Measurement of the Neutral Pion Transition Form Factor at low Q^2: the Proposed Measurement at Jefferson Lab

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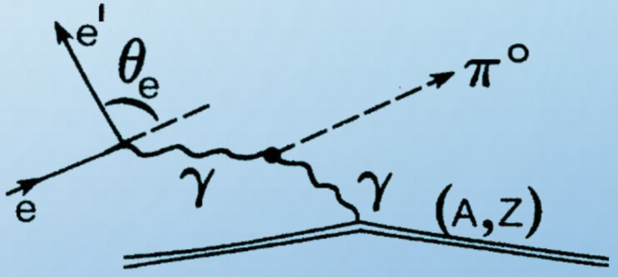
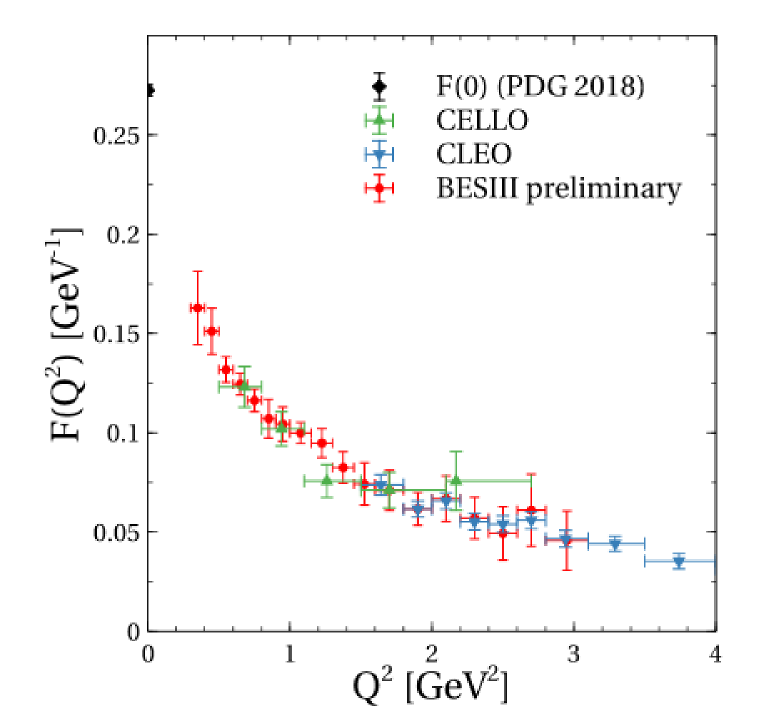
Physics Motivation

- There is high interest in measurement of the neutral pion transition formfactor (TFF) as a mean to constrain hadronic corrections to the muon magnetic moment, as it currently has 4.2 standard deviations from the SM prediction
- Primakoff neutral pion electroproduction can be used for the TFF measurement at low Q2 values: 0.001—0.1 GeV2.
- Measurement of the TFF at such low Q2 values can fix the TFF slope parameter and determine the electromagnetic pi0 radius.
- The neutral pion TFF measurement has been originally proposed by the PrimEx collaboration and included in white papers as one of the key experiments in Jefferson Lab 12 GeV program



