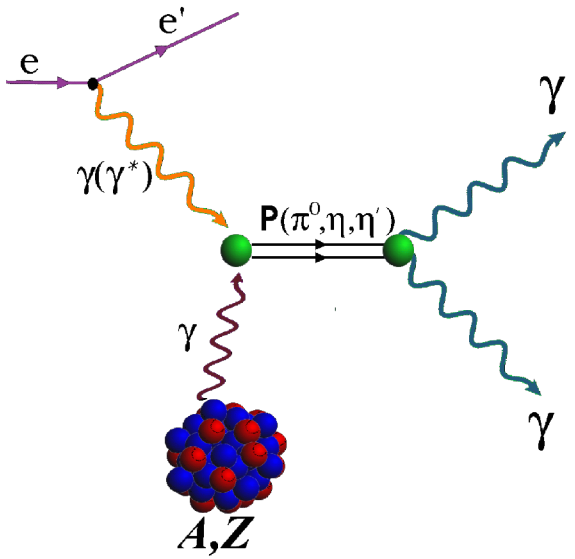
The PrimEx Project with 12 GeV at JLab

- **Experimental program:**

1) Precision measurements of two-photon decay widths (real photon exchange):
   - a) $\Gamma(\pi^0 \to \gamma\gamma)$
   - b) $\Gamma(\eta \to \gamma\gamma)$
   - c) $\Gamma(\eta' \to \gamma\gamma)$
2) Transition Form Factors at very low Q^2 range, 0.001-0.5 GeV^2/c^2 (virtual photon exchange):
   - a) $F(\gamma\gamma^* \to \pi^0)$
   - b) $F(\gamma\gamma^* \to \eta)$
   - c) $F(\gamma\gamma^* \to \eta')$



- **Physics reach:**

a) precision tests of chiral symmetry and anomalies
b) determination of light quark mass ratio
c) mixing angles
d) π^0, η and η' interaction electromagnetic radii
e) Is η' an approximate Goldstone boson?

- **This program is included in the JLab @12 GeV upgrade CDR** under:

"Test of the Standard Model of electro-weak interactions and the determination of fundamental parameters of this model"

Other Physics Proposals for "Run Group"

1) $\gamma\gamma^* \rightarrow \pi^0$ Transition Form Factor at very low Q^2 range: PrimEx-IV

2) $\gamma\gamma^* \rightarrow \eta$ Transition Form Factor at very low Q^2 range: PrimEx-V

3) Proposal to Search for a "Dark-Omega" Vector Boson in Direct Electroproduction Processes Using Intense High Energy Electron Beams

Other Physics Proposals for "Run Group"

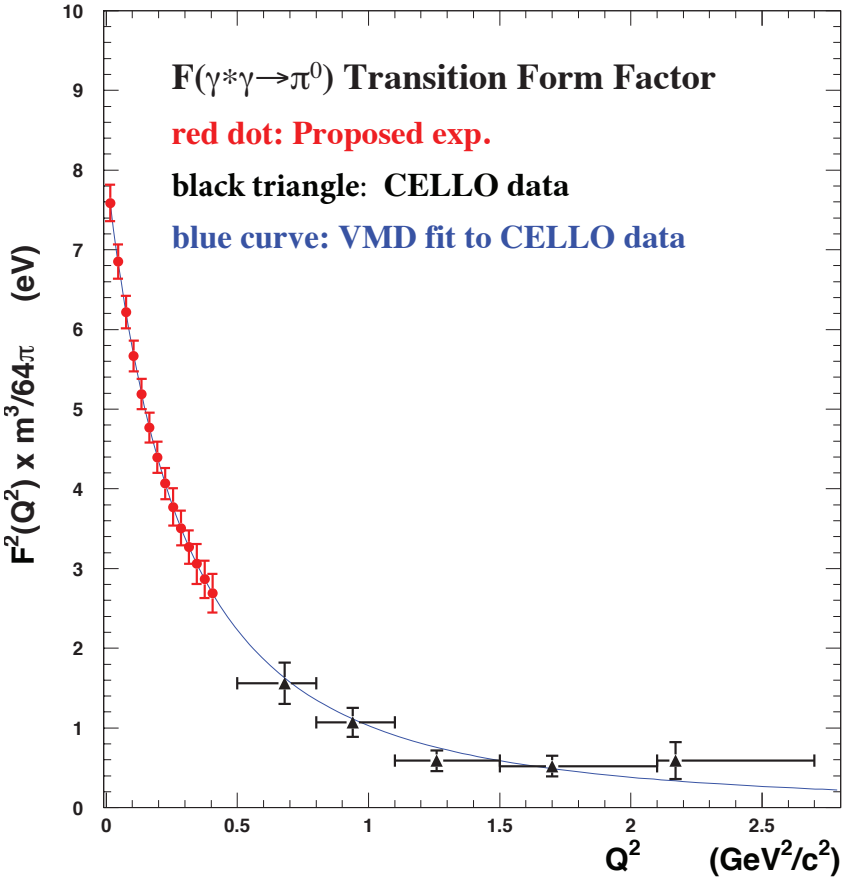
1) $\gamma\gamma^* \rightarrow \pi^0$ Transition Form Factor at very low Q^2 range: PrimEx-IV

