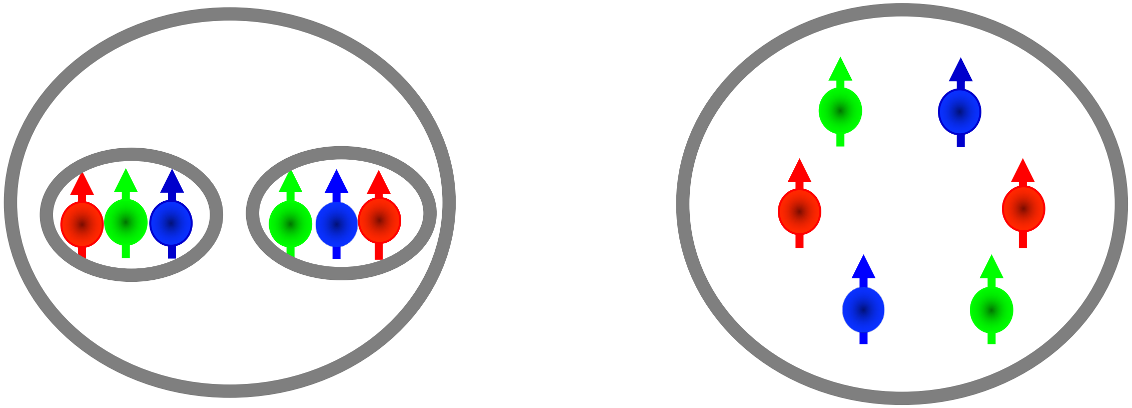
Recent results for EM coupling of d*(2380) (& a speculative aside)

Dan Watts
University of York

Outline

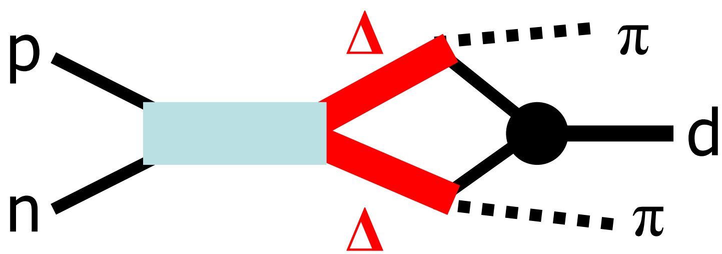
- **d*(2380) – a multiquark state ?**
  - Evidence for the d*(2380)
  - First calculation of potential impact on neutron stars



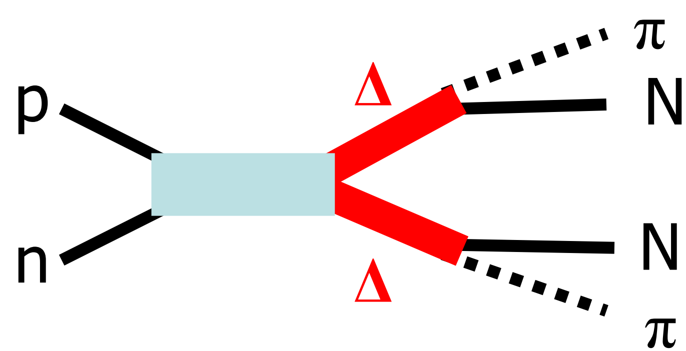
- A new method for extracting nucleon momentum distributions?

pn scattering with large acceptance

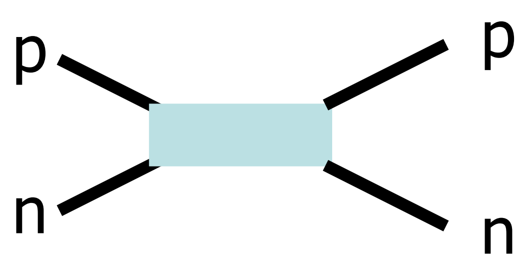
- $pn \rightarrow d^* \rightarrow \Delta\Delta \rightarrow d\pi\pi$



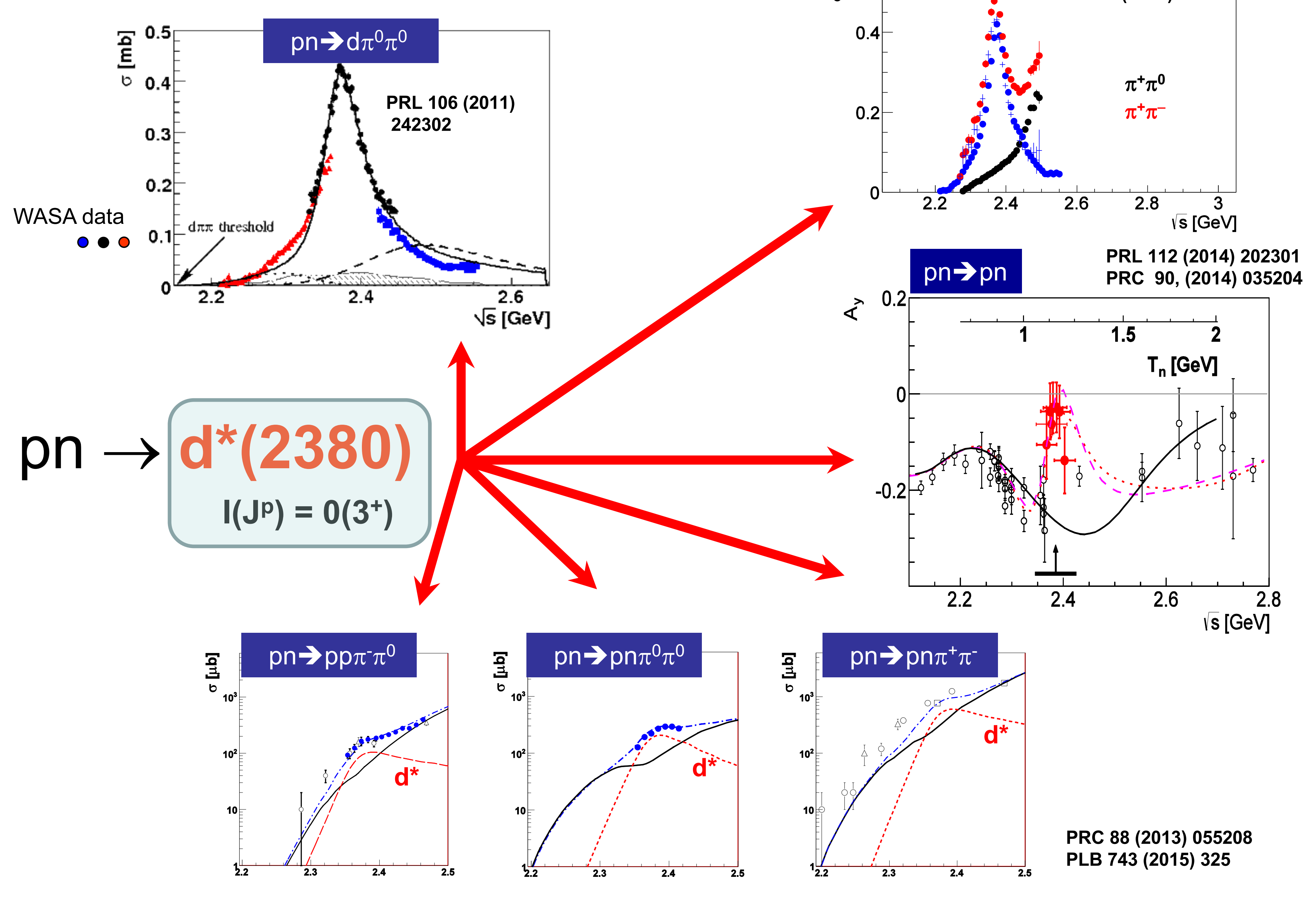
- $pn \rightarrow d^* \rightarrow \Delta\Delta \rightarrow NN\pi\pi$



- $pn \rightarrow d^* \rightarrow pn$

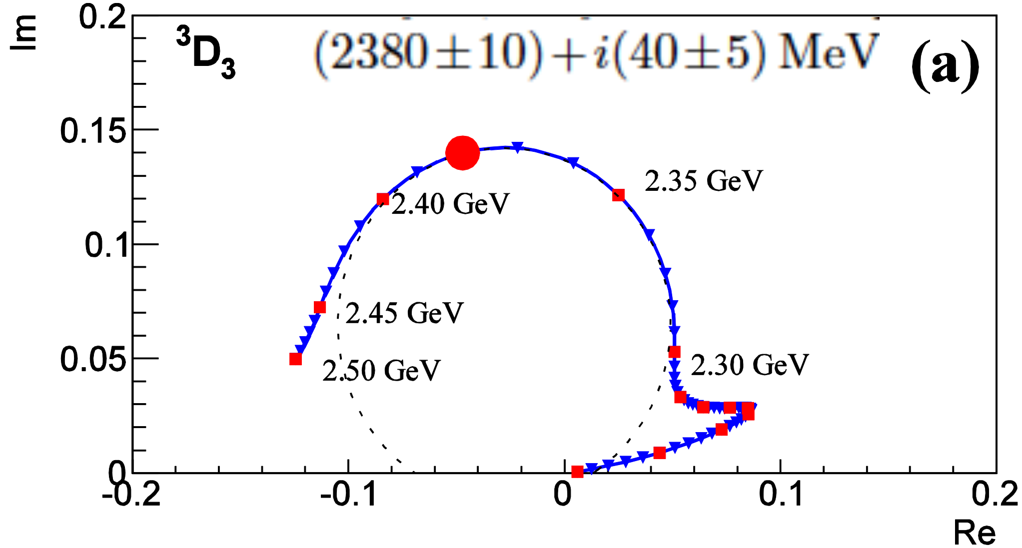


d* evidence in p-n scattering



PWA including new polarized np data

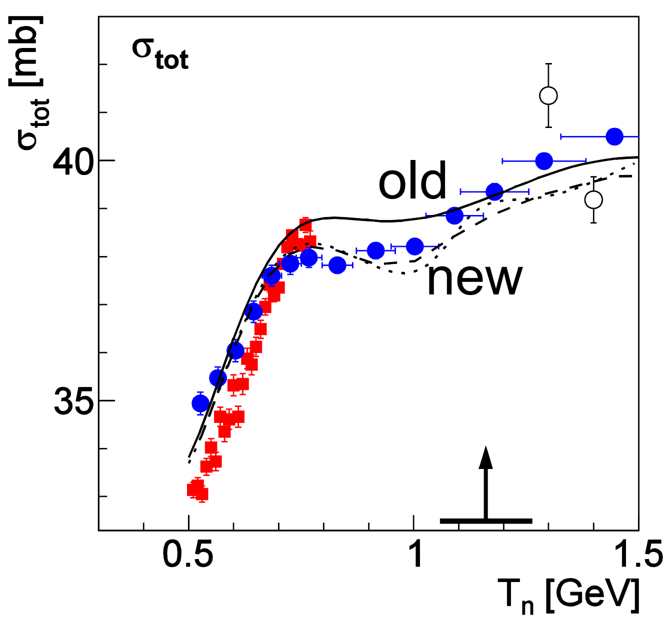
PRL 112, 202301, (2014)
PRC 90, 035204 , (2014)



- Strong resonance signature for d* in $^3D_3$ wave

$I(J^p) = 0(3^+)$

d*(2380)



- Gives an explanation for (previous) inability for PWA to describe total np cross section !

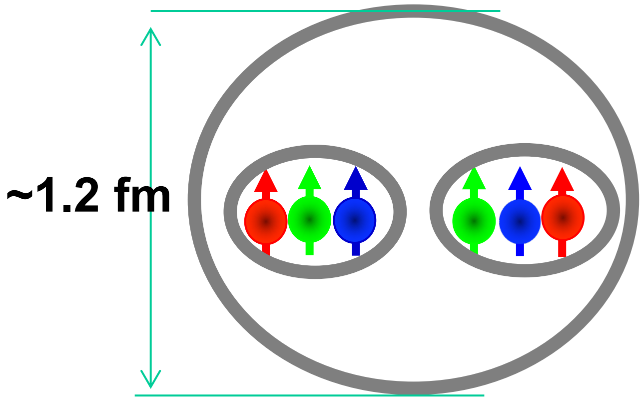
ΔΔ decay ~ 90%
pn decay ~10%
(ang. mom. barrier, double spin-flip)

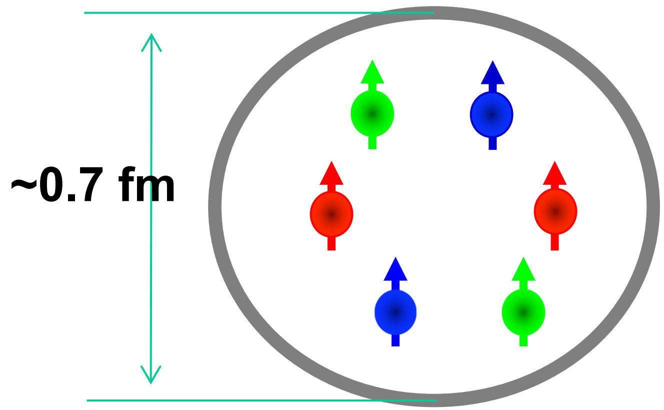
What is the d* - Hexaquark ?

- Any quark model with confinement and one gluon exchange *inevitably* predicts a d* with (I)J^P=(0)3^+
  T Goldman et. al. Phys. Rev. C 39, 1889 (1989)

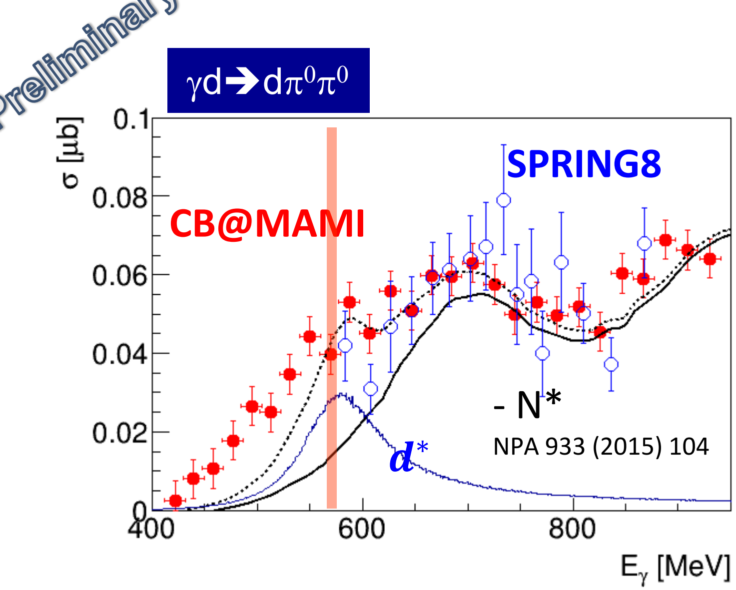
- Recent microscopic CC chiral quark model ΔΔ + **hidden colour**
  F. Huang et al, Chin.Phys. C39 (2015) 7, 071001

- Does the d* have EM coupling – can we *measure* it's size ??

