LHCf program for Run III

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on behalf of the LHCf collaboration

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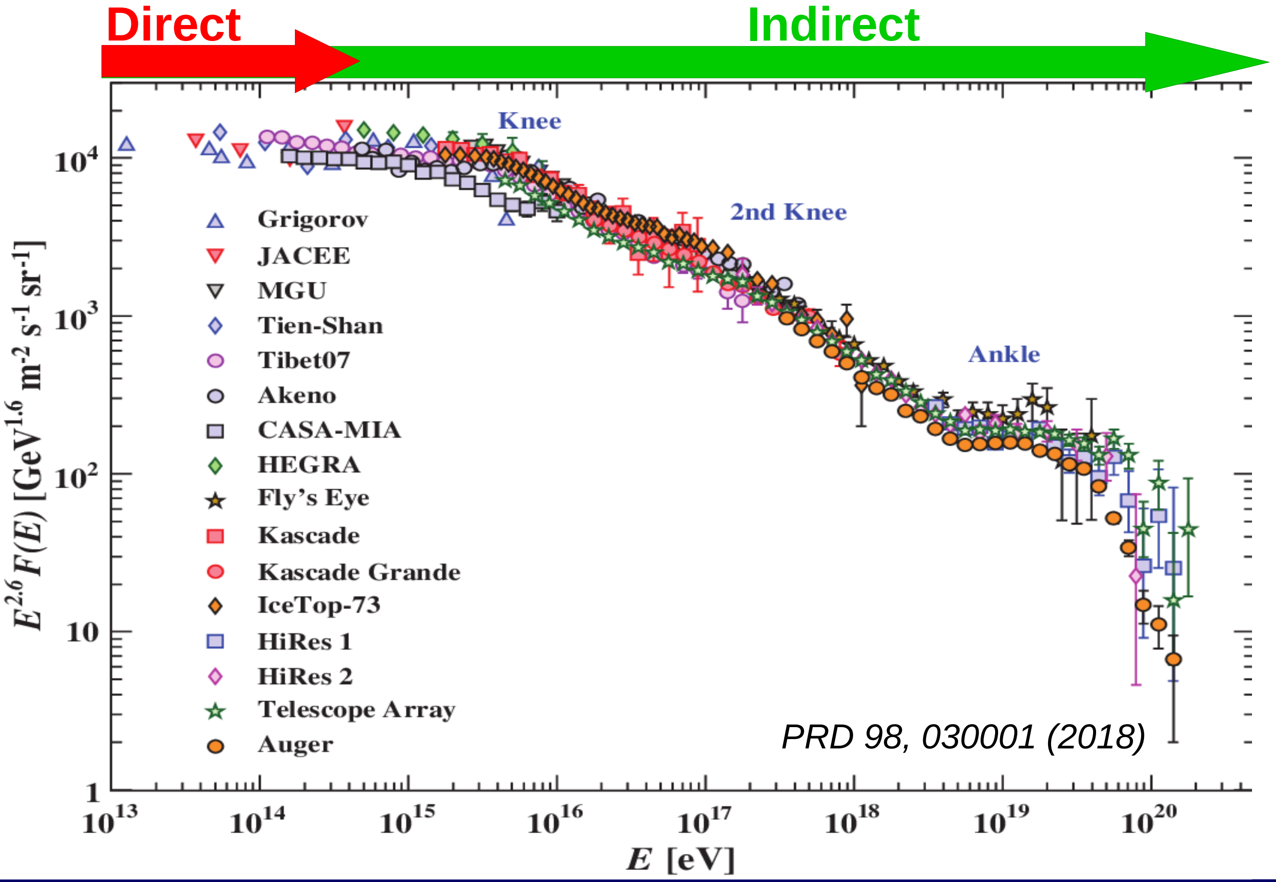
Outline

- **The LHCf experiment**
  - Physics motivations
  - Experimental setup
- **Program for LHC Run III**
  - p-p run @ $\sqrt{s}$ = 14 TeV
  - p-O run @ $\sqrt{s}$ = 9.9 TeV
  - Detector upgrade

