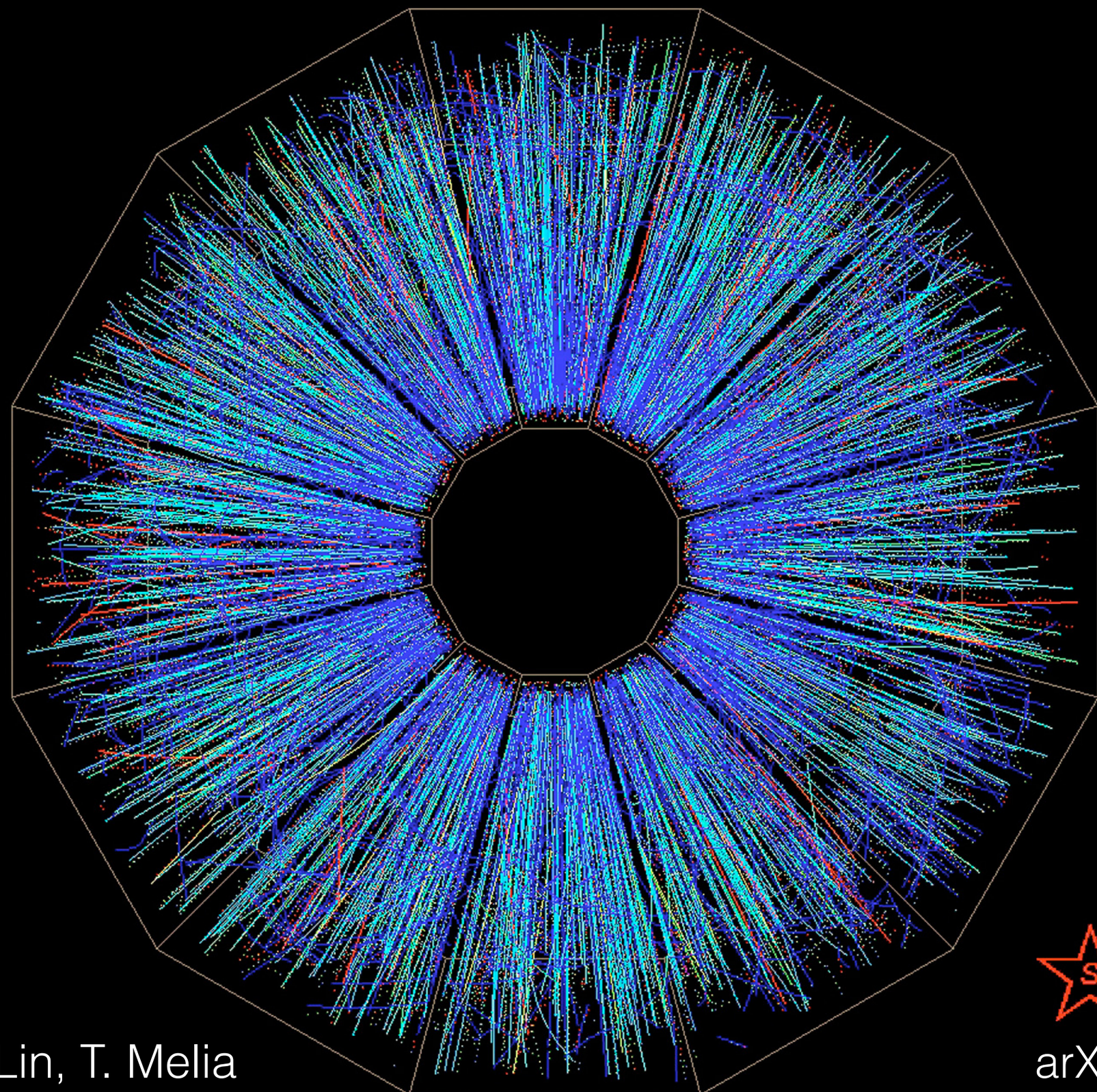
Searching for ALPs with heavy ion collisions

