Measurements of charged pion and neutral pion polarizabilities at GlueX

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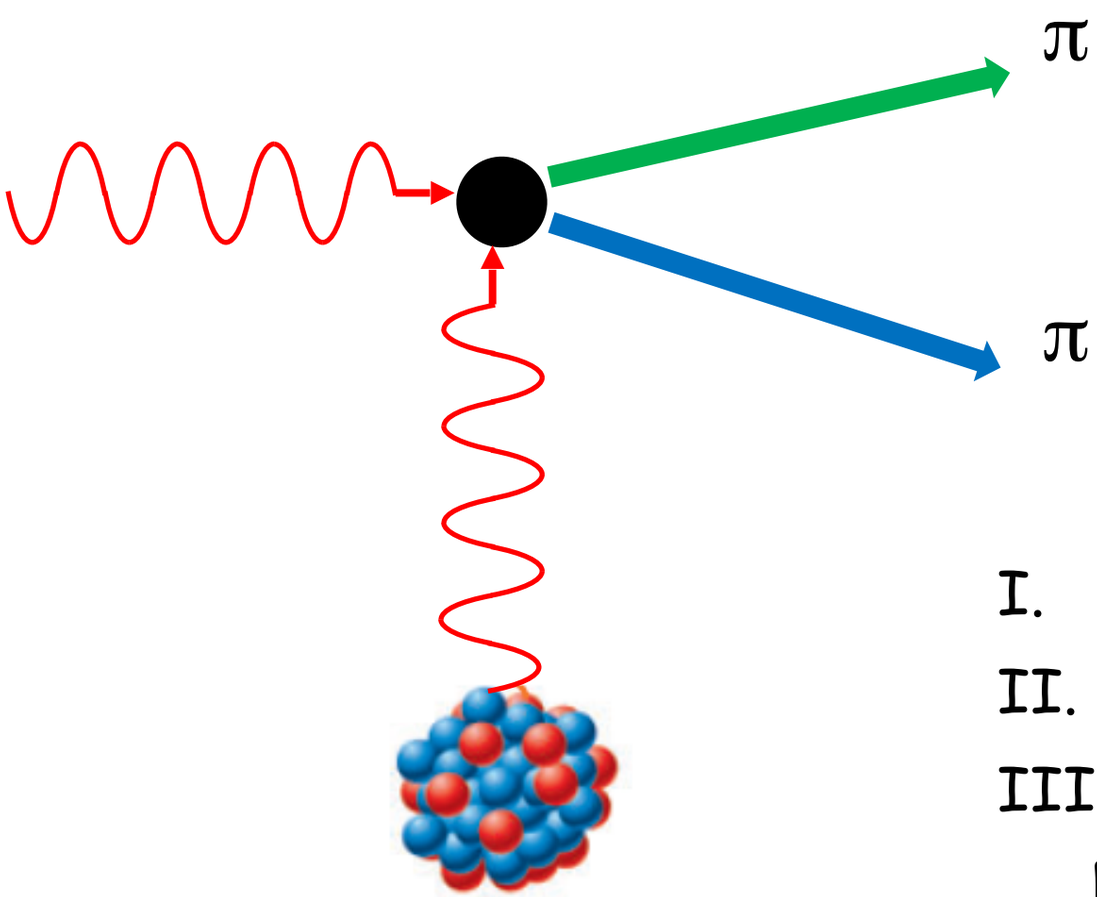


I. Charged and neutral pion polarizabilities

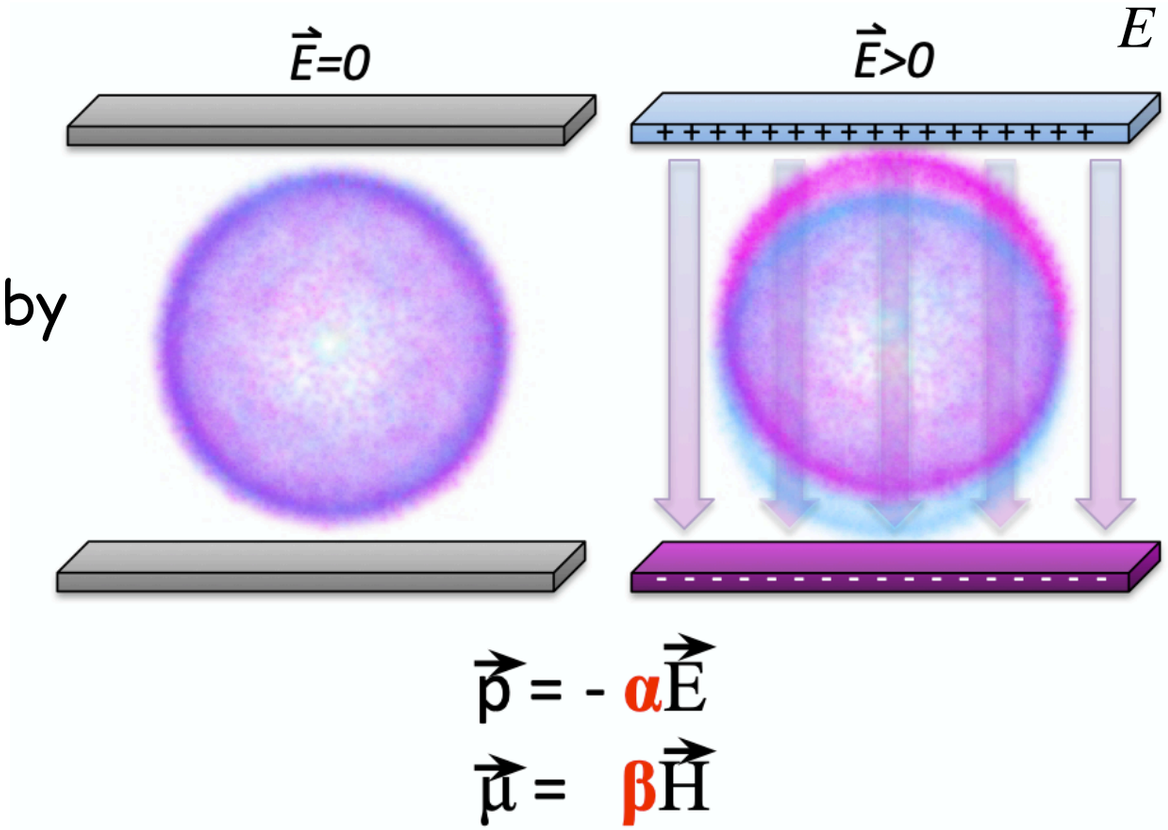
II. Overview of previous measurements

III. Update on the charged and neutral pion polarizbility measurements at GlueX

I. Consider placing a hadron in a parallel plate capacitor at very high electric field

$$E \approx \frac{0.1 GeV}{1\ fm} = 10^{23} \frac{volts}{m}$$

Hadron surrounded by pion cloud



Hadron surrounded by displaced pion cloud

Electric polarizability $= \alpha \approx 10^{-4} \times Volume$

Magnetic polarizability $= \beta \approx 10^{-4} \times Volume$

Small numbers because hadrons are "stiff"!

Polarizability measurements provide an important test of Chiral Perturbaton Theory (ChPT), dispersion relation predictions, and QCD lattice calculations

Pion polarizability has special importance because it tests fundamental symmetries, in particular chiral symmetry and its realization in QCD

Charged pion polarizability

O(p^4) prediction: $\alpha_\pi = -\beta_\pi = \frac{4\alpha_{EM}}{m_\pi F_\pi^2}\left(L_9^r - L_{10}^r\right) \approx \frac{F_A}{F_V}$

where F_A and F_V are the weak FFs in $\pi^+ \to e^+\nu\gamma$

$$\alpha_\pi = -\beta_\pi = 2.78 \pm 0.1 \times 10^{-4} e\ fm^3$$

O(p^6) prediction: $\alpha_\pi - \beta_\pi = 5.7 \pm 1.0 \times 10^{-4} e\ fm^3$

$$\alpha_\pi + \beta_\pi = 0.16 \pm 0.1 \times 10^{-4} e\ fm^3$$

<u>O(p^6) corrections are predicted to be small</u>

Neutral pion polarizability

NLO calculation: $\alpha_{\pi^0} + \beta_{\pi^0} = 0$

$$\alpha_{\pi^0} - \beta_{\pi^0} = -\frac{\alpha_{EM}}{48\pi^2 m_\pi F_\pi^2} \approx -1.1 \times 10^{-4}\, fm^3$$

