Study of Kaonic Nuclear States with DISTO and Belle Data

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5.6.2017 Jaggiellonian Symposium

Overview

- Introduction: kaonic nuclear states
  - a short history
  - recent developments
- How to proceed?
  - DISTO
  - Belle

Kaonic Nuclear States

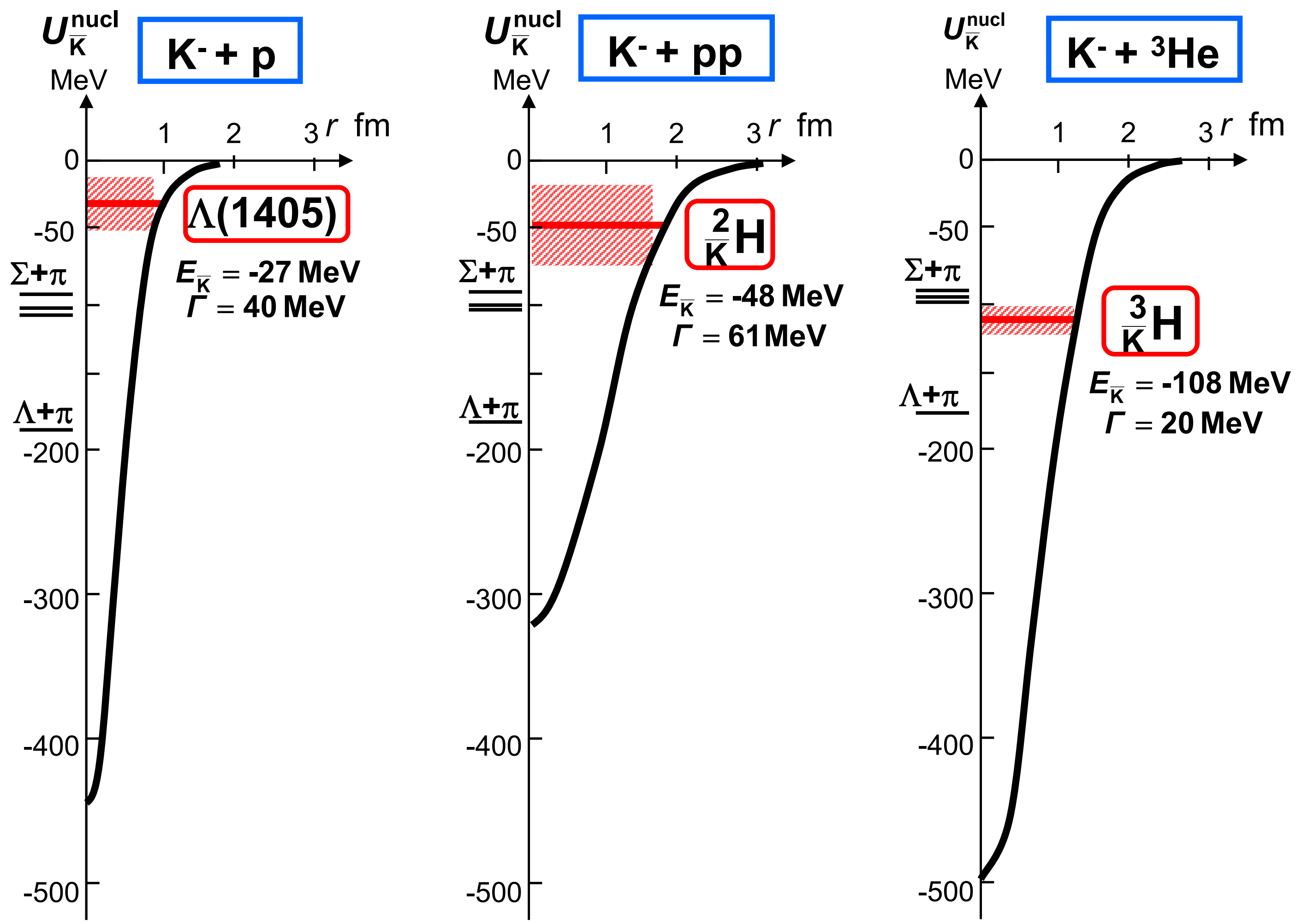
-a short history

-recent developments

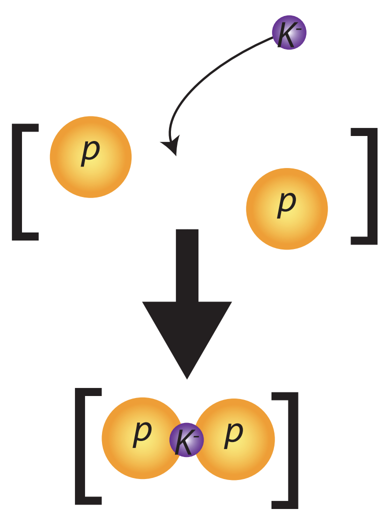
Kaon in nuclei

Strong attraction (I=0)

Kaon forms bound states with nuclei



Kaon as a glue

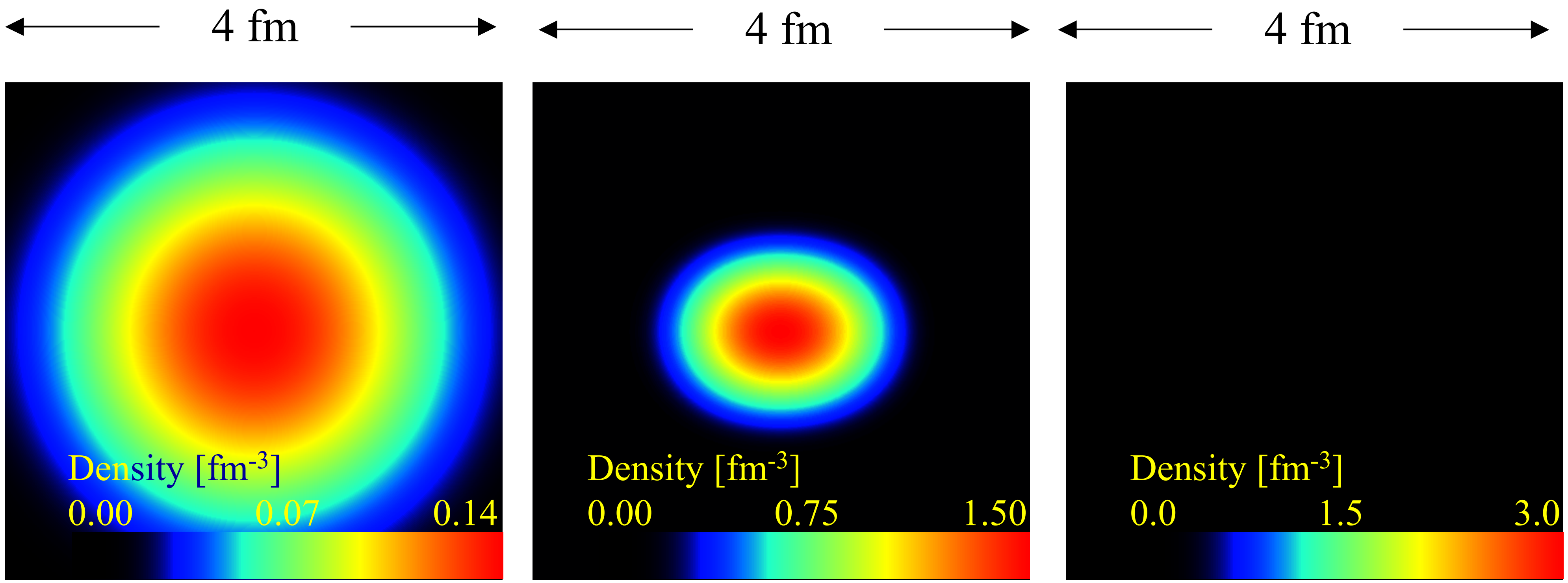


1. *Kaonic Hydrogen*
2. *K-scattering*
3. *Λ*(1405)*

- K⁻pp, K⁻ppn, K⁻ppp, …
- Exoticness / Cold compression / Λ(1405) problem
- K^{bar}N interaction extrapolated to far below the threshold

Y. Akaishi and T. Yamazaki PRC 65 (2002) 044005

Kaon(s) in nuclei



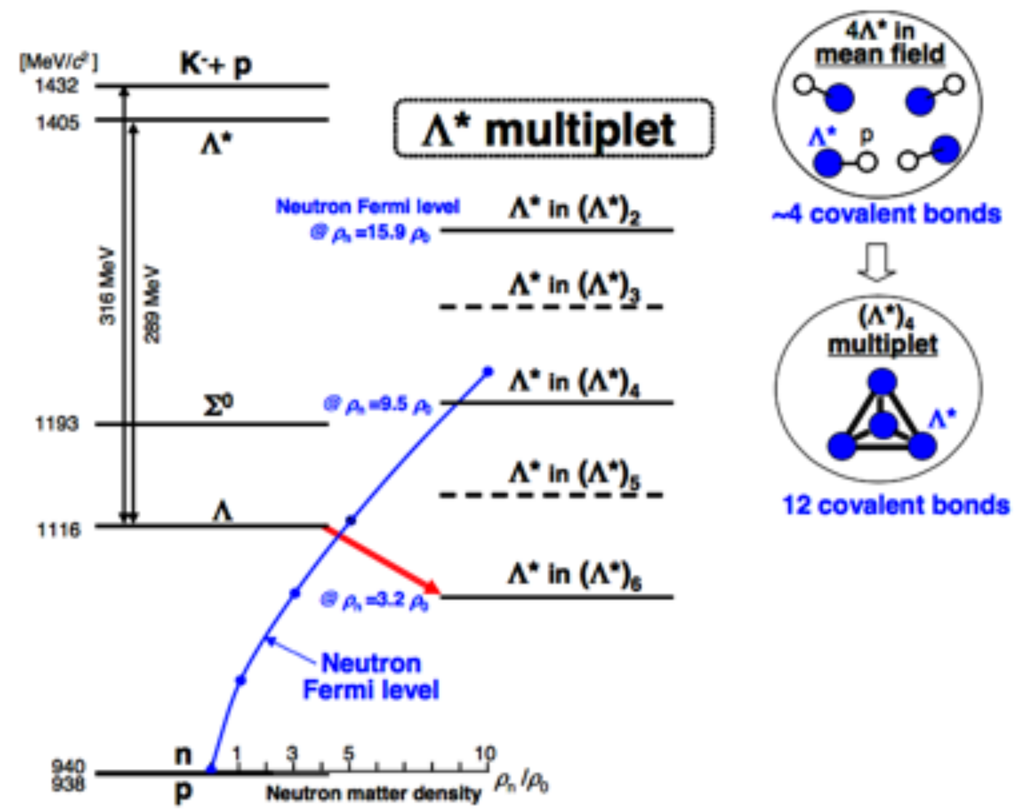
ppn	$ppnK^-$	$ppnK^-K^-$
total B.E. = 6.0 MeV	total B.E. = 118 MeV	total B.E. = 221 MeV
rms Radii = 1.59 fm	rms radii = 0.72 fm	rms radii = 0.69 fm

A. Doté et al., PLB490 (2004) 51

Cold Compression??

Multiple Kaonic System

Binding energy keeps to increase?



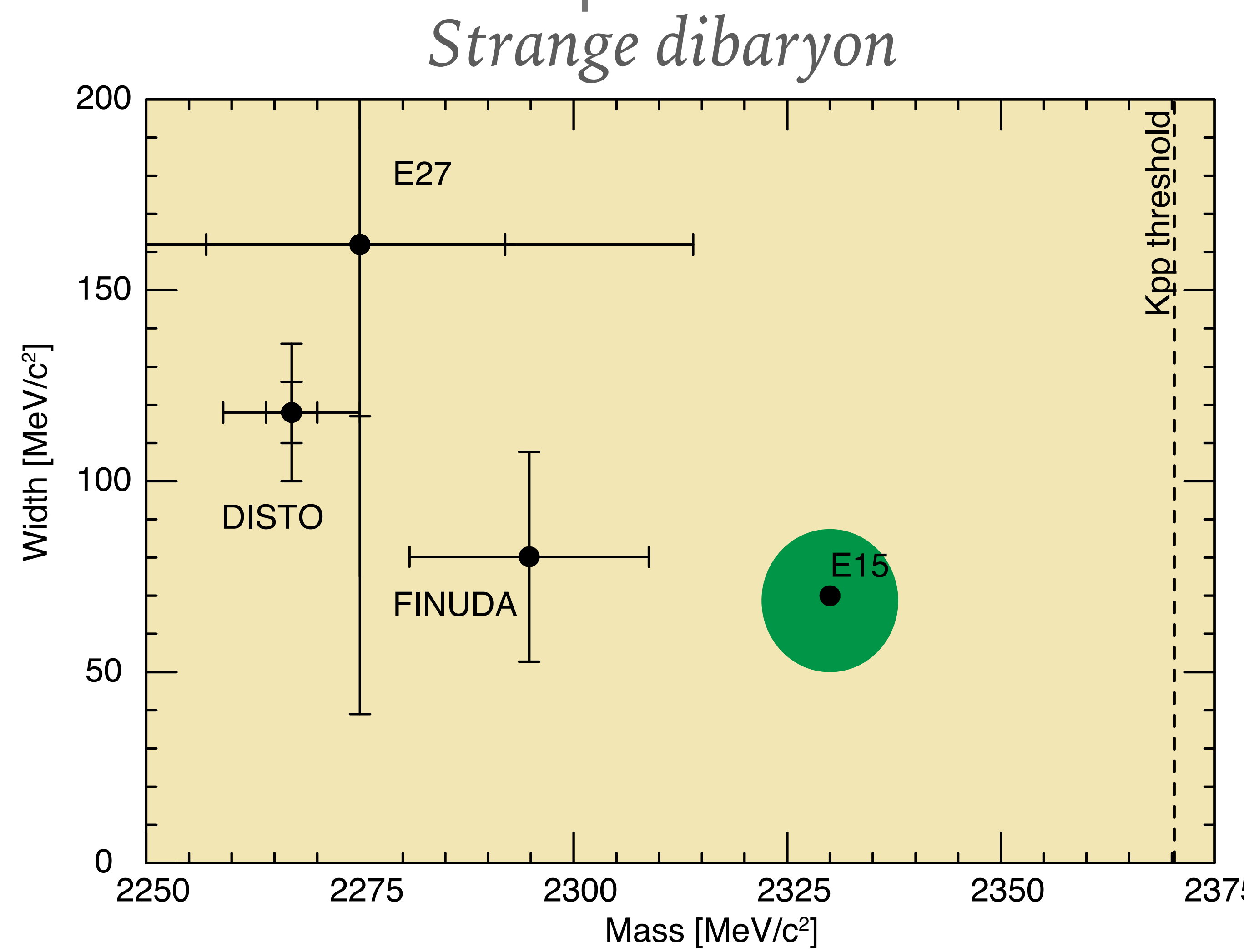
Above ~6-multiplet, a mass per $K^{-}p$ pair (Λ^{*}) becomes smaller than the mass of nucleon?

Became stable, stable co-existence of matter and antimatter??

Y. Akaishi and T. Yamazaki, 2017

Symposium on Kaonic Nuclei @JPS Meeting Mar2017

- Preliminary result of the E15@J-PARC experiment was presented.
    - BE=~2330 MeV/c^2
    - Γ=~70 MeV/c^2



DISTO: T. Yamazaki, M. Maggiora, P. Kienle, K. Suzuki, et al. “Indication of a Deeply Bound and Compact K-pp State Formed in the pp→pΛK+ Reaction at 2.85 GeV. *Physical Review Letters*, *104*, 132502.