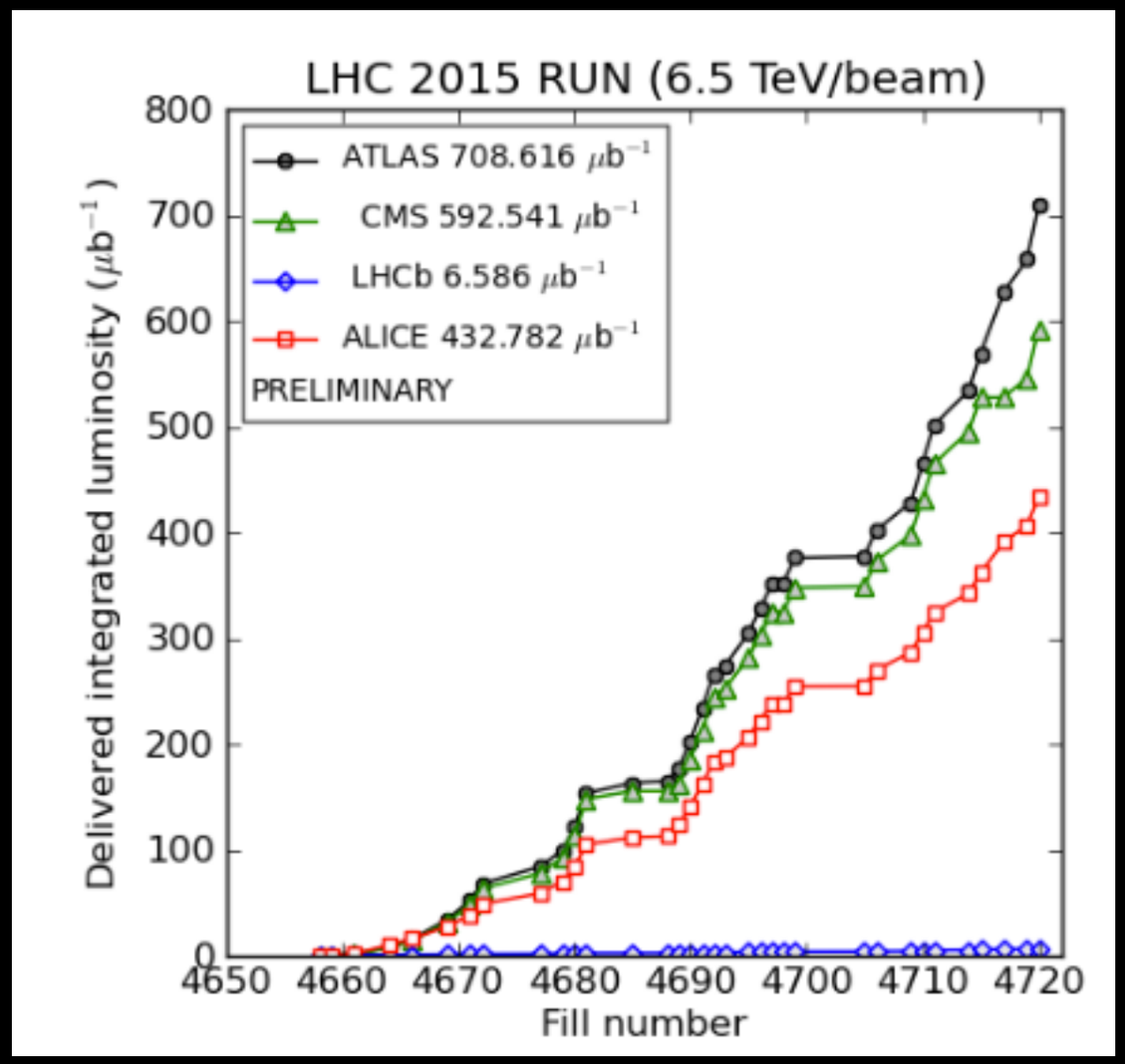


SK, T. Lou, T. Lin, T. Melia

arXiv:1607.06083

The LHC heavy ion program

Pb-Pb



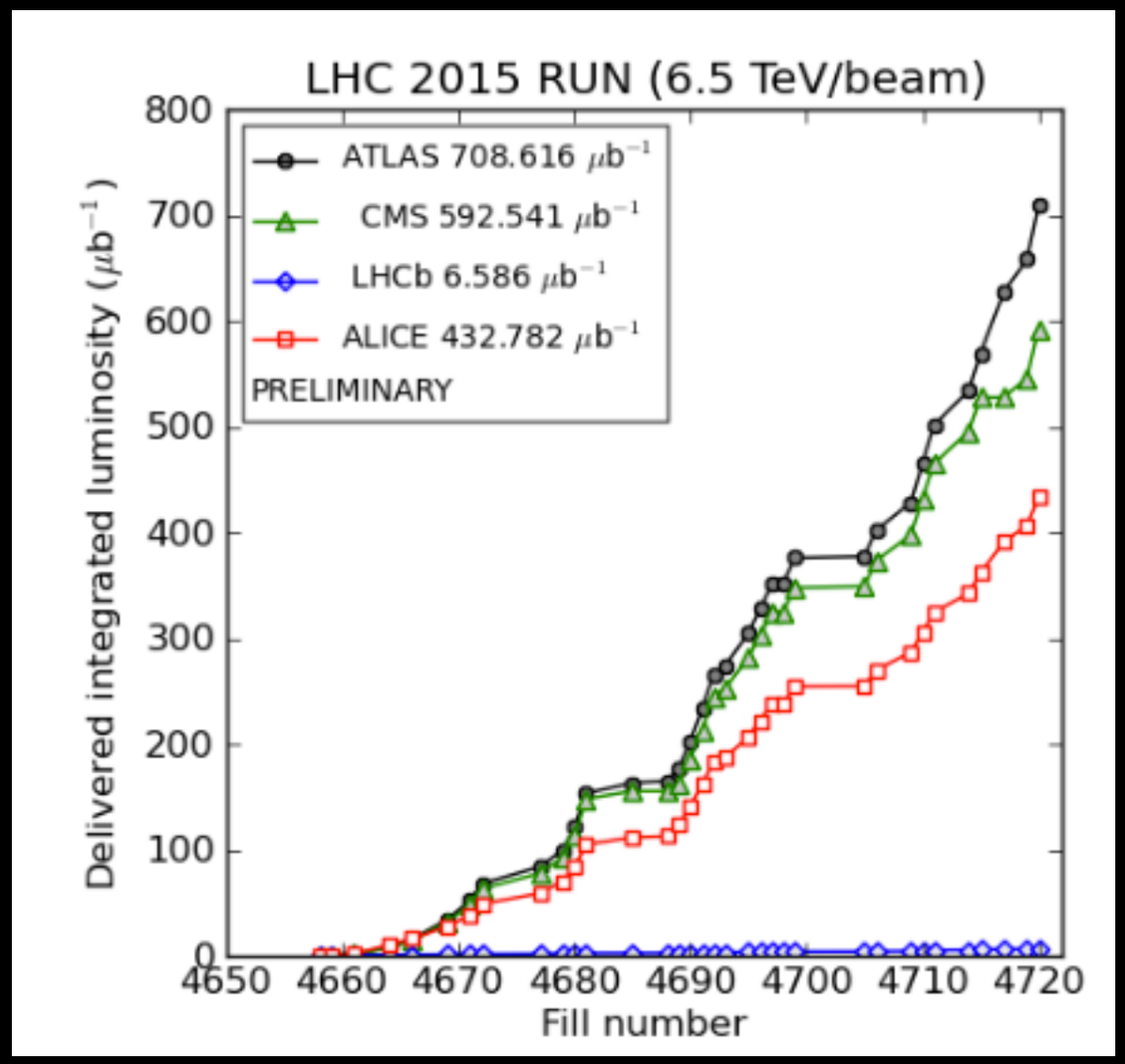
Heavy ion trivia

All 4 major experiments participate…

…but roughly 10^{-5} times the data

The LHC heavy ion program

Pb-Pb



Heavy ion trivia

$Pb^{82+}\ Pb^{82+} \rightarrow Pb^{82+}\ Pb^{81+}\ e^{+}$

↓

Secondary beam quenches magnet ~ 300 m downstream

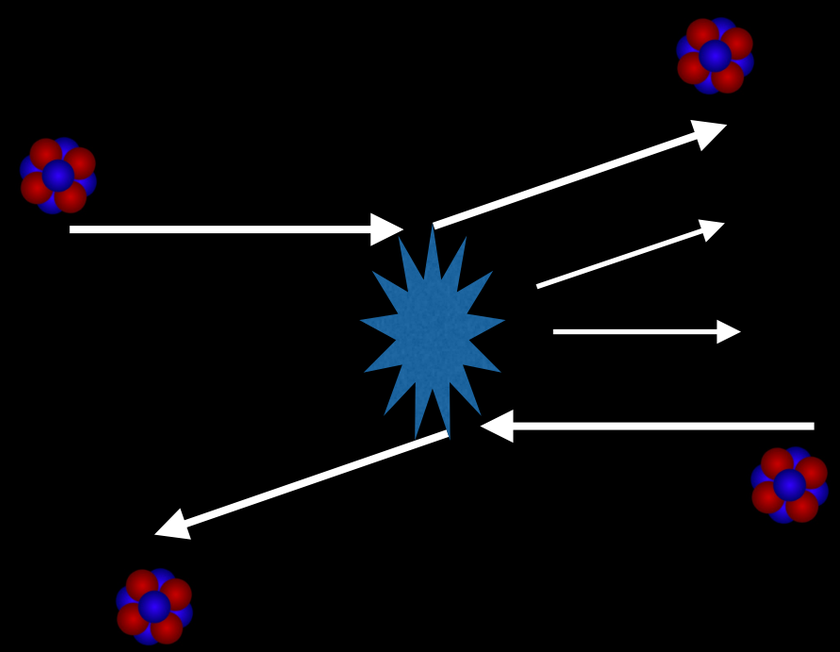
All 4 major experiments participate…

…but roughly 10^{-5} times the data

Ultra-peripheral collisions

High impact parameter (“grazing”) collisions

See also David’s talk later

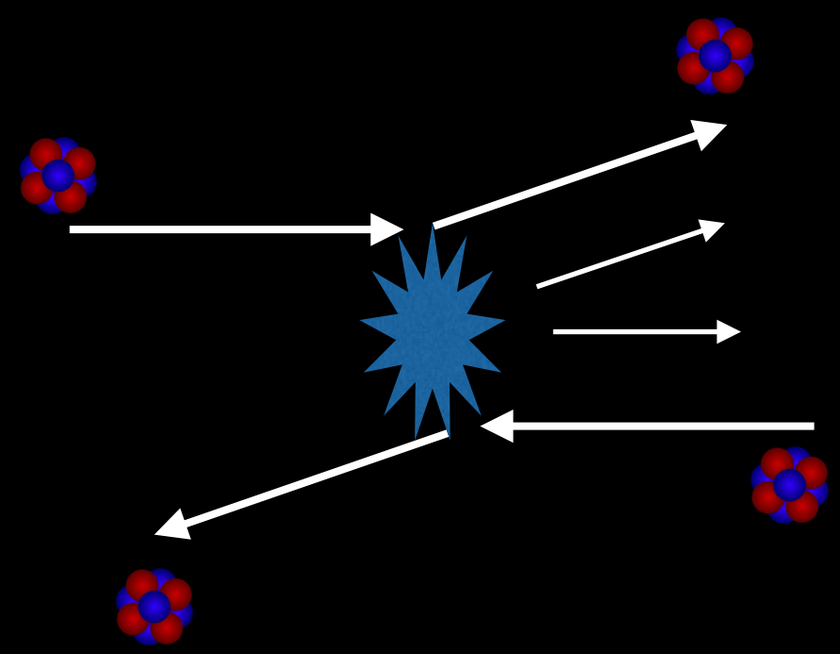


Ions remain intact
Low multiplicity particle production

Ultra-peripheral collisions

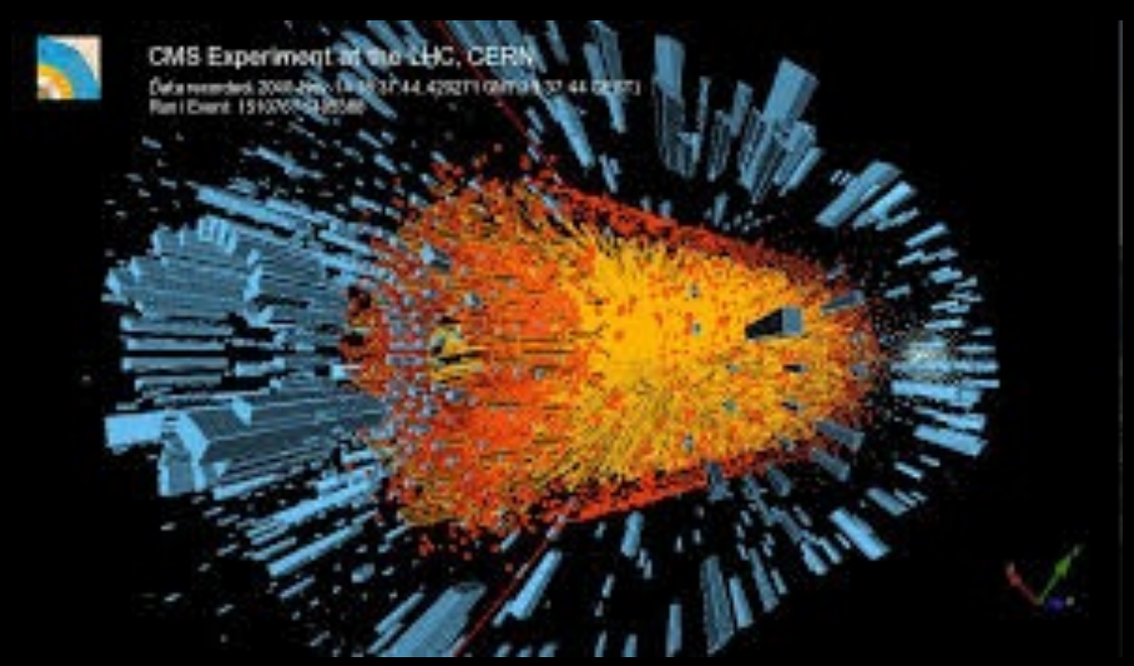
High impact parameter (“grazing”) collisions

See also David’s talk later

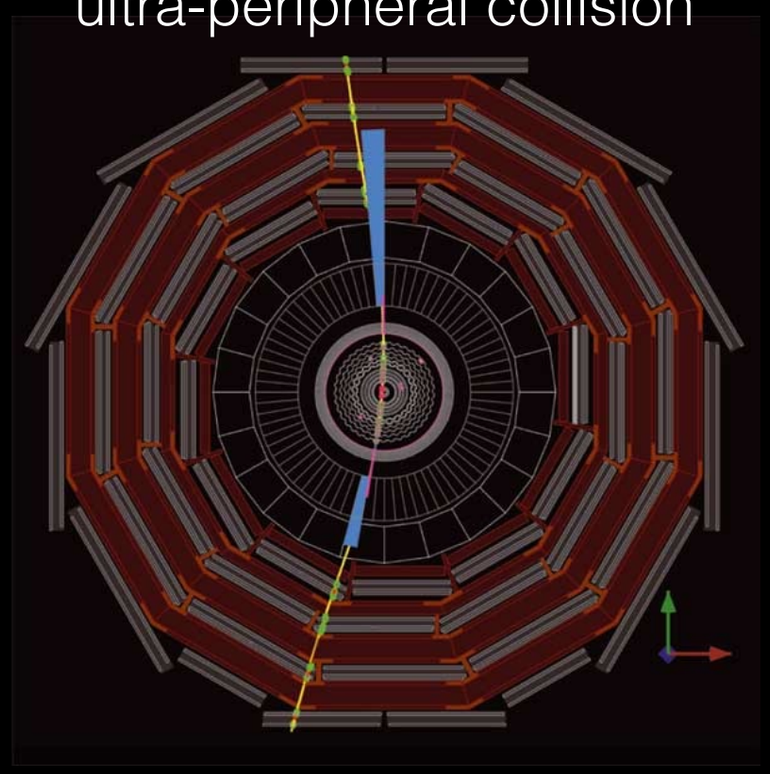


Ions remain intact
Low multiplicity particle production

head-on collision

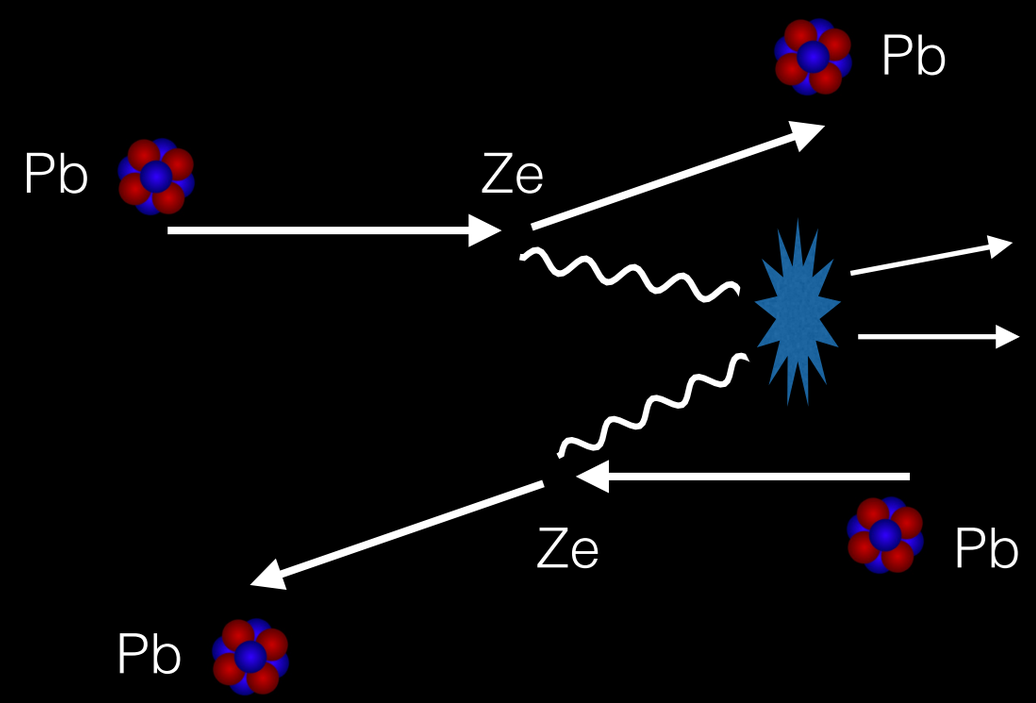


ultra-peripheral collision



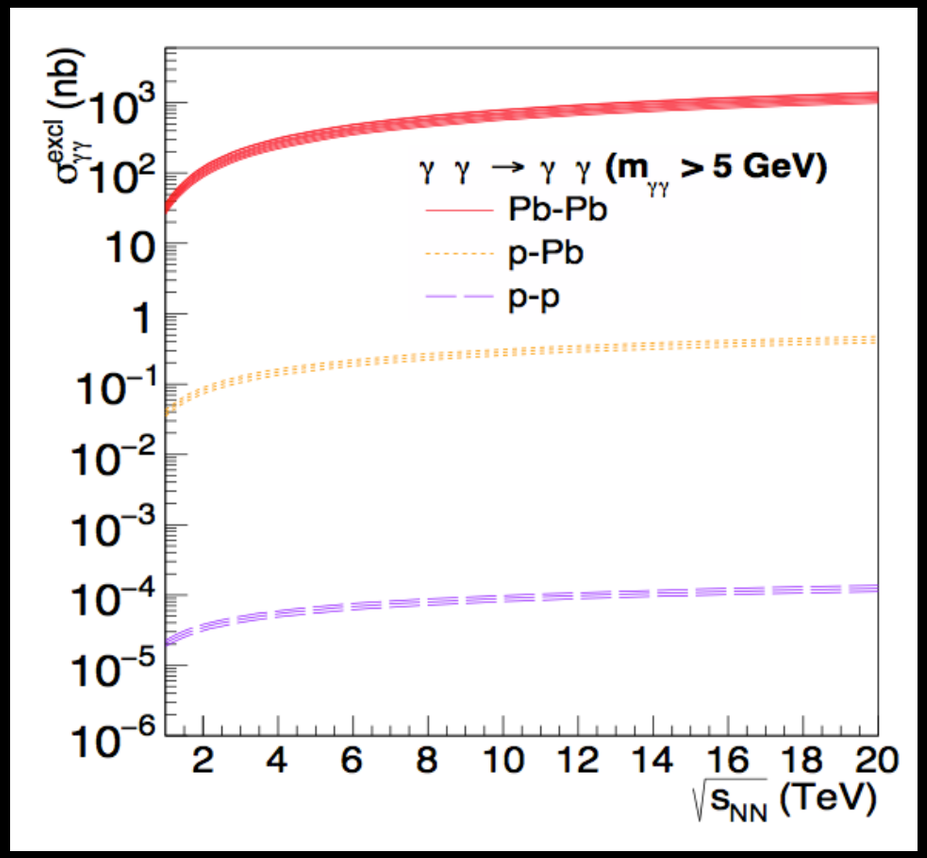
A γ-γ collider

RHIC: “golden flashlight”



~ 5.5 TeV per nucleon @ LHC

(this is a 1000 TeV collider)



