Photon-photon & UHE cosmic-ray physics opportunities at the FHC with ions

“Ions at the Future Hadron Collider”

CERN, Dec. 16th 2013

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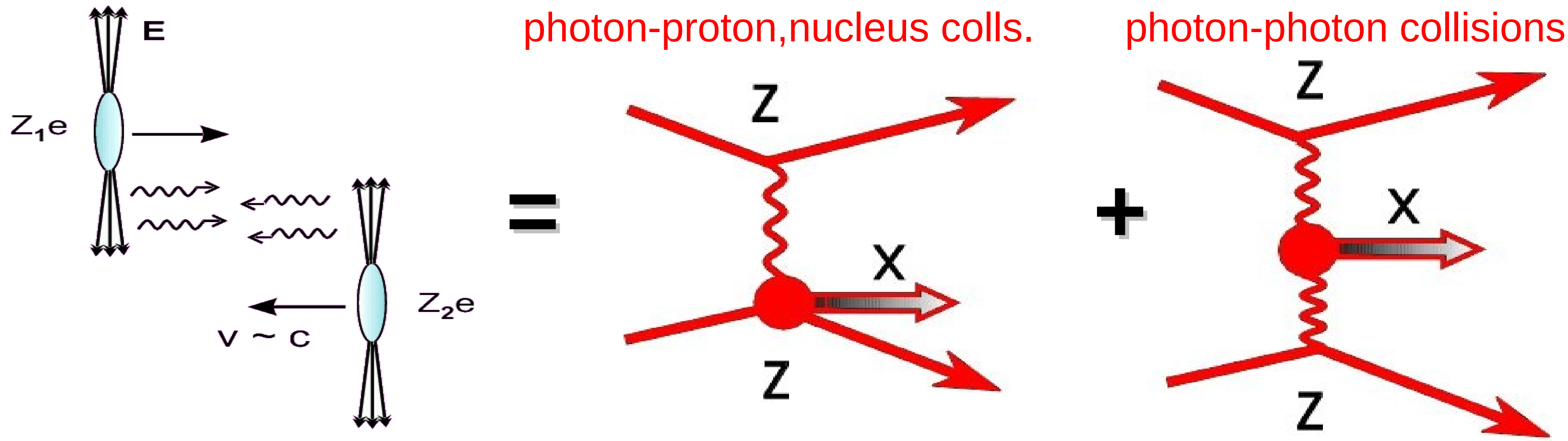
CERN

Photon-induced collisions at the FHC

- 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:



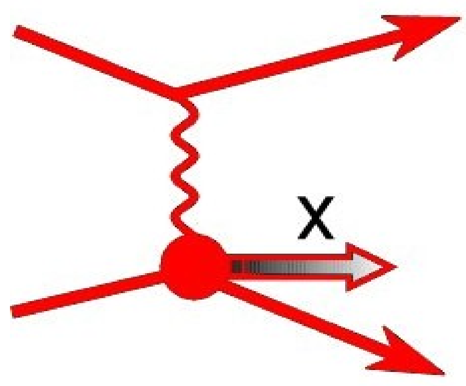
- Huge photon fluxes:
  $\sigma(\gamma\text{-Pb,p}) \sim Z^2$ (~10^4 for Pb) larger than p,e$^\pm$
  $\sigma(\gamma\text{-}\gamma) \sim Z^4$ (~$5{\cdot}10^7$ for PbPb) larger than p,e$^\pm$
- Beam-energy dependence:
  Photon luminosities increase as $\propto \log^3(\sqrt{s})$

- Quasi-real photons (coherence): Q ~ 1/R ~ 0.06 GeV (Pb), 0.28 GeV (p)
- Max. FHC γ energies: $\omega < \omega_{max} \approx \frac{\gamma}{R}$ ~ 600 GeV (Pb-beam), ~ 17 TeV (p-beam)
- Max. FHC γ γ ,γ N c.m. energies:

  Assume √s(FHC)= 7×√s(LHC)

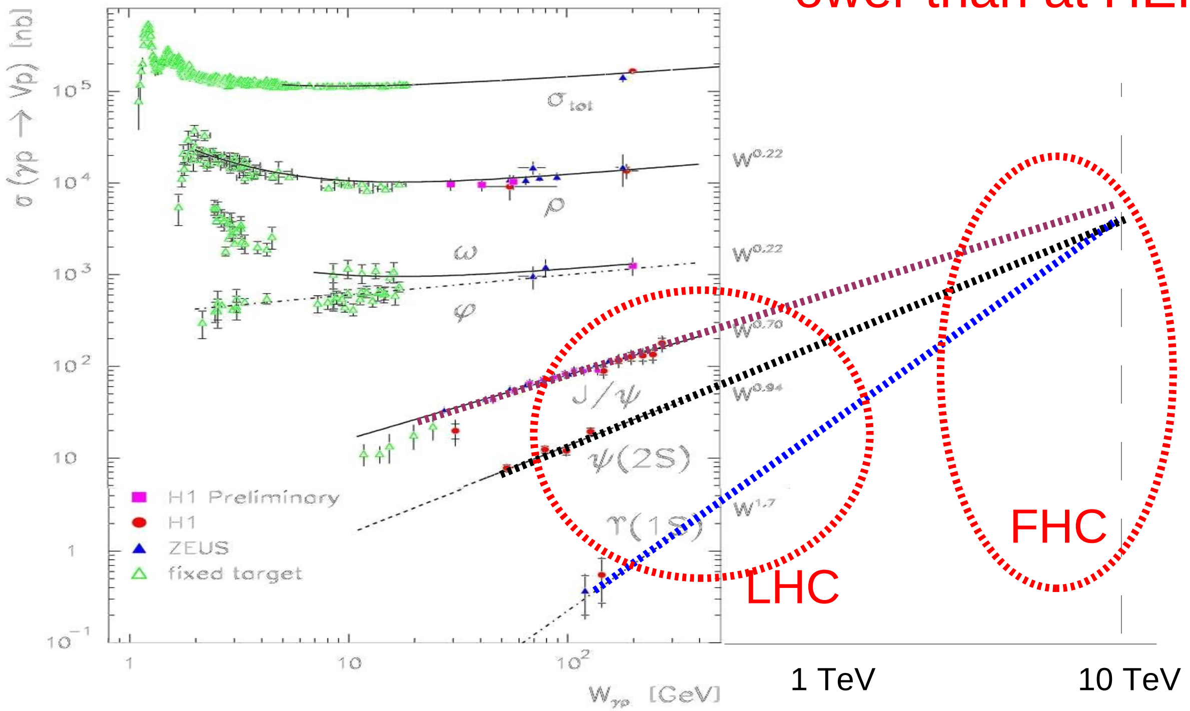
PbPb:	$\sqrt{s_{\gamma\gamma}}$ ~ 1.2 TeV	$\sqrt{s_{\gamma Pb}}$ ~ 7 TeV
pPb:	$\sqrt{s_{\gamma\gamma}}$ ~ 6 TeV	$\sqrt{s_{\gamma p}}$ ~ 10 TeV

