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Fachbereich Physik

CERN Courier September 2011

Two-Pion Production in NN-Collisions – back to Dibaryons?

*From Quarks and Gluons to Hadrons and Nuclei –
Erice Sept. 16 – 24, 2011*

Heinz Clement

Content

- 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**

- $pp \rightarrow pp\pi^0\pi^0 \,/\, \pi^+\pi^-$

- $\rightarrow pn\pi^+\pi^0$

- $\rightarrow nn\pi^+\pi^+$

- …………………
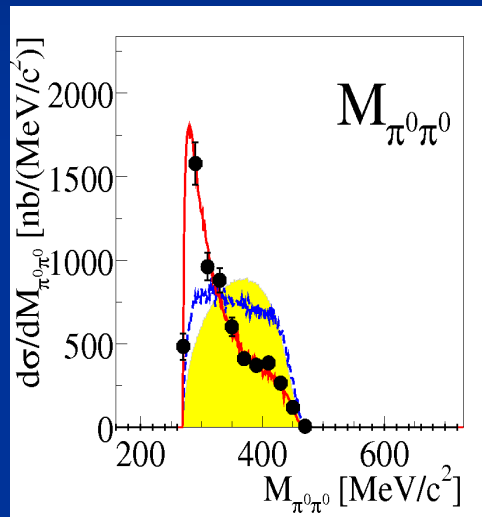
- $\rightarrow d \; \pi^+\pi^0$

- pure **isoscalar**

…………………………

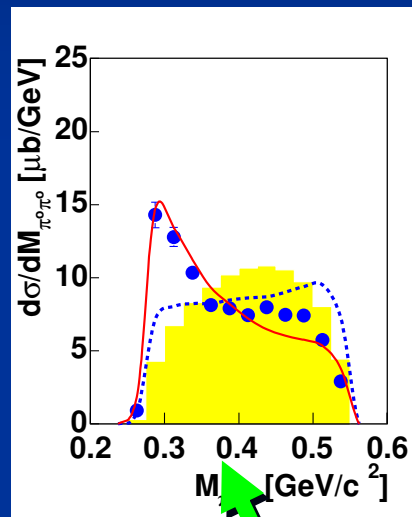$pn \rightarrow d \; \pi^0\pi^0$

$pd \rightarrow {}^3He \; \pi^0\pi^0$

$dd \rightarrow {}^4He \; \pi^0\pi^0 \,/\, \pi^+\pi^-$

ABC effect

The ABC Gallery

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

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

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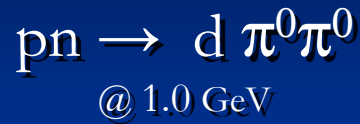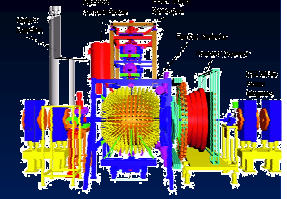
heavier
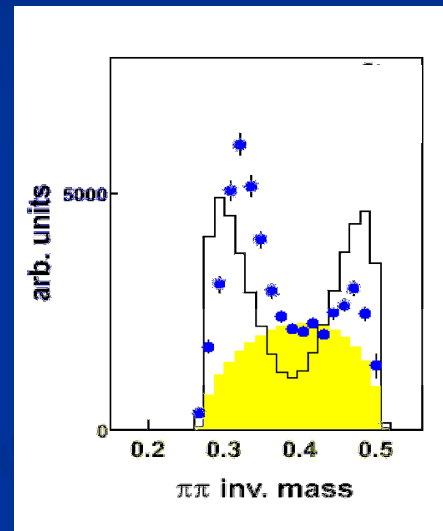nuclei ??

PRL 102 (2009) 052301

PL B 637 (2006) 223

NP A 825 (2009) 71

CELSIUS-WASA measurements
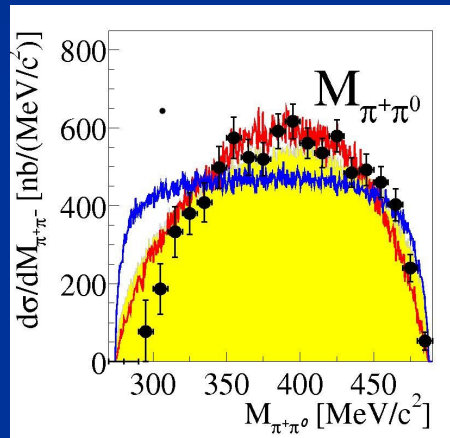
WASA-at-COSY: new exclusive measurements

Two-Pion Production in NN-Collisions --
- back to Dibaryons?

over the full $\Delta\Delta$ region!

The "no-ABC" Gallery

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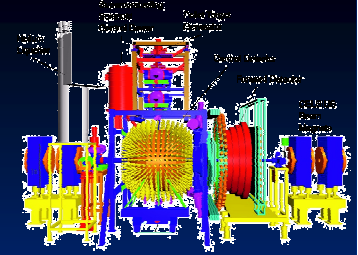
$pp \rightarrow pp\, \pi^0\pi^0$
@ 1.3 GeV

$pp \rightarrow \text{„}^2\text{He"}\, \pi^0\pi^0$
@ 1.3 GeV

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

Phys. Lett. **B** 695 (2011) 115
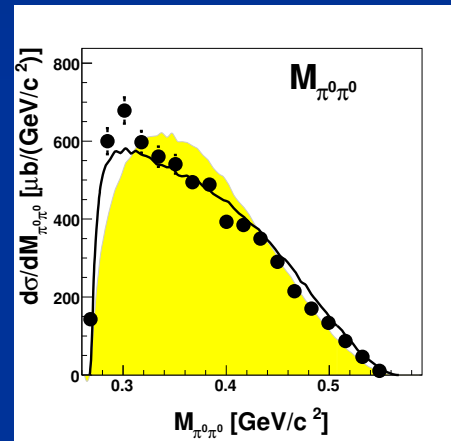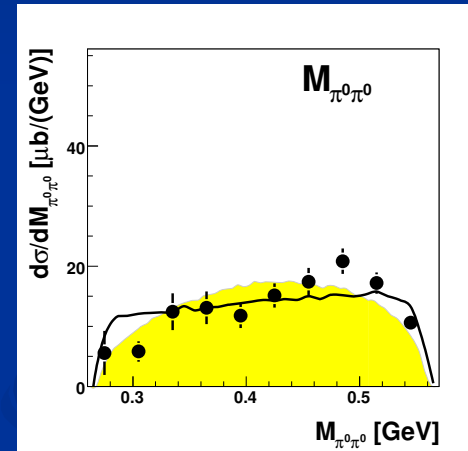
fully described by t-channel $\Delta\Delta$ process

Two-Pion Production in NN-Collisions --
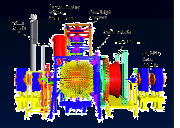- back to Dibaryons?

H. Clement
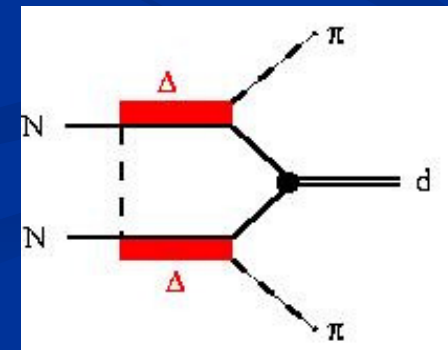
ABC Conclusions I

- 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 ?**
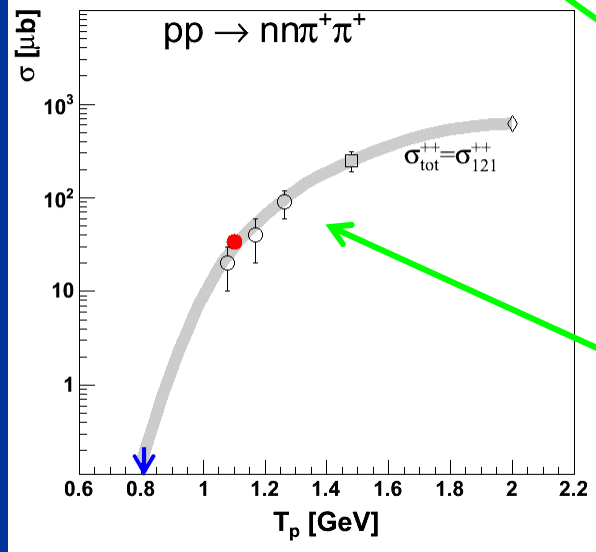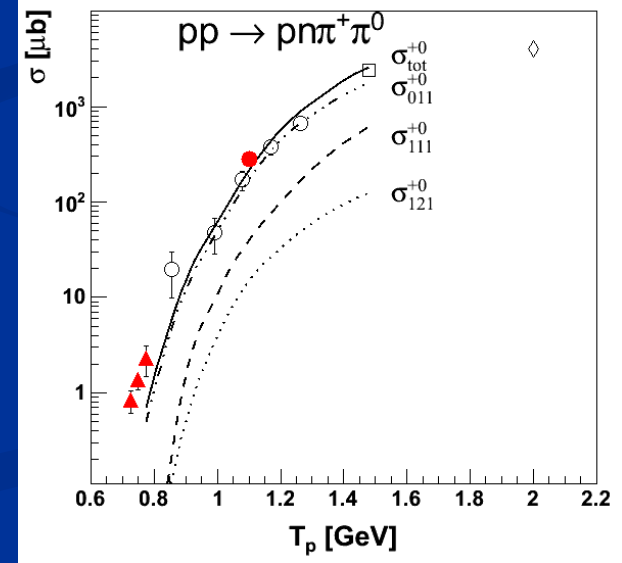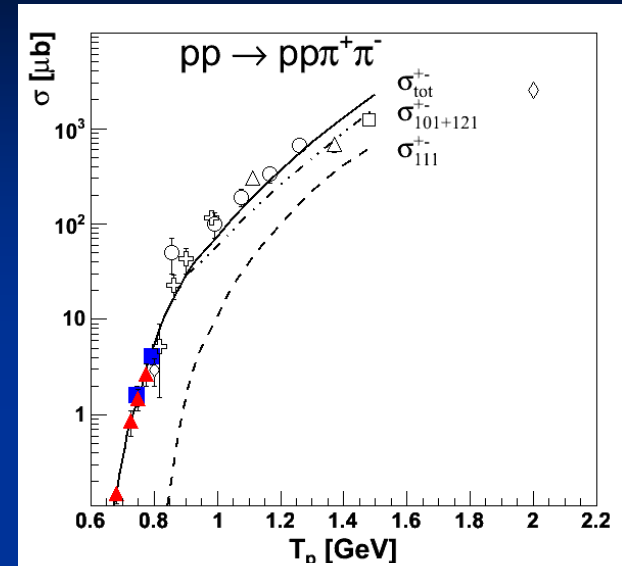
Isoscalar : Results from WASA at COSY

