JLab Physics Analysis Center (JPAC)

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Indiana University/JLab

- Analysis strategy
- Current projects :
  - diffractive dissociation
  - light meson properties

Specific goals

- Develop state-of-the-art description of hadronic interactions to take the full advantage of the information contained in the high quality experimental data.

- Build software tools to analyze high statistics data on a large number of reactions channels simultaneously.

- Develop framework for data preservation.

Current Channels

Final state	meson	experiment	availability	people	Date available
3π	η	g12	now	D. Schott, [1]	
		g11	disk failure	[1,2]	Fall 2014
	ω	g12	thesis in progress	FSU, NSU	winter 2014/2015
		g11	now	A. Celentano [2]	Being copied
		g1c/g8b	soon		Being copied
pK+K-		g12	now	D. Schott	
		g11	pub. In progress	S. Lombardo [2]	End of summer?

Rough Data Sizes

$$O(100K)\ \eta' s, \omega' s, \phi' s$$

$$O(1M)\ pK^+K^-, p\pi^+\pi^-$$

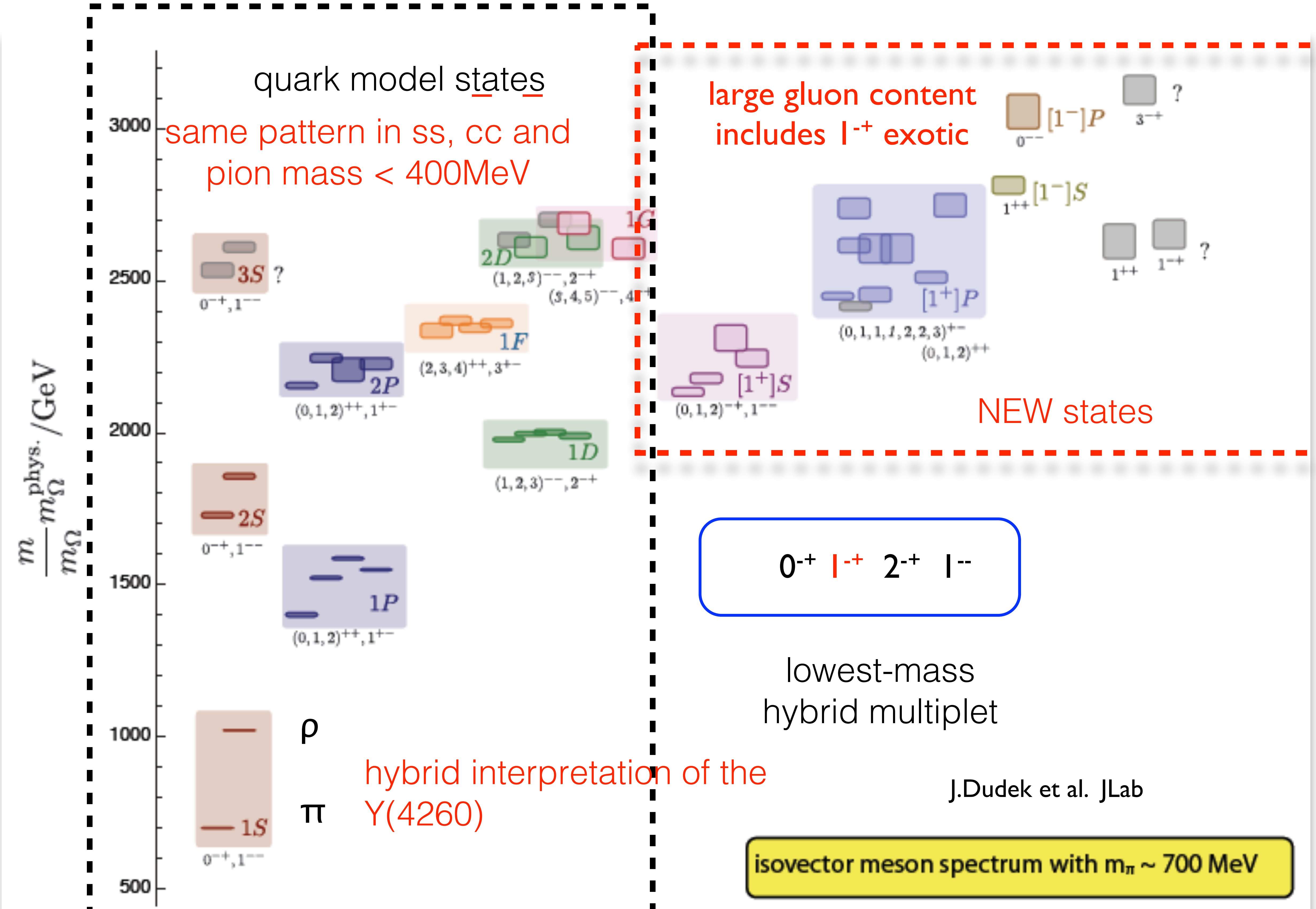
Future Channels (from existing data)

Final state	meson	experiment	availability	people	Date available
3π	η′	g11	in progress	A. Rizzo [2], [1]	
$K\bar{K}\pi$		g11	in progress	A. Filippi [2]	
Xe+e-	$\omega \to \pi^0 e^+ e^-$	g12/g11	thesis in progress	H. Shah [1]	Fall or spring?
	$\phi \to \pi^0 e^+ e^-$			[1]	
$K^+K^-\pi$		g11	in progress	S. Fegan [2]	
$p\pi^+\pi^-$		g11	pub. in 2009	M. Battaglieri [2]	

GlueX and CLAS12 data arriving soon

"Can we quantitatively understand quark and gluon confinement in quantum chromodynamics and the existence of a mass gap"

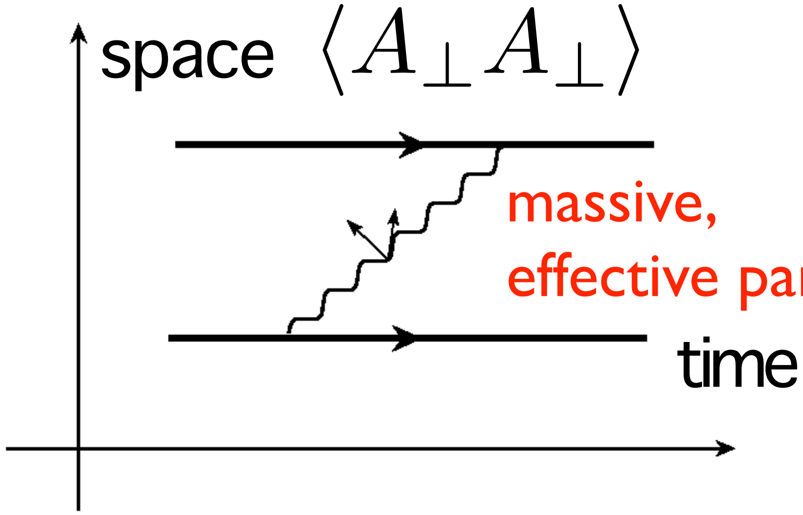
in 10 Physics Questions to Ponder for a Millennium or Two

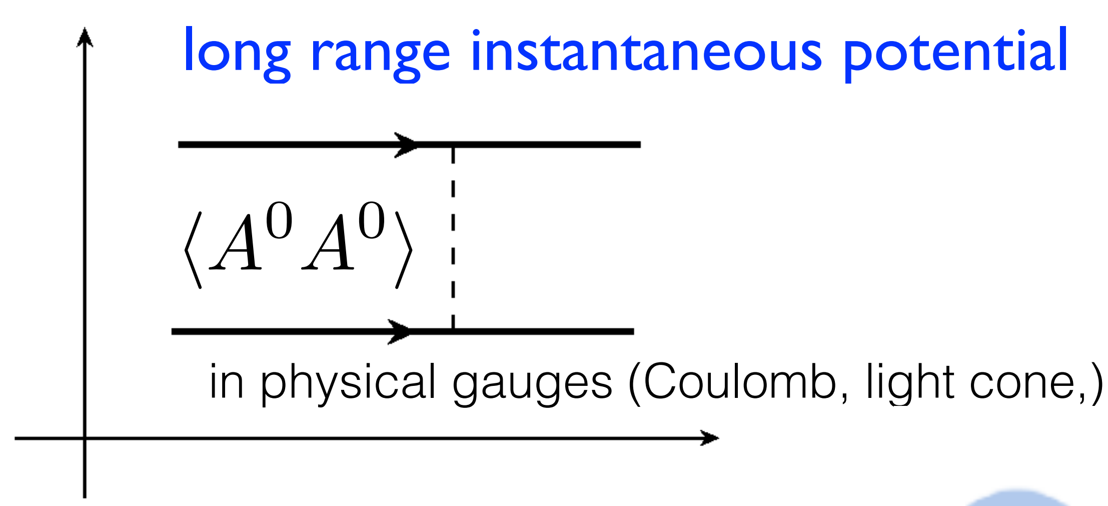


All gluons are equal but some are more equal than others:

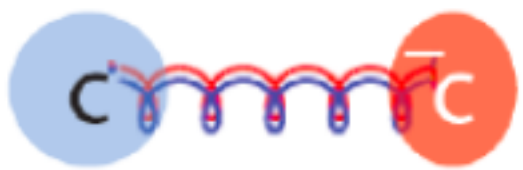
provide confinement => long range correlations

are confined => short range correlations





Lightest hybrids have "constituent" gluons !

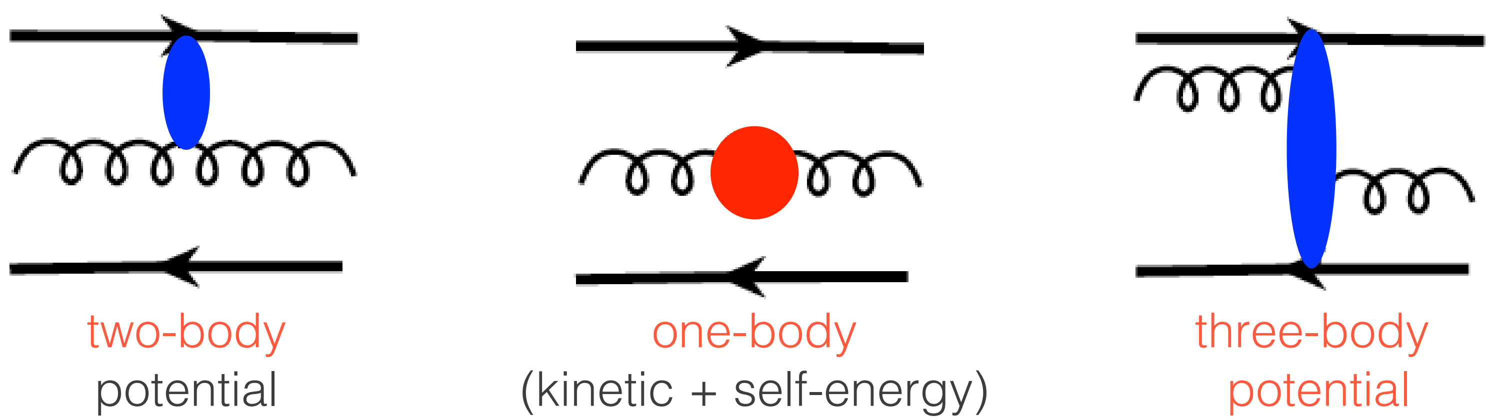


J^{PC} glue

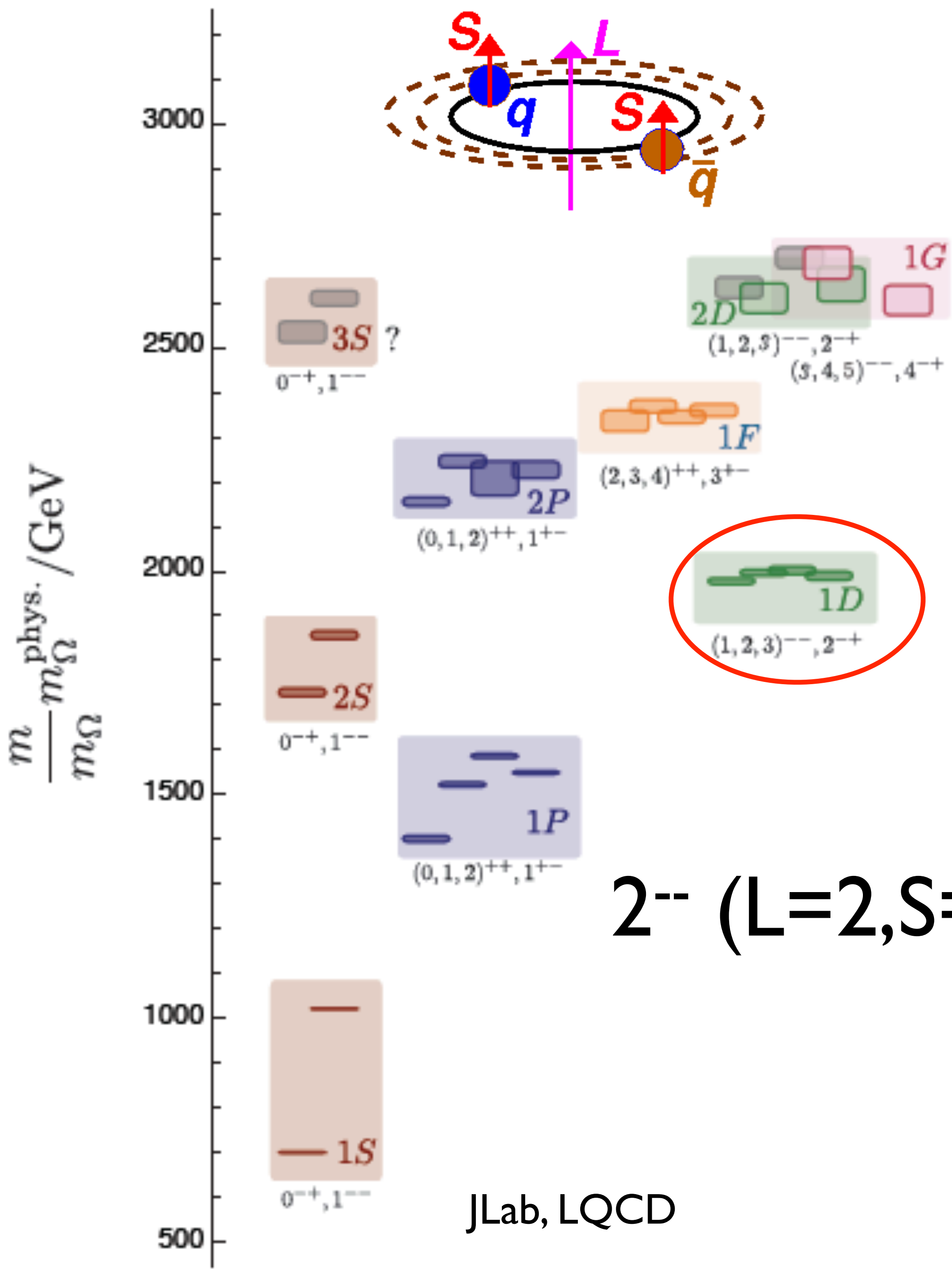
J^{PC} $Q\bar{Q}$

$$1^{+-} \times 0^{-+}_{S_{Q\bar{Q}}} = \boxed{1^{--}}$$

$$1^{+-} \times 1^{--}_{S_{Q\bar{Q}}=1} = \boxed{0^{-+}, 1^{-+}, 2^{-+}}$$



"quark model" states

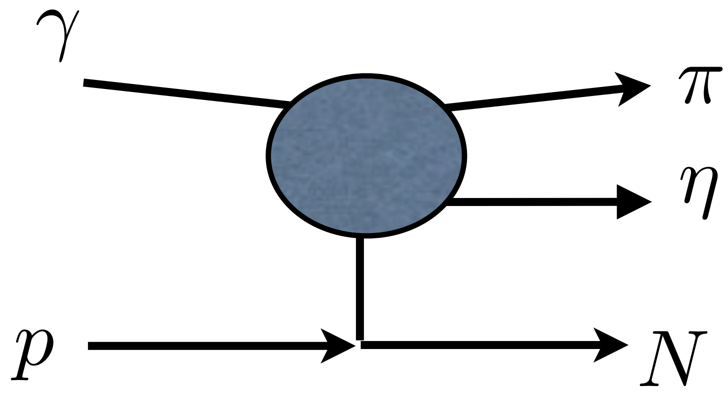


2^{--} (L=2,S=1)

JLab, LQCD

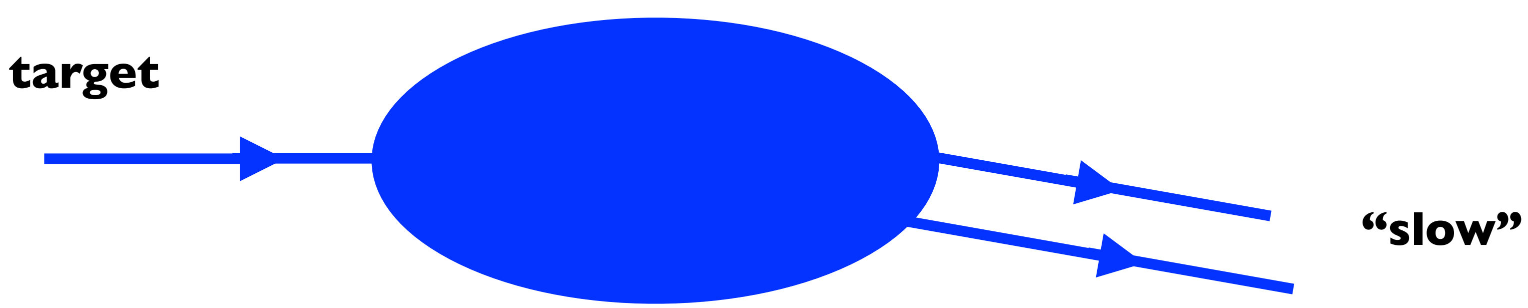
I^G	naturality $=P(-1)^J$	twist =+1 if J=0,2,.. =-1 if J=1,3...	name
0^+	+1	+1	$f_0,f_2,...$
0^+	+1	-1	$\eta/\eta'_1,\eta/\eta'_3,...$ ($1^{-+},3^{-+},..$)
0^+	-1	+1	$\eta/\eta'_0,\eta/\eta'_2,...$
0^+	-1	-1	$f_1,f_3,...$
0^-	+1	+1	$h_0,h_2,..$ ($0^{+-},2^{+-},..$)
0^-	+1	-1	$\omega/\phi_1,\omega/\phi_3,...$
0^-	-1	+1	$\omega/\phi_0,\omega/\phi_2,...$($0^{--},2^{--},..$:not seen)
0^-	-1	-1	$h_1,h_3,...$
1^+	+1	+1	$b_0,b_2,..$ ($0^{+-},2^{+-},..$)
1^+	+1	-1	$\rho_1,\rho_3,...$
1^+	-1	+1	$\rho_0,\rho_2,...$ ($0^{--},2^{--},..$:not seen)
1^+	-1	-1	$b_1,b_3,..$
1^-	+1	+1	$a_0,a_2,...$
1^-	+1	-1	$\pi_1,\pi_3,...$ ($1^{-+},3^{-+},..$)
1^-	-1	+1	$\pi,\pi_2,...$
1^-	-1	-1	$a_1,a_3,...$