1305.7142: D. d’Enterria, G. Silveira

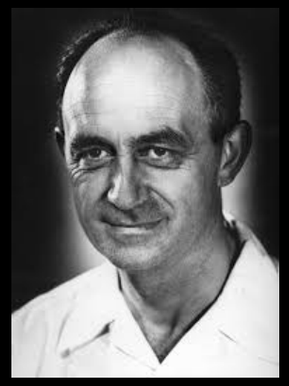
Z=82 for Pb ions

$Z^4 \sim 5 \times 10^7$

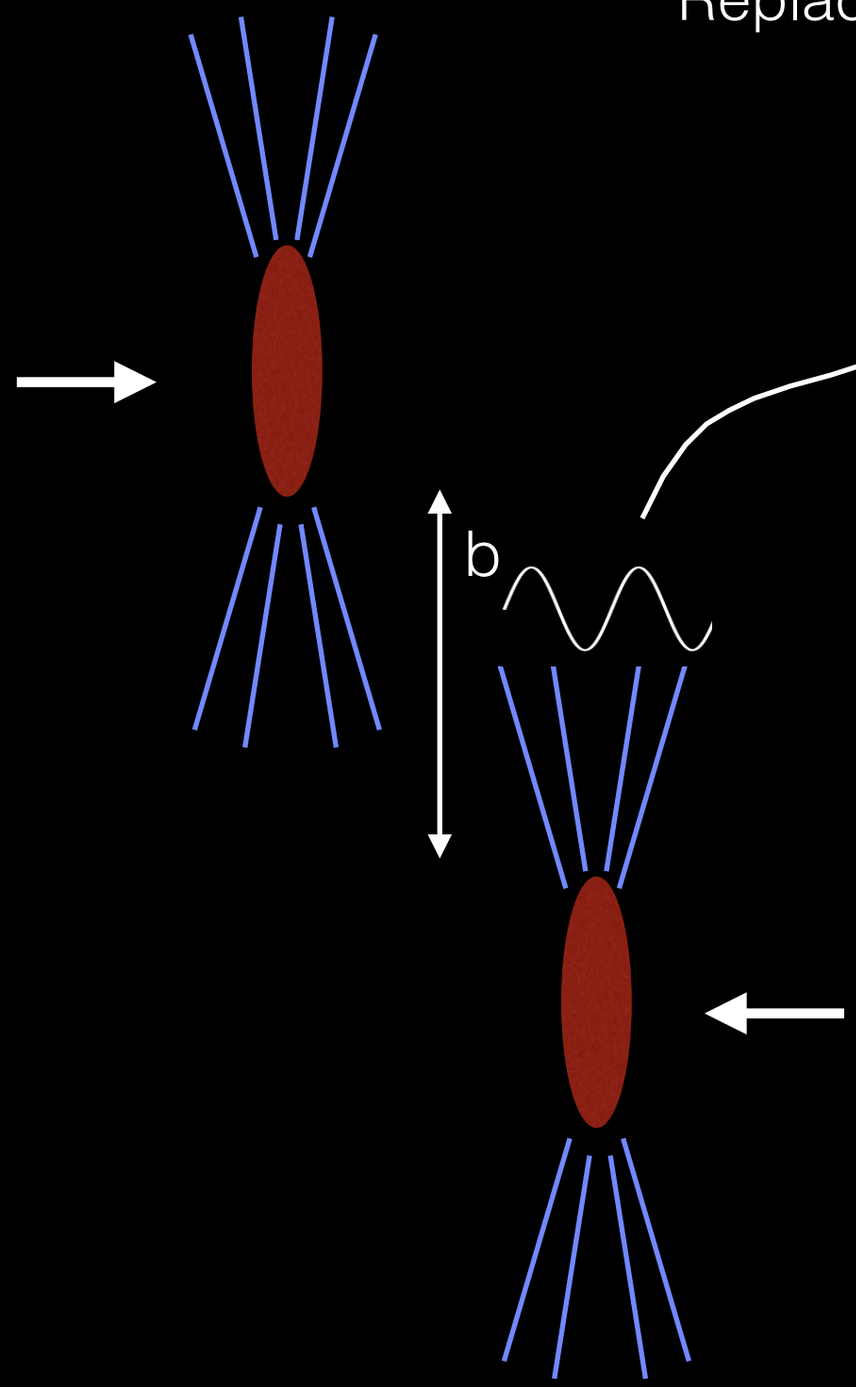
$Z^2\ \alpha >> 1$

QED in non-perturbative regime

Equivalent photon approximation



Replace E, B fields with an equivalent flux of nearly on-shell photons

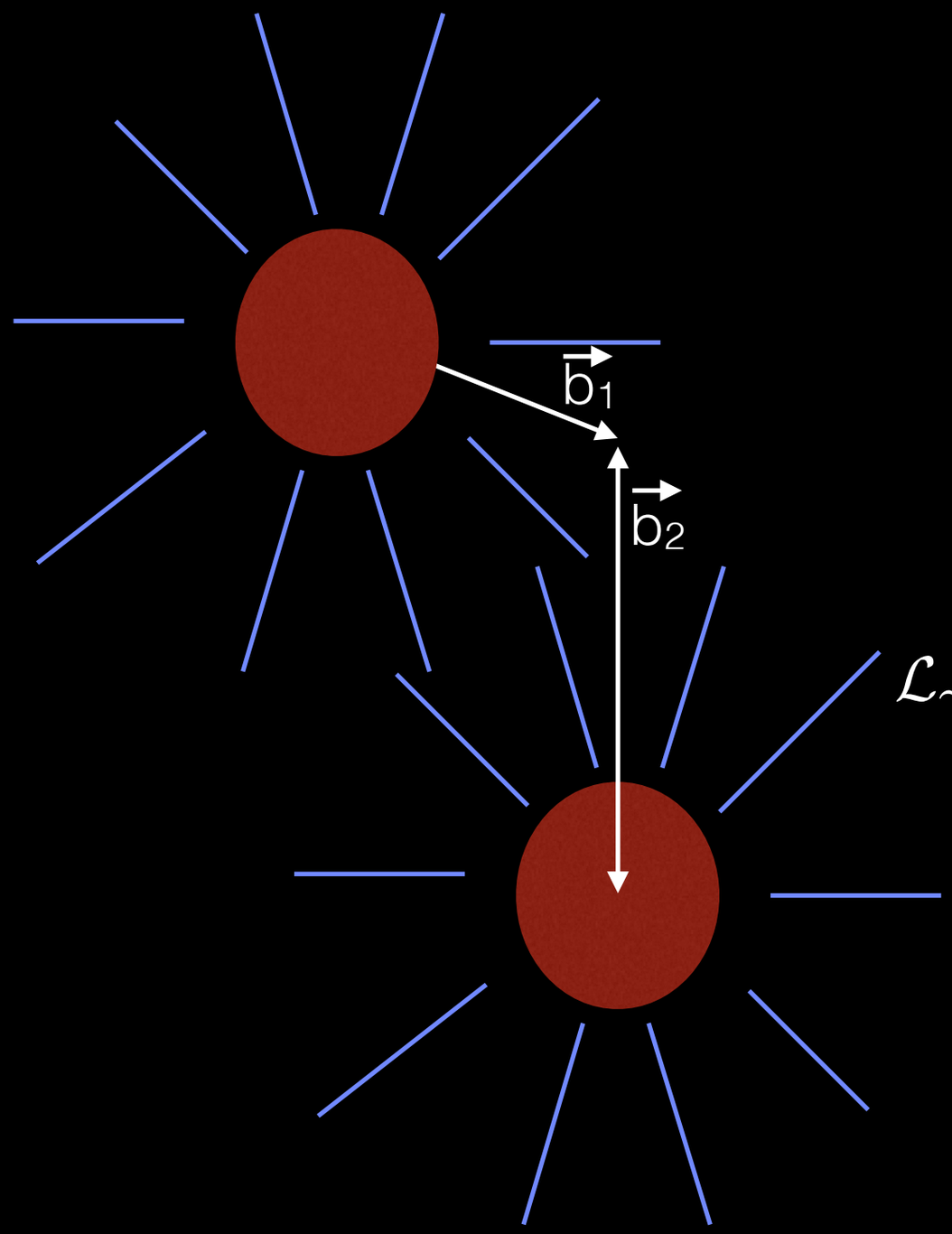


$$\omega_{max} \sim \frac{\gamma}{R}$$

	$b_{min} = 2R$	$\sqrt{s}$	$2\omega_{max}$
p	1.6 fm	13 TeV	1.5 TeV
Pb	14 fm	1050 TeV	160 GeV

Low Björken x: $x \sim 10^{-5}$

Computing the photon flux



Weizsäcker-Williams calculation

$$N_\gamma(\omega, b) = \frac{Z^2 \alpha \omega^2}{\pi^2 \gamma^2 \hbar^2 v^2} \left(K_1^2(x) + \frac{1}{\gamma^2} K_0^2(x) \right)$$

with $x \equiv \omega b / \gamma v \hbar$

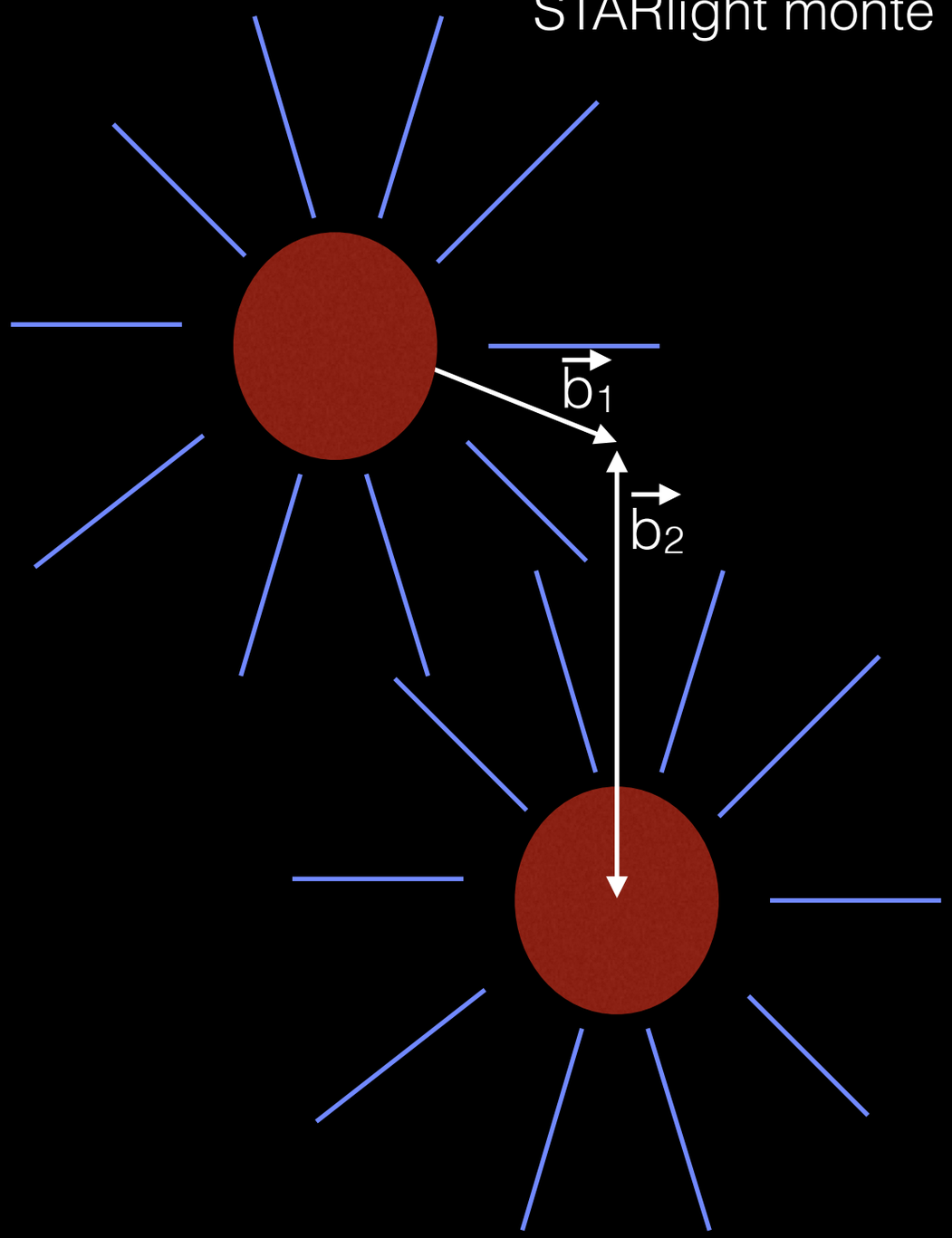
Photon-photon luminosity

$$\begin{aligned} \mathcal{L}_{\gamma\gamma}(\hat{s}) &= \frac{1}{\hat{s}} \int d^2 b_{1,2}\, d\omega_{1,2}\, N_\gamma(\omega_1, b_1)\, N_\gamma(\omega_2, b_2) \\ &\quad \times F(|b_1 - b_2|)\, \delta(\hat{s} - 4\omega_1\omega_2) \end{aligned}$$

nuclear form factor

Computing the photon flux

STARlight monte carlo (S. Klein et. al., 1607.03838)



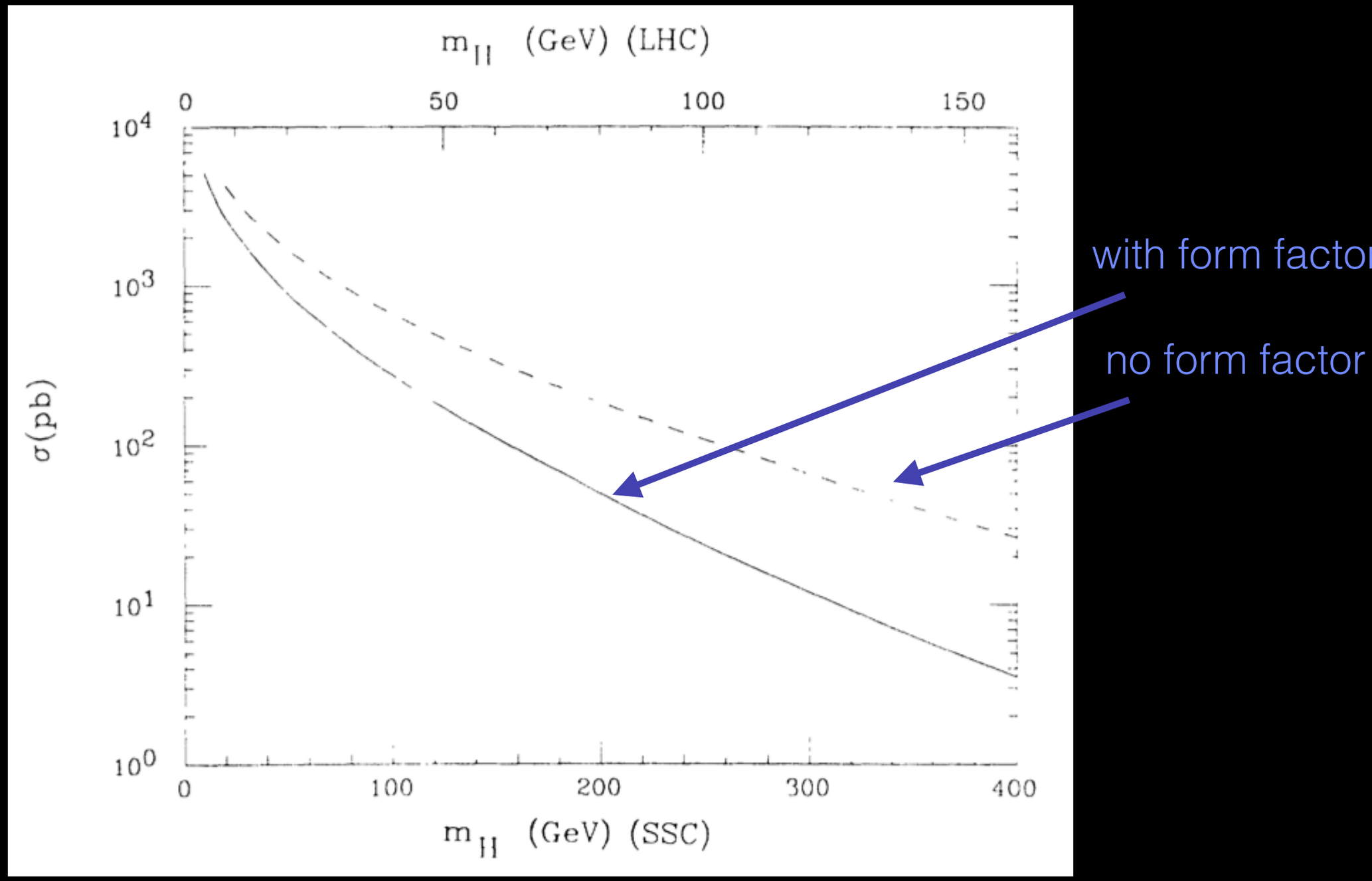
from latest STARlight manual

```
-----------------------------------------------------------------------
Channels of Interest:

2-Photon Channels
Currently supported 2-photon (prod. mode = 1) channel options:
      jetset id        particle
   --------------------------------
      221          eta
      331          eta-prime
      441          eta-c
      9010221      f0(975)
      225          f2(1270)
      115          a2(1320)
      335          f2(1525)
      33           rho0 pair
      11           e+/e- pair
      13           mu+/mu- pair
      15           tau+/tau- pair
      88           axion-like particle (ALP)

Process 88 refers to the single production of a hypothetical axion-like
particle (ALP), which decays to a pair of photons. The ALP mass has to be
specified by the user through the parameter AXION_MASS. The narrow width
approximation is assumed here, with a fixed axion decay constant of
\Lambda=1 TeV. (See equation (1) of arXiv:1607.06083 for the appropriate
```

