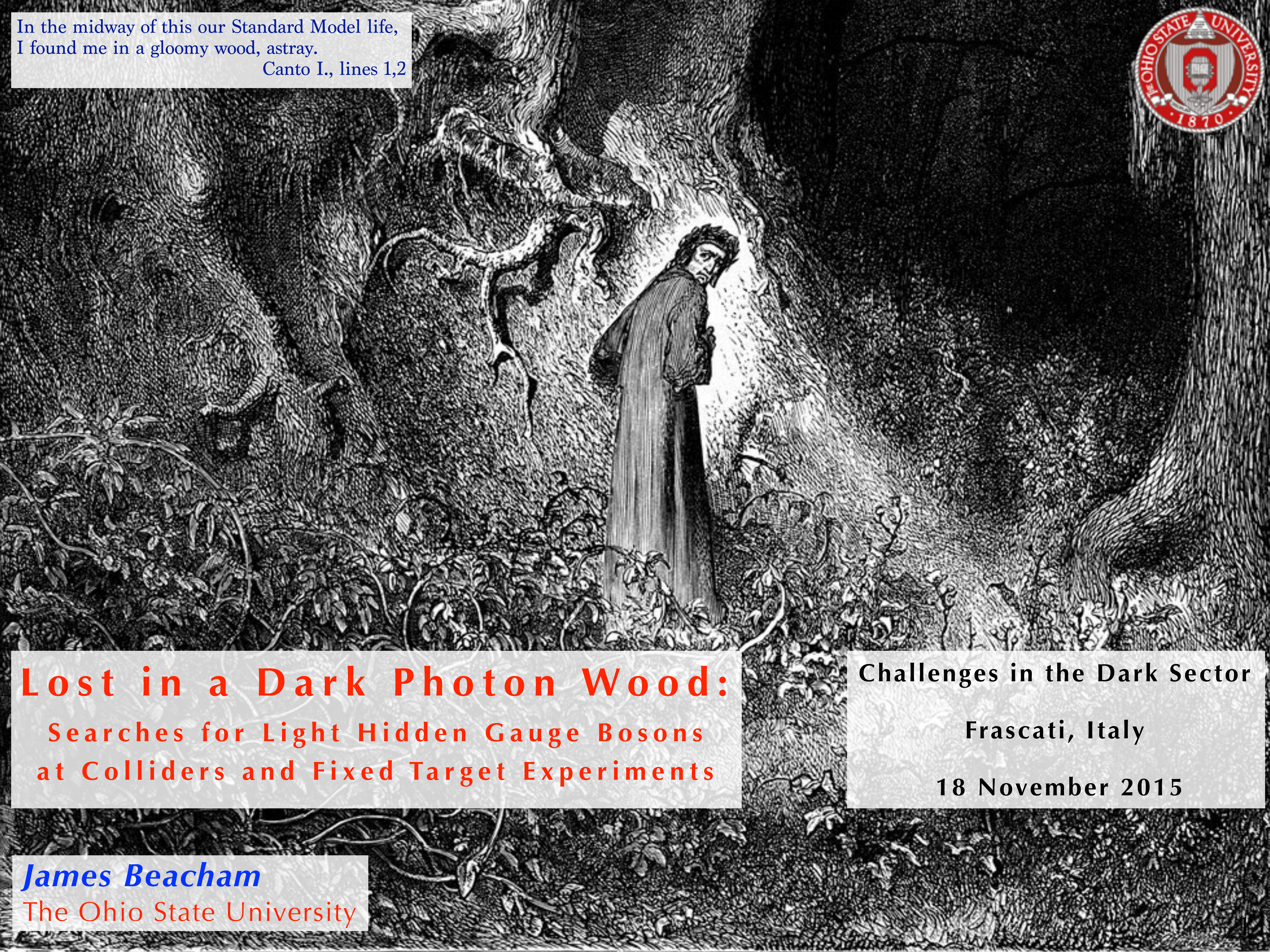


In the midway of this our Standard Model life,
I found me in a gloomy wood, astray.
Canto I., lines 1,2

Lost in a Dark Photon Wood:

Searches for Light Hidden Gauge Bosons at Colliders and Fixed Target Experiments

Challenges in the Dark Sector

Frascati, Italy

18 November 2015

James Beacham
The Ohio State University

Outline

Light hidden gauge bosons at colliders and fixed target experiments

Existence

Tension

Dark photon redemption

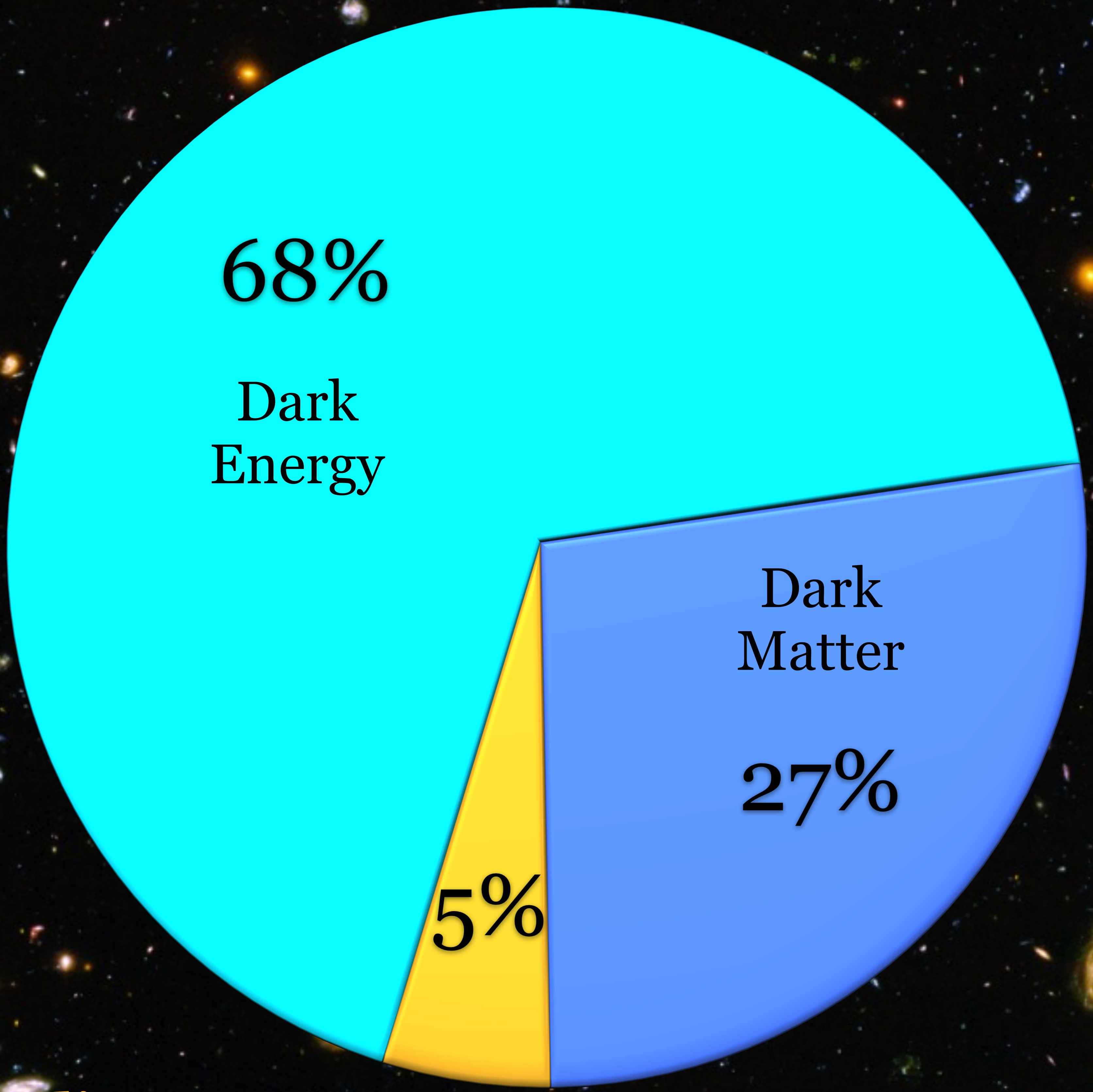
Explosion of experimental activity

The search

The future

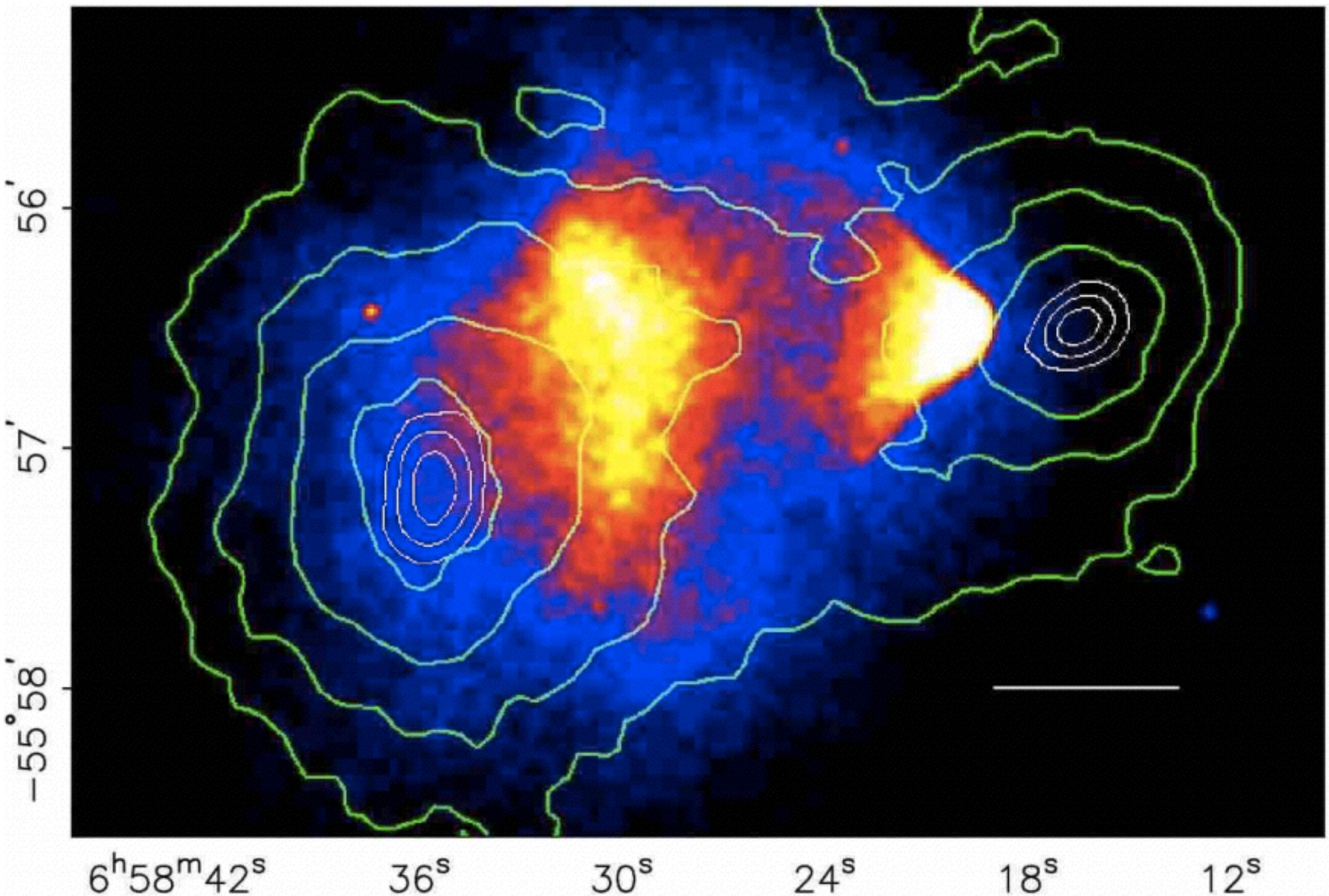
What exists?

What exists?



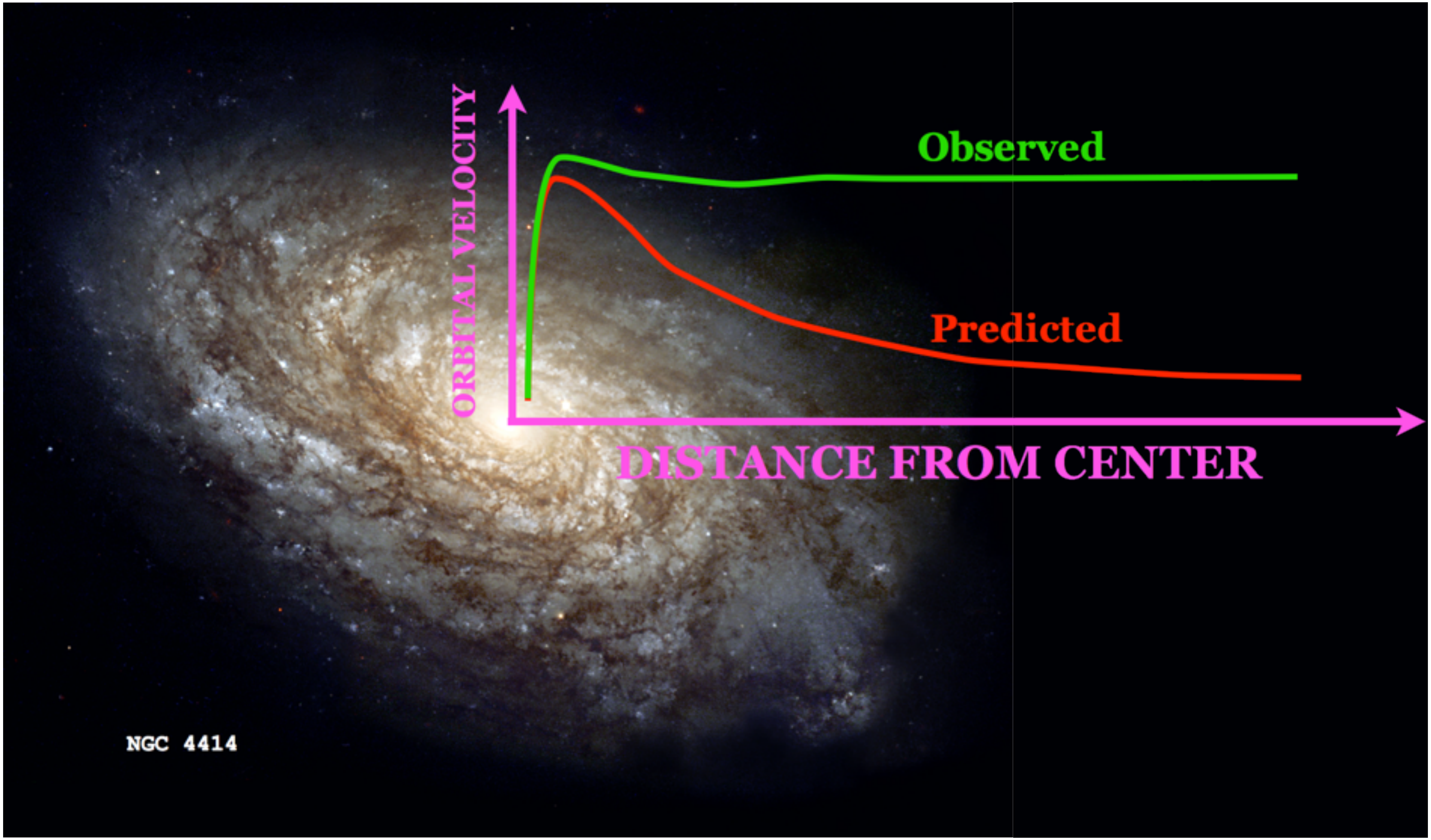
Ordinary Matter

Dark matter exists



astro-ph:0608407

Gravitationally interacting dark matter exists

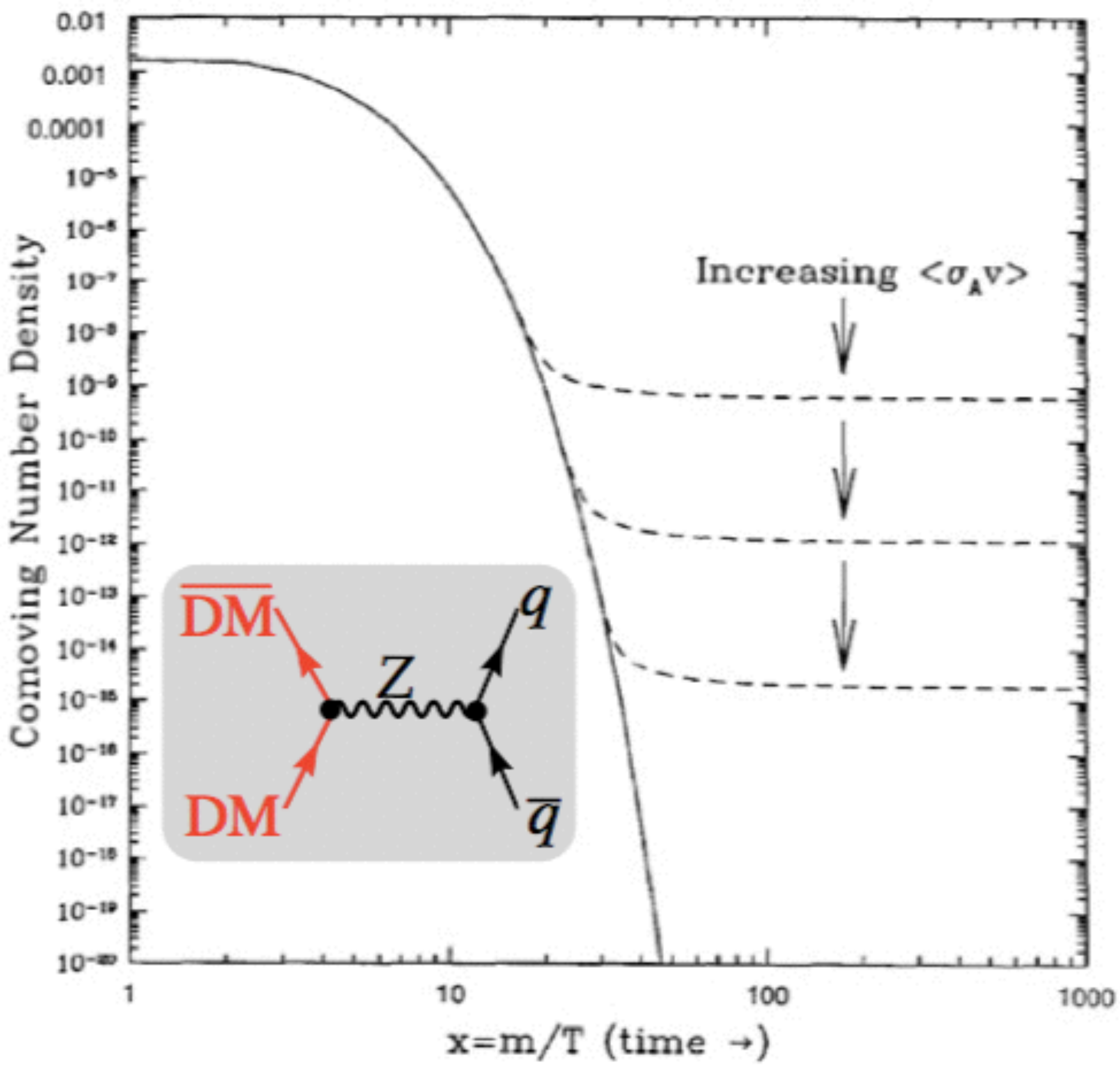


Does it only interact gravitationally?

If so, abandon all hope.

Does dark matter interact non-gravitationally?

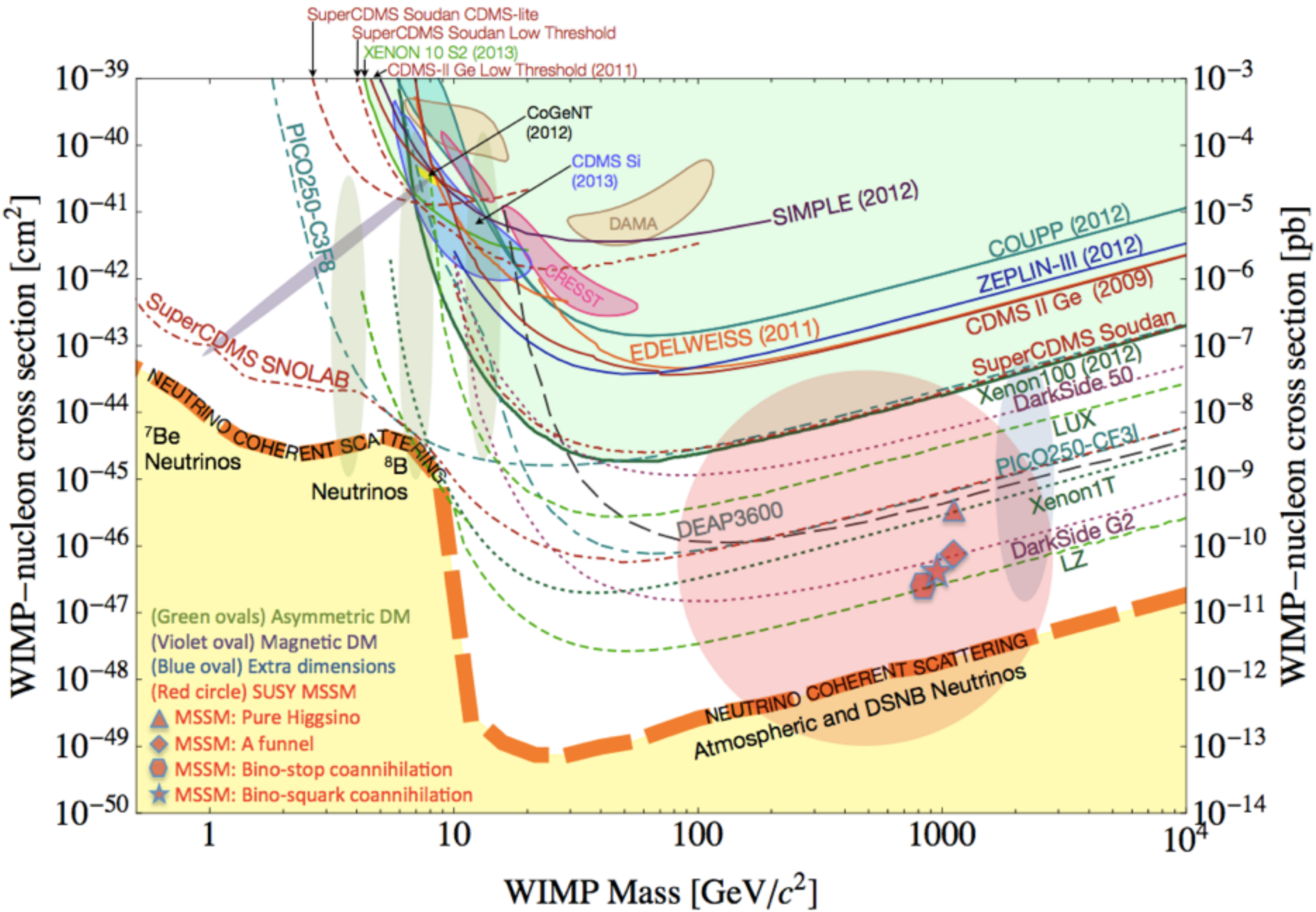
Simple thermal-origin argument suggests weak-scale interactions.



For ~100 GeV DM mass, weak-scale mediators provide reasonable annihilation rate and range of DM-scattering rates

==> the WIMP scenario.

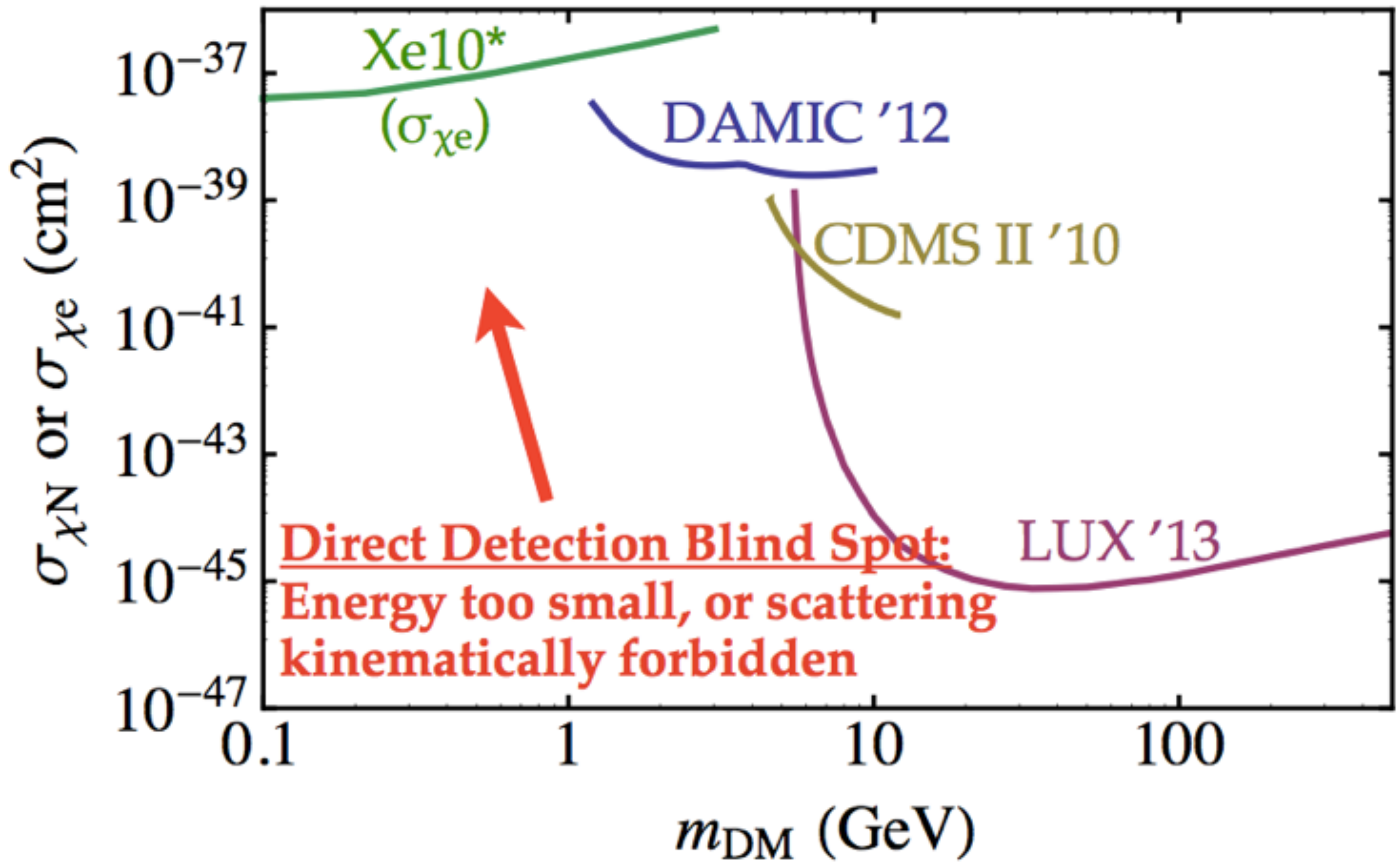
The WIMP scenario in tension



Beyond the WIMP scenario

Expanding our horizons

What about low-mass or light dark matter *in the vicinity of* the weak scale?



Philip Schuster

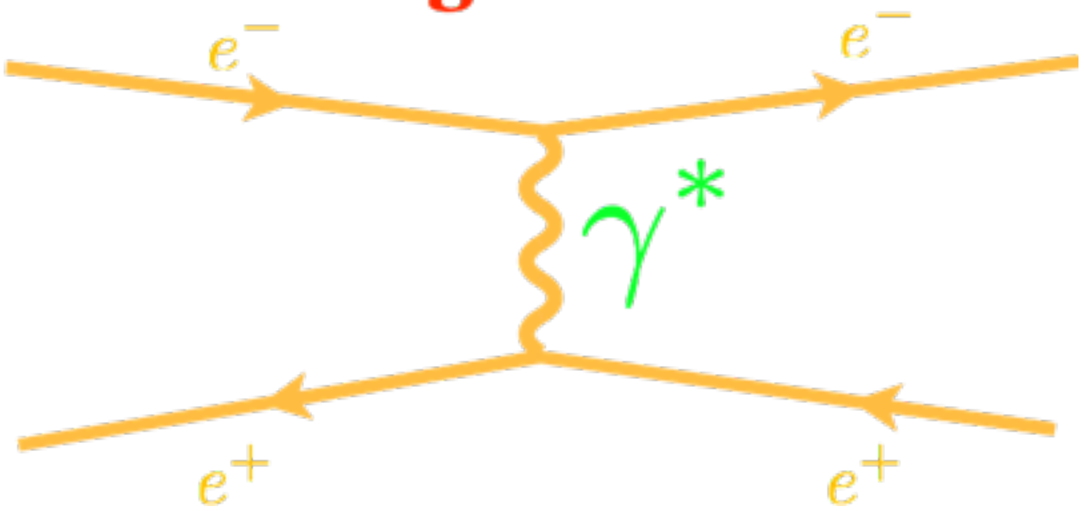
Direct detection experiments are limited in this range.

Perhaps dark matter is charged under a new force.

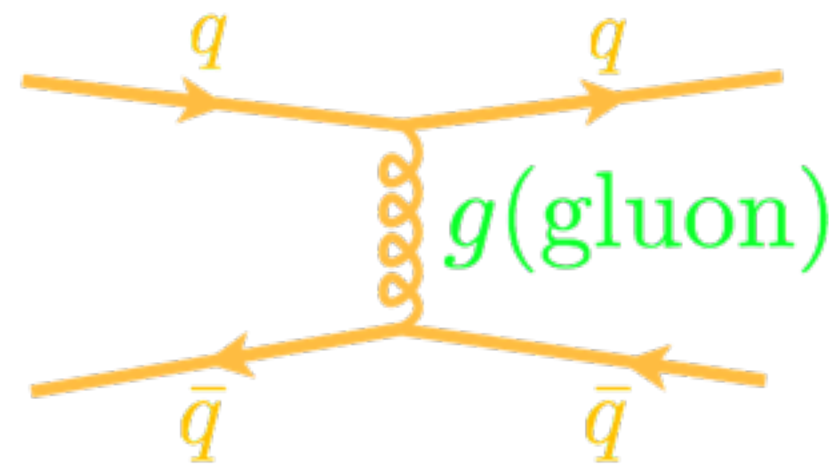
New forces

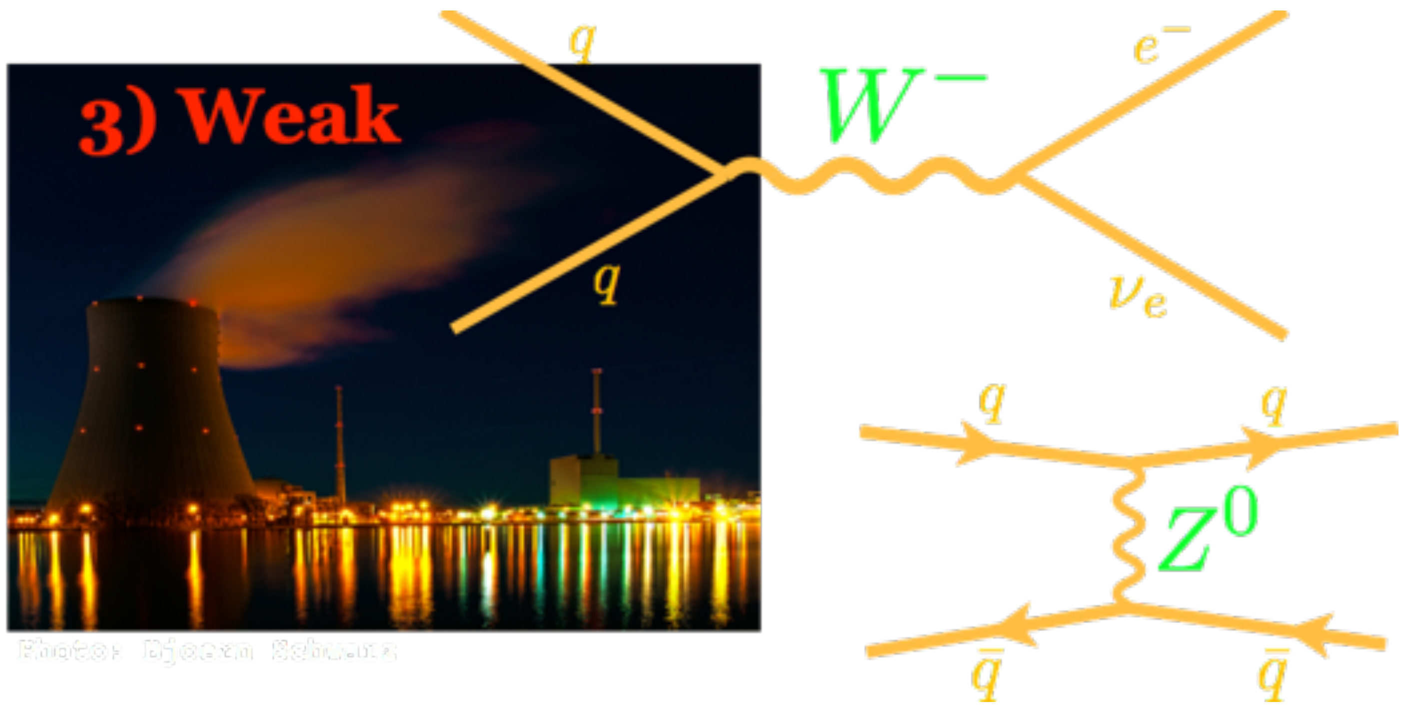
Forces that we care about at colliders

1) Electromagnetism



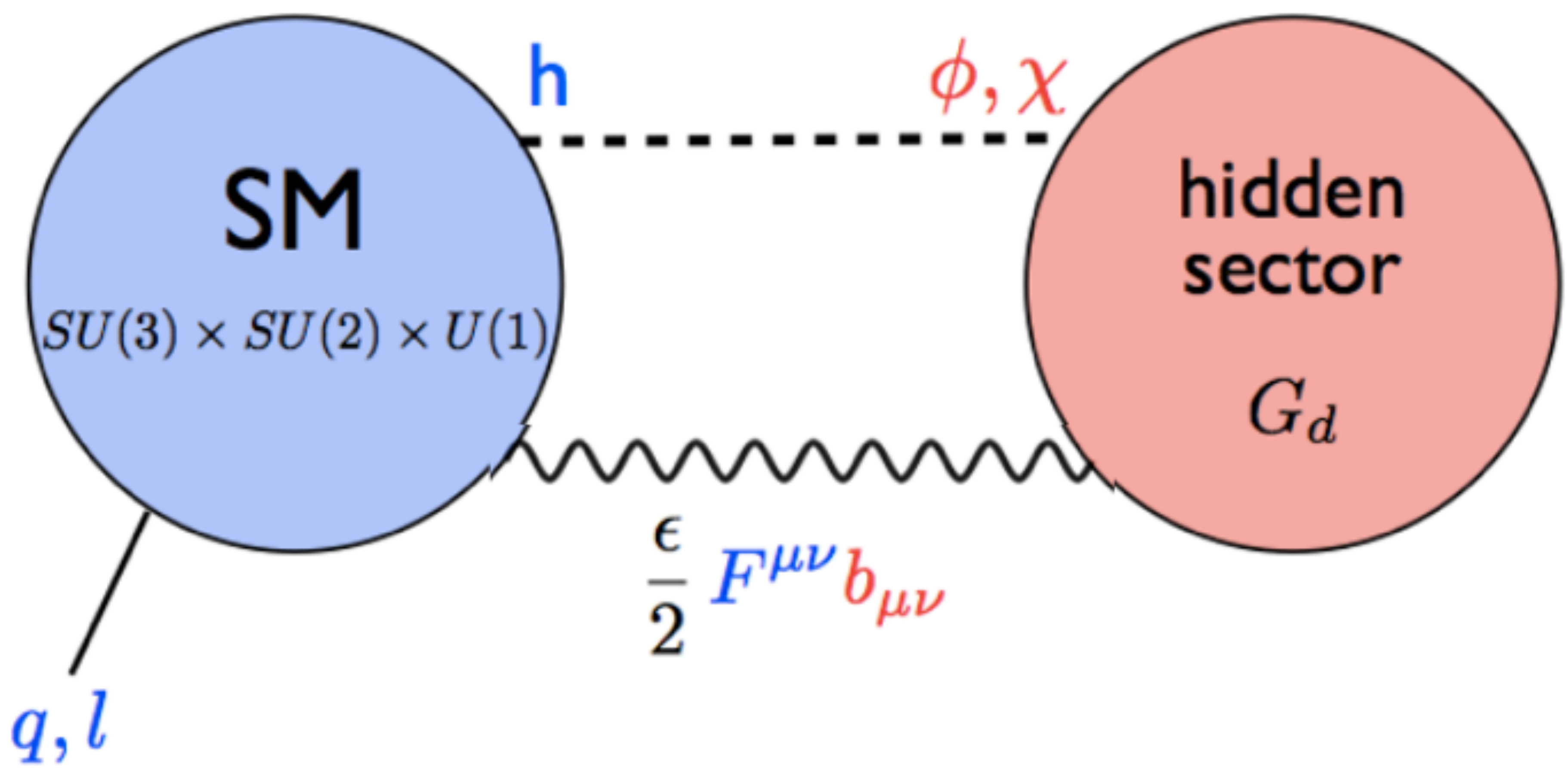
2) Strong





But is that it?

How could we have missed new forces?



