Measurement of the beam asymmetry Σ in π^0- and η-photoproduction

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for the
CBELSA/TAPS collaboration

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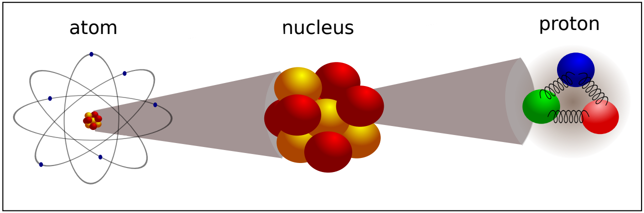
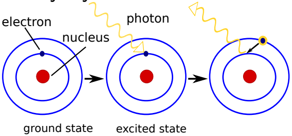
Outline

Why baryon spectroscopy?

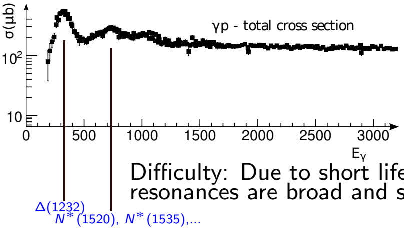


Study dynamics inside atom



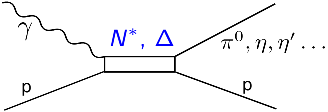
Argon:

E.D. Bloom et. al., SLAC-PUB-653 (1969)



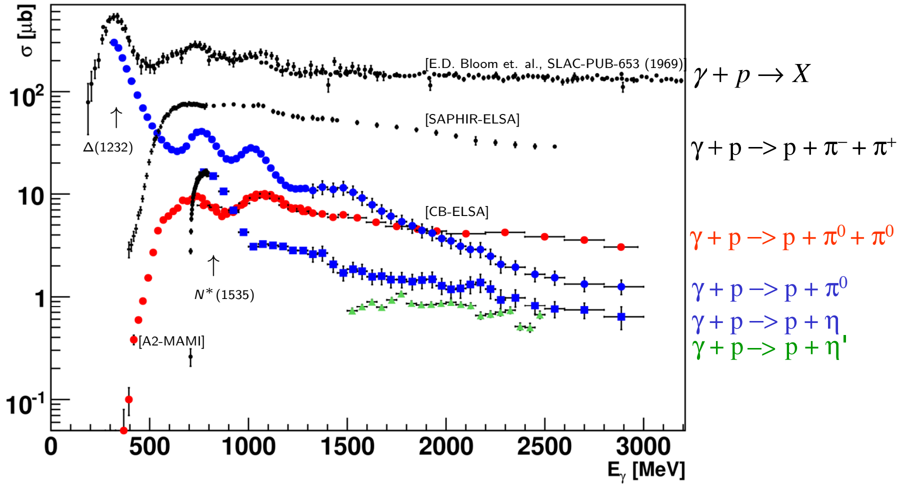
Difficulty: Due to short lifetime, resonances are broad and strongly overlap

Study dynamics of constituents inside the nucleon



Photoproduction reactions

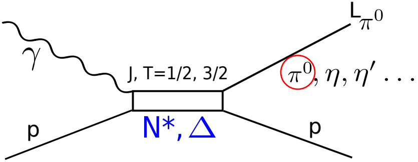
Study of different reaction channels gives access to different resonant structures
$\Rightarrow$ Worldwide effort to get high precision data (ELSA, JLab, MAMI,...)



Why study π^0 and η in the final state?

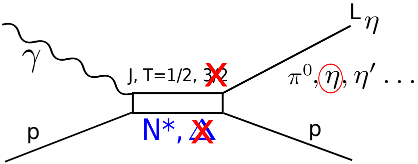
π^0-photoproduction

- high cross section
  $\rightarrow$ Large statistics



η-photoproduction

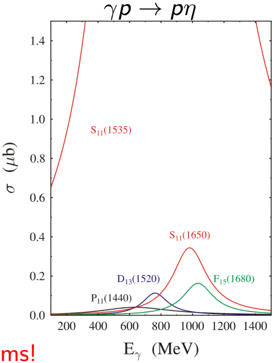
- η (T=0) $\rightarrow$ exclusive access to intermediate states N^* with T=1/2
- low contributions from non-resonant terms



Which observables to measure?