Physics motivations

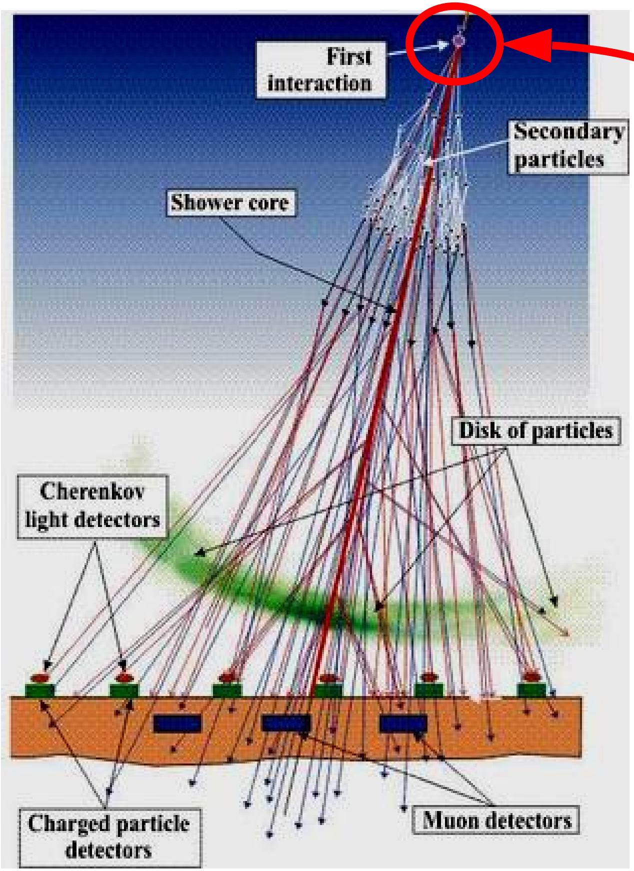
Cosmic rays spectrum



- **Direct measurements** limited by low flux of particles at high energies

- Only **indirect measurements** (with ground based experiments) are possible above ~10^{14} eV

Contribution from accelerators



$\sqrt{s}$ = 13 TeV → $E_{CR} = 0.9 \cdot 10^{17}$ eV

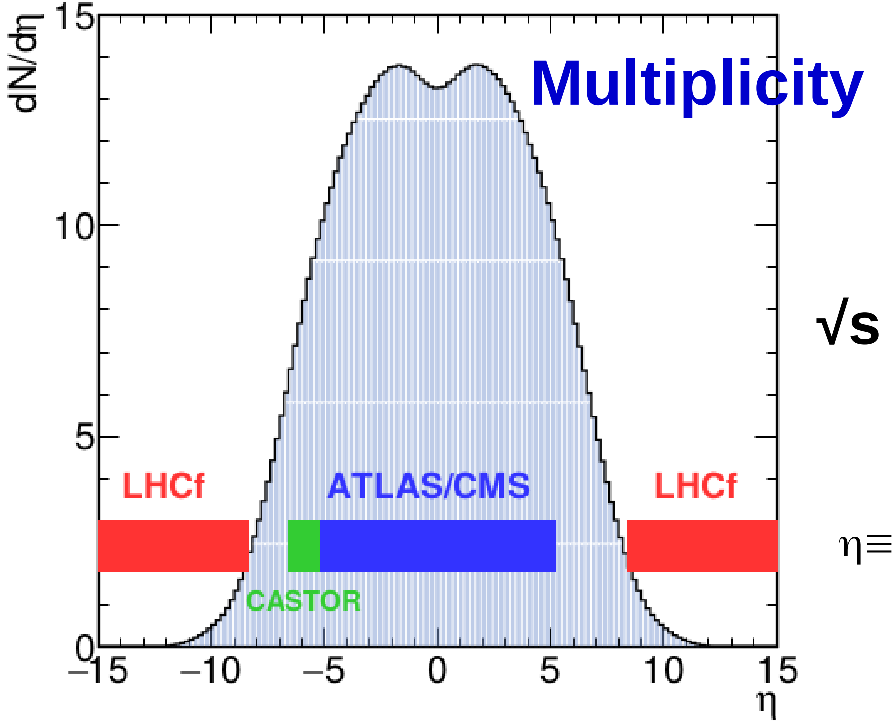
First interaction

- **Inelastic cross section**
- **Multiplicity**
- **Elasticity = p_{lead} / p_{beam}**
- **Forward energy spectrum**
- **Nuclear effects** → **p-Pb collisions (p-O 2023?)**

