Search for Hidden Sector Scalar Bosons in $X \rightarrow \gamma\gamma$ Channel with Intense Medium Energy Electron Beams

(a proposal for new search experiments)

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Outline

- physics motivation (very short)
- experiments with projected 300 MeV electron beams
- experiment with current 6 and 12 GeV electron beams
- summary and outlook

Physics Motivation
(Search for Hidden-Sector (Pseudo)Scalars)

- Spin-zero particles usually arise in field theories from spontaneous U(1) symmetry breaking effects (massless Goldstone particles)
- explicit symmetry breaking effects add mass (pseudo - Goldstone particles)

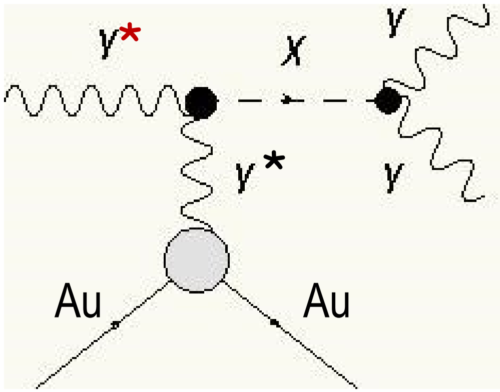
  - Scalar bosons ($J^p=0^+$)
    - Higgs', milli-Higgs [Pospelov&Ritz]
    - Light inflaton mass ~90 MeV [Bezrukov et al., JHEP 1005:010,2010]
    - Dilatons (from string compactification)
  - Pseudo-scalar bosons ($J^p=0^-$)
    - Axions and axion-like particles (solving strong CP-problem)
    - Neutral pion "impostor" [McKeen & Pospelov, [arXiv 1112:2207]
      (new- particle scenario for pion-photon transition form factor from BaBar)
    - Phenomenology of pseudo Nambu-Goldstone bosons [Frigerio et et al, Phys.Rev. X1 (2011) 021026] (masses ~ 1 MeV)

✓ Recent renewed activities in search for hidden gauge vector bosons ($A' \rightarrow e^+e^-$ experiments)

➢ We propose to search for their (pseudo)-scalar partners in $X\rightarrow\gamma\gamma$ channel within [1 - 100] MeV mass range (complimentary to A' searches).

The Proposed Experimental Method

- These particles, if exist, have very small coupling with ordinary matter, therefore:
  - ✓ maximize the production mechanism
  - ✓ maximize the detection efficiency

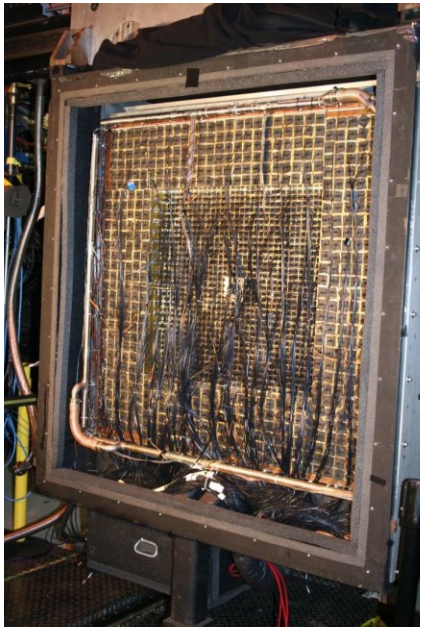


- We propose to search for hidden sector scalar bosons in
  - ➢ electro-production experiments:

$$e^- + Au \rightarrow e' + \gamma^* + Au \rightarrow e' + X + Au$$

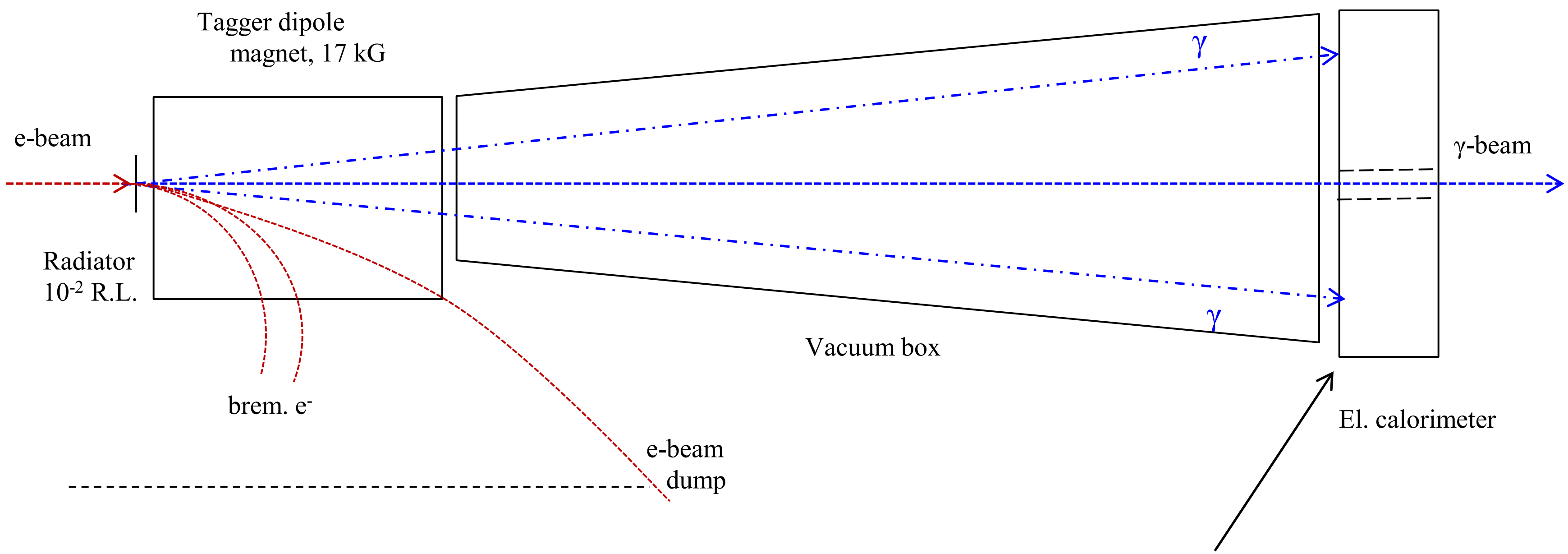
with $X \rightarrow \gamma\gamma$

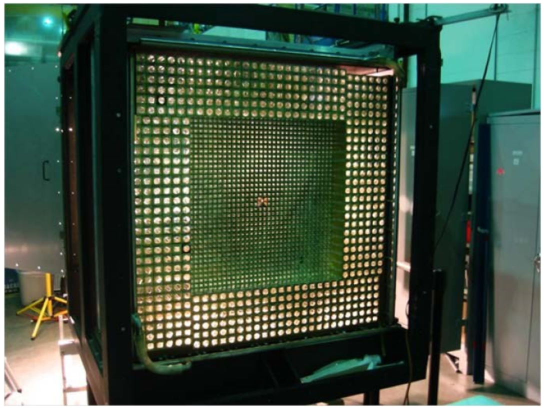
  - ➢ Using:
  - ✓ zero-degree photon tagging technique (virtual photon tagging)
  - ✓ upgraded $PbWO_4$ crystal calorimeter (HyCal) (1x1 m^2)



- Electromagnetic calorimeter (HyCal at Jlab, 118x118 cm^2)
  - ✓ 1200 $PbWO_4$ crystal counters (2x2x18 cm^3 each)
  - ✓ 700 Pb-glass counters (4x4x40 cm^3 each)

The Proposed Experiment with 300 MeV Electron Beams
(schematic view)





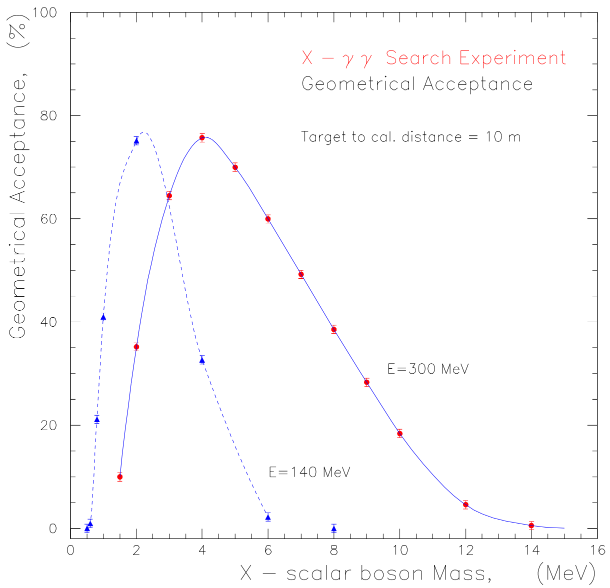
Characteristics of the Proposed Experiment (with 300 MeV Beams)