NNLO calculation: $\alpha_{\pi^0} + \beta_{\pi^0} = 1.15 \pm 0.30 \times 10^{-4} fm^3$

$$\alpha_{\pi^0} - \beta_{\pi^0} = -1.90 \pm 0.20 \times 10^{-4} fm^3$$

Neutral pion polarizability has never been reliably determined

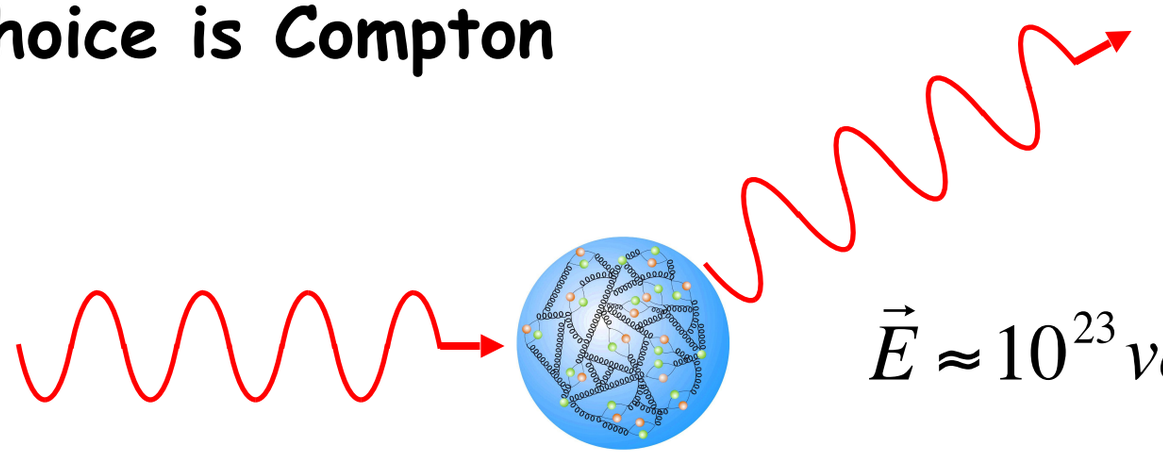
Measuring hadron polarizabilties

Strong electric field is needed to polarize a hadron:

$$E \approx \frac{100MeV}{1fm} = 10^{23}\frac{V}{m}$$

Probe of choice is Compton scattering:

~100 MeV



$$\vec{E} \approx 10^{23} volts/m$$

$$H = H_{Born}\left(e, \vec{\mu}\right) - 4\pi\left(\frac{1}{2}\alpha\vec{E}^2 + \frac{1}{2}\beta\vec{H}^2\right)$$

≈10%

II. Since a pion target doesn't exist, alternative methods must be used to determine pion polarizability

Charged pion:

i. Radiative pion photo-production: $\gamma p \rightarrow \gamma' \pi^+ n$

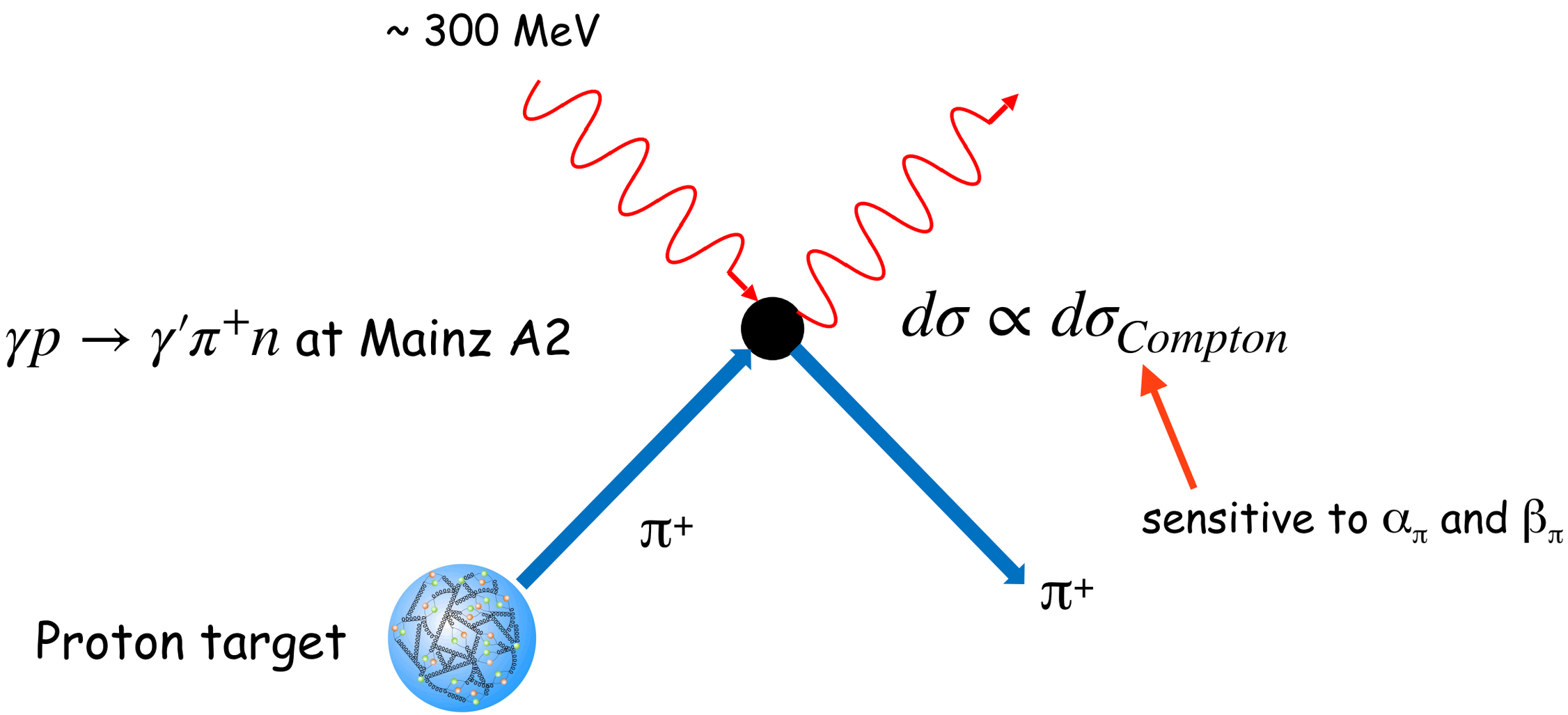
ii. Pion radiative scattering: $\pi^- A \rightarrow \gamma \pi^- A$

iii. $\pi^+\pi^-$production in two photon collisions: $\gamma\gamma \rightarrow \pi^+\pi^-$

