Cosmic rays and accelerators: future

Oscar Adriani
University of Florence & INFN Firenze

The p-He cross section measurement: a physics case from Cosmic Rays
Torino, July 6th, 2015

+ Contents

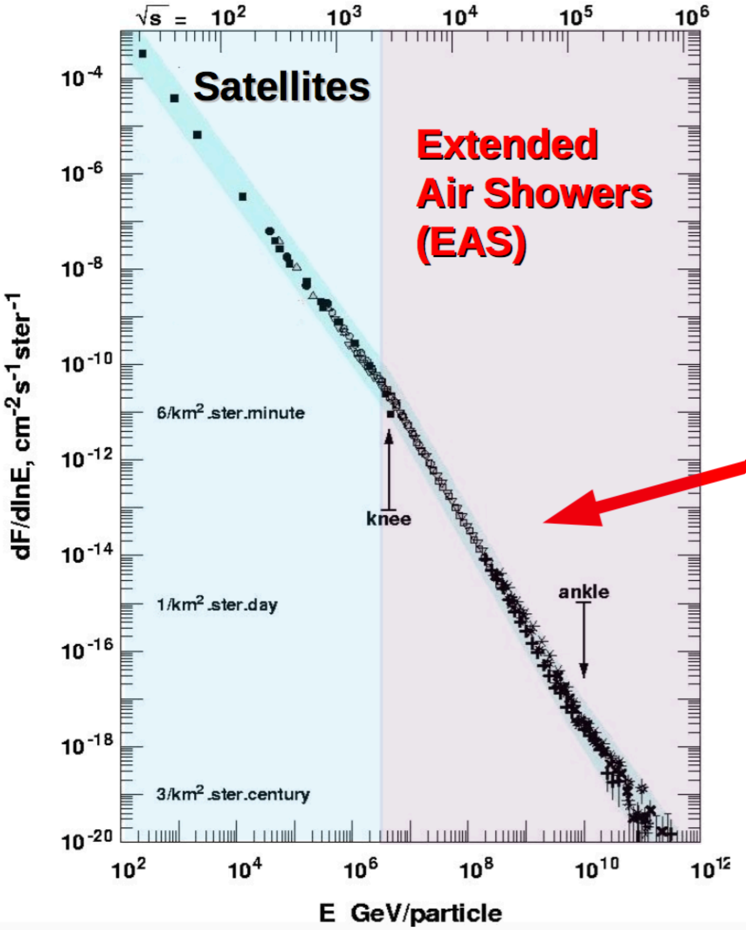
- Introduction
- Few LHC@<8 TeV results
- Close future: LHC @ 13 TeV
  - Upgraded detectors
  - Run conditions/DAQ strategy
  - Expected spectra
- Future @ LHC

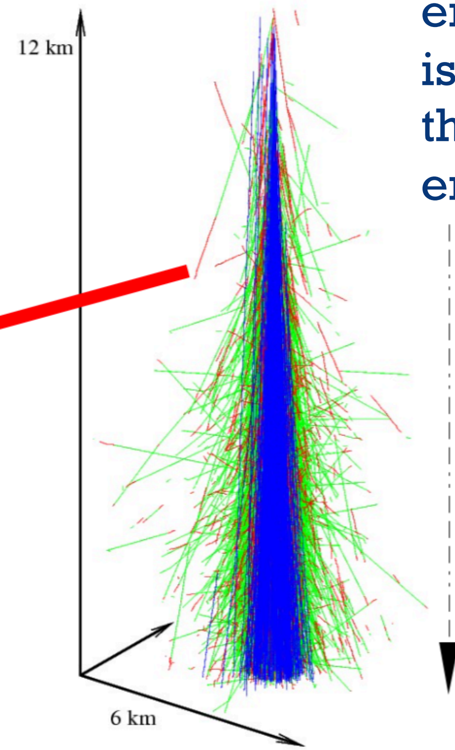
+

Introduction

The High Energy cosmic ray spectrum

- The spectrum falls very rapidly with energy ($\sim E^{-2.7}$)
- No direct measurements are possible for $E>10^{15}$ eV (Flux< $1/m^2$/year)
- We have to rely on the atmospheric showers measurements



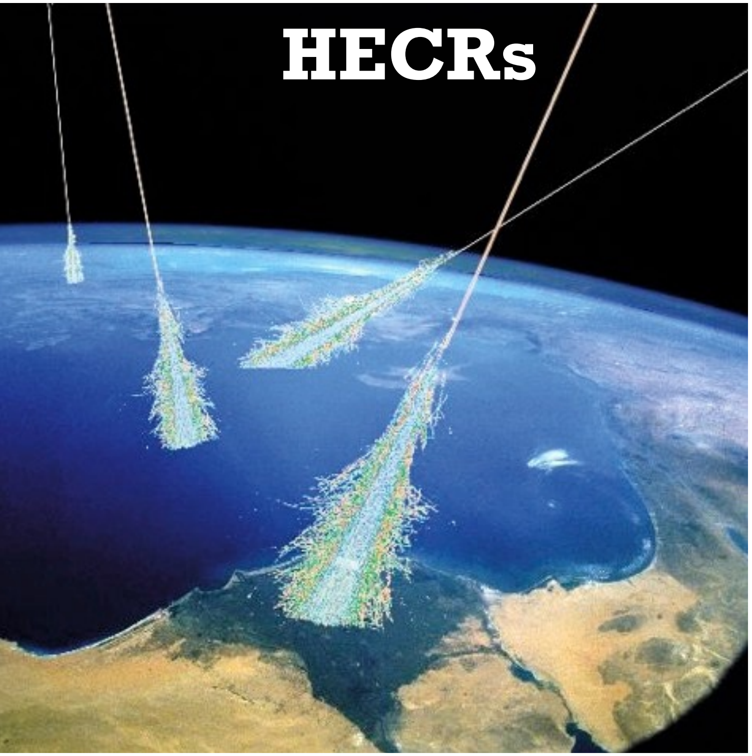


Detailed knowledge of high energy hadronic interactions is necessary to reconstruct the primary CR type and energy!

$\sim 27\ X_0$

$\sim 11\ \lambda_{int}$

High Energy CR Showers main Observables



- X_{max} : depth of air shower maximum in the atmosphere
- **RMS(X_{max})**: fluctuations in the position of the shower maximum
- **N_{μ}**: number of muons in the shower at the detector level

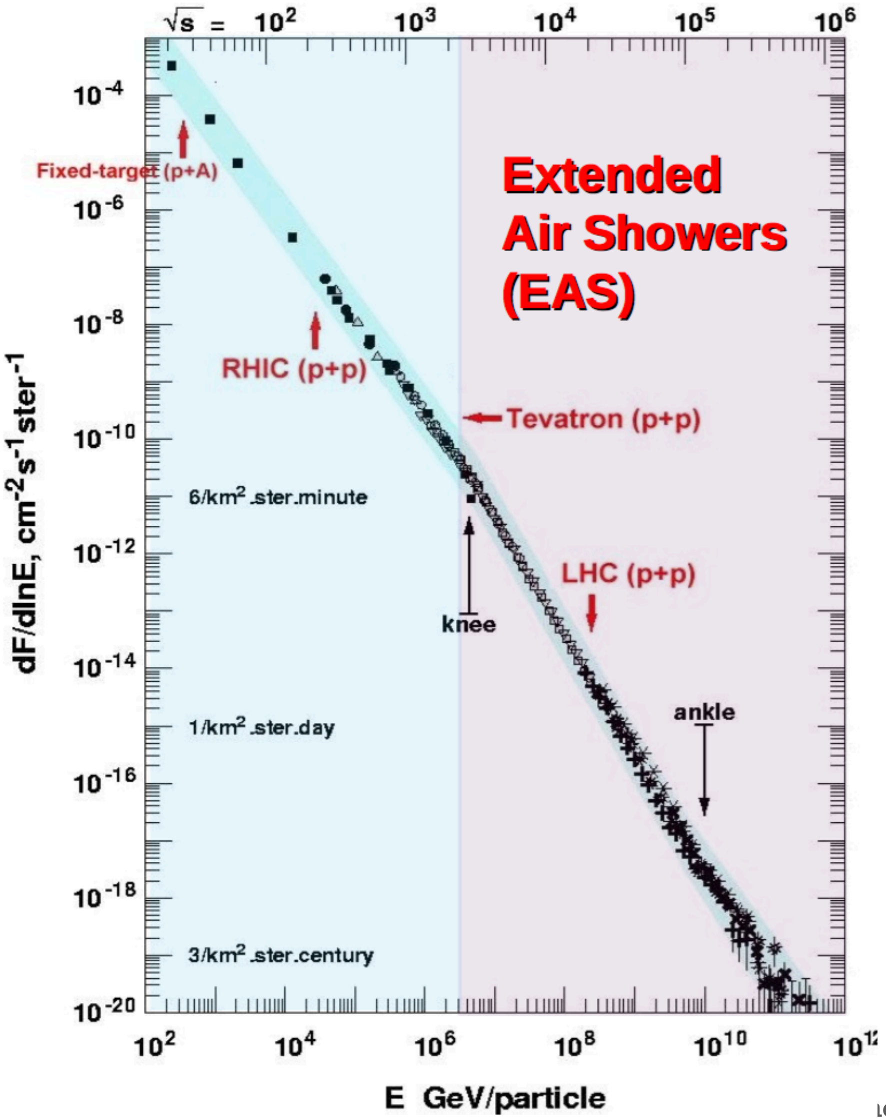
- To go from these observables to the CR composition and energy determination passing through the hadronic interaction models is mandatory

Uncertainty of hadron interaction models

⬇

Uncertainty in the interpretation of the observables

+ The role of the accelerators experiments

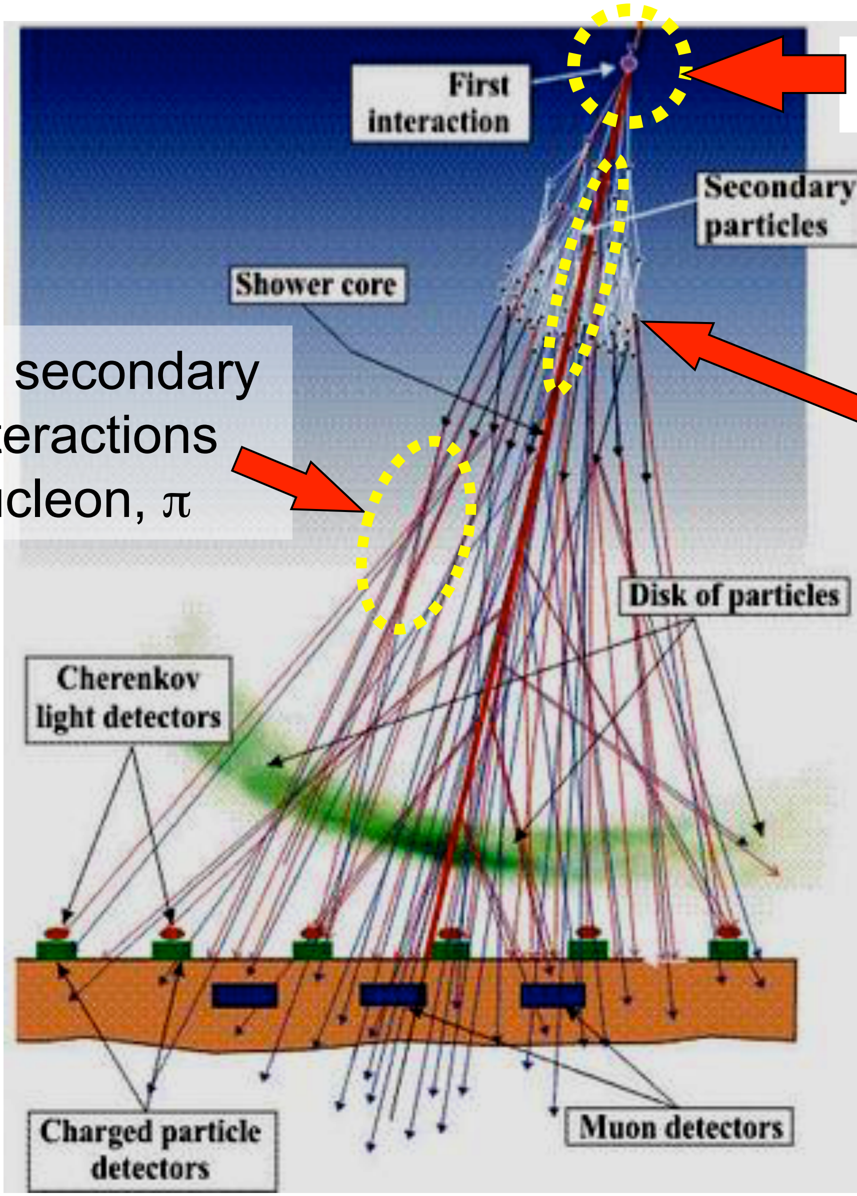


Accelerator based experiments are the most powerful available tools to determine the high energy hadronic interactions characteristics

→ Hadronic interactions models tuning

LHC 13 TeV → 9.10^{16} eV
Unique opportunity to calibrate the models in the 'above knee' region

How accelerator experiments can contribute?



④ secondary interactions nucleon, π

① Inelastic cross section

If large σ: rapid development
If small σ: deep penetrating

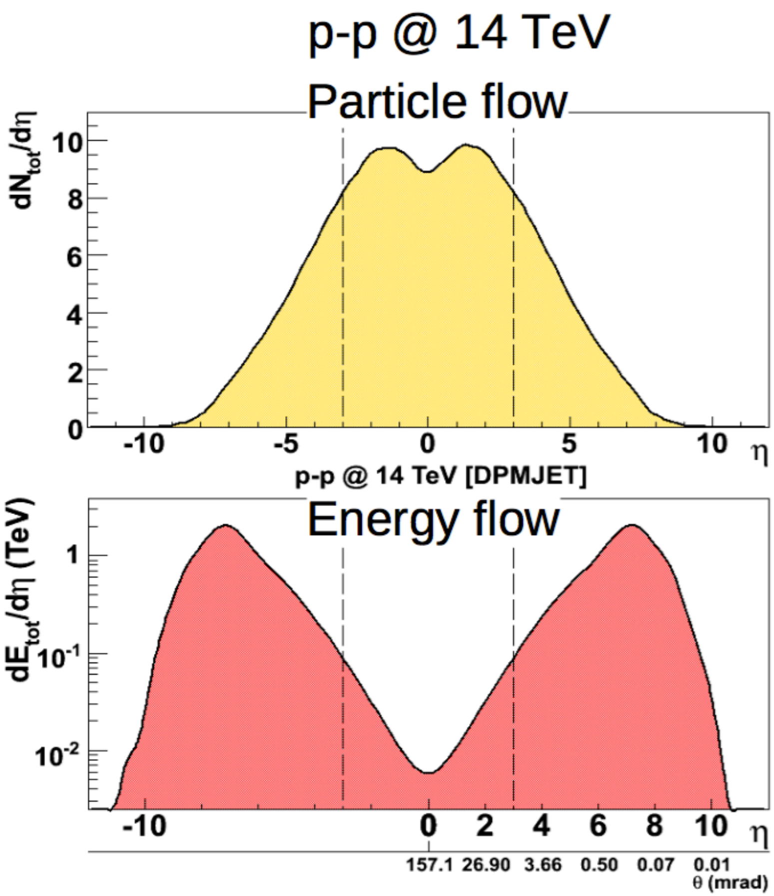
② **Forward energy spectrum**

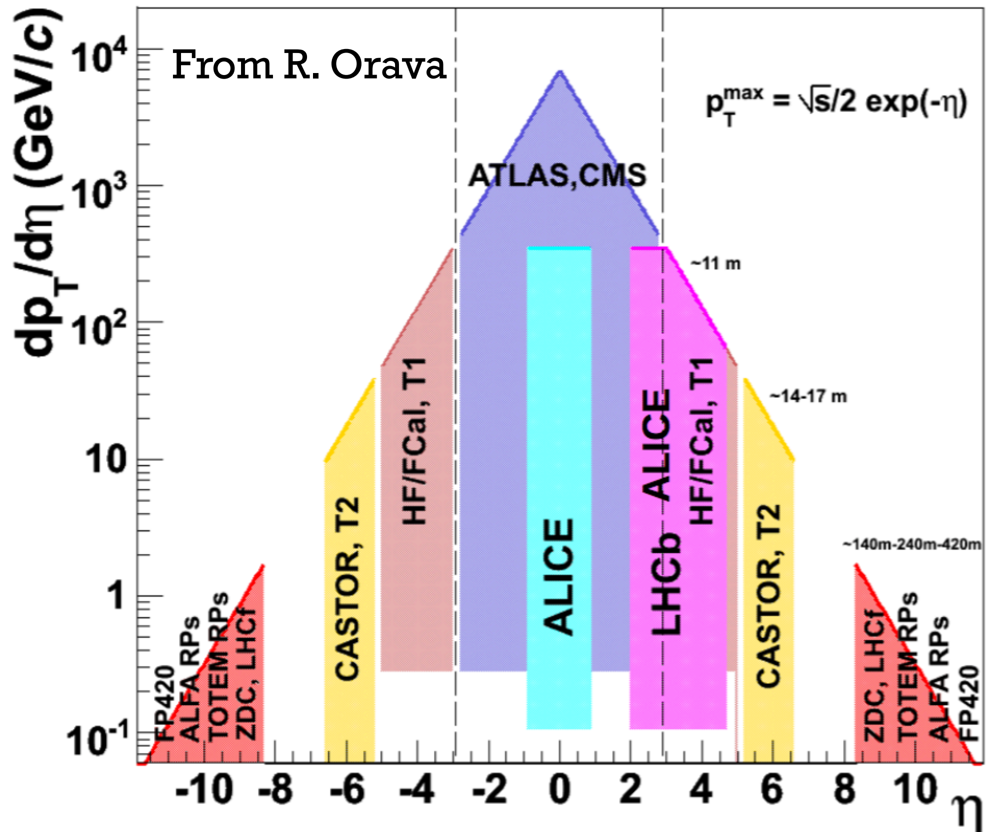
If softer shallow development
If harder deep penetrating

③ **Inelasticity** **$k=1-E_{lead}/E_{avail}$**

If large k (π^0s carry more energy)
rapid development
If small k (baryons carry more energy)
deep penetrating

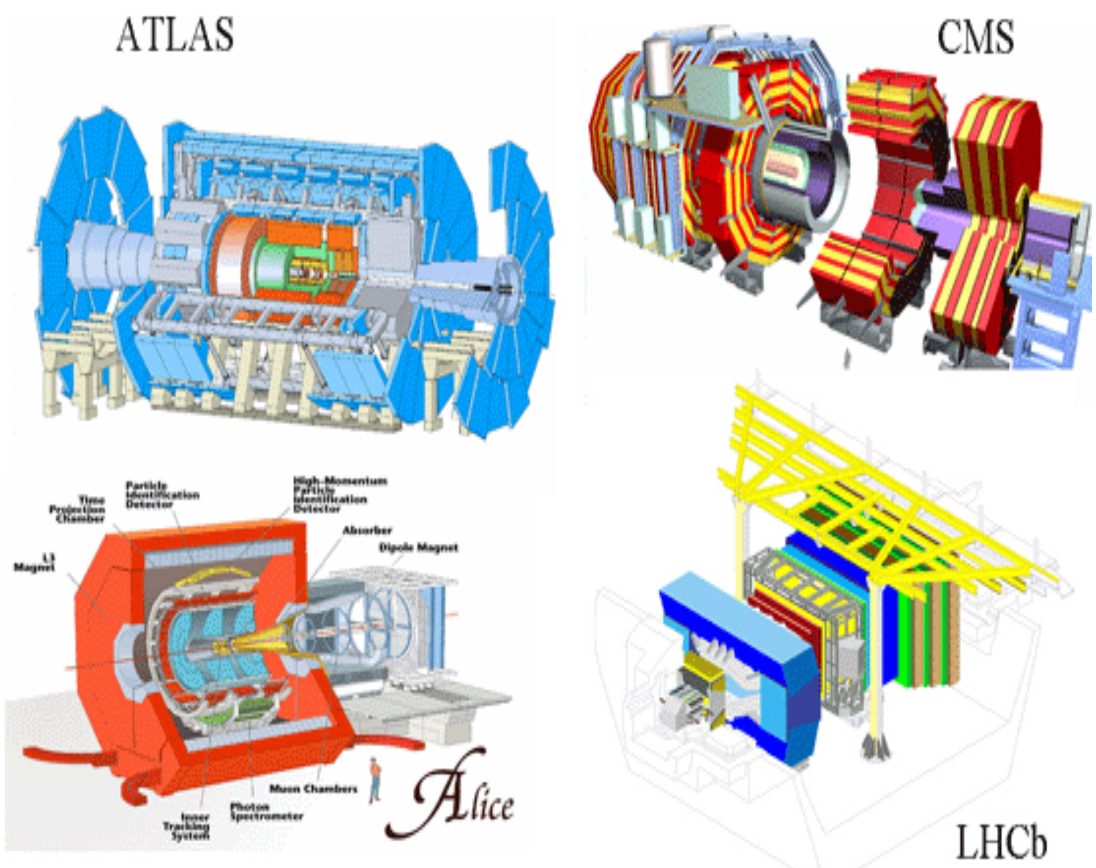
+ LHC phase space coverage



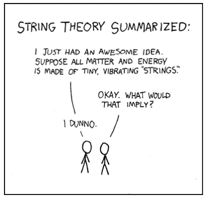


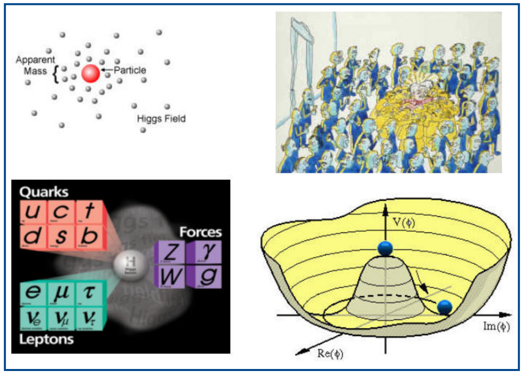
We may profit (and we are profiting) of the very broad coverage!
Dedicated forward detectors for a better measurement of the energy flow

Impressive coverage of the central region



- The largest detectors for particle physics
- Surrounding the LHC Interaction Points
- Covering many fundamental physics items
- Designed for discoveries!





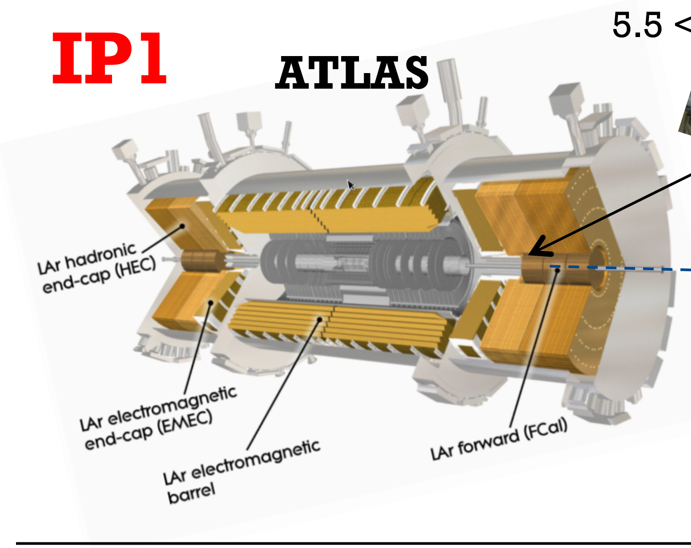
General purpose detectors (ATLAS, CMS,…) cover the spatial region at low rapidity.

Special detectors to access forward particles are necessary (TOTEM, ALFA)!

