Outlook

(Worst week of my life in Cracow)

Laura Fabbietti

Fundamental Questions

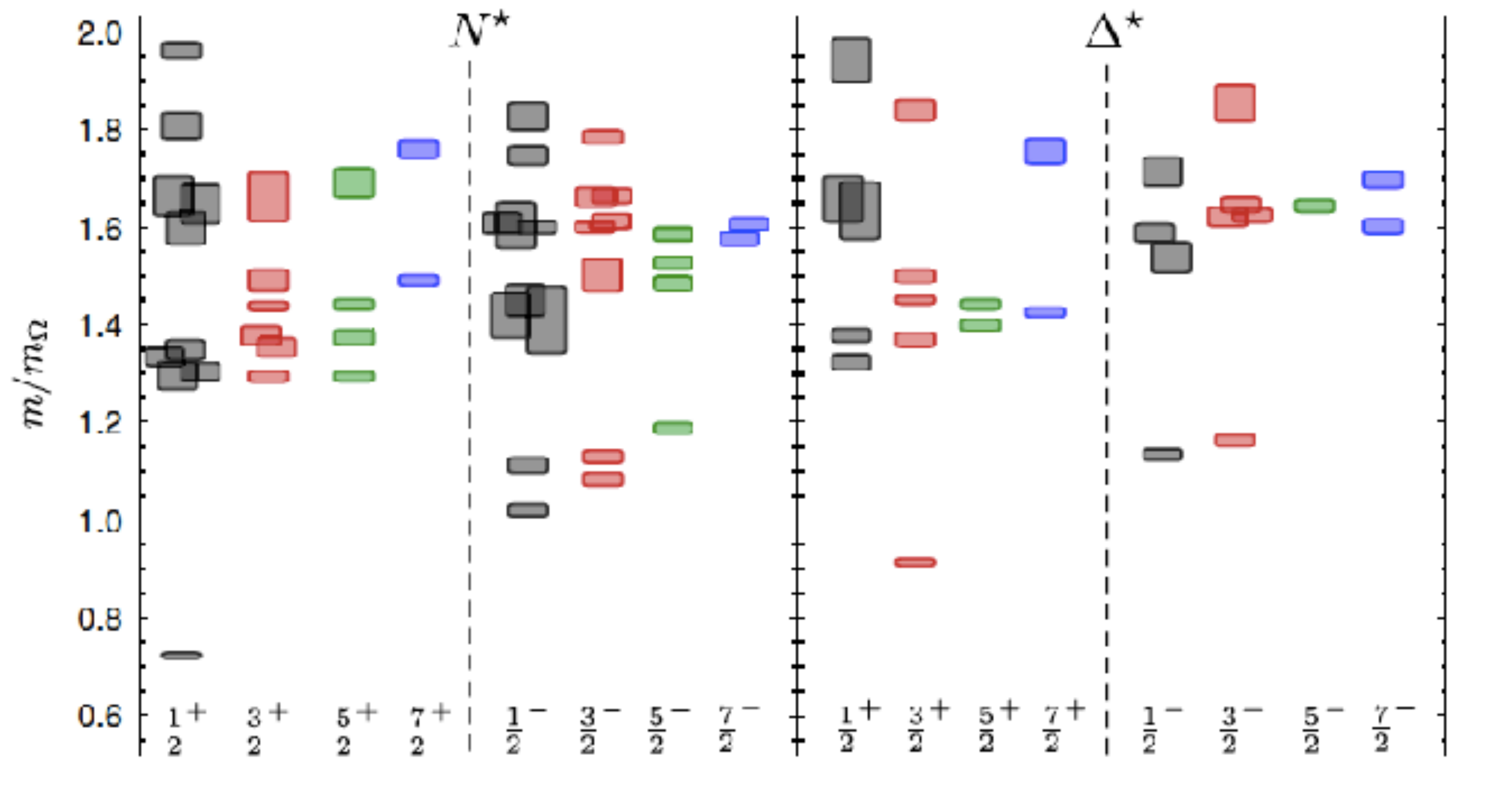
- Chiral Symmetry Restoration
- Equation of State of matter under Extreme Conditions
- Low energy QCD in the u-d-s sector
- Extension of the Quark model: 3 Examples

From Baryonic resonances decaying into mesons and nucleons to the Quest of Chiral Symmetry restoration

Partial Wave Analysis SU(3): non exotic states

A. Sarantsev

P. Edwards et al., Phys. Rev. D84 (2011) 074508



	J^P	Status
Σ(1660)	$1/2^+$	***
Σ(1385)	$3/2^+$	****
Σ(1915)	$5/2^+$	****
Σ(2030)	$7/2^+$	****
Σ(1670)	$3/2^-$	****
Σ(1750)	$1/2^-$	***
Σ(1775)	$5/2^-$	****
Σ(1940)	$3/2^-$	***
Σ(1665)	$1/2^-$	
Σ(2150)	$1/2^-$	
Σ(2250)	$5/2^-$	

How to confirm these states (EXTREMELY BROAD!) experimentally?

➡ Partial wave analysis

$$A(s,t) = \sum_{\beta\beta' n} A_n^{\beta\beta'}(s) Q^{(\beta)+}_{\mu_1\ldots\mu_n} F^{\mu_1\ldots\mu_n}_{\nu_1\ldots\nu_n} Q^{(\beta')}_{\nu_1\ldots\nu_n}$$

Bonn-Gatchina partial wave analysis (http://pwa.hiskp.uni-bonn.de)

- Energy Dependent approach, **200 data sets** fitted at the same time, **20 Millions likelihood**

Partial Wave Analysis SU(3): non exotic states

$\sqrt{s} = 1 - 2\,\mathrm{GeV}$

V. Crede, A. Sarantsev

DATA
$\gamma n \to \Lambda K, \Sigma^- K$
$\gamma n \to \pi^- p$
$\gamma n \to \eta n$
$\gamma p \to \eta p$
$\gamma p \to \eta' p$ $\gamma p \to K^+ \Lambda$ $\gamma p \to K^+ \Sigma^0$
$\pi^- p \to \pi^+ \pi^- n$ $\pi^- p \to \pi^- \pi^0 p$
$\gamma p \to \pi^0 \pi^0 p$ $\gamma p \to \pi^+ \pi^- p$
$\gamma p \to \omega p$
$\gamma p \to K^* \Lambda$

$$N^*(1535 - 2000) \to \pi^- + p$$

$$N^*(1535 - 2000) \to \eta + N$$

$$N^*(1535 - 2000) \to \Lambda + K$$

Determination of N* mass, quantum
Numbers and relative branching ratios

Partial Wave Analysis SU(3): non exotic states

$\sqrt{s} = 1 - 2\,\mathrm{GeV}$

V. Crede

DATA
$\gamma n \to \Lambda K, \Sigma^- K$
$\gamma n \to \pi^- p$
$\gamma n \to \eta n$
$\gamma p \to \eta p$
$\gamma p \to \eta' p$ $\gamma p \to K^+ \Lambda$ $\gamma p \to K^+ \Sigma^0$
$\pi^- p \to \pi^+ \pi^- n$ $\pi^- p \to \pi^- \pi^0 p$
$\gamma p \to \pi^0 \pi^0 p$ $\gamma p \to \pi^+ \pi^- p$
$\gamma p \to \omega p$
$\gamma p \to K^* \Lambda$

Some Resonances can be produced only in 3 body reactions

Strange Baryon perspective:

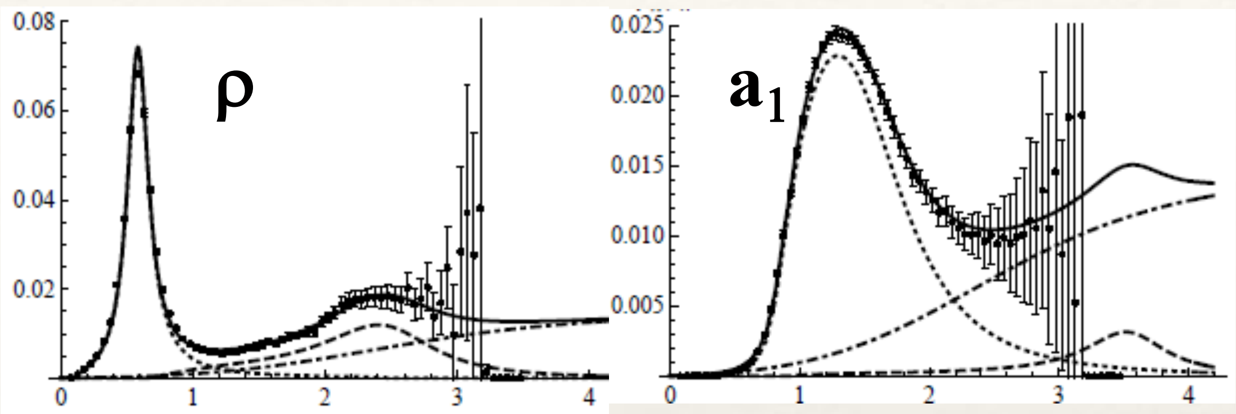
Mapping out the spectrum of Ξ, Σ^*, Λ^* baryons.

p+p data should be analysed within this framework

Vector Mesons

R. Rapp

Vector mesons properties within nuclear matter under **extreme conditions**



Determine rho properties in the medium

$$\int_0^\infty ds\, \frac{\Delta\rho(s)}{s} = f_\pi^2 \,,$$

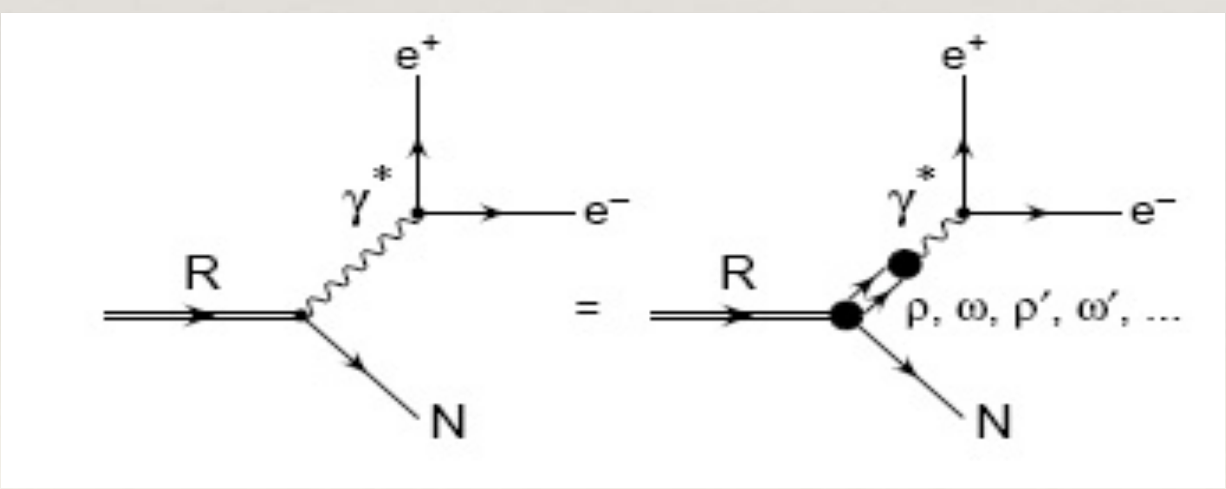
$$\int_0^\infty ds\, \Delta\rho(s) = f_\pi^2 m_\pi^2 = -2m_q\langle\bar{q}q\rangle$$

$$\int_0^\infty ds s \Delta\rho(s) = -2\pi\alpha_s\langle\mathcal{O}_4^{SB}\rangle$$

$$\Delta\rho = \rho_V - \rho_A$$

[Weinberg ’67, Das et al ’67; Kapusta+Shuryak ‘94]

Vector Meson Dominance



Also at ultra-relativistic colliding energies Resonances play an important role

$\Sigma_{\rho B,M}$ =

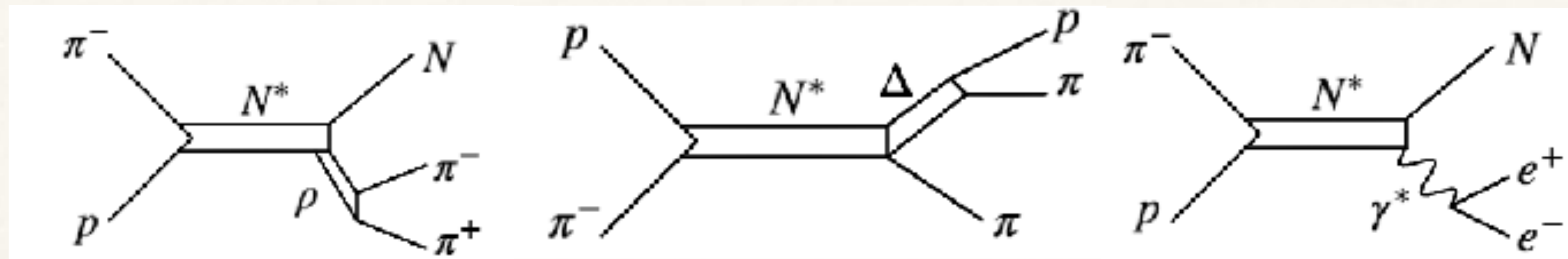
R=Δ, N(1520), a_1, K_1, …

h=N, π, K, …

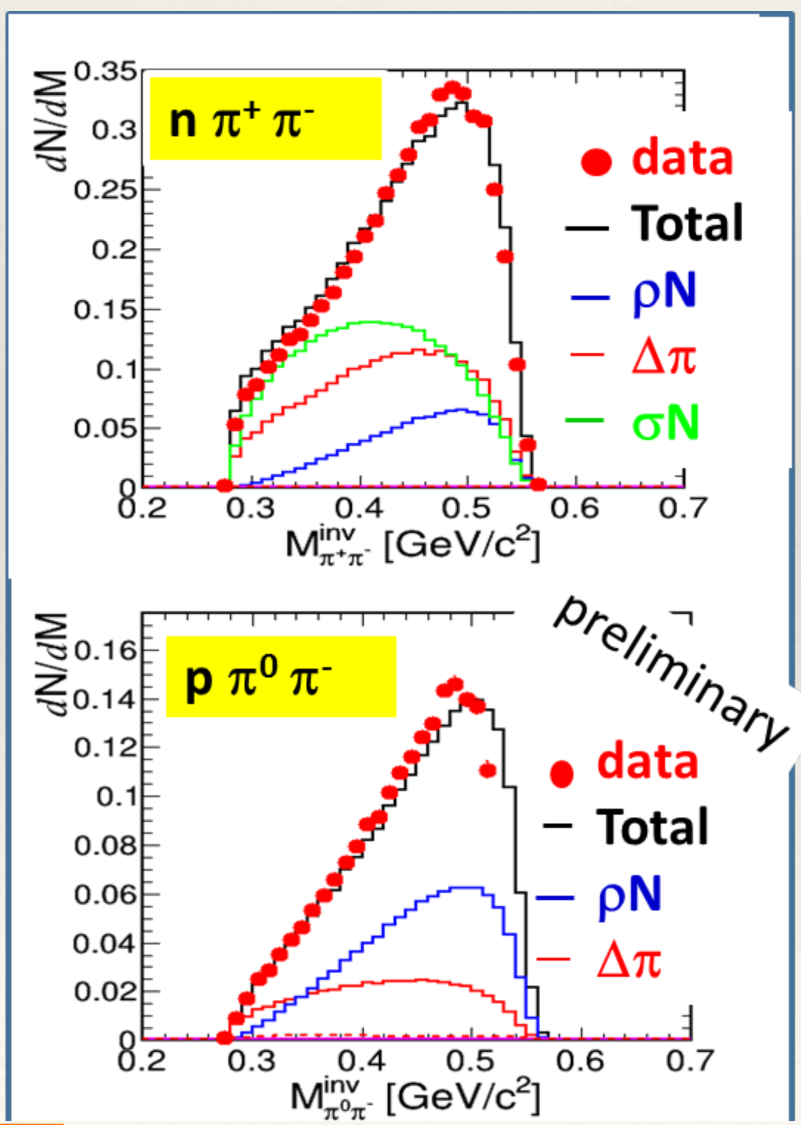
Coupling through Mesons

B. Ramstein, I. Ciepal, A.Belounnas

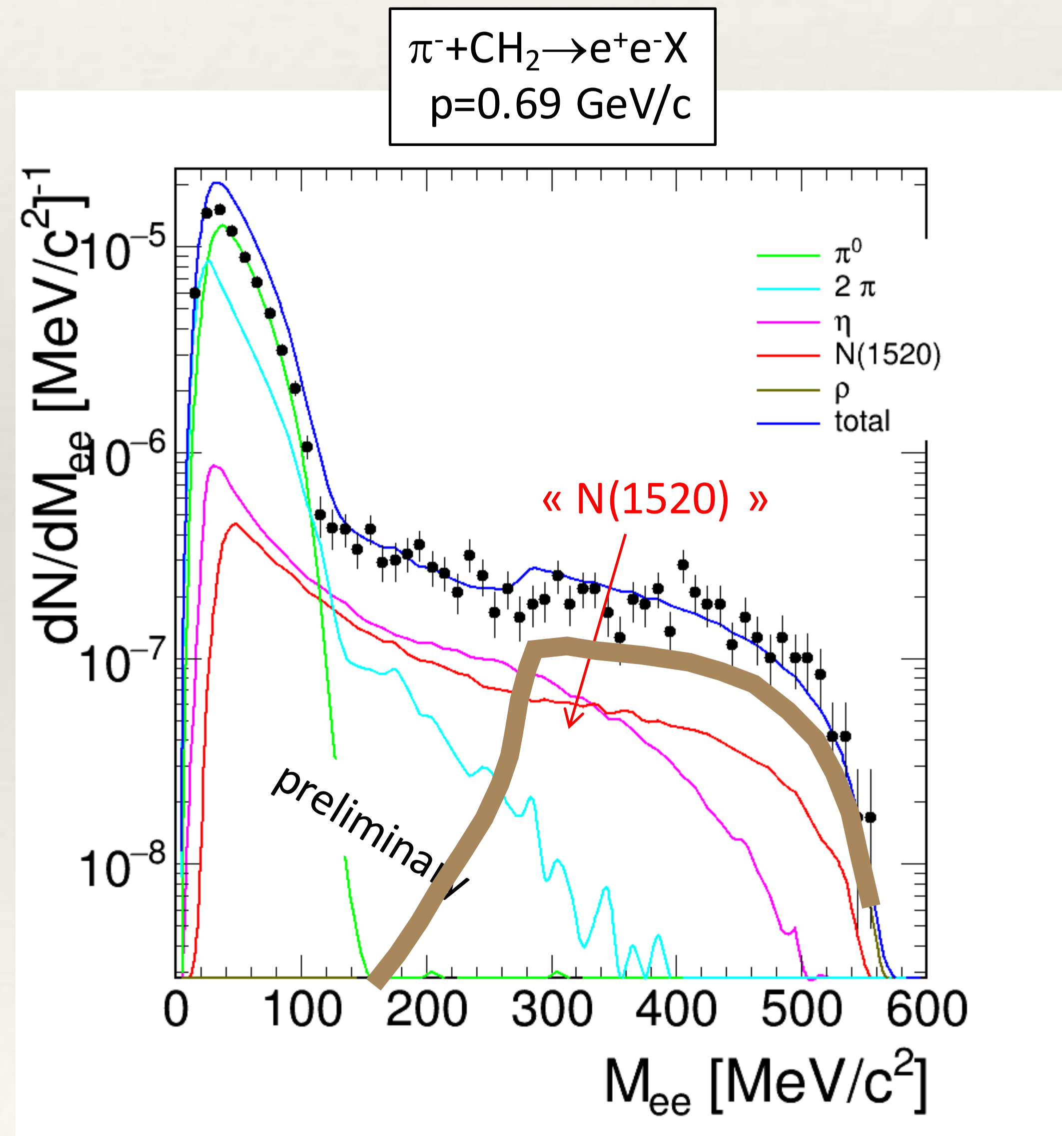
ρN coupling



ρ contribution to the dilepton spectra extracted from PWA of the reaction $\pi^- p \to n\rho$



