Coherent and incoherent nuclear pion photoproduction

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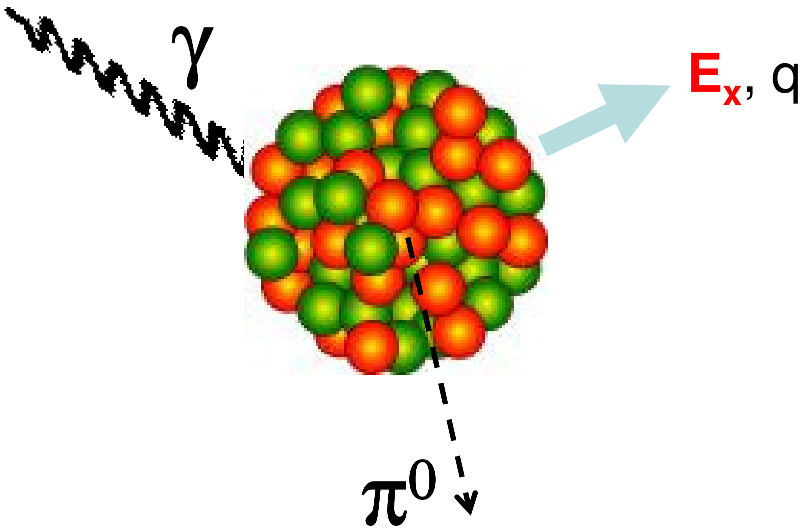
Crystal Ball and A2 collaboration at MAMI

Gordon Conference on photonuclear reactions, August 2008

Talk Outline

- Nuclear (π^0) photoproduction

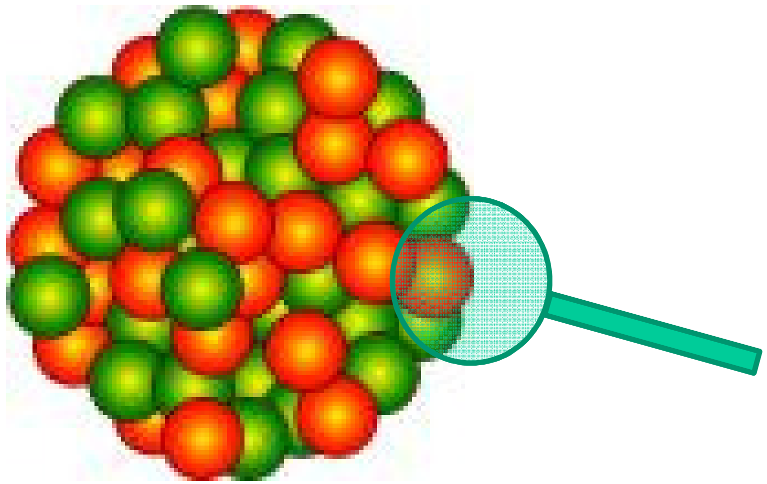


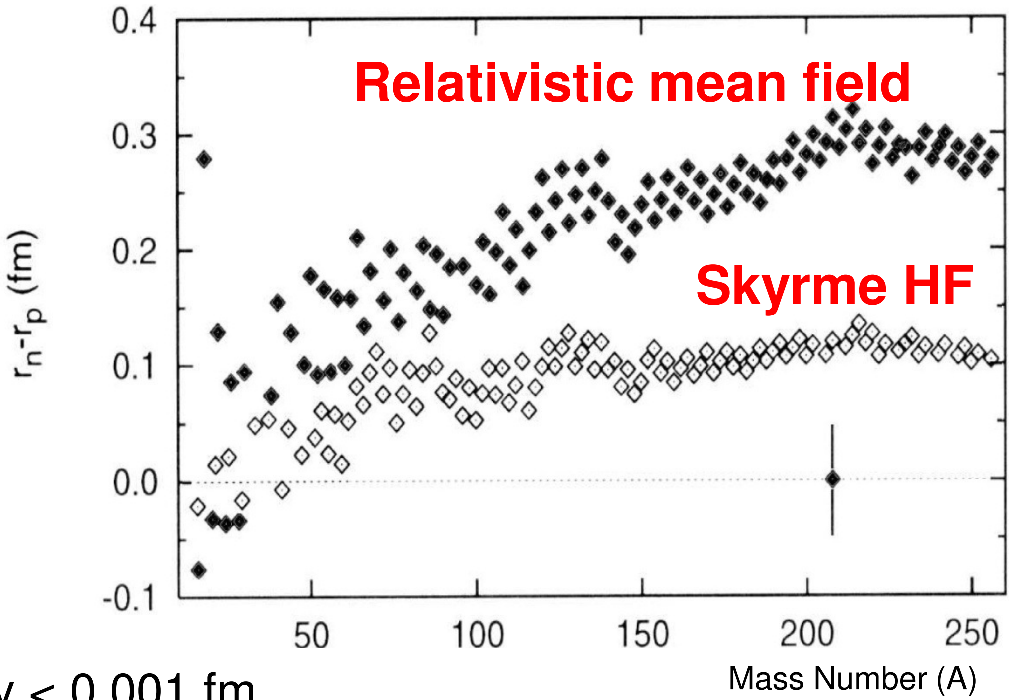
Coherent - Accurate Matter form factors
Neutron skins of stable nuclei (neutron stars)

Incoherent - Transition matter form factors
New observable for production amplitude

Why measure the matter form factor?

