Virtual Photon Tagging:
Probing Confinement Scale QCD

R. G. Milner for A.M. Bernstein, MIT
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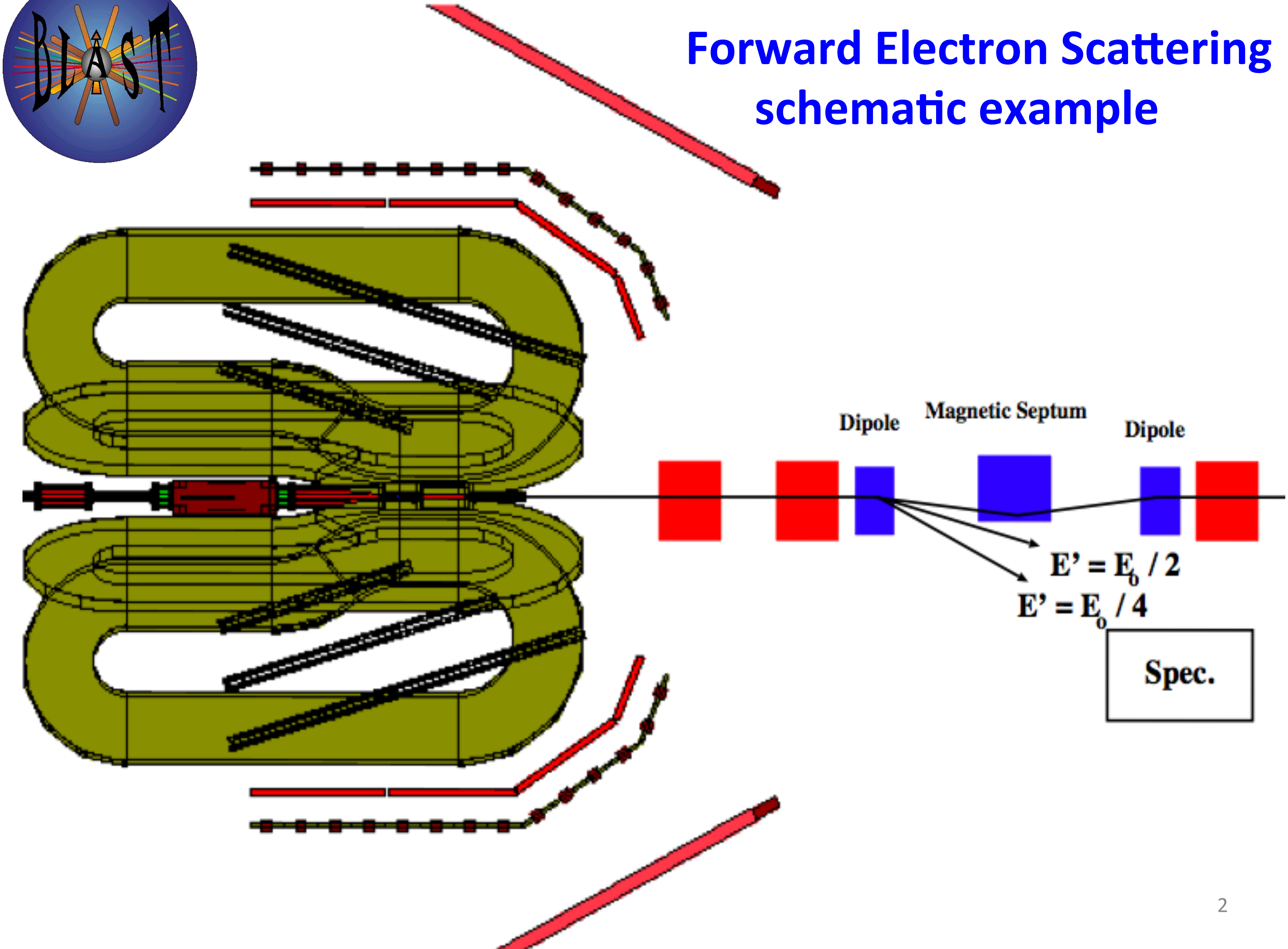
Symmetry Tests in Photo-pion Production
A.M. Bernstein
AIP Conf. Proc. **1563**, 159 (2013)

