HADRON PHYSICS AT MAMI

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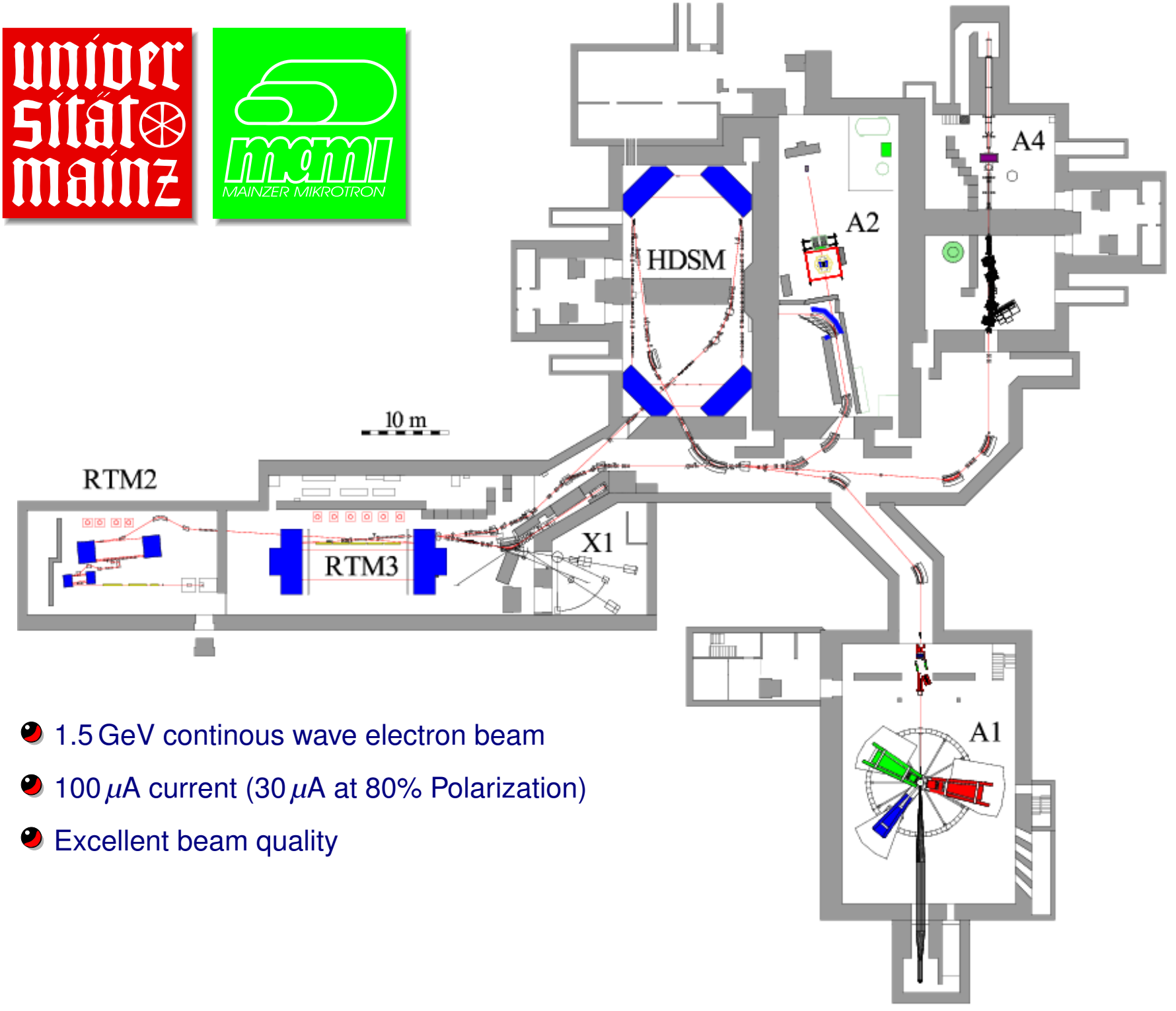
10^{th} International Workshop on Meson Production, Properties and Interaction
Kraków, Poland

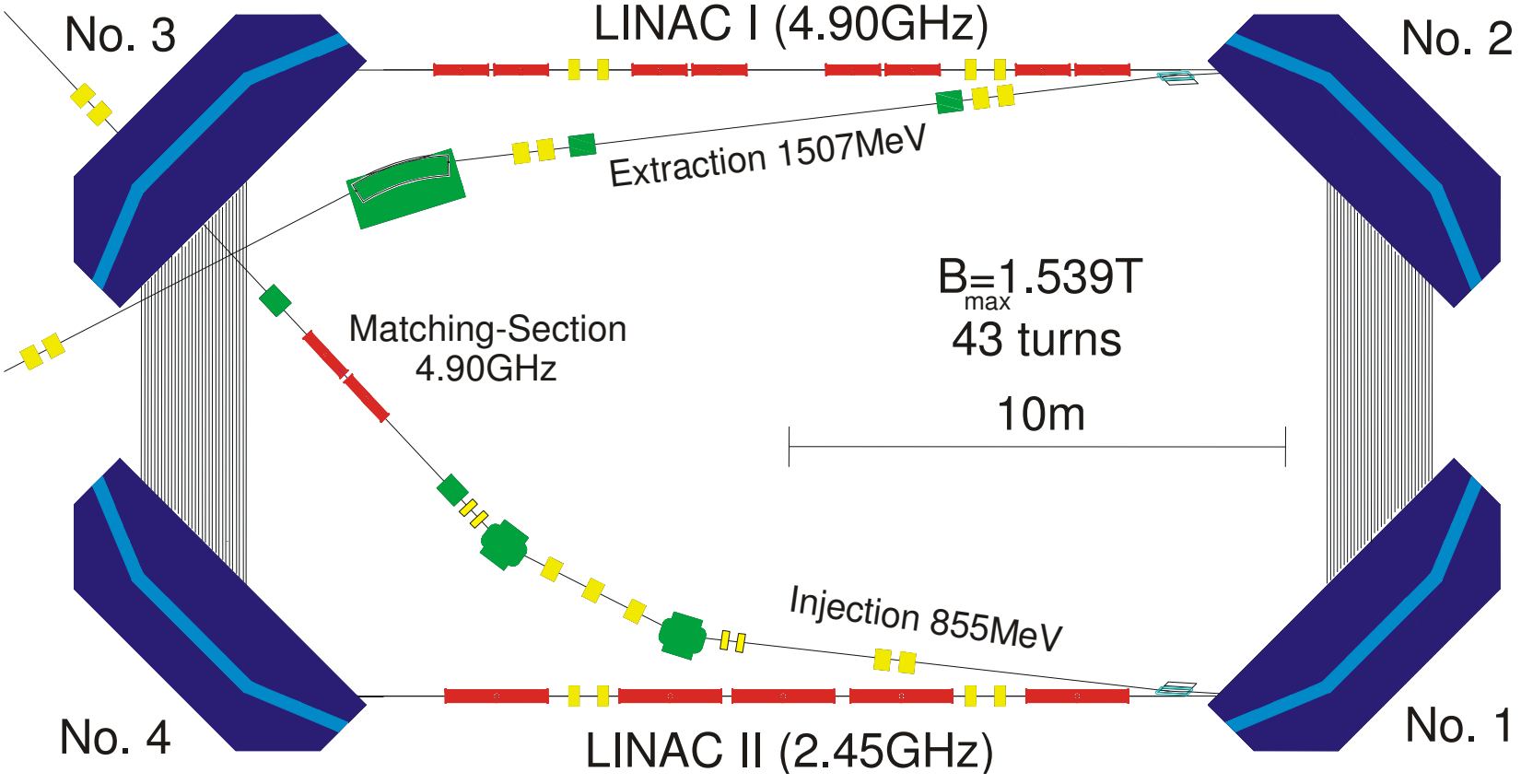
June 7, 2008

- The Mainz Microtron
- Physics Program
- Selected Experiments
  - Transverse Beam Spin Asymmetry
  - Double polarized η Electroproduction
  - Hypernuclei



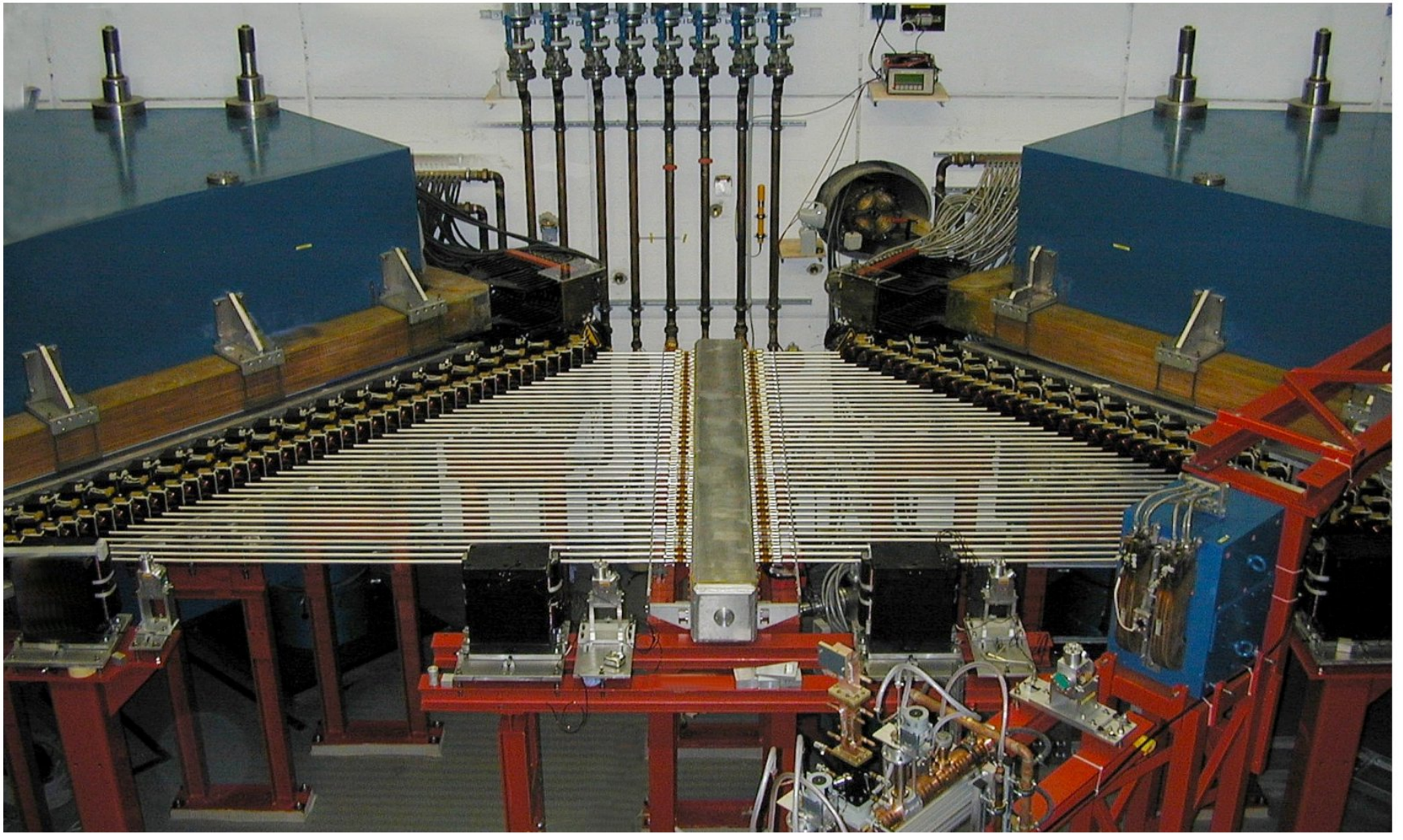
- 1.5 GeV continous wave electron beam
- 100 μA current (30 μA at 80% Polarization)
- Excellent beam quality