Low-x via photoproduction at the FHC



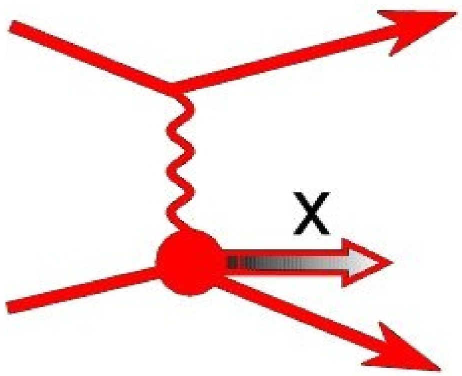
- Effective lumis up to $W_{\gamma p,\gamma Pb}$~ 10 TeV
- QCD: Low-x PDF & saturation in proton /nucleus via photoproduction:
  - inclusive dijet, heavy-Q (also t-tbar)
  - exclusive QQbar

x values about 2-3 orders of magnitude lower than at HERA



Similar x-sections ~ O(1 μb) at ~10 TeV for all exclusive VM photoproduction: J/ψ,ψ',ϒ

UPC at the FHC: Physics opportunities



0. Effective lumis up to $W_{\gamma p,\gamma Pb}$~ 10 TeV
1. QCD: Low-x PDF & saturation in proton /nucleus via photoproduction:
   - inclusive dijet, heavy-Q (also t-tbar)
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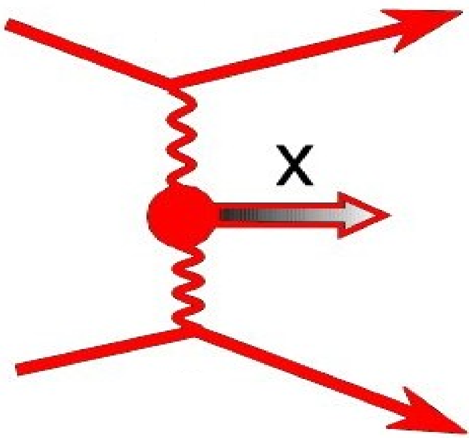

0. Effective lumis up to $W_{\gamma\gamma}$~ O(few TeV)
1. QCD: double VM $\gamma\gamma \to \rho\rho$, $J/\psi J/\psi$, $\Upsilon\Upsilon$
2. QED (non pertubative, $Ze \approx 0.6$): $\gamma\gamma \to l^+l^-$
3. EW: Triple&Quartic GC $\gamma\gamma W(Z)$, $\gamma\gamma WW(ZZ)$
4. Higgs(*), Beyond SM(*)

(*) Depend chiefly on p-Pb, Pb-Pb integrated luminosities achievable

“Golden” physics channels for a $\gamma\gamma$ collider

Reaction	Remarks	
$\gamma\gamma \to H, h \to bb$	SM/MSSM Higgs, $M_{H,h} < 160$ GeV	SM Higgs
$\gamma\gamma \to H \to WW(^*)$	SM Higgs, 140$< M_H <$ 190 GeV	
$\gamma\gamma \to H \to ZZ(^*)$	SM Higgs, 180$< M_H <$ 350 GeV	
$\gamma\gamma \to H \to \gamma\gamma$	SM Higgs, 120$< M_H <$ 160 GeV	
$\gamma\gamma \to H \to t\bar{t}$	SM Higgs, $M_H >$ 350 GeV	
$\gamma\gamma \to H, A \to bb$	MSSM heavy Higgs, interm. $\tan\beta$	SUSY
$\gamma\gamma \to \tilde{f}\bar{\tilde{f}},\ \tilde{\chi}_i^+\tilde{\chi}_i^-$	large cross sections	
$\gamma\gamma \to \tilde{g}\tilde{g}$	measurable cross sections	
$\gamma\gamma \to H^+H^-$	large cross sections	
$\gamma\gamma \to S[\tilde{t}\bar{\tilde{t}}]$	$\tilde{t}\bar{\tilde{t}}$ stoponium	
$\gamma\gamma \to \gamma\gamma$	non-commutative theories	BSM
$\gamma\gamma \to \phi$	Radions	
$\gamma\gamma \to W^+W^-$	anom. W inter., extra dimensions	Anomalous couplings
$\gamma\gamma \to 4W/(Z)$	WW scatt., quartic anom. W,Z	
$\gamma\gamma \to t\bar{t}$	anomalous top quark interactions	top
$\gamma\gamma \to$ hadrons	total $\gamma\gamma$ cross section	QCD
$\gamma g \to q\bar{q},\ c\bar{c}$	gluon in the photon	
$\gamma\gamma \to J/\psi\, J/\psi$	QCD Pomeron	