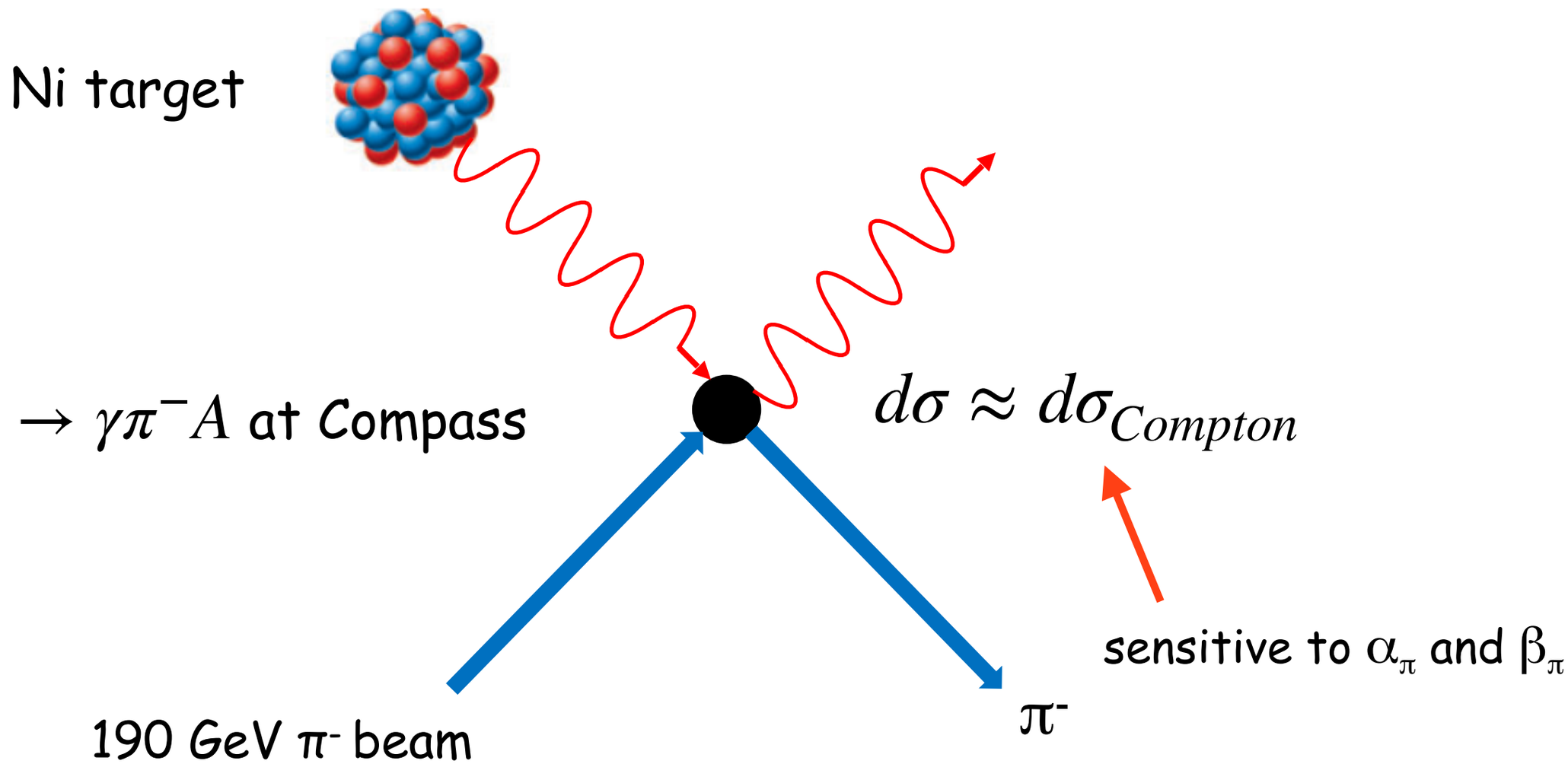
Neutral pion:

i. $\pi^0\pi^0$production in two photon collisions: $\gamma\gamma \rightarrow \pi^0\pi^0$

i. Charged pion polarizabilty: radiative pion photoproduction

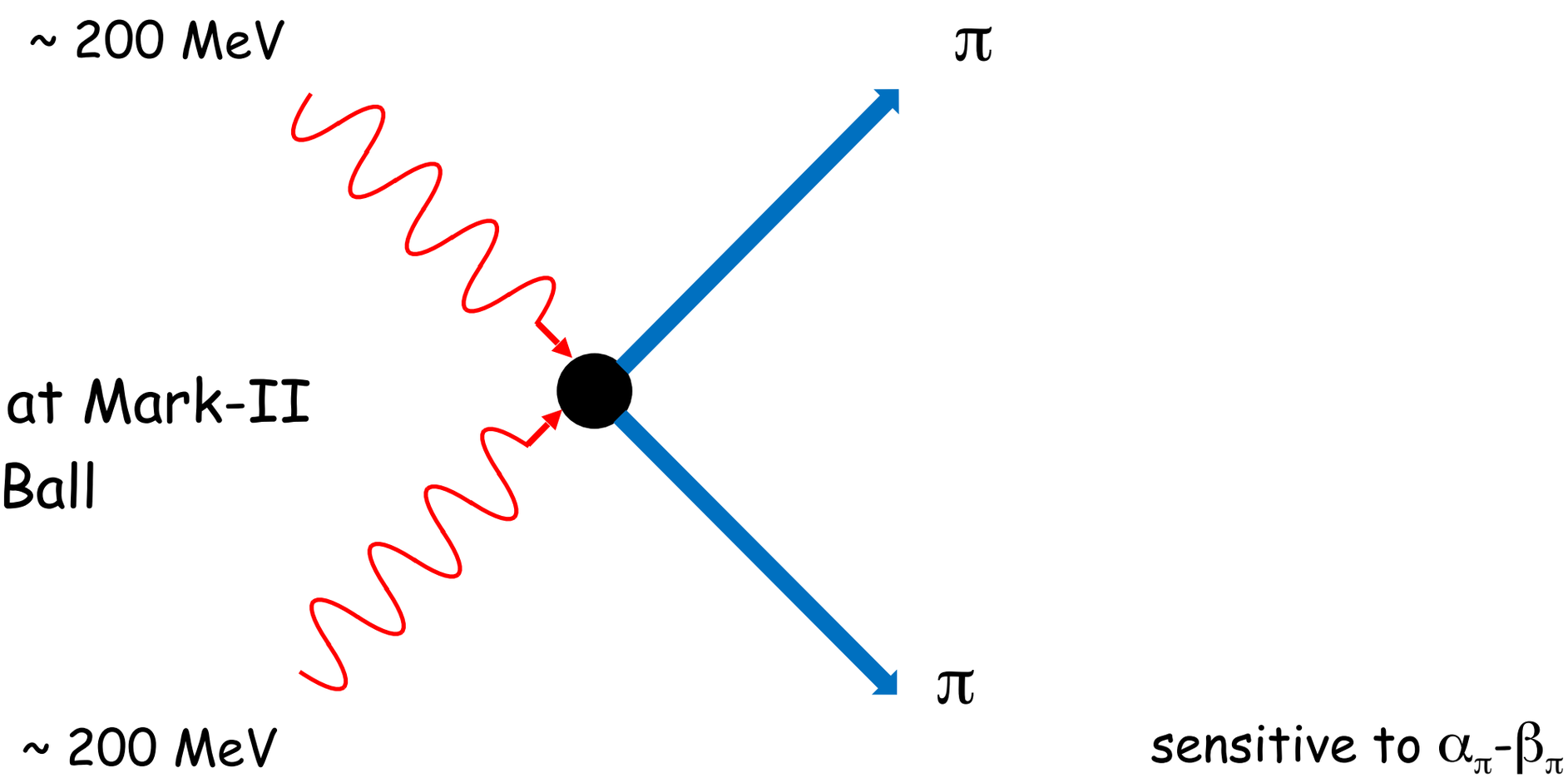


ii. Charged pion polarizabilty: pion radiative scattering



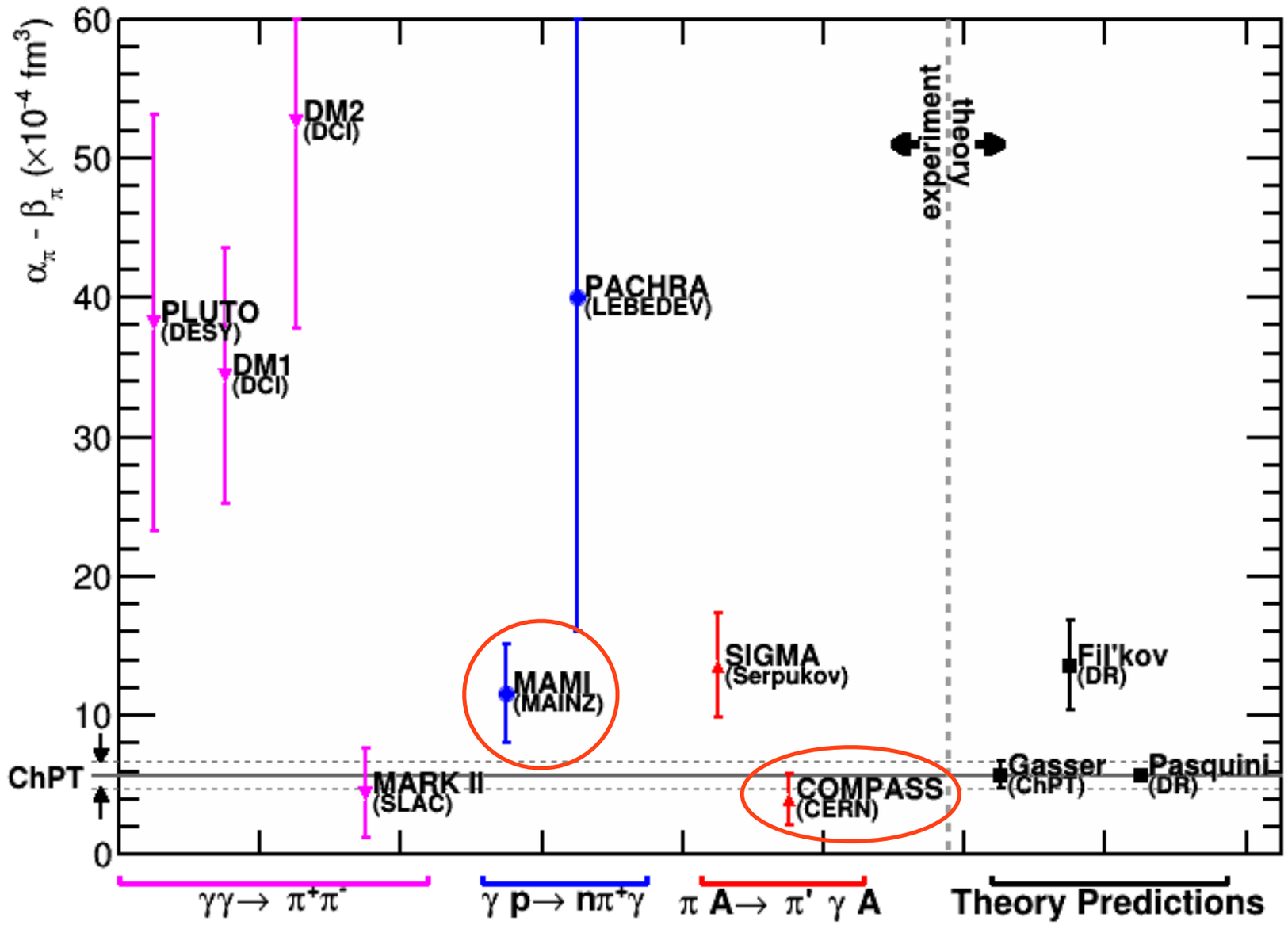
iii. Charged and neutral pion polarizabilty: $\gamma\gamma \to \pi\pi$

