Measurement of tensor asymmetry T_{20} in coherent π° photoproduction on deuteron

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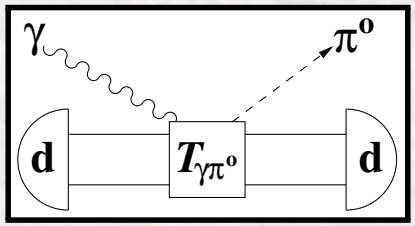
Introduction

d – the simplest compound nucleus and the only bound system of two nuleons

Coherent π^o photoproduction on deuteron

$$\gamma + \vec{d} \to \pi^0 + d$$



the only pion photoproduction reaction on deuteron with two-body final state.

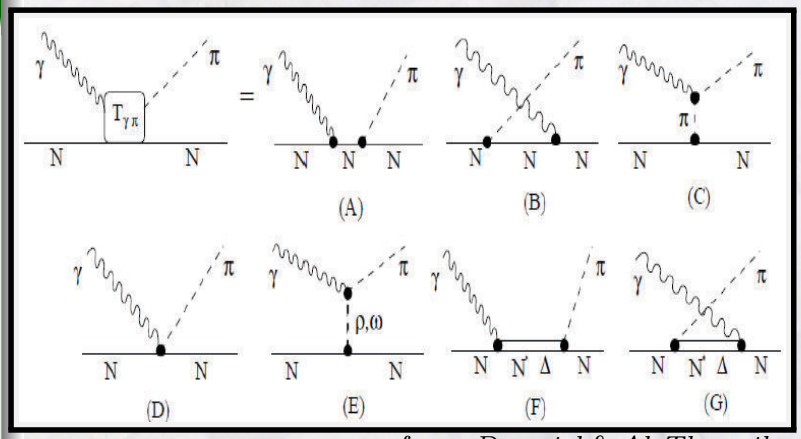
motivations to investigate this reaction:

- elementary photoproduction reaction on neutron
- influence of a nuclear environment on the elementary production amplitude
- pion production on off-shell nucleon
- $N\Delta$-interaction in a nuclear medium
- elastic $\pi^o - d$ scattering
- nuclear structure, NN-interactions
- at threshold – chiral dynamics on neutron
- ...

Theoretical approaches

PWIA: $(\gamma N \to \pi N)$ + DWF

- π^o production on single nucleon:
  - Feynman diagrams: Born, vector meson exchange and resonance terms
  - MAID – Unitary Isobar model
  - ELA – Effecitve Lagrangian Approach
- Fermi motion: factorization or full account
- Deuteron Wave Function: various NN potentials

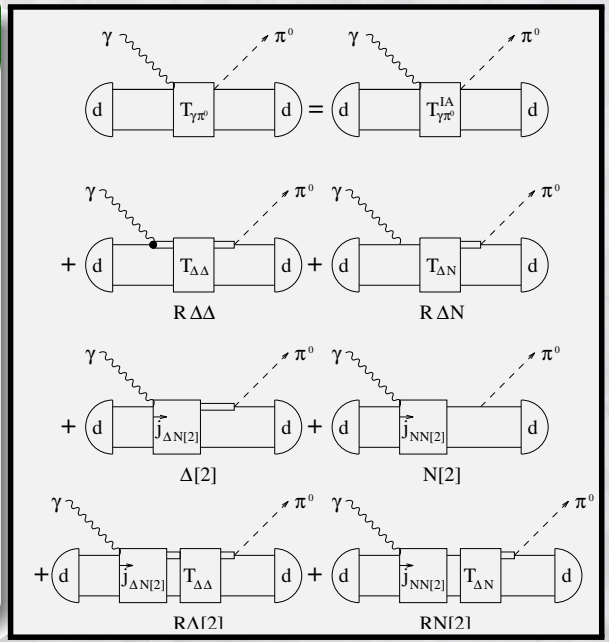


from Darwish&Al-Thoyaib

but rescattering is important in this process!

beyond IA – FSI, MEC

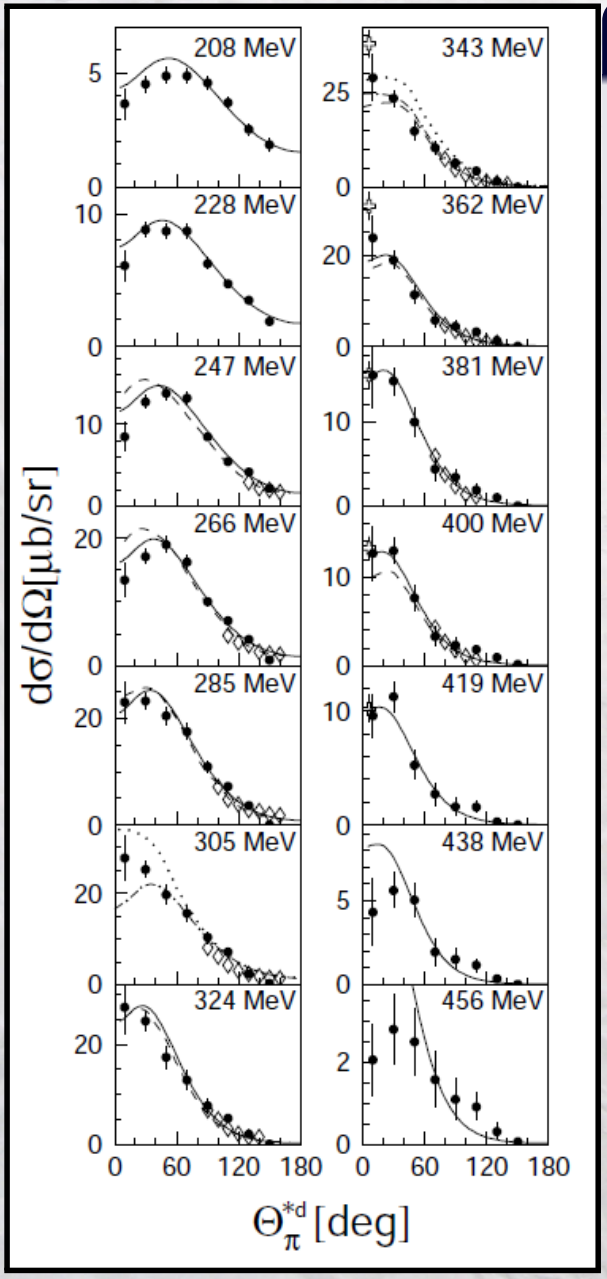
- perturbatively (e.g. Garchilazo *et al*)
  – ***questionable:*** $N\Delta$ ***is strong interacting system!***
- Faddeev equations for the πNN system (Blaazer *et al*)
- $N\Delta$ - πNN - NN coupled-channels approach (Wilhelm&Arenhövel)
- KMT multiple-scattering approach (Kamalov *et al*)
- Coupled-channels retarded interaction model (Schwamb)



from Wilhelm&Arenhövel

Experimental data for $\gamma d \to \pi^0 d$

TAPS@MAMI

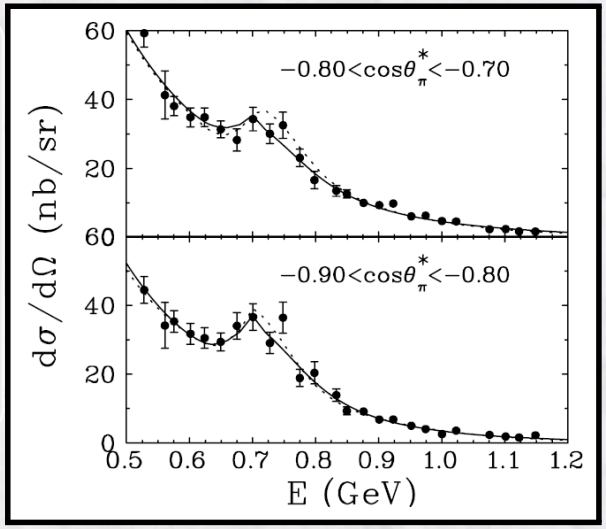


Cross Section

Long history of studying total and differential cross section.

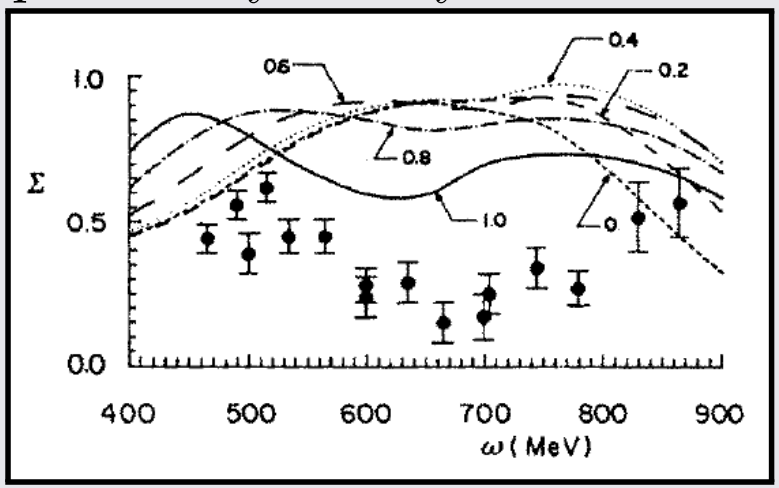
Latest accurate data – from MAMI and JLab

CLAS@JLab



Polarisation observables

Polarized data are very limited. Only linear photon asymmetry Σ was measured.



$\Theta_{\pi^o} = 130°$

Data:
Adamyan(1984)
Imanishi(1985)

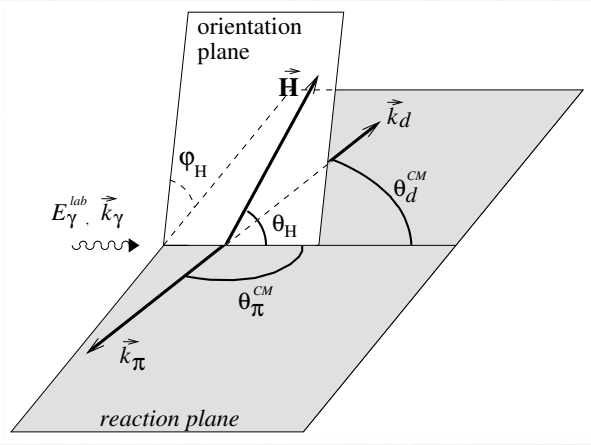
Curves:
Garcilazo(1994)

Tensor observables

cross section in case of polarized spin-1 target and unpolarized photon beam:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\left\{1 - \sqrt{3/4}\,\mathbf{P_z}\sin\theta_H\sin\phi_H \cdot \mathbf{T_{11}}(E\gamma,\theta_\pi^{CM}) + \sqrt{1/8}\,\mathbf{P_{zz}}\left[(3\cos^2\theta_H - 1) \cdot \mathbf{T_{20}}(E\gamma,\theta_\pi^{CM}) - \sqrt{3/2}\sin 2\theta_H\cos\phi_H \cdot \mathbf{T_{21}}(E\gamma,\theta_\pi^{CM}) + \sqrt{3/2}\sin^2\theta_H\cos 2\phi_H \cdot \mathbf{T_{22}}(E\gamma,\theta_\pi^{CM})\right]\right\}$$

$\mathbf{P_z}$ – degree of target vector polarization $[-1\ldots+1]$
$\mathbf{P_{zz}}$ – degree of target tensor polarization $[-2\ldots+1]$
θ_H, ϕ_H define orientation of polarization axis



in the described experiment ($\theta_H = 0$)

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\left[1 + \sqrt{1/2} \cdot \mathbf{P_{zz}} \cdot \mathbf{T_{20}}(E\gamma,\theta_\pi^{CM})\right]$$

