

**$\gamma$ -Pb &  $\gamma$ - $\gamma$  collisions,  
cosmic-rays connections  
at FCC-ions**

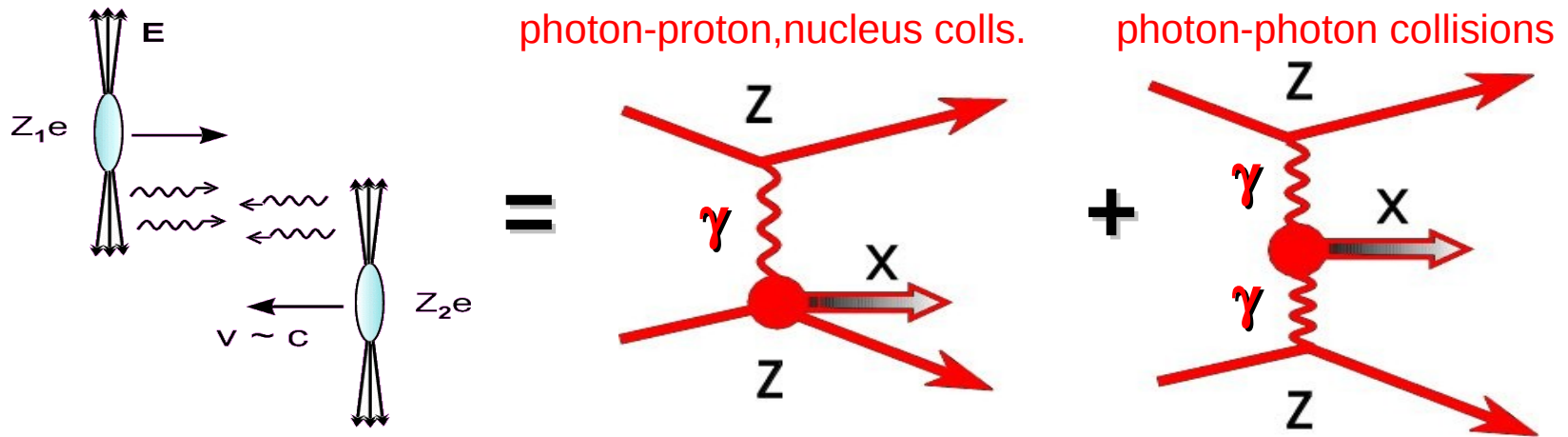
**Ions at the FCC Meeting  
CERN, Nov. 2015**

**David d'Enterria**

**CERN**

# Photon-induced collisions at FCC-ions

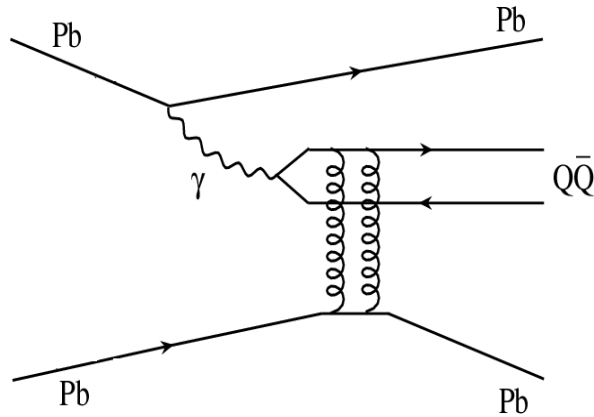
- **Electromagnetic** ultra-peripheral collisions (UPC):  $b_{\min} > R_A + R_B$
- HE ions generate **strong EM fields** from coherent emission of  $Z=82$  p's:



- **Huge photon fluxes:**
  - $\sigma(\gamma\text{-Pb}, p) \sim Z^2$  ( $\sim 10^4$  for Pb) larger than  $p, e^\pm$
  - $\sigma(\gamma\text{-}\gamma) \sim Z^4$  ( $\sim 5 \cdot 10^7$  for PbPb) larger than  $p, e^\pm$
- **Beam-energy dependence:**
  - Photon luminosities increase as  $\propto \log^3(\sqrt{s})$
- **Quasi-real photons (coherence):**  $Q \sim 1/R \sim 0.06 \text{ GeV}$  (Pb),  $0.28 \text{ GeV}$  (p)
- **Max. FHC  $\gamma$  energies:**  $\omega < \omega_{\max} \approx \frac{\gamma}{R} \sim 600 \text{ GeV}$  (Pb-beam),  $\sim 17 \text{ TeV}$  (p-beam)
- **Max. FHC  $\gamma\gamma, \gamma N$  c.m. energies:**

PbPb:	$\sqrt{s_{\gamma\gamma}} \sim 1.2 \text{ TeV}$	$\sqrt{s_{\gamma\text{Pb}}} \sim 7 \text{ TeV}$
pPb:	$\sqrt{s_{\gamma\gamma}} \sim 6 \text{ TeV}$	$\sqrt{s_{\gamma p}} \sim 10 \text{ TeV}$

# $\gamma$ -Pb physics at FCC-ions



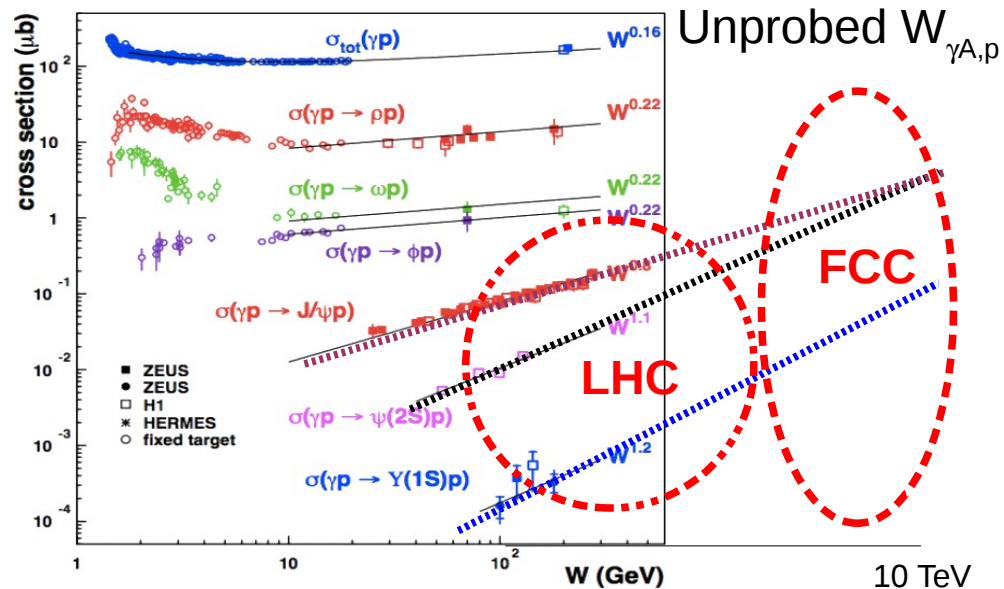
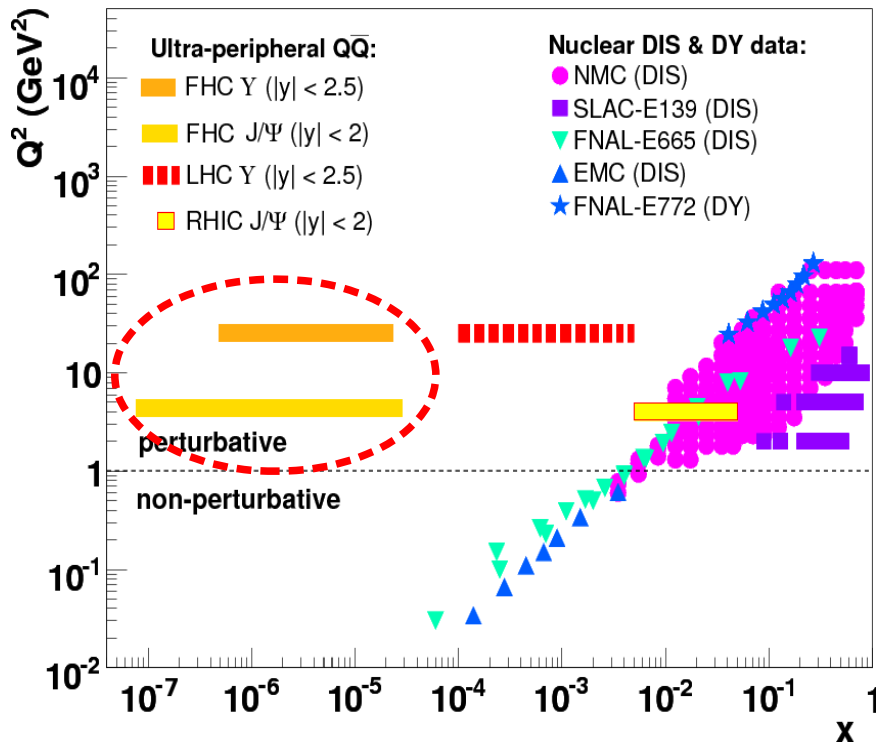
Effective lumis up to  $W_{\gamma p, \gamma Pb} \sim 10$  TeV

