Latest results from LHCf on very forward particle production at LHC

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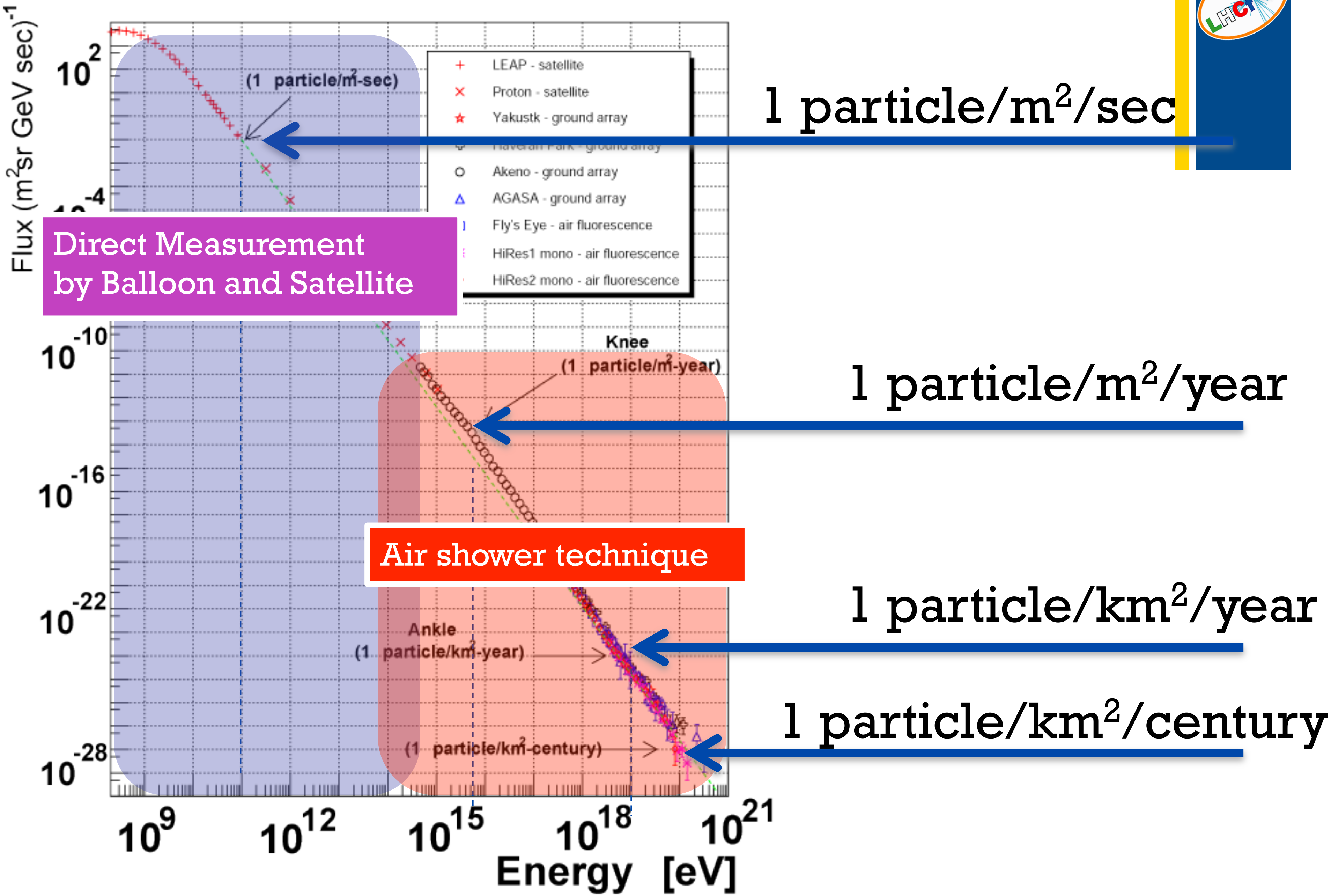
Latest results from the LHC
CERN, July 12th, 2012

Physics Motivations

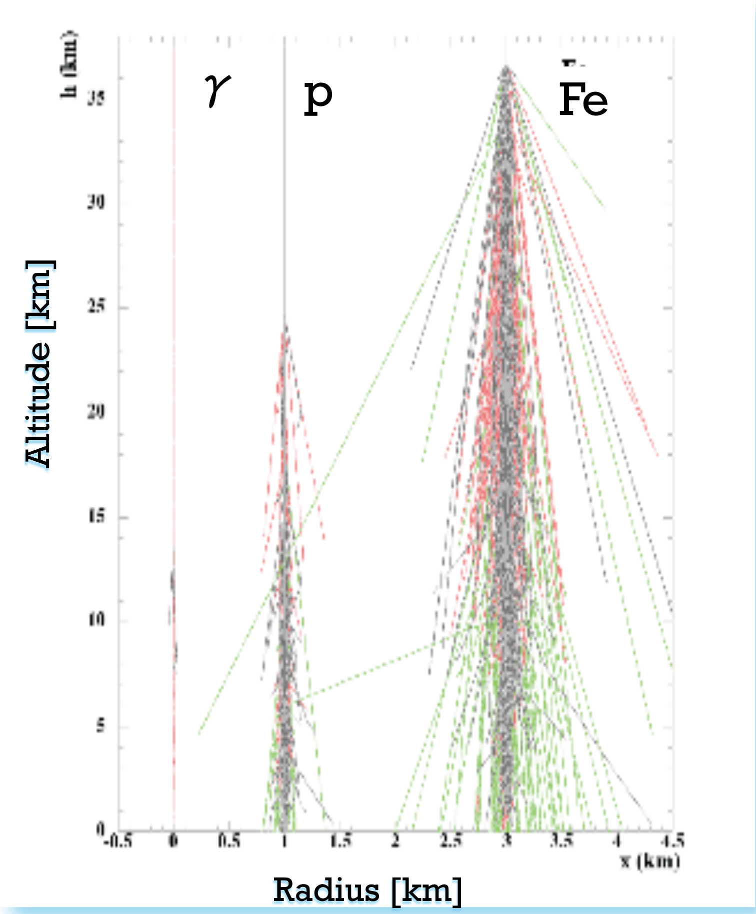
Impact on High Energy Cosmic Ray Physics

The Cosmic Rays energy spectrum

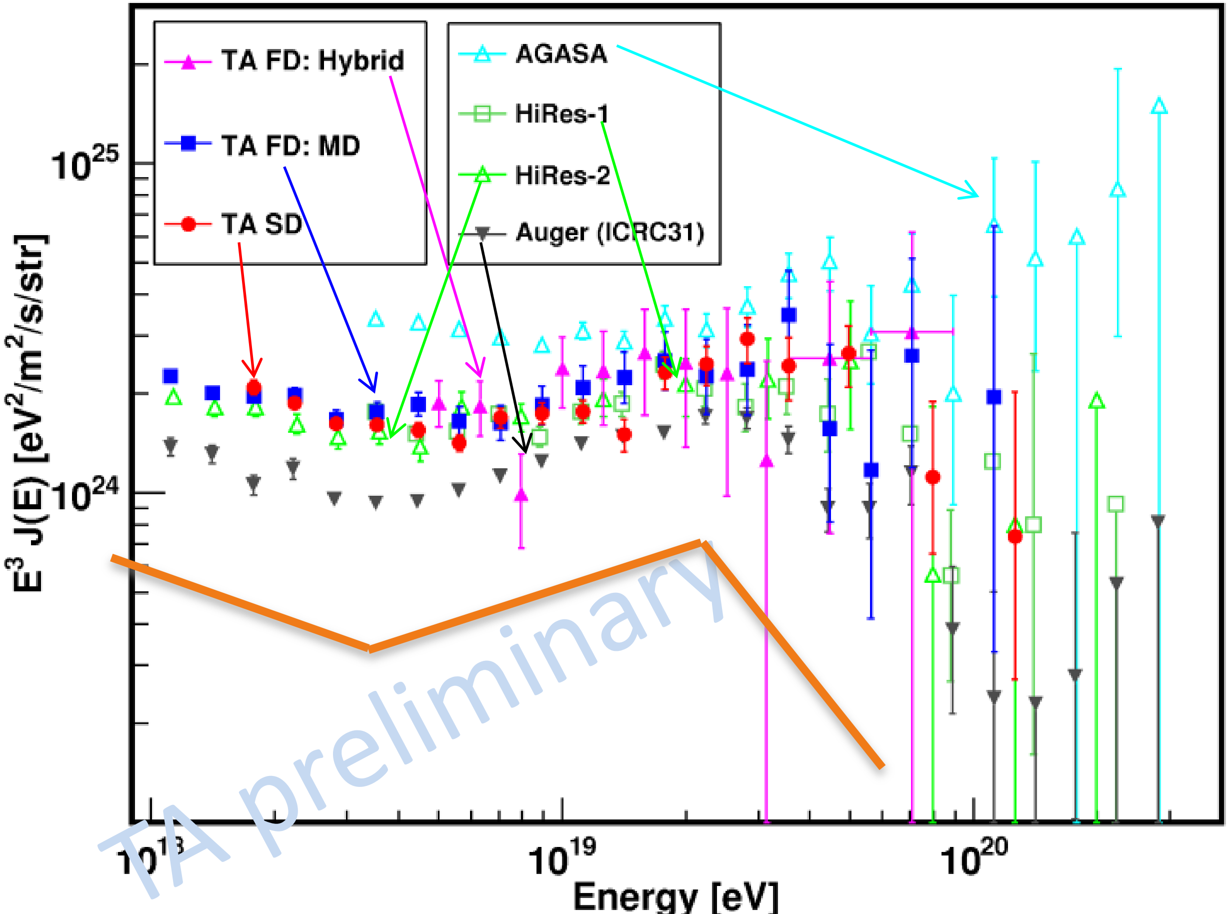


+ Indirect measurement of cosmic rays

- Composition and energy of cosmic rays affect the generation of Extended Air Showers
- Precise understanding of high-energy cosmic ray should be achieved with the indirect measurement technique
- Comparison between the MC simulation of EAS and observation is necessary to infer the information on the primary CR from the measurement of the shower
- Largest systematic uncertainty of indirect measurement is caused by the finite understanding of the hadronic interaction of cosmic ray in atmosphere



+ *Example I: the VHECR Energy spectrum*



Auger and Telescope Array are currently taking data

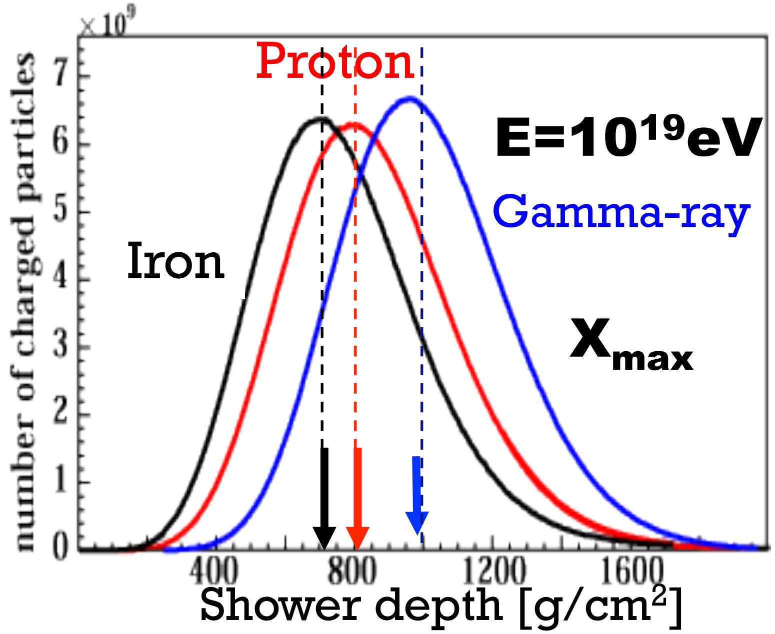
Auger has the highest statistics.