Elasticity and forward energy spectrum: **neutrons, photons, π^0**

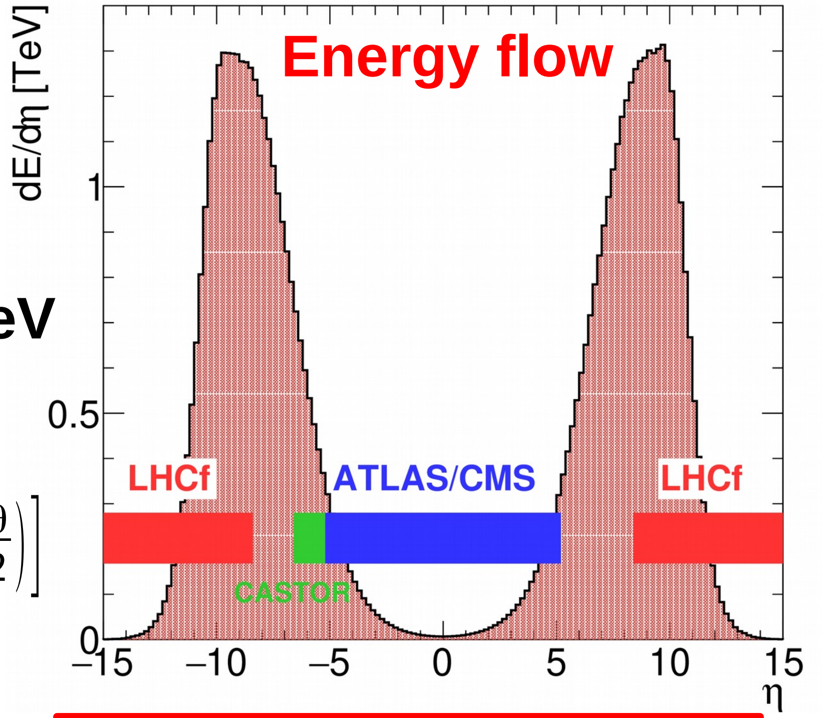
Neutrons, photons, π^0 and p-Pb collisions: **LHCf**

Why forward?



p-p
$\sqrt{s}$ = 13 TeV

$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

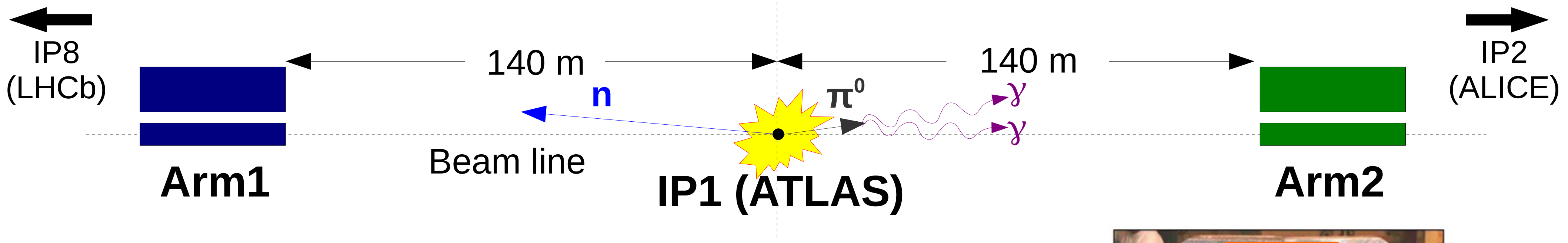


Maximum multiplicity in the central region

Peak of energy flow around $\eta \sim 9$ ($\theta \sim 0.25$ mrad)

Experimental setup

Experimental setup

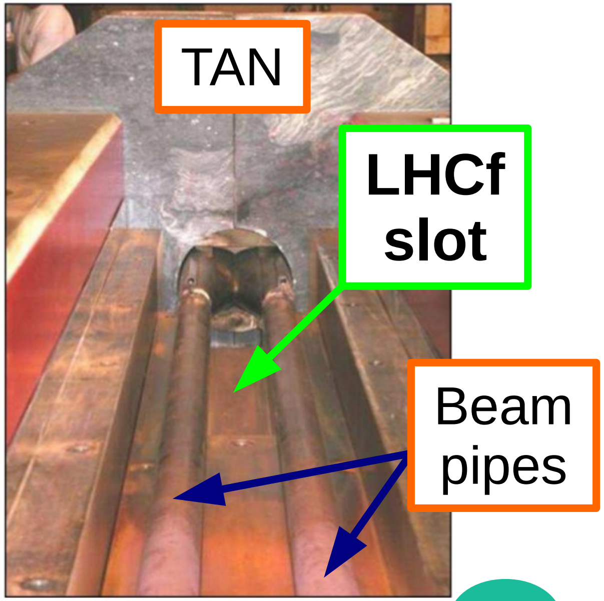


LHCf is located in TAN slot

Zero degree particles!
Coverage: **η > 8.4** (with 140 μrad crossing angle)