Only a few allowed ways:

1) Neutrino portal — heavy neutral leptons

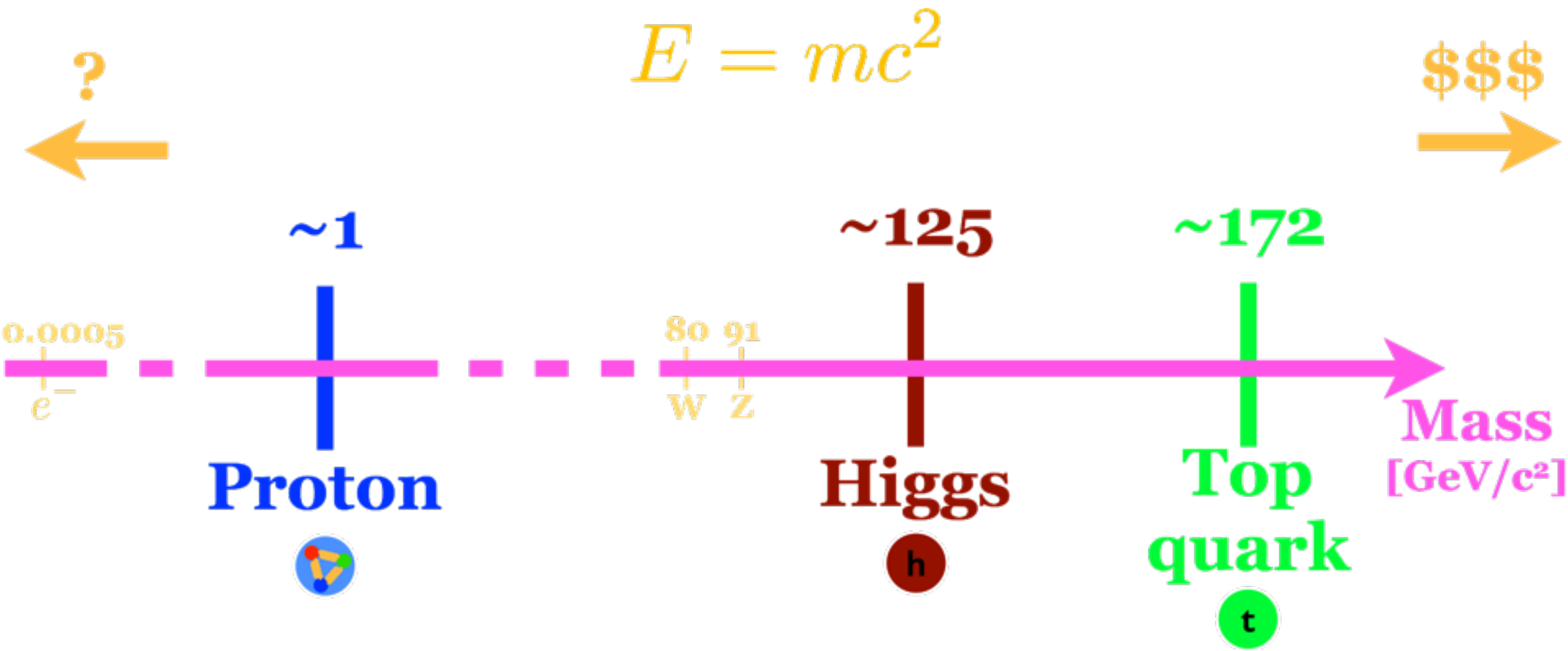
2) Higgs portal — exotic decays of h125

3) Vector portal — kinetic mixing of SM and hidden gauge groups

—> New forces = new hidden gauge bosons

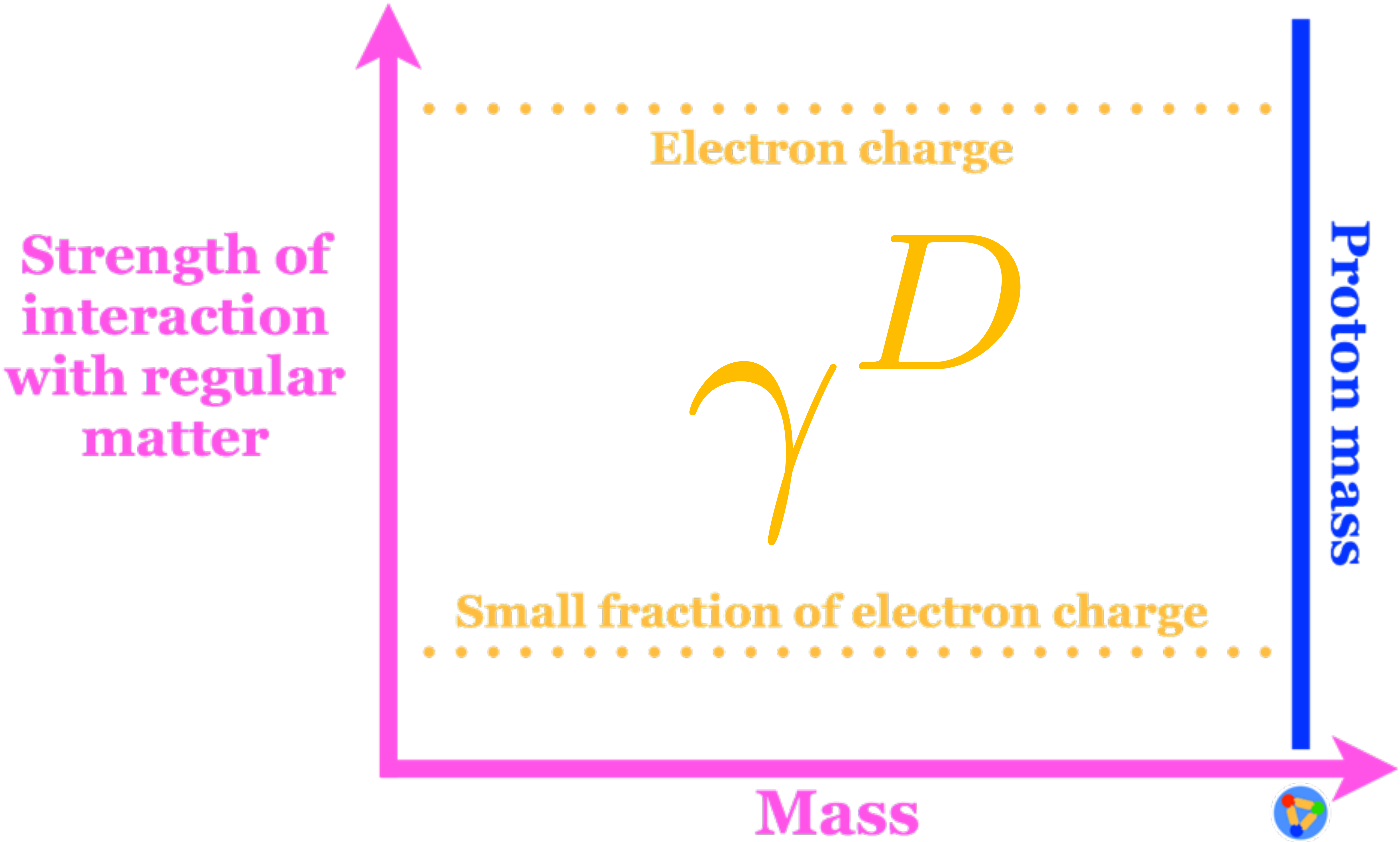
How could we have missed new forces?

One way: The gauge bosons associated to these forces are super massive.



How could we have missed new forces?

Another way: The gauge bosons have a very small mass…



…and couple *very slightly* to Standard Model particles.

A new (old), low-ish mass hidden gauge boson

U(1) extension of the Standard Model

Old-school idea

- Holdom, Phys.Lett. B166 (1986) 196
- Galison, Phys.Lett. B136 (1984); Manohar
- Later revisitation/developments: Fayet, Pospelov, et al.

γ^D

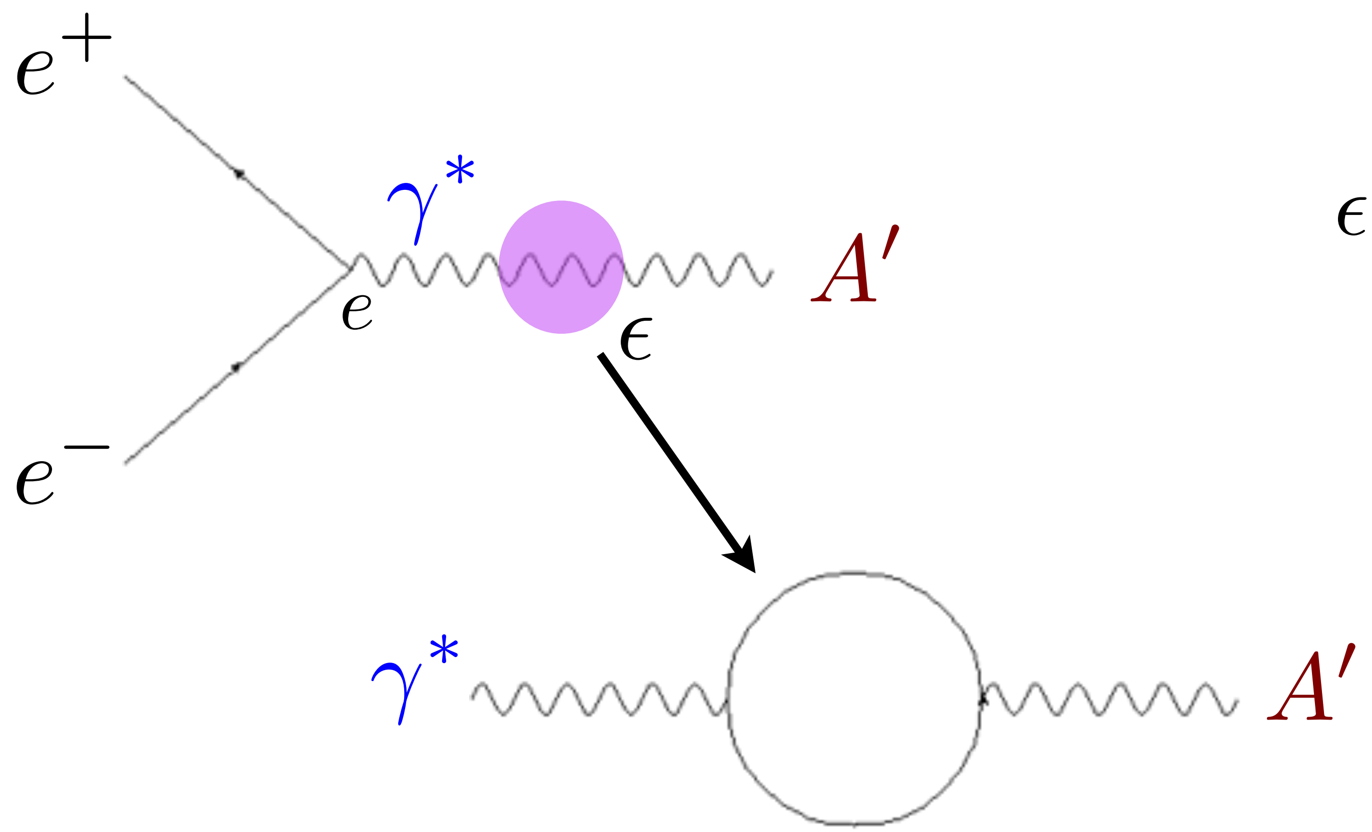
Dark photon
A′
Heavy photon
Z_{dark}
Hidden photon
U-boson
etc.

Kinetic mixing

- Lagrangian contains a term

$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

Note: $\alpha'/\alpha = \epsilon^2$



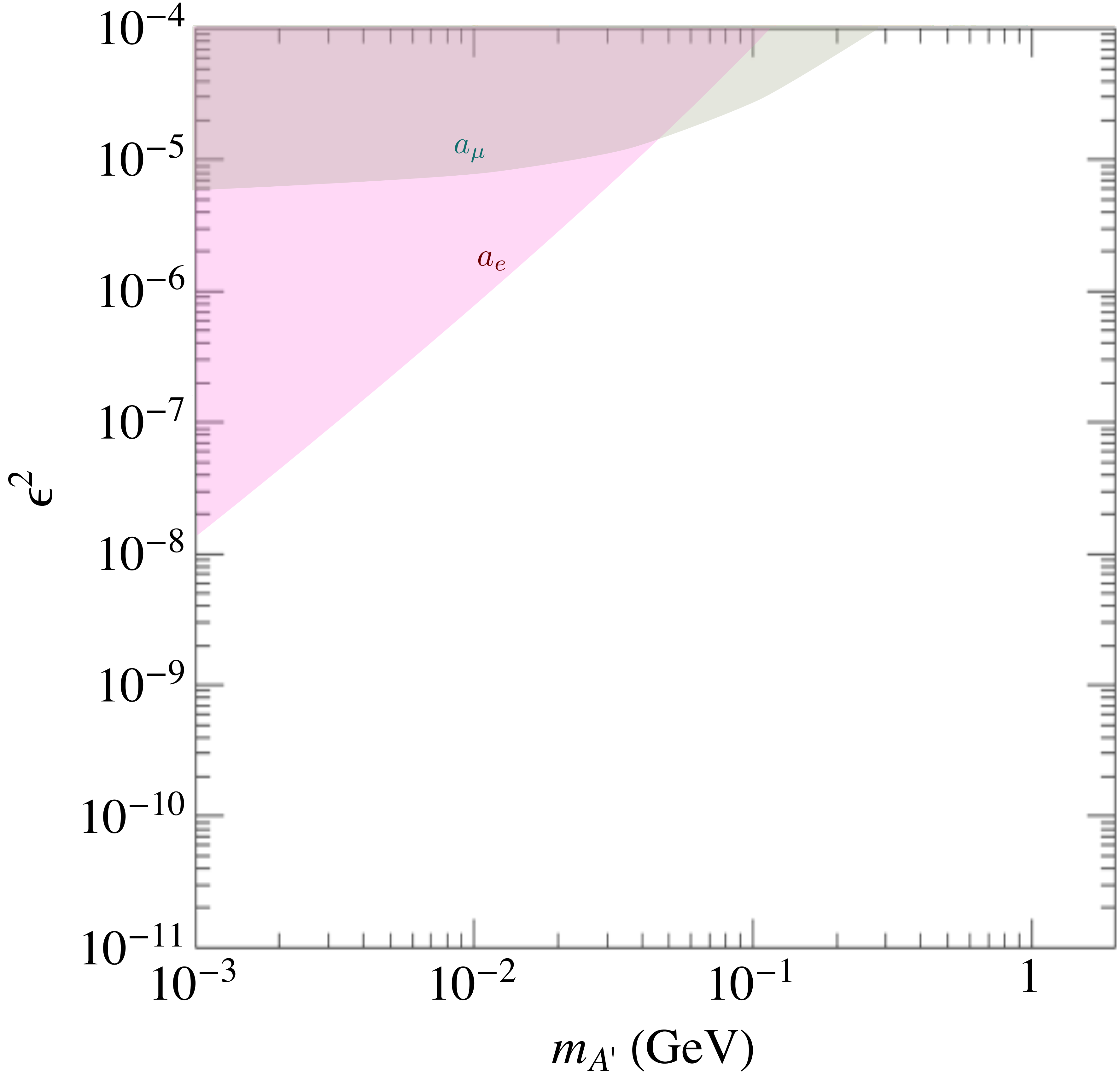
$$\epsilon_Y = \epsilon \cos\theta_W$$

$$\epsilon = g'/e$$

$$\epsilon \sim 10^{-6} - 10^{-2}$$

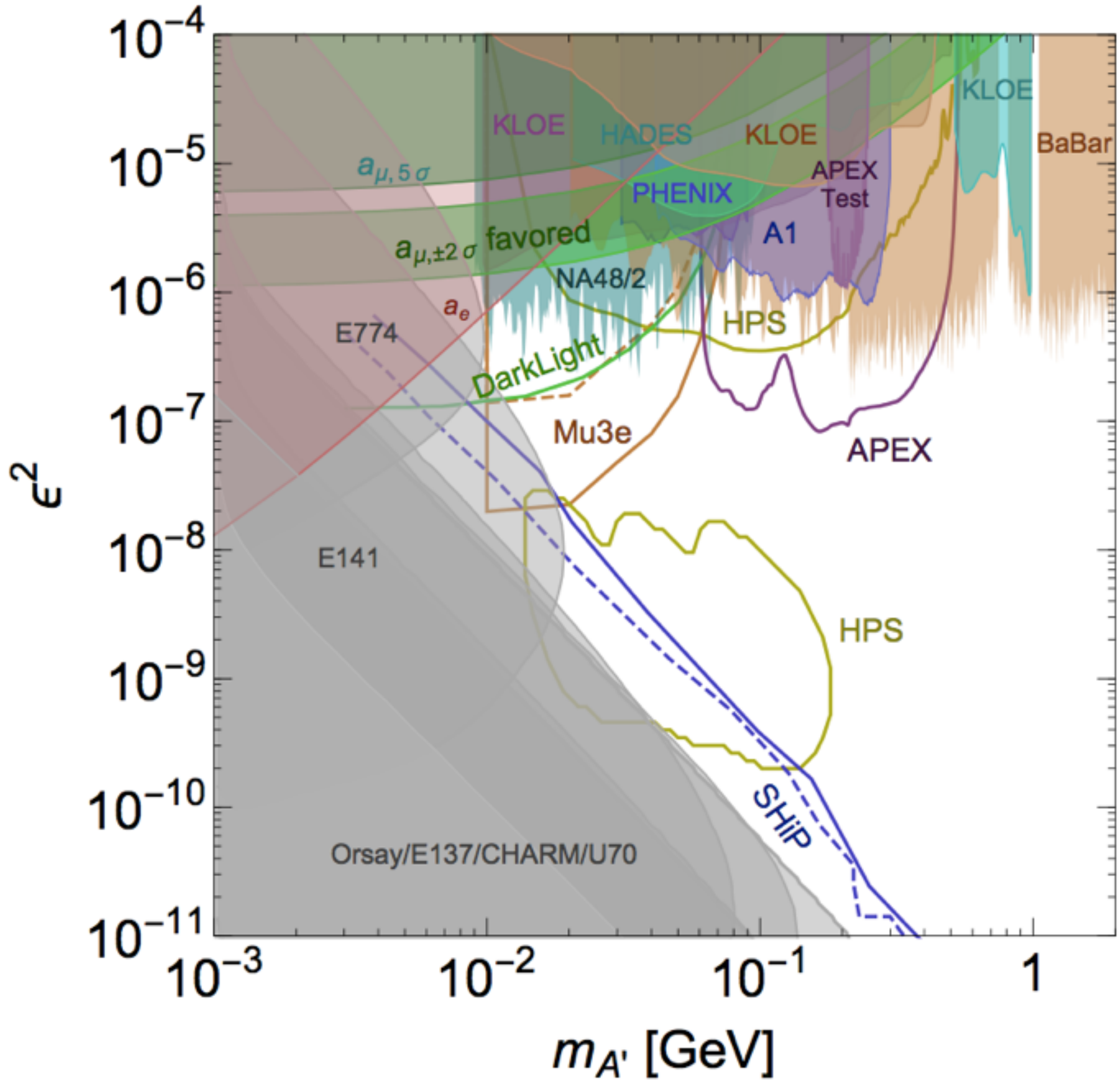
$$m_{A'} \sim \text{MeV} - \text{GeV}$$

Existing constraints



2008

Existing constraints



Now

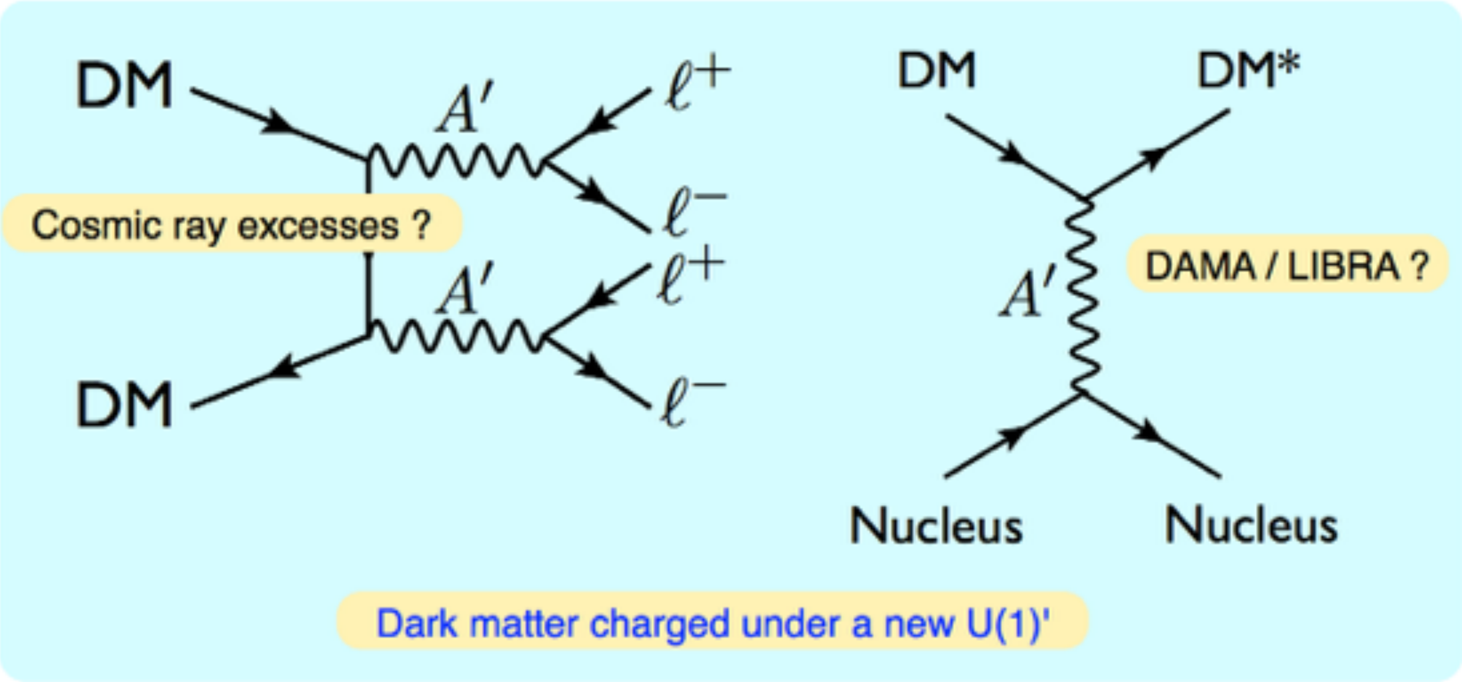
What happened?

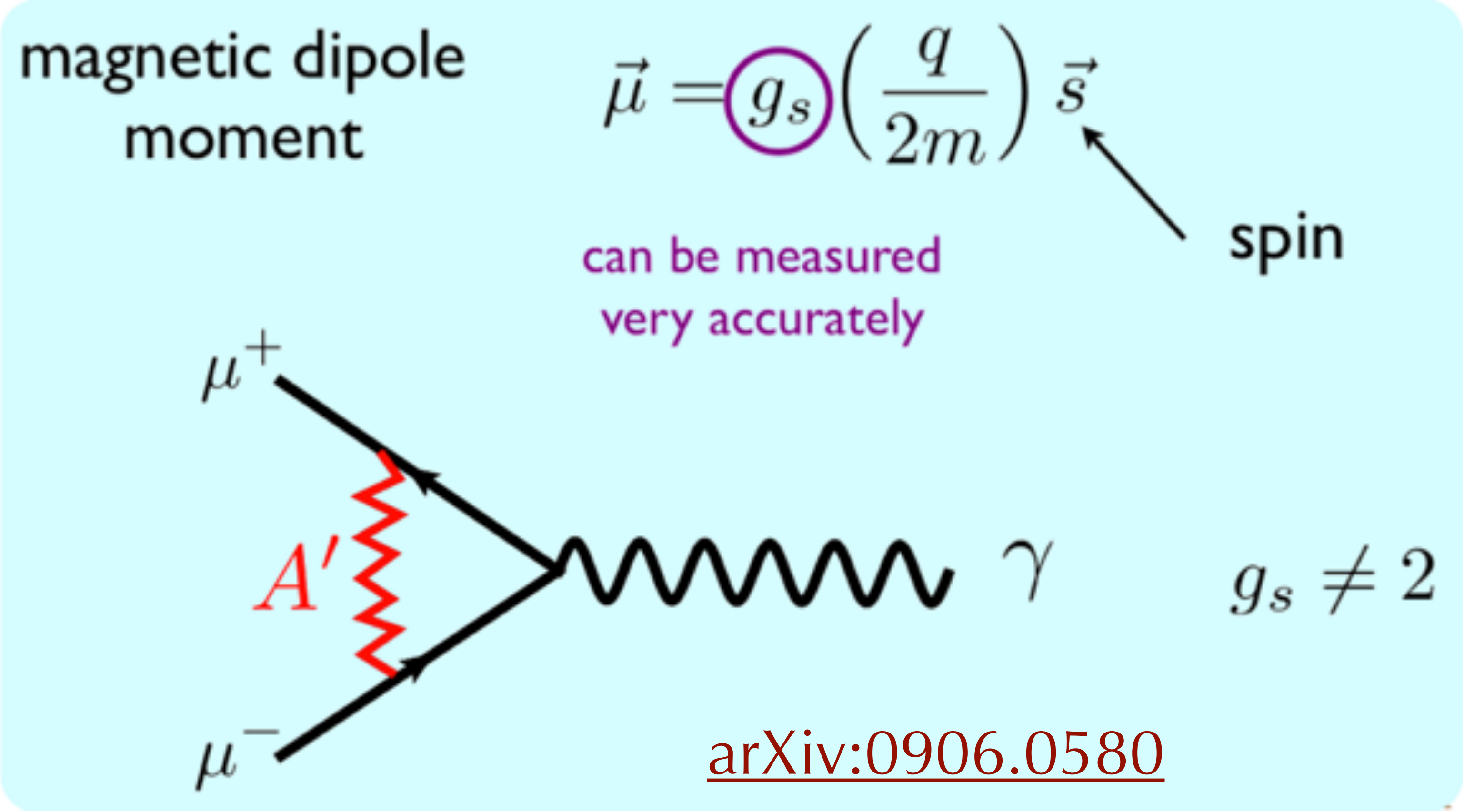
Two realizations and one reminder.

Explosion of interest in dark photons at colliders

1) The realization that a dark photon in this range could explain a lot of things.

A sub-GeV mass for the A' could explain dark matter anomalies...

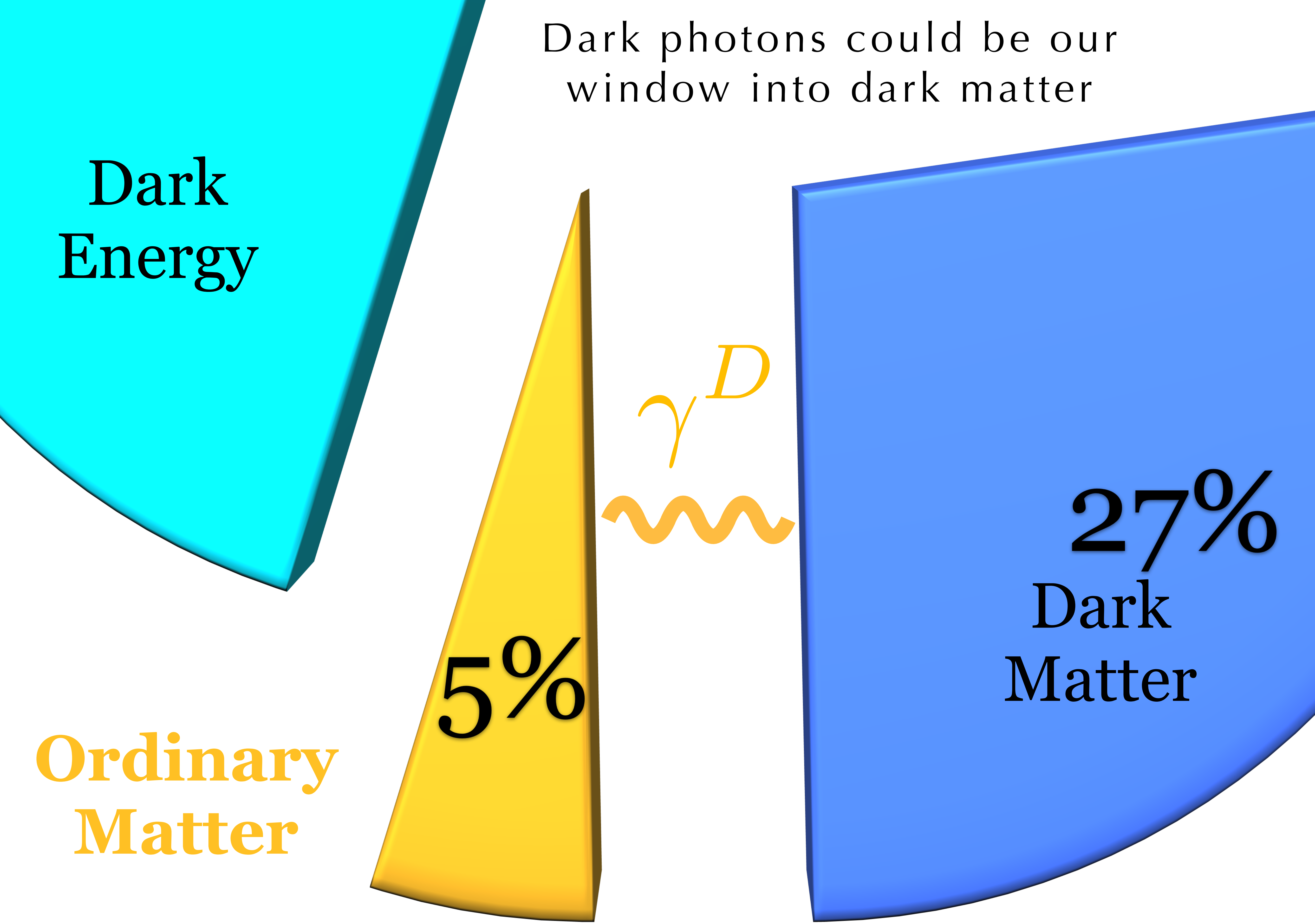




arXiv:0906.0580

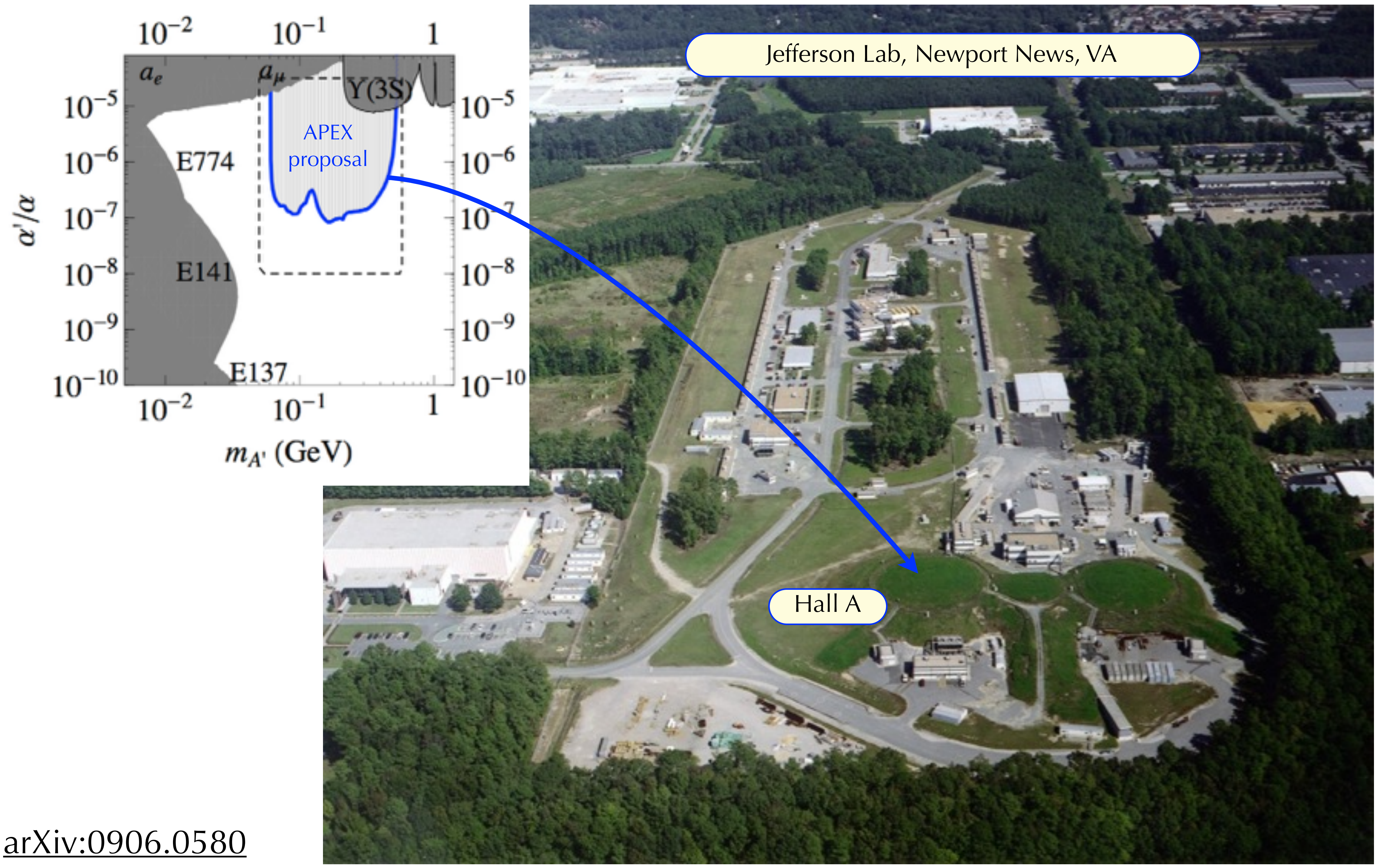
...and the anomalous magnetic moment of the muon

Dark photons could be our window into dark matter



Explosion of interest in dark photons at colliders

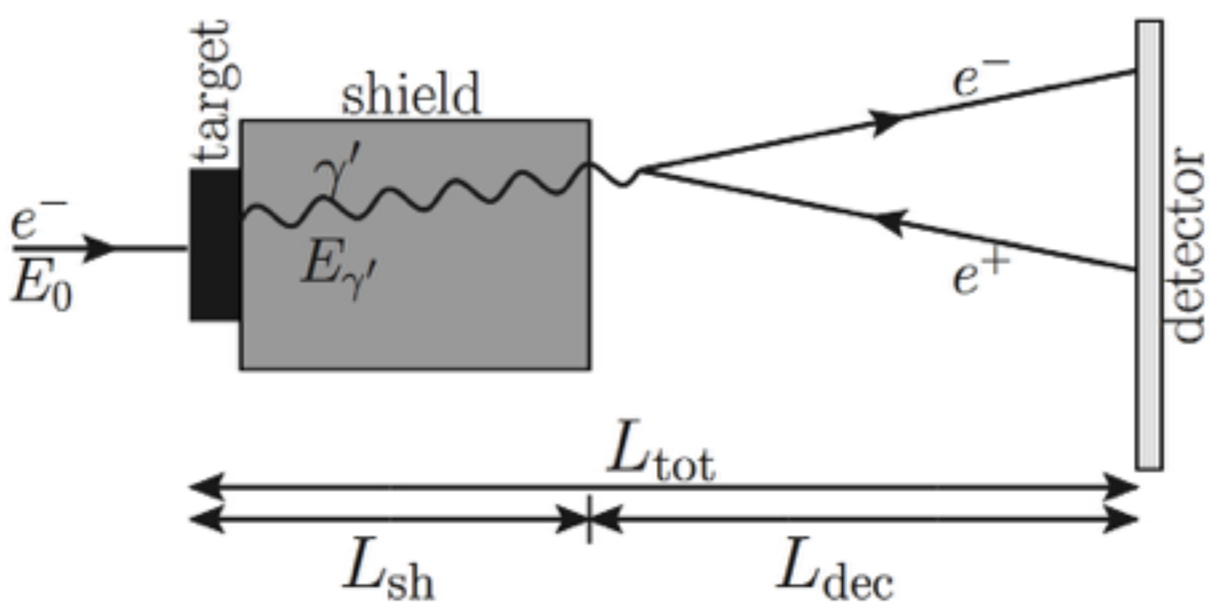
2) The realization that we can handily search for a dark photon in this range at existing fixed target facilities

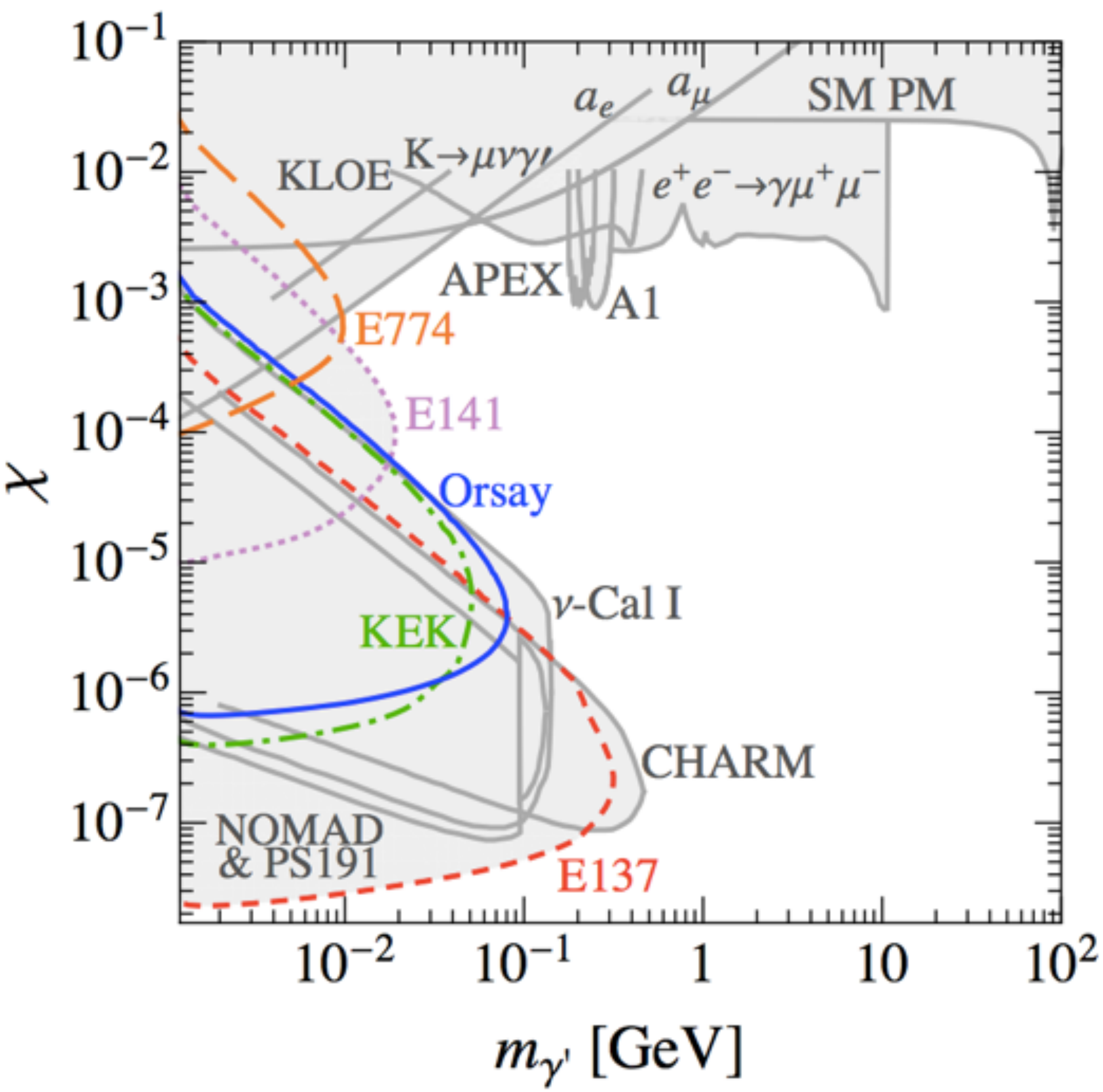


arXiv:0906.0580

Explosion of interest in dark photons at colliders

3) The reminder that we've already been effectively looking for dark photons in this range at beam dump experiments





Example: arXiv:1209.6083

Dark photons from legacy beam dump experiments

Example: arXiv:1406.2698
2014 recasting of SLAC E137, from 1980-82, for invisible dark photon decays

Fermi National Accelerator Laboratory

FERMILAB-Pub-88/44
[VPI-IHEP 88/2]

Search for Neutral Metastable Penetrating Particles Produced in the SLAC Beam Dump
(SLAC Experiment E-137)

