A dark photon search with JLab positron beam

Positron A' collaboration

P.Achenbach, A.Gasparian, N.Liyanage,
B.Raydo, B.Wojtsekhowski, W.Xiong

S.Boyarinov, A.Camsonne, P.Degtiarenko, D.Gaskell, J.Grames, W.Henry, D.Higinbotham, I.Jaegle, D.Jones, M.Jones, D.Mack, D.Meekins, R.Michaels, E.Pasyuk, A.Somov, S.Stepanyan, H.Szumila-Vance, S.Taylor, A.S.Tadepalli, A. Ahmidouch, A.Ahmed, X.Bai, G.Cates, H.Nguyen, V.Nelyubin, D.Hamilton, I.Rachek, D.Nikolenko, E.King, J.Napolitano, S.Mayilyan, H.Mkrtchyan, A.Shahinyan, V.Tadevosyan, D.Dutta, C.Peng, I.Larin, R.Miskimen, T.Averett, L.Gan, M.Khandaker, B.Vlahovic and

the PRAD collaboration and the Positron Working Group

Outline of the talk

- Highlights of the proposal
- PAC51 review
- Theory review
- TAC review– the reply was submitted, also shown in backup
- Overview of the existing/proposed A' searches
- Experimental method
- Layout in Hall B
- Radiation and neutron dose
- Geant4-based MC results
- Detector response calibrations and uniformity
- DAQ rate capability
- Projected results
- Beam time request

A dark photon search

- We propose an experiment to search for a new particle, the U/A′-boson, by measuring the missing mass spectra in the positron annihilation in flight with an atomic electron with one final particle (photon) detected.

- The missing mass reconstructed from the energy and angle of the detected photon will provide the means for the search for any type of secondary particle produced in the reaction -“production experiment”.

- The projected statistical sensitivity for the reduced coupling constant $\varepsilon^2 = f_e^2/e^2$ reaches 2×10^{-8} with 55 days of run at a positron beam current of 50 nA.

- Experiment is in the same physics category which at Jefferson Lab includes several related approved experiments – HPS, APEX, DarkLight, X17. The important complementarity of this proposal is due to the ability to observe A’ which decays dominantly to the invisible particles.

PAC51 review

PR12+23-005

Scientific Rating: N/A

Recommendation: Deferred

Title: A Dark Photon Search with a JLab positron beam

Spokespersons: A. Gasparian, N. Liyanage, B. Raydo, B. Wojtsekhowski (contact)

Motivation: The proposal aims at a search for the A′-boson in the mass range from 15 to 90 MeV using the missing mass method. The A′-boson is the kinetically mixed dark photon. Knowledge of the A' boson mass and its coupling to an electron (or an upper limit on this coupling) is of large interest to the dark matter research field. The proposed sensitivity might allow the collaboration to resolve the question whether there is a connection between the hypothetical X17 particle and the A'-boson.

Measurement and Feasibility: The proposed experiment is to be carried out in Hall B using detectors and equipment that have been employed with success in the PRAD experiment E12-11-106. A positron beam with energies of 2.2, 4.4 and 11 GeV and a current of 50 nA will impinge on the atomic electrons of the target material. The signal process is $e^+ e^- \rightarrow \gamma A'$ and the main background comes from $e^+ e^- \rightarrow \gamma \gamma$. The experiment will detect a single photon and search for the A' in the missing mass spectrum.

Issues: While some physics background has been simulated for the proposal, the committee feels that a full Geant4 simulation of the measurement is needed to assess the sensitivity of the experiment. This should include a study of how the foreseen veto will exclude possible signal events. In addition, a more detailed discussion of the reach in comparison to competing experiments is needed.

Summary: The PAC finds that the proposal presents an exciting and important search experiment. It encourages the proponents to resubmit this proposal after addressing the issues noted above.

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Main additions in the current proposal are a Geant4-based MC, a magnet for sweeping of the low energy charge particles, and a local beam dump.

Issues: While some physics background has been simulated for the proposal, the committee feels that a full Geant4 simulation of the measurement is needed to assess the sensitivity of the experiment. This should include a study of how the foreseen veto will exclude possible signal events. In addition, a more detailed discussion of the reach in comparison to competing experiments is needed.

Summary: The PAC finds that the proposal presents an exciting and important search experiment. It encourages the proponents to resubmit this proposal after addressing the issues noted above.

Theory review

PR12-24-005: *A Dark Photon Search...*

Y.-T. Chien, D. Richards

This is a resubmission of the proposal last year with additional simulations requested by PAC51. In that sense, there are no additional theory comments other than to note that the updated simulations leading to increased sensitivities for the dark photon coupling for a slightly decreased runtime request. We reiterate the "discovery" potential of this proposal, and its advantage as a "missing energy" experiment that does not rely on the details of the dark-photon decay. We list the theory report of last year, by Kostas Orginos and Ian Balitsky, below:

> This proposal aims to utilize a possible positron beam at JLab to search for dark gauge bosons using positron anihilation on atomic electrons. The proposal describes well the state- of-the-art in this area and makes the case that this project fits well with current and future activities in the searches for dark gauge bosons. The discovery potential of this project is significant, in the sense that a non-zero signal will have profound implications to our understanding of particle physics. However, the risk of a null result is also very high. It is a high-risk/high-gain project and perhaps one should carefully weigh the risk of failure with the potential discoveries. Certainly, if a positron beam becomes available at JLab this project may be an interesting addition to the physics JLab can do.

Replies to TAC review

Answers/reply to TAC review of PR12+24-005

For the section Findings:

4. A new GEM tracker is planned for installation in front of HyCal to act as a charged particle veto to reduce backgrounds and enhance sensitivity to possible signal events. This new tracker will be built by the UVa Group for the PRad-II experiment and should be considered as existing basic instrumentation.

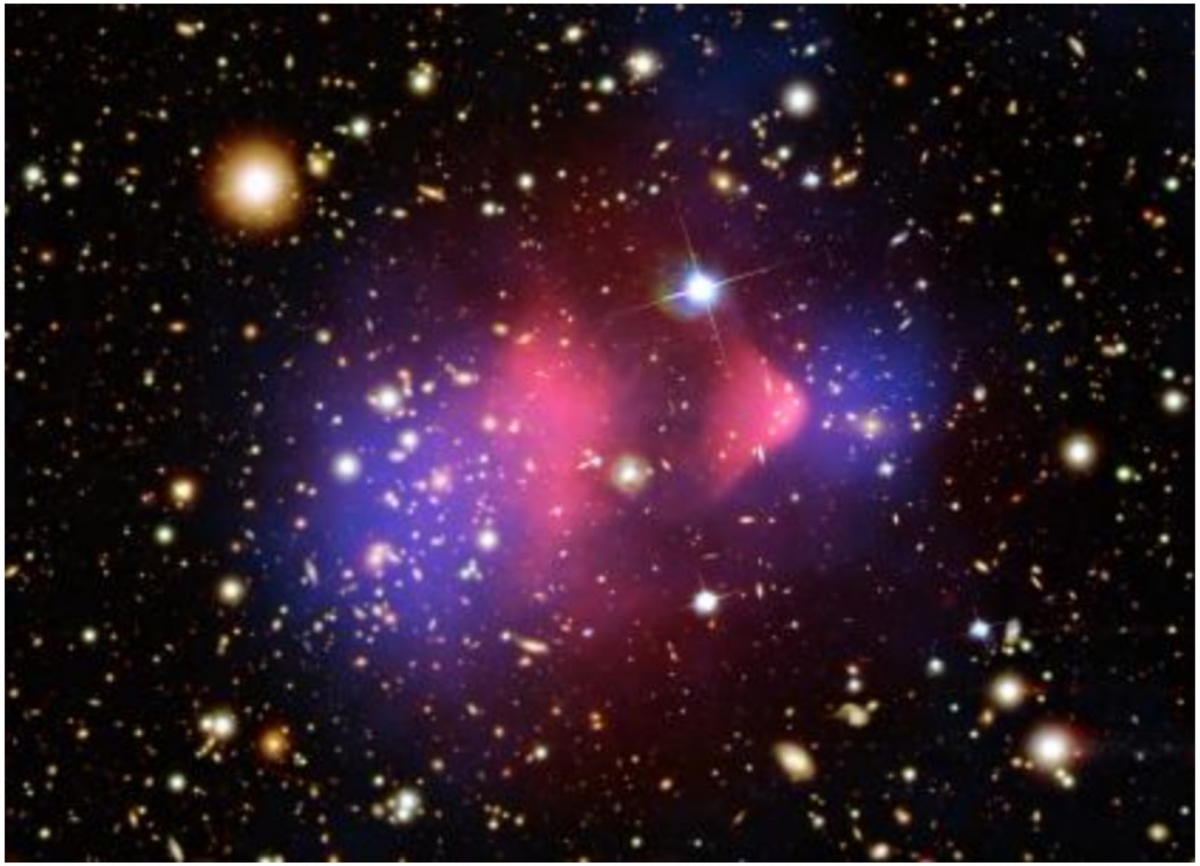
As it is presented in the current proposal, **the GEM detector** will be used for coordinate calibration of the calorimeter with elastic scattering events and in off-line analysis for rejection of the remaining charged particles but **not as a veto in the trigger.**
Most of the charged particles will be removed from the calorimeter acceptance by the sweeper magnet. The off-line analysis uses the tracker for veto of the charged single clusters, which reduces the background rate by **a factor of 1.5**.

Please see the full reply in the backup slides and slides 31-32

Dark matter is an elephant in the room

NASA FINDS DIRECT PROOF OF DARK MATTER

Motivation from 2006



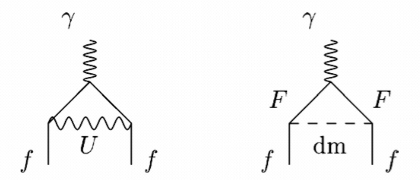
Credit: X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.

The processes which could have a U-boson

C.Boehm, P.Fayet, Nuclear Physics B 683 (2004)

g_e-2, g_μ-2
π,η decays to $U\gamma$
π,φ,ψ decays to γ + invisible

A.4. Constraints from $g-2$

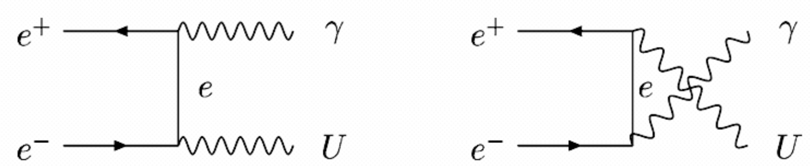


If the U boson mainly decays into dark matter, then the U production process turns out to be of the type $e^+e^- \to \gamma + \not{E}$, where $\not{E}$ is missing energy, which is of interest in experiments searching for single photon production events. But, in the case of a light dark matter candidate, such a process is likely to remain unobserved, owing to the large background associated with $e^+e^- \to \gamma\gamma$, in which one of the two photons escapes detection.

Upper limit for the coupling constant $|f_{eU}|^2 < 2\ 10^{-8}\ (m_U)^2$

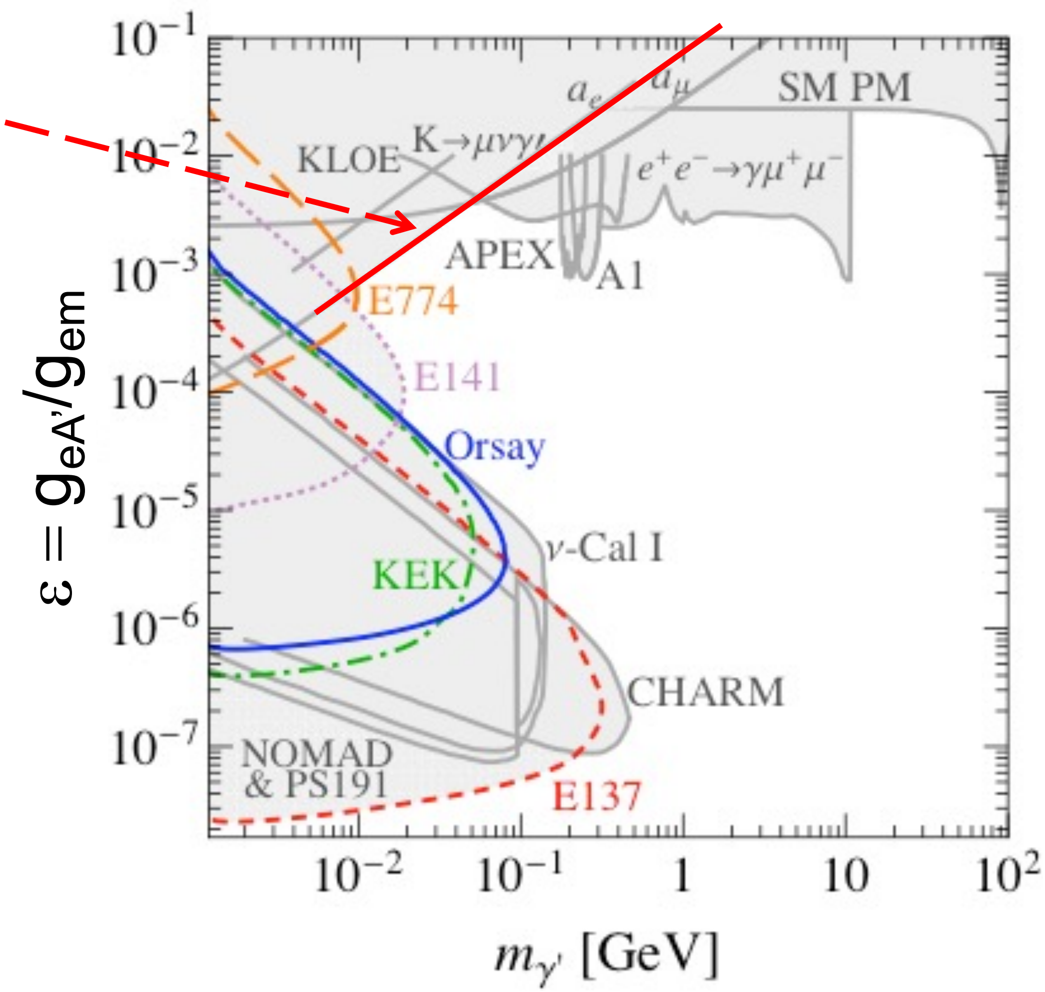
A.6.1. Direct U boson production

$\varepsilon^2 < 10^{-4}$ at 10 MeV



2012 summary of the searches

g-2 of muon and electron



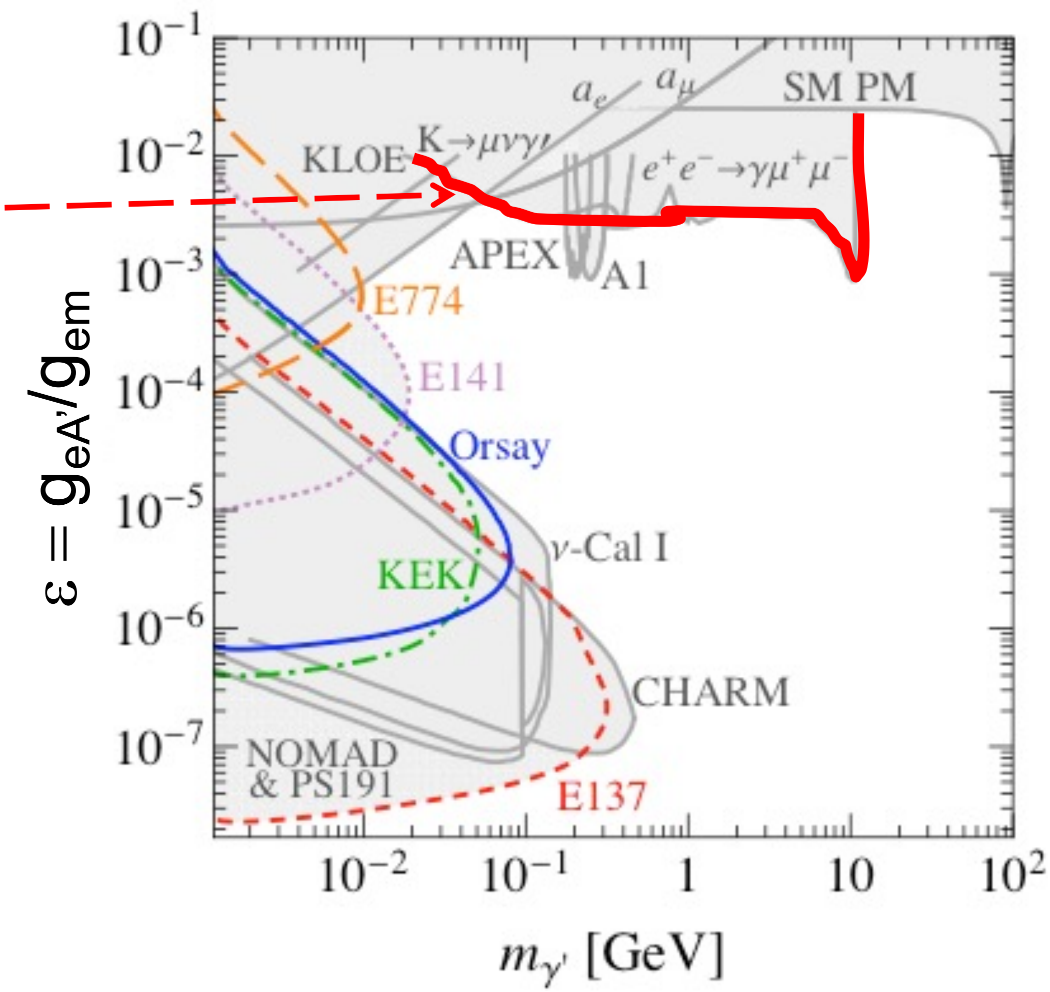
S. Andreas, C. Niebuhr, A. Ringwald, arXiv:1209.6083

2012 summary of the searches

Missing particle in e+e- to γA'