Pb-Pb Luminosity
now: ~ 1 nb^{-1}
HL-LHC: ~ 10 nb^{-1}

SM Application (I)

Higgs production in photon fusion



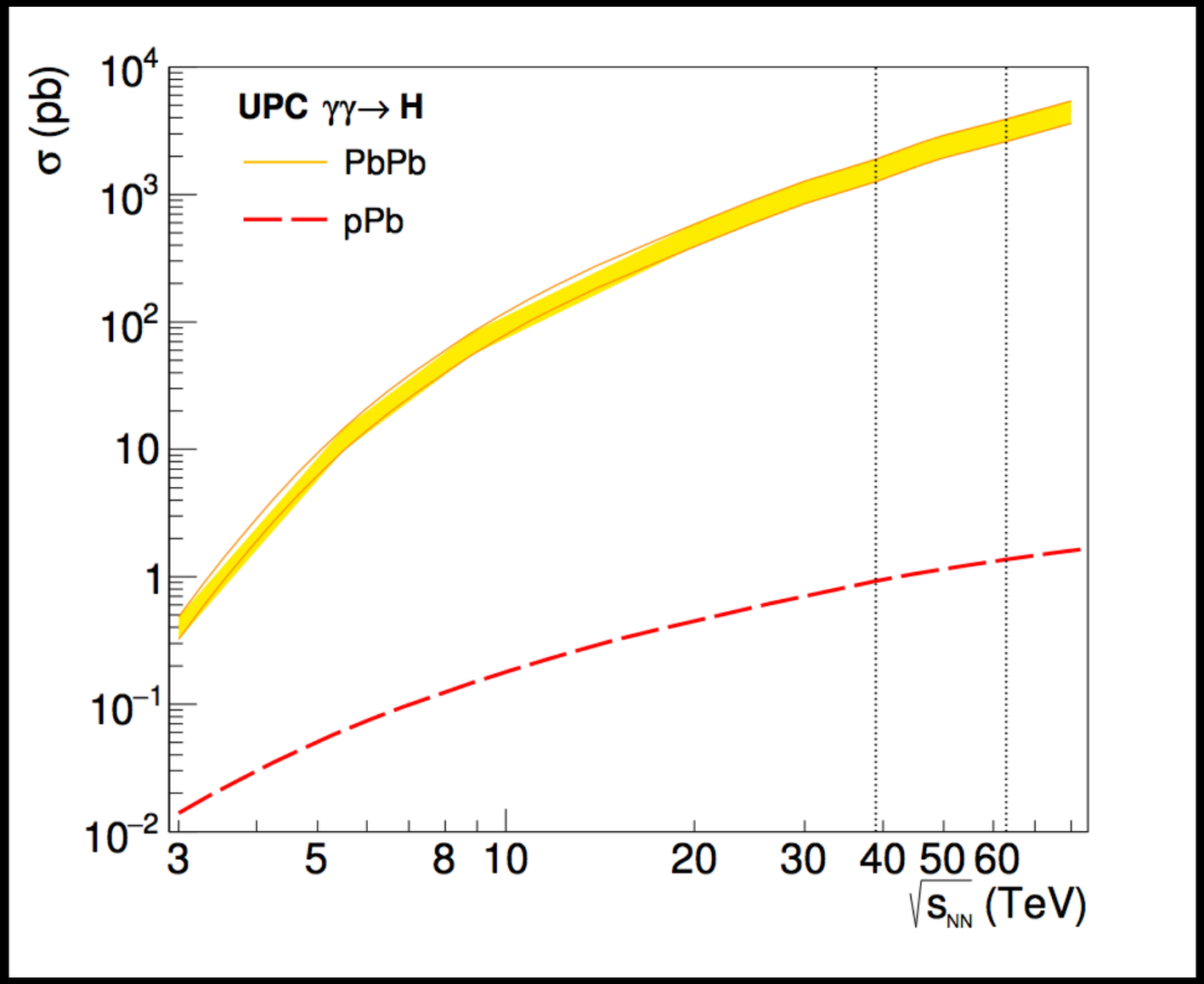
Unfortunately, this rate is too low…

B. Cahn, D. Jackson (1990)

Pb-Pb Lumi~ 100 nb^{-1}

SM Application (I)

At FCC

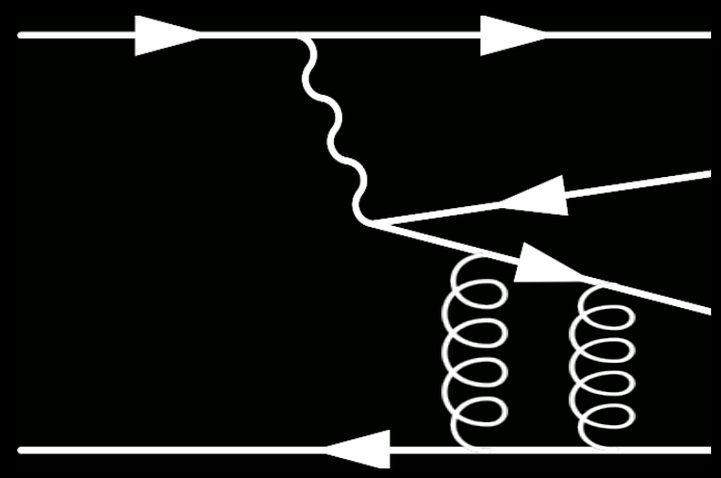


Observation of Higgs in UPC is possible!

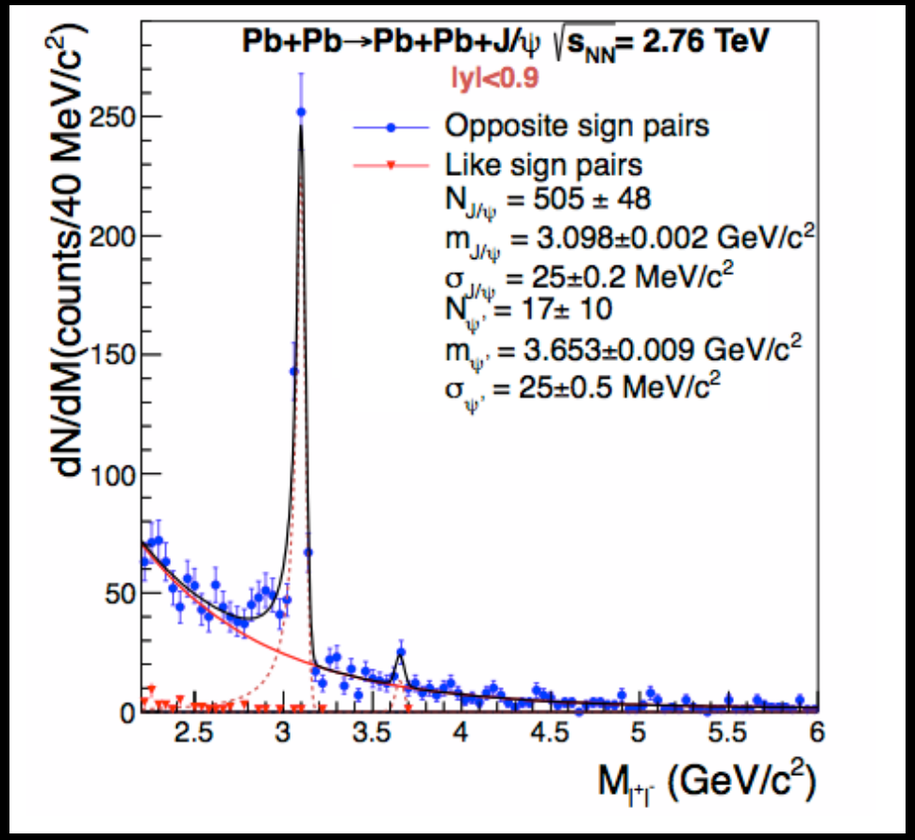
d'Enterria et.al. 1712.10104

SM Application (II)

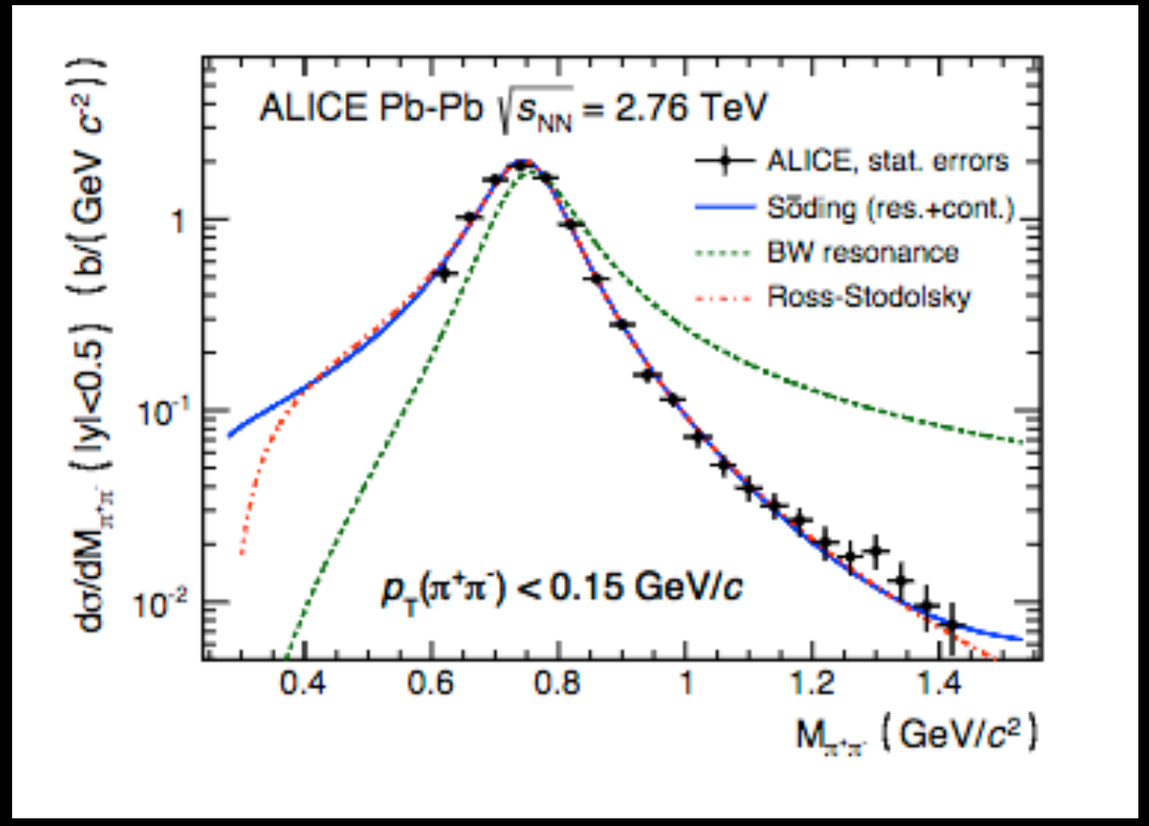
Exclusive meson production



J/Ψ production



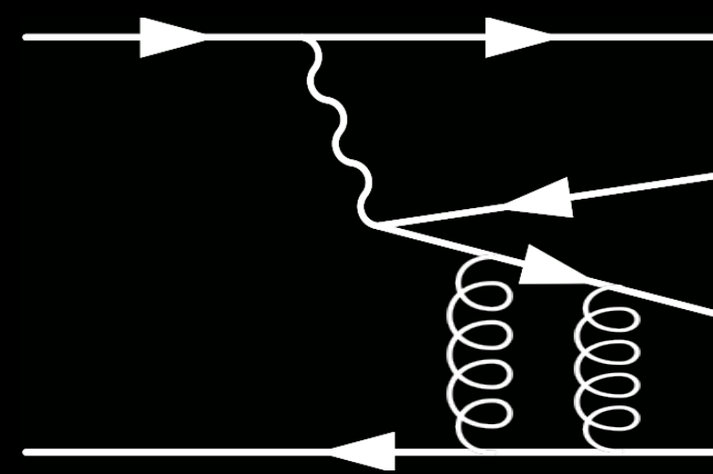
ρ^0 production



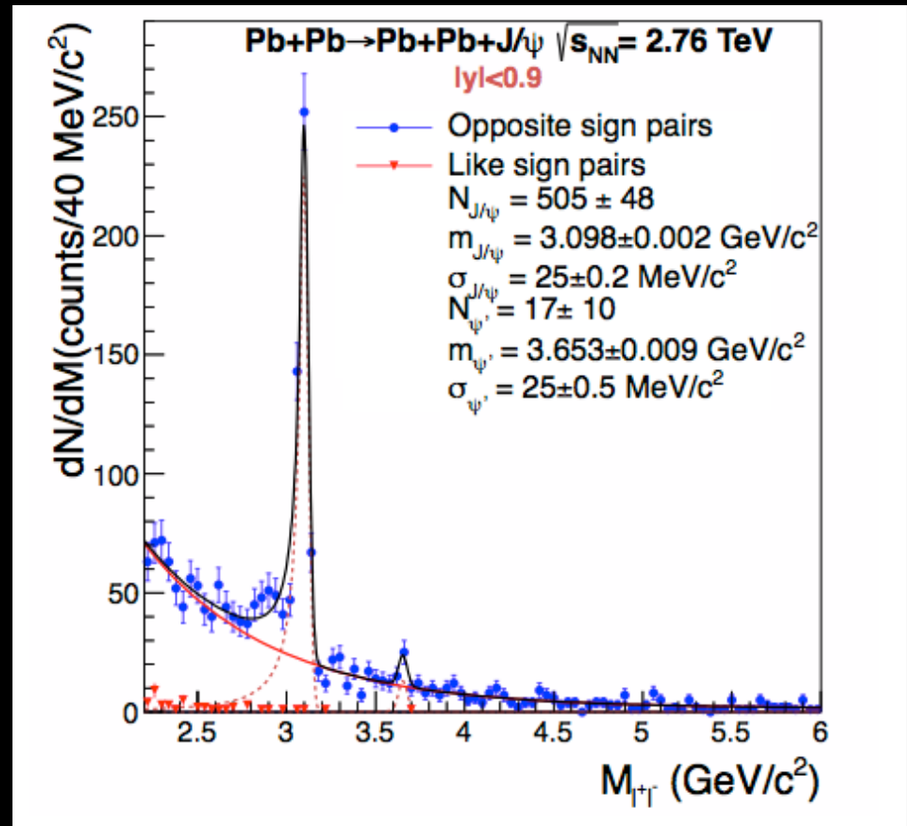
(Similar results from CMS and ATLAS)