$pn \longrightarrow d\pi^0\pi^0$

$M \approx 2.37$ GeV
$\Gamma \approx 70$ MeV

$2m_\Delta$

$d\pi\pi$ threshold

Phys.Rev.Lett.106, 242302 (2011)
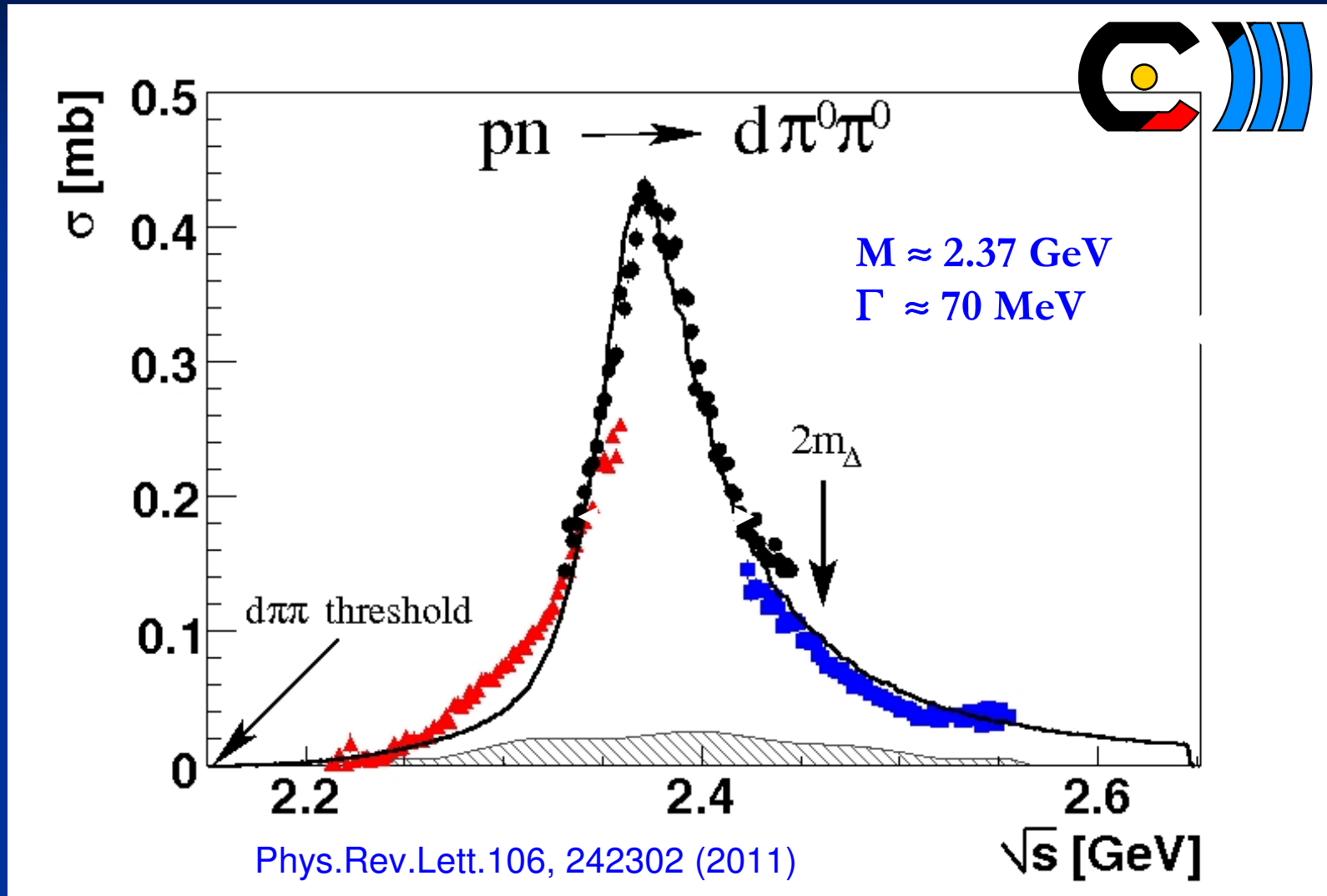
Isovector : Total Cross Sections
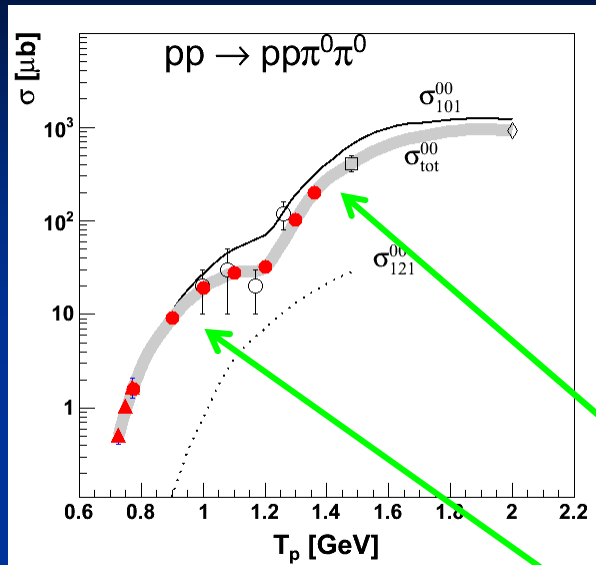
isospin decomposition

$\Rightarrow$

$\Delta\Delta$

$N^*(1440)$

$\Delta(1600)$ (?)

Phys. Lett. B 679 (2009) 30

Isovector : pp→pp $\pi^0\pi^0$

Roper dominated
$T_p = 0.9$ GeV
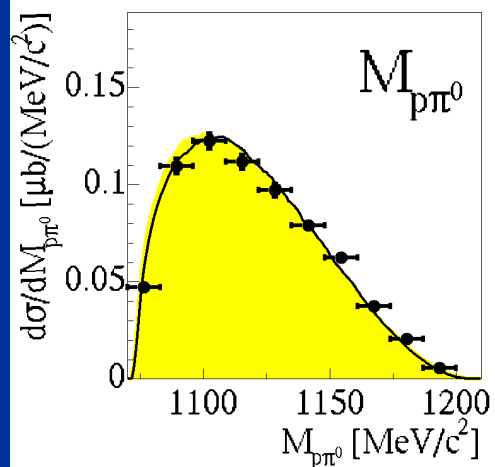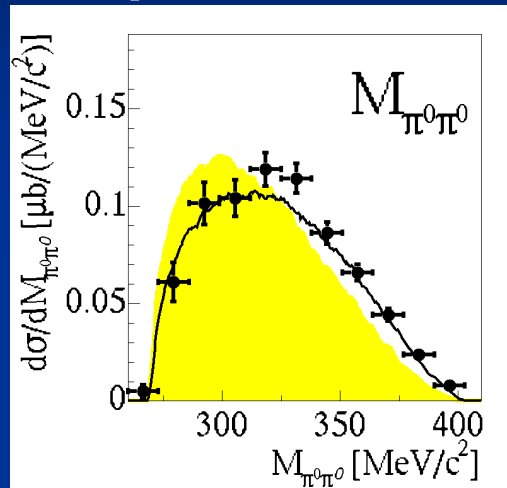
ΔΔ dominated
$T_p = 1.3$ GeV
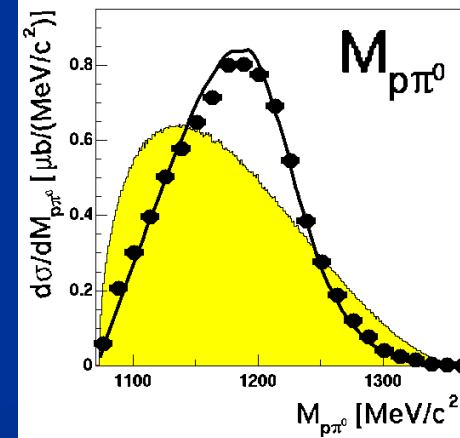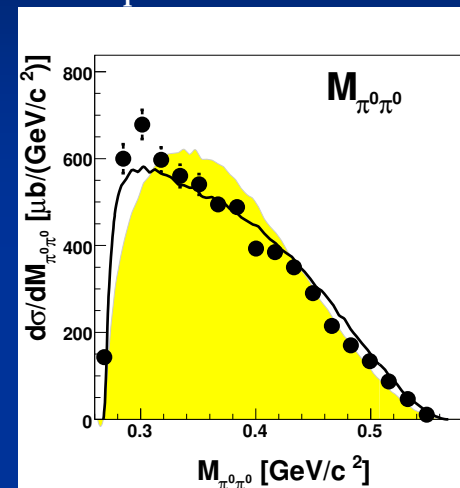
phase space