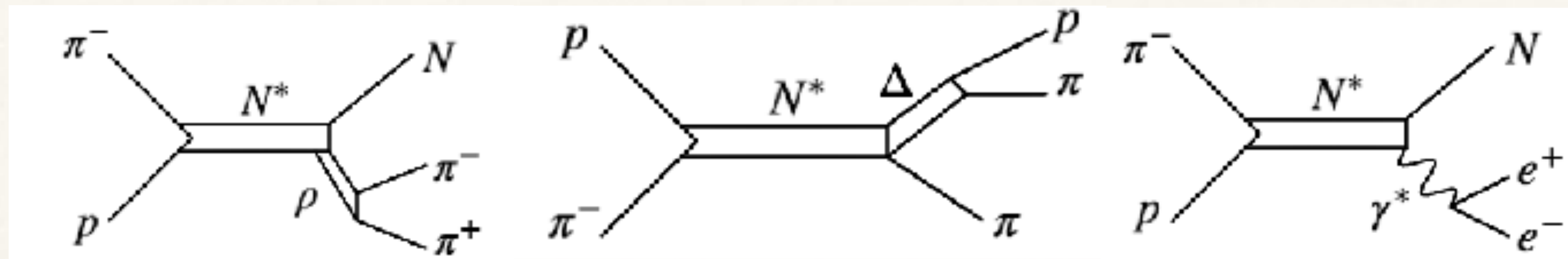
- Constrain VM spectral function
- Measure time-like form factor in a data driven way



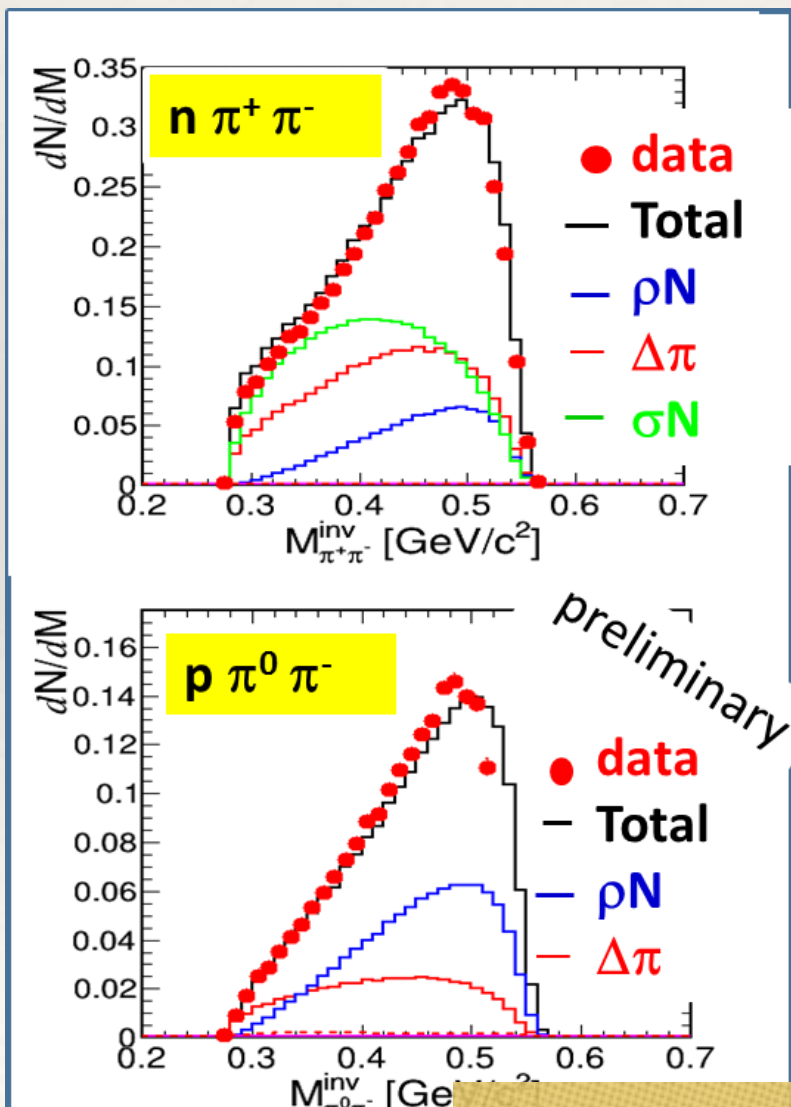
Coupling through Mesons

B. Ramstein, I. Ciepal, A.Belounnas

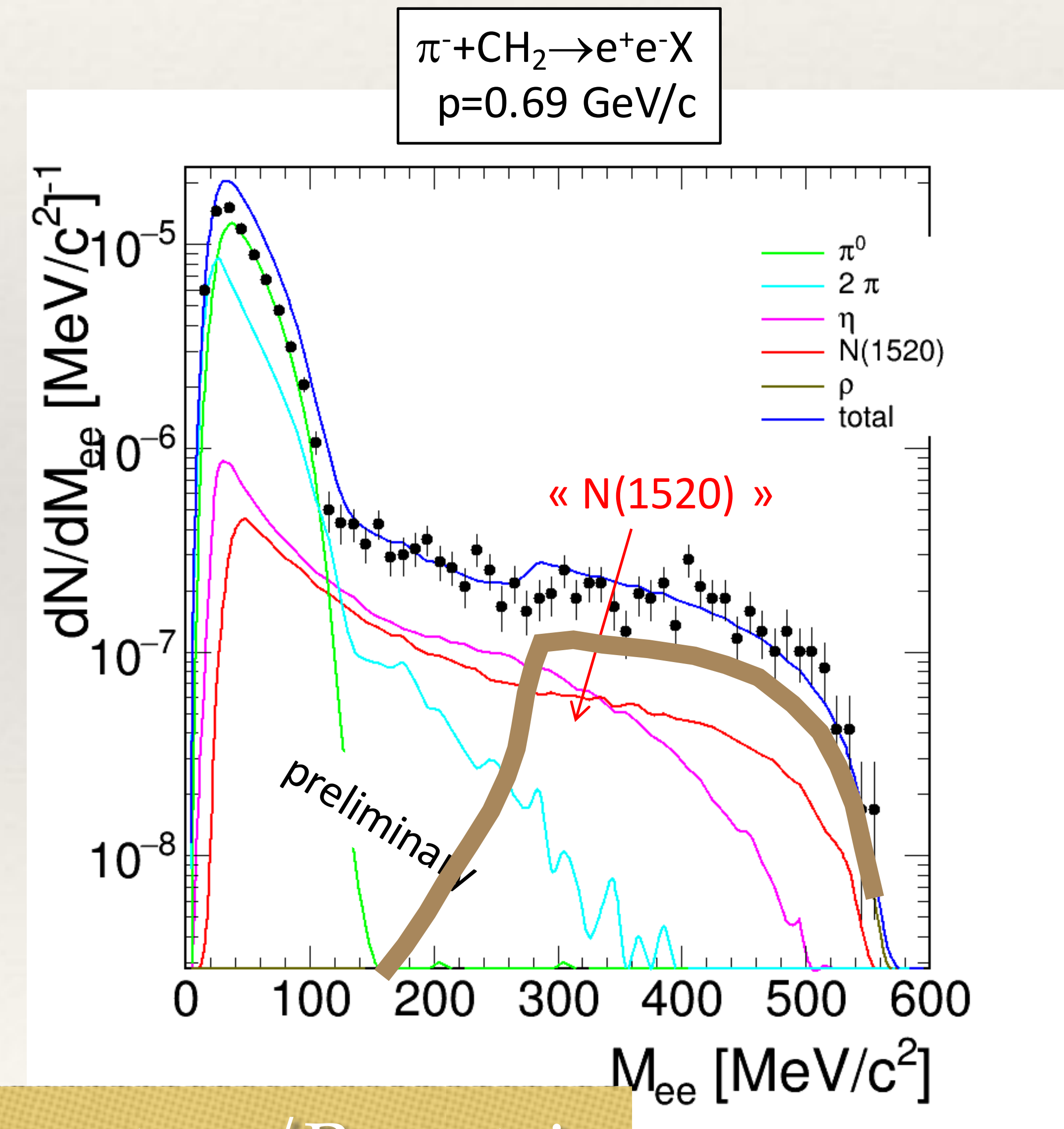
ρN coupling



ρ contribution to the dilepton spectra extracted from PWA of the reaction $\pi^- p \to n\rho$



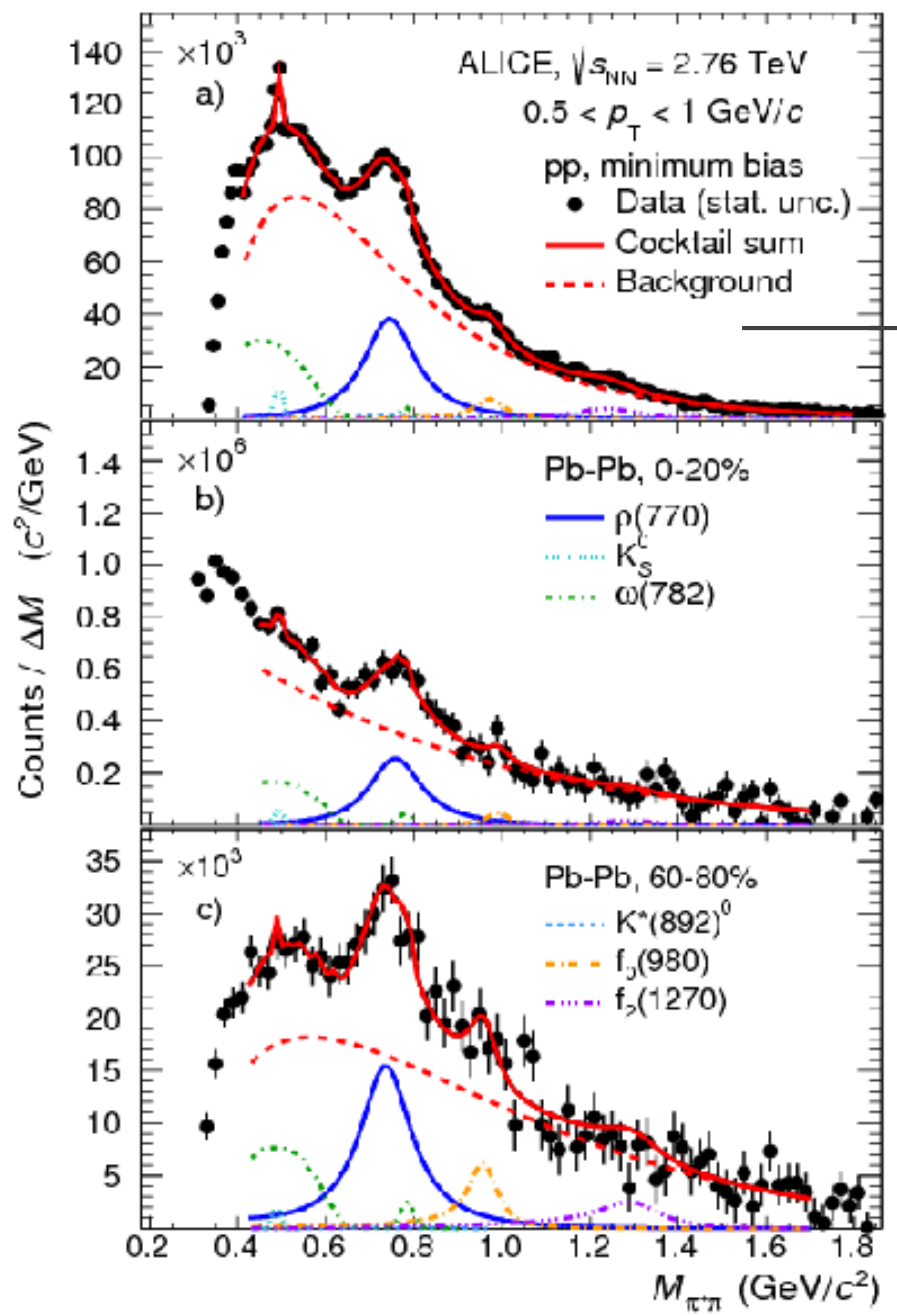
- Constrain VM spectral function
- Measure time-like form factor in a data driven way



More Pion Beam for Salabura/Sarantsev/Ramstein

Chiral Symmetry Restoration: a_1?

ALICE coll. arXiv:1805.04365



$6 * 10^7$ evts

ρ spectral shape does not change from pp to PbPb

$$a_1^{\pm} \to \pi^+ + \pi^- + \pi^{\pm}$$

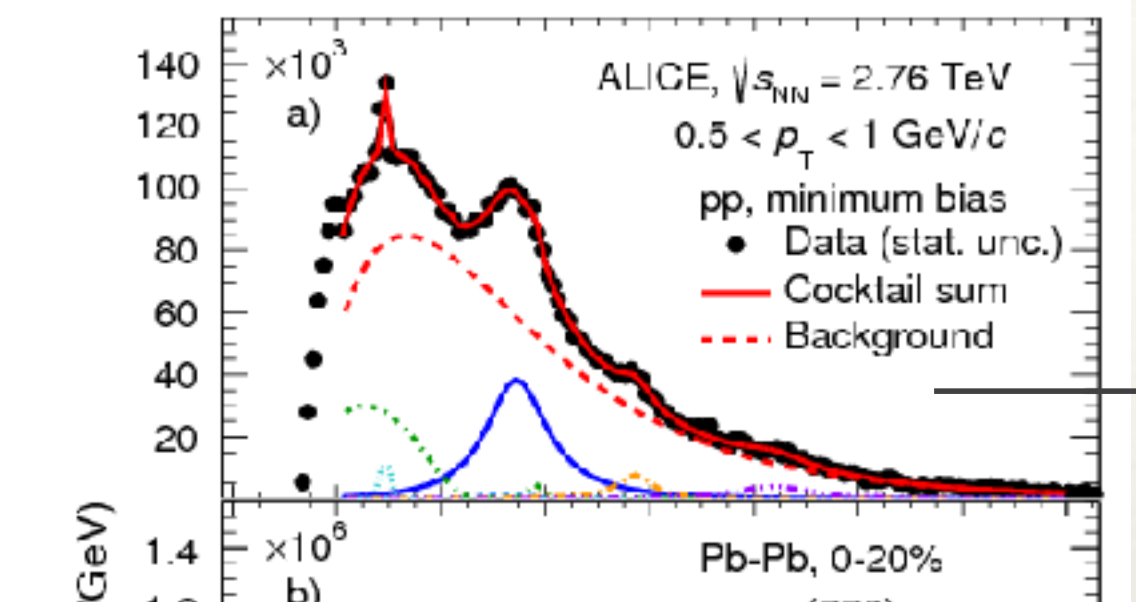
check for the a1 in pp at 13 TeV **10^9 evts**

if a1 is observed
-> check PbPb data against the a1-vacuum hypothesis

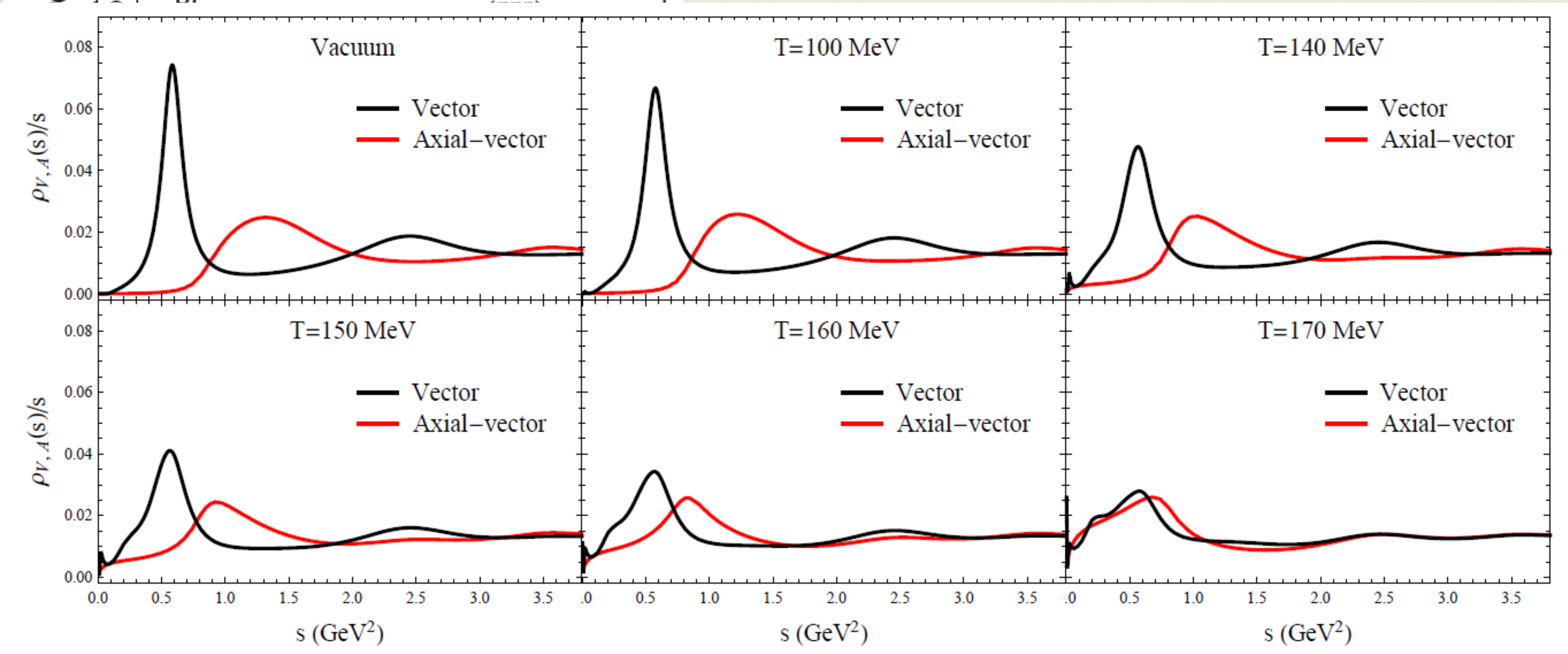
Chiral Symmetry Restoration: a_1?