Two kinks: the ankle and the GZK cutoff

Both Auger and TA spectra shows two kinks… **BUT…**
The fluxes are significantly different!
Energy scale problem? → Precise knowledge of the hadronic interaction mechanism at VHE is necessary

Example II: Chemical Composition

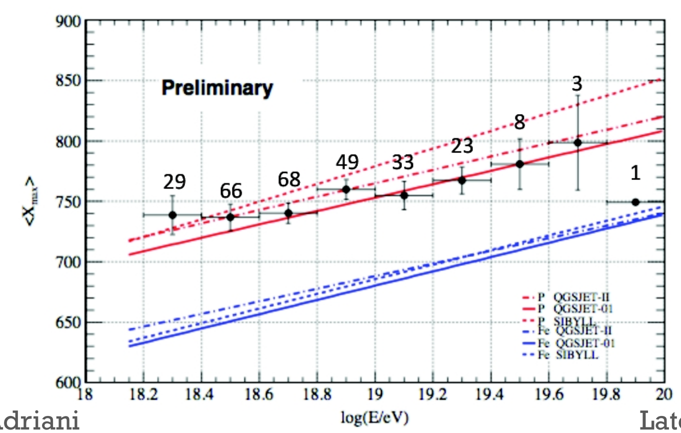
- The Chemical composition can be inferred from the depth of the maximum of the shower (X_{max})



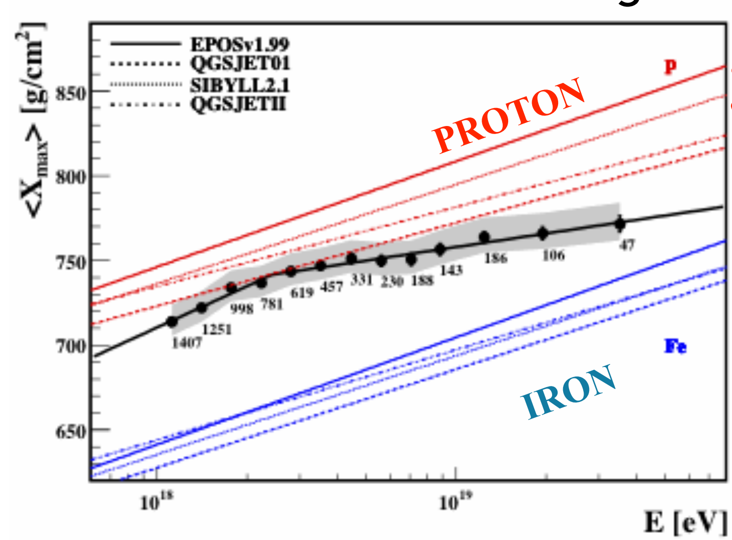
BUT….

The results depend on the precise knowledge of the hadronic interaction mechanism!!!!!

TA



Auger



Model uncertainty

Example II: Chemical Composition

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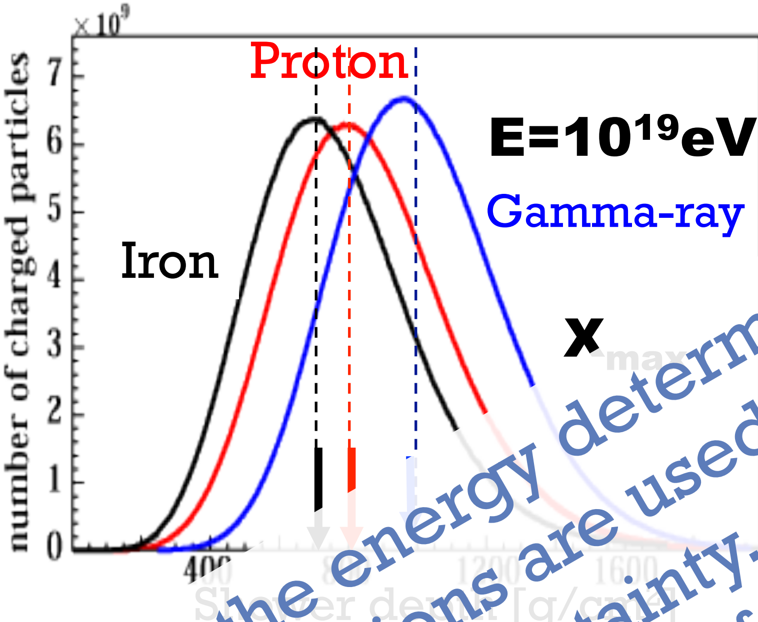
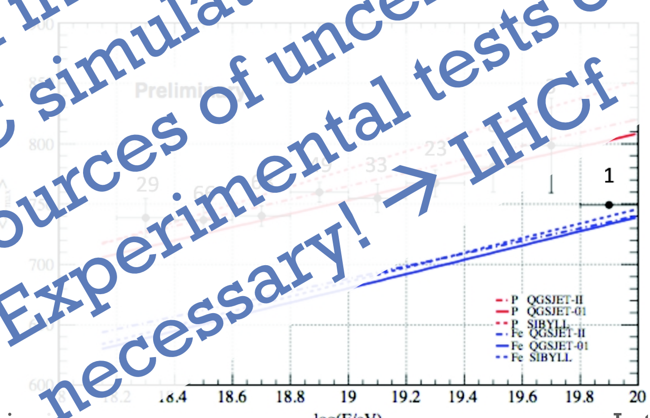
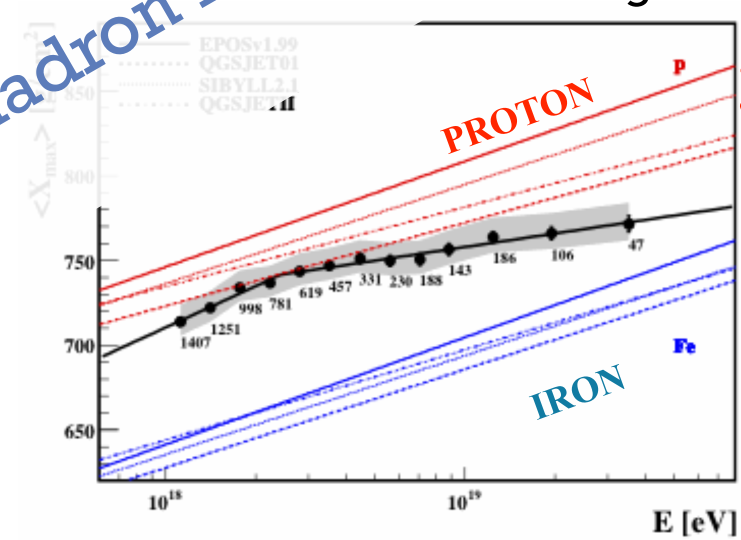


BUT….

The results depend on the precise knowledge of the hadronic interaction mechanism!!!!!

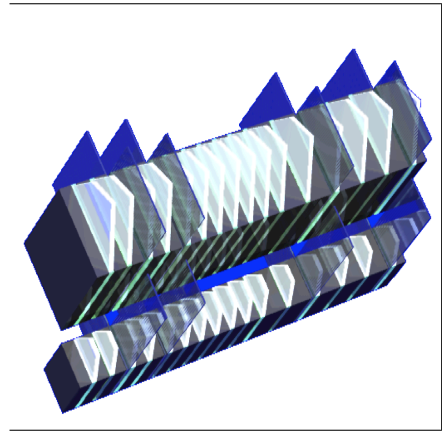


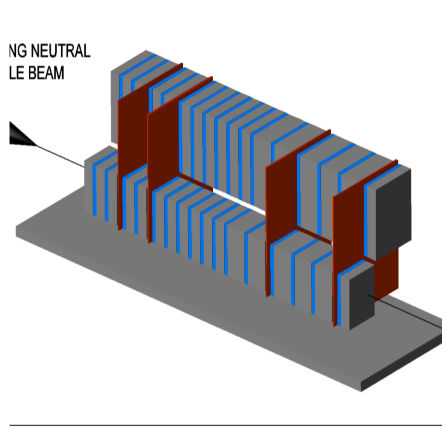


Both in the energy determination and X_{max} prediction MC simulations are used, and are one of the greater sources of uncertainty. Experimental tests of hadron interaction models are necessary! → LHCf

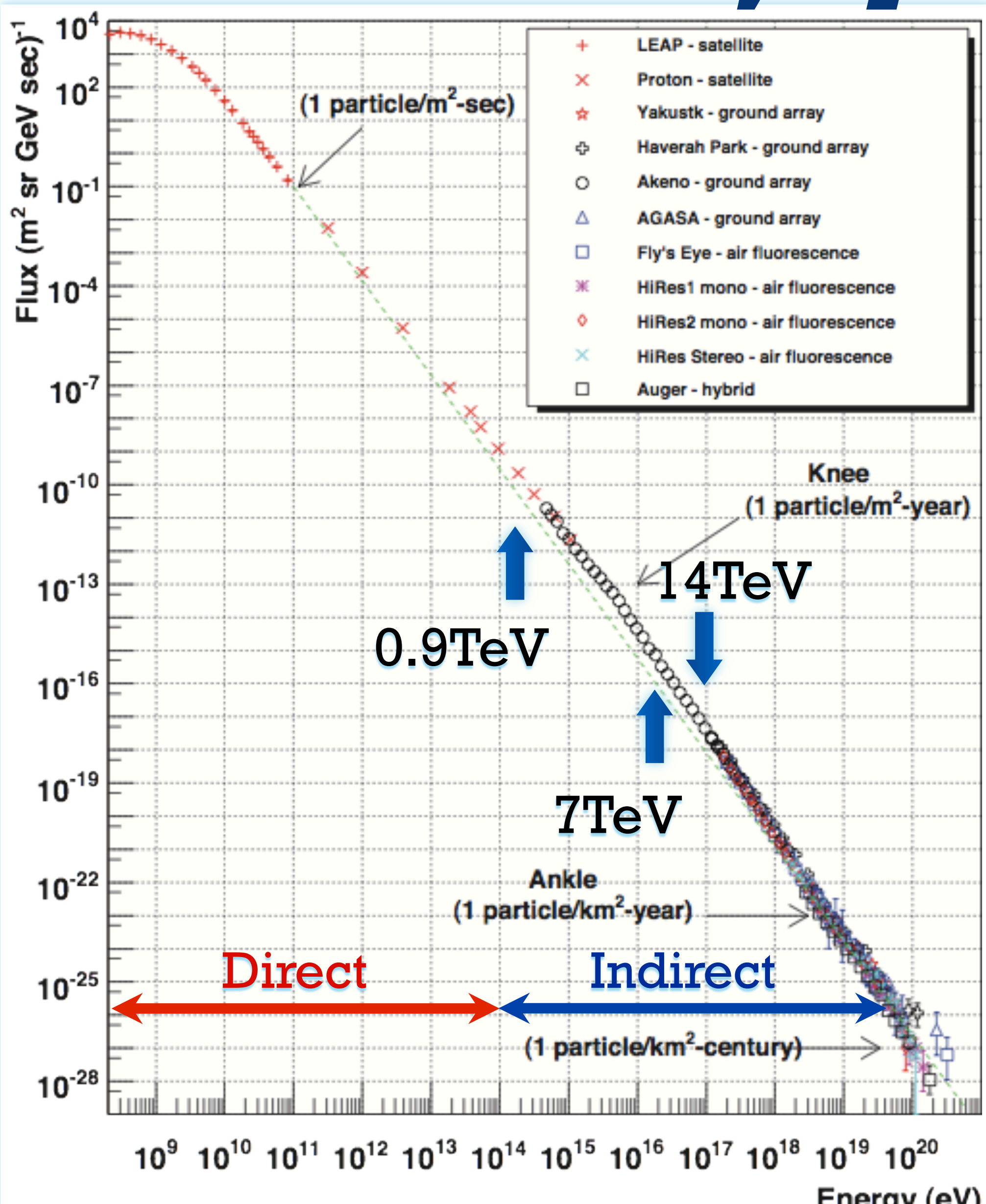
Why LHCf @ LHC?

