η Photoproduction off Neutrons

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CHIPP Annual Plenary Meeting 2015

Château de Bossey
June 29th 2015

A2

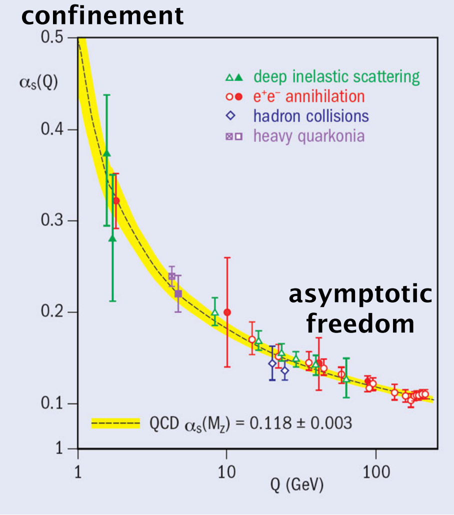
University of Basel

CB-ELSA

Outline

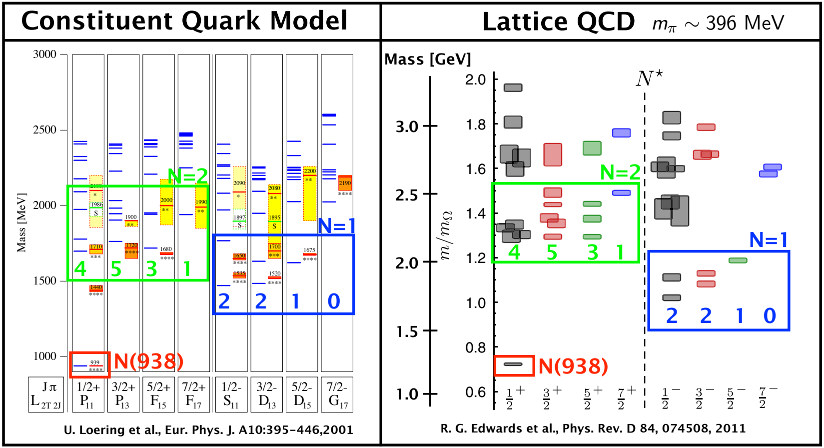
QCD

- QCD: fundamental theory of strong interaction
- pQCD successful at high energies
- Low energies: pQCD not applicable
- Phenomenological descriptions: Quark Models
- Numerical methods: Lattice QCD



S. Bethke, arXiv:hep-ex/0606035

Structure of the Nucleon



Mismatch between experiment and models:

- Ordering of states, missing resonances!
- Model effective dof's or experimental bias?

Experimental Bias

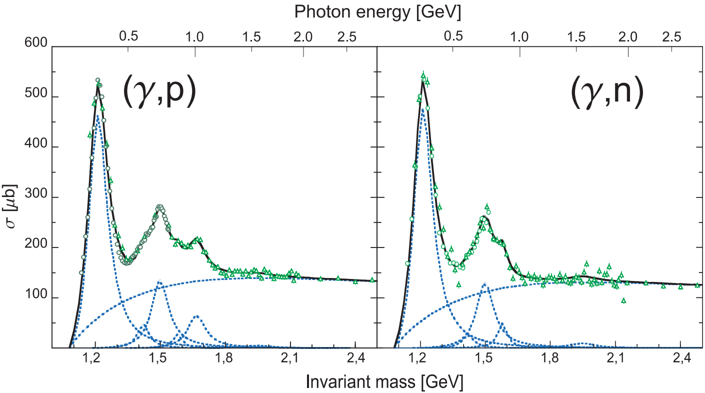
- Most results only πN scattering: photoproduction

	PDG 2010	PDG 2012
$N(1860)5/2^+$		⋆⋆
$N(1875)3/2^-$		⋆ ⋆ ⋆
$N(1880)1/2^+$		⋆⋆
$N(1895)1/2^-$		⋆⋆
$N(1900)3/2^+$	⋆⋆	⋆ ⋆ ⋆
$N(2060)5/2^-$		⋆⋆
$N(2160)3/2^-$		⋆⋆
$\Delta(1940)3/2^-$	⋆	⋆⋆

A. V. Anisovich et al., Eur. Phys. J. A 48 (2012) 15

Experimental Bias

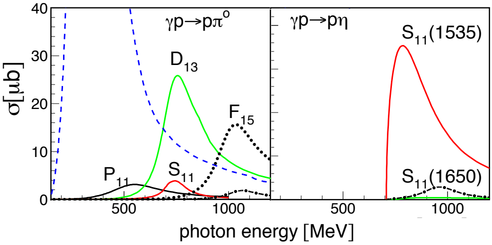
- Most results only πN scattering: photoproduction
- Elm. excitation isospin dependent: neutron



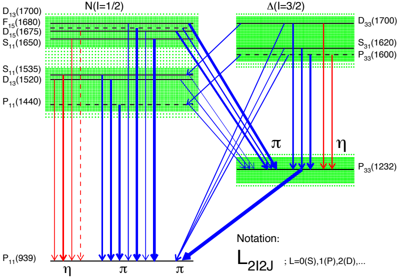
B. Krusche, J. of Physics, Conf. Ser. 349(2012) 012003

Experimental Bias

- Most results only πN scattering: photoproduction
- Elm. excitation isospin dependent: neutron
- Resonances broad and overlapping: η-meson

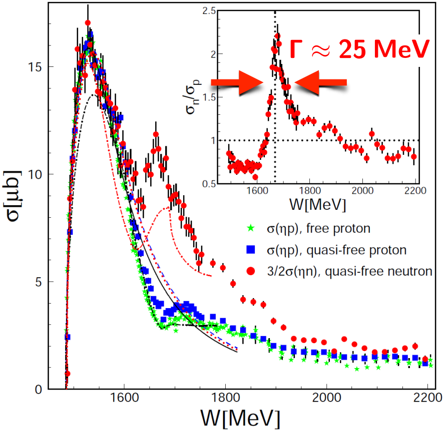


B. Krusche, arXiv:1110.0192



Former Results $\gamma + d \rightarrow \eta + n + (p)$

narrow structure:
W = 1.66 GeV



ELSA, I.Jaeglé et al. Eur. Phys. J A47 (2011) 89

- Seen by GRAAL, LNS Sendai and CBELSA/TAPS collaborations
- **Unusual** properties compared to other nucleon resonances ($\Gamma \sim 150$ MeV)
- **Various explanations**

Various Explanations

Interference of known resonances:

- BnGa: interference effects from $S_{11}(1535)$ and $S_{11}(1650)$ (Anisovich et al.)
- Giessen Model: Interference effect from $S_{11}(1650)$ and $P_{11}(1710)$ (Shklyar et al.)
- η-MAID: $D_{15}(1675)$ resonance (Chiang et al.)

