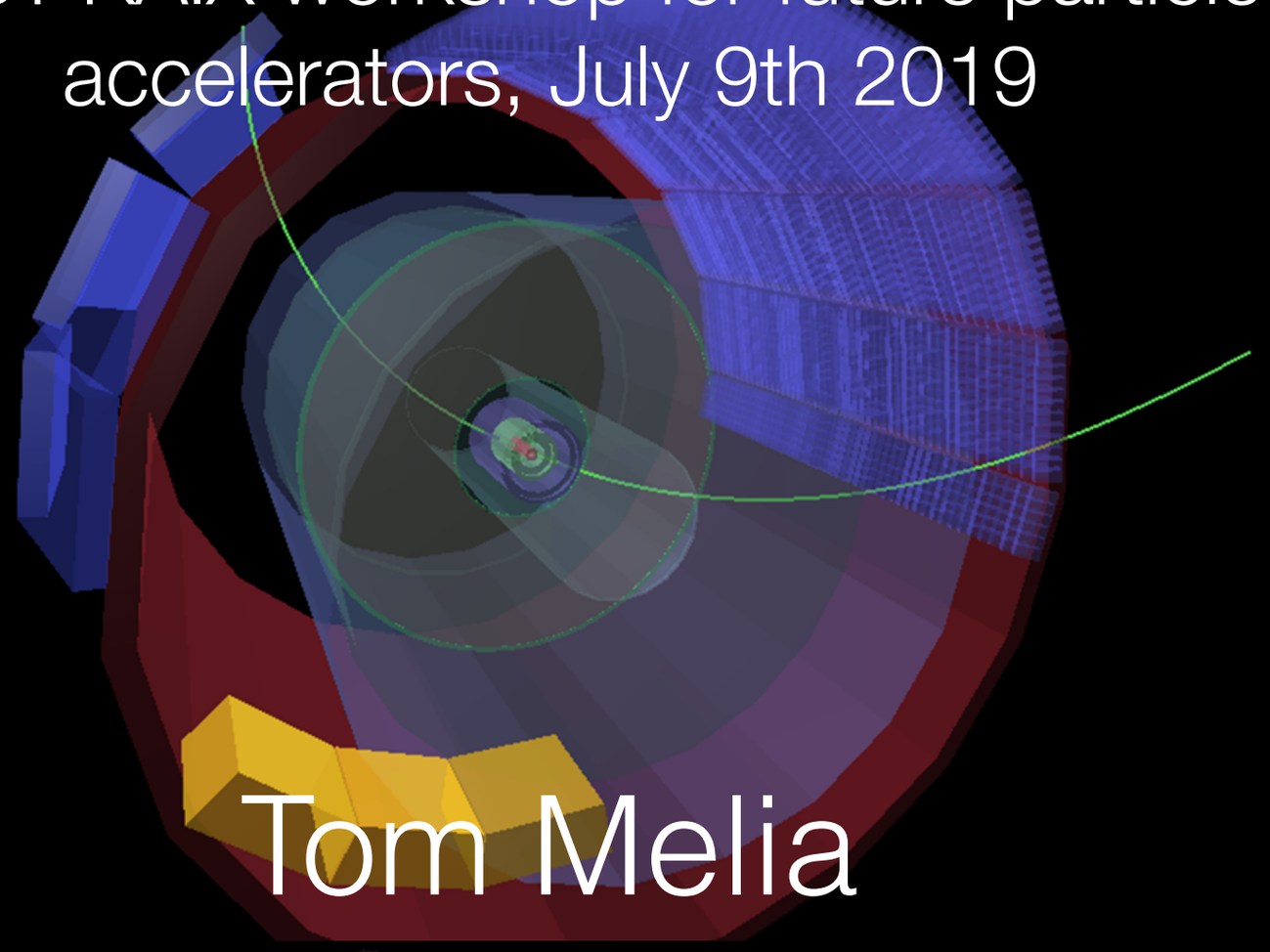
Axion searches in heavy ion collisions

KAIST-KAIX workshop for future particle accelerators, July 9th 2019



Tom Melia

KAVLI IPMU

東京大学 国際高等研究所 カブリ数物連携宇宙研究機構

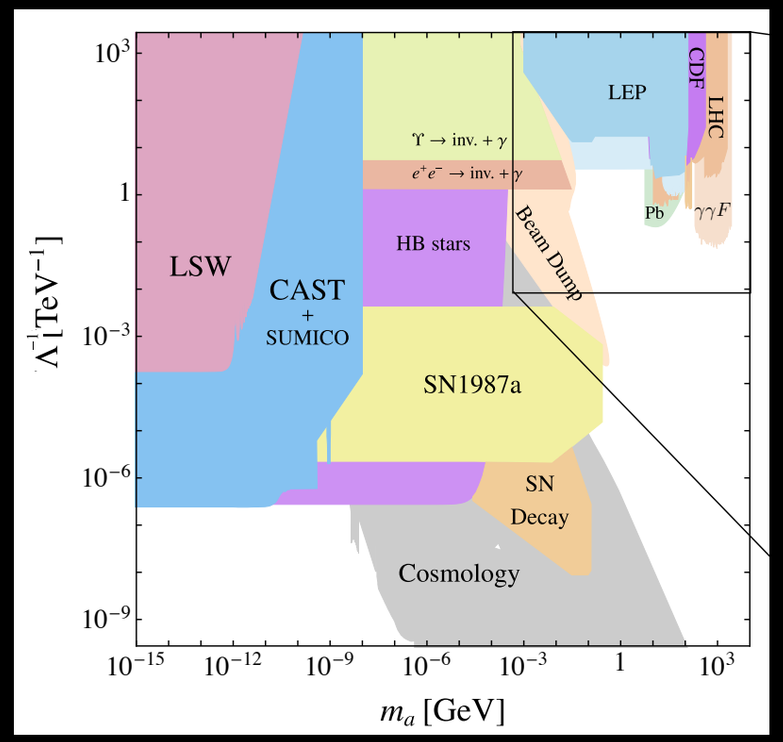
KAVLI INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

Axions (axion-like particles/ALPS) are pseudo-scalar particles that are well motivated in many extensions of the standard model

Like pions, they may be Nambu-Goldstone bosons, hence naturally light (e.g. QCD axion)

