Search for Dark Sector Particles in the SpinQuest experiment

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For the E1039/SpinQuest Collaboration and dark sector working group

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Overview

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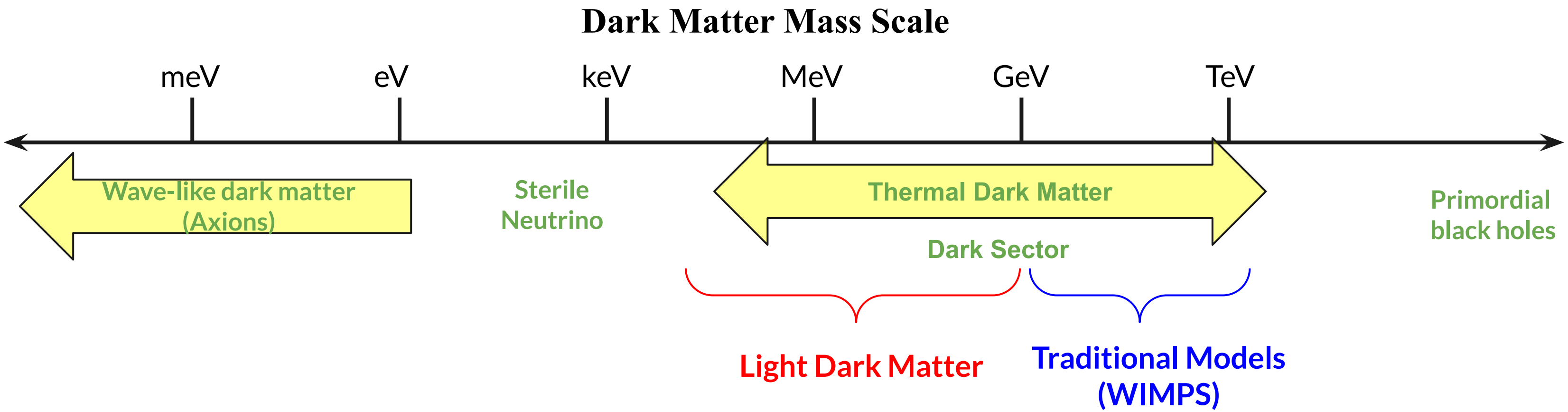
- New Fiber Hodoscope Trigger
  - General FPGA trigger system
  - New displaced trigger algorithm
  - Background reduction
- Future Upgrade: DarkQuest
- Summary

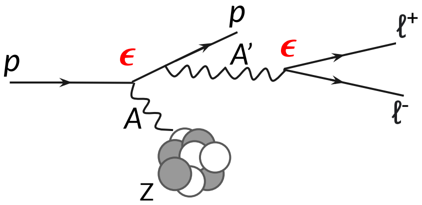
Physics Motivation



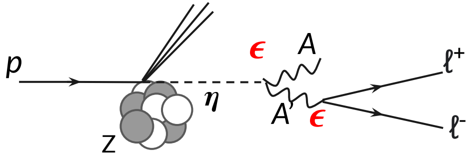
- Dark Sectors provide the DM candidates, and can also address many other open problems in particle physics.
- High-intensity accelerators and fixed-target experiments provide an ideal environment to probe dark sector physics in MeV-GeV range.