• Our knowledge of the shape of stable nuclei is presently incomplete

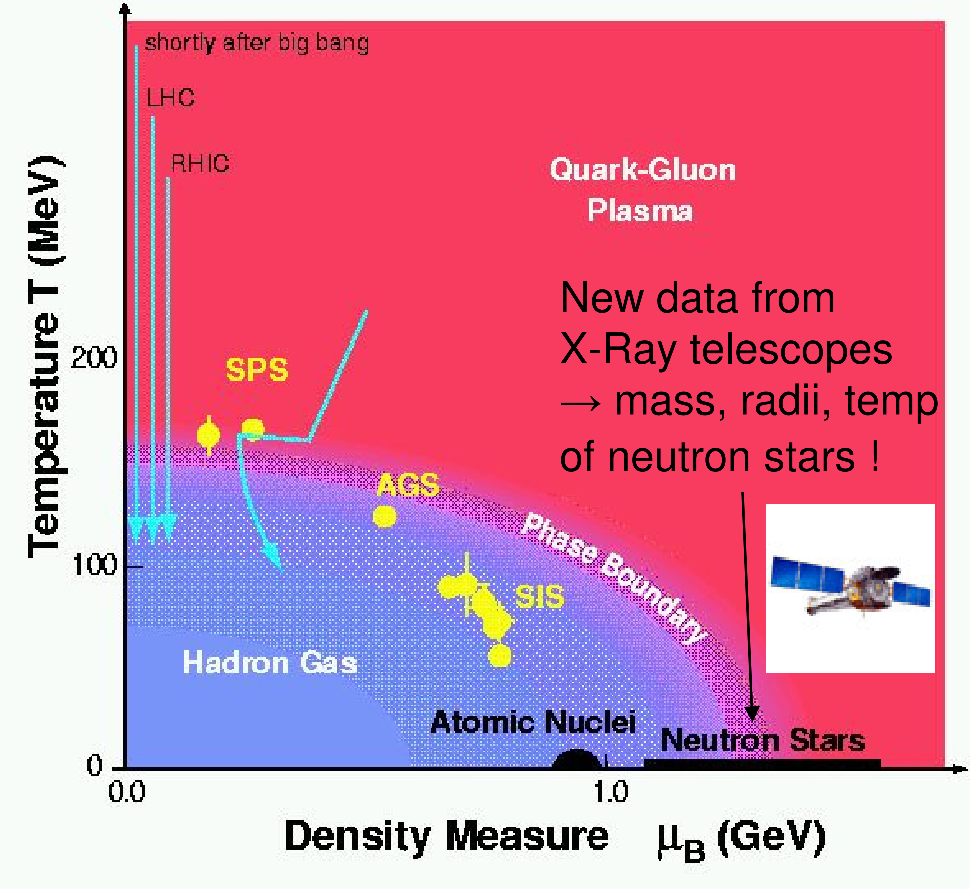




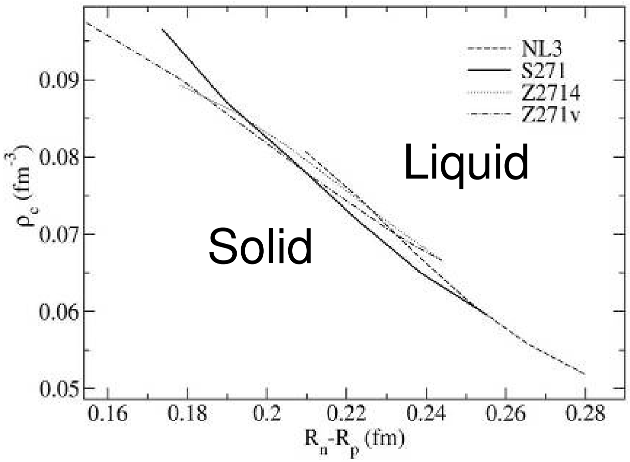
e.g. ^{208}Pb RMS charge radius accuracy < 0.001 fm
RMS neutron radius accuracy ~0.2 fm !!

Horowitz et al. PRC63 025501 (2001)
Piekarewicz et al. NPA 778 (2006)

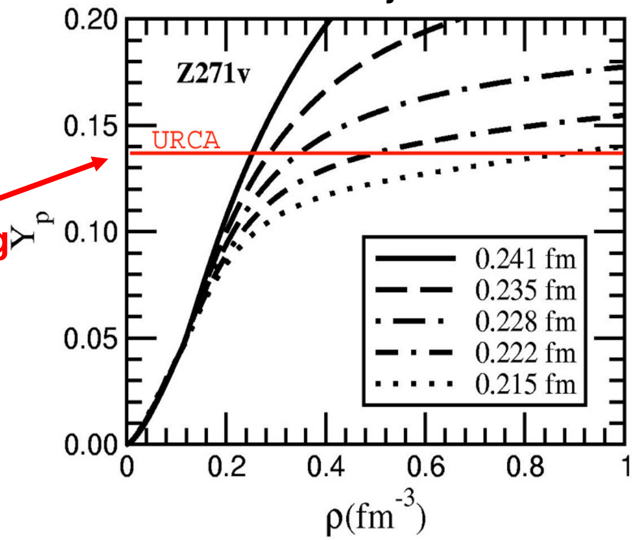
Matter form factor and neutron stars



Thick neutron skin
→ Low transition density in neutron star



Proton fraction as a
function of density in neutron star



Direct URCA Cooling

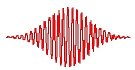
$n \rightarrow p + e^- + \bar{\nu}$

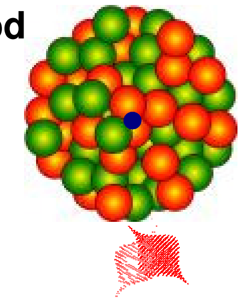
$e^- + p \rightarrow n + \nu$

Rutel et al, PRL 95 122501 (2005)
Horowitz, PRL 86 5647 (2001)
Horowitz, PRC 062802 (2001)
Carriere, Astrophysical Journal 593 (2003)
Tsuruta, Asttrophysical Journal Lett. 571 (2002)

Coherent pion photoproduction

Photon probe ✓
Interaction well understood





π^0 meson – produced with ~equal probability on protons *AND* neutrons.