Coupling to photons described by a simple Lagrangian

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



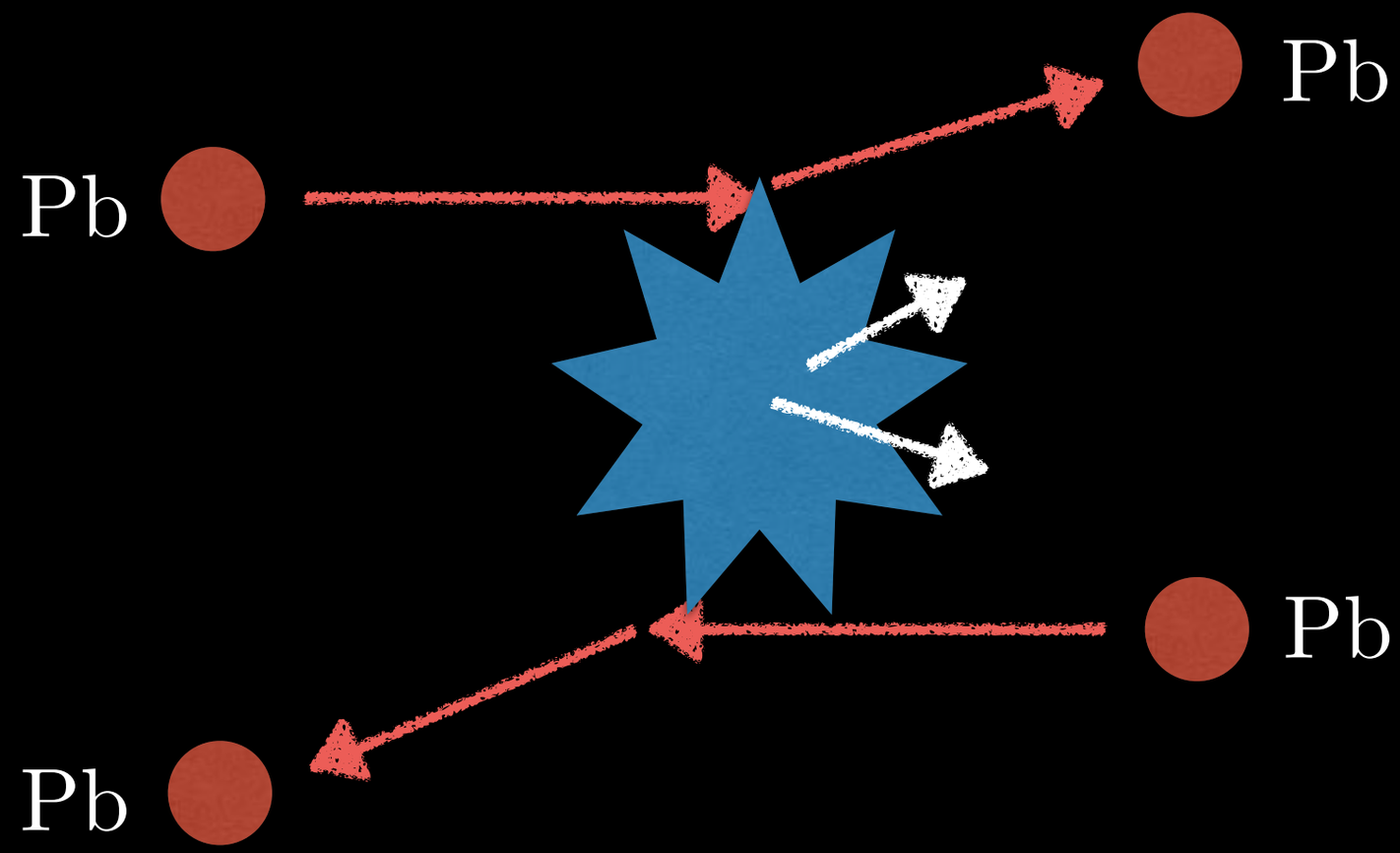
Bauer et al, *Eur.Phys.J. C79 (2019) no.1, 74*

It turns out that, in a particular mass range (~GeV), heavy ion collisions at the LHC provide the best sensitivity to these particles

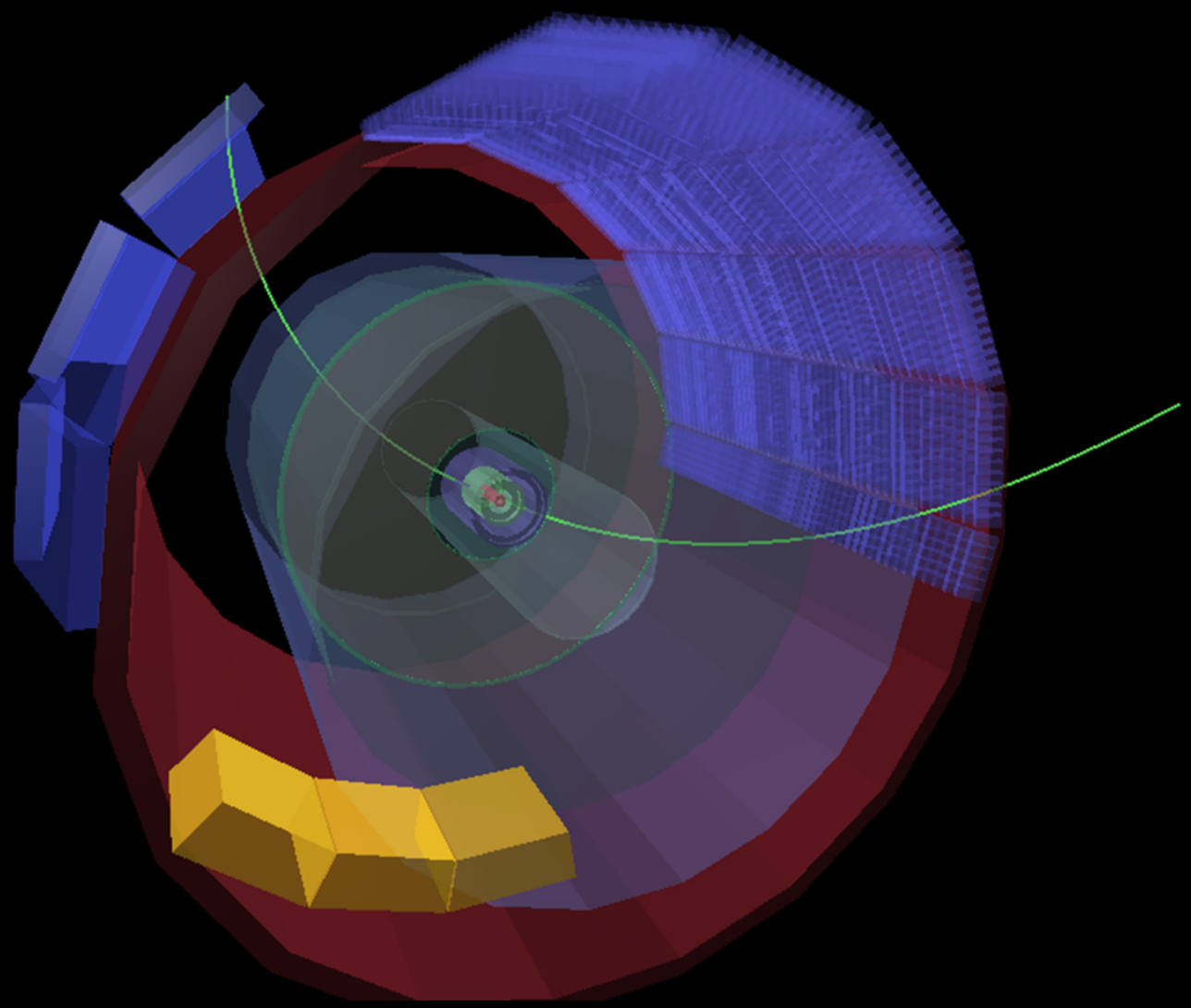
This is unusual: at the LHC, proton-proton collisions are the drivers of BSM searches (this is the only instance I know of where they lose out)

I think it is an important example to keep in mind when considering future collider programs

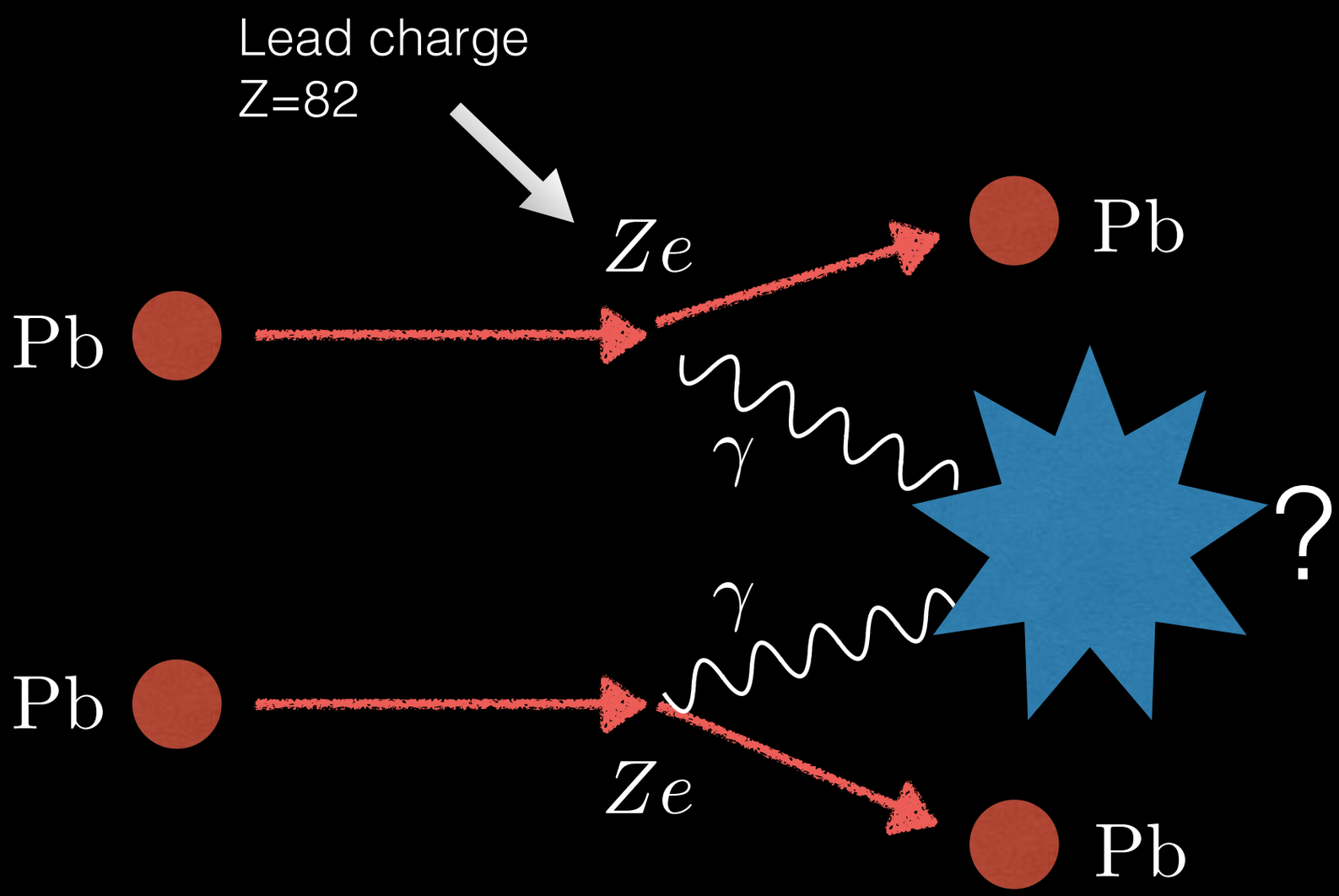
Heavy ion collisions include a class of events called Ultra-peripheral collisions:



Heavy ion collisions include a class of events called Ultra-peripheral collisions:



Ultra-peripheral collisions via electromagnetism

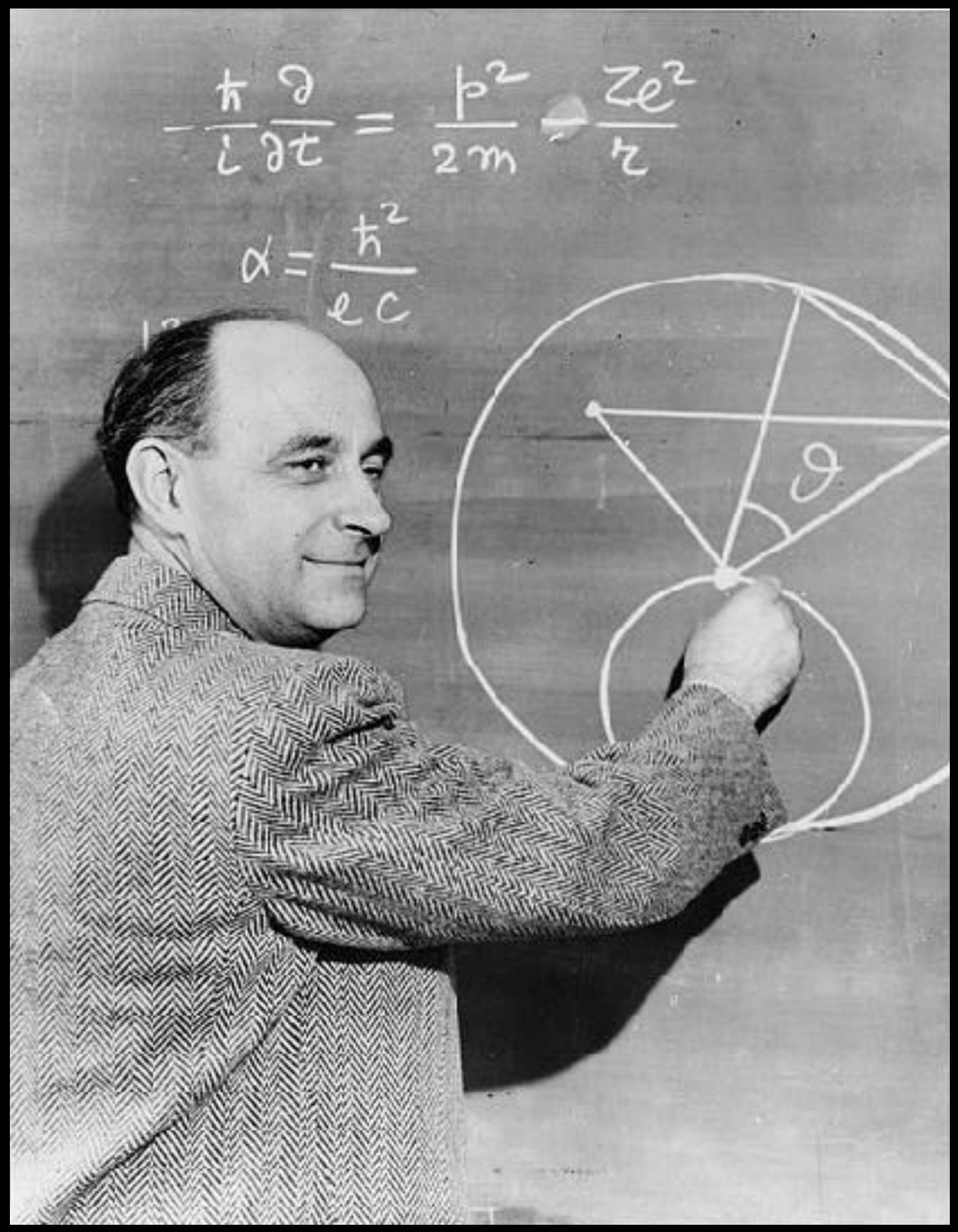


Ultra-peripheral collisions via electromagnetism

Expansion in

$$Z^2\alpha \sim 50$$

‘Strong’ QED