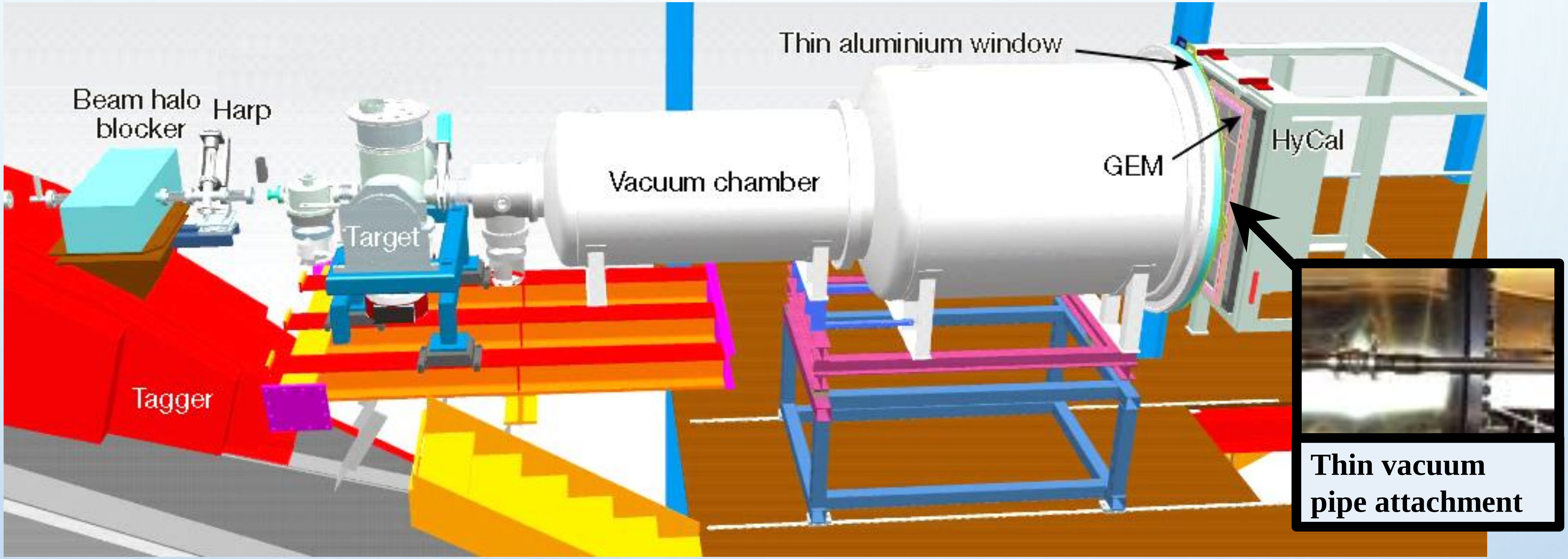
Previous Measurements



The Proposed Measurement

- We propose experiment to run in Hall-B at Jefferson Lab to measure the neutral pion transition formfactor via the Primakoff reaction with a virtual incident photon
- The proposed experiment will have sensitivity to the neutral pion TFF over 0.001 - 0.2GeV^2 Q^2 range allowing a clean determination of the TFF slope parameter and having good sensitivity to the neutral pion radiative decay width
- The large uncertainty in the SM prediction for the muon magnetic moment, HLBL scattering critically depends on the knowledge of TFF in the low Q^2 region
- We propose measurement with 10nA electron beam, 250 micron thick silicon-28 target and the upgraded PRad experiment setup. The estimated physics running time is about two months

Experimental Setup

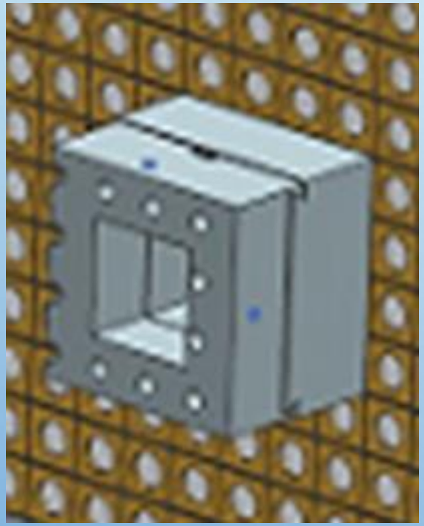


The existing low background **PRad experiment setup** perfectly fits TFF measurement needs: high resolution hybrid e.-m. calorimeter, low background vacuum chamber, and charge particle identification with the GEM detector (minor modifications required)

GEM detector will be additionally used to VETO charged background in π^0 candidate selection

Modifications to the existing PRad setup

- Calorimeter shielding:



Tungsten absorber covering central layer of the calorimeter modules needs to be increased to cover two central layers to reduce scattered beam background.

