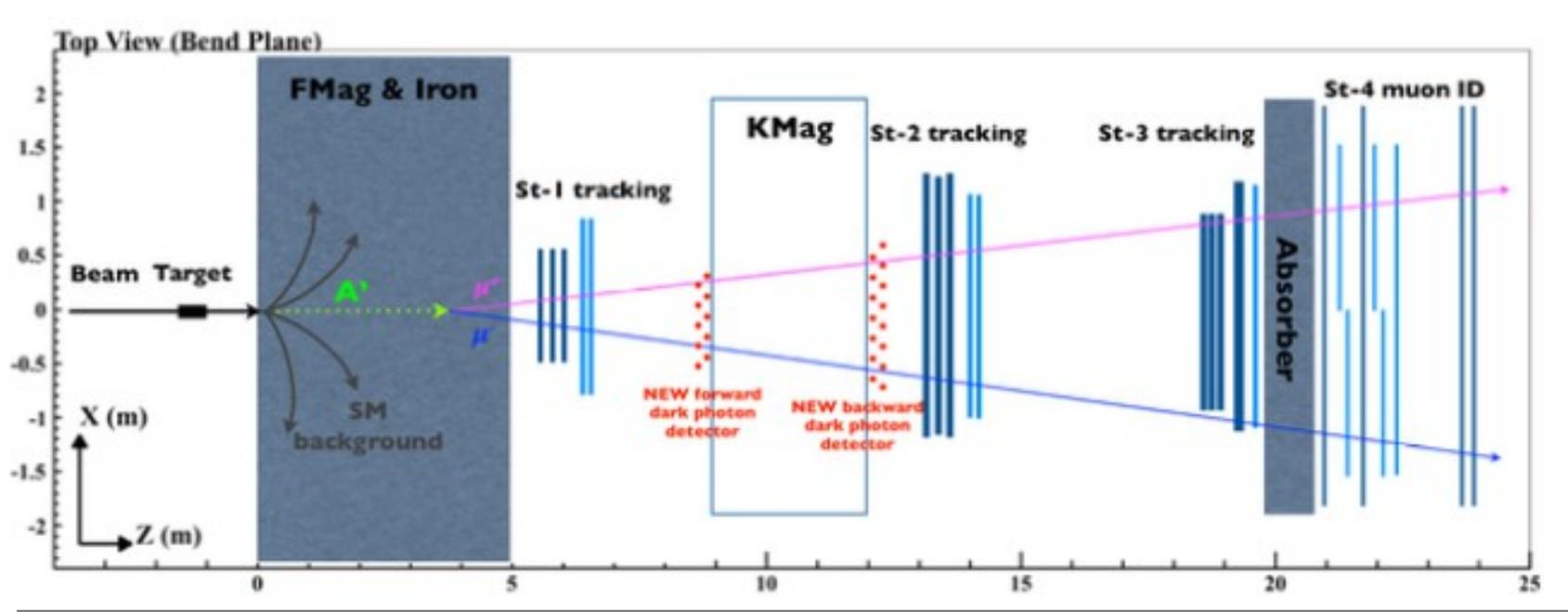# Proton beam dump Experiments & Inelastic Dark Matter

Stefania Gori

University of Cincinnati

Dark Sectors workshop 2016,
DM@Accelerators Working Group

SLAC,
April 28nd 2016

Proton beam of 120 GeV,
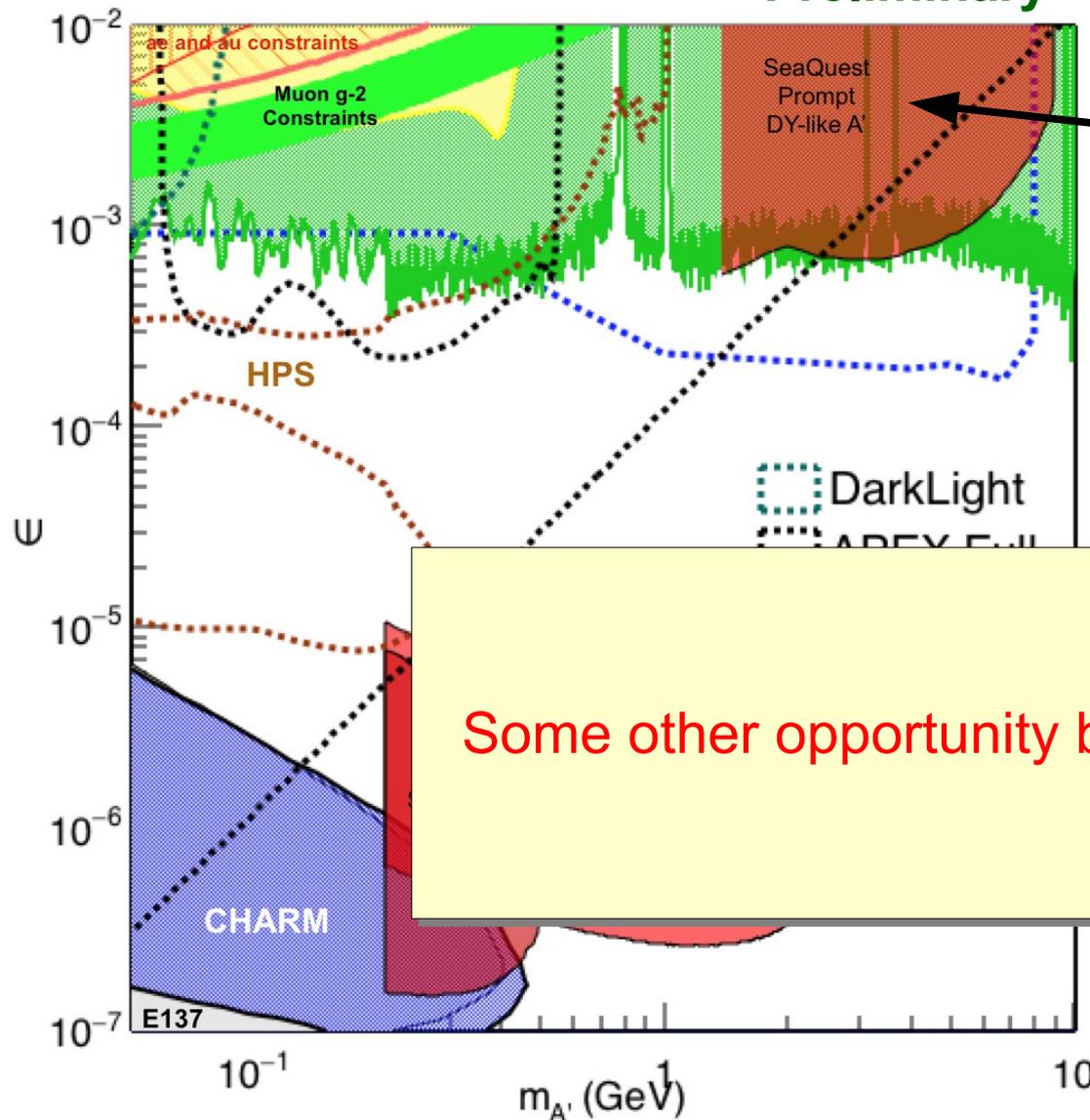
$$\sqrt{s} \sim 15.5\,\text{GeV}$$