Signal Processes: Dark Photon Example

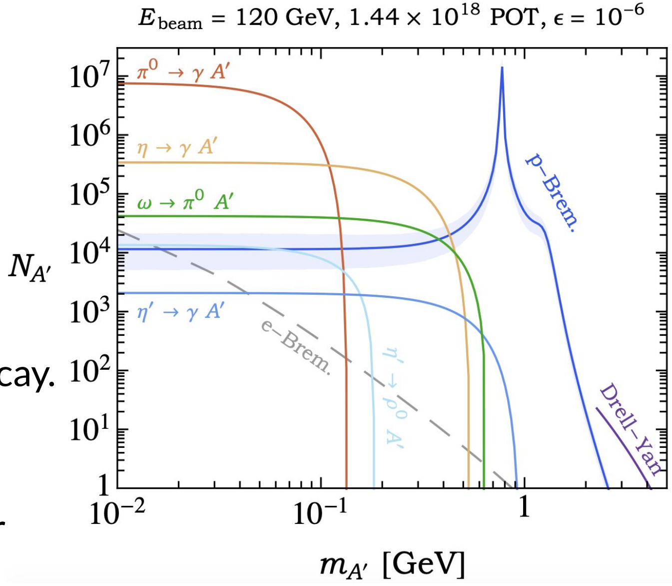
bremsstrahlung



meson decay

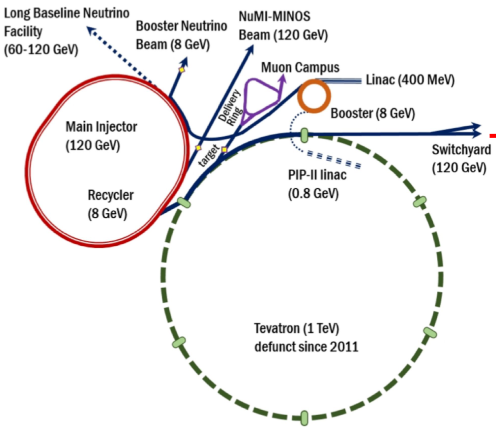


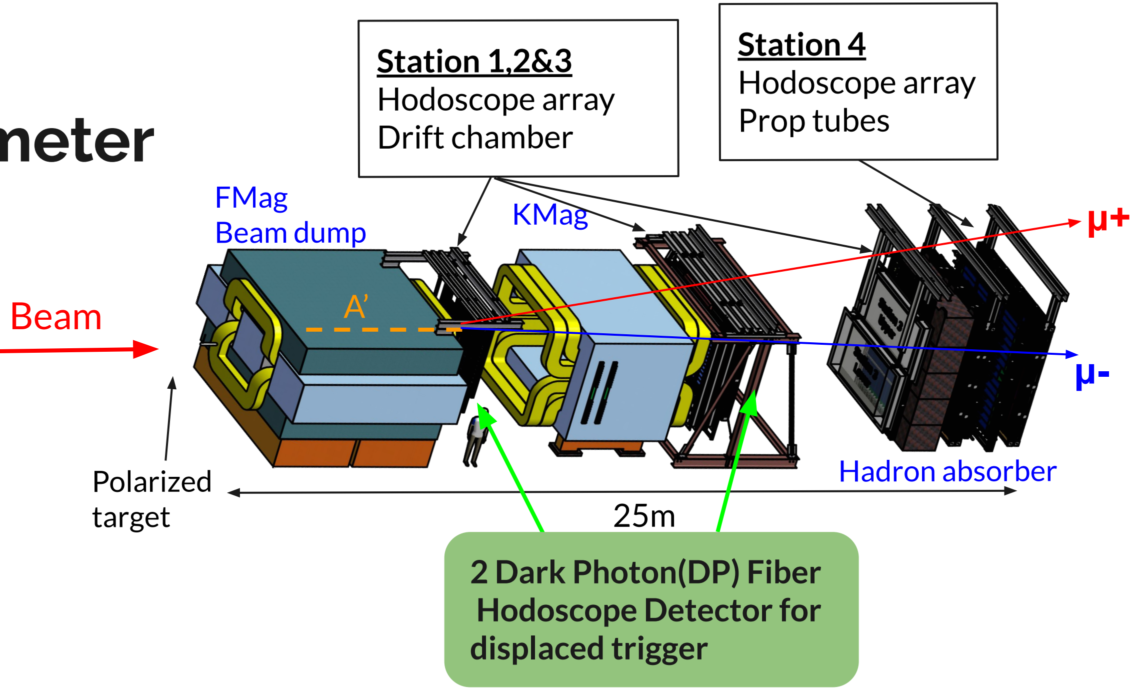
- Two domaint dark photon production mechanisms from proton beam interacting with fixed-target:bremsstrahlung & meson decay.
- Dimuon decay products can be triggered and reconstructed by SpinQuest spectrometer.
- Displacement in z-vertex position provides unique signature for identifying the long lived dark photons.



