ПРЕДСКАЗАНИЯ, ПОИСК И ОБНАРУЖЕНИЕ РЕЗОНАНСА d*(2380)

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25.03.2025

- # КХД

Цветные кварки

u c t
d s b

и глюоны

g

Белые объекты:

qqq , $q\bar{q}$

Нестандартные конфигурации

gg, ggg, $q\bar{q}g$ глюболы и гибридные состояния

$q\bar{q}q\bar{q}$ $qqqq\bar{q}$ тетракварки и пентакарки

$6q$ дибарионы или гексакварки

Методы, предсказания, итоги

E. Wigner. Phys. Rev 51, 106, (1937)

Теоретические предсказания состояний **$I(J^p)=0(3^+)$**
F. J. Dyson, N-H. Xuong. Phys. Rev. Lett. 13, 815, (1964).

H.Clement, nucl-ex> arXiv:1610.0559 **On the History of Dibaryons and their Final Observation** be given by the Kronecker product of the octet with itself: $8\otimes8$. It can be decomposed into irreducible SU(3) representations $8\otimes8 = 1\oplus8\oplus8\oplus10\oplus\overline{10}\oplus27$, where the deuteron belongs to the antidecuplet - $\overline{10}$ [42]. So one should expect at least 9 other deuteron-like states with strangeness -1,-2,-3:

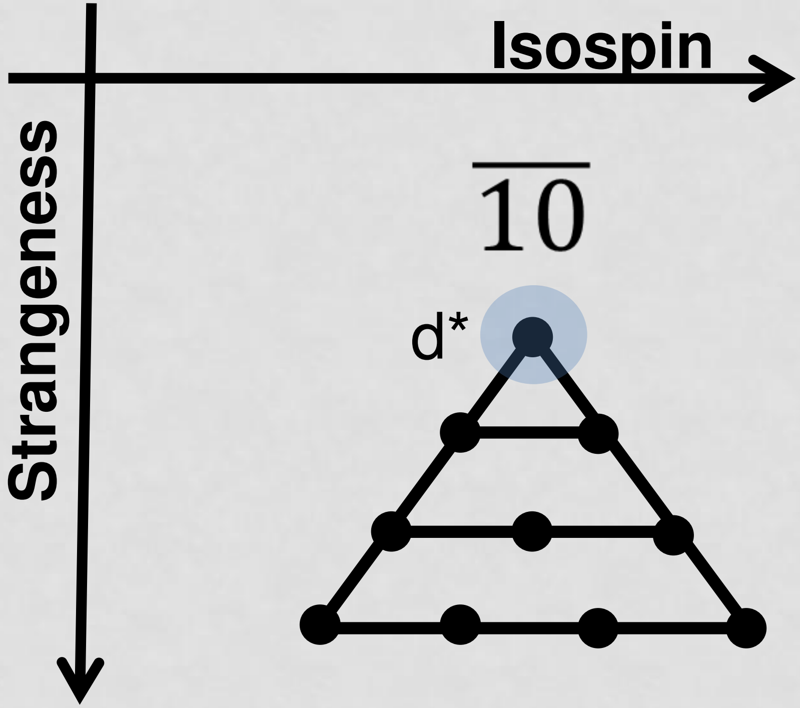
Table 1 SU(3) anti-decuplet of the B=2 states from [42]. Strangeness S=0 state is deuteron.

Strangeness	Wave Function	Multiplicity
S=0	$\frac{1}{\sqrt{2}}(pn - np)$	1
S=-1	$\frac{1}{\sqrt{12}}\left[\sqrt{3}(p\Lambda - \Lambda p) + (\Sigma^0 p - p\Sigma^0) + \sqrt{2}(\Sigma^+ n - n\Sigma^+)\right]$	2
S=-2	$\frac{1}{\sqrt{12}}\left[\sqrt{3}(\Sigma^+\Lambda - \Lambda\Sigma^+) + (\Sigma^0\Sigma^+ - \Sigma^+\Sigma^0) + \sqrt{2}(\Xi^0 p - p\Xi^0)\right]$	3
S=-3	$\frac{1}{\sqrt{2}}[(\Xi^0\Sigma^+ - \Sigma^+\Xi^0)]$	4

Due to SU(3) breaking the hyperon interaction is weaker. So despite the fact that hyper-tritium gets bound by about 100 keV, the ΛN system stays slightly unbound [43].

As one can see one may arrive at the concept of two-baryon states even without the notion of

6Q НА I-S ПЛОСКОСТИ

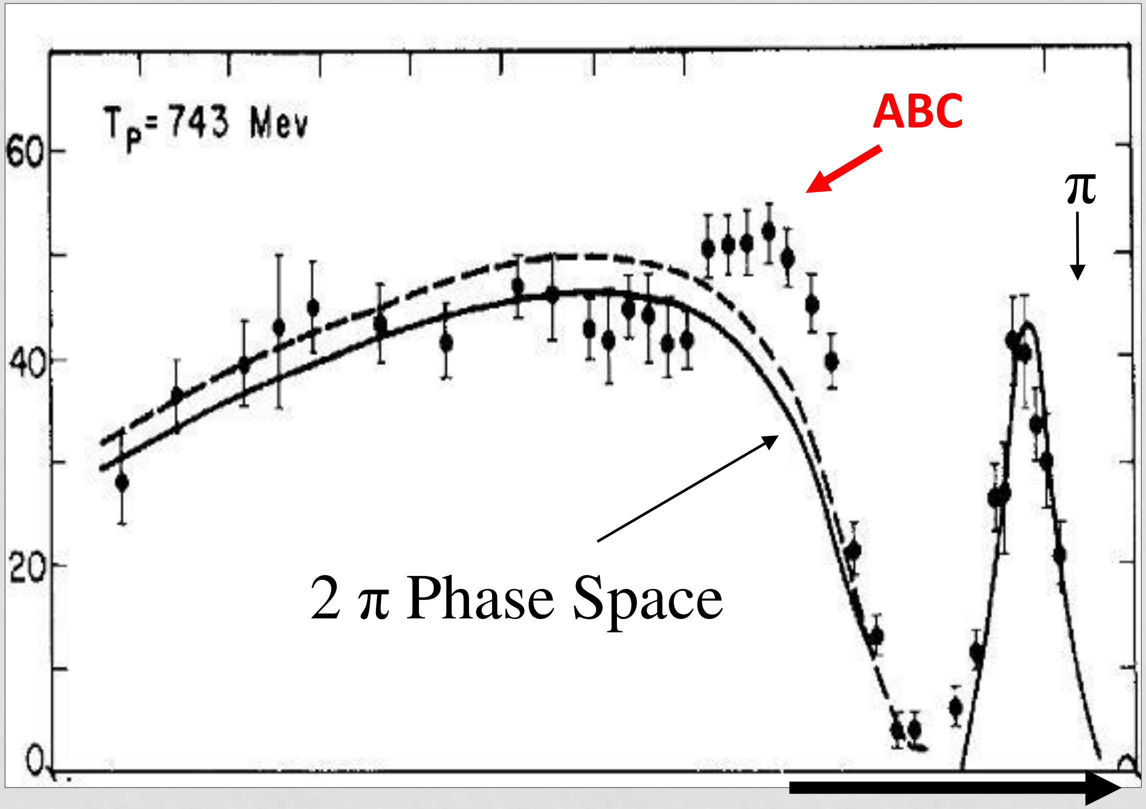


обнаружение ABC эффекта
(инклюзивный эксперимент)

$pd \to {}^3He\,X$

$T_p = 743\ MeV$

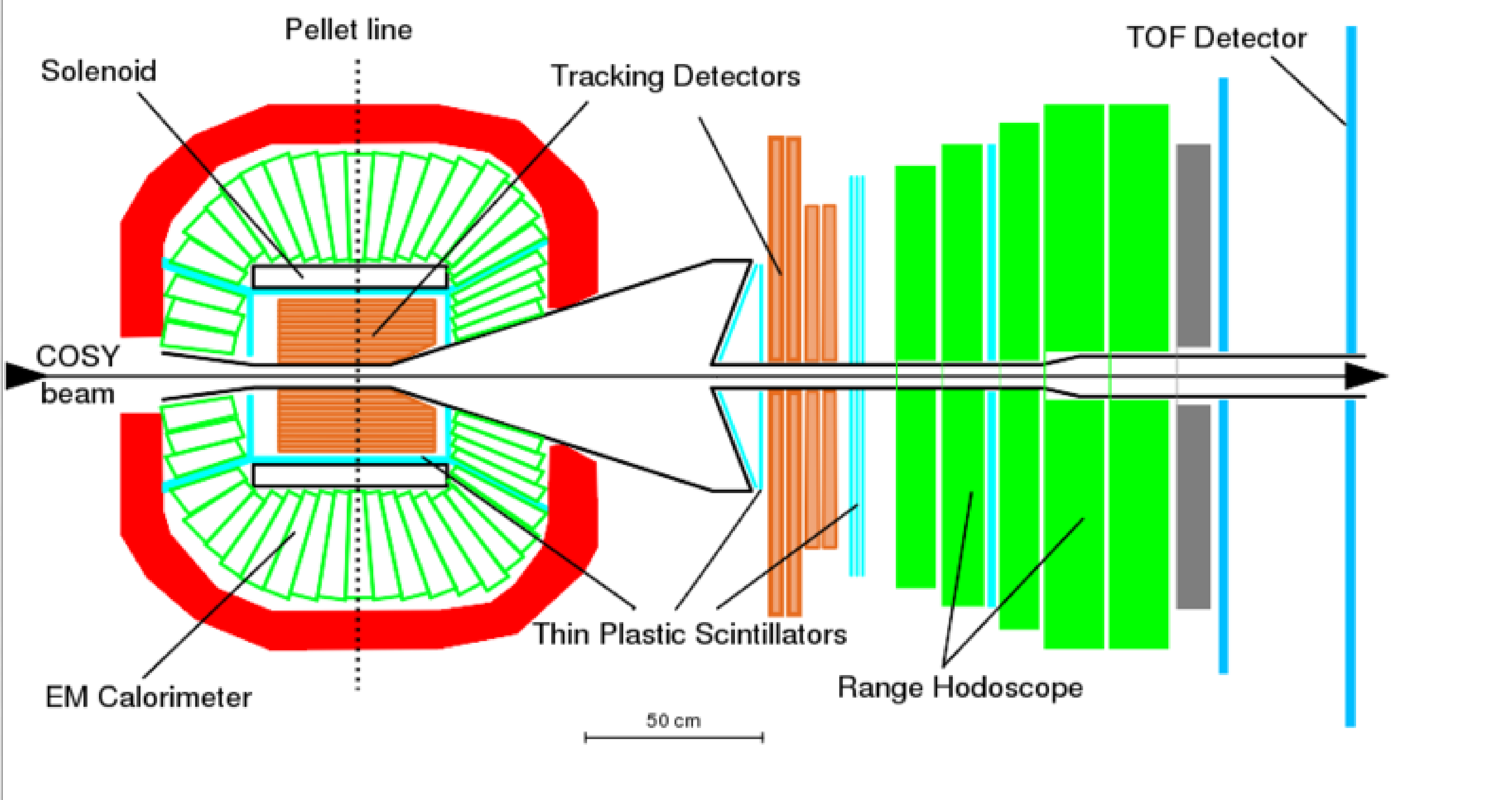
Alexander Abashian, Norman E. Booth and Kenneth M. Crowe, Phys. Rev. Lett. 5, 258 (1960)