Coupled channel effects:

- s-wave model: $K\Lambda$, $K\Sigma$ loops (Döring et al.)

New narrow resonance:

- Reggeized η-MAID: narrow $P_{11}(1670)$ (Fix et al.)
- Chiral quark soliton model: narrow P_{11} state, N(1680) (Diakonov et al.)

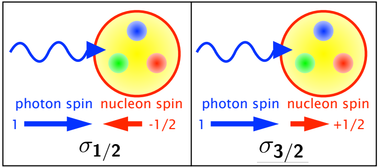
➢ **Multipole analysis** needed to identify quantum numbers!

Complete Experiment

Model independent multipole analysis (Chiang & Tabakin):

- 4 single observables: σ_0, Σ, T, P
- 4 carefully chosen double polarisation observables

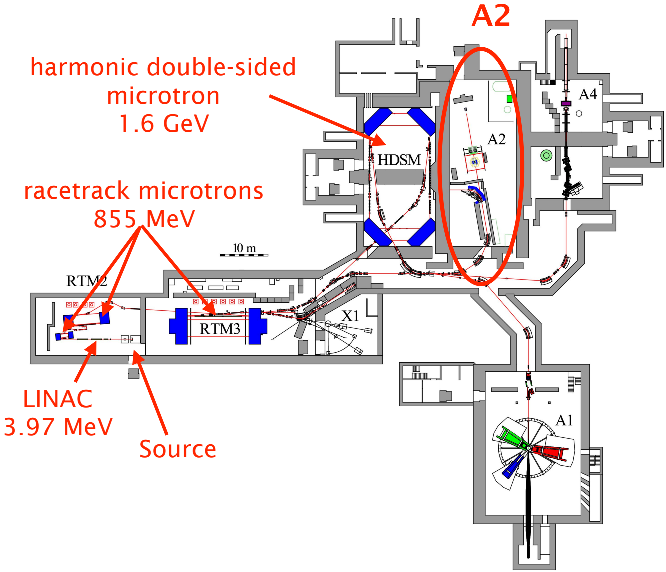
photon	target -	x	y	z
-	σ_0		T	
linearly	Σ	H	-P	-G
circularly	-	F	-	-E



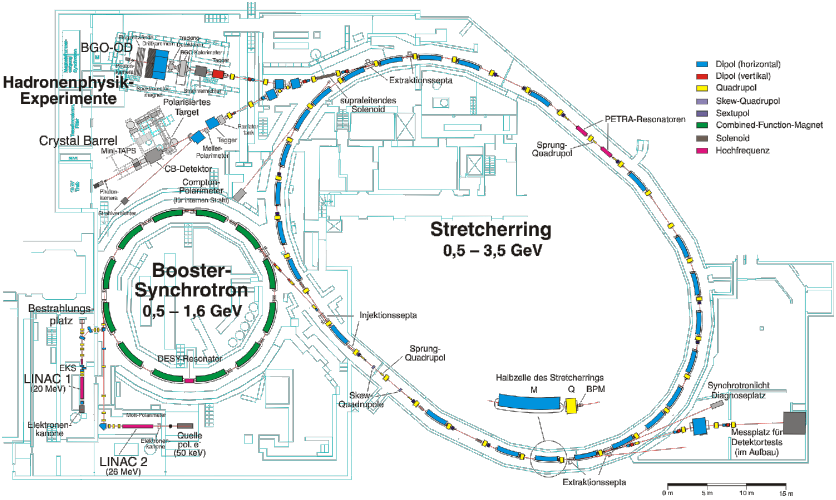
$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\sigma_{1/2} - \sigma_{3/2}}{2\sigma_0}$$

circularly polarised photons
+
longitudinally polarised target

MAinzer MIcrotron (Mainz)



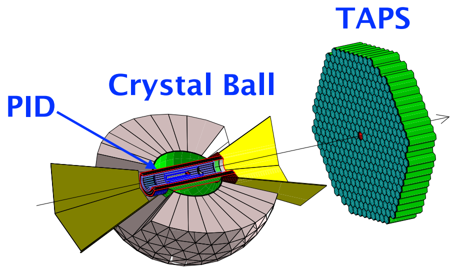
ELectron Stretcher Accelerator (Bonn)



Experimental Setup

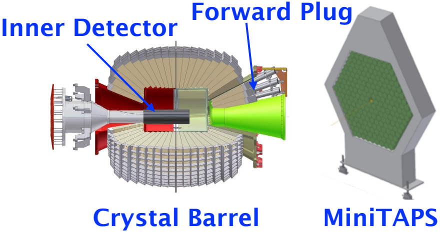
A2 @ MAMI

- Continuous beam
- $E_\gamma \leq 1.6$ GeV
- CB: 672 NaI
- TAPS: BaF_2 & $PbWO_4$
- PID

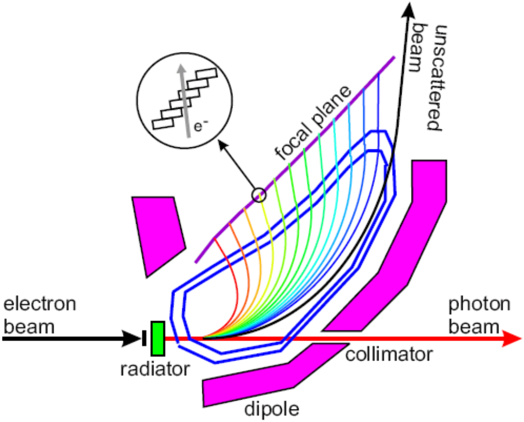


CBELSA/TAPS @ ELSA

- Quasi-continuous beam
- $E_\gamma \leq 3.2$ GeV
- CBB: 1230 CsI
- MiniTAPS: 216 BaF_2
- Inner Detector