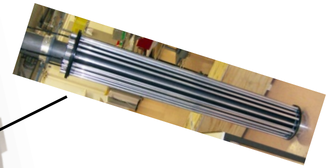
+ The forward regions

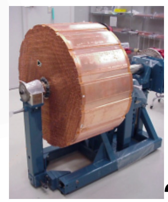
IP1

ATLAS



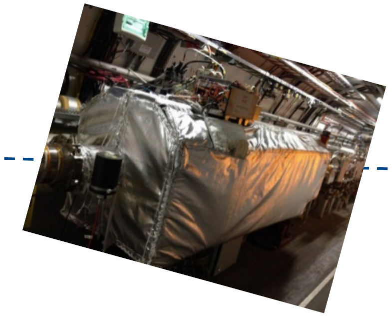
ATLAS LUCID
$5.5 < |\eta| < 6$



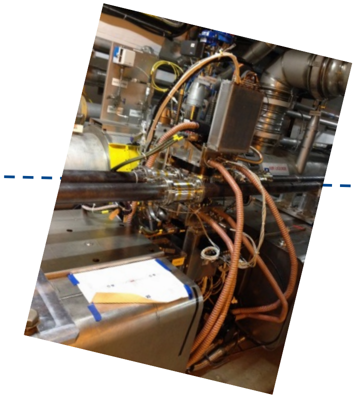


ATLAS FCAL
$3 < \eta < 5$

LHCf and ATLAS ZDC
(± 140 m); $|\eta| > 8.4$

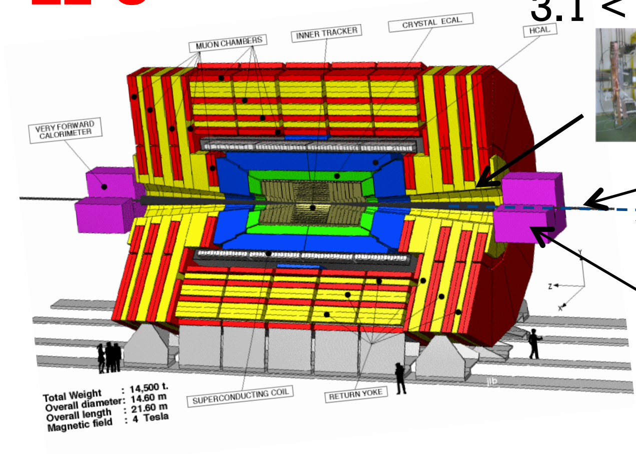


ATLAS ALFA RPs (± 240 m)
$10.6 < \eta < 13.5$

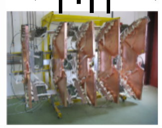


IP5

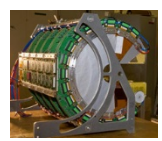
CMS



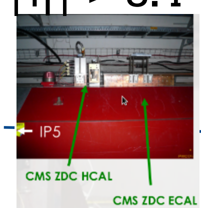
TOTEM T1 (CSC)
$3.1 < |\eta| < 4.7$



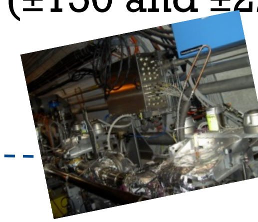
TOTEM T2 (GEM)
$5.3 < |\eta| < 6.5$



CMS ZDC (±140 m)
$|\eta| > 8.4$

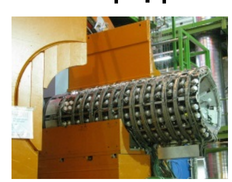


TOTEM RPs
(±150 and ±220 m)



CMS HF
$2.9 < |\eta| < 5.2$

CMS CASTOR
$5.1 < |\eta| < 6.6$



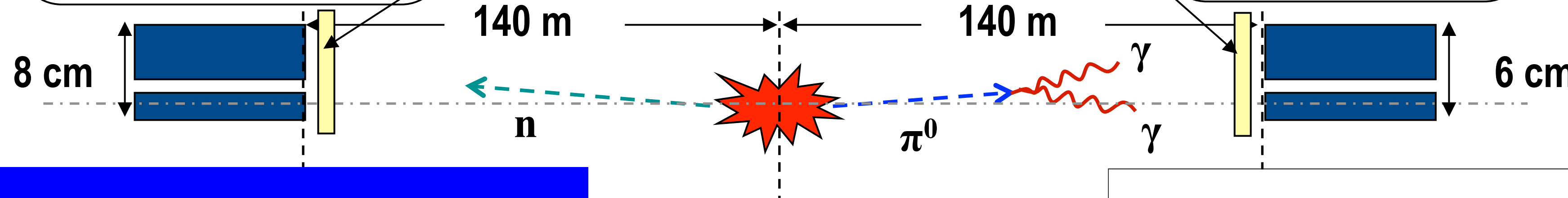
W/quartz
Cherenkov calo

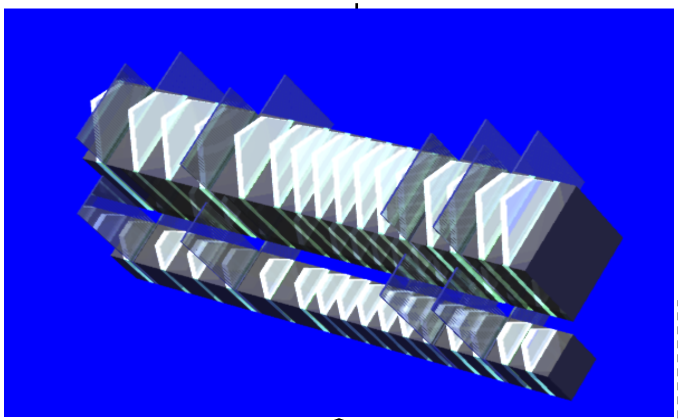
+ LHCf: location and detector layout

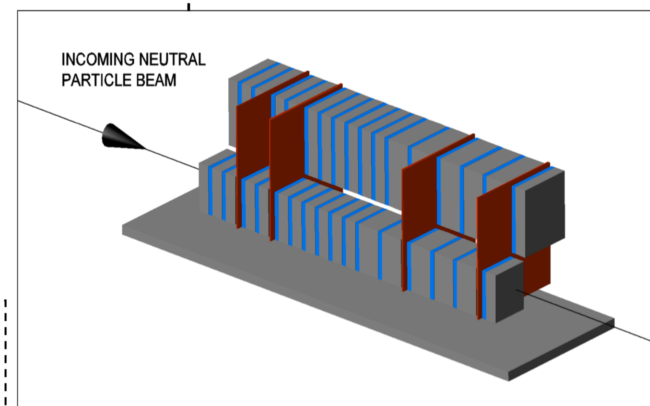
Detector I
Tungsten
GSO
GSO bars

INTERACTION POINT
IP1 (ATLAS)

Detector II
Tungsten
GSO
Silicon μstrips







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

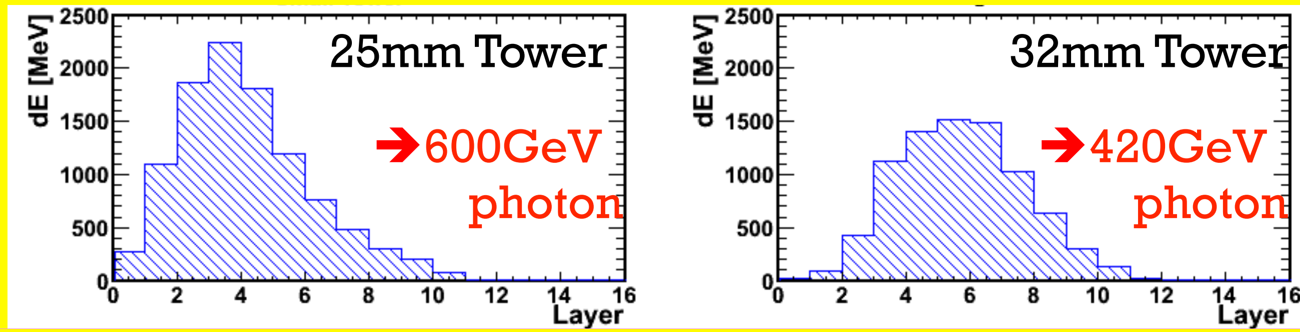
Arm#1 Detector
20mmx20mm+40mmx40mm
4 X-Y GSO Bars tracking layers

Energy resolution:
< 5% for photons
30% for neutrons
Position resolution:
< 200 μm (Arm#1)
40 μm (Arm#2)
Pseudo-rapidity range:
η > 8.7 @ zero Xing angle
η > 8.4 @ 140urad

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

+ π^0 in LHCf

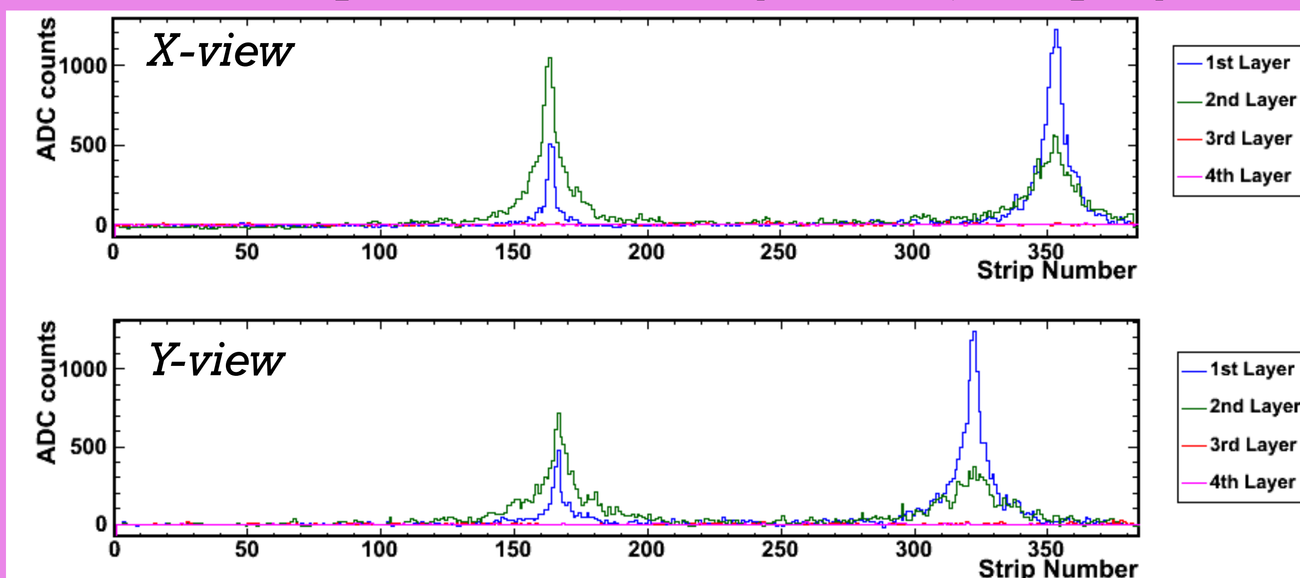
Longitudinal development measured by scintillator layers



Determination of **energy** from total energy release

PID from shape

Transverse profile measured by silicon μ–strip layers



Determination of the **impact point**

Measurement of the **opening angle** of gamma pairs

Identification of **multiple hit**

Reconstruction of π^0 mass $M_{\pi 0} = \sqrt{E_{\gamma 1} E_{\gamma 2}} \cdot \theta$

Few selected <8 TeV LHC results

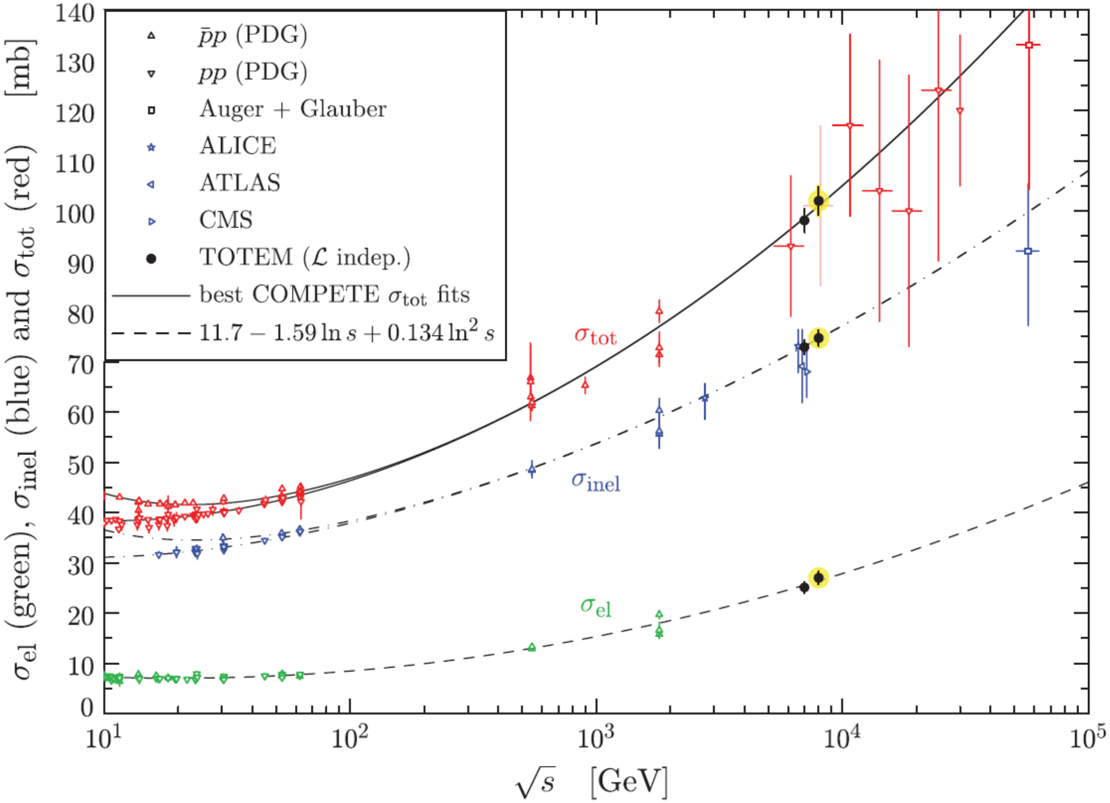
+ TOTEM cross section measurements

Phys. Rev. Lett. 111, 012001 (2013)

ELASTIC CROSS SECTION:
- Events triggered by RPs in coincidence on both sides

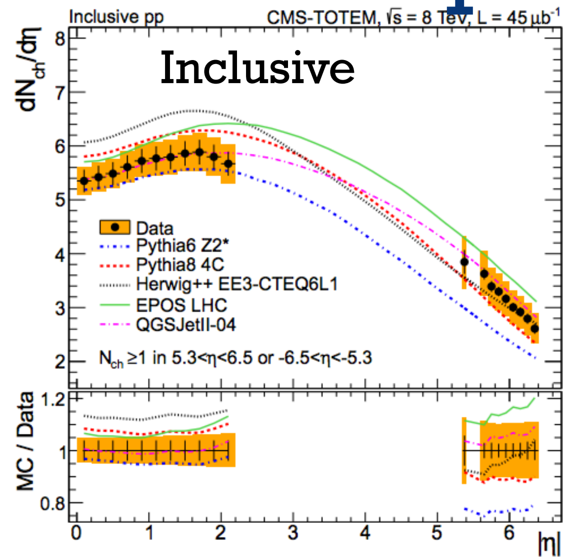
INELASTIC CROSS SECTION:
- Events triggered by the T2 tracker on either arm

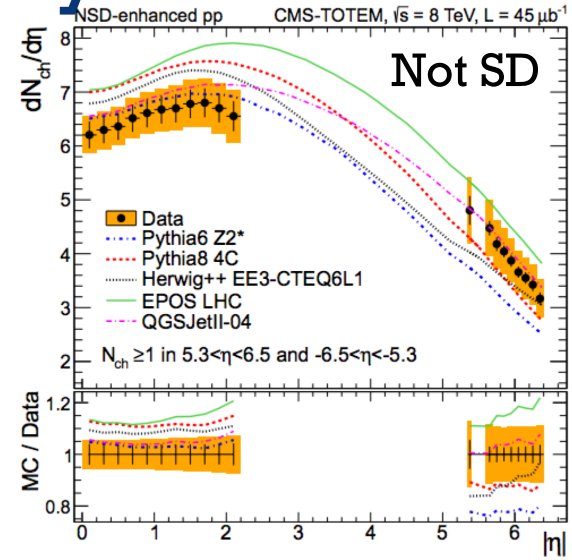
Triggers taken in random bunch crossings used for calibration.



Compilation of the total (σ_{tot}), inelastic (σ_{inel}) and elastic (σ_{el}) cross-section measurements: the TOTEM measurements are highlighted. The continuous black lines (lower for *pp*, upper for *p p*) represent the best fits of the total cross-section data by the COMPETE collaboration. The dashed line results from a fit of the elastic scattering data. The dash-dotted lines refer to the inelastic cross section and are obtained as the difference between the continuous and dashed fits.

+ 8 TeV results by Totem/CMS on charged particles multiplicity

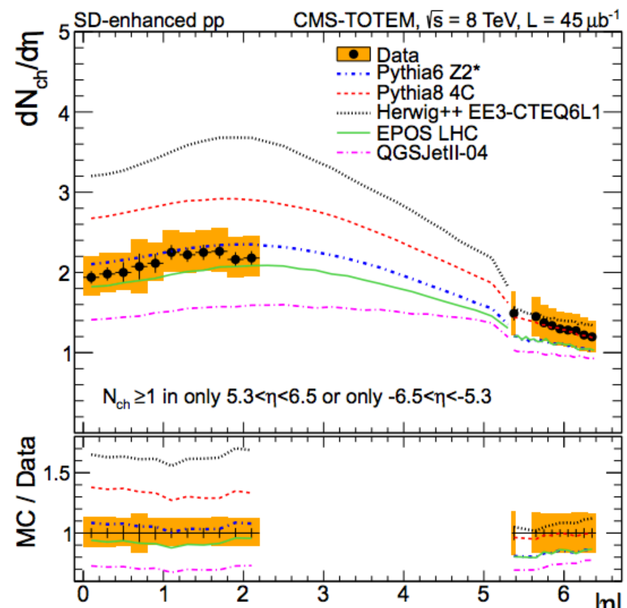




The Single Diffractive selection clearly enhance the difference btw models!

What happens if we tag the forward proton?

Measurement should certainly be repeated at 13 TeV!

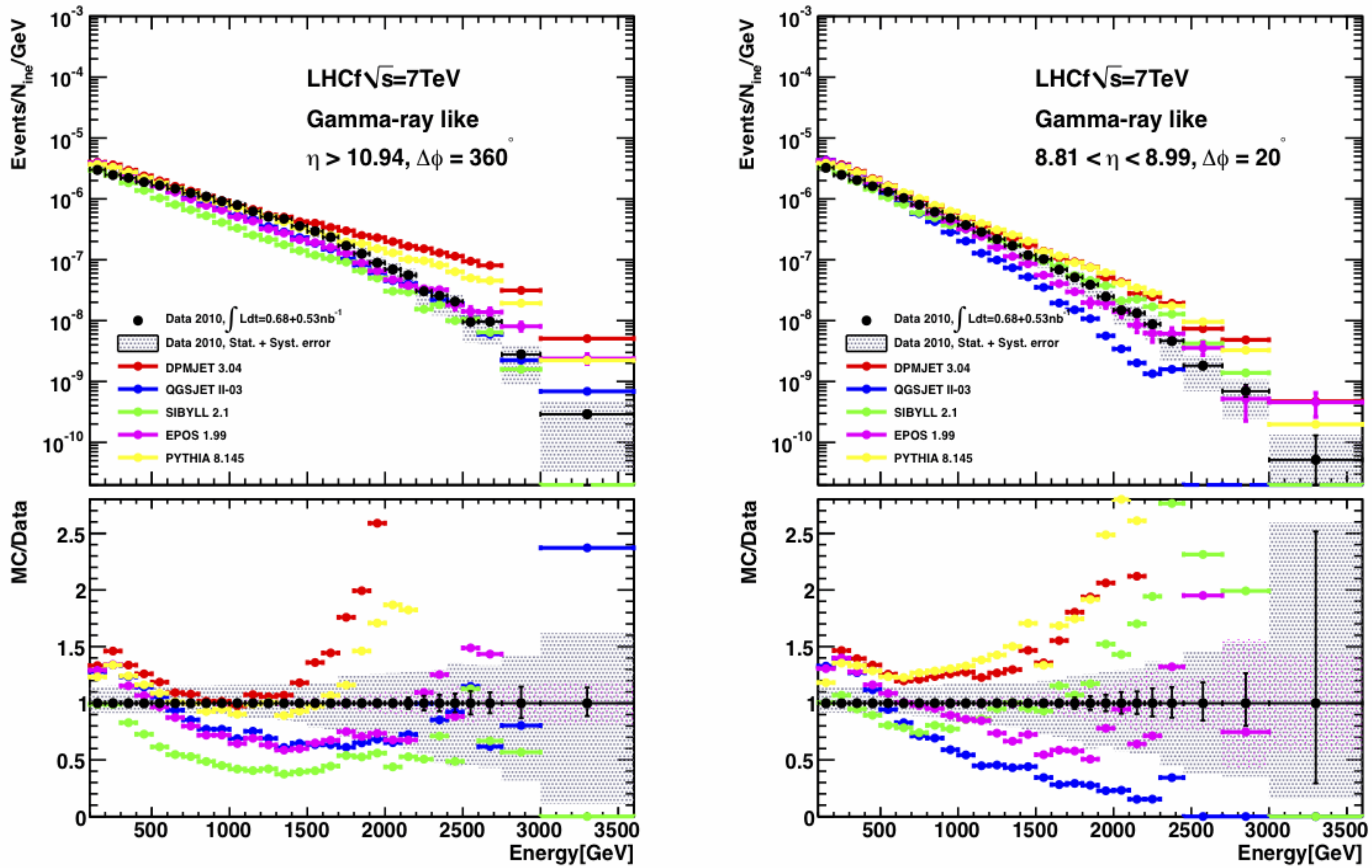


Single Diffractive enhanced

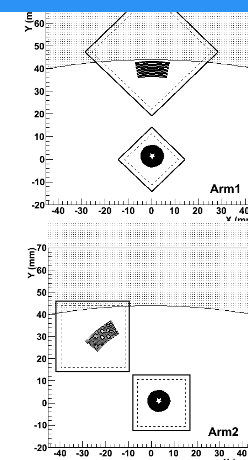
Table 3: Event selection criteria applied at the stable-particle level in the MC simulation.

Inclusive sample				
$N_{\text{charged particles}} > 0$	in	$5.3 < \eta < 6.5$	or	$-6.5 < \eta < -5.3$, $p_T > 0$
NSD-enhanced sample				
$N_{\text{charged particles}} > 0$	in	$5.3 < \eta < 6.5$	and	$-6.5 < \eta < -5.3$, $p_T > 0$
SD-enhanced sample				
$N_{\text{charged particles}} > 0$	in only	$5.3 < \eta < 6.5$	or only in	$-6.5 < \eta < -5.3$, $p_T > 0$

+ LHCf γ spectra @ 7 TeV



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

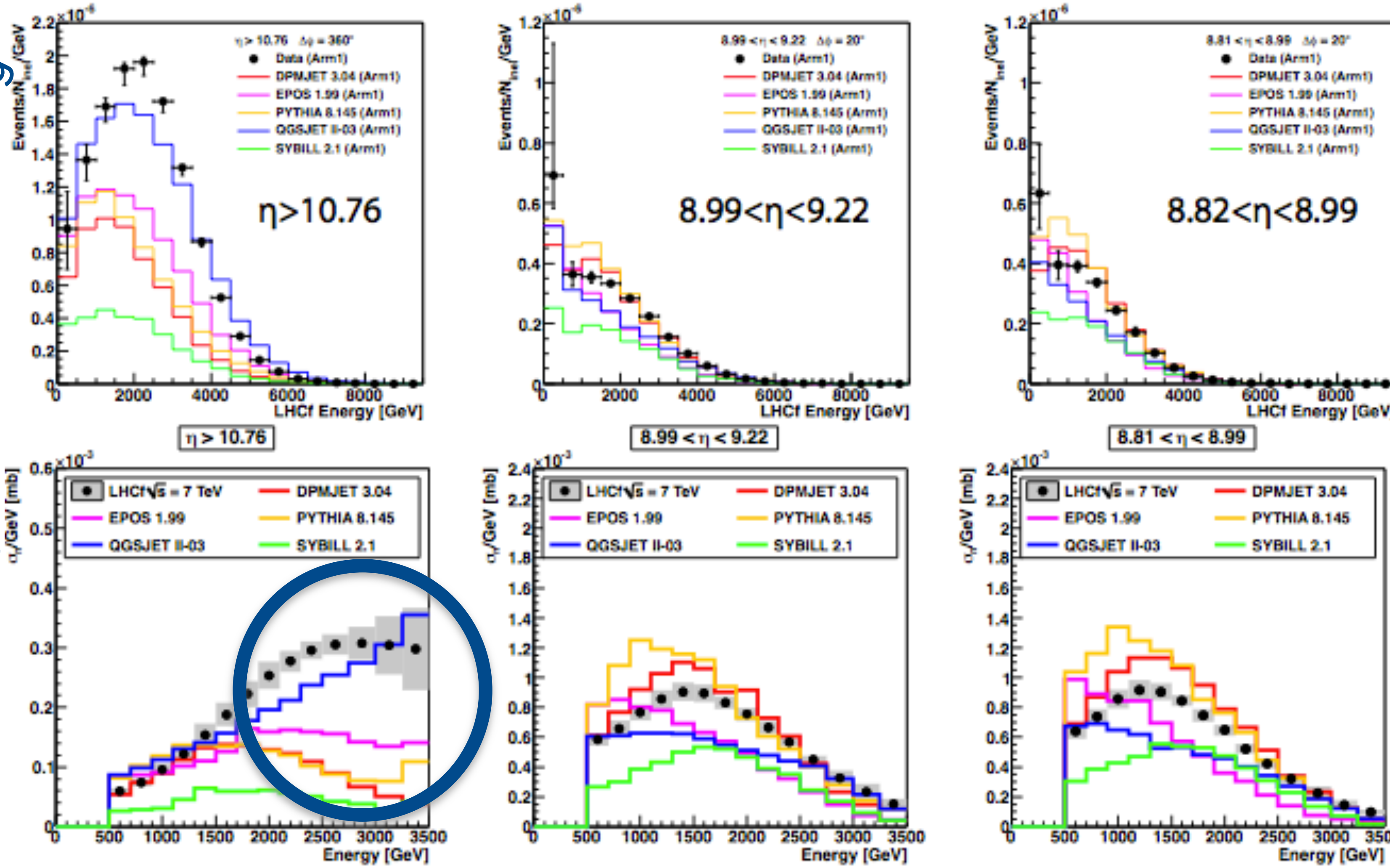


- No model can reproduce the **LHCf data** perfectly.
- **DPMJET** and **PYTHIA** are in good agreement at high-η for E_γ<1.5TeV, but harder in E>1.5TeV.
- **QGSJET** and **SIBYLL** shows reasonable agreement of shapes in high-η but not in low-η
- **EPOS** has less η dependency against the LHCf data.

+ Inclusive neutron spectra (7 TeV pp)

Before unfolding

After unfolding



Very large high energy peak in the η>10.76 (predicted only by QGSJET)

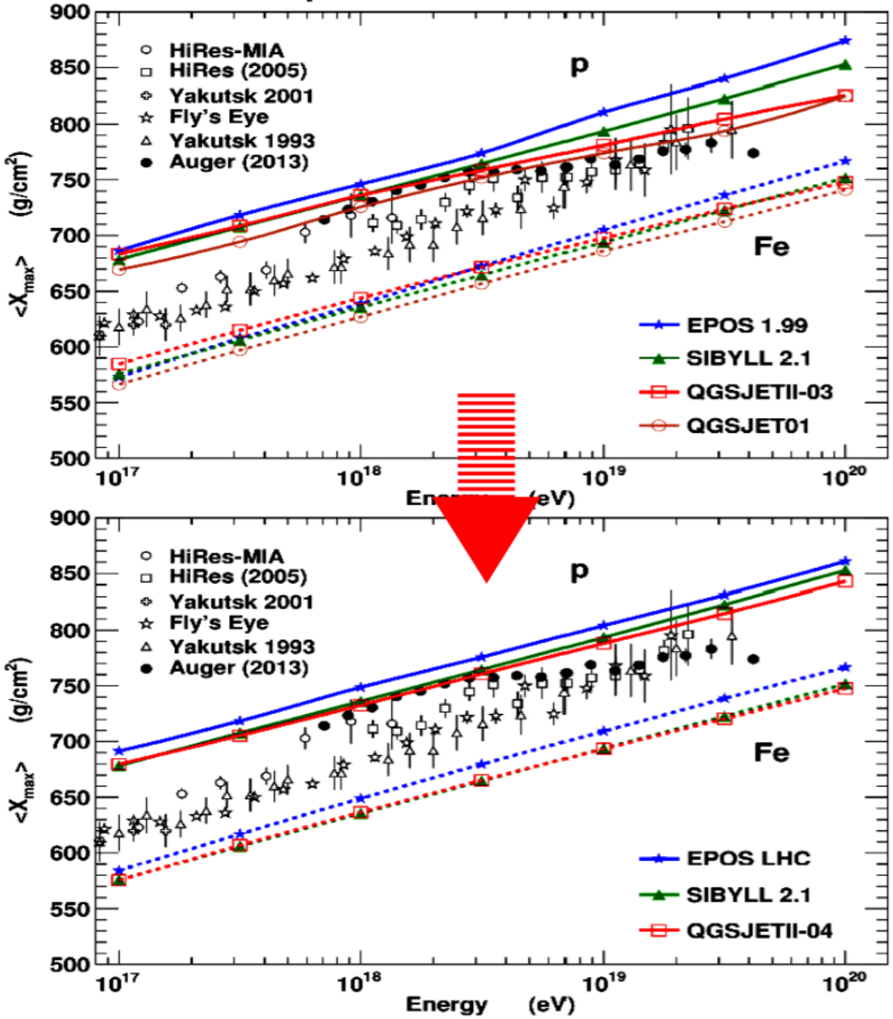
→ Small inelasticity in the very forward region!

