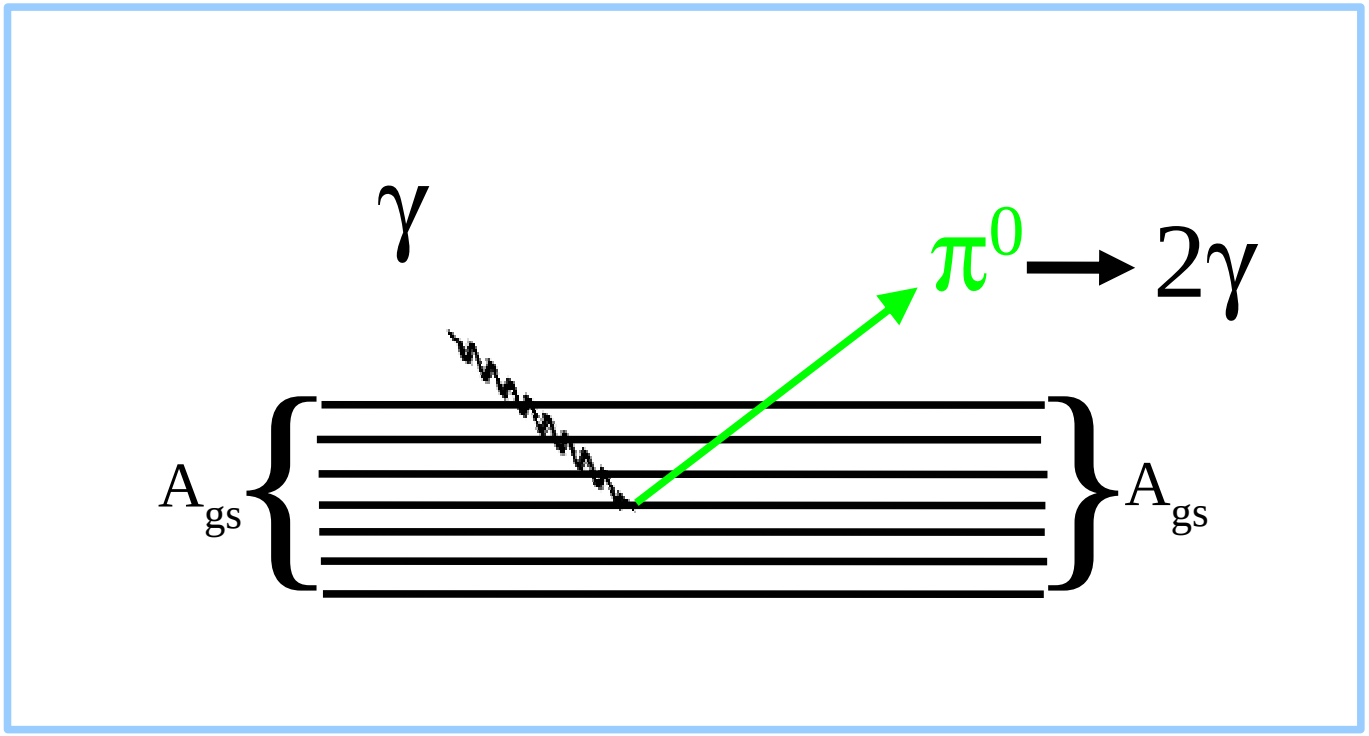
Measuring the distribution of nucleons in nuclei using photon beams

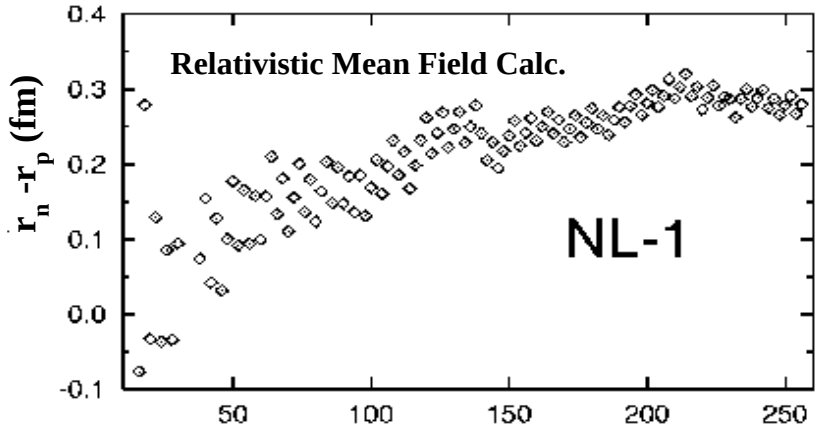


DP Watts (University of Edinburgh, UK)

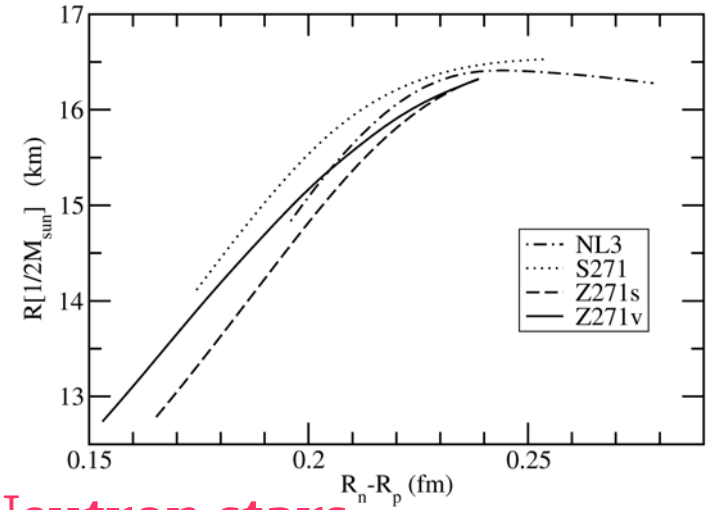
Talk outline

- **Coherent pion photoproduction** (Crystal Ball &TAPS at MAMI) – Accurate measurement of matter distribution in ^{208}Pb.

- **Positive pion photoproduction** (Ge6 at Lund) - investigation of halo nuclei, nucleon resonances in ground state of nuclei.



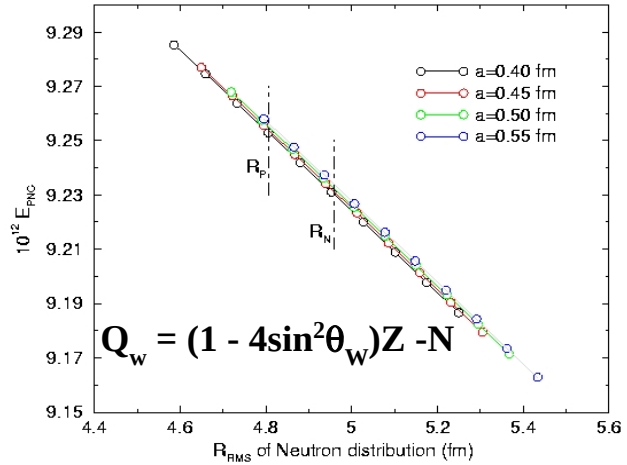
Modern nuclear theories (NPA624 349 (1997))



Neutron stars (PRL 66 5647 (2001)

Matter distribution

Atomic PNC (PLB 464 p177 (1999))



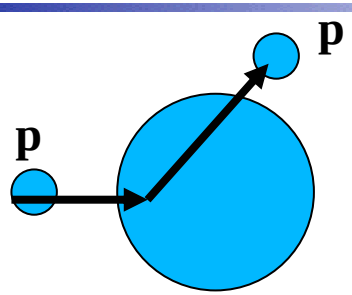
Astrophysics

Extrapolation to n,p rich isotopes

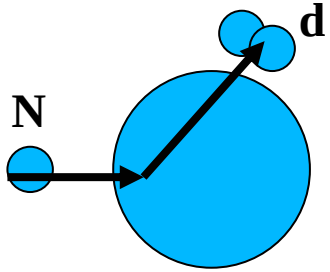
Antiprotonic atoms (PRL 87 082501(2001))

Present situation & proposed experiments

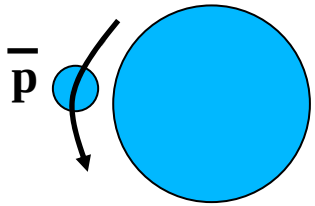
- **Proton scattering**
  Seminal analysis by Hoffman for all data (0.3 - 1 GeV).
  Δr_{np} (^{208}Pb) = -0.02 →0.5 fm



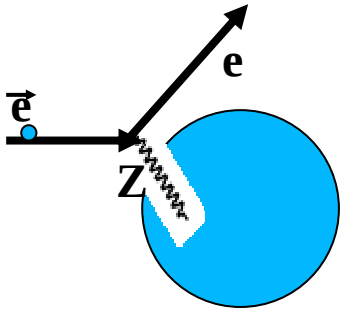
- **Pickup reactions**.
  Recent analysis of p and n pickup gave Δr_{np}~0.5fm for ^{208}Pb



- **Antiprotonic atoms**
  Δr_{np} ~ 0.15fm for ^{208}Pb.



