Probing QCD in the nuclear medium with real photons and nuclear targets @ GlueX

PR12-17-007 (GlueX collaboration proposal)

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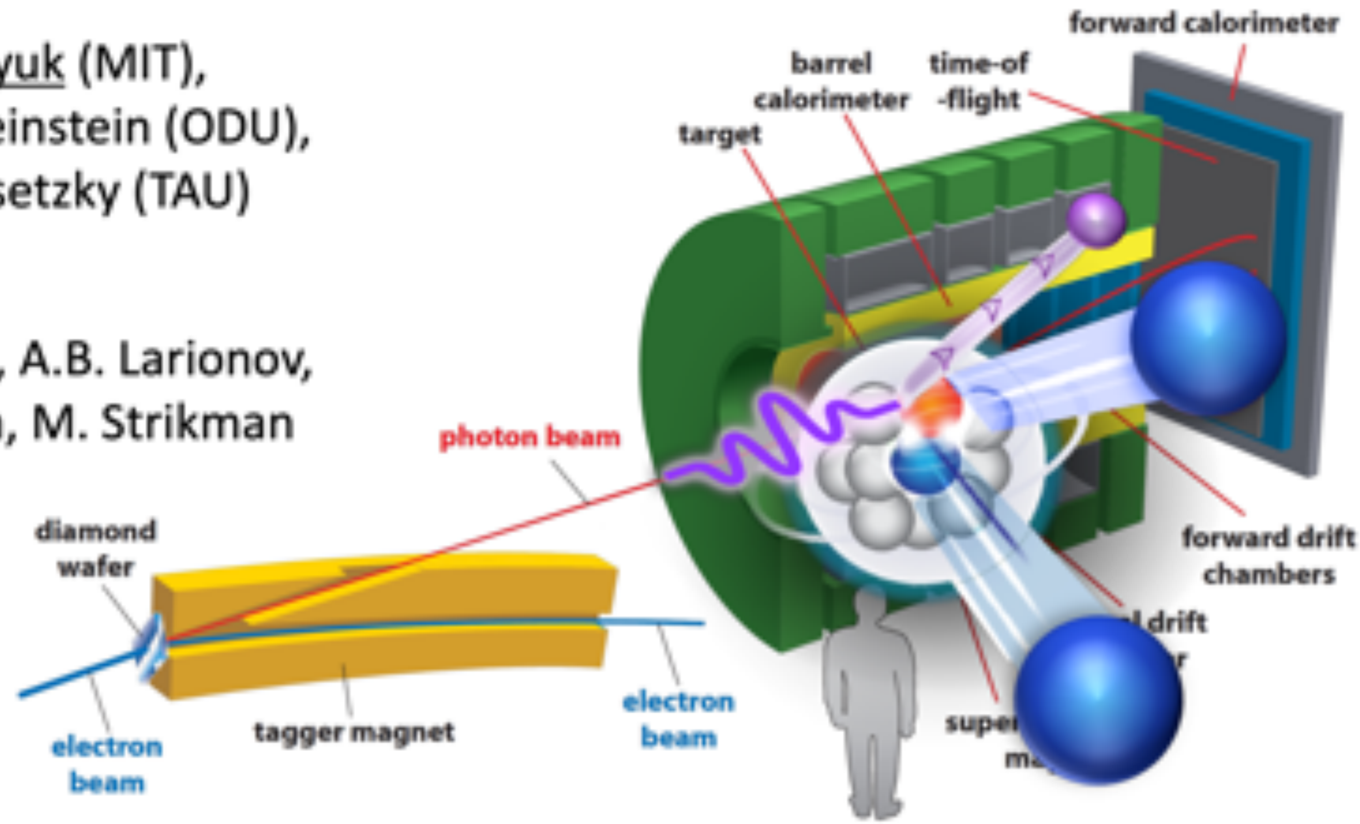

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Balanced 3 Course Meal To Start The Day

$|t| > 3\ \text{GeV}^2$ (3) SRC

$|t| > 3\ \text{GeV}^2$ (2) Color Transparency

$1 < |t| < 3\ \text{GeV}^2$ (1) Photon Structure

(1) Photon Structure in QCD

In production processes

Soft interaction: Photon = **Vector Meson Pair (VM)**

Hard interaction: Photon = **Point-Like Particle (PL)**

Regge model

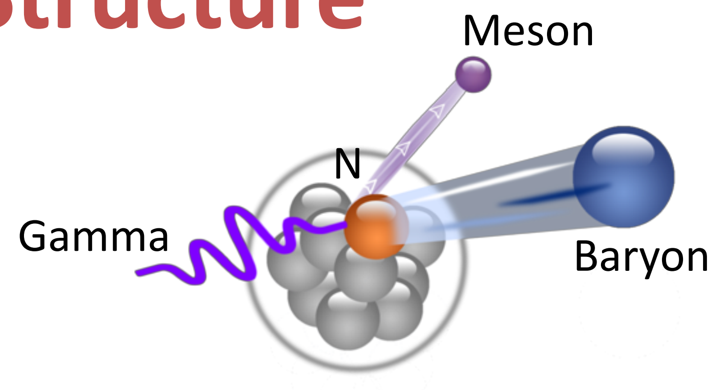
Fundamental question of the photon structure!

Soft-hard transition was never observed!

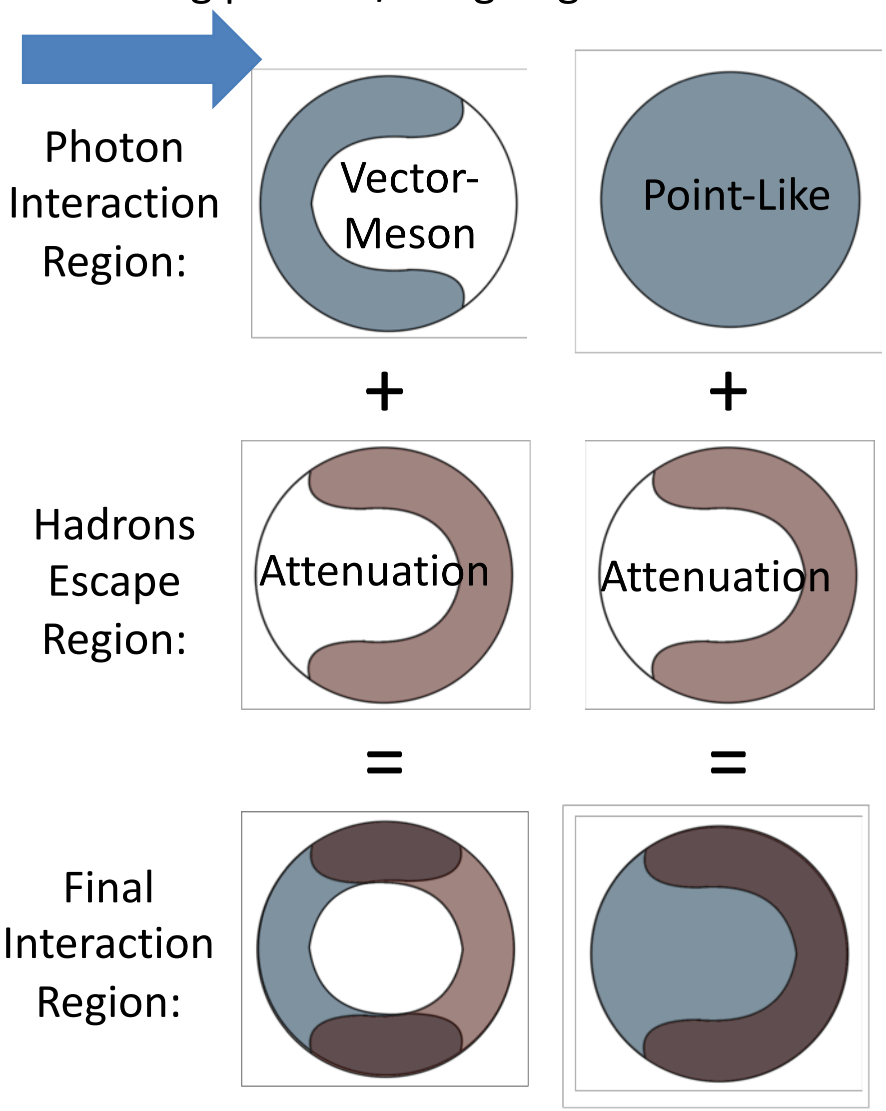
Soft-hard transition gives insight about the onset of QCD applicability for exclusive processes and origin of scaling behavior (constituent counting rules)

$$\frac{d\sigma}{d\Omega_{c.m.}} = \frac{1}{s^{\sum n_i - 2}} f(\cos\Theta_{c.m.})$$

Probing Photon Structure



Incoming photon / outgoing Hadrons direction



Measurements of exclusive photoproduciton off nuclei requires:

(A) Photon penetrates the nucleus
(B) Hadrons escape the nucleus

Reaction cross-section will have different value and A-dependence for Vector-Meson vs. point like photon!