"Golden" physics channels for a γγ collider

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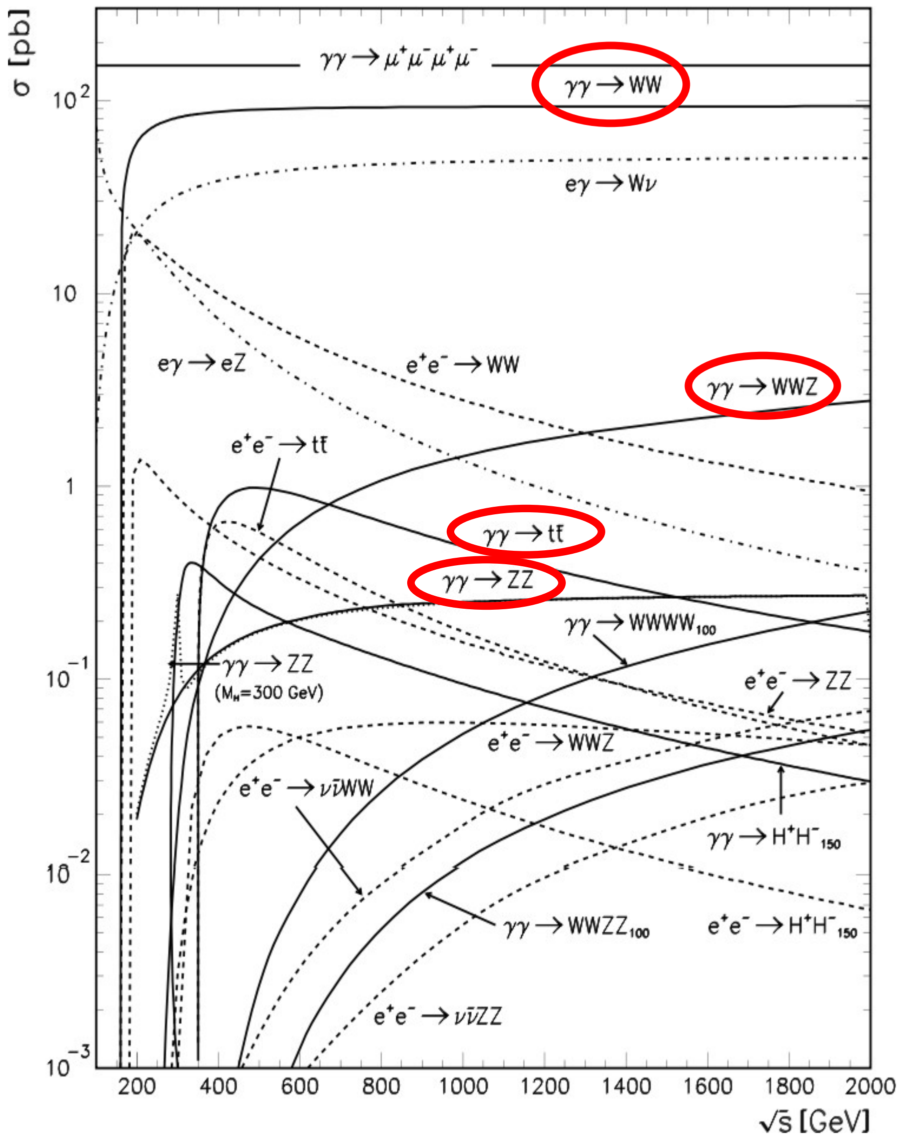
A fraction of them can be studied at FHC(γγ)

A few simple cases (anomal.couplings,Higgs) follow ...

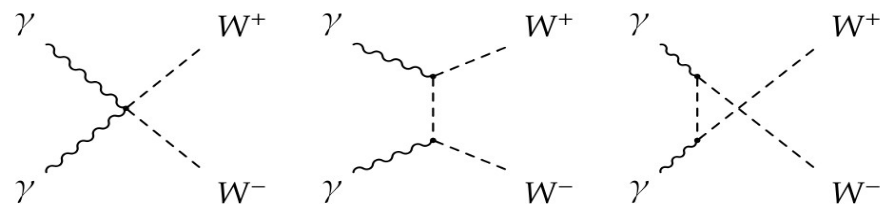
Real quantitative studies needed

Anomalous couplings at FHC (γγ)



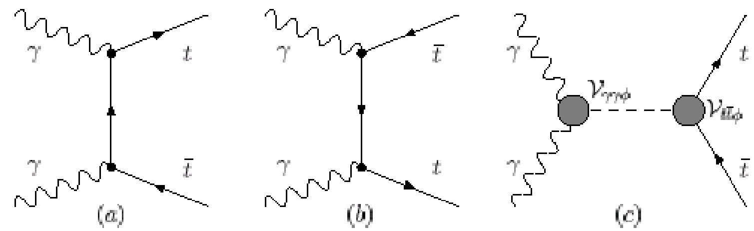
[PLC, TESLA hep-ex/0108012]

- $\gamma\gamma \to WW$ quartic/trilinear couplings:



σ ~ 100 pb

- $\gamma\gamma \to$ t-tbar : σ ~ 1 pb



- $\gamma\gamma \to ZZ$, $\gamma\gamma \to WWZ$

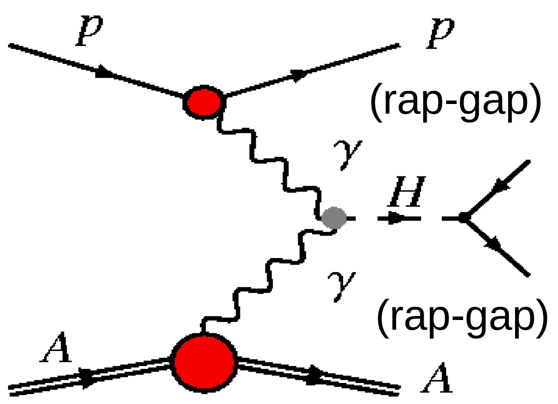
quartic couplings: σ ~ 0.15 – 1 pb

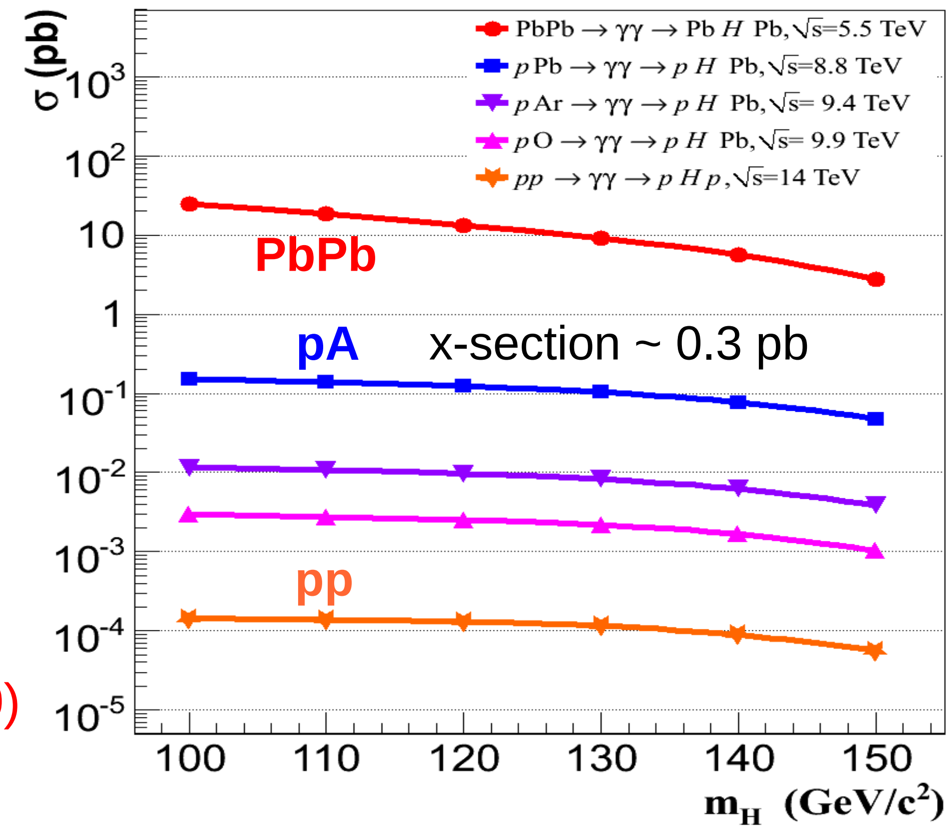
➔ Observation of such channels Depends chiefly on reachable Pb-Pb, p-Pb integrated luminosities

Higgs γ γ production in UPC collisions

DdE&J.P.Lansberg PRD81 (2010)014004

- Exclusive electromagnetic Higgs production:





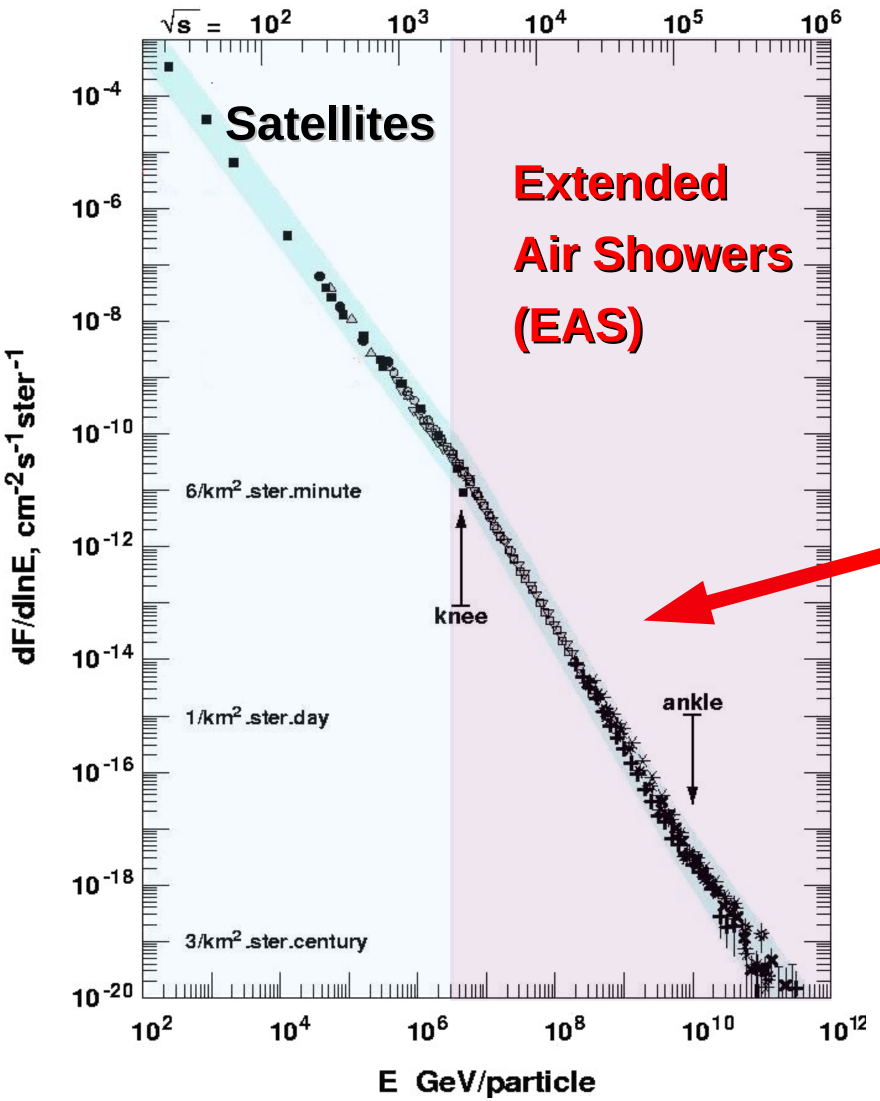
➔ FHC x-sections & yields should be scaled up by a factor O(10-100) compared to LHC

