JPAC : Introduction

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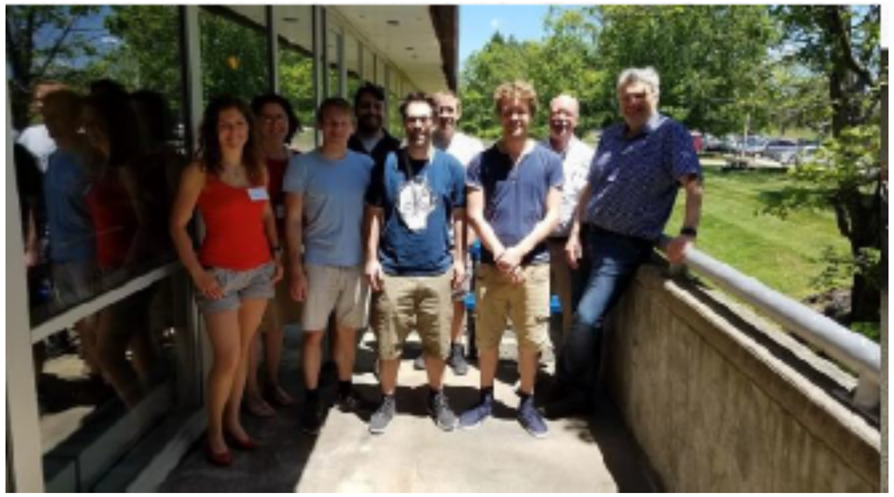
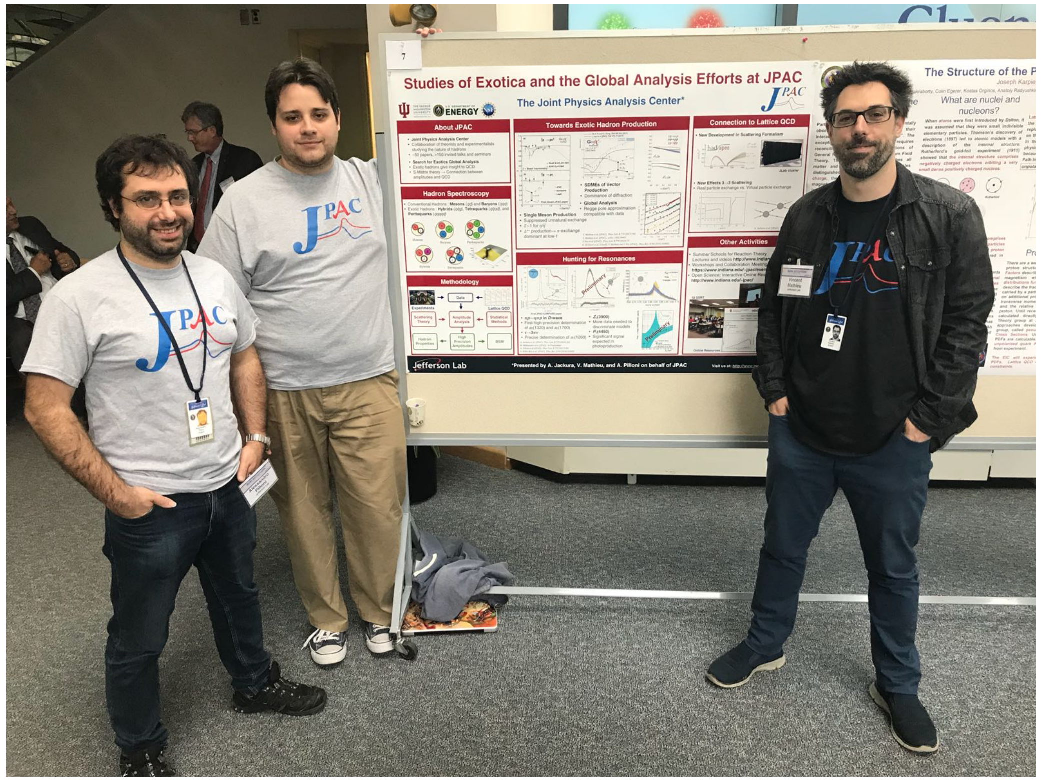
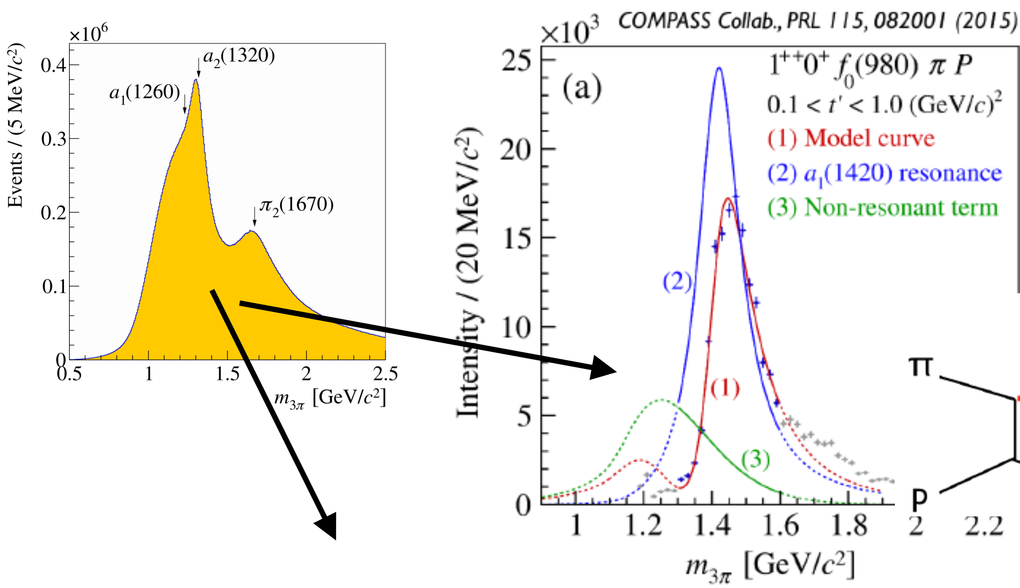
Joint Physics Analysis Center

- JPAC: theory, phenomenology and analysis tools in support of experimental data from JLab12 and other accelerator laboratories.
- Contribute to education of new generation of practitioners in physics of strong interactions.
- In this talk : JPAC's role in spectroscopy analysis : Data vs QCD structure

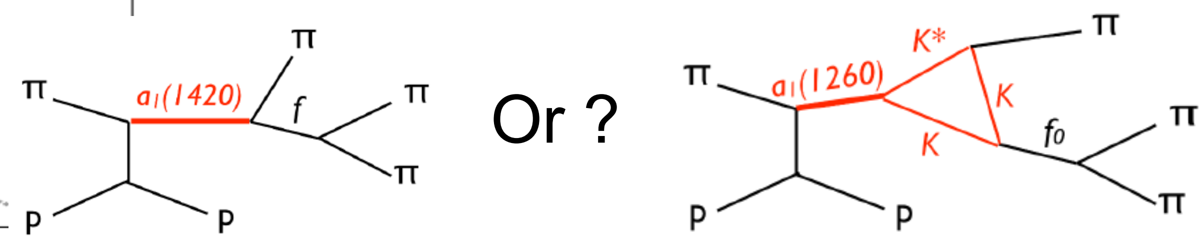




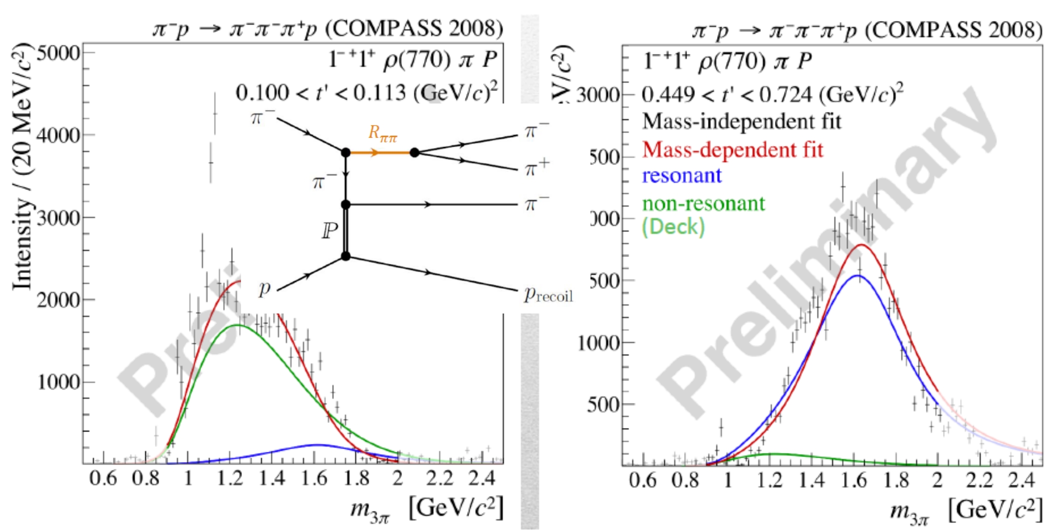
Signatures of new, unusual light resonances



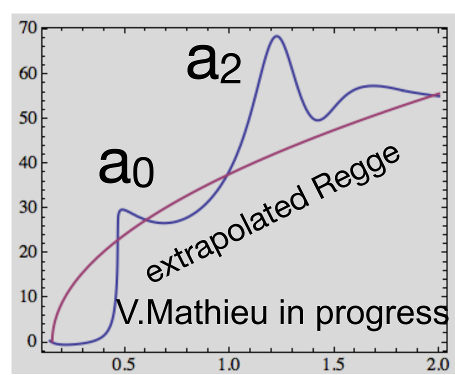
- High precision PWA of 3pi diffractive association yields a new $a_1(1420)$ incompatible with the quark model/Regge expectations.

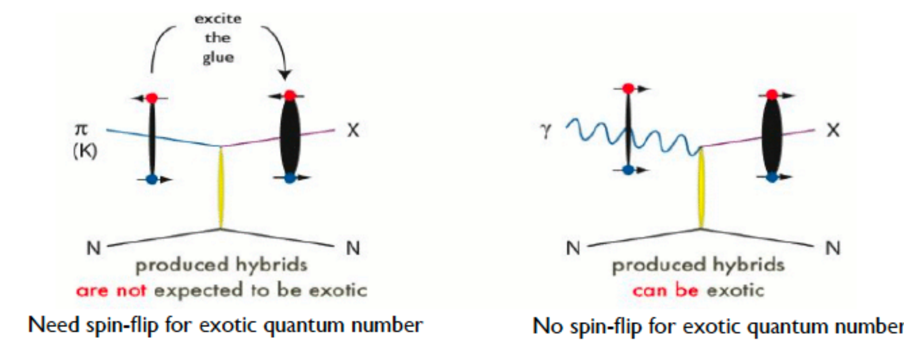


- At low-t exotic wave production compatible with one pion exchange

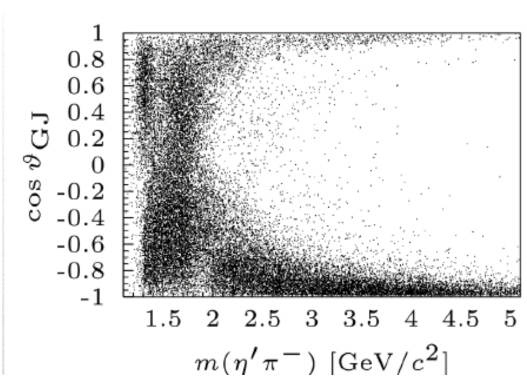


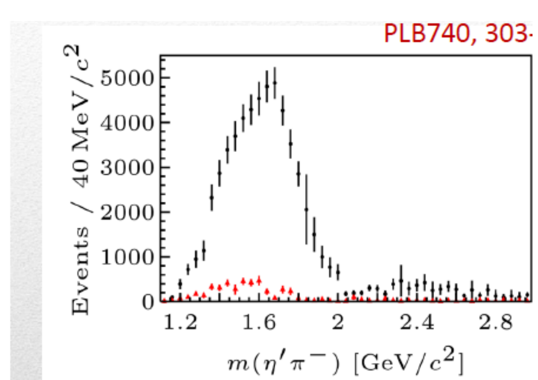
- In photoproduction exotic mesons produced via pion exchange

