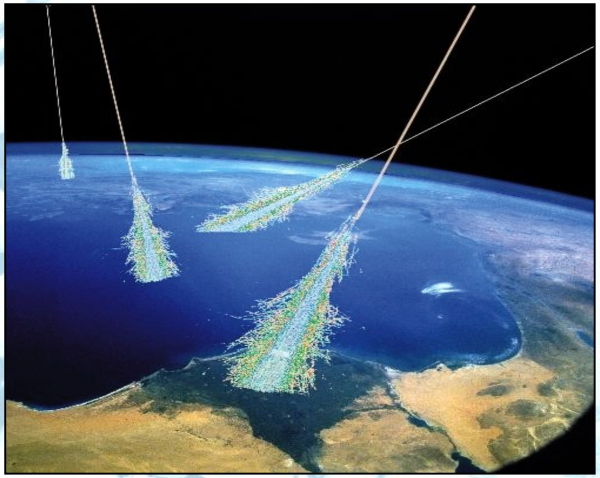
CERN Council - Open Session

18 December 2015

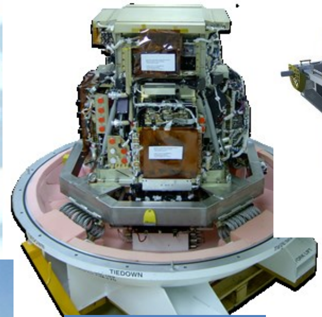
LHCf 2015
The Short(est) Report

Lorenzo Bonechi - INFN Firenze, Italy
On behalf of the LHCf Collaboration

LHC and cosmic rays



- ***Cosmic rays***: flux of charged particles hitting the Earth atmosphere at a rate ~1000 $m^{-2}s^{-1}$; officially discovered on 1912. **Energies up to one million times greater than the proton energy @ LHC!!!**
- Cosmic rays produce "**showers**" of secondary particles in atmosphere
- Primary cosmic radiation can be studied:
  - Outside the atmosphere on board of satellites (e.g. PAMELA) or the International Space Station (e.g. AMS-02).
    - Direct measurement.
  - On balloon (e.g. CAPRICE, CREAM).
    - Direct measurement.
  - At ground level (e.g. AUGER, TA)
    - Indirect measurement.



PAMELA

AMS-02

CREAM

AUGER =

× N

View of “Duomo di Firenze”

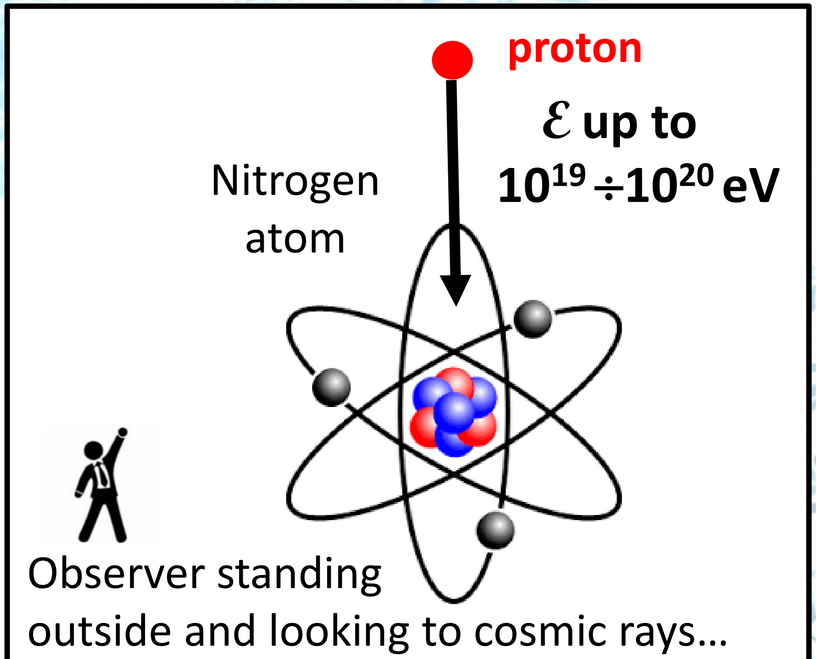
Clock Tower in San Casciano V.P.

Artistic representations…

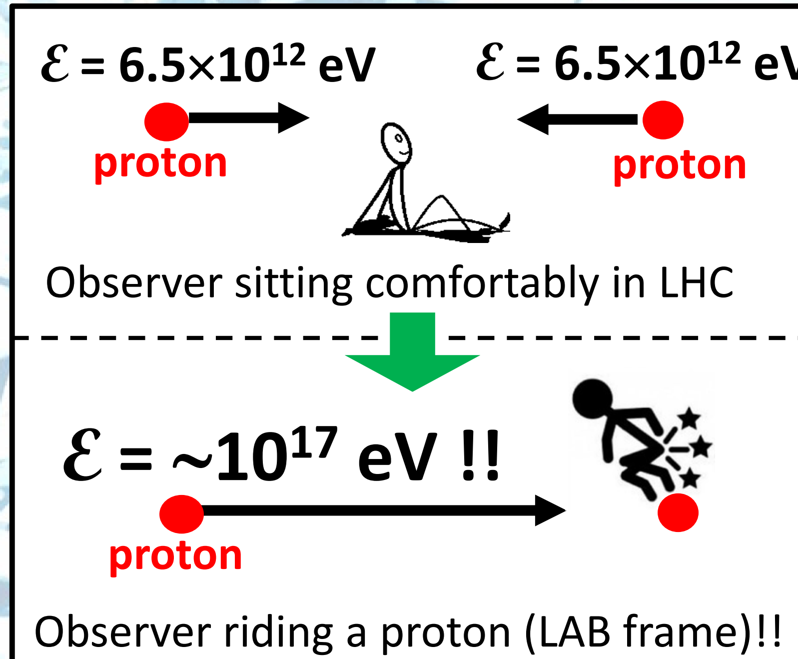
LHCf: LHC $\overset{?}{\leftrightarrow}$ COSMIC RAYS

- Possibility to study particles in the **forward direction** at LHC (neutrals: γ, π^0, n)
  - Forward secondary particles carry a great fraction of the primary energy
- 6.5 TeV + 6.5 TeV in the LHC frame → **~10^{17} eV** in the laboratory frame (LAB)
- Calibration of **hadronic interaction models** used for the simulation of atmospheric showers

