Study of baryon resonances with meson photoproduction

F. Zehr, University of Basel, Department of Physics

Overview Talk   Group Professor B. Krusche

- **Introduction to nucleon resonances and meson photoproduction**

- **The setup at MAMI in Mainz and ELSA in Bonn**

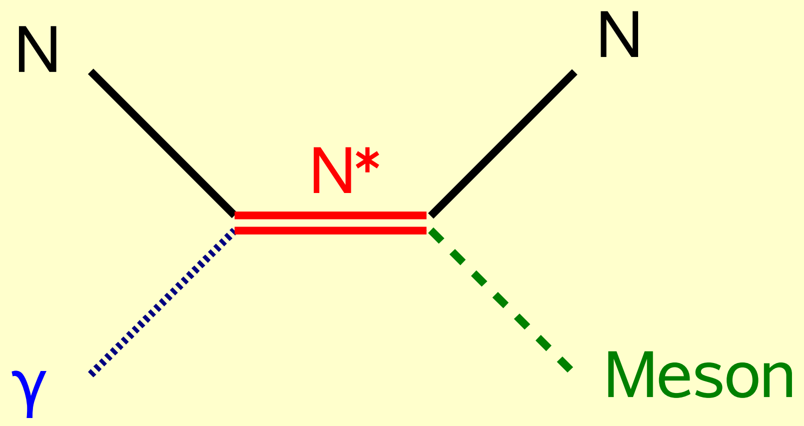
- **Some selected topics:**
  - Magnetic moment of the Δ(1232) resonance
  - η' photoproduction
  - η photoproduction off light nuclei: ^{2}H, ^{3}He and ^{7}Li
  - Isospin structure of excitations
  - Coherent η production & η mesic nuclei

- **Double pion photoproduction off the proton**

- **Outlook**

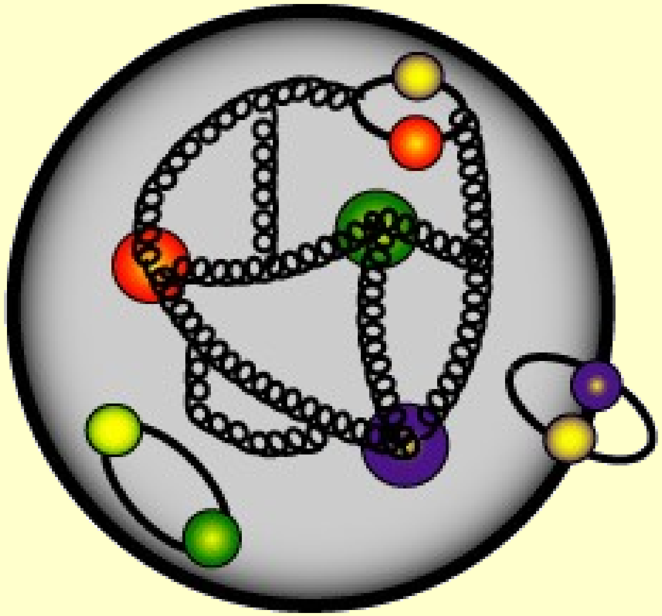
What do we have in common?

We study meson photoproduction off the nucleon via the excitation of nucleon resonances (or production at threshold)



Nucleon Resonances

What is the structure of the nucleon?



QCD

Valence quarks

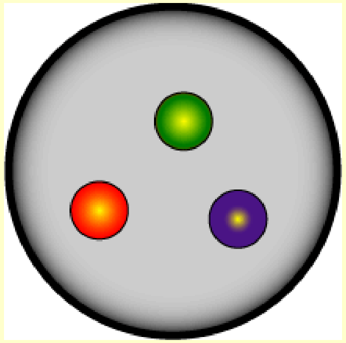
Sea quarks

Gluons

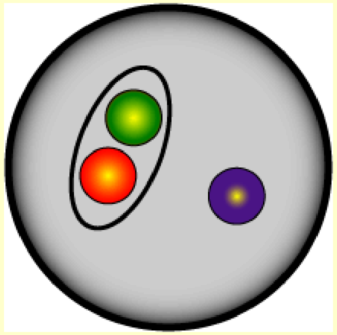
Complex structure

Nucleon at Low Energies

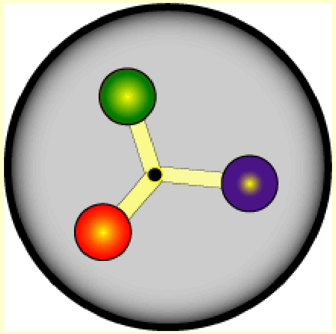
→ **Constituent Quark Models with effective degrees of freedom**



3 equivalent constituent quarks



quark diquark

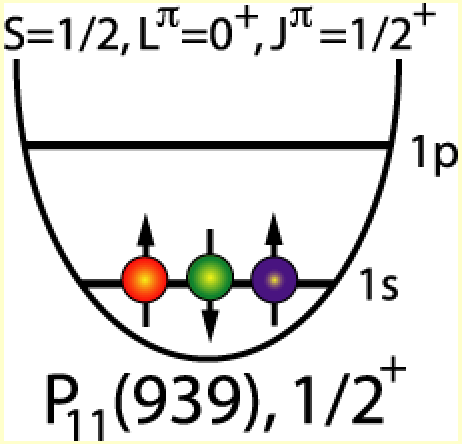


quark flux tubes

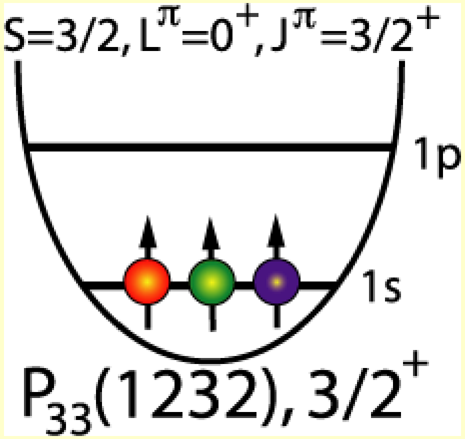
... much more models available *(chiral soliton models, coupled chanel dynamics)*
with different number of degrees-of-freedom

Resonances: Excited states of the nucleon

→ Related to the number of degrees-of-freedom



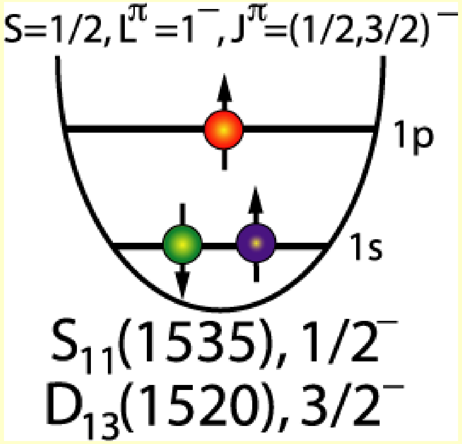
Ground State: Nucleon



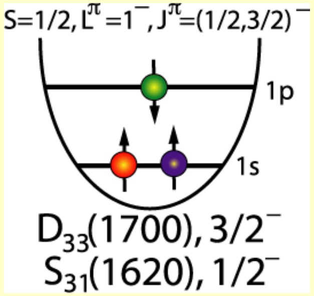
Spin-Flip →
First Resonance: 'Delta'

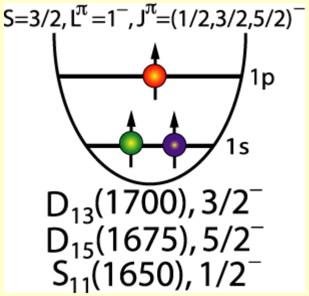
Resonances: Excited states of the nucleon

→ Related to the number of degrees-of-freedom



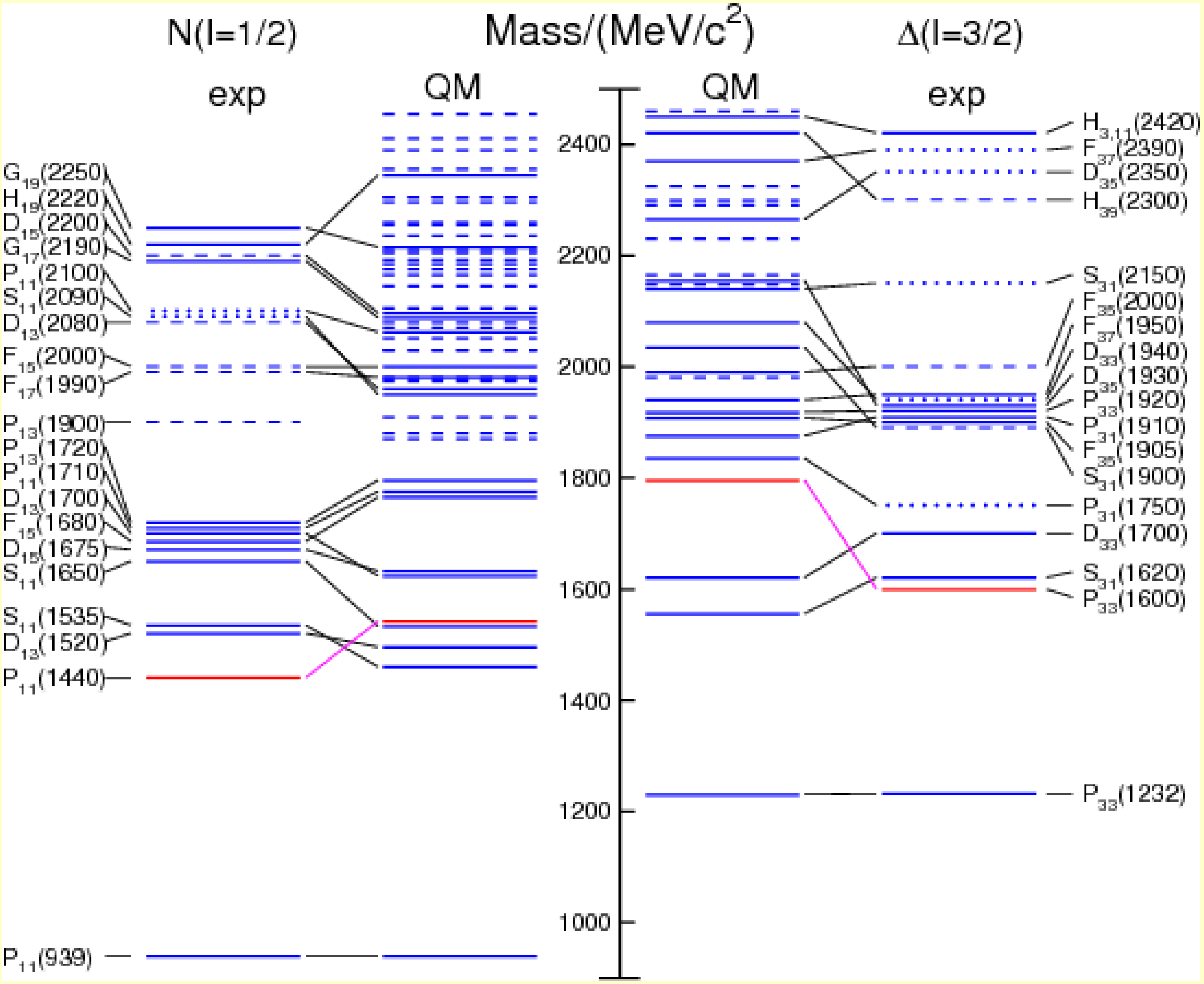
Quark → 1p
S_{11} and D_{13}: Second resonance region





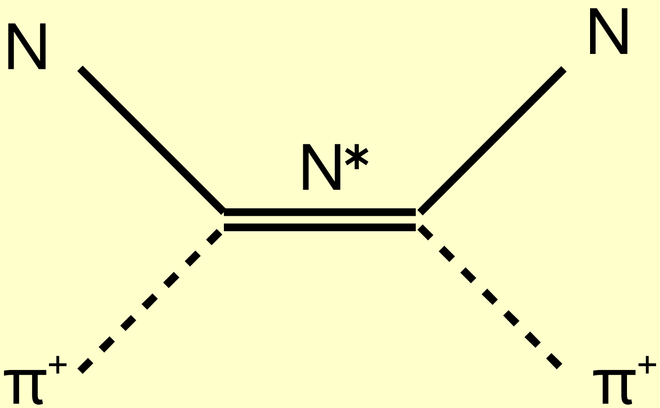
And so on ...

Resonances: Comparison between Constituent Quark Model and experiment



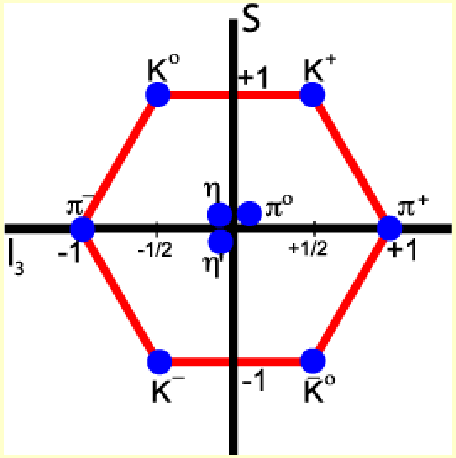
S. Capstick and W. Roberts
Phys. Rev. D 1994

How do we study resonances?



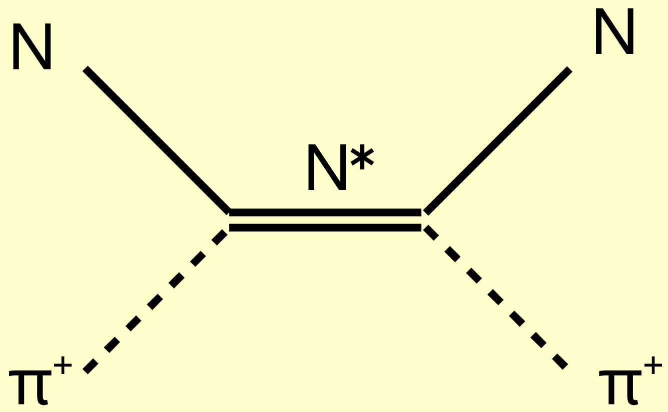
Resonances decay into mesons is dominant
→ large cross sections

Historically, lots of results on resonances provided by elastic and inelastic scattering of charged pions



QCD:
Meson octet

How do we study resonances?



