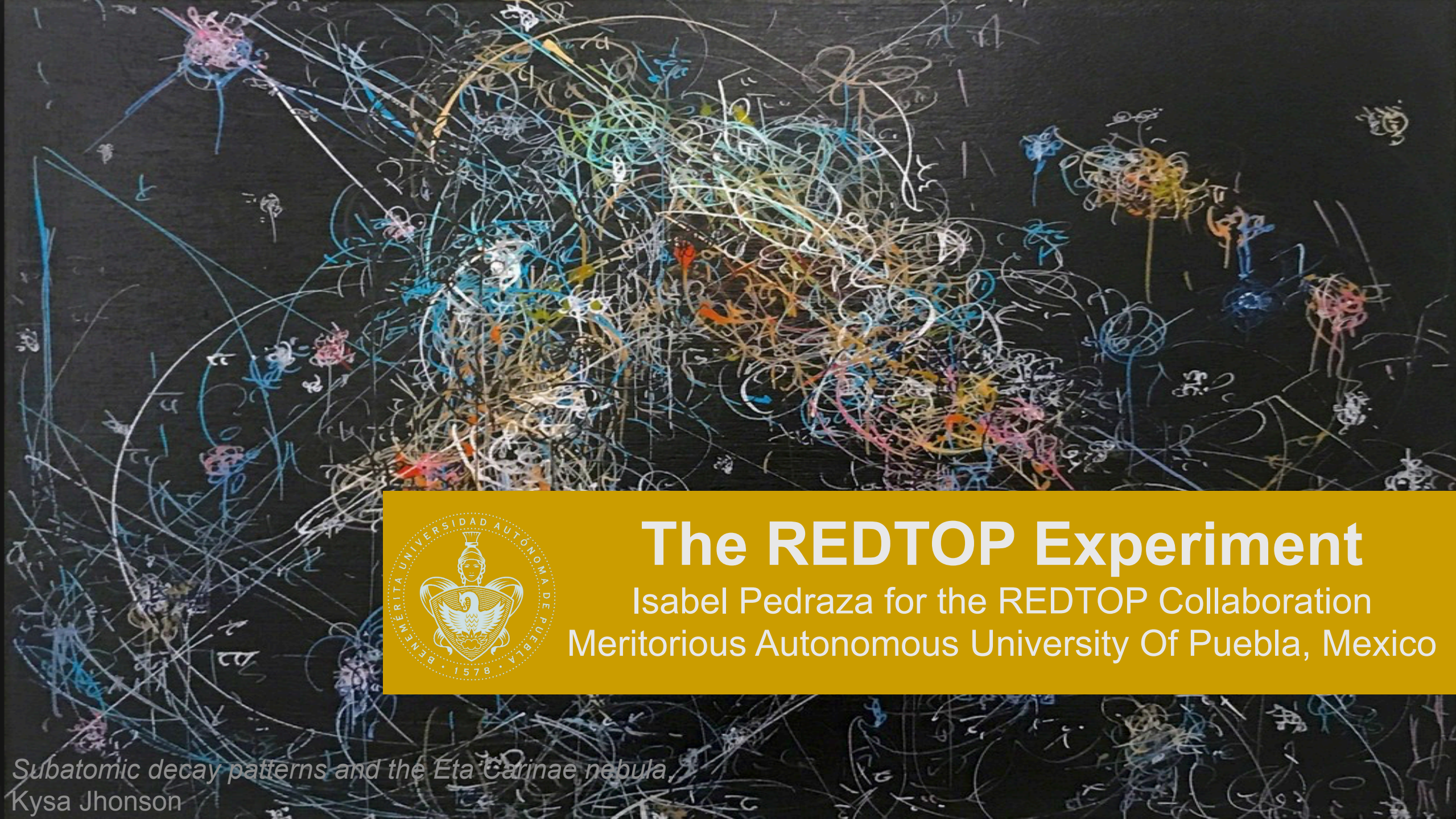


The REDTOP Experiment

Isabel Pedraza for the REDTOP Collaboration
Meritorious Autonomous University Of Puebla, Mexico

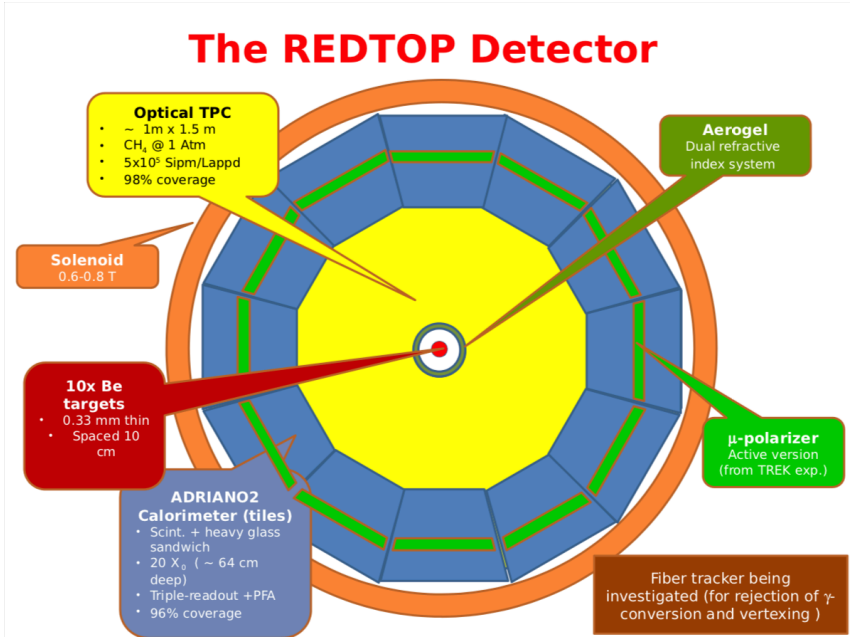
Subatomic decay patterns and the Eta Carinae nebula,
Kysa Jhonson

REDTOP

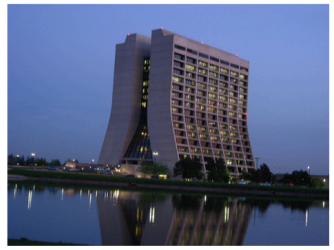
REDTOP presented on November workshop for the first time in the PBC.

Since then developments on simulations, detector R&D and CERN accelerators compatibility have been done.

1.8 or 3.5 GeV proton beam under study at the CERN PS. Initial studies for 10^{18} POT. Nevertheless 10^{17} will also allows to provide large sensitivity for physics BSM.



***R**are **E**ta **D**ecays with a **T**PC for **O**ptical **P**hotons*



R. Carosi, *INFN Pisa*
Workshop on Physics Beyond Colliders
CERN, 22 nov. 2017
For the REDTOP Collaboration

Fermilab

INFN

REDTOP a $\eta - \eta'$ meson factory

η factories are excellent laboratories to search for physics Beyond Standard Model

It is a Goldstone boson → Symmetry constrains its QCD dynamics

It is an eigenstate of the C, P, CP and G operators (very rare in nature): $I^G J^{PC} = 0^+ 0^{-+}$ → It can be used to test C and CP invariance.

All its additive quantum numbers are zero (very clean state)

$$Q = I = j = S = B = L = 0$$

→ Its decays are not influenced by a change of flavor (as in K decays) and violations are "pure"

All its possible strong decays are forbidden in the lowest order by P and CP invariance, G-parity conservation and isospin and charge symmetry invariance.

