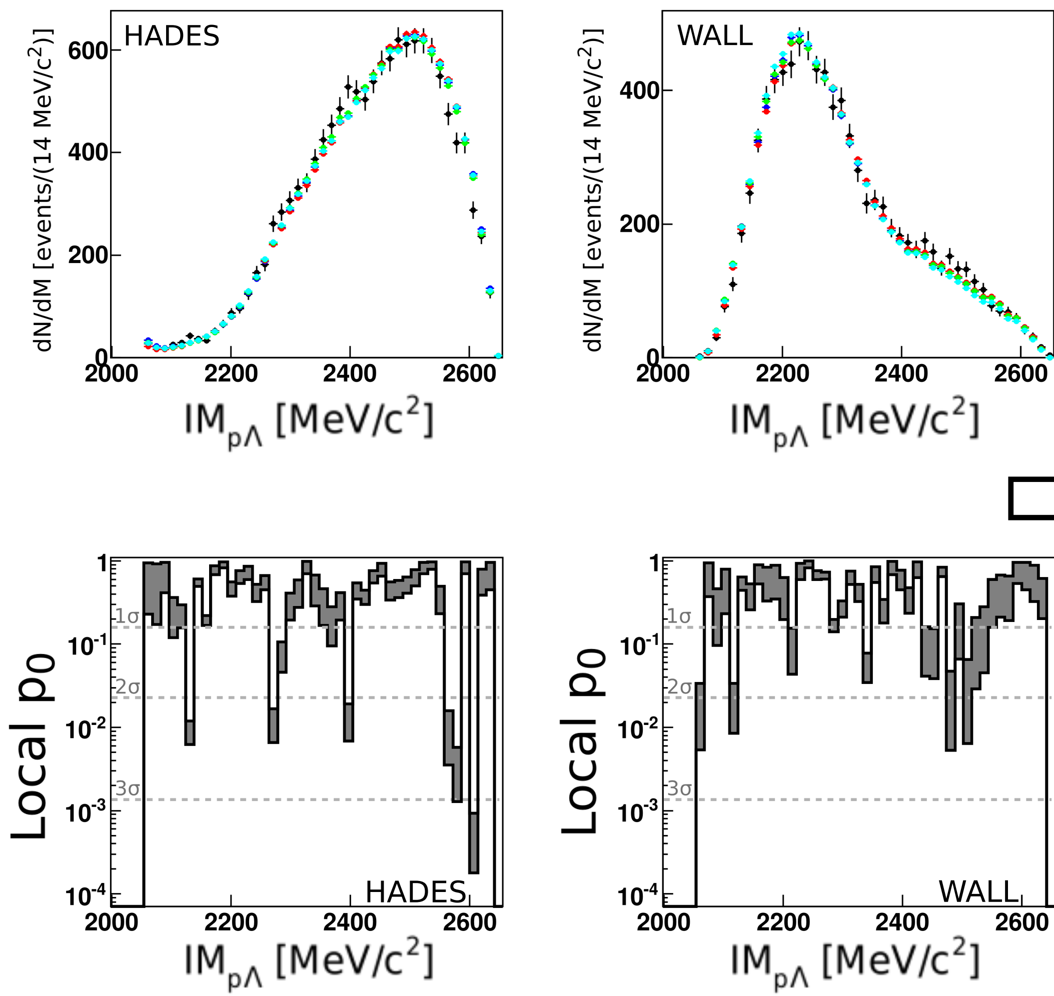
$$|cos\theta_p| < 0.6$$
$$-0.2 < cos\theta_{K^+} < 0.4$$

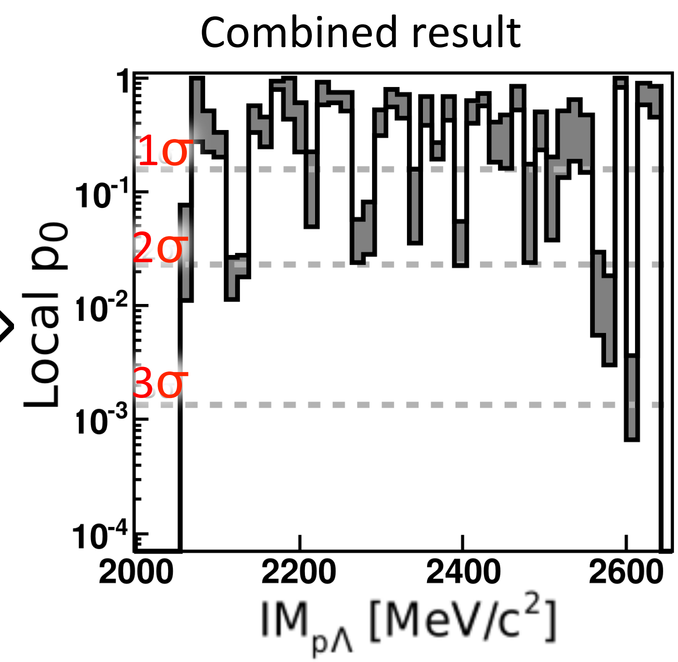
$$|cos\theta_p| < 0.4$$
$$-0.2 < cos\theta_{K^+} < 0.4$$

