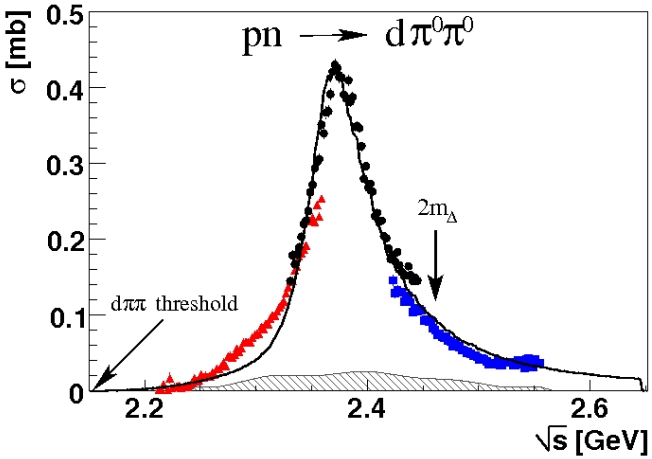
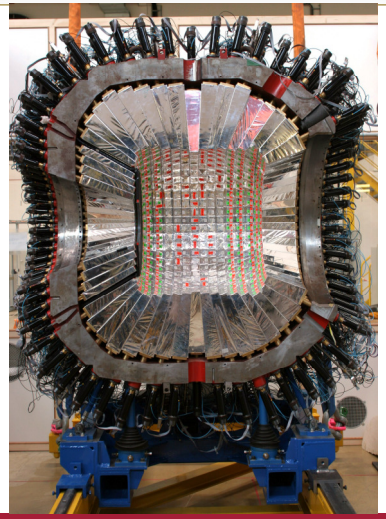
EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

Kepler Center for Astro and Particle Physics

Fachbereich Physik





CERN Courier September 2011

ABC Effect in Double Pionic Fusion

Facets of Strong-Interaction Physics
Hirschegg Jan. 15 – 21, 2012

Heinz Clement

Outline

- Two-Pion Production in general
- Double-Pionic Fusion: the ABC Effect
- from the ABC Effect to the ABC Resonance
- consequences
- what is it?

$NN \rightarrow NN\pi\pi$

- pure **isovector**
  - $pp \rightarrow pp\pi^0\pi^0 / \pi^+\pi^-$
  - $\rightarrow pn\pi^+\pi^0$
  - $\rightarrow nn\pi^+\pi^+$
  - .....
  - $\rightarrow d\ \pi^+\pi^0$

- pure **isoscalar**
  - .....
  - $pn \rightarrow d\ \pi^0\pi^0$
  - $pd \rightarrow {}^3He\ \pi^0\pi^0$
  - $dd \rightarrow {}^4He\ \pi^0\pi^0 / \pi^+\pi^-$

ABC effect

First Observation of ABC

- Alexander **A**bashian, Norman E. **B**ooth and Kenneth M. **C**rowe, Phys. Rev. Lett. **5**, 258 (1960)

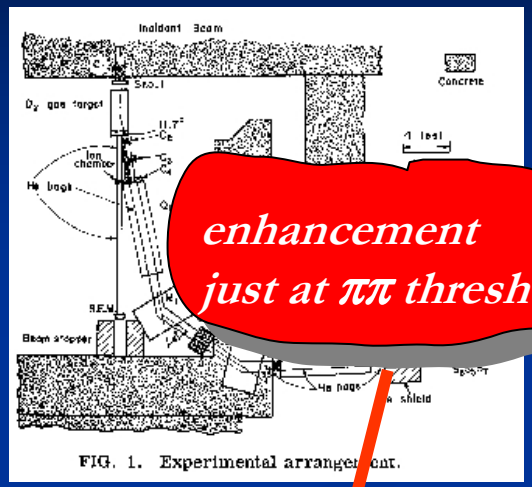
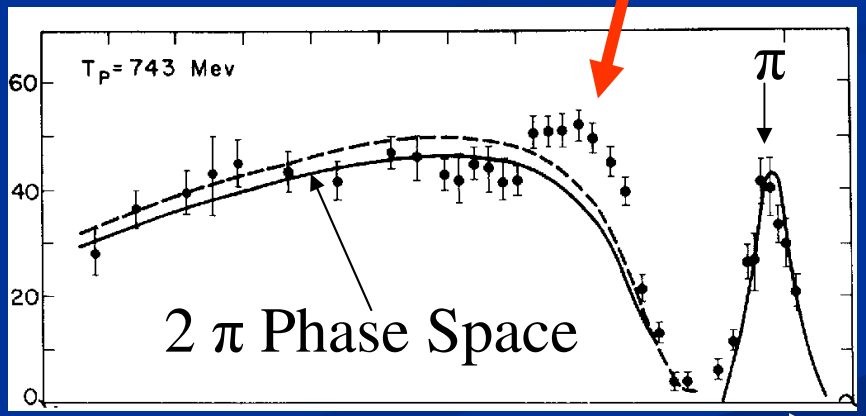


FIG. 1. Experimental arrangement.

$$pd \rightarrow {}^3\mathrm{He}\, X$$

$$T_p = 0.743\ \mathrm{GeV}$$



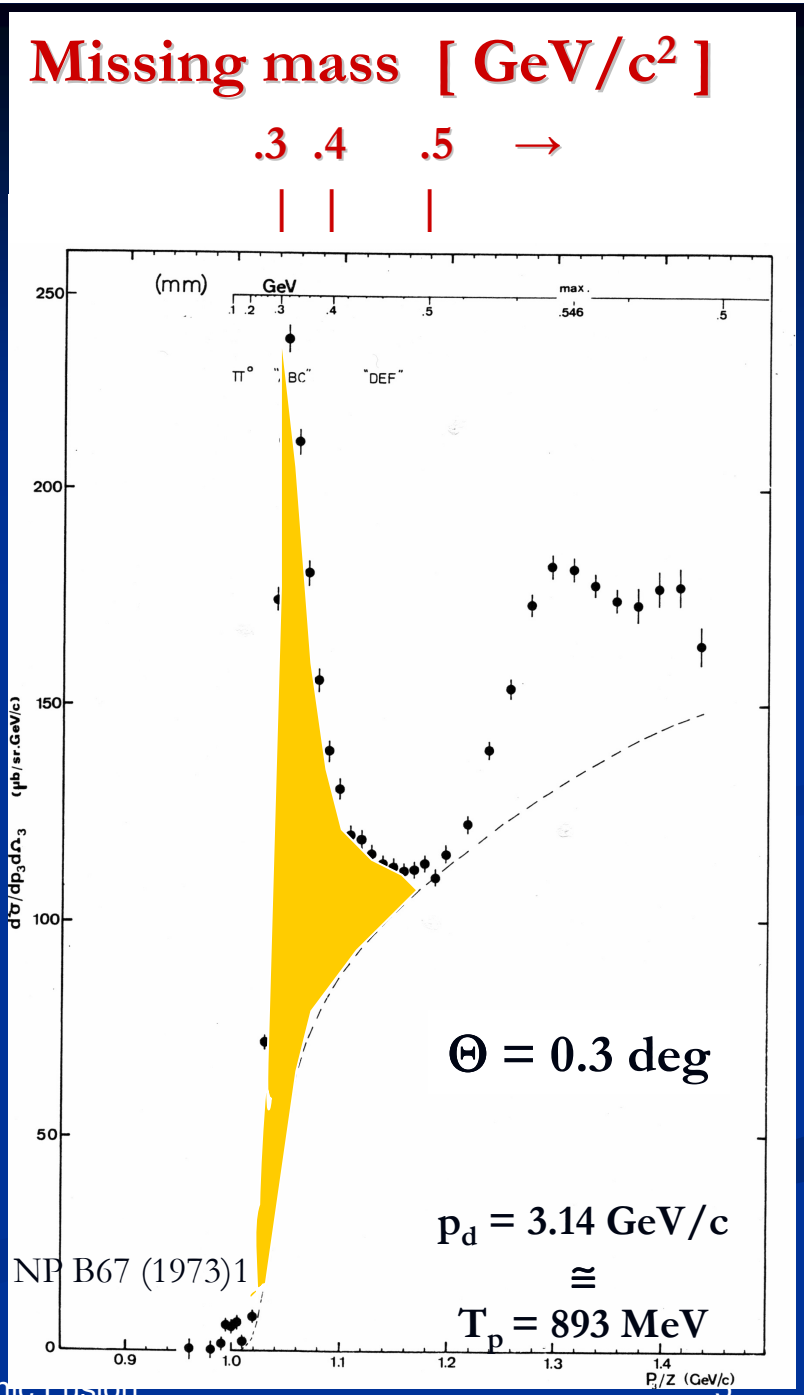
$$\Theta_{^3He} = 11.5°$$

$$P^{lab}_{^3He}$$

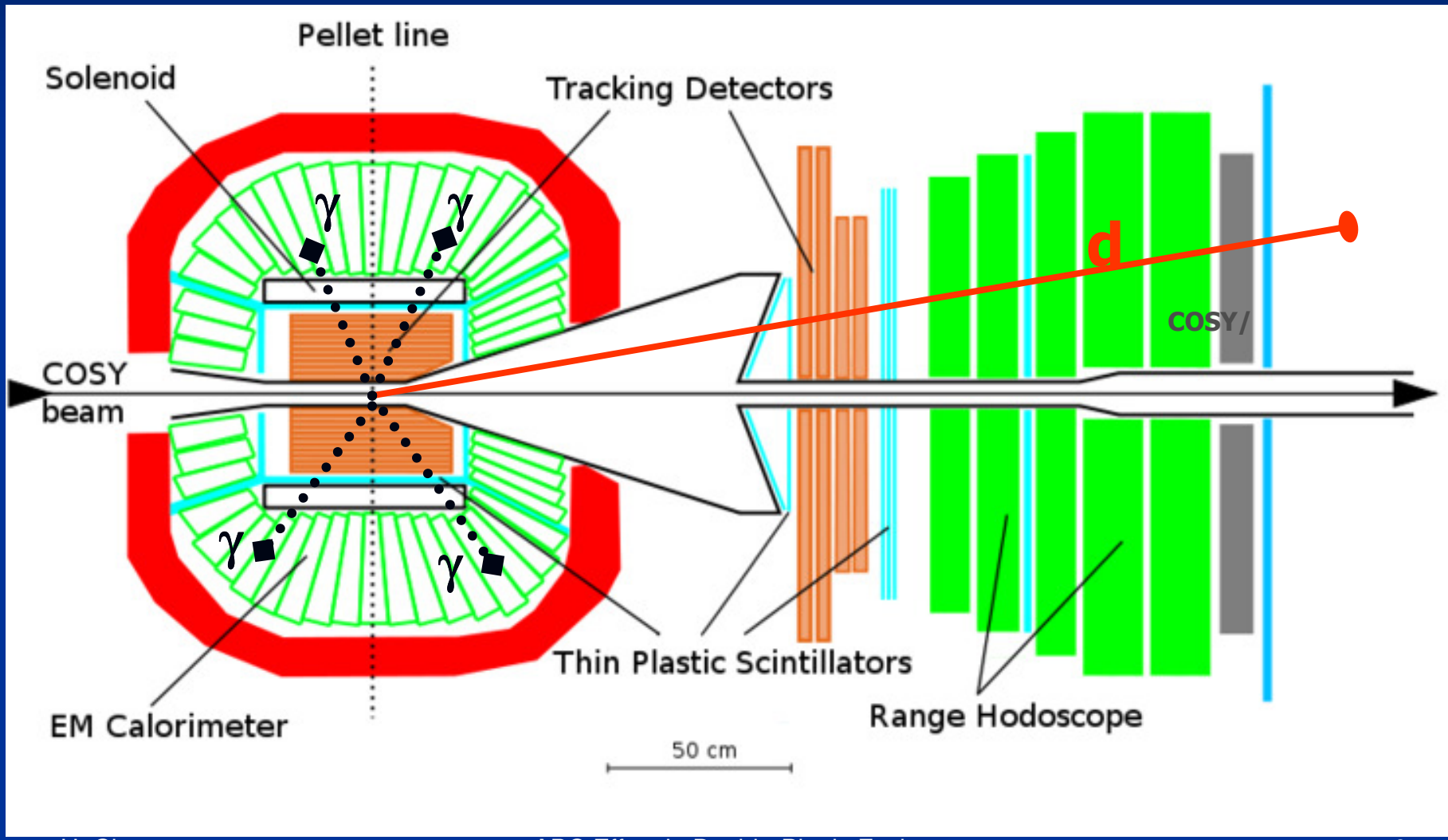
ABC effect

(**A**bashian, **B**oth, **C**rowe)

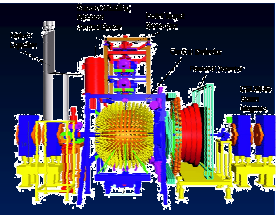
- **Inclusive measurements:**
- **pd → ^{3}He X**
- Abashian et al. Berkeley
- Banaigs et al. Saclay
- ⇒
- **low-mass enhancement !**