Charged particles are deflected by D1 dipole magnet

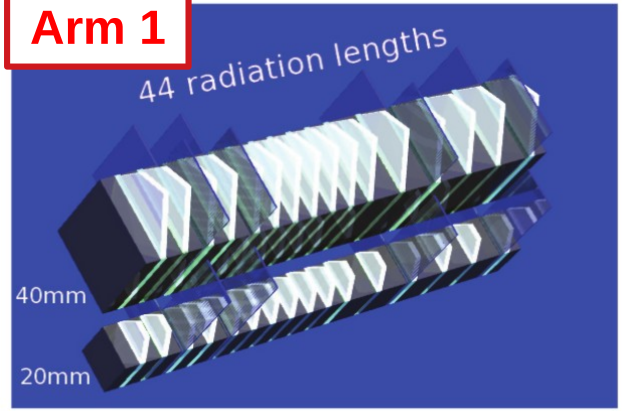
Only neutral particles (**photons** and **neutrons**) are detected



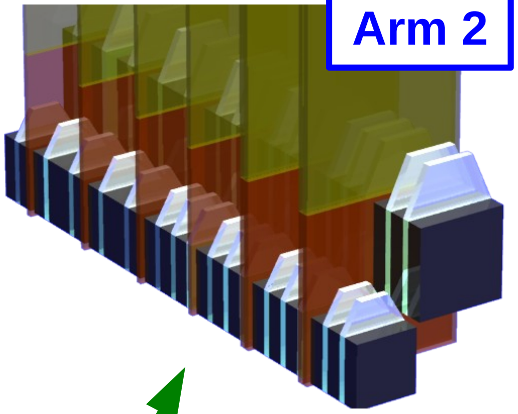
Detectors performance

- Two sampling and position sensitive calorimeters
- Tungsten + **GSO scintillators**
- Depth: 44 X_0, 1.6 λ
- Energy resolution:
  - < 3% (photons, E > 200 GeV)
  - ~ 40% (neutrons)

Arm 1



Arm 2



Arm 1

- Transverse size: 20 x 20 mm^2 and 40 x 40 mm^2
- 4 x-y **GSO bars** layers
- Position resolution: 100 μm (photons, E > 200 GeV)

Arm 2

- Transverse size: 25 x 25 mm^2 and 32 x 32 mm^2
- 4 x-y **silicon μstrip** layers
- Position resolution: 40 μm (photons, E > 200 GeV)