SM Application (II)

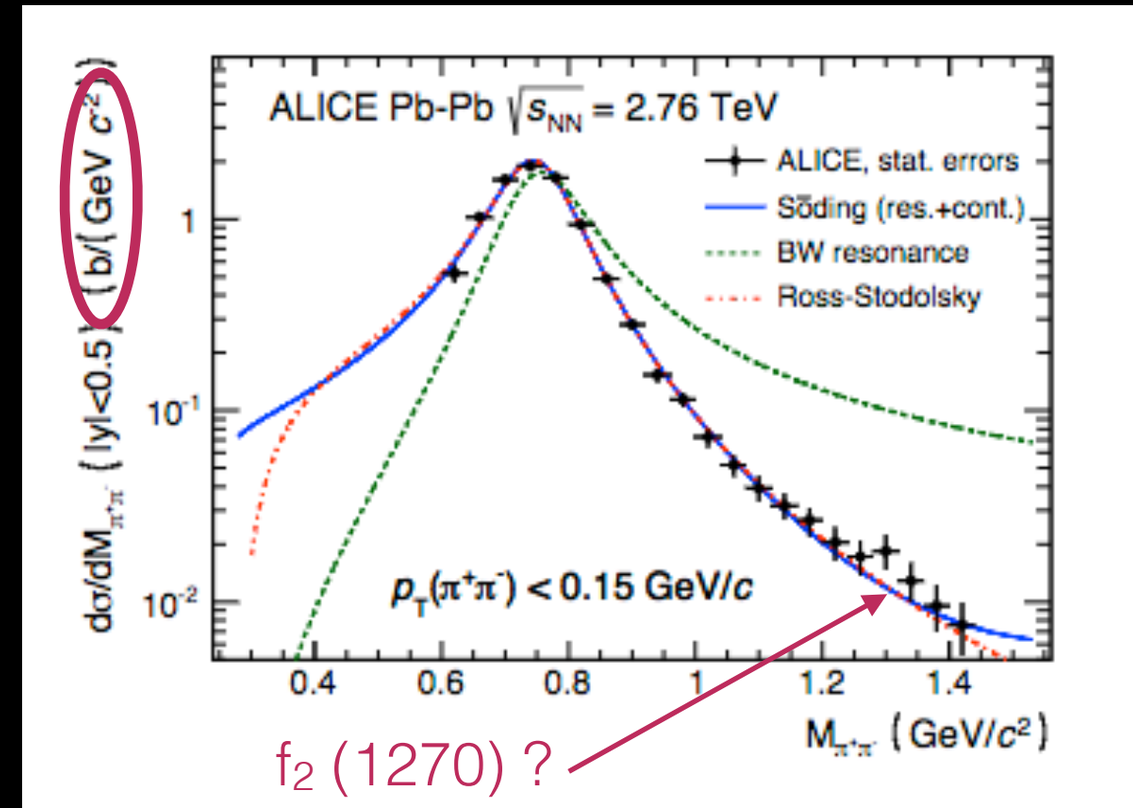
Exclusive meson production



J/Ψ production



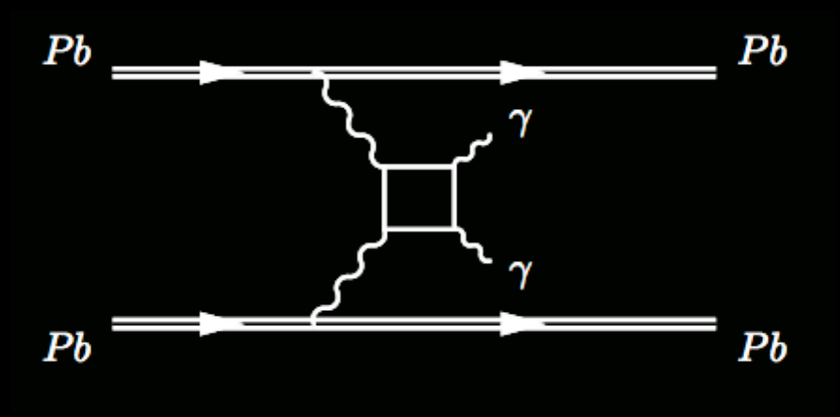
ρ^0 production

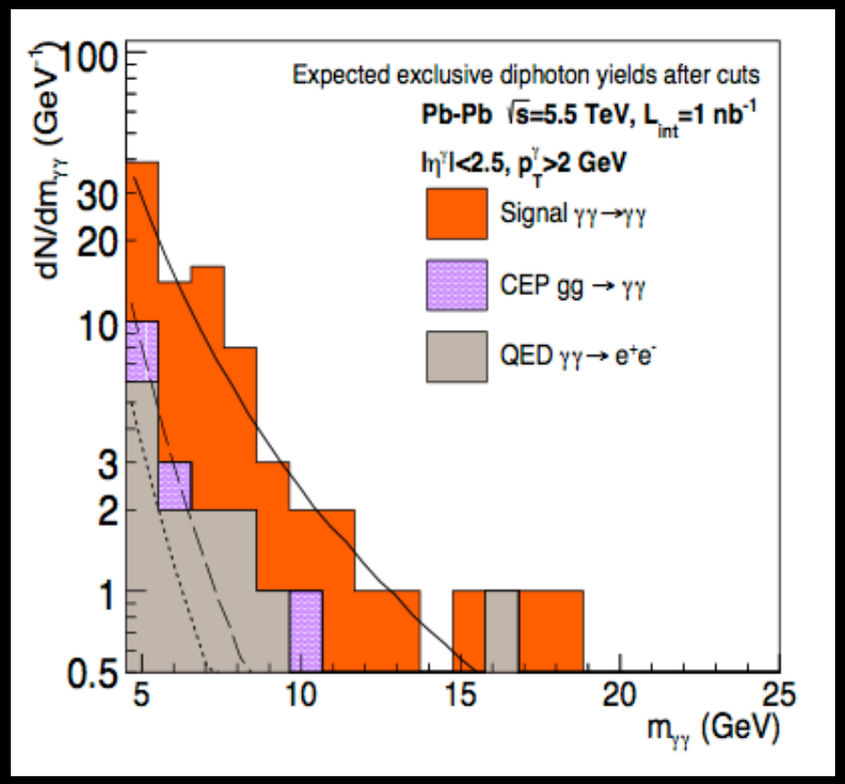


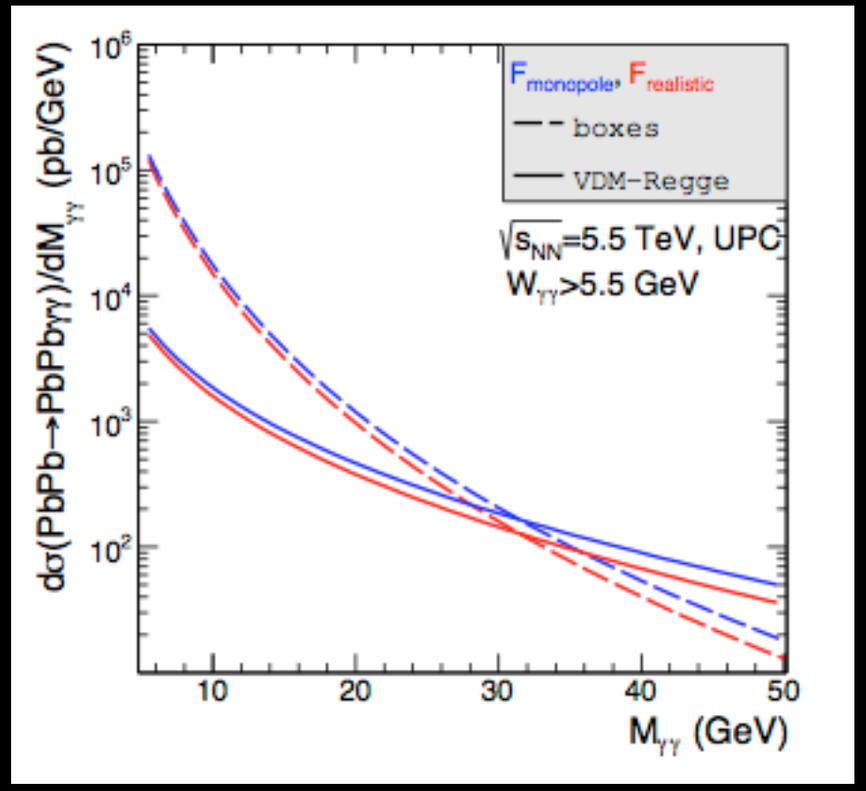
(Similar results from CMS and ATLAS)

SM Application (III)

Light-by-Light scattering







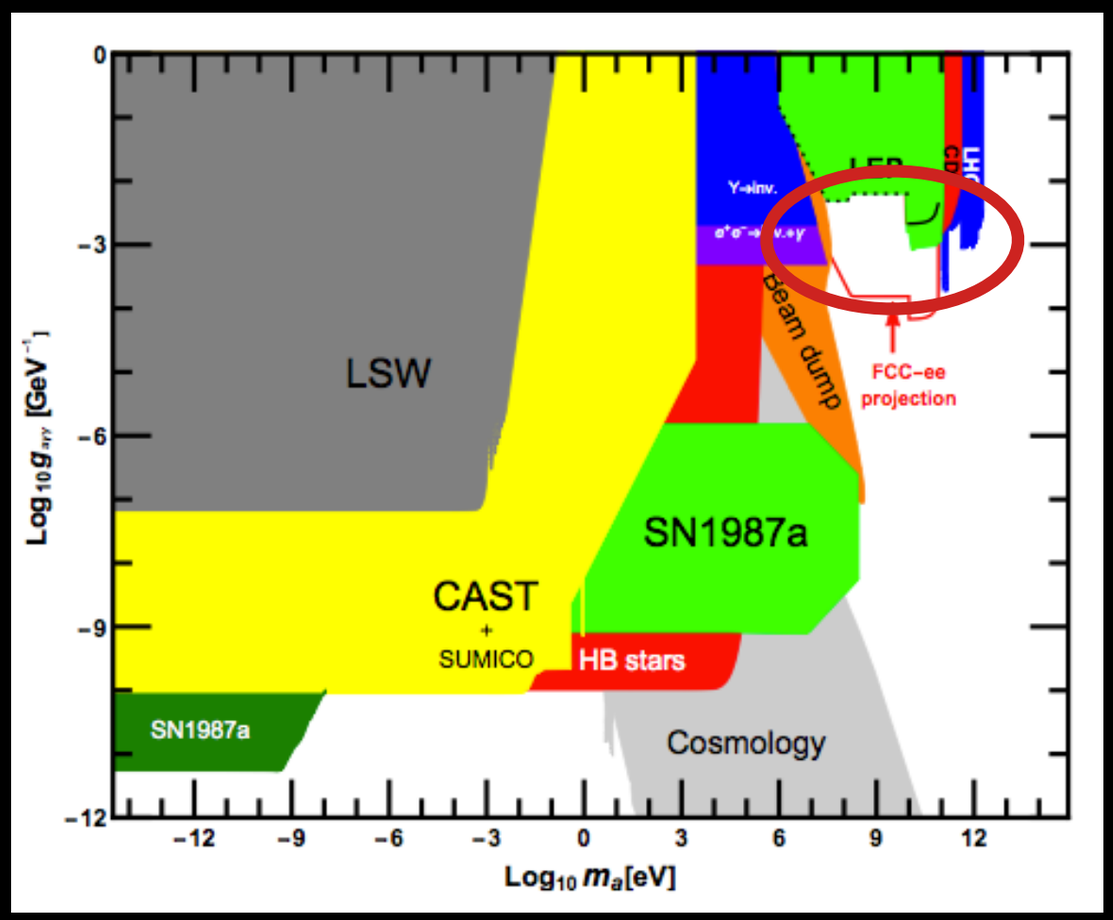
1305.7142: D. d'Enterria, G. Silveira

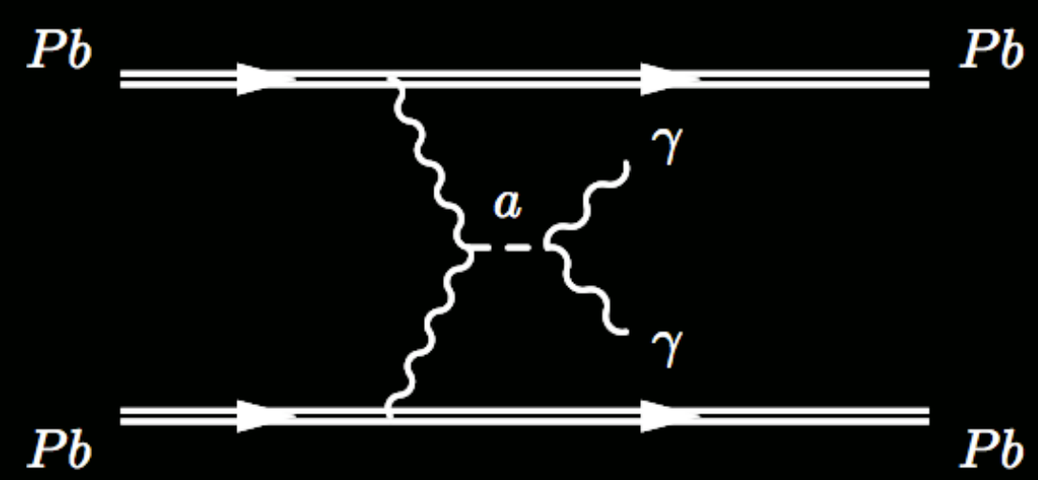
1601.07001: M. Kłusek-Gawenda, et. al.