R. Rapp

ALICE coll. arXiv:1805.04365

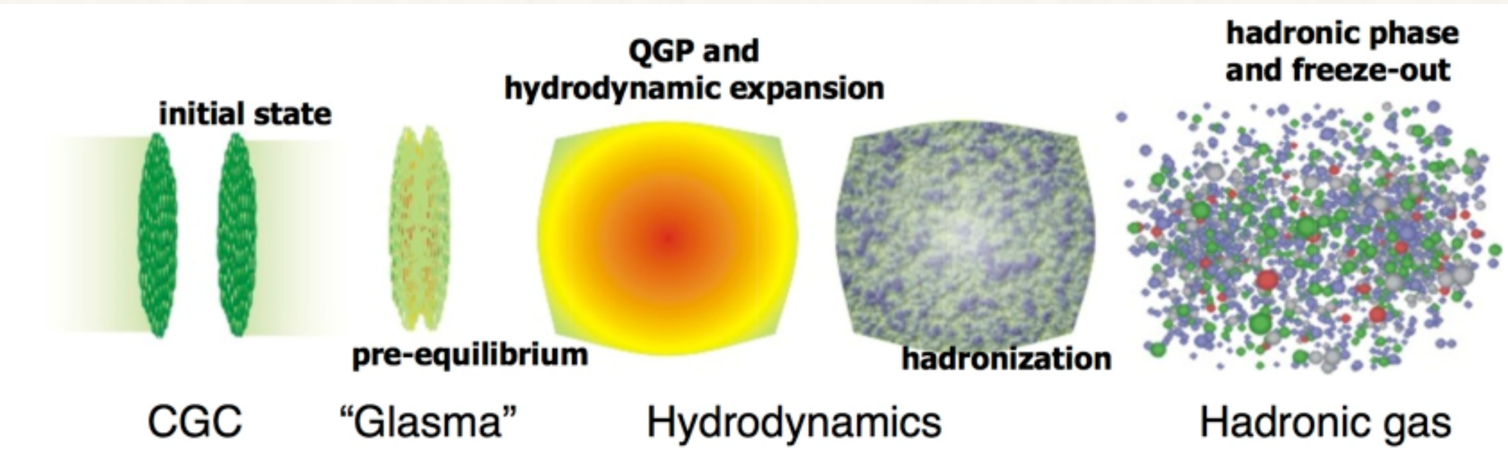


6 * 10 ^{7} evts

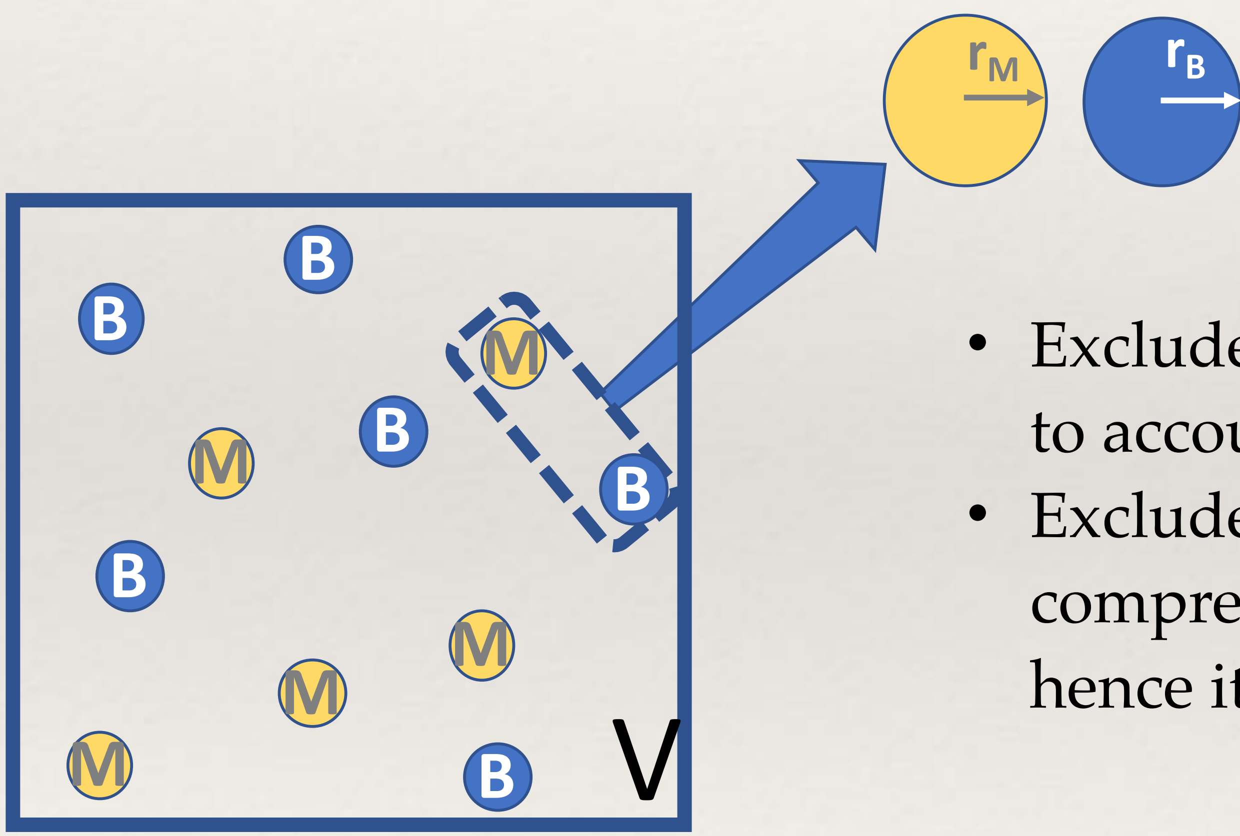


How can these resonances (N^*, Σ, Δ ...) and their decays be useful to better constraint the Equation of state of matter under extreme conditions?

Equation of State of Dense and Hot Matter



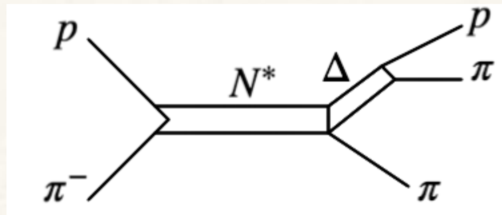
- evidence from Lattice of missing strange states in the low T regime
- Hyperons yields not well reproduced by HRG hadronic spectrum $\Longrightarrow$ underestimate by HRG calculations

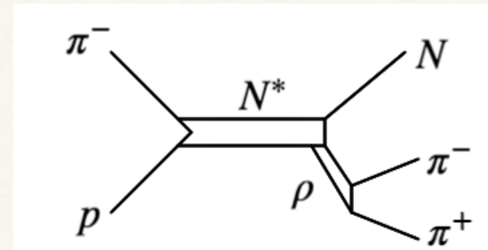


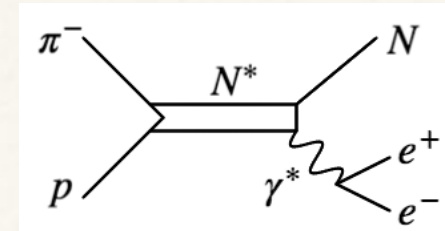
- Excluded volume introduced in the model to account for the missing resonances
- Excluded Volume influences the compressibility of the hadronic gas and hence its **Equation of State**

A more complete list of Resonances will lead to a more realistic EoS
But: why are the already discovered resonances not included in the hadron gas yet ??

Equation of State of Hadronic Matter







- Fundamental ingredient for RMF Lagrangians used for **hadronic** EoS
- Coupling of nucleons and hyperons at finite densities

$$\mathcal{L} = \sum_B \bar{\Psi}_B \left(i\gamma_\mu \partial^\mu - m_B + g_{\sigma B}\sigma - g_{\omega B}\gamma_\mu \omega^\mu - g_{\rho B}\gamma_\mu \mathbf{t}_B \cdot \boldsymbol{\rho}^\mu \right) \Psi_B$$

Relevant to solve the **HYPERON Puzzle** within Neutron Stars

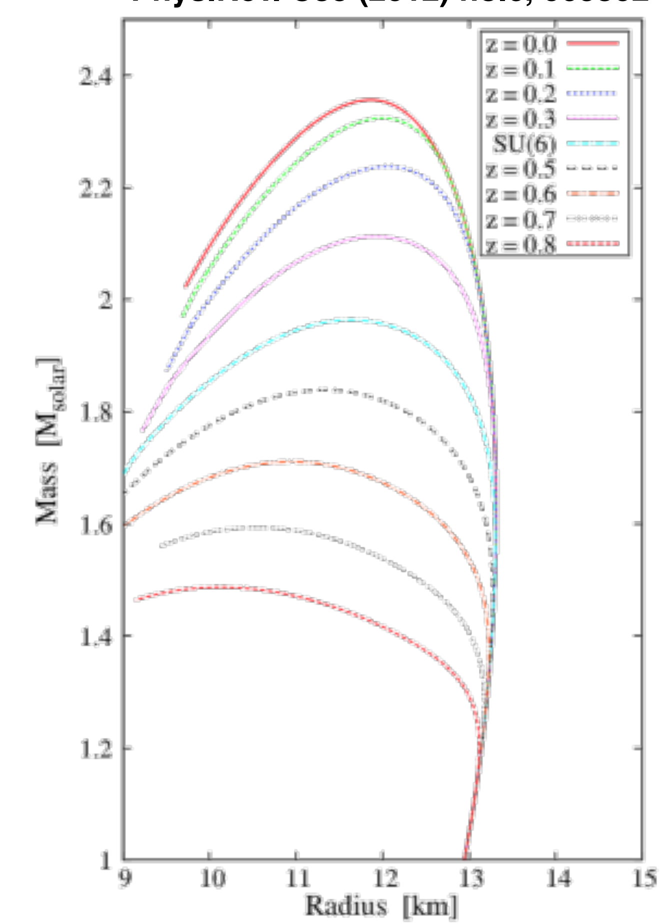
$$\frac{1}{3} g_{\omega N} = \frac{1}{2} g_{\omega \Lambda} = \frac{1}{2} g_{\omega \Sigma} = g_{\omega \Xi},$$

$$g_{\rho N} = \frac{1}{2} g_{\rho \Sigma} = g_{\rho \Xi},$$

$$g_{\rho \Lambda} = 0,$$

$$2 g_{\phi \Lambda} = 2 g_{\phi \Sigma} = g_{\phi \Xi} = -\frac{2\sqrt{2}}{3} g_{\omega N}.$$

Phys.Rev. C85 (2012) no.6, 065802



Low Energy QCD: non perturbative.

$\Lambda(1405)$ and $\bar{K}N$

Finally we see kaonic bound states!!!

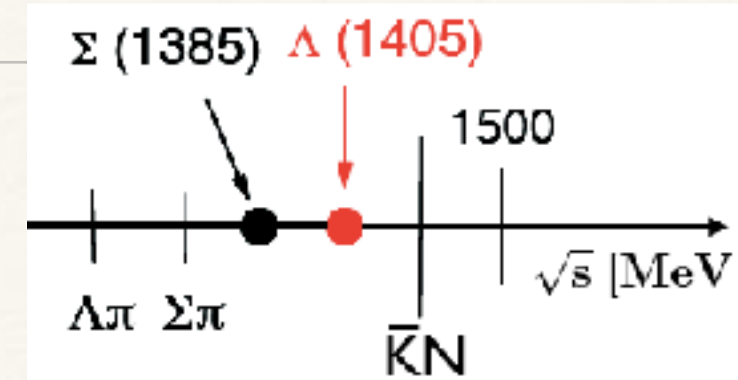
If we connect this to Vector mesons what do we learn?

The ϕ case

Low energy QCD in the u-d-s sector

T. Hyodo, K. Piscicchia

Broad resonances present below the $\overline{K}N$ threshold makes ChPT not applicable for $\overline{K}N$ interaction

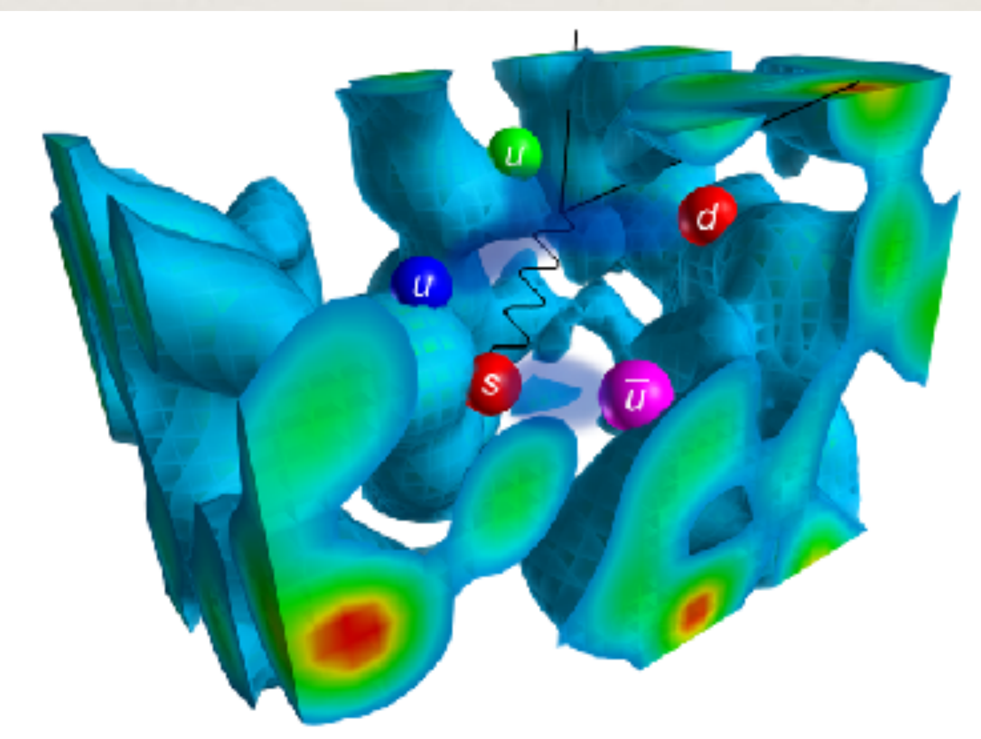


$\Lambda(1405)$:ONLY state about which we are rather sure we have a molecular state MB

Proof: spectral shape moves around with different reactions

Lattice QCD Evidence that the Λ(1405) Resonance is an Antikaon-Nucleon Molecule

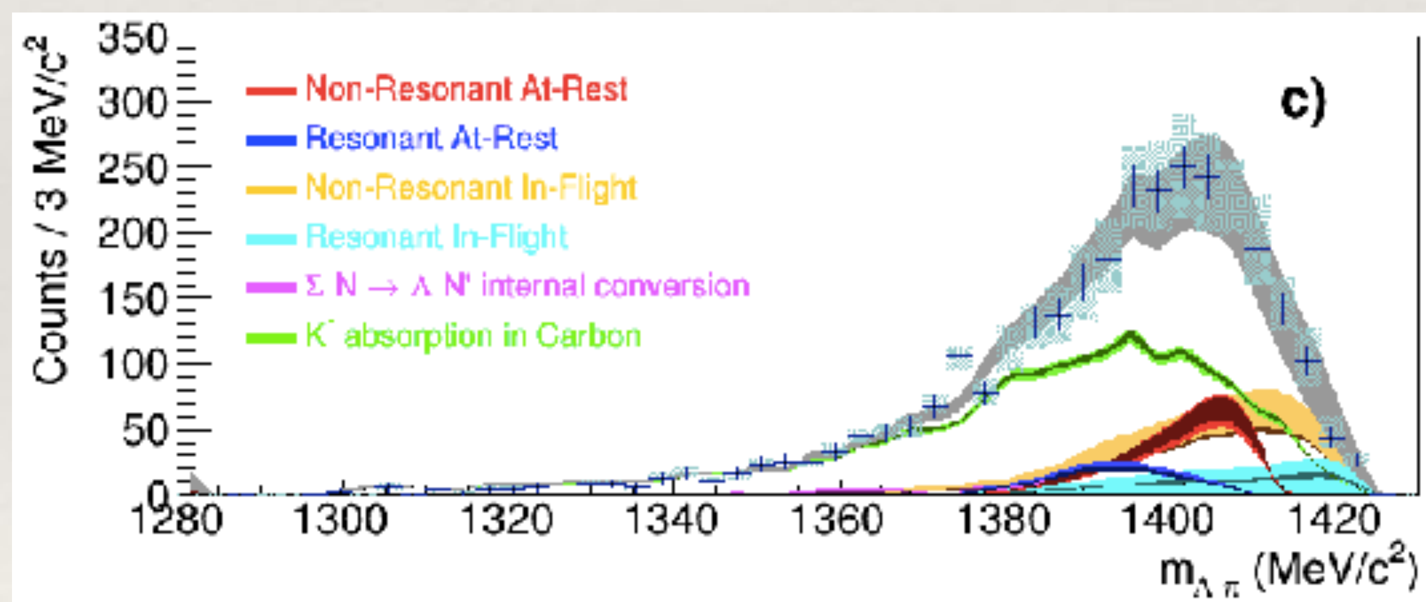
Phys. Rev. Lett. **114**, 132002 (2015)