Physics Opportunities

- $\gamma N \rightarrow \pi N$ amplitudes: chiral symmetry predictions
- Use proton, D, and ^{3}He thin gas targets => recoil detection
- Test first principle few-body calculations
- Test isospin violation: m_d-m_u
- Measure NN charge symmetry violations
- Measure Compton scattering -> nucleon polarizabilities
- Elastic ep scattering -> proton charge radius

Forward Electron Scattering schematic example



γp -> $\pi^o p$ Forward Proton Detector Near Threshold

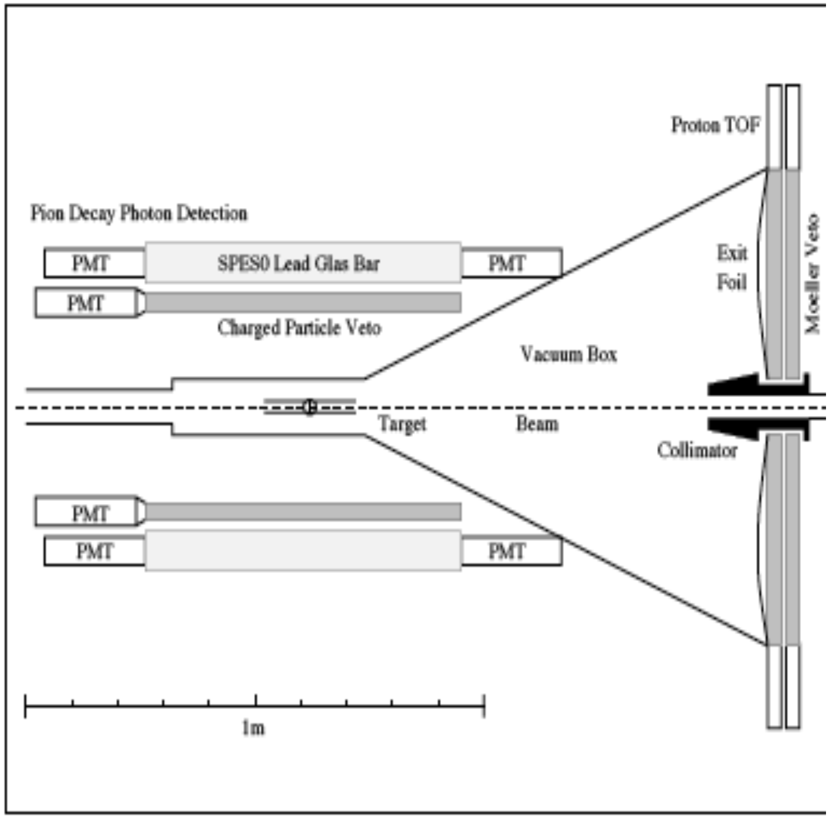
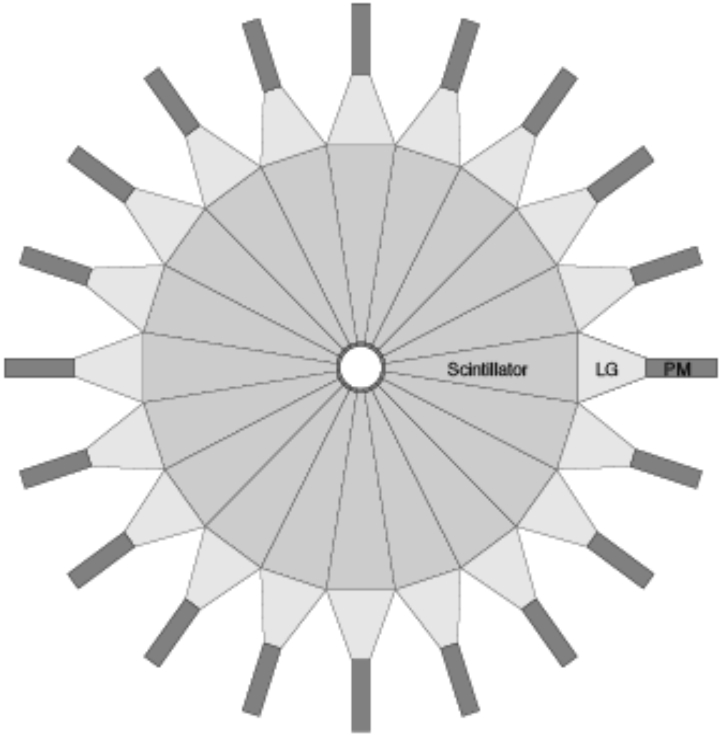


Figure 35: Schematic representation of a possible hadron and photon d
study threshold $\gamma p \to \pi^0 p$ and $\gamma p \to \eta p$.



Detailed scientific proposal document available

Small Angle Electron Scattering

- Measures electrons that have interacted in target
- Has higher efficiency than conventional taggers

  most photons do not interact in target
- Can use high currents with pure, thin targets
- Can observe low energy recoil particles

  $\gamma p \to \pi^0 p, \pi^+ n$ $\gamma n \to \pi^0 n, \pi^- p$ $\gamma D \to \pi^0 D$
- Coherent π^0 production in D, ^{3}He

  measure relative signs of $\gamma p \to \pi^0 p$, $\gamma n \to \pi^0 n$ amplitudes
- Low Q^2, virtual photons almost real (transverse)
- Small transverse beam spot

Mainz photon tagger and detector state-of-the art

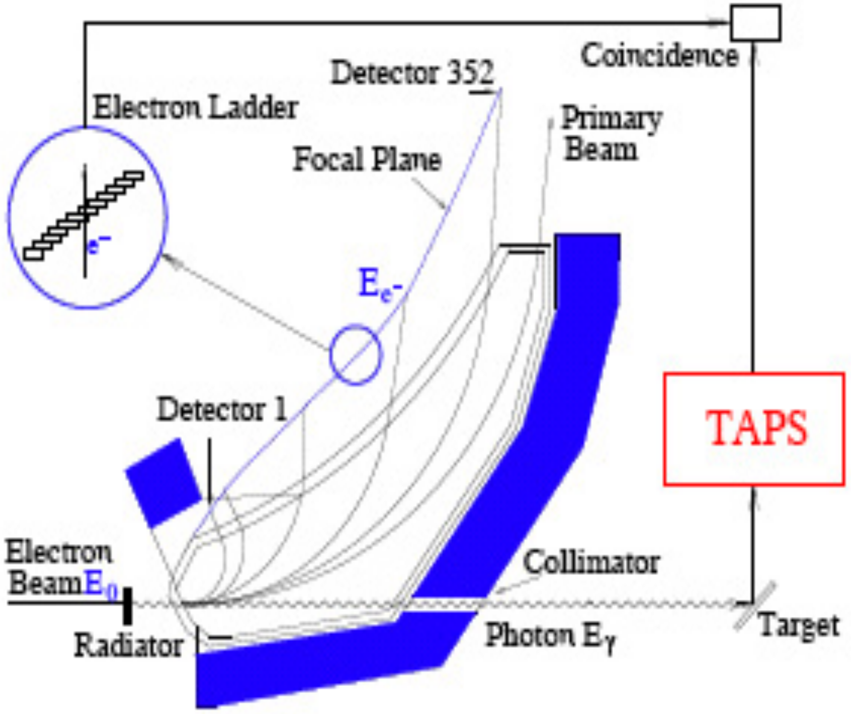
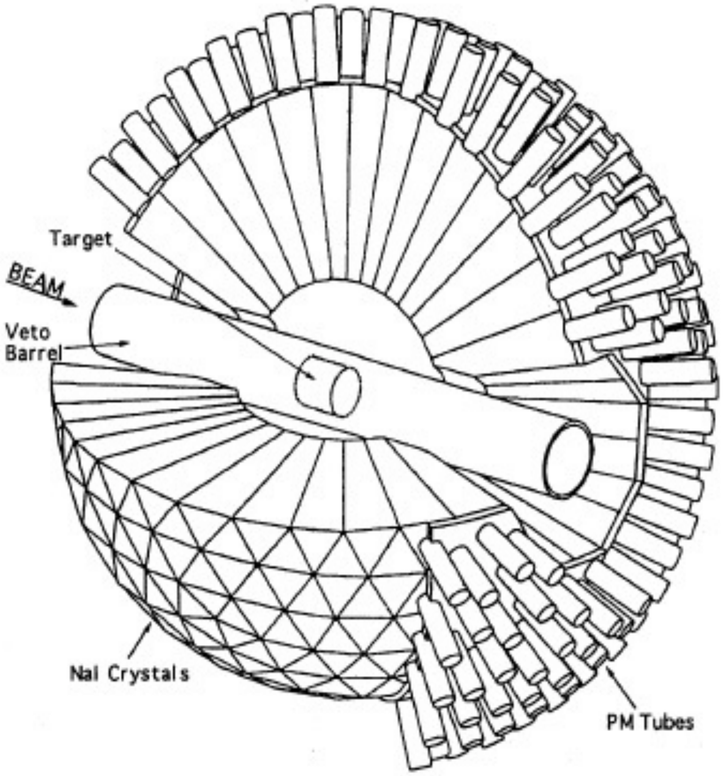
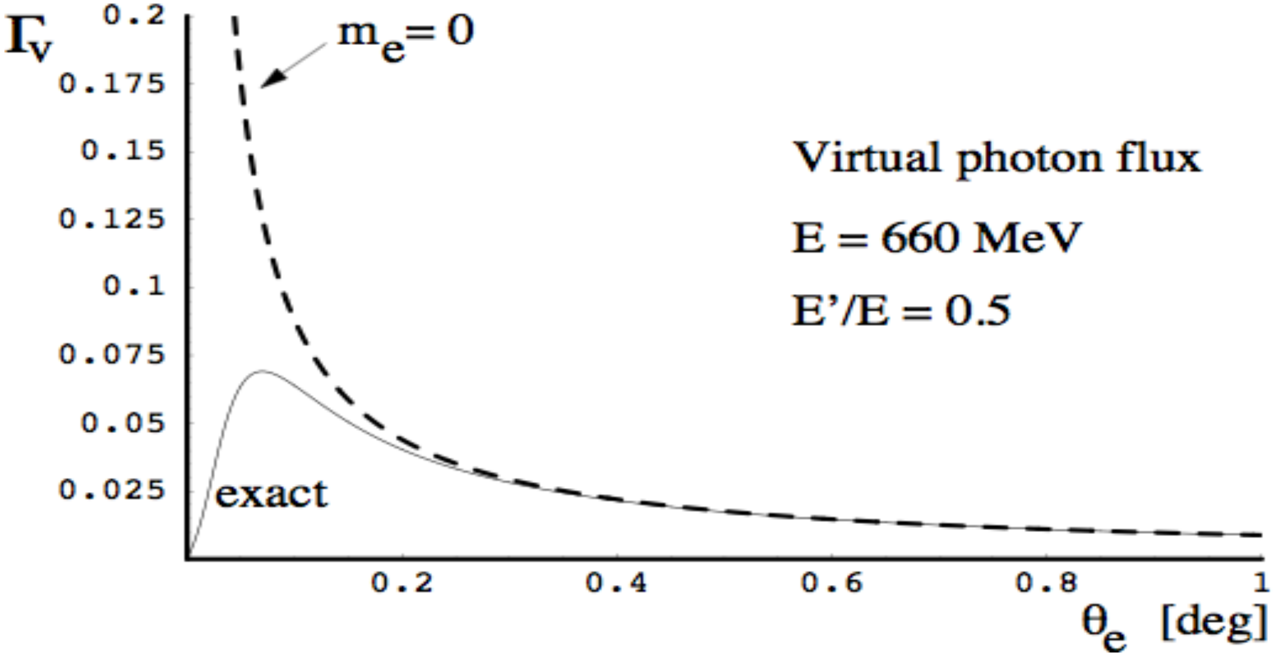


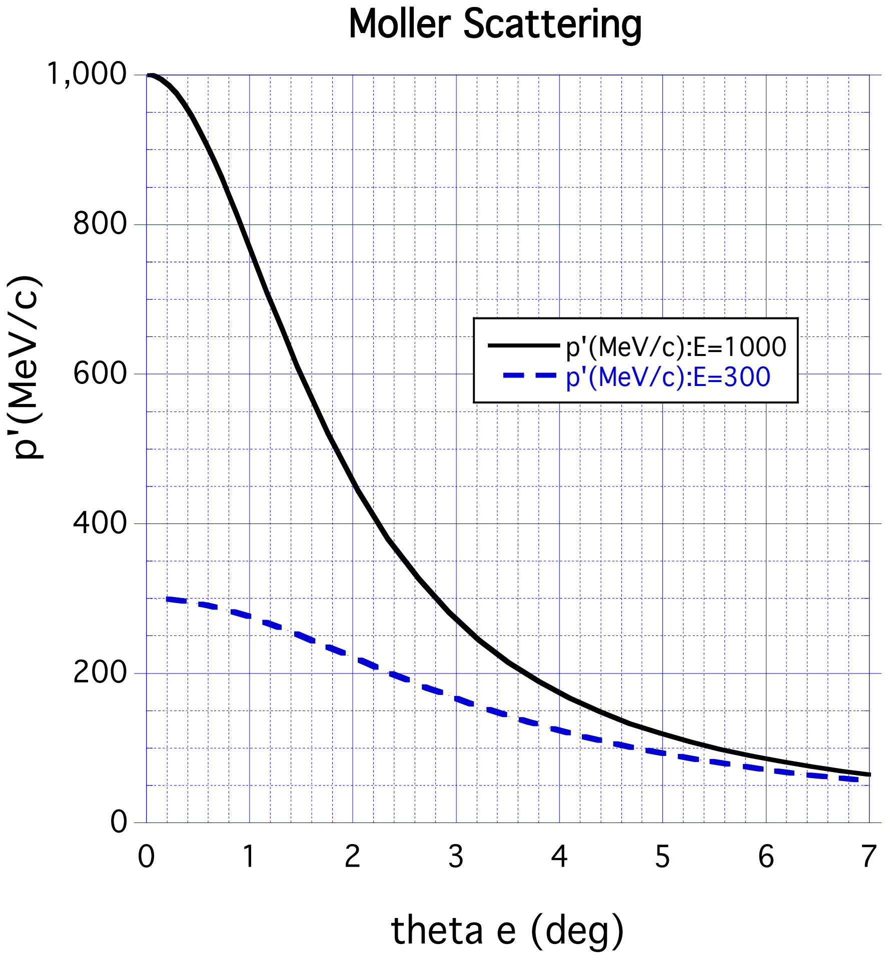
Figure 13: The photon tagger in the A2 experimental hall at MAMI.

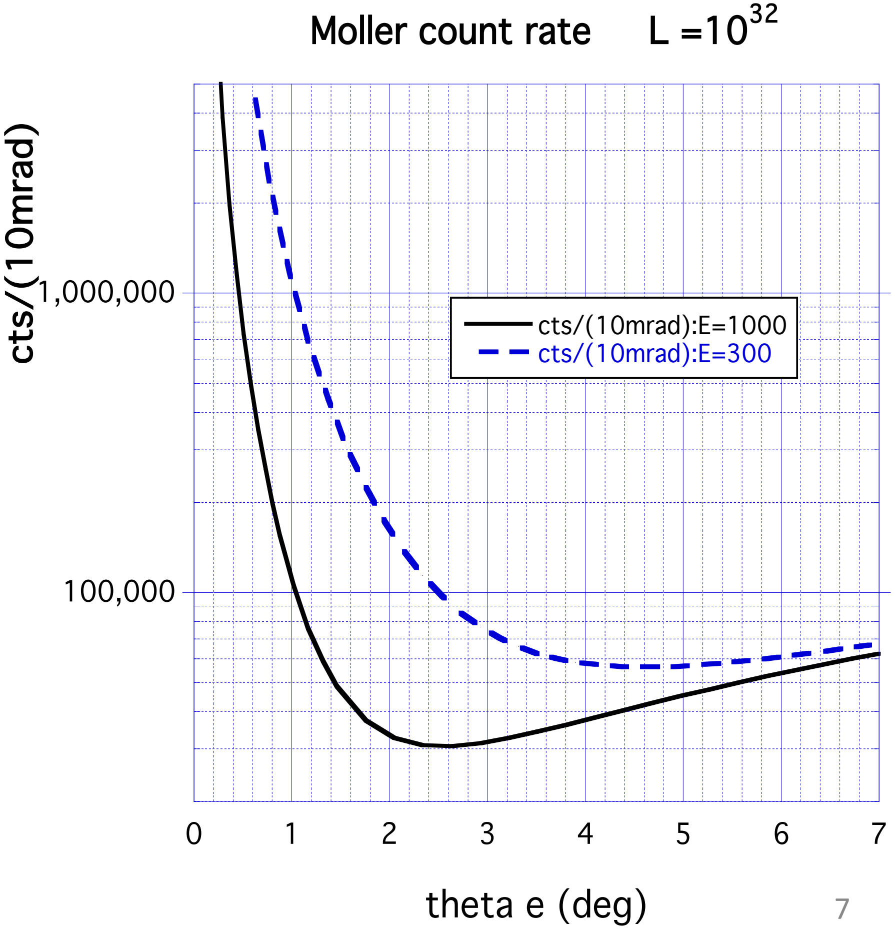


Virtual Photon Flux



Møller – major background for e-detector


Moller Scattering


Moller count rate $L = 10^{32}$

Tagged vs. Virtual Photons

In Tagged Photon Experiments:

- Most photons do not interact in the target
- Data taking is limited by rates in the tagger
- Thick targets are required, which limits the energy region
- Polarized targets have extraneous material, e.g. butanol: C, O produce background

Using Virtual photons:

- Is more efficient
- Require **energy > 300 MeV** for pion production experiments
- Detected electrons have interacted in the target
- Thin targets allow **detection of low energy recoils** limited by rates in forward electron counter

Low current ≈ 1 mA

- thin, **windowless** unpolarized gas targets $p \approx 1$ mm Hg
- measure low energy π^+, p recoil

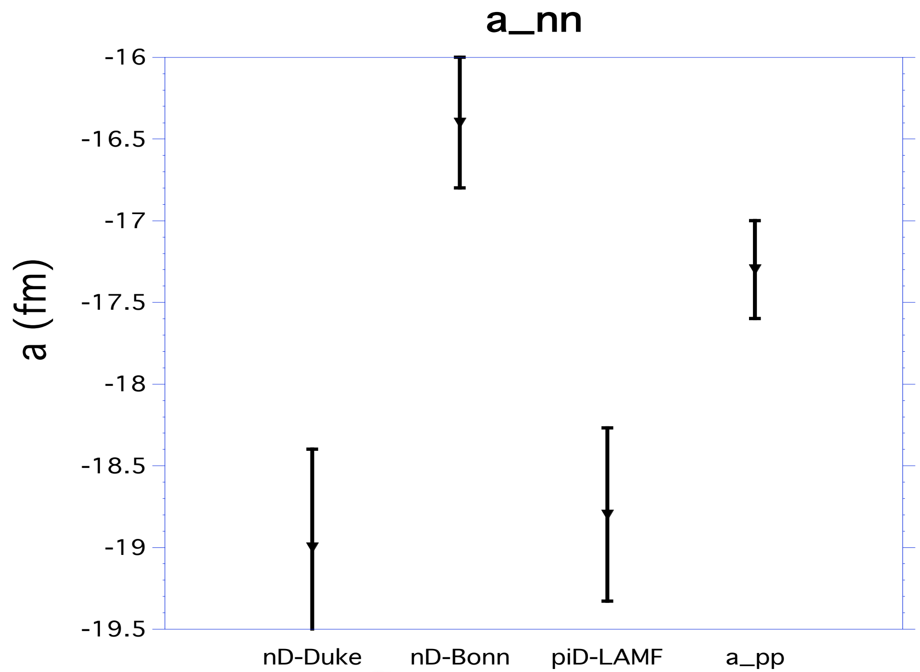
High current ≈ 100 mA

- Utilize windowless **polarized gas targets (transverse and longitudinal)**
- **Polarized electrons** for complete program

Is $a_{nn} = a_{pp}$?
Testing charge symmetry

- NN S-wave scattering lengths
- Measure with $\gamma D \to nn\,\pi^+$
- Check a_{np} with $\gamma D \to np\,\pi^0$

exp. problem



CSB?

nD -> nnp

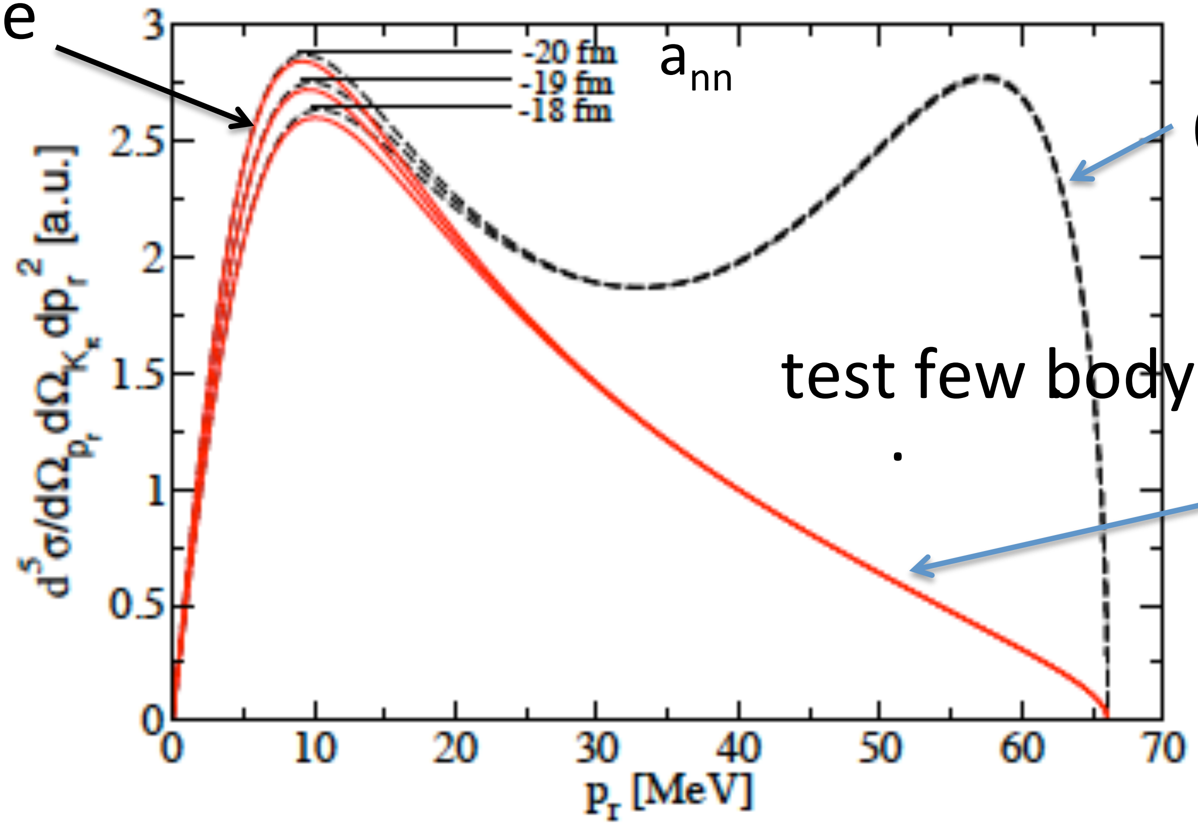
$\pi^- D \to nn\,\pi^0$

$\gamma D \to nn\pi^+$

$$\gamma(\vec{k})D \to \; n(\vec{p_1}) + n(\vec{p_2}) + \pi^+(\vec{p_\pi})$$

$$\vec{p_r}(\theta_r, \phi_r) = (\vec{p_1} - \vec{p_2})/2$$

Θ_r = angle between neutron momenta



Measure a_{nn}

a_{nn}

θ_r=0

test few body calc.

θ_r=90

Testing Isospin Conservation
$\gamma N \to \pi N$

There are 3 isospin matrix elements,

4 reaction channels.

The test of isospin conservation is:

$$A(\gamma p \to \pi^+ n) + A(\gamma n \to \pi^- p)$$
$$= \sqrt(2)[A(\gamma n \to \pi^0 n) - A(\gamma p \to \pi^0 p)]$$

A = multipole matrix elements

s wave (E_{0+}), 3 p wave)

Make four measurements to test IS conservation via relation above.

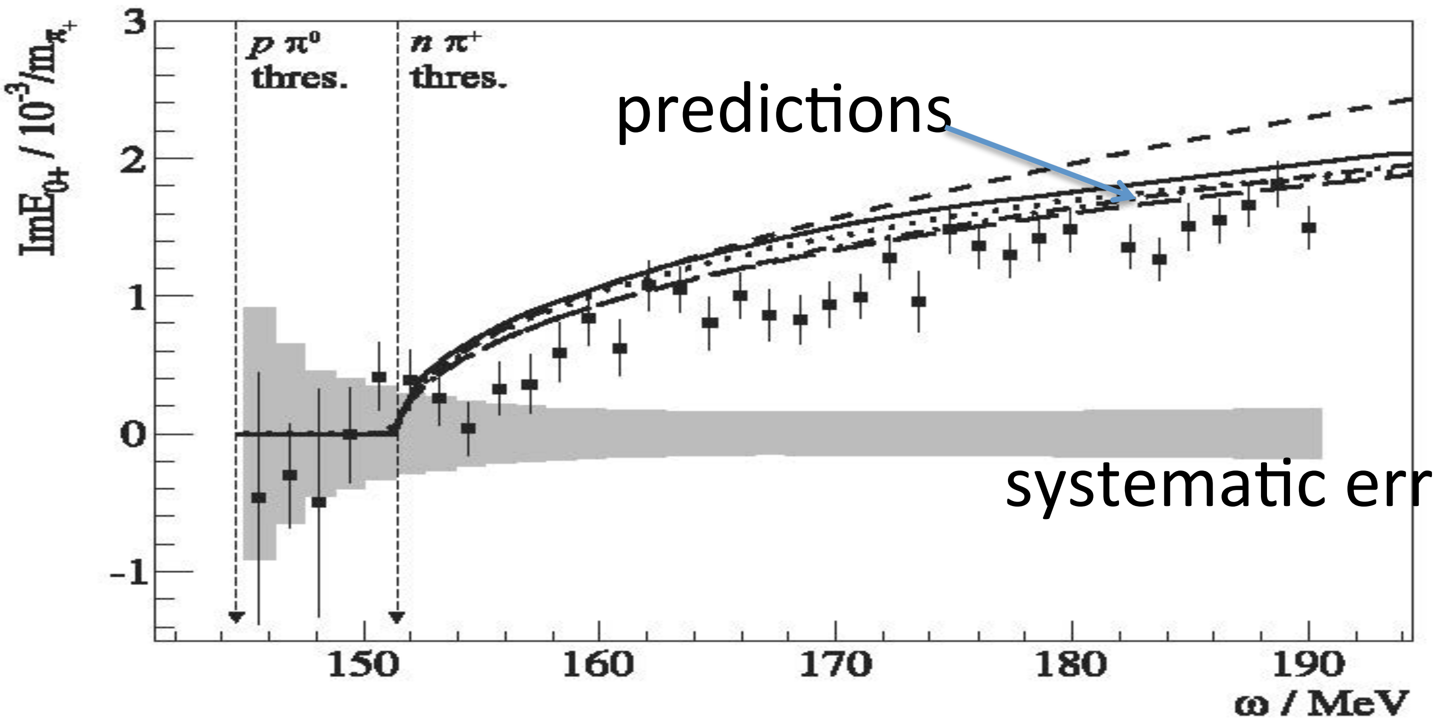
Expect IS breaking from QCD

- $L_{QCD} = L_0$ $(m_q \rightarrow 0)$ + L_m (quark mass term)
- L_0 has chiral symmetry; spontaneously broken
  $\Rightarrow$ Nambu-Goldstone Bosons (π, η, K)
  $\Rightarrow$ ChPT: effective theory of QCD
- $L_m = A(m_u + m_d) + B(m_u - m_d)$
  explicitly breaks chiral symmetry,
  B term also breaks IS symmetry
- Strong isospin symmetry violation
  - In general: $(m_d - m_u)/\Lambda_{QCD} \approx 2\%$.
  - However, $\Delta a(\pi^o N)/a(\pi^o N) \approx 30\ \%$ (Weinberg)
  - **Needs to be tested experimentally:** $\gamma N \rightarrow \pi^o N$ near threshold

Experimental Tests of Isospin Breaking

- $\gamma N \rightarrow \pi^o N$ near threshold, transverse polarized target
  sensitive to πN scattering
- Recent result: submitted for publication

Mainz A2 collaboration-S.Schumann *et al.* submitted May 2015
photon tagging, butanol target, C,O produce background



predictions

systematic error

Summary

There is a bright future using Virtual Photon Tagging to probe the confinement scale in QCD

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