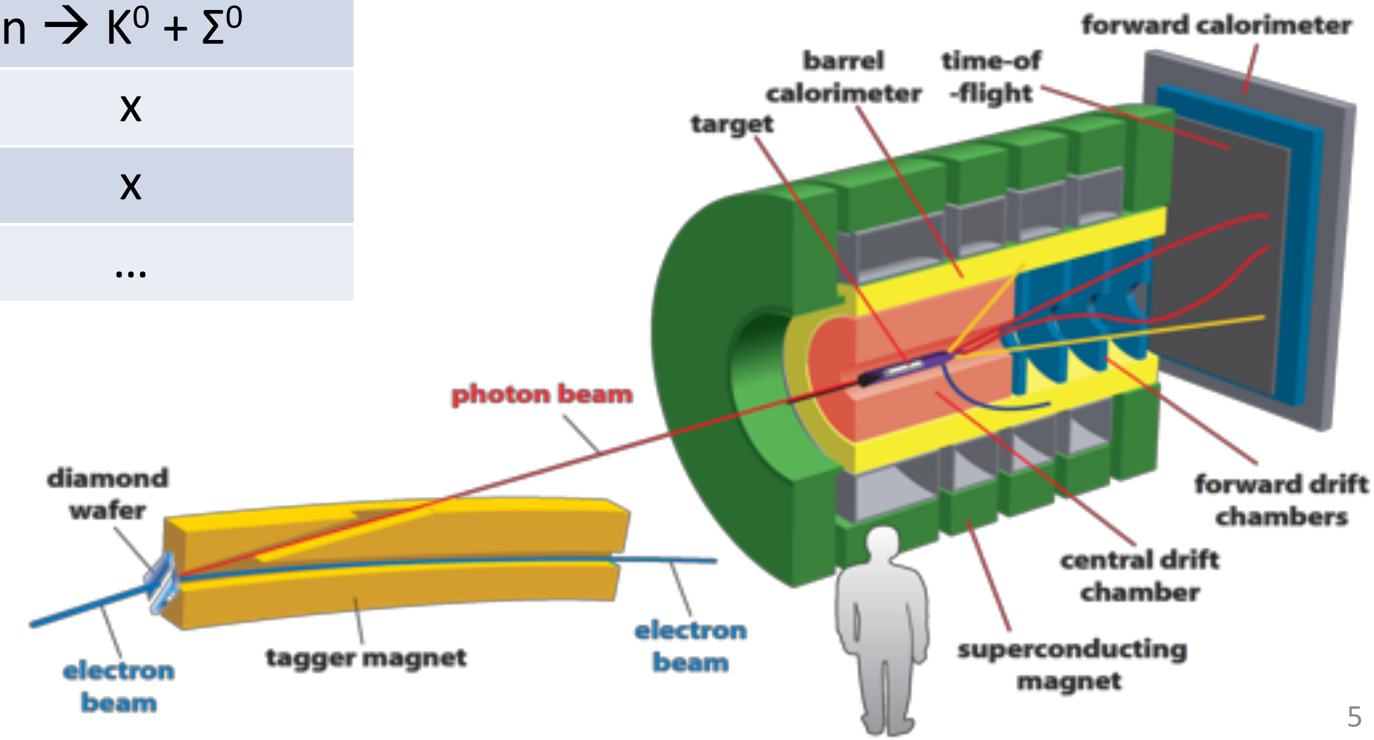
Details of soft-hard transition

Exclusive Proton Reactions	Exclusive Neutron Reactions
$\gamma + p \rightarrow \pi^0 + p$	$\gamma + n \rightarrow \pi^- + p$
$\gamma + p \rightarrow \pi^- + \Delta^{++}$	$\gamma + n \rightarrow \pi^- + \Delta^{++}$
$\gamma + p \rightarrow \rho^0 + p$	$\gamma + n \rightarrow \rho^- + p$
$\gamma + p \rightarrow K^+ + \Lambda^0$	$\gamma + n \rightarrow K^0 + \Lambda^0$
$\gamma + p \rightarrow K^+ + \Sigma^0$	$\gamma + n \rightarrow K^0 + \Sigma^0$
$\gamma + p \rightarrow \omega + p$	x
$\gamma + p \rightarrow \phi + p$	x
…	…

Simultaneous measurement of a wide range of final states allows probing the **quark composition** (π vs. η) and **spin** dependence (π vs. ρ) of the soft-hard transition

Targets:

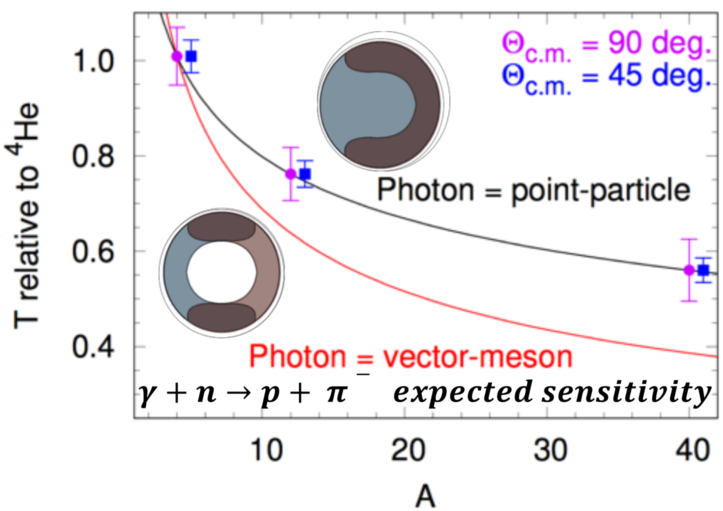
H, D, ^{4}He, ^{12}C, ^{40}Ca

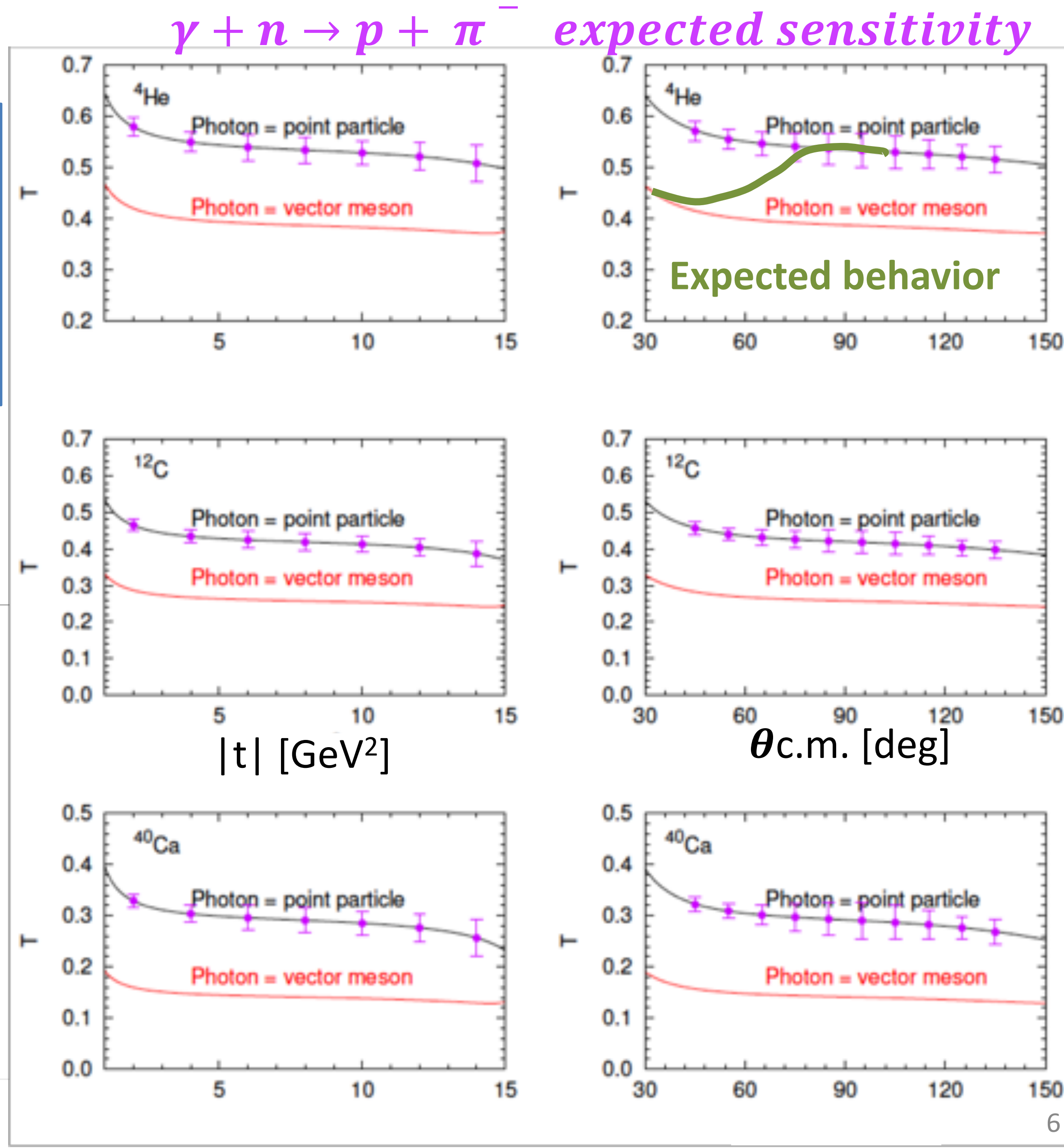


Mapping of soft-hard transition: A, |t|, |u|

Absolute transparency and ratios for **A= 4, 12, and 40** over a wide range of **|t|** and **|u|** → detailed map of the soft-hard transition!