Select reactions which leave nucleus in ground state

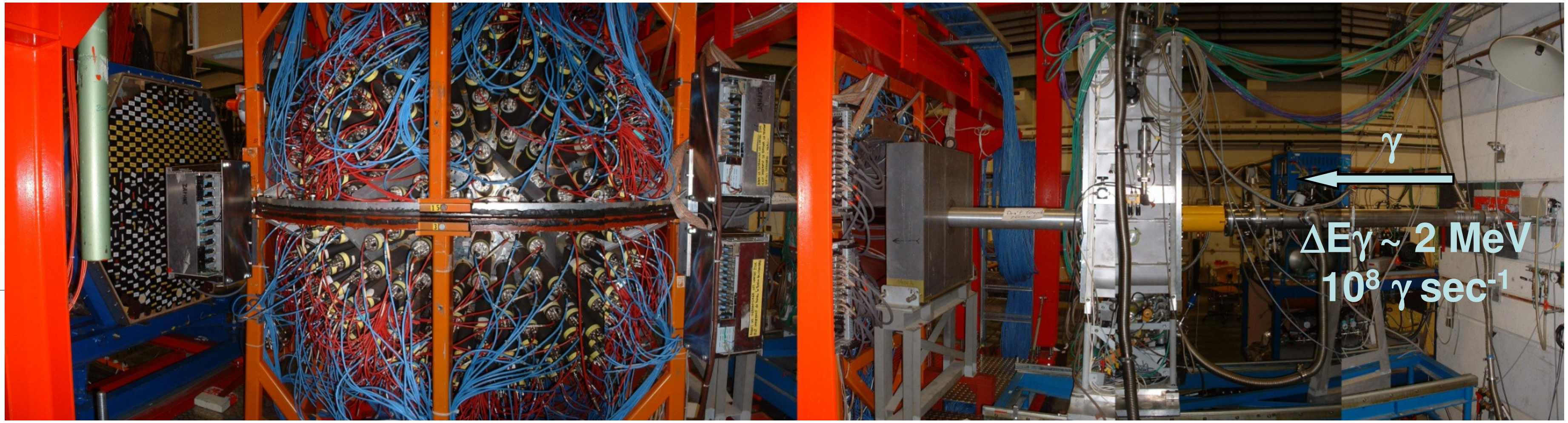
Reconstruct π^0 from $\pi^0 \rightarrow 2\gamma$ decay

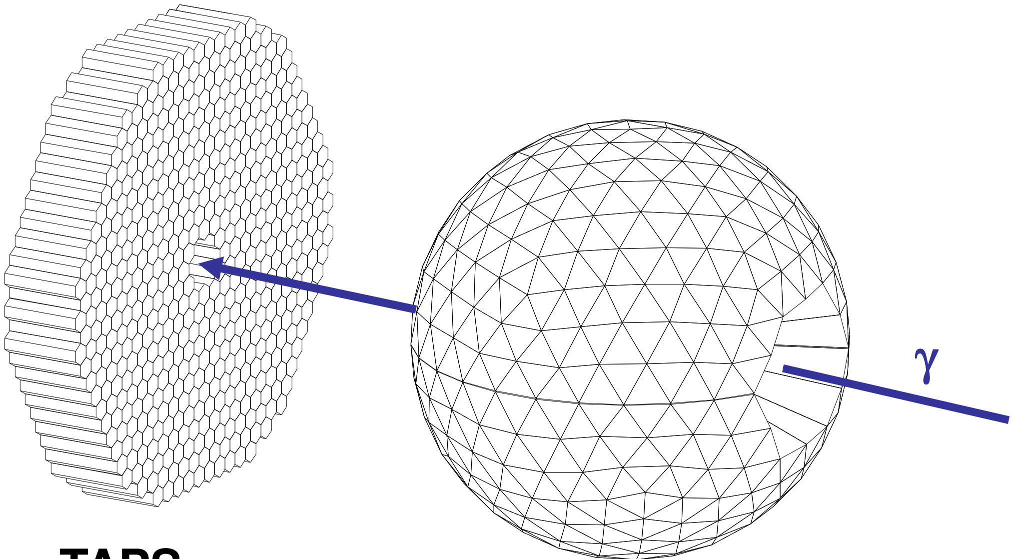
- Angular distribution of π^0 $\rightarrow$ PWIA contains the matter form factor

$$d\sigma/d\Omega(\text{PWIA}) = (s/m_N^2)\, A^2\, (q_\pi^*/2k_\gamma)\, F_2(E_\gamma^*,\theta_\pi^*)^2\, |F_m(q)|^2 \sin^2\theta_\pi^*$$

- π^0 final state interactions - use latest complex optical potentials tuned to π-A scattering data. Corrections modest at low pion momenta

