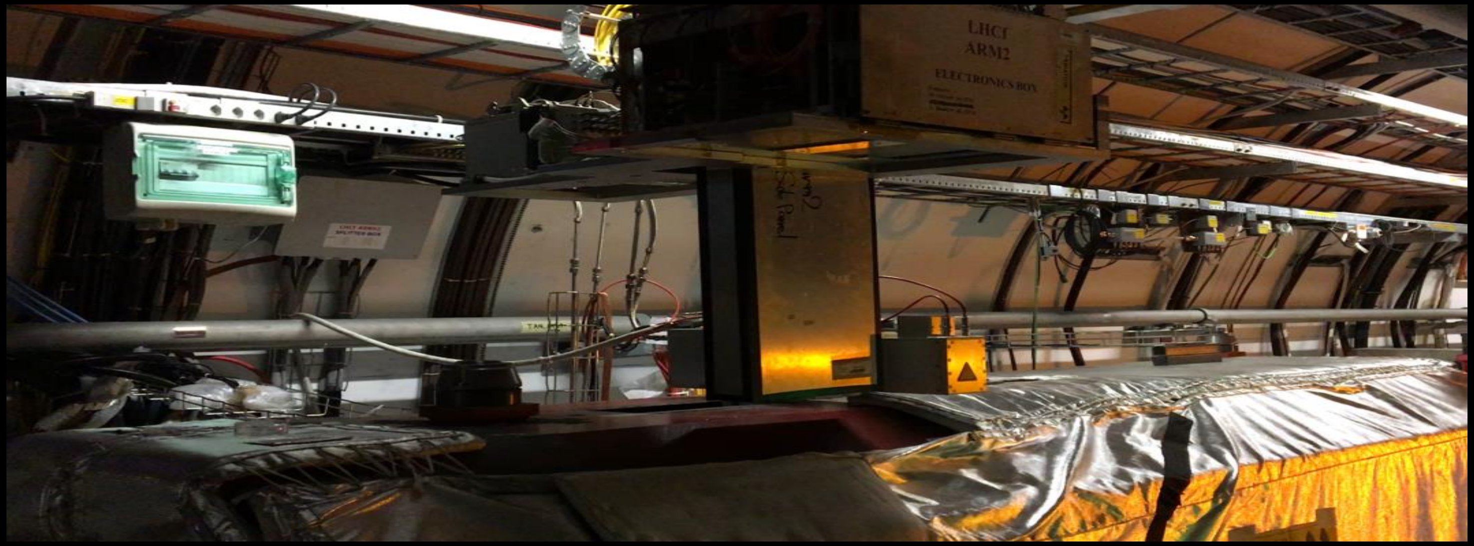


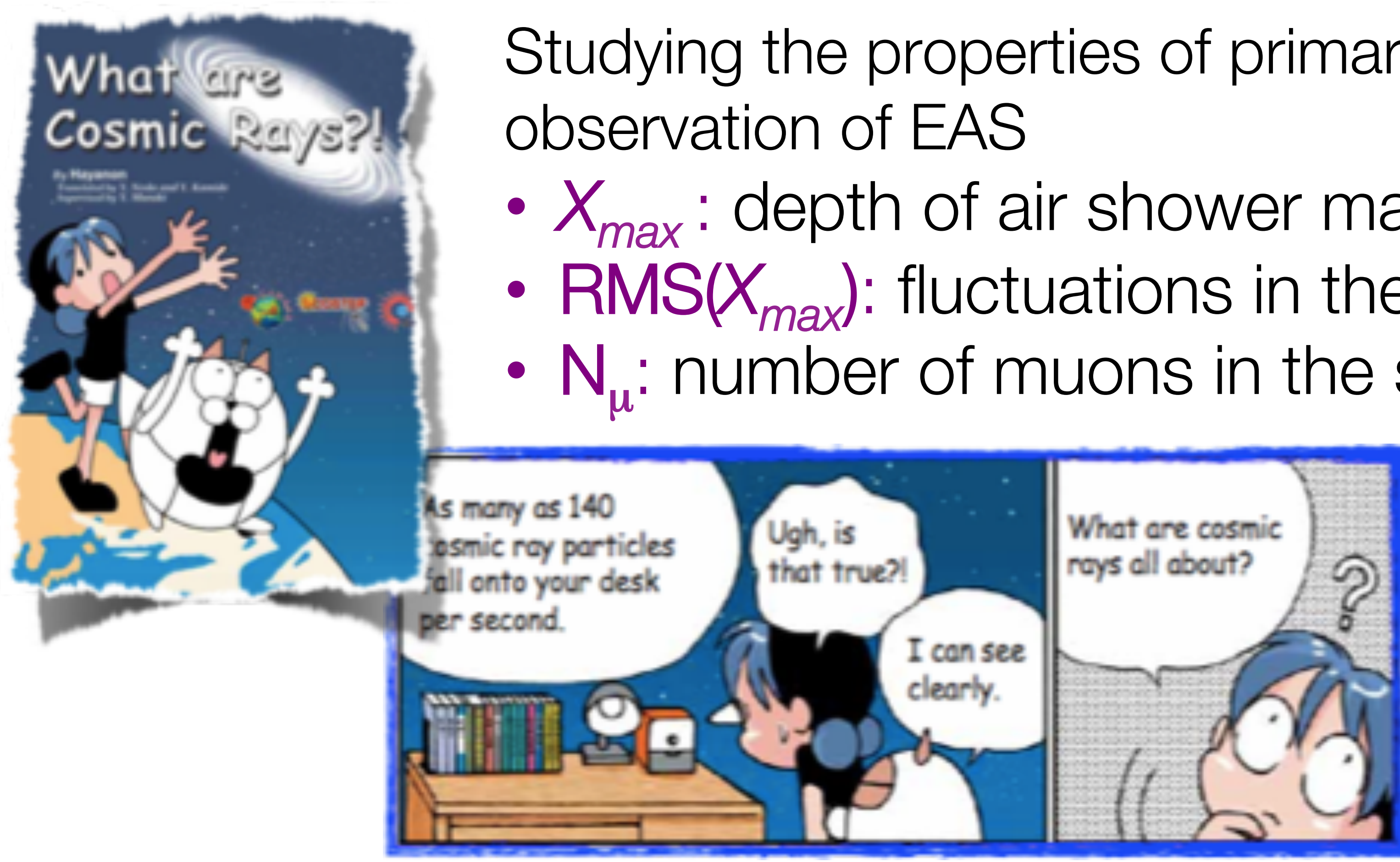



# Latest Results of the LHCf experiment at LHC

Alessia Tricomi
University and INFN Catania, Italy

- Physics Motivations