Models tuning after the first LHC data (EPOS and QGSJET)

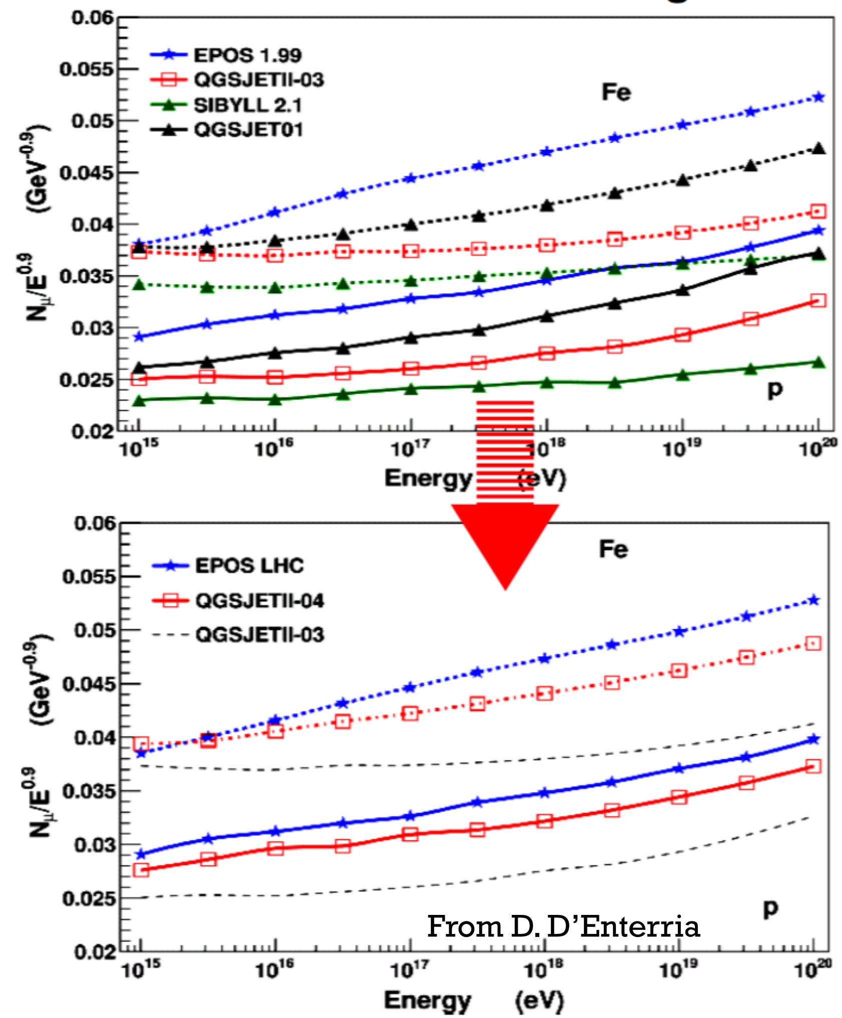
Mean depth of shower maximum:

(pre-LHC)

(post-LHC)



Number of muons on ground:



Significant reduction of differences btw different hadronic interaction models!!!

LHC @ 13 TeV

Charged multiplicity

Energy flow

Forward neutral particles spectra

+

What is new in the detectors/ triggers/analysis?

- LHCf completed an upgrade to improve radiation hardness
- Very forward proton tag to identify the event topology
  - ATLAS/Alfa
- ATLAS-LHCf combined data analysis
  - LHCf trigger will be used by ATLAS to trigger the detector
  - Offline synchronization of the events will be possible
- Some improvements in the trigger algorithms by big experiments
- Clearly all the previous measurements will be done at higher energies!

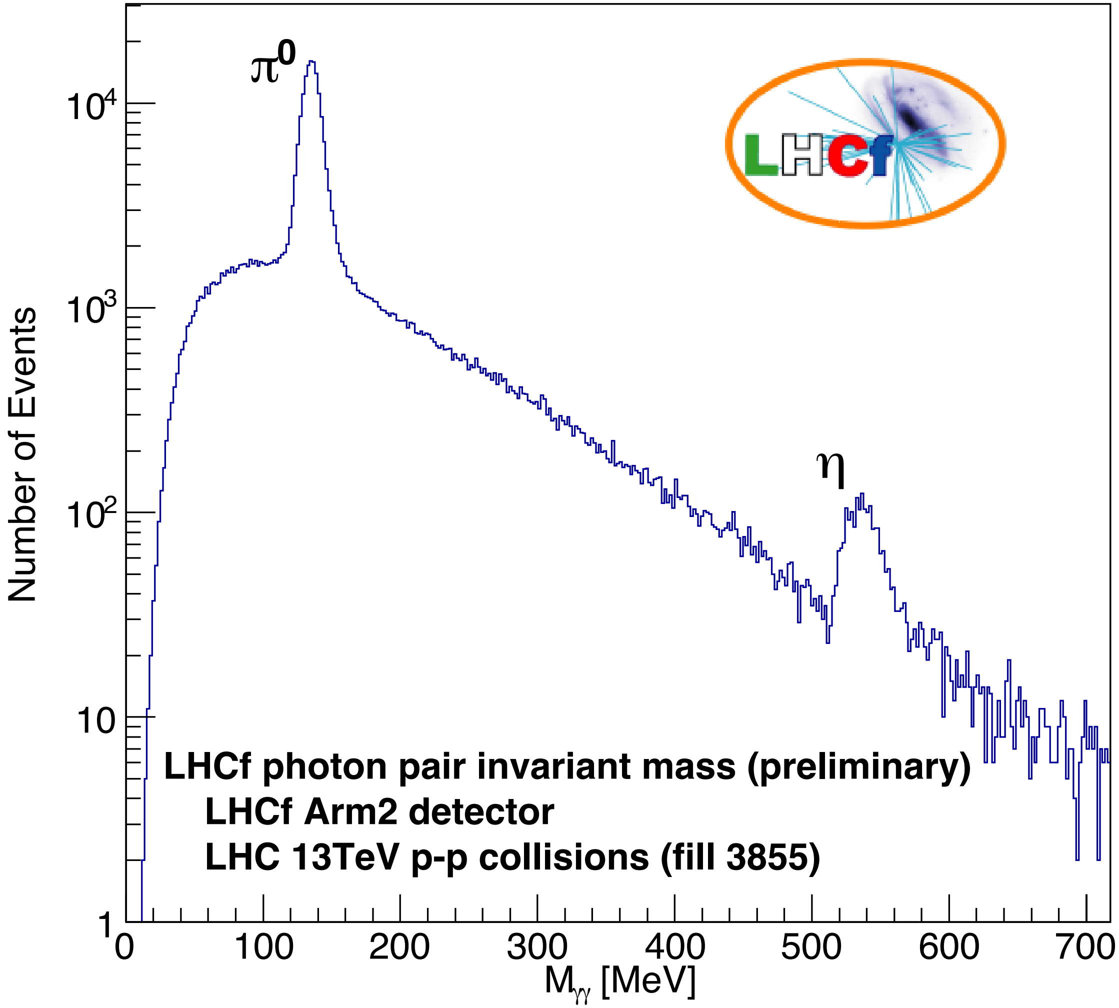
+ LHCf/ATLAS common operation strategy

- Beam conditions:
- Low luminosity ($L<6.10^{28}$ $cm^{-2}s^{-1}$), low pileup ($\mu<0.03$) at the beginning of the LHC run
- Very clean beam conditions
- LHCf trigger delivered to ATLAS + Offline matching of the events
- $>50.10^{6}$ commonly triggered events
- Excellent statistics for clean measurements of:
  - γ
  - Neutrons
  - π^0

for different conditions of central activity

+ A quick look to the LHCf 2015 data taking

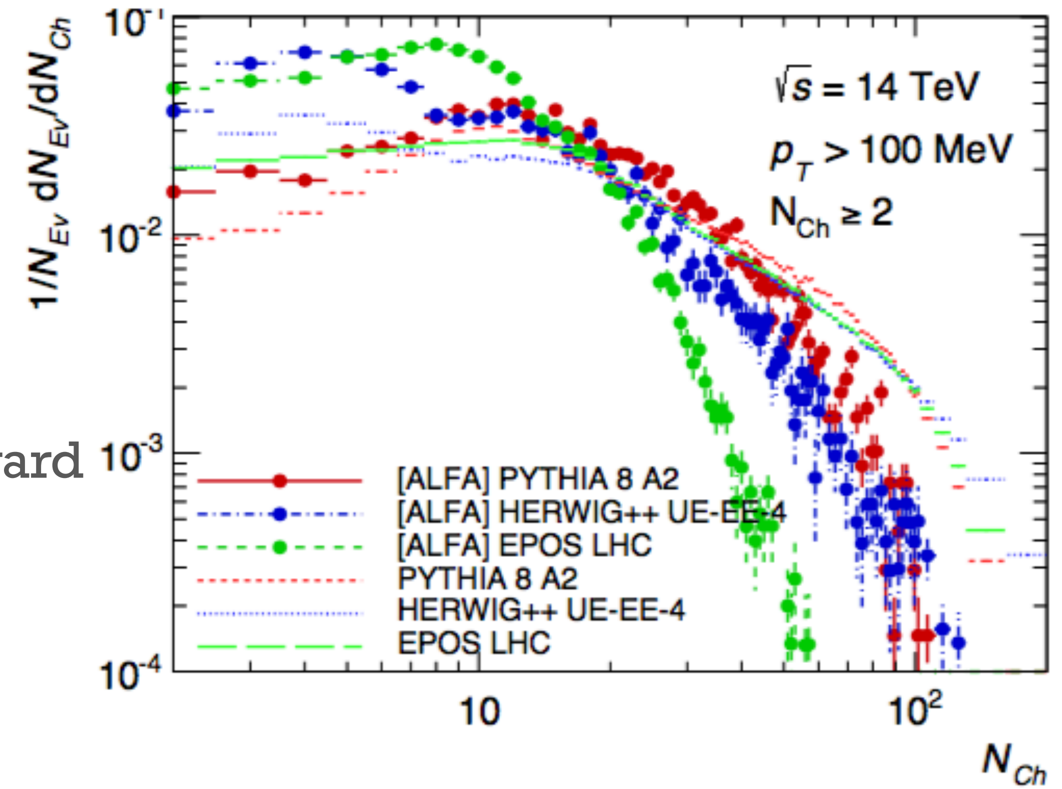
- Data taking was very successful
- Six LHCf dedicated fills (9-12 June 2015)
- 32 hours of operation
- 18.10^6 events for Arm1
- 21.10^6 events for Arm2
- Trigger exchange with Atlas worked fine without problems



+ Charged particles multiplicity

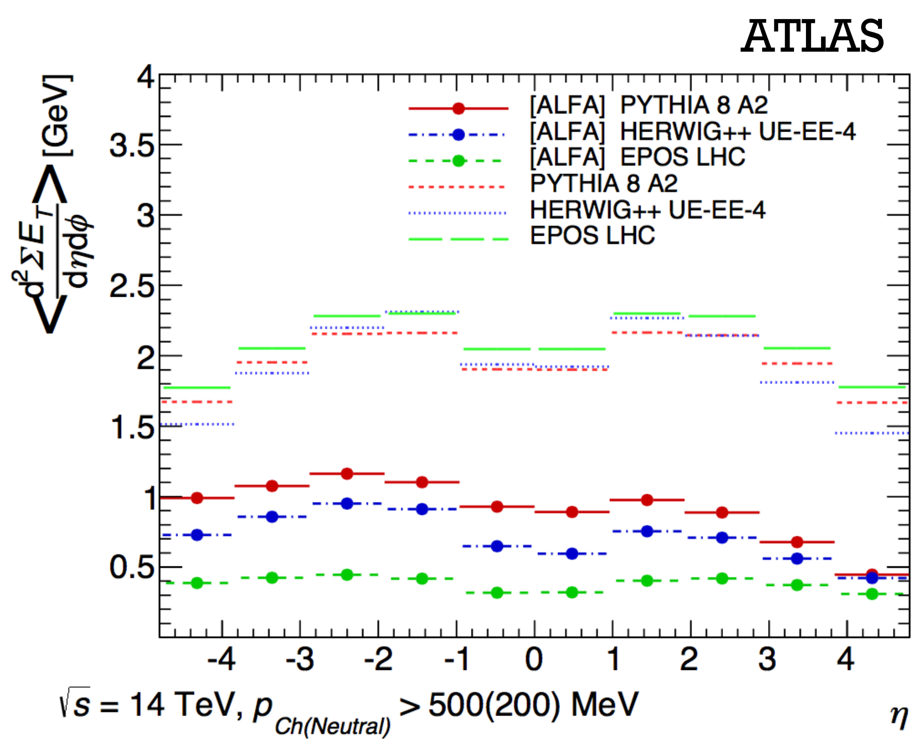
- Important for the longitudinal dependence of the showers → X_{max}
- 'Standard measurements' will be done at 13 TeV
  - |η|<2.5 (Atlas, CMS, Alice)
  - 2<|η|<4.5 (LHCb)
  - 3.1<|η|<6.5 (TOTEM)
- For the first time the measurement could be correlated with the very forward proton tag!

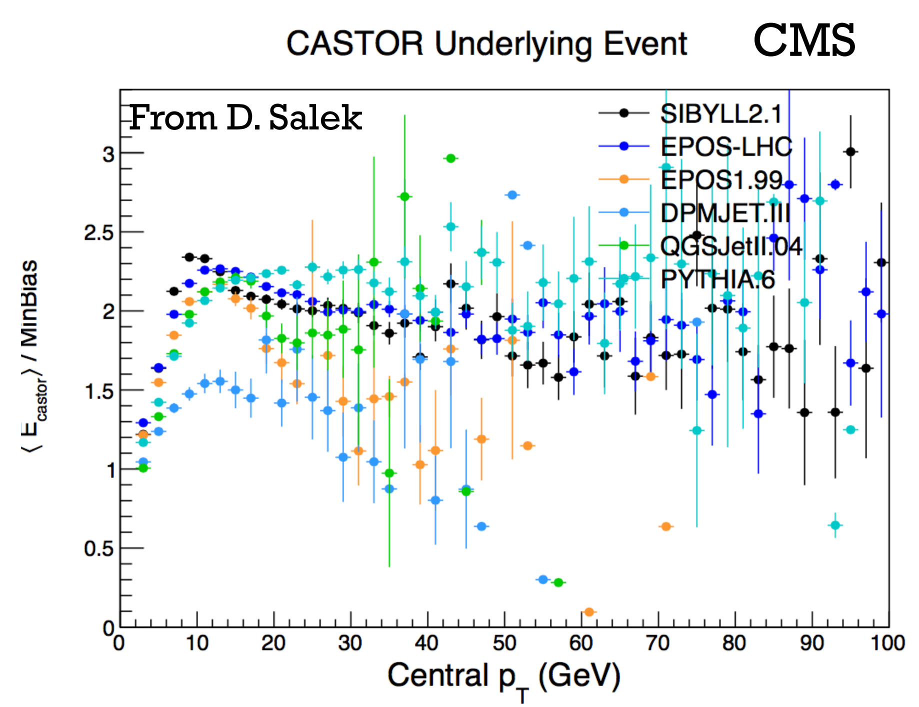
From D. Salek



Energy flow

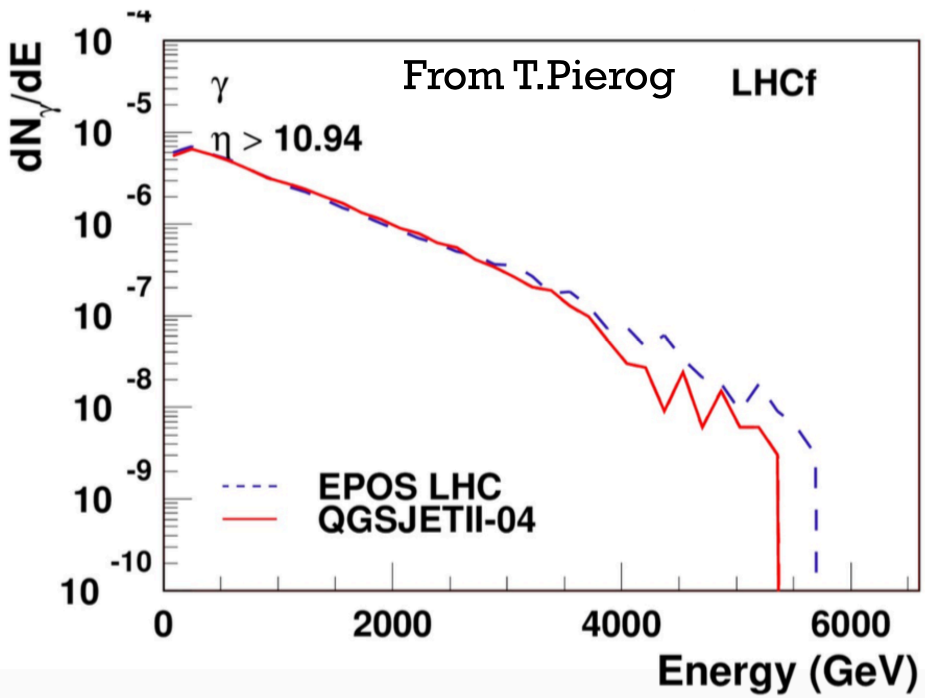
- Energy flow is the most important ingredient for the air shower development
- This measurement can greatly profit of the forward proton tag
  - Energy flow is significantly affected by the presence of a leading very forward high energy particle

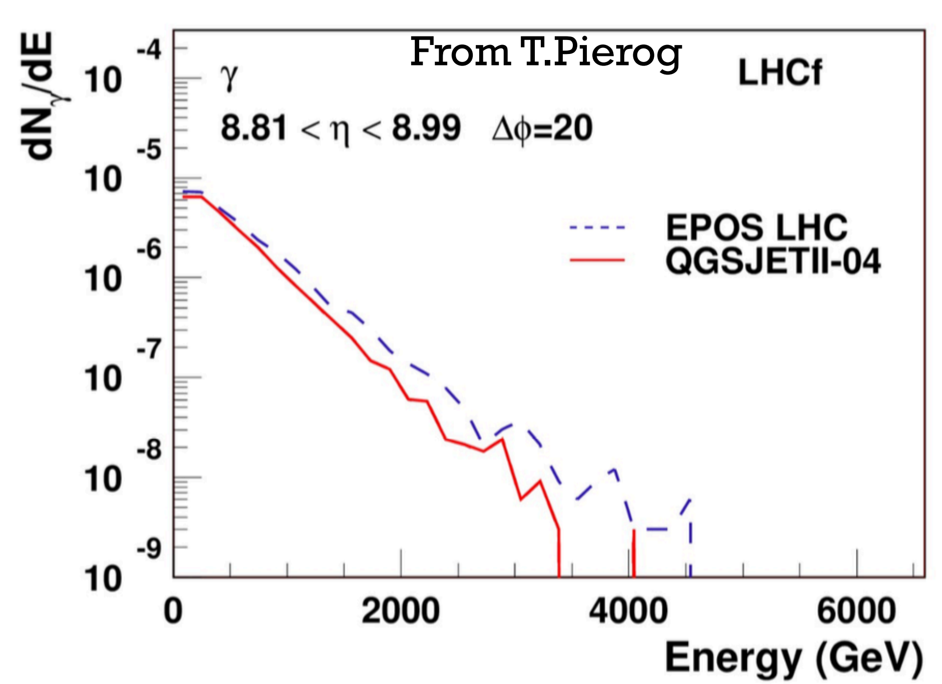




Very forward neutral particle spectra I: photons

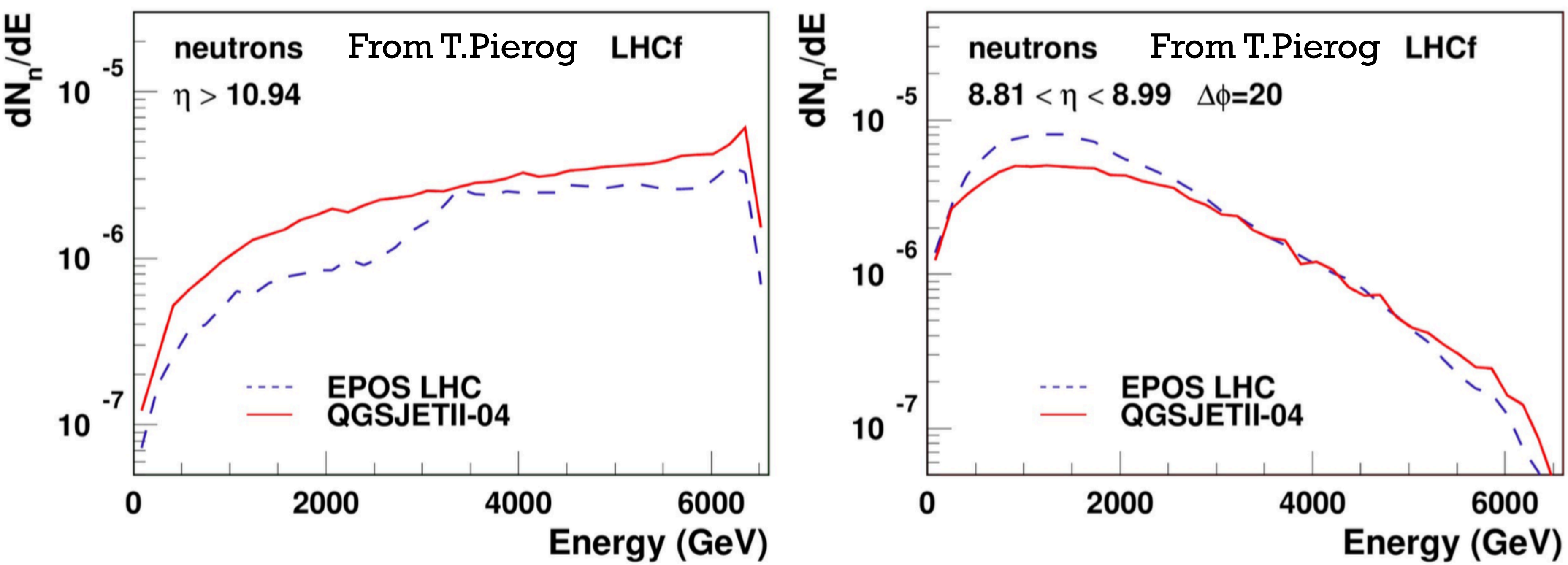
- LHCf is optimized for the very forward neutral particle detection
- $|\eta| > 8.4$
- Excellent performances in the γ measurement (~2%)
- Large difference even with tuned models





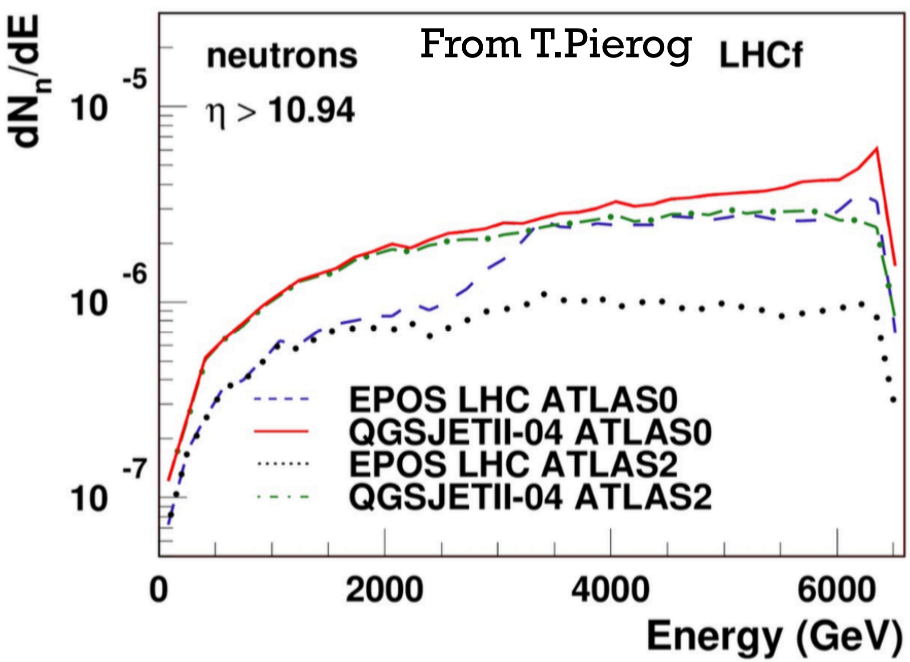
Very forward neutral particle spectra II: neutrons

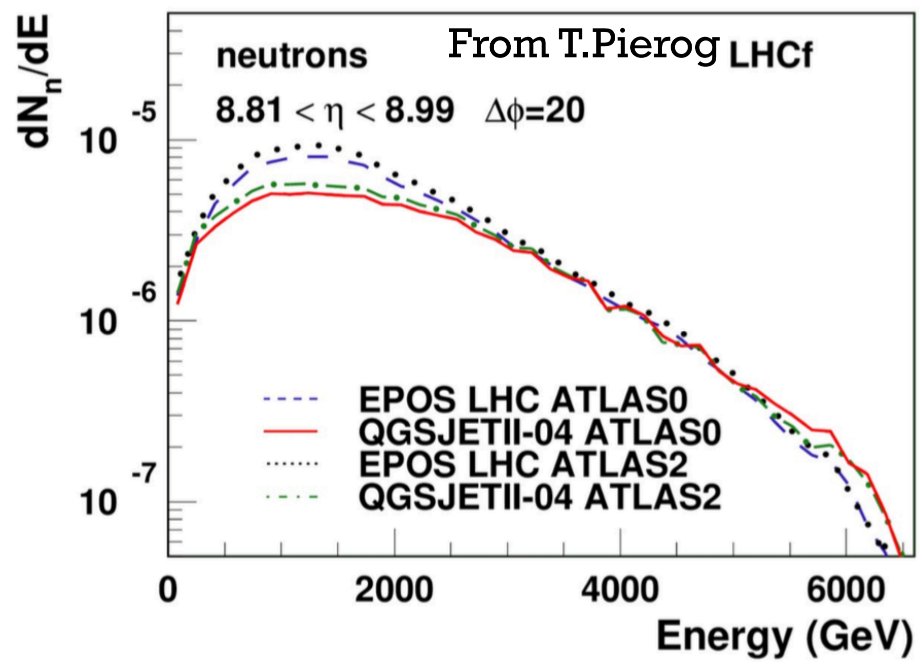
- Even larger differences wrt γ!
- 30% energy resolution is not taken into account
- …. But unfolding works well! (See Bonechi's talk)



What happens if we off-line combine ATLAS and LHCf?

- ATLAS0: no charged particles in the $|\eta|<2.5$ and $p_t>0.1$ GeV/c
- ATLAS2: >1 charged particles in the $|\eta|<2.5$ and $p_t>0.1$ GeV/c
- Central activity selection enhance the differences btw models
- Could be used to tune different components of the models

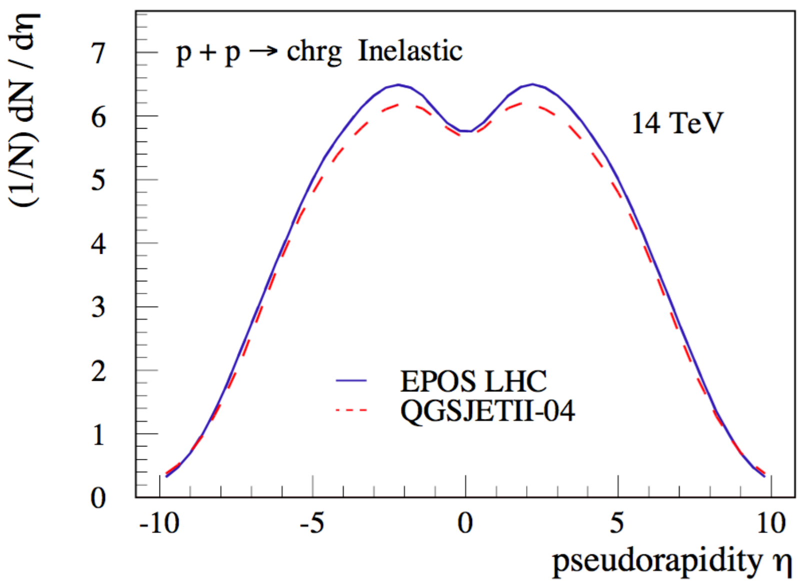


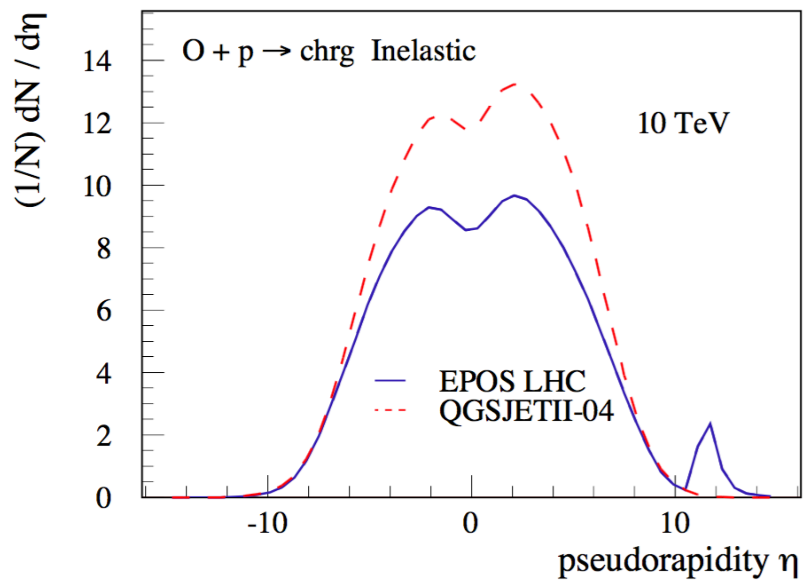


The future….

