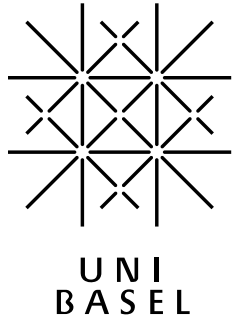
Photoproduction of η Mesons off Light Nuclei

Lilian Witthauer

Hadron 2011

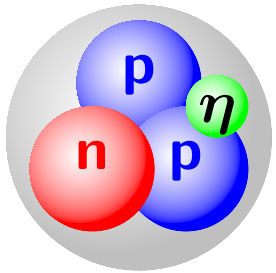
Munich, June 13^{th} 2011



Outline

Light η-Mesic Nuclei (F. Pheron et al.)

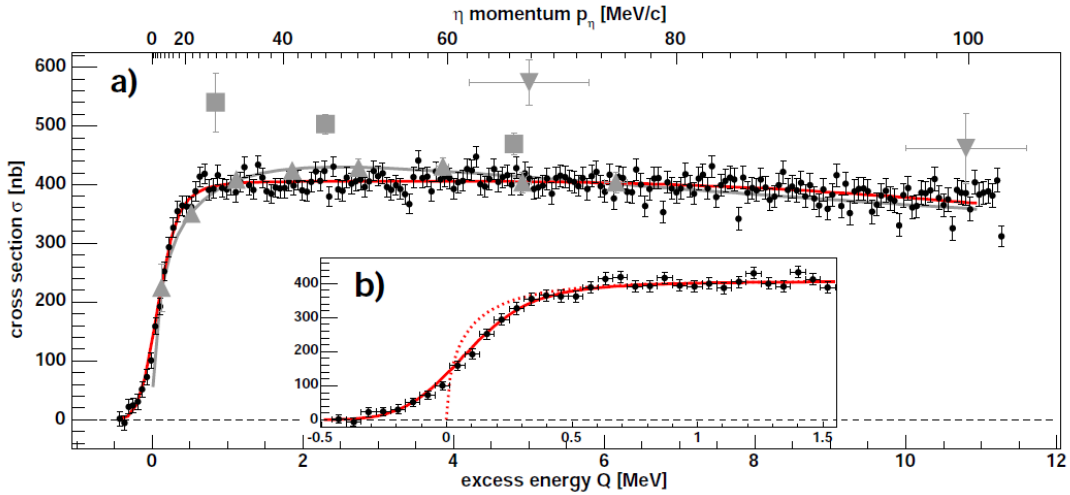
Do the properties of the strong interaction allow the formation of meson-nucleus bound states?



- Several model predictions:
  - Bhalerao and Liu (1985): attractive s-wave ηN-interaction for $A > 12$.
  - Liu and Haider (1986): interaction migth lead to the formation of quasi-bound η-nucleus states for $A > 10$ (η-mesic nuclei)
  - new analyses prefer larger values for the scattering length (above 0.5fm)
    ➢ existence of very light η-mesic nuclei (^{2}H, ^{3}H, ^{3}He, ^{4}He)?
- Quasi-bound states should give rise to an enhancement at threshold of the cross section relative to the expectation for phase space behavior.

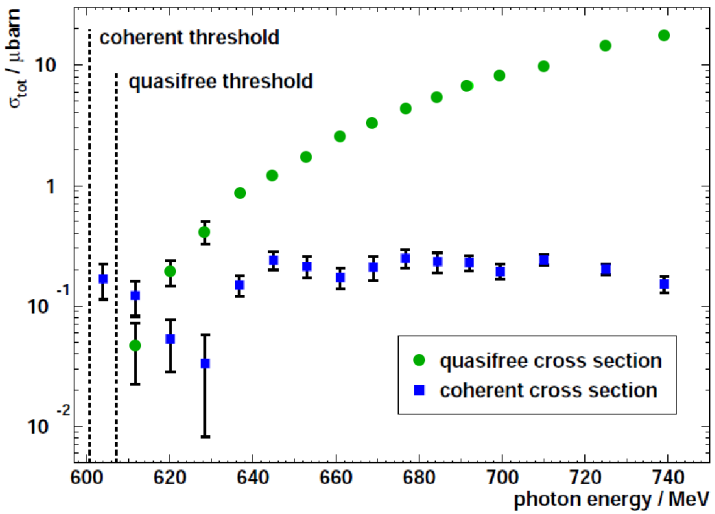
Light η-Mesic Nuclei: Experimental Evidence

➢ hadronic induced reactions:



- ● T. Mersmann et al. $dp \rightarrow {}^3\mathrm{He}\eta$ (COSY-ANKE)
- ▲ H.-H. Adam et al. $dp \rightarrow {}^3\mathrm{He}\eta$
- ▼ B. Mayer et al. $pd \rightarrow {}^3\mathrm{He}\eta$
- ■ J. Berger et al. $dp \rightarrow {}^3\mathrm{He}\eta$

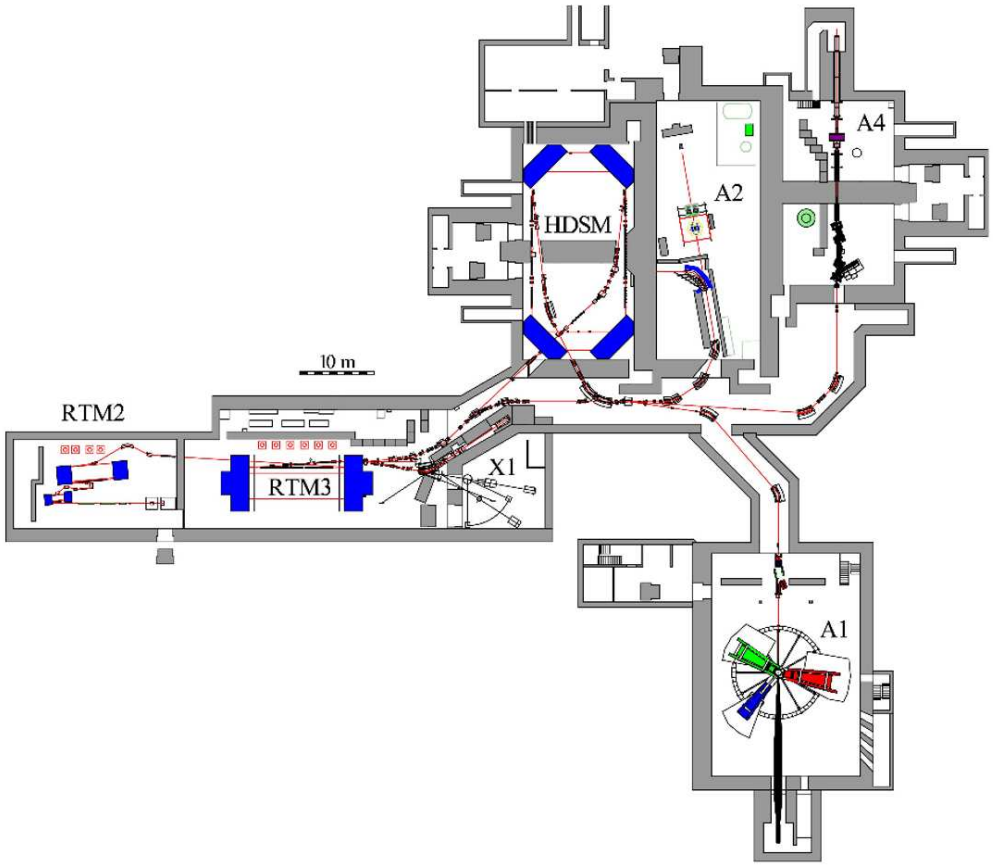
➢ photon induced reactions:



M. Pfeiffer et al.

Phys. Rev. Lett. 92 (2004) 252001

MAinzer MIcrotron: Electron Accelerator



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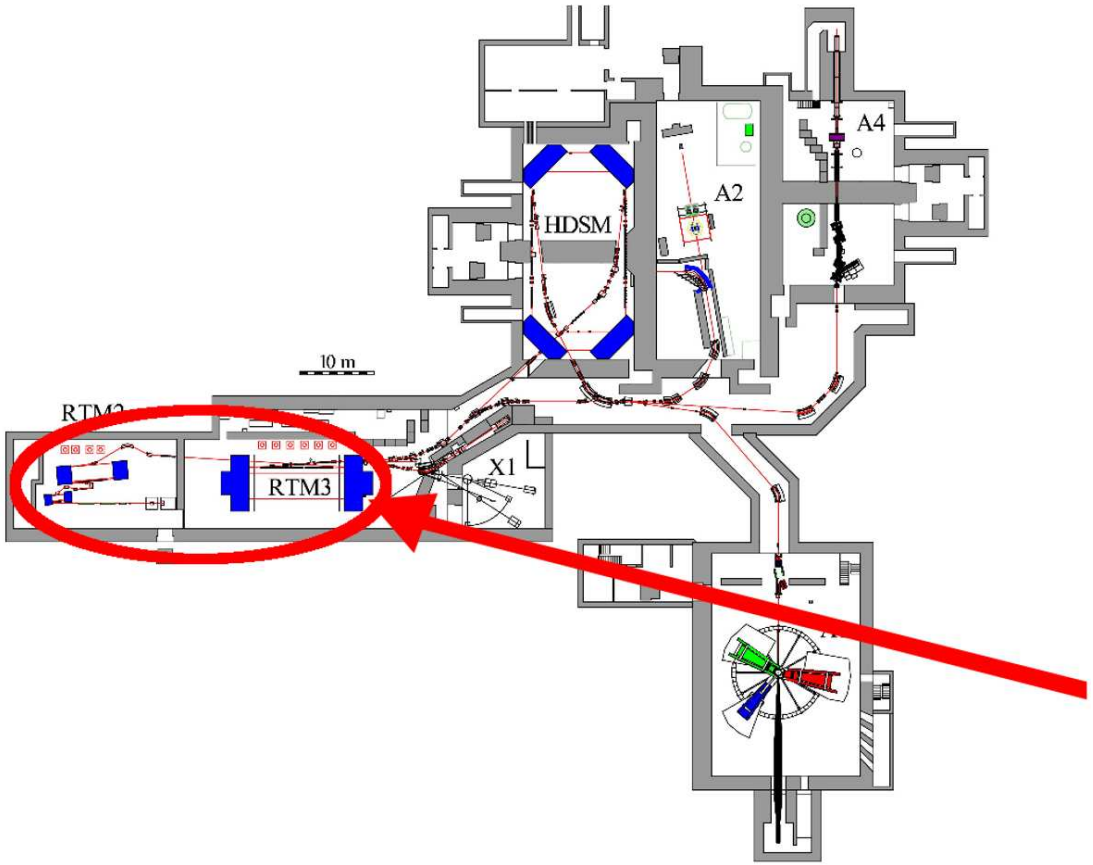
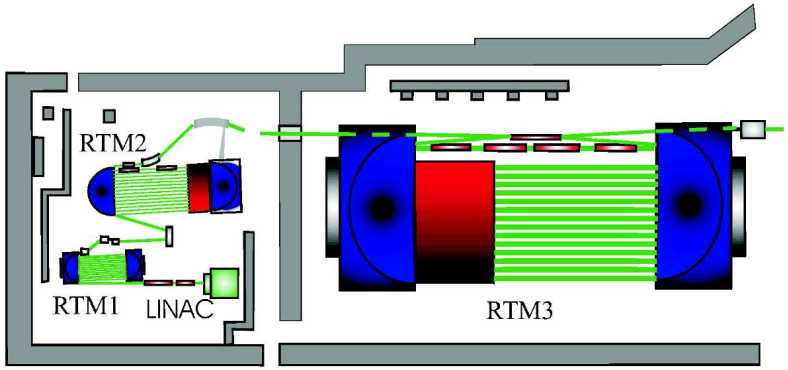


Stage:	Turns:	Energy:
LINAC	–	3.97 MeV
RTM1	18	14.9 MeV
RTM2	51	180 MeV
RTM3	90	855.1 MeV



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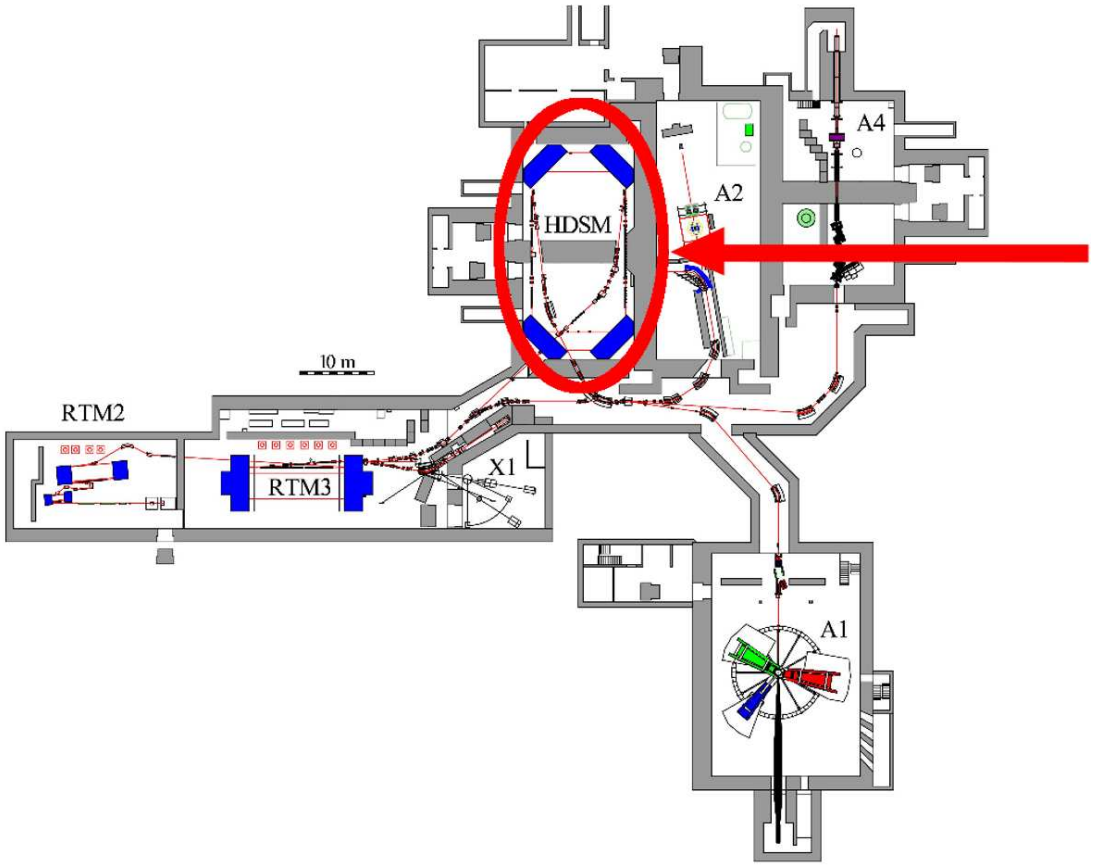
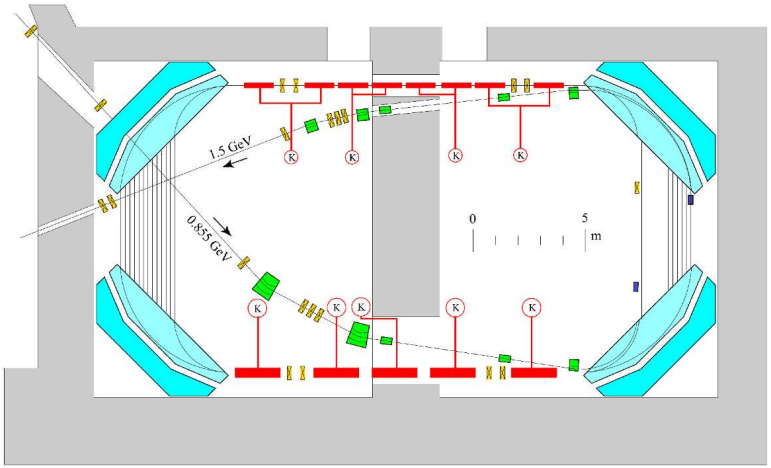
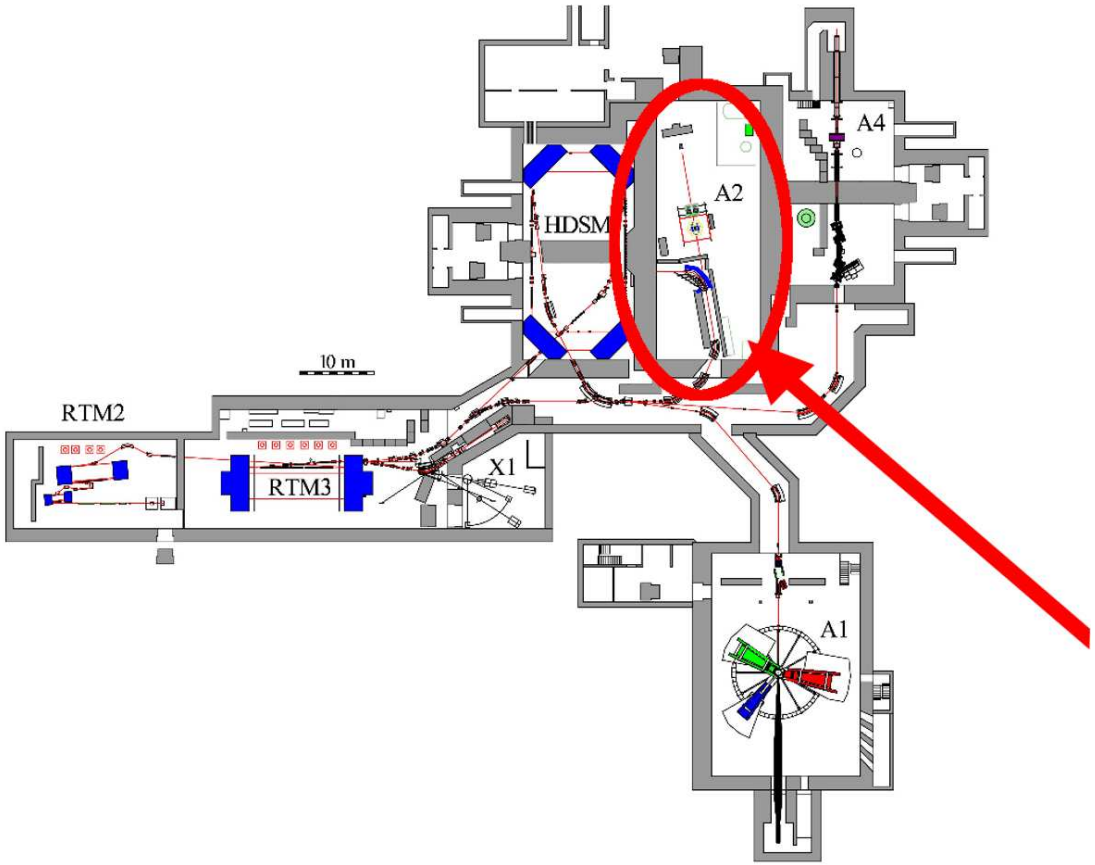