- Direct measurements of transition form factors at very low Q^2 (0.001-0.5 GeV^2/c^2)
  $F(\gamma\gamma^* \rightarrow \pi^0)$, $F(\gamma\gamma^* \rightarrow \eta)$

- ✓ interaction radii:
  $F_{\gamma\gamma^* P}(Q^2) \approx 1 - \langle r^2 \rangle_P Q^2 / 6$
- ✓ experimental input to light-by-light scattering for muon (g-2) theoretical calculations
- ✓ test of upcoming lattice calculations

- Experimental setup can be the same as the new PRad2 with different target:
- ✓ very thin ^{12}C or ^{28}Si

- Possible to submit an experimental proposal to Jlab's PAC48.
- Needs 12 GeV



Other Physics Proposals for "Run Group"

2) $\gamma\gamma^* \rightarrow \eta$ Transition Form Factor at very low Q^2 range: PrimEx-IV

- Direct measurements of transition form factors at very low Q^2 (0.001-0.5 GeV^2/c^2)
  $F(\gamma\gamma^* \rightarrow \eta)$

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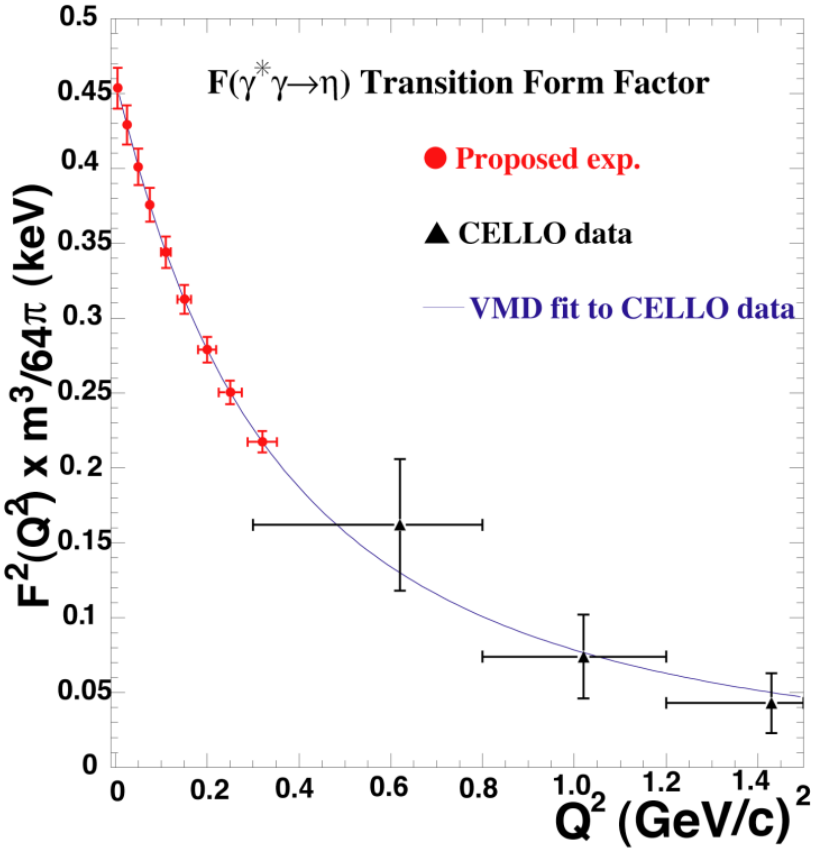
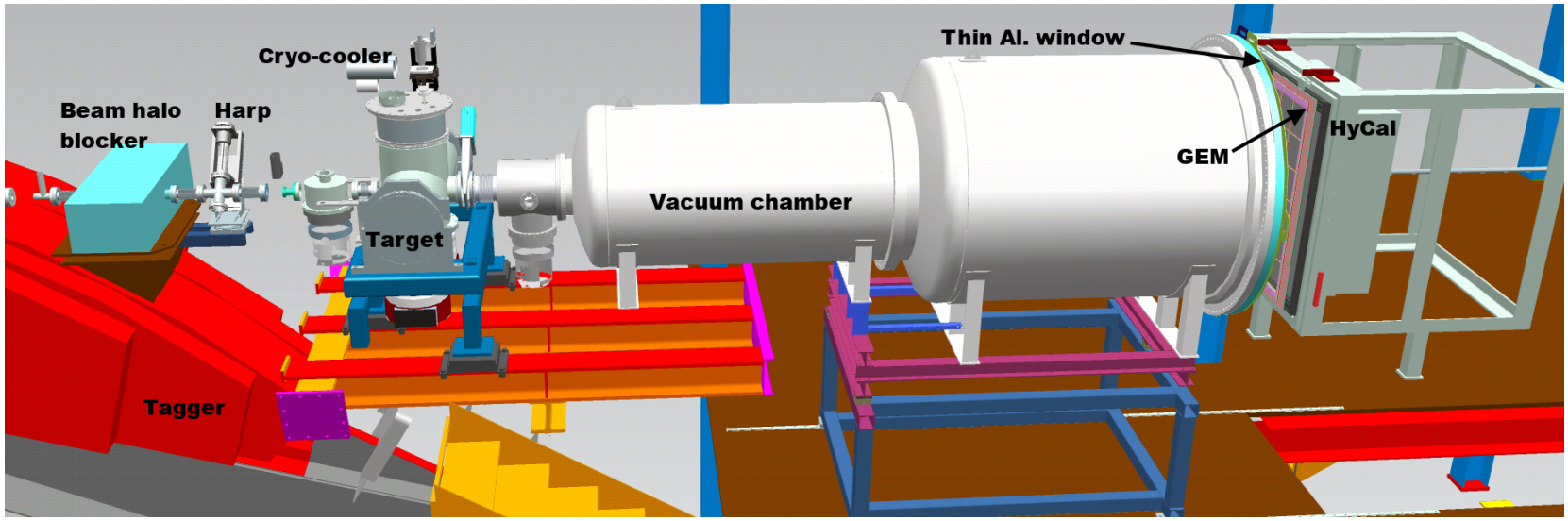