Amplitude Analysis



The Golden Channel for ground state exotic meson search

Reggion- beam closely related to particle-beam (analyticity understood)



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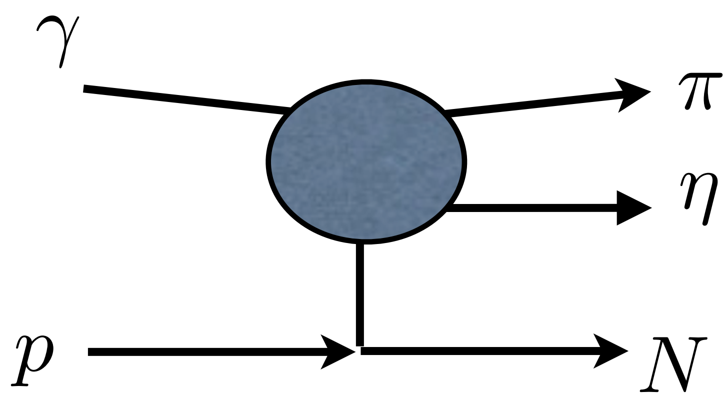

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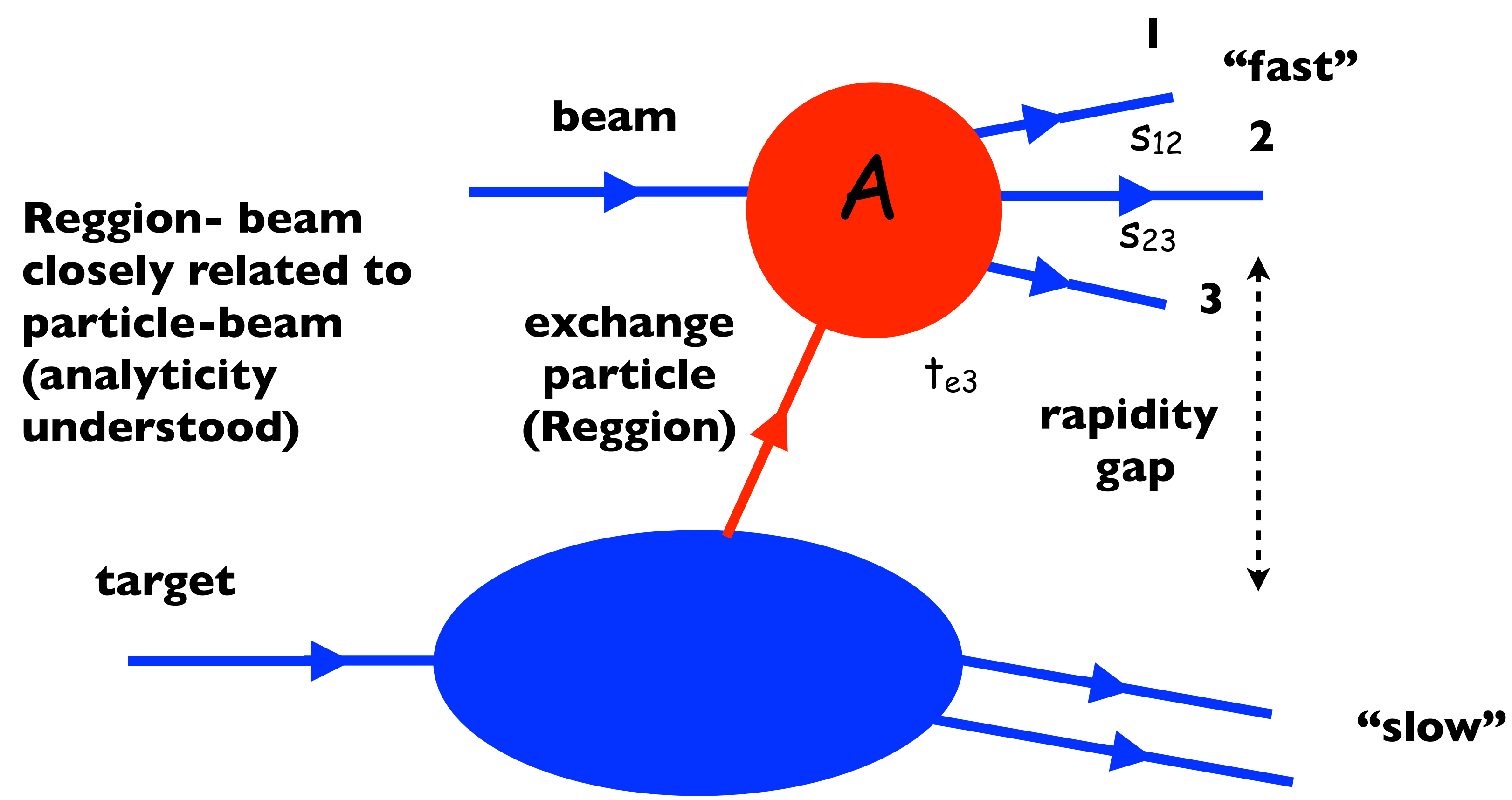

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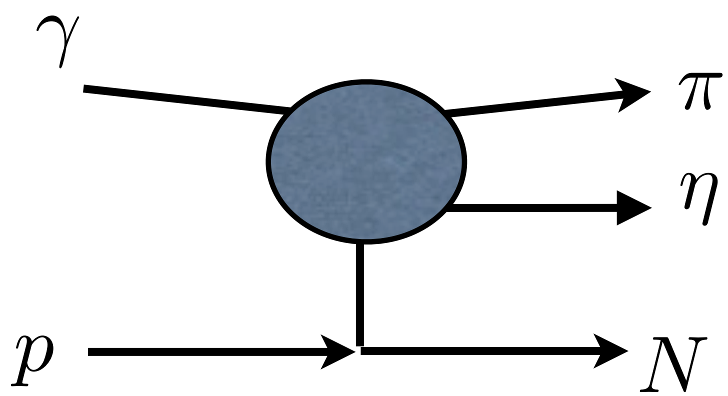
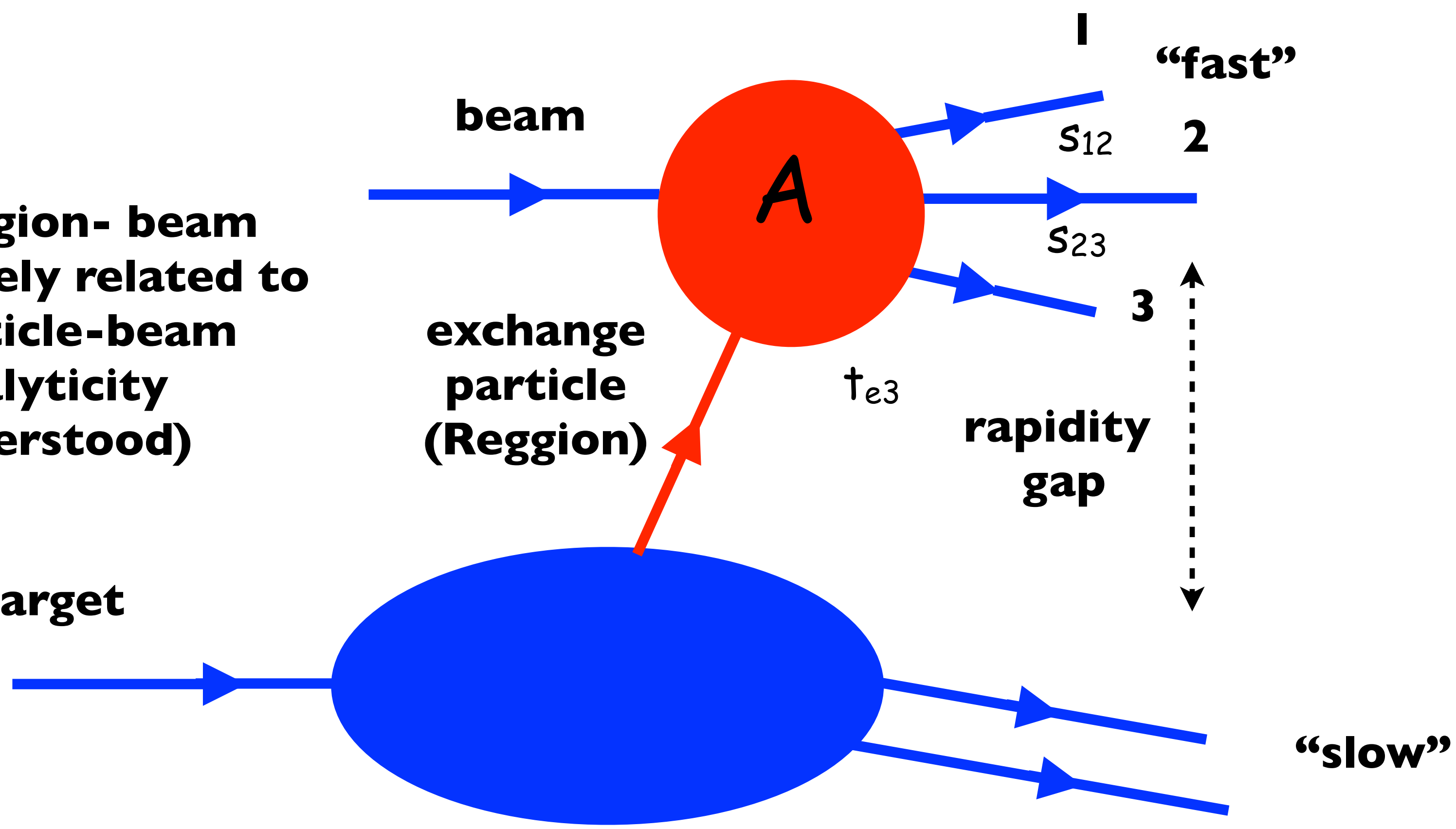


The Golden Channel for ground state exotic meson search

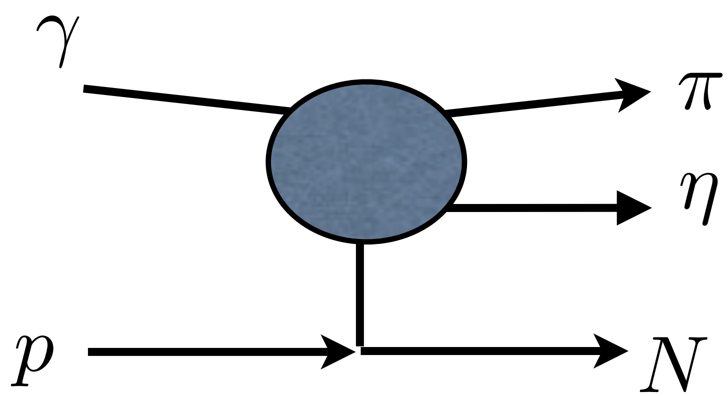
Effects to include

(similar for lower vertex)

Reggion- beam closely related to particle-beam (analyticity understood)



Amplitude Analysis

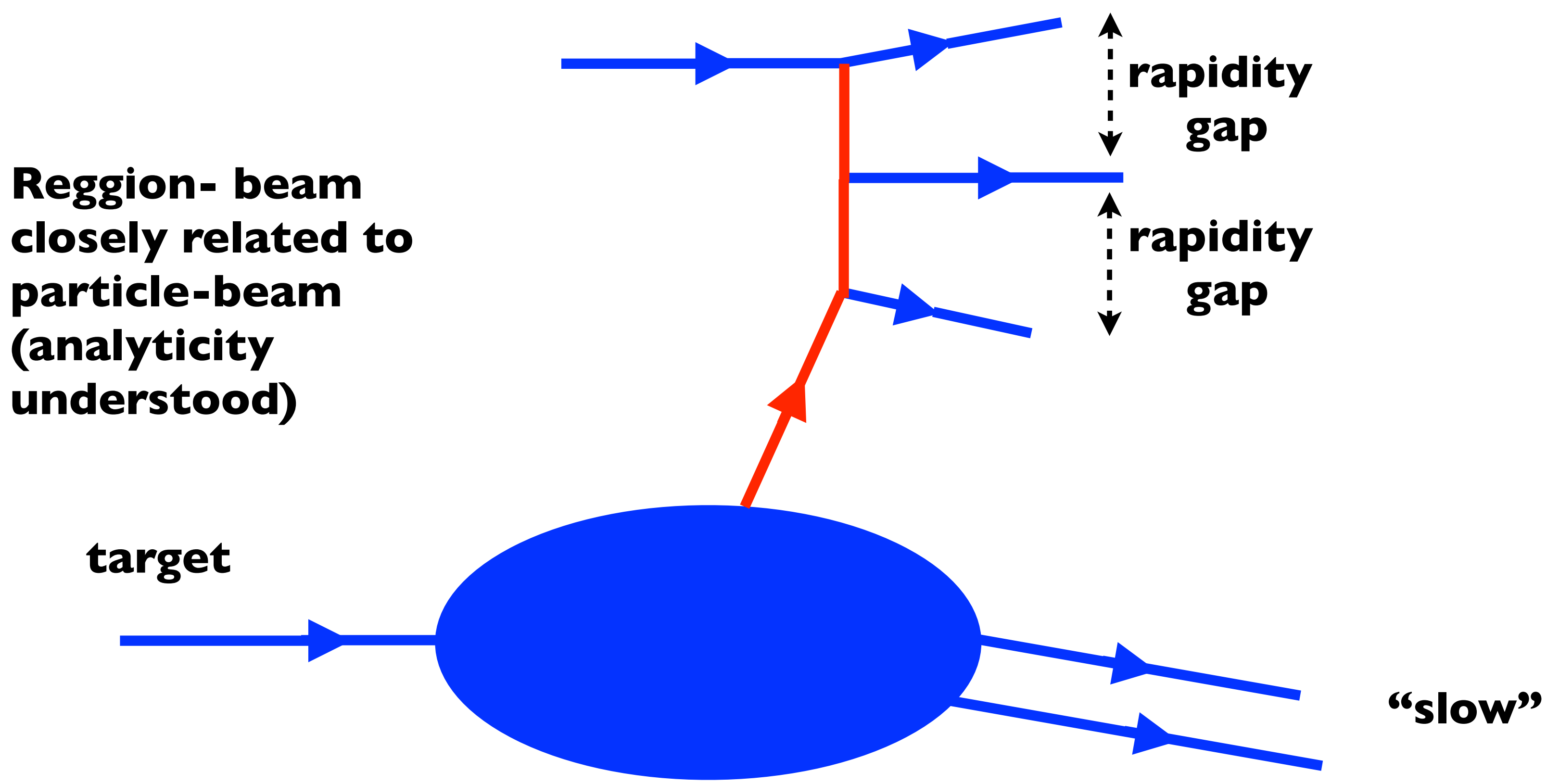


The Golden Channel for ground state exotic meson search

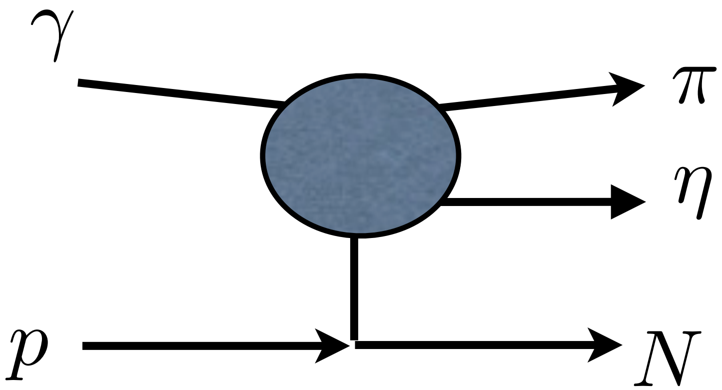
Effects to include

(similar for lower vertex)