- Solid silicon targets

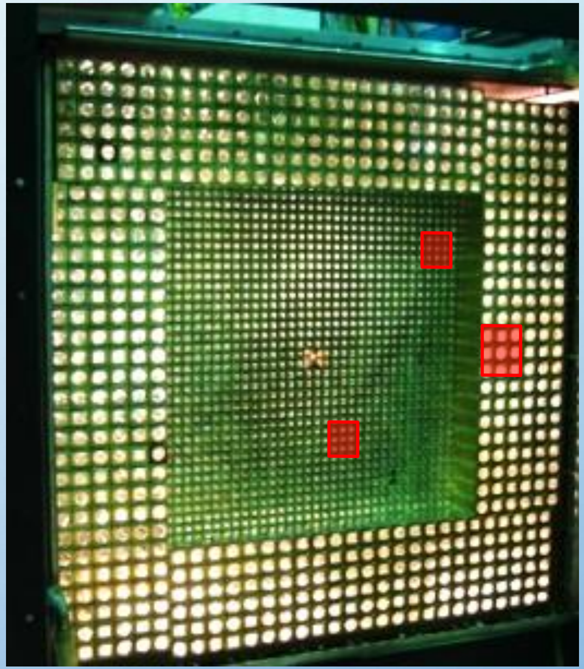
New silicon targets ~250 µm thick replaces PRad windowless gas target

- Sophisticated trigger working with **flash-ADC** calorimeter electronics (**upgrade** to HyCal)

Trigger organization

- The simple "total energy in the calorimeter" trigger rate is estimated to be about 220…250kHz for the 4GeV total energy deposition threshold, which is too high for the DAQ
- Therefore more sophisticated "3-clusters" trigger is proposed: it requires at least 3 cluster in the calorimeter (3x3 modules size) with minimum energy deposition of 0.3GeV AND 4GeV total energy deposition. The rate for such a "3-cluster" trigger is estimated to be at 5…10kHz level (15…30kHz for "two clusters" requirement)
- The calorimeter electronics needs to be upgraded with flash-ADCs

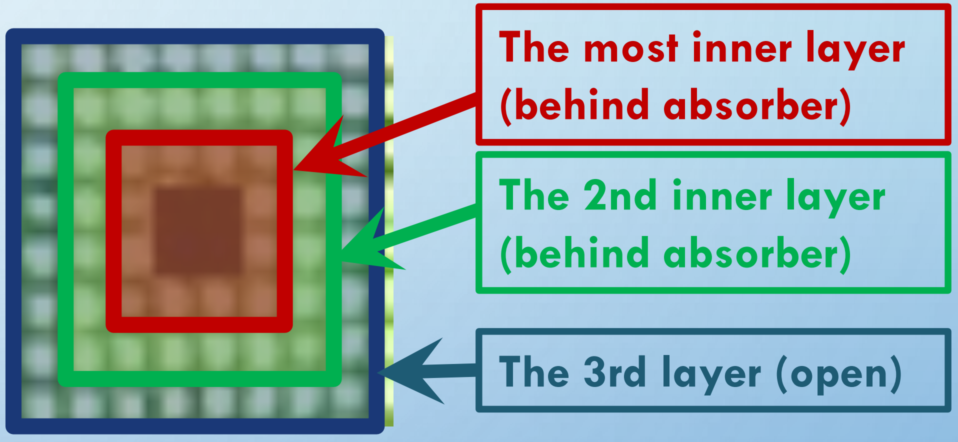
The PrimEx high resolution hybrid electromagnetic calorimeter HyCal



Radiation dose to the calorimeter

- We estimate radiation dose to the calorimeter modules as 8…10 rad/hr for the most inner layer, and 4…6 rad/hr for the 2nd and 3rd layers. Others layer dose decreases with the distance from the beamline.
- This dose will cause about 2…5% degradation in transparency and light yield and self reversable with time
- The calorimeter module rates in the most inner layer expected to be as high as 2MHz in most inner layer, and within 250kHz in the 2nd and 3rd layers. The most inner modules HV needs to be switched OFF
- The absorber size is increased by 1.5 in width and twice in thickness in comparison with the existing one