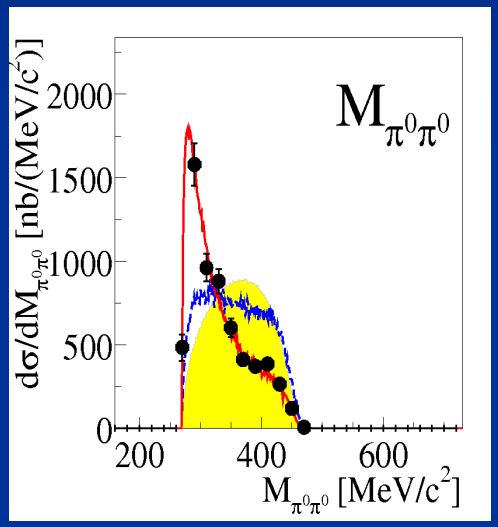
WASA Detector



The ABC Gallery

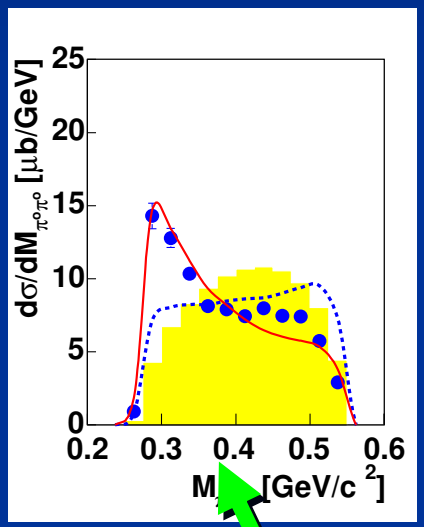


$pn \rightarrow d\,\pi^0\pi^0$ @ 1.0 GeV



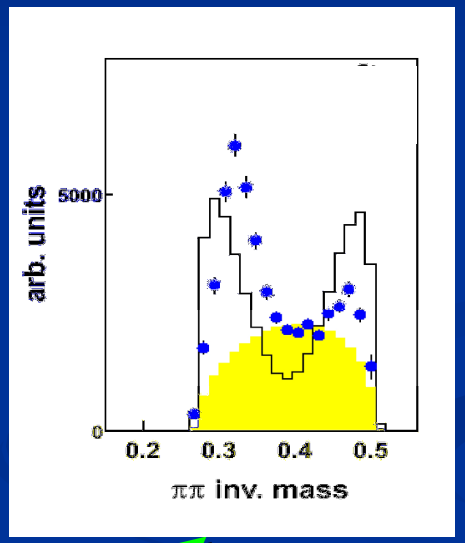
PRL 102 (2009) 052301

$pd \rightarrow {}^3He\,\pi^0\pi^0$ @ 0.9 GeV



PL B 637 (2006) 223

$dd \rightarrow {}^4He\,\pi^0\pi^0$ @ 1.0 GeV



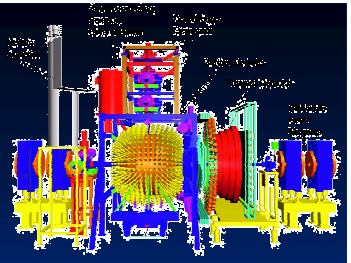
NP A 825 (2009) 71

heavier nuclei ??

CELSIUS-WASA measurements

WASA-at-COSY: new exclusive measurements over the full ΔΔ region!

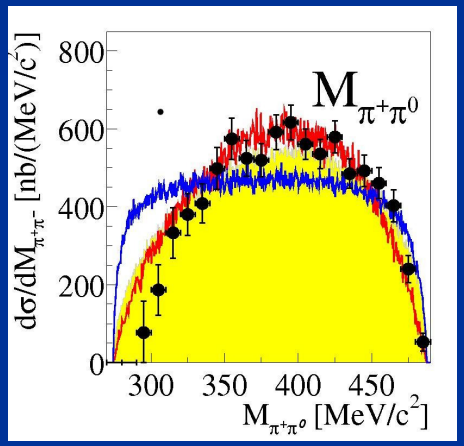
The "no-ABC" Gallery

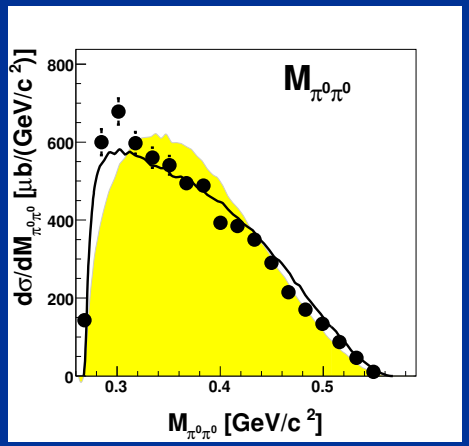


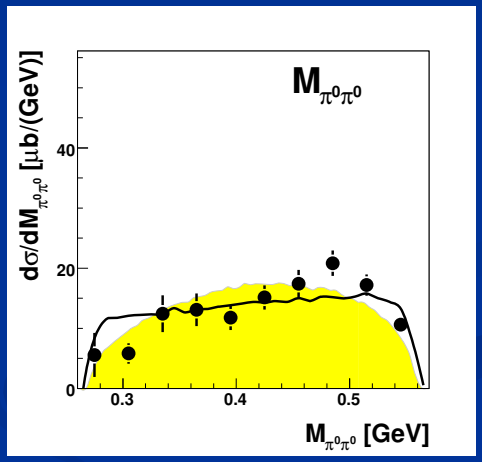
$pp \rightarrow d\,\pi^+\pi^0$ @ 1.1 GeV

$pp \rightarrow pp\,\pi^0\pi^0$ @ 1.3 GeV

$pp \rightarrow$ „^{2}He“ $\pi^0\pi^0$ @ 1.3 GeV



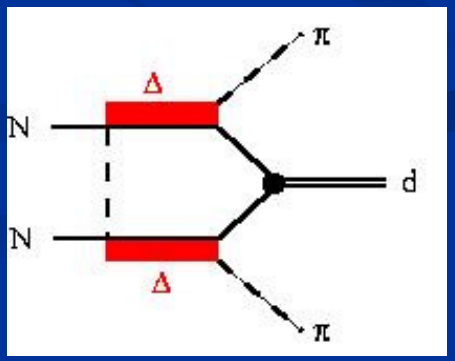




Phys.Lett. **B** 684 (2010) 110

Phys. Lett. **B** 695 (2011) 115

fully described by t-channel ΔΔ process

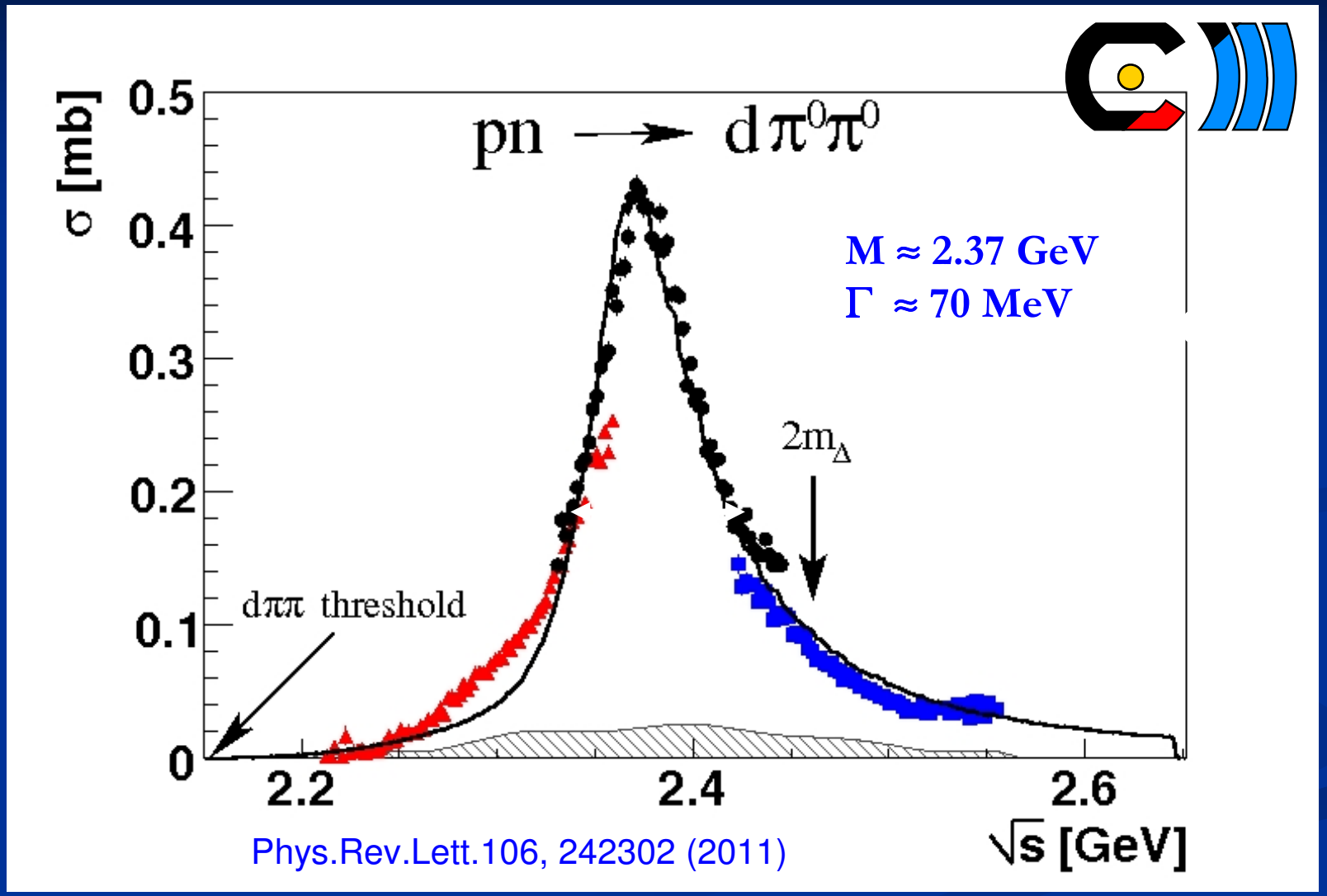


ABC Conclusions I

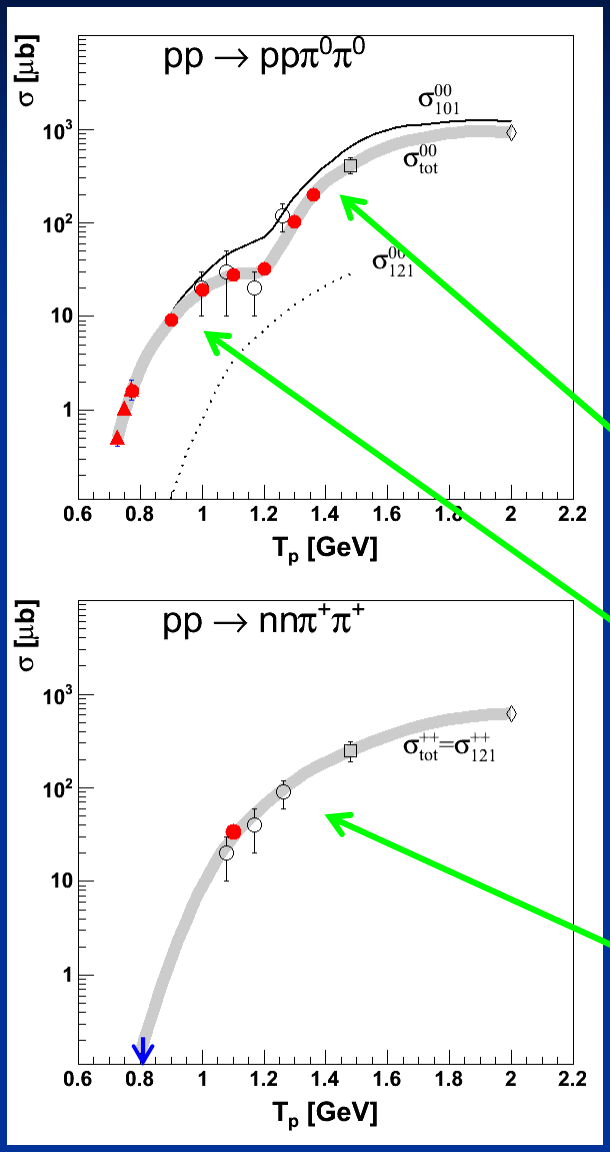
- ABC effect occurs only in the production of
  - an scalar-isoscalar pion-pair (σ)
  - at an isoscalar nucleon pair,
  - and correlated with $\Delta\Delta$ excitation

$\Rightarrow$ **energy dependence ?**

Isoscalar : Results from WASA at COSY



Isovector : Total Cross Sections



isospin decomposition

⇒

ΔΔ

N*(1440)

Δ(1600) (?)