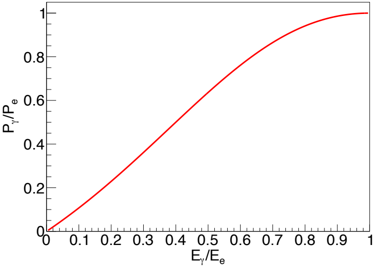
Bremsstrahlung Tagging



$$E_\gamma = E_{e^-}^{beam} - E_{e^-}^{tagged}$$

- longitudinal polarised electrons
- Møller radiator
- circularly polarised photons

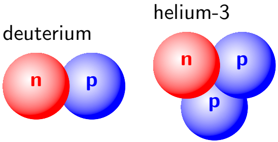
Polarisation Transfer:

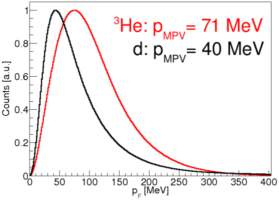


Targets

Neutron Targets

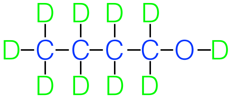
- light nuclei: deuterium, ^{3}He

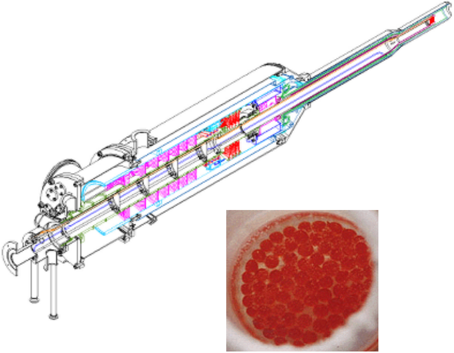




Polarised Target

- deuterated Butanol





Challenges of Quasi-Free Nucleons (Bound)

Detection of recoil nucleons:

- neutrons: 10-30% efficiency
- deposited energy $\neq$ kinetic energy
- but: kinematics completely defined without measuring energy: use only angular information

Fermi Motion:

- momentum of the initial state nucleon not known
- smears out structures
- solution: use final state particles

FSI:

- meson-nucleon, nucleon-nucleon
- compare quasi-free to free proton results!

Basic Analysis Concept

- **neutral and charged particles:**
  use information from charge sensitive detectors
- **event classes:**

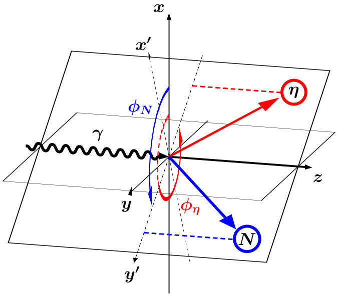
	$\sigma_{\mathbf{p}}$ $\gamma p \rightarrow \eta p$	$\sigma_{\mathbf{n}}$ $\gamma n \rightarrow \eta n$
$\eta \rightarrow 2\gamma$	$2n$ & $1c$	$3n$
$\eta \rightarrow 3\pi^0 \rightarrow 6\gamma$	$6n$ & $1c$	$7n$

- **best solution from χ^2-test:**
  for events with >2 neutral hits to find η and recoil neutron

Kinematical Cuts

Coplanarity:

$$\Delta\phi = \phi_N - \phi_\eta$$

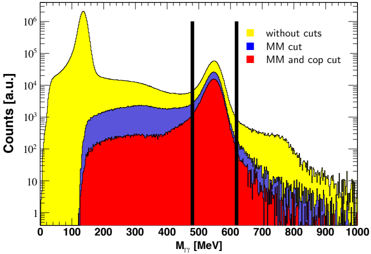


Missing Mass:

$$\Delta M = |P_{Beam} + P_N^I - P_\eta| - m_N$$

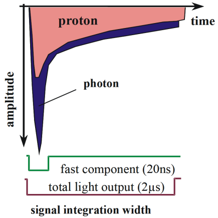
Invariant Mass:

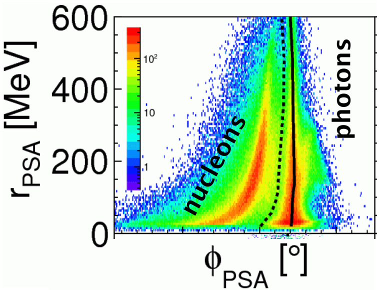
$$M_{\gamma\gamma} = \sqrt{E_{\gamma_1} E_{\gamma_1} (1 - \cos\psi_{12})}$$



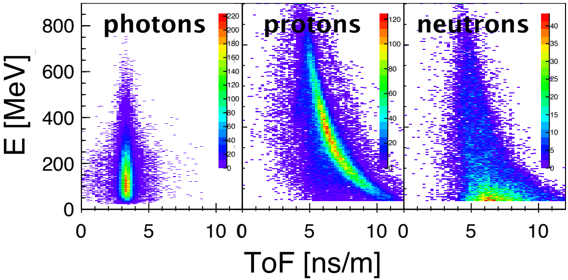
Other Identification Possibilities (TAPS)

Pulse Shape Analysis:

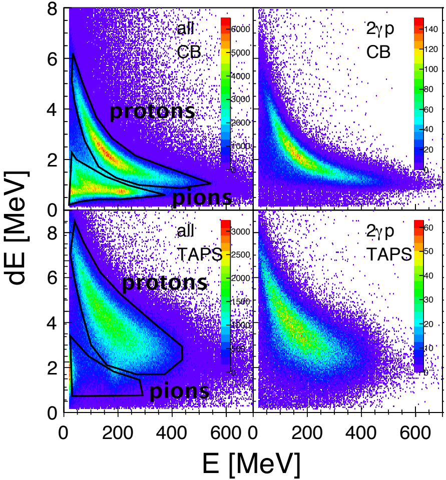




ToF versus energy:



ΔE versus E (CB/TAPS)

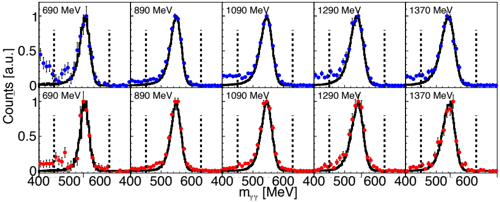


Extraction of Unpolarised Cross Sections

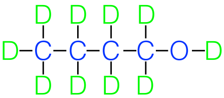
$$\left.\frac{d\sigma}{d\Omega}\right|_{unpol}(E,\cos\theta^*_\eta) = \frac{N(E,\cos\theta^*_\eta)}{\epsilon(E,\cos\theta^*_\eta)\cdot N_\gamma(E)\cdot n_t\cdot \Gamma_i/\Gamma\cdot\Delta\Omega}$$

