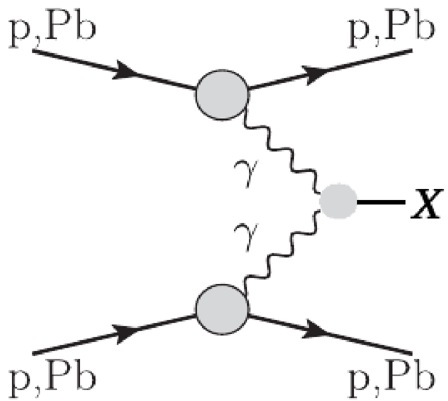
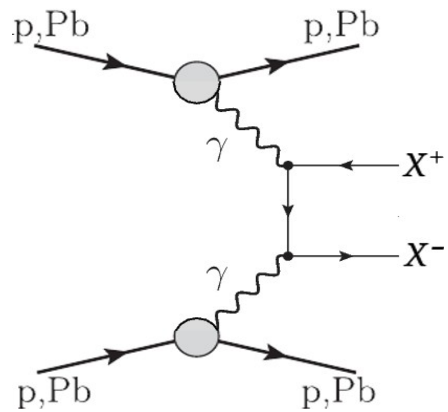
BSM physics via γγ collisions with ions at the LHC





Heavy-ions & Hidden Sectors

UC Louvain, 4th December 2018

David d'Enterria (CERN)

BSM searches with protons/ions at the LHC

- Physics beyond the Standard Model (BSM) needed to explain many open empirical and/or theoretical problems in HEP:
  - Empirical: Dark-matter, matter-antimatter asymmetry, ν's masses
  - Theoretical: Higgs mass fine-tuning, θ_{QCD}, origin of fermion families/ mixings, charge quantization, cosmological constant, quantum gravity,...

- Most of the solutions to all these problems require new particles and/or new interactions (SUSY, WIMP, ν_R, axions, monopoles,..). LHC reach:
  - BSM at high masses: Increase the sqrt(s) as much as possible.
  - BSM at low couplings: Increase the luminosity as much as possible.
    Hiding well? Reduce pileup, kin. thresholds. Look at exclusive final-states.

- Heavy-ions collisions have 2 important drawbacks:

– Low sqrt(s): PbPb runs at 5.5 TeV compared to 14-TeV pp [$\times$2.5 less]
– Low lumis: $L_{PbPb} = A^2 \cdot 6 \cdot 10^{27}$ cm^{-1}s^{-2} = $2.5 \cdot 10^{32}$ cm^{-2}s^{-1} << $L_{pp} = 2 \cdot 10^{34}$ cm^{-2}s^{-1} [$\times$100 less]
[integrated: $\times 10^3$ less]

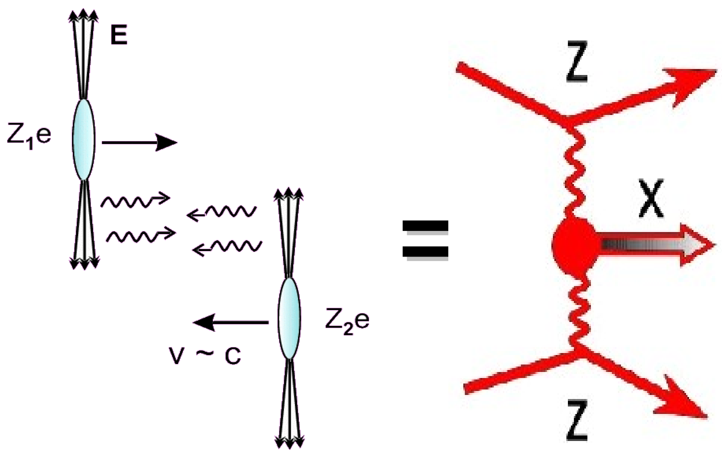
- Heavy-ions collisions have 2 advantages:

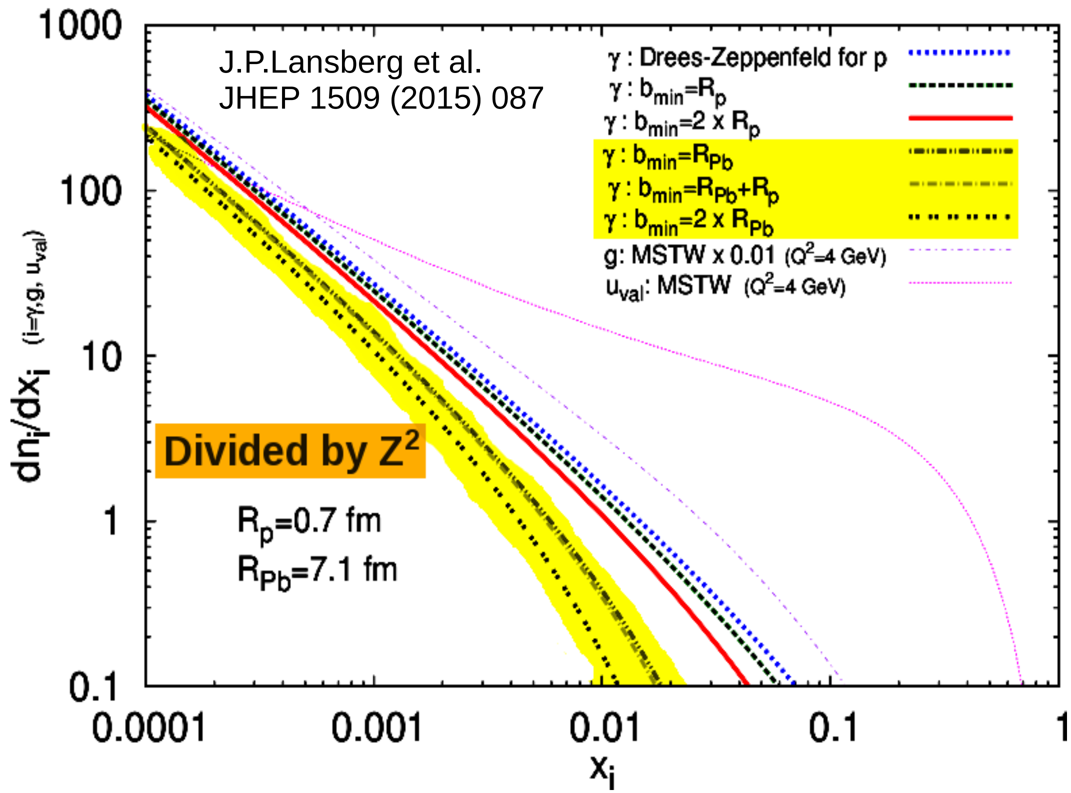
– No pileup: Excellent vertexing, Lower kin. trigger thresholds [$\times$2? lower p_T values]
– Large γ lumis: $L_{pbPb}(\gamma\gamma)/L_{pp}(\gamma\gamma) = Z^4 \times L_{pbPb}/L_{pp} = 4.5 \cdot 10^7 \times (6 \cdot 10^{27}/2 \cdot 10^{34}) \sim 12$ [$\times$10 more]

Photon-photon collisions at the LHC

- Electromagnetic ultra-peripheral collisions (UPC): $b_{min} > R_A + R_B$
- HE ions create huge EM fields (10^{14} T) from coherent action of Z protons:

Weizsäcker-Williams (EPA) power-law photon flux:

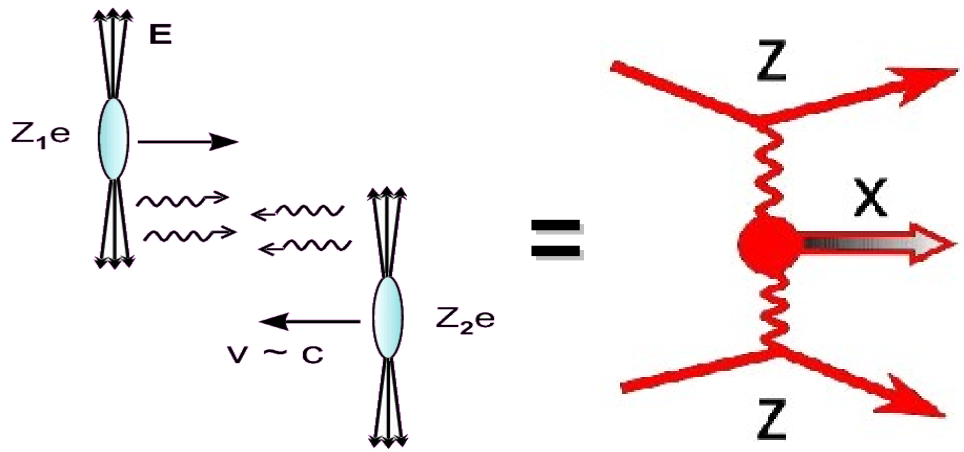




- Quasi-real photons (coherence): Q ~ 1/R ~ 0.06 GeV (Pb), 0.28 GeV (p)
- Maximum γ energies (LHC): $\omega < \omega_{max} \approx \frac{\gamma}{R}$ ~ 80 GeV (Pb), ~ 2.5 TeV (p)