The calorimeter central modules:

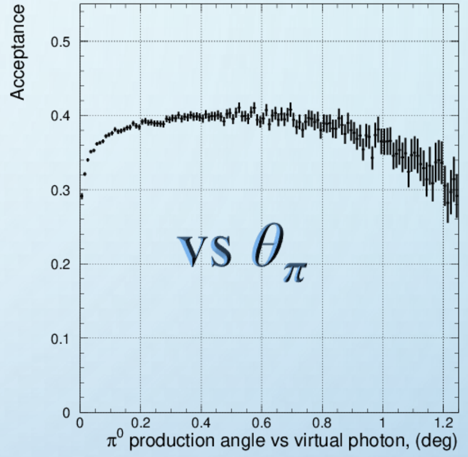


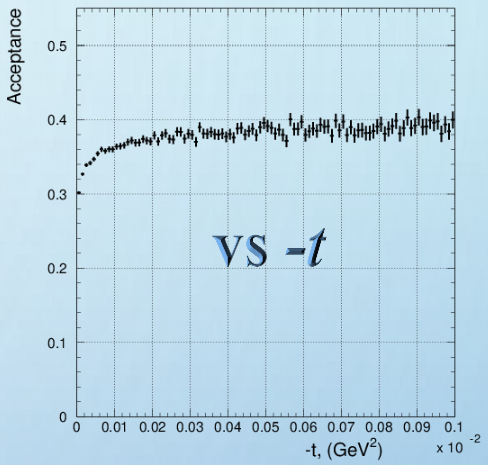
Acceptance and resolution

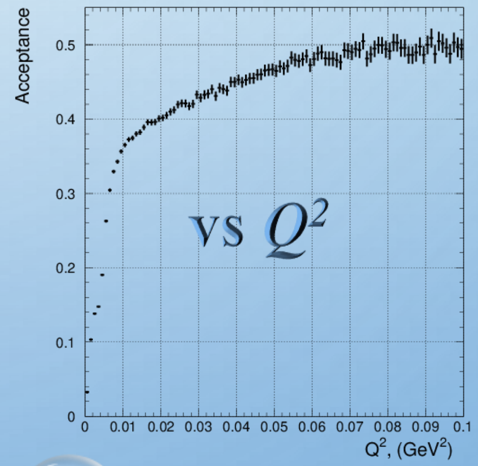
- The final state particles will be detected with a high resolution lead tungstate hybrid electromagnetic calorimeter with the central part resolutions $\frac{2.7\%}{\sqrt{E[GeV]}}$ for energy and $\frac{2.5mm}{\sqrt{E[GeV]}}$ for coordinate, in addition the GEM detector will be used to improve electron coordinate spatial resolution to < 0.1mm value
- The expected resolutions
  - for pion: mass ~3MeV, production angle ~$(27\cdot10^{-3})°$, energy ~1.8%
  - for electron: production angle ~$(7\cdot10^{-3})°$, energy ~2.3%
  - for Q^2: ~6.7% at $Q^2=2\cdot10^{-3}GeV^2$, ~2.7% at $Q^2=10^{-2}GeV^2$,

