Using the SeaQuest Spectrometer to Search for Dark Photons

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Argonne National Laboratory
(for the SeaQuest Collaboration)

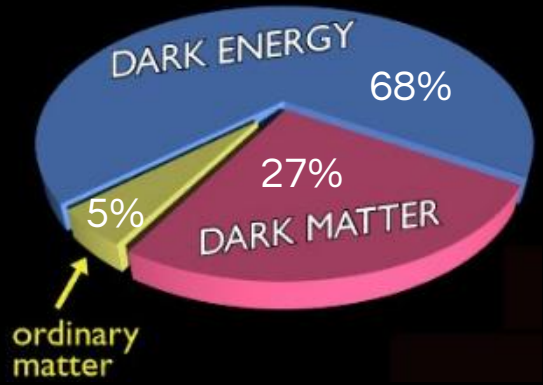
7th Workshop of the APS Topical Group on Hadronic Physics - Feb. 3, 2017

Dark Energy

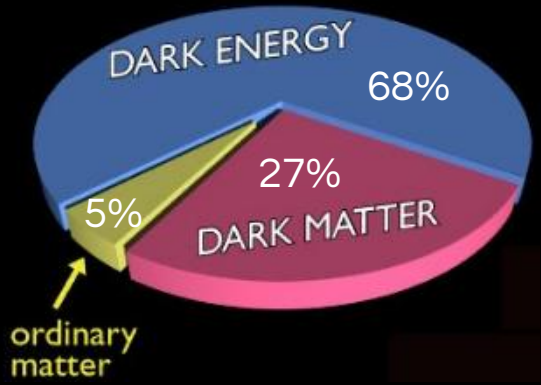
→ expansion of the universe

Dark Matter

→ excess of gravitational effect with respect to the visible matter in the universe


DARK ENERGY
68%
27%
DARK MATTER
5%
ordinary
matter

What if we could see in the dark???



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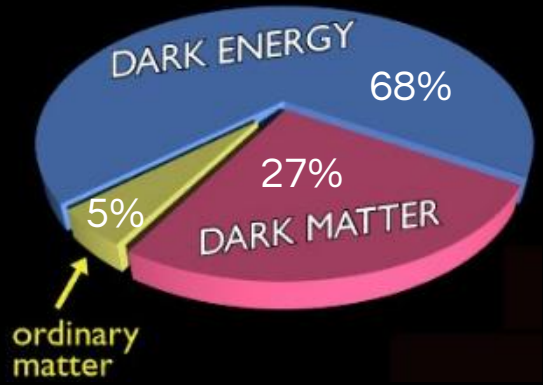

The 5th force: DARK FORCE

Carried by a massive gauge boson → DARK PHOTON

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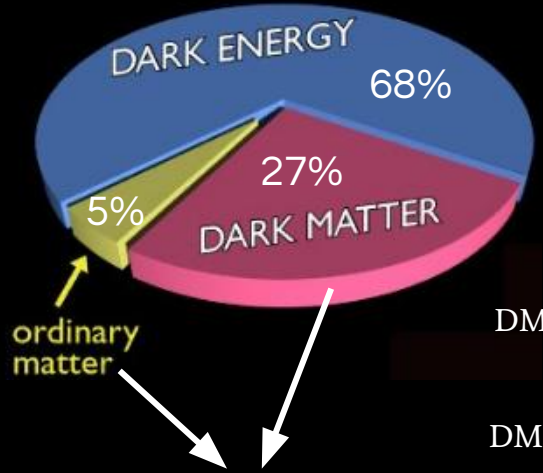
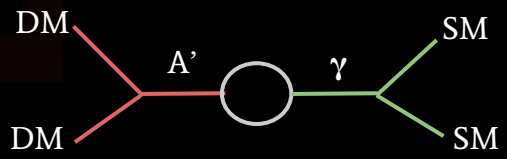




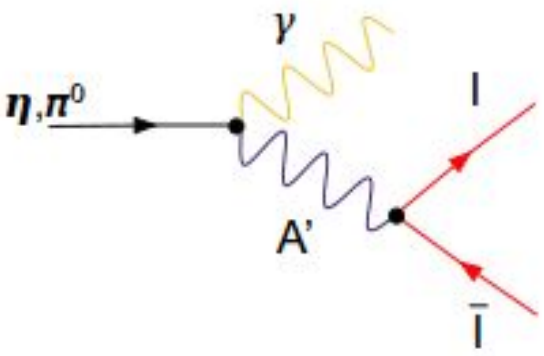
Possible coupling between dark matter and ordinary matter

The 5th force: DARK FORCE

Carried by a massive gauge boson → DARK PHOTON

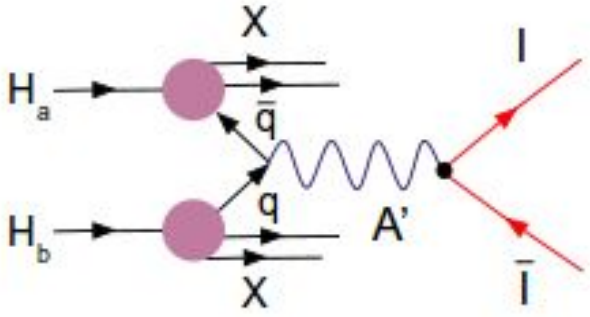
It wouldn't be so dark after all, would shed a light on the dark matter.

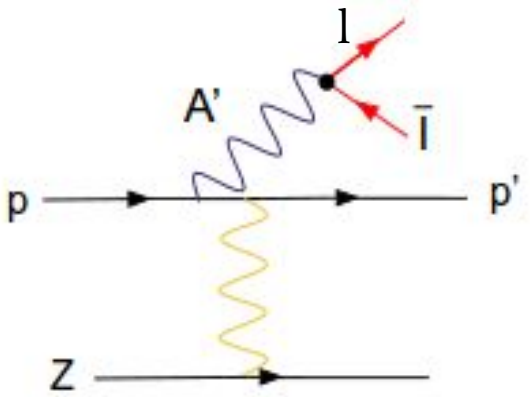
Possible Ways to Detect a Dark Photon



Eta decay

Dark Drell-Yan





Proton Bremsstrahlung

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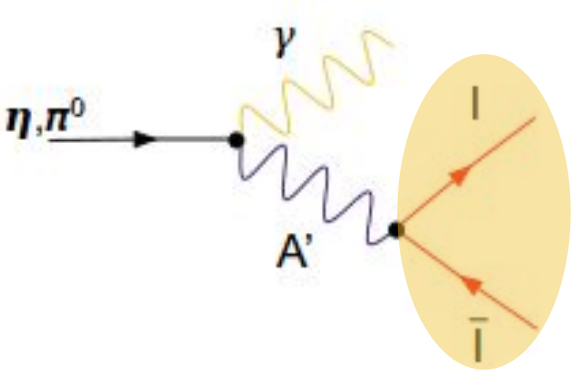