- Scattering amplitude $f \longleftrightarrow$ 4 complex amplitudes (CGLN amplitudes) $f(F_1(W,\cos\theta_{cm}), F_2(W,\cos\theta_{cm}), F_3(W,\cos\theta_{cm}), F_4(W,\cos\theta_{cm}))$
- PWA: $F_1 = \sum_{l=0}^{\infty}(lM_{l+} + E_{l+})P'_{l+1} + [(l+1)M_{l-} + E_{l-}]P'_{l-1}$
  - $E_{l\pm}(W), M_{l\pm}(W)$: Multipoles
  - $P'_{l\pm1}(\cos\theta_{cm})$: Legendre polynomials
- Measurable observables $\longleftrightarrow$ Multipoles $\longleftrightarrow$ Resonance parameters

Photon polarization		Target polarization			Recoil nucleon polarization			Target and recoil polarizations			
		X	Y	Z(beam)	X'	Y'	Z'	X' X	X' Z	Z' X	Z' Z
unpolarized	σ	-	T	-	-	P	-	$T_{x'}$	$L_{x'}$	$T_{z'}$	$L_{z'}$
linear	$-\Sigma$	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(L_{x'})$	$(-T_{x'})$
circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-

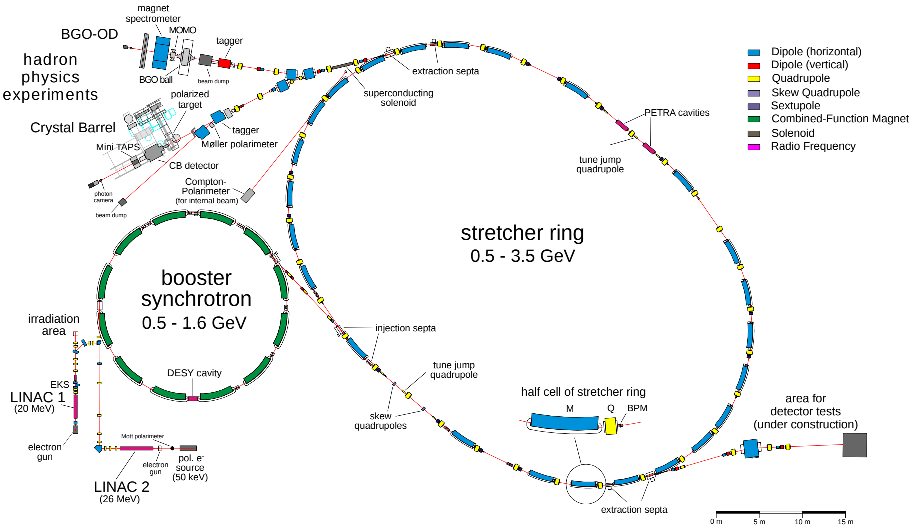


$$\sigma \sim |E_{0+}|^2 + |E_{1+}|^2 + |M_{1+}|^2 + |M_{1-}|^2 + \ldots$$

$$\Sigma \sim -2E^*_{1+}M_{1+} + 2M^*_{1-}E_{1+} - 2M^*_{1-}M_{1+} + \ldots$$

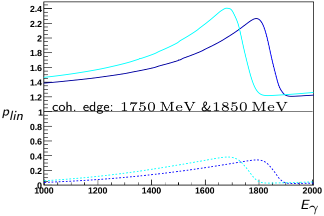
$\Rightarrow$Polarization observables are sensitive to interference terms!