The far future @ LHC

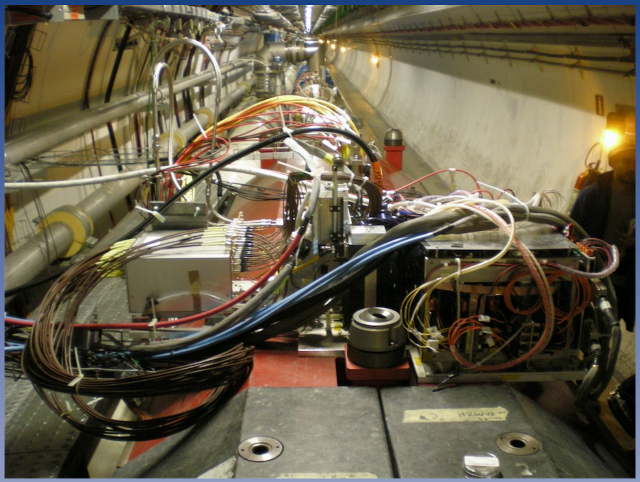
- The most promising future at LHC involve the proton-light ions collisions
- To go from p-p to p-Air is not so simple….
  - Comparison of p-p, Pb-Pb and p-Pb is useful, but model dependent extrapolations are anyway necessary
- Direct measurements of p-O or p-N could significantly reduce some systematic effects



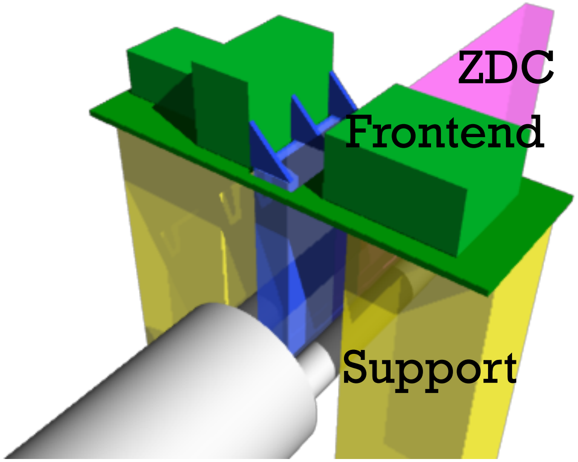


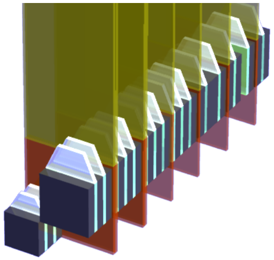
+ The future @ RHIC: From the Large Hadron Collider to the Longisland Hadron Collider

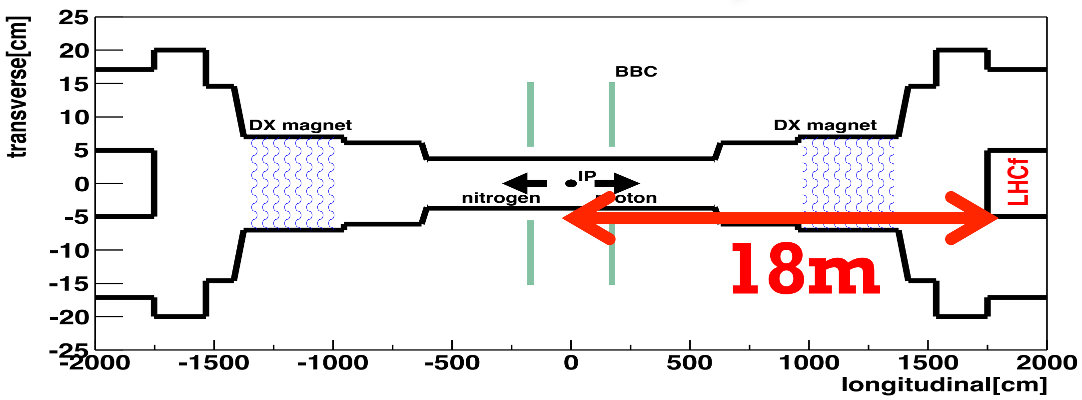
LHCf Arm2 detector in the LHC tunnel

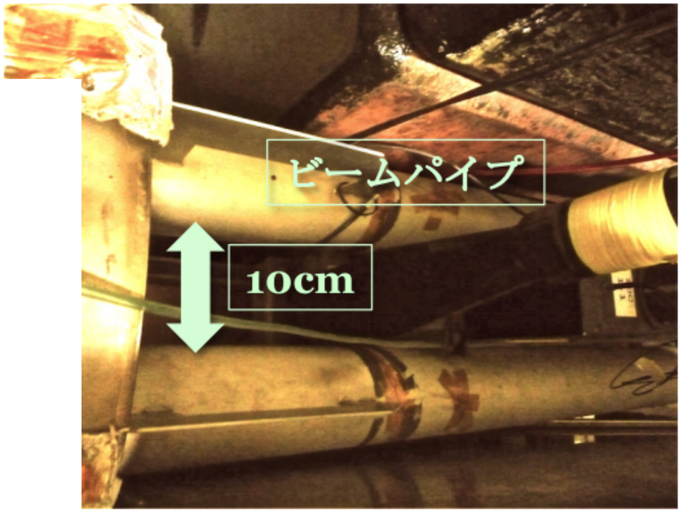


Schematic view of the RHICf installation



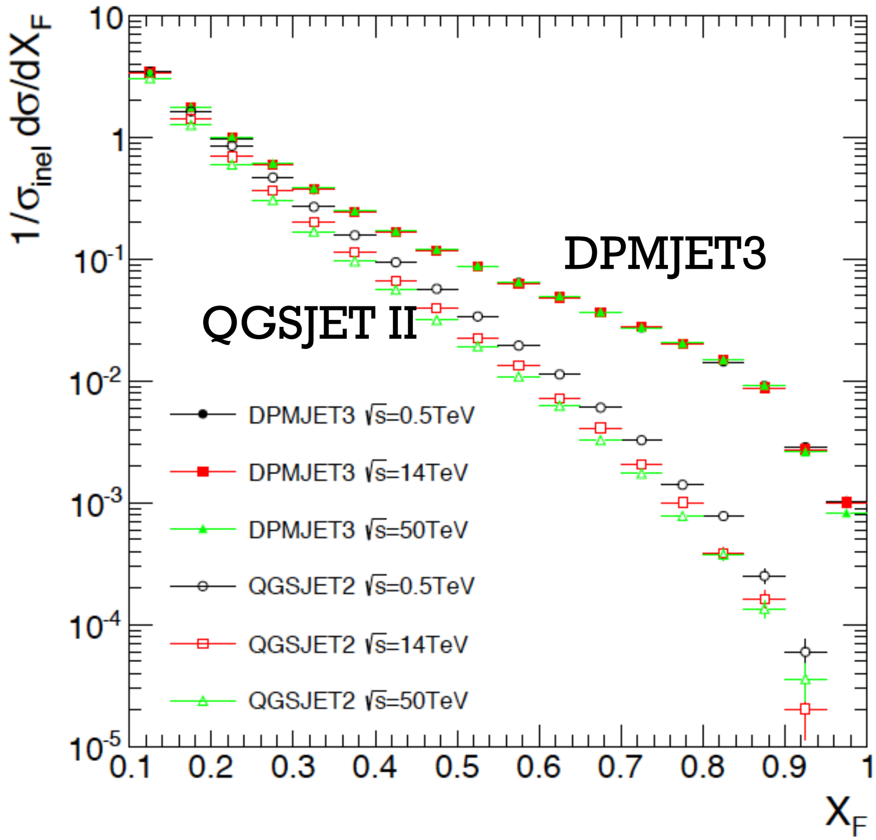




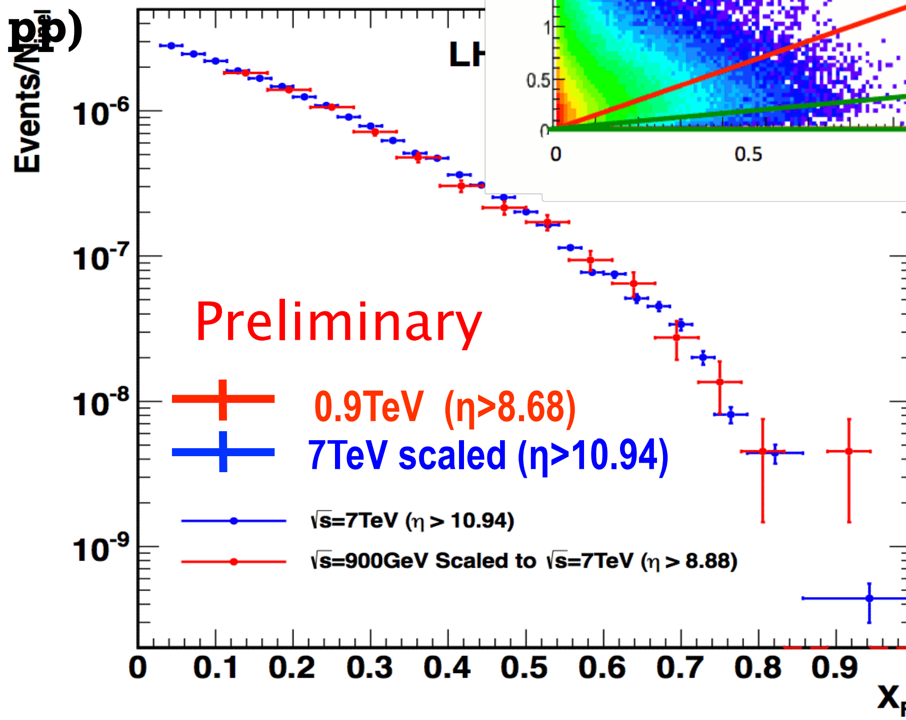


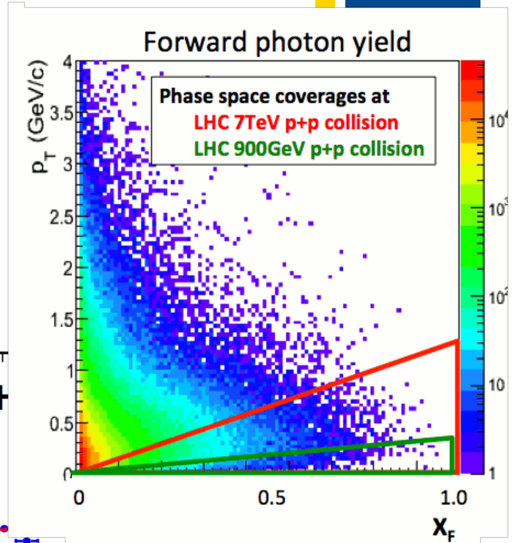
+ √s scaling : a key for extrapolation beyond the LHC

All π^0 expected from models (0.5TeV, 14TeV and 50TeV)



LHCf single photon data (900GeV pp , 7TeV pp)

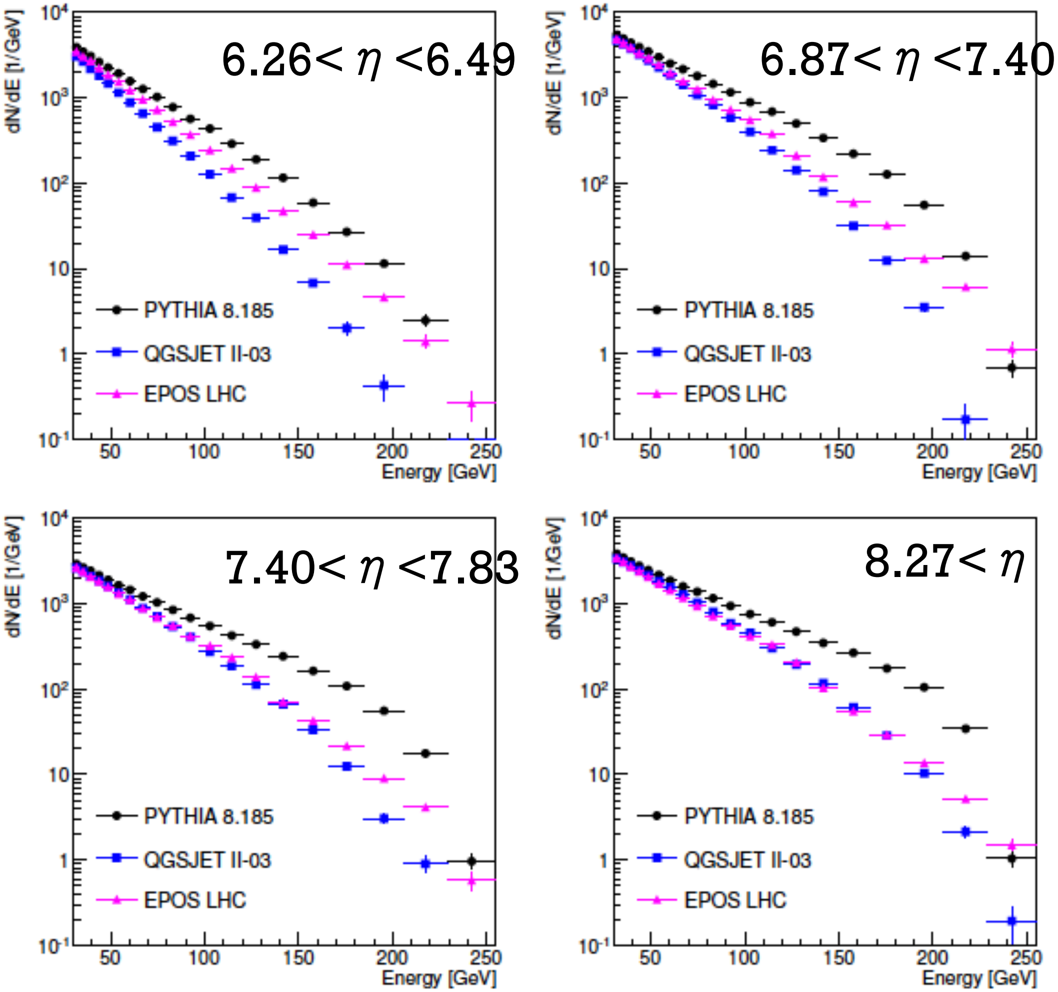




Comparison done in the very limited phase space of 900GeV collisions

(green triangle in the phase space plot)

+ Expected Results (single photons)



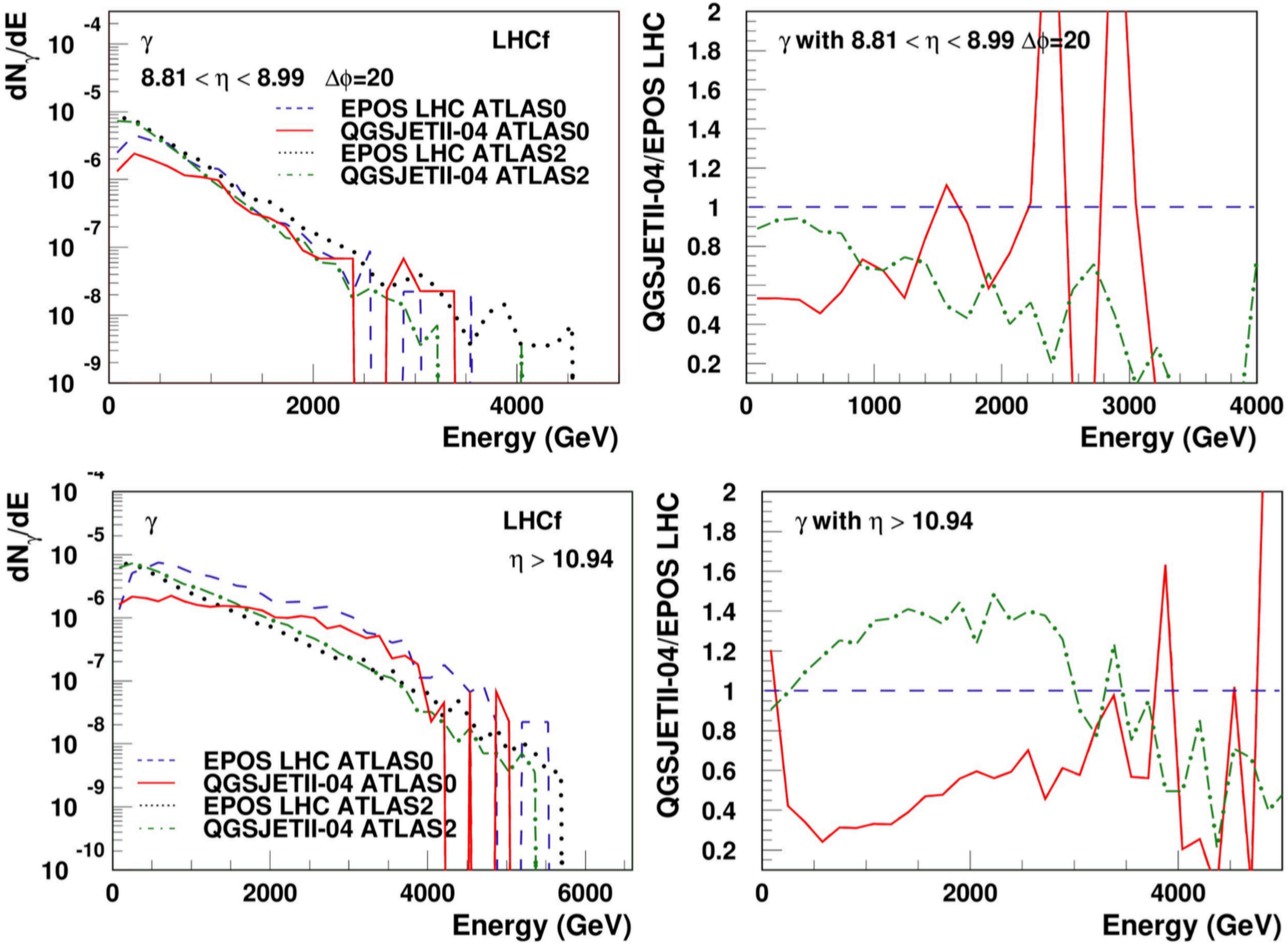
- Photon spectra at 4 rapidity samples
- 12 hours statistics (12 nb^{-1} effective luminosity; 360nb^{-1} delivered)
- Statistical error is almost negligible except at the highest energy bins

Conclusions

- In the last few years the importance of accelerator based measurements useful for Cosmic Ray physics came up very clearly
- LHC is the ideal laboratory for these studies
- Many important measurements have already been done
  - Significant improvement of EPOS_LHC and QGSJET-04 hadronic interaction models
- Synergies between dedicated forward detectors and large acceptance central detectors are coming up
  - Next generation measurements, profiting of these synergies, will be soon performed, allowing further improvements of the models in their different components

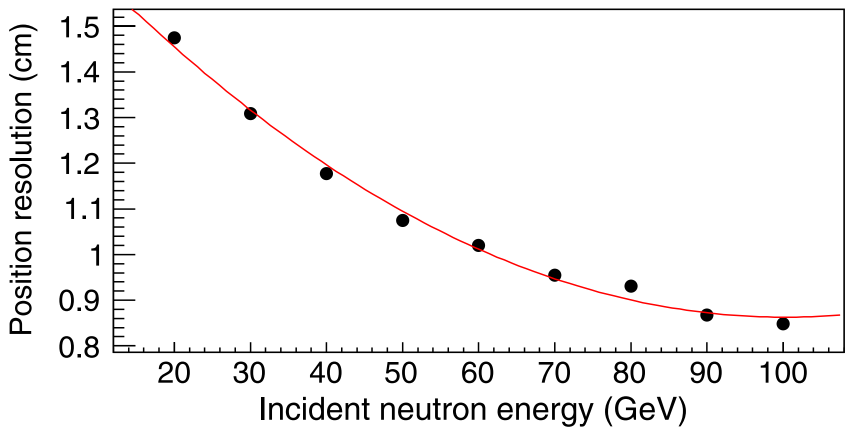
Backup slides

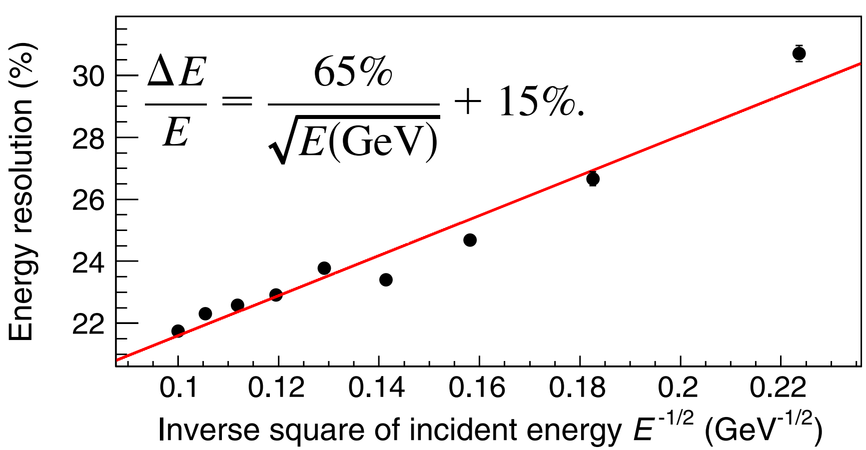
+ LHCf-Atlas: photons



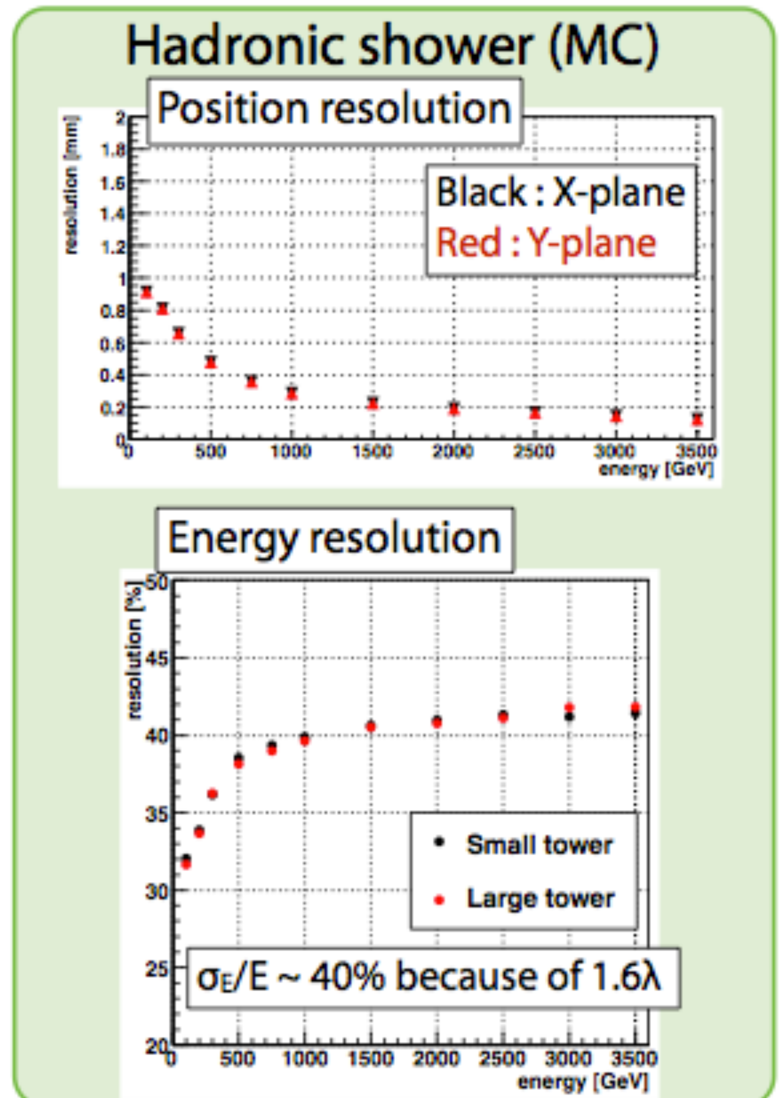
+ ZDC resolution @PHENIX vs RHICf

PHENIX ZDC





RHICf



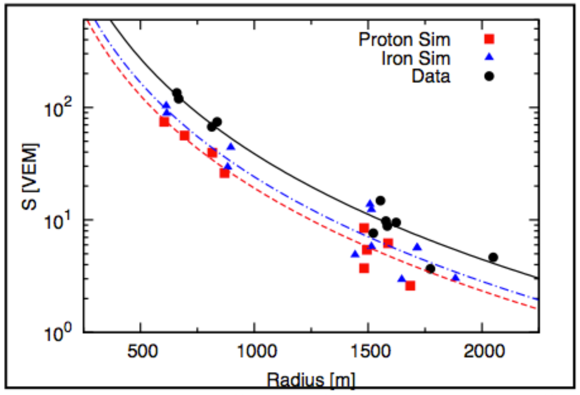
+ RHICf beam condition proposal

- Constraints
  - RHICf DAQ speed is limited to 1kHz
  - Collision pile up cannot be resolved
  - Small angular dispersion is preferred
- Beam Proposal
  - 510GeV p+p collisions
  - $\beta^* = 10$m
  - Radial (horizontal) polarization; 0.4-0.5
  - $\varepsilon = 20$mm mrad, $I_b = 2\times10^{11}$, $n_{b\text{-colliding}} = 100$, $n_{b\text{-noncolliding}} = 20$ (nominal)
  - Luminosity=1.1 10^{31} $cm^{-2}s^{-1}$
- Operation
  - Few days for physics and few days for contingency
  - π^0 (double tower event) enhanced and single shower prescaled triggers are used simultaneously
  - Trigger exchange with PHENIX
  - Stay at the garage position not to interfere ZDC when RHICf does not take data