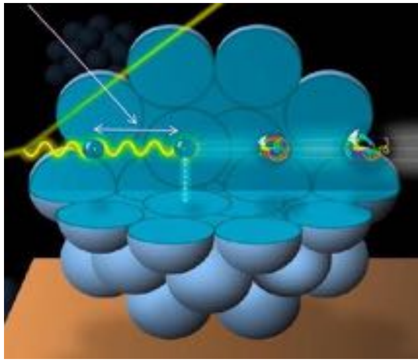
$$T = \sigma_{\gamma A} / A\sigma_{\gamma N}$$





Larionov and Strikman, PLB (2016)

(2) Color Transparency

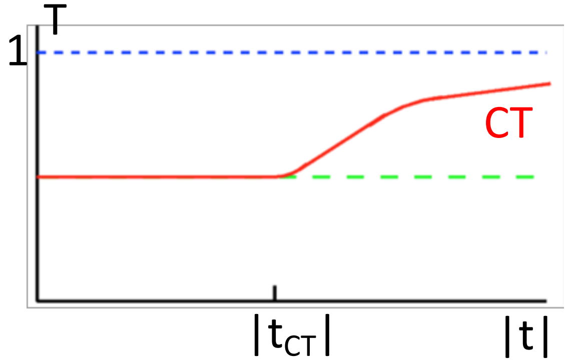


At high |t| photon couples to small transverse sized configuration of a nucleon

"squeezing" – defined by |t|, |u|

Fundamental QCD prediction: small sized configurations interact less with hadronic matter

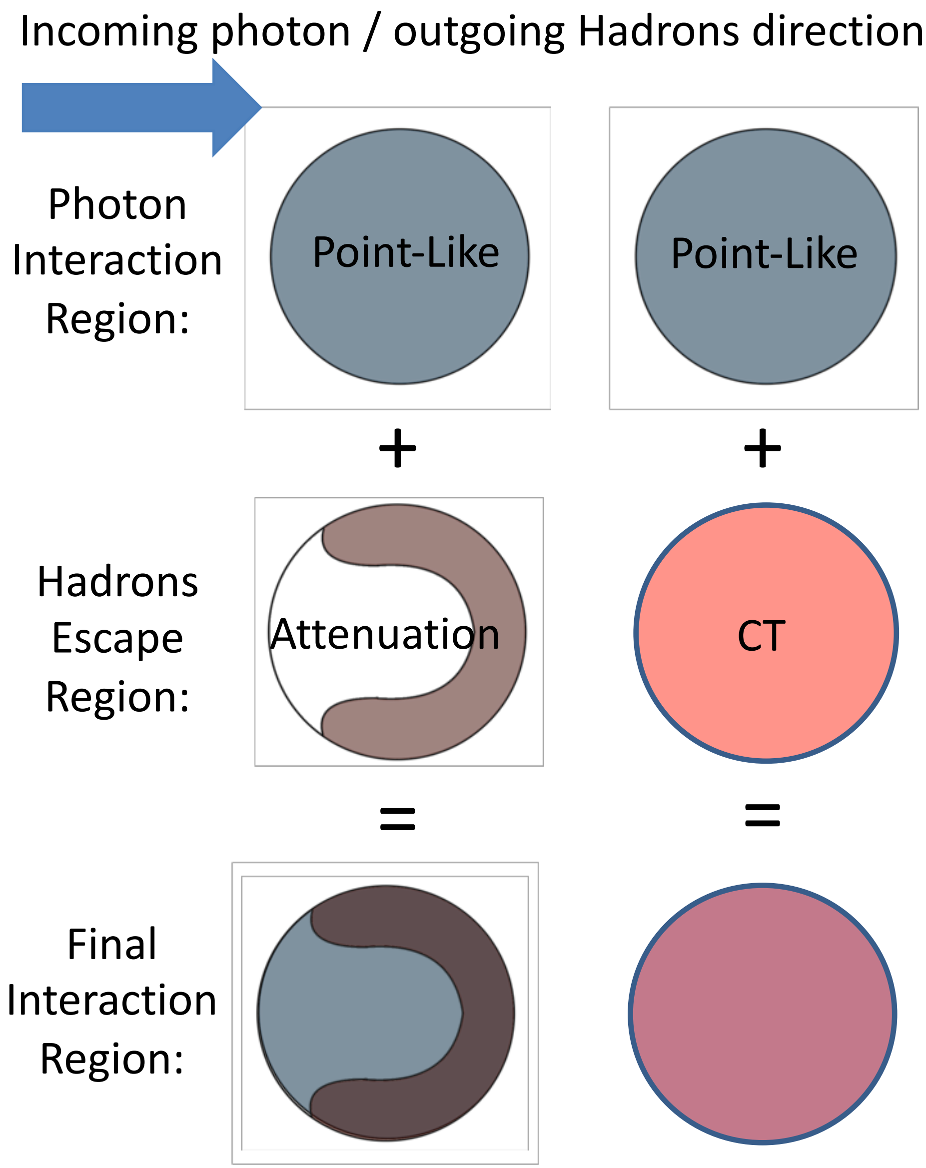
"freezing" – defined by energy transfer

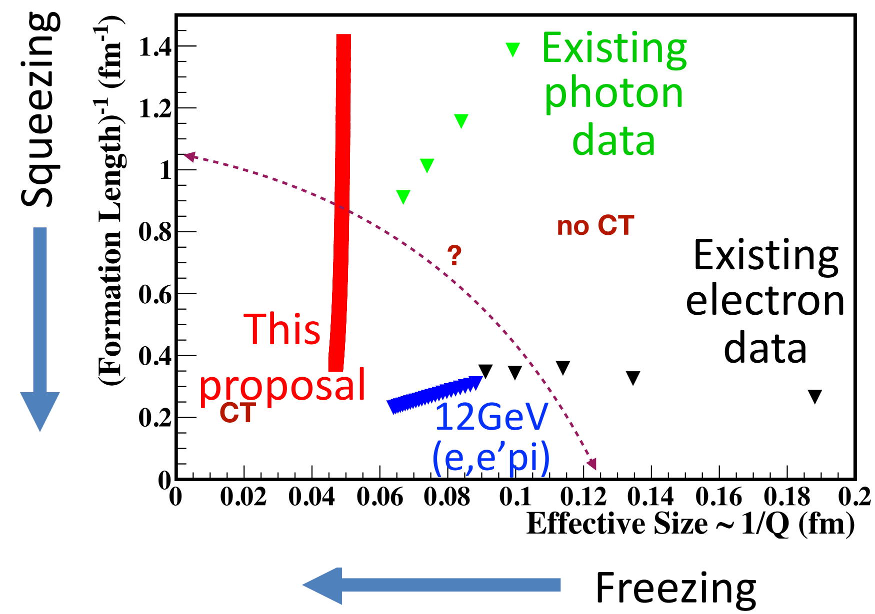


GlueX – unique machine to study CT:

high energy transfers even for moderate momentum transfers |t|!

Probing Color Transparency





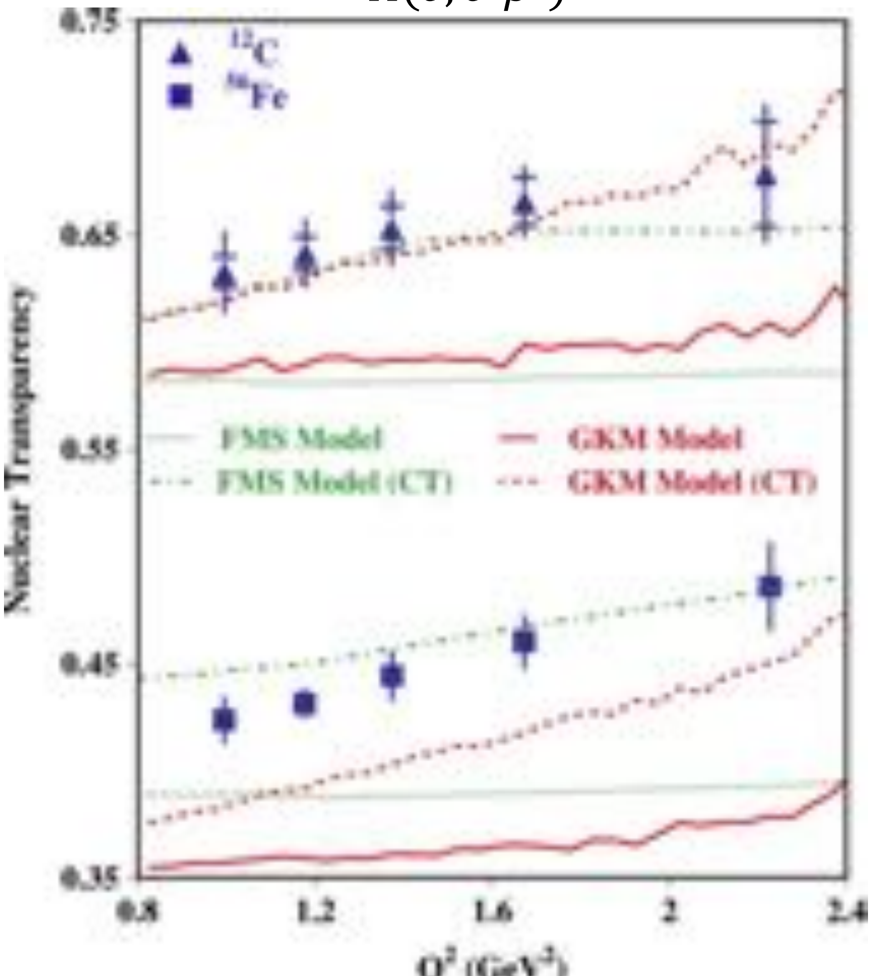
CT – is assumed for QCD factorization in GPD framework -

yet never observed for baryons!