- **Parity violating electron scattering**
  Accepted proposal at Jefferson Lab (USA) - 1 month beam for ^{208}Pb. Expected accuracy ±0.06fm

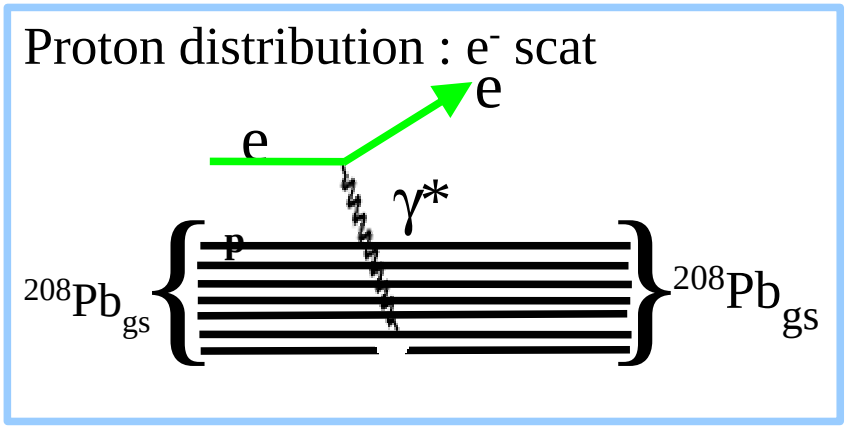


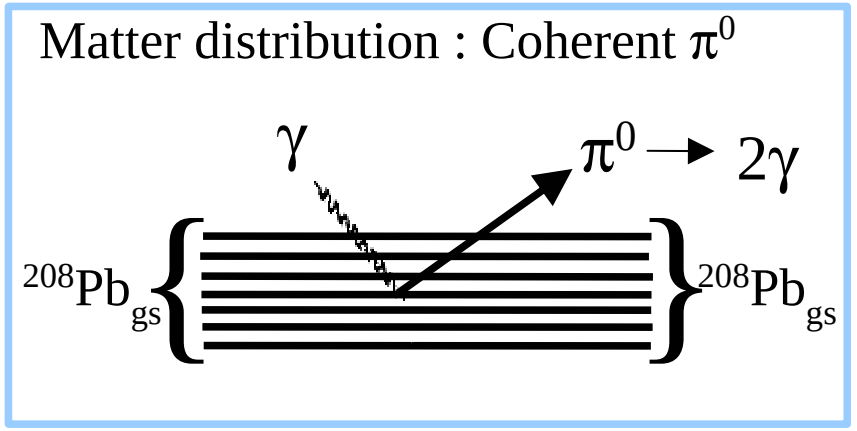
Coherent pion photoproduction

- $\rho_p(r)$ ✓ $\rho_n(r)$ **?**
- $A_{gs}\ (\gamma,\pi^0)A_{gs} \rightarrow F_m(q)$

$$d\sigma/d\Omega \sim A^2(q/k_\gamma)P_3^{\,2}|F_m(q)|^2\sin^2\theta_\pi$$

- Photon probes the entire nuclear volume
- Multiple scattering of incident probe negligible





Sensitivity to matter distribution

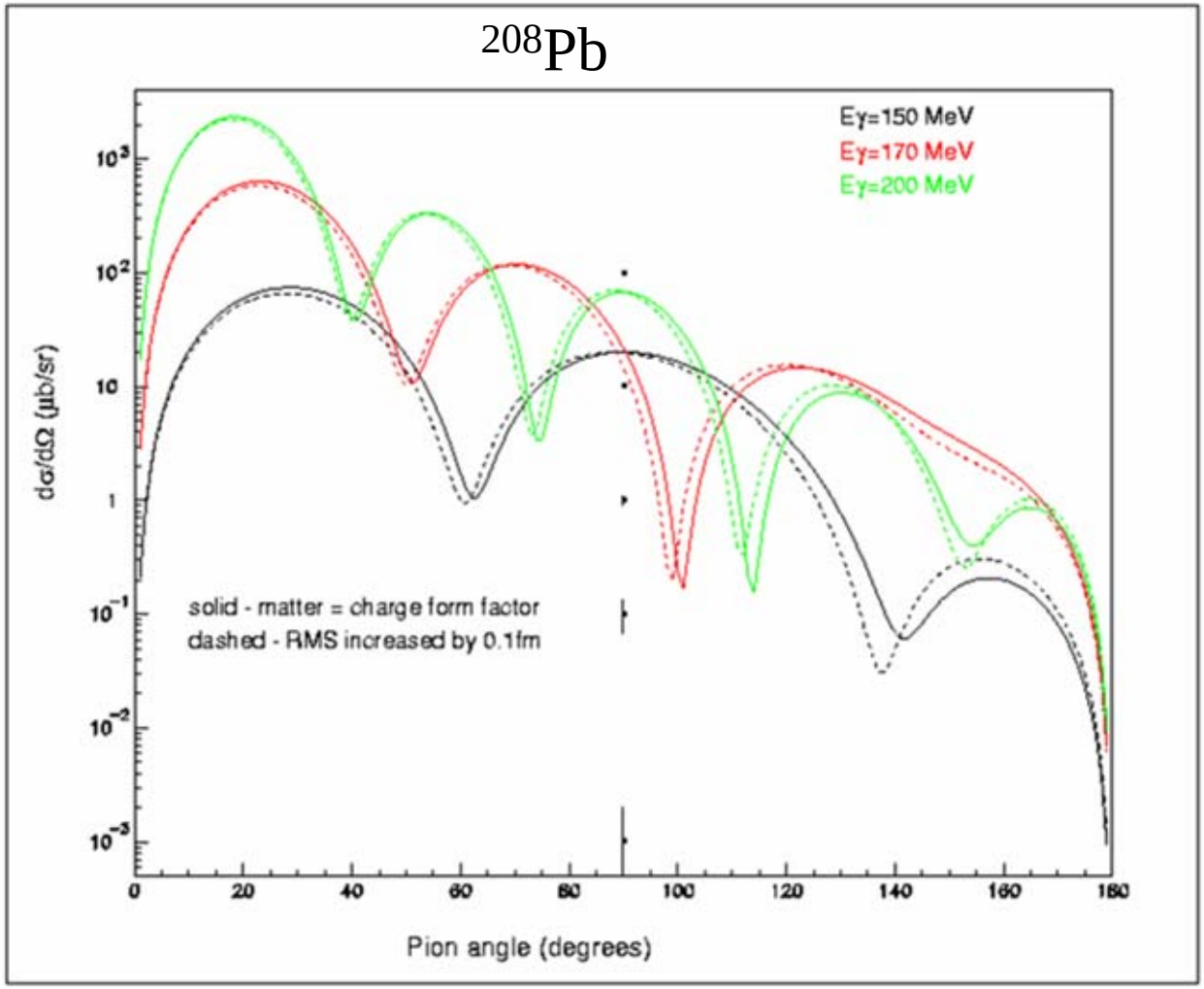
- Expect characteristic diffraction pattern in $\theta_{\pi 0}$

- Minima shift with Eγ – occur at same $\mathbf{q} = \mathbf{P}_{\gamma}\text{-}\mathbf{P}_{\pi}$

- Sensitivity to ρ_m in 1st minima 0.07 fm/degree

- ~0.3° → ~± 0.02fm

- Significant advances in theory in recent years



Pion – Nucleus interactions

- Diffraction pattern distorted due to effects of π-A interactions (FSI)

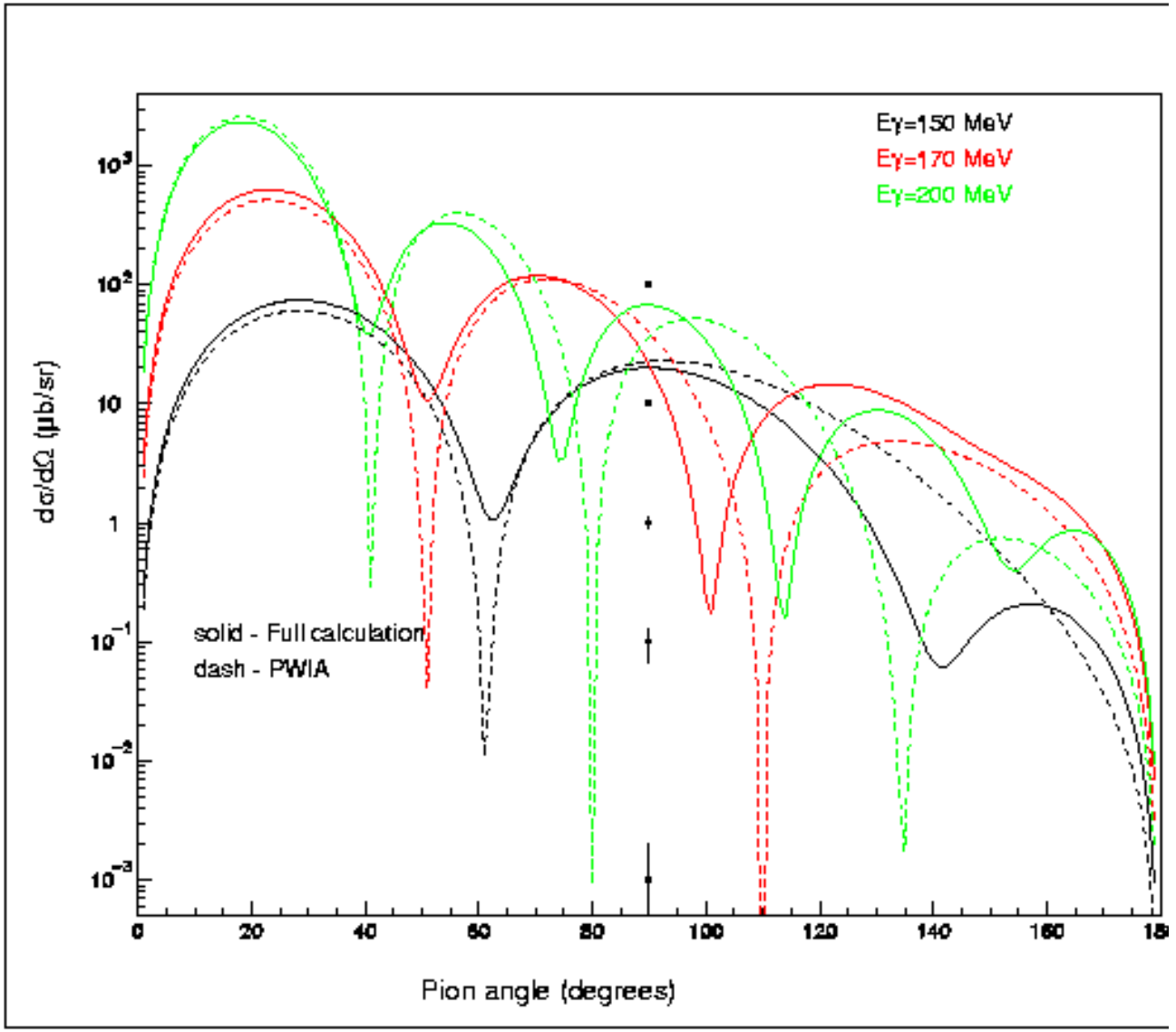
- Optical potential constructed from pi-N amplitude in **p** space