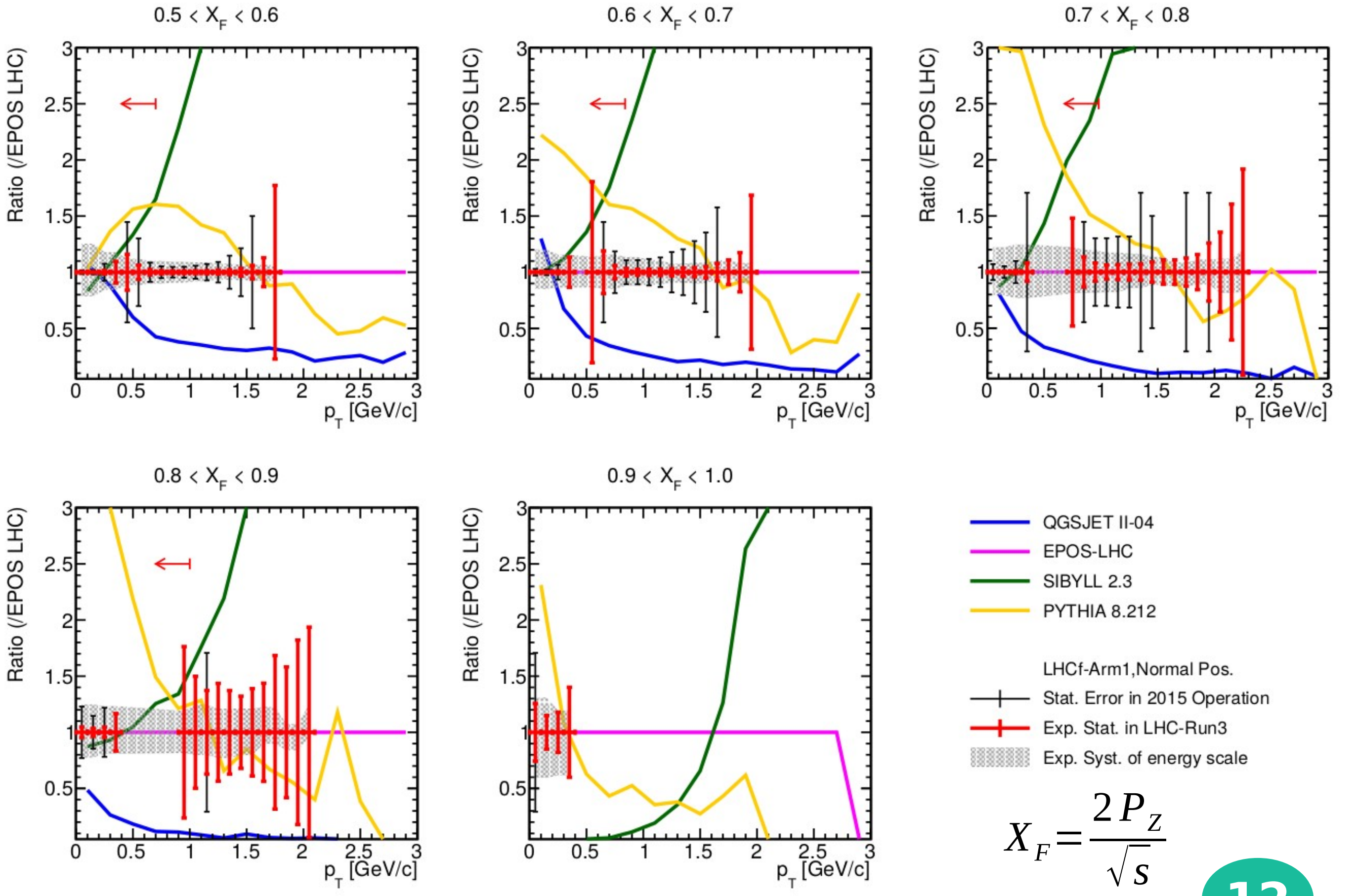
Run III: p-p @ 14 TeV

Motivations for p-p run @ 14 TeV

- **Extend the energy coverage to E_{CR} = 10^{17} eV** (however, no dramatical changes in CR physics are expected)
- **Increase of statistics:** the upgrade of Arm2 readout electronics and the adoption of a new trigger scheme will give the capability to run at an higher luminosity ($L \sim 10^{30}$ cm^{-2} s^{-1}, 10 times larger than luminosity of 13 TeV run)
  - Reduce statistic uncertainty of π^0 spectra
  - Allow the analysis of η and K^0 mesons spectra

p-p @ 14 TeV: π^0 spectrum

- The increase of statistics will reduce the statistic uncertainty and will extend the coverage in P_T and X_F
- The precision is sufficient to discriminate between different hadronic interaction models

