A Direct Detection Search for Hidden Sector New Particles in the 3-60 MeV Mass Range

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and the PRad collaboration

Outline

- Physics objectives
- the method
- experimental setup
- resolutions
- background and statistics
- summary

Physics Goals of this Proposal

- Most of cosmological observations suggest that:
  - ✓ ≈85% of Universe consist of matter with "unknown origin", the so-called Dark Matter (DM)
  - ✓ DM either does not interact with the known, ordinary matter (SM) or
    if interacts, then very weakly (WIMPs), weak enough we can not detect them so far;
  - ✓ many theoretical models, many search experiments …
  - ✓ no experimental detection of DM so far.
- DM can be detected through their interactions with the SM objects (particles/fields).
- A viable theoretical model suggests:
  - ✓ existence of "intermediate particles/fields" (portals) between DM and SM objects;
  - ✓ providing interaction between DM and SM through the so-called "kinetic mixing" mechanism;
  - ✓ U(1) gauge boson (dark photon or X-particle);
  - ✓ the [1 — 100] MeV mass range is well motivated, in particular.
- Recent experimental evidence: excess of e^+e^- pairs in excited ^{8}Be and ^{4}He decay spectrum (ATOMKI anomaly, → hypothetical X17 particle or 5th-force carrier).
  - ✓ requires an urgent independent experimental validation.
- We propose to search for hidden sector intermediate particles (or fields) in low MeV-scale mass range through a direct detection method.

Experimental Objectives of this Proposal

- This proposal has two experimental objectives:

  1) Search for "hidden sector" intermediate particles (or fields) in [3 − 60] MeV mass range produced in electron-nucleus collisions and detected in e^+e^- (or $\gamma\gamma$) channels.

  2) Establish an experimental upper limit on the electroproduction of the hypothetical X17 particle claimed in two ATOMKI low-energy proton-nucleus experiments.

  Many past and recent publications suggesting models predicting existence of scalar or pseudoscalar new particles in low mass range, [1−50] MeV, decaying through $\gamma\gamma$ channel.

  The proposed experiment is equally sensitive to neutral decay channels ($X \rightarrow \gamma\gamma$).
  (Significant advantage over many other proposals or running experiment).

arXiv:1707.09749

ATOMKI ^{8}Be Experiment

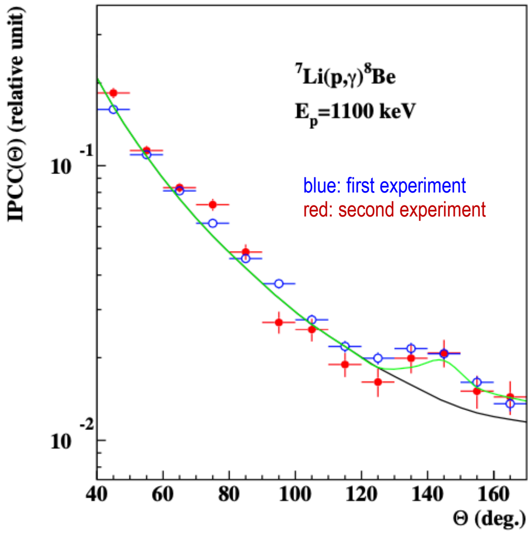
- ^{8}Be anomaly in nuclear transitions (*PRL 116(4):042501 (2016)*):
  - ✓ ^{8}Be excited states, decaying to ground state by E/M transitions.

$p + {}^{7}Li \rightarrow {}^{8}Be^{*} \rightarrow 7Li + p$ (hadronic decay)

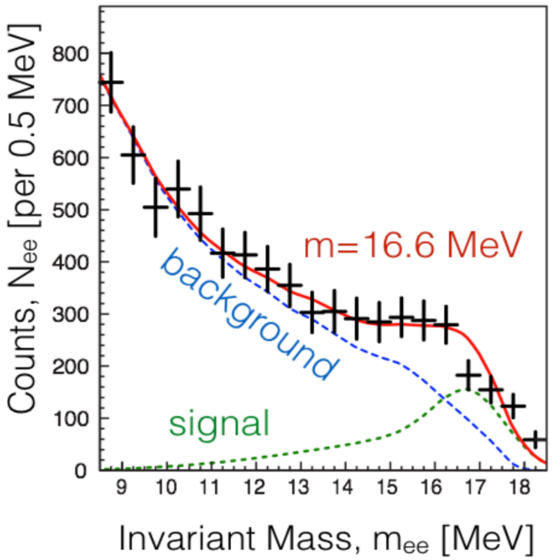
$\rightarrow {}^{8}Be + \gamma$ (E/M decay)

$\rightarrow {}^{8}Be + \gamma^{*},\ \gamma^{*} \rightarrow e^{+}e^{-}$ (IPC)

✓ excess of $e^{+}e^{-}$ pairs in angular distributions (inv. mass) beyond the expectation of the Internal Pair Conversion (IPC).



- Over hundred theory papers:
  - ✓ Feng *et al*. *PRL 1 17, 071803 (2016):*
    X17 vector boson, 5th force mediator with SM;
  - ✓ Ellwanger *et al*. *JHEP 11, 039 (2016):*
    possible light pseudoscalar particle;
  - ✓ Kozaczuk *et al*., *PR D 95 115024 (2017):*
    possible axial vector boson;
  - ✓ Zhang and Miller, *PL B773:159-165, (2017):*
    … nuclear physics cannot explain the signal!
  - ✓ Zhang and Miller, *PL B 813:136061 (2021):*
    … protophobic X17 requires smooth energy spectrum over threshold…
  - ✓ ATOMKI group presented new data proving that requirement.



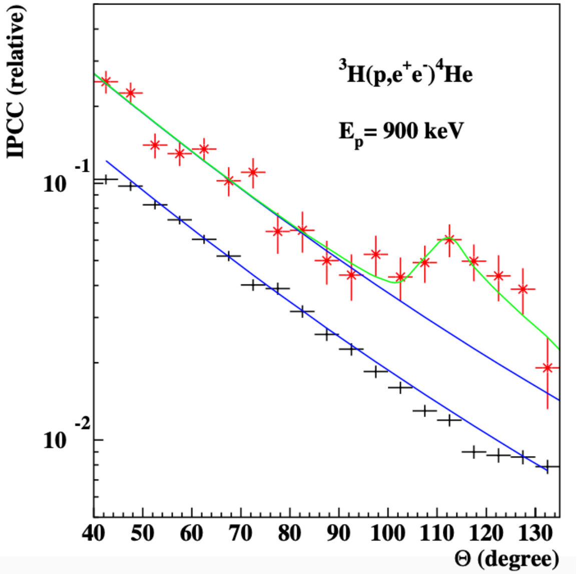
ATOMKI ^4He Experiment

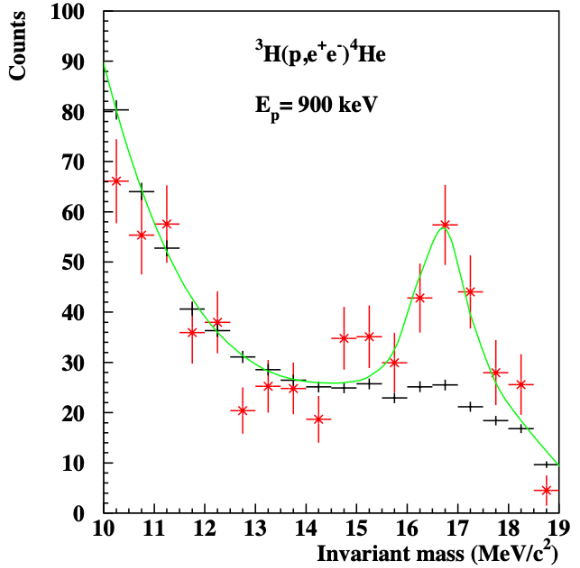
- New results on ^4He with updated experimental setup and reduced background, *J. Phys.: Conf. Ser. 1643, 012001 (2020)* :

$$p + {}^3H \rightarrow {}^4He^* + \gamma \rightarrow {}^4He + \gamma^*, \;\; \gamma^* \rightarrow e^+e^- \text{ (IPC)}$$

  - ✓ e^+e^- peak at different angles but the same invariant mass.
  - ✓ recently approved for publication.
    (based on recent MESON-2021 Workshop presentation)

- Requires an urgent independent experimental validation.





Experimental Method

- The method:
  - ✓ "bump hunting" in the invariant mass spectrum over the beam background.
  - ✓ direct detection of all final state particles (e', e^+e^- and/or $\gamma\gamma$) → full control of kinematics

- Electroproduction on heavy nucleus in forward directions:

$$e^- + Ta \rightarrow e' + \gamma^* + Ta \rightarrow e' + X + Ta, \quad \text{with} \quad X \rightarrow e^+e^- \text{ (with tracking)}$$
$$\text{and/or } X \rightarrow \gamma\gamma \text{ (without tracking)}$$

in mass range: [3 - 60] MeV
target: Tantalum, ($_{73}Ta^{181}$), 1 μm (2.4×10^{-4} r.l.) thick foil.

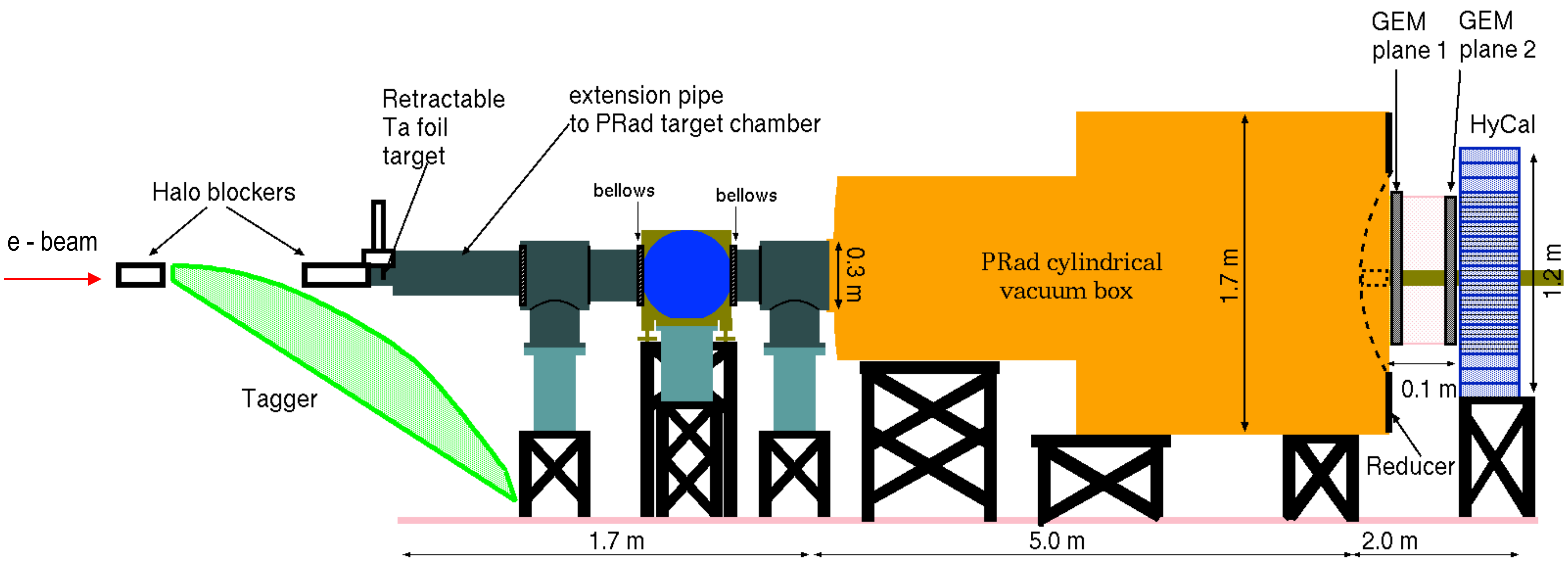
- All 3 final state particles will be detected in this experiment:
  - ✓ scattered electron, e' , with 2 GEMs and $PbWO_4$ calorimeter;
  - ✓ decay e+ and e- particles, with 2 GEMs and $PbWO_4$ calorimeter;
  - ✓ or decay $\gamma\gamma$ pairs, with $PbWO_4$ calorimeter.