FINUDA: A. Filippi “The FINUDA Experiment, Recent Result” EXA2014.

E27: Y. Ichikawa, T, Nagae, H. Fujioka, et al. Observation of the “K- pp-”like structure in the d(+, K+) reaction at 1.69 GeV/c. *PTEP 2015 21D01.*

E15: T. Yamaga “Forefront of experimental study of the Kpp cluster”, A symposium on kaonic nuclear clusters and high density matter, JPS meeting March 2017, Osaka

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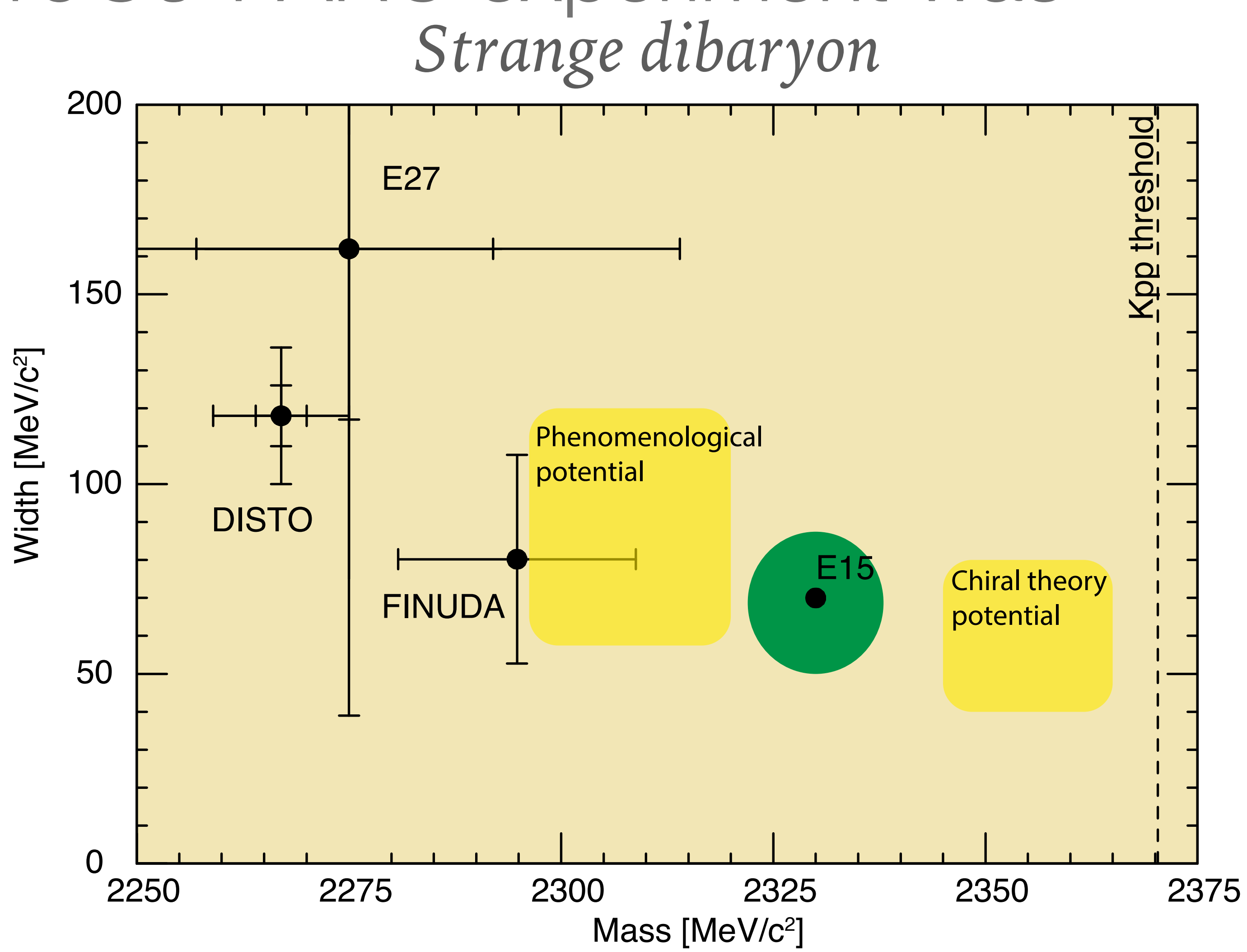

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Symposium on Kaonic Nuclei @JPS Meeting Mar2017

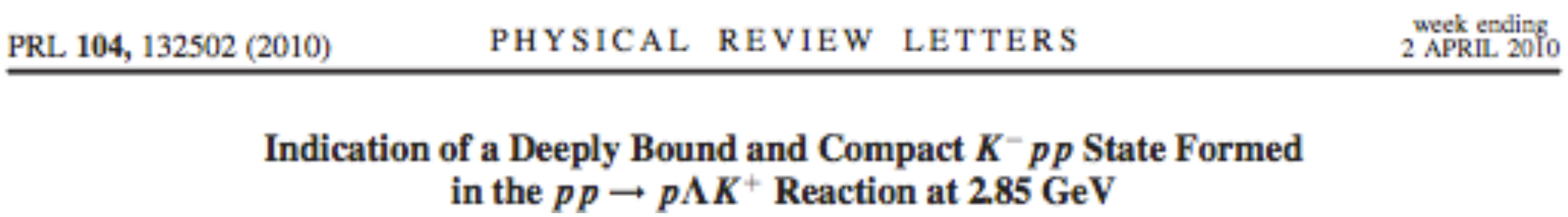
- Summary talk
  - “probably we can say, we have now **a** $K^{-}pp$”
  - what’s next?
    - study more about the nature of observed resonance?
    - look for siblings?

DISTO Data Analysis

Ken Suzuki[1], Toshimitsu Yamazaki[2], Marco Maggiora[3], Paul Kienle[1,4†] for the DISTO collaboration

[1]Stefan-Meyer-Institut für subatomare Physik, Österreichische Akademie der Wissenschaften, [2]Nishina center, RIKEN, [3]INFN-Torino, [4]Technische Universität München

Introduction: X(2265) in the DISTO data

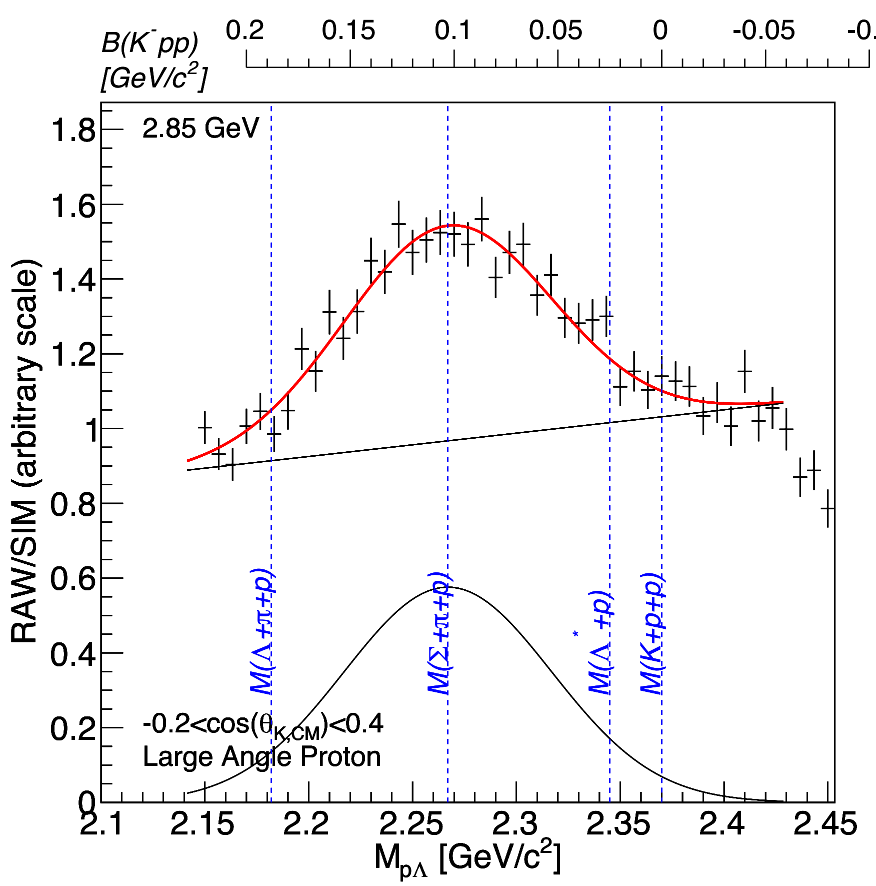

PRL 104, 132502 (2010) PHYSICAL REVIEW LETTERS week ending 2 APRIL 2010

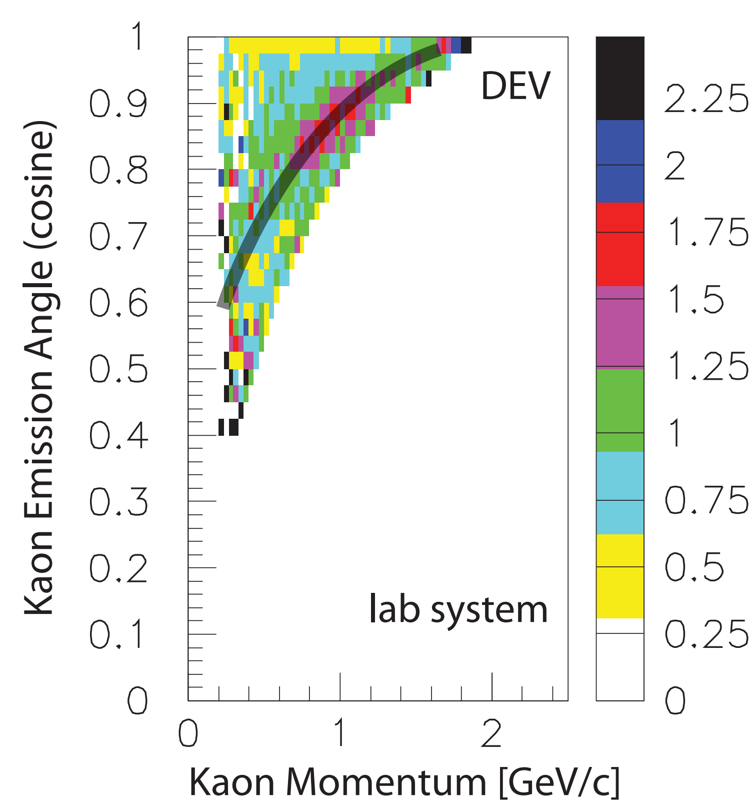
Indication of a Deeply Bound and Compact $K^- pp$ State Formed in the $pp \to p\Lambda K^+$ Reaction at 2.85 GeV

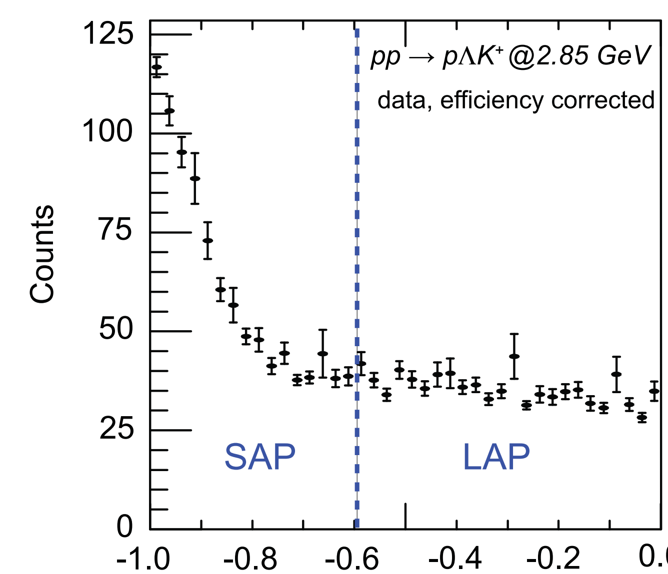
High momentum transfer: Large angle proton cut $\equiv |cos\vartheta_{CM,p}|<0.6$

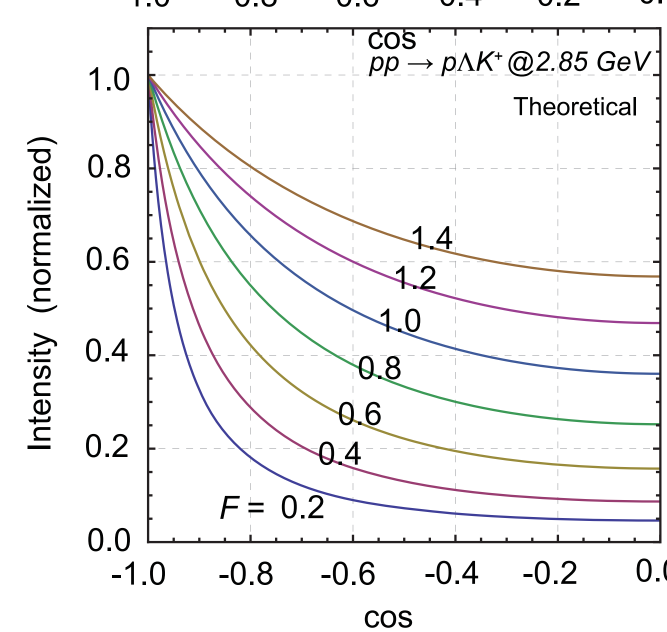
high quality, high statistics (~120k), high purity data sample of exclusive $pp \to p\Lambda K+$ final state (~98%)

$pp \to XK^+$: X(2265)