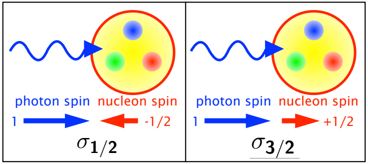
- **yields**: integrate invariant mass
- **photon flux**
- **detection efficiency**: Geant, nucleon detection efficiency correction (hydrogen data)
- **factors**: target density, branching ratio, solid angle

Invariant Mass:

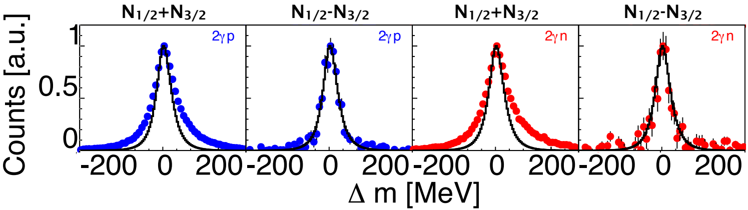


Extraction of Observable E





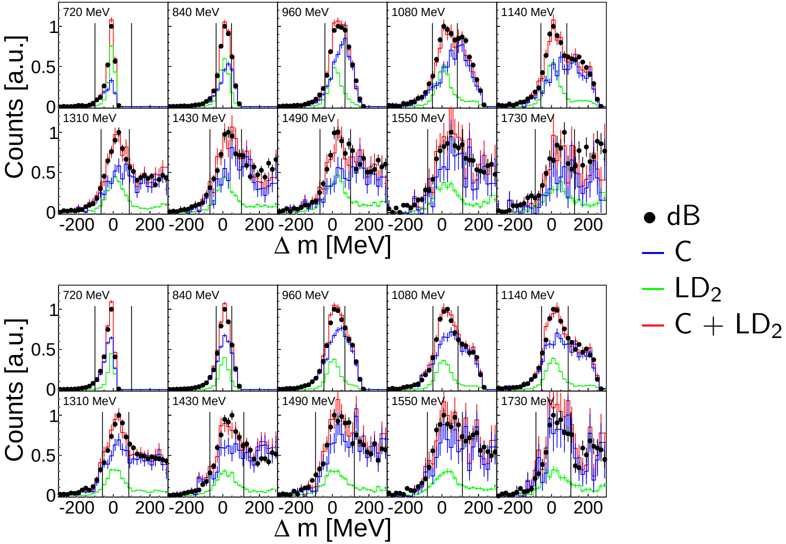
$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{1}{P_\gamma \cdot P_T} \cdot \frac{N_{1/2} - N_{3/2}}{N_{1/2} + N_{3/2} + 2N_C}$$



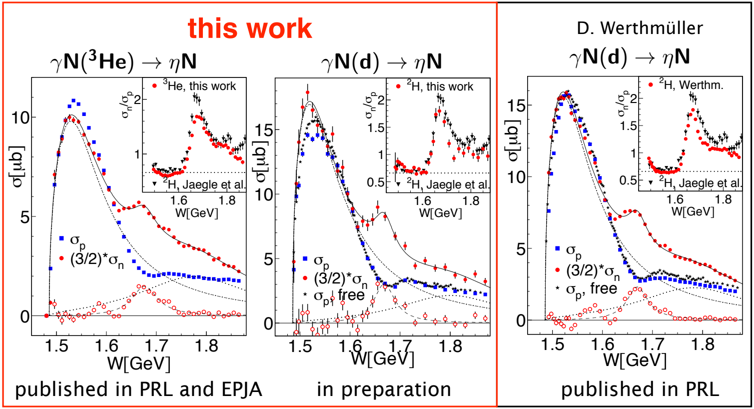
Carbon Subtraction: Missing Mass

p

n

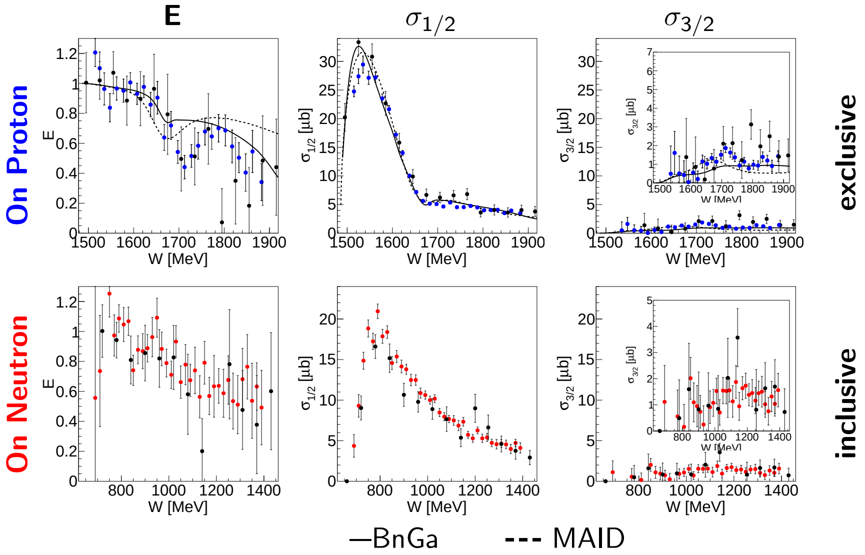


Cross Sections ^{3}He (A2) and LD$_2$ (CBELSA/TAPS)

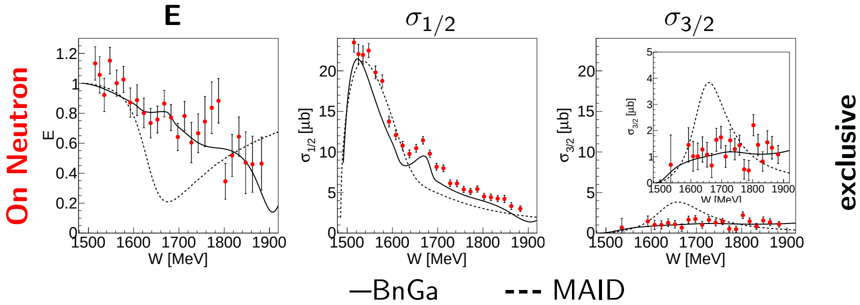


- Nucleon system with different momentum distribution and different neutron/proton ratio
- Exclude nuclear effects (re-scattering of mesons, FSI)
- Narrow structure no artefact!