ALP's in ultra-pheripheral collisions

SK, T. Lou, T. Lin, T. Melia: arXiv:1607.06083

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





1 GeV - 100 GeV range

J. Jaeckel, M. Spannowsky: 1601.07001

see also
A. B. Balantekin, et.al. Phys. Rev. Lett. 55, 461 (1985)
A. Natale, Mod. Phys. Lett. A, 09, 2075 (1994)

Triggers

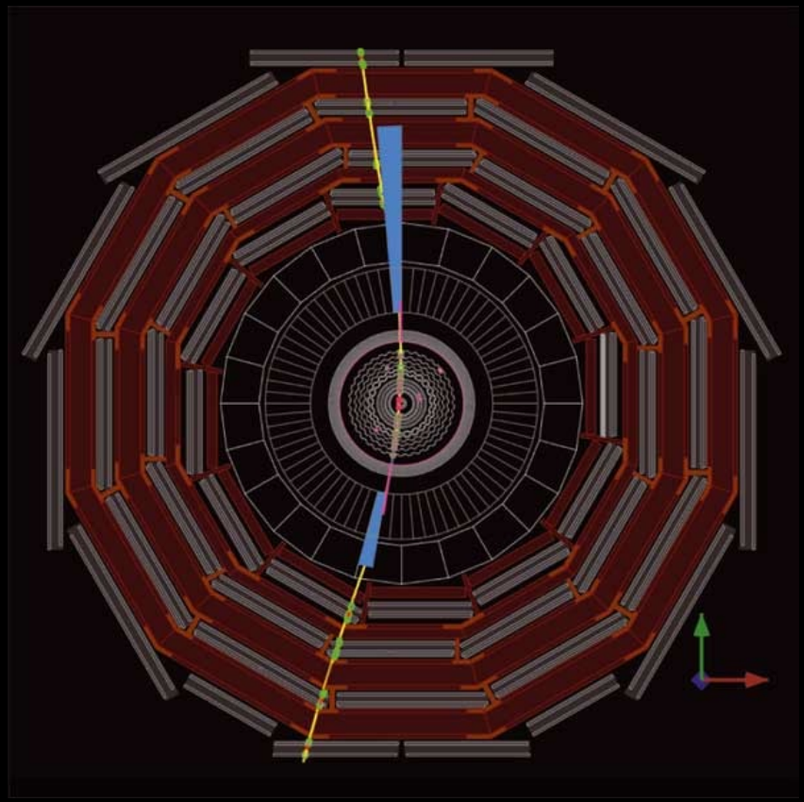
CMS has two dedicated UPC triggers

2 photons with $E\gamma > 2$ GeV

or

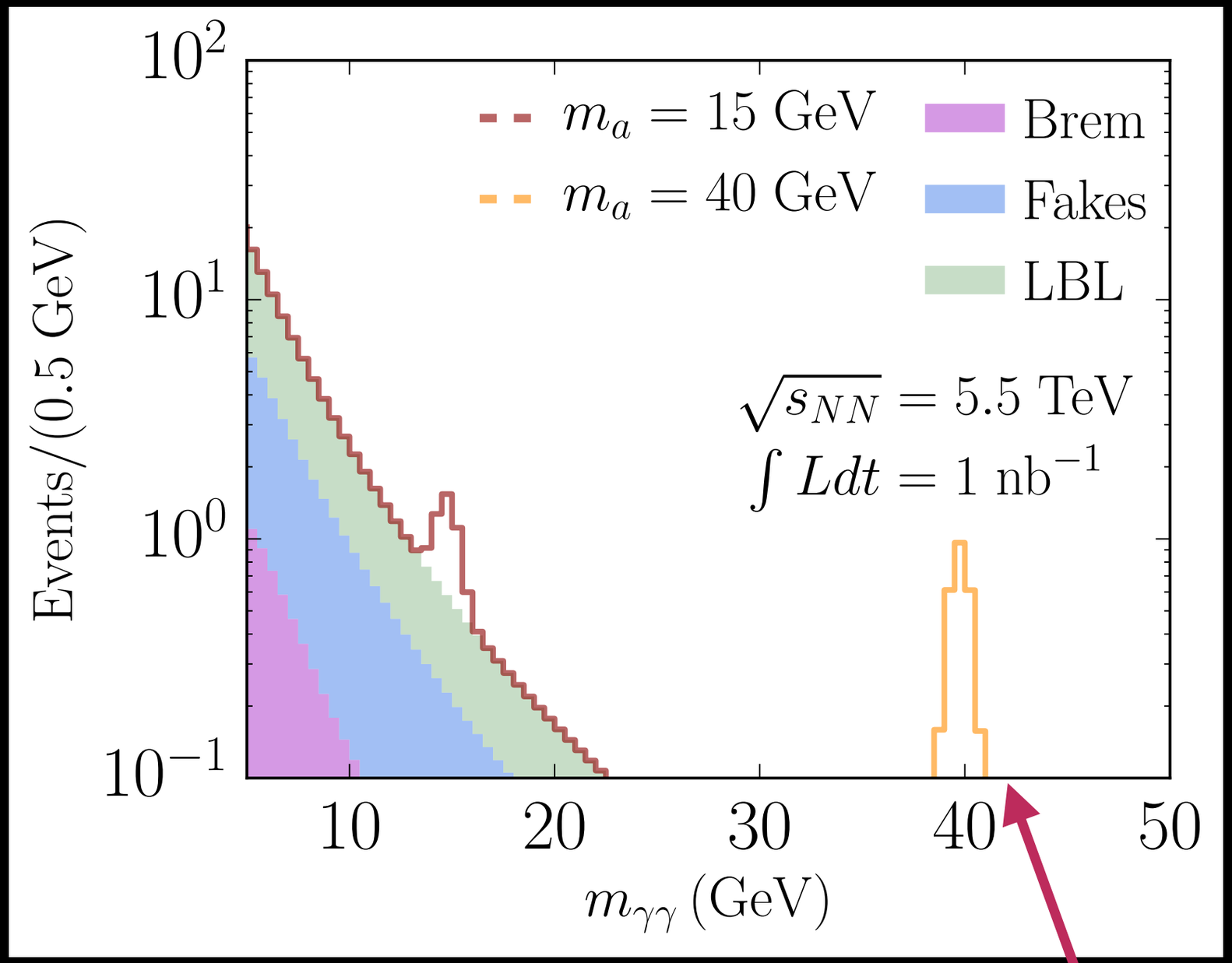
1 photon with $E\gamma > 5$ GeV

Veto activity in at least one of the forward calorimeters



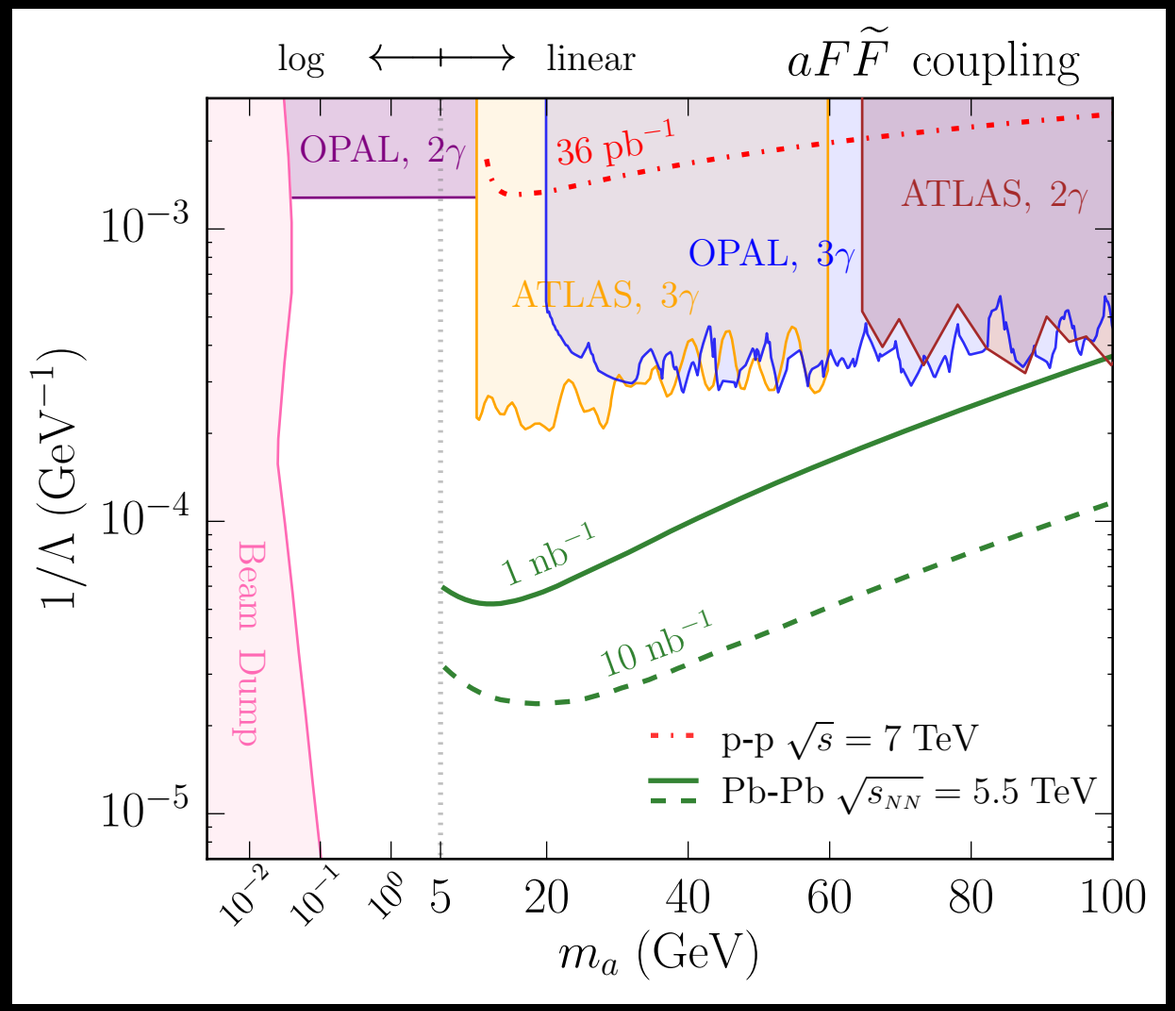
Events as clean as LEP but with LHC-grade detectors!

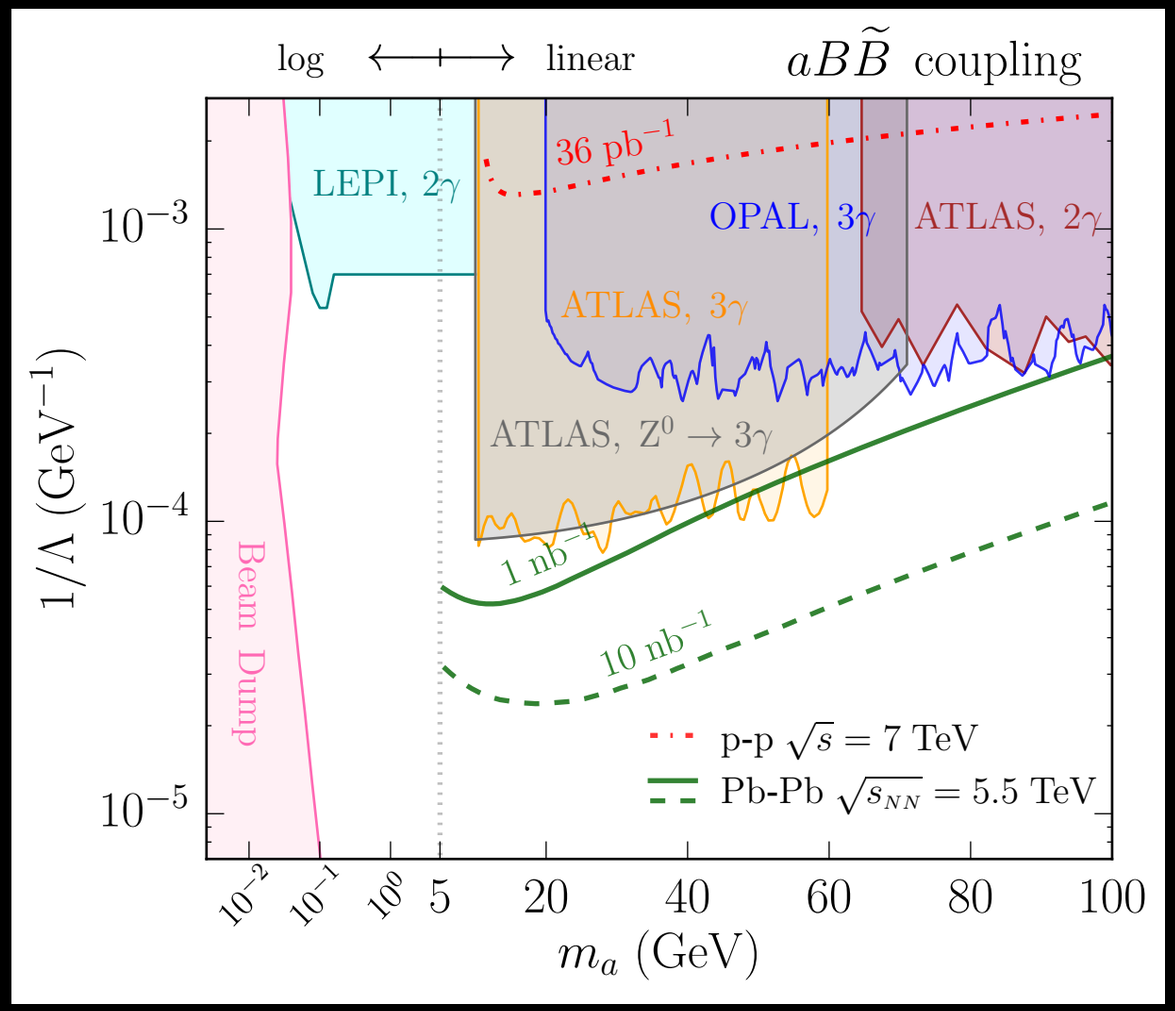
Results



Background free!