$\gamma\gamma \to \pi^+\pi^-$ at Mark-II and Crystal Ball



$$A_{\gamma\gamma\to\pi\pi} \to \textit{dispersion theory} \to A_{Compton}$$

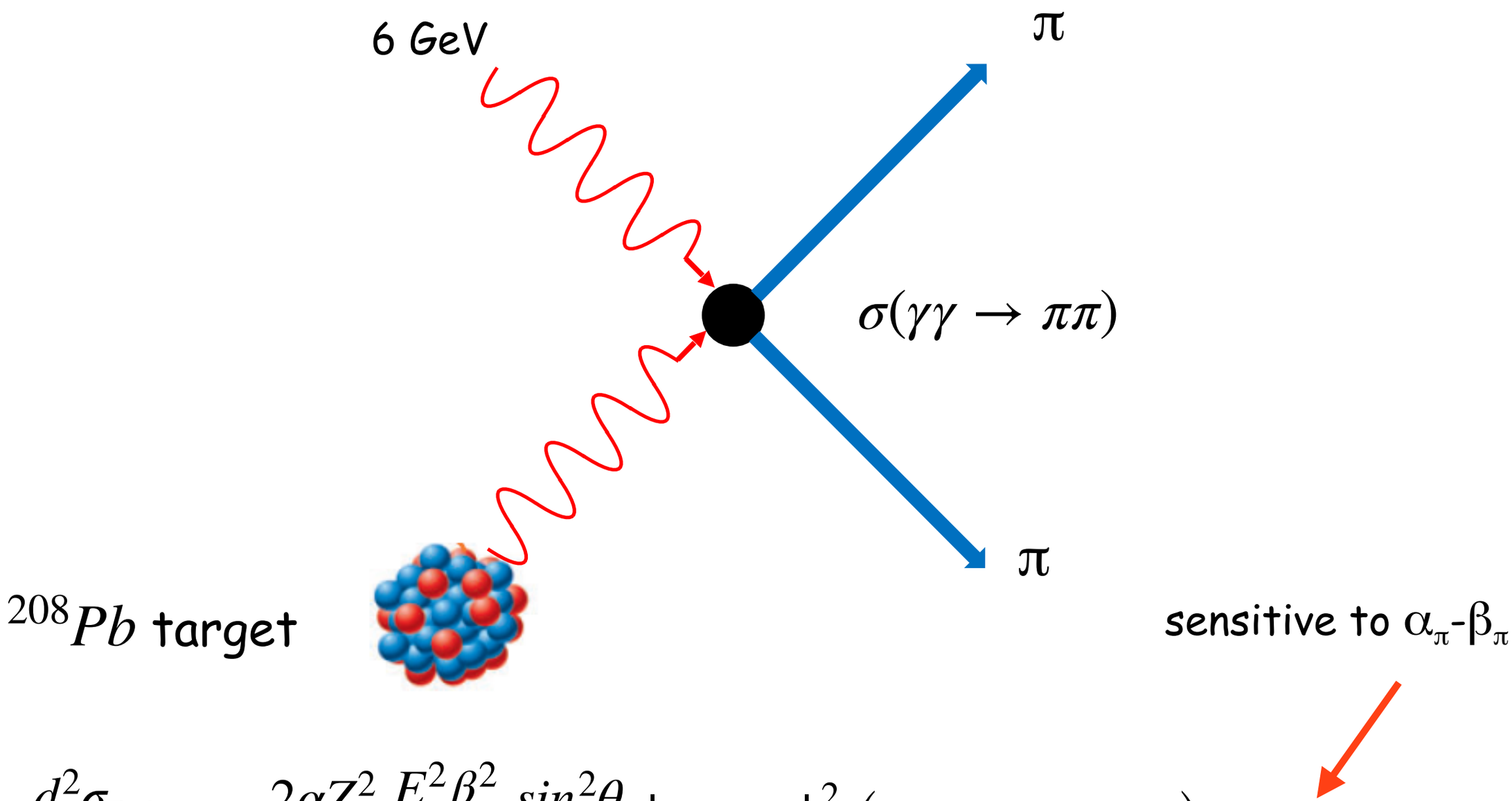
Published measurements of charged pion polarizability



COMPASS: $\pi^- Ni \to \pi^- \gamma\ Ni$ @ 160 GeV

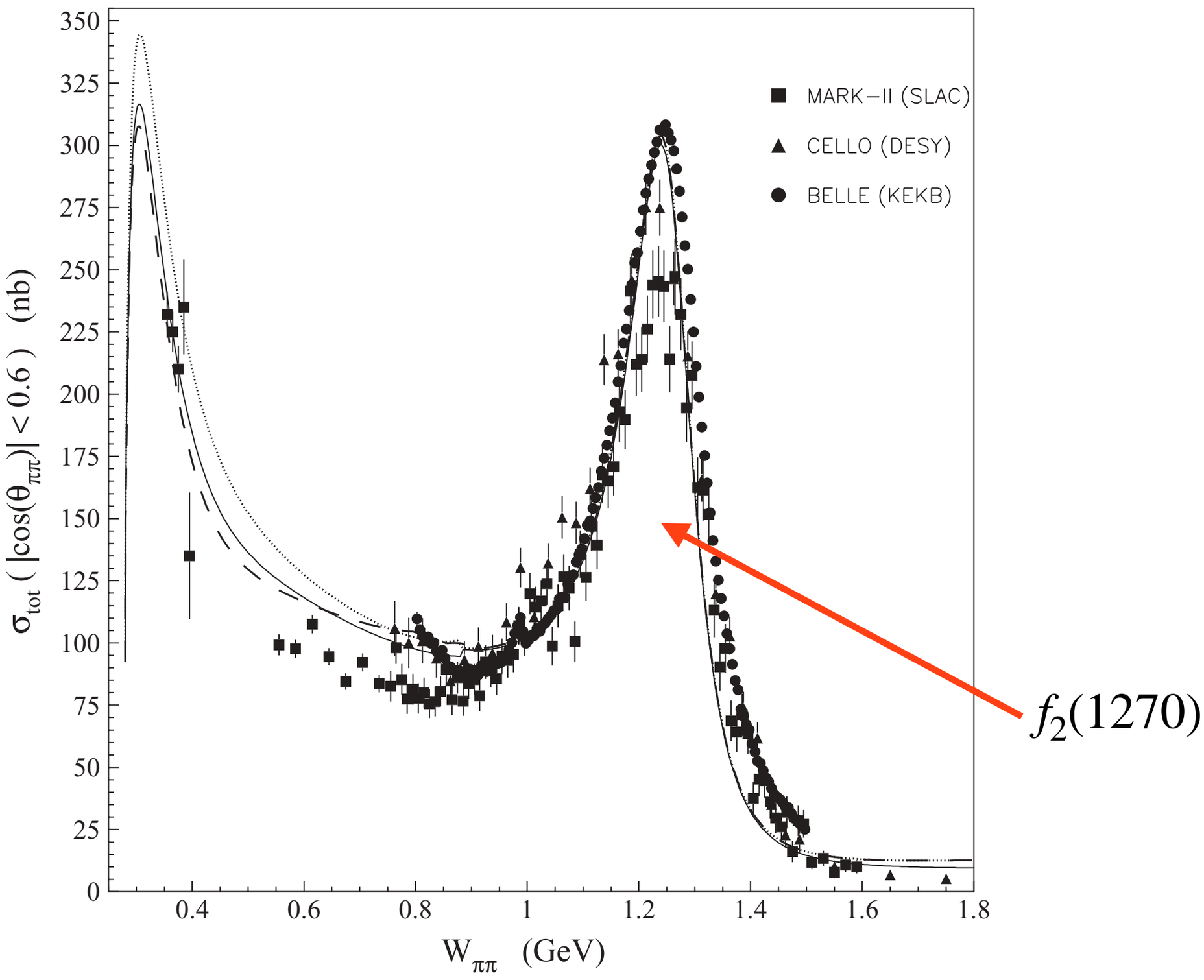
$$\alpha_\pi - \beta_\pi = 4.0 \pm 1.2(stat) \pm 1.4(sys) \times 10^{-4} fm^3$$