The Electron Stretcher Accelerator (ELSA)

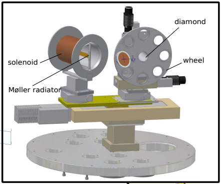


The CBELSA/TAPS experiment at ELSA in Bonn

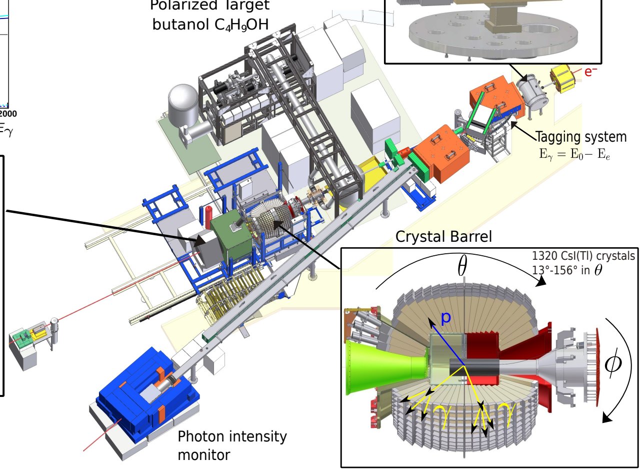
Measurement of Σ (July-October 2013)
Linearly polarized photons + H_2 target



goniometer

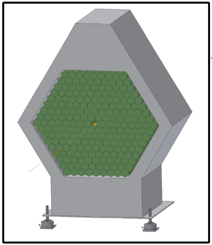


Polarized Target
butanol C_4H_9OH



Tagging system
$E_\gamma = E_0 - E_e$

MiniTAPS



216 BaF_2 crystals
1°-12° in

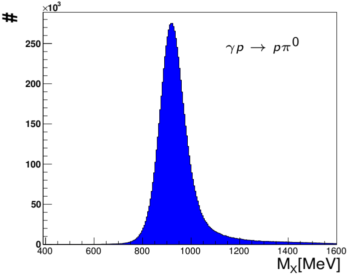
Crystal Barrel

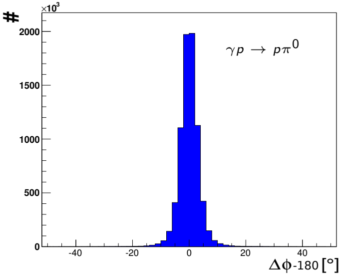
Photon intensity
monitor

Selection process of $\gamma p \to \gamma\gamma p$

Selected events had to fulfill kinematic constraints:

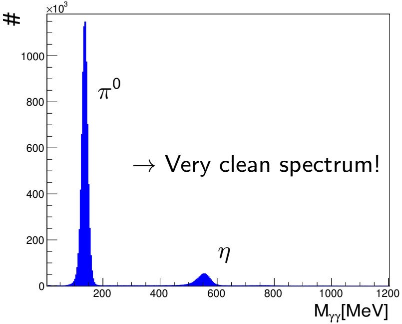
- 3 hits in calorimeters (p+2γ)
- Proton: calculated as missing particle of $\gamma p \to \gamma\gamma X$
- Angular-cuts:
    - Agreement of missing mass and measured charged particle in θ
    - Coplanarity-cut: $\Delta\Phi = |\Phi_{\gamma\gamma} - \Phi_p| = 180^\circ$ within 2.5σ
- Beam photon: $E_\gamma > E_{prod.threshold}$ and time coincidence with reaction products

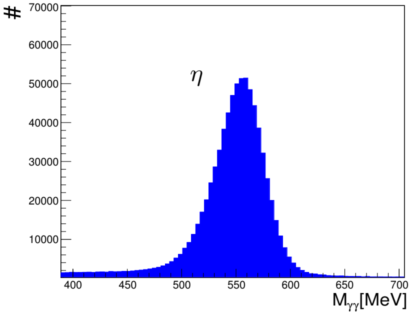




Selection process of $\gamma p \rightarrow \gamma\gamma p$

- The $\gamma\gamma$ invariant mass:



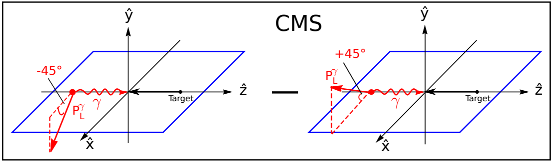


- $5.4 \cdot 10^6$ π^0-events were selected
- $6.6 \cdot 10^5$ η-events were selected