System	nominal runs				upgraded pA scenario			
	$\mathcal{L}_{AB}$ ($cm^{-2}s^{-1}$)	Δt (s)	$\langle N_{pileup}\rangle$	N_{Higgs} total ($H \to b\bar{b}$)	$\mathcal{L}_{AB}$ ($cm^{-2}s^{-1}$)	Δt (s)	$\langle N_{pileup}\rangle$	N_{Higgs} total ($H \to b\bar{b}$)
pp (14 TeV)	10^{34}	10^7	25	77. (55.)	10^{34}	10^7	25	77. (55.)
pO (9.9 TeV)	$2.7{\cdot}10^{30}$	10^6	0.20	0.022 (0.016)	$1.6{\cdot}10^{32}$	10^7	3.9	13. (10.)
pAr (9.4 TeV)	$1.5{\cdot}10^{30}$	10^6	0.18	0.045 (0.032)	$1{\cdot}10^{32}$	10^7	3.6	30. (22.)
pPb (8.8 TeV)	$1.5{\cdot}10^{29}$	10^6	0.05	0.050 (0.035)	$1{\cdot}10^{31}$	10^7	1	34. (25.)
PbPb (5.5 TeV)	$5{\cdot}10^{26}$	10^6	$5{\cdot}10^{-4}$	0.009 (0.007)	$5{\cdot}10^{26}$	10^7	$5{\cdot}10^{-4}$	0.15 (0.1)

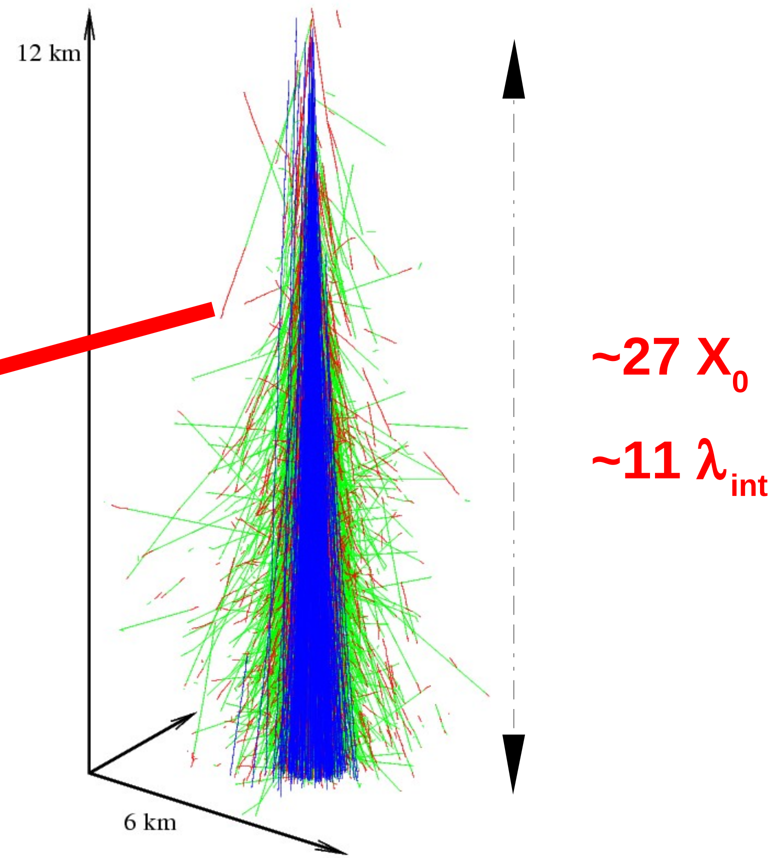
Ultra-high energy cosmic-rays & FHC

Ultra High Energy Cosmic-Rays (UHECRs)

- For E_{lab} >10^{15} eV flux too low for satellites/balloons (1 CR per m^2-year):