HADES and WALL

Deviation plot remains flat if normalized to PWA solution

Test of the Null Hypothesis





We found no new signal in the data

Test of the Signal Hypothesis

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

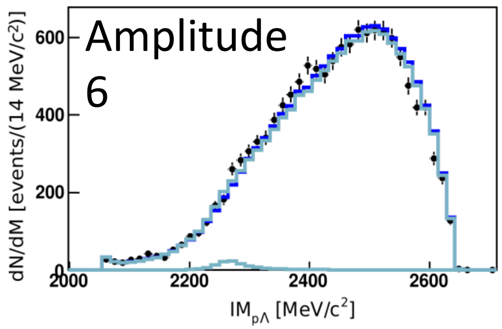
$$^{2S+1}L_J$$

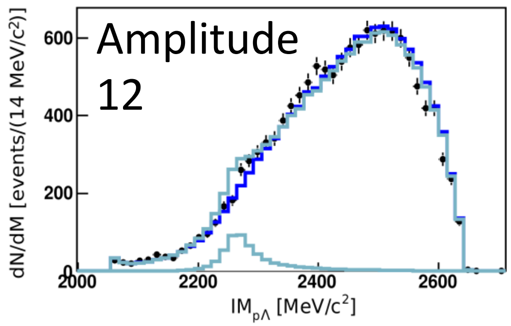
$$WaveA: \ 'p+p' \ \ ^1S_0 \rightarrow \ 'ppK(2250)-K' \ \ ^1S_0$$