The experimental set-up



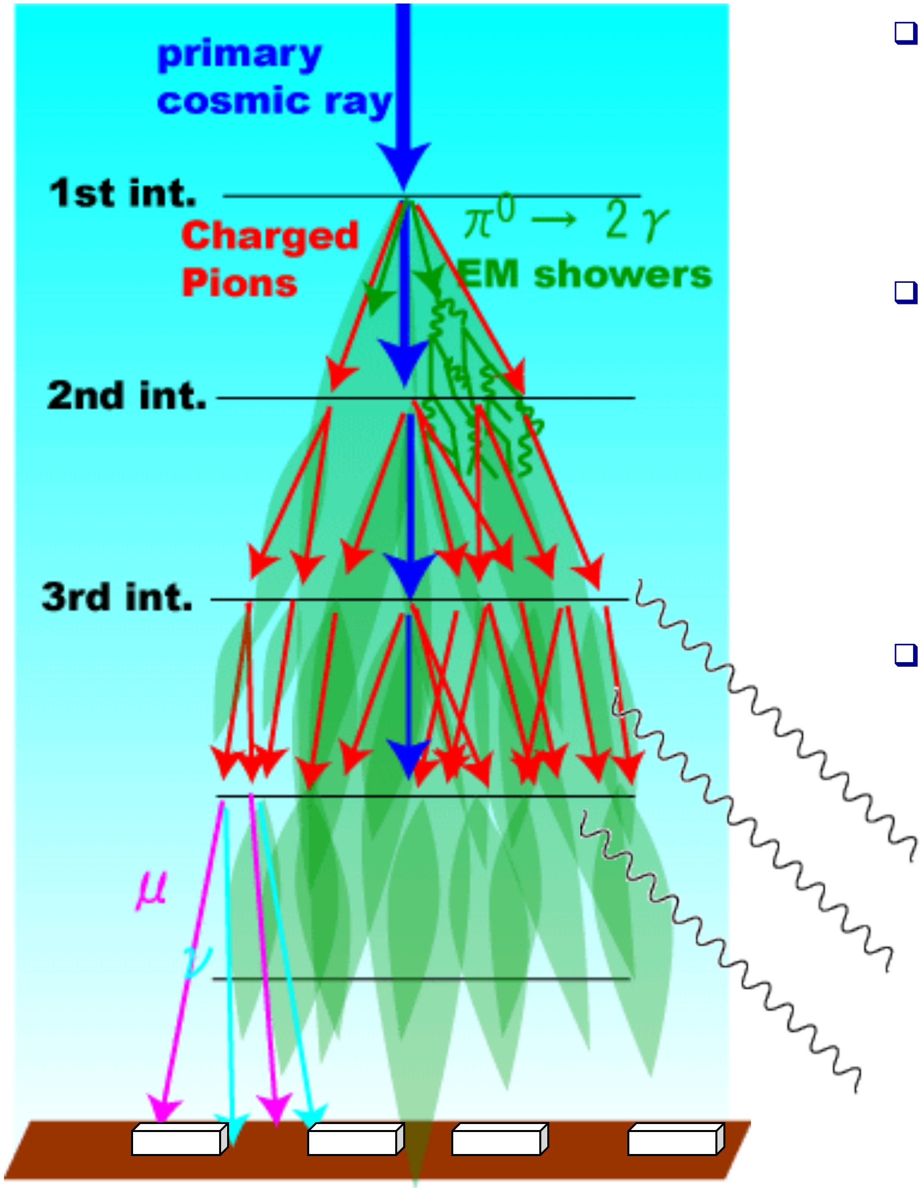


The Cosmic Ray spectrum

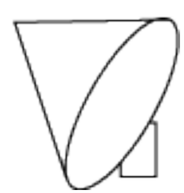


LHC Energy range is very interesting for Cosmic Ray Physics!

Air Shower development

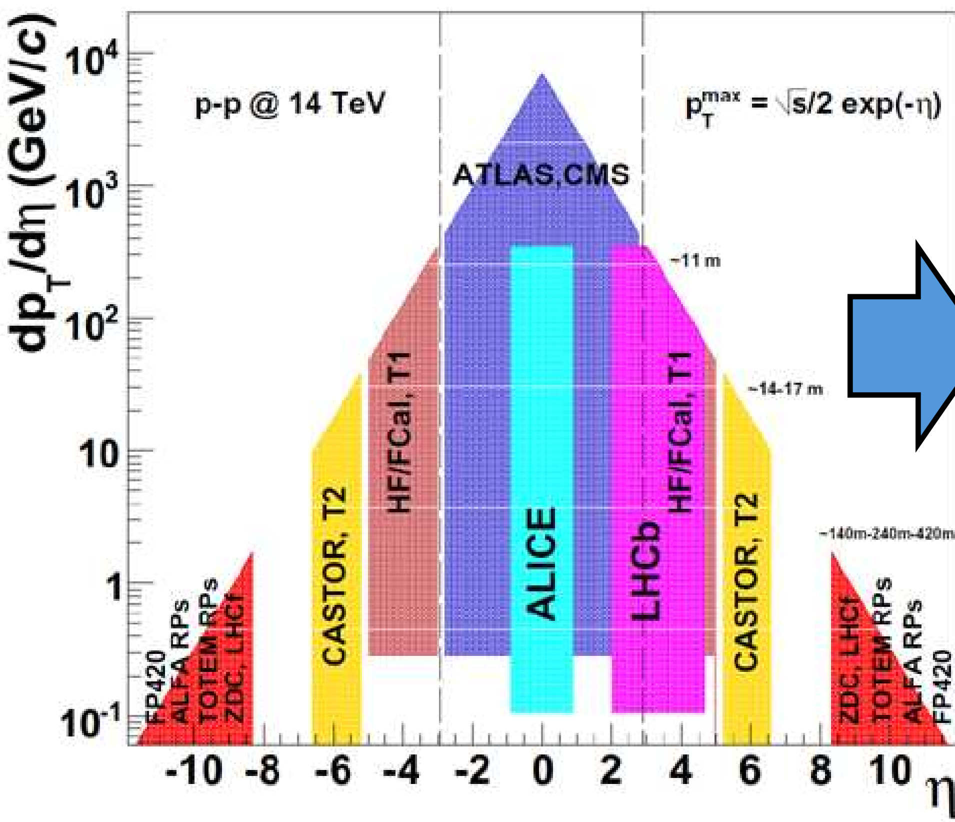


- Total cross section
  - Large σ ➔ rapid development
  - Small σ ➔ deep penetrating
- Multiplicity (N)
  - Large N ➔ rapid development
    large number of muons
  - Small N ➔ deep penetrating
    small number of muons
- Inelasticity(k)/Secondary spectra
  - Large k, Softer spectra
    ➔ rapid development
  - Small k, harder spectra
    ➔ deep penetrating



+ *LHC experiments*

Whole pseudo-rapidity is covered by the different LHC experiments



R. Orava, (2005)

Key parameters
for air shower developments

- Total cross section
  - ↔ TOTEM, ATLAS, CMS
- Multiplicity
  - ↔ Central detectors
- Inelasticity/Secondary spectra
  - ↔ Forward calorimeters
  - LHCf, ZDCs

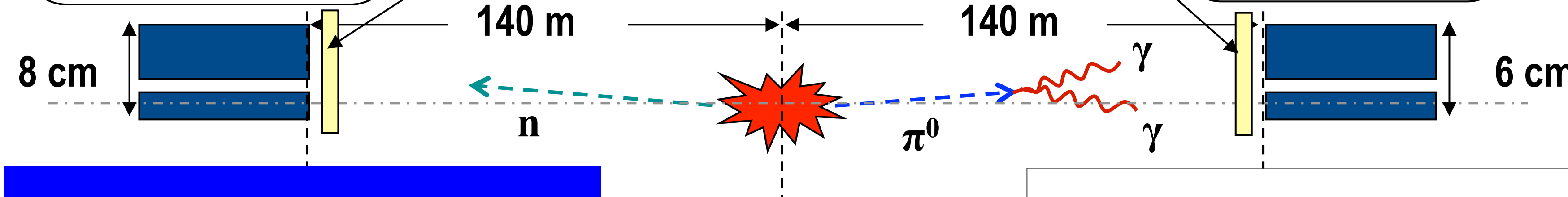
+ LHCf: location and detector layout

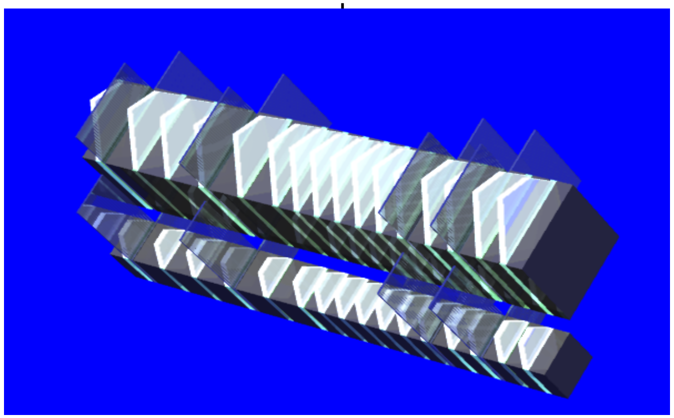
Detector I
Tungsten
Scintillator
Scintillating fibers

INTERACTION POINT

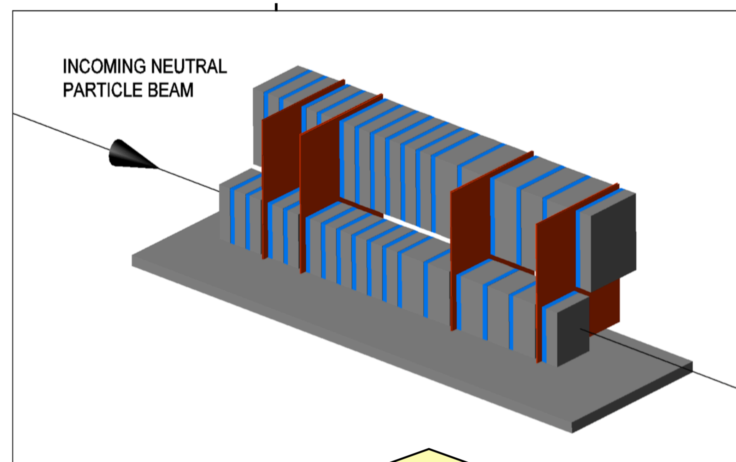
IP1 (ATLAS)