$\Theta_{^3He} = 11.5°$

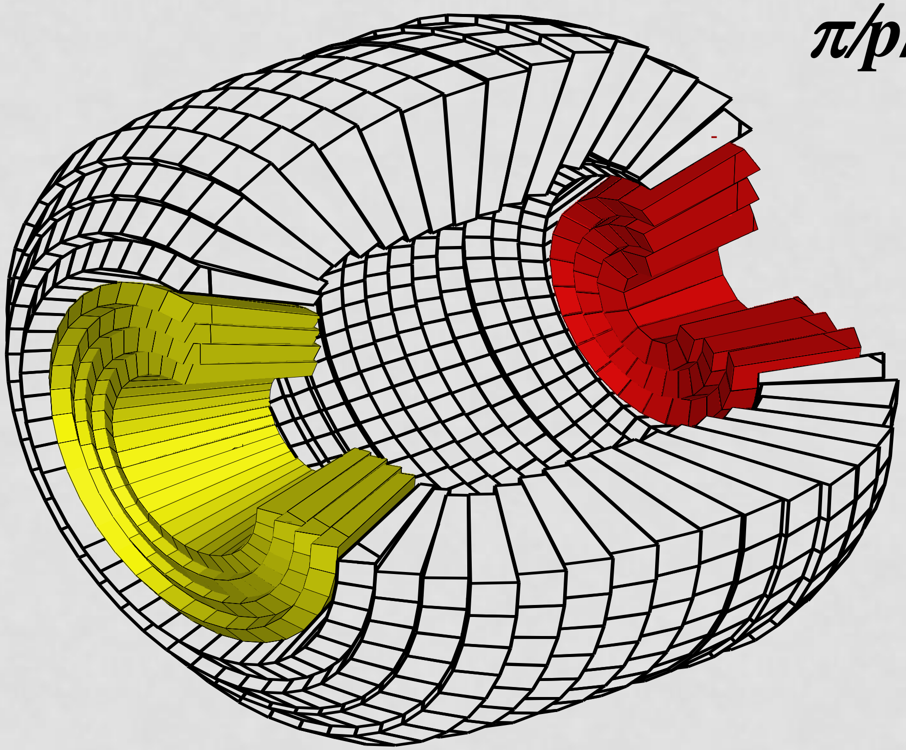
$P^{lab}_{^3He}$

WASA DETECTOR AT COSY



WASA - CsI CALORIMETER

1012 crystals



max. kin. energy for stopping

$\pi/p/d$ *190/400/500 MeV*

Energy resolution

charged particles 5%

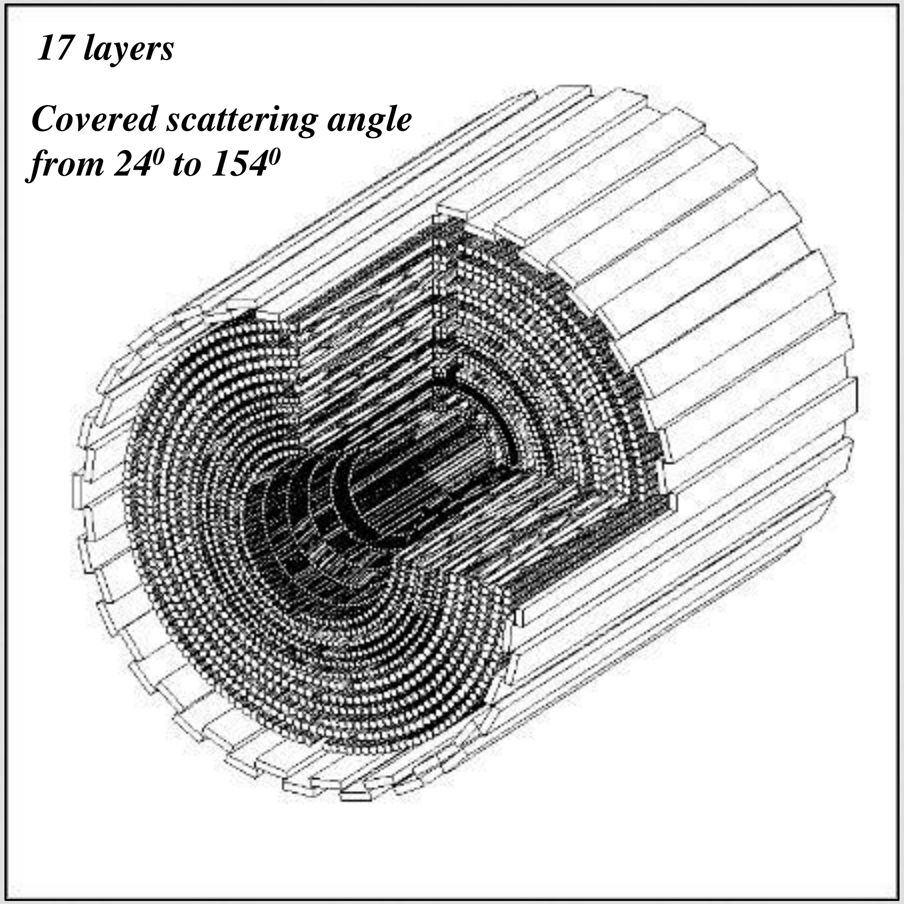
photons 8 %

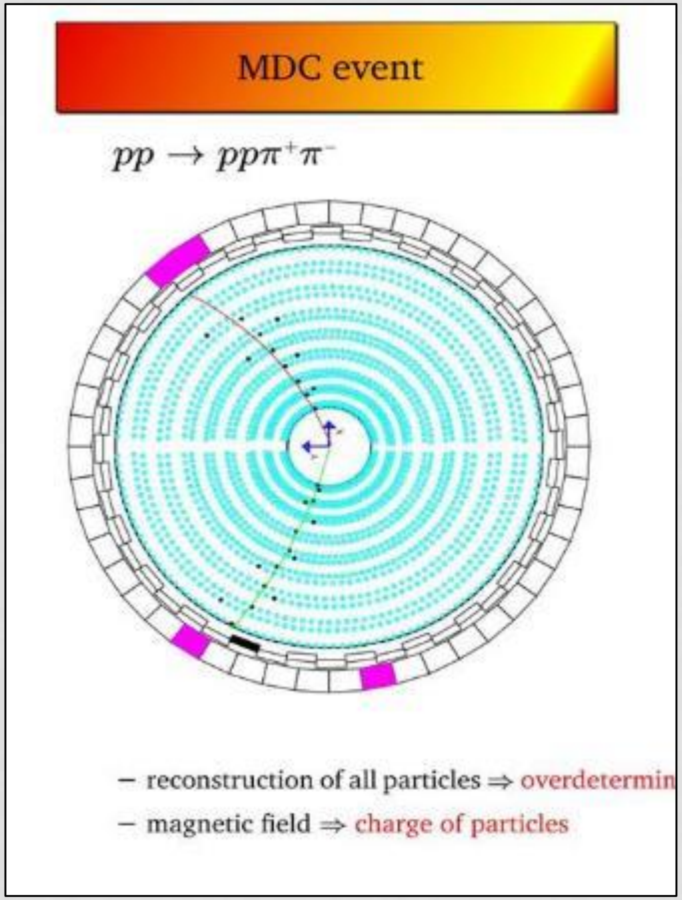
Time resolution

charged particles 5 ns

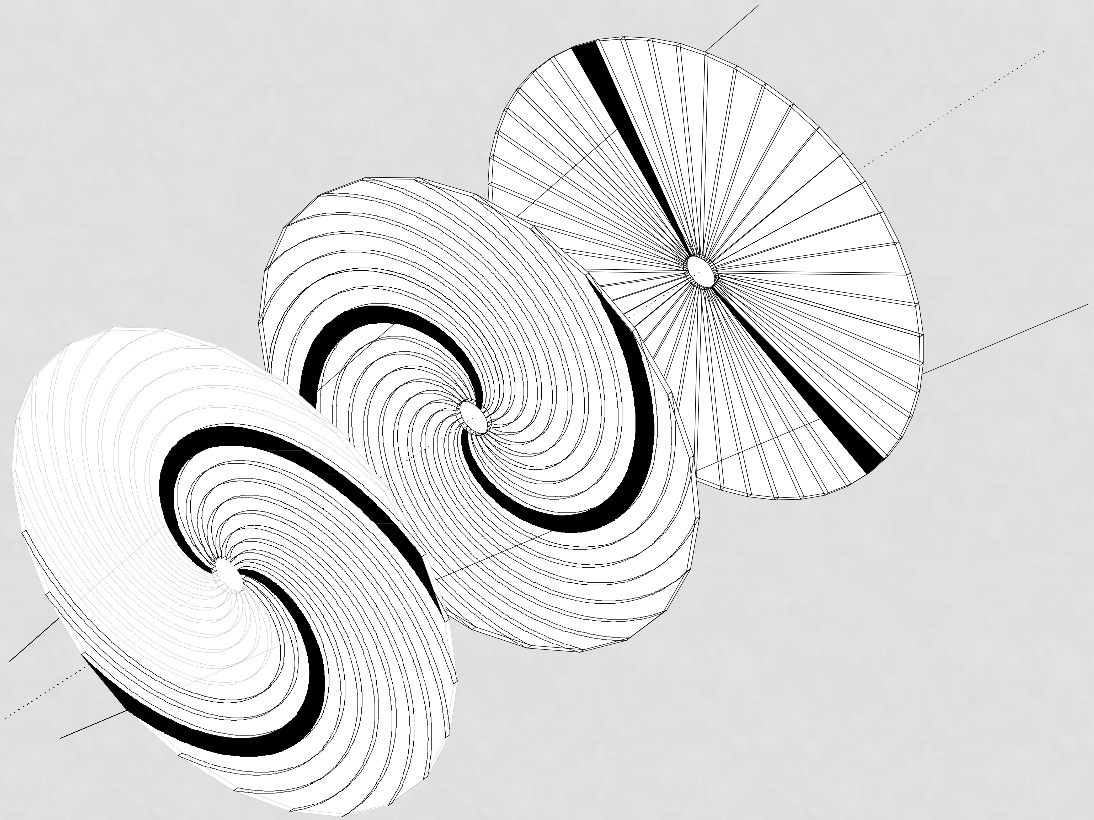
photons 40 ns

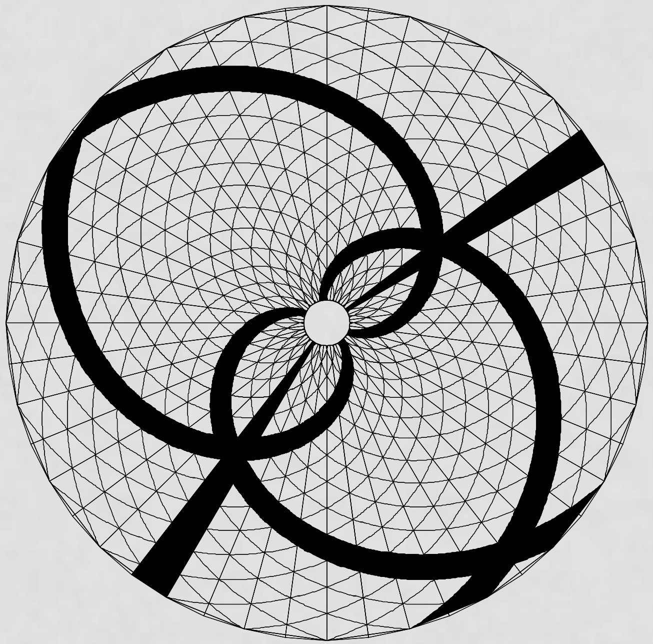
WASA - MINI DRIFT CHAMBER



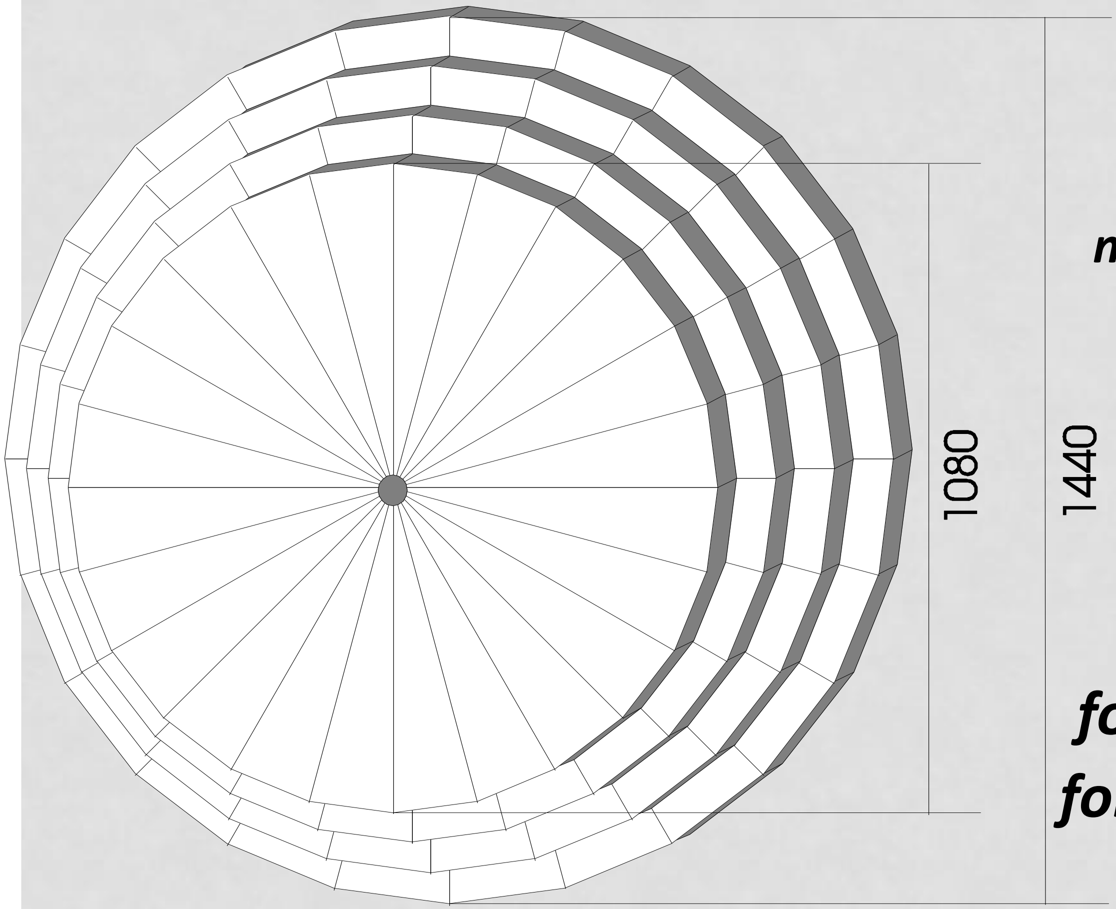


WASA - FORWARD TRIGGER HODOSCOPE





WASA - FORWARD RANGE HODOSCOPE



covered scattering angle

3 - 18^0

max. kin. energy for stopping

$\pi/p/d/\alpha$

170/300/400/900 MeV

energy resolution

for stop particles 3%

for punch through 4 – 8%

TRIGGERS

- - **the Number of charged tracks**

  in Forward Detector ≥ 2
- - **the Number of Clusters**

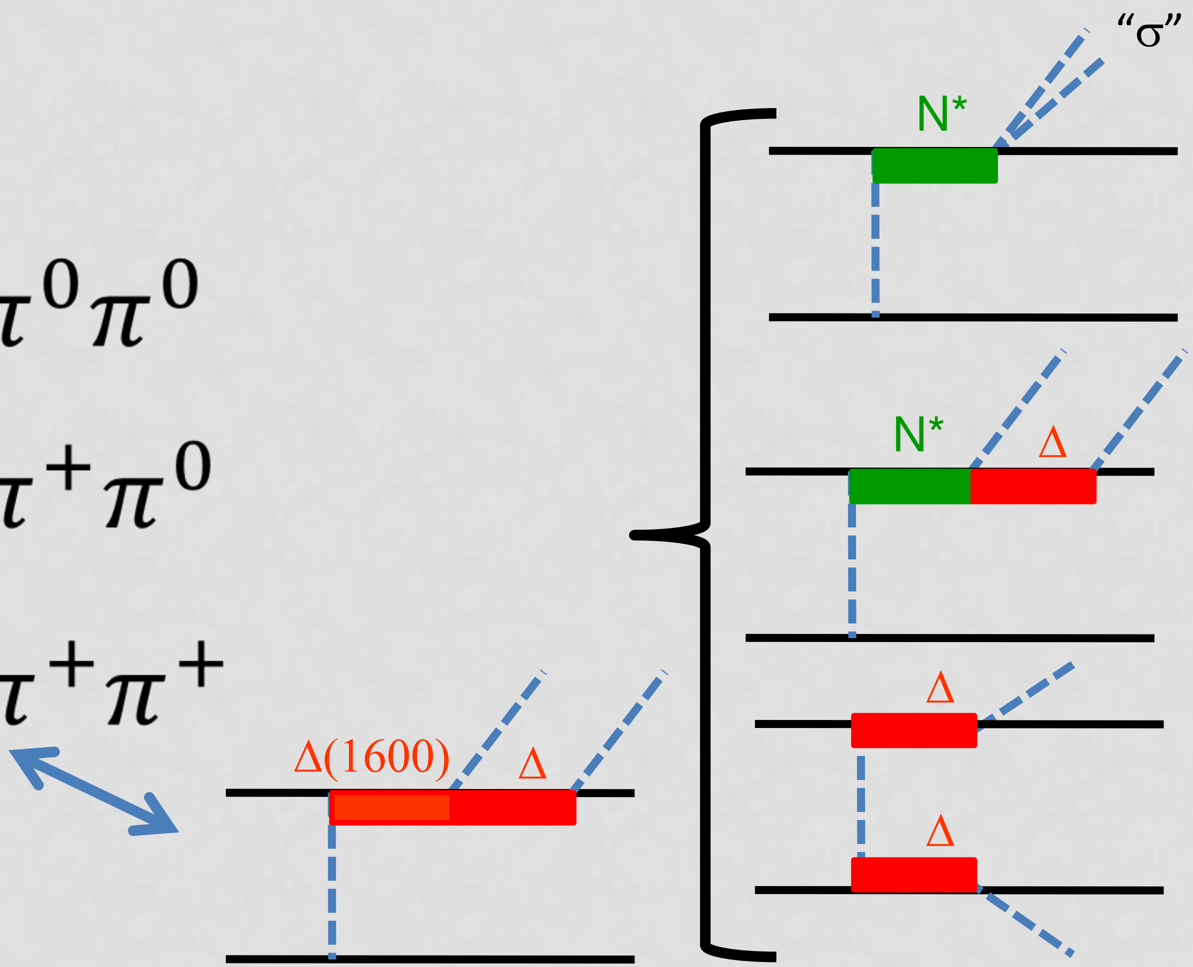
  in Central Detector ≥ 2
- - **Energy Trigger: E_{dep} ≥ threshold**

TWO-PION PRODUCTION

$pp \rightarrow pp\pi^0\pi^0$

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

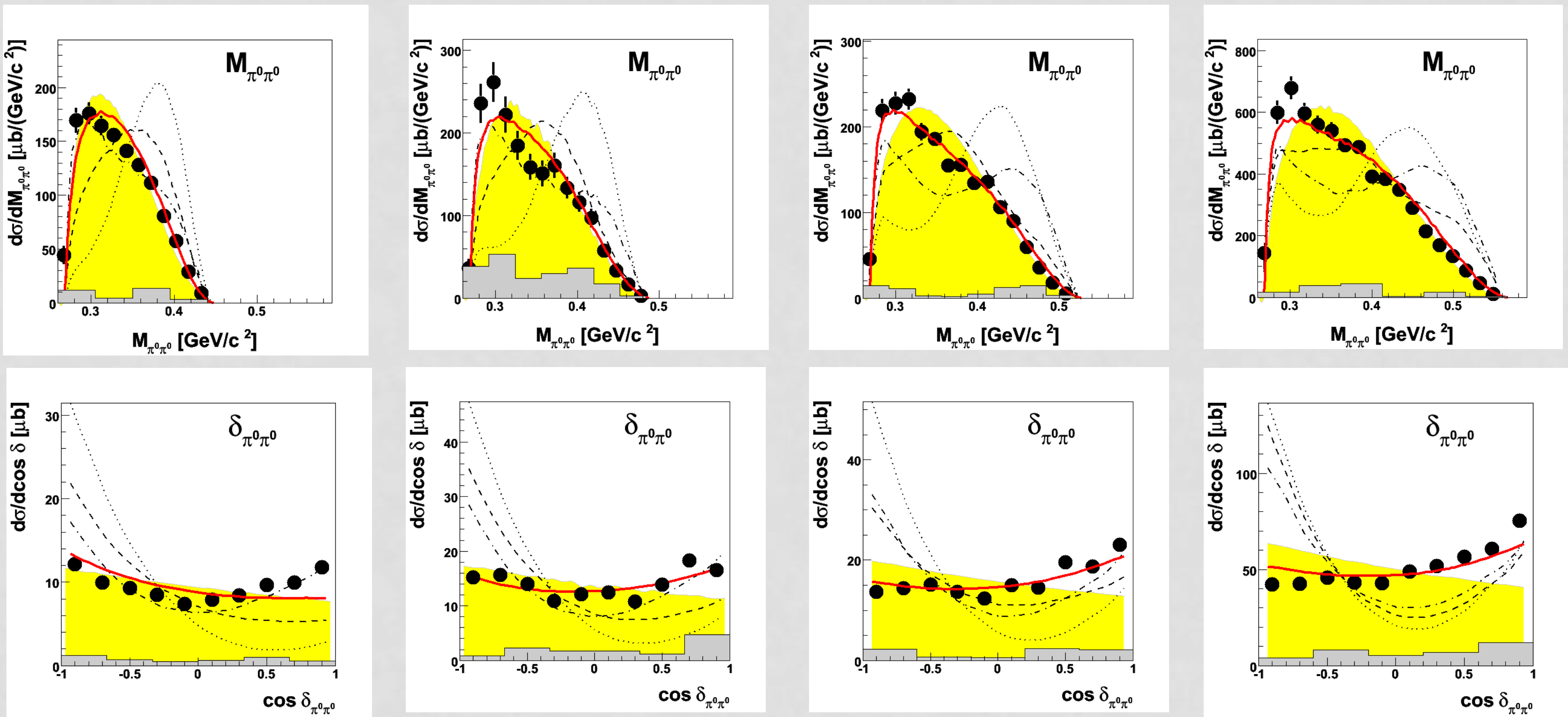
$pp \rightarrow nn\pi^+\pi^+$



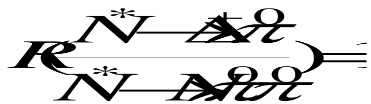
$T_p < 1.5$ GeV

$\pi^0\pi^0$ PRODUCTION at T_p > 1 GeV
pp -> pp $\pi^0\pi^0$

Tp=1.0 GeV | Tp=1.1 GeV | Tp=1.2 GeV | Tp=1.3 GeV



L. Alvarez-Ruso et al., Nucl.Phys.A633(1998)519



toy model

ρ-exchange reduced by 12 times

АВС эффект в зависимости от условий измерений

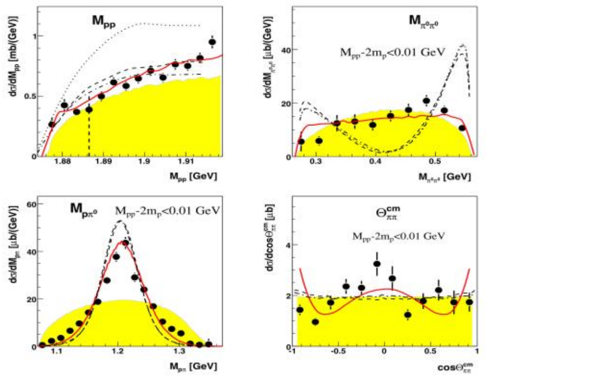


Fig. 6. Differential distributions at $T_p = 1.3$ GeV for the ^{2}He scenario. Top left: M_{pp} spectrum for the full phase space (only low-mass part shown). The distributions for $M_{\pi^0\pi^0}$ (top right), $M_{p\pi^0}$ (bottom left) and $\Theta_{\pi^0\pi^0}$ (bottom right) are plotted with the ^{2}He condition $M_{pp} < 2m_p + 10$ MeV (vertical line in the M_{pp} spectrum). The drawn lines represent calculations as described in the caption of Fig. 2 and text. The shaded areas show the phase space distributions.