Number of dark photons produced at phase 1 of seaquest experiment(A.Berlin)

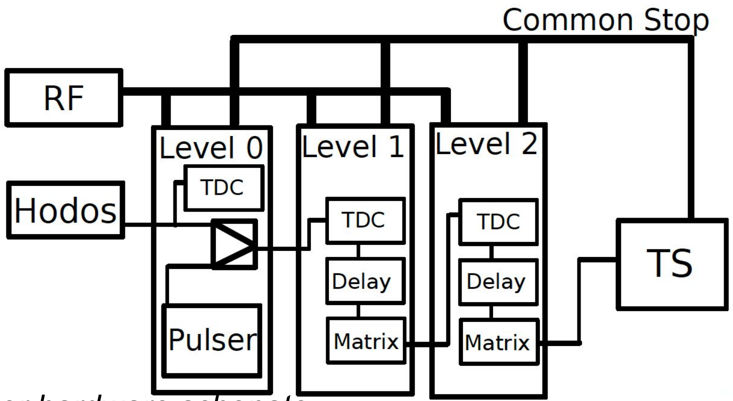
SpinQuest Spectrometer





- 120 GeV high-intensity proton beam from the Fermilab Accelerator Complex. We expect integrated luminosity of ~10^18 POT in 2 year SpinQuest running.

Current FPGA Trigger System



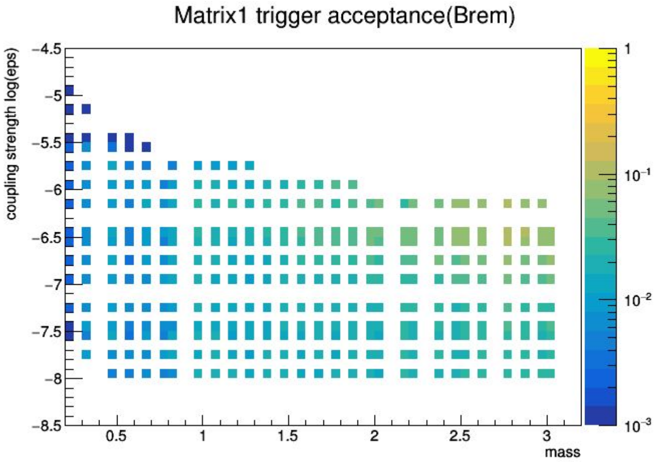
Trigger hardware schenatc (R. E. McClellan)

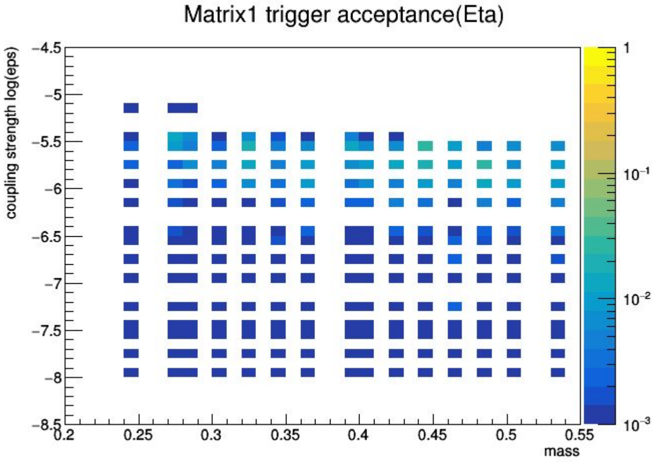
- Three Levels of CAEN V1495 VME modual FPGA Trigger
- Level 1 identify the single muon tracks by specific "trigger road" defined as 4 coincidence hodoscope hits from 4 station respectively
- Level 2 combine the information to trigger dimuon events.
- Trigger rate upper limit:~5kHz.