J. D. Bjorken
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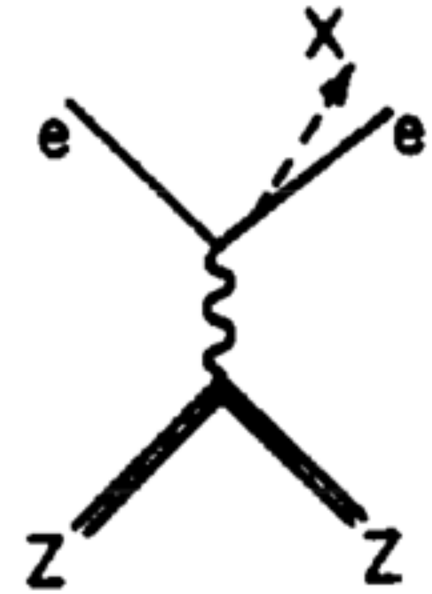
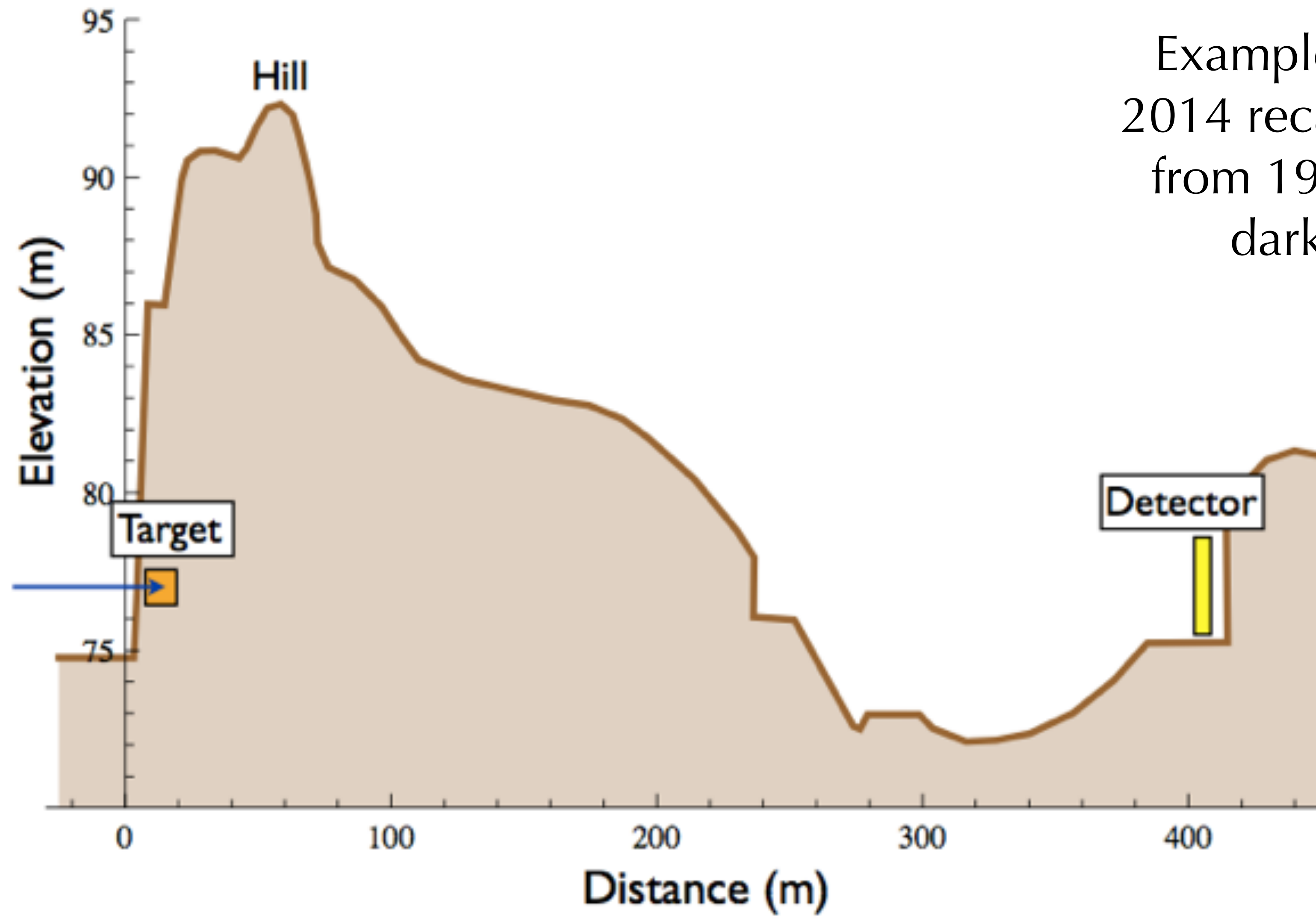
S. Ecklund and W. R. Nelson
Stanford Linear Accelerator Center
Stanford, California 94305



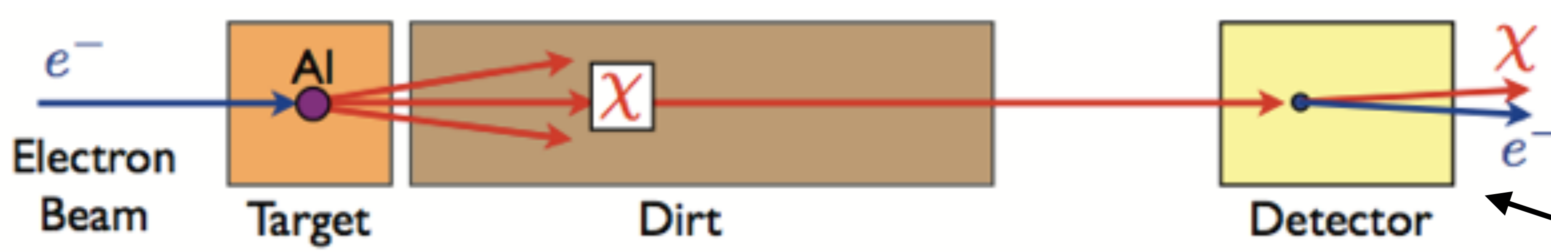
(b)

There are several classes of conjectured low-mass, neutral particles with little coupling to matter which are of special interest as objects of such an experimental search. Among candidate objects are neutral neutrino-like leptons, the photinos of super-symmetric theories, and axions. However, it must be kept in mind that the most relevant object in such a speculative search experiment as this may well be "none of the above". For example, the predecessor[1] of

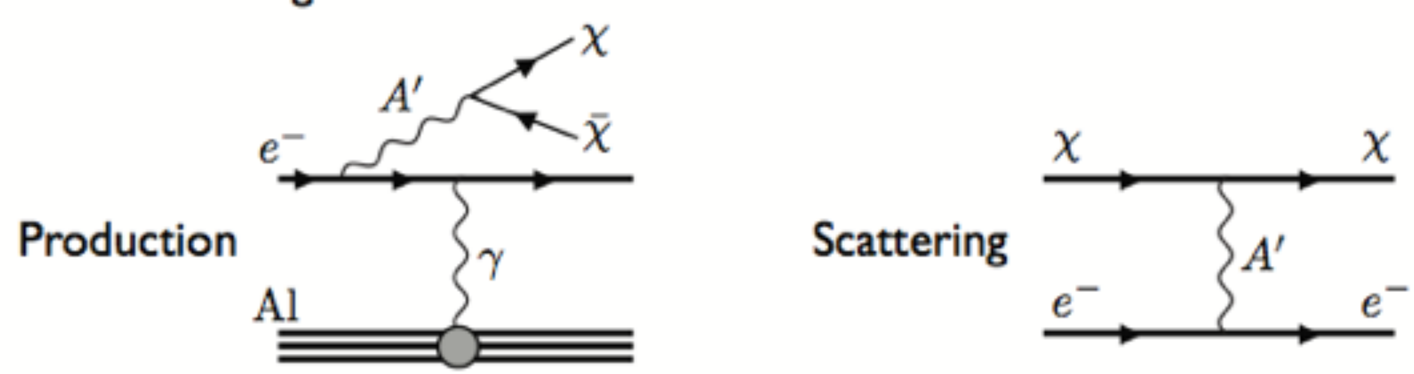
Dark photons from legacy beam dump experiments



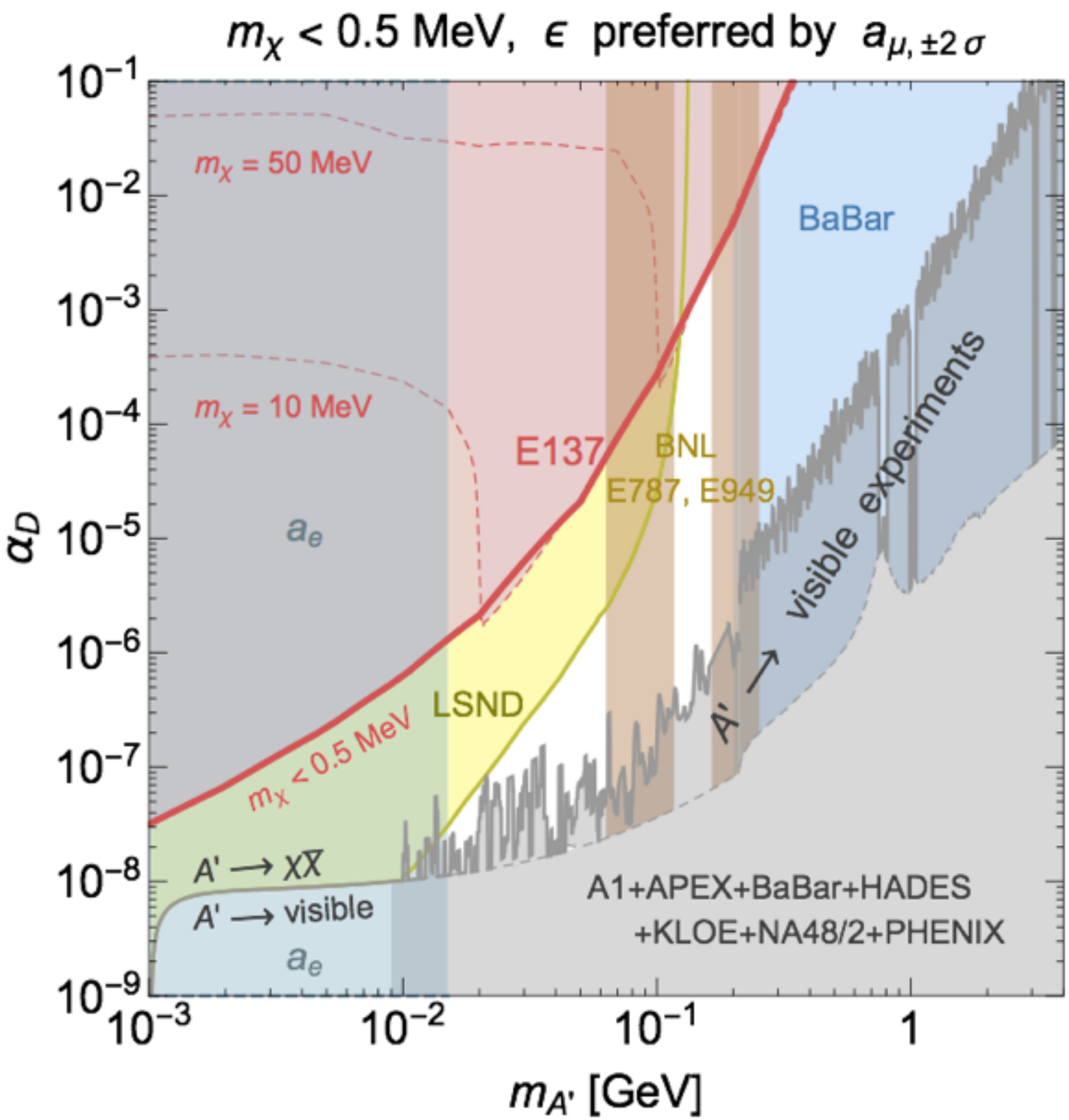
Example: arXiv:1406.2698
2014 recasting of SLAC E137, from 1980-82, for invisible dark photon decays



Electromagnetic shower counter



Dark photons from legacy beam dump experiments



Example: arXiv:1406.2698
2014 recasting of SLAC E137, from 1980-82, for invisible dark photon decays

Fix ϵ to the smallest possible value that can explain the $(g\text{-}2)_\mu$

Some parameter space survives!

Fixed target experiments

Searching for a dark photon in fixed target experiments is simple

1) Find a nearly-continuous low-to-medium energy electron beam

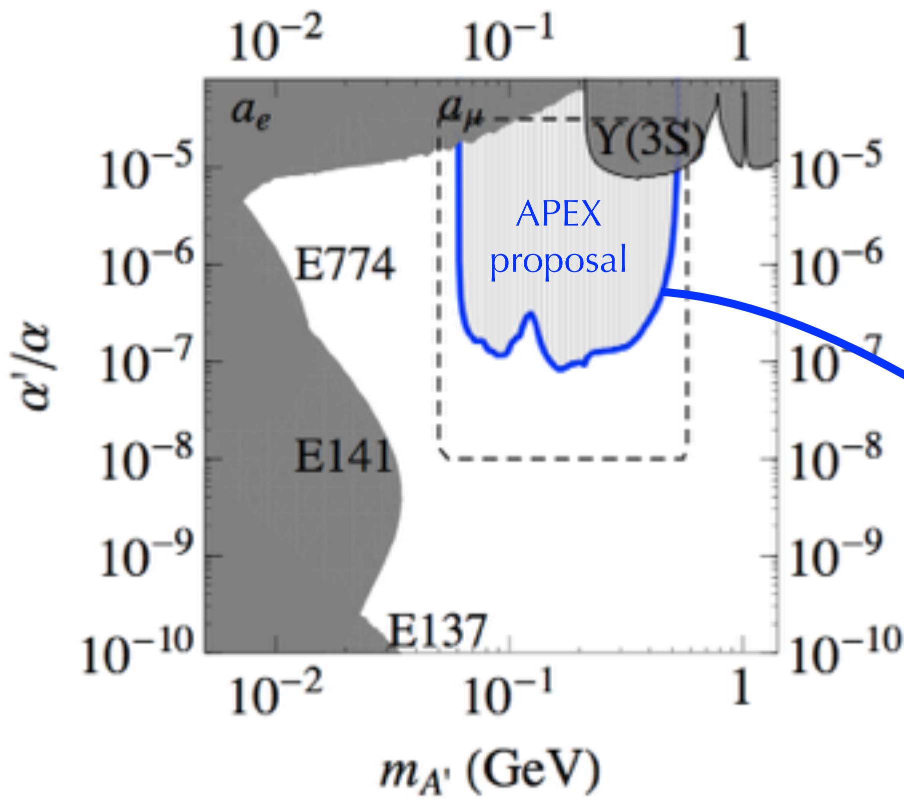
2) Shoot it at a chunk of metal with a high-Z nucleus

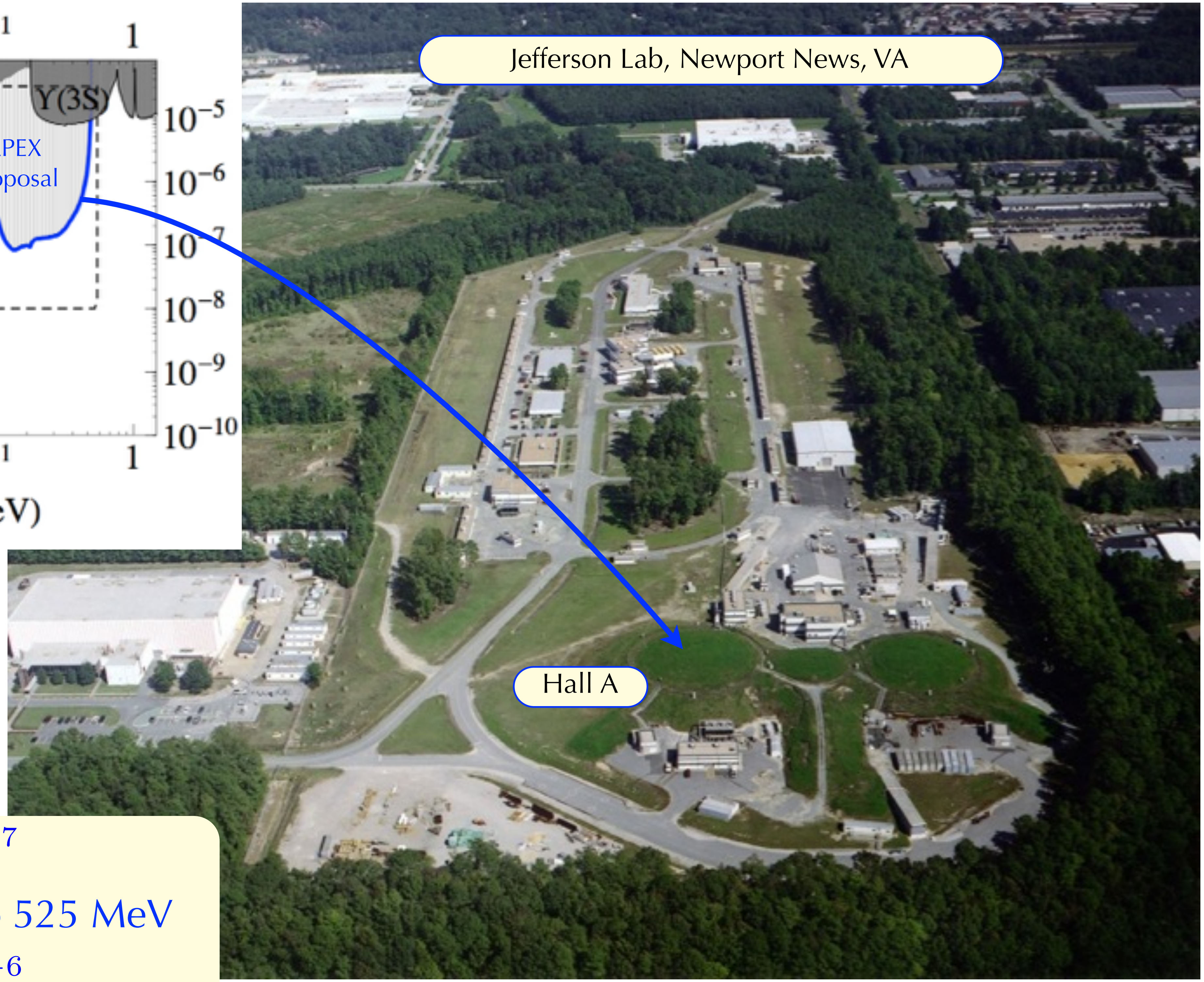
3) Collect the outgoing e+e- pair with a detector apparatus featuring extremely good momentum resolution, angular resolution, particle ID and pion rejection

4) Look for a tiny excess on top of a smooth background histogram of m_{e+e-}

This sounds like Jefferson Lab's Hall A.

APEX: Dark photon search in fixed target experiment at Jefferson Lab

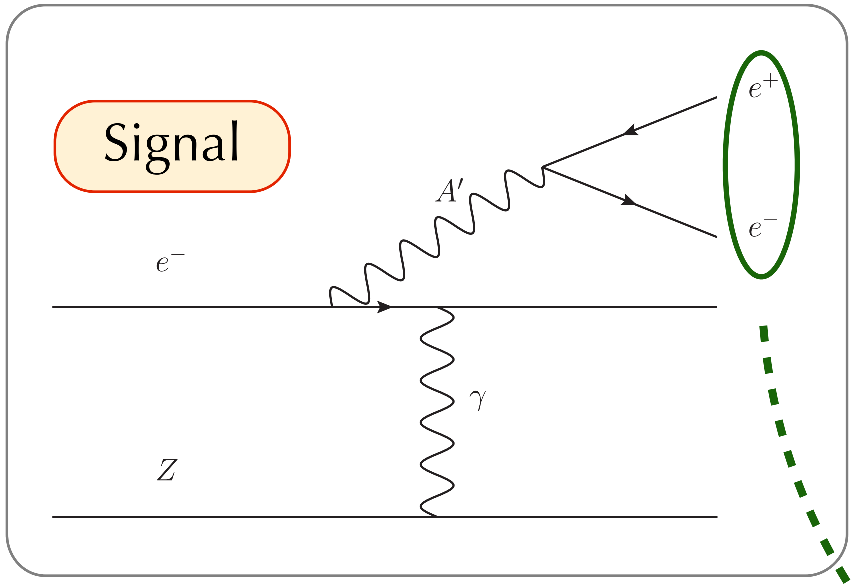


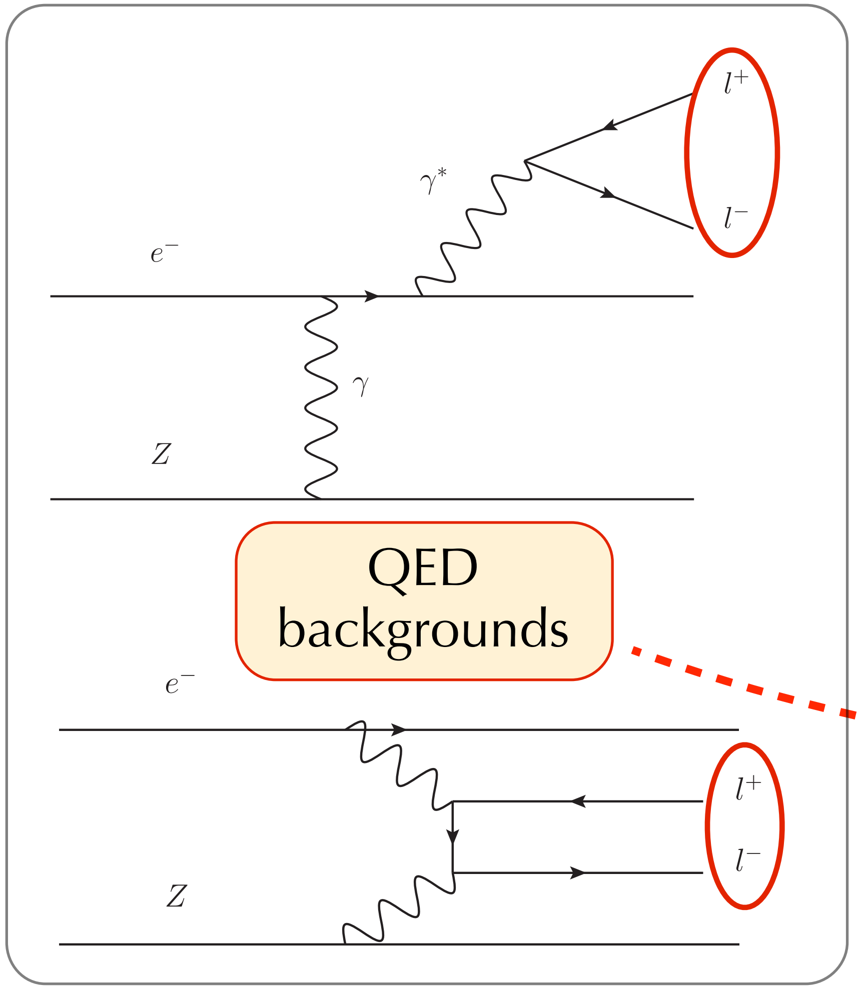


Bjorken, Essig, Schuster, Toro, Wojtsekhowski, et al. proposed a fixed target experiment to be conducted at Thomas Jefferson National Accelerator Facility, in Virginia; **test run for experiment in June/July 2010**

- Full run: $\alpha'/\alpha \gtrsim 10^{-7}$
  $m_{A'}$ = 65 to 525 MeV
- Test run: $\alpha'/\alpha \gtrsim 10^{-6}$
  $m_{A'}$ = 178 to 250 MeV

Experimental signature



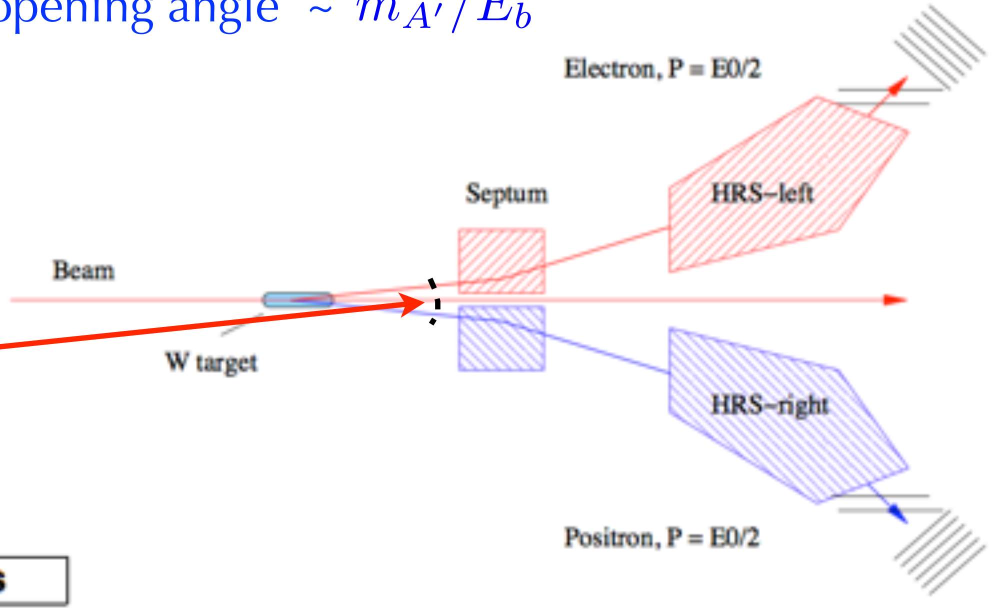


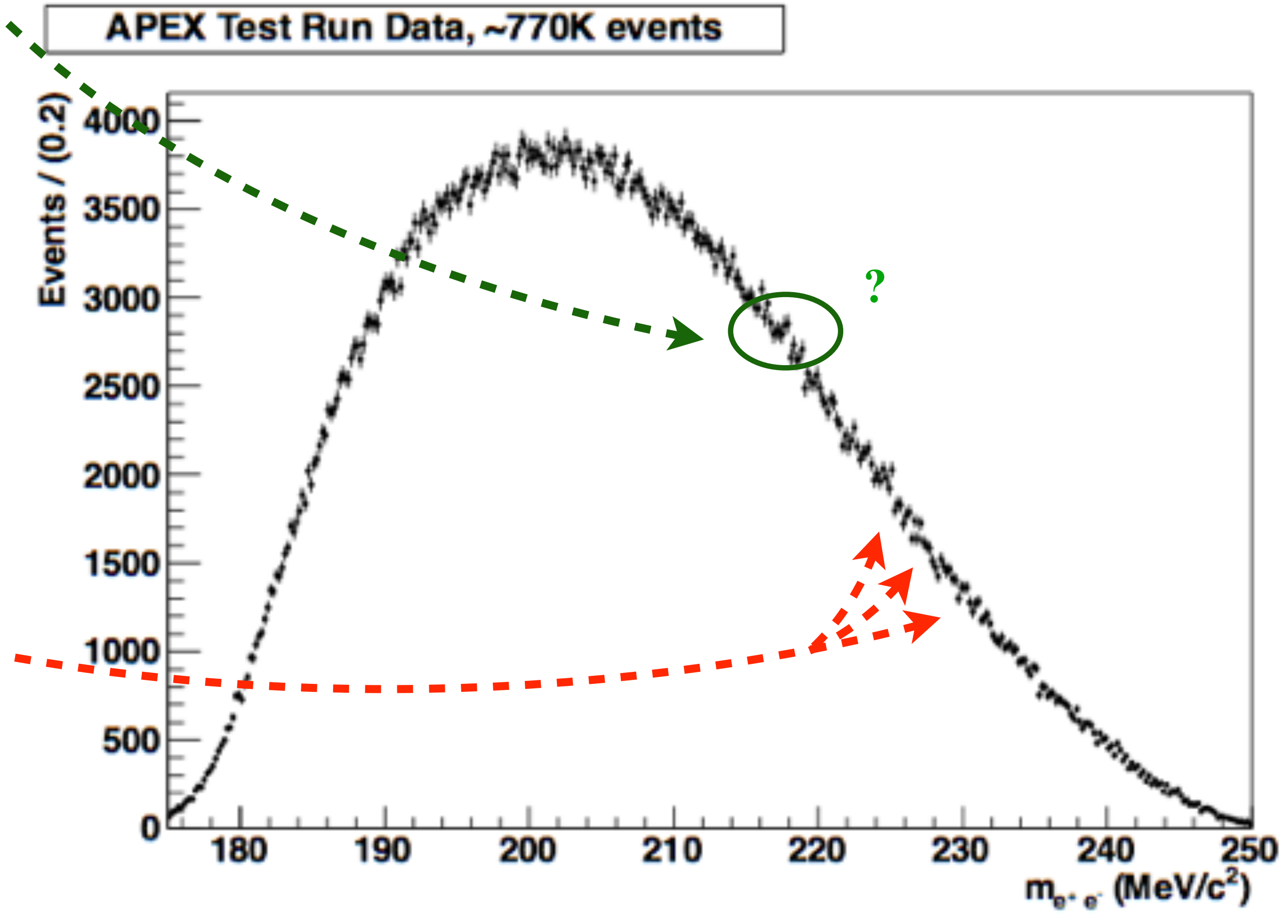
Direct production of A' at JLab

- Produced via high energy e⁻ beam incident on fixed high-Z (Ta) target
- Decays to e^+e^- pair with opening angle $\sim m_{A'}/E_b$

Dipole septum magnets allow for detection of e^+e^- produced at small angles

$\Theta_0 \approx 5°$

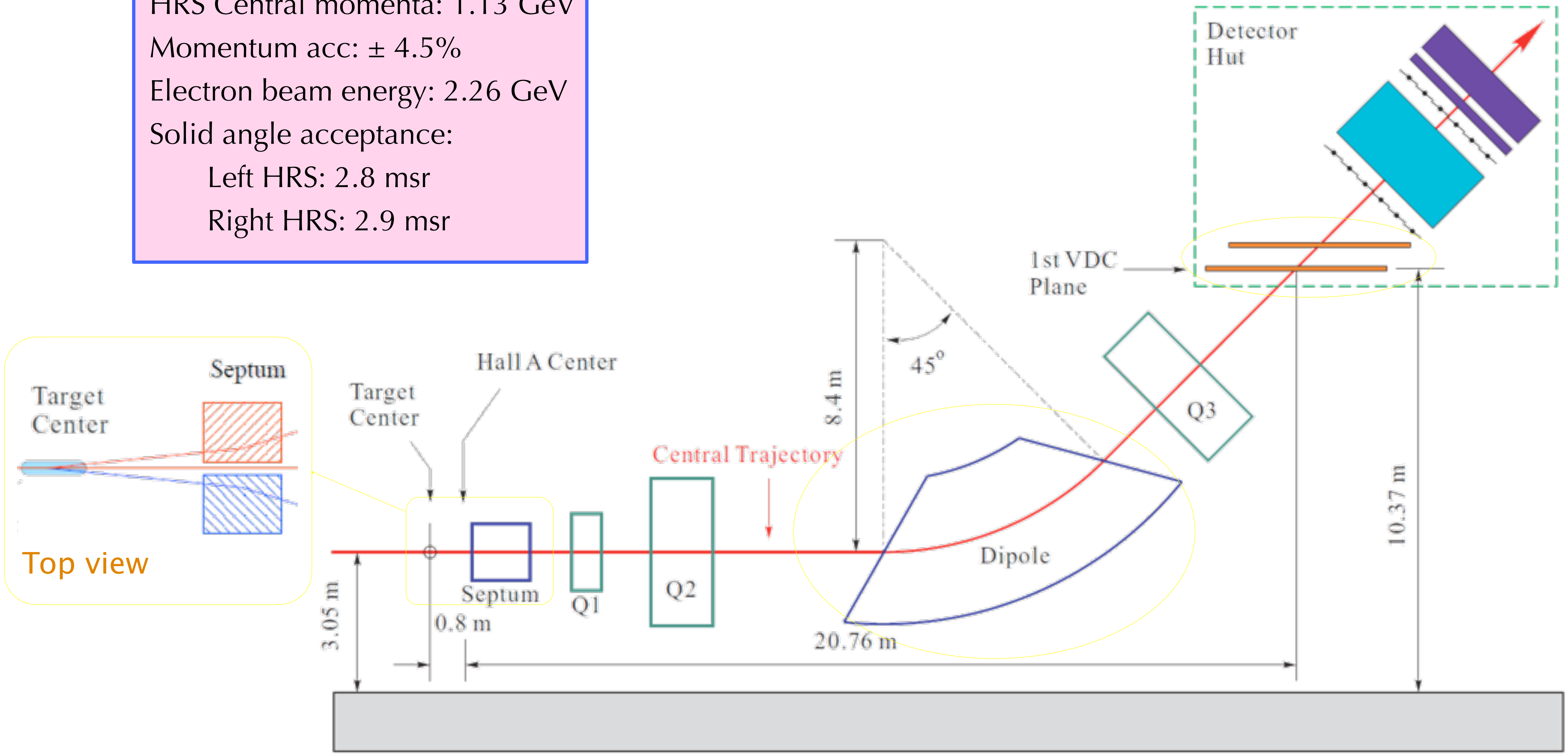




Looking for a small, narrow bump on top of a smooth histogram of QED processes; excellent mass resolution required

Jefferson Lab's Hall A experimental apparatus

APEX test run:
Beam current up to 150μA
Target: Ta foil, 22 mg/cm^2
HRS Central momenta: 1.13 GeV
Momentum acc: ± 4.5%
Electron beam energy: 2.26 GeV
Solid angle acceptance:
Left HRS: 2.8 msr
Right HRS: 2.9 msr

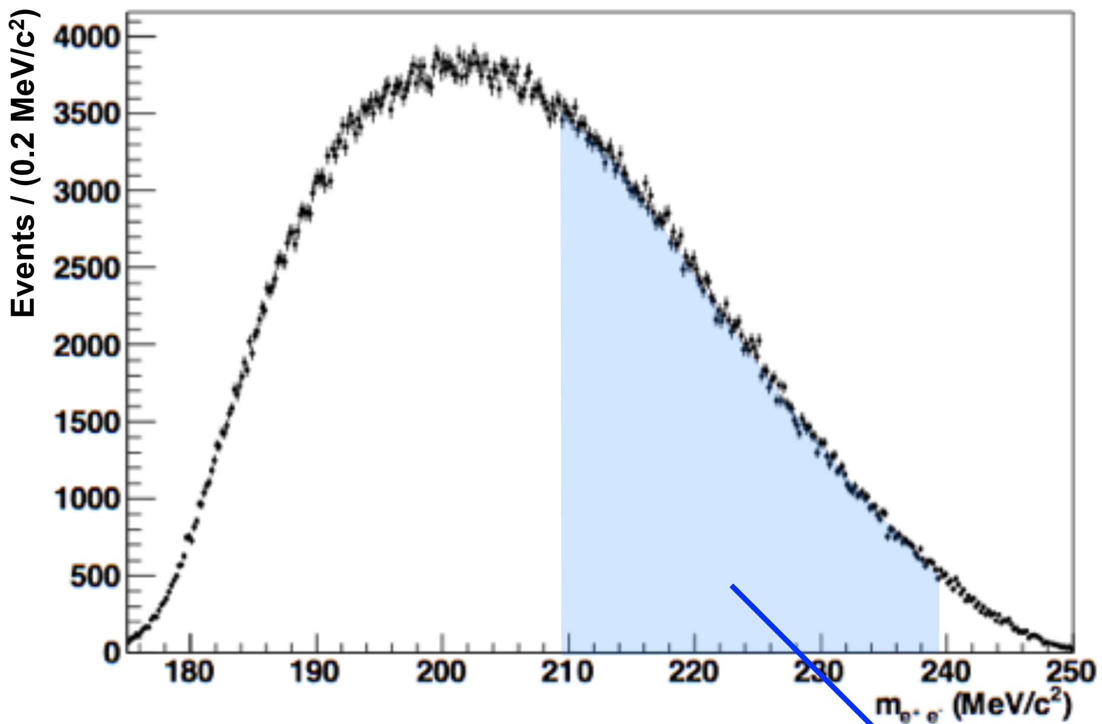


J. Huang

Bump hunt / resonance search

Final invariant mass spectrum QED radiative trident / Bethe-Heitler events

APEX Test Run Data, ~770K events



Bump hunt for small, narrow resonance

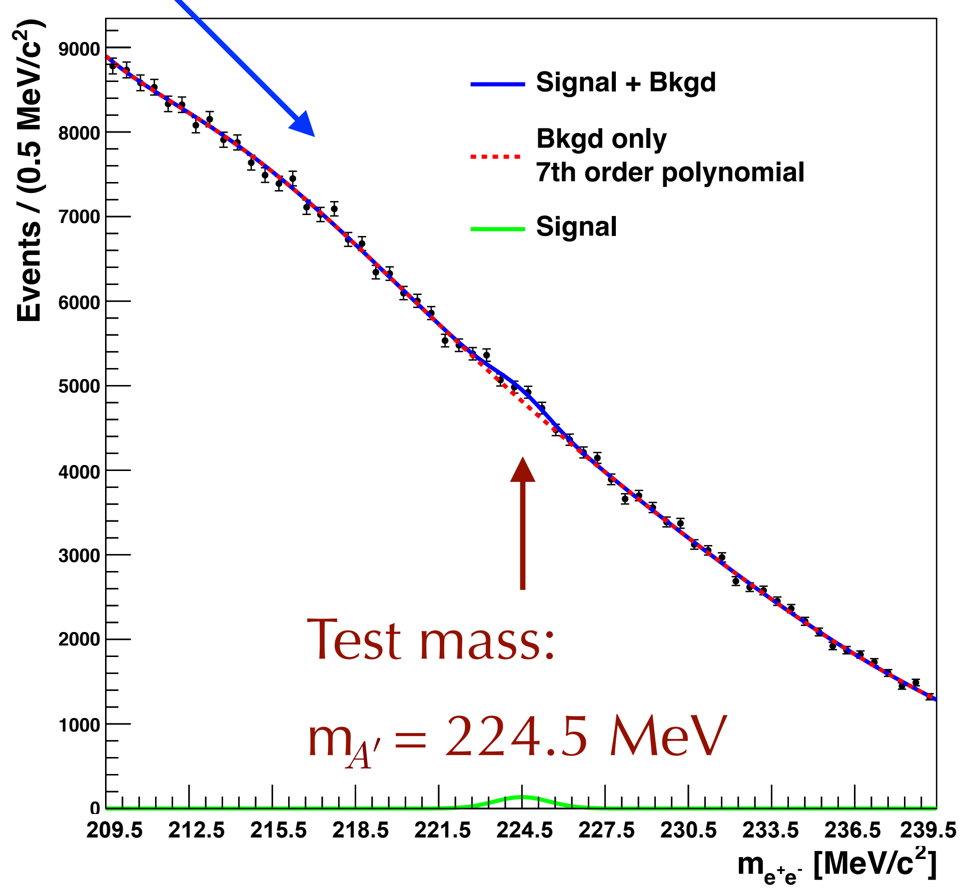
Test run mass resolution: σ~ 0.85 - 1.11 MeV