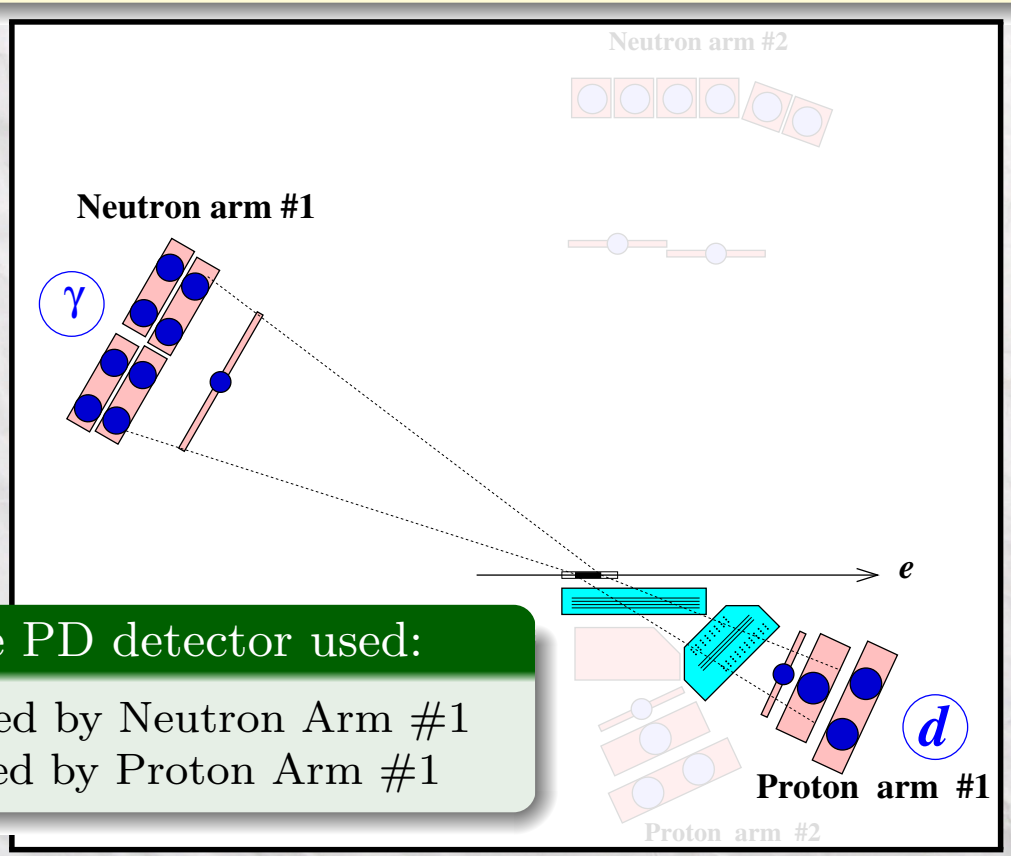
in terms of 9 helicity amplitudes $A_{\lambda_i\lambda_f}$, $\lambda_i,\lambda_f = -1,0,+1$

$$\frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2 s}\frac{|\vec{q}|}{|\vec{k}|}\frac{1}{6}\cdot\mathbf{Tr}, \qquad \mathbf{Tr} = 2\sum|A_{\lambda_i\lambda_f}|^2,$$

$$\mathbf{T_{20}} = \frac{\sqrt{2}}{\mathbf{Tr}}\cdot\sum_{\lambda_f}|A_{-1\lambda_f}|^2 - 2|A_{0\lambda_f}|^2 + |A_{+1\lambda_f}|^2$$

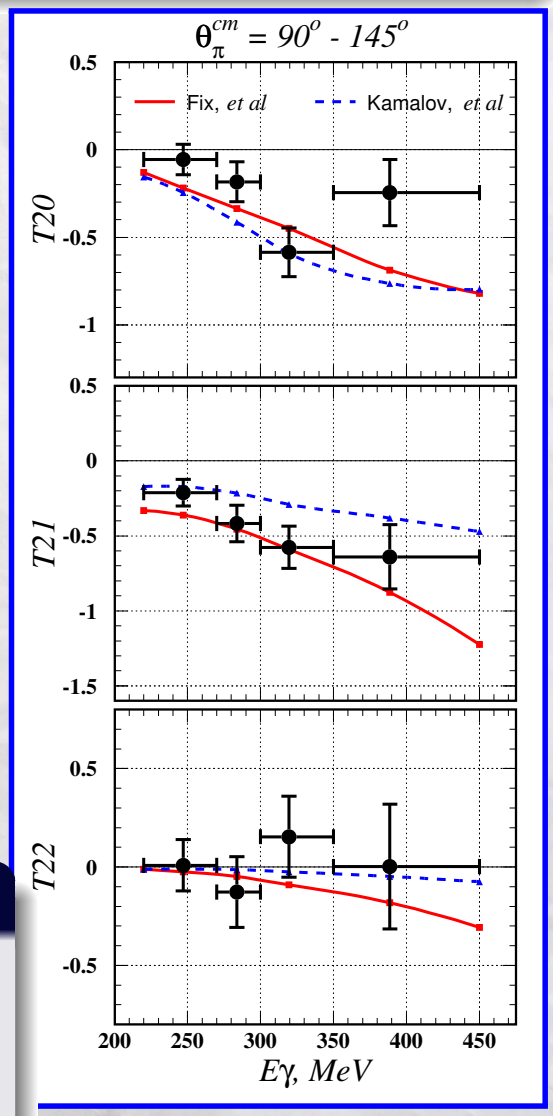
Previous data on T_{2i} in $\gamma d \to \pi^\circ d$

$\gamma + \vec{d} \to \pi^0 + d'$ events have been selected from the statistics collected during the deuteron photodisintegration experiment at VEPP-3 [PRL 98 (2007) 182303].



part of the PD detector used:

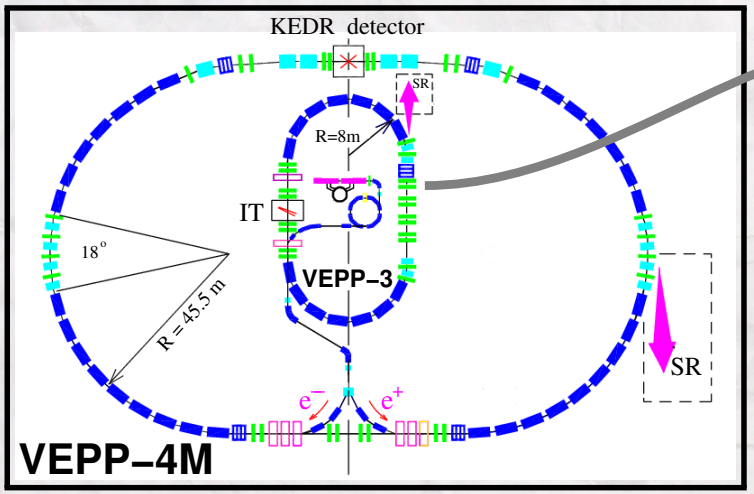
- γ detected by Neutron Arm #1
- d detected by Proton Arm #1



existing data on tensor asymmetries in $\gamma d \to \pi^\circ d$

Data: D.M.Nikolenko, *et al.*, JETP Lett.**89**, 518 (2009)
Theoretical curves:
solid – A.Fix, private communication,
dashed – S.S.Kamalov, L.Tiator, C.Bennhold, PRC 55(1997)98

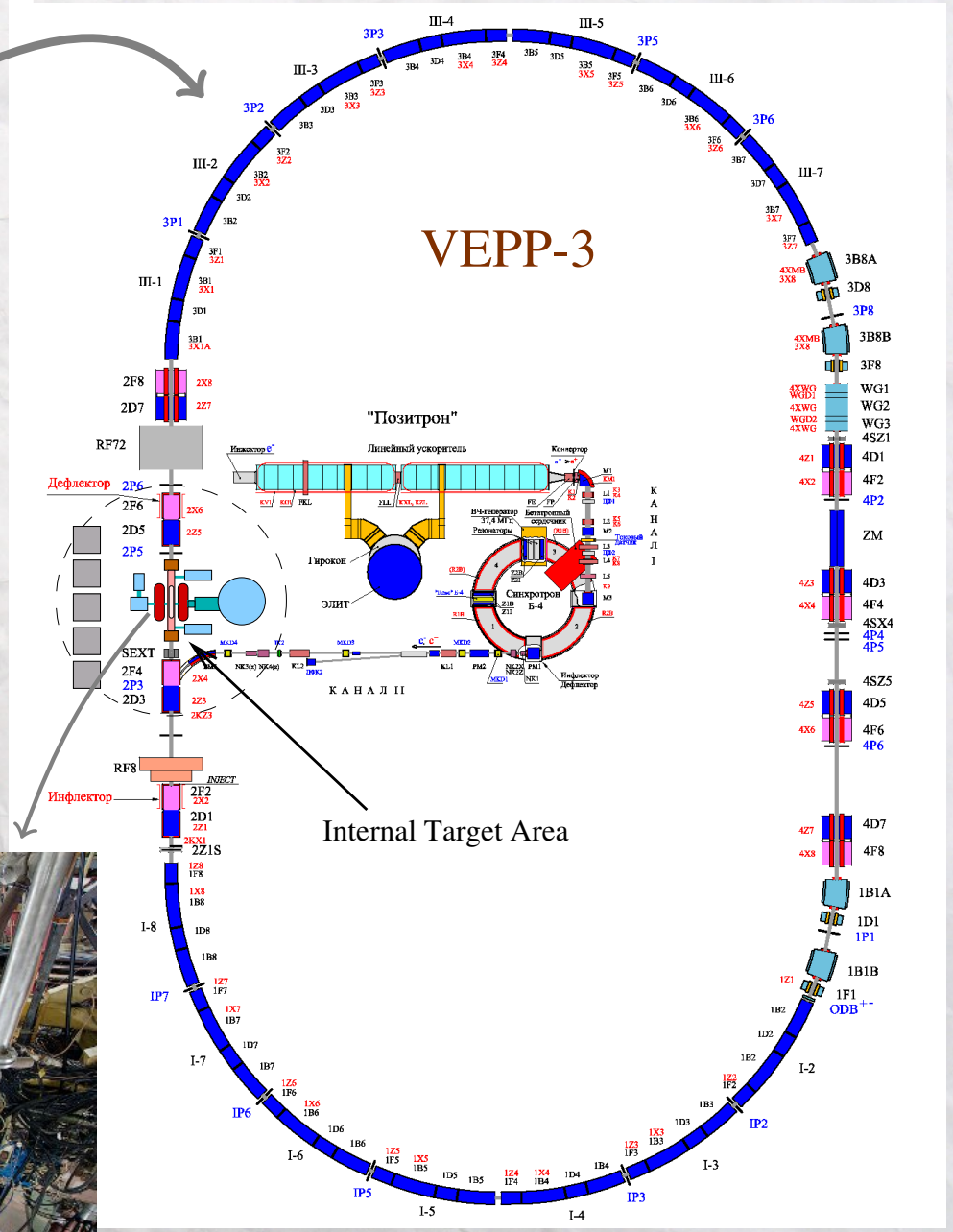
VEPP–3 electron-positron storage ring



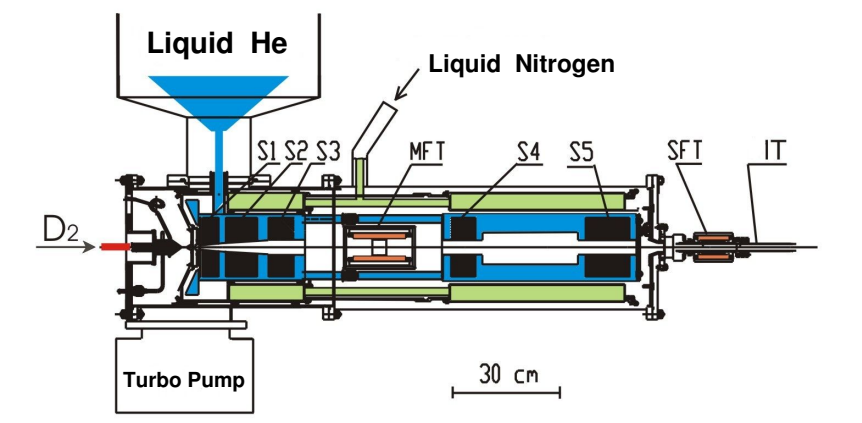
VEPP–3 is a booster for the VEPP–4M electron-positron collider.