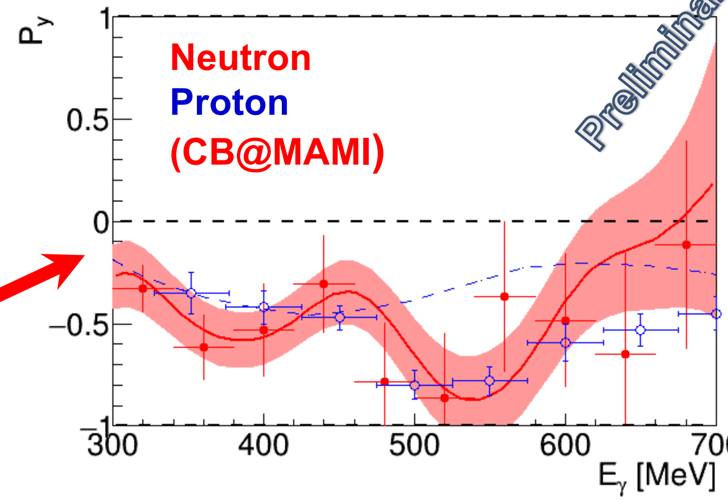




Photoproduction of the d*

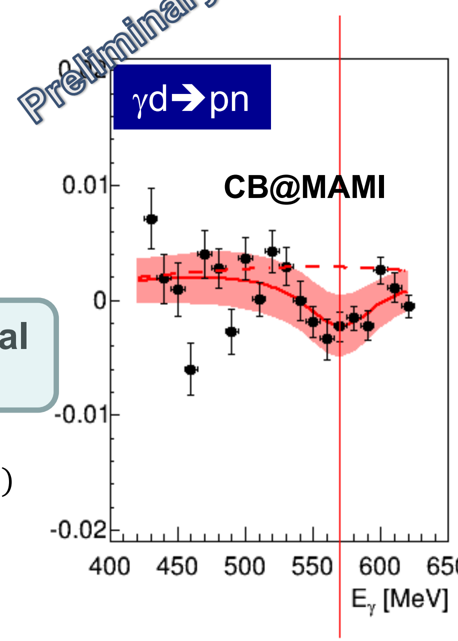


First measurement of final state neutron polarisation



$\gamma + d \rightarrow$ **d*(2380)**

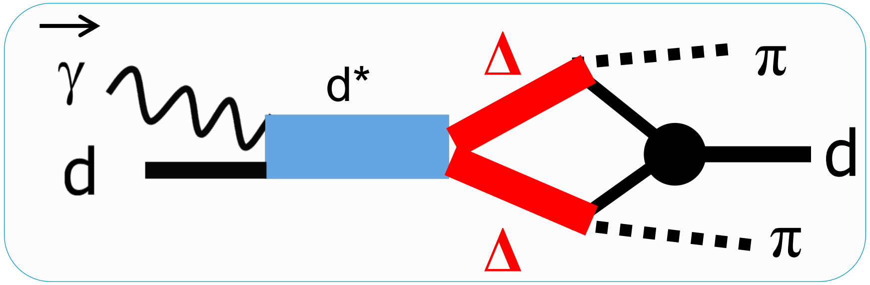
I(J^p) = 0(3^+)



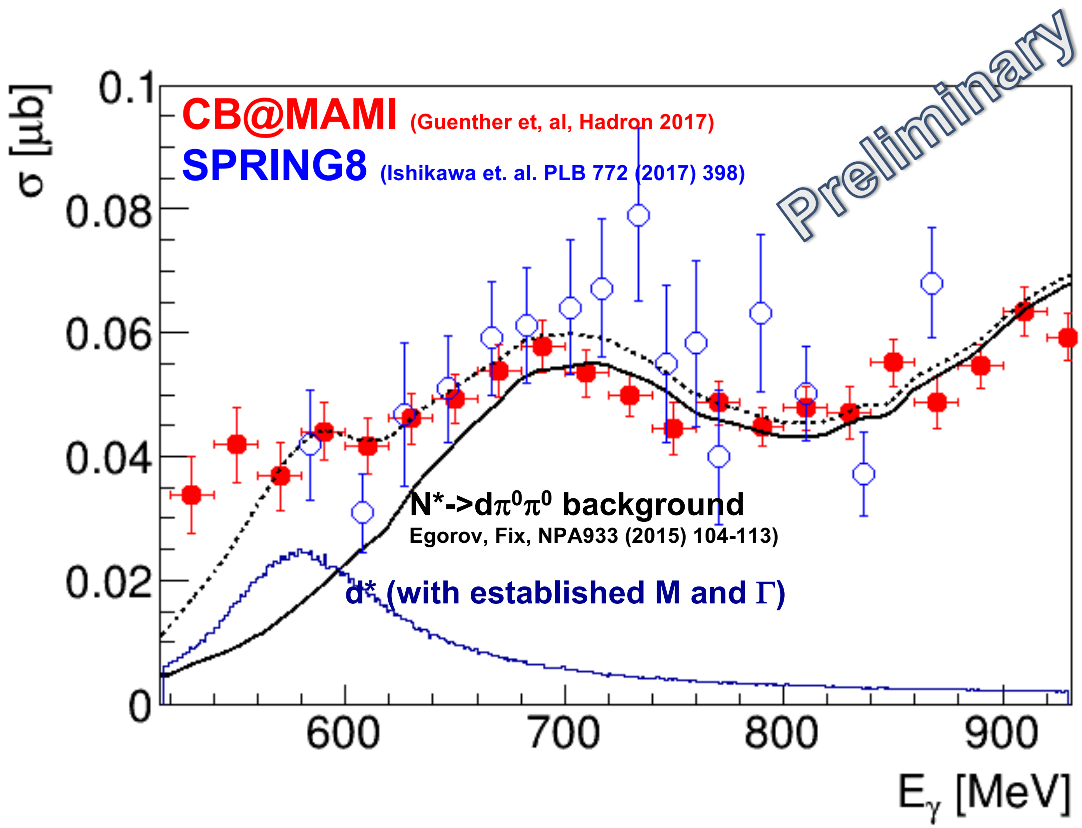
Legendre polynomial Analysis of σ, Σ

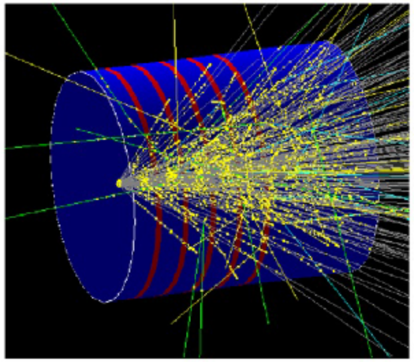
$$\frac{\Sigma(\Theta)\sigma(\Theta)}{\sigma_0} \sim \sum_{J=2} B_J P_J^2(cos\Theta)$$

d* search in dominant decay channel



$\gamma + d \rightarrow d\pi^0\pi^0$ - (equivalent of $pn \rightarrow d\pi^0\pi^0$)

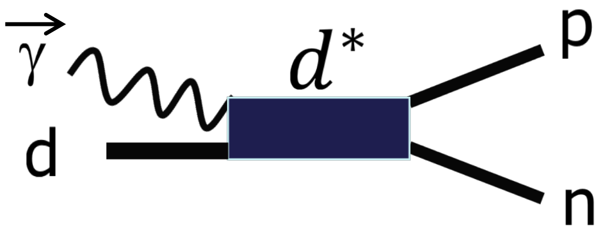




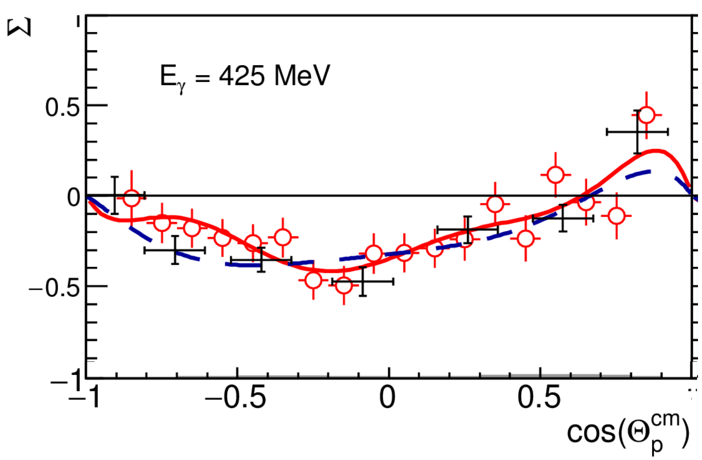
- Accurate data in region of d* -> need detection low T_D

  -> active deuteron target

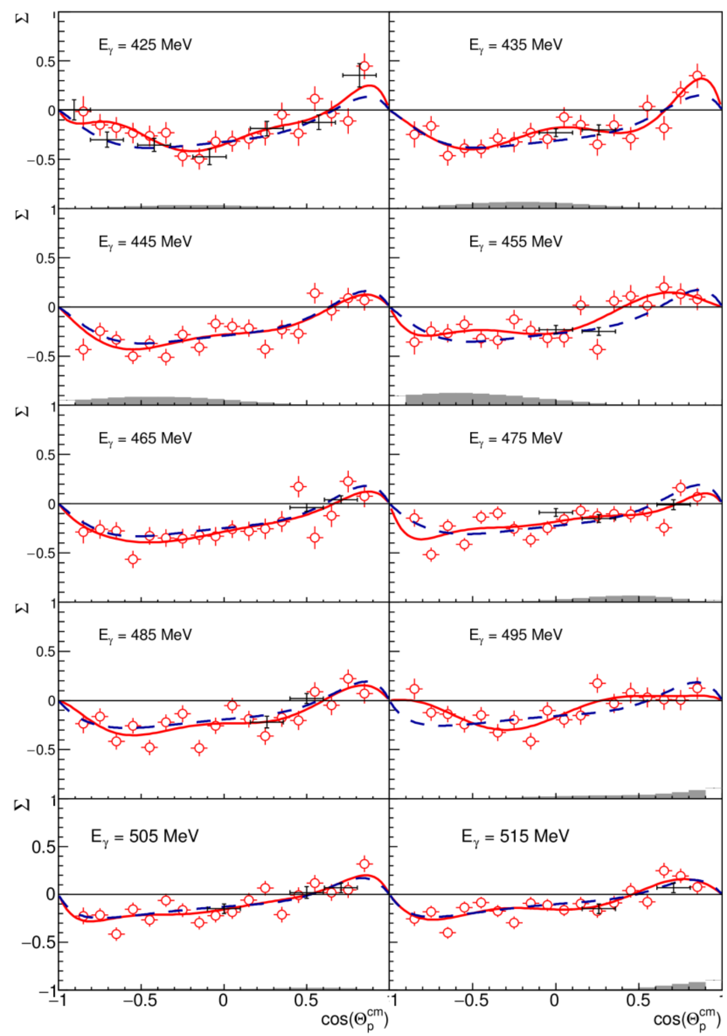
Deuterium photodisintegration with linearly polarised photons



$$\frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = P_\gamma \boldsymbol{\Sigma} cos2\phi$$

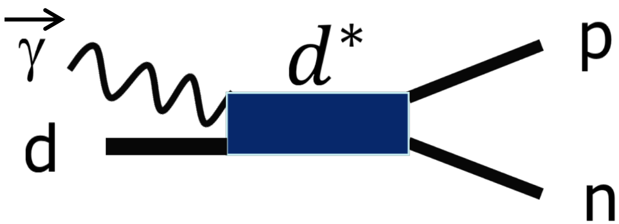


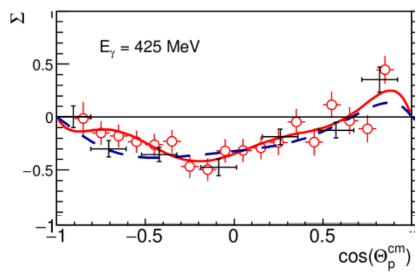
$$\Sigma \sim \sum_{l=2} a_l P_l^2(cos\Theta)$$



Bashkanov, DPW, Kay, CB@MAMI; PLB789 (2019) 7-12

Deuterium photodisintegration with linearly polarised photons





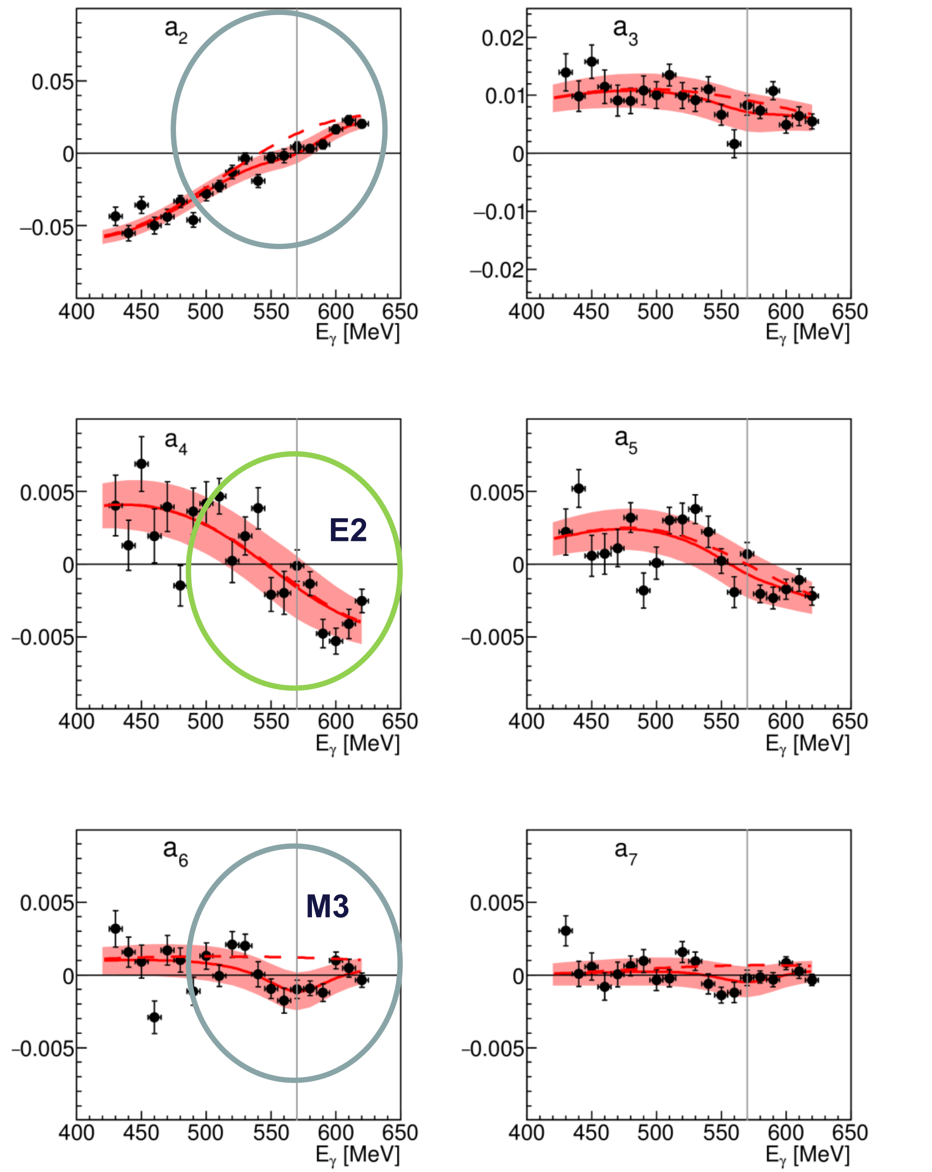
$$\Sigma \sim \sum_{l=2} a_l P_l^2(\cos\Theta)$$

H.Ikeda *et al.*,NPB172,509,(1980)