Stage:	Turns:	Energy:
HDSM	43	1508 MeV

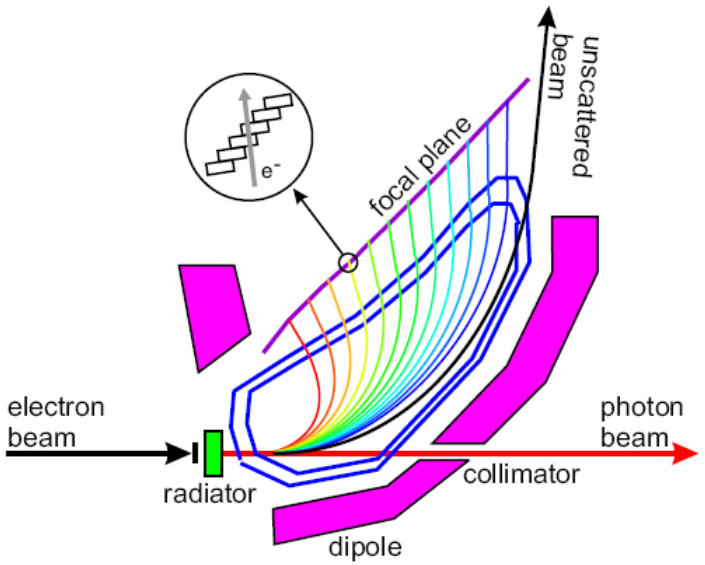
MAinzer MIcrotron: Electron Accelerator



A2 Experimental Hall

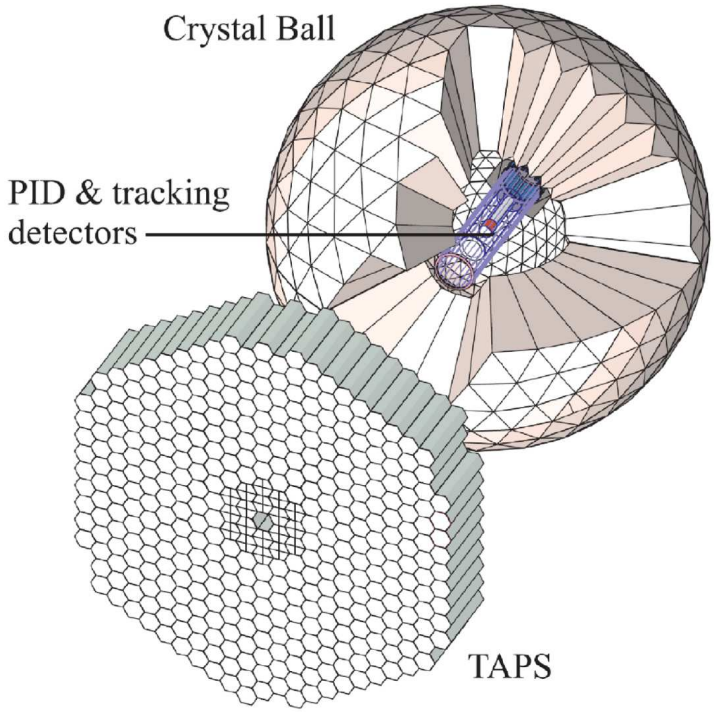
Bremsstrahlung Tagging

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



Experiment: Crystall Ball and TAPS

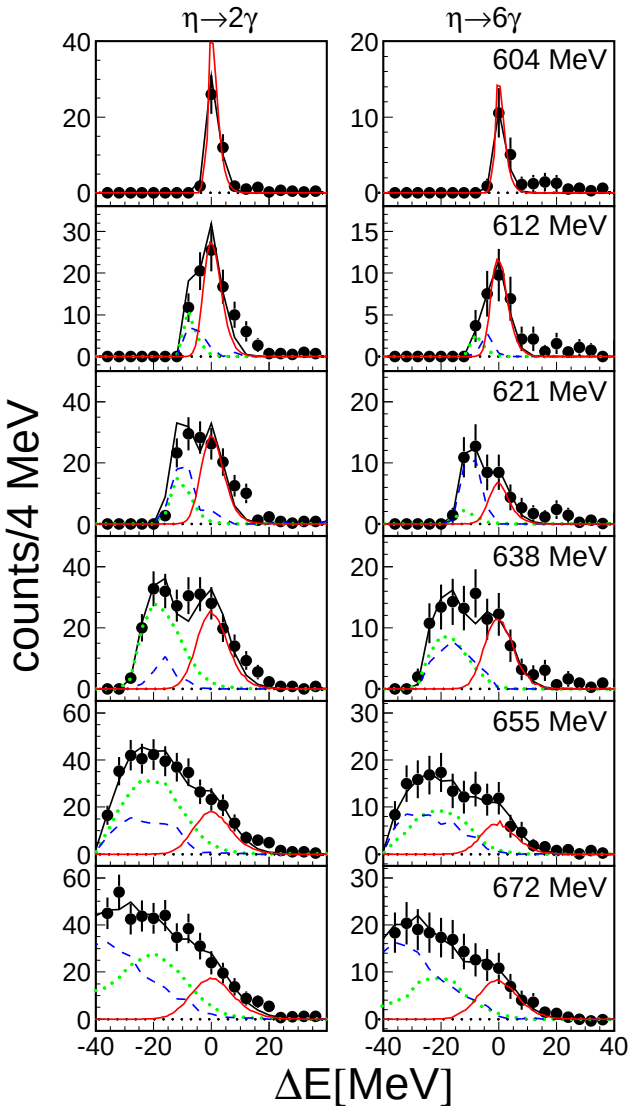
- Circularly polarised tagged photon beam (0.45 GeV to 1.4 GeV)
- Crystal Ball: Highly segmented sphere made of NaI
- PID: Cylinder of scintillation counters surrounds target, charged particle detector
- TAPS: Forward wall, BaF_2 & $PbWO_4$ crystals
- ^{3}He Target: 5.3 cm long, density: 0.069 g/cm^3