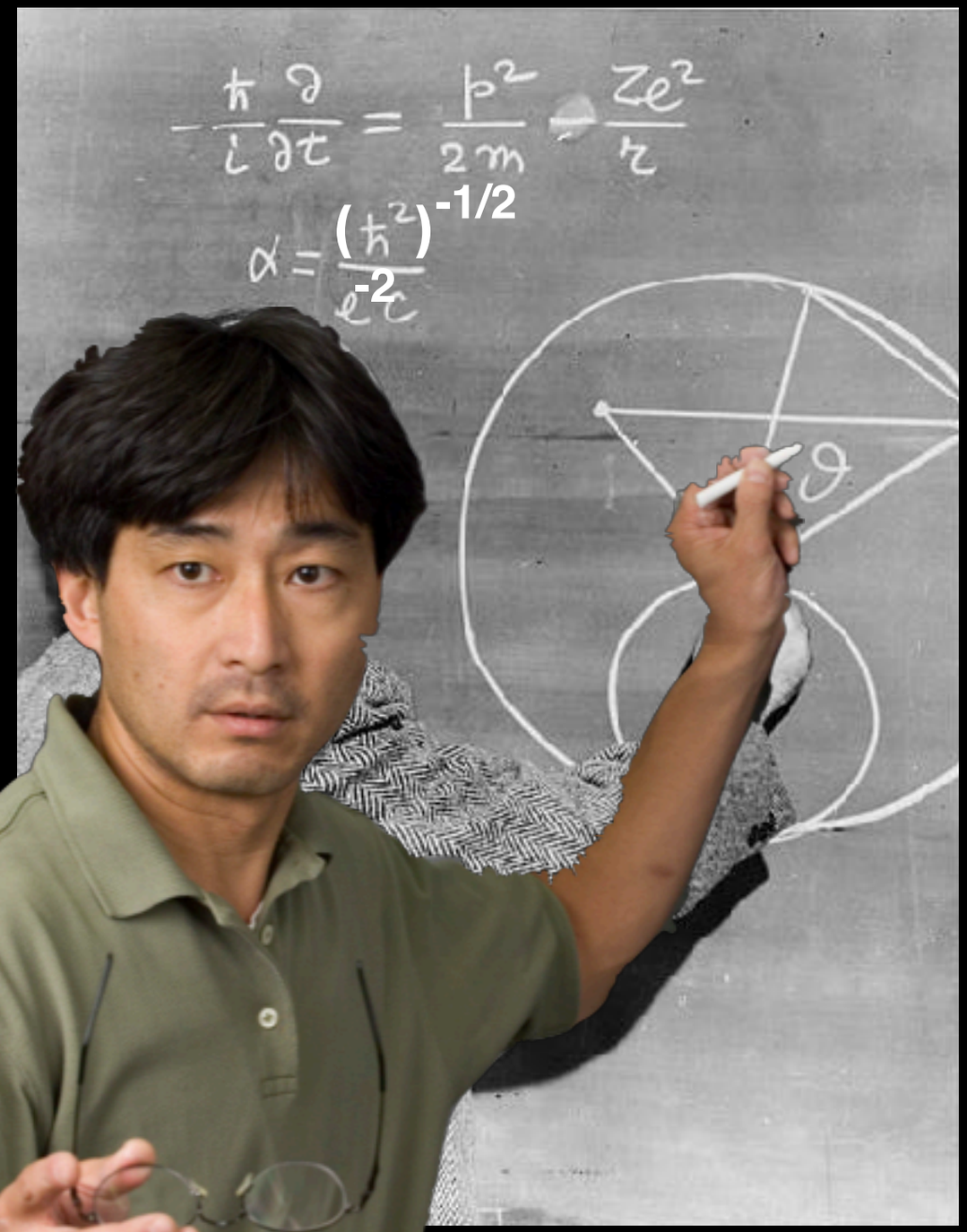
Enrico Fermi

Ultra-peripheral collisions via electromagnetism

Expansion in

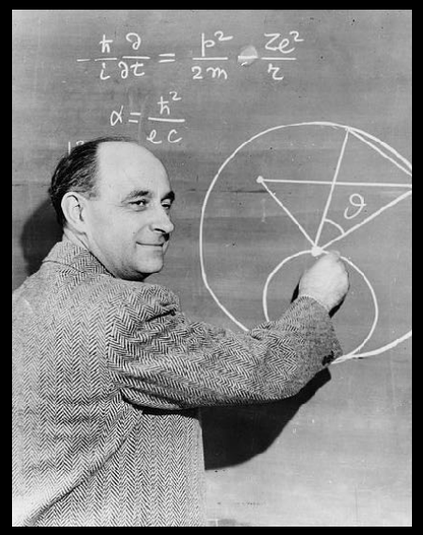
$$Z^2\alpha \sim 50$$

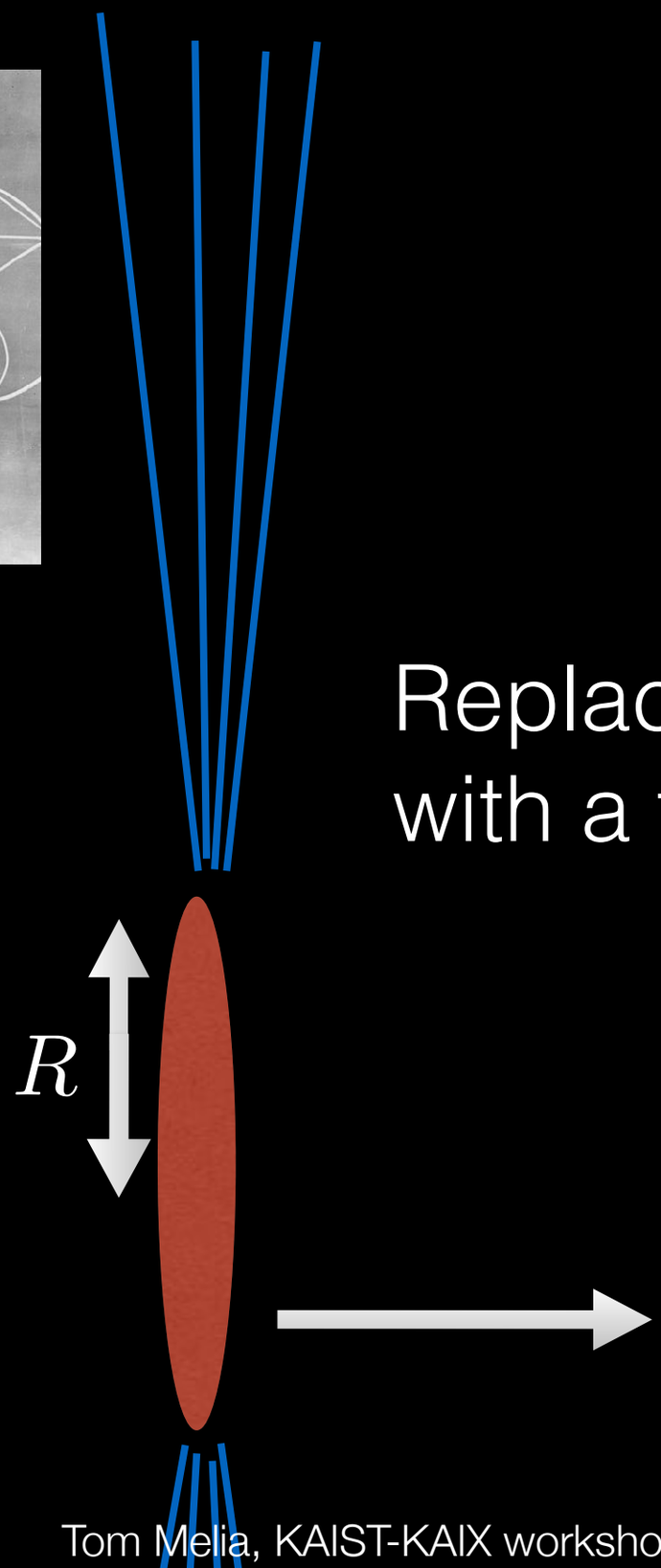
‘Strong’ QED



(Hitoshi’s talk yesterday)