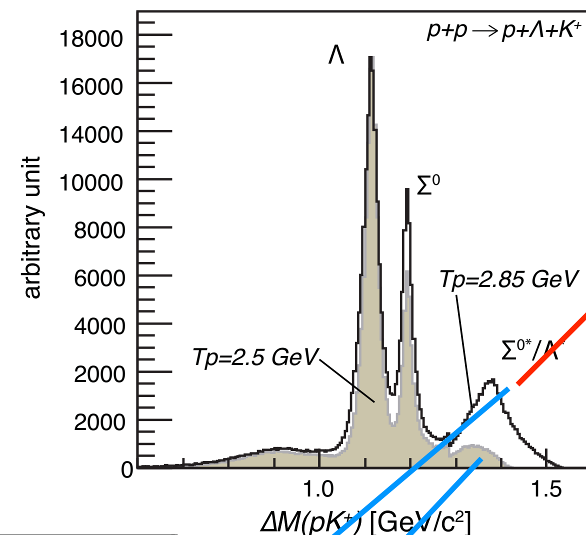
Mx=2267 MeV/c² Γx=118 MeV

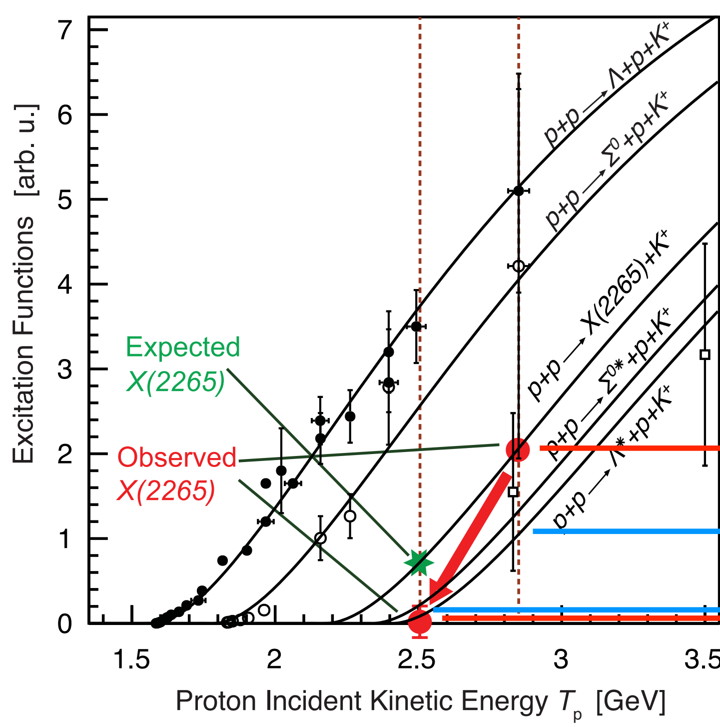
X(2265) energy

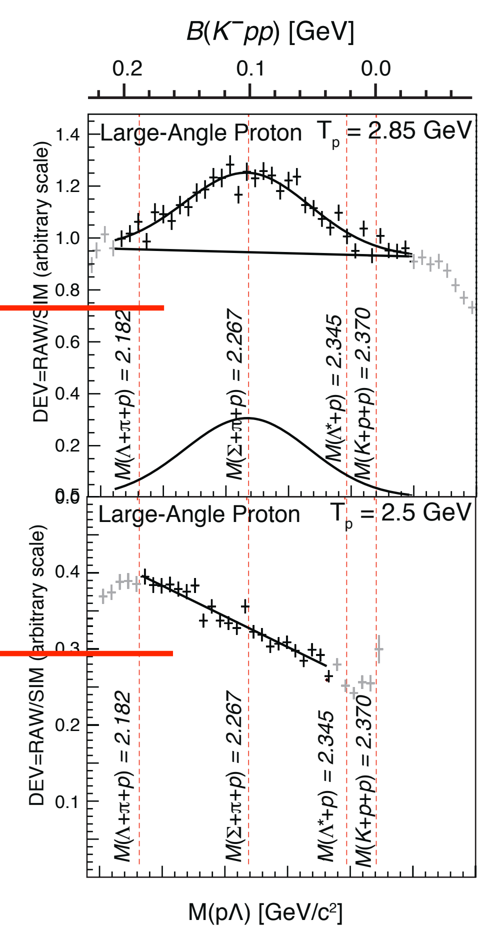
almost no Y* at T_p=2.5 GeV

elementary process

$p+p \rightarrow p+\Lambda^{*}+K^{+}$







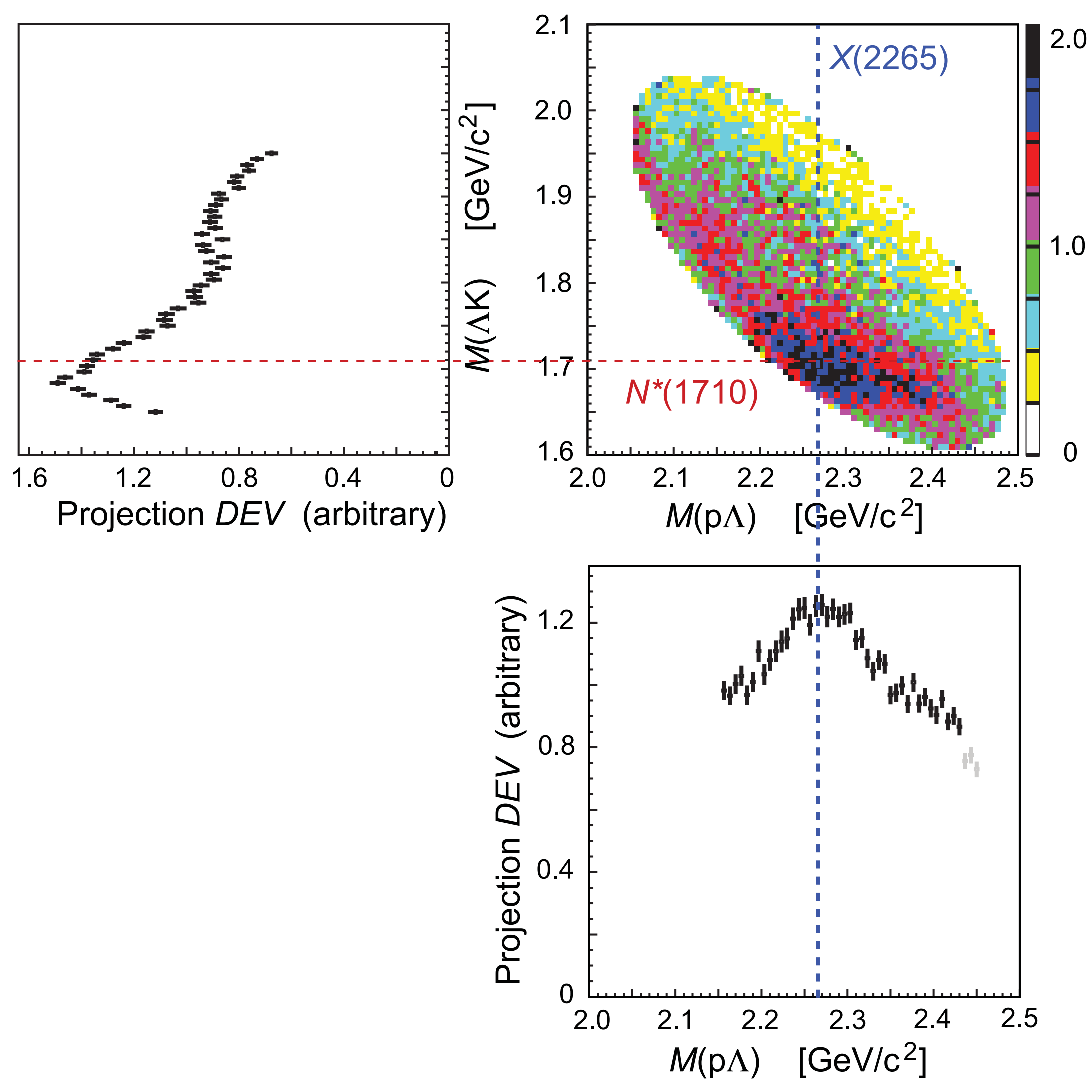
P. Kienle *et al.*, EPJ A48 (2012) 183

Λ^{*}(1405) involved in the X(2265) production mechanism

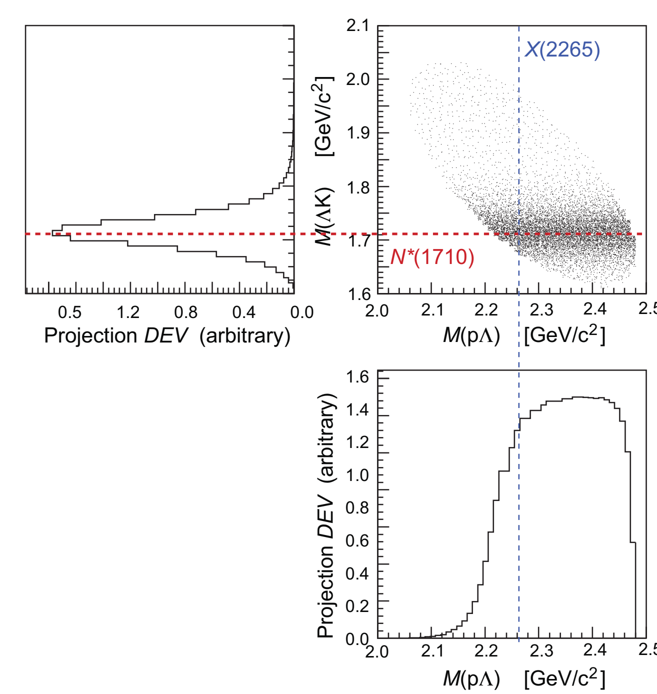
X(2265) in a Dalitz plot

Large Angle Proton cut

$\rightarrow p+(K^{+}+\Lambda=N^{*})\rightarrow p+K^{+}+\Lambda$



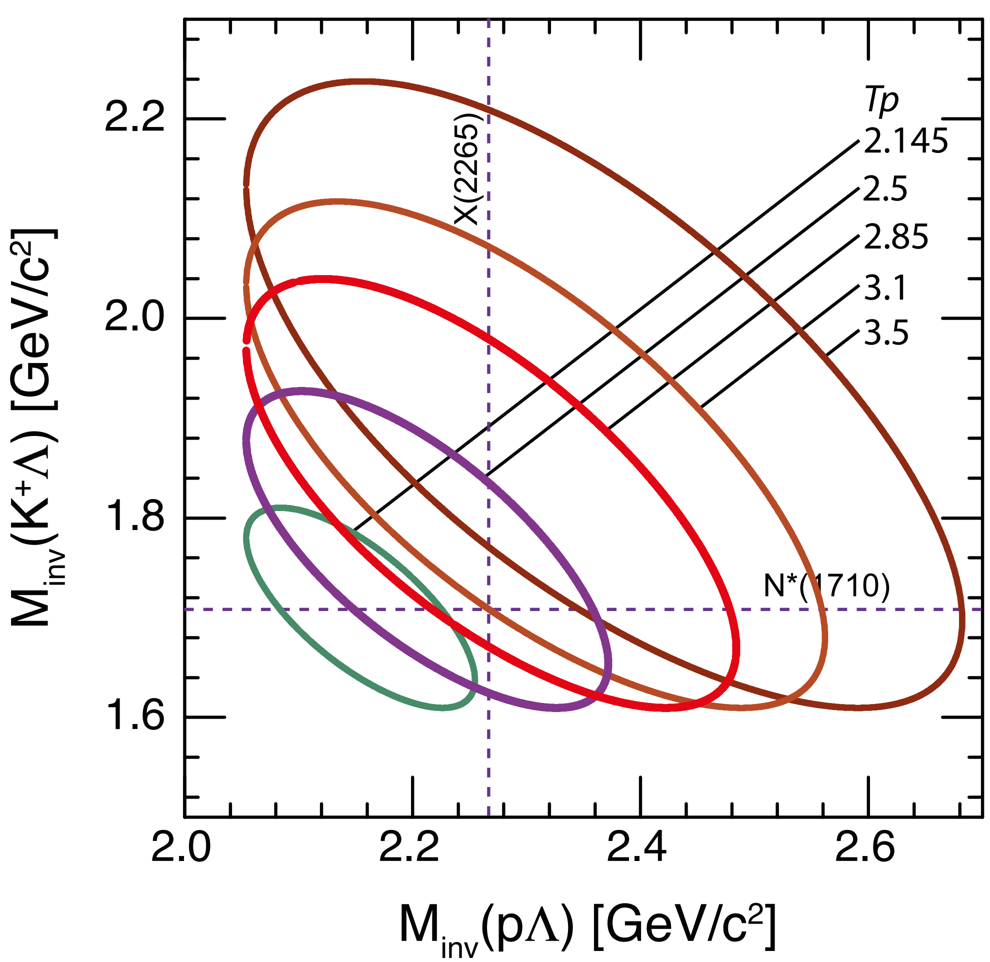
$\rightarrow K^{+}+X\rightarrow K^{+}+p+\Lambda$

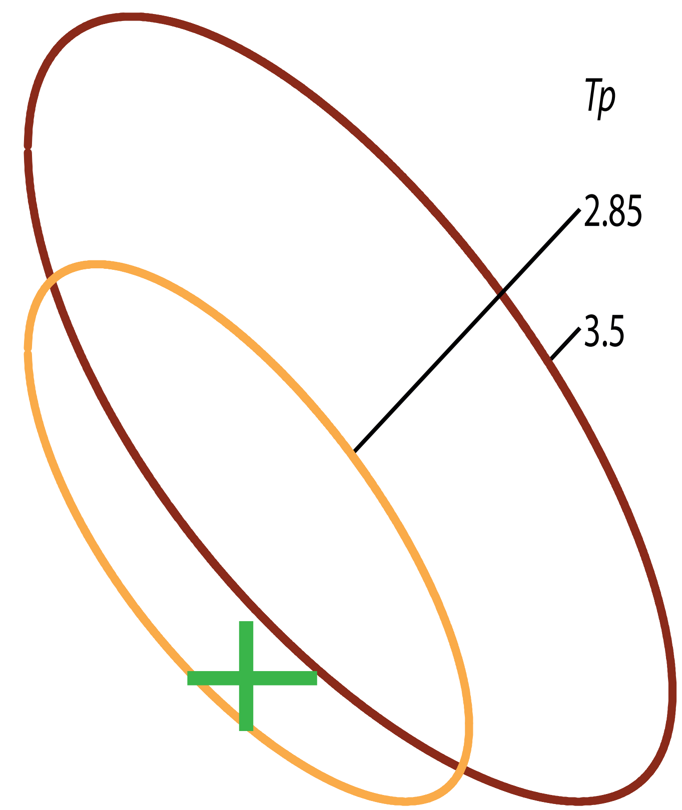


simple MC of N*(1710) and projections

Population of the X(2265) is localised at the crossing point of two resonance band, X(2265) and N*(1710) ⇒ **Double Resonance**

Another consequence of the Double Resonance: Comment on the HADES Data at Tp=3.5 GeV



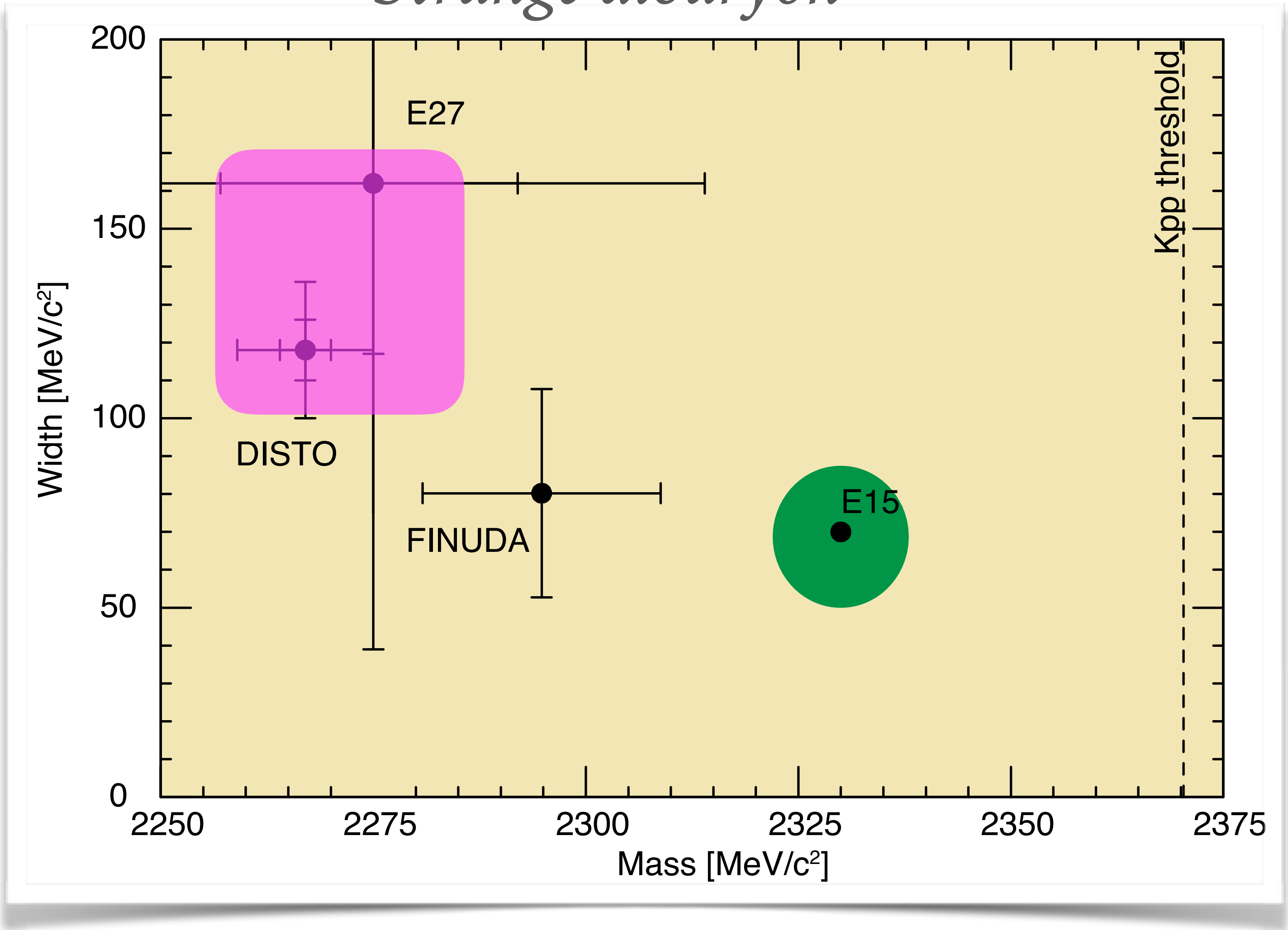


Double resonance feature of the X(2265) population set an upper limit on Tp to be ~ 3.1 GeV.
At Tp=3.5 GeV the X(2265) population zone is outside the kinematically allowed area.

