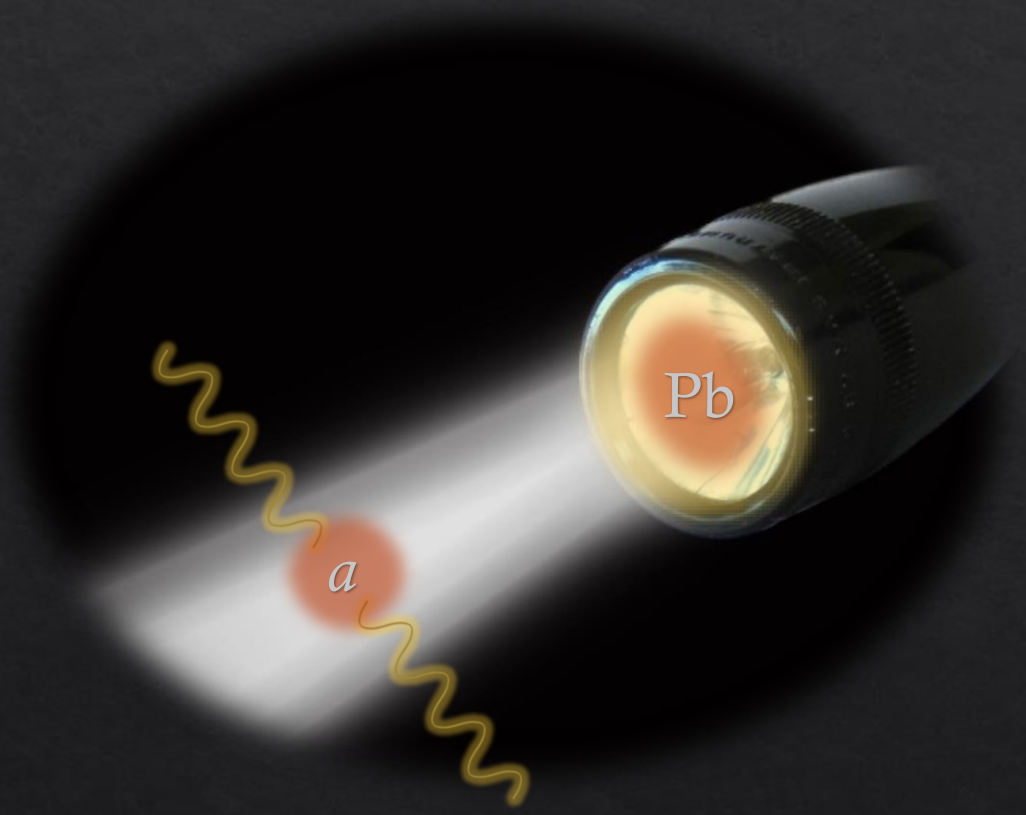


Searching for Axion-like particles with heavy-ions

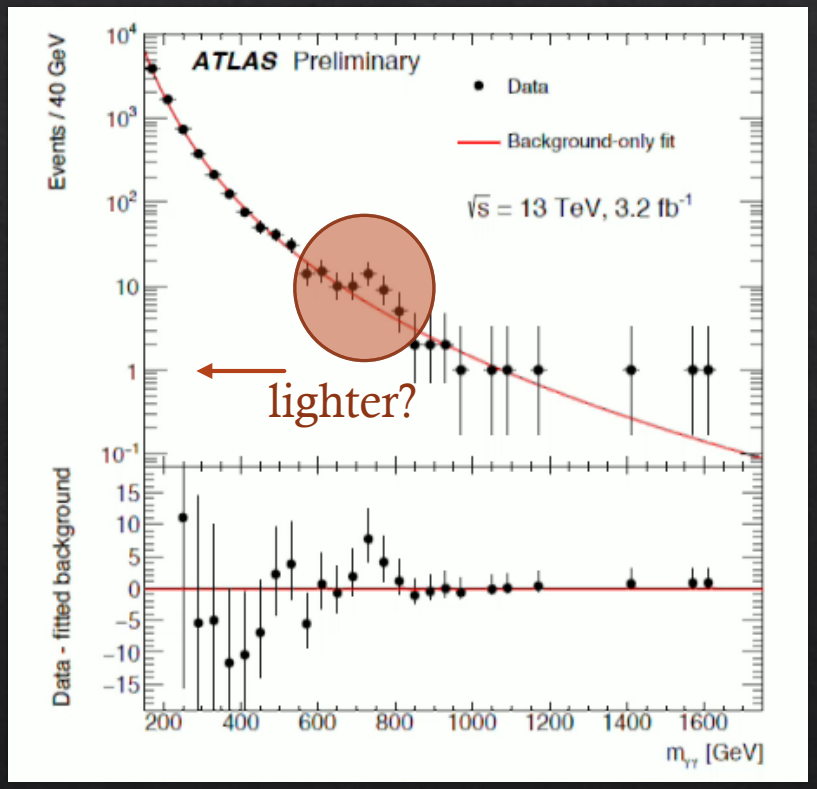
Hou Keong (Tim) Lou,

Simon Knapen, Tongyan Lin and Tom Melia

PhysRevLett.118.171801

New Physics @LHC

- Must leave no stone unturned!
- There may be many surprises!
  - 750 GeV (false alarm)
- Can we be missing cousins of 750 GeV?
- Yes:
  - What is resonance is lighter?
  - Axion-like particle $\sim aF\tilde{F}$



Axion-like Particle

- Only couple to EM

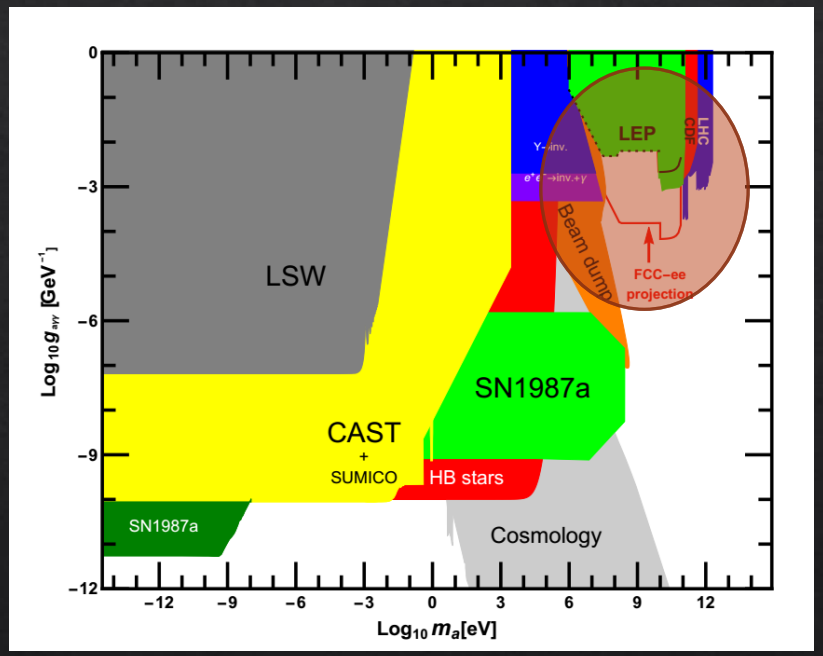
$$\mathcal{L}_a = \frac{1}{2}(\partial a)^2 - \frac{1}{2}m_a^2 a^2 - \frac{a}{4\Lambda}F\widetilde{F}$$

- Decay rate

$$\Gamma_{a\to\gamma\gamma} = \frac{1}{64\pi}\frac{m_a^3}{\Lambda^2}$$

- Heavy ALPs mainly constrained by colliders
- UV completion straightforward (750 GeV literature)