Decay to SM (e+/e-) -

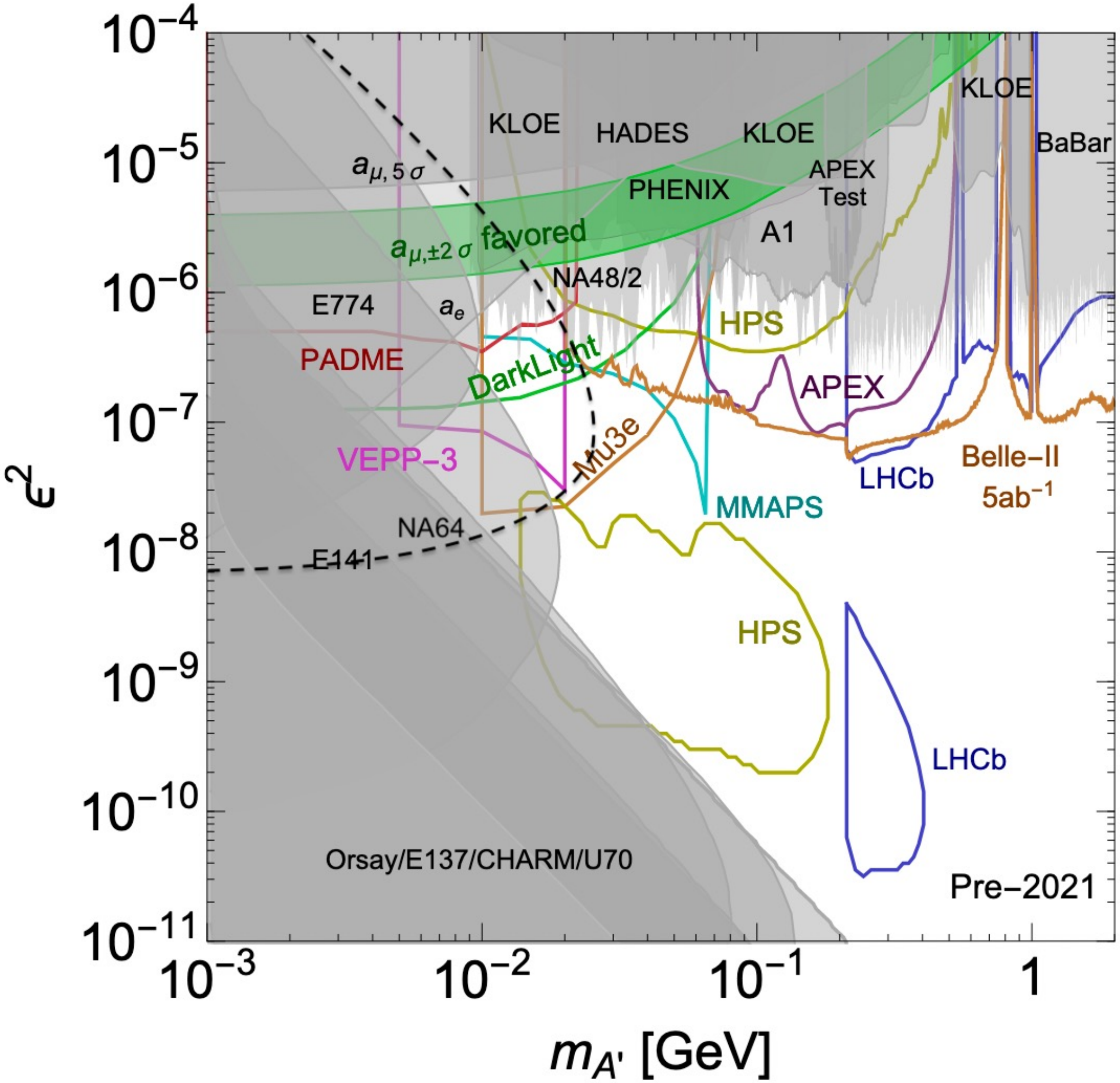
Beam Dump



S. Andreas, C. Niebuhr, A. Ringwald, arXiv:1209.6083

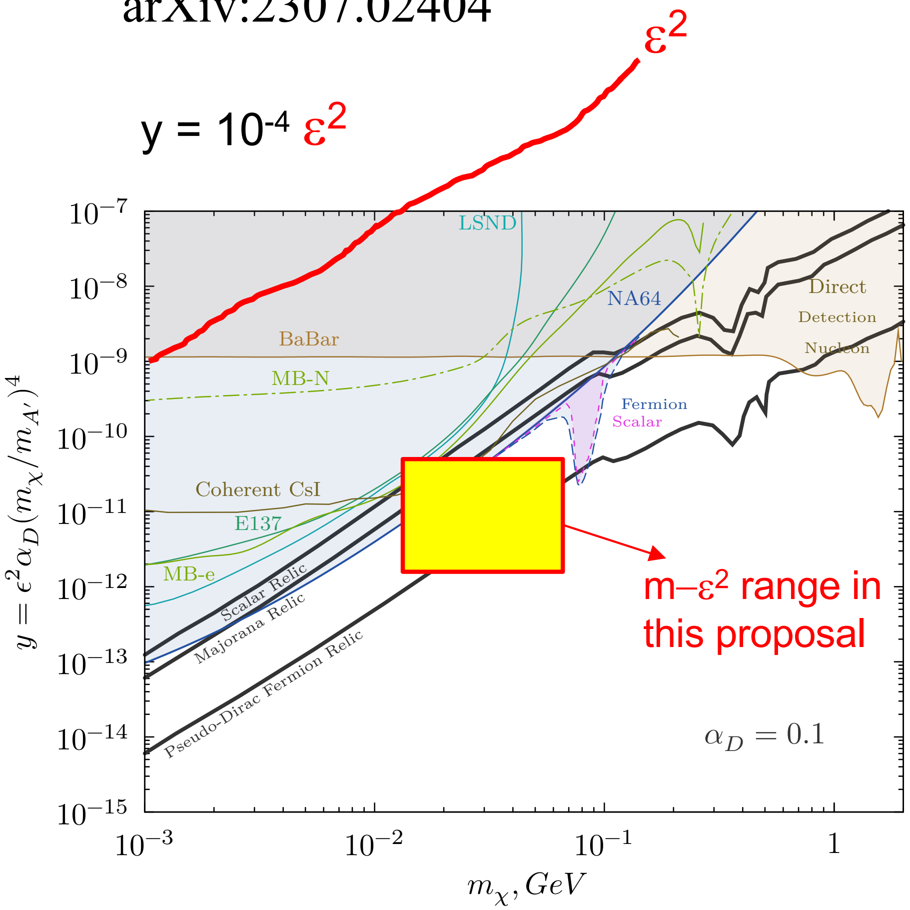
A' parameter space summary in 2017

US Cosmic Visions ... : arXiv:1707.04591



NA64 recent analysis

arXiv:2307.02404



100 GeV e on Z -> e Z A'
with active ECAL target

NA-64 more analysis

Eur. Phys. J. C (2021) 81:959

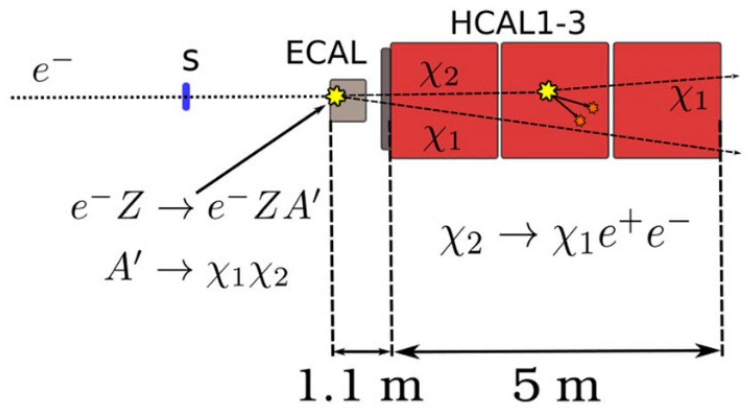


Fig. 3 A schematic view of an event $A' \to \chi_1\chi_2(\chi_2 \to \chi_1 e^+e^-)$ from a A' produced after a 100 GeV e^- scatters off in the active dump, $e^- Z \to e^- Z A'$. The χ_2 particle decaying within HCAL2 corresponds to the S1 signature (see text for more details)

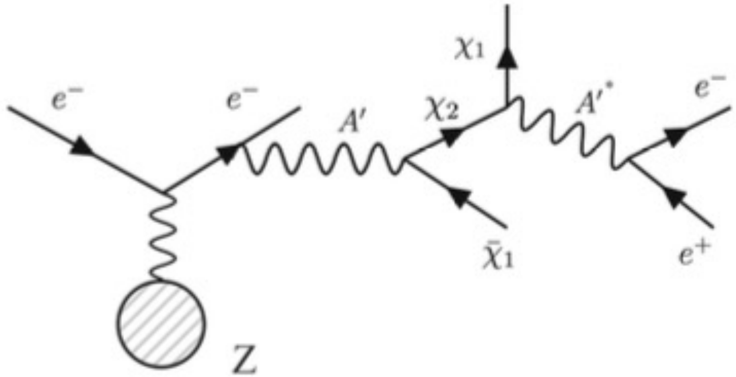
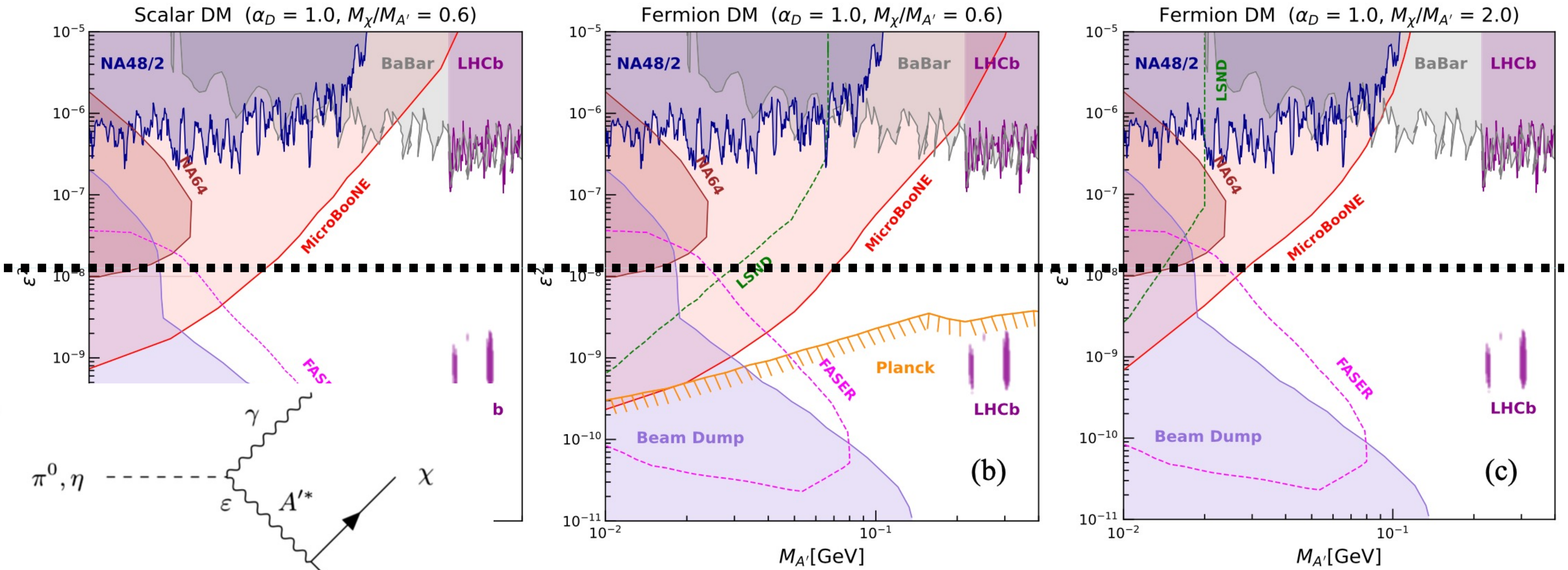
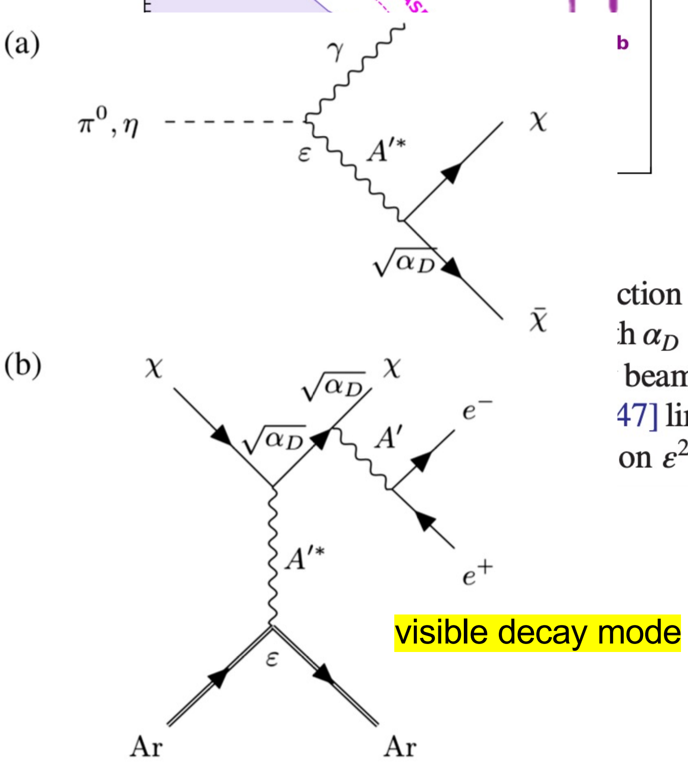


Fig. 1 Production of A' and subsequent semi-visible decay chain of a Dark Photon, $e^- Z \to e^- Z A'$; $A' \to \chi_1\chi_2(\chi_2 \to \chi_1 e^+ e^-)$

First Search for Dark-Trident Processes Using the MicroBooNE Detector, PRL 32, 241801 (2024)

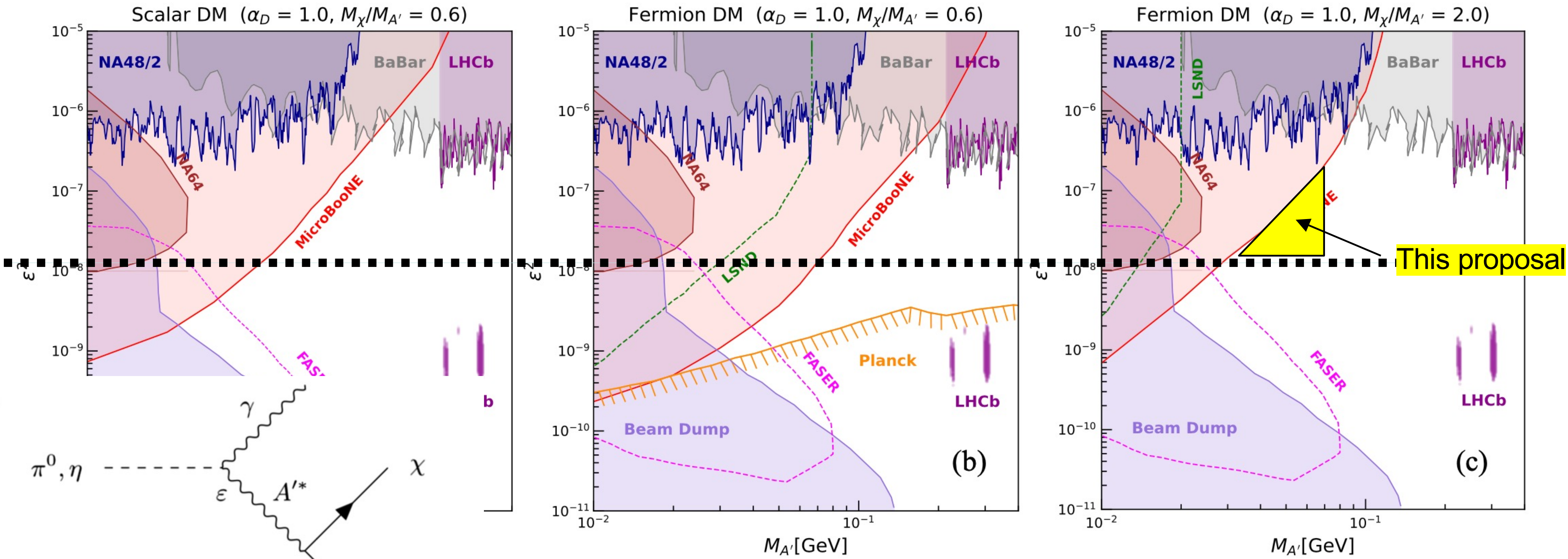


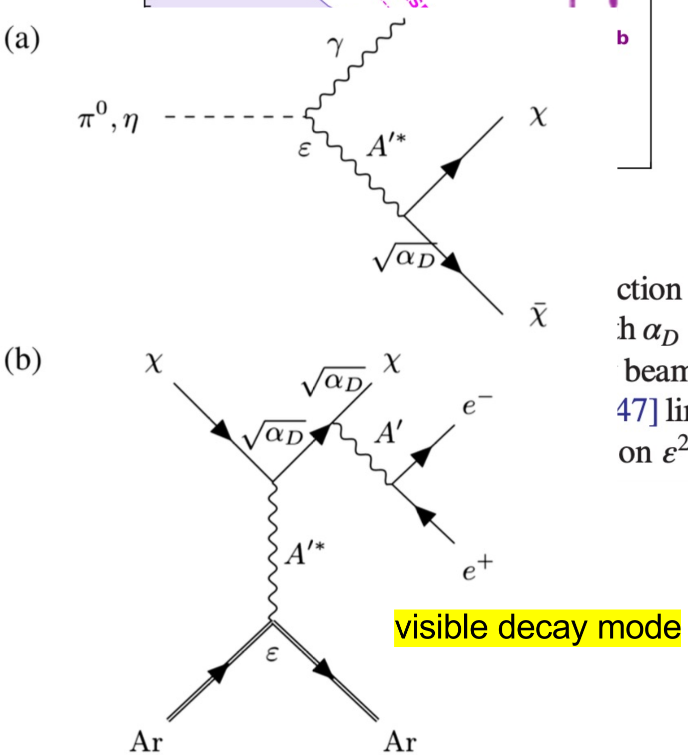


visible decay mode

ction of $M_{A'}$ for (a) scalar DM with $\alpha_D = 1.0$, $M_\chi/M_{A'} = 0.6$; (b) fermion DM with $\alpha_D = 1.0$, h $\alpha_D = 1.0$, $M_\chi/M_{A'} = 2.0$. The constraints provided by the NA48/2 [45], *BABAR* [46], NA64 beam dump experiments [9–11] are displayed as shaded regions. The reinterpretations of LSND 47] limits are shown as dashed lines. The two isolated contours at $M_{A'} \approx 200$–300 MeV are also on ε^2 from Planck data [52,53] apply for fermion DM with $M_\chi/M_{A'} = 0.6$.