$$WaveB: \ 'p+p' \ \ ^3P_1 \rightarrow \ 'ppK(2250)-K' \ \ ^1P_1$$

$$WaveC: \ 'p+p' \ \ ^1D_2 \rightarrow \ 'ppK(2250)-K' \ \ ^1D_2$$

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

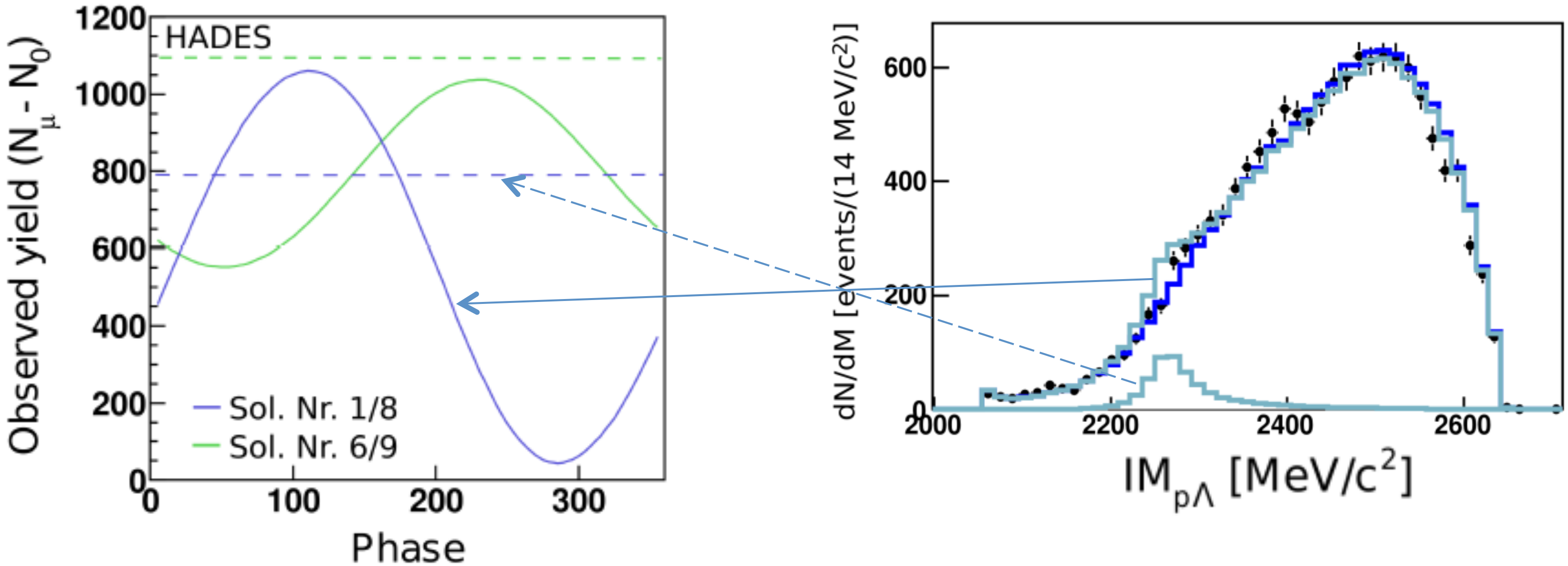




Data Points
Null Hypothesis
Hypothesis with ppK-

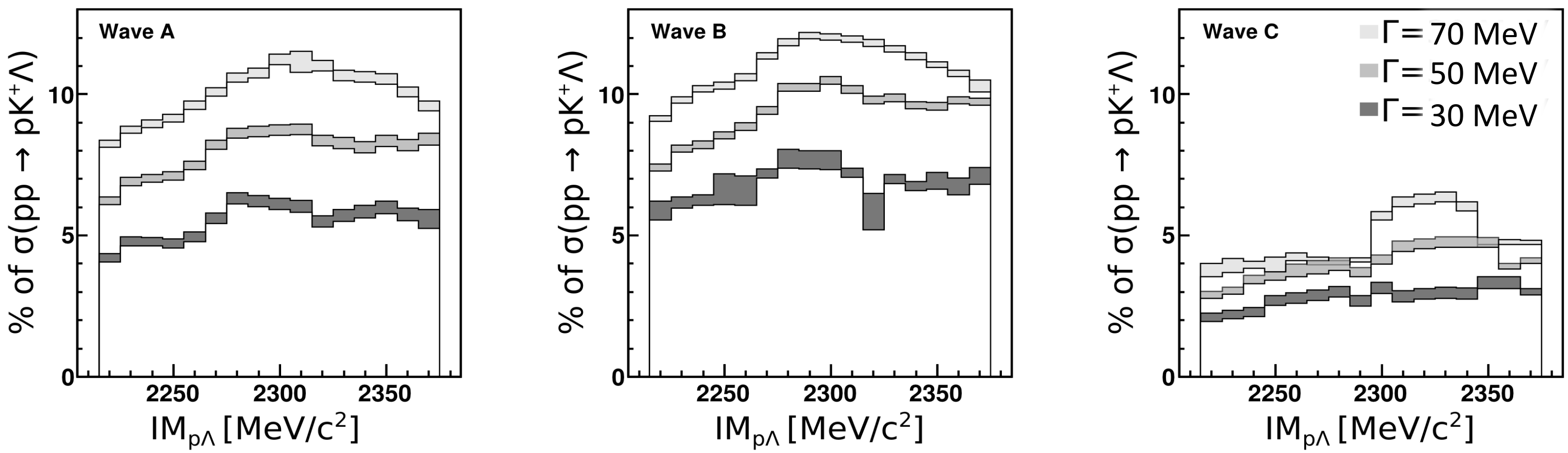
Test of the Signal Hypothesis

… Interferences



The minimum has to be found by the fit

Coherent 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

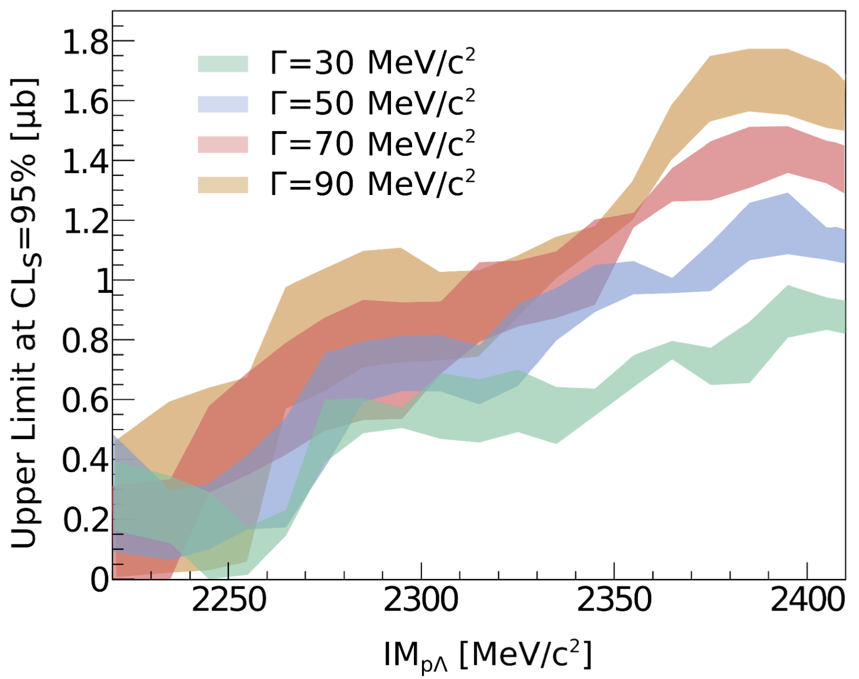
Production Cross Section Λ(1405)

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

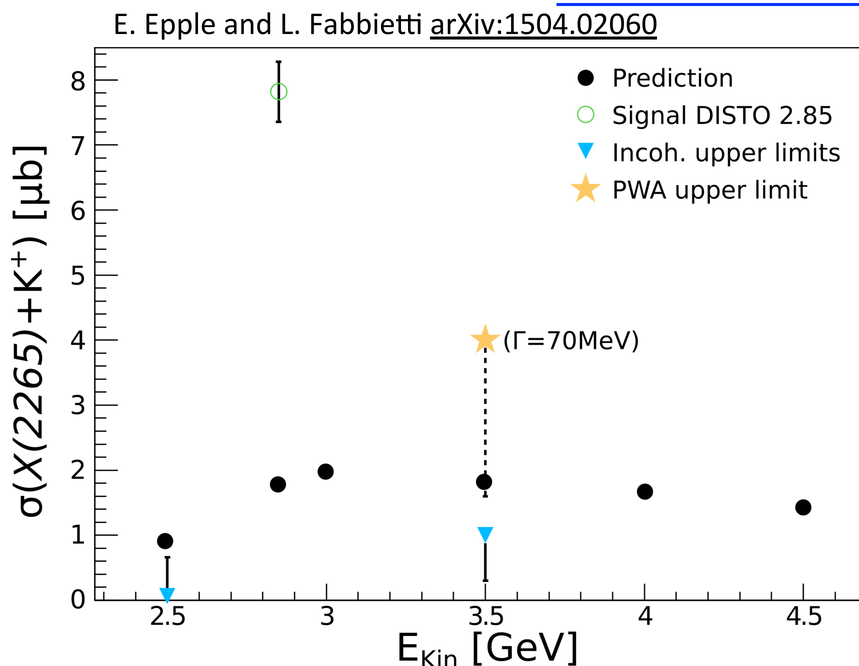
HADES coll. (G. Agakishiev et al.)
Phys. Rev. **C 87**, 025201 (2013)

Incoherent Upper limits

Exzellenzcluster Universe



arXiv:1504.02060



Prediction: K. Suzuki et al. (FOPI Collaboration), Nucl. Phys. A 827, 312C (2009).

The cross-section extracted from the DISTO analysis does not fit in the trend
Coherent (calculated only by HADES with PWA for p+p at 3.5 GeV) and uncoherent upper limits are rather high ~ μb
New data are necessary to either observe the state or decrease the upper limit.