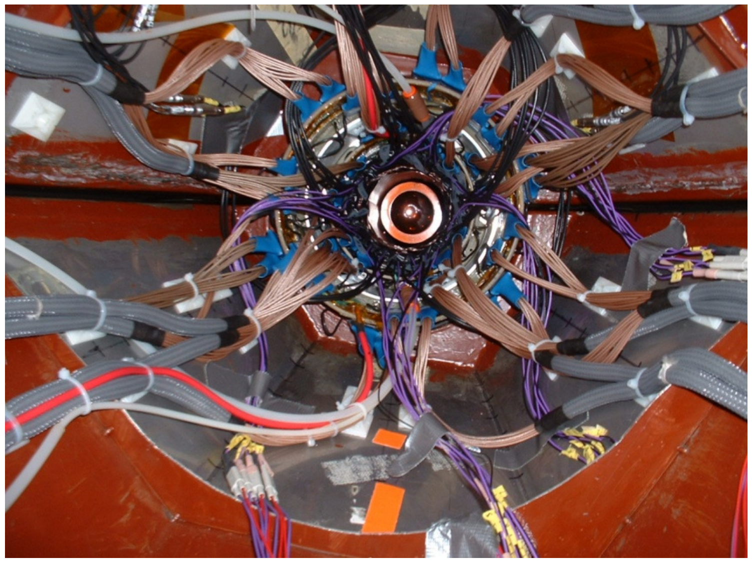
Coherent pion photoproduction



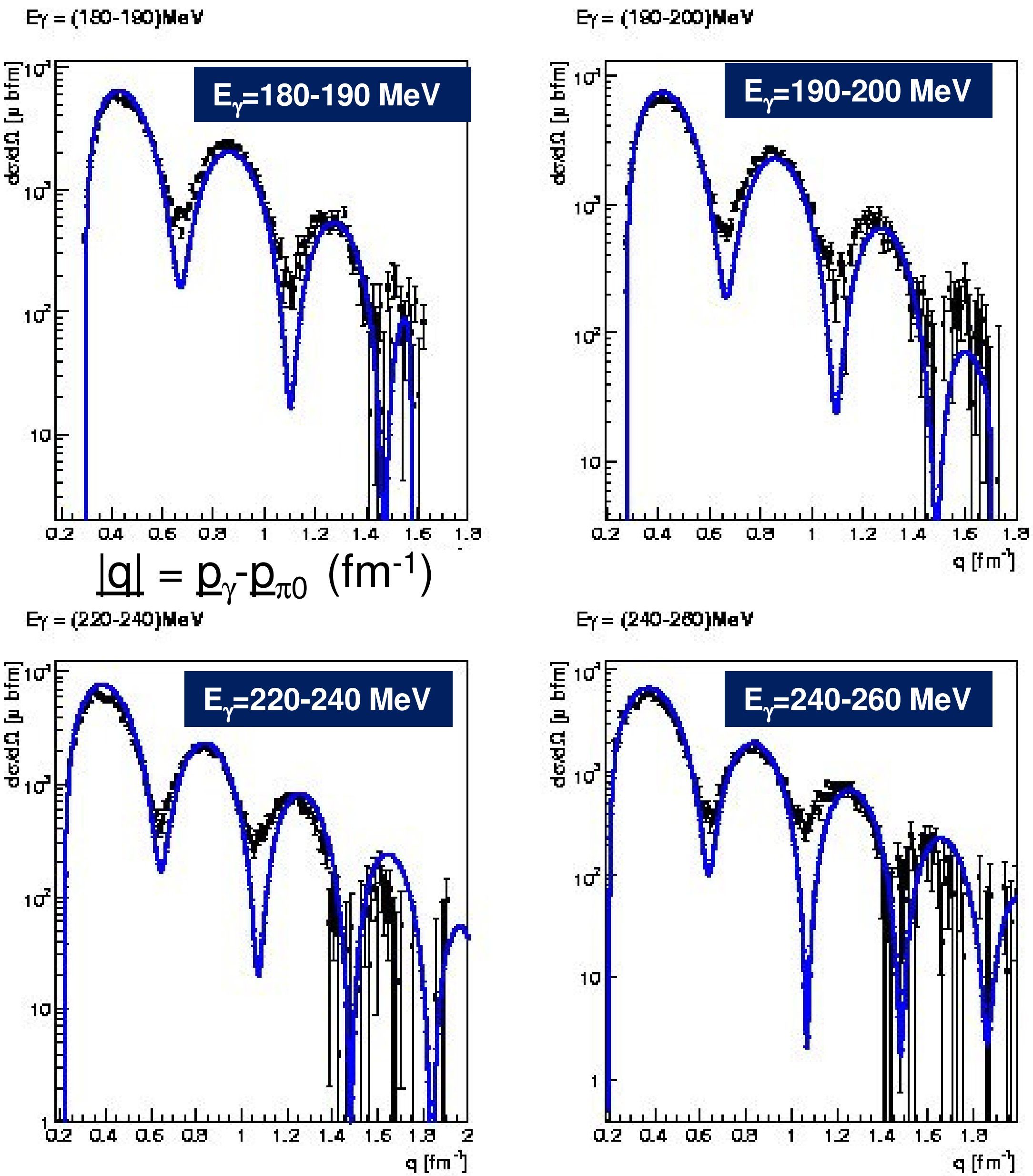


TAPS
528 BaF_2 crystals

Crystal Ball
672 NaI crystals



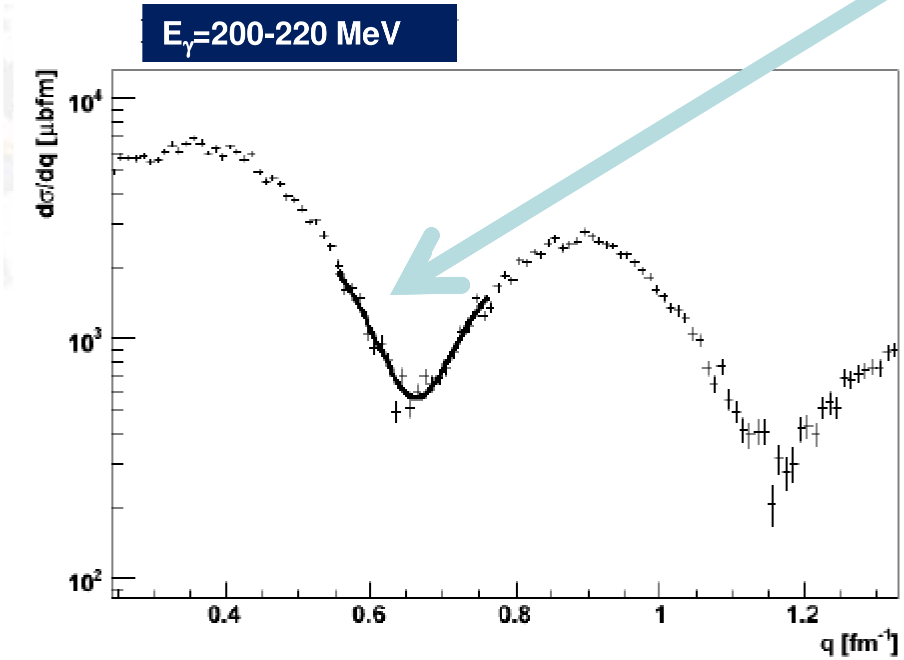
^{208}Pb : Momentum transfer distributions



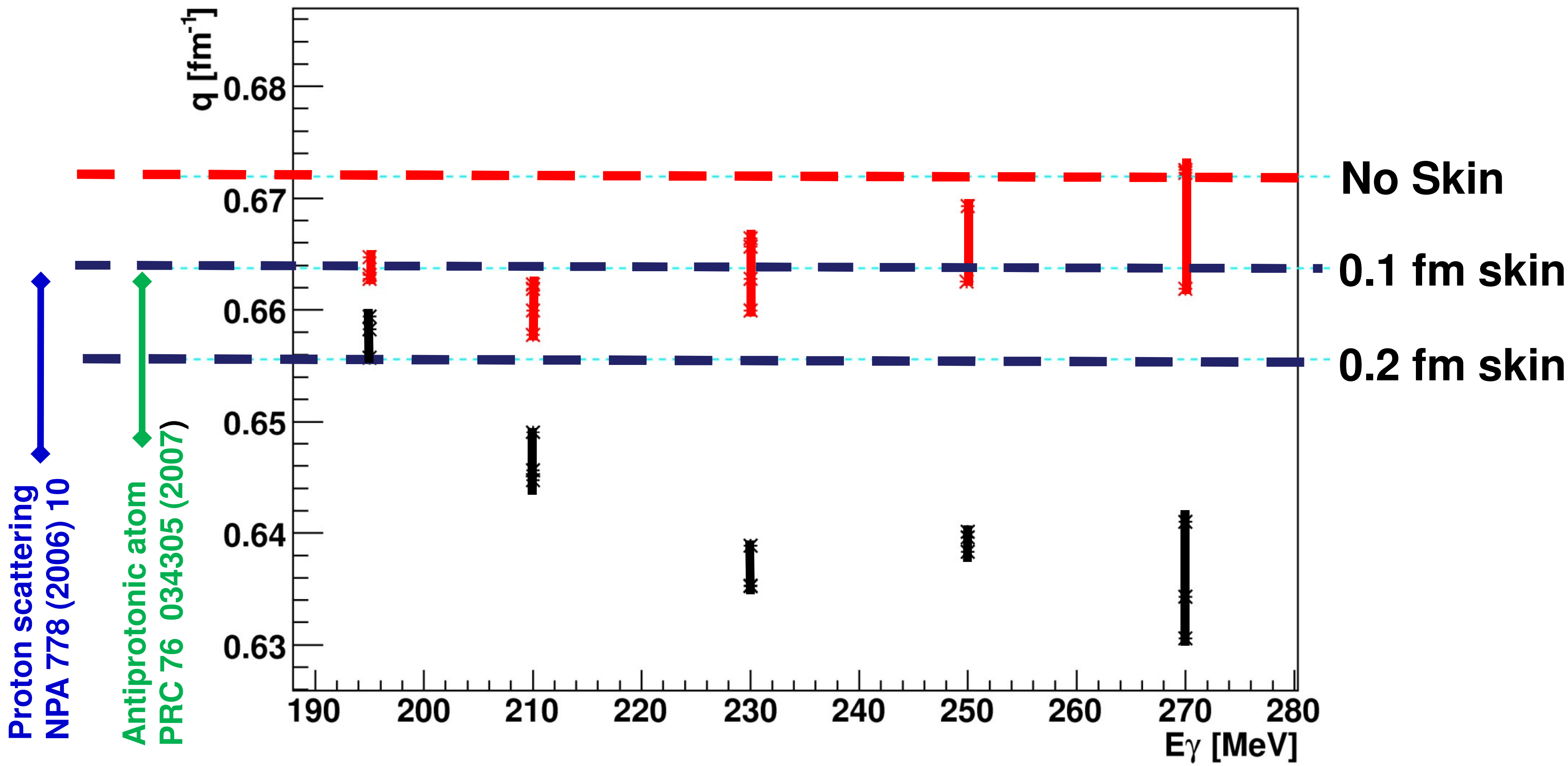
— Unitary isobar model (γ,π)
with complex optical potential
Dreschel et. al. NPA 660 (1999)

^{208}Pb: Simple correction for distortion

- For first preliminary assessment
  1) Carry out simple correction of q shift using the theory
  2) Analyse corrected minima - fit with Bessel fn.