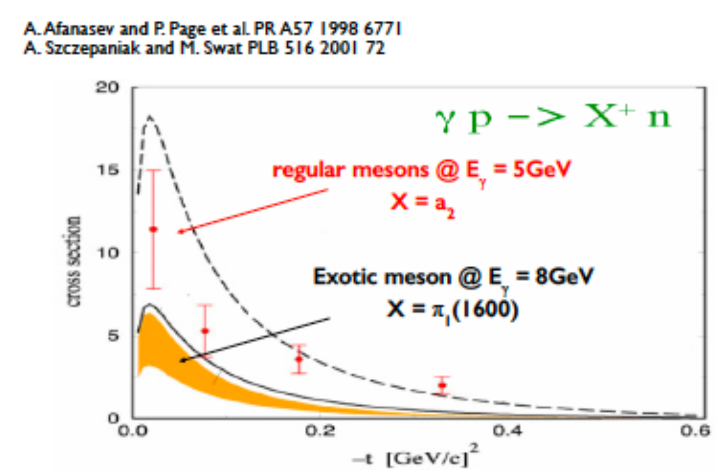




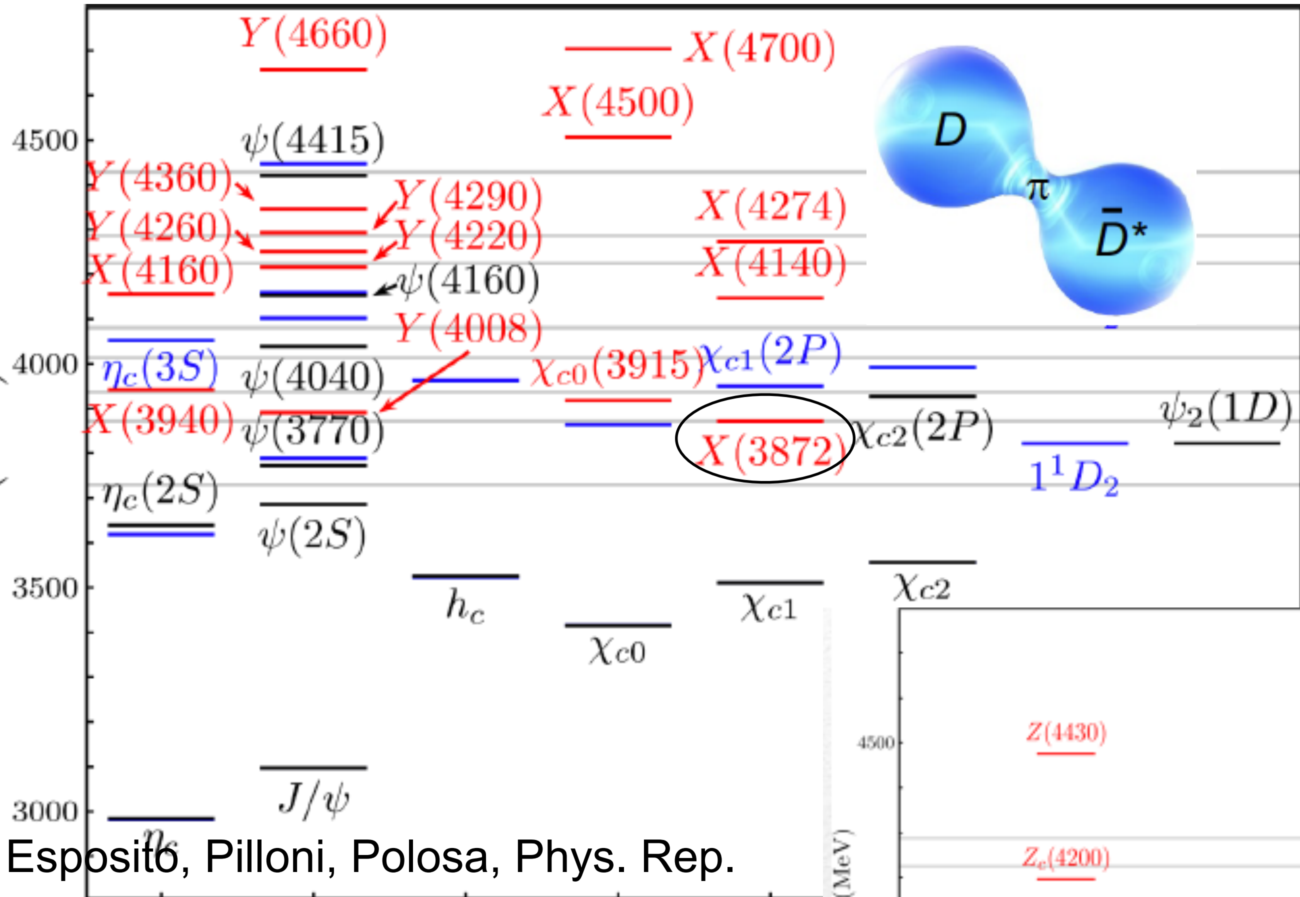
- Large exotic wave seen in $\eta^{(\prime)}\pi$ production : FESR's to constrain P-wave



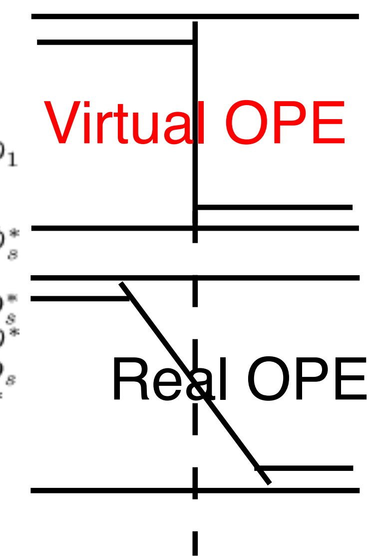




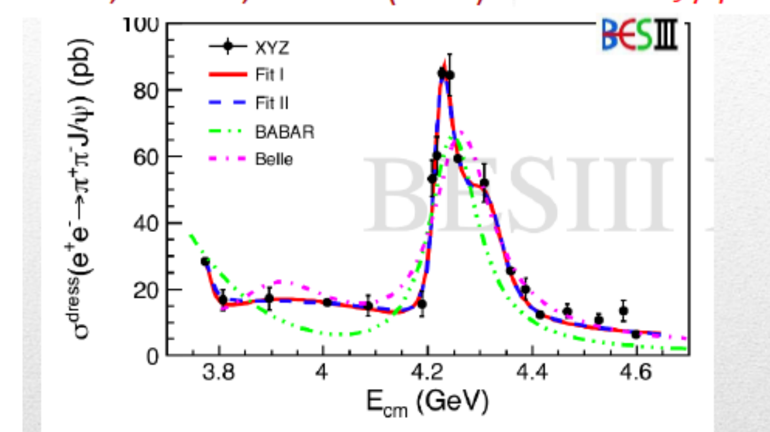
Signatures of unusual heavy quark resonances

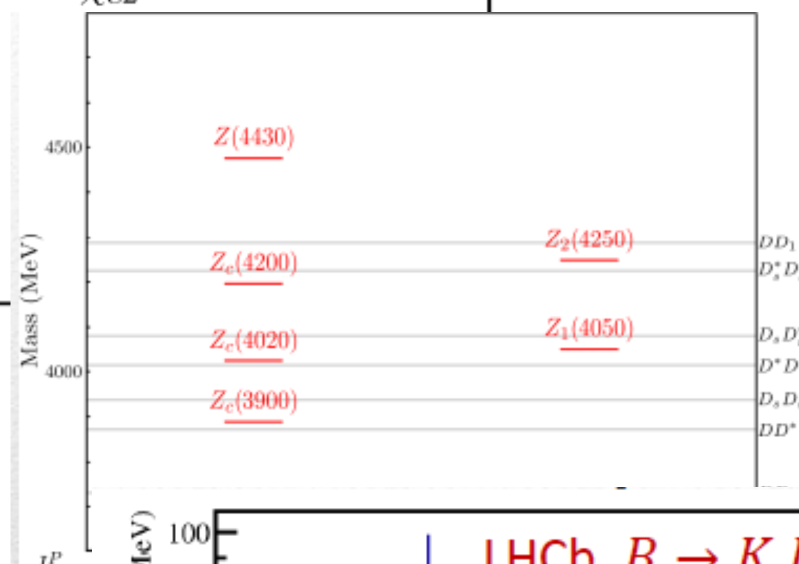


Esposito, Pilloni, Polosa, Phys. Rep.



BESIII, PRL118, 092001 (2017) $e^+e^- \to J/\psi\,\pi\pi$



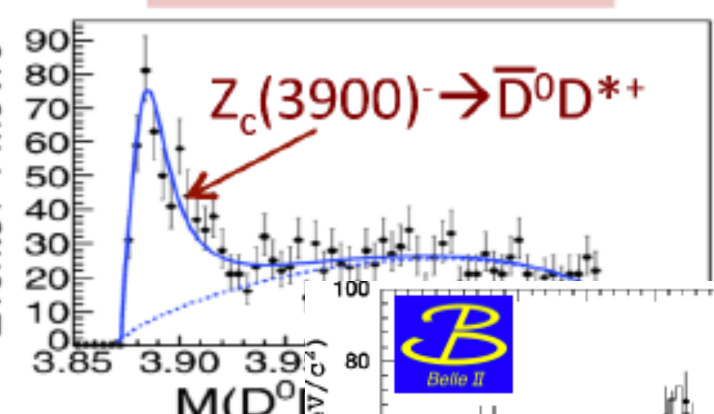


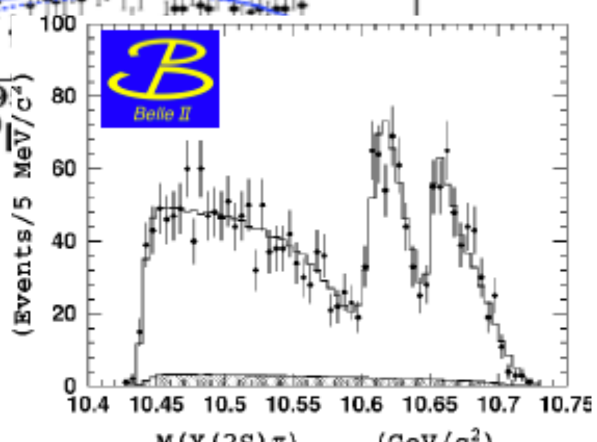
EMARK ON ENERGY PEAKS IN MESON SYSTEMS

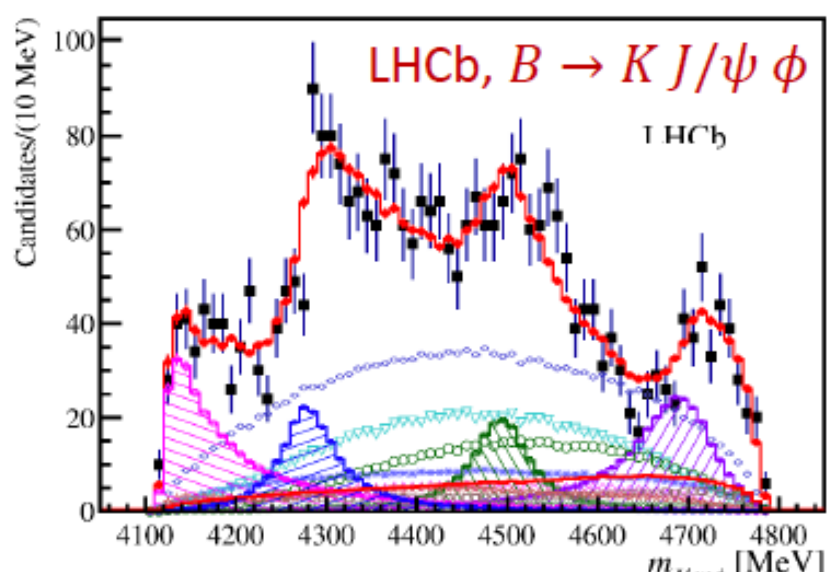
M. Nauenberg A. Pais

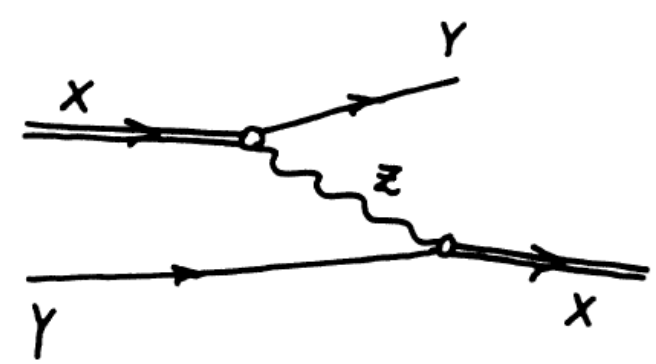
If the width of particle X is not very large we will stay close to the physical region. This almost singular behavior of $A(s)$ for certain physical s causes the peaking effect to which we refer as an (X, Y, Z) peak.

BESIII PRL 112, 022001



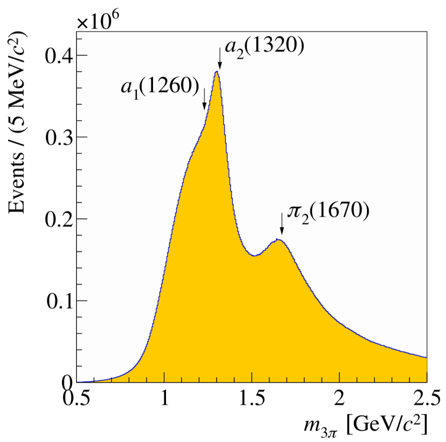


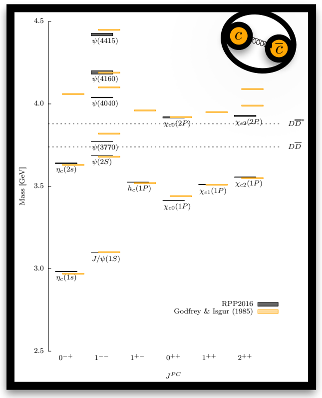




Data vs Quarks

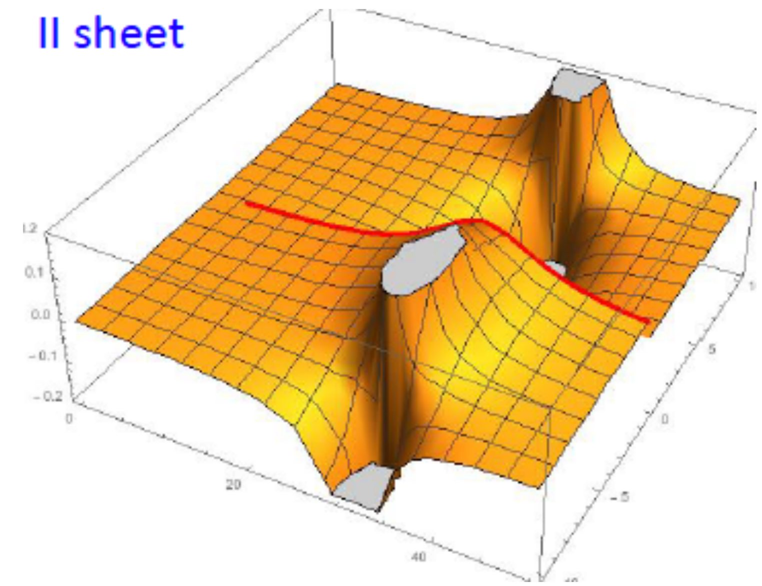
Experimental or lattice signatures (real axis data: cross section bumps and dips, energy levels)