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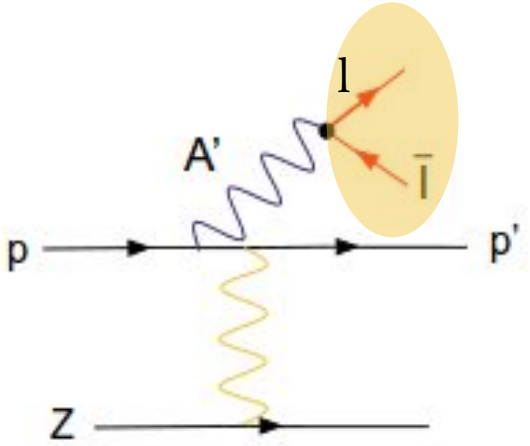

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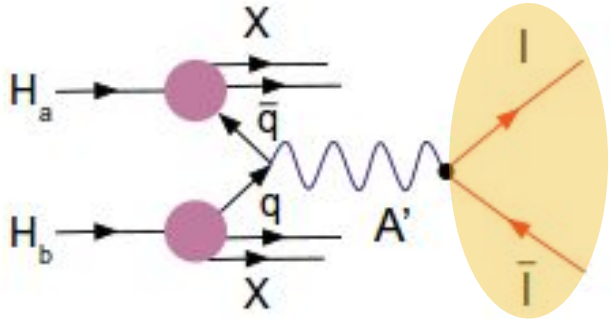
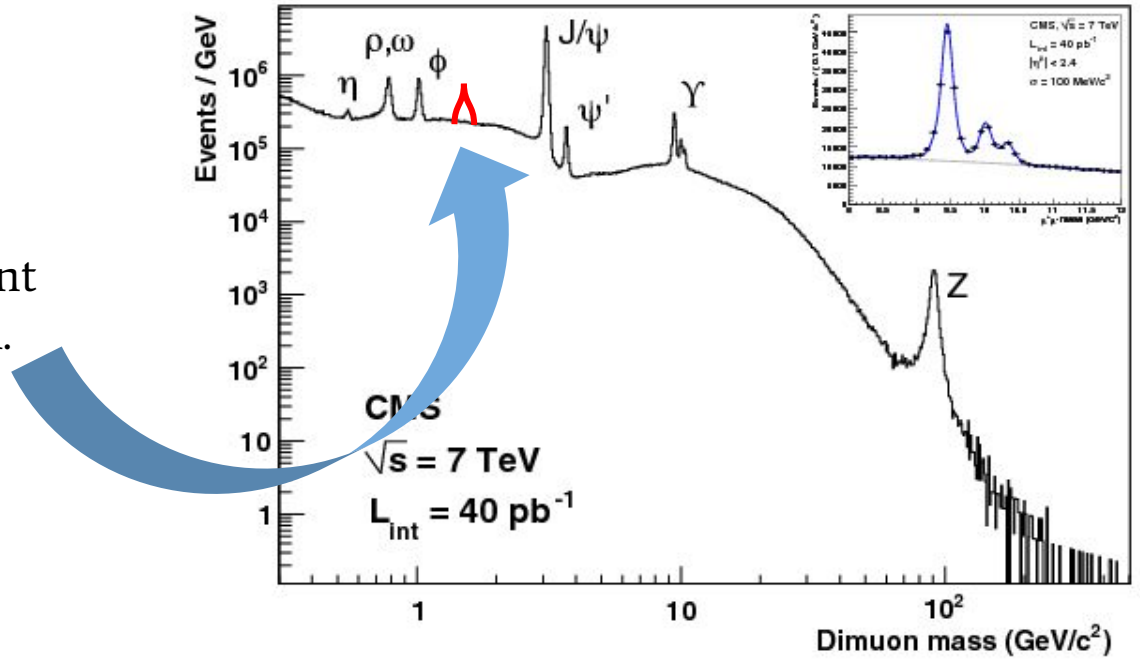


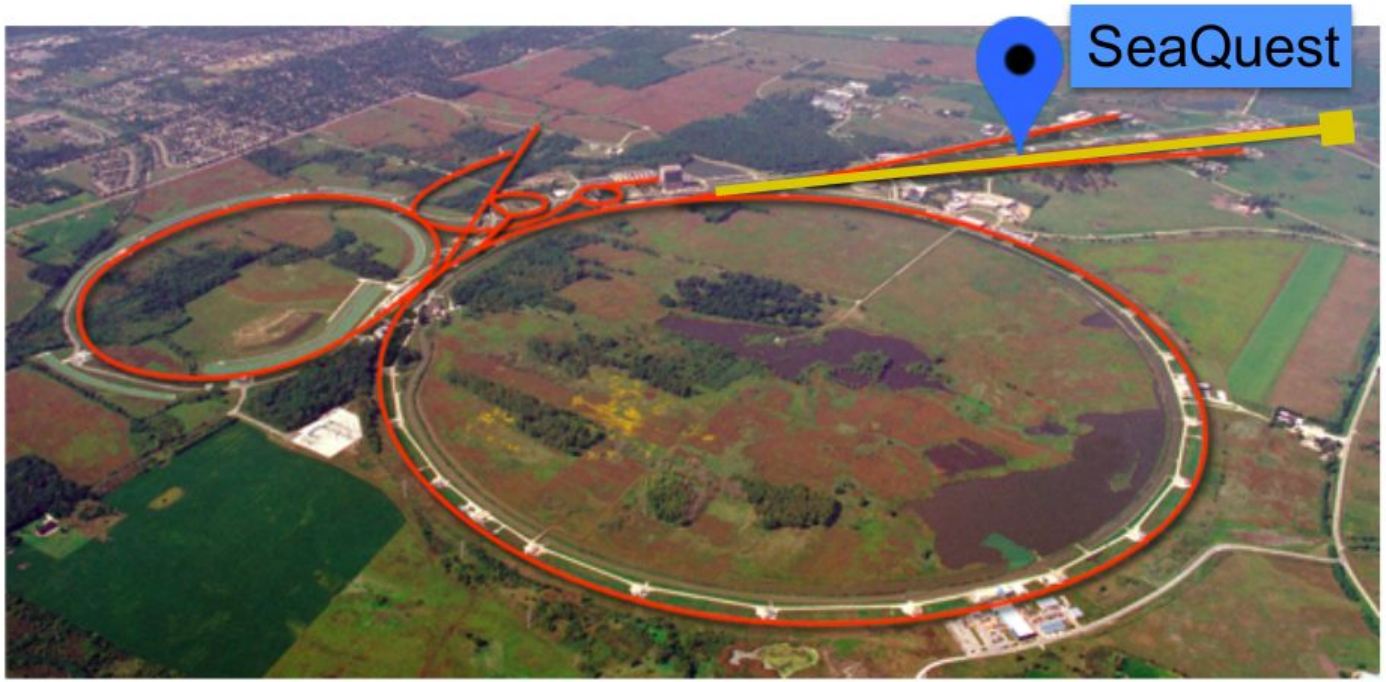
Detection Technique

- Bump hunt in the invariant dimuon mass distribution.