Phase I

- Parasitic data taking with the upcoming E1039 in 2017-2019

- 1.4×10^{18} POT in 200 days
  ⟹ 47000 fb⁻¹ / year

- Displaced decay vertex trigger

In general: - What do we gain from a high intensity proton beam for our dark particle searches?

- What are the signatures we can look for?

An opportunity to test dark particles

Preliminary

Drell-Yan production
of a dark photon
decaying prompt
to two muons

Some other opportunity beyond bump hunt?

See Ming Liu talk in the visible dark photon session earlier today

The SeaQuest spectrometer could be used for di-muon non resonant searches

➡️ Chance to test Dark Matter scenarios?

The Inelastic Dark Matter (IDM) scenario is an interesting setup for a dark-sector DM

Tucker-Smith, Weiner,
0101138

The SeaQuest spectrometer could be used for di-muon non resonant searches

➡ Chance to test Dark Matter scenarios?

The Inelastic Dark Matter (IDM) scenario is an interesting setup for a dark-sector DM

Tucker-Smith, Weiner, 0101138

In a nutshell:

- Dirac spinor charged under a U(1)$_D$ symmetry $\psi = (\eta, \xi^\dagger)$

$$-\mathcal{L} \supset m_D \eta \xi + \frac{m_\eta}{2} \eta\eta + \frac{m_\xi}{2} \xi\xi + h.c.$$

It is natural that m_η, $m_\xi \ll m_D$

$$m_{1,2} = \sqrt{m_D^2 + (m_\eta - m_\xi)^2/4} \pm (m_\eta + m_\xi)/2 \implies \Delta = m_\eta + m_\xi$$
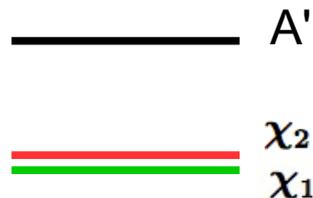
- Inelastic interaction with the dark photon:

$$A'_\mu(\chi_1^\dagger \bar{\sigma}^\mu \chi_2 - \chi_2^\dagger \bar{\sigma}^\mu \chi_1)$$