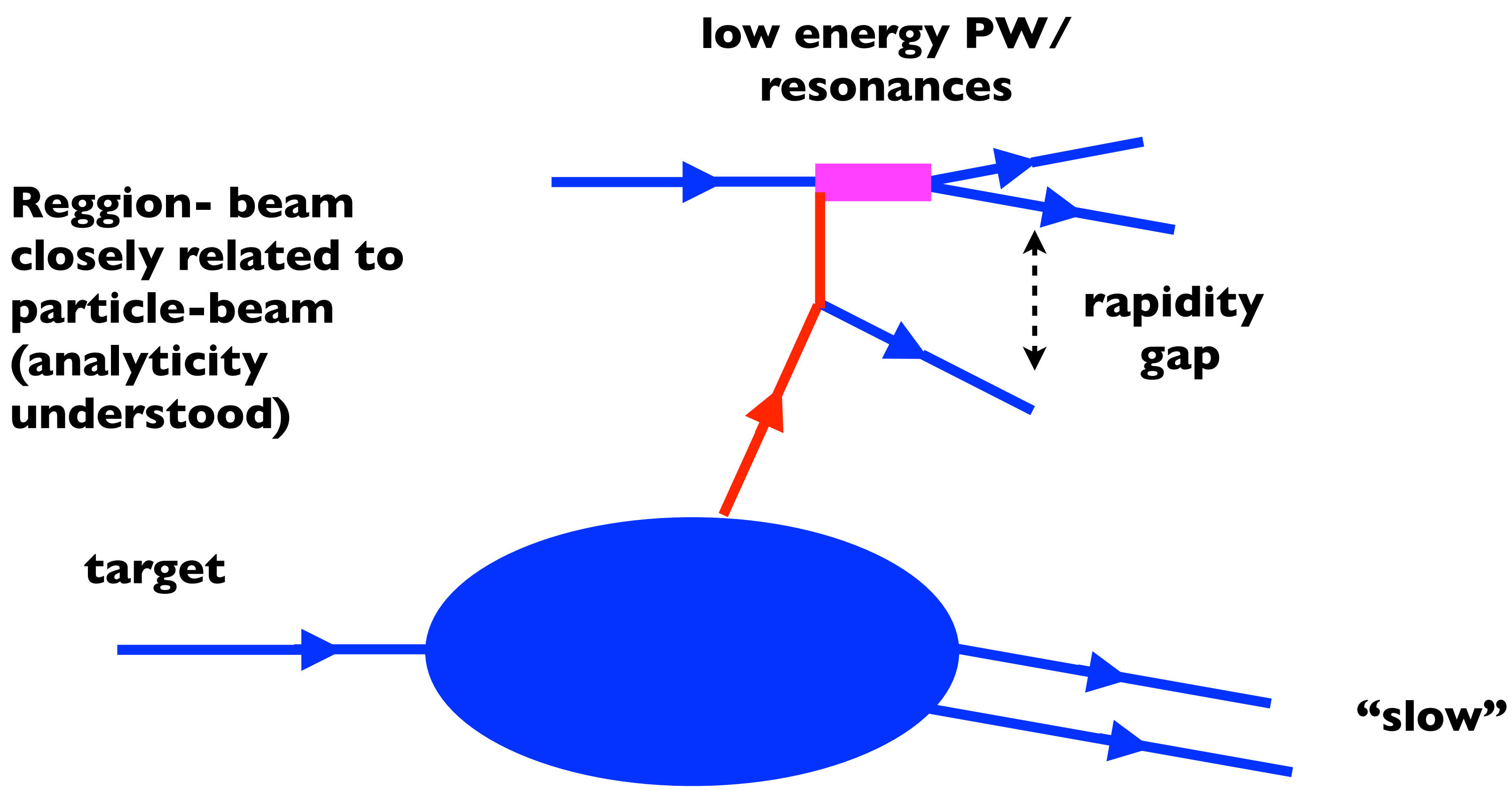
1. Double-Regge amplitudes for higher masses/spins



Amplitude Analysis



The Golden Channel for ground state exotic meson search



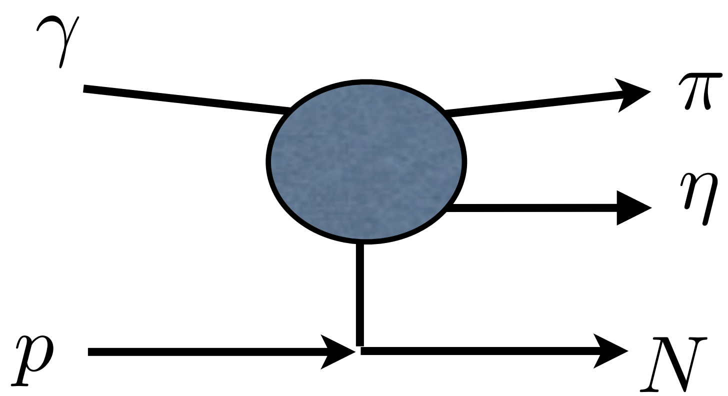
Effects to include

(similar for lower vertex)

1. **Double-Regge amplitudes for higher masses/spins**

2. **Single-Regge (Deck)**

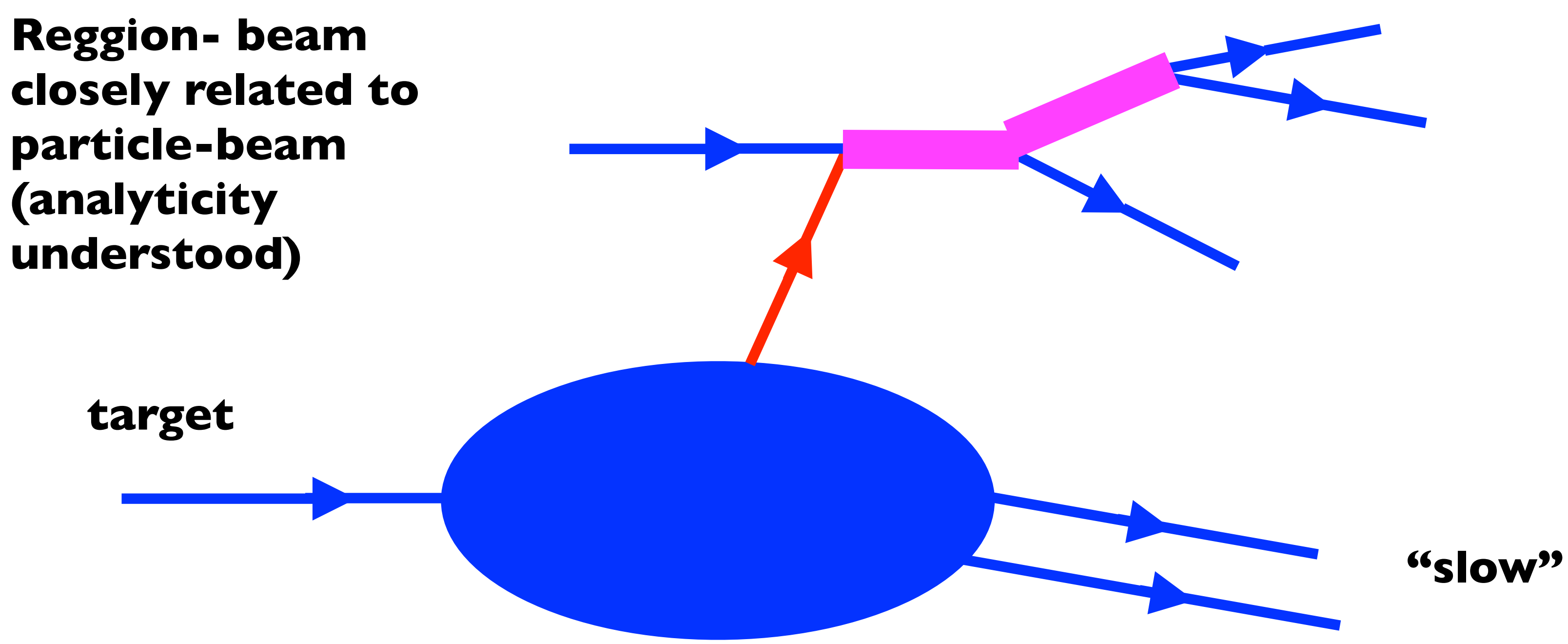
Amplitude Analysis



The Golden Channel for ground state exotic meson search

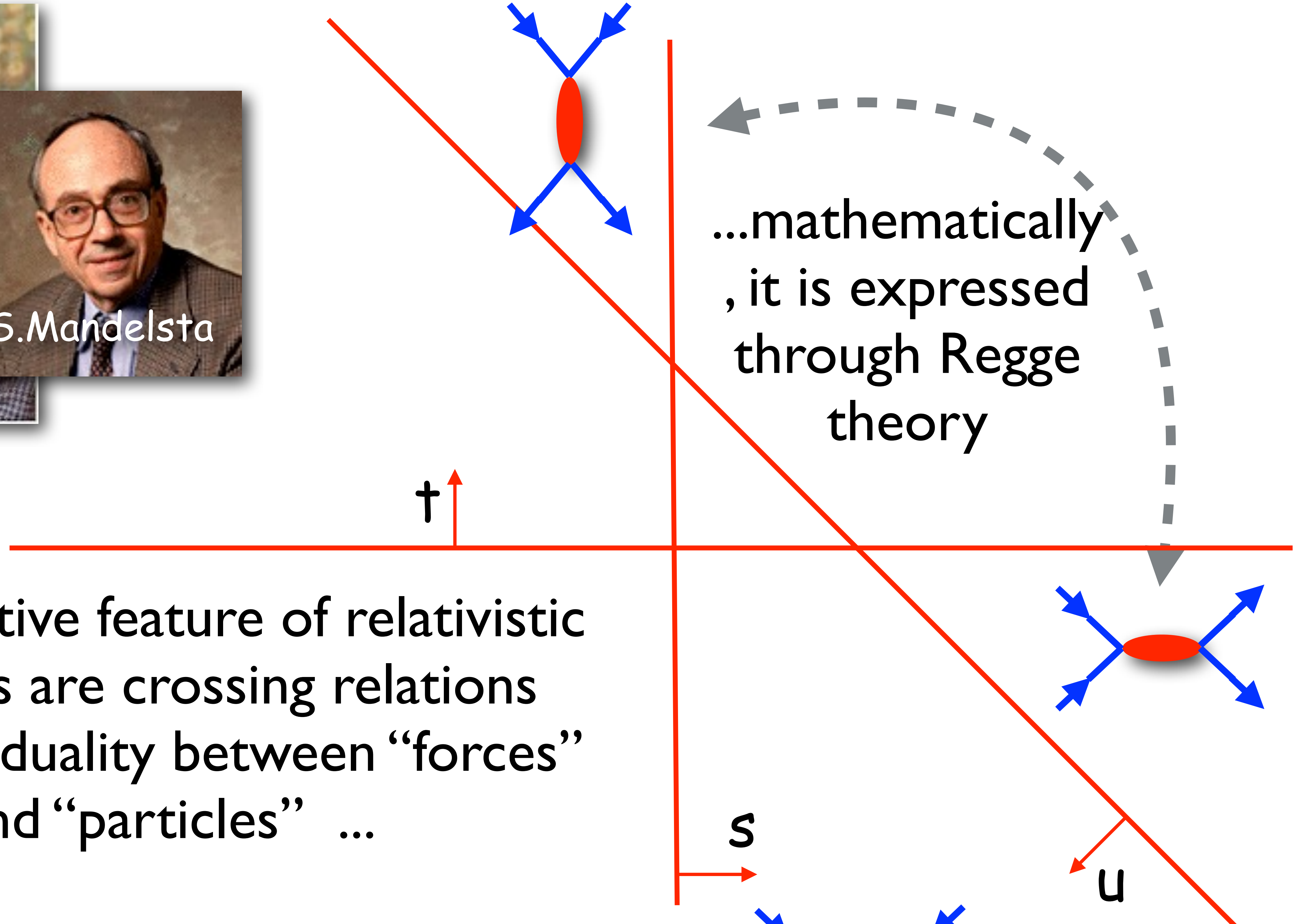
Effects to include

(similar for lower vertex)



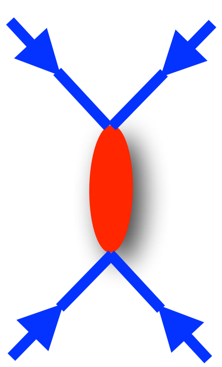
1. Double-Regge amplitudes for higher masses/spins
2. Single-Regge (Deck)
3. Quasi-elastic (isobar) parametrized low-energy waves (unitarity/coupled channels)

Use duality/FESR to constrain parameters

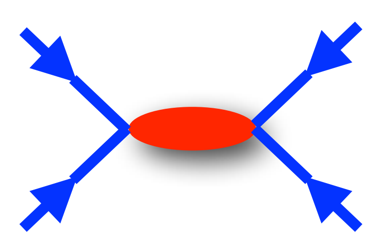


...mathematically, it is expressed through Regge theory

the distinctive feature of relativistic dynamics are crossing relations leading to duality between “forces” and “particles” ...



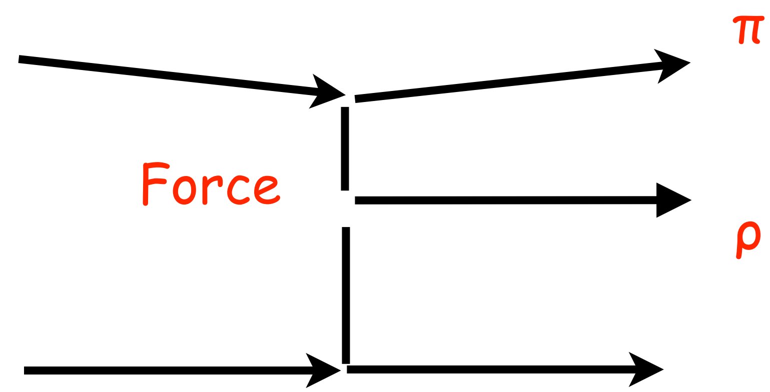
“force” <duality>“particle”

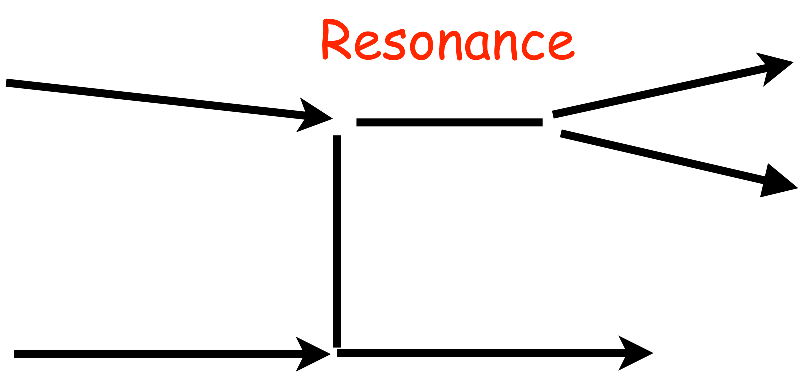


two component duality: Reggeons <> Resonances

Pomeron <> backgrounds

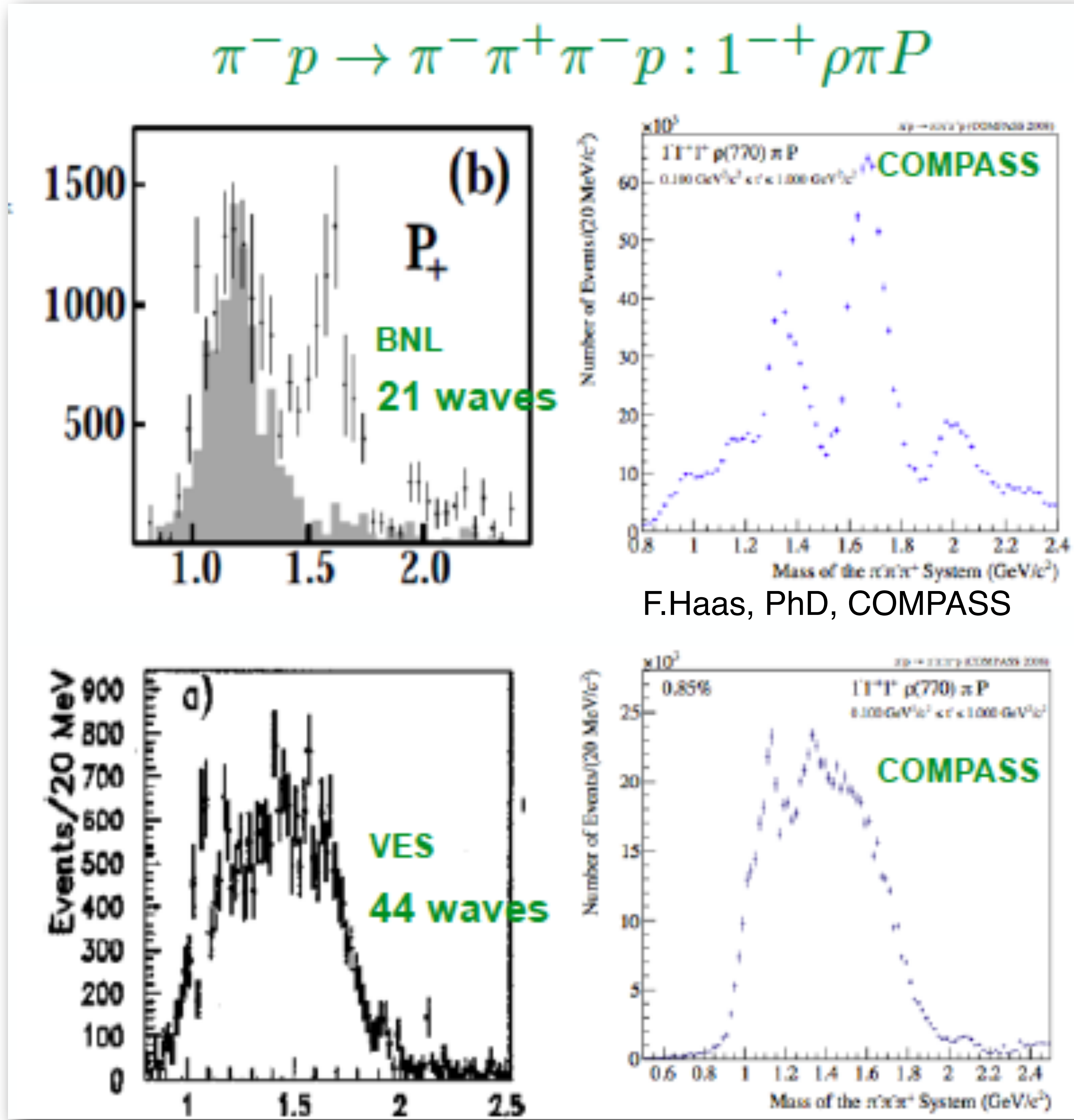
Is “bump” a resonance:





two component duality:

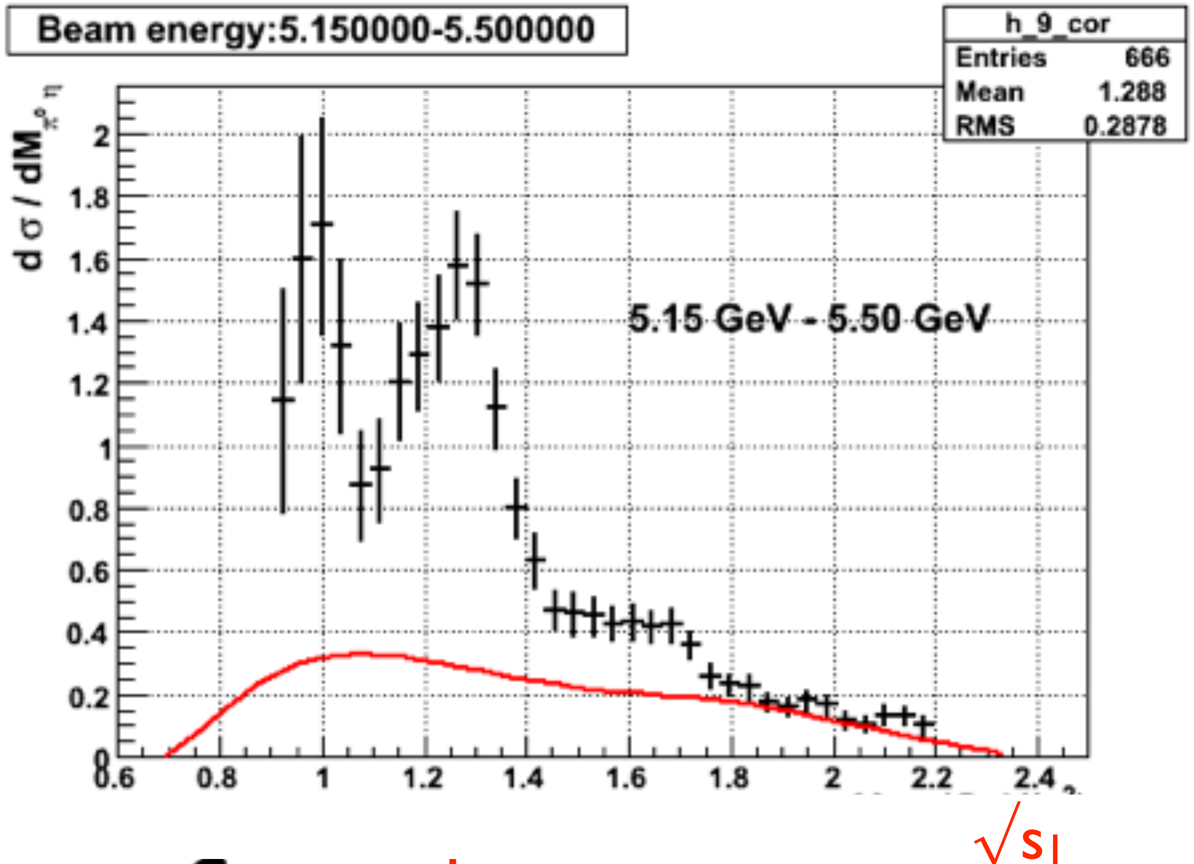
Reggeons <> Resonances
Pomeron <> backgrounds

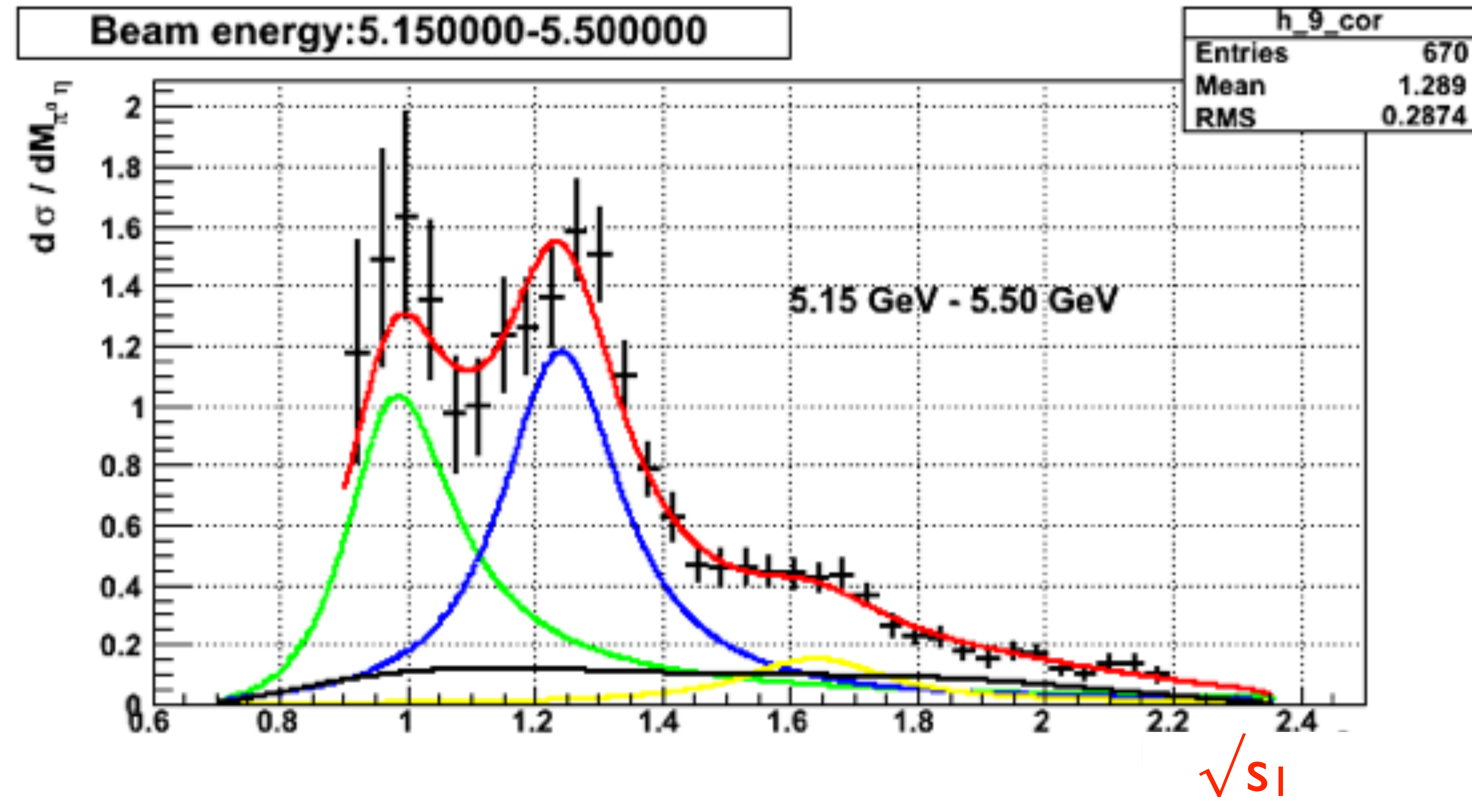


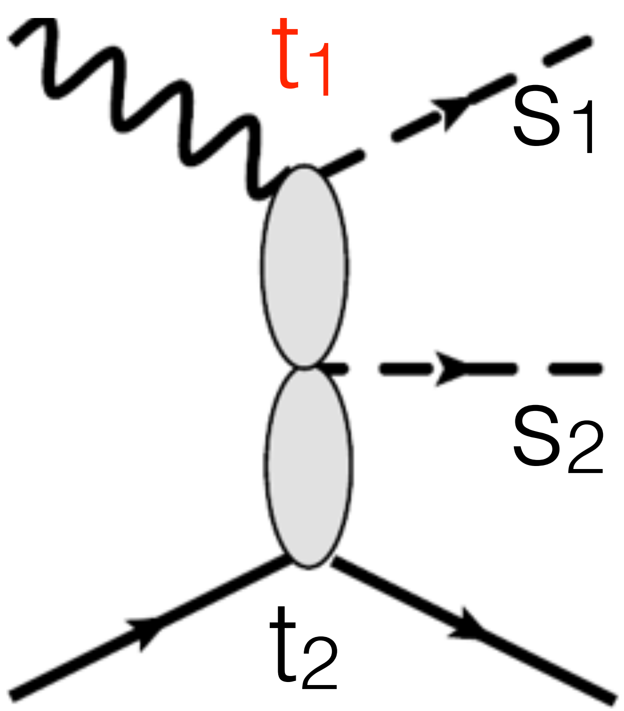
interpretation ambiguous without constraints

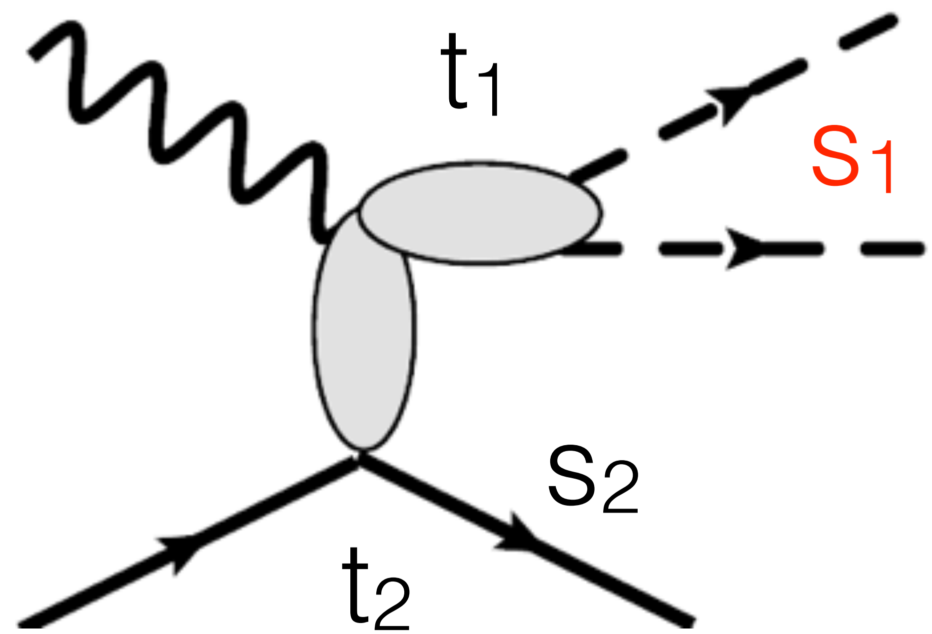
$\gamma p \to \eta\pi^0 p$ (g12)

A.Celentano, PhD, HASPEC/JPAC

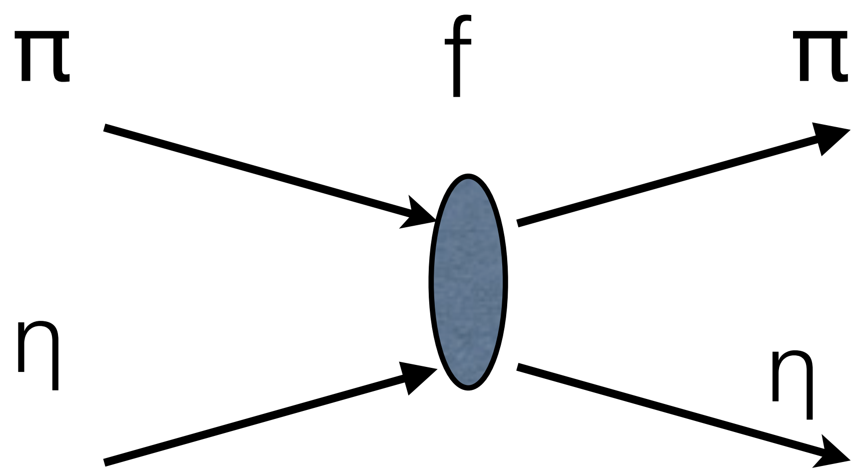




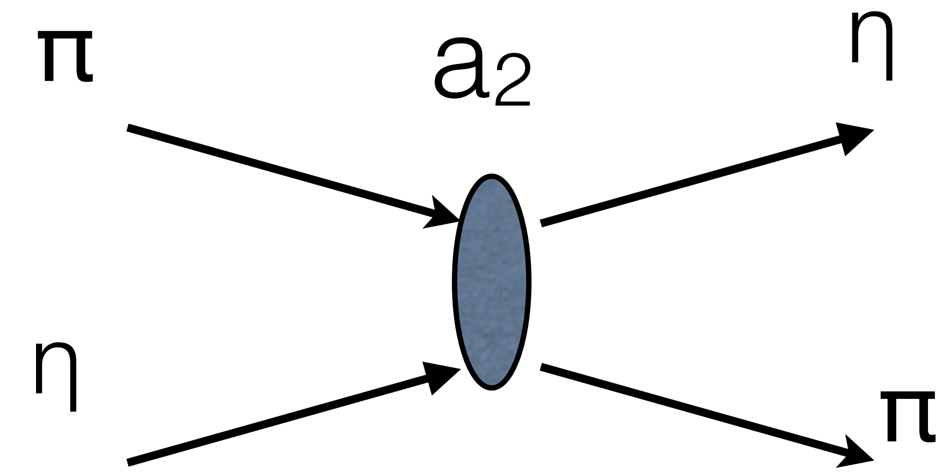




Duality and exotic mesons

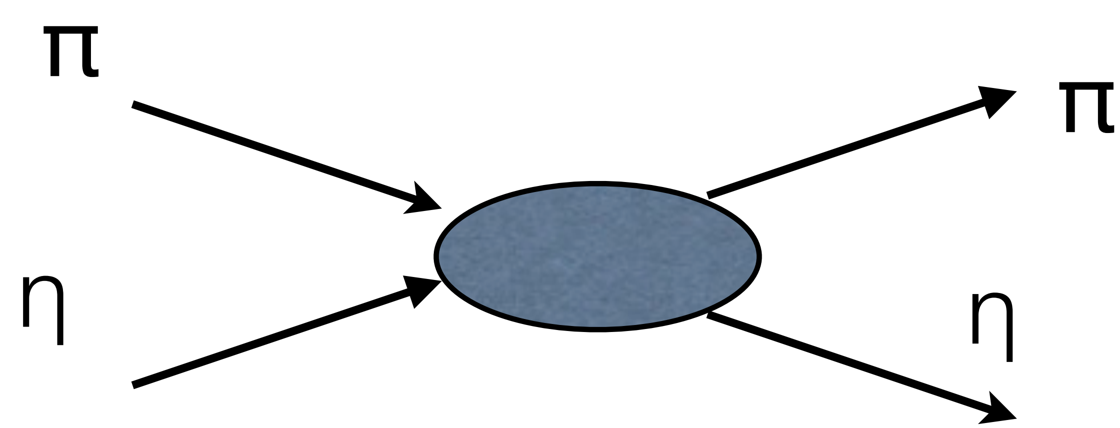


t-channel



u-channel

f,a_2 exchange degeneracy implies



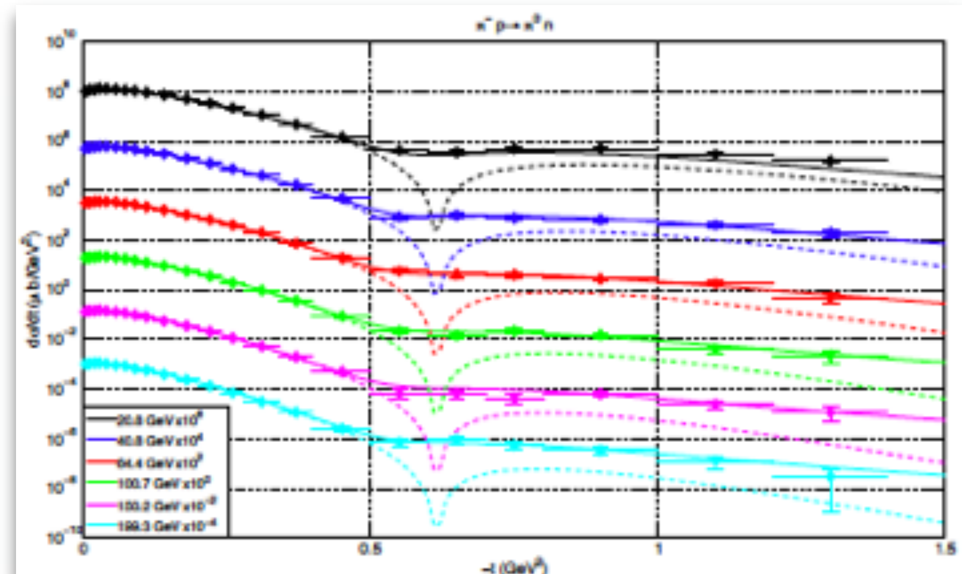
that the direct (s-channel) channel is dominated by spin-even partial waves.

Hybrids dual to Regge/Pomeron cuts?