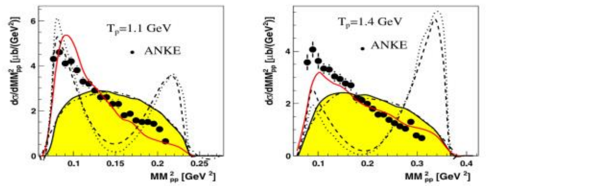


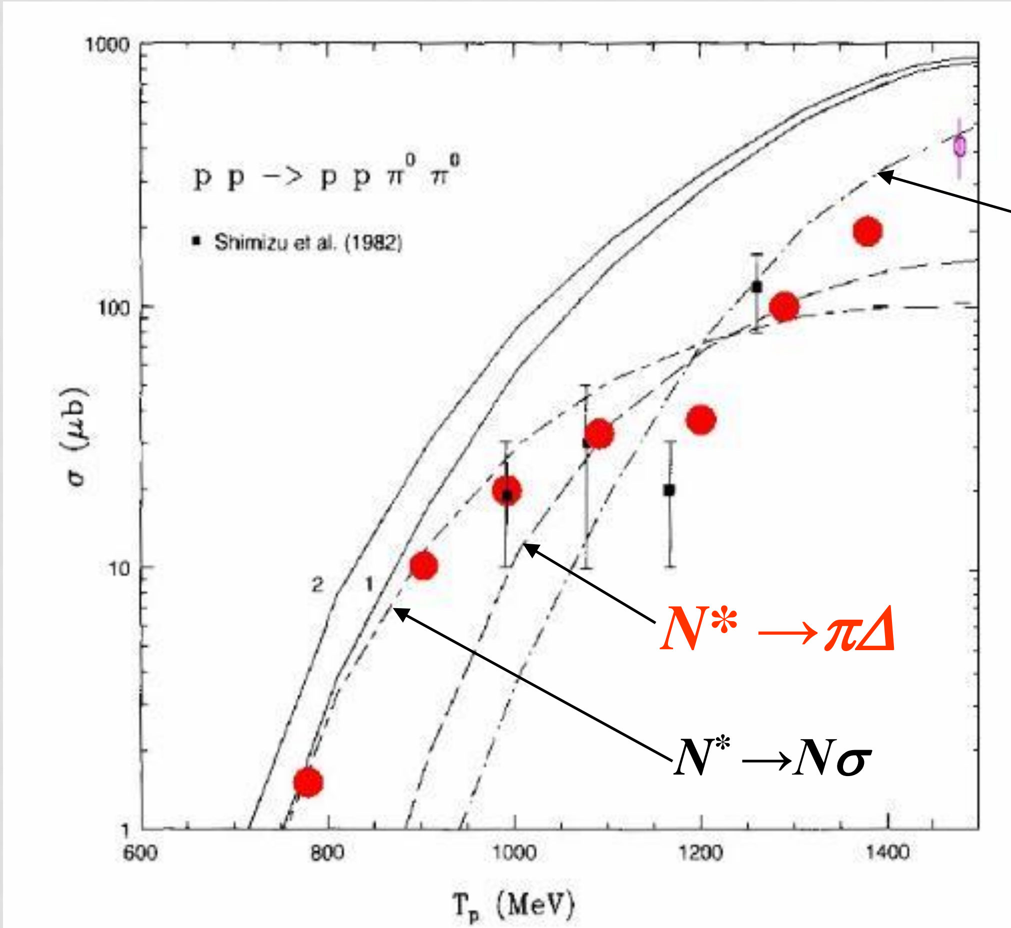
Fig. 7. $M_{\pi^0\pi^0}$ spectra at $T_p = 1.1$ and 1.4 GeV for the ^{2}He condition $M_{pp} < 2m_p + 3$ MeV and the ANKE angular constraints $\cos\Theta_{pp} > 0.95$ with $\Theta_{pp} = 180° - \Theta_{\pi^0\pi^0}$ and $\Theta_p^{lab} \leqslant 12°$. The solid dots represent the ANKE data [5] and the drawn lines calculations as described in the caption of Fig. 2 and text. The shaded areas show the phase space distributions.

We see that many of the experimental differential distributions are not far from the phase space distributions. With regard to angular distributions significant deviations from isotropy are observed only for the Θ_p and $\delta_{\pi^0\pi^0}$ distributions. The first one is largely characterized by the t-channel exchange as demonstrated in Ref. [8], whereas the latter one is strongly correlated with the $M_{\pi^0\pi^0}$ spectrum as discussed in some detail in Ref. [9]. In fact, we observe some deviations from phase space also for the $M_{\pi^0\pi^0}$ spectrum as will be discussed below. However, really large deviations from phase space are observed in spectra, which are correlated with Δ excitation: $M_{p\pi^0}$, $M_{p\pi^0\pi^0}$ and $M_{pp\pi^0}$. The peaks in all these invariant mass spectra build up increasingly with increasing energy and reflect the increasing excitation of the $\Delta\Delta$ system, the resonance maximum of which is reached at $T_p \approx 1.3$ GeV, *i.e.* the highest energy considered in this work. The M_{pp} spectrum, a sample of which is shown in part in Fig. 6, is kinematically complementary to the $M_{\pi^0\pi^0}$ spectrum.