- Intermediate Δ also included (important at higher P_π)

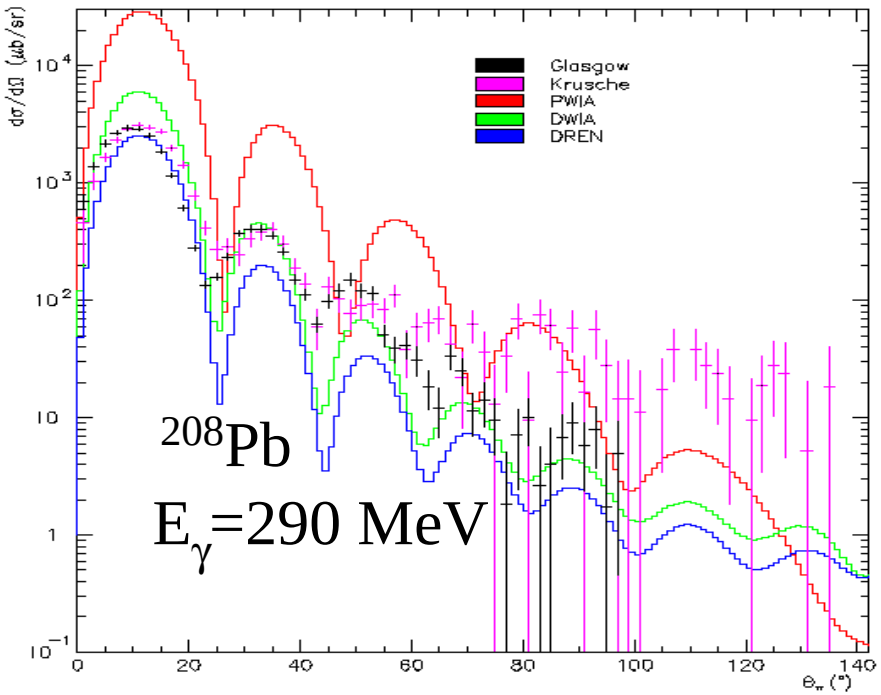
- Accurately describes wealth of $A(\pi,\pi')$ data

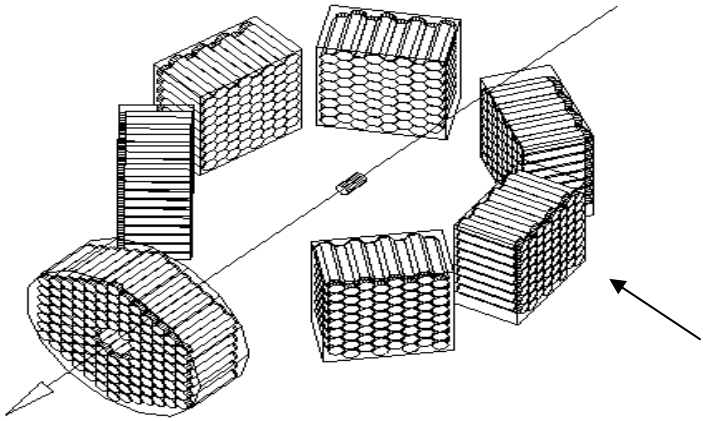
- If Δ(FSI) ~ 10%
$\Delta\theta_\pi \sim (0.07)\times(\pm 2^o)\times 0.1 = \pm 0.014$ fm

- Each **q** occurrs for different **Pπ** at different incident **Eγ** – check predicted FSI effects



Present situation – $A(\gamma,\pi^0)A$

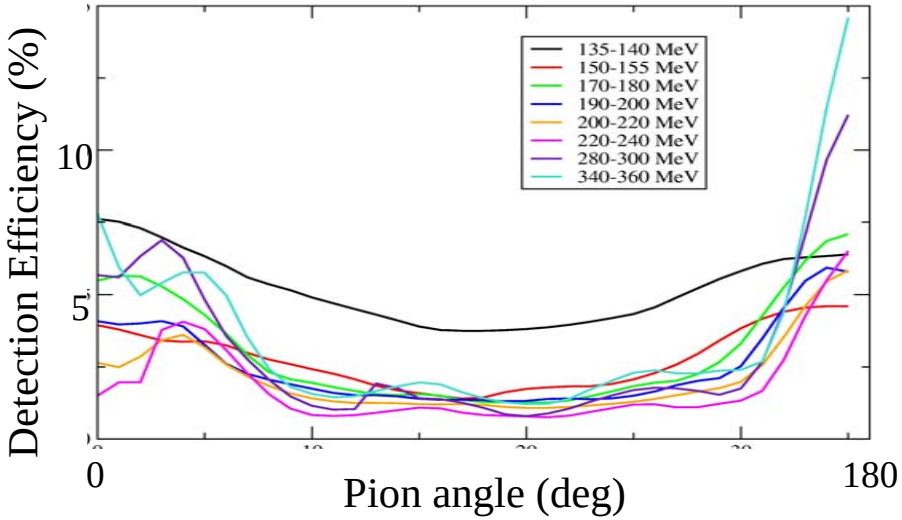


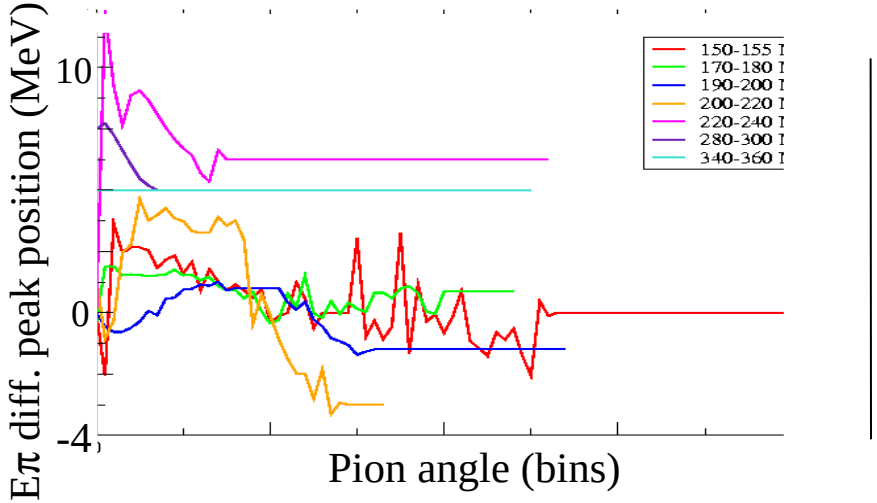


TAPS (in pre-CB era configuration)

- Accuracy of previous measurements bedevilled by problems due to small segmented detector systems
- Coherent σ has large systematic uncertainties (up to 40%) in cross section magnitude
- Cannot attempt to extract info. on matter form factor
- Confirm predicted effects of pion-nucleus interaction in Δ region

