Measurements of charged pion and neutral pion polarizabilities at GlueX

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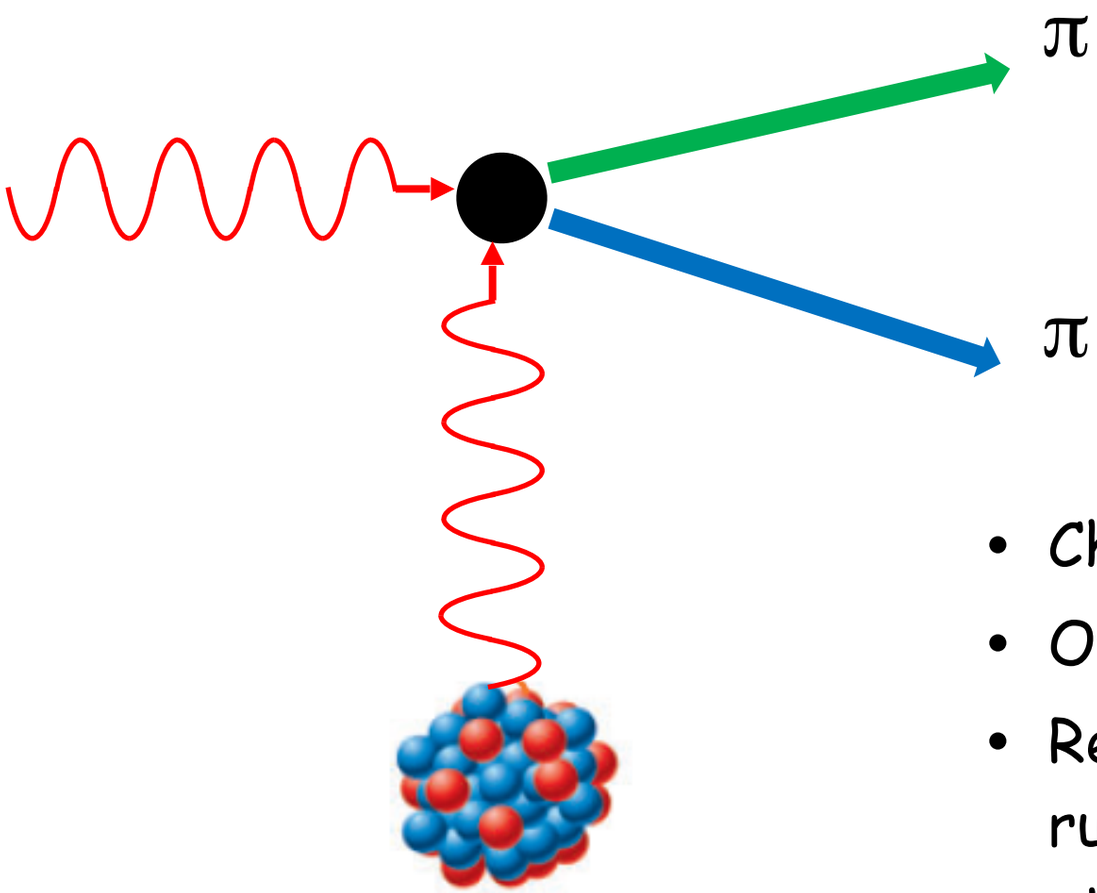
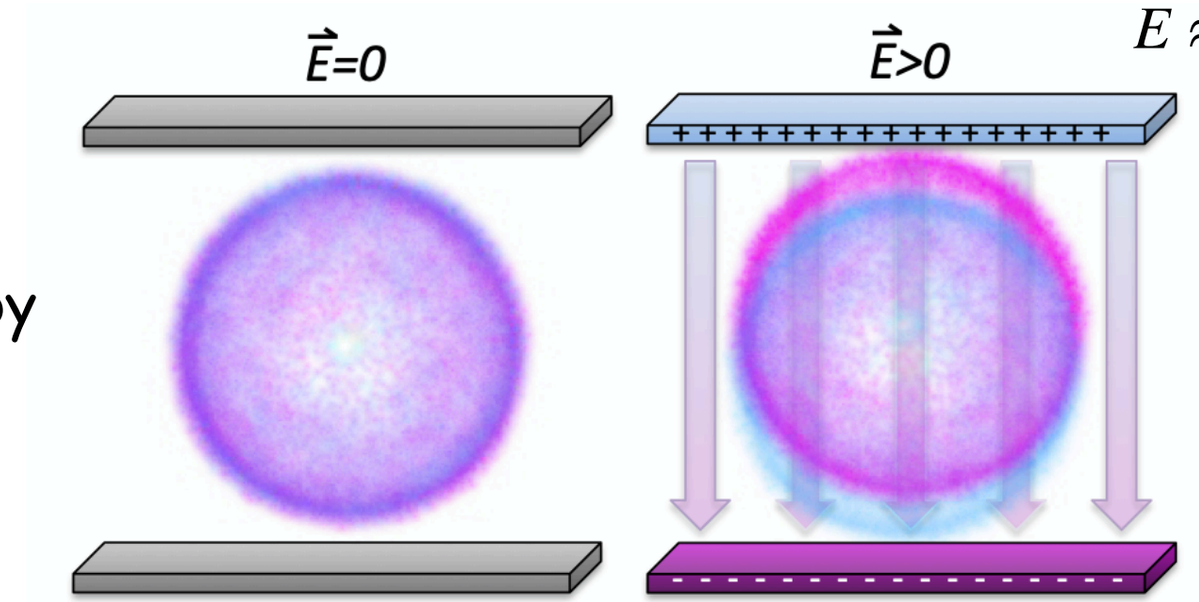


- Charged and neutral pion polarizabilities
- Overview of previous measurements
- Review progress and preparations for running the pion polarizbility experiment at GlueX

- **Consider placing a pion in a parallel plate capacitor at very high electric field**

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

Pion surrounded by pion cloud



Pion surrounded by displaced pion cloud

$$\vec{p} = -\alpha \vec{E}$$
$$\vec{\mu} = \beta \vec{H}$$

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

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

Small numbers because hadrons are "stiff"!

Polarizabilities provide information about the excited states of hadrons, and can test effective field theories

- **Charged pion polarizability: arguably the most solid theoretical prediction we have for a hadron 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: a severe challenge for chiral perturbation theory**

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 calculations for $\alpha_{\pi^0} - \beta_{\pi^0}$ vary from -50% to -70% of NLO