- The heavier (excited) state in unstable: $\Gamma(\chi_2 \to \chi_1 e^+ e^-) = \dfrac{4\epsilon^2 \alpha \alpha_D \Delta^5}{15\pi m_{A'}^4}$
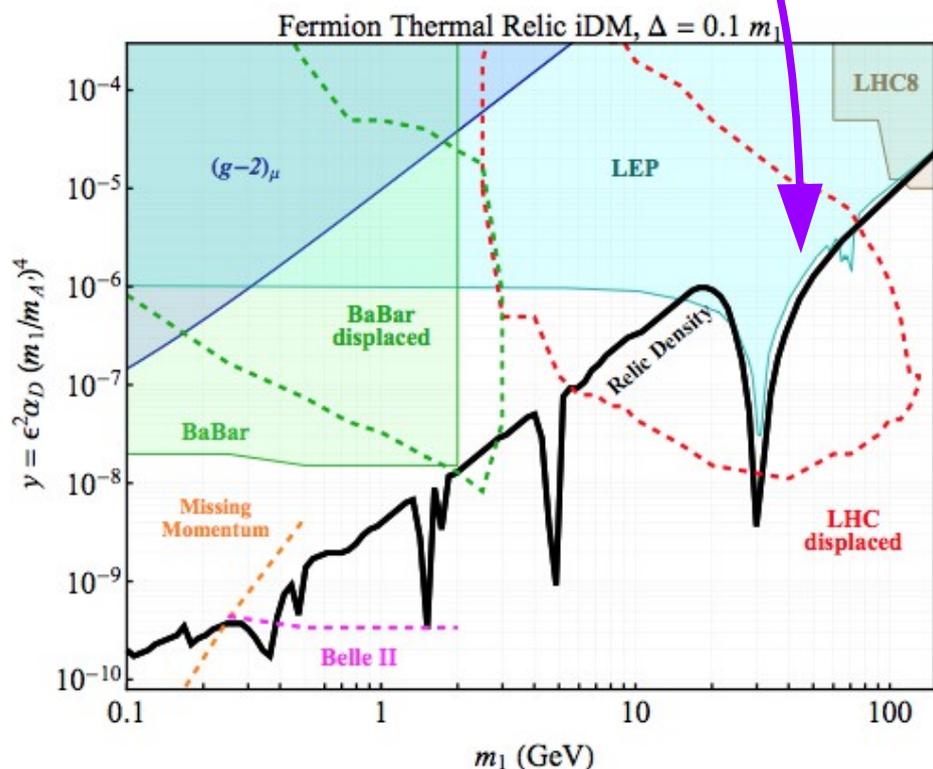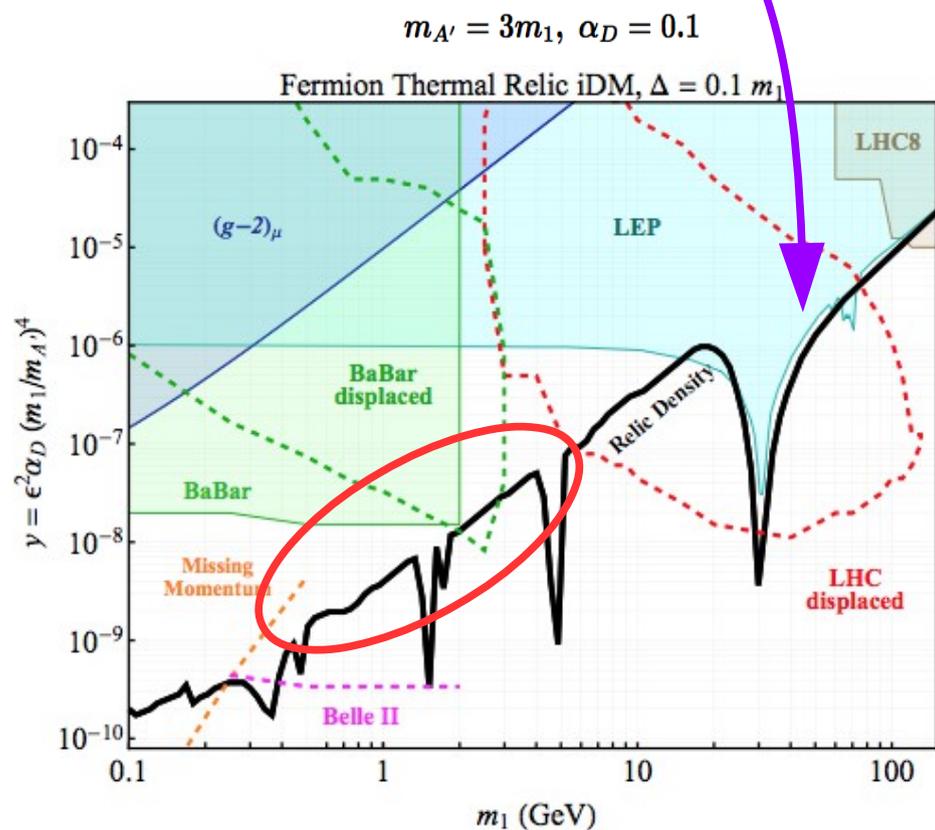
In the limit $\Delta \ll m_1 \le m_{A'}/2$
the DM annihilation rate largely depends
on only two parameters:

—————— A'

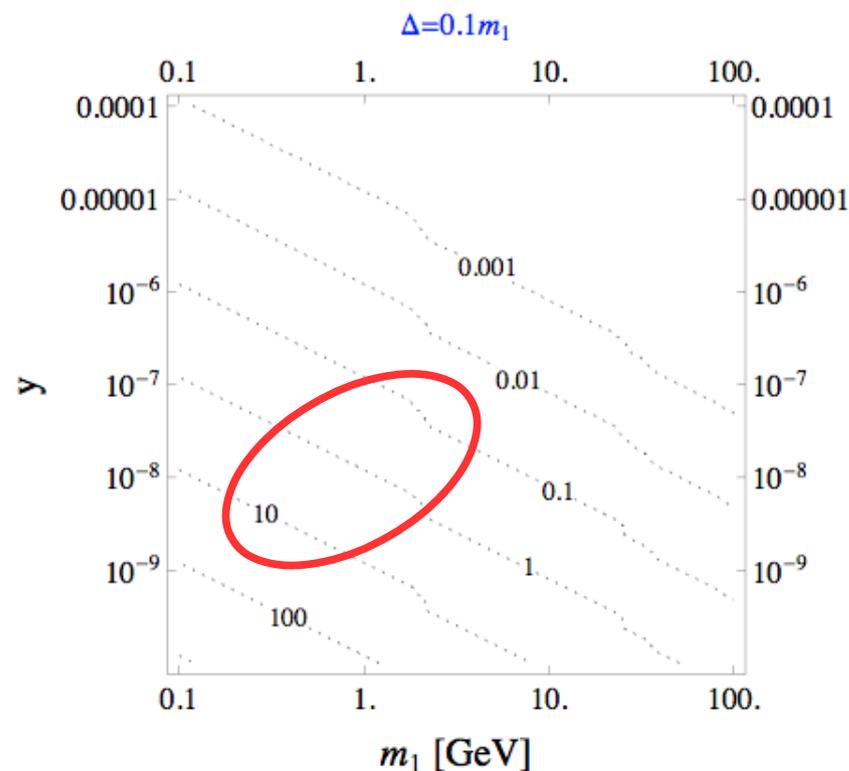$$m_1, \quad y \equiv \epsilon^2 \alpha_D \left(\frac{m_1}{m_{A'}} \right)^4$$