MAMI-C: Harmonic Double Sided Microtron



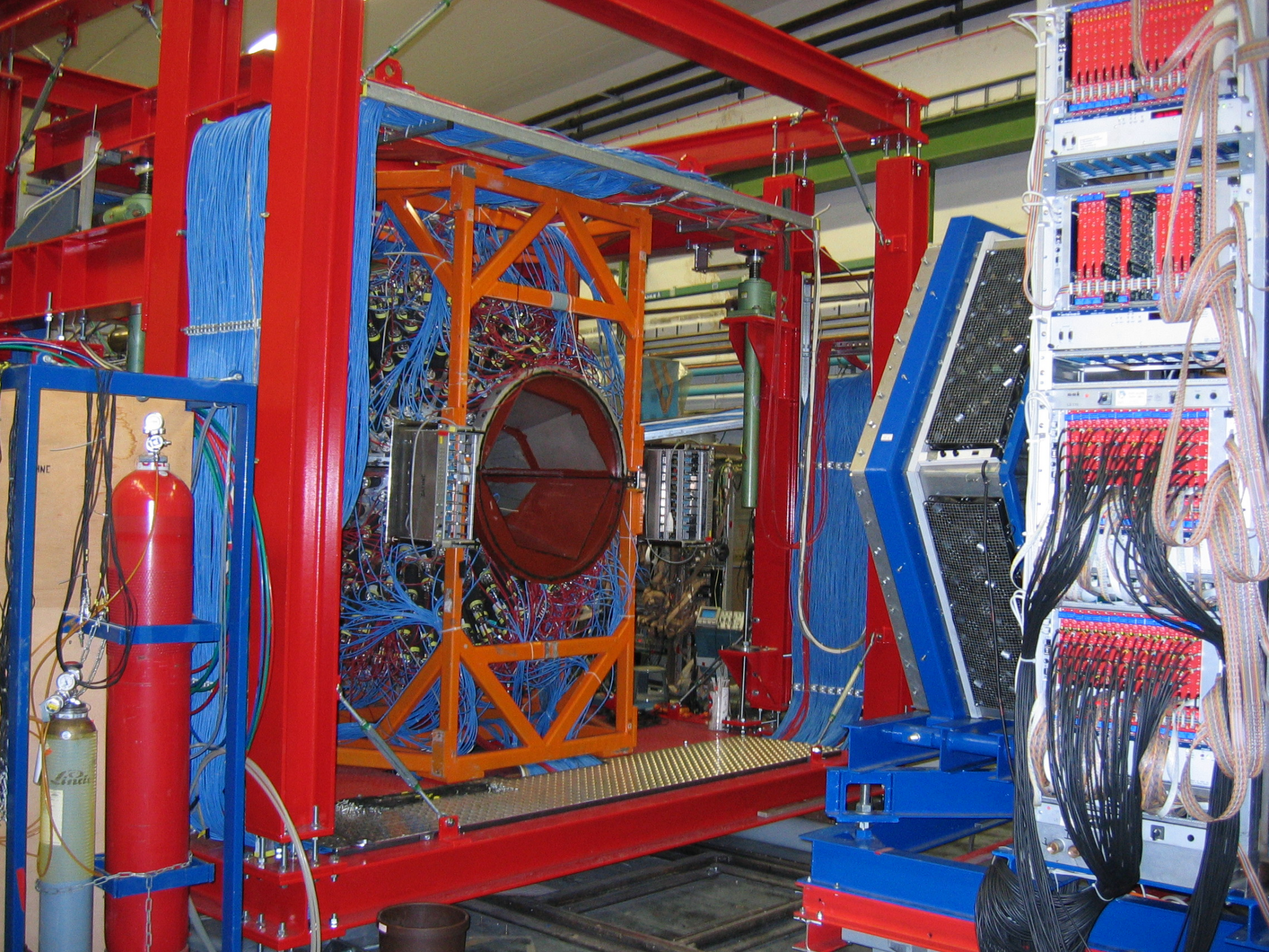
- Double sided microtron saves a lot of iron!
- Second linac operates at double frequency → Improved phase stability
- First beam in HDSM: 12/2006
- First experiment: 2/2007, 2400h with MAMI C in 2007 (+3500h MAMI B!)

HDSM: Return path section



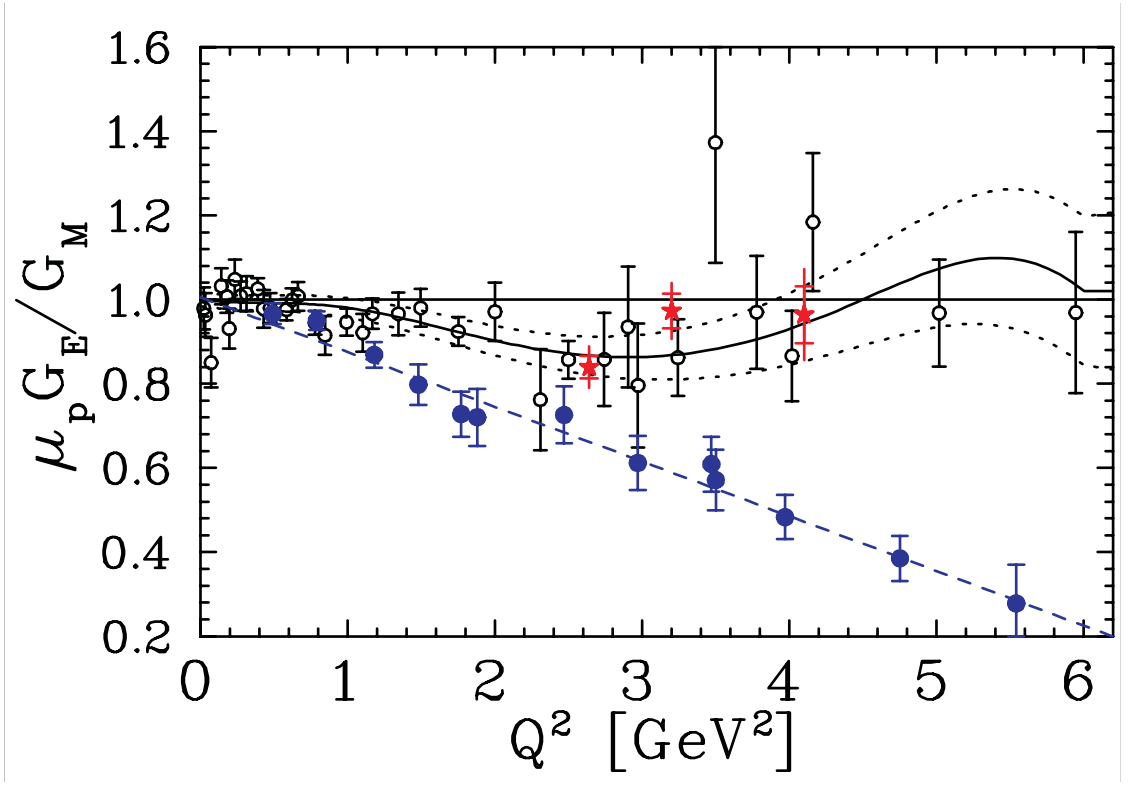
Overview

- Nucleon structure
  - Electromagnetic and weak form factors of the nucleon
  - Polarizabilities of the nucleon
  - Helicity structure of the nucleon
- Mesonic structure of the Nucleon
  - Threshold meson production
  - Coherent and incoherent meson production from the nucleus
  - Resonances *e.g.* $P_{11}(1440)$, $S_{11}(1535)$
  - Meson decays *e.g.* $\eta \to 3\pi^0$, $\eta' \to 3\pi^0$, $\eta' \to \eta\pi^0\pi^0$
- Strangeness
  - Hyperon production
  - Hypernuclei
  - Coherent $\phi(1020)$-meson production
- Few-Body physics
  - ${}^3He$ Spinstructure $\vec{e} + {}^3\vec{H}e \to \vec{p} + d$
- ...



2-Photon Exchange

Nucleon Elastic Formfactor

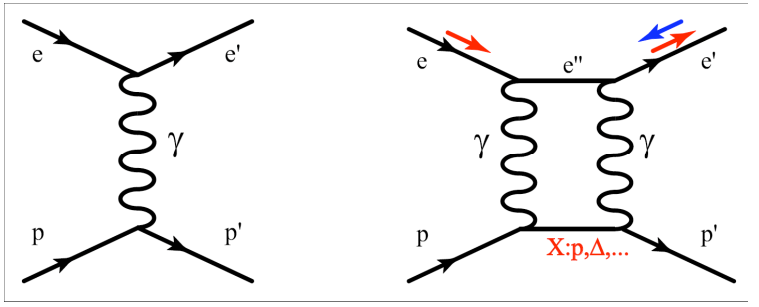


Measurement of $G_E(Q^2)$

- via Rosenbluth separation
- via Polarization transfer
- Different results from different experimental techniques

$\Rightarrow$ 2-Photon Exchange

Two-Photon-Exchange



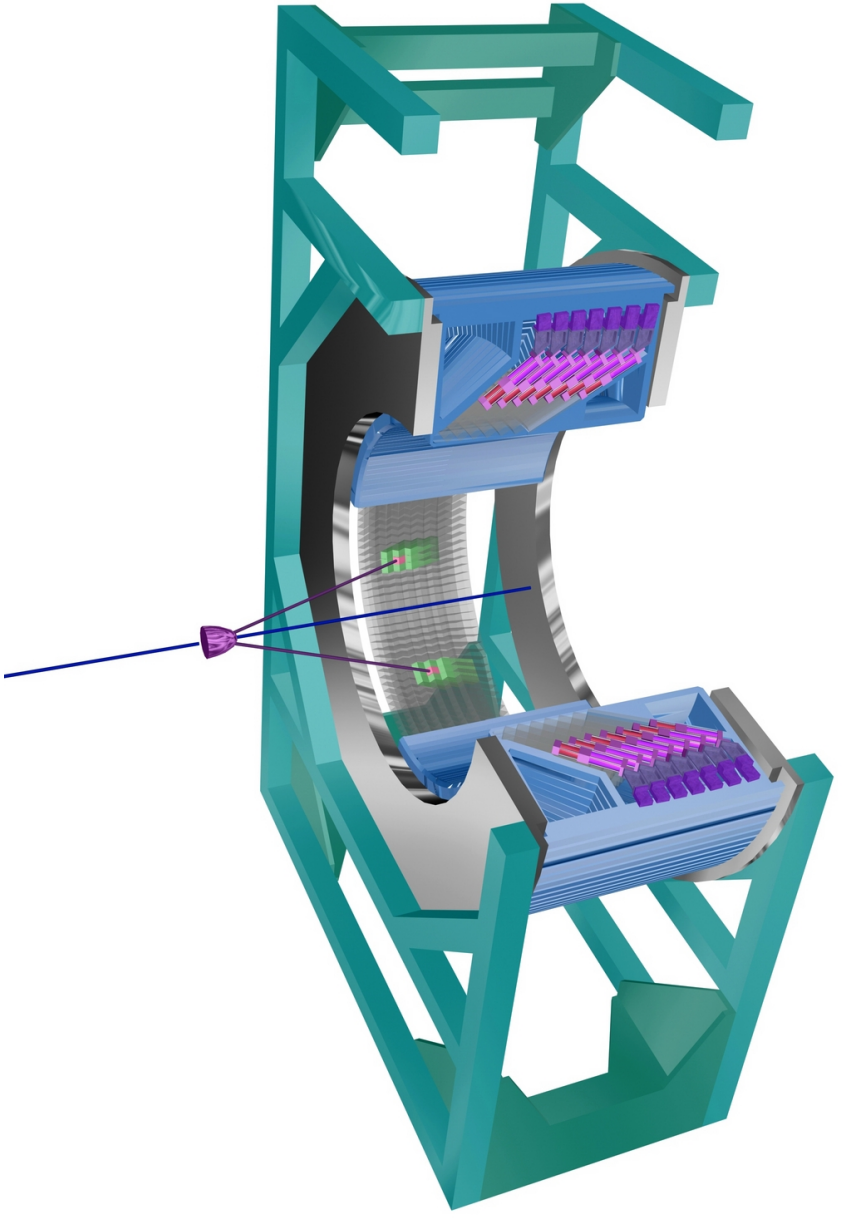
- Generalized Form Factors

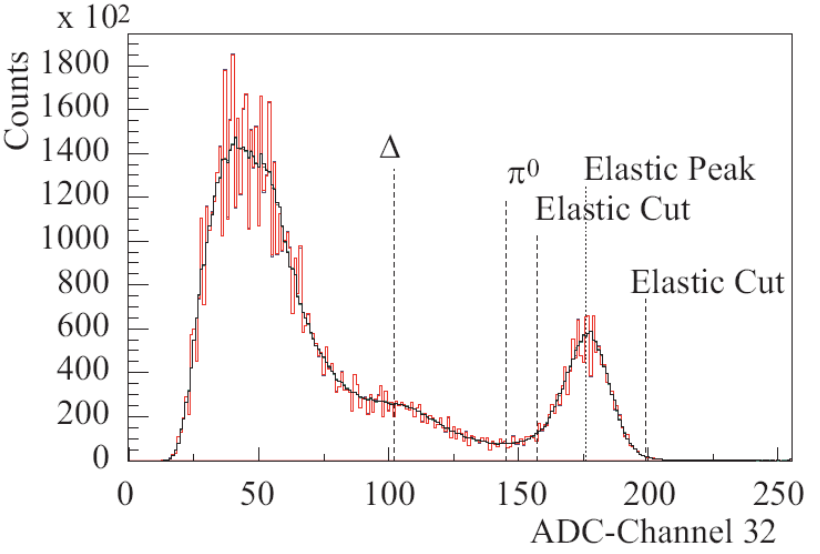
$$G_E(s,Q^2),\ \ G_M(s,Q^2),\ \ F_3(s,Q^2),\ \ \ F_4(s,Q^2),\ \ F_5(s,Q^2),\ \ F_6(s,Q^2)$$

- Complex functions of Q^2 and s
- Real parts contribute to Cross Sections
- Imaginary Parts contribute to Asymmetries, e.g. Transverse Beam Spin Asymmetry:

$$A_\perp = \frac{\sigma_{\uparrow\uparrow} - \sigma_{\downarrow\uparrow}}{\sigma_{\uparrow\uparrow} + \sigma_{\downarrow\uparrow}} \sim \left[-\tau\, Im\left(\frac{F_3}{G_M}\right) - \frac{|G_E|}{|G_M|} Im\left(\frac{F_4}{G_M}\right) - \frac{1}{1+\tau}\left(\tau + \frac{|G_E|}{|G_M|}\right) Im\left(\frac{\nu F_5}{M^2 |G_M|}\right) \right]$$