- Results @ 13 TeV
- p-Pb Run
- RHICf

# Ultra High Energy Cosmic Rays



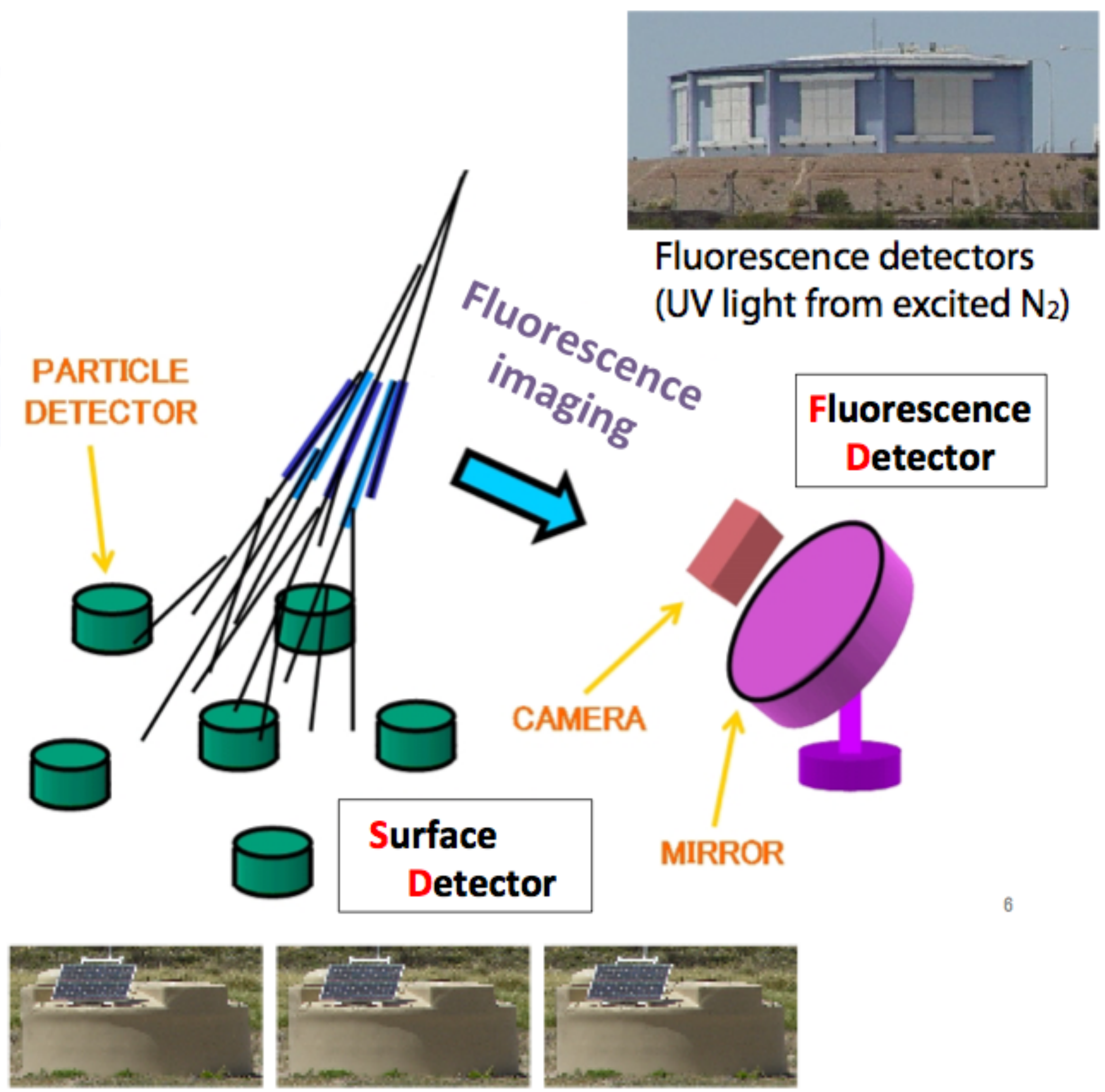

Studying the properties of primary High Energy Cosmic Rays based on observation of EAS