Name	Side	Charge	p_x Req.	Notes
Matrix 1	TB/BT	$+-/-+$	None	Main physics trigger
Matrix 2	TT/BB	$+-/-+$	None	Same-Side trigger
Matrix 3	TB/BT	$++/--$	None	Like-Charge trigger
Matrix 4	T/B	$+/-$	None	All singles trigger
Matrix 5	T/B	$+/-$	p_x >3 GeV/c	High-p_T singles trigger

The five outputs of the Level 2 trigger module. "Matrix1" is the main production trigger. (arXiv:1706.09990v2)

Current FPGA Trigger Efficiency on A' signals



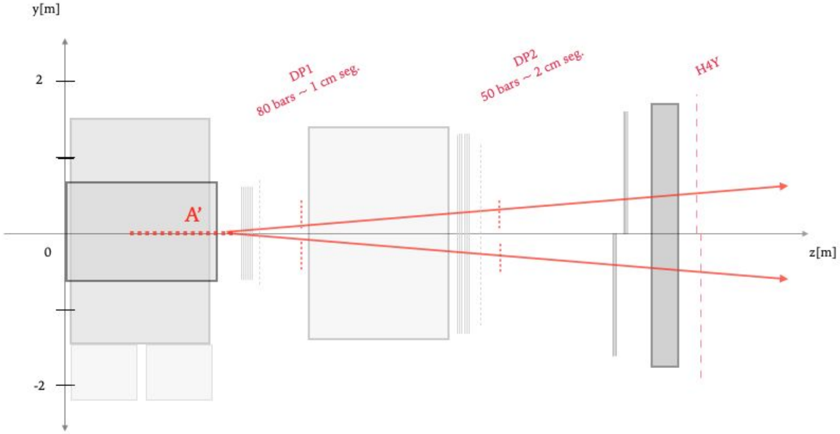


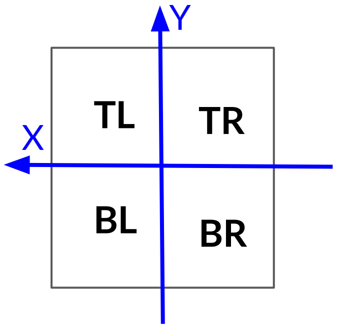
Low trigger efficiency, especially in the low mass region.

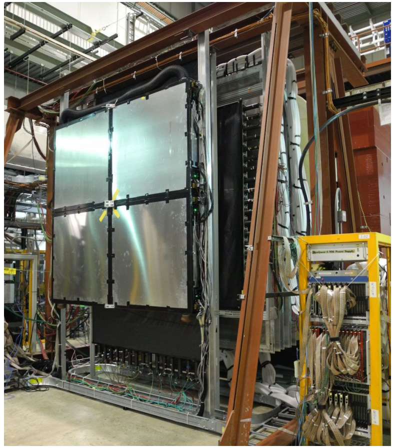
Trigger road_103 is used here

- Reconstruct the simulated displaced A' -> dimuon events based on different masses, coupling constants, and mechanisms (Bremsstrahlung or eta decay).
- Calculate the trigger efficiency defined by:
  eff = events # pass the fpga trigger/total events between 5-6m