A4 - Parity Violating Electron Scattering



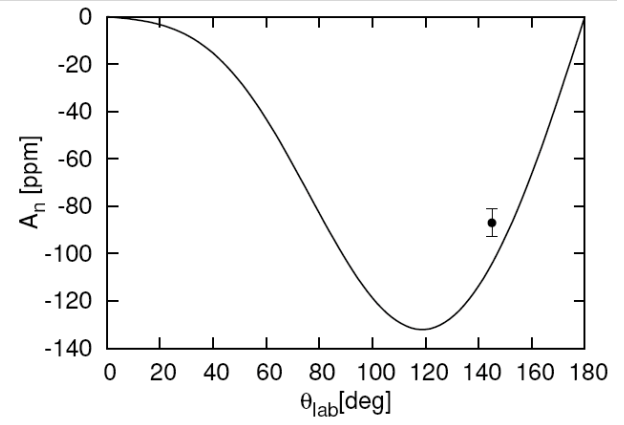


Spin asymmetries $\approx 10^{-6}$
$\Rightarrow$ PbF_2 Calorimeter with 100 MHz count rate

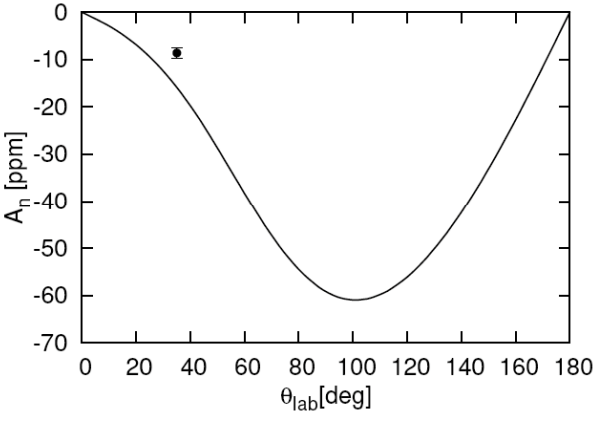
- Parity violating beam helicity Asymmetry
  $\rightarrow$ Strangeness content of the nucleon
- Transverse polarized electrons
  $\rightarrow$ Two photon exchange amplitude

Results - Transverse Beam Asymmetry

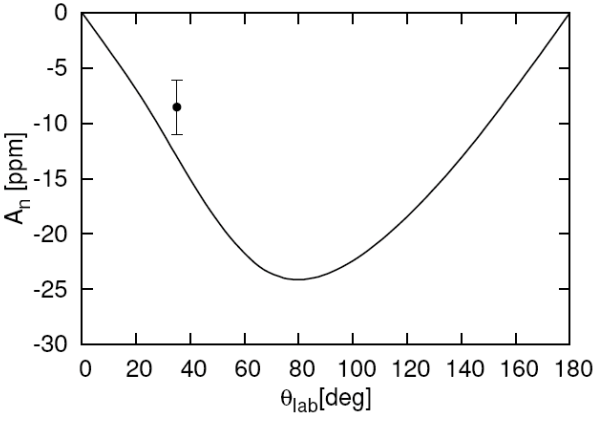
$E_{Beam} = 315\,\mathrm{MeV}$



$510\,\mathrm{MeV}$

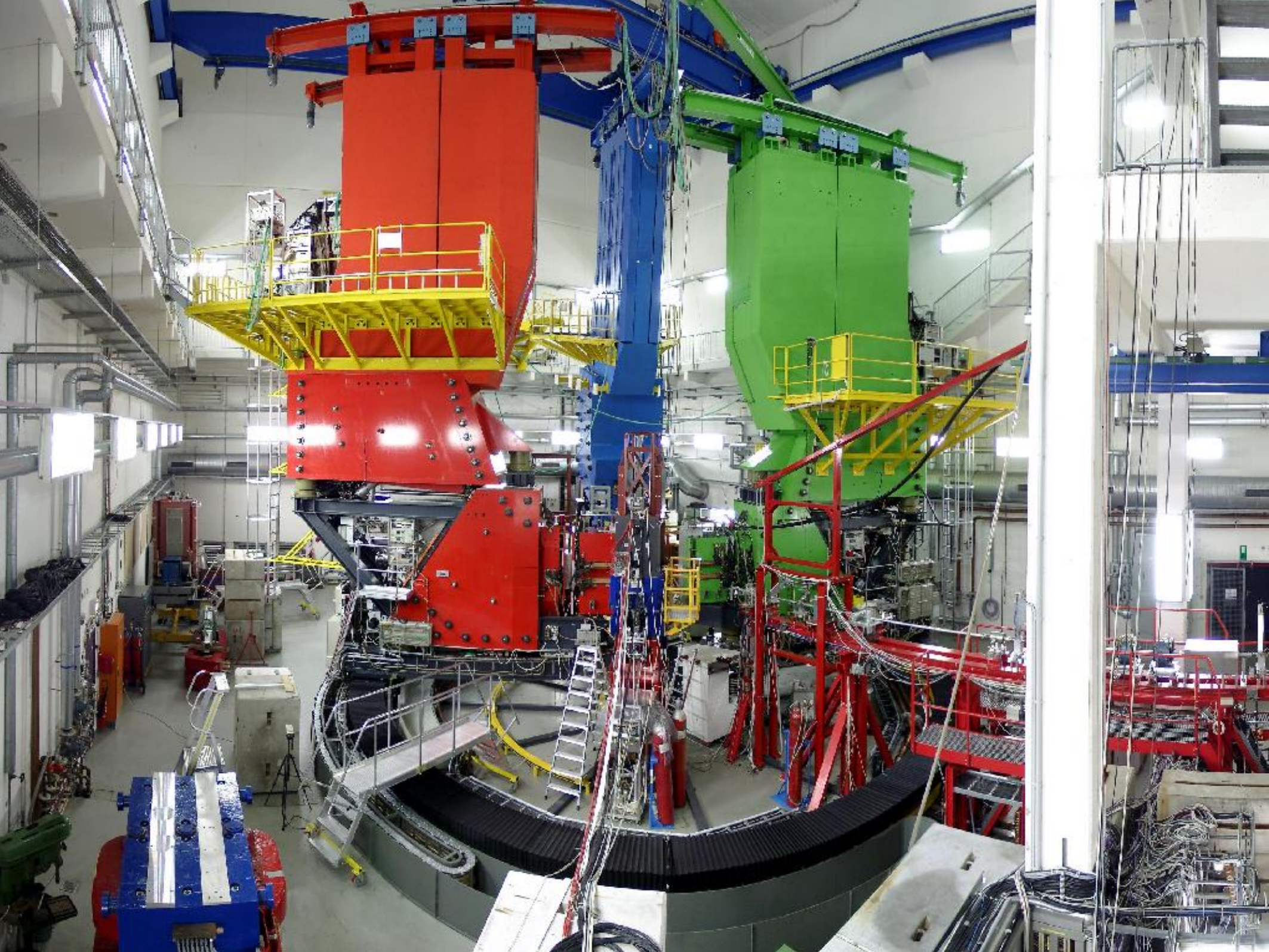


$855\,\mathrm{MeV}$

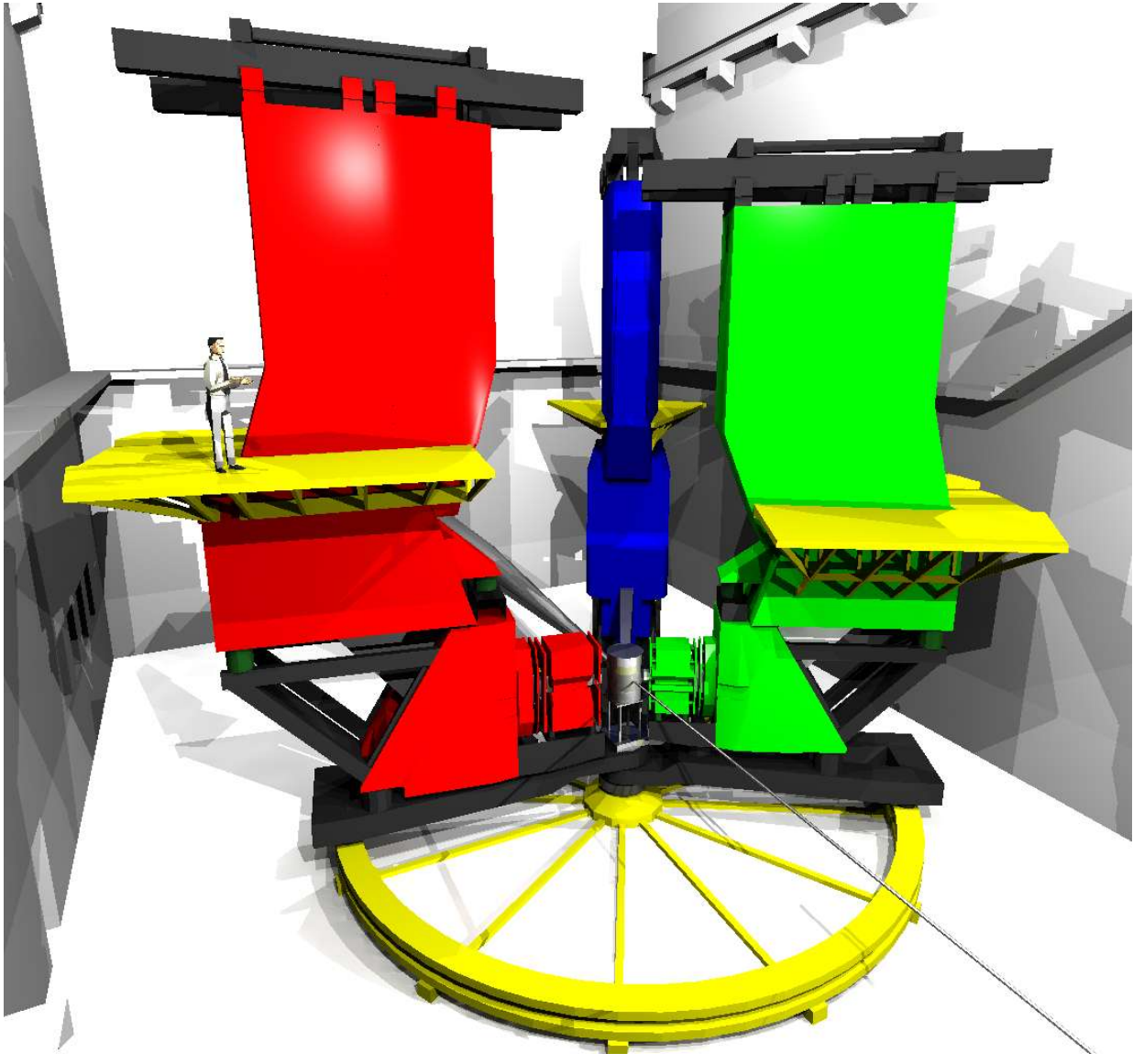


Model: B. Pasquini, MAID

η Electroproduction



A1: 3-Spectrometer-Setup at MAMI



Spectrometer A:

$$\begin{aligned} \alpha &> 20^\circ \\ p &< 735\,\frac{\mathrm{MeV}}{c} \\ \Delta\Omega &= 28\,\mathrm{msr} \\ \Delta p/p &= 20\% \end{aligned}$$

Spectrometer B:

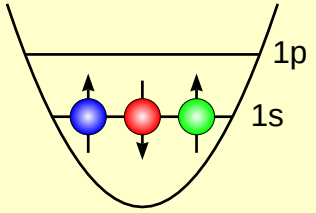
$$\begin{aligned} \alpha &> 8^\circ \\ p &< 870\,\frac{\mathrm{MeV}}{c} \\ \Delta\Omega &= 5.6\,\mathrm{msr} \\ \Delta p/p &= 15\% \end{aligned}$$

Spectrometer C:

$$\begin{aligned} \alpha &> 55^\circ \\ p &< 655\,\frac{\mathrm{MeV}}{c} \\ \Delta\Omega &= 28\,\mathrm{msr} \\ \Delta p/p &= 25\% \end{aligned}$$