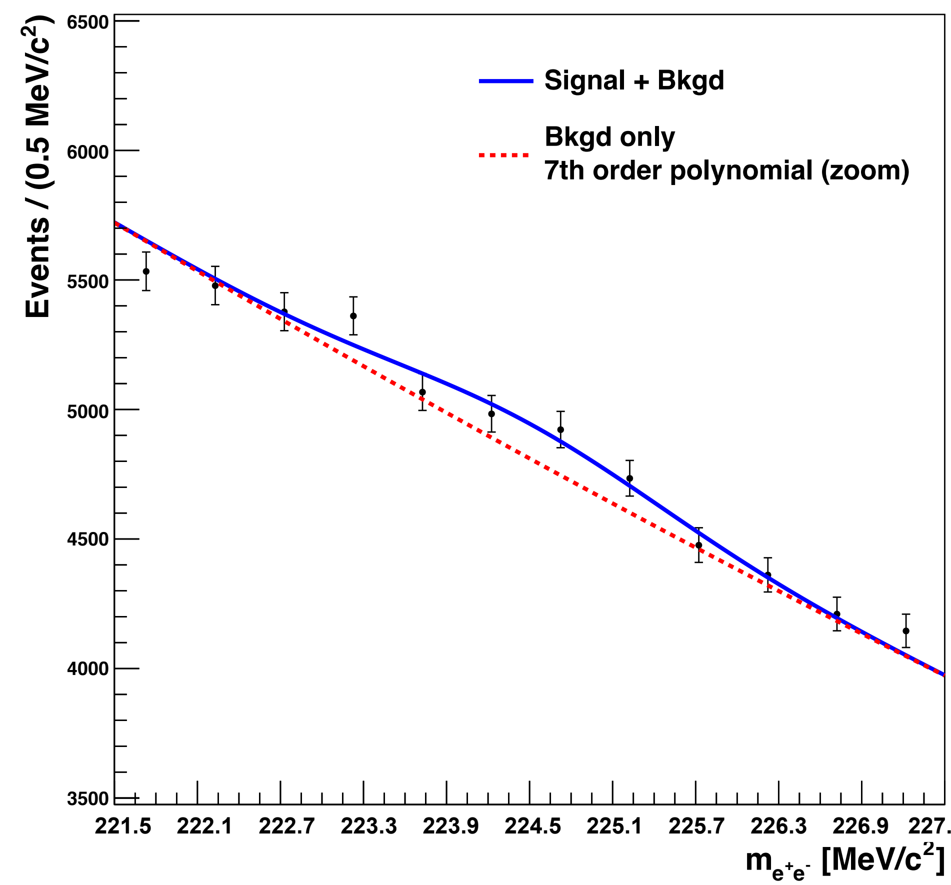
$$P(m_{e^+e^-} \mid m_{A'}, \sigma, S, B, a_i) = \frac{S \cdot \mathrm{N}(m_{e^+e^-} \mid m_{A'}, \sigma) \; + \; B \cdot \mathrm{Polynomial}(m_{e^+e^-}, a_i)}{S + B}$$

Probability model and profile likelihood ratio

$$\lambda(S) = \frac{L(S, \hat{\hat{B}}, \hat{\hat{a}}_i)}{L(\hat{S}, \hat{B}, \hat{a}_i)}$$

Scanning window (raster scan) approach, with sidebands symmetric around mass hypothesis





Upper limit on S ⟶ upper limit on coupling

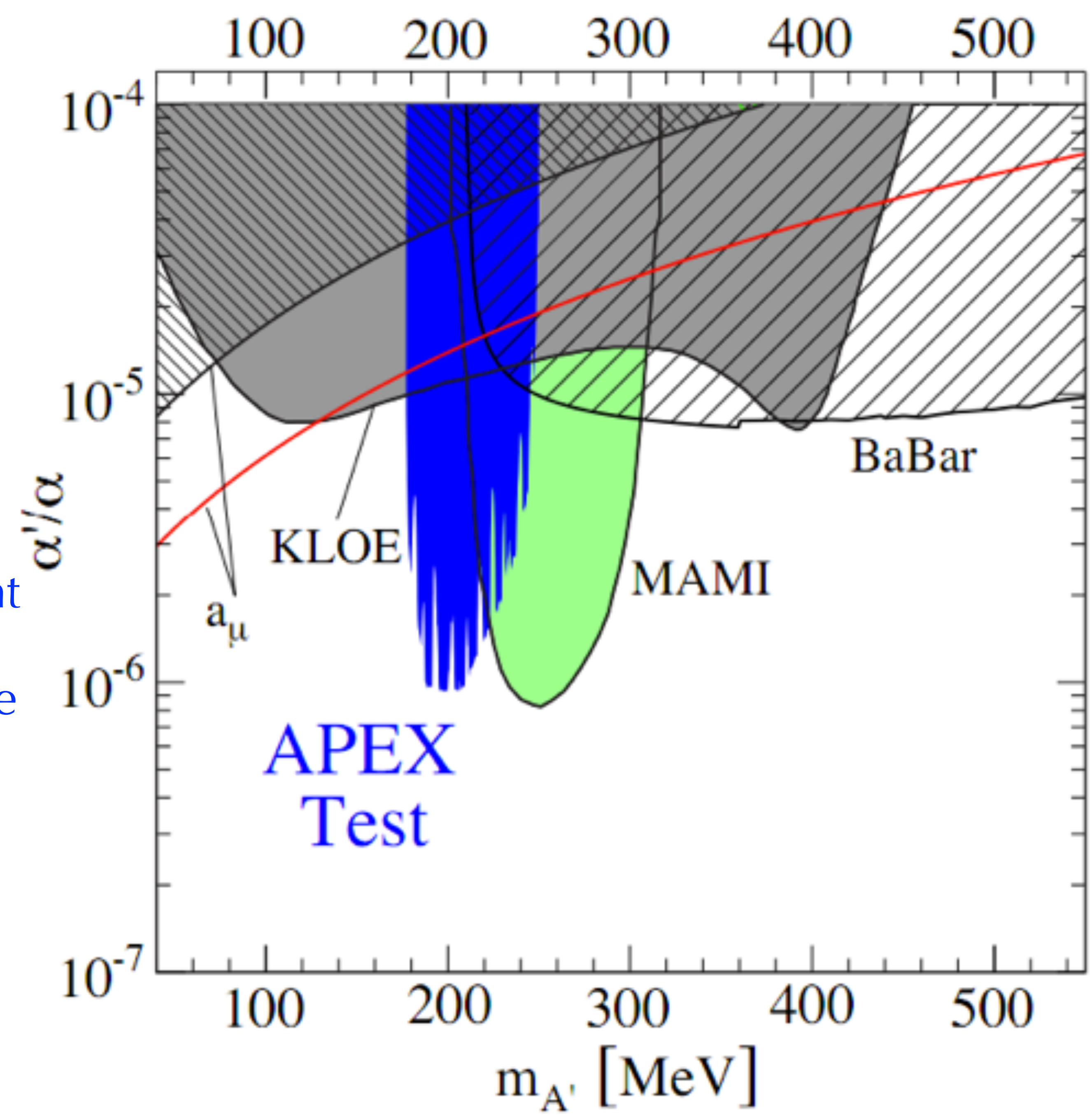
$$\frac{d\sigma(A')}{d\sigma(\gamma^*)} = \left(\frac{3\pi\epsilon^2}{2N_{\text{eff}}\alpha}\right)\frac{m_{A'}}{\delta m} = \frac{S_{\delta m}}{B_{\delta m}^{\gamma^*}}$$

(See APEX proposal)

Normalize all backgrounds to γ^* background

- Ratio *f* of radiative-only cross section to full trident cross section determined via Monte Carlo to vary linearly from 0.21 to 0.25 across APEX mass range

$$\left(\frac{\alpha'}{\alpha}\right)_{max} = \left(\frac{S_{max}/m_{A'}}{f\cdot\Delta B/\Delta m}\right)\times\left(\frac{2N_{\text{eff}}\alpha}{3\pi}\right)$$

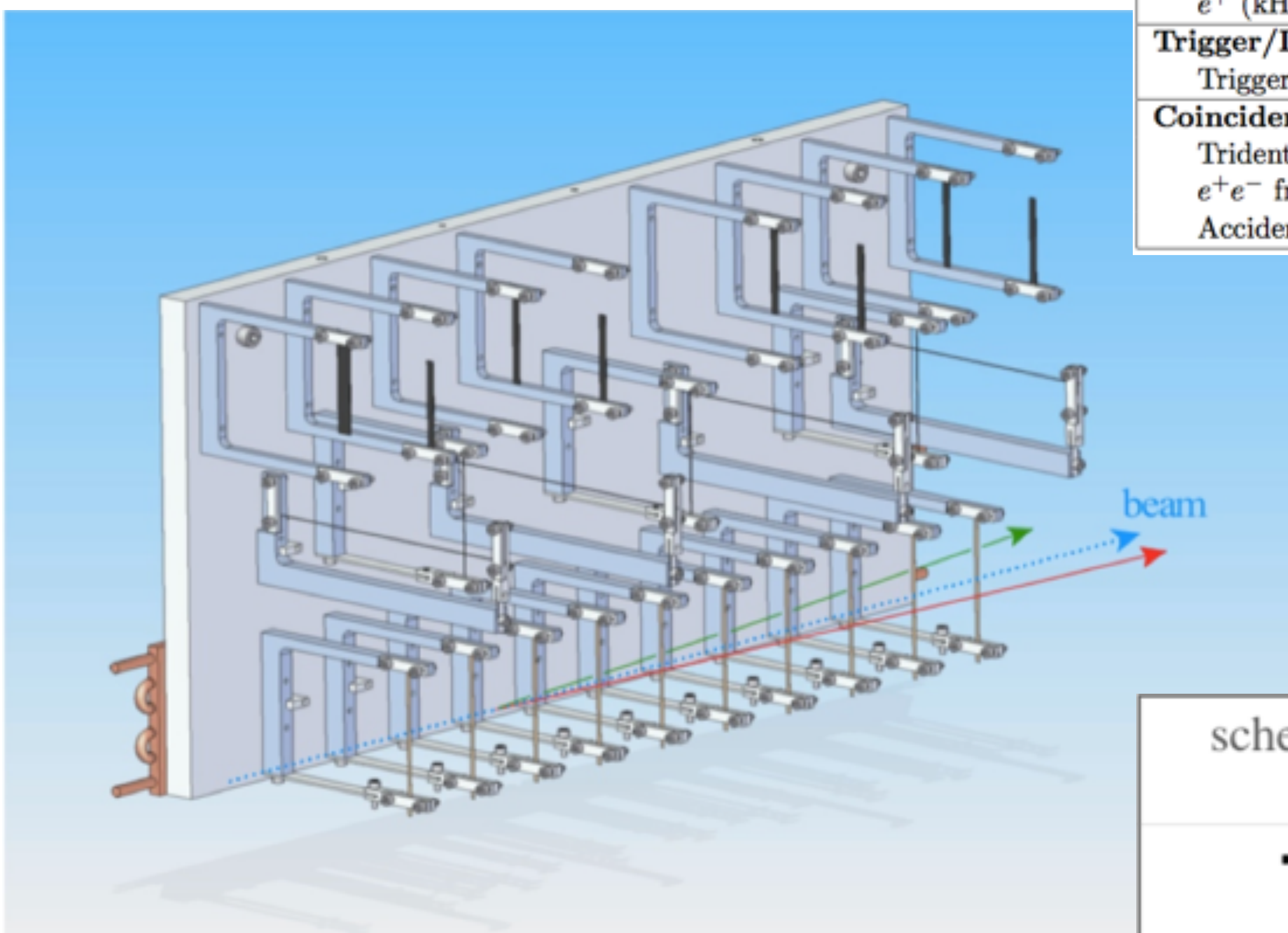


Plan for full run

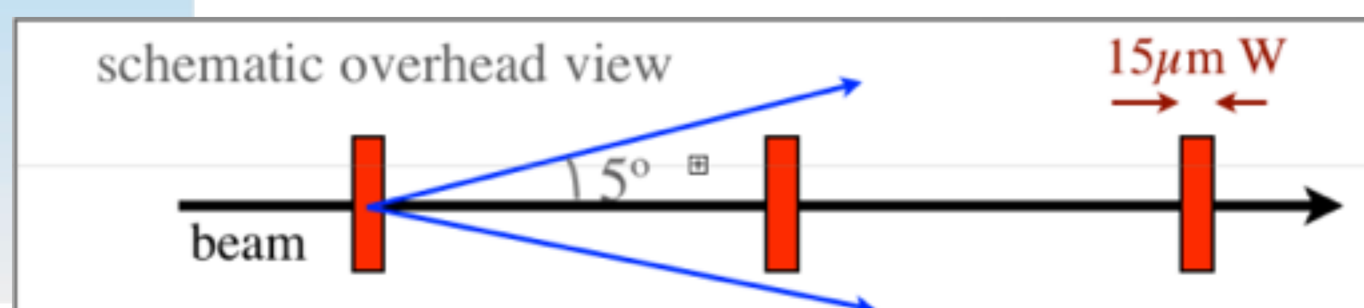
Full run at JLab will take data for ~34 days at several energy and spectrometer settings

- Possible modifications to original run plan could take advantage of higher beam energies and wider angles (with adjustment of septum magnets) to access higher $m_{A'}$ region

Settings	A	B	C	D
Beam energy (GeV)	2.2	4.4	1.1	3.3
Central angle	5.0°	5.0°	5.0°	5.0°
Effective angles	4.5–5.5	4.5–5.5	4.5–5.5	4.5–5.5
Target T/X_0 (ratio[a])	4%	8%	0.69% (1:3)	8%
Beam current (μA)	70	60	65	80
Central momentum (GeV)	1.095	2.189	0.545	1.634
Singles (negative polarity)				
e^- (MHz)	4.1	0.7	5.8	2.2
π^- (MHz)	0.1	1.7	0.03	0.9
Singles (positive polarity)				
$\pi+$ [p] (kHz)	90	1700	30	900
e^+ (kHz)	27	5	23	17
Trigger/DAQ:				
Trigger[b] (kHz)	3.0	3.1	3.15	3.3
Coincidence Backgrounds:				
Trident: $e^-Z \to e^-e^+e^-Z$ (Hz)	500	110	330	370
e^+e^- from real γ conversion (Hz)	30	16	4	45
Accidentals [c] (Hz)	55	30	70	40



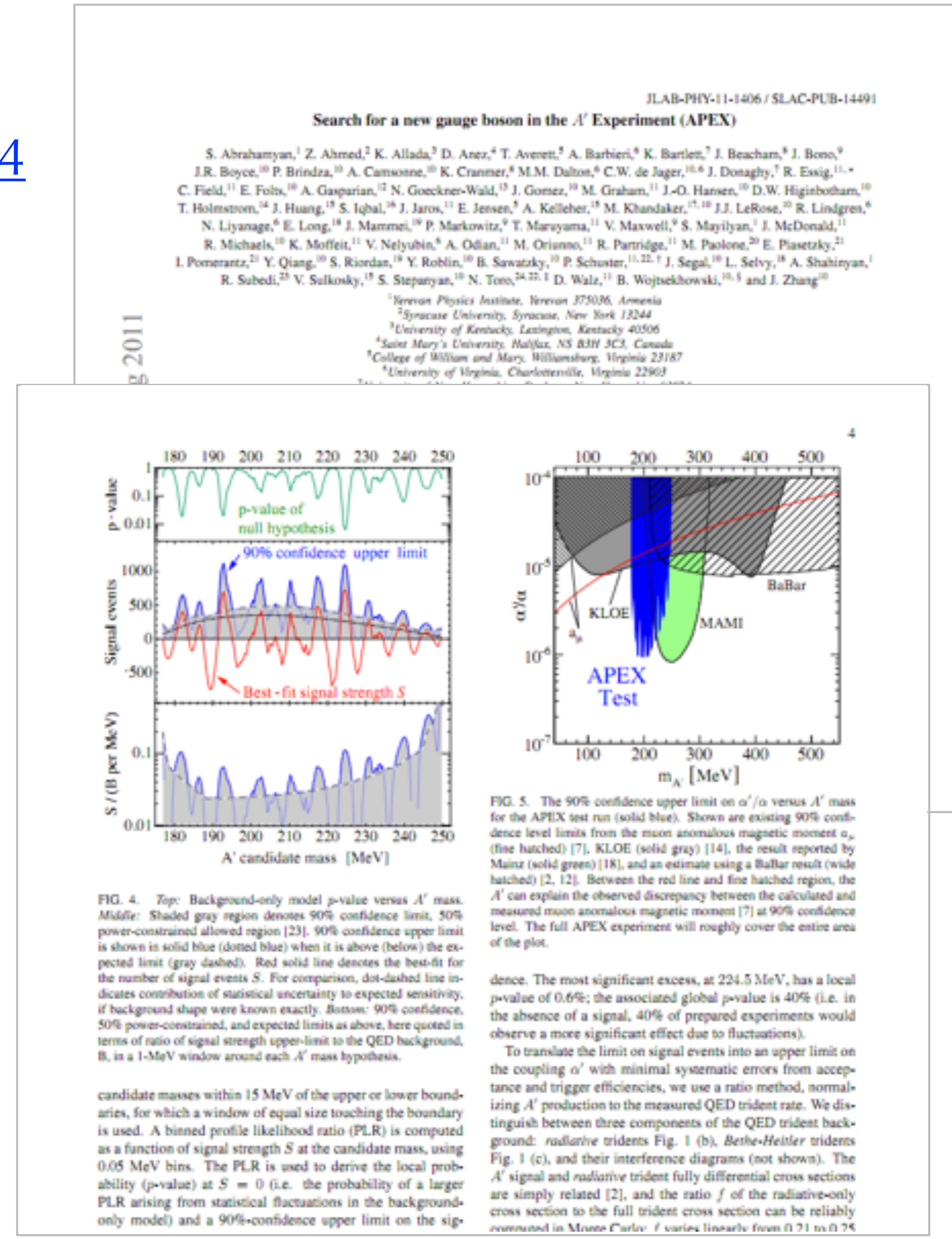
Cover a larger mass range using a 50-cm long multifoil target



Test run results and full run status

Test run results in PRL

- prl.aps.org/abstract/PRL/v107/i19/e191804
- arXiv:1108.2750


JLAB-PHY-11-1406 / SLAC-PUB-14491

Search for a new gauge boson in the A' Experiment (APEX)

S. Abrahamyan,[1] Z. Ahmed,[2] K. Allada,[3] D. Anez,[4] T. Averett,[5] A. Barbieri,[6] K. Bartlett,[7] J. Beacham,[8] J. Bono,[9] J.R. Boyce,[10] P. Brindza,[10] A. Camsonne,[10] K. Cranmer,[8] M.M. Dalton,[6] C.W. de Jager,[10,6] J. Donaghy,[7] R. Essig,[11,*] C. Field,[11] E. Folts,[10] A. Gasparian,[12] N. Goeckner-Wald,[13] J. Gomez,[10] M. Graham,[11] J.-O. Hansen,[10] D.W. Higinbotham,[10] T. Holmstrom,[14] J. Huang,[15] S. Iqbal,[16] J. Jaros,[11] E. Jensen,[5] A. Kelleher,[15] M. Khandaker,[17,10] J.J. LeRose,[10] R. Lindgren,[6] N. Liyanage,[6] E. Long,[18] J. Mammei,[19] P. Markowitz,[9] T. Maruyama,[11] V. Maxwell,[9] S. Mayilyan,[1] J. McDonald,[11] R. Michaels,[10] K. Moffeit,[11] V. Nelyubin,[6] A. Odian,[11] M. Oriunno,[11] R. Partridge,[11] M. Paolone,[20] E. Piasetzky,[21] I. Pomerantz,[21] Y. Qiang,[10] S. Riordan,[18] Y. Roblin,[10] B. Sawatzky,[10] P. Schuster,[11,22,†] J. Segal,[10] L. Selvy,[18] A. Shahinyan,[1] R. Subedi,[23] V. Sulkosky,[15] S. Stepanyan,[10] N. Toro,[24,22,‡] D. Walz,[11] B. Wojtsekhowski,[10,§] and J. Zhang[10]

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[6]University of Virginia, Charlottesville, Virginia 22903

FIG. 4. *Top:* Background-only model p-value versus A' mass. *Middle:* Shaded gray region denotes 90% confidence limit, 50% power-constrained allowed region [23]. 90% confidence upper limit is shown in solid blue (dotted blue) when it is above (below) the expected limit (gray dashed). Red solid line denotes the best-fit for the number of signal events S. For comparison, dot-dashed line indicates contribution of statistical uncertainty to expected sensitivity, if background shape were known exactly. *Bottom:* 90% confidence, 50% power-constrained, and expected limits as above, here quoted in terms of ratio of signal strength upper-limit to the QED background, B, in a 1-MeV window around each A' mass hypothesis.

candidate masses within 15 MeV of the upper or lower boundaries, for which a window of equal size touching the boundary is used. A binned profile likelihood ratio (PLR) is computed as a function of signal strength S at the candidate mass, using 0.05 MeV bins. The PLR is used to derive the local probability (p-value) at $S = 0$ (i.e. the probability of a larger PLR arising from statistical fluctuations in the background-only model) and a 90%-confidence upper limit on the sig-

FIG. 5. The 90% confidence upper limit on α'/α versus A' mass for the APEX test run (solid blue). Shown are existing 90% confidence level limits from the muon anomalous magnetic moment a_μ (fine hatched) [7], KLOE (solid gray) [14], the result reported by Mainz (solid green) [18], and an estimate using a BaBar result (wide hatched) [2, 12]. Between the red line and fine hatched region, the A' can explain the observed discrepancy between the calculated and measured muon anomalous magnetic moment [7] at 90% confidence level. The full APEX experiment will roughly cover the entire area of the plot.

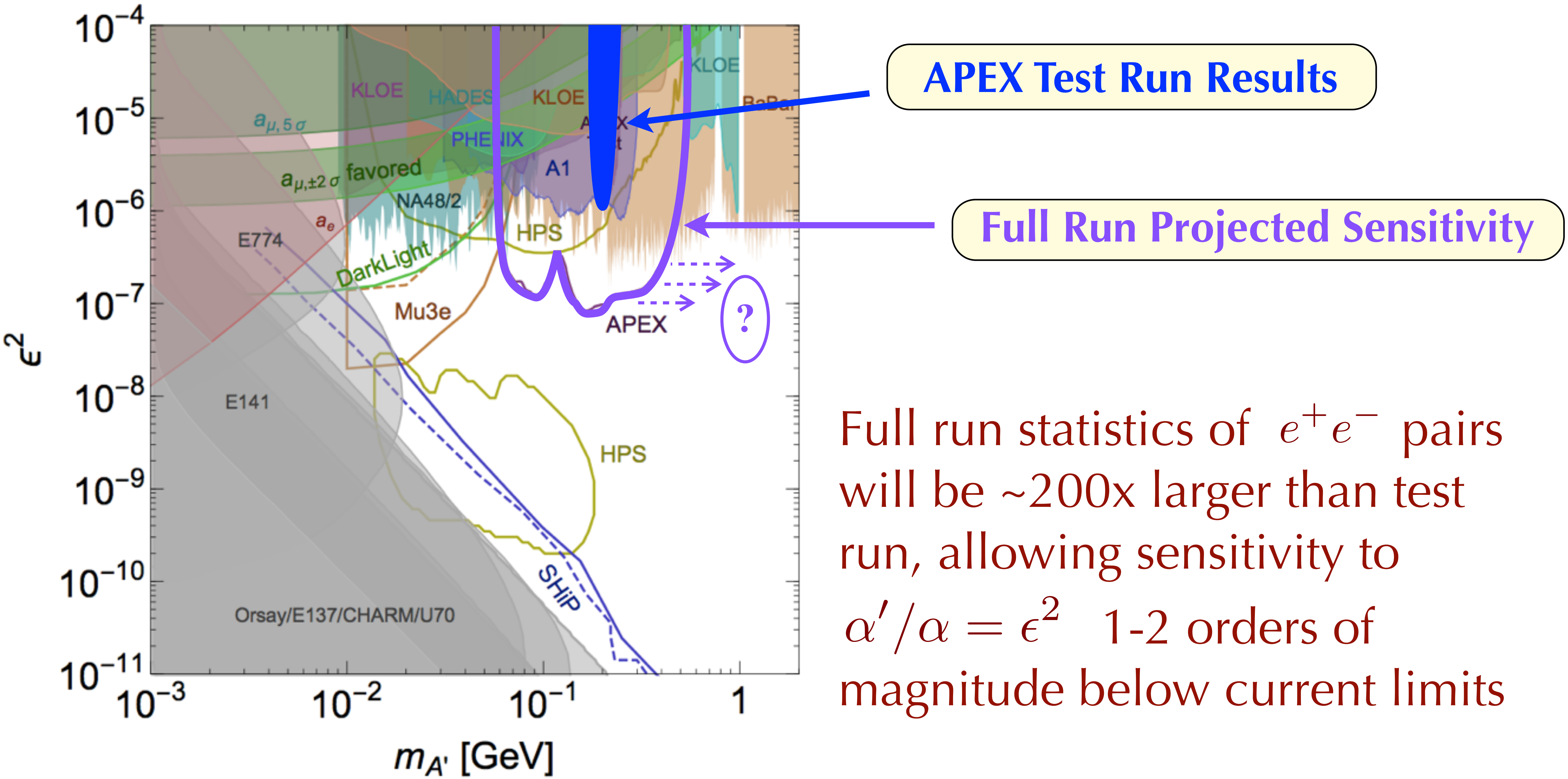
dence. The most significant excess, at 224.5 MeV, has a local p-value of 0.6%; the associated global p-value is 40% (i.e. in the absence of a signal, 40% of prepared experiments would observe a more significant effect due to fluctuations).

To translate the limit on signal events into an upper limit on the coupling α' with minimal systematic errors from acceptance and trigger efficiencies, we use a ratio method, normalizing A' production to the measured QED trident rate. We distinguish between three components of the QED trident background: *radiative* tridents Fig. 1 (b), *Bethe-Heitler* tridents Fig. 1 (c), and their interference diagrams (not shown). The A' signal and *radiative* trident fully differential cross sections are simply related [2], and the ratio f of the radiative-only cross section to the full trident cross section can be reliably computed in Monte Carlo; f varies linearly from 0.21 to 0.25

APEX is approved; 12 GeV JLab program currently in full swing

- APEX equipment fully funded
- Experiment will be ready to run in Spring 2016

Plan for full run



Full run statistics of e^+e^- pairs will be ~200x larger than test run, allowing sensitivity to $\alpha'/\alpha = \epsilon^2$ 1-2 orders of magnitude below current limits

JLab 12 GeV program underway

- APEX is the back-up experiment for Spring 2016 (more likely Fall 2017/Spring 2018)
- New SciFi optics calibration method and septum magnets
- Data acquisition rate improvements (up to 5 kHz) and high-rate VDC updates

MAMI at Mainz

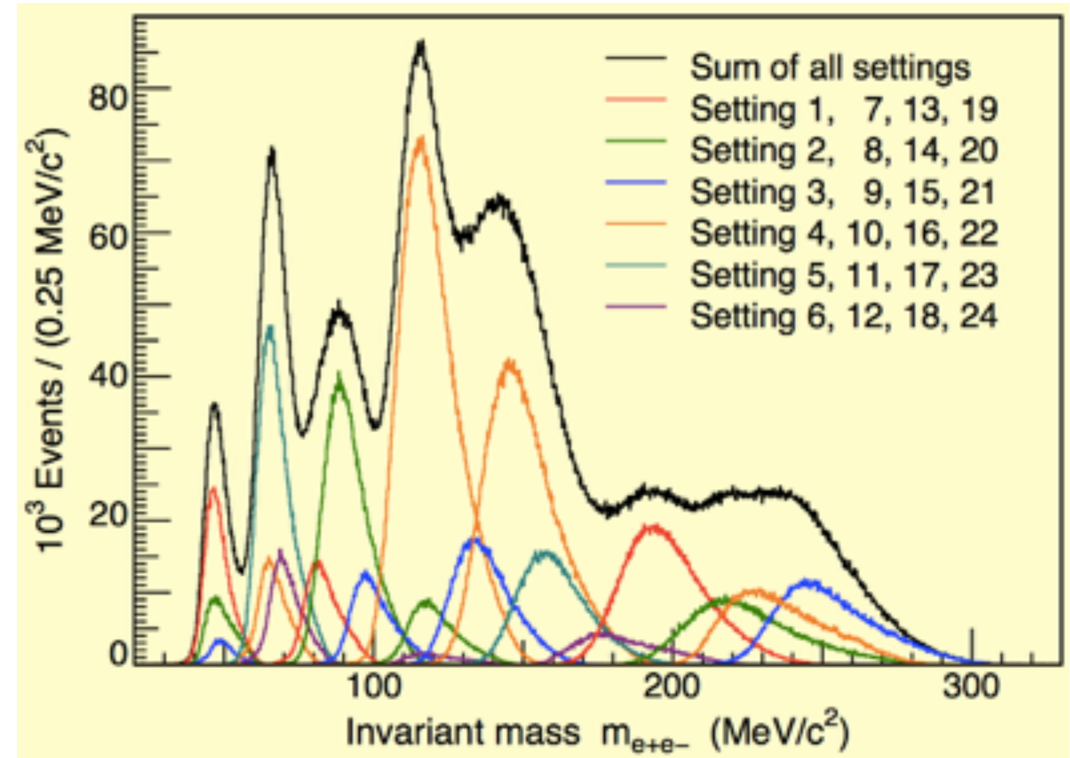
A1: Spectrometer setup at MAMI

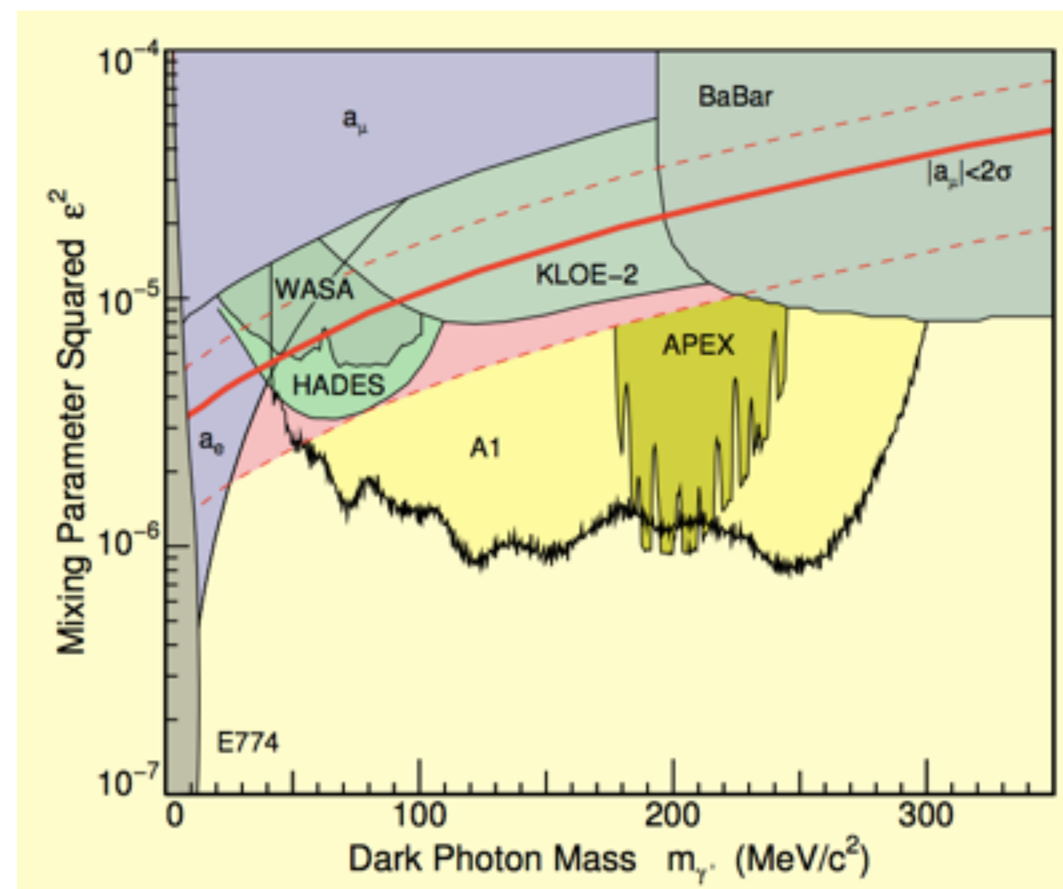
Spectrometer A:
$\alpha > 20°$
$p < 735\,\frac{\text{MeV}}{c}$
$\Delta\Omega = 28\,\text{msr}$
$\Delta p/p = 20\%$

Spectrometer B:
$\alpha > 8°$
$p < 870\,\frac{\text{MeV}}{c}$
$\Delta\Omega = 5.6\,\text{msr}$
$\Delta p/p = 15\%$

Spectrometer C:
$\alpha > 55°$
$p < 655\,\frac{\text{MeV}}{c}$
$\Delta\Omega = 28\,\text{msr}$
$\Delta p/p = 25\%$

$\delta p/p < 10^{-4}$





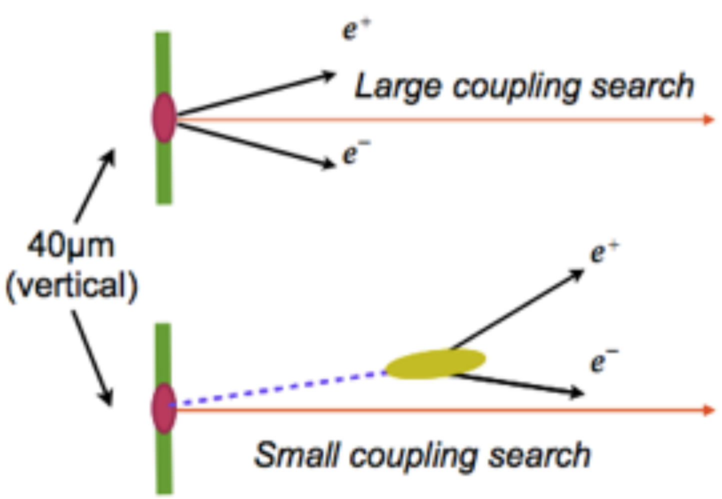
Similar approach and reach to APEX

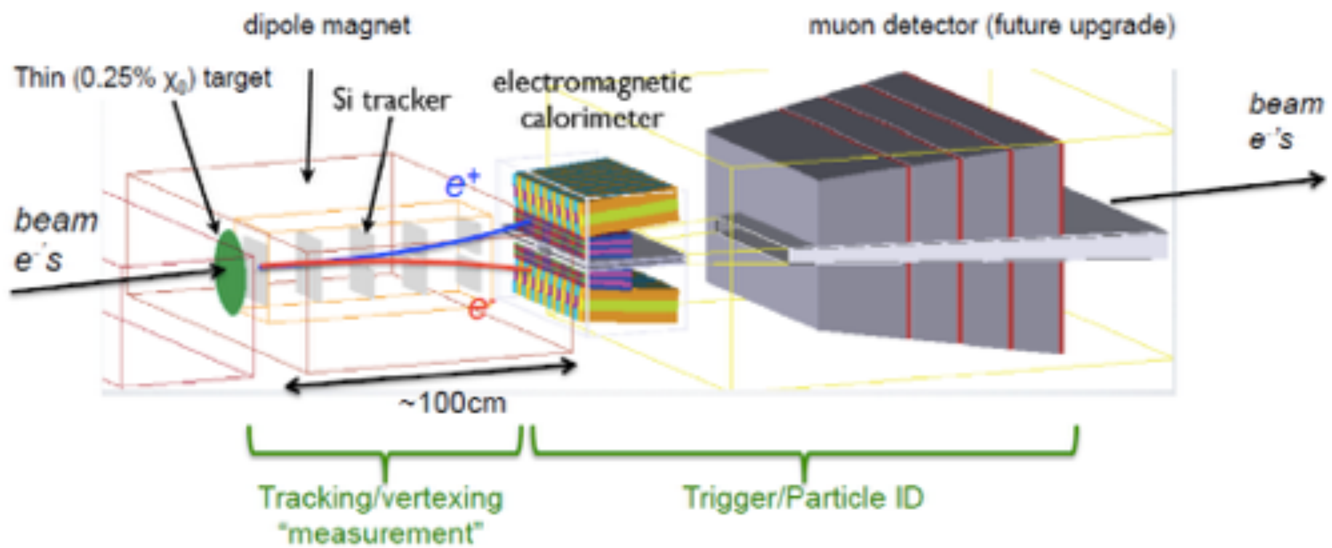
Phenomenal built-in momentum resolution wins the day

PRL 112, 221802 (2014)

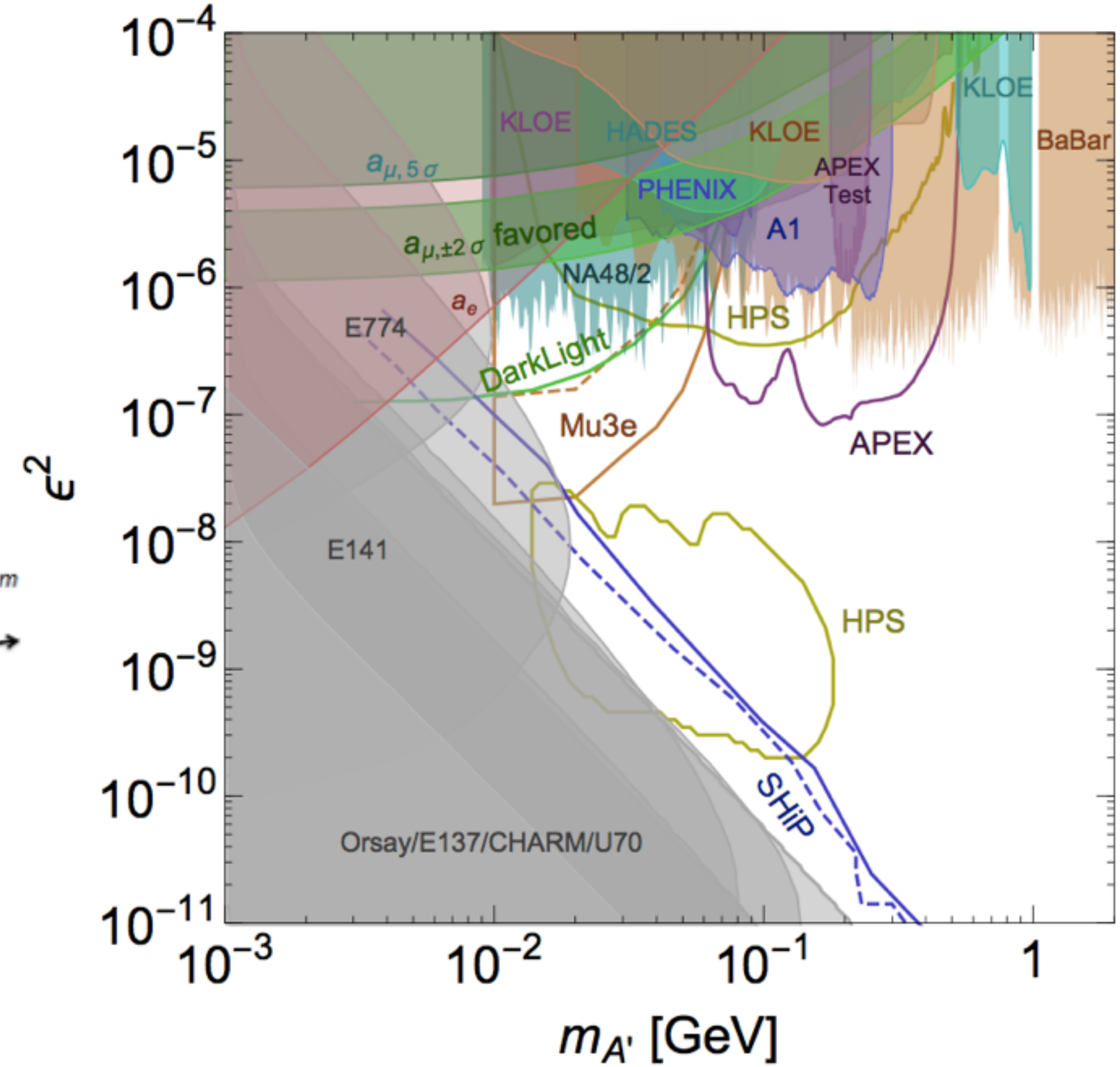
HPS in JLab Hall B

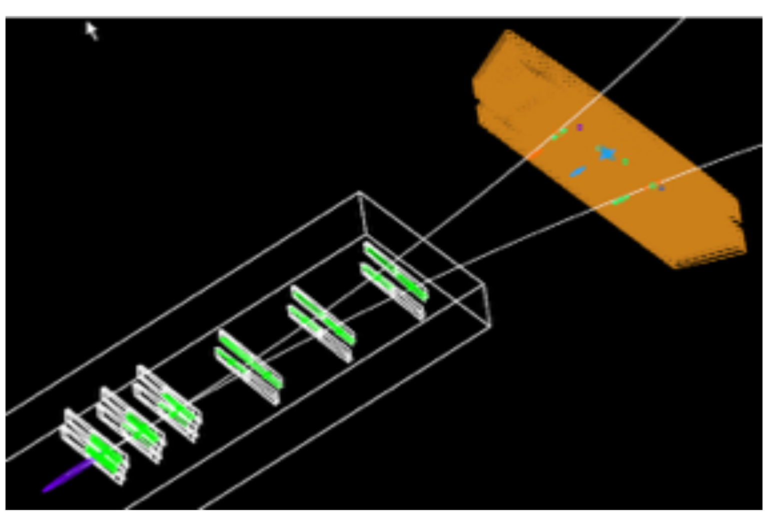
Designed to be sensitive to both prompt and displaced decays — unique reach