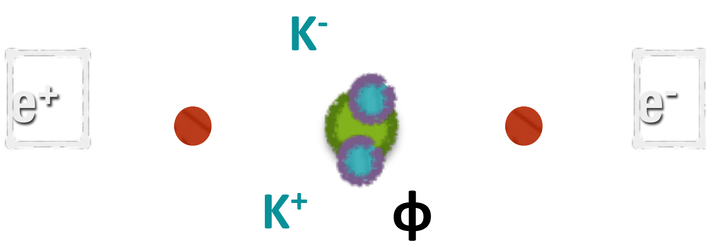
Criticism nr. 2: Null Hypothesis

Example: KLOE-AMADEUS analysis

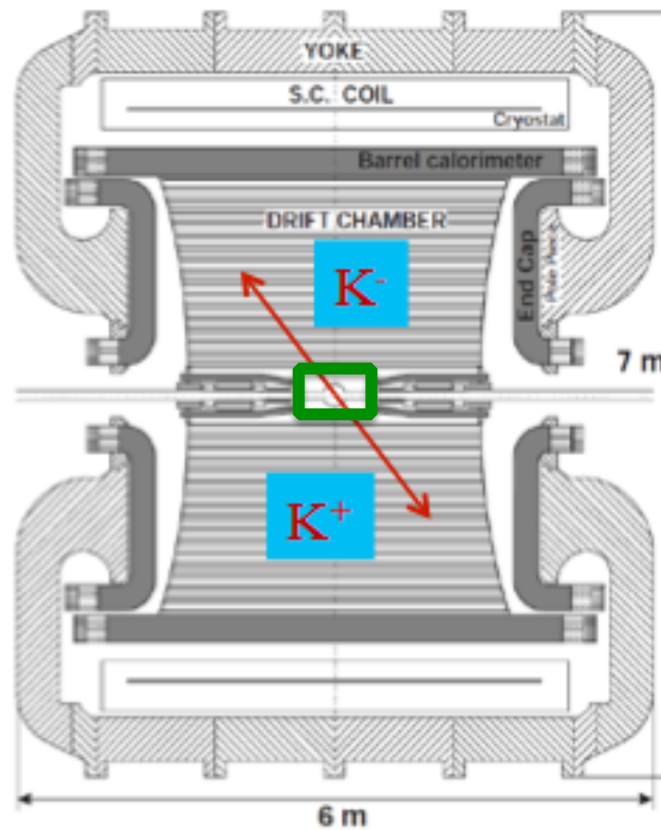
Fits similar to the FINUDA analysis

K^- + C reactions at Daφne

KLOE and Pre-AMADEUS (C. Curceanu, L. Fabbietti, O. Vasquez-Doce, K. Piscicchia, A. Scordo , I. Tukanovic, H. Zmeskal ..)



KLOE Experiment

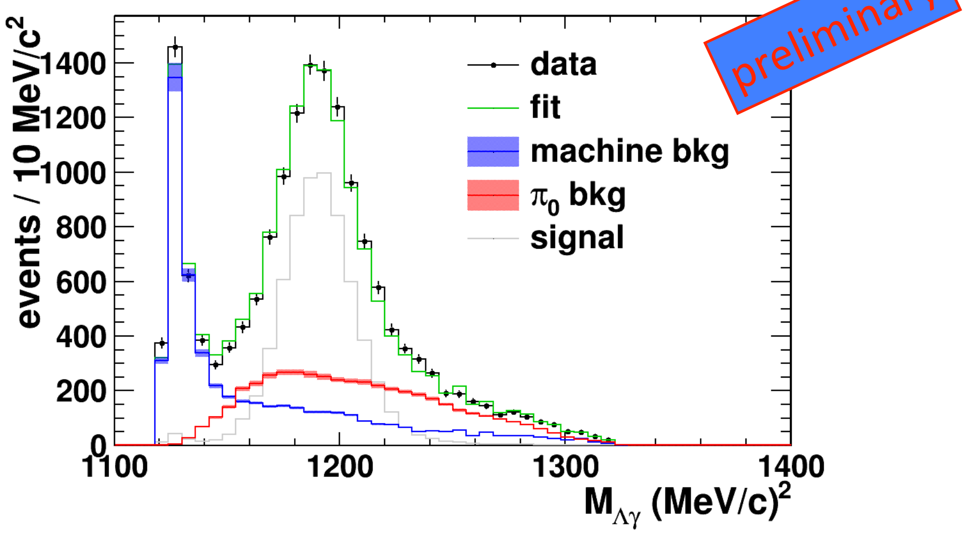


- K^- Momentum = 127 MeV/c
- σ_p/p ~ 0.4 MeV/c
- 96% geometrical acceptance
- Calorimeter for γs: σ_m ~ 18 MeV/c^2
- Vertex resolution: 1 mm
- Gas: 90% He, 10% C_4H_{10}