First Search for Dark-Trident Processes Using the MicroBooNE Detector, PRL 32, 241801 (2024)





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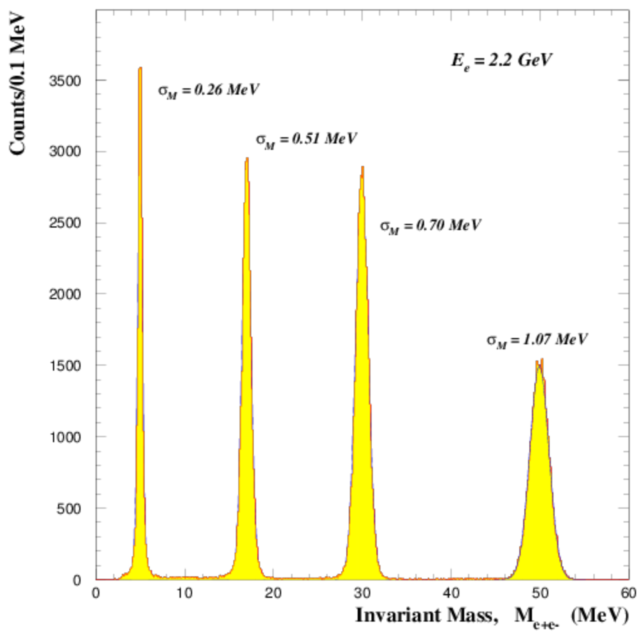
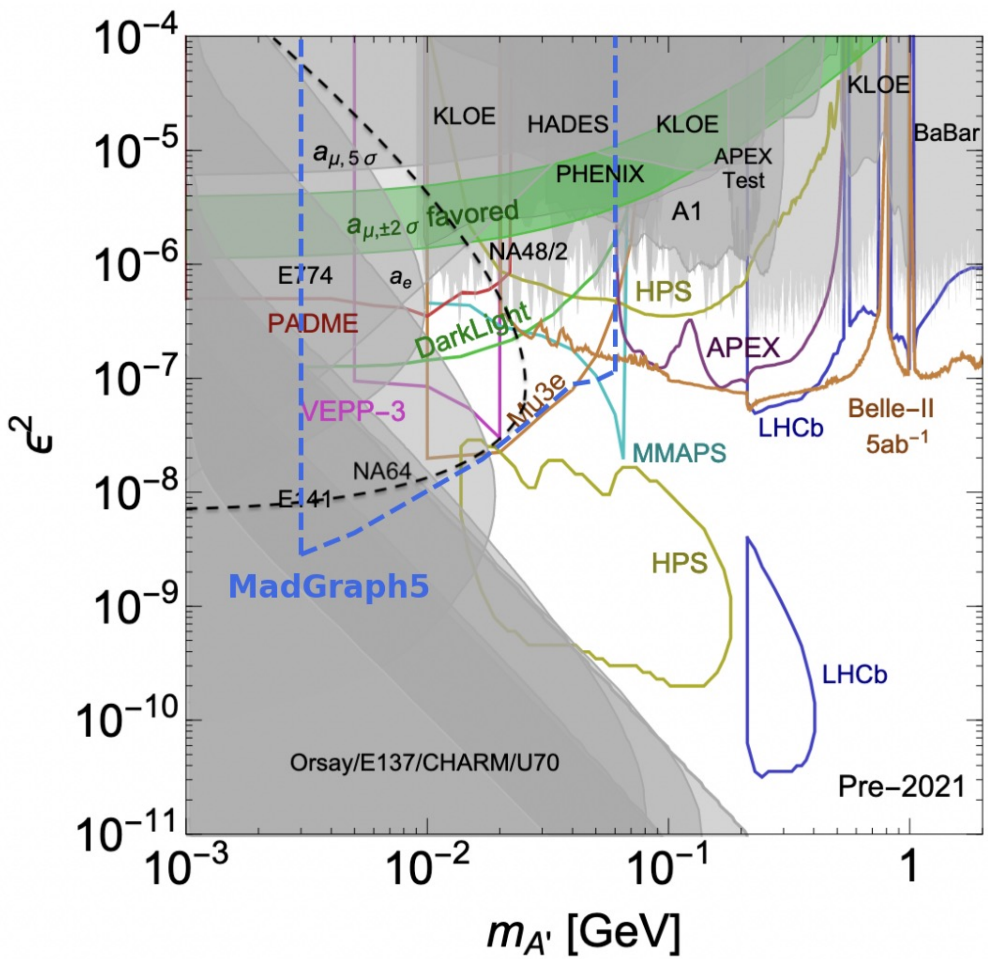
on ε^2 from Planck data [52,53] apply for fermion DM with $M_\chi/M_{A'} = 0.6$.

A Direct Detection Search for Hidden Sector New Particles in the 3-60 MeV Mass Range , X17

E12-21-003

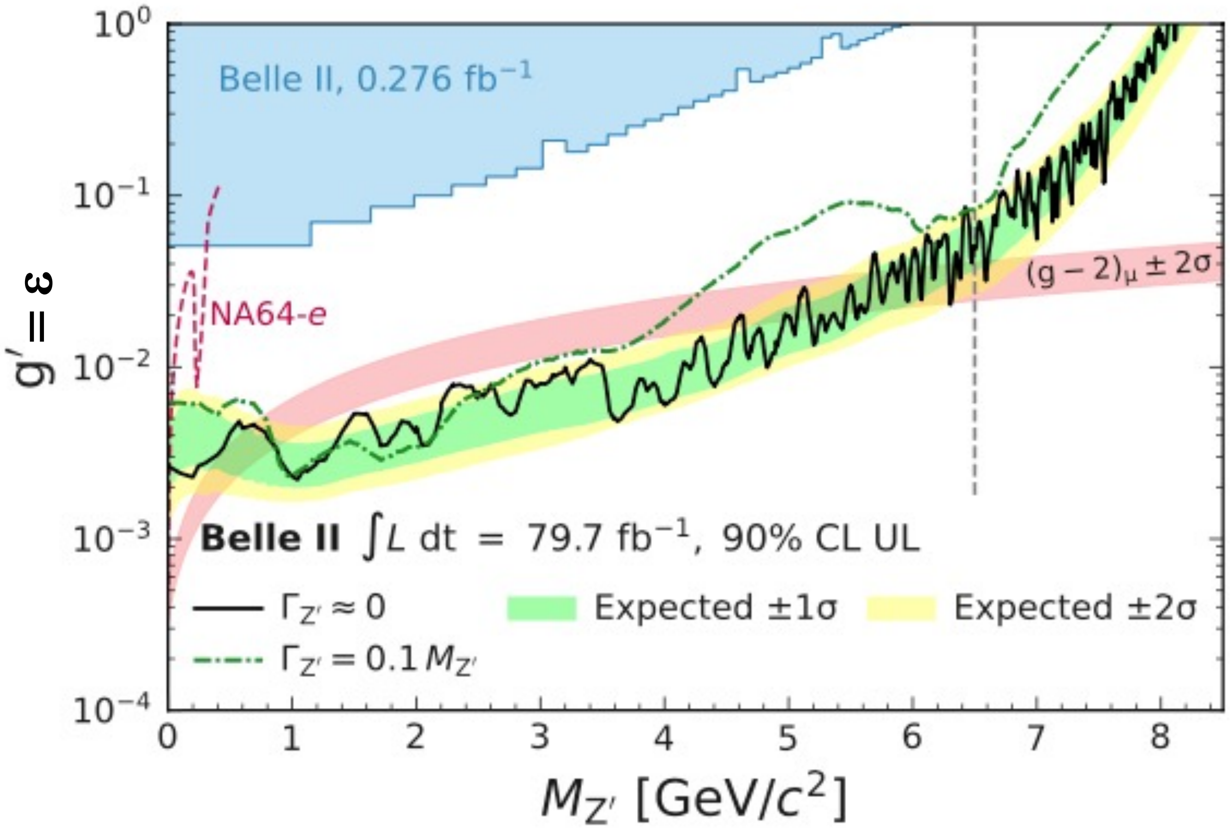
visible decay mode





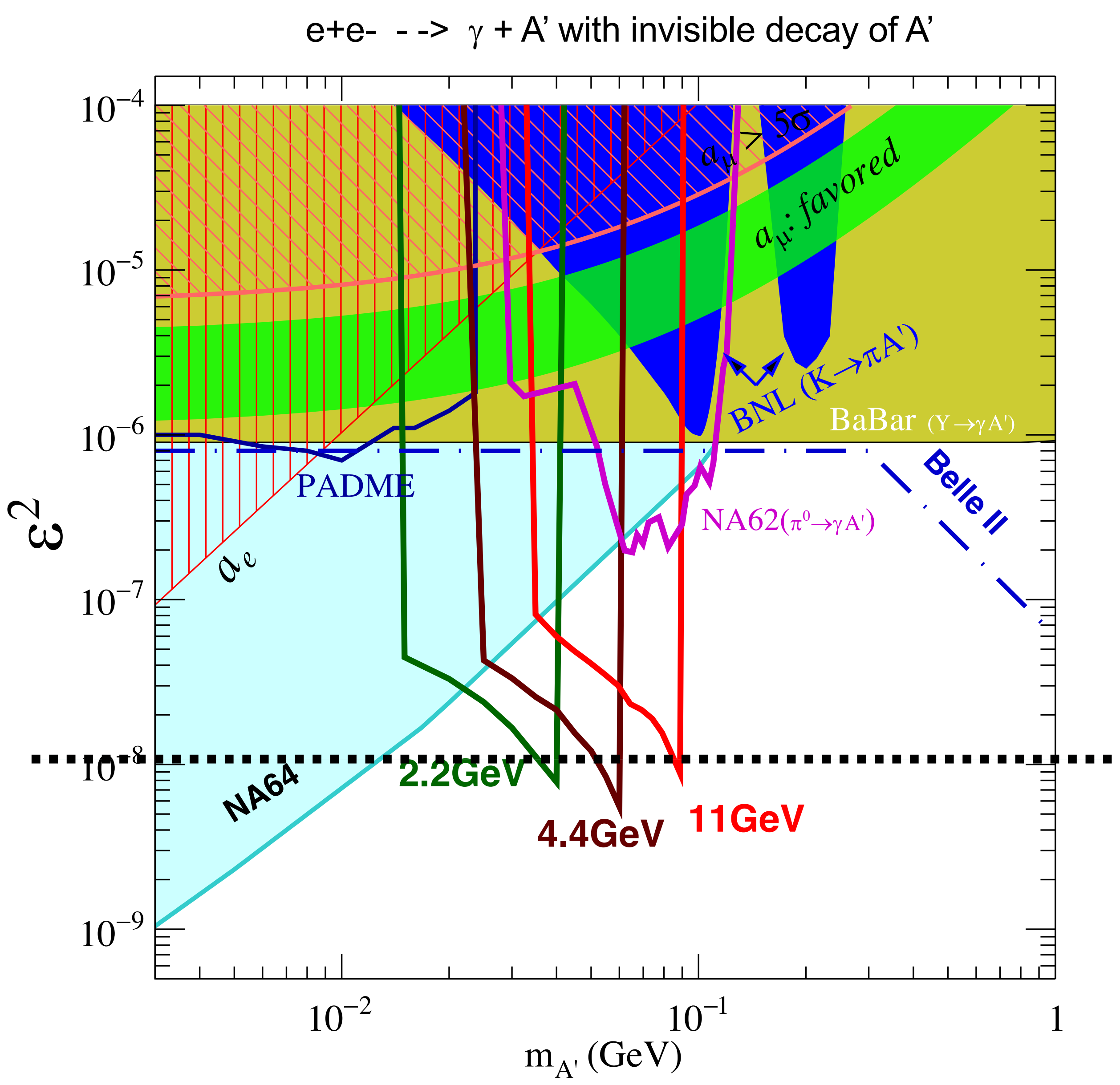
Belle-II recent analysis invisible decay

arXiv:2212.03066v3 e+e- - -> $\gamma*$ + Z' with invisible decay of Z'

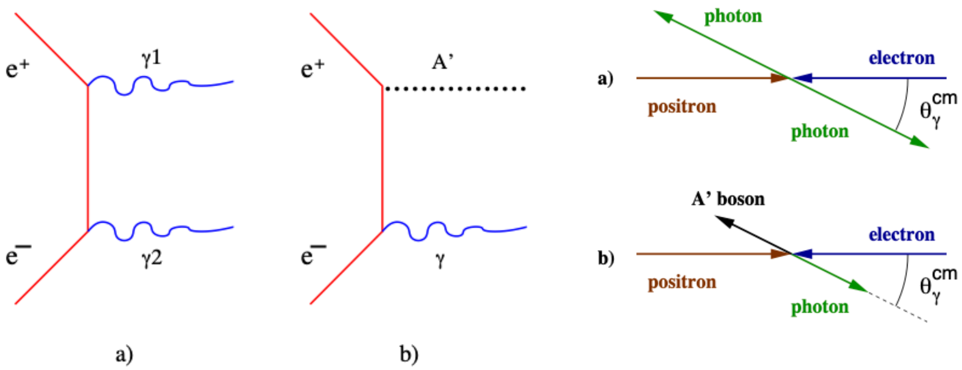


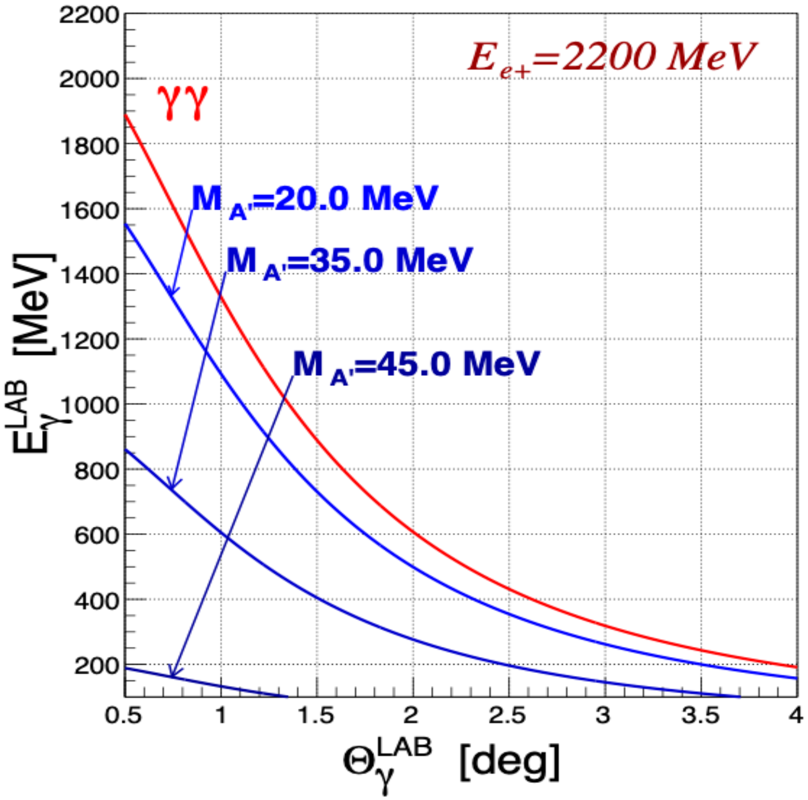
Good mass resolution for $m_{Z'} < 0.1$ GeV is hard to get

Current summary of A' invisible decay



The experimental method

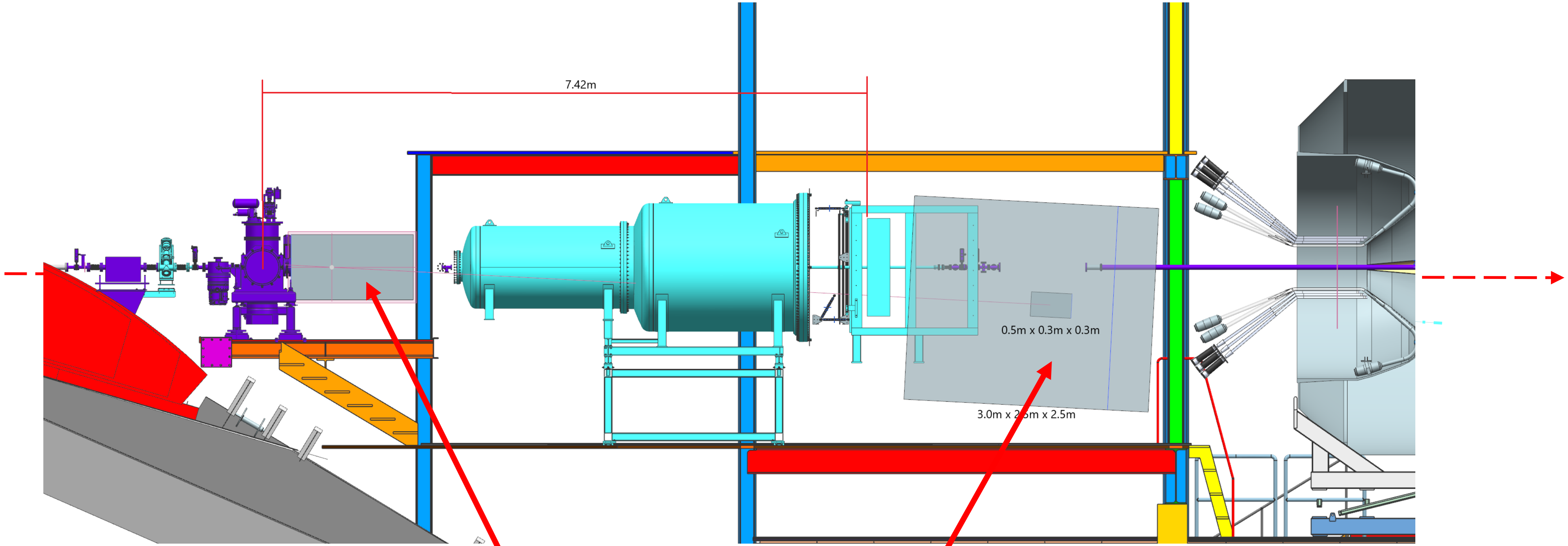


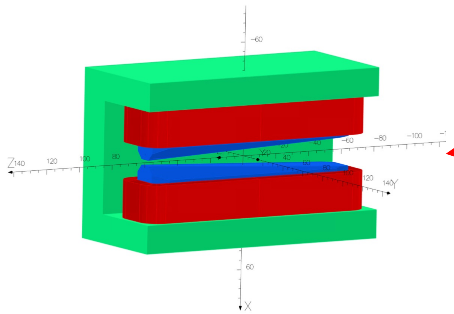


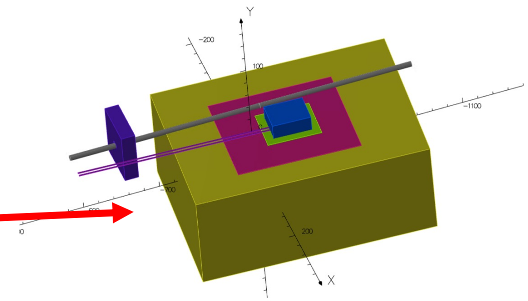
- A positron beam on a hydrogen target (e^+e^- annihilation)
- Selection of the one-photon final state events
- Search for a bump in the missing mass spectrum
- Connection between A' and the dark matter is not essential for the proposed study

$$M_{A'}^2 = 2m_e^2 + 2m_e * (E_+ - E_\gamma) - 4E_+ * E_\gamma * \sin^2(\frac{\theta_\gamma}{2})$$