COSMIC RAYS



LHC



THE LHCf COLLABORATION

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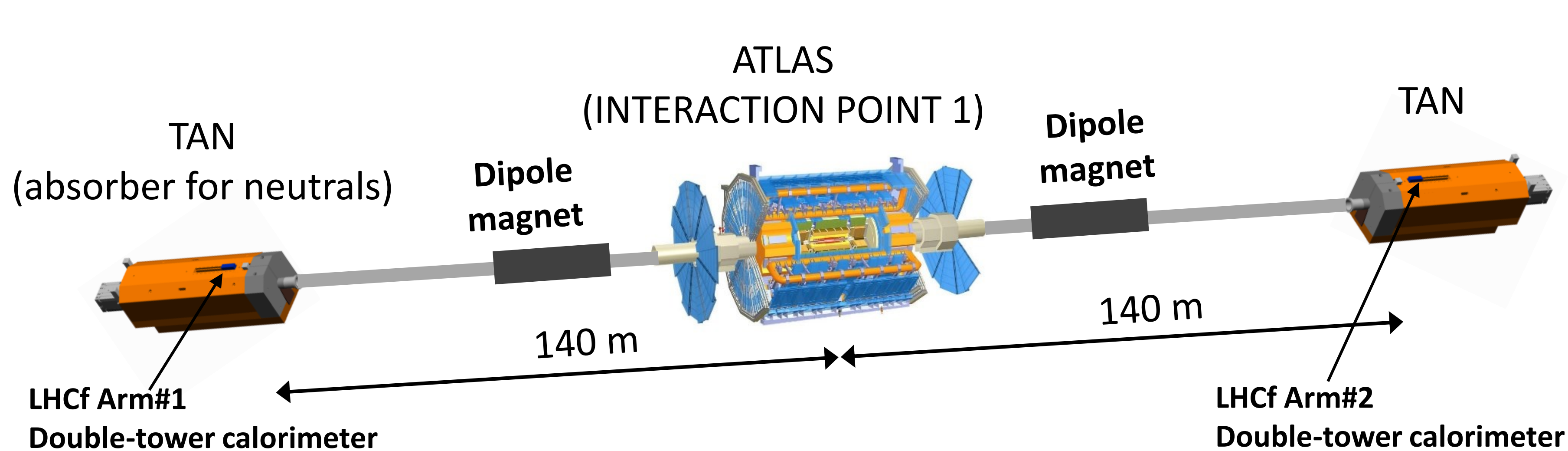
LHCf EXPERIMENTAL SET-UP



Position resolution: < 200 µm (Arm1) and 40 µm (Arm2)

Energy resolution: < 5% for photons; 30% for neutrons

Pseudo-rapidity range:

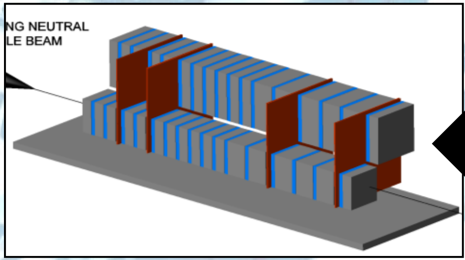
η > 8.7 @ zero X-ing angle

η > 8.4 @ 140 µrad

Arm1 Detector

2cm x 2cm + 4cm x 4cm

4 X-Y GSO bars tracking layers



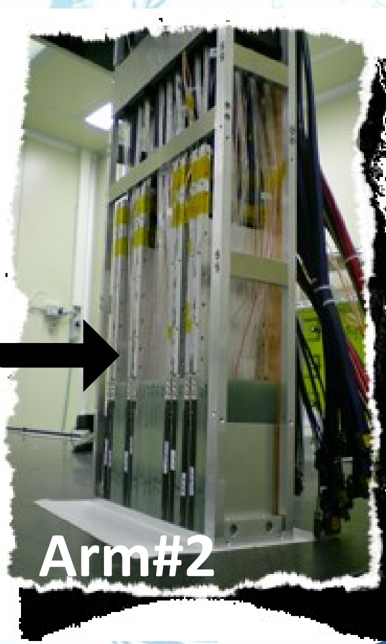
Arm2 Detector

2.5cm x 2.5cm + 3.2cm x 3.2cm

4 X-Y Silicon strip tracking layers

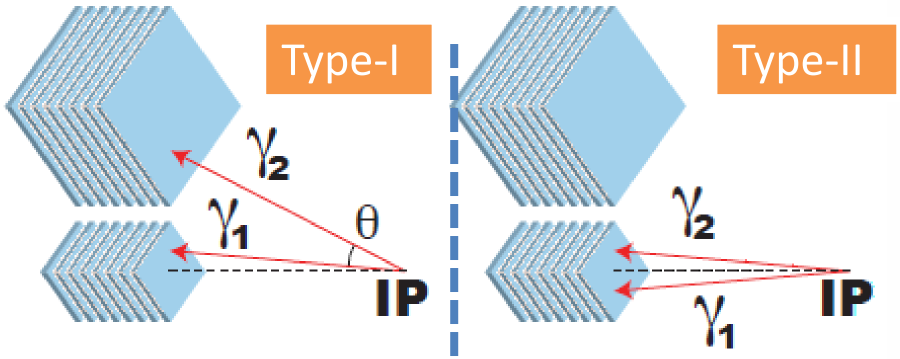
44 X_0

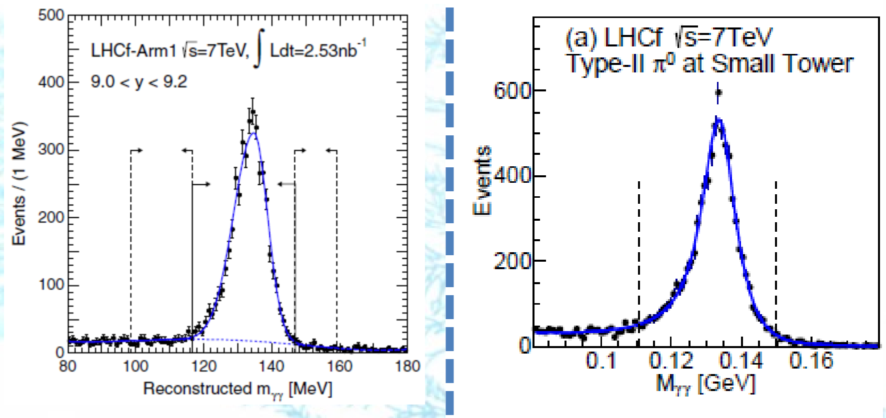
1.6 λ_{int}

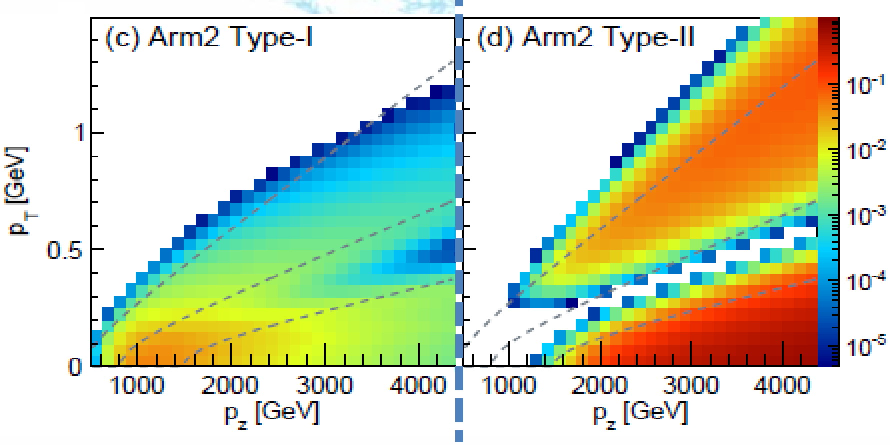


Physics program and table of publications

<table>
<tr><th></th><th>Proton equivalent energy in LAB (eV)</th><th>γ</th><th>n</th><th>π^0</th></tr>
<tr><td>SPS test beam</td><td></td><td>NIM A, 671, 129 (2012)</td><td>JINST 9 P03016 (2014)</td><td></td></tr>
<tr><td>p-p 900 GeV</td><td>4.3×10^{14}</td><td>Phys. Lett. B 715, 298 (2012)</td><td></td><td></td></tr>
<tr><td>p-p 7 TeV</td><td>2.6×10^{16}</td><td>Phys. Lett. B 703, 128 (2011)</td><td>Phys. Lett. B 750 (2015) 360-366</td><td>Phys. Rev. D 86, 092001 (2012)
+
Submitted to Phys. Rev. D (Type-II)</td></tr>
<tr><td>p-p 2.76 TeV</td><td>4.1×10^{15}</td><td></td><td></td><td rowspan="2">Phys. Rev. C 89, 065209 (2014)
+
Submitted to Phys. Rev. D (Type-II)</td></tr>
<tr><td>p-Pb 5.02 TeV</td><td>1.3×10^{16}</td><td></td><td></td></tr>
<tr><td>p-p 13 TeV</td><td>9.0×10^{16}</td><td colspan="3">Data taken in June 2015 after the restart of LHC</td></tr>
</table>







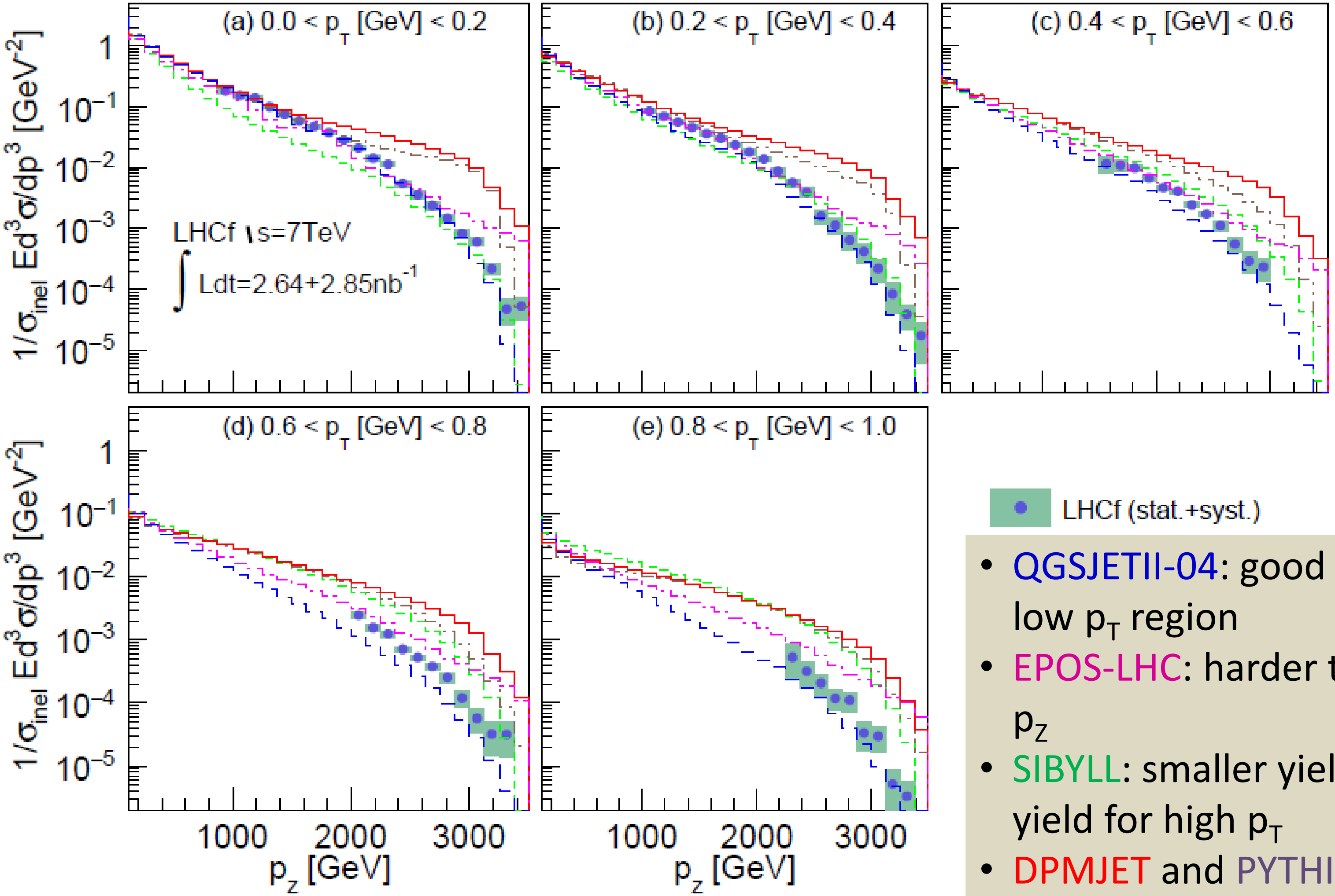
- pair of photons each detected in one of the towers (Type-I) or both in the same tower (Type-II)
- multi-hit events excluded
- p_T and p_Z of π^0 reconstructed from energy and incident position of photon pair
- invariant mass distribution to select π^0 candidates

$$(M_{\gamma\gamma})^2 = 4 \cdot E_1 \cdot E_2 \cdot \sin^2(\theta/2)$$

- data are corrected for experimental effects:
  - background contamination
  - detector response and reconstruction efficiency (unfolding)
  - detector acceptance
  - multi-hit rejection efficiency