- Will provide a tight control of experimental background.

Proposed Experimental Setup in Hall B

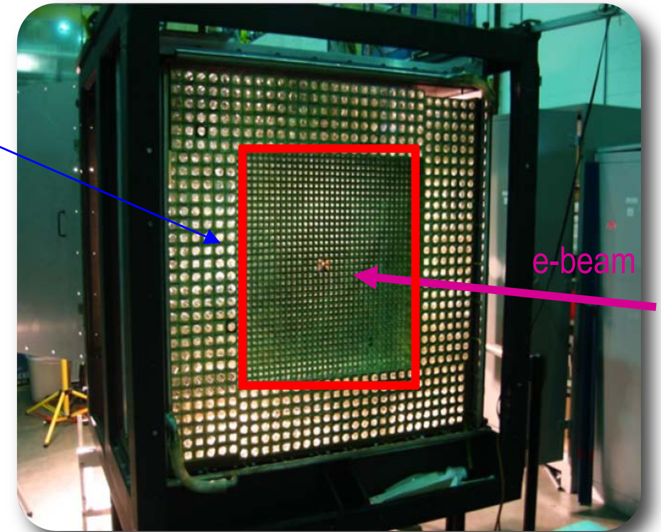
- Experimental setup is based on the PRad apparatus:
  - Hall B Photon Tagger will be used for $PbWO_4$ calorimeter calibration;
  - 1 μm Ta solid targets (2.4x10^{-4} r.l.) will be placed on a target ladder (multiple foils) (TAC Q#5);
  - Two planes of GEM detectors on front of the $PbWO_4$ calorimeter, providing limited tracking;
  - Only the $PbWO_4$ part of the HyCal calorimeter will be used in this experiment.

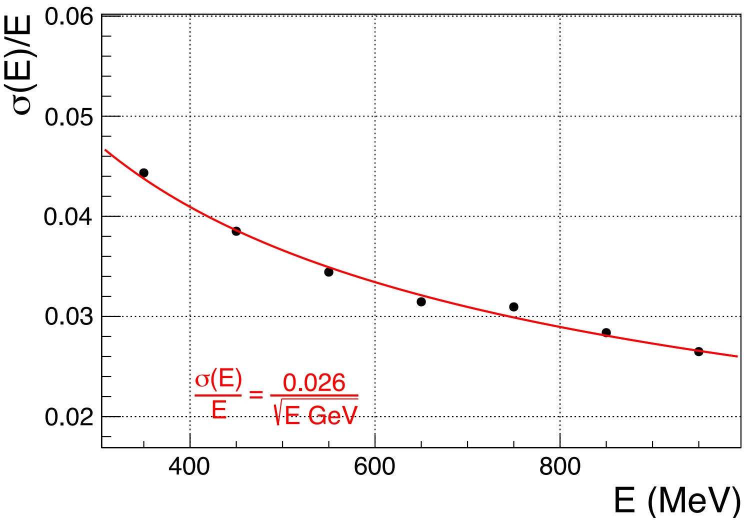
Experimental Setup (Side View)



Experimental Apparatus: $PbWO_4$ Electromagnetic Calorimeter

- The inner $PbWO_4$ part of HyCal only will be used:
  - ✓ 34 x 34 =1156 crystal modules, each with 2x2x18 cm^3;
  - ✓ with 68 x 68 cm^2 total detection area;
  - ✓ 2x2 crystals are removed from center for beam passage





Energy resolution (PrimEx measurement, limited by Hall B Photon Tagger).

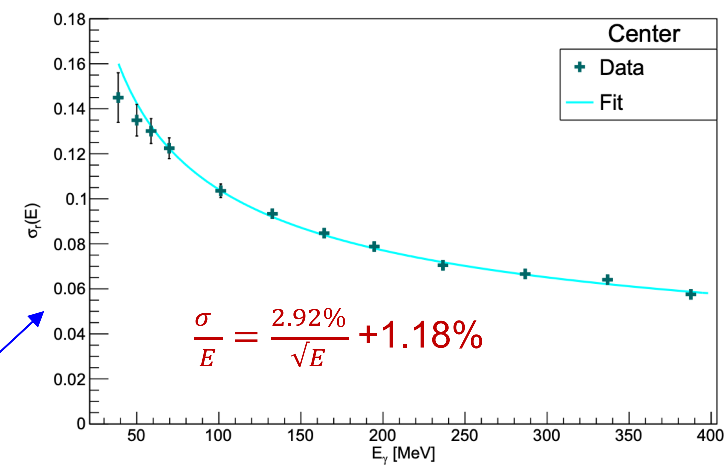


Figure 43: Measured relative resolution of the cluster energy response as a function of the incident photon energy E_γ for the center irradiation position in element 8. The errors are systematic.

M. Erzer, Masters Thesis, Mainz, 2020

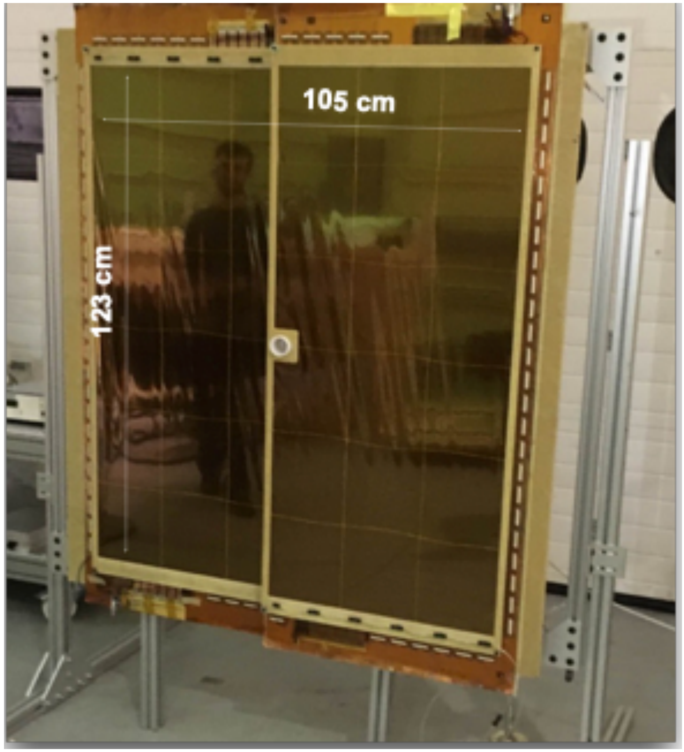
- $PbWO_4$ crystals have excellent detection characteristics at MeV range energies too.
- example: recent Mainz measurements down to 30 MeV energies (crystals were not cooled): similarly good energy resolutions. (TAC Q.#8)

Experimental Apparatus: GEM Coordinate Detectors (Tracking)

- Two planes of GEM detectors for tracking (limited tracking):
  - ✓ similar to PRad-II GEMs but smaller size: 68x68 cm^2 each;
  - ✓ located on front of $PbWO_4$, after the vacuum window;
  - ✓ relative distance (10 cm) optimized between resolution and available material after the vacuum window;
  - ✓ good position resolution (σ=72 μm);
  - ✓ will also be used to veto/select neutral clusters (like γ).

- Electronics: APV-25 based readout:
  - ✓ available in the collaboration;

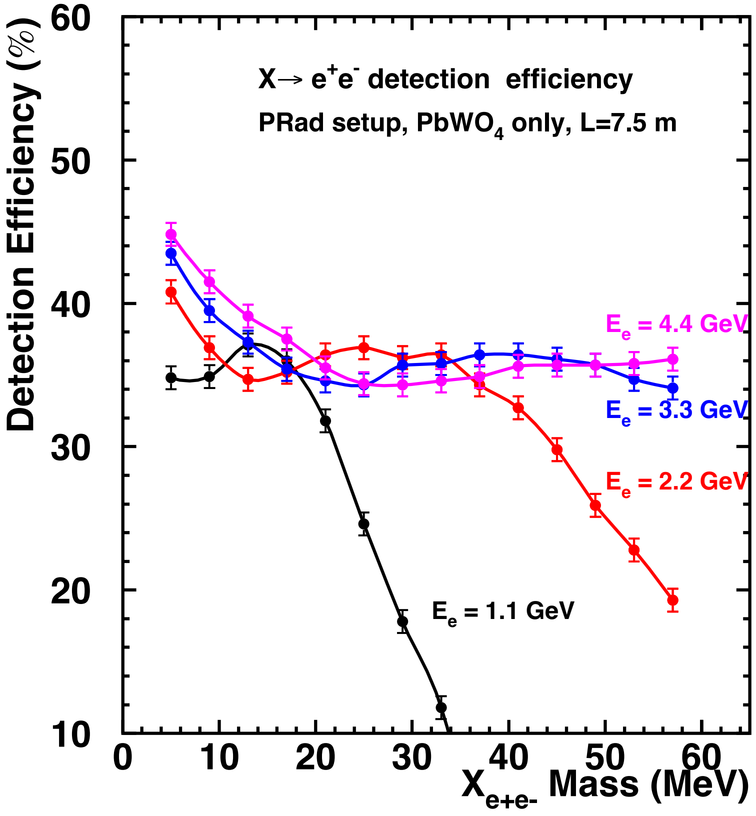
  (ITAC Q.#9)



PRad GEMs (large size) before installation in Hall B.