VEPP–3 parameters for e^- beam:

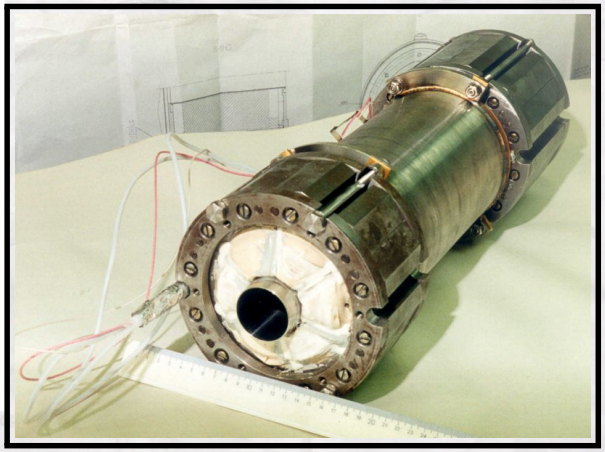
Perimeter	P	75 m
Electron energy	E_0	0.35÷2 GeV
Energy spread	$\Delta E/E$	0.05%
Mean beam current	I_0	150 mA



Polarized Deuterium Gas Target

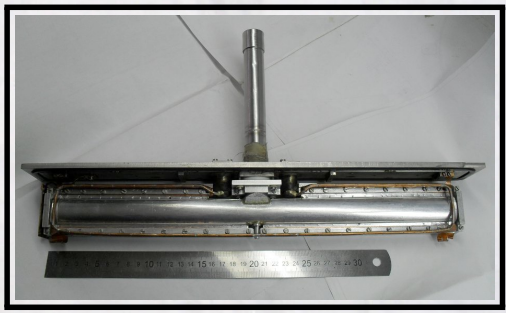


S1–S5 – 6-pole magnets
MFT, SFT – RF transition units
IT – inlet tube

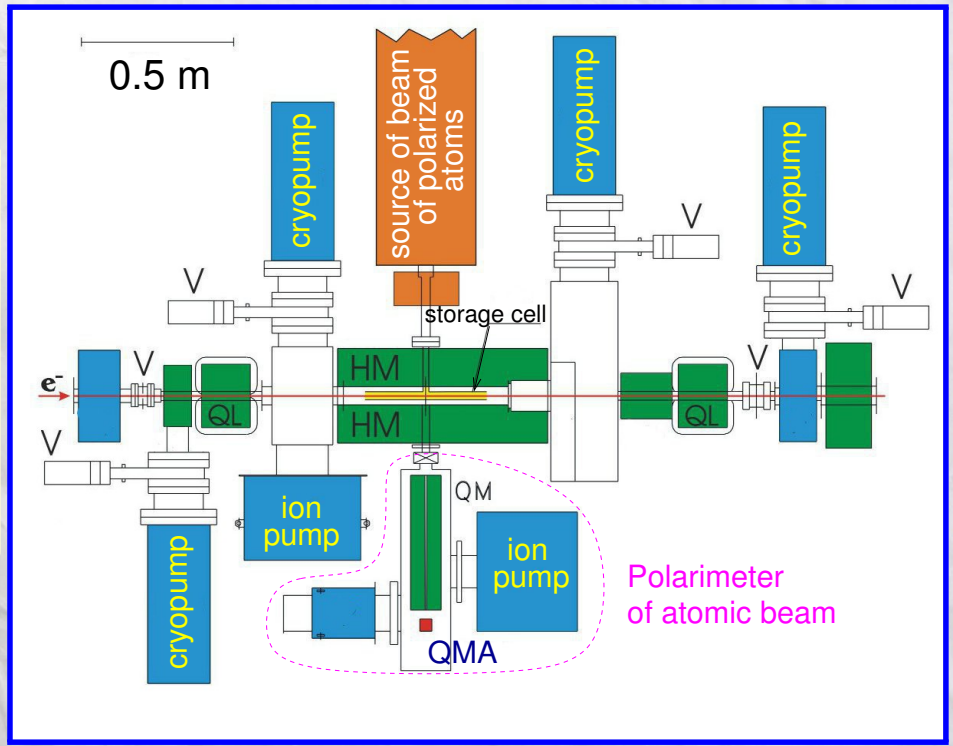


superconducting 6-pole magnets

storage cell



top view at the target section



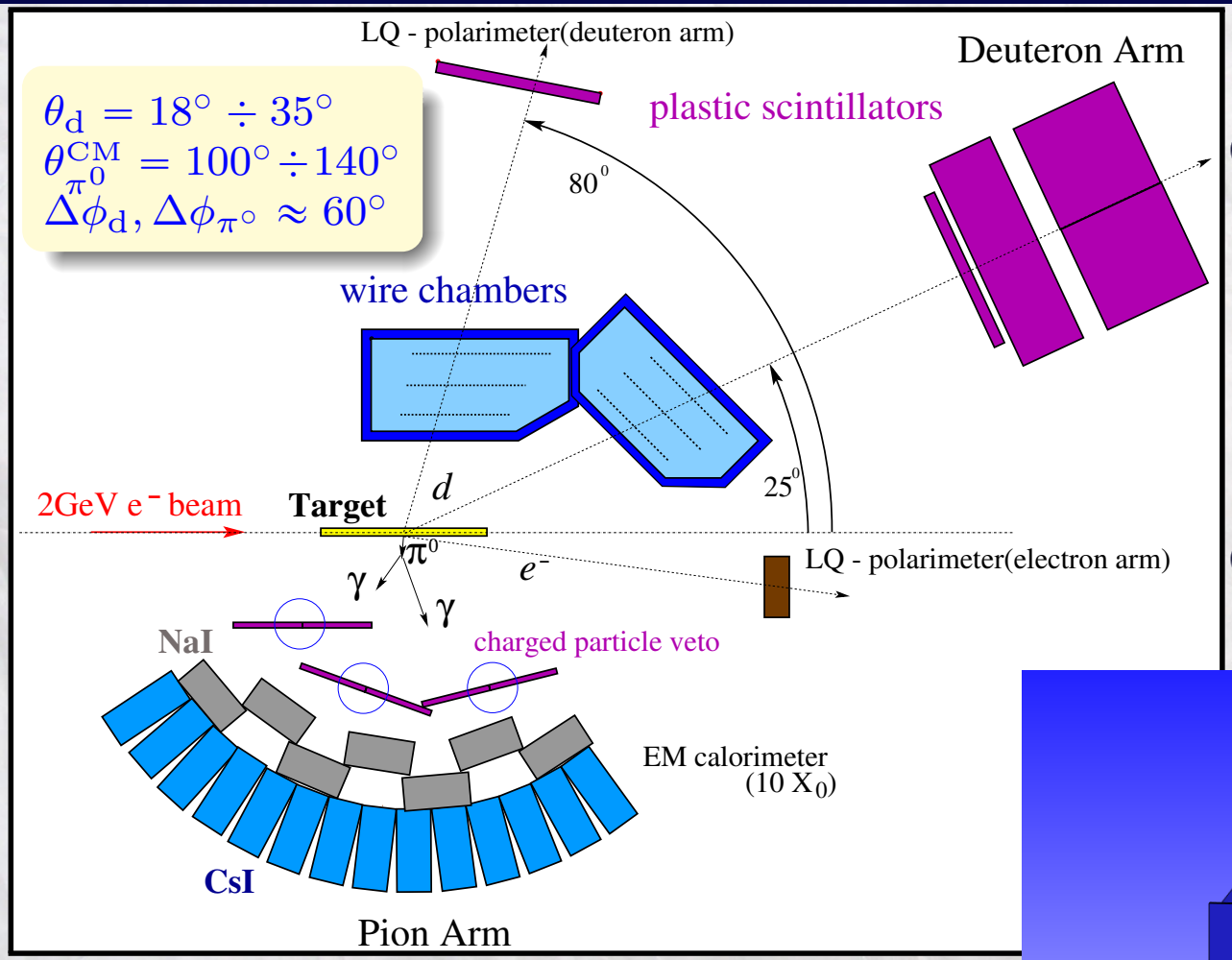
ABS:

Flux of deuterium atoms	$8 \cdot 10^{16}$ at/sec
Degree of tensor polarization	$> 98\%$
Degree of vector polarization	$< 2\%$
Time of polarization switching	< 1 sec

Storage cell:

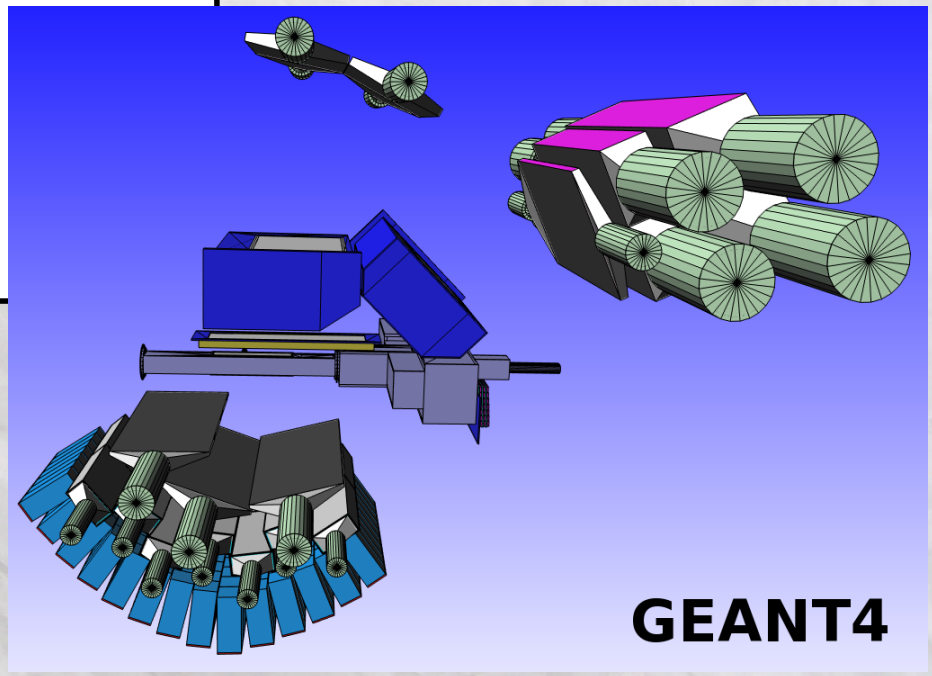
Target thickness:	$0.5 \cdot 10^{14}$ at/cm^2
Degree of tensor polarization:	$30 \div 50\%$

Particle Detector



reactions:

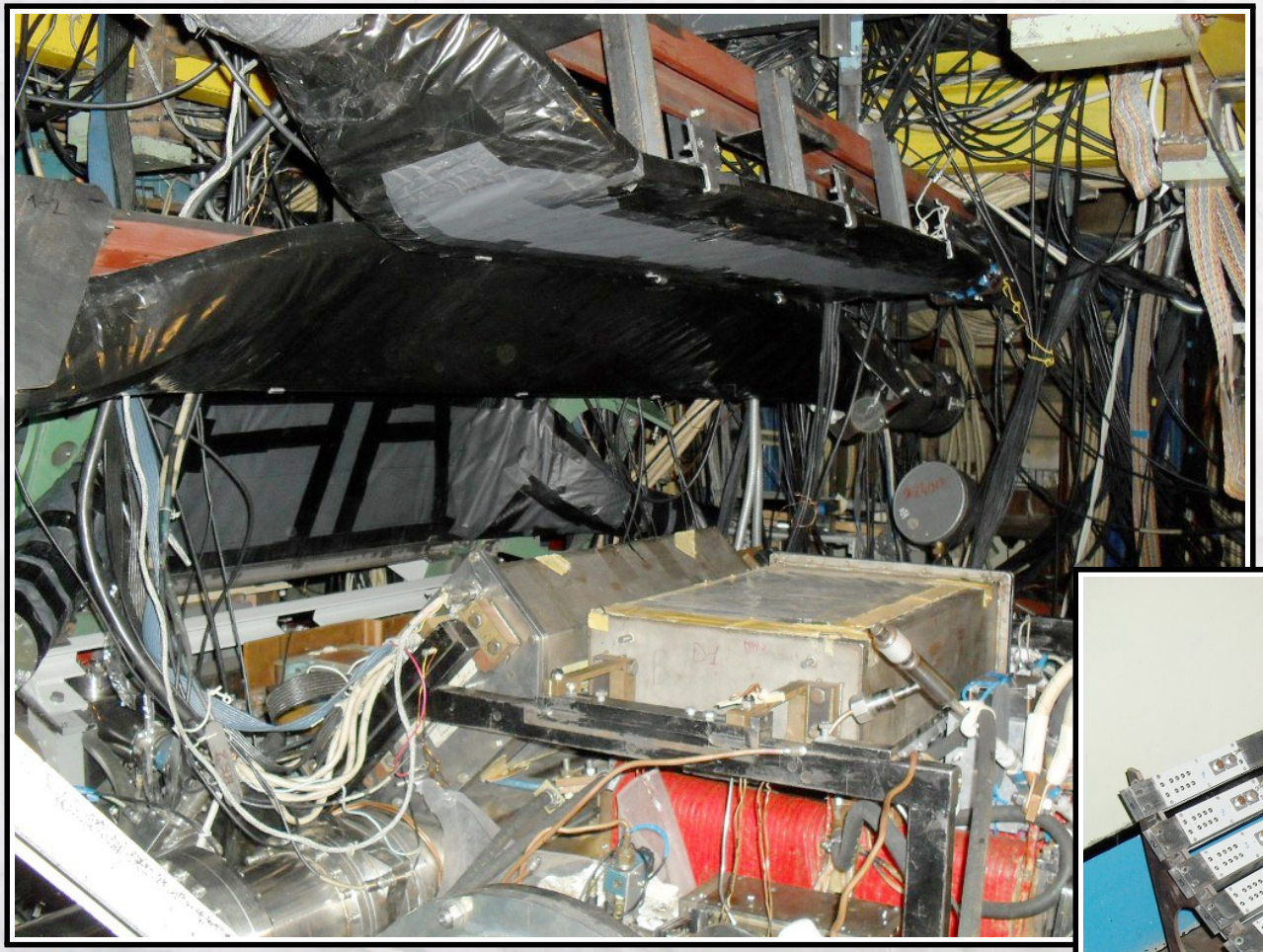
1. $d(e, \pi^0 d)e'$
   e' is not detected $\rightarrow$ $Q^2 \approx 0$
   $\rightarrow$ equivalent to:
   $$\gamma + d \rightarrow d + \pi^0 \hookrightarrow 2\gamma$$
   "almost-real photon approach"
2. $$e + d \rightarrow e' + d$$



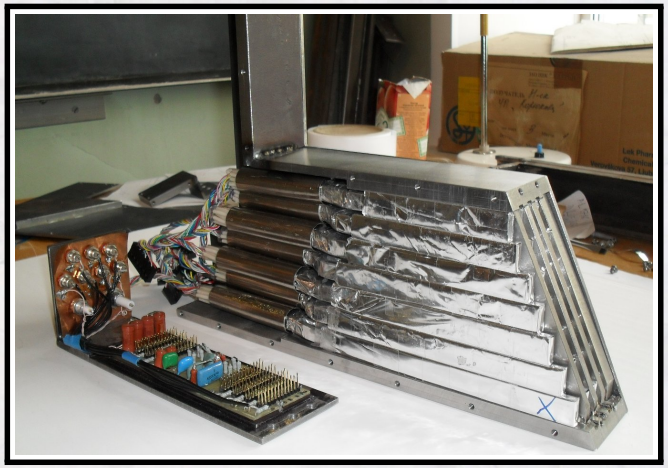
- wire chambers for tracking
- plastic scintillators 1,2,12,20 cm-thick
- 144 CsI crystals $6 \times 6 \times 15$ cm^3
- 14 NaI crystals $30 \times 11 \times 5$ cm^3

Detector pictures

drift chambers, scintillators at VEPP–3



LQP electron arm



CsI crystals assembly

LQ-Polarimeter

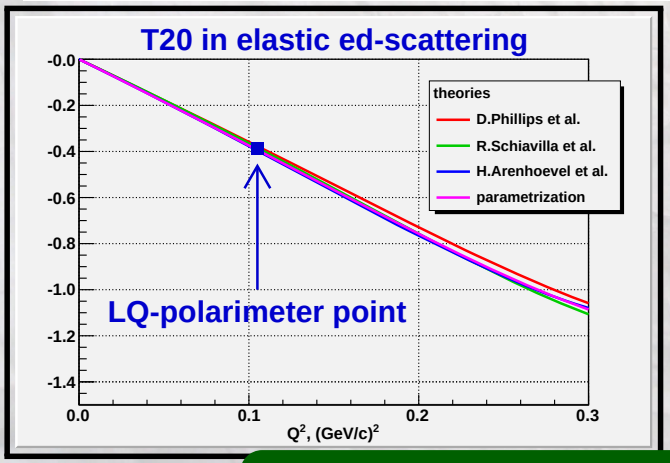
elastic *(ed)*-scattering at small angle:

$Q^2 \approx 0.1(\mathrm{GeV/c})^2$

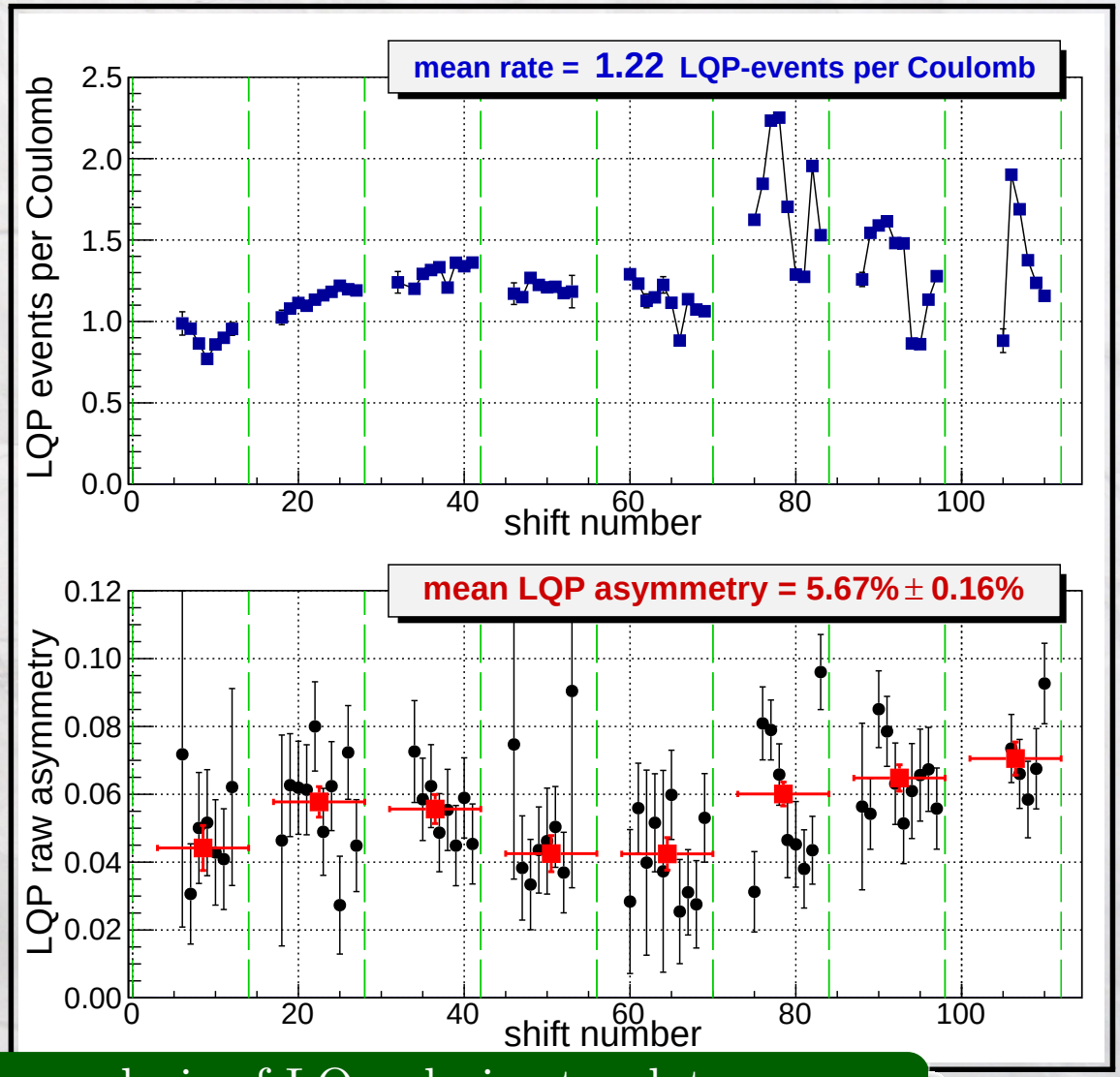
Form factors of **d** at small Q^2 are known with high accuracy

$\Rightarrow d\sigma/d\Omega$ and T_{20} are known

$\Rightarrow$ allows to measure target parameters: **polarization and effecitve thickness**



LQ-polarimeter performance during the run



Target parameters from analysis of LQ polarimeter data:

Degree of tensor polarization: $P^+_{zz} = 0.42,\ P^-_{zz} = -0.72$

Thickness 3.5×10^{13} atoms/cm^2

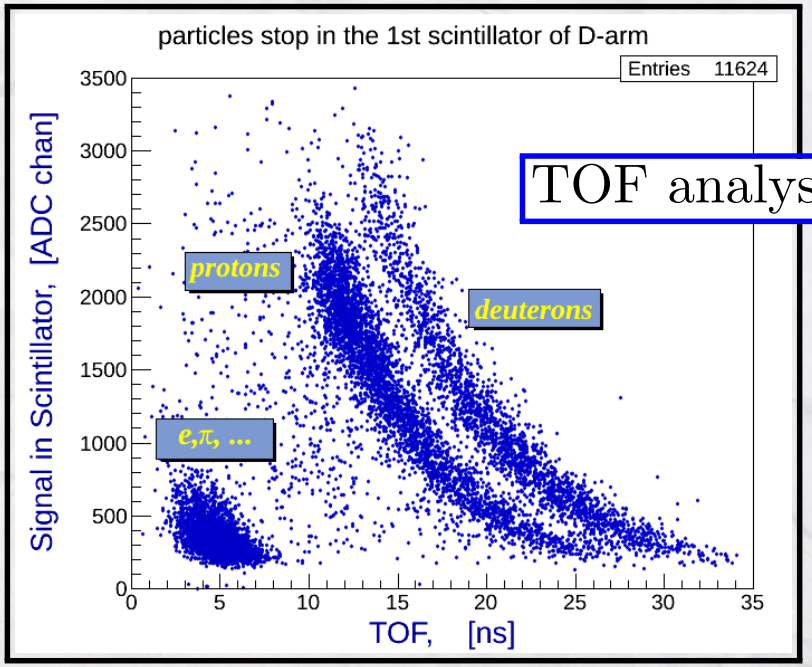
Event selection

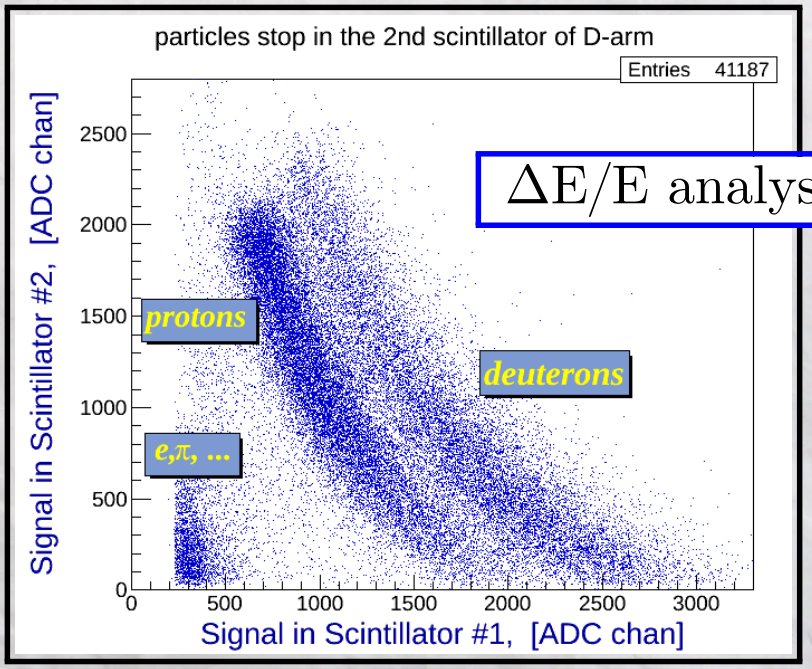
selection criteria

- in **deuteron**-arm:
  - single track in wire chamber
  - large signal in plastics
  - deuteron identification
- in π^0-arm:
  - no signal in charged veto
  - large signal in calorimeter
- **d**–π^0 angular correlations (for 2-γ events in calorimeter)

deuteron identification

- Time of Flight analysis: flight distance $\sim$ 115cm, $v_d/c = 0.1 \div 0.5$
- ΔE/E analysis – for deuterons stopped in 2nd scintillation layer



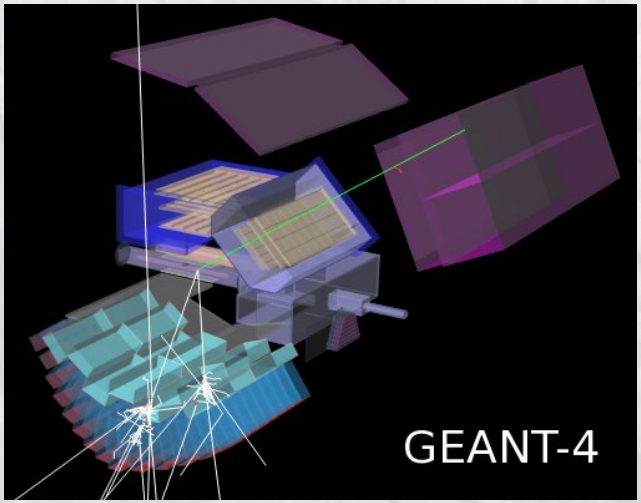


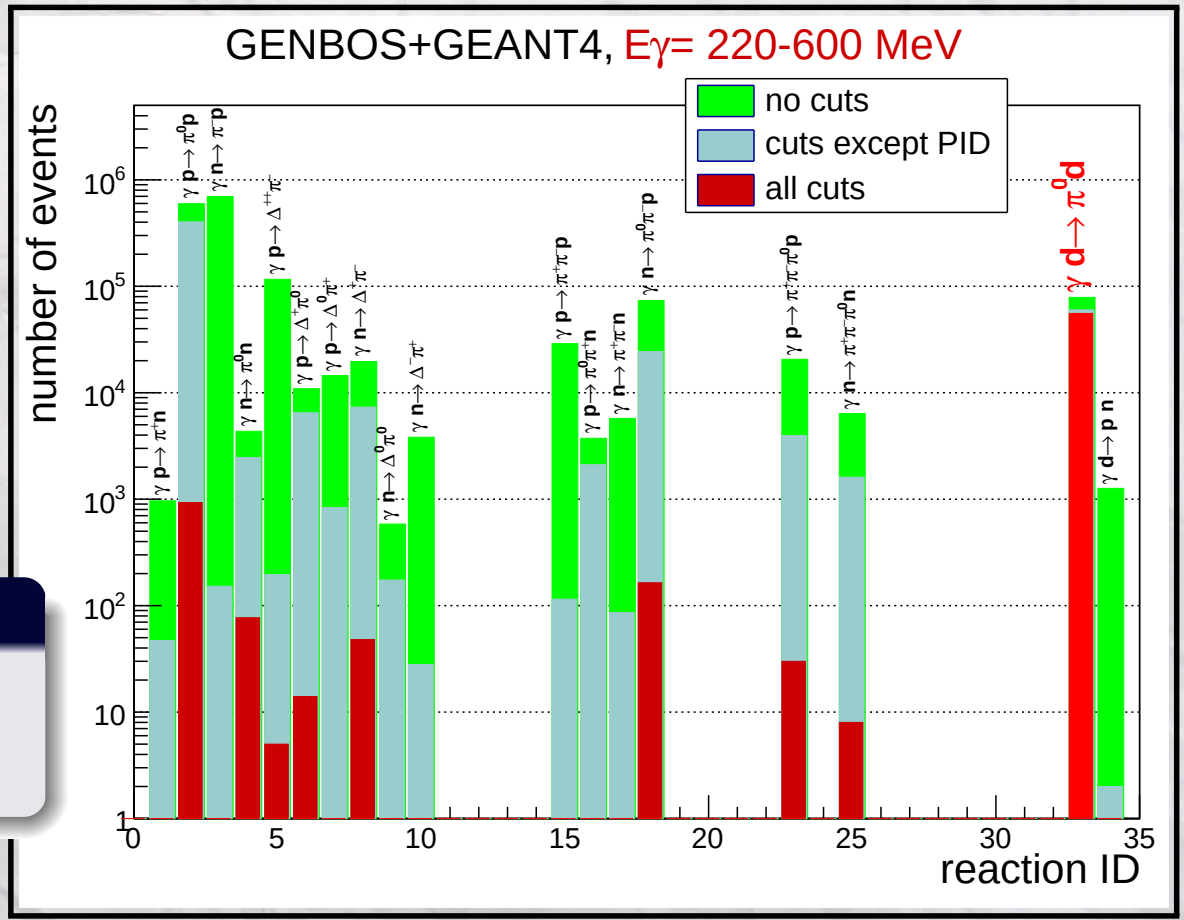
Monte Carlo simulation

Based on GEANT-4 toolkit and GENBOS event generator from JLab/INFN

GENBOS:

- *describes photoreactions on free nucleons and on deuterons for photon energy from pion production threshold up to 10 GeV.*
- *31 different reaction channels in a phenomenological way*
- *both the resonant and non resonant contributions are taken into account.*





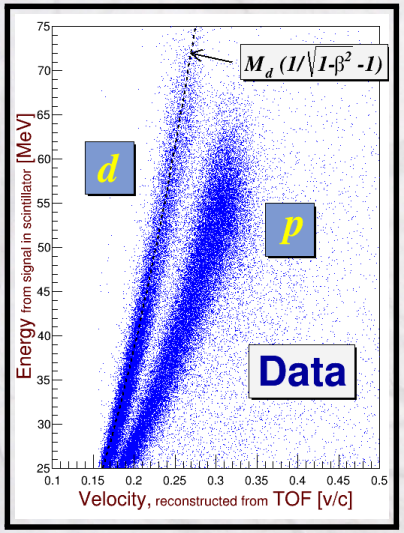
MC simulation of event selection

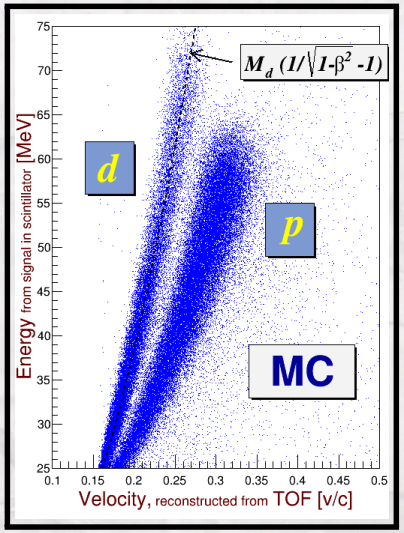
green – after on-line trigger

red – after all cuts applied

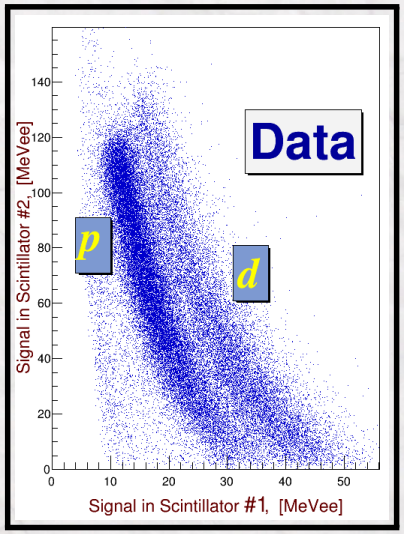
Background Subtraction

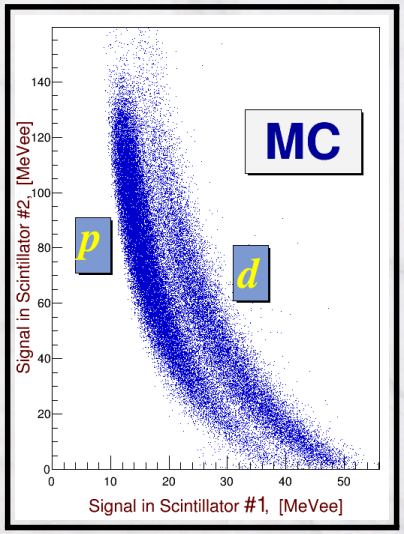
TOF PID for particles which stop in **1st** scintillator ($E\gamma < 360$MeV)