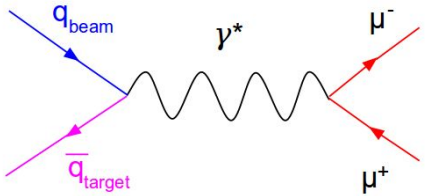
CMS Collaboration (Boer, W.)
arXiv:1309.0721, 2013

Why SeaQuest?



SeaQuest

Drell-Yan interaction

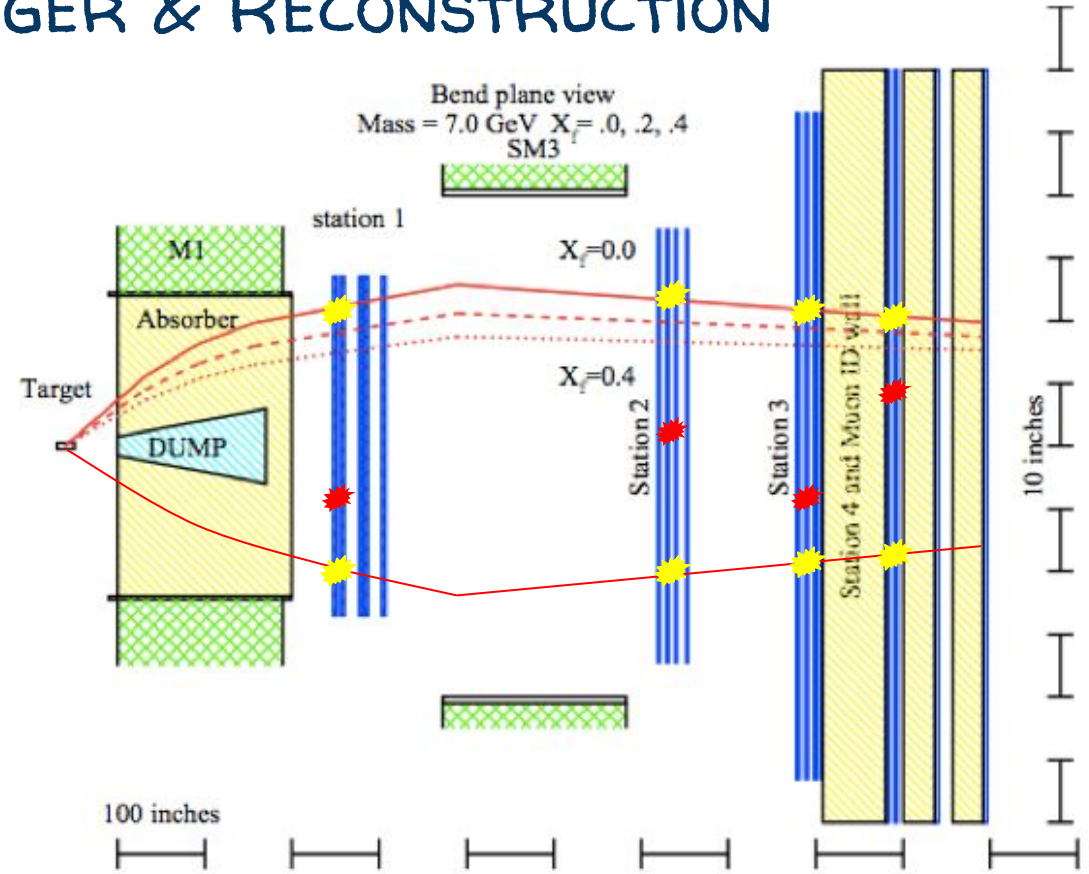


- Primarily studies sea anti-quarks in different nuclei targets through Drell-Yan interactions.
- The SeaQuest spectrometer detects the dimuons.

Event Trigger & Reconstruction

Trigger of possible dimuons coming from interactions in the dump and target.

- Able to reconstruct dimuon's:
  - Momentum / energy
  - Mass
  - Vertex position



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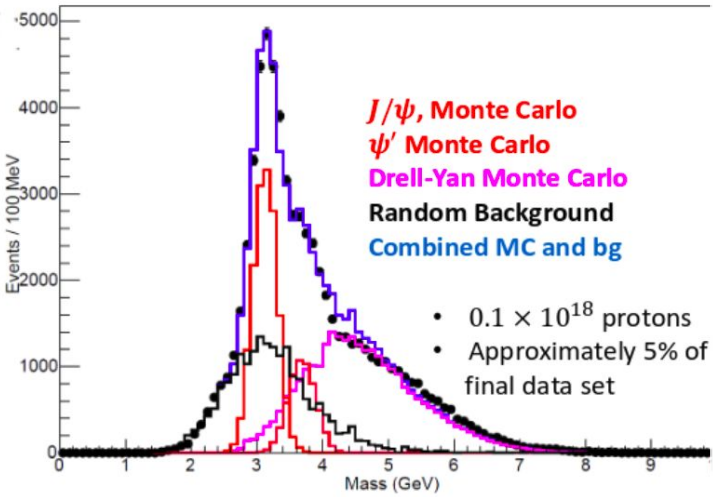
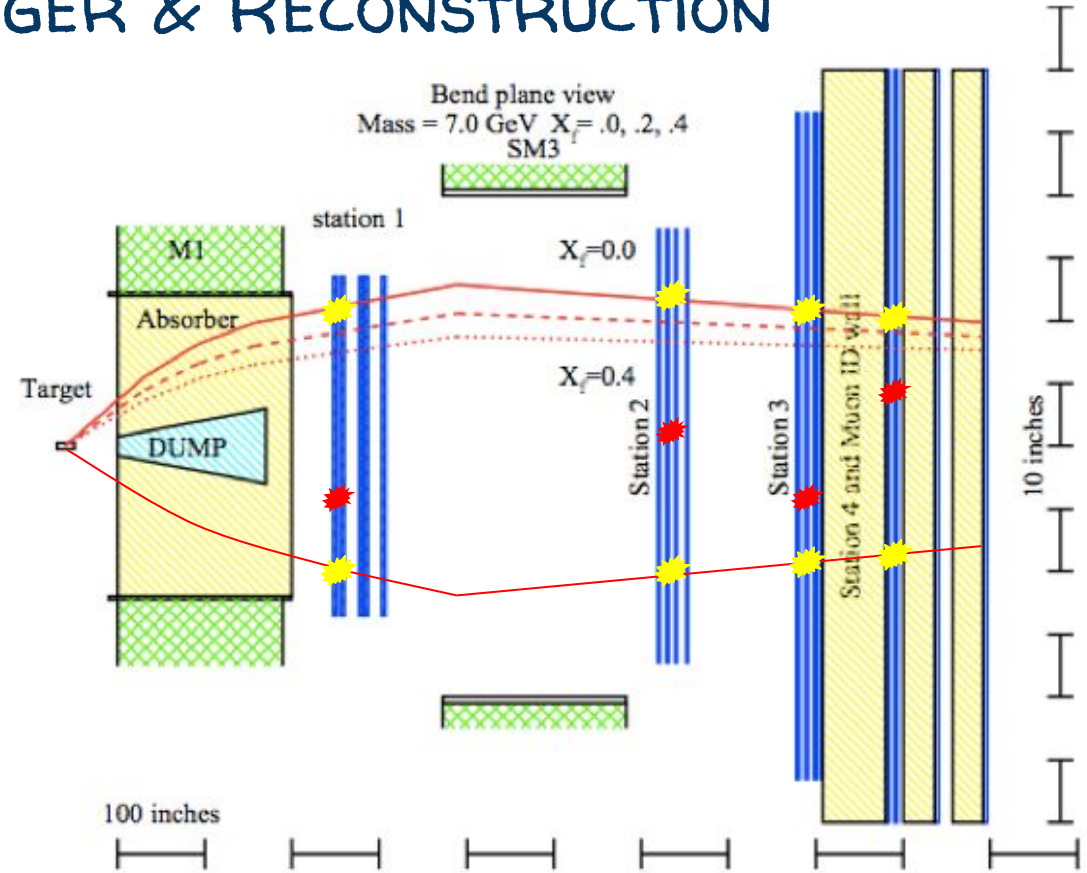
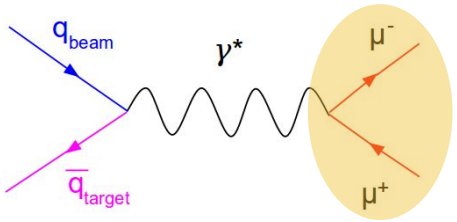