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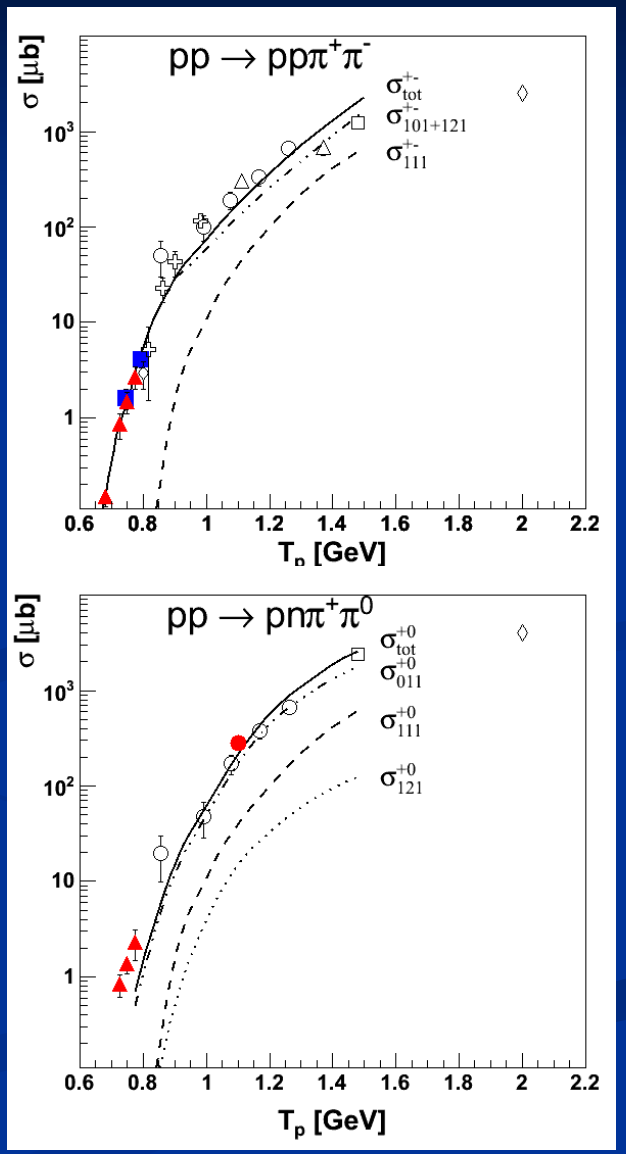
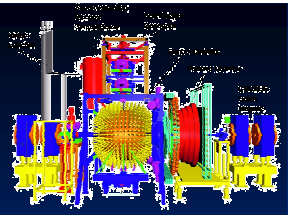
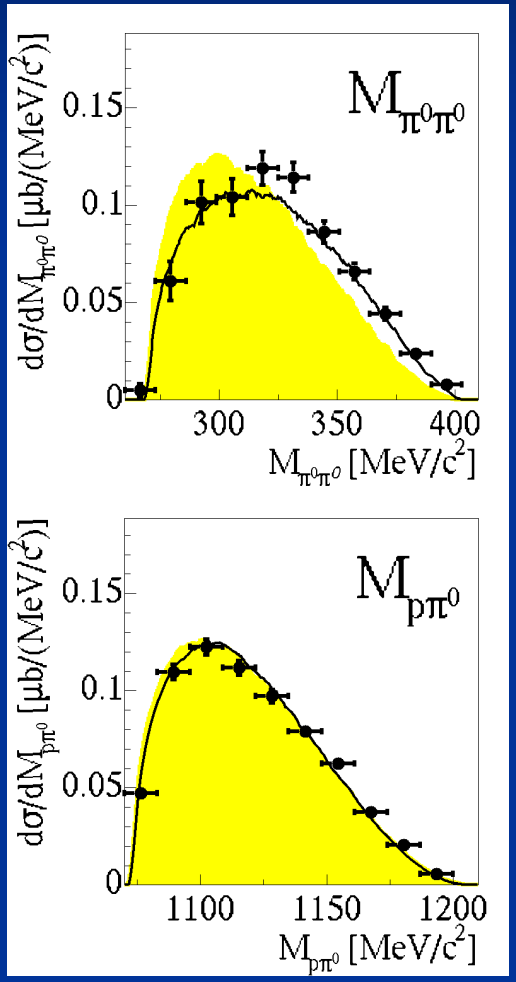


Isovector : $pp \rightarrow pp\ \pi^0\pi^0$



Roper dominated

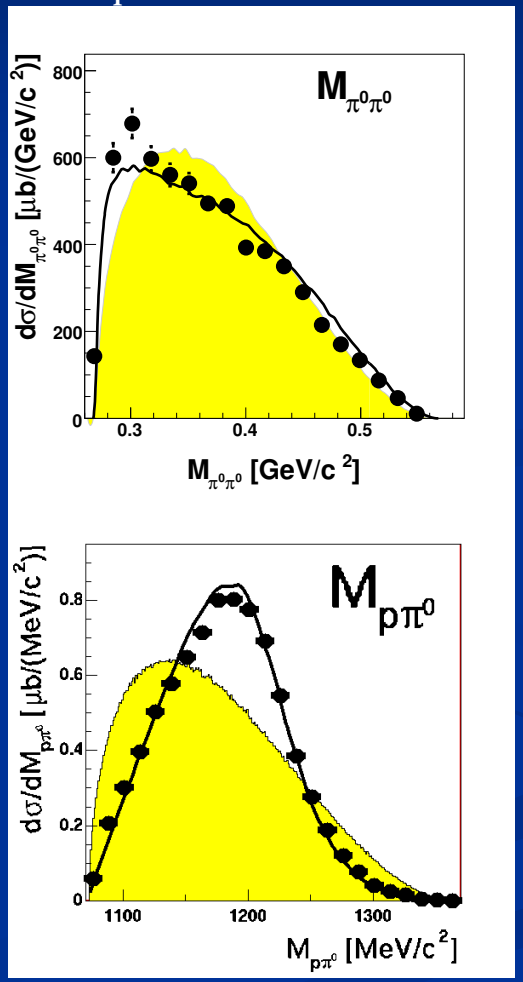
$T_p = 0.9$ GeV



Eur. Phys. J. A 35 (2008) 317

ΔΔ dominated

$T_p = 1.3$ GeV



phase space

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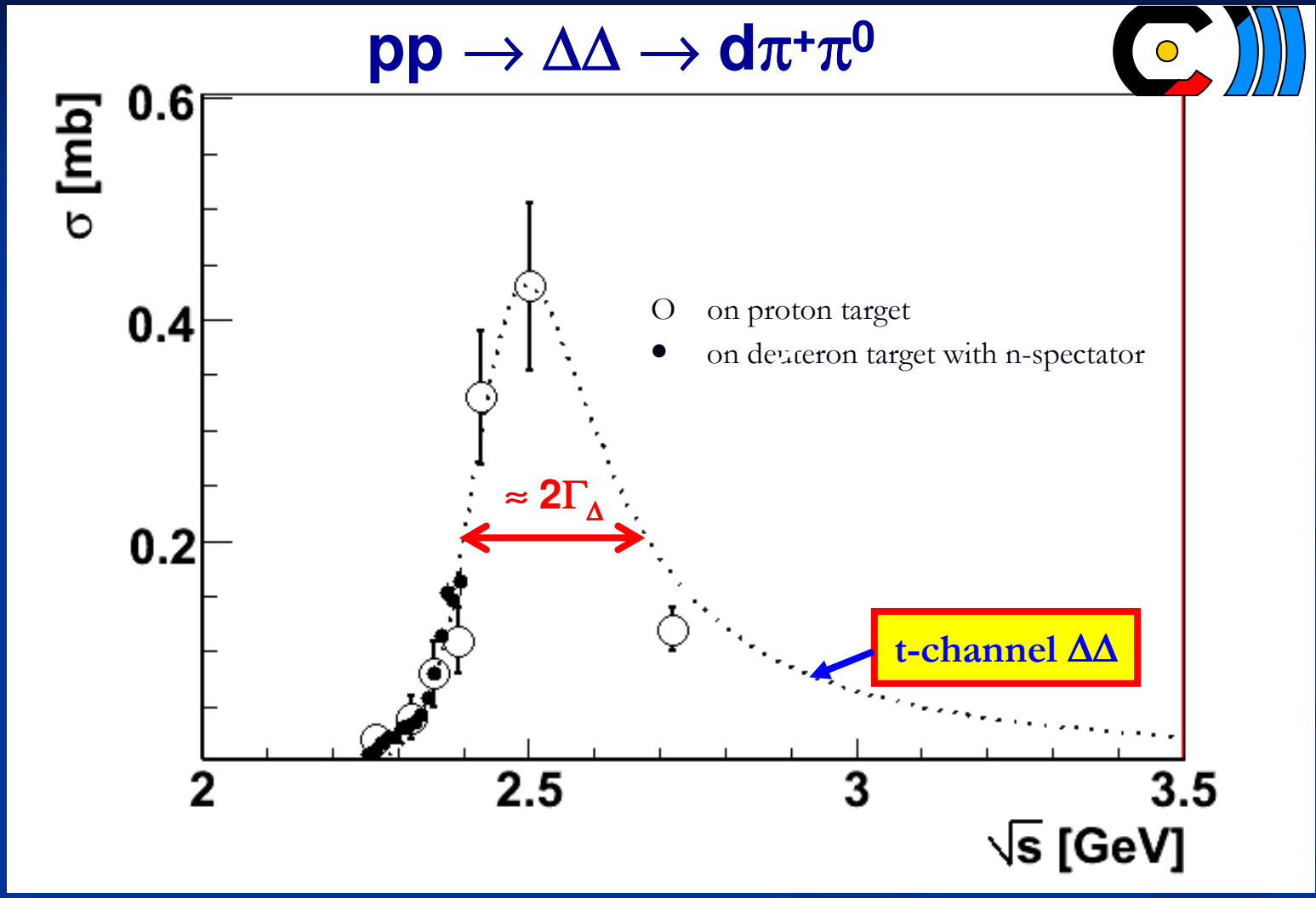
Isovector Fusion (no ABC)



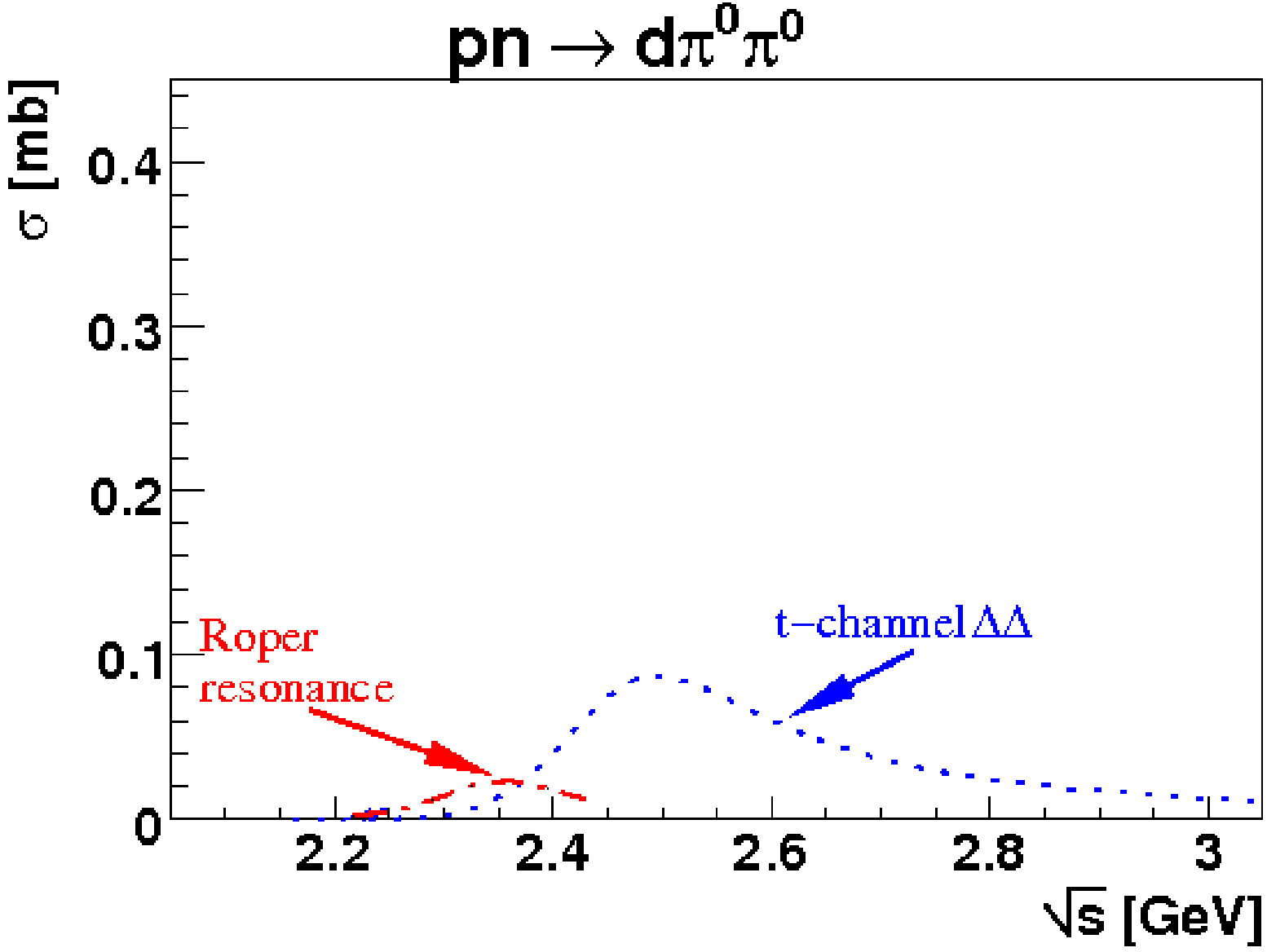
Phys.Lett. **B** 684 (2010) 110 and 702 (2011) 312