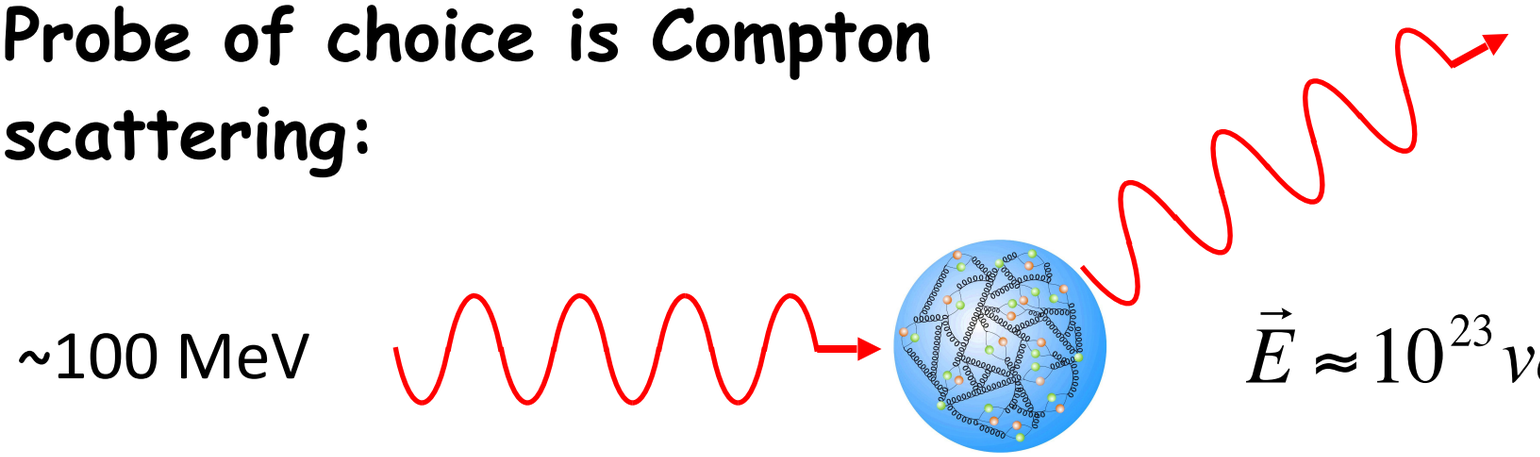
- **Neutral pion polarizability has never been measured**

- **Measuring hadron polarizabilties**

Strong electric field is needed to polarize a hadron:

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

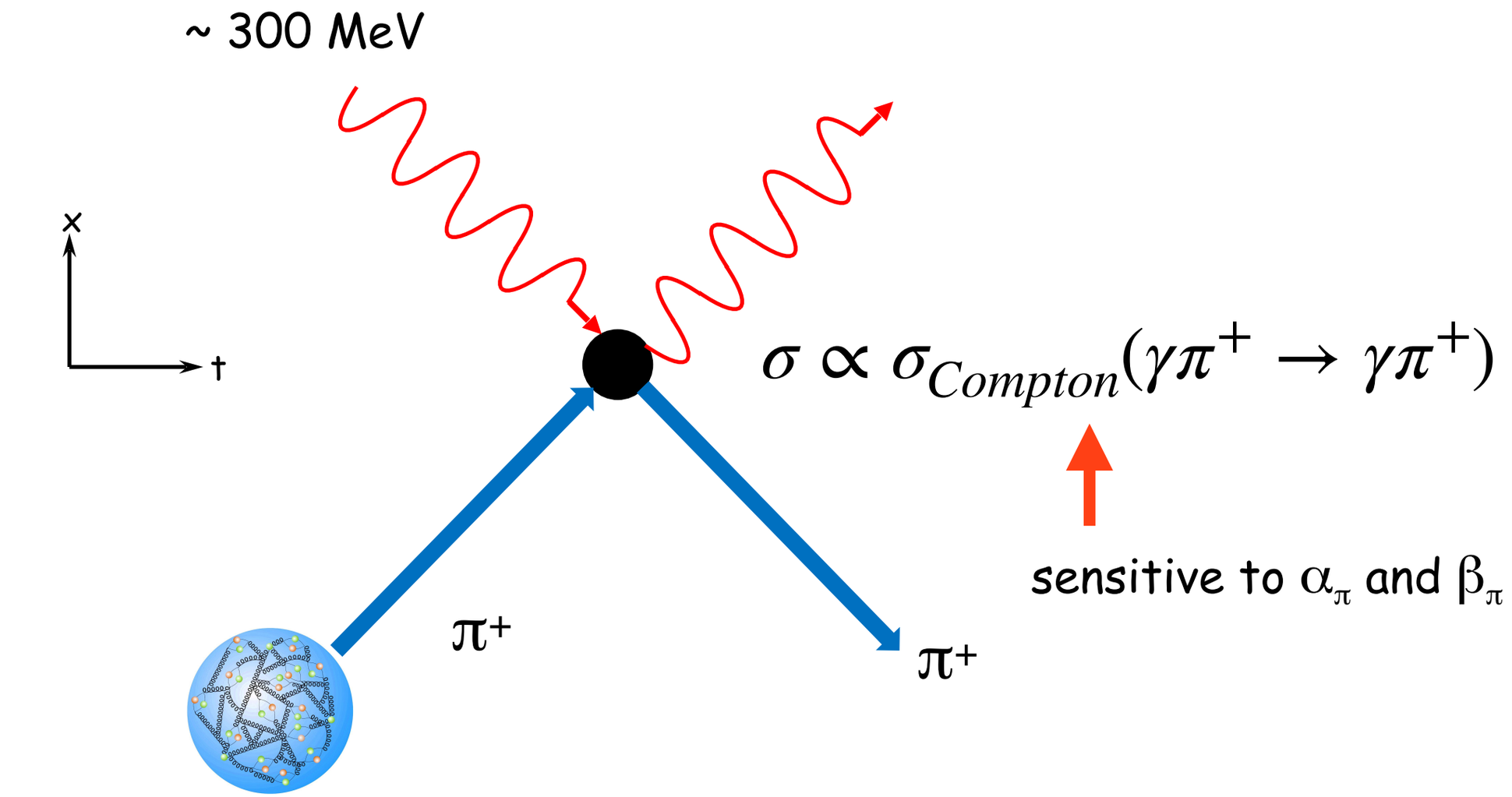
Probe of choice is Compton scattering:



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

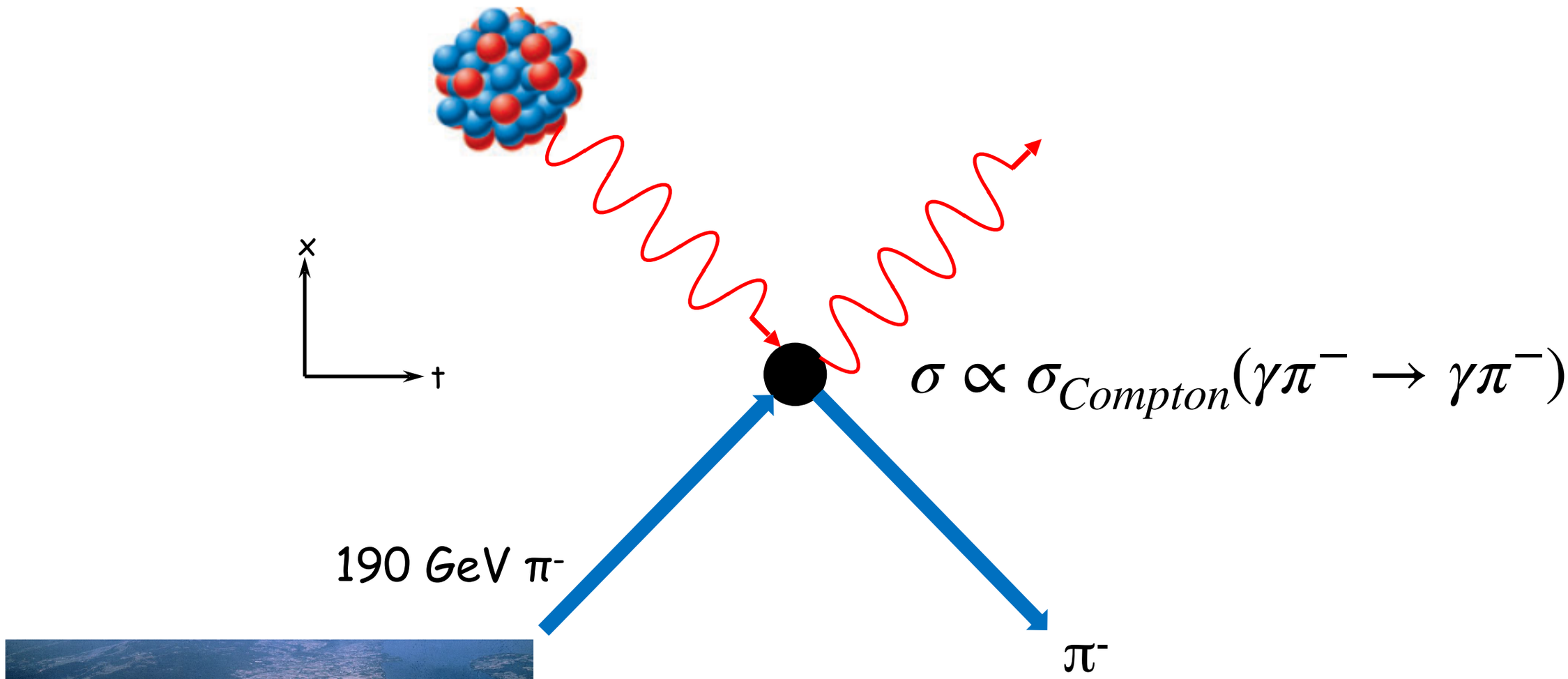
≈10%

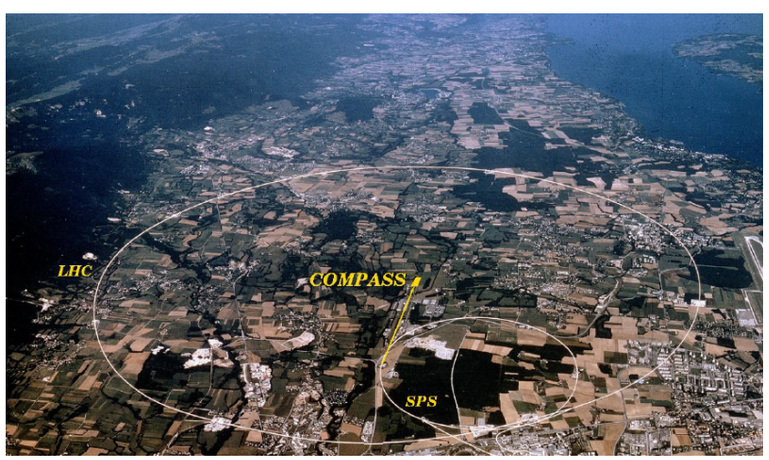
- **Measuring charged pion polarizabilty: radiative charged pion photoproduction**



Proton target as a
source of charged pions

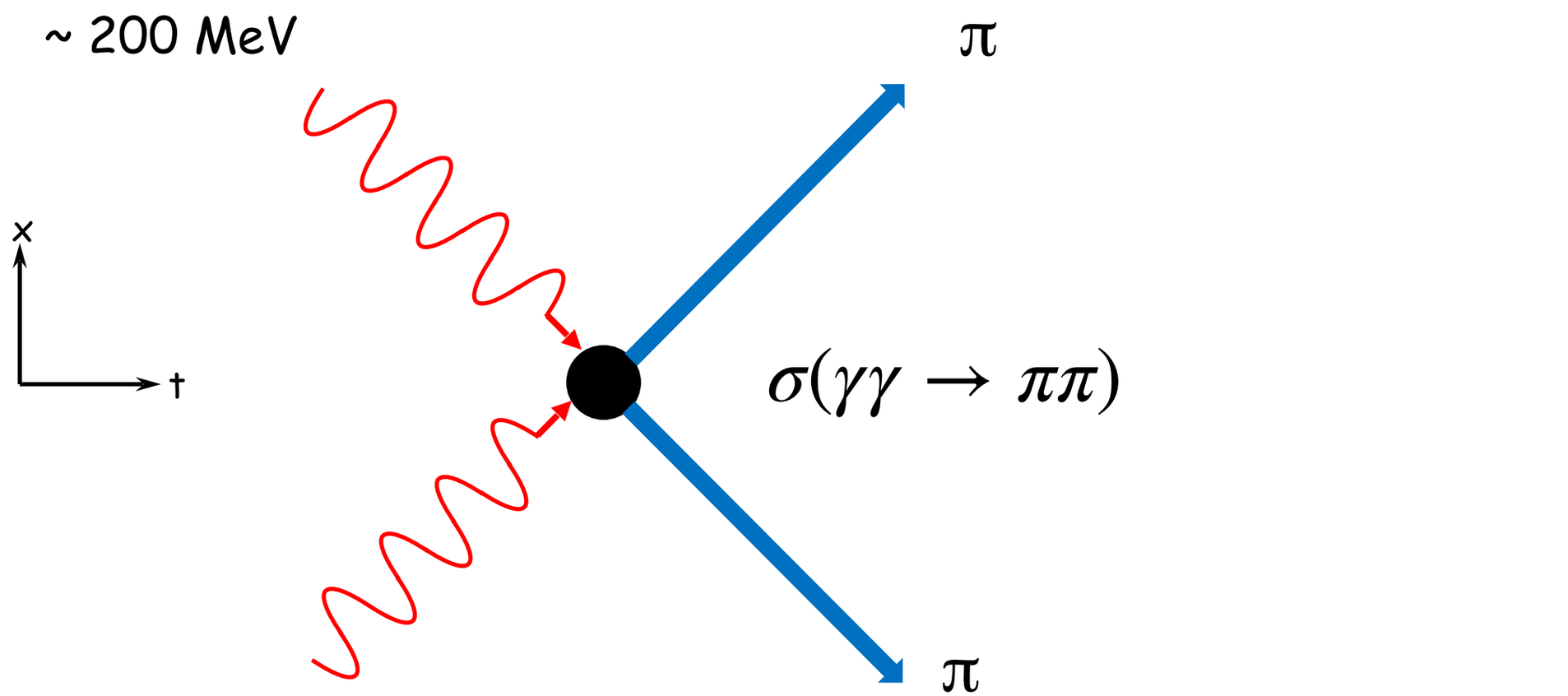
- **Measuring charged pion polarizabilty: radiative Primakoff production**