E2 transition ⇒ small

M3 transition ⇒ dominant

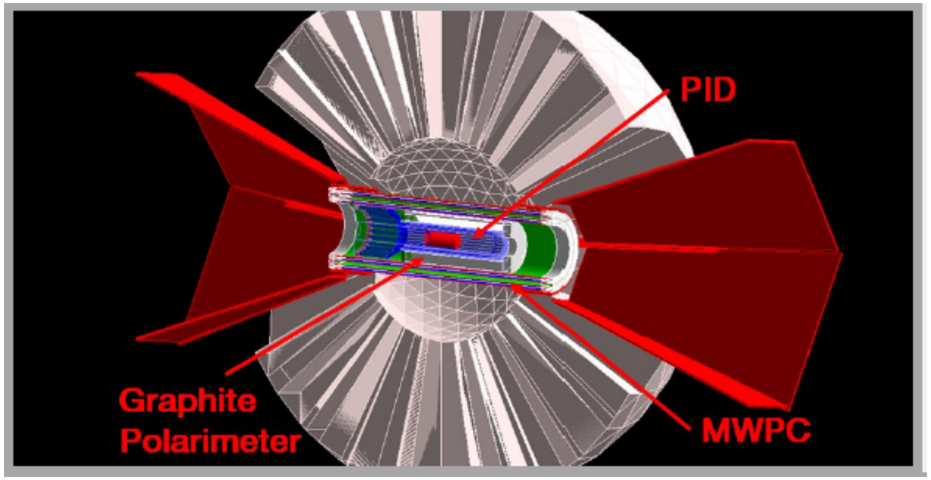
Consistent with d*(2380)
as a compact object

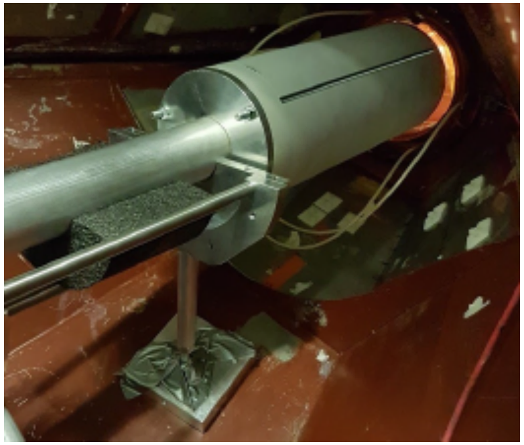


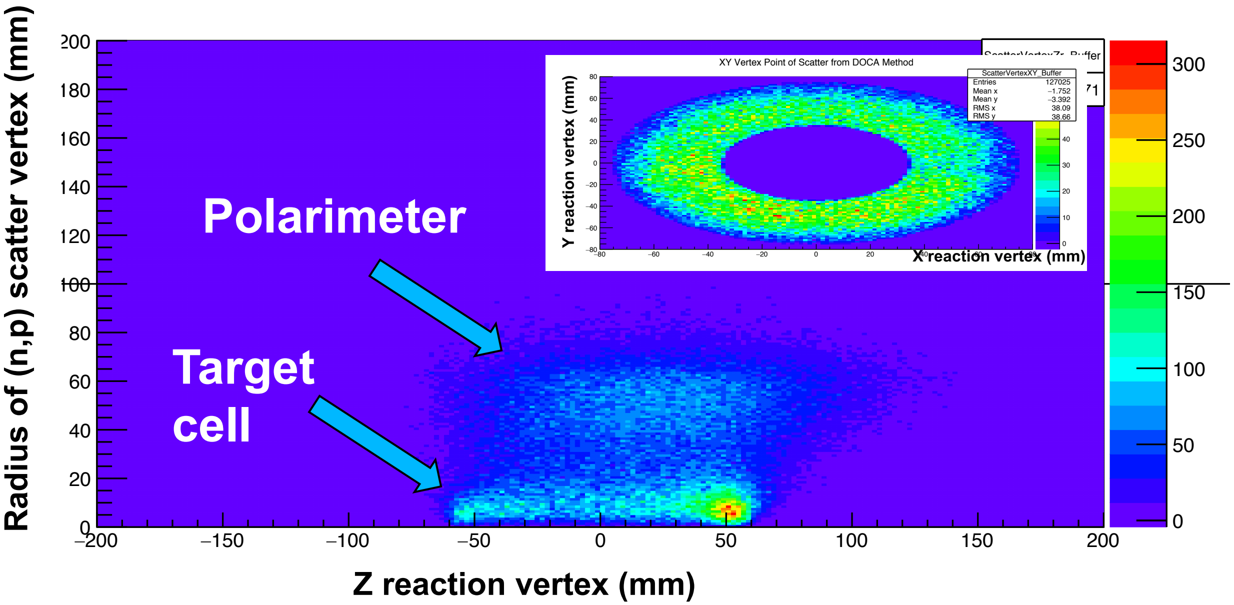
Bashkanov, DPW, Kay, CB@MAMI; PLB789 (2019) 7-12

Large acceptance nucleon polarimeter at MAMI

Experimental beamtime - late 2016



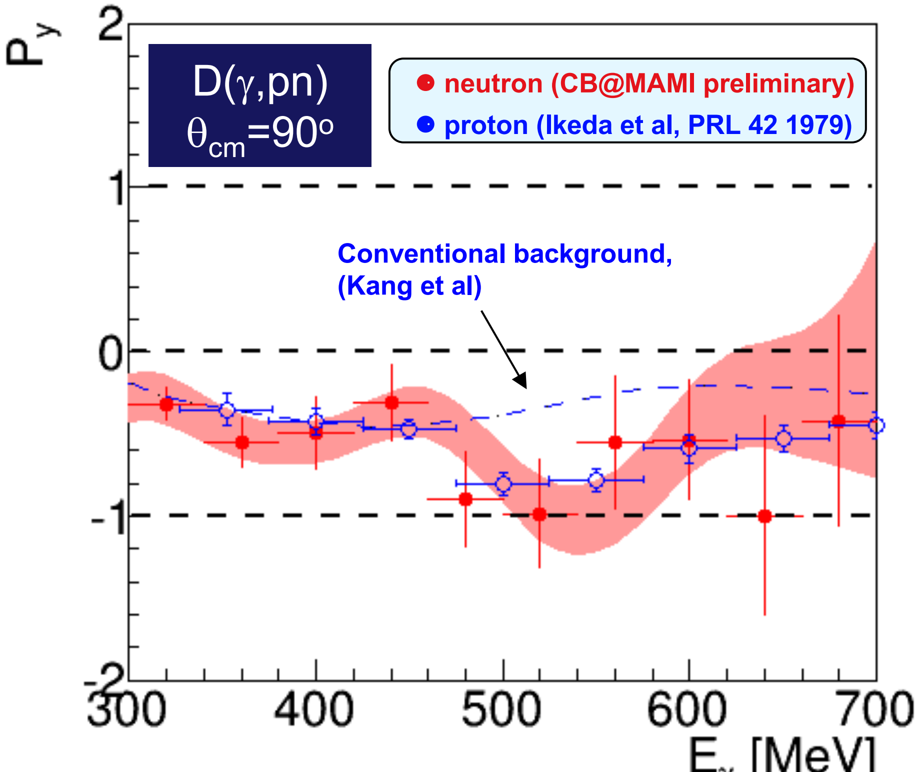




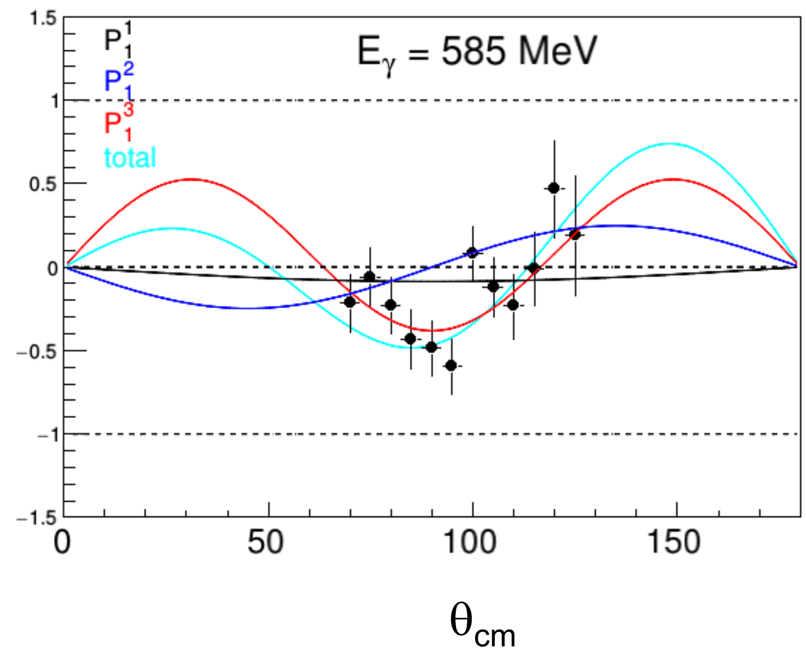
Induced nucleon polarisation (P)

- First detailed measurement of final state neutron polarization in D(γ,pn)

Preliminary



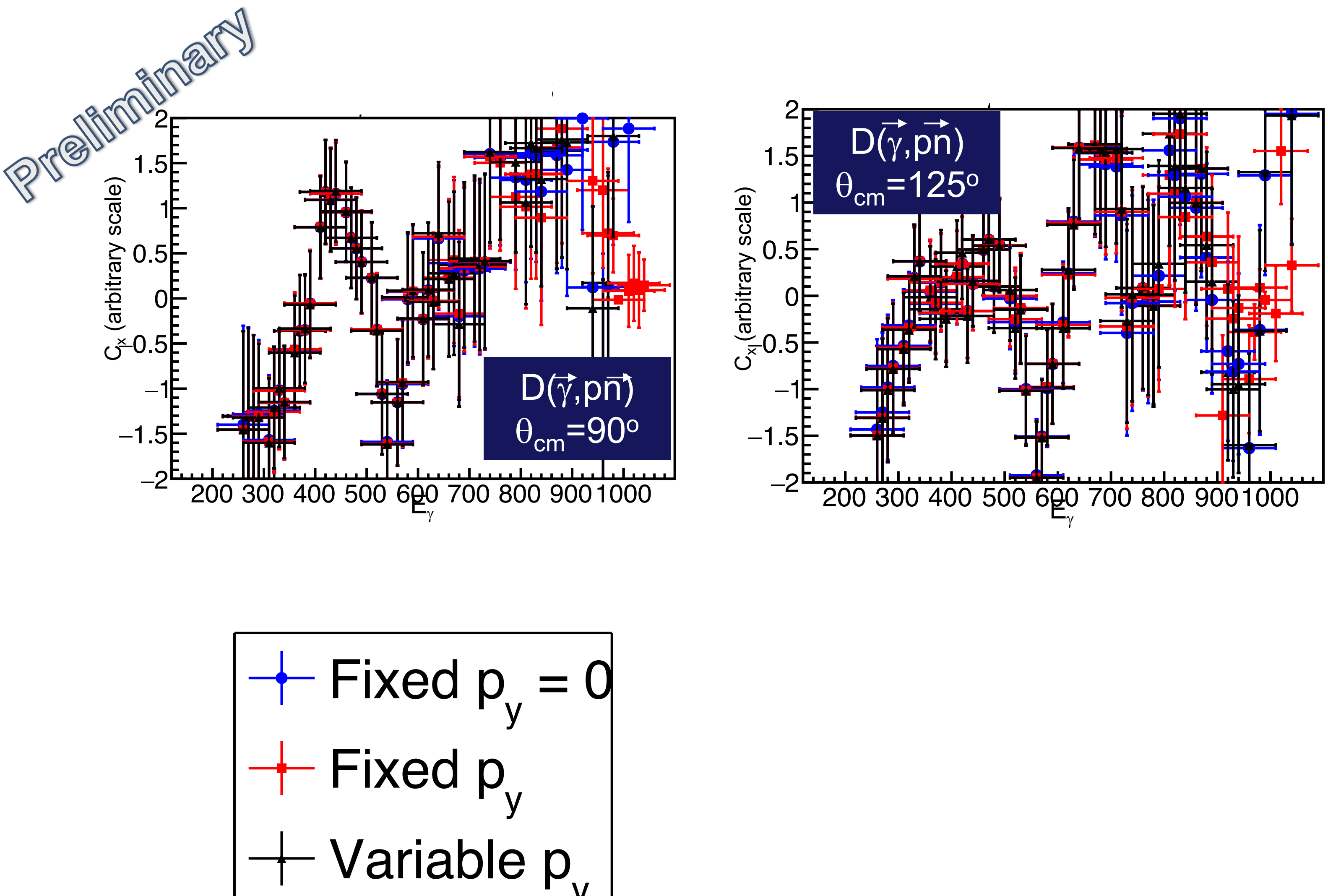
Preliminary



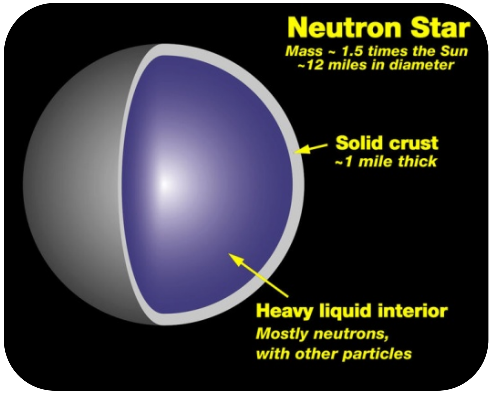
Bashkanov, DPW, Kay, CB@MAMI; in preparation

Transferred polarisation (C_x)

- Early stage results – polarization transfer circ polarized γ to neutron
- Next stage – include analyzing power -> Cx



The d*(2380) in neutron stars ?



- Neutron star model:

Nucleons –> Relativistic mean field (GM1)
–> Compatible with recent GW data

electrons,muons, Δ –> Free fermi gas

d*(2380) –> Free boson gas

- Tolmann–Oppenheimer–Volkoff equations -> hydrostatic equilibrium with GR

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The $d^*(2380)$ in Neutron Stars – A New Degree of Freedom?