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

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Two-Pion Production in NN-Collisions --
- back to Dibaryons?
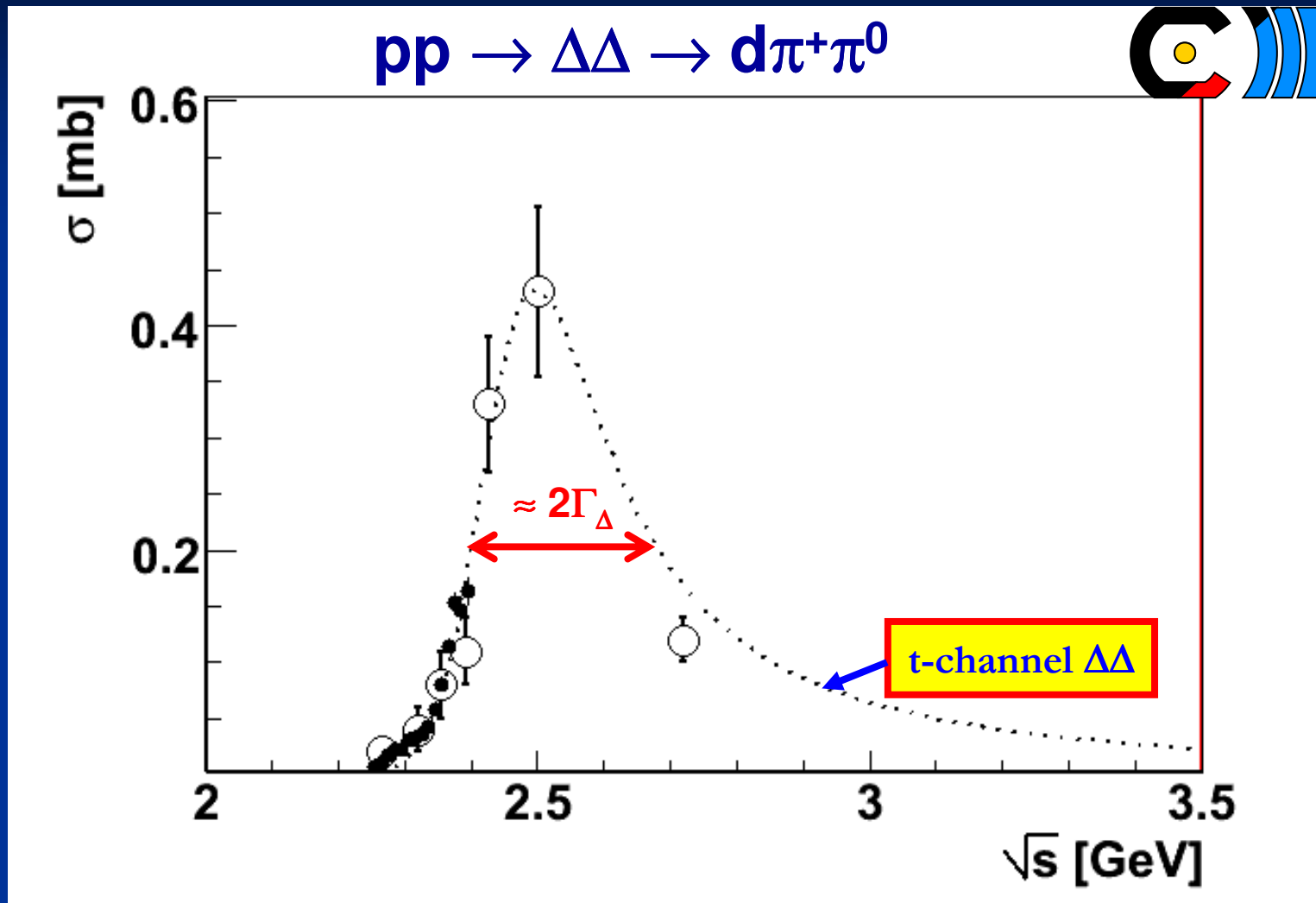
Isovector Fusion (no ABC)

$$pp \rightarrow \Delta\Delta \rightarrow d\pi^+\pi^0$$

$\approx 2\Gamma_\Delta$

t-channel $\Delta\Delta$

On proton target
On deuteron target with n-spectator

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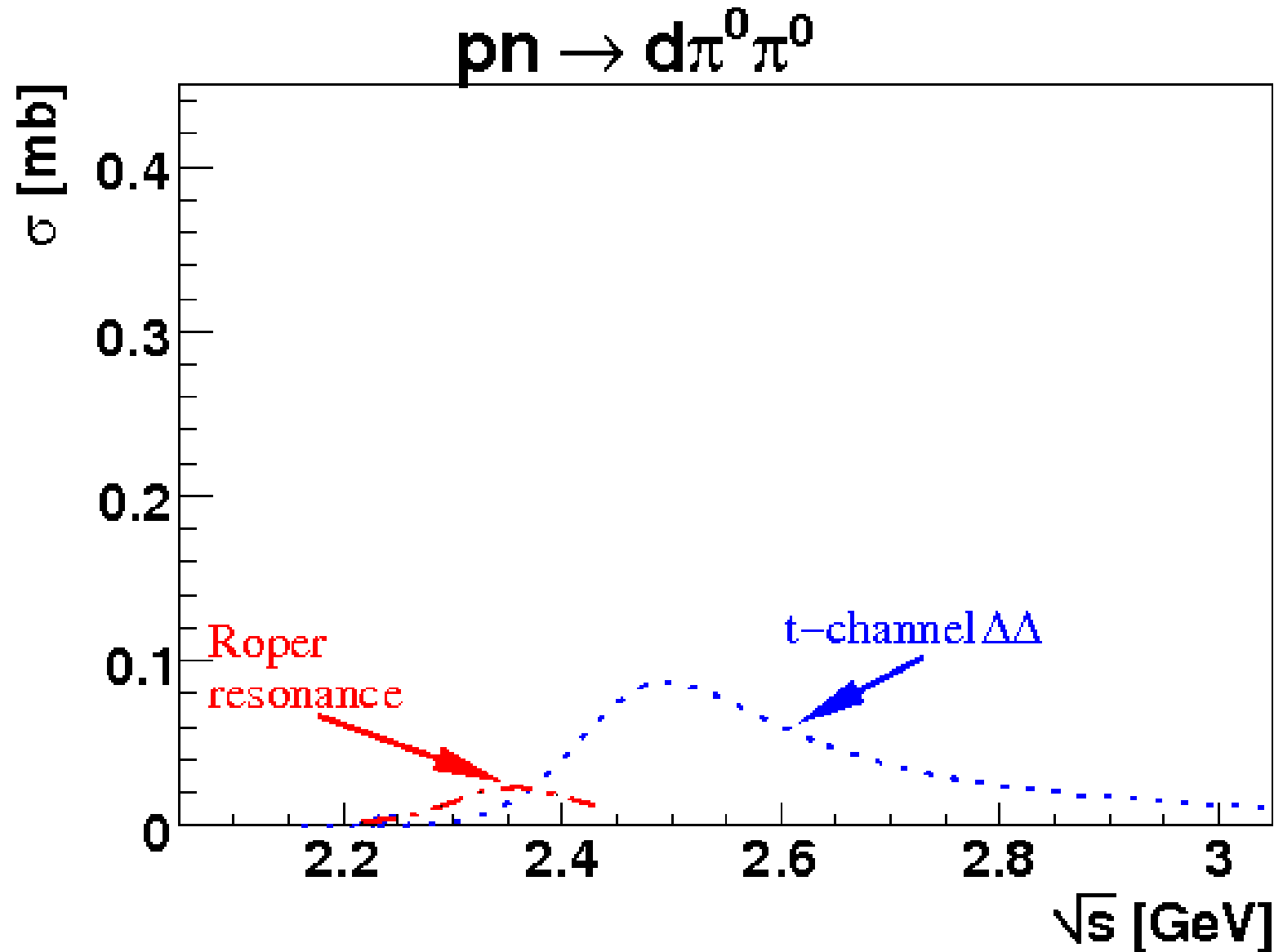Two-Pion Production in NN-Collisions --
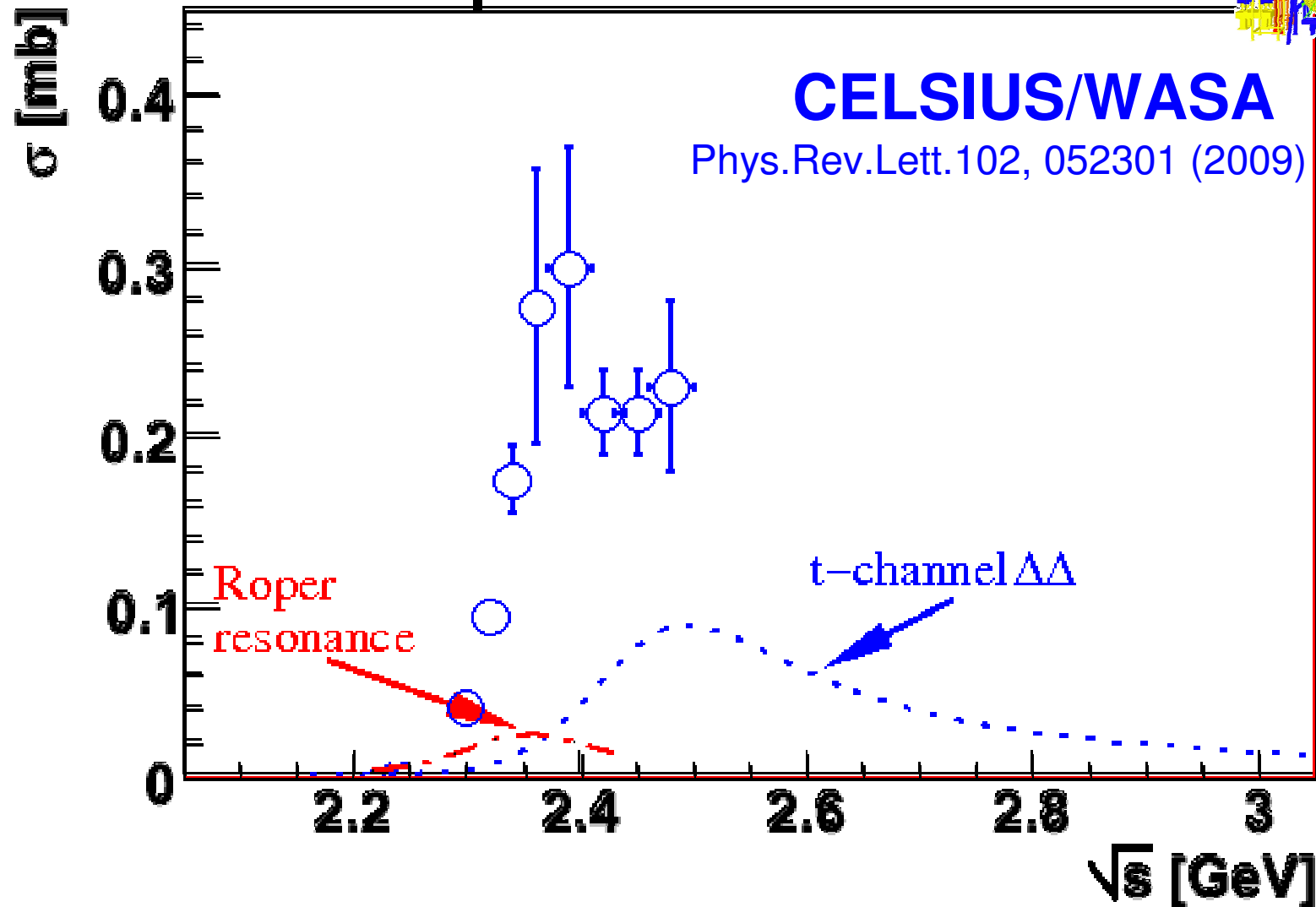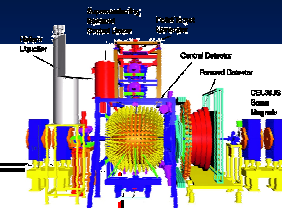- back to Dibaryons?