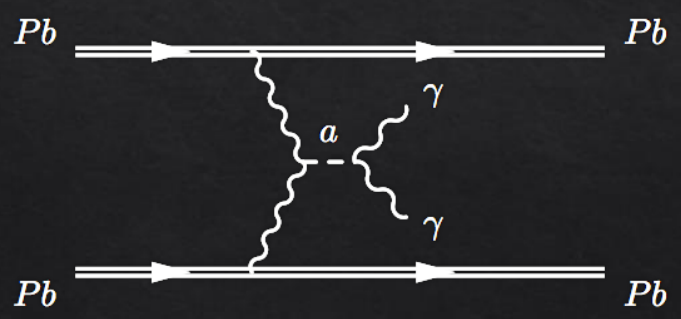
- Existing Constraints



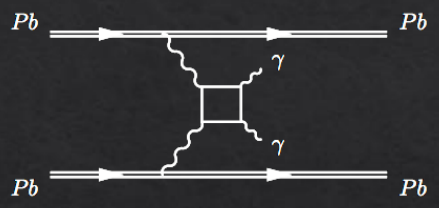
J. Jaeckel et.al. 1509.00476

Heavy-ion as a γ source

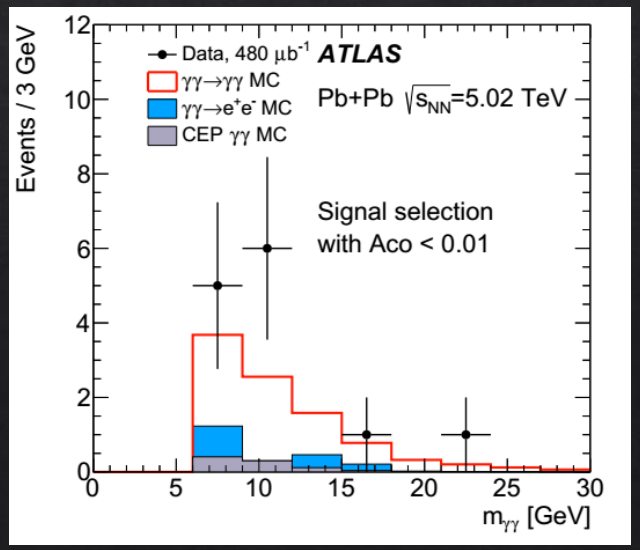
- Old idea A. Balantekin et.al. 1985, M. Greiner et.al. 1993…
- Enhanced production at Heavy-ion collisions (~GeV)
- QED is strongly coupled!
- $Z^4 \sim 50 \times 10^6$ enhancement