Detector II
Tungsten
Scintillator
Silicon μstrips





$44\ X_0$,
$1.6\ \lambda_{int}$



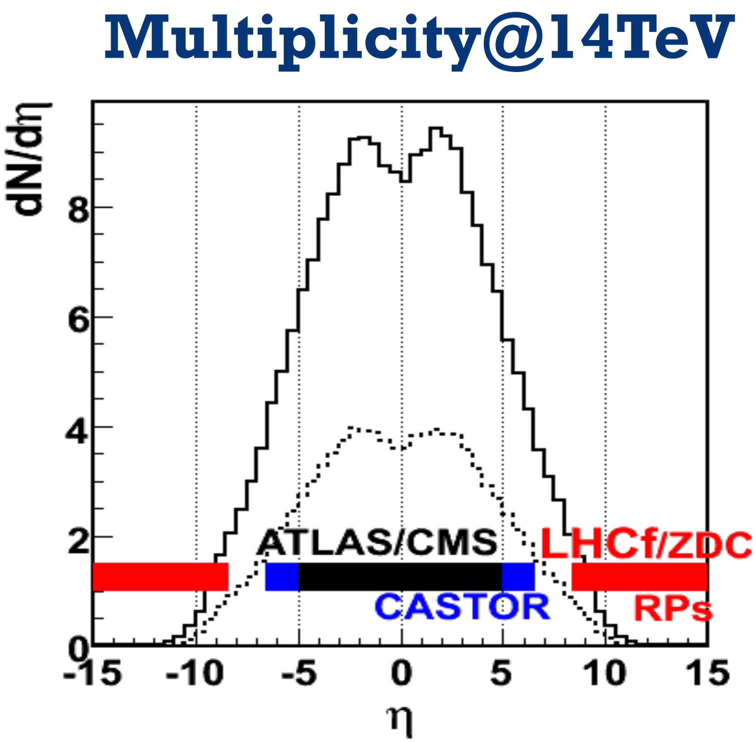
Arm#1 Detector
20mmx20mm+40mmx40mm
4 X-Y SciFi tracking layers

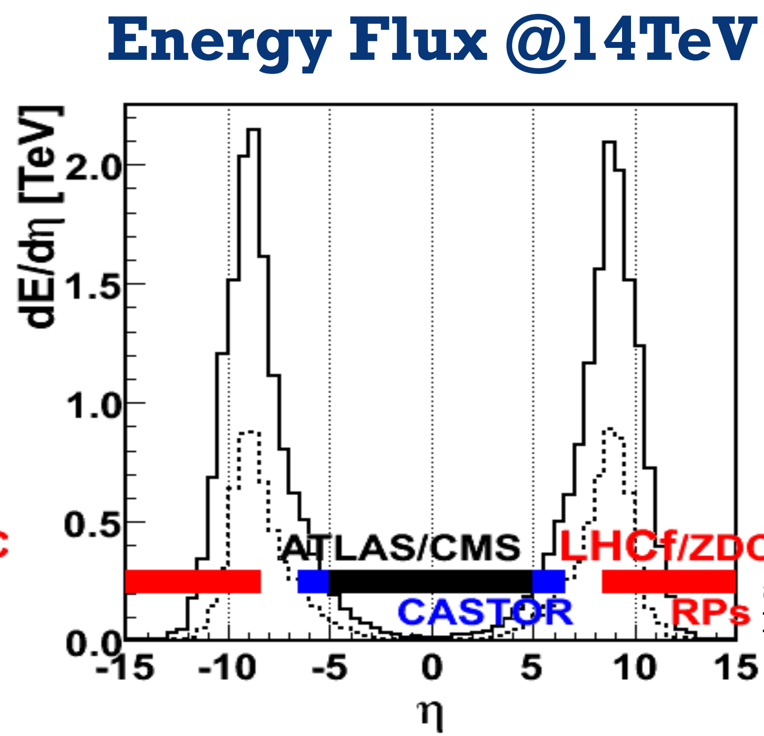
Expected Performance
Energy resolution
< 5% for γ
~30% for neutrons
Position resolution
~ 100 μ m

Arm#2 Detector
25mmx25mm+32mmx32mm
4 X-Y Silicon strip layers

+ What LHCf can measure?

Energy spectra and Transverse momentum distribution of photons, neutrons and π^0 in the pseudorapidity region η > 8.4





simulated by DPMJET3

Low multiplicity !!

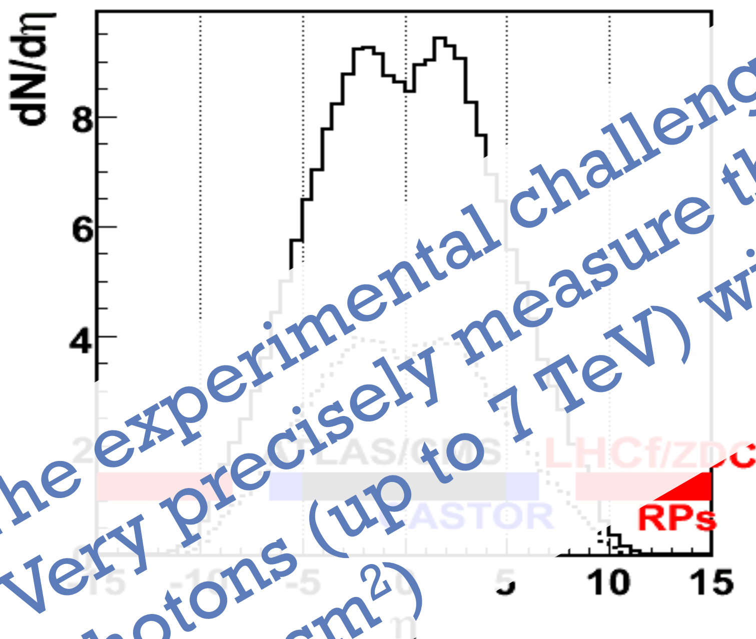
High energy flux !!

What LHCf can measure?

Energy spectra and Transverse momentum distribution of photons, neutrons and π^0 in the pseudorapidity region > 8.4

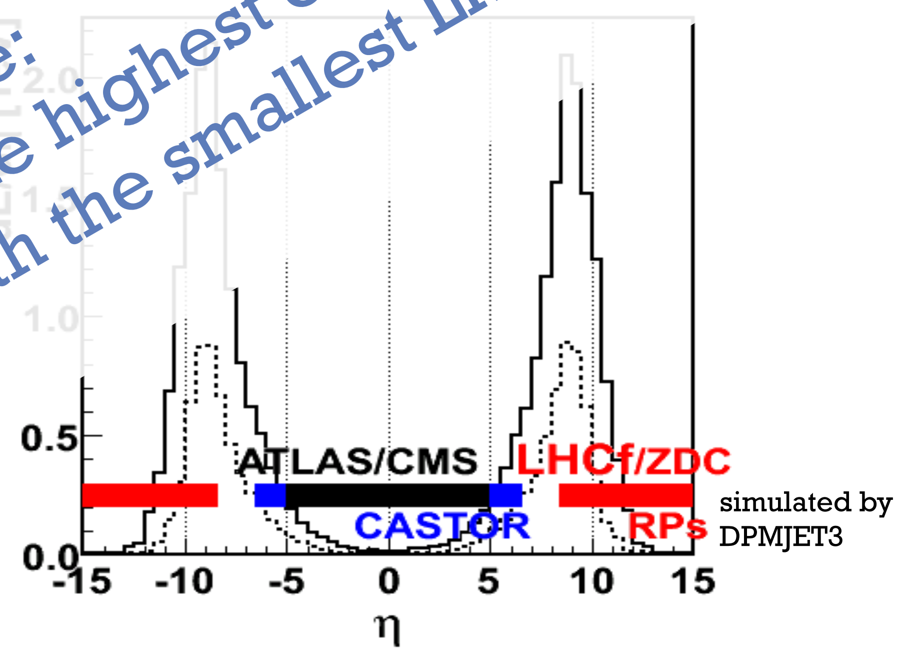
The experimental challenge:
Very precisely measure the highest energy LHC photons (up to 7 TeV) with the smallest LHC detector (~few cm^2)

Multiplicity@14TeV

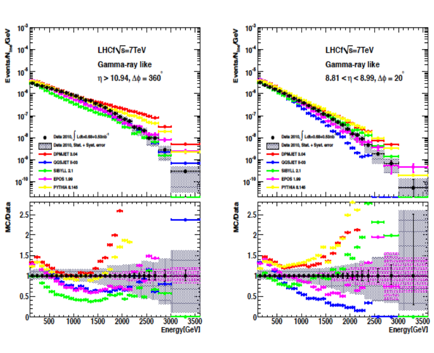


Low multiplicity !!

Energy Flux @14TeV



High energy flux !!



LHCf main physics results

"Measurement of zero degree single photon energy spectra for √s = 7 TeV proton-proton collisions at LHC"

PLB 703 (2011) 128

"Measurement of zero degree single photon energy spectra for √s = 900 GeV proton-proton collisions at LHC"

Submitted to PLB

CERN-PH-EP-2012-048

"Measurement of forward neutral pion transverse momentum spectra for √s = 7TeV proton-proton collisions at LHC"