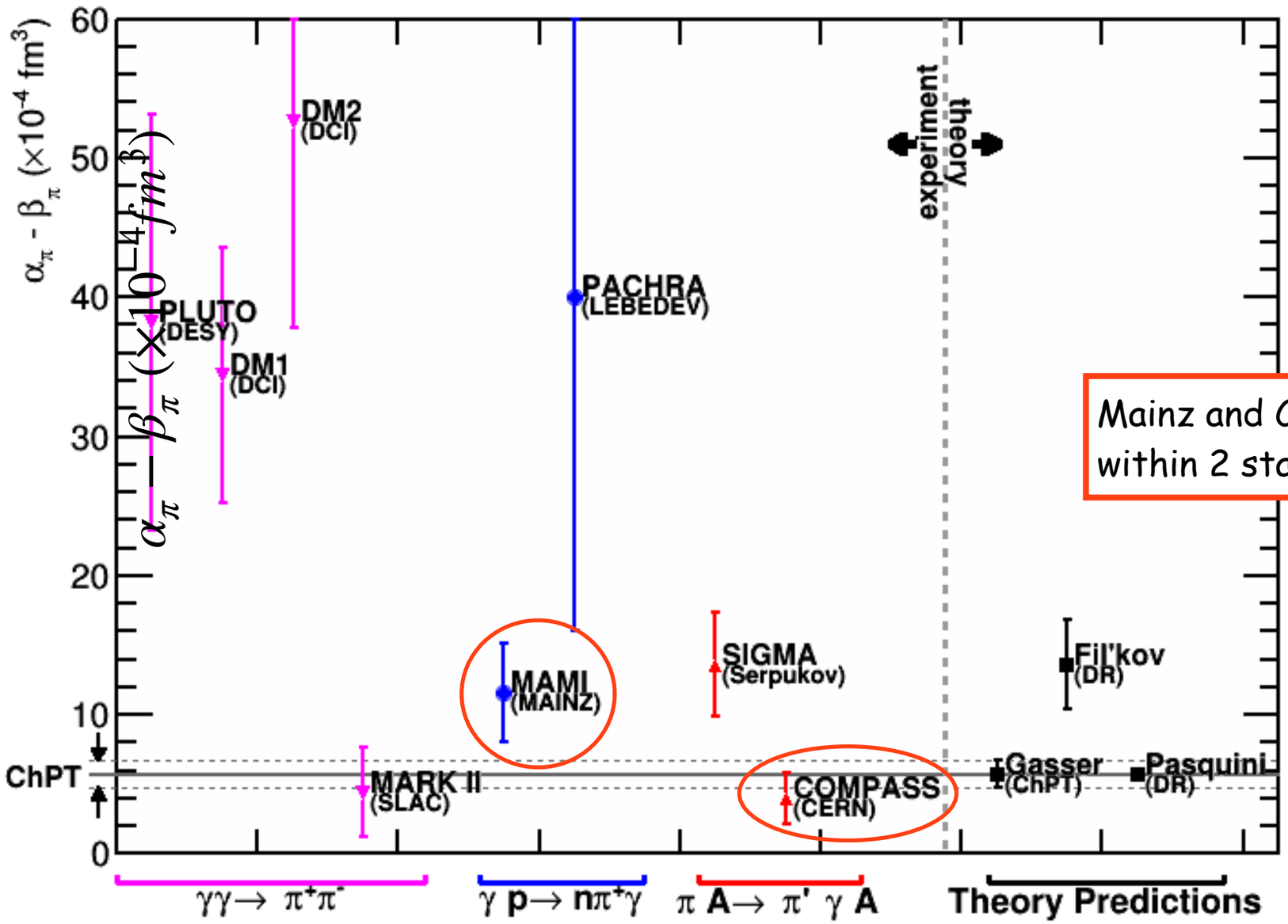


CERN

- **Measuring charged or neutral pion polarizabilty:** $\gamma\gamma \rightarrow \pi\pi$