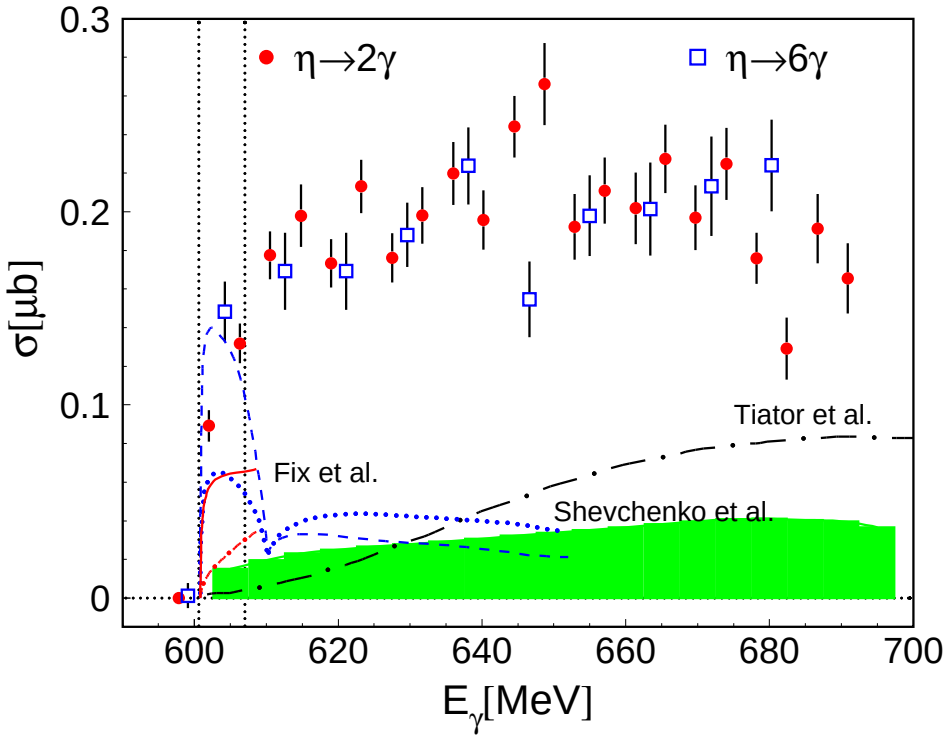
geometrical exeptance close to 4π

Identification of $\gamma\,^3\mathrm{He}\rightarrow{}^3\mathrm{He}\eta$ (F. Pheron et al.)

- Decay channels: $\eta \rightarrow 2\gamma$, $\eta \rightarrow 6\gamma$
- Invariant mass analysis for each energy and meson cm-polar angle
- 6γ: photons combined via χ^2-test to 3 pairs (best solution for $3\pi^0$ IM)
  $\rightarrow$ 110 MeV - 150 MeV cut
- use overdetermined kinematics to separate coherent from breakup reactions. $\rightarrow$ missing energy
  - ➢ strong coherent component visible
  - ➢ recoil taken by quasi-free nucleon
  - ➢ recoil taken by di-nulceon

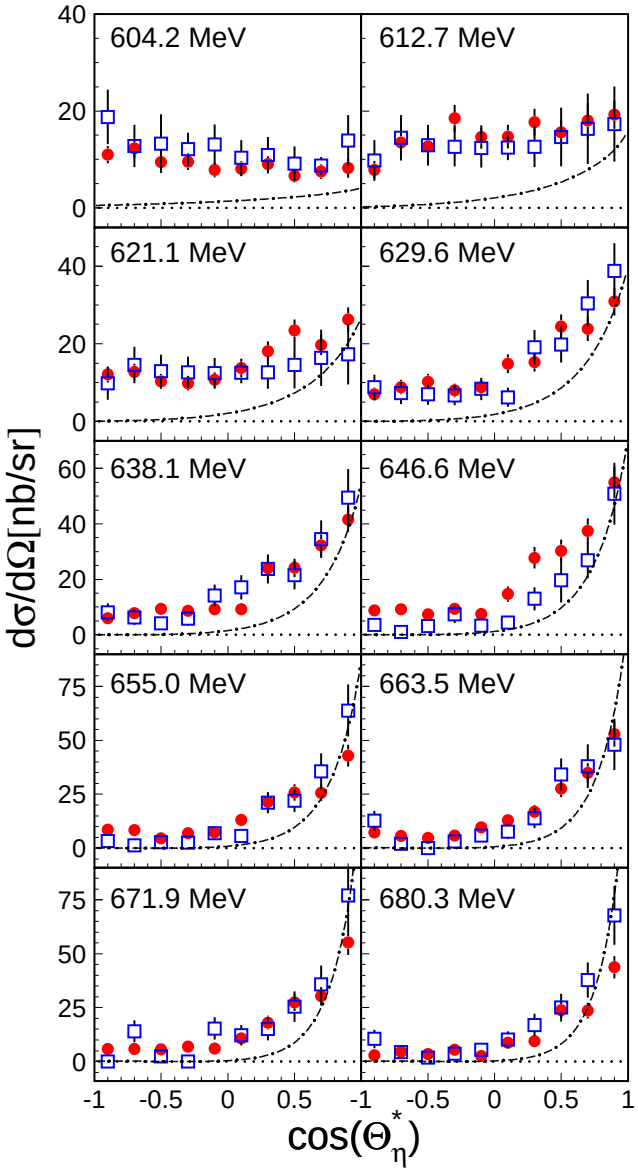


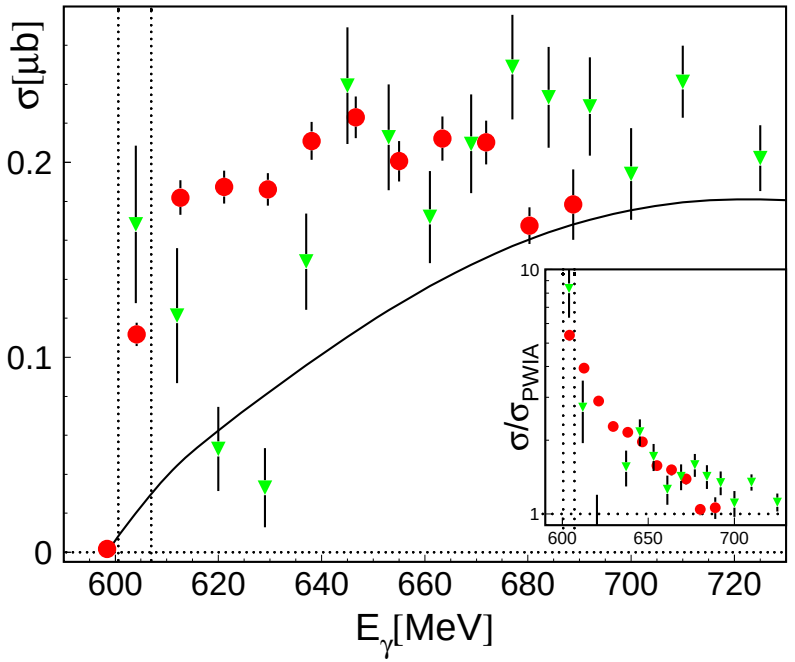
$\gamma^3\text{He}\rightarrow{}^3\text{He}\eta$ Cross Section (F. Pheron et al.)



- agreement between 2γ and 6γ
- disagreement between existing models and data
- **Tiator et al.**: PWIA
- **Fix and Arenhövel**: 1. PWIA 2. DWIA $\rightarrow$ strong FSI effects, full four-body model
- **Shevchenko et al.**: 2 examples for different FSI modelling $\rightarrow$ strong threshold effects

$\gamma\,^3\mathrm{He} \rightarrow\, ^3\mathrm{He}\eta$ Cross Section (F. Pheron et al.)