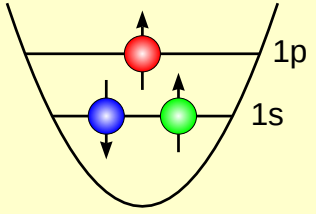
Resonance Structure of the Nucleon

$S = \frac{1}{2}, \quad L^\pi = 0^+$



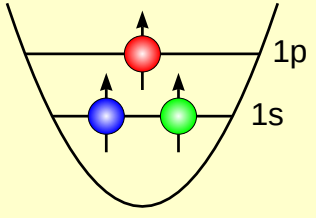
$P_{11}(939), J^\pi = \frac{1}{2}^+$

$S = \frac{1}{2}, \quad L^\pi = 1^-$

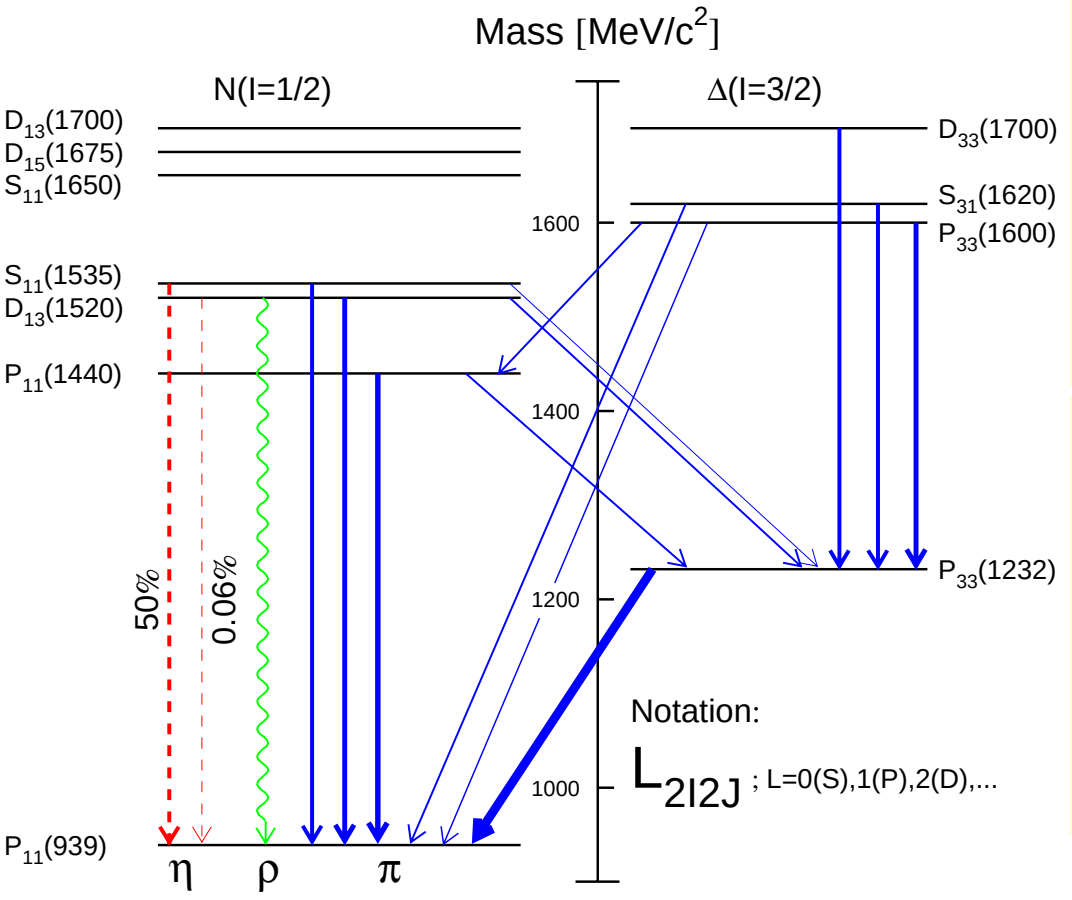


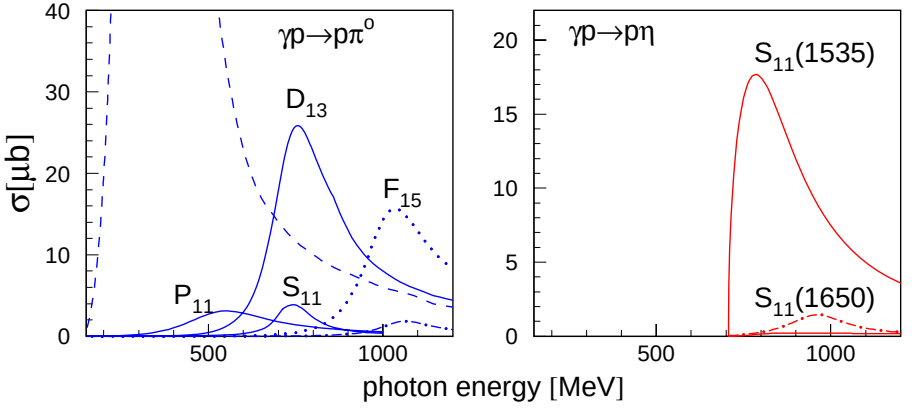
$S_{11}(1535), J^\pi = \frac{1}{2}^-$
$D_{13}(1520), J^\pi = \frac{3}{2}^-$

$S = \frac{3}{2}, \quad L^\pi = 1^-$

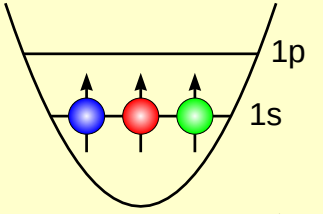


$S_{11}(1650), J^\pi = \frac{1}{2}^-$
$D_{13}(1700), J^\pi = \frac{3}{2}^-$
$D_{15}(1675), J^\pi = \frac{5}{2}^-$



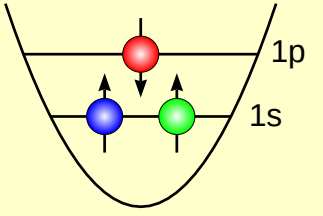


$S = \frac{3}{2}, \quad L^\pi = 0^+$



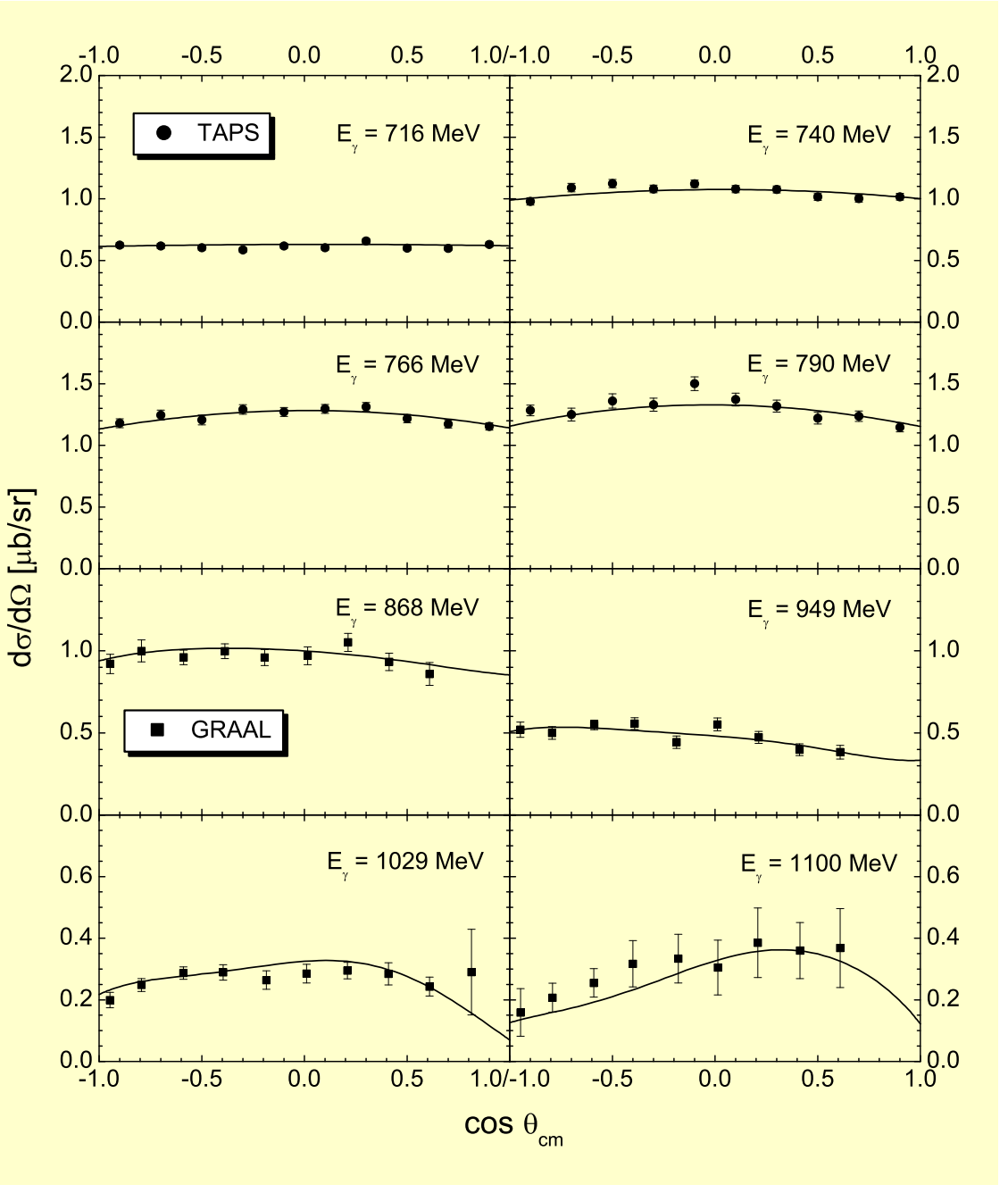
$P_{33}(1232), J^\pi = \frac{3}{2}^+$

$S = \frac{1}{2}, \quad L^\pi = 1^-$



$S_{31}(1620), J^\pi = \frac{1}{2}^-$
$D_{33}(1700), J^\pi = \frac{3}{2}^-$

Differential Cross Section

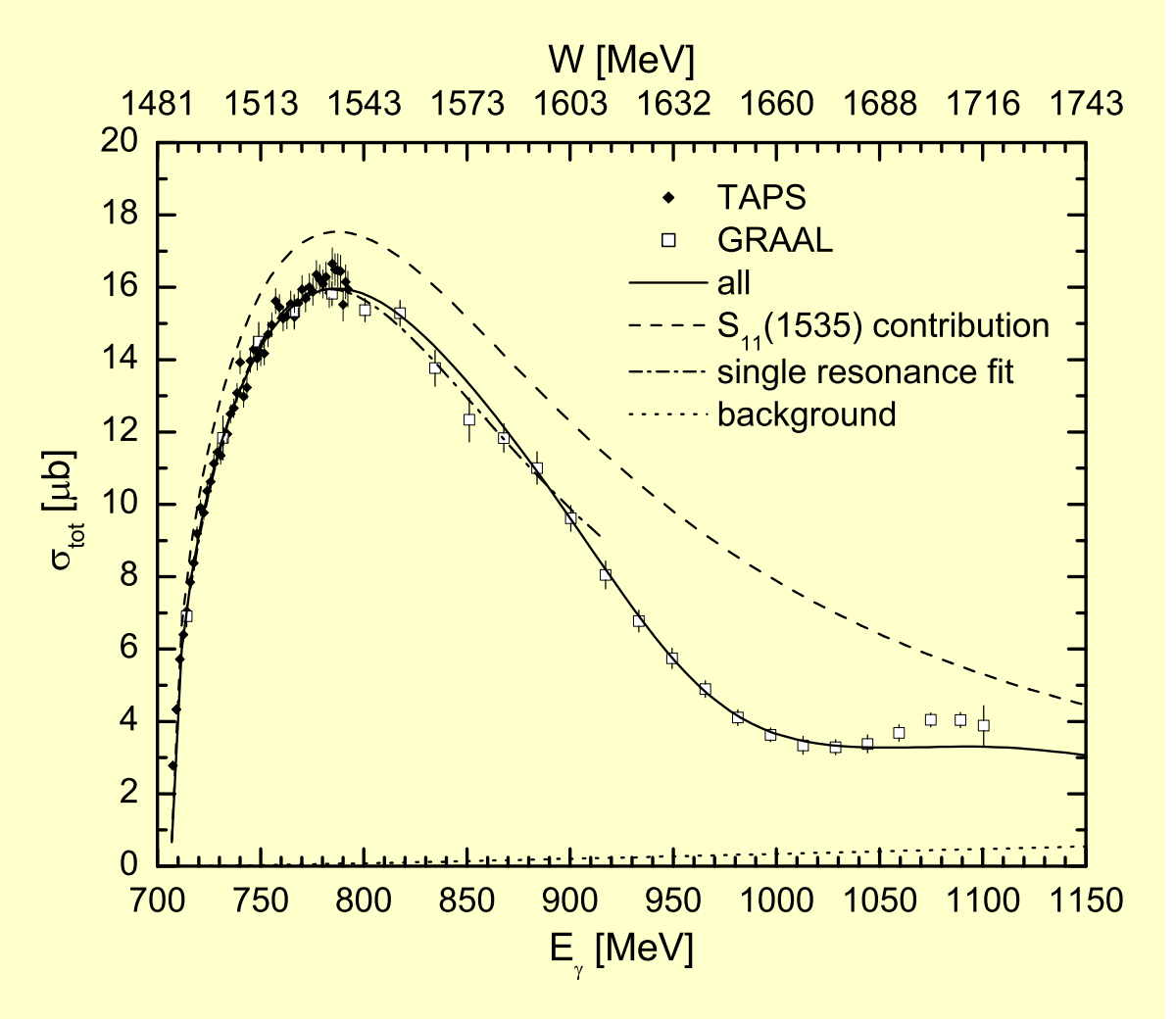


Low Energy:

- Isotropic angular distribution

$\Rightarrow$ s-wave dominant!