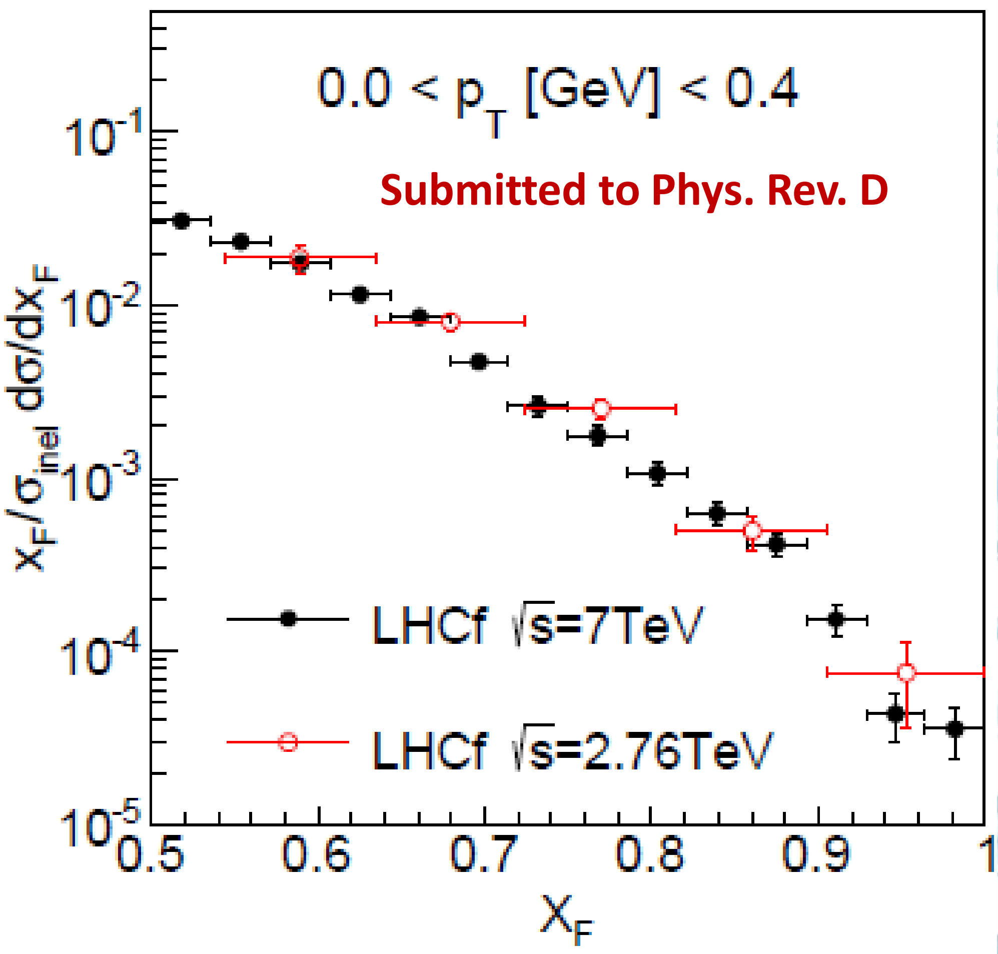
π^0 MOMENTUM SPECTRA - 7 TeV pp

Submitted to Phys. Rev. D



- QGSJETII-04: good agreement in the low p_T region
- EPOS-LHC: harder than data for high p_Z
- SIBYLL: smaller yield for low p_T, larger yield for high p_T
- DPMJET and PYTHIA: ok for low p_Z (and low p_T)

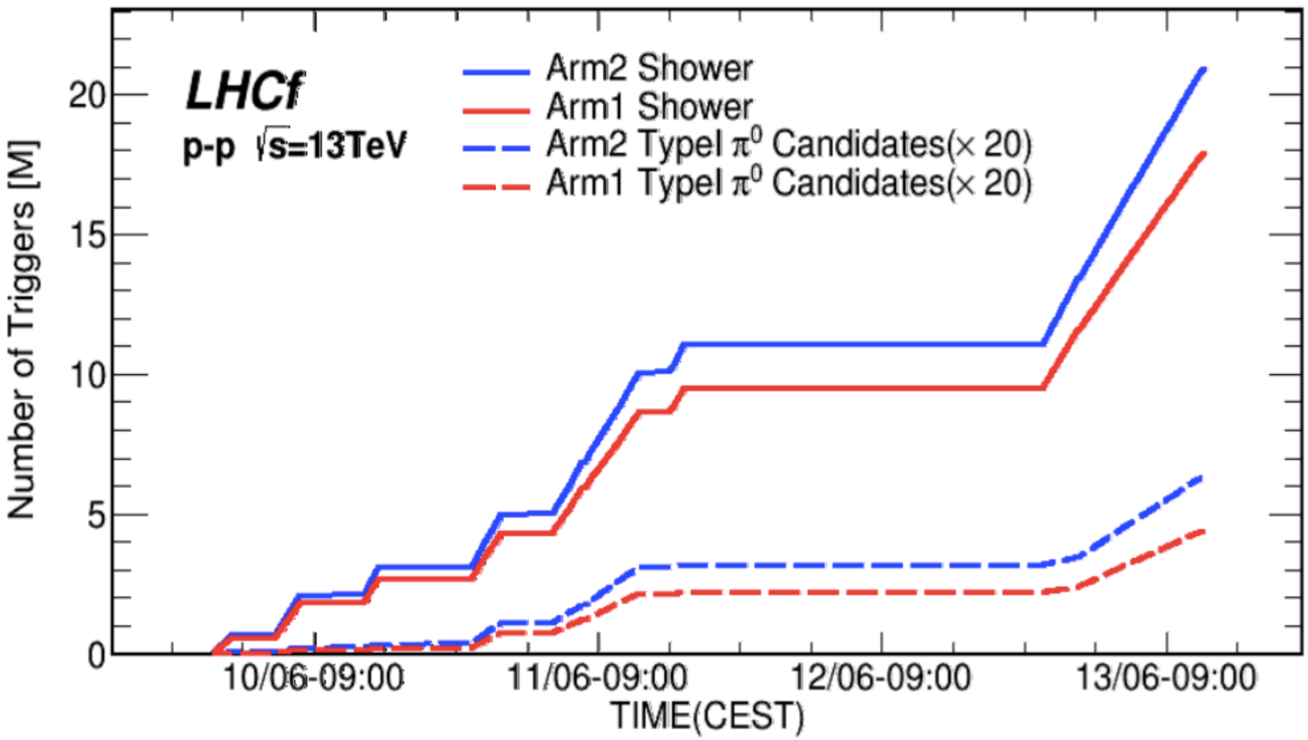
FEYNMAN SCALING IN FORWARD π^0 PRODUCTION