- Can observe LBL scattering

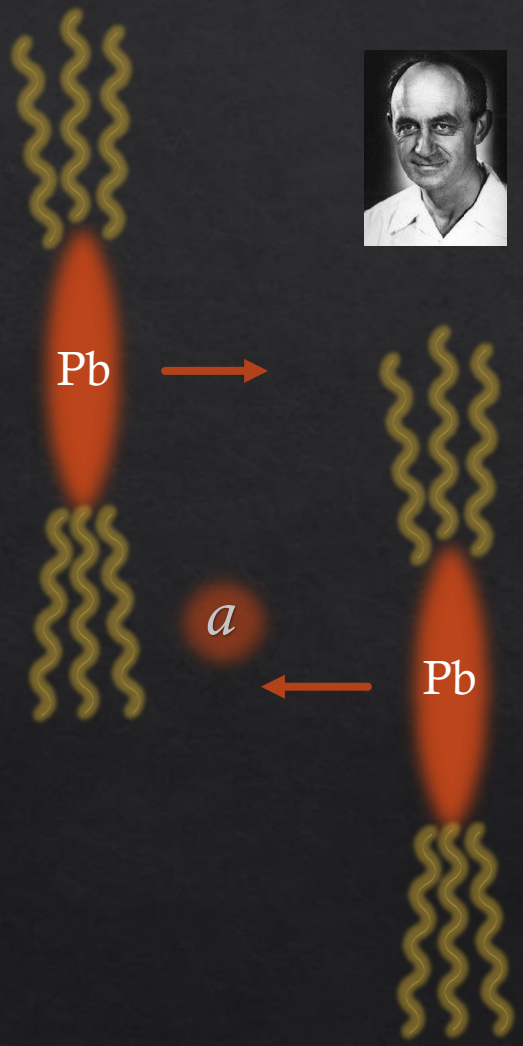


D. d'Enterria et.al. 1305.7142



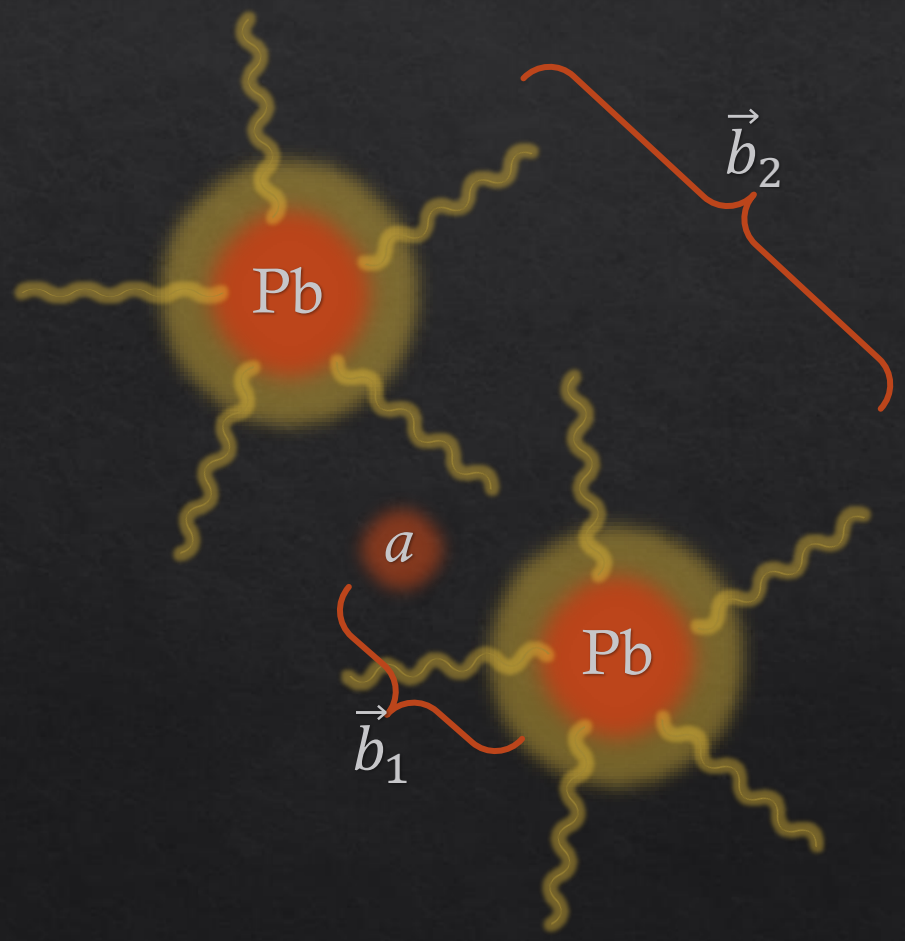
ATLAS 1702.01625

Ultra-Peripheral Collisions



- Grazing collision, ion does NOT breakup
- ALPs are created in the strong EM field of the ions (photons almost on-shell)