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Isoscalar Channels

- Which energy dependence do we expect?
  - $pn \rightarrow d \ \pi^0\pi^0$

  - $pd \rightarrow {}^3He \ \pi^0\pi^0$
  - $dd \rightarrow {}^4He \ \pi^0\pi^0 / \pi^+\pi^-$

  $\Rightarrow$ from isospin decomposition we may expect …

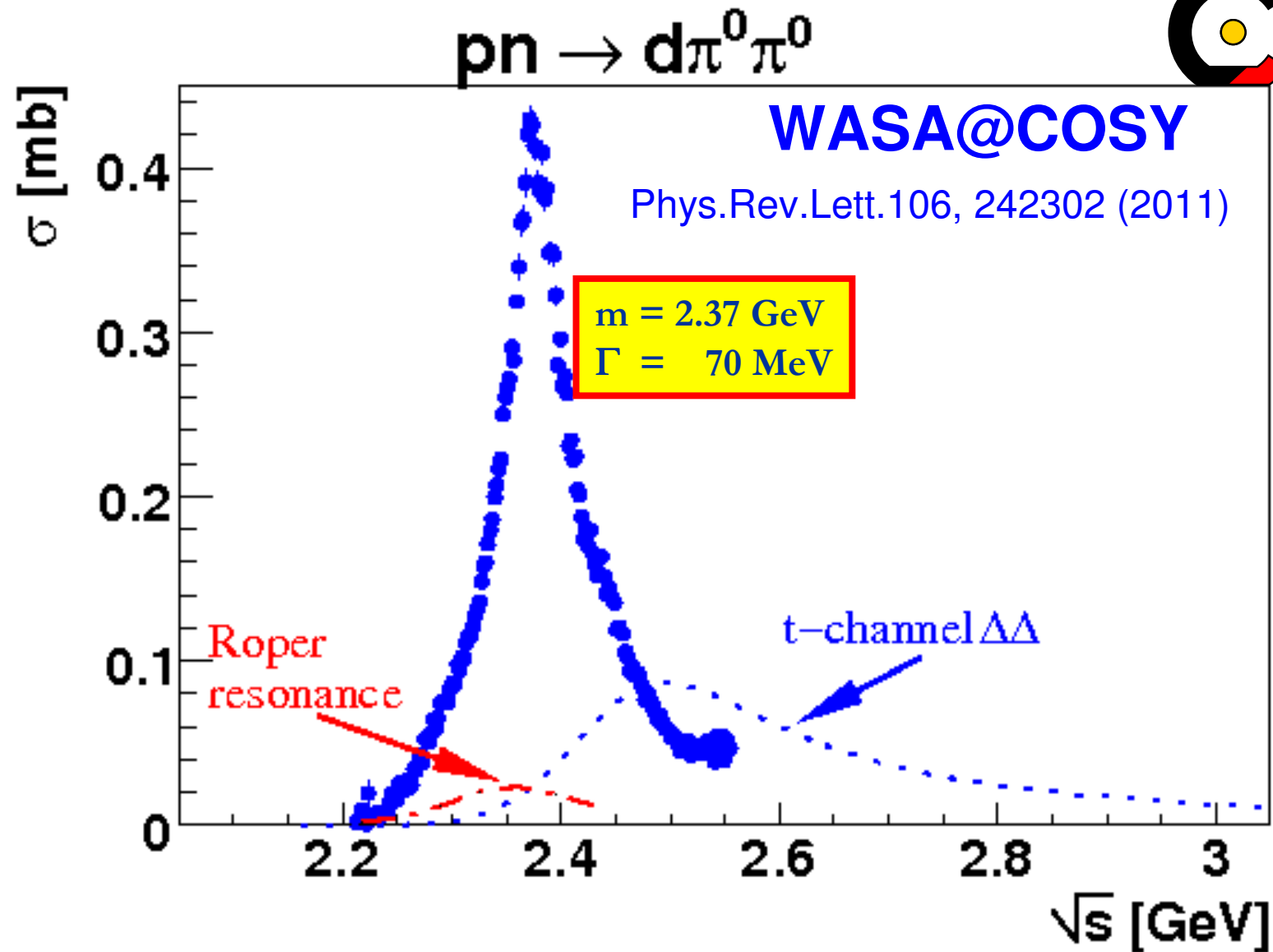# Isoscalar : … this is what we expect !

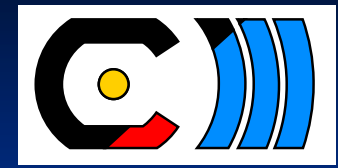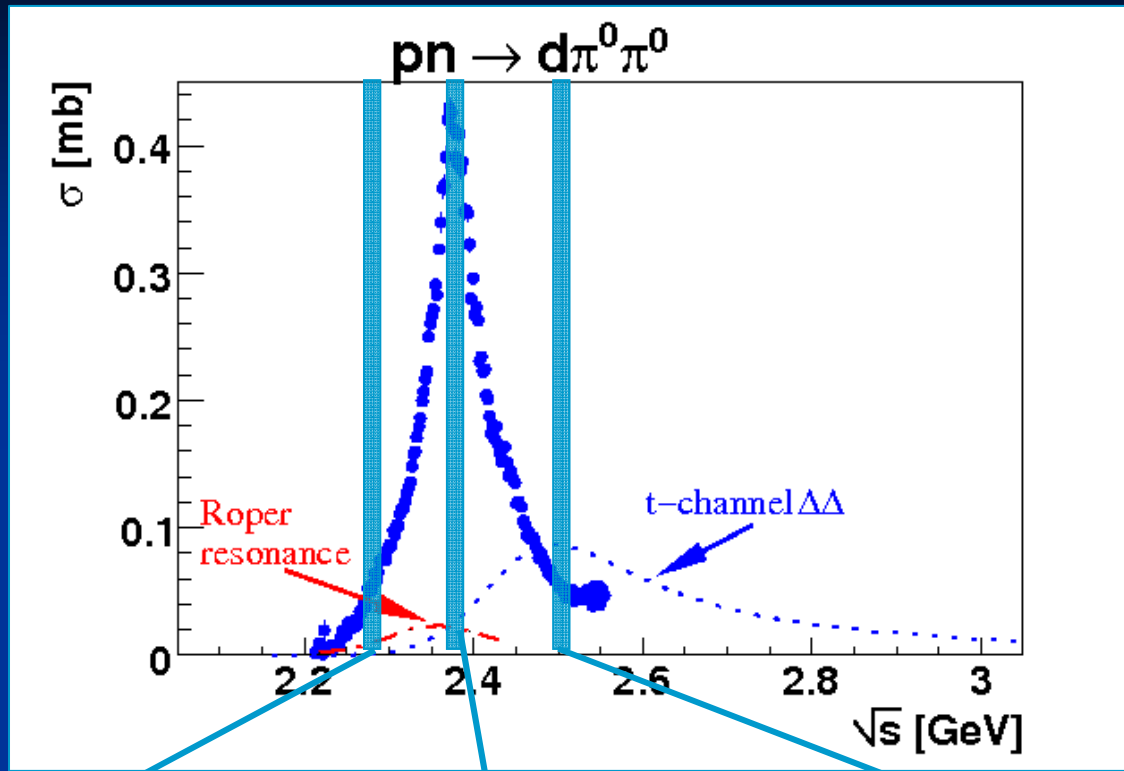

$pn \rightarrow d\pi^0\pi^0$

Roper resonance

t-channel $\Delta\Delta$

$$pn \rightarrow d\pi^0\pi^0$$

CELSIUS/WASA

Phys.Rev.Lett.102, 052301 (2009)