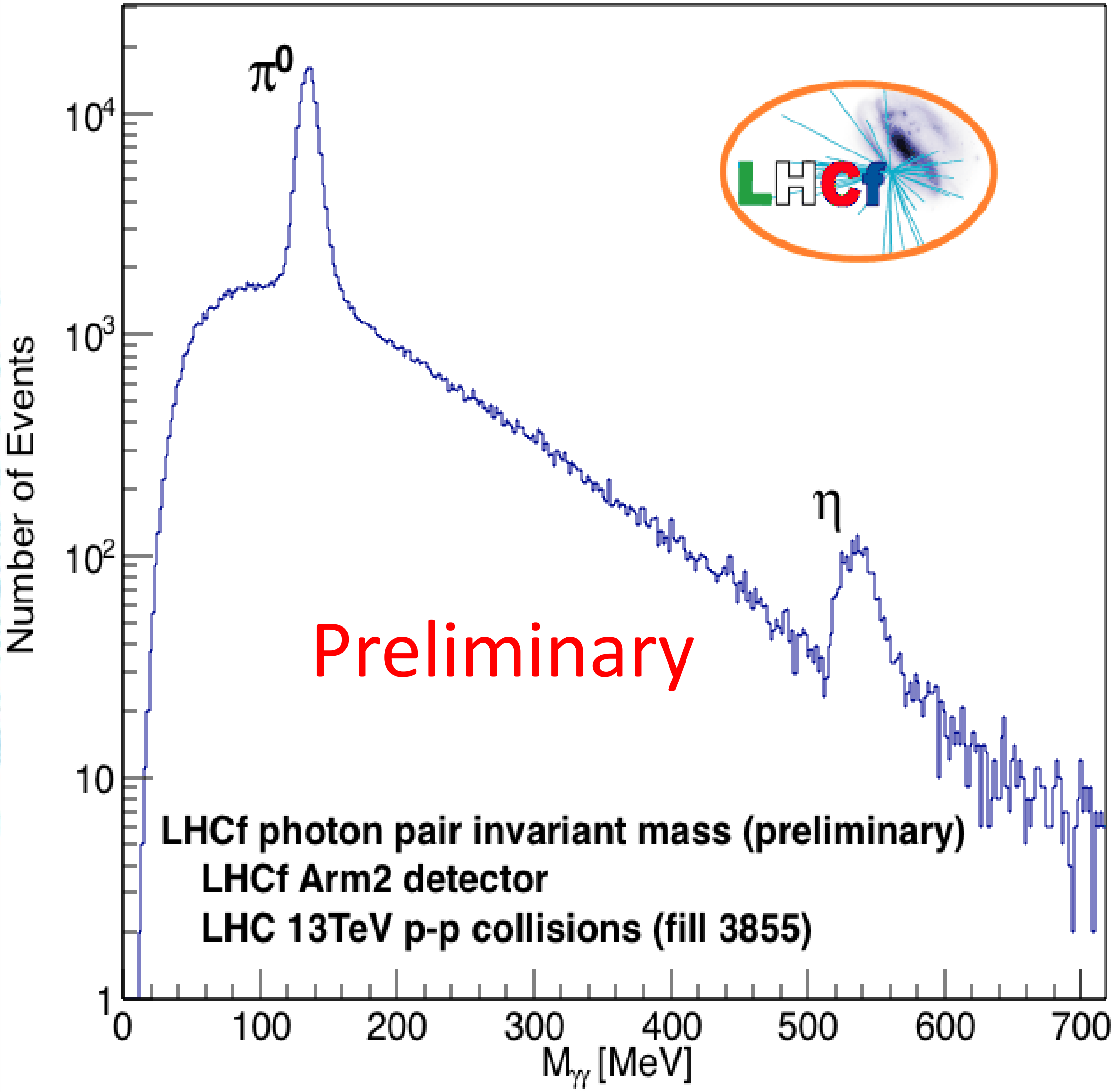
- Test of independence of cross section of secondary particles as a function of $x_F = 2p_Z/\sqrt{s}$ in the very forward rapidity region wrt the c.m. energy $\sqrt{s}$
- **Feynman scaling holds at ±20% level**

LHC 13 TeV p-p run in 2015

- **Detector upgrade in 2014: plastic scintillators → GSO, new silicon detectors**
- During Week24, June 9th-13th, **LHCf dedicated low-luminosity run**
- Total of 26.6 hours with $L = 0.5 \div 1.6 \cdot 10^{29}\ cm^{-2}s^{-1}$
- **~ $39 \cdot 10^6$ showers → $0.5 \cdot 10^6$ π^0 events**
- Trigger exchange with ATLAS
- Detector removal on June 15th during TS1
- Run was very successful!



FIRST LOOK AT 13 TeV DATA



Interest for p-Pb run in 2016 or 2017

- Interest of LHCf for a p-Pb run (8 TeV ?)
- We are considering the installation of one detector to measure in the proton remnant side
- Simulation: work in progress
- **Presentation of a LOI at the beginning of 2016**

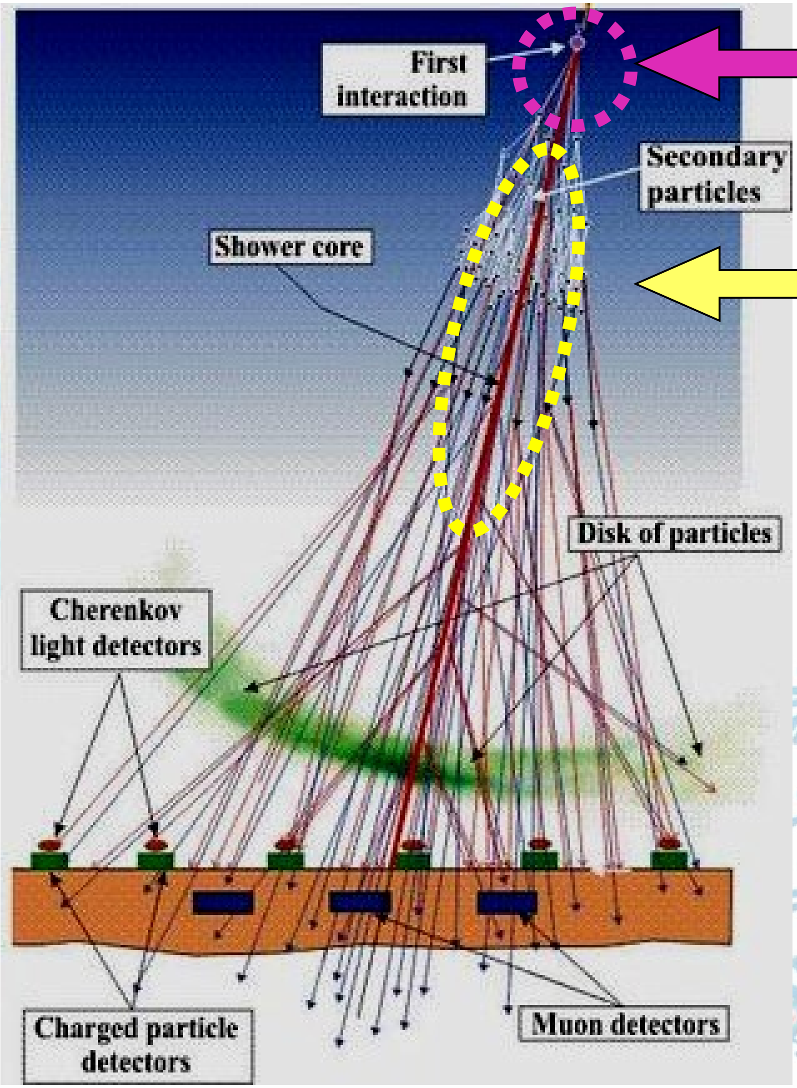
Conclusions

- LHCf is a LHC experiment to measure neutral particle produced in the very forward region at LHC → connection to CR physics
- Many results already published for the previous runs
- **Very successful 13 TeV p - p run in June 2015 after detector upgrade**
- Trigger sharing with ATLAS and ALFA
- Data analysis is continuously in progress
- **Interest for the p-Pb run** (on 2016 or 2017)
  - LOI to be presented at LHCC at the beginning of next year
- **The LHCf Collaboration would like to thank all the people involved: LHCC, LHC machine people, Physics Coordinators, ATLAS management…**