- Typical setup acceptance for 3 particles detecting ~0.4

Acceptance

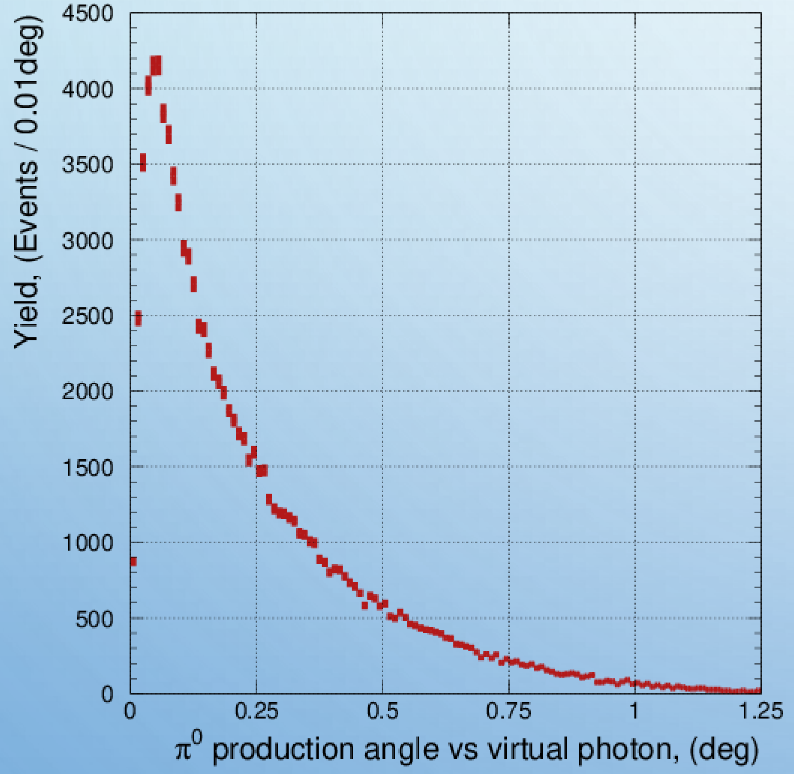




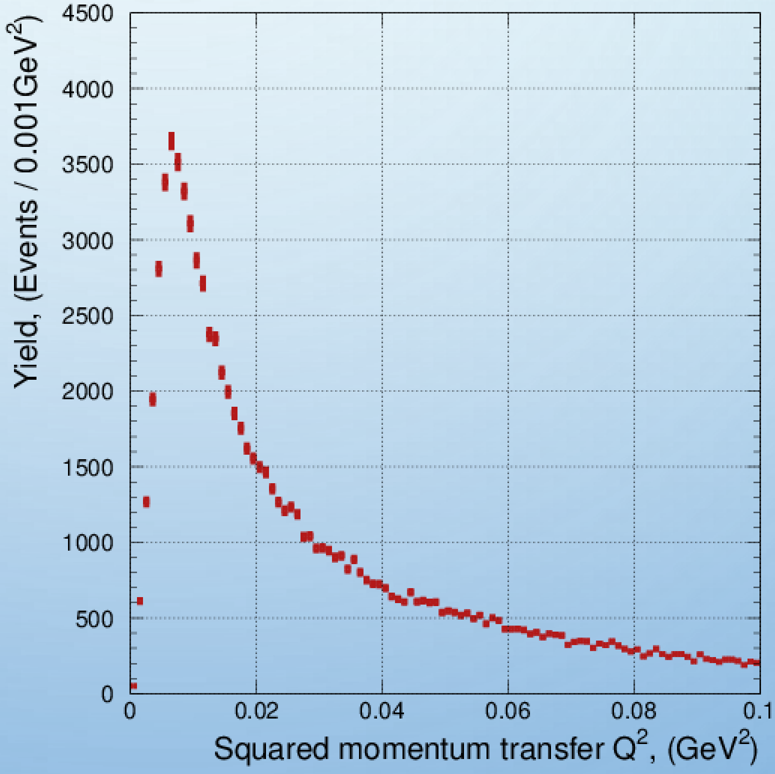


Expected Primakoff π^0 yield

Yield vs "production" angle



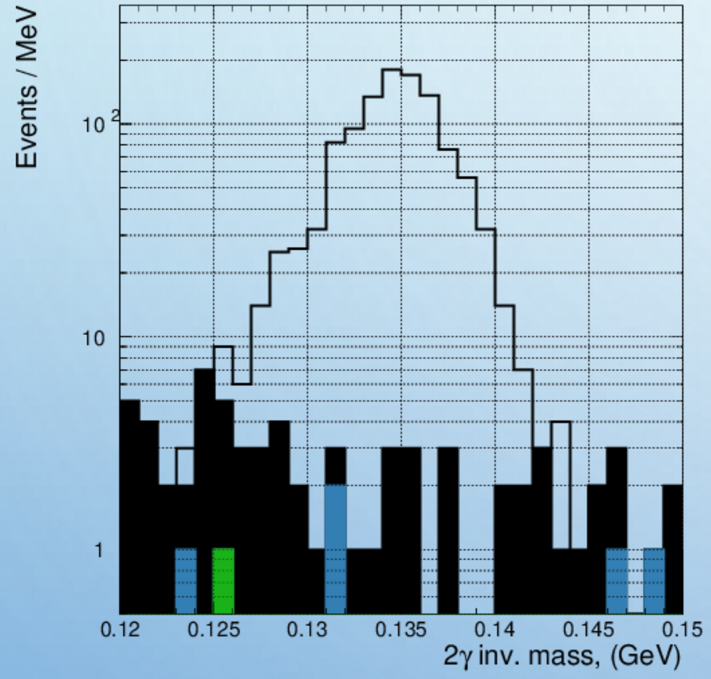
Yield vs Q^2



We expect about 70K Primakoff events in the region of Q^2<0.1GeV^2 for 2 month running

Background conditions

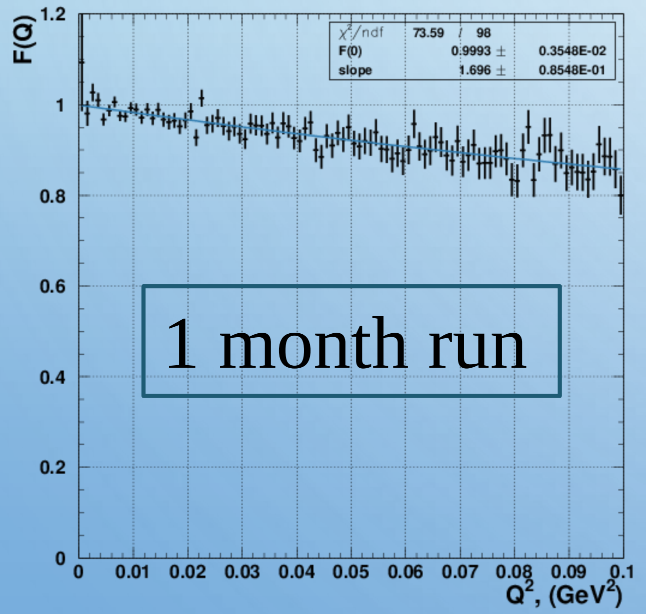