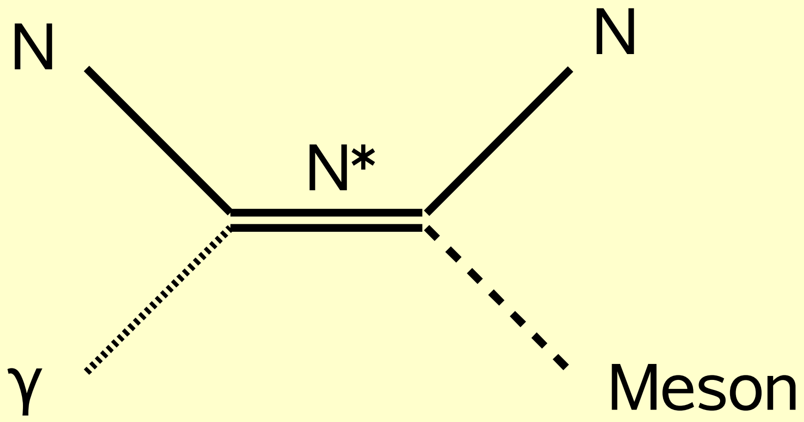
Resonances decay into mesons is dominant
→ large cross sections

Historically, lots of results on resonances provided by elastic and inelastic scattering of charged pions

But

Not suited for resonances coupling weakly to pions → experimental bias: missing resonances?

Photoproduction:



Gives another access to nucleon resonances

Advantage:

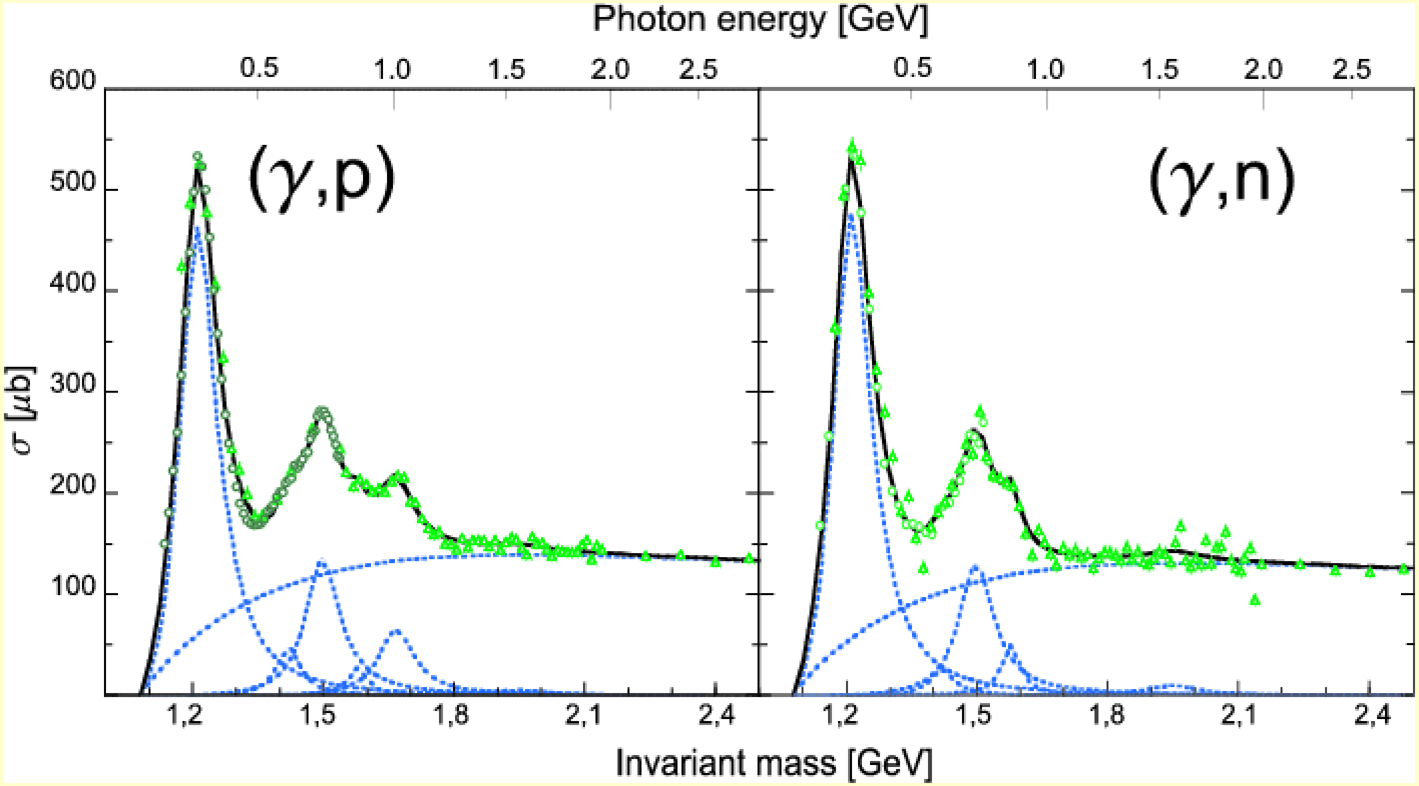
Gives access to additional information: electromagnetic transition amplitude

Drawback:

Very small cross sections (~ 3 orders of magnitude smaller)

Lots of background (non resonant terms)

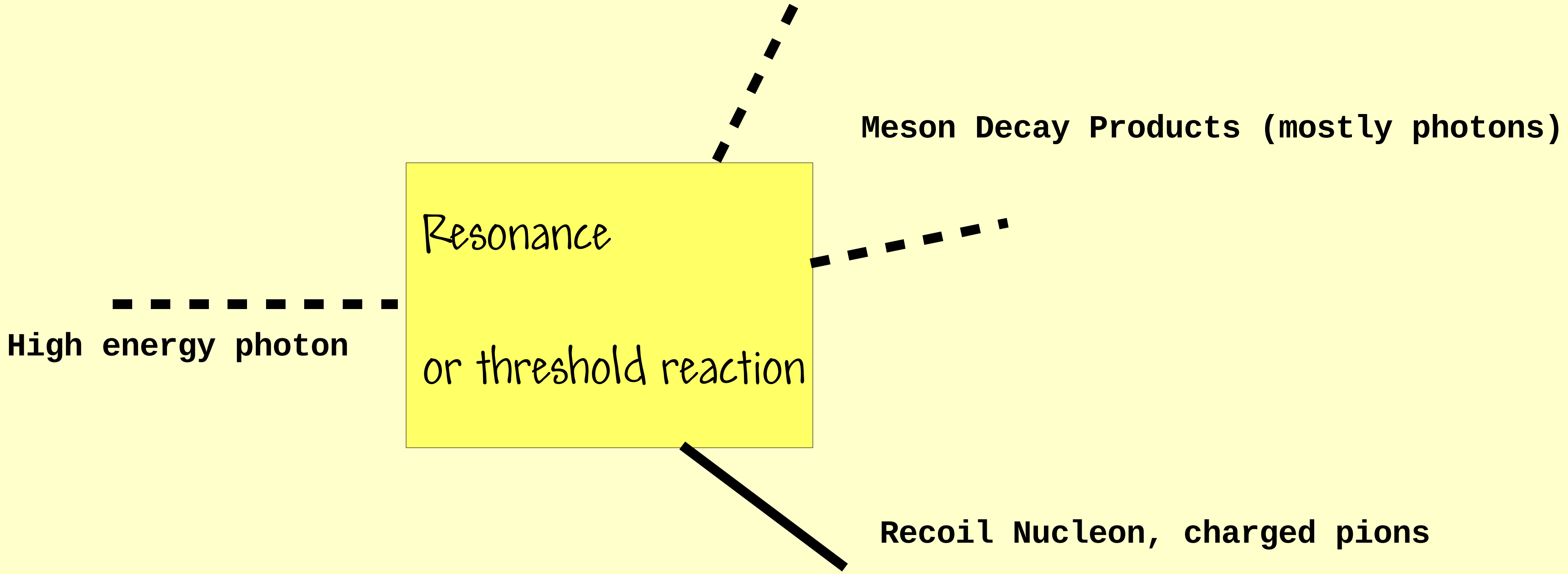
Total photoabsorption cross section:



From left to right: P_{33}(1232), P_{11}(1440), D_{13}(1520), S_{11}(1535), F_{15}(1680)

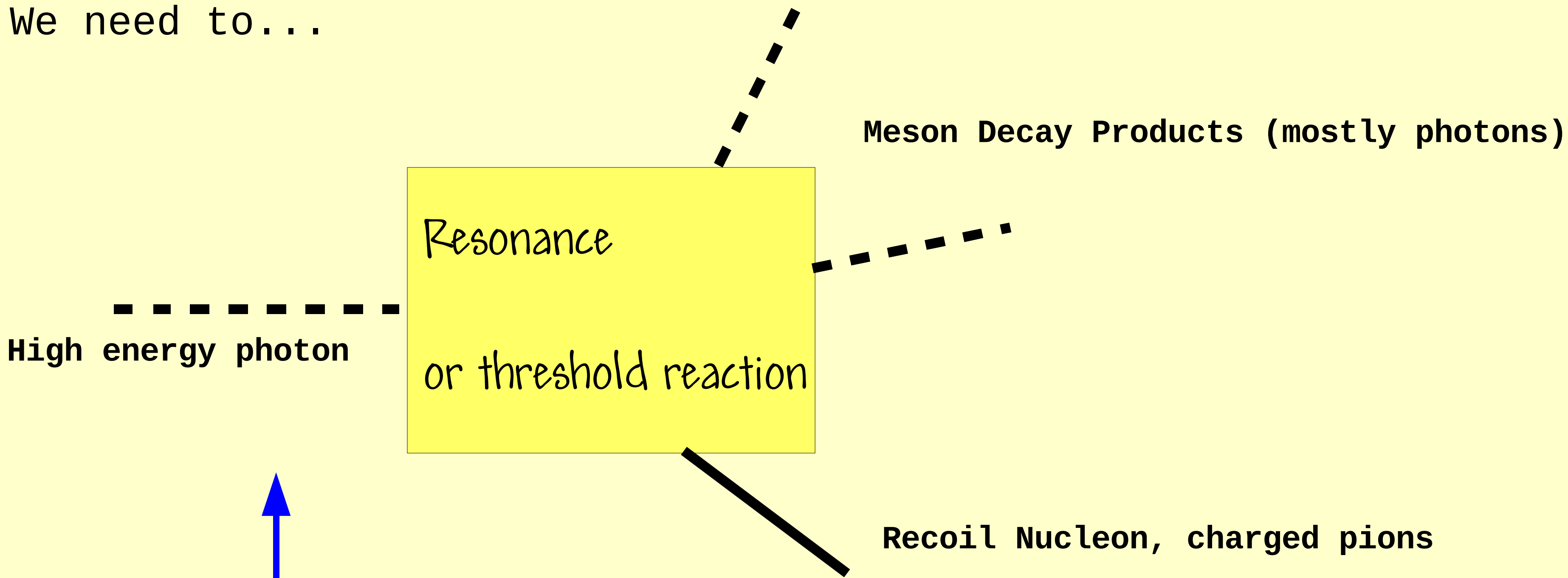
Difficulty: Due to short lifetime, resonances are broad and strongly overlapping

What we all have in common:



What we all have in common:
The Setup

We need to...

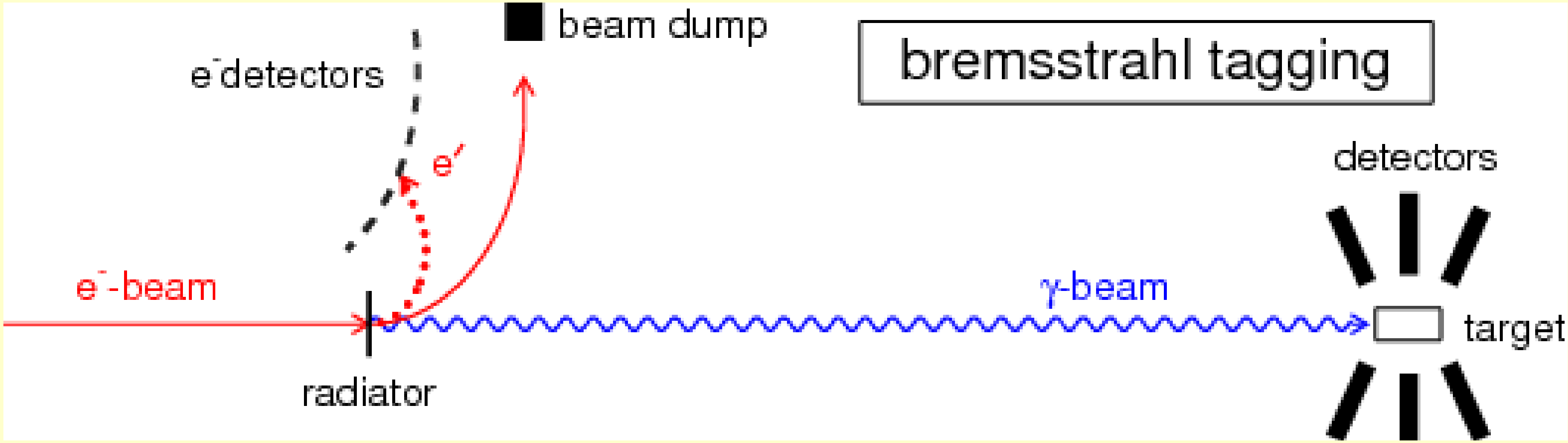


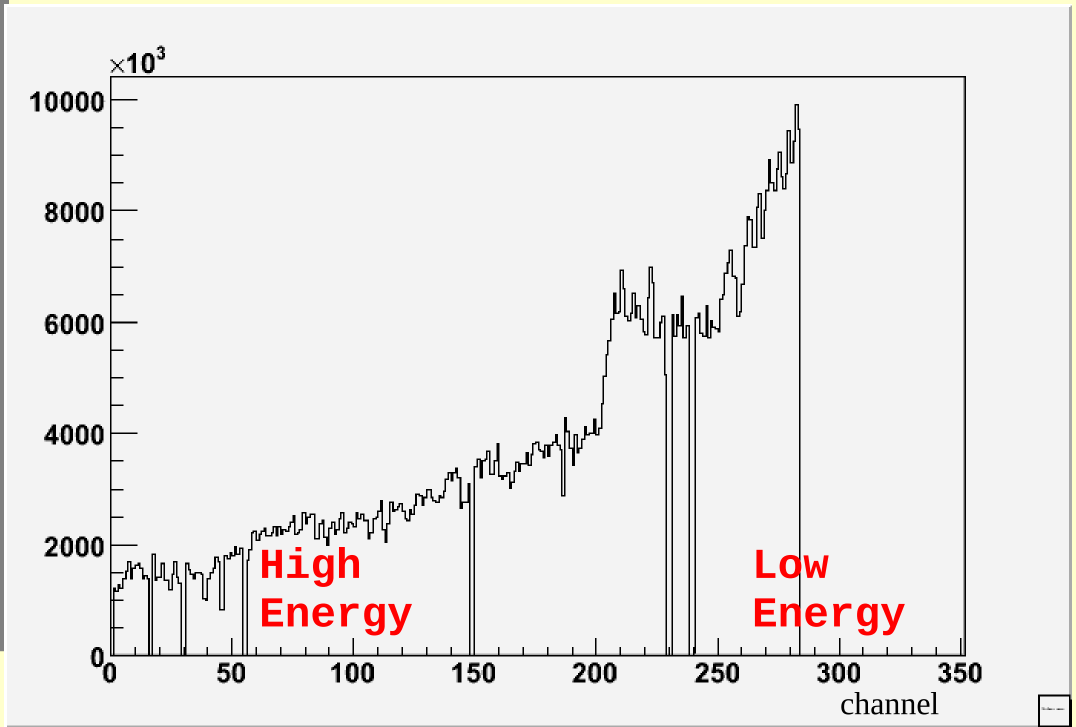
1: **Produce high energy photons**
100MeV to ... (3.2 GeV)

2: **Detect decay products**
photons, protons, neutrons,
charged pions, electrons, ...