Polarisation Observable E (CBELSA/TAPS & A2)



Polarisation Observable E - Neutron (A2)



- Model predictions by BnGa: constructive interference of $S_{11}(1535)$ and $S_{11}(1650)$
  $\rightarrow$ change of sign of the electromagnetic coupling of the $S_{11}(1650)$ resonance for the neutron
  $\rightarrow$ contradictory to Quark Model descriptions!

Summary

Unpolarised cross sections on ^{3}He and LD_2:

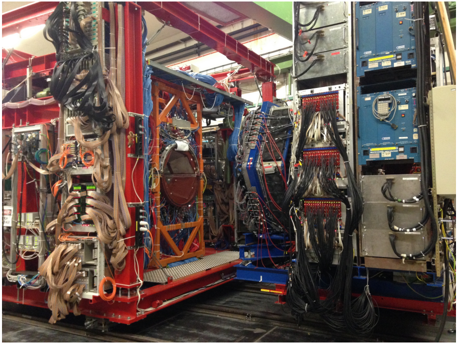
- Confirmed narrow structure
- Exclude nuclear effects
- ^{3}He published in PRL and EPJA
- LD_2 ready for publication

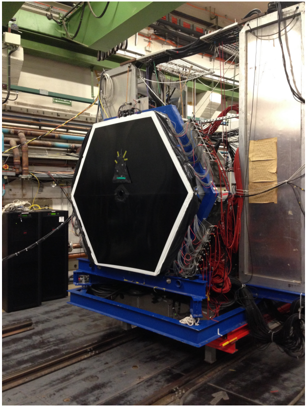
Double polarisation observable E for quasi-free p & n:

- Narrow structure only visible in $\sigma_{1/2} \rightarrow S_{11}$ or P_{11} state
- Ready for publication

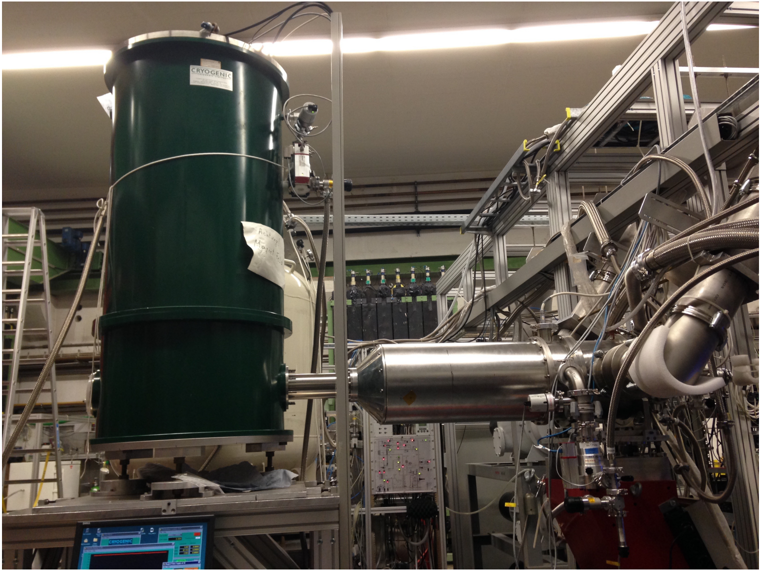
Thanks for your attention!

A2 Experiment

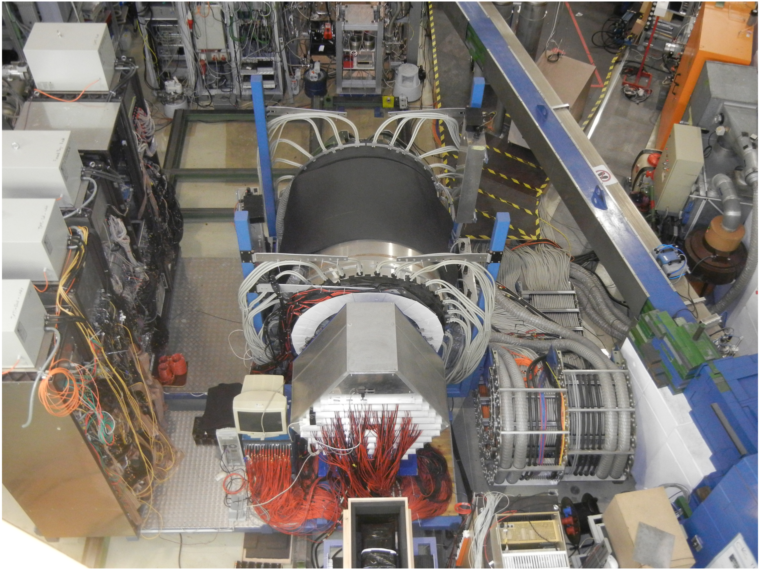




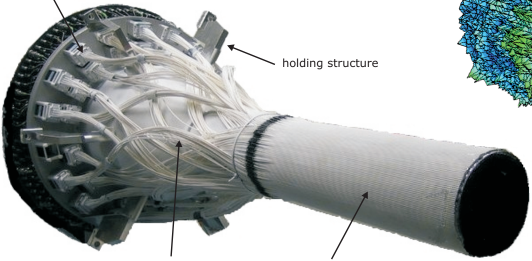
A2 Frozen Spin Target

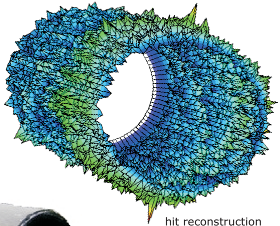


CBELSA/TAPS Experiment



CBELSA/TAPS: Inner Detector





Influence of Photoproduction

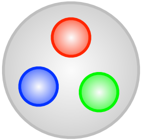
	PDG 2010	PDG 2012
$N(1860)5/2^+$		⋆⋆
$N(1875)3/2^-$		⋆ ⋆ ⋆
$N(1880)1/2^+$		⋆⋆
$N(1895)1/2^-$		⋆⋆
$N(1900)3/2^+$	⋆⋆	⋆ ⋆ ⋆
$N(2060)5/2^-$		⋆⋆
$N(2160)3/2^-$		⋆⋆
$\Delta(1940)3/2^-$	⋆	⋆⋆

A. V. Anisovich et al., Eur. Phys. J. A 48 (2012) 15

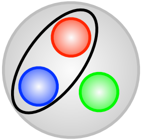
∗∗∗∗	Existence is certain, and properties are at least fairly well explored.
∗∗∗	Existence is very likely but further confirmation of quantum numbers and branching fractions is required.
∗∗	Evidence of existence is only fair.
∗	Evidence of existence is poor.