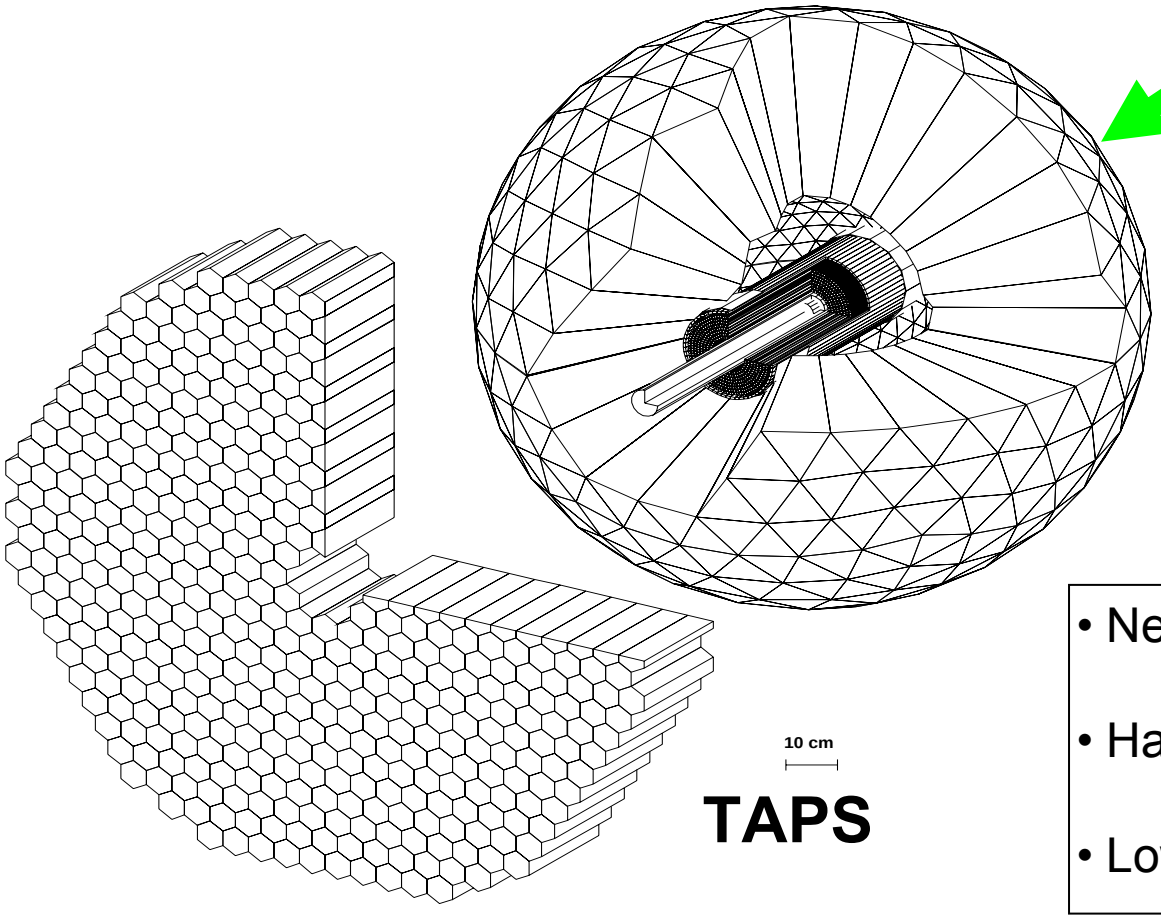
Systematics in π^0 determination





- Previous measurements pushed TAPS capabilities
- ε_π = ~3%, sharply θ_π dependent
- Systematic errors in reconstructed T_π
- Complicated fitting procedure → stematic errors

Crystal Ball & TAPS at Mainz



Eγ = 0.15 – 1.5 GeV

Photon tagger

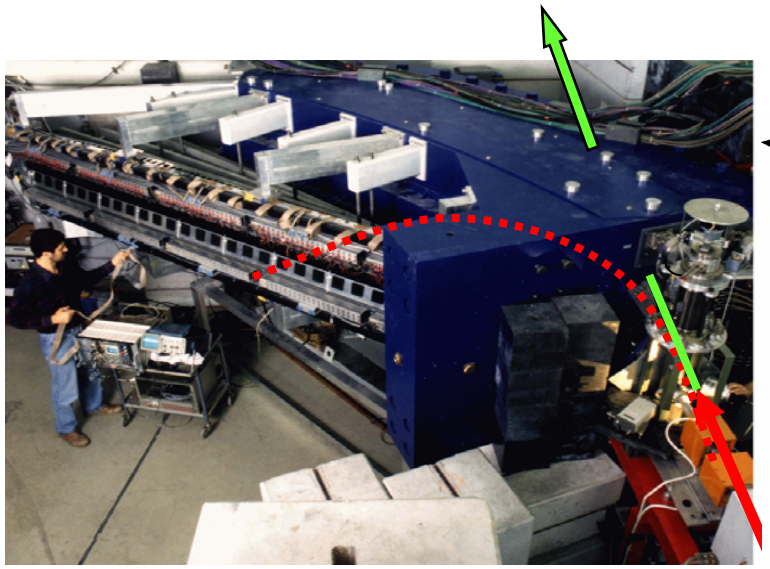
Crystal Ball

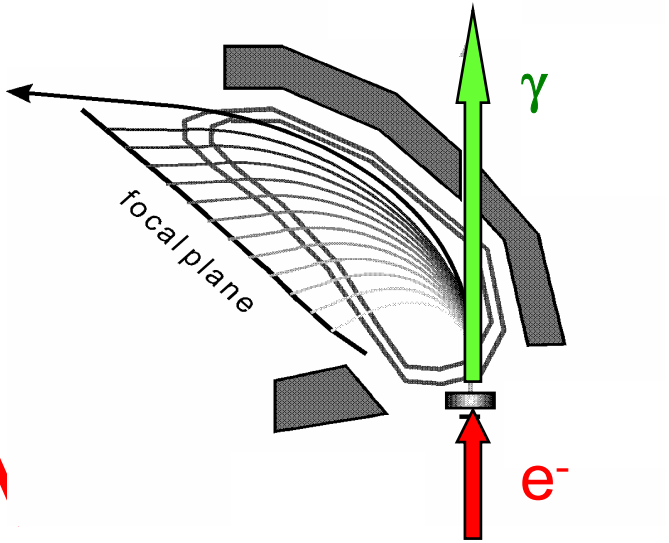
TAPS

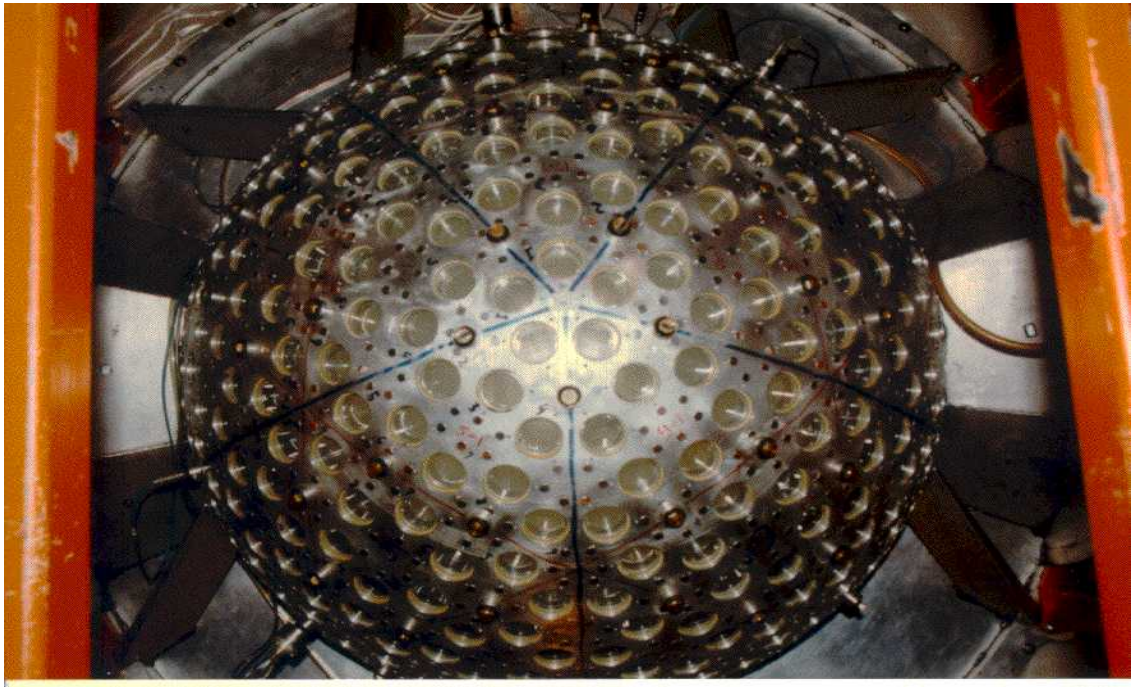
- Neutral mesons ($\pi^0 \rightarrow 2\gamma$ $\eta \rightarrow 2\gamma$)
- Hadrons (Gla/Edin PID) p, n, π+
- Low energy decay γ