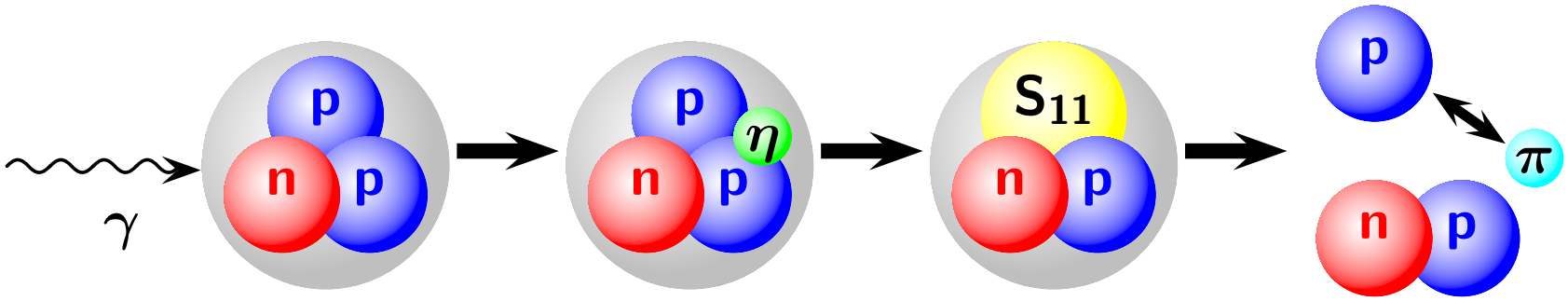


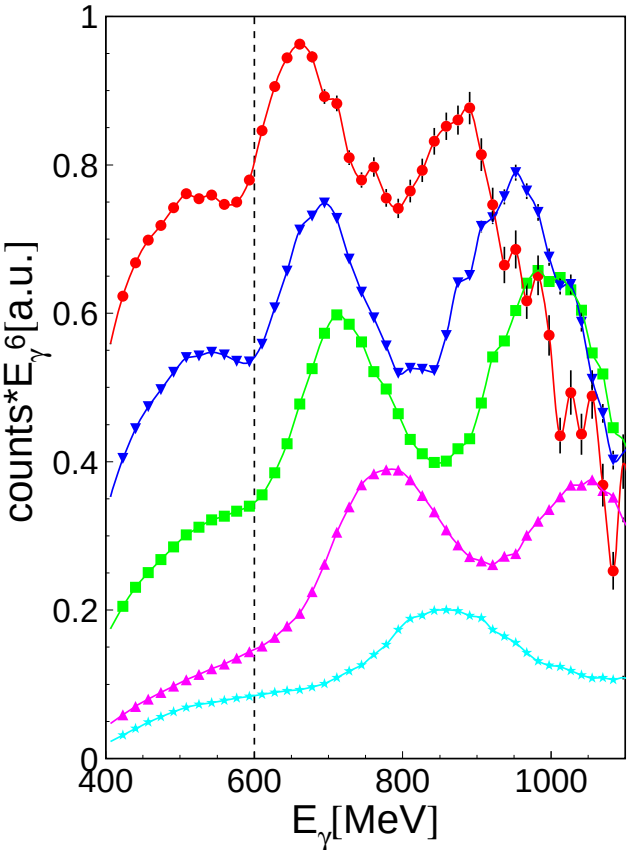


- average of 2γ and 6γ F. Pheron et al.
- M. Pfeiffer et al., Phys. Rev. Lett. 92 (2004) 252001.
- PWIA:

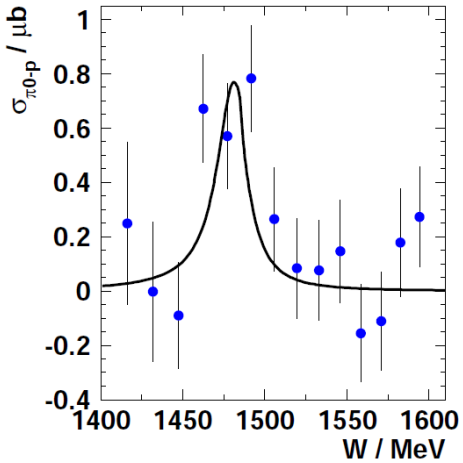
$$\frac{d\sigma_{PWIA}}{d\Omega}(E_\gamma, q) = \frac{q_\eta^{(A)}}{k_\gamma^{(A)}} \cdot \left(\frac{k_\gamma^{(N)}}{q_\eta^{(N)}} \frac{d\sigma_{elem}}{d\Omega} \right) \cdot \frac{F_A^2(q^2)}{F_p^2(q^2)}$$

π^0-p back-to-back (F. Pheron et al.)





$\Psi_{\pi p}$=165°-180°
$\Psi_{\pi p}$=150°-165°
$\Psi_{\pi p}$=140°-150°
$\Psi_{\pi p}$=130°-140°
$\Psi_{\pi p}$=120°-130°



M. Pfeiffer et al., Phys. Rev. Lett. 92 (2004) 252001.

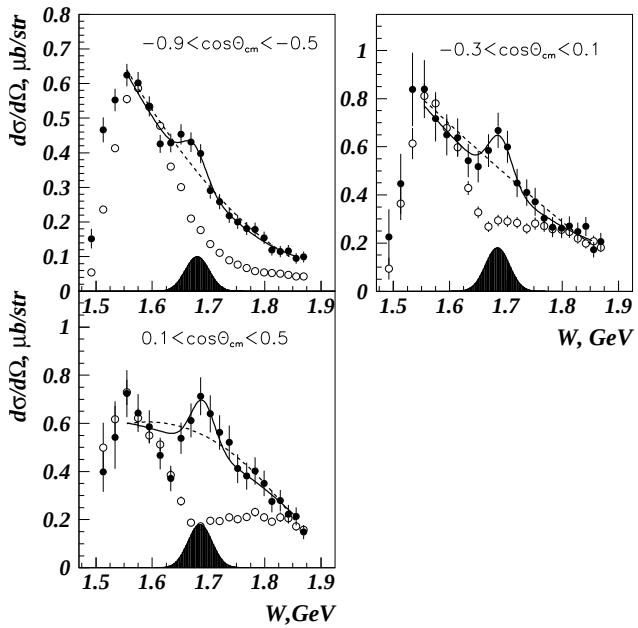
Peak is an artefact arising from the complicated background structure of quasi-free π^0 production!

Quasi-Free η Photoproduction

GRAAL collaboration:

narrow structure in the cross section:

$$\gamma + \mathbf{d} \rightarrow \eta + \mathbf{n(p)}$$



GRAAL, V.Kuznetsov et al., hep-ex 0606065

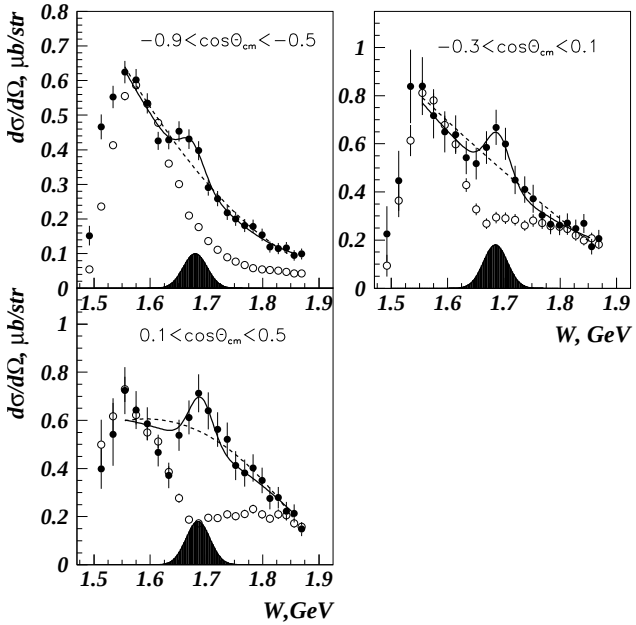
Quasi-Free η Photoproduction

GRAAL collaboration, **CBELSA/TAPS collaboration**, LNS-Sendai:

narrow structure in the cross section:

$$\gamma + \mathbf{d} \rightarrow \eta + \mathbf{n(p)}$$

W = 1.66 GeV
Γ ≈ 25 ± 12 MeV



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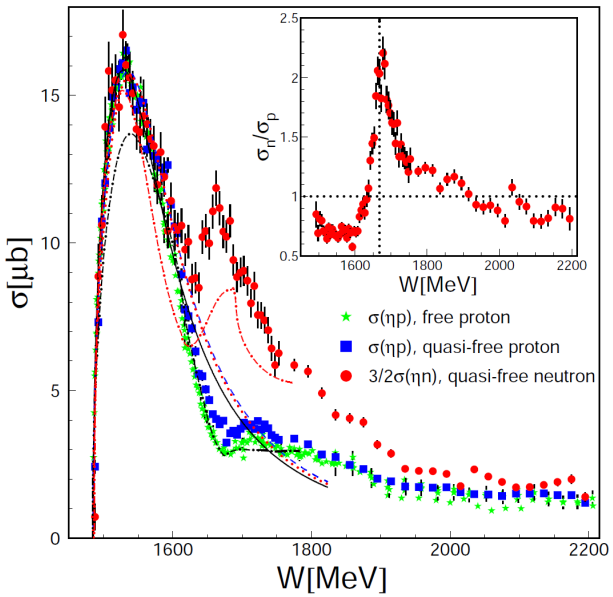
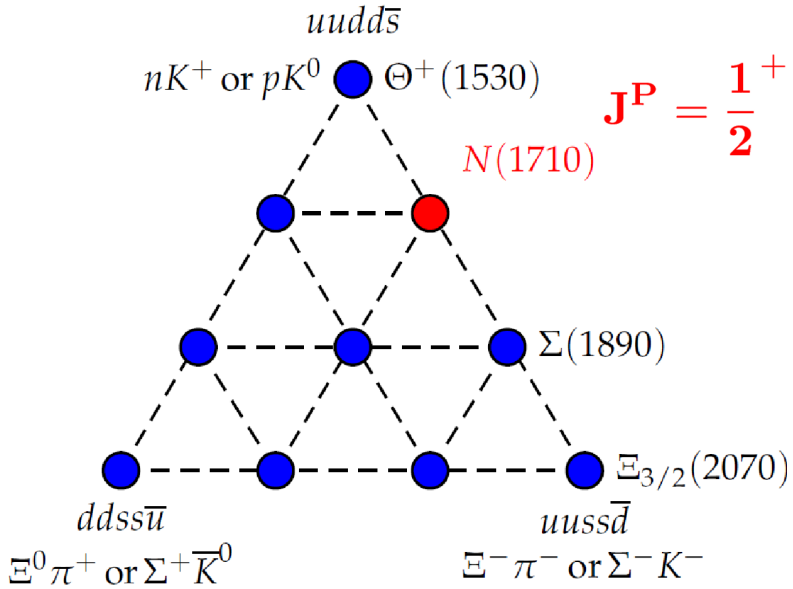