EM decays are forbidden in lowest order by C invariance and angular momentum conservation

→ It is a very narrow state (Γ_η=1.3 KeV vs Γ_ρ=149 MeV)

Contributions from higher orders are enhanced by a factor of ~100,000

Excellent for testing invariances

Very rich BSM Physics Program (η and η' factory)

C, T, CP-violation

- *CP Violation via pattern of mirror symmetry breaking asymmetry in the Dalitz plot : $\eta \to \pi^o \pi^+\pi^-$ (New paper from S. Gardner soon on arXiv).*
- *CP Violation (Type I – P and T odd , C even): $\eta \to 4\pi^o \to 8\gamma$*
- *CP Violation (Type II - C and T odd , P even): $\eta \to \pi^o \ell^+\ell^-$ **and** $\eta \to 3\gamma$*
- *Test of CP invariance via μ longitudinal polarization: $\eta \to \mu^+\mu^-$*
- *Test of CP invariance via γ^* polarization studies: $\eta \to \pi^+\pi^-e^+e^-$ and $\eta \to \pi^+\pi^-\mu^+\mu^-$*
- *Test of CP invariance in angular correlation studies: $\eta \to \mu^+\mu^-e^+e^-$ and $\eta \to l^+l^-l^+l^-$*
- *Test of T invariance via μ transverse polarization: $\eta \to \pi^o\mu^+\mu^-$ and $\eta \to \gamma\mu^+\mu^-$*
- *CPT violation: μ polariz. in $\eta \to \pi^+\mu^-\nu$ vs $\eta \to \pi^-\mu^+\nu$ and γ polarization in $\eta \to \gamma\gamma$*

Other discrete symmetry violations

- *Lepton Flavor Violation: $\eta \to \mu^+e^-$ + c.c.*
- *Double lepton Flavor Violation: $\eta \to \mu^+\mu^+e^-e^-$ + c.c.*
- *Lepton Flavor universality $\eta \to \pi^o \ell^+\ell^-$, $\eta \to \gamma \ell^+\ell^-$*

Very reach BSM Physics Program (η and η' factory)

New particles and forces searches

- *Scalar meson searches (charged channel): $\eta \to \pi^o S$ with $S \to e^+e^-$ and $S \to \mu^+\mu^-$*
- *Dark photon searches: $\eta \to \gamma A'$ with $A' \to \ell^+\ell^-$ (considered the PBC benchmark)*
- *Protophobic fifth force searches : $\eta \to \gamma X_{17}$ with $X_{17} \to e^+e^-$*
- *New leptophobic baryonic force searches : $\eta \to \gamma B$ with $B \to e^+e^-$ or $B \to \gamma \pi^o$*
- *Indirect searches for dark photons, new gauge bosons, and leptoquark: $\eta \to \mu^+\mu^-$ and $\eta \to e^+e^-$*
- *Search for true muonium: $\eta \to \gamma (\mu^+\mu^-)|_{2M_\mu} \to \gamma e^+e^-$*

Other Precision Physics measurements

- *Proton radius anomaly: $\eta \to \gamma \mu^+\mu^-$ vs $\eta \to \gamma e^+e^-$*
- *All unseen leptonic decay mode of η / η ' (SM predicts 10^{-6} -10^{-9})*

Non-η/η' based BSM Physics

- *Dark photon and ALP searches in Drell-Yan processes: qqbar → A'/a → l^+l^-*
- *Dark photon and ALP searches in proton bremsstrahlung processes: p N → p N A'/a with A'/a → l^+l^- (J. Blümlein and J. Brunner)*
- *ALP's searches in Primakoff processes: p Z → p Z a → l^+l^-*

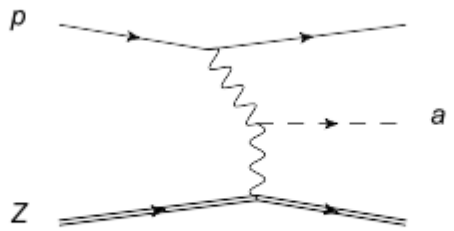


Figure 2. Primakoff production of ALPs in proton-nucleus collisions.

Babette Döbrich,[a] Joerg Jaeckel,[b] Felix Kahlhoefer,[c] Andreas Ringwald,[c] and Kai Schmidt-Hoberg[c]

- *Charged pion and kaon decays: $\pi^+ \to \mu^+\nu\, A' \to \mu^+\nu\, e^+e^-$ and $K^+ \to \mu^+\nu\, A' \to \mu^+\nu\, e^+e^-$*
- *Neutral pion decay: $\pi^o \to \gamma A' \to \gamma e^+e^-$*

Non-BSM Physics Program (η and η' factory)

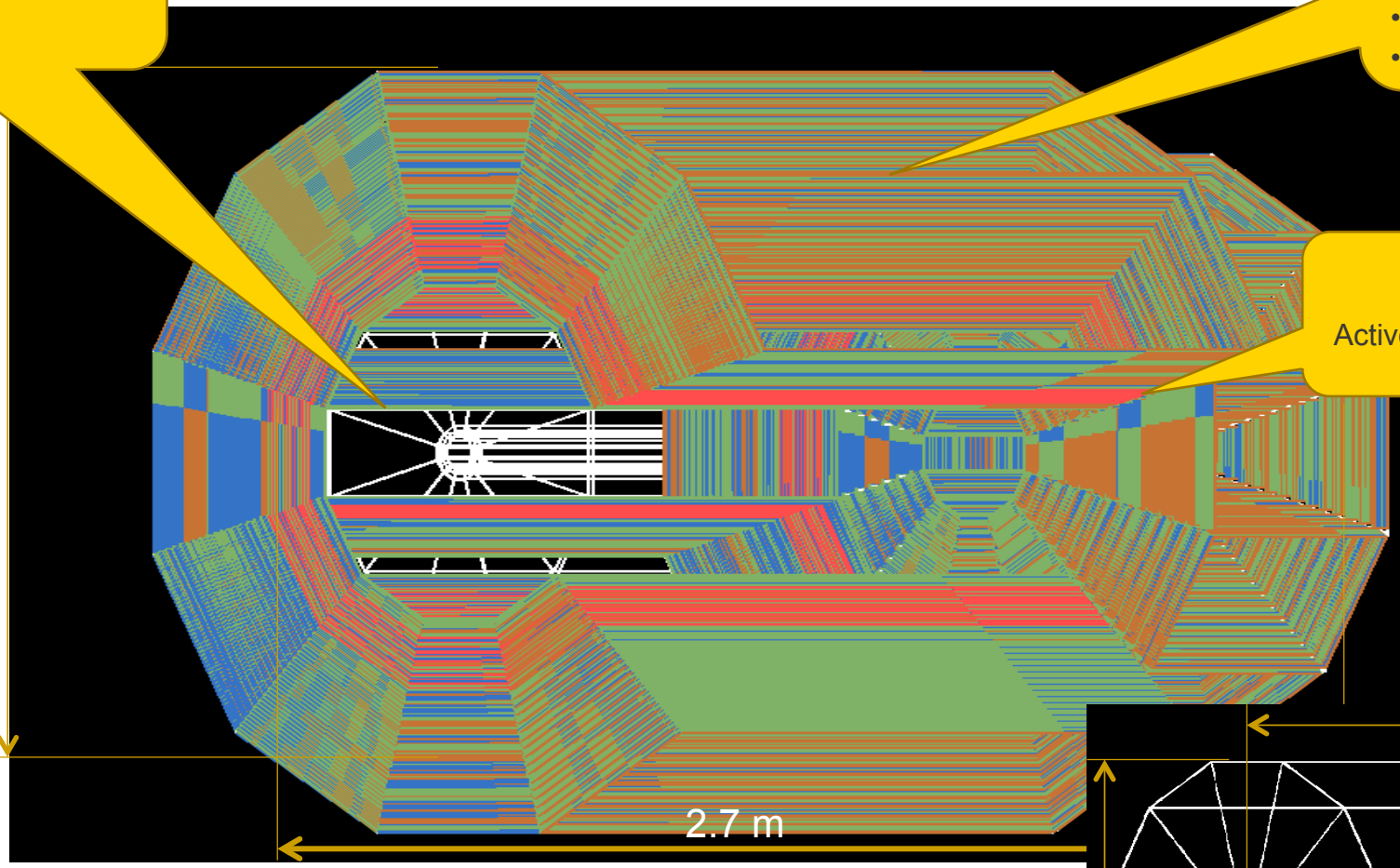
High precision studies on low energy physics

- *Nuclear models*
- *Chiral perturbation theory*
- *Non-perturbative QCD*
- *Isospin breaking due to the u-d quark mass difference*
- *Octet-singlet mixing angle*
- *ππ interactions*
- *Electromagnetic transition form-factors (important input for g-2)*

REDTOP detector

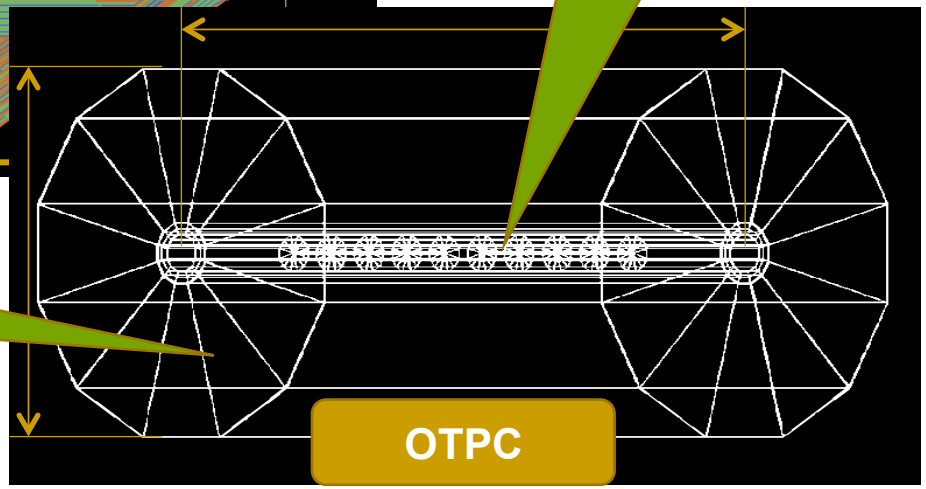
Optical TPC
- ~ 1m x 1.5 m
- CH_4 @ 1 Atm
- $5x10^5$ Sipm/Lappd
- 98% coverage

ADRIANO2 Calorimeter (tiles)
- Scint. + heavy glass sandwich
- 20 X_0 (~ 64 cm deep)
- Triple-readout +PFA
- 96% coverage



μ-polarizer
Active version (from TREK exp.)