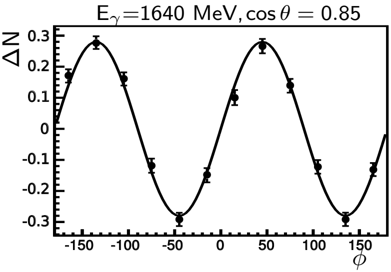
Determination of the beam asymmetry Σ

- linearly polarized beam, unpolarized liquid hydrogen target

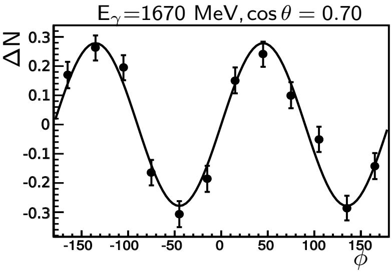
$$\Delta N = \frac{N_{-45^\circ} - N_{+45^\circ}}{N_{-45^\circ} + N_{+45^\circ}} = p_\gamma^{lin} \Sigma \sin(2\phi)$$



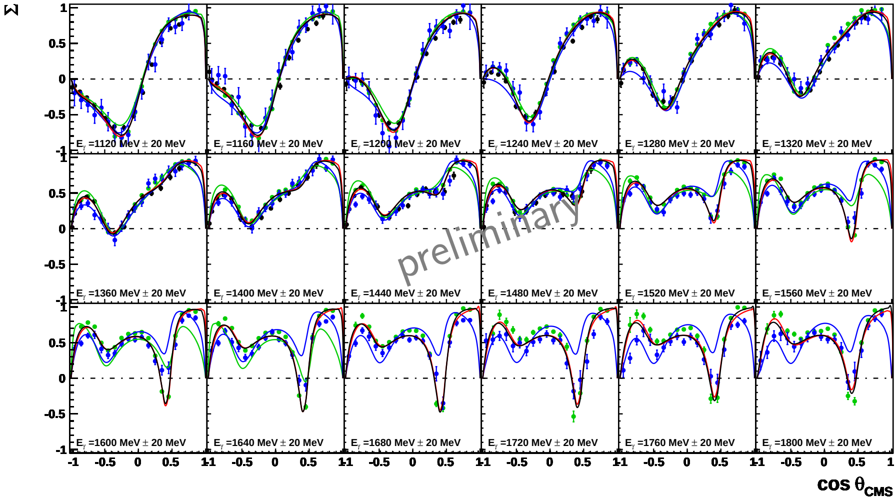
$\gamma p \to \pi^0 p$



$\gamma p \to \eta p$



The beam asymmetry Σ in π^0-photoproduction



● this work ● CLAS data (M.Dugger et al., Phys.Rev.C 88, 2013) ● GRAAL data (O. Bartalini et al., Eur.Phys.J.A26, 399, 2005)

PWA solutions: —BnGa(2014_01) —BnGa(2014_02) —SAID(CM12) —MAID2007

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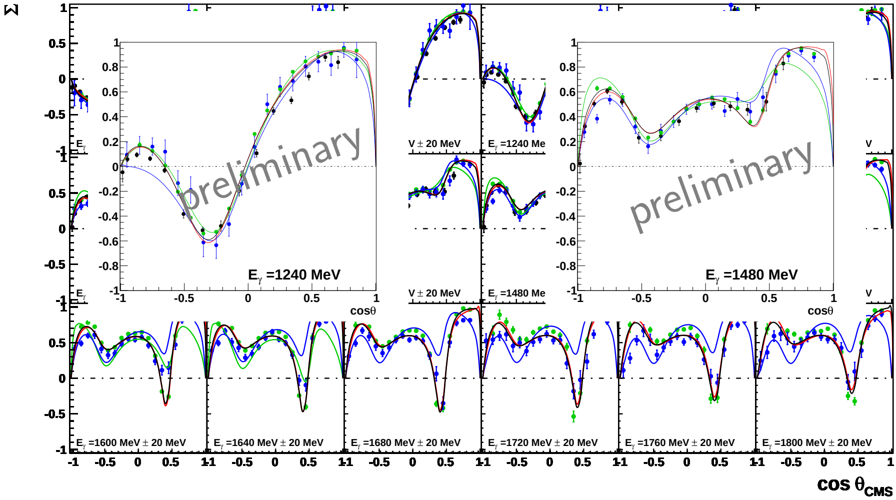