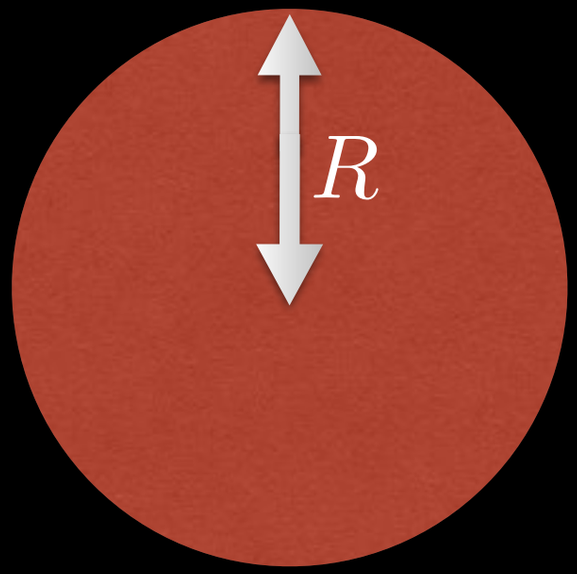
Enrico Fermi's effective photons

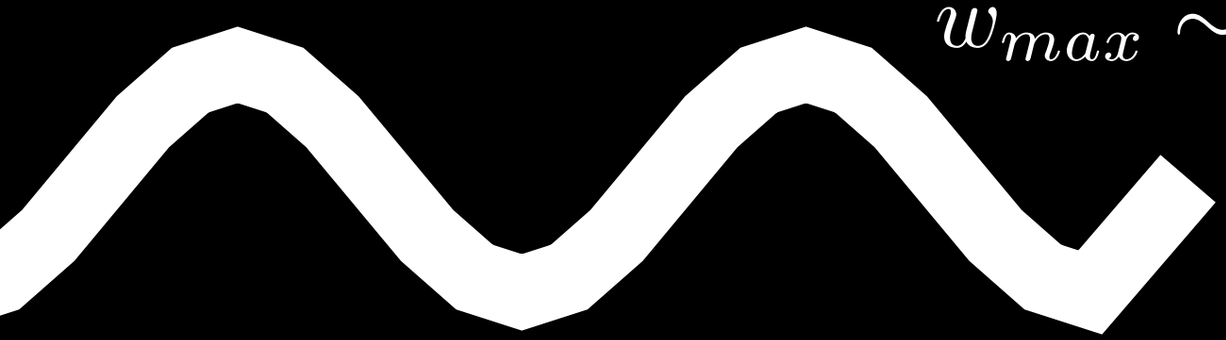




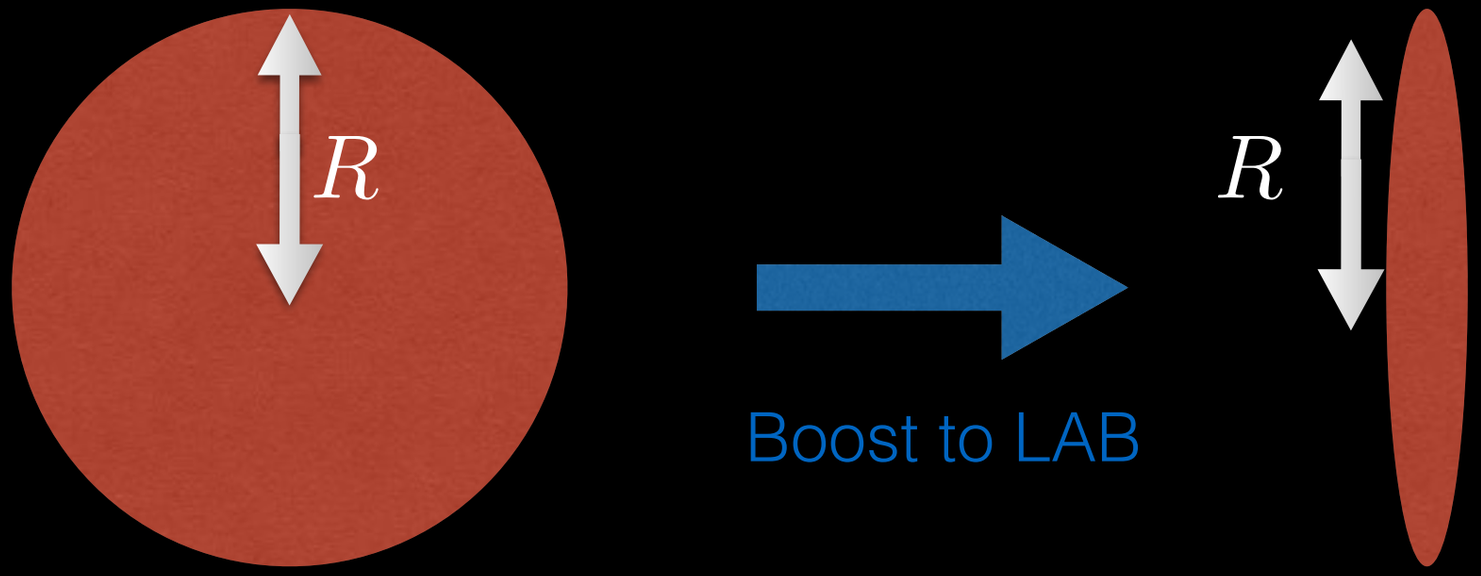
Replace E and B fields
with a flux of photons