K^- + C Reactions at Daφne

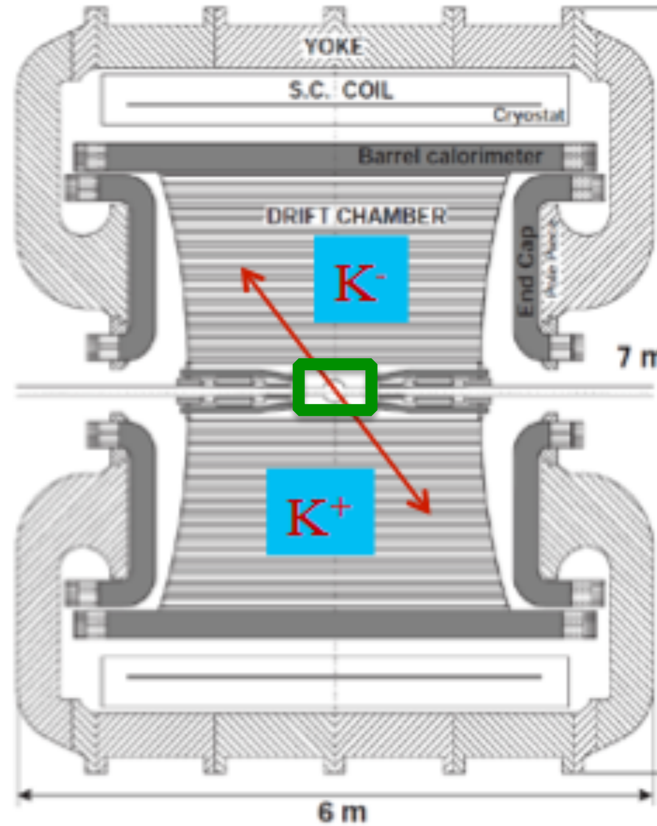
- K^- Momentum = 127 MeV/c
- σ_p/p ~ 0.4 MeV/c
- 96% geometrical acceptance
- Calorimeter for γs: σ_m ~ 18 MeV/c^2
- Vertex resolution: 1 mm
- Gas: 90% He, 10% C_4H_{10}