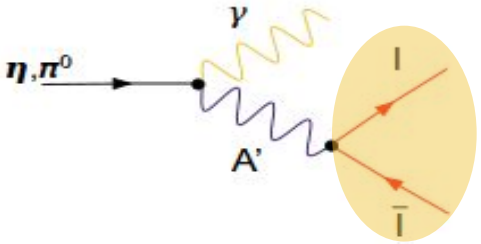


Drell-Yan vs. Dark Photon in SeaQuest

Drell-Yan interaction



Dark photon from eta decay



Drell-Yan vs. Dark Photon in SeaQuest

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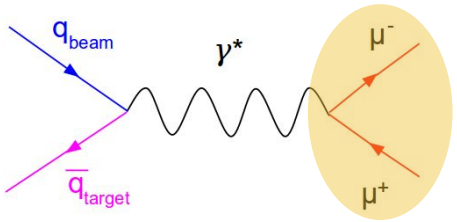

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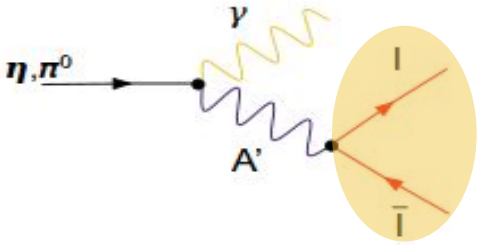
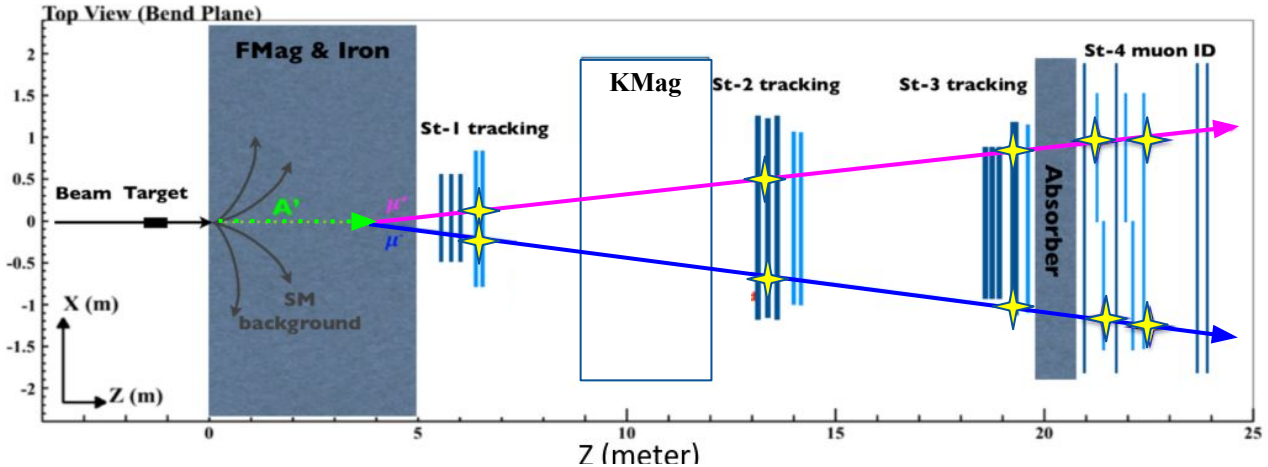
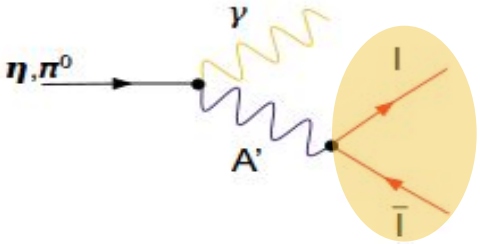


- Vertex: target
- Vertex: downstream the beam dump (FMAG)

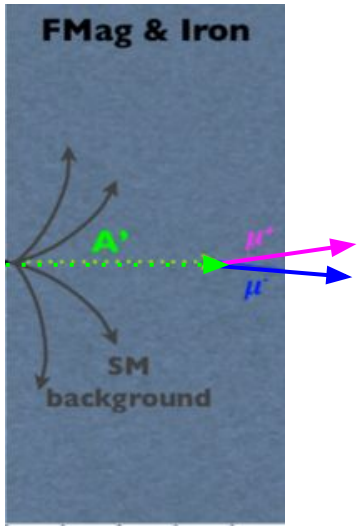


Dark Photon in SeaQuest

$$l_0 = \frac{0.8\text{cm}}{N_{eff}} \left(\frac{E_0}{10\text{GeV}}\right) \left(\frac{10^{-4}}{\varepsilon}\right)^2 \left(\frac{10\text{MeV}}{m_{A'}}\right)^2$$



- l_0 = distance traveled
- N_{eff} = number of decay products
- E_0 = dark photon energy
- $m_{A'}$ = dark photon mass
- ε = coupling between standard model and dark sector



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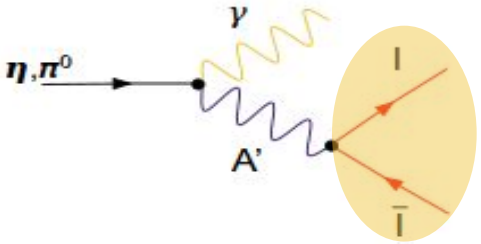