Finite Energy Sum Rules $\pi N \to \pi N$

Construct Im(amplitude) from 0 to infinity via FESR
Reconstruct Re(amplitude) from dispersion relation

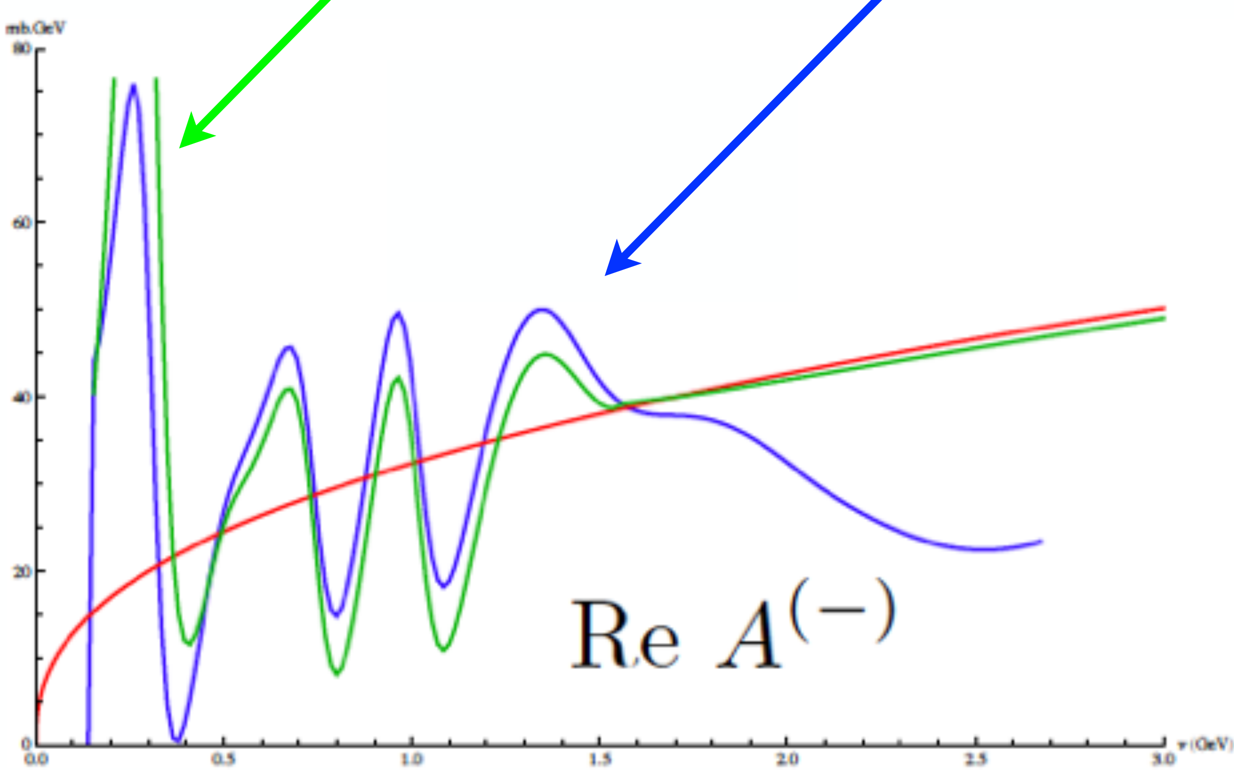
V.Mathieu, JPAC

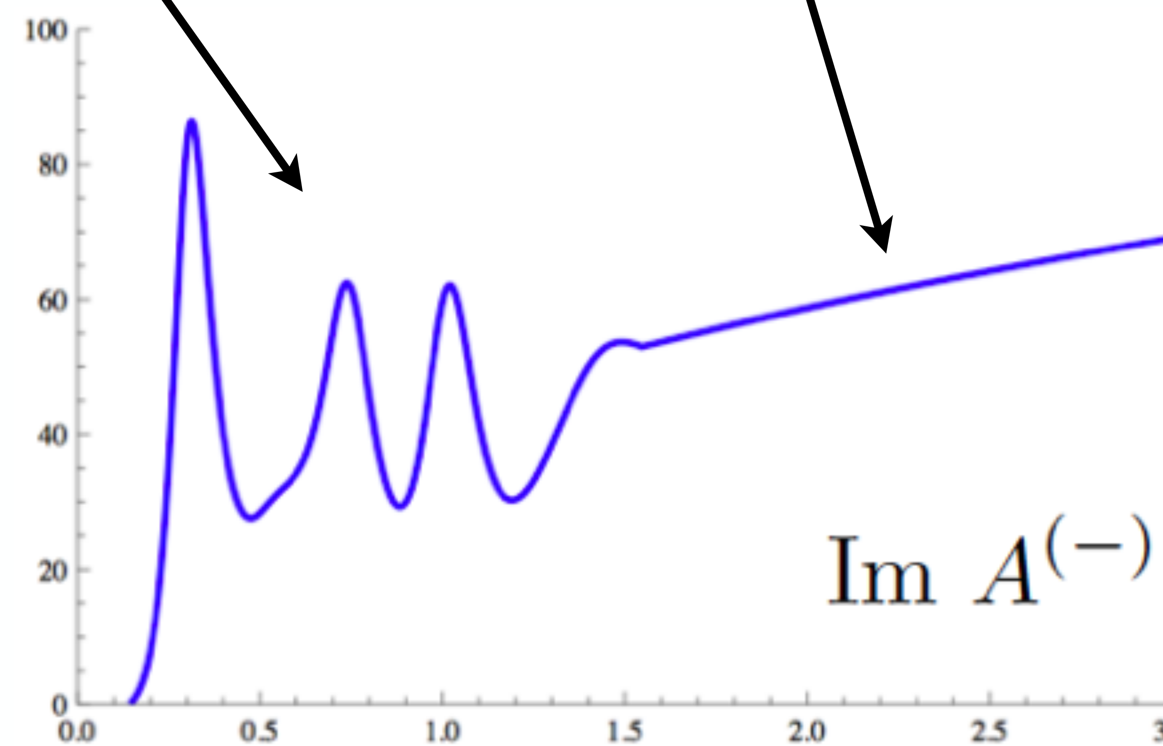


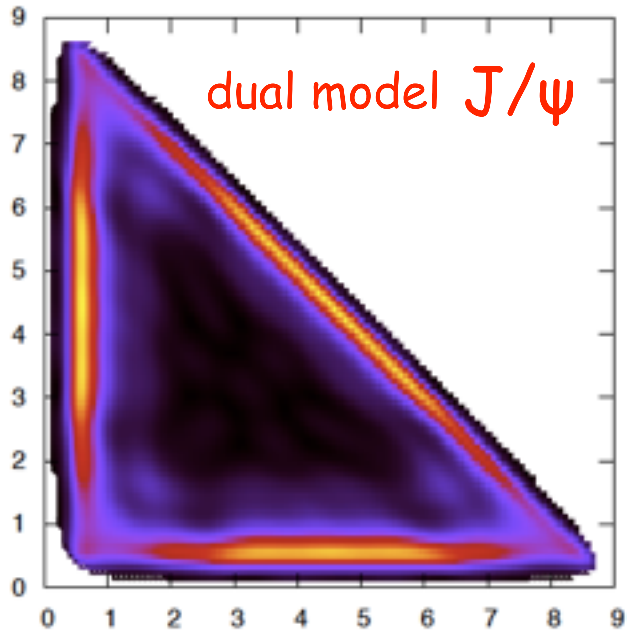
$$A^{(-)}(\nu, t) = \frac{2\nu}{\pi} \int_{\nu_0}^{\infty} \frac{\text{Im } A^{(-)}(\nu', t)}{\nu'^2 - \nu^2} d\nu'$$

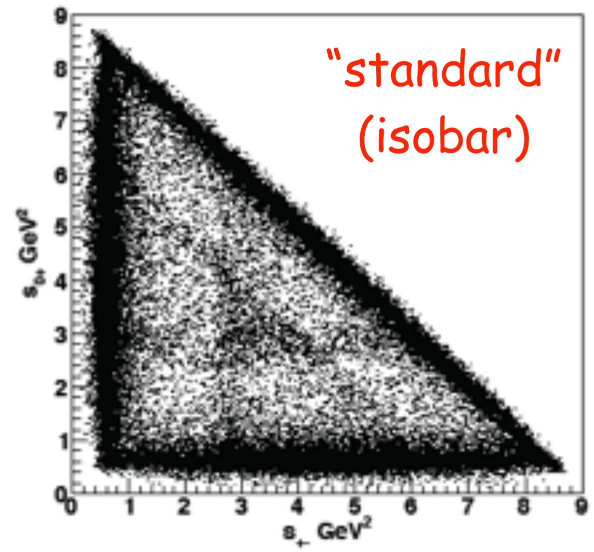
Reconstructed from Dispersion Relations

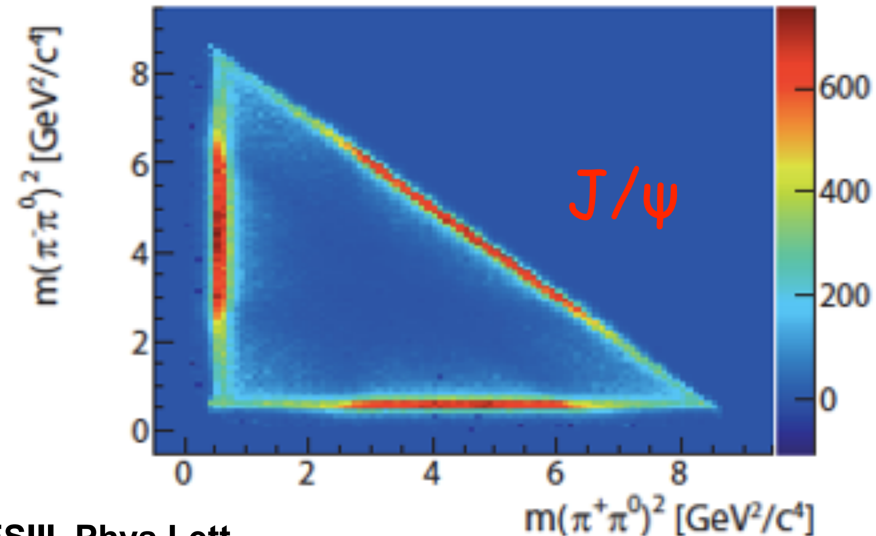
SAID:
WI08
R. Workman et al.
2008



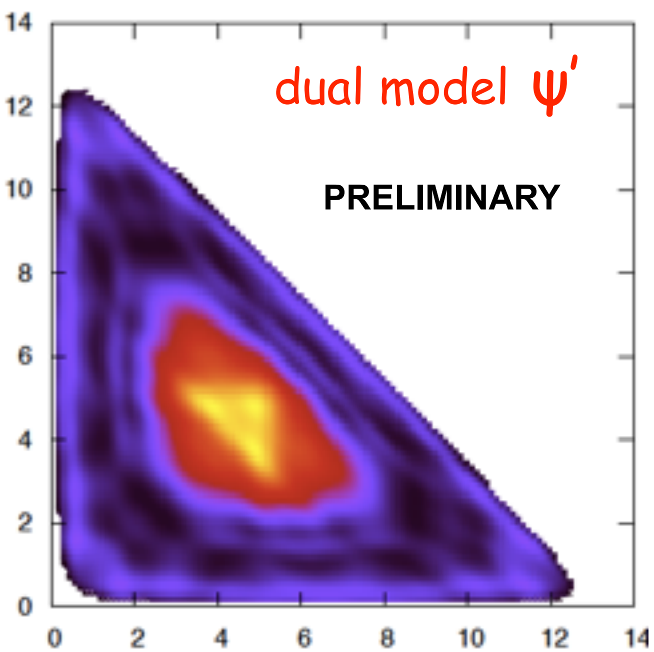


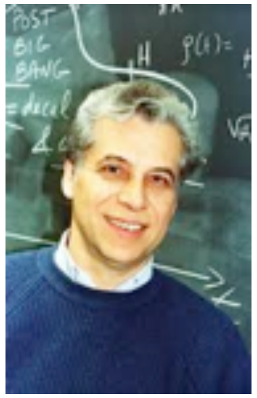






BESIII, Phys.Lett. B710 (2012) 594-599

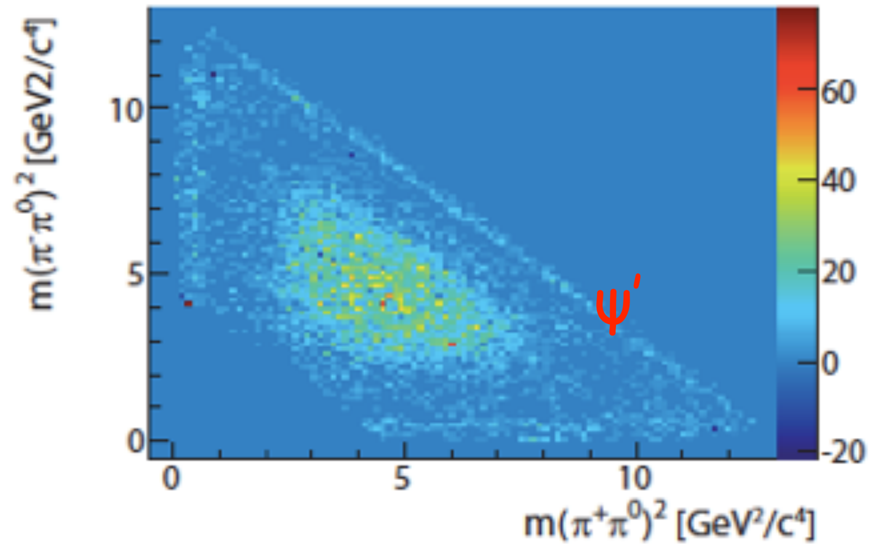




$$A(s,t) = \frac{\Gamma(-J(s))\Gamma(-J(t))}{\Gamma(-J(s)-J(t))}$$

$$\omega \to 3\pi$$

Veneziano or B4

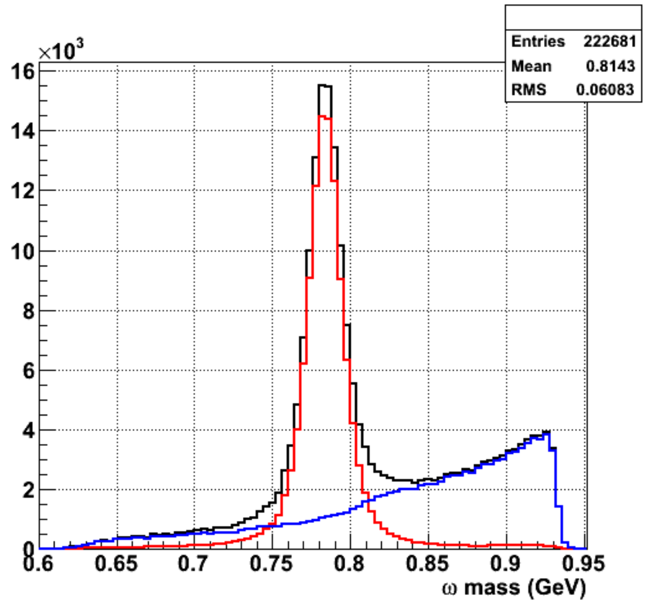


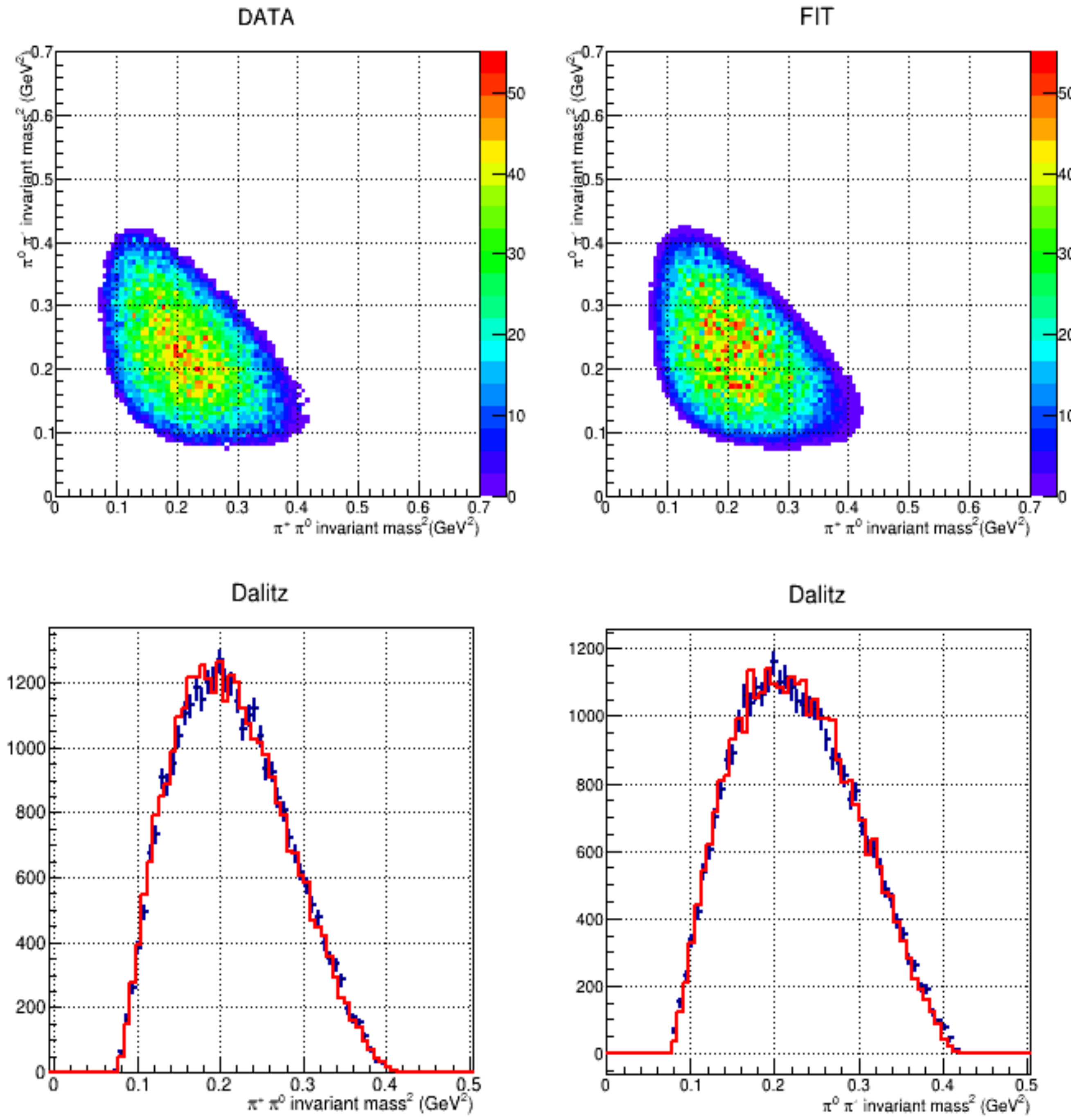
- Duality: resonances in direct channel dual to reggeons in cross channels and backgrounds are dual to the pomeron
- All resonances are "connected": resonances belong to Regge trajectories (reggeons)
- Asymptotics: determined by Regge poles
- Unitarity: imaginary parts determined by decay thresholds

The B_4 amplitude and the ω decay

The $\omega \rightarrow 3\pi$ decay process is a good candidate to test the B_4 amplitude approach.

$$A_\lambda = \varepsilon_{\mu\nu\alpha\beta}\, p_+^\nu p_-^\alpha p_0^\beta \varepsilon_\lambda^\mu\, F(s,t,u)$$





First results look very promising

Work plan:

- Use the full g11 statistics, merge different E_γ bins.
- Try different numbers of trajectories
- Investigate the $M_{3\pi}$ dependence

Fit performed with 2 trajectories (2 real parameters)