Detection Efficiency

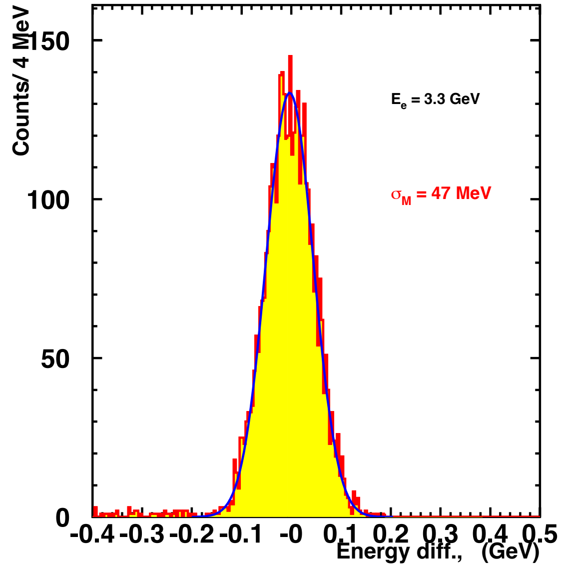
- Hardware trigger:
  - ✓ 3 clusters in $PbWO_4$ calorimeter;
  - ✓ each cluster energy: 30 MeV $< E_{clust} < 0.8 \mathrm{x} E_{beam}$ (rejects the elastic scattered electrons)
  - ✓ total energy sum in calorimeter: $\Sigma E_{clust} > 0.7 \mathrm{x} E_{beam}$
- Large phase space for virtual photon, γ^*:
  - ✓ energy interval: $E_{\gamma^*} \approx [0.2 - 1]\, E_{beam}$;
  - ✓ $\vartheta_{e'} \approx [0.4^0 \text{--} 3.7^0]$ angular range.
    (ITAC Q.#12, provides X-particle production in wide energy spectrum in forward solid angle)
- Target to detector distance: L = 7.5 m provides good (integrated) detection efficiency in [3-60] MeV mass range for E_e = 2.2, 3.3 and 4.4 GeV.



- E_e = 2.2 and 3.3 GeV were chosen for relative ease of scheduling during CEBAF low-energy runs.
- E_e = 2.2 and 4.4 GeV also feasible to ease scheduling between different experimental Halls. (TAC Q.#2 and ITAC Q.#8)

Experimental Resolutions

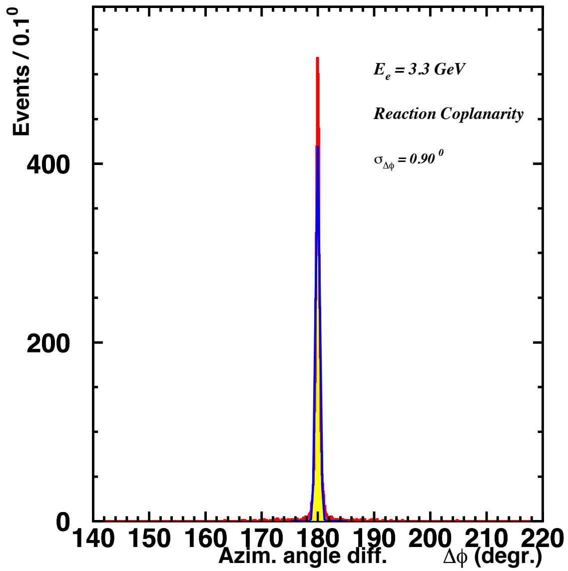
- Good energy resolution of $PbWO_4$ calorimeter (2.6% @ E=1 GeV) and 1 μm thin target provides powerful energy cut in this experiment (ΔE = 47 MeV @ 3.3 GeV beam).
  - ✓ important selection criterion for multi-channel and;
  - ✓ accidental events;
  - ✓ critical cut at low-mass range (see next slides).



- Coplanarity (between $\overrightarrow{P_{e'}}$ and ($\vec{P}_{e+}$ + $\vec{P}_{e-}$) vectors):

GEMs excellent position resolution (σ=72 μm), together with very thin 1 μm target (2.4×10^{-4} r.l.) provides event selection criterion, important for:

- ✓ multi-particle and;
- ✓ accidental coincidence events.

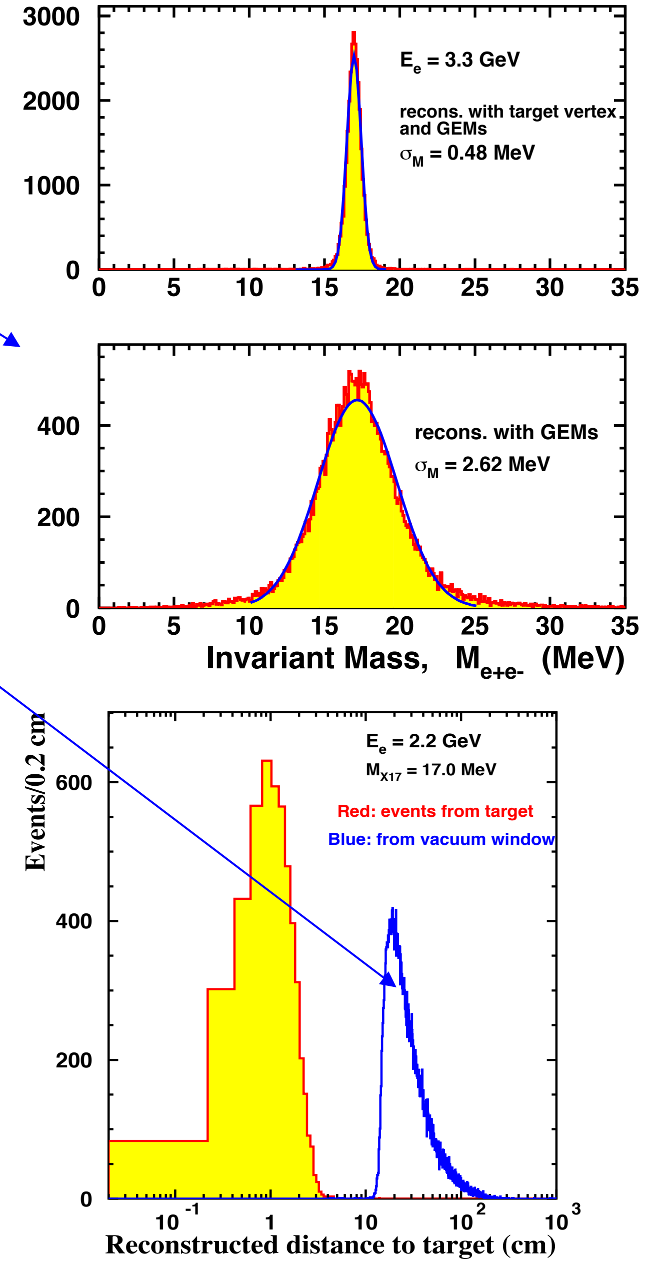


Experimental Resolutions (cont.)

- Invariant mass reconstruction (in two ways):
  - ✓ with vertex, GEMs and $PbWO_4$ calorimeter,
    σ_m =0.48 MeV for X17 particle;
  - ✓ with GEMs and $PbWO_4$ calorimeter (no vertex).
  - ✓ This will be used to check if "peak events" are coming from target.

- Two GEM planes (with $PbWO_4$) will effectively discriminate events not originating from the target (for example, from the vacuum chamber exit window).

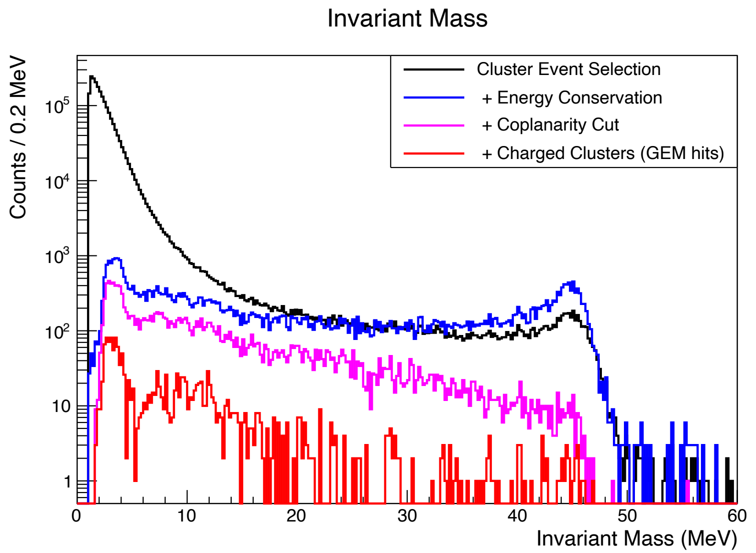
- However, in this proposal GEMs are not designed to measure the "decay length".
  This is not a "displaced vertex" search experiment.
  (ITAC Q.#7)

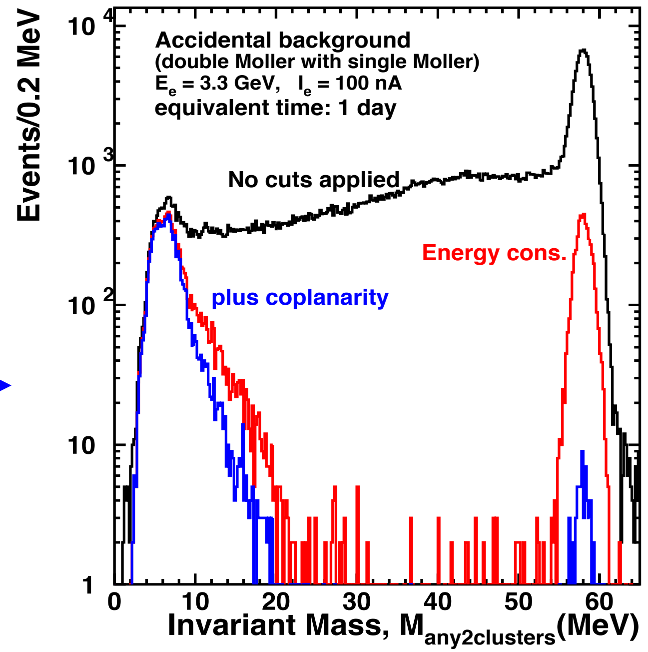


Event Selection Criteria

- Detection of all 3 final state particles provides following event selection criteria:
  - ✓ conservation of total energy;
  - ✓ reaction coplanarity;
  - ✓ invariant mass;
  - ✓ particles charge;
  - ✓ reconstructed position on target plane.
- Important feature of this experiment.
- Effects of these "cuts" are shown for PRad short test run on ^{12}C target.

… and for MC accidental events simulated for this experiment.