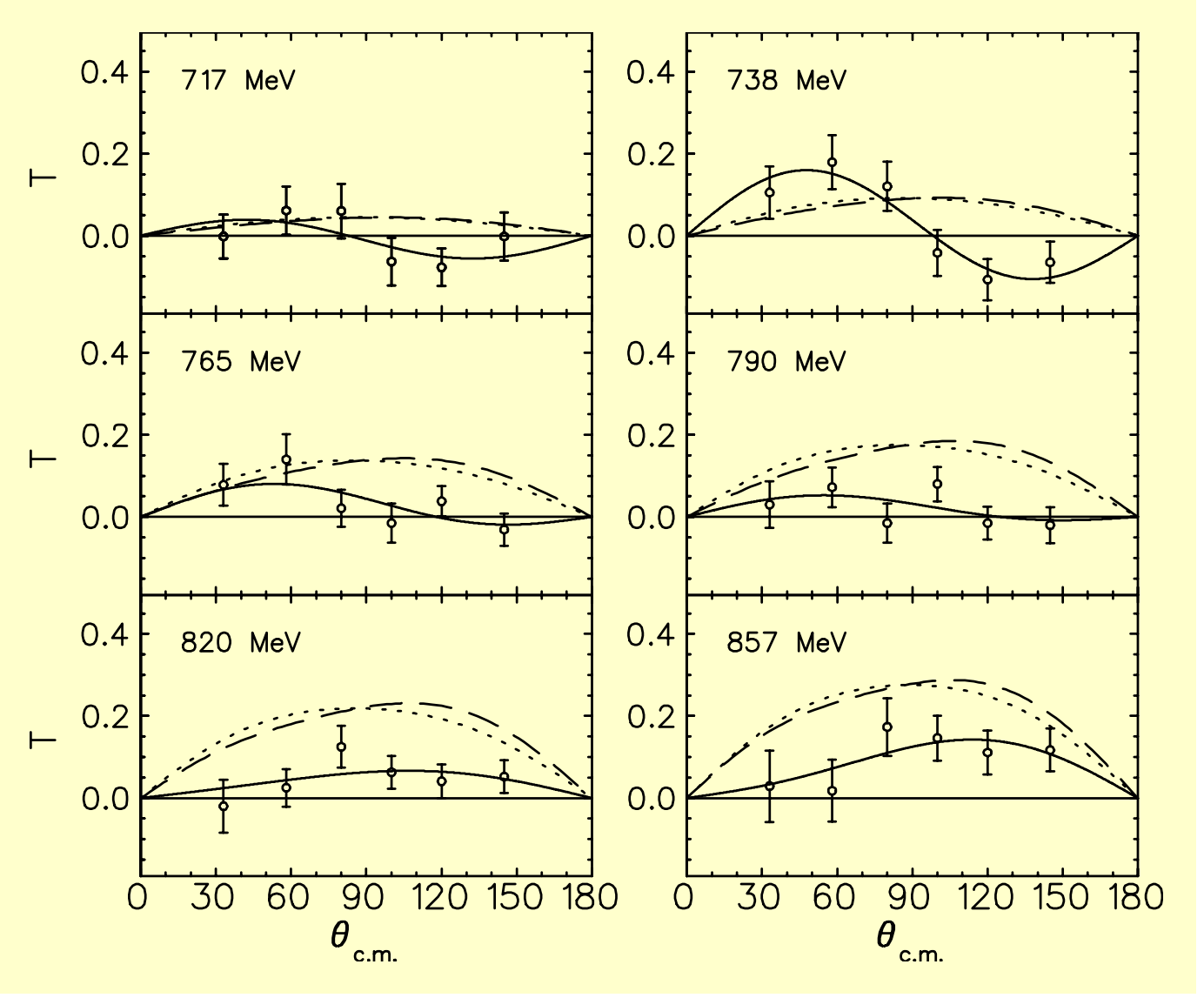
Total Cross Section



- Resonance structure in s-wave $\Rightarrow$ dominant $S_{11}(1535)$ resonance
- Background is small

Eta-MAID: W.-T. Chiang, *et al.*, Nucl. Phys. A 700 (2002)

PHOENICS (Bonn): Polarized target asymmetry T

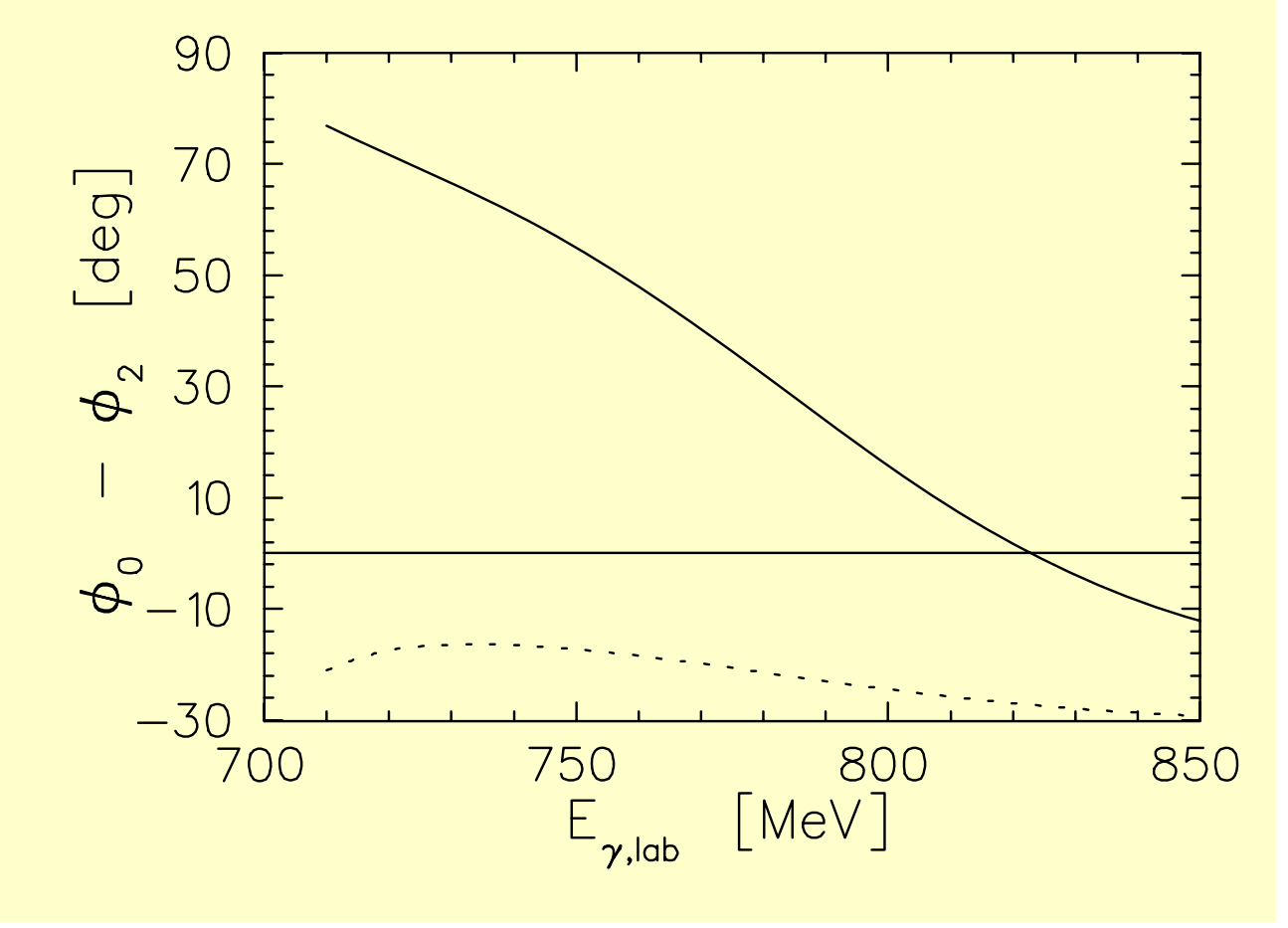


$$\sigma T \approx 3\sin\Im[E_{0+}^{*}(E_{1+}-M_{1+})] - 3\sin\theta\cos\theta\Im[E_{0+}^{*}(E_{2-}+M_{2-})]$$

A. Bock *et al.*, Phys. Rev. Lett. 81, 534-537 (1998)

Phase problem

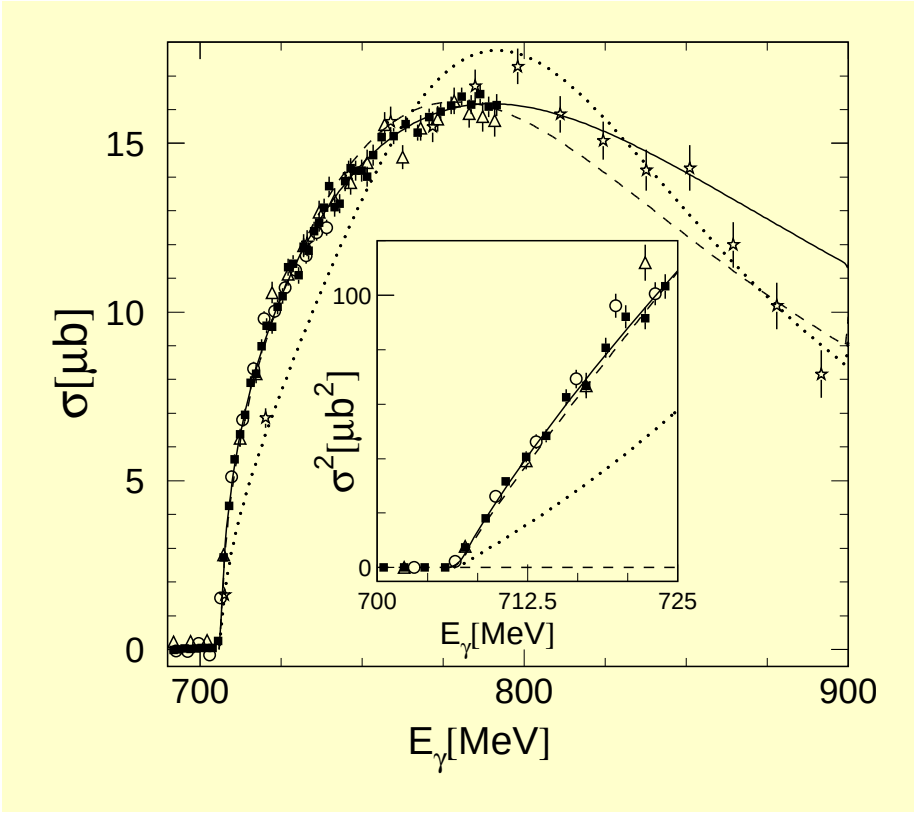
$$\sigma T \approx 3 \sin \Im [E_{0+}^{*}(E_{1+} - M_{1+})] - 3 \sin\theta \cos\theta \Im [E_{0+}^{*}(E_{2-} + M_{2-})]$$

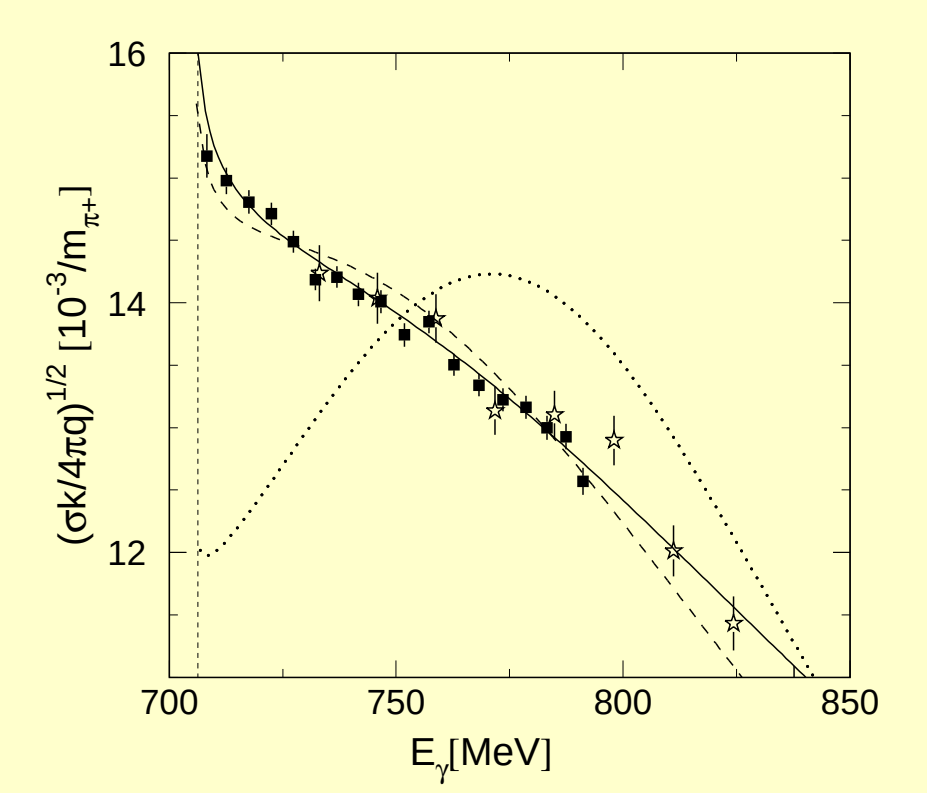


- Phase-difference $\phi_0 - \phi_2$ between E_{0+} and $E_{2-} + M_{2-}$ has to be adjusted!
- Problem of the $S_{11}(1535)$- or of the $D_{13}(1520)$-resonance?
- Breit-Wigner shape?