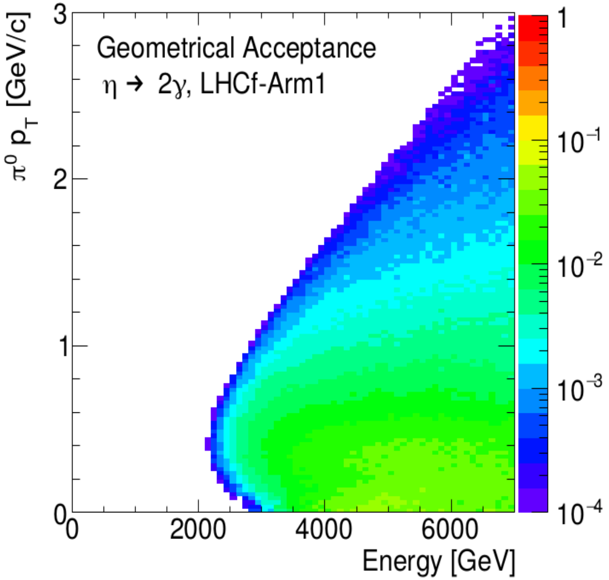


$$X_F = \frac{2P_Z}{\sqrt{s}}$$

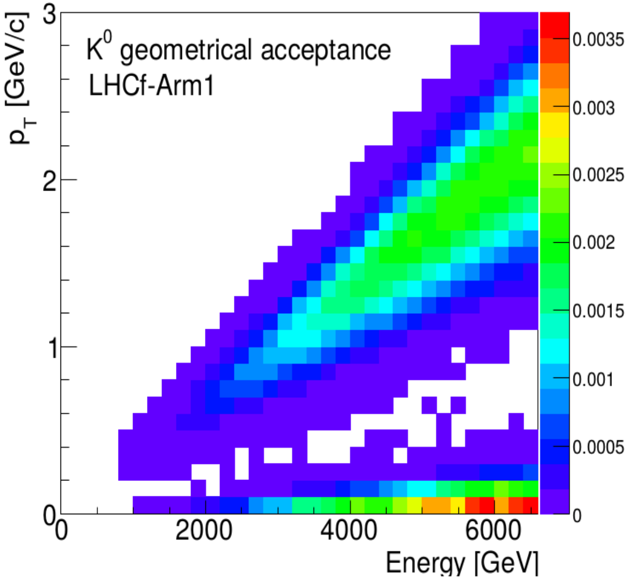
p-p @ 14 TeV: η and K^0 spectra

- **η meson ($\eta \to 2\gamma$, BR=39.4%)**
  - reconstructed from one photon in each calorimeter
  - expected ~5000 event with L_{int} ~20 nb^{-1}
- **K^0 meson ($K_S^0 \to 2\pi^0 \to 4\gamma$, BR=30.7%)**
  - 4 photons hitting the calorimeters
  - expected few hundreds of events with L_{int} ~20 nb^{-1}

η acceptance



K^0 acceptance



p-p @ 14 TeV: LHCf-ATLAS

- **Combined operation with ATLAS**
  - successfully performed during 13 TeV operation
  - using central particle production information from ATLAS, a sample of low-mass diffractive events ($M_X < 50$ GeV) can be selected
- **Combined operations with ALFA roman pots (under discussion)**
  - identification of single diffractive events, measurements of Δ resonance ($p+p \rightarrow p+\Delta \rightarrow p+p+\pi^0$) and bremsstrahlung ($p+p \rightarrow p+p+\gamma$) events
- **Combined operations with ZDC (under discussion)**
  - improve neutron energy resolution from 35-40% to 20%

p-p @ 14 TeV: beam requirements

- **Proposed beam parameters**
  - colliding bunches: ~500
  - minimum bunch spacing: 200 ns
  - luminosity: $< 10^{30}$ cm^{-2} s^{-1}
  - pile-up (μ): 0.014
  - beam crossing: vertical, downward (best: 290 μrad)
  - β*: ~10 m
- **Operation time**
  - with optimal conditions, 1-2 days (beam setup + data taking) are enough to achieve our minimum physics program (L_{int} ~20 nb^{-1})