Mass reach—quick estimate

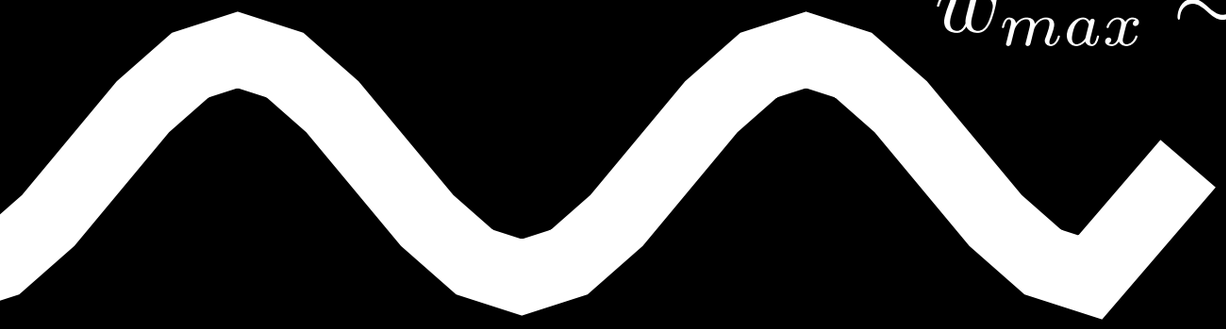




Mass reach—quick estimate

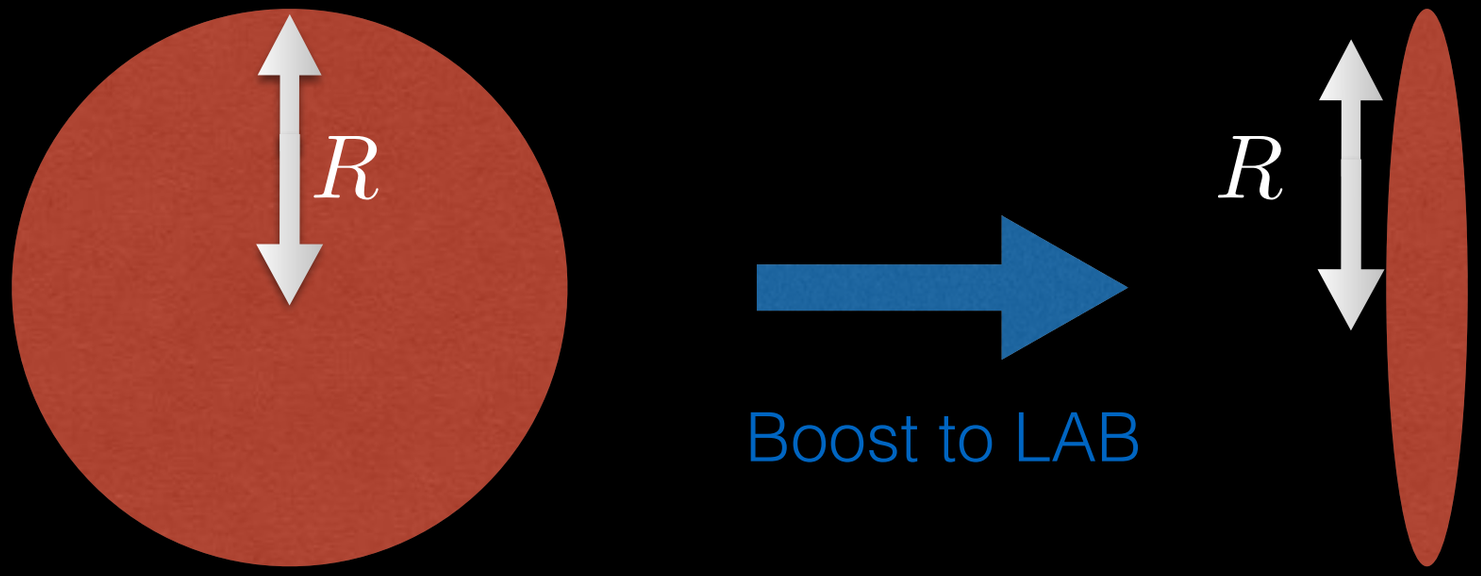


$w_{max} \sim 1/R$



$w_{max} \sim \gamma/R$

Mass reach—quick estimate

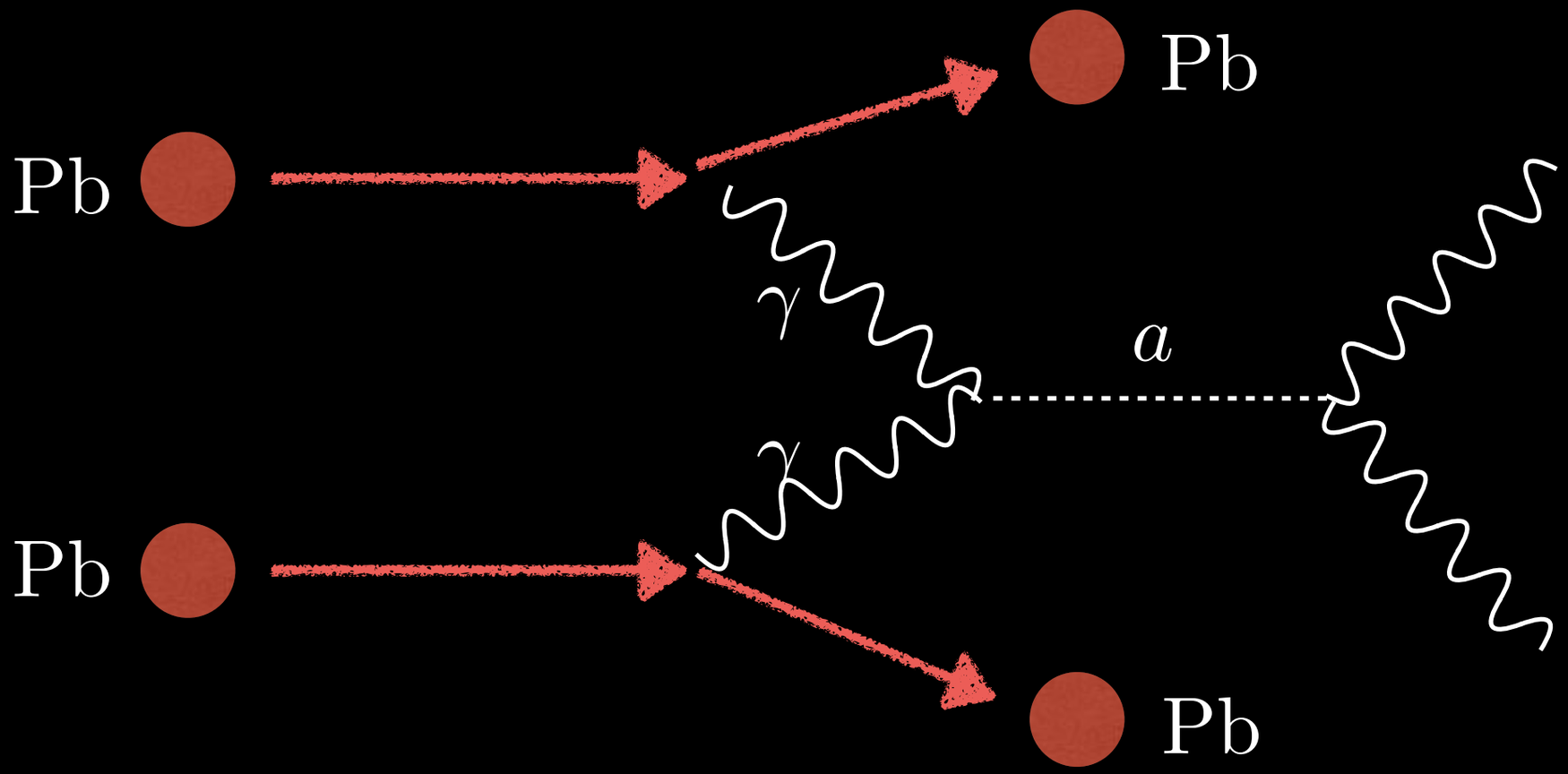


$w_{max} \sim 1/R$

$w_{max} \sim \gamma/R$

	$b_{\rm min} = 2R$	$E_{\rm nucleon}$	$2\omega_{\rm max}$
p	1.6 fm	7.5 TeV	1500 GeV
Pb	14 fm	5.6 TeV	160 GeV

Axions in Ultra-peripheral collisions



Knapen, Lin, Lou, TM Phys Rev Lett 118 (2017)

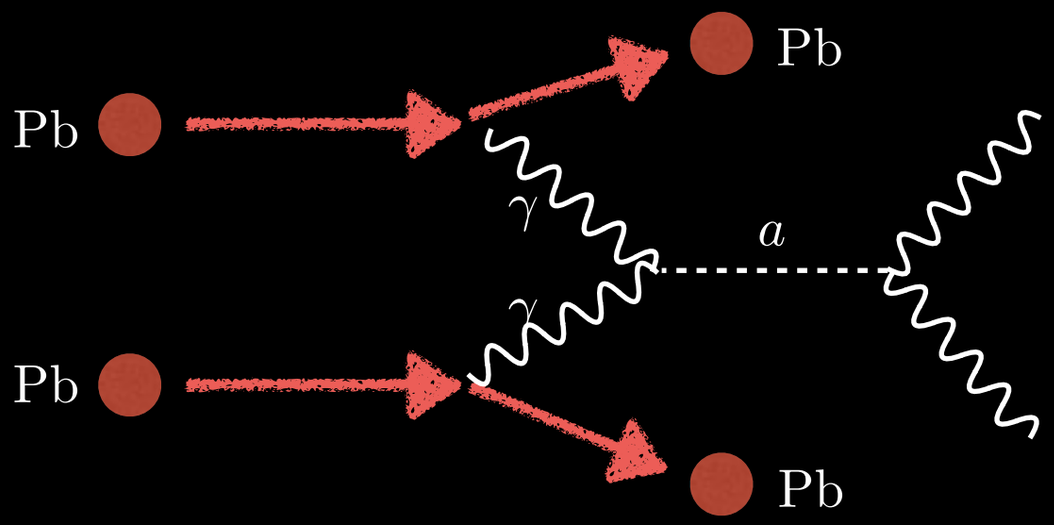
s/a

A. B. Balantekin, C. Bottcher, M. R. Strayer, and S. J. Lee
Phys. Rev. Lett. **55**, 461 (1985)

A.A. NATALE, *Mod. Phys. Lett. A*, **09**, 2075 (1994)

Heavy ion collisions are not optimised for typical BSM searches

(lower luminosity, lower per nucleon collision energy)

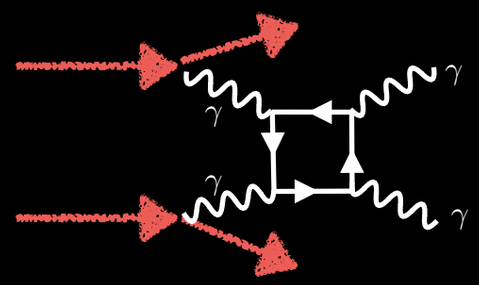


$$\sigma_a = \frac{8\pi^2}{m_a}\Gamma(a \to \gamma\gamma)\mathcal{L}_{\gamma\gamma}(m_a^2)$$