- Luminosity ~ classical formula (lead flashlight!)
- Coherence requires photon wavelength $\gtrsim$ Pb radius / boost
- $2E_\gamma < 170\ \mathrm{GeV} \left(\frac{7\ \mathrm{fm}}{R}\right) \left(\frac{\sqrt{s_{NN}}}{5.5\ \mathrm{TeV}}\right)$

Photon Luminosity



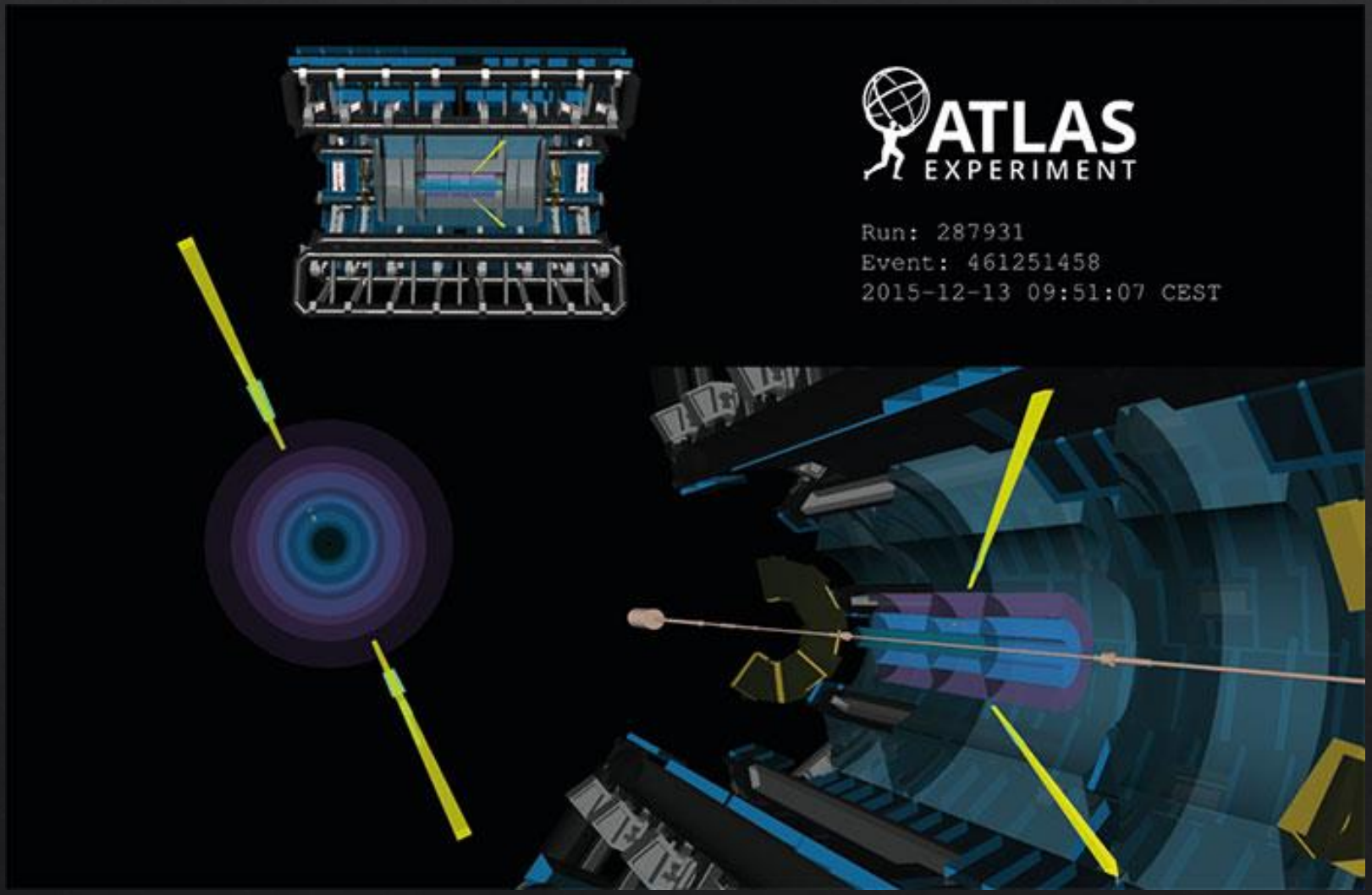
- Photon-photon luminosity:

$$\mathcal{L}_{\gamma\gamma} = \frac{1}{\hat{s}} \int db_{1,2} dE_{1,2}\, N_1 N_2 \times \delta(\hat{s} - 4E_1 E_2) P$$

  - $N_{1,2}$ = flux from Pb
  - P = probability that no breakup occurs
- $N_{1,2} \sim$ charge form factor
  - Low energy $\sim \frac{2\alpha Z^2}{\pi} \log \frac{E_{\max}}{E_\gamma}$
- $P \sim \theta(b_2 - 2R)$
- Requires nuclear physics to get all factors correct

Pb-Pb vs p-p

	p-p Collisions	Pb-Pb Collisions
Luminosity	~ 1000 fb^{-1}	~ 10^{-6} fb^{-1} (1 nb^{-1})
Z^4 Enhancement	None	~ 5×10^7
Max γ Energy	~ 1 TeV (elastic)	~ 170 GeV
Background	Large pile-up background	Clean exclusive events
Regions of sensitivity	m_a~100 GeV	m_a~10 GeV


ATLAS
EXPERIMENT
Run: 287931
Event: 461251458
2015-12-13 09:51:07 CEST

Signal & Background

Signal

- Intact Pb-Pb ions, no tracks, very little calorimeter activity
- Veto on tracks
- Two ~GeV back to back photons (cut on $\Delta\phi_{\gamma\gamma}$)
- Intact ions may be tagged
- Prominent mass peak!

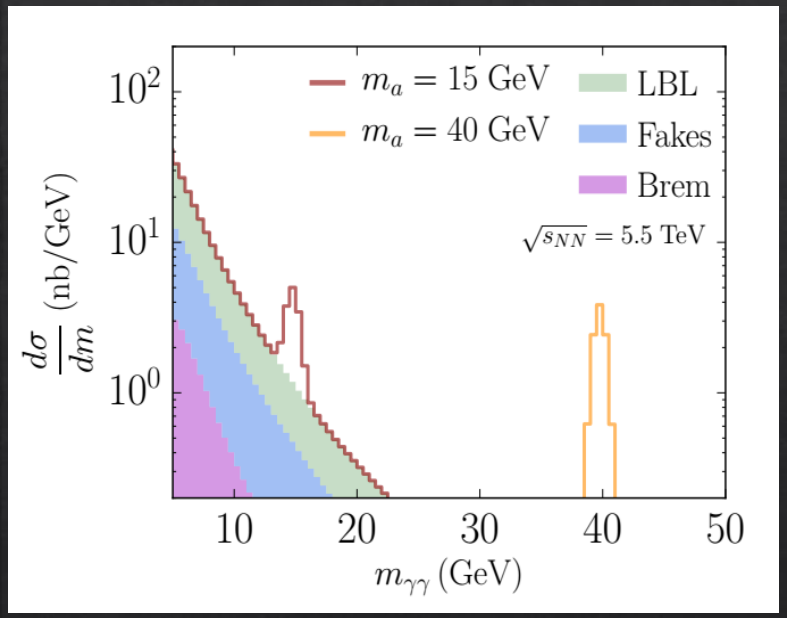
Background

- LBL scattering
  - Irreducible
  - Has been measured! Can be calculated reliably
- Electrons fakes/brem and CEP (photons from QCD)
  - Photons not back to back
- All background smoothly falling in $m_{\gamma\gamma}$!