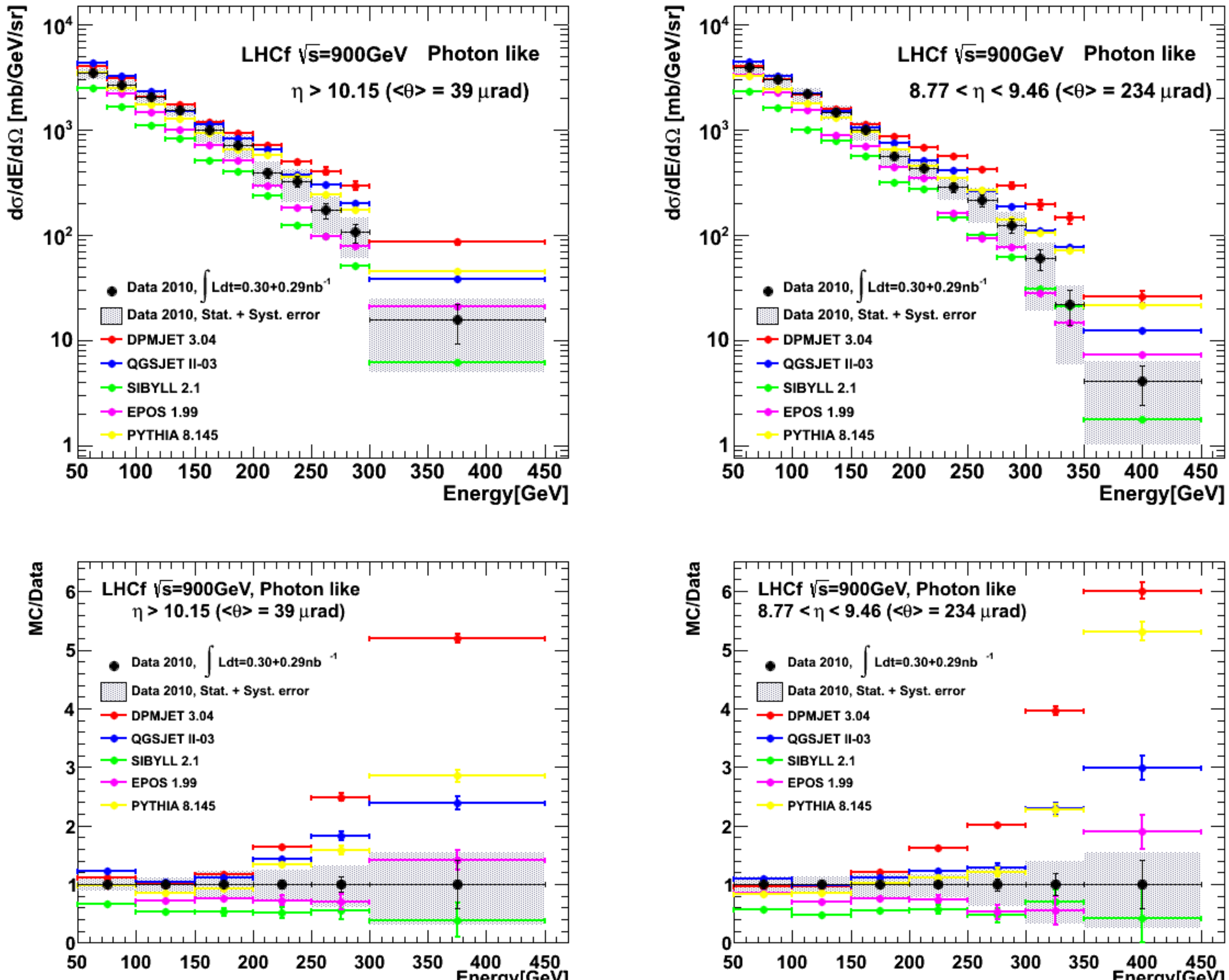
Submitted to PRD

CERN-PH-EP-2012-145

Inclusive γ spectrum at 900 GeV

Data

MC/Data



DPMJET 3.04
SIBYLL 2.1
EPOS 1.99
PYTHIA 8.145
QGSJET II-03

Gray hatch : Systematic Errors

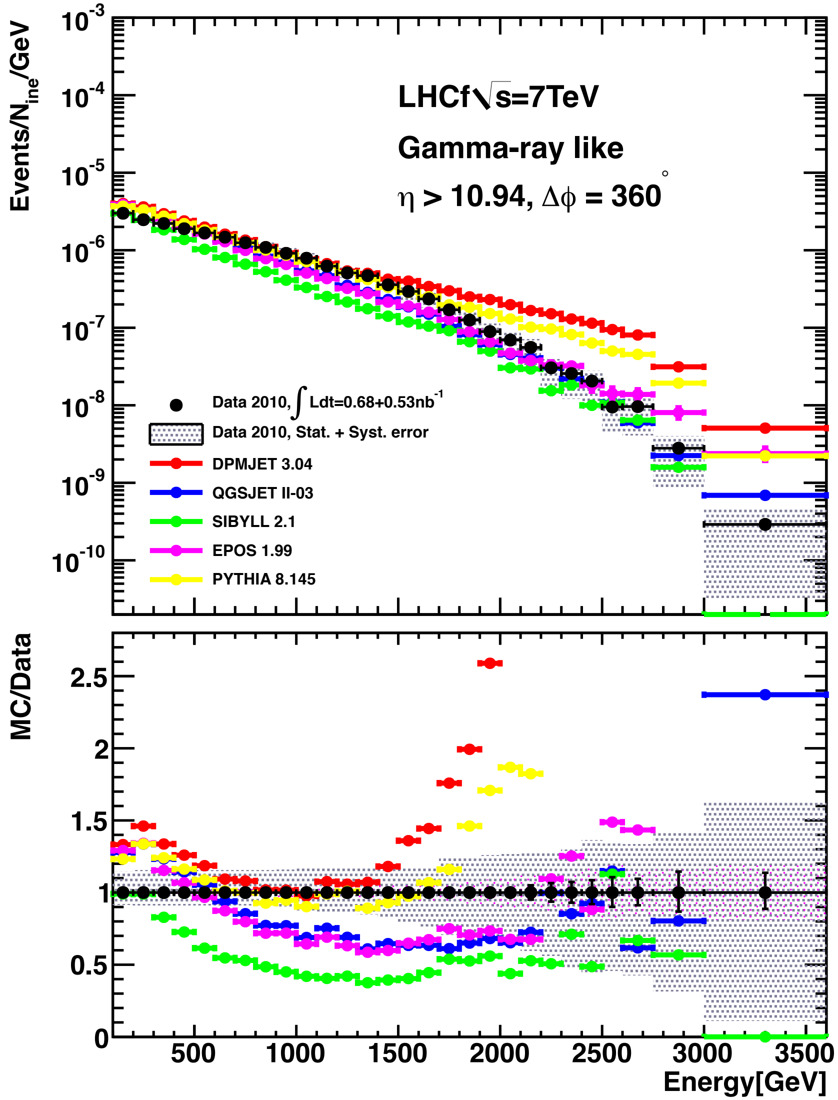
+ *Inclusive γ spectrum at 7 TeV*

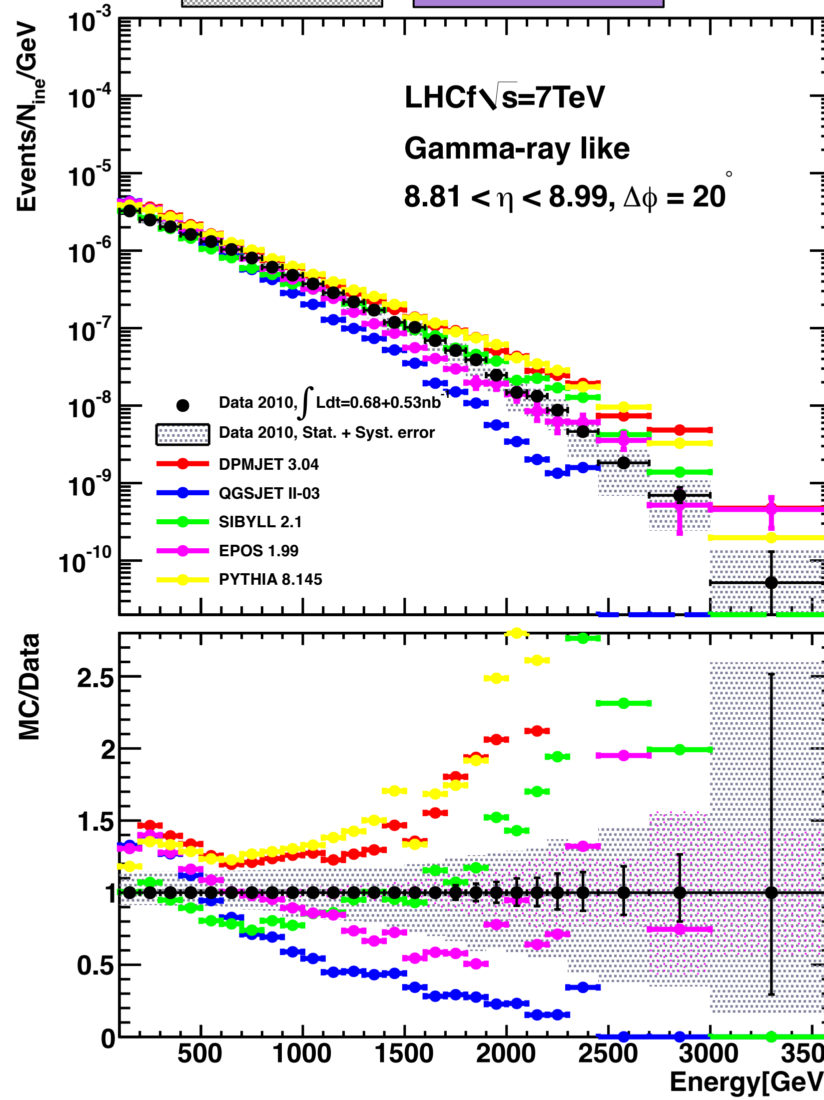
Gray hatch : Systematic Errors

Magenta hatch: MC Statistical errors

Data

MC/Data

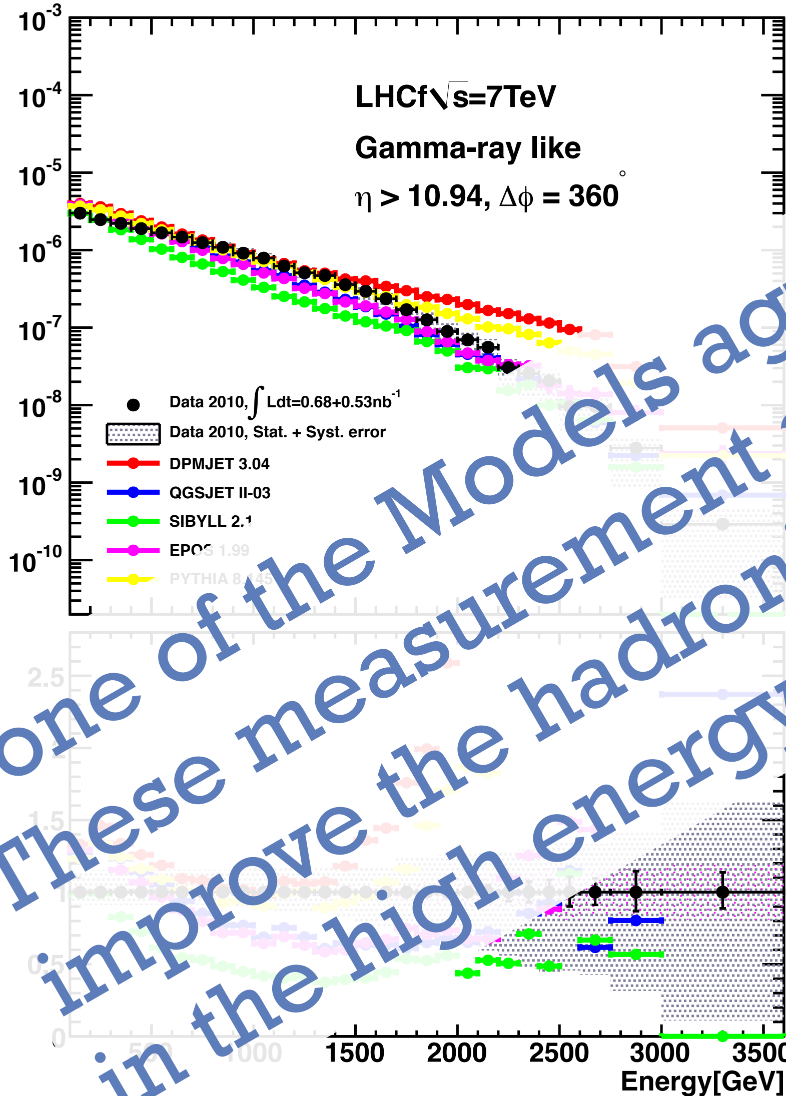


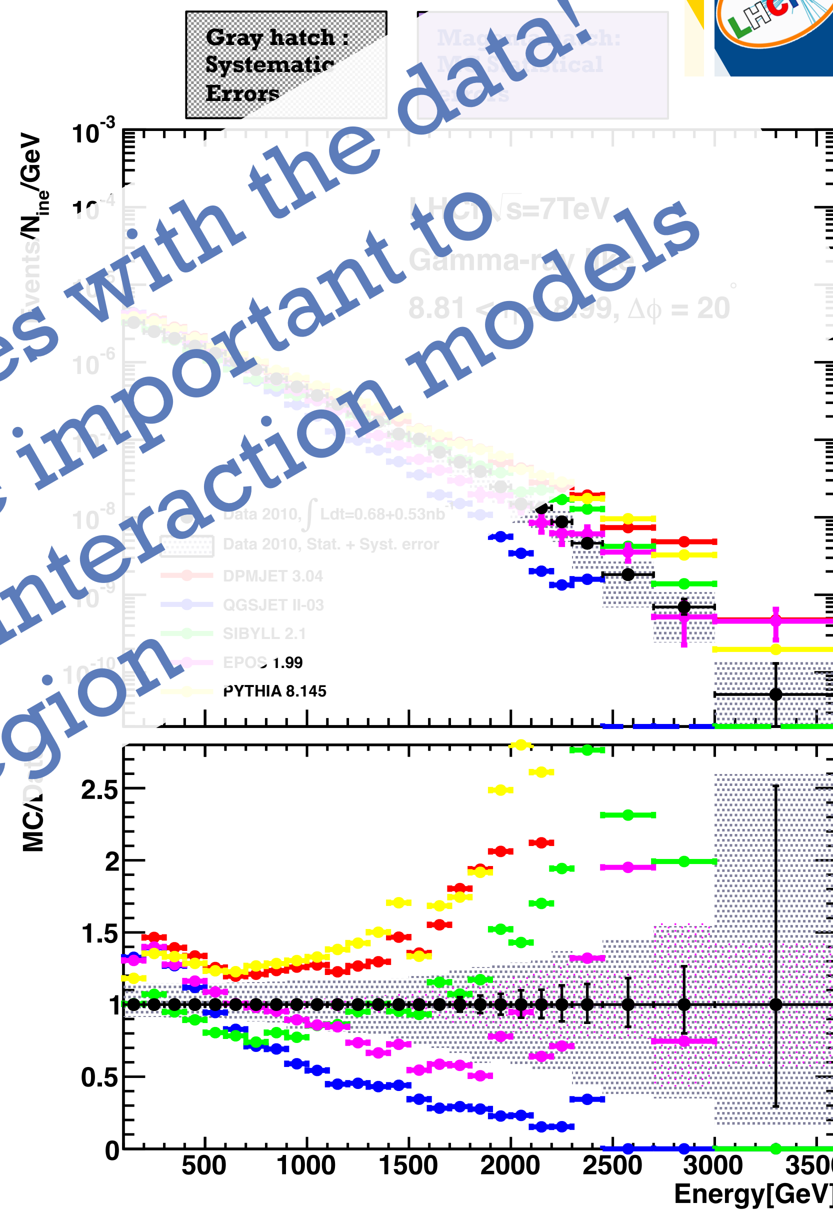


+ *Inclusive γ spectrum at 7 TeV*

Data

MC/Data



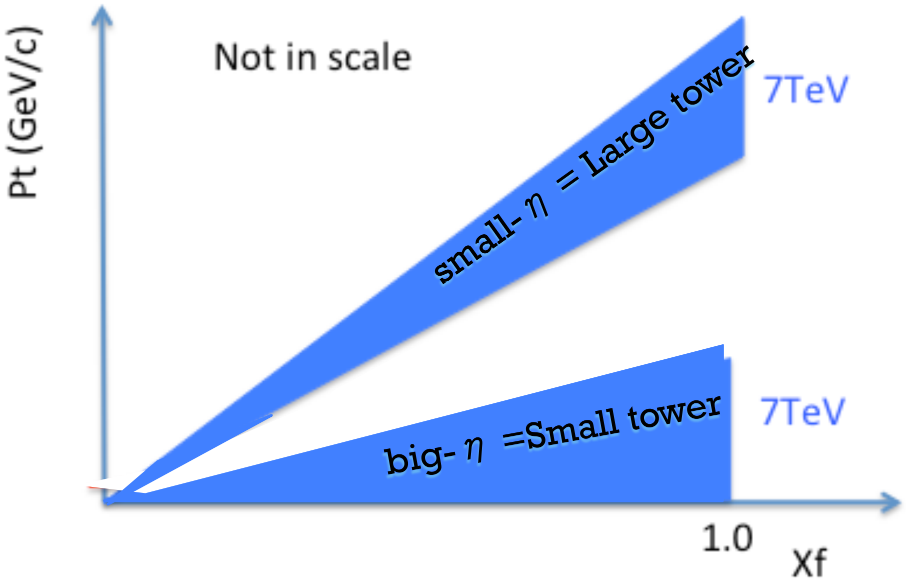


None of the Models agrees with the data!