- **Published measurements of charged pion polarizability**

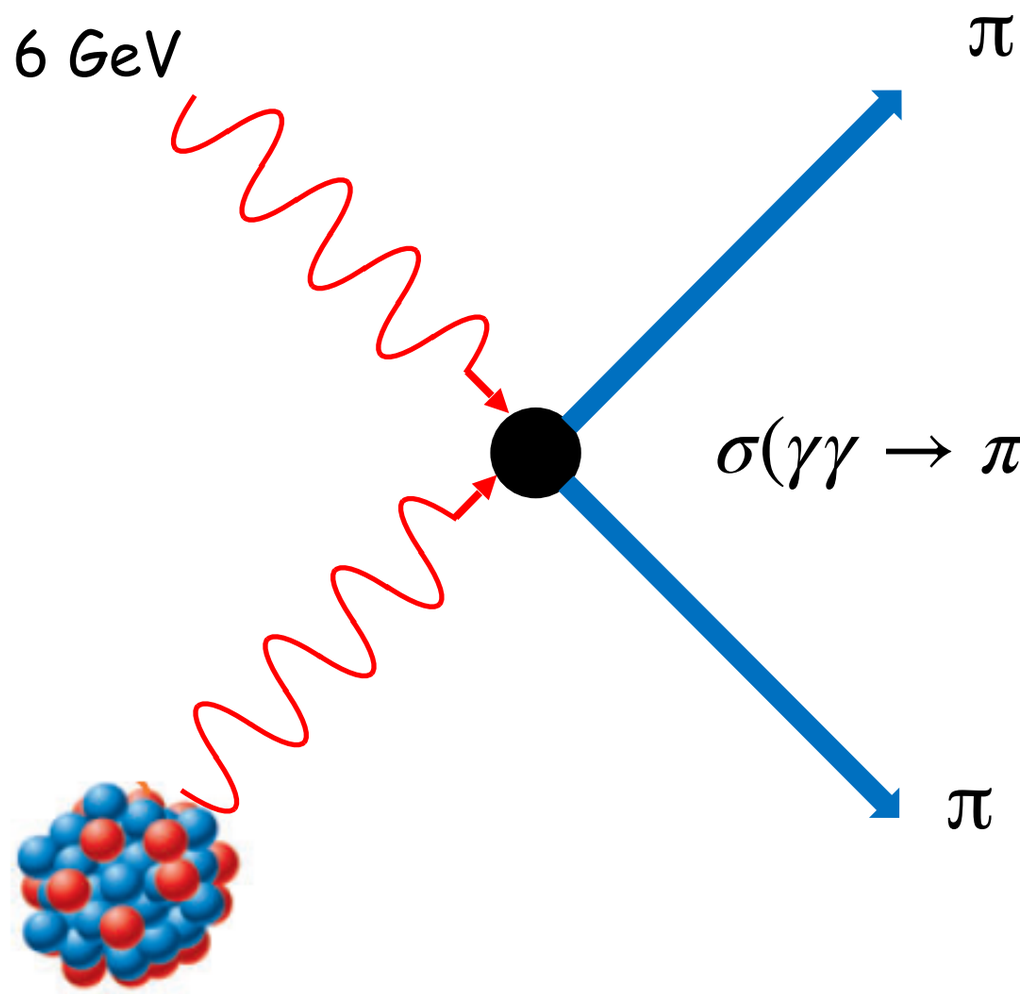


Mainz and Compass agree within 2 standard deviations

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

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

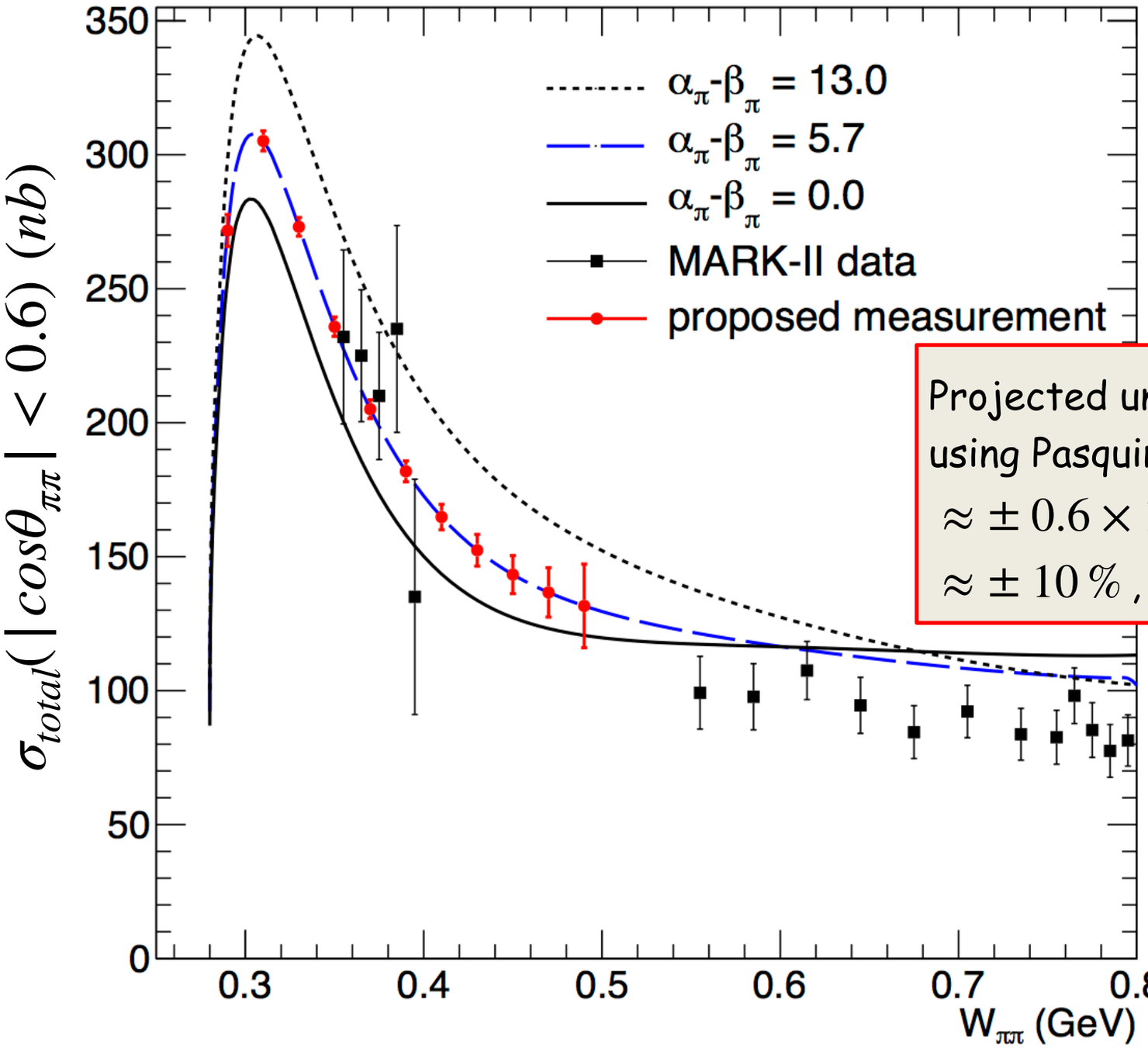
- New technique for measuring charged and neutral pion polarizability: Primakoff photoproduction of $\pi^+\pi^-$ and $\pi^0\pi^0$ pairs from nuclear target



sensitive to α_π-β_π

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

$\sigma(\gamma\gamma \to \pi^+\pi^-)$

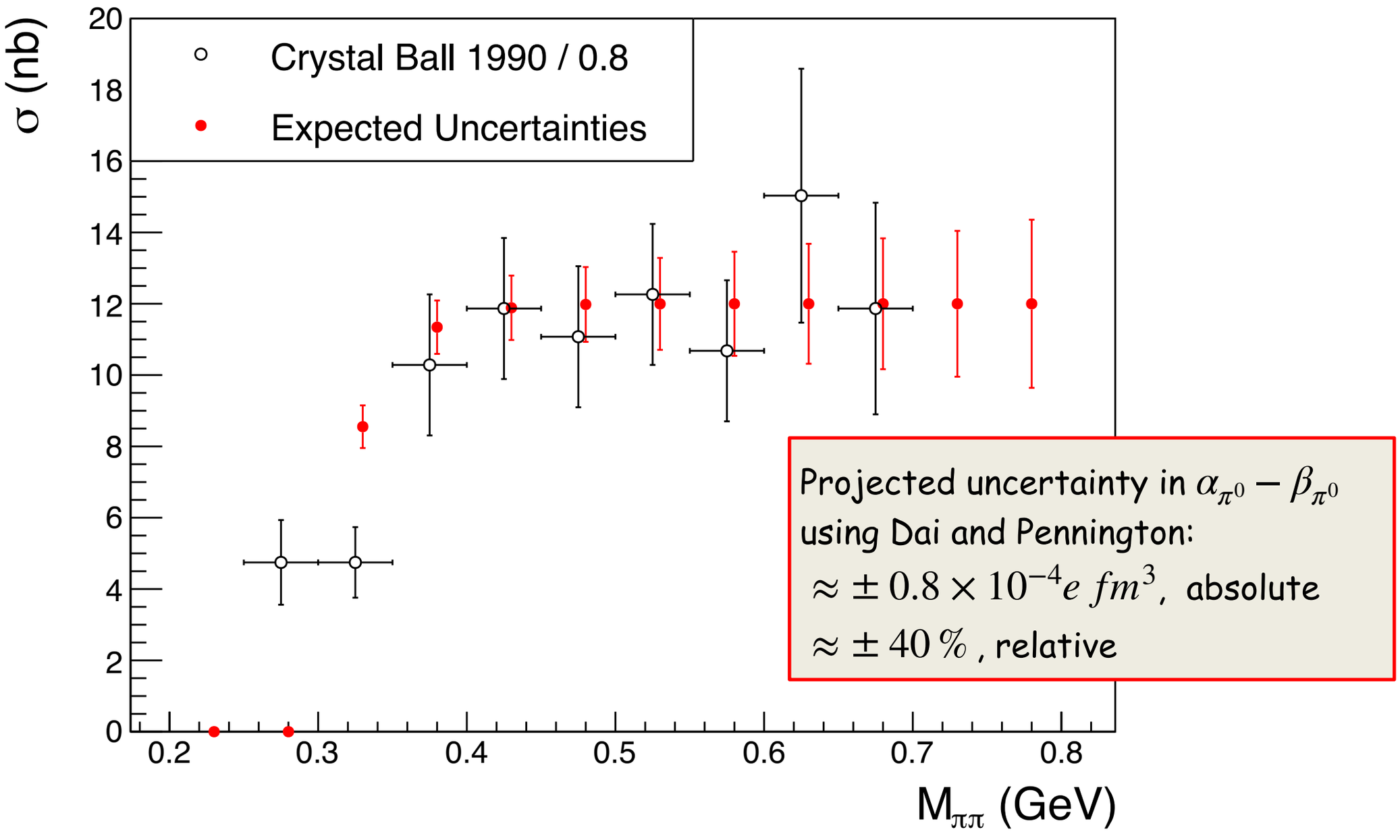


Projected uncertainty in $\alpha_{\pi^+} - \beta_{\pi^+}$ using Pasquini et al:

$\approx \pm 0.6 \times 10^{-4} e\ fm^3$, absolute

$\approx \pm 10\,\%$, relative

$\sigma(\gamma\gamma \to \pi^0\pi^0)$

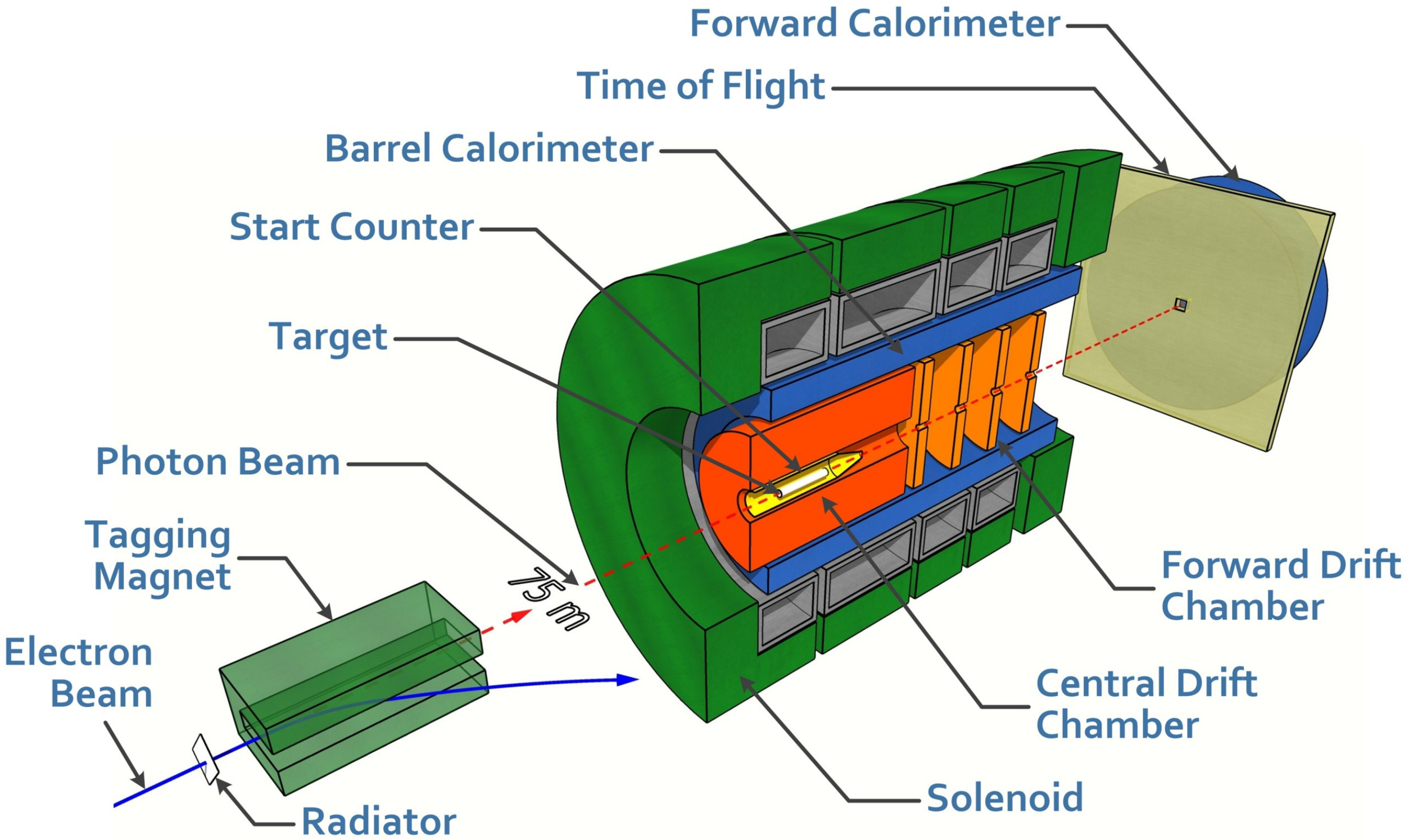


Projected uncertainty in $\alpha_{\pi^0} - \beta_{\pi^0}$ using Dai and Pennington:

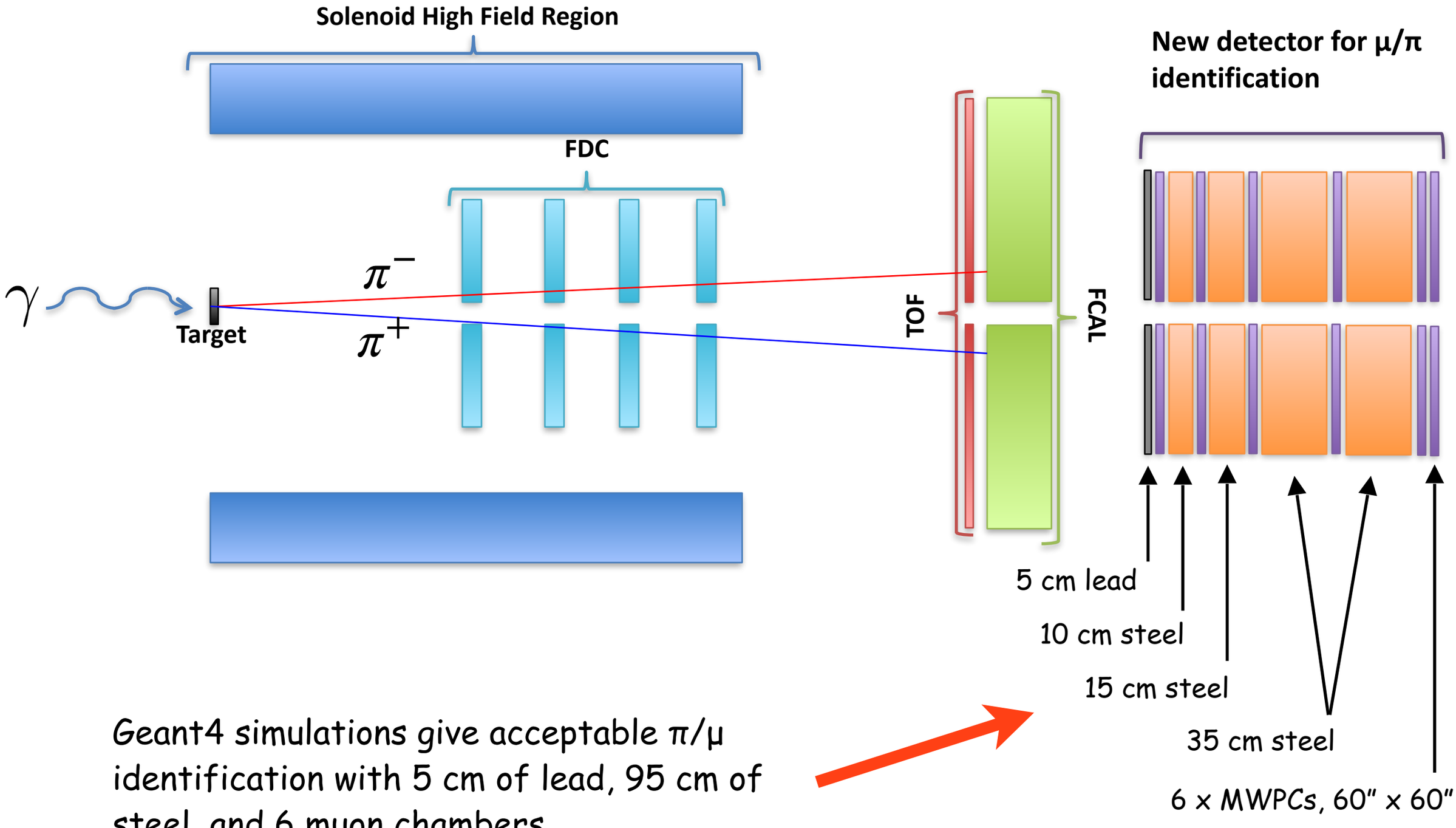
$\approx \pm 0.8 \times 10^{-4} e\ fm^3$, absolute