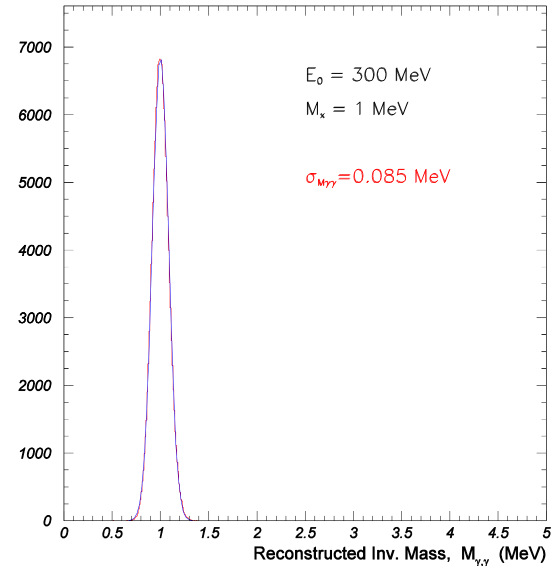
Combination of:

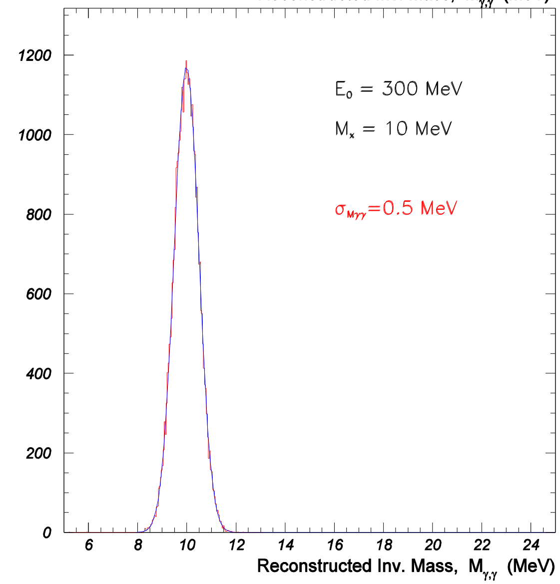
- ✓ virtual photon tagging technique
- ✓ high resolution, large acceptance $PbWO_4$ calorimeter

will provide:

- ➢ good Mγγ resolution (0.1 – 0.5 MeV)
- ➢ moderate Mγγ range (1 MeV – 15 MeV)
- ➢ reaction elasticity (ΔE)
- ➢ good timing resolution (σ ≈ 1 ns)
- ➢ relatively low background experiment

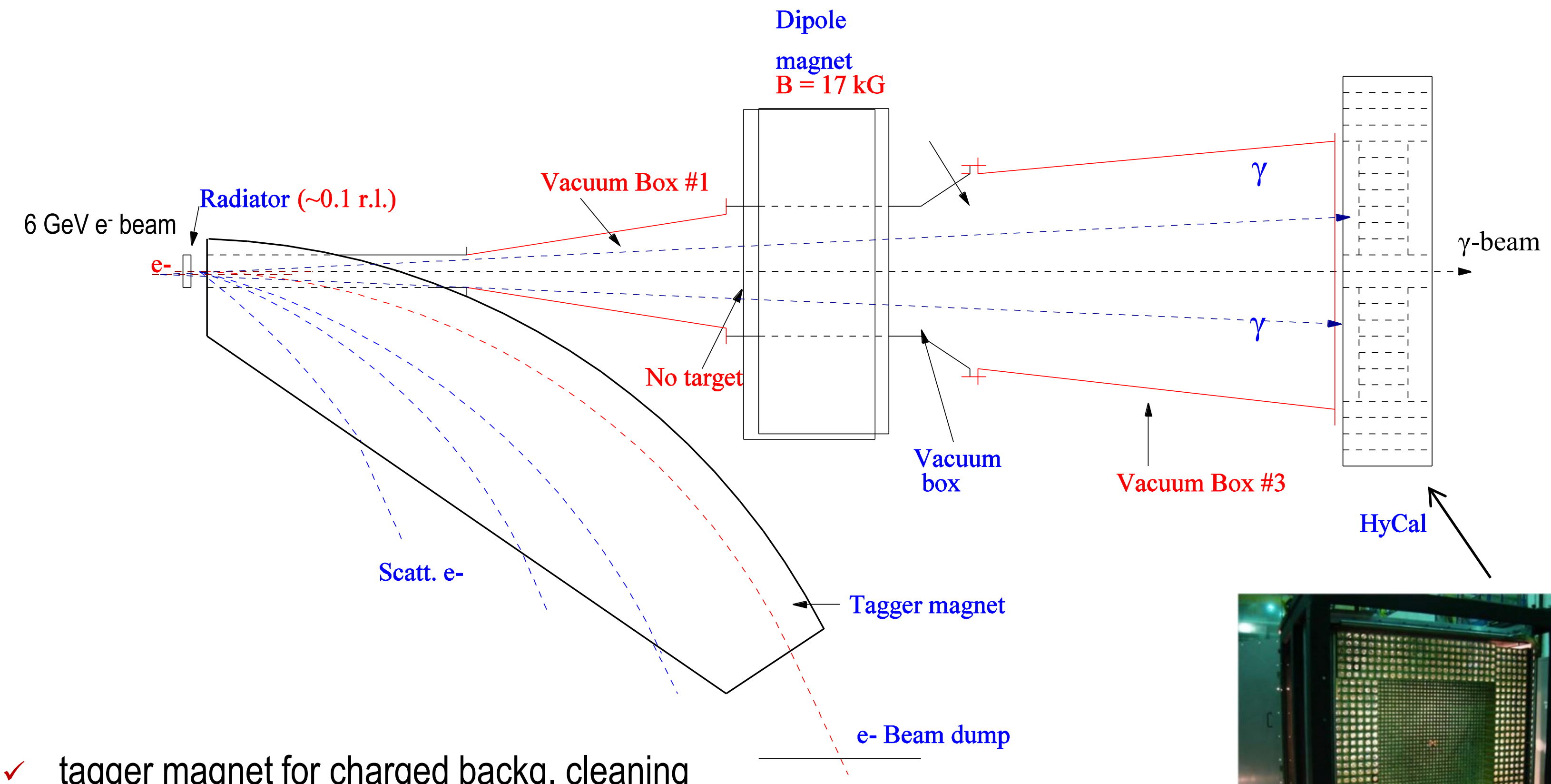


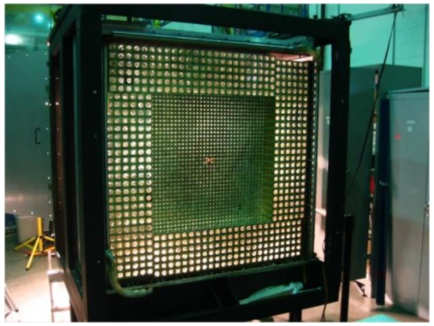




Search Experiment with 6 GeV Tagger in Hall B at JLab

- To use:
  - ✓ existing high resolution high intensity photon tagging facility in Hall B at JLab
  - ✓ upgraded $PbWO_4$ crystal calorimeter (HyCal) (1x1 m^2)