- 2.3 GeV < sqrt(s) < 2.31 GeV
- 0.78 GeV < $M_{3\pi}$ < 0.79 GeV

A.Celentano, PhD, HASPEC/JPAC

B_n amplitudes

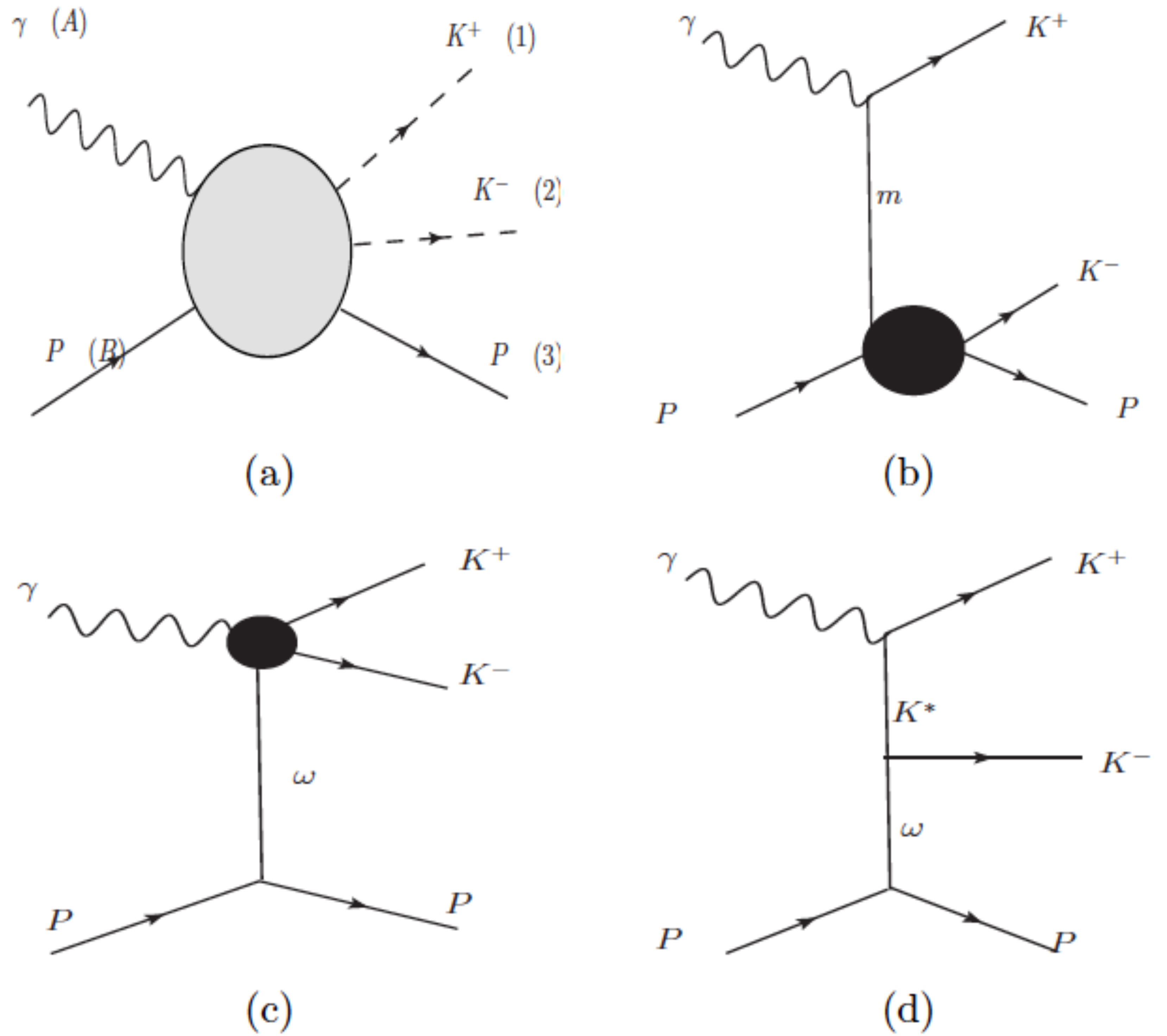
single Regge limit

Generalizations of the Veneziano model:

Force - Resonance Duality

Reggeone and resonances

B_5

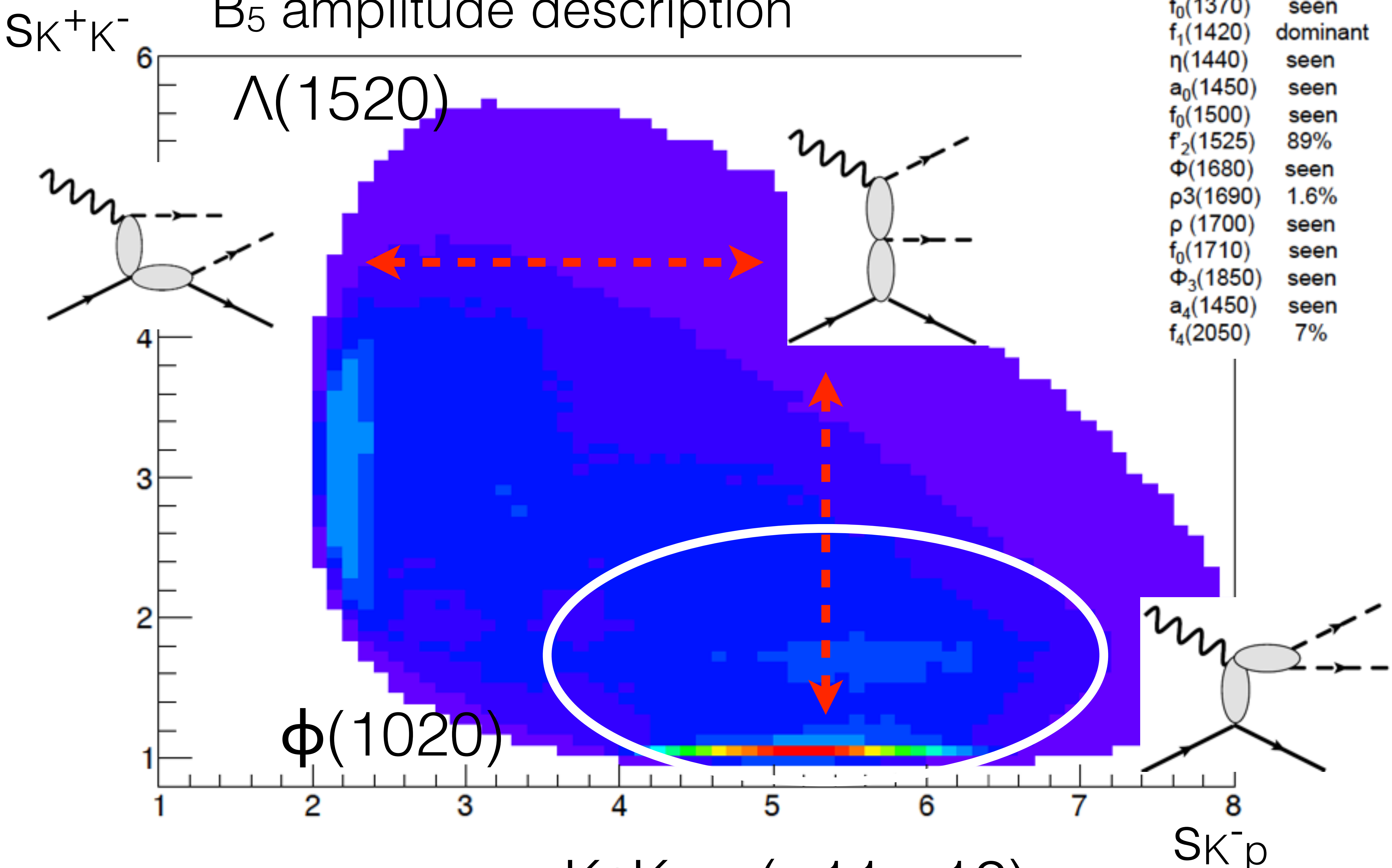


single Regge limit

double Regge limit

Duality @ JLab

B_5 amplitude description

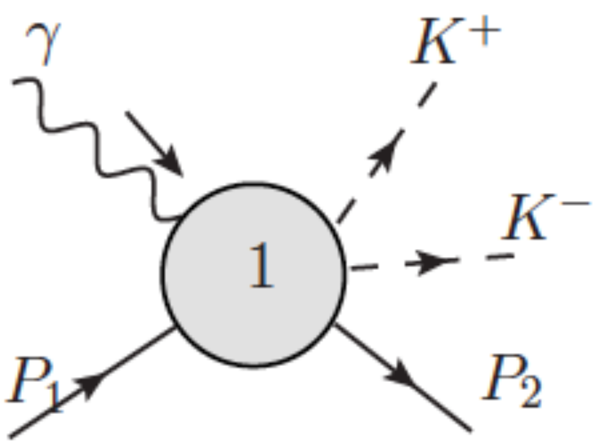


Φ(1020)	49%
f_2(1270)	46%
f_1(1285)	9%
a_2(1320)	49%
f_0(1370)	seen
f_1(1420)	dominant
η(1440)	seen
a_0(1450)	seen
f_0(1500)	seen
f'_2(1525)	89%
Φ(1680)	seen
ρ3(1690)	1.6%
ρ (1700)	seen
f_0(1710)	seen
$Φ_3$(1850)	seen
a_4(1450)	seen
f_4(2050)	7%

$\gamma p \rightarrow K^+K^-p$ (g11,g12)

D.Schott, JPAC/GWU
M. Shi JPAC/Pekin U.

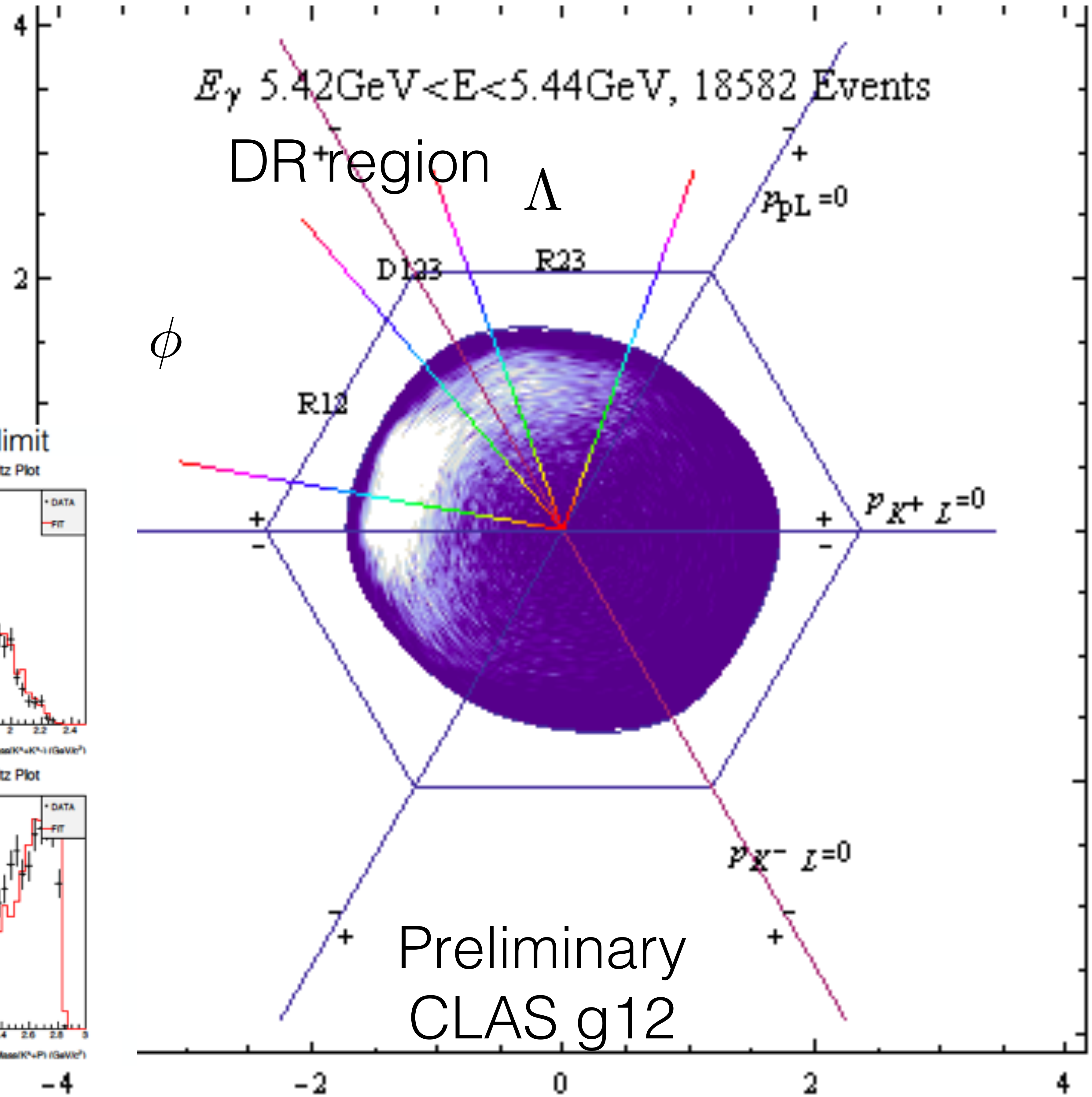
van Hove longitudinal plot



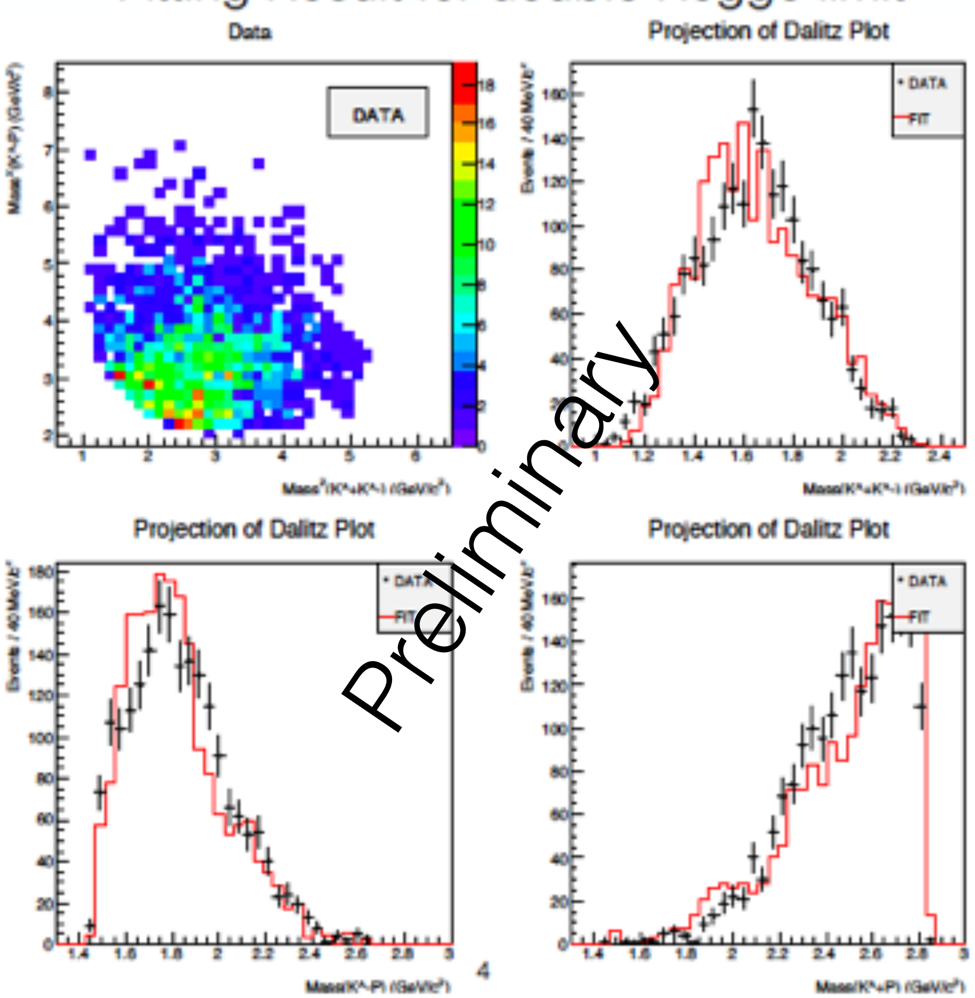
1

2

3

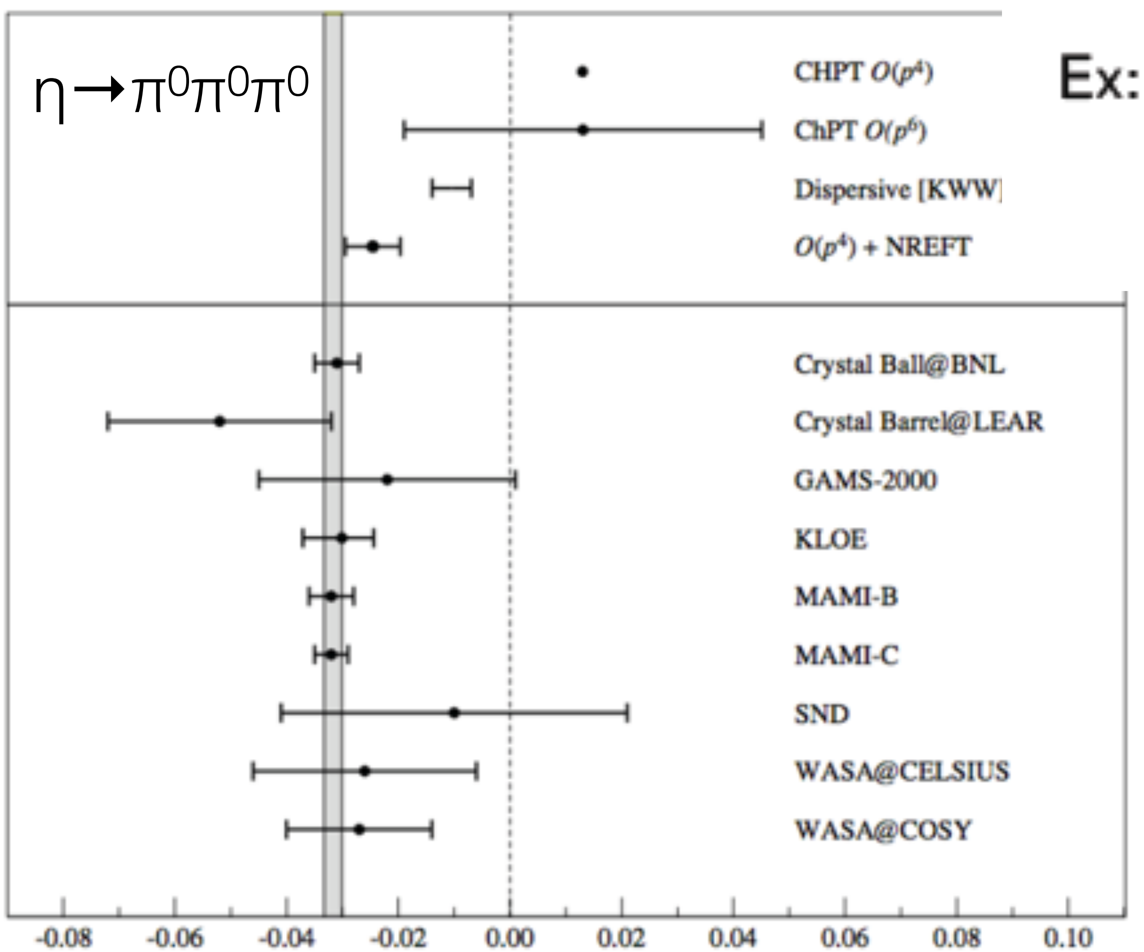


Fitting Result for double Regge limit



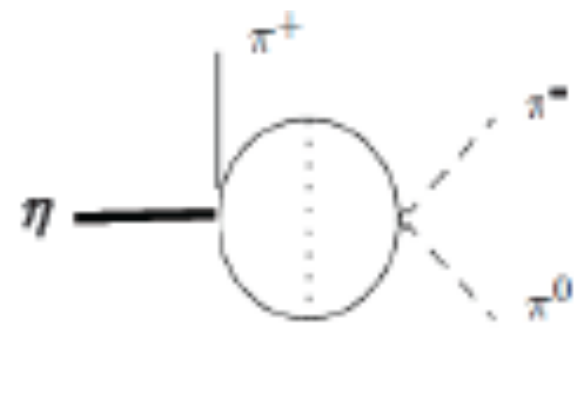
- Light meson properties

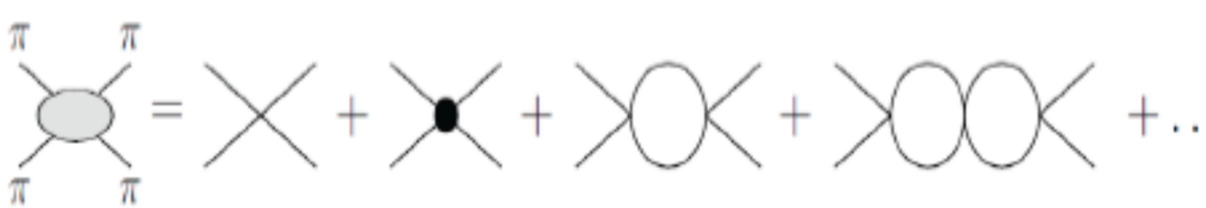
$\eta \to 3\pi$ $\omega \to 3\pi$ $\phi \to 3\pi$