Search Strategy

Signal Selection

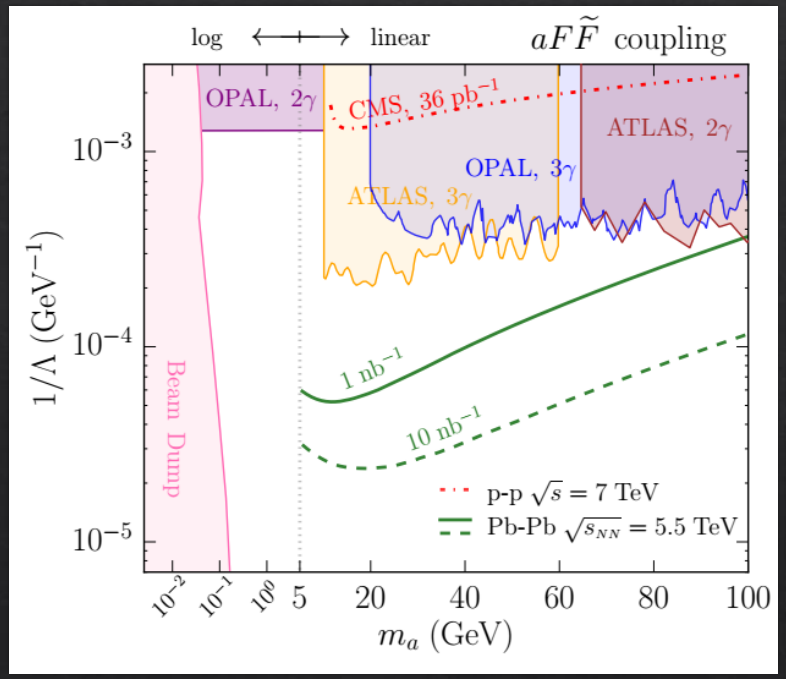
- Veto tracks with ($p_T > 1$ GeV, $|\eta| < 2.5$)
- Two photons ($p_T > 2$ GeV, $|\eta| < 2.5$)
- $|\Delta\phi_{\gamma\gamma} - \pi| < 0.04$
- Efficiency ~70% low mass to ~90% at high mass
- Signal MC implemented in Starlight (w/ help from S. Klein)
- Background:
  - Analytic approx. for $\gamma\gamma$-lumi
  - ME done analytically / Madgaph5



Integrated lumi ~ 1nb eventually

Results

Standard ALP coupling

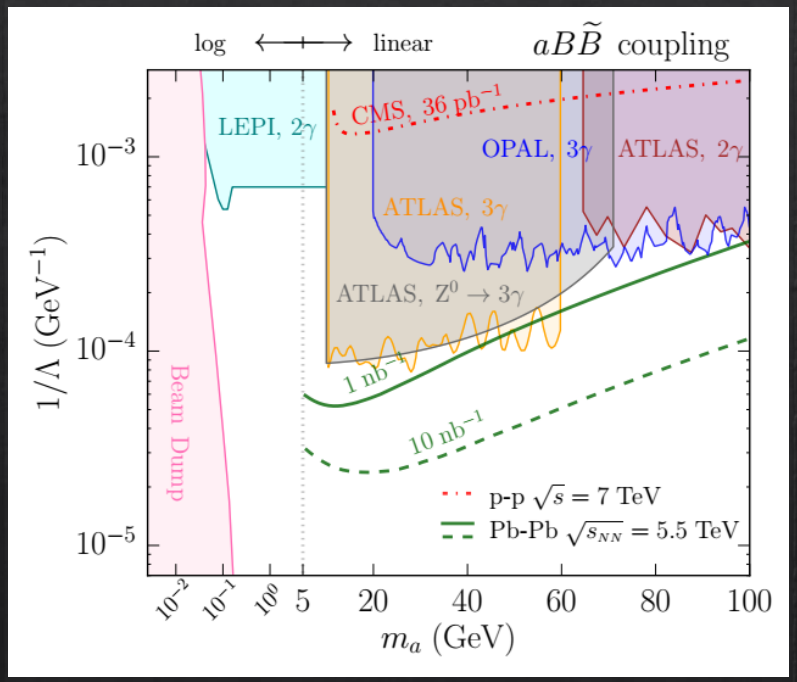


- Collider searches dominated by associated production
  - $p + p \to \gamma^* \to a + \gamma$
  - LEP/CMS/ATLAS comparable
- Photon fusion sub-dominant
- 8 TeV re-cast (13 TeV high lumi results will be stronger)