Next we confront the data with model predictions [7] of the Valencia group and subsequent modifications of the original calculations. The dotted lines in Figs. 1–5 show the original predictions,

Полное сечение
pp -> pp $\pi^0\pi^0$ при T_p > 1 GeV

CELSIUS/WASA data



Исследование ABC эффекта в эксклюзивном эксперименте $p\,d \rightarrow d\pi\pi + p_{spect}$

leaving the other one untouched. This nucleon is called a spectator. Since nucleons inside a deuteron

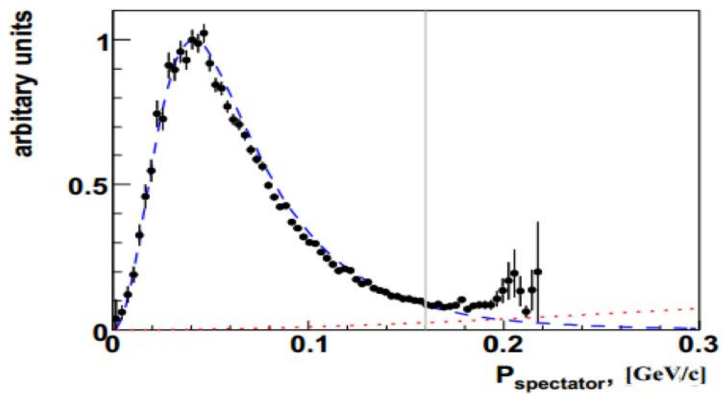


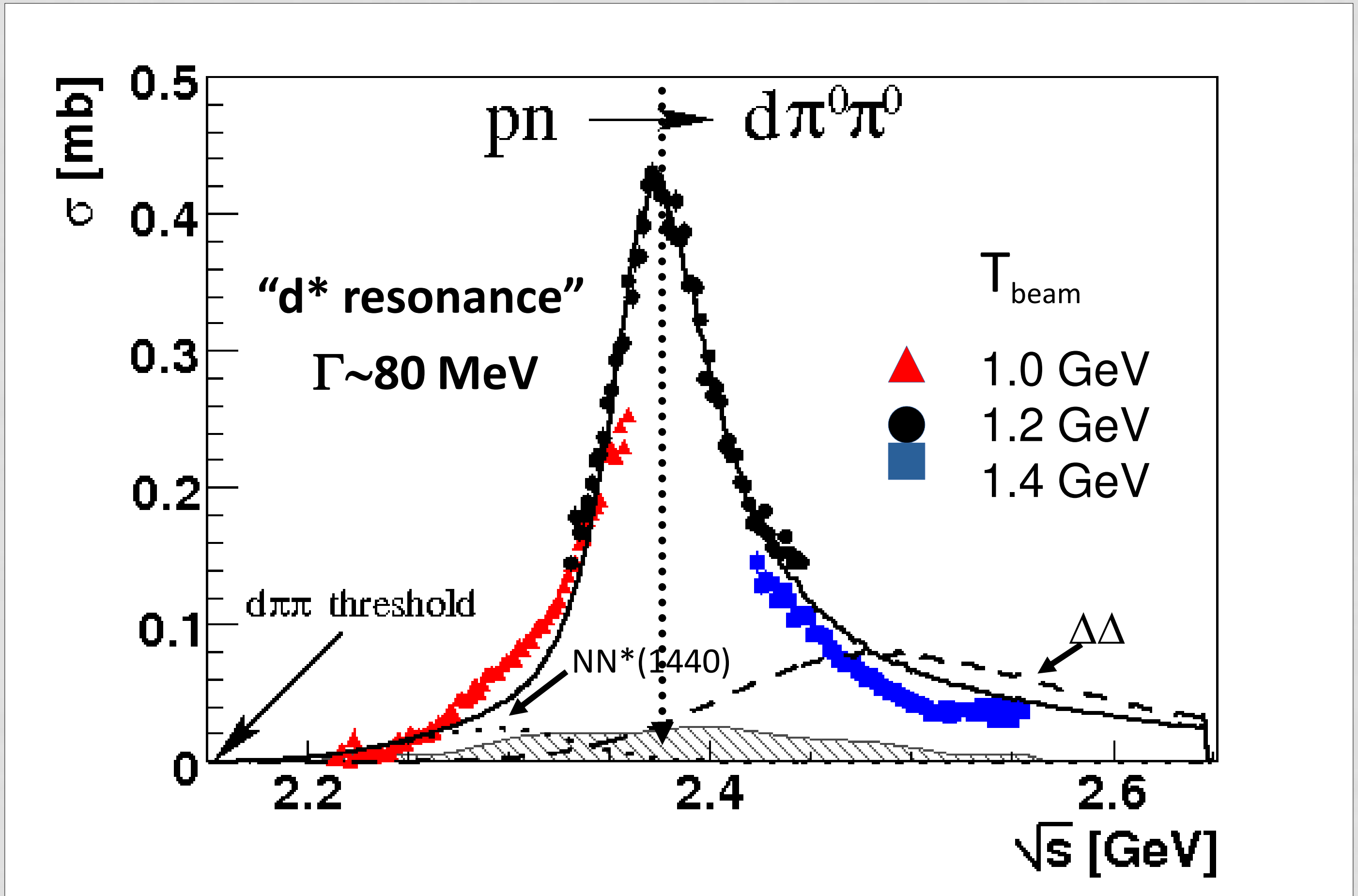
Figure 10: Distribution of the spectator proton momenta in the $pd \rightarrow d\pi^0\pi^0 + p_{spectator}$ reaction. Data are given by solid dots. The dashed line shows the expected distribution for the quasi-free process based on the CD Bonn potential [101] deuteron wave-function. For comparison the dotted line gives the pure phase-space distribution as expected for a coherent reaction process. It extends up to momenta of 1.5 GeV/c and peaks around 0.7 GeV/c. For the data analysis only events with $p_{spectator} < 0.16\ GeV/c$ (vertical line) have been used. From Ref. (25), Fig. 1.

experience Fermi motion, the momentum of the spectator nucleon is not 0, but distributed according to the deuteron wave function having a maximum probability at $p_{spec} \approx 40\ MeV/c$, see Figure 10.

Since the total momentum is conserved, the active nucleon of the target deuteron has the same

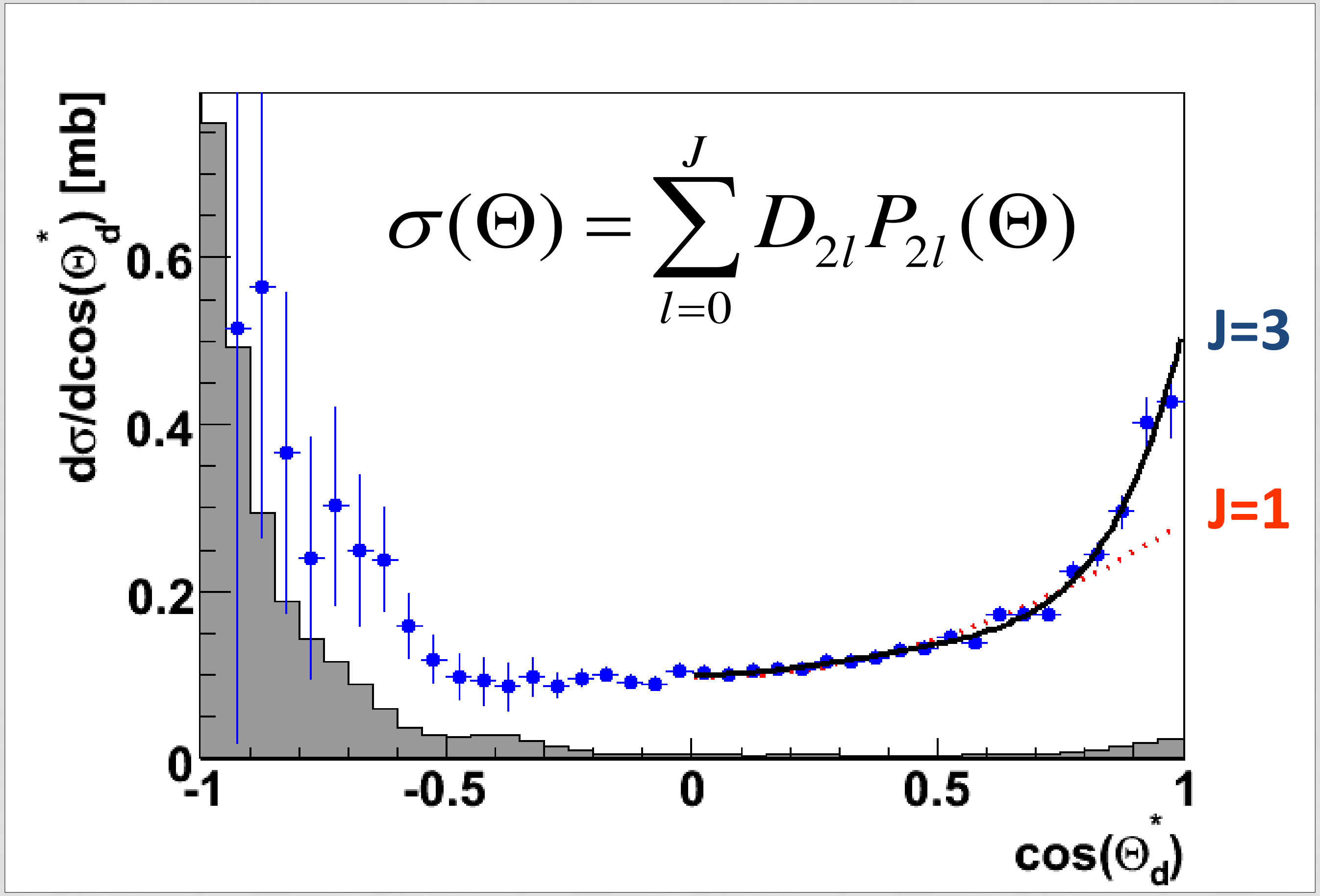
ПОЛНОЕ СЕЧЕНИЕ pn $\rightarrow d\pi^0\pi^0$

ДЛЯ 1.0, 1.2, 1.4 ГЭВ



P. Adlarson et. al
Phys. Rev. Lett.
106:242302, 2011

УГЛОВОЕ РАСПРЕДЕЛЕНИЕ d В С.Ц.М.



P. Adlarson et. al Phys. Rev. Lett. 106:242302, 2011

КВАНТОВЫЕ ЧИСЛА РЕЗОНАНСА

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

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

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

$D_0P_0 + D_2P_2$: 1^+

$D_0P_0 + D_2P_2 + D_4P_4 + D_6P_6$: 3^+

1^+ excluded.

3^+ assigned

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

pn: I=0,1

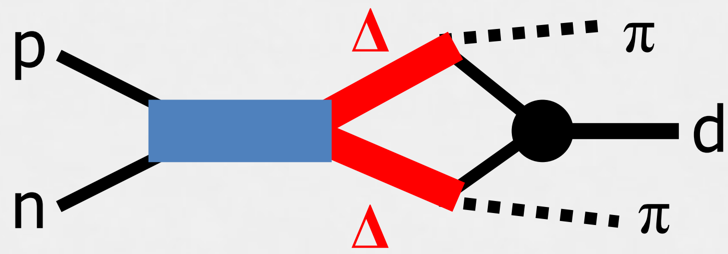
d: I=0

$\pi^0\pi^0$: I=0,2

I=0

ХАРАКТЕРИСТИКИ РЕЗОНАНСА d*(2380)

pn –> **dibaryon** → ΔΔ–> $d\pi^0\pi^0$



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

$$M_{d*} = 2380 \pm 10 МэВ \approx 2M_{\Delta} - 90 МэВ$$

$$\Gamma_{d*} = 80 \pm 10 МэВ << \Gamma_{\Delta\Delta} \approx 240 МэВ$$

ABC ЭФФЕКТ В РЕАКЦИЯХ

$$pd \rightarrow d\pi^0\pi^0 + p_{spect}$$

$$pd \rightarrow d\pi^+\pi^0 + n_{spect}$$

$$pd \rightarrow d\pi^+\pi^- + p_{spect}$$

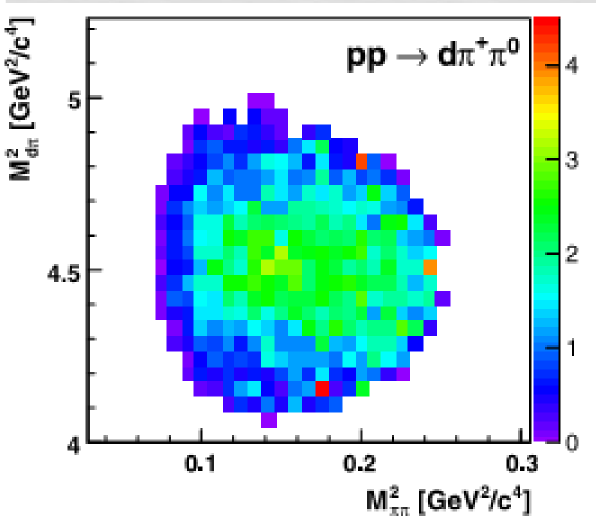
P. Adlarson et. al Phys.Lett. B721 (2013) 229-236