Layout of the experiment in Hall B

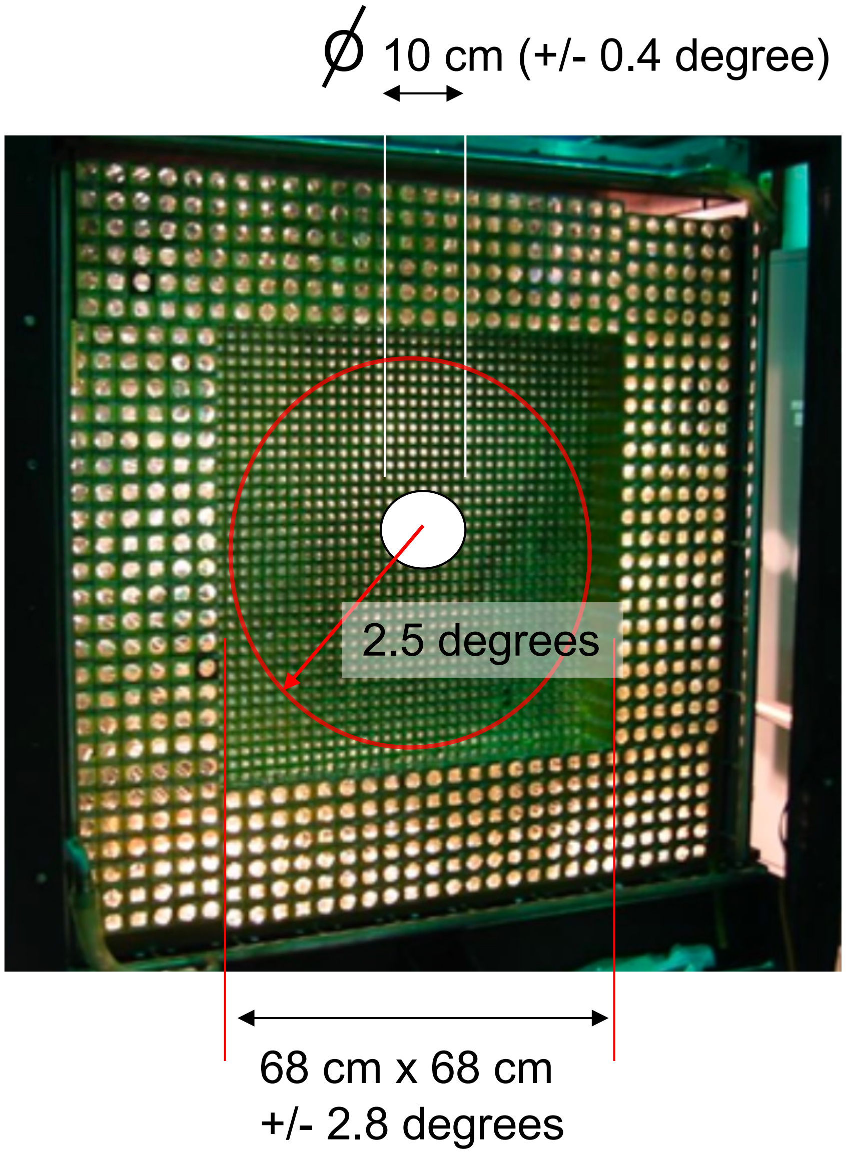


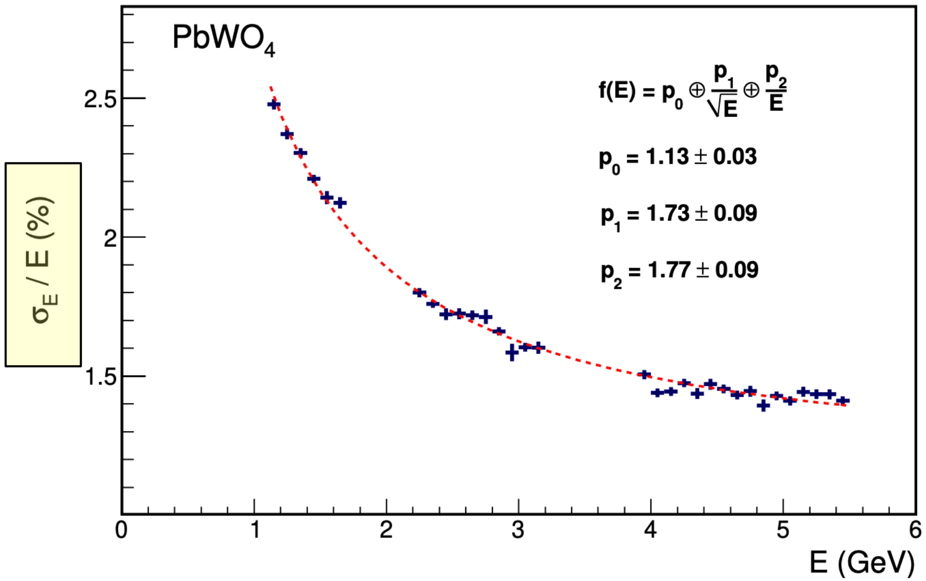


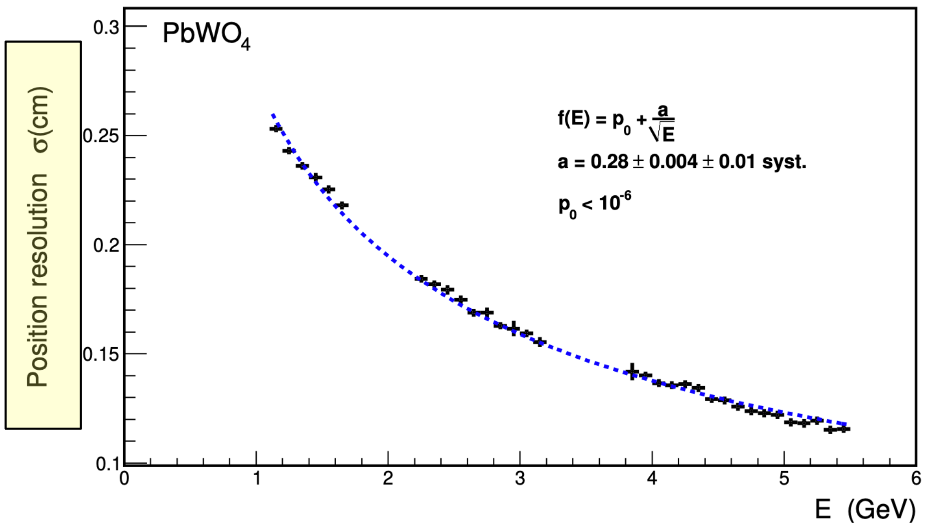


- NEW for PAC52 –
  - Geant4-based MC
  - sweeper
  - dump
- 50 nA positron beam on 5 cm long LH2
- High resolution part of PRIMEX HyCal calorimeter
- fADC - based DAQ with programmable trigger, 20 MHz

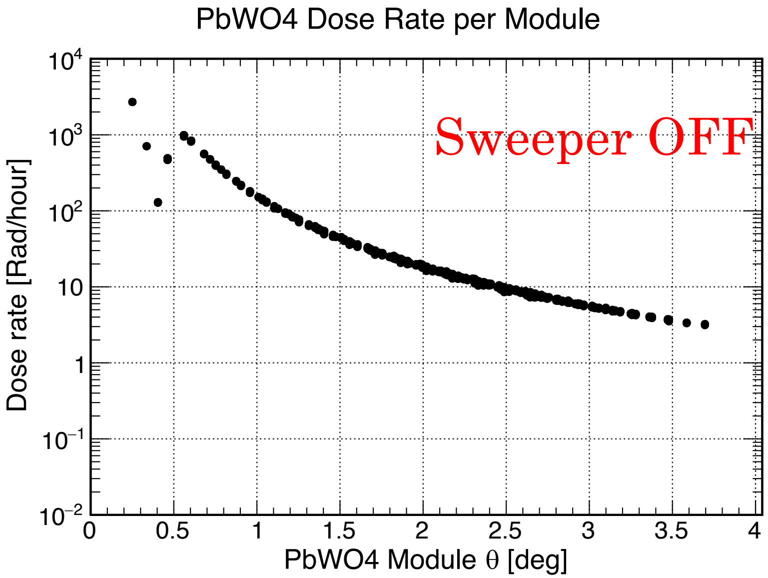
Calorimeter parameters

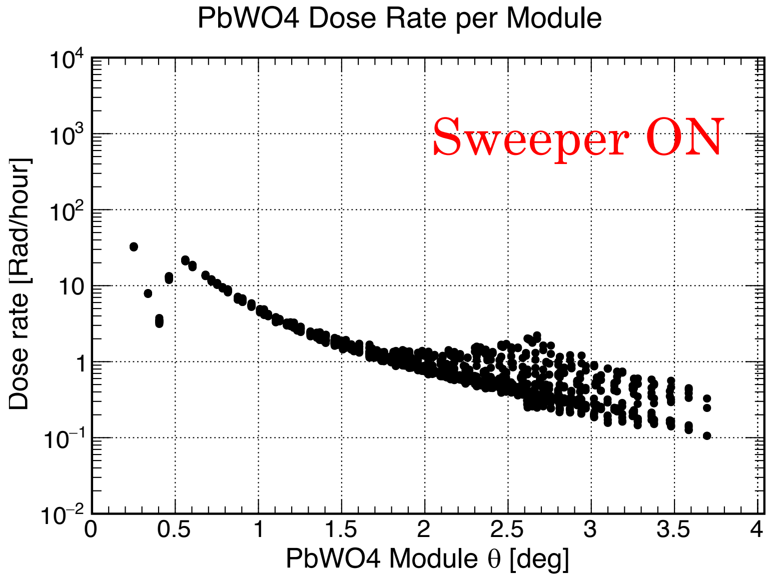


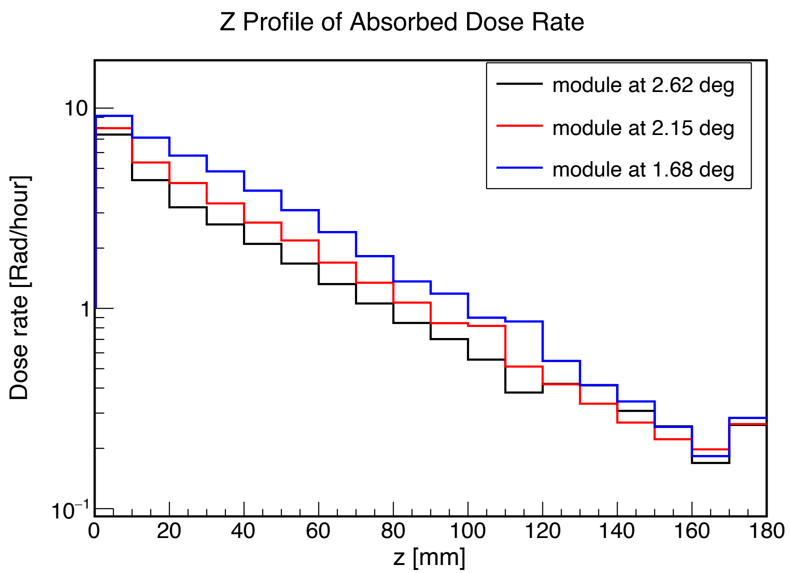


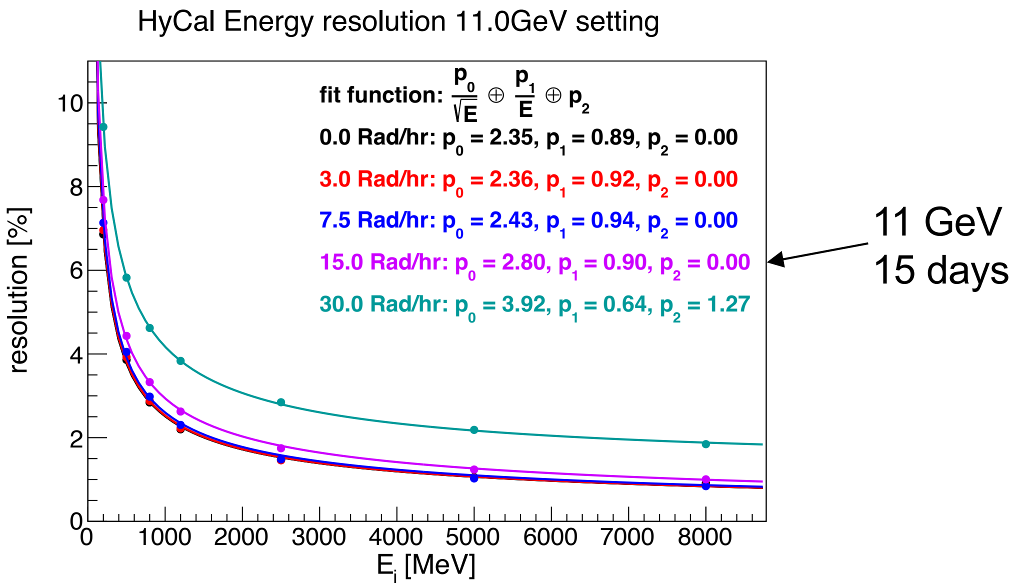


Calorimeter radiation load and resolution

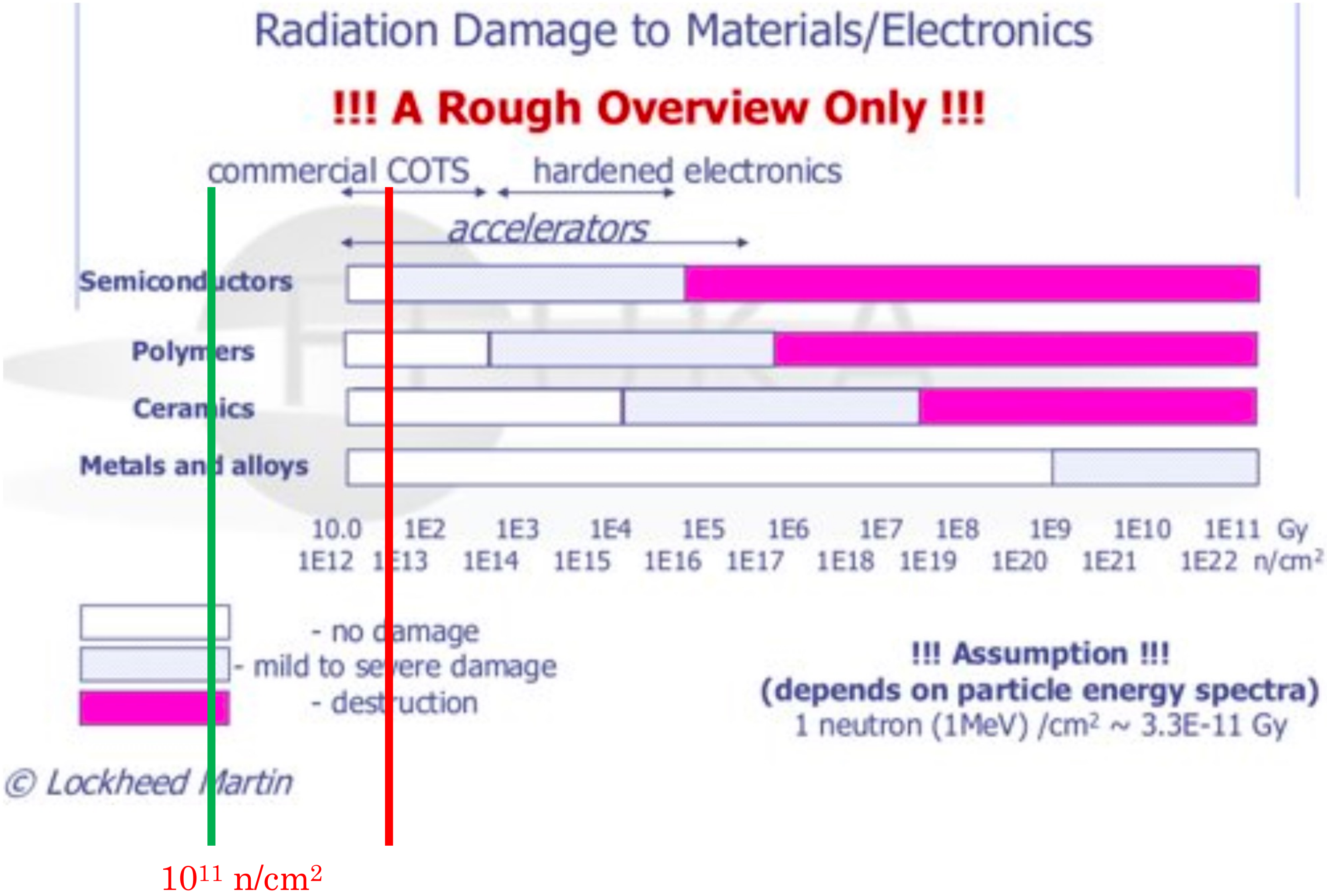








Neutron radiation impact



Typical neutron radiation in Hall B

Another estimate was made by using a calculation made for the recent experiment, see Fig. 35. The fluence at the entrance of the solenoid was found to be close to 3×10^9 n/cm^2, so at a distance

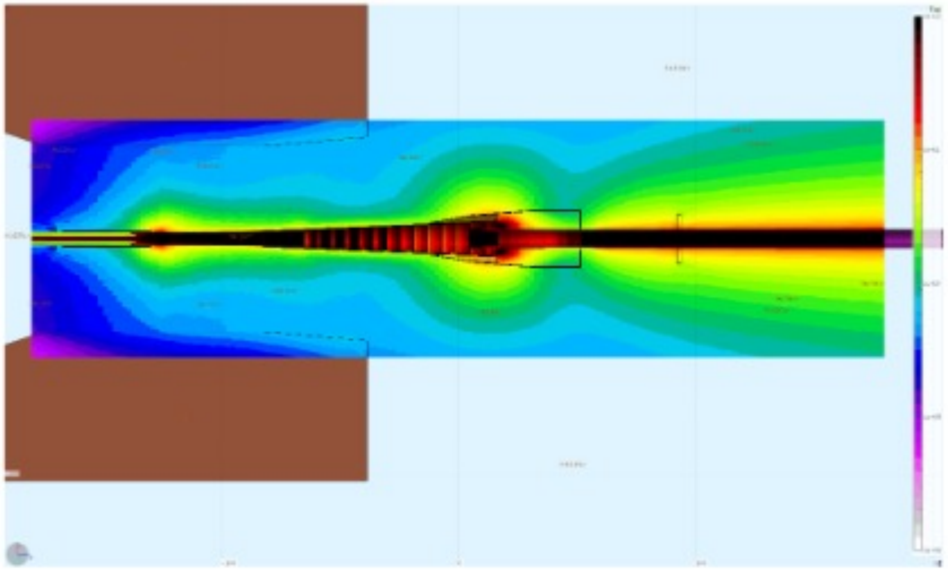


FIG. 35. Neutron dose after the recent experiment in Hall B according to calculations by L. Zana.

of 5 meters the estimated level is $10^7 - 10^8$ n/cm^2. The upper value (10^8 n/cm^2) is 2000 times below the value reported in Ref. [67].