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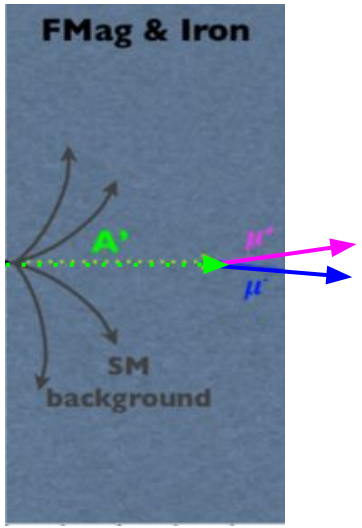
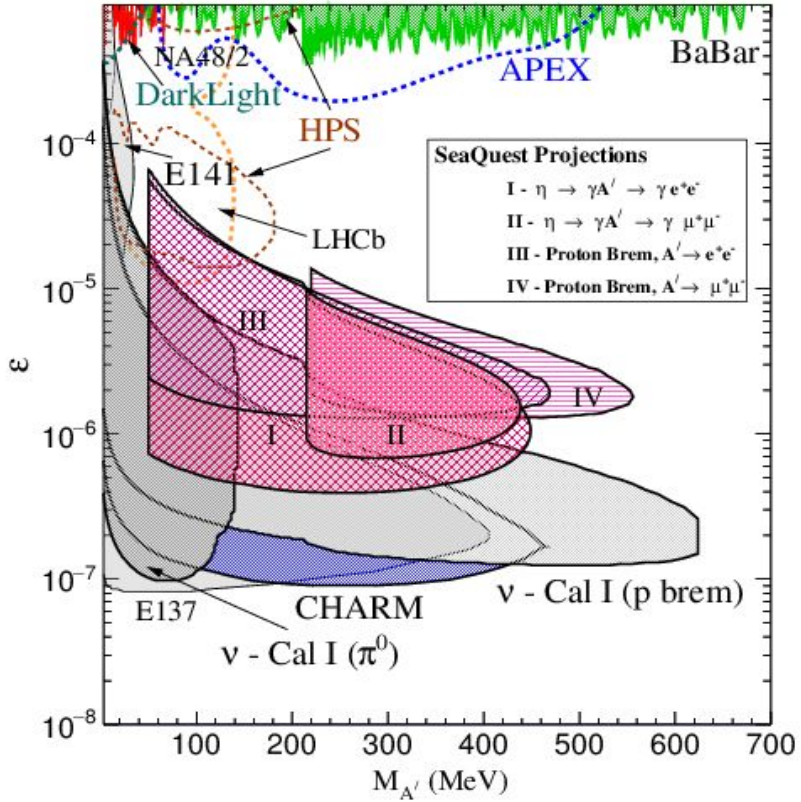


Characterize the dark photon

Projected Sensitivity in SeaQuest

$$l_0 = \frac{0.8\text{cm}}{N_{eff}} \left(\frac{E_0}{10\text{GeV}}\right) \left(\frac{10^{-4}}{\varepsilon}\right)^2 \left(\frac{10\text{MeV}}{m_{A'}}\right)^2$$

- Can probe ε with values as low as 10^{-7}.
- Able to probe wide mass range, from 0.2 to ~6 GeV.



S. Gardner, R. J. Holt, A. S. Tadepalli
Phys. Rev. D 93, 115015, 2016

The Challenges in SeaQuest

- Create a simulation that includes all the possible dark photon channels.
- Optimize the trigger for dark photons (next experiment: E1067).
- Optimize the reconstruction to find displaced events.
- Separate candidate events from the possible background.
- Analyze and take into account all the systematic errors.

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- Optimize the trigger for dark photons (next experiment: E1067).
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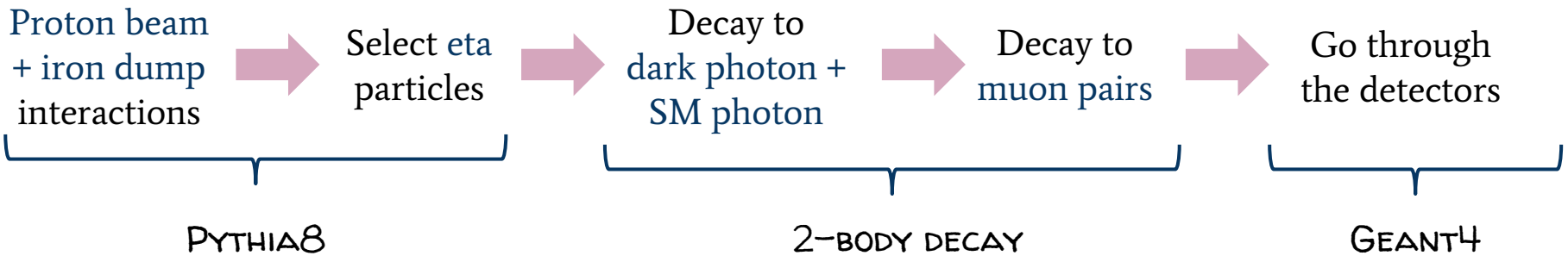
- Separate candidate events from the possible background.
- Analyze and take into account all the systematic errors.
- **Convince the scientific community that we found dark photons.**

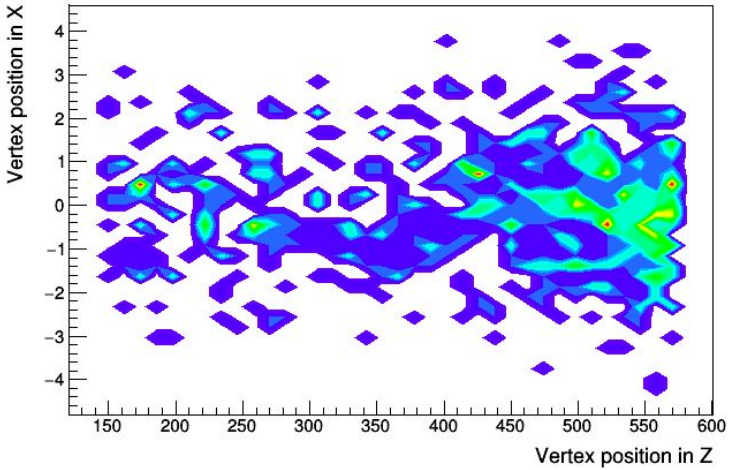
Preliminary Simulation



Preliminary Simulation

Proton beam + iron dump interactions → Select eta particles → Decay to dark photon + SM photon → Decay to muon pairs → Go through the detectors

Pythia8 | 2-body decay | Geant4



800,000 first interactions

↓

523 dimuons from dark photon decay in the fiducial region

Tracking Optimization in SeaQuest

- Optimization of the track finding for events downstream.
- Optimization of the track fitting using Kalman filter for events downstream with mass in the sensitivity range for dark photons.