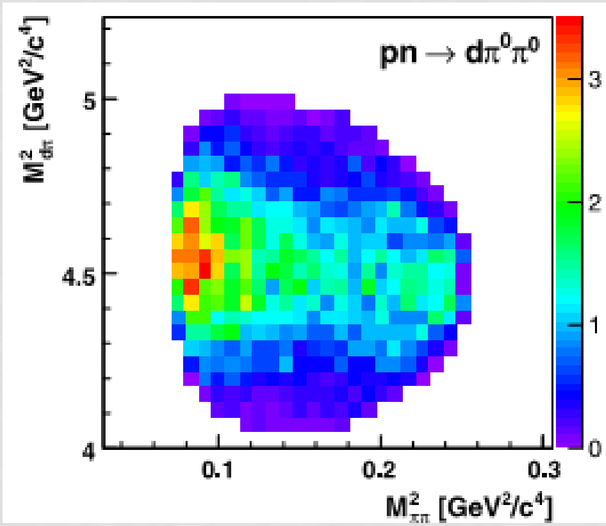
ДИАГРАММЫ ДАЛИЦА

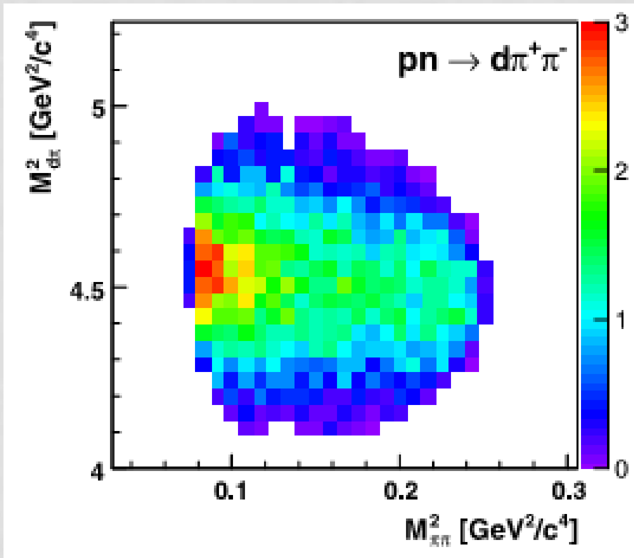
$(M_{d\pi})^2$ VS $(M_{\pi\pi})^2$ for pN -> $d\pi\pi$

$$\sqrt{s} = 2.37 GeV$$

$$pp \to d\pi^+\pi^0 \quad pn \to d\pi^0\pi^0 \quad pn \to d\pi^+\pi^-$$



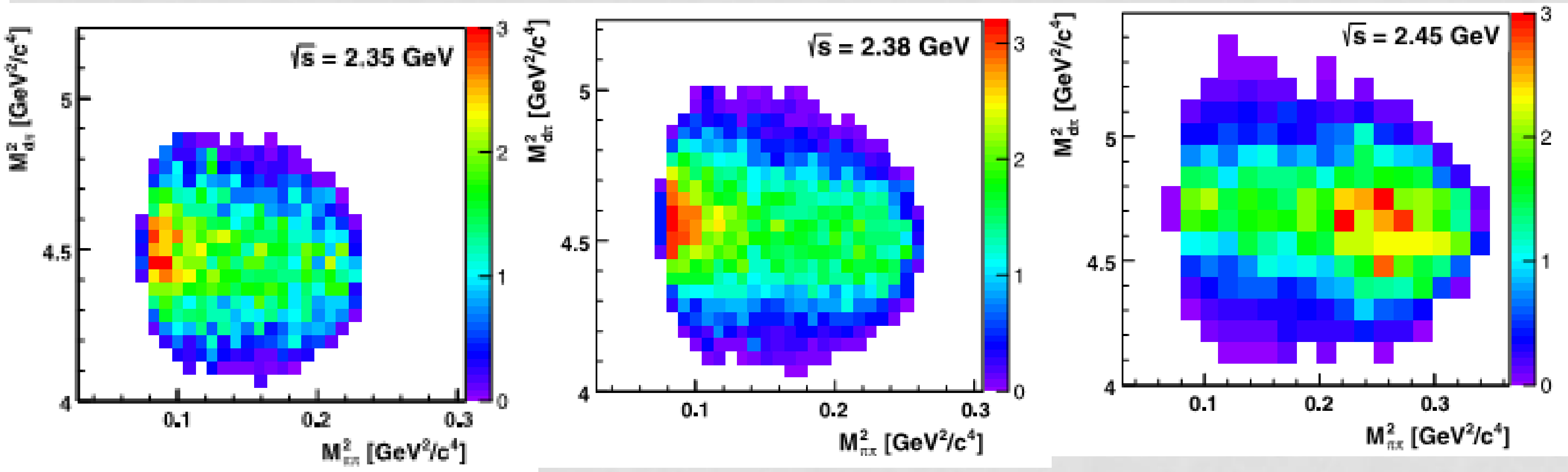




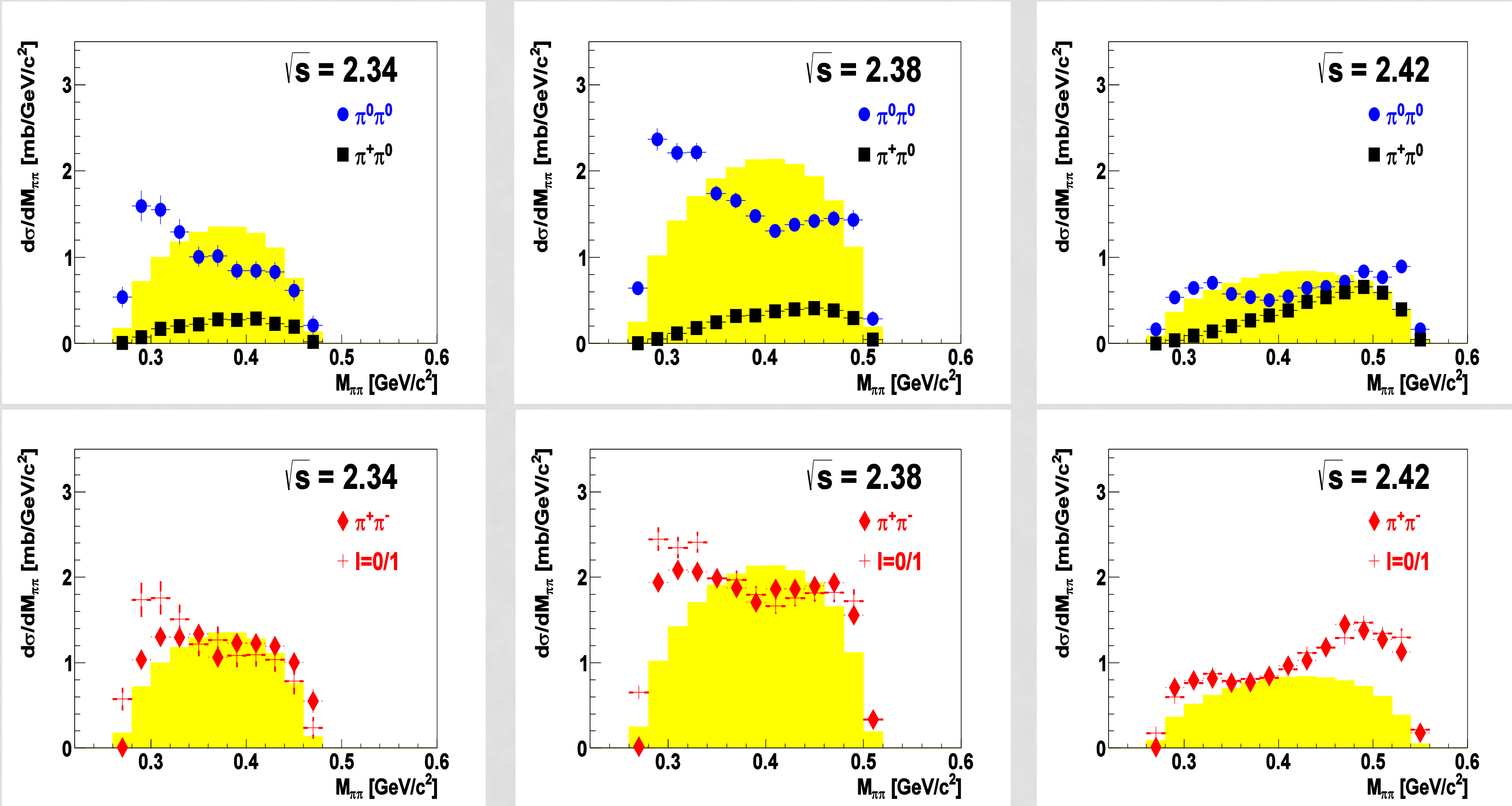
ДИАГРАММЫ ДАЛИЦА

$(M_{d\pi})^2$ VS $(M_{\pi\pi})^2$ for pn –> $d\pi^0\pi^0$

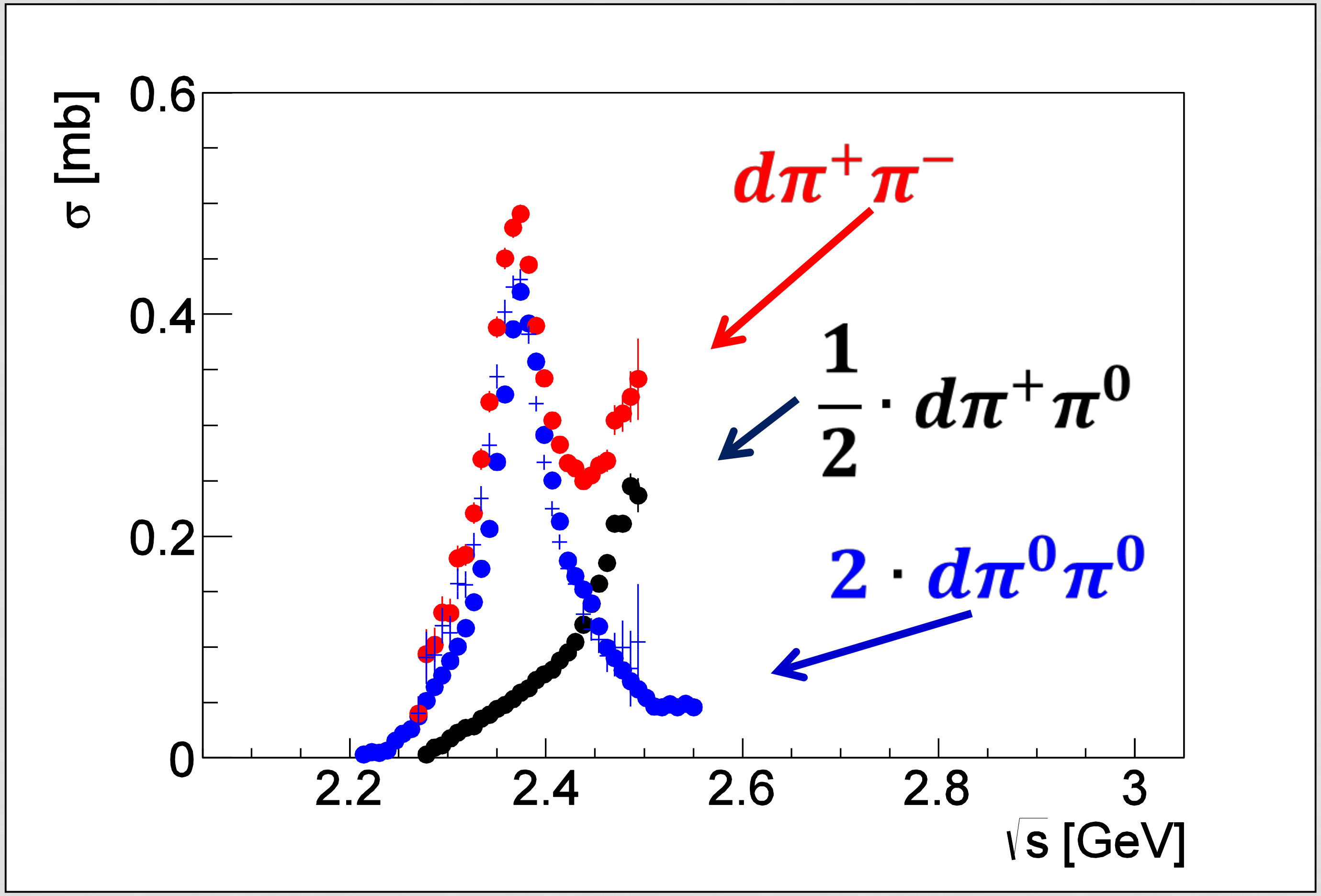
E



ABC-effect in $M_{\pi\pi}$ FOR pN-> $d\pi\pi$



ПОЛНЫЕ СЕЧЕНИЯ pN-> dππ



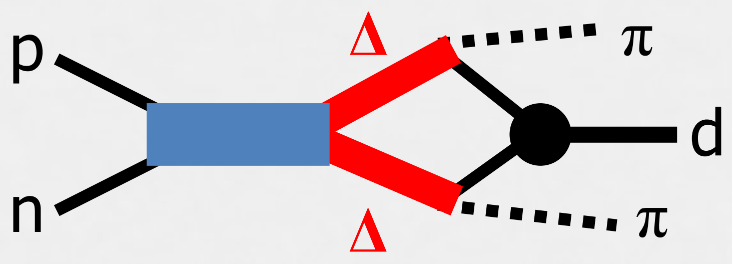
P. Adlarson et. al Phys. Lett. B721 (2013) 229

СООТНОШЕНИЕ ИЗОСПИНОВ

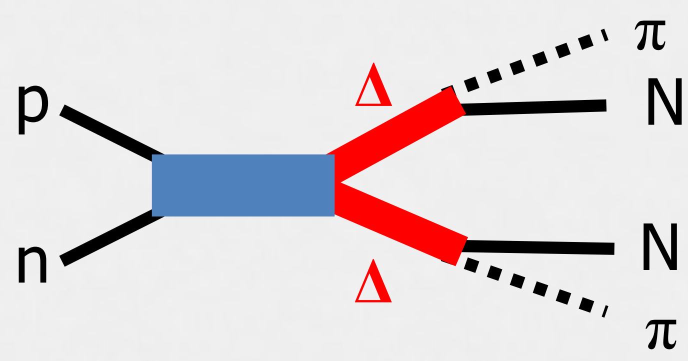
$$\sigma[pn \to d\pi^+\pi^-] = \overbrace{\frac{1}{2}\sigma[pp \to d\pi^+\pi^0]}^{I=1} \underbrace{+2\sigma[pn \to d\pi^0\pi^0]}_{I=0}$$