Roper resonance

t−channel $\Delta\Delta$

σ [mb]

$\sqrt{s}$ [GeV]

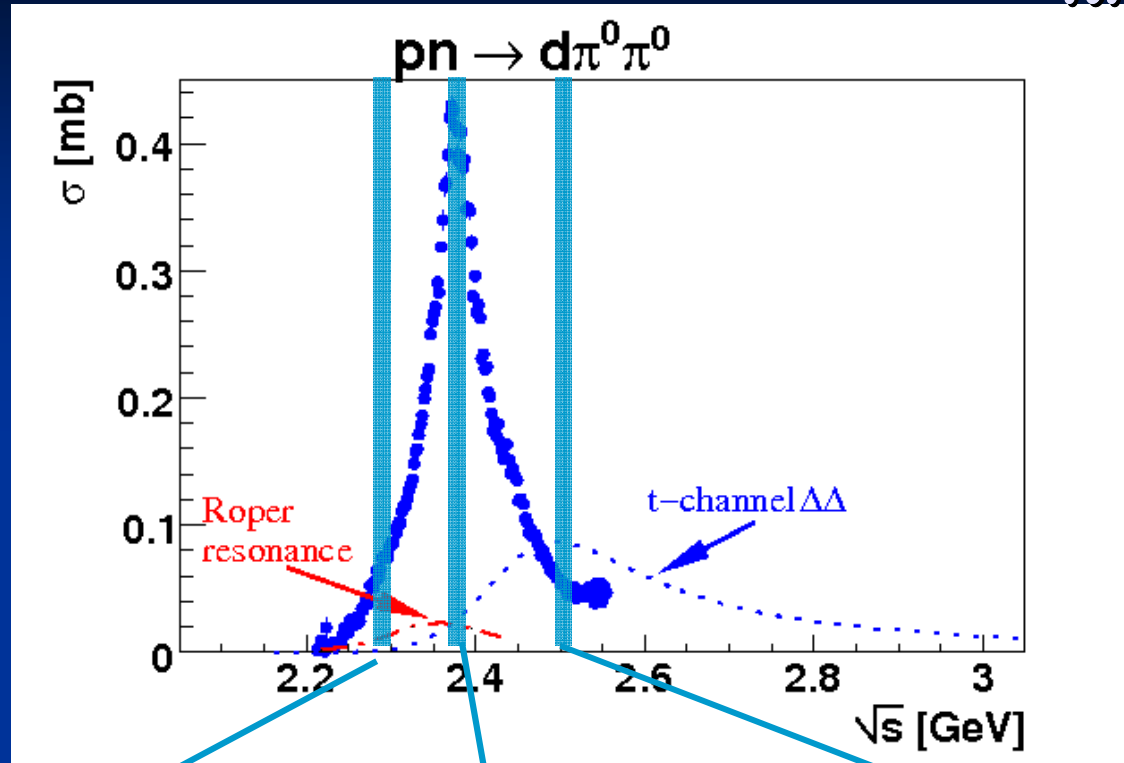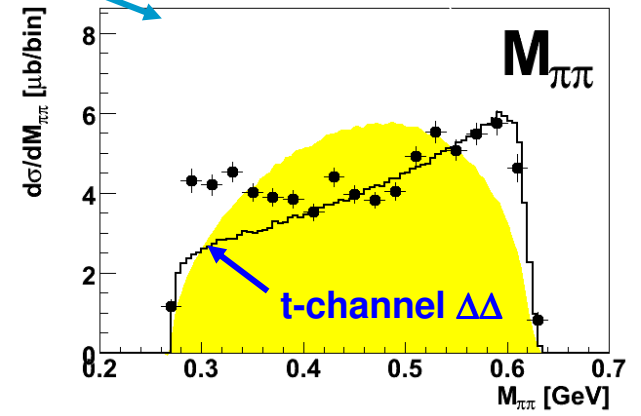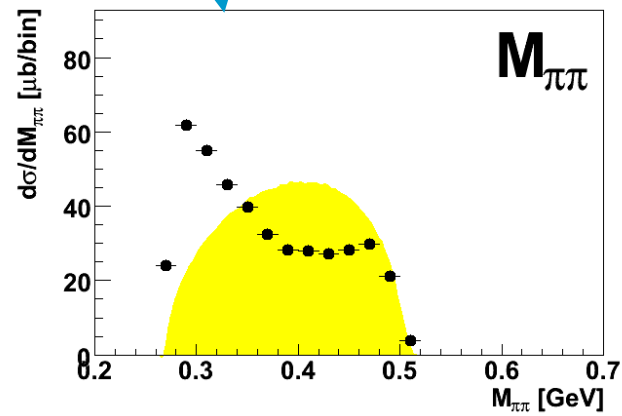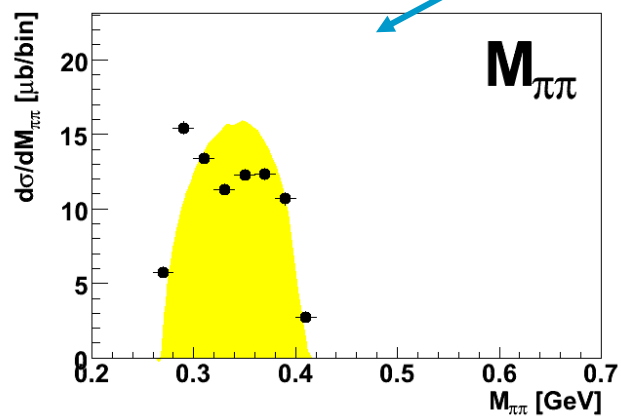# Isoscalar : … and these are the new measurements