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

+

MC Simulation to describe hadronic interaction with atmosphere

Energy, mass composition, direction
—> source of primary cosmic rays
—> origin of the universe (final goal)




Surface detectors (charged+photon)

# HECR Physics at LHC: LHCf Physics

Model-originated uncertainties or even discrepancies

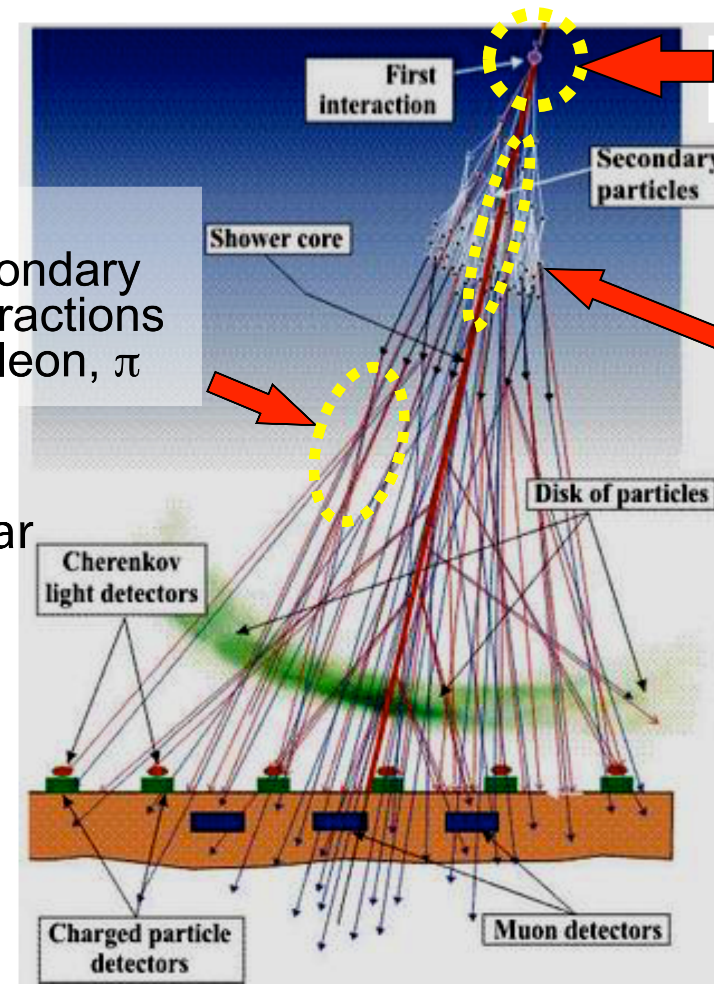
- Energy
  - $E_{SD} > E_{FD}$ :
    discrepancy
  - missing energy (μ,ν) in FD :
    uncertainty
- Mass
  - Mass vs. $X_{max}$ in FD:
    uncertainty
  - Mass vs. e/μ or μ excess in SD :
    discrepancy

p-p + p-Pb

p-Pb

④ secondary interactions nucleon, π

⑤Nuclear effects




① Inelastic cross section

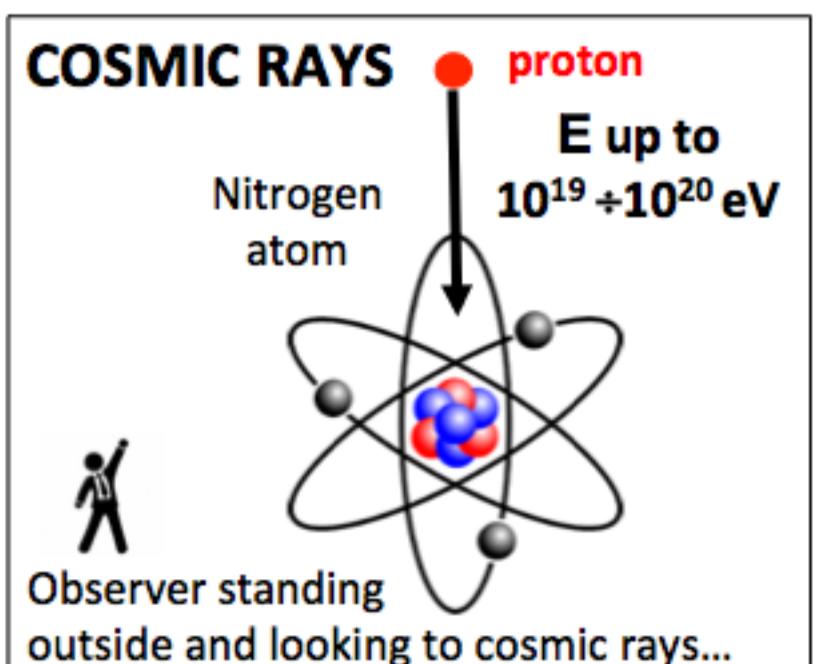
If large σ: rapid development
If small σ: deep penetrating