■ QCD: Low-x PDF & saturation in proton /nucleus via photoproduction:

- Inclusive dijet, heavy-Q (also t-tbar)
- Exclusive QQbar

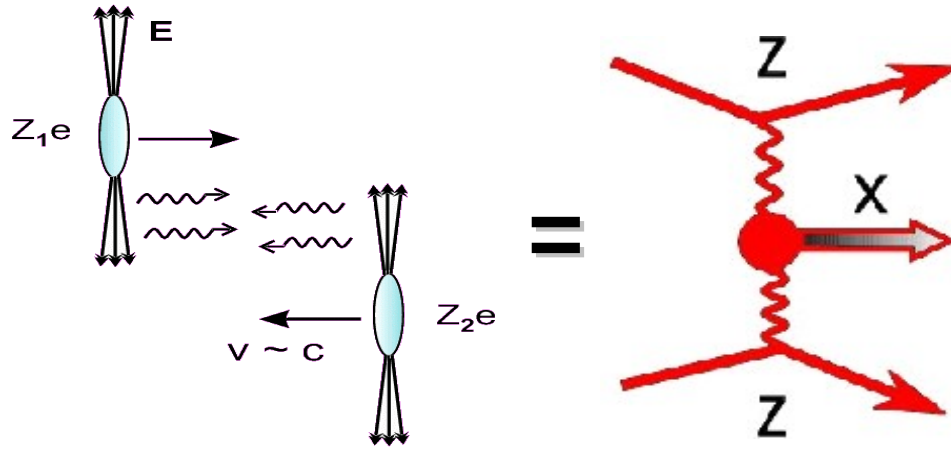
$$x \sim m_{QQ}^2 / W_{\gamma p, \gamma Pb}^2 \sim 10^{-7}$$

$\sim 2$  orders of magnitude below LHC



# $\gamma$ - $\gamma$ collisions at FCC-ions

- **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:



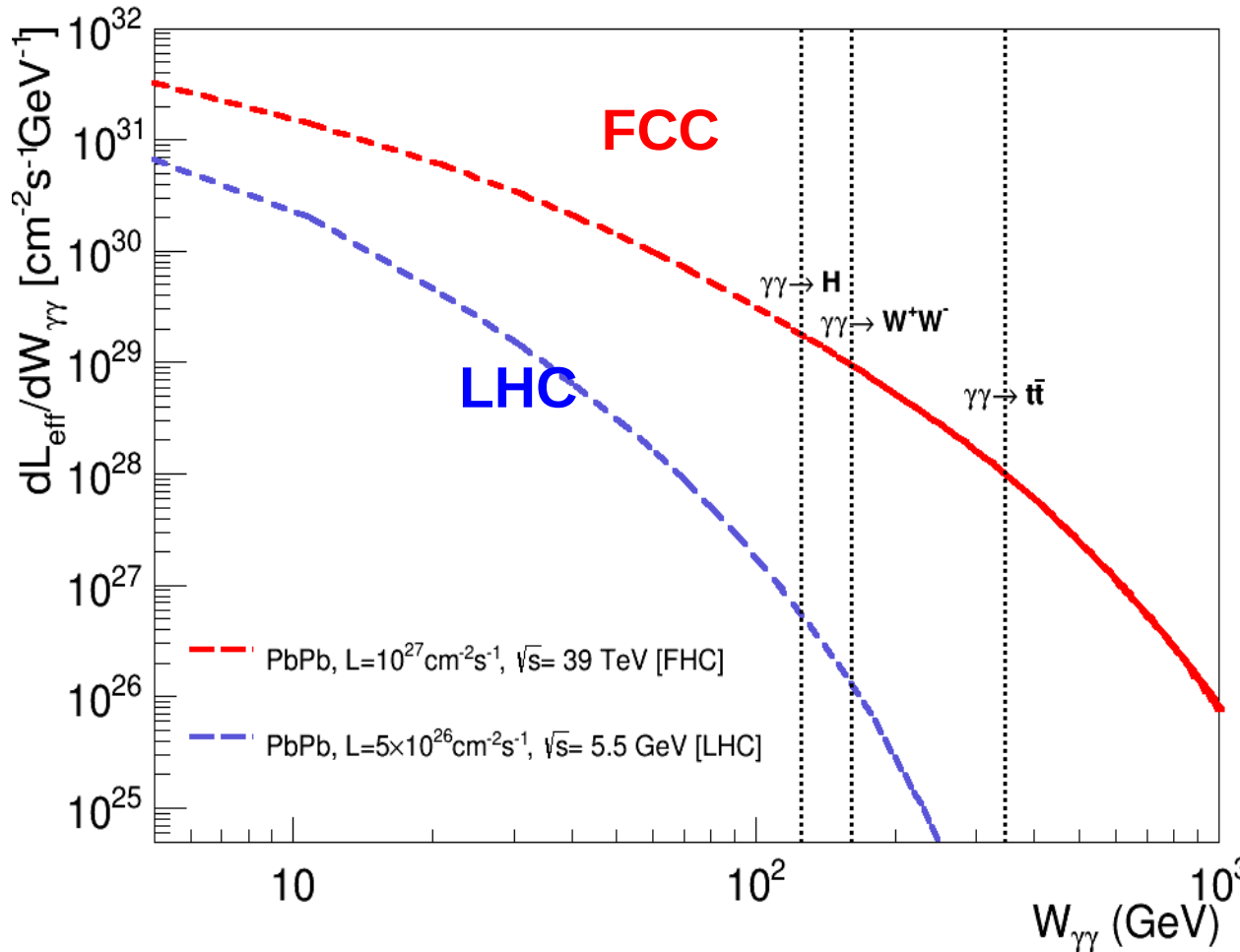
- **Huge photon fluxes:**  
 $\sigma(\gamma-\gamma) \sim Z^4$  ( $\sim 5 \cdot 10^7$  for PbPb)  
 larger than  $p, e^\pm$
- **Beam-energy dependence:**  
 Photon luminosities increase as  $\propto \log^3(\sqrt{s})$

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

System	$\sqrt{s_{NN}}$ (TeV)	$\mathcal{L}_{AB} \cdot \Delta t$ (per year)	$\gamma$ ( $\times 10^3$ )	$\omega_{\max}$ (TeV)	$\sqrt{s_{\gamma\gamma}^{\max}}$ (TeV)
p-p	100	1 fb <sup>-1</sup>	53.	17.6	35.2
p-Pb	64	1 pb <sup>-1</sup>	33.5	0.95	1.9
Pb-Pb	39	5 nb <sup>-1</sup>	21.	0.60	1.2

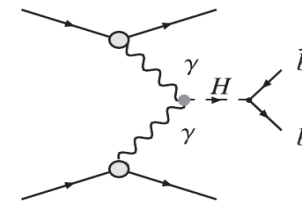
# $\gamma\text{-}\gamma$ luminosity & physics at FCC-ions