ПЕРЕХОД К НЕСВЯЗАННОМУ КОНЕЧНОМУ СОСТОЯНИЮ

$pn \to d^* \to \Delta\Delta \to d\pi\pi$



$pn \to d^* \to \Delta\Delta \to NN\pi\pi$

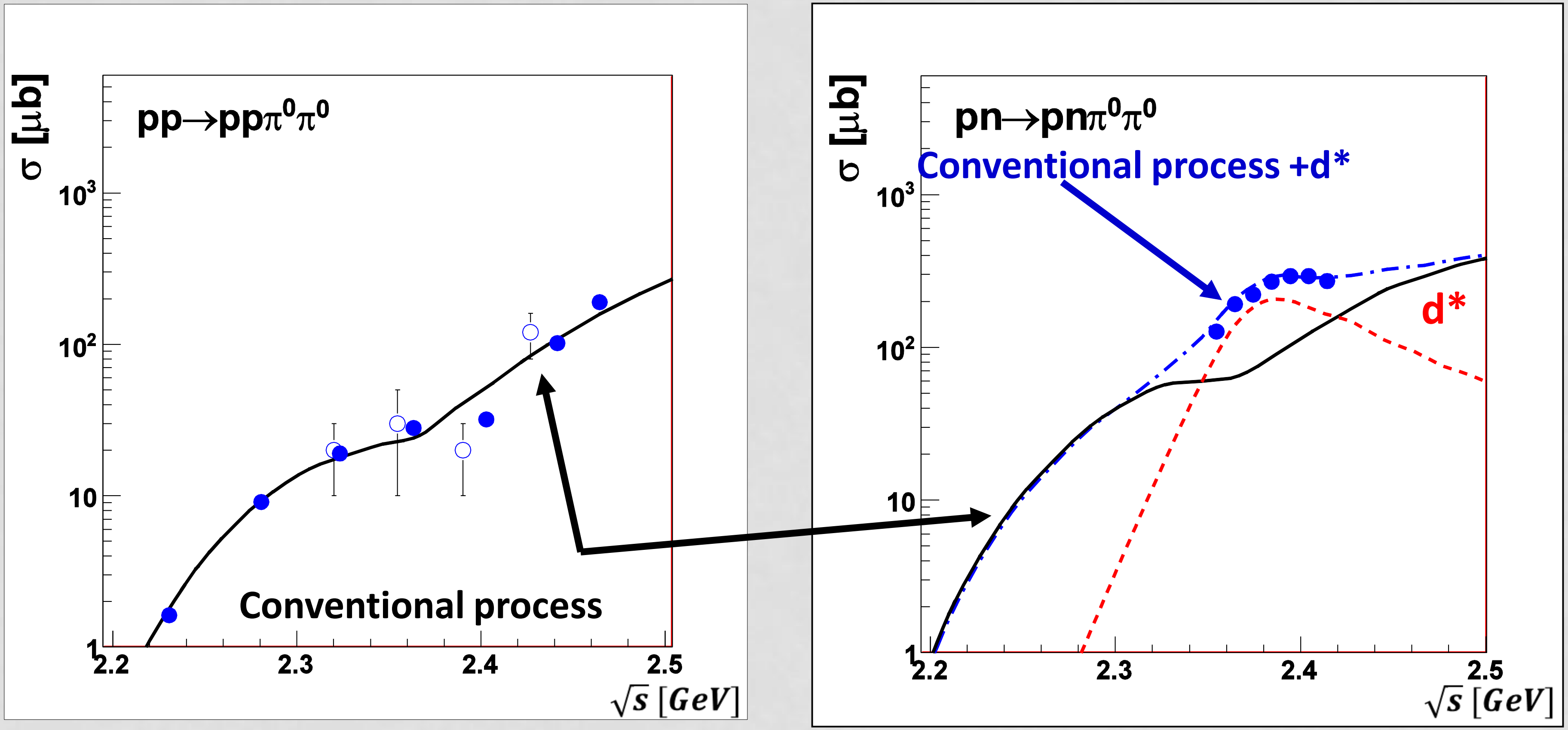


Есть ли проявдения d* в сечениях этих процессов?

Fäldt & Wilkin, PLB 701 (2011) 619

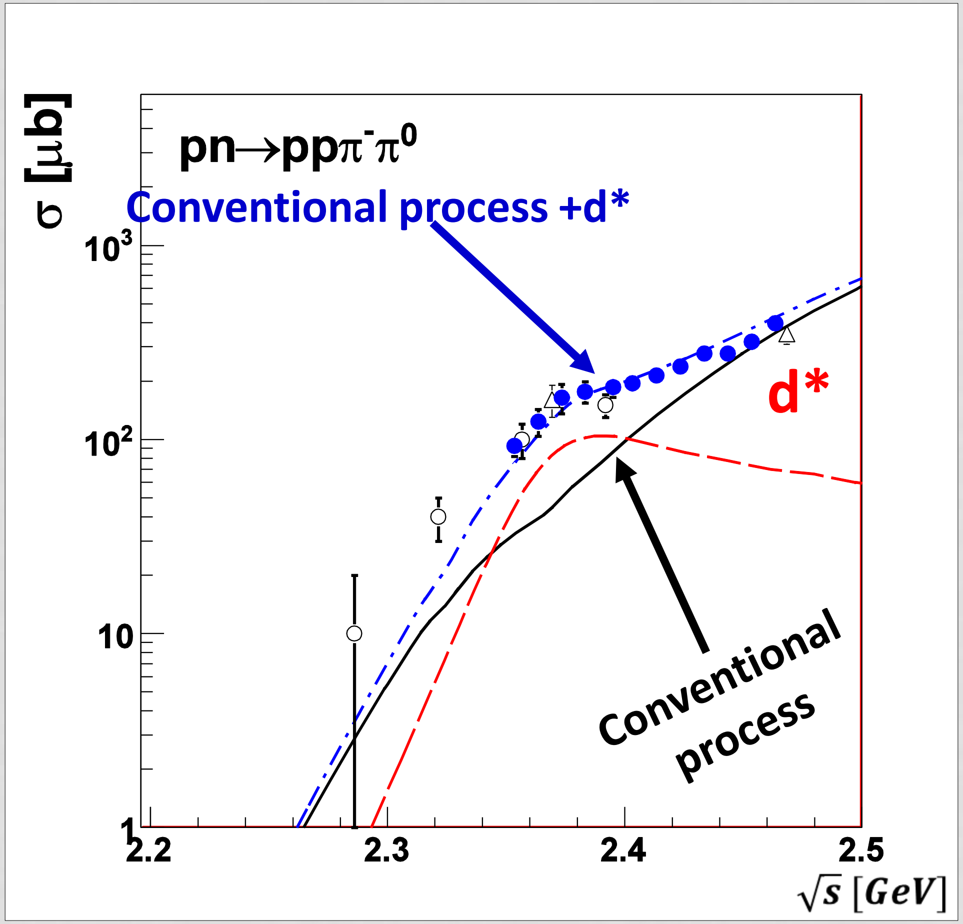
Albaladejo & Oset, Phys.Rev. C88 (2013) 014006