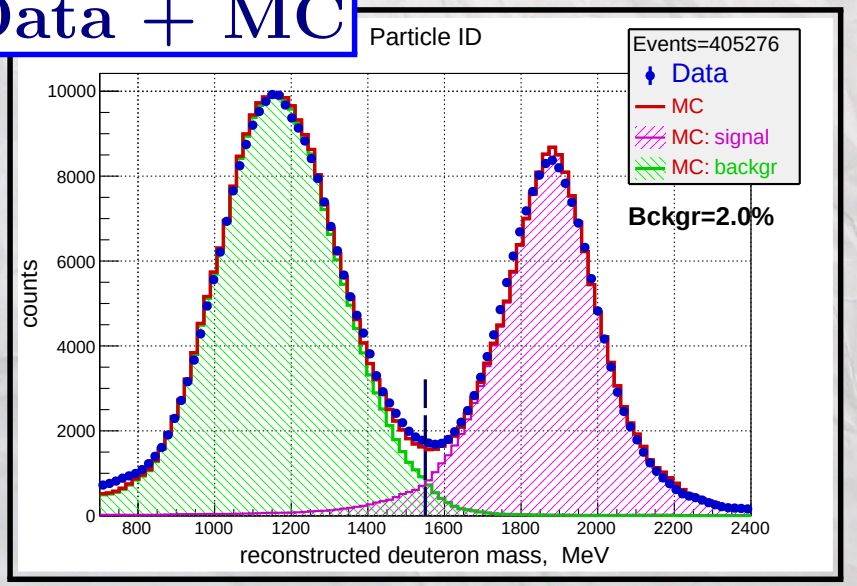


$\Delta E/E$ PID for particles which stop in **2nd** scintillator ($E\gamma = 360 \div 600$MeV)



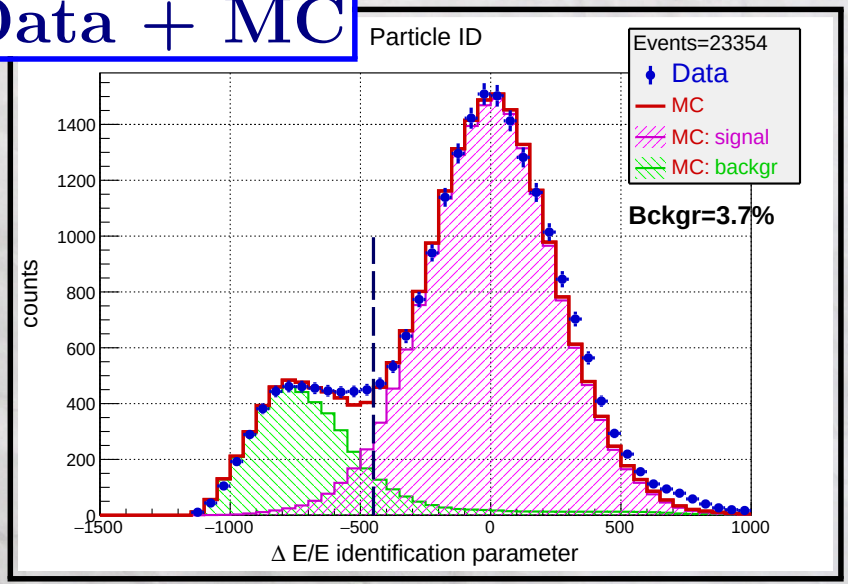


Data + MC



. . . all cuts except on TOF PID applied

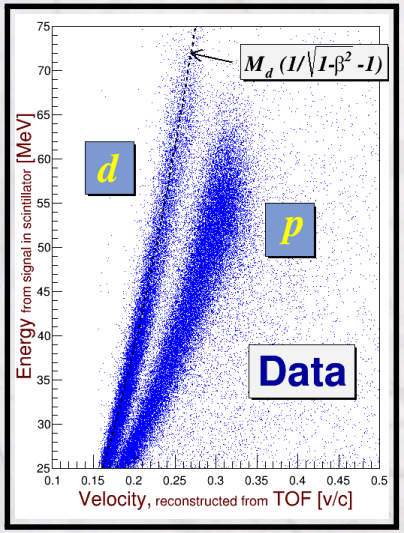
Data + MC

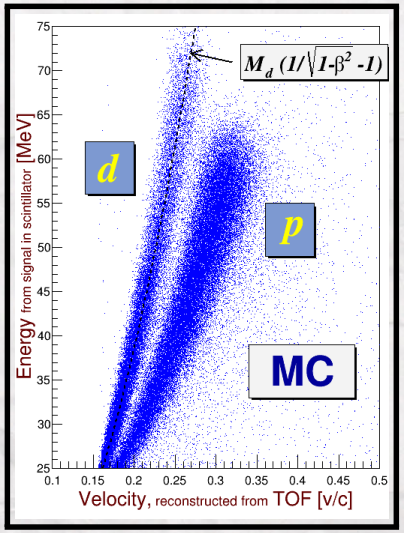


. . . all cuts except on $\Delta E/E$ PID applied

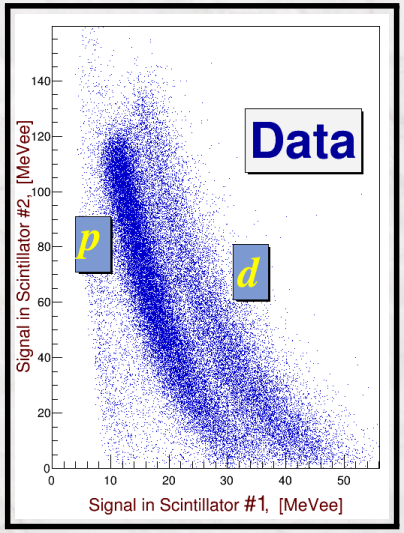
Background Subtraction

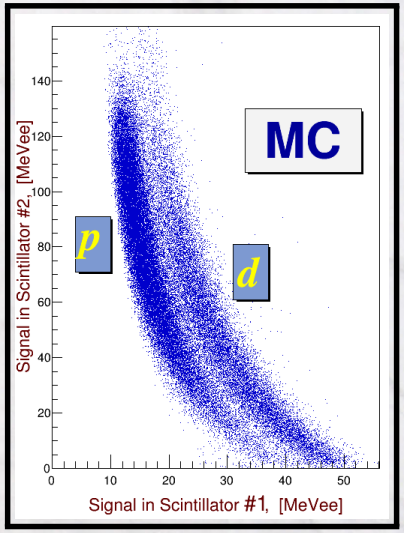
TOF PID for particles which stop in **1st** scintillator ($E\gamma < 360$MeV)



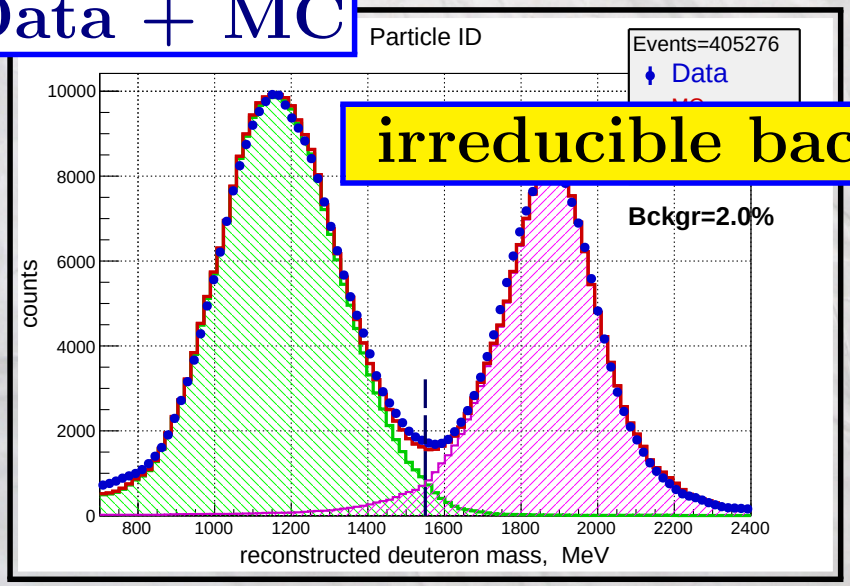


$\Delta E/E$ PID for particles which stop in **2nd** scintillator ($E\gamma = 360 \div 600$MeV)