Results

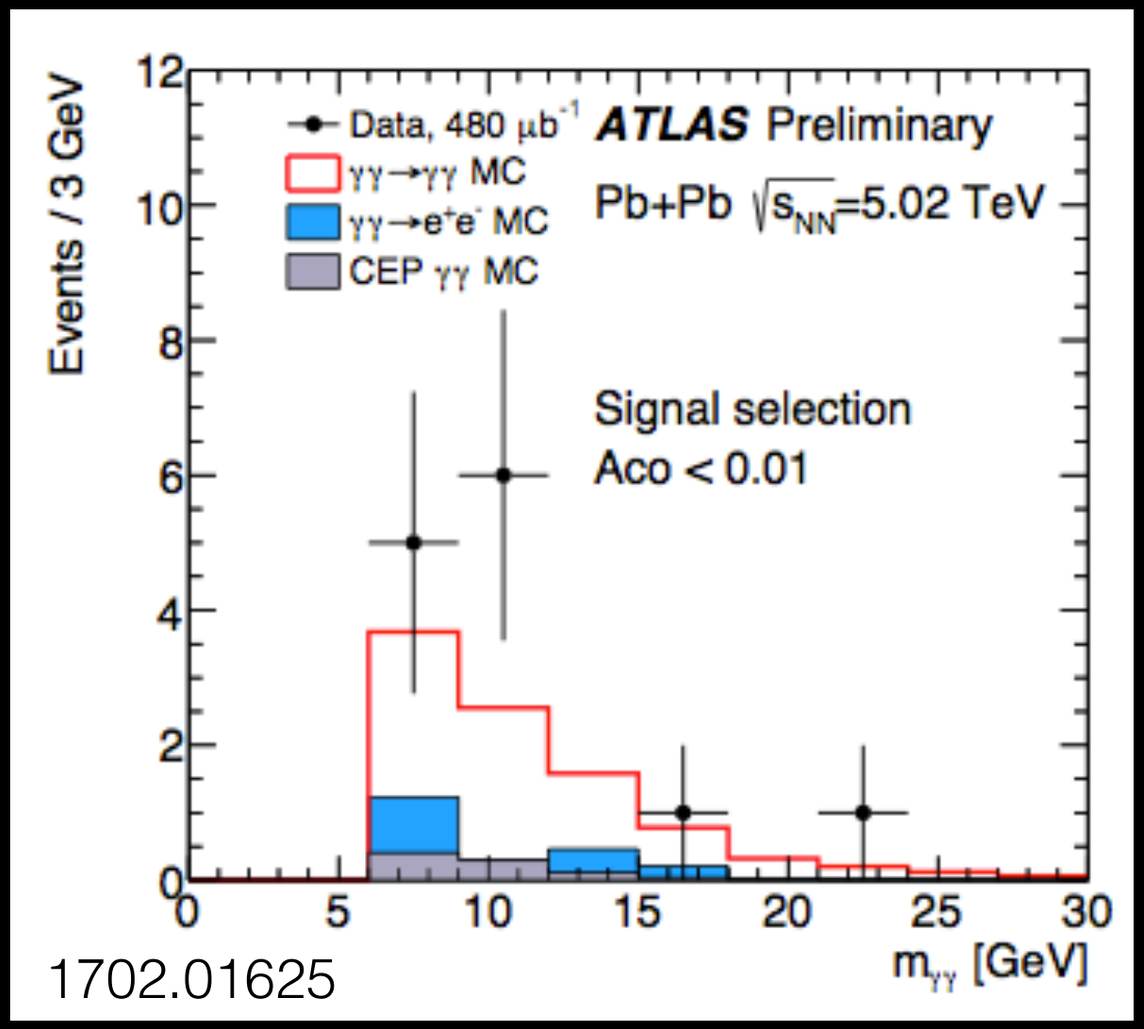


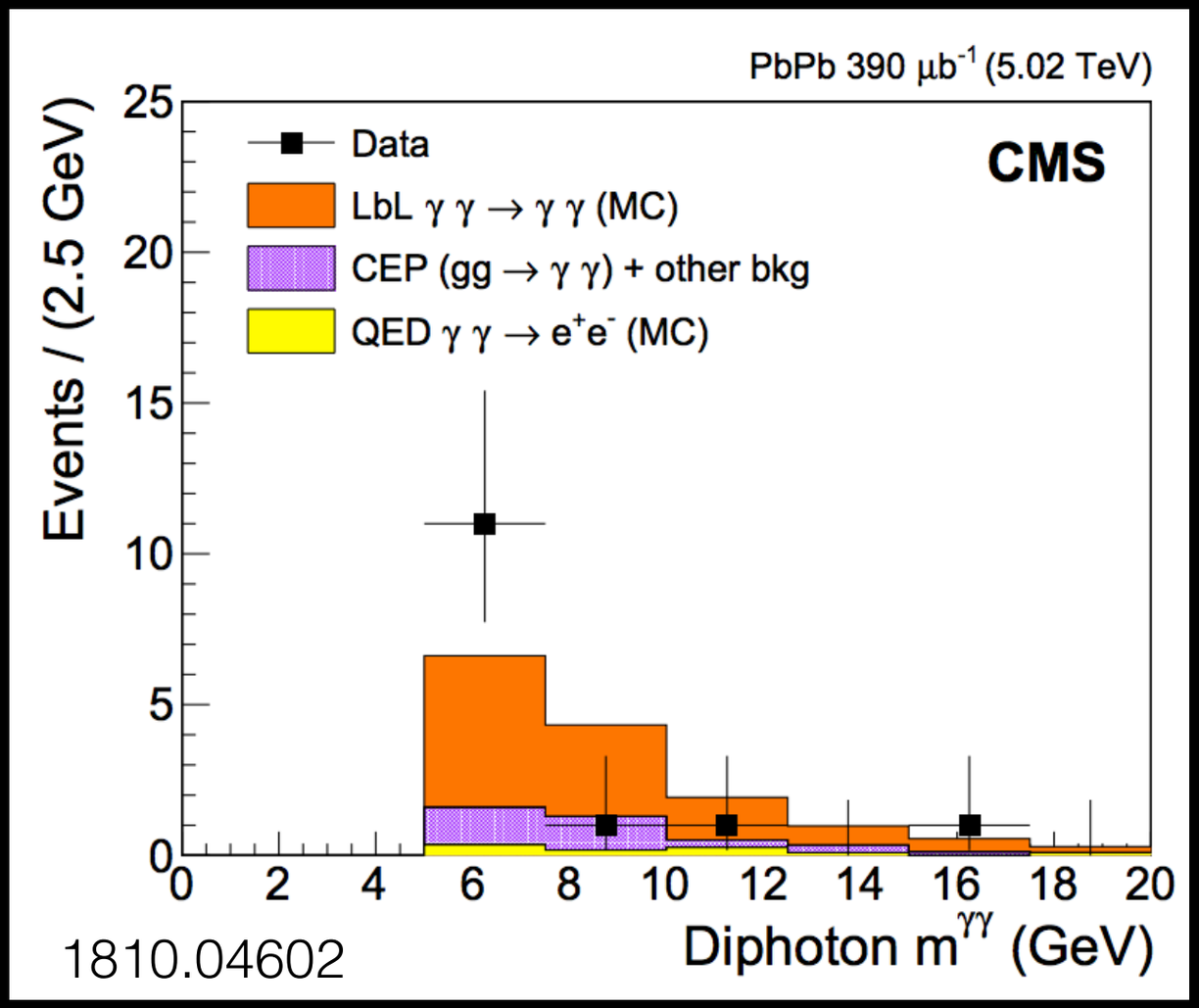


Most other limits are also new recastings

SK, T. Lou, T. Lin, T. Melia:1607.06083

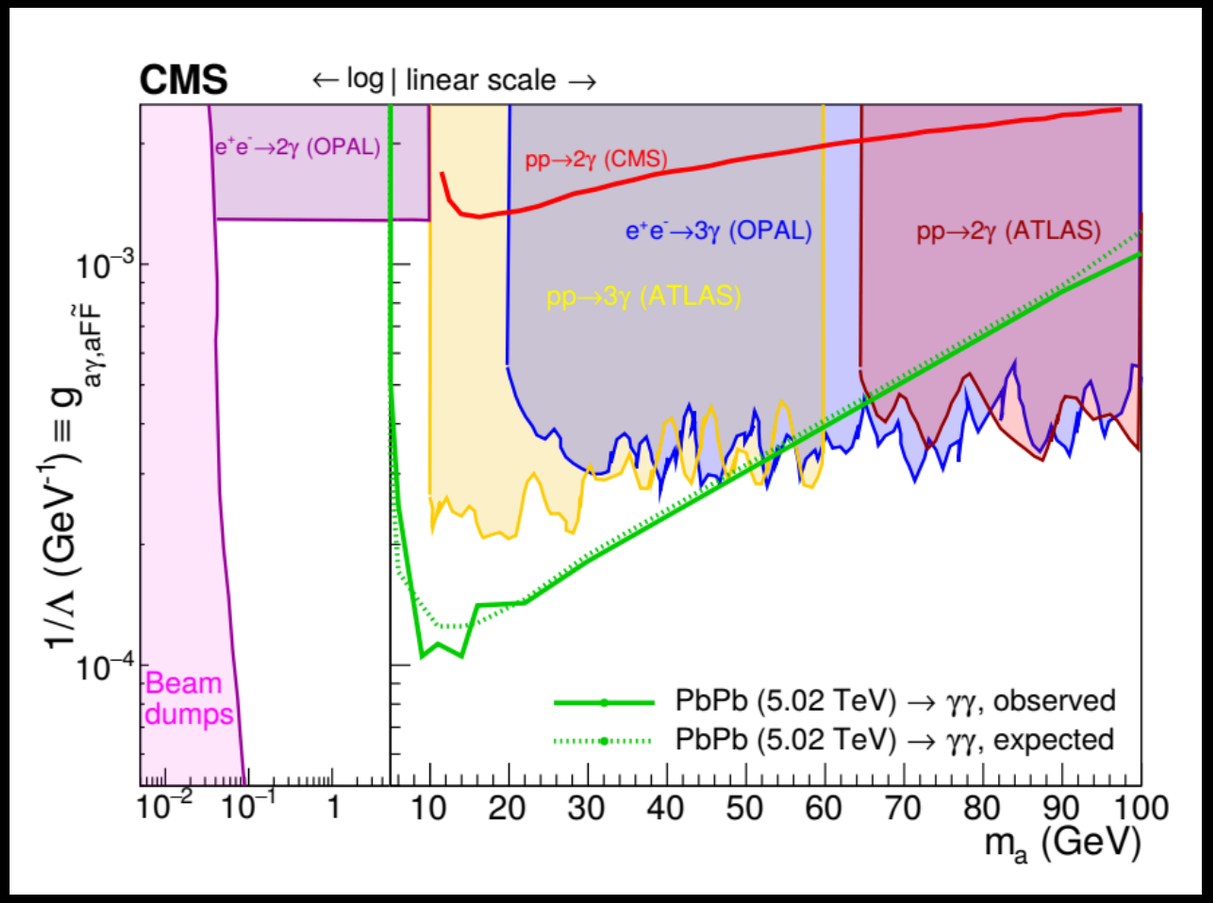
Data

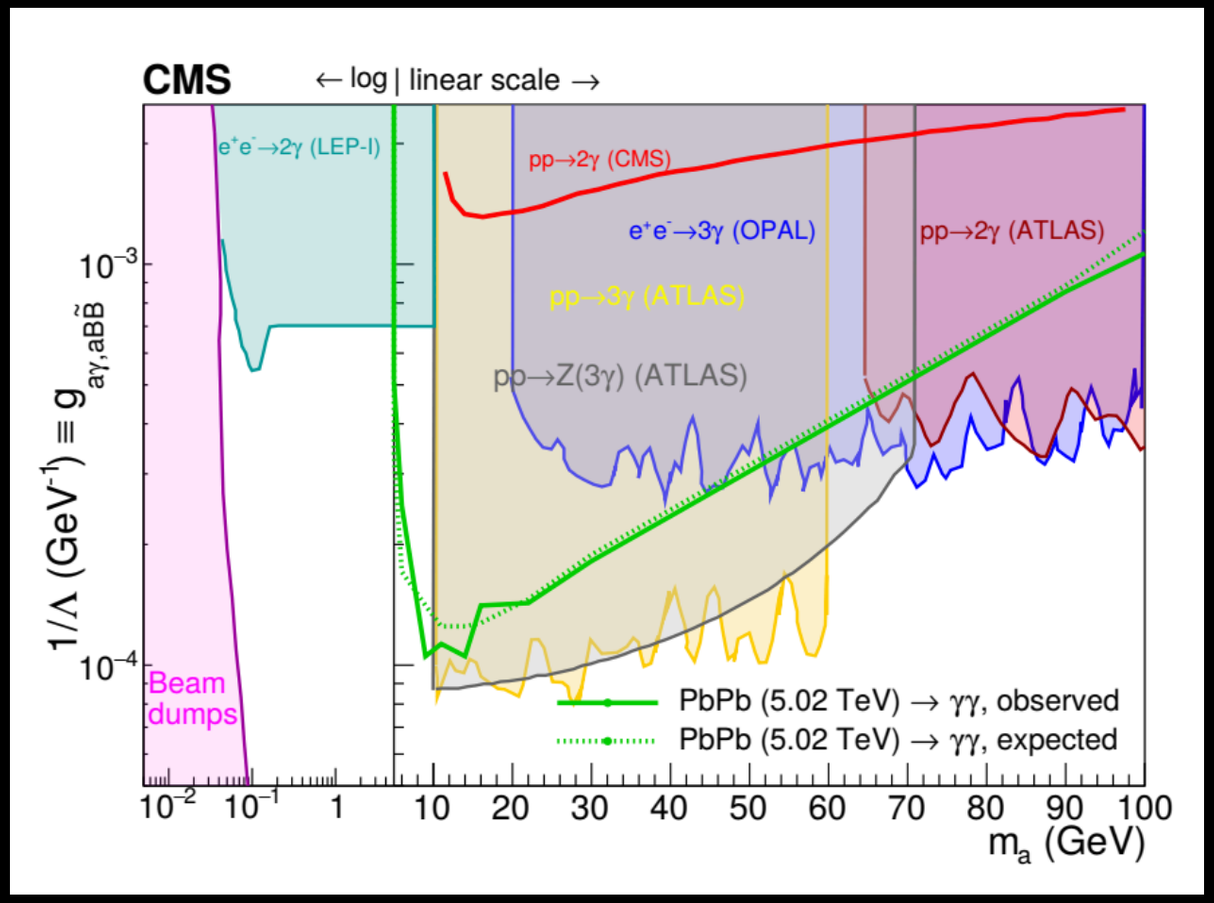




Standard Model is victorious once more! (~4σ)