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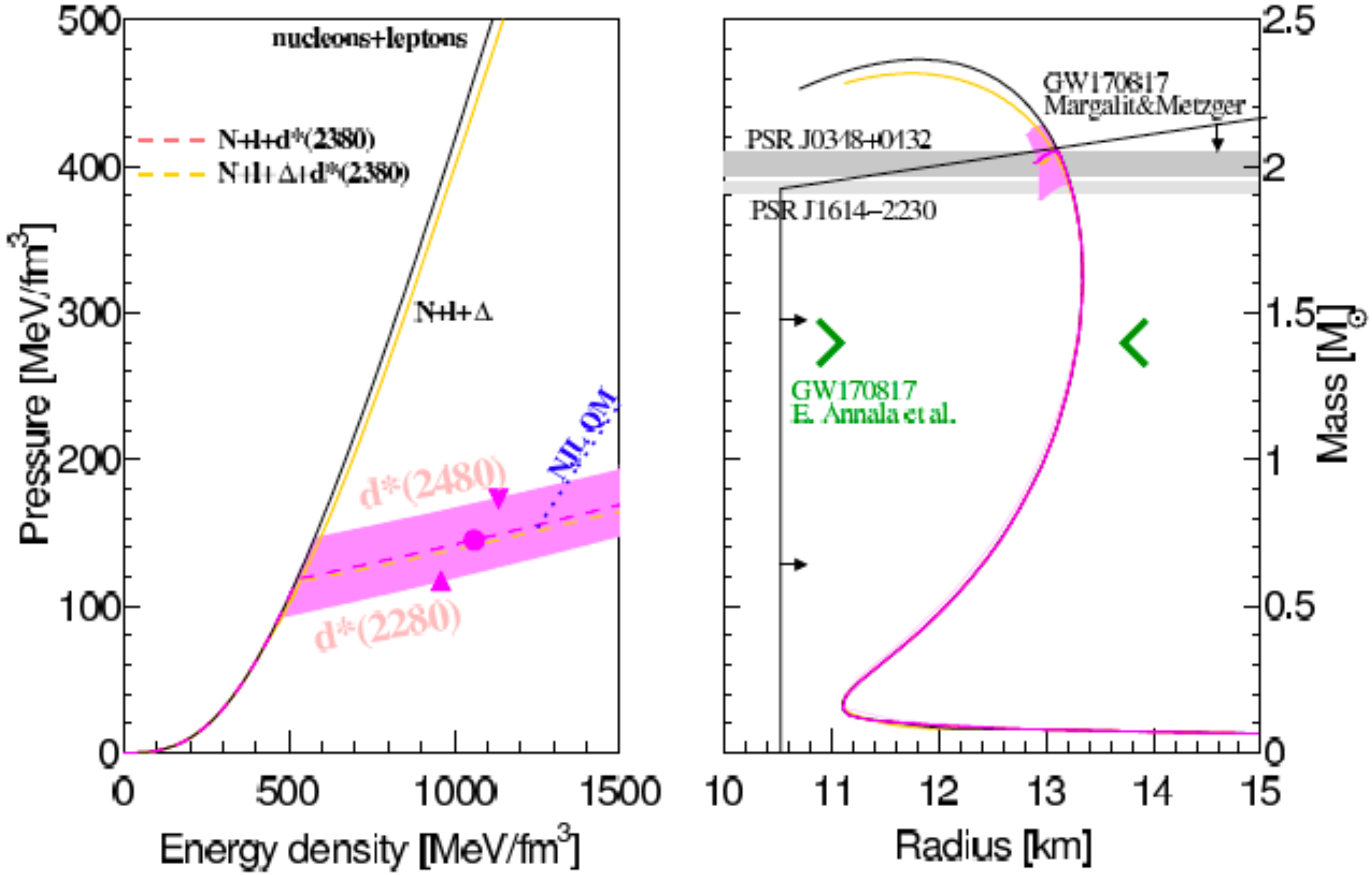
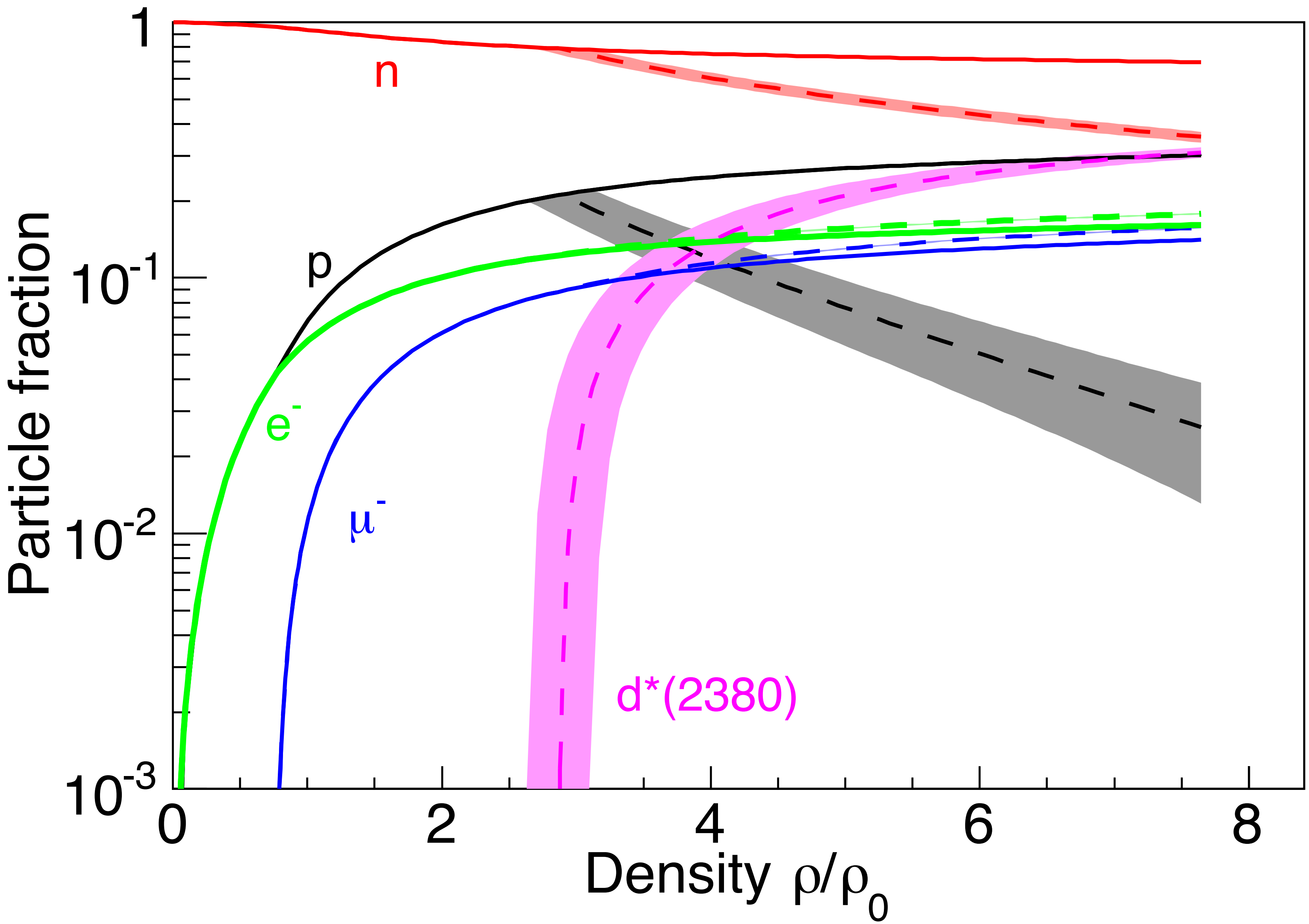
d*(2380) – influence on the EoS

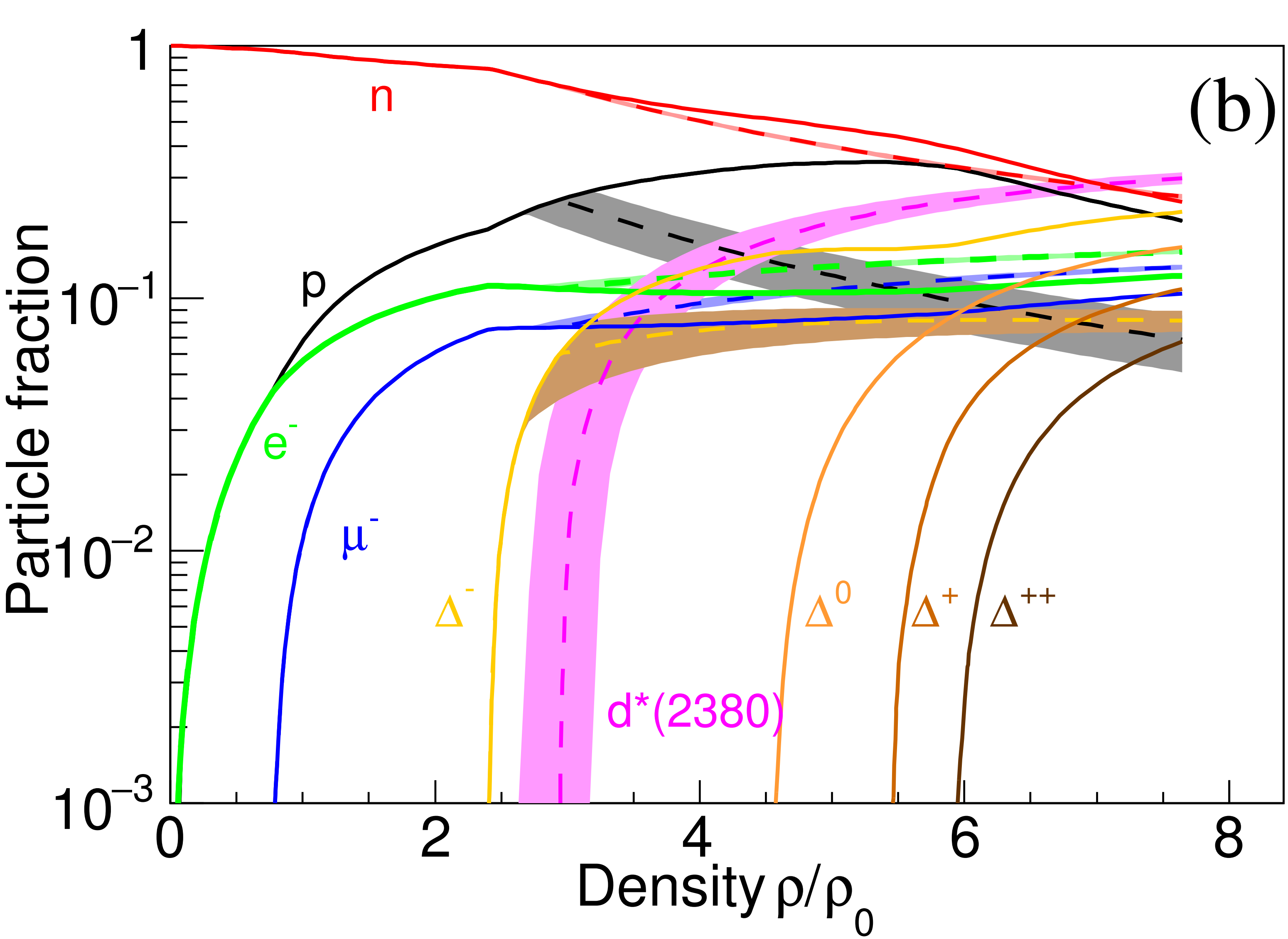


- d*(2380) -> Higher energy densities achieved with lower pressure (Bosonic!)
  -> Abrupt cutoff in maximum neutron star mass around 2M$_\odot$

Composition – “Standard” with d*(2380)



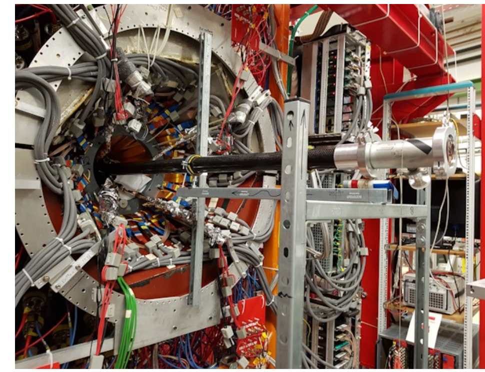
Composition – "Standard" with Δ quartet and d*(2380)

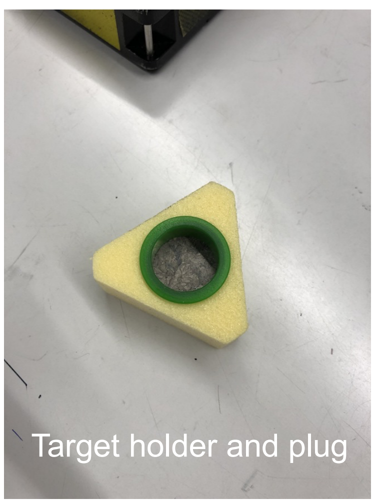


Recent running @ MAMI

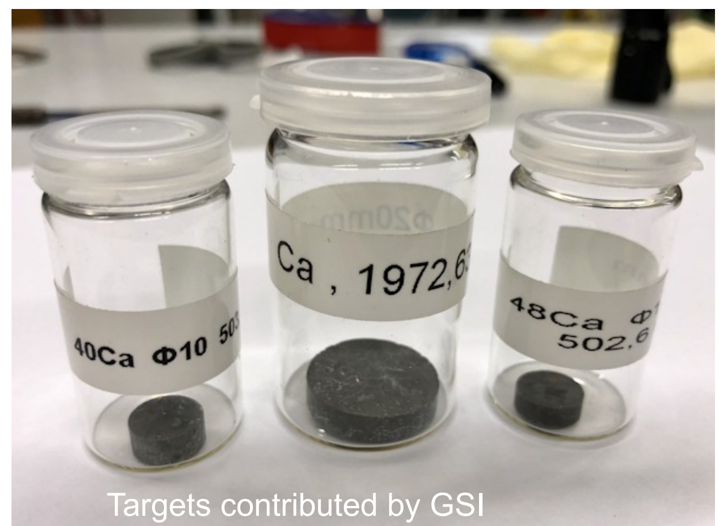
- Experiment carried out in Feb 19

Target	Diameter	mass	Beamtime (hours)
^{48}Ca	10mm	502.6	180
^{40}Ca	10mm	503.2	120
^{112}Sn	20mm	3800	54