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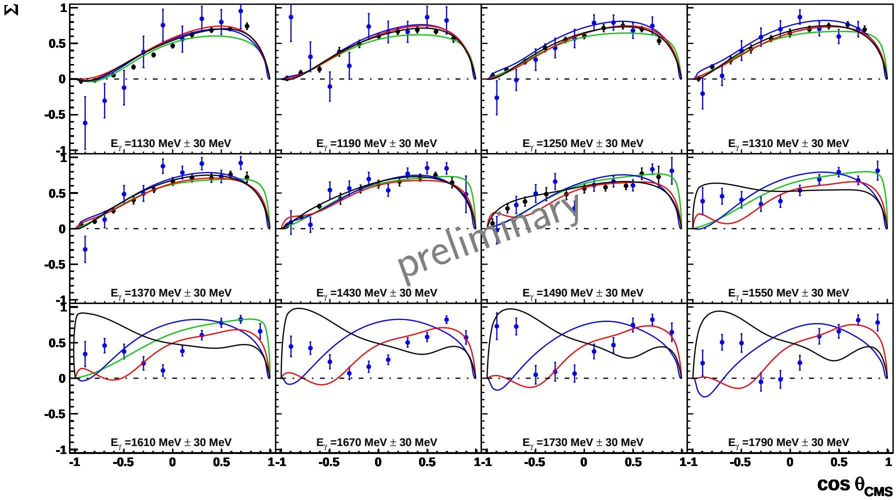

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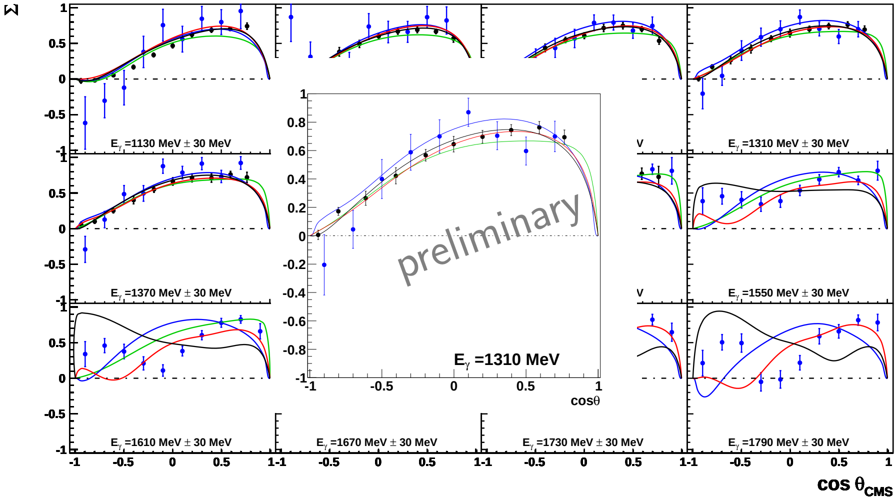
The beam asymmetry Σ in η-photoproduction



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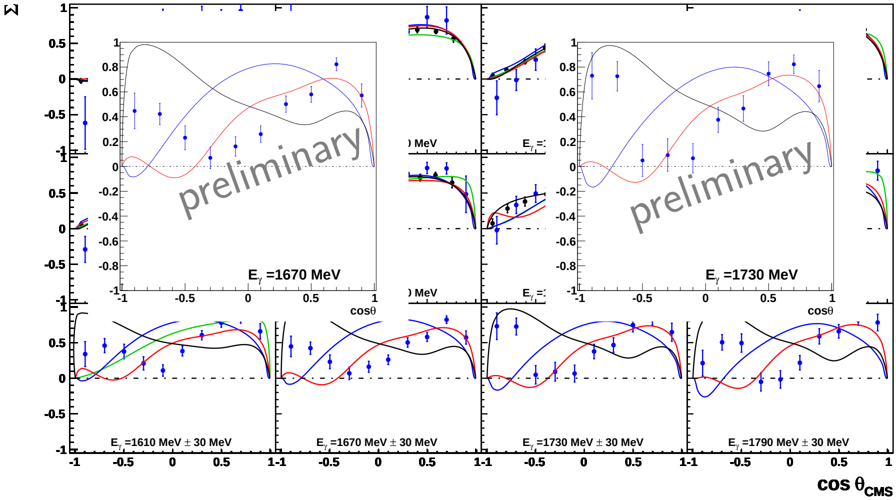