Results

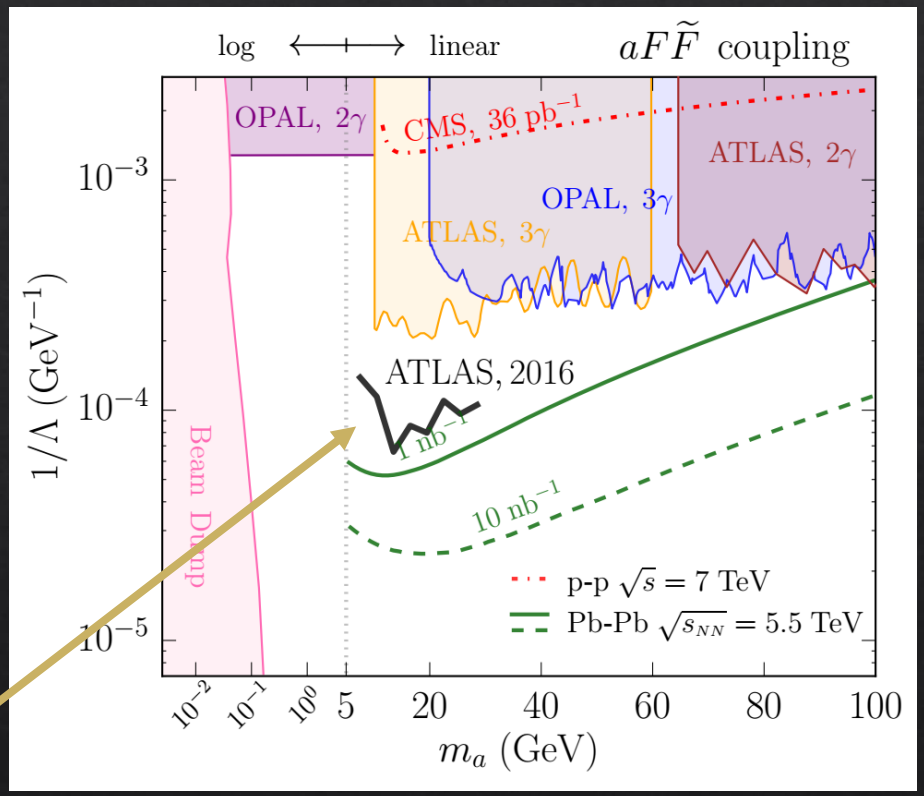
- Introduces $aZ\gamma$ coupling
  - $p + p \to \gamma/Z^* \to a + \gamma/Z$
  - On-shell $Z \to a + \gamma$
- Heavy-ion limits comparable to 8 TeV results
- High-Luminosity LHC will likely yield stronger limits

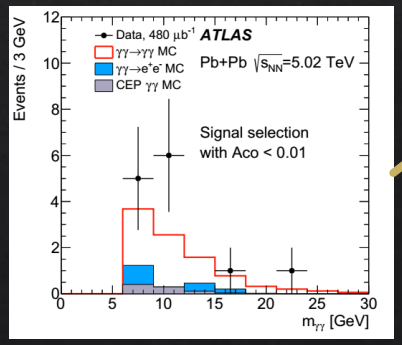
Hypercharge coupling



ATLAS recast

- $\sqrt{s_{NN}} = 5.02$ TeV
- $\int Ldt = 480\ \mu b^{-1}$
- Current best limit on ALPs with EM coupling!





Future Directions ?

New decay channel?

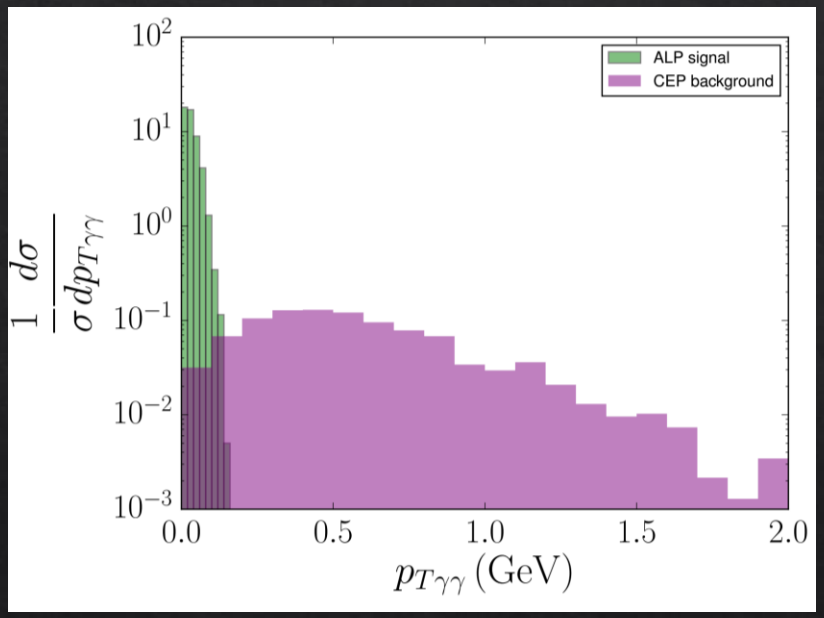
- $b\bar{b}/\tau\tau$ decay for light scalar mixing with higgs?
- Invisible decay? Can we measure the outgoing beam?
- Exotic decay into hidden sector? e.g. long-lived particles?