BACKUP SLIDES

Cosmic Ray Showers

Animation taken from http://astro.uchicago.edu/cosmus/projects/aires/

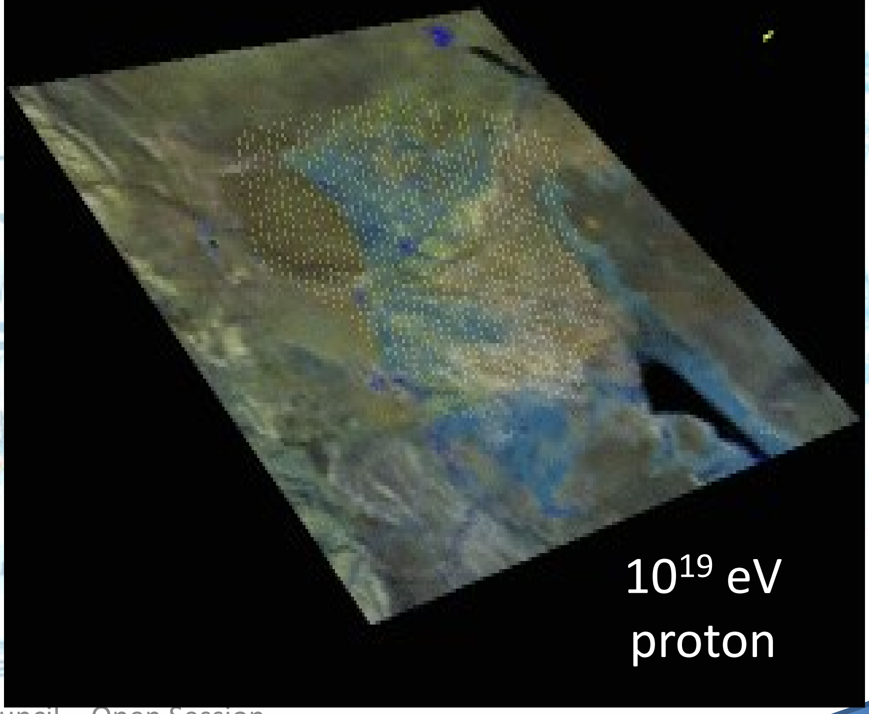


Inelastic cross section

→ Probability of interaction in atmosphere

Forward energy spectrum

→ Development of the shower



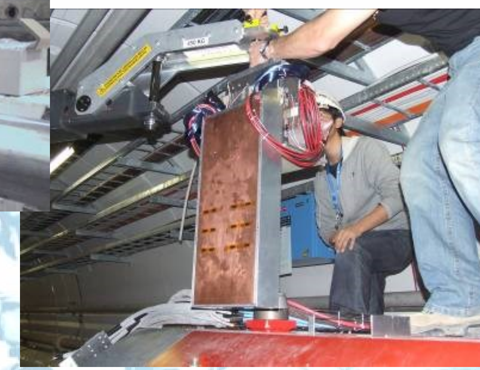
BRIEF HISTORY OF LHCf

- May 2004 LOI
- Feb 2006 TDR
- June 2006 LHCC approved

Jul 2006
construction

Aug 2007
SPS test beam

Jan 2008
installation
Sep 2008
1st LHC beam



Dec 2009 - Jul 2010
0.9TeV & 7TeV pp,
detector removal

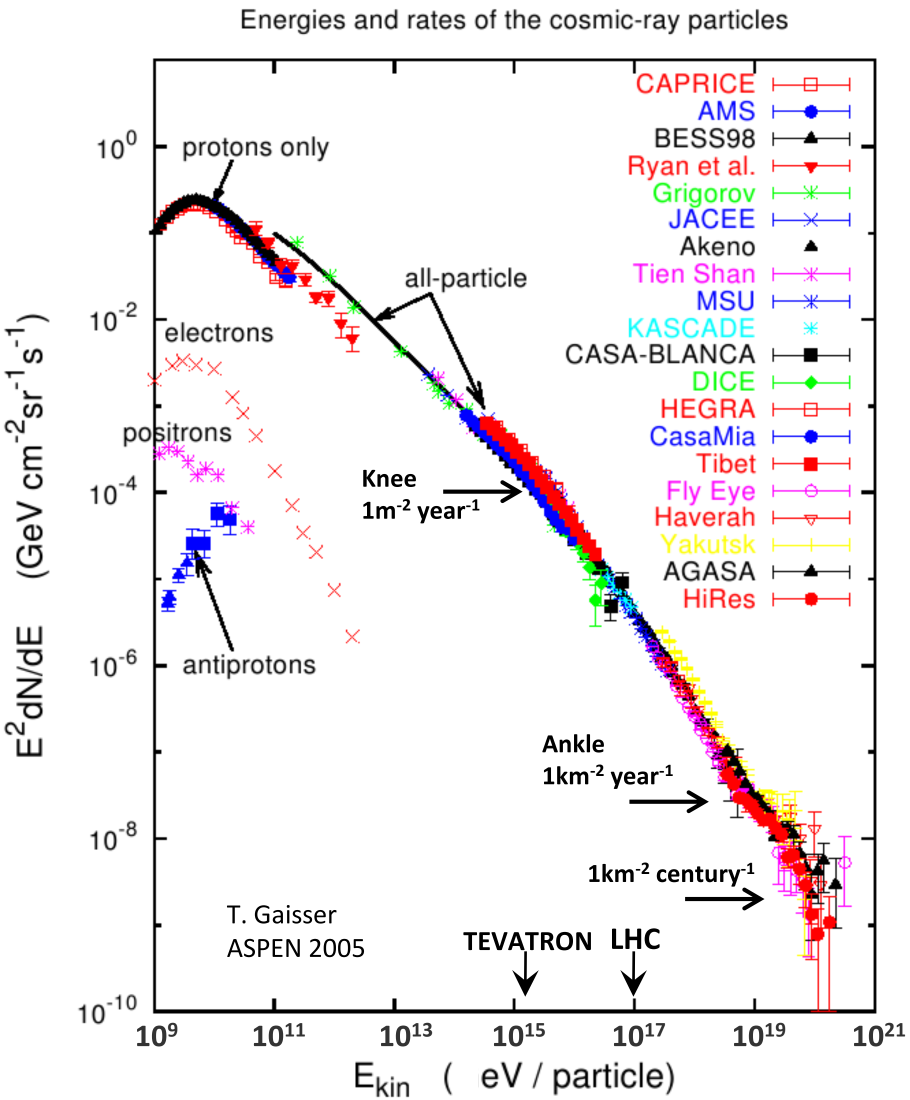
Dec 2012 - Feb 2013
5.02 TeV/n pPb & 2.76TeV
pp (Arm2 only),
detector removal