Next Step?

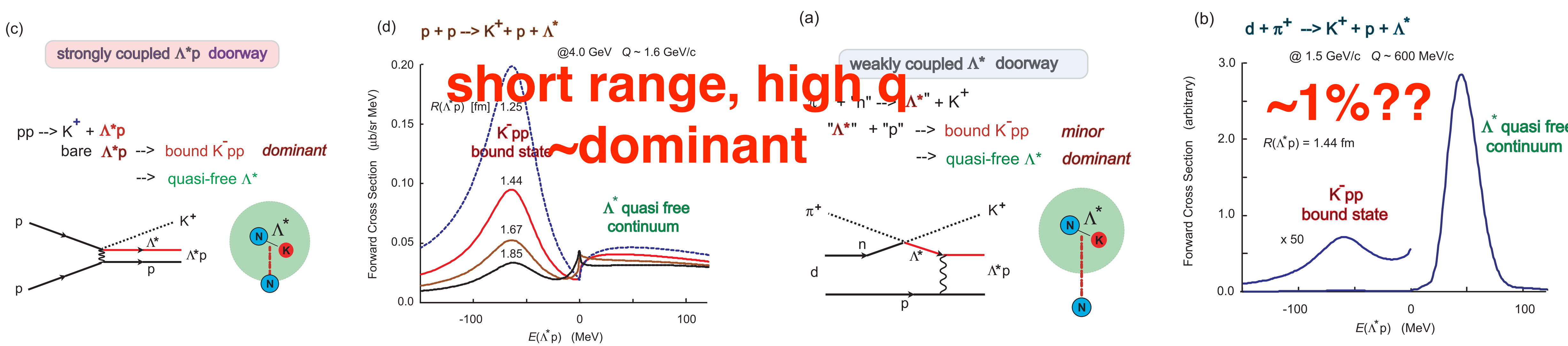
DISTO & E27

Strange dibaryon



K^-pp production mechanism
$\Lambda(1405)p \rightarrow K^-pp$

<u>p+p, unconventional</u> | <u>(π, K), conventional</u>



T. Yamazaki and Y. Akaishi, PRC76 (2007) 045201.

<u>“hard collision/formation mechanism”</u>

DISTO

T. Yamazaki *et al.*, PRL 104 (2010) 132502

Mass 2.267±3(stat.)±5(syst.) GeV/c^2

width 118±8(stat.)±10(syst.) MeV

E27@J-PARC

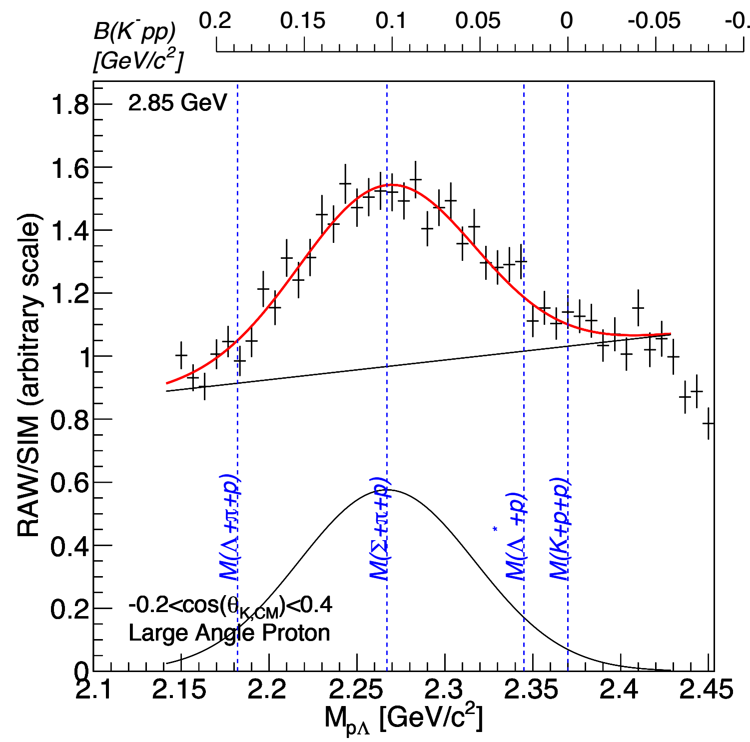
Y. Ichikawa *et al.*, PTEP 2015 021D01

Mass 2.27^{+18}_{-17}(stat.)$^{+30}_{-21}$ (syst.) GeV/c^2

width 162^{+87}_{-45}(stat.)$^{+66}_{-78}$(syst.) MeV

$K^{-}pp$ production mechanism
$\Lambda(1405)p \rightarrow K^{-}pp$

p+p, unconventional



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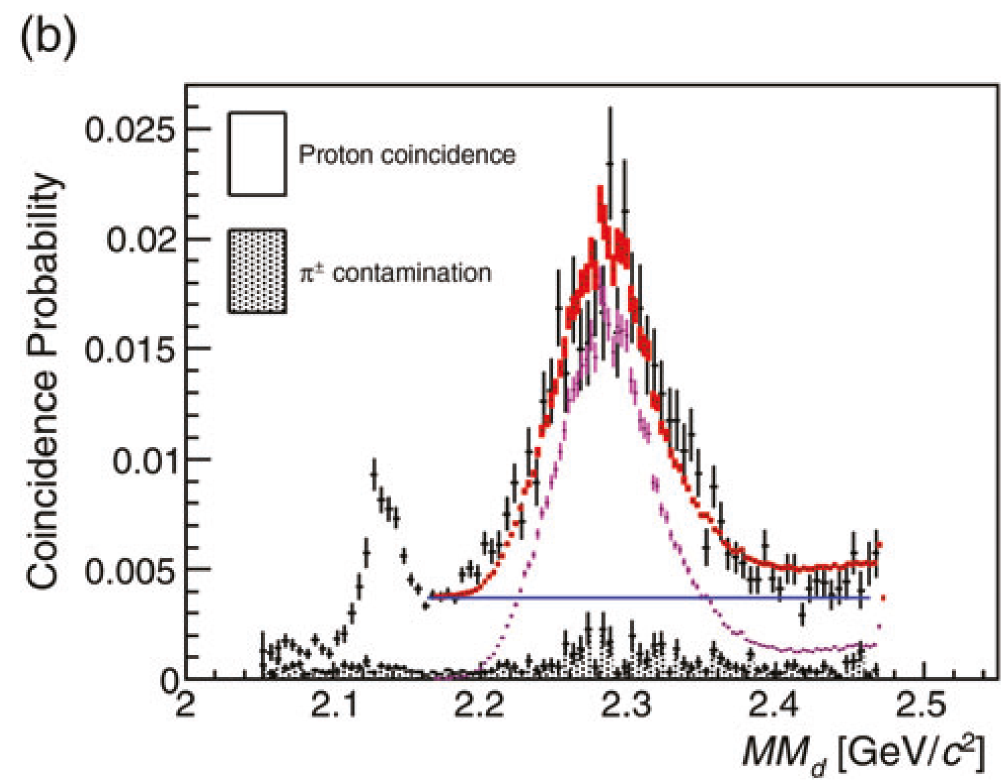

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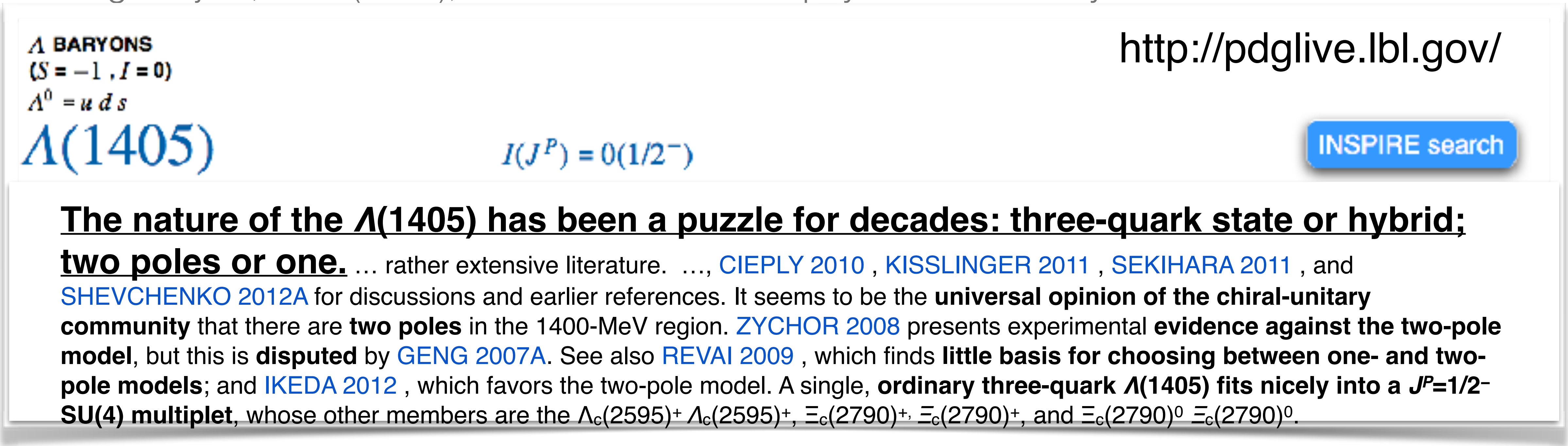
Belle Data Analysis

Ken Suzuki[1], Manfred Berger[1], Christoph Schwanda[2], Felicitas Breibeck[2] ,
K. Miyabayashi[3], T. Nakano[4], Niiyama[5], J. Yelton[6] for the Belle collaboration

[1]Stefan-Meyer-Institut für subatomare Physik, Österreichische Akademie der Wissenschaften, [2]Institut für Hochenergiephysik, Österreichische Akademie der Wissenschaften, [3]Nara-WU, [4]RCNP, [5]Kyoto, [6]Florida

Λ(1405)

- The strange object, the Λ(1405), still attracts/confuses physicists over 50 years



Λ BARYONS
($S = -1$, $I = 0$)
$\Lambda^0 = uds$

Λ(1405) $I(J^P) = 0(1/2^-)$

http://pdglive.lbl.gov/

INSPIRE search

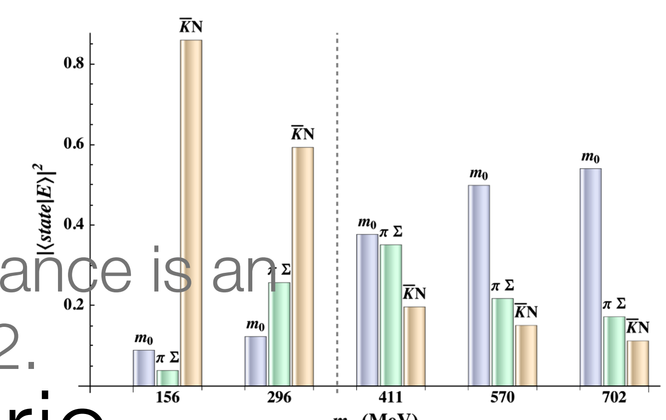
The nature of the Λ(1405) has been a puzzle for decades: three-quark state or hybrid; two poles or one. … rather extensive literature. …, CIEPLY 2010 , KISSLINGER 2011 , SEKIHARA 2011 , and SHEVCHENKO 2012A for discussions and earlier references. It seems to be the **universal opinion of the chiral-unitary community** that there are **two poles** in the 1400-MeV region. ZYCHOR 2008 presents experimental **evidence against the two-pole model**, but this is **disputed** by GENG 2007A. See also REVAI 2009 , which finds **little basis for choosing between one- and two-pole models**; and IKEDA 2012 , which favors the two-pole model. A single, **ordinary three-quark Λ(1405) fits nicely into a J^P=1/2⁻ SU(4) multiplet**, whose other members are the $\Lambda_c(2595)^+$ $\Lambda_c(2595)^+$, $\Xi_c(2790)^+$, $\Xi_c(2790)^+$, and $\Xi_c(2790)^0$ $\Xi_c(2790)^0$.

Λ(1405) really not a 3-quark state?

- Comment by an internal referee
  - "…I always thought that it was very easy to describe in the quark model… Sometimes I have got frustrated with some of the lower energy community who ignore the charm/B data, some of which can be extrapolated down to strange sector very successfully - it seems that there are two communities out there amongst the theorists who don't talk each other very much…"

Λ(1405) really not a 3-quark state?