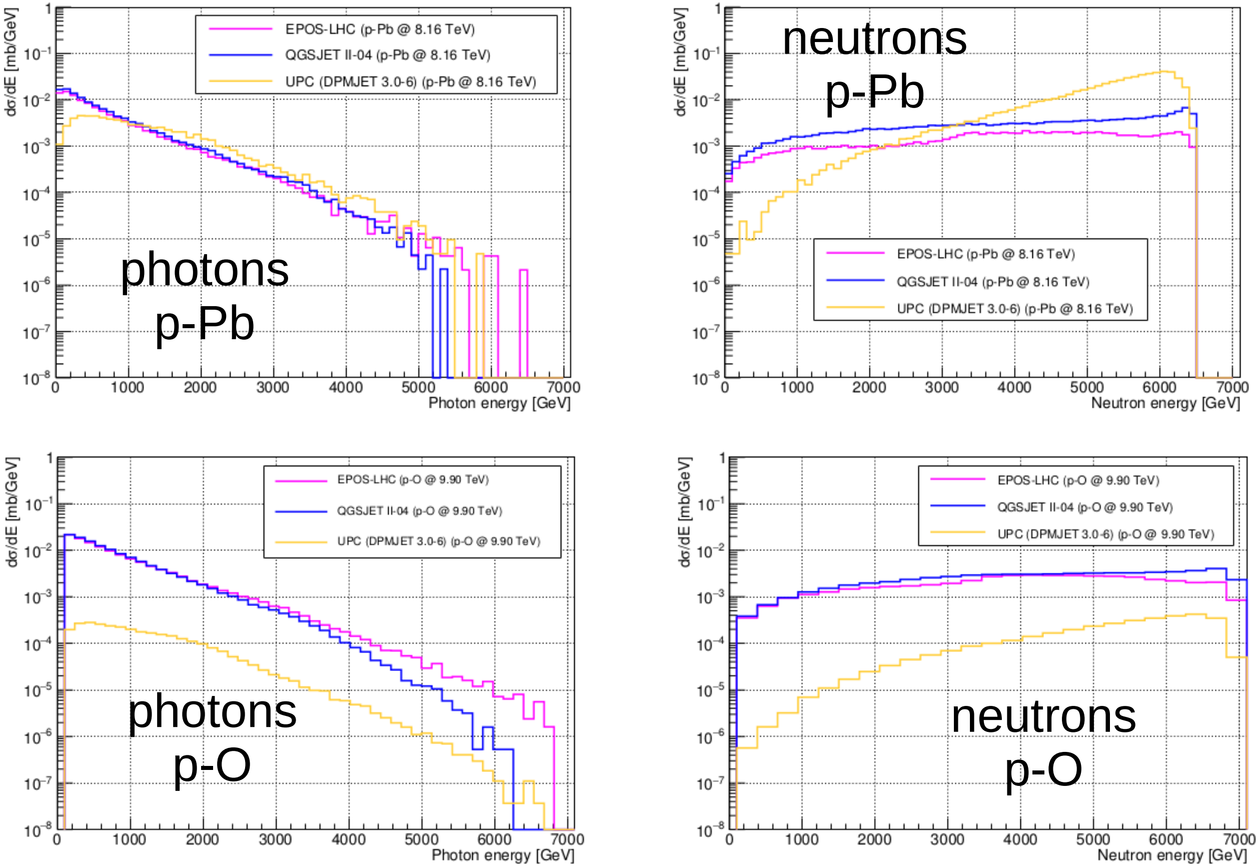
Run III: p-O @ 9.9 TeV

Motivations for p-O run @ 9.9 TeV

- **Best configuration to test CR-atmosphere interaction**
  - operation on p-remnant side
- **Reduced Ultra Peripheral Collisions (UPC) contribution with respect to p-Pb collisions**
  - LHCf detectors can not discriminate UPC events from QCD ones
  - UPC contribution is estimated with MC simulations and subtracted from data
  - Large systematic uncertainty associated to UPC MC simulations:
    - virtual photon flux (~10%)
    - proton-photon interaction (up to 20%)