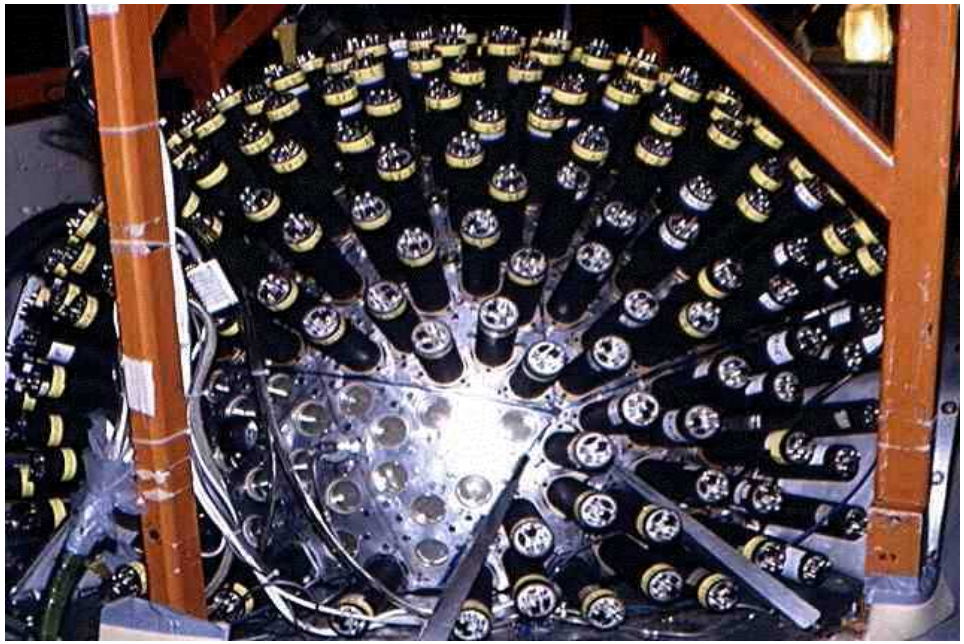
Glasgow Photon Tagger @ MAMI

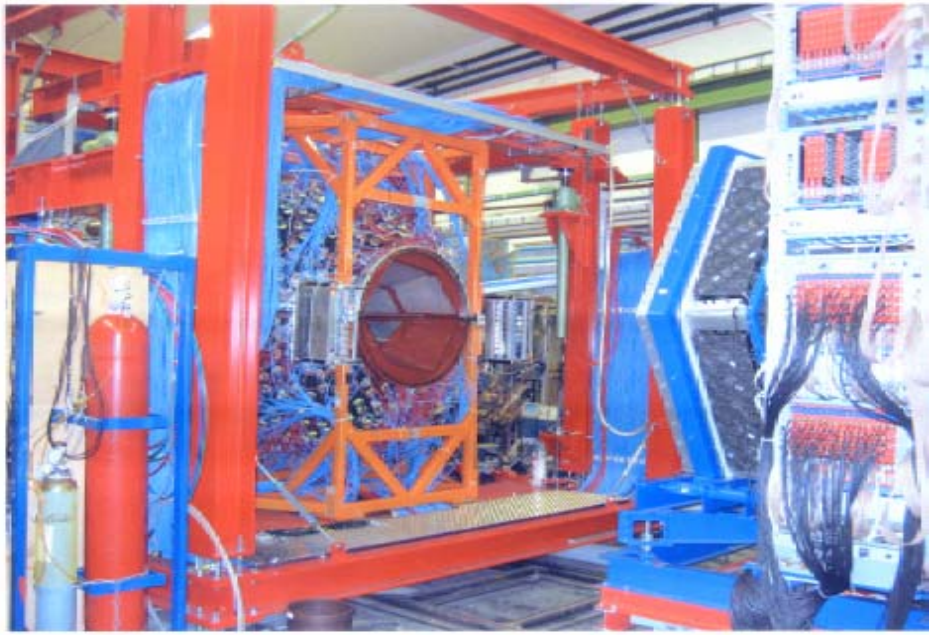
- Magnetic spectrometer
- $\Delta E_\gamma \sim 2$ MeV
- Flux $10^8\,\gamma s^{-1}$





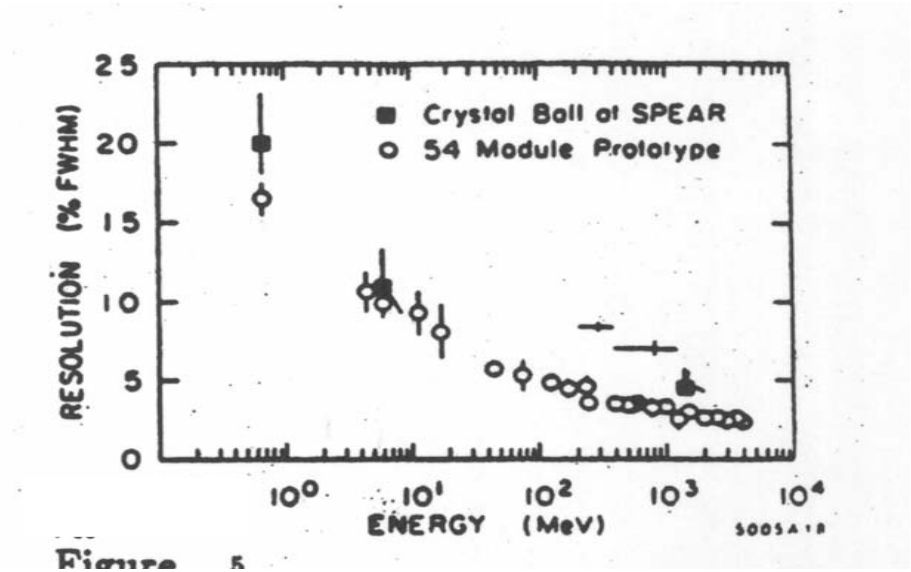


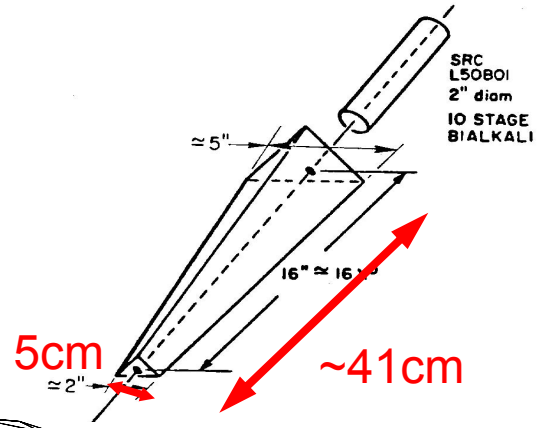


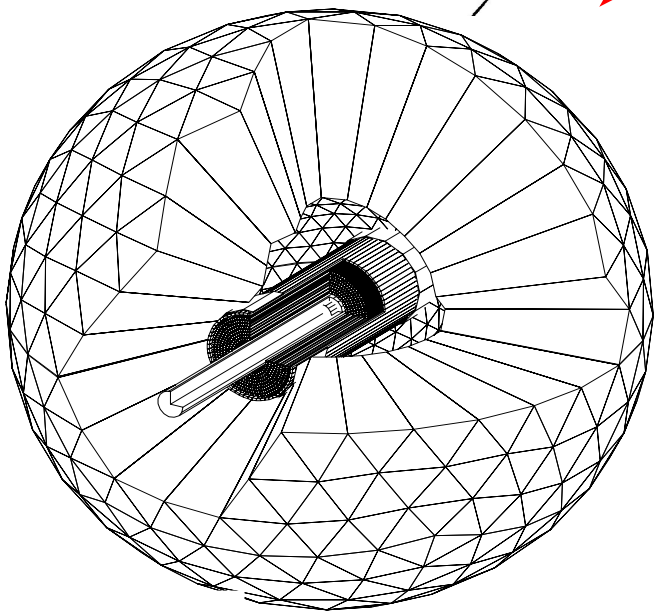


Crystal Ball

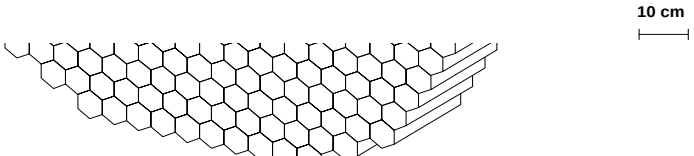
- 672 * NaI(Tl) (94% of 4π)
- 15.7 rl
- $\sigma_\theta = 2–3^o$; $\sigma_\phi = 2^o/\sin\theta$