III. The charged pion polarizability (CPP) and neutral pion polarizability (NPP) experiments at GlueX

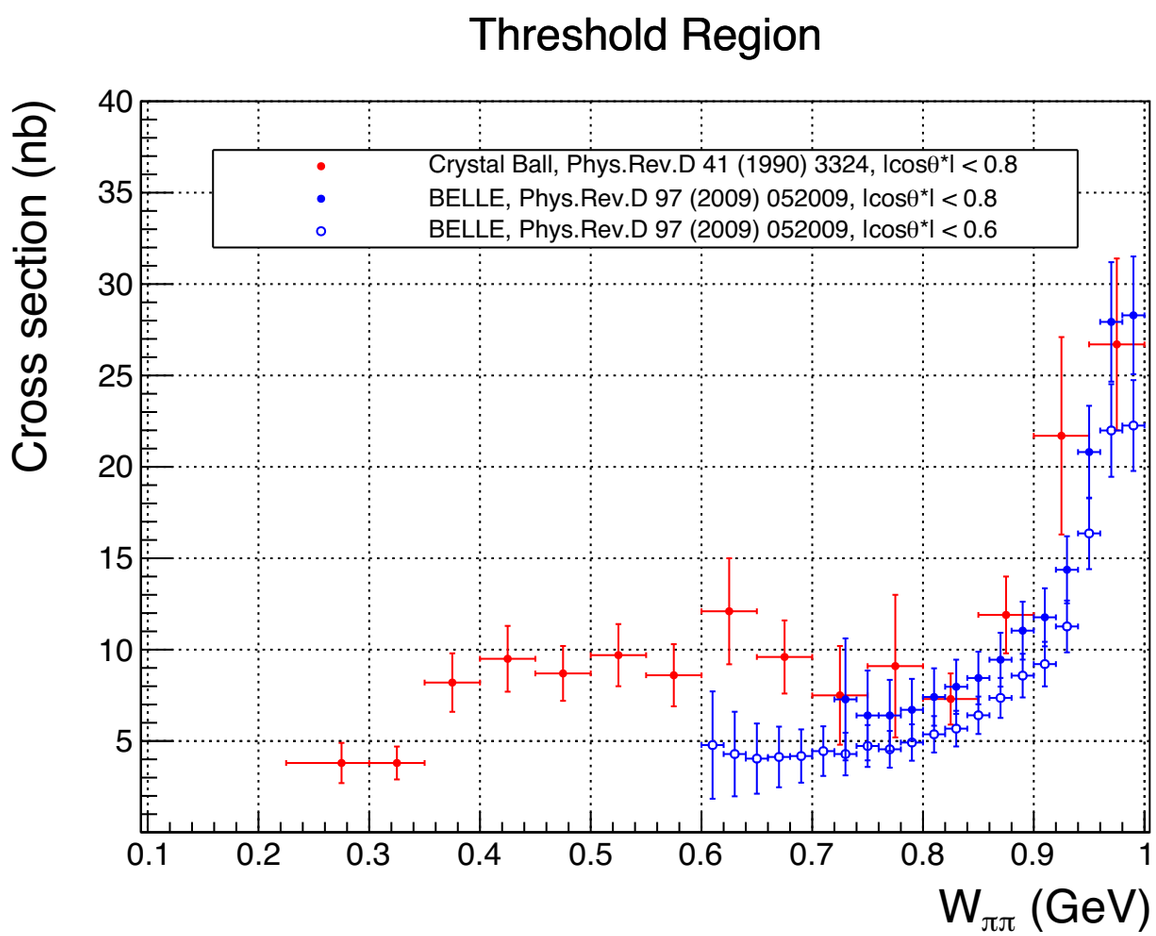


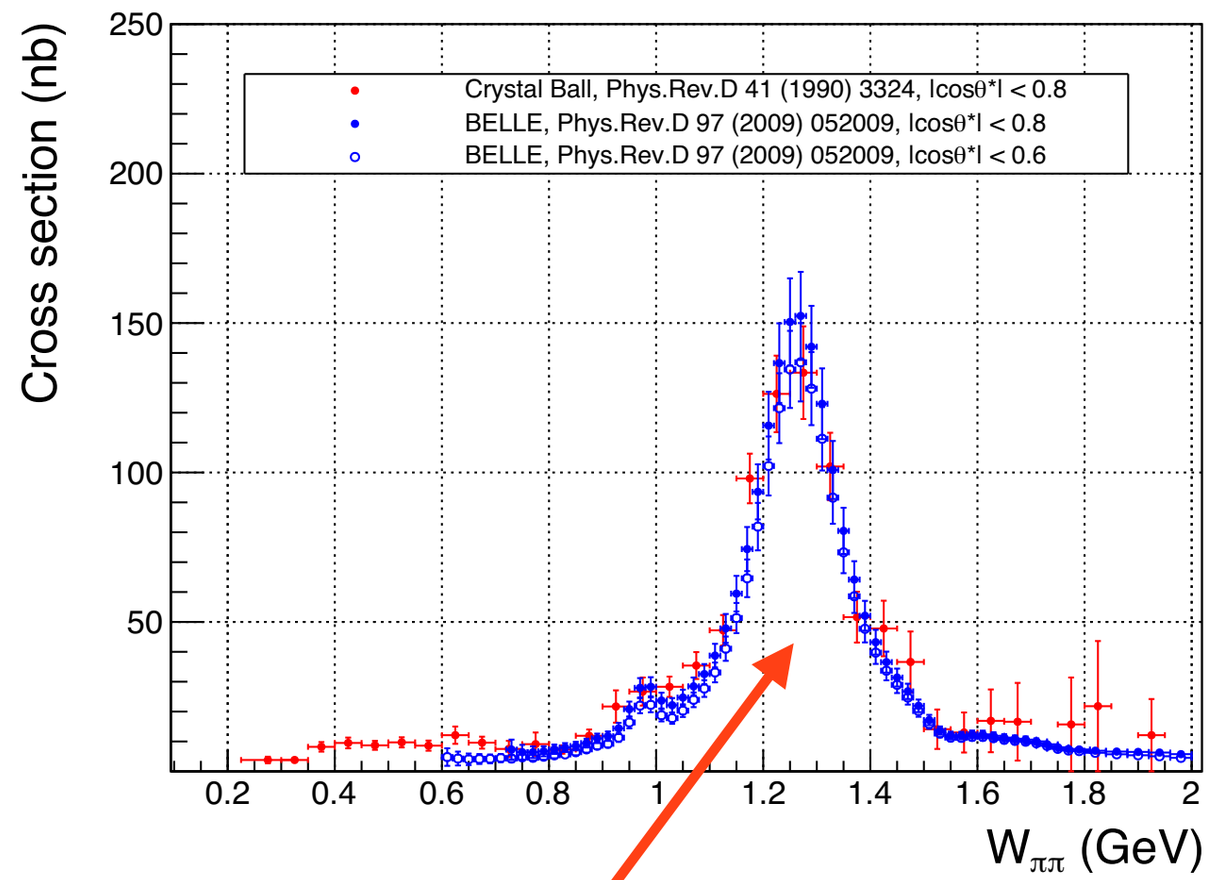
$$\frac{d^2\sigma_{Prim}}{d\Omega dM_{\pi\pi}} = \frac{2\alpha Z^2}{\pi^2}\frac{E_\gamma^2\beta^2}{M_{\pi\pi}}\frac{sin^2\theta}{Q^4}\left|F(Q^2)\right|^2\left(1+P_\gamma cos2\phi_{\pi\pi}\right)\sigma(\gamma\gamma \to \pi\pi)$$