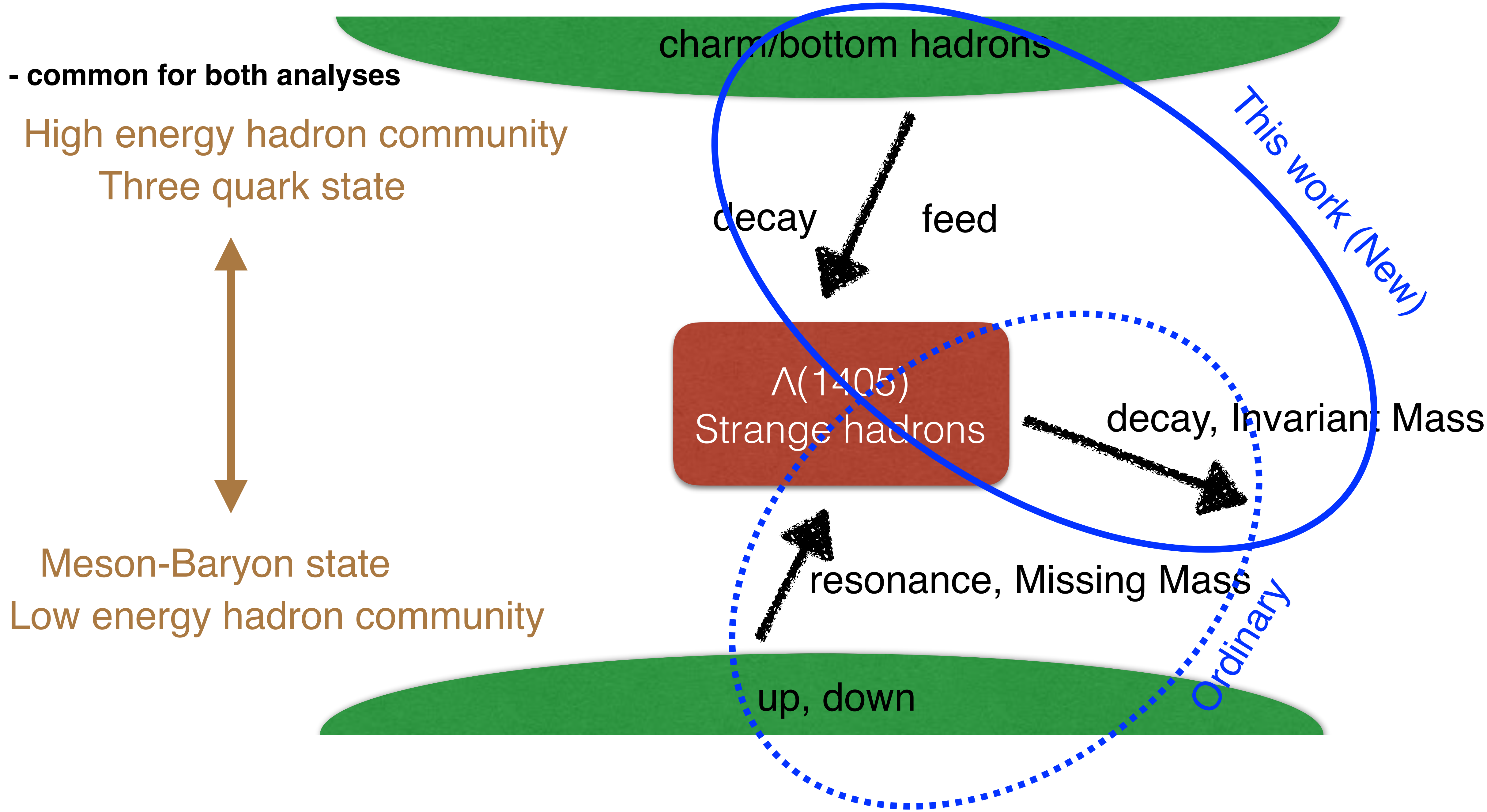
- Meson-Baryon picture is successful in describing experimental data in low energy strangeness sector.
    - T. Hyodo and D. Jido, "*The nature of the Λ(1405) resonance in chiral dynamics*", Progress in particle and nuclear physics 67 (2012) 55-98.
- Σπ photo production line shapes by CLAS.
    - K. Moriya et al., "Measurement of the Σπ photo production line shapes near the Λ(1405)", arXiv:1301.5000v3.
    - R.A. Schumacher and K. Moriya, "Isospin decomposition of the photo produced Σπ system neat the Λ(1405)", arXiv:1303.0860v1.
- Recent lattice calculation
    - J.M.M. Hall et al., "Lattice QCD evidence that the Λ(1405) resonance is an antikaon-nucleon molecule", Phys. Rev. Lett. 114 (2014) 132002.



No, MB is still the more likely scenario.
Bridging two hadron physics communities

Key Method 1 - Weak decay of charmed hadron

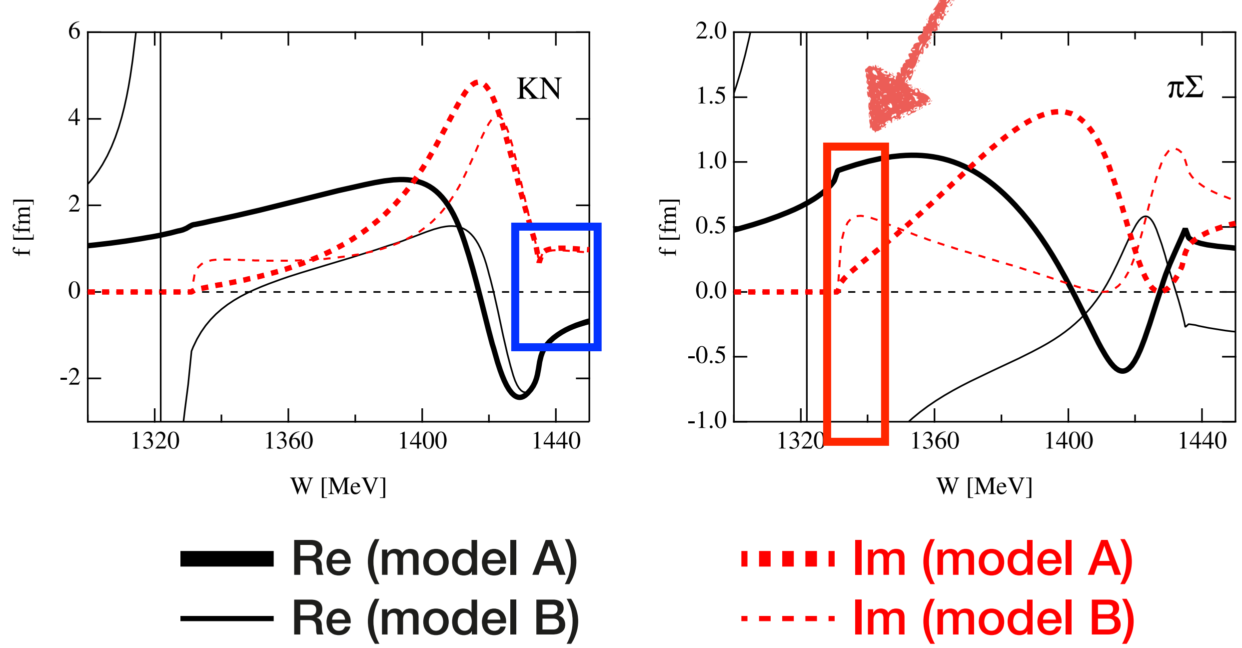
to access the research objects: Λ(1405) and strange hadrons



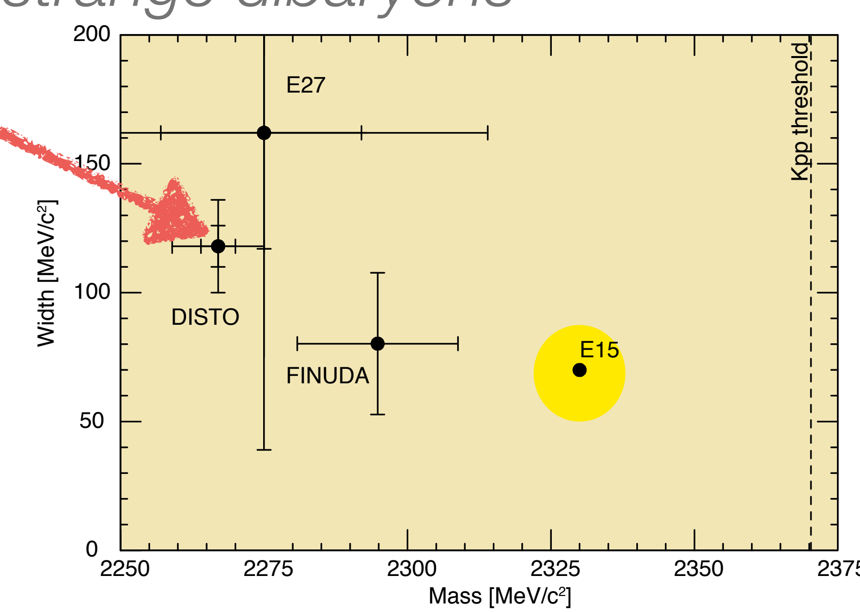
Bringing together light/heavy, strange/charm, low energy/high energy communities

Research Goal

- to understand the nature of the Λ(1405)
  - two-pole or single pole?
    - Σπ scattering length: <u>**first** experimental constraint to the theory</u>
    - $\overline{K}N$ interaction deep or shallow?
      - kaonic nuclear state (another puzzle since a decade)
      - interpretation of <u>X(2265)</u>* as well as other *strange dibaryons*



Y. Ikeda et al., Structure of Λ(1405) and Threshold Behavior of πΣ Scattering. Prog. of Theo. Phys., 125 (2011) 1205.

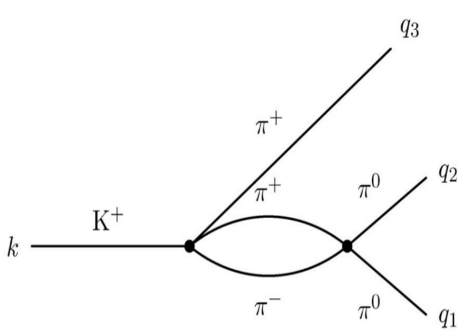


Y. Ichikawa et al., Observation of the "K- pp-"like structure in the d(π+, K+) reaction at 1.69 GeV/c. Prog. of Theo. and Exp. Phys., 2015, 21D01–0.

*T. Yamazaki, M. Maggiora, P. Kienle, K. Suzuki *et al.*, "Indication of a Deeply Bound and Compact K-pp State Formed in the pp→pΛK+ Reaction at 2.85 GeV", Phys. Rev. Lett., 104, (2010) 132502.

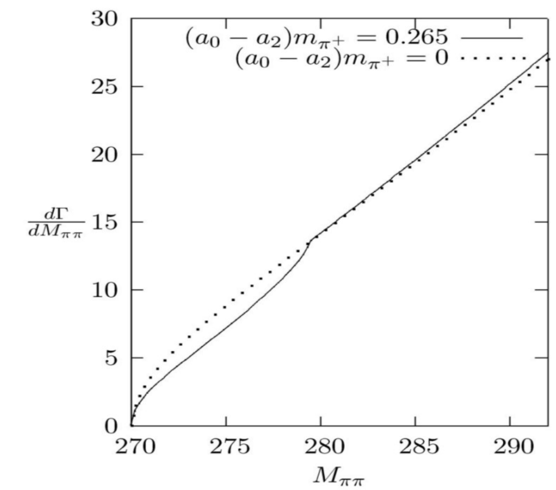
Key Method 2 - Budini-Fonda-Cabibbo method

- Budini-Fonda-Cabibbo method for a determination of scattering length of short-lived particles
  - successfully applied to the $K^{\pm} \rightarrow (\pi\pi\pi)^{\pm}$ system to determine the ππ scattering length by the NA48/2 experiment

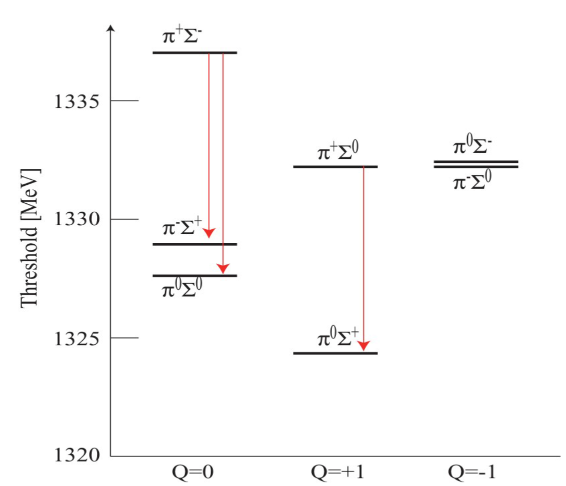


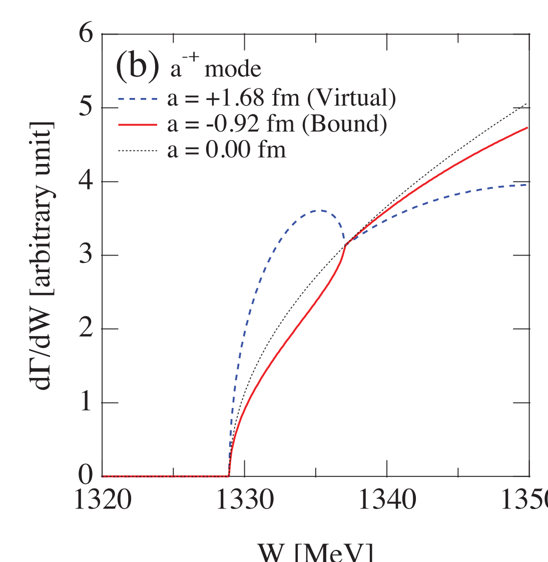
- charge exchange final state interaction
- isospin violation
- interference

→ threshold cusp



- An extension to $\Lambda_c^+ \rightarrow (\Sigma\pi\pi)^+$ system proposed by T. Hy
  - $\Lambda_c^+ \rightarrow \Sigma^+ \pi^- \pi^+$ (3.6±1.0 %)
  - $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0 \pi^0$ (n.A.) ← **byproduct**
  - $\Lambda_c^+ \rightarrow \Sigma^0 \pi^- \pi^0$ (1.8±0.8 %)

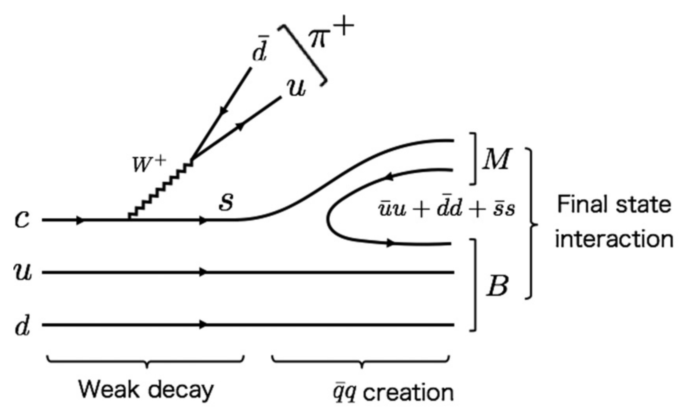




T. Hyodo and M. Oka (2011). Determination of the πΣ scattering lengths from the weak decays of Λc. *Phys. Rev. C84*

Key method 3 - Isospin filtering

- πΣ spectrum contains I=0 and I=1 components
  - source of ambiguity to interpret experimental spectra
- $\Lambda_c^+ \rightarrow \pi MB$ (MB=πΣ, ηΛ, Kp)
  - T=0 isospin filtering effect due to several factors*