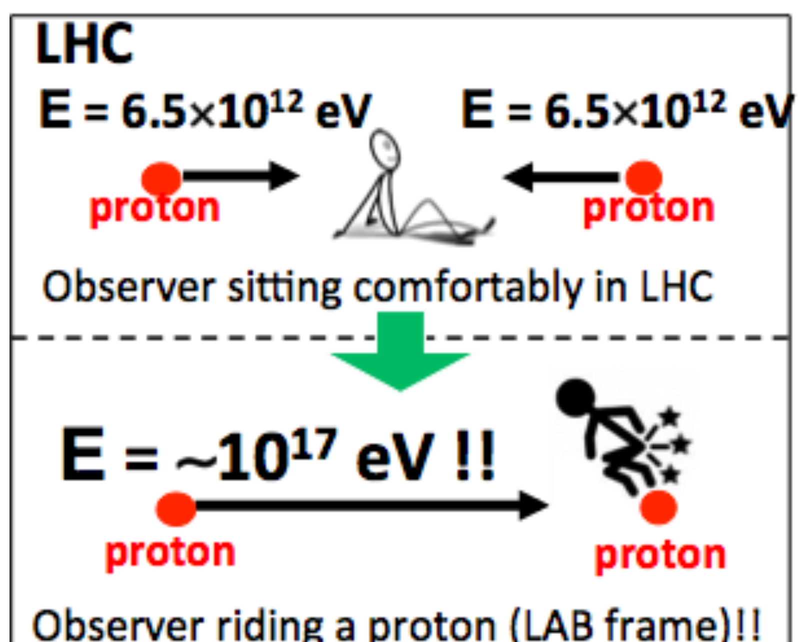
② Forward energy spectrum

If softer shallow development
If harder deep penetrating

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

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




LHCf —>use LHC

6.5 TeV+6.5 TeV⇒$E_{lab}=9*10^{16}$ eV

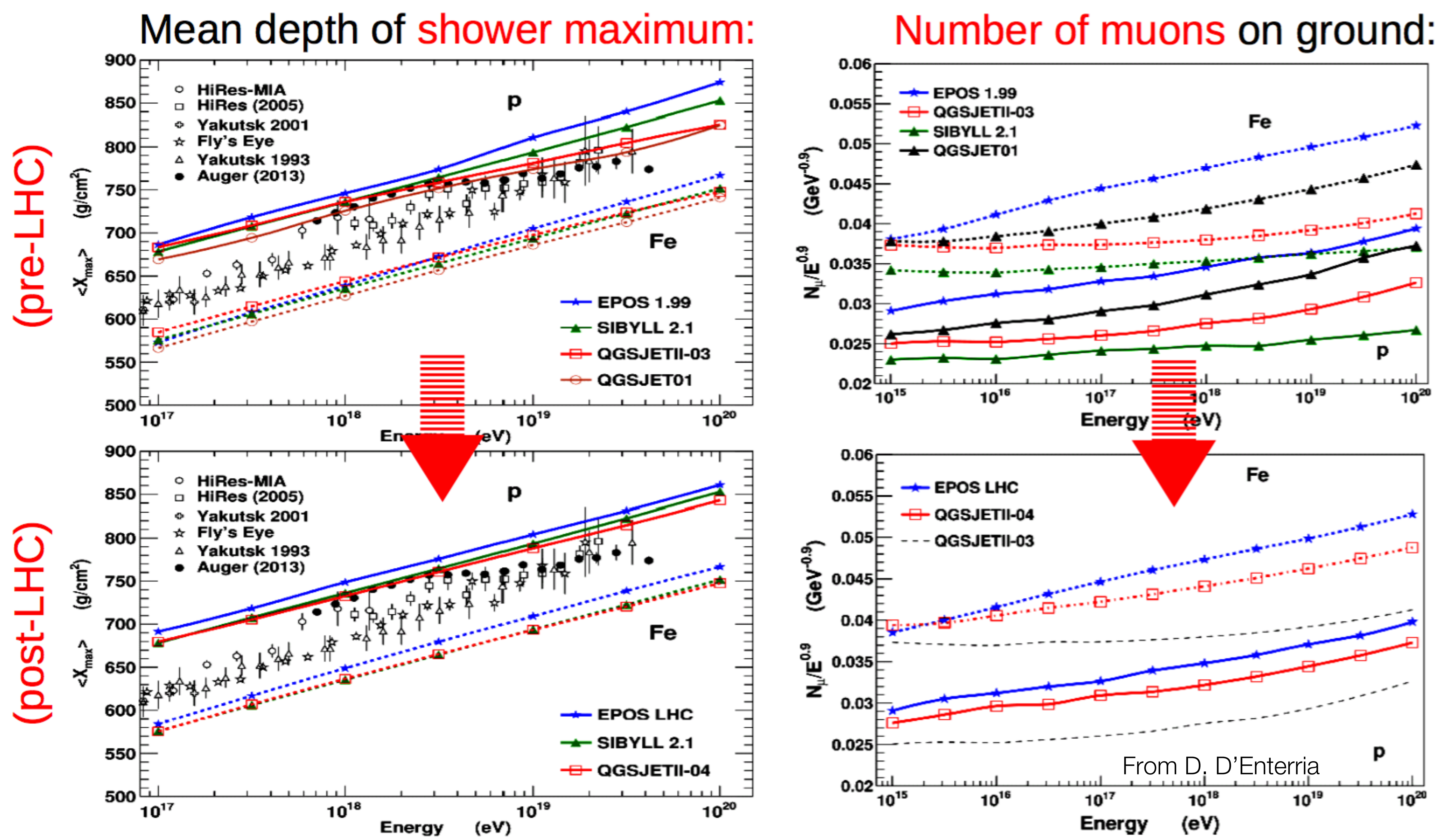
3.5 TeV+3.5 TeV⇒$E_{lab}=2.6*10^{16}$ eV