Proposed Experimental Apparatus (The PRad experimental Setup)

- Main detector elements:
  - windowless H_2 gas flow target
  - PrimEx HyCal calorimeter
  - vacuum box with one thin window at HyCal end
  - X,Y – GEM detectors on front of HyCal

- Beam line equipment:
  - standard beam line elements (0.1 – 50 nA)
  - photon tagger for HyCal calibration
  - collimator box (6.4 mm collimator for photon beam, 12.7 mm for e^- beam halo "cleanup")
  - Harp 2H00 I



Other Physics Proposals for "Run Group"

3) Proposal to Search for a "Dark-Omega" Vector Boson in Direct Electroproduction Processes Using Intense High Energy Electron Beams

- Theoretical motivations to look for an extra U(1) gauge group;
- New results from astrophysical observations (511 KeV line, PAMELA e^+ rise, …);
- More than a decade old discrepancy of the muon $(g\text{-}2)_\mu$
- Proton radius puzzle ????
- Long-standing puzzles in neutrino experiments (LSND, MiniBooNe, …)
- …

Baryonic Vector Models with Mass Under 1 GeV ("dark omega", V_B, …)

- New gauge field (B_μ) coupling primarily to baryon number (quarks):
  The interaction Lagrangian:

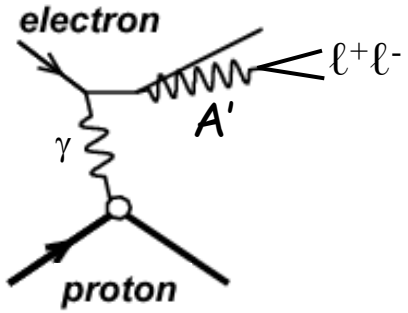
$$\frac{1}{3} g_B \bar{q} \gamma^\mu q B_\mu$$

or in more general:

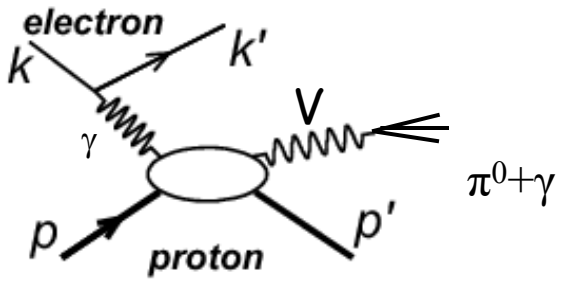
$$\mathcal{L}| = \mathcal{L}_\chi - \frac{1}{4} V_{\mu\nu}^2 + \frac{1}{2} m_V^2 V_\mu^2 - \frac{\kappa}{2} V_{\mu\nu} F^{\mu\nu} + g_B V_\mu J_B^\mu$$

$$J_B^\mu \equiv \tfrac{1}{3} \textstyle\sum_i \bar{q}_i \gamma^\mu q_i$$

- If mixing parameter (kappa) is small, this new vector state is an isospin singlet, like ordinary ω meson, "dark omega" with quantum numbers: $J^{PC} = 1^{--}$
  T.D. Lee and C.N. Yang, S. Tulin, M. Pospelov, …