L. Tiator *et al.*, Phys. Rev. C 60 (1999) 035210

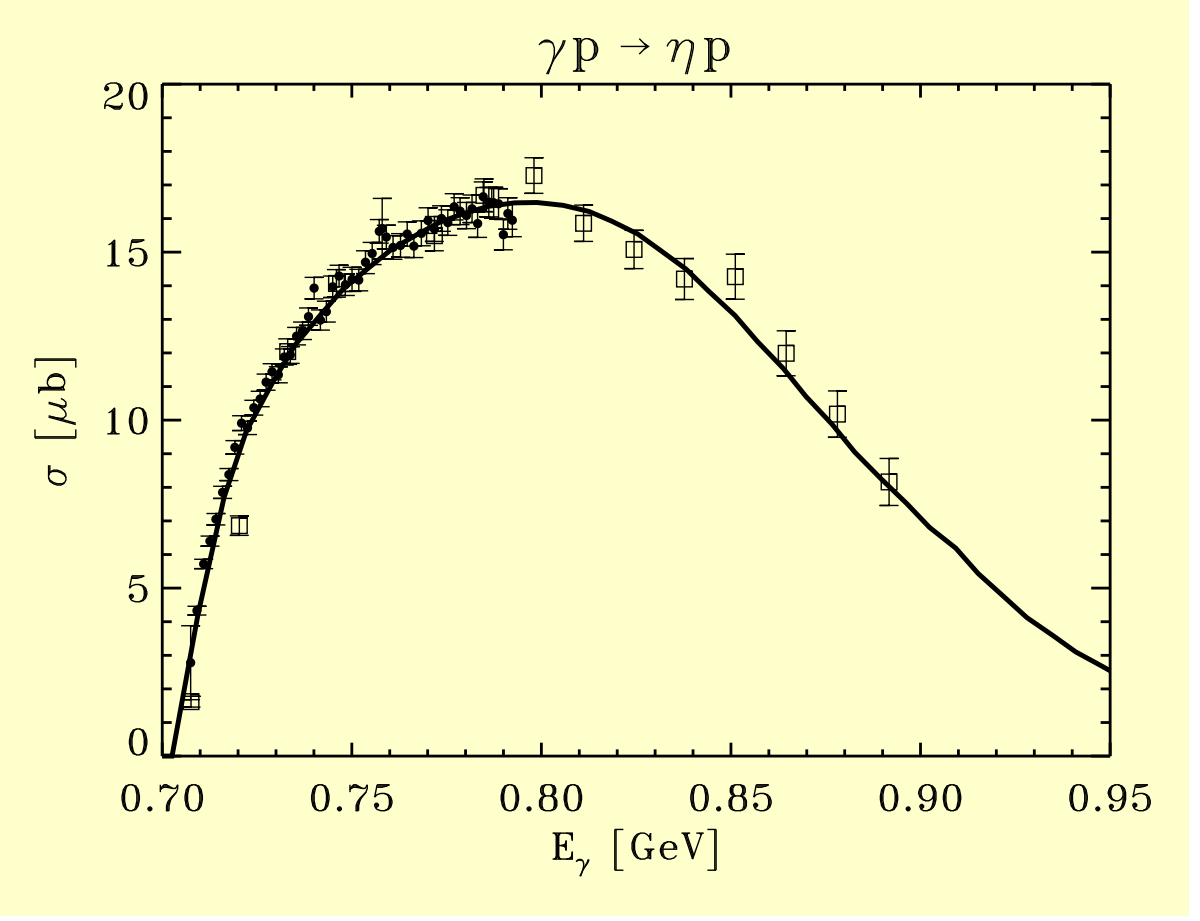
s-wave Dominance = $S_{11}(1535)$?





- Angular distribution: flat
- Energy dependence is well described by Breit-Wigner shape
- But: Reduced cross section $\approx E_{0+}$ is **flat!**

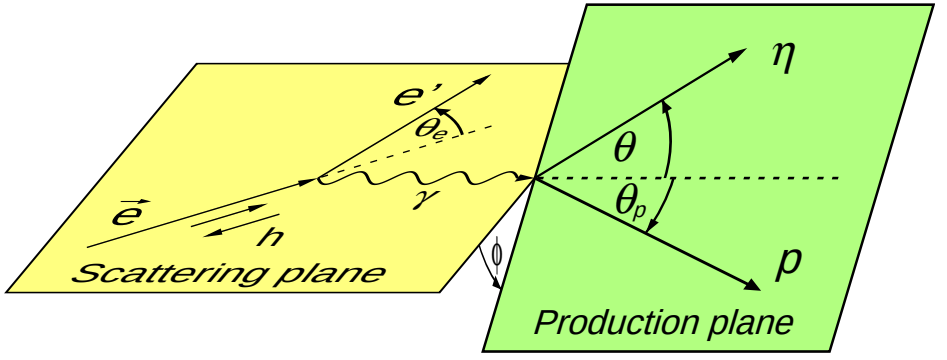
Dynamical generated $S_{11}(1535)$-Resonance



- Chirale Lagrangian + coupled channels
- No resonance!
- Interpretation: bound $K\Sigma$ state

N. Kaiser, T. Waas, W. Weise, Nucl. Phys. A 612, 297-320 (1997)

Double polarization experiment



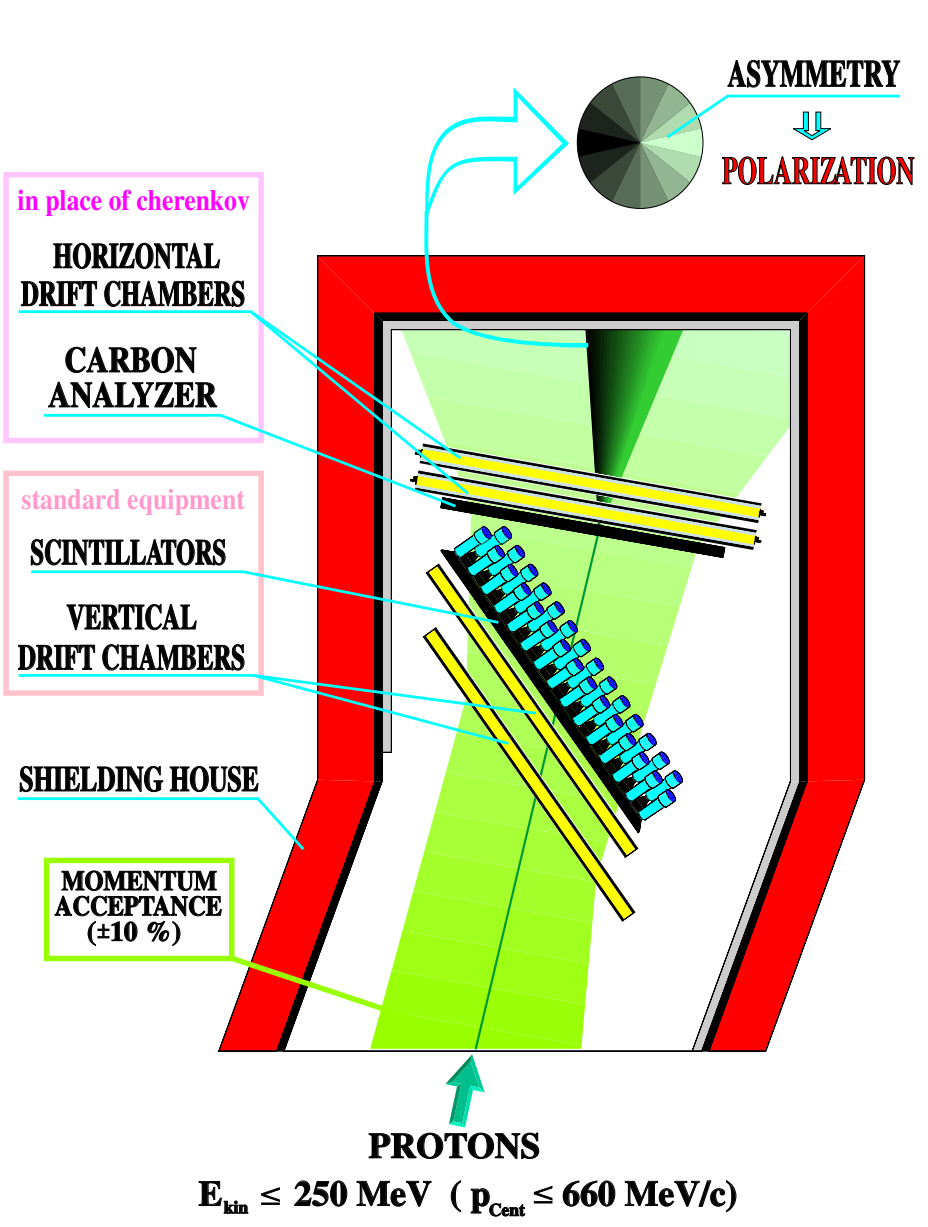
P_y: similar interference as σT!

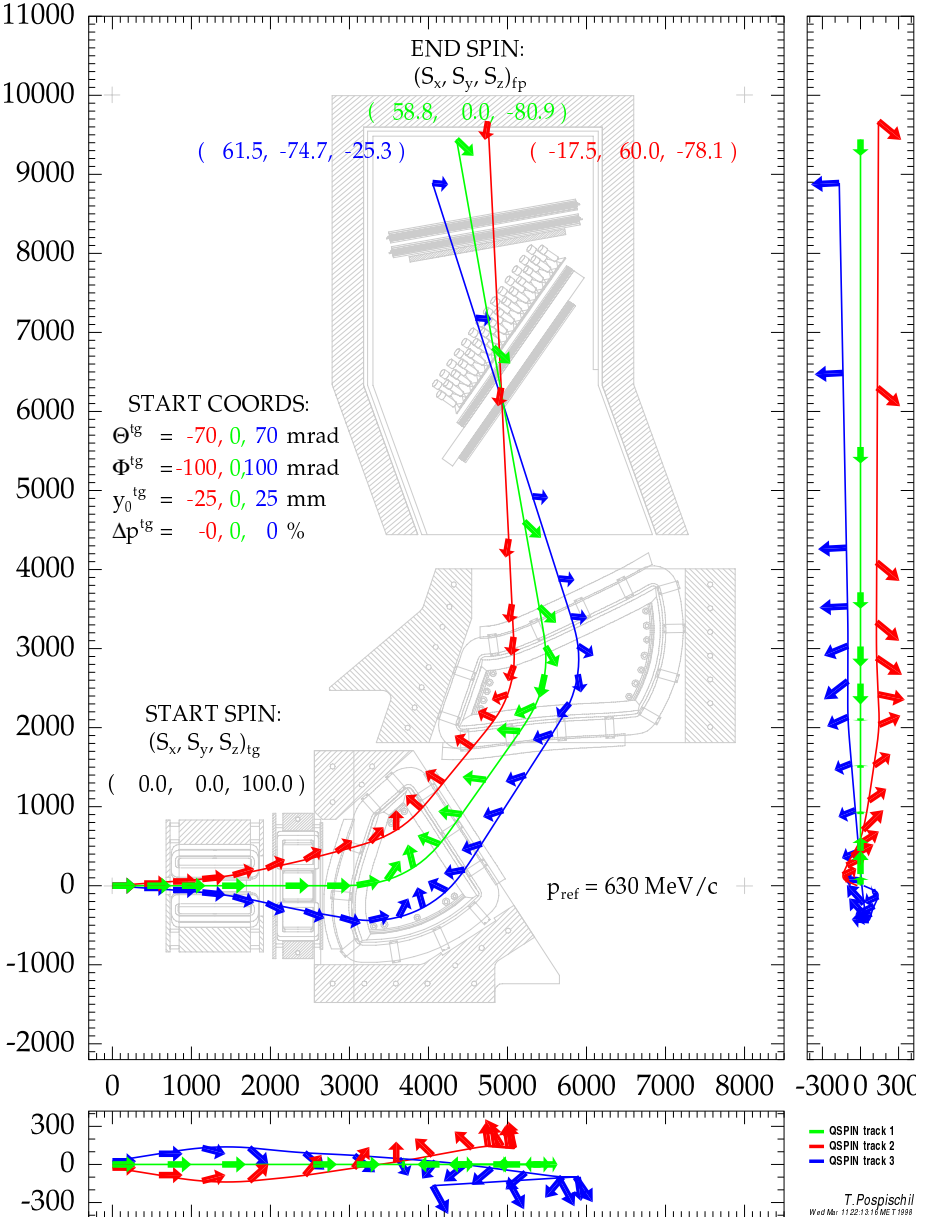
$$P_y \sim \sin\theta\,\Im\left\{E_{0+}^*(3\cos\theta(E_{2-}-3M_{2-})-2M_{1-})\right\}+\ldots$$