450 GeV+450 GeV⇒$E_{lab}=2*10^{14}$ eV

to calibrate MCs

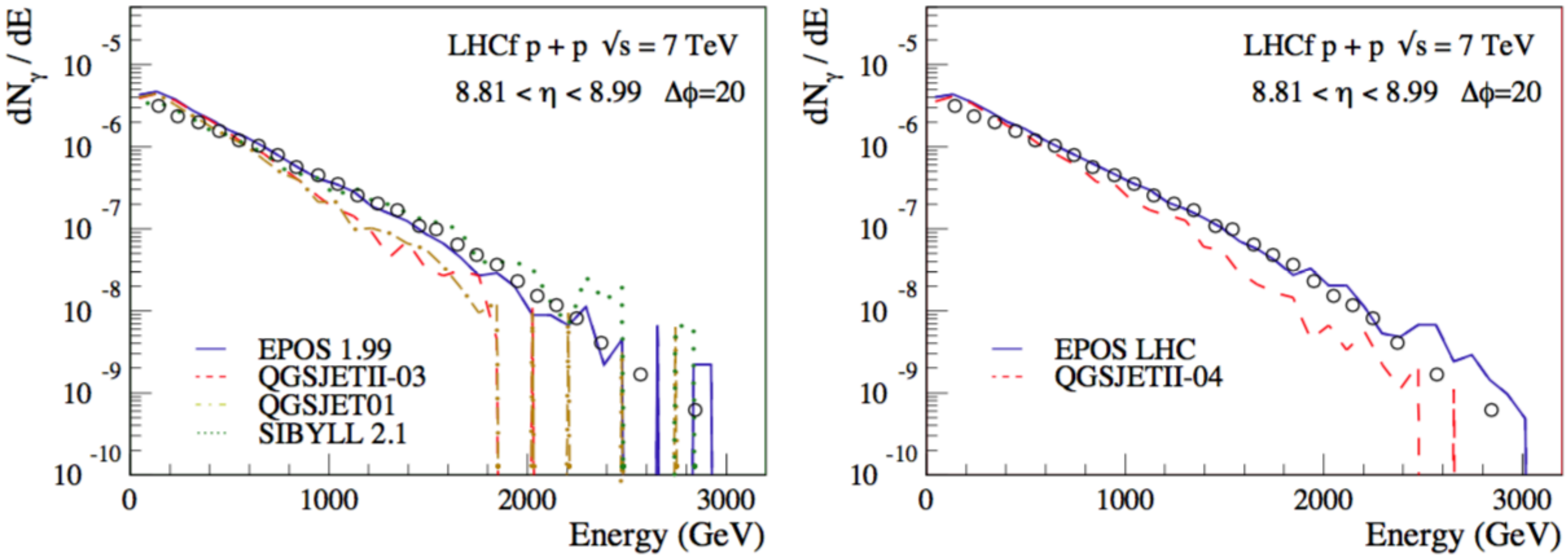
In addition: p-Pb collision at 5.02&8TeV to study nuclear effect