$pn \rightarrow d\pi^0\pi^0$

WASA@COSY

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

m = 2.37 GeV
Γ = 70 MeV

Roper resonance

t−channel ΔΔ

Dalitz plots

$\pi\pi$-invariant mass $M_{\pi\pi}$

dπ^0 –invariant mass $M_{d\pi^0}$

$pn \rightarrow d\pi^0\pi^0$

Roper resonance

t–channel $\Delta\Delta$

$M_{d\pi^0}$

$M_{d\pi^0}$
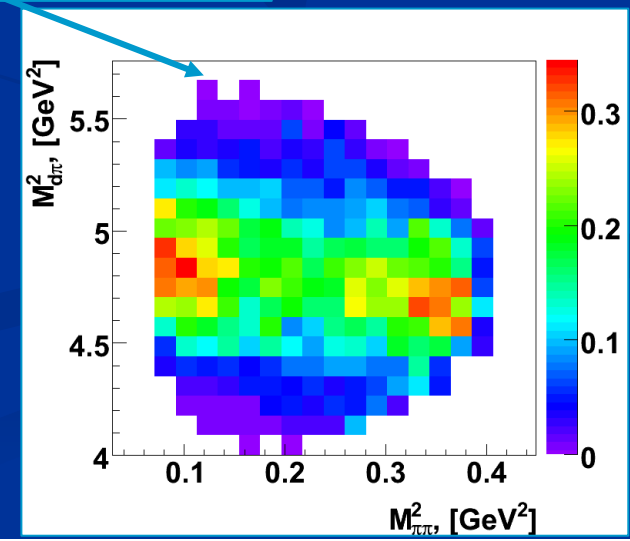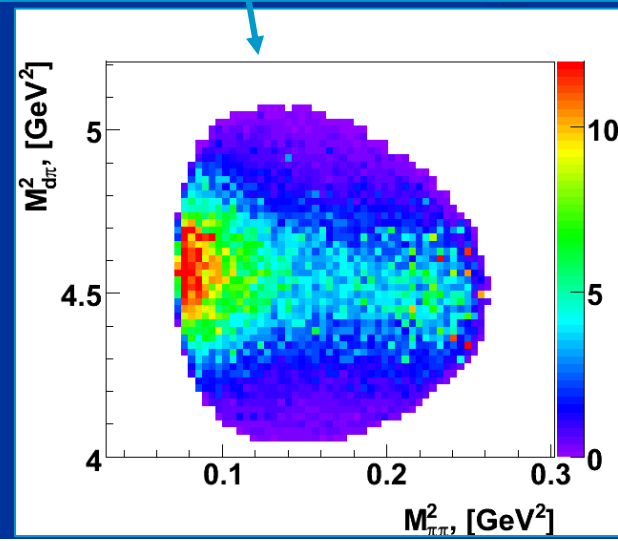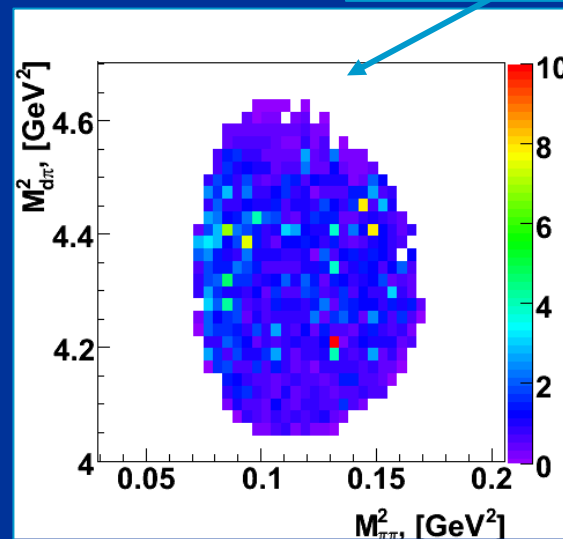
$M_{d\pi^0}$
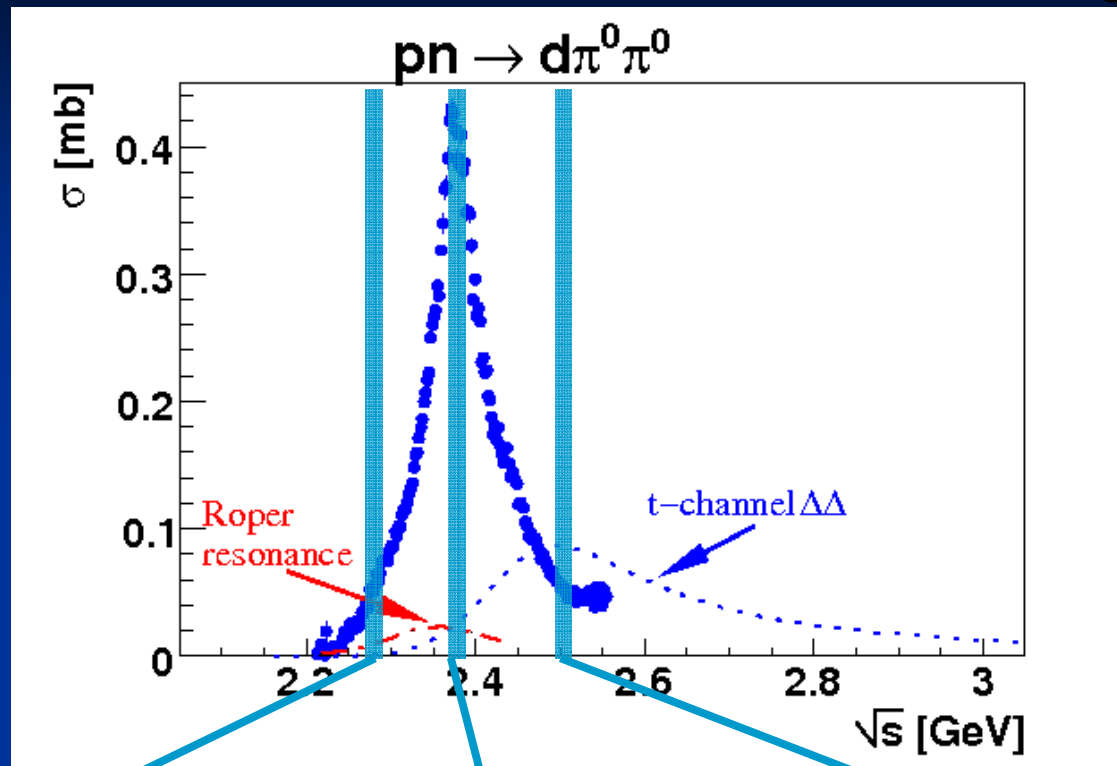
Phys.Rev.Lett.106, 242302 (2011)
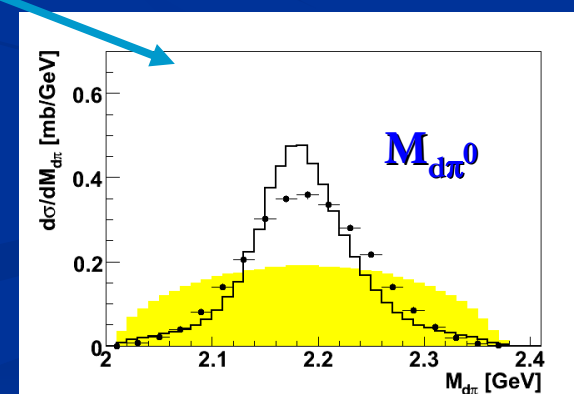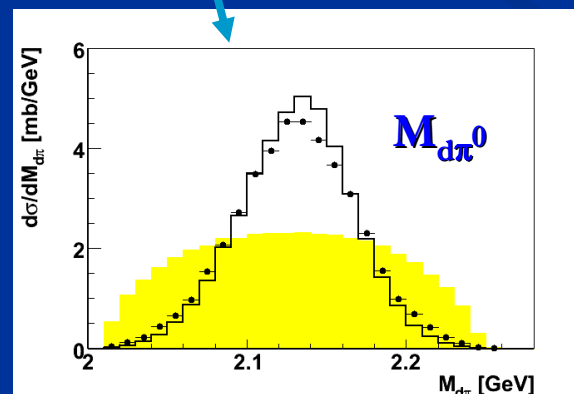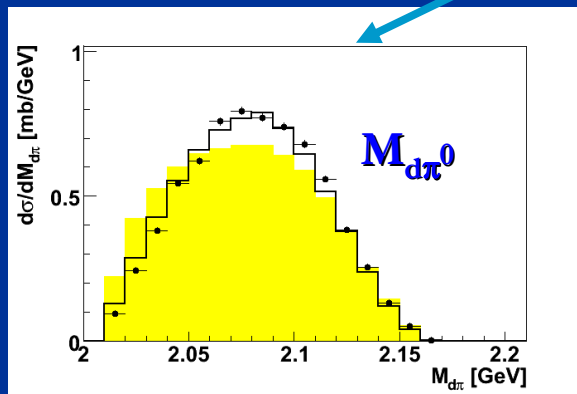
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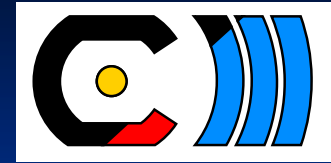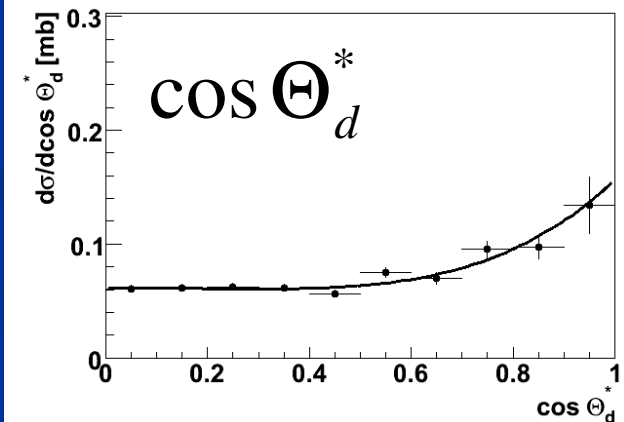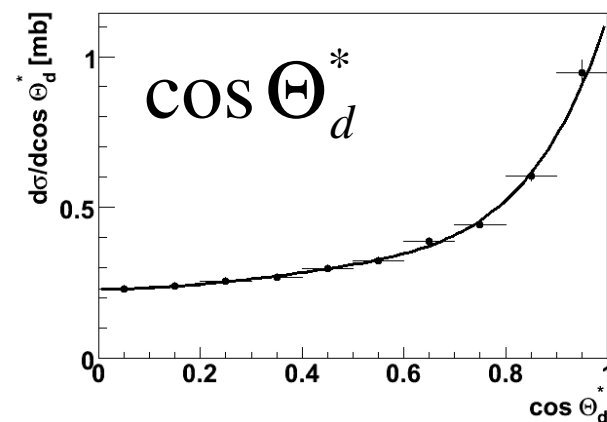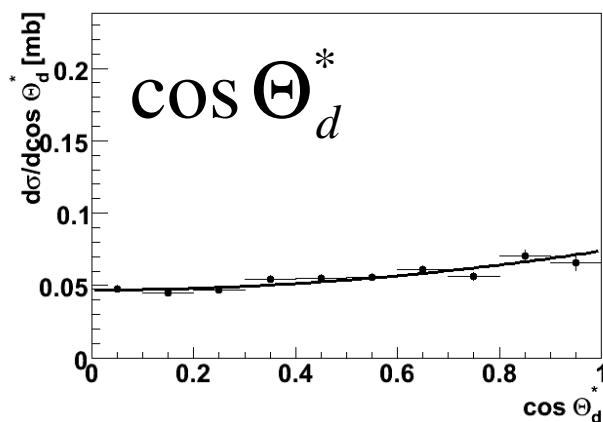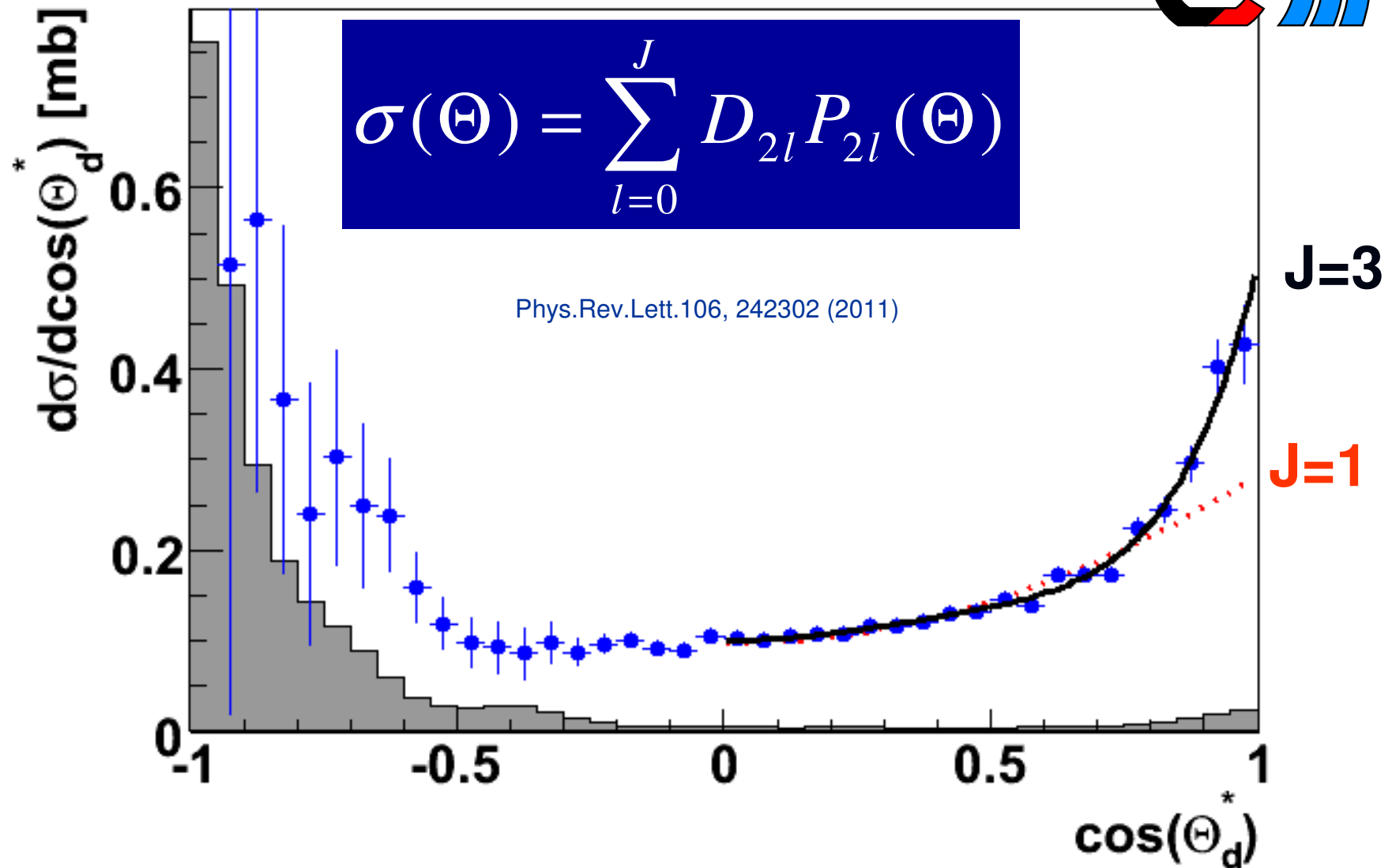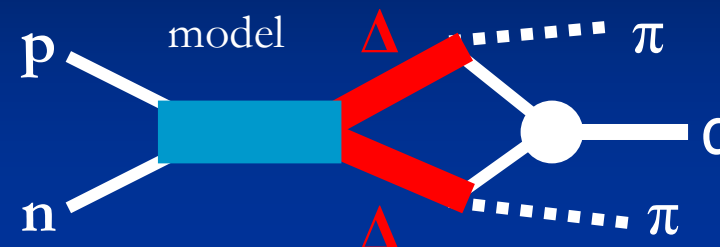Two-Pion Production in NN-Collisions -- - back to Dibaryons?