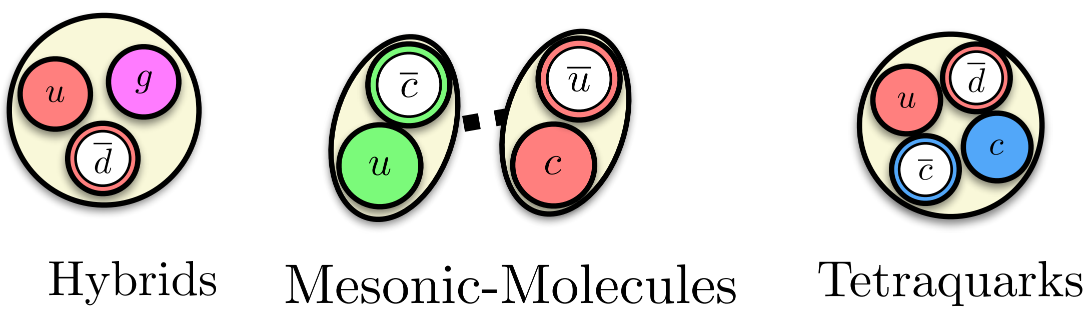




$$d\sigma \propto |T(s,t,\cdots)|^2$$

Luscher quantization condition

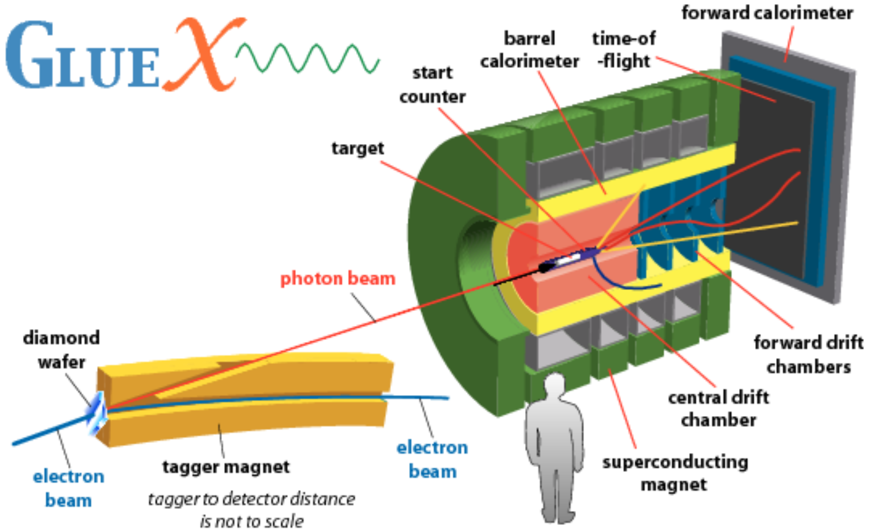


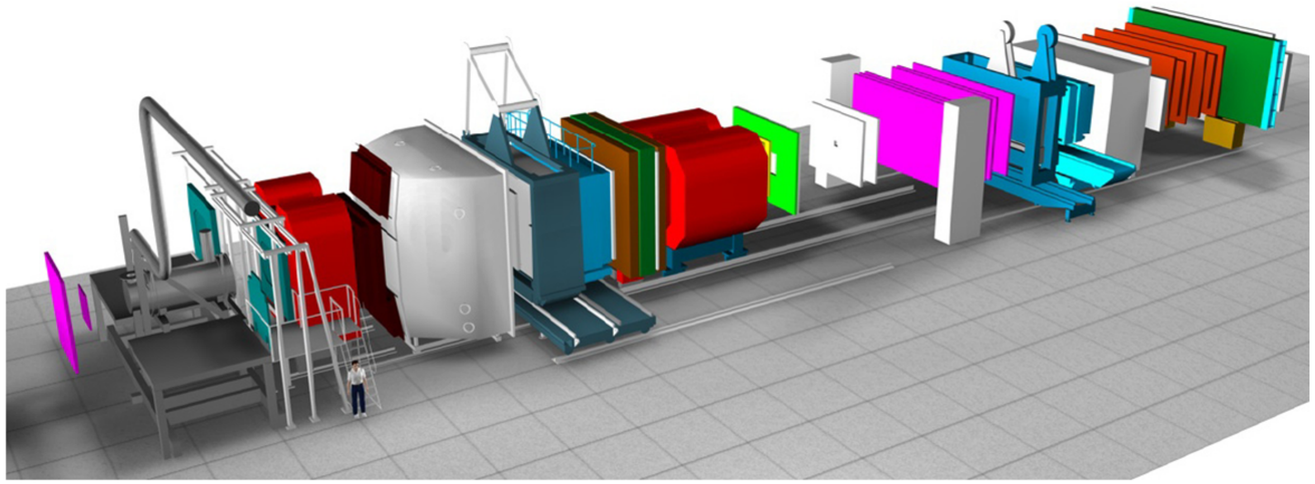


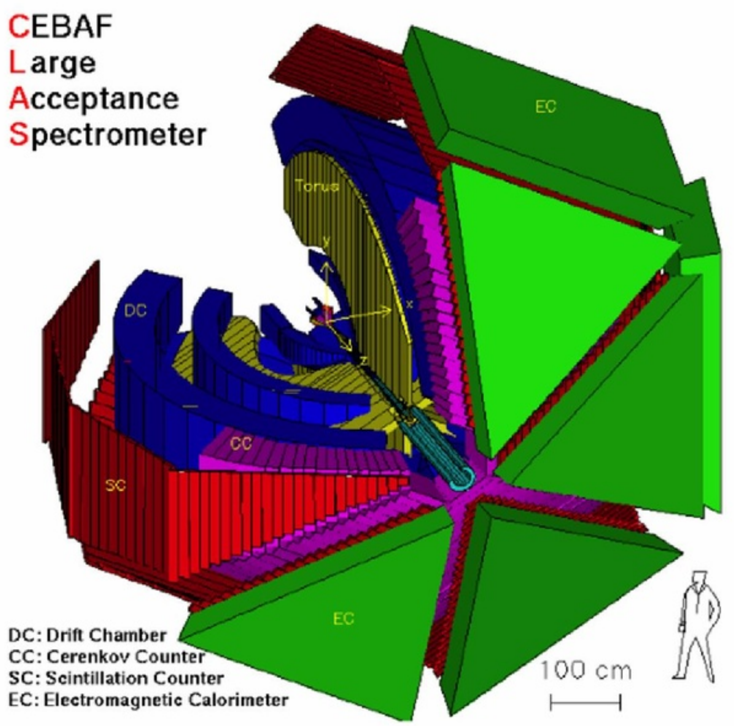
What is the interpretation (constituent quarks, molecules, …) ?

Theoretical signatures (complex plane singularities: poles, cusps)

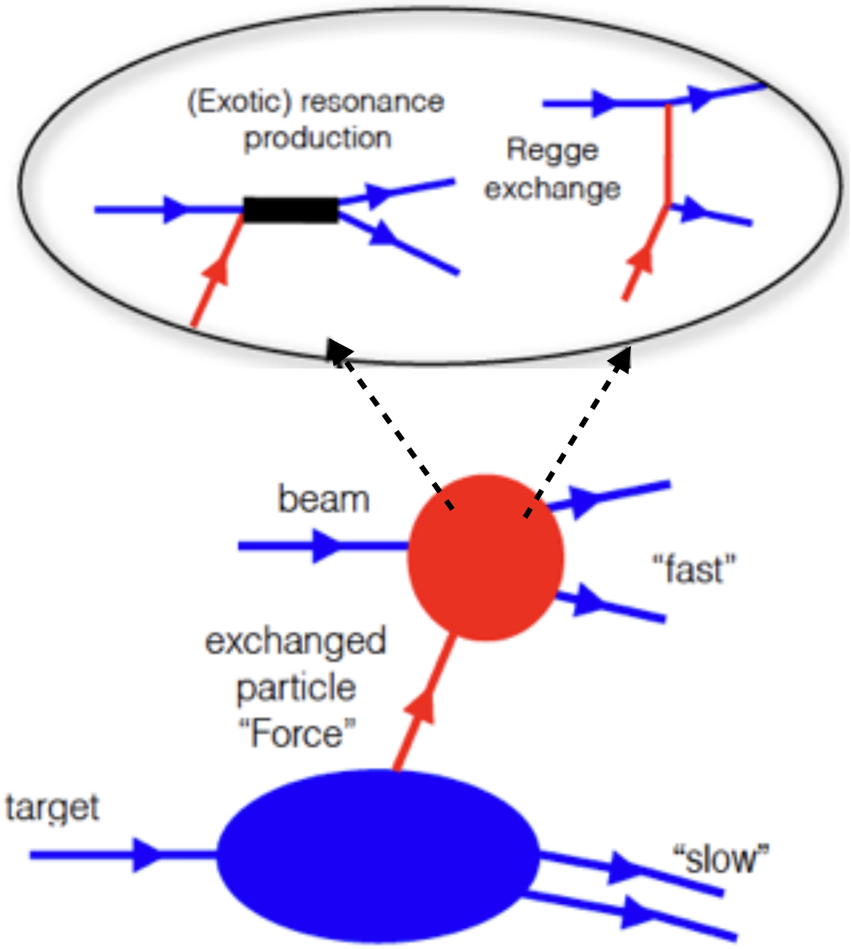
Spectroscopy from peripheral production





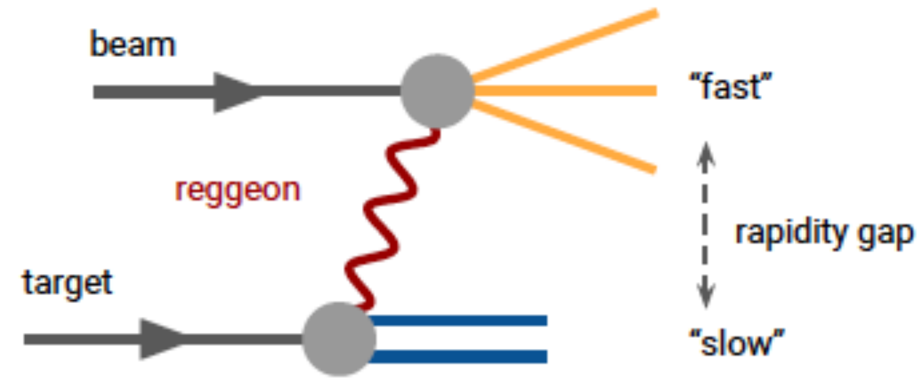


- Need to establish factorization between beam and target fragmentation (Regge factorization)
- Single Regge pole exchange dominate over cut other singularities (cuts, daughters)



Global Regge analysis

- Test Regge pole hypothesis and estimate corrections (daughters, cuts)



- Factorizable Regge pole exchange

$$\mathcal{R}(s,t) \equiv \left(\frac{1-z_s}{2}\frac{\nu}{-t}\right)^{\frac{1}{2}|\mu-\mu'|}\left(\frac{1+z_s}{2}\right)^{\frac{1}{2}|\mu+\mu'|}$$

$$A_{\mu_4\mu_3\mu_2\mu_1} = \mathcal{R}(s,t)\sqrt{-t}^{|\mu_1-\mu_3|}\sqrt{-t}^{|\mu_2-\mu_4|}\ \hat{\beta}^{e13}_{\mu_1\mu_3}(t)\hat{\beta}^{e24}_{\mu_2\mu_4}(t)\mathcal{F}_e(s,t)$$

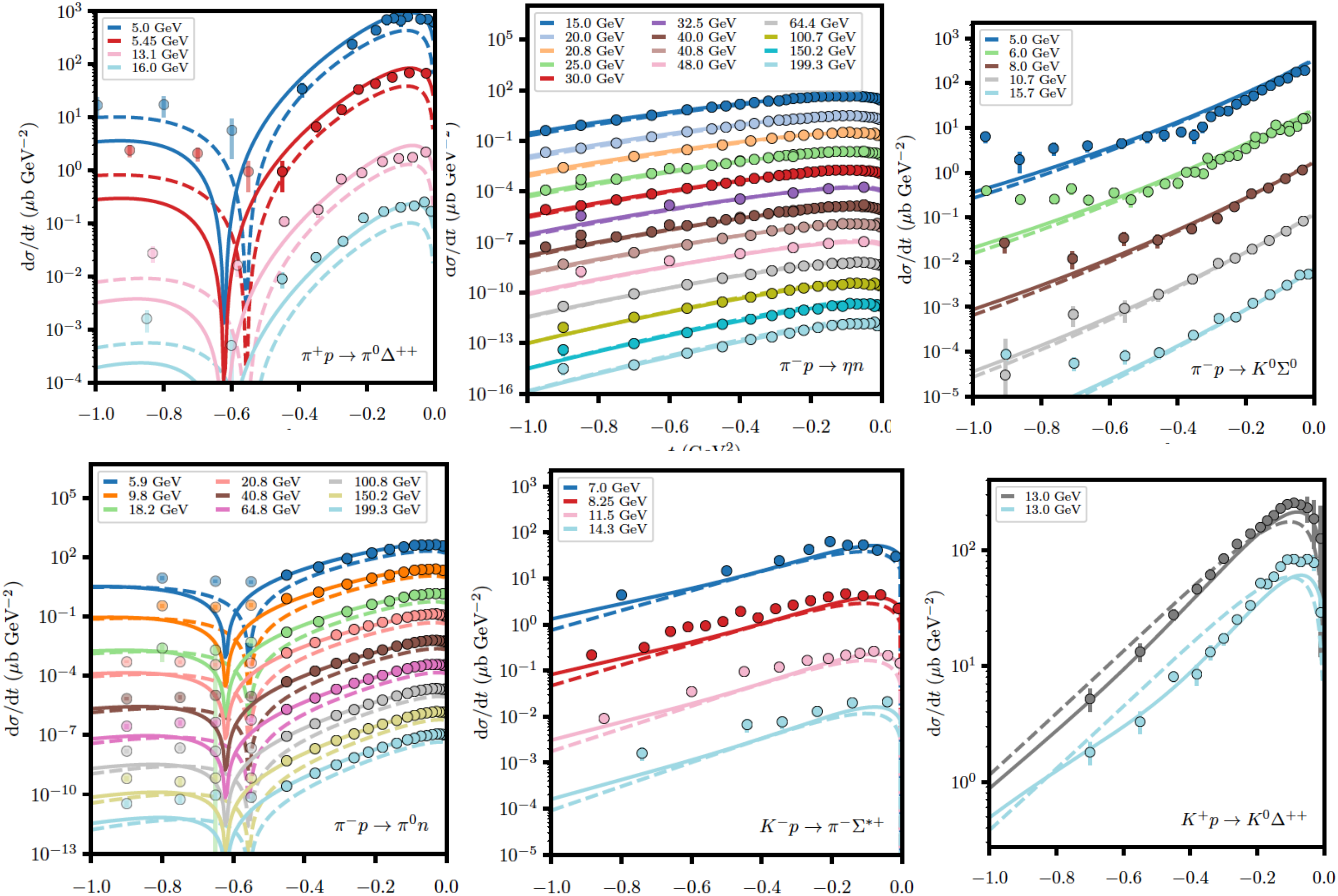
$$\mathcal{F}_e(s,t) = -\frac{\zeta_e \pi \alpha_e^1}{\Gamma(\alpha_e(t)-l_e+1)}\frac{1+\zeta_e e^{-i\pi\alpha_e(t)}}{2\sin\pi\alpha_e(t)}\left(\frac{s}{s_0}\right)^{\alpha_e(t)}$$