These measurement are important to improve the hadronic interaction models in the high energy region

Comparison between 900 GeV and 7 TeV spectra

Coverage of the photon spectra in the plane Feynman-X vs P_T



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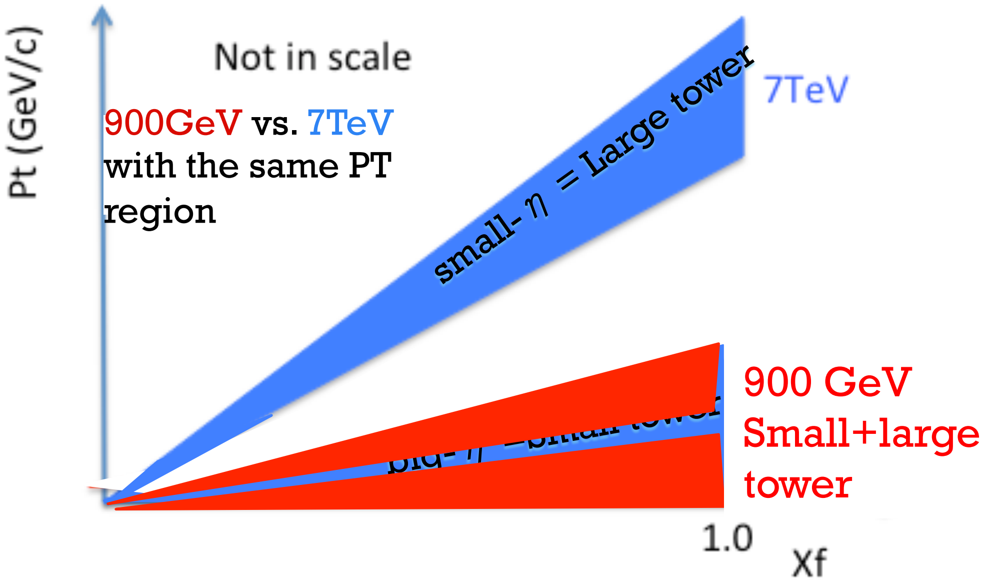

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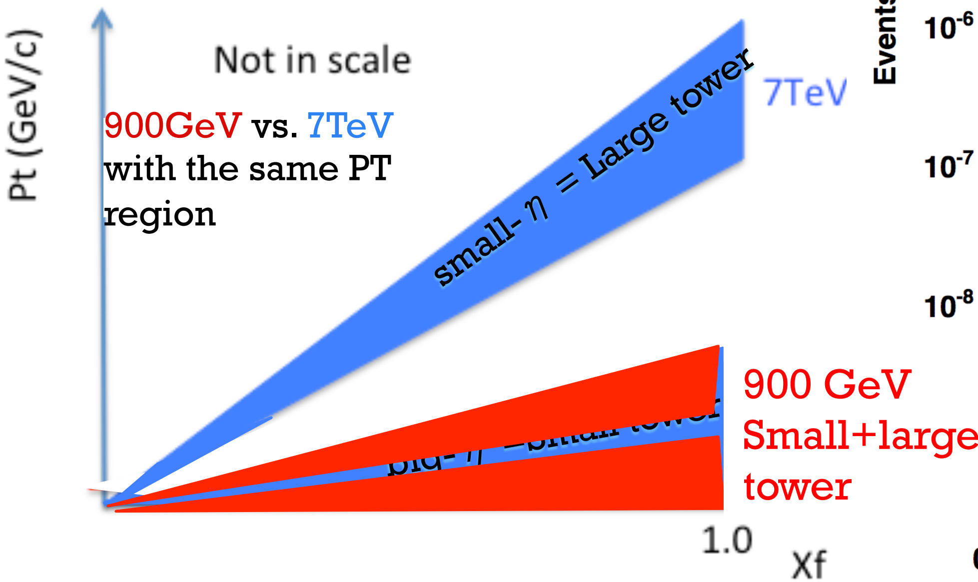
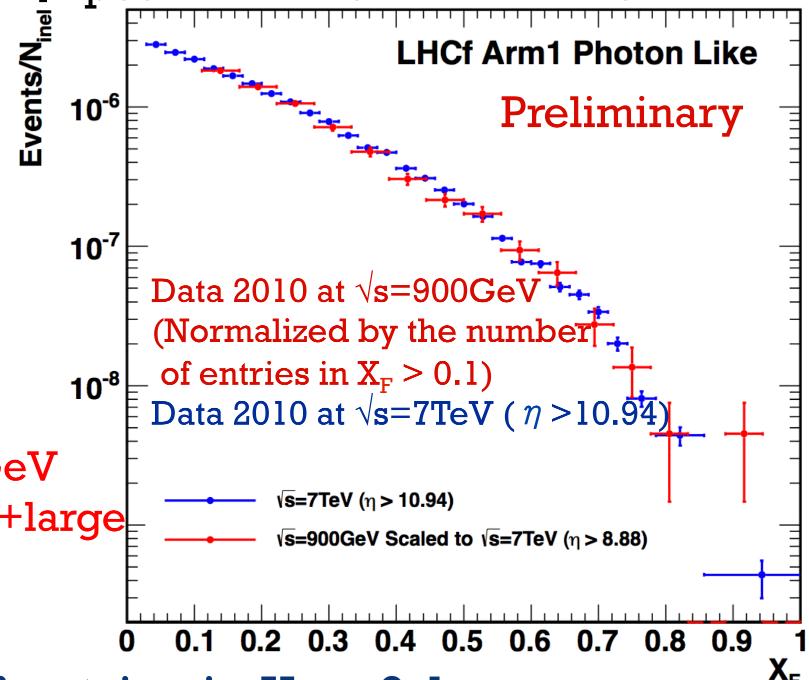


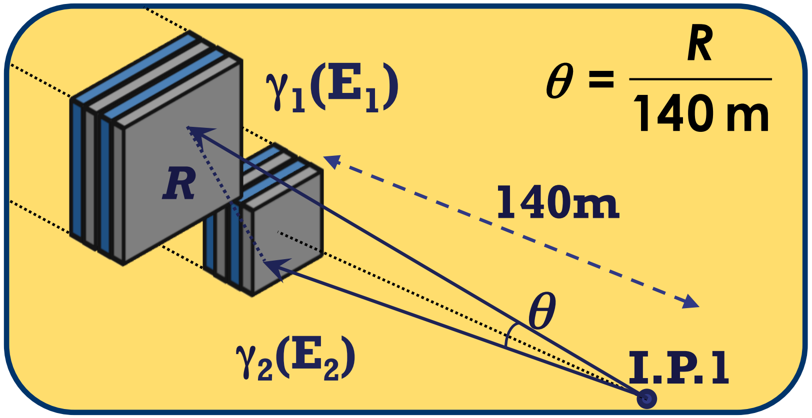
X_F spectra : 900GeV data vs. 7TeV data



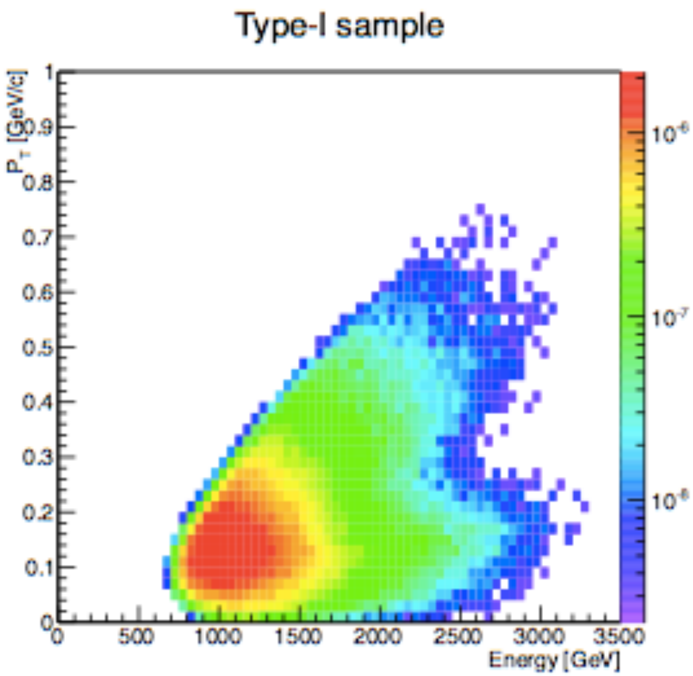
- ✓ Normalized by the number of entries in $X_F > 0.1$
- ✓ No systematic error is considered in both collision energies.