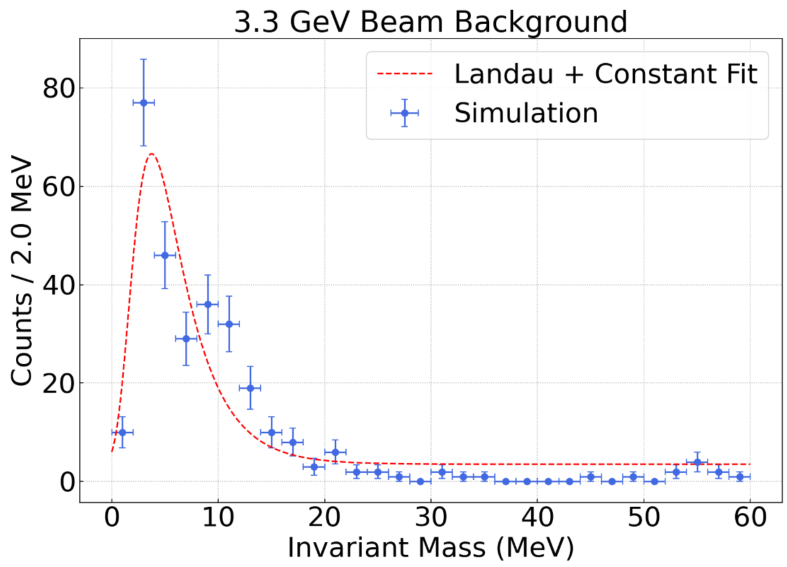


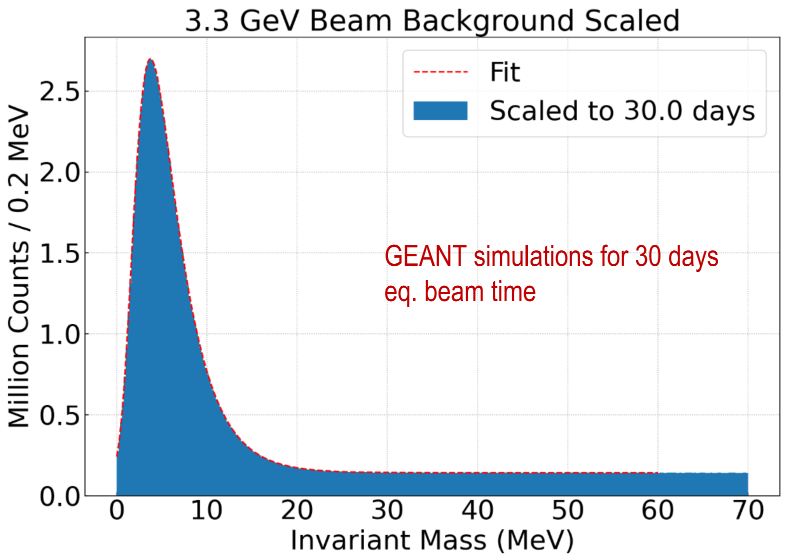


Physics Background Simulations

- Physics background was simulated in two different ways (similar to the HPS proposal):
  1) with GEANT based simulation MC package;
  2) with MADGRAPH5 event generator and GEANT for tracing and detecting.

1) GEANT based Monte Carlo simulations
   - ✓ PRad-II GEANT based simulation package was adapted to this experimental setup;
   - ✓ all physics processes have been activated in GEANT;
   - ✓ large amount of beam electrons ($N_e = 3.5 \times 10^{12}$, equivalent to 5.6 s of beam time) passed through the target during MC simulations (statistics updated after proposal submission);
   - ✓ events with $N_{cluster} \geq 3$ were analyzed in the same way as the signals.

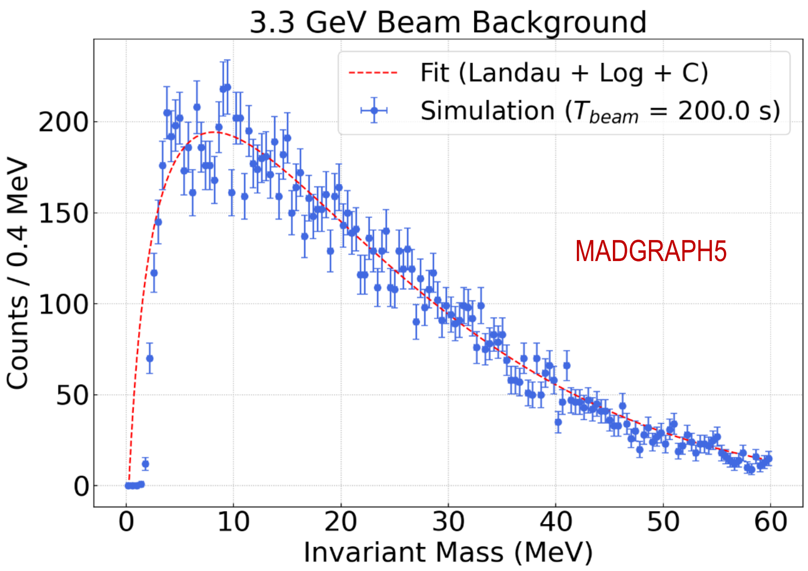


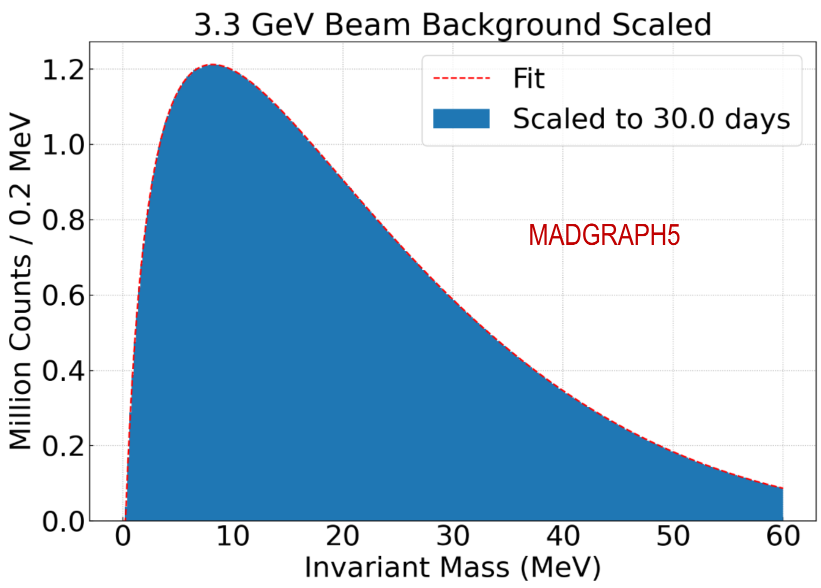


Physics Background Simulations (Method #2)

2) MADGRAPH5 based Monte Carlo simulations

- ✓ MADGRAPH5 was used to generate large statistics (2M) trident events (Bethe-Heitler, Radiative Trident, interference);
- ✓ these events were fed into the GEANT MC simulation package;
- ✓ events with $N_{cluster} \geq 3$ were analyzed as the signals.

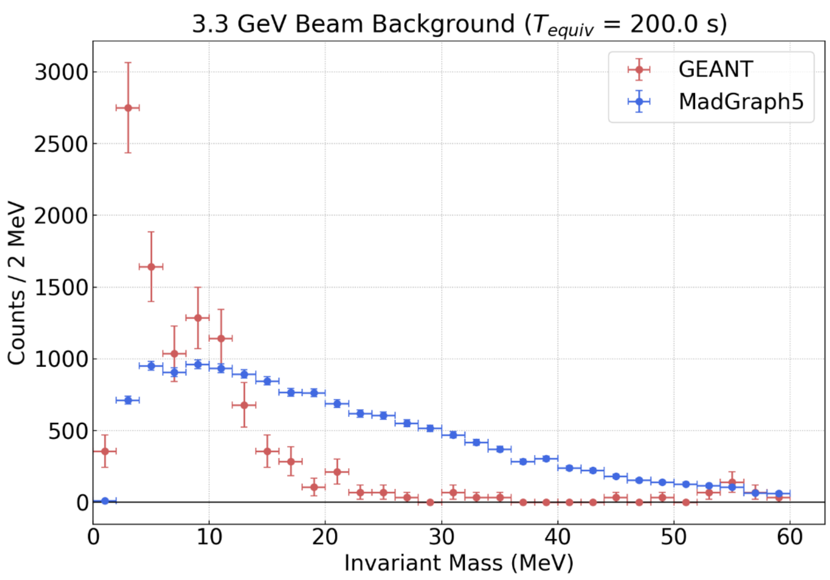


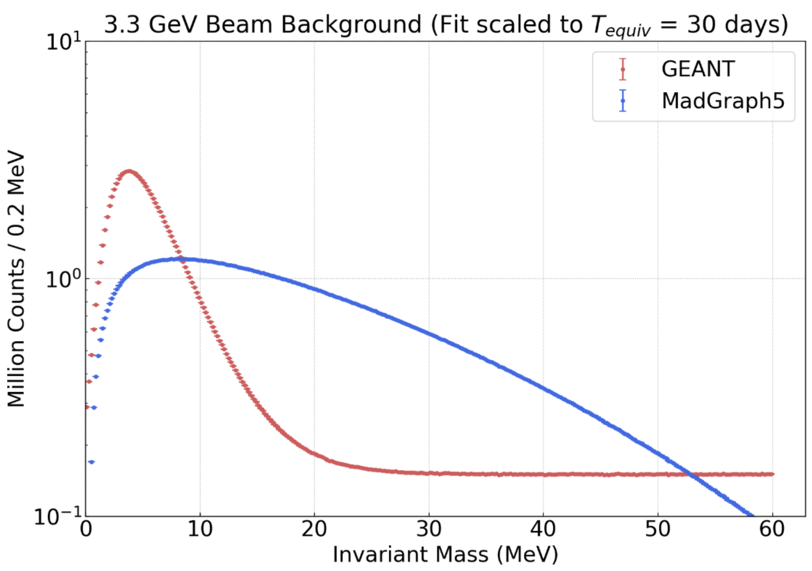


Physics Background Simulations (Comparison of Two Methods)

- Background simulation results were scaled to 200 seconds of beam time for comparison (left plot)
  - ✓ General agreement between two simulation methods;
  - ✓ slight shape difference (GEANT samples more small angle scattering events);
  - ✓ difference in total numbers is ≈37% (14016 vs. 10571, integrated over the mass)

- Both simulated backgrounds were scaled to 30 days of beam time (right plot)
  - ✓ they are used to estimate the 5σ sensitivity in the coupling constant (ε) $vs. mass$ phase space.