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



P. Adlarson et al., arXiv:1409.2659

pn → ppπ⁻π⁰



P. Adlarson et al., Phys. Rev. C 88, 055208 (2013)

ABC ЭФФЕКТ В РЕАКЦИЯХ

$$pd \to {}^3He\pi^0\pi^0(\pi^+\pi^-)$$

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

pd→^{3}Heππ, T_P=0.890 GeV

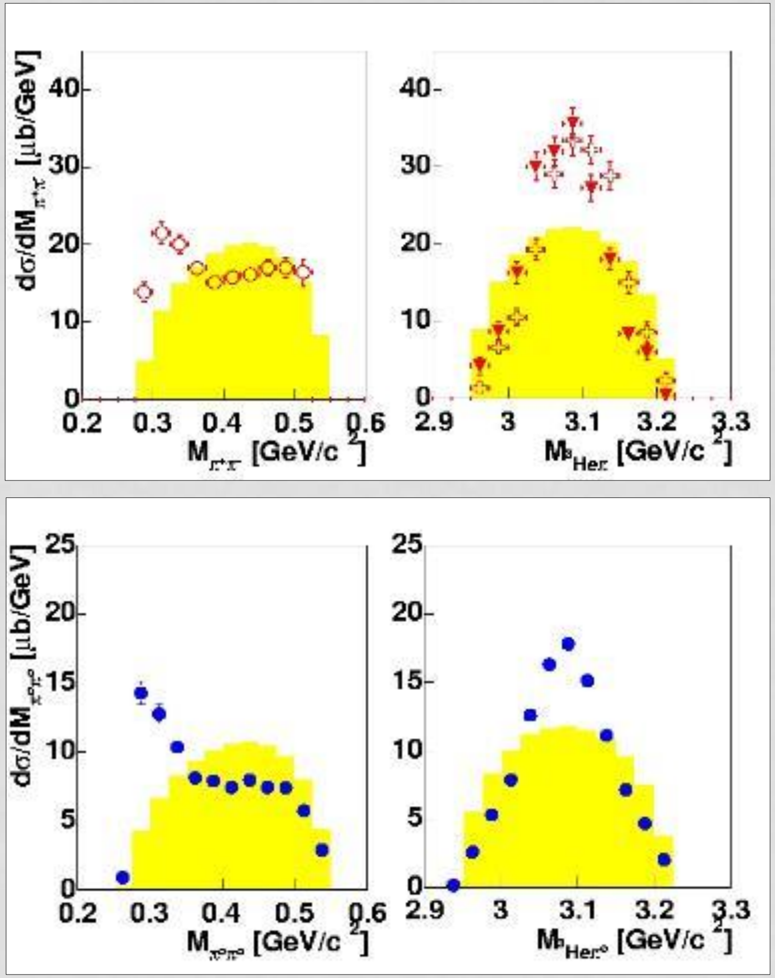
$^3He\pi^+$

$^3He\pi^-$

$M_{\pi\pi}$ $M_{^3He\pi}$

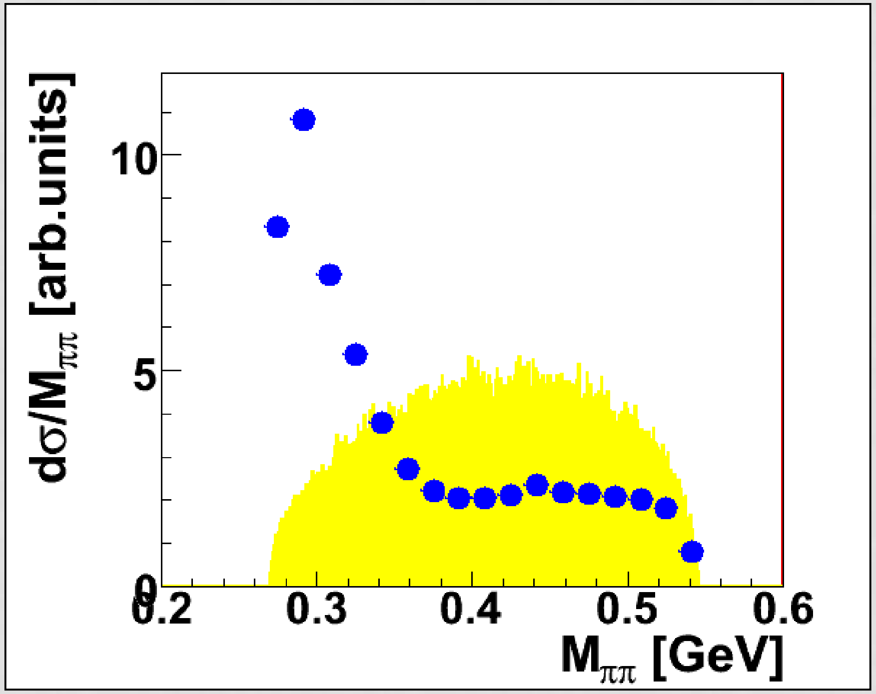
$\pi^+\pi^-$ $(I=0,1)$

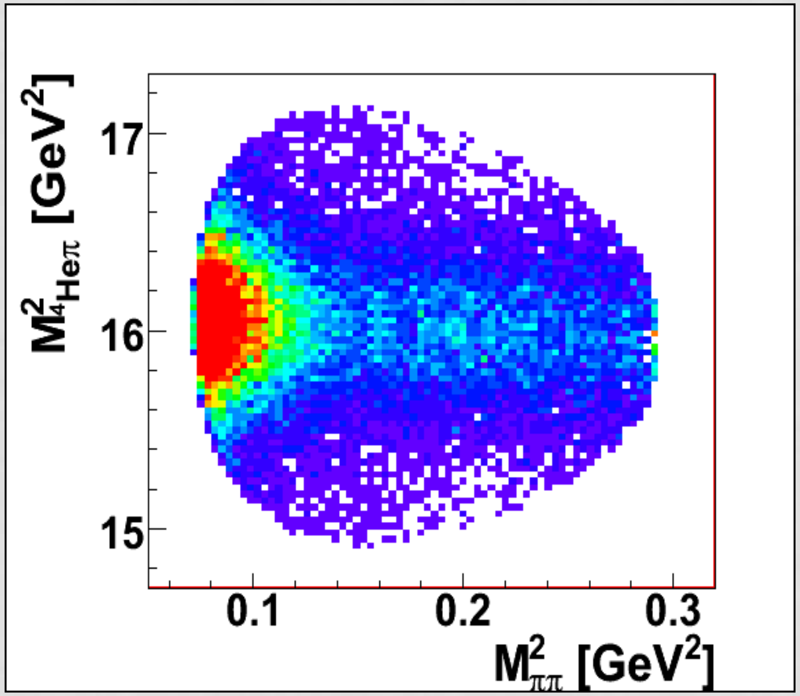
$\pi^0\pi^0$ $(I=0)$



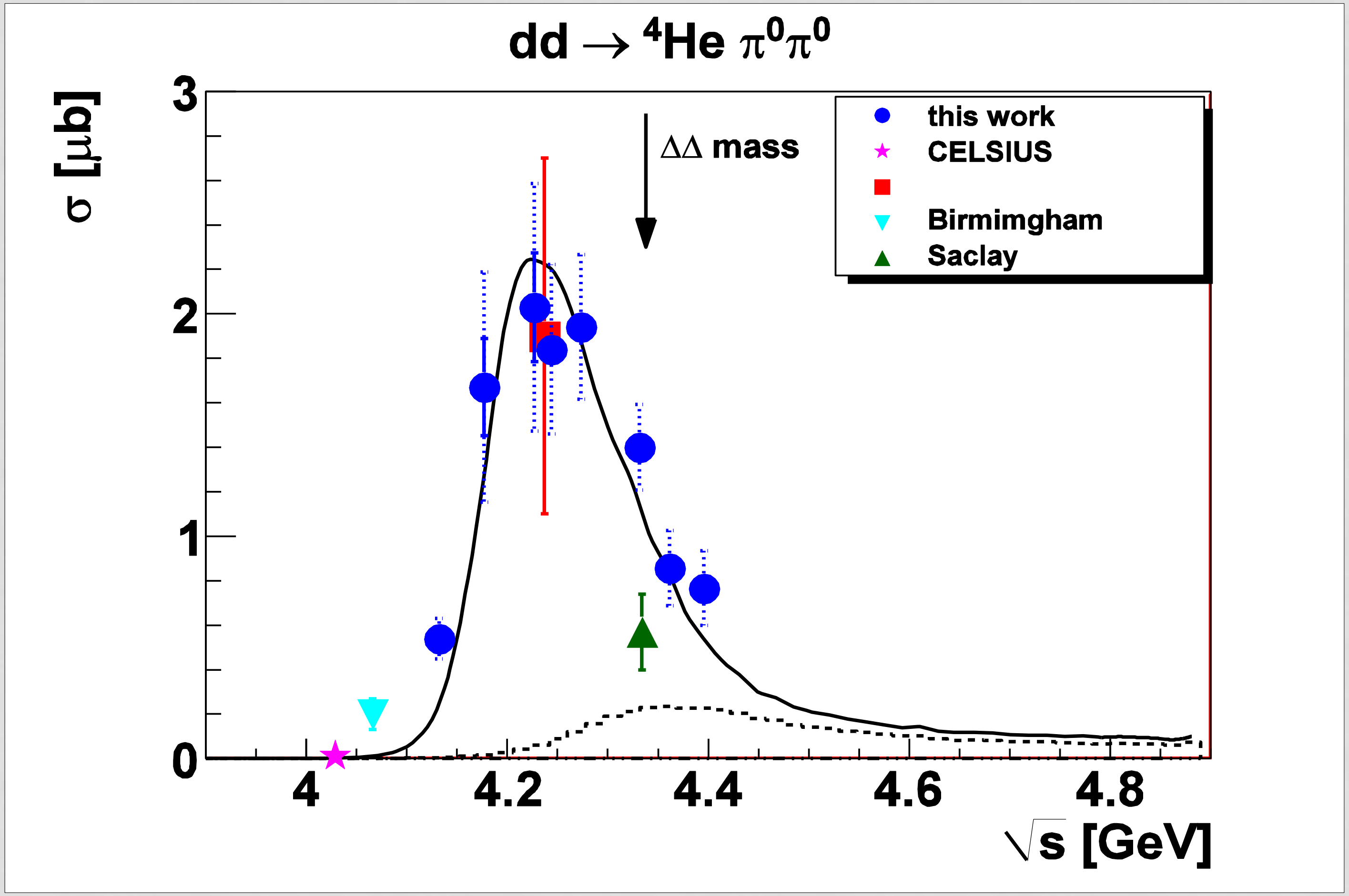
*M.Bashkanov et. al, Phys. Lett. **B637** (2006) 223-228*

$dd \rightarrow {}^4He\pi^0\pi^0$ Td=1.117 GeV

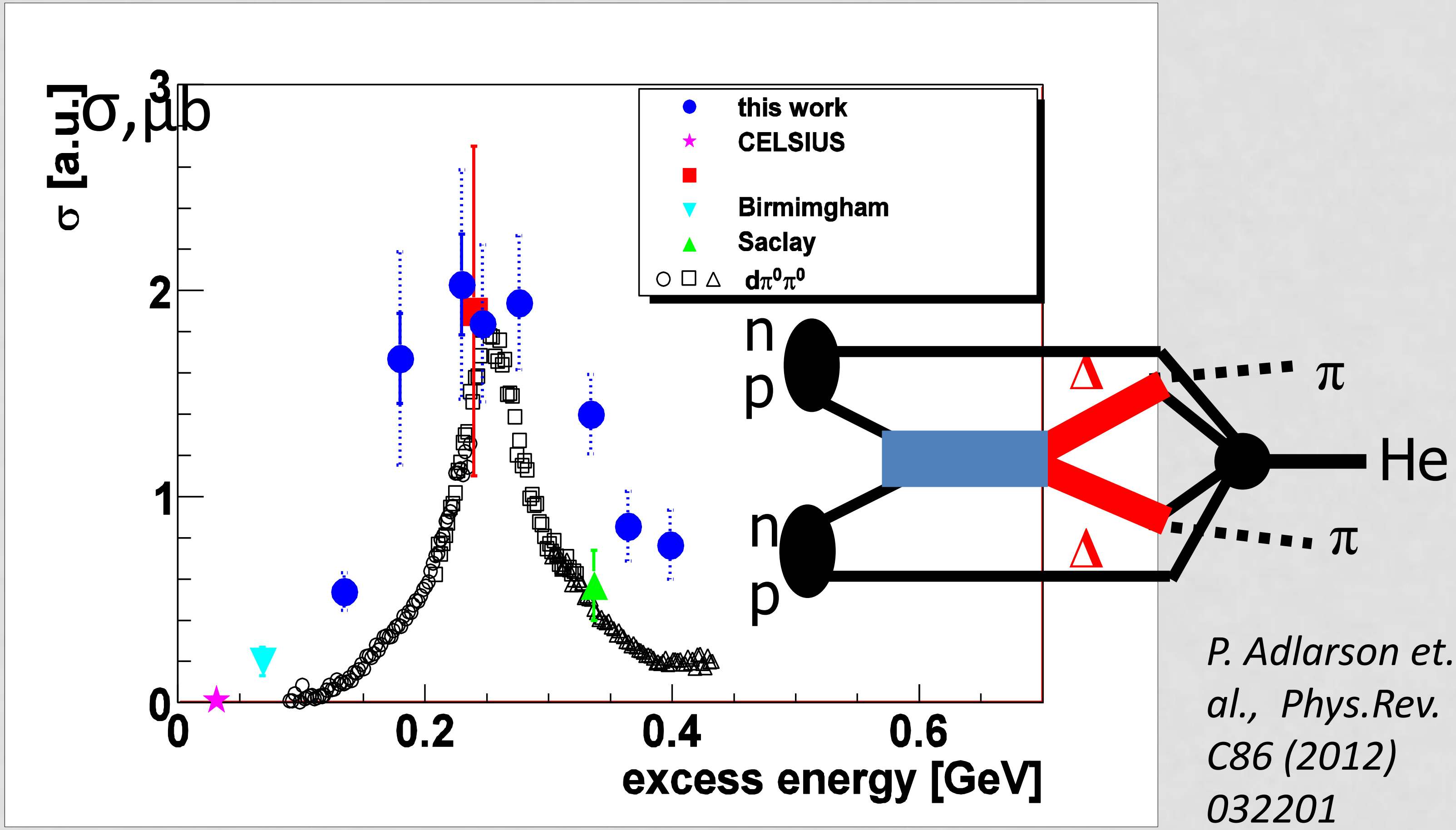




TOTAL CROSS SECTION dd $\rightarrow$ ^{4}He$\pi^0\pi^0$



TOTAL CROSS SECTION dd $\rightarrow$ $^4He\pi^0\pi^0$



P. Adlarson et. al., Phys.Rev. C86 (2012) 032201

КАНАЛЫ ABC ЭФФЕКТА

$$pn \to d\pi^0\pi^0 \,/\, d\pi^+\pi^-$$

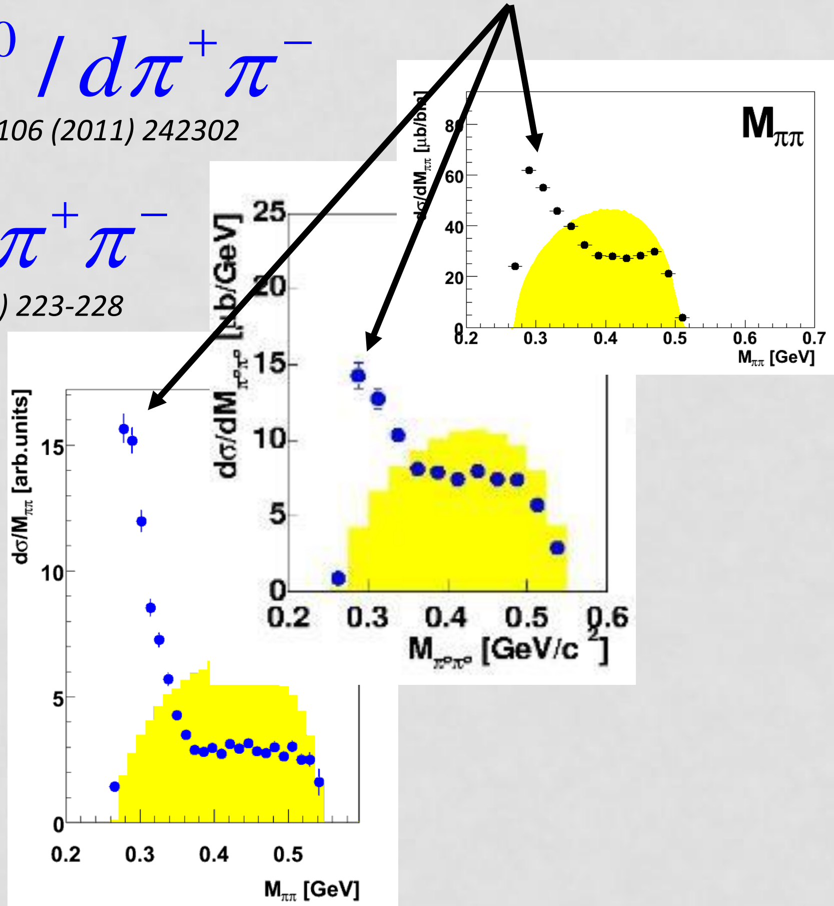
P. Adlarson et. al, Phys. Rev. Lett. 106 (2011) 242302

$$pd \to {}^3He\,\pi^0\pi^0 \,/\, \pi^+\pi^-$$

*M.Bashkanov et. al, Phys. Lett. **B637** (2006) 223-228*

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

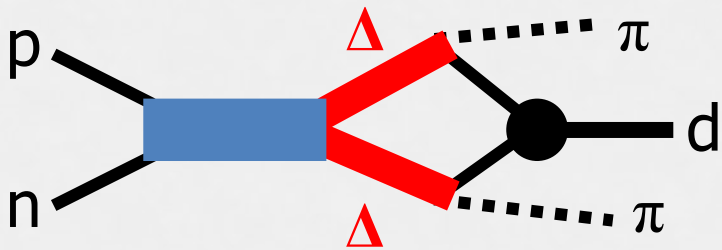
*P. Adlarson et. al, Phys. Rev. **C86** (2012) 032201*



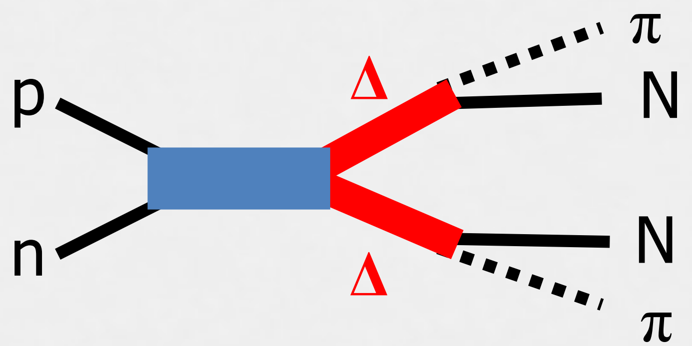
*Alexander **A**bashian,*
*Norman E. **B**ooth,*
*Kenneth M. **C**rowe,*
*Phys. Rev. Lett. **5**, 258 (1960)*