Limits on ALP's





CMS: 1810.04602

Competitive limits if the a-Z-γ coupling is somewhat smaller

(difference with projections driven by slightly lower lump and lower reco efficiency)

Future directions? (I)

(Or “why I didn’t write more papers”)

Baur et. al. 0112211

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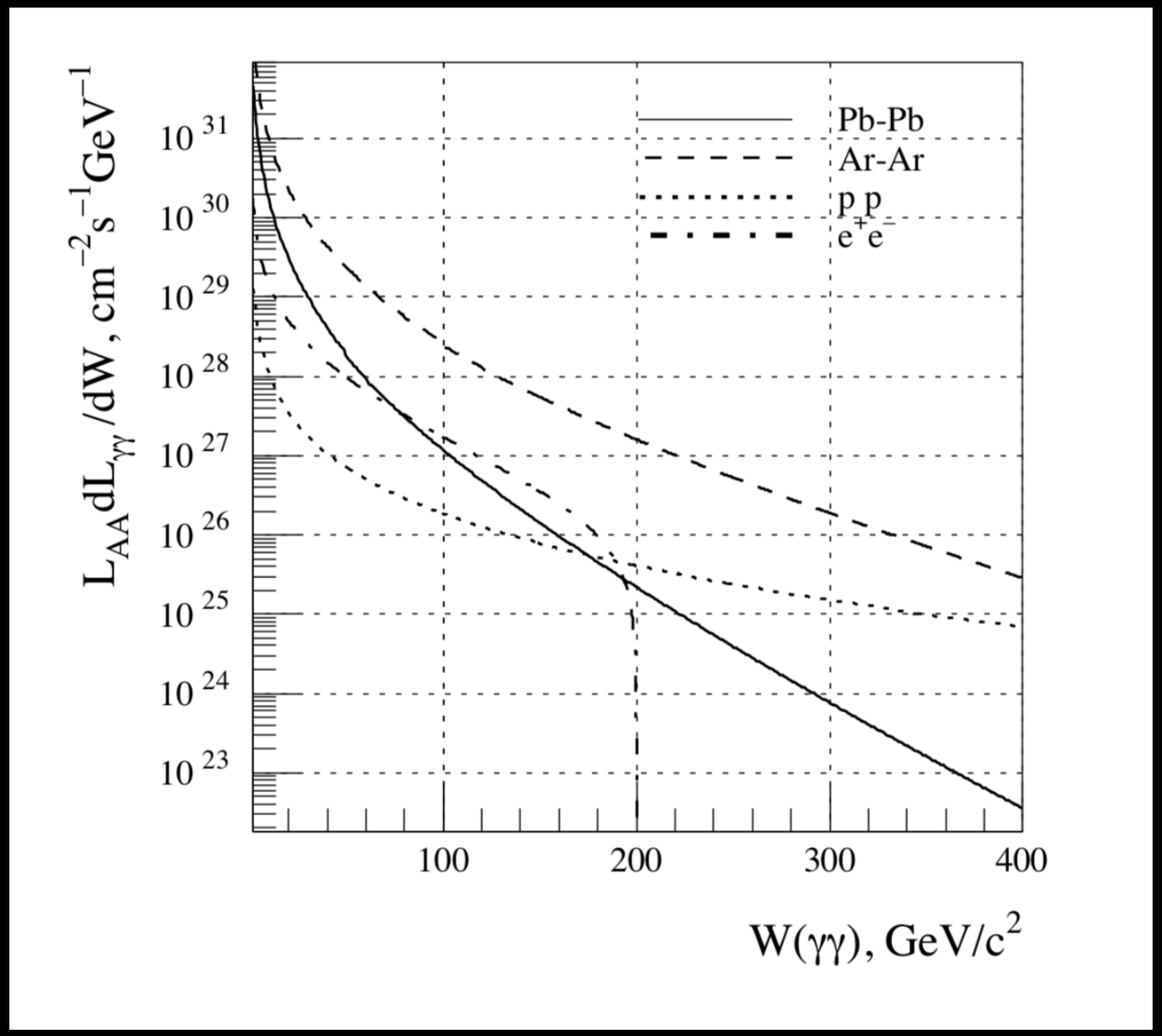
(Or “why I didn’t write more papers”)



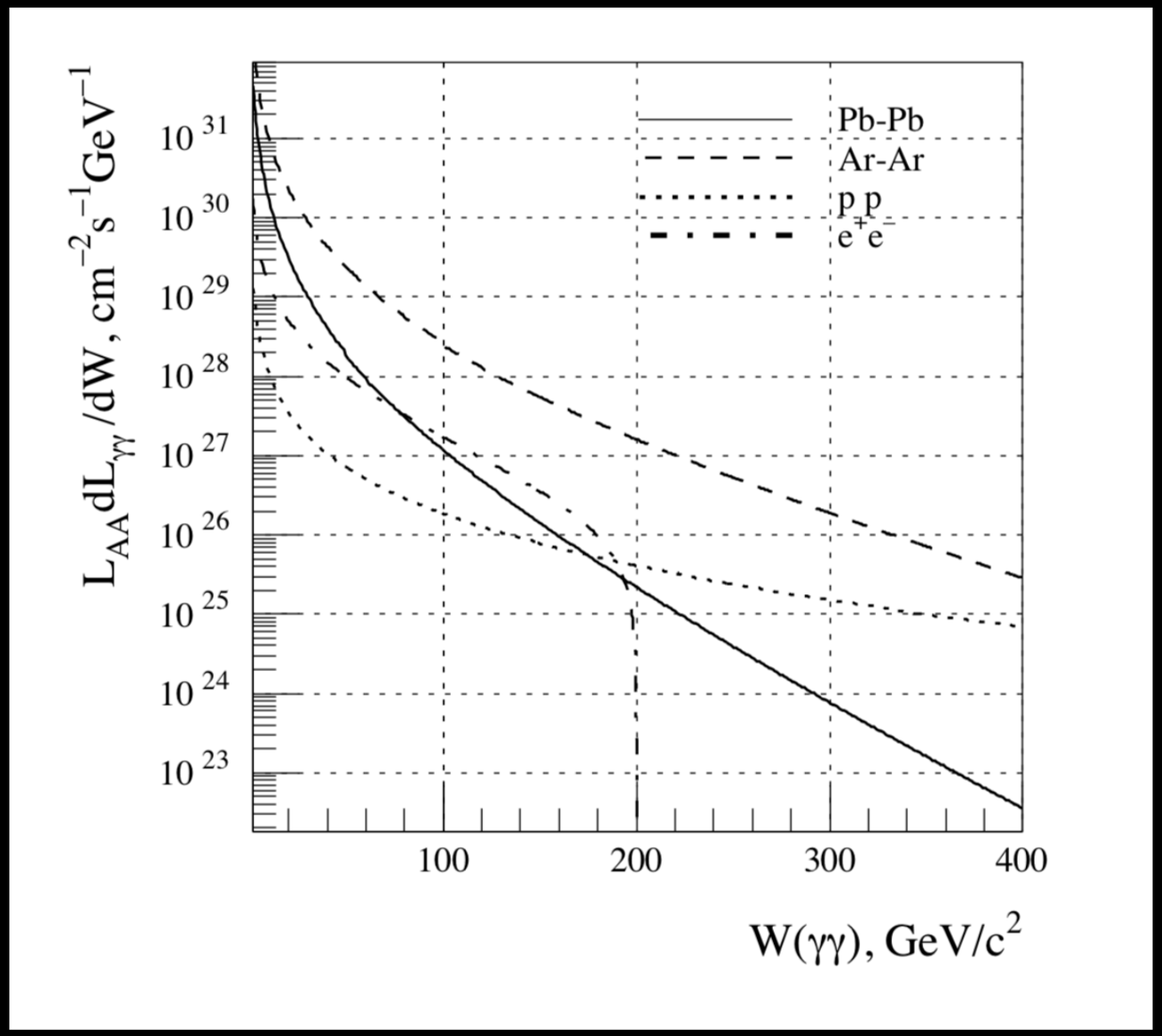
Baur et. al. 0112211

The pdf falls like a rock

You have to be light-ish AND only pay small parameter once

Future directions? (I)

(Or “why I didn’t write more papers”)



Baur et. al. 0112211

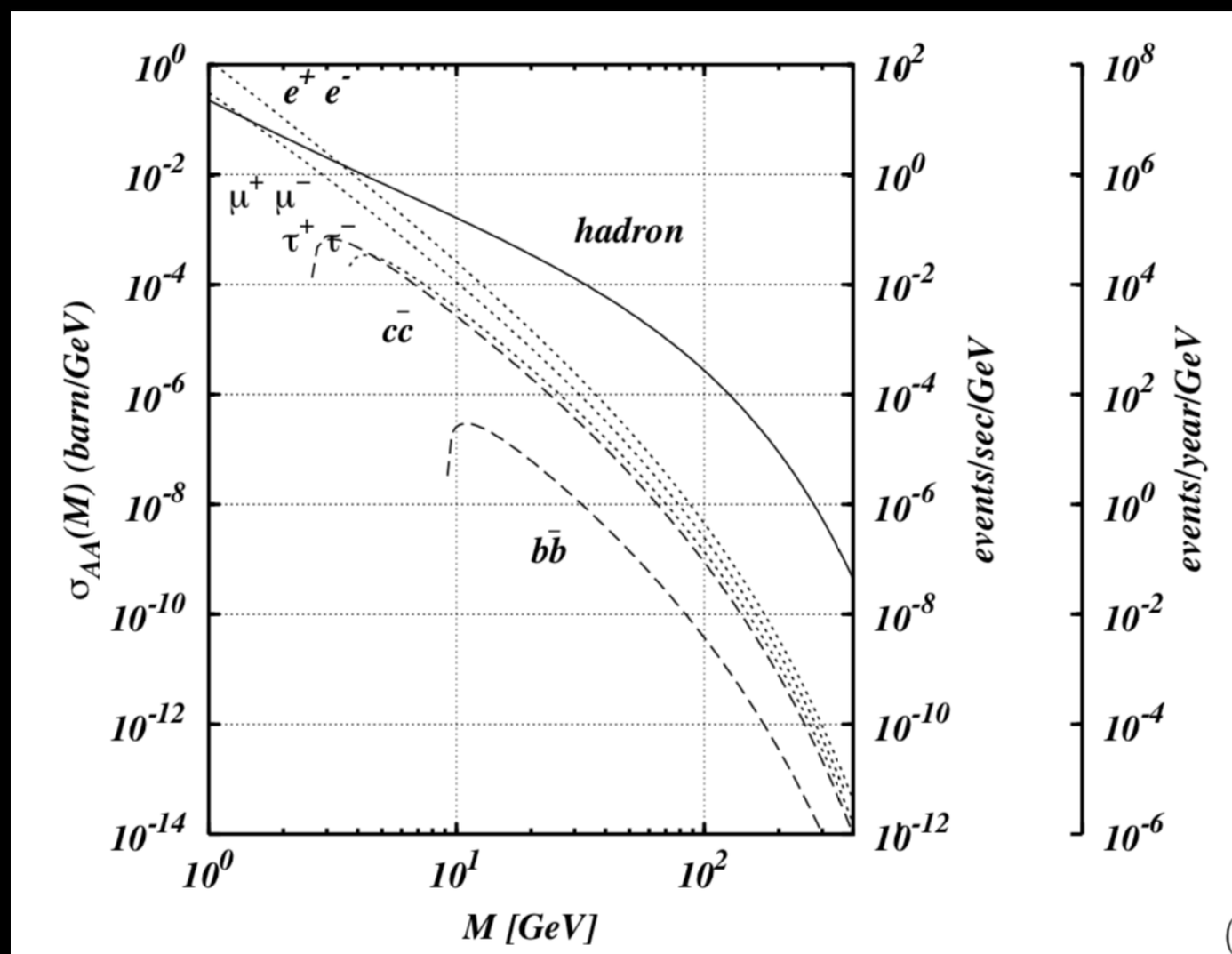
The pdf falls like a rock

You have to be light-ish AND only pay small parameter once

Checked: chargino’s, dark photons, milicharged particles, …

Future directions? (II)

(Or “why I didn’t write more papers”)



Many backgrounds are also Z^4 enhanced

Diphoton final state is the exception, not the rule

Baur et. al. 0112211

Thanks!