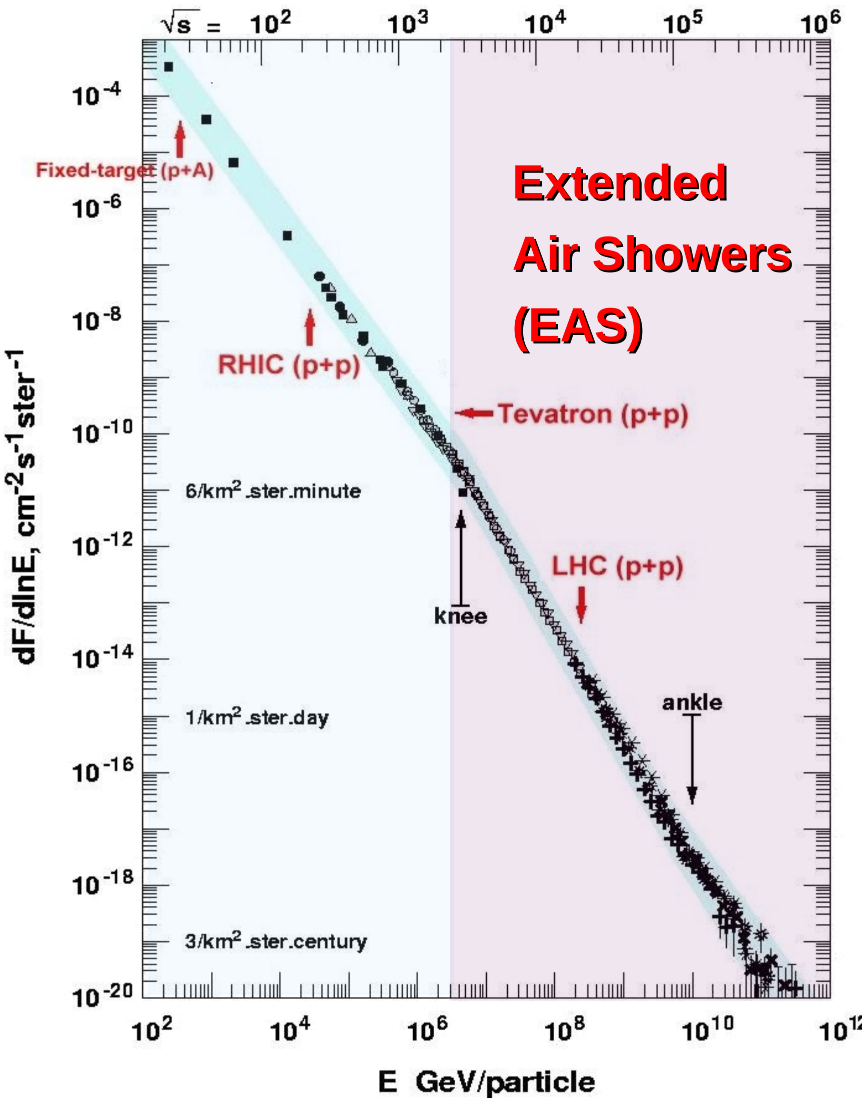


- Indirect measurements using the atmosphere as a "calorimeter":