Dark Photon, A'

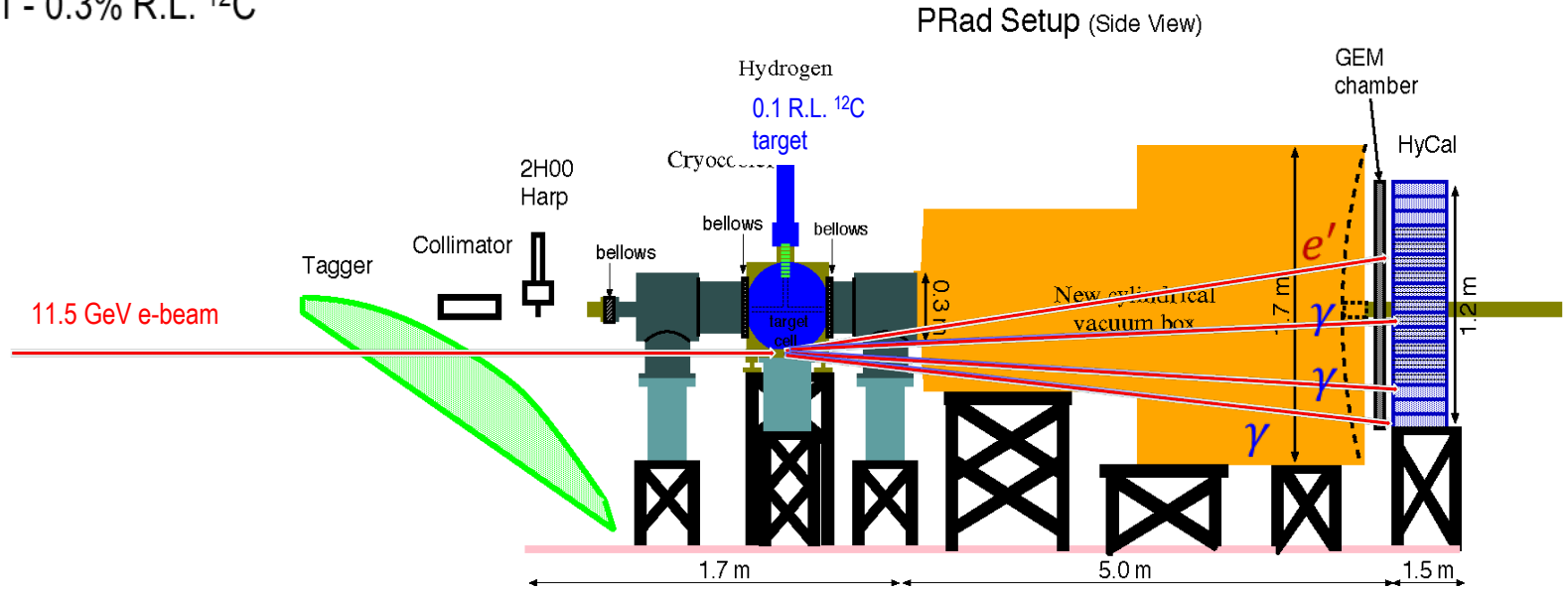


Dark Omega, V_B

The Proposed Experiment: Search for Hidden Sector V_B Boson in Direct Production Channels

$$e^- + {}^{12}C \rightarrow V_B + X$$
$$\downarrow\rightarrow \pi^0 + \gamma \rightarrow \gamma + \gamma + \gamma$$

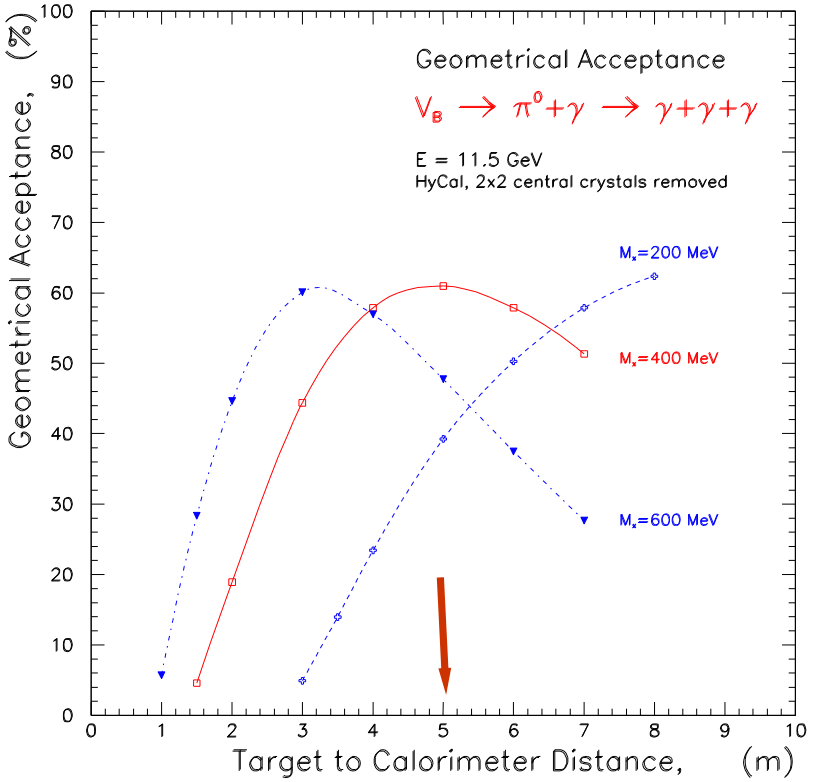
Beam: 11.5 GeV electron beam in Hall B at Jlab
Target: 0.1 - 0.3% R.L. ^{12}C