- “Low masses”: x4 higher effective lumi than at LHC-5.5 TeV  
Huge stats for:  $\gamma\gamma \rightarrow \gamma\gamma$ , double VM ( $\gamma\gamma \rightarrow \rho\rho, J/\psi J/\psi, \Upsilon\Upsilon$ ),...
- High masses : x400 more lumi than LHC for Higgs  
x700 more lumi than LHC for  $W+W-$  (anomalous QGC)

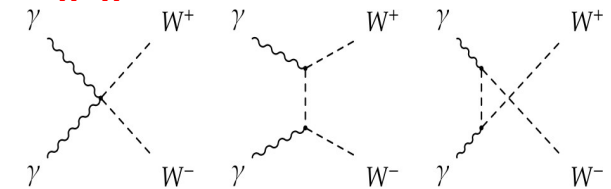


$$N_X = \int \frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}} W_{\gamma\gamma} \sigma_X^{\gamma\gamma}(W_{\gamma\gamma})$$

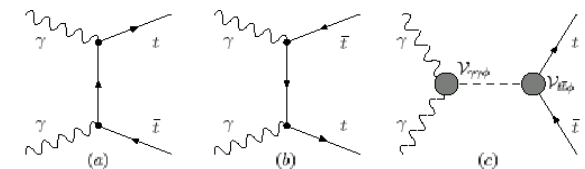
$N_{\text{Higgs}} \sim 10$  counts/month



$N_{W+W-} \sim 1000$  counts/month

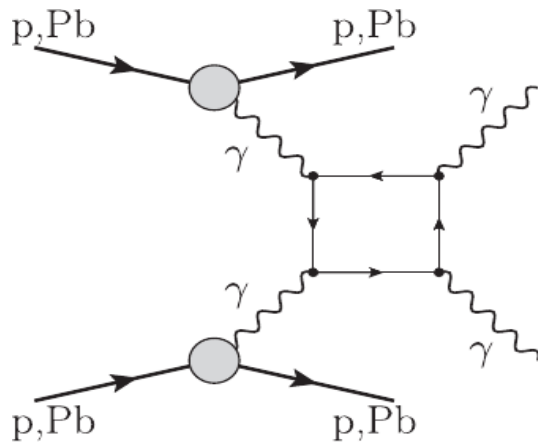


$N_{t\text{-tbar}} \sim \text{few}$  counts/month



# $\gamma\text{-}\gamma$ example: Light-by-light scattering

[DdE & G.Silveira, in preparation]



- MadGraph v5.0 MC event generator.

- Equivalent photon approximation (EPA):

$$\sigma_{\gamma\gamma\rightarrow\gamma\gamma}^{\text{excl}} = \sigma(AB\overset{\gamma\gamma}{\rightarrow}A\gamma\gamma B) = \int d\omega_1 d\omega_2 \frac{f_{\gamma/A}(\omega_1)}{\omega_1} \frac{f_{\gamma/B}(\omega_2)}{\omega_2} \sigma_{\gamma\gamma\rightarrow\gamma\gamma}(\sqrt{s_{\gamma\gamma}})$$

- Photon fluxes:

p: Budnev et al. elastic FF [Phys. Rep. 15 (1975)181]

$$A: f_{\gamma/A}(x) = \frac{\alpha Z^2}{\pi} \frac{1}{x} \left[ 2x_i K_0(x_i) K_1(x_i) - x_i^2 (K_1^2(x_i) - K_0^2(x_i)) \right]$$

- Elementary NLO  $\sigma(\gamma\gamma\rightarrow\gamma\gamma)$  from Bern et al. [JHEP 11 (2001) 031]