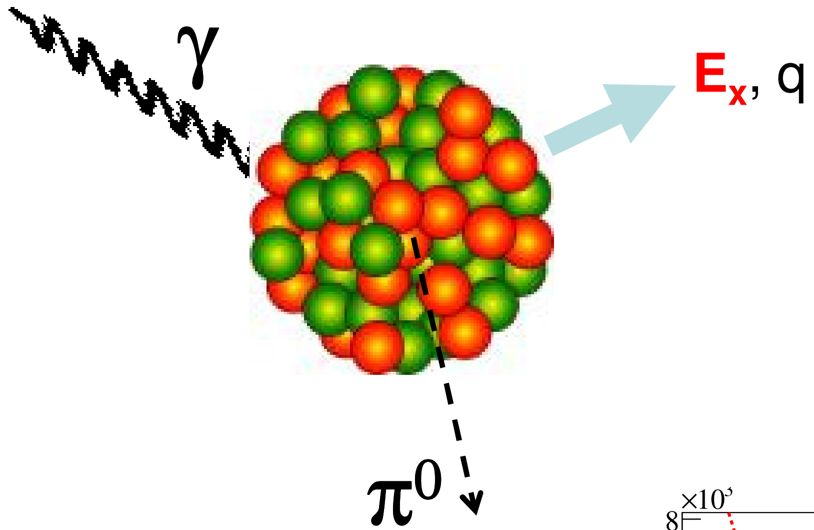


^{208}Pb neutron skin – preliminary assessment



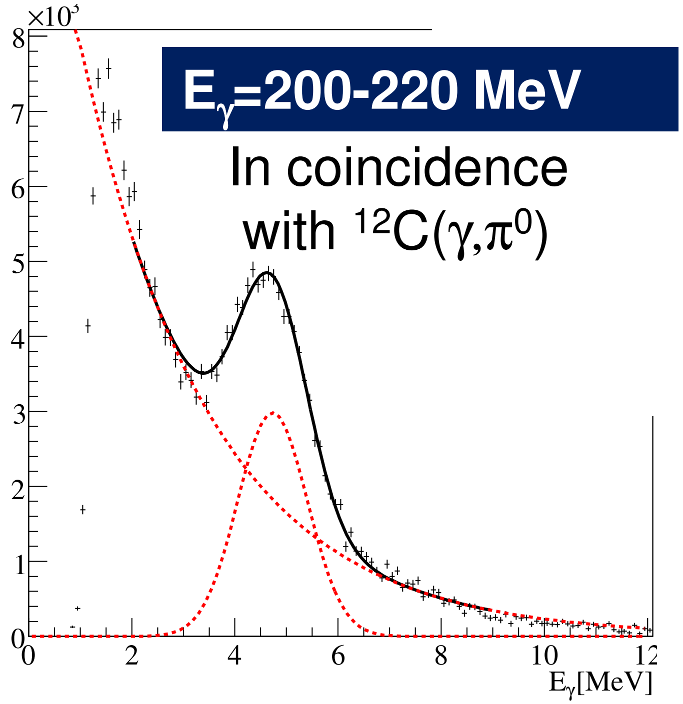
- See effects of a neutron skin of ~0.1 fm **(preliminary!!)**
- More detailed analysis in progress — implement various predicted FF
  — "model independent" analysis