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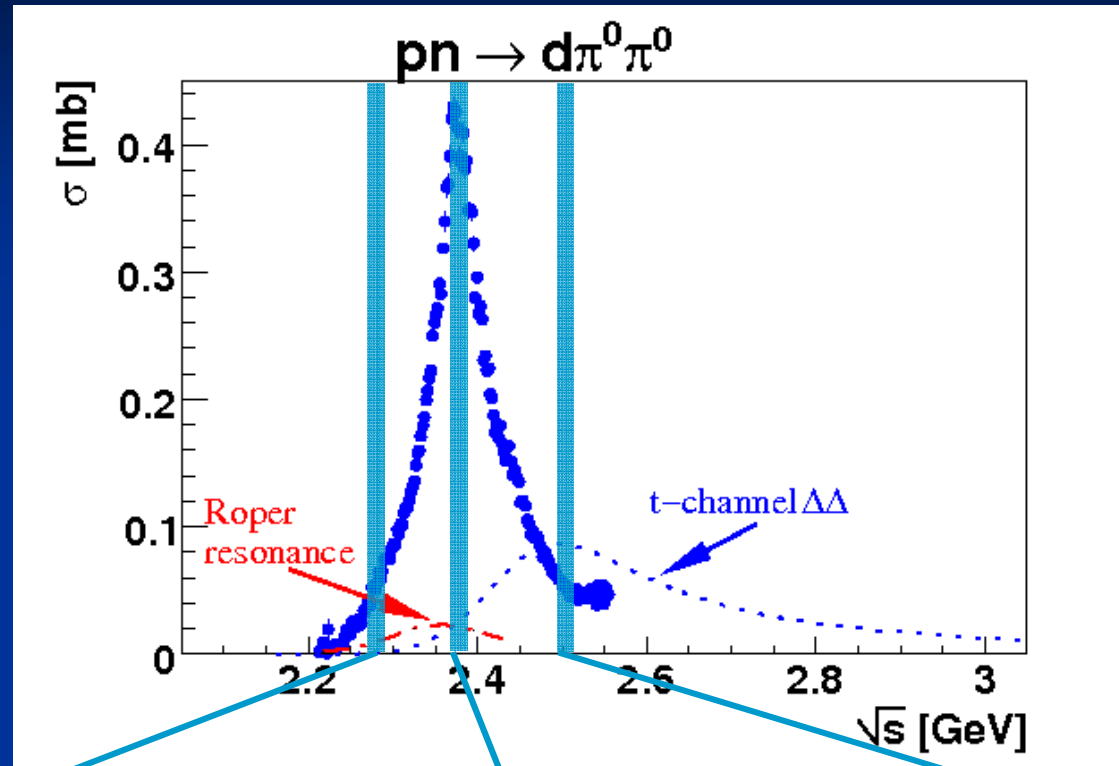
Phys.Rev.Lett.106, 242302 (2011)

Angular distribution at the peak cross section

$$\sigma(\Theta) = \sum_{l=0}^{J} D_{2l} P_{2l}(\Theta)$$

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

J=3

J=1

Quantum numbers of the structure

$$pn \rightarrow \text{``R''} \rightarrow \Delta\Delta \rightarrow d\,\pi^0\pi^0$$

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

$$\sigma(\cos\,\Theta_d^*) = D_0 P_0 + D_2 P_2 + D_4 P_4 + D_6 P_6$$

1^+

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

Isospin :

$$pn \quad \rightarrow \quad d \quad \pi^0\pi^0$$

$$I = \quad 0,1 \qquad\qquad 0 \qquad 0,2$$

$I = 0$

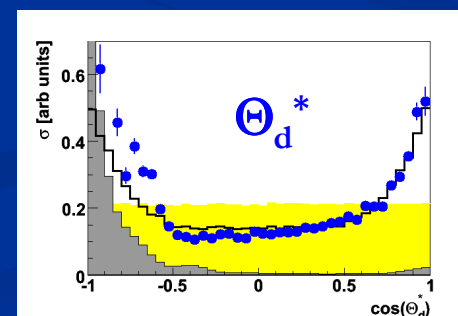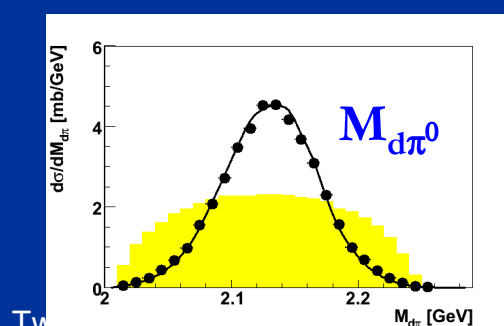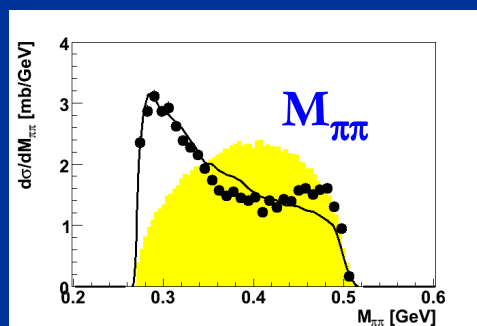# Assume $pn \to R \to \Delta\Delta \to d\pi^0\pi^0$
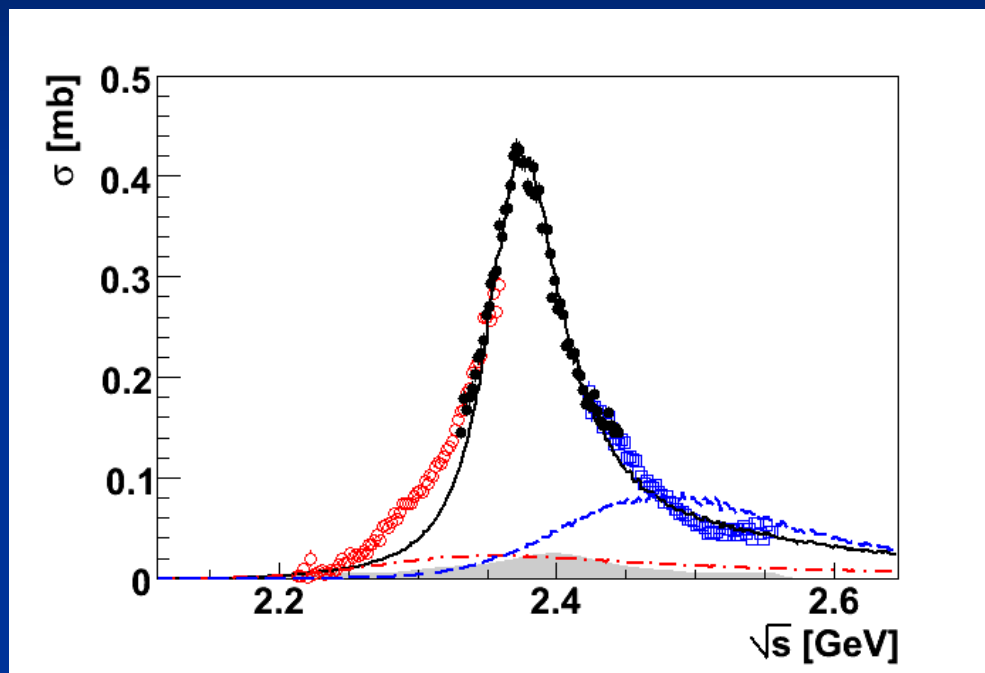
$I(J^P) = 0(3^+)$