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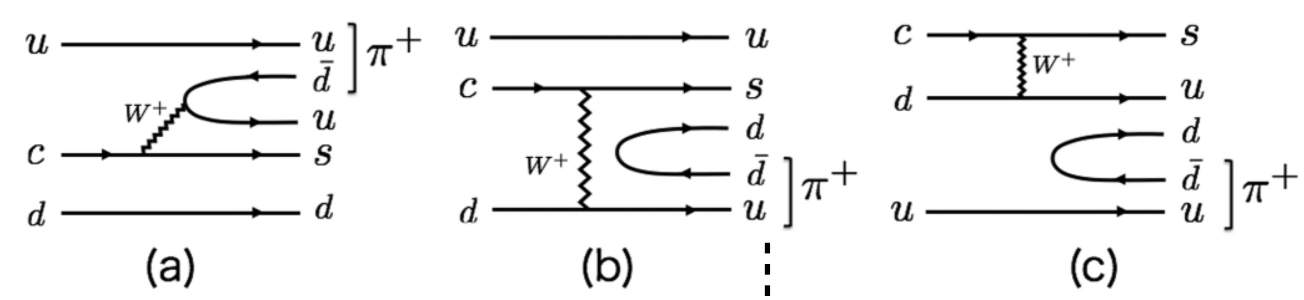
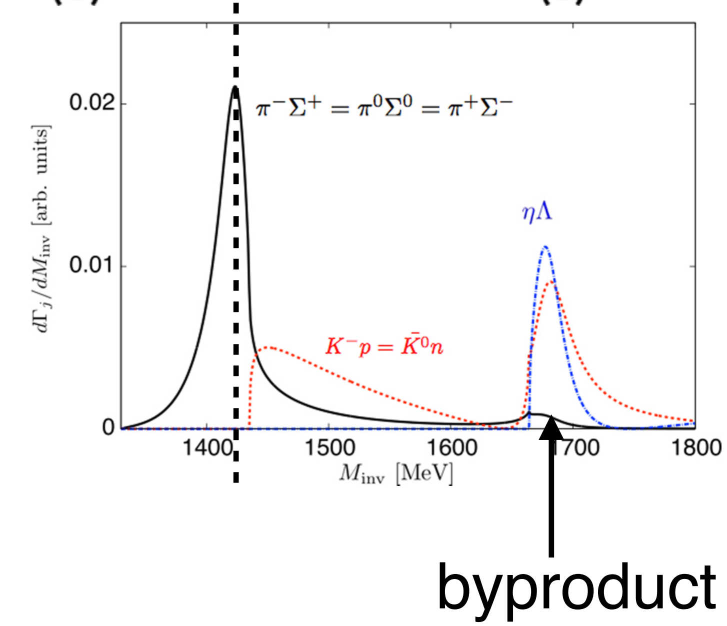




  - CKM matrix $|V_{ud}| \gg |V_{cd}|$
  - colour suppression
  - kinematical condition
- Λ(1405) from $\Lambda_c^+ \rightarrow \pi^+ (\pi\Sigma)^0$ reaction could be a rather pure I=0 state
  - test the two-pole scenario

*K. Miyahara, T. Hyodo & E. Oset, Weak decay of Λc+for the study of Λ(1405)and Λ(1670). Phy. Rev. C 92 (2015) 055204.

Belle data analysis Status

- Data analysis is in a matured stage, Λc reconstructed successfully.
- First paper draft on the $\Lambda c \rightarrow \Sigma\pi\pi$ branching fractions in preparation.
- Further analysis may require PWA. PAWIAN software adapted to our analysis and is running.

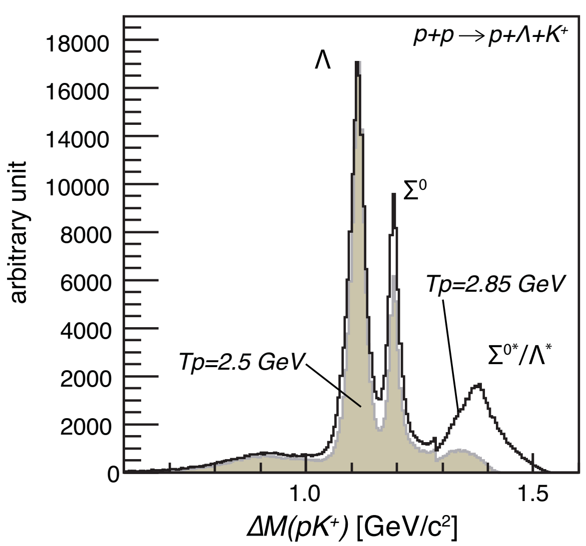
Summary and Outlook

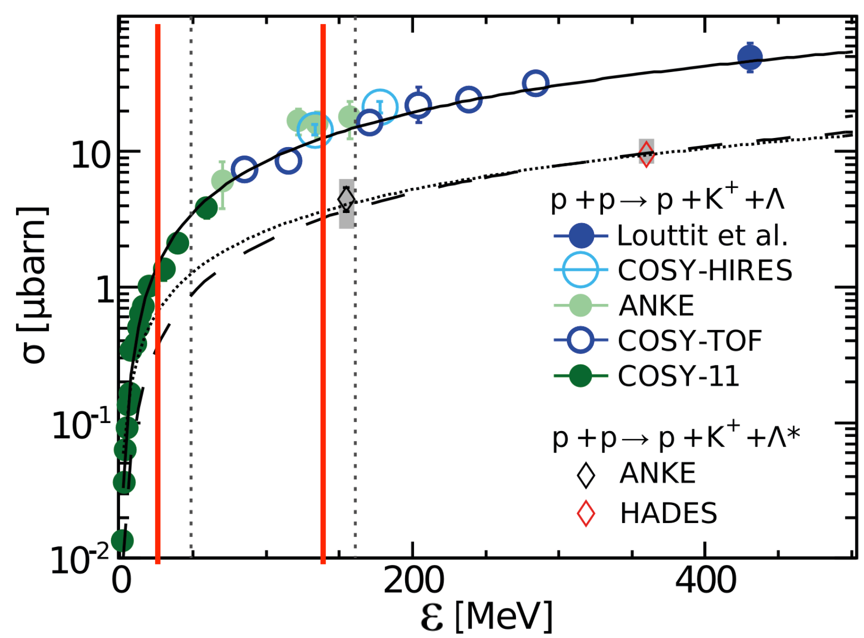
- Kaonic nuclei, ~15 years.
  - New era, new experimental data.
- A symposium at JPS meeting (March 2017), a milestone.
  - What’s next?
    - more careful study on the nature of the observed resonance?
    - look for siblings?
- DISTO data.
- Belle data.
  - $\Lambda(1405)$ problem.

BACKUP

Comment on Epple/Fabbietti paper on DISTO analysis (arXiv:1504.02060v1)

"The two vertical dashed lines mark the excess energy for the Λ(1405) production for the two data sets, measured by DISTO (48.8 MeV and 161.2 MeV). .... With help of the two curves the ratio of the Λ* production cross section between the two DISTO energies was determined to be $\sigma_{pK + \Lambda(1405)}$ (2.5 GeV)/$\sigma_{pK + \Lambda(1405)}$ (2.85 GeV)=0.23, for the scaled curve and 0.3 for the curve based on the free" Epple and Fabbietti, arXiv:1504.02060v1





$p+p \rightarrow p+K^{+}+\Lambda^{*}$ T_p = 2.85 GeV ⇔ ε = ~~139~~ MeV

$p+p \rightarrow p+K^{+}+\Lambda^{*}$ T_p = 2.5 GeV ⇔ ε = ~~27~~ MeV

?

$\sigma_{pK + \Lambda(1405)}$ (2.5 GeV)/$\sigma_{pK + \Lambda(1405)}$ (2.85 GeV) ~ 0.1

experimentally almost no population

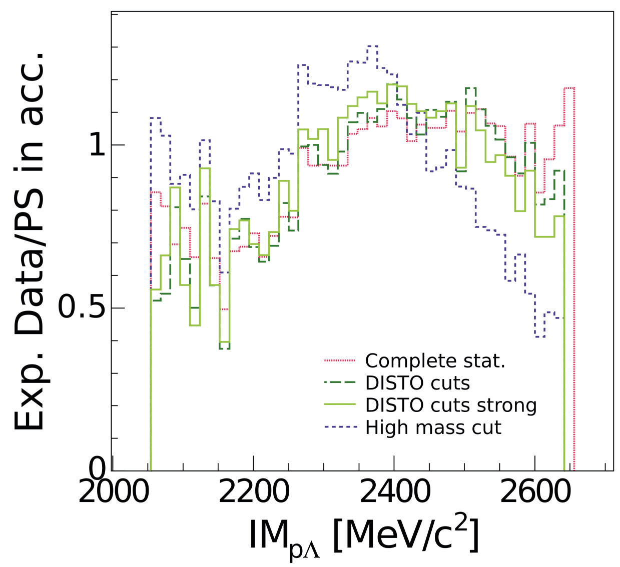
Summary and Outlook

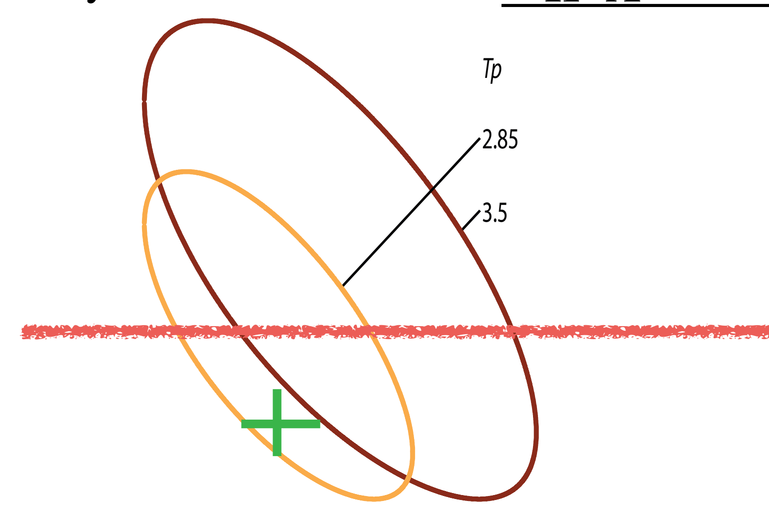
- Various data are by now available related the DISTO X(2265)
  - DISTO X(2265) localised at $M_{p\Lambda}$~2.265 GeV/c^2, $M_{K\Lambda}$~1.71 GeV/c^2 in the Dalitz plot
  - X(2265) production pronounced at T_p=2.85 GeV cannot be populated at higher T_p, as seen by HADES
  - suggesting the validity of the "hard collision/formation mechanism"
- Consistent with the picture, K^-pp produced with Λ* as a doorway, PRC76 (2007) 045201, both in *p*+*p* and *d*(π^+,K^+) reactions
- Full efficiency/acceptance correction coming

Comment on Epple/Fabbietti paper on DISTO analysis (arXiv:1504.02060v1)

Epple and Fabbietti, arXiv:1504.02060v1

An remarkable result (violet dashed in Fig. 2) is obtained if one only selects events where **$M_{K+\Lambda}$ >1810 MeV/c^2.**

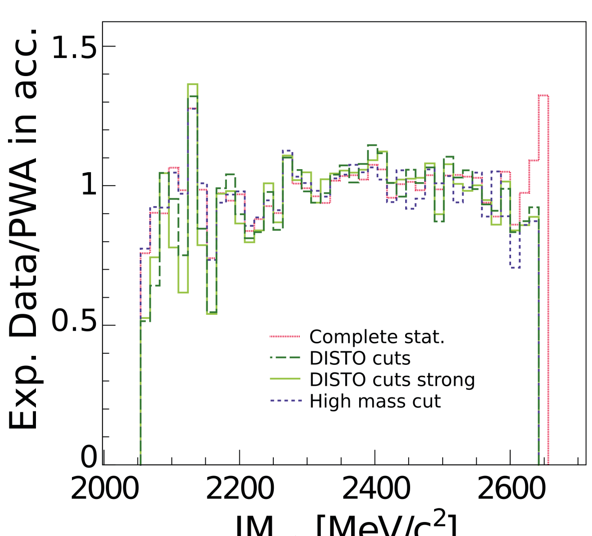




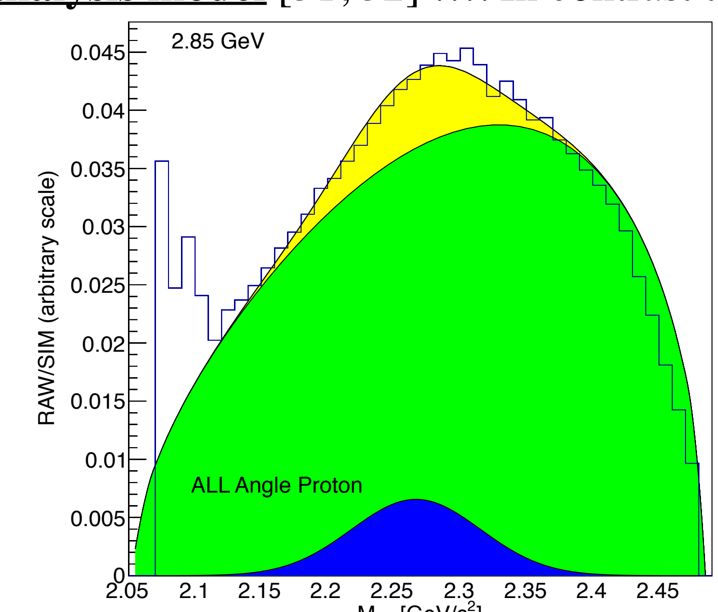
cut on a correlated distribution, especially such an drastic one, influences in its projection as a trivial consequence.

Epple and Fabbietti, arXiv:1504.02060v1

… deviation spectra that we have obtained **by dividing the measured spectra by a partial wave analysis model** [31, 32] …. In contrast to the Figs. 2 and 3, **the deviation spectra are in this case rather flat** around one and …



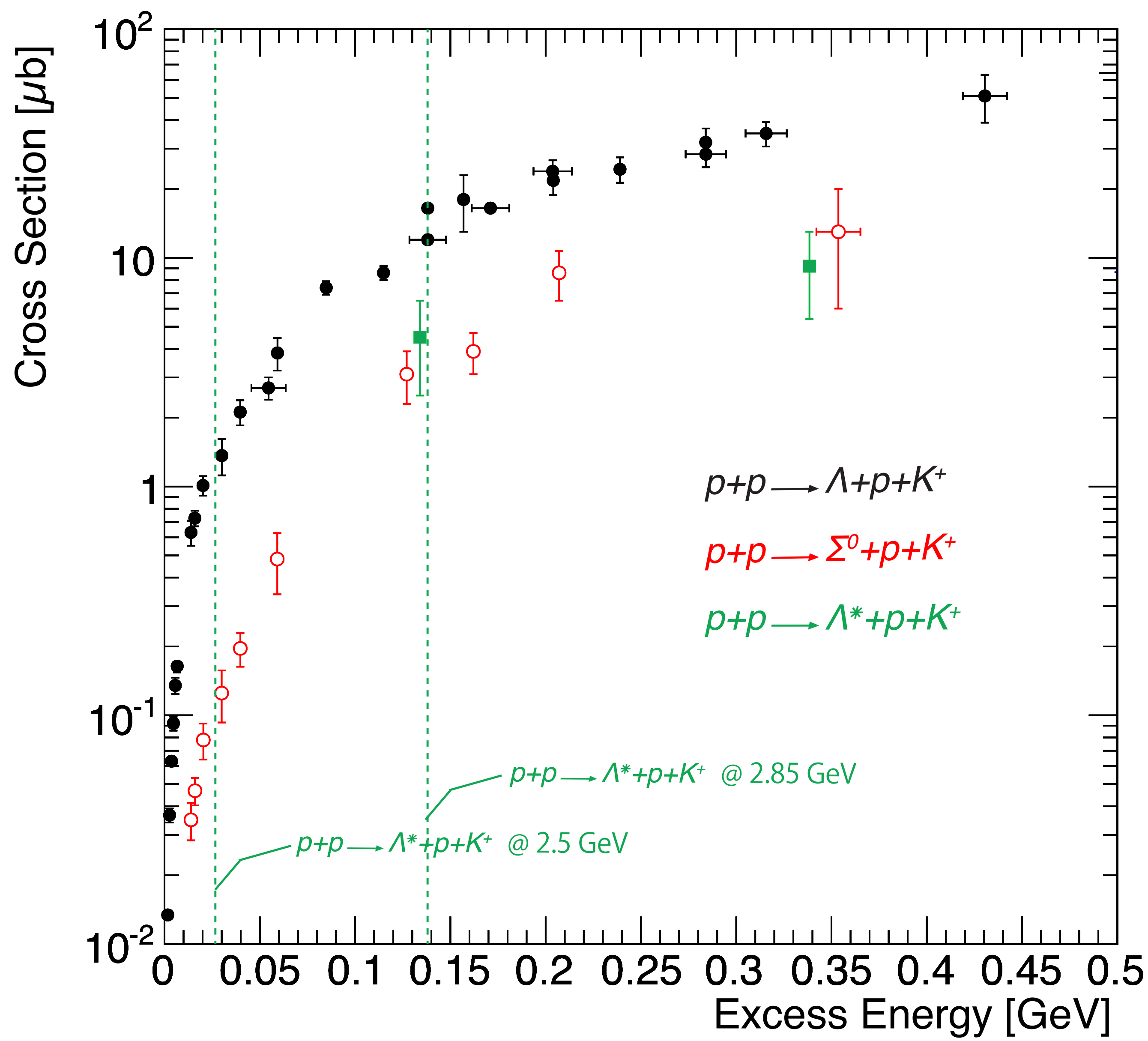
Our DEV plot is to see a deviation from PS distribution. If you change the denominator of divisional operation, by including something else, the results changes as a trivial consequence.