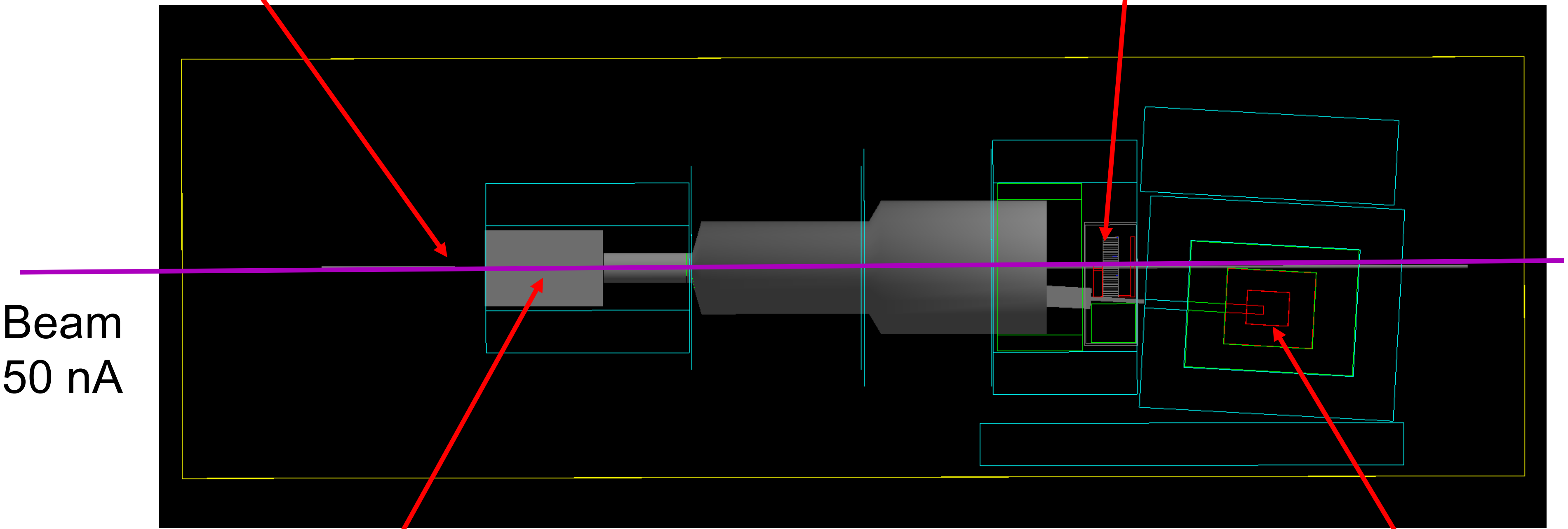
Using the value 10^8 n/cm^2 as a benchmark, we come to the first level of design/calculation of the beam dump for the proposed experiment, see Figs. 18 and 32.

Geant4 model of A’ experiment

5 cm LH2 target

Detector

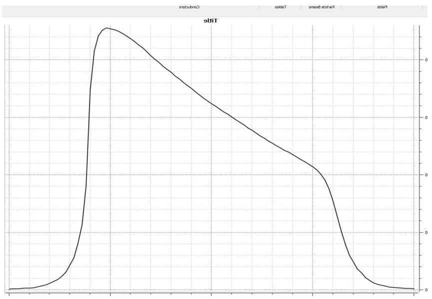
Beam
50 nA



Sweeper, Bdl ~ 2 T-m

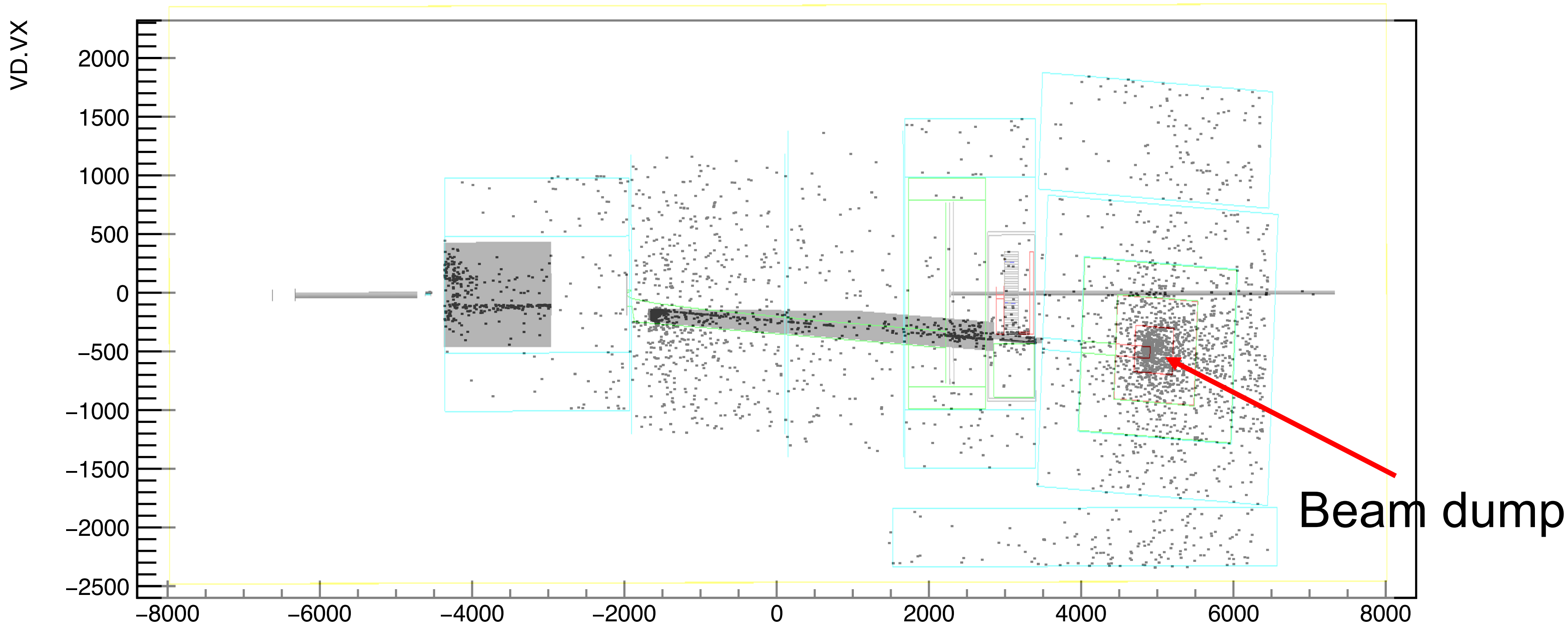
Beam dump
power < 550 W

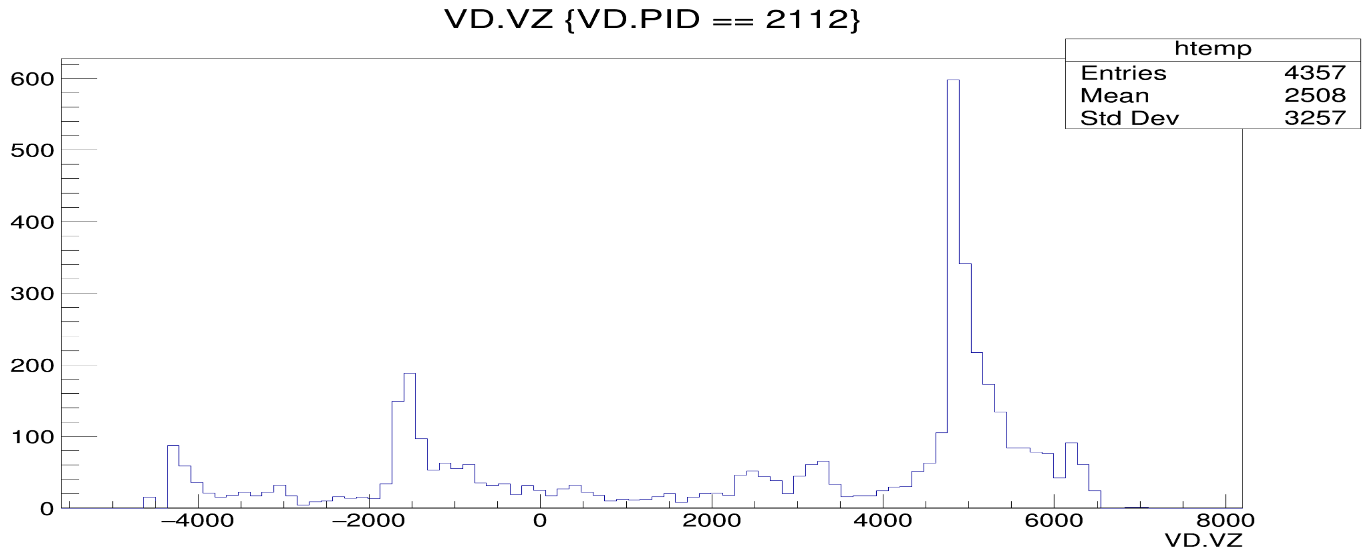
B



z

Neutron sources locations





Neutron radiation expectation

The Geant4-based radiation analysis was found to be consistent with the FLUKA-based calculation performed by the Radcon group (Fig. 36). At a distance of 5 m, after an 11-GeV 50-nA 15-day run, the dose is below 0.7×10^8 n/cm^2, so it is below the benchmark level. Additional contributions from 2.2 and 4.4 GeV runs will increase the budget to 0.9×10^8 n/cm^2.

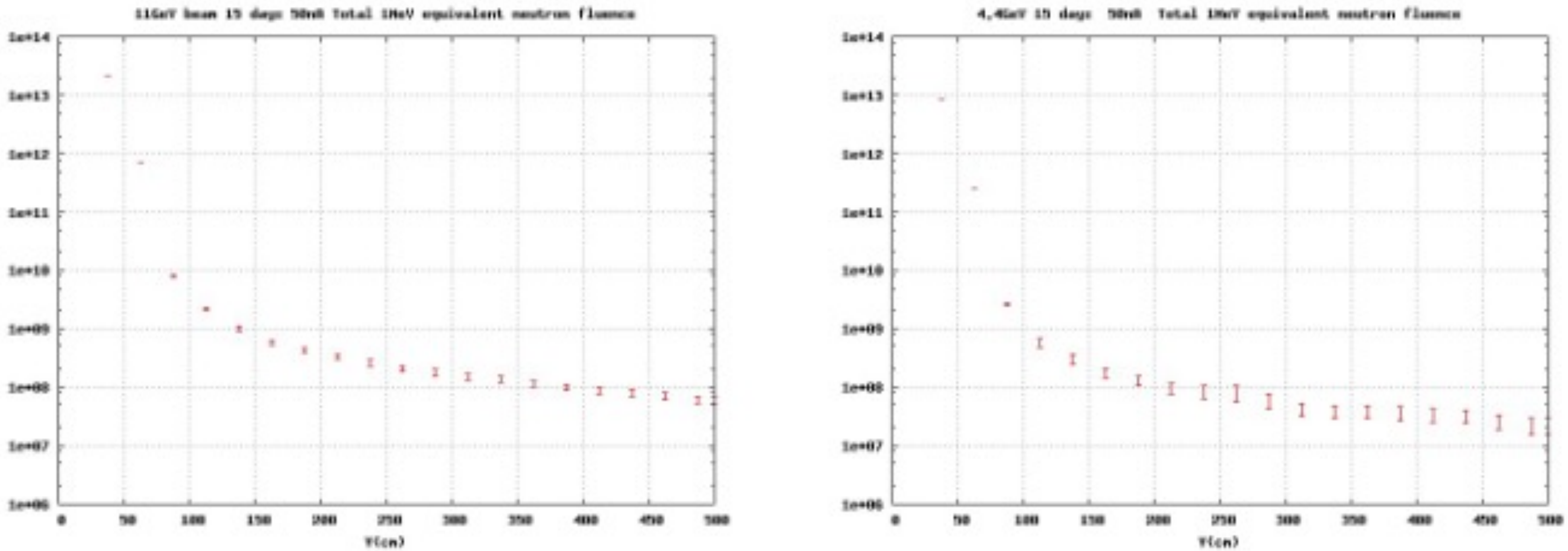
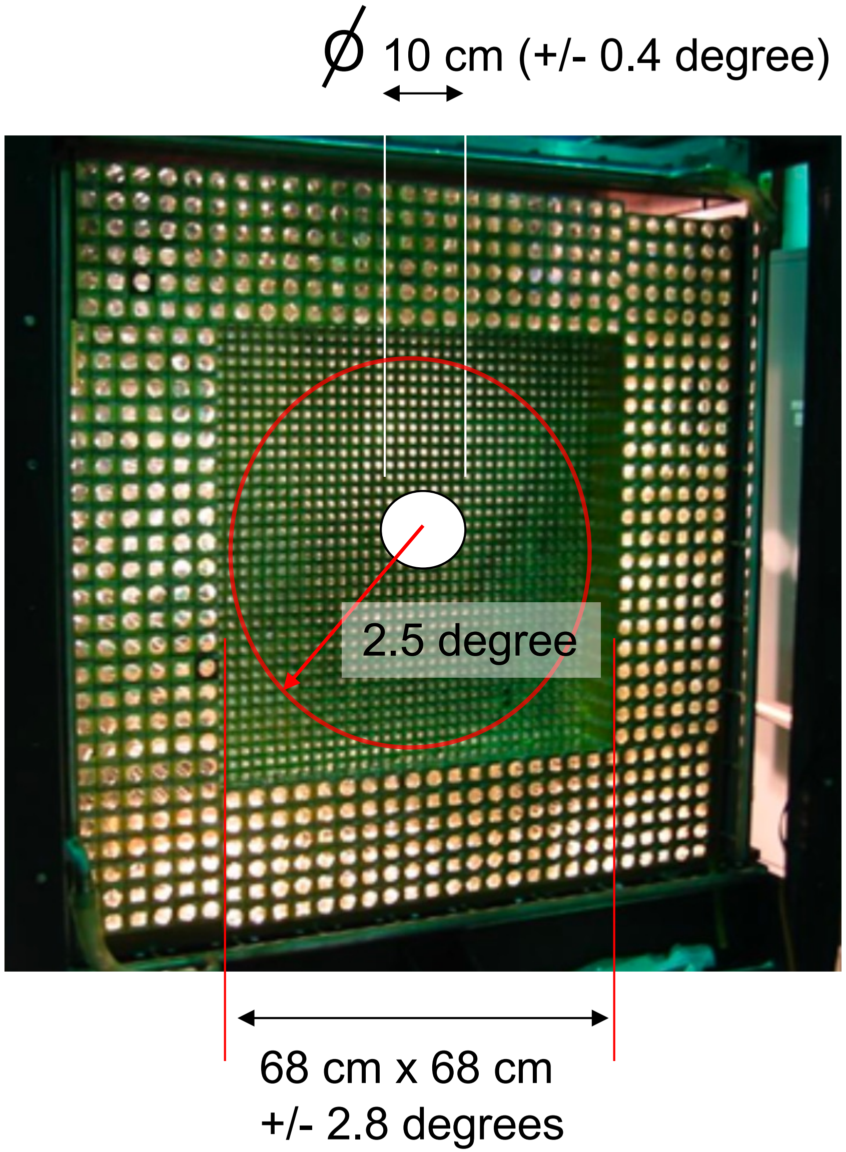
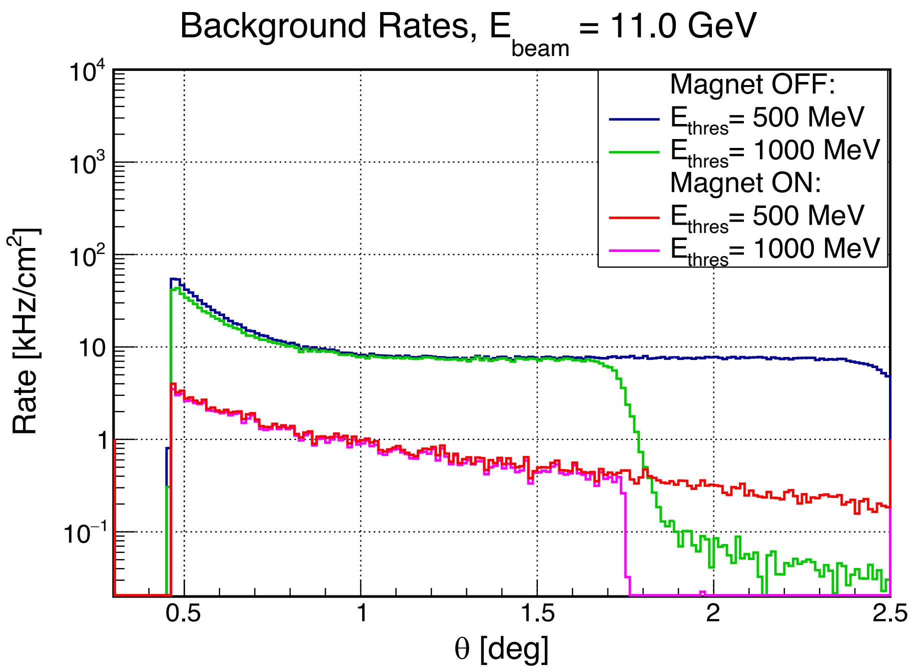


FIG. 36. Neutron radiation dose around the local beam dump vs. distance from dump center according to L. Zana in 4.4 GeV and 11 GeV parts of this experiment.