$$K^- N \rightarrow \Lambda\pi^-$$

Resonant and Non resonant amplitude

Important to constrain the background of the $\Lambda(1405)$

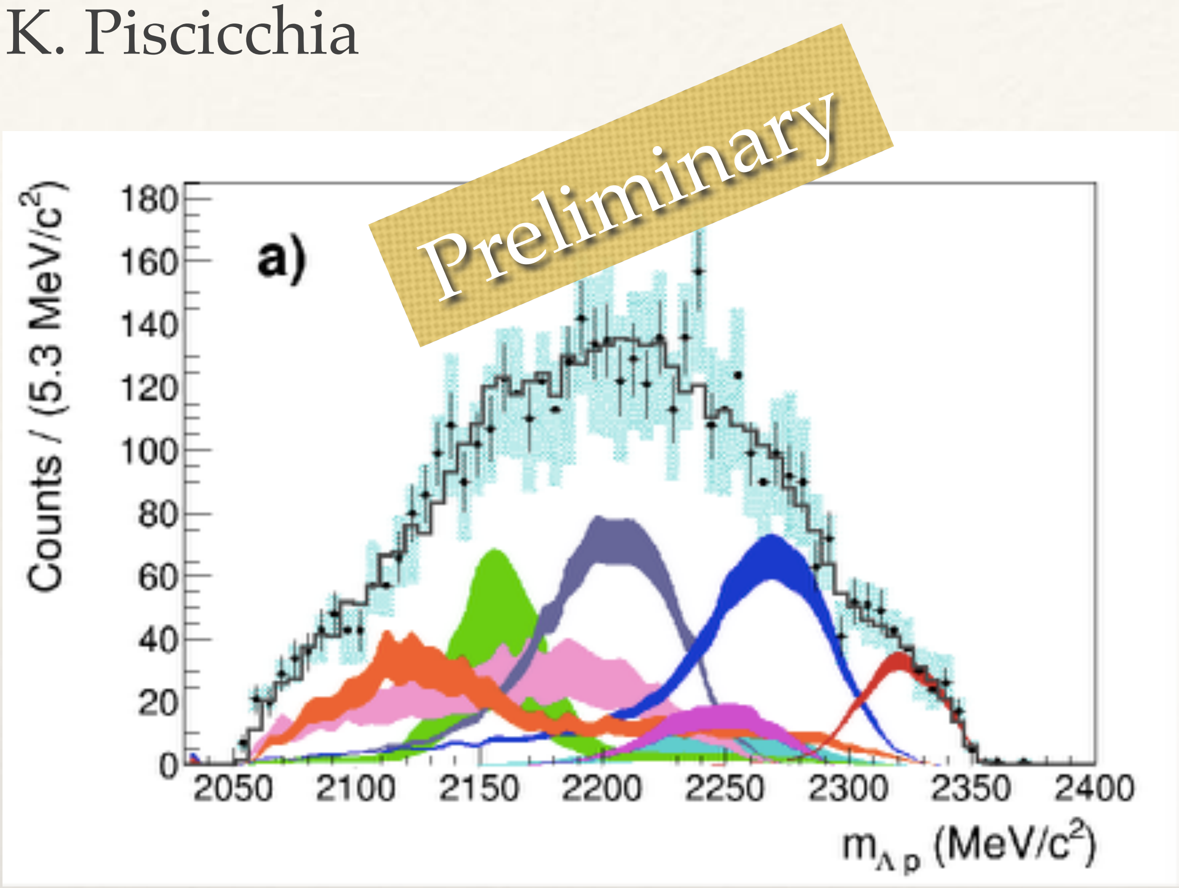


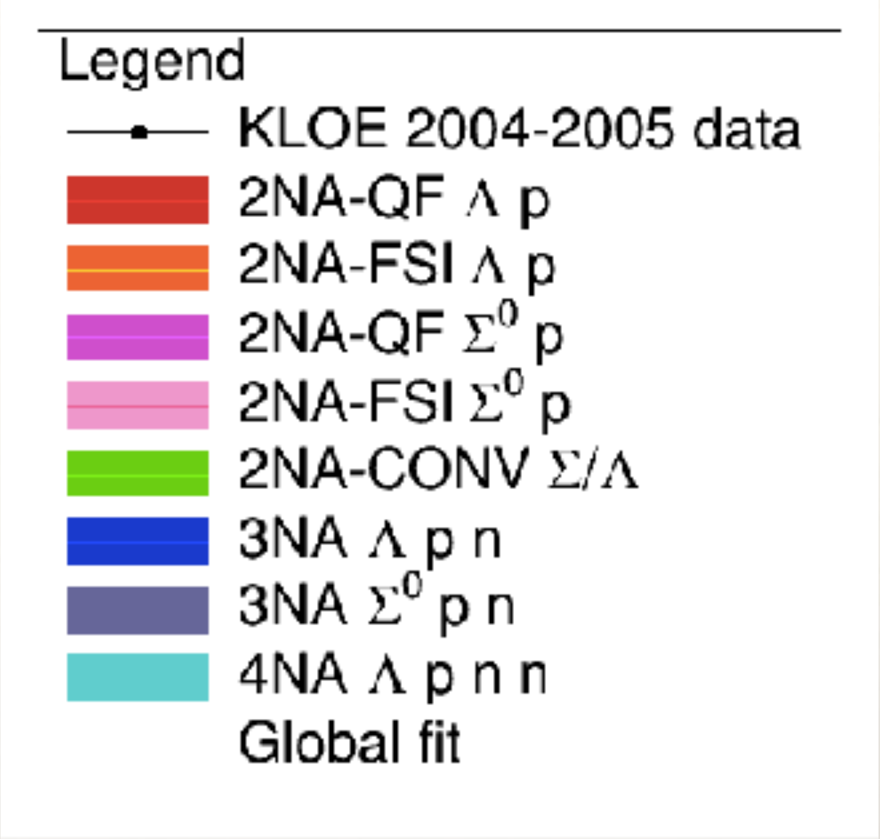
K. Piscicchia et al. Phys.Lett. B782 (2018) 339345

Reaction mechanism included in the theoretical calculations!!
Currently Experimentalists are partially doing the job by themselves

$\overline{K}$-Nucleon interaction

K. Piscicchia





Phys. Lett. B, 758, 134-139 (2016)

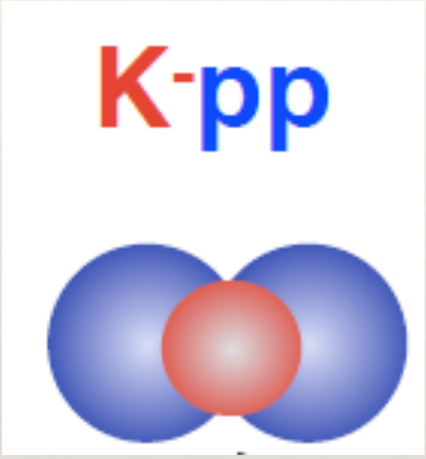
Nucl. Phys. A, 954, 75-93 (2016).

Spectra are described in terms of K^- multi nucleon absorption processes only

No kaonic bound states for slow absorbed K^-

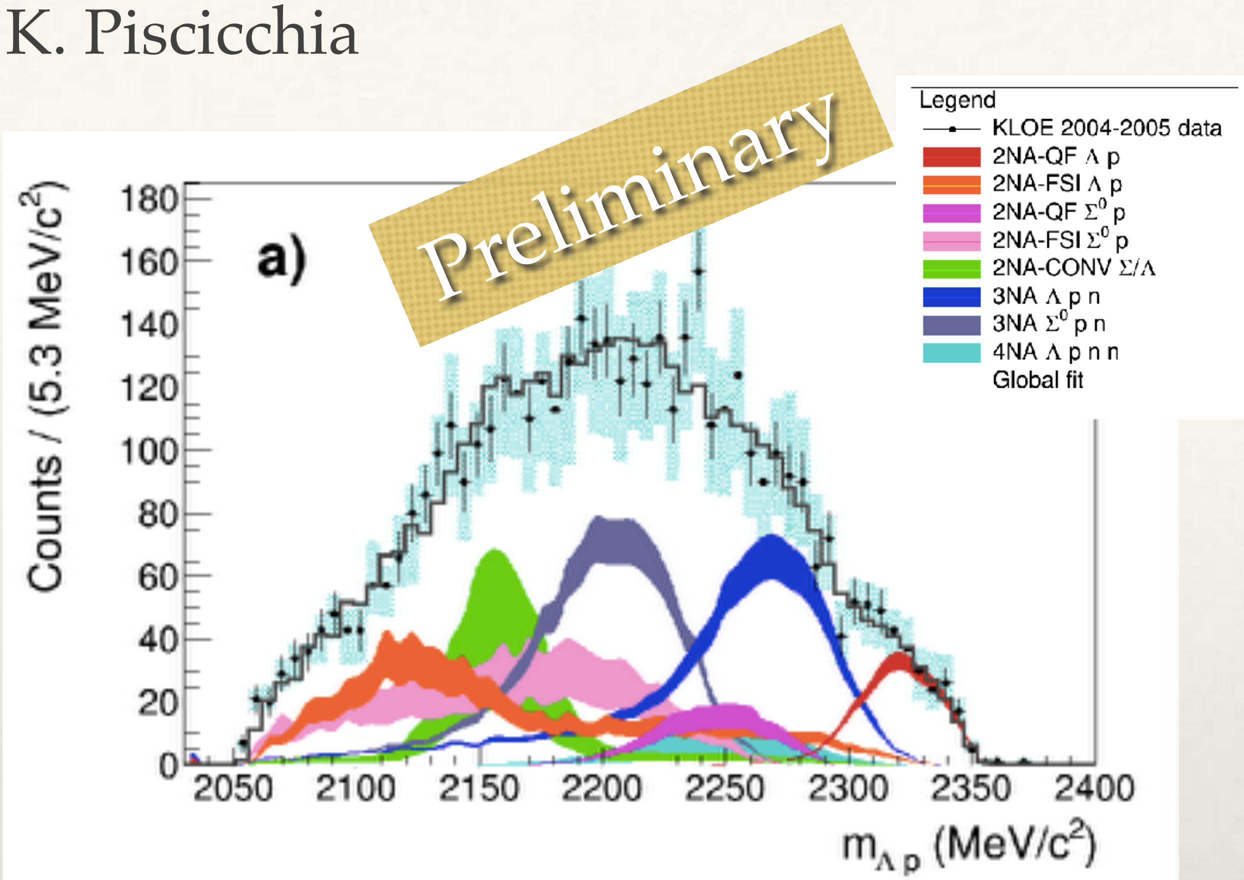
Kaonic Bound States

A lot of wrongly interpreted results on the market
Ex: FINUDA and DISTO



Kaonic Bound States

K. Piscicchia



Phys. Lett. B, 758, 134-139 (2016)

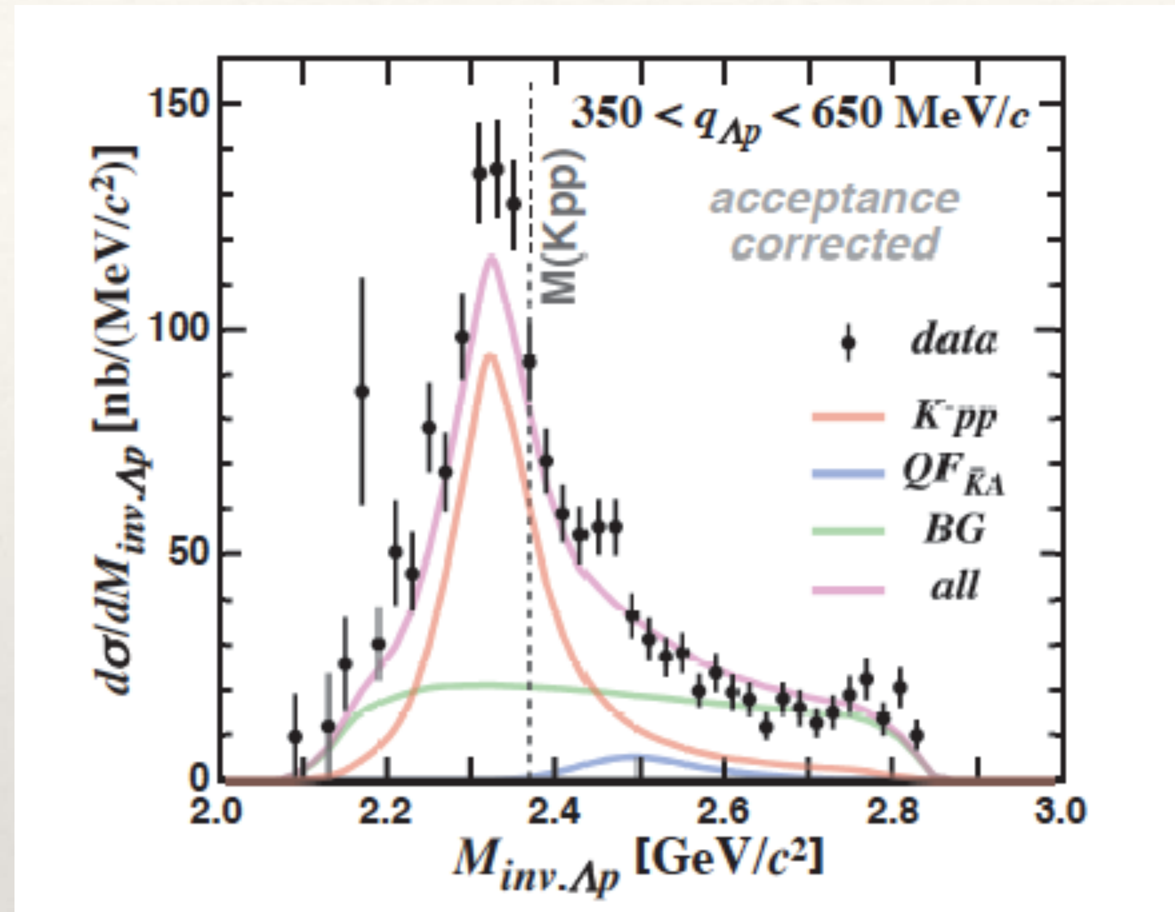
Nucl. Phys. A, 954, 75-93 (2016).

Spectra are described in terms of K- multi nucleon absorption processes only

No kaonic bound states for <u>slow</u> absorbed K-

F. Sakuma

E15@JPARC arXiv:1805.12275



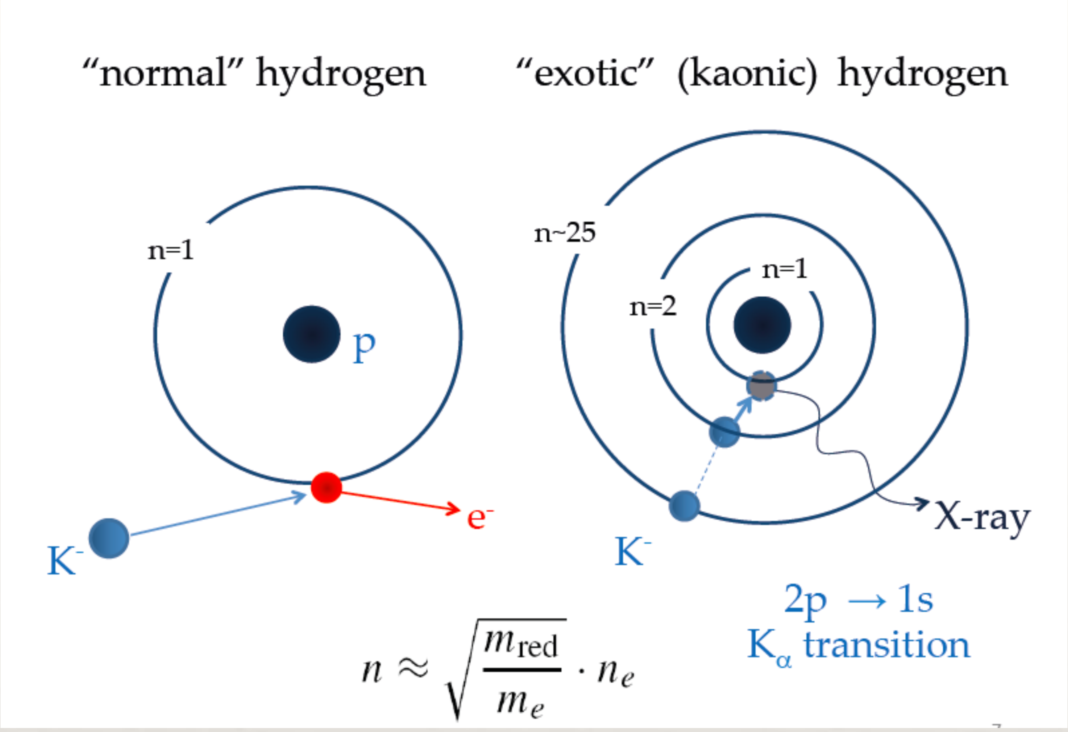
$$B_{Kpp} = 47 \pm 3(stat.)^{+6}_{-3}(sys.)\ \mathrm{MeV/c^2}$$

$$\Gamma_{Kpp} = 115 \pm 7(stat.)^{+10}_{-9}(sys.)$$

Kaonic bound states for <u>fast</u> interacting K-

Meson-Baryon Interaction

Kaonic hydrogen and deuterium



ε_{1S}= −283 ± 36(stat) ± 6(syst) eV

Γ_{1S}= 541 ± 89(stat) ± 22(syst) eV

Physics Letters B704 (2011) 113

$$\epsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3\mu_c^2 a_p\left(1 - 2\alpha\mu_c(\ln\alpha - 1)a_p\right)$$