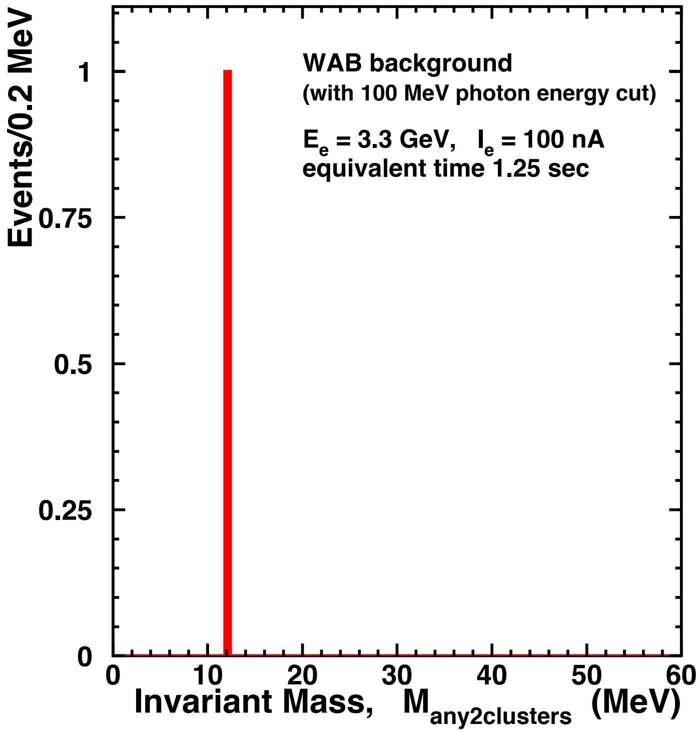




Physics Background Simulations (WAB Generator)

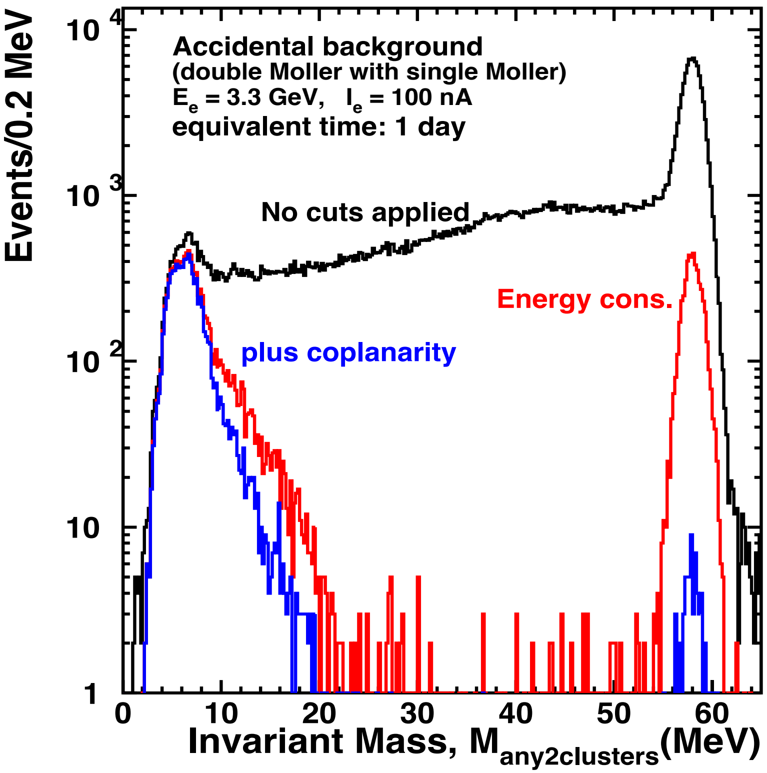
- Wide Angle Bremsstrahlung (WAB) generator was also used to estimate the background (suggested by HPS people).
  - ✓ 1 M events were generated for $E_e = 3.3$ GeV beam, equivalent to 1.25 sec of $I_e = 100$ nA beam;
  - ✓ generator thresholds: $E\gamma = 100$ MeV, $\vartheta_{x,y} = 0.003$ rad;
  - ✓ these events also fed to the GEANT MC code,
  - ✓ detected events with $N_{cluster} \geq 3$ were analyzed same way as the signals.

- Estimated rate for this process is: ~1 Hz
  - ✓ not significant contribution to the background



Accidental Background (Accidental Coincidence Rate)

- Hardware trigger requires 3-claster events:
  - ✓ $N_{cluster} \geq 3$
  - ✓ each one within: 30 MeV $< E_{cluster} < 0.8xE_{beam}$
  - ✓ $E_{total} > 0.7xE_{beam}$
- Two high-rate processes in this experiment are:
  - ✓ electron-nucleus (Rutherford) elastic scattering (trigger will effectively suppress these events).
  - ✓ Moller scattering (source of major accidentals).
- Estimated rates for two main sources are:
  - ✓ singles from Moller: Rate $\approx$ 107 kHz
  - ✓ doubles from Moller: Rate $\approx$ 81.7 kHz
- Assuming 2 ns time resolution (bunch size):
  - ✓ accidental coincidence rate: $\approx$17 Hz
  - ✓ is not significant background contribution.



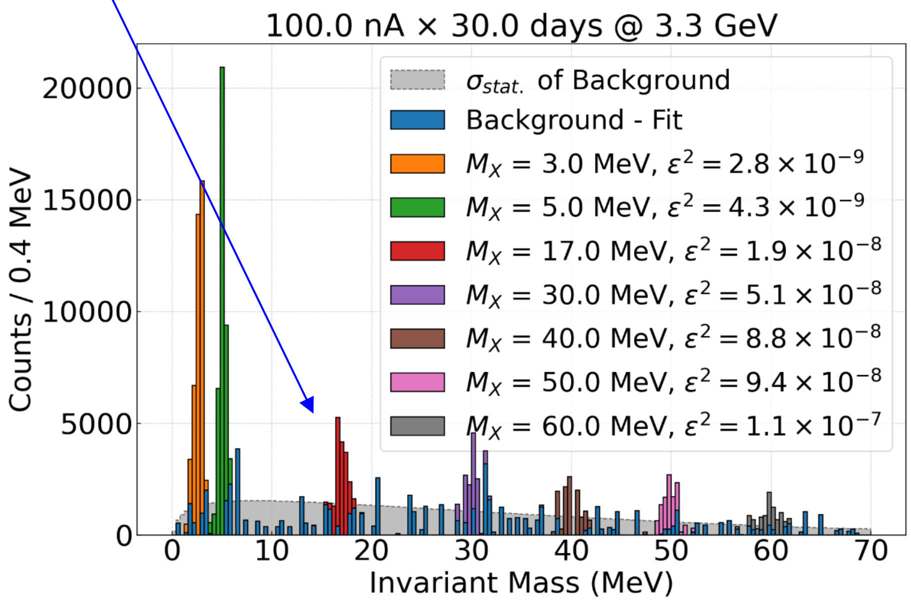
Beam Time Request and Statistics

- Target: Ta; thickness: 1 μm ($t = 2.4\times10^{-4}$ r.l.), $N_{tgt} = 0.56\times10^{19}$ atoms/cm^2
  for $E_e = 3.3$ GeV and $I_e = 100$ nA ($N_e = 6.25\times10^{11}$ e$^-$/s),

  Example: the estimated X17 production rate:

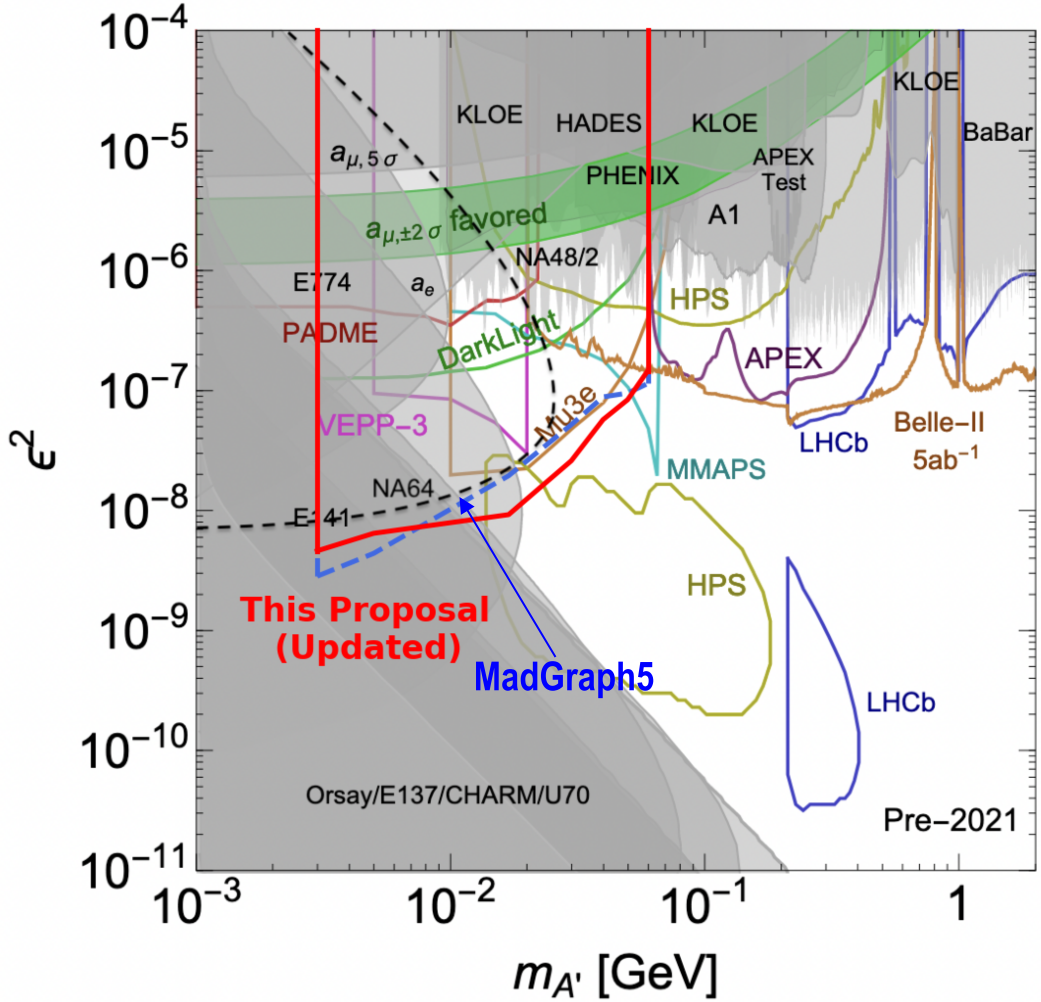
  $N_{X17} \sim N_C * N_e * t * \varepsilon^2 * (m_e/m_x)^2$
  $\approx$ 32,000 produced events per 30 days for $\varepsilon^2 = 1.9\times10^{-8}$ ($N_C \approx 5$)

	Time (days)
Setup checkout, calibration	4.0
Production at 2.2 GeV, 50 nA	20.0
Production at 3.3 GeV, 100 nA	30.0
Energy change	0.5
Empty target runs	5.5
Total	60



ε^2 *vs.* Mass Parameter Space

- Invariant mass range: [3 -- 60] MeV
- Coupling constant: $\varepsilon^2 \approx [10^{-9}–10^{-8}]$
- This proposal uses 5σ limits (discovery criterion as per PDG), while the common practice is to use 2 - 2.4σ.
- NA64 results are 90% confidence limits.



Summary

- We propose a cost-effective, ready-to-run experiment based on the PRad apparatus to:
  1) search for hidden sector new particles (fields) in [3 ÷ 60] MeV mass range within a coupling constant sensitivity in $\varepsilon^2 \approx [10^{-9} - 10^{-8}]$ range;
  2) Validate existence or set an experimental upper limit on a search for hypothetical X17 particle, recently claimed by the ATOMKI group (up to $\varepsilon^2 \approx 1.9\text{x}10^{-8}$ level).