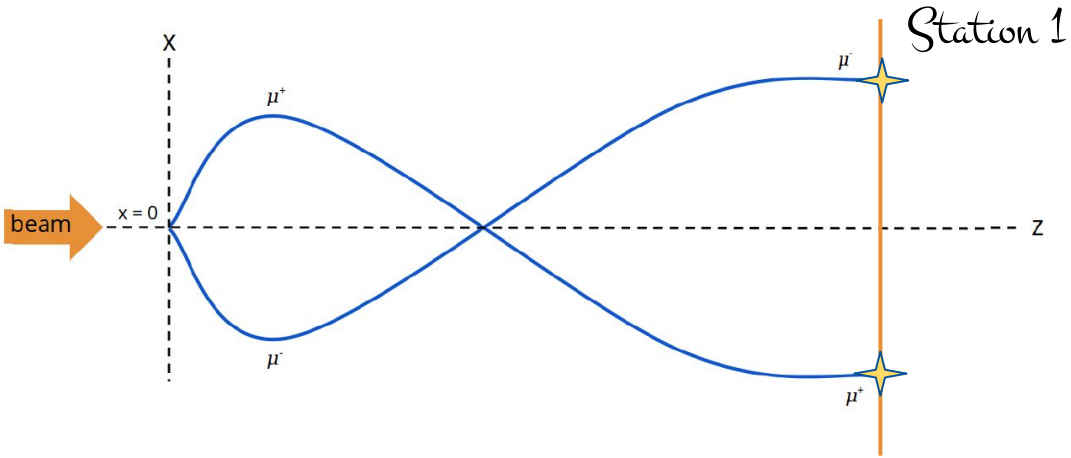
Tracking Optimization in SeaQuest

- **Optimization of the track finding for events downstream.**
- Optimization of the track fitting using Kalman filter for events downstream with mass in the sensitivity range for dark photons.

CHALLENGE:

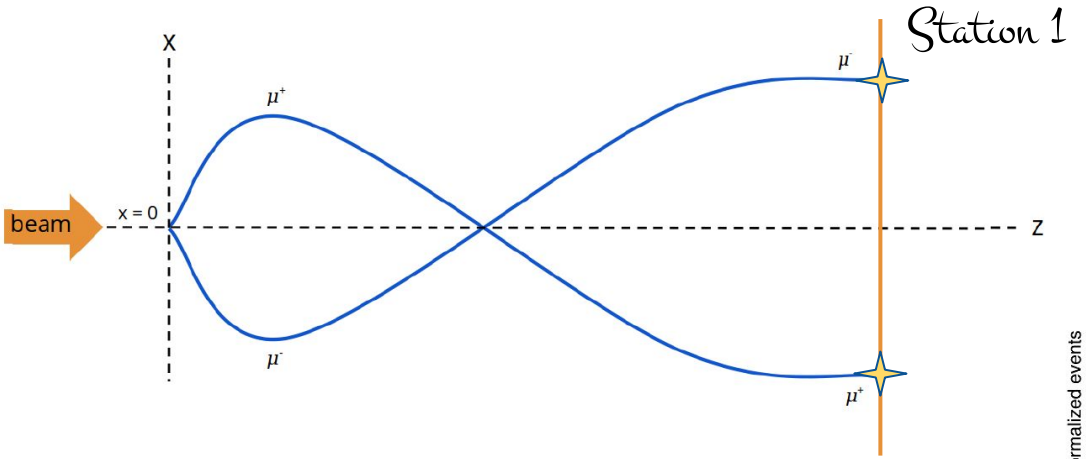
"fish" Drell-Yan events ⟺ events downstream

Reconstruction of "fish" Drell-Yan events



- Ignores vertex downstream and attempts to find the event vertex as close to the target as possible.

Reconstruction of "fish" Drell-Yan events



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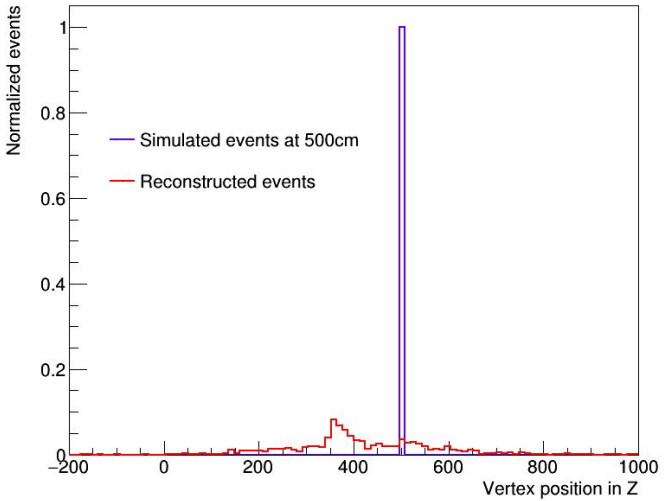
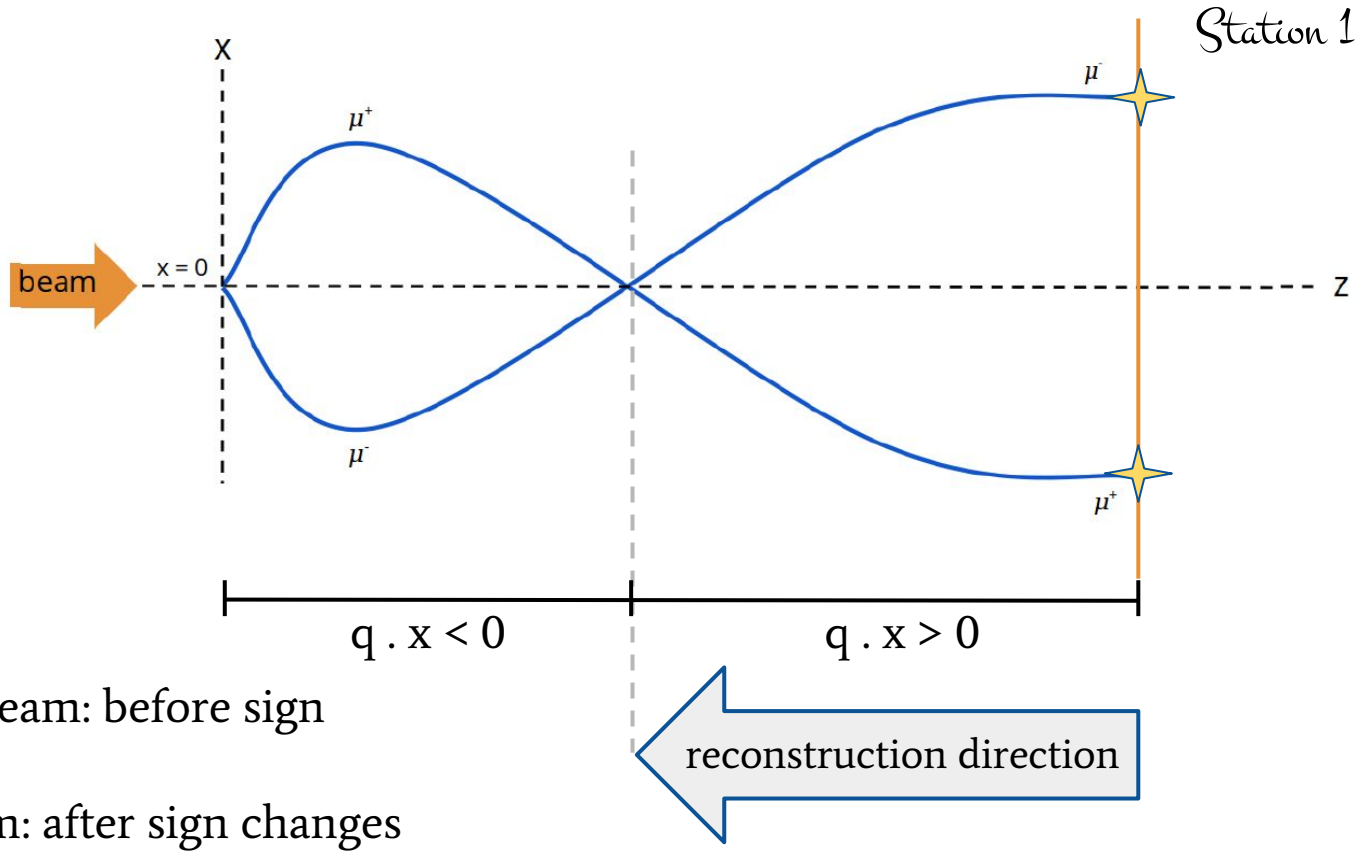