New dispalced trigger algorithm

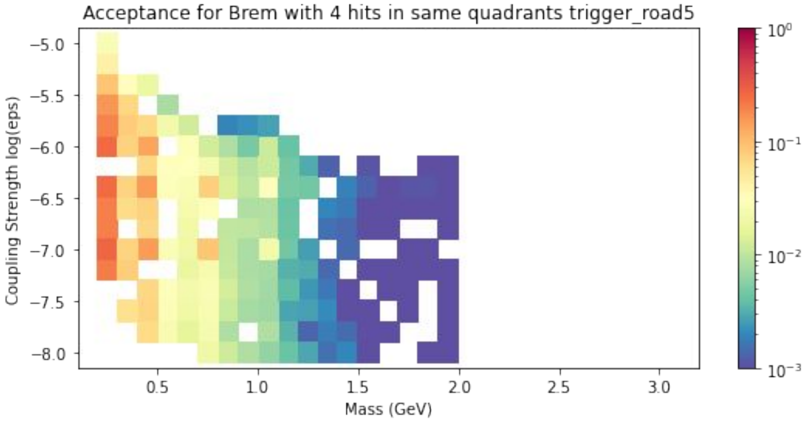


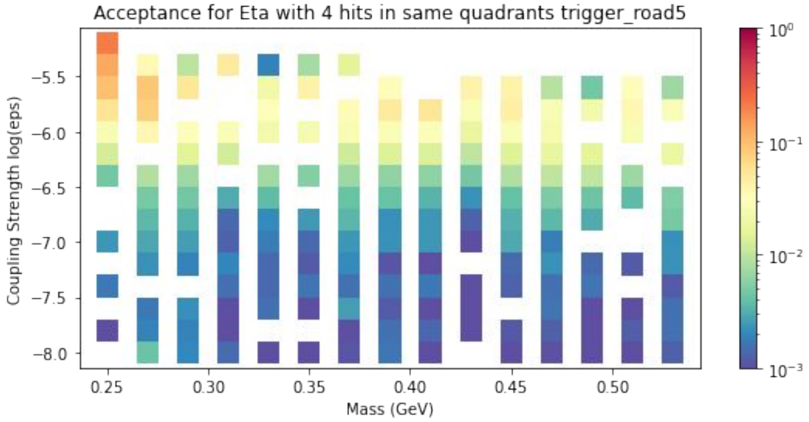




- Adding two dark photon hodoscopes in order to improve the trigger efficiency on displaced signals.
- Trigger fires if hits are in the same quadrant for DP1, DP2, and H4Y detector.
- Z-vertex reconstruction can be made based on the hit positions on DP1 & DP2.