$$K^- + C \to \Sigma^0 + p + X$$



Clear Σ^0 signal and sound estimation of the background

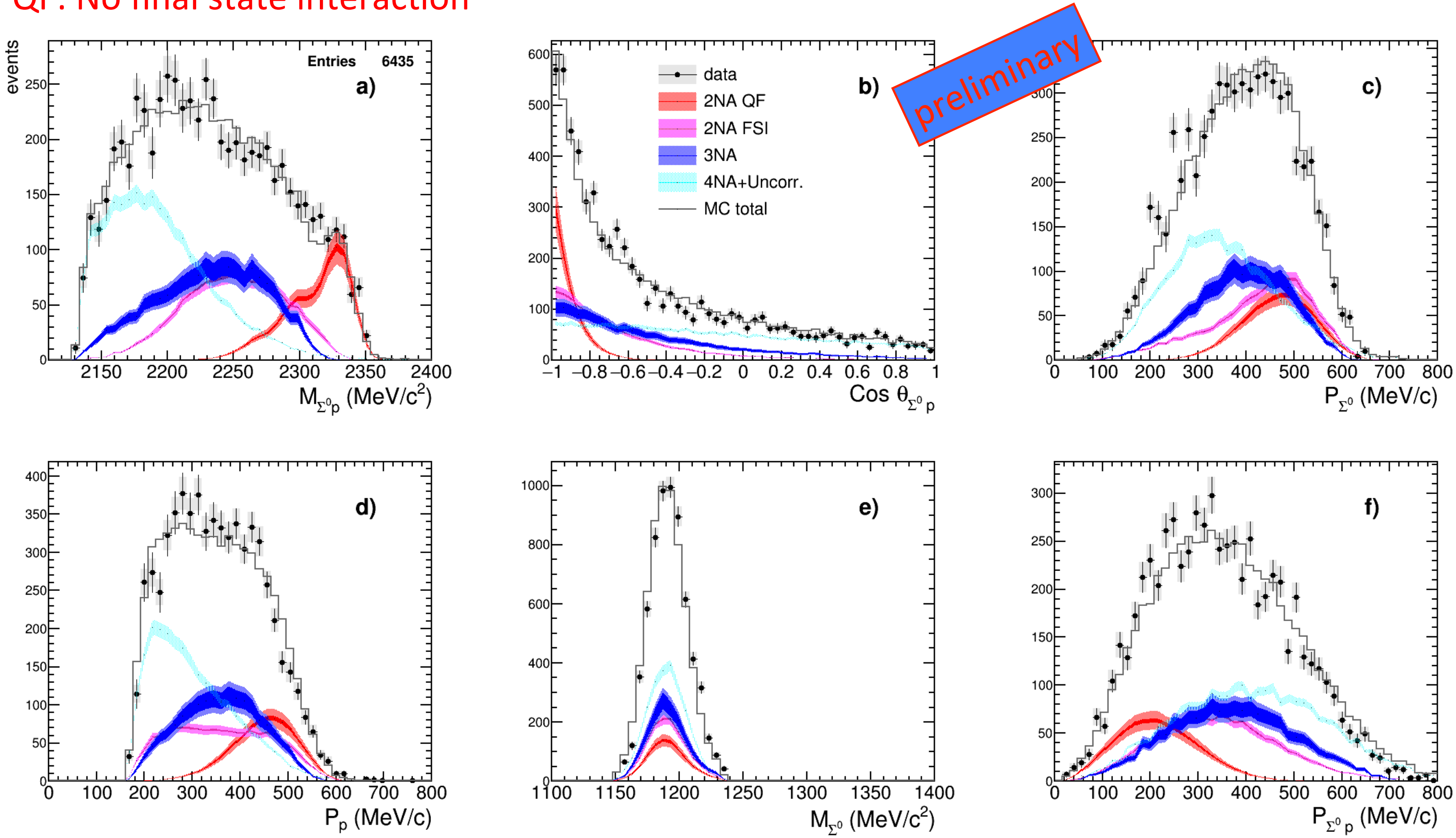
KLOE Experiment



Fit results

2NA= K- absorption on 2 nucleons

QF: No final state interaction



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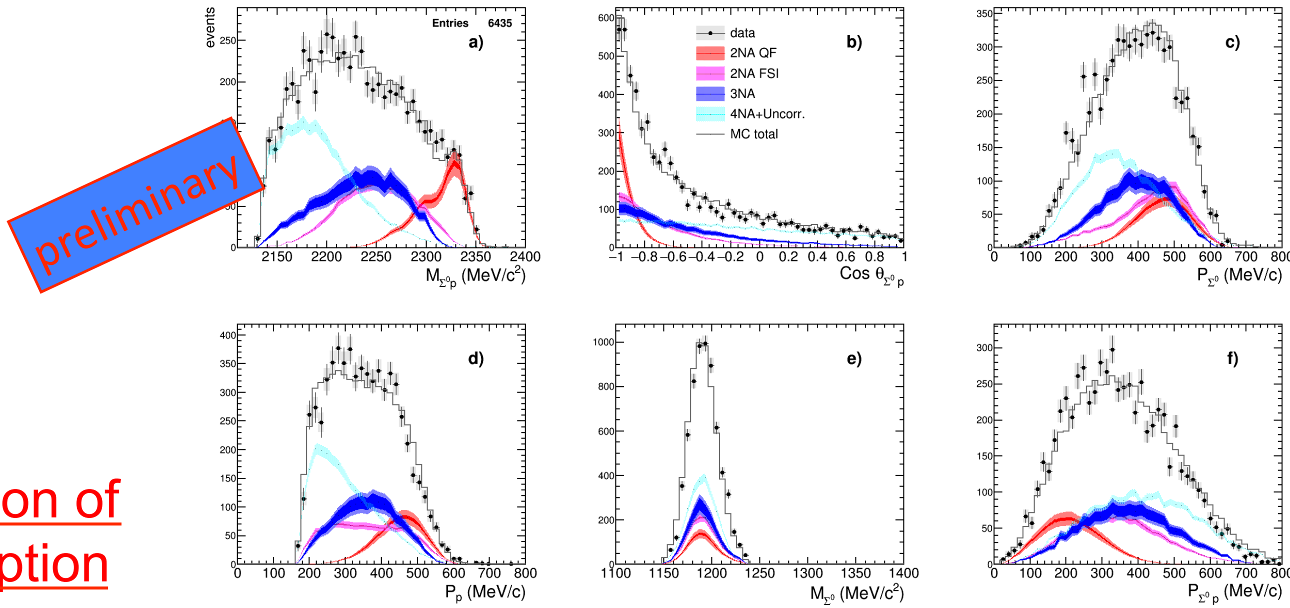


Dominant Contribution of Multi-nucleon absorption

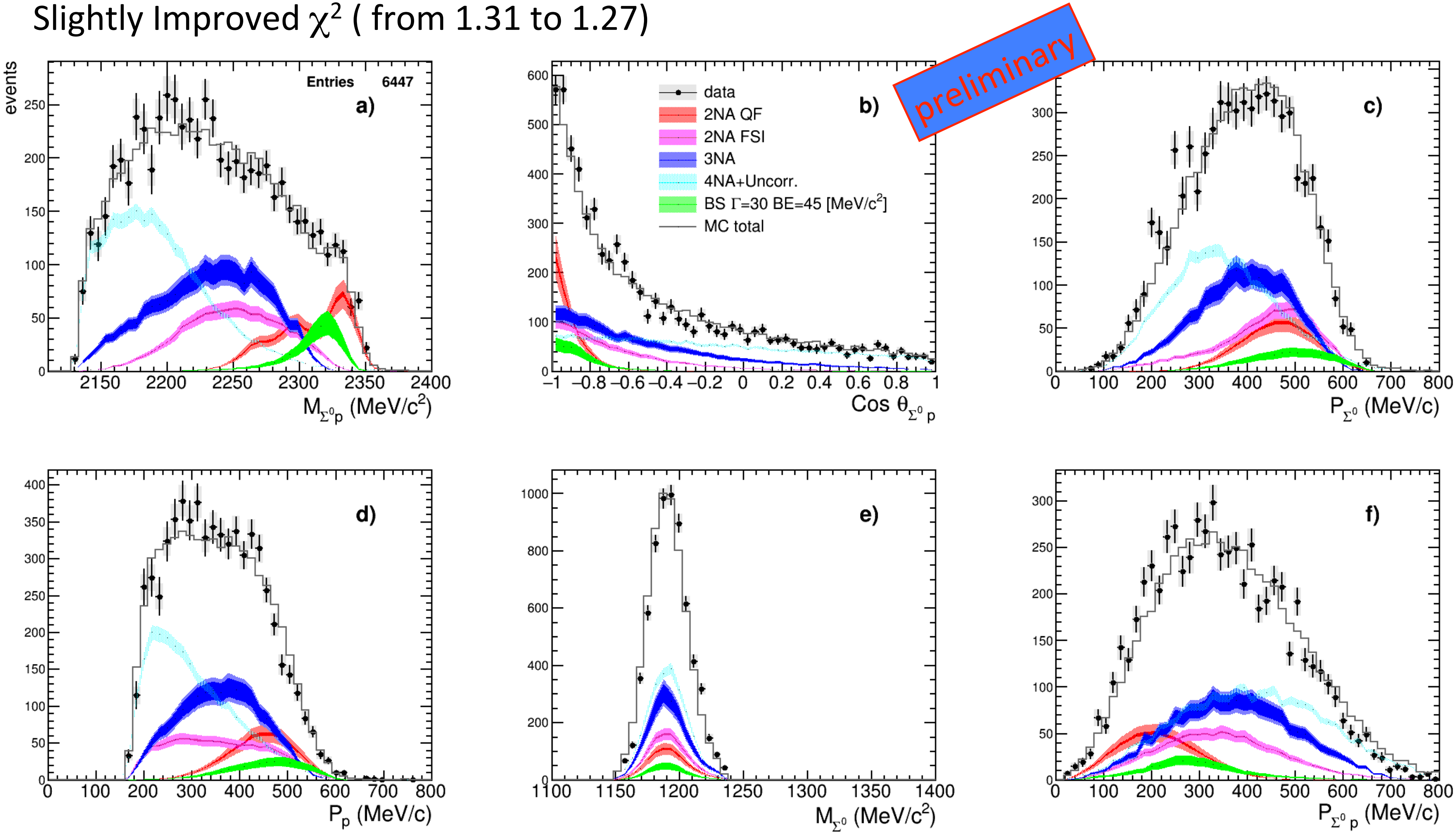
	yield / $K^-_{stop} \cdot 10^{-2}$	$\sigma_{stat} \cdot 10^{-2}$	$\sigma_{syst} \cdot 10^{-2}$
2NA-QF	0.075	± 0.012	+0.0025 -0.0031
2NA-FSI	0.16	± 0.014	+0.0028 -0.0032
Tot 2NA	0.23	± 0.019	+0.013 -0.004
3NA	0.19	± 0.041	+0.015 -0.025
Tot 3body	0.35	± 0.043	+0.011 -0.012
4NA + Uncorr. bkg.	0.43	± 0.021	+0.021 -0.024