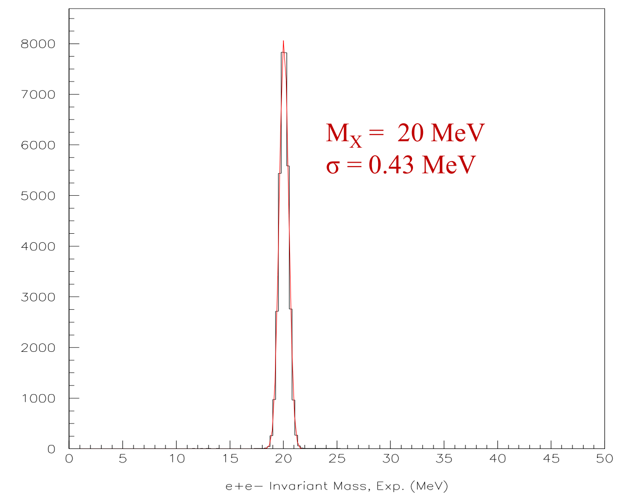


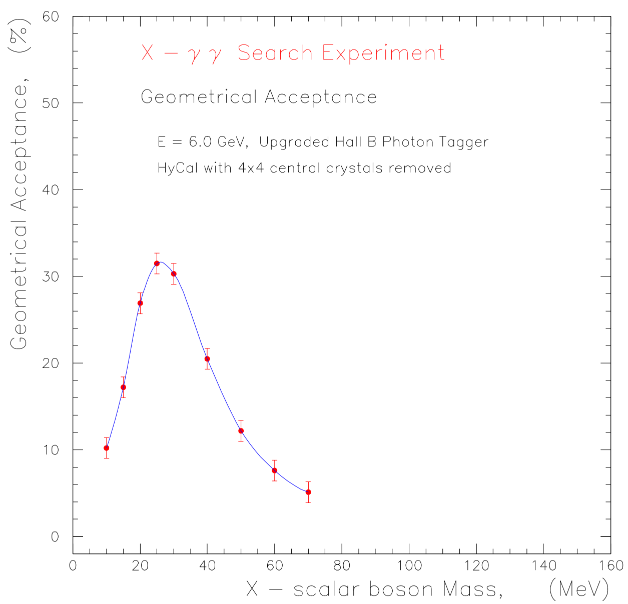
- ✓ tagger magnet for charged backg. cleaning
- ✓ PS dipole as second cleaning magnet

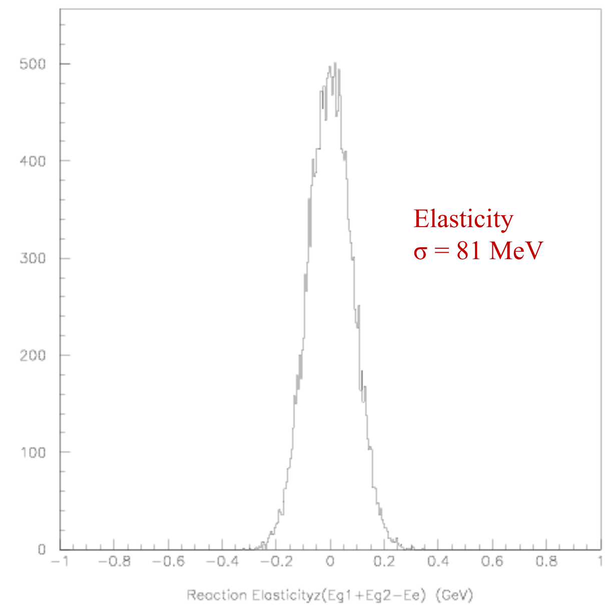
Characteristics of the Proposed Experiment (with 6 GeV Beam)

- **Advantages of the experiment:**

  Combination of
  - virtual photon tagging and
  - $PbWO_4$ calorimeter will provide:
    - good $M_{\gamma\gamma}$ resolution ($\sigma \sim 0.5$ MeV)
    - reaction elasticity (ΔE)
    - good timing information ($\sigma \approx 2\ ns$)
  - two cleaning magnets
    - relatively low background experiment
  - moderate $M_{\gamma\gamma}$ acceptance ($M_X = 10 - 50$ MeV)

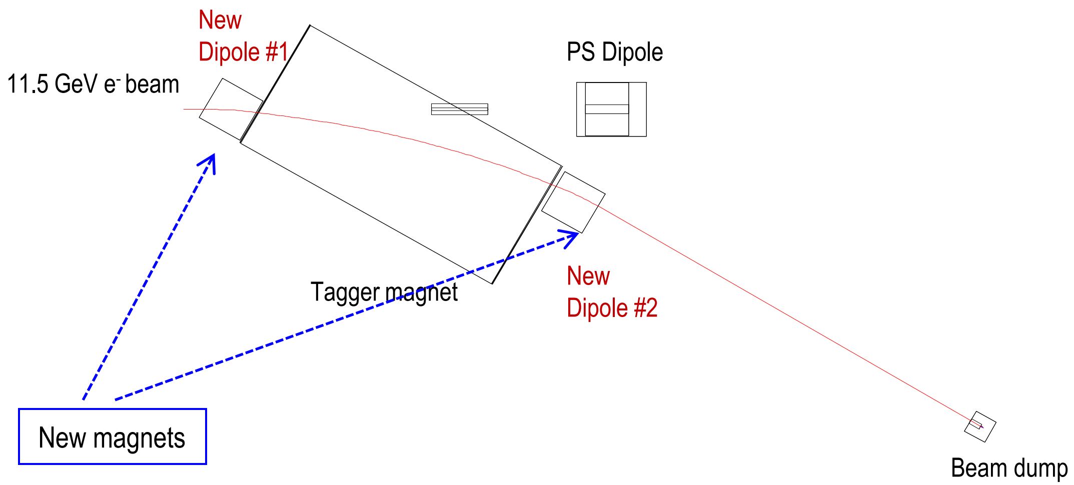






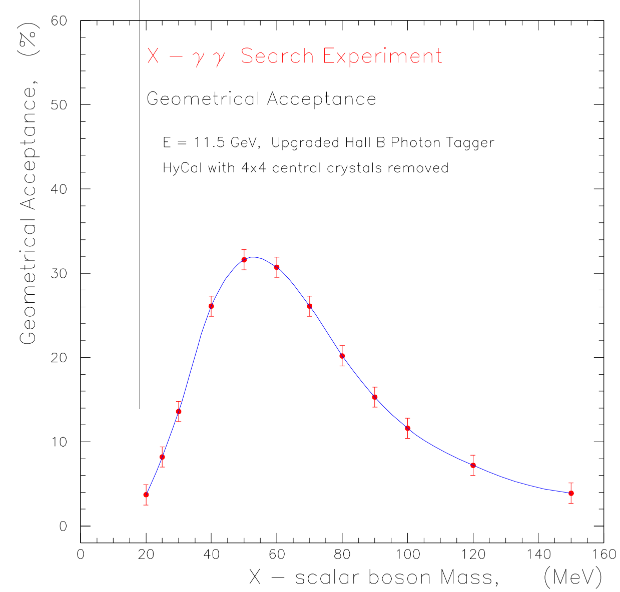
Solution with Two New Magnets for 11.5 GeV Tagger

- Current tagger is limited to ~ 6 GeV electron beam
- We propose to add two identical superconducting magnets:
  - ✓ length 1.0 m
  - ✓ integral BdL 5.5 Tm



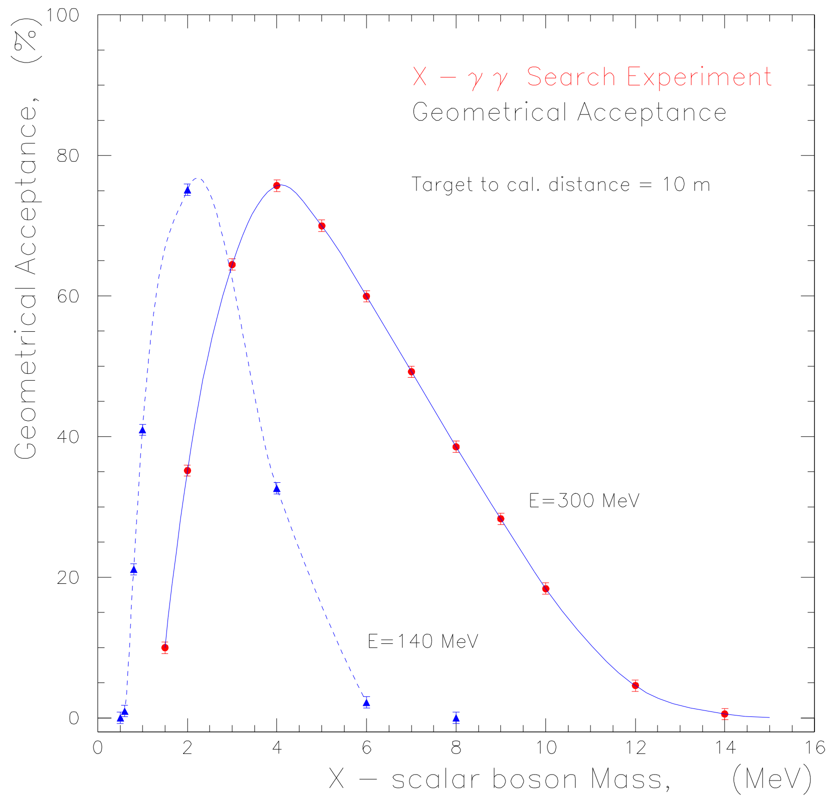
✓ Tagger field map from D. Sober
- initial bend angle: θ = 6.5^0
- entrance height change: -7.5 cm
- exit height change: -4.5 cm