$\approx \pm 40\,\%$, relative

- Pion polarizability experiment at JLab GlueX

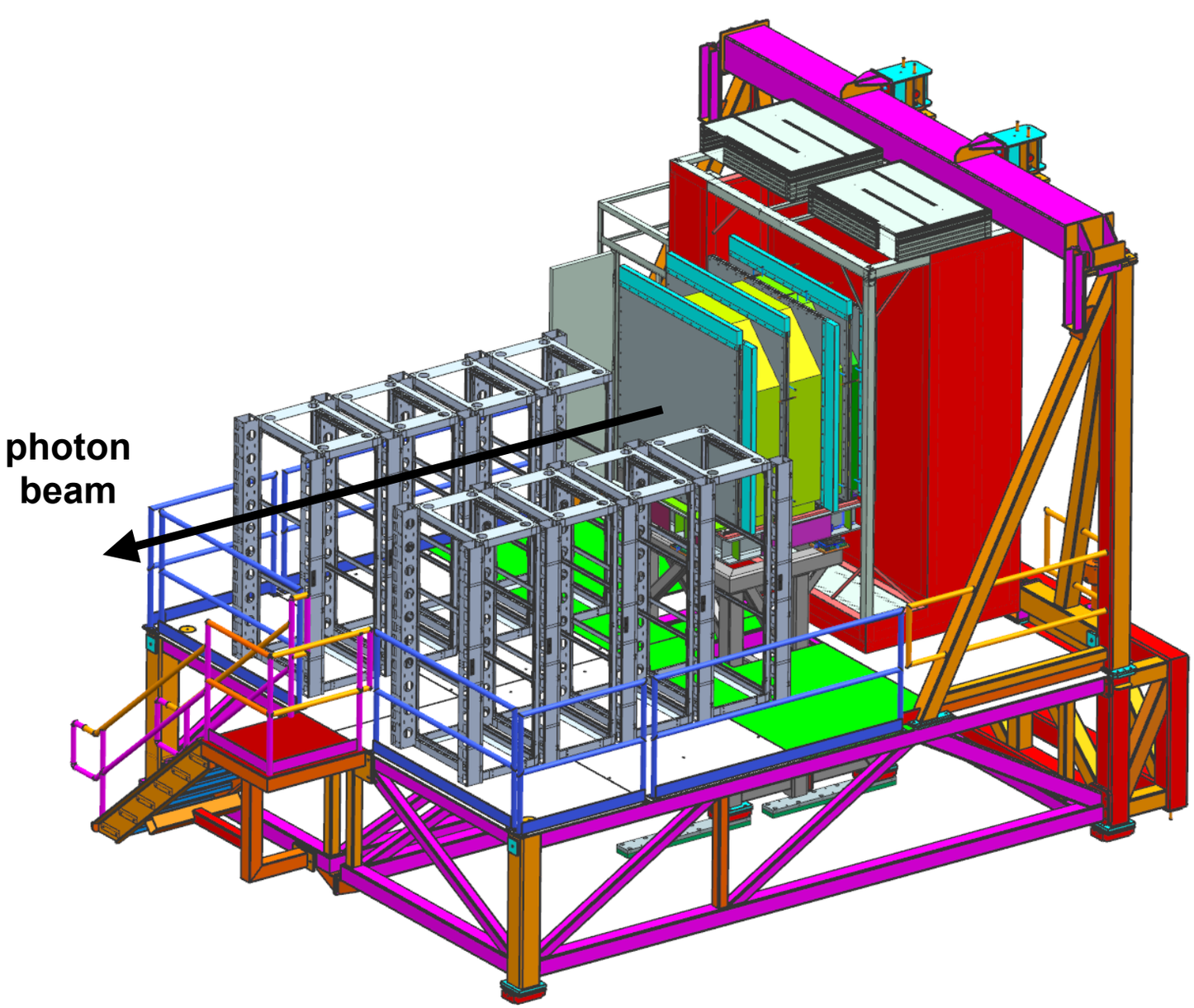


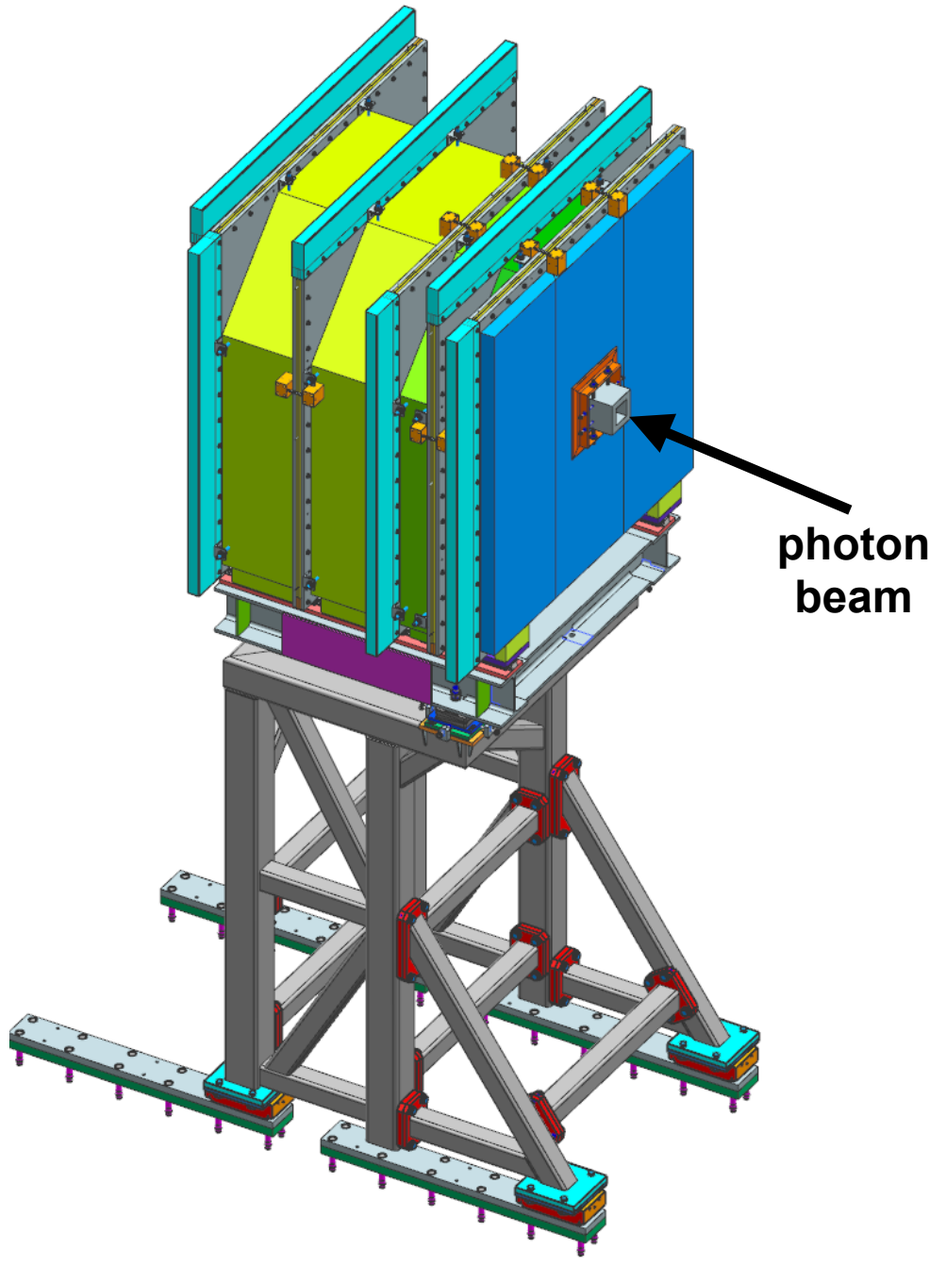
• Pion polarizability experiment at JLab GlueX



Geant4 simulations give acceptable π/μ identification with 5 cm of lead, 95 cm of steel, and 6 muon chambers.