Photon-photon collisions at the LHC

- Electromagnetic ultra-peripheral collisions (UPC): $b_{min} > R_A + R_B$
- HE ions generate huge EM fields (10^{14} T) from coherent action of Z=82 p:



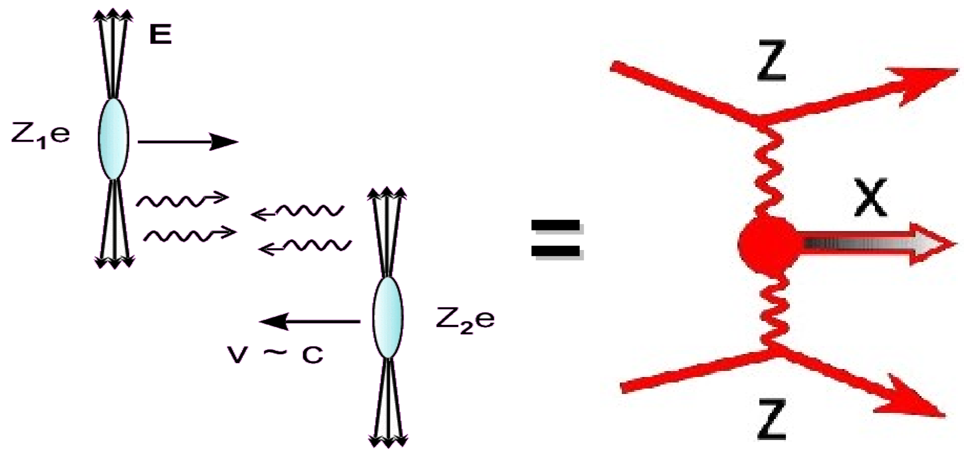
- Huge photon fluxes:
  $\sigma(\gamma\text{-}\gamma) \sim Z^4$ (~$5{\cdot}10^7$ for PbPb) larger than p,$e^{\pm}$
- Beam-energy dependence:
  Photon luminosities increase as $\propto \log^3(\sqrt{s})$

- Quasi-real photons (coherence): Q ~ 1/R ~ 0.06 GeV (Pb), 0.28 GeV (p)
- Maximum γ energies (LHC): $\omega < \omega_{max} \approx \frac{\gamma}{R}$ ~ 80 GeV (Pb), ~ 2.5 TeV (p)

System	$\sqrt{s_{NN}}$ (TeV)	γ	R_A (fm)	ω_{max} (GeV)	$\sqrt{s_{\gamma\gamma}^{max}}$ (GeV)
p-p	14	7455	0.7	2450	4500
p-Pb	8.8	4690	7.1	130	260
Pb-Pb	5.5	2930	7.1	80	160

Photon-photon collisions at the FCC

- Electromagnetic ultra-peripheral collisions (UPC): $b_{min} > R_A + R_B$
- HE ions generate huge EM fields (10^{14} T) from coherent action of Z=82 p:



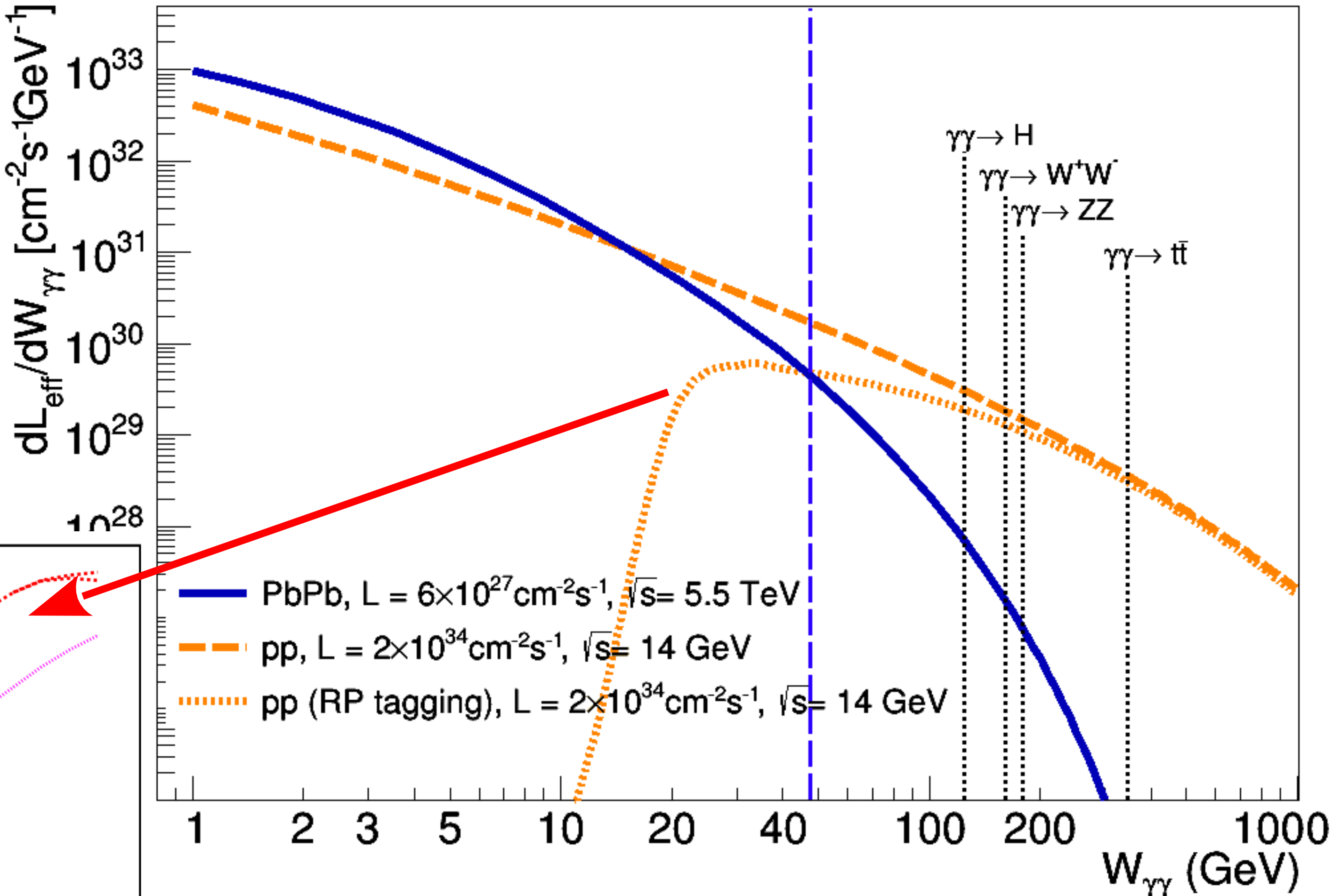
- Huge photon fluxes:
  $\sigma(\gamma\text{-}\gamma) \sim Z^4$ (~$5\cdot10^7$ for PbPb) larger than p,$e^\pm$
- Beam-energy dependence:
  Photon luminosities increase as $\propto \log^3(\sqrt{s})$

- Quasi-real photons (coherence): Q ~ 1/R ~ 0.06 GeV (Pb), 0.28 GeV (p)
- Maximum γ energies (FCC): $\omega < \omega_{max} \approx \frac{\gamma}{R}$ ~ 0.6 TeV (Pb), ~ 18 TeV (p)

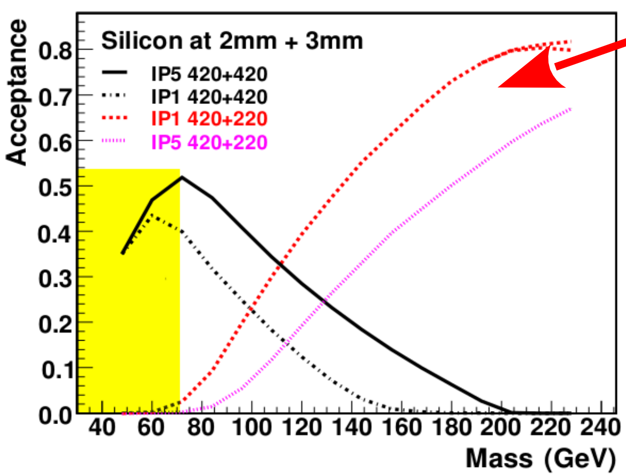
System	$\sqrt{s_{NN}}$ (TeV)	$\mathcal{L}_{AB}\cdot\Delta t$ (per year)	γ ($\times10^3$)	ω_{max} (TeV)	$\sqrt{s_{\gamma\gamma}^{max}}$ (TeV)
p-p	100	1 fb^{-1}	53.	17.6	35.2
p-Pb	64	1 pb^{-1}	33.5	0.95	1.9
Pb-Pb	39	5 nb^{-1}	21.	0.60	1.2

Effective γγ luminosities at the LHC

- Thanks to $Z^4 = 5\cdot10^7$ factor, PbPb γγ luminosities are well above the pp ones up to $W_{\gamma\gamma}$ ~45 (100) GeV assuming fwd. proton-taggers at 420m (220m) required to remove huge pp pileup(!).