- N_{Data}=1271, N_{par}=9

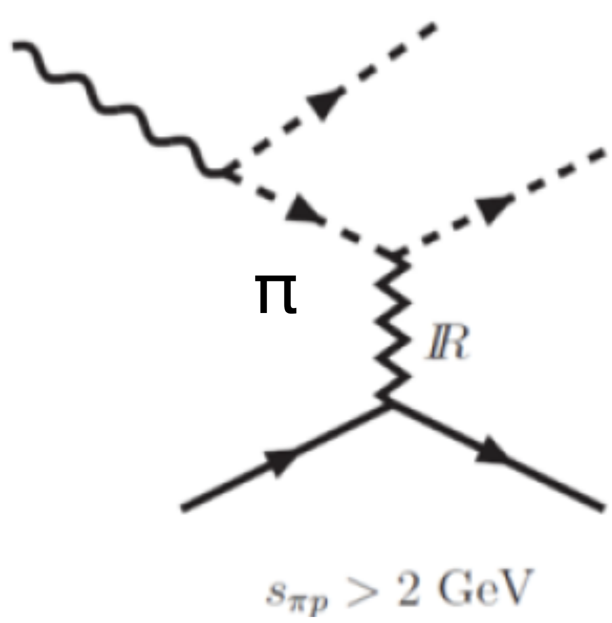
$$\mathcal{F}_e(s,t) \underset{t\to m_e^2}{\longrightarrow} \frac{(s/s_0)^{J_e}}{m_e^2-t}.$$

(6 SU(3) couplings, 1 mixing angle, 2 exp. slopes)

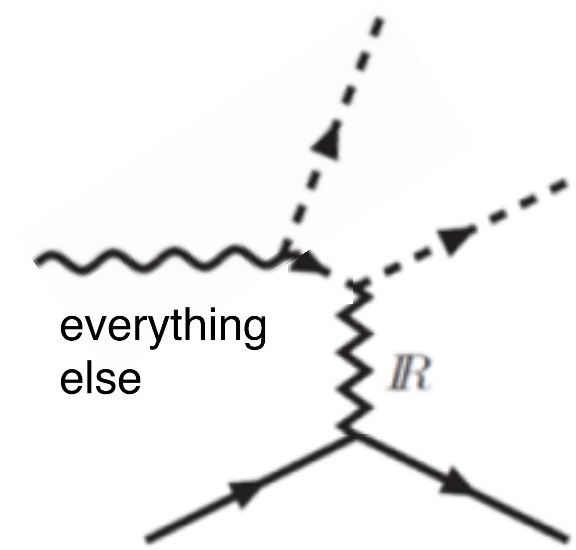
Global Regge pole analysis



OPE vs other exchanges

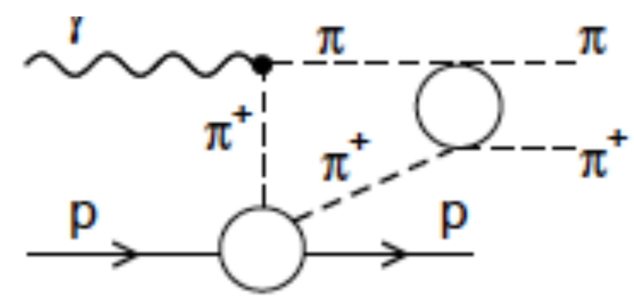


- Long range exchange

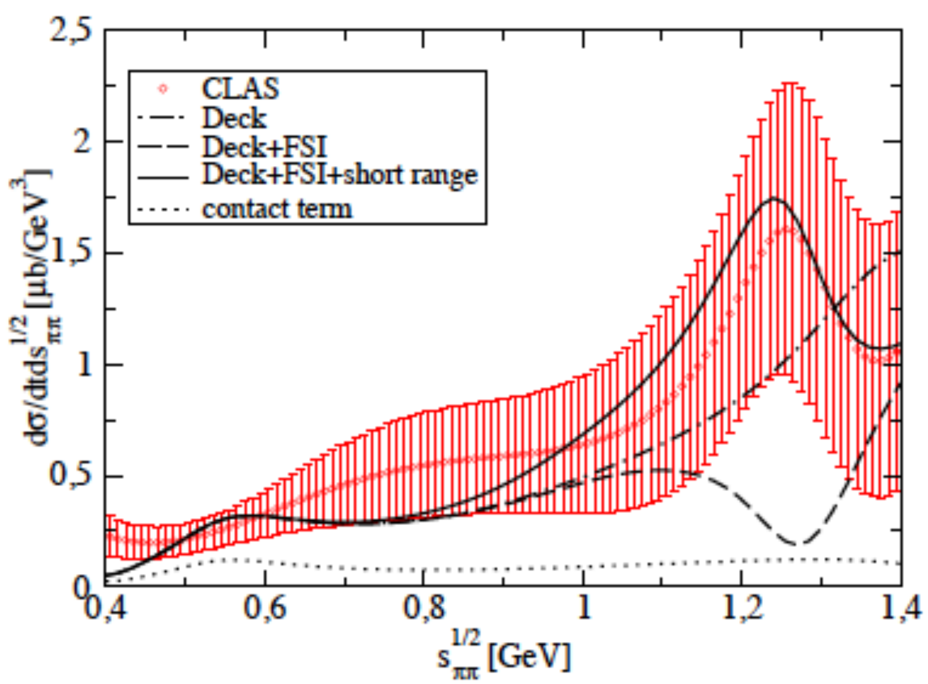


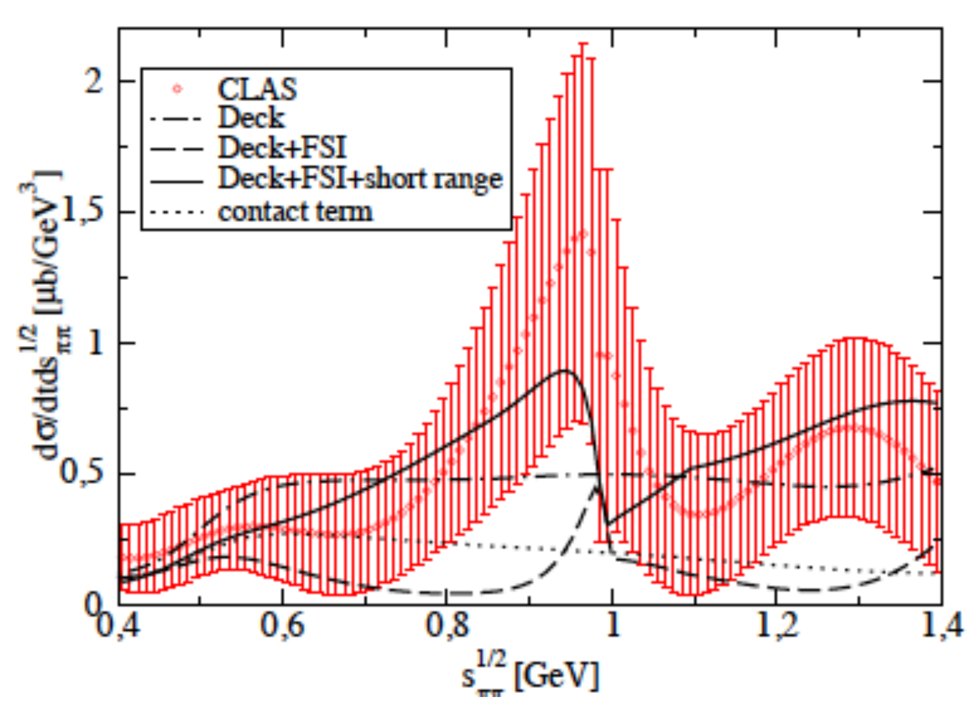
- Short range exchange

- S-wave (f_0(980)) production sensitive to OPE



Bibrzycki,Bydzovsky,Kaminski,AS (2018)





Multi-quark hadrons

Standard argument for non-existence of multi quark sates: they can fall apart to ordinary mesons and baryons .

But confinement requires quarks are connected by flux tubes and it is possible that certain multi quark configurations are more favorable than “fall apart configurations”

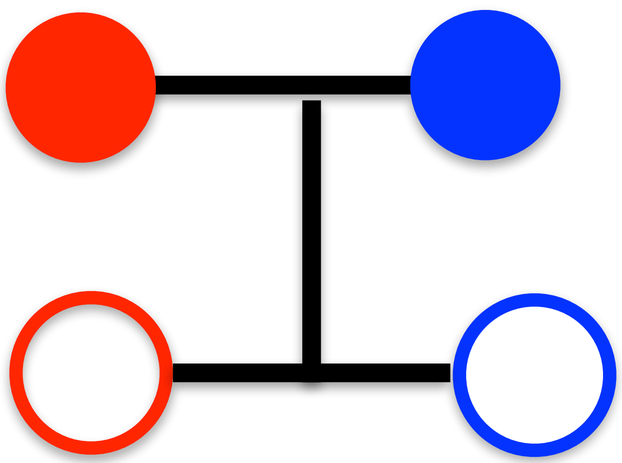
vs

$$3 \times \bar{3} = 8 + 1$$

2 Mesons

$$3 \times \bar{3} = 8 + 1$$

$$3 \times 3 = 6 + \bar{3}$$



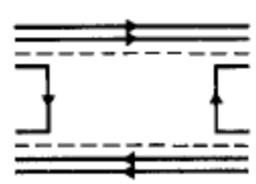
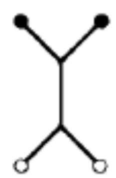
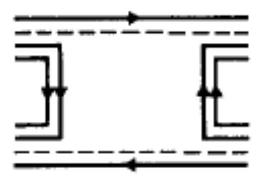
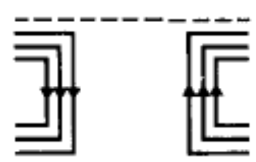
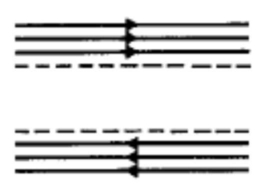
$$\bar{3} \times \bar{3} = 6 + 3$$

2 di-quarks = tetra-quark

s-channel mesons are dual to t-channel tetra quarks

tetra quarks should form Regge trajectories just like mesons

Table 3a
Contributions to $B\bar{B}$ scattering ($N_c = 3$)

	$B\bar{B} \to B\bar{B}$ Junction duality diagrams annihilation	s-channel formation	Multiplicity[(a)]	t-channel[(b)] exchange	Slope
1		M_4^J 	$\bar{n}(s') \simeq \bar{n}_{e^+e^-}(s')$	$s^{\alpha_R - 1} \sim s^{-1/2}$ Regge pole	α'_R
2		M_2^J 	$\bar{n}(s') \simeq 2\bar{n}_{e^+e^-}(s'/4)$	$s^{2\alpha_R - 2} \sim s^{-1}$ 2-Reggeon cut	$\frac{1}{2}\alpha'_R$
3		M_0^J 	$\bar{n}(s') \simeq 3\bar{n}_{e^+e^-}(s'/9)$	$s^{3\alpha_R - 3} \sim s^{-3/2}$ 3-Reggeon cut	$\frac{1}{3}\alpha'_R$
4		Non-resonant two jet background	$\bar{n}(s') \simeq 2\bar{n}_{e^+e^-}(s'/4)$	$s^{\alpha_P - 1} \sim s^0$ Pomeron	$\frac{1}{2}\alpha'_R$

[(a)] s' is the invariant mass of the final state excluding the leading baryons.
[(b)] To estimate the s-behaviour we have taken $\alpha_R = 0.5$.