10x Be targets
0.33 mm thin
Spaced 10 cm



Aerogel
Dual refractive index system

A fiber tracker has being considered for rejection of γ-conversion and vertexing

Recent developments on simulations

Almost full simulation

- *Event generation: GenieHad (fortran+ and C++)*
  - *Urqmd + Abla7 for proton-target interaction (signal and background)*
- *Background*
  - *$2 \cdot 10^7$ Standard Model events (corresponding to about 10^9 POT)*
  - *$7 \cdot 10^5$ p+ ^{7}Li->η X with η -> γ e^+e^- (corresponding to about 10^{12} POT)*
- *Detector prototyping: Slic (C++) , lcsim (java)*
- ***Almost Full simulations for the η-factory**: ilcroot*
  - *All 3 subdetectors are digitized*
  - *Pattern recognition from MC truth*
  - *Reconstruction: mix of full reco and gaussian smearing*
- *Efficiency extrapolated for the **η'-factory***
- *PID is important. Assume the following particle identification efficiency (not impossible to achieve with dual-readout + OTPC):*

species	Particle identification efficiency
e+, e-	98%
muon	95%
pion	95%
proton	99%
γ	99%
n	99%

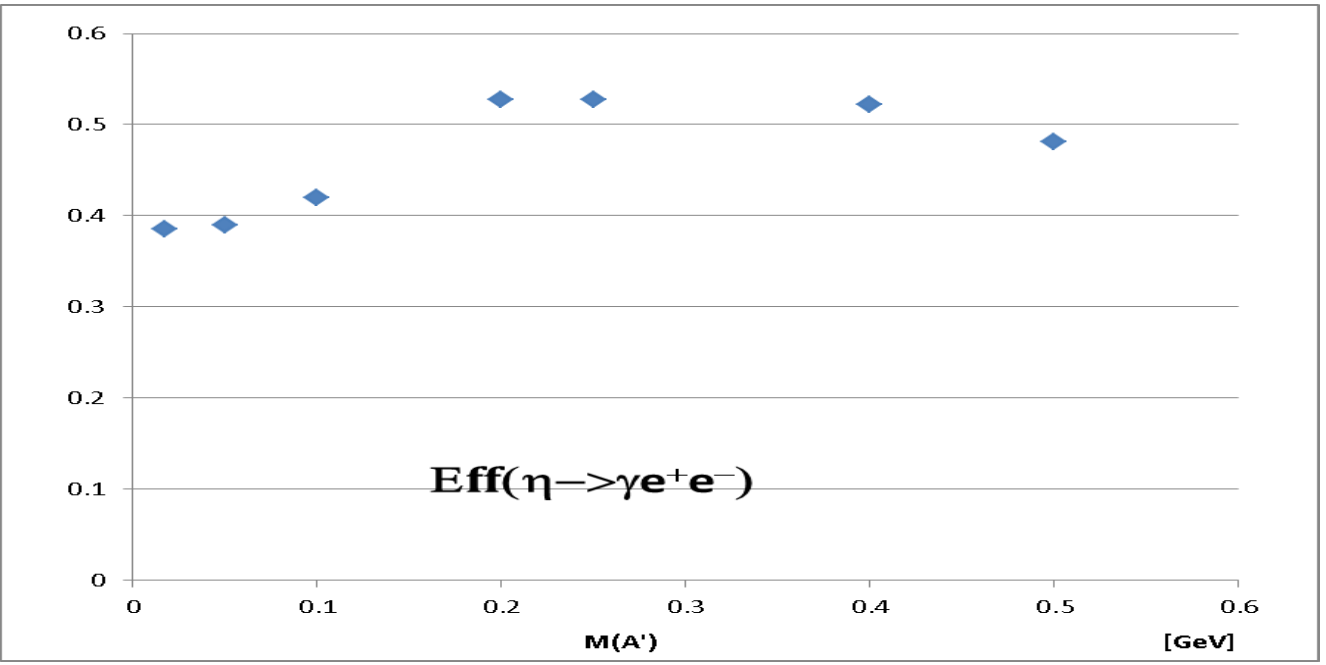
REDTOP ongoing simulations for PBC's Benchmarks

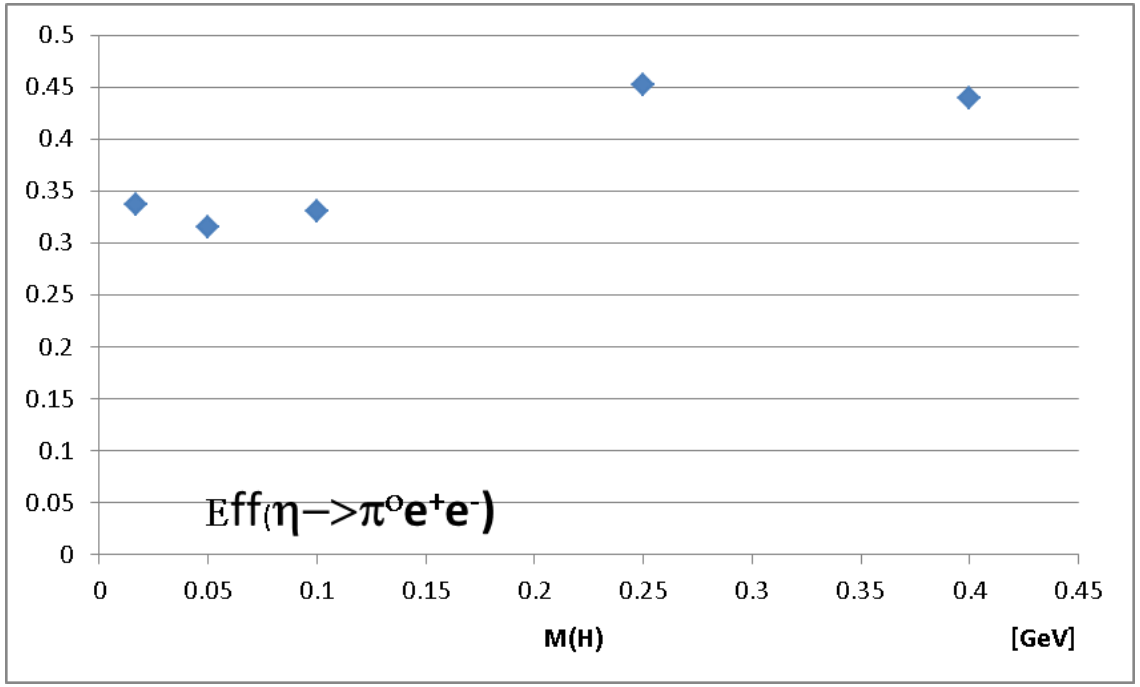
REDTOP is looking into DM using **visible** final states

- Two portals have/are being explored:
  - Dark photon: η-> γ lepton – antilepton (BC1). Prompt analysis results presented by Gaia.
  - Dark scalar: η-> π^o lepton – antilepton (It has small coupling to η . REDTOP can help to differentiate between Higgs models (M. Pospelov et al.) BC4 and BC5 and electrophobic models (J. Miller et al.) – NOT AMONG PBC BENCHMARKS

The ALP's portal will be explored with *Primakoff processes:* $p\ Z \rightarrow p\ Z\ a \rightarrow \ell^+\ell$ *(BC11)*