Target holder and plug

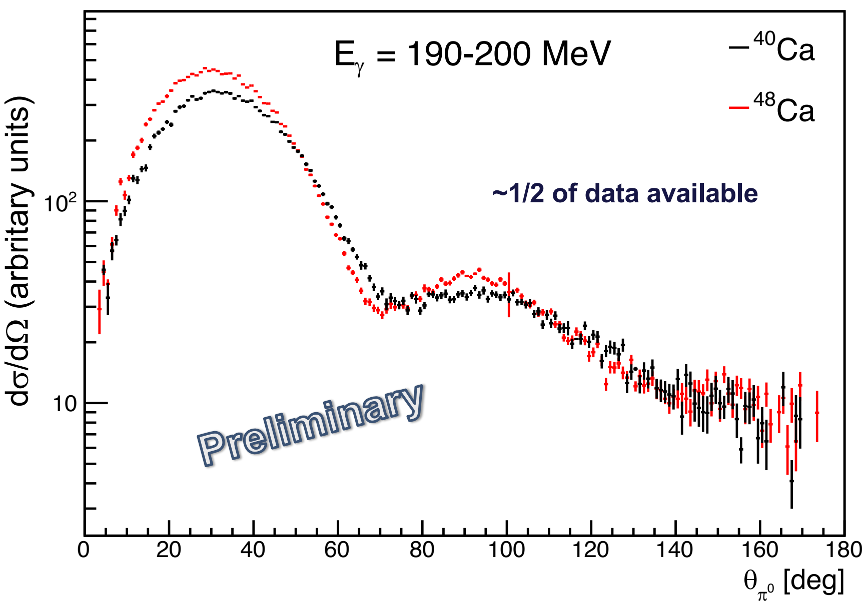


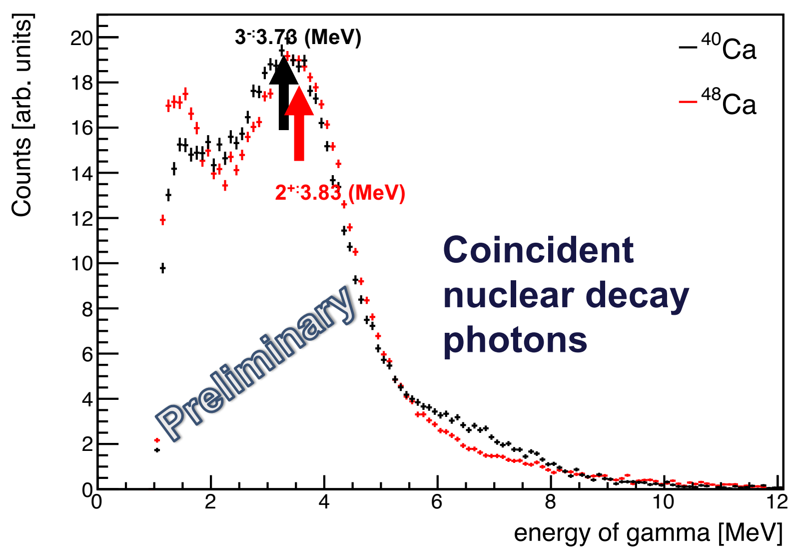
Targets contributed by GSI

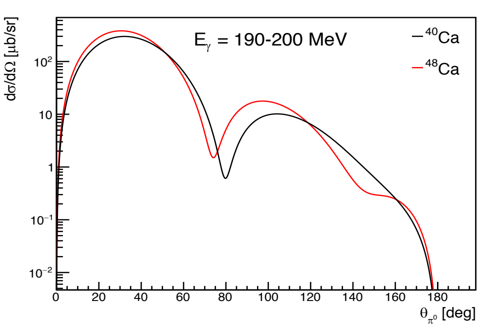
$^{48}Ca(\gamma,\pi^0)$ @ MAMI

- Analysis at **very early** stage

  -> Cannot draw physics conclusions but can see data quality



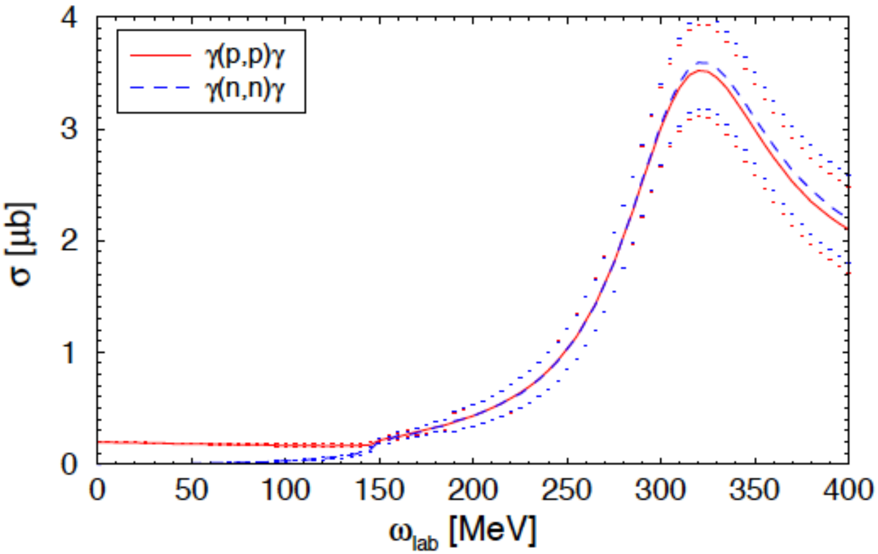


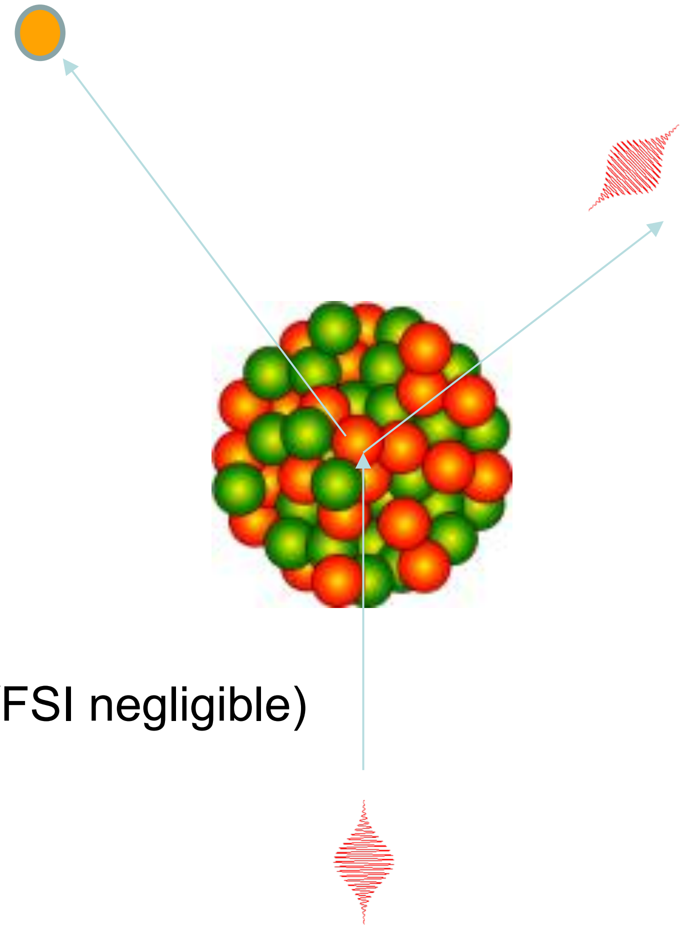


!!! Caveats !!!

Calibrations not complete, incoherent backgrounds/empty target not removed, detector acceptance crudely incorporated, …

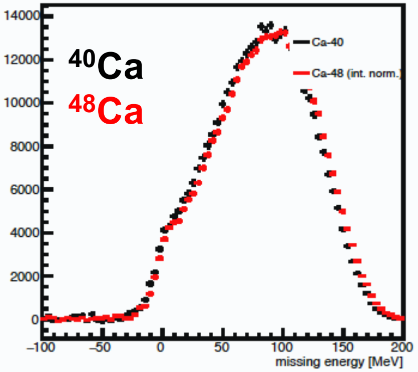
In medium nucleon Compton scattering

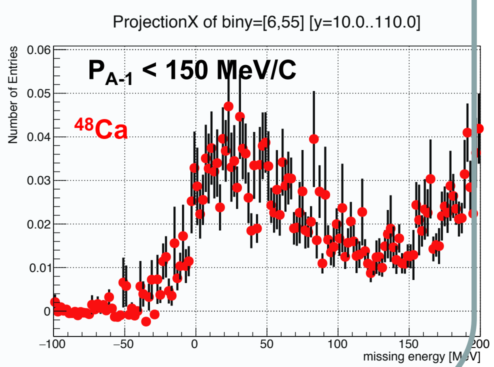


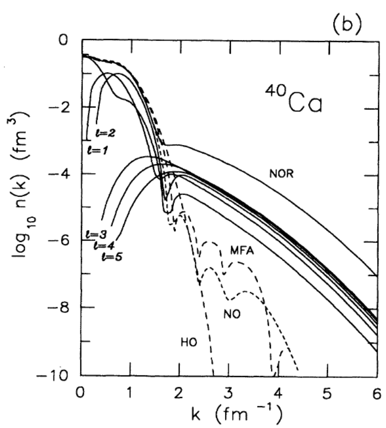


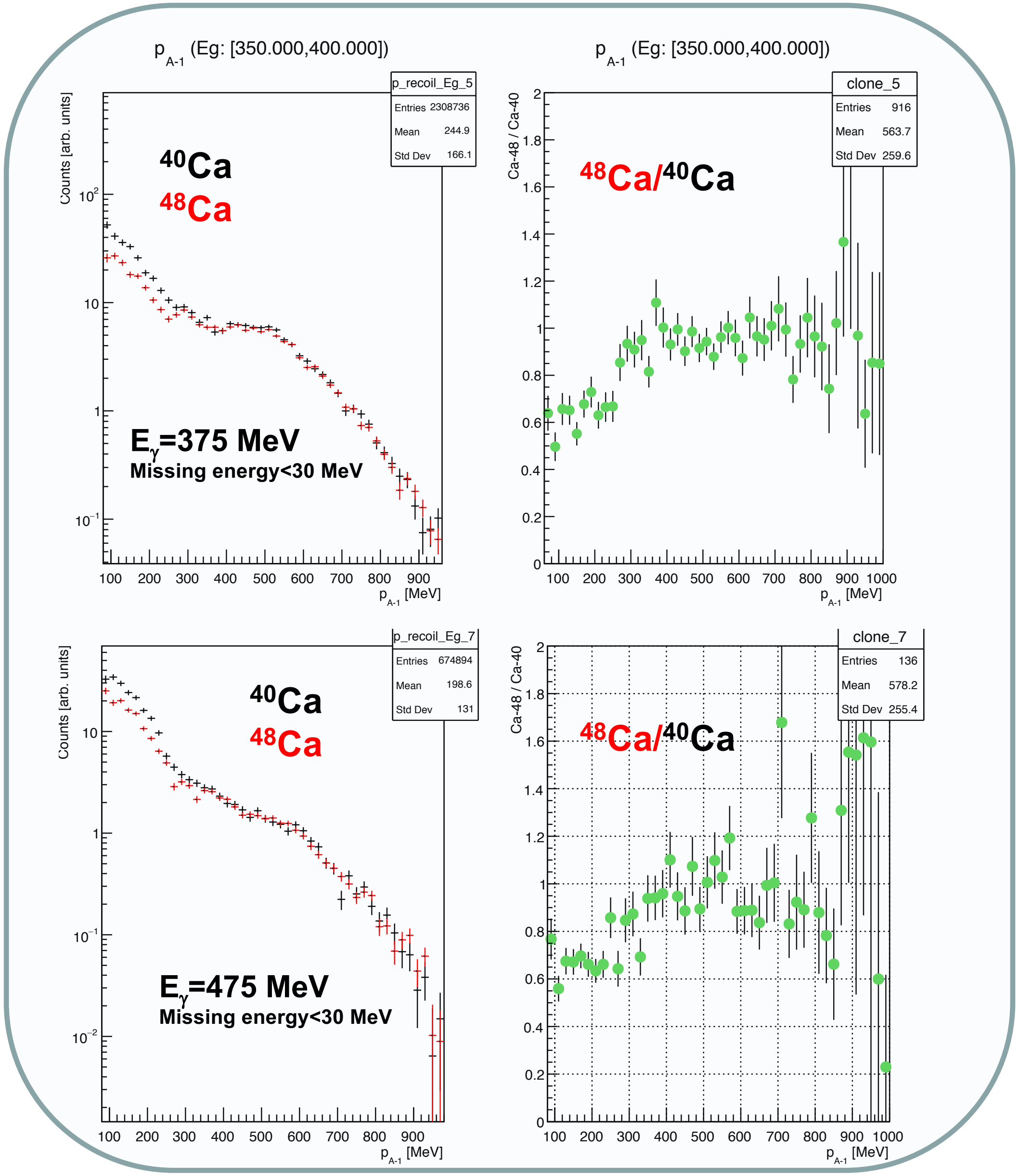
- Favourable entrance and exit probe (ISI/FSI negligible)
- Amplitude ~identical protons/neutrons
- Can we see it in nuclei ??

Compton scattering from in medium nucleons?

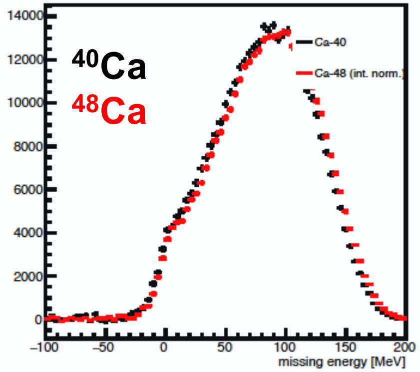


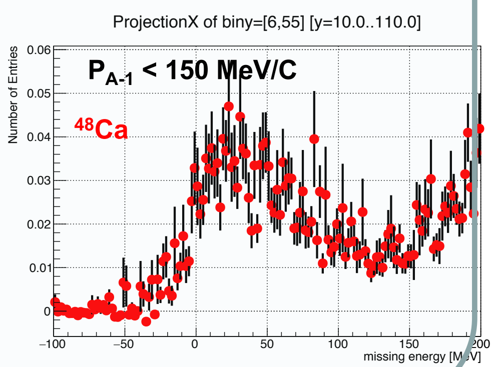


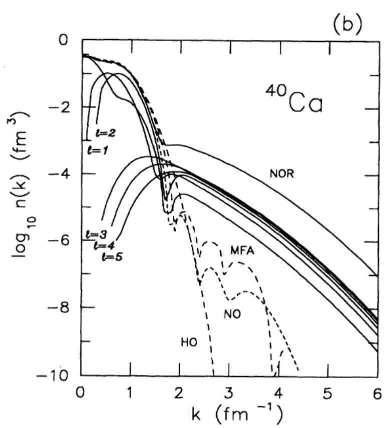


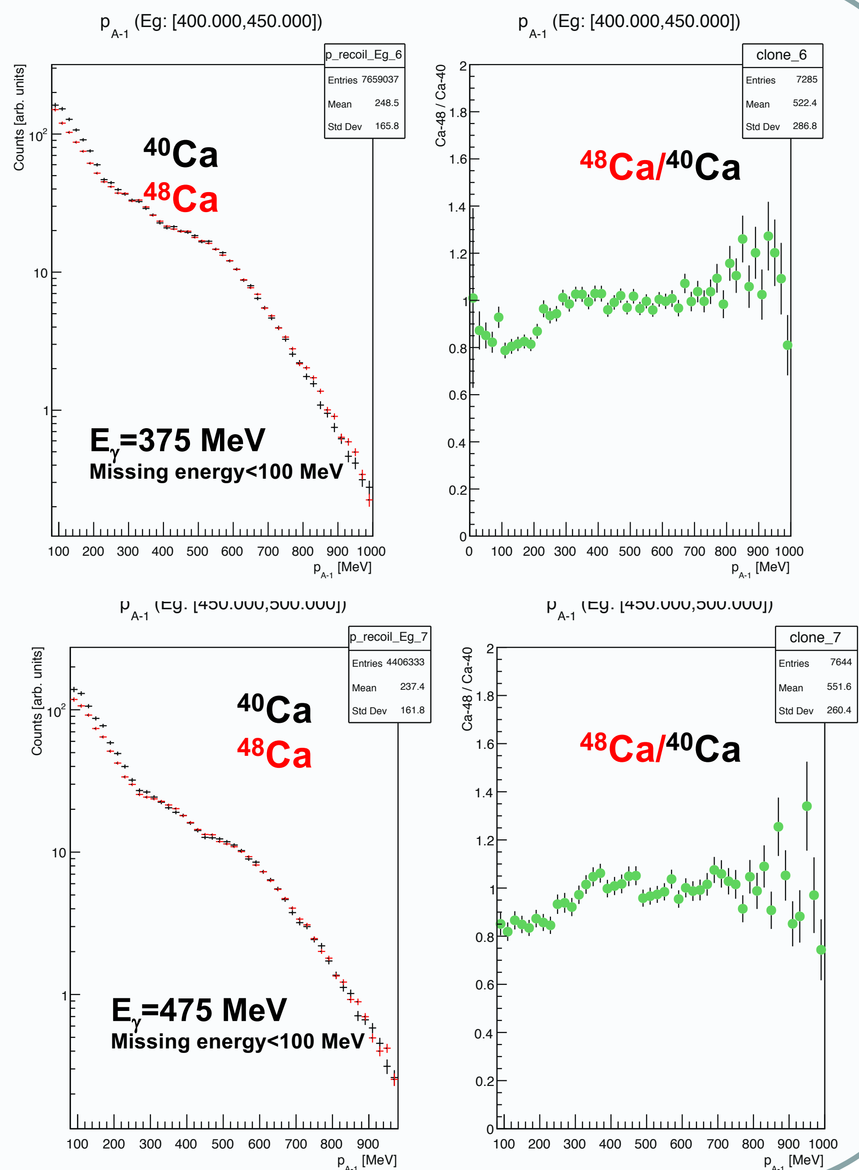


Compton scattering from in medium nucleons?