ELSA, I.Jaeglé et al. EPJA accepted

Nature of this Structre is unknown

1. **etaMAID:**
   Large contribution of the $D_{15}(1675)$
   ➢ high value for the branching ratio of $\Gamma_{\eta N}/\Gamma_{tot} = 17\%$
   (PDG: $\Gamma_{\eta N}/\Gamma \simeq 0 - 1\%$)
   (L.Tiator, NSTAR2005)

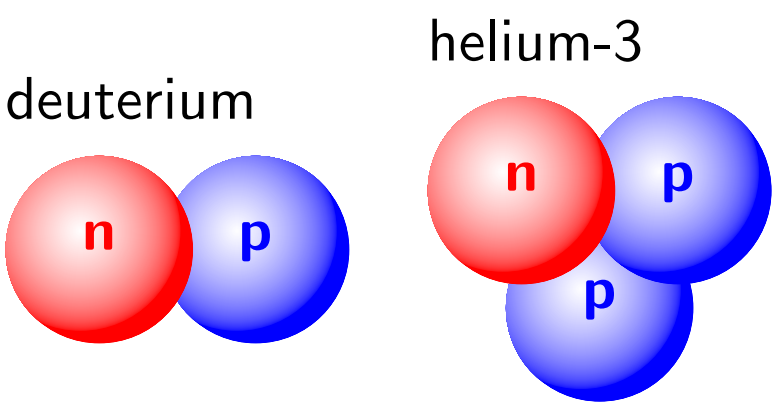
2. **Chiral Soliton model:**
   Predicts the existence of a nonstrange member of the baryon antidecuplet (P_{11}-like state).
   Photoexcitation of this state is thought to have a bigger coupling to the neutron than to the proton
   (D.Diakonov et al., arXiv:hep-ph/9703373v2)

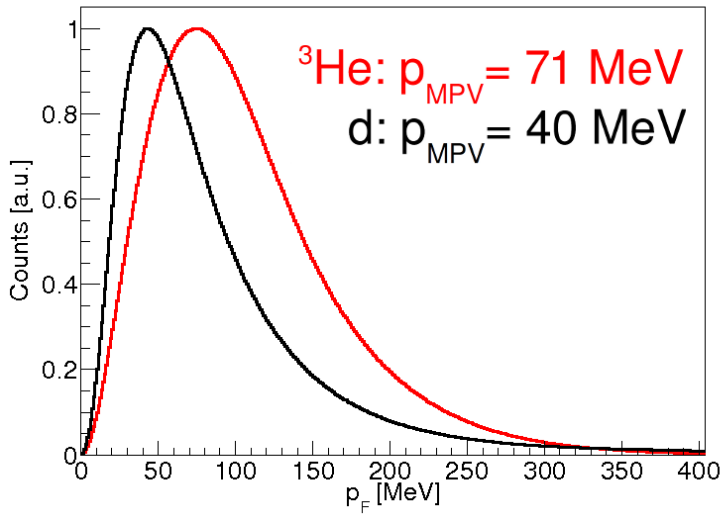


Why on ^{3}He ?

Exclude possibility that the structure could arise from nuclear effects: rescattering of mesons, final state interaction

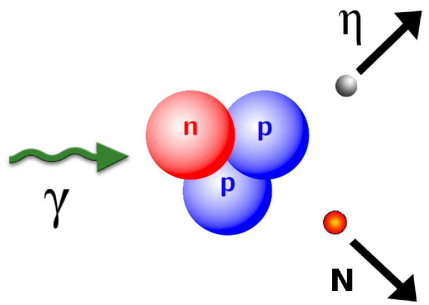
- study it for a nucleon system with different momentum distribution and different neutron/proton ratio: **^{3}He**





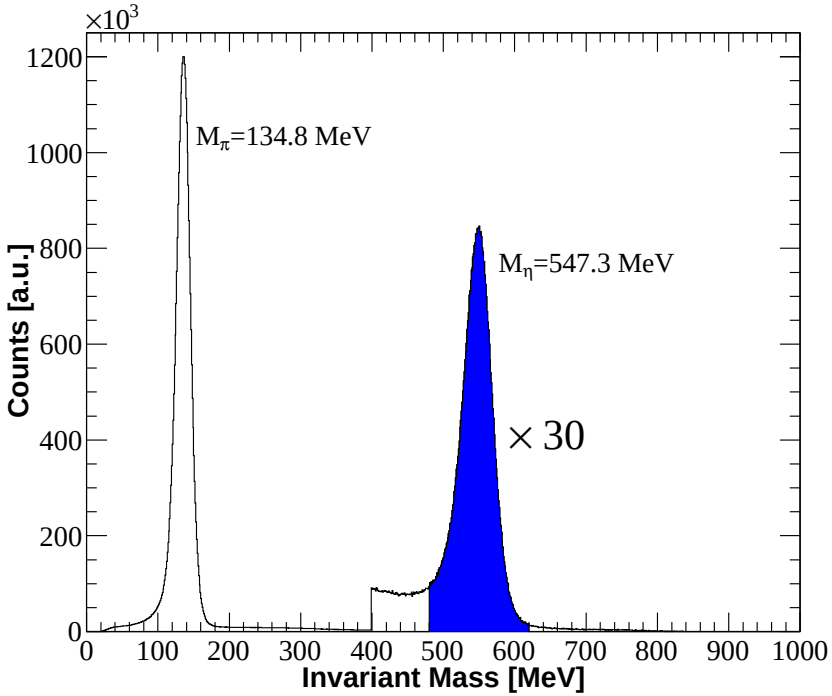
Reaction Identification of the Quasi-Free Reaction

$$\gamma + {}^3He \rightarrow \begin{matrix} p(np) \\ n(pp) \end{matrix} + \eta$$



➢ Reconstruct η out of 2 photons with invariant mass technique:
$M_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos(\phi_{\gamma_1\gamma_2}))}$

➢ Clean invariant mass because of other cuts on decay photons: Coincidence cuts, random subtraction...

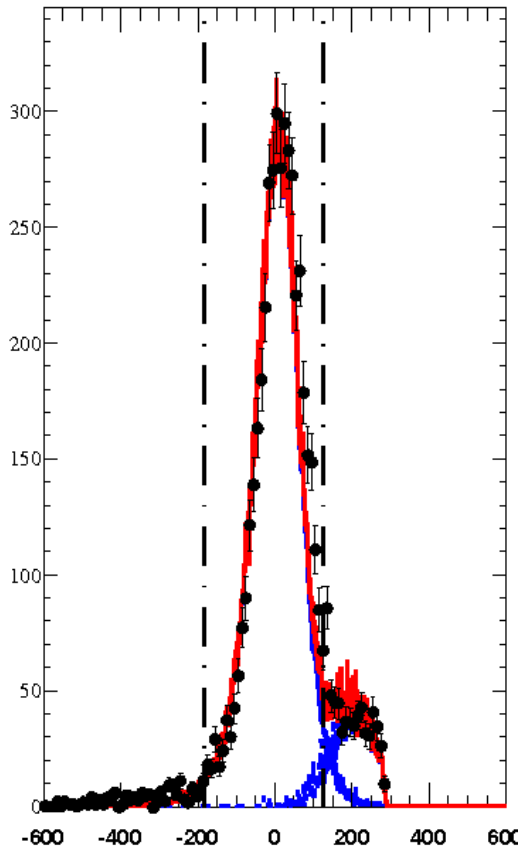


Background Suppression

Main background from $\gamma + {}^3He \rightarrow \eta\pi X$

Missing Mass cut:

$M^2 = (P_{Beam} + P_N - P_\eta)^2$



Data

Simulation: Signal & Background

Total Fit

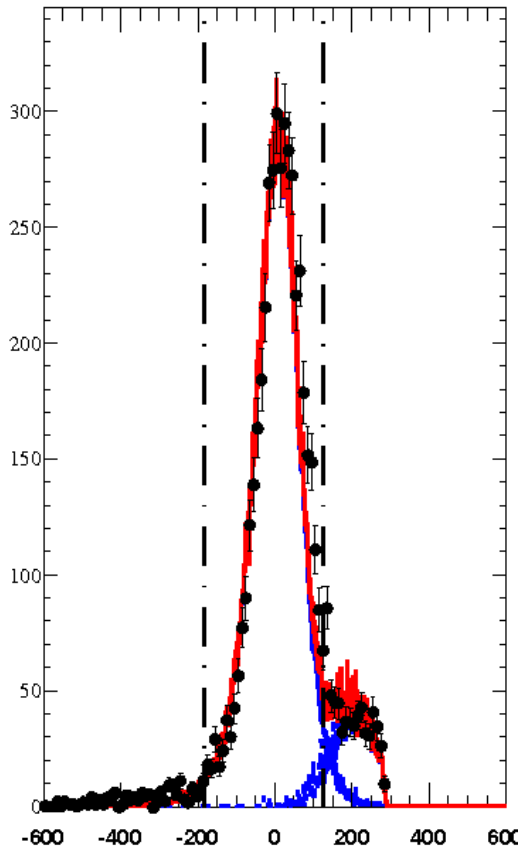
Background Suppression

Main background from $\gamma + {}^3He \rightarrow \eta\pi X$

Missing Mass cut:

$M^2 = (P_{Beam} + P_N - P_\eta)^2$

Coplanarity cut: Cut on $\Delta\phi$ between 170° and 190°



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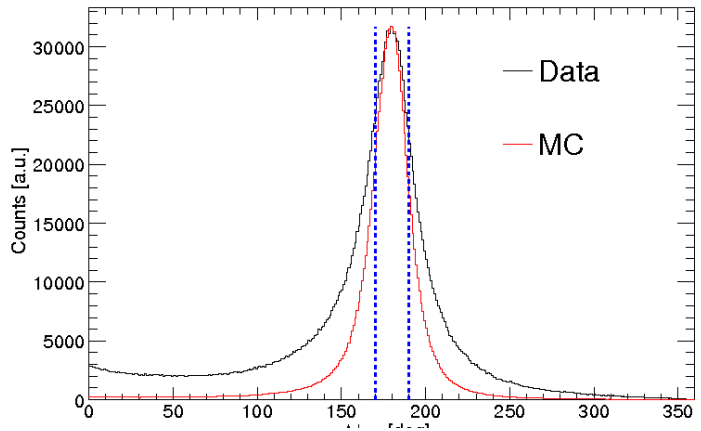
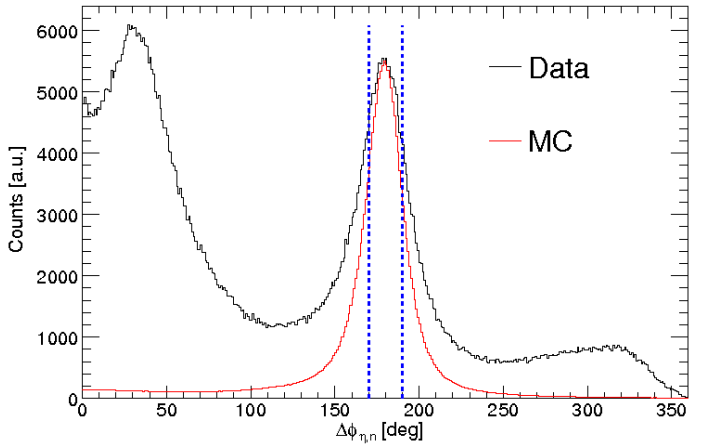
Simulation: Signal & Background

Total Fit

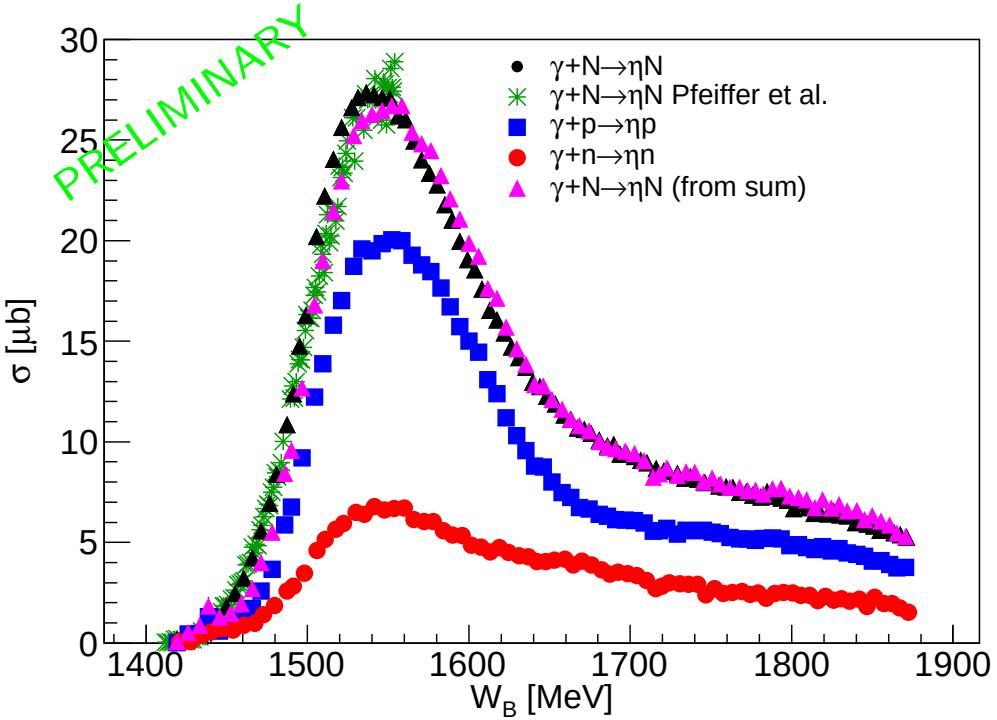


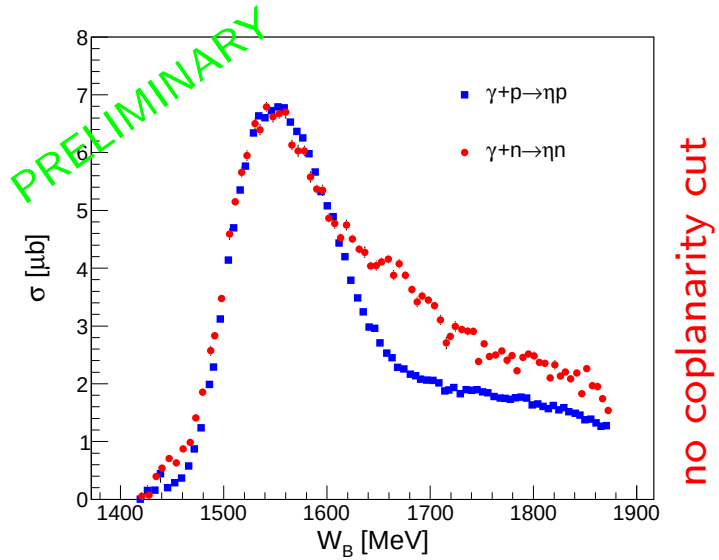
proton

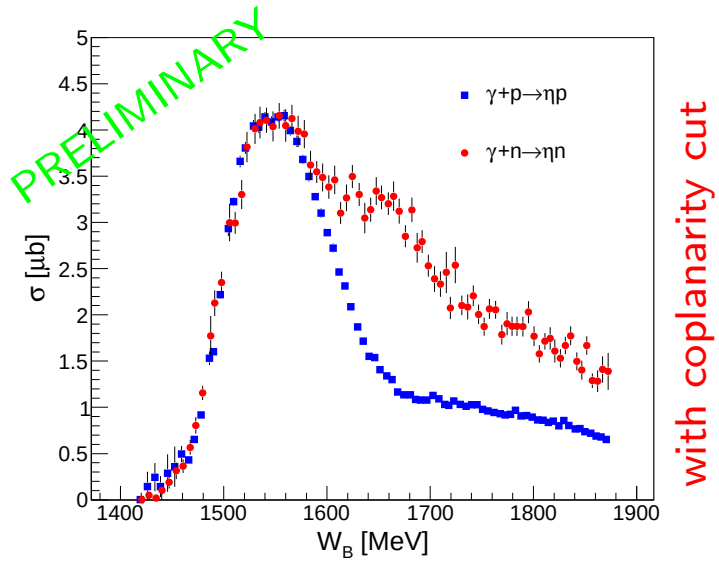


neutron

Total Cross Sections on p/n







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

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:

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

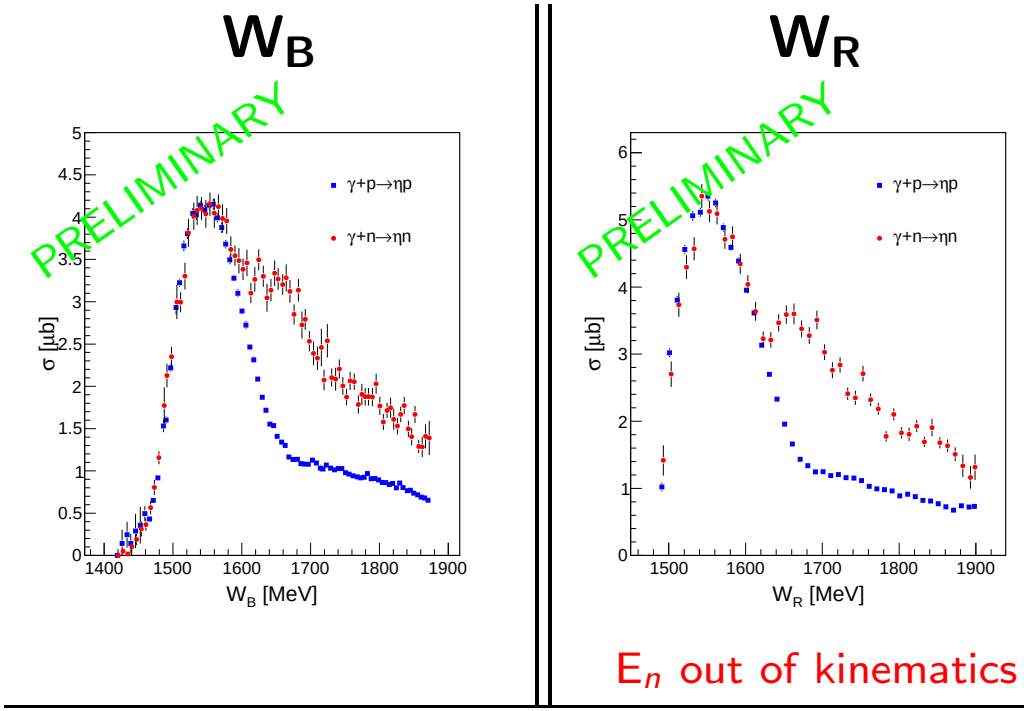
➢ Structures are smeared out because of Fermi motion

- $\mathbf{W_R}$: $\sqrt{s}$ 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

Defolding Fermi Motion

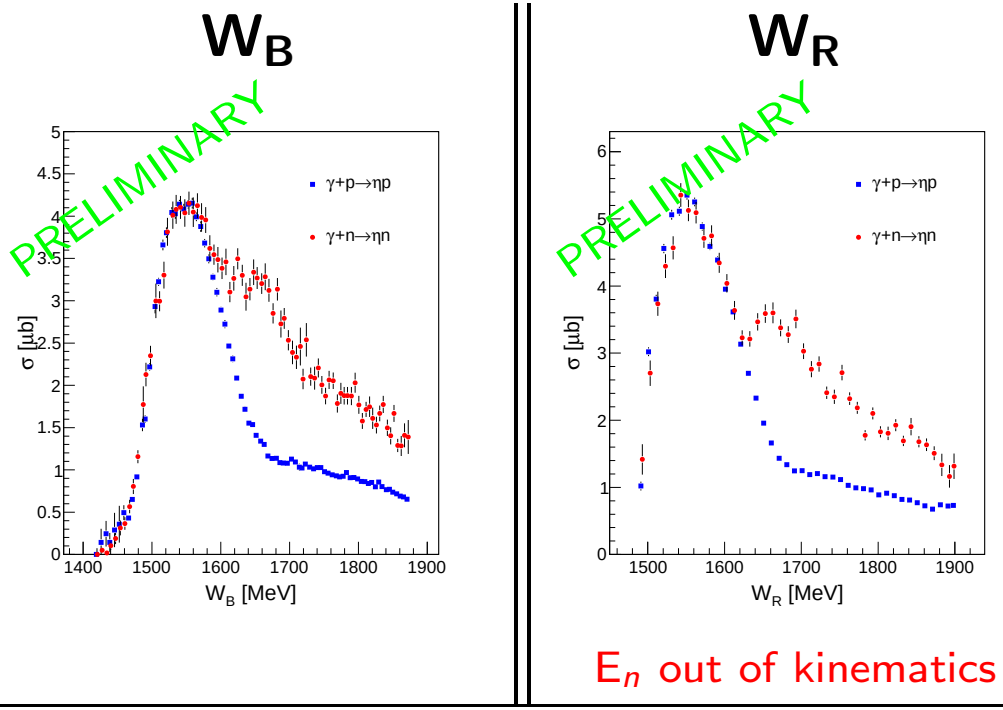


E_n out of kinematics

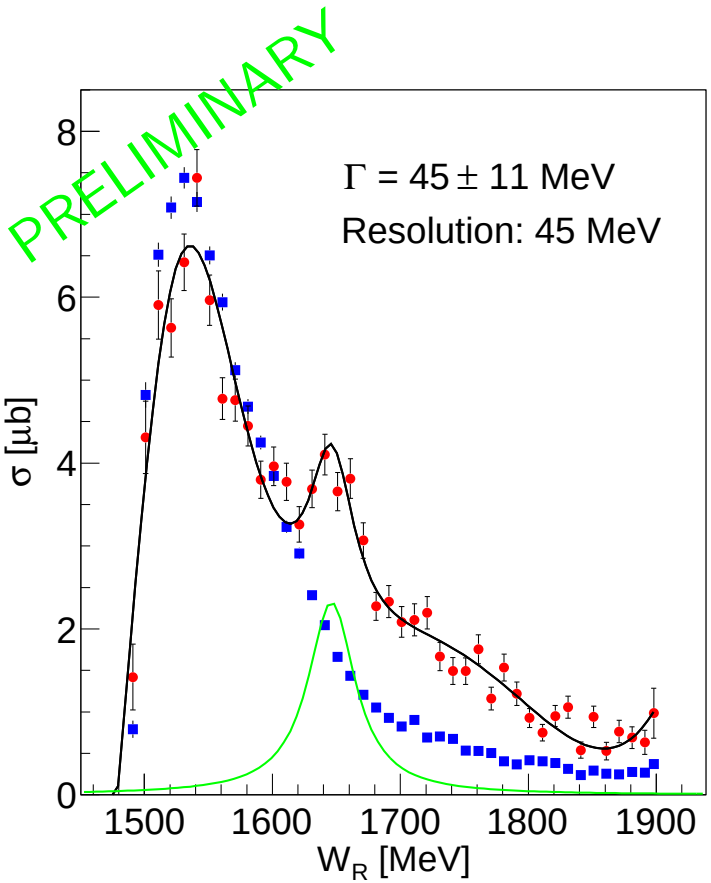
^{3}He: Calculation of recoil nucleon momentum is more approximate than in the case of LD_2

➢ calculate E_n with TOF

Defolding Fermi Motion



E_n out of kinematics



E_n out of TOF

^{3}He: Calculation of recoil nucleon momentum is more approximate than in the case of LD_2

➢ calculate E_n with TOF

Conclusion & Outlook

- Coherent photoproduction of η-mesons off ^{3}He:
  - improved statistical quality
  - total cross section rises extremely between the coherent and breakup thresholds
  - angular distributions at threshold are almost isotropic or have even an angular dependence opposite to the expectation for the form factor behavior
    ➢ strong evidence for dominant FSI effects, related to a resonant state at η production threshold.
- Quasi-Free photoproduction of η-mesons off ^{3}He:
  - Narrow structure:
    Position and width consistent with deuteron data!
  - Next step:
    Try to identify responsible partial waves
    ➢ Single/double polarisation observables

Thanks for your attention!

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and
Deutsche Forschungsgemeinschaft