- It is suggested to run with the "π^0 Transition Form Factor Measurement at Very Low Q^2 Range, (PrimEx-IV)"
- Kind of a "by-product" experiment, (more chances to run!)

$V_B \rightarrow \pi^0 + \gamma \rightarrow \gamma + \gamma + \gamma$ Detection Acceptance

- HyCal calorimeter is defining the acceptance:
  - ✓ 118 x 118 cm^2 cross sectional area:
  - ✓ 35 x 35 cm^2 $PbWO_4$ crystals in central part;
  - ✓ 2 x 2 $PbWO_4$ crystals are removed for the beam (4 x 4 cm^2).
- GEM detector covers entire HyCal
- E_{clust} > 0.5 GeV cut is included



- Z = 5 m distance will provide 30 ÷ 60% detection acceptance for the [150 ÷ 650 MeV] mass range

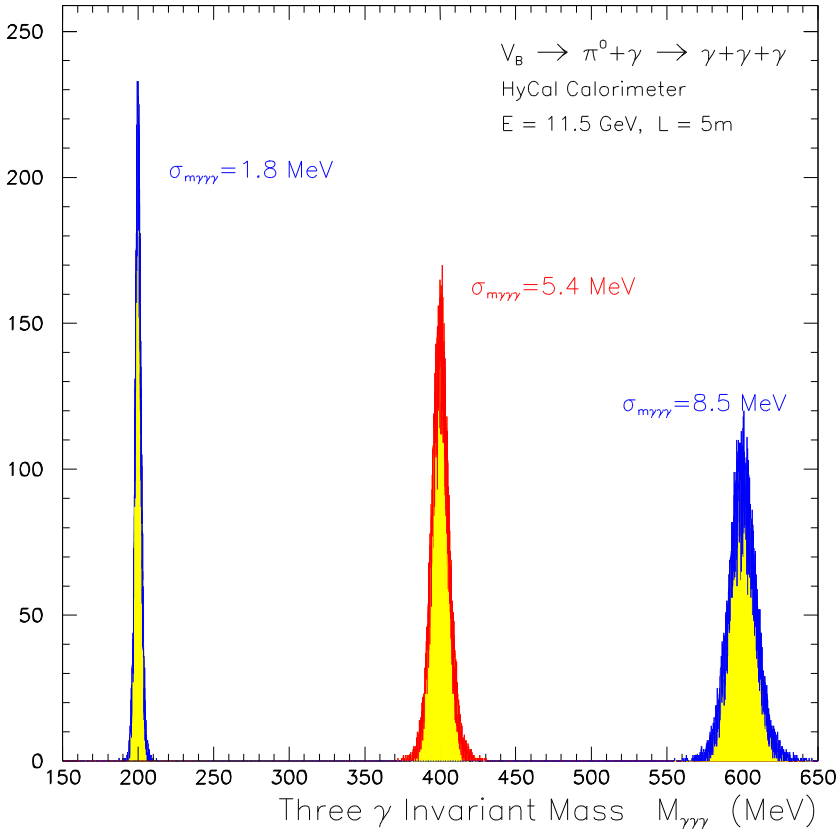
$V_B \rightarrow \pi^0 + \gamma \rightarrow \gamma + \gamma + \gamma$ Invariant Mass Reconstruction

- HyCal position and energy resolutions are defining the $M_{\gamma\gamma\gamma}$ resolution:
  - ✓ Pb-glass part:

$$\sigma_E/E = 5.6\%/\sqrt{E}\ ,$$
$$\sigma_{x,y} = 5.4\frac{mm}{\sqrt{E}}$$

  - ✓ $PbWO_4$ crystal part;