Isoscalar Channels

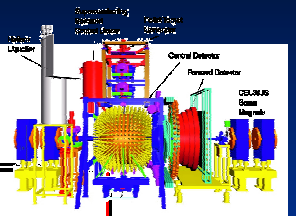
- Which energy dependence do we expect?
  - pn $\rightarrow$ d $\pi^0\pi^0$
  - pd $\rightarrow$ ^{3}He $\pi^0\pi^0$
  - dd $\rightarrow$ ^{4}He $\pi^0\pi^0$ / $\pi^+\pi^-$

$\Rightarrow$ from t-channel processes we may expect …

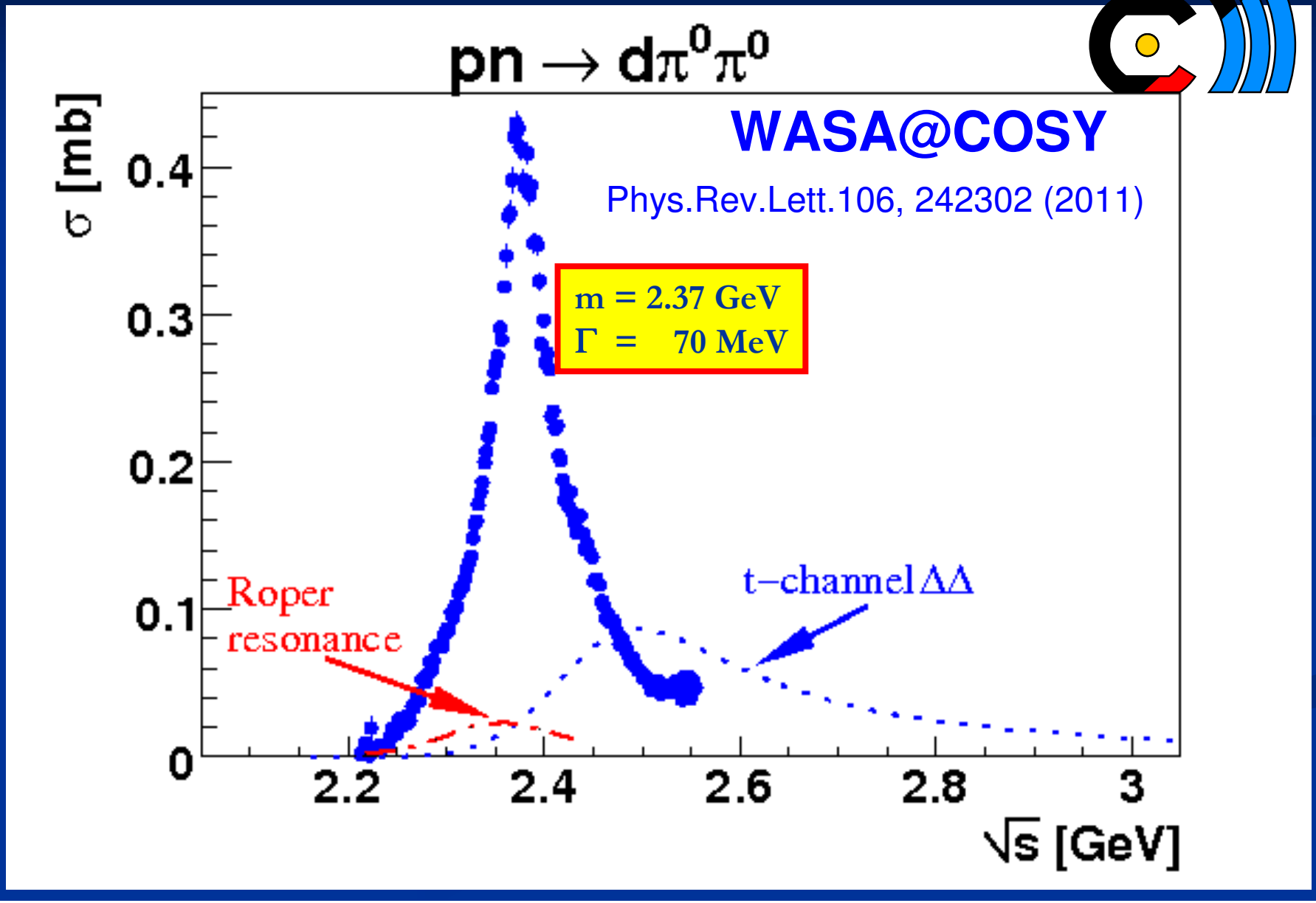
Isoscalar : … this is what we expect !



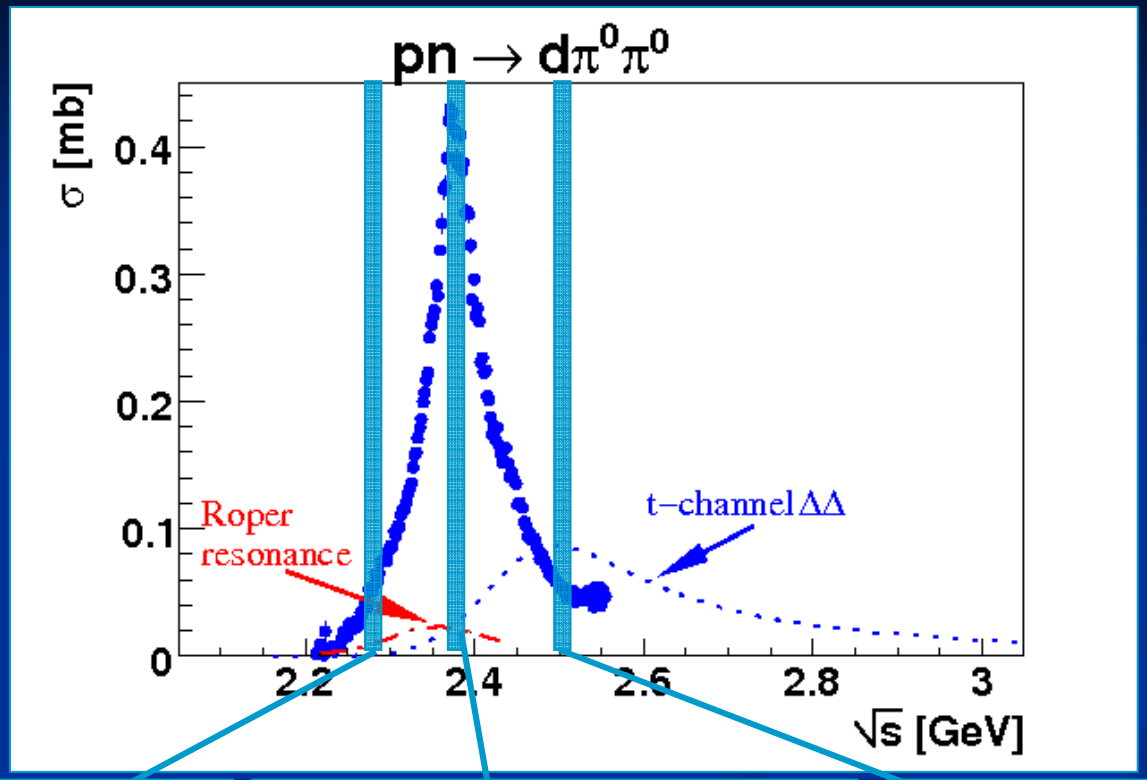
Isoscalar : … and this is what we find experimentally



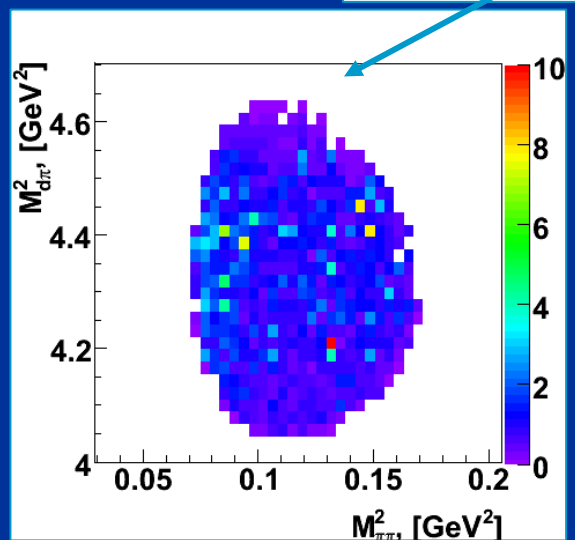
Isoscalar : … and these are the new measurements

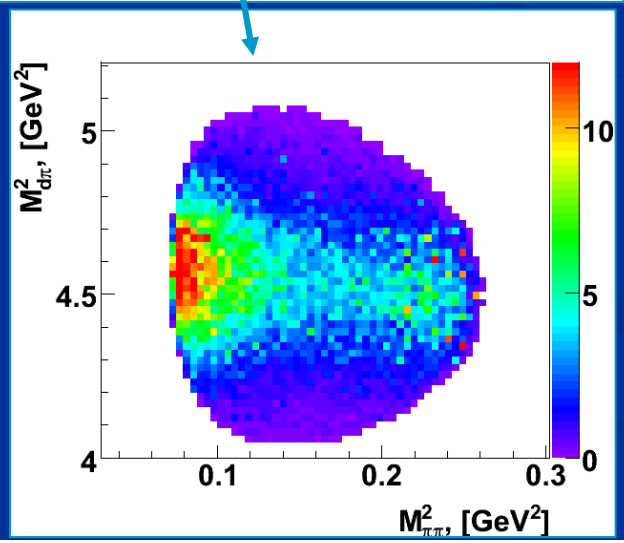


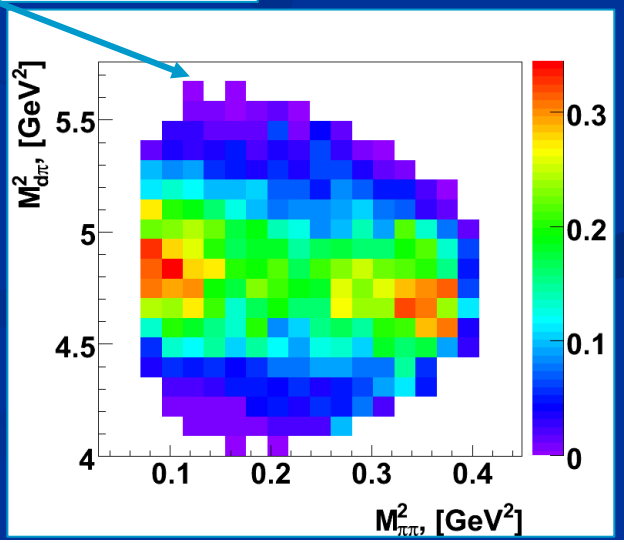
Dalitz plots



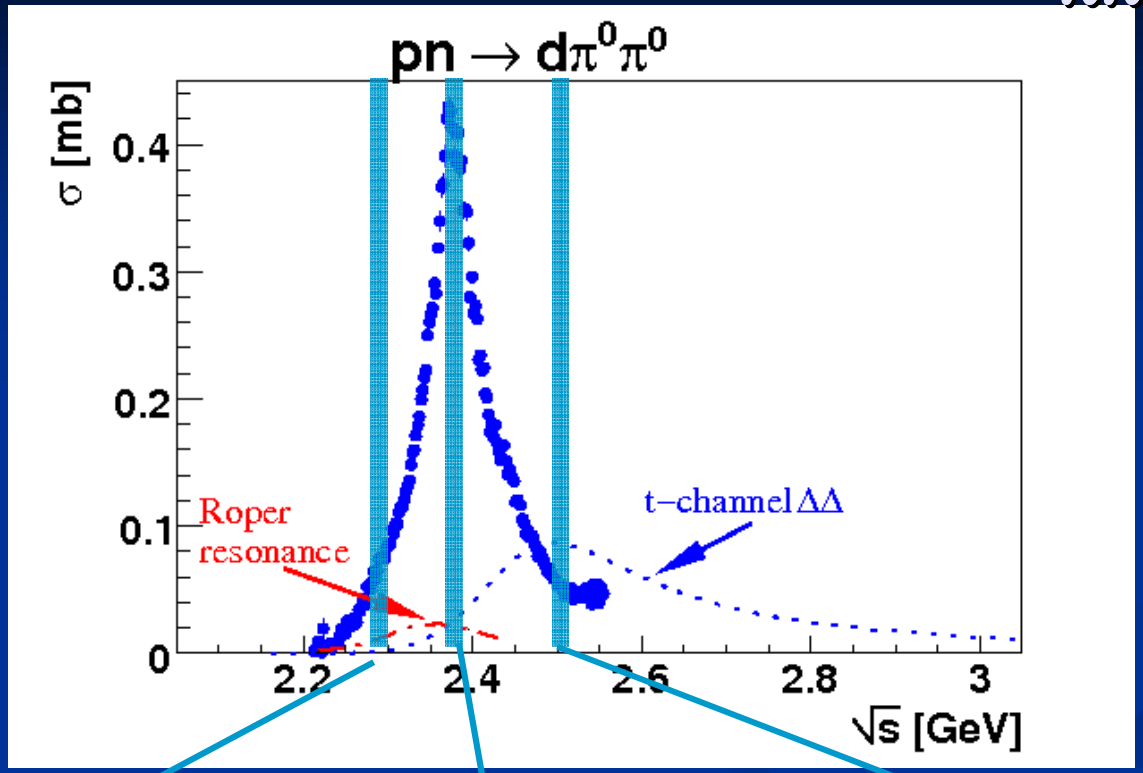
Phys.Rev.Lett.106, 242302 (2011)