χ_2
χ_1

$$m_{A'} = 3m_1, \quad \alpha_D = 0.1$$

Fermion Thermal Relic iDM, $\Delta = 0.1\, m_1$

Izaguirre, Krnjaic, Shuve, 1508.03050

In the limit $\Delta \ll m_1 \leq m_{A'}/2$
the DM annihilation rate largely depends
on only two parameters:

$$\Gamma(\chi_2 \to \chi_1 e^+ e^-) = \frac{4\epsilon^2 \alpha \alpha_D \Delta^5}{15\pi m_{A'}^4}$$

$$m_1, \quad y \equiv \epsilon^2 \alpha_D \left(\frac{m_1}{m_{A'}}\right)^4$$

For these values of y,
the DM excited state is typically long lived

$m_{A'} = 3m_1, \ \alpha_D = 0.1$

Izaguirre, Krnjaic, Shuve, 1508.03050

$\Delta = 0.1 m_1$

Life time in meters

μ (e)

(A')*

A'

χ_2

χ_1
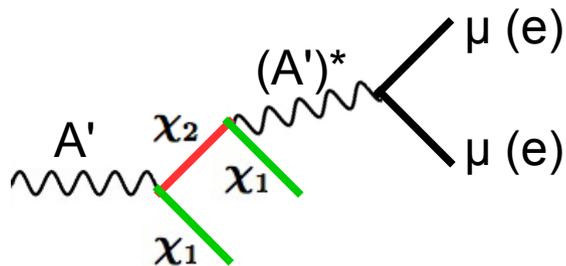
χ_1

μ (e)
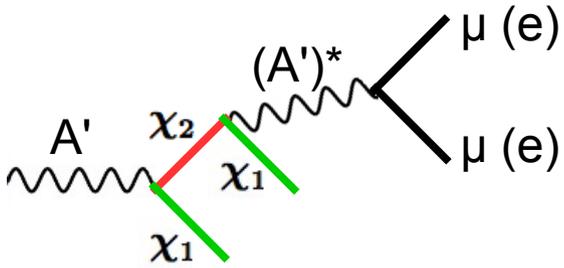
Izaguirre, Krnjaic, Shuve, 1508.03050
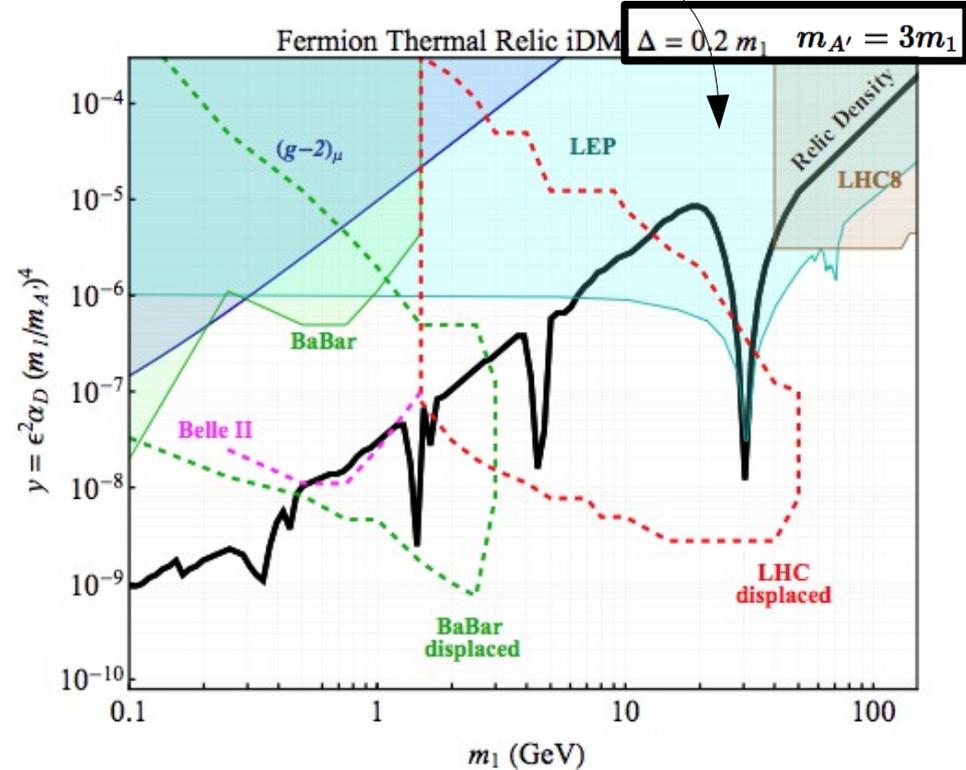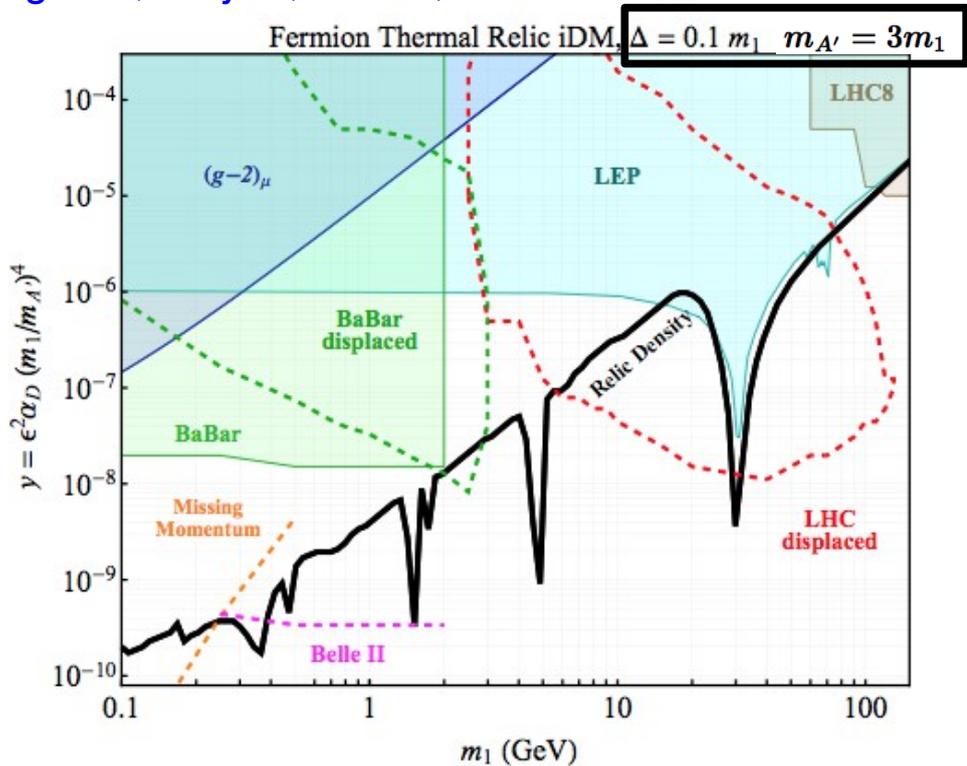
Because of the dark-photon-Z mixing
Hook, Izaguirre, Wacker, 1006.0973
Curtin, Essig, SG, Shelton, 1412.0018