$$\Gamma = \frac{1}{64\pi}\frac{m_a^3}{\Lambda^2}$$

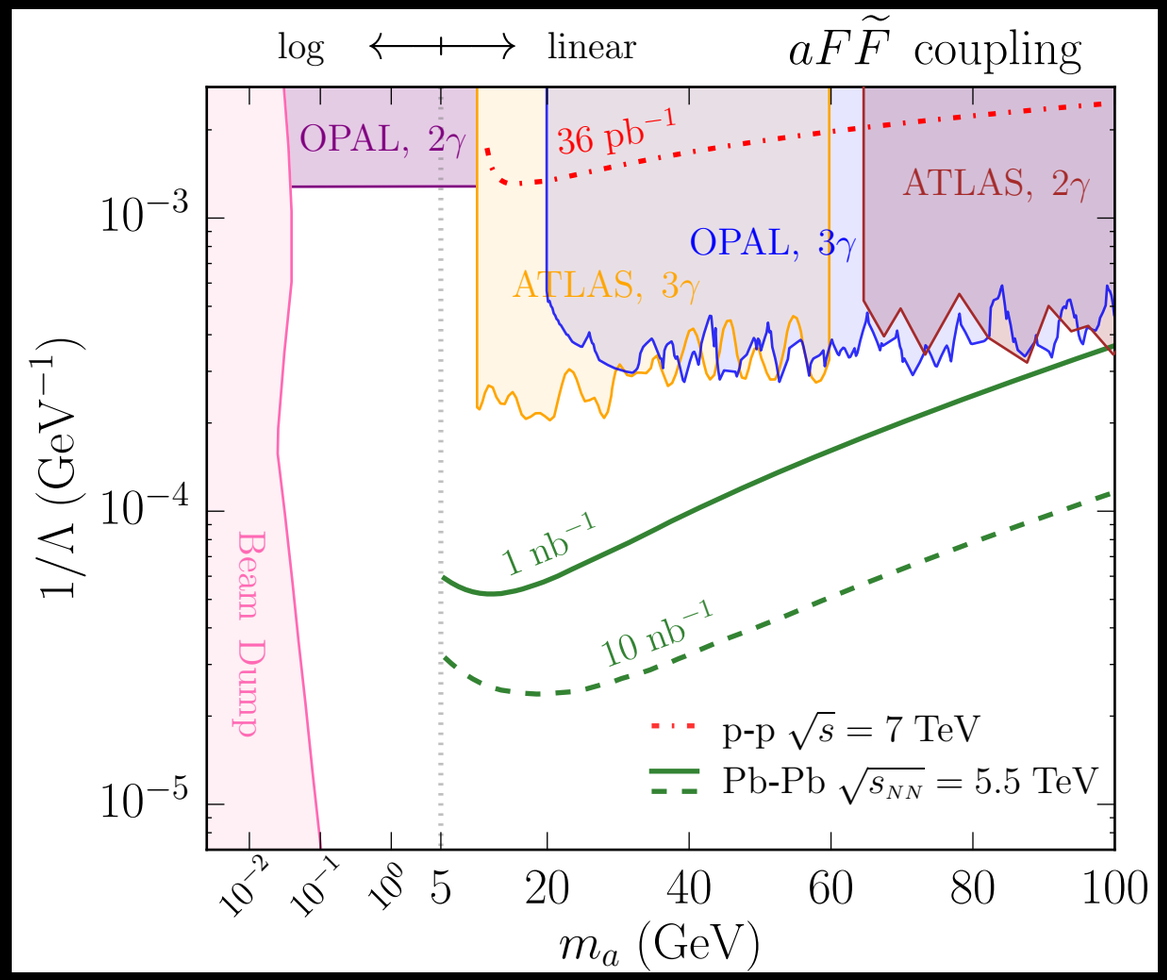
4.5×10^7

However, there is a Z^4 enhancement on our side, clean environment, and tiny background (light by light)



For these reasons, we showed heavy ions can place best limits in the mass-coupling plane between 5-100 GeV

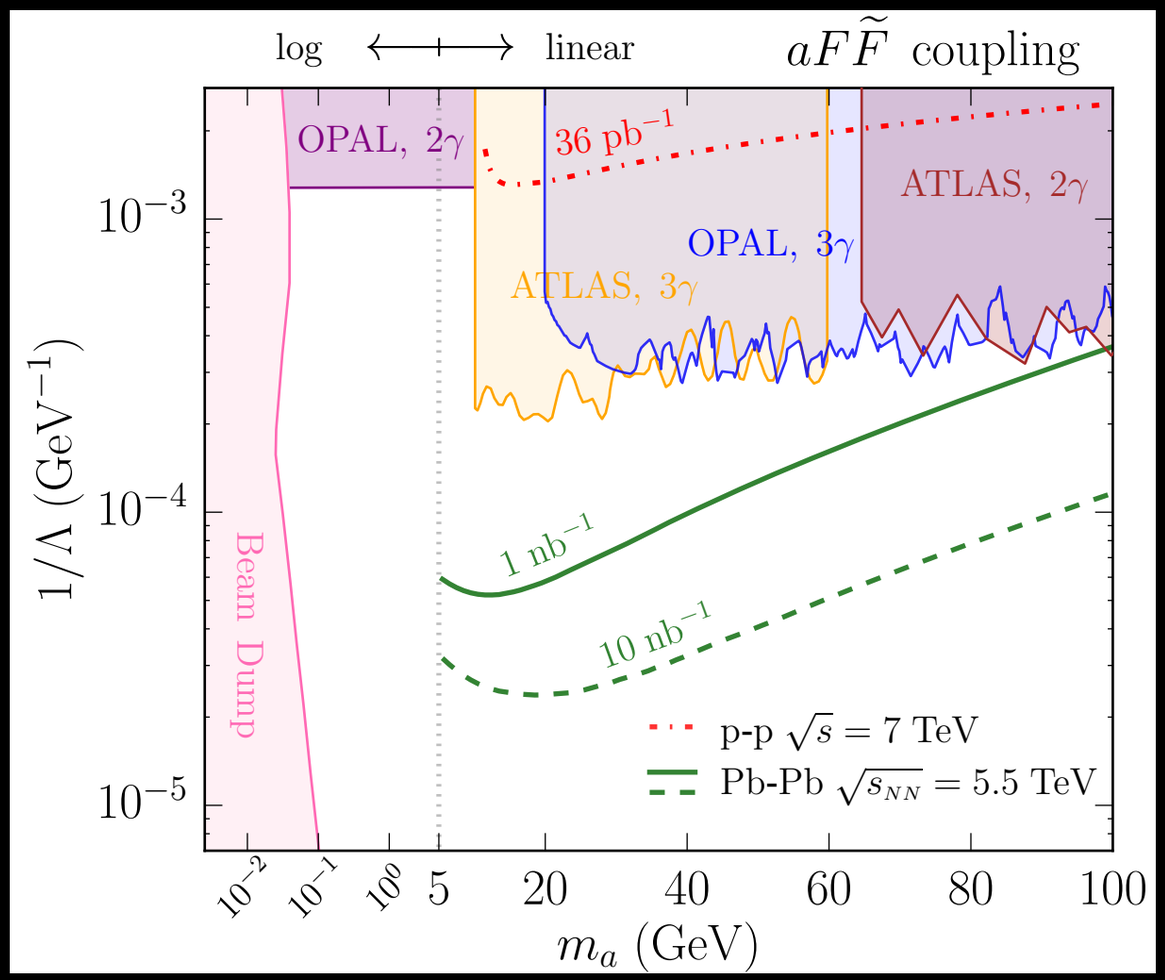
Trigger: 2 photons E>2 GeV and no hadronic activity in at least 1 fwd calorimeter



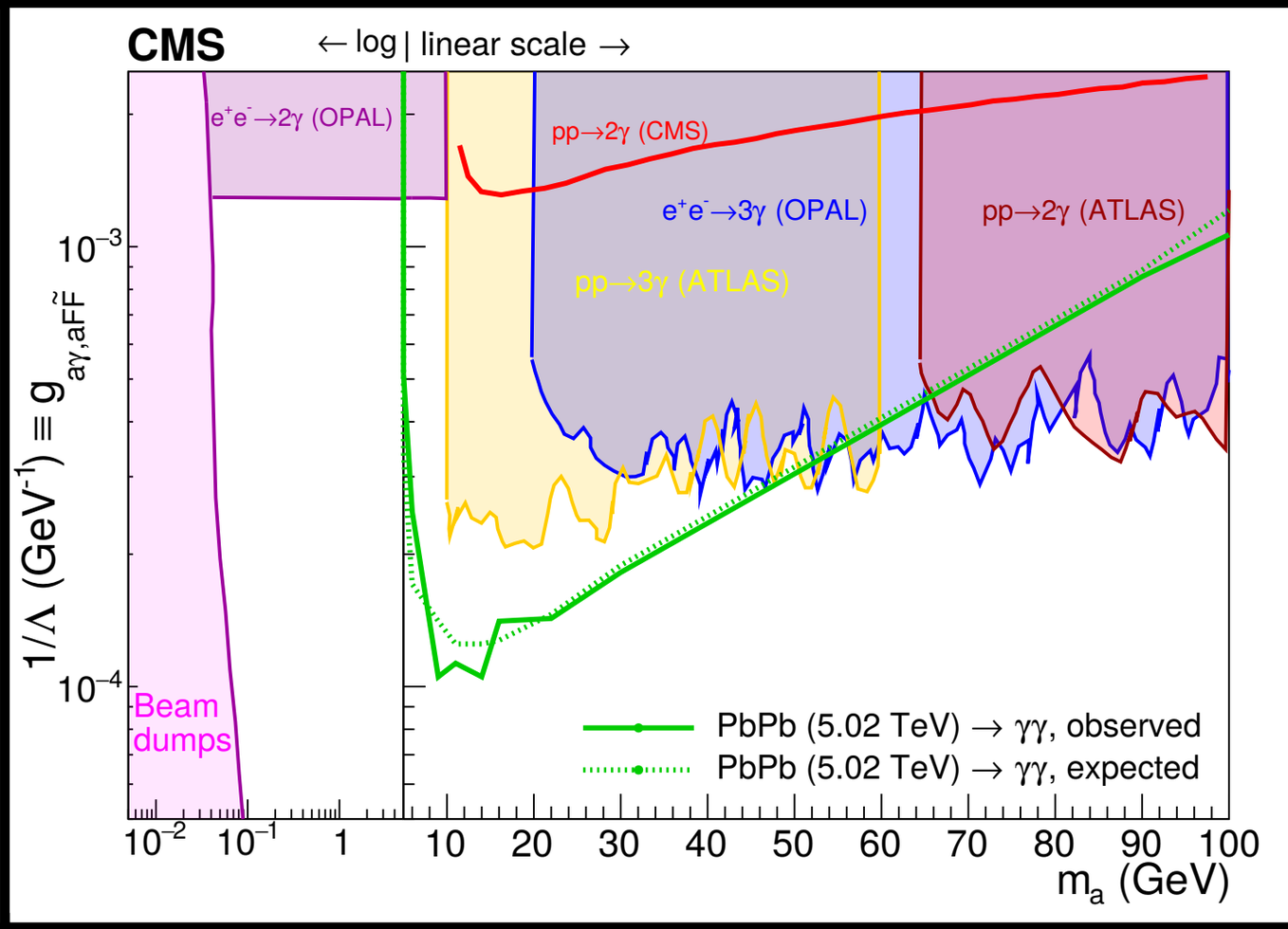
Knapen, Lin, Lou, TM Phys Rev Lett 118 (2017)