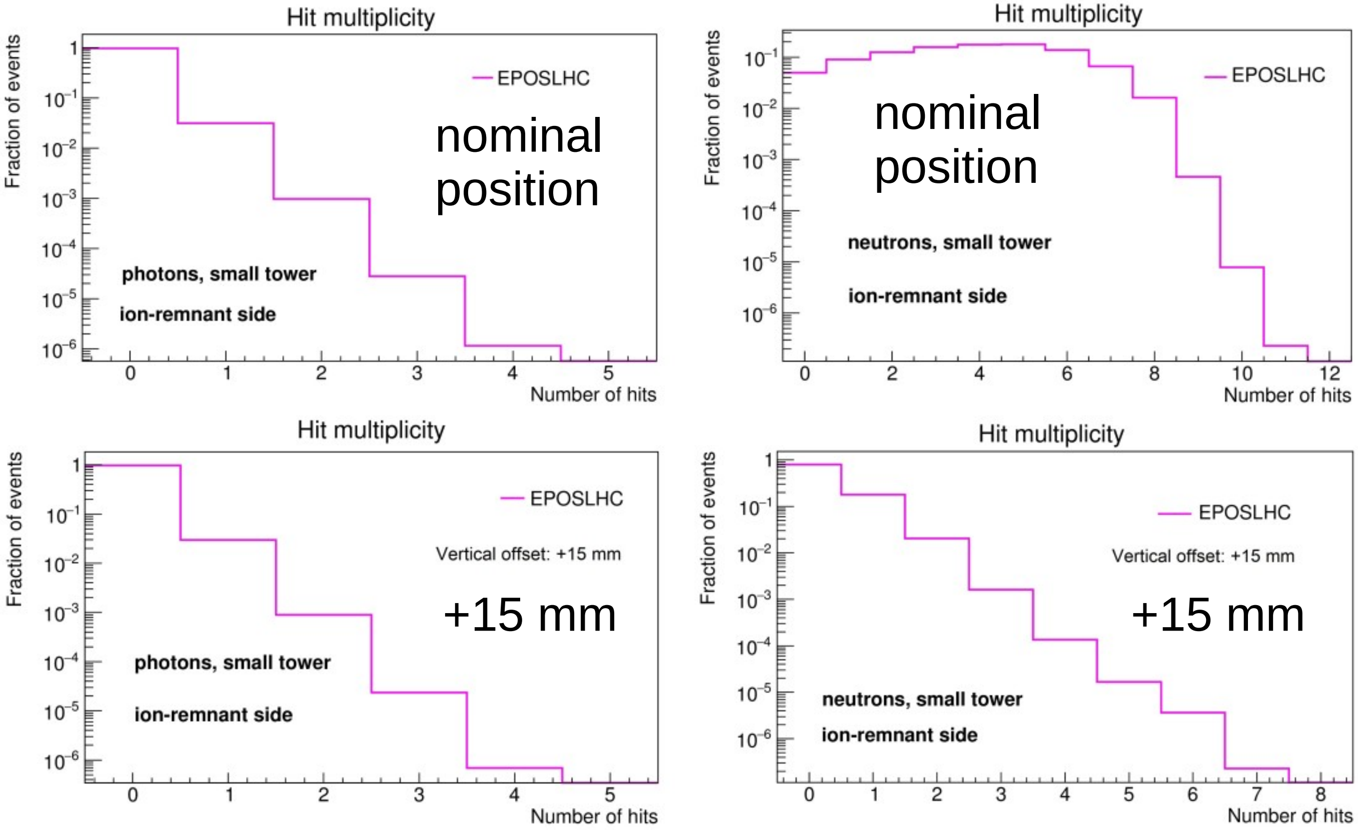
p-O @ 9.9 TeV: UPC contribution

- **p-Pb:** the UPC contribution is of the same order (or greater) of QCD one
- **p-O:** the UPC contribution is 1-2 order of magnitude smaller than QCD one → negligible systematic error associated to UPC subtraction



p-O @ 9.9 TeV: O-remnant side

- Too much multiplicity leaving the detector in the nominal position on the beam centre
- The detector must be shifted 15 mm upward to perform the measurements
- Similar setup in case of O-O collisions



p-O @ 9.9 TeV: beam requirements

- **Proposed beam parameters**
  - colliding bunches: 43
  - minimum bunch spacing: 2 μs
  - luminosity: $< 10^{28}$ cm^{-2} s^{-1}
  - pile-up (μ): < 0.01
  - beam crossing: vertical, downward (best: 290 μrad)
  - β*: ~10 m
- **Operation time**
  - with optimal conditions, 2 days (beam setup + data taking) are enough to achieve our minimum physics program (L_{int} ~0.7 nb^{-1})

Detector upgrade

Trigger logic

- **“Shower” trigger**
  - prescale factor: 14
  - ~100% efficiency for photons (E > 200 GeV)
  - ~70% efficiency for neutrons (E > 1 TeV)
- **“Type I” trigger**
  - prescale factor: 1
  - π^0 with one photon in each calorimeter (efficiency ~98%)
  - η
- **“High EM” trigger**
  - prescale factor: 1
  - high energy photons (E > 1 TeV)
  - π^0 with both photons in the same calorimeter (efficiency ~97%)

Arm2 DAQ upgrade

- **Replace aged electronics**
  - lack of replacements for FOXI optical transmitters/receivers, control ring boards, ...
- **Speed-up the readout by a factor ~10**
  - Arm2 silion DAQ gives the main contribution to dead time (~1 ms)
  - GbEthernet (~1 Gbps) protocol will be used instead of FOXIchip protocol (~100 Mbps)

Summary

- **LHCf will operate during Run III of LHC**
- **p-p run @ 14 TeV (2021)**
  - increase of statistics (π^0)
  - η, K^0
- **p-O run @ 9.9 TeV (2023?)**
  - ideal condition for cosmic rays study
  - suppression of UPC contribution with respect to p-Pb collisions
- **The technical proposal of LHCf has already been approved by LHCC Research Board**
- **The upgrade of Arm2 DAQ electronics is ongoing**

Thank you for your attention!

if you have more questions:

https://cern.zoom.us/j/5653173681?pwd=RUxEOEsreXE1VVNoVWkxM0FTOHZpZz09