# First models tuning after the first LHC data (EPOS and QGSJET)

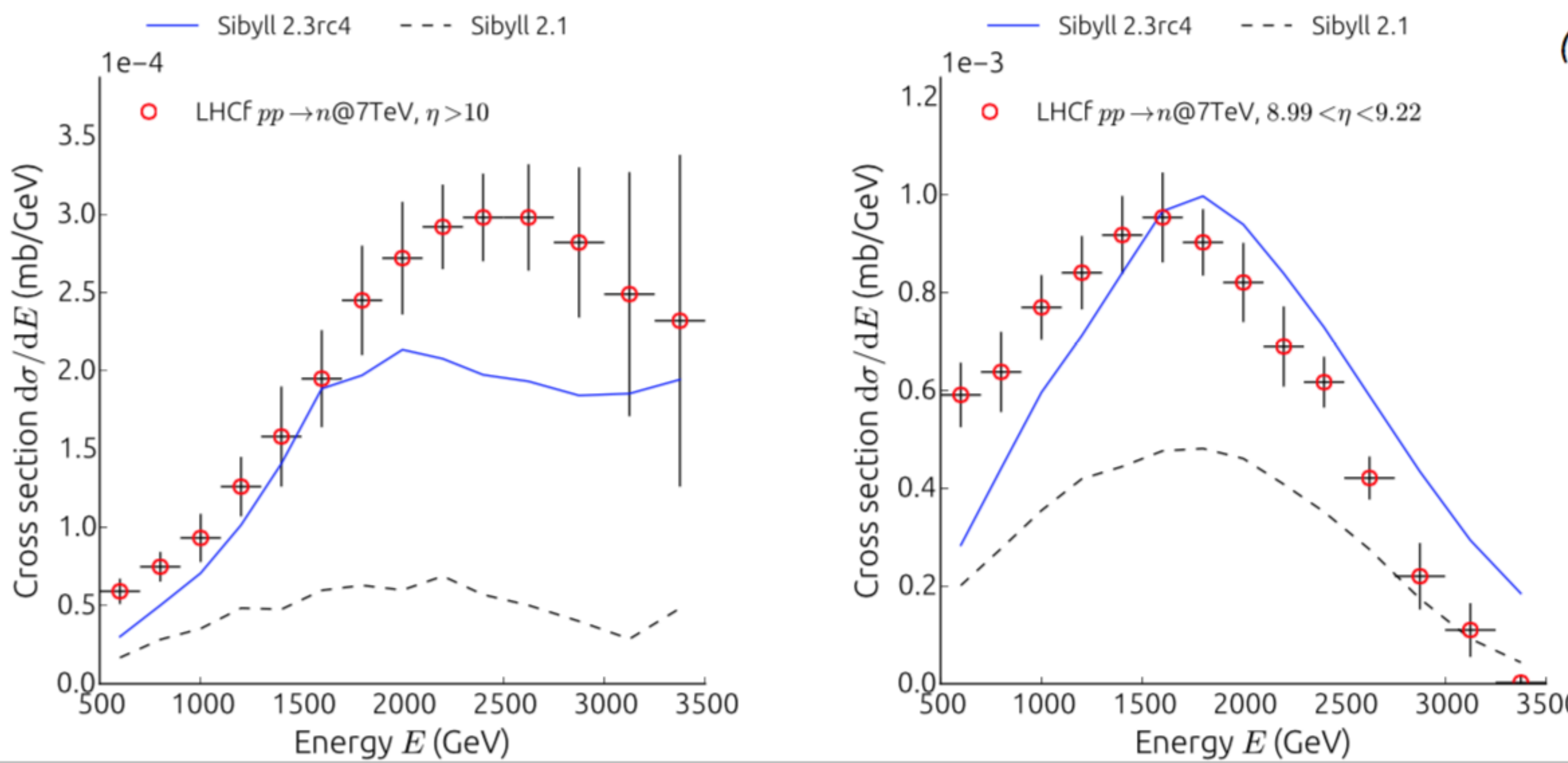



Significant reduction of differences btw different hadronic interaction models!!!

# But not everything is perfect….

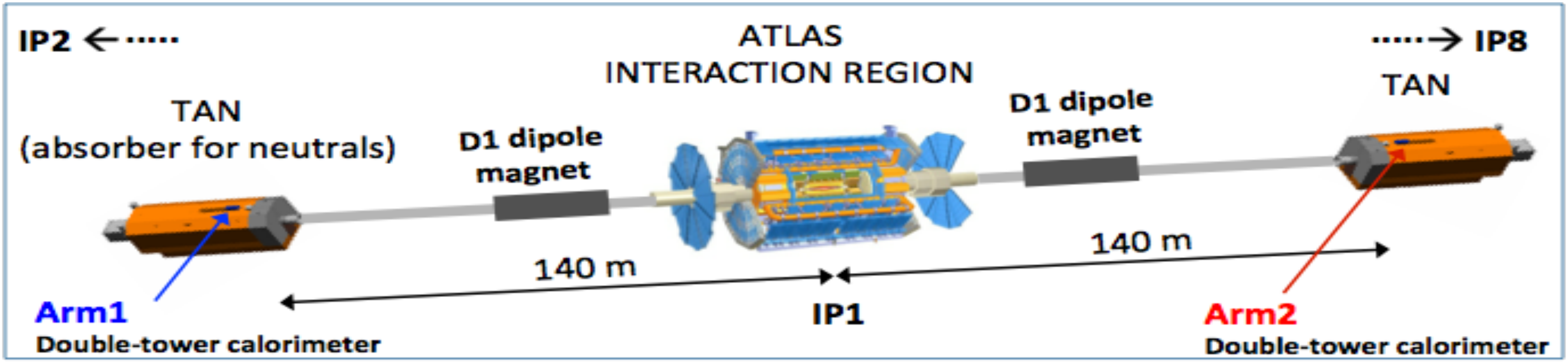


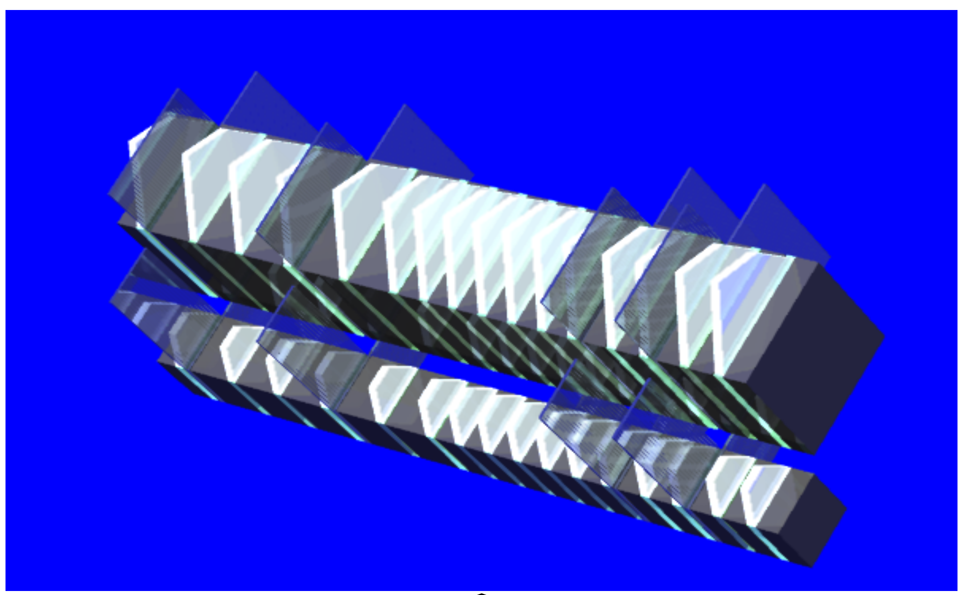

(Pierog 2014)