Incoherent nuclear π^0 photoproduction

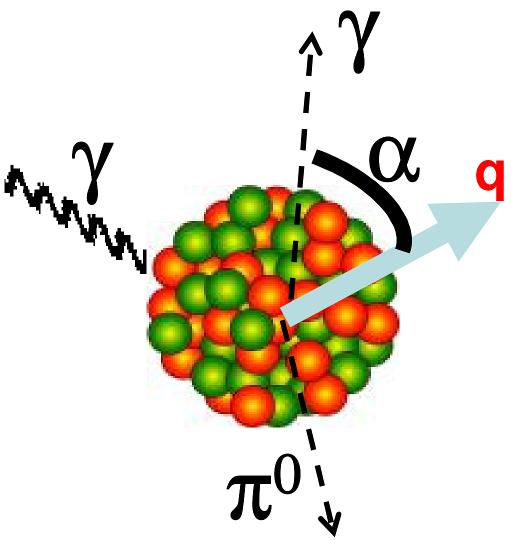


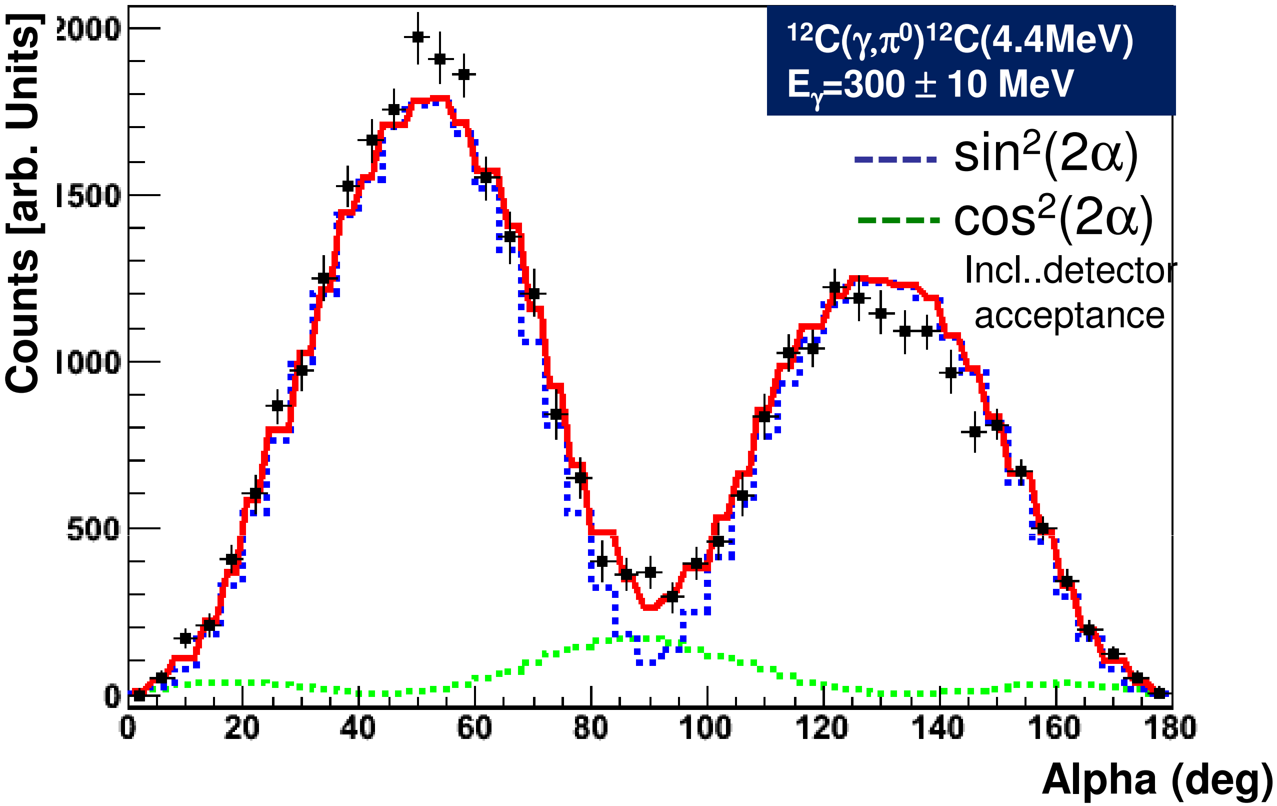
- Measurement of neutral pion production to a discrete excited nuclear state has proven elusive for many decades

- → Detect nuclear decay photon *in the same detector* as the π^0 decay photons

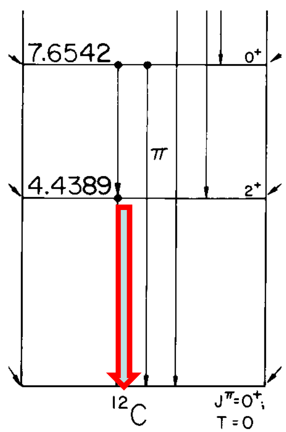


Alignment of recoiling ^{12}C nucleus



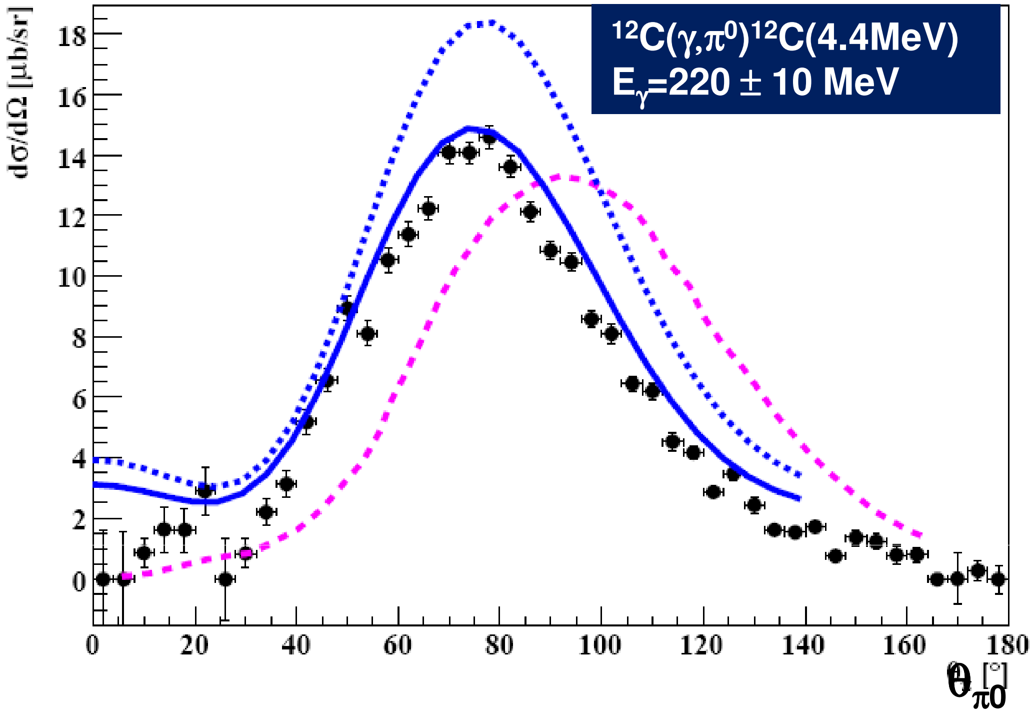


- Strong $\sin^2(2\alpha)$ distribution for 4.4 MeV photons
  - Spin independent amplitude dominant ($\Delta(1232)$)
  - (Tryasuchev and Kolchin Phys. At. Nuc. 70 827 (2007))



- Spin dependent predicted to give $\cos^2(2\alpha)$
  - – use α to separate the in medium amplitude?