$$a_{K^-p} = \frac{1}{2}[a_0 + a_1]$$

$$a_{K^-n} = a_1$$

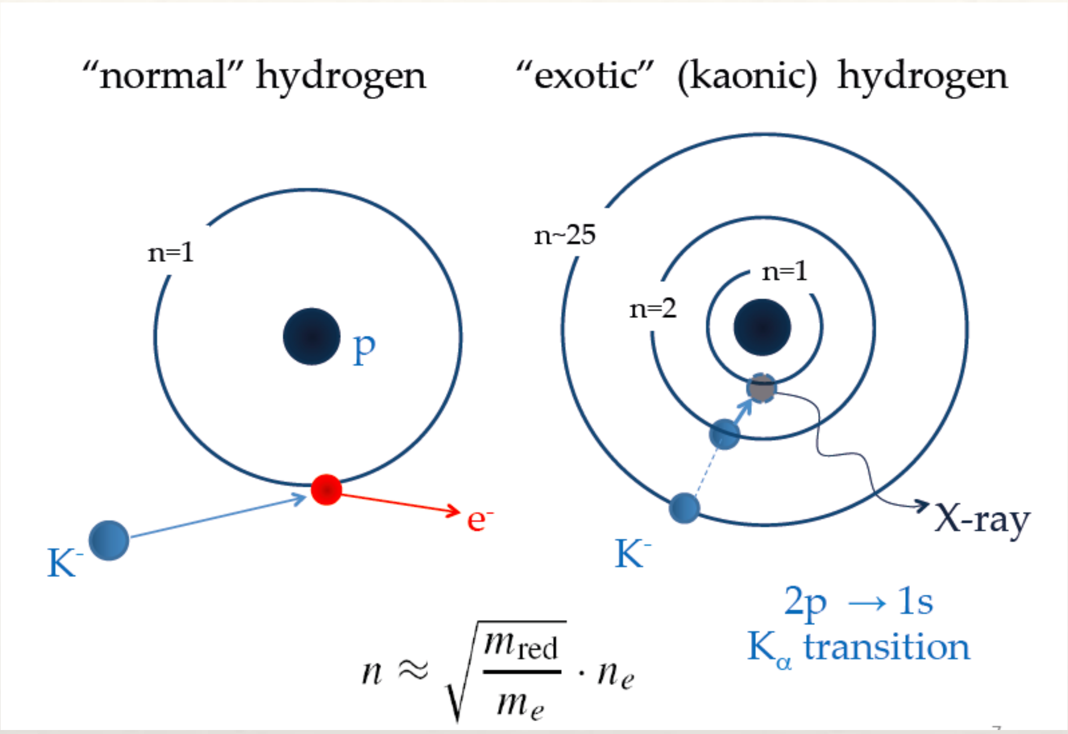
$$a_{K^-d} = [a_0 + 3a_1]Q + C$$

$$Q = \frac{[m_N + m_K]}{[2m_N + m_K]}$$

J. Marton

Meson-Baryon Interaction

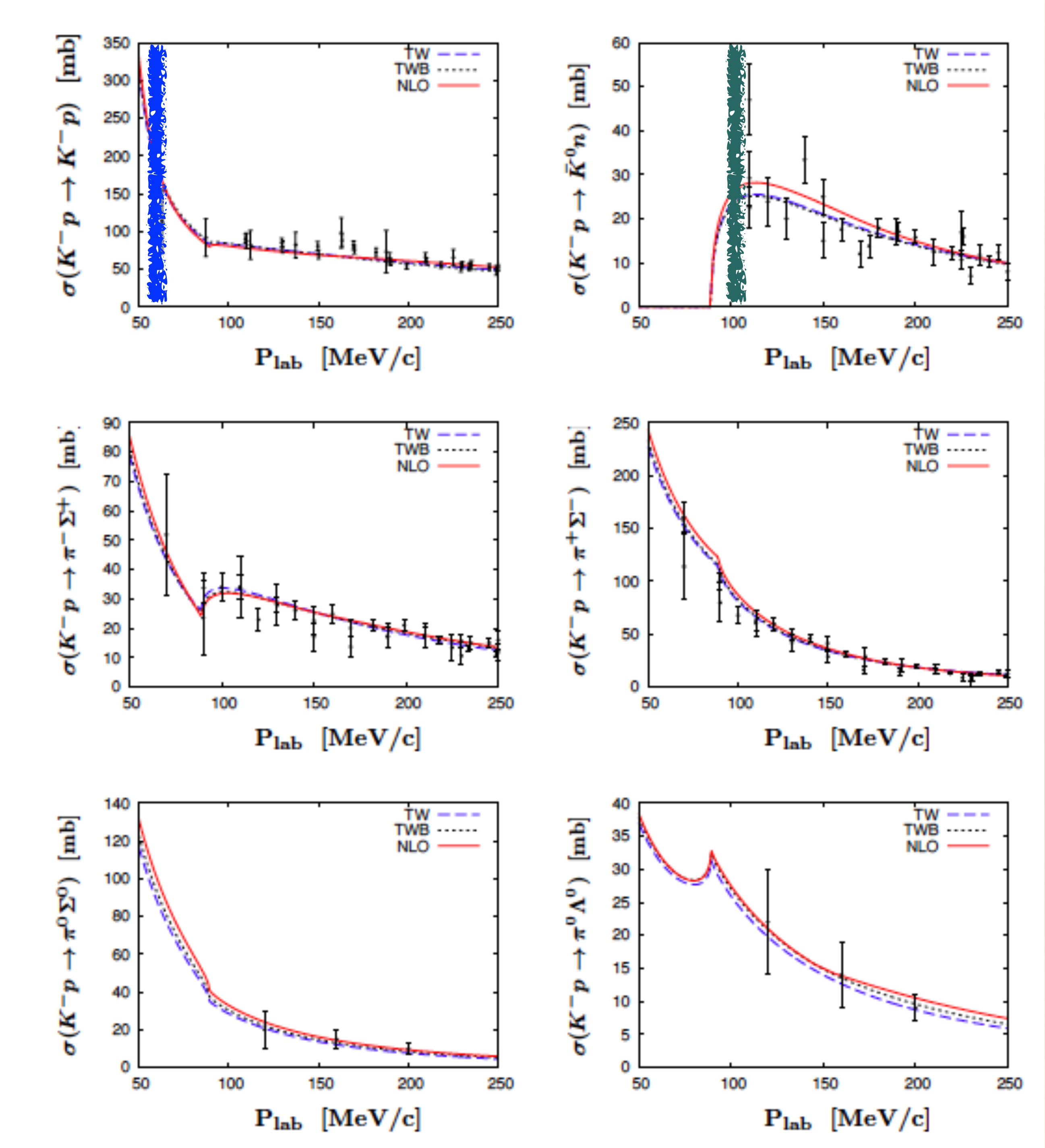
Kaonic hydrogen and deuterium + scattering Data



ε_{1S}= −283 ± 36(stat) ± 6(syst) eV

Γ_{1S}= 541 ± 89(stat) ± 22(syst) eV

Physics Letters B704 (2011) 113



$$\epsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3\mu_c^2 a_p\big(1 - 2\alpha\mu_c(\ln$$

Scattering data ….

Femtoscopy in pp collisions at the LHC

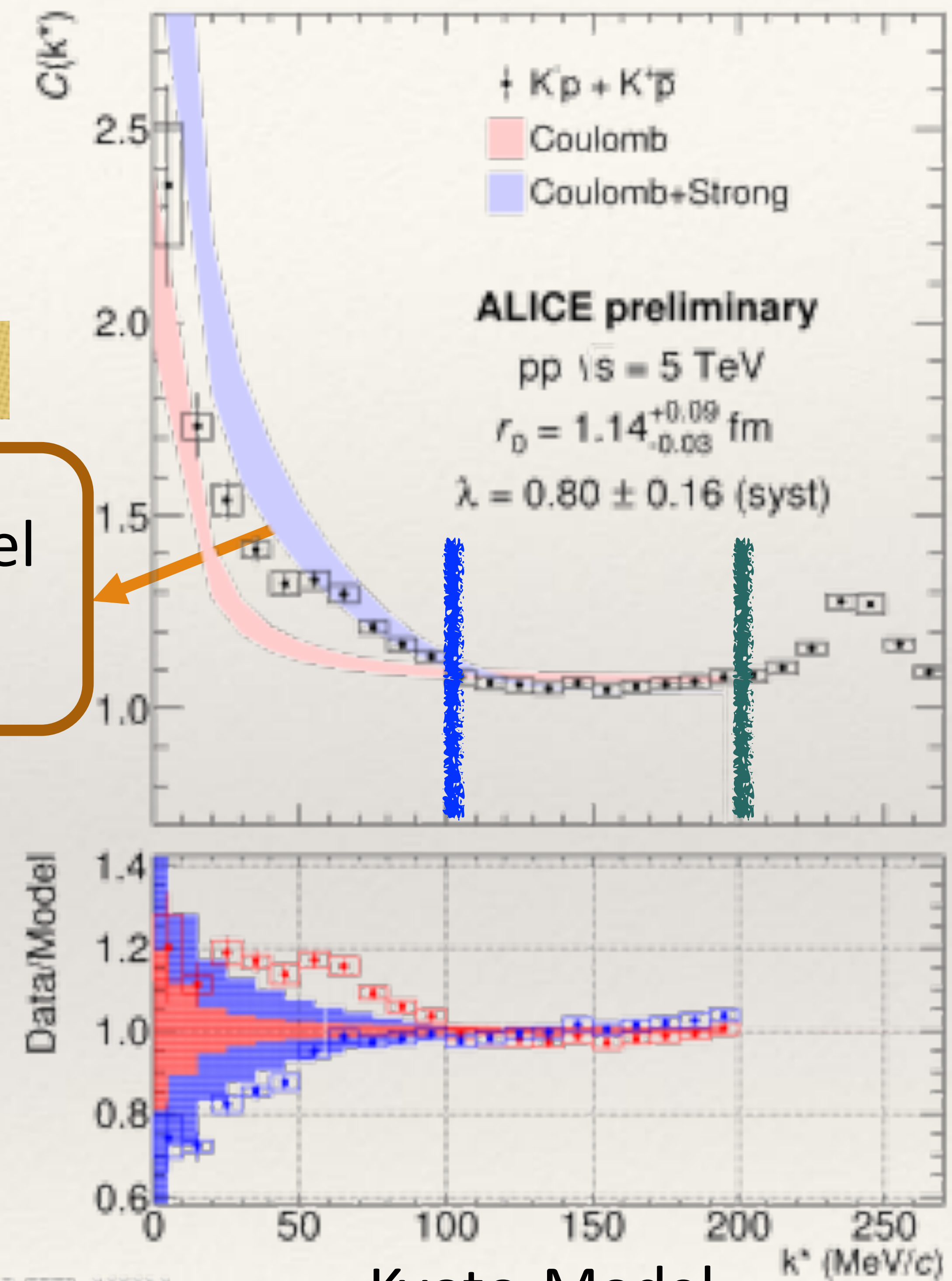
Precise data above threshold

In particular: sensitivity to **charge exchange processes**

Sensitive to the SHAPE of the K-p and K-d potential

Complementary measurements to kaonic atoms

$\overline{K^0}$n channel opening



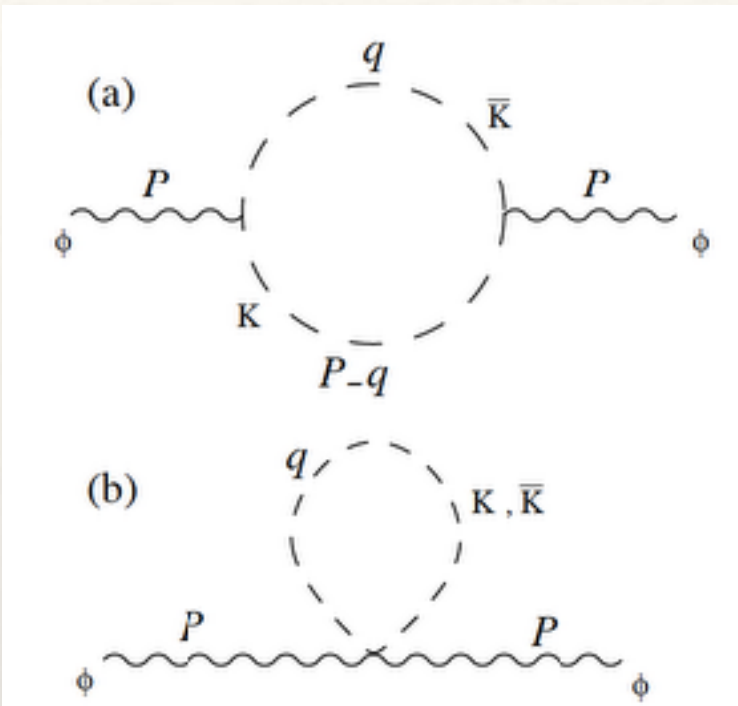
Kyoto Model

2) (Hyodo et al., Phys.Rev. C95 (2017) no.6,065202)

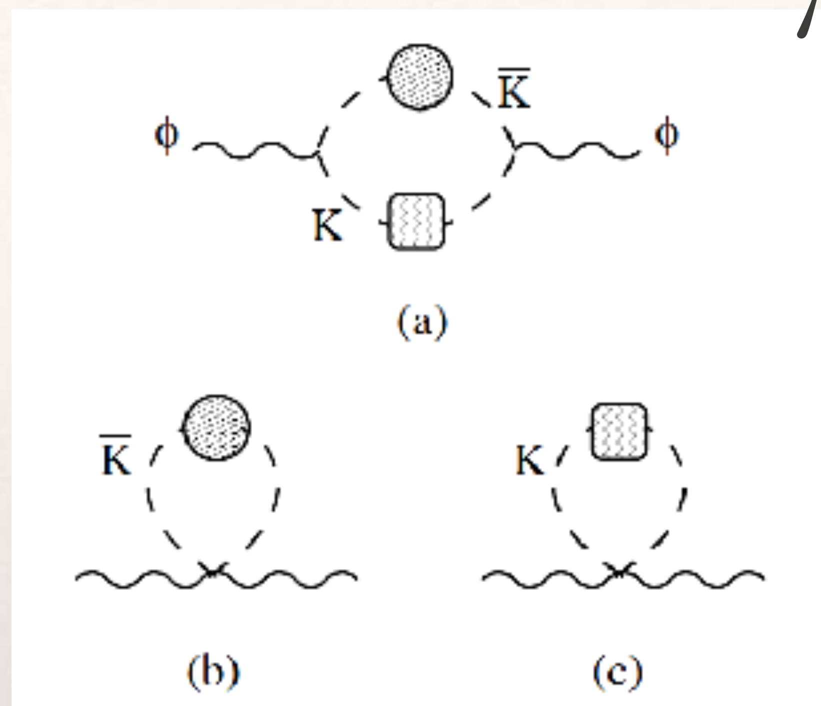
ϕ Coupling to $\bar{K}$

J. Wirth

In Vacuum



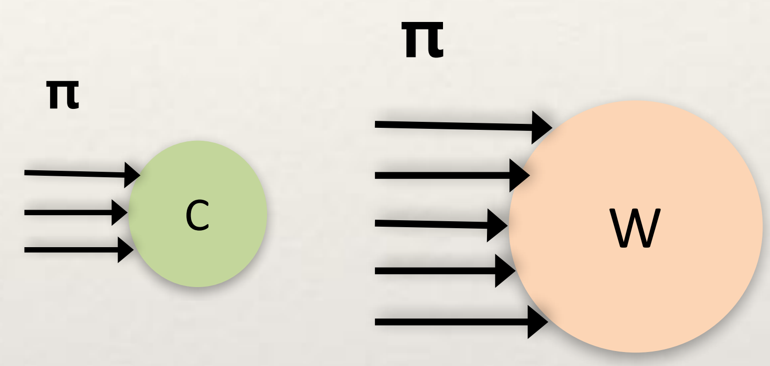
In Medium

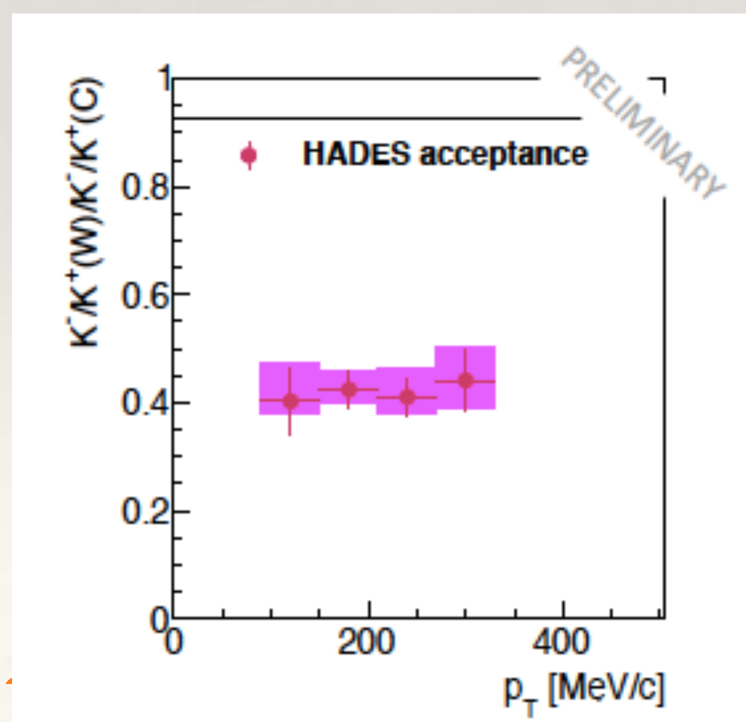


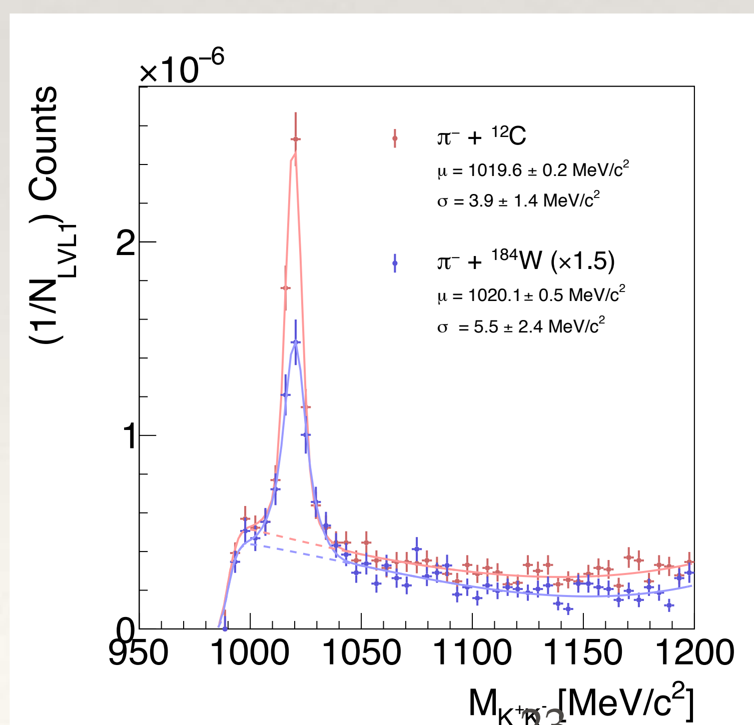
D. Cabrera et al. PHYSICAL REVIEW C 67, 045203 (2003)

π-induced reactions off light and heavy targets (HADES, GSI)

$$P_\pi = 1.7\,\mathrm{GeV/c}$$







$$\phi/K^- = 0.58 \pm (0.044)^{stat} {}^{+0.059^{syst}}_{-0.061^{syst}}$$

$$\phi/K^- = 0.63 \pm (0.057)^{stat} \pm 0.1^{syst}$$

Measure them together !