(Riehn 2015)

# LHCf: location and detector layout

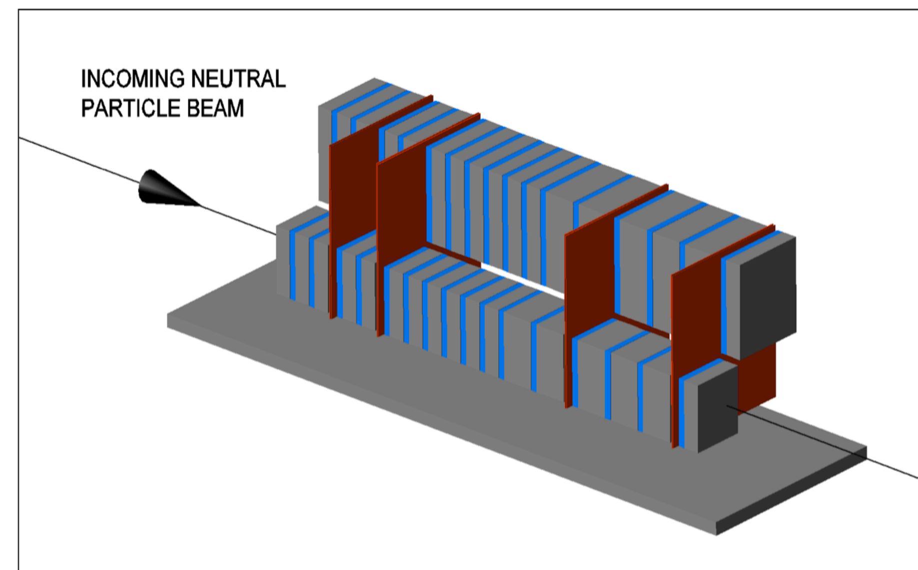


Arm#1 Detector
20mmx20mm+40mmx40mm
4 X-Y GSO Bars tracking layers

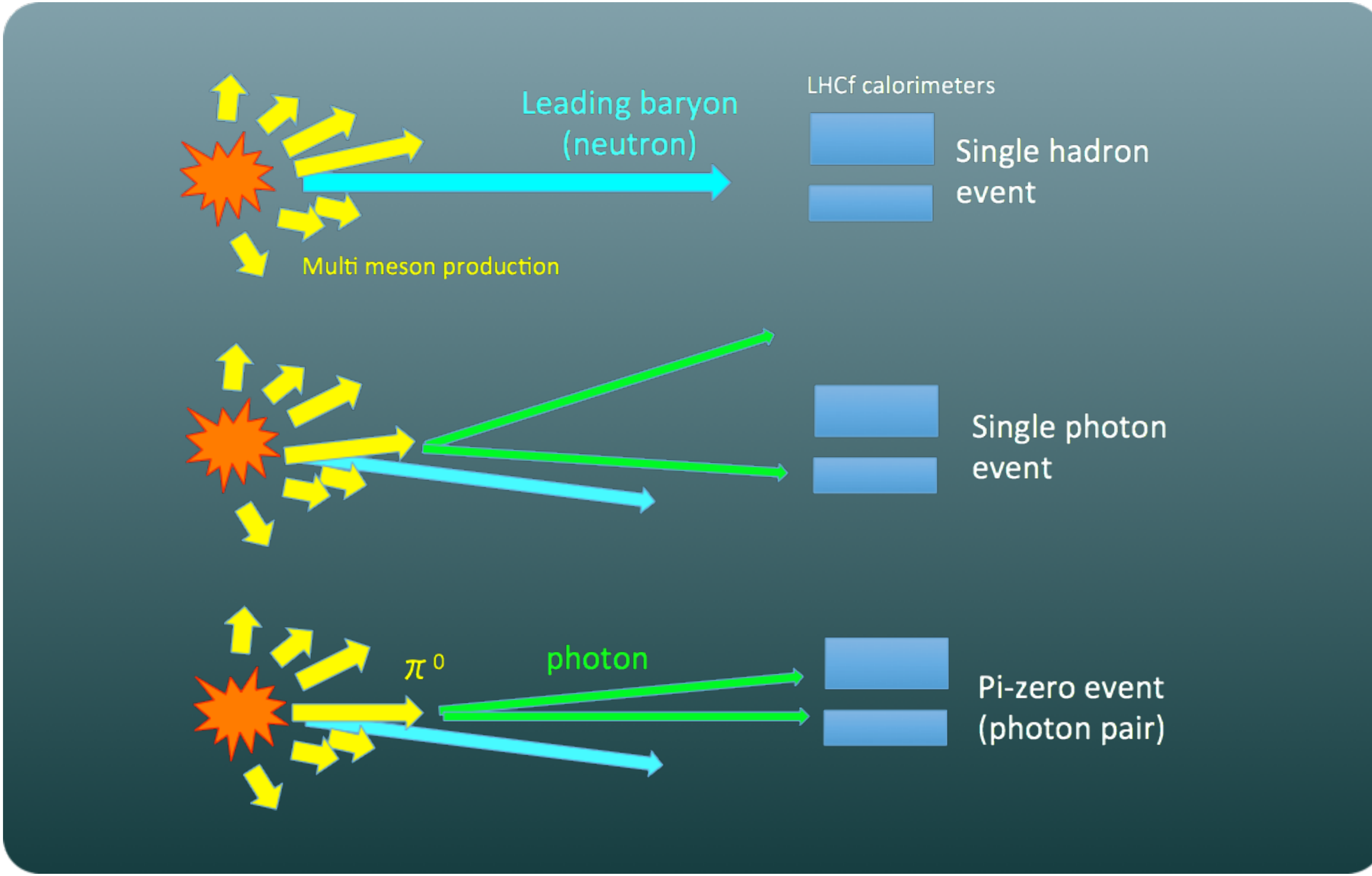
$44X_0$,