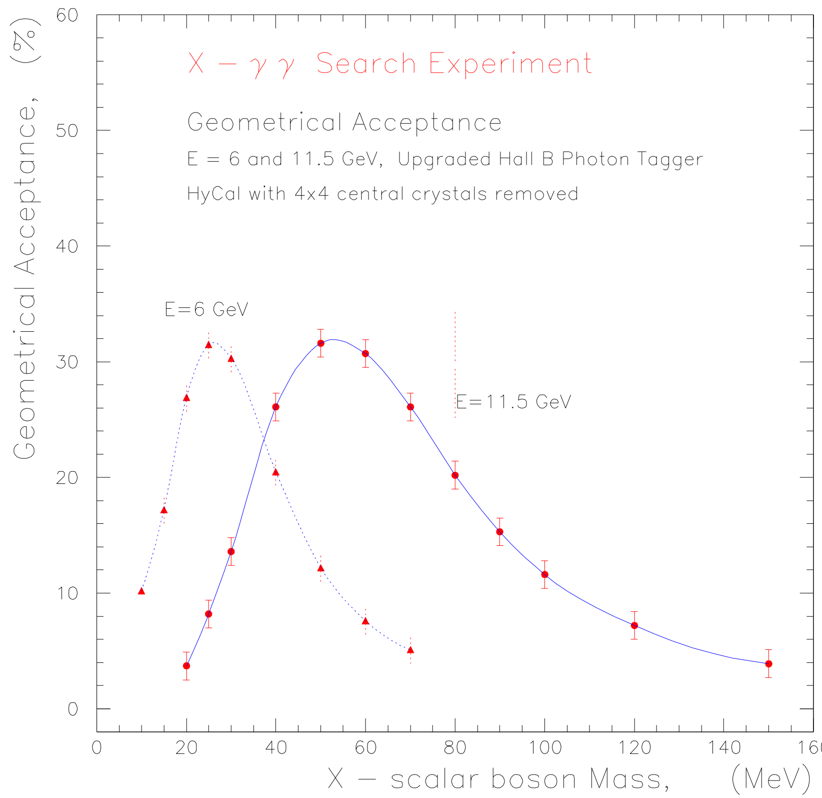
- Mγγ acceptance [30 – 120] MeV



Combined Invariant Mass Range

- Combination of accessible e^--beam energies will provide:
  - ✓ good $M_{\gamma\gamma}$ acceptance: [1 – 120] MeV
  - ✓ high resolution in $M_{\gamma\gamma}$: [0.5 – 1] MeV
  - ✓ with high geometrical acceptance: $\varepsilon \sim 20\%$





Estimated Count Rates

- Based on model predictions we estimated to be:

  $\sigma_X \sim 400$ pb for $M_X = 50$ MeV

- Assume:
  - Electron beam current: $I_e = 0.1\ \mu A = 6.25\text{x}10^{+11}$ e/sec
  - Au target with 0.001 r.l., $N_{Au} = 0.2\text{x}10^{+20}$ Au/cm^2
  - Detection efficiency: 20%

- Estimated Rate:

$$N_X \approx N_e\ N_{Au}\ \sigma\ \varepsilon$$
$$\approx 6.25\text{x}10^{+11}\ 0.2\text{x}10^{+20} \text{ x } 400\text{x}10^{-12} \text{ x } 10^{-24} \text{ x } 0.2$$
$$\approx 3.6\ (X \rightarrow \gamma\gamma)/\text{hour}$$
$$\approx 86\ (X \rightarrow \gamma\gamma)/\text{day}$$

Estimated Background Rate on the HyCal Calorimeter (Trigger Rate)

- Monte Carlo simulations
  - ✓ target: 0.5% Au
  - ✓ beam intensity: I_e = 0.1 μA
  - ✓ run equiv. time ~0.2 msec

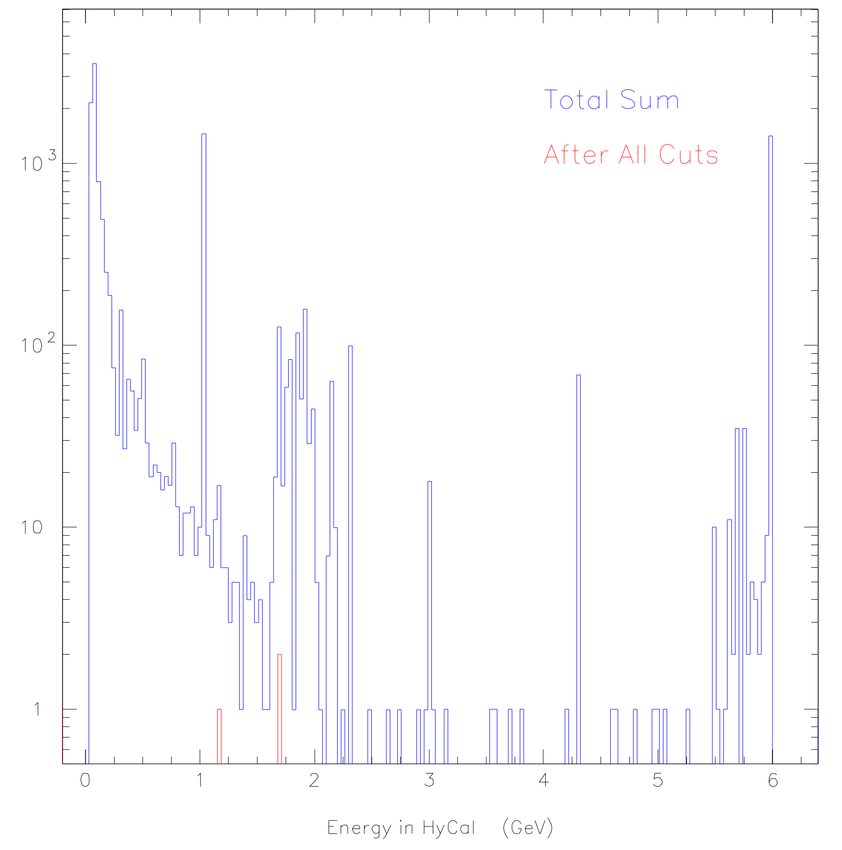
➢ Total rate (single clusters) on HyCal: ~ 60 MHz

- Applied Cuts:
  - ✓ Σ ($E_{cluster}$) > 4 GeV
  - ✓ more than one cluster
  - ✓ $E_{cluster}$ > 0.1 GeV
  - ✓ (cluster separ.) > 15 cm

➢ Trigger Rate ~ 3 / 0.2 msec ~ 15 KHz

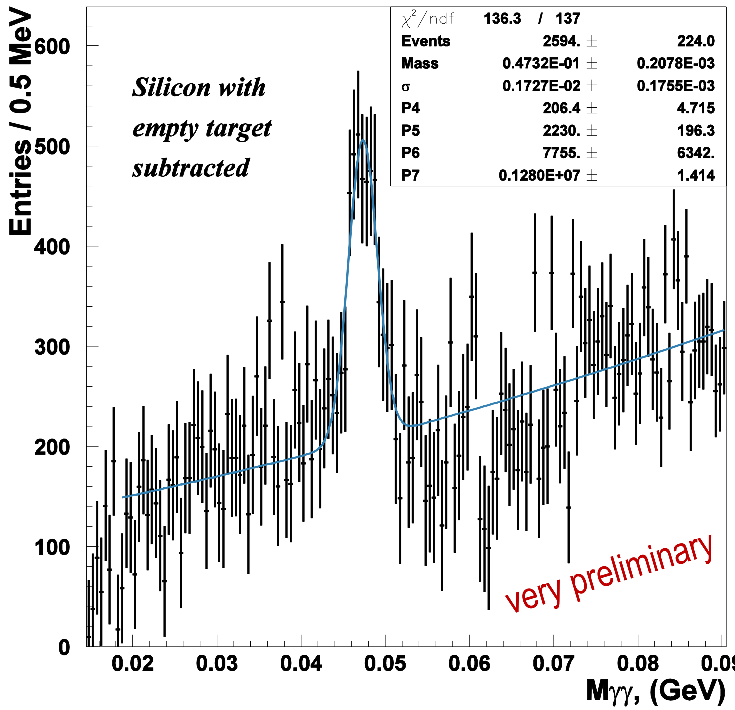
(a reasonable rate for current DAQ)