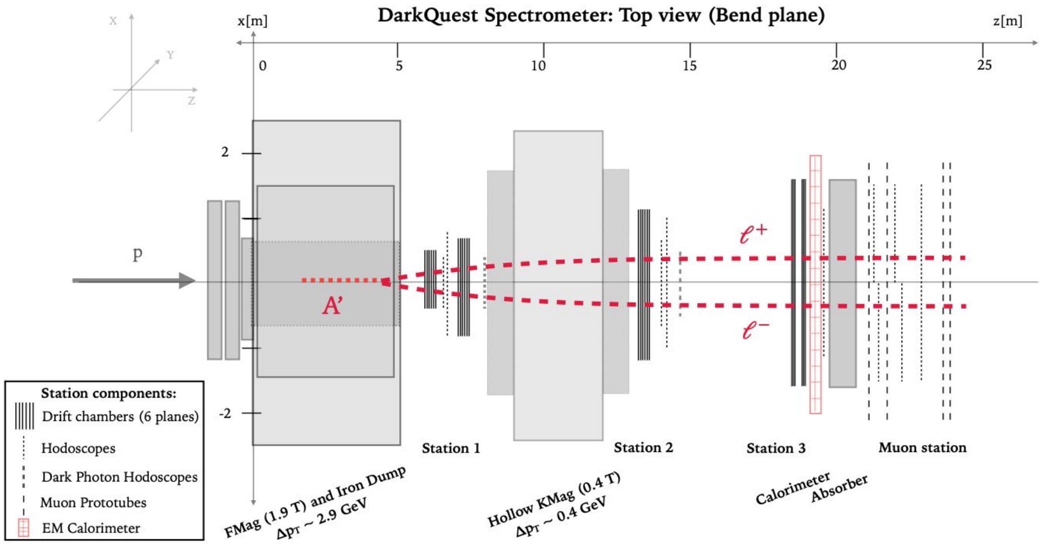
Specific road & background rejection





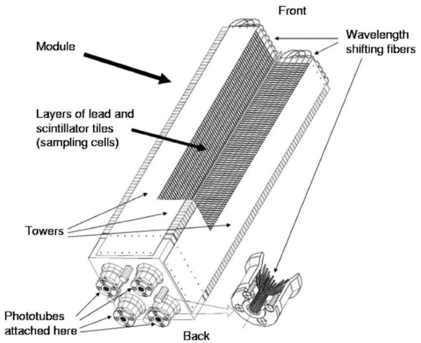
- Specific trigger road is defined by 4 coincidence fiber hodoscope hits in the same quadrant: (dp1_hit_elmID1, dp1_hit_elmID2, dp2_hit_elmID1, dp2_hit_elmID2)
- Rule out all of the road hitted by ~14k NIM3 triggered events in 2017 experimental data.
- Choose most frequent hitted road by signal files. (Road optimization is still ongoing)

Future Upgrade: DarkQuest experiment



- Make full use of the existing SpinQuest spectrometer

- Upgrade with one Electromagneic calorimeter (EMCal) sector(2m×4m, from PHENIX Experiment)



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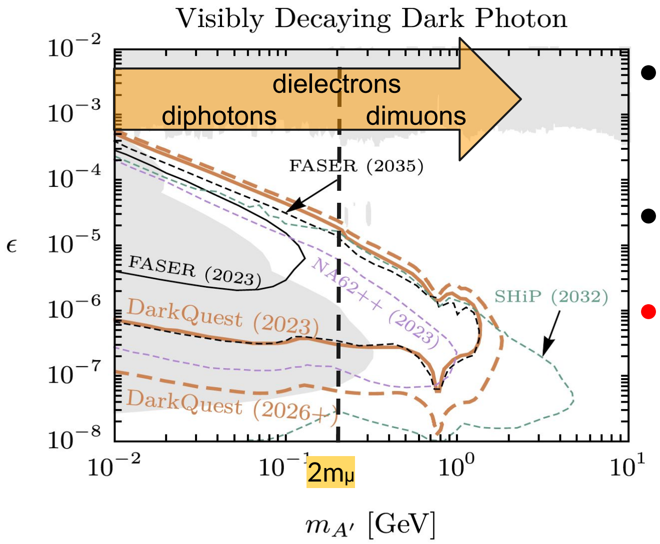

Projected sensitivity: Darl Photon as an example

- Provide access to electron and proton final states. Broaden the coverage to lower masses
- Provide more sensitivity by rejecting muon and hadron backgrounds.
- With most already existing experi-mental component, the upgrade is very low cost.

Signature	Model
e^+e^-	dark photon dark Higgs leptophilic scalar*
$e^+e^-e^+e^-$	Higgsed dark photon
$e^\pm\pi^\mp, e^\pm K^\mp, \cdots$	sterile neutrino
e^+e^- + MET	inelastic dark matter strongly interacting dark matter hidden valleys
$\pi^+\pi^-, K^+K^-, \cdots$	dark Higgs*
$\gamma\gamma$	axion-like particle*

various experimental signatures and the relevant models that can be searched for at DarkQuest with the EMCal upgrade

Snowmass paper on this:
https://arxiv.org/pdf/ 2203.08322.pdf

Summary

- Searching for light dark matter and dark sector particles is an important part of the worldwide particle physics program.
- SpinQuest Spectrometer provides a good oppotunity to search for such long lived dark sector particles.
- New displaced trigger algorithm is developed, improving the trigger efficiency for dark photons signal a lot.
- A new proposed DarkQuest Experiment can perform new world-leading searches in next few years with low cost.