For these reasons, we showed heavy ions can place best limits in the mass-coupling plane between 5-100 GeV

Trigger: 2 photons E>2 GeV and no hadronic activity in at least 1 fwd calorimeter



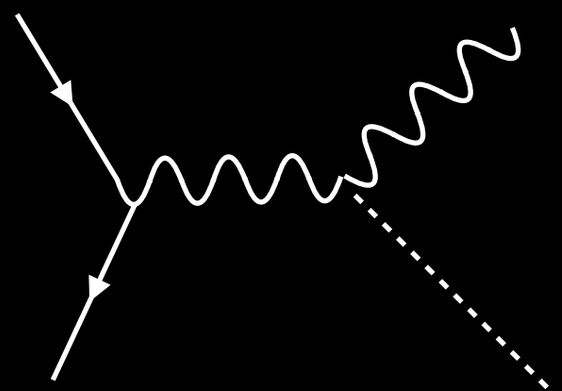
Knapen, Lin, Lou, TM Phys Rev Lett 118 (2017)

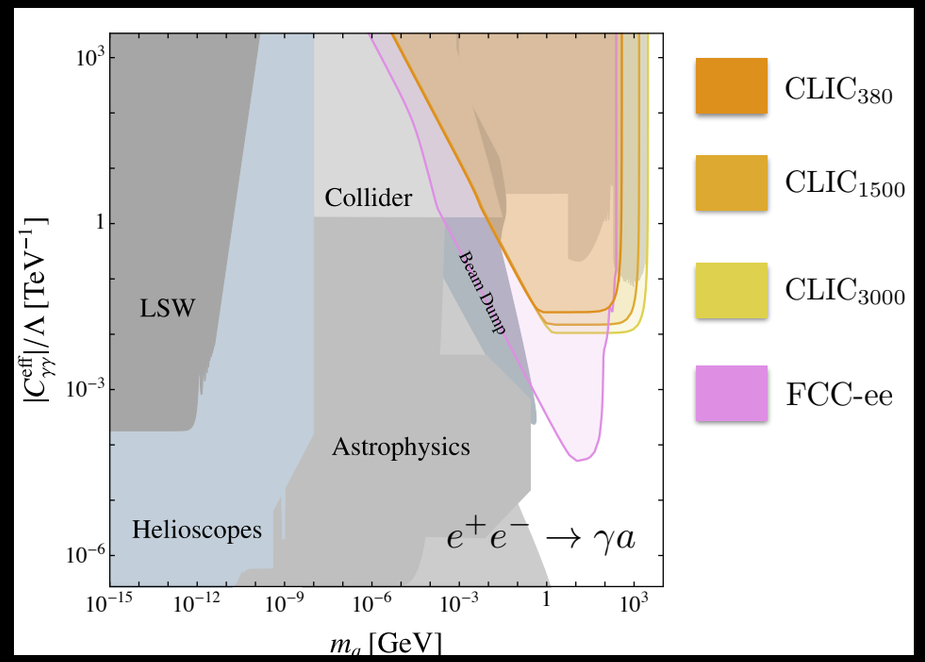


CMS 1810.04602 with 390/microbarn

In future colliders…

Future lepton colliders can extend reach to much lower couplings and wider mass range

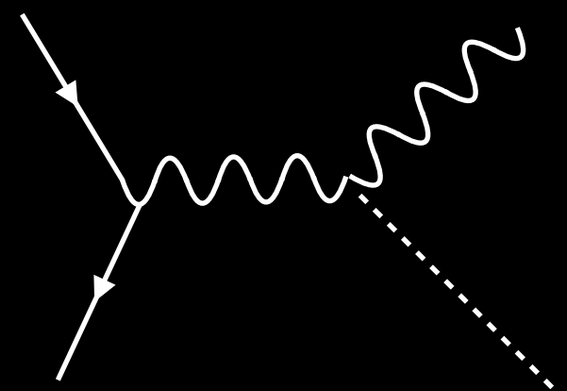


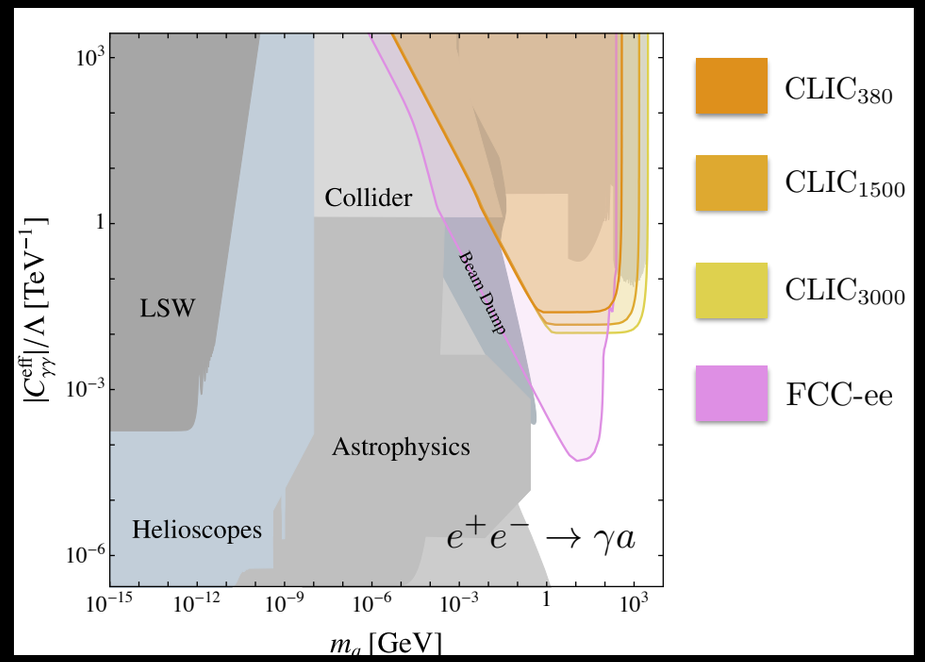


Bauer et al, *Eur.Phys.J. C79 (2019) no.1, 74*

In future colliders…

Future lepton colliders can extend reach to much lower couplings and wider mass range





Bauer et al, *Eur.Phys.J. C79 (2019) no.1, 74*

Future heavy ion colliders provide new (and perhaps unexpected) physics opportunities

Large Z (and N), low background of ultra peripheral collisions, is rather unique

Thank you for your attention!