Existing data for $\sigma(\gamma\gamma \to \pi^+\pi^-)$



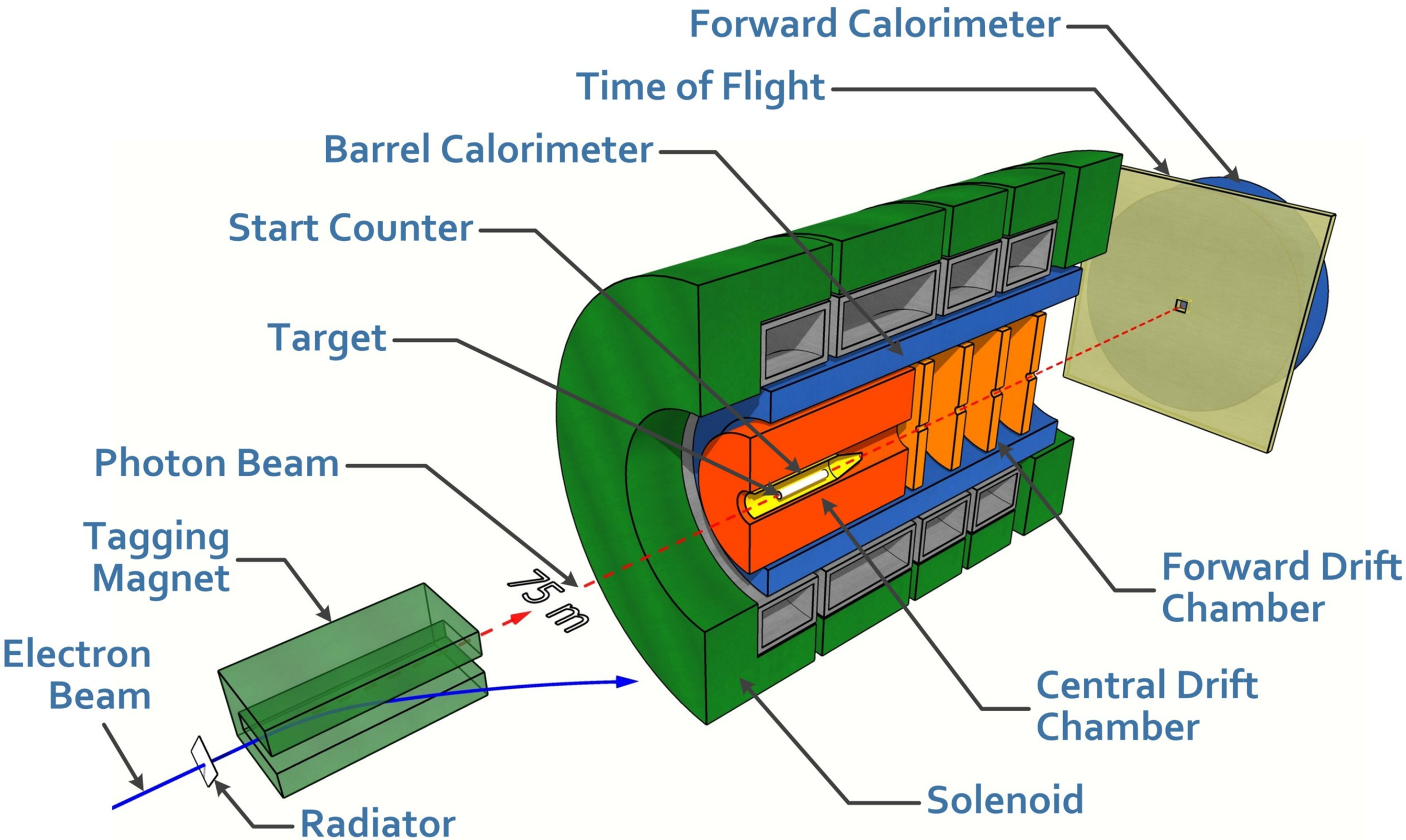
Existing data for $\sigma(\gamma\gamma \to \pi^0\pi^0)$