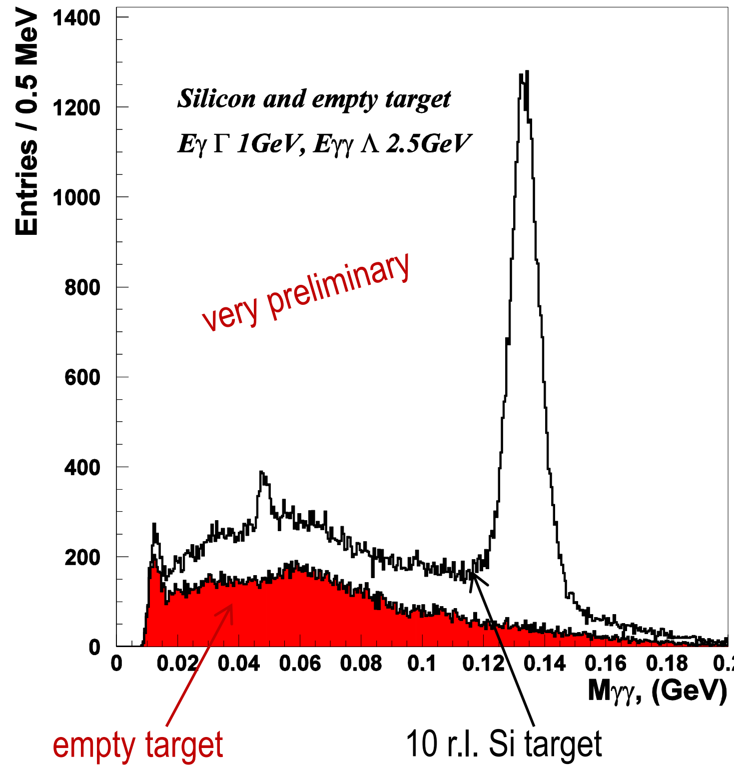
- Work is in progress to finalize simulations and optimize the trigger



Possible "Kinematical Reflections" in this Type of Experiments
(usually claimed as missing new particles)

- PrimEx data set has large statistics of multi-photon events, though it was optimized for π^0 decay
- $M\gamma\gamma$ spectrum of multi-cluster events (without energy constraint) shows ~6σ "effect" at $M\gamma\gamma = 47$ MeV (left plot)

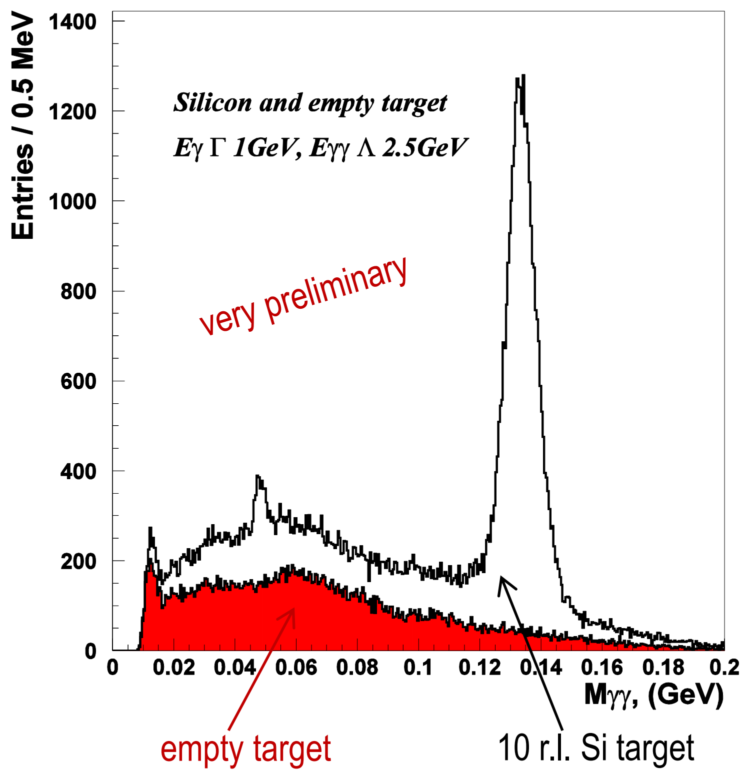




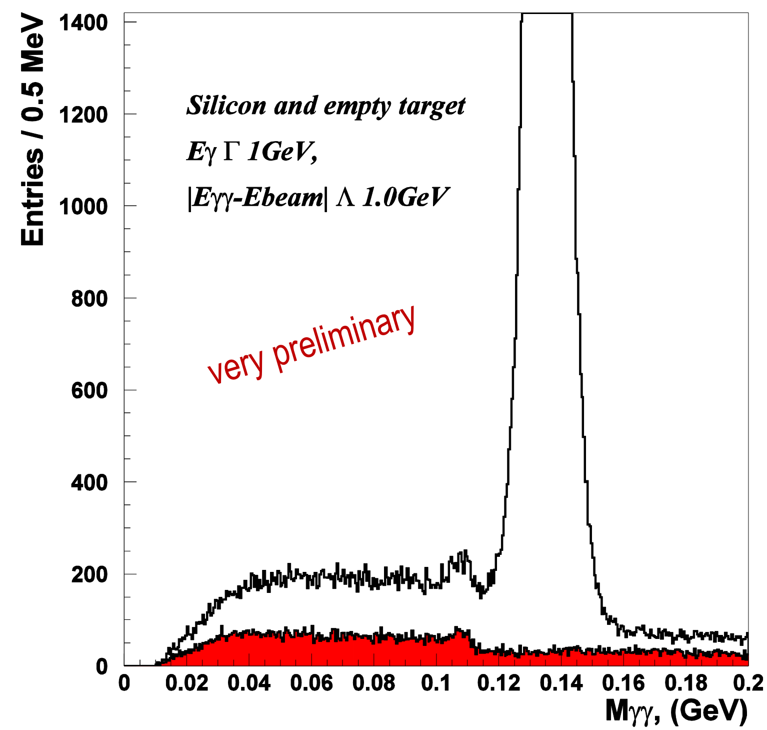
Possible "Kinematical Reflections" in this Type of Experiments

- Apply more kinematical constraints (ex., the reaction elasticity)

Without Energy Constraint



With Energy Constraint



Summary and Outlook

- An experimental program is proposed to search for hidden sector scalar bosons in neutral channel decays: $X \rightarrow \gamma\,\gamma$ with intense, medium energy electron beams:
  - implement virtual photon (zero-degree) tagging technique
  - use high resolution large acceptance $PbWO_4$ crystal calorimeter
  - low-cost exploratory search experiments
  - complimentary to current on-going heavy photon search experiments

- Advantages of the proposed experiments:
  - ✓ large acceptance range for M_X (1 – 120) MeV
  - ✓ high resolution in invariant mass (0.5 MeV @ M_X = 50 MeV)
  - ✓ high detection efficiencies (~20%)
  - ✓ relatively low experimental background (practically no charged background)

- Work in progress for evaluation of sensitivity limits in X-boson parameter space and optimization of experiment s