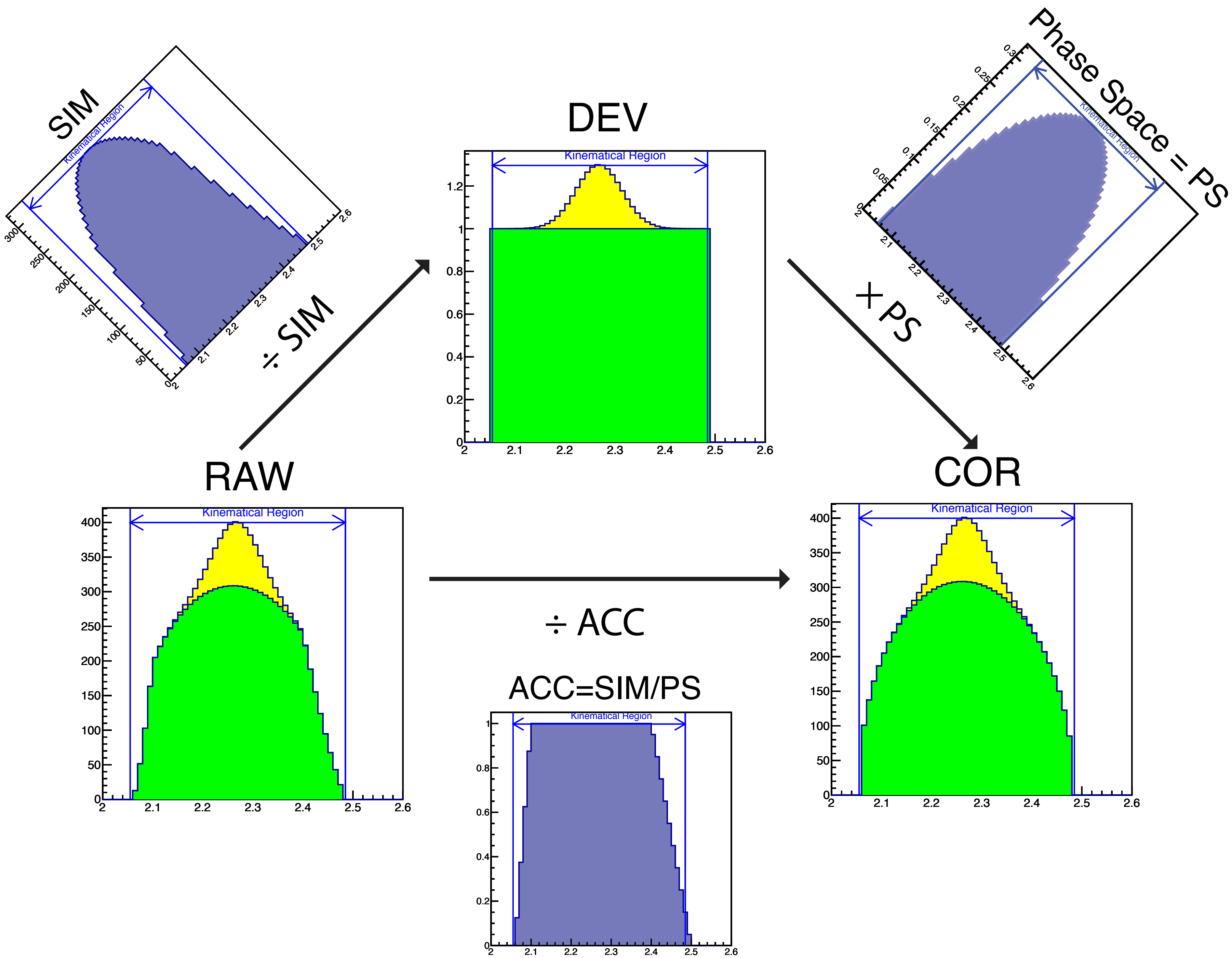
A consistent picture on production mechanisms that explains these experimental observations would be ..

- X(2265) is the $\bar{K}$ *pp* state
  - which is populated by the "hard collision/formation" mechanism
    - Λ(1405)-p produced in short range has a high sticking probability even at *q* as high as 1.6 GeV/c, provided the object is high density object
    - Otherwise $\bar{K}$ *pp* is not populated in the *p+p* reaction
- $\bar{K}$ *pp* population in the *pp* reaction by the hard collision/formation mechanism
  - requires minimum T_p~2.7 GeV. At T_p=2.5 GeV the Λ(1405) is not populated and thus no population of X(2265)
  - requires maximum T_p~3.1 GeV.
    - because of the Double resonance feature of its population
      - K^+-Λ emission into the same direction, indicating attractive FSI and/or N* resonance
    - X(2265) cannot be populated at T_p=3.5 GeV (HADES) because it is outside the kinematically allowed zone
  - making *p+p* reaction T_p=2.85 GeV very unique
- X(2265) population in d(π+,K+) reaction at J-PARC E27
  - the small sticking probability around 1% as observed in the J-PARC E27 is consistent with the expectation in Ref. *Yamazaki and Akaishi, PRC76 (2007) 045201*