Collaboration

- A strong team assembled of both experimentalists and theorists.
- Integration with the Snowmass project; have one Snowmass paper on this: [https://arxiv.org/pdf/ 2203.08322.pdf](https://arxiv.org/pdf/2203.08322.pdf)

DarkQuest: A dark sector upgrade to SpinQuest at the 120 GeV Fermilab Main Injector

Aram Apyan[1], Brian Batell[2], Asher Berlin[3], Nikita Blinov[4], Caspian Chaharom[5], Sergio Cuadra[6], Zeynep Demiragli[5], Adam Duran[7], Yongbin Feng[3], I.P. Fernando[8], Stefania Gori[9], Philip Harris[6], Duc Hoang[6], Dustin Keller[8], Elizabeth Kowalczyk[10], Monica Leys[2], Kun Liu[11], Ming Liu[11], Wolfgang Lorenzon[12], Petar Maksimovic[13], Cristina Mantilla Suarez[3], Hrachya Marukyan[14], Amitav Mitra[13], Yoshiyuki Miyachi[15], Patrick McCormack[6], Eric A. Moreno[6], Yasser Corrales Morales[11], Noah Paladino[6], Mudit Rai[2], Sebastian Rotella[6], Luke Saunders[5], Shinaya Sawada[21], Carli Smith[17], David Sperka[5], Rick Tesarek[3], Nhan Tran[3], Yu-Dai Tsai[18], Zijie Wan[5], and Margaret Wynne[12]

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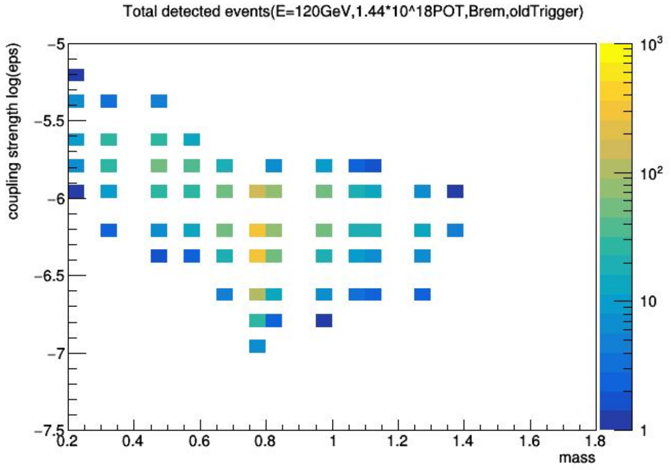
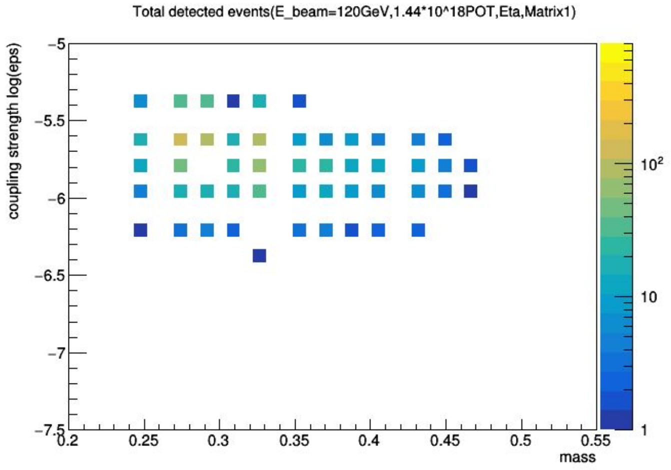
Backup

Knowing the trigger efficiency, we can calculate the total number of Aprime Events that can be detected.