Proposal to JLab





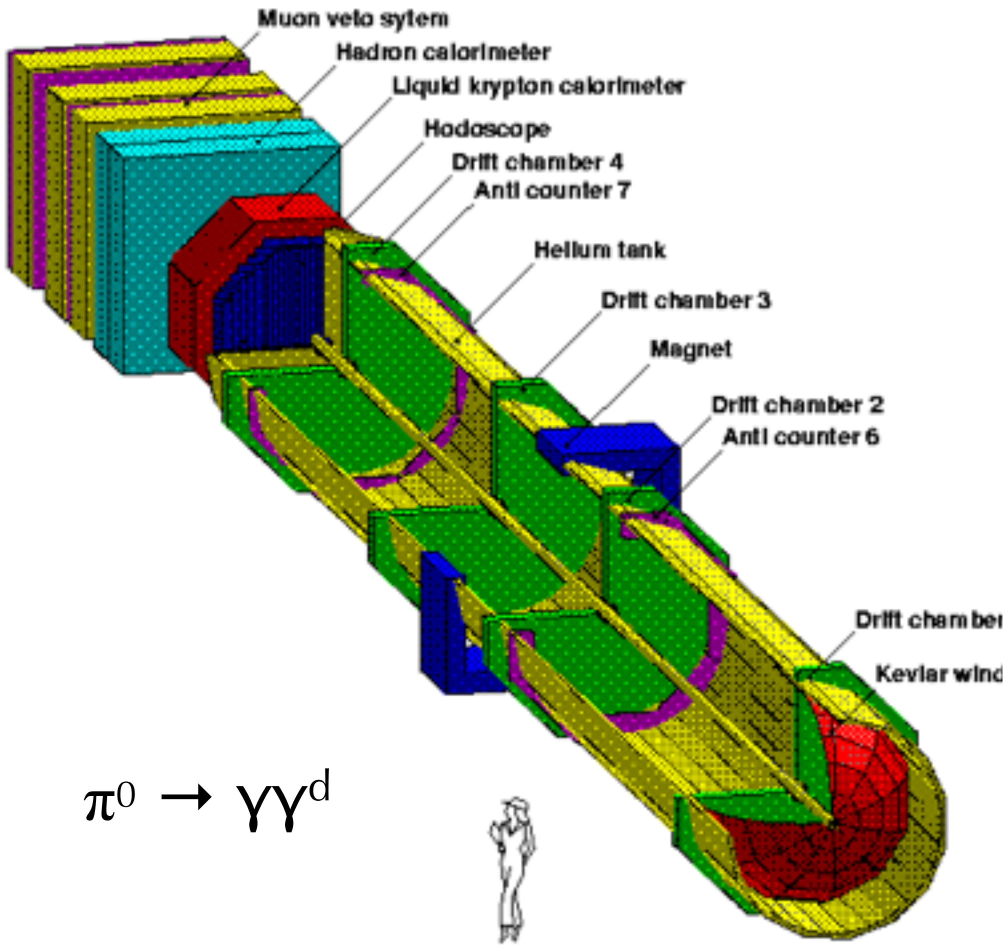
Engineering run earlier this year

Targeting APS 2016 for publication of engineering run data

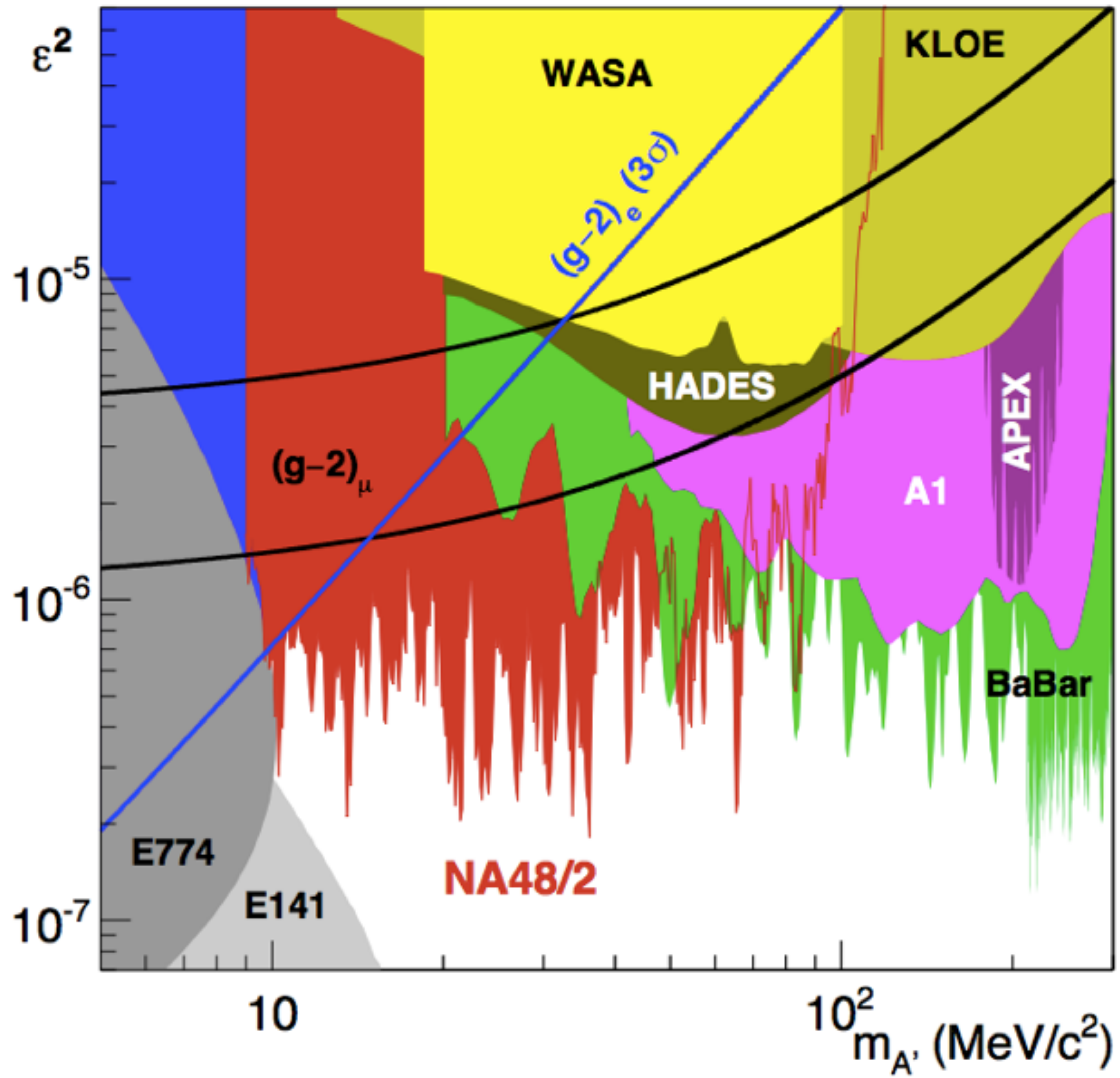
Full-run sometime in 2016

NA48/2 Recasting

arXiv:1504.00607



$\pi^0 \rightarrow \gamma\gamma^d$



Ran in 2003-4 at the CERN SPS

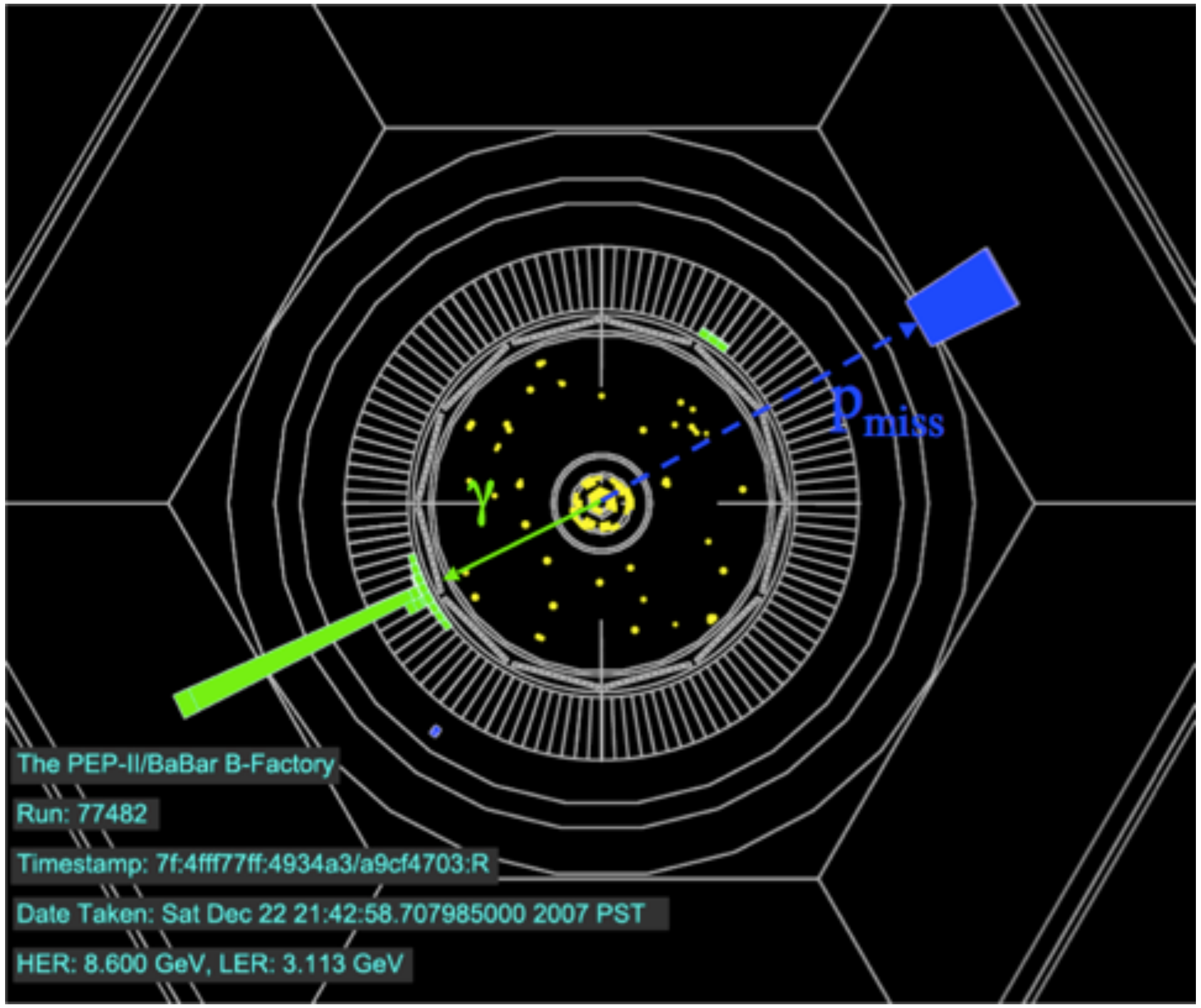
K^+ K^- beams

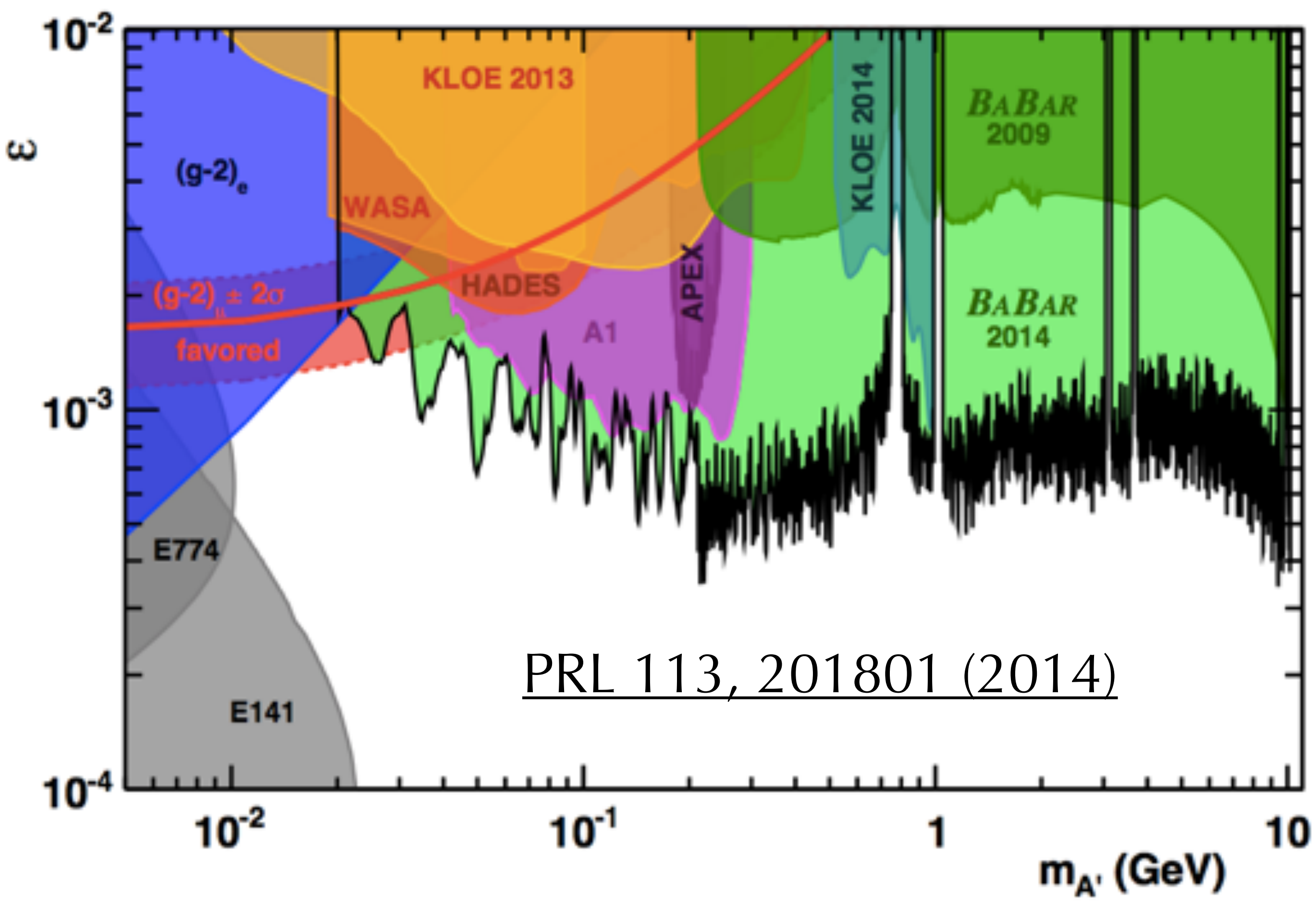
Data revisited this year

Effectively kills the $(g\text{-}2)_\mu$ band for dark photon to visible!

High-intensity collider experiments: BaBar

High-intensity, low-to-medium energy collider experiments have excellent dark photon reach





B-factories have huge datasets (BaBar: 514/fb, Belle: >1000/fb)

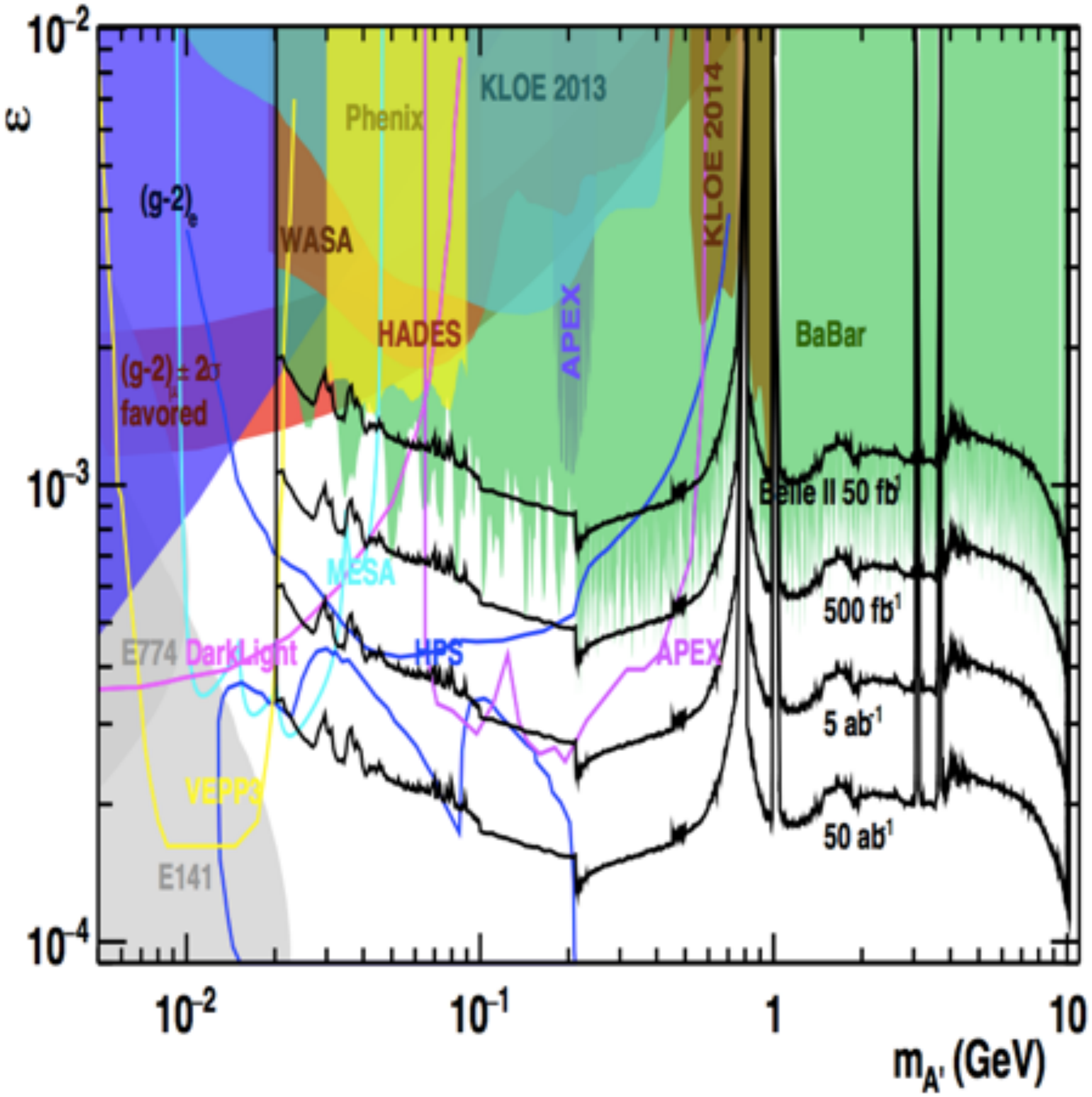
==> Ideally suited for high-statistics resonance searches

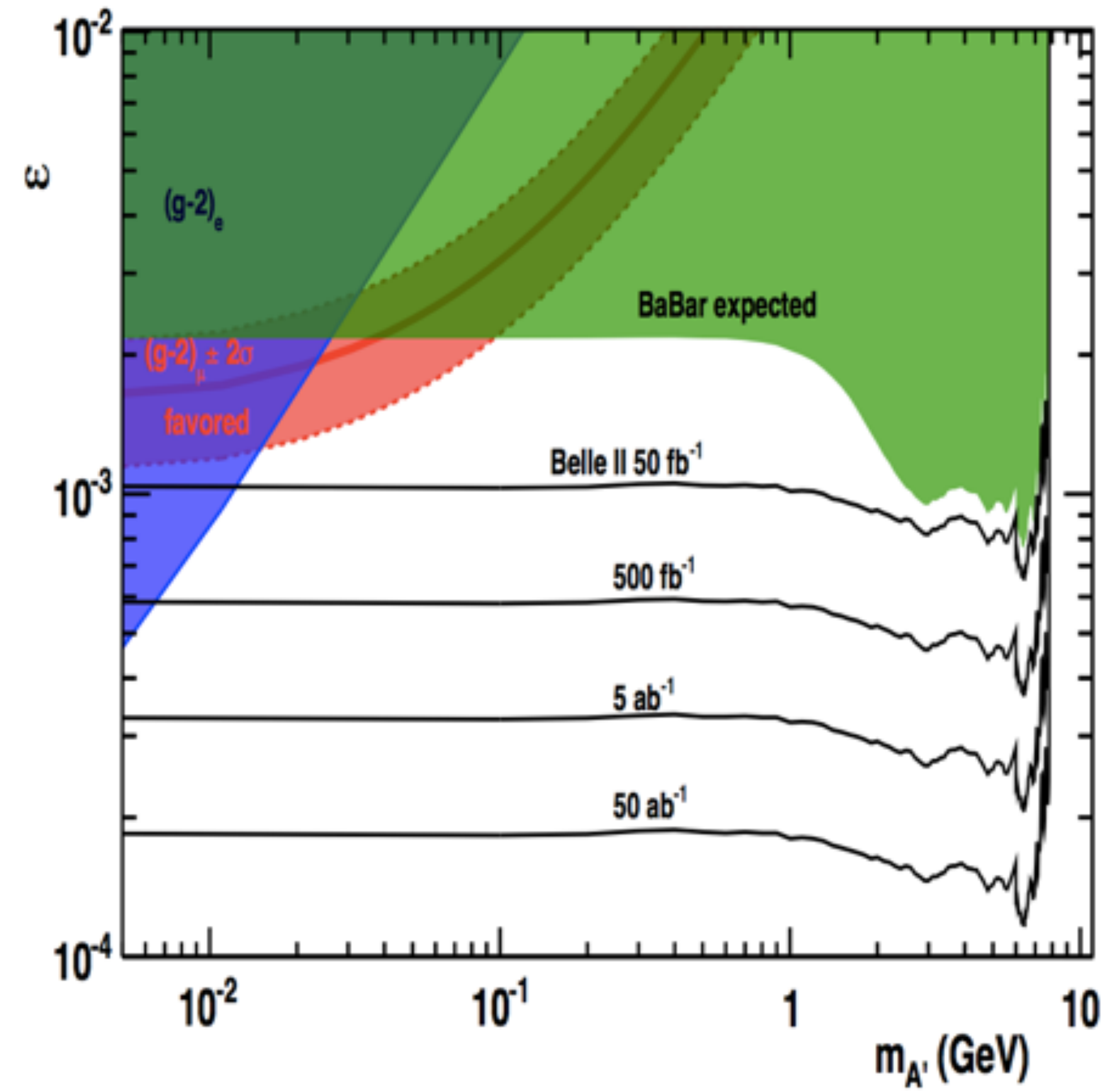
BaBar:

$e^+e^- \longrightarrow \gamma\gamma^d,\ \gamma^d \longrightarrow \mu^+\mu^-$ or e^+e^-

$e^+e^- \longrightarrow \gamma + invisible$

High-intensity collider experiments: Belle

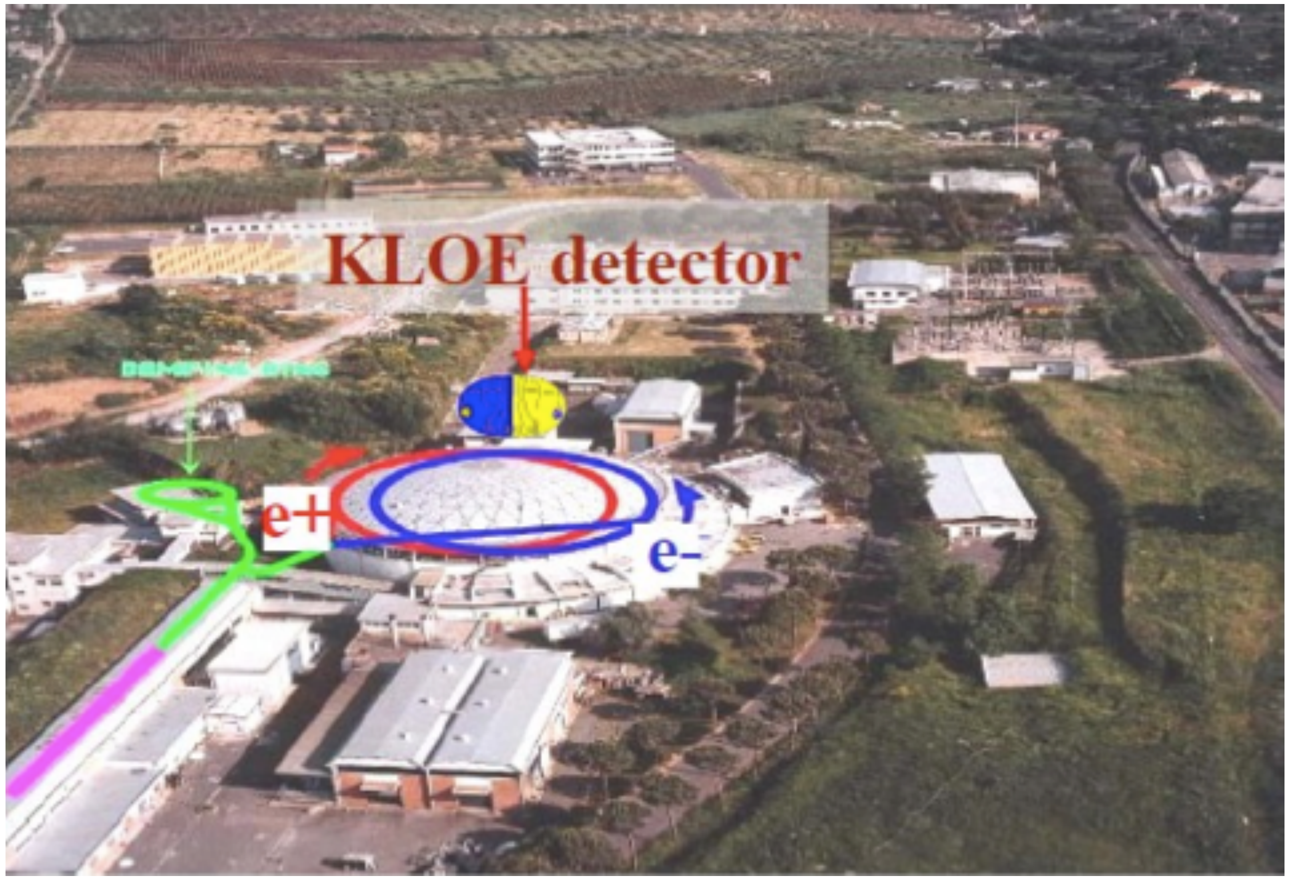




Belle conducted dark photon searches in a large number of leptonic and hadronic decays and multiplicities with similar reach to BaBar

Things get very interesting with Belle II

Dark photons with KLOE@DAΦNE



e^+e^- collider designed (appropriately) to study

the Φ, so $\sqrt{s}$ = 1.0195 GeV

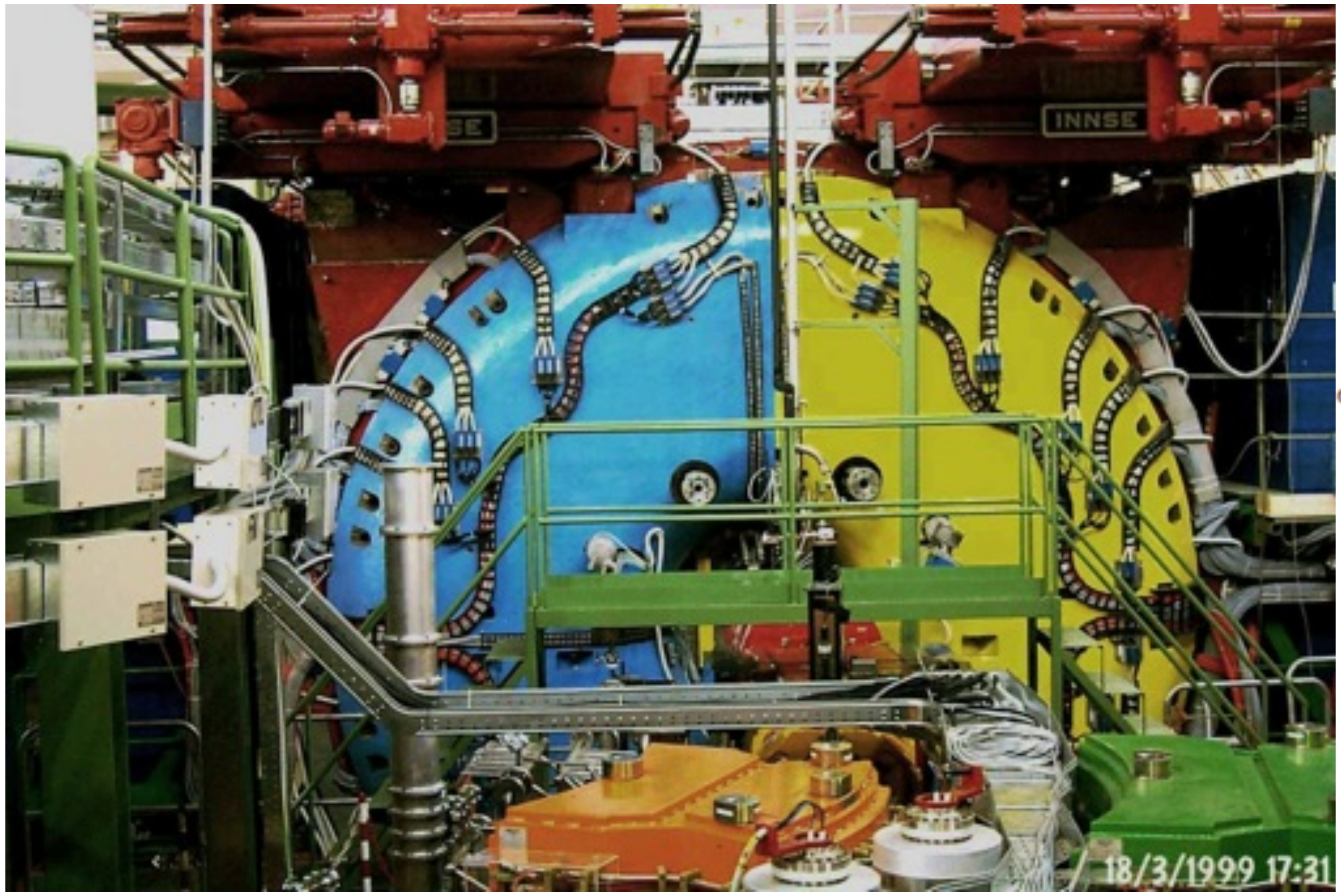
$e^+e^- \rightarrow \mu^+\mu^- \gamma$

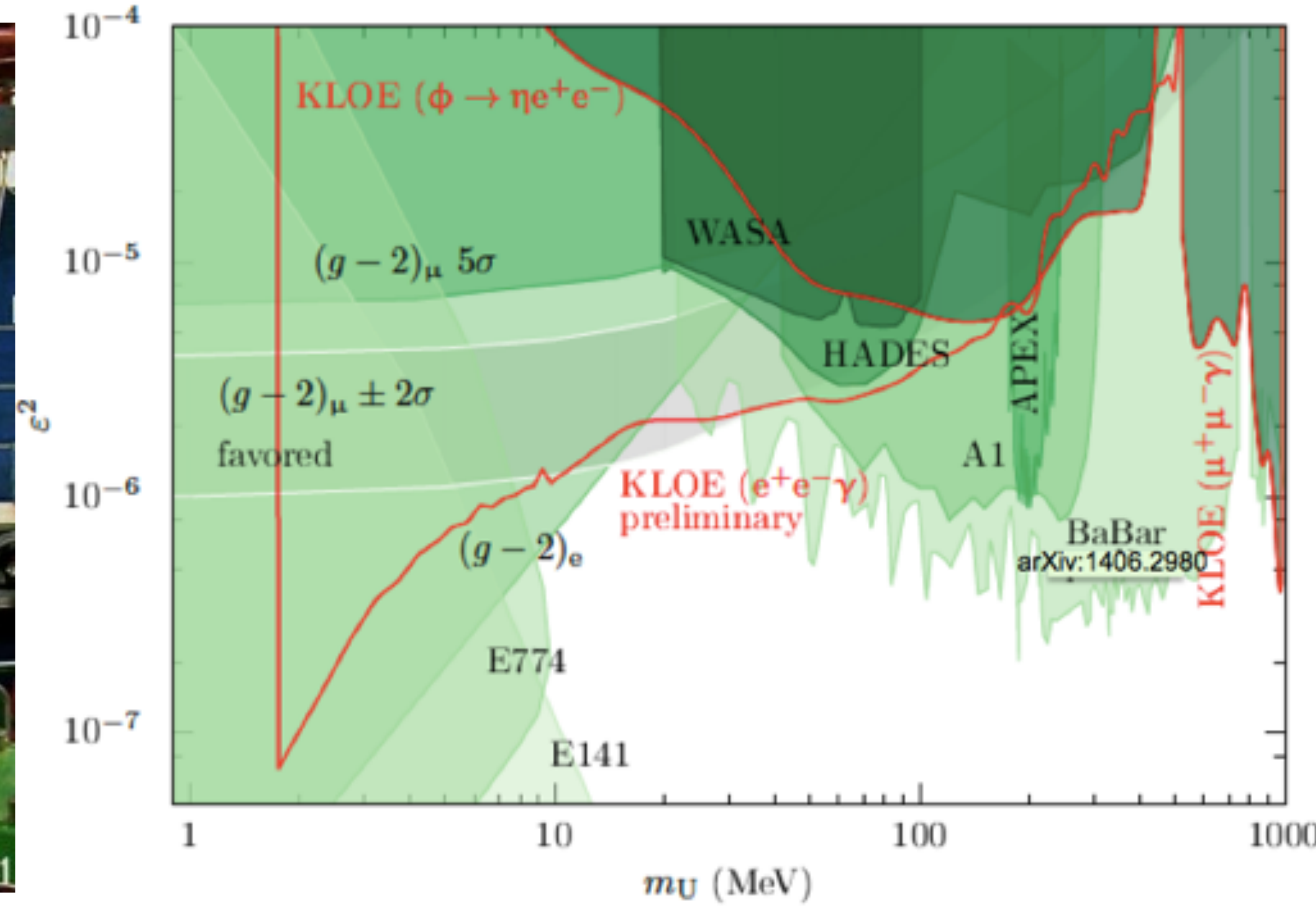
$e^+e^- \rightarrow e^+e^- \gamma$

$e^+e^- \rightarrow \eta\, e^+e^-$

==> Possible sources of dark photons

Dark photons with KLOE@DAΦNE





Big Drift chamber

Stereo wires and carbon-fiber structure, $\sigma_{PT} < 0.4\%$ PT ($\theta > 45°$)

Hermetic sampling calorimeter

Loose trigger conditions (high acceptance across a broad physics program)