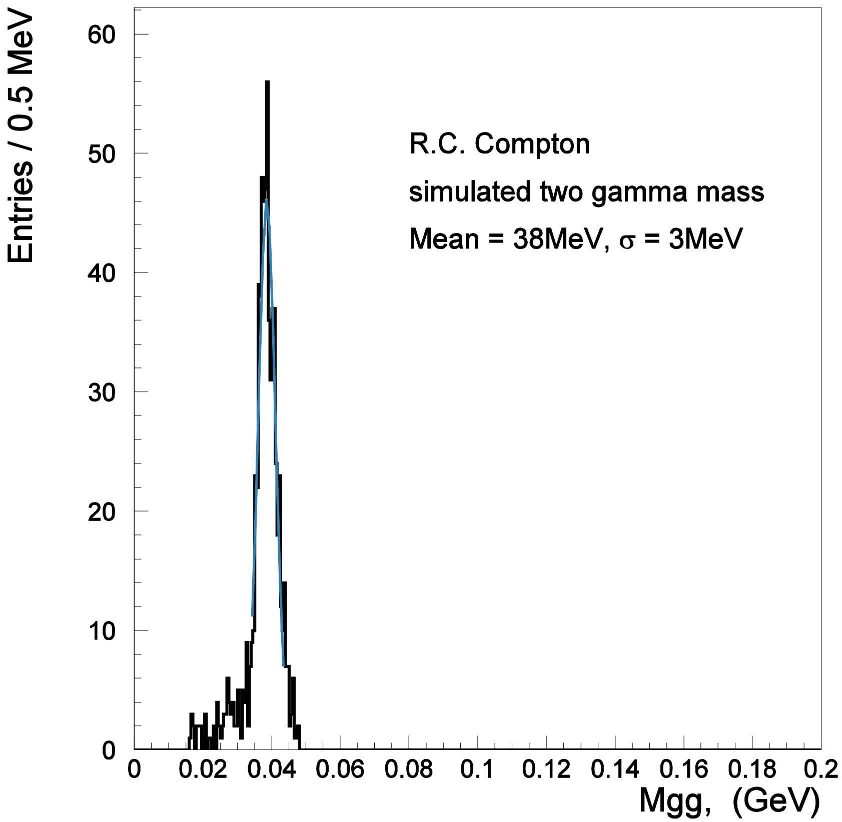
- Enrich search program in Physics Beyond the Standard Model

Full Monte Carlo Simulations Including All Possible Known Processes is Critically Important

- Double-photon events from radiative Compton process:

$\gamma + e^{-} \rightarrow \gamma + e' \rightarrow \gamma + e' + \gamma \rightarrow \gamma + \gamma$

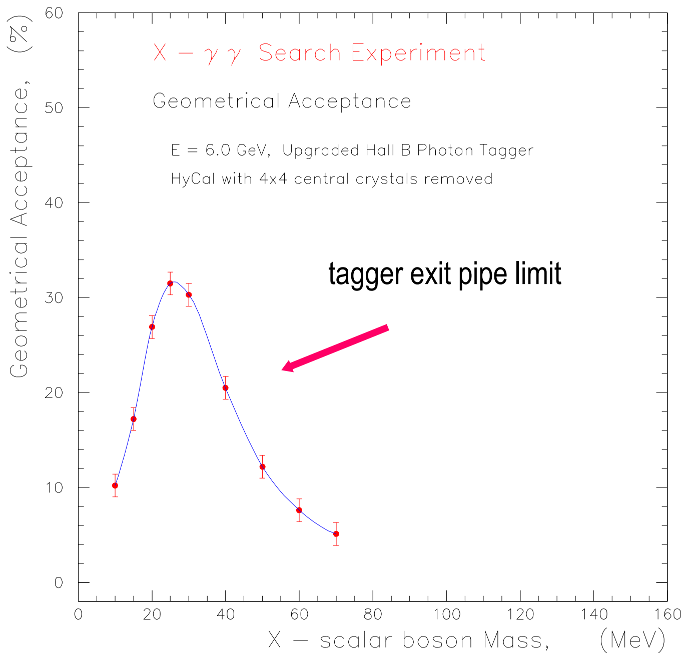
with e' deflected in magnetic field



Proposed Experiment Limitations with the Current Hall B Tagger

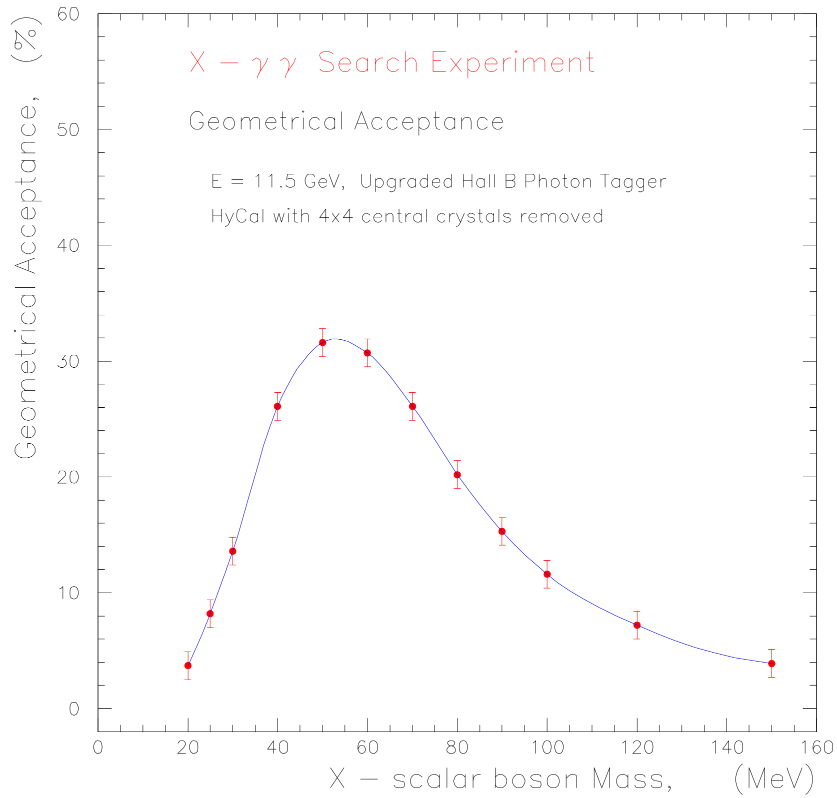
Disadvantages of experiment:

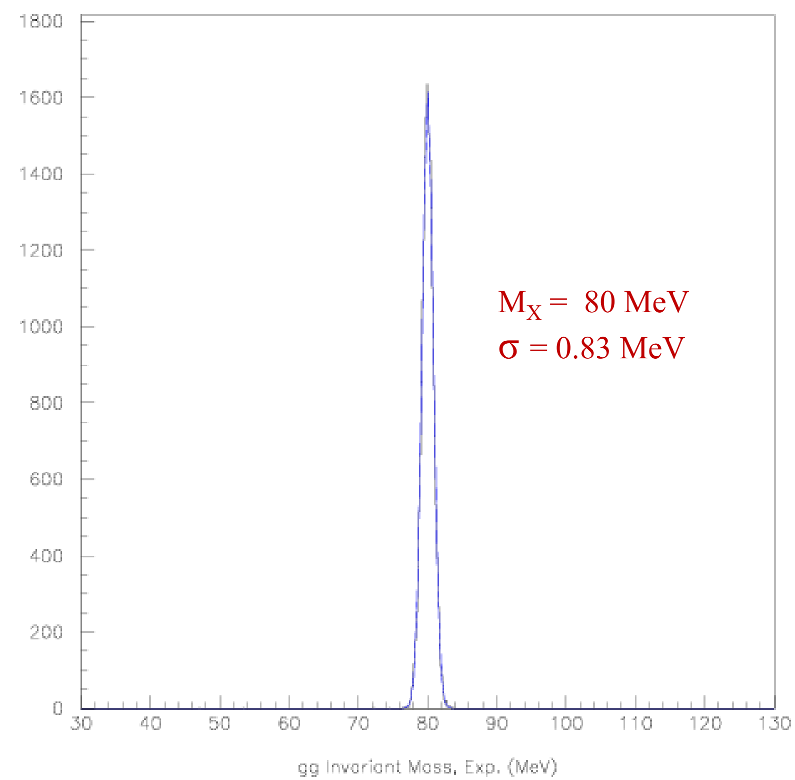
- No vertex information
  - ✓ elasticity will strongly suppress the background (γ^*-tagging will provide ΔE information)
- Tagger exit pipe (6.35cm) limits the aperture in this experiment (upper limit to $M_X \sim 50$ MeV)
-
- Proposed sulutions:
  - ✓ use low energy beam to reach low mass range ($M_X \sim 5$ MeV)
  - ✓ Use 12 GeV beam to reach higher mass range
  - ✓ ($M_X \sim 120$ MeV)
  - ➢ Current tagger magnet is limited to ≈6 GeV