- 2013-2015 detector upgrade
- Several test beams

May - June 2015
13 TeV pp (dedicated run),
detector removal

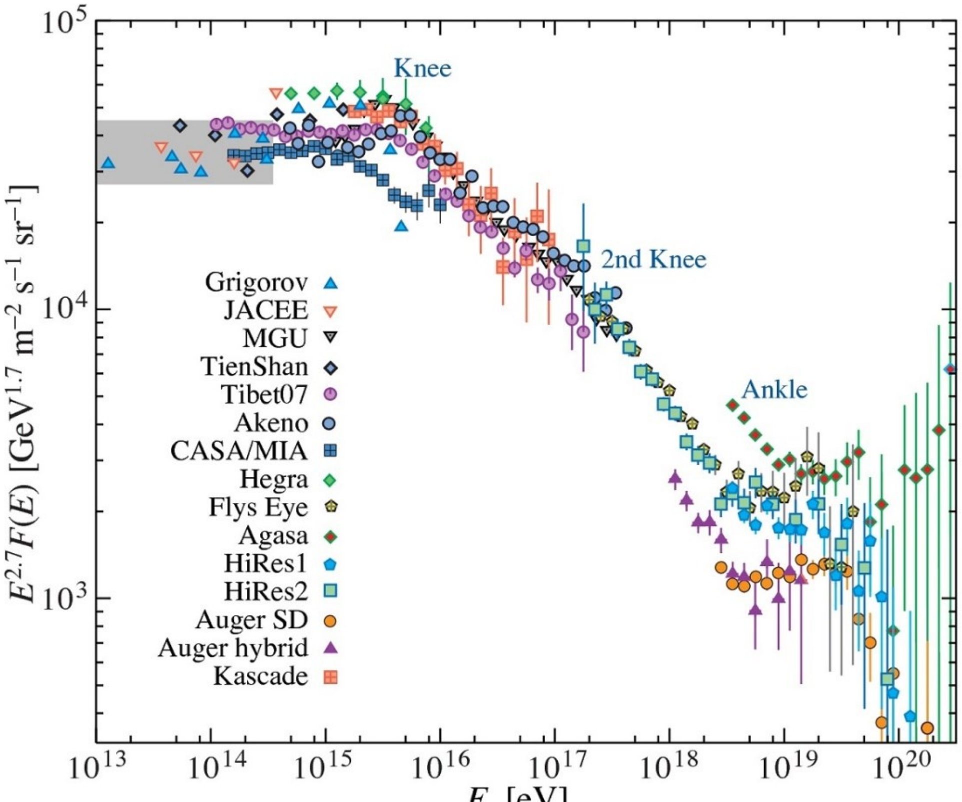
Energy spectrum of charged cosmic rays

- Measured over 12 decades of energy per particle
- **Direct measurement** up to E~TeV/particle by space or balloon experiments
- **Indirect measurement** by ground based experiments up to 10^{20} eV
  - Extremely rare events: large geometrical acceptance is required
- Knee: CR acceleration mechanisms?
- Ankle: due to the shape of cross sections for p-γ_{CMB} interaction?