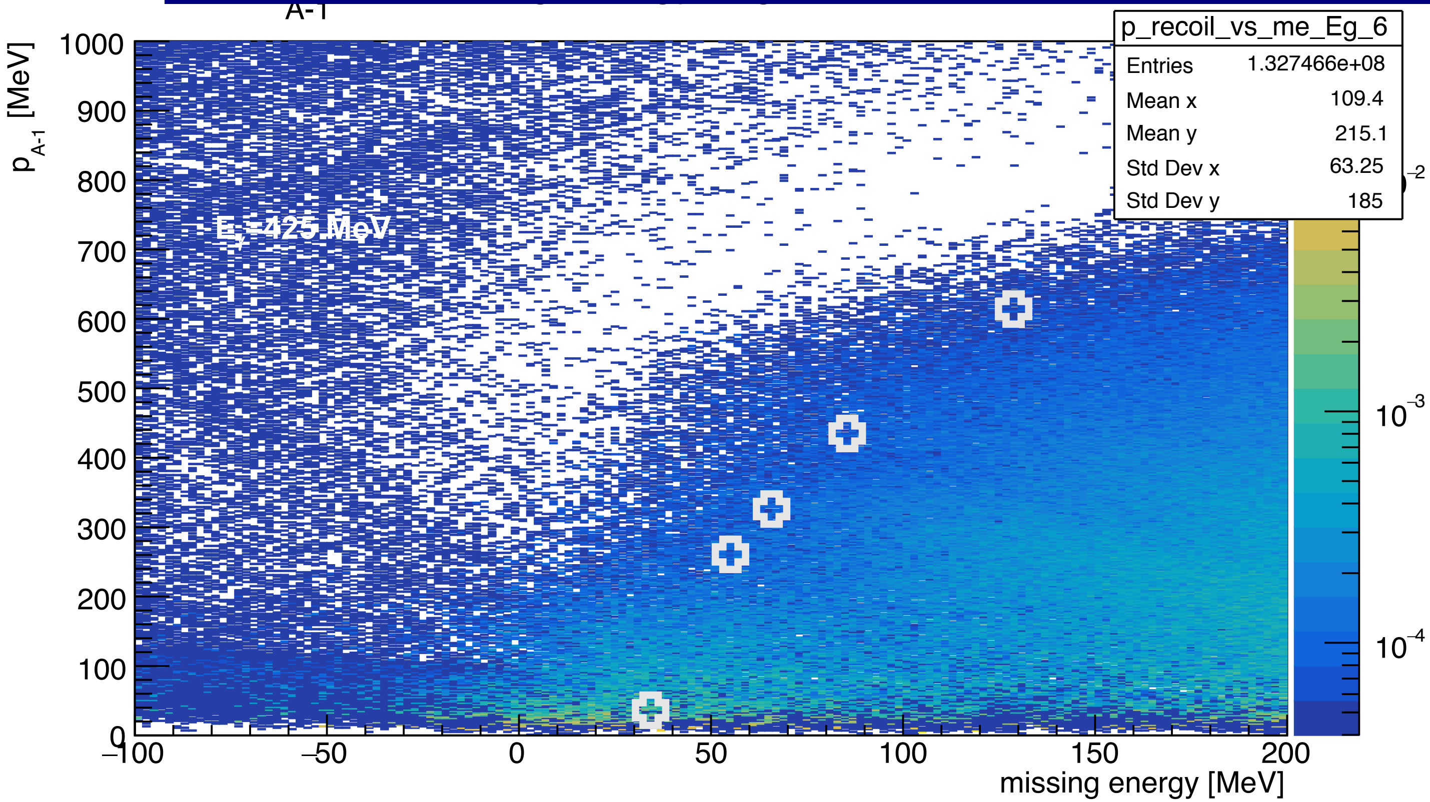


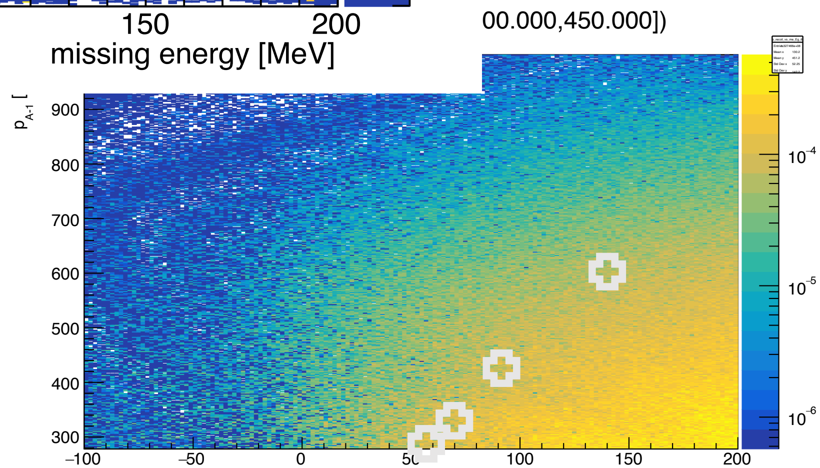






Compton scattering from in medium nucleons?

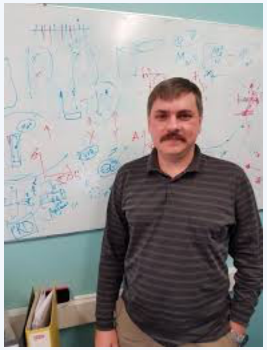




Summary

- EM probes -> helping to elucidate the detailed physics of strongly interacting matter and nuclei
- Ongoing programme will provide valuable data to constrain the nucleonic (and non-nucleonic) contributions to the equation of state

Hadron & medical physics group at York



Dr Mikhail Baskanov
Rutherford fellow

Dr Nick Zachariou
Rutherford fellow

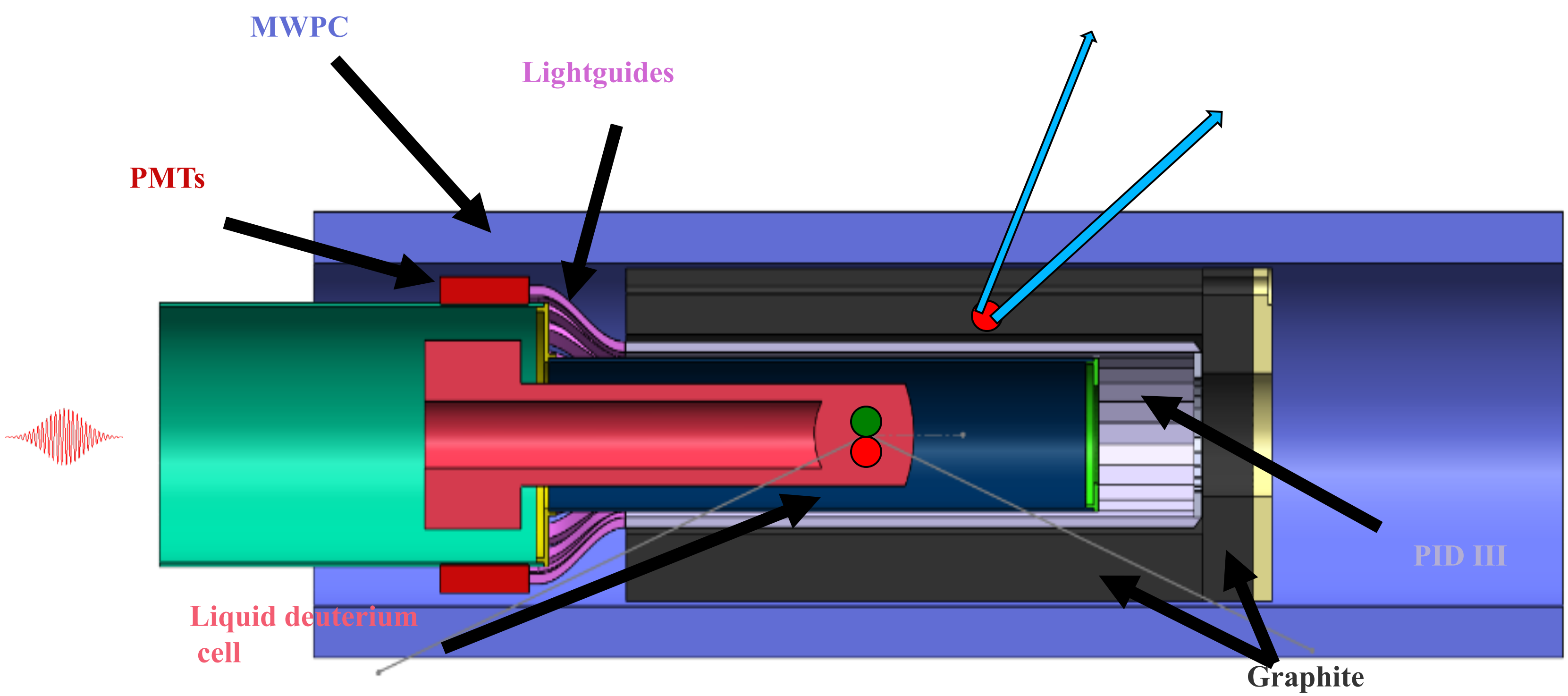
Dr Dominik Werthmueller
PDRA

Dr Jamie Brown
PDRA (medical)

Dr Julien Bordes
PDRA (medical)

Large acceptance nucleon polarimeter

Sikora, DPW, Glazier et. al. PRL112 022501 (2014)



$$n(\theta,\phi) = n_o(\theta)\{1+A(\theta)[P_y\cos(\phi)-P_x\sin(\phi)]\}$$

Number of nucleons scattered In the direction θ, ϕ

Polar angle distribution for unpolarised nucleons

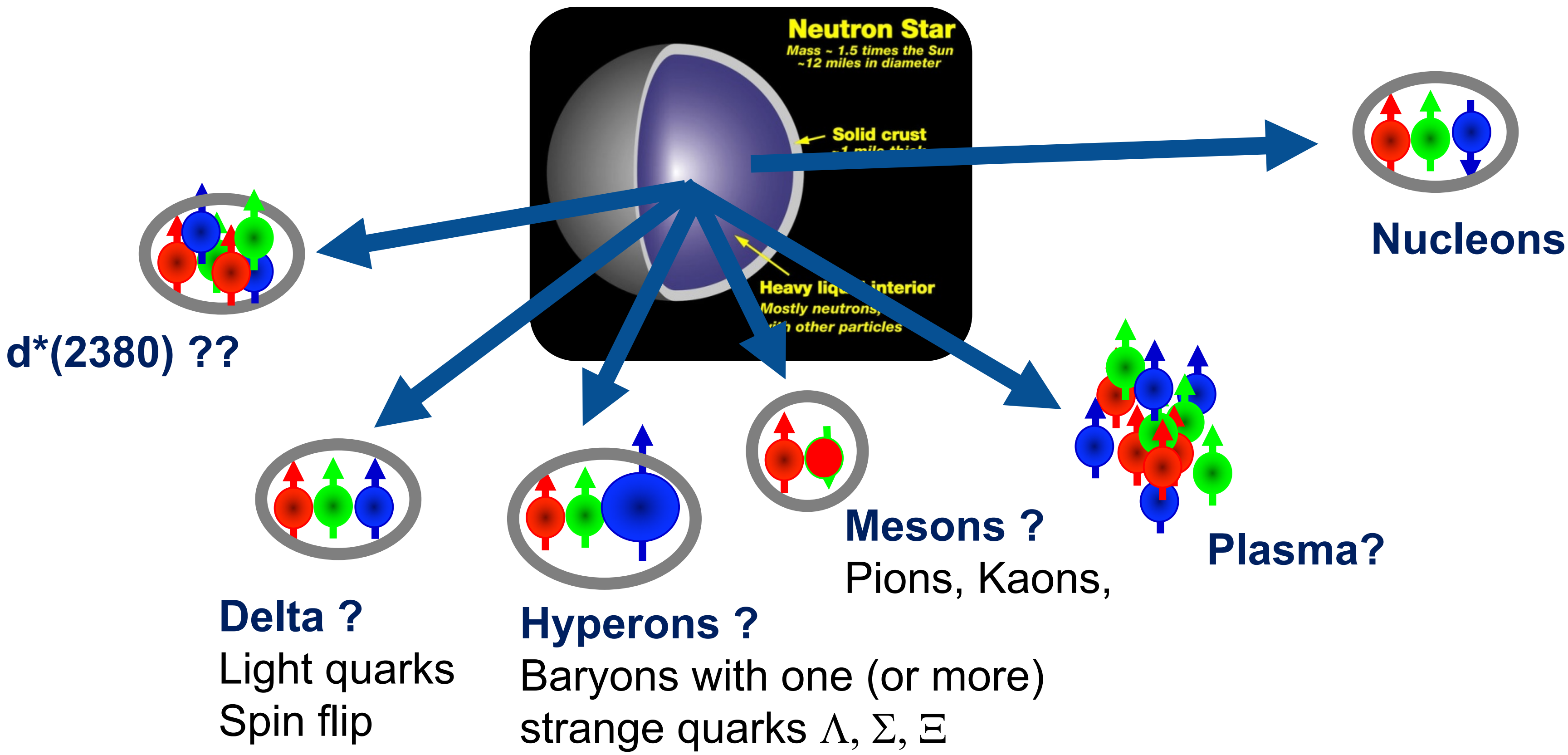
Analysing power of scatterer

x and y (transverse) components of nucleon polarisation

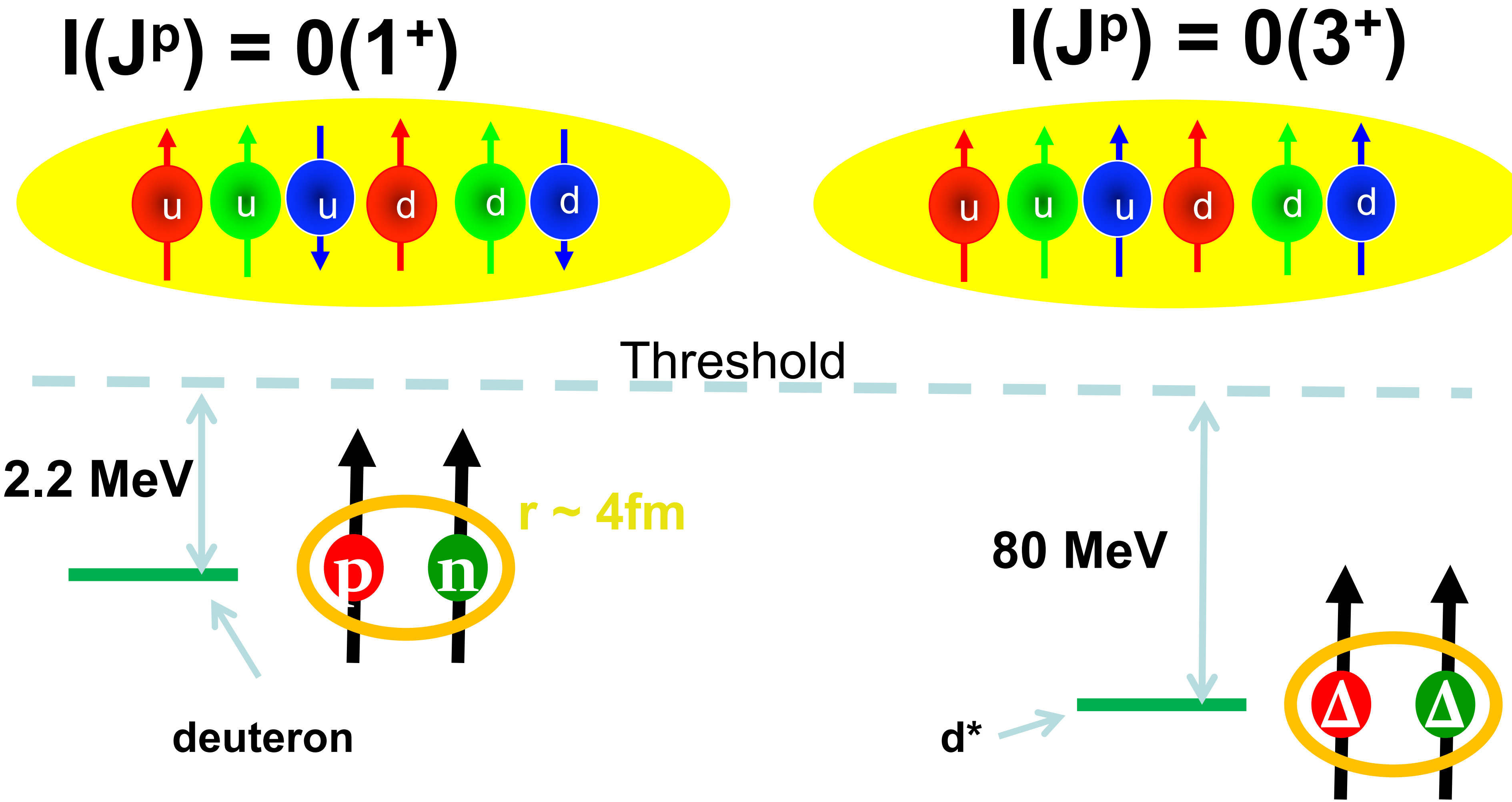
Hadronic matter at high density

- Neutron skins -> experimental constraint on **nucleonic** based matter

- At *higher* densities (>2-3ρ_o): our understanding of strongly interacting matter is still evolving –> better nuclear data



What is the d* - Deltaron hypothesis



But width of d* is 70 MeV – width(ΔΔ)~240 MeV?
& strong decay open (NNππ, NΔπ) ?