Current status of CT

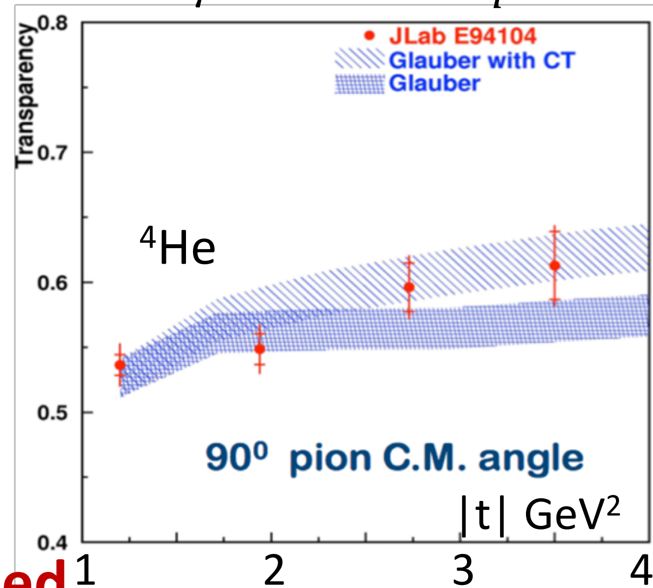
Mesons: observation

$A(e, e'\rho^0)$

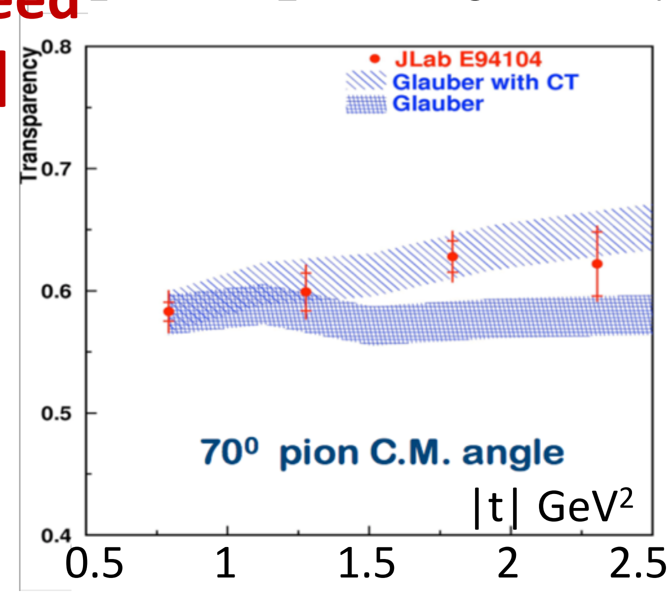


L. El-Fassi, et al., PLB 712, 326 (2012)

$\gamma + n \rightarrow \pi^- + p$



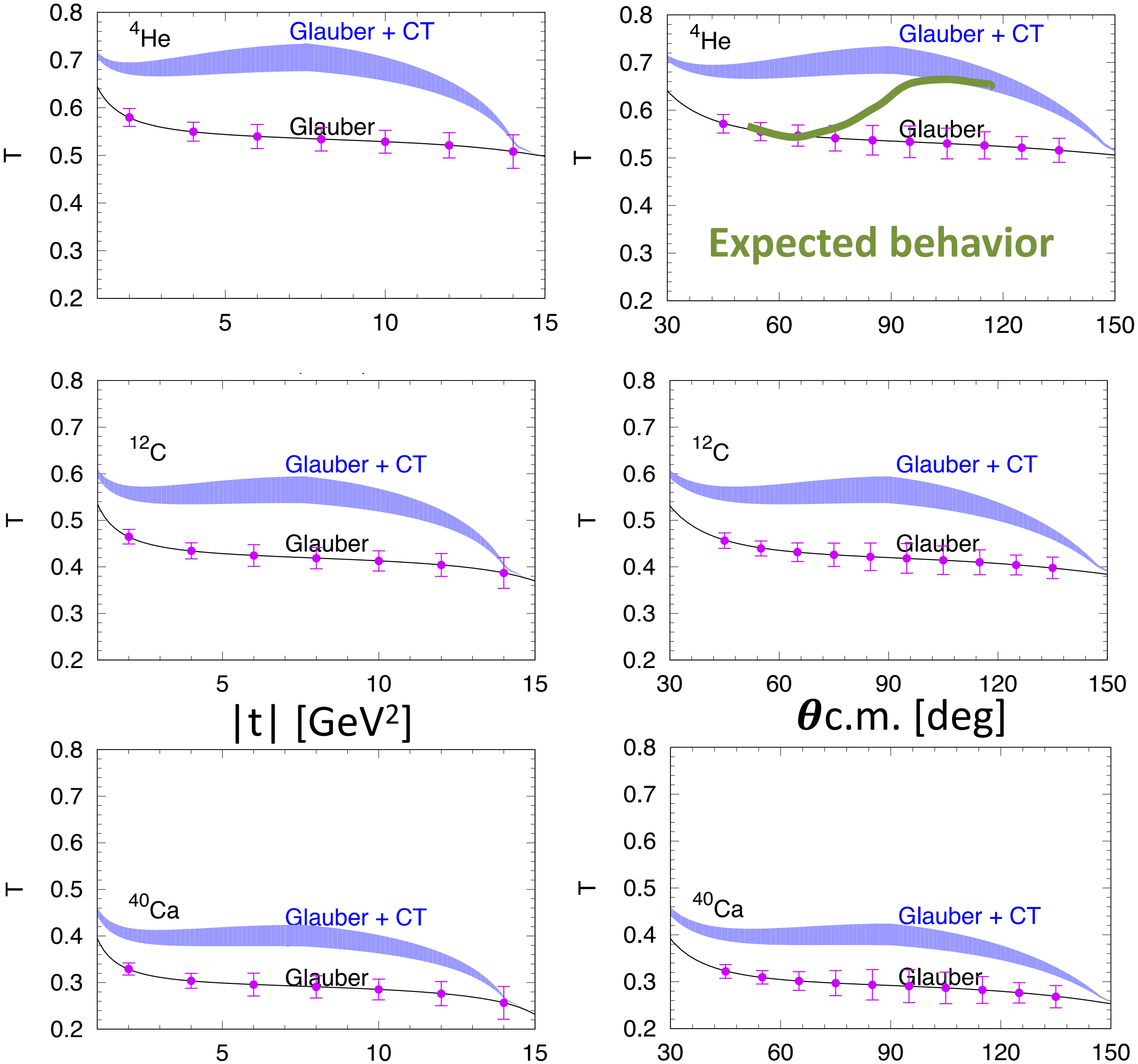
Baryons: need larger |t|



Dutta et al. PRC 68, 021001R (2003)

GlueX advantages

$\gamma + n \rightarrow p + \pi^-$ *expected sensitivity*



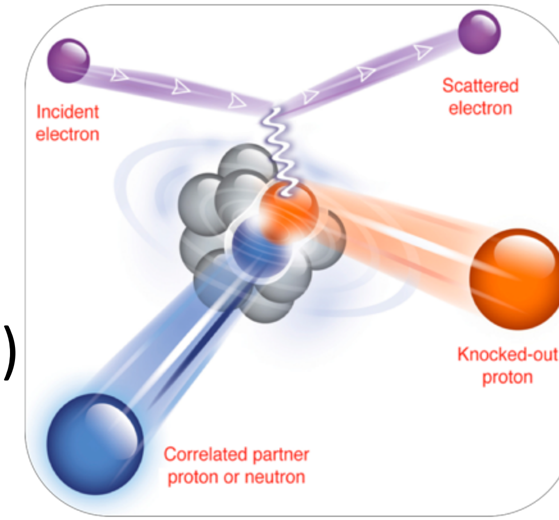
Previous measurements:
$|t| < 3.5$ GeV^2

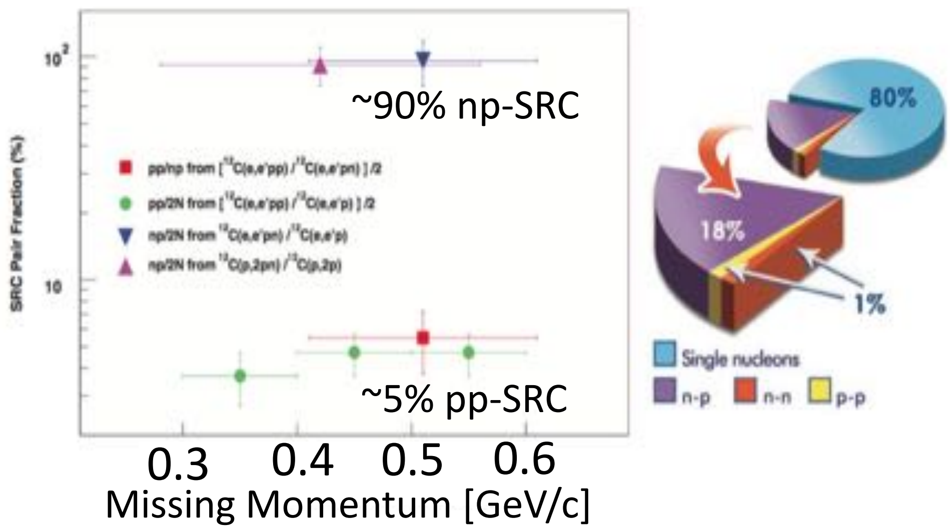
1. **Extends $|t_{max}|$ from 3.5 GeV^2 to >10 GeV^2!**
2. **Higher photon energy (enhanced "freezing")**
3. **Many baryon-meson final states**
4. **Wide c.m. angle coverage**