- It is a non-magnetic experiment with the detection of all 3 final state particles, providing a tight control of background, reaching to a low range in coupling constants.

- The proposed experiment is fully complimentary to currently approved and/or running experiments by its suggested experimental method and by the mass range of sensitivity (including HPS and APEX at JLab), more focusing on the low-mass range.

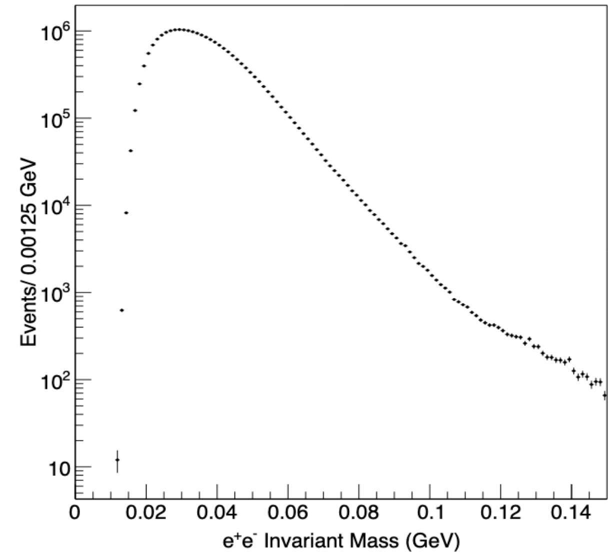
- It is offering a unique experimental opportunity to search for the hypothetical X17 particle with a direct and full detection method (including a possible X17 $\rightarrow \gamma\gamma$).

my research work is supported in part by NSF award: PHY-1812421

Backup Slides

Other Similar Experiments/Projects at JLab

- HPS (running experiment at JLab)
  - ✓ search for A' → e^+e^- in $M_{A'}$ = [20-1000] MeV;
  - ✓ magnetic spectrometer method;
  - ✓ only e^+e^- detected, $\varepsilon^2 > 10^{-7}$;
  - ✓ with displaced vertex detection: $10^{-8} \leq \varepsilon^2 \leq 10^{-10}$



HPS: [hep-ex] arXiv:1807.11530, 2018

- APEX (running experiment at JLab)
  - ✓ search for A' → e^+e^- in $M_{A'}$ = [65−525] MeV;
  - ✓ magnetic spectrometer method;
  - ✓ only e^+e^- detected, $\varepsilon^2 > 9\times10^{-8}$;

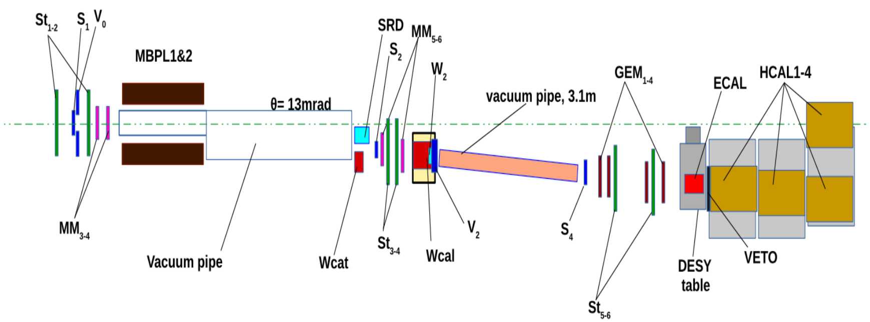
- DarkLight (approved JLab experiment)
  - ✓ search for A' → e^+e^- in $M_{A'}$ = [10-90] MeV;
  - ✓ magnetic spectrometer method;
  - ✓ e^+e^- detected, $\varepsilon^2 > 3\times10^{-7}$;

- The proposed experiment:
  - ✓ non-magnetic, will detect all 3 particles, e',e^+,e^-
  - ✓ search for X → e^+e^- ($\gamma\gamma$) in M_X = [3 − 60] MeV;
  - ✓ similar range: $10^{-7} \leq \varepsilon^2 \leq 10^{-9}$
  - ✓ sensitive to neutral channels.

Other Similar Experiments/Projects

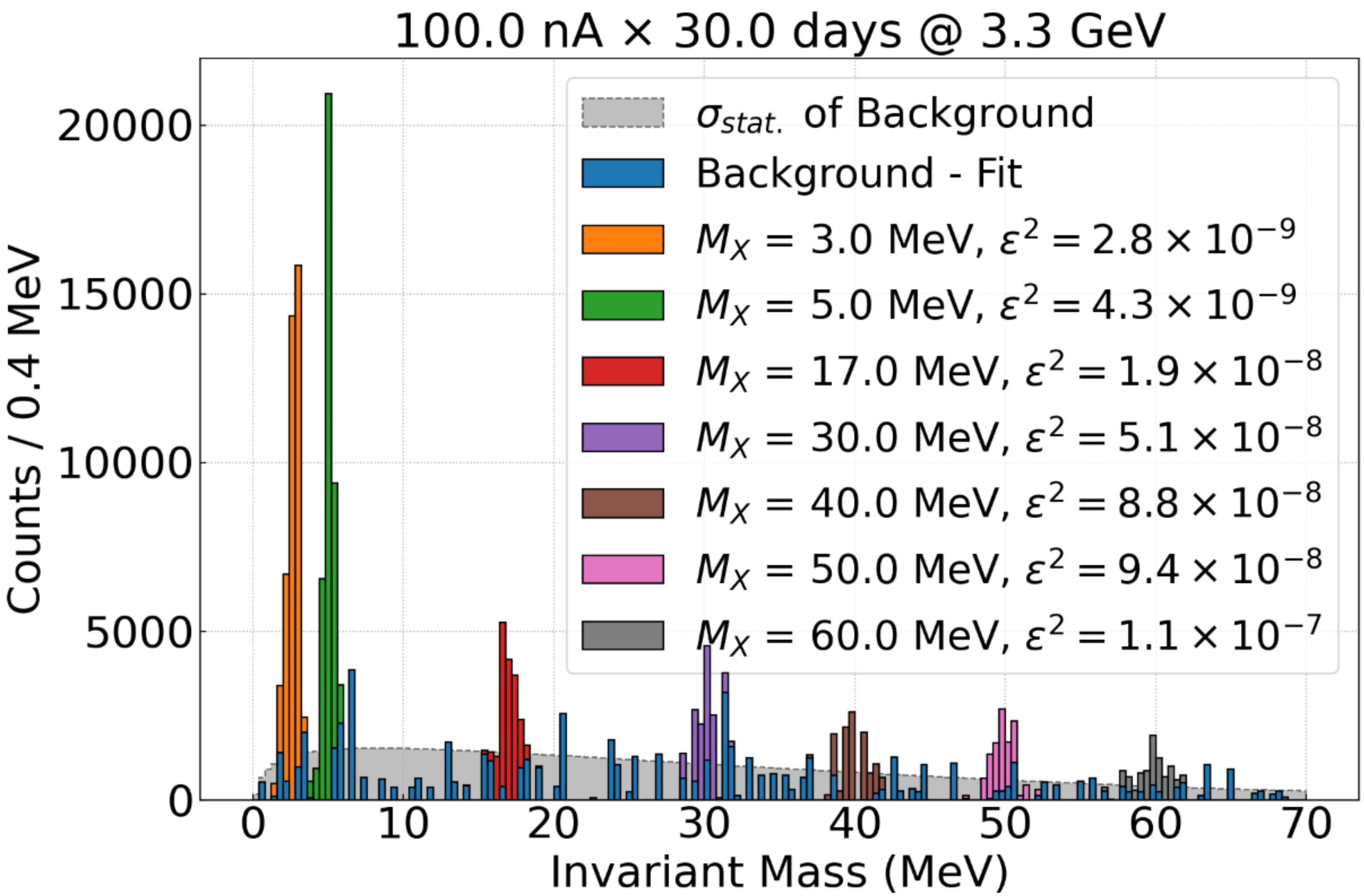
- NA64 (experiment and new proposal with SPS at CERN
  - ✓ combination of "beam dump" and direct e^+e- detection;
  - ✓ first EM calorimeter is an active "dump" (~40 r.l.), second EM detects e+e- pairs;
  - ✓ assumes relatively long decay length for A' (or X);
  - ✓ total energy conservation;
  - ✓ mass range: $\leq$ 23 MeV,
  - ✓ experiments in 2018 and 2020:

    $1.4x10^{-8} \leq \varepsilon^2 \leq 4.6x10^{-7}$ (90% confidence limit)
  - ✓ new proposal for 2021.



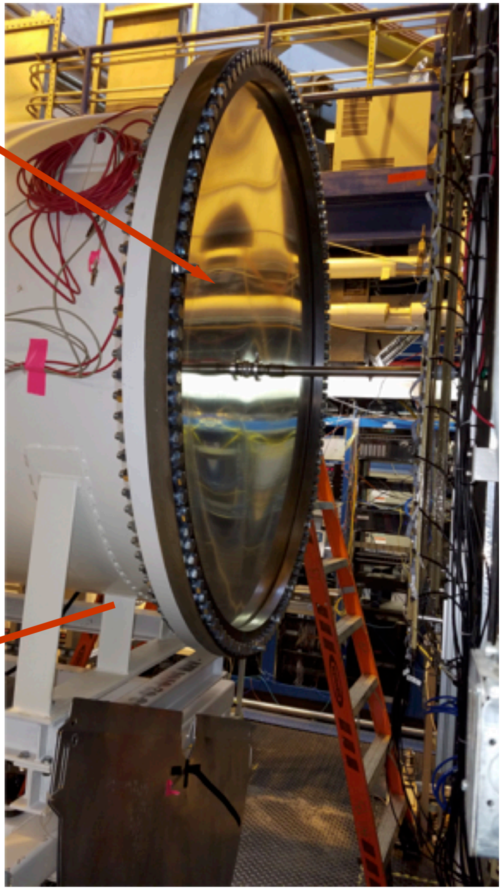
- MAGIX (proposed experiment with MESA at Mainz)
  - ✓ search for $A' \rightarrow e^+e^-$ in $M_{A'}$ = [$8 - 70$] MeV;
  - ✓ magnetic spectrometer method;
  - ✓ only e^+e^- detected, $\varepsilon^2 \approx [2x10^{-7} - 8x10^{-9}]$