PHYSICAL REVIEW D **89,** 043014 (2014)

Can very compact and very massive neutron stars both exist?

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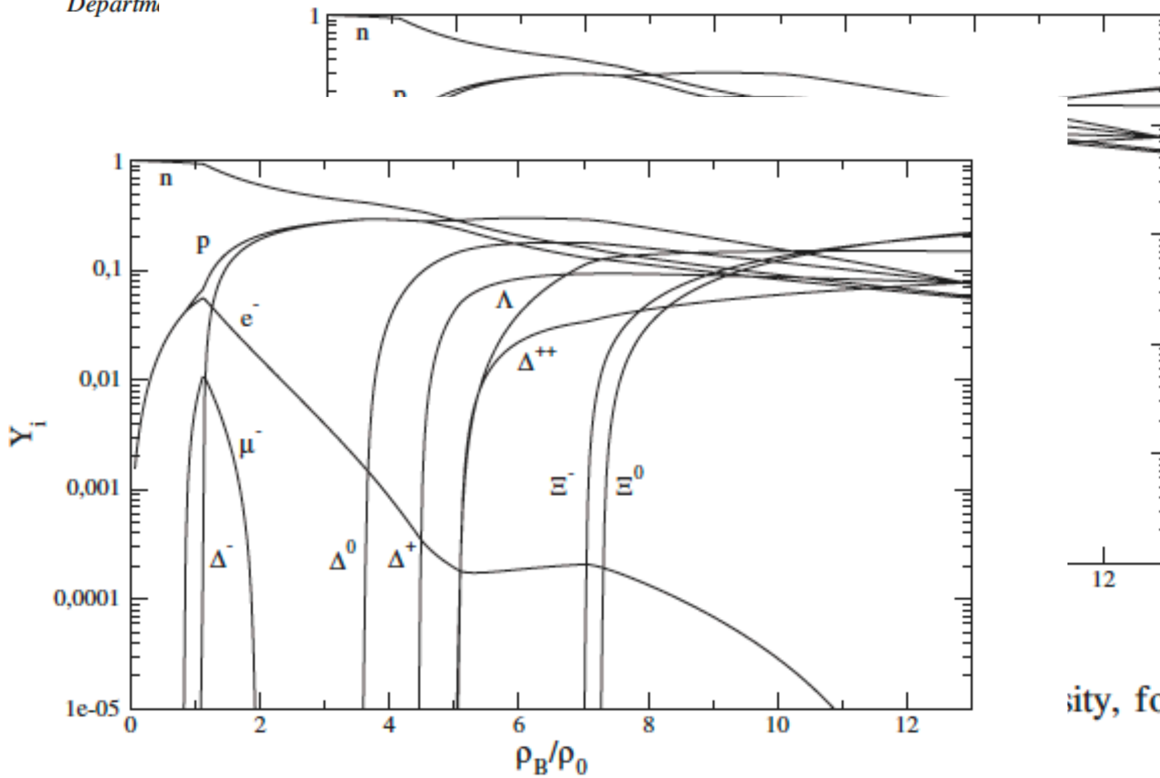
[1]*Dipartimento di Fisica e Scienze della Terra dell'Università di Ferrara and INFN Sezione di Ferrara,*

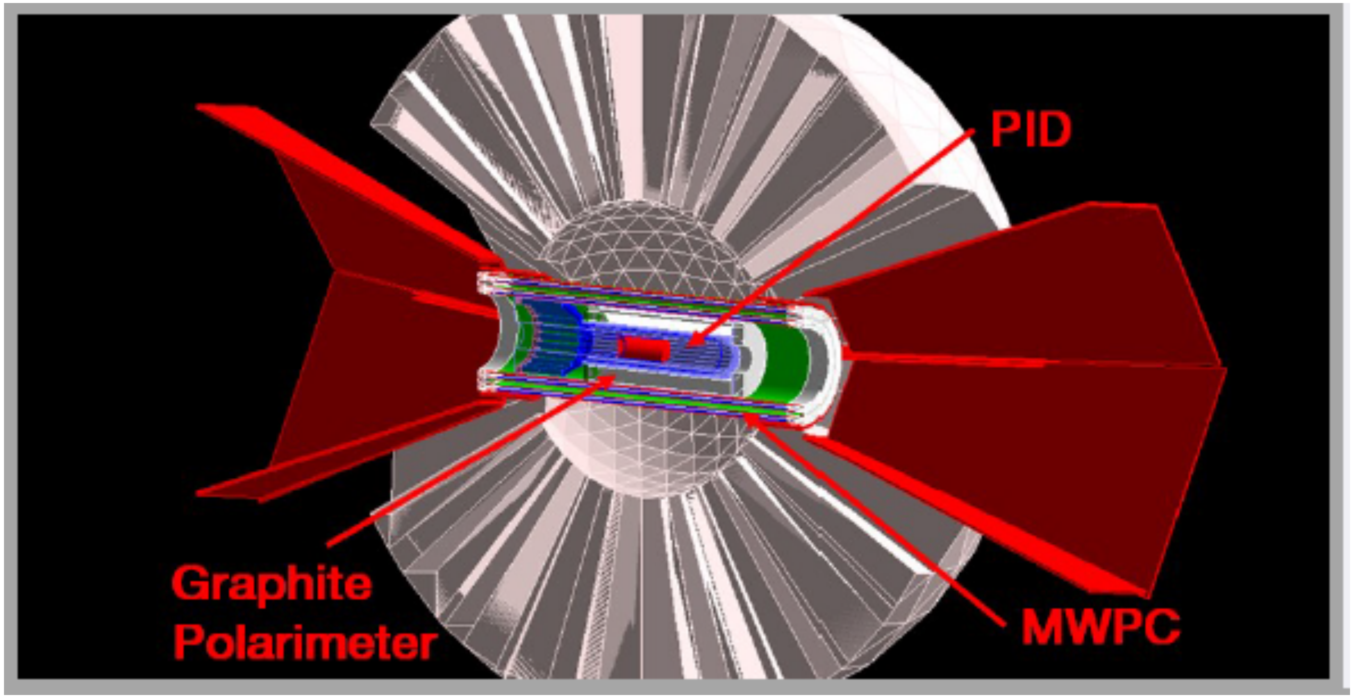
[2]*Departm*



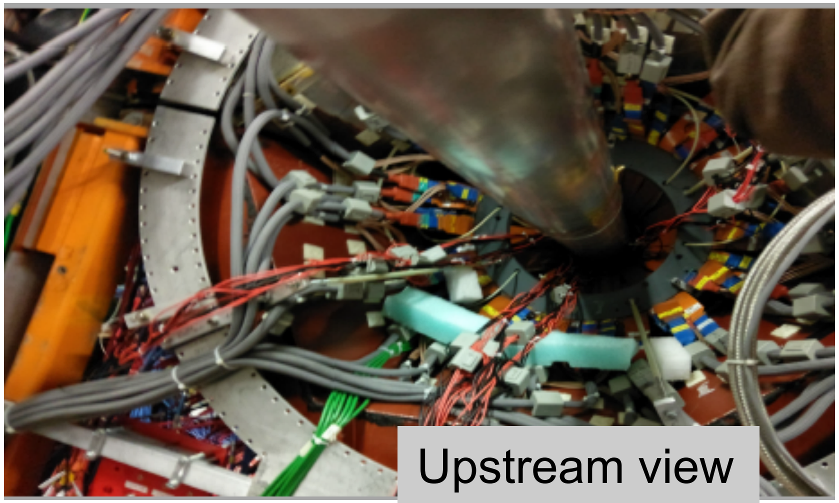
sity, for

FIG. 1. Particle fractions as functions of baryon density, for $x_{\sigma\Delta} = 1.25$, $x_{\omega\Delta} = 1$.