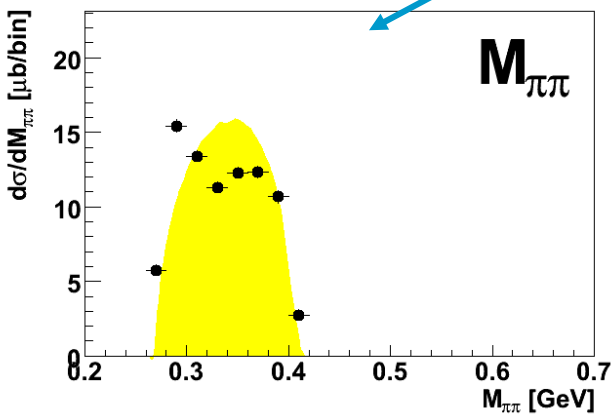


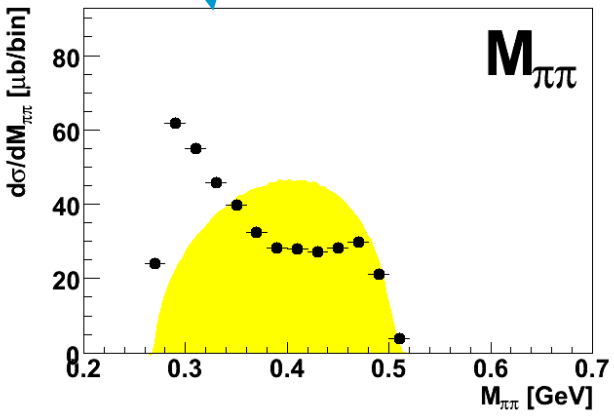


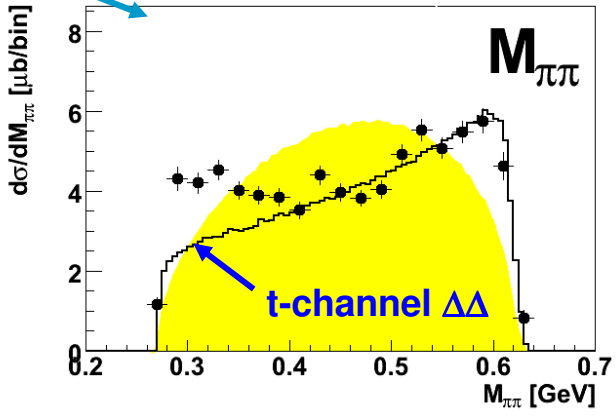
ππ-invariant mass $M_{\pi\pi}$



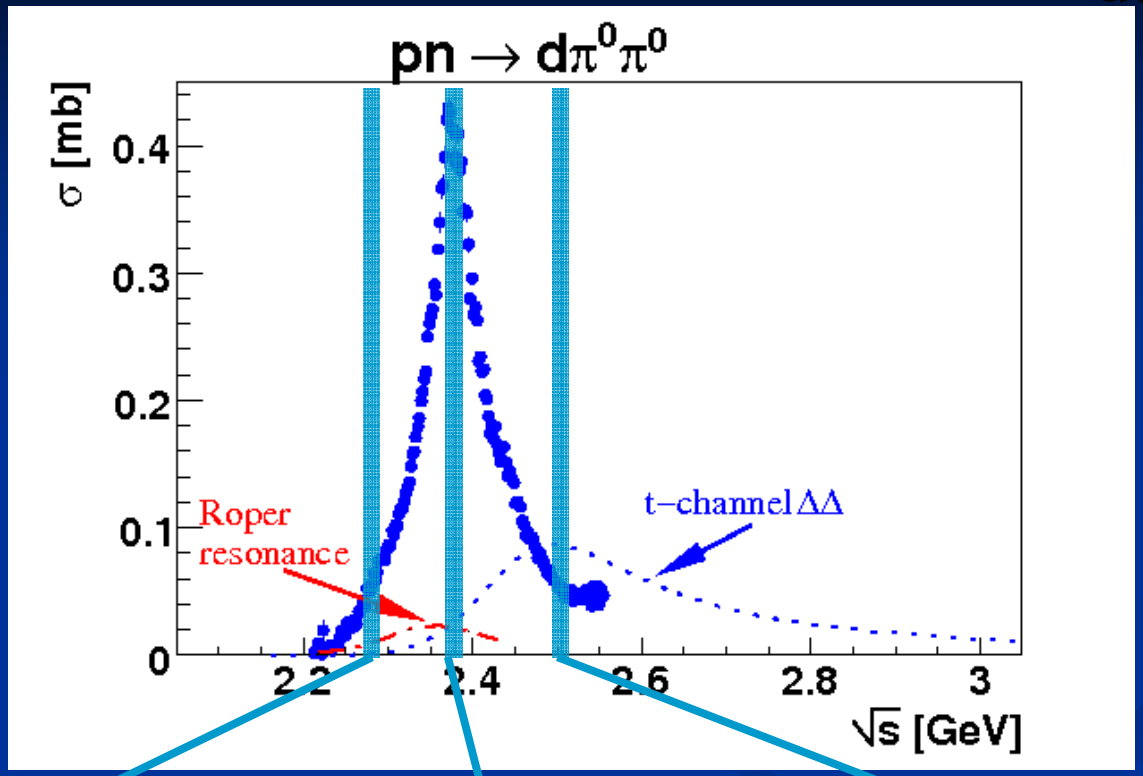
Phys.Rev.Lett.106, 242302 (2011)







$d\pi^0$ –invariant mass $M_{d\pi^0}$



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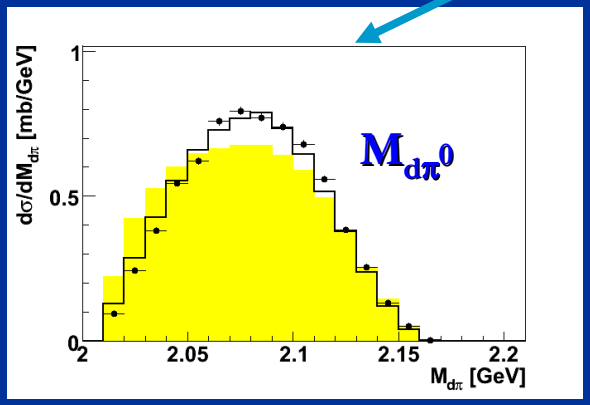
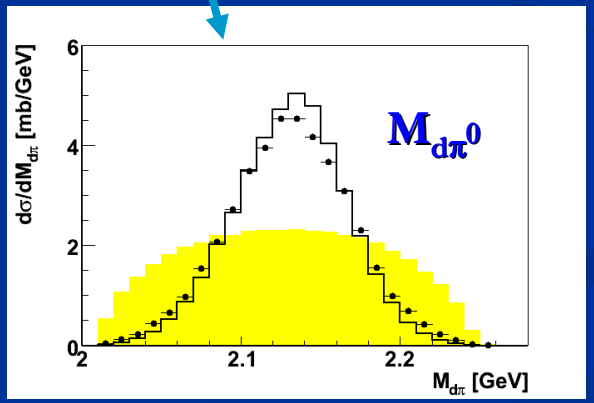
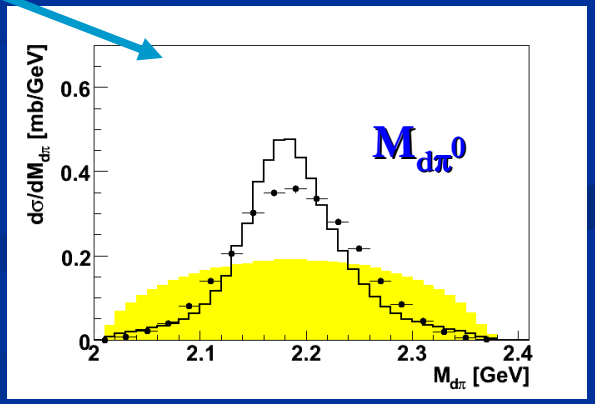
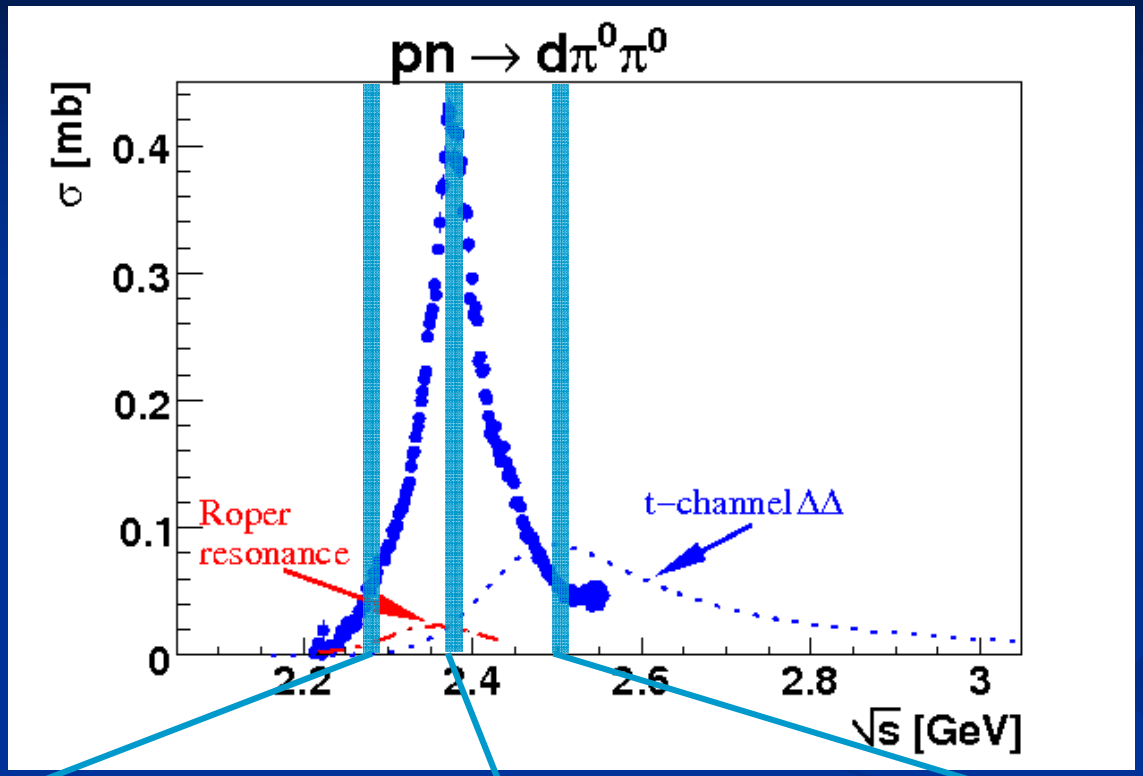