Producing high energy photons:

Bremsstrahlung tagging



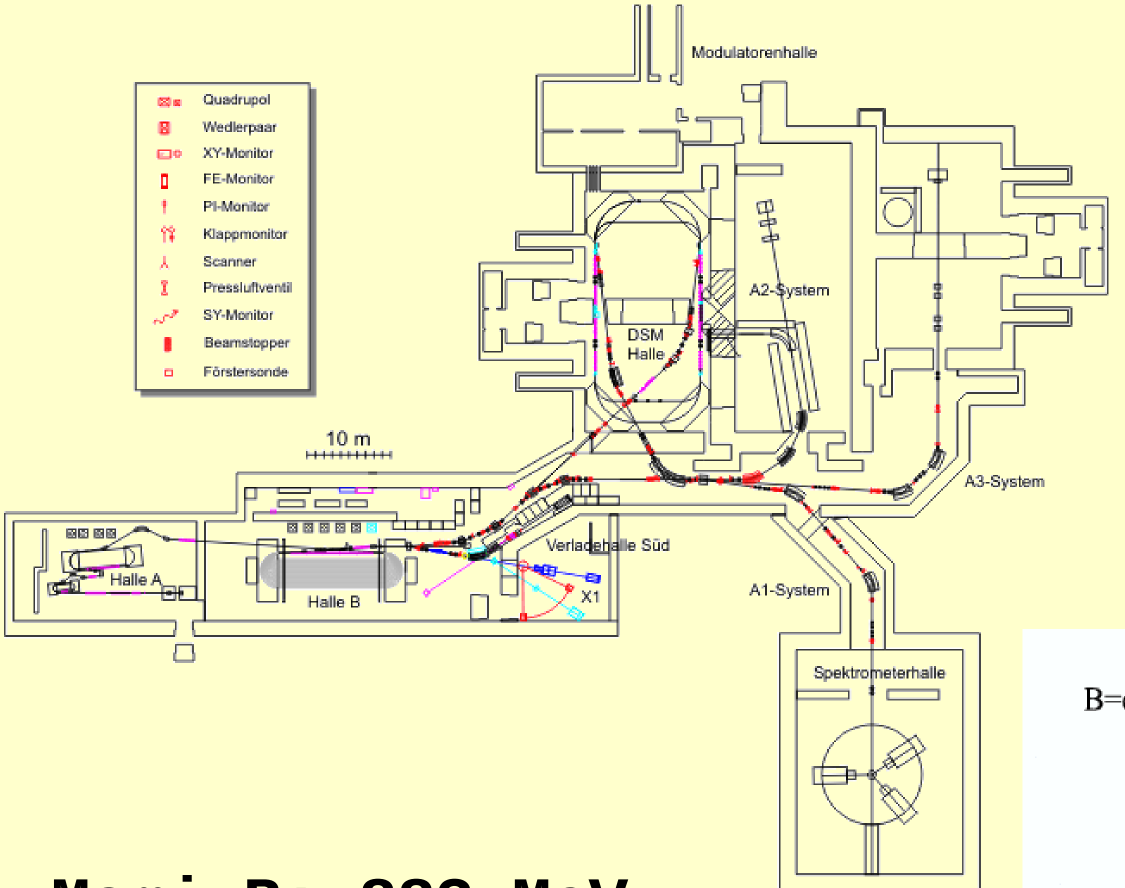


1/E spectrum

$E_\gamma = E_e - E_{e'}$

Polarized photons are produced on a diamond radiator via coherent bremsstrahlung

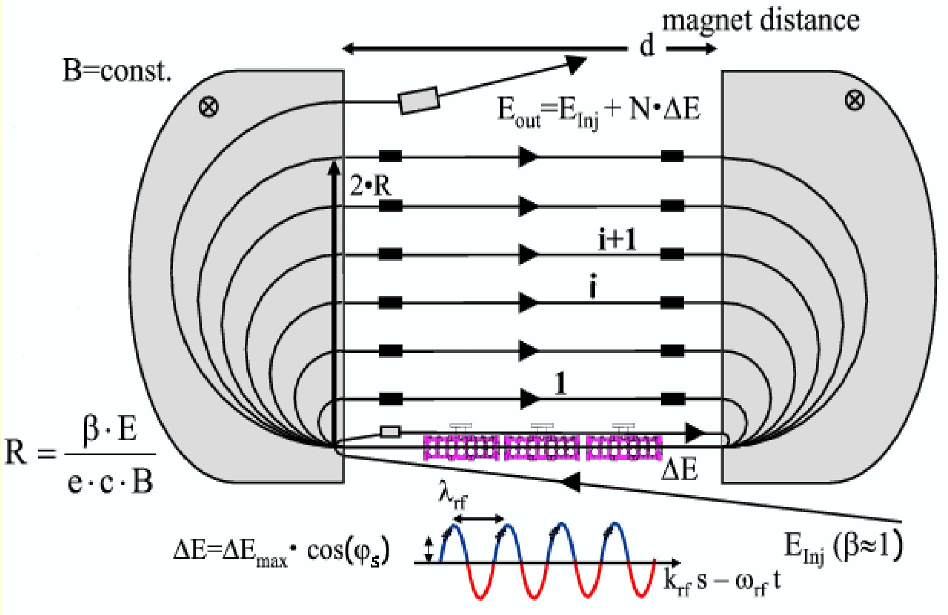
Accelerators: MAMI in Mainz



Upgrade:
Mami C → 1.5 GeV
First data taking
in progress

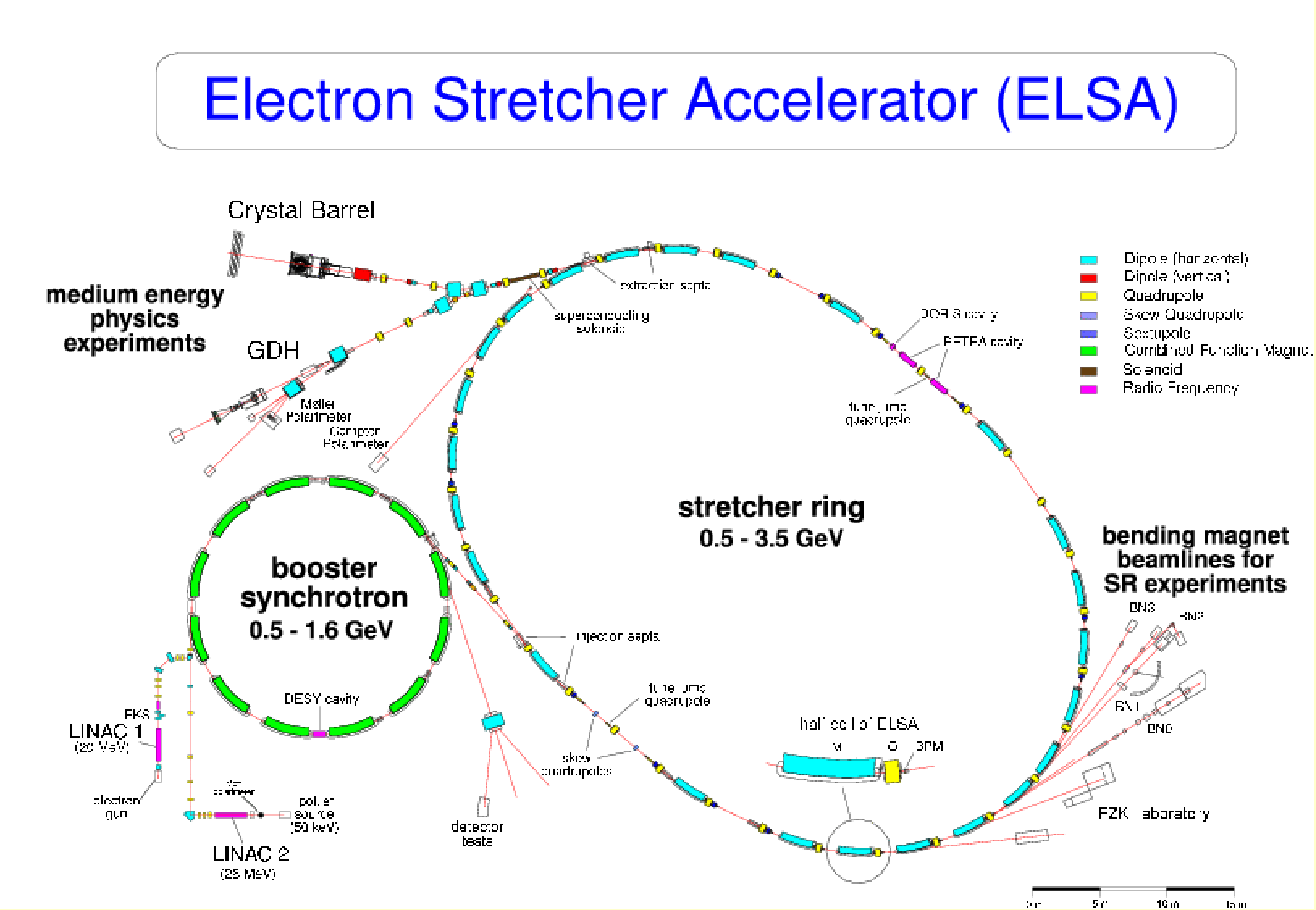
Mami B: 883 MeV
Until march 2007

3 cascaded racetrack microtrons



Very High Current: 80 µA

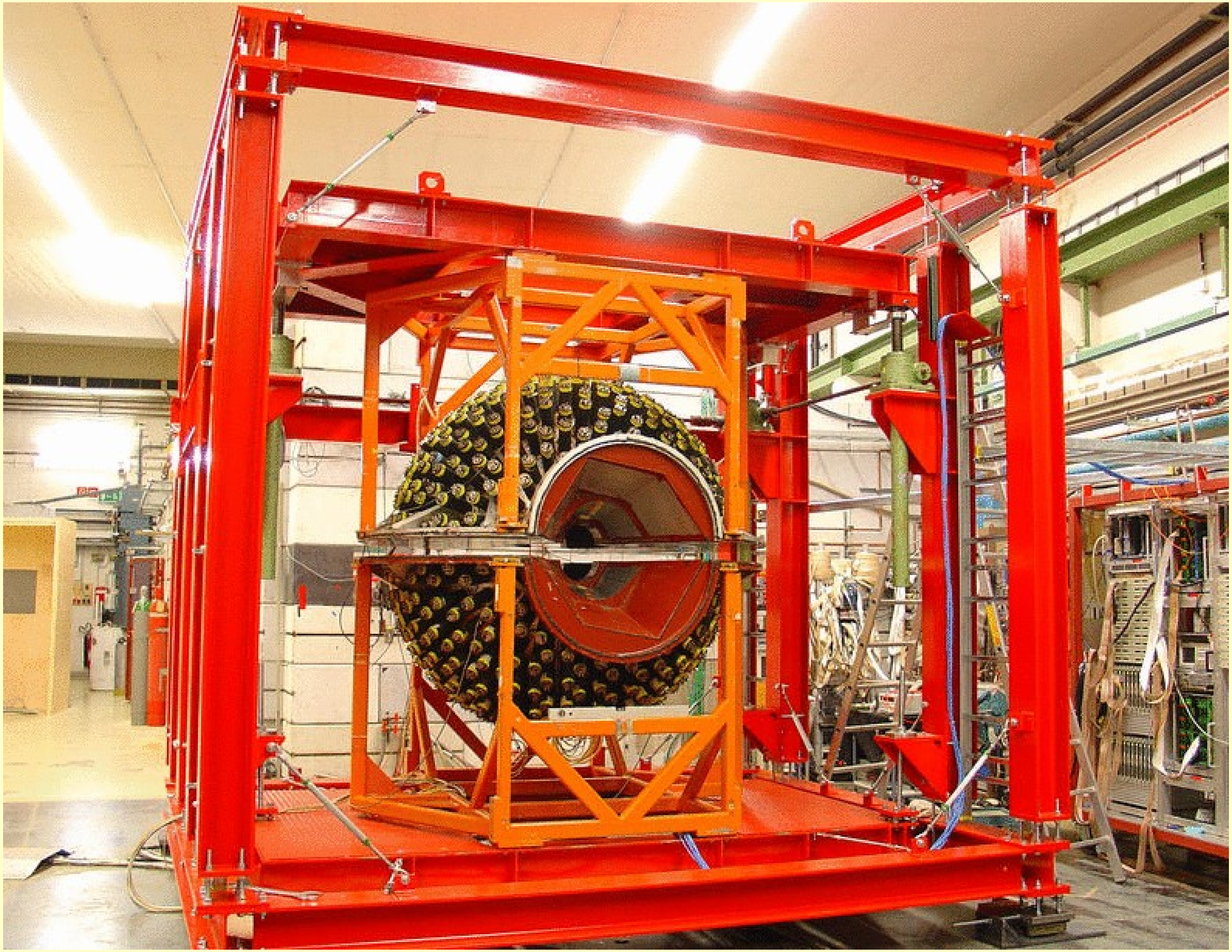
Accelerators: ELSA in Bonn



Up to 3.5 GeV

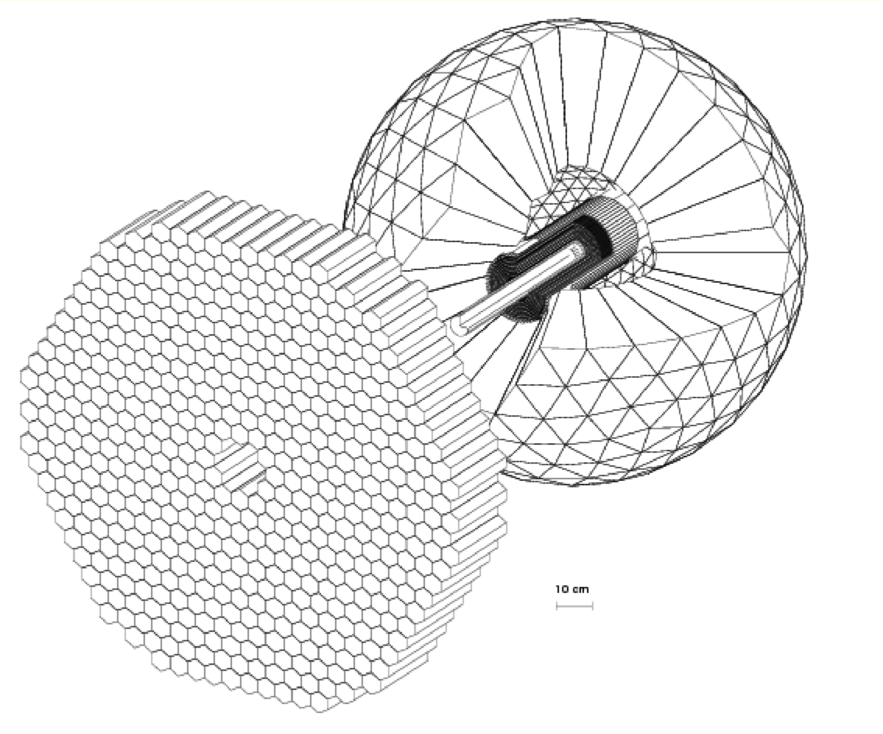
Current: 5 μA

Detectors:
In Mainz, Crystal Ball and TAPS

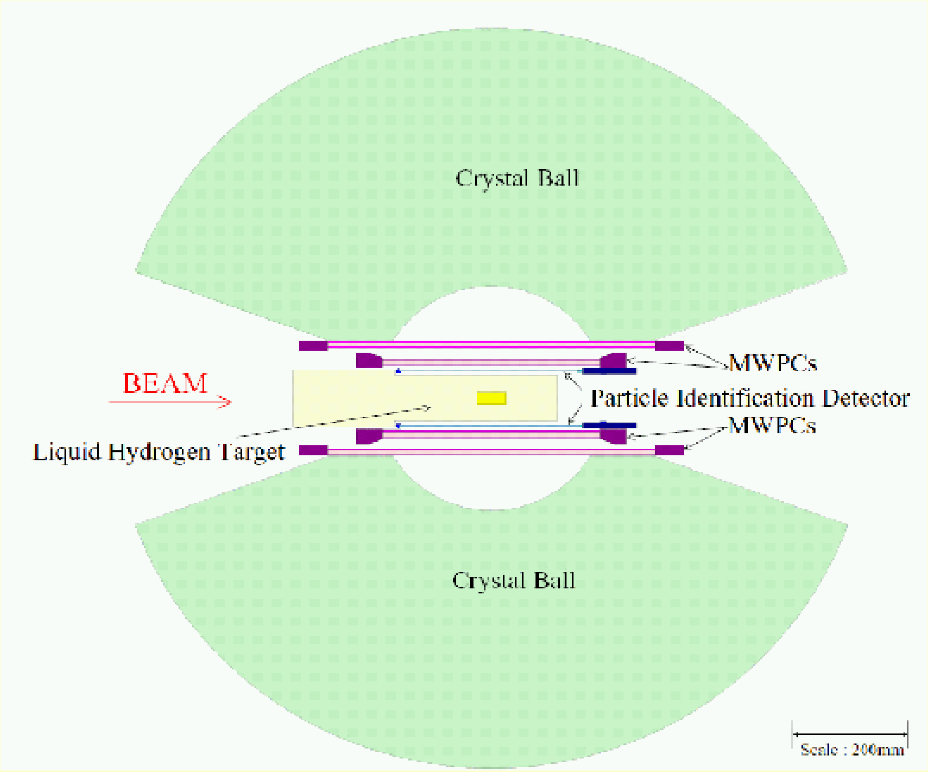


Detectors:

In Mainz, Crystal Ball and TAPS, highly segmented calorimeters



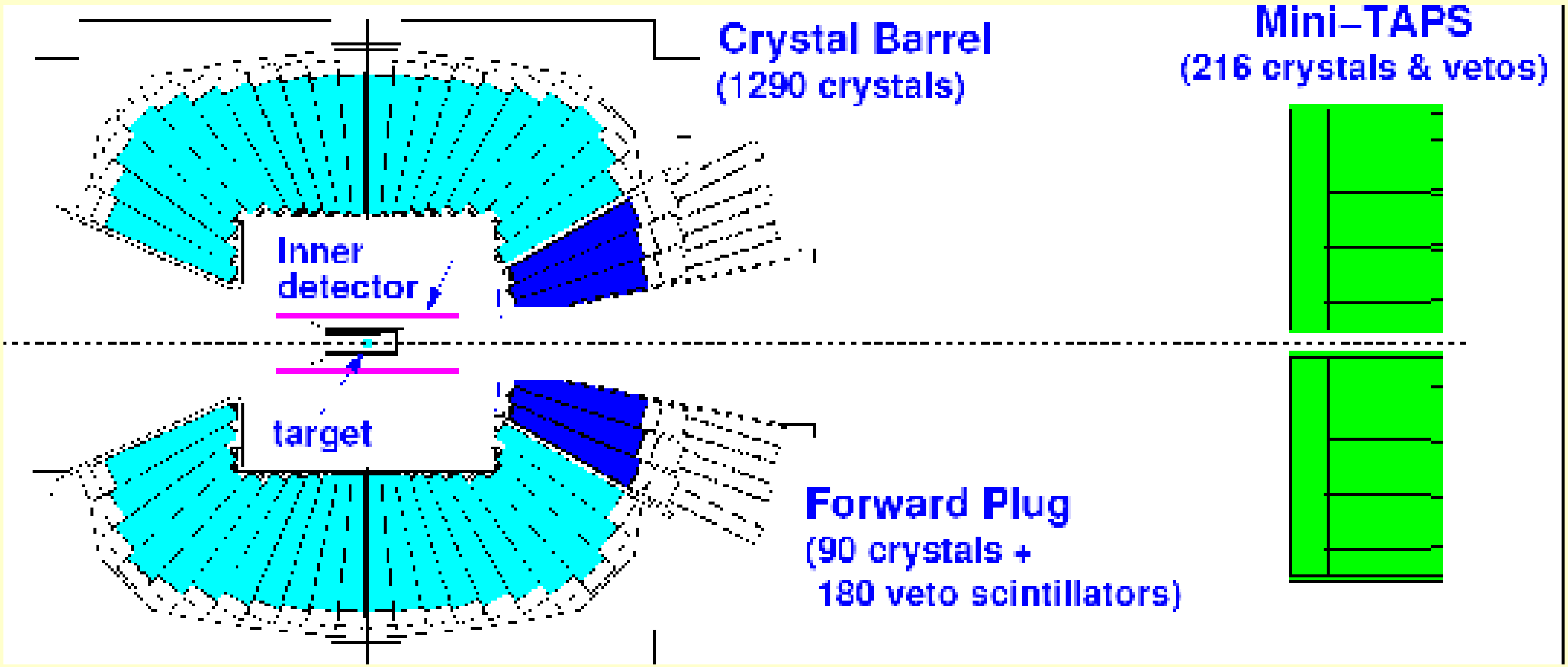
Crystal Ball:
- 672 NaI Crystals
- Vetos
- 2 MWPCS



TAPS as forward wall:
- 510 BaF2 Crystals
- Veto wall

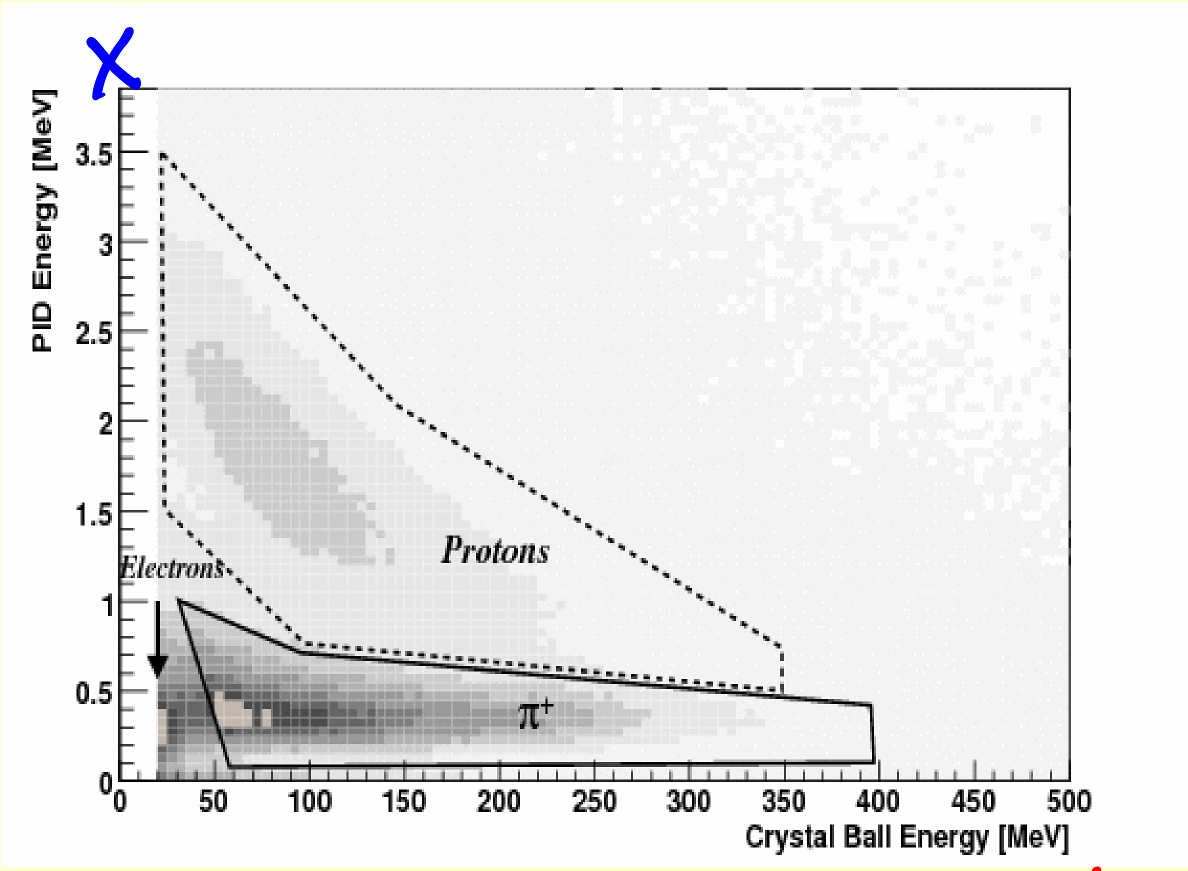
Detectors:

In Bonn, Crystal Barrel and TAPS,



Detection Technique 1/3:

Vetos



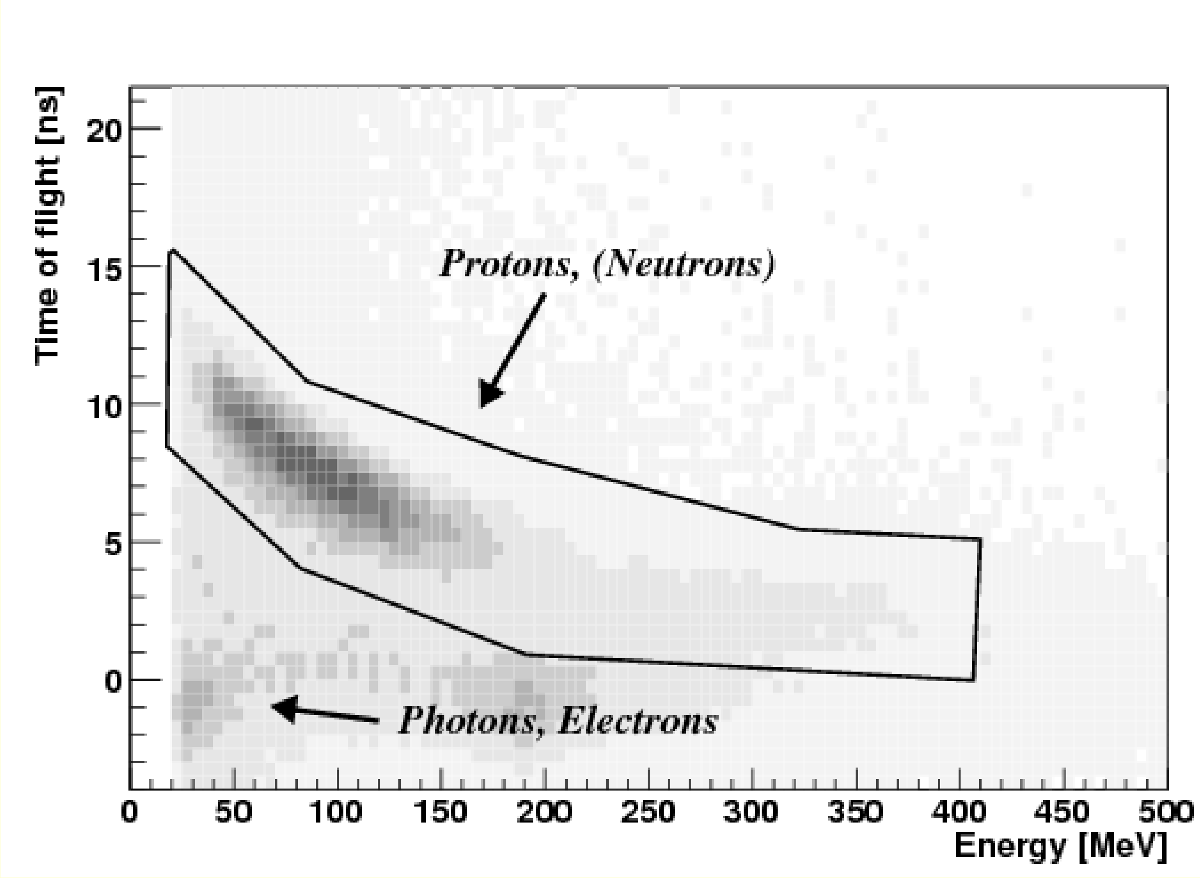
Small energy deposition in the vetos

Large energy deposition in the Crystal Ball

Ratio is different for each type of charged particle

Detection Technique 2/3:

Time Of Flight



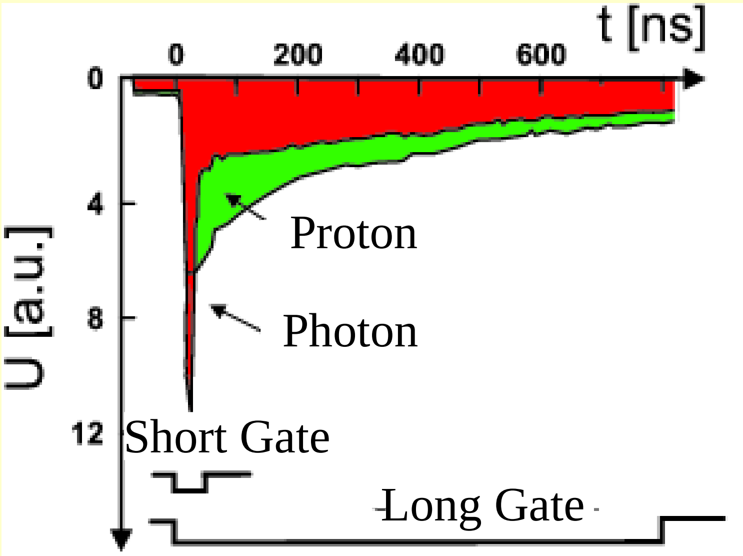
Photon Speed: c
→straight line

Nucleon Speed: v(E_N)
→'banana'

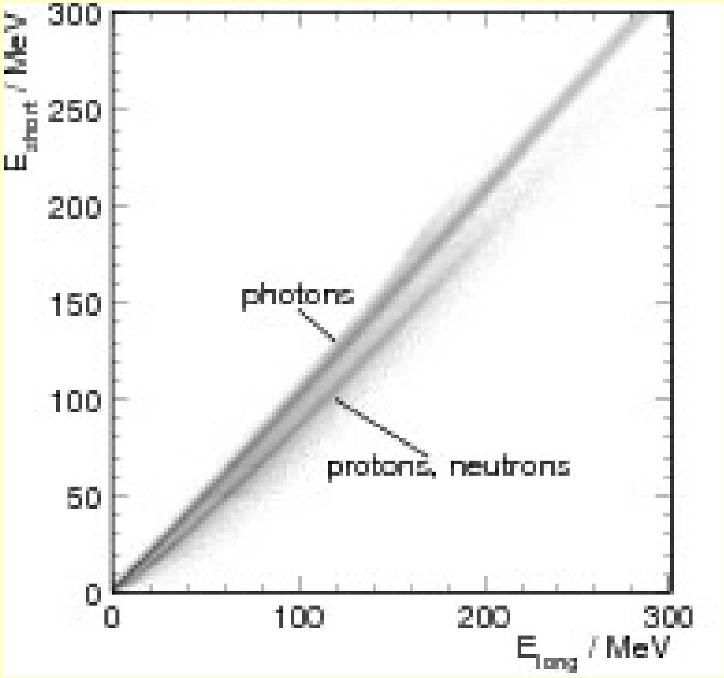
Only possible for TAPS

Detection Technique 3/3:

Pulse Shape Analysis (TAPS)

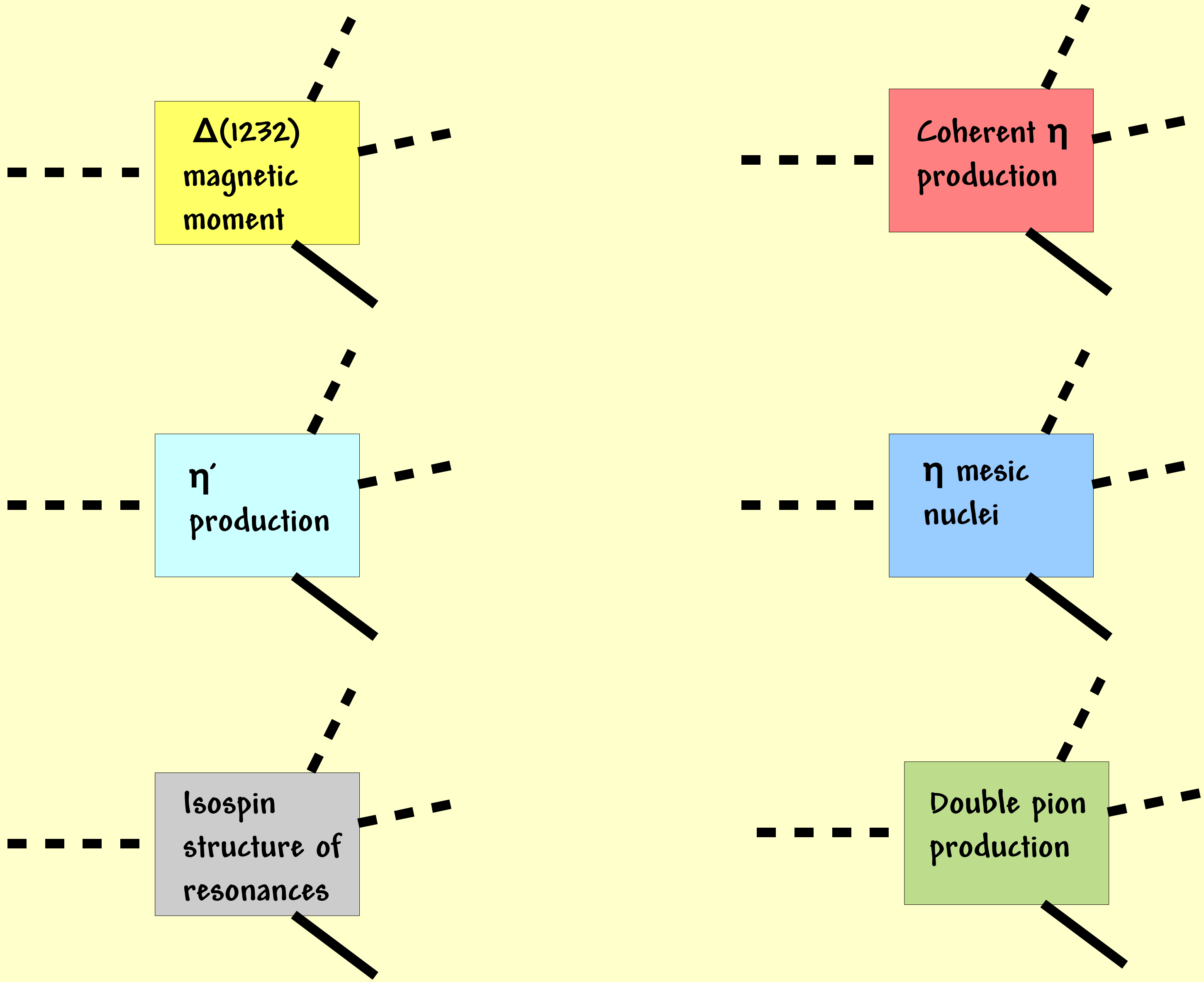


BaF2 has a short (2 us)
and a long (some ms)
light component.



the ratio is different
for each type of particle

What do we want to do:
Some selected topics



We want a precise description of the lowest lying resonances

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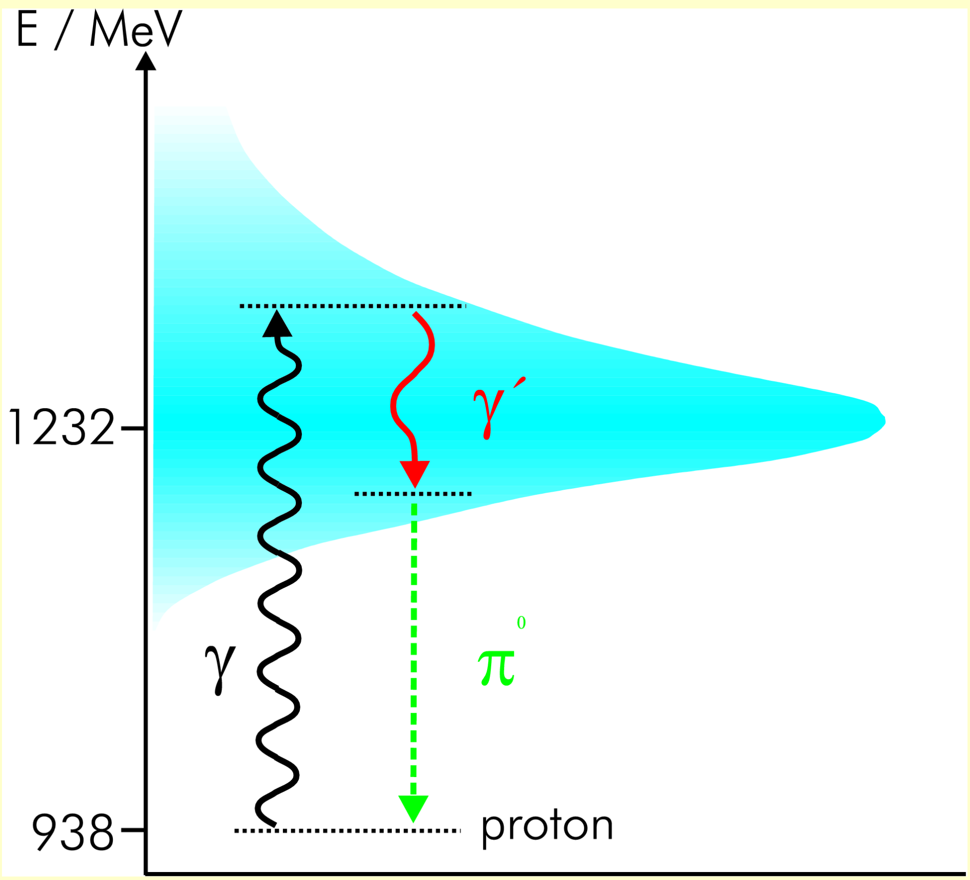


$\gamma p \rightarrow \Delta \rightarrow \gamma' \Delta \rightarrow \gamma' \Delta \pi^0$

Δ(1232)

Mass: 1232 ± 2 MeV ☆☆
Width: 118 ± 2 MeV ☆☆

Next fundamental quantity:

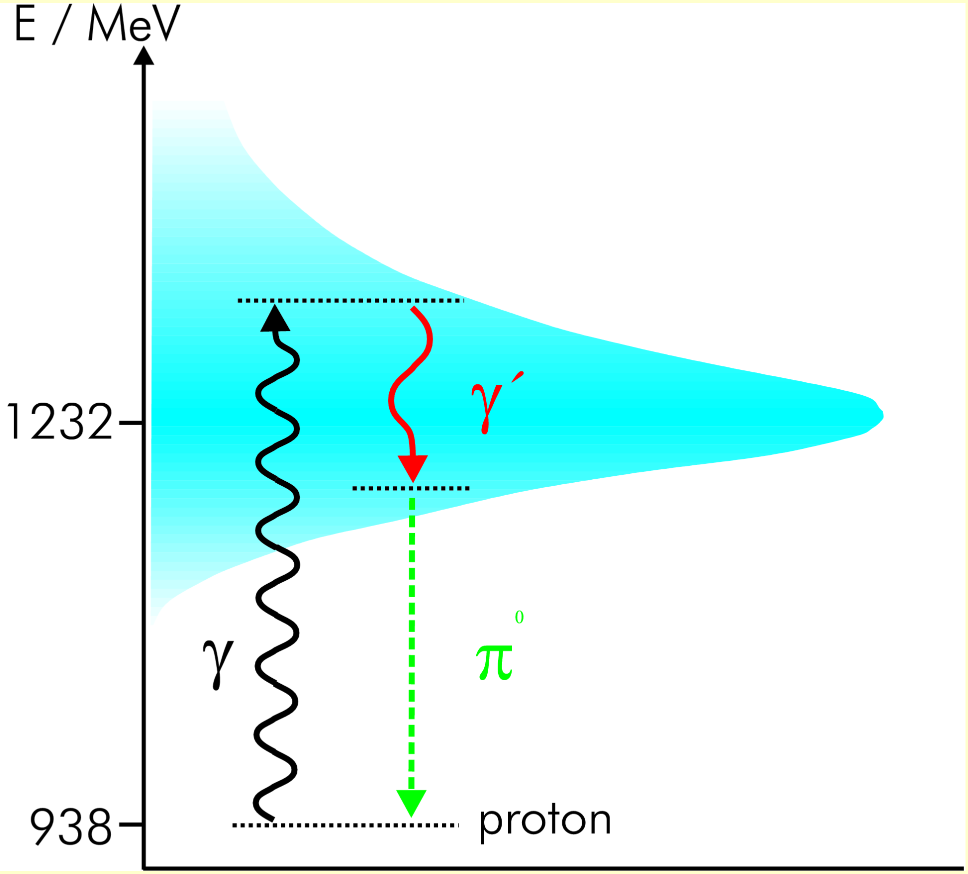
Magnetic moment

Due to quark spins and to the average of quark currents

Very sensitive test of the theoretical hadron description

→ *Benedicte Boillat (11h00)*

We want a precise description of the lowest lying resonances



Remark:

Magnetic moment of the $S_{11}(1535)$ is determined in the same way

$\gamma p \longrightarrow S_{11} \longrightarrow \gamma' S_{11} \longrightarrow \gamma' \Delta \eta$

Measurement under way ...