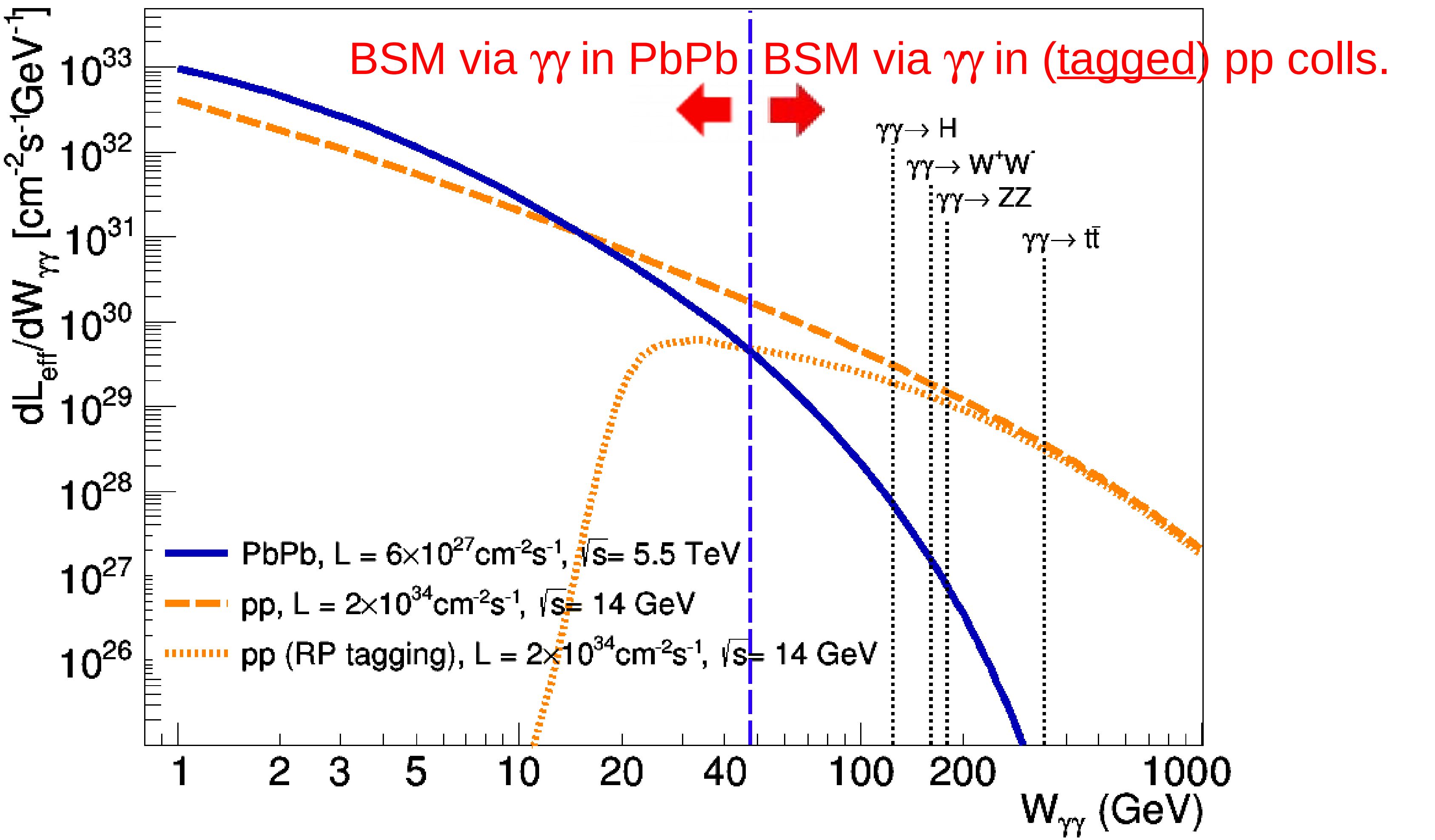


- Fwd-p acceptance vs. central mass:



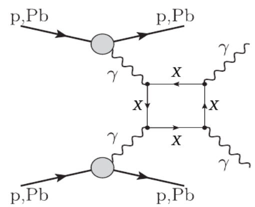
Effective γγ luminosities at the LHC

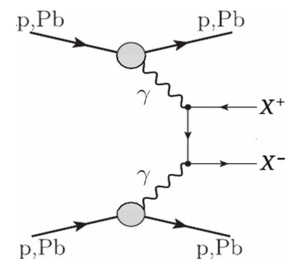
- Competitive mass range for BSM searches in UPCs PbPb collisions: $W_{\gamma\gamma}$ ~ 0.5–45 GeV ($W_{\gamma\gamma}^{min}$~0.5 GeV for ALICE/LHCb, 4 GeV for ATLAS/CMS)

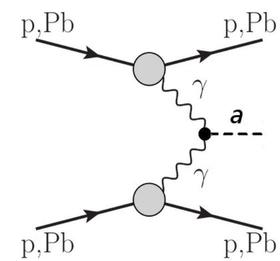


Which BSM physics via γγ→X collisions?

- New physics signals via photon-photon fusion:
  - New charged particle: $\gamma\gamma \to (X^{\pm}\text{ loop}) \to$ SM SM
  - New charged pairs: $\gamma\gamma \to X^{+}X^{-}$
  - New scalar particles: $\gamma\gamma \to a$
  - New tensor particles: $\gamma\gamma \to G$





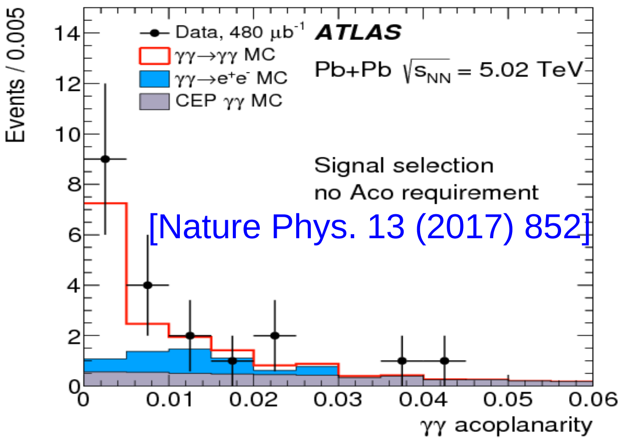


- Examples (photon-collider "golden channels"):

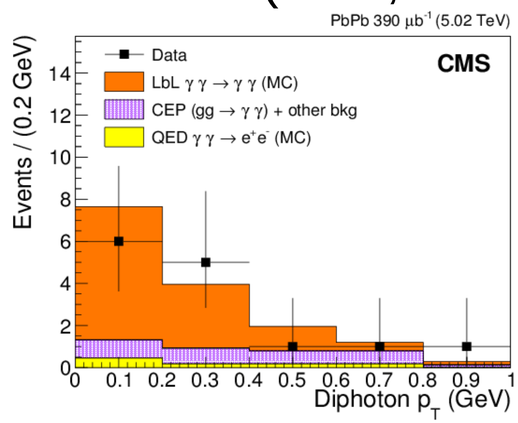
		PbPb	pp (tagged)
$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^{+}\tilde{\chi}_i^{-}$	pairs of sfermions, charginos	NO	m_X>45 GeV
$\gamma\gamma \to \tilde{g}\tilde{g}$	pairs of gluinos	NO	m_X>45 GeV
$\gamma\gamma \to M^{+}M^{-}$	pairs of monopoles	m_X<45 GeV	>45 GeV
$\gamma\gamma \to H^{+}H^{-}$	pairs of charged-Higgs	NO	YES?
$\gamma\gamma \to W^{+}W^{-}$	anom. W inter., extra dimensions	NO	YES
$\gamma\gamma \to 4W/(Z)$	WW scatt., quartic anom. W,Z	NO	NO (σ<ab)
$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions	NO	NO (σ<ab)
$\gamma\gamma \to \gamma\gamma$	Born-Infeld QED, non-conmutat. theories)	<45 GeV	>45 GeV
$\gamma\gamma \to \phi$	Scalars (axions, radions, ...)	<45 GeV	>45 GeV
$\gamma\gamma \to G$	Tensors (gravitons,...)	<45 GeV	>45 GeV
$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	-onia (monopolium, $\tilde{t}\bar{\tilde{t}}$ stoponium)	<45 GeV	>45 GeV
$\gamma\gamma \to H, A \to b\bar{b}$	MSSM heavy Higgs, interm. tan β	NO	>45 GeV