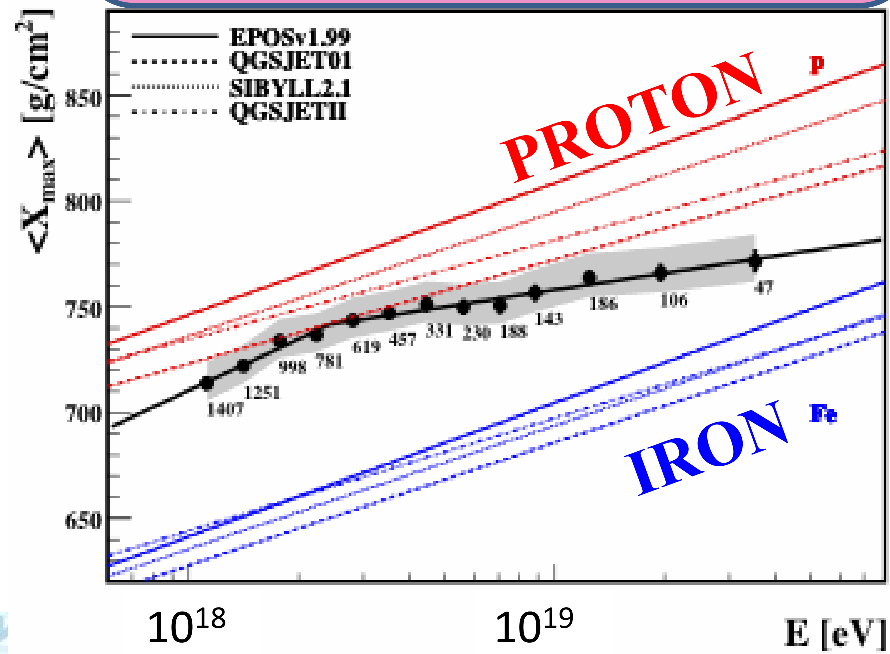
UHE Cosmic-Ray data

K. Nakamura et al. (Particle Data Group)
J. Phys. G 37, 075021 (2010)



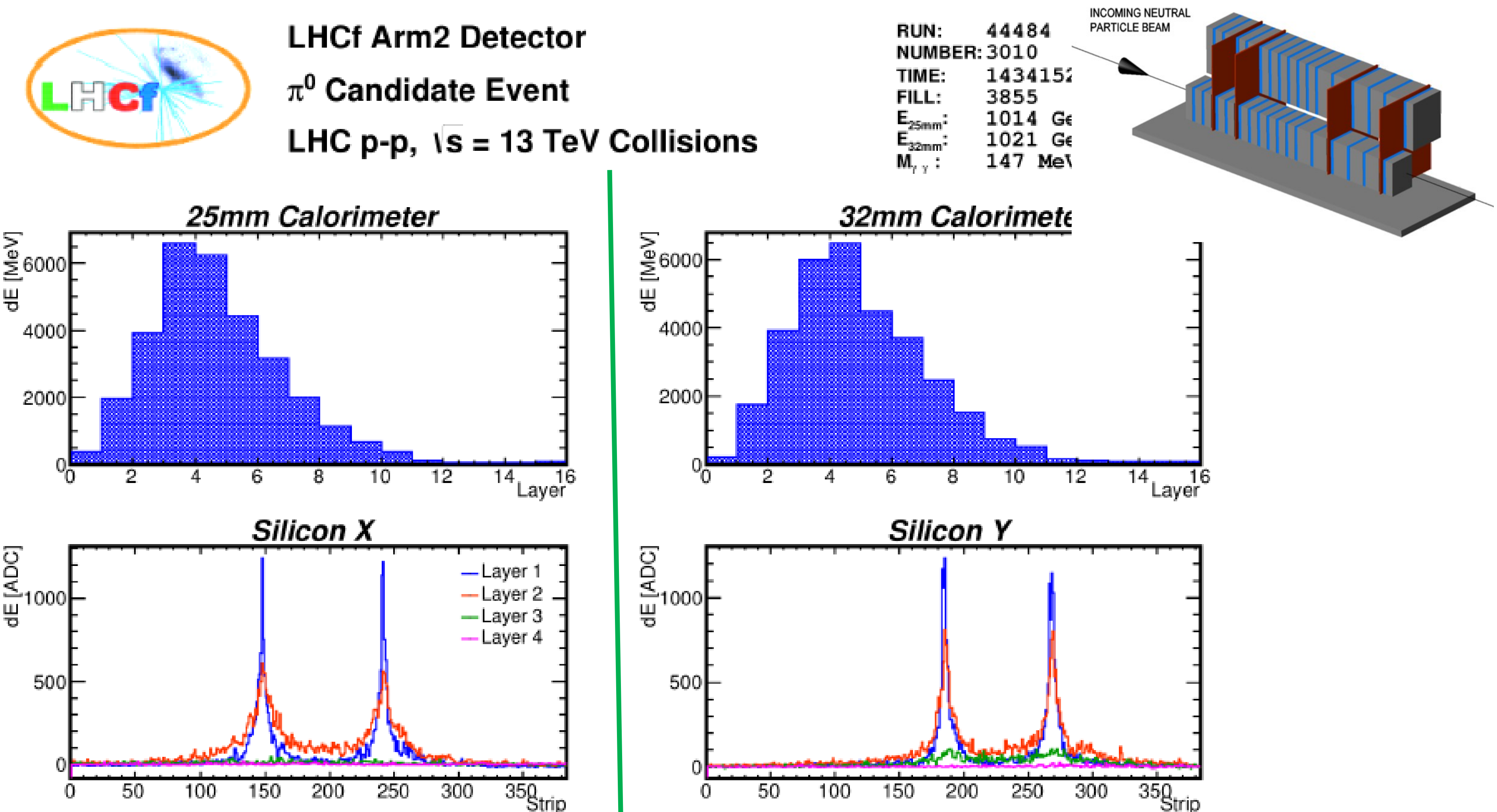
Log of energy spectrum multiplied by $E^{2.7}$ as a function of the measured primary energy

Mean depth of showers ($<X_{max}>$) as function of the measured primary energy (E)



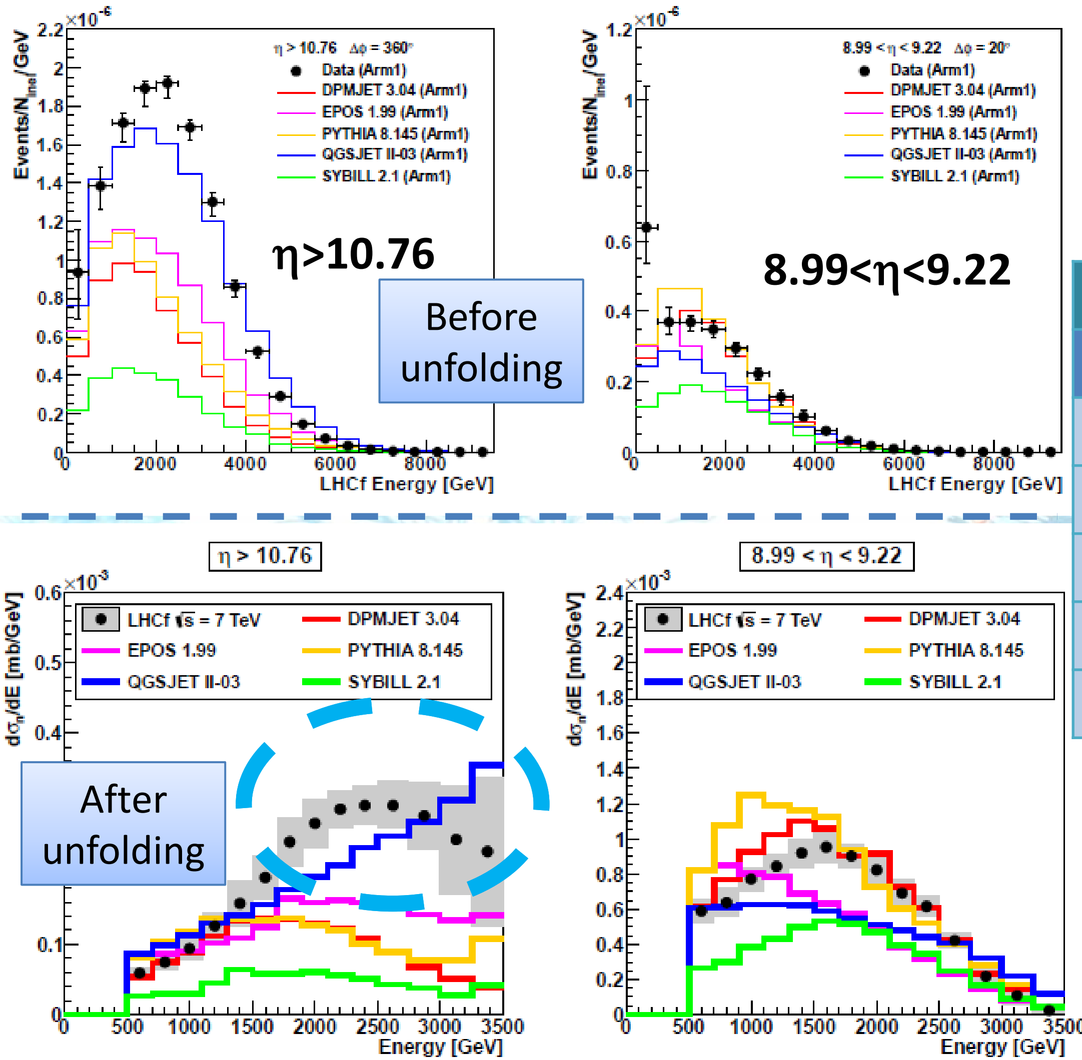
Auger Collaboration, XXXII ICRC

An impressive high energy π^0



SMALL TOWER **LARGE TOWER**

Inclusive neutron spectra (7 TeV pp)



Phys. Lett. B 750 (2015) 360-366

n / γ ratio	η>10.76	8.99<η<9.22
LHCf data	3.05±0.19	1.26±0.08
DPMJET3.04	1.05	0.76
EPOS 1.99	1.80	0.69
PYTHIA 8.145	1.27	0.82
QGSJET II-03	2.34	0.65
SYBILL 2.1	0.88	0.57

More abundant neutron yield wrt photons, not expected from MC

Large high-energy peak in the η>10.76 region (predicted only by QGSJET)
→ small inelasticity in the very forward region