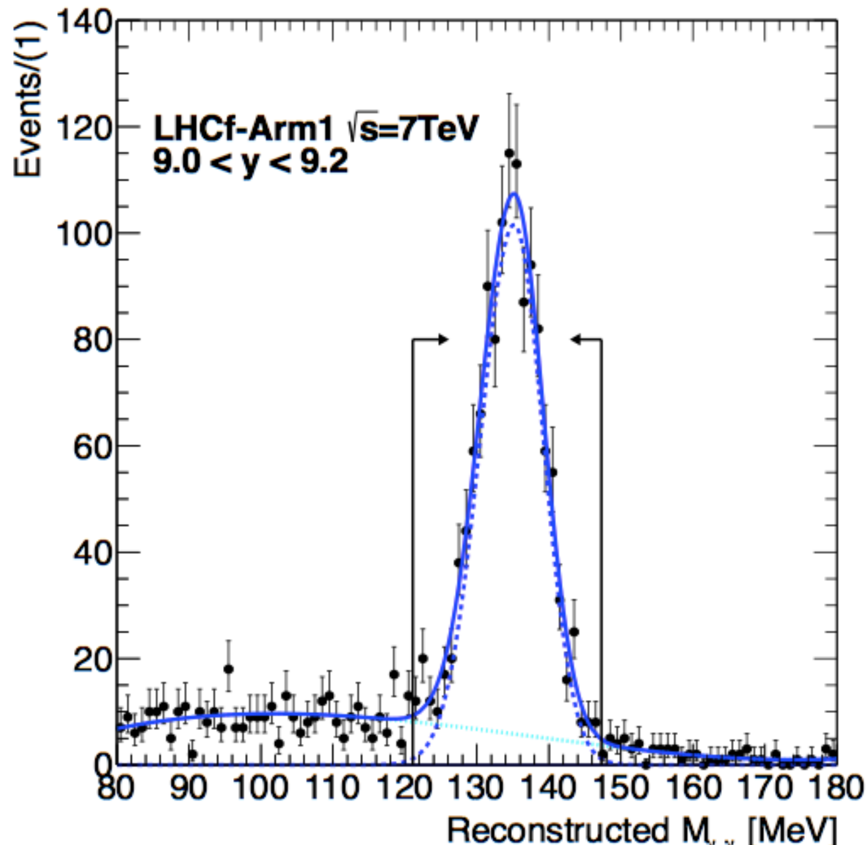
Good agreement of X_F spectrum shape between 900 GeV and 7 TeV.
➔ weak dependence of <p_T> on E_{CMS}

+ 7 TeV π^0 analysis

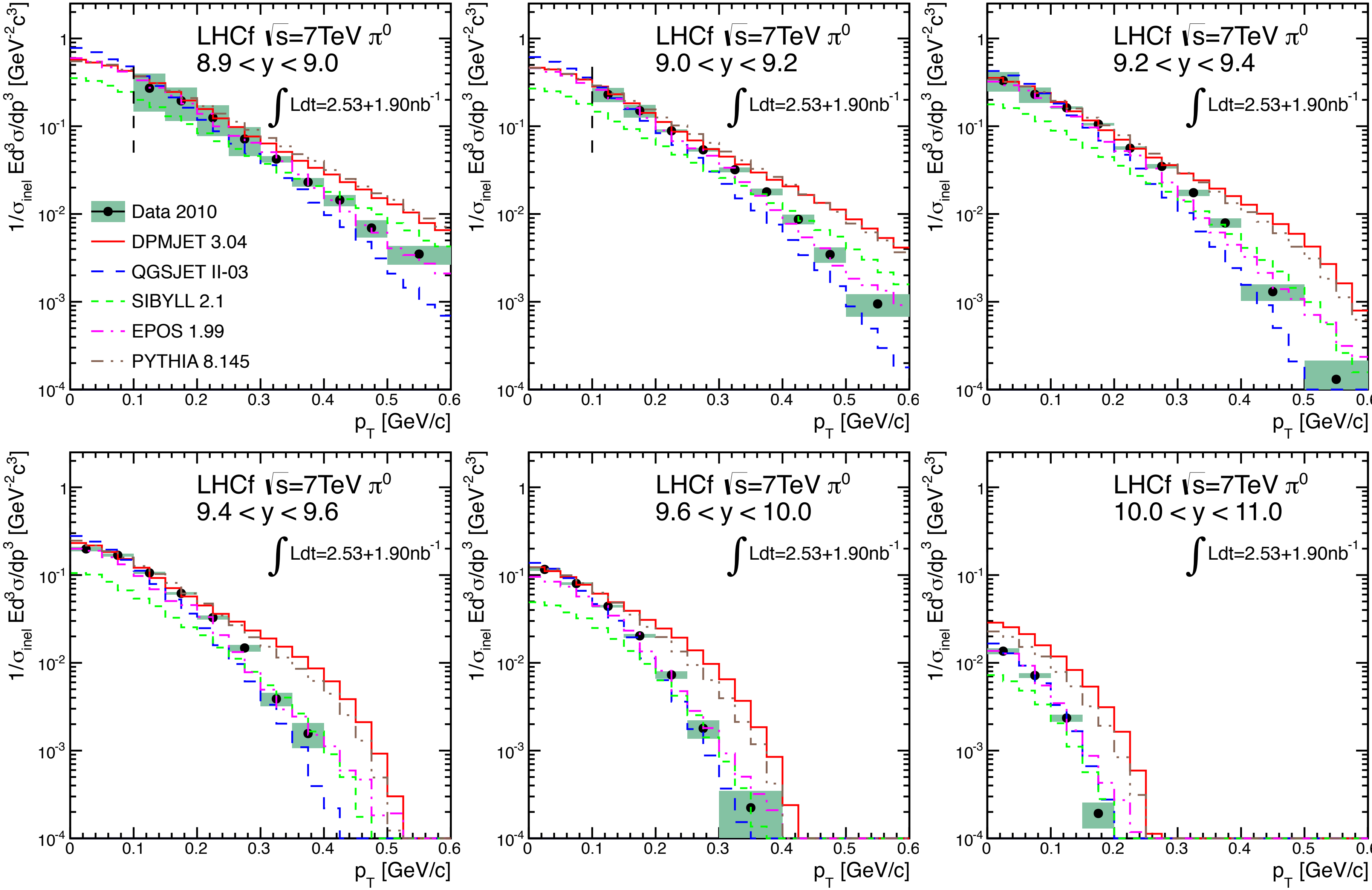


Mass, energy and transverse momentum are reconstructed from the energies and impact positions of photon pairs measured by each calorimeter





π^0 Data vs MC: P_T spectra for different rapidity bins



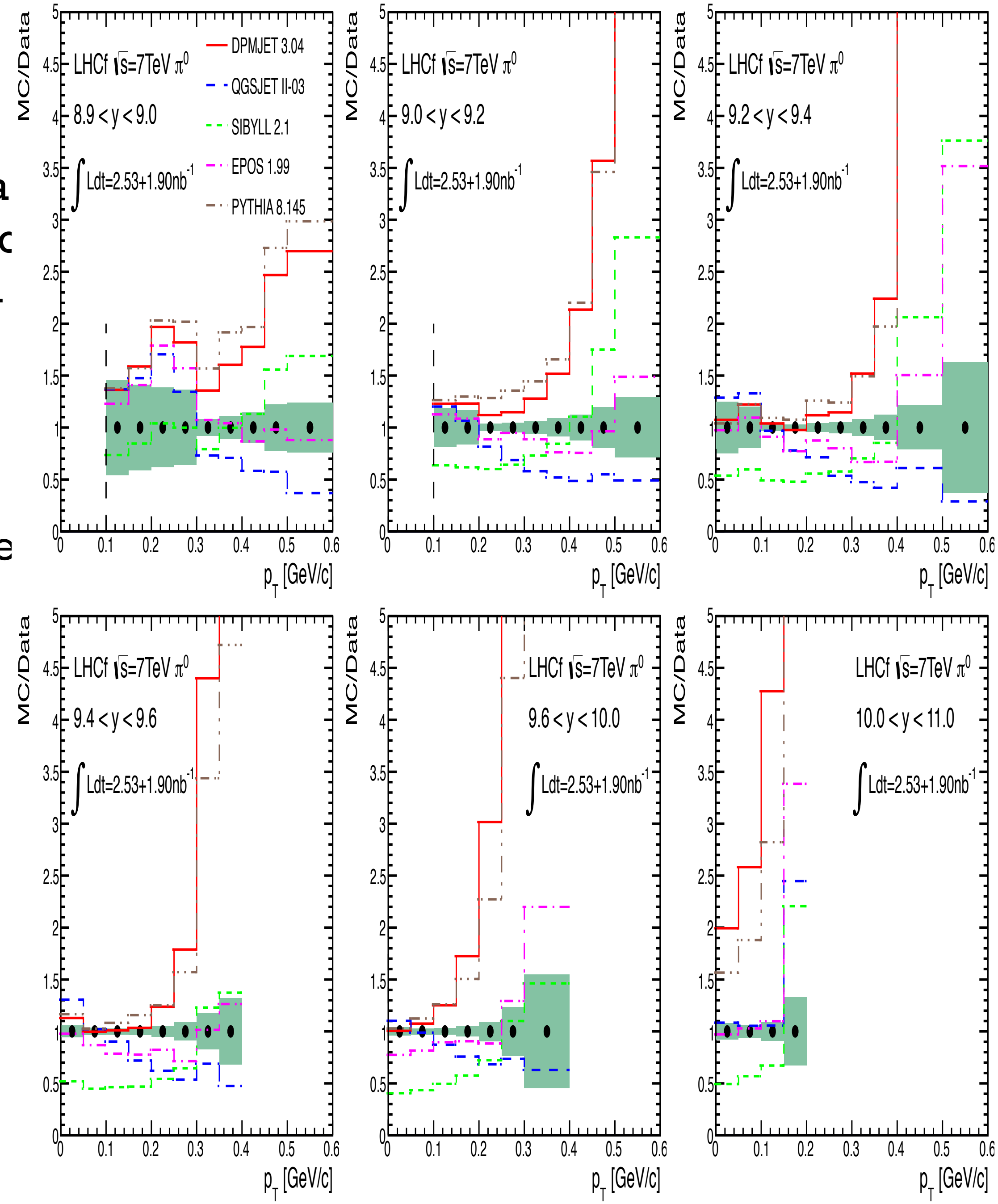
+ π^0 Data vs MC

- dpmjet 3.04 & pythia 8.145 show overall agreement with LHCf data for 9.2<y<9.6 and p_T <0.25 GeV/c while the expected π^0 production rates by both models exceed the LHCf data as p_T becomes large