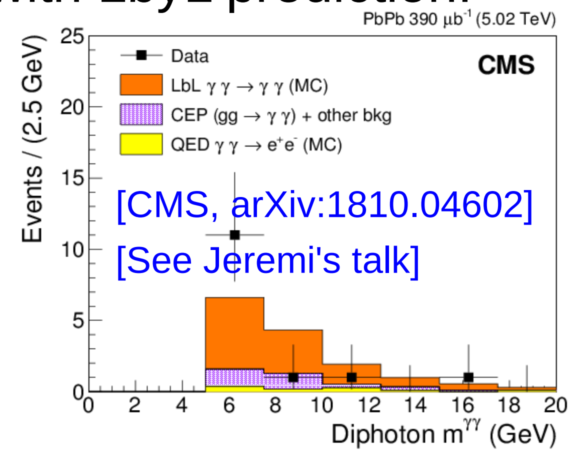
First BSM searches & limits from $\gamma\gamma \rightarrow \gamma\gamma$

- ATLAS, CMS measured 13, 14 exclusive di-γ counts (2.6, 3.8 backgds) consistent (4.3σ, 4.1σ) with LbyL prediction:



[Nature Phys. 13 (2017) 852]



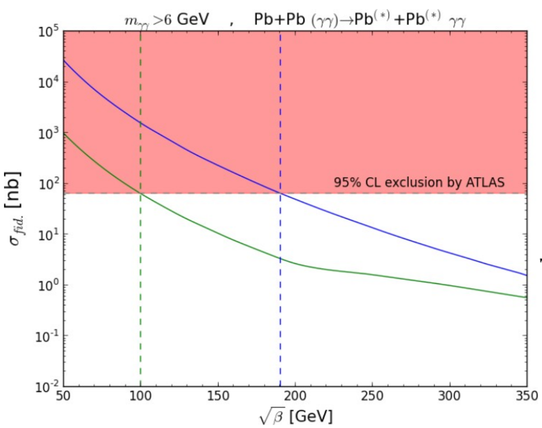


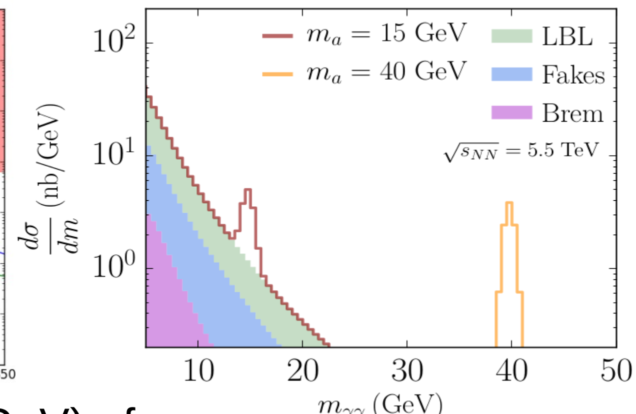
[CMS, arXiv:1810.04602]

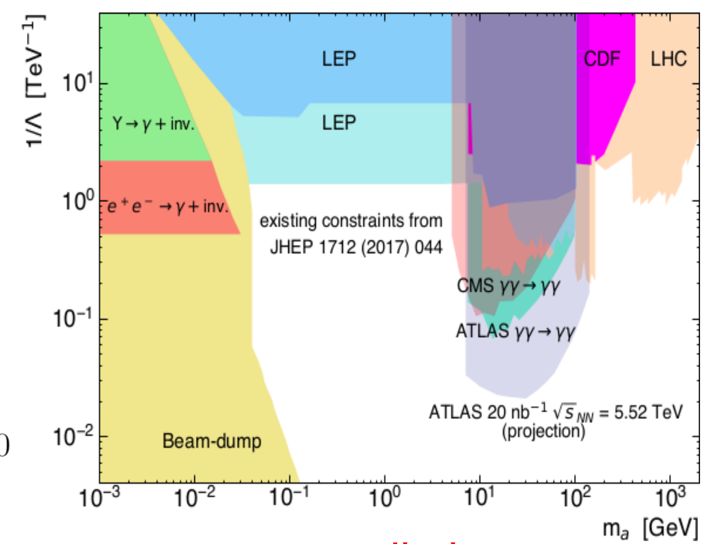
[See Jeremi's talk]

- BSM searches limits:

[See Simon's talk]