The value (10^8 n/cm^2) is 2000 times below the value recommended in the published studies of the radiation impact on the electronics.

Expected rate in the calorimeter

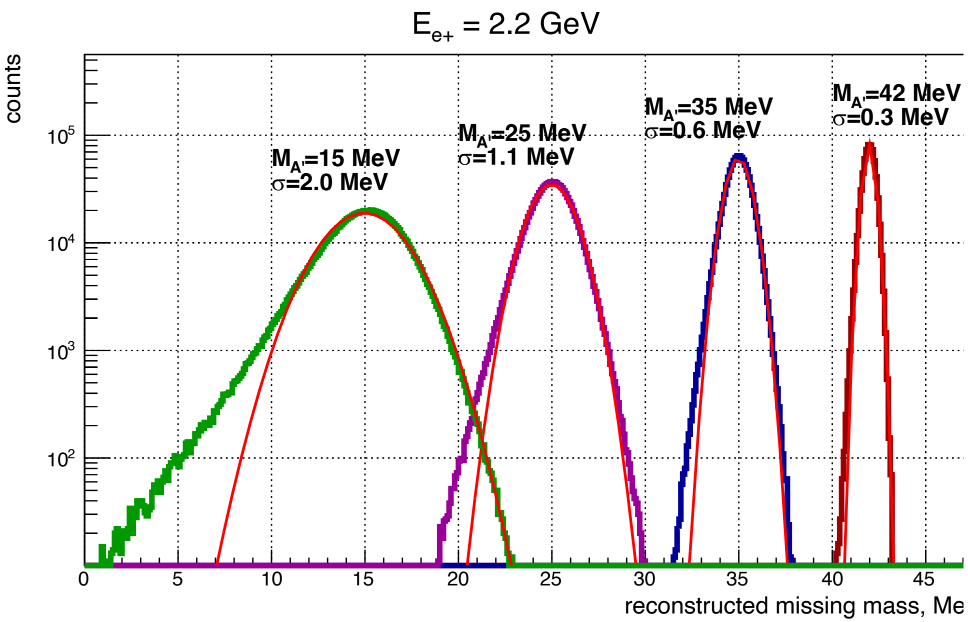


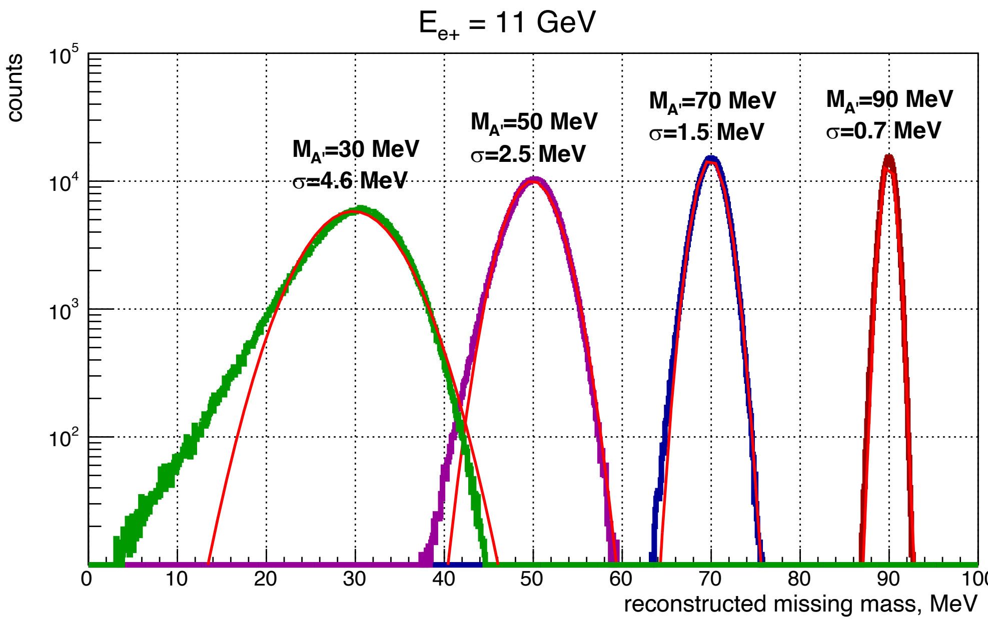


Mass resolution

the photon energy and angle allow us to calculate
the missing mass:

$$M_{A'}^2 = 2m_e^2 + 2m_e * (E_+ - E_\gamma) - 4E_+ * E_\gamma * \sin^2(\frac{\theta_\gamma}{2})$$





Projected detector rates

TABLE I. Statistics for $E_{e+} = 11$ GeV, $\mathcal{L} = 7 \times 10^{34} cm^{-2}/s$, 15 days, $E_\gamma > 0.5$ GeV, $\theta = 0.5^\circ - 2.5^\circ$, $\epsilon^2 = 1 \times 10^{-7}$.

Whole M_{miss} acceptance, Total rate [Hz]

	Physics MC	Geant4-based MC
Sweeper OFF	1.9e+07	2.6e+07
Sweeper ON	1.8e+06	1.5e+06
Single γ-cluster	1.3e+06	1.4e+06

in the interval $M_{miss} = 80 \pm 1\sigma$, Events in 15 days

	Background	A'	$Signal/\sqrt{Background}$
Sweeper OFF	4.3e+10	1.3e+06	6.1 (resol. corrected)
Sweeper ON	1.1e+10	1.3e+06	11.9
Single γ-cluster	0.9e+10	1.3e+06	13.2

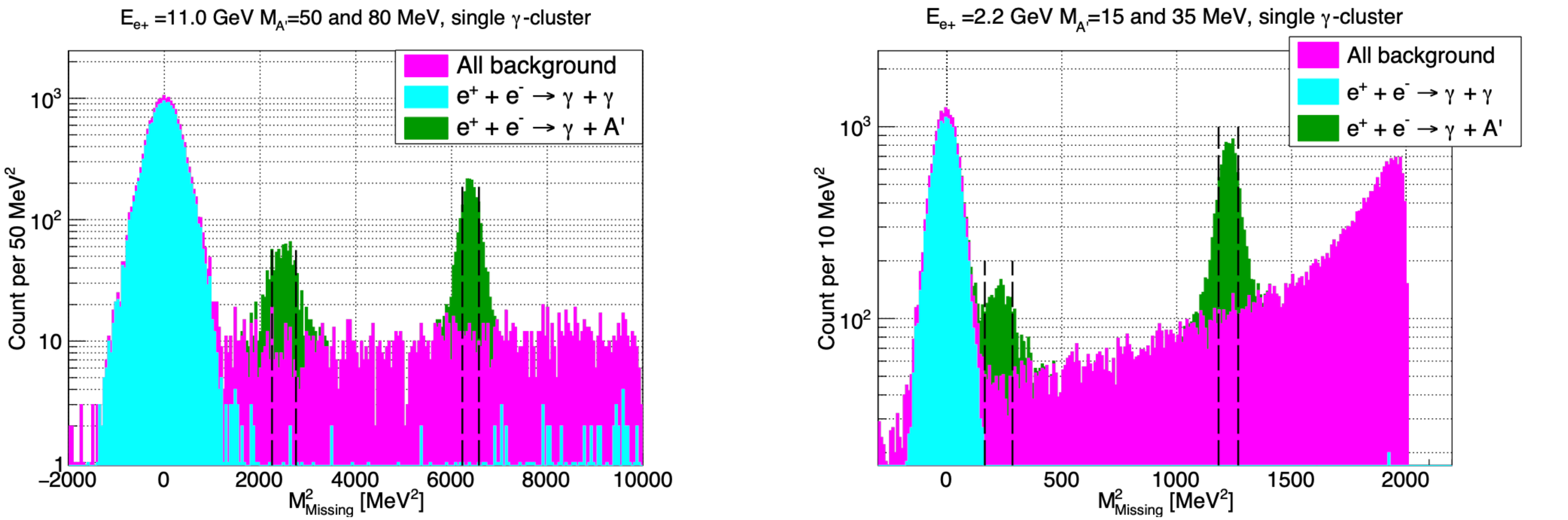
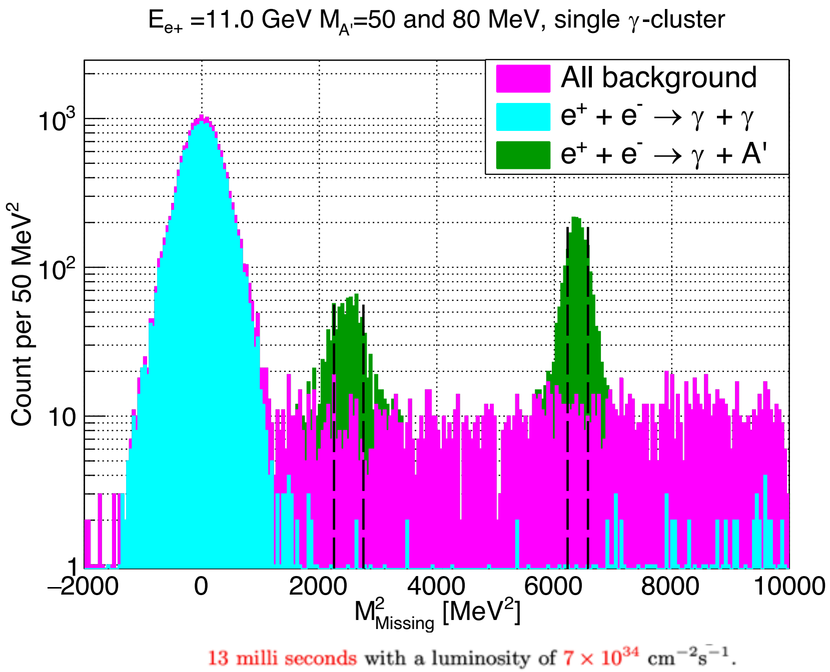
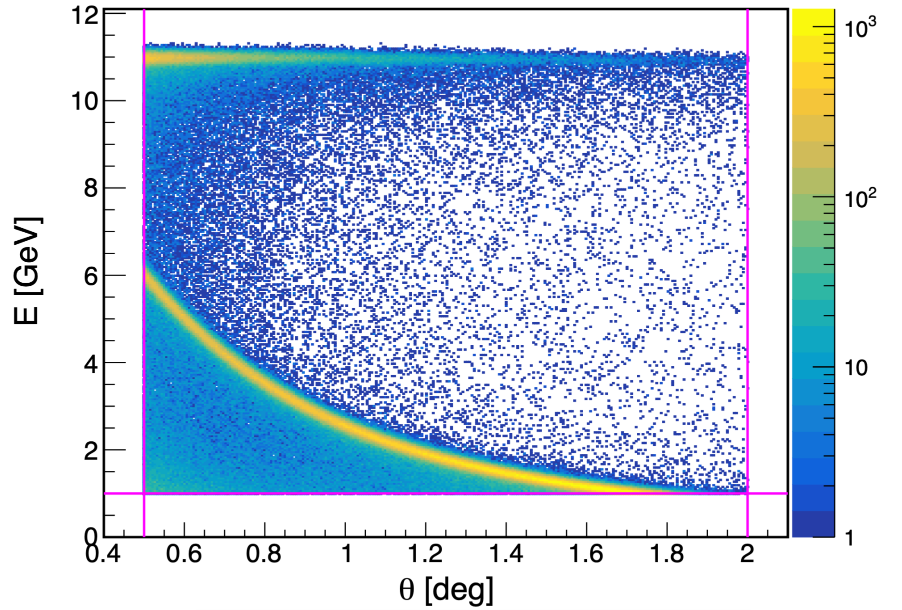


FIG. 16. Results of the Monte Carlo simulation for the missing mass distribution. The mixing constant is taken to be $\epsilon^2 = 10^{-2}$ to simplify visualization on the plot. Left – for $E_{e+} = 11$ GeV beam energy, $M_{A'} = 50$ and $M_{A'} = 80$ MeV. Right – for $E_{e+} = 2.2$ GeV beam energy, $M_{A'} = 15$ and $M_{A'} = 35$ MeV. Vertical dashed lines indicate the width of a sliding search window ($\pm 1\sigma_{M^2}$). Each spectrum corresponds to data taking for 13 milli seconds with a luminosity of 7×10^{34} cm^{-2}s^{-1}.

Detector non-uniformity estimation-I



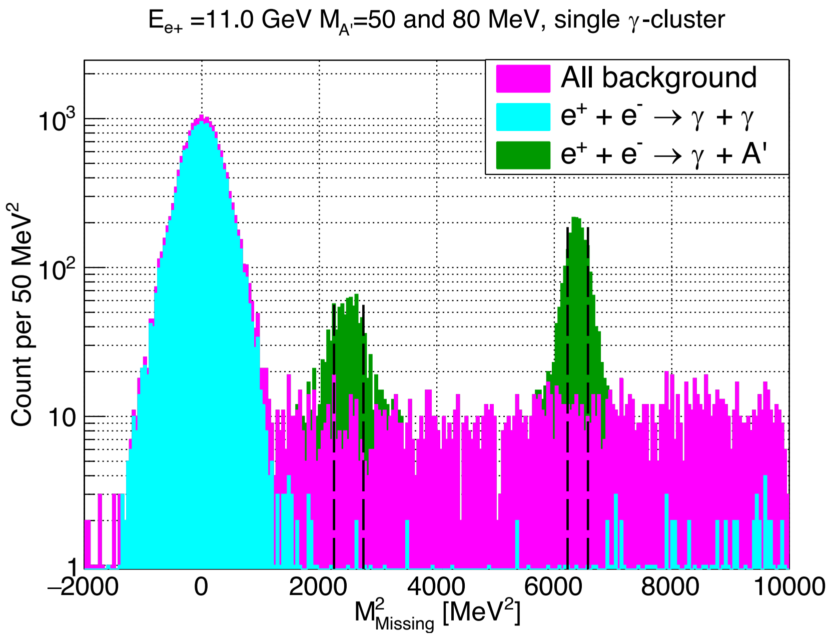


$$M^2_{A'} = 2m_e^2 + 2m_e * (E_+ - E_\gamma) - 4E_+ * E_\gamma * \sin^2(\frac{\theta_\gamma}{2})$$

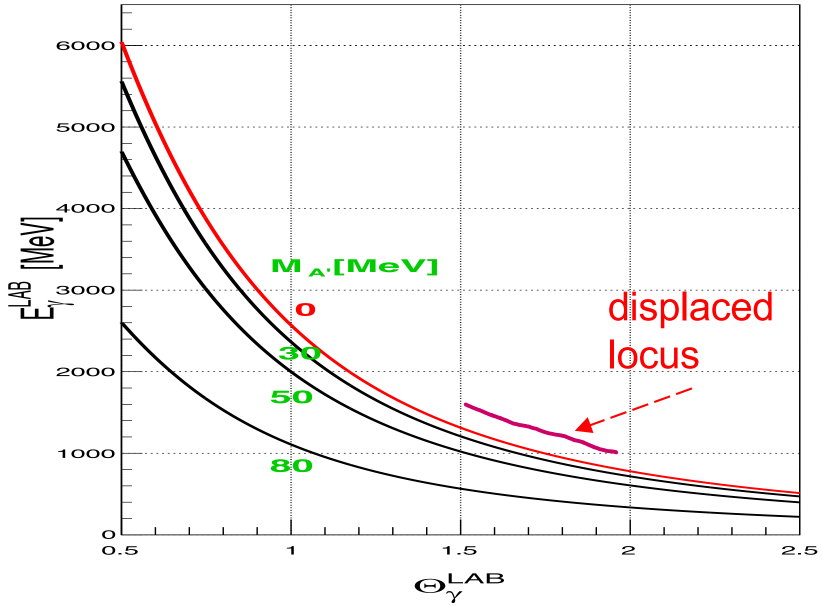
Mass spectrum quality contributions:

- Photon angle, θ - calibrated using GEM chamber with 1×10^{-6} radian steps
- Detector efficiency - calibrated using e^+-e^- rate and the photon angle, 10^{-6}
- Photon energy - calibrated using e^+-p and e^+-e^- elastic locus/band and θ

Detector non-uniformity estimation-II



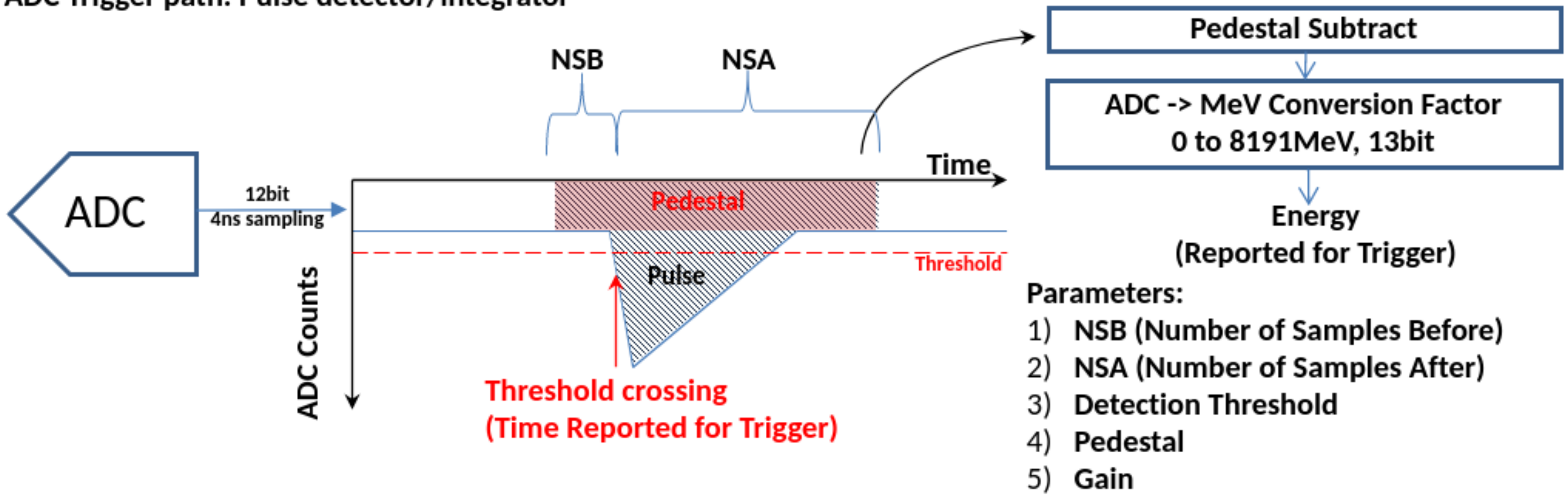
13 milli seconds with a luminosity of 7×10^{34} cm^{-2}s^{-1}.