We want to know precisely the isospin structure of the electromagnetic excitations of the resonances

We want to use the ***difference between the proton and the neutron*** (Isospin) to characterize resonances

Electromagnetic interaction violates isospin

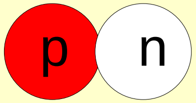
In a meson photoproduction reaction, the transition operator is split into an isoscalar (A^{IS}, $I=0$) and an isovector part (A^{IV}, $I=0,\pm 1$).

$$\sigma(\gamma p \to \eta p) \sim |A^p|^2 = |A^{IS} + A^{IV}|^2$$
$$\sigma(\gamma n \to \eta n) \sim |A^n|^2 = |A^{IS} - A^{IV}|^2$$

Clebsch Gordan,
Isospin Composition

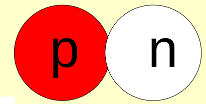
Values of A^{IS} and A^{IV} *different for each resonance*

Neutron Target? → **Deuterium Target**



Nuclear effects
have to be taken in account

Neutron Target? → Deuterium Target



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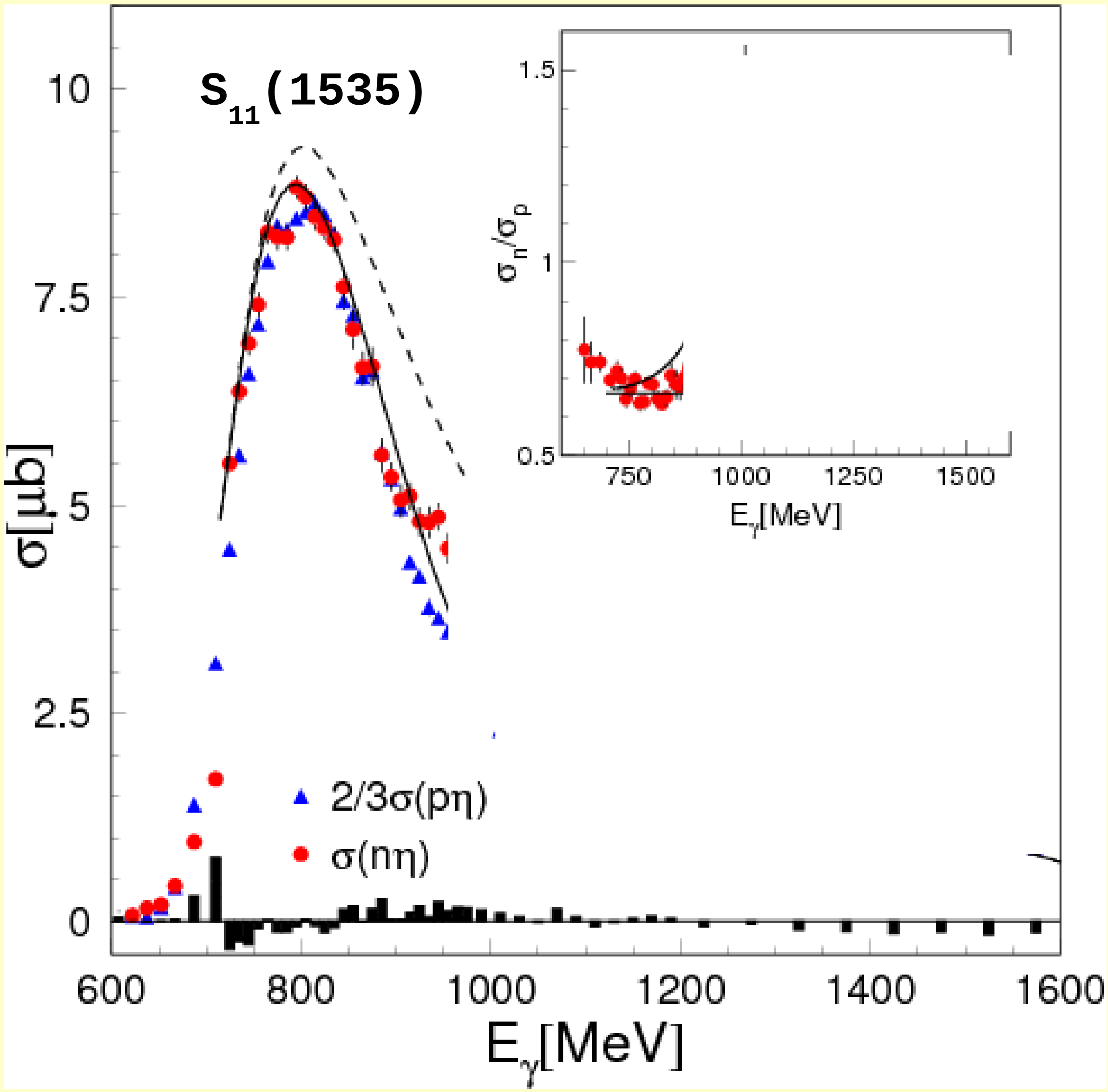


First try on the S_{11}
which has a large (50%)
coupling to the eta

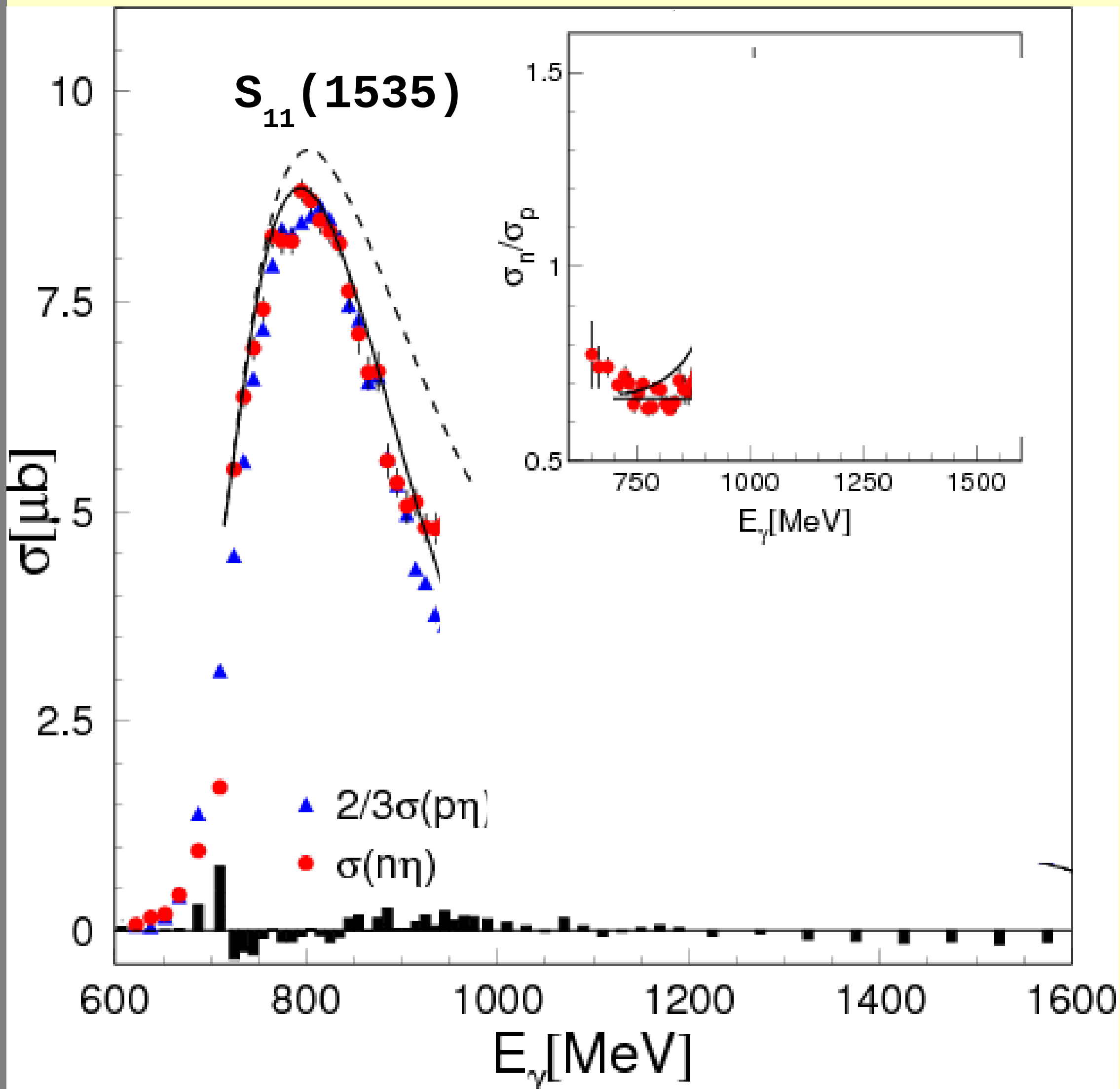
$\sigma(\gamma n \rightarrow \eta n) / \sigma(\gamma p \rightarrow \eta p) = 0.66 \pm 0.08$

$|A^{IS} - A^{IV}| / |A^{IS} + A^{IV}| = 0.82 \pm 0.02$

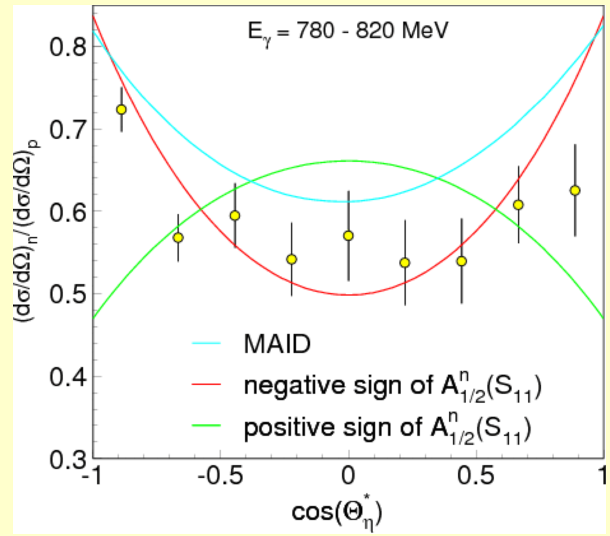
Close to 1: Either A^{IS}
or A^{IV} is dominant

$\sigma(\gamma n \to \eta n) / \sigma(\gamma p \to \eta p) = 0.66 \pm 0.08$

$|A^{IS} - A^{IV}| / |A^{IS} + A^{IV}| = 0.82 \pm 0.02$



Close to 1: Either A^{IS} or A^{IV} is dominant



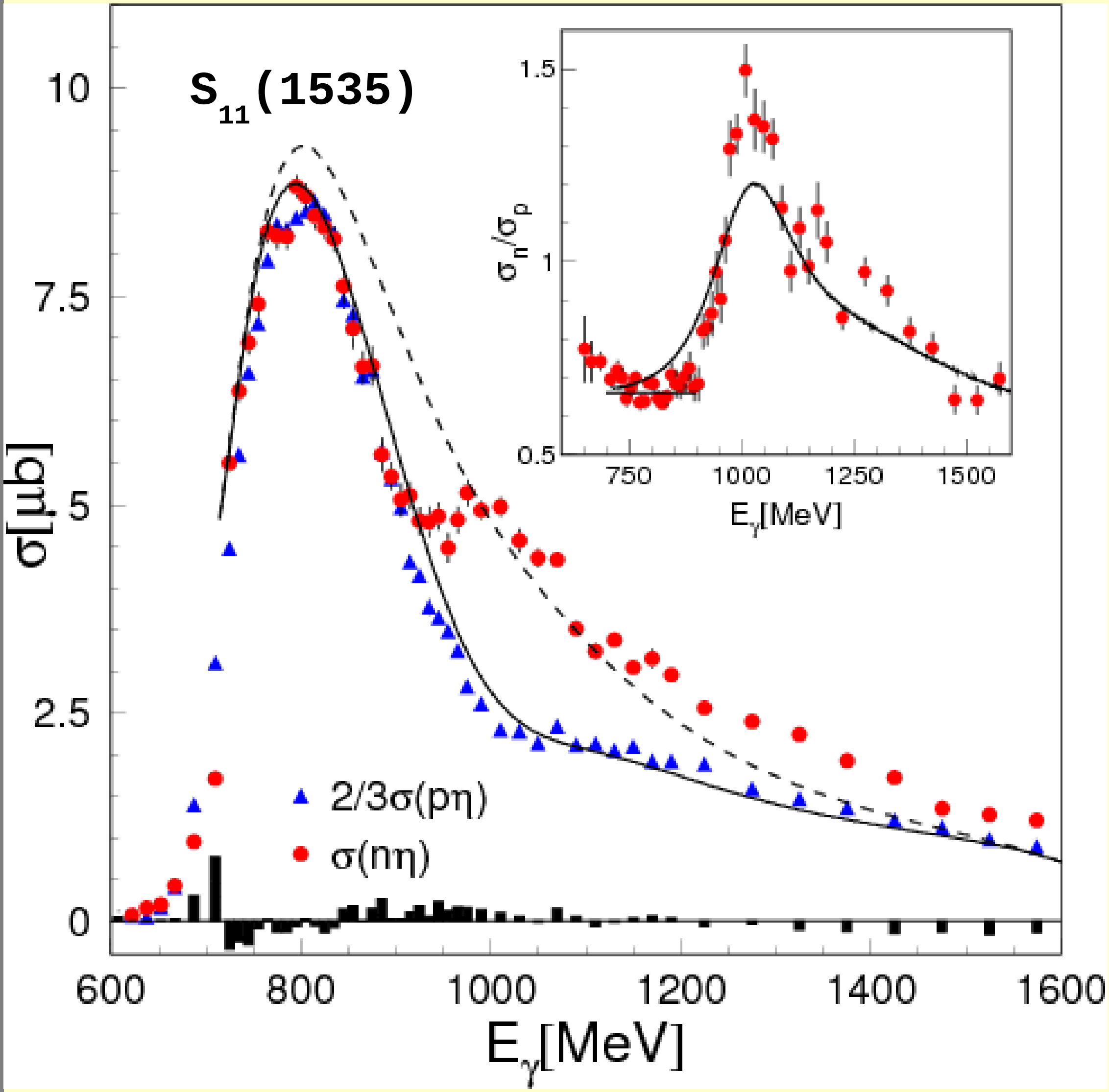
Further analysis

↓

A^{IV} is dominant:
$A^{IS}/A^{P} = 0.09$

Isoscalar contribution to S_{11} cross section is small (9%)

Beyond the $S_{11}(1535)$



Igal Jaeglé Thesis

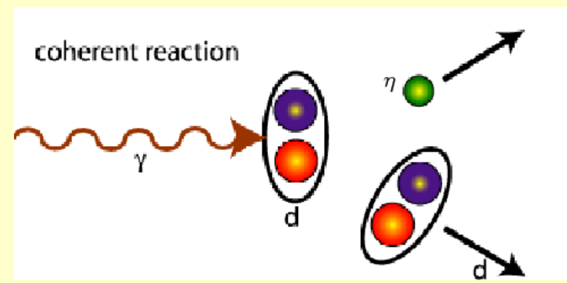
Behaviour of σ_n/σ_p completely different at higher energies

Signature of higher lying resonances that couple stronger to the neutron than to the proton.