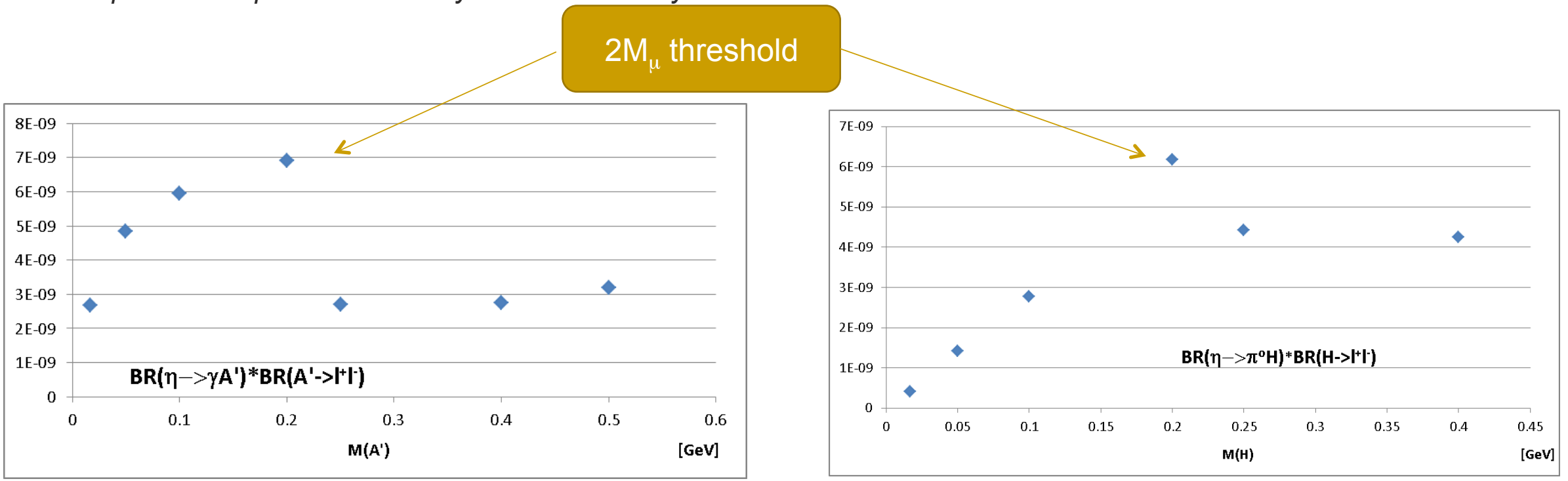
BSM Physics Program (η and η' factory): reconstruction efficiency for dileptons in searches for DM vectors or scalars





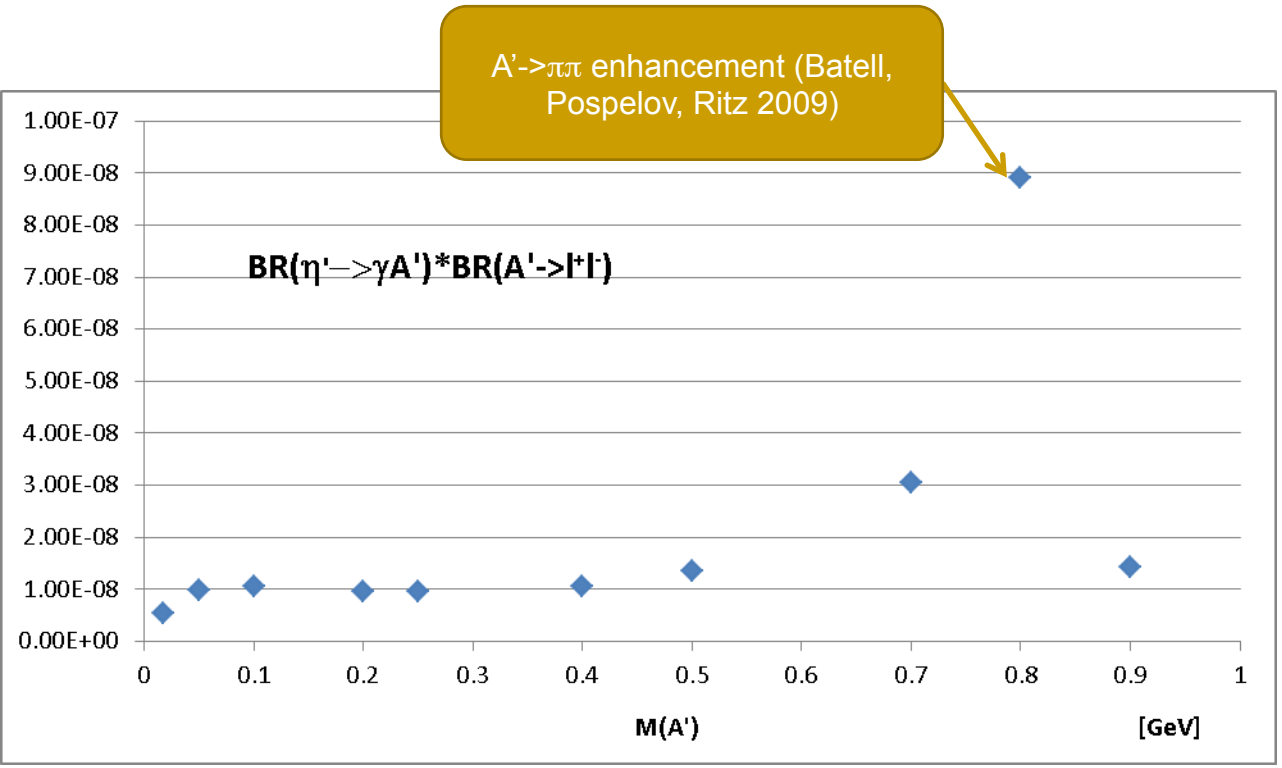
DM Branching Ratios Sensitivity for η-factory (1.8 GeV) for final states with dileptons in searches for DM vectors or scalars

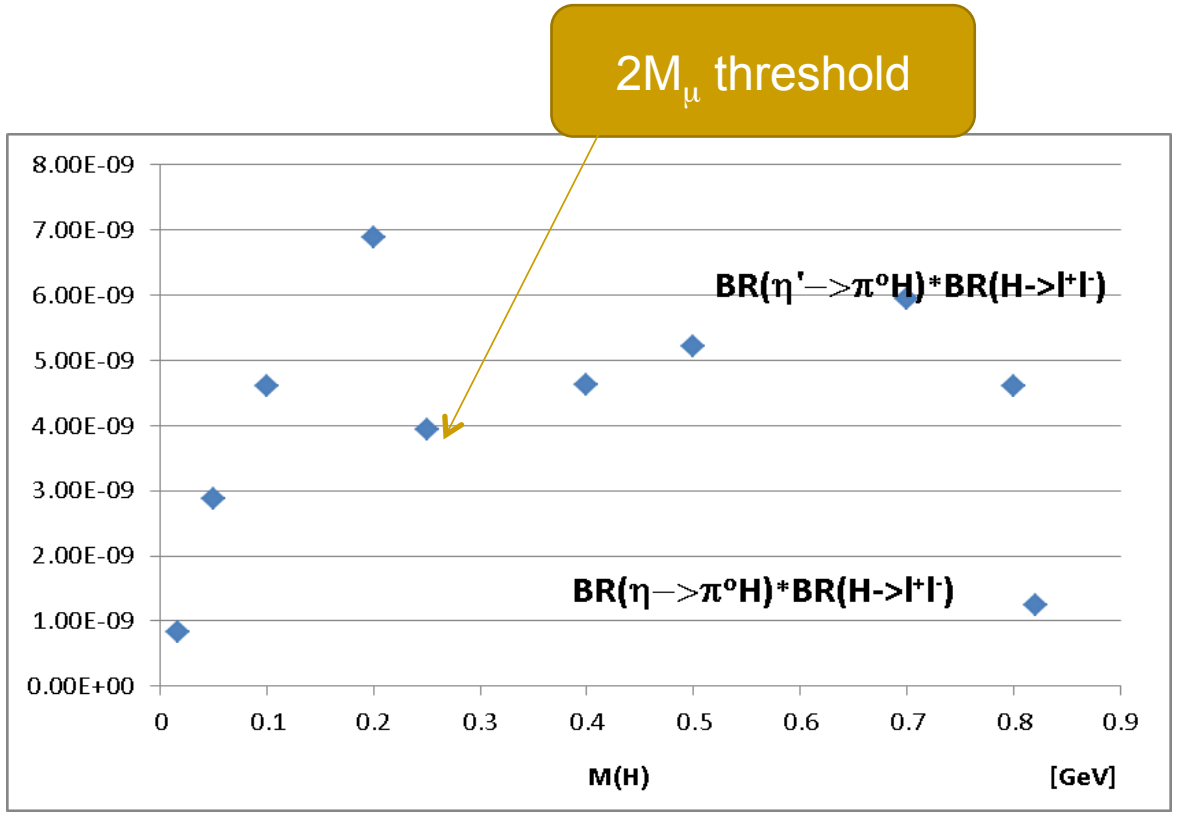
- *Assume 10^{18} POT*
- *Interactions 2.29E+16*
- *Eta production. 8.24E+13*
- *S/√B>3*
- *Prompt analysis only (non detached vertex analysis yet)*
- *Expect x10 improved sensitivity with vertex analysis*