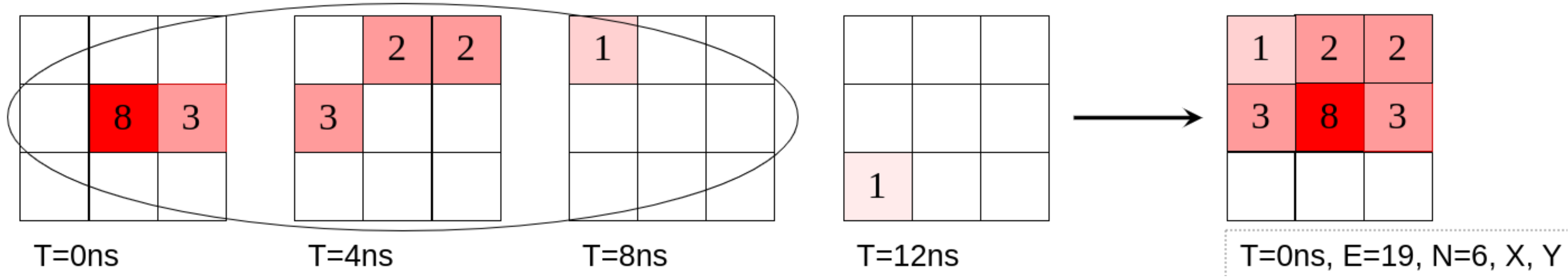
- Relative size of the statistical fluctuation of background in the spectrum for a 200 MeV^2 interval (at M_A=80 MeV) is $1\text{x}10^{-5}$. The fake bump with the amplitude essential for the A' search corresponds to fluctuation by two sigma or $2\text{x}10^{-5}$.
- The locus width of E_γ vs. θ in 2D plot is 2%. The shift by $2\text{x}10^{-5}$ of the width size will create a fake bump. However, the whole plot is calibrated by using the locus of M_A=0 whose statistics is $1.8\text{x}10^{12}$ => one sigma fluctuation is $0.8\text{x}10^{-6}$.
- So, displacement of the locus by $2\text{x}10^{-5}$ /$0.8\text{x}10^{-6}$ = 25 sigma will lead to a sufficient amplitude of the fake bump. At high M_A the length of the locus is a few times shorter, so the estimate of probability of the fake bump: A fake bump is suppressed at least by 10 sigma.

High rate capability DAQ

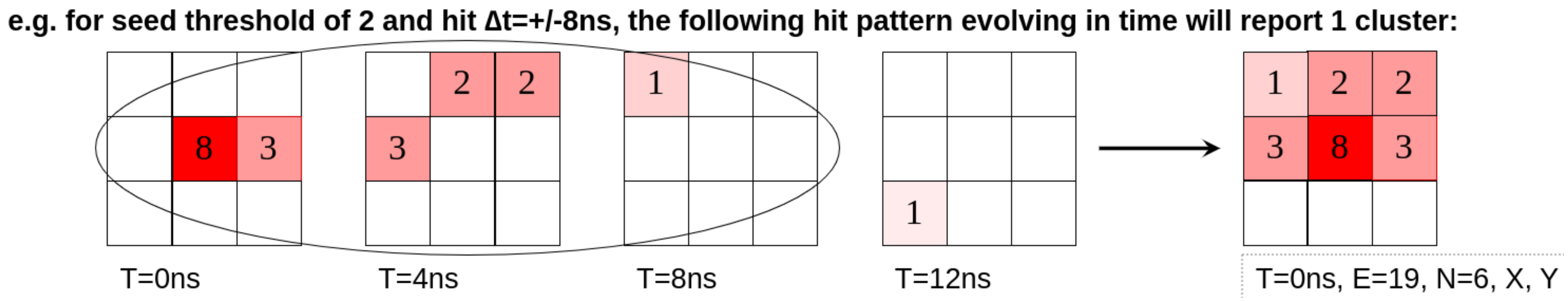
FADC Trigger path: Pulse detector/integrator

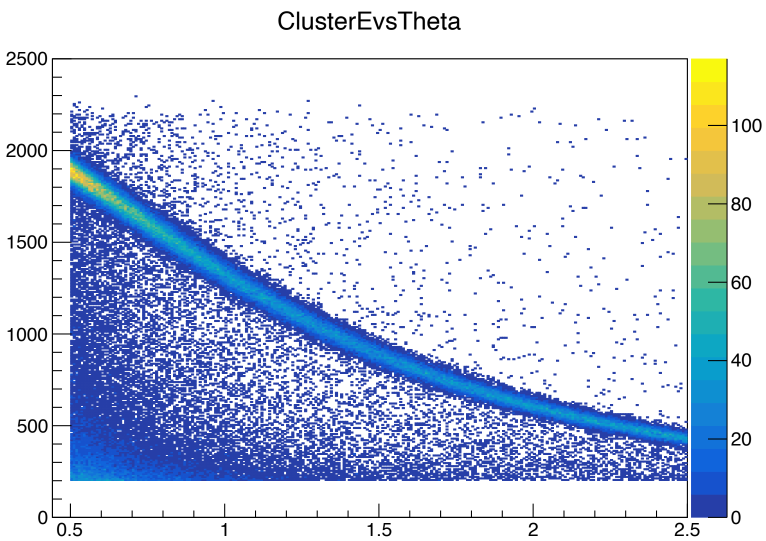


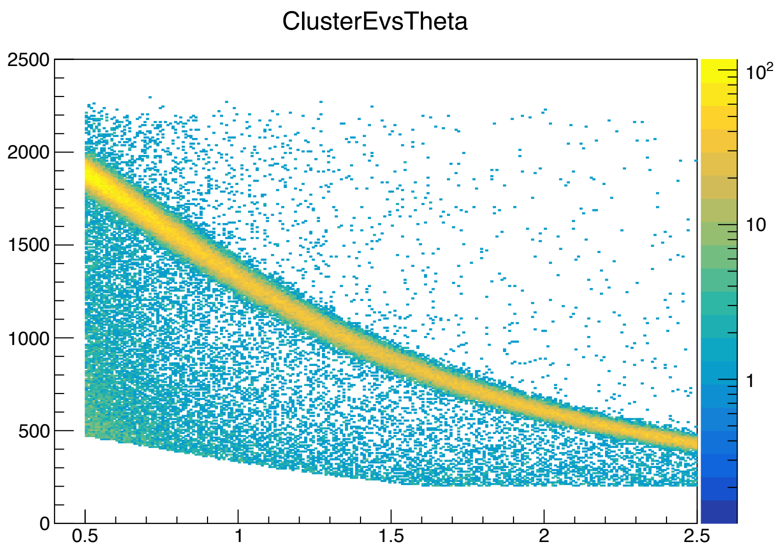
e.g. for seed threshold of 2 and hit Δt=+/-8ns, the following hit pattern evolving in time will report 1 cluster:



High rate capability DAQ







- Calculated DAQ capability for single cluster events is certainly above 20 MHz.
- Expected event rate is 1.5 MHz for 11 GeV run and 10 MHz at 2.2 GeV run.

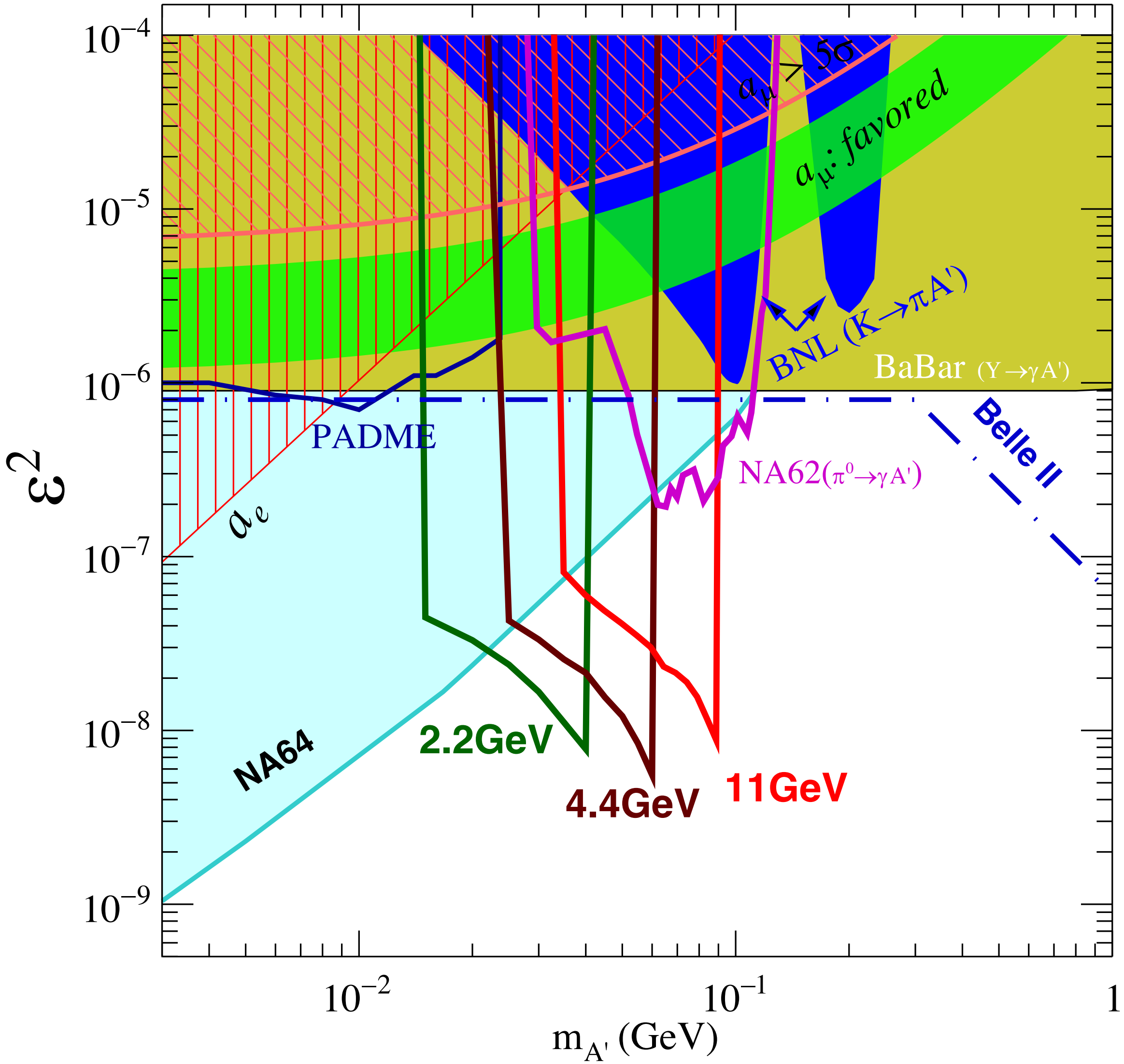
Projected sensitivity of this proposal

Uniqueness of the missing mass method

1. Sensitivity does not rely on specific decay mode of A' : e+e-, or hadrons, or semi-dark … 100 times more sensitive than (g_μ-2)

2. Good mass resolution allows us to make a productive search for a signal with a 55-day run in mass range 15-90 MeV.

two-sigma level limit



Beam time request

1. Sensitivity does not rely on specific decay mode of A' : e+e-, or hadrons, or semi-dark …
100 times more sensitive than (g_μ-2)
2. Good mass resolution allows us to make a productive search for a signal with a 55-day run
3. Does not require new detector development
4. The sweeper dipole has been designed in OPERA (2x of the existing CPS magnet)
5. The beam dump was calculated in FLUKA and Geant4

Kin. #	Beam energy, GeV	Beam, μA	Mass range, MeV	Time, days
C1	2.2	0.050 e^+	15-40	15 + 1
C2	4.4	0.050 e^+	40-60	15 + 1
C3	11	0.050 e^+	60-90	15 + 1 +7
	Total requested time			55

Summary

1. We propose a search for the A'-boson in the process of e+e- annihilation using the upcoming JLab positron beam.

2. This experiment will be sensitive to the A' coupling constant ε^2 on the level of 2×10^{-8} in the 15-90 MeV mass range.

3. The experiment will based on the existing PRAD experimental setup in Hall B. Required beam line development is well understood.

4. We are requesting 55 days with 50 nA positron beam time for this experiment.

Backup slides

Replies to TAC review, page I

Answers/reply to TAC review of PR12+24-005

For the section Findings:

4. A new GEM tracker is planned for installation in front of HyCal to act as a charged particle veto to reduce backgrounds and enhance sensitivity to possible signal events. This new tracker will be built by the UVa Group for the PRad-II experiment and should be considered as existing basic instrumentation.

As it is presented in the current proposal, **the GEM detector** will be used for coordinate calibration of the calorimeter with elastic scattering events and in off-line analysis for rejection of the remaining charged particles but **not as a veto in the trigger.**
Most of the charged particles will be removed from the calorimeter acceptance by the sweeper magnet. The off-line analysis uses the tracker for veto of the charged single clusters, which reduces the background rate by **a factor of 1.5**.

Replies to TAC review , page II

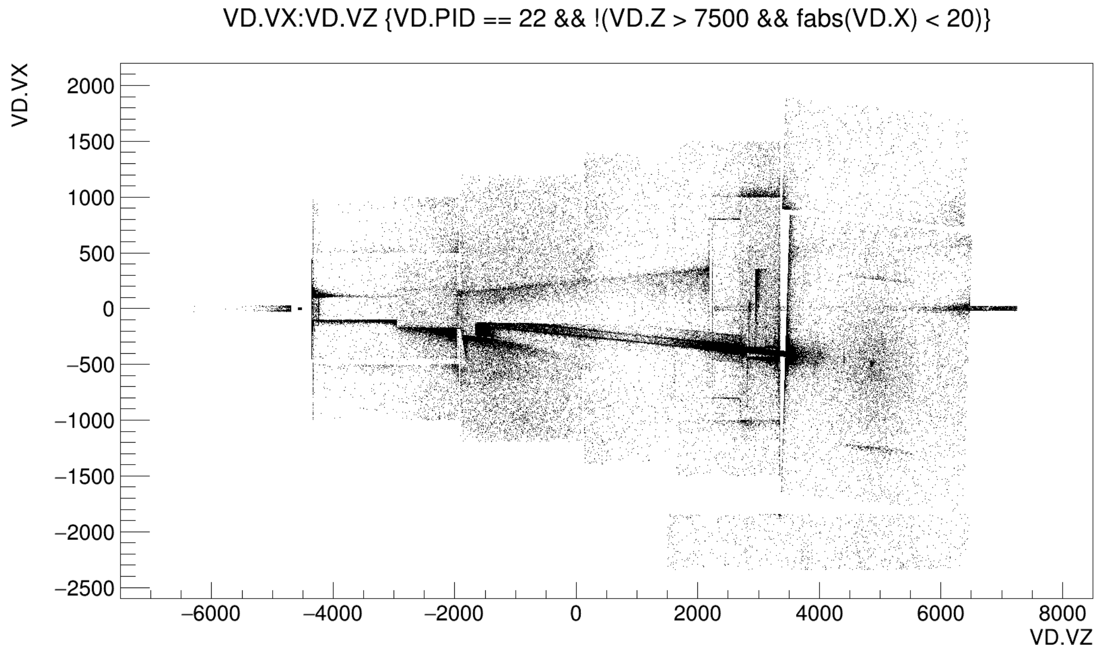
For the section Comments

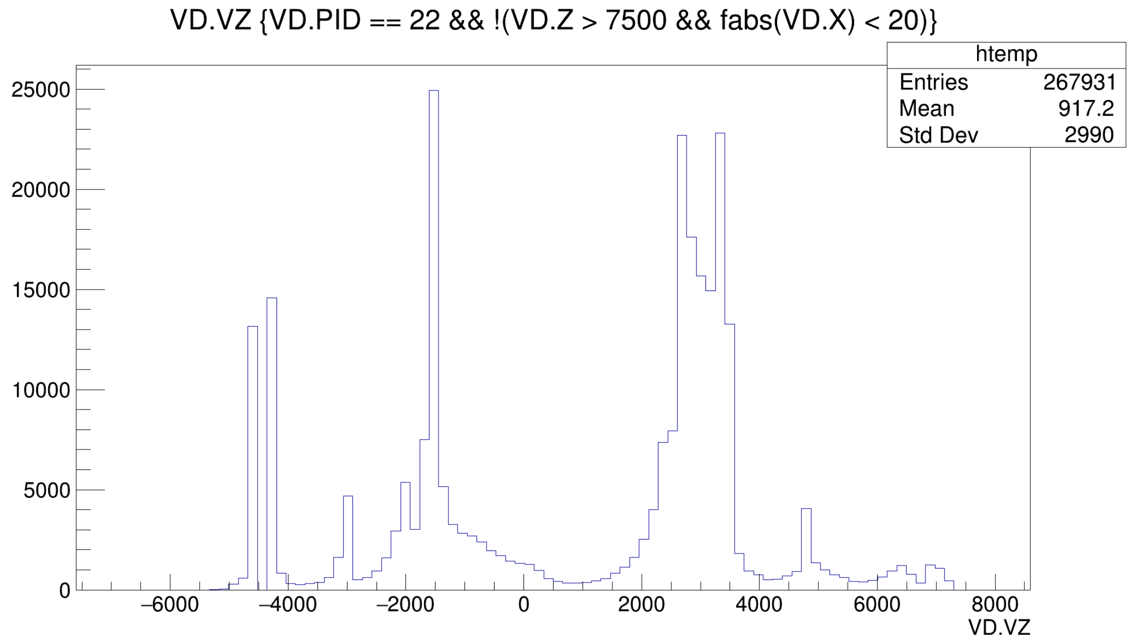
3. Downstream of the HyCal system a new compact beam dump is planned. Given the space constraints and loading requirements on the Target Level of the Space Frame in Hall B, a detailed model with the Hall B engineers needs to be developed. The dump should be carefully developed with the appropriate experts to be sure that it is properly designed for the most extreme running conditions and should include tight shielding not only for neutrons but also for the EM background. Collaboration with the JLab Radiation Control Group will be required. Shielding of local electronics from the high doses expected from neutron radiation should be considered. The cited work on the tagger yoke beam dump is not a good comparison as conditions are very different.