$f_2(1270)$

The CPP and NPP experiments at JLab GlueX



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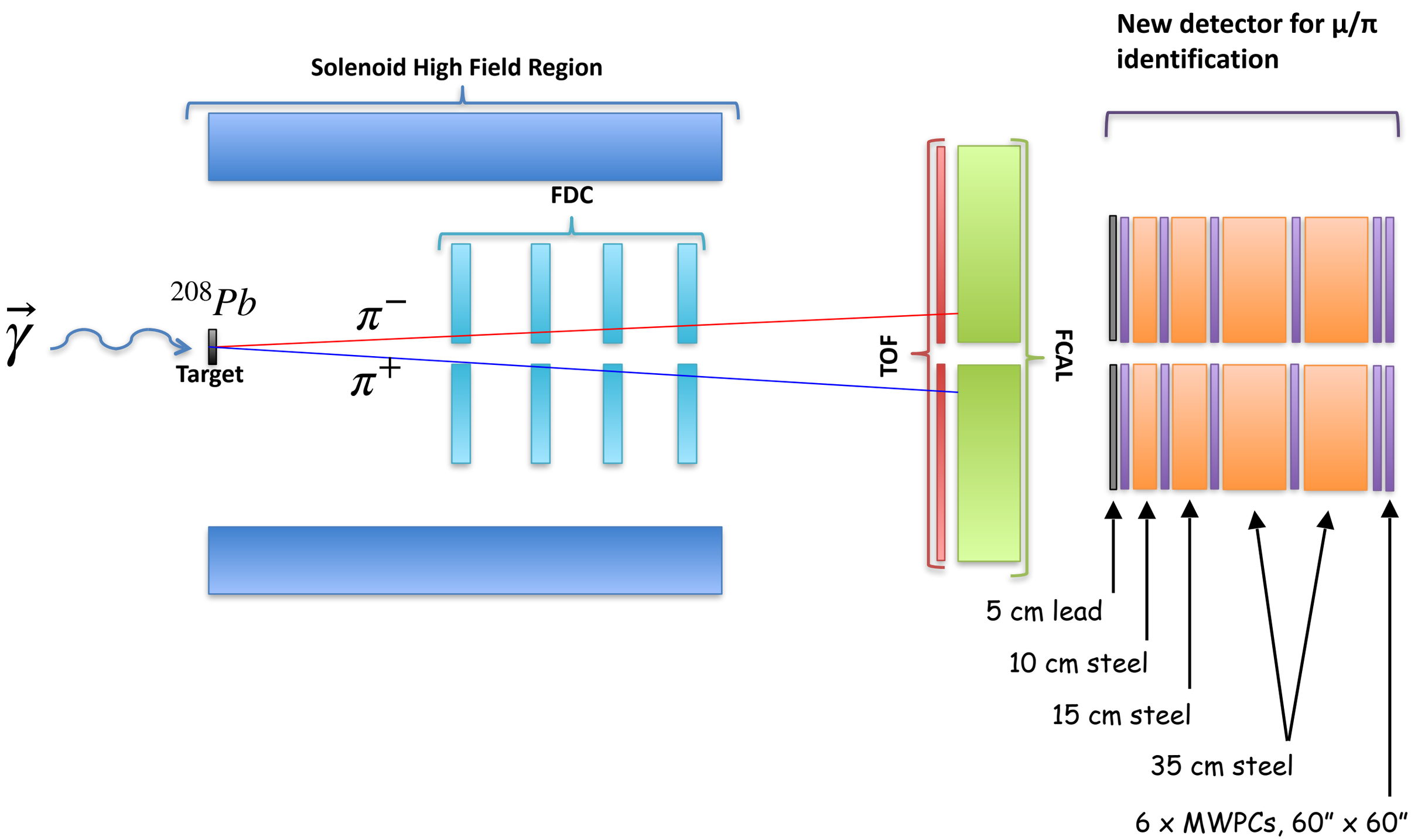
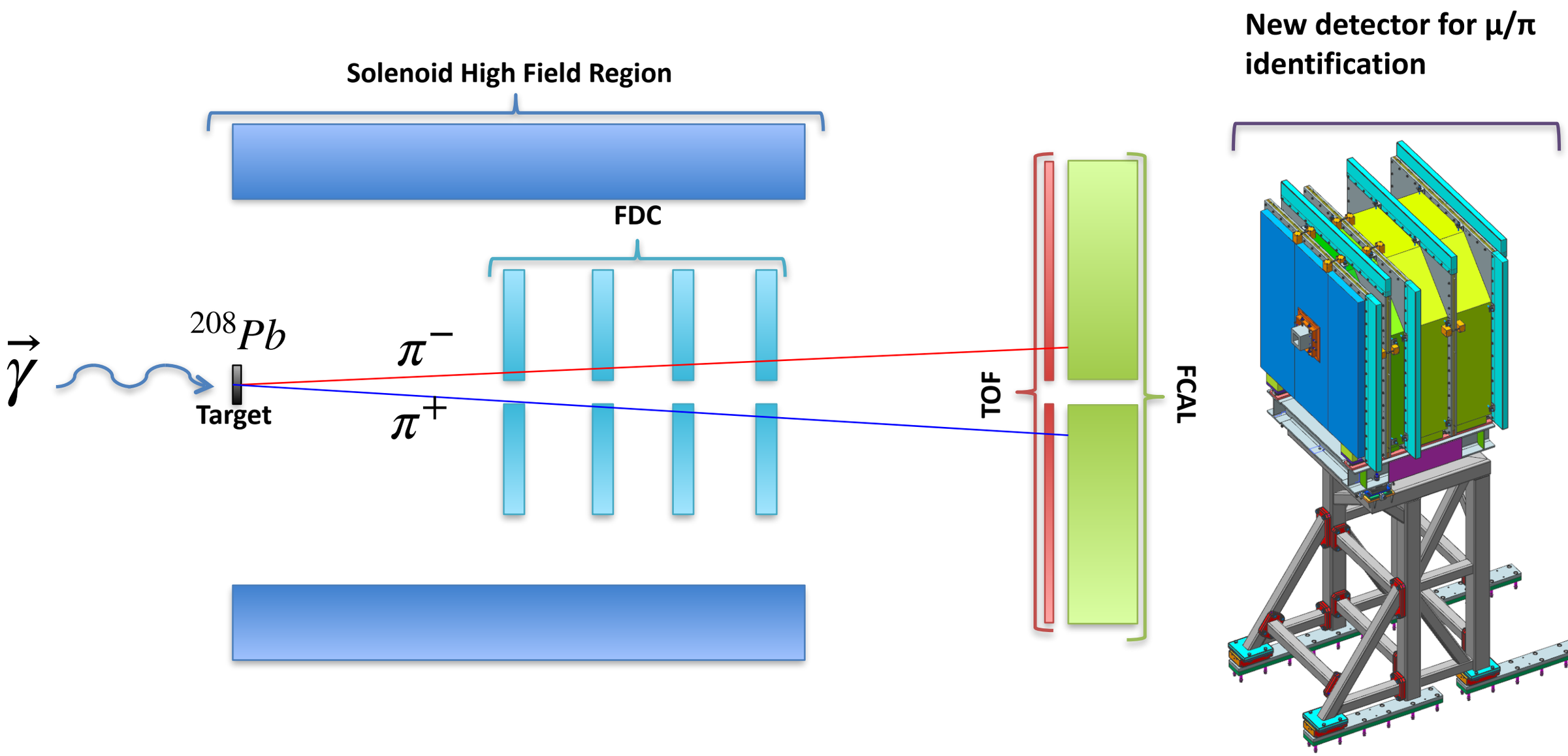


The CPP and NPP experiments at JLab GlueX



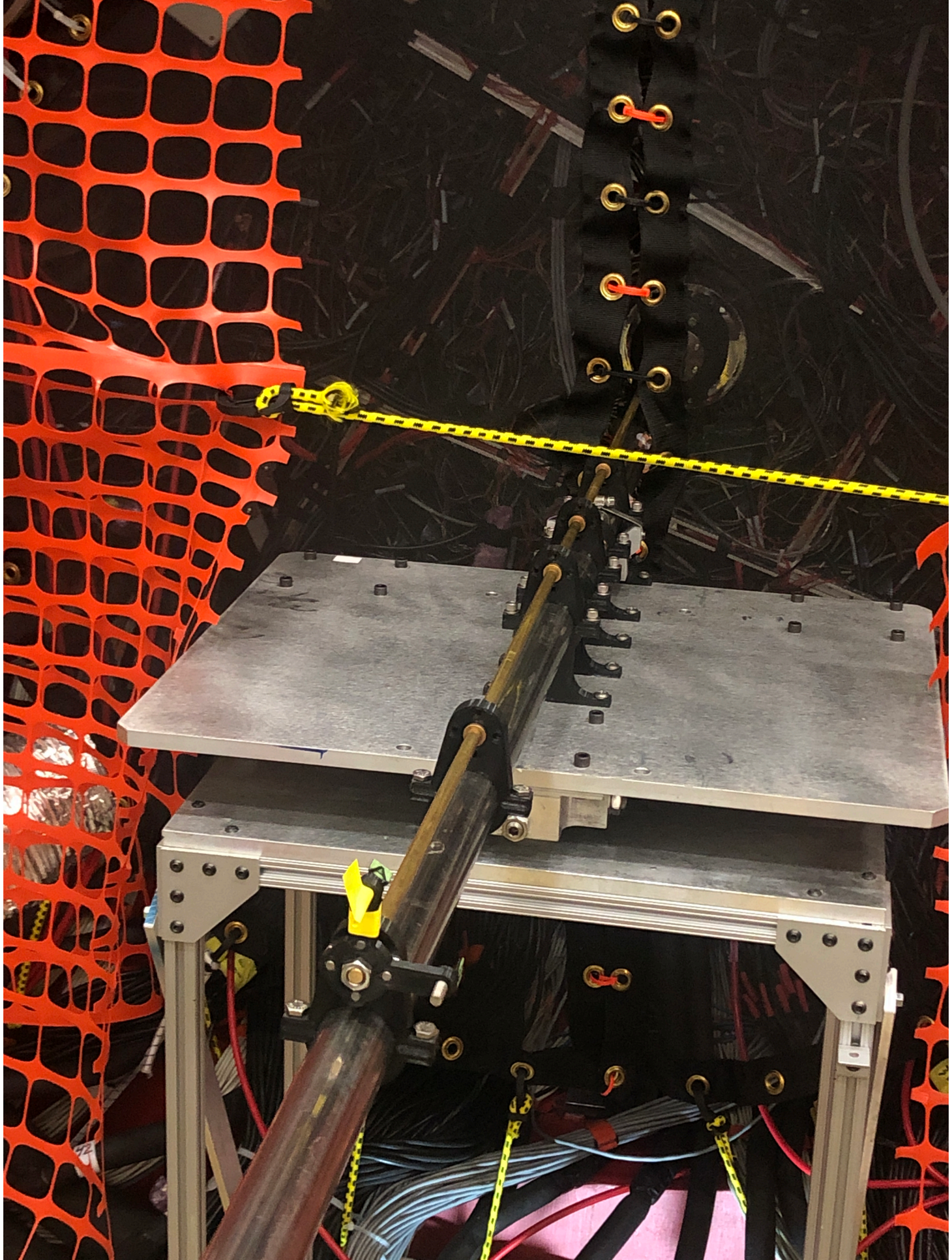
Eight MWPCs were built at UMass for the CPP measurement

Time-of-flight trigger for the CPP measurement

A trigger based on two charged tracks going into the forward time-of-flight (TOF) scintillator system was commissioned for CPP