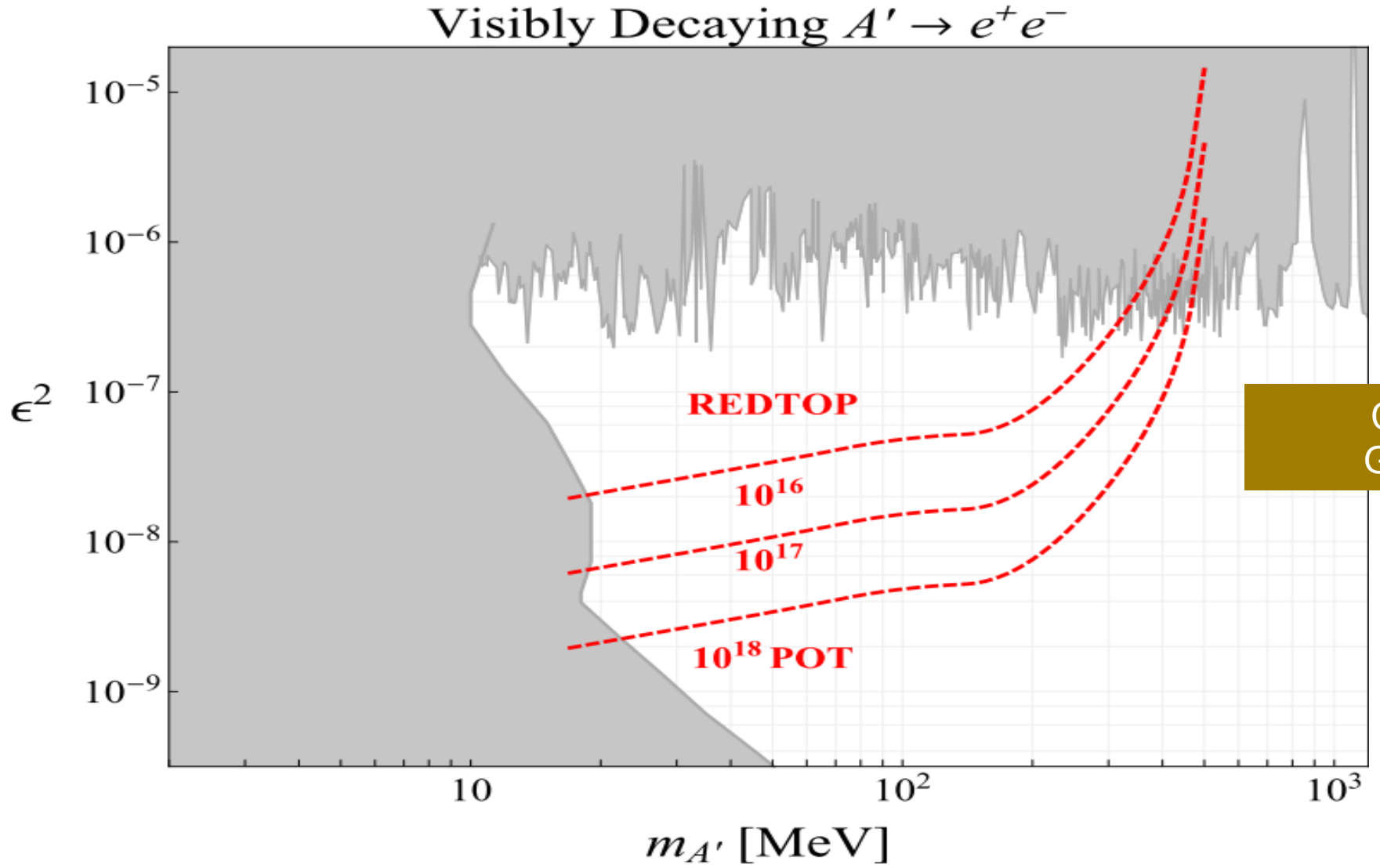
DM Branching Ratios Sensitivity for η'-factory (3.5 GeV) for final states with dileptons in searches for DM vectors or scalars

- *Assume 10^{18} POT*
- *Interactions 2.29E+16*
- *Eta-prime production. 1.4E+12*
- *S/√B>3*
- *Prompt analysis only (non detached vertex analysis yet)*
- *Expect x10 improved sensitiviry with vertex analysis*



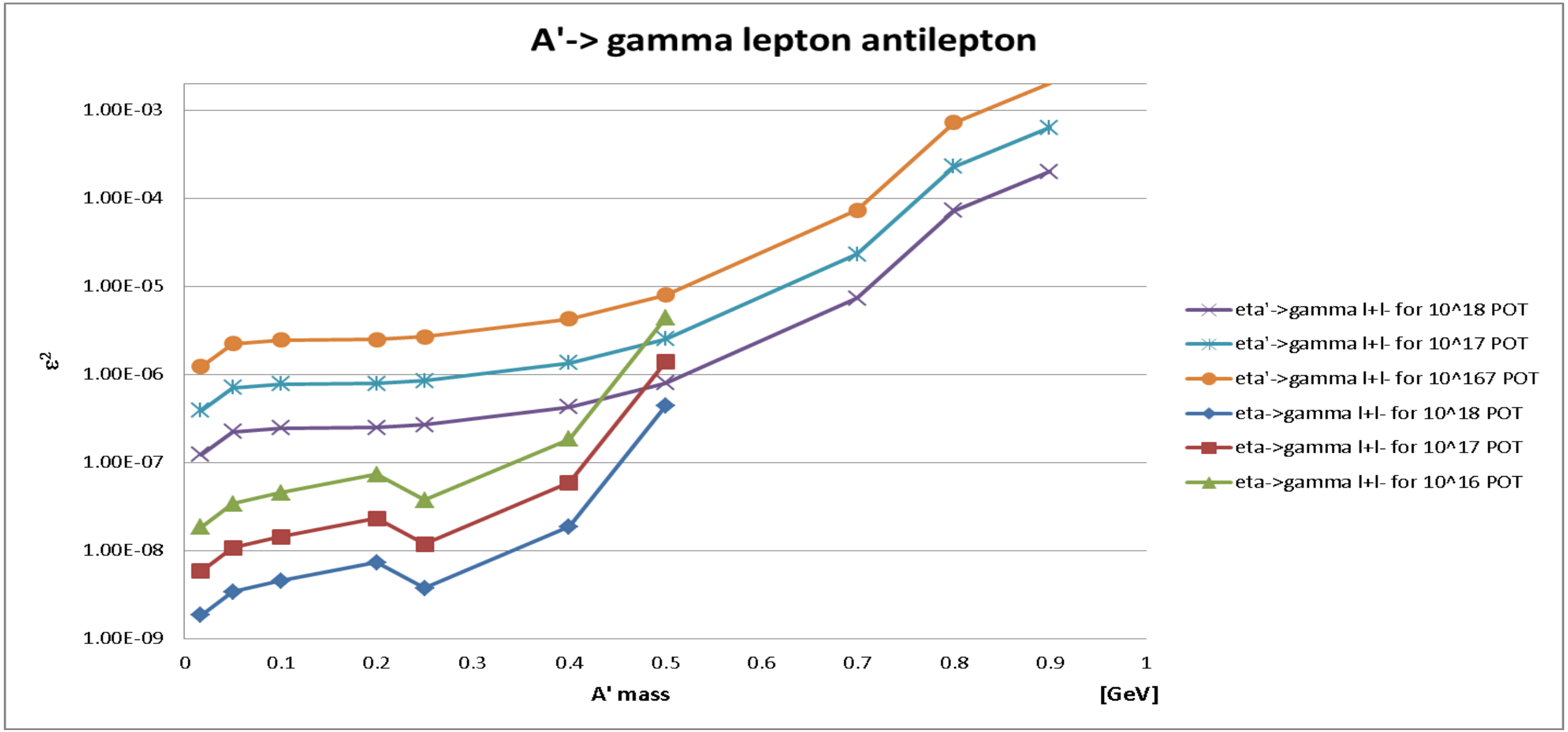


Sensitivity to A' (η-factory, e^+e^- only)



Courtesy
G. Krnjaic

Sensitivity to A' (η and η', e/μ)



REDTOP

- The physics
- The detector
- The accelerator complex
- Collaboration
- Collaboration tools
- Documents
- Useful links

Search this site... Search

Links

- Job Opportunities
- Documents

The REDTOP collaboration

8 Countries, 23 Institutions, 66 Collaborators

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University of Uppsala, (Sweden)

More details at: http://redtop.fnal.gov

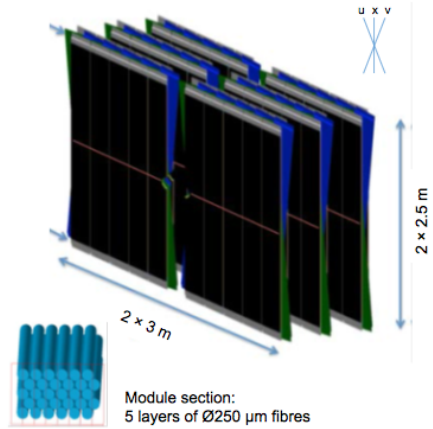
On Detector R&D

ADRIANO Calorimeter

Almost 8 yrs R&D by T1015 Collaboration
Proved technology but need a cheaper construction technique
Ongoing R&D at NIU (NIU+INFN Collaboration)

Fiber tracker

Use LHCb technology without modifications
Simulations indicates that the technique has an acceptable performance at REDTOP energies.