- sibyll 2.1 predicts harder pion spectra than data, but the expected π^0 yield is generally small

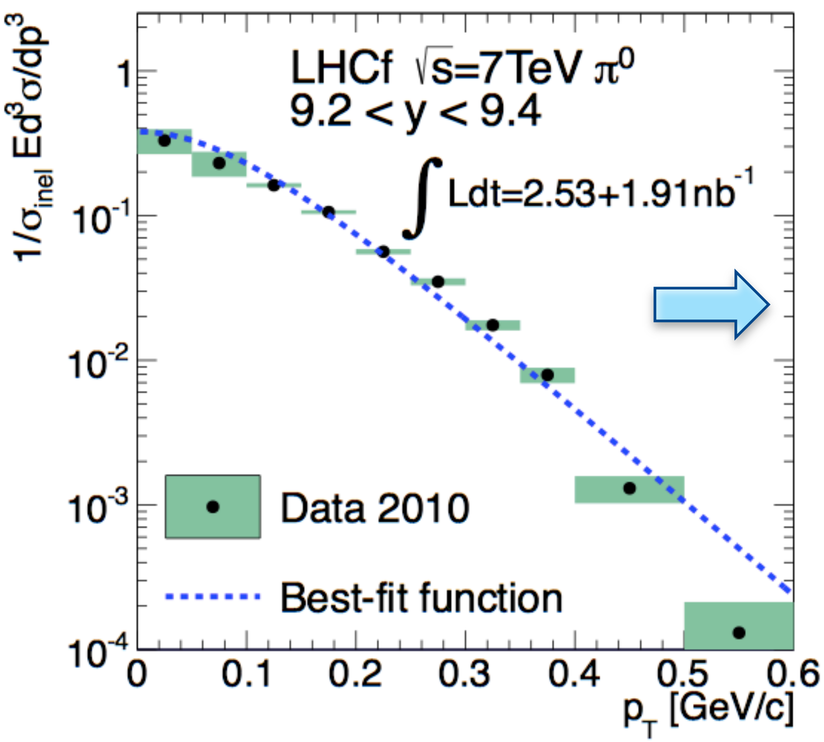
- qgsjet II-03 predicts π^0 spectra softer than LHCf data

- epos 1.99 shows the best overall agreement with the LHCf data.
  - behaves softer in the low p_T region, p_T < 0.4GeV/c in 9.0<y<9.4 and p_T <0.3GeV/c in 9.4<y<9.6
  - behaves harder in the large p_T region.



+ π^0 analysis at $\sqrt{s}$=7 TeV

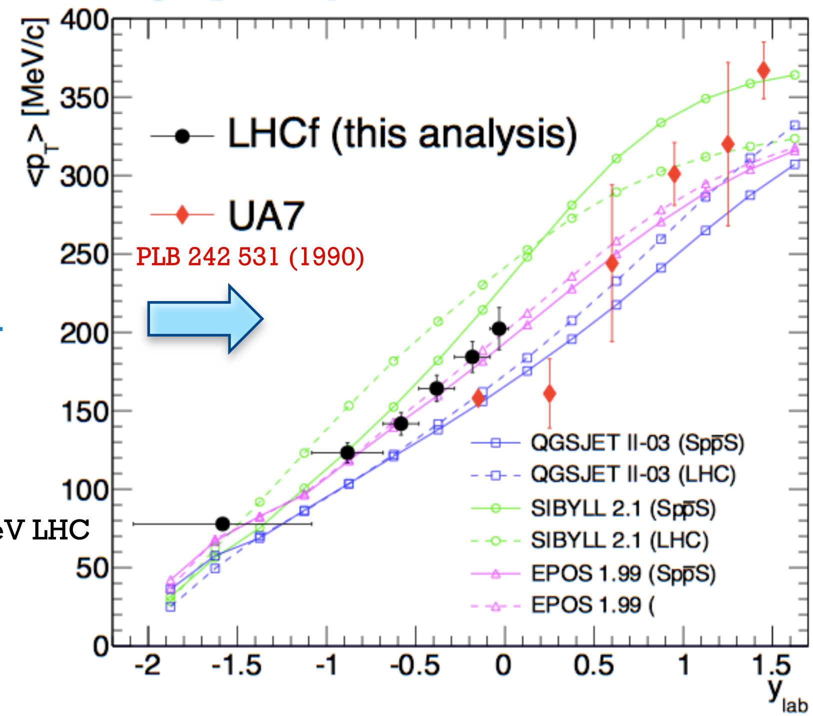
p_T spectra vs best-fit function



$<P_T>$ for different y bins

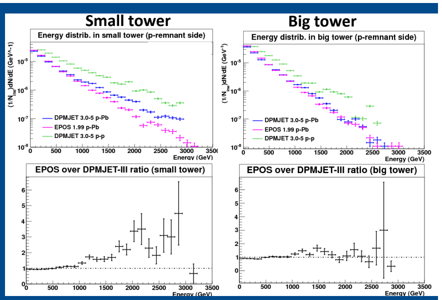
Y_{Beam}=6.5 for SPS
Y_{Beam}=8.92 for7 TeV LHC

Average p_T vs y_{lab}



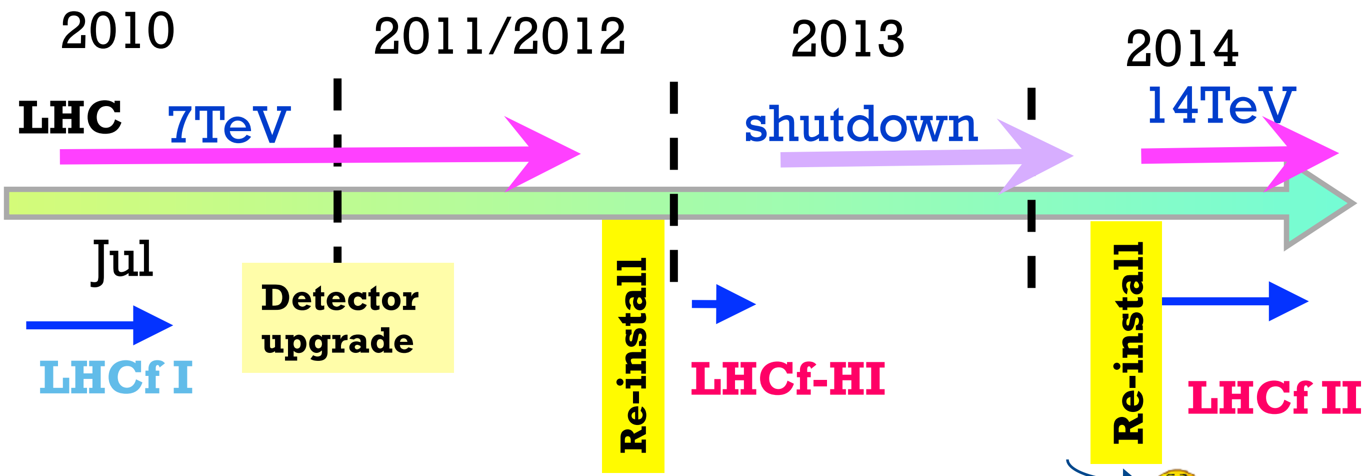
$y_{lab} = y_{beam} - y$

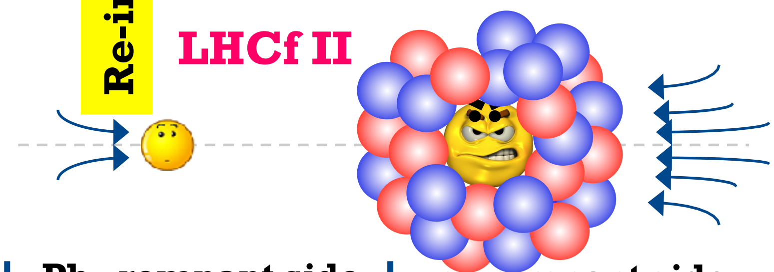
Systematic uncertainty of LHCf data is 5%.
Comparison with the UA7 data ($\sqrt{s}$=630GeV) and MC simulations (QGSJET, SIBYLL, EPOS).
Two experimental data mostly appear to lie along a common curve
→ No evident dependence of $<p_T>$ on E_{CMS}.
Smallest dependence on E_{CMS} is found in EPOS and it is consistent with LHCf and UA7.
Large E_{CMS} dependence is found in SIBYLL



What's next and … conclusions …

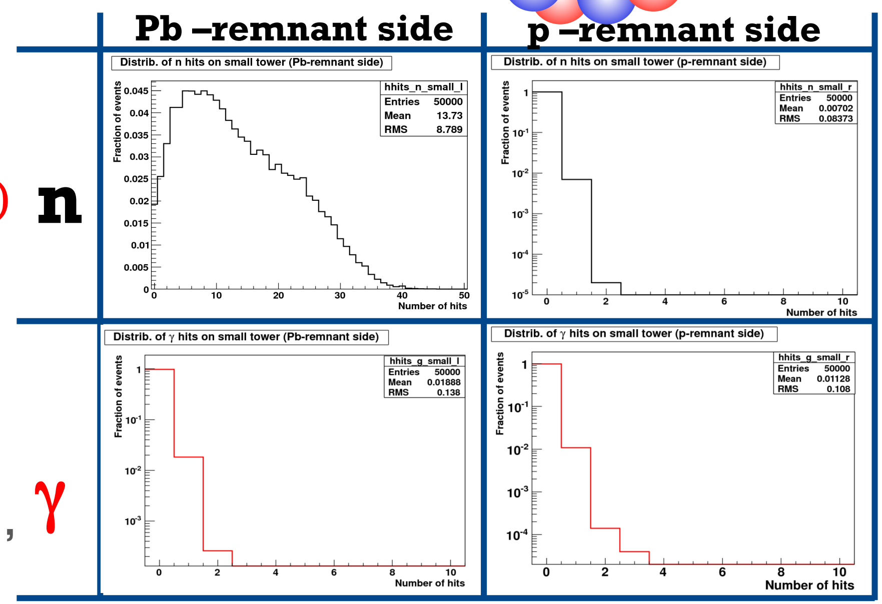
LHCf Future PLANS: Ion run and 14 TeV





2013: p-Pb runs

- Interest in Ion runs
- Physics case study well motivated
- We will reinstall one ARM on p-remnant side during p-Pb run (beginning of 2013)



2014: 14 TeV p-p runs

- Necessary to complete the LHCf physics program
- The highest E_{lab} will be reached (10^{17} eV), to go closer to the VHECR region

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Conclusions

- LHCf represent a very interesting and useful link between accelerator physics and cosmic ray physics
- The experiment has been carefully designed to precisely measure the highest energy LHC photons (up to 7 TeV), despite being the smallest LHC detector (few cm^2)
- Nice physics results have been performed both on γ and π^0
- LHCf results have shown to be very useful for the very high energy cosmic rays models developer to improve their codes
- p/Pb run in 2013 and 14 TeV p/p run in 2014 are the next important steps