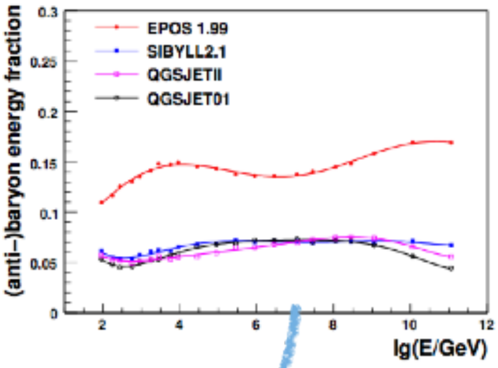
LHCf @ pp 7 TeV: neutron analysis

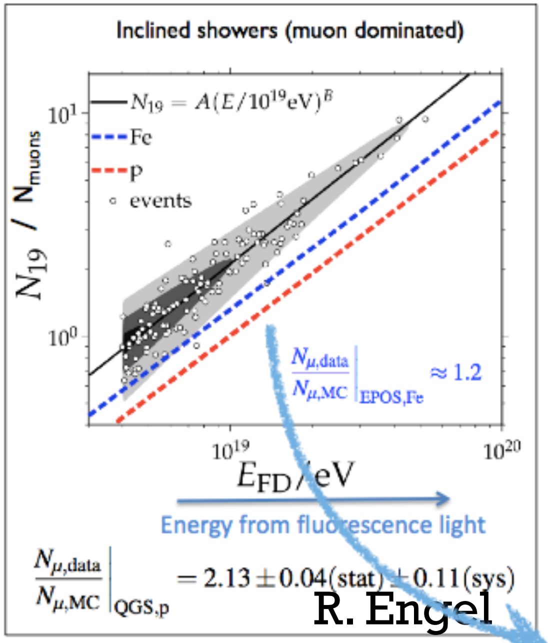
Motivations:

- Inelasticity measurement $k=1-p_{leading}/p_{beam}$
- Muon excess at Pierre Auger Observatory
  - Cosmic rays experiment measure PCR energy from muon number at ground and florescence light
  - 20-100% more muons than expected have been observed

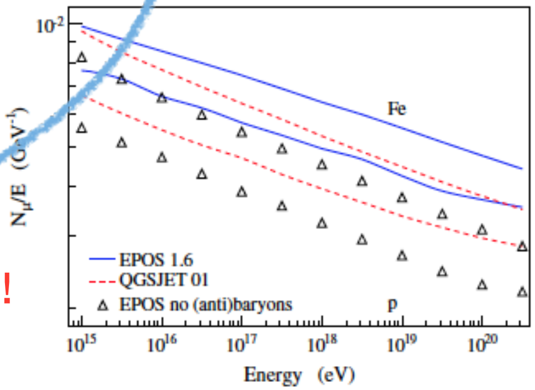


[J.Allen, et al. ICRC2011 Proceedings]





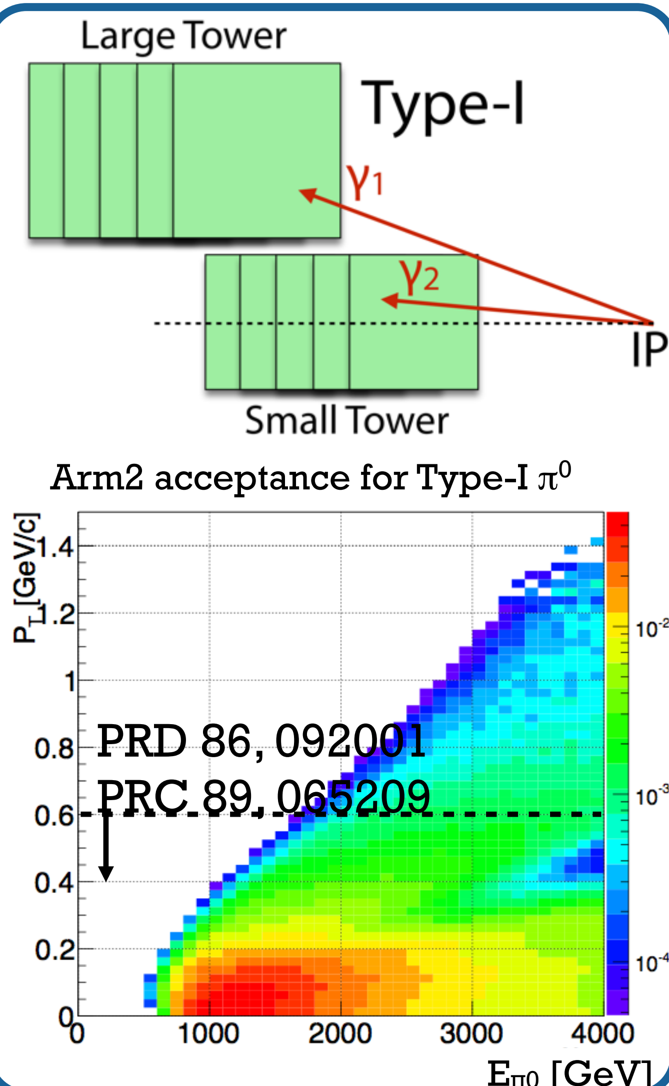
- Number of muons depends on the energy fraction of produced hadron
- Muon excess in data even for Fe primary MC!!!!
- EPOS predicts more muons due to larger baryon production, even if it is not sufficient to reproduce the experimental data

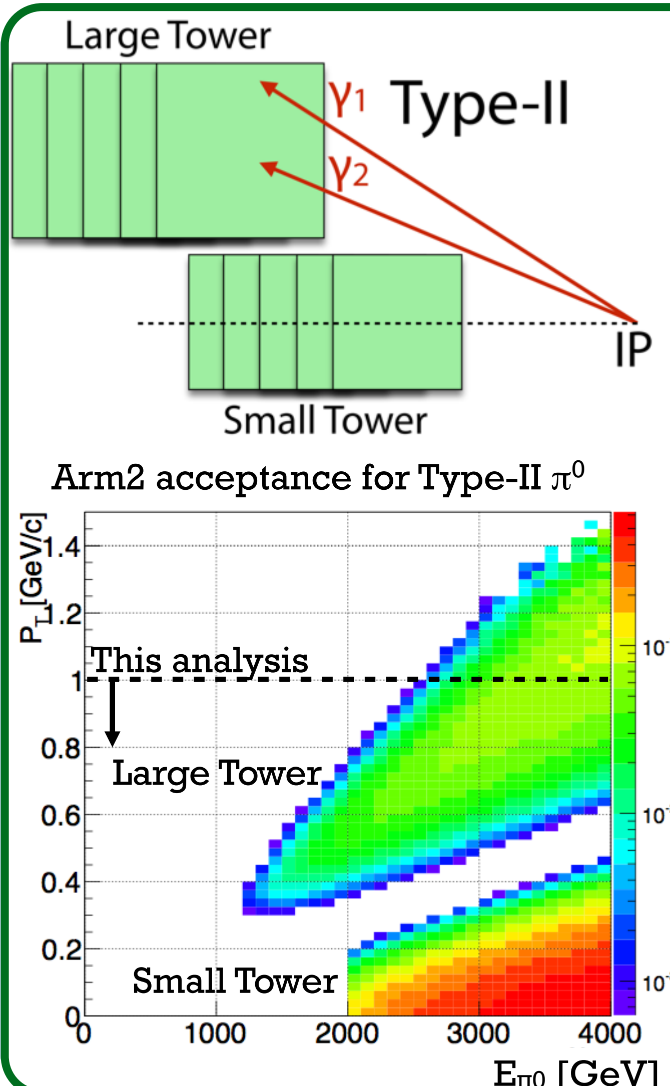


importance of baryon measurement!!!

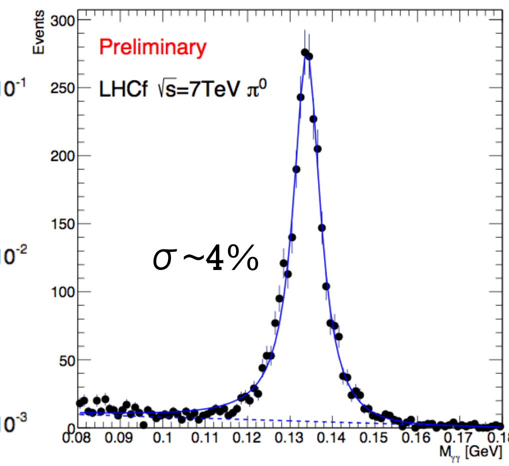
+ Type II π^0 in pp 7 TeV collisions

Present LHCf results are based on the Type-I π^0 events.
Improved π^0 reconstruction, Type-II, is now ready for use in analysis.

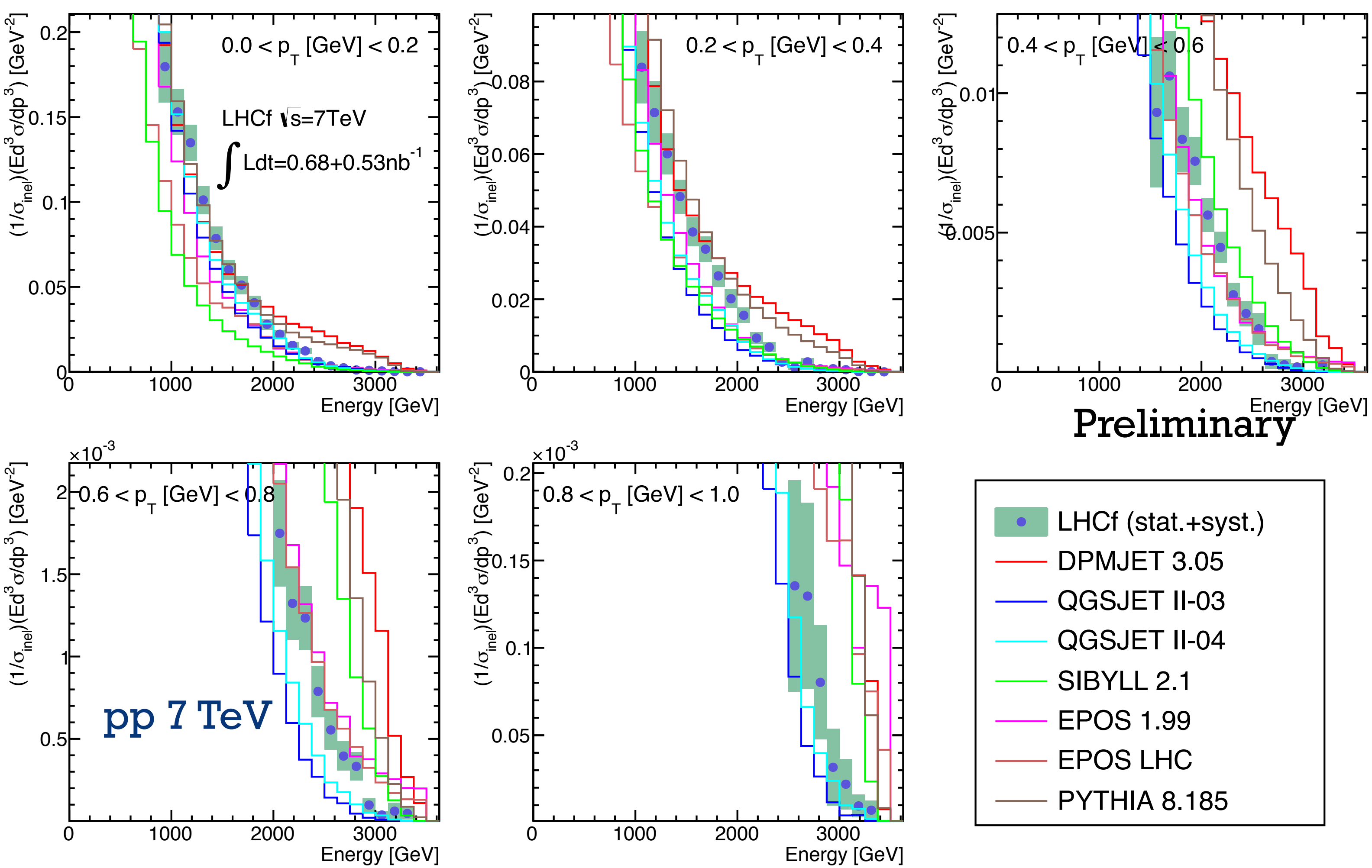




Motivation of Type-II
- extended p_T range
- applicable to Λ and K
- di-hadron.

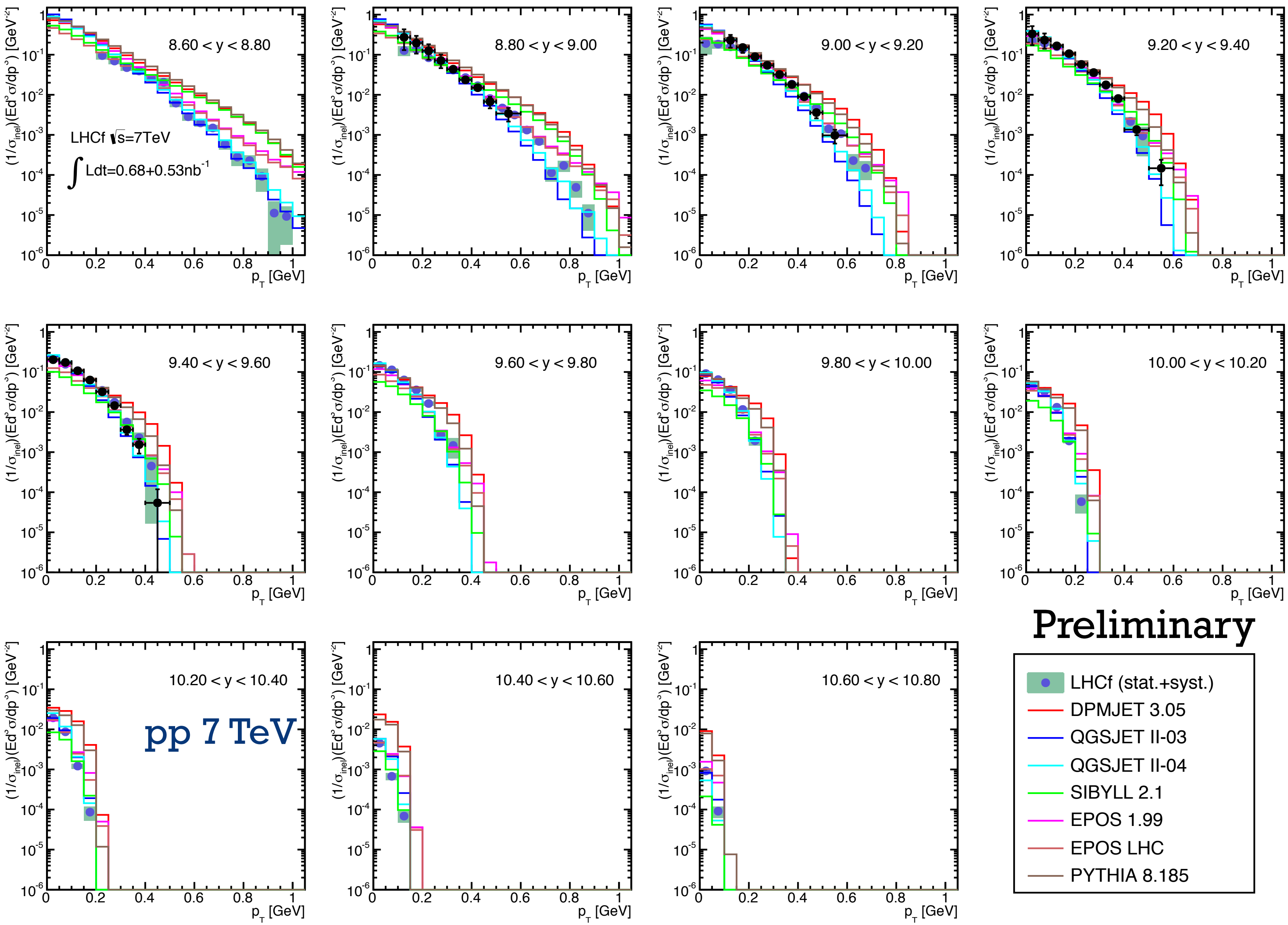


+ π^0 energy spectra (for different p_T bins)

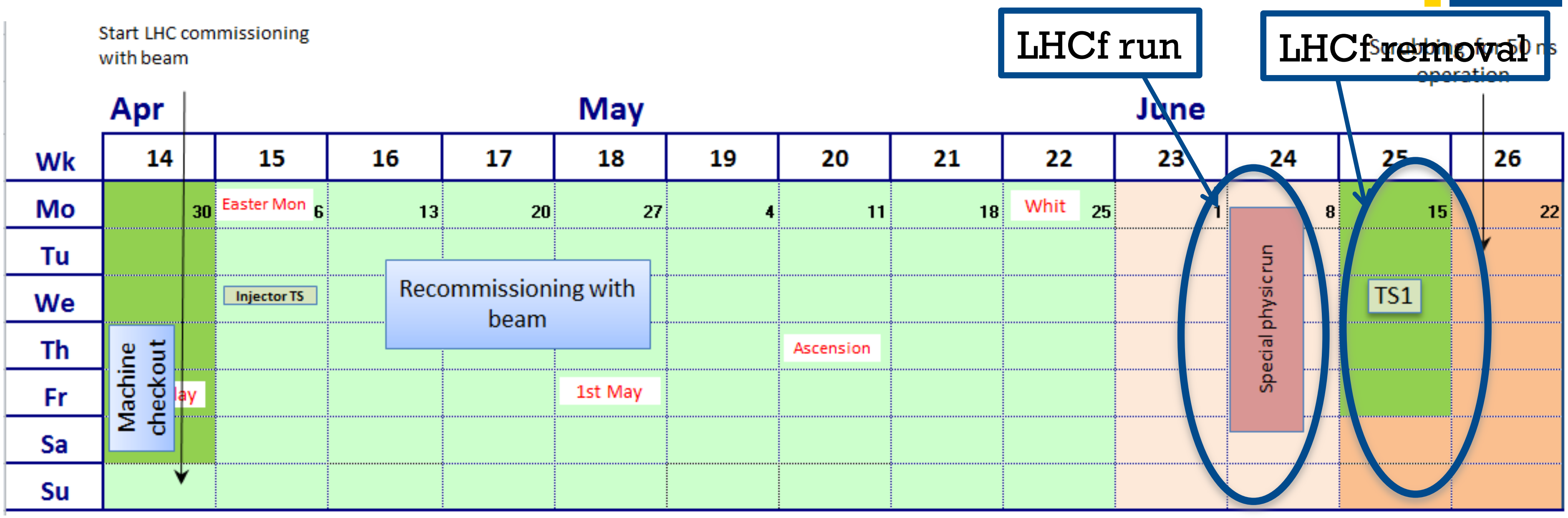


- DPMJET and PYTHIA are harder than LHCf $p_T < 1.0$ GeV, although compatible at low p_T and low E.
- QGSJET II gives good agreement at $0 < p_T < 0.2$ GeV and $0.8 < p_T < 1.0$ GeV.
- EPOS 1.99 agrees with LHCf at $0.4 < p_T < 0.8$ GeV. LHCf prefers EPOS 1.99 than EPOS LHC.

+ π^0 p_T spectra (for different rapidity bins)



+ 2015 updated LHC operation schedule



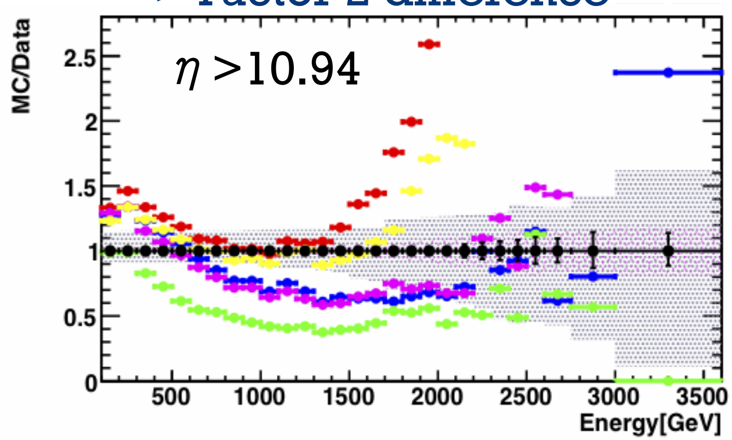
From M. Lamont, LMC Meeting, 15/04/15

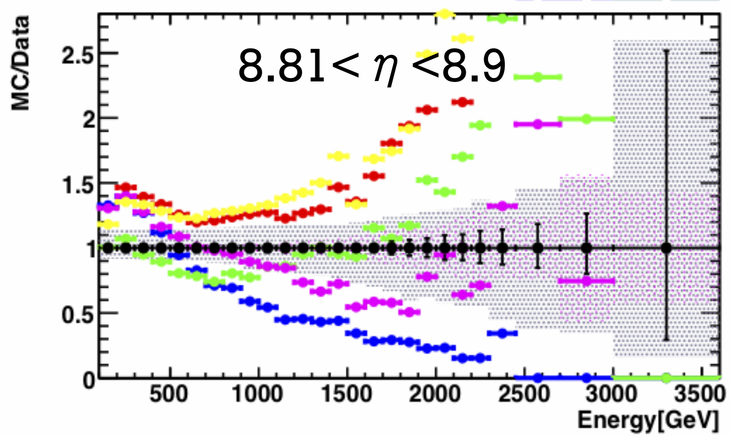
- 8 weeks beam commissioning
- 5 days special physics at beta* = 19 m (VdM, LHCf, TOTEM & ALFA)
- Start TS1 – 15th June. 24 hour technical stop in SPS in parallel followed by SPS scrubbing.

+ DATA vs MC : comp. 900GeV/7TeV

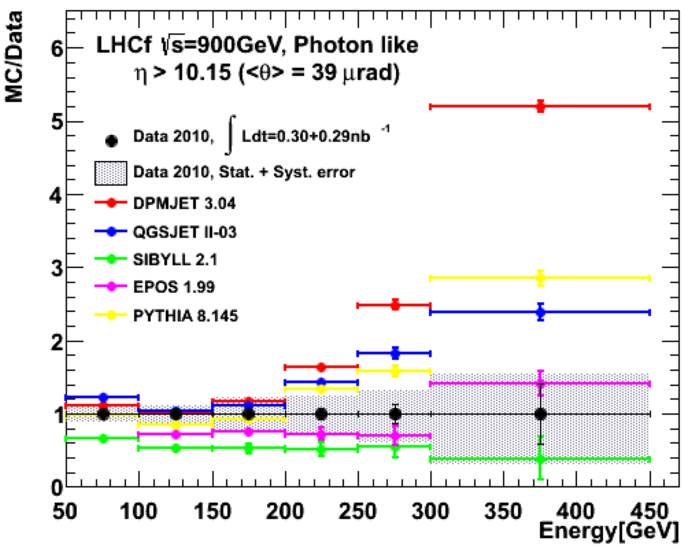
- None of the model nicely agrees with the LHCF data
- Here we plot the ratio MC/Data for the various models
- > Factor 2 difference

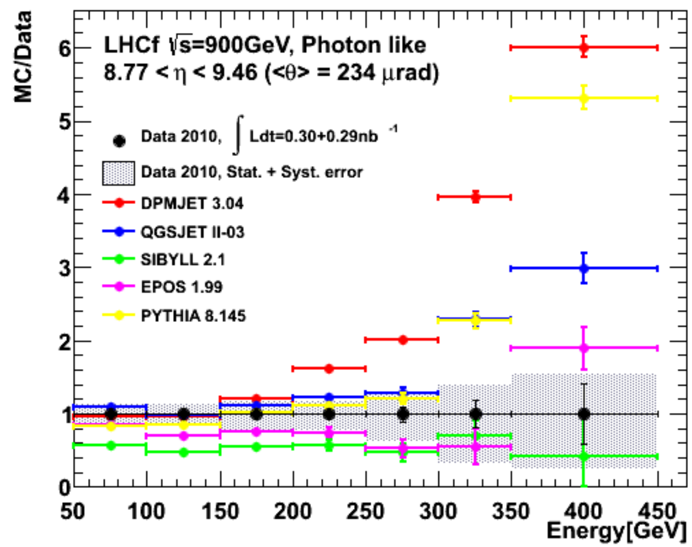
7TeV





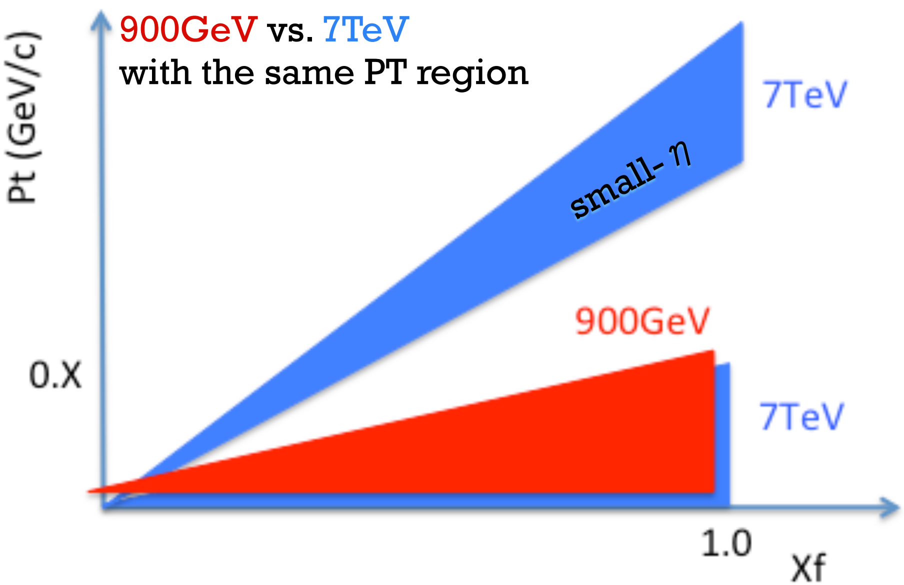
900GeV



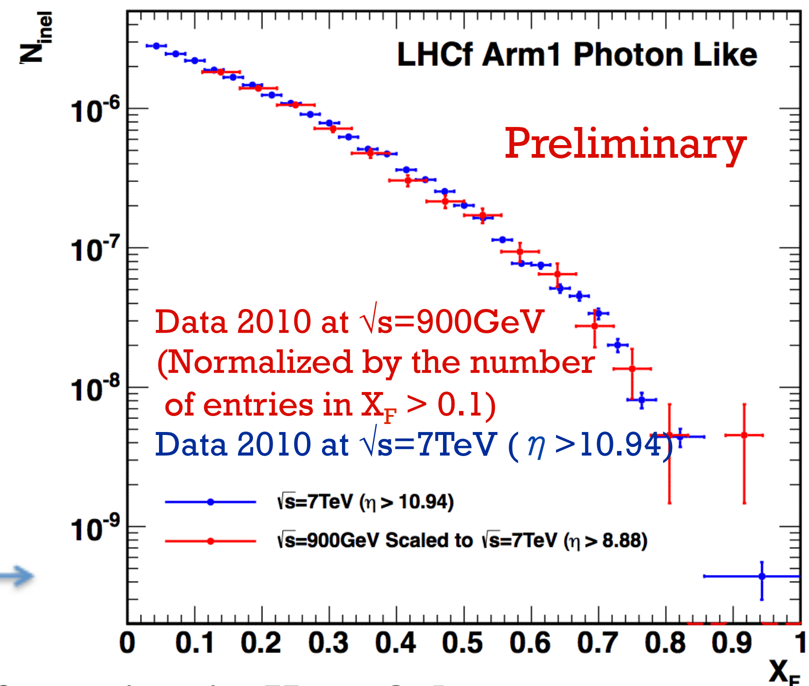


+ DATA : 900GeV vs 7TeV

Coverage of 900GeV and 7TeV results in Feynman-X and P_T



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.