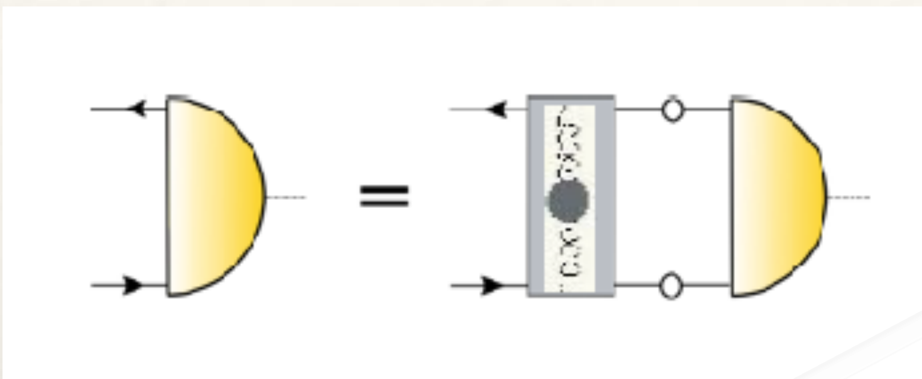
Exotics states: our attempt to extend the quark models

First light stuff

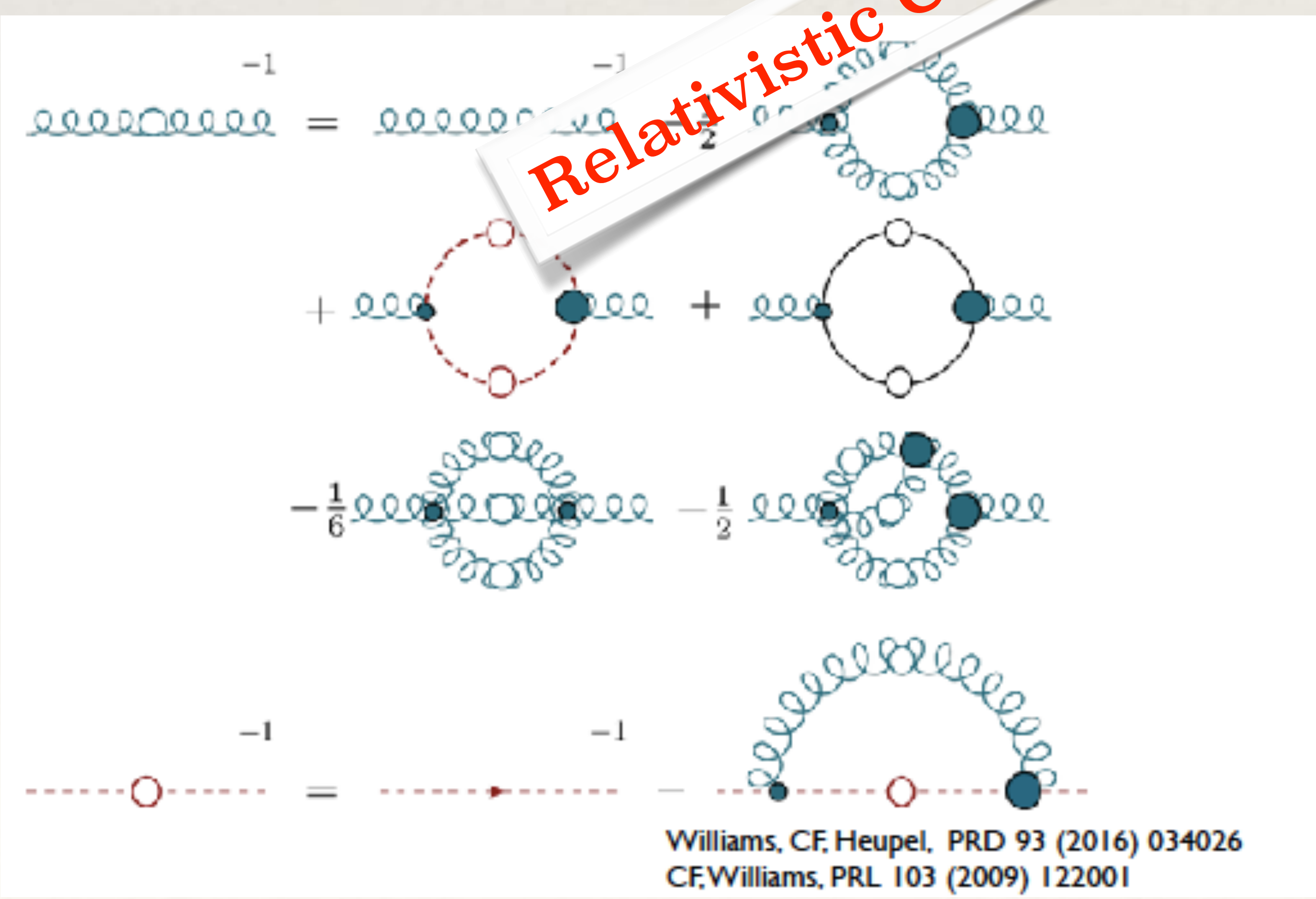
Exotic predictions in the light sector

C. Fischer

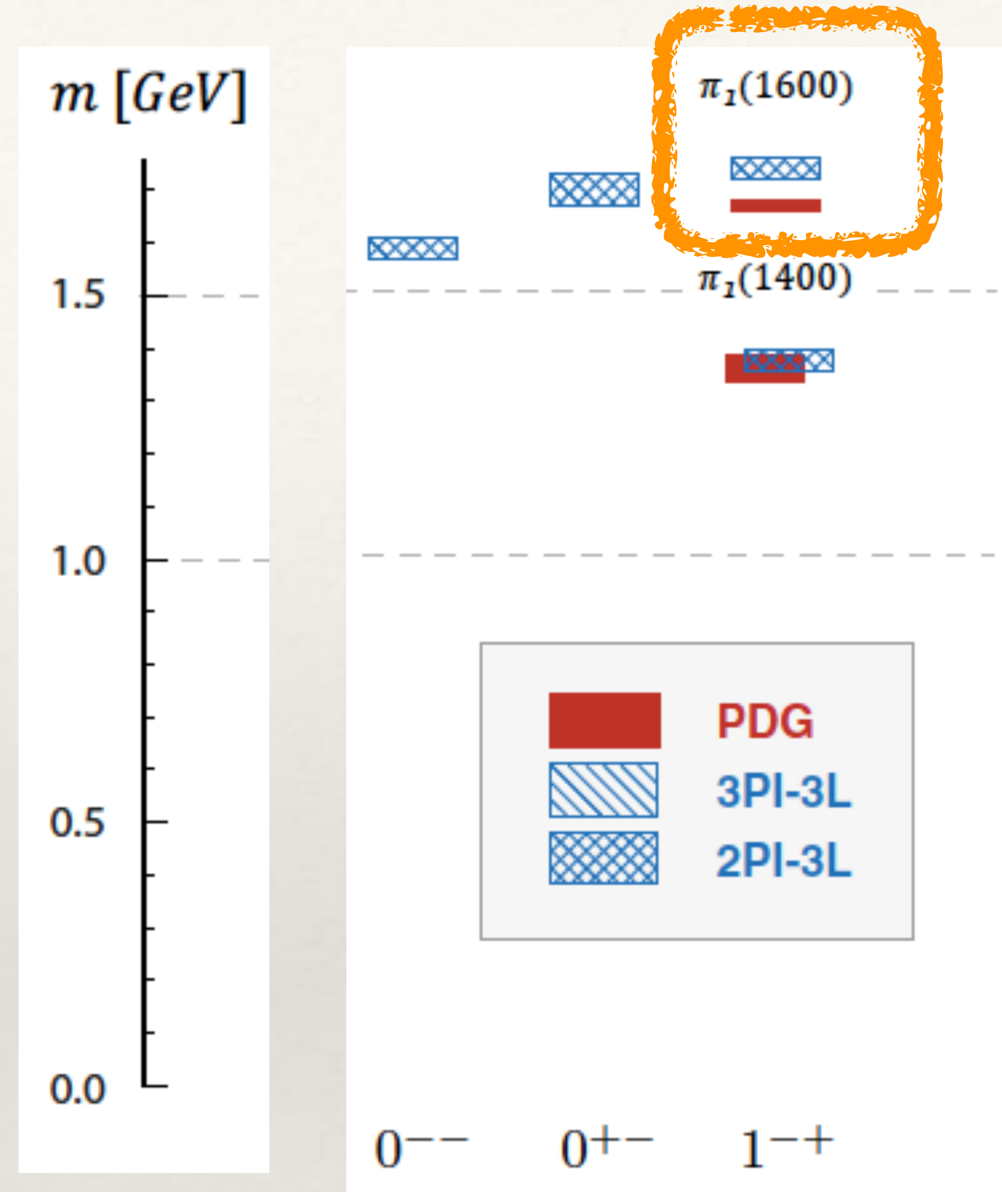
Rainbow Ladder and beyond



Relativistic Calculation!!



CF, Kubrak, Williams, EPJA 50 (2014) 126
Williams, CF, Heupel, PRD93 (2016) 034026



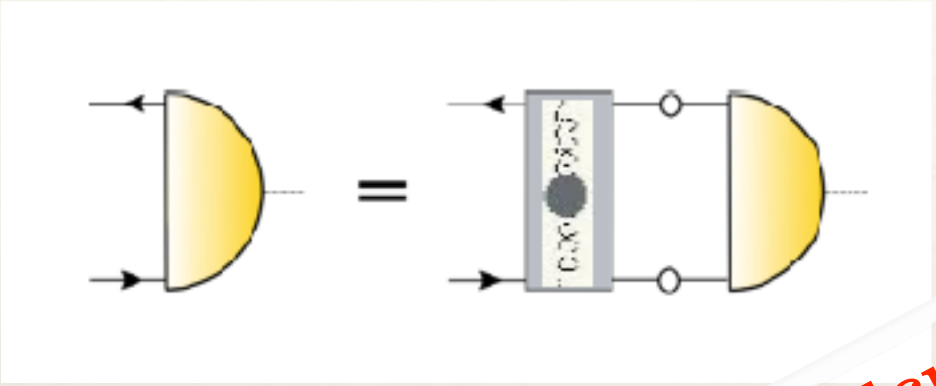
2 quarks + strong gluons interacting kernel does predict the **exotic candidate**

COMPASS coll. Phys.Rev.Lett.104:241803,2010

Exotic predictions in the light sector

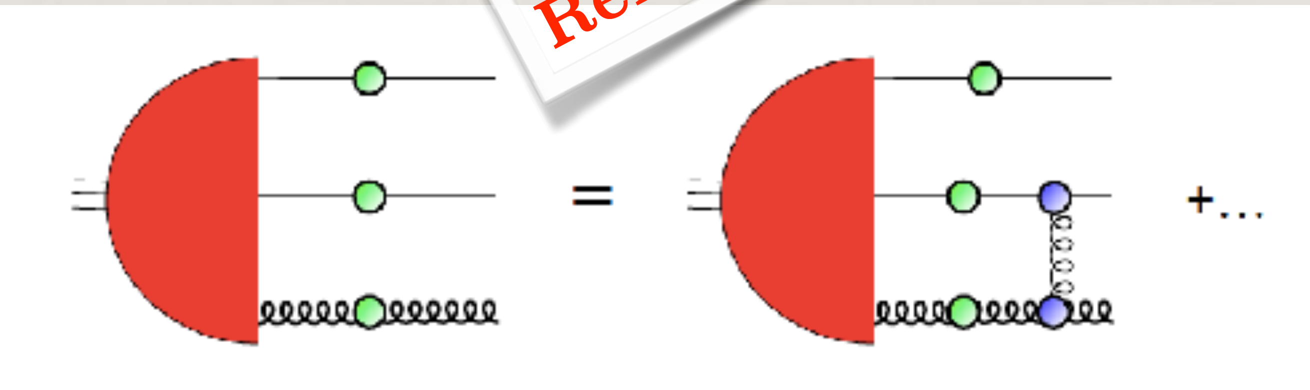
C. Fischer

Rainbow Ladder and beyond



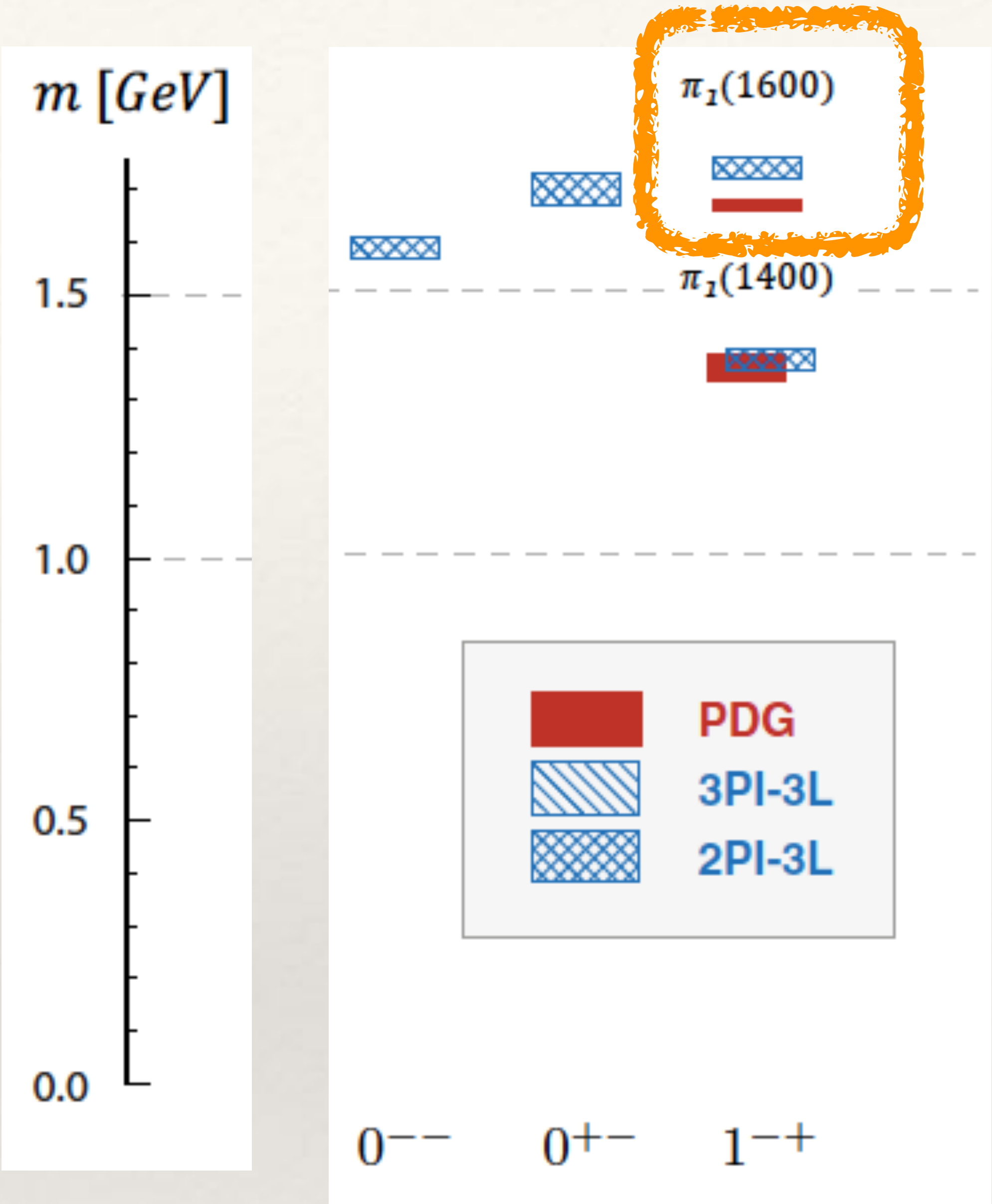
Outlook:

Relativistic Calculation!!



2 quarks + valence gluon
-> Will the same come out??

CF, Kubrak, Williams, EPJA 50 (2014) 126
Williams, CF, Heupel, PRD93 (2016) 034026

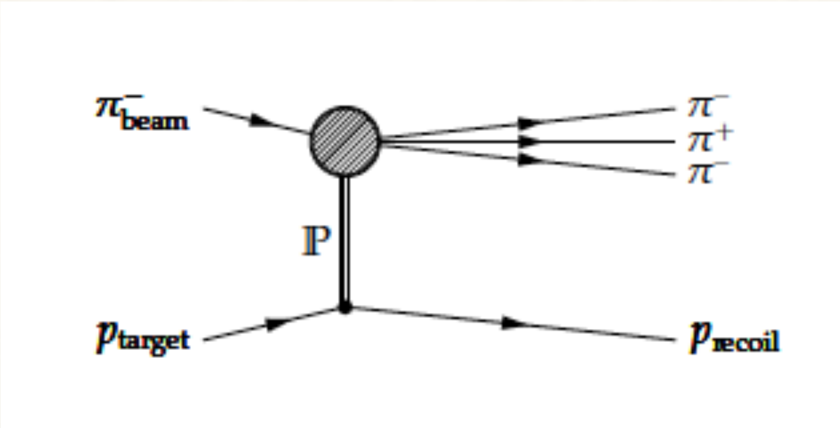


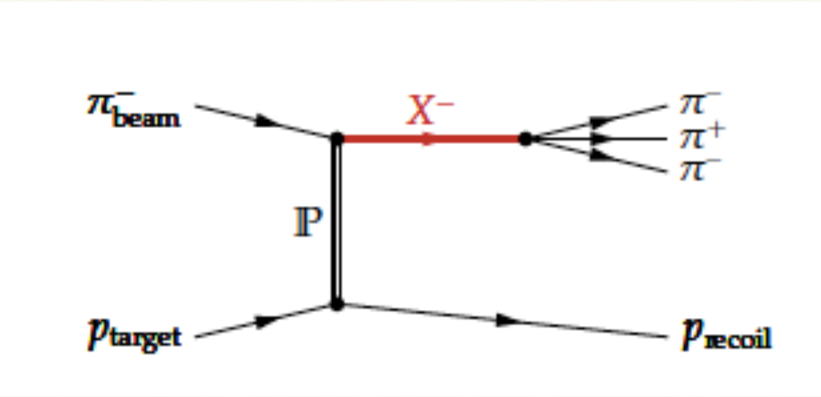
2 quarks + strong gluons interacting kernel does predict the **exotic candidate**

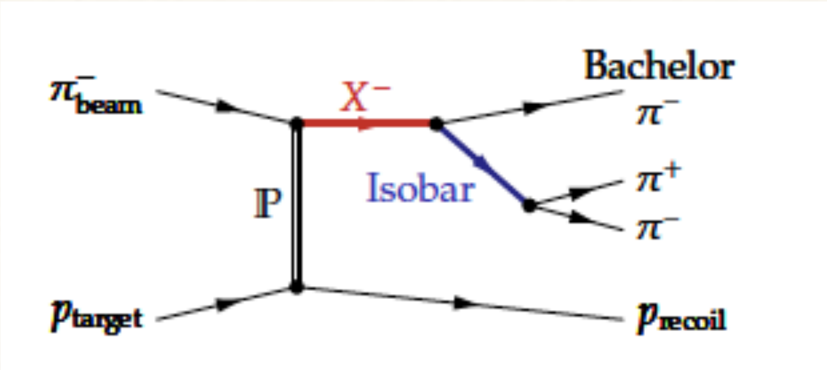
COMPASS coll. Phys.Rev.Lett.104:241803,2010