Ex: $\eta \to 3\pi$ $\Gamma_{\eta\to 3\pi} = 66\ \text{eV} + 94\ \text{eV} + \ldots = 296\ \text{eV}$

LO NLO Experiment



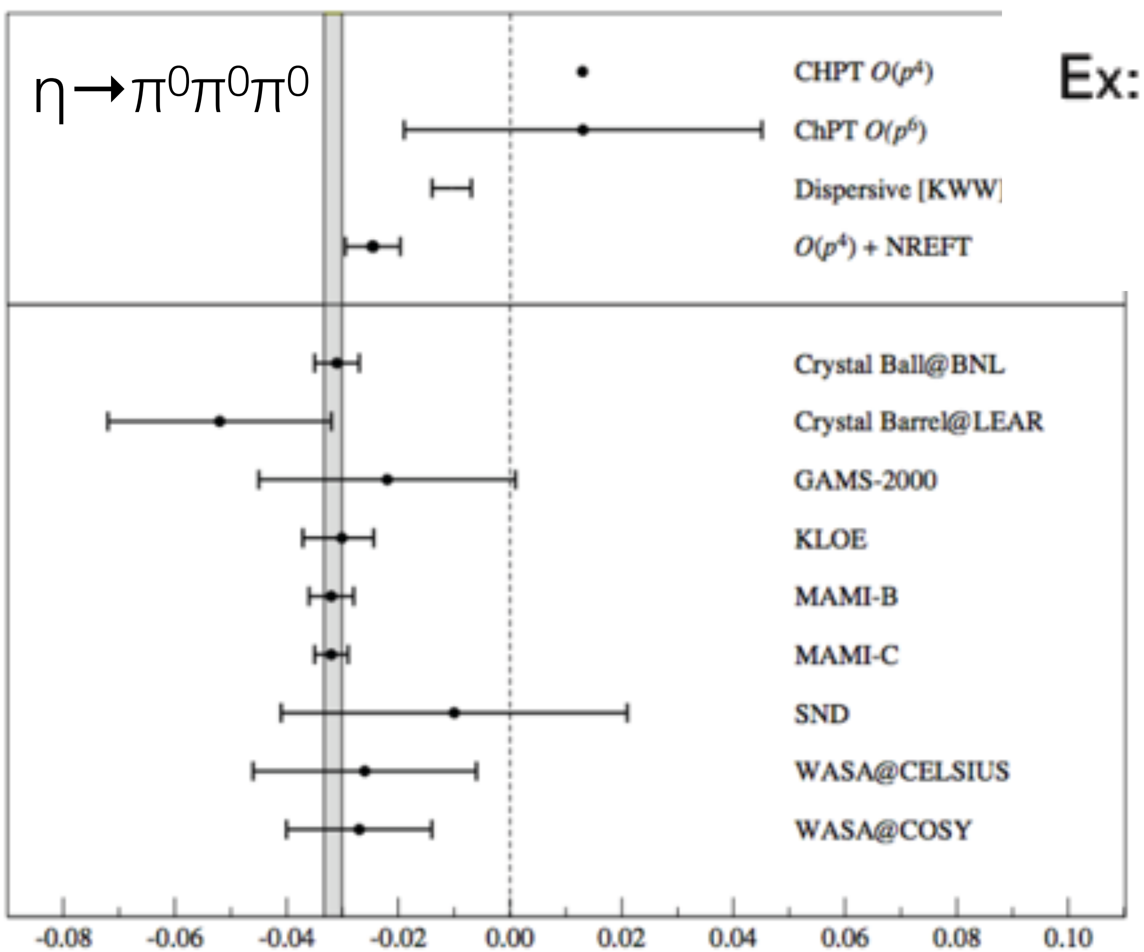


$A_{3\pi^0} \sim (m_u - m_d)[1 + \alpha(s_1 - s_m) + ..]$

- Light meson properties

$\eta \to 3\pi$ $\omega \to 3\pi$ $\phi \to 3\pi$

Amplitudes constrained phase space: effective (chiral) dynamics, low partial waves



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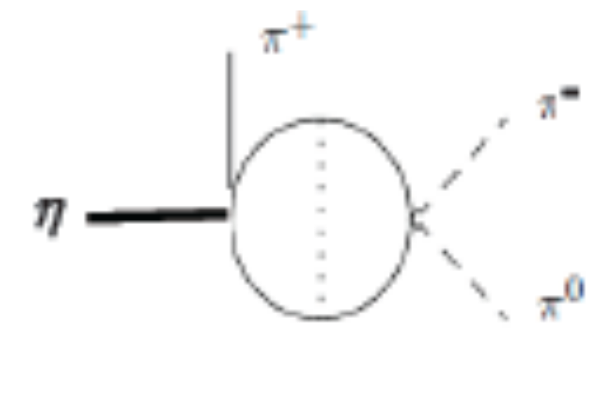
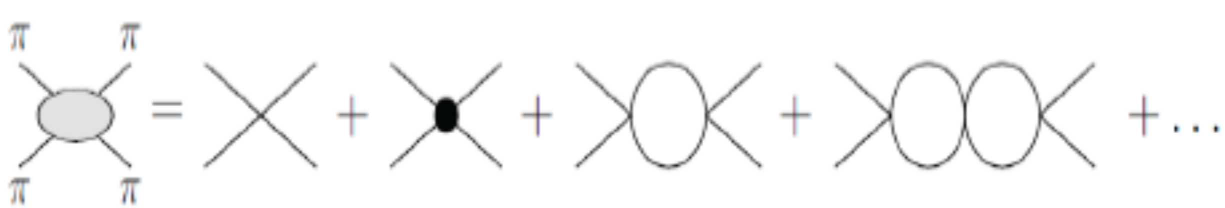
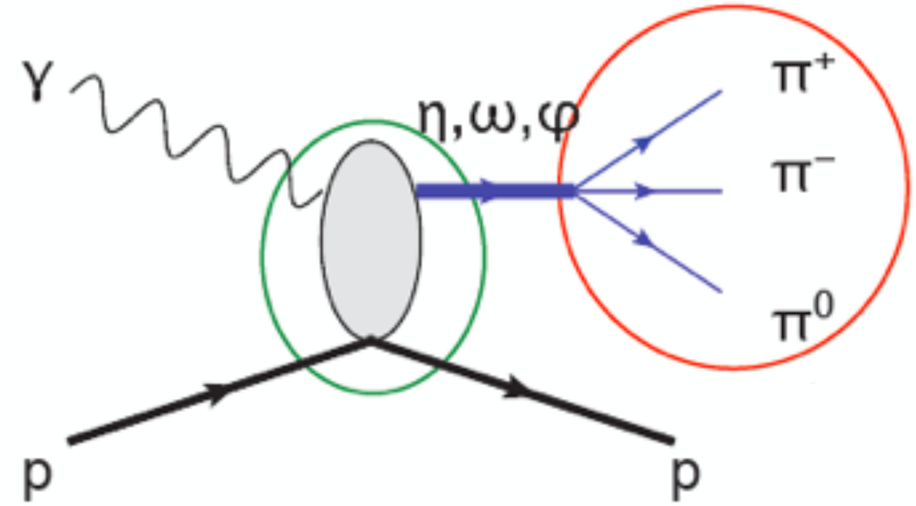
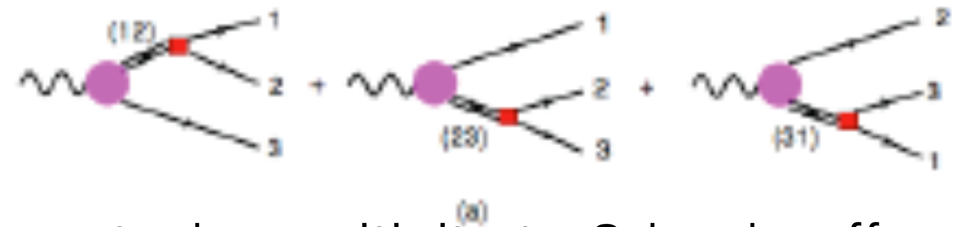
LO NLO Experiment



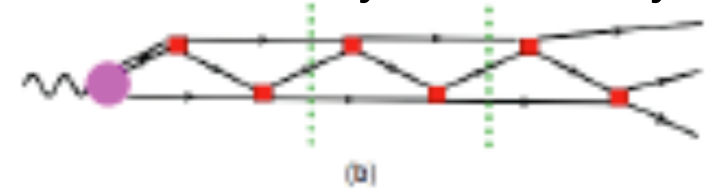


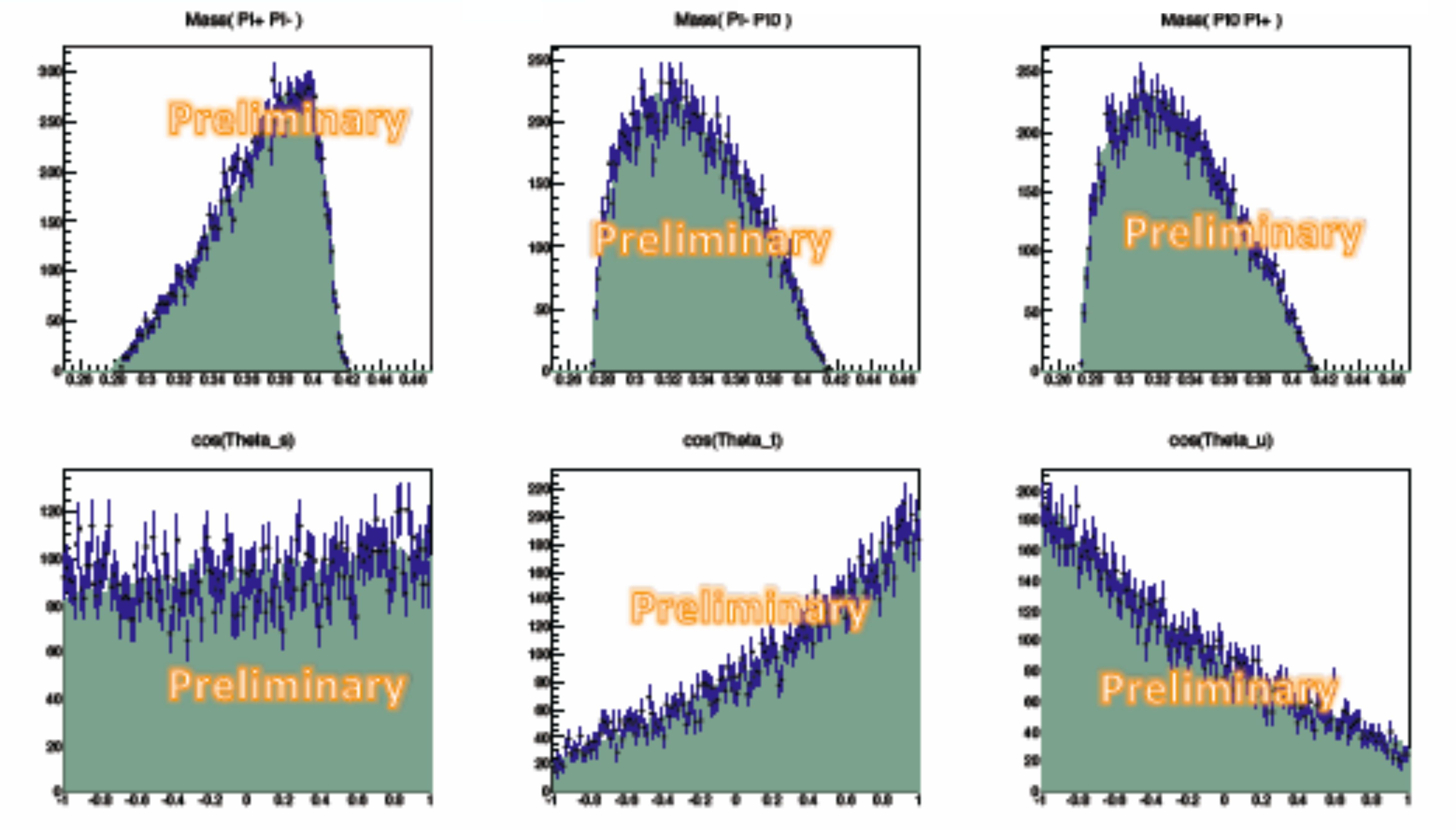
$A_{3\pi^0} \sim (m_u - m_d)[1 + \alpha(s_1 - s_m) + ..]$





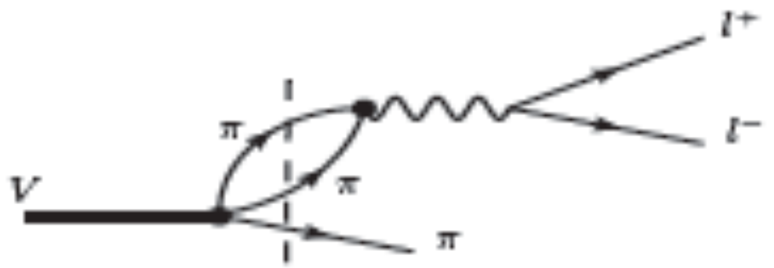
Expected sensitivity to 3-body effects





D.Schott, JPAC/GWU
P.Guo JPAC/IU

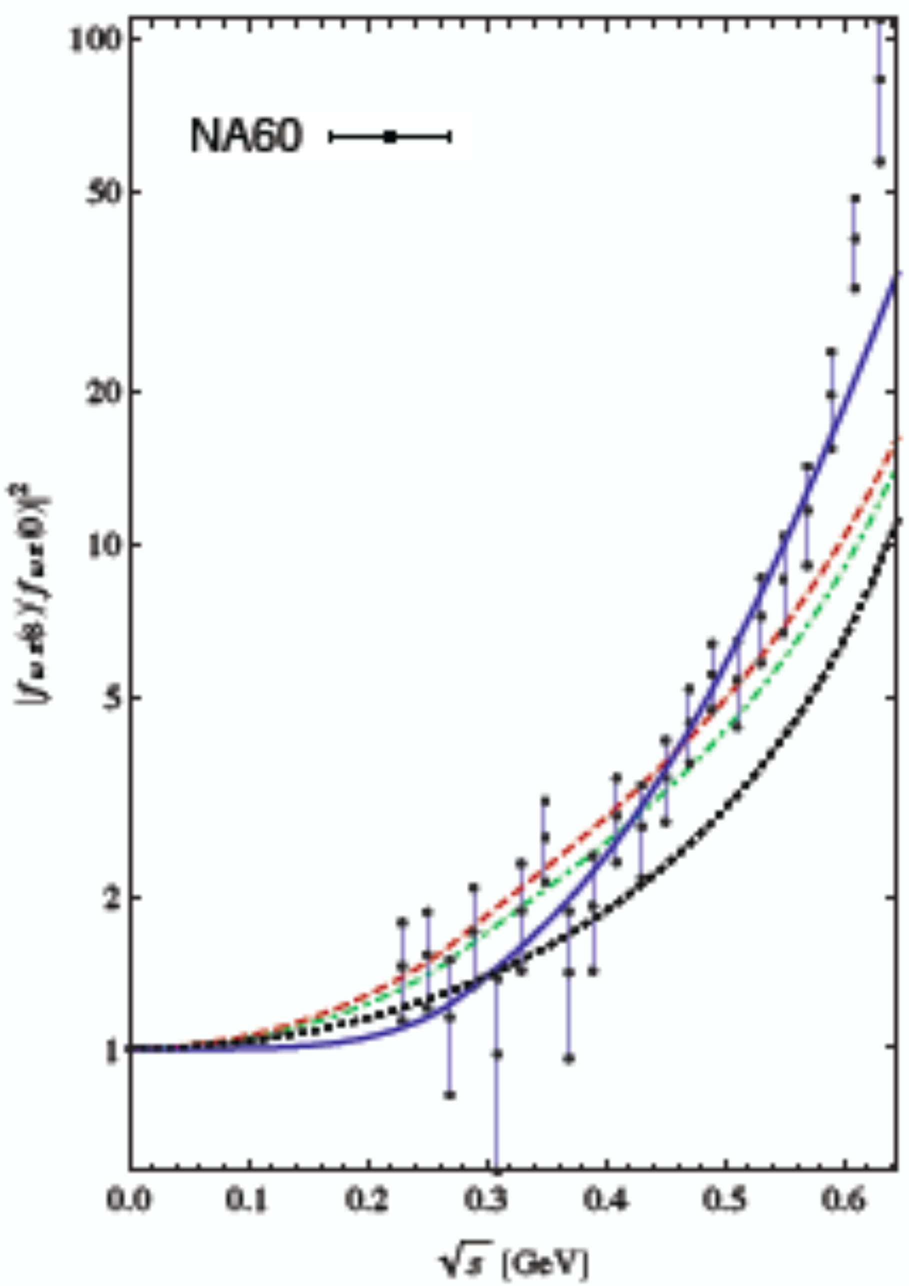
Transition form factors: ω/ϕ→πγ



$$\text{Disc}\, f_{V\pi}(s) = \frac{\rho^3\, s}{96\,\pi}\left(F(s)+\hat{F}(s)\right) F^*_\pi(s)$$

$V \to 3\pi$ $\quad$ $\pi\pi \to \gamma$

$$f_{V\pi}(s) = \int_{s_\pi}^{s_i} \frac{ds'}{\pi}\frac{\text{Disc}\, f_{V\pi}(s')}{s'-s} + \sum_{i=0}^{N} C_i\,\omega(s)^i$$



- Black: standard VMD (fails to describe the data)
- w(s) is the conformal map (inelastic contrb)
- Green: N=0 and C_0 determined from $\Gamma_{exp}(V\to\pi\gamma)$
- Red: N=1 and Blue: N=2 (fit to the data)
- Nature of the steep rise? -> Exp analysis of ϕ→πγ is very important

I.Danilkin JPAC

Hadron Spectroscopy Portal

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This page contains details of how to parametrize two pions isobar.