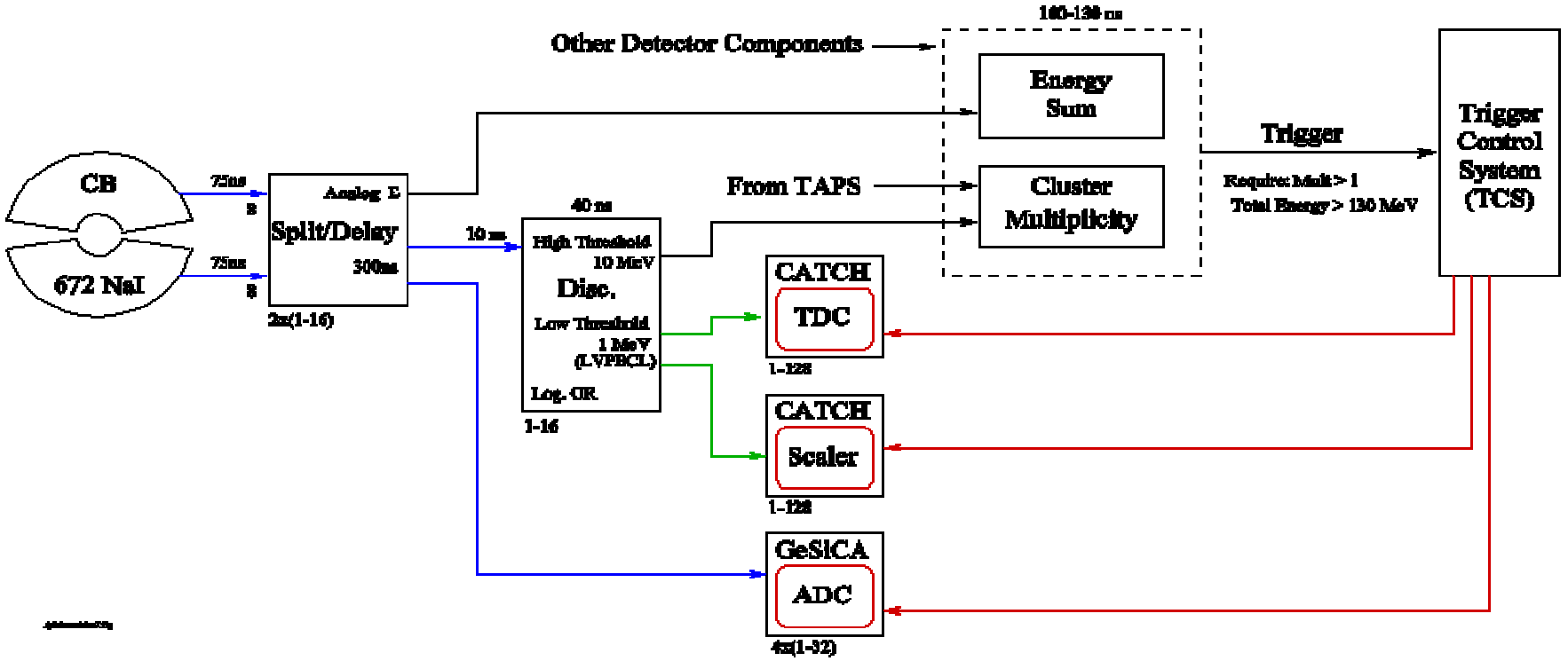


$\sigma/E\gamma = 1.7\% / E_\gamma(\mathbf{GeV})^{0.4}$



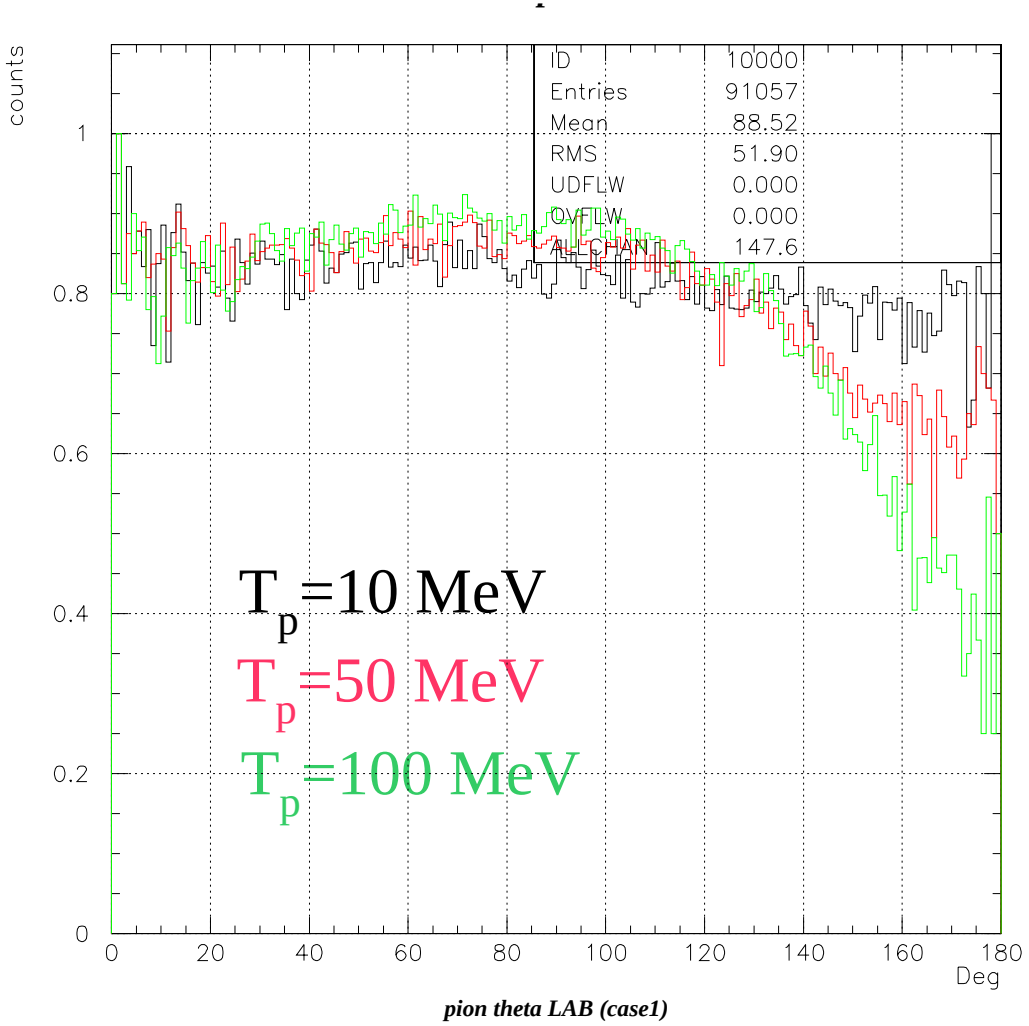
Crystal Ball electronics

- Complete overhaul for use at Mainz



DP Watts et. al., Proceedings of 24th International conference on calorimetry in high energy physics, Perugia, Italy (2004)

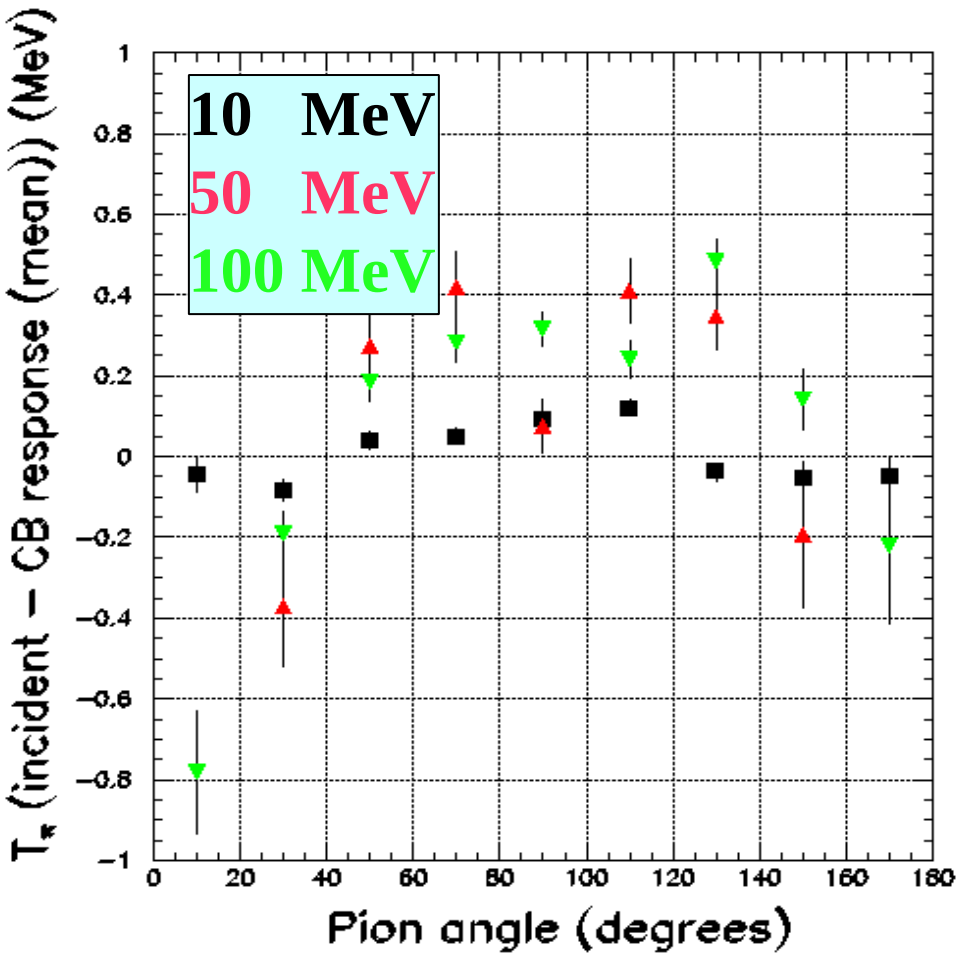
CBTAPS Detection efficiency



pion theta LAB (case1)