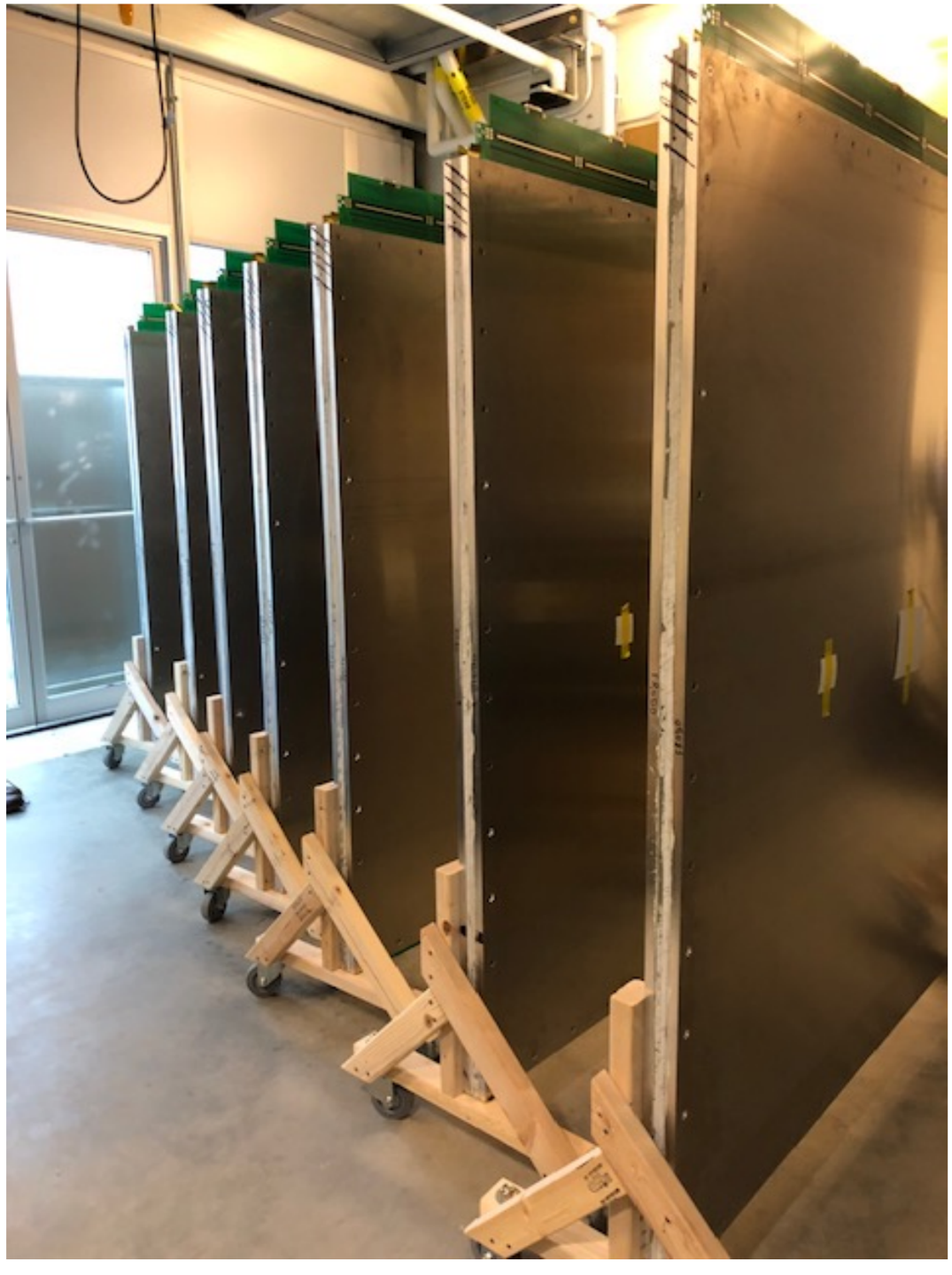
Engineering design for muon detector installation in GlueX



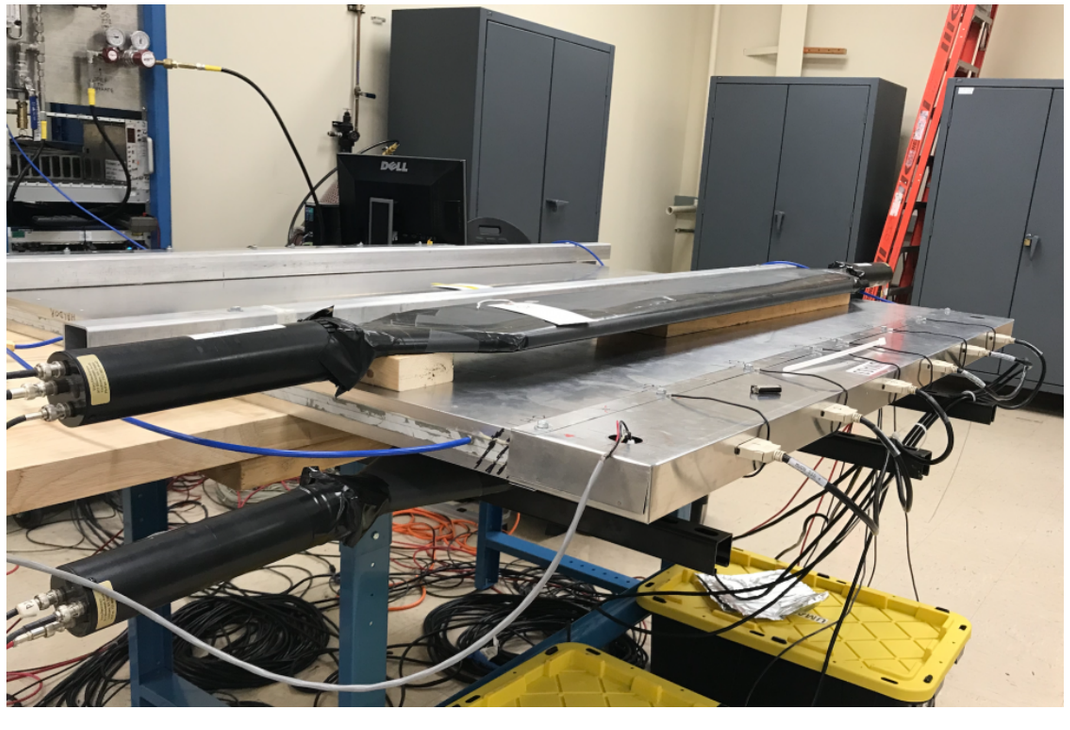


- Design is complete
- Procurement of parts and materials for installation is nearly complete

- **Muon chambers for charged pion polarizability measurement**



- Eight muon chambers were constructed at UMass for the measurement. All of them are now at JLab
- Bench testing of the detectors using cosmic rays is underway at JLab
- Design of neural-net for $e^{\pm}/\pi^{\pm}$ separation finalized, and design of a machine learning A.I. for $\mu^{\pm}/\pi^{\pm}$ identification using the muon chambers is underway



- **Time-of-flight trigger for GlueX measurment**

Experiment uses a non-standard GlueX trigger based on two charged tracks going into the time-of-flight (TOF) scintillator system

Results from trigger tests:

✓ The 30 kHz TOF trigger rate at the nominal 20 nA CPP current is within the operational range of the GlueX DAQ system.

✓ It may be possible to run CPP at a higher beam current than 20 nA.

Summary

- ✓ Charged pion polarizability provides an excellent test of ChPT , with neutral pion polarizability providing a challenge for theory
- ✓ An experiment that utilizes a new technique for measuring pion polarizability, Primakoff production of $\pi^+\pi^-$ and $\pi^0\pi^0$ pairs, is being prepared at GlueX (JLab)
- ✓ Preparations are well along for running this experiment at GlueX, with all major components in-hand or committed
- ✓ Tentative JLab schedule shows the experiment taking data June 2022