Diffractive 3π Production

J. Friedrich, F. Krinner





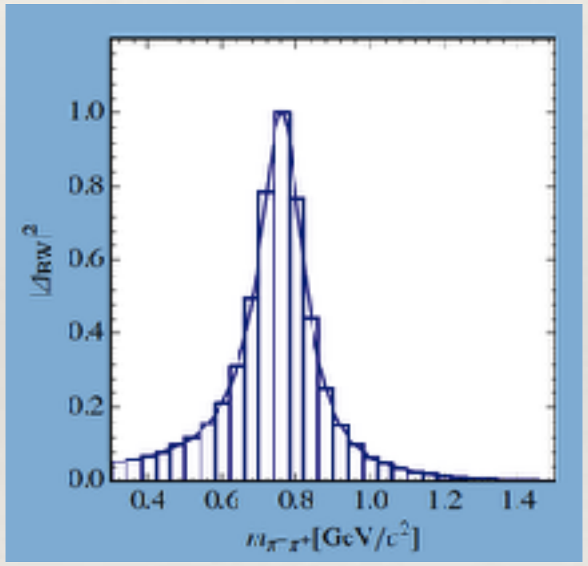


Good old $\pi_1(1600)$

ONLY exotic candidate

Confirmation with a2 partner

$$\Delta_{BW}(m) = \frac{m_0\Gamma_0}{m_0^2 - m^2 - i m_0\Gamma_0}$$



Freed-isobar analysis: much more freedom than fixed-isobar analysis

New Method with non-fixed shapes for the amplitudes

Not yet tried out on $\pi_1(1600)$

$a_2(1420)$: The fake exotic

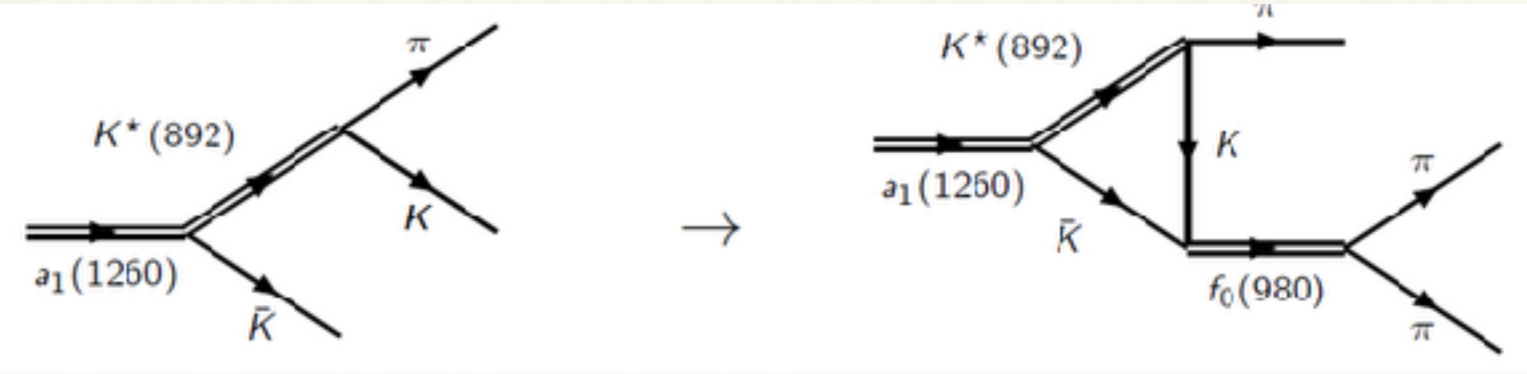
J. Friedrich, F. Krinner

- Mass:

$m_{a_1(1420)} = 1411.8^{+1.0}_{-4.4}$ MeV/c^2

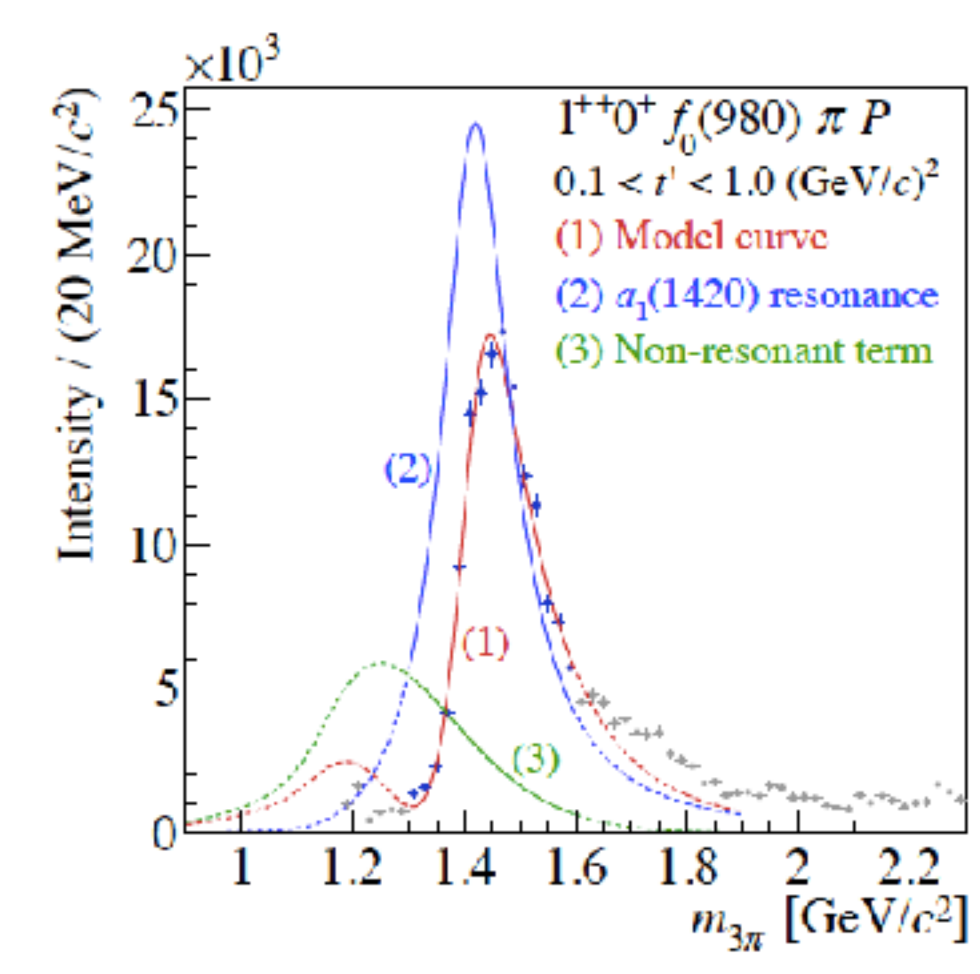
Width:

$\Gamma_{a_1(1420)} = 158^{+8}_{-8}$ MeV/c^2



Plublished as a resonance by COMPASS
Interpreted as the signature of "scattering" in three different models

* M. Mikhasenko, B. Ketzer, and A. Sarantsev, Phys. Rev. D 91, 094015 (2015).
* X. H. Liu, M. Oka, and Q. Zhao, Phys. Lett. B 753, 297 (2016).
* F. Aceti, L. R. Dai, and E. Oset, Phys. Rev. D 94, 096015 (2016).



Why is on the PDG??

Outlook: Extending of the TUM PWA to include triangle diagrams and rescattering as waves

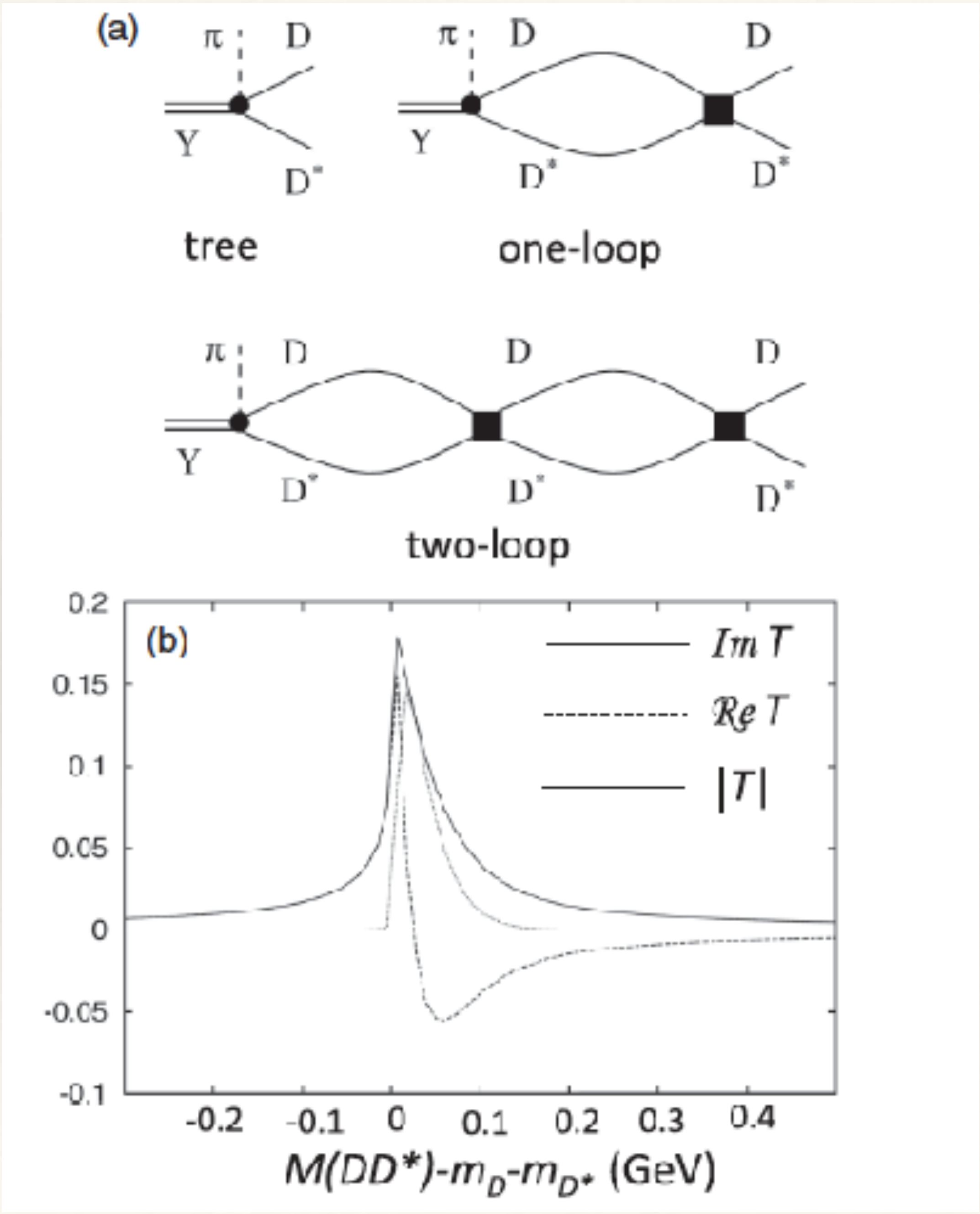
Exotics states X,Y ,Z and Pc…

The worst part of the week…

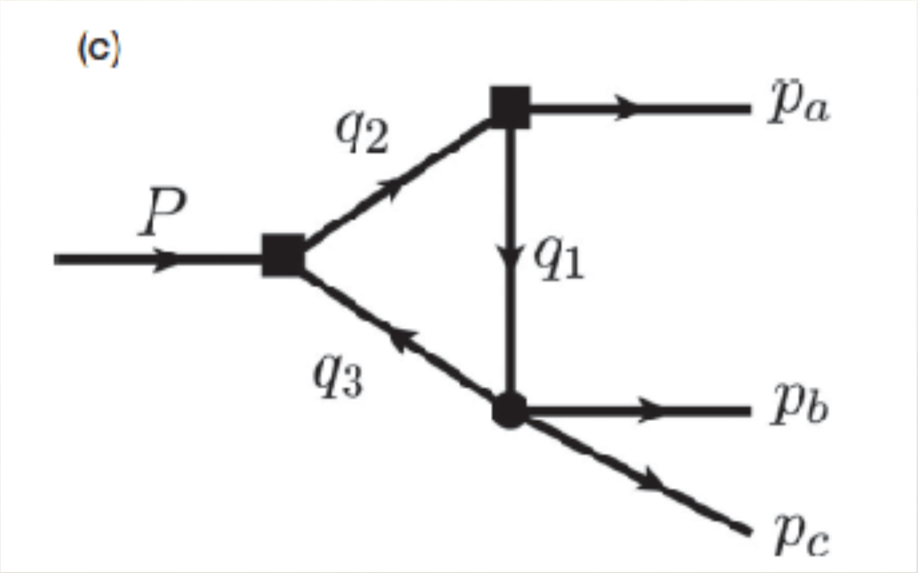
We can make use of what we have learned in SU(3)

S. Olsen et al. Rev. Mod. Phys., Vol. 90, 1, (2018)

Threshold Cusp:



Anomalous Triangle Singularity:



generates a peak in the final state if all three particles in the triangle are on-shell.

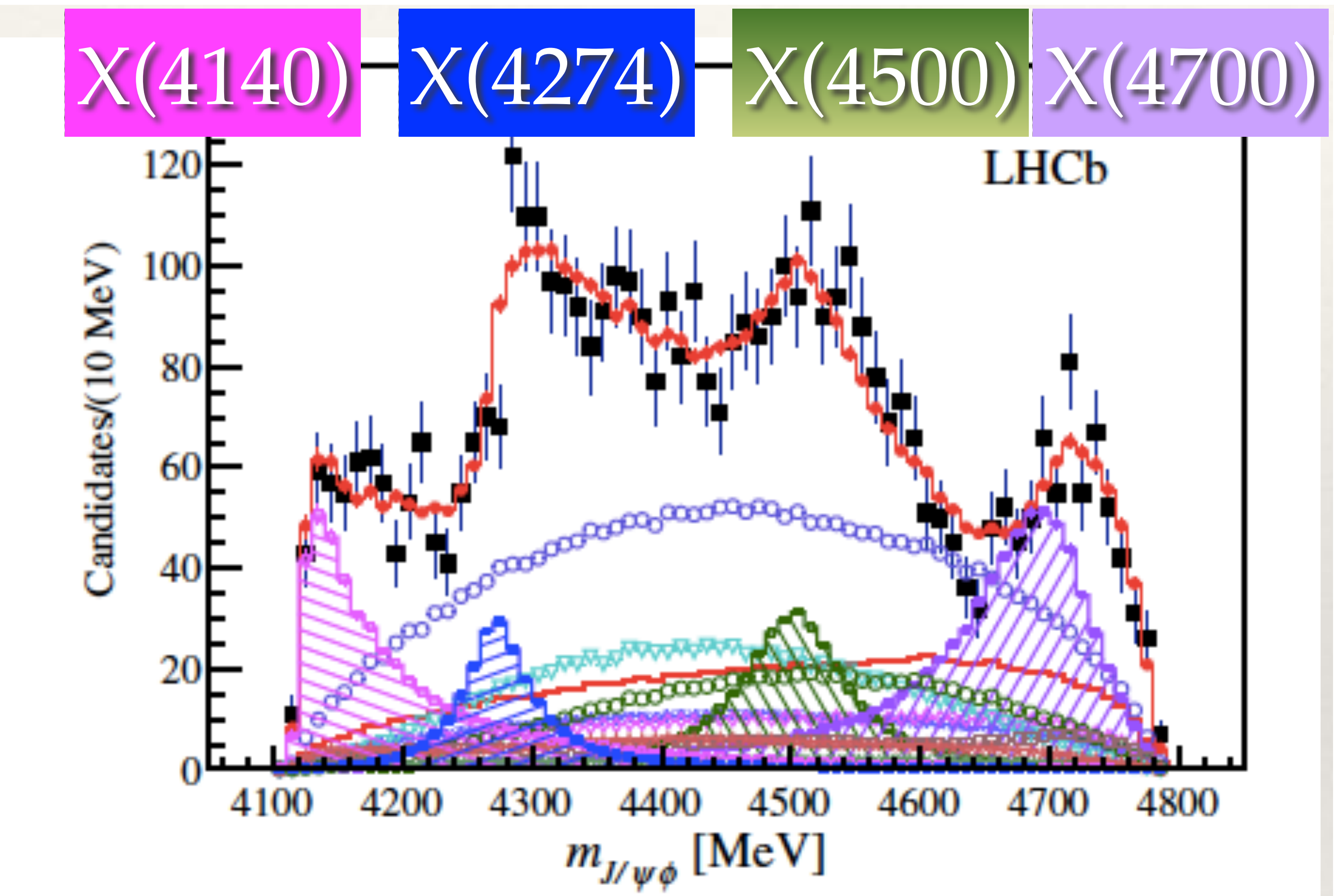
M. Kucharczyk

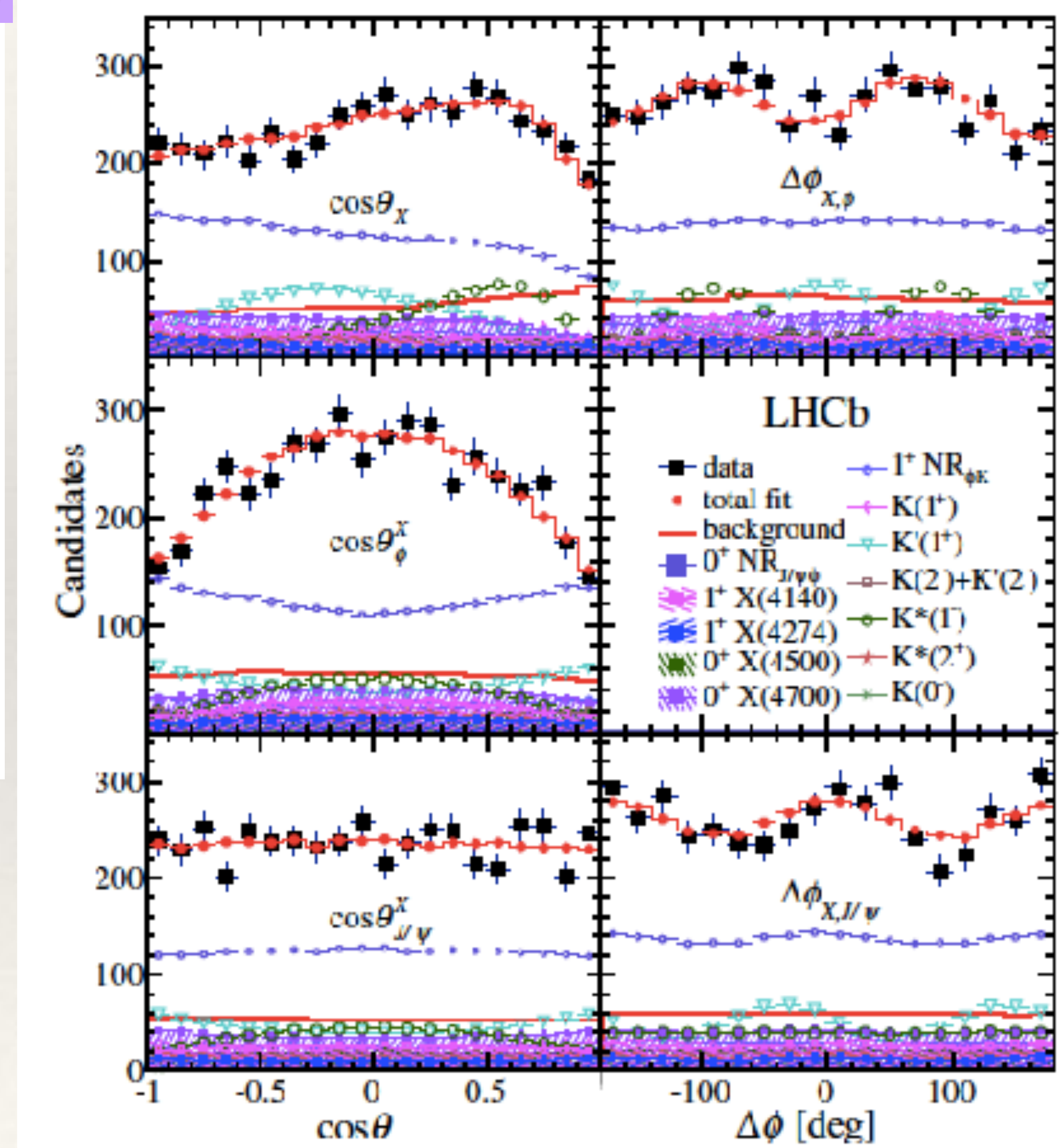
$X \to J/\psi\phi$ States (LHCb)