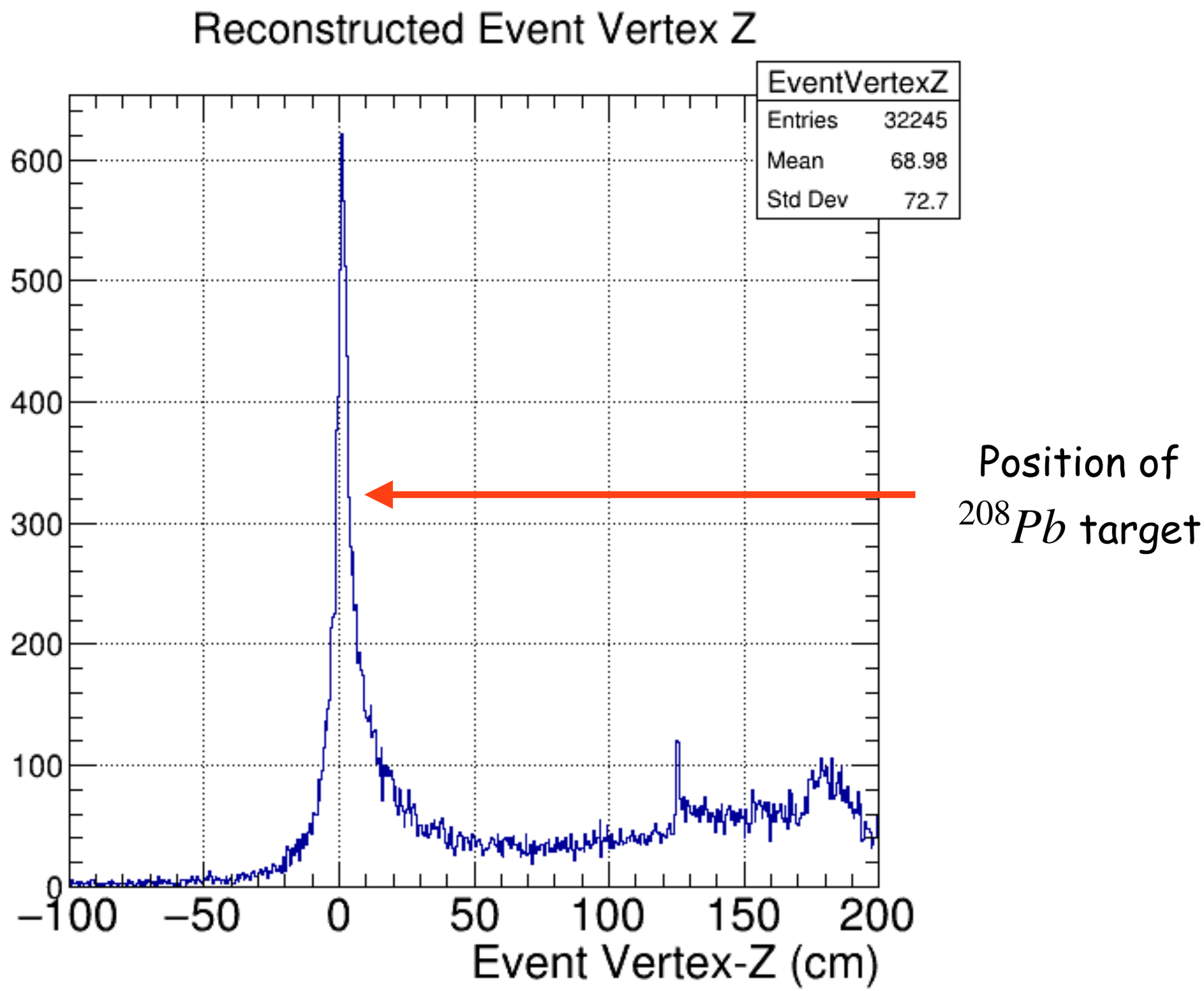
Update on the CPP and NPP experiments at GlueX

- ☑ A muon detector system was installed and commissioned for the experiment
- ☑ A trigger based on 2 charged tracks going into the forward time-of-flight scintillators was commissioned
- ☑ The Hall D photon tagger was reconfigured to provide a coherent photon peak at 6 GeV with 80% polarization
- ☑ A 5% RL lead target was installed 64 cm upstream of the nominal target position to give better acceptance at low $W_{\pi\pi}$
- ☑ The experiment started data taking June 9 and concluded on Aug. 18, taking the full allotment of 25 PAC awarded days

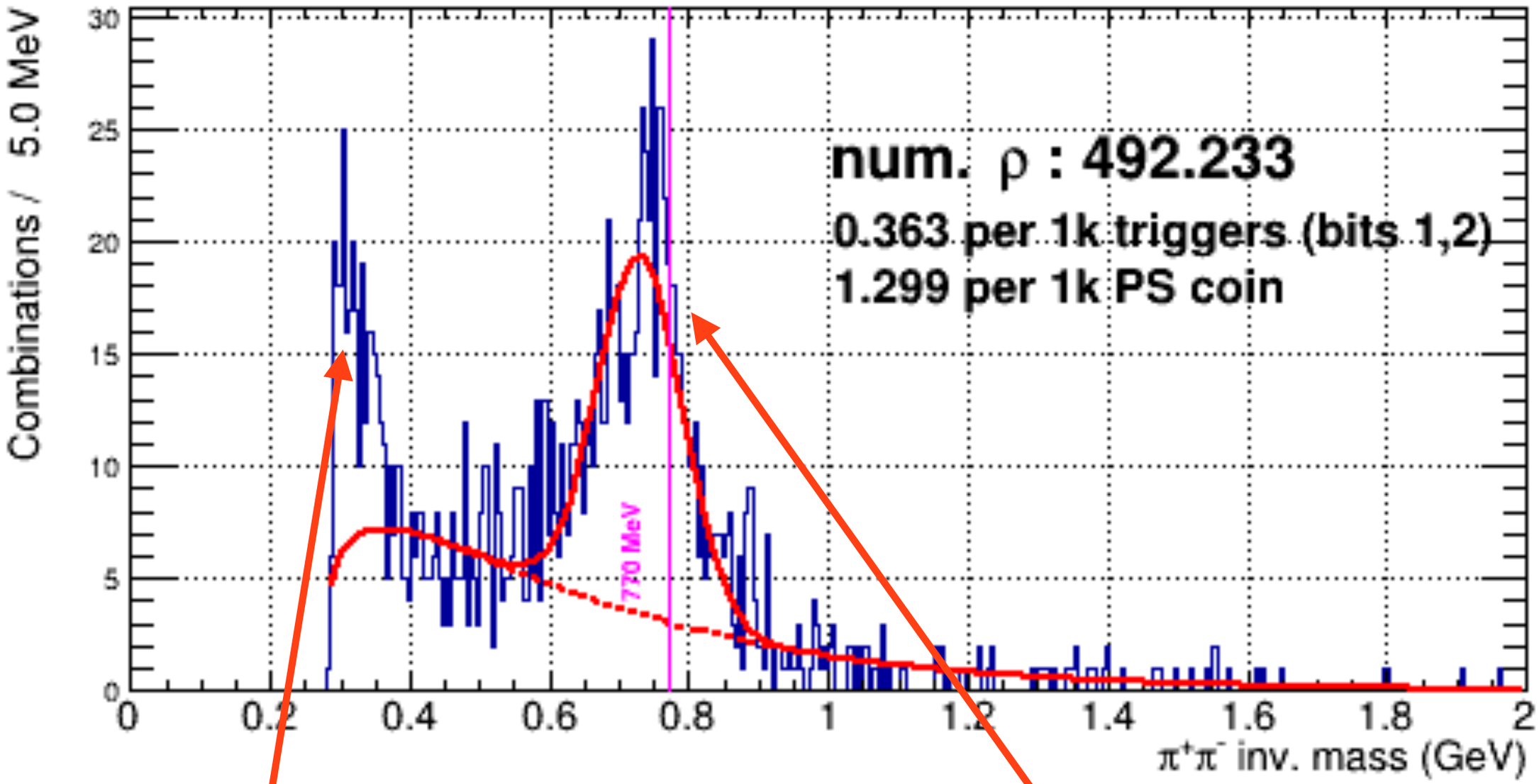



CAUTION
CAREFUL
LOW HEAD
CLEARANCE
CAEN
Nuclear
CPP4
CPP3

Reconstructed target vertex position observed during the run



Invariant mass of h^+h^- pairs observed during the run (no particle ID at this point)



Bethe-Heitler $\gamma A \rightarrow e^+e^-A$

$\rho^0 \rightarrow \pi^+\pi^-$

Summary

- Pion polarizability has special importance because it tests fundamental symmetries, specifically chiral symmetry and its realization in QCD
- The GlueX CPP and NPP experiments utilize a new technique for measuring pion polarizability: Primakoff photo-production of $\pi^+\pi^-$ and $\pi^0\pi^0$ pairs
- Data taking for the CPP and NPP experiments has been completed, and we look forward to physics results in the near future

Thank you !