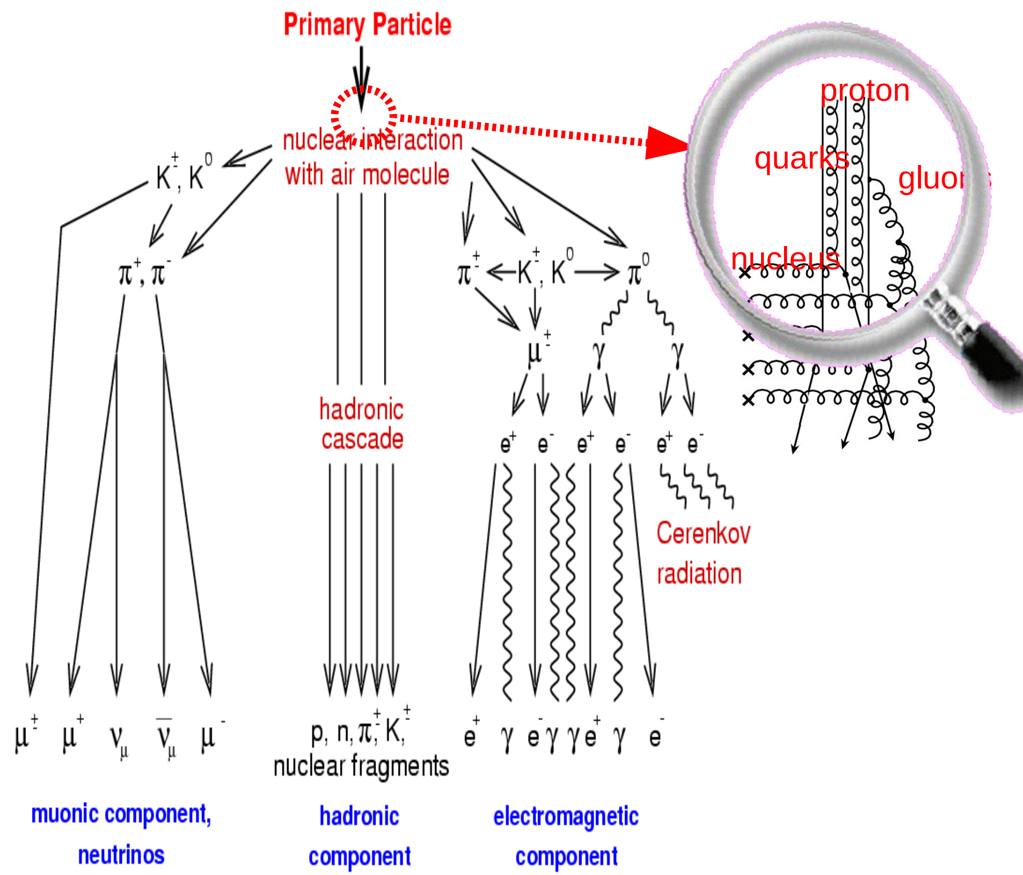


Ultrahigh-energy cosmic rays & QCD

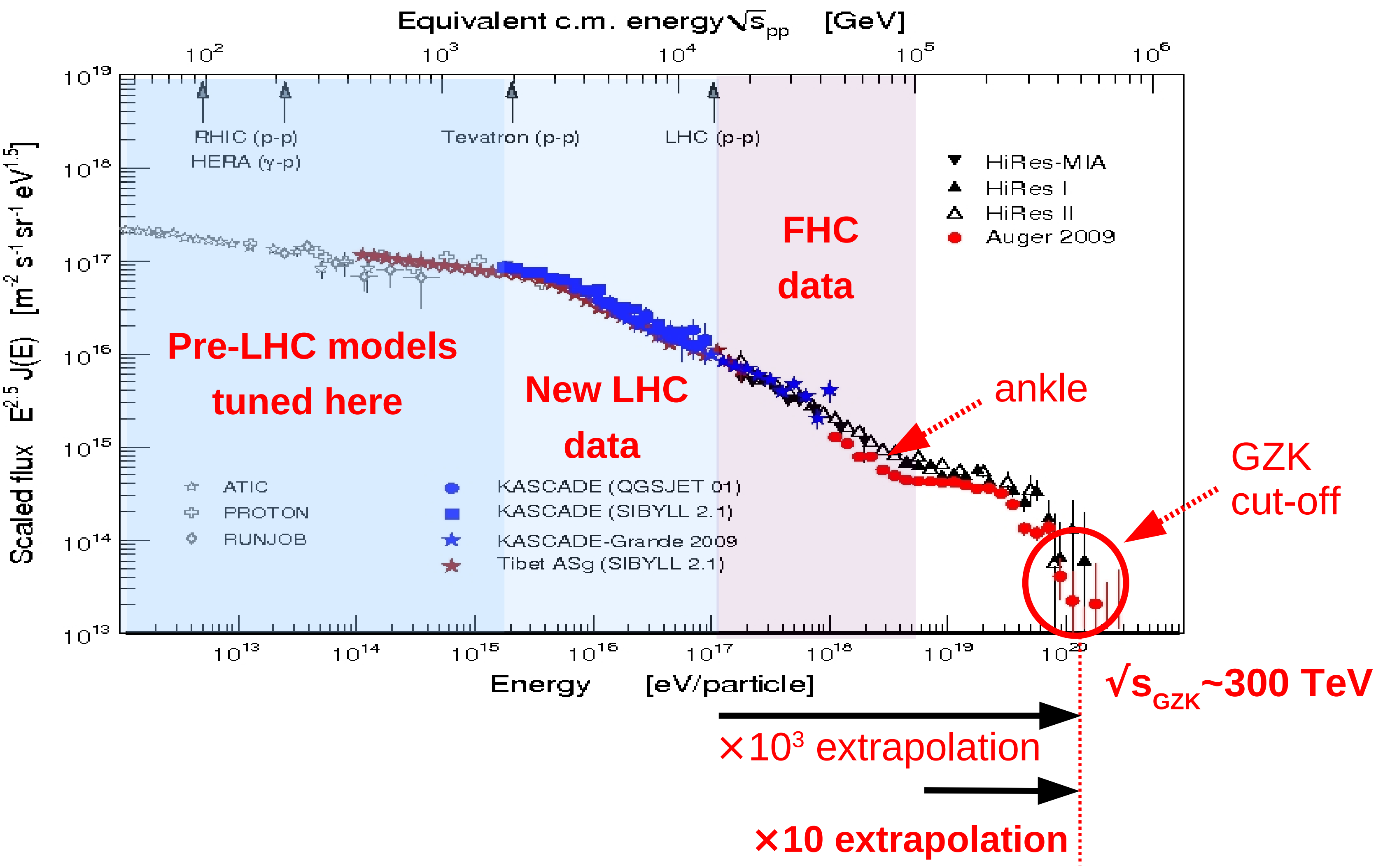
- Above 10^{15} eV CR energy & id determined via hadronic Monte Carlos:



- Comparison of X_{max},N_{μ}... to predictions for p,Fe+Air collisions up to $\sqrt{s}_{GZK}$~300 TeV



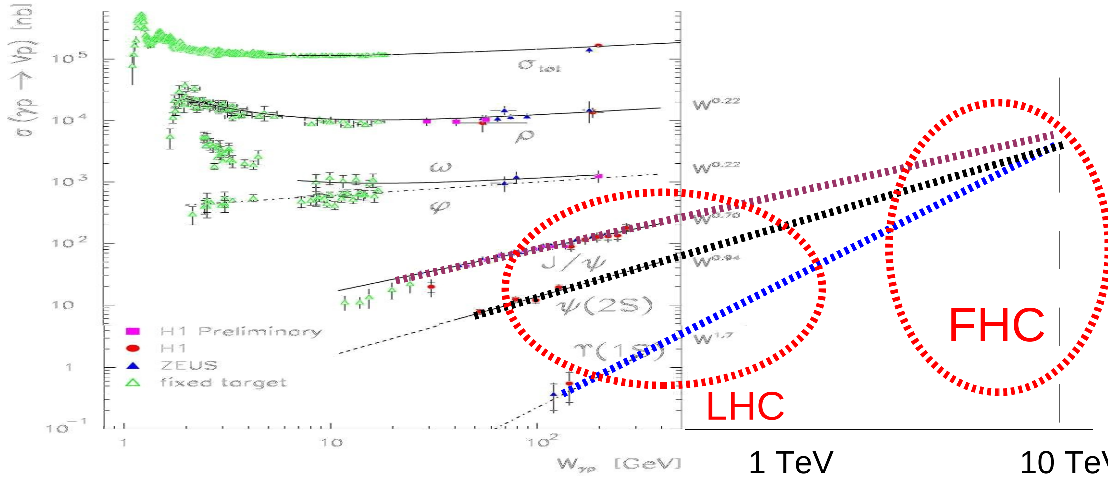
Hadronic MCs tuning with collider data



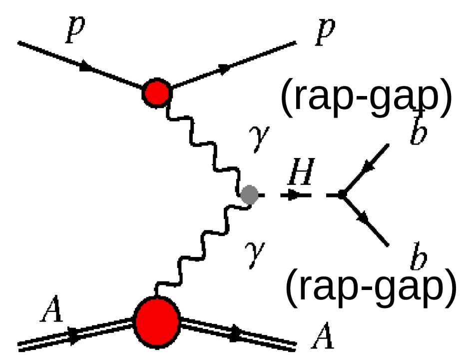
- The FHC probes ankle-energy and provides a significant lever-arm in providing constraints for hadronic Monte Carlos for UHECR