Transition matter form factors

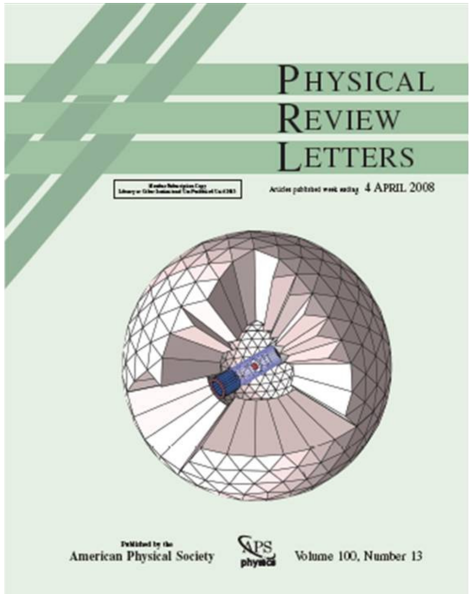


Takaki Δ-hole model (NPA 443 p570 (1985))

- **— Full calculation**
- **--- Without Δ-N interaction**

Tryasuchev model (Phys At.Nuc. 70 827 (2007))

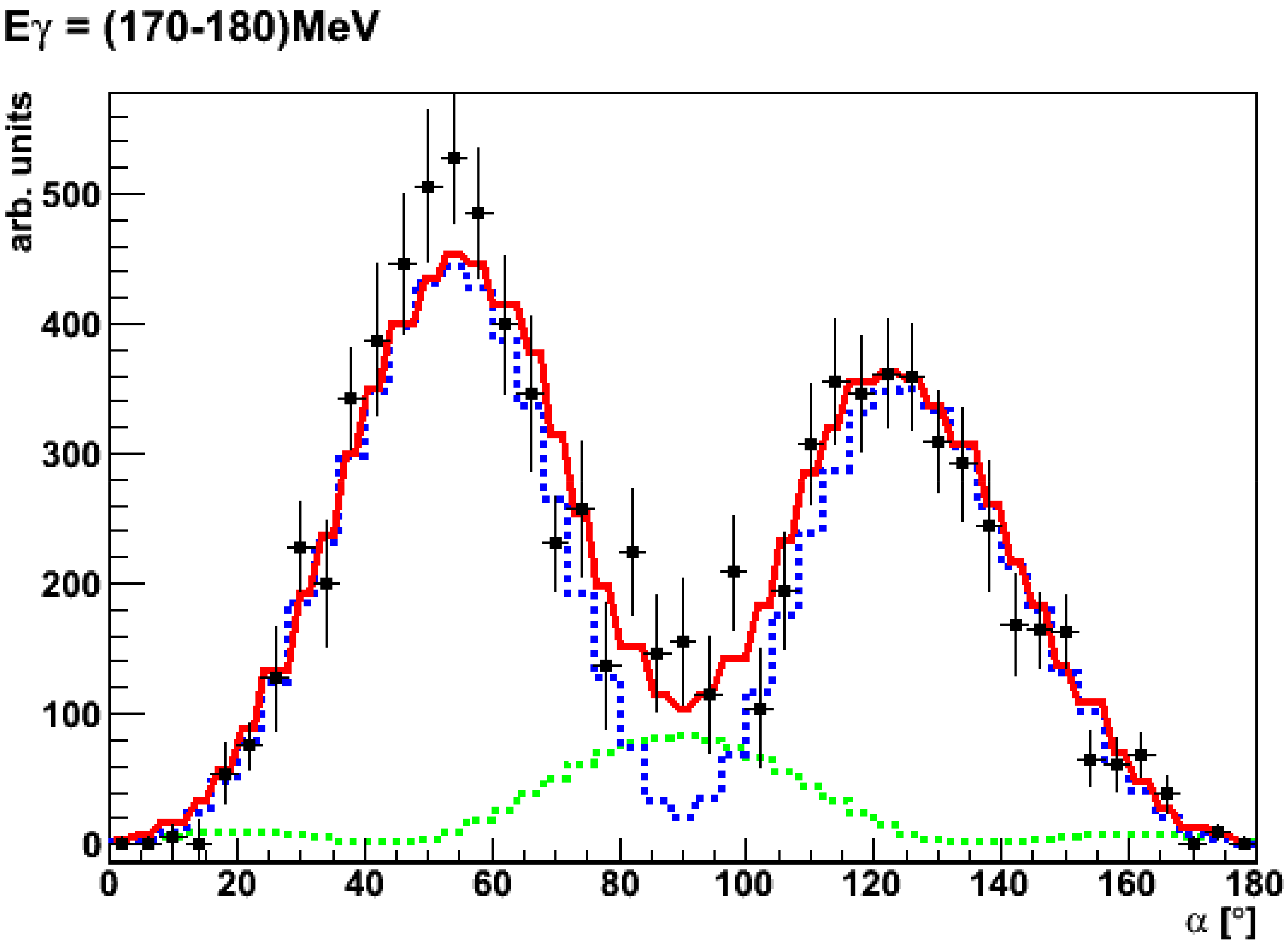
- **--- Full calculation**



CM Tarbert et. al., PRL 100 132301 (2008)

Summary

- New high quality nuclear π^0 photoproduction data will give timely constraints on nuclear structure and neutron stars


Eγ = (170-180)MeV
arb. units
0
100
200
300
400
500
0
20
40
60
80
100
120
140
160
180
α [°]