Inclusion of the kaonic bound state

Scan of several Width and Binding energy for the intermediate state:

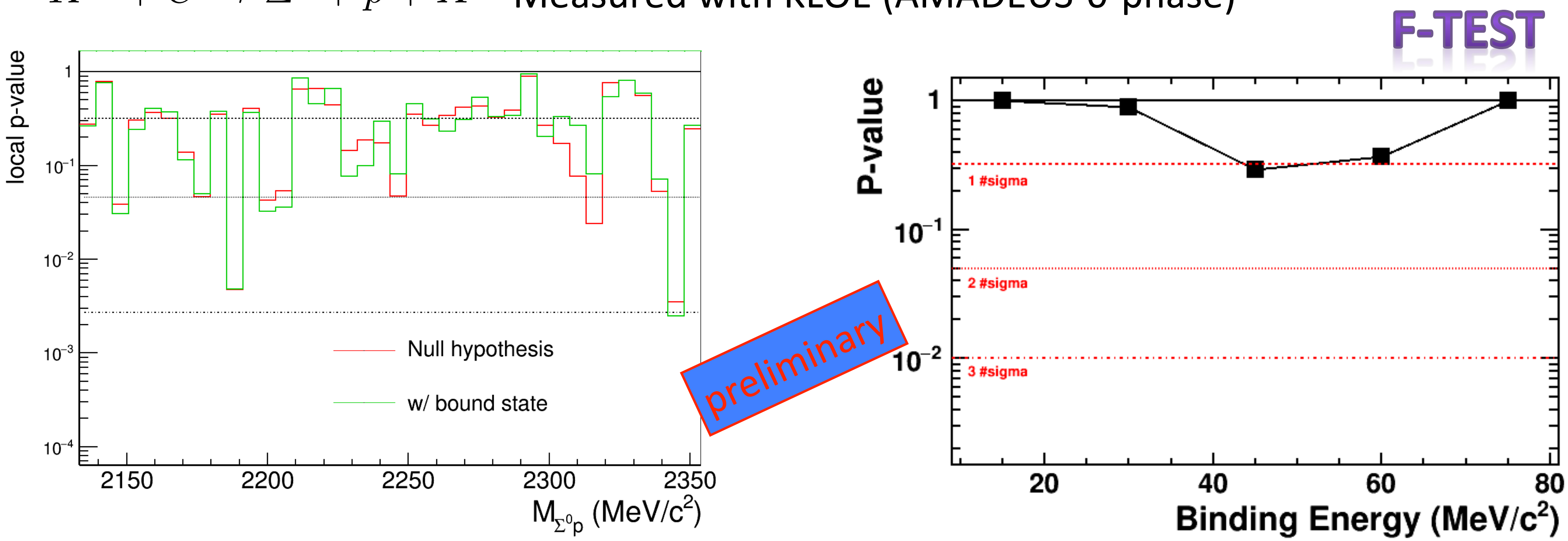
$$K^- + C \rightarrow ppK^-(\rightarrow \Sigma^0 + p) + X$$

Slightly Improved χ^2 (from 1.31 to 1.27)



Pvalues and F-Test

$K^- + C \rightarrow \Sigma^0 + p + X$ Measured with KLOE (AMADEUS-0-phase)



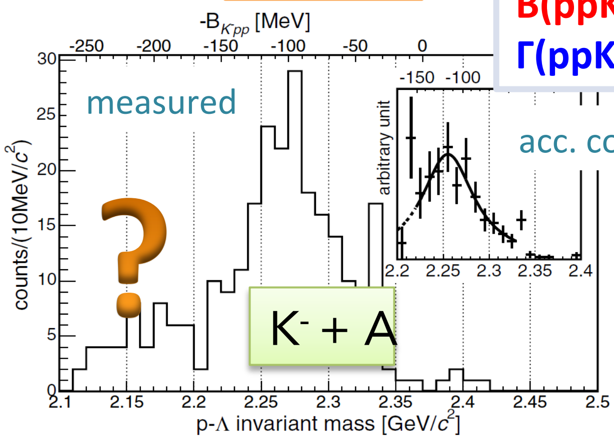
A statistical analysis including a kaonic bound state $ppK^- \rightarrow \Sigma^0 + p$ delivers a better χ^2 (for Γ= 30 MeV/c² and BE= 45 MeV/c²) but the local pValues is o nly slightly different than the one obtained fitting the data without the kaonic boun d state.