*N = cross section(eps^2) * L(POT) * decay_prob(5-6m) * acc(trigger)*





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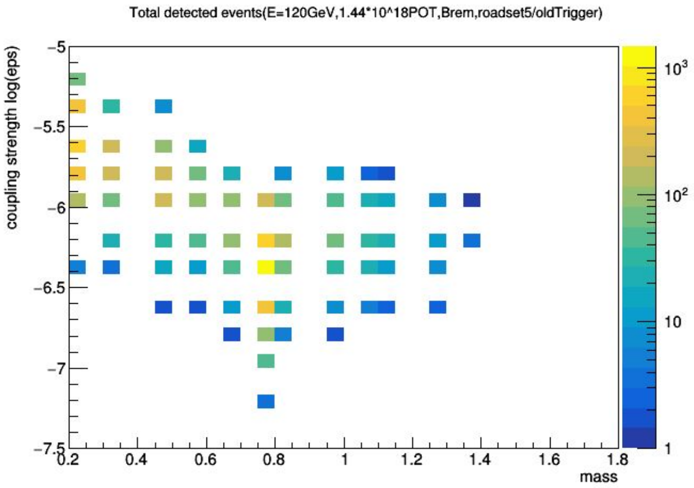

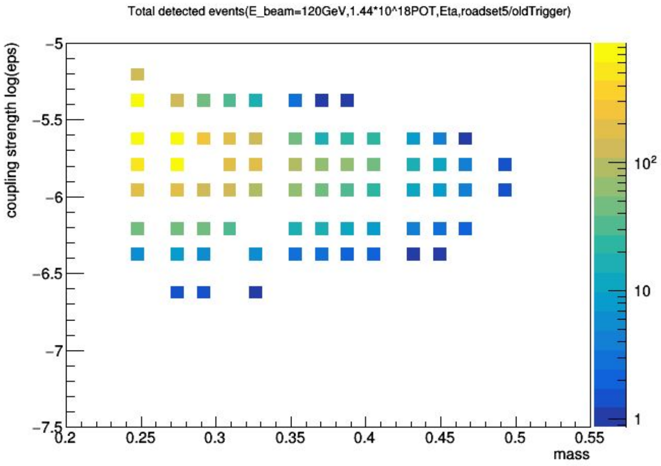

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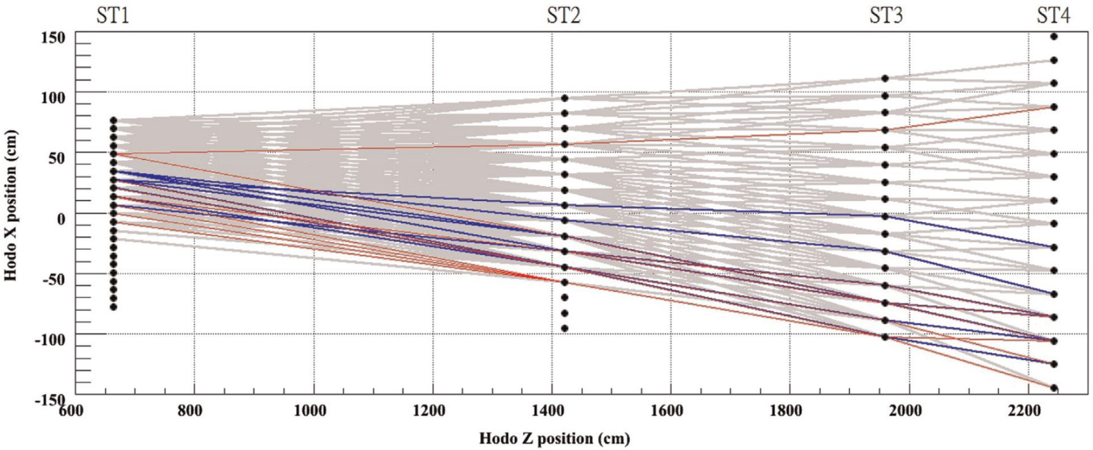

visualization of the hit patterns of μ+ on X-hodoscope (current trigger road). black points represent scintillator paddles viewed from the top. red and blue line shows the most-frequent hit patterns (doi:10.1016/j.nima.2015.09.001)