Pictures: C. Joram, "LHCb SciFi, the new Fibre Tracker for LHCb", ECFA High Luminosity LHC ExperimentsWorkshop. Aix-Les-Bains, France, 2014. url: http://ooo.ol/xF8sL6

Optical-TPC

Not yet started, an possible weak point for REDTOP. Nevertheless, taking into account POT we may consider a different technology.

Summary

The η /η' meson is an excellent laboratory for studying rare processes

Existing world sample not sufficient for breaching into decays violating conservation laws or searching for new particles

Broad physics program expands beyond the benchmark proposed by the PBC

Complementary to most other projects participating to the PBC program in the MeV-GeV mass scale

REDTOP goal is to produce 10^{13} η mesons with a 1.8 GeV beam and (~ 10^{11} η') with a 3.5 GeV beam – Assume 10^{17} POT for CERN implementation

Currently the collaboration is forming and working at a full proposal.

Endorsement by a laboratory will help to get funds for the detector R&D.

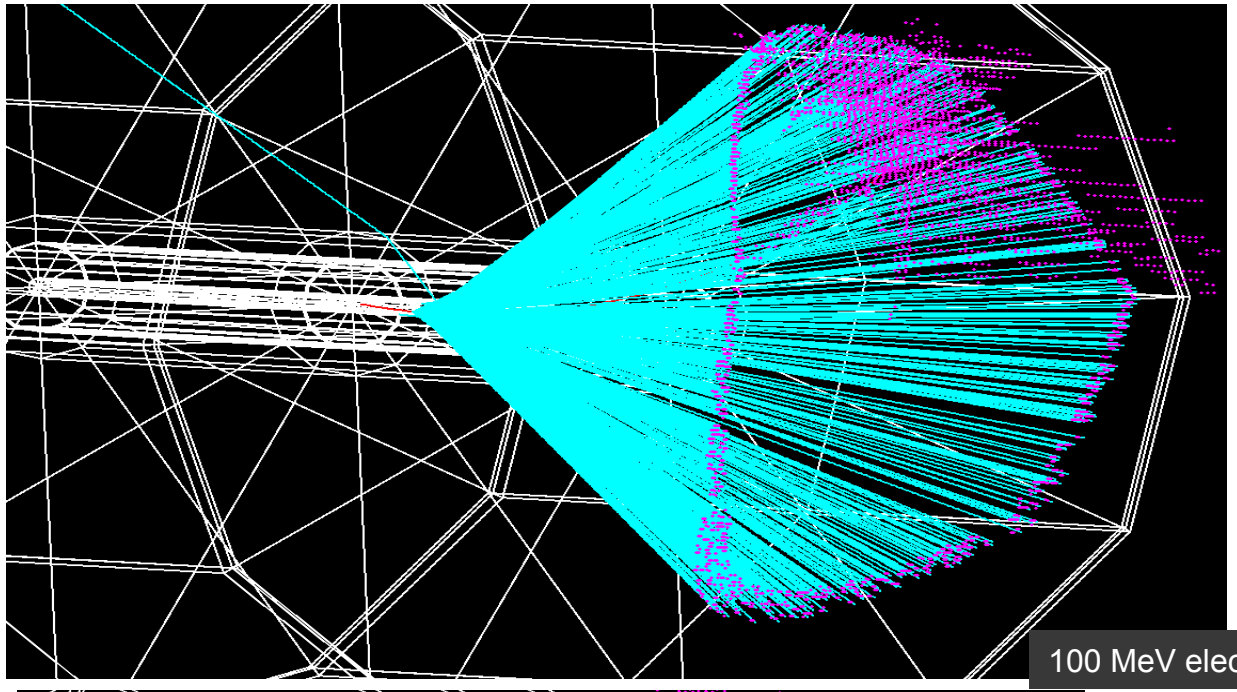
Rough cost estimation is around 50 M$ (depending on re-use of existing infra-structure).

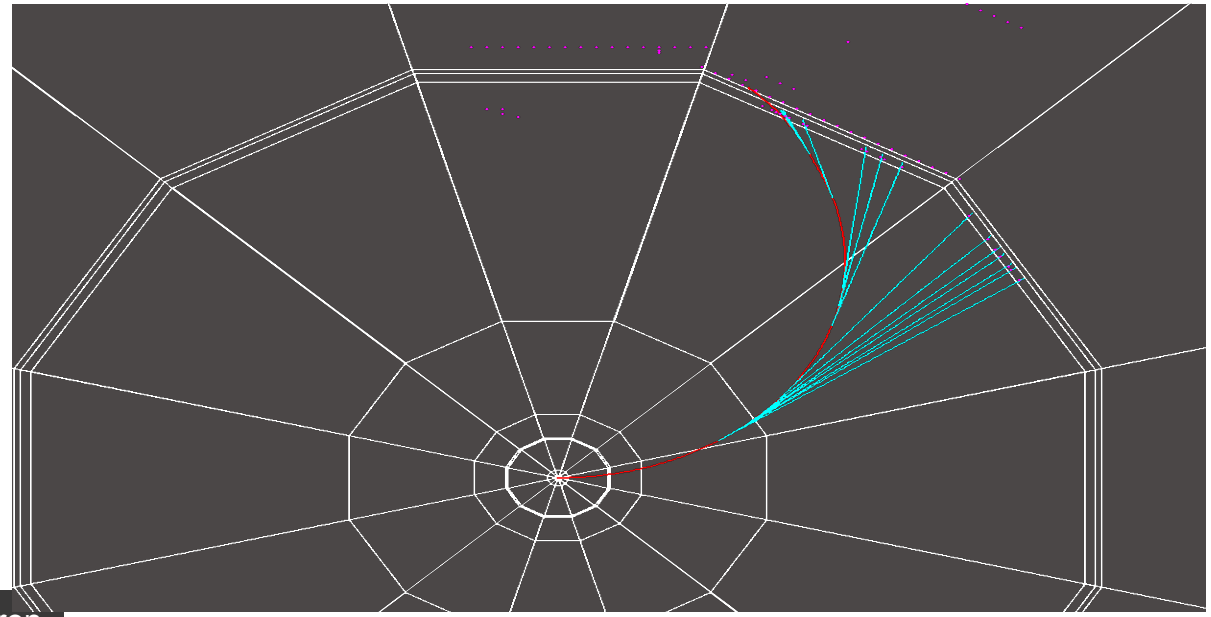
Working on a time line to be presented to the PBC.