Rossi, Veneziano

Dolen Horn Schmit duality

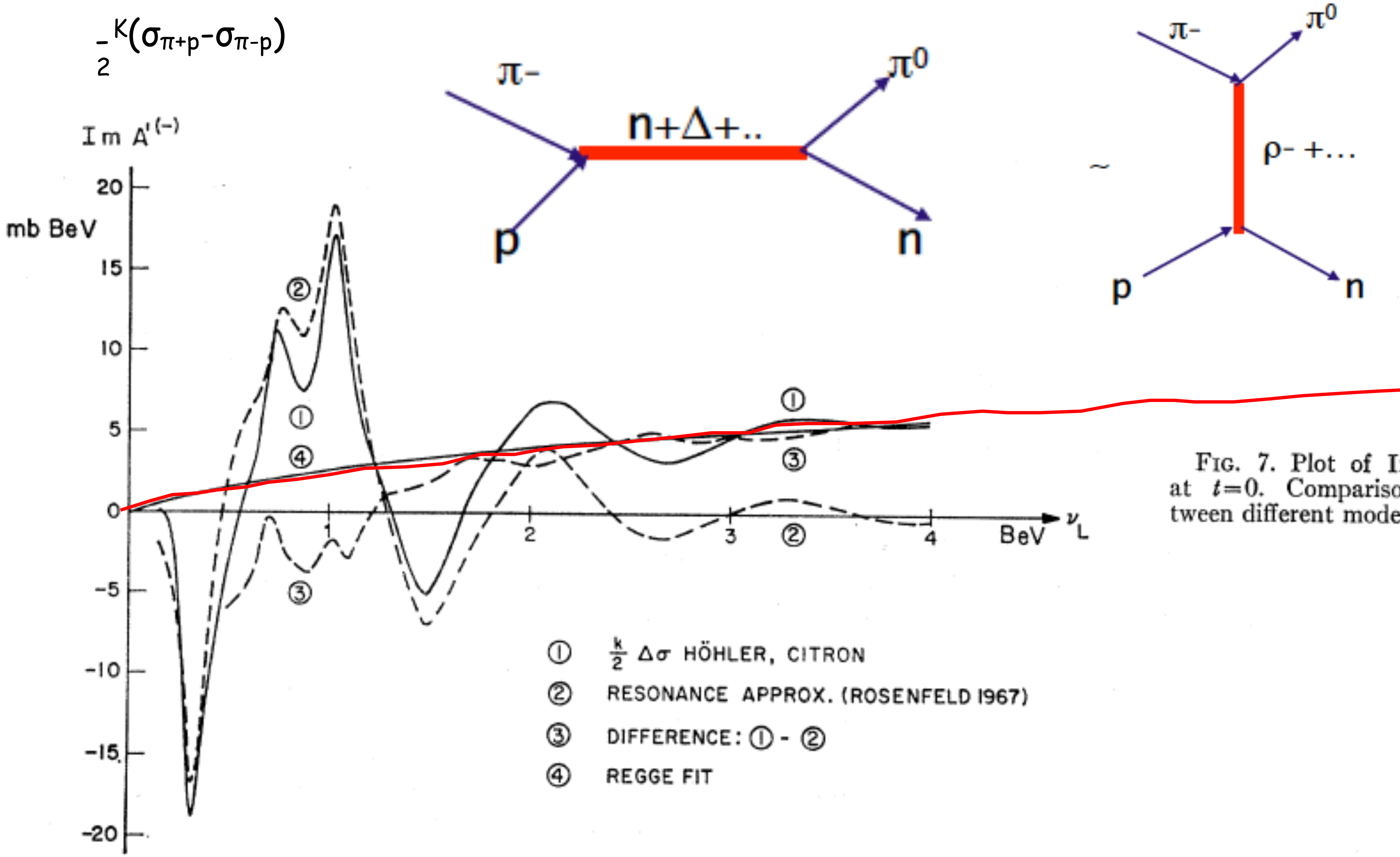
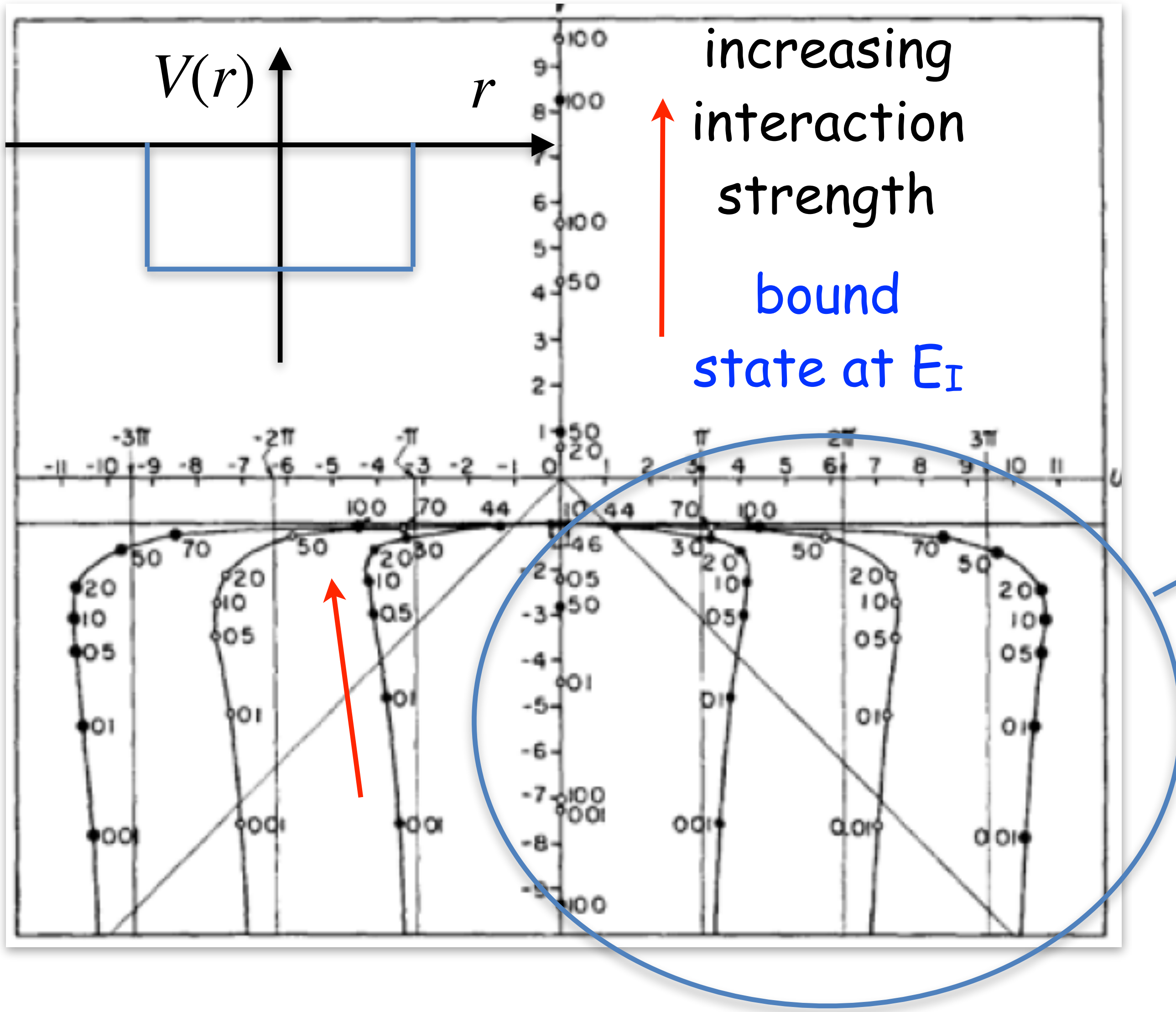


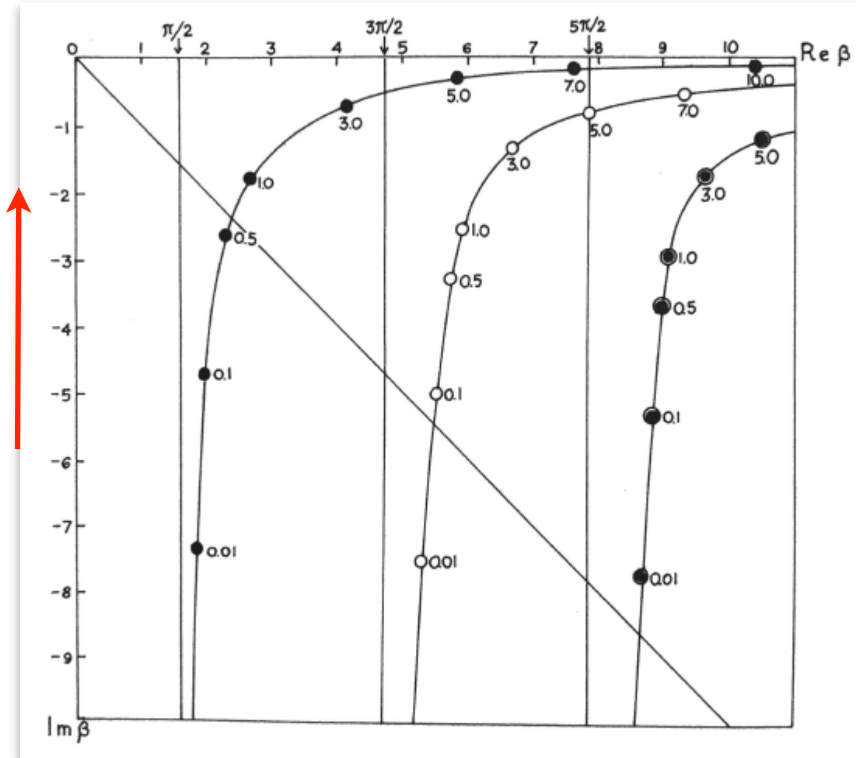
FIG. 7. Plot of Im$A'^{(-)}$ at $t=0$. Comparison between different models.

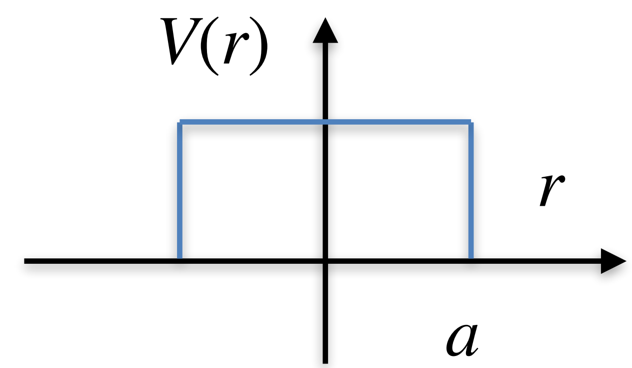
$$\bar{u}(p_1,\lambda_1)[A(s,t)+(k_1+k_2)_\mu\gamma^\mu B(s,t)]u(p_2,\lambda_2)$$

Not every pole comes from a bound state



increasing interaction strength





- Resonances have minimum width before they become bound states

$$\Gamma \sim \frac{1}{\tau} \sim \frac{v}{a}$$

- Average velocity inside the Well is always finite

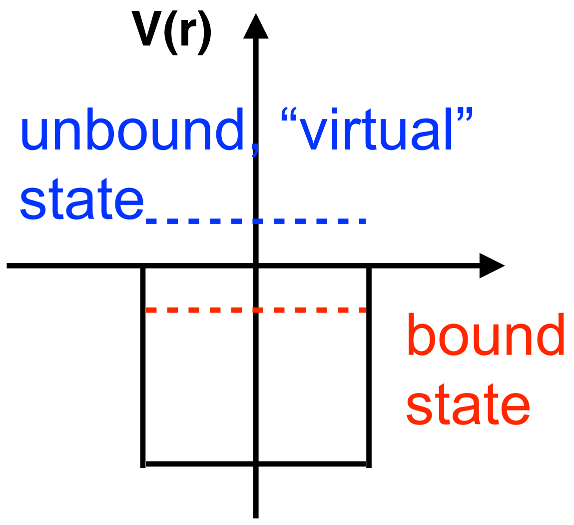
$$\sim \frac{k}{a} \sim \frac{\sqrt{E-V}}{a}$$

- Resonances move to + ∞ with wishing width
- Average velocity of the wave infinitesimal -> long time spend on top of the barrier

Need to establish which poles are connected to bound states

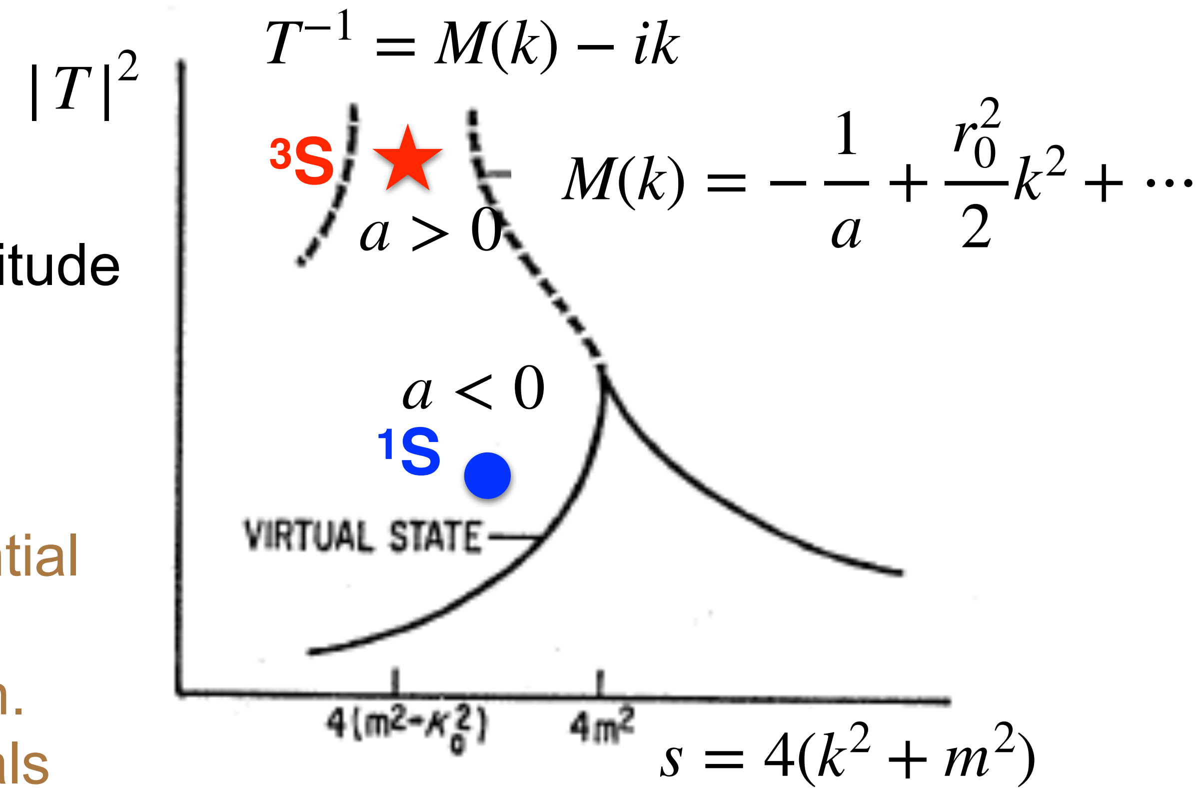
Identifying Physical States

Potential scattering
(e.g. np scattering)



Effective rage expansion for near threshold scattering amplitude

… but the analogy with potential scattering is non trivial for unitized EFT (renormalization. e.g there are contact potentials n D=4, eg. ϕ^4)



Test sensitivity of the data to various hypotheses (singularities of amplitudes)

Study how poles move as a function of amplitude parameters, channel couplings, location of thresholds, etc.