- ? $D_{15}(1675)$ (MAID)
- ? $P_{11}(1710)$ Member of the decuplet predicted by chiral soliton model
- ? Interference between $S_{11}(1535)$ and $S_{11}(1650)$
- ? Due to ΣK threshold

Isovector part is dominant in $S_{11}(1535)$ excitation $A^{IS}/A^{P} = 0.09$

Test with coherent eta production on different nuclei
S_{11} is dominant



Quantum Numbers

$$\gamma(E1) + N \rightarrow S_{11} \rightarrow N + \eta$$

J_z: -1 +1/2 -1/2 -1/2 0

Spin Flip

Isovector part is dominant in $S_{11}(1535)$ excitation $A^{IS}/A^{P} = 0.09$

Quantum Numbers

$\gamma(E1) + N \rightarrow S_{11} \rightarrow N + \eta$

J_z: -1 +1/2 -1/2 -1/2 0

Spin Flip

Test on light nuclei

^{4}He: I=0, J=0 (Isoscalar, non spin-flip) **no** coherent production

^{2}H: I=0, J=1 (Isoscalar, spin-flip) **small** coherent production

^{3}He: I=1/2, J=1/2 (Isovector, spin-flip) **large** coherent production

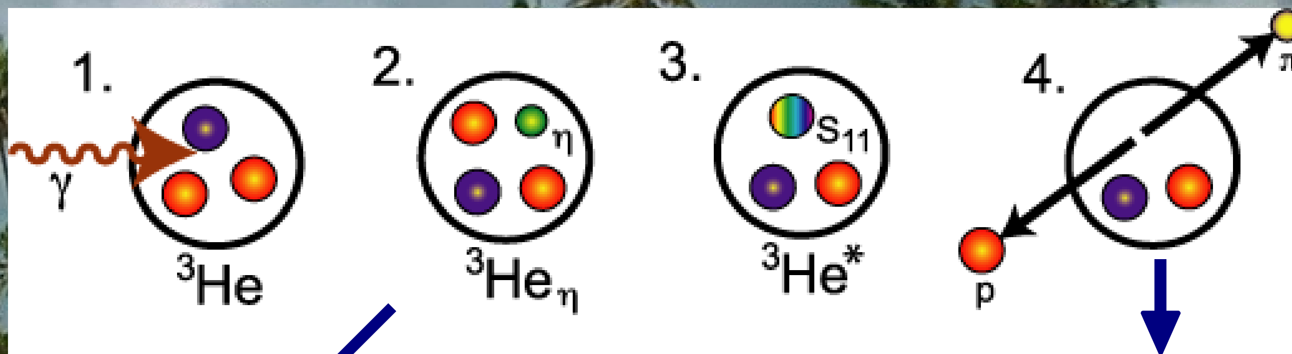
^{7}Li: I=1/2, J=3/2 (Isovector, spin-flip) **large*** coherent production

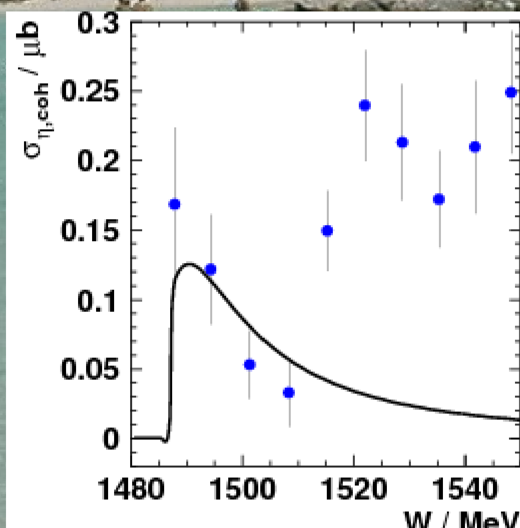
* Due to nuclear form factor, coherent cross section on ^{7}Li smaller by ~ 1 order of magnitude

^{3}He: Francis Pheron (11h40) *^{7}Li: Yasser Maghrbi (11h20)*

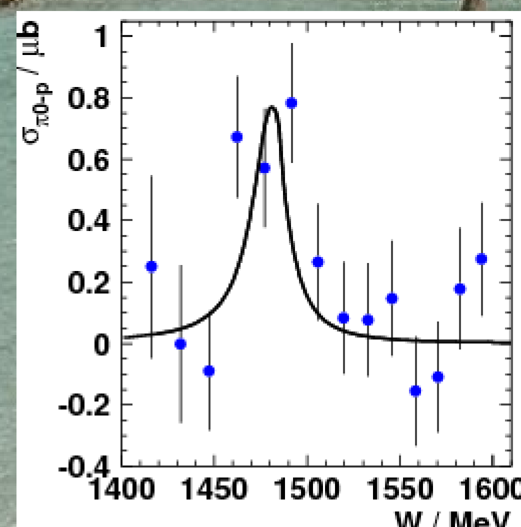
More Exotic: η mesic nuclei on ^{3}He

Search of a 3He-η quasi-bound state





Coherent eta production enhanced at threshold

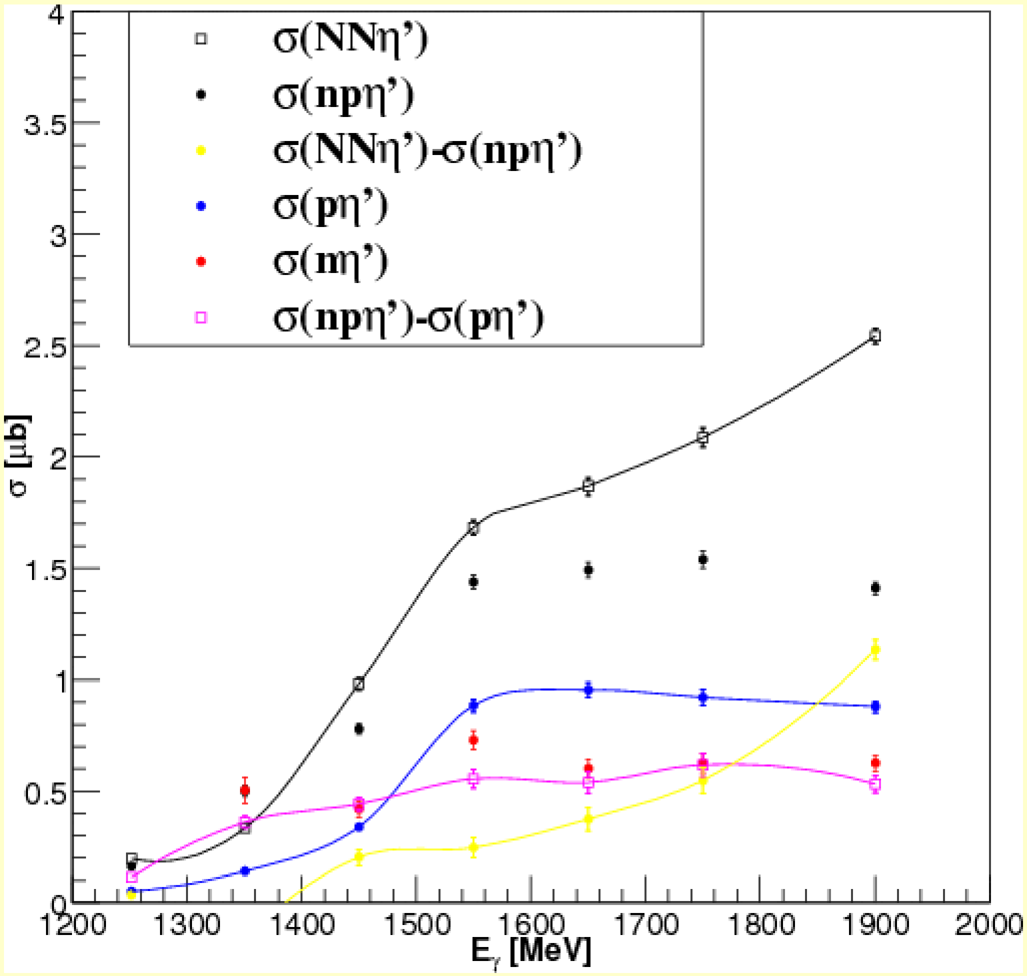


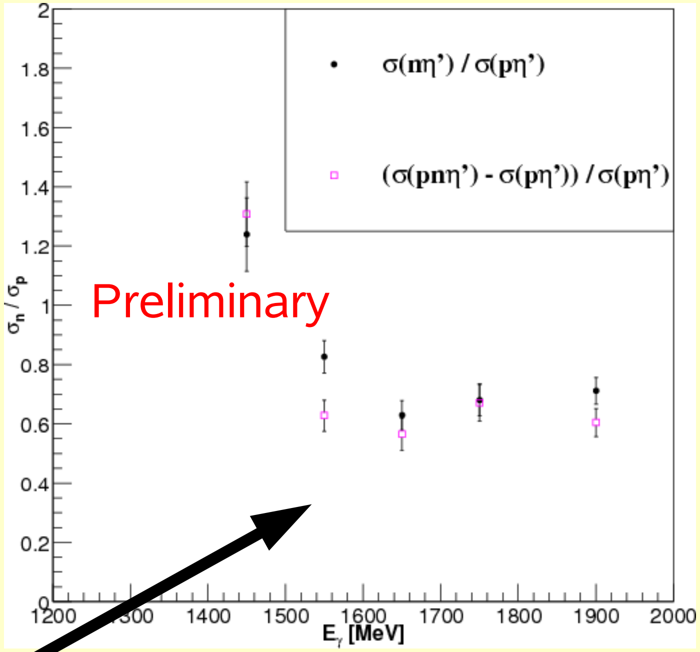
Search for back-to-back pion-proton

M.Pfeiffer
Phys. Rev. Lett. 92 (2004)

More statistics needed → *Francis Pheron (11h40)*

η': same work with a different probe





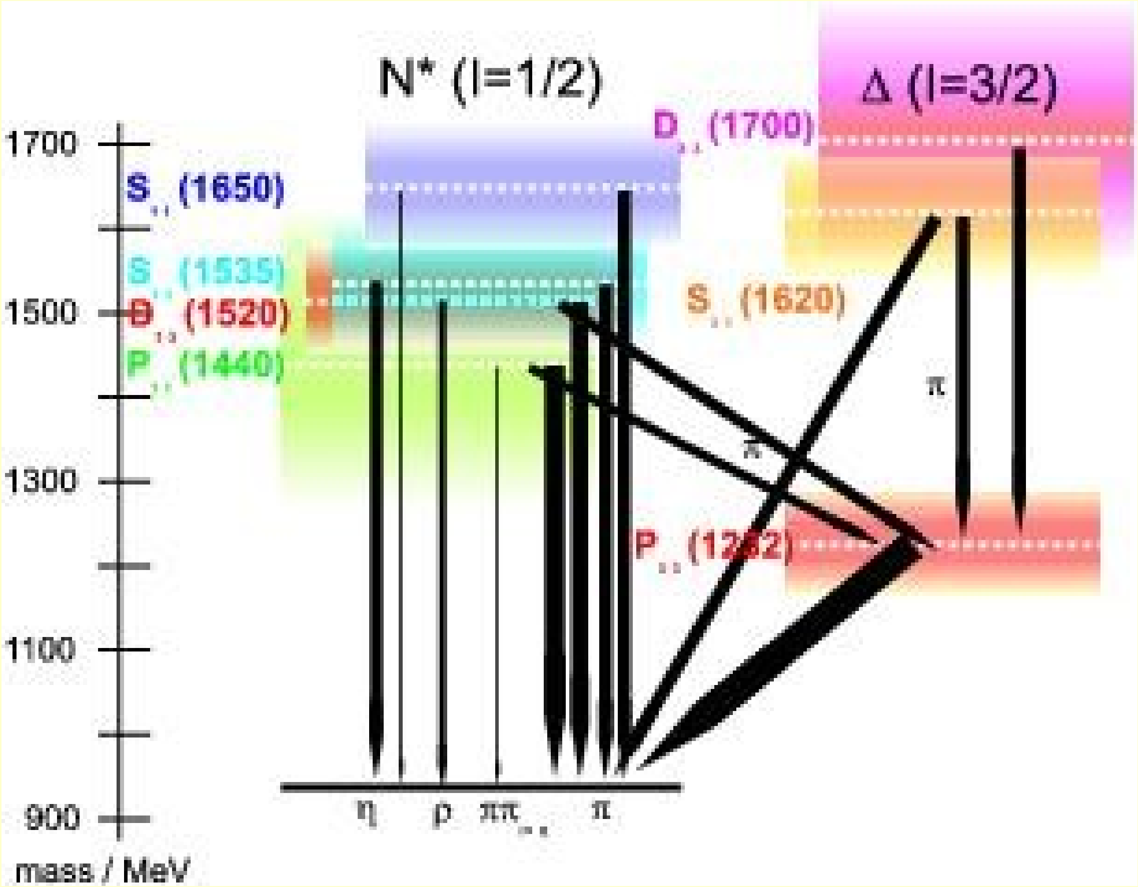
$\sigma_n/\sigma_p = 0.68\pm0.05$

Resonance(s)...

New experiment in progress

Dominik Werthmüller (next year)