Reinterpretation of BABAR-CONF-08/019: Y(3S), Mono-γ + MET

Proposed search @ Babar: Mono-γ + displaced tracks + MET

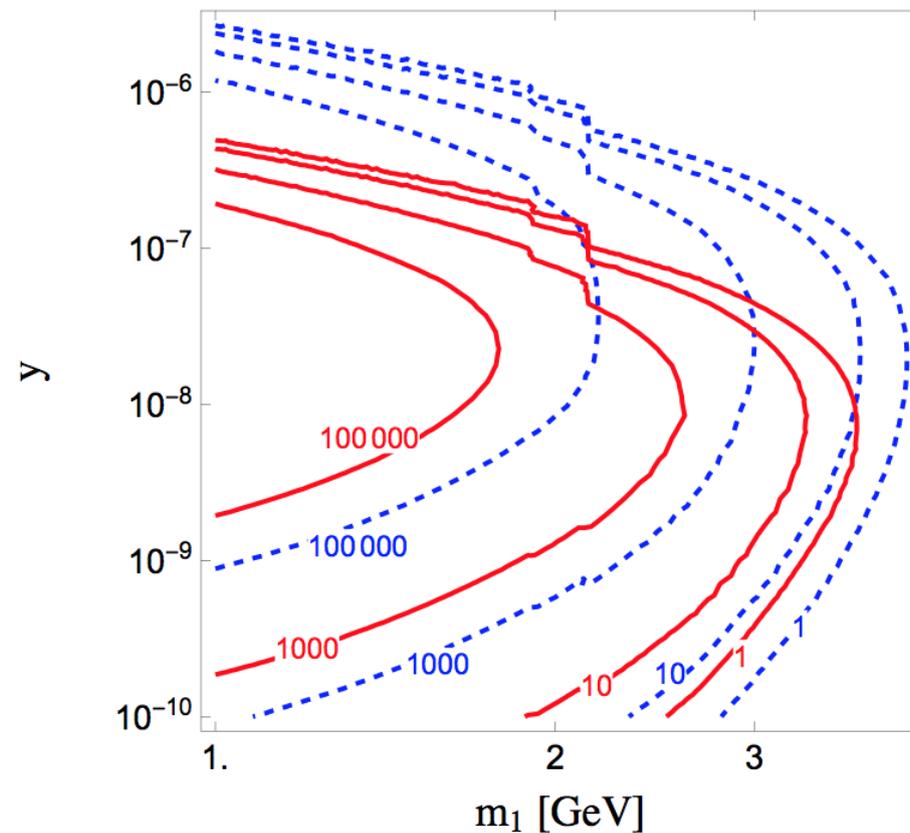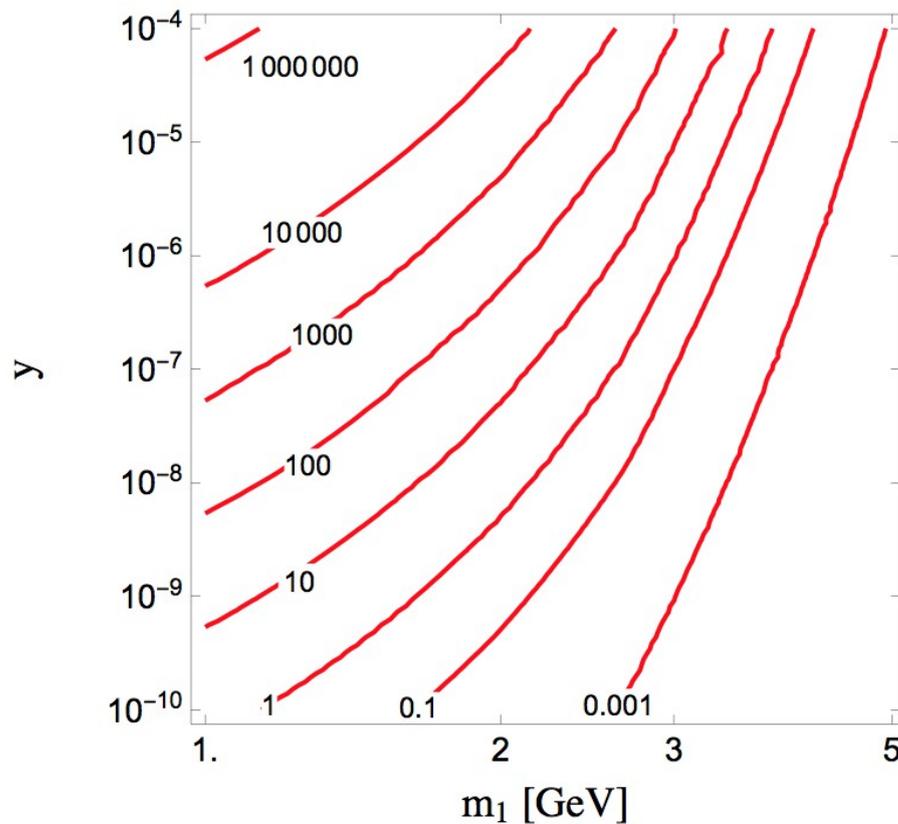Proposed search @ LHC: (boosted) jet + displaced di-muon jet + MET