We calculated the total energy flow of EM particles, see the Figures below.
The total flux in the downstream direction is $E = 2\times10^{10}$ MeV/c => 3×10^{-3} Joules. The distance to the equipment is about 5 meters. The typical absorption depth is about 10 gram/cm^2. The radiation absorbed in the mass of M = 2.5 10^3 kG.
The dose rate is Energy/Mass = 1×10^{-6} Gray/s; integrated over experiment beam time 45 days – 4×10^6 s. The total dose is 4 Gy or 400 Rad, which is too low to worry about for typical electronics. The estimated safety factor is on the order of 100 or higher.

Collaboration with the JLab Radiation Control Group has already started.

Replies to TAC review , page III





EM radiation analysis

Locations show where the escaped photon is produced

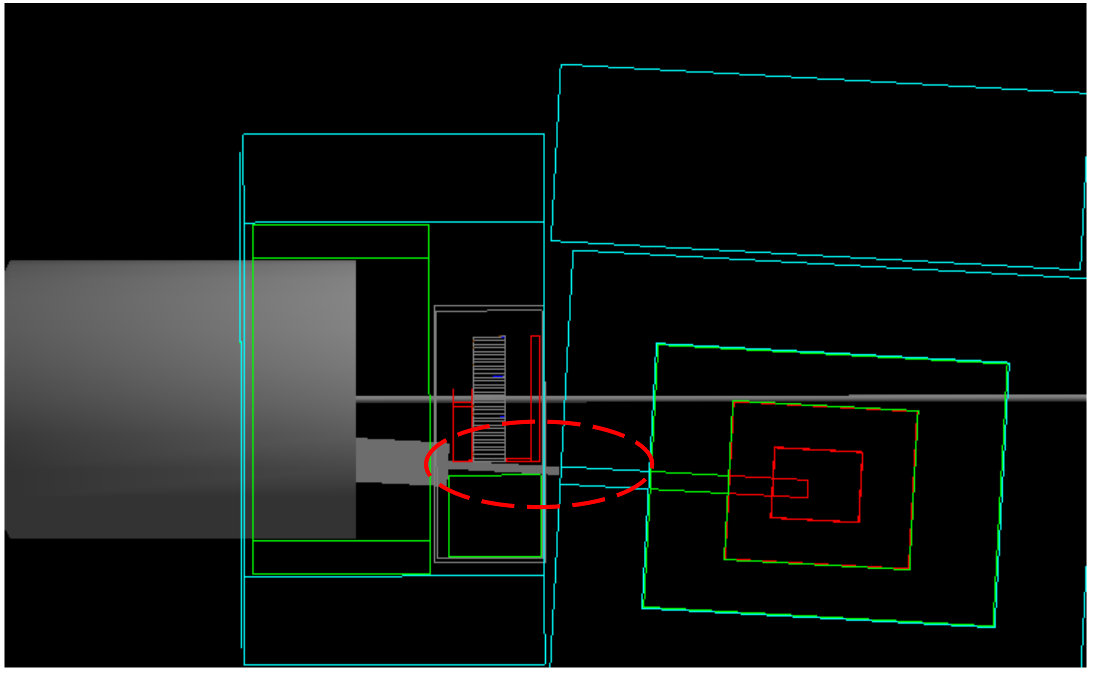
Total dose is below 400 Rad

Replies to TAC review , page IV

For the section Comments

4. The engineering of the beamline must incorporate a vacuum line to the dump not only for the primary beam but also for bremsstrahlung positrons. The presented pipe as an extension to the PRad vacuum vessel should be a flat vacuum chamber to allow a large fraction of bremsstrahlung positrons to reach the dump without interacting with the flange or the vacuum vessel.

Thanks for the recommendation. In fact, since submission of the proposal, we have updated the MC model, which now has a beam line profile similar to the one you suggested, see Figure below in the area of the red dash-line ellipse.



Replies to TAC review , page V

For the section <u>Comments</u> from others …

1. In Eqn 1, the differential cross section for dark photon production should be proportional to α^2 rather than α^1.

Thanks for the note. Eqn 1, as shown in the text, has **a typo** because it uses the ε instead of f_{eA} a coupling between a U/A' boson and an electron. The ε is normalized to the EM coupling, so α should be power 2. In the MC of the experiment we used the Geant4 cross section for $e^+e^- \rightarrow \gamma+\gamma$ process and a factor $2x\varepsilon^2$ for the rate of $A'+\gamma$ events, so the results are not affected by the typo.

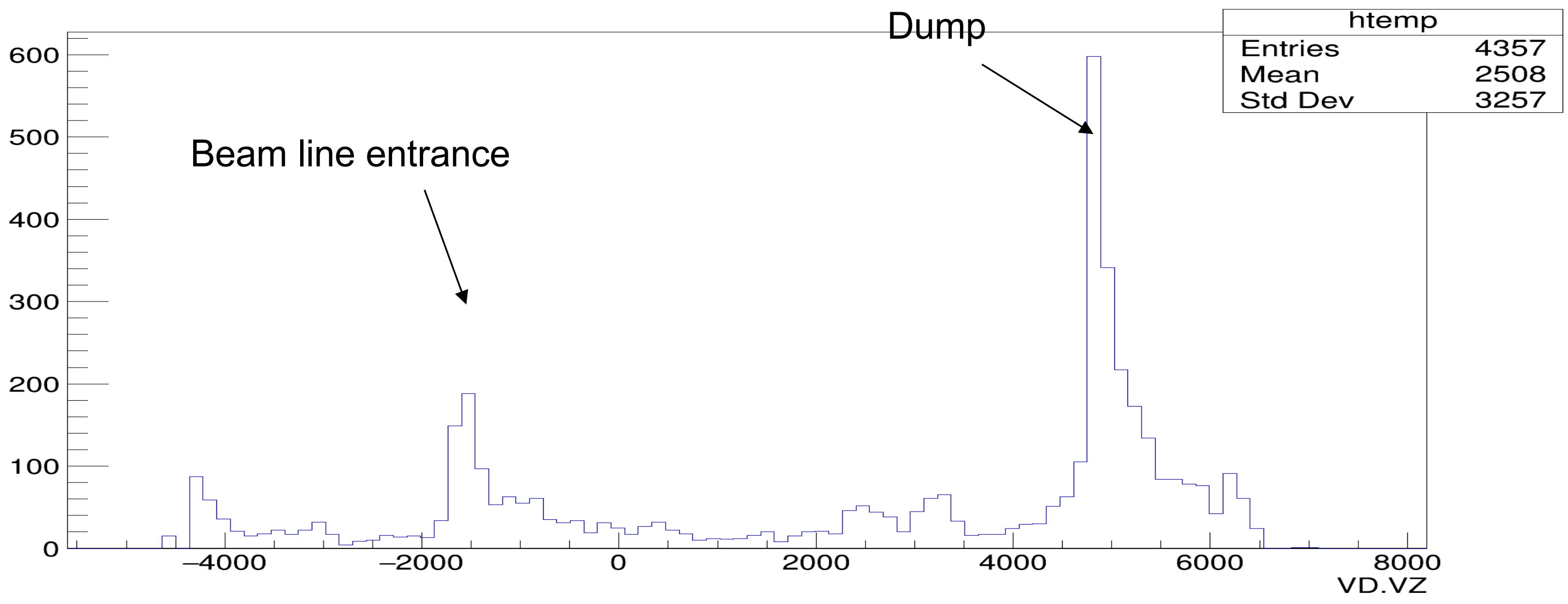
Replies to TAC review , page VI

For the section Comments from others …

2. ·

calorimeter. The collaboration should clarify whether the background from these off-energy e+ (which is likely time-consuming to simulate) has been included in the GEANT4 simulations in Table I.

We developed a full Geant4-based MC with the beam line and added the shielding.
The resulting distribution of the neutron sources is shown below. Yes, this result is Included the "off- energy" positrons interacting with the beam line (see below for vz < 4000).
The contribution from the beam dump is dominant.



Replies to TAC review , page VII

For the section <u>Comments</u> from others …

3. Downstream of the HyCal system a **new compact beam dump** is planned. Given the space constraints and loading requirements on the Target Level of the Space Frame in Hall B, a detailed model with the Hall B engineers needs to be developed. The dump should be carefully developed with the appropriate experts to be sure that it is properly designed for the most extreme running conditions and should include tight shielding not only for neutrons but also for the EM background. Collaboration with the JLab Radiation Control Group will be required. Shielding of local electronics from the high doses expected from neutron radiation should be considered. The cited work on the tagger yoke beam dump is not a good comparison as conditions are very different.

The Hall B engineers are already involved in development of the conceptual design, see the CAD model in Fig. 18 in the proposal.
RadCon collaborators have already made several key contributions to the radiation analysis as shown e.g. in Figs. 35-36 in the proposal.

Replies to TAC review, , page VIII

For the section <u>Comments</u> from others …

4. Vertical or horizontal (inconsistent in Figs 11, 18 and 27) ray of positrons, away from the beamline at the calorimeter, will interact with the vacuum chamber window and frame, and with detector supports (this can and should be mitigated with a new support and calorimeter arrangement). There is no discussion of the impact of this BG on the detector operations. (Note: In CLAS-6GeV, we had to pile up a lot of shielding at the exit of the tagger vacuum chamber and eventually build a bunker to be able to operate CLAS).

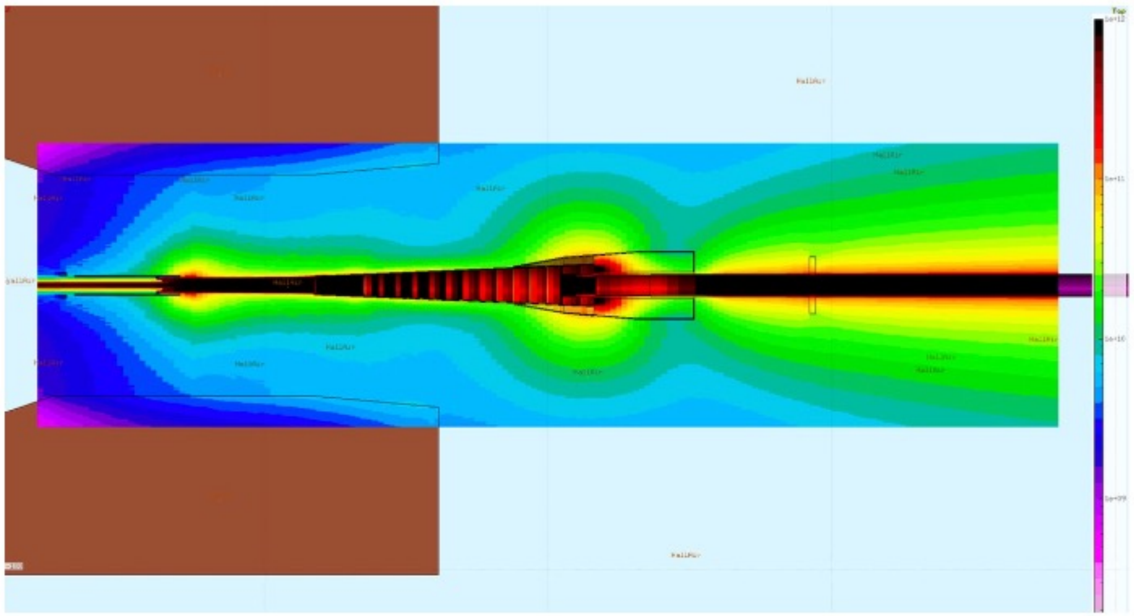
We made a study by using Geant4 and added a tungsten shield on the beam line side of the calorimeter. Sorry for a typo in the caption of Fig. 11: It should be “side view”.
In Fig. 27 the picture of the equipment is rotated for better visibility.

Replies to TAC review, , page IX

For the section Comments from others …

5. The radiation on the CLAS12 detectors, especially CTOF, CND, and the solenoid from the dump, is not considered. High flux of high-energy charged and neutral background will degrade scintillators and possibly damage thermocouples in the solenoid.

The collaboration plans to measure the radiation at such detectors in the CLAS12 experiment and compare the results with FLUKA. See Fig. 35 in the proposal, also shown below. The level of radiation during a typical CLAS12 experiment is much higher inside and downstream of the solenoid. For the A'prime experiment radiation analysis, we used the level of radiation in the upstream exit of the solenoid as a reference. It is much lower than that in the downstream area.



Replies to TAC review, page X

For the section Comments from others …

6. No details on how one will measure the non-uniformity of detector efficiency at the 1E-8 level. With a 3 MHz cluster readout rate, the number of 1150 crystals, it will be about 2E8 clusters per-day. Is this enough?

Thanks for the suggestion. Section VII-A needs clarification of the subject and more details. The detector uniformity discussion is supposed to show what detector parameters are required for **the projected sensitivity of the A' search on the 10^{-8} level of the \epsilon^2.**
The value of non-uniformity of the detector efficiency vs. the A' mass value is an important parameter. The bump search relies on the smoothness of background distribution which is discussed below:

Using data with the sweeper magnet OFF, the calorimeter cluster coordinates will be calibrated using the GEM detector to the level at least 50 micron (systematics), which corresponds to a polar angle of < 10^{-5} radian or 4×10^{-4} relative to the cluster average polar angle 1 degree. After that, the energy calibration of the crystals will be done (using the beam energy value and the scattering angle) with the relative systematic uncertainty of energy calibration of 1.5×10^{-6}. Using results from e^+-p and e^+-e^- elastic processes at **three different positron beam energies** the energy-amplitude response for each crystal will be calibrated to the level of 10^{-6} in the six energy ranges.

Replies to TAC review, , page XI

For the section Comments from others …

To evaluate the impact of the detector imperfections on the probability of a fake bump, let us use the formula for the mass $M_A^2 = S \times (1-\frac{E_{cluster}}{E_{annihilation}}$, which is included in the proposal text on page 9. The event spectrum of E_{cluster} will be made with the events in each small \theta interval (0.02 degree), and the value of E_{annihilation} will be calculated from the annihilation peak position (with a relative accuracy of 10^{-7}). Then, the M_{A}^2 will be calculated using such a local value of E_{annihilation}. The value of E_{annihilation} will also be compared with calculations based on the polar angle value and detector energy calibration. Finally, the event spectrum vs M_{A}^2 with all events will be made.

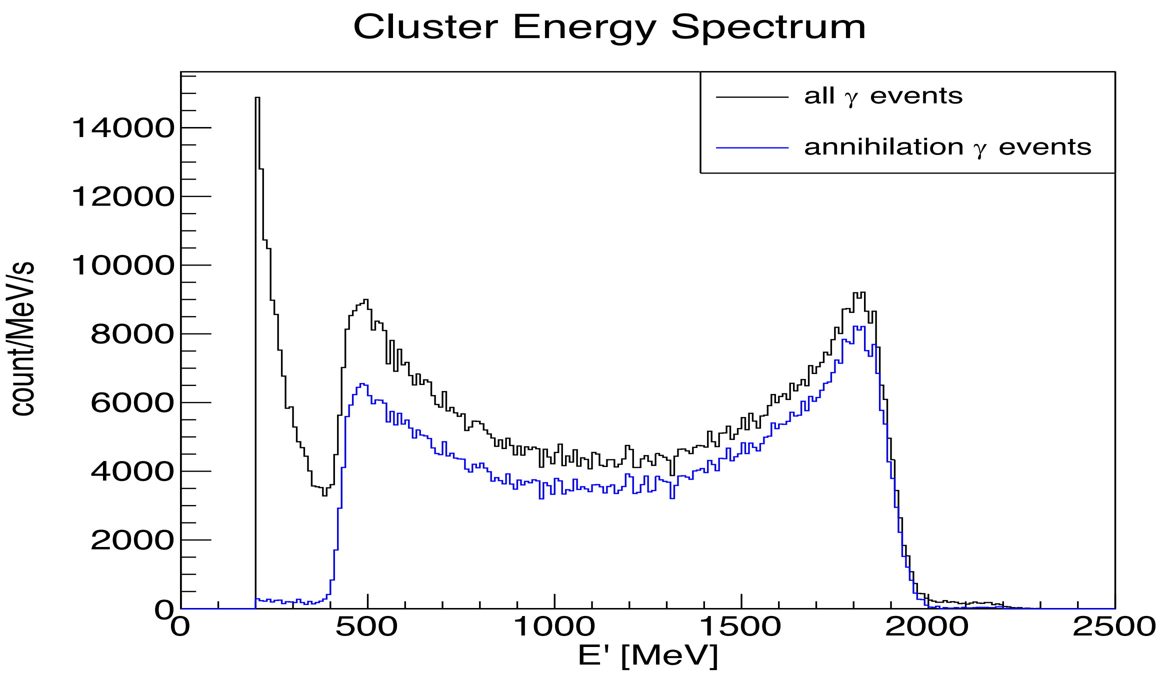
A non-statistical “fake” bump can appear as a result of a problem in a small region of M_A^2: large local variation of linearity with the same sign in “many” crystals. Such a problem can be due to imperfection in the crystal, or PMT, or DAQ electronics. The calibrations discussed above allow us to correct for most such imperfections.

The final check will be done using events from an annihilation peak. The events will be selected by using a peak in M_A^2 distribution as above. Selected events will be plotted vs E_{cluster}. Using MC simulated data we got the following:

Replies to TAC review, , page XII

Non-uniformity in M_A^2 and in E_γ are related, so we can used the E_γ spectrum

$$M_A^2 = 2m_e E_+ \times \left(1 - \frac{E_\gamma(\theta)}{<E_{\gamma\gamma}(\theta)>}\right)$$



- The relative size of statistical fluctuation in the spectrum above for a relevant interval M_A^2 width (200 MeV^2 for M_A=80 MeV) is $1.8\text{x}10^{-6}$, so a fake bump with an amplitude essential for the A' search (with relative amplitude - $2\text{x}10^{-5}$) will be detected in the E_γ spectrum on the level of 10 sigma.