- Fails to correctly reconstruct the vertex for events downstream in the dump → dark photons events will come from this region.

Optimizing the Tracking in SeaQuest

Solution:



- Vertex downstream: before sign changes
- Vertex upstream: after sign changes

Optimizing the Tracking in SeaQuest

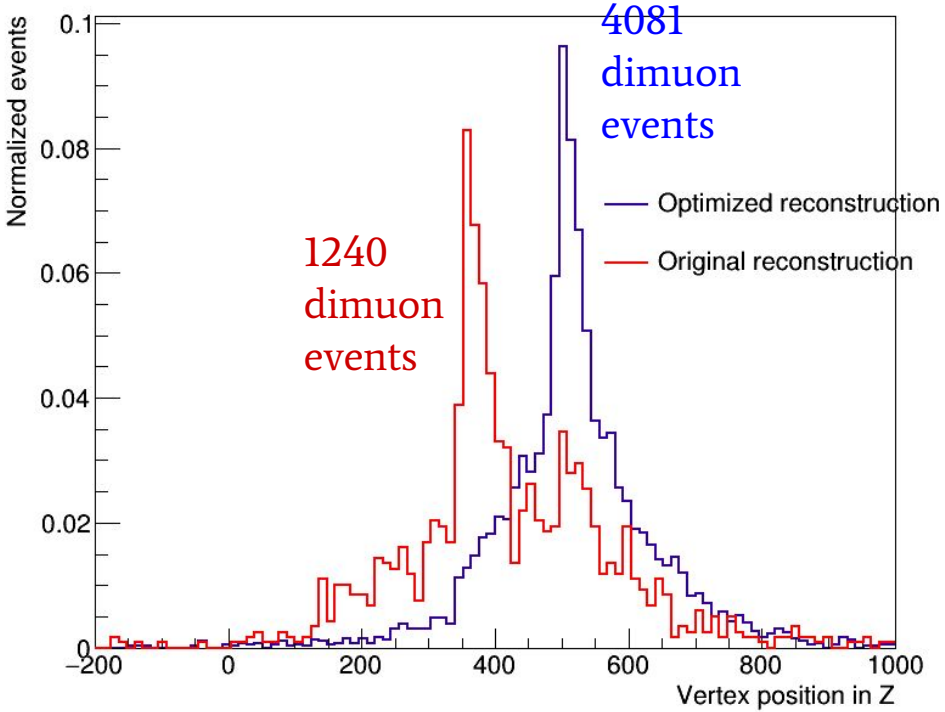
- Vertex finding optimization.

+

- Optimized cuts for dark photon events: sagitta ratio used in the track finding.

Optimizing the Tracking in SeaQuest

- Simulation for events at z = 500cm.



- Vertex distribution centered at the simulated vertex.
- Finds > 3 times the number of events.

This was just a teaser! Coming Soon...

- Optimization of the vertex fitting.
- Full simulation of dark photon production through eta decay and proton bremstrahlung.
- Study of the background and systematic errors.


EPISODE VII
➔ Analysis of real data.
DARK
THE FORCE AWAKENS
PHOTONS

THE PLAN:

1. Finish optimizing the tracking reconstruction.

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THE PLAN:

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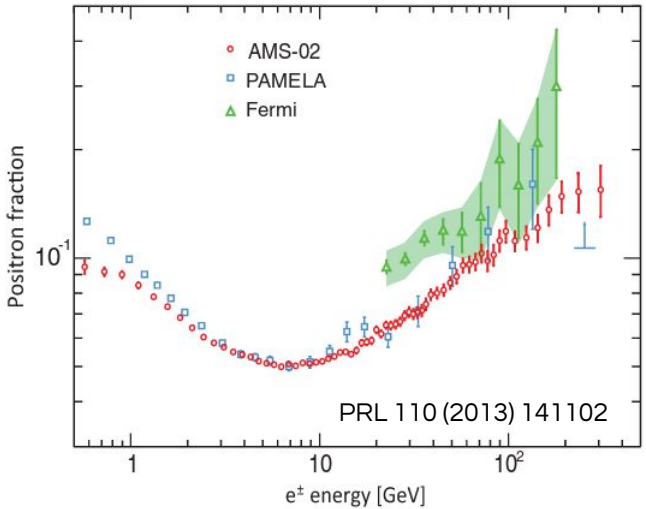
3. If we see a peak in the mass, publish. **Collect Nobel Prize.**
4. If not, use simulation to set limits on the mass and coupling. Publish.


DARK
THE FORCE AWAKENS
PHOTONS
THANK YOU!

BACK UP

Indirect Evidences of Dark Matter

- Unexpected excess of positrons from satellite data.