Quark Models: Effective degree of freedom

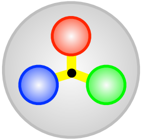
3 equivalent
Constituent Quarks



Quark-Diquark
->2 dof
less states



Flux Tubes
->more states
via rotation
or vibration

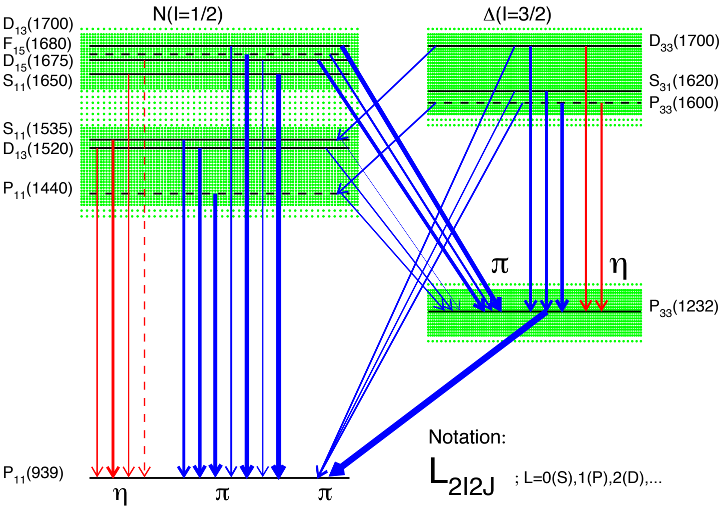


⋮

Models

- **SAID:** Database for electro and photoproduction, partial wave analysis with energy independent fits
- **MAID:** unitary isobar model, Partial wave analysis of SAID and additional data. Uses Breit-Wigner distributions and background contributions as Born term and vector meson exchange term in t-channel (effective Lagrangians)
- **BnGa:** Coupled channel approach. Simultaneous fitting of different channels and observables. K-matrix parametrisation at low energies, relativistic Breit-Wigner at energies > 2.2 GeV. Non-resonant terms from t- and u-channel amplitudes.

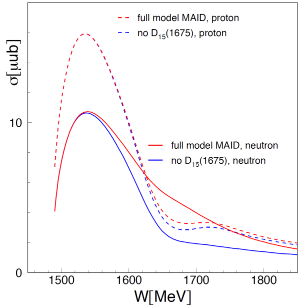
Isospin Filter



Narrow Structure: Models

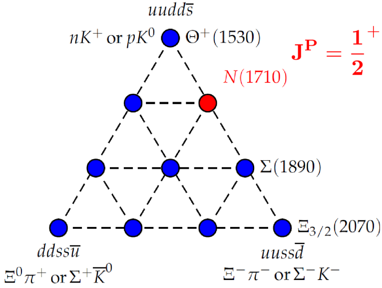
- **etaMAID:**
  $D_{15}(1675)$ resonance
  ➢ $\Gamma_{\eta N}/\Gamma_{tot} = 17\%$
  (PDG: $\Gamma_{\eta N}/\Gamma \simeq 0 - 1\%$)

  (L.Tiator, NSTAR2005)



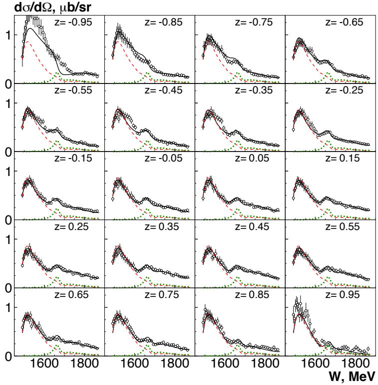
- **Chiral Soliton Model:**
  non-strange member of the baryon antidecuplet:
  P_{11}

  (D.Diakonov et al., arXiv:hep-ph/9703373v2)

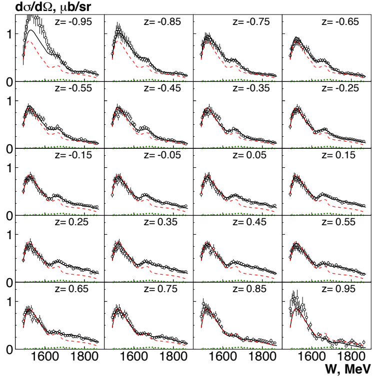


Narrow Structure: Fit with BnGa

Narrow $P_{11}(1685)$:



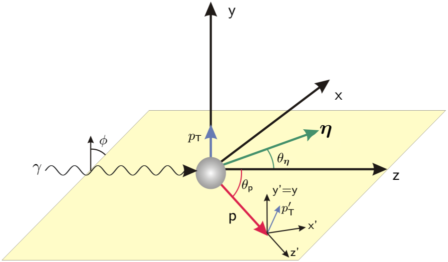
$S_{11}(1650)$ Interference :



$\longrightarrow$

sign change of elm.
$A_{1/2}$coupling of $S_{11}(1650)$

Polarisation Observables



photon		target			recoil			target + recoil		
		x	y	z	-	-	-	x	y	z
		-	-	-	x'	y'	z'	x'	y'	z'
-	σ_0	-	T	-	-	P	-	$T_{x'}$	$T_{y'}$	$T_{z'}$
linearly	Σ	H	-P	-G	$O_{x'}$	-T	$O_{z'}$	-	-	-
circularly	-	F	-	-E	$-C_{x'}$	-	$-C_{z'}$	-	-	-

Polarisation Observables

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} \cdot \{1 - P_{lin}\Sigma \cos 2\phi$$
$$+ P_x \cdot [-P_{lin}H \sin 2\phi + P_{circ}F]$$
$$- P_y \cdot [+P_{lin}P \cos 2\phi - P_{circ}T]$$
$$- P_z \cdot [-P_{lin}G \sin 2\phi - P_{circ}E]\ \}$$