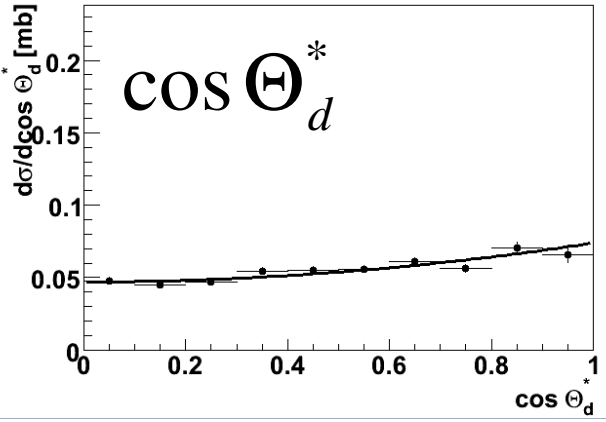


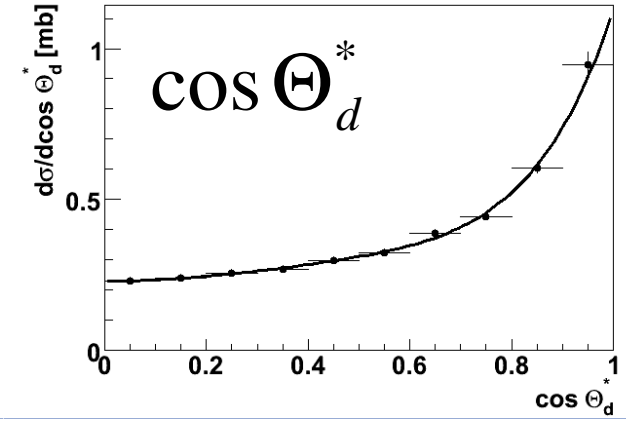


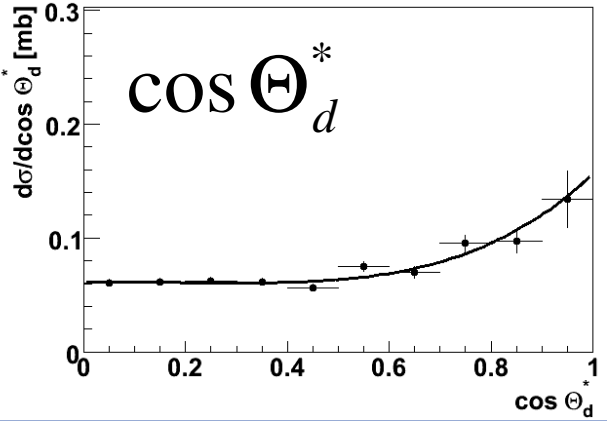
Angular distributions



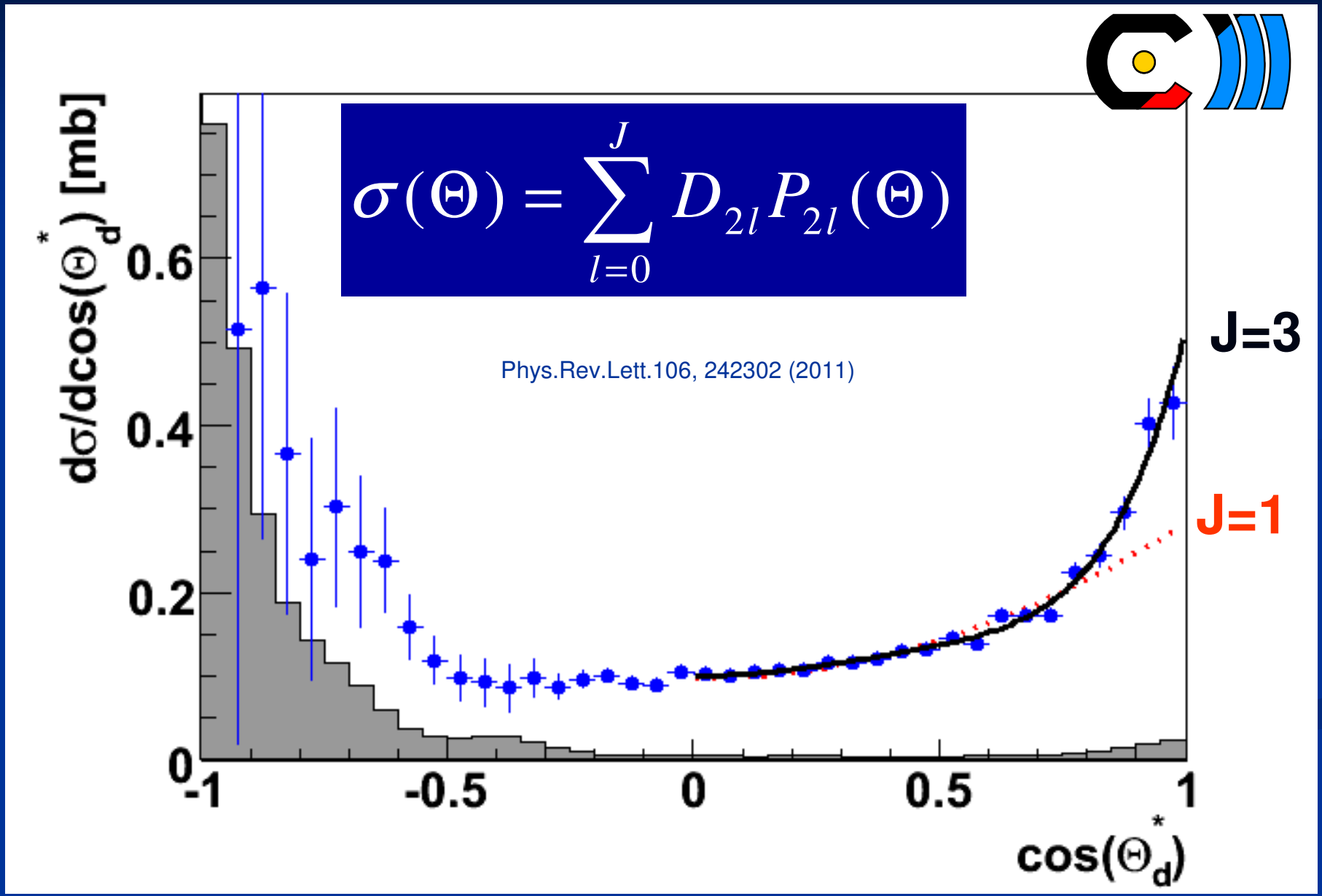
Phys.Rev.Lett.106, 242302 (2011)







Angular distribution at the peak cross section



Quantum numbers of the structure

$pn \rightarrow$ "R" $\rightarrow \Delta\Delta \rightarrow d\,\pi^0\pi^0$

Antisymmetrization: $J^P=1^+$ or 3^+ : if $L_{\Delta\Delta}=0$

$$\sigma(\cos\ \Theta^*_d) = D_0P_0 + D_2P_2 + D_4P_4 + D_6P_6$$

1^+

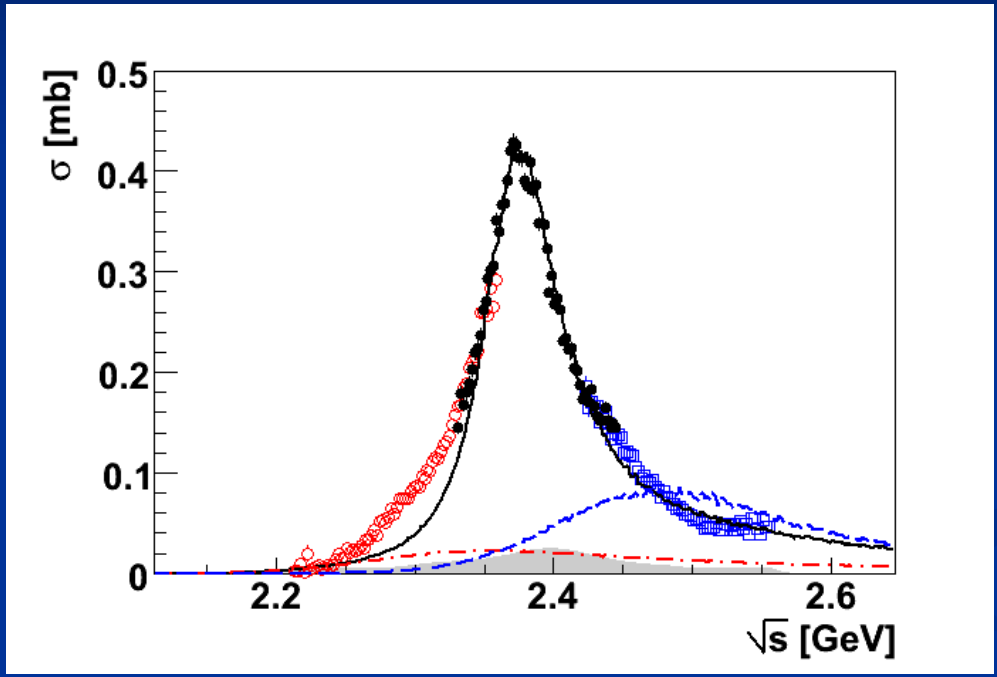
Spin-Parity: $J^P =$ 3^+

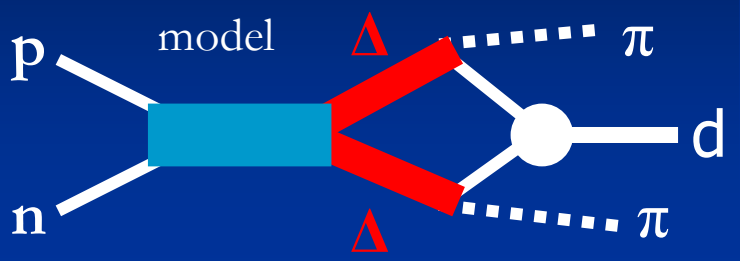
Isospin :

	pn	$\rightarrow$	d	$\pi^0\pi^0$
I=	0,1		0	0,2

} I=0

Assume $pn \to R \to \Delta\Delta \to d\pi^0\pi^0$

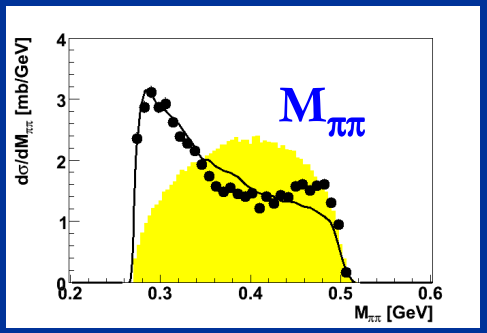


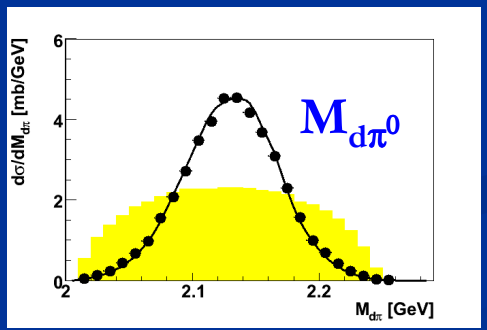


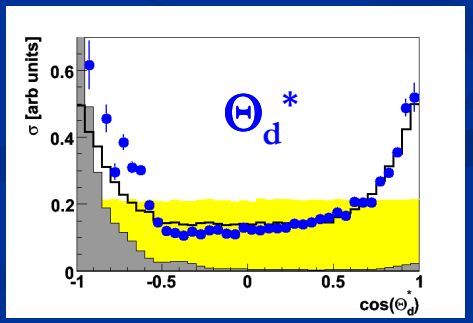
$I(J^P) = 0(3^+)$

$M, \Gamma, \Gamma_i * \Gamma_f, F(q_{\Delta\Delta})$

Phys.Rev.Lett.106, 242302 (2011)







Conclusions II

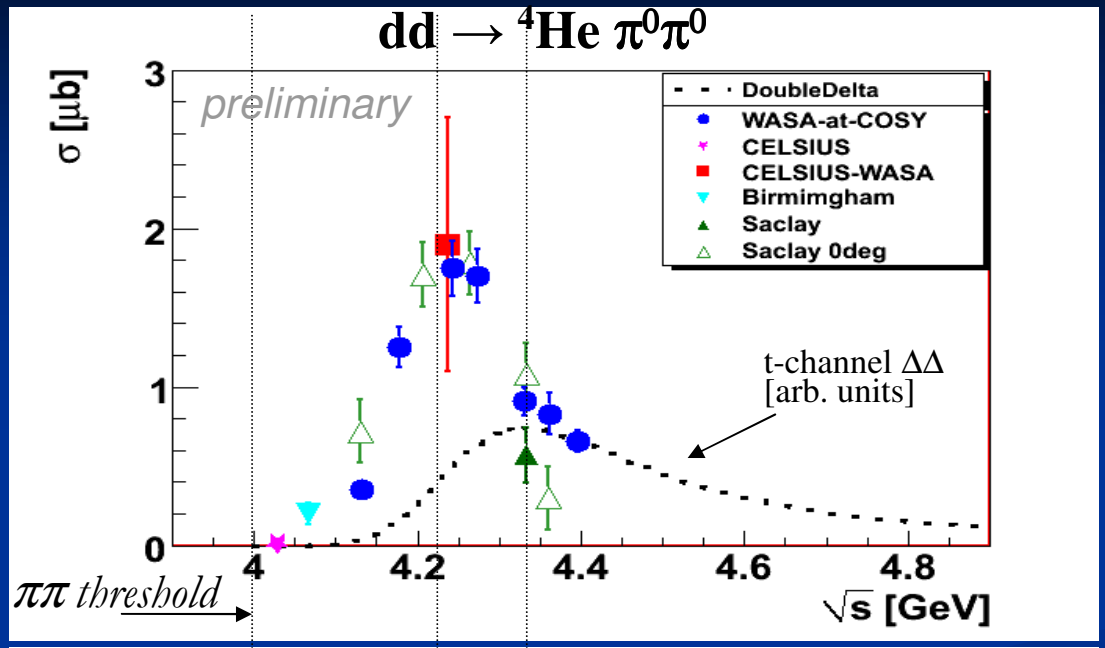
- Two-pion production in *pp* collisions:
  - basically understood by t-channel excitations of N*, ΔΔ and Δ(1600)

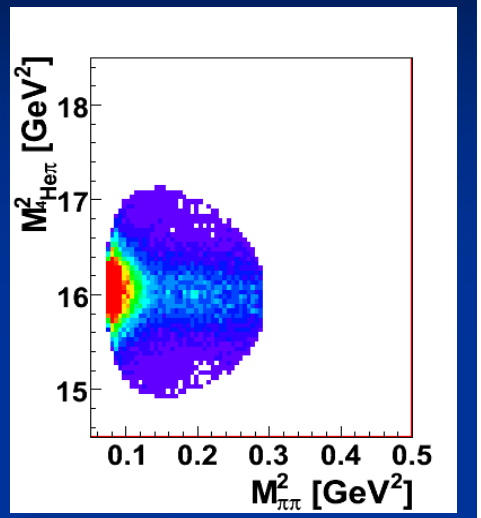
- Two-pion production in *pn* collisions:
  - ABC:
    low mass enhancement in $M_{\pi\pi} \Leftrightarrow$ resonance strcuture in σ_{tot}
    - **$I(J^P) = 0(3^+)$**
    - **$M \approx 2370$ MeV $= 2M_\Delta - 80$ MeV**
    - **$\Gamma \approx 70$ MeV $<< 2\,\Gamma_\Delta \approx 230$ MeV**