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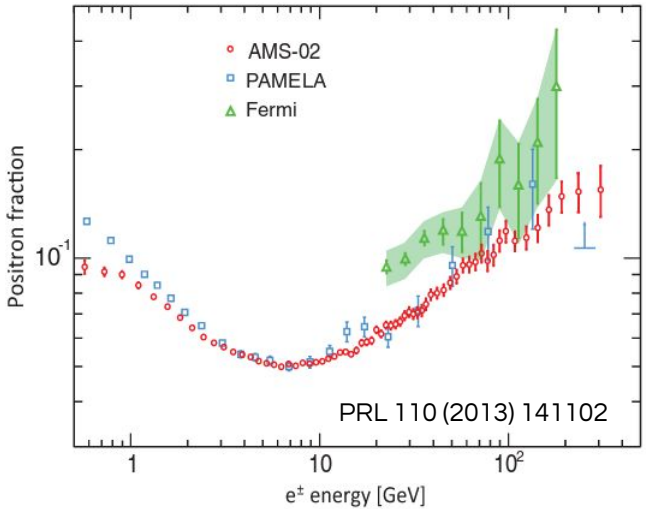
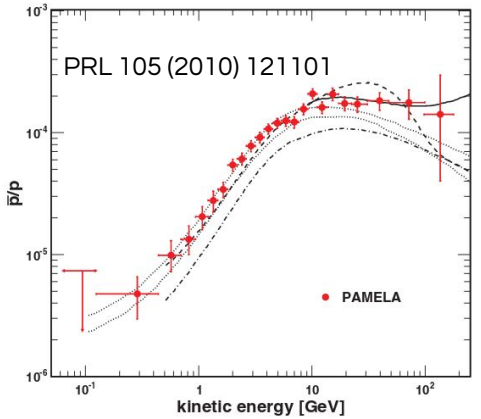


- No anti-proton excess, meaning that the source of positrons should be:
  - Below 1 GeV, or
  - Interact mainly with leptons



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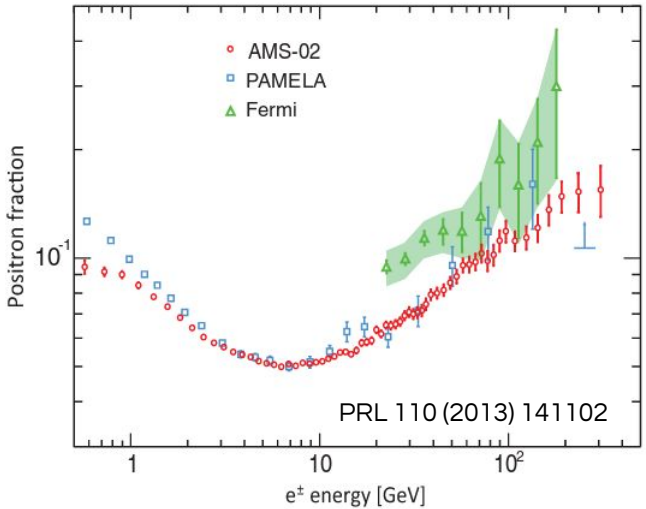

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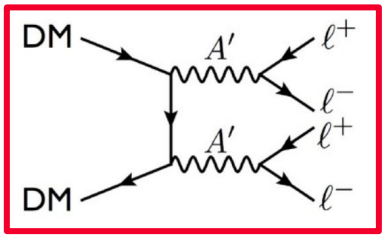
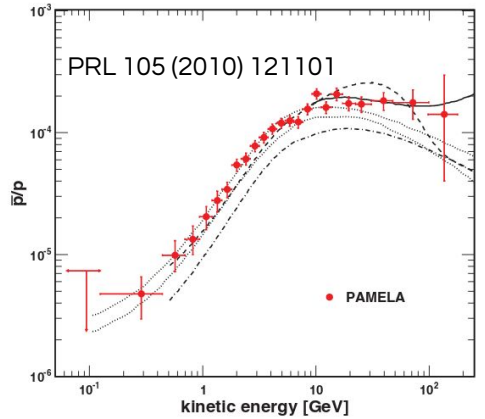
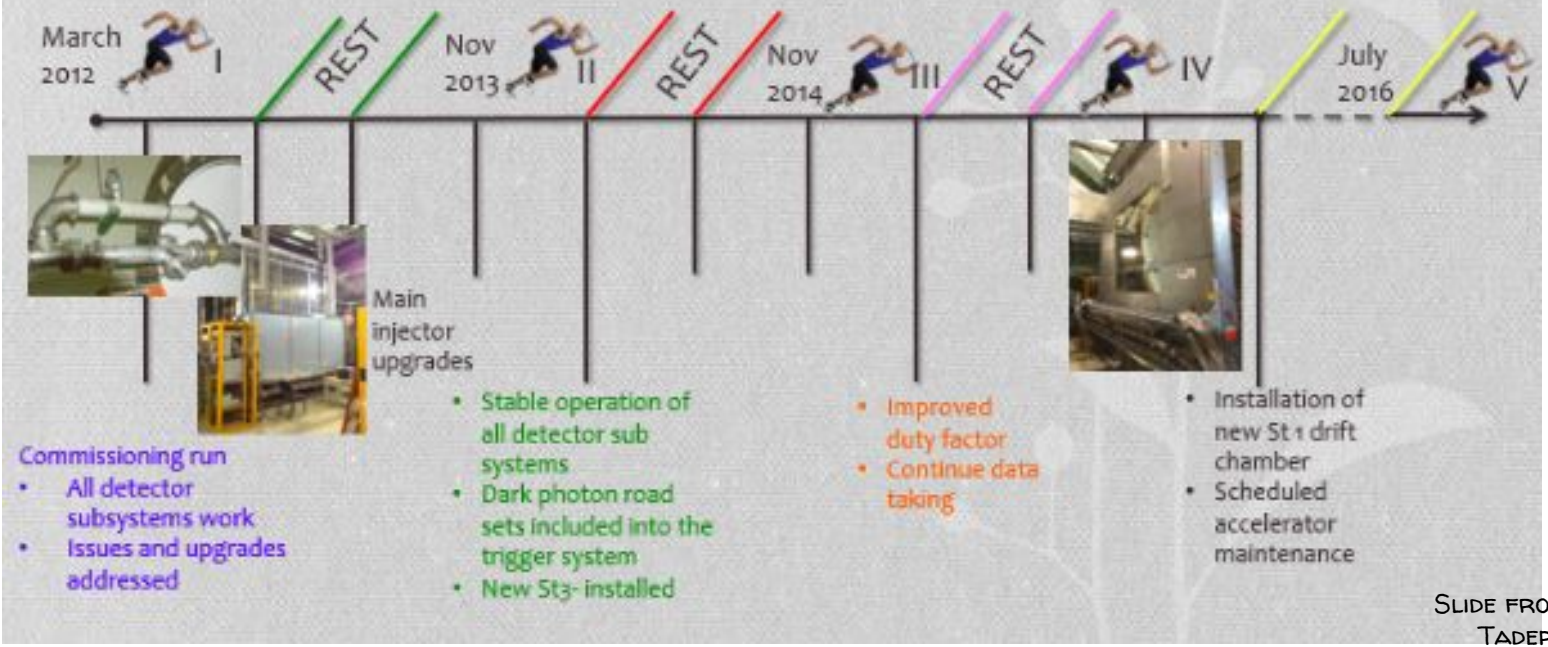




- Gamma-ray excess from galactic center.

Timeline of SeaQuest



Slide from Arun Tadepalli

Dark Photon Decay Modes