Excellent integrated luminosity in 2002 and 2004-2005 runs

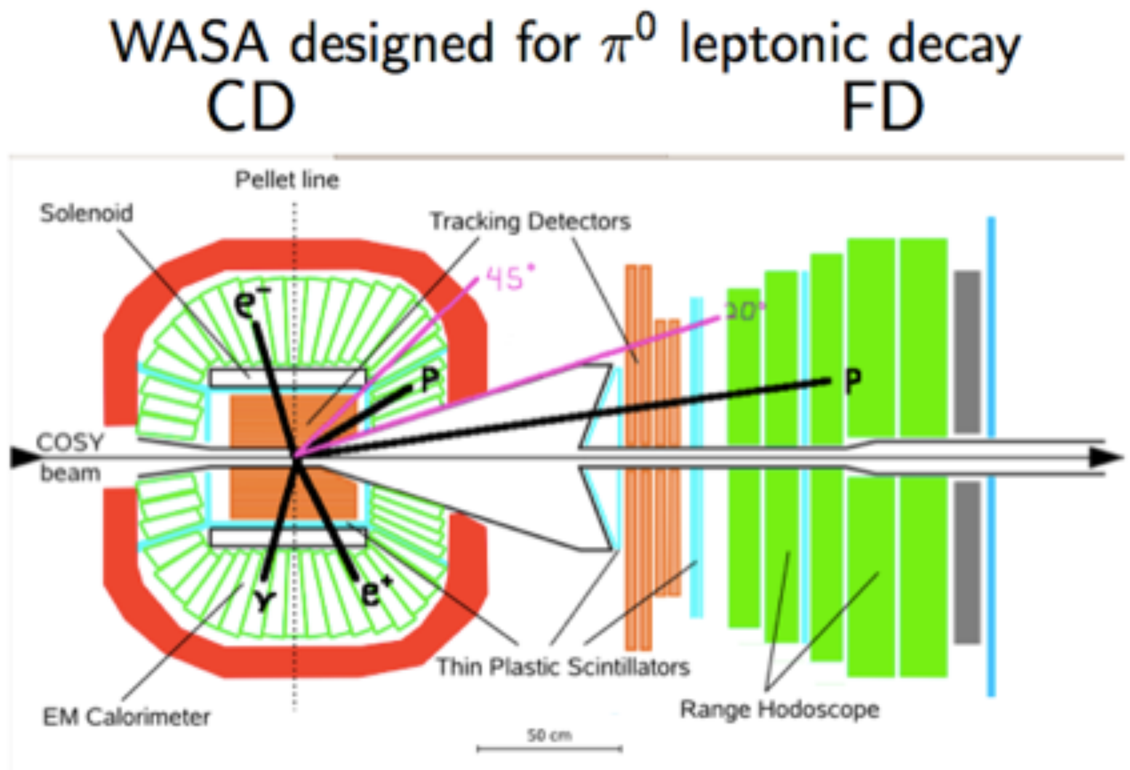
Upgrades

An excellent venue for dark photon searches

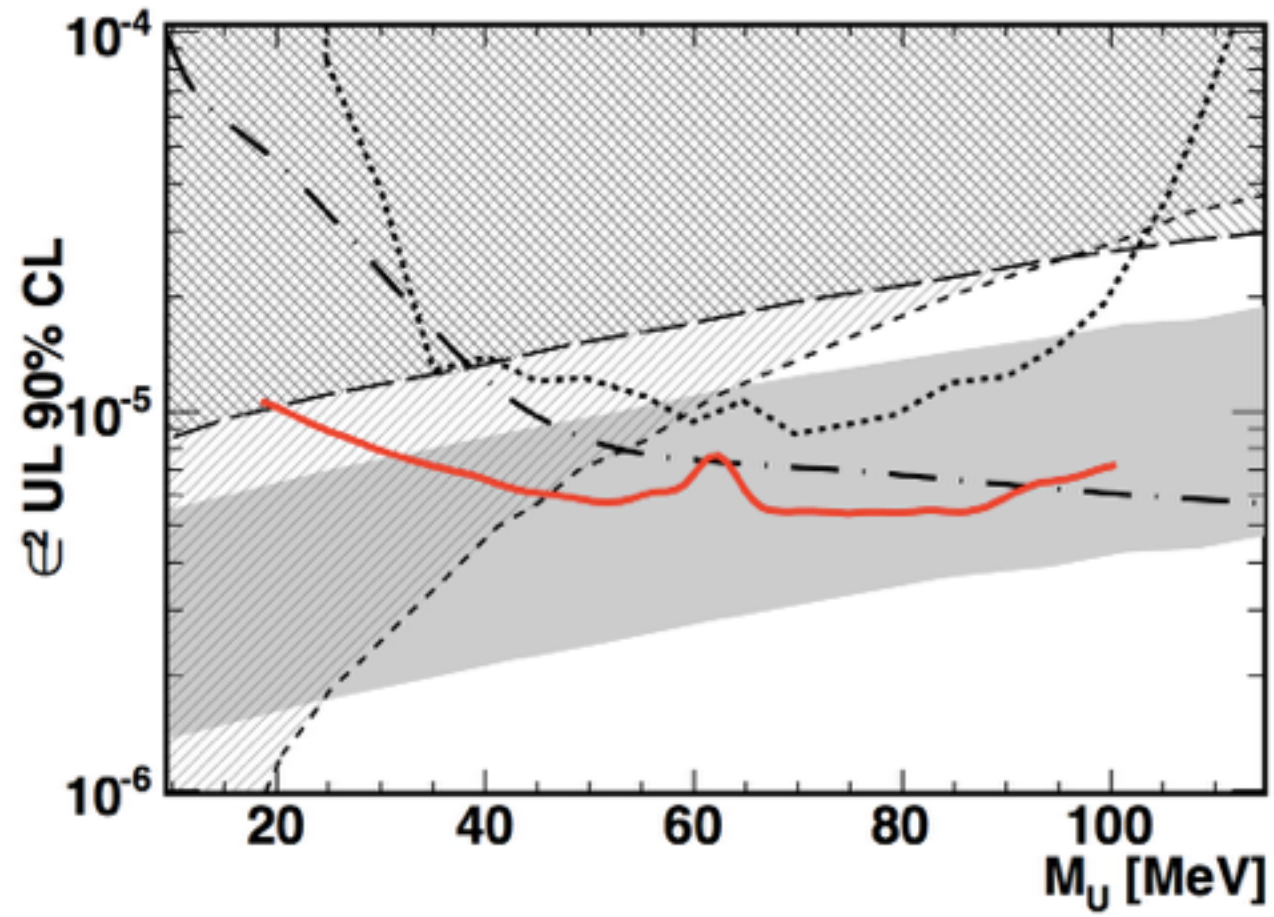
Hadronic dark photon decay searches proposed

arXiv:1509.00740

Dark photons with WASA@COSY



WASA-at-COSY setup with $pp \to pp\,(\pi^0 \to e^+e^-\gamma)$



WASA detector designed to study rare pion decays

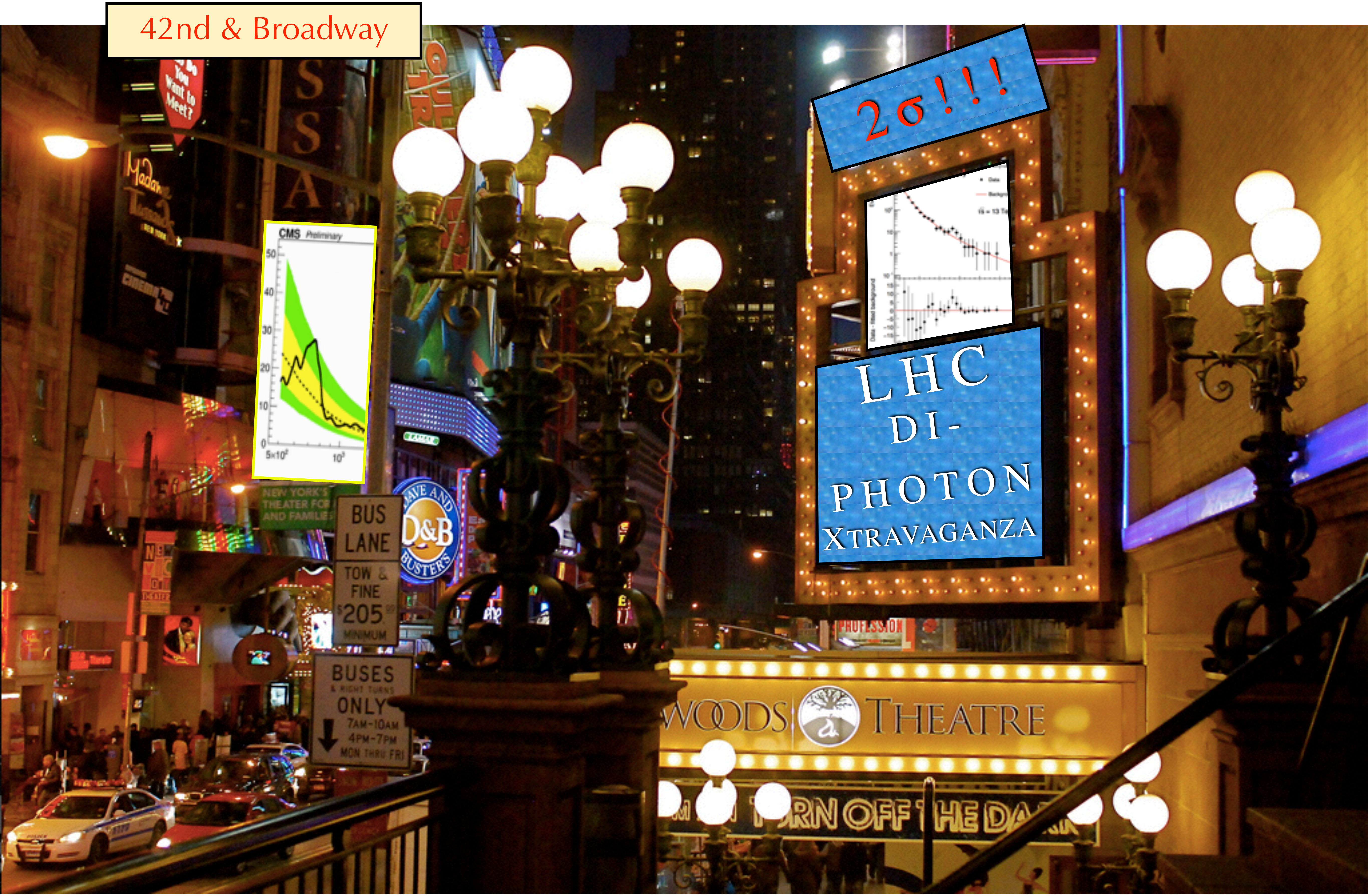
Moved from Uppsala to Jülich

Excellent repurposing of existing experimental equipment to put an exclusion right in the $(g\text{-}2)_\mu$ sweet spot

arXiv:1304.0671

The LHC

The LHC

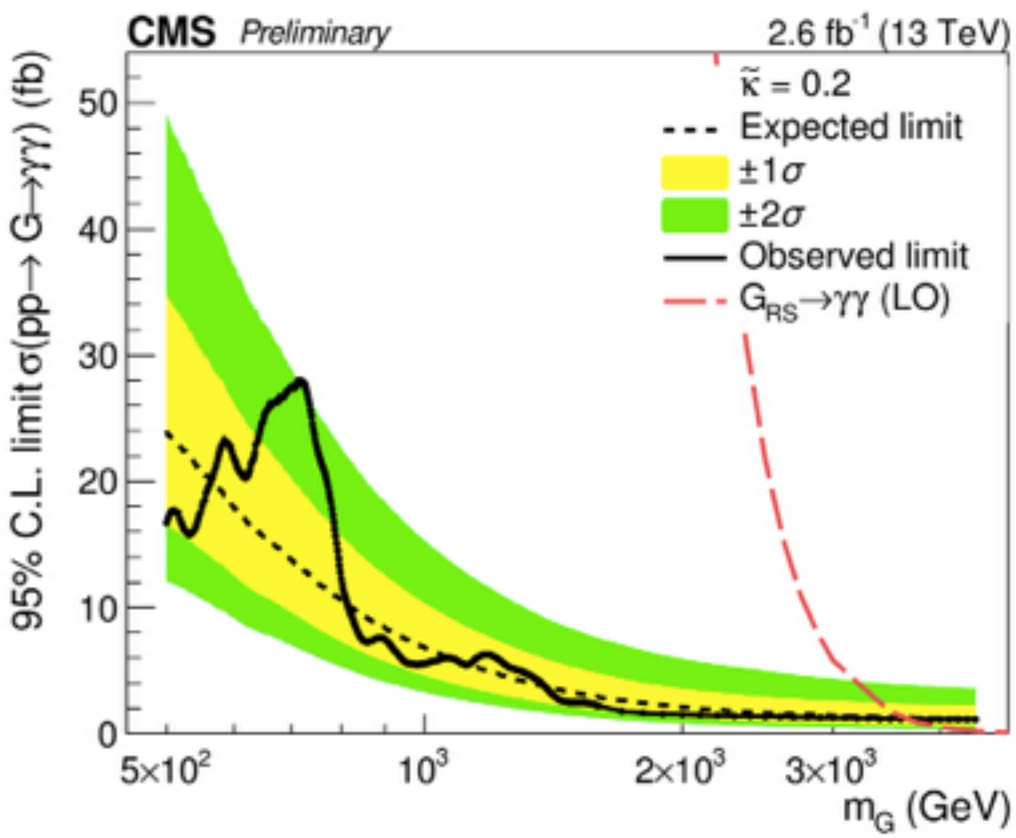

42nd & Broadway
2σ!!!
LHC DI-PHOTON XTRAVAGANZA
CMS Preliminary
BUS LANE
TOW & FINE $205 MINIMUM
BUSES & RIGHT TURNS ONLY 7AM-10AM 4PM-7PM MON THRU FRI
DAVE AND BUSTERS
D&B
THEATRE

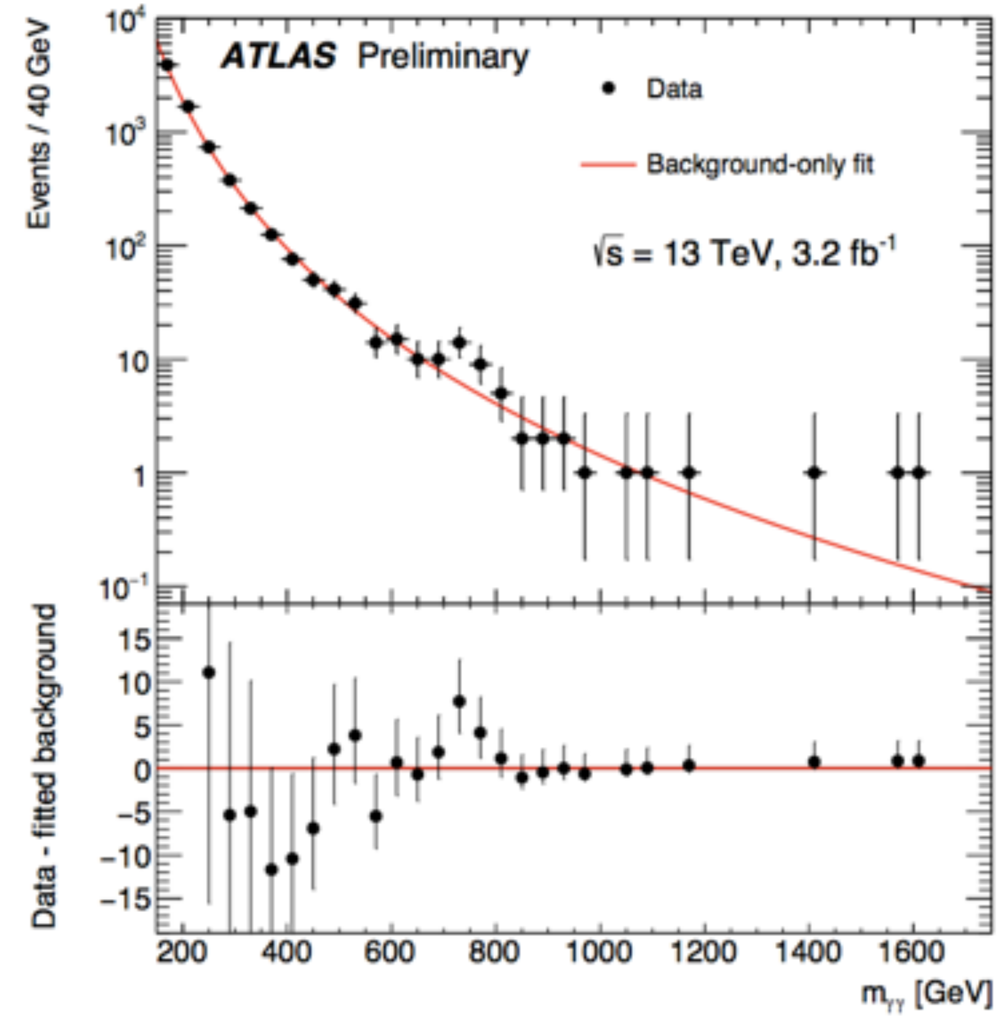
The LHC

East Village Off-Off-Broadway
Waiting for
Dark Photons
Samuel Beckett
ATLAS
m$_{\gamma_d}$ [GeV]
La MaMa etc

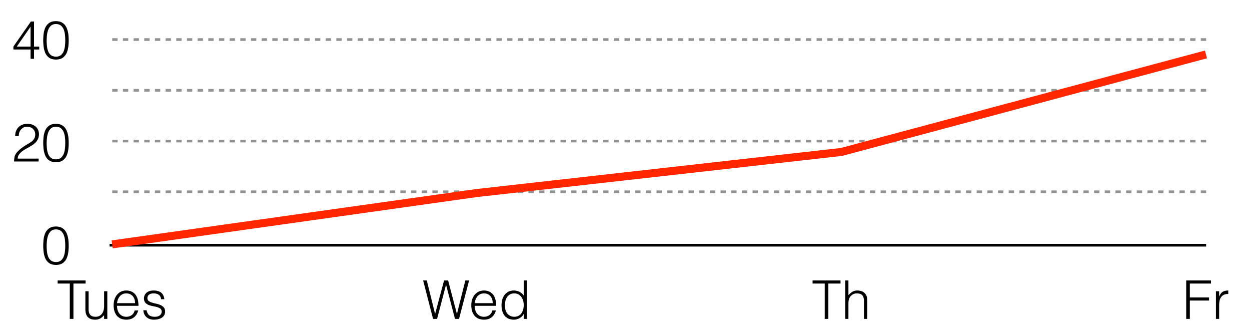
The LHC

At the LHC we're not just slight, intriguing diphoton excesses at 750 GeV.





arXiv pheno $m_{\gamma\gamma}$ = 750 GeV papers, cumulative, after our seminar @CERN on Tues. 15 Dec. 2015

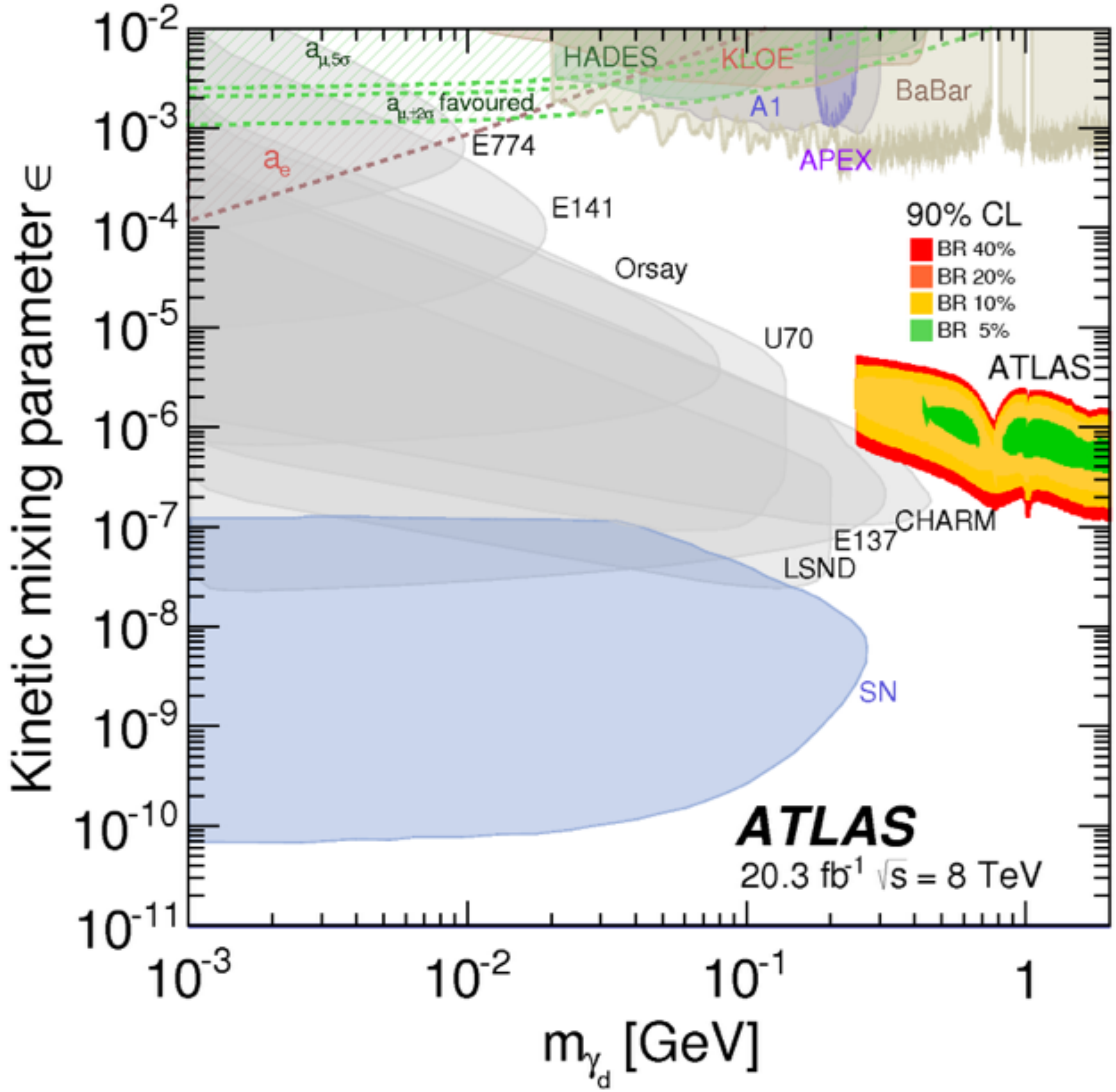


Run 2 is a playground of fascinating signatures, approaches and final states, including dark photons.

Dark photons at the LHC

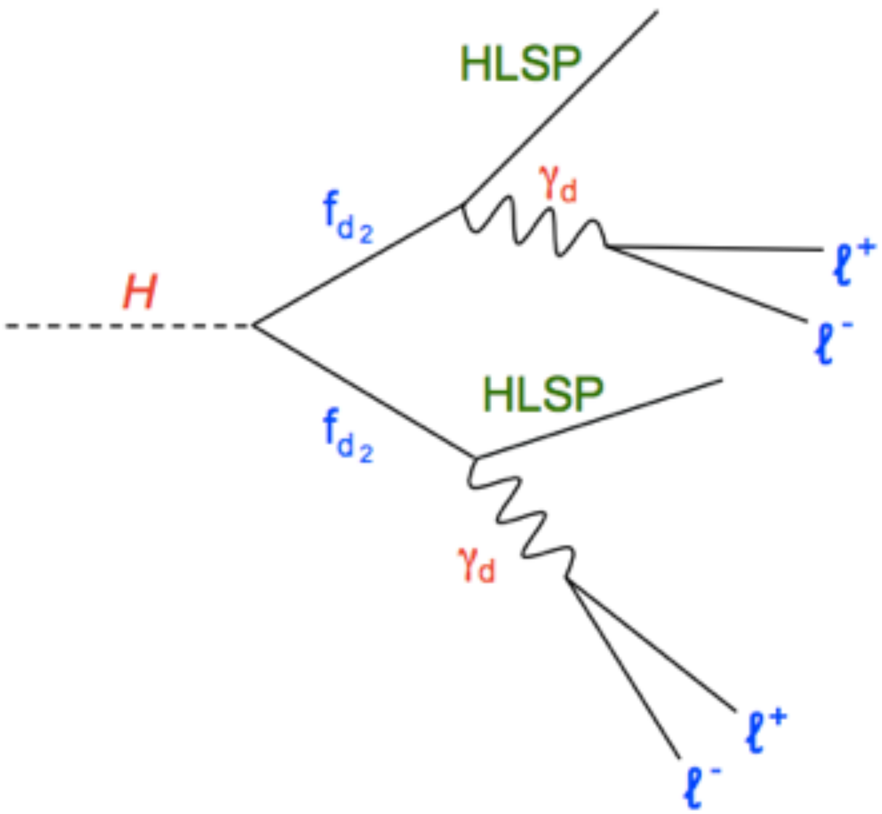
The LHC is now getting in on the dark photon action…

…via *lepton-jets*.



Dark photons at the LHC

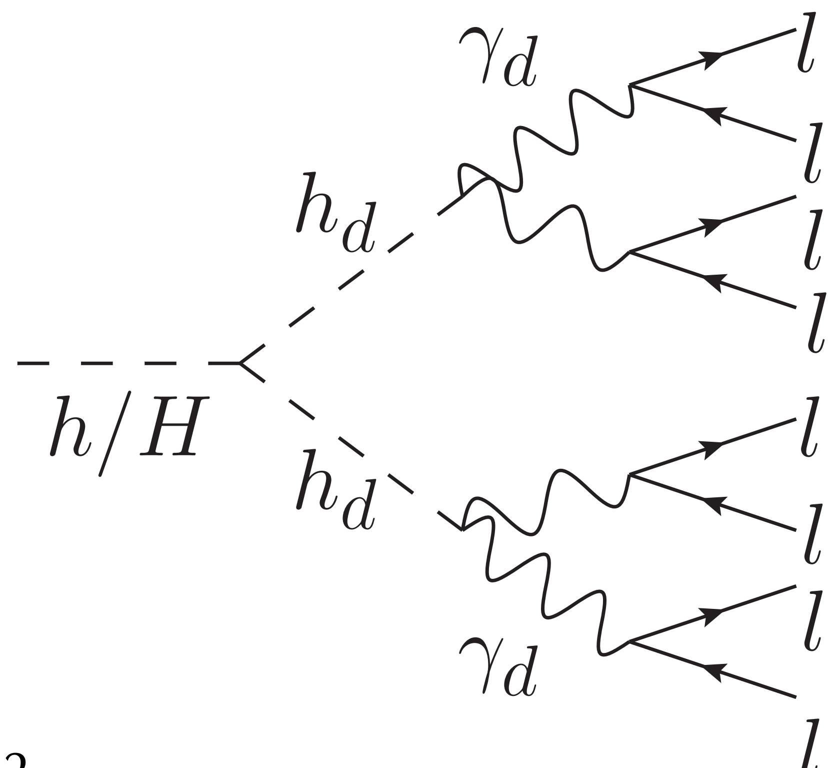
Highly collimated groupings of leptons: *lepton-jets*; distinct LHC signature

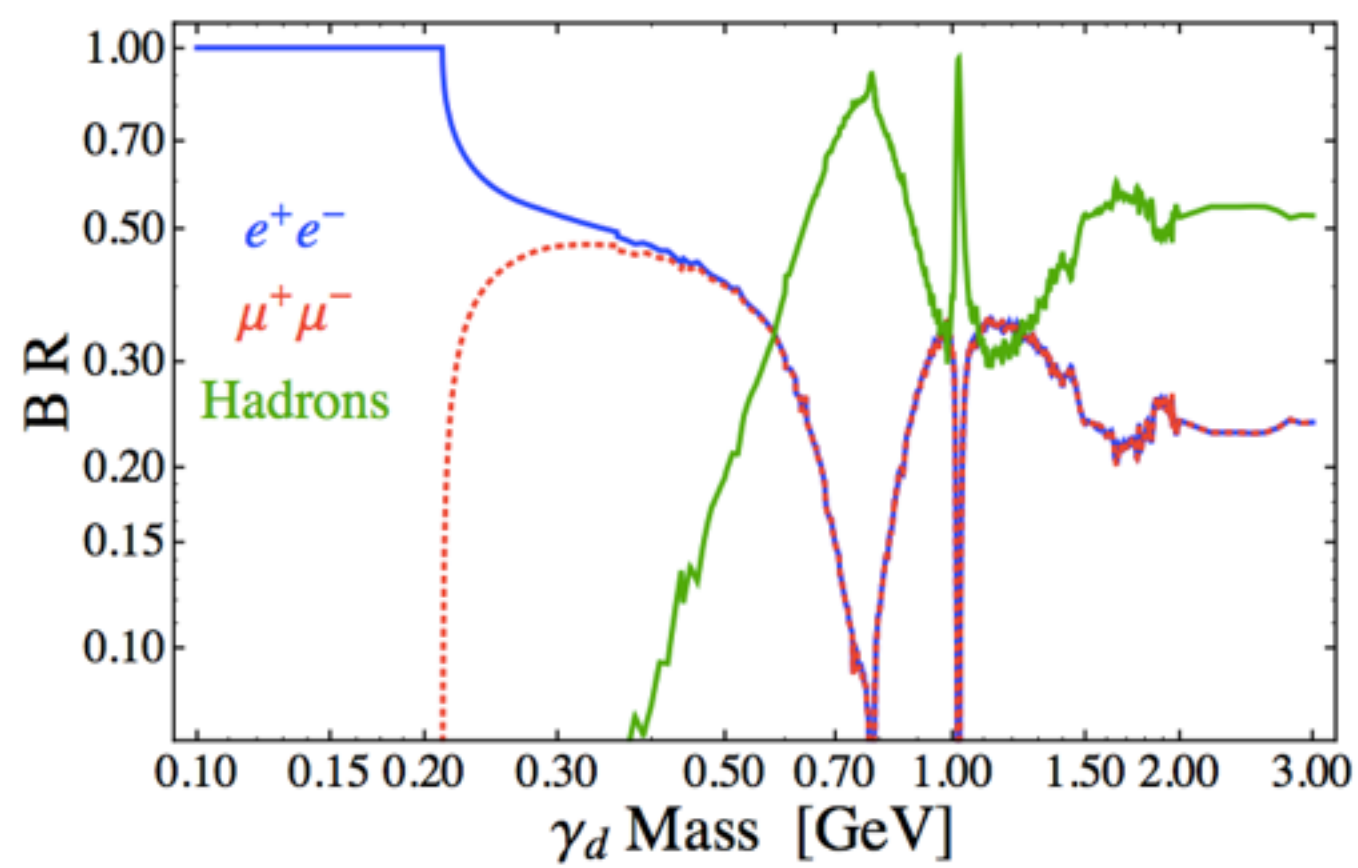


Low-mass dark photons can be produced via cascade decays of heavier states

Low-mass
—> large boost
—> collimated decay products

Leptonic decays prominent over wide (low) mass range





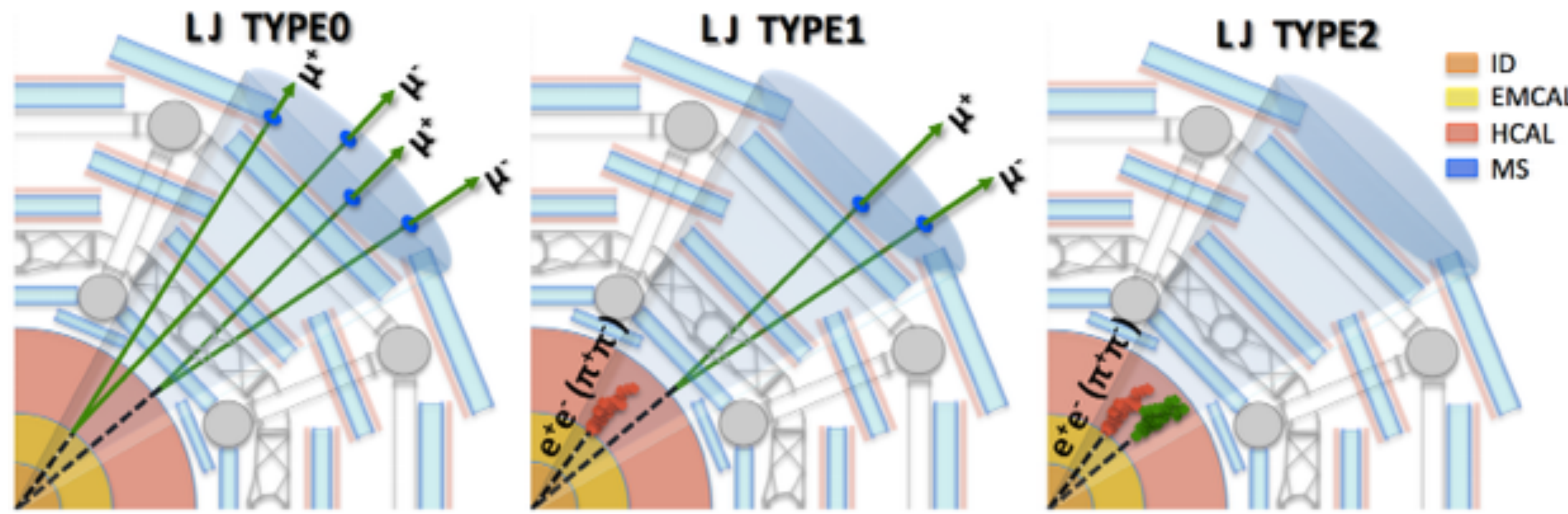
arXiv:1002.2952

Prompt and displaced lepton-jets at the LHC

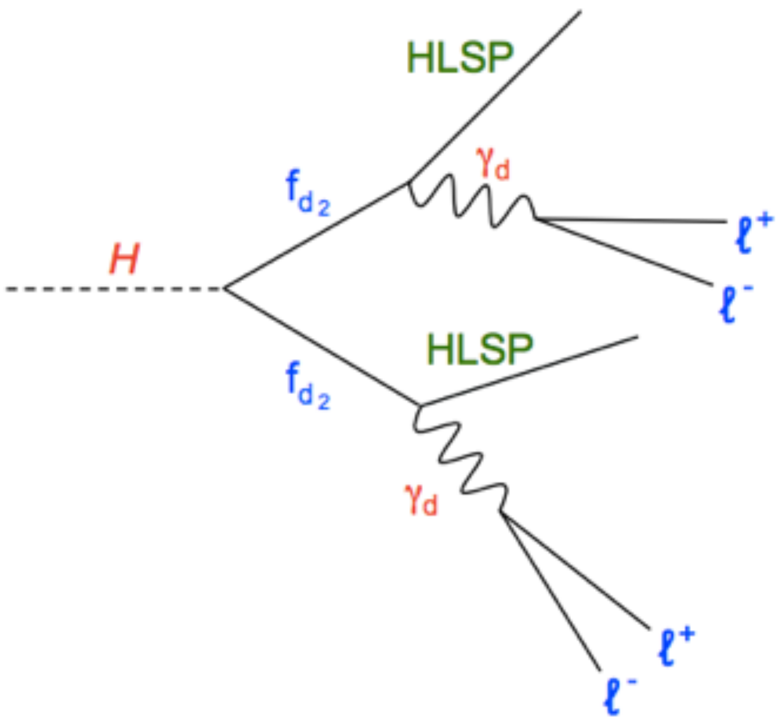
Highly collimated groupings of leptons: *lepton-jets*; distinct LHC signature

- Standard muon ID benefits from isolation; here need dedicated clustering algorithm with a cone of ΔR

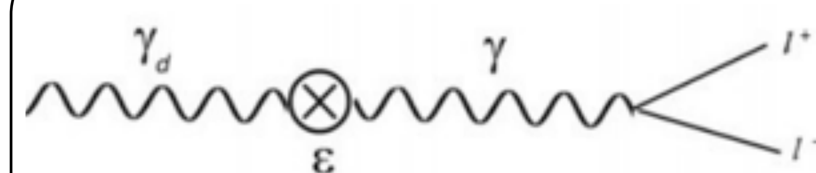
Model-independent search for lepton-jet objects, with a few benchmark signal interpretations



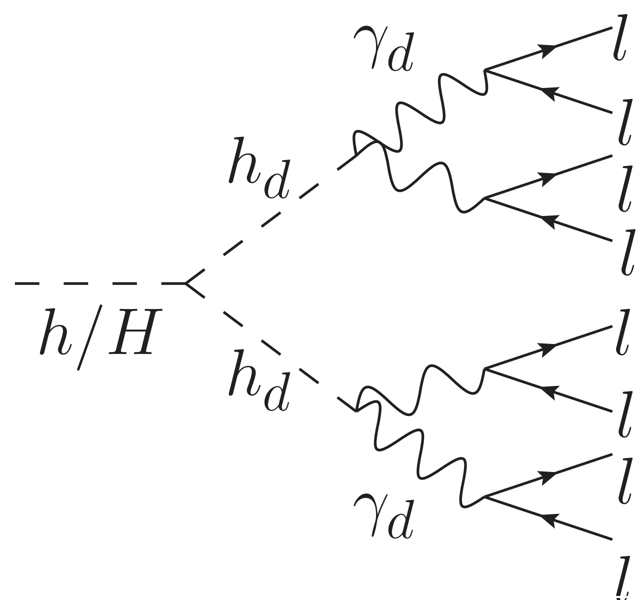
Weak interaction ==> non-negligible dark photon lifetime

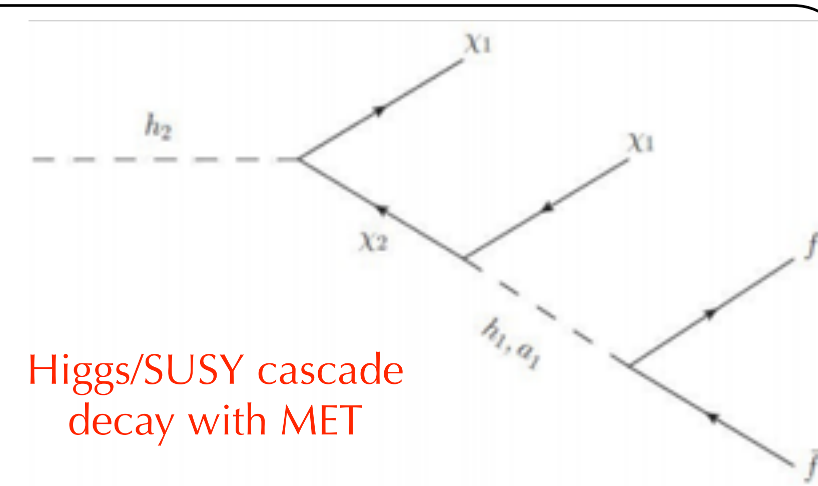


Dark/hidden sector coupled to SM Higgs and leptons via very light dark sector particles