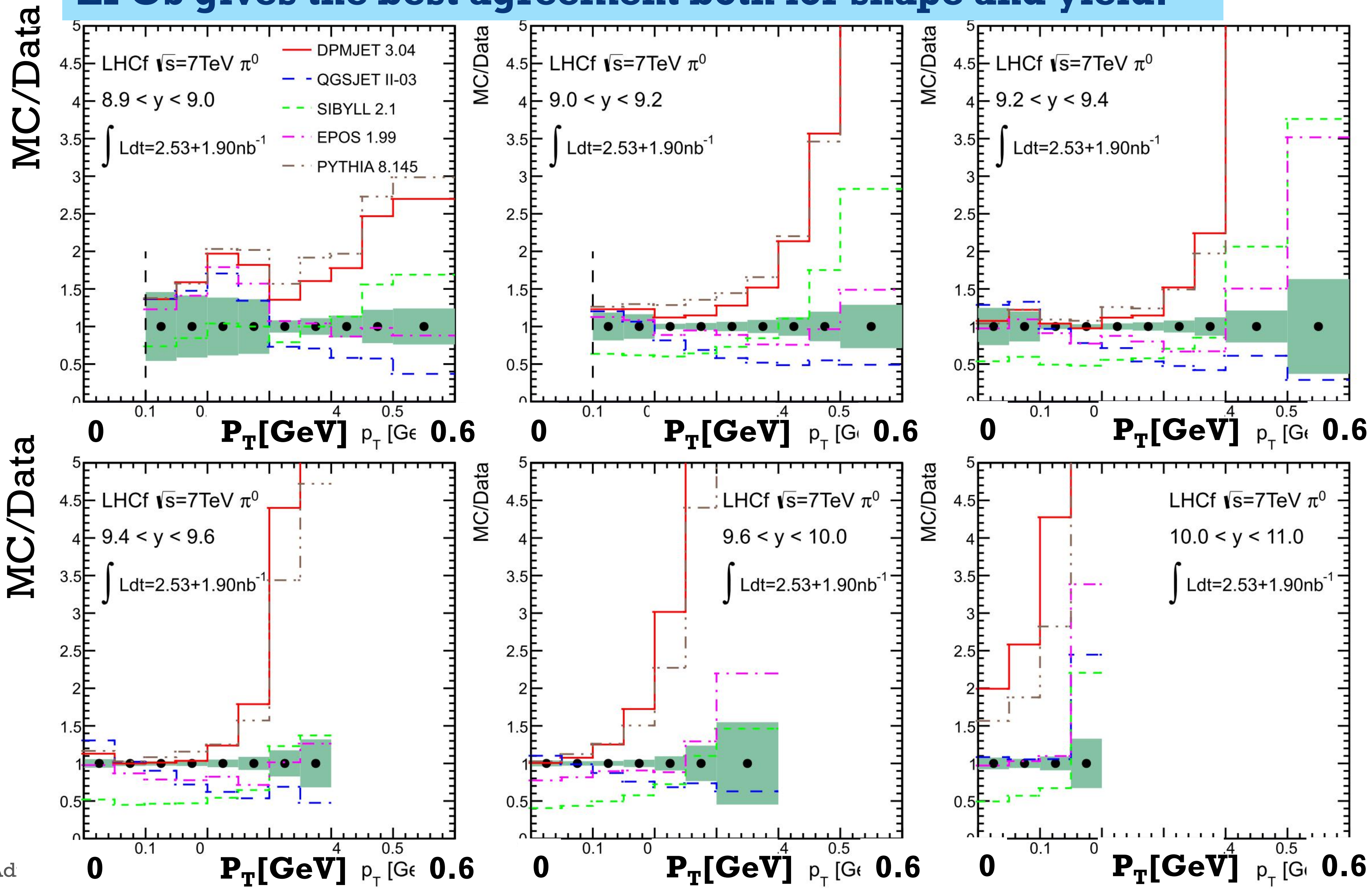
Good agreement of X_F spectrum shape between 900 GeV and 7 TeV.
➔weak dependence of $\langle p_T \rangle$ on E_{CMS}

$$\frac{1}{\sigma_{\rm inel}}\frac{d\sigma_\gamma}{dX_{\rm F}}\bigg|_{\eta<{\rm limited}} \propto \frac{1}{\sigma_{\rm inel}}\frac{d\sigma_\gamma}{p_{\rm T}dp_{\rm T}dX_{\rm F}}\langle p_{\rm T}\rangle dp_{\rm T}$$

+ π^0 P_T spectra for various y bin: MC/data

DPMJET 3.04 QGSJETII-03 SIBYLL 2.1 EPOS 1.99 PYTHIA 8.145

EPOS gives the best agreement both for shape and yield.

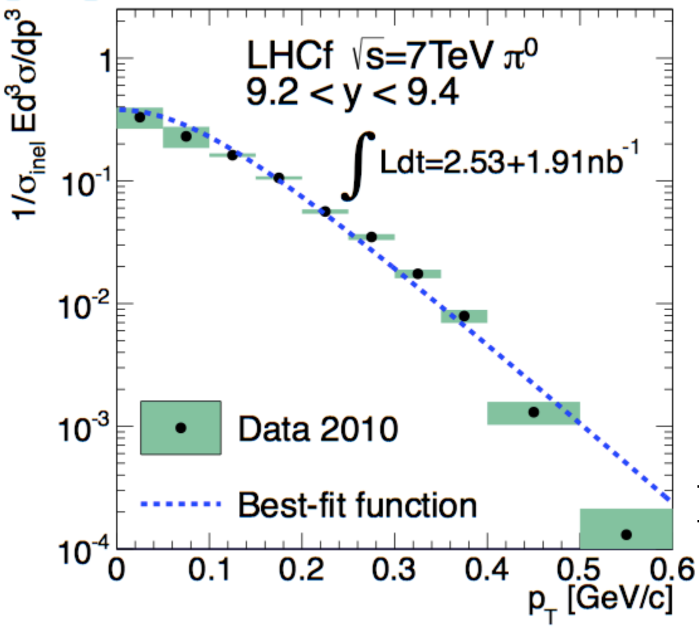


O. Ad

π^0 analysis at $\sqrt{s}$=7TeV

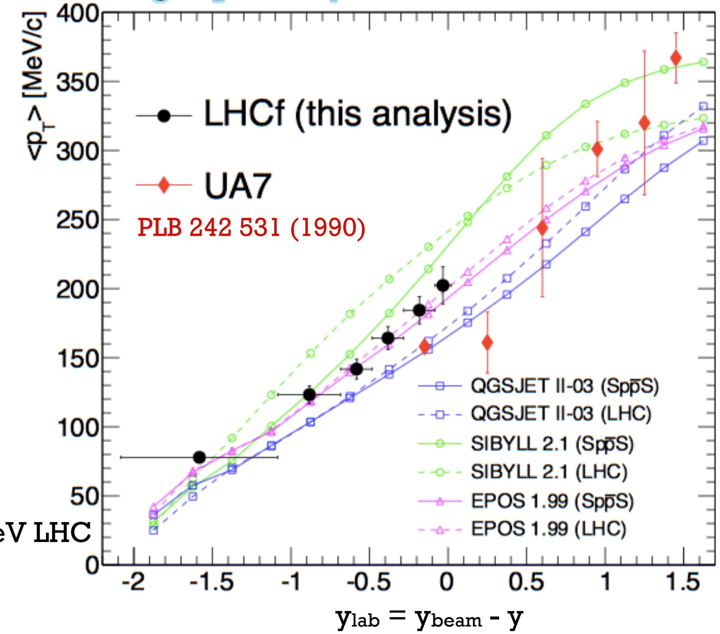
1205.4578).

p_T spectra vs best-fit function



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

Average p_T vs y_{lab}



1. Thermodynamics
   (Hagedron, Riv. Nuovo Cim. 6:10, 1 (1983))

$$\frac{1}{\sigma_{\rm inel}} E\frac{d^3\sigma}{dp^3} = A\cdot\exp(-\sqrt{{p_{\rm T}}^2c^2 + m_{\pi^0}^2c^4}/T)$$

$$\langle p_{\rm T}\rangle = \sqrt{\frac{\pi m_{\pi^0}c^2T}{2}}\frac{K_2(m_{\pi^0}c^2/T)}{K_{3/2}(m_{\pi^0}c^2/T)}$$

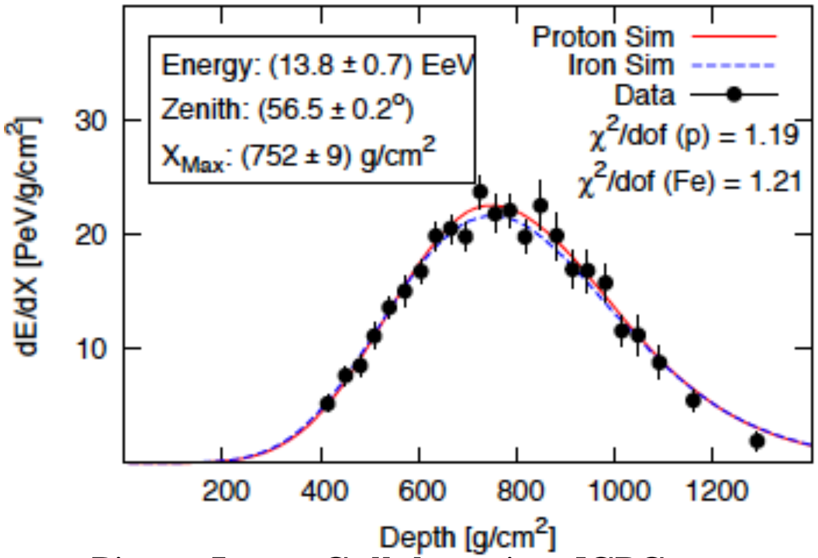
2. Numerical integration

$$\langle p_{\rm T}\rangle = \frac{\int_0^\infty 2\pi p_{\rm T}^2 f(p_{\rm T})dp_{\rm T}}{\int_0^\infty 2\pi p_{\rm T} f(p_{\rm T})dp_{\rm T}}$$

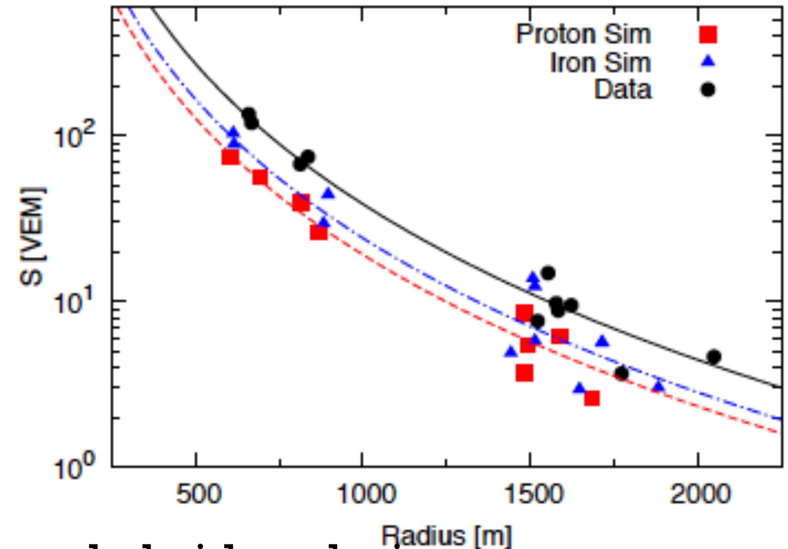
actually up to the upper bound of histogram

- Systematic uncertainty of LHCf data is 5%.
- Compared 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 $\langle p_T \rangle$ 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

Muon excess at Pierre Auger Obs.

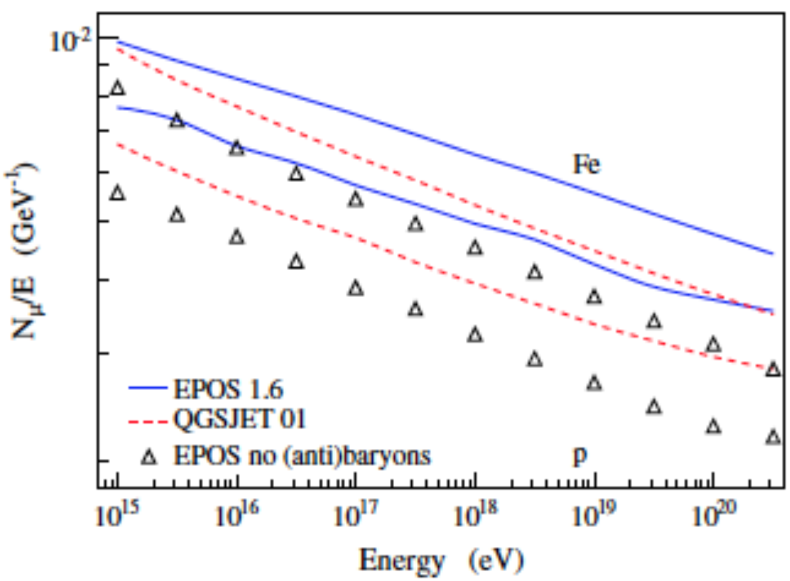


Pierre Auger Collaboration, ICRC 2011 (arXiv:1107.4804)



Auger hybrid analysis

- event-by-event MC selection to fit FD data (top-left)
- comparison with SD data vs MC (top-right)
- muon excess in data even for Fe primary MC



EPOS predicts more muon due to larger baryon production

=> importance of baryon measurement

Pierog and Werner, PRL 101 (2008) 171101

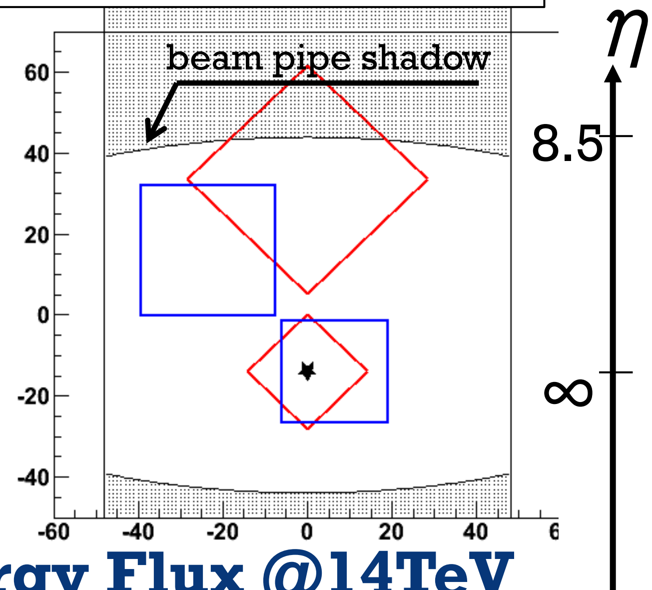
+ What LHCf can measure

Energy spectra and
Transverse momentum distribution of

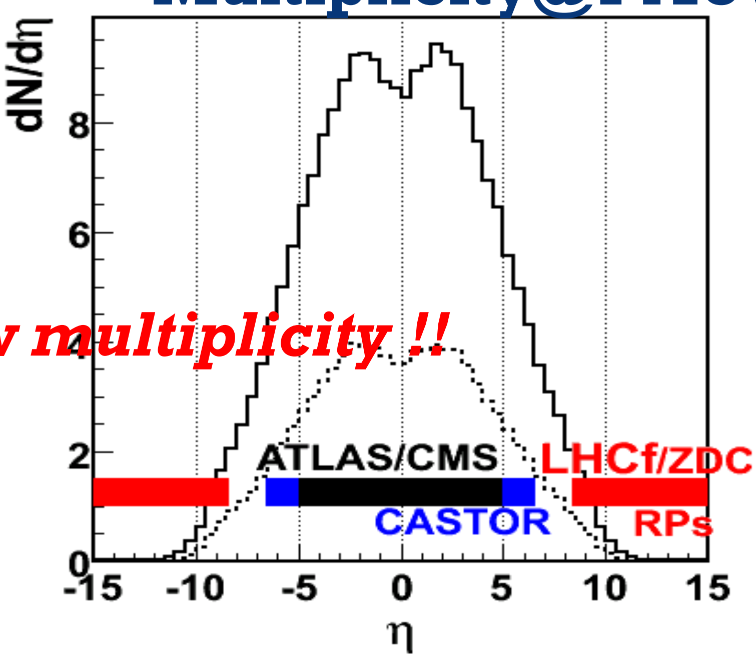
- Gamma-rays (E>100GeV,dE/E<5%)
- Neutral Hadrons (E>a few 100 GeV, dE/E~30%)
- π^0 (E>600GeV, dE/E<3%)

at pseudo-rapidity range >8.4

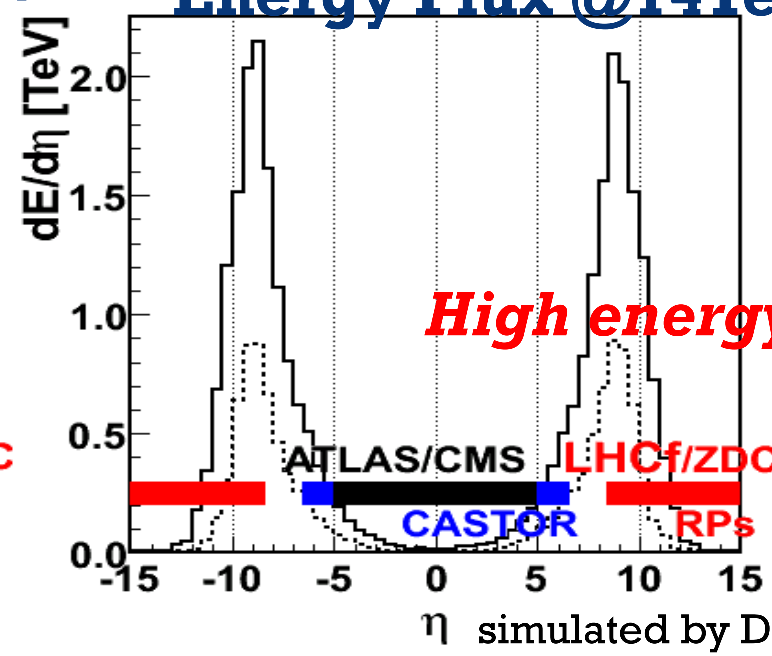
Front view of calorimeters
@ 100 μ rad crossing angle



Multiplicity@14TeV

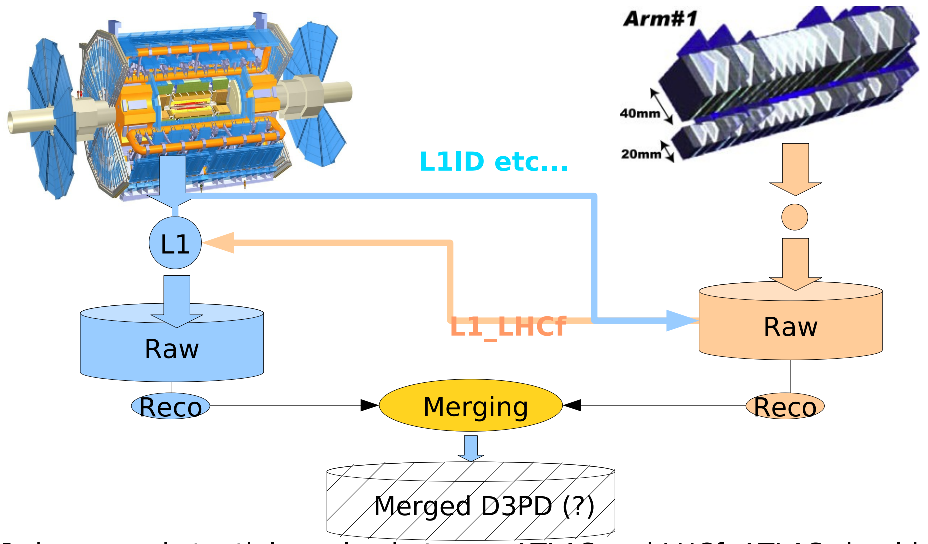


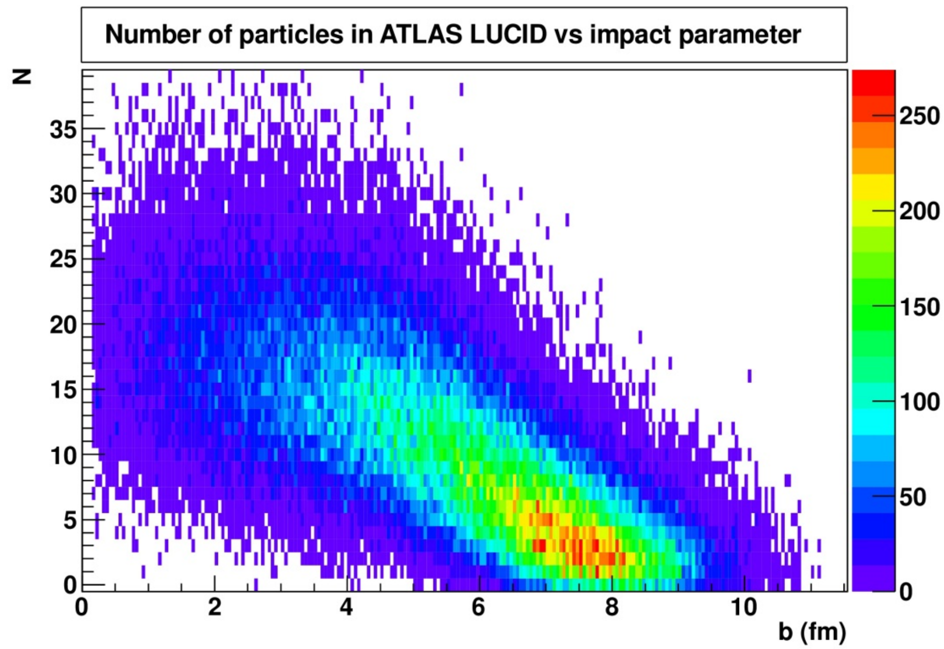
Energy Flux @14TeV



simulated by DPMJET3

Common trigger with ATLAS

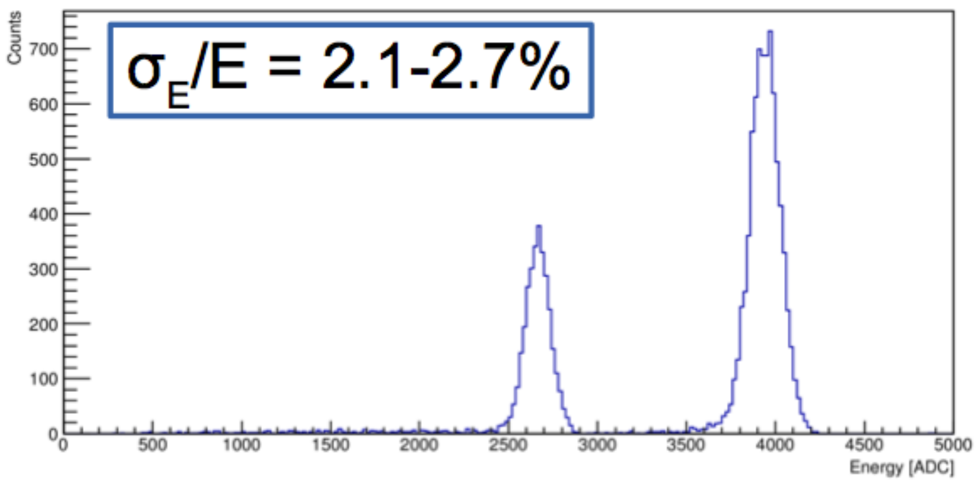




MC
impact parameter vs. # of particles in ATLAS LUCID

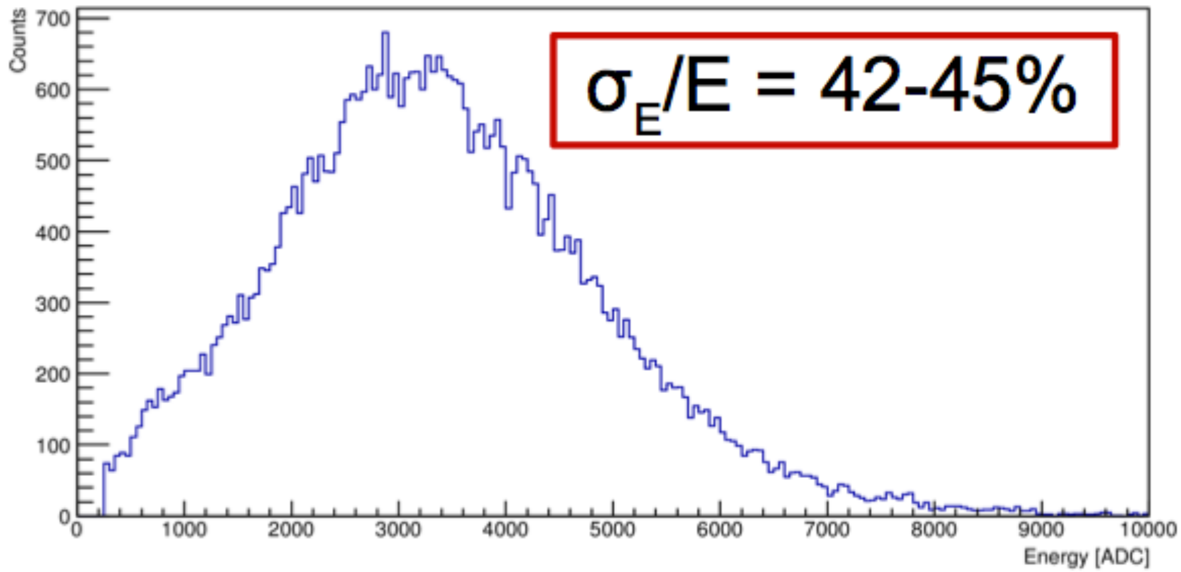
- LHCf forced to trigger ATLAS
- Impact parameter may be determined by ATLAS
- Identification of forward-only events

Arm2 Energy Reconstruction



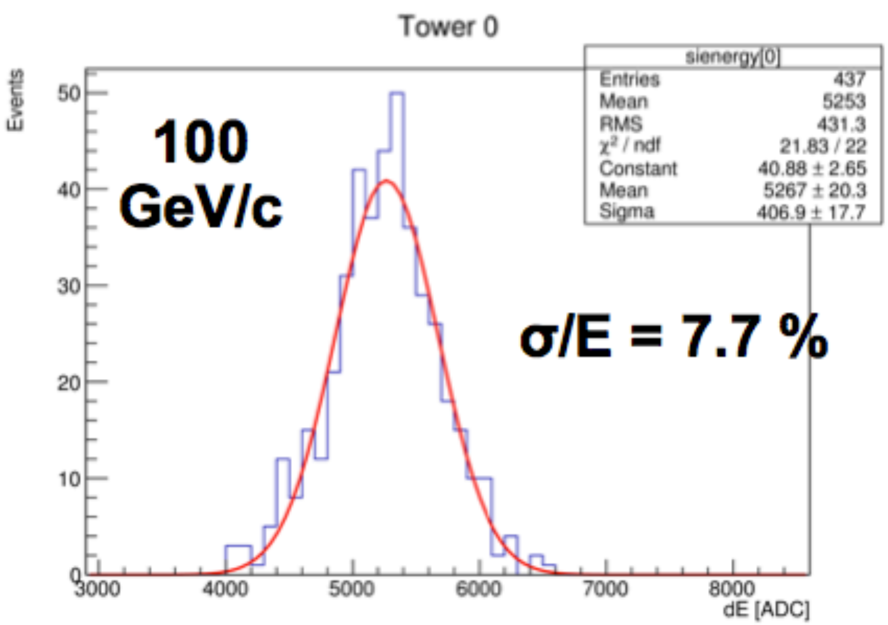
100 & 150 GeV electron beam on small tower center