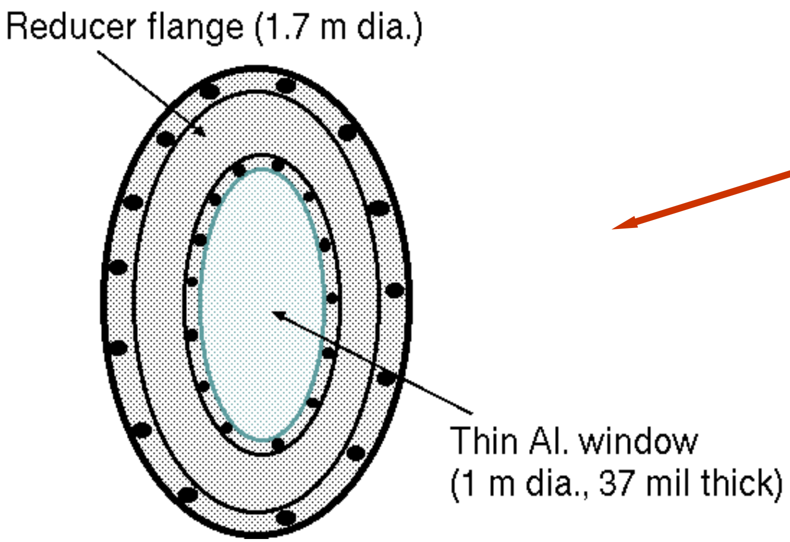
Signals and ε^2 Reach



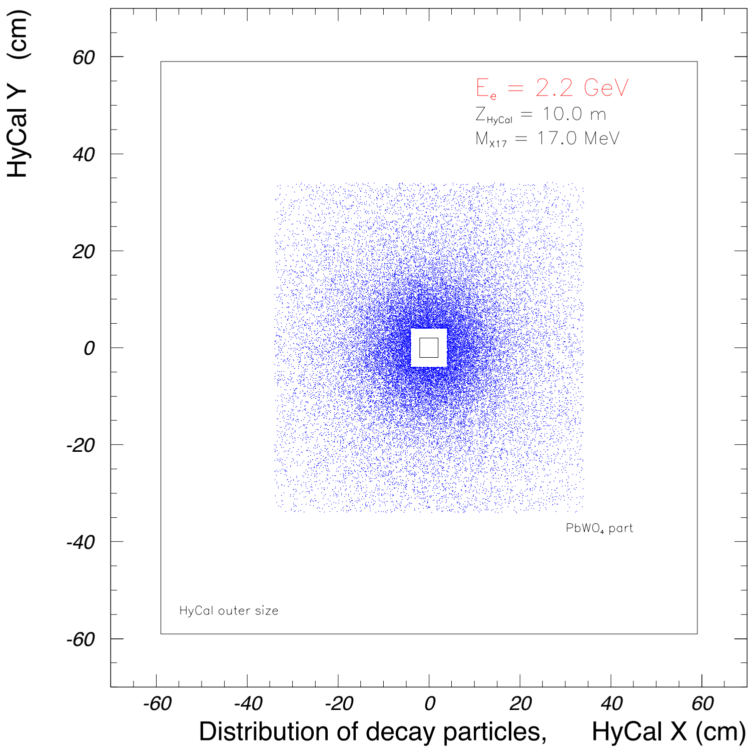
New Vacuum Window

- Twice reduced vacuum window will be used: 1m diameter and 1mm Al foil

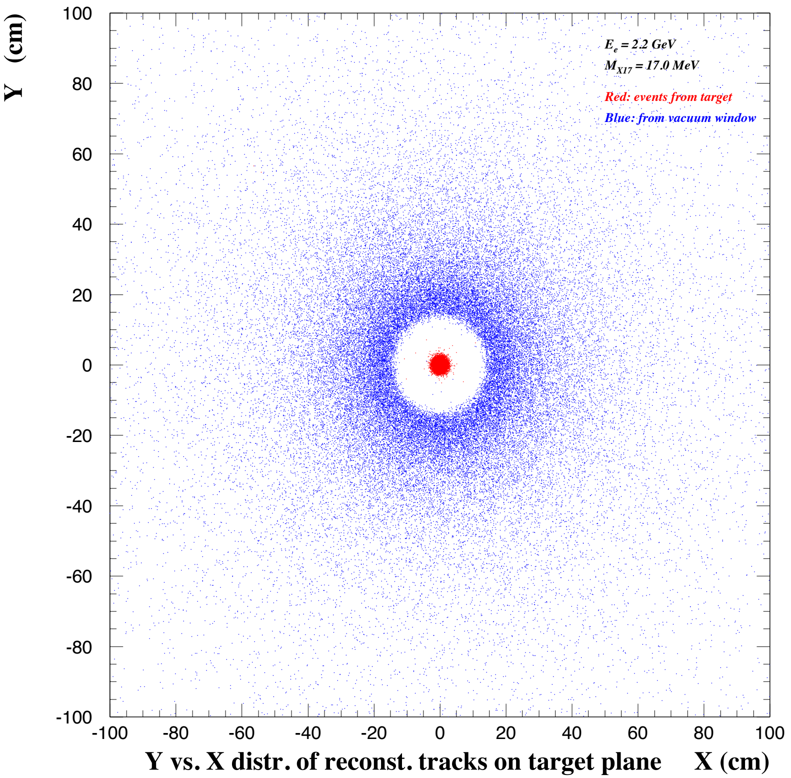




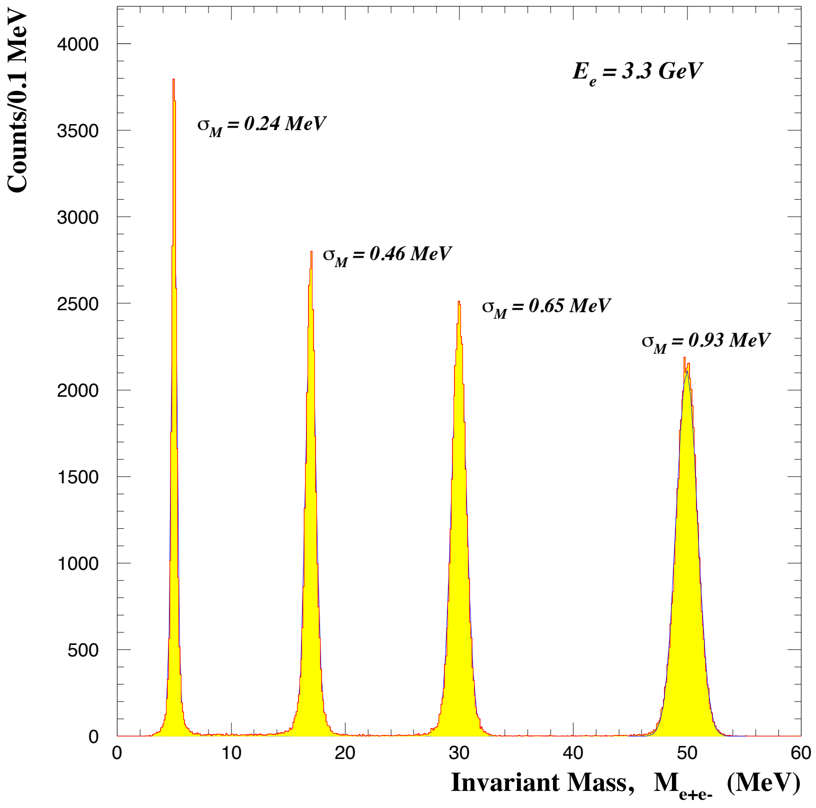
Kinematics (X-Y distribution of all 3 particles on HyCal)



Kinematics (reconstructed positions on target plane)



Kinematics (invariant mass Resolutions)



TAC Questions

TAC Review

1. There are some concerns about the way the EM background under a possible resonance peak was evaluated: 1) a more conservative estimate based on the same theoretical framework used to evaluate the expected signal, would bring the background x5 to x76, depending on the resonance mass; 2) the formula used to evaluate the bg as S/SQR(B+BG) seems to be oversimplified and does not reflect the sophisticated statistical analyses performed by other experiments.

Answer:

To estimate the expected background level in the proposed experiment we followed the HPS procedure, (see page 48 of [1]): "... We use two generators to produce events: MadGraph for signal and trident events, and EGS5 for beam electrons that interact in the target. In MadGraph, we have produced large samples of signal events at various A' masses as well as large samples of Bethe-Heitler and radiative trident events. The passage of the electron beam through the target is simulated using EGS5; ... We use a Geant-4 based simulation[84] to propagate events through the detector and model the energy deposition. ...".

(more detail answer was given in the "Background" section above)

TAC Questions

3. The installation of the vacuum chamber requires a major downtime to work around the beam line.

Answer: The vacuum chamber is a part of the PRad-II experiment and this proposal's experimental setup. The anticipated downtime for installation of the setup, including the vacuum chamber, will be similar to that of the previous PRad experiment (about 3 weeks).

4. Compatibility with PRAD-II installation: can the two experiments runs in sequence or the experimental configuration is significantly different?

Answer: There is no significant difference in experimental configurations between the PRad-II experiment and this proposal. If approved, this experiment could be run in sequence with PRad-II.