(3) Short-Range Correlations (SRC)

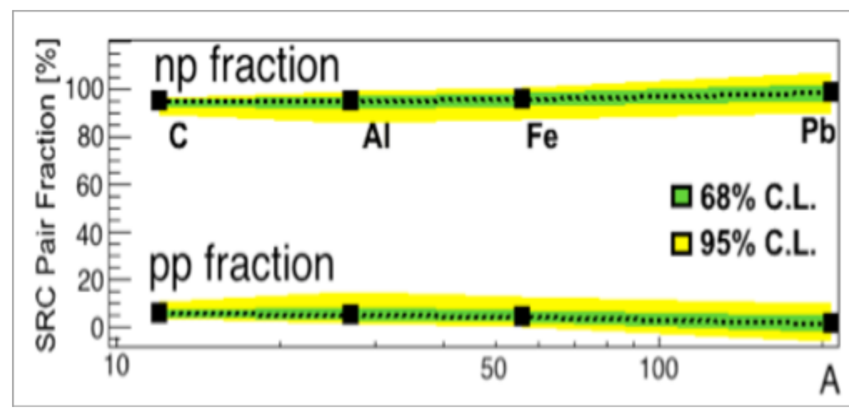
Nucleon pairs with high relative momentum and low c.m. momentum compared to k_F

Studied primarily with A(e,e’pN) and A(p,2pn) reactions





Subedi et al., Science (2008)

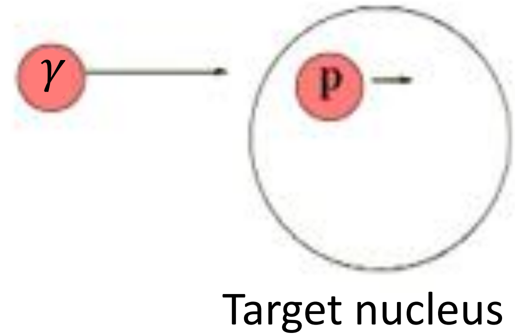


Hen et al., Science (2014)

Why photons ?

Interaction is more likely with high momentum forward going nucleon (SRC)

$$\frac{d\sigma}{dt} \propto s^{-7}$$



Probe independence on reaction mechanism:

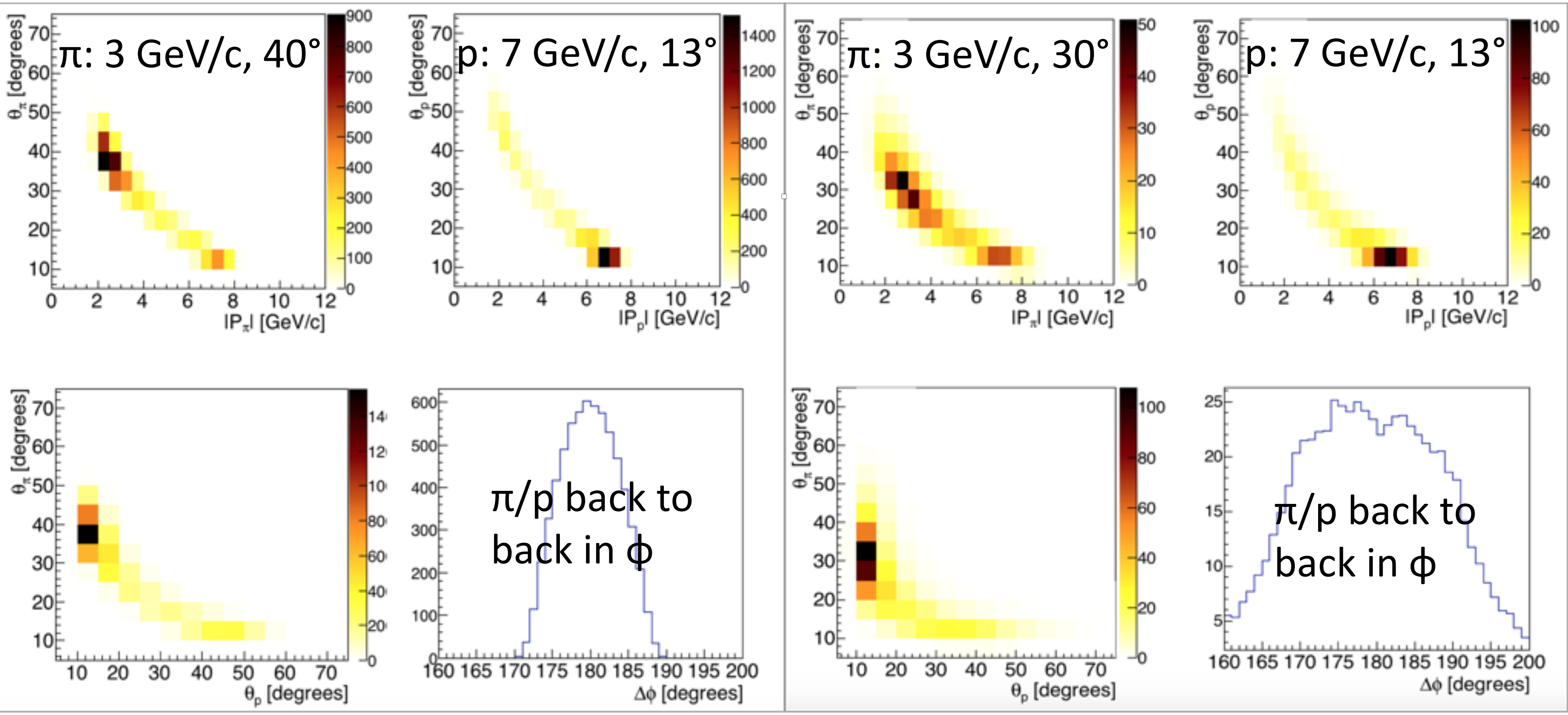
- e and p data show good consistency
- e vs. γ – different reaction mechanisms and kinematics
- Isospin structure: np/pp ratio
- Momentum transfer |t| dependence

Kinematical distributions

$\gamma + n \rightarrow \pi^- + p$ (smallest expected rate)

Mean Field (MF):
P_{miss} < 0.25 GeV/c

SRC:
P_{miss} > 0.3 GeV/c, θ_{recoil} < 160°



Reconstruction of final state particles in GlueX software

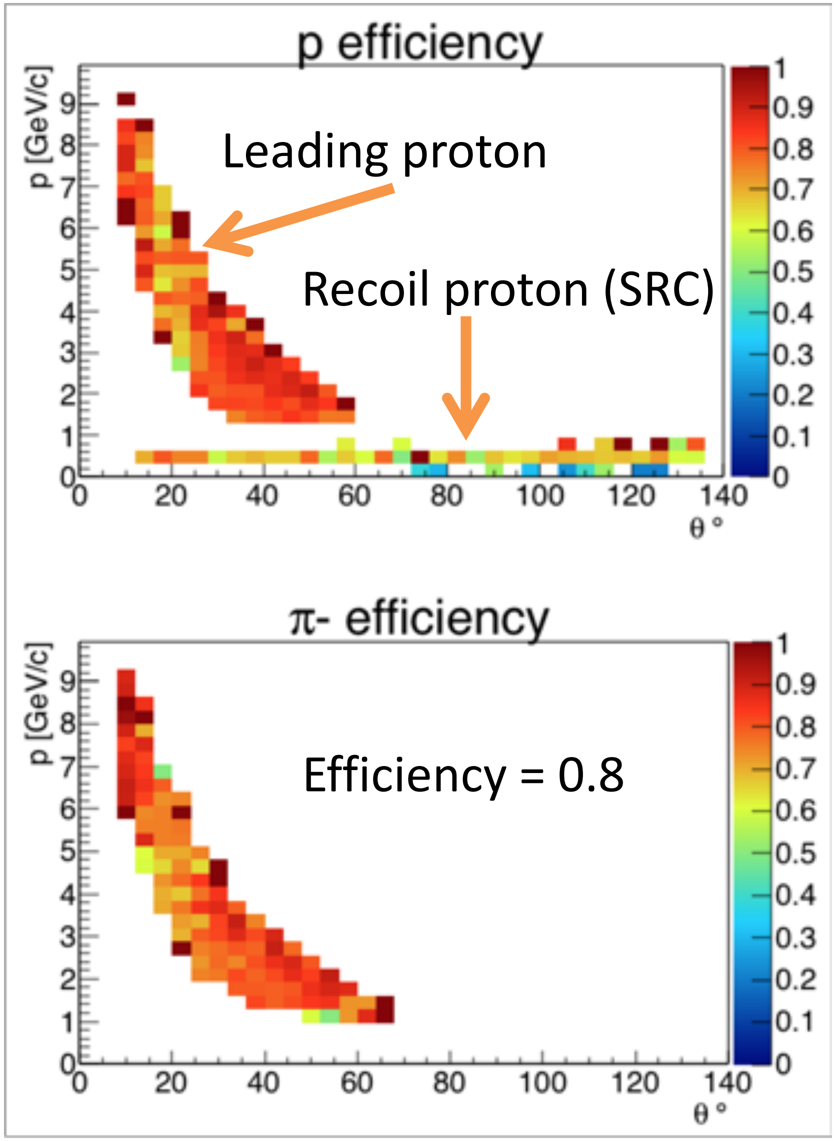
$$\gamma + n \rightarrow \pi^- + p$$

Detection efficiency:

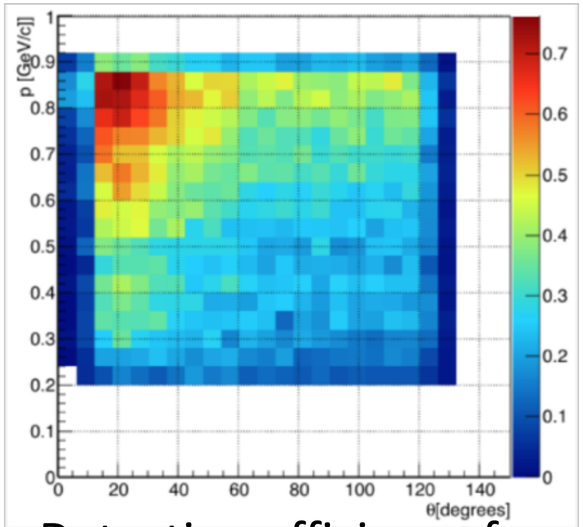
80% → each of leading particles

65% → recoil proton (SRC)

30% → reconstruction of ρ^0

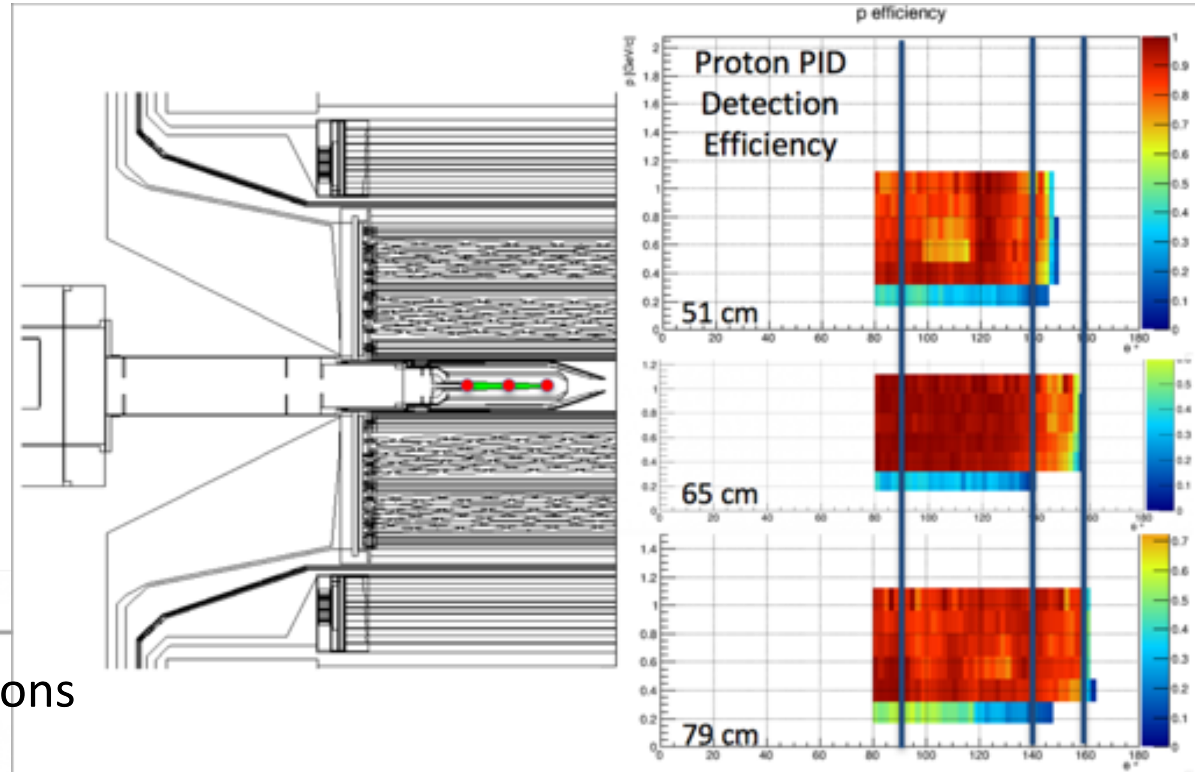


Detection efficiency for the recoil (SRC)

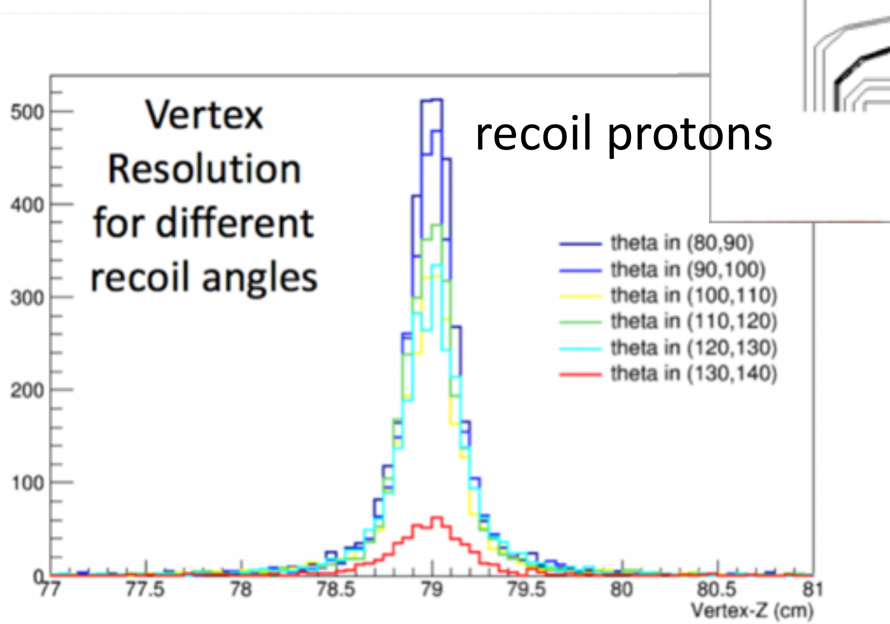


Detection efficiency for neutrons vs. angle and p

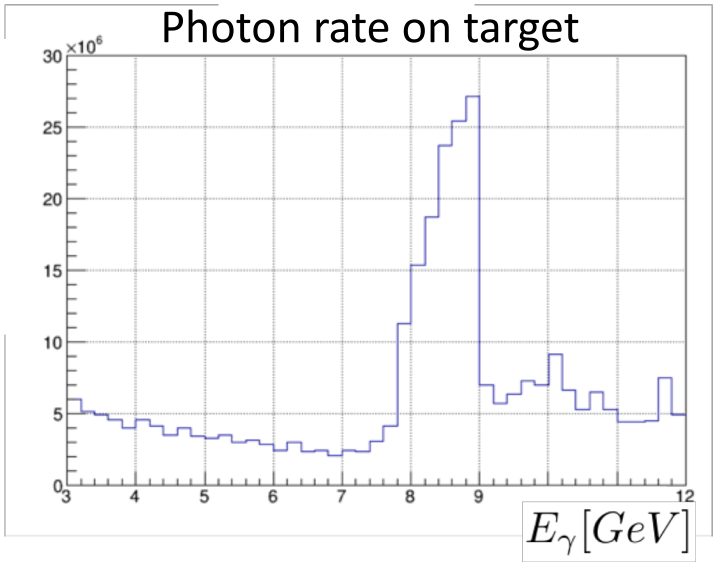
Estimated using full GlueX Geant-based software

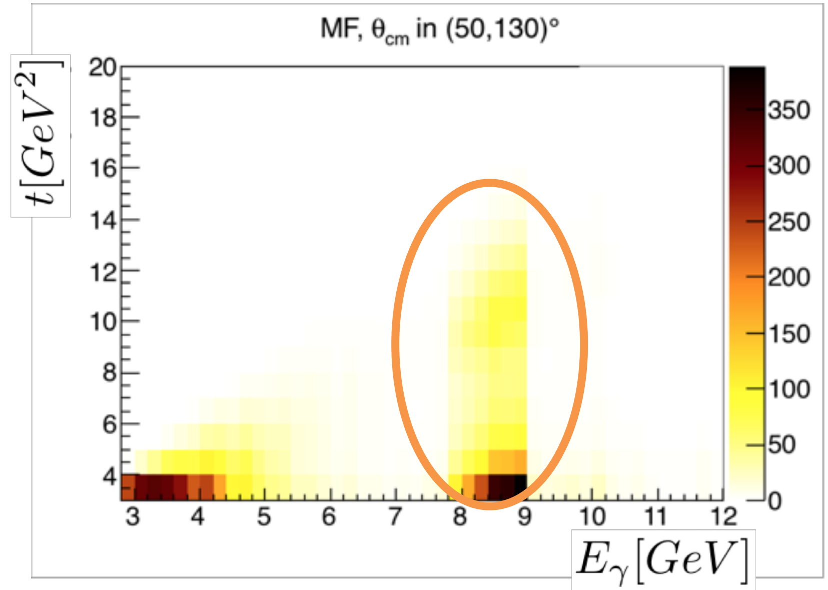


Detection efficiency for recoil protons vs. angle and p for 3 target locations



Beam conditions





Can not use the whole photon spectrum because of tagger occupancy

$$\frac{d\sigma}{dt} \propto s^{-7},$$ need large |t| values

Coherent peak [8.4, 9.1] GeV and **5 mm collimator**

Rate optimization for a set of targets

Prioritized list of factors limiting the event rates:

1. GlueX detector capabilities: limited flux on target of 2 x 10^7 photons/s in the coherent peak
2. Target thickness → electromagnetic background ~ X_0
3. Neutron background $\propto \rho_{target} \cdot A$
4. Coincidental rate in the tagger (up to 24% for this flux)

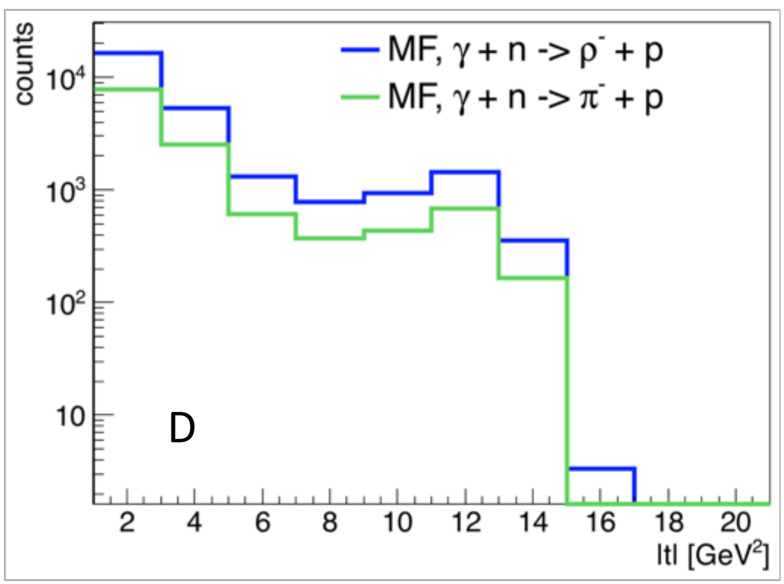
Target	Thickness [cm] / % X_0	Atoms/cm^2 for the given target thickness	EM bkg. rel. to GlueX	Neutron bkg. rel. to GlueX
D	30 / 4.1	1.51×10^{24}	0.5	1.3
^{4}He	30 / 4	5.68×10^{23}	0.5	1
^{12}C	1.9 / 7	1.45×10^{23}	1	0.8
^{40}Ca	0.73 / 7	1.70×10^{22}	1	0.3
LH	30 / 3.4	1.28×10^{24}	1	1*

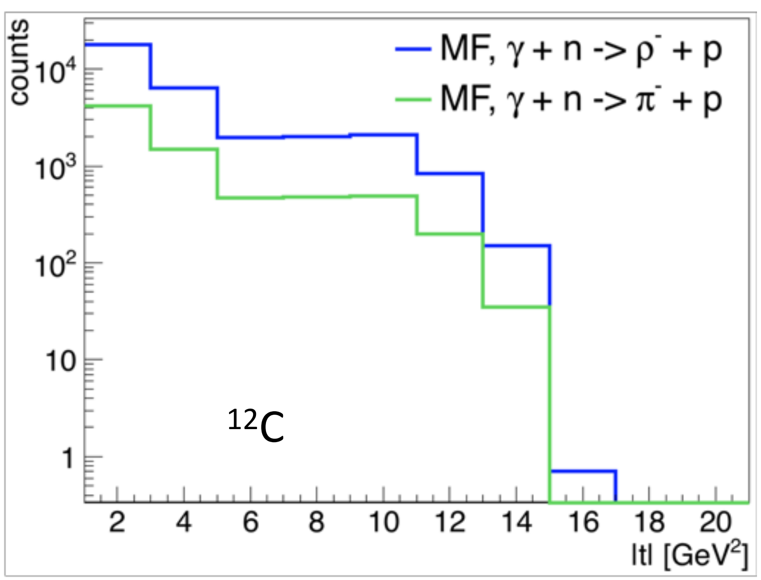
* For nominal flux in the coherent peak of 10^8 photons/s

Proposed Measurement

Event rates for reactions with the smallest and largest cross sections

Target	$\gamma + n \to \pi^- p$		$\gamma + n \to \rho^- p$		PAC Days
	MF	SRC	MF	SRC	
D	13,600	750	57,000	3,000	5
^{4}He	13,000	670	54,500	2,800	8
^{12}C	7,400	2,300	31,000	9,500	10
^{40}Ca	2,600	840	10,900	3,500	14
Calibration, commissioning, and overhead:					3
Total PAC Days:					40





Summary

- A new photonuclear program for Hall-D
- Standard GlueX conditions and no changes to the GlueX spectrometer and Hall-D beam line
- Physics focus:
  1. Photon Structure
  2. Color Transparency and SRC
  3. Many more ideas being suggested by theoreticians…

     (e.g. M. Sargsian contribution to arXiv:1704.00816)

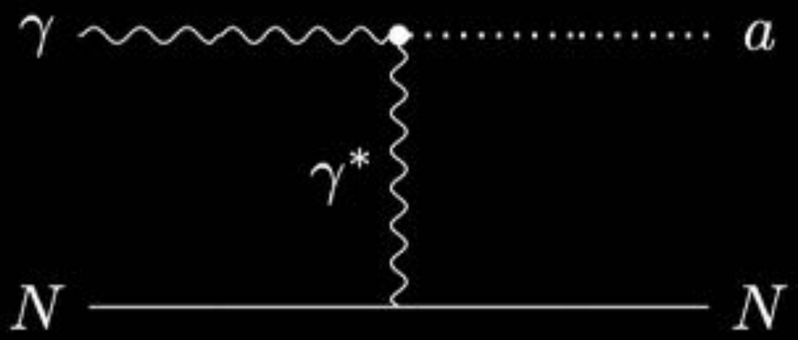
Axion-like particles photoproduced at GlueX

Daniel Aloni, Cristiano Fanelli, Yotam Soreq, and Mike Williams

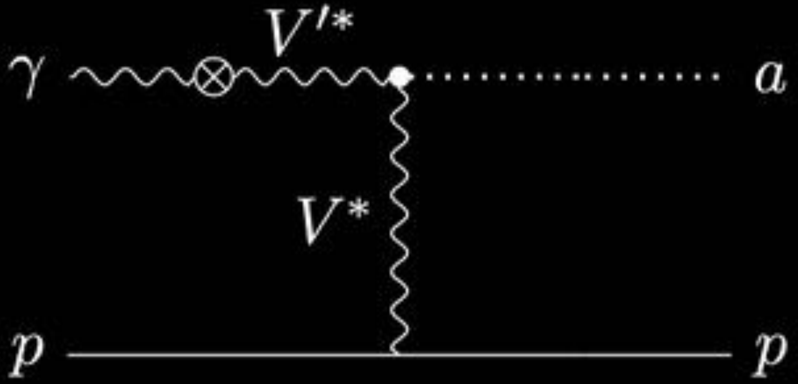
Outline

- Study of ALP with QCD-scale masses whose dominant coupling to SM is to photons or gluons
- Introduced data-driven method (no knowledge of nuclear form factors or photon-beam flux) when considering coherent Primakoff off of a nuclear target
- PrimEx data (2004) can improve sensitivity by an order of magnitude
- Estimated potential sensitivity of GlueX with a nuclear target (and using CompCal calorimeter)
- The case where the dominant coupling is to gluons has been studied for the first time in photoproduction and future GlueX sensitivity is predicted.