$1.6\ \lambda_{int}$

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

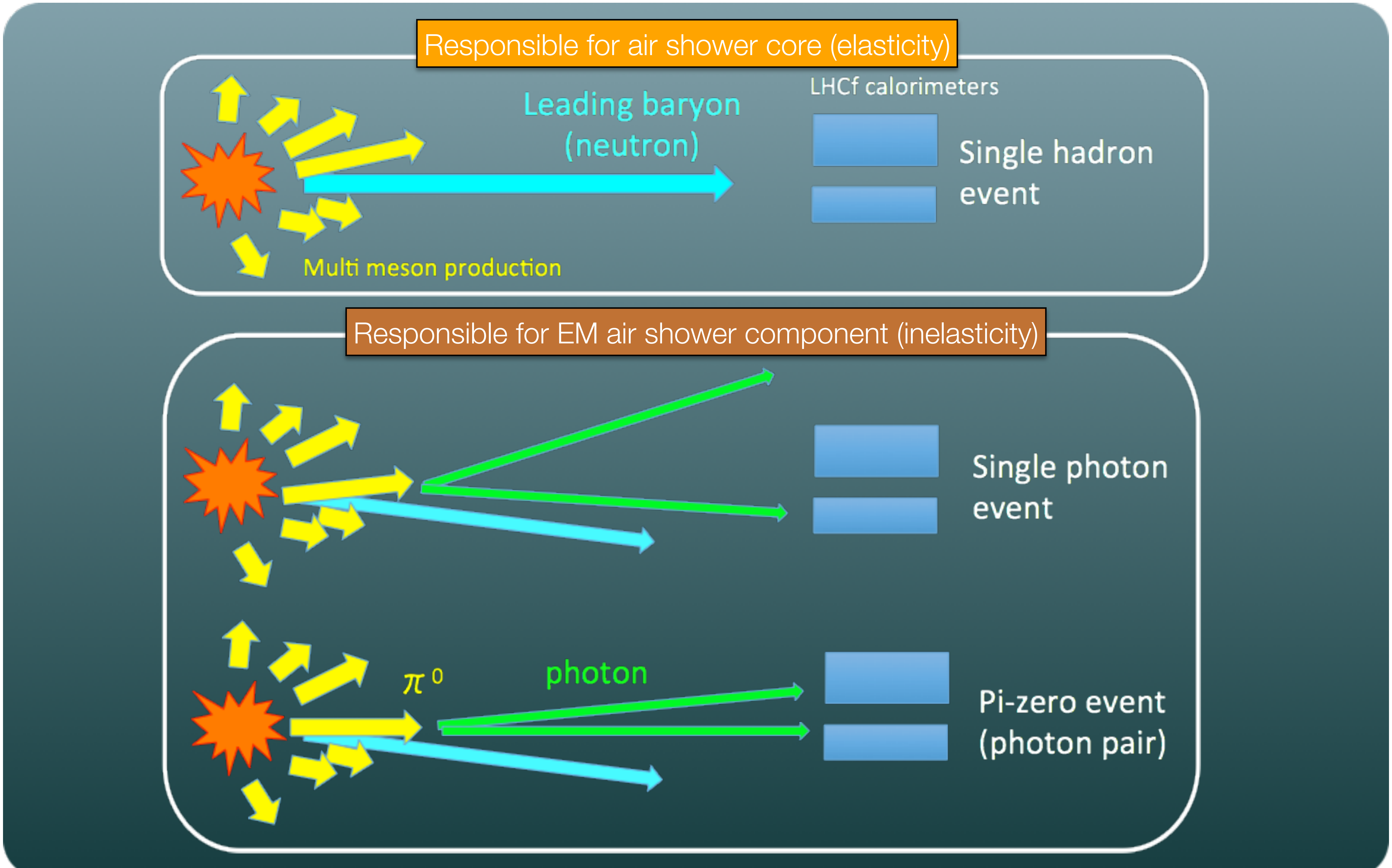



Arm#2 Detector
25mmx25mm+32mmx32mm
4 X-Y Silicon strip tracking layers

# Event category in LHCf