Expected two gamma candidates inv. mass distribution for **16hr** run

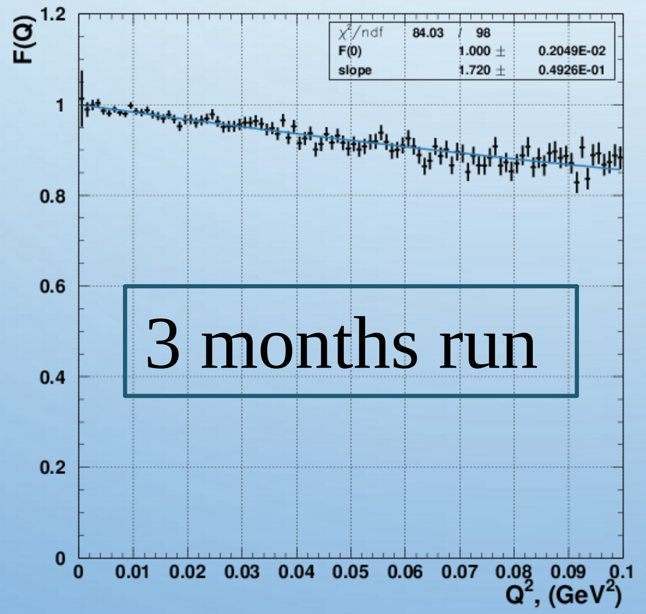


- Open histogram – Primakoff events
- Solid histograms – electromagnetic background with GEM used as a veto and 1 GeV energy conservation requirement
- **Green** – absolutely efficient VETO
- **Blue** – 1% inefficient VETO (expected performance)
- **Black** – 5% inefficient VETO