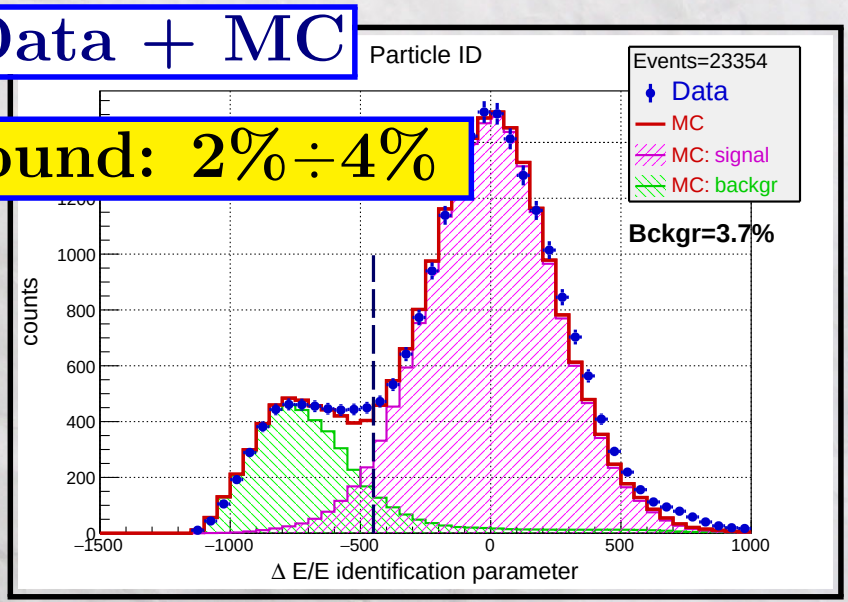
Data + MC



. . . all cuts except on TOF PID applied

irreducible background: 2%÷4%

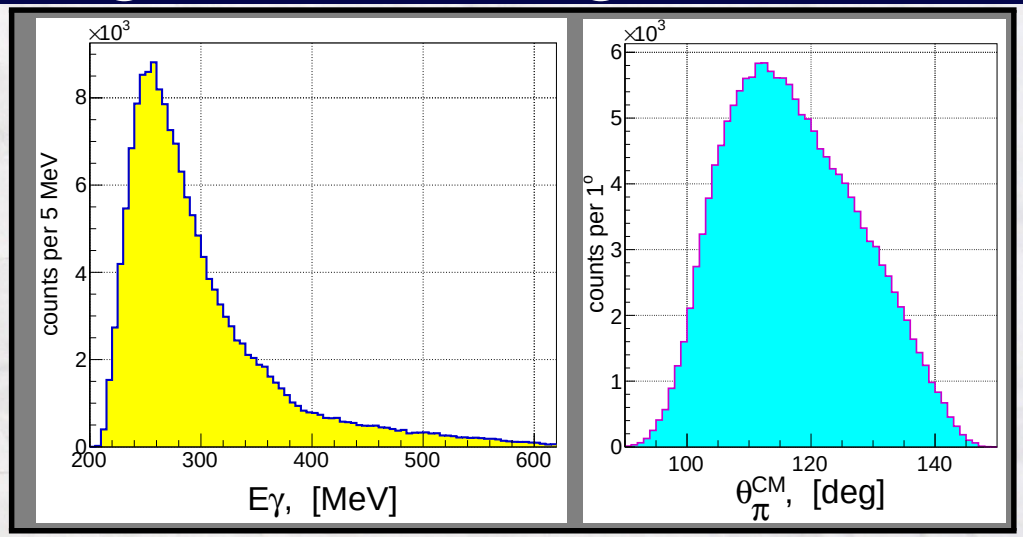
Data + MC



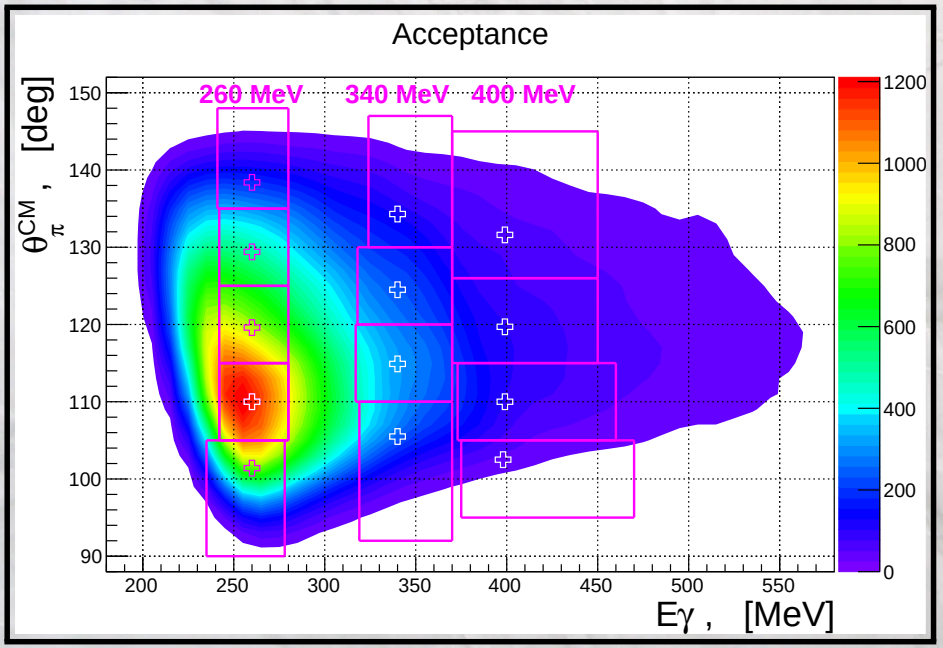
. . . all cuts except on $\Delta E/E$ PID applied

Kinematic Coverage and Binning

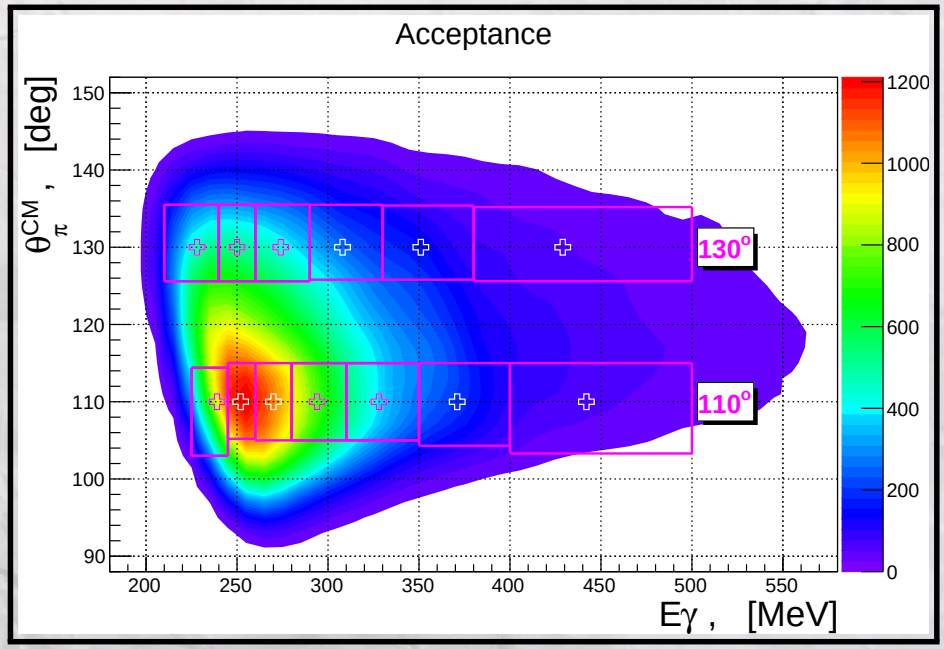
- wide coverage of $E\gamma$ and θ_π^{CM}
- binning choices:
  for θ_π^{CM}-dependence or
  for $E\gamma$-dependence



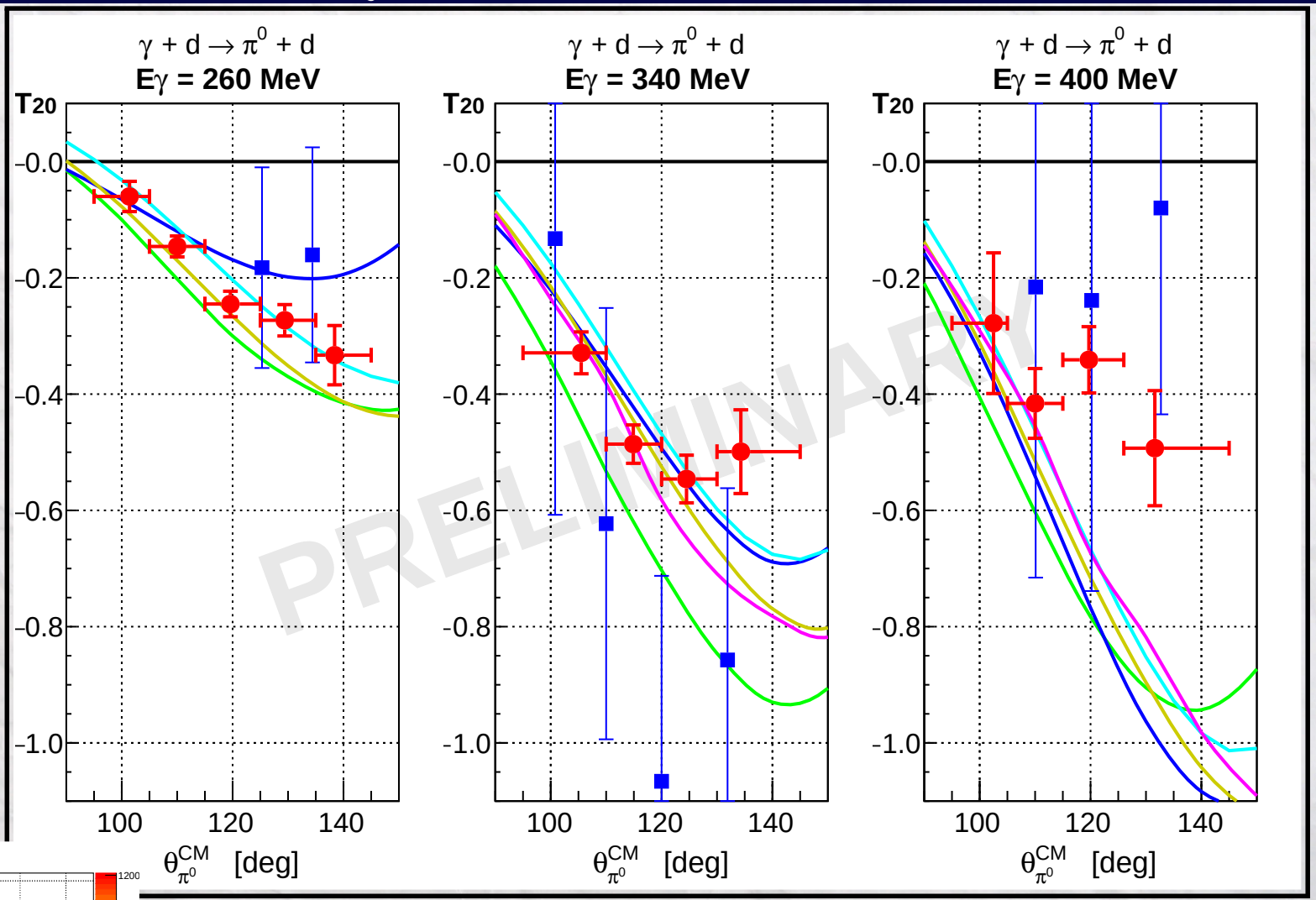
... to draw T_{20} vs. θ_π^{CM} for fixed $E\gamma$