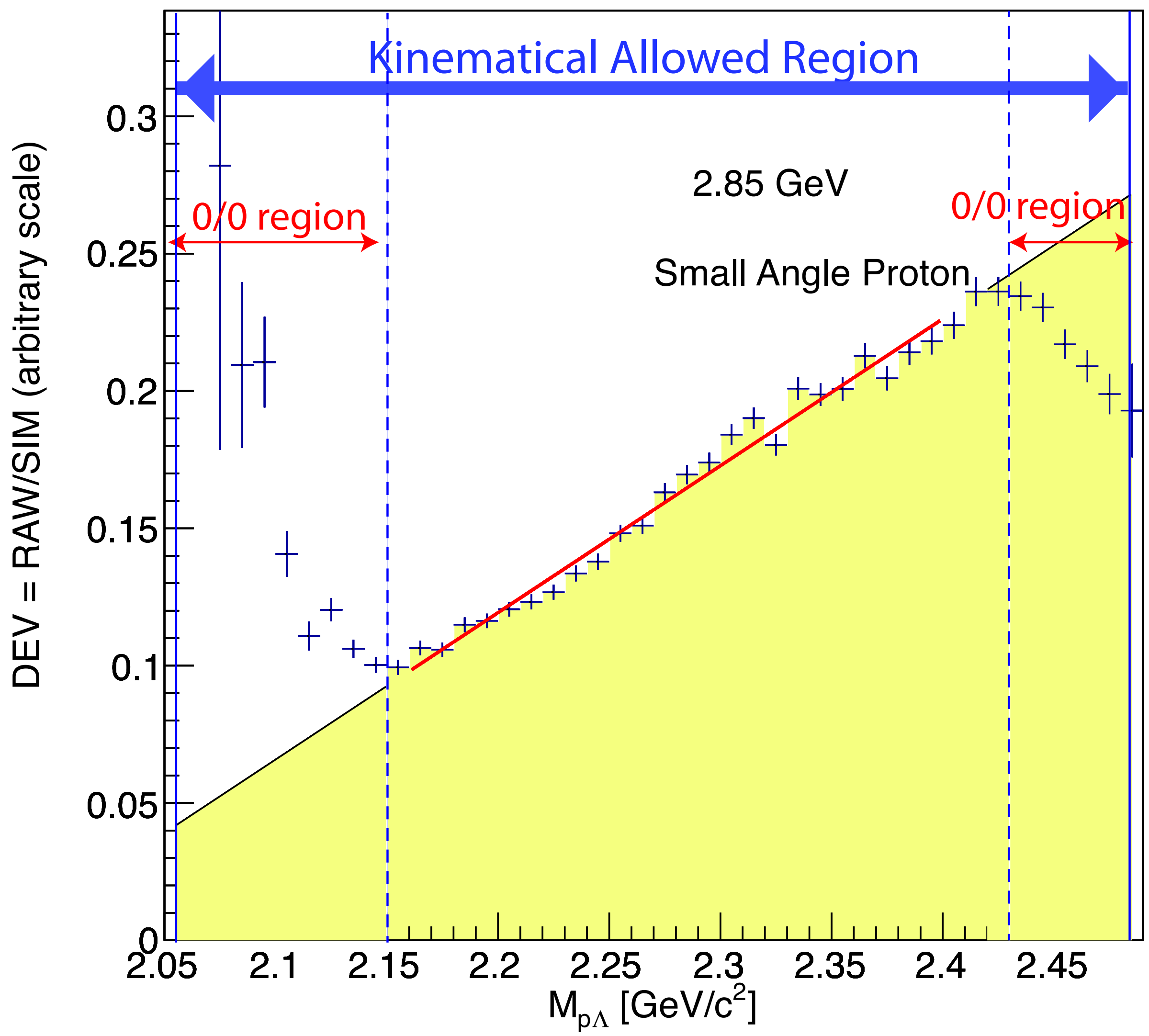
Comment on arXiv:1504.02060v1



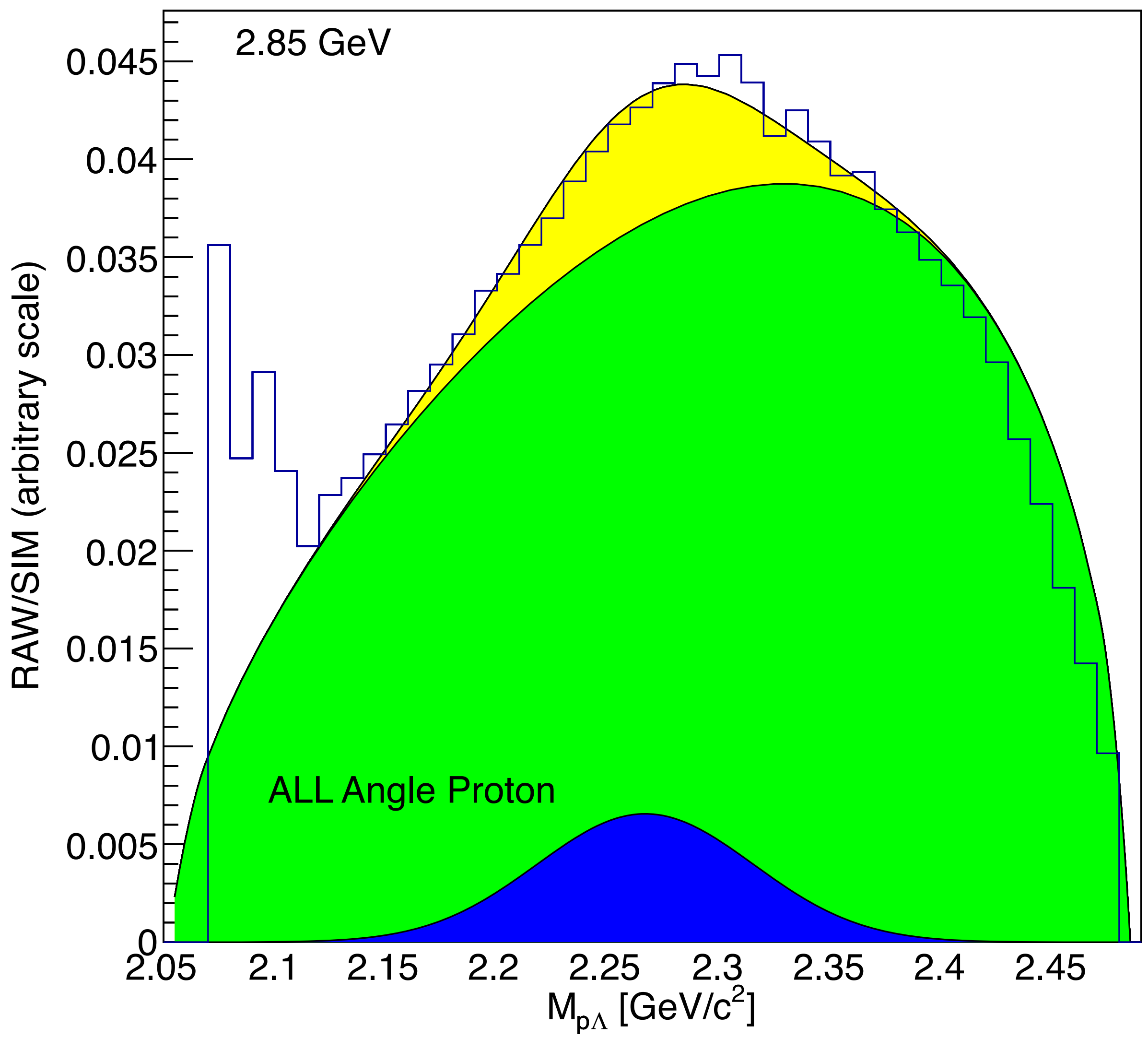
Deviation Method



Helps in finding a broad structure comp. the kinematical region

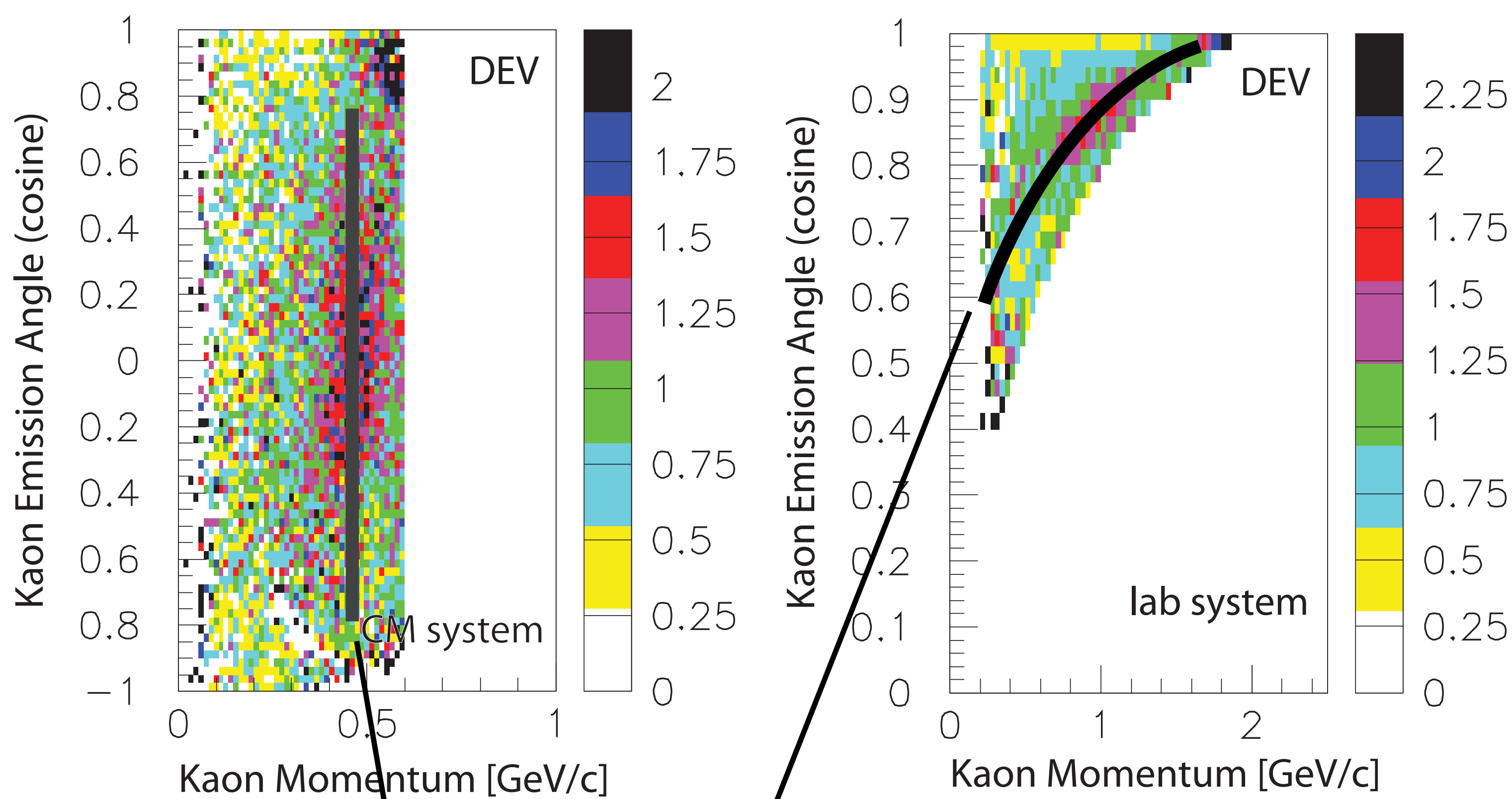


Kinematical Allowed Region
2.85 GeV
0/0 region
0/0 region
Small Angle Proton
DEV = RAW/SIM (arbitrary scale)
0.3
0.25
0.2
0.15
0.1
0.05
0
2.05
2.1
2.15
2.2
2.25
2.3
2.35
2.4
2.45
$M_{p\Lambda}$ [GeV/c^2]



2.85 GeV
ALL Angle Proton
RAW/SIM (arbitrary scale)
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
2.05
2.1
2.15
2.2
2.25
2.3
2.35
2.4
2.45
$M_{p\Lambda}$ [GeV/c^2]

$pp \rightarrow K^+X \rightarrow K^+(p\Lambda)$ two-body reaction



mono-energetic Kaon

$p+p \rightarrow p+K^+ + \Lambda^*$ P_p = 2.85 GeV ⇔ ε = 161 MeV

$p+p \rightarrow p+K^+ + \Lambda^*$ P_p = 2.5 GeV ⇔ ε = 48.8 MeV

?

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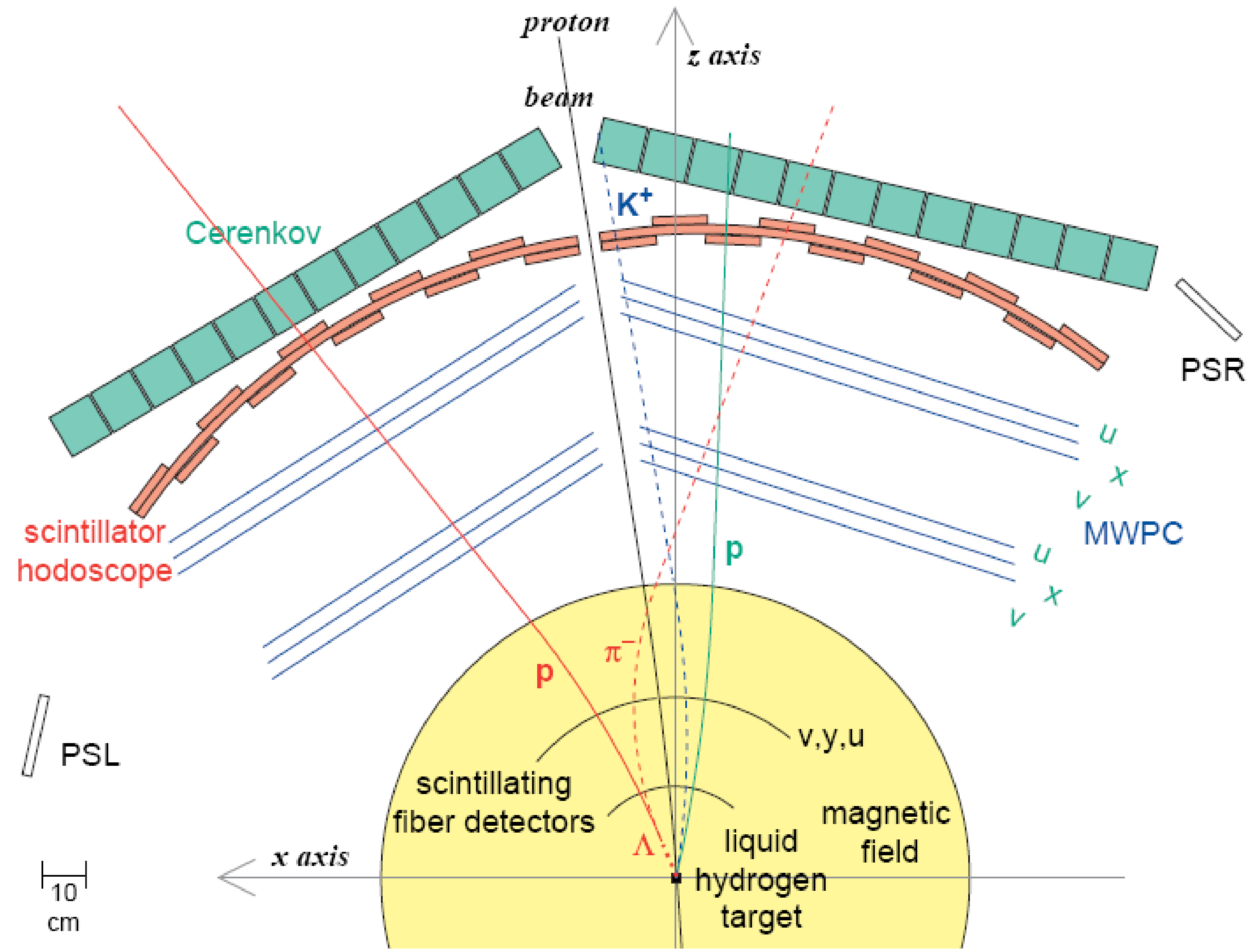
DISTO@Saturne (polarised) proton

- Acceptance: **Δφ**=±15.5°, **Δθ**=±4
- LH_2 Target: 2cm
- Magnet: <14.7 k gauss
- semi-cylindrical scintillating fibres
- MWPCs
- Scintillator hodoscopes
- doped Water Cherenkov counter
- First exclusive measurement with
- T_p = 2.145, 2.5, 2.85 GeV



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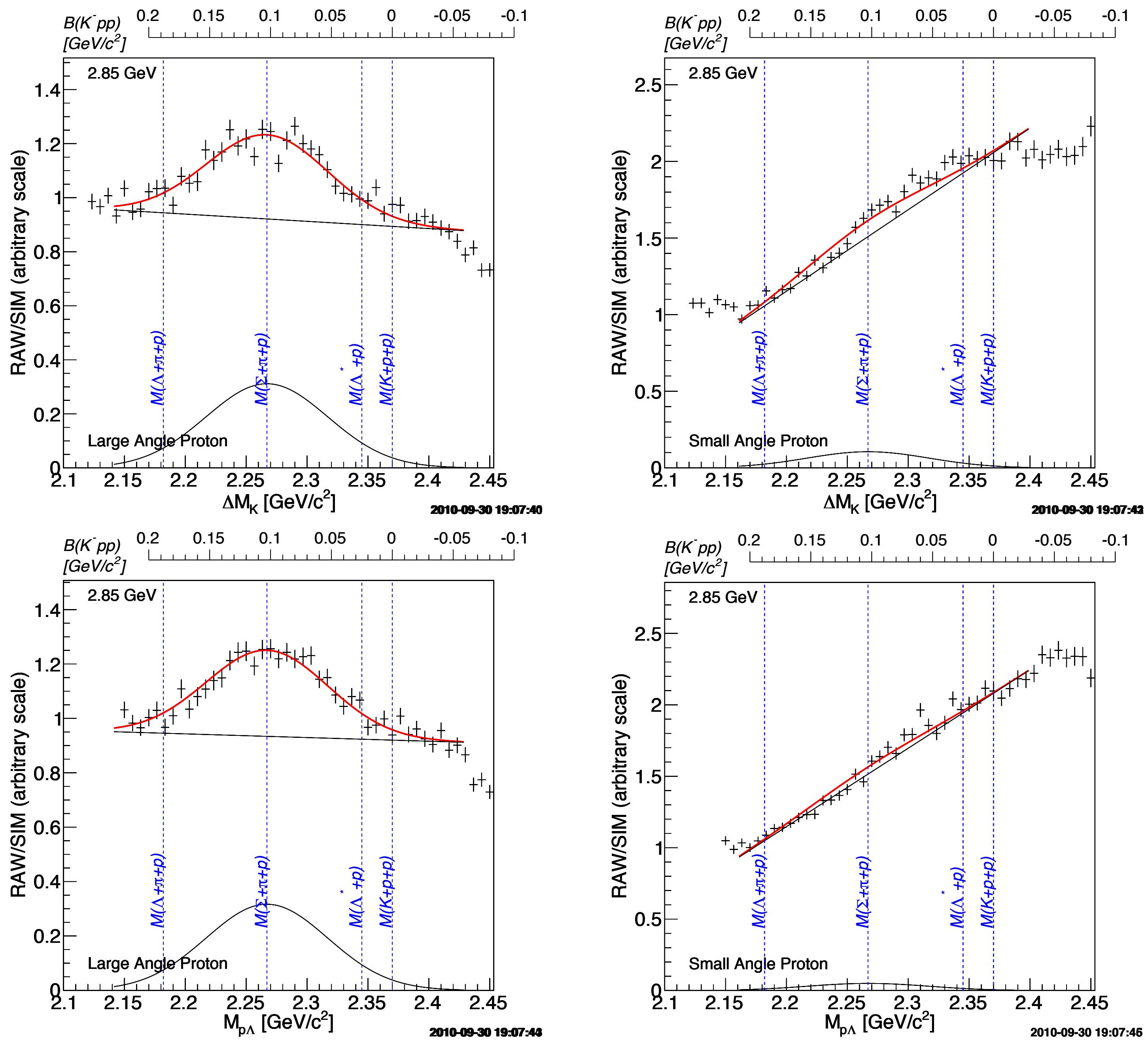
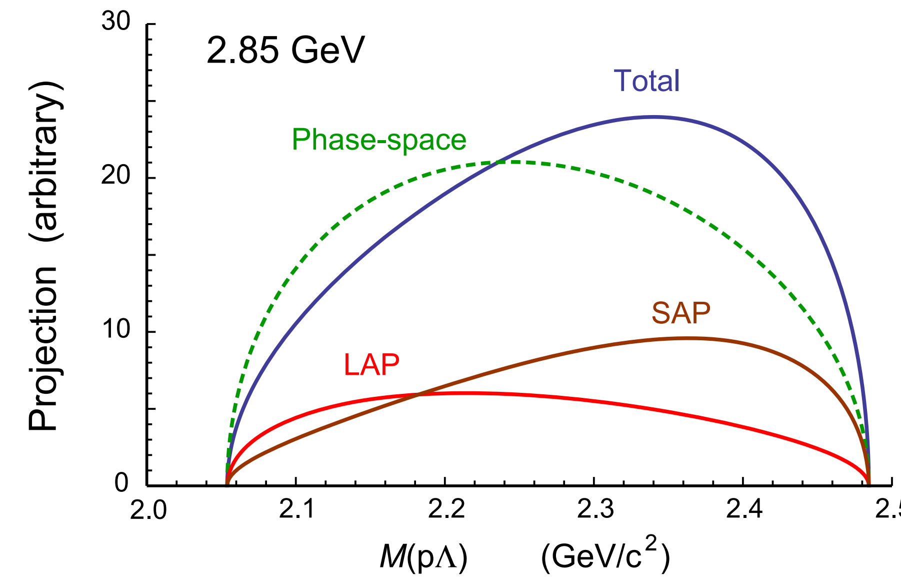
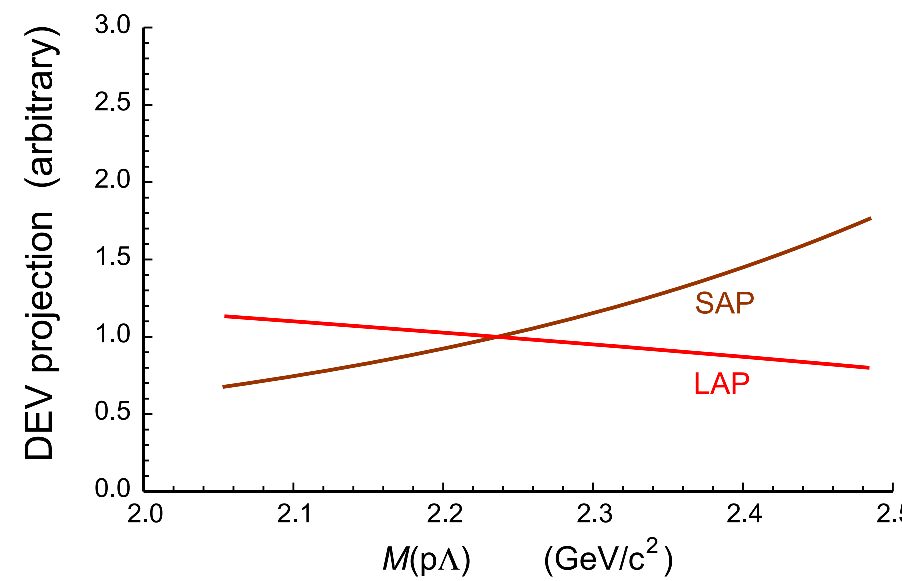
Exclusive data sample of $pp \rightarrow p\Lambda K^{+}$

The most essential cut: Large angle proton cut ≡ $|cos\vartheta_{CM,p}|<0.6$







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