Light quark exotic candidate

search for

$\pi^- p \to \eta\pi^- p$

$M = 1370 \pm 16^{+50}_{-30}$ MeV / c^2

$\Gamma = 385 \pm 40^{+65}_{-105}$ MeV / c^2

$\pi^- p \to \eta\pi^0 n$

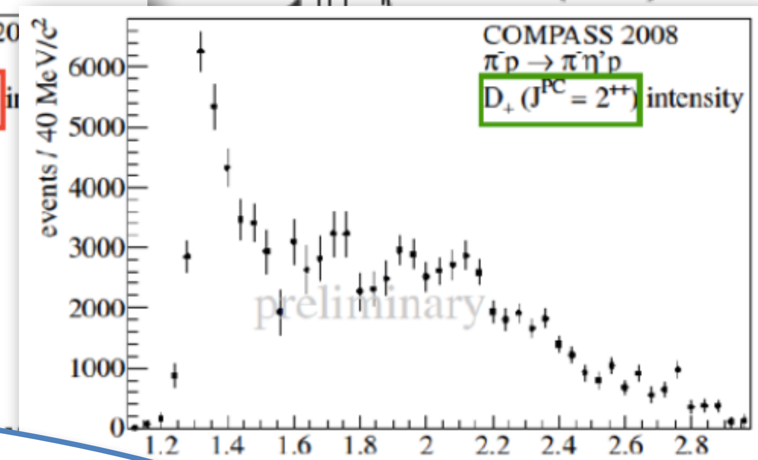
No consistent B-W interpre… possible but a weak ηπ inte… exists and can reproduce th…

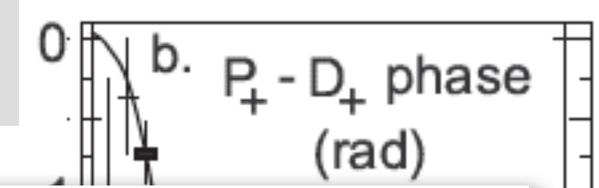
$\pi^- p \to \eta'\pi^-$…

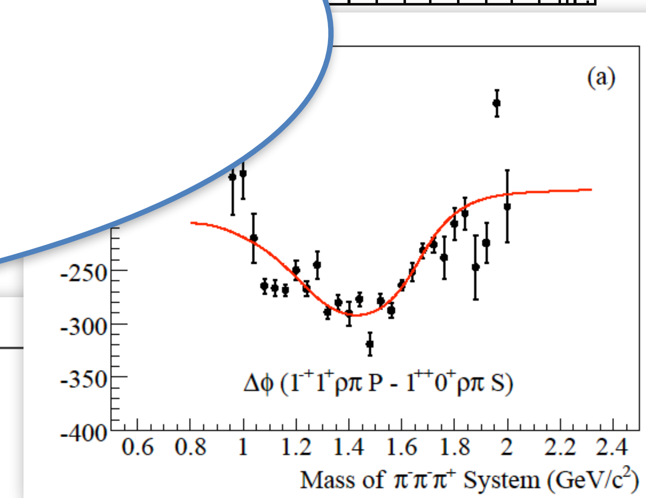
$\pi^- p \to \rho^0\pi^- p$

Γ = …

Need to be confirmed







E852 result

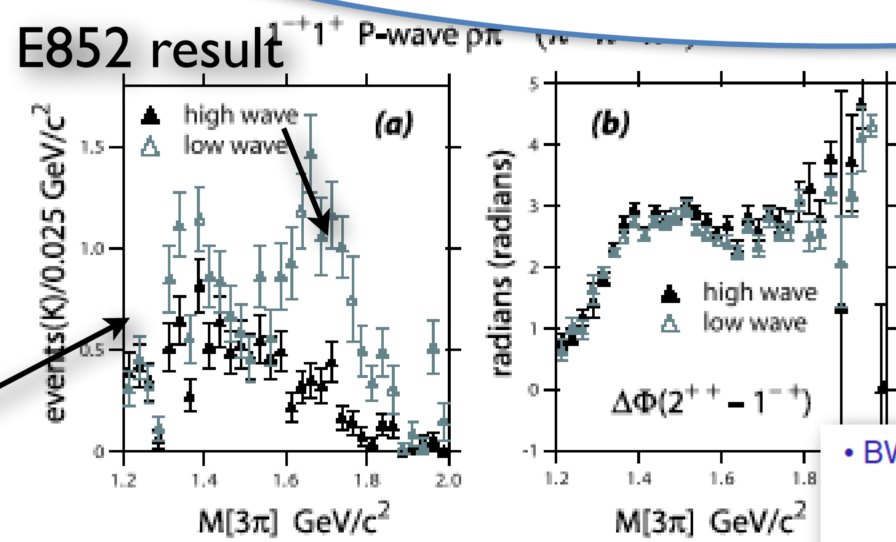
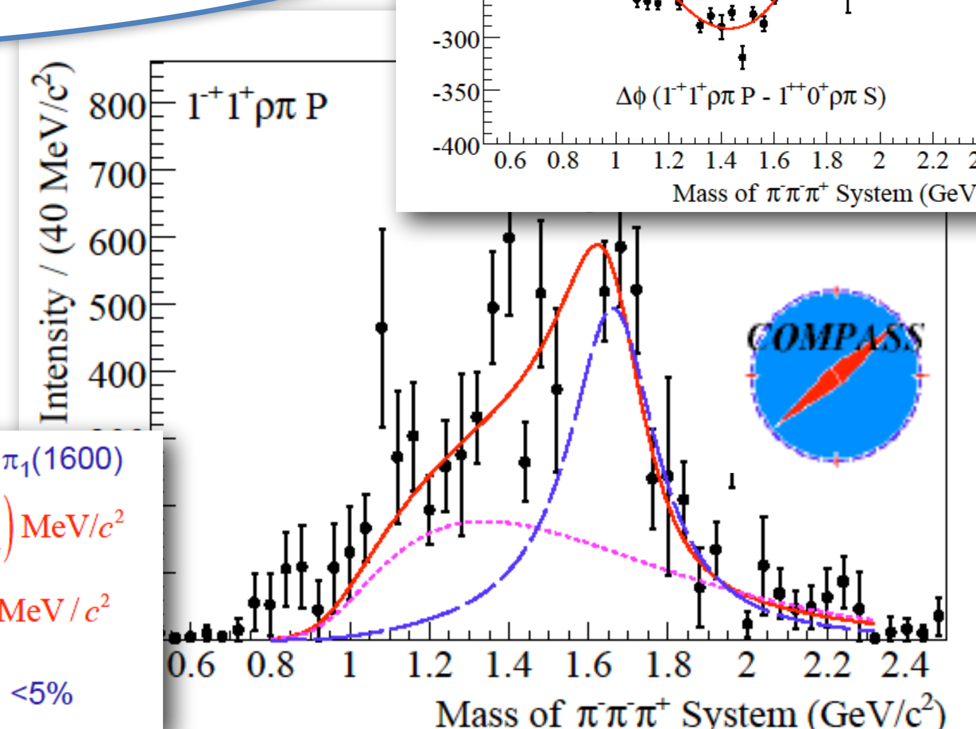


FIG. 25: (a) The $1^{-+}1^+$ P-wave $\rho\pi$ partial wave charged mode ($\pi^-\pi^-\pi^+$) for the high-wave set PWA a… low-wave set PWA and (b) the phase difference $\Delta\Phi$ b… the 2^{++} and 1^{-+} for the two wave sets.

$\pi^- p \to \pi_2^-(1600)p$

$\pi_2^- \to \rho^0\pi^-$

$\rho^0 \to \pi^+\pi^-$



- BW parameters for $\pi_1(1600)$

$M = \left(1660 \pm 10^{+0}_{-64}\right)$ MeV/c^2

$\Gamma = \left(269 \pm 21^{+42}_{-64}\right)$ MeV / c^2

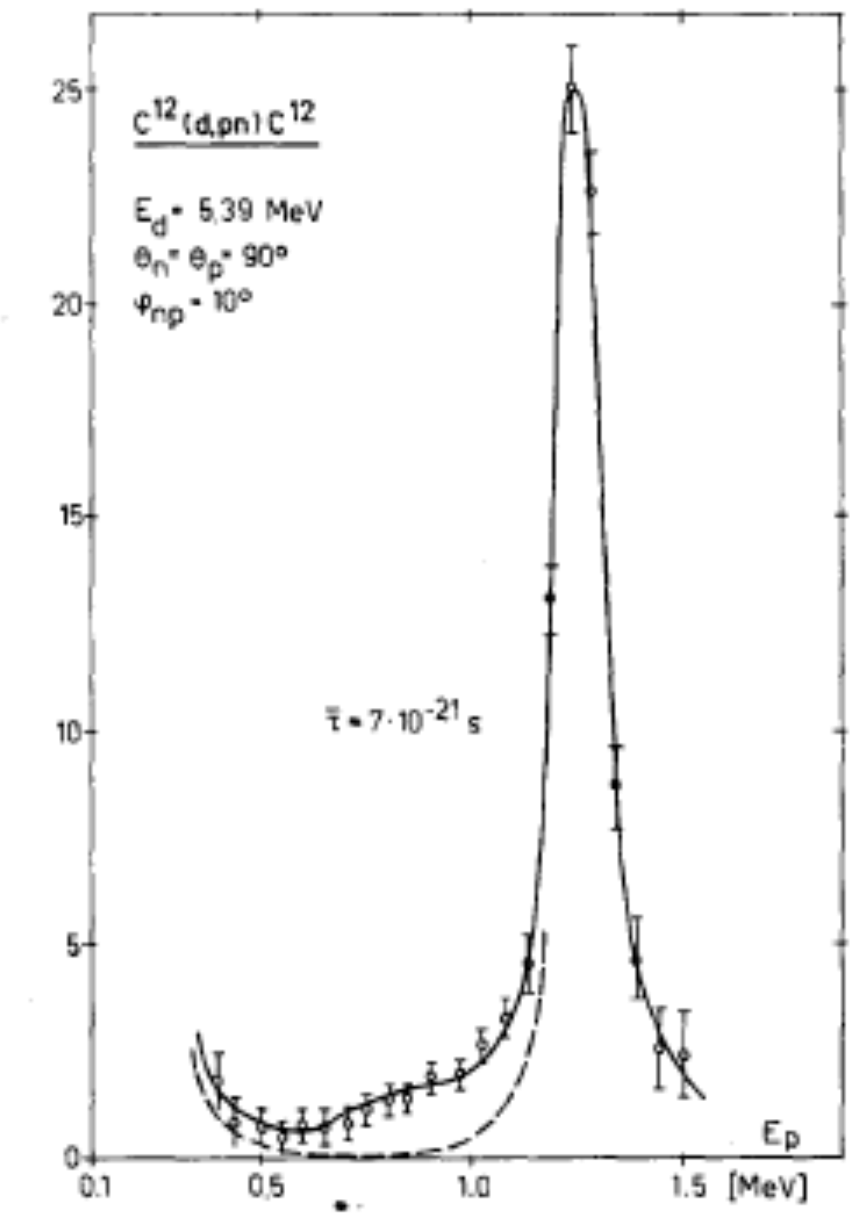
- Leakage negligible: <5%

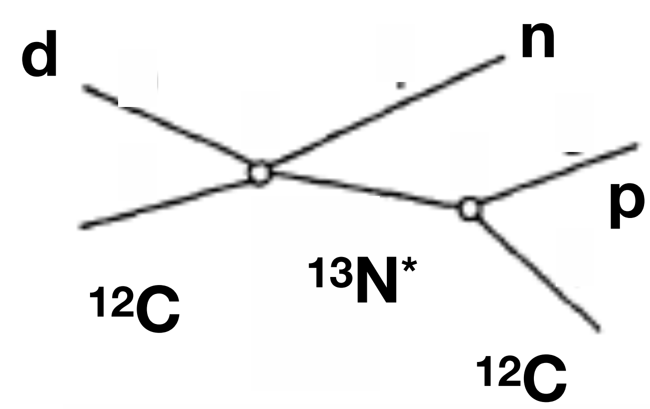
Triangle singularities

DIRECT DETERMINATION OF A SHORT NUCLEAR LIFETIME ($\approx 10^{-20}$ s) BY THE PROXIMITY SCATTERING METHOD

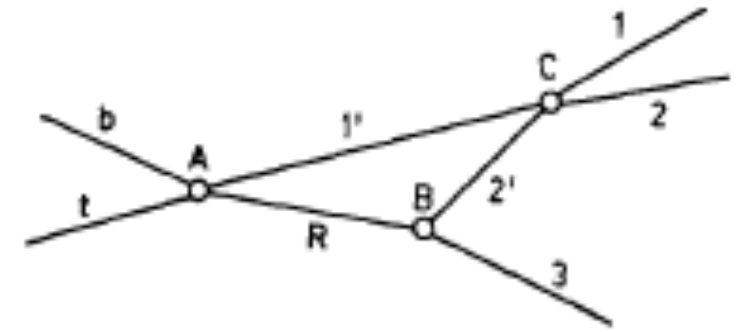
J. LANG, R. MÜLLER, W. WÖLFLI, R. BÖSCH and P. MARMIER
Laboratorium für Kernphysik, Eidg. Techn. Hochschule, Zürich †