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Summary and Outlook

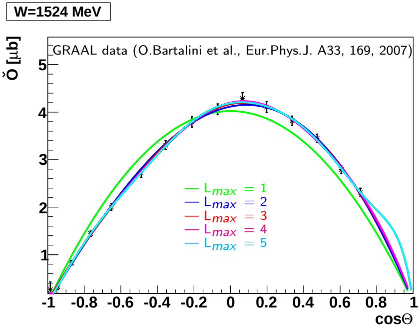
- The beam asymmetry Σ was determined in π^0- and η-photoproduction
- Results:
  - very precise π^0 data was measured for $E_\gamma = 1100\,\mathrm{MeV}$ - $1800\,\mathrm{MeV}$
  - precise η data was measured for $E_\gamma = 1100\,\mathrm{MeV}$ - $1800\,\mathrm{MeV}$
  - η data can not be described by either PWA models
  - data will provide new constraints for the PWA
- More results in other polarization observables
  $\rightarrow$ See next talk by Jonas Müller

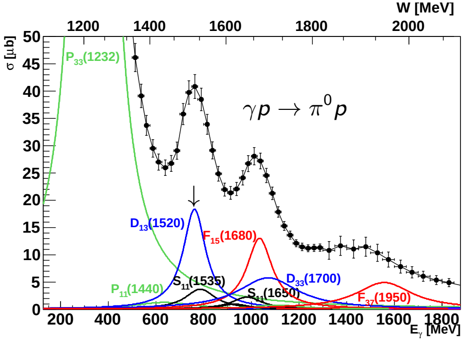
Thank you!

Truncated PWA (which L_{max} is seen in the data?)

$$\hat{\Sigma}(W, \cos\theta) = \Sigma(W, \cos\theta) \cdot \frac{d\sigma}{d\Omega}(W, \cos\theta) = \sum_{k=2}^{2+2L_{max}} (a_L(W))_k \cdot P_k^2(\cos\theta)$$

$L_{max} = 0$ S-wave	$L_{max} = 1$ P-wave	$L_{max} = 2$ D-wave	$L_{max} = 3$ F-wave	$L_{max} = 4$ G-wave
$S_{11}(1535)$	$P_{11}(1440)$	$D_{13}(1520)$	$F_{15}(1680)$	$G_{17}(2190)$
$S_{11}(1650)$	$P_{13}(1720)$	$D_{15}(1675)$	$F_{35}(1905)$	
$S_{31}(1620)$	$P_{33}(1232)$	$D_{33}(1700)$	$F_{37}(1950)$	





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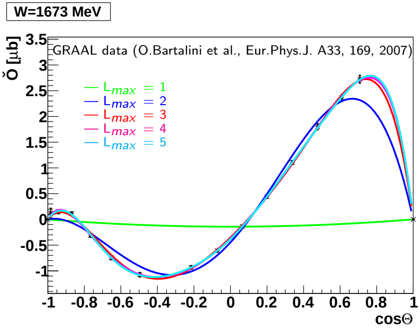

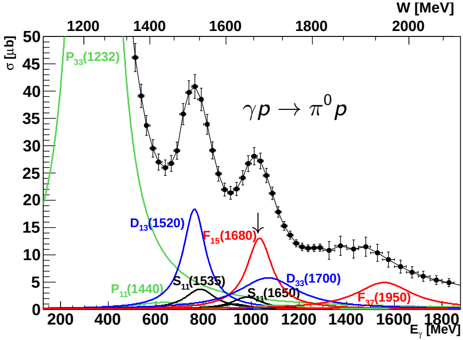

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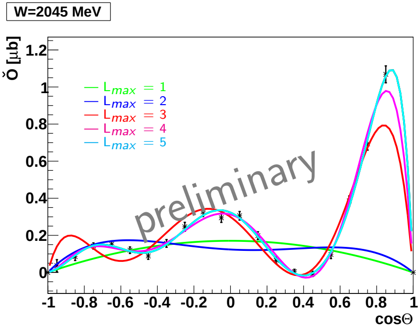