LHCb: Full amplitude fit to $B^+ \to J/\psi\, \varphi\, K^+$

[PRL 118 (2017) 02203]
[PR D95 (2017) 012002]

- Run 1, 3fb^{-1} *(4289 ± 151 candidates with minor background)*
- 6D phase space: $m(\varphi K)$, helicity angles and $\Delta\varphi$ angles
- includes interferences between $B \to J/\psi K^*$, $K^* \to \varphi K$ and $B \to X^0 K$, $X^0 \to J/\psi\varphi$

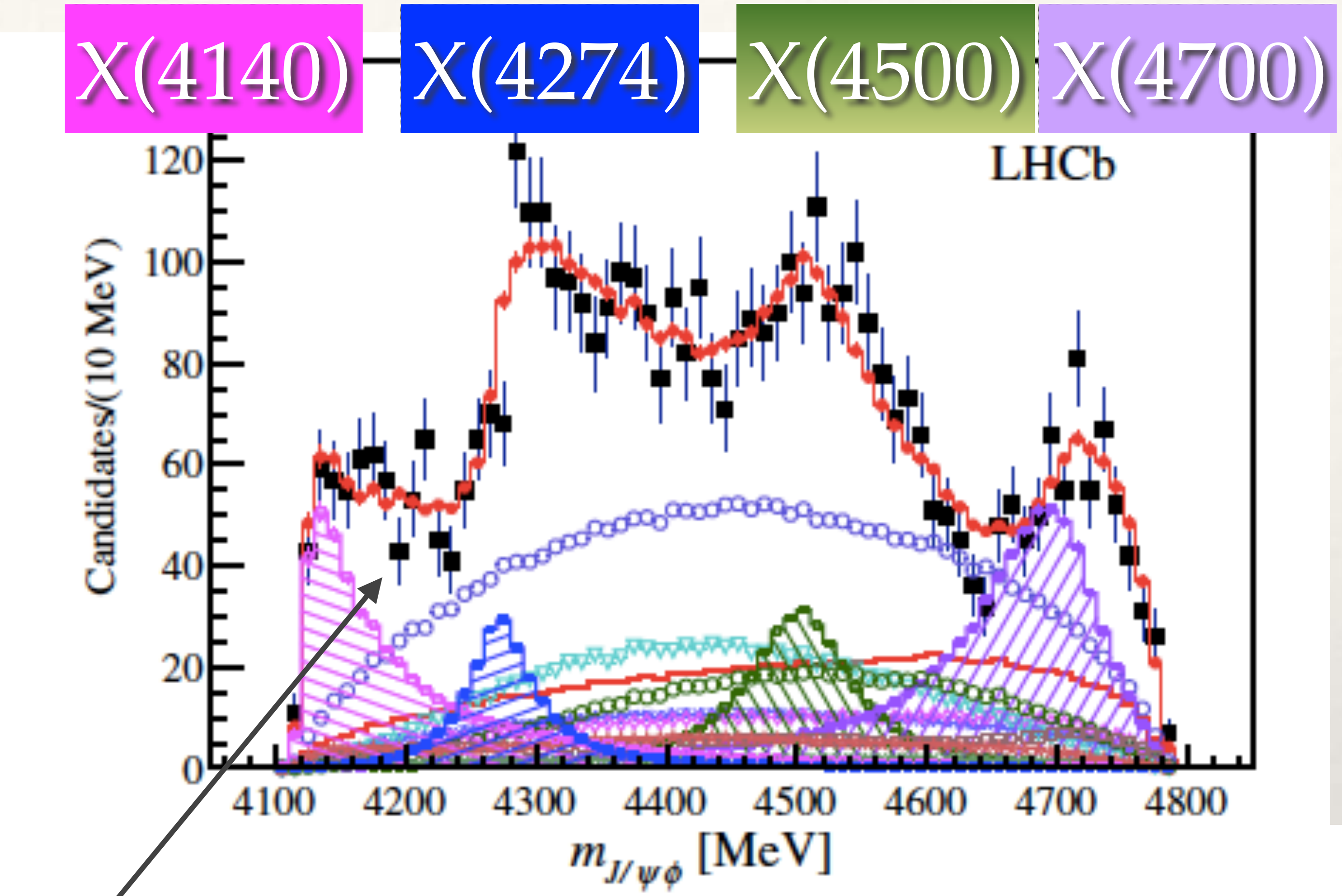


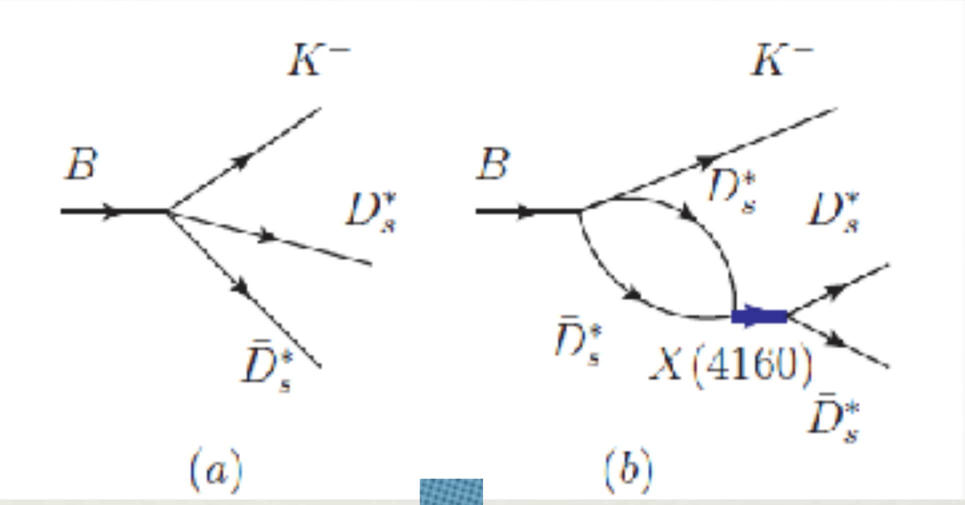


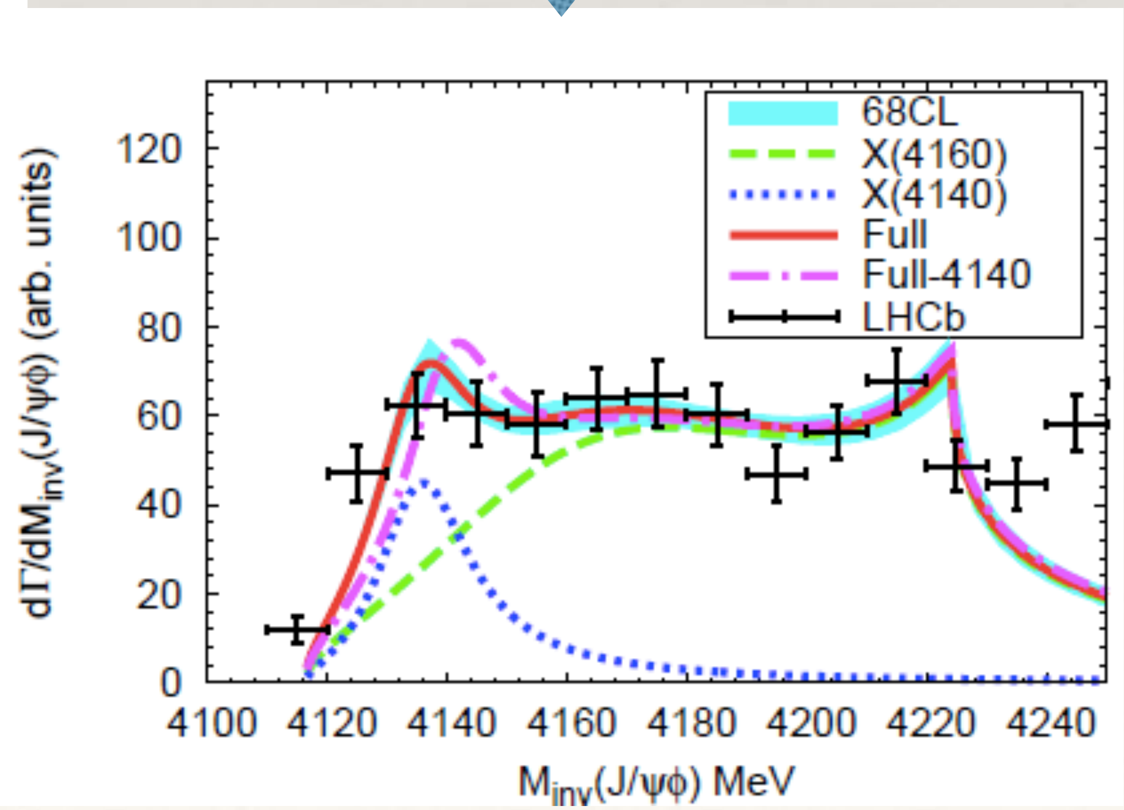
Even with PWA one can not disentangle all the properties of the states

X(4140), X(4274) incompatible with cusps or molecular bound states maybe **tetraquarks**

Alternative explanation







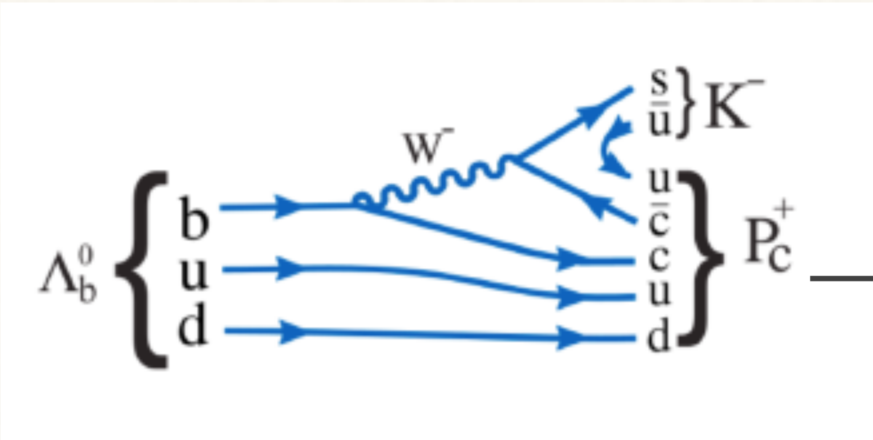
$D_S^* \bar{D}_S^*$ Threshold

—One correspondingto X(4140) with mass around 4135 MeV, and width around 15 MeV.

—Another one corresponding to X(4160)

--A third one corresponding to a cuspof related to $D_S^* \bar{D}_S^*$

Pentaquark from LHCb



$\longrightarrow J/\Psi + p$

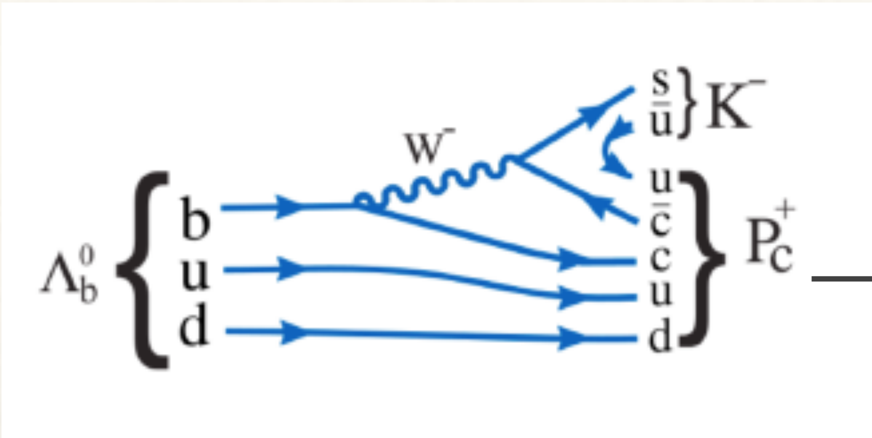
Partial Wave analysis in m(K-p) and 5 angles including

$\Lambda_b^0 \to J/\psi \Lambda^*, \Lambda^* \to pK^-$ $\Lambda_b^0 \to P_c^+ K^-, P_c^+ \to J/\psi p$

If one considers only Λ^* one cannot reproduce the experimental data

State	J^P	M_0 (MeV)	Γ_0 (MeV)	# Reduced	# Extended
Λ(1405)	$1/2^-$	$1405.1^{+1.3}_{-1.0}$	50.5 ⊥ 2.0	3	4
Λ(1520)	$3/2^-$	1519.5 ⊥ 1.0	15.6 ⊥ 1.0	5	6
Λ(1600)	$1/2^+$	1600	150	3	4
Λ(1670)	$1/2^-$	1670	35	3	4
Λ(1690)	$3/2^-$	1690	60	5	6
Λ(1800)	1/2	1800	300	4	4
Λ(1810)	$1/2^+$	1810	150	3	4
Λ(1820)	$5/2^+$	1820	80	1	6
Λ(1830)	$5/2^-$	1830	95	1	6
Λ(1890)	$3/2^+$	1890	100	3	6
Λ(2100)	$7/2^-$	2100	200	1	6
Λ(2110)	$5/2^+$	2110	200	1	6
Λ(2350)	$9/2^+$	2350	150	0	6
Λ(2585)	5/2	≈2585	200	0	6

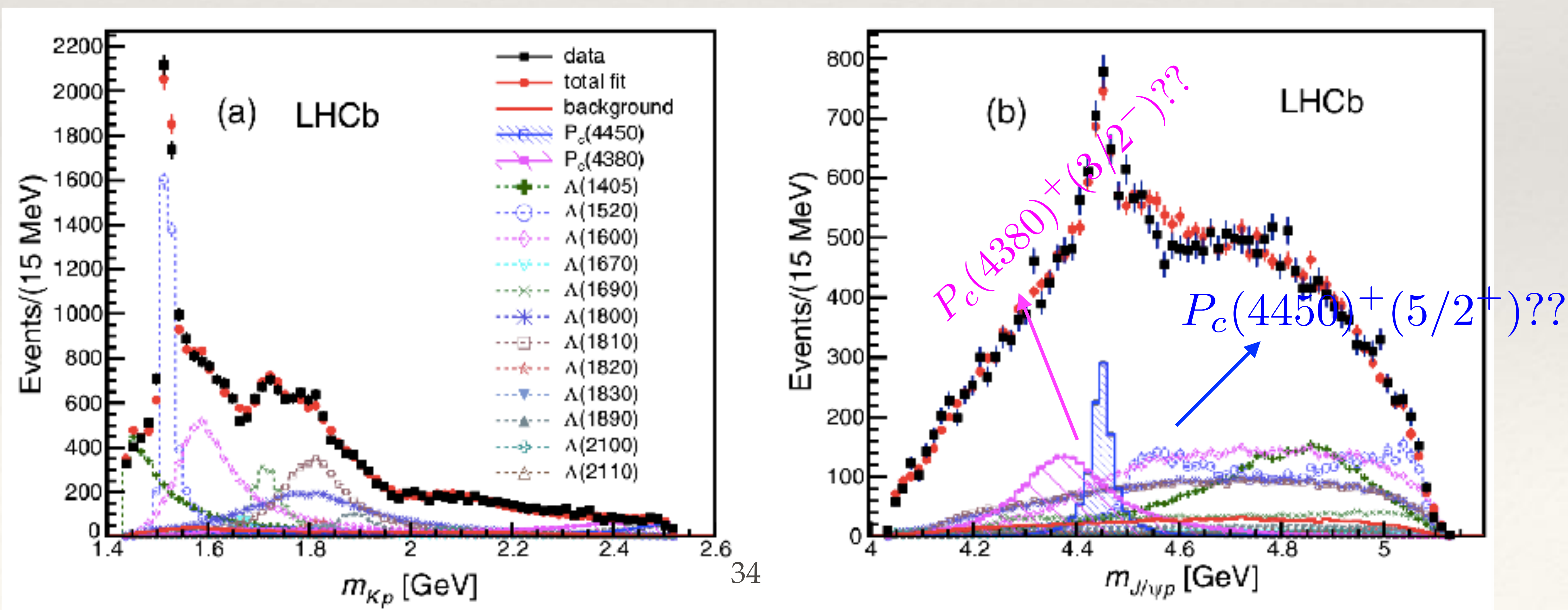
Pentaquark from LHCb



$\longrightarrow J/\Psi + p$

Partial Wave analysis in m(K-p) and 5 angles including

$$\Lambda_b^0 \to J/\psi \Lambda^*, \Lambda^* \to pK^- \quad \Lambda_b^0 \to P_c^+ K^-, P_c^+ \to J/\psi p$$



Summary

- Chiral Symmetry Restauration
  -> VM in nuclear matter and coupling to resonances
  -> Search for a_1

- Equation of State of matter under Extreme Conditions
  -> Missing resonances to be added to Hadron Resonance Gas
  -> meson-nucleon Coupling determines EoS within mean field approaches

- Low energy QCD in the u-d-s sector
  -> Kbar-N data: improve precision below and above threshold
  -> ϕ :)

- Extension of the Quark model
  -> PWA + coupled channel + rescattering + ..
  -> Lattice???