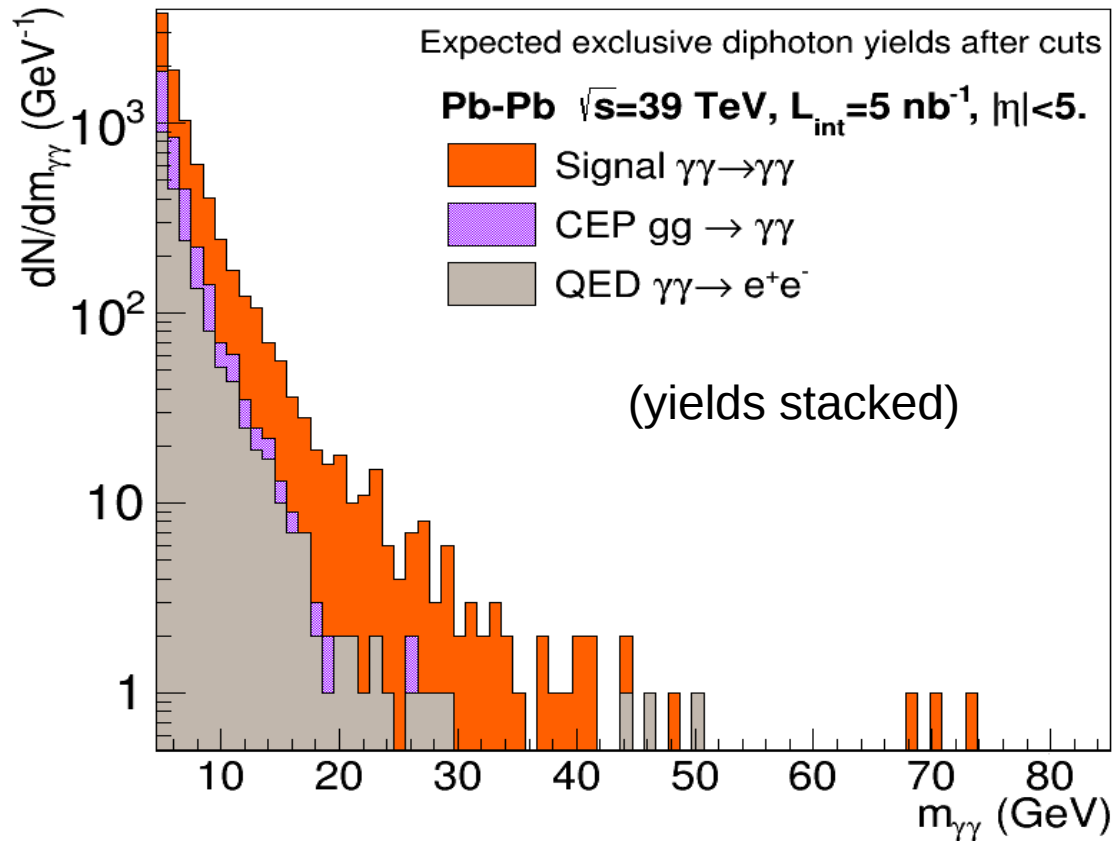
- Expected light-by-light scattering cross sections & yields:

System	$\sqrt{s_{NN}}$ (TeV)	$\mathcal{L}_{AB} \cdot \Delta t$ (per year)	$\sigma_{\gamma\gamma\rightarrow\gamma\gamma}^{\text{excl}}$ [ $m_{\gamma\gamma} > 5 \text{ GeV}$ ]	$N_{\gamma\gamma}^{\text{excl, cuts}}$ [ $m_{\gamma\gamma} > 5 \text{ GeV}$ ]
p-p	100	1 fb <sup>-1</sup>	240 ± 24 fb	90
p-Pb	64	1 pb <sup>-1</sup>	780 ± 78 pb	320
Pb-Pb	39	5 nb <sup>-1</sup>	1.85 ± 0.37 μb	4 930

# $\gamma\text{-}\gamma$ example: Light-by-light scattering

[DdE & G.Silveira, in preparation]

- Combination of **LbyL signal + CEP & QED** backgrounds after cuts  
Pb-Pb at 39 TeV ( $L_{\text{int}} = 5 \text{ nb}^{-1}$ ):