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

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

$M_{\pi\pi}$

$M_{d\pi^0}$

Θ_d^*

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:
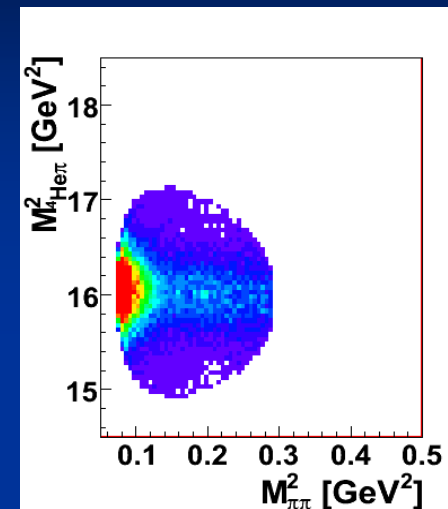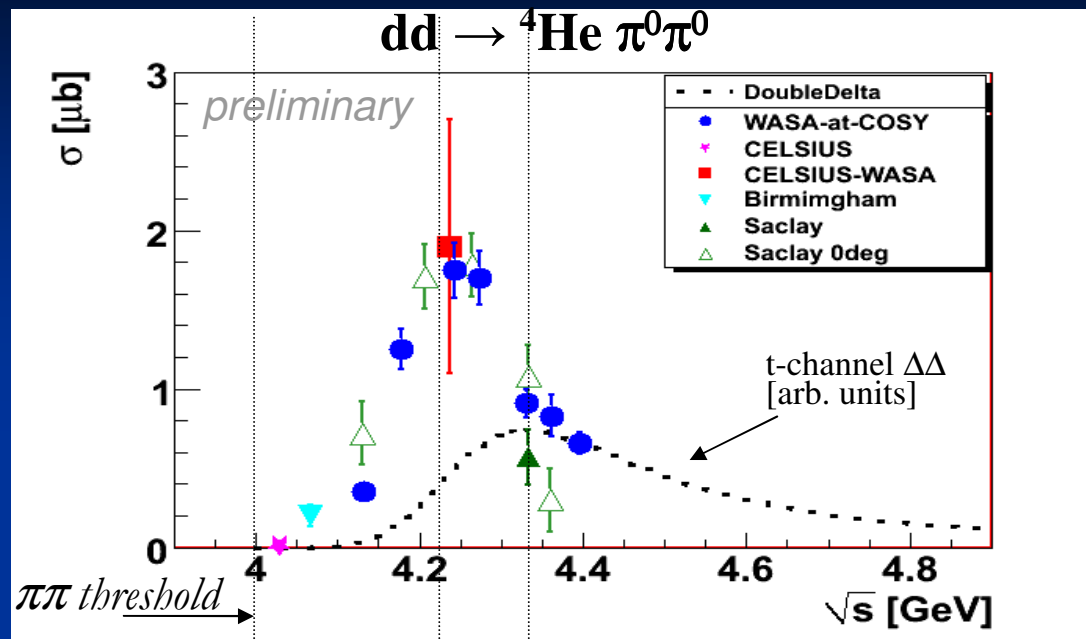   low mass enhancement in $M_{\pi\pi}$ ⟺ resonance strcuture in σ_{tot}
    - $I(J^P) = 0(3^+)$
    - $M \approx 2370$ MeV $= 2M_\Delta - 80$ MeV
    - $\Gamma \approx 70$ MeV $<< 2\ \Gamma_\Delta \approx 230$ MeV

    … and

… survives even in heavier nuclei!

$dd \to {}^4He\, \pi^0\pi^0$

^{4}He

d

$pn \to d\pi^0\pi^0$
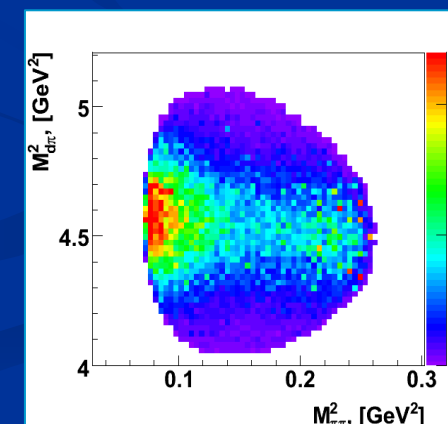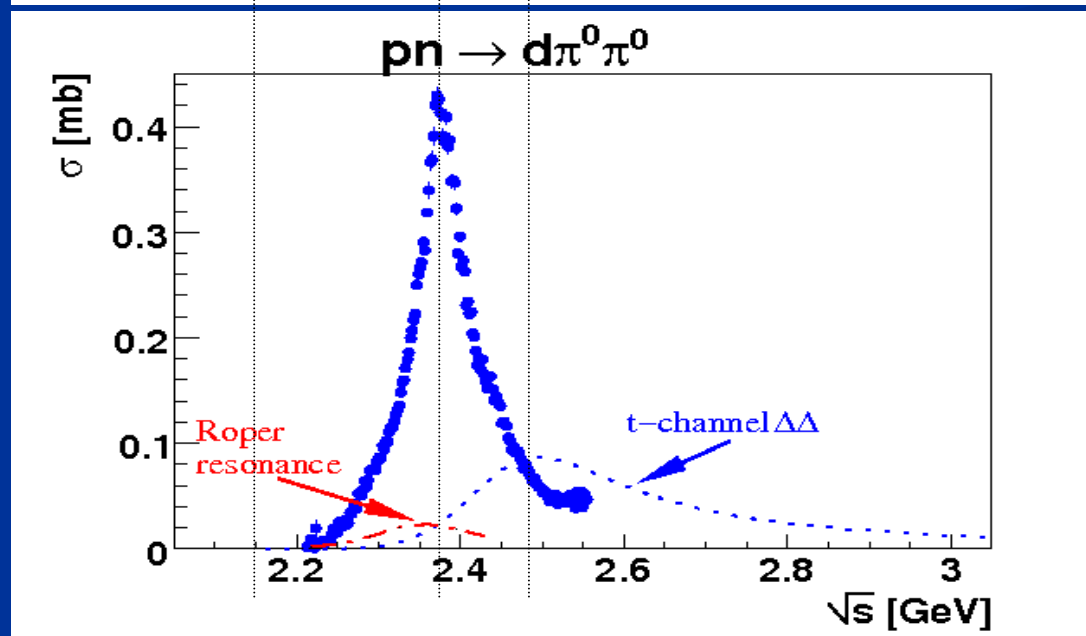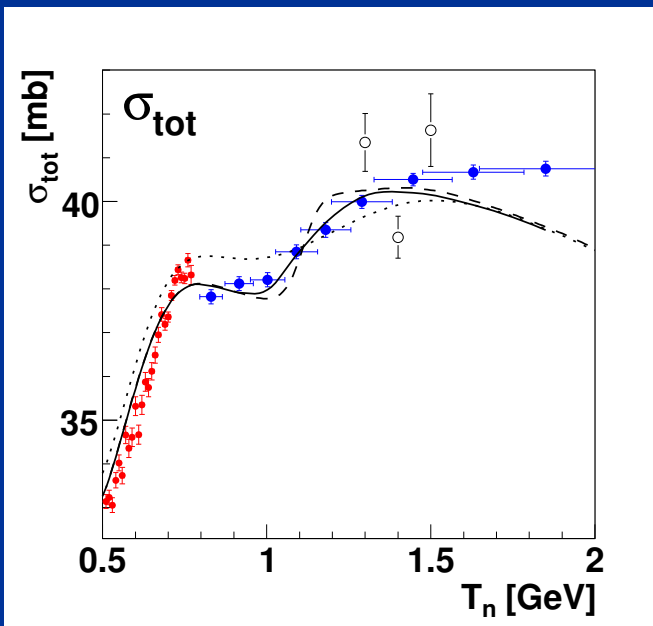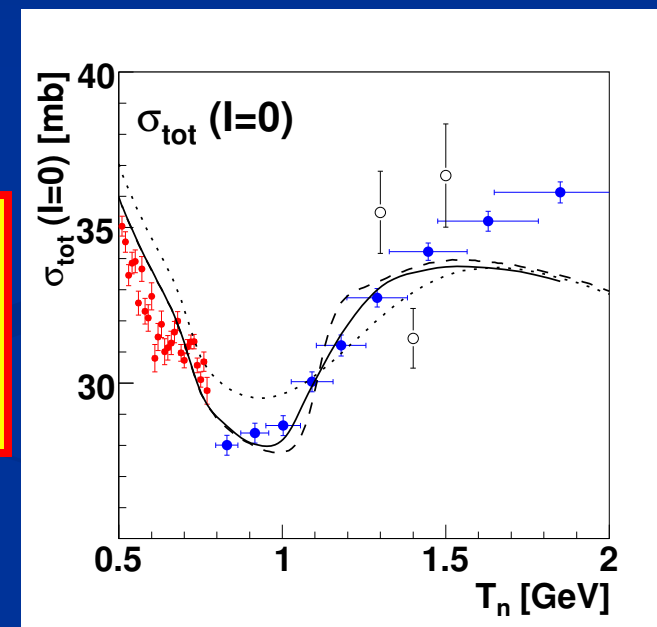
Consequences and Outlook

■ To-do list:

  ■ Search for resonance effects in

    ■ pn scattering

    ■ pn $\rightarrow$ d $\pi^+\pi^-$

    ■ pn $\rightarrow$ pn $\pi^0\pi^0$

    ■ pn $\rightarrow$ pp $\pi^0\pi^-$

  ■ Polarisation measurements

Resonance Effects in pn Scattering

- **Total cross sections**

… SAID

--- SAID +
   ABC resonance

… so what is it?