Production Mechanism



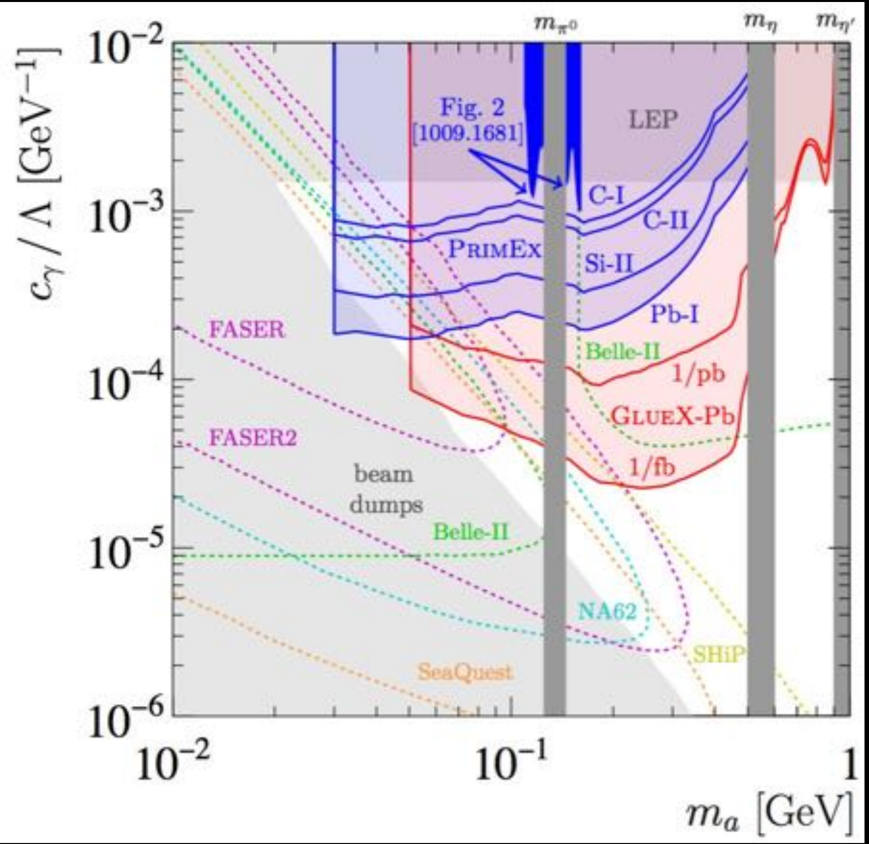
Primakoff production
via t-channel photon exchange



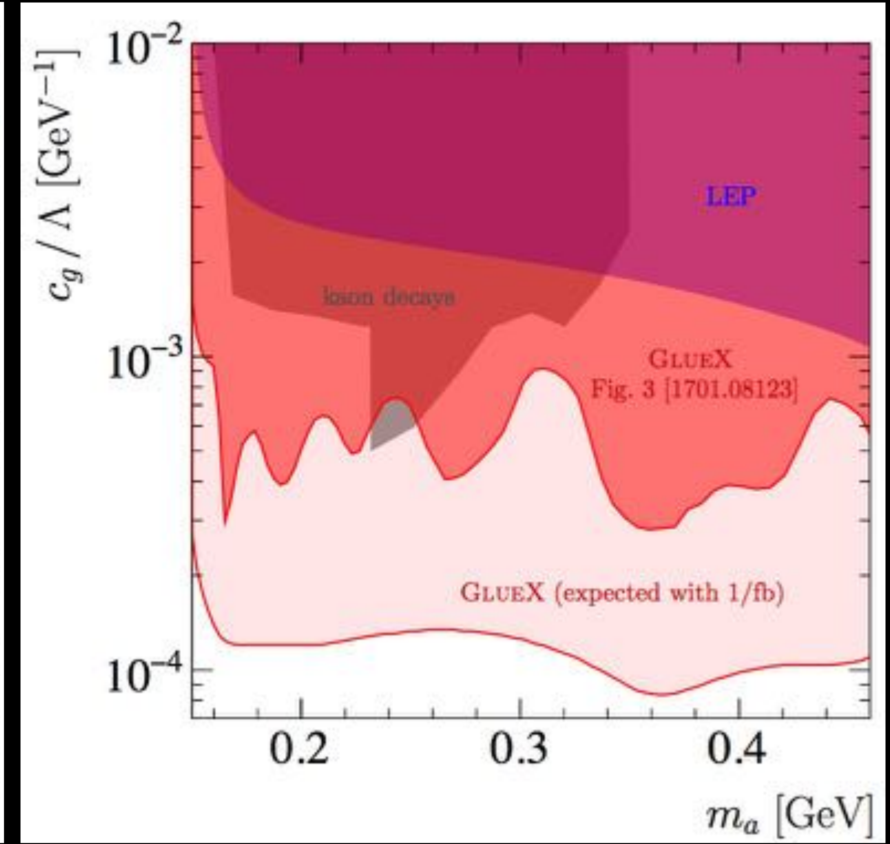
Photon-vector meson mixing and
t-channel vector meson exchange

$\gamma\gamma$ is the main decay mode at low mass

Limits



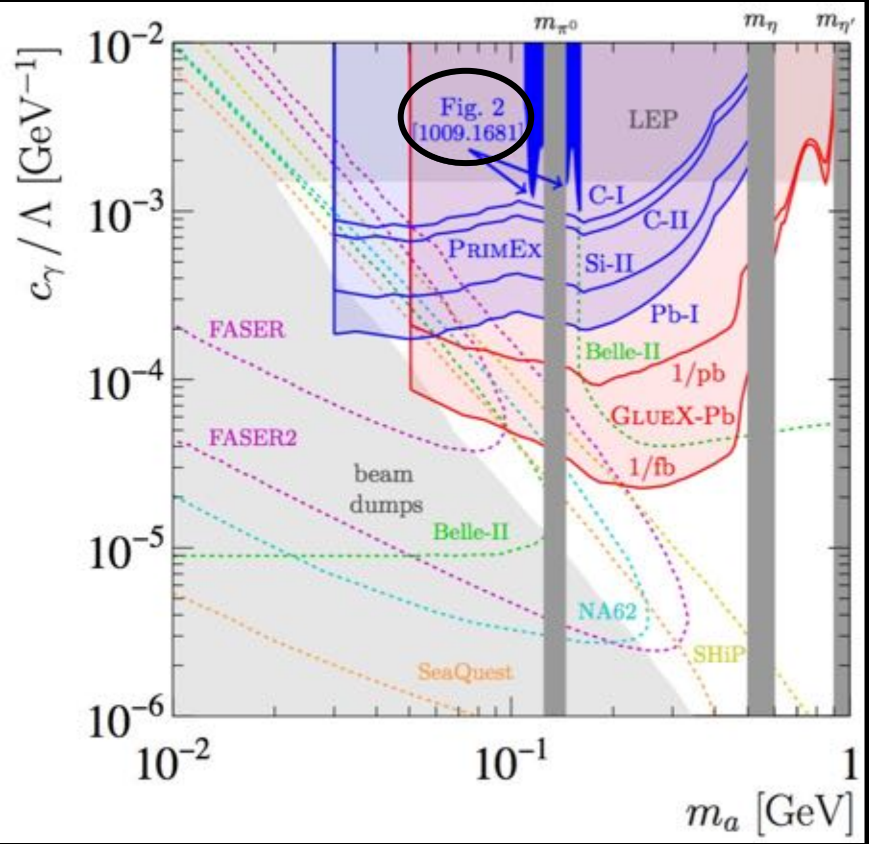
Projections for the ALP-photon coupling (c_γ=1,c_g=0)



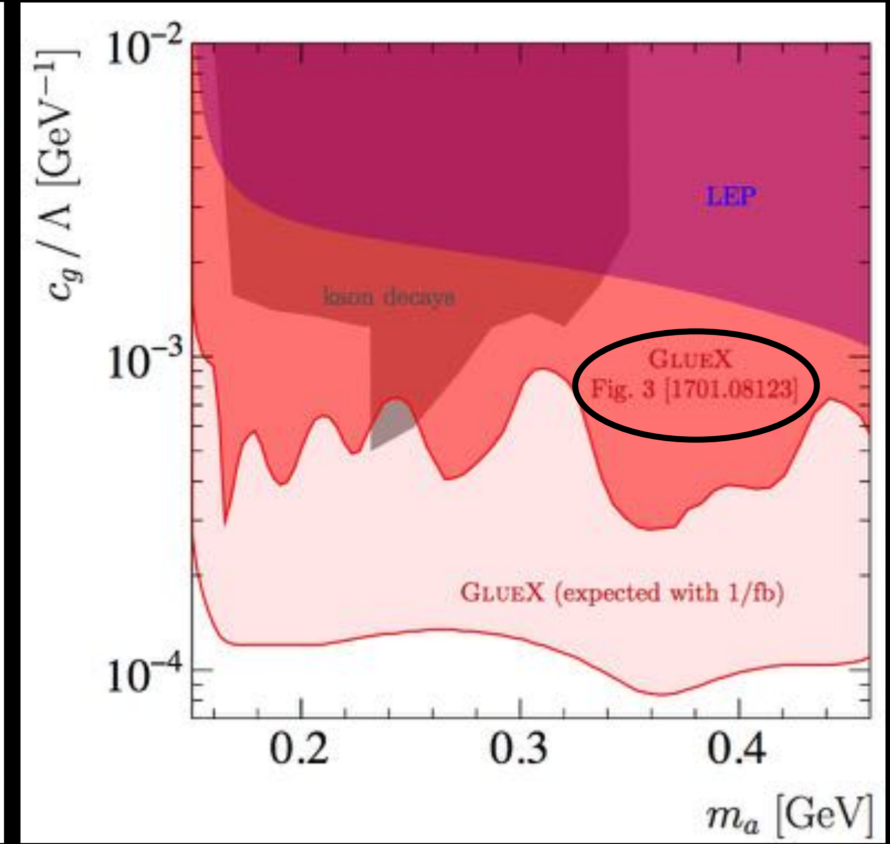
Projections for the ALP-gluon coupling (c_γ=0,c_g=1)

Limits

world-leading limits based on public plots



Projections for the ALP-photon coupling (c_γ=1,c_g=0)



Projections for the ALP-gluon coupling (c_γ=0,c_g=1)

Final Remarks

- Explored sensitivity of photon-beam experiments to ALPs
- Two scenarios (dominant coupling to photons or gluons) presented but can be generalized to any other set of ALP couplings.
- Set world-leading limits determined with public data
- Explored potential sensitivity of GlueX with a nuclear target