Kinetic mixing portal





Higgs/SUSY cascade decay with MET

Three separate types of lepton-jet definitions considered

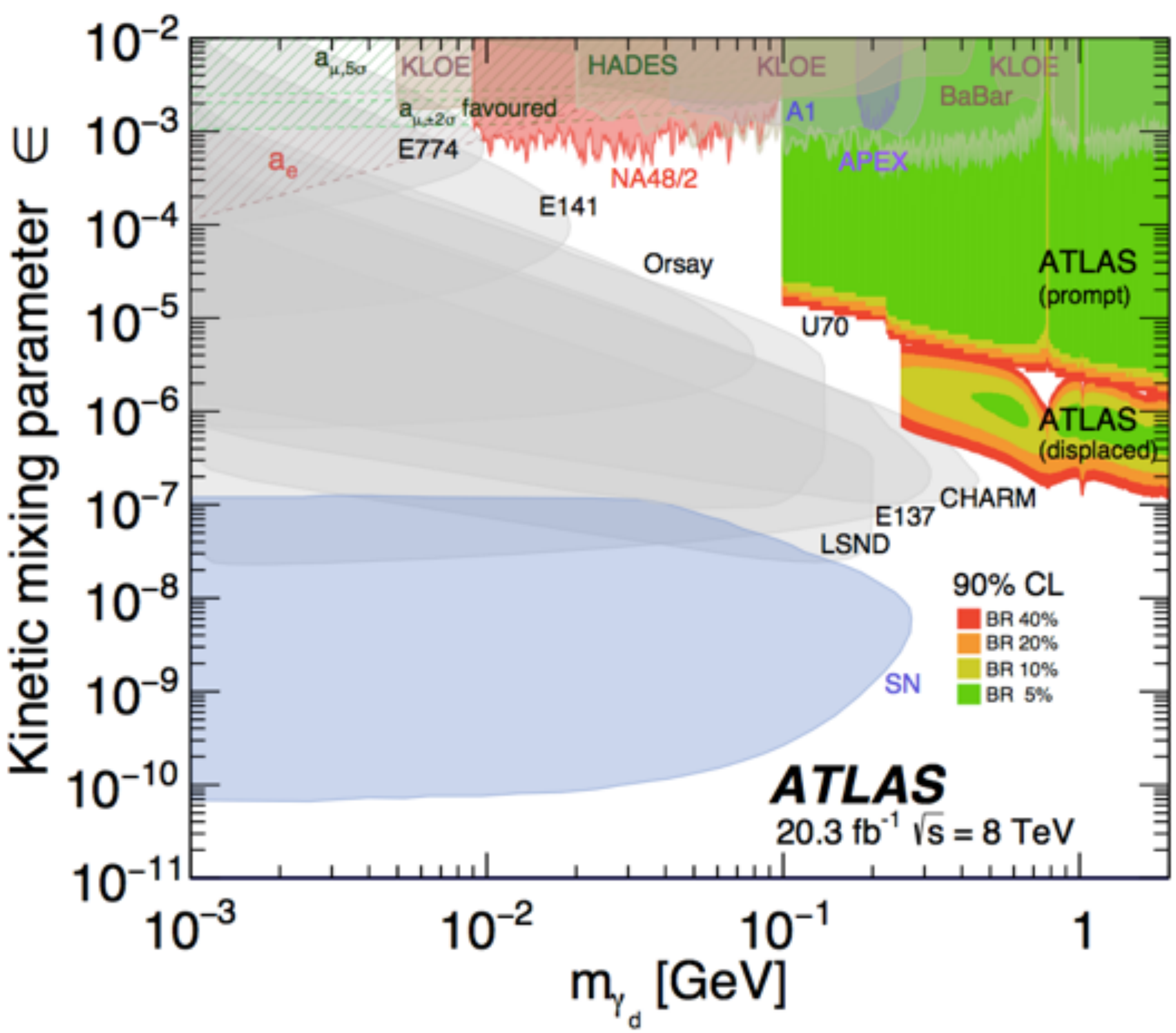
Cosmic backgrounds important

Prompt and displaced lepton-jets at the LHC

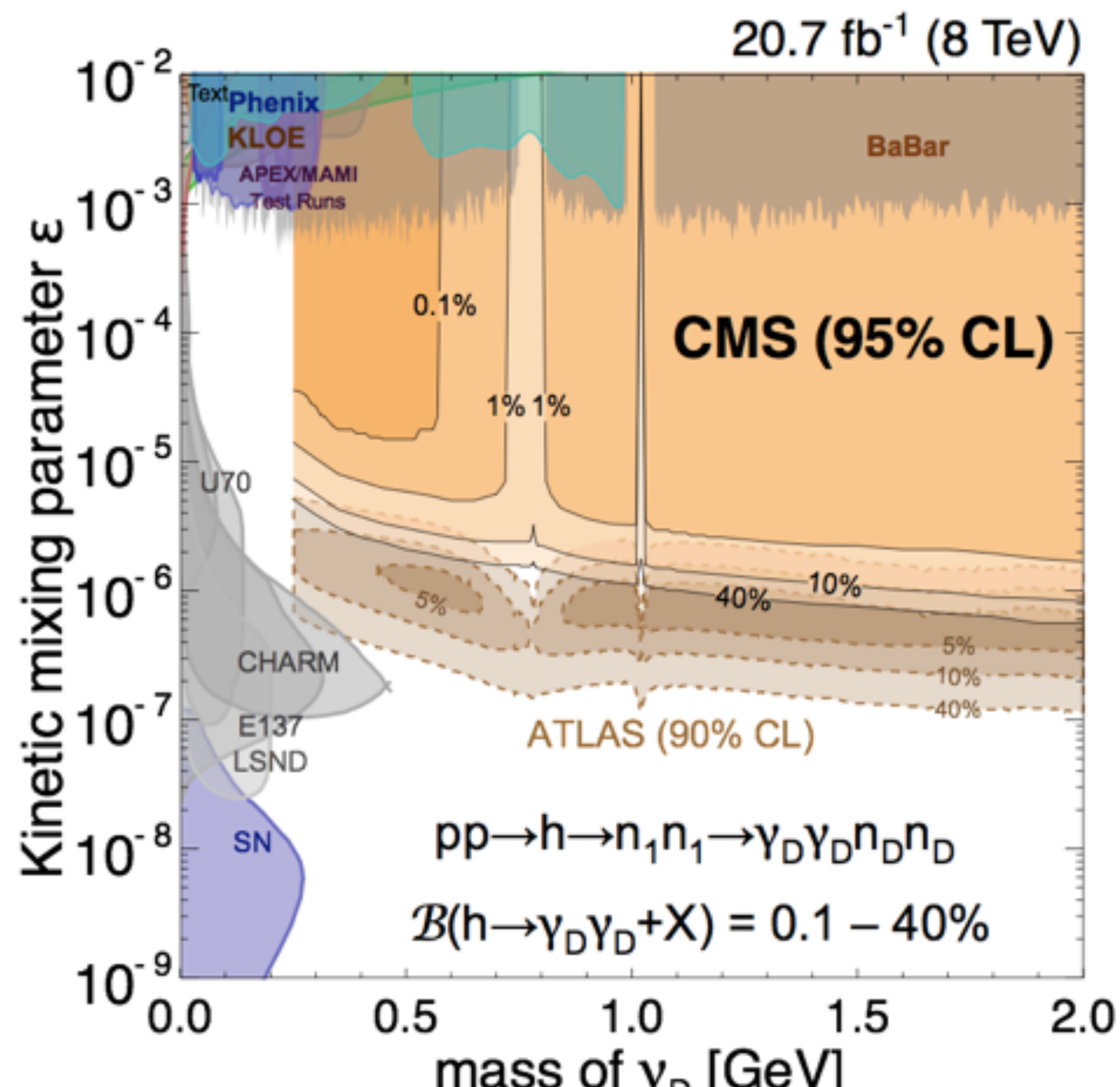
ATLAS: JHEP11(2014)088
arXiv:1511.05542

CMS: arXiv:1506.00424

ATLAS lepton-jets

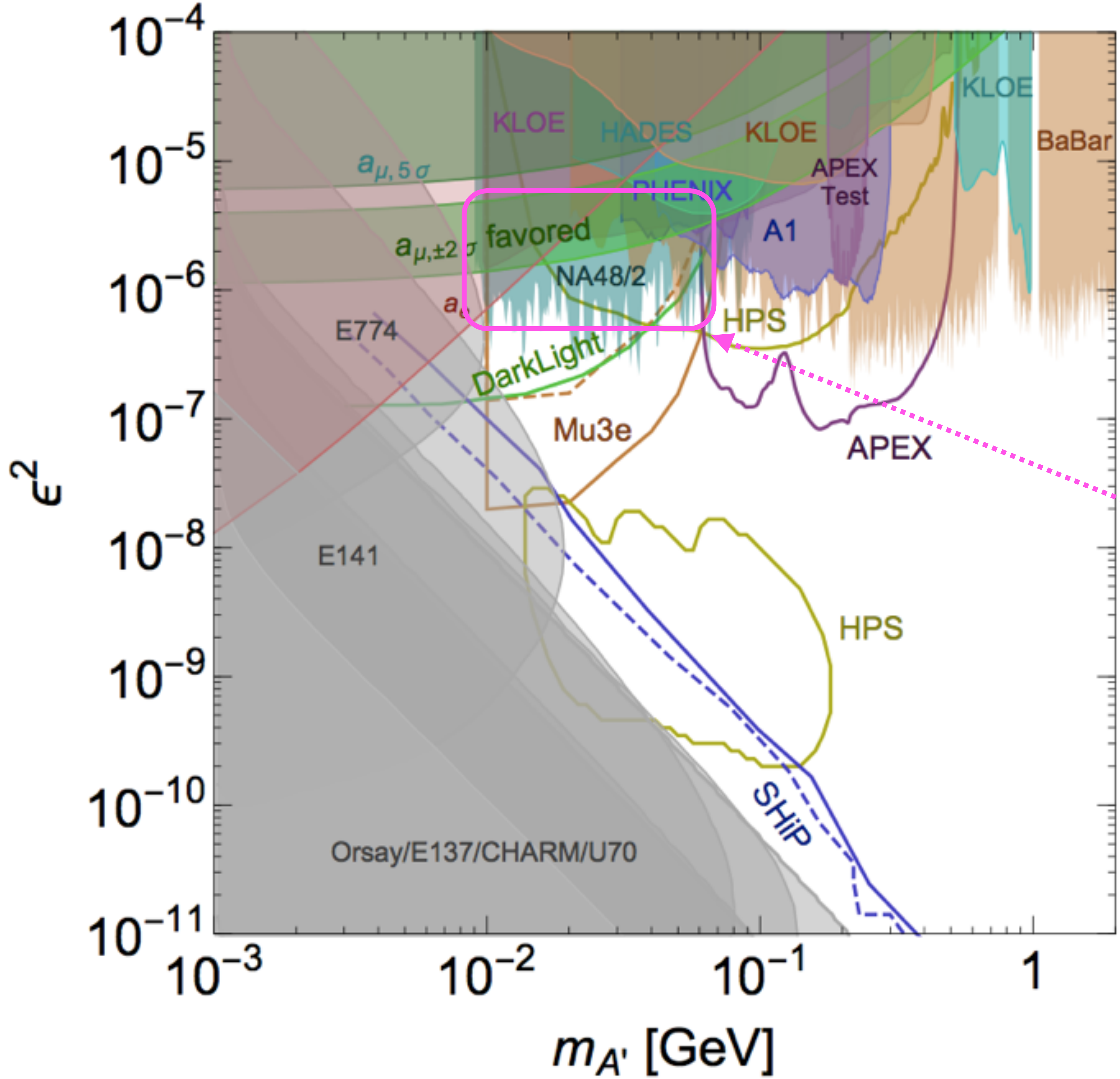


CMS dark photon interpretation of H —> aa —> 4μ



Parameter space getting squeezed

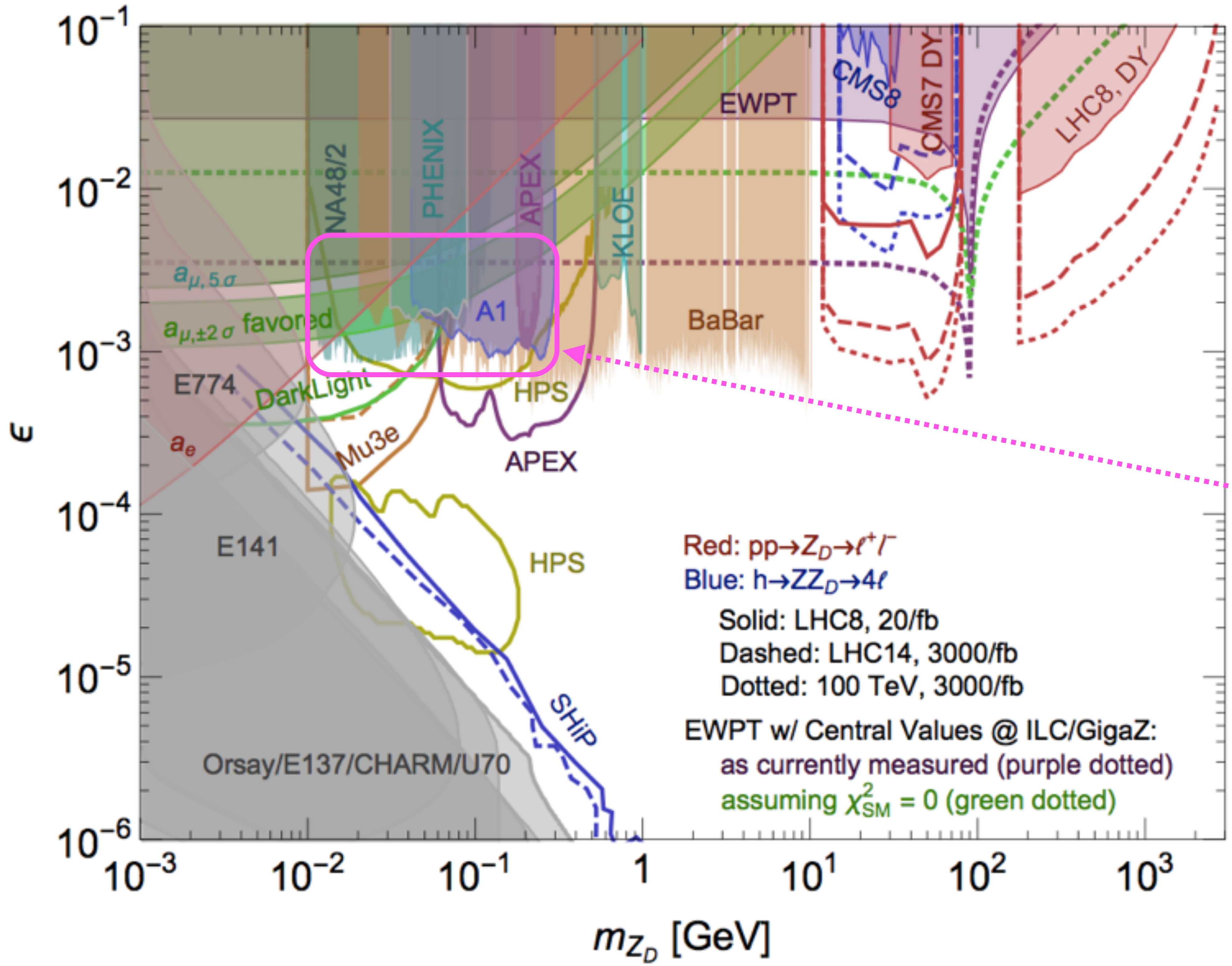
Parameter space getting squeezed — for visible decays



Recent results disfavor A′ —> SM solution to muon g-2 (also beam dump reinterpretation)

A′ —> invisible a stronger possibility

Parameter space getting squeezed — for visible decays



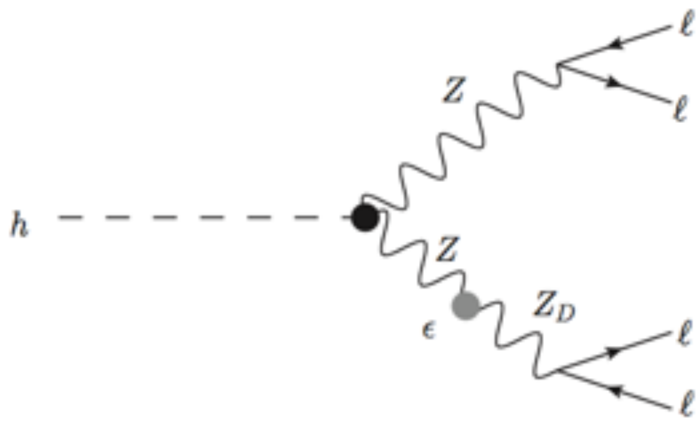
Recent results disfavor A′ —> SM solution to muon g-2 (also beam dump reinterpretation)

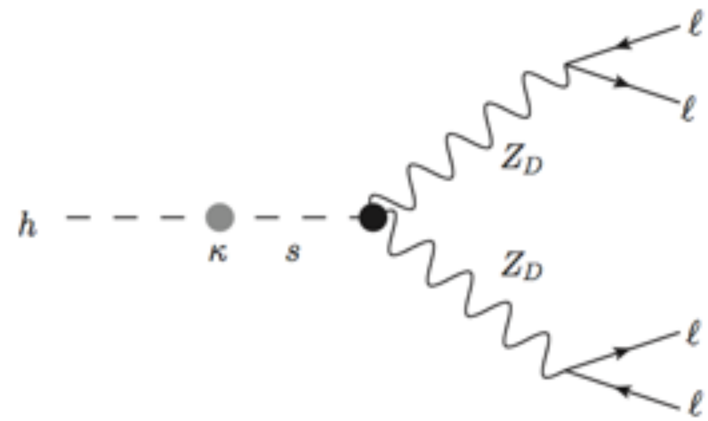
A′ —> invisible a stronger possibility

arXiv:1412.0018

Extend our thinking to higher masses

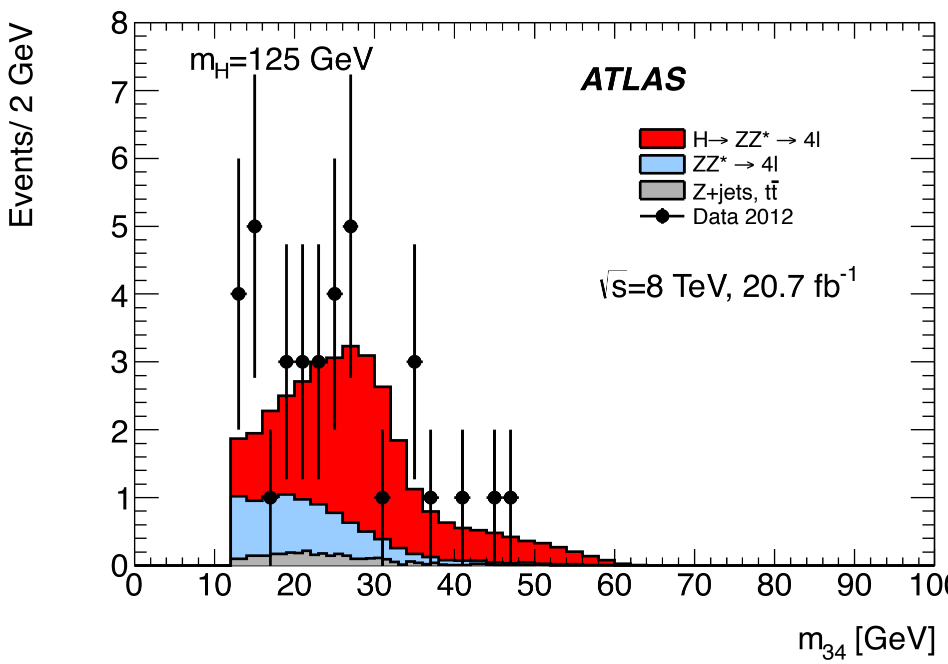
Higher mass hidden gauge bosons: H ⟶ $Z_{(d)}Z_d$ ⟶ 4l



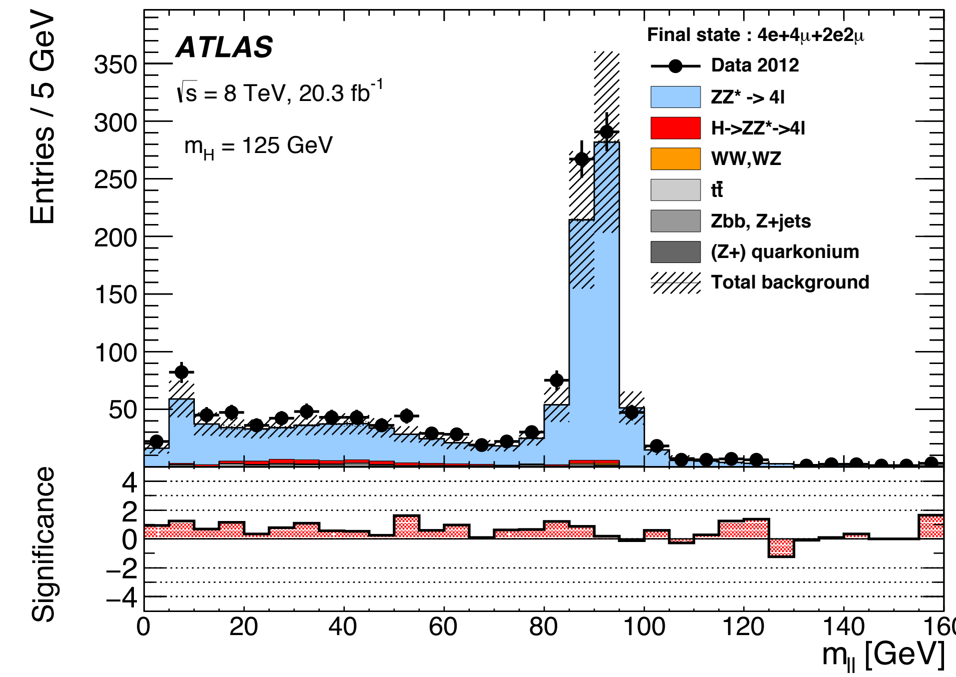


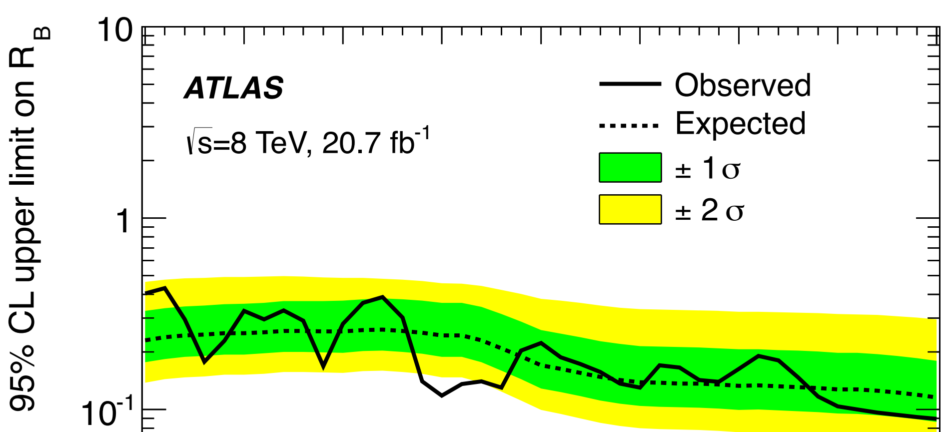
ATLAS (8 TeV): arXiv:1505.07645

Dedicated search in ATLAS Higgs-to-four-leptons events



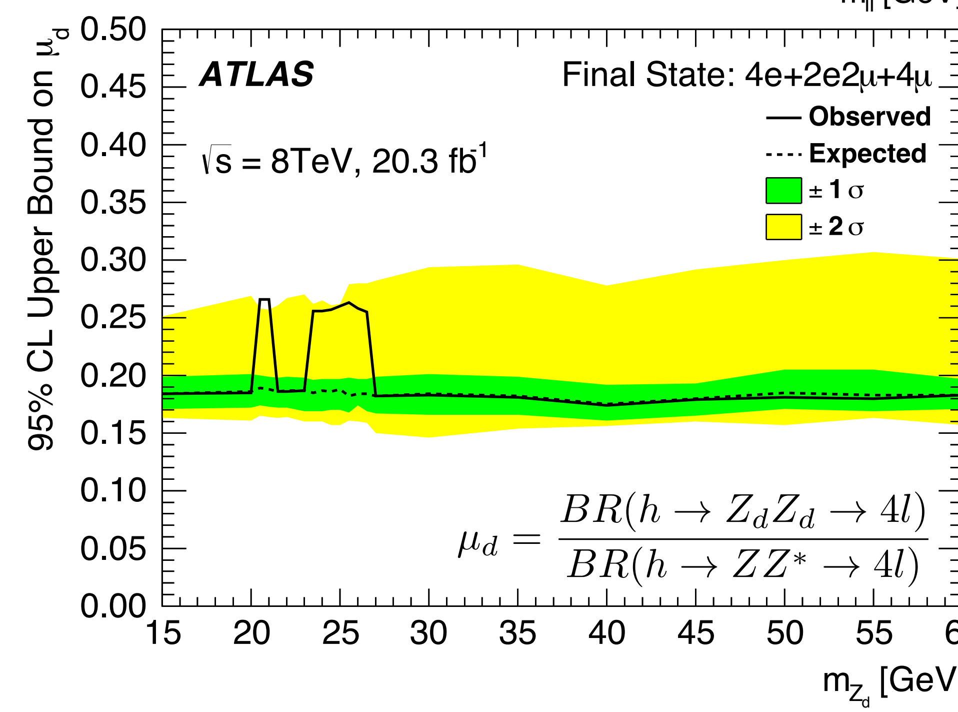
ZZ_d: Look for excesses in m_{34} spectrum (where m_{12} is closest to m_Z)





$$R_B = \frac{BR(h \to ZZ_d \to 4l)}{BR(h \to ZZ^* \to 4l)}$$

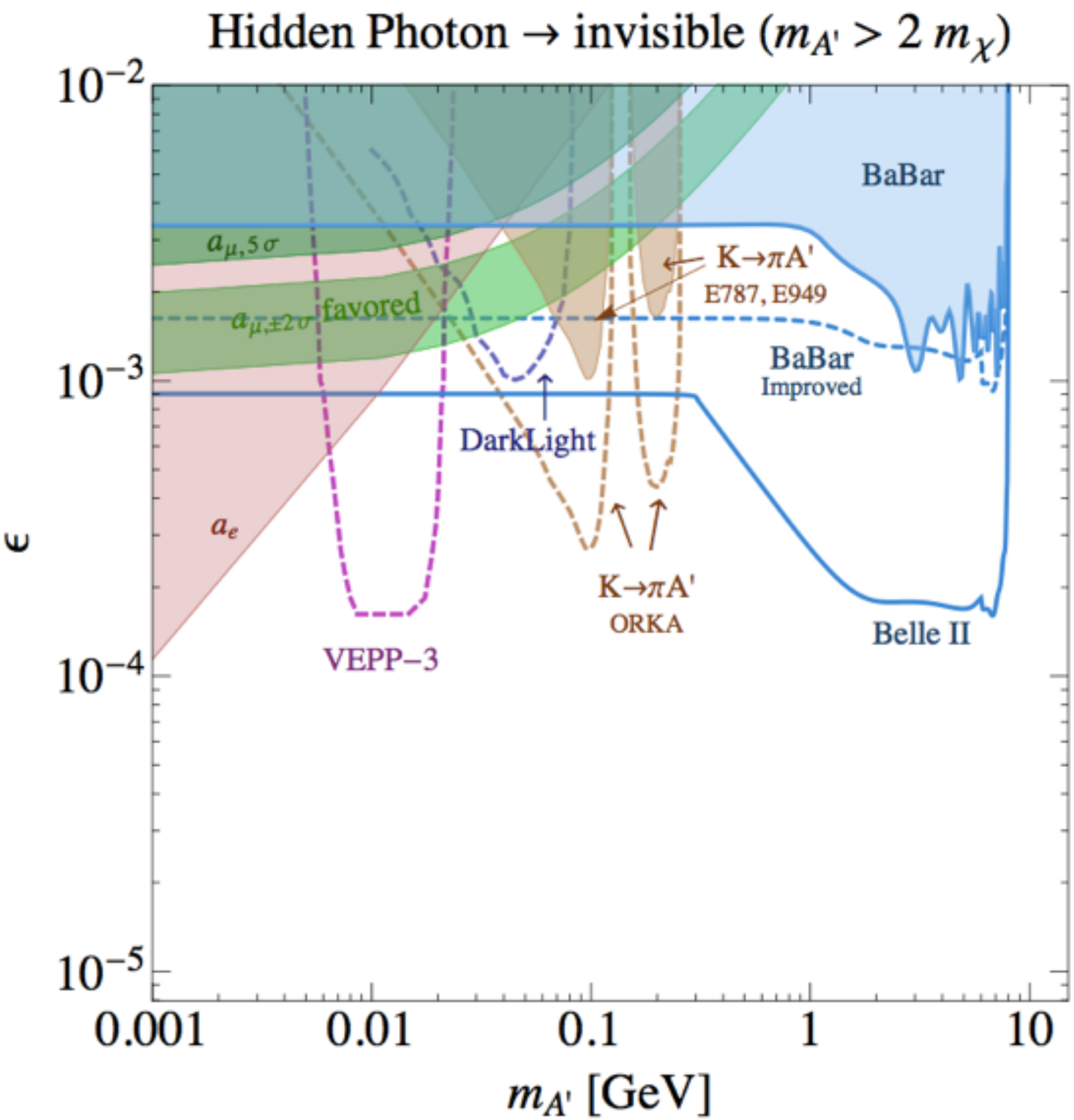
Z_dZ_d: keep events with a unique quadruplet where the mass difference between the 2 dilepton system $|m_{12}-m_{34}|$ is minimal; then apply a Z-veto and a J/ψ and Υ veto

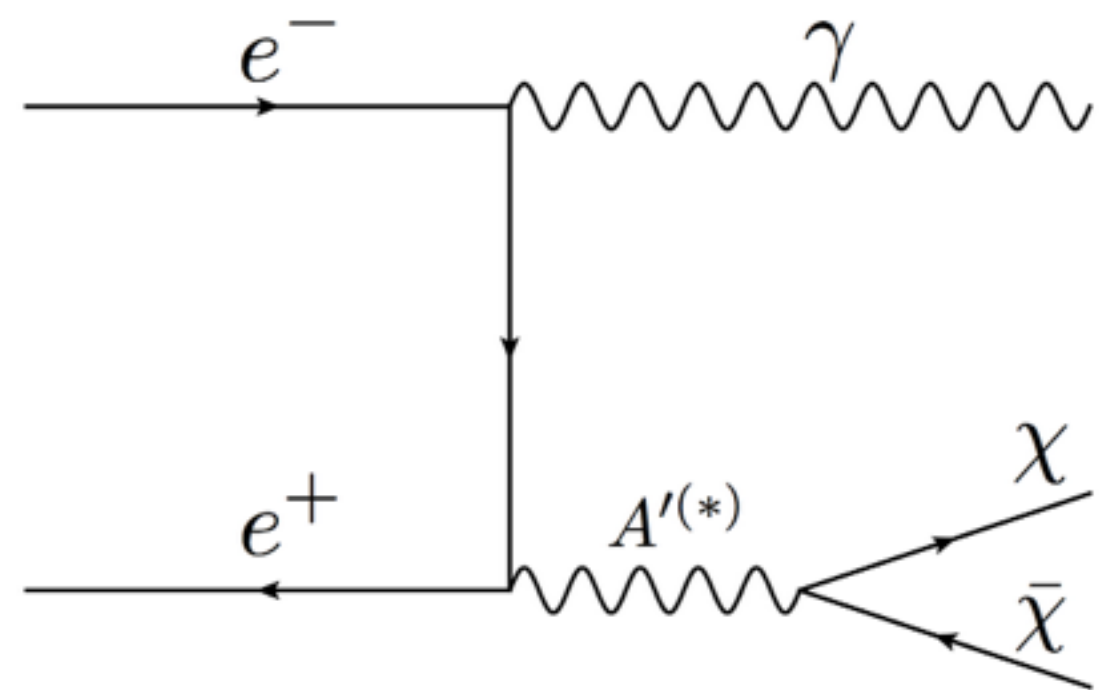


$$\mu_d = \frac{BR(h \to Z_dZ_d \to 4l)}{BR(h \to ZZ^* \to 4l)}$$

Invisible dark photon decays

arXiv:1309.5084





Excellent prospects at Belle 2

Monophoton trigger essential

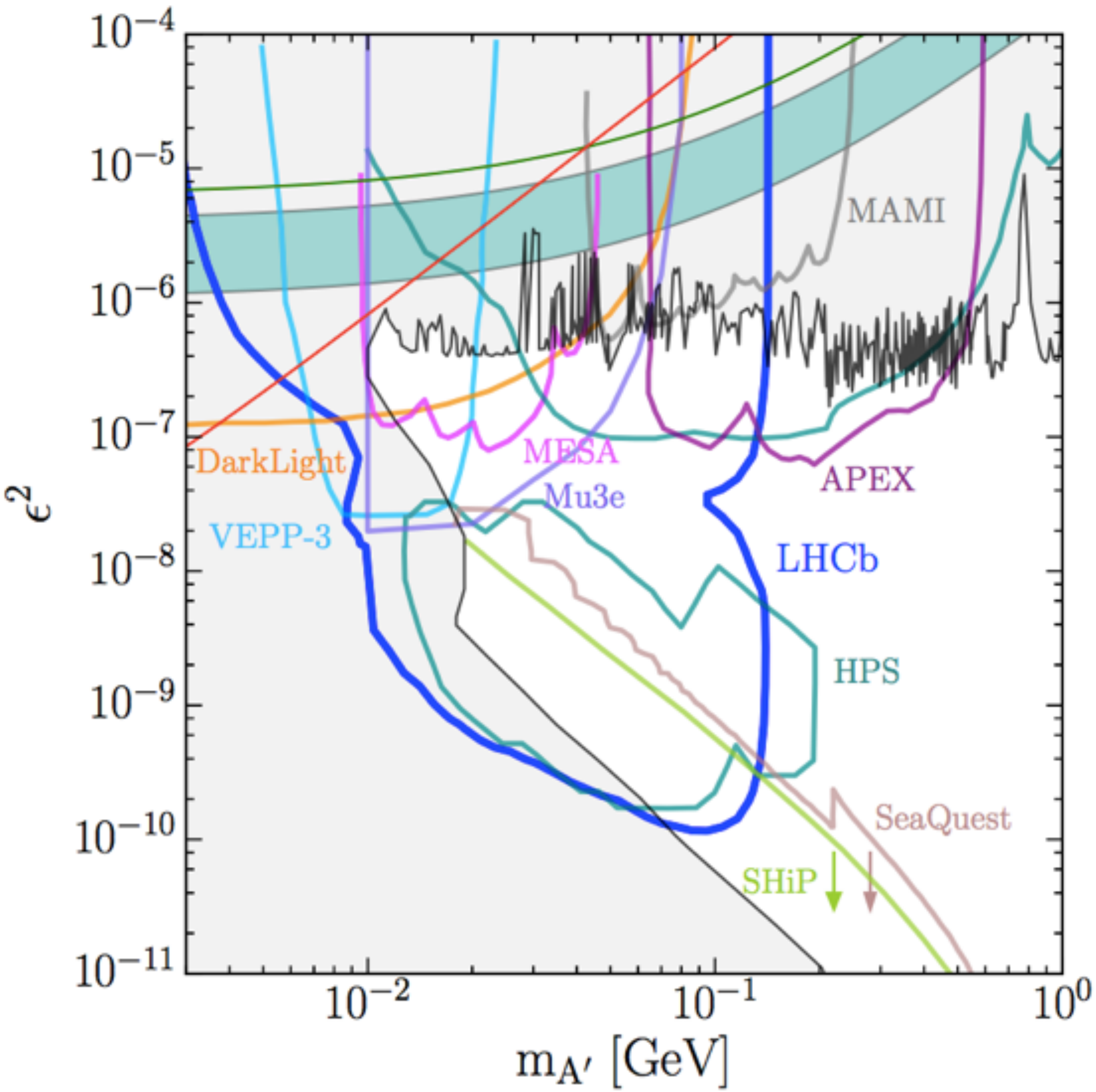
Others:

NA62, Project X

[ORKA canceled!]

On the horizon: Dark photons at LHCb Run 3

arXiv:1509.06765

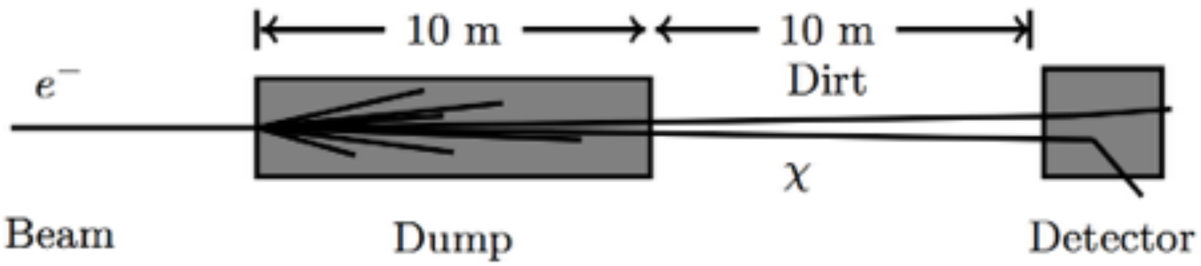


Hidden gauge boson from charm meson decays $D^{*0} \to D^0 \gamma$

Rate in LHCb ~ 700 kHz —> ~5 trillion events in LHC Run 3

Closes (some of) the gap between APEX/HPS resonance search and vertexing searches

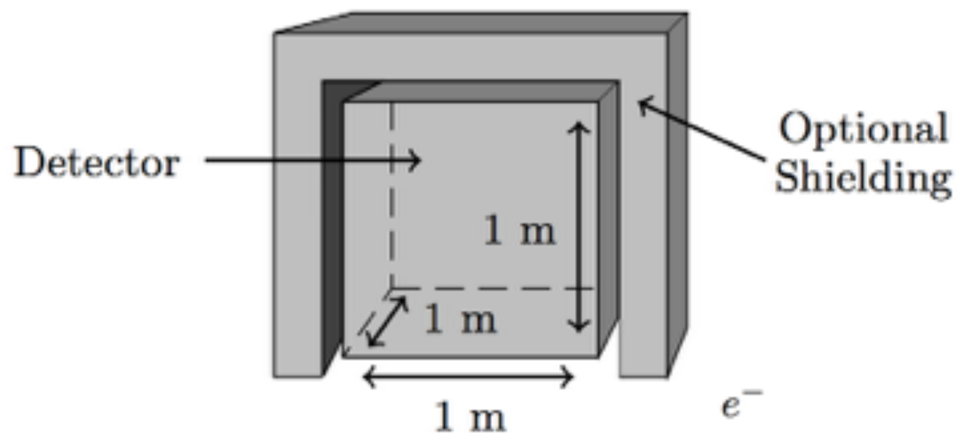
On the horizon: New beam dumps



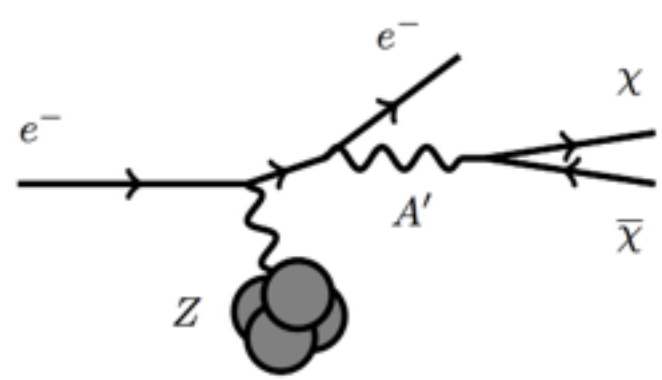
Example: BDX

Probe higher $m_{\gamma d}$

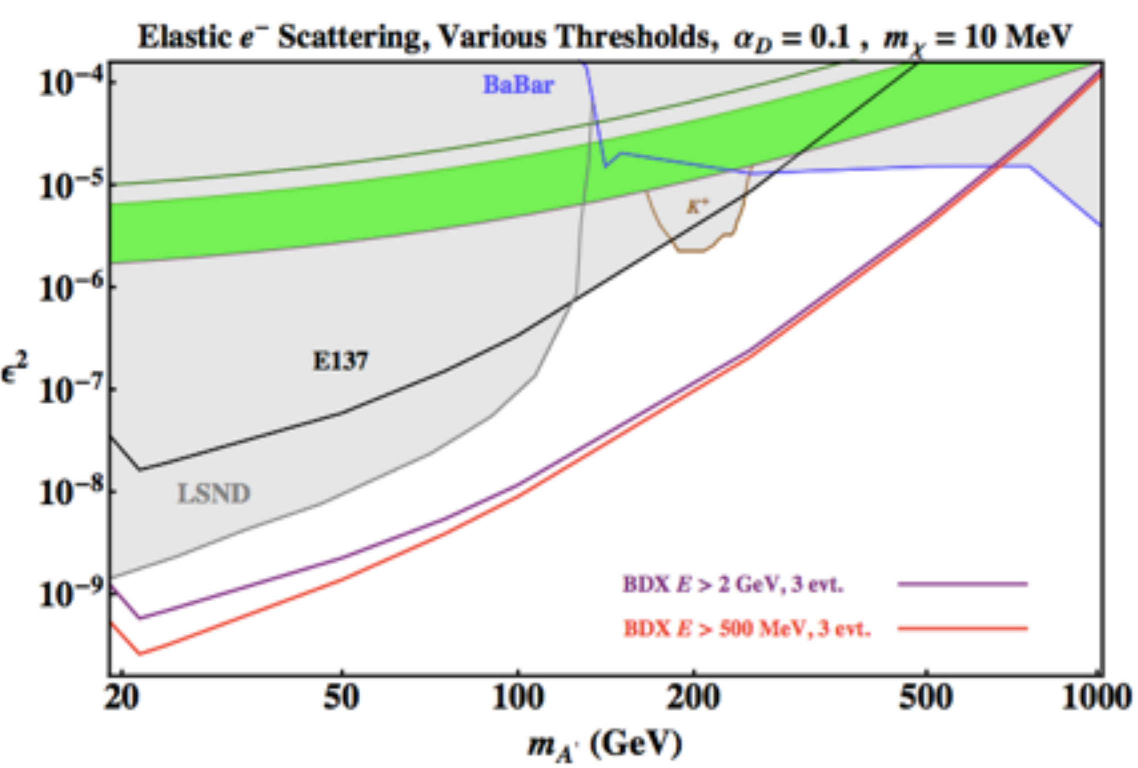
arXiv:1406.3028



Detected energy deposit is low, so the detector concept is shockingly simply, but the background estimate is difficult.