Received 4 February 1966

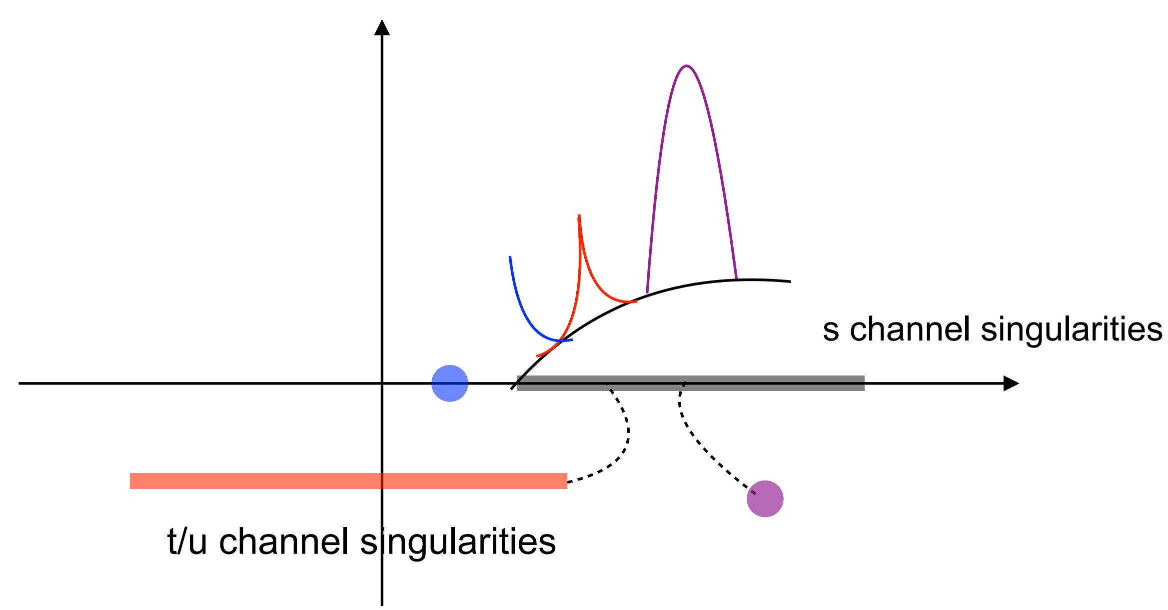




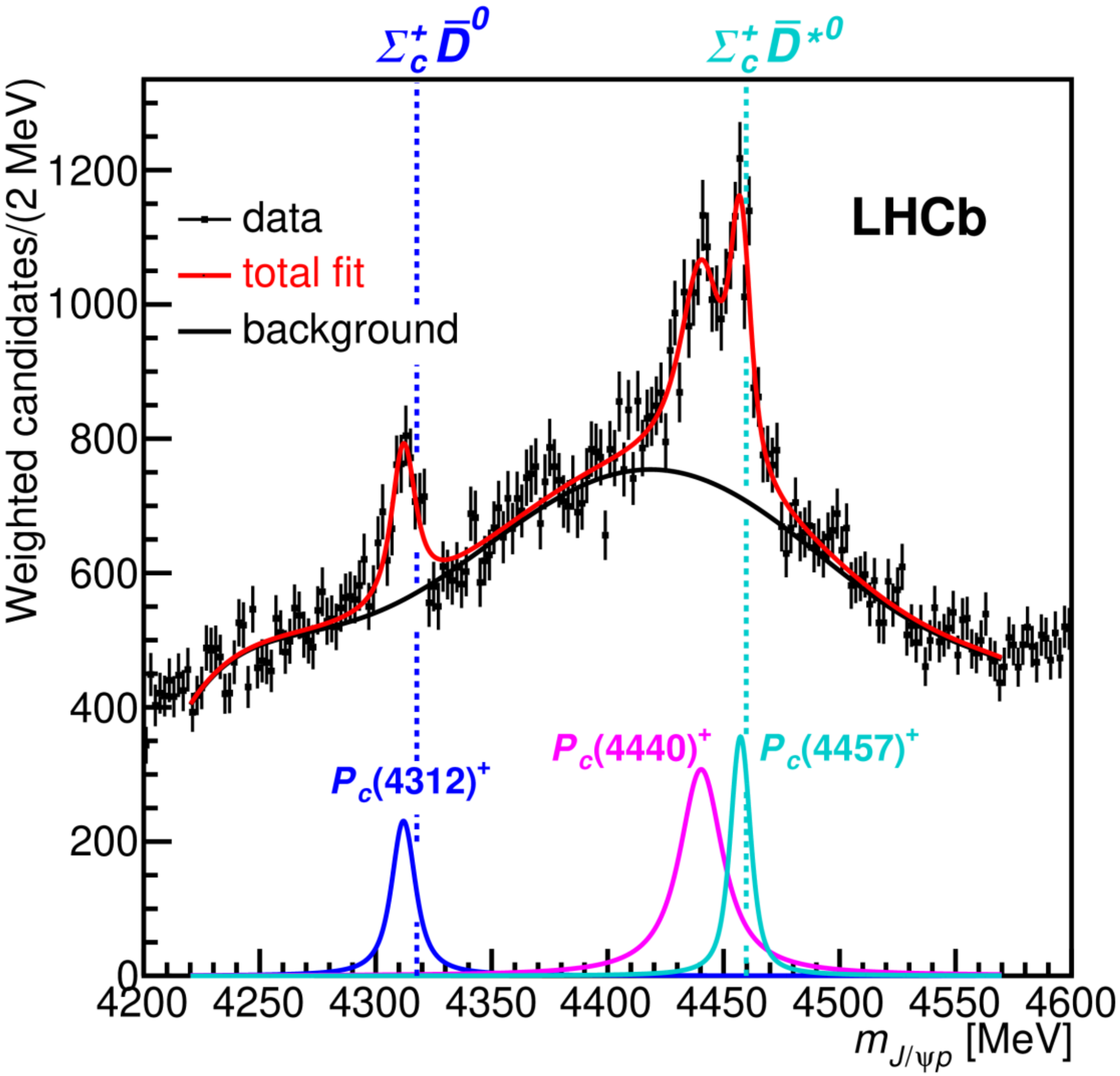
$[d + {}^{12}C \rightarrow n + p + {}^{12}C]$,

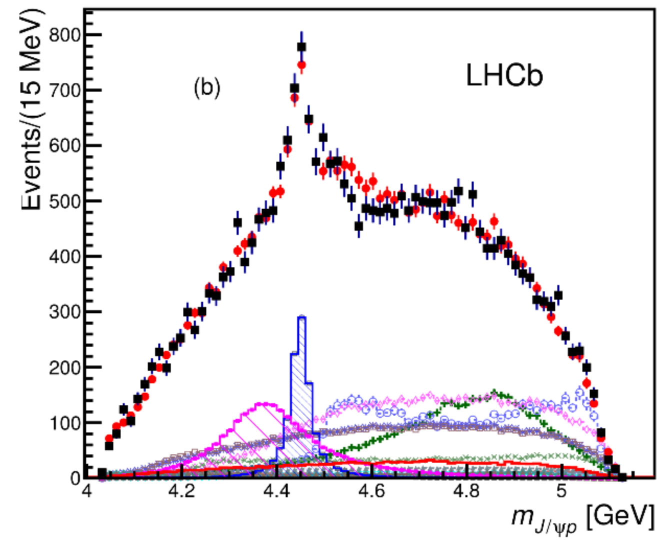


$[{}^{13}N^{*} \rightarrow p + {}^{12}C$,



New pentaquarks ?





The lowest $Pc(4312)$ appears as an isolated peak at the $\Sigma_c^+ D^0$ threshold

A detailed study of the lineshape provides insight on its nature.

Is the resolution good enough to distinguish between, molecules, unbound virtual states, or compact pentaquarks?

New pentaquarks ?

higher p.w's

$$\frac{N}{\sqrt{s}} = \rho(s)[A(s)|^2 + B(s)]$$

signal (assumed in a single p.w)