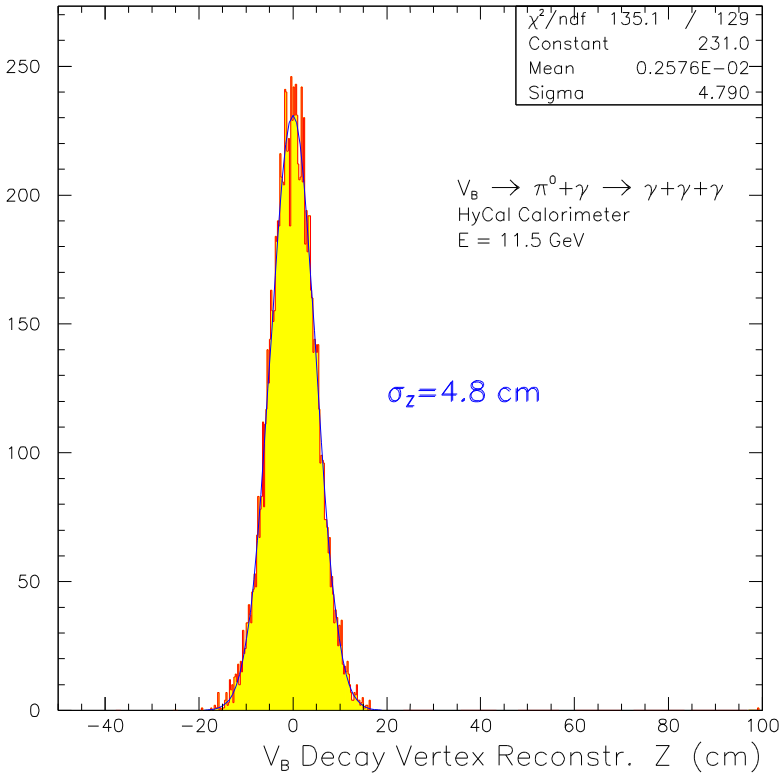
$$\sigma_E/E = 2.6\%/\sqrt{E}$$
$$\sigma_{x,y} = 2.5\frac{mm}{\sqrt{E}}$$

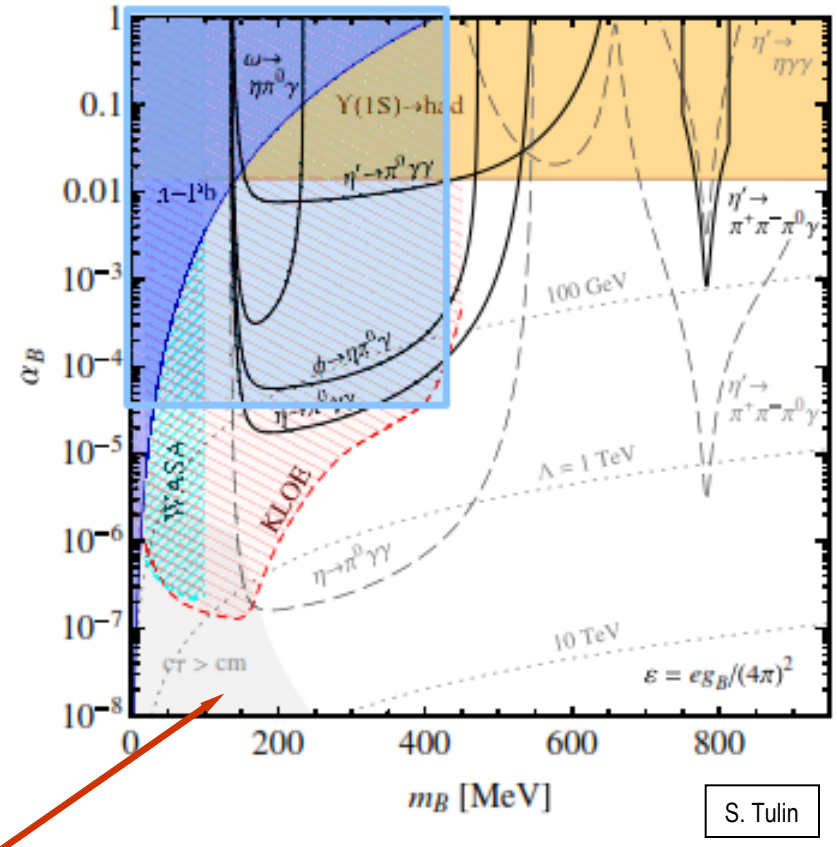


- Good $M_{\gamma\gamma\gamma}$ resolution is expecting in this experiment [1.8 ÷ 8.5] MeV
- Critically important for the signal identification over the background

$V_B \rightarrow \pi^0 + \gamma$ Displaced Vertex Reconstruction: Resolution

- $\pi^0 \rightarrow \gamma+\gamma$ defines the decay vertex, assuming the $M_{\gamma\gamma}$ is known