Data Overview

	beamtime	target material	length [cm]	E_{e^-} [GeV]	collimator [mm]	photon pol.	current [nA]	trigger
CBELSA/TAPS	2008	LD_2	5.258	2.35	4	circular	0.32	eta3
				2.35	7	circular	0.32	eta3
				2.35	7	circular	0.32	eta3nC
	2008	LH_2	5.262	2.35		circular	0.19	trig42
	02.03.-22.04.2011	dbutanol	1.88	2.35	4	circular	0.70	eta4
	08.06.-21.06.2011	dbutanol	1.88	2.35	4	circular	0.70	eta4
	04.12.-10.12.2011	carbon	1.88	2.35	4	circular	0.70	eta4
A2	28.10-17.11.2008	^{3} He	5.08	1.508	4	circular	8.0	M2+ 300 MeV
	31.03-30.04.2009	LH_2	10.0	1.558	4	circular	10.0	M3+ 360 MeV
	08.05-25.05.2009	LD_2	3.02	1.558	4	circular	4.5	M2+ 300 MeV
	15.07.-24.07.2013	dbutanol	2.0	1.557	2	circular	8.3	M2+ 300 MeV
	23.02.-28.02.2014	dbutanol	2.0	1.557	2	circular	9.0-10.0	M2+ 250 MeV
	28.02.-03.03.2014	carbon	2.0	1.557	2	circular	9.0	M2+ 250 MeV
	24.03.-30.03.2015	dbutanol	2.0	1.557	2	circular	10.0	M2+ 250 MeV

W_B versus W_R

Cross Sections as function of...

- $\mathbf{W_B}$ $(\mathbf{E}_\gamma)$: $\sqrt{s}$ calculated with 4-momenta of initial state particles:

$$W_B^2 = (P_\gamma + P_{N,i})^2 = 2E_\gamma m_N + m_N^2$$

➢ Structures are smeared out because of Fermi motion

$\mathbf{W}_B$ versus $\mathbf{W}_R$

Cross Sections as function of...

- $\mathbf{W_B}$ ($\mathbf{E}_\gamma$) : $\sqrt{s}$ calculated with 4-momenta of initial state particles:

$$W_B^2 = (P_\gamma + P_{N,i})^2 = 2E_\gamma m_N + m_N^2$$

➢ Structures are smeared out because of Fermi motion

- $\mathbf{W_R}$: $\sqrt{s}$ calculated with measured 4-momenta of final state particles (η, participant nucleon):

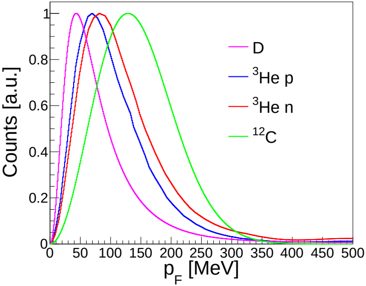
$$W_R^2 = (P_\eta + P_{N,f})^2$$

➢ No effects from Fermi motion,
but experimental resolution for recoil nucleon

Corrections - Monte Carlo Simulation

Requires Event Generator (Pluto,GSI)

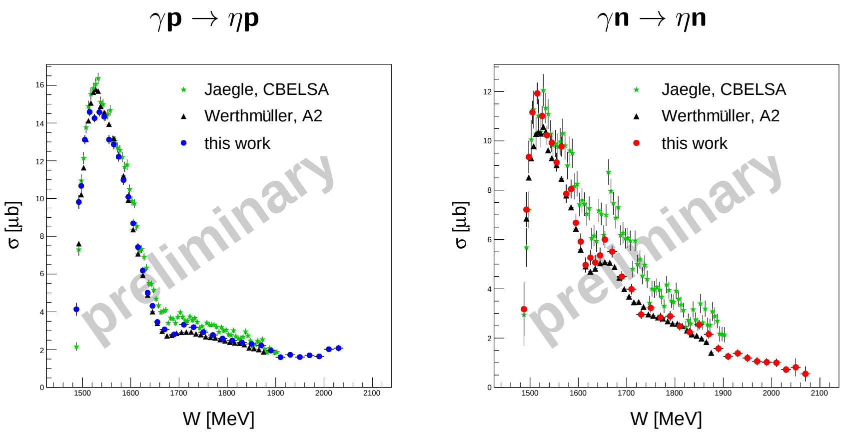
- Implementation of Fermi motion
- Fermi Plugin
- Used by other collaborations



Nucleon Detection Efficiency

- Hard to simulate
- Different interaction mechanisms than photons
- Deposited energy $\neq$ total energy
- Recalculate energy with kinematical considerations
- Additional corrections using hydrogen data.

Cross Sections Deuterium (CBELSA/TAPS)