Two Pions

- Descriptions
- Parametrization
- Applications
- References
- Comments
- Resources

TWO PIONS PARAMETRIZATION

Description

The $\pi\pi$ amplitude depends on two variables, the invariant mass squared s and the scattering angle in the center of mass θ .
Final states are not eigenstates of the isospin. For neutral systems we have

$$\pi^0\pi^0 = -\frac{1}{\sqrt{3}}F^{(0)}(s,\theta) + \frac{2}{\sqrt{3}}F^{(2)}(s,\theta),$$
$$\pi^+\pi^- = +\frac{1}{\sqrt{3}}F^{(0)}(s,\theta) + \frac{1}{\sqrt{2}}F^{(1)}(s,\theta) + \frac{1}{\sqrt{6}}F^{(2)}(s,\theta)$$

Resources

- Notes: PiPiParam.pdf
- Fortran: IsobarPiPi.f90, pipiscat.f90, BaseMod.f90, OmnesMod.f90 intx.f
- S0 wave: PiPi Amplitude, Omnes function, Ln functions, Rn functions
- S2 wave: PiPi Amplitude, Omnes function, Ln functions, Rn functions
- P1 wave: PiPi Amplitude, Omnes function, Ln functions, Rn functions
- D0 wave: PiPi Amplitude, Omnes function, Ln functions, Rn functions
- D2 wave: PiPi Amplitude, Omnes function, Ln functions, Rn functions
- Publication:
- Contact person: Vincent Mathieu
- Last update: September 2013

IsobarPiPi.f90 is the program calling

- pipiscat.f90: generate the $\pi\pi$ amplitude in term of phase shift, inelasticity, argument.
  Results are printed in pipiXX.txt with the columns being s, δ, η, ϕ
- Omnes.f90: generate the Omnes function $D(s)$.
  Results are printed in omnXX.txt with the columns being $s, \text{Re } D(s), \text{Im } D(s)$
- BaseMod.f90: generate the base functions $\mathcal{L}_n(s), \mathcal{R}_n(s)$.
  Results are printed in baseLXX.txt and baseRXX.txt with the columns being $s, \text{Re } L_1(s), \text{Im } \mathcal{L}_1(s), \text{Re } \mathcal{L}_2(s), \text{Im } \mathcal{L}_2(s), \text{Re } \mathcal{L}_3(s), \text{Im } \mathcal{L}_3(s)$
- intx.f90: the integration routine

Webpage template with summary of publication results, data. MC, codes, etc.

The JPAC team

JPAC@JLab	JPAC@IU	JPAC@GW
Igor Danilkin	Lingun Dai	Ron Workman
Viktor Mokeev	Geoffrey Fox	Michael Doering
Peng Guo	Andrew Jackura	Diane Schott
Michael Pennington	Vincent Mathieu	
Cesar Ramirez	Emilie Passemar	
Meng Shi		

New collaborators are welcomed !

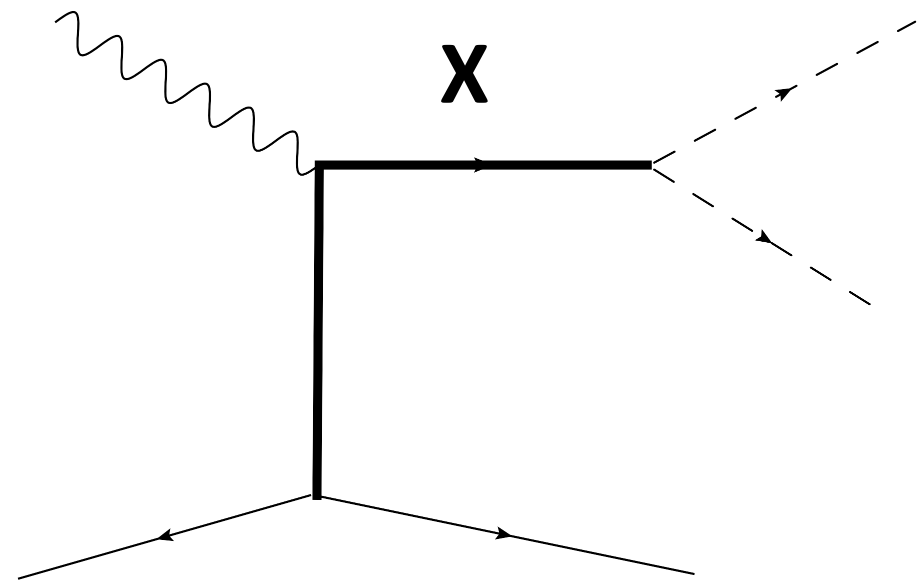
Weekly meetings (Tue. 1pm, Thu. 9:30)

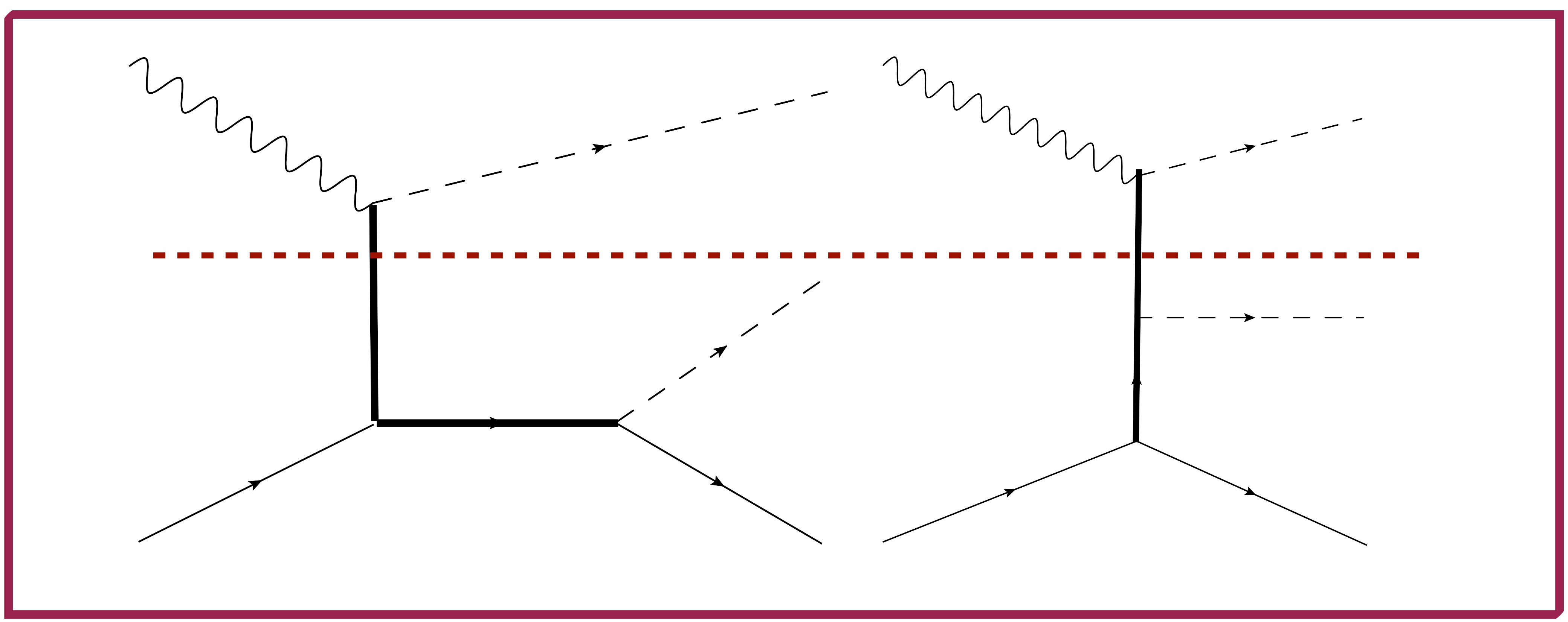
Weekly "lecture series" (Mon. 10am)

Joint CLAS/JPAC Seminar series

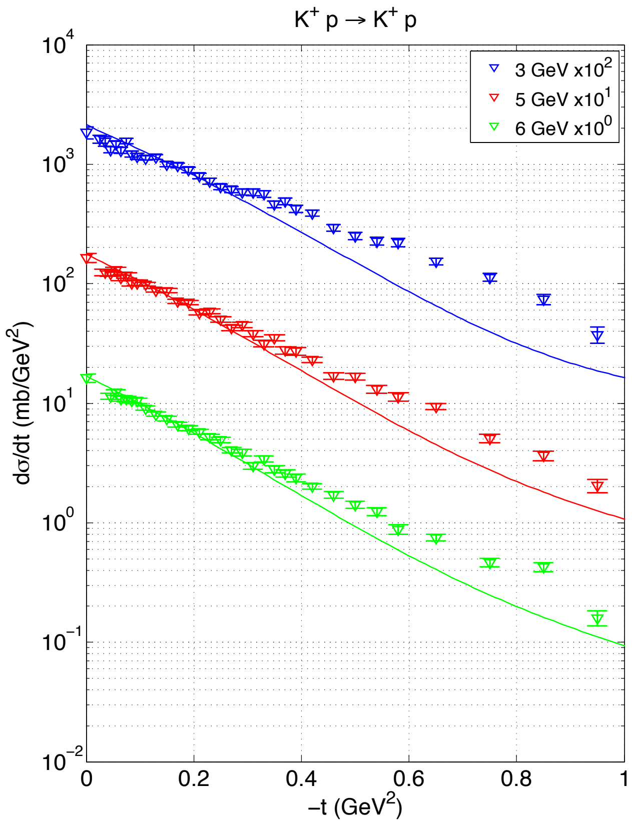
https://wiki.jlab.org/jpac/

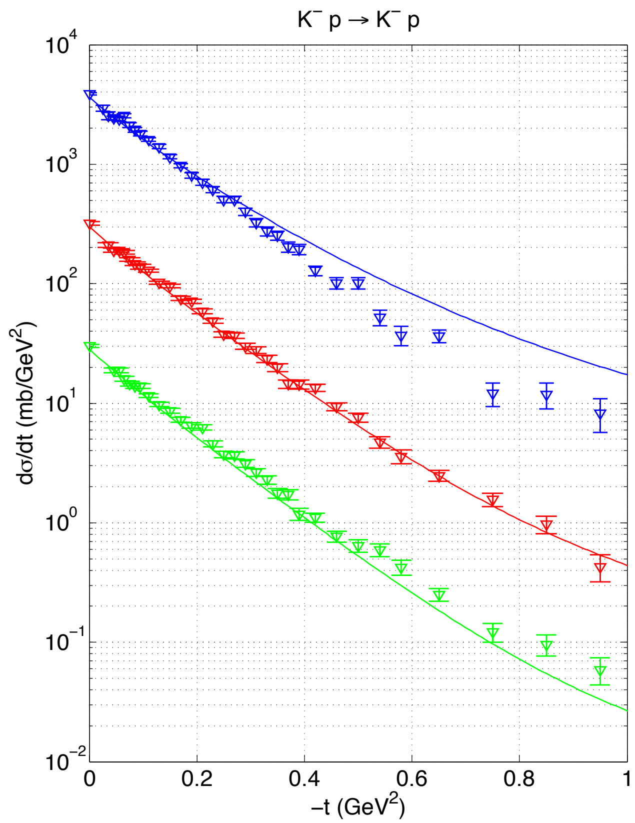
Deck Model: One Step at a Time



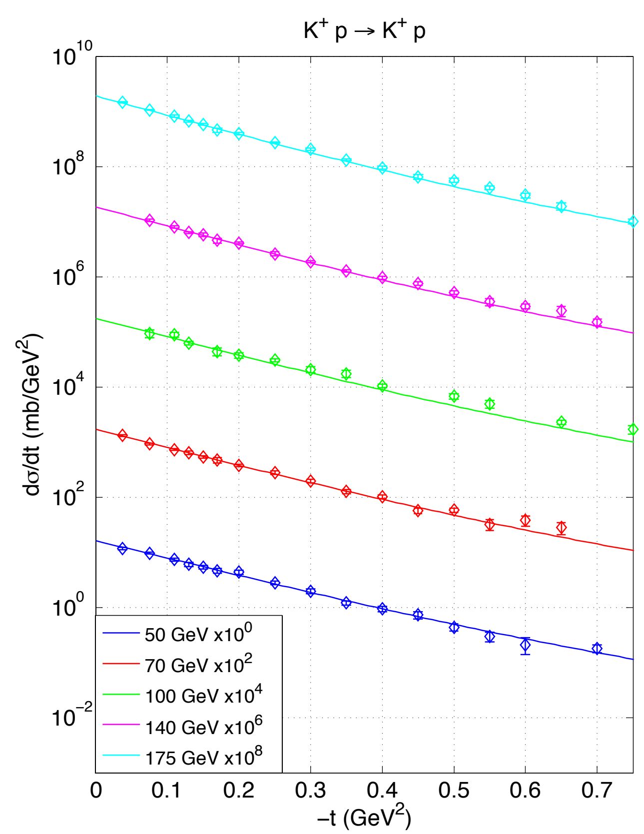


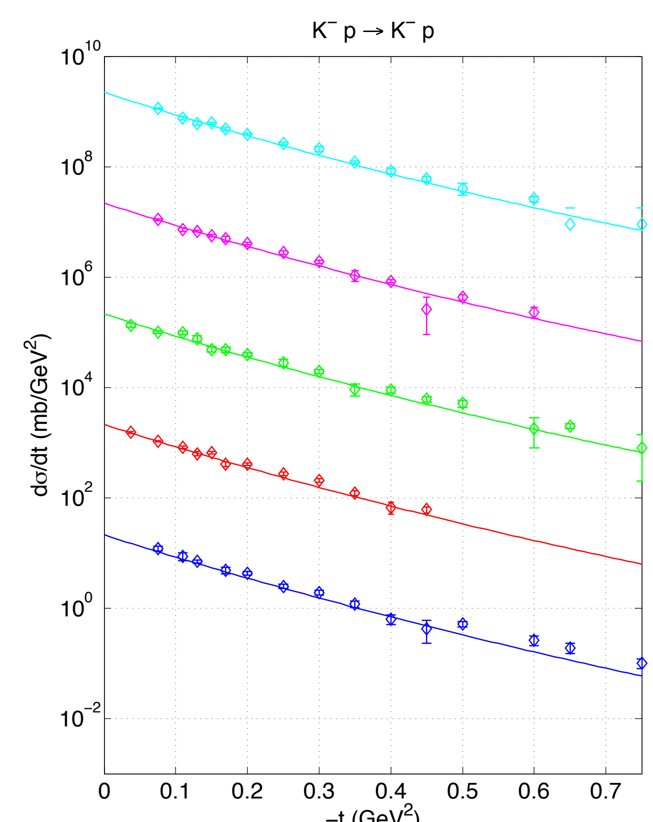
KN→KN: High-Energy Region





Regge exchange
ρ, ω, a, f, Pomeron





$$T^s_{++} = \cos\frac{\theta}{2}\left[2mA + \left(s - m^2 - \mu^2\right)B\right]$$

$$T^s_{+-} = -\sin\frac{\theta}{2}\left[\left(s + m^2 - \mu^2\right)A + \left(s - m^2 + \mu^2\right)mB\right]/\sqrt{s}$$

A and B are free of kinematical singularities

KN→KN: Resonance Region

Coupled-channels Unitary model

KN, πΣ, πΛ,ηΛ,ηΣ, K^*_1N,K^*_3N,KΔ, πΣ(1385), πΛ(1520)

34 resonances

Manley et al. PRC88, 035204 (2013)

Partial waves: S_{01}, P_{01}, P_{03}, D_{03}, D_{05}, F_{05}, F_{07}, G_{07}

S_{11}, P_{11}, P_{13}, D_{13}, D_{15}, F_{15}, F_{17}, G_{17}

$$f = \frac{1}{q}\sum_{\ell=0}^{\infty}\left[(\ell+1)\,f_{\ell+} + \ell f_{\ell-}\right]P_\ell(z)$$

$$g = \frac{1}{q}\sum_{\ell=1}^{\infty}\left[f_{\ell+} - f_{\ell-}\right]P_\ell^1(z)$$

$$T = \bar{u}\left[A + \frac{1}{2}(q_1+q_2)^\mu\gamma_\mu B\right]u$$