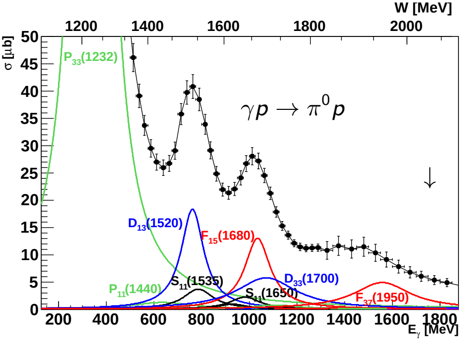

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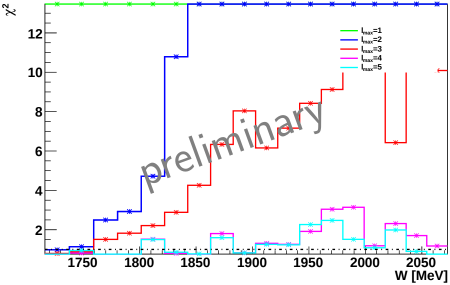
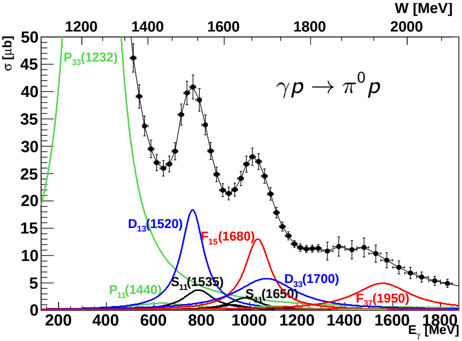
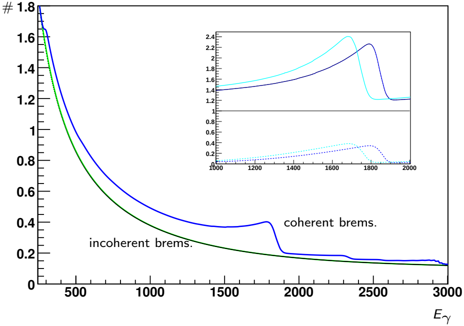
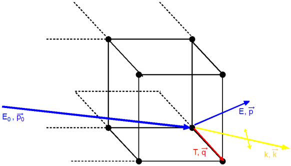




Linearly polarized photons

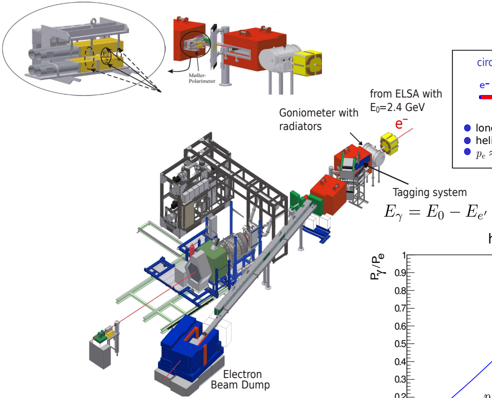
- coherent bremsstrahlung produced on diamond crystal
- Bragg: if $\vec{q} = n \cdot \vec{g} \rightarrow$ constructive interference

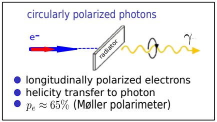




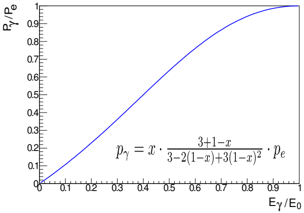
Circularly polarized photons

- Need longitudinally polarized electrons
- helicity transfer from electrons to photons





helicity transfer



Frozen-spin butanol target

- polarize electrons $(2.5\,\mathrm{T},\ 300\,\mathrm{mK})$
- transfer polarization to the protons dynamically via irradiation of microwaves
- "freeze spin" $(70\,\mathrm{mK}) \rightarrow$ long relaxation times