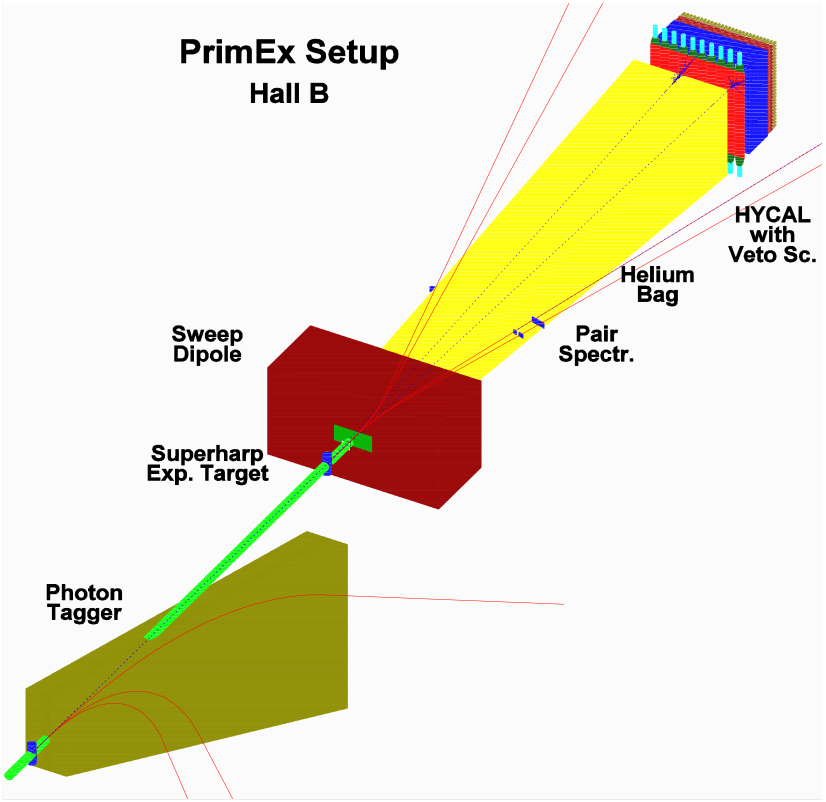
Invariant Mass Range with 11.5 GeV Beam

- good invariant mass range: M_x=[30 – 120] MeV
- high resolution in invariant mass: $\sigma \approx 1\ MeV$
- good geometrical acceptance: ε ~20%





PrimEx Experimental Setup



Physics Motivation
Neutral Pion “Impostor”

Pion-Photon Transition Form Factor and New Physics in the τ Sector

David McKeen,[1,*] Maxim Pospelov,[1,2,†] and J. Michael Roney[1,‡]

[1] *Department of Physics and Astronomy, University of Victoria, Victoria, BC V8P 5C2, Canada*
[2] *Perimeter Institute for Theoretical Physics, Waterloo, ON N2J 2W9, Canada*

(Dated: March 15, 2012)

Recent measurement of the $\gamma\gamma^*$ form factor of the neutral pion in the high Q^2 region disagrees with *a priori* predictions of QCD-based calculations. We comment on existing explanations, and analyze a possibility that this discrepancy is not due to poorly understood QCD effects, but is a result of some new physics beyond the standard model (SM). We show that such physics would necessarily involve a new neutral light state with mass close to the mass of π^0, and with stronger than π^0 couplings to heavier SM flavors such as c, τ, and b. It is found that only the coupling to the τ lepton can survive the existing constraints and lead to the observed rise of the pion form factor relative to Q^{-2} at high Q^2. We perform numerical fits to data and determine the allowed range of masses and couplings for such new particles. This range of masses and couplings could also reduce or eliminate the tension between the e^+e^- and τ decay determinations of the hadronic vacuum polarization. Dedicated experimental analysis of τ pair production in association with such new states should provide a conclusive test of the new physics hypothesis as an explanation of the pion form factor rise. We also comment on the calculations of the pion form factor in the chiral quark model, and point out a possible dynamical origin of the quark mass scale inferred from the form factor measurement.

PACS numbers: 13.40.Gp, 14.40.Be, 14.60.Fg, 14.80.Ec

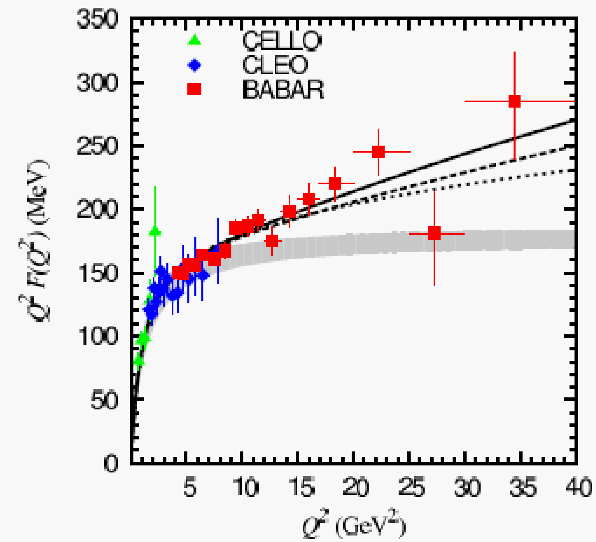


FIG. 3. The best-fit total form factors in the pseudoscalar impostor (solid), scalar impostor (dashed), and hardcore pion (dotted) cases when fit to the data from *BABAR* [1], CLEO [3], and CELLO [4] using the form factors of Eqs. (32) and (33). The resultant couplings are $g_\tau = 0.63$, $h_\tau = 0.84$, and $g_\tau^\pi = 0.18$, see Table I. The shaded region indicates the range of BMS form factors. The scalar impostor coupling is limited by the $(g-2)_\tau$ constraint [24].

- Introduced new pseudo-scalar or scalar neutral particles with masses close to π^0
- coupling to leptons to explain the BaBar experimental result.
- predicts a 1.8% change in π^0 lifetime it is within uncertainty of PrimEx current 2.8% result.

Physics Motivation
Phenomenology of Pseudo Nambu-Goldstone Bosons

PHYSICAL REVIEW X 1, 021026 (2011)

Sub-GeV Dark Matter as Pseudo-Nambu-Goldstone Bosons from the Seesaw Scale

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[3]*Institut de Física d'Altes Energies, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain*
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[5]*Grup de Física Teòrica, Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain*
(Received 5 August 2011; published 29 December 2011)

Pseudo-Nambu-Goldstone bosons (pNGBs) are naturally light, spin-zero particles that can be interesting dark-matter (DM) candidates. We study the phenomenology of a pNGB θ associated with an approximate symmetry of the neutrino seesaw sector. A small coupling of θ to the Higgs boson is induced radiatively by the neutrino Yukawa couplings. By virtue of this Higgs-portal interaction, (i) the pNGB acquires a mass m_θ proportional to the electroweak scale, and (ii) the observed DM relic density can be generated by the freeze-in of θ particles with mass $m_\theta \simeq 3$ MeV. Alternatively, the coupling of θ to heavy sterile neutrinos can account for the DM relic density, in the window 1 keV $\lesssim m_\theta \lesssim 3$ MeV. The decays of θ into light fermions are suppressed by the seesaw scale, making such pNGBs sufficiently stable to play the role of DM.