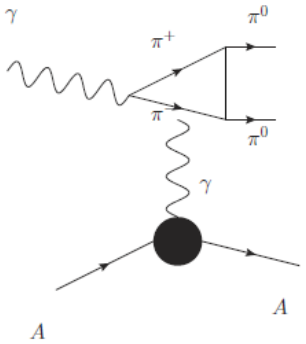
S. Tulin

- Decay Length: $Z \cong (E_{VB}/M_{VB}) \times c\tau \approx 10 \times c\tau$ for this experiment
- Has a good potential to play a good role in this search experiment

Physics Background: *Forward Production of* Two π^0 *Mesons*

- $\gamma^* + {}^{12}C \rightarrow \pi^0 + \pi^0 + X$

  $\downarrow \rightarrow \gamma + \gamma \rightarrow \gamma + \gamma + \gamma$



$$\frac{d\sigma}{d\Omega dM} = \frac{\alpha}{\pi^2}\frac{\beta^2 k^4 sin^2\theta}{Q^4}\frac{1}{M}\sigma(\gamma\gamma)F^2(M,Q^2)$$

S. Gevorkyan, in publication

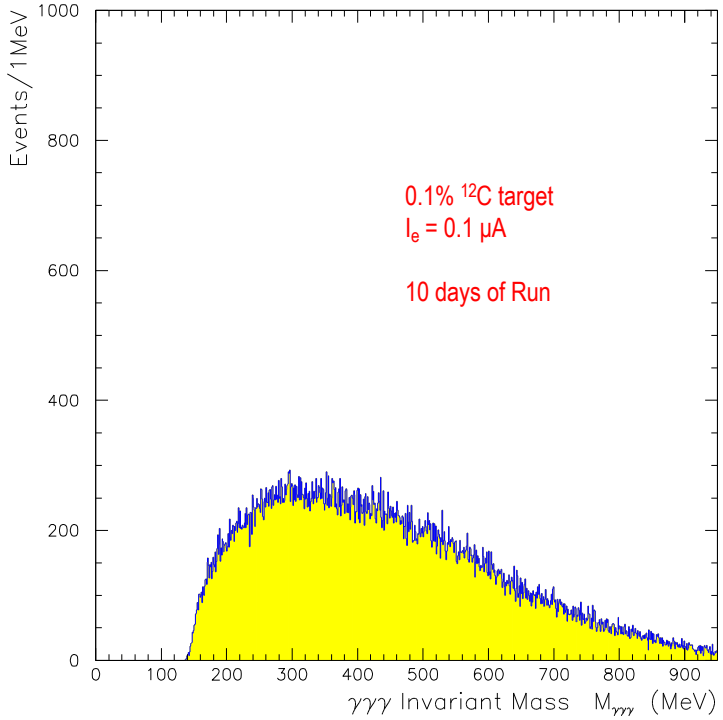
for E_γ = 11 GeV, ΔE=1.GeV, ΔM=0.4 GeV

$\Delta\sigma(\gamma* + P \rightarrow \pi^0 + \pi^0 + P) \approx 0.008$ μb

then:

$\Delta\sigma(\gamma* + {}^{12}C \rightarrow \pi^0 + \pi^0 + X) \approx 0.1$ μb

- Selection rule:
  - ✓ any combination of 3γ was treated as $V_B \rightarrow \pi^0 + \gamma$ event



Physics Background: *Electro-production of ρ Mesons*

- $\gamma^* + {}^{12}C \rightarrow \rho + 12C$

  $\downarrow\rightarrow \pi^0 + \gamma \rightarrow \gamma + \gamma + \gamma$

  Branching ratio: 6×10^{-4}

  $M_\rho = 775.26$, *Full width:* $\Gamma = 149.1$ MeV

- *VDM model predicts:*

  $\Delta\sigma(\gamma^* + P \rightarrow \rho + P) \approx 10 \times \Delta\sigma(\gamma^* + P \rightarrow \omega + P)$