SG, Schuster, Toro, to appear

Requirement of displacement:

N. raw events after 2 years parasitic run

Production in fb

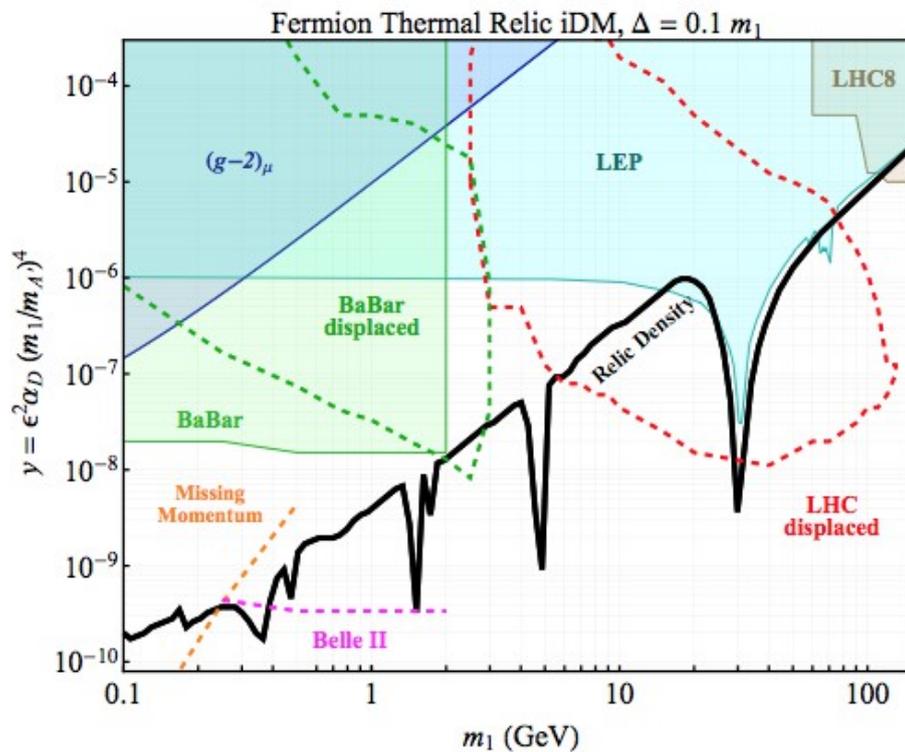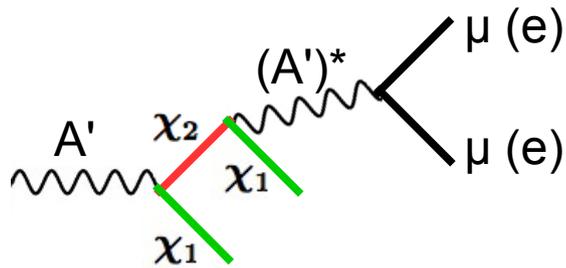Preliminary

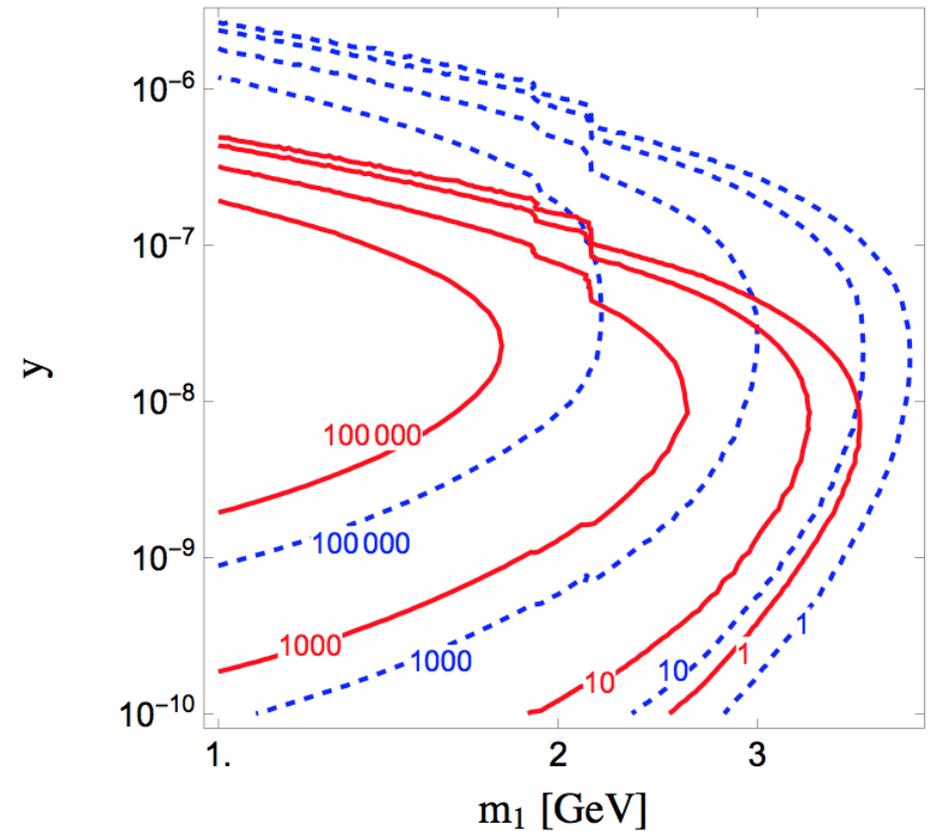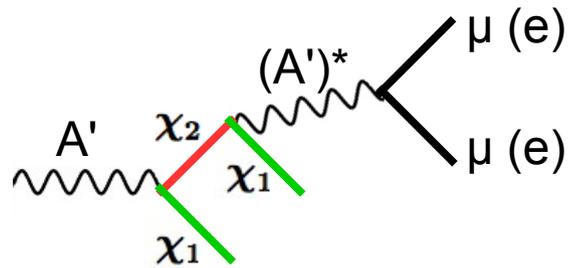$$\Delta = 0.1 m_1, \quad m_{A'} = 3 m_1$$