… and

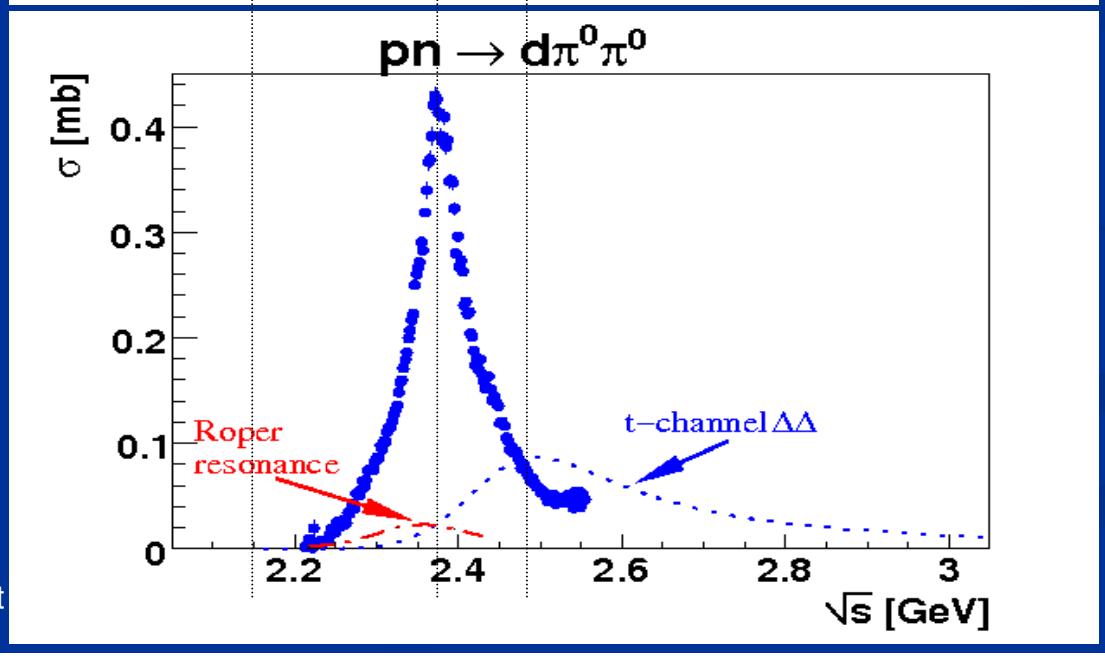
… survives even in heavier nuclei!

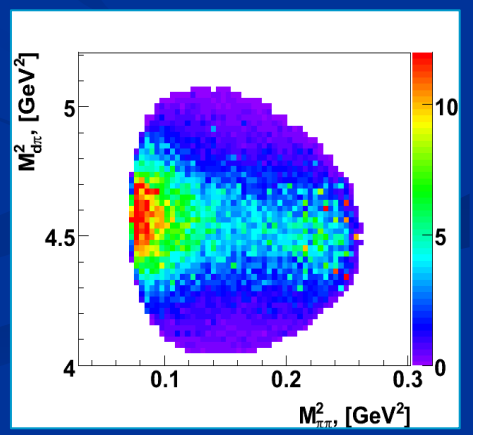
^{4}He





d





Consequences and Outlook

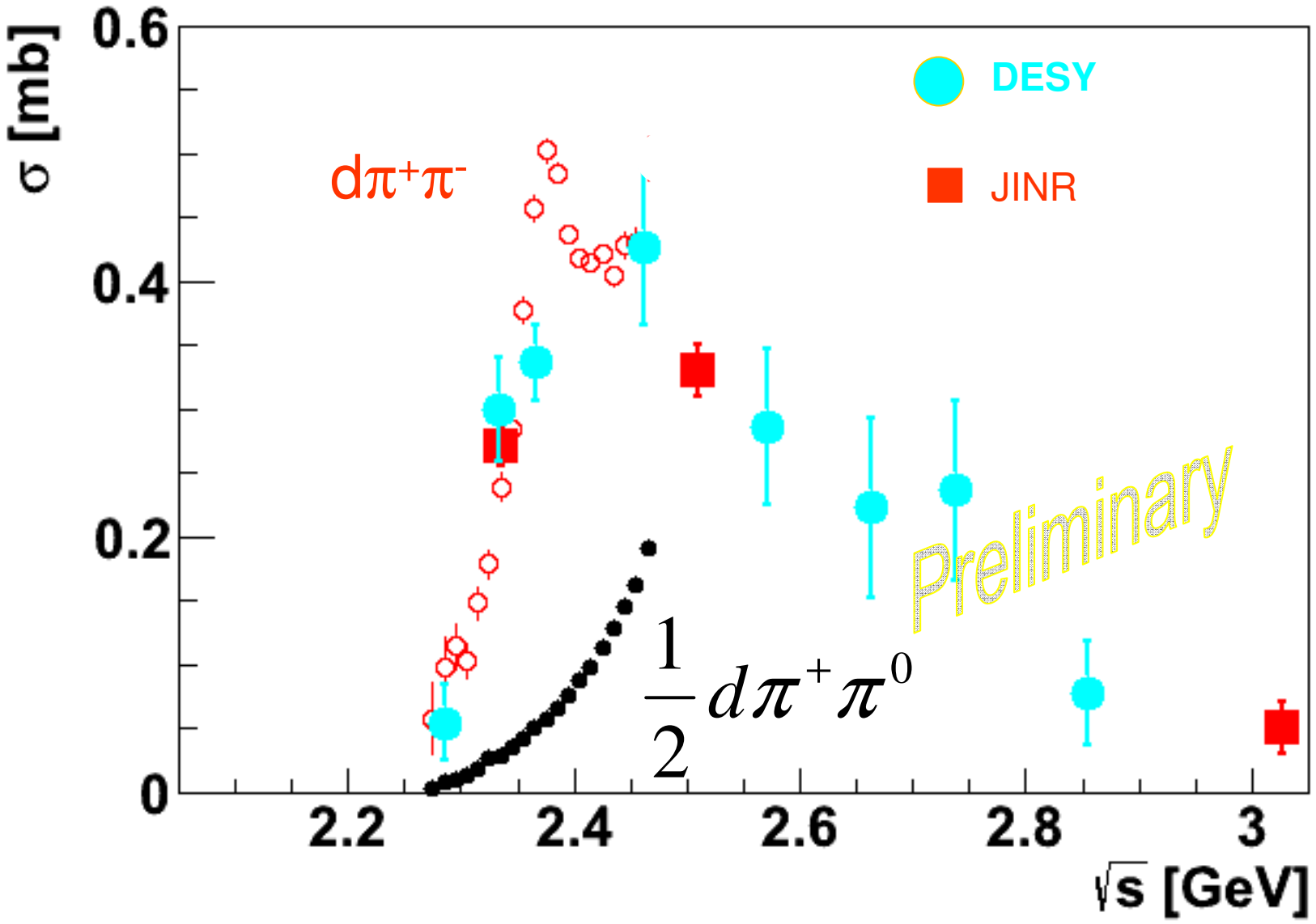
- To-do list:
  - Search for resonance effects in **all** possible channels:
    - pn $\rightarrow$ d $\pi^+\pi^-$
    - pn $\rightarrow$ pn $\pi^0\pi^0$
    - pn $\rightarrow$ pp $\pi^0\pi^-$
    - NN $\rightarrow$ NNπ (I = 0)
    - pn scattering (polarized beam)

1.2 GeV data Sep09

$$p\,d \rightarrow d\,\pi^+\pi^- + p_{spectator}$$
$$\rightarrow d\,\pi^+\pi^0 + n_{spectator}$$
$$\rightarrow d\,\pi^0\pi^0 + p_{spectator}$$

$$\rightarrow pp\,\pi^- + p_{spectator}$$
$$\rightarrow pp\,\pi^0 + n_{spectator}$$