- *from experiment:*

  $\Delta\sigma(\gamma^* + P \rightarrow \omega + P) \approx 0.23\ \mu b$

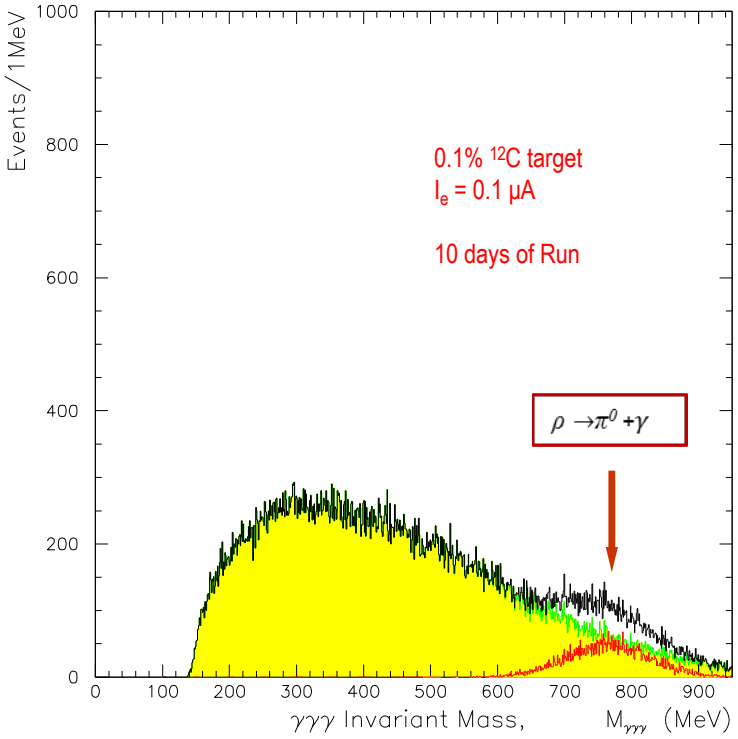
  and:

  $\Delta\sigma(\gamma^* + A \rightarrow \omega + A) \approx (A)^{1.5}\ \Delta\sigma(\gamma^* + P \rightarrow \omega + P)$

  then:

  $\Delta\sigma(\gamma^* + {}^{12}C \rightarrow \rho + {}^{12}C) \approx 10.\ \mu b$

- Selection rule:
  - ✓ $\rho \rightarrow \pi^0 + \gamma$ events generated with different mass according to $\Gamma = 149.1$ MeV.



$V_B \rightarrow \pi^0 + \gamma$ Signal Events

- Theoretical activities are in progress to estimate $\Delta\sigma(e^- + A \rightarrow V_B + X)$ based on realistic models.

  (S. Tulin, M. Pospelov, …)

- At this stage it is assumed:

$$\sigma(e^- P \rightarrow V_B) \sim$$
$$\sim (\alpha_{em}/\pi)\,(\alpha_B/\alpha_{em})\,(M_\omega/M_B)^2\,\sigma(\gamma P \rightarrow \text{hadrons})$$

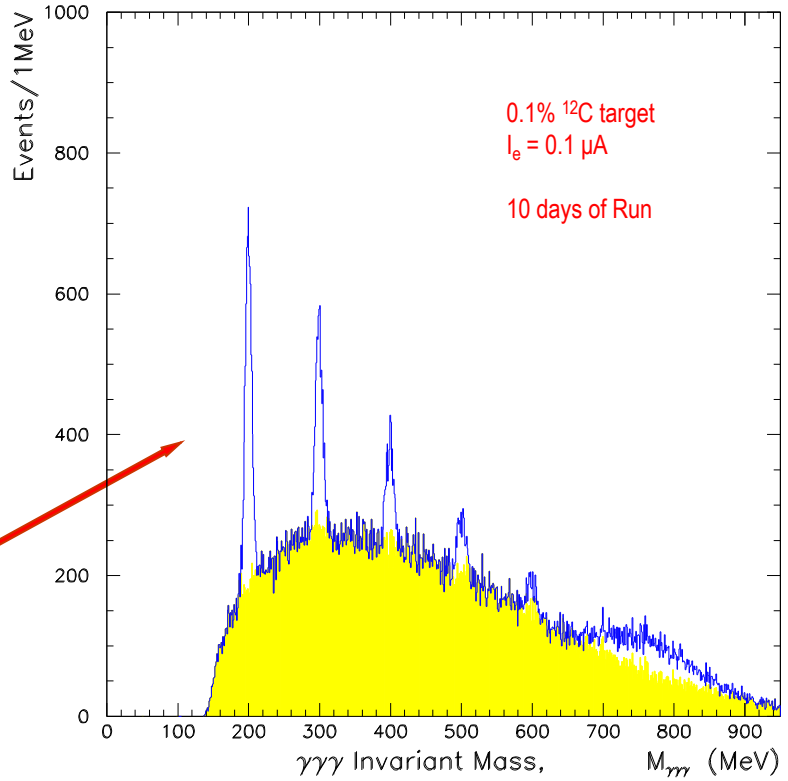
(M. Pospelov, private communication)

For estimation purposes, take $\sigma(\gamma P) \sim 1$ μb

Then:

$\sigma(V_B) \sim 1$ pb at $\alpha_B = 10^{-8}$

for ^{12}C target and $M_B = 200$ MeV



- (Signal)/sqrt(backgr.) = 750/sqrt(6084) = 9.6 for $M_B = 600$ MeV

Sensitivity of the Proposed Experiment
(Physics Reach)

- With assumption that:
  $\sigma(V_B) \sim 1$ pb at $\alpha_B = 10^{-8}$
- Needs more input from theory part