L = (5,7)m

L = (1,10)m

μ (e)

(A')*

A' χ₂

χ₁

μ (e)

χ₁

Requirement of displacement:

N. raw events after 2 years parasitic run

$\Delta = 0.1 m_1, \quad m_{A'} = 3m_1$

Preliminary

—— L = (5,7)m
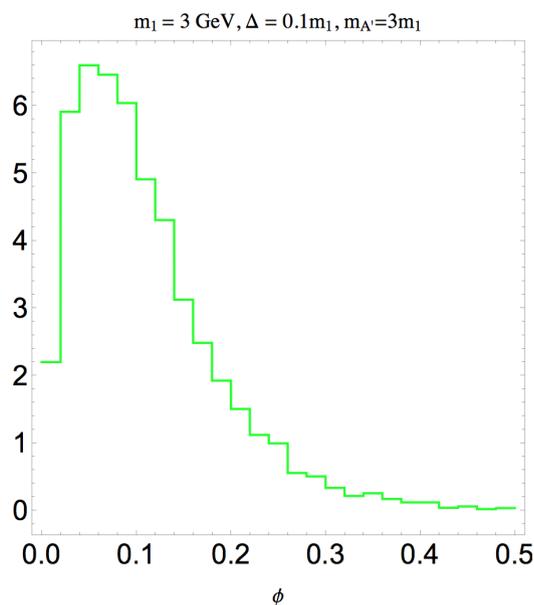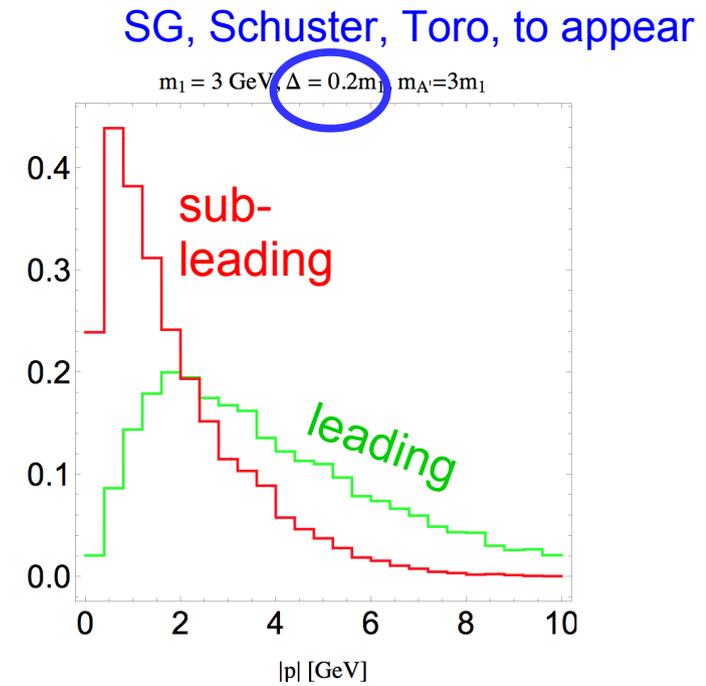
- - - L = (1,10)m

Some kinematics + questions
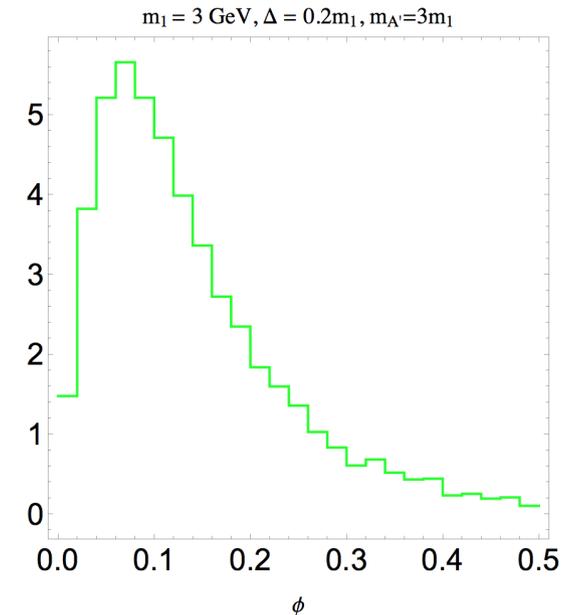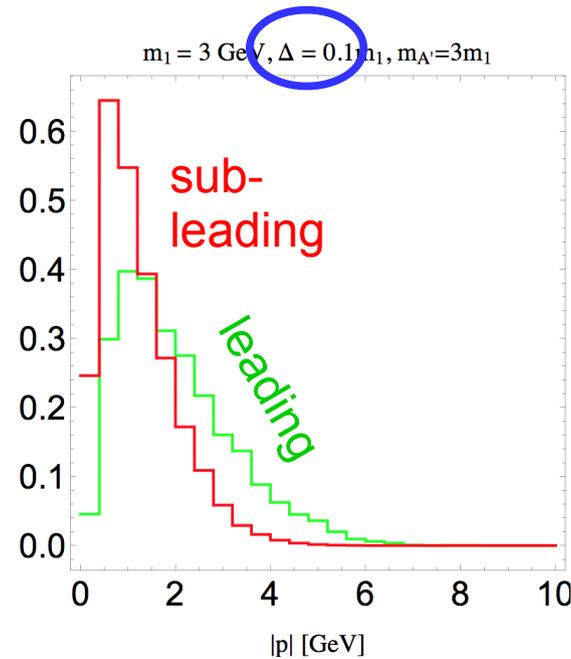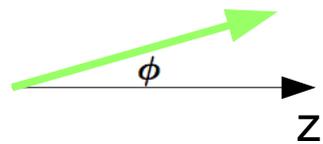
Conclusions