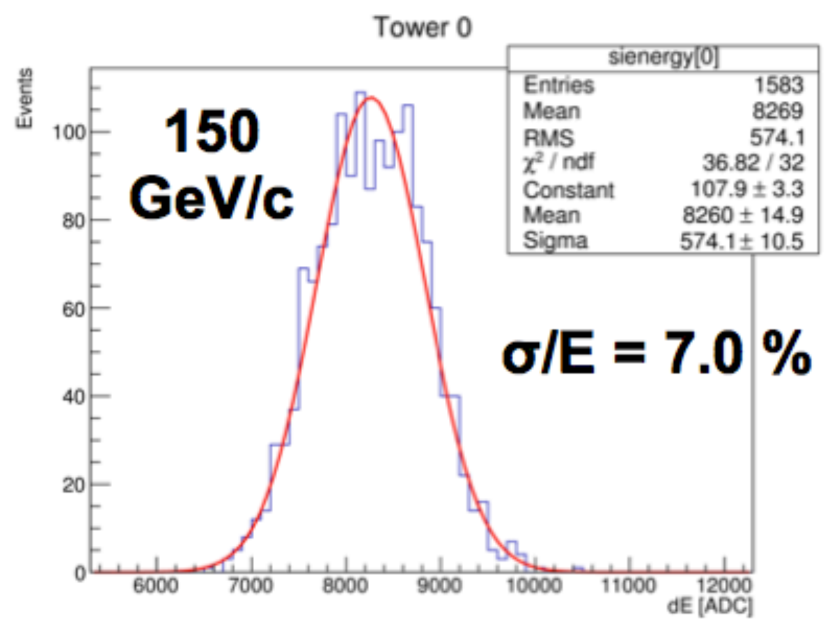
300 GeV proton beam on small tower center



+ Arm2 silicon energy measurement (small tower)

- Sum of energy releases over all silicon layers
- Only strips with signal > 3σ are considered
- Central events (5 mm x 5 mm square)



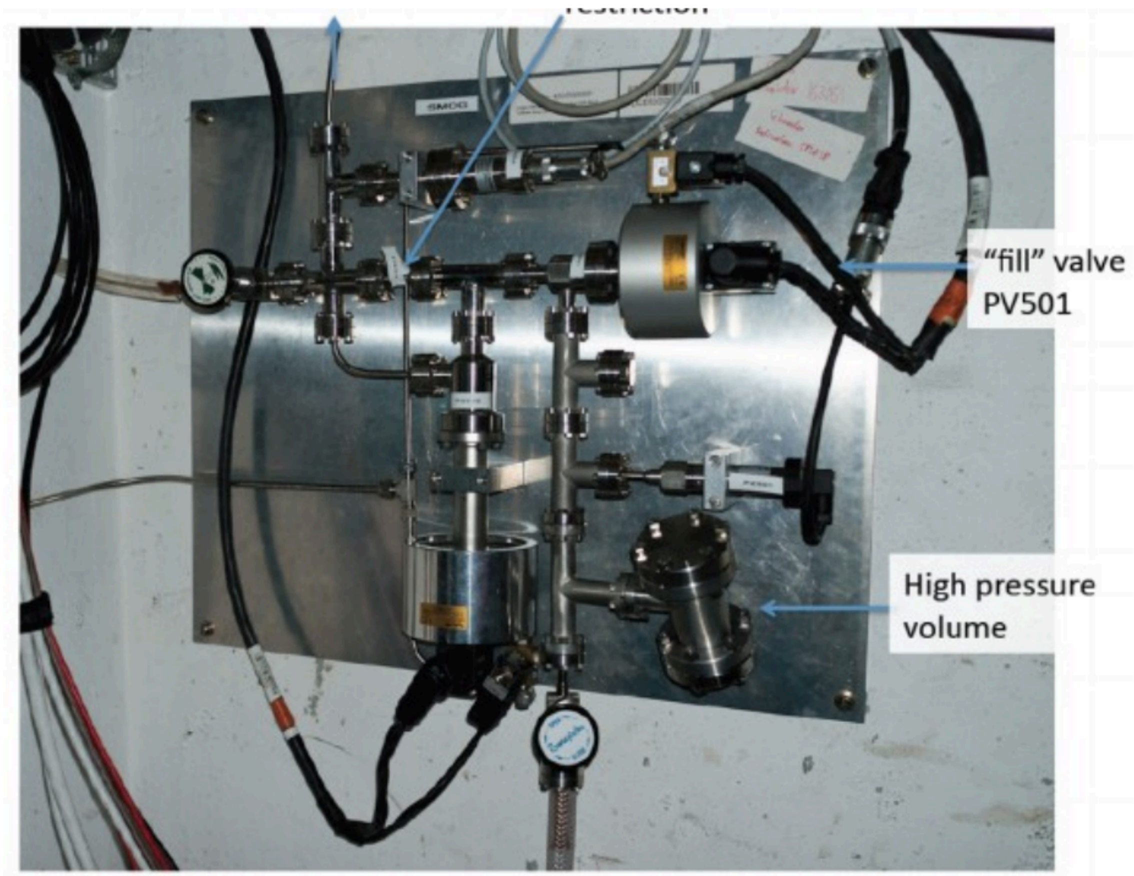


- Resolution with old configuration: 8.4 % @100 GeV
  8.2 % @150 GeV

A new idea!

- After the talk of F. Donato yesterday a new idea came to my mind
- The SMOG system has already been tested in 2012 in LHCb
  - Injection of noble gas atoms inside the beam pipe to:
    - Measure the beam profile
    - Measure the luminosity
- Why don't use SMOG to measure cross section relevant for Cosmic Ray Physics???
  - P-He→Antiprotons+X
- We could make use of 'perfect' Particle Identification Detectors
- We could make use of the highest possible energies
  - Direct access to protons in the most interesting energy region

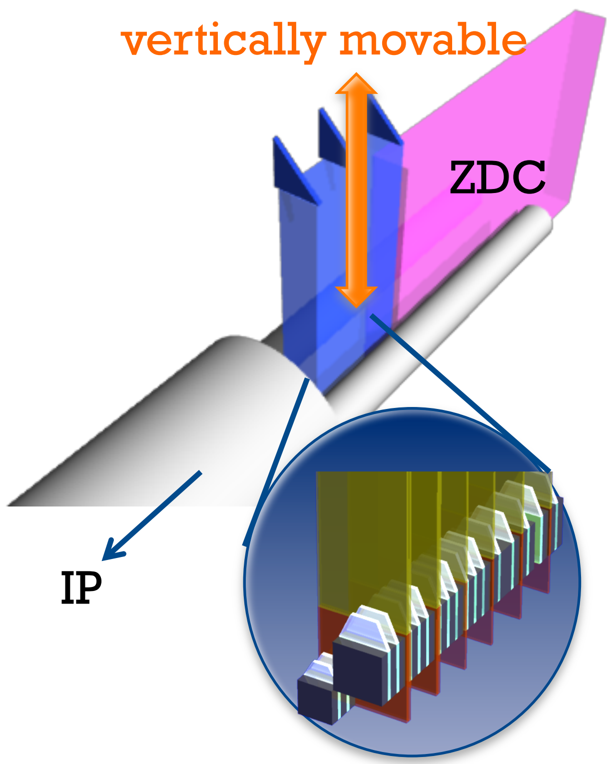
SMOG: System for Measuring Overlap with Gas

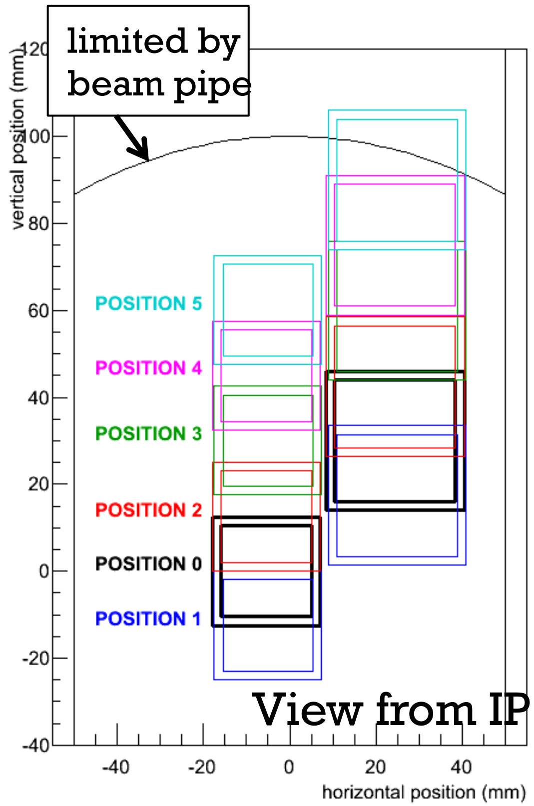


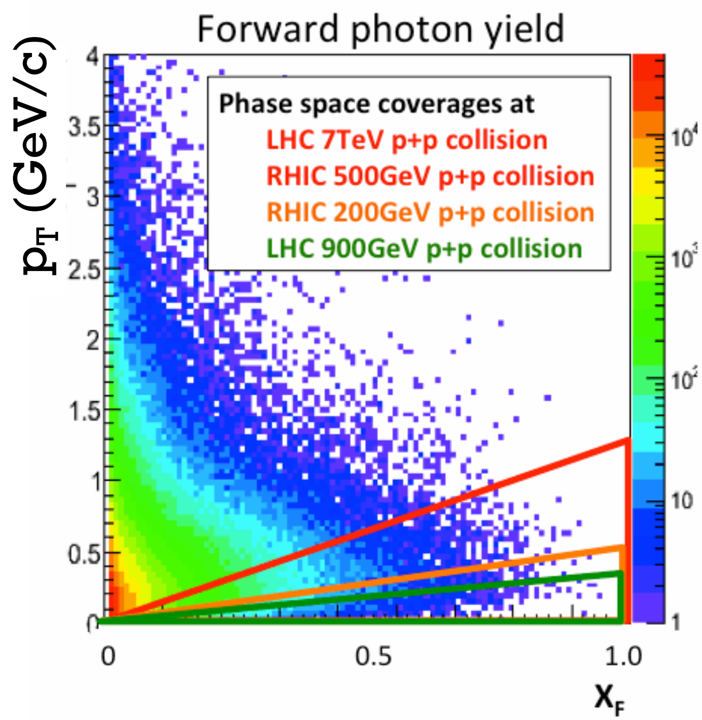
→ injection of Ne gas into interaction region

+ RHICf coverage

Installing the LHCf Arm2 detector at RHIC (PHENIX IP)



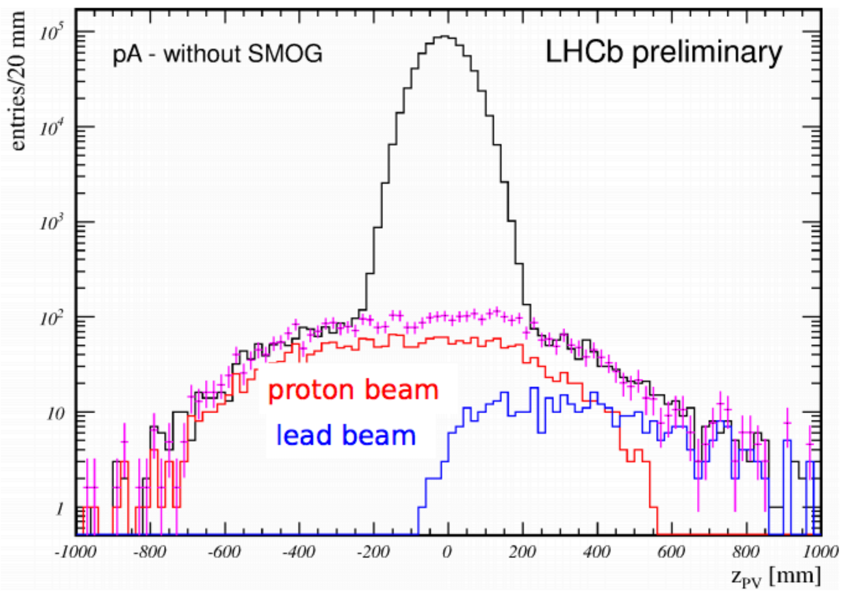




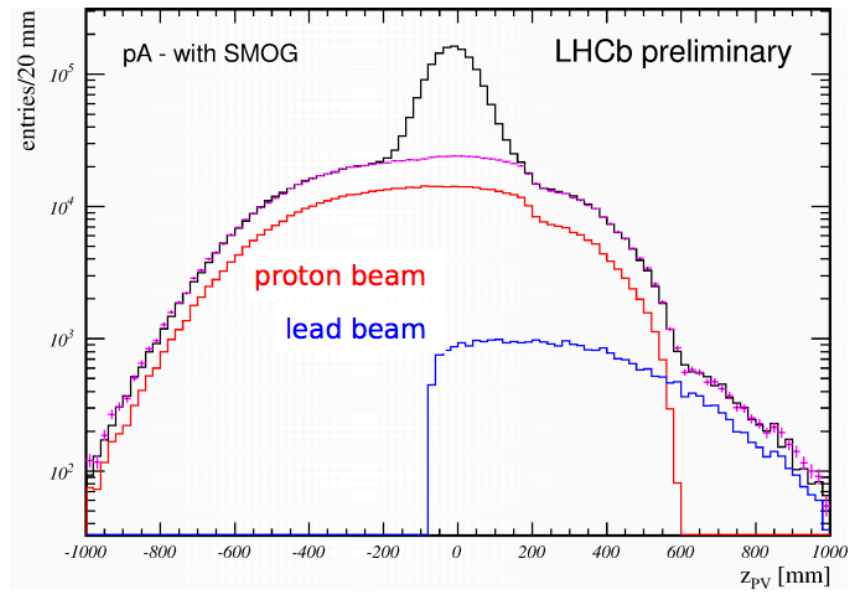
- Detector is moved up-down; wide p_T coverage
- x_F-p_T coverage identical to LHC 7 TeV collision
- Wider coverage and higher resolution in p_T than PHENIX ZDC+SMD measurements (joint analysis between ZDC and RHICf)

→ injection of Ne gas into interaction region

no SMOG



with SMOG

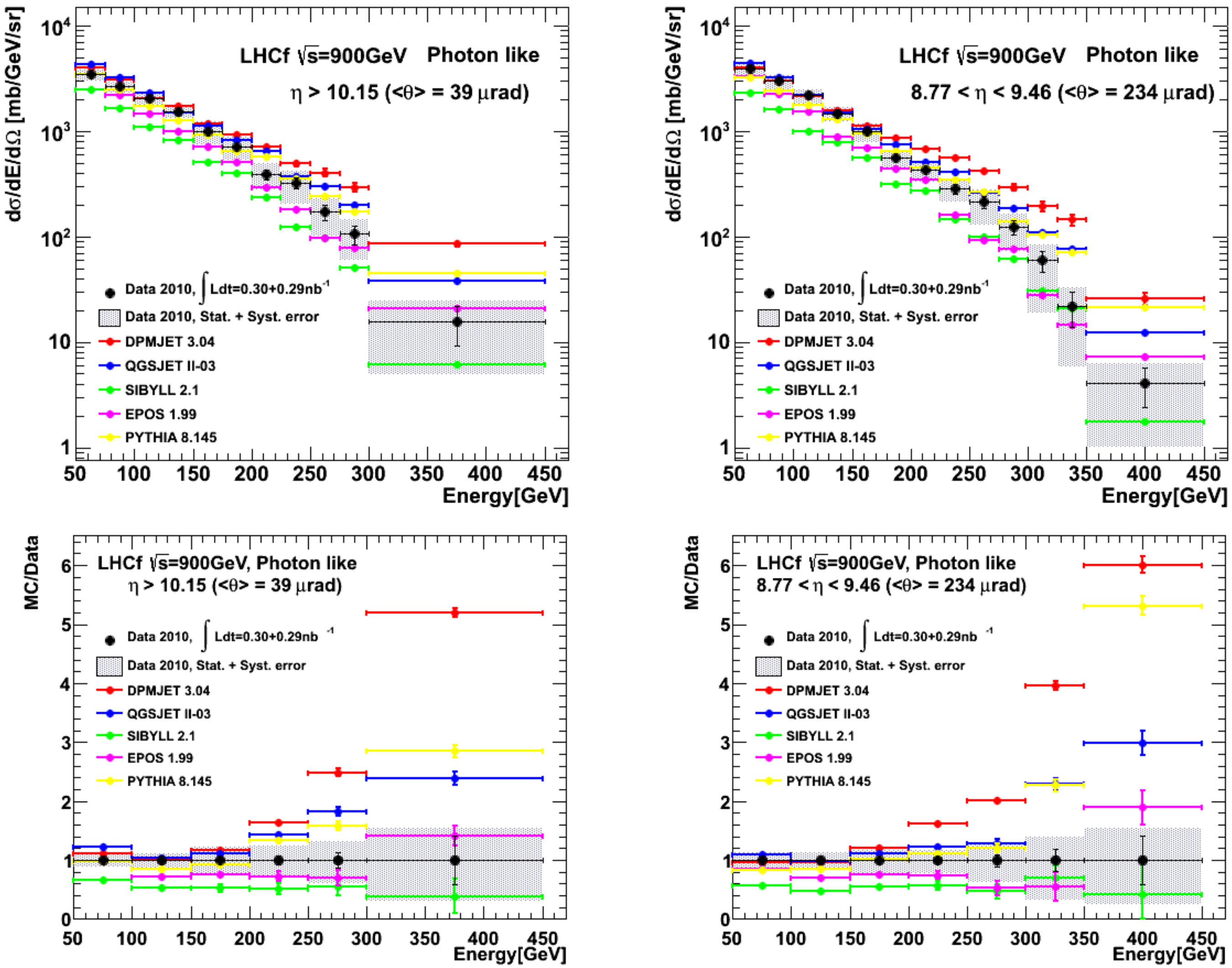


z-distribution of primary vertex

- increase of beam-gas interaction rate by two orders of magnitude
- accurate measurement of beam profile → precise luminosity determination

→ also allows to study pNe interactions at $\sqrt{s}$=87 GeV
shift of cm system by 4.5 units in rapidity in proton direction
→ LHCb is a central detector for fixed target collisions

Comparison of single γ data for pp @ 900 GeV with hadronic interaction models (pre-LHC versions)



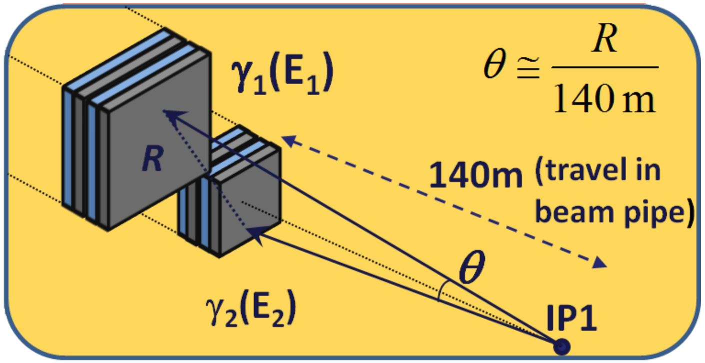
DATA
DPMJET 3.04
QGSJET II-03
SIBYLL 2.1
EPOS 1.99
Syst.+Stat.
PYTHIA 8.145

No strong evidence of η-dependence

DPMJET and **SYBILL** show reasonable agreement of shape

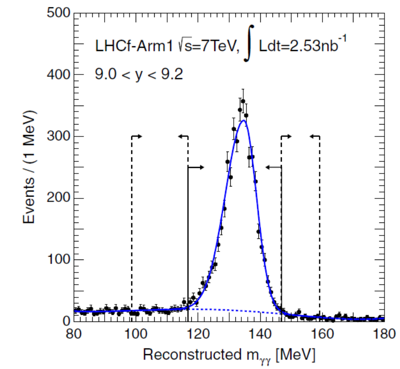
None of the models reproduces the data within the error bars

Comparison of π^0 data for pp @ 7 TeV with hadronic interaction models (pre-LHC versions)



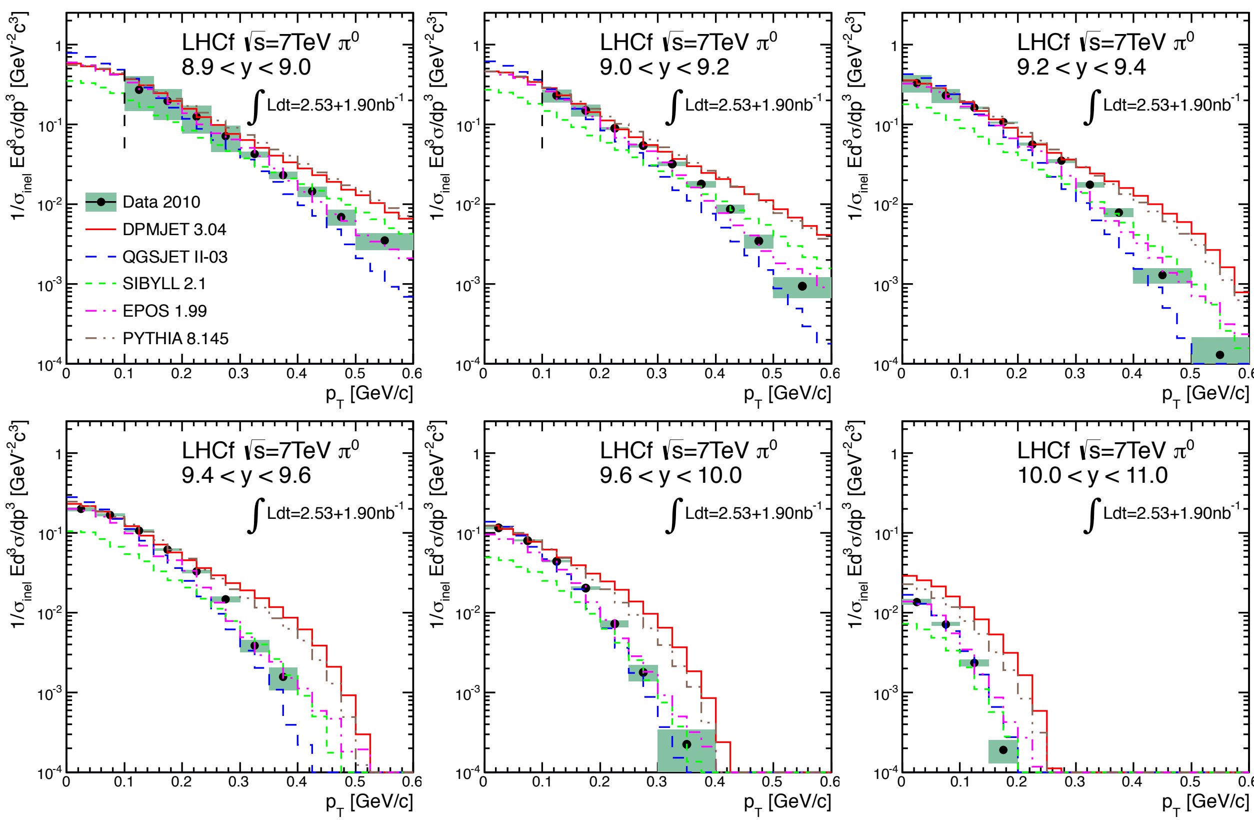
$$\theta \cong \frac{R}{140\,\mathrm{m}}$$

Reconstruction of the invariant mass of two-photon events

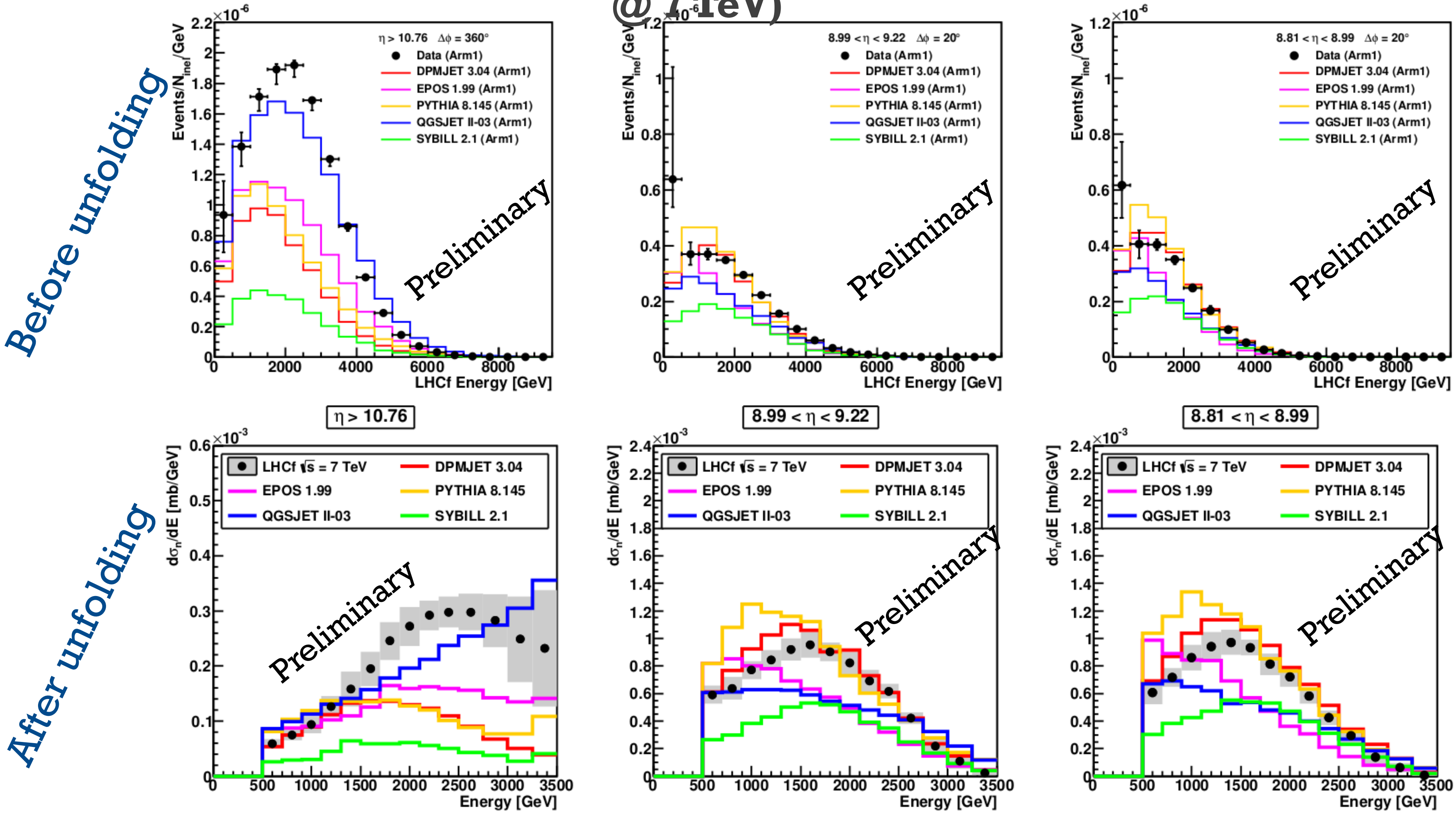


Identification of events with two particles hitting the two towers

- **EPOS1.99** show the best agreement with data in the models.
- **DPMJET** and **PYTHIA** have harder spectra than data ("popcorn model")
- **QGSJET** has softer spectrum than data (only one quark exchange is allowed)



More recent analysis: neutron energy spectra before and after unfolding (pp @ 7 TeV)

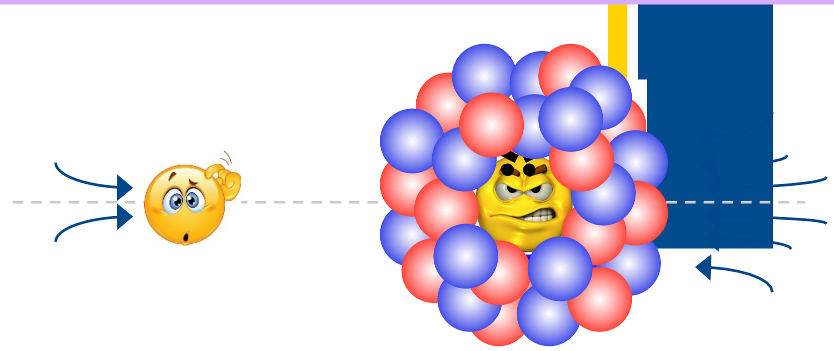


Very large high energy peak in the $\eta > 10.76$ (predicted only by QGSJET)

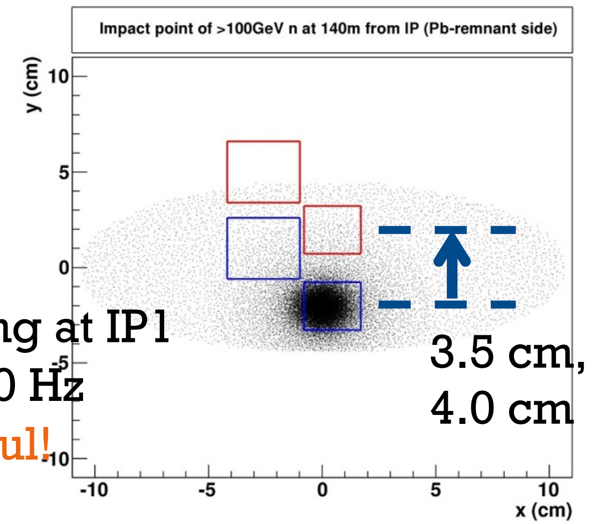
→ Small inelasticity in the very forward region!