Limits on scale (>100 GeV) of Born-Infeld non-linear QED extensions

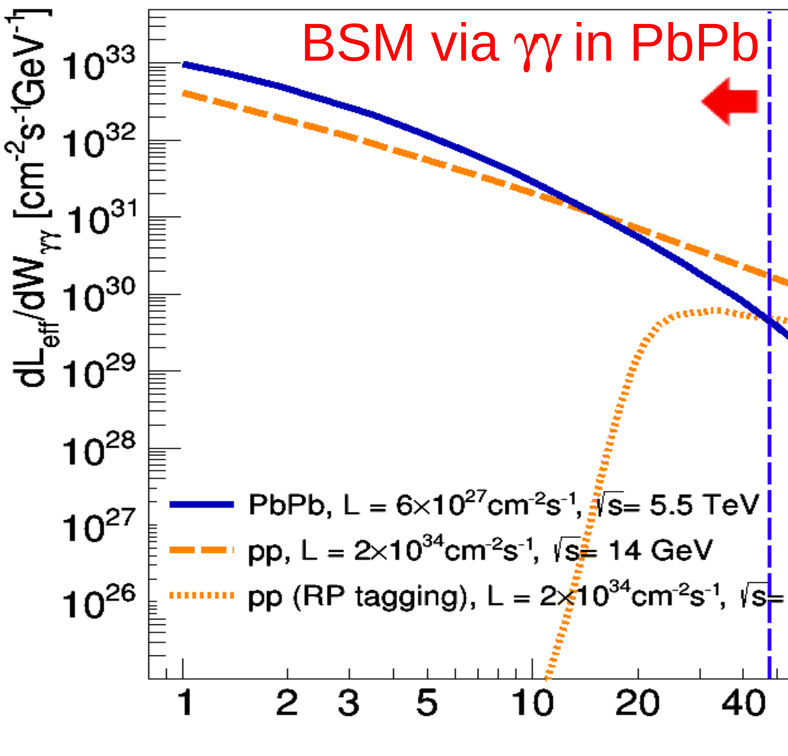
[J. Ellis et al., PRL118 (2017) 261802]

Competitive ALPs: $\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$ limits

[S. Knapen et al., PRL118 (2017) 171801]

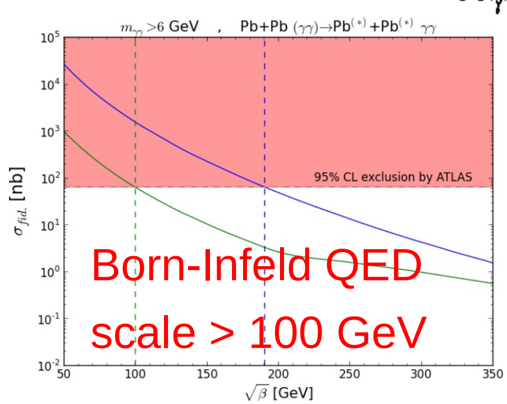
Summary: BSM searches via UPC PbPb@LHC

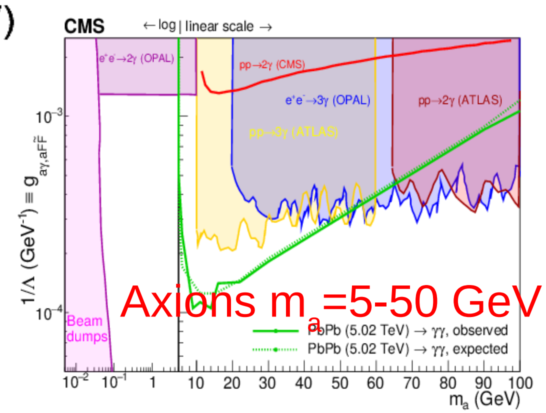
- Competitive mass range for BSM in UPCs PbPb: $m_{\gamma\gamma\to X}$=0.5–45 GeV



$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-$	pairs of sfermions, charginos	NO
$\gamma\gamma \to \tilde{g}\tilde{g}$	pairs of gluinos	NO
$\gamma\gamma \to M^+M^-$	pairs of monopoles	YES
$\gamma\gamma \to H^+H^-$	pairs of charged-Higgs	NO
$\gamma\gamma \to W^+W^-$	anom. W inter., extra dimensions	NO
$\gamma\gamma \to 4W/(Z)$	WW scatt., quartic anom. W,Z	NO
$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions	NO
$\gamma\gamma \to \gamma\gamma$	Born-Infeld QED, non-conmutat. theories)	YES
$\gamma\gamma \to \phi$	Scalars (axions, radions, ...)	YES
$\gamma\gamma \to G$	Tensors (gravitons,...)	YES
$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	-onia (monopolium, $\tilde{t}\bar{\tilde{t}}$ stoponium)	YES
$\gamma\gamma \to H, A \to bb$	MSSM heavy Higgs, interm. $\tan\beta$	NO

- First BSM limits set:





Back-up slides