EDPOL2



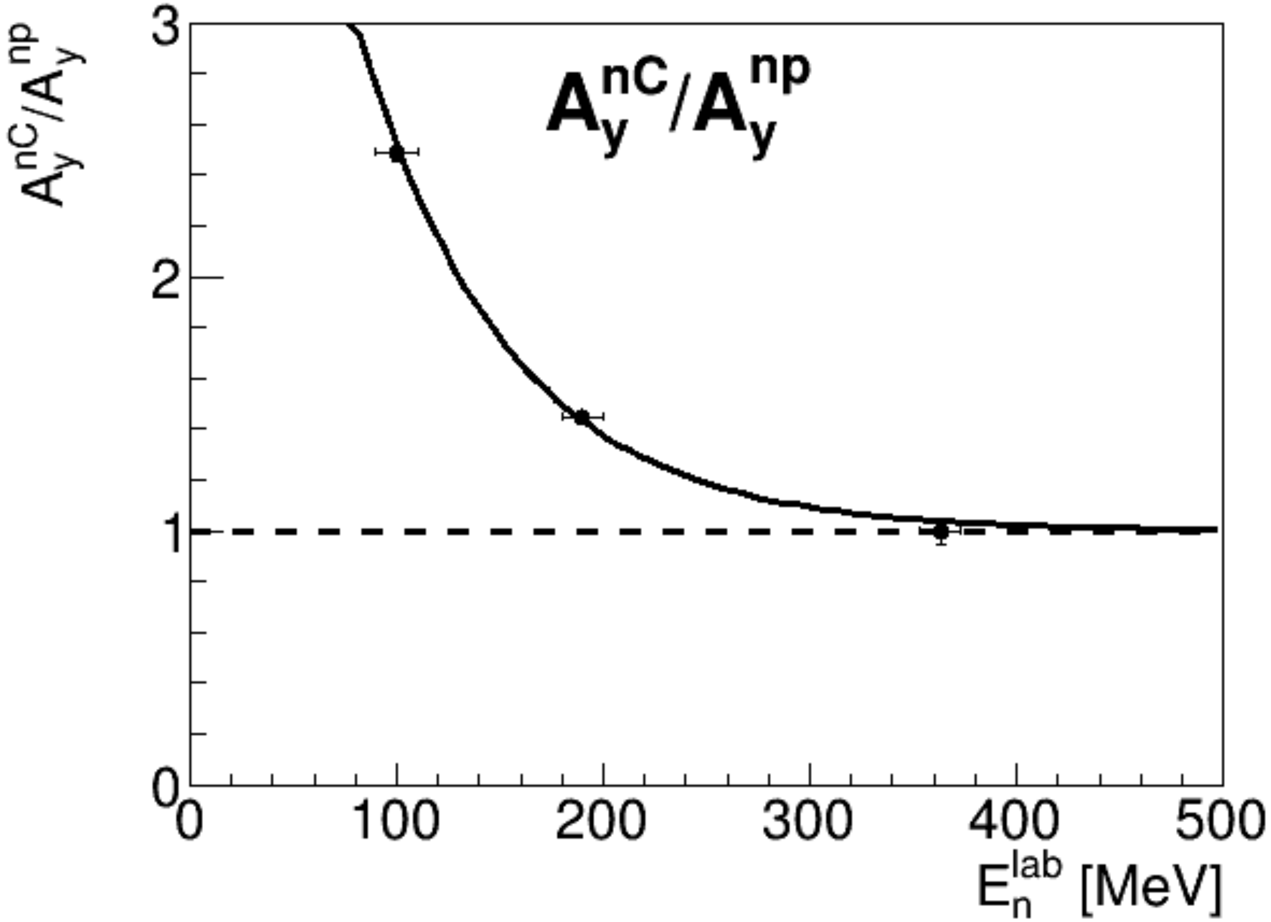
PID
Graphite
Polarimeter
MWPC



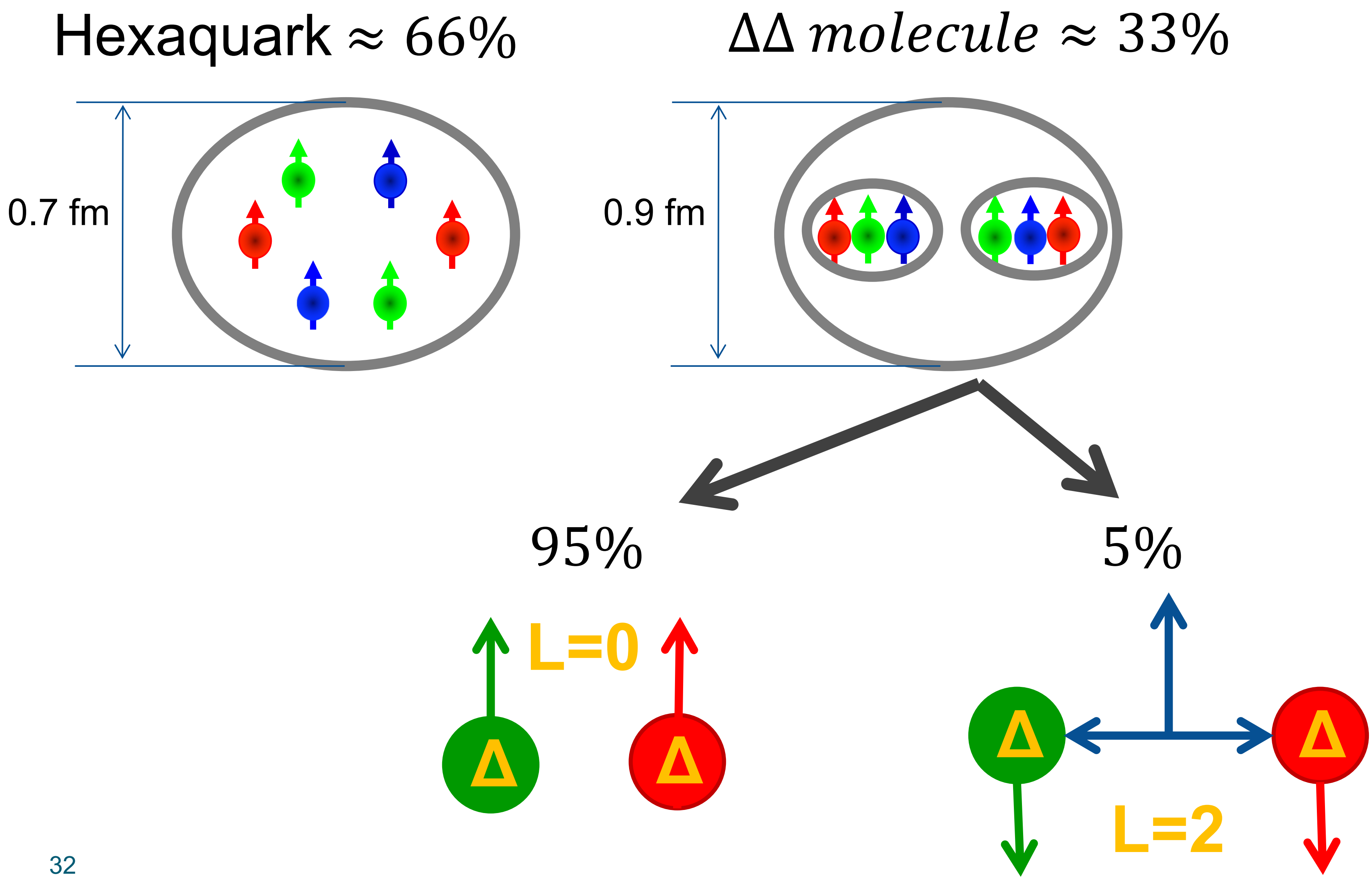
Upstream view

Downstream view

Neutron A_y on Carbon



$d^*(2380)$ internal structure



$\gamma d \to d^* \to pn$

Conventional background

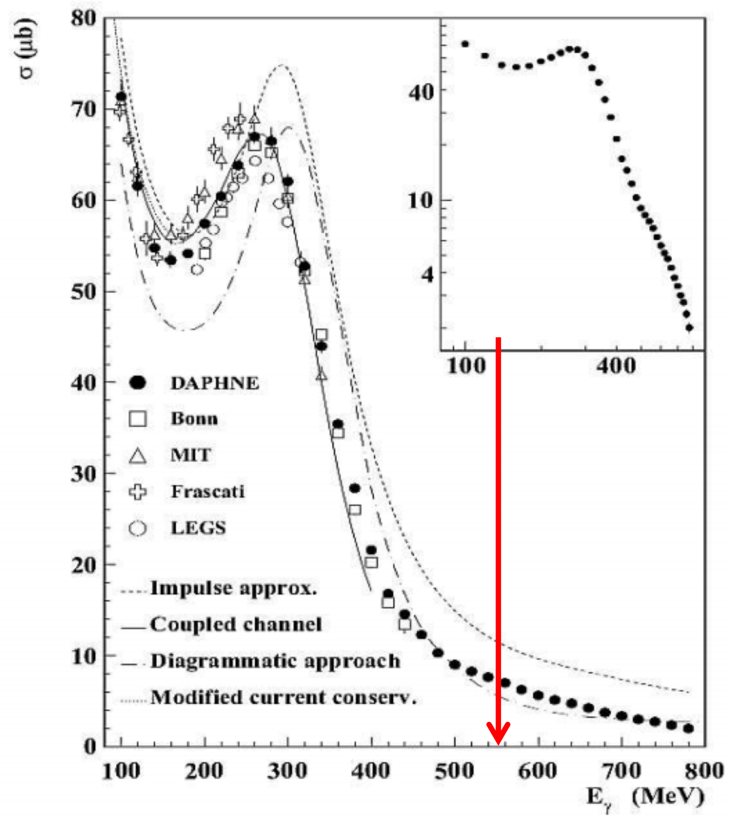
$\sigma(\gamma d \to pn) \sim 8\mu b$

$\sigma(\gamma d \to d^*(2380) \to pn) \sim 10nb$

$$\frac{\sigma(\gamma d \to pn)}{\sigma(\gamma d \to d^*(2380) \to pn)} \sim 1000$$

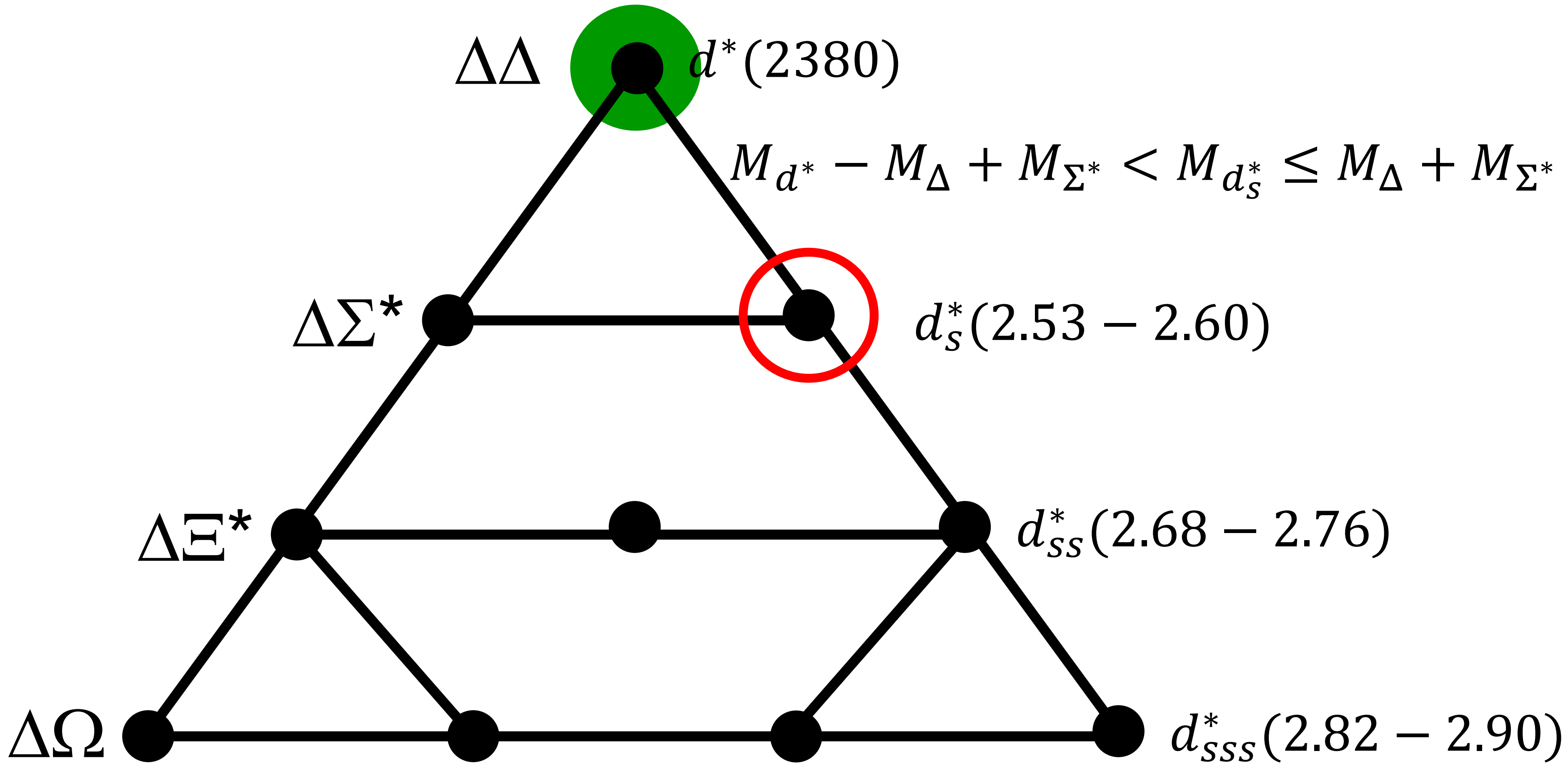
BUT

Polarization observables

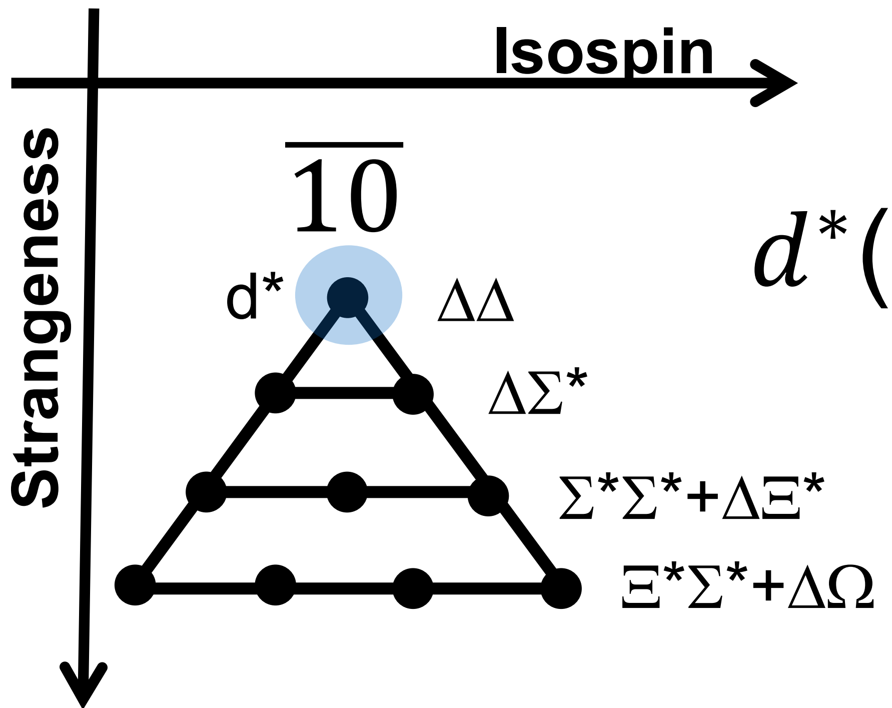


Federico Ronchetti arXiv 1301.5886

d*(2380) SU(3) multiplet



Strange Dibaryon decays



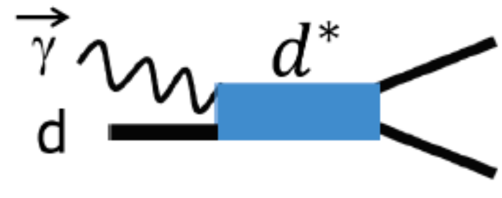
d^*(2380) → pn

d^*(2380) → $\Delta\Delta \rightarrow NN\pi\pi$

d_s^*(2530-2600) → $N\Lambda$

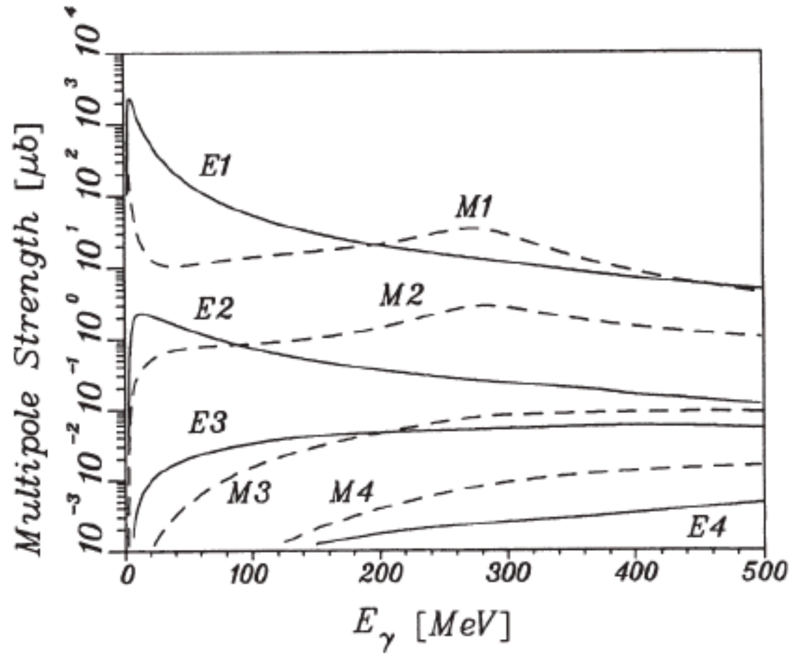
d_s^*(2530-2600) → $\Delta\Sigma^* \rightarrow (N\pi)(\Lambda\pi) \rightarrow NN\pi\pi\pi$

E2 transition (2^+)
M3 transition (3^+)
E4 transition (4^+)



$^3D_3$ & $^3G_3$

90% 10%

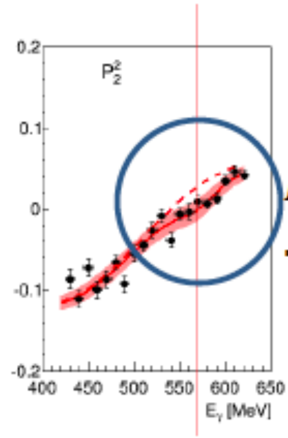


$$\frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = P_\gamma \boldsymbol{\Sigma} cos2\phi$$

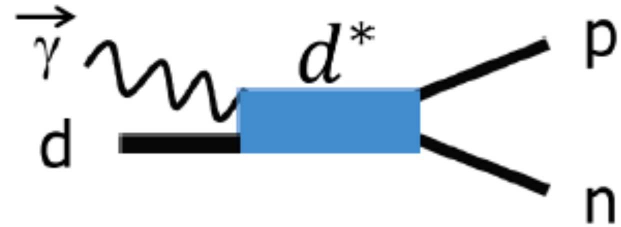
Fig. 7.1.3: Multipole strengths up to $L = 4$ contributing to the total cross section with inclusion of MEC, IC and RC for the Bonn r-space potential.

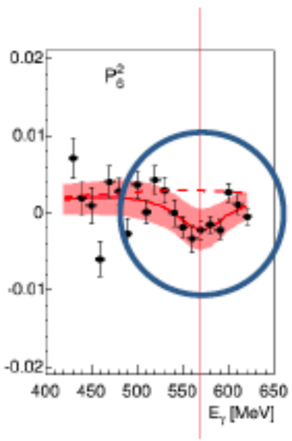
H. Arenhoevel, M. Sanzone "Photodisintegration of the deuteron"

$$\frac{\Sigma(\Theta)\sigma(\Theta)}{\sigma_0} \sim \sum_{J=2} B_J P_J^2(cos\Theta)$$



$$B_2 \sim c_1|^3D_3(E2)|^2 + c_2|^3D_3(M3)|^2 + c_3|^3G_3(E2)|^2 + c_4|^3G_3(M3)|^2 + \cdots$$





$$B_6 \sim d_1|^3G_3(M3)|^2 + \cdots$$
$$+d_i|^3D_3(M3)||^3G_3(M3)|cos\delta_i + \cdots$$
$$+d_j|^3D_3(E2)||^{2S+1}L \geq 4_J(E4)|cos\delta_j + \cdots$$

Magnetic M3 transition might be sizable

Strange Dibaryon decays

$$d_s^*(2530\text{-}2600) \rightarrow N\Lambda$$

$$d_s^*(2530\text{-}2600) \rightarrow \Delta\Sigma^* \rightarrow (N\pi)(\Lambda\pi) \rightarrow NN\pi\pi\pi$$

$$\gamma d \rightarrow (K^+) + d_s^* \rightarrow (K^+) + pp\pi^-\pi^-\pi^0$$

$$d_s^* \downarrow \Delta^0\Sigma^{*0}$$

$$\Delta^0 \rightarrow p\pi^-$$

$$\Sigma^{*0} \rightarrow \Lambda\pi^0$$

$$\Lambda \rightarrow p\pi^-$$

$$\gamma d \rightarrow (K^+) + d_s^* \rightarrow (K^+) + \vec{\Lambda}\vec{n}$$