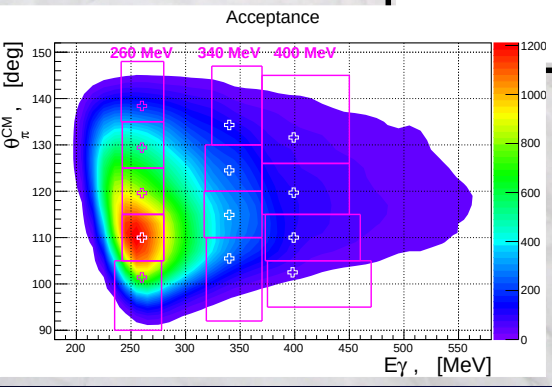


... to draw T_{20} vs. $E\gamma$ for fixed θ_π^{CM}



Preliminary results: T_{20} vs. θ_{π^0}



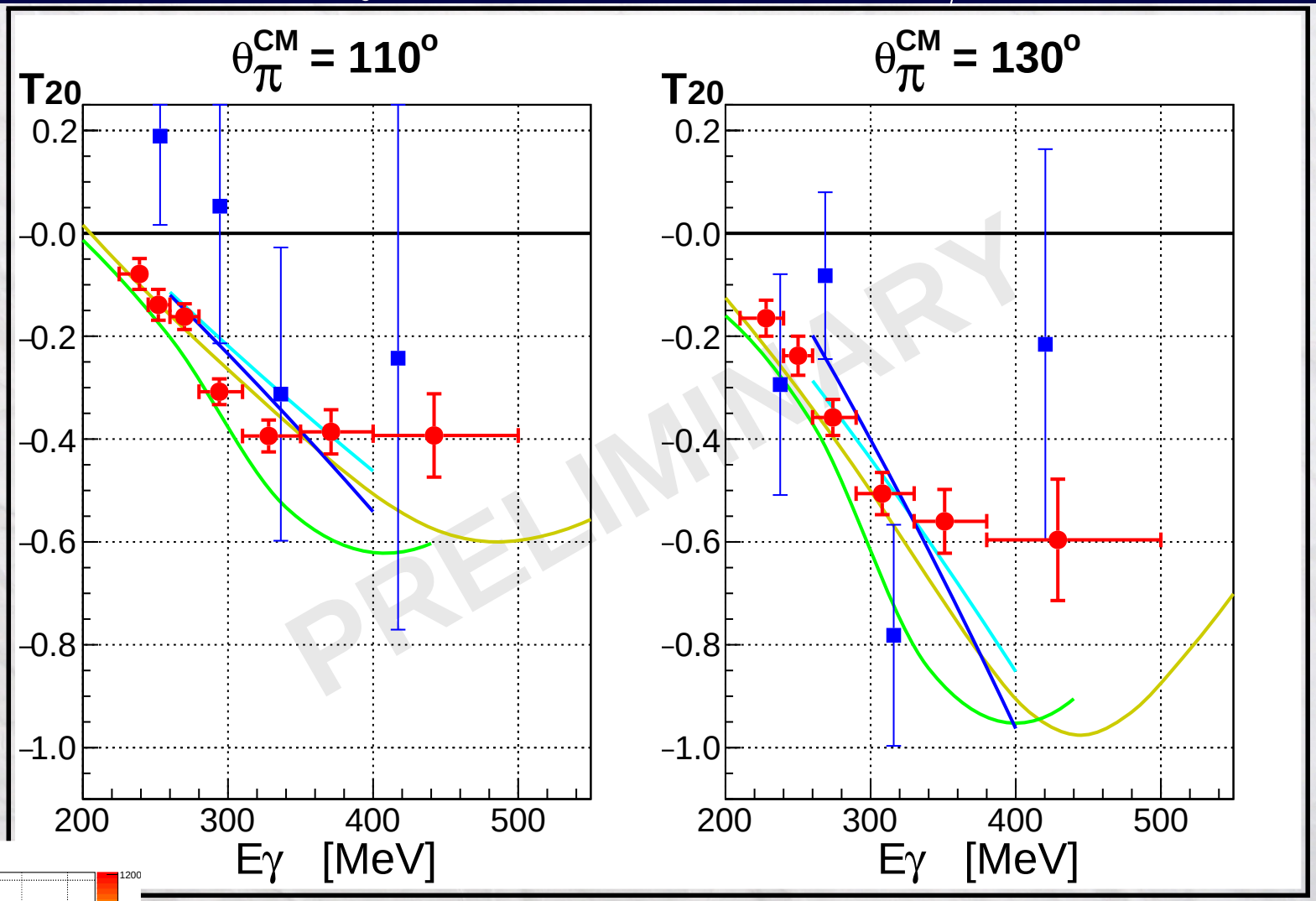


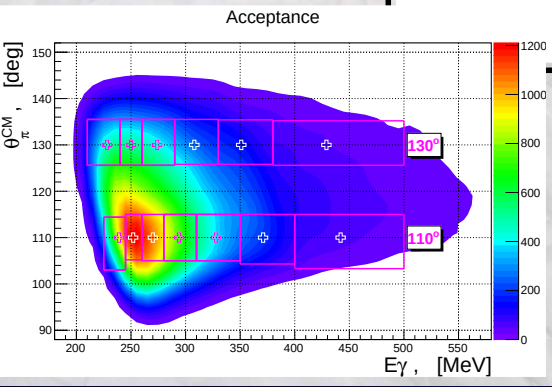
preliminary results for T_{20} vs. θ_π^{CM} (3 photon energies)

data: ● VEPP-3 [2013], *preliminary* ■ VEPP-3 [2009]

curves: S.S.Kamalov et al. — E. M. Darwish, et al. — A. Fix — M.Levchuk — P.Wilhelm&H.Arenhövel

Preliminary results: T_{20} vs. E_γ





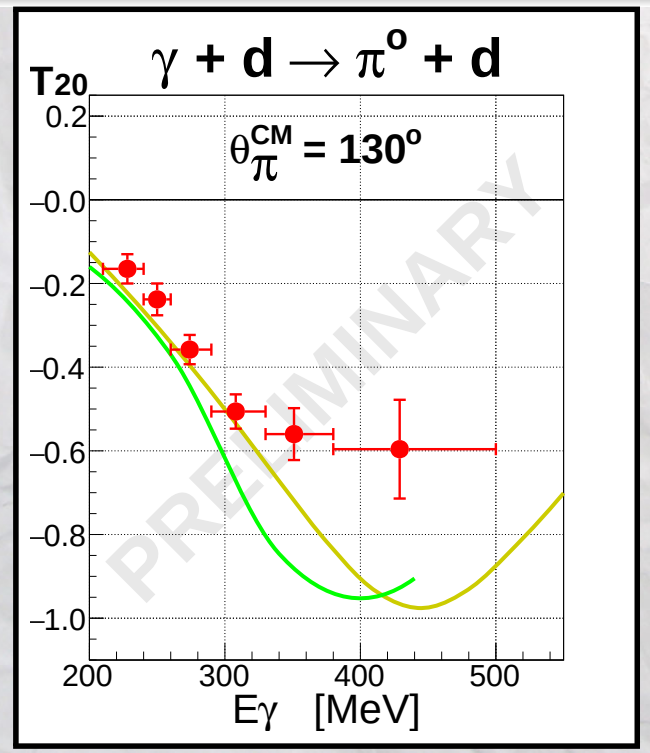
preliminary results for T_{20} vs. $E\gamma$ (2 pion angles)

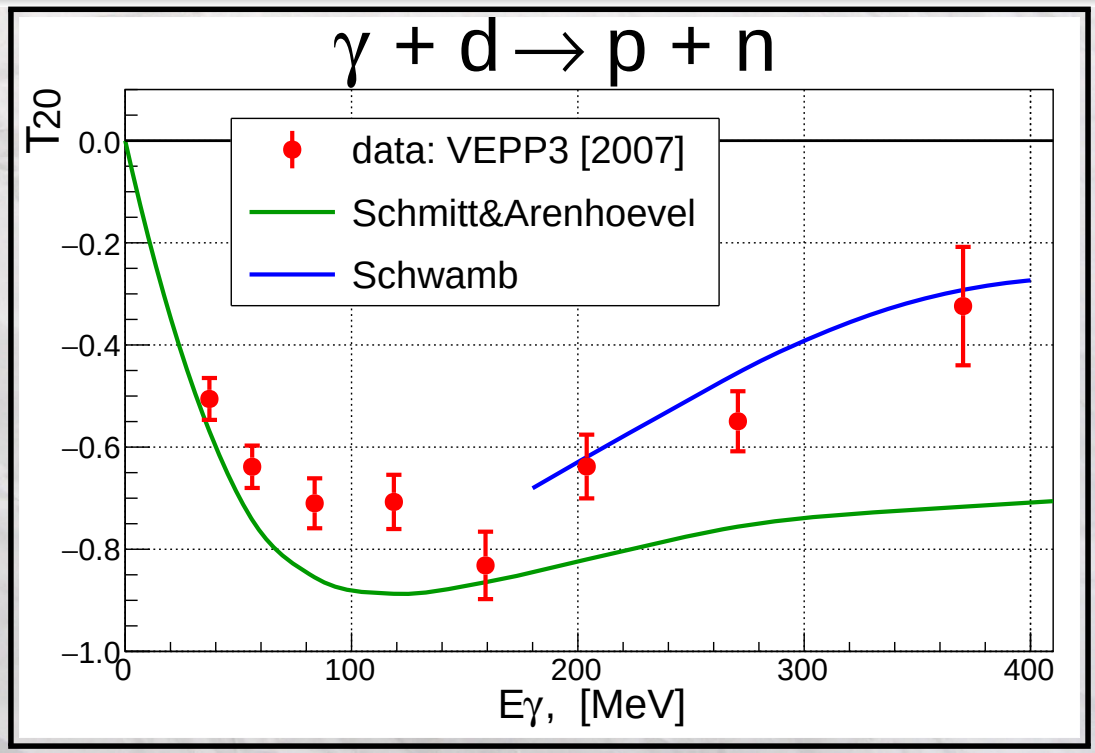
data: ● VEPP-3 [2013], *preliminary* ■ VEPP-3 [2009]

curves: S.S.Kamalov et al. — A. Fix — E. M. Darwish, et al. — M.Levchuk

Discussion

- the quality of agreement between theory and experiment decreases at higher energies.
- this looks very similar to what was seen in deuteron photodisintegration
- in PD it was demonstrated that a novel approach by M.Schwamb&Co, incorporating a π-MEC retardation mechanism, provides much better description
- we are waiting for similar calculations for π^0 photoproduction.





Summary

- An accurate measurement of energy and angular dependencies of tensor asymmetry T_{20} in coherent π^0 photoproduction on deuteron has been performed at VEPP–3 for photon energy up to 500 MeV, using the method of superthin internal target in electron storage ring and an approach of almost-real photons.
- Preliminary results of data analysis are available.
- It is seen that a number of theoretical calculations provide good description of our data at photon energy below ~ 300 MeV.
- The quality of agreement between theory and experiment decreases at higher photon energies $\Rightarrow$ *improvements in theoretical models are needed.*

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THANK YOU FOR YOUR ATTENTION!

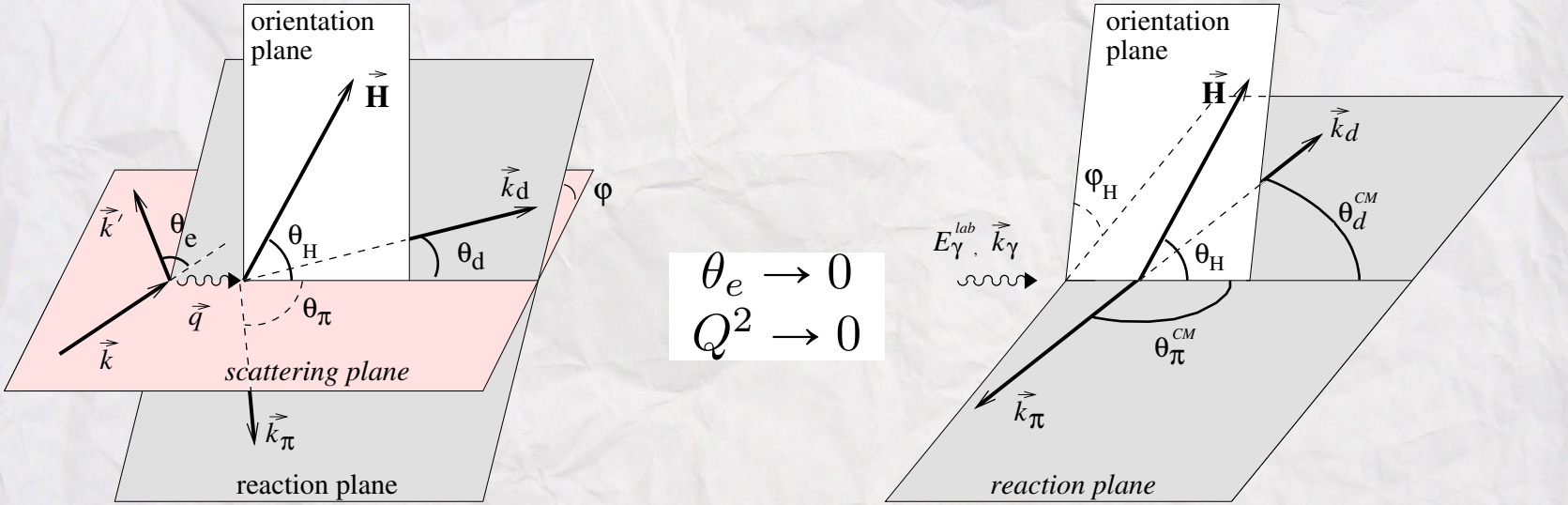
Support

This work was supported by Ministry of Education and Science of the Russian Federation and by RFBR grant No 13-02-00991-a, *except* the part, related to the photon reconstruction algorithm in the electromagnetic calorimeter, which was supported by the Russian Science Foundation (project No. 14-50-00080).

Backup slides

Almost–real photon approach

Electro-production $\longrightarrow$ Photo-production



- electron is not detected.
- Electroproduction cross-section is strongly forward peaked (due to $\sim 1/Q^2$ dependence of virtual photon flux)
- therefore such approach is nearly equivalent to photo-production, while the systematic error due to small virtuality can be estimated as:

$$for\ \theta_e \approx 0: \qquad T_{2M}^{electro}(\theta_e) \approx T_{2M}^{photo} \cdot \left(1 - \frac{\rho_L}{\rho_T}\right)$$

$$\text{for small } \theta_e: \quad \rho_L/\rho_T = \left[\frac{1-r}{r(1-r/2)} \cdot \theta_e\right]^2, \quad \text{where } r = E_\gamma/E_e.$$

e.g. for $E_\gamma/E_e = 500/2000 = 0.25$ and $\overline{\theta_e} \approx 0.5^\circ$: $\quad \delta\mathbf{T_{2M}}/\mathbf{T_{2M}} \approx \mathbf{10^{-3}}$

- photon energy E_γ is reconstructed from E_d, θ_d: $\quad E_\gamma = \dfrac{M_d + M_\pi^2/E_d}{\sqrt{1+2M_d/E_d}\cdot\cos\theta_d - 1}$

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