Preprint submitted to PLB

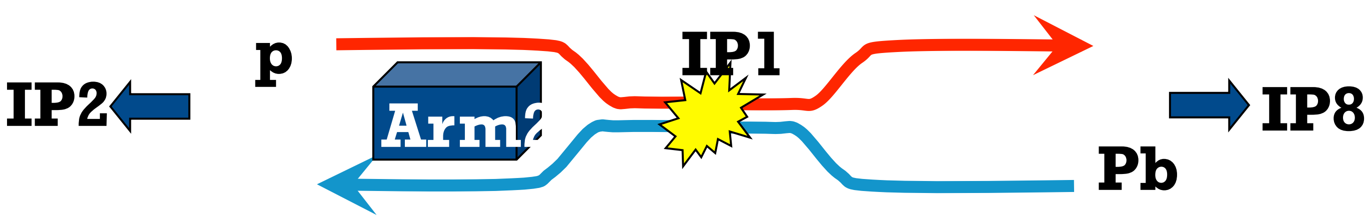
The LHC proton-Lead run on 2013 at $\sqrt{S_{NN}} = 5\ TeV$



- Motivation: study of nuclear effects for CR interactions
- 2013 Jan-Feb for p-Pb/Pb-p collisions
  - Installation of the **only Arm2** at one side (silicon tracker good for multiplicity)
  - Data both at **p-side** (20Jan-1Feb) and **Pb-side** (1fill, 4Feb), thanks to the **swap of the beams**

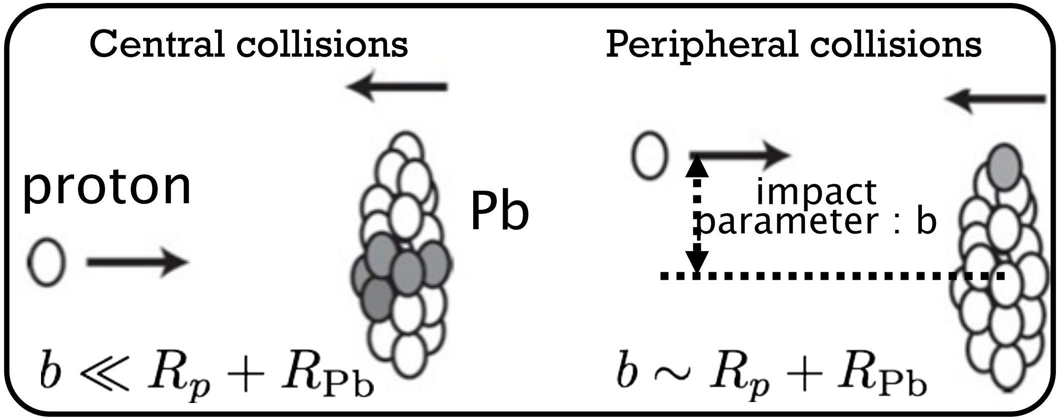


- Details of beams and DAQ
  - $L = 1x10^{29} – 0.5x10^{29} cm^{-2}s^{-1}$
  - ~200.10^{6} events
  - $\beta^* = 0.8$ m, 290 μrad crossing angle
  - 338p+338Pb bunches (min.ΔT = 200 ns), 296 colliding at IP1
  - 10-20 kHz trig rate downscaled to approximately 700 Hz
  - 20-40 Hz ATLAS common trig. Coincidence successful!
  - p-p collisions at 2.76 TeV have also been taken

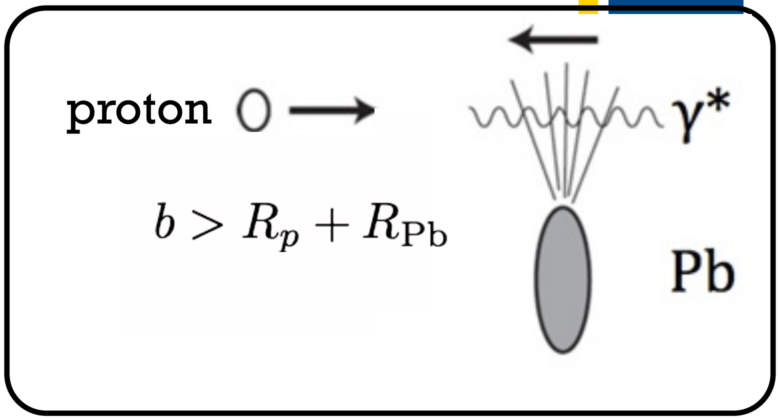


E.M. contribution to fwd particle production (p-Pb)

(Soft) QCD :
central and peripheral collisions



Ultra peripheral collisions :
virtual photons from rel. Pb collides a proton



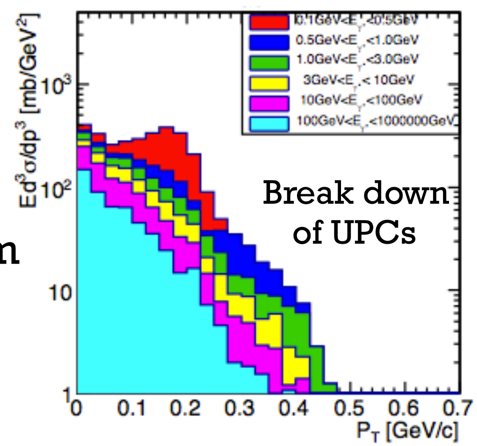
Estimation of momentum distribution of the UPC induced secondary particles (Lab frame+Bo

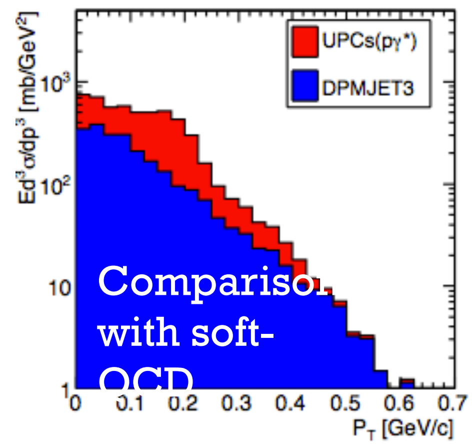
1. energy distribution of virtual photons is estimated by the Weizsacker Williams approxima
2. photon-proton collisions are simulated by the SOPHIA model (E_γ > pion threshold)

Dominant channel to forward π^0 is

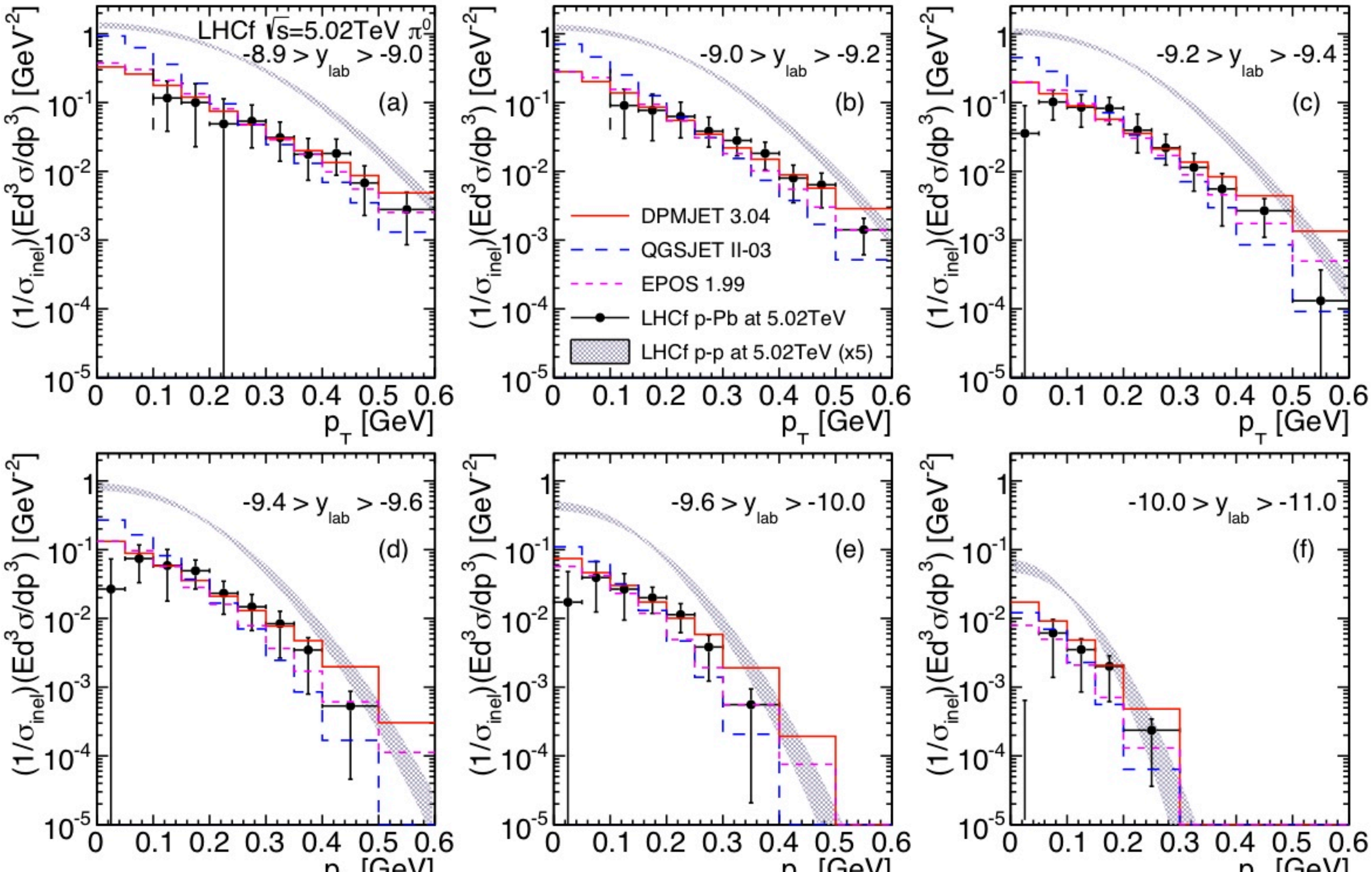
$$\gamma + p \rightarrow \Delta(1232) \rightarrow p + \pi^0$$

About half of the observed π^0s originate from UPC
About half is from soft-QCD
Need to subtract UPC component



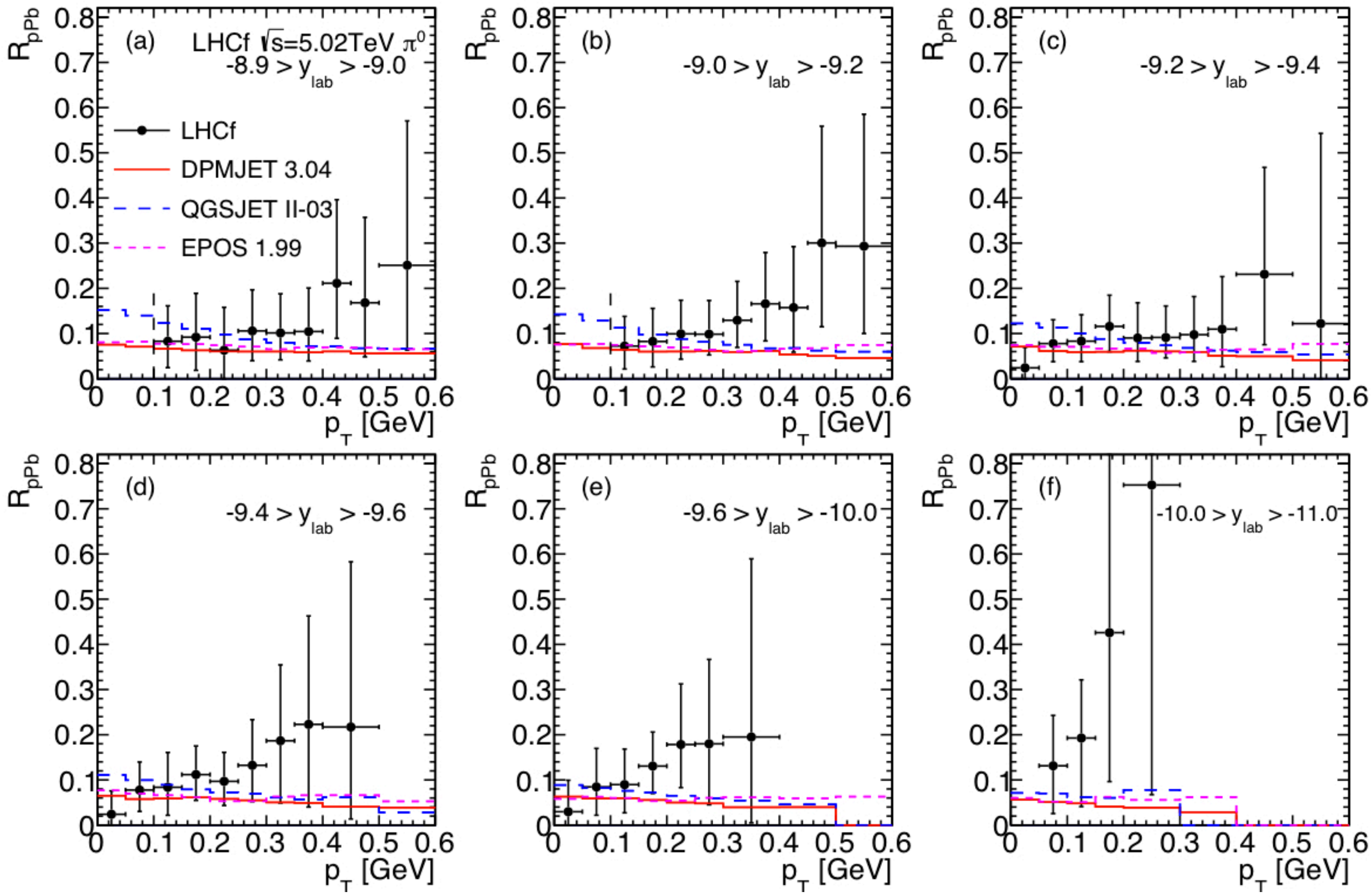


Invariant cross section for π^0 production (p-Pb)



- LHCf data in p-Pb (filled circles) show good agreement with DPMJET and EPOS.
- LHCf spectra in p-Pb are clearly less steep than the LHCf data in p-p at 5.02 TeV (shaded area, spectra multiplied by 5). The latter is interpolated from the results at 2.76 TeV and 7 TeV.

Nuclear Modification Factor for π^0 production (p-Pb)



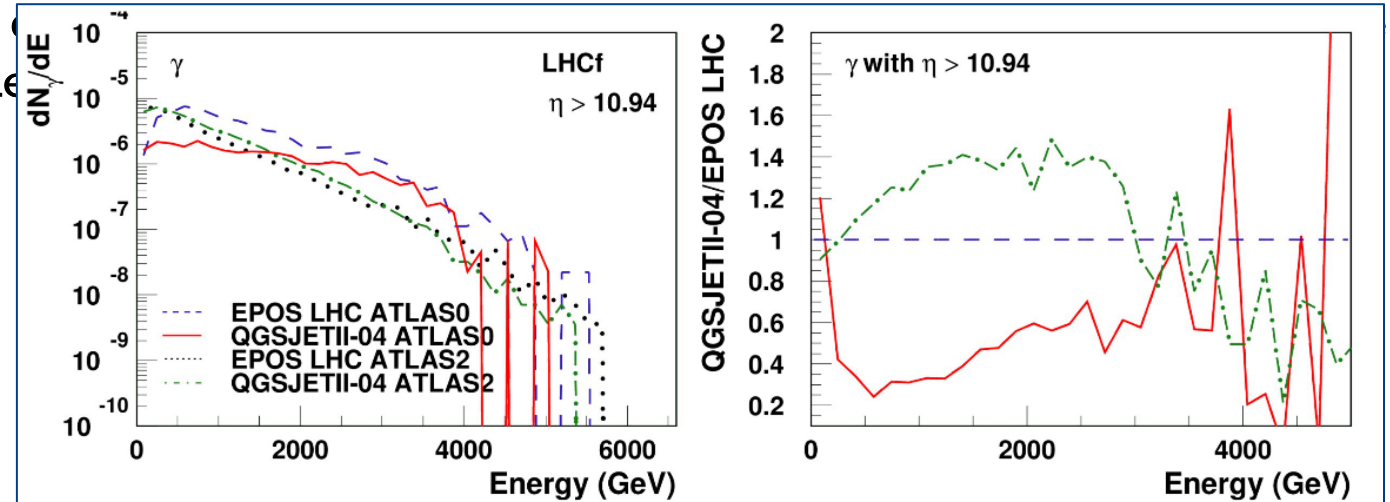
$$R_{\rm pPb}(p_{\rm T}) \equiv \frac{\sigma^{\rm pp}_{\rm inel}}{\langle N_{\rm coll}\rangle \sigma^{\rm pPb}_{\rm inel}} \frac{Ed^3\sigma^{\rm pPb}/dp^3}{Ed^3\sigma^{\rm pp}/dp^3}$$

$$\langle N_{\rm coll}\rangle = 6.9$$

- Both LHCf and MCs show strong suppression.
- NMF grows with increasing p_T, as can be expected by the p_T spectrum that is steeper in p-p 5 TeV than in p-Pb 5 TeV collisions

Combined analysis with ATLAS

- During the 2013 p-Pb run LHCf trigger was used for triggering the ATLAS detector. Combined data taking is foreseen also for the next run (pp @ 13 TeV).
- Activity in the central detector can be used to separate diffractive and non diffractive events. It will be used also to remove the UPC events (which give no activity in ATLAS) for the analysis of p-Pb data.
- Important for improving the quality of the hadronic interaction models, where
treatme

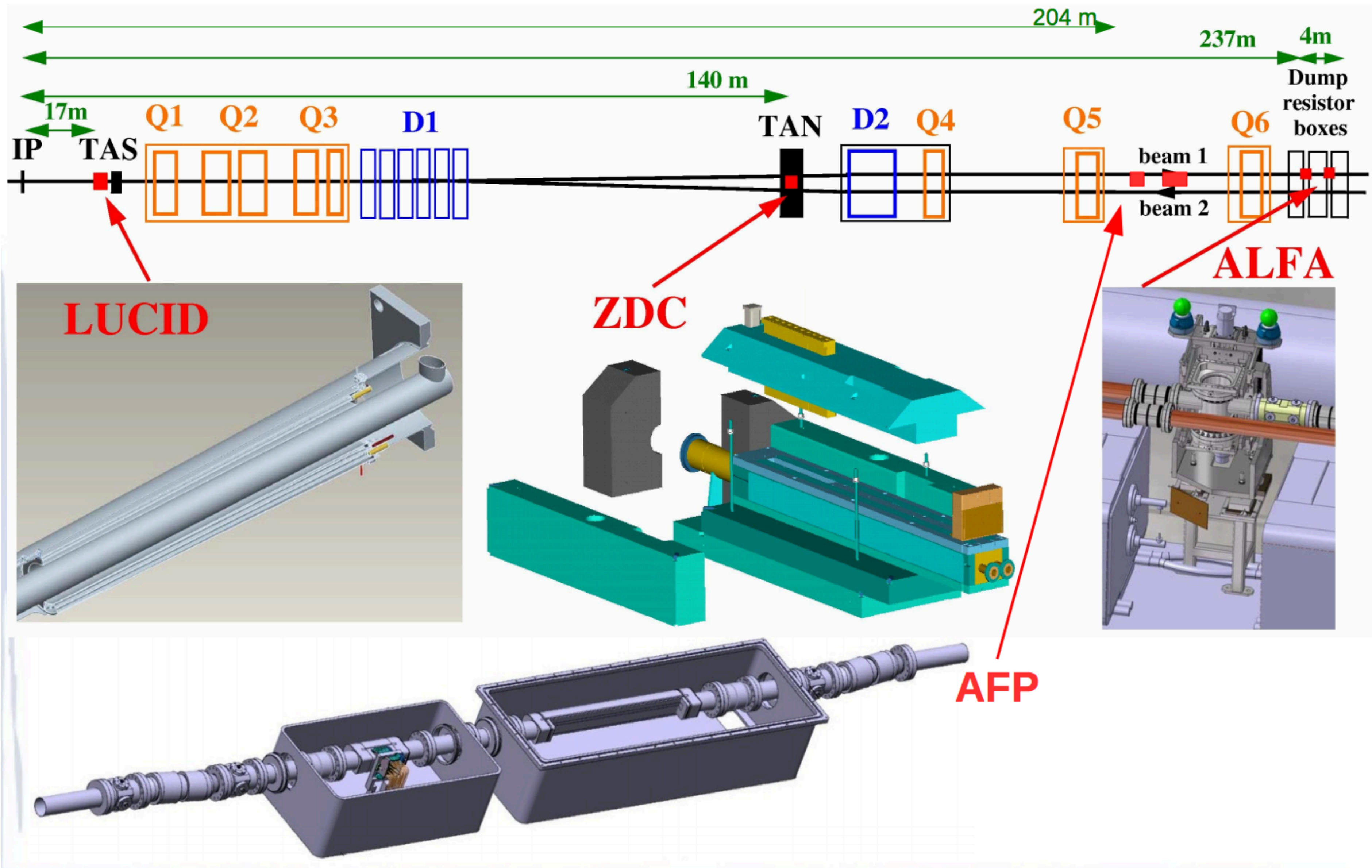


➔ ATLAS0 = no charge particle particle with $|\eta|<2.5$ and $p_t>0.1$ GeV/c

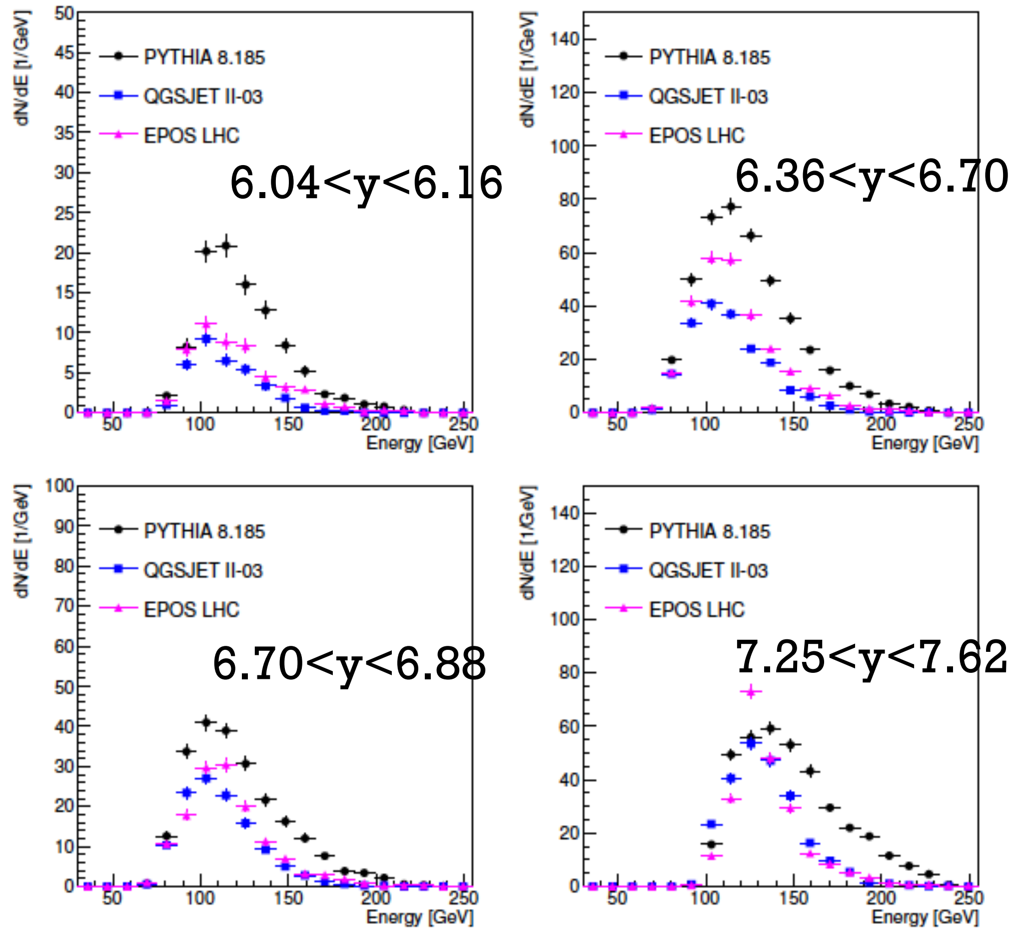
➔ ATLAS2 = at least 2 charged particles particle with $|\eta|<2.5$ and $p_t>0.1$ GeV/c

Courtesy of Tanguy Pierog

+ ATLAS upgraded forward region



+ Expected Results (π^0)



- π^0 spectra at 4 rapidity samples
- <60GeV not detectable due to large opening angle of $\gamma\gamma$
- 24 min statistics (12 nb^{-1} effective luminosity; 12 nb^{-1} delivered)
- Statistical error will be negligible with a reasonable run time