$$A(s) = P(s)T_{11}(s)$$

$$T^{-1}(s) = M(s) - ik(s)$$

use effective range expansion for M

Case A

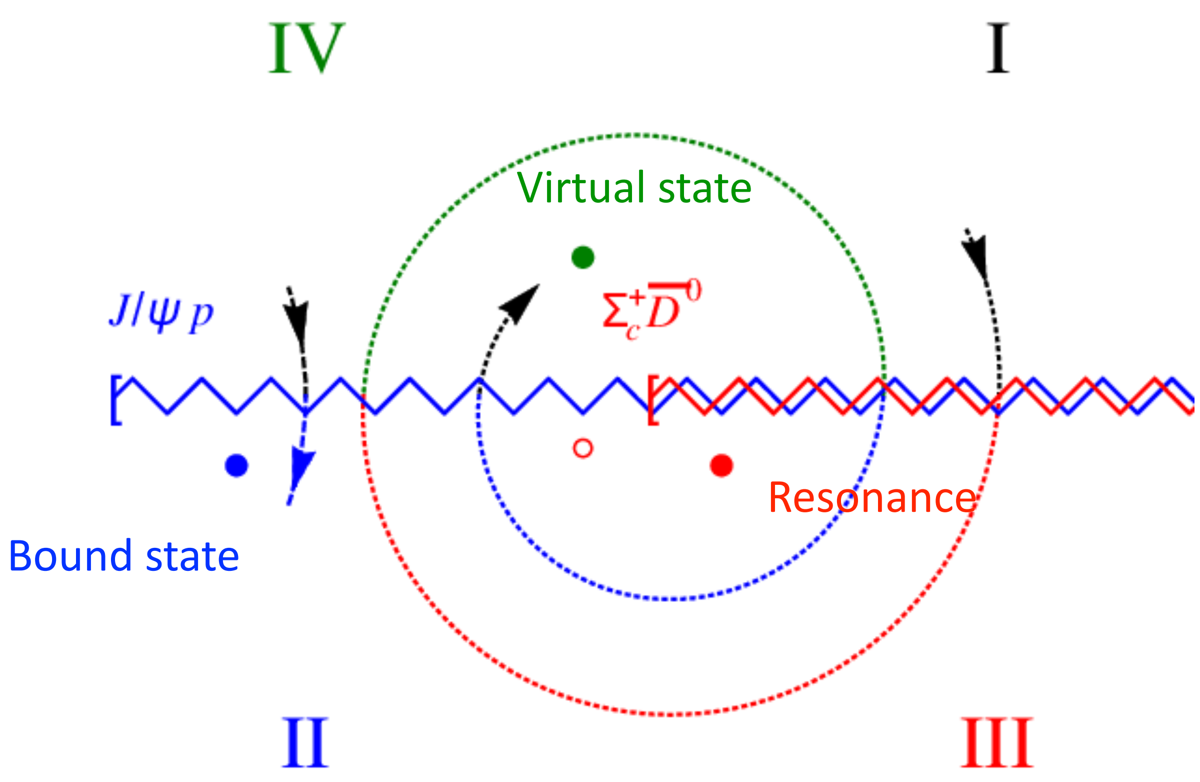
$$M(s) = M$$

virtual or bound states

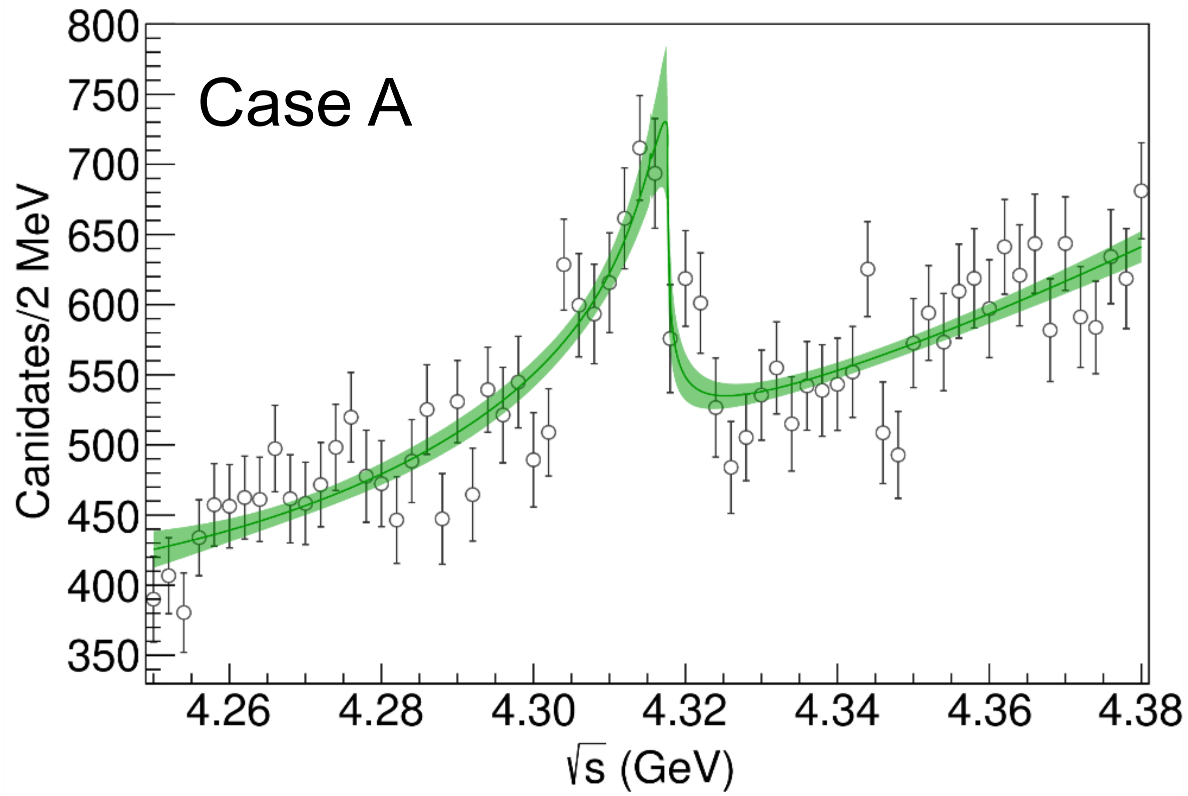
Case B

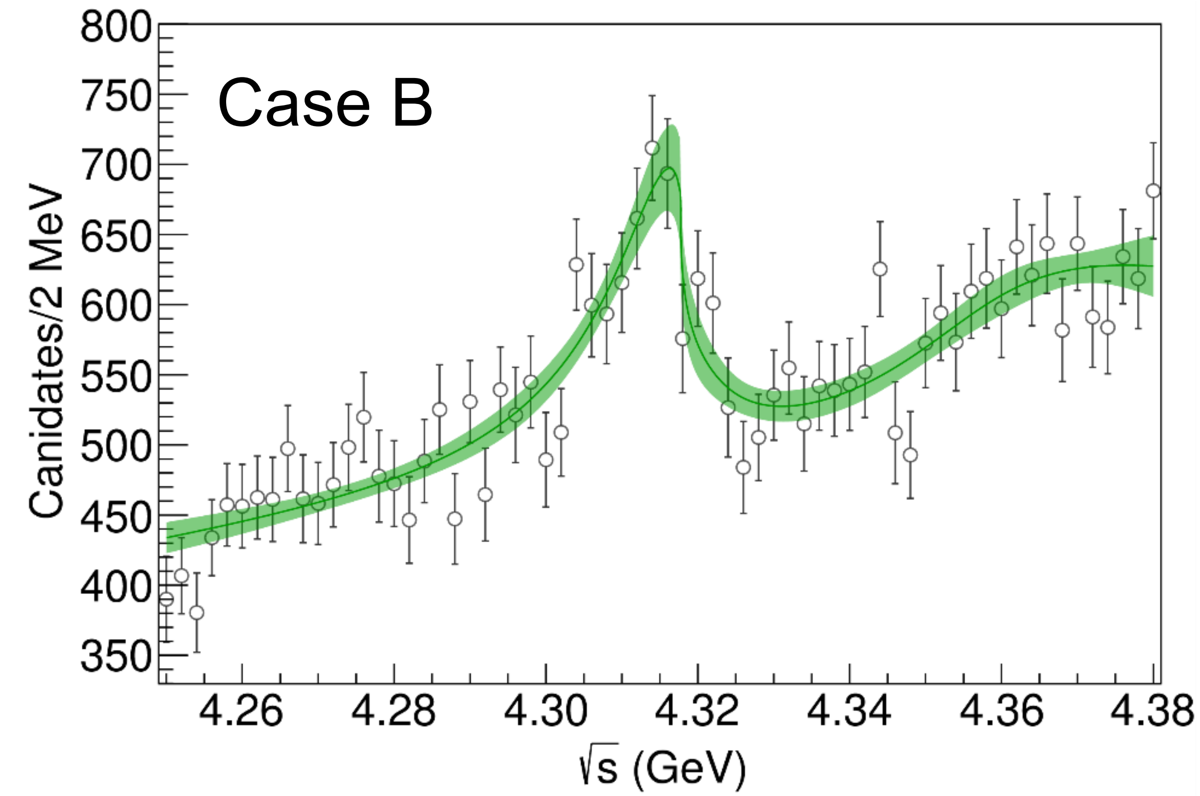
$$M(s) = M + Cs$$

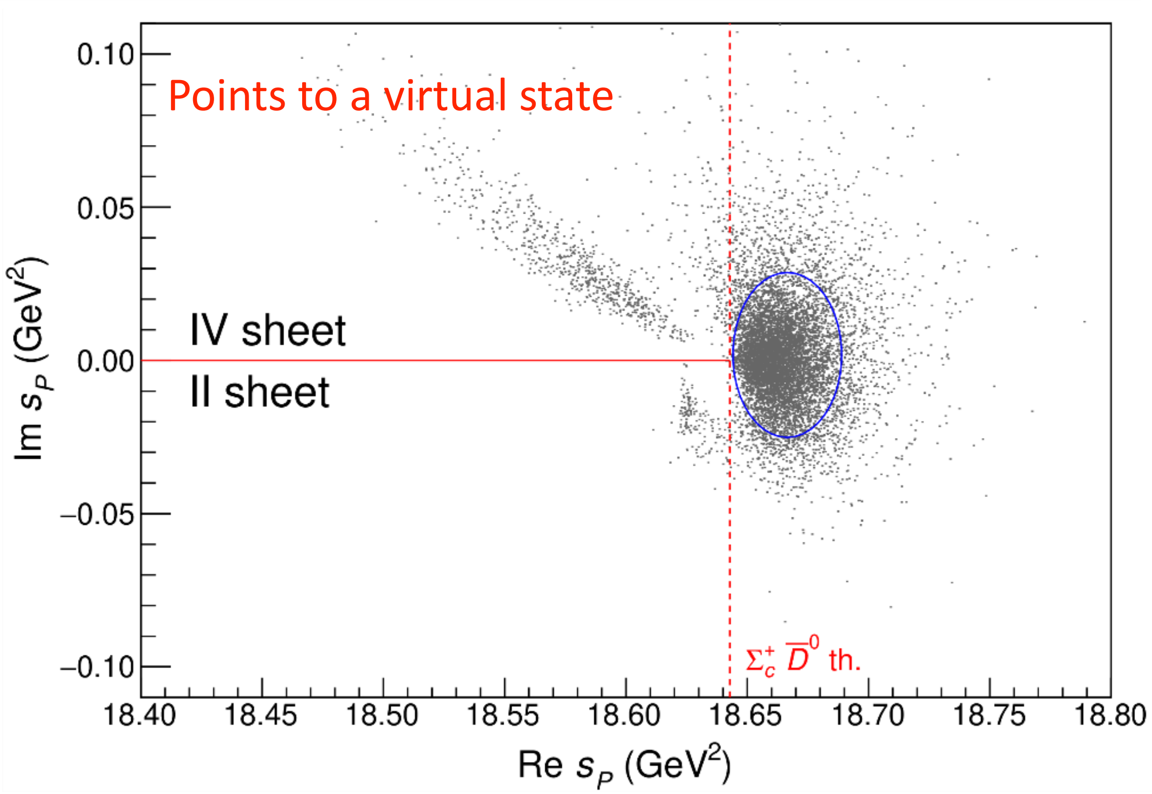
additional compact states

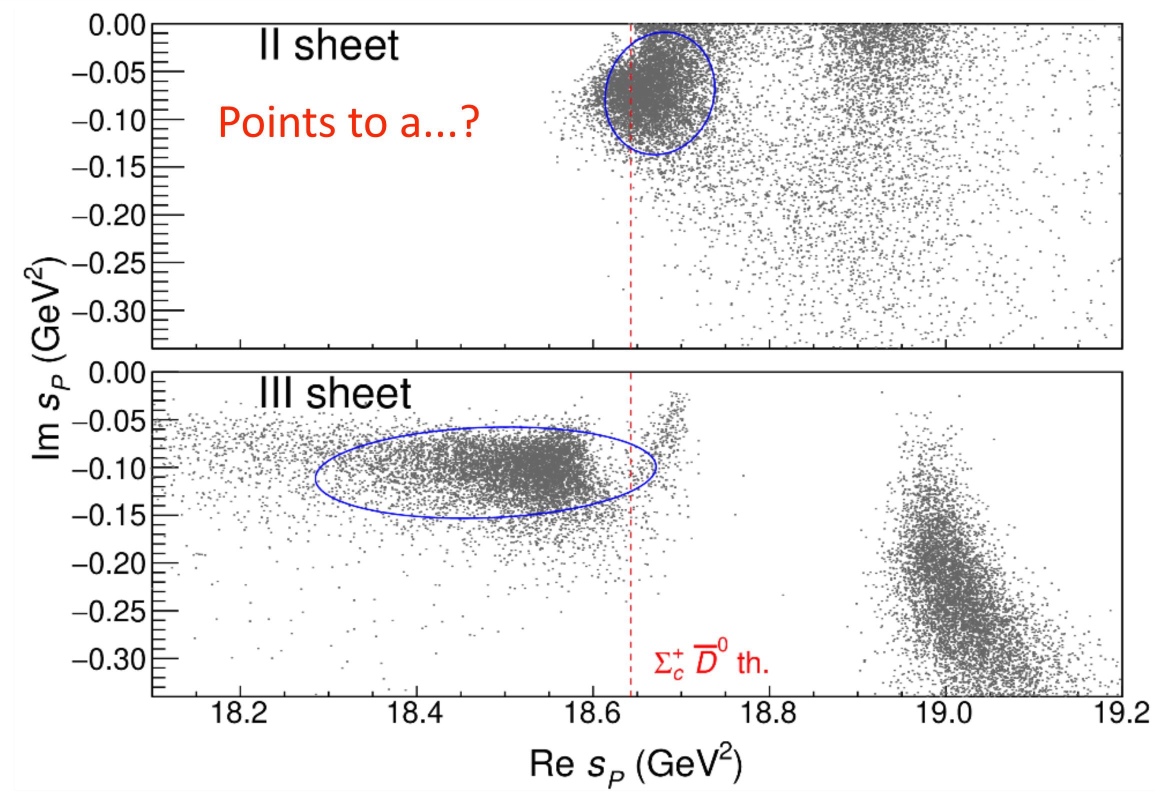


New pentaquarks ?

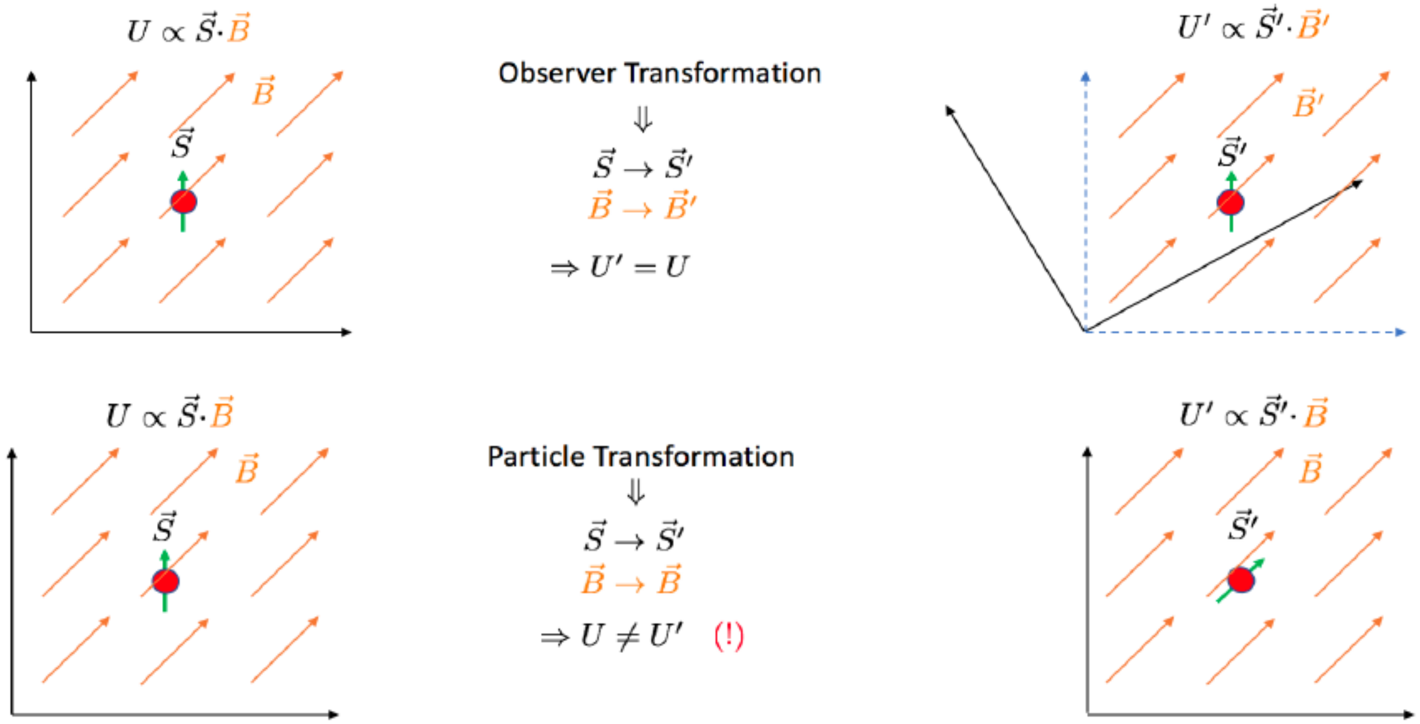








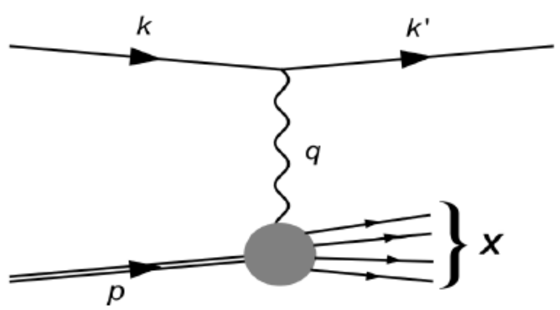
(Very) exotic physics: constraining Lorentz symmetry violation



- Observer transformations do not affect results.
- Particle transformation, e.g. rotation of the experiment in the background filed produces a physical effect.

- There is a well defined SME $\mathcal{L}_{SME} = \mathcal{L}_{Gravity} + \mathcal{L}_{SM} + \mathcal{L}_{LV}$ e.g $a_\mu \bar{\psi}\gamma^\mu\psi,\ c_{\mu\nu}\bar{\psi}\gamma^\mu \overleftrightarrow{D}^\nu\psi$
  (D.Colladay & V.A. Kostelecky, PRD55, 6760 (1997); PRD58, 1166002 (1998); PRD69, 105009 (2004))

- Only a few constraints in the quark sector : use DIS, SDIS, Drell-Yan, …



$$W^{\mu\nu} \simeq i \int d^4x e^{iq\cdot x} \int_0^1 d\xi \sum_{f=u,d} \frac{f_f(\xi)}{\xi} \langle \xi P | T\{J^\mu(x) J^\nu(0)\} | \xi P\rangle$$

$$\Gamma_f^\mu = \gamma^\mu + c_f^{\mu\nu}\gamma_\nu$$

- The first estimate on the sidereal time dependent coefficients c_f were obtained using HERA data: $O(10^{-5})$
  (V.A.Kostelecky, E.Lunghi, A.Vieira, PLB729, 272 (2017))

- Sensitivity studies for EIC are under way: N.Sherrill, A.Accardi, E.Lunghi.

JPAC 2018/19

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Impact (first 3 years)

- > 40 Research Papers (Phys. Rev. Lett., Phys.Rev., Phys.Lett., Eur.J. Phys.)
- ~120 Invited Talks and Seminars
- $O(10)$ on going analyses
- Many projects, e.g.,
  - $\pi N \to \eta\pi N$ — *A. Jackura et al.,* arXiv:1707.02848
  - η, η' beam asymmetry — *V. Mathieu et al.,* arXiv:1704.07684
  - $Z_c(3900)$ — *A. Pilloni et al.,* PLB772 (2017) 200
  - $\gamma p \to \eta p$ — *J. Nys et al.,* PRD95 (2017) 034014
  - $P_c(4450)$ — *A. Hiller Blin et al.,* PRD94 (2016) 034002
  - $\eta \to \pi^+\pi^-\pi^0$ — *P. Guo et al.,* PRD92 (2015) 054016, PLB (2017) 497
  - $\Lambda(1405)$ — *C. Fernández-Ramírez et al.,* PRD93 (2016) 074015
  - $KN \to KN$ — *C. Fernández-Ramírez et al.,* PRD93 (2016) 034029
  - $\pi N \to \pi N$ — *V. Mathieu et al.,* PRD92 (2015) 074004
  - $\gamma p \to \pi^0 p$ — *V. Mathieu et al.,* PRD92 (2015) 074013
  - $\omega,\phi \to \pi^+ \pi^- \pi^0$ — *I. Danilkin et al.,* PRD91 (2015) 094029
  - $\gamma p \to K^+K^- p$ — *M. Shi et al.,* PRD91 (2015) 034007
  - …
- Collaboration between JPAC and experimental collaborations: co-authoring papers
  - GlueX, CLAS12, COMPASS, BaBar, Belle, BES
  - KLOE, LHCb *in preparation*