P_x^h, P_z^h: dominated by $|E_{0+}|^2$

$$P_x^h \sim -\sin\theta\left[|E_{0+}|^2-\Re\{E_{0+}^*(E_{2-}-3M_{2-}\}\right]$$
$$P_y^h \sim \cos\theta|E_{0+}|^2-2\Re\{E_{0+}^*[M_{1-}-\cos\theta(E_{2-}-3M_{2-})]\}$$

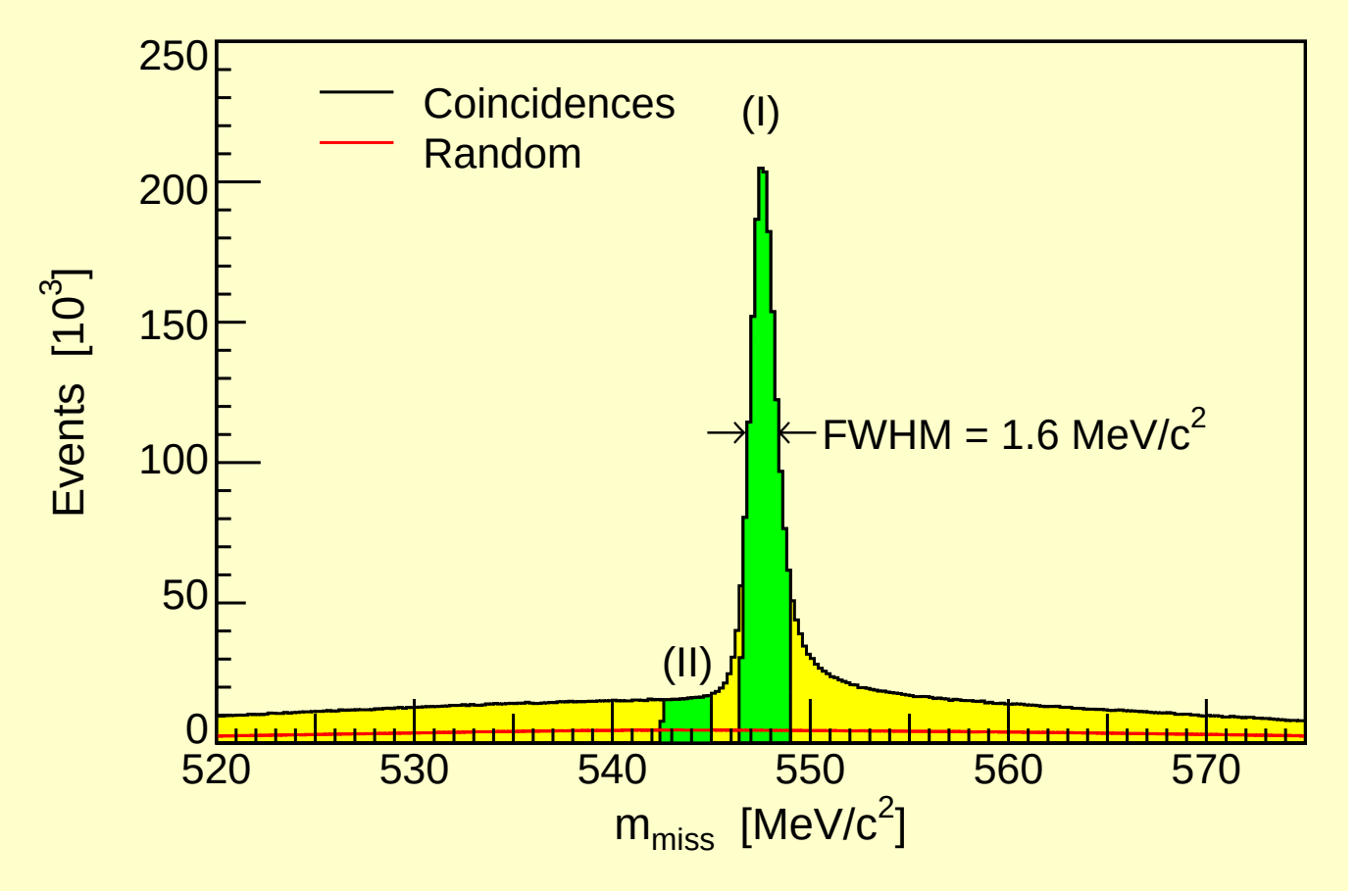
Focal Plane Polarimeter





Missing mass

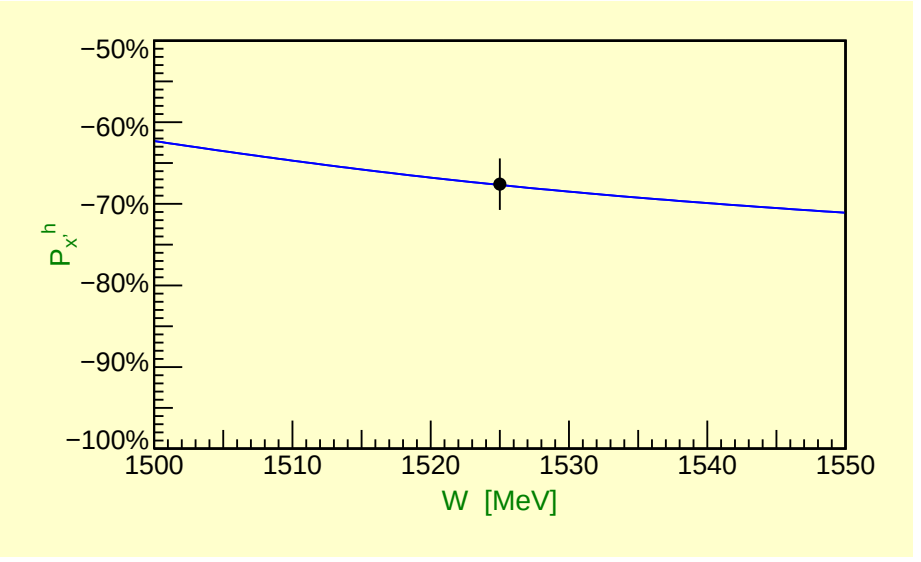
$$m^2_{miss} = (e + p_{in} - e' - p_{out})^2$$

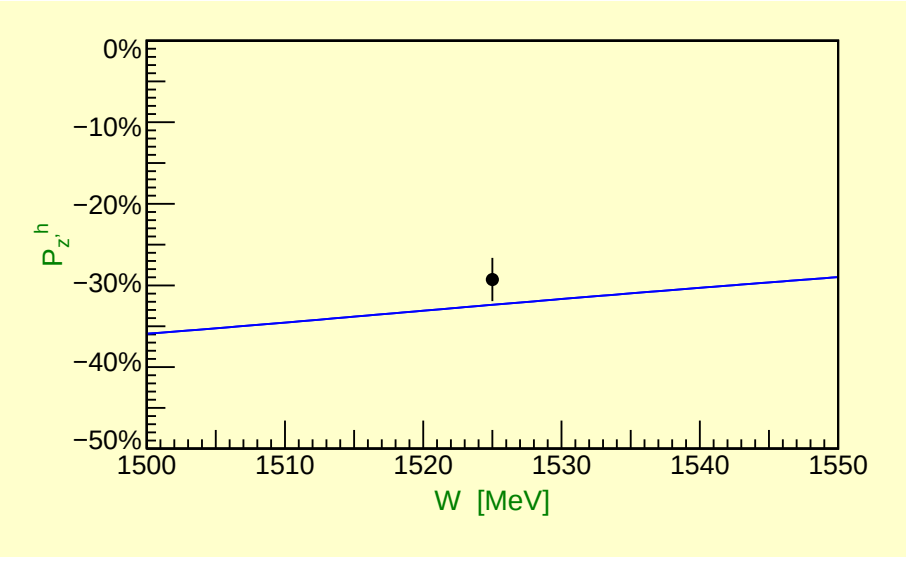


- Random background $\approx 2\%$
- Physical background $\approx 8\%$

  e.g. $\gamma^* + p \to p + \underbrace{\pi^+ + \pi^-}_{\approx m_\eta}$

Result helicity dependent polarizations

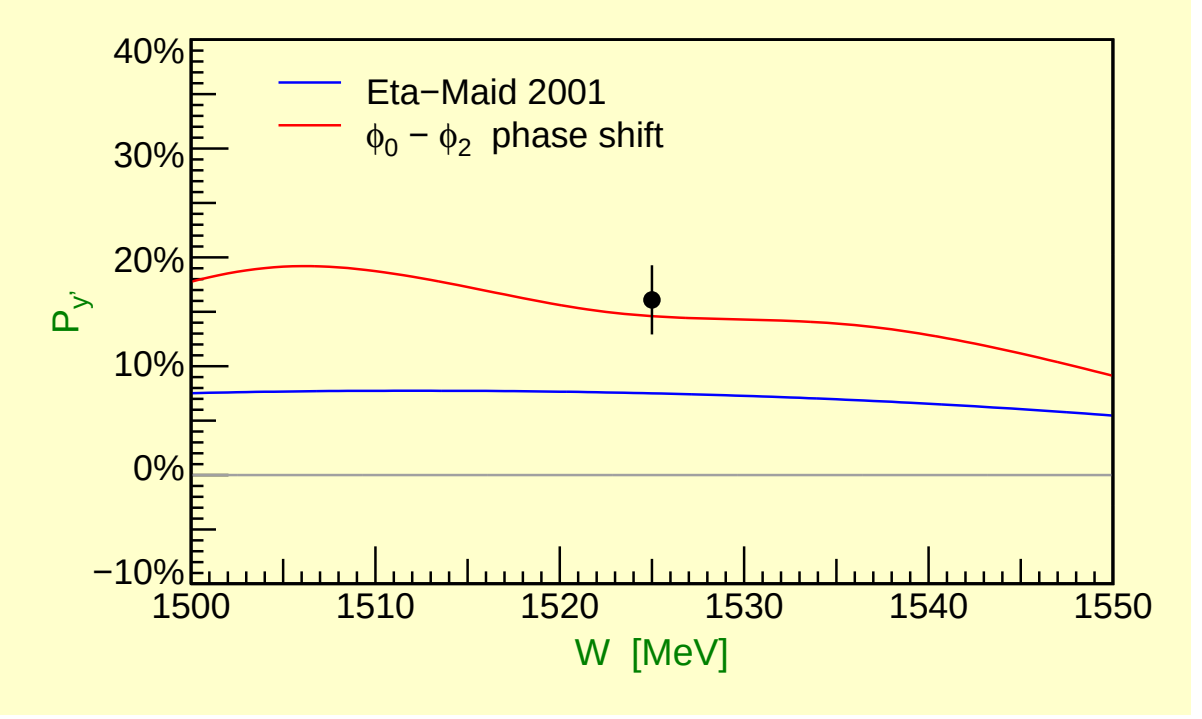




No surprises:

- Dominant $|E_{0+}|^2$
- Consistent with existing data
- No visible S_{0+} contribution