New production?

- New kinds of coherent enhancement (baryon number)?
- Lighter ALPs? (pair production and off-shell rates are too small)
- Changes in inclusive elastic cross-sections?

Backup Slides

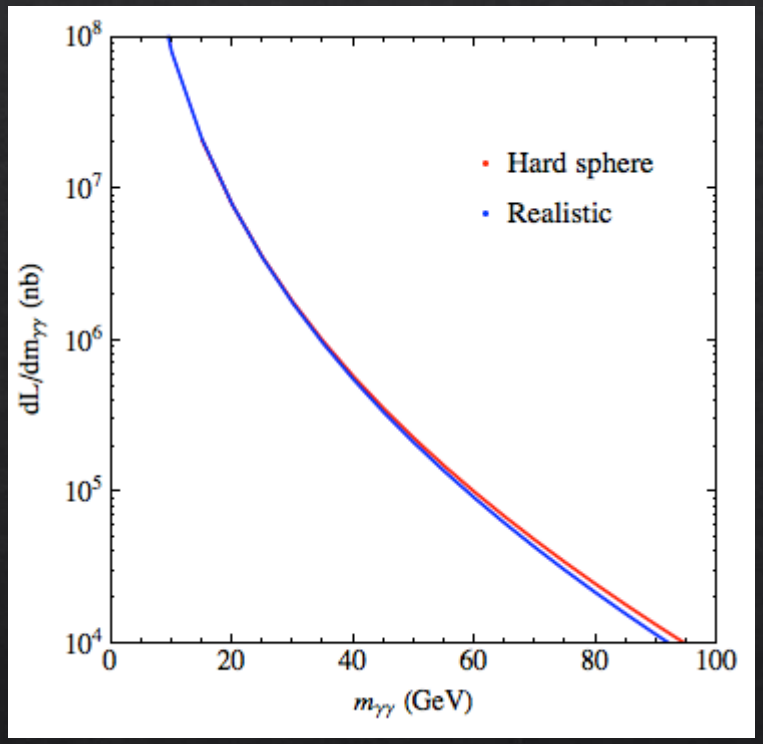
p_T distribution

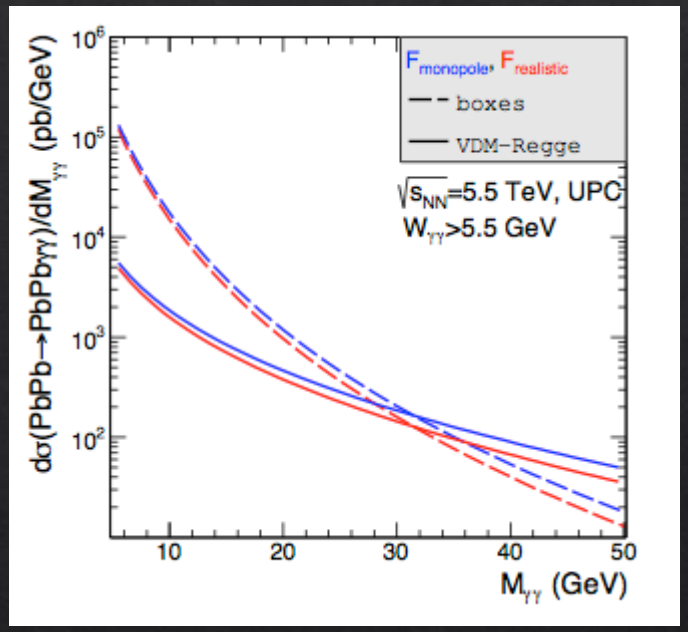


- $p_T \sim$ virtuality of the photon
- Correction beyond equivalent photon approximation

- ALPs: $p_T \sim 1/R \sim 60$ MeV
- CEP: $p_T \sim \Lambda \sim$ GeV
  - p-p collisions shown
  - Pb-Pb requires convolution with breakup factor

Form Factors Effects





M. Klusek-Gawenda et.al.
1601.07001