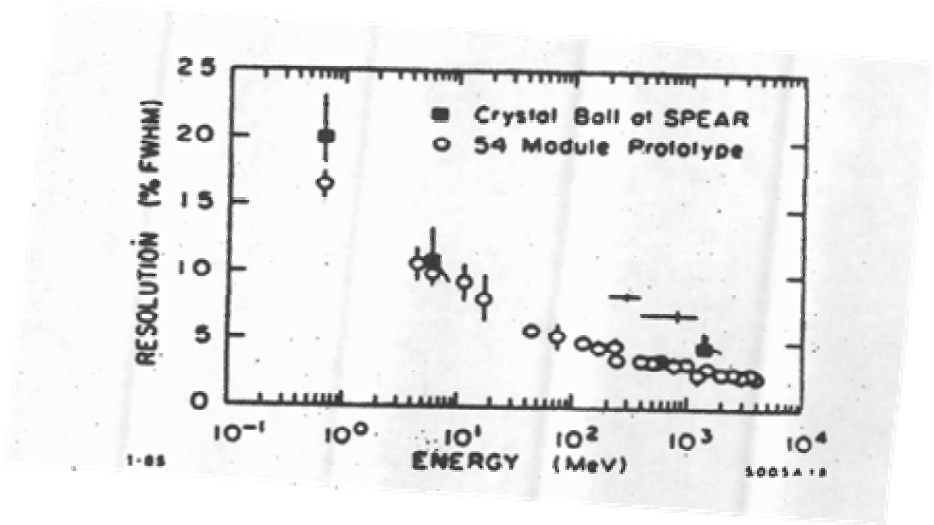
- ~Factor 40 larger than previous measurements
- Smooth and mostly flat variation with θ_π

T_π reconstruction

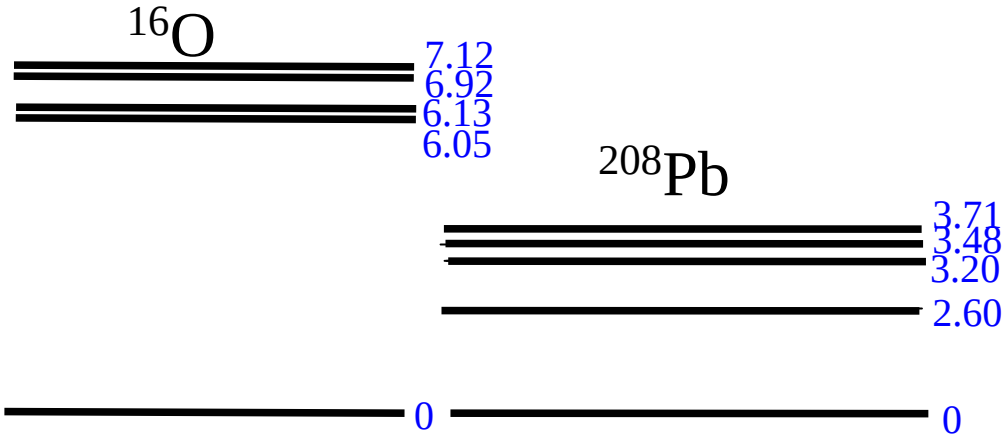


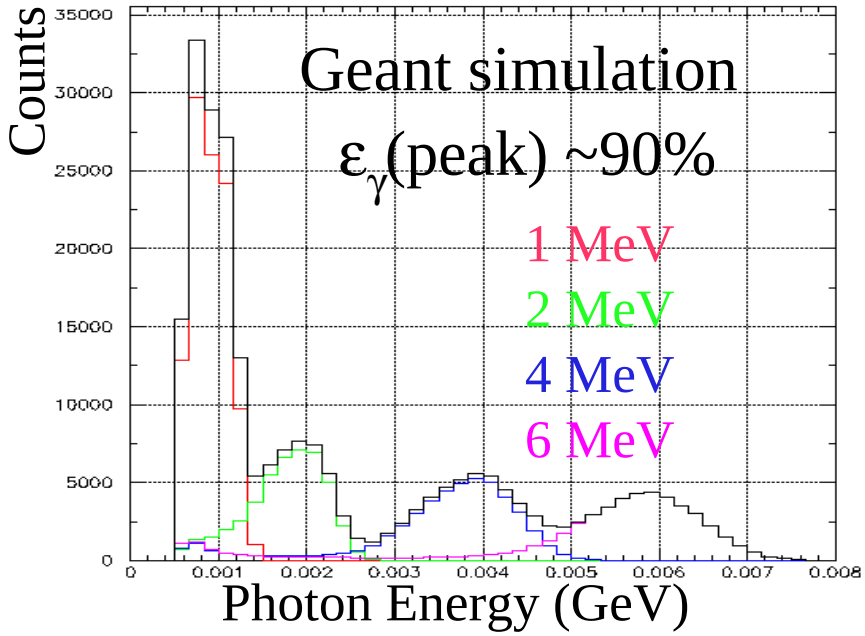
- Isotropic layout of crystals & TAPS in single block → better θ_π, T_π reconstruction
- T_π - little dependence on θ_π
- T_π only uses ratio γ energies improve with kinematic fits?

CB@MAMI: Nuclear decay photons

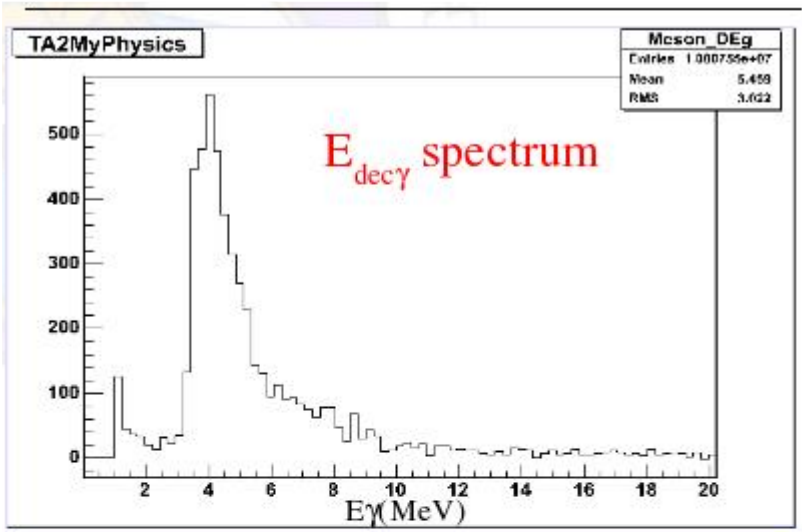


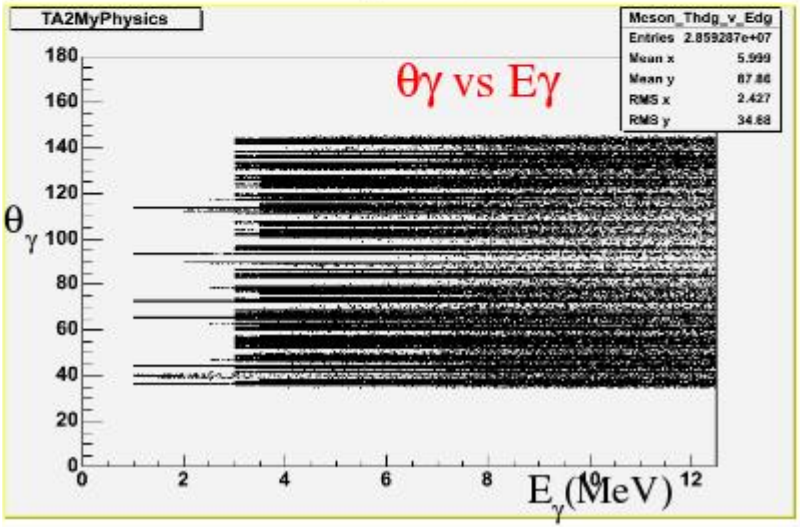
- ΔE_γ~15-20% @ 1MeV
- Reject (and identify?) $A(\gamma,\pi^0)A^*$





Nuclear decay photons – “real” data





- ~3hours of test data with graphite target. First test run from CBTAPS@MAMI!

- Low energy photons in timing coincidence with a pion.

- Teething trouble with new electronics. Unphysical drop off ~3 MeV. New test in November

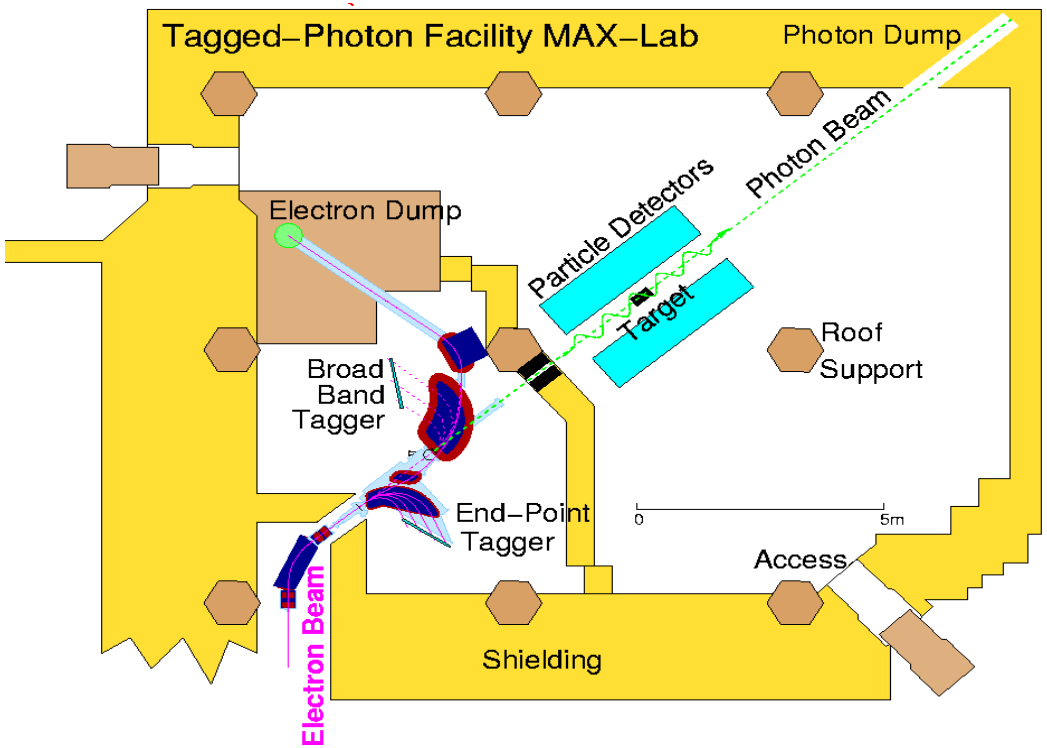
- Hints of turnover at 4.4 MeV?