Pair produce a dark matter beam with enough recoil energy to show up in a scintillator cube



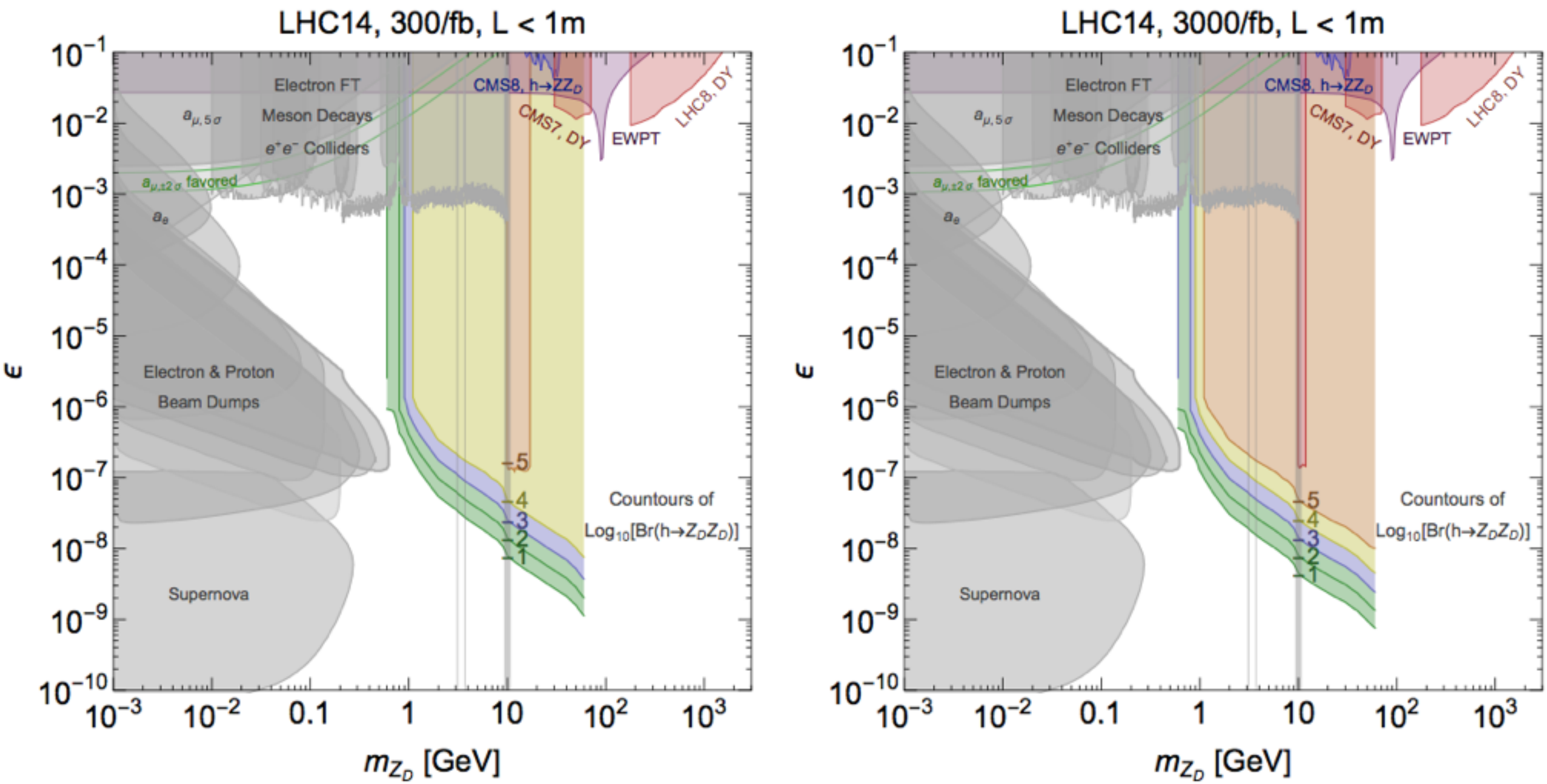
Proposed to take place at JLab, but SLAC also a possibility

Currently working on prototype detector, simulation, full JLab proposal

Others: “Missing momentum” [arXiv:1411.1404]

Mini-BooNE

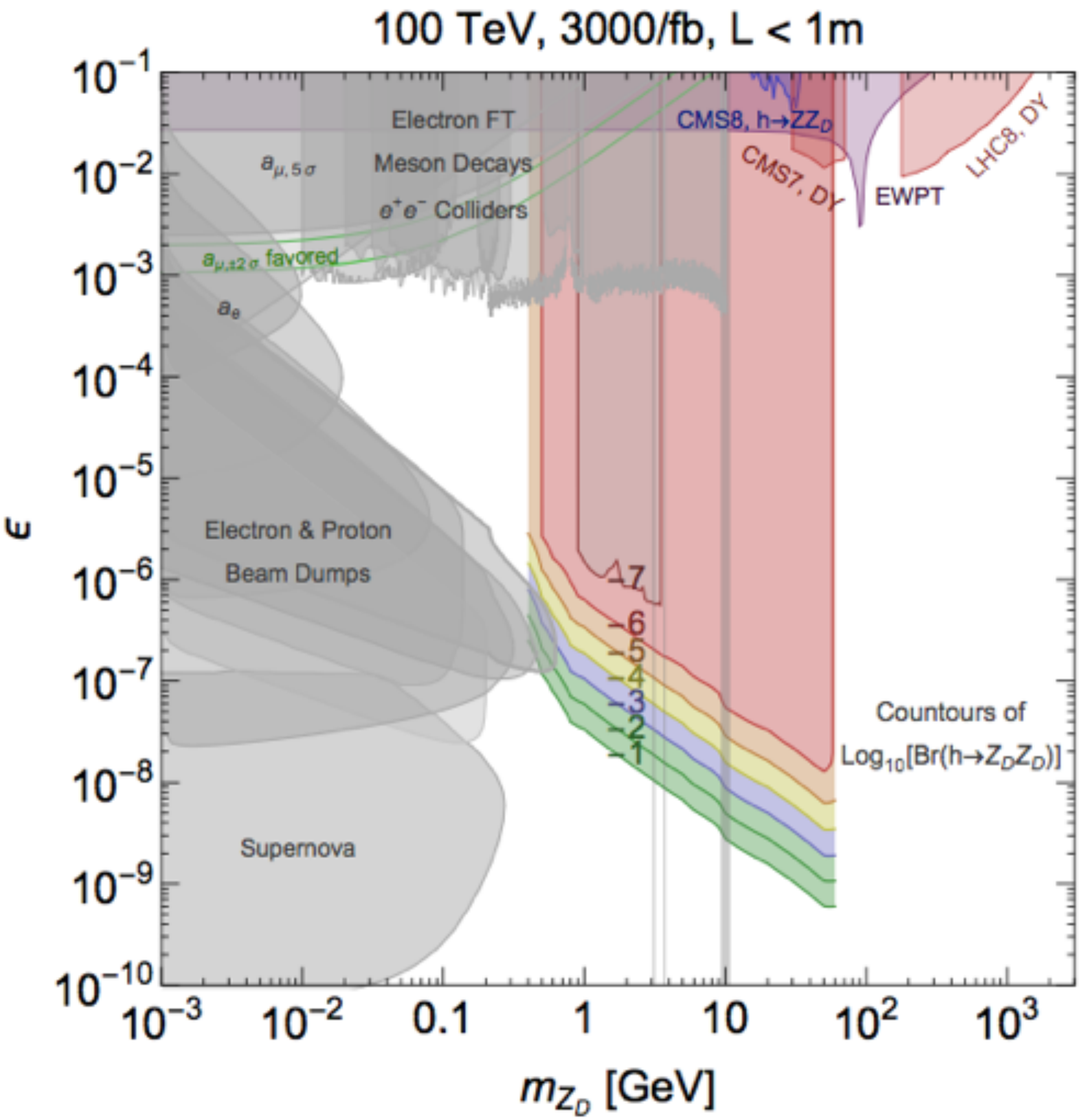
On the horizon: New reaches for ATLAS/CMS

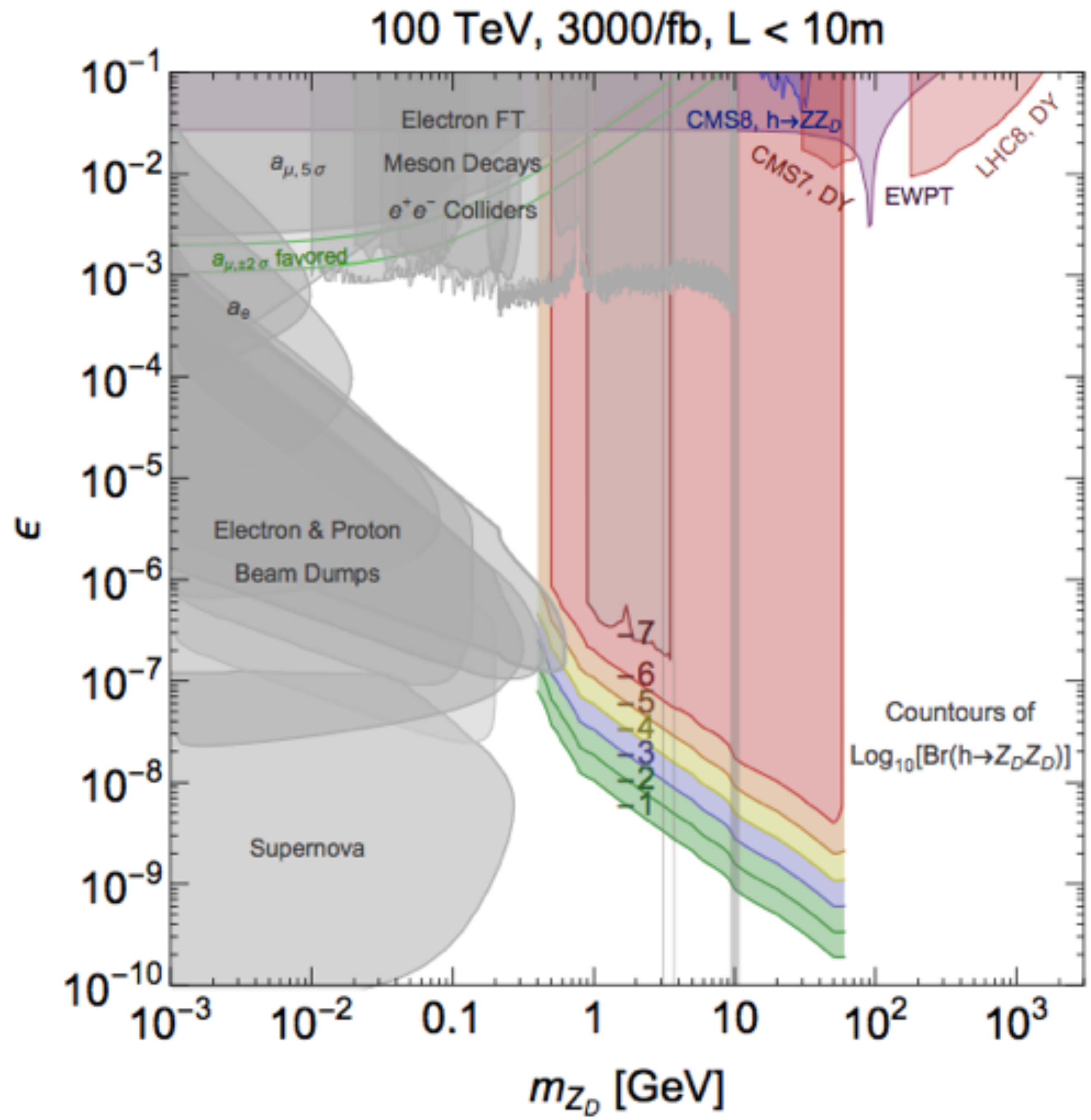


Higgs mixing with displaced decays

arXiv:1412.0018

The future: FCC





Higgs mixing with displaced decays

arXiv:1412.0018

Impossibilities: h125 as a photon source

$h \longrightarrow \gamma\gamma^{d}$, $m_{\gamma d} < m_h/2$

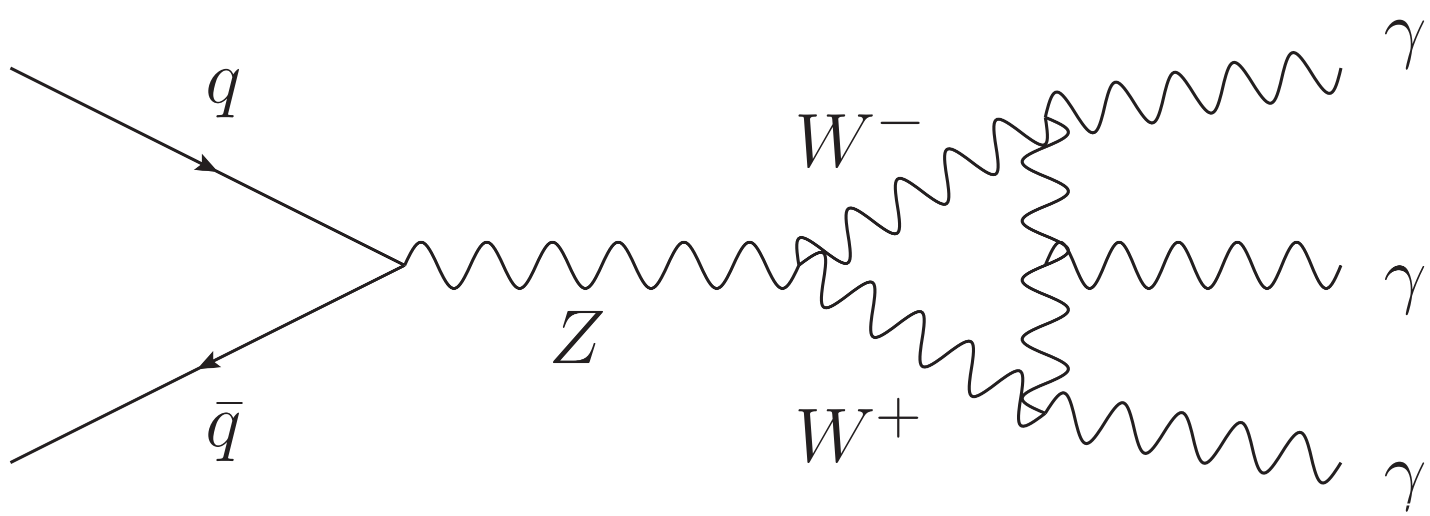
Experiment	N_{h125}
ILC at 1 TeV	$10^{4\text{-}5}$ / year
TLEP	10^{5} / year
Muon collider	10^{4} / year
LHC 14 TeV 3000/fb	10^{8}
Photon linear collider	60 x e+e- collider

V.Telnov, Photon2015

BR($h \longrightarrow \gamma\gamma$) ~2e-3 —> X years at a photon collider?

Impossibilities: Z —> 3γ as a photon source

Z —> $\gamma^{(d)}\gamma^{(d)}\gamma^{(d)}$



Recent ATLAS result: World's best limit on SM Z to three photons

One of many results in an inclusive three photon search for new phenomena arXiv:1509.05051

Obs. (exp.) 95% CL upper limit on BR(Z—>3γ)

- 2.2 (2.0)e-6
  (almost 5 times better than LEP)
- SM prediction: 5e-10

If you have a source of 10^{15} Zs, let me know.

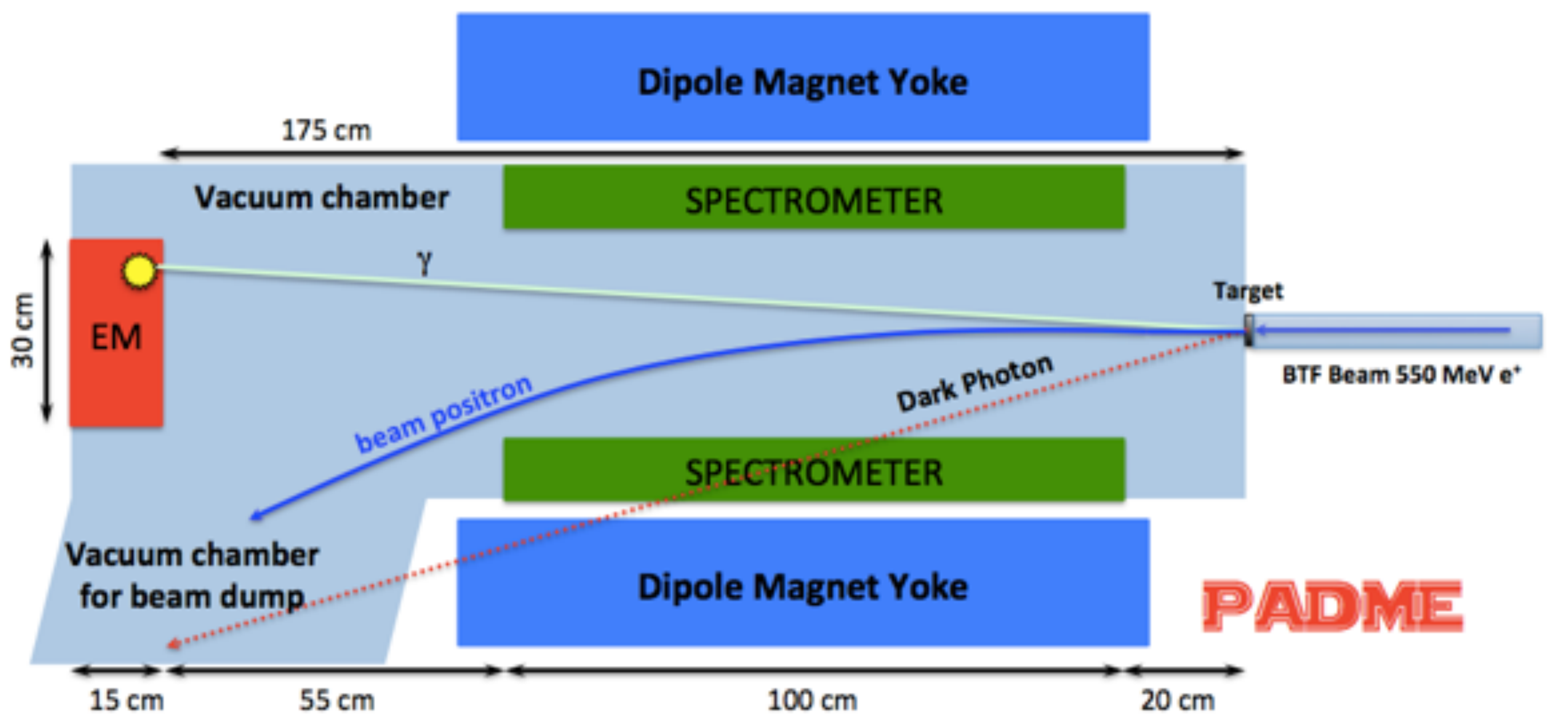
Peta-Z @ FILC?

New ideas

?

What else?

PADME!



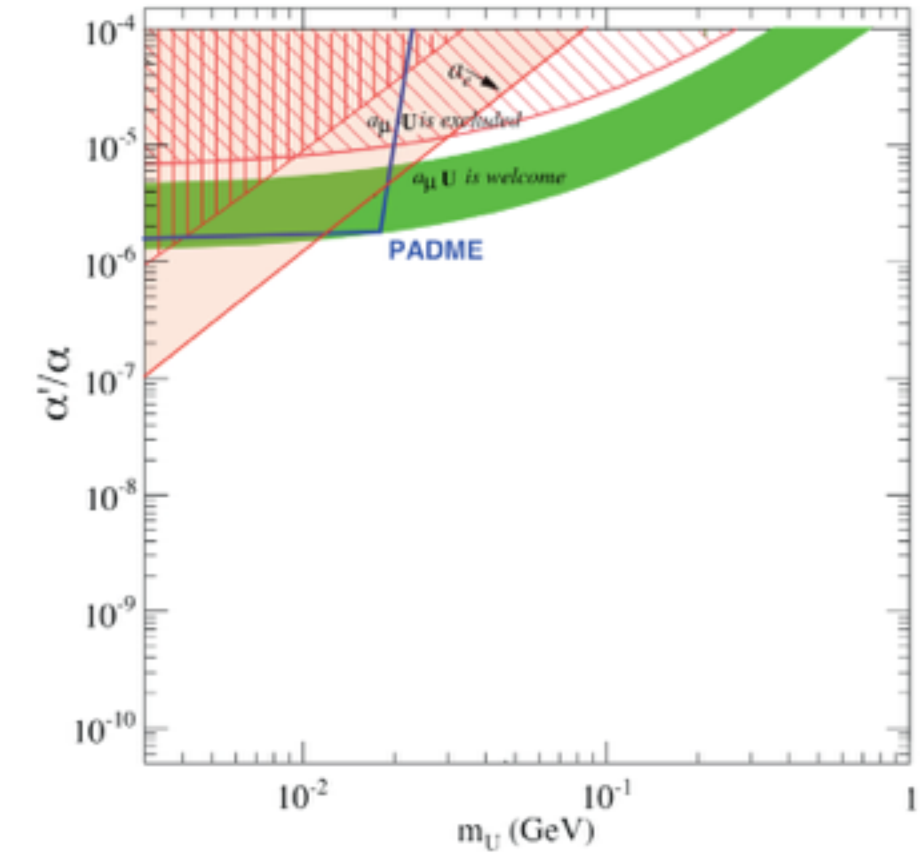


Figure 3: *Schematic of the Positron Annihilation into Dark Matter Experiment (PADME).*

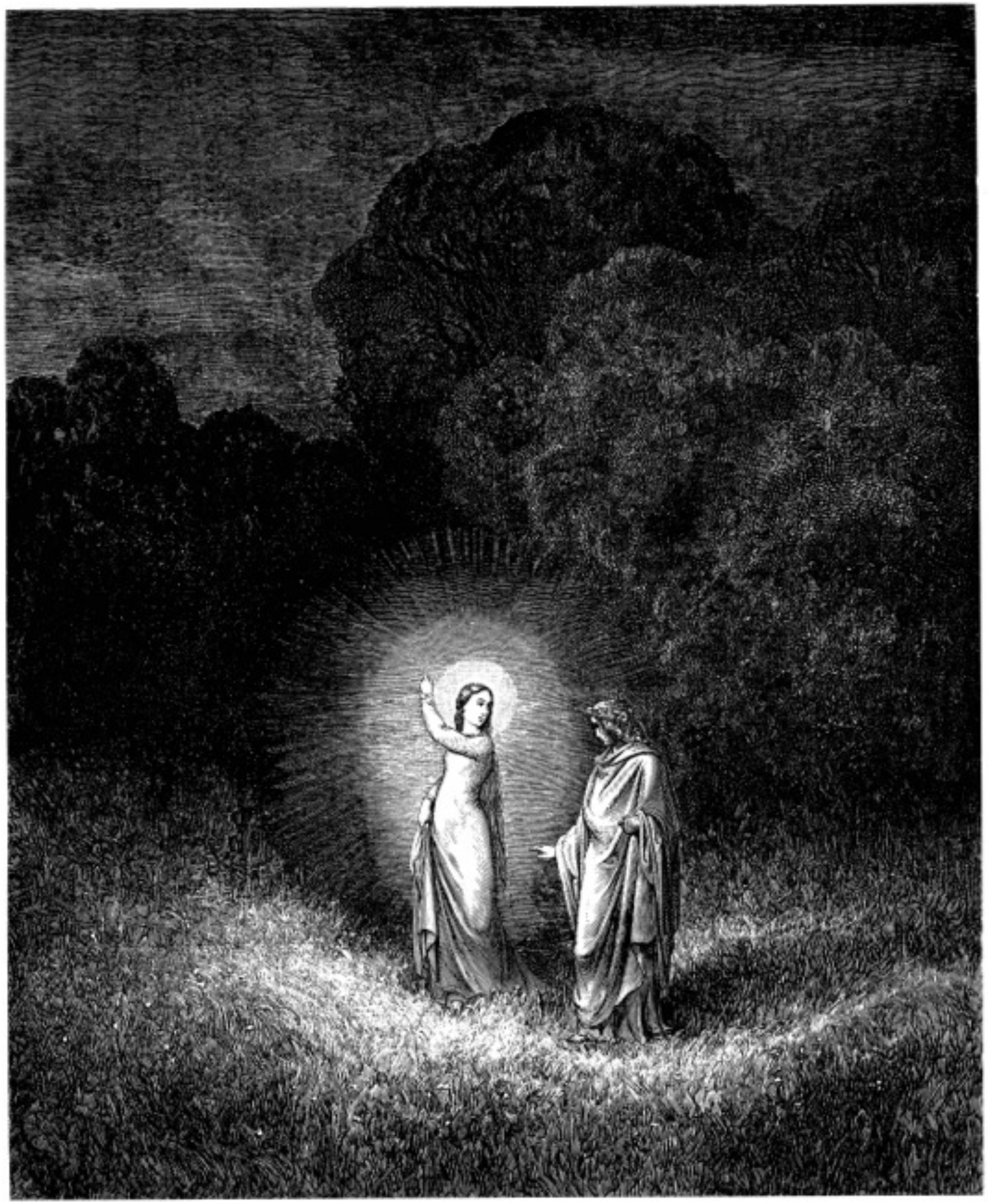
Sensitive to both visible and invisible decays, $\varepsilon^2 \sim 1{\cdot}10^{-6}$ in the mass range $2.5 < M_{A'} < 22.5$ MeV.

arXiv:1501.01867

Approved and financed!

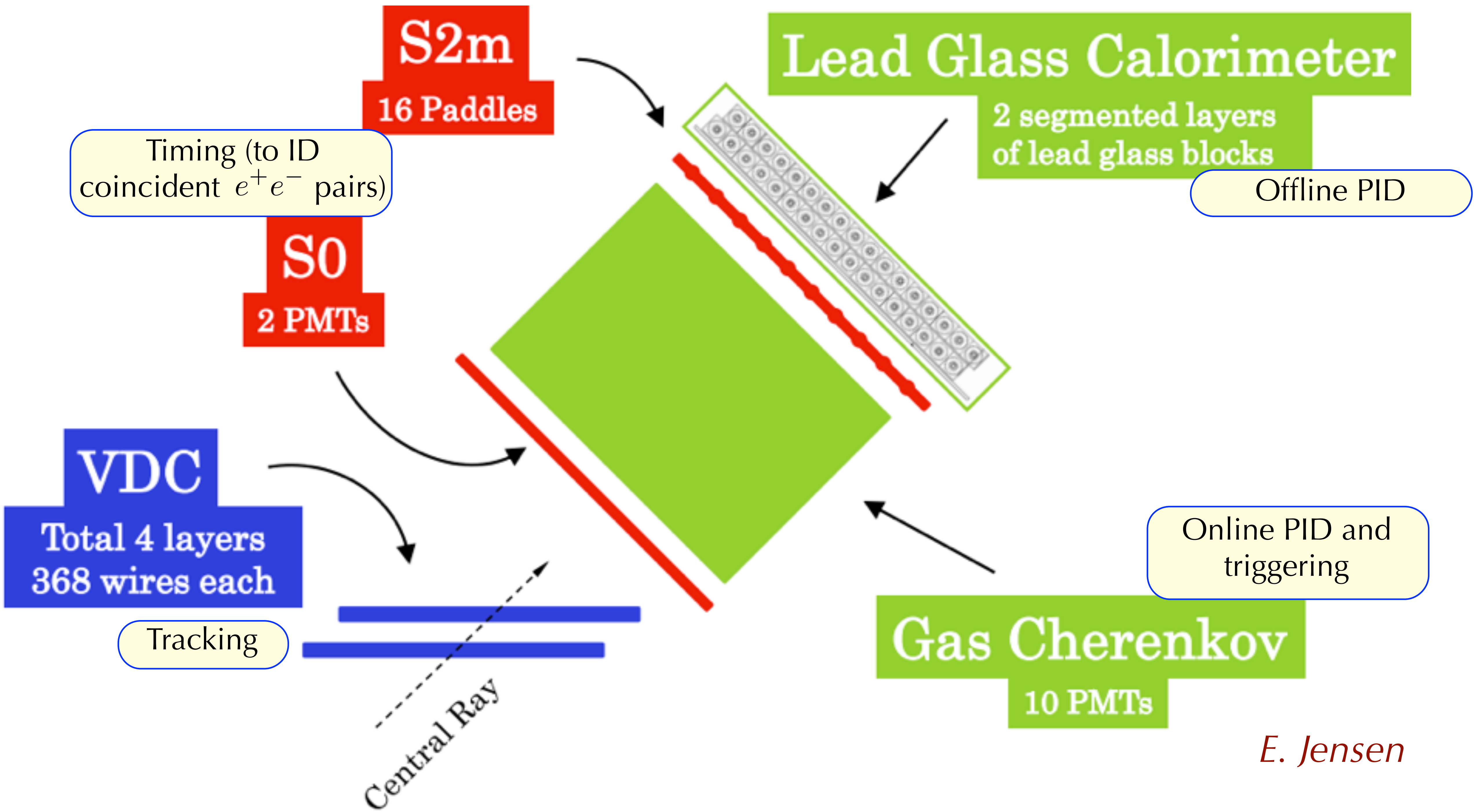
Talk to Mauro.

Stepping from the dark photon wood into the light



Backups

Hall A High Resolution Spectrometers (HRSs)

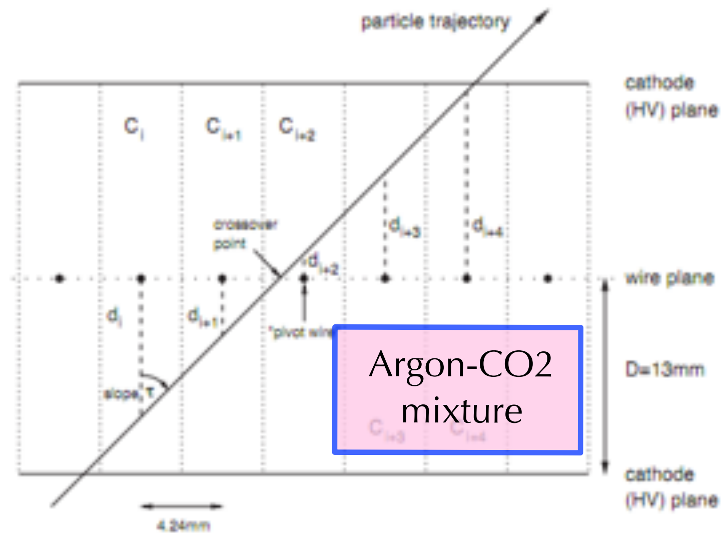


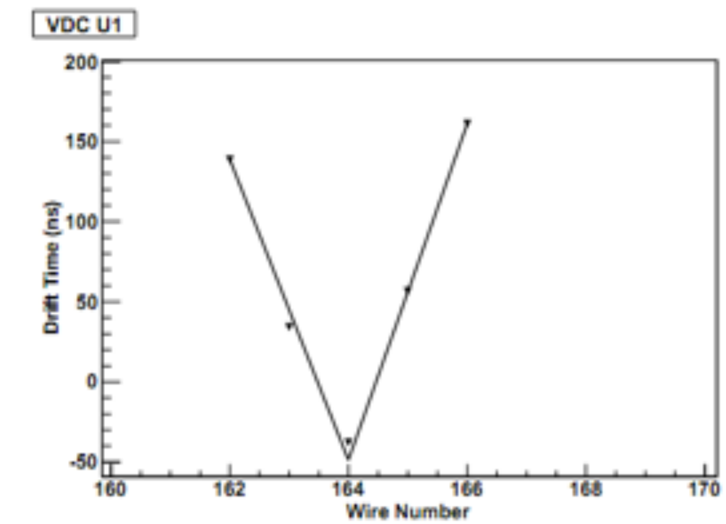
E. Jensen

APEX: Determining mass resolution

Two parallel VDCs provide accurate reconstruction of full 3D track of particle as it enters the HRS

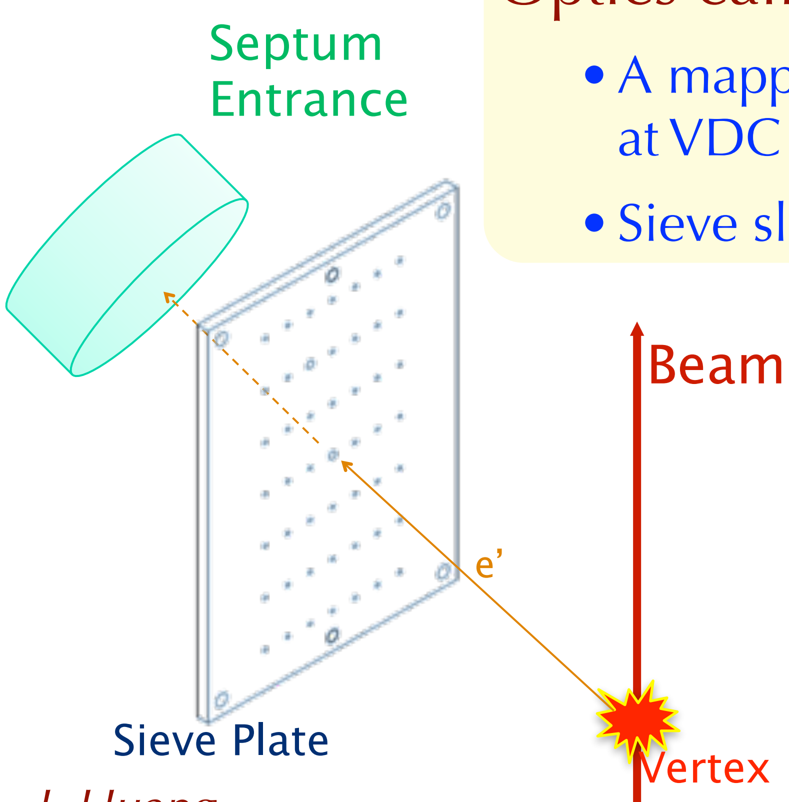
- APEX: Electron singles rate from 0.7 to 5.8 MHz
- Rates are higher than ever used in Hall A -- 5 MHz (75 kHz/wire, 368 wires)





- Algorithm scans for 'V' shaped clusters in time

S. Riordan



J. Huang

Optics calibration

- A mapping from measured coord. at VDC to 3-momentum at target
- Sieve slit method

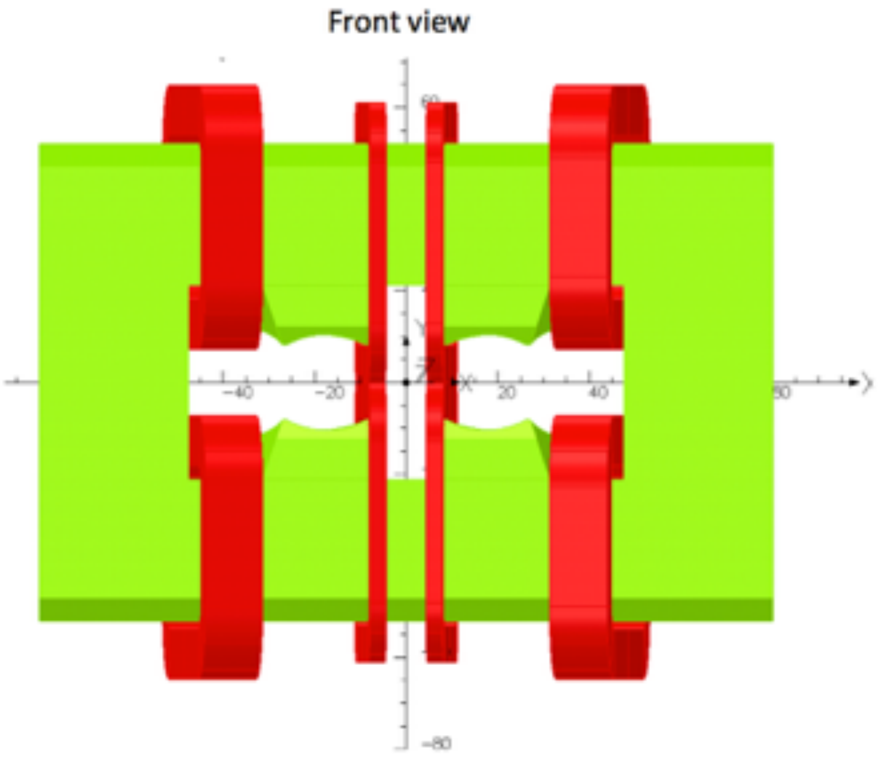
Mass resolution depends on angular and momentum resolution

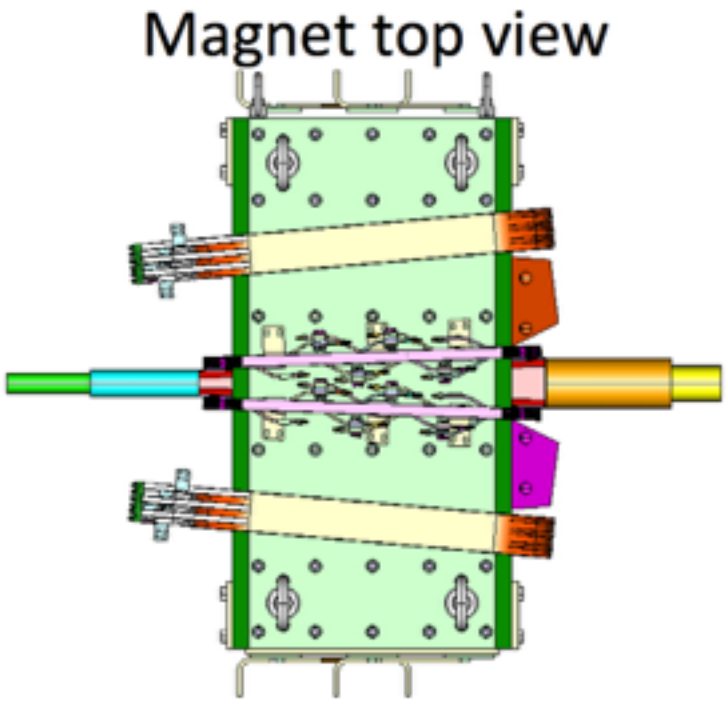
- HRS momentum resolution excellent, 10^{-4}; negligible
- **Angular resolution** and **multiple scattering in target** dominate

mrad	Optics	Tracking	MS in target
σ(horiz)	0.11	~0.4	0.37
σ(vert)	0.22	~1.8	0.37

Test run mass resolution: σ ~ 0.85 - 1.11 MeV (varies over mass range)

APEX: Work in progress for full run





New septum magnets

- Magnet parts produced
- Contractor, Buckley Systems, has finished testing coils
- Magnet shipped to JLab for further testing
- Sensitivity projections currently being updated with new acceptance and dedicated Monte Carlo

New optics method

- Scintillating fiber (SciFi) hodoscope