**PRELIMINARY**

$$N_{\gamma\gamma-\gamma\gamma} \sim 4950$$

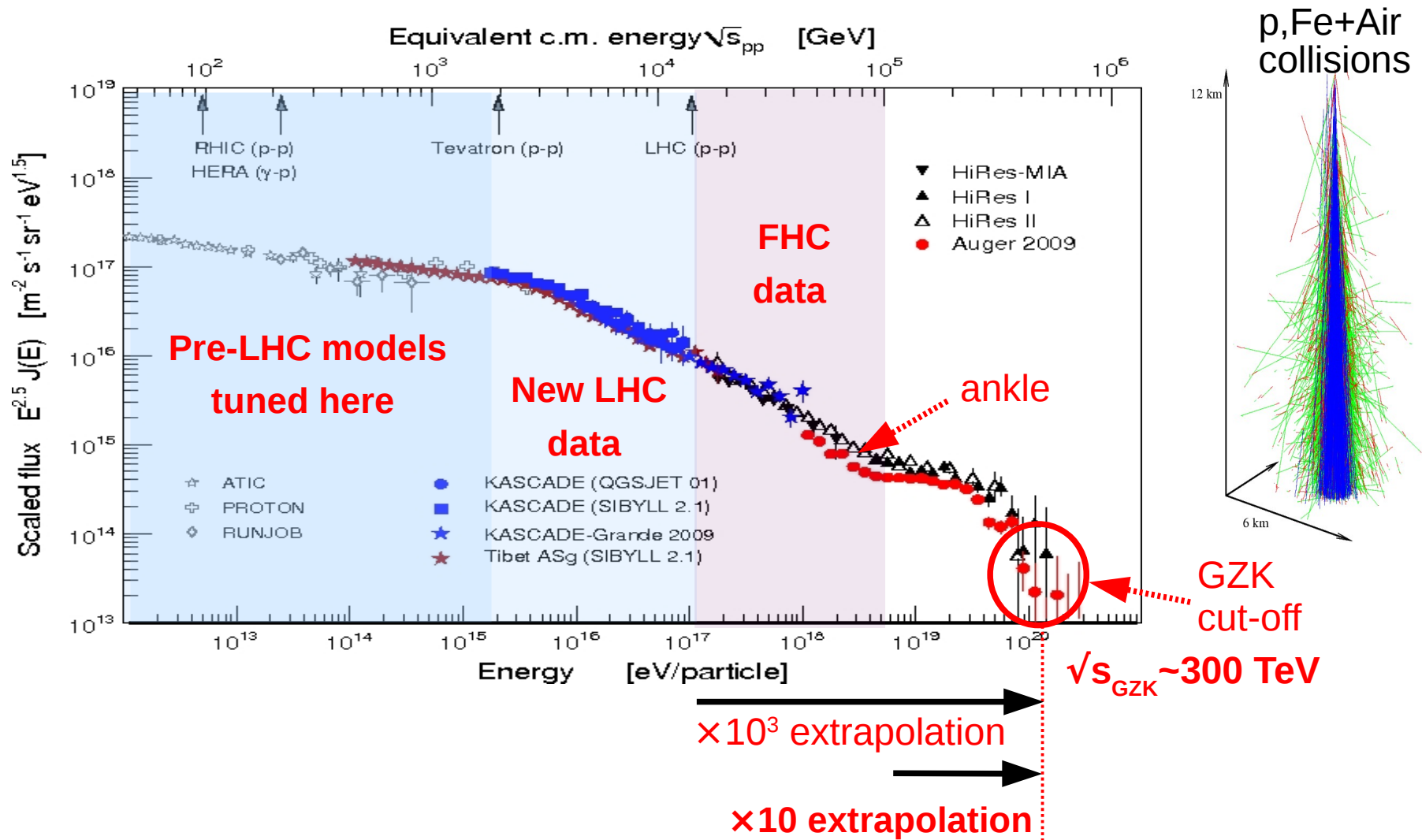
$$N_{\text{CEP}-\gamma\gamma} \sim 1800$$

$$N_{\text{QED-ee}} \sim 2000$$

Significance  $\sim 60$ .  
(profile likelihood ratio)

- **LbyL signal** clearly observable over backgrounds (esp. high  $m_{\gamma\gamma}$ )

# Cosmic-rays MC tuning with FCC-ions



- The FHC probes **ankle-energy** and provides a **significant lever-arm** in providing constraints for hadronic Monte Carlos for UHECR