Back up

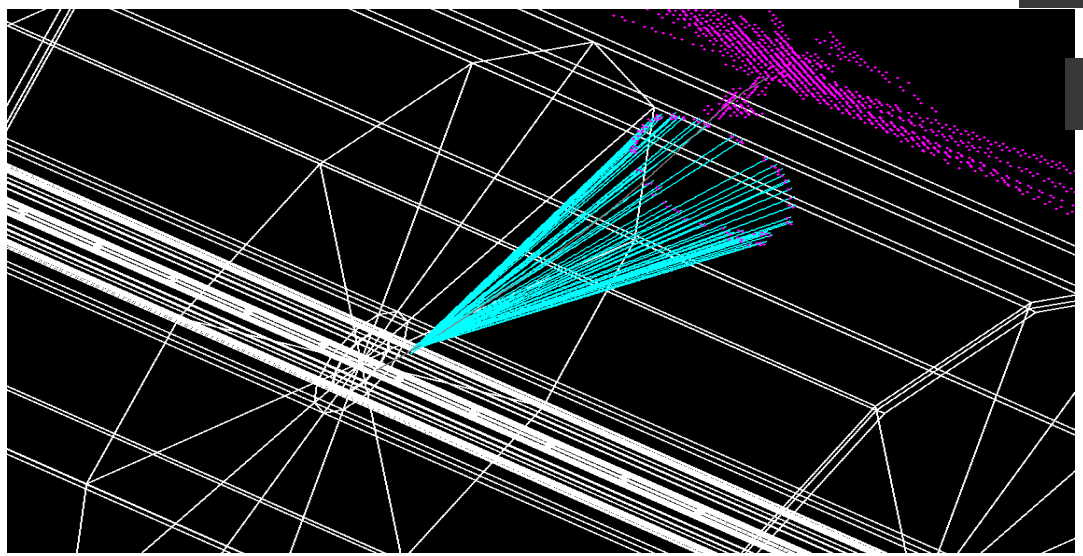
Charged Tracks Detection

Slic/lcsim simulation





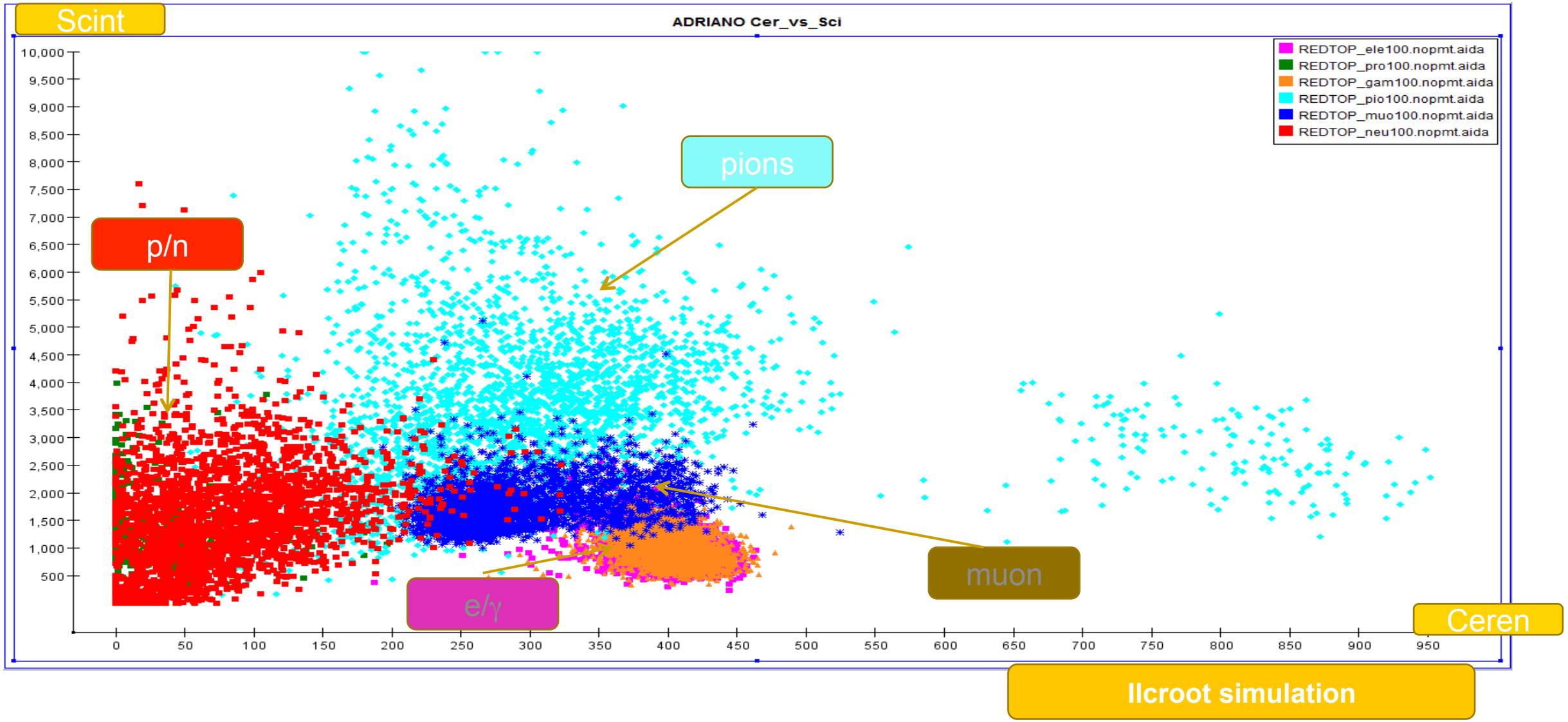
100 MeV electron



95 MeV muon

Cerenkov light in the OTPC

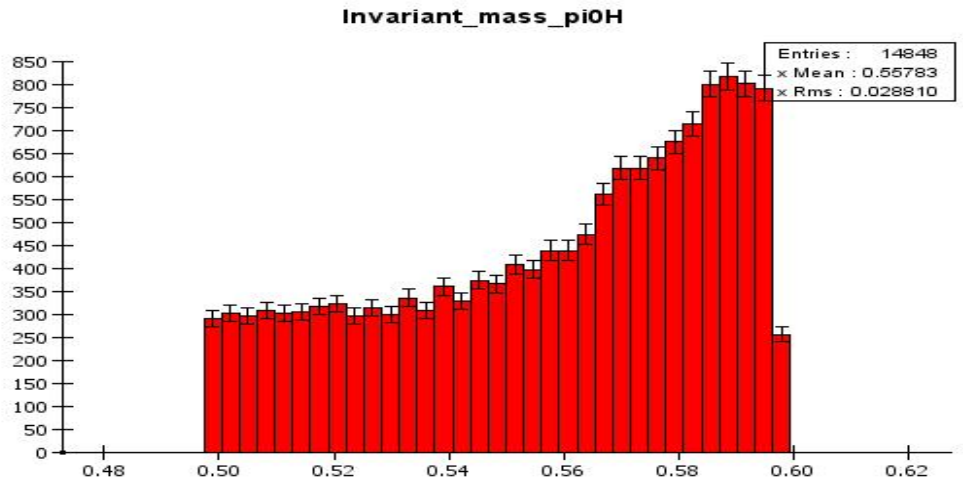
PID with ADRIANO @ 100MeV

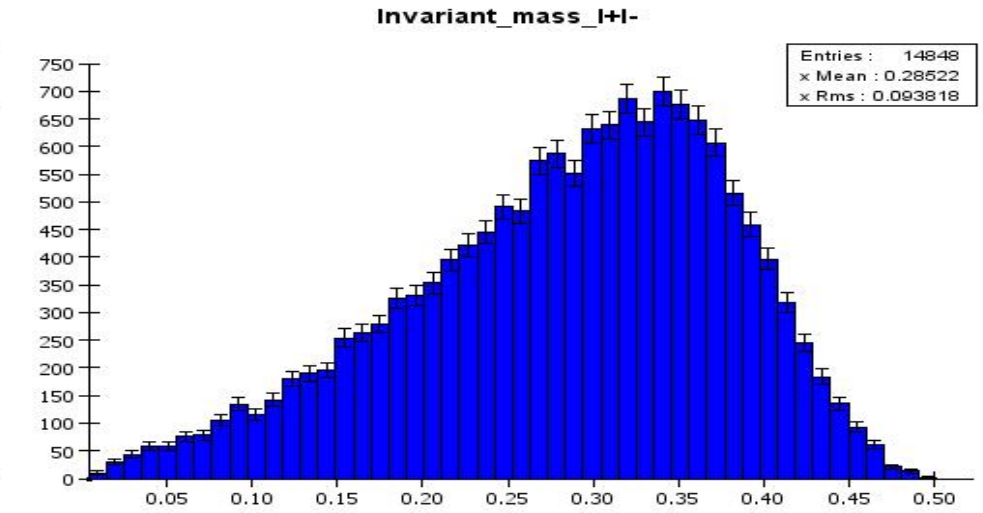


Ilcroot simulation

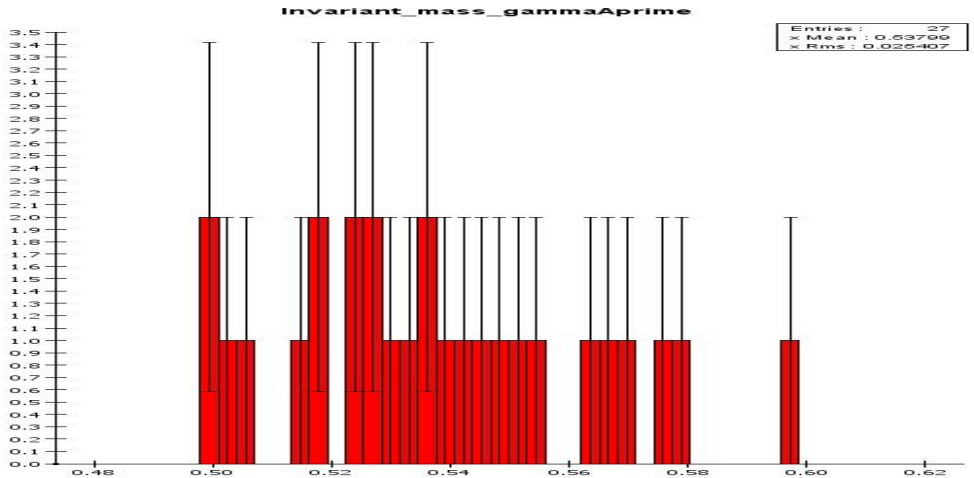
Major Backgrounds

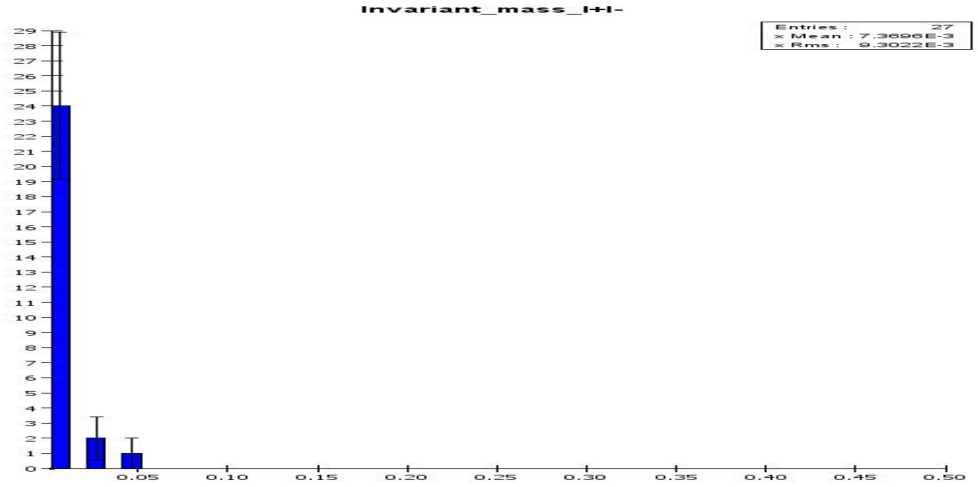
- $\eta \rightarrow \gamma e^{+} e^{-}$





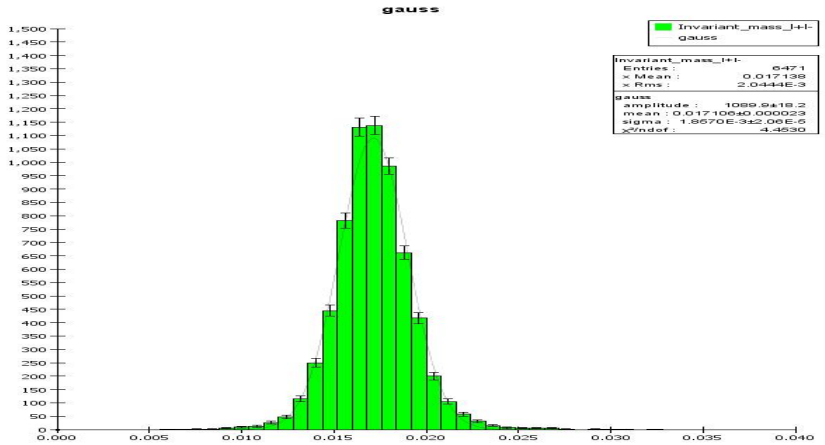
$p\,Li \rightarrow \gamma X$





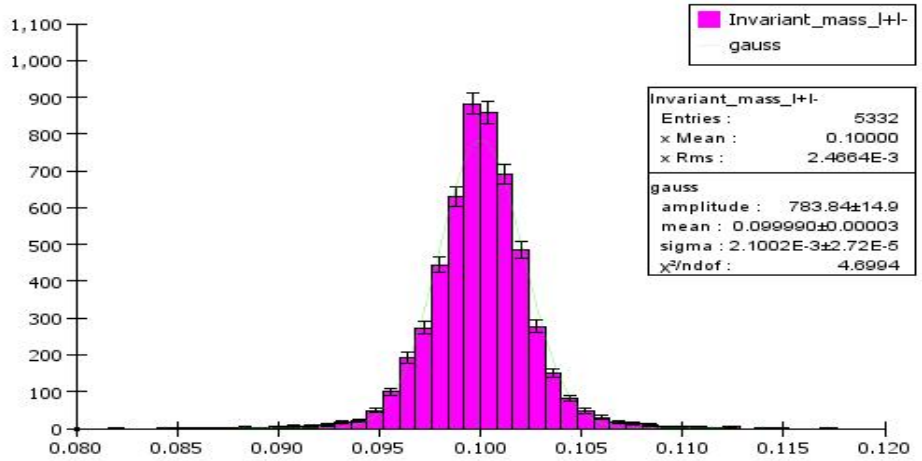
Typical Signals from Dark Bosons

$\eta \to \gamma A'$ (17 MeV)



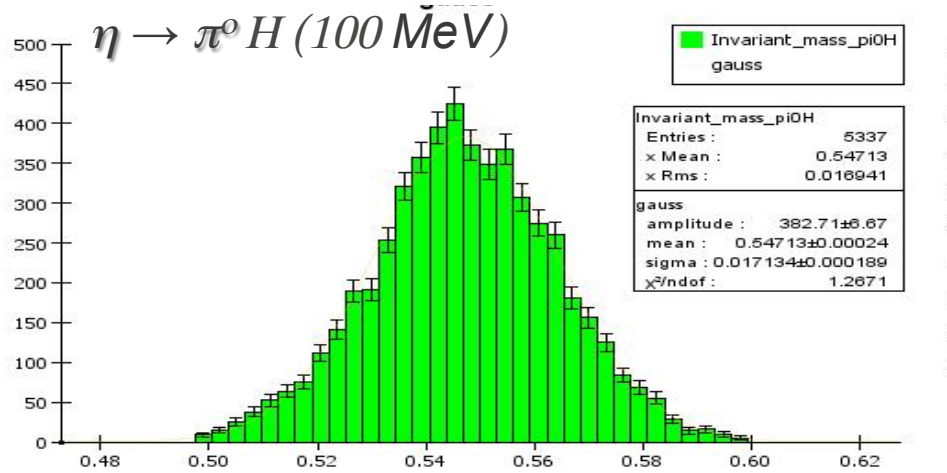
γγ+Di-lepton invariant mass

$\eta \to \pi^o H$ (100 MeV)

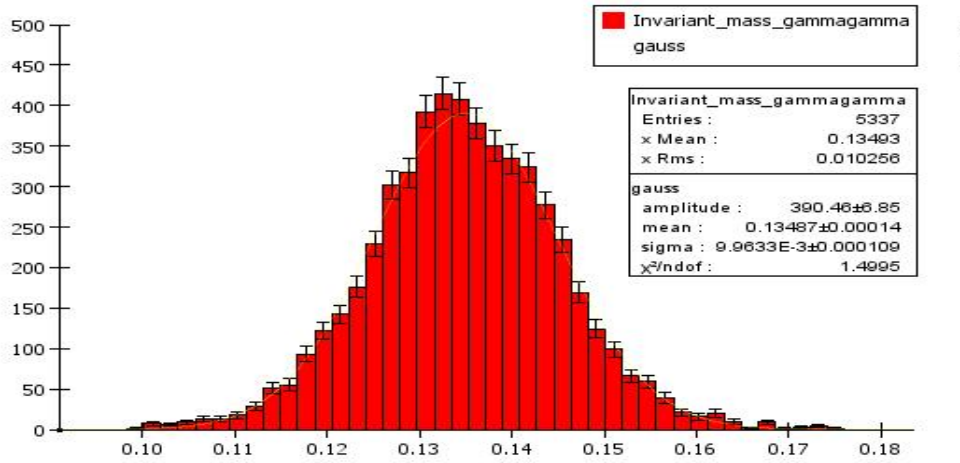


Di-lepton invariant mass

$\eta \to \pi^o H$ (100 MeV)



γγ+Di-lepton invariant mass



γγ invariant mass

Experimental Techniques

η/η' production

- η and η' hadro-produced from 1.8 and 3.5 GeV CW proton beams
- Use 10 x 0.33mm Be foils targets , spaced 10 cm apart to minimize combinatorics background

charged tracks detection

- Use Cerenkov effect in an **Optical-TPC** for tracking charged particles

- Baryons and most pions are below Č threshold
- Electrons and most muons are detected and reconstructed
- Use LHCb-style **Fiber tracker** vertexing and rejection of γ-conversion

γ detection

- Use **ADRIANO** calorimeter for reconstructing EM showers

- $\sigma_E/E < 5\%/\sqrt{E}$
- PID from dual-readout to disentangle showers from γ/μ/hadrons
- 96.5% coverage
- Use tiles for high granularity and PFA reconstruction
- 200 psec resolution for high rate DAQ