- Coherent pion photoproduction experiment scheduled for Feb 2005

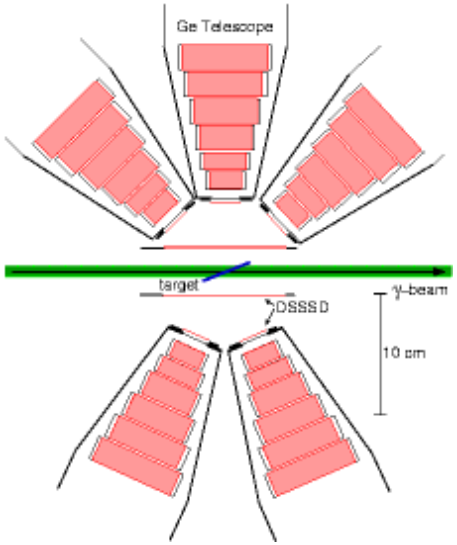
Max- Laboratory

- Sited in Lund, Sweden

• Provides intense tagged γ beam
up to 250 MeV energy



Edinburgh HpGe array, Si strip



Halo nucleon distributions

• Ge6 and Si strip detector array – unique system to measure charged photopion production to *discrete* residual nuclear states.

$$\gamma + {}^{N}_{Z}A \rightarrow {}^{(N+1)}_{(Z-1)}A + \pi^{+}$$

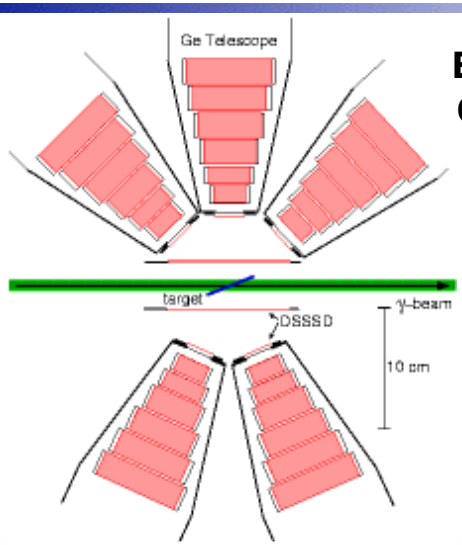
$$d\sigma/d\Omega \propto \int \Psi_f^* \phi_\pi^* t_{\gamma,\pi} \Psi_i d\tau,$$

^{6}Li(γ,π^{+})^{6}He

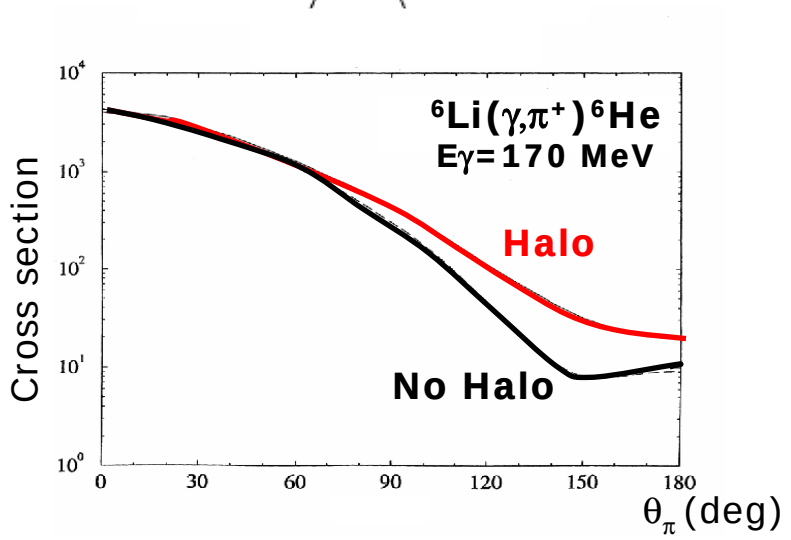
^{11}B(γ,π^{+})^{11}Be

^{17}O(γ,π^{-})^{17}F

• Learn about nucleon wavefunction in final state nucleus



Edinburgh Ge6 array

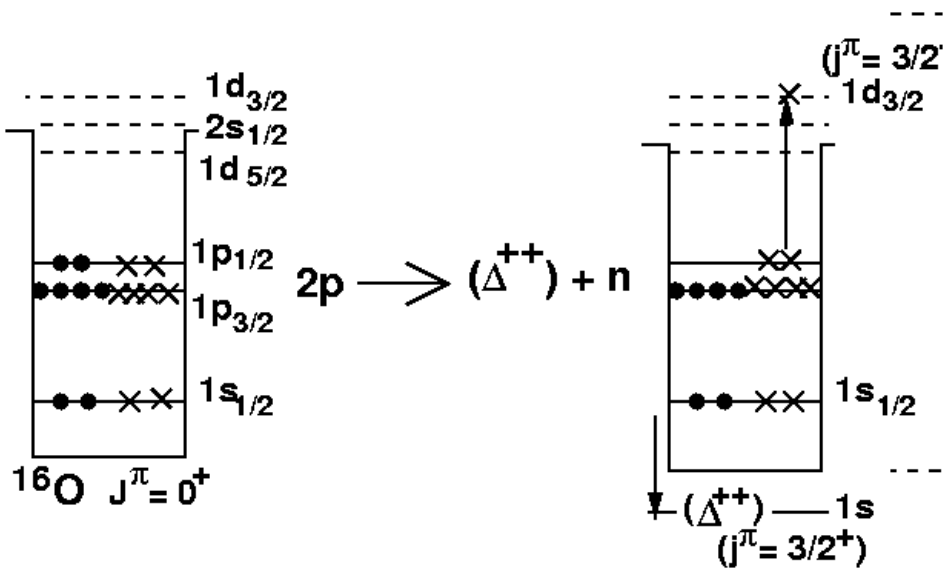


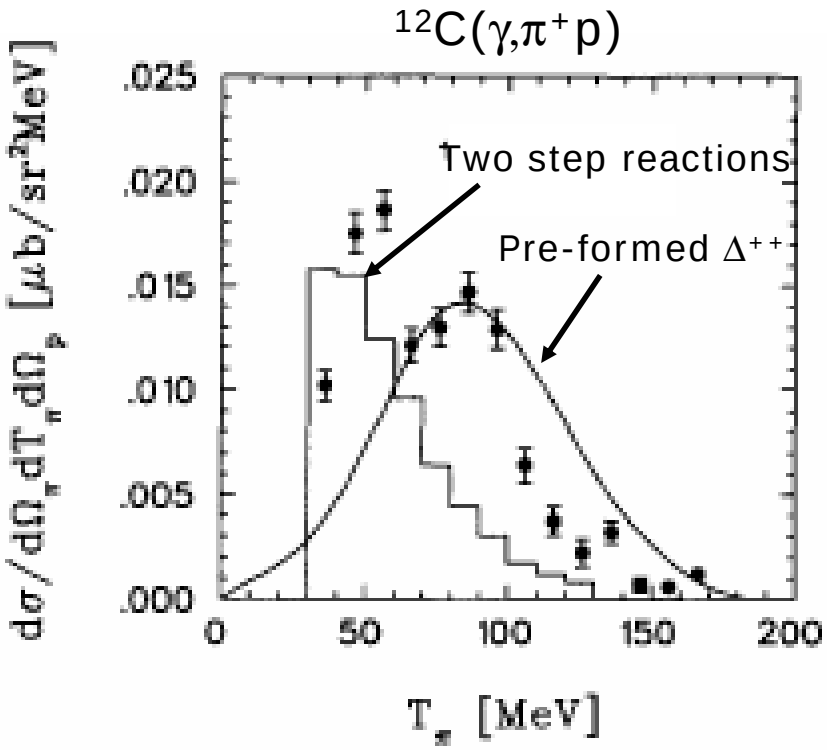
Resonances in the nucleus

- What fraction of the nuclear ground state involves nucleons in an excited state from previous collisions ?

eg $p + p \rightarrow \Delta^{++} + n$?

• Ge6@Lund $^{16}O(\gamma,p\pi^+)^{15}C$ – select $J^\pi=3/2+$ final state (4.78 MeV) to emphasize contribution from pre-existing Δ





Conclusion

- New experiments should give new insights into distribution of nucleons in nuclei
- Future:

1) Further programme of matter distribution measurements depending on success of pilot experiment.

2) Use coherent π^0 photoproduction from ^{4}He to search for certain classes of exotic hybrid mesons (12 GeV beam@Jlab)