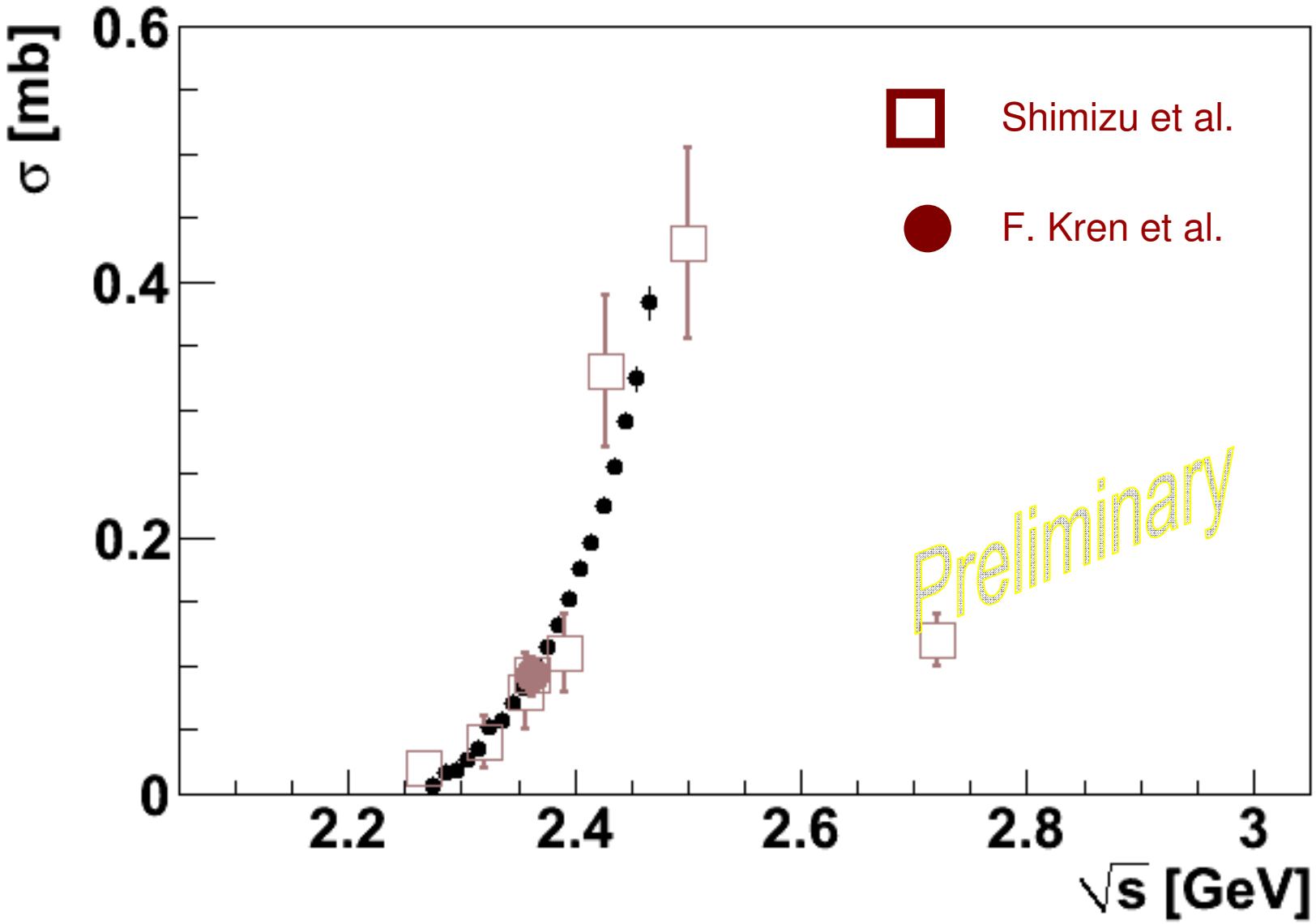
Total cross section $pN \to d\pi\pi$



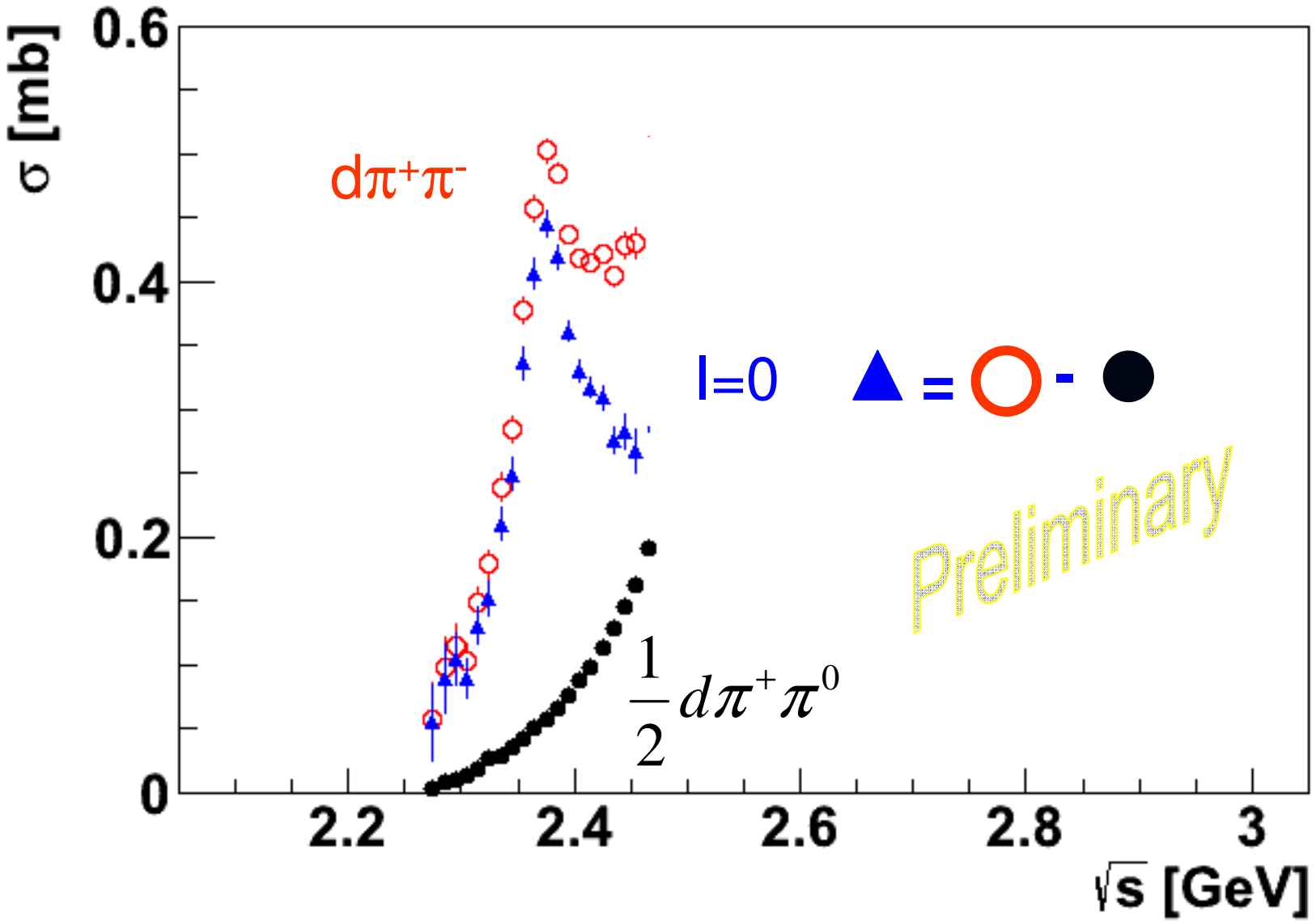
Isospin factors

$$\sigma\left[pn \to d\pi^+\pi^-(I=1)\right] = \frac{1}{2}\sigma\left[pp \to d\pi^+\pi^0\right]$$

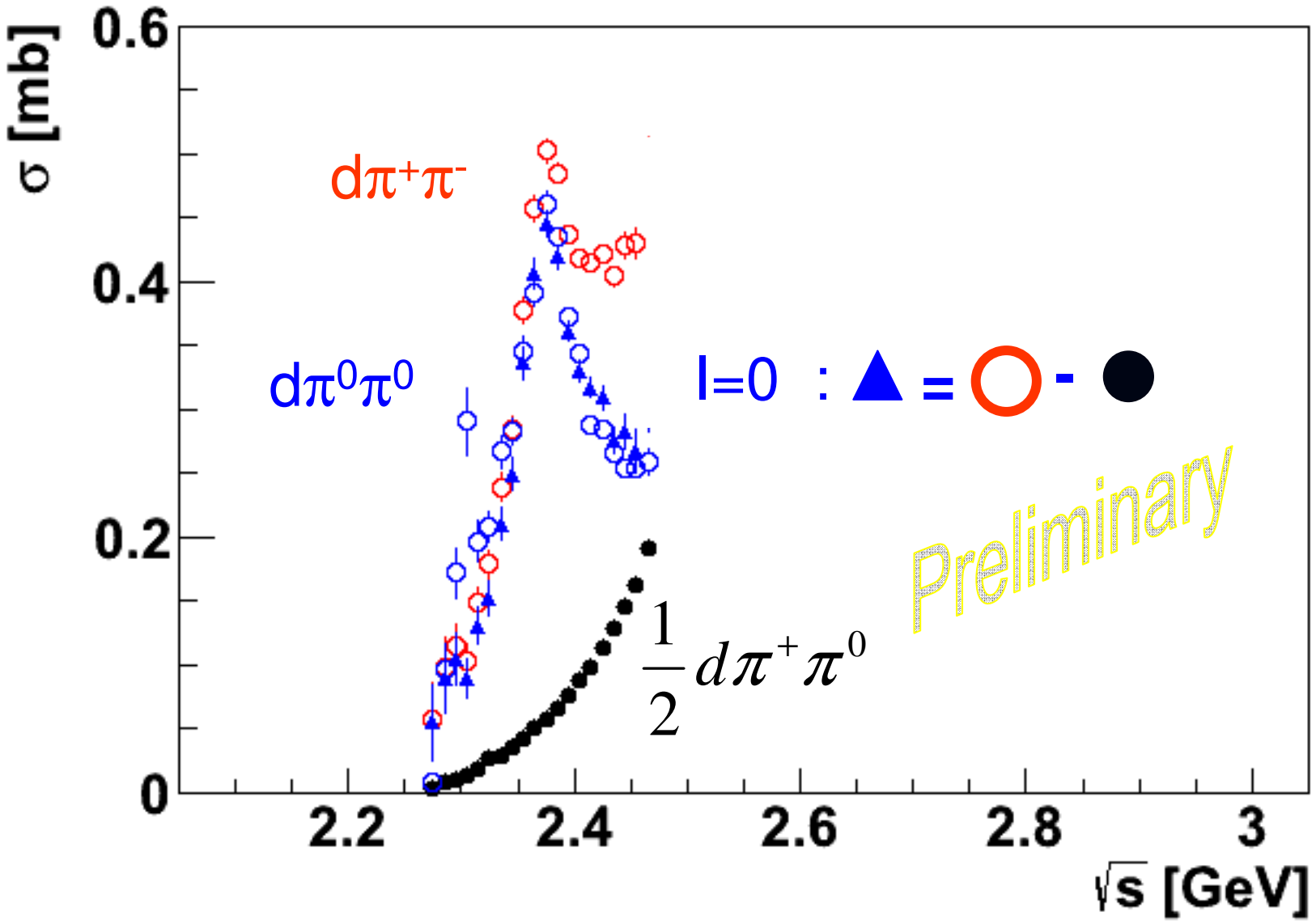
Total cross section $pp \rightarrow d\pi^+\pi^0$



Total cross section $pN \rightarrow d\pi\pi$



Total cross section $pN \to d\pi\pi$

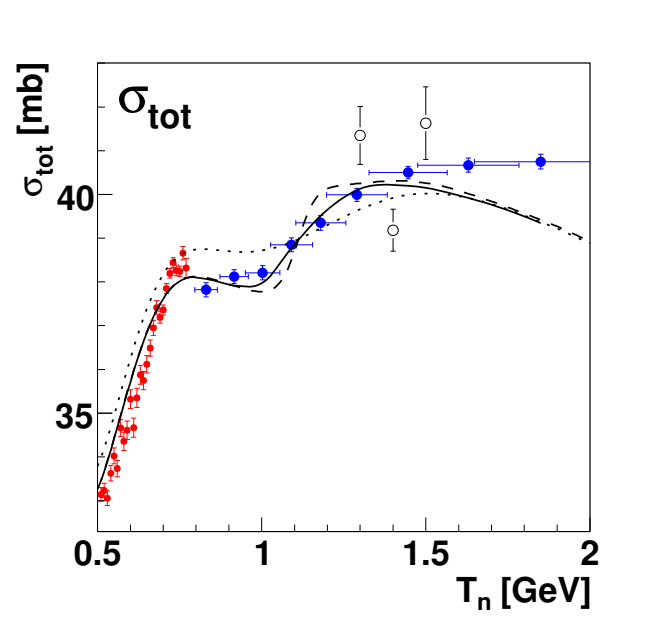


Consequences and Outlook

- To-do list:
  - Search for resonance effects in **all** possible channels:
    - pn → d $\pi^+\pi^-$ √
    - pn → pn $\pi^0\pi^0$
    - pn → pp $\pi^0\pi^-$ √
    - NN → NNπ (I = 0)
    - pn scattering (polarized beam)

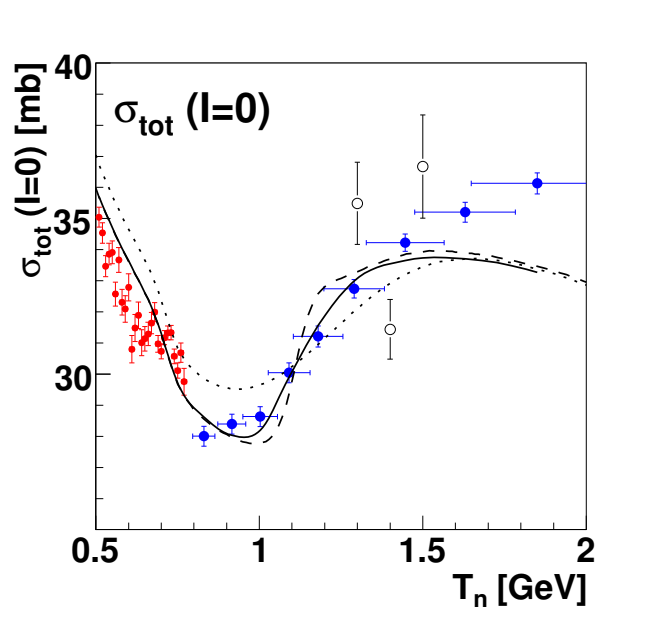
Resonance Effects in pn Scattering

- Total cross sections



... SAID

--- SAID + ABC resonance



… so what is it?

… so what is it?

Some hint?

PHYSICAL REVIEW C VOLUME 39, NUMBER 5 MAY 1989

"Inevitable" nonstrange dibaryon

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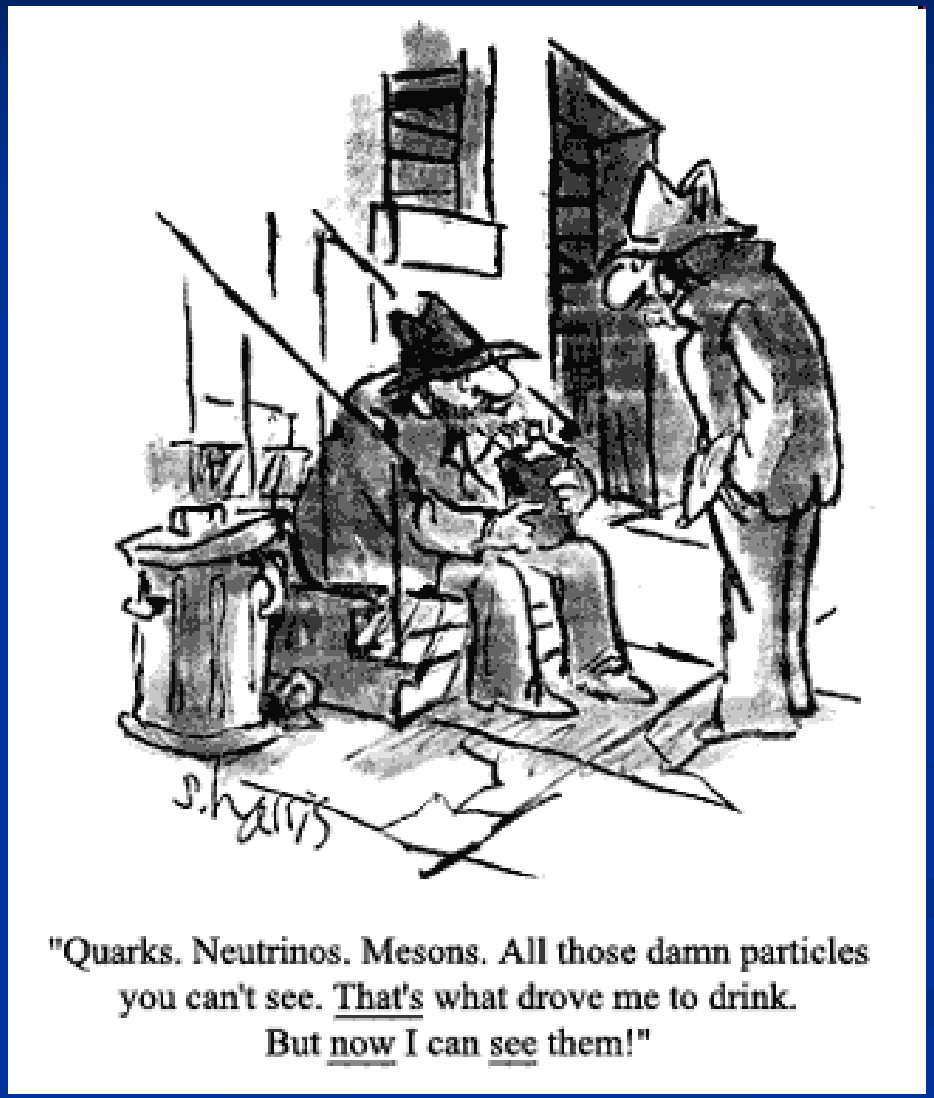
Certain basic features, common to all phenomenological models of hadron structure based on the picture of confinement at large distances and effective one-gluon exchange within the confinement region, necessarily lead to the prediction of the existence of a nonstrange dibaryon resonance with quantum numbers $IJ^P=03^+$, the d^*, independent of more detailed features of the dynamics of any of the models. We discuss the qualitative physics underlying this claim, comment on the probable mass and decay properties of the resulting state, and provide estimates of the expected production cross sections in $np \to d^*$ and $\pi^\pm d \to \pi^\pm d^*$.

… so what is it?

Some hint?



"Quarks. Neutrinos. Mesons. All those damn particles you can't see. That's what drove me to drink. But now I can see them!"