Result helicity independent polarization



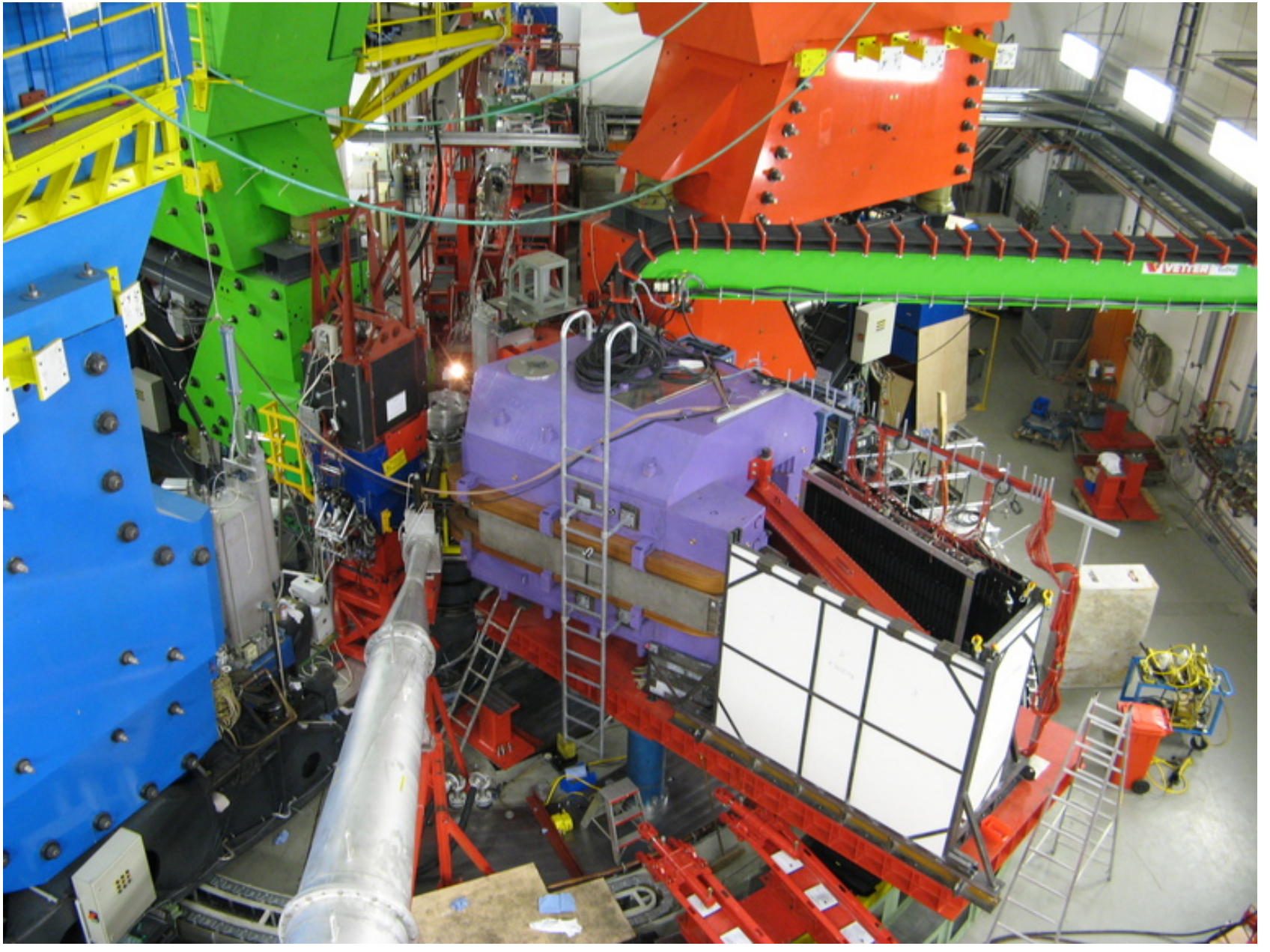
- Clear deviation from Eta-Maid
- Consistent with phase rotation $\phi_0 - \phi_2$

$\Rightarrow$ consistent with ELSA results on T

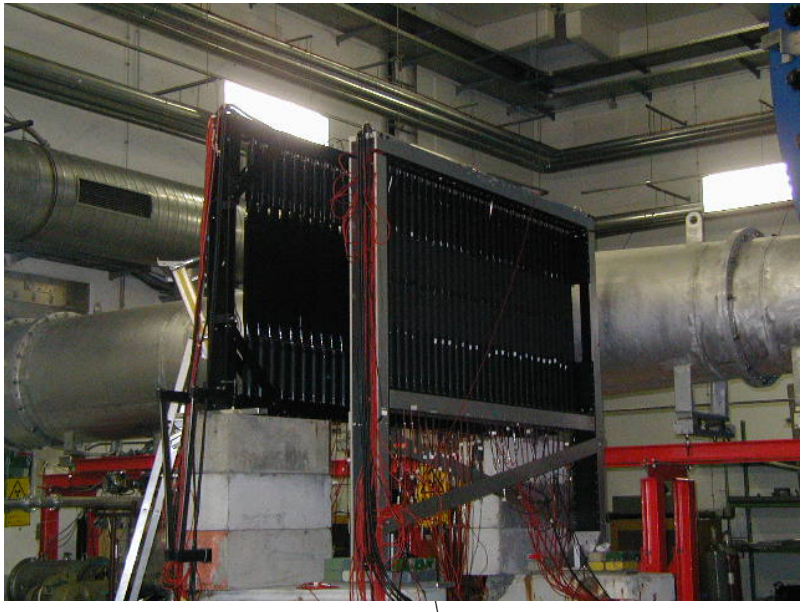
H. Merkel et al., Phys. Rev. Lett. 99, 132301 (2007)

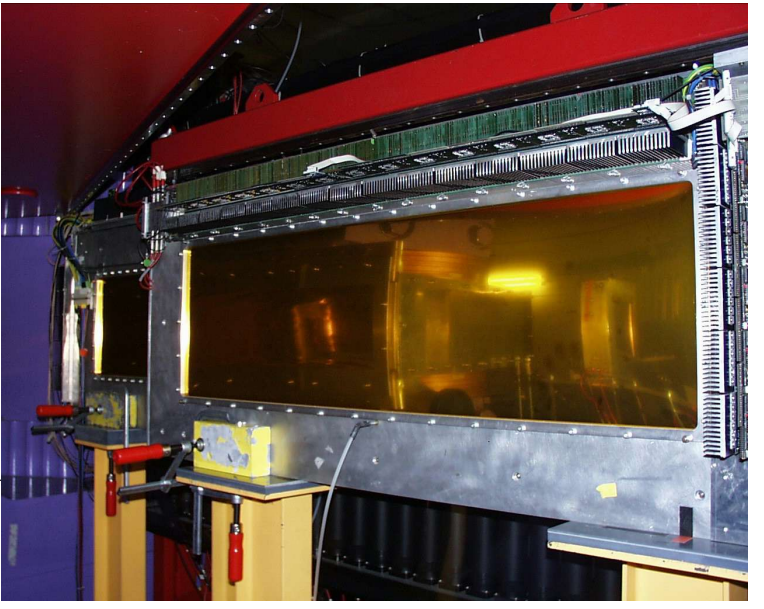
Strangeness

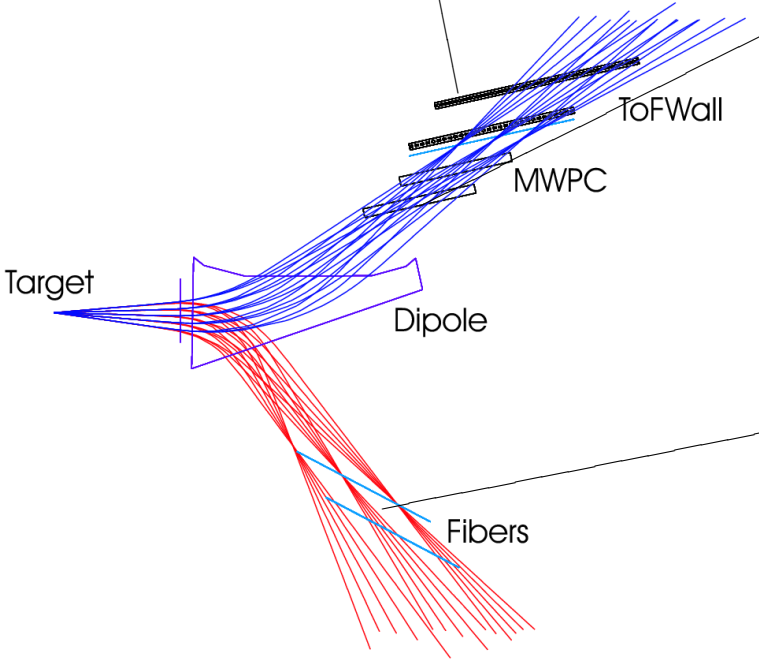
Strangeness Production - Kaon Spectrometer (KAOS)

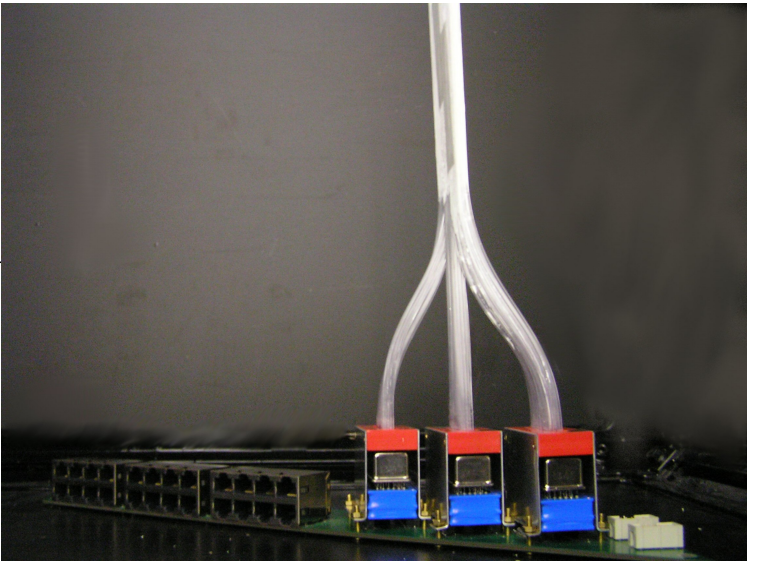


Kaos Focal Planes



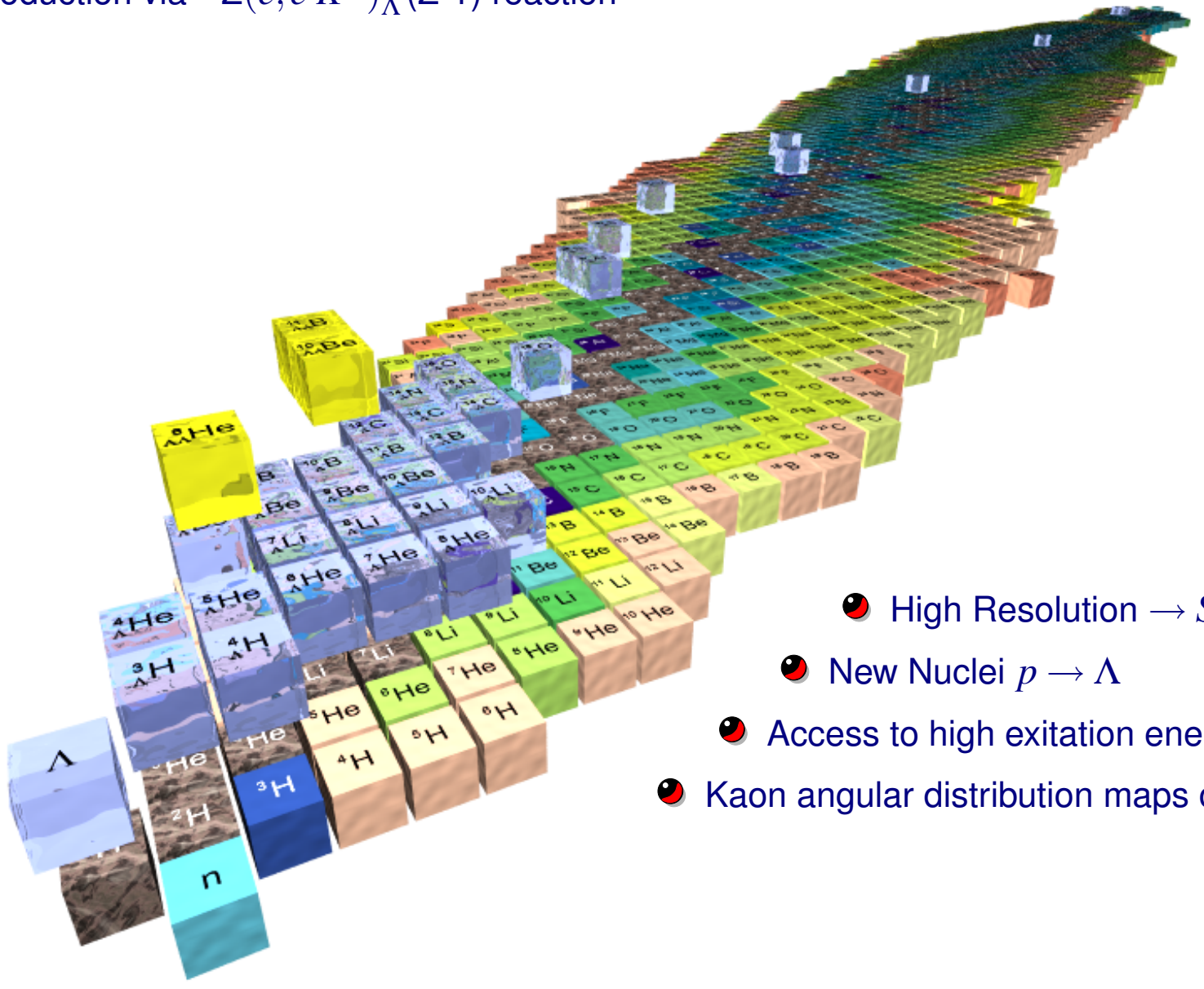






Hypernuclei

- Production via ${}^{A}_{Z}(e,e'K^{+})^{A}_{\Lambda}$(Z-1) reaction



- High Resolution $\rightarrow$ *Spectroscopy*
- New Nuclei $p \rightarrow \Lambda$
- Access to high exitation energy
- Kaon angular distribution maps out Λ wave function

Summary

- MAMI C
  - 1.5 GeV electron beam
  - High beam quality, intensity, and polarization
  - Various detector systems
  - Polarization of beam, target, and recoil particle
- Extensive hadronic program
  - Hadron Structure: formfactors, $2-\gamma$ amplitudes, polarizabilites, etc.
  - Meson Production: threshold production, nucleon resonances, coherent production
  - Meson decays: η, η'
  - Hypernuclei
  - ...