Proton beam dump experiments

- Interesting setup for looking for Dark particles. Huge rates!

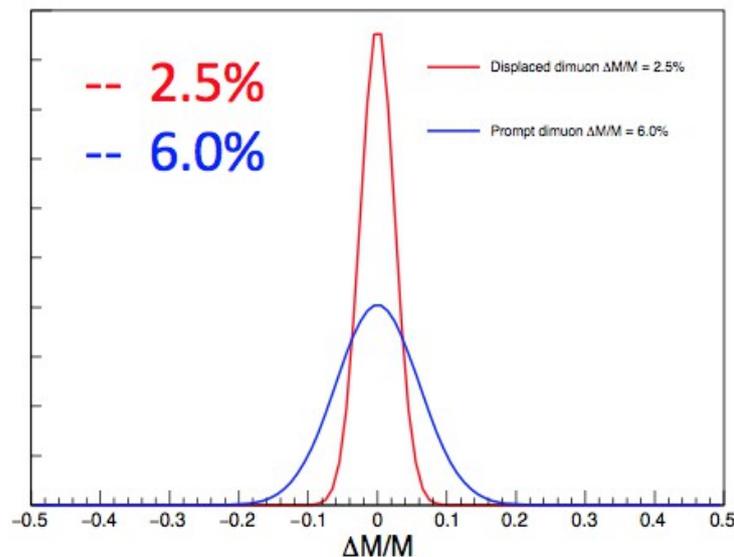- Beyond di-muon bump-hunt, an experiment like Seaquest
  - can efficiently look for displaced signatures
  - Unique opportunity to test the remaining parameter space of Inelastic Dark Matter (IDM) models

- Additional "dark signatures" to look for?

What about lower masses?

Mass resolution is a problem

**From studies
of the J/Ψ meson:**

-- 2.5%
-- 6.0%

This corresponds to
ΔM ~ 200 MeV

Going to lower masses:

Mass resolution dominated by
multiple scattering:

$$m_{\mu\mu} \sim \sqrt{p_1 p_2}(\theta_1 + \theta_2)$$

$$\Delta\theta_1 \sim \Delta\theta_2 \sim 13.6\,\text{MeV}\sqrt{T}$$

$$\Delta M \sim \sqrt{2}\,13.6\,\text{MeV}\sqrt{T} \sim 320\,\text{MeV}$$

$$T \sim 300$$
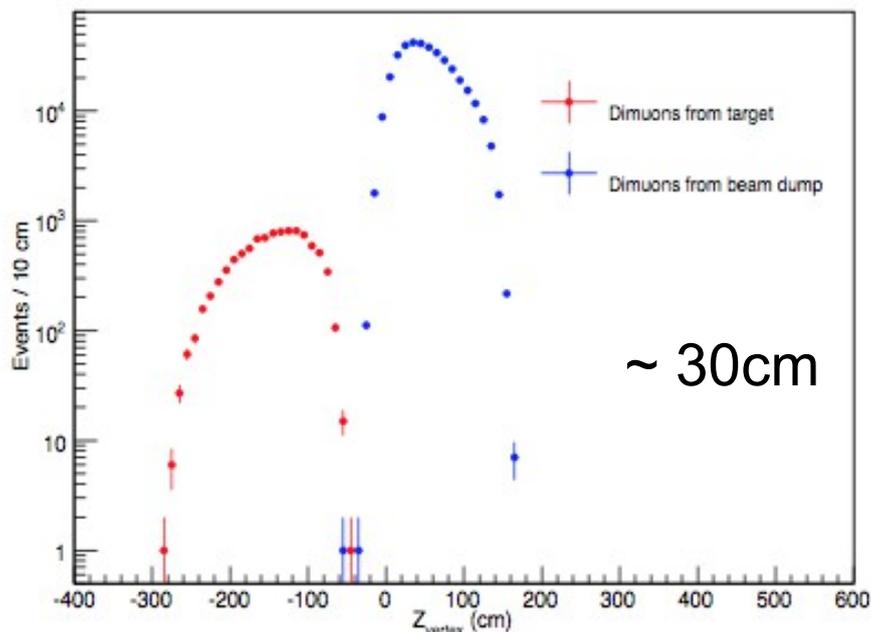for 5m of iron

6% ⟶ 30 MeV @ 500MeV!

Access to very small values of ε, from DY production
with dark photon displaced decay?

Vertex resolution:

At higher masses

~ 30cm

At lower masses:

Multiple scattering affect
the vertex resolution for muons

$$\sigma_z \propto \frac{13.6\,\mathrm{MeV}\sqrt{T}z}{M}$$

$$\sigma_z \sim 2\,\mathrm{m} \quad \text{for M ~ 350 MeV}$$