Yield (ppK⁻) / K⁻ stop = $0.027 \pm 0.013 stat + 0.008 - 0.04 syst \cdot 10^{-2}$

Conclusions

FINUDA

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



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

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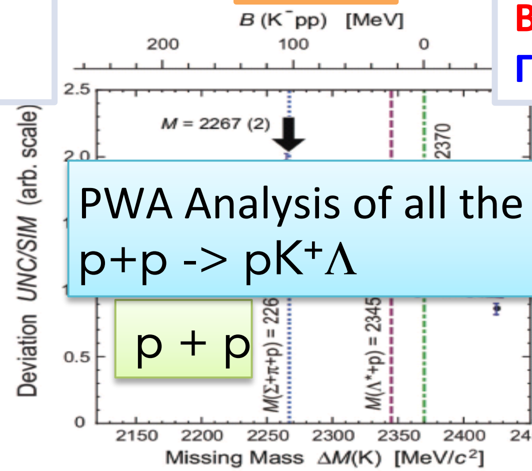
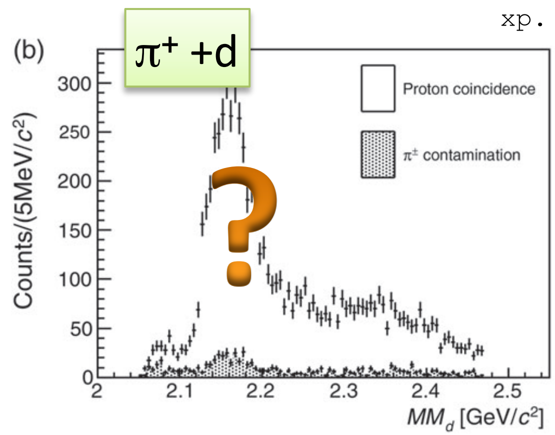


PWA Analysis of all the available
p+p -> pK$^+$Λ

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

J-PARC E27

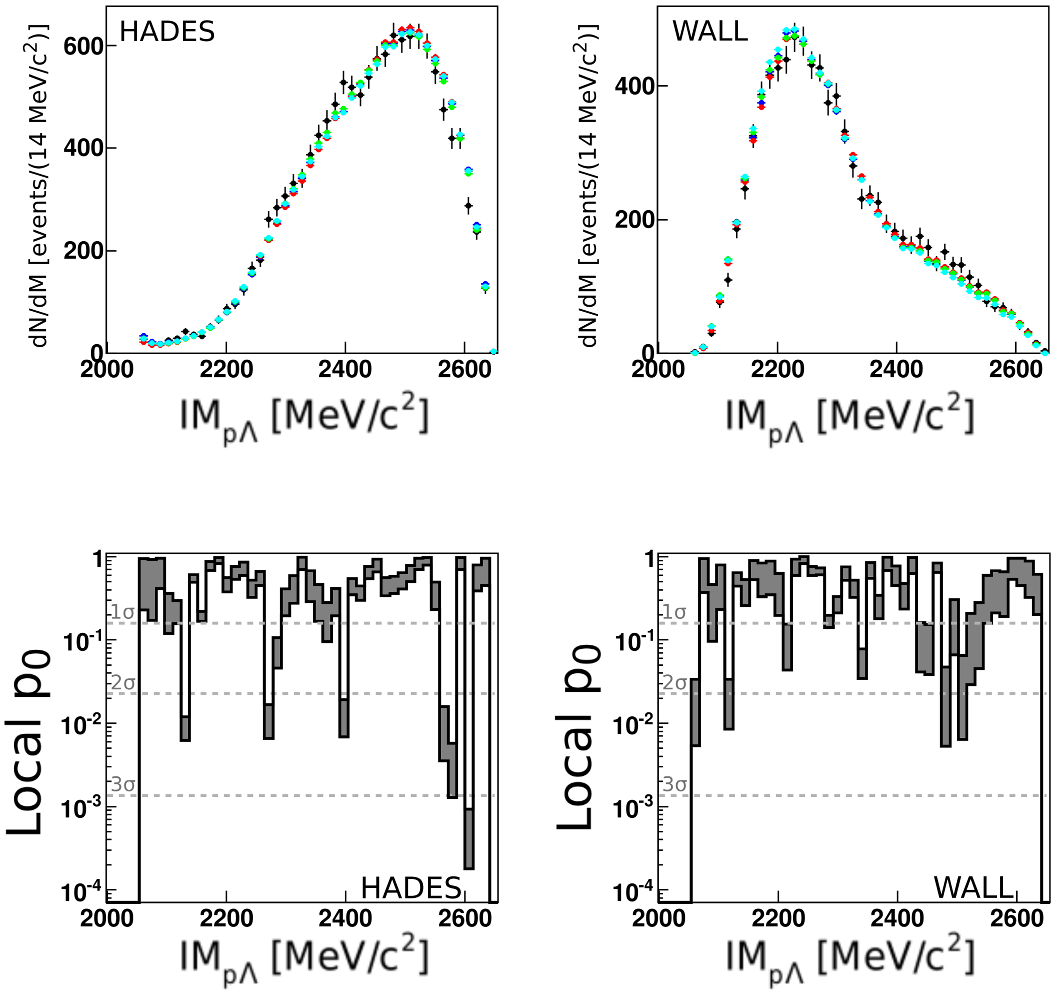
Y. Ichikawa et al. Prog. Theor. Exp. Phys. 2015, 021DOI



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

But...
Kaonic clustes might very well exist
We need hermetic detector and modern analysis techniques

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