DOI: 10.1103/PhysRevX.1.021026 Subject Areas: Particles and Fields

Physics Motivation
Phenomenology of Pseudo Nambu-Goldstone Bosons

In the specific seesaw models that we will build, λ is generated by logarithmically divergent neutrino loops, involving both the $\theta - N$ coupling g as well as neutrino Dirac Yukawa couplings, denoted generically by y. It turns out that the relation between the mass of θ and the neutrino parameters can be written schematically as

$$m_\theta^2 = \lambda v^2 \simeq g^2 y^2 v^2 \frac{\log(\Lambda^2/m_N^2)}{8\pi^2}, \quad (3)$$

where Λ is some cutoff scale at or above f. The light-neutrino-mass scale is given by the standard seesaw relation, $m_\nu = y^2 v^2 / m_N$. It is useful to use Eq. (3) to express the coupling g as a function of the relevant energy scales in the theory:

$$g = 10^{-3}\left(\frac{m_\theta}{\text{MeV}}\right)\left(\frac{\text{eV}}{m_\nu}\right)^{1/2}\left(\frac{10^9 \text{ GeV}}{m_N}\right)^{1/2}\left(\frac{8\pi^2}{\log(\Lambda^2/m_N^2)}\right)^{1/2}. \quad (4)$$

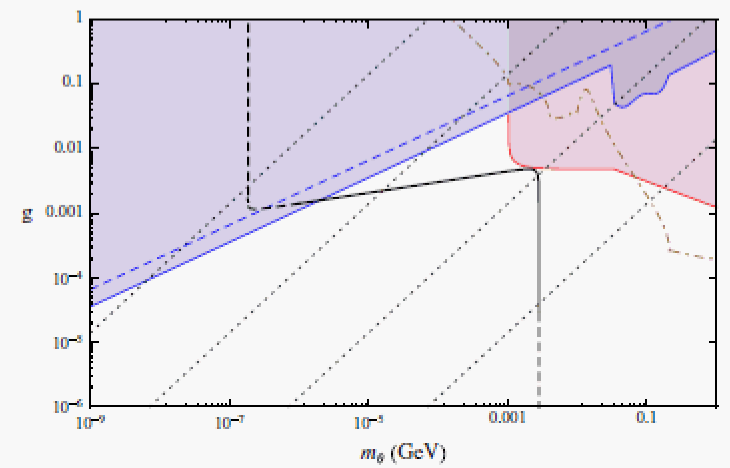

FIG. 3. The constraints on the DM lifetime in the m_θ-g plane, for $m_\nu = 0.05$ eV. The thick black curve, corresponding to the correct DM relic density, as well as the dotted vertical lines, corresponding to constant values of m_N, are the same as presented in Fig. 1. The curve is dashed for $m_\theta \lesssim 1$ keV, because DM is warm in this region (see the text), and for $g \lesssim 10^{-5}$, because of the theoretical bound $f < M_P$, shown in Fig. 1. The blue solid (dashed) line is the upper bound on g from DM decays into neutrinos coming from astrophysics and cosmology (from the Universe lifetime); the blue shaded region is therefore excluded. The red solid line is the analog bound for DM decays into e^+e^-; the red shaded region is correspondingly excluded. Finally, the brown dash-dotted line is a conservative estimate of the upper bound on g from DM decays into photons (see the text).

- More detail questions to A. Afanasev

Physics Motivation
Inter-quark Exchange of a New Scalar Boson

Material evidence of a 38 MeV boson

Eef van Beveren[1] and George Rupp[2]
[1] *Centro de Física Computacional, Departamento de Física, Universidade de Coimbra, P-3004-516 Coimbra, Portugal*
[2] *Centro de Física das Interacções Fundamentais, Instituto Superior Técnico, Technical University of Lisbon, P-1049-001 Lisboa, Portugal*
(Dated: February 13, 2012)

We present further and more compelling evidence of the existence of $E(38)$, a light boson that most probably couples exclusively to quarks and gluons. Observations presented in a prior paper will be rediscussed for completeness.

PACS numbers: 11.15.Ex, 12.38.Aw, 12.39.Mk, 14.80.Ec

Here, we will find that the phenomenon is most likely to be associated with the interquark exchange of a boson with a mass of about 38 MeV. Moreover, from the fact that the observed oscillations are more intense for bottomonium than for light quarks, we assume that the coupling of this light boson to quarks increases with the quark mass. This seems to correspond well to the scalar

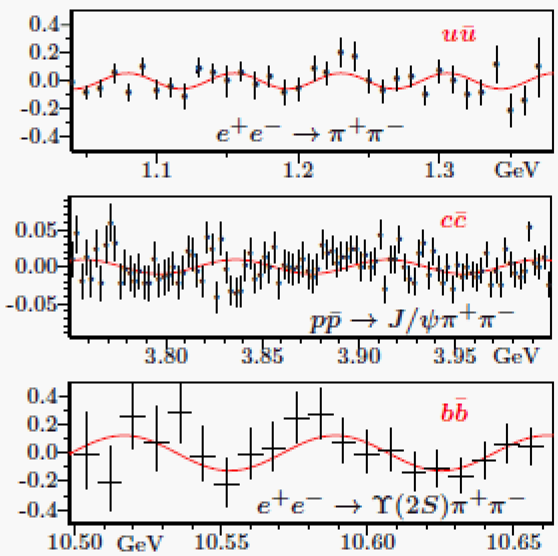

FIG. 1. Fits to the residual data, after subtraction of global fits to: $e^+e^- \to \pi^+\pi^-$ data of the CMD-2 Collaboration [7], with a period of 78±2 MeV and an amplitude of ≈5% (*top*); $pp \to J/\psi\pi^+\pi^-$ data of the CDF Collaboration [8], with a period of 79±5 MeV and an amplitude of about 0.75% (*middle*); $e^+e^- \to \Upsilon(2S)\pi^+\pi^-$ data of the BABAR Collaboration [9], with a period of 73±3 MeV and an amplitude of some 12.5% (*bottom*).

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PACS numbers: 11.15.Ex, 12.38.Aw, 12.39.Mk, 14.80.Ec

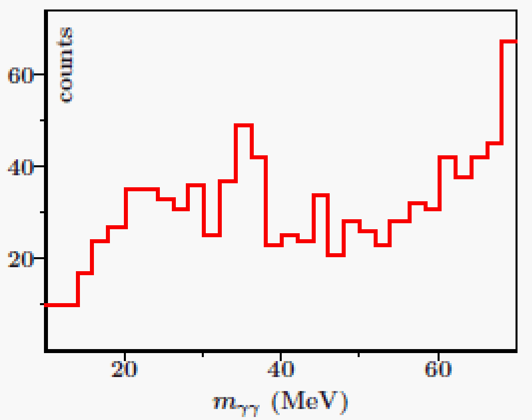


FIG. 6. A modest signal at about 37 MeV in the two-photon distribution published by the CB-ELSA Collaboration [13].

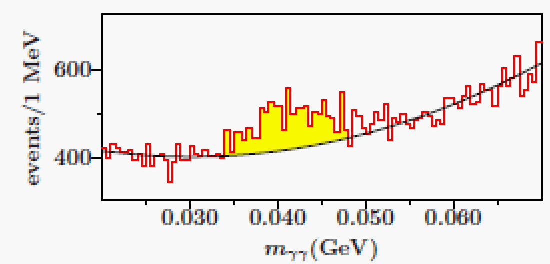
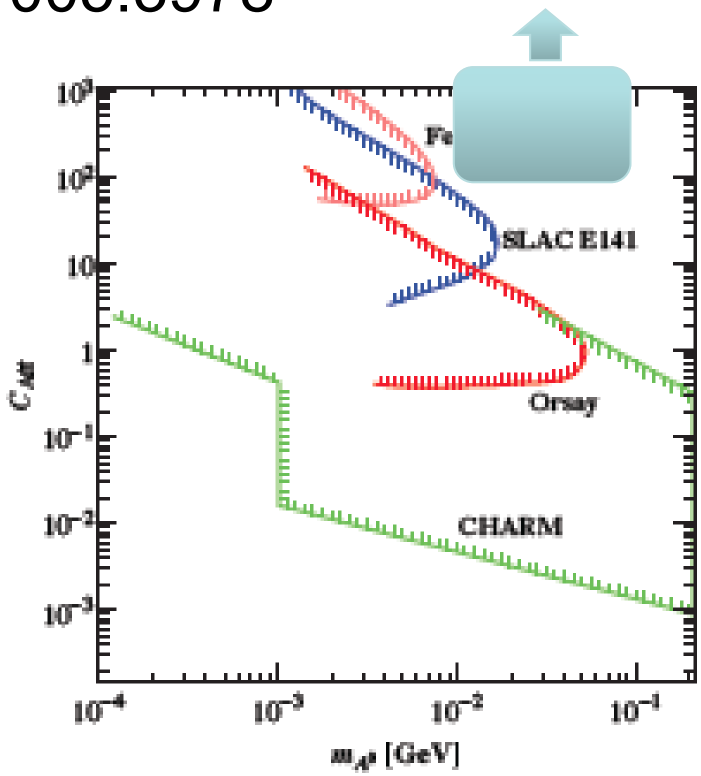


FIG. 7. A modest signal in the $\gamma\gamma$ COMPASS [14] data at around 40 MeV.

- However, these results are unpublished (arXiv:1202.1739v2)

Anticipated Sensitivity vs Beam Dump Experiments

- Beam dump constraints compiled in Andreas et al, arXiv 1005.3978



Estimated region of parameter space to be probed in the proposed measurement