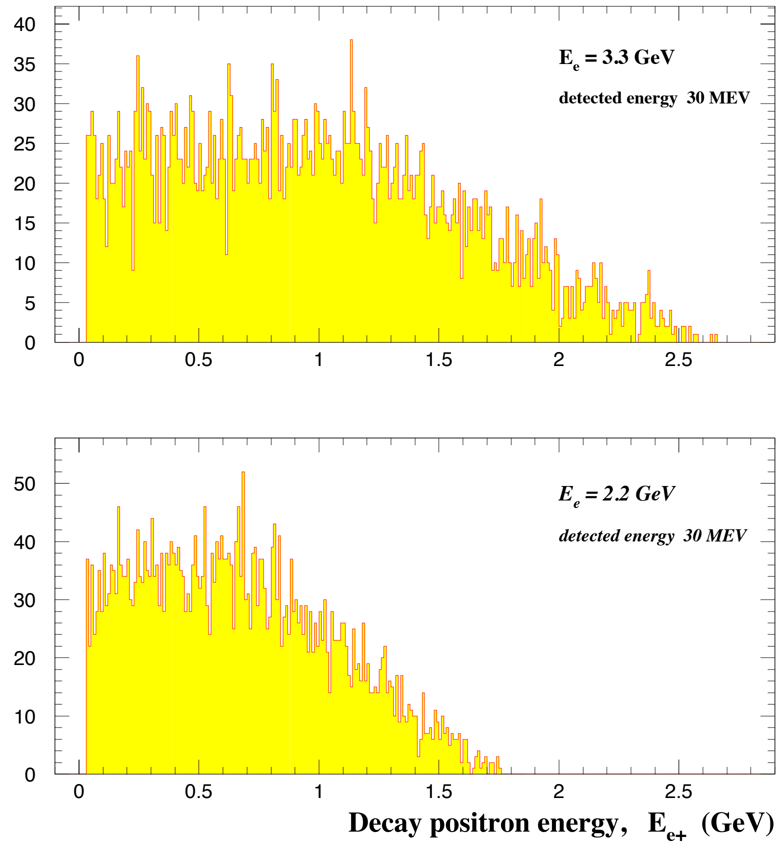
TAC Questions

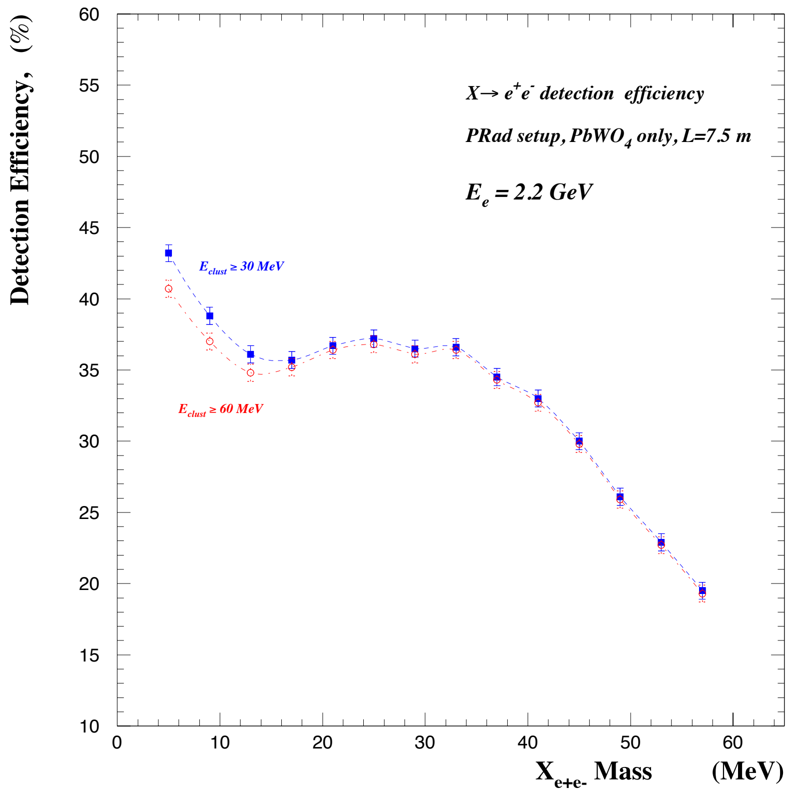
8. The invariant mass range of the e+ e- pairs down to 10 MeV requires good energy resolution to detect low energy EM shower. HyCal performance for electron energy <1 GeV should be reported and discussed.

Answer: Good energy resolution is required for all e+e− detection for these low-mass range parti- cles. The energies of the decay e+e− pairs for beam energies in the GeV range are predominantly defined by the energy of the initial virtual photon that produced the X-particle (the Lorentz-boost effect). As an example, the energy spectra of the decay positrons from a 10 MeV particle are shown in Fig. 5 (left) for both 3.3 GeV (top) and 2.2 GeV (bottom) beam energy for a 30 MeV minimum energy cut (as described in the proposal). To demonstrate the sensitivity of the detection efficiencies to the minimum energy cut, we doubled the minimum energy cut to 60 MeV (see Fig. 5 (right)). As seen in this figure, the change in the detection efficiency is on the few percent level, mostly in the lower mass range.

(see plots on next slide)

TAC Question #8 (cont.)





ITAC Questions

2. The coplanarity cut can only be used for reducing random and 4 cluster backgrounds and not for purification of the 3 cluster signal events.

Answer: In this proposed experiment we do not claim that the coplanarity cut will purify 3-cluster elastic physical events. Rather, the coplanarity cut is used to reject random uncorrelated clusters. This cut is very powerful in that regard, as can be seen in the analysis of PRad data documented in Appendix A of the proposal (Figures 30-32). Please see our answer to the previous question #1 regarding this.

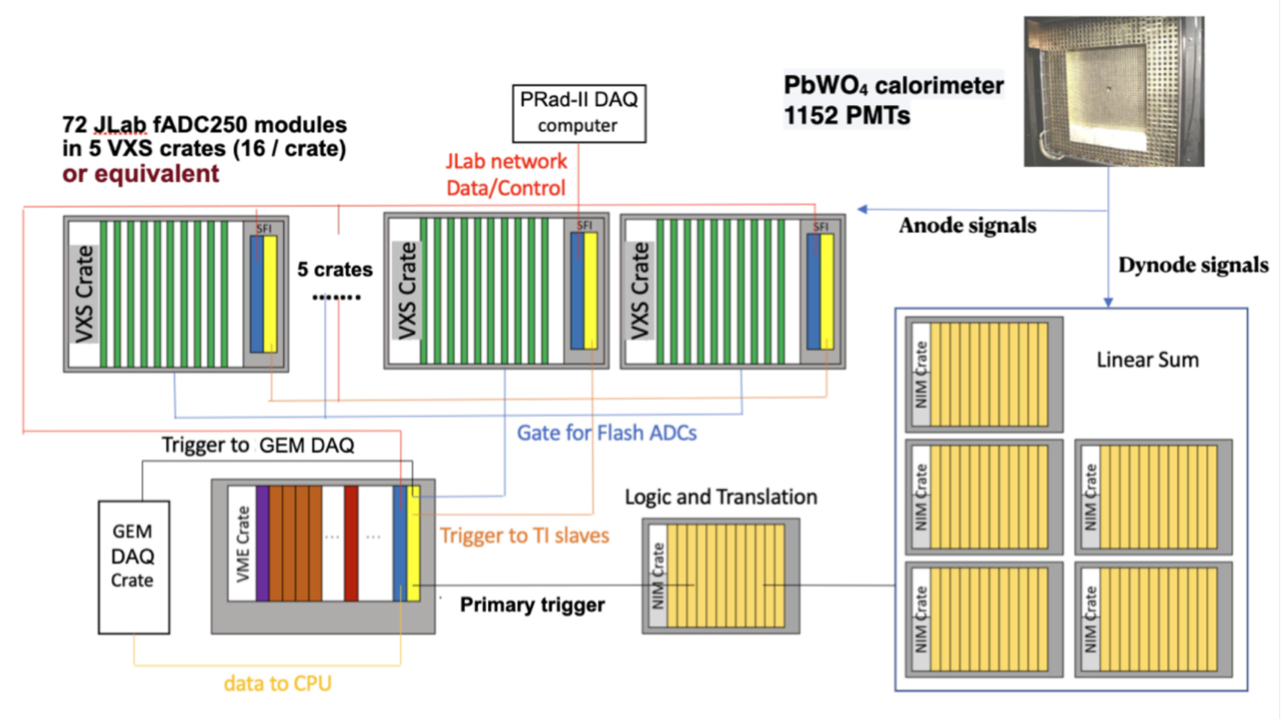
ITAC Questions

4. The expected signal to background rates presented in fig. 26 are unrealistic where the S/B ratio for a 17 MeV candidate is about 1/10 in the left plot while assuming an epsilon of 0.001 in the legend. A realistic S/B ratio is of the same order as the value of epsilon for such experiments. The argument that ep-elastic, Moller and Bethe-Heitler backgrounds are all kinematically suppressed and only the radiative process is left as the background is not realistic, in particular with an open detector configuration with no magnetic separation and shielding. This will also lead to a background shape that is more complicated to what is shown (fig. 26) and a simple functional form fit approach over the whole mass range will not be possible.

Answer: Again, we strongly disagree with the statement that our background rates are unrealistic. As mentioned in the caption of Fig. 26, this figure is for ”illustration purposes only”. In this figure we are only trying to show the width of the invariant mass peaks for the X particles of various masses. To help visualize the signal width the signal was enhanced by a factor of 1000. On the other hand, the comparison between the two background simulations and the analysis of the PRad calibration data on $_{12}C$ (Fig. 32 in the proposal) all conclusively demonstrate that we have made a reasonable estimate of the background shape. In fact, it is shown by our background simulations that a significant part of the Bethe-Heitler events are indeed the background in this experiment. As we stated several times, we have performed background simulations in two ways using most software packages appropriate for this experiment (see our answers to TAC Question #1 and ITAC Question #1).

ITAC Questions

6. This proposal is compatible with the existing HyCAL but requires a different DAQ setup. The proposed flash ADCs require about a 1 million US $ investment and does not include the required VXS crates with CPU, trigger interface and switch slot modules. It would however make the NIM crate system forming the trigger energy sum obsolete as this can be done with the flash ADC system. The DAQ will not be able to read out full wave forms at a trigger rate of 25kHz.



ITAC Questions

11. Trigger rate: Although purely electromagnetic processes may dominate the detector rates, electron hadron-production such as (e,e'pi) or (e,e'rho) is likely to contribute significantly to the "> 0.7*Ebeam" trigger rate in this experiment. Similarly, electromagnetic background contributions that were underestimated in the simulations will also affect the expected trigger rates.

Answer: The cross sections for hadron productions (like the pi or rho) are usually 2-3 orders of magnitude smaller than the pure EM processes used to estimate the trigger rates. Furthermore, the charged pions from electroproduction and from rho decay are suppressed by an additional factor of ~ 100 in the $PbWO_4$ calorimeter. We did not intend to estimate the trigger rate with a sub-percent precision in this proposal.
We strongly disagree that the electromagnetic backgropund contributions are underestimated, please see our answers to TAC Question #1 and ITAC Question #1 demonstrating that the background level is estimated correctly.

ITAC Questions

12. X → e+e- acceptance: The kinematics are admittedly complicated, and it is beyond our scope to do a full simulation, but we have tried to check the simulation to the extent feasible.
a. Using the angle formulae in Ref [7] for the 2.2 GeV beam energy, and the 7.5m distance between the target and the calorimeter front face, it appears that the majority of the X → e+e- pairs for masses below about 20 MeV/c2 go down the beam hole. The situation is worse at 3.3 GeV beam energy. Qualitatively, this behavior is not unexpected: with decreasing mX, both the -tmin and the X→e+e- opening angle decrease. Also, in the limit of mX→me, normal experience with QED pair production must be recovered.
b. It is perplexing why the simulated accepted in Figure 20 of the proposal does not indicate this expected rapid drop for lower X masses. While it is possible to detect an X→e+e- with a mass of 10 MeV/c2 in the proposed setup, this requires the exchange of a higher virtuality photon. Most of the FOM in the X rate equation from ref[7] is from low virtuality photons which leads to the "C" 5 approximation arising from integration of equation A17 using the screened nuclear form factor in equation A18.

Answer: We disagree, the kinematics of the proposed experiment are transparent and simple. We will detect events with three clusters within the energy range of 30 MeV to 70% of the incident beam energy. This fact will allow for the X-particles production by virtual photons over a wide energy range in the forward solid angle coverage of the PbWO4 calorimeter. The capability of detecting events produced in a wide energy and angle range, in a single experimental setting, is one of the important features of our experiment which stands in contrast to all other magnetic spectrometer methods. This fact alone explains the misunderstanding stated in the part (a) of this question. If one takes the beam energy (either 2.2 or 3.3 GeV) as the initial energy of the produced X-particle then the result for the acceptance will be close to zero, since, as stated in the question, the events will go down the beam hole. In order to calculate the acceptance correctly the entire energy interval of the virtual photons must be considered, as we have done. For part (b) of this question: once again because of the detection of events produced in a wide energy and angle range in a single experimental setting, as explained above, the detection efficiencies presented in the proposal in Fig. 20, behave as expected and are correctly simulated for the proposed experiment.