Summary: γPb,γγ & UHECR physics at FHC

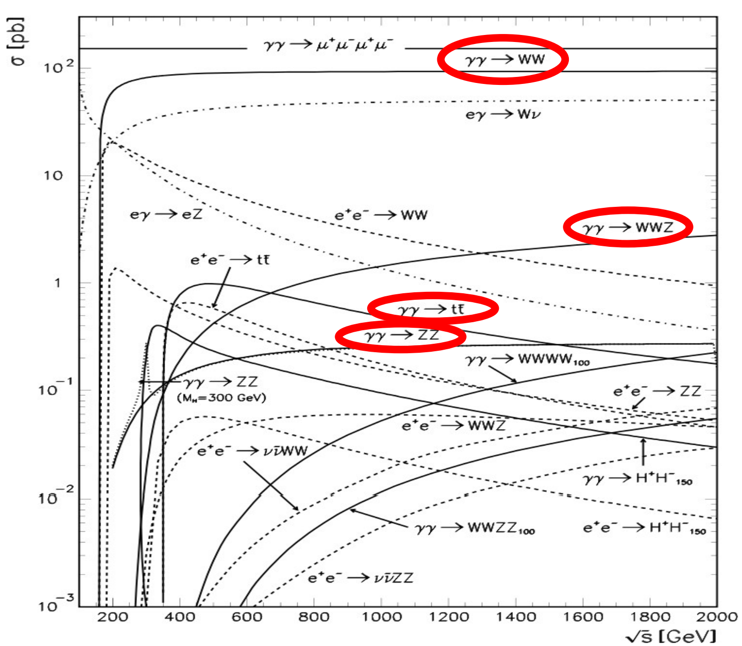
- Low-x via J/ψ,ψ',ϒ photoprod. beyond 1 TeV:



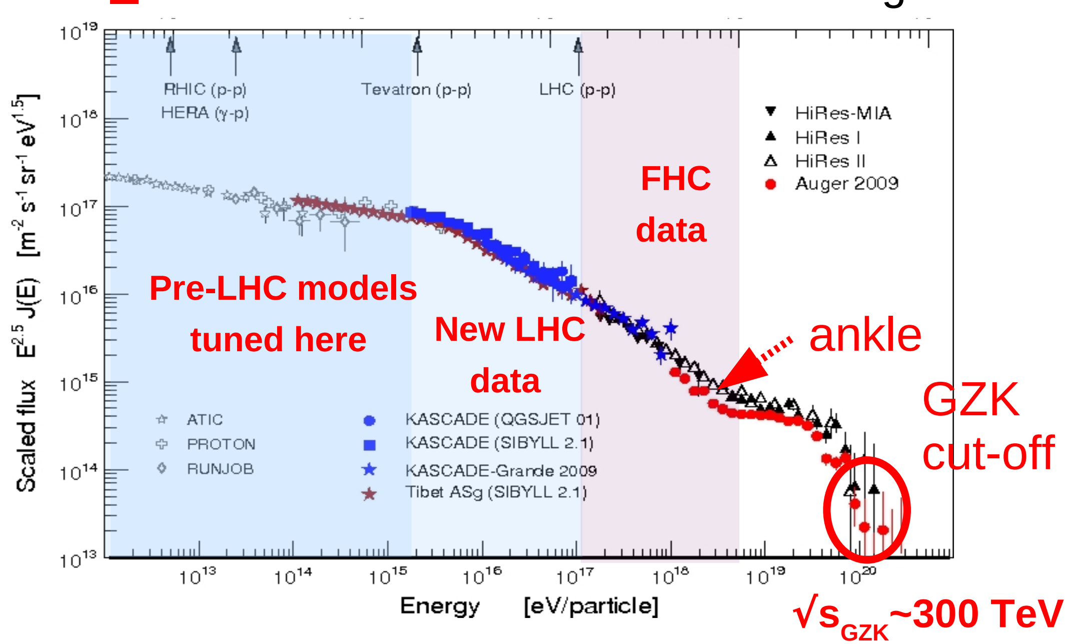
- Electromagnetic Higgs production:



- Anomalous boson & top couplings:



- MC constraints at ankle & GZK energies:



Back-up slides

UPCs: p-Pb vs p-p & Pb-Pb

- Advantages of p-Pb over Pb-Pb UPCs:

1. Higher machine luminosities: $\times 10^3$ (10^{30} or higher vs 10^{27} cm^{-2}s^{-1})
2. Higher hadronic beam energy: x1.6 ($\sqrt{s}$=8.8 TeV vs $\sqrt{s}$=5.5 TeV)
3. Higher $\gamma\gamma$ c.m. energies:
   - harder proton γ spectrum + smaller impact param ($R_p+R_{Pb}<2R_{Pb}$)
4. Easier to separate γ- from |P-induced backgds:
   - extra γ exchanges in PbPb lead to fwd. neutron production
5. Possibility to tag scattered proton w/ Roman Pots: full kin. reco possible

- Advantages of p-Pb over p-p UPCs:

1. Increased photon flux of one beam by Z^2: $\times 10^4$
2. Possible to trigger-on & carry out measurements with ~zero event pileup
3. Easier to remove diffractive backgds:
   - forward nucleons emitted in p-Pb.