We want to study resonances with double pion decay

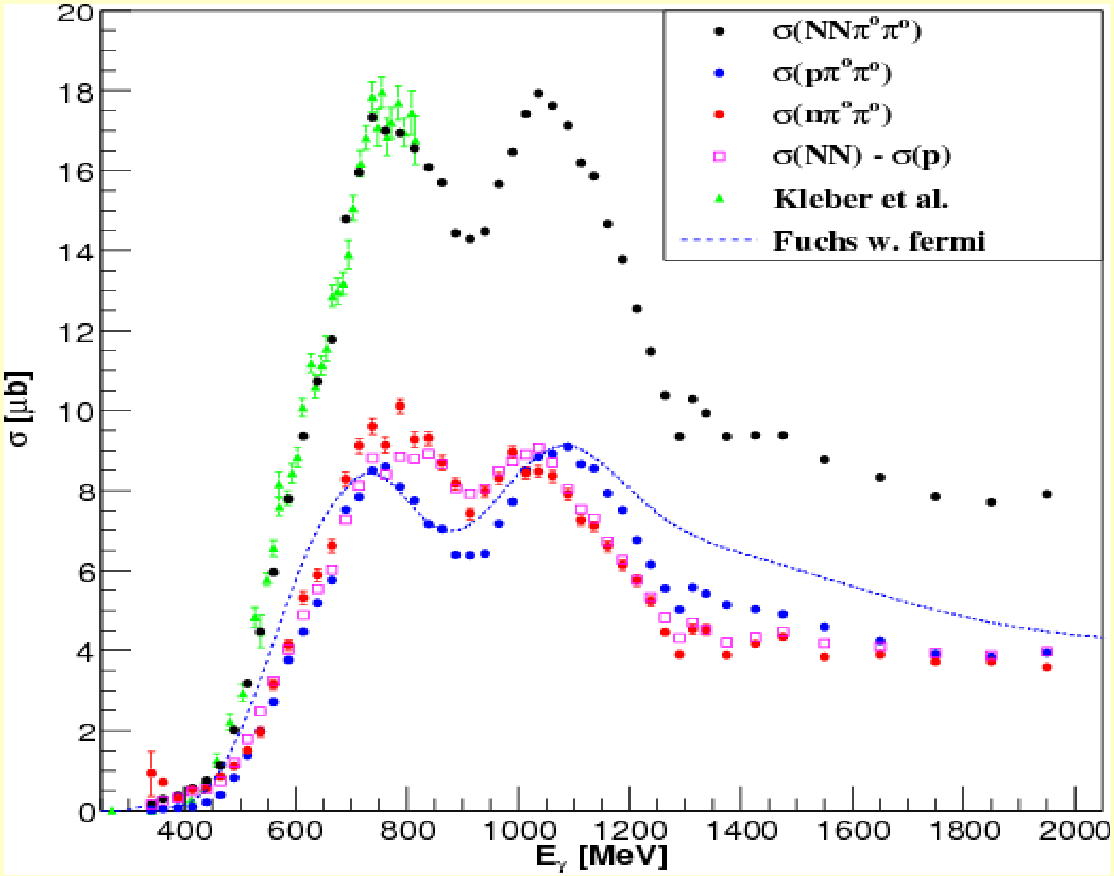


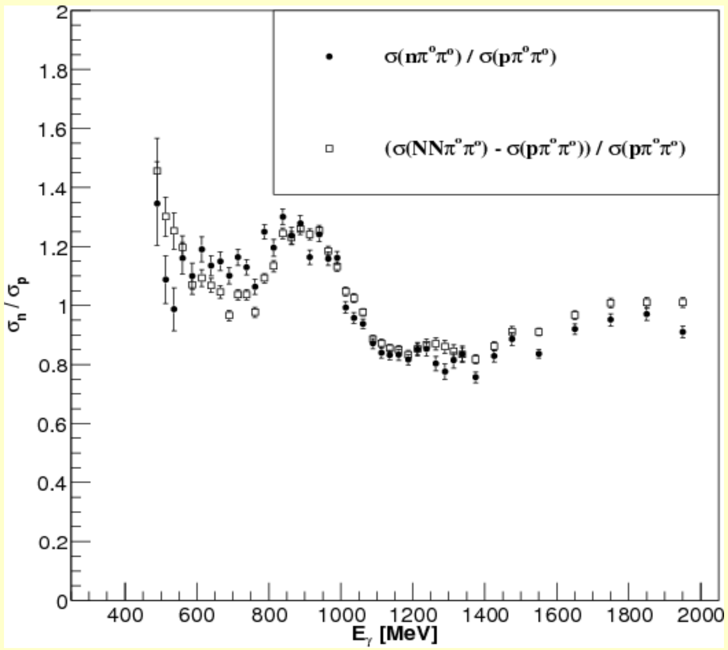
Decay with double pion final states opens new ways to study resonances.

$P_{11}(1440) \rightarrow (\pi^0\pi^0)_{s\text{-wave}}$

$D_{13}(1520) \rightarrow \rho n \rightarrow \pi^0\pi^+ n$

Double ^{0} photoproduction off deuterium





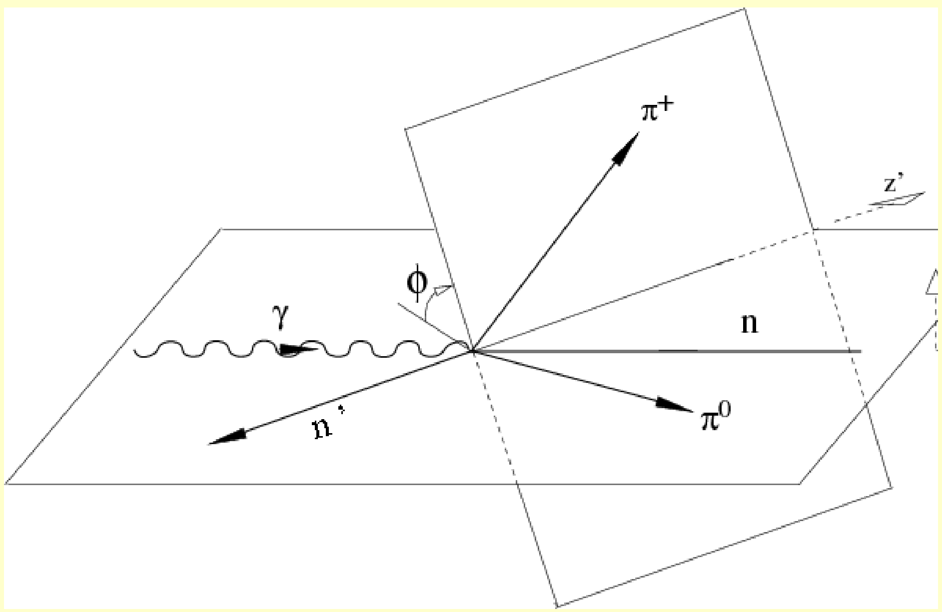
Precise measurement of the **neutron** and **proton** cross sections

Input for complex theoretical models

Double pion off the proton:

The asymmetry: a good tool to disentangle resonances

The asymmetry is defined by the angle between the reaction plane and the plane defined by the two pions



Asymmetry: $\vec{\gamma}\, p \rightarrow \pi^0 \pi^+ n$

$$A = \frac{1}{P_\gamma} \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

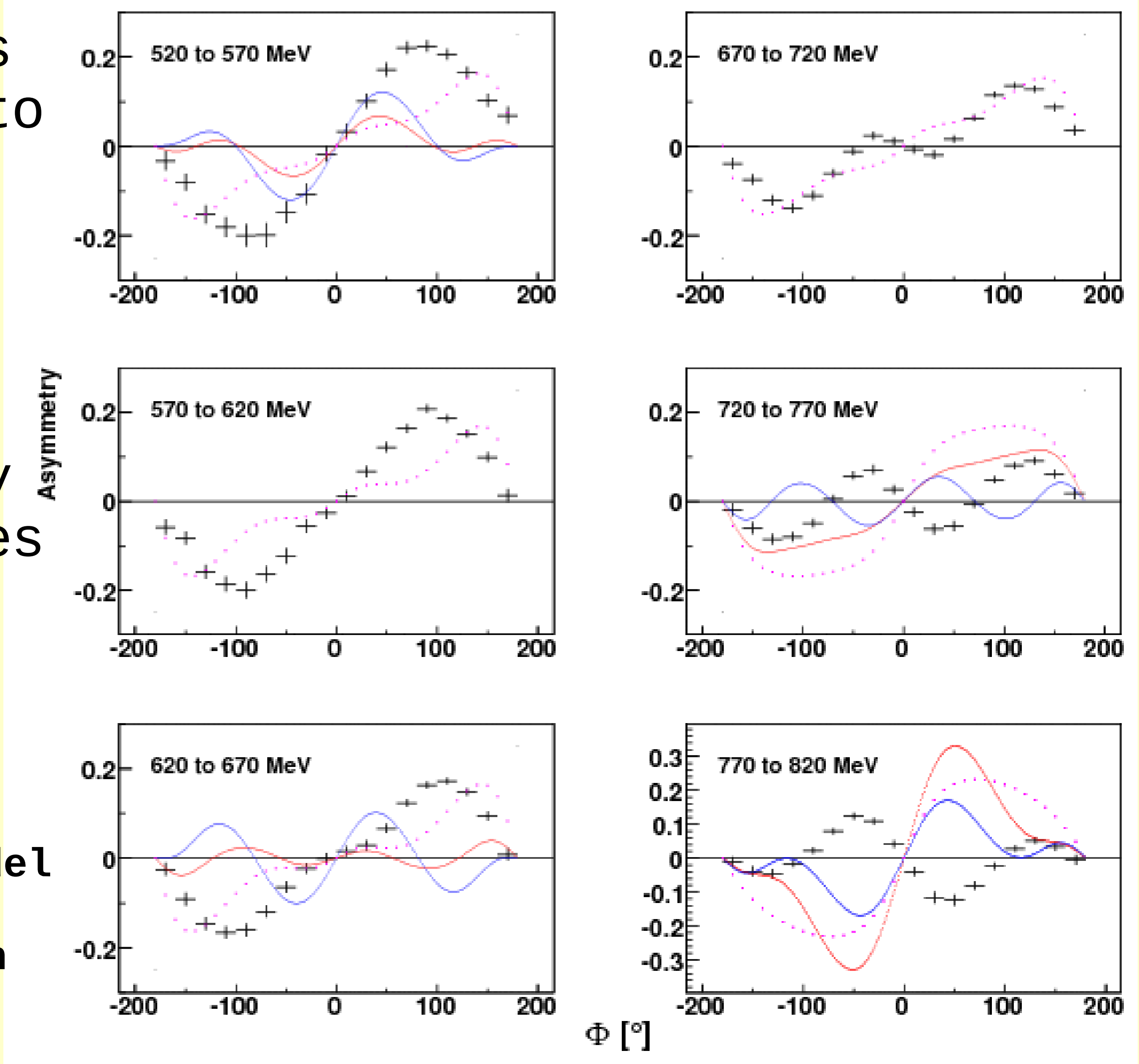
For circularly polarized photons (left and right handed)

Rich information due to the presence of 3 particles in the final state

The asymmetry: results

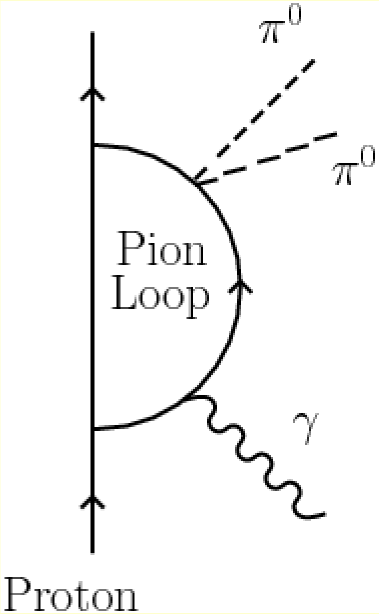
The asymmetry is very sensitive to the internal detail of the models.

Suited for an individual study of the resonances



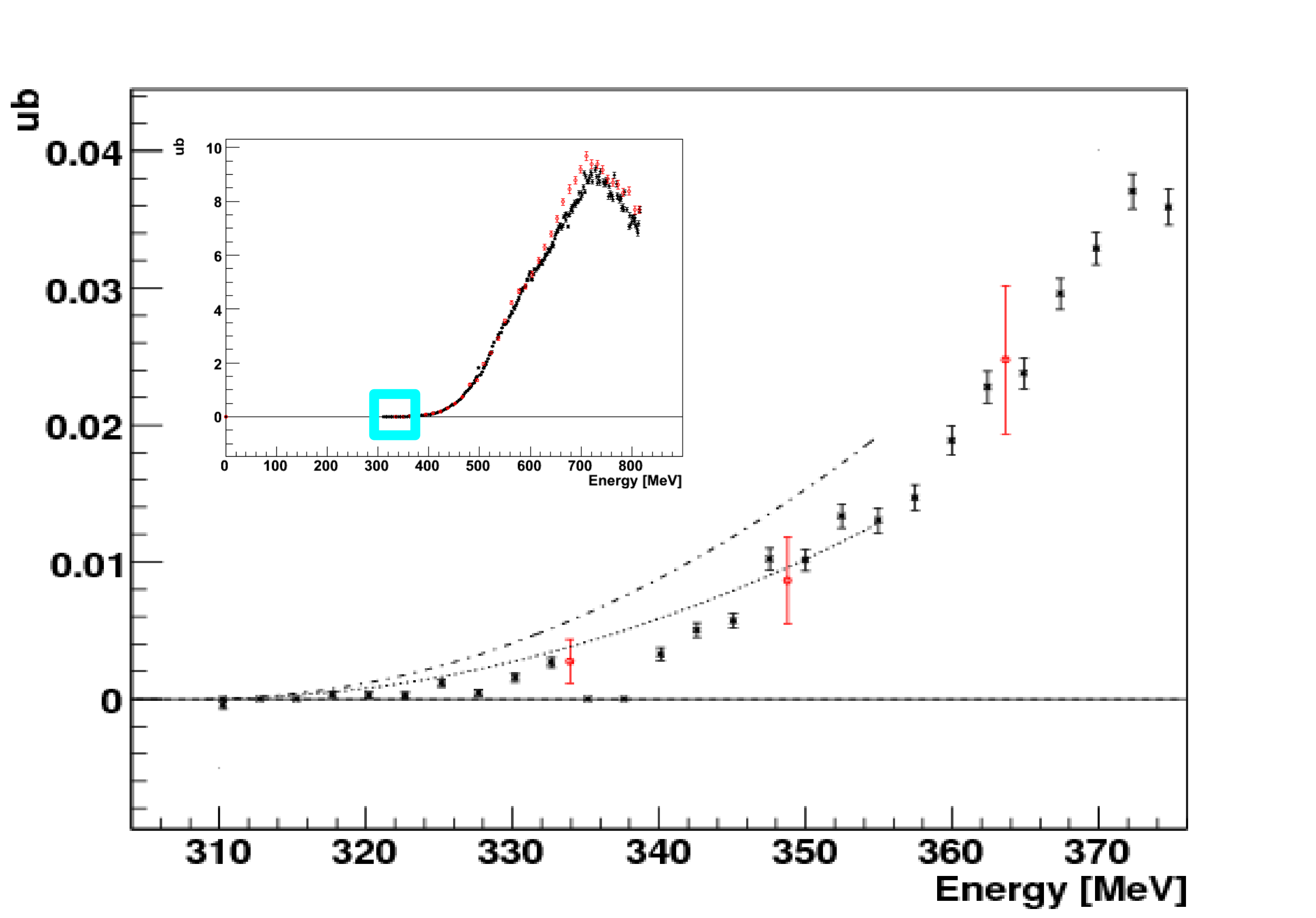
Black: This Work
Purple: A. Fix
Red: L. Roca full model
Blue: L. Roca without D_{13}(1520) contribution

$\gamma p \to \pi^0\pi^0 p$ at threshold: test of Chiral Perturbation Theory



ChPT predicts that cross section at threshold is dominated by 'pion loops' for double π^0 but not for $\pi^0\pi^+$ and $\pi^-\pi^+$

Thus $\sigma^{thresh}(\pi^0\pi^0) > \sigma^{thresh}(\pi^0\pi^+)$ but $\sigma(\pi^0\pi^0) < \sigma(\pi^0\pi^+)$



Black: This work

Red: Previous TAPS measurement
M. Kotulla
Phys: Lett. B578 (2004)

Curves: ChPT Average and Upper Limit
V. Bernard
Phys: Lett. B382 (1996)

Outlook

Meson photoproduction is a broad and precise tool to study nucleon resonances

In a 35 minutes talk, $P_{11}(1232)$, $S_{11}(1535)$, $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1650)$, $D_{15}(1675)$ and $P_{11}(1710)$ and various threshold processes have been mentioned

Well established & speculative ones

Very active field: new double polarization experiments

Next year: meson photoproduction on heavy nuclei, in-medium modification of mesons and resonances.