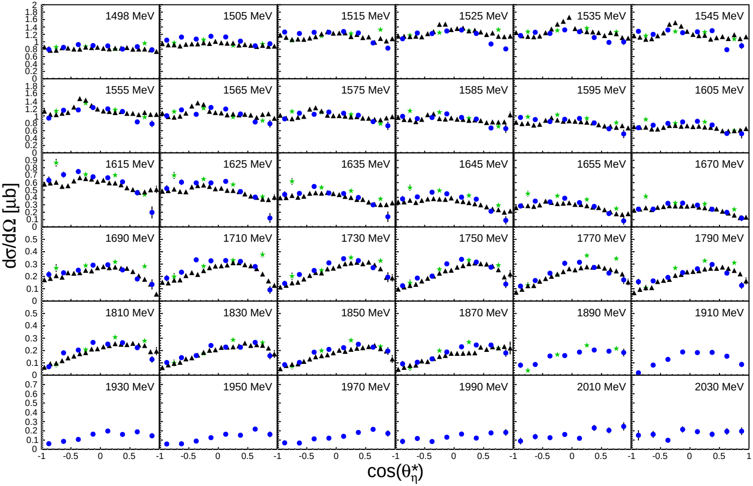


- Consistent with A2 data
- Deviation from old CBELSA/TAPS data

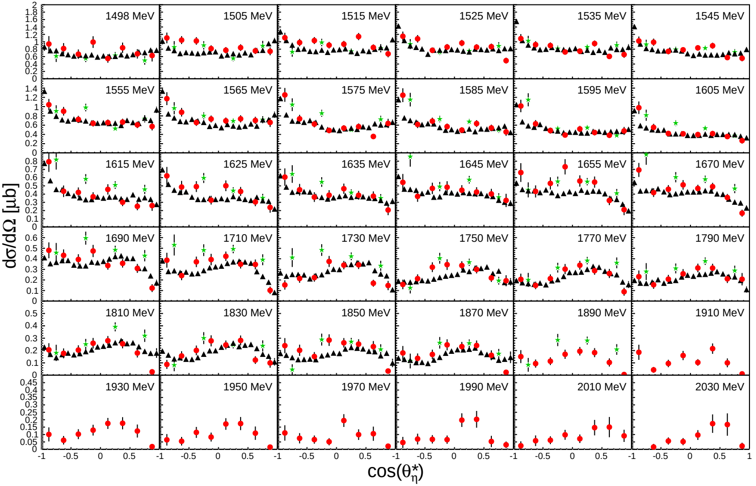
Extracted Parameters

	W[MeV]	Γ [MeV]	$b_\eta A^n_{1/2}$ [$10^{-3} GeV^{-1/2}$]
LD_2 (D. Werthmueller)	1670 ± 1	29 ± 3	12.3 ± 0.8
LD_2 (this work)	1676 ± 4	30 ± 3	15.3 ± 1.8
^{3}He (this work)	1675 ± 2	46 ± 8	11.9 ± 1.2

Differential Cross Sections LD_2, Proton (Bonn)

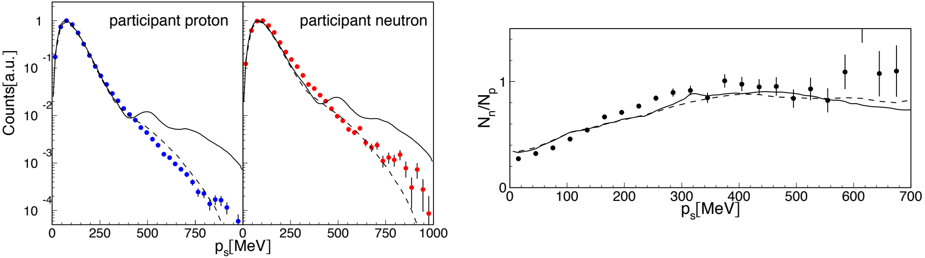


Differential Cross Sections LD_2, Neutron (Bonn)



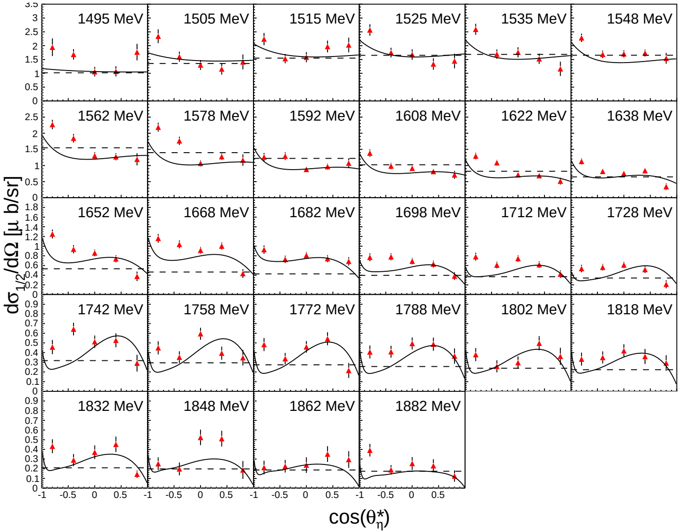
Fermi Momentum ^{3}He (A2)

$$\vec{p}_F = \vec{p}_P^{IS} = \vec{p}_P^{FS} + \vec{p}_\eta - \vec{p}_\gamma$$

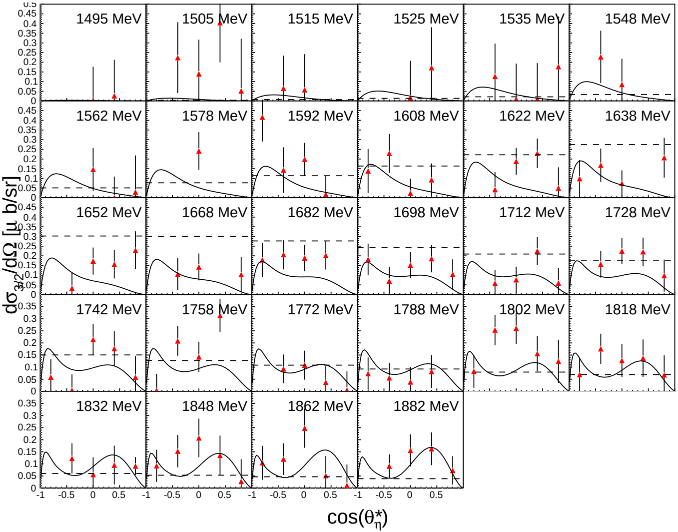


- $p_s < 300$ MeV: Long range interactions ratio $\sim N/Z = 0.5$
- $p_s > 300$ MeV: Ratio ~ 1 as for deuterium, SRC, high Fermi momenta are produced by isospin singlet pairs!
- Dedicated experiments are planned at JLAB!

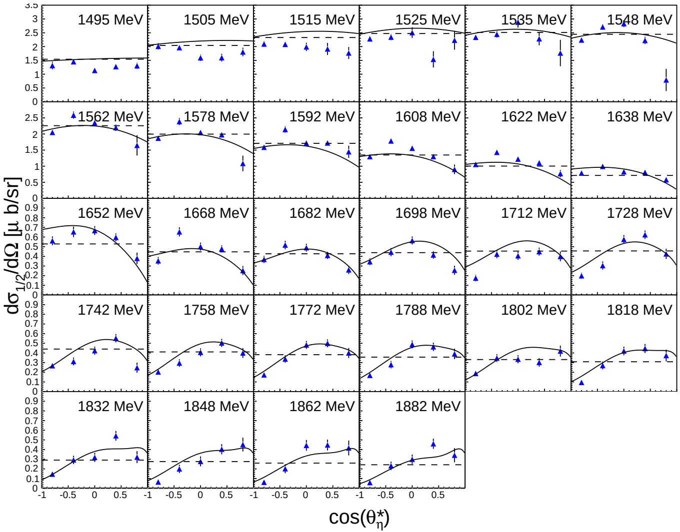
$\sigma_{1/2}$ Neutron



$\sigma_{3/2}$ Neutron



$\sigma_{1/2}$ Proton



$\sigma_{3/2}$ Proton