ОТ КАНАЛА ΔΔ ДО pn РАССЕЯНИЯ

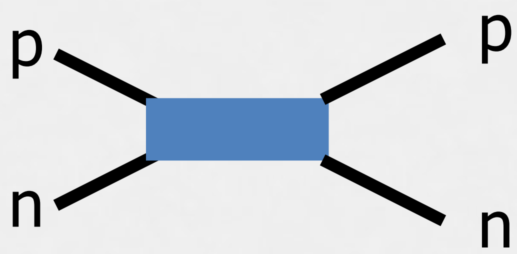
$pn \to d^* > \Delta\Delta \to dpp$



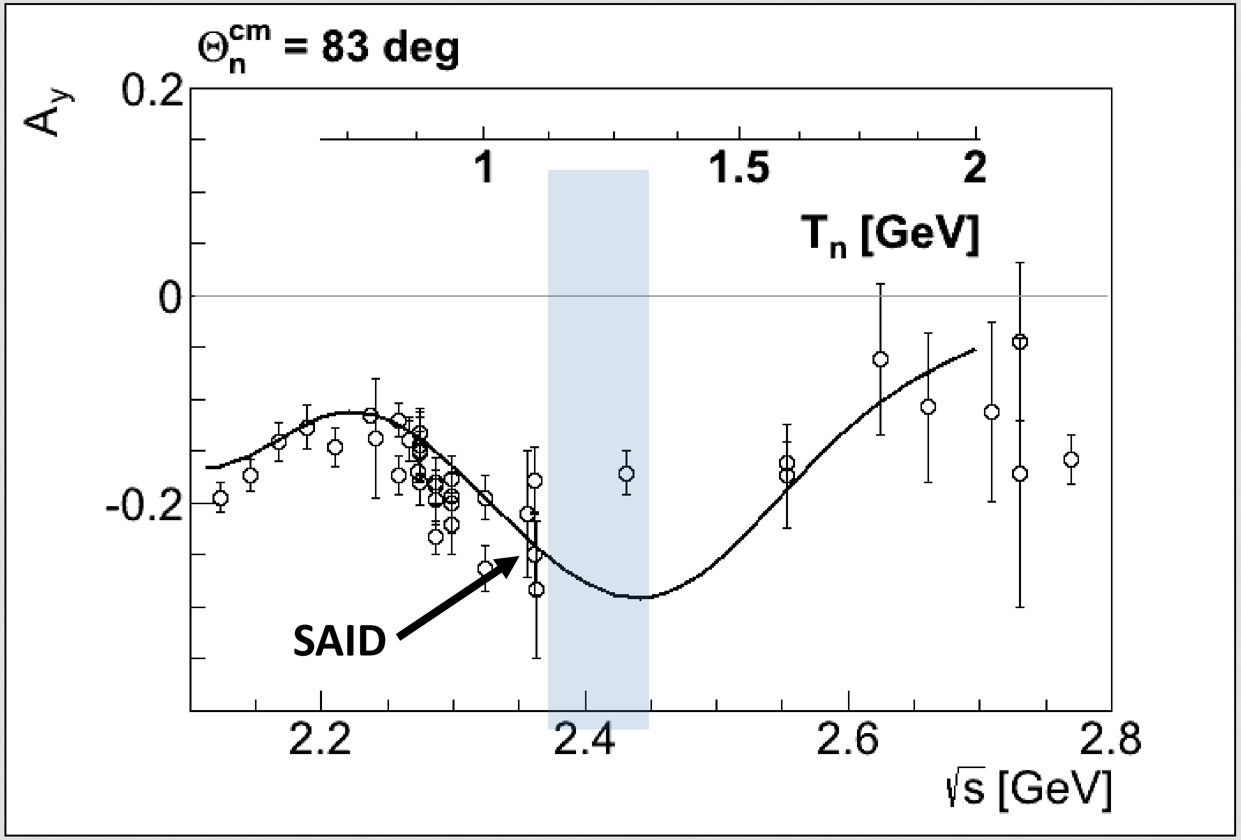
$pn \to d^* \to \Delta\Delta \to NN\pi\pi$

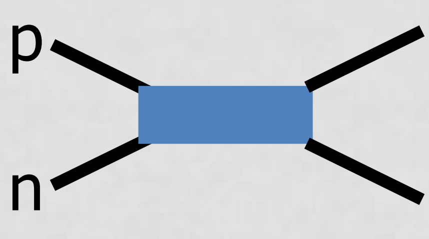


$pn \to d^* \to pn$



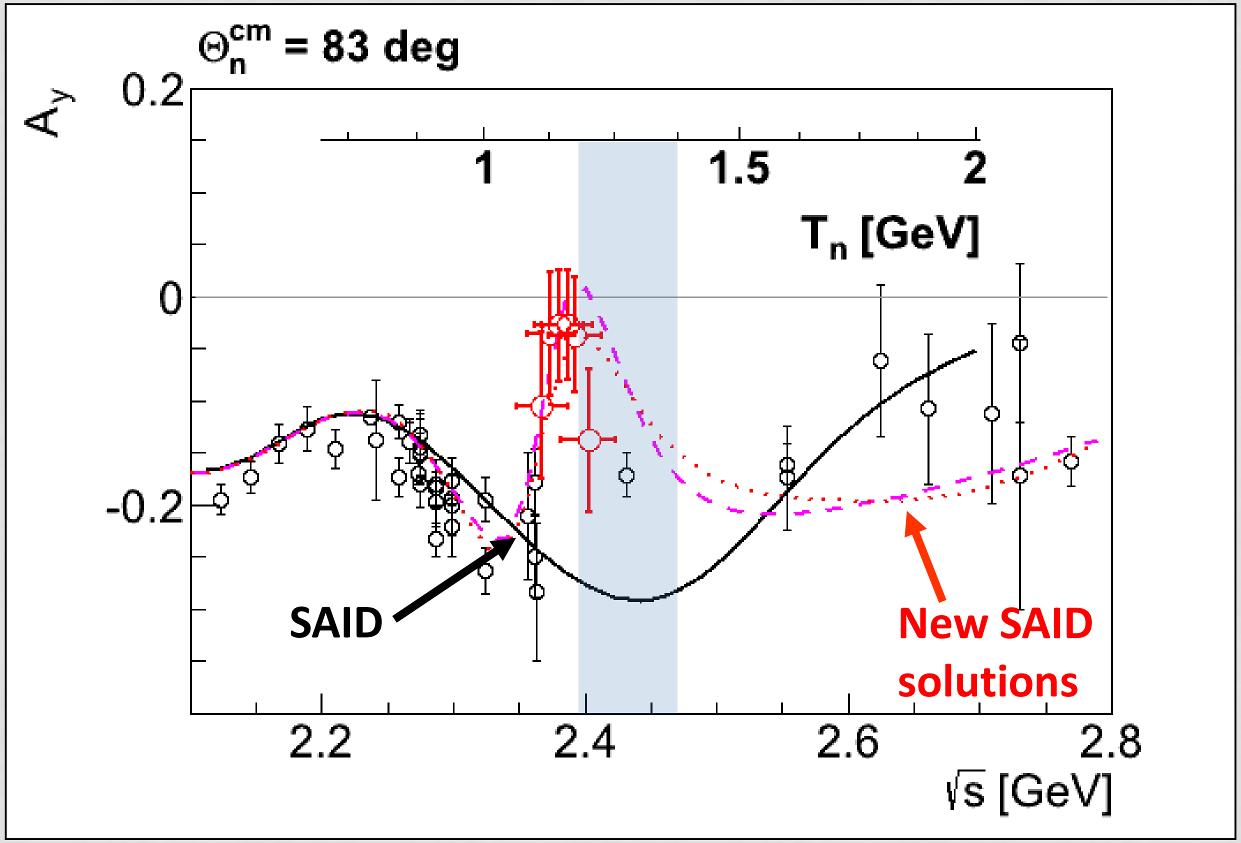
A_y ENERGY DEPENDENCE AT 83°

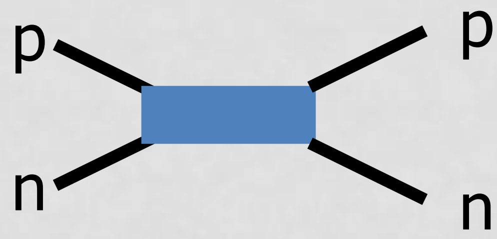




A. Pricking, M. Bashkanov, H. Clement: arXiv:1310.5532

A_y ENERGY DEPENDENCE AT 83°





P. Adlarson et al. Phys. Rev. Lett. 112, 202301, (2014)

STATUS OF THE D* RESONANCE

decay channel	branching	status
d $\pi^0\pi^0$	15 %	observed
d $\pi^+\pi^-$	25 %	observed
pp$\pi^0\pi^-$	7 %	observed
np$\pi^0\pi^0$	(12 %, predicted*)	observed
np$\pi^+\pi^-$	(31 %, predicted*)	HADES
np	(10 %, predicted)	observed

* Fäldt & Wilkin, PLB 701 (2011) 619
Albaladejo & Oset, Phys.Rev. C88 (2013) 014006

ПУБЛИКАЦИИ

Channel	Publications
d $\pi^0\pi^0$	M. Bashkanov et. al Phys.Rev.Lett. 102 (2009) 052301 P. Adlarson et. al Phys. Rev. Lett. 106:242302, 2011 P. Adlarson et. al Phys.Lett. B721 (2013) 229-236
d $\pi^+\pi^-$	P. Adlarson et. al Phys.Lett. B721 (2013) 229-236
pp$\pi^0\pi^-$	P. Adlarson et. al Phys. Rev. C 88, 055208
np$\pi^0\pi^0$	arXiv:1409.2659
np	A. Pricking, M. Bashkanov, H. Clement. arXiv:1310.5532 P. Adlarson et al. Phys. Rev. Lett. **112**, 202301, (2014) P. Adlarson et al. Phys. Rev. C **90**, 035204 , (2014)
pn e^+e^-	M. Bashkanov, H. Clement, Eur.Phys.J. A50 (2014) 107
^{3}He $\pi\pi$	M. Bashkanov et. al Phys.Lett. B637 (2006) 223-228 arXiv:1408.5744
^{4}He $\pi\pi$	P. Adlarson et. al Phys.Rev. C86 (2012) 032201

ОСНОВНЫЕ РЕЗУЛЬТАТЫ

- Измерение дифференциальных и полных сечений изовекторных реакций $pp \to NN\pi\pi$ в области возбуждения барионных резонансов $\Delta(1230)$ или $N^*(1440)$, ABC эффекта нет
- ABC связан с резонансом d*(2380) в реакциях $pn \to d\pi\pi$
- Измерение полных сечений реакций

$pn \to d\pi^0\pi^0$, $pn \to d\pi^+\pi^-$, $pp \to d\pi^+\pi^0$, $pn \to pp\pi^-\pi^0$

- Исследование ABC аномалий с участием ядер ^{3}He и ^{4}He.
- Описание экспериментальных результатов с использованием гипотезы об s-канальном дибарионном резонансе d^* **$I(J^p) = 0(3^+)$**
- .
- Определение квантовых чисел резонанса $d^*(2380)$.

ВЫВОДЫ

резонанс d^* наблюдается в реакциях

$$pn \to d\pi^0\pi^0$$

$$pn \to d\pi^+\pi^-$$

$$pn \to pp\pi^-\pi^0$$

$$pn \to pn\pi^0\pi^0$$

в pn упругом рассеянии

Характеристики резонанса:

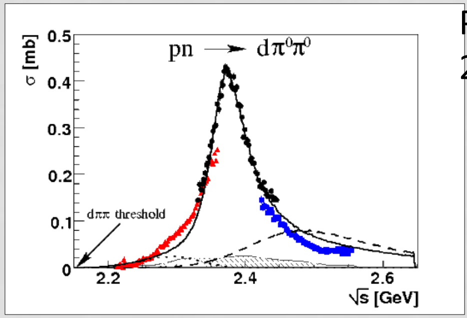
$\mathrm{M} = 2380 \pm 10$ МэВ

$\Gamma = 80 \pm 10$ *МэВ*

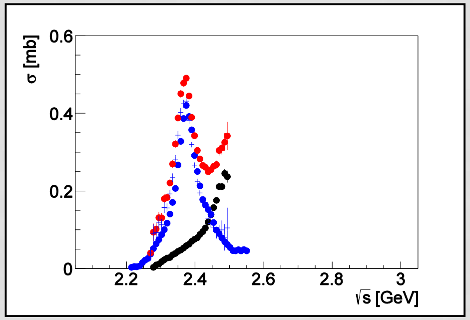
$I(J^p) = 0(3^+)$

Возможны другие резонансные состояния

ИЗМЕРЕННЫЕ КАНАЛЫ d*



PRL 106 (2011) 242302



PLB 721 (2013) 229

WASA data

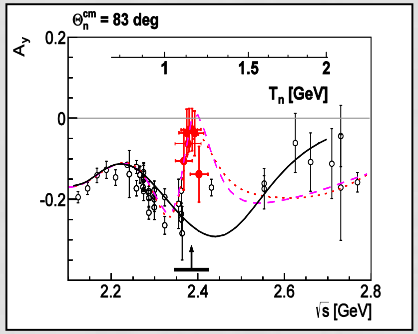
pn → **d*(2380)**

$d\pi^0\pi^0$

dππ

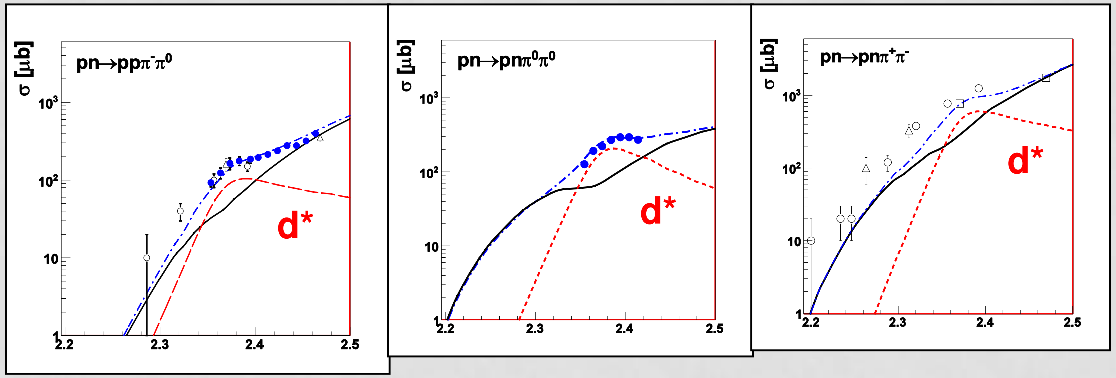
pn

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



PRL 112 (2014) 202301 arXiv:1408.4928

B.L.G. Bakker, I.M. Narodetsky, Yu.A. Simonov.
Lett.Nuovo Cim. 19 (1977) 265
[On Pseudoresonances: Nonresonant Argand Loops]



PRC 88 (2013) 055208 arXiv:1409.2659

СПАСИБО ЗА ВНИМАНИЕ!

РЕЗОНАНС d*(2380) В СИСТЕМЕ НУКЛОНОВ И ПИОНОВ

• Е. ДОРОШКЕВИЧ, ИЯИ РАН

25.04.2019