Expected statistical uncertainty of the π^0 TFF parameters (from $F(Q^2)$ dependence)

Ratio of the "measured" and expected for $F \equiv 1$ yields vs Q^2

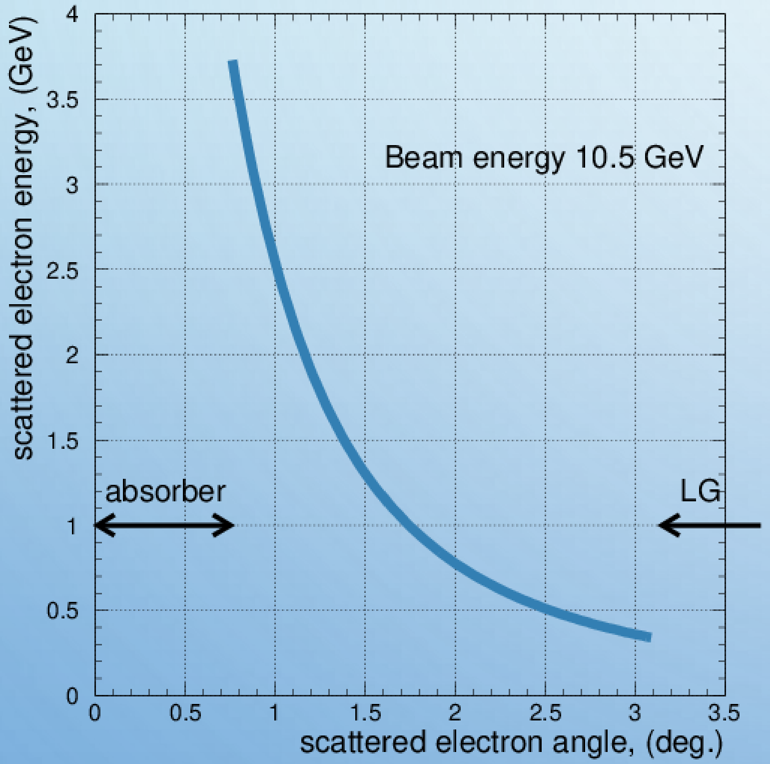




$F(Q^2)$ fit errors vs run time

Run time, [months]	*Slope* , [%]	*F*(0), [%]	*Slope* with the fixed *F*(0), [%]
1	5.0%	0.35	3.3%
2	3.6%	0.25	2.5%
3	3.0%	0.20	2.0%

Verification with the Møller process cross section



- Well-known Møller process, which has already been successfully used by the PRad experiment, can be used here for the cross section verification or normalization
- Special Møller trigger needs to be implemented and added (prescaled) to the data stream
- Precise absolute π^0 electroproduction cross section measurement provides connection between the measured values and the well-known neutral pion life time: $\Gamma(\pi^0 \to \gamma\gamma) = \frac{1}{4}\pi\alpha^2 m_\pi^3 |F(0)|^2$

Estimated Impact on $(g\text{-}2)_\mu$

Summary

- The proposal for the neutral pion transition formfactor (TFF) measurement in Hall-B at Jefferson Lab is under preparation for the upcoming PAC. The experiment will use existing PRad setup.
- For the proposed running conditions: 10nA electron beam current, 10.%GeV beam energy, and 250 micron silicon-28 target the desired physics data taking time is about 2 months. Special physics trigger needs to be organized.
- Parallel Møller measurement will be used for the verification and possible normalization of the absolute cross section measurement at the percent precision level
- The measurement will be first precision measurement of the neutral pion TFF at the low Q^2 range and will significantly improve known TFF parameters. It will also have an impact on the $(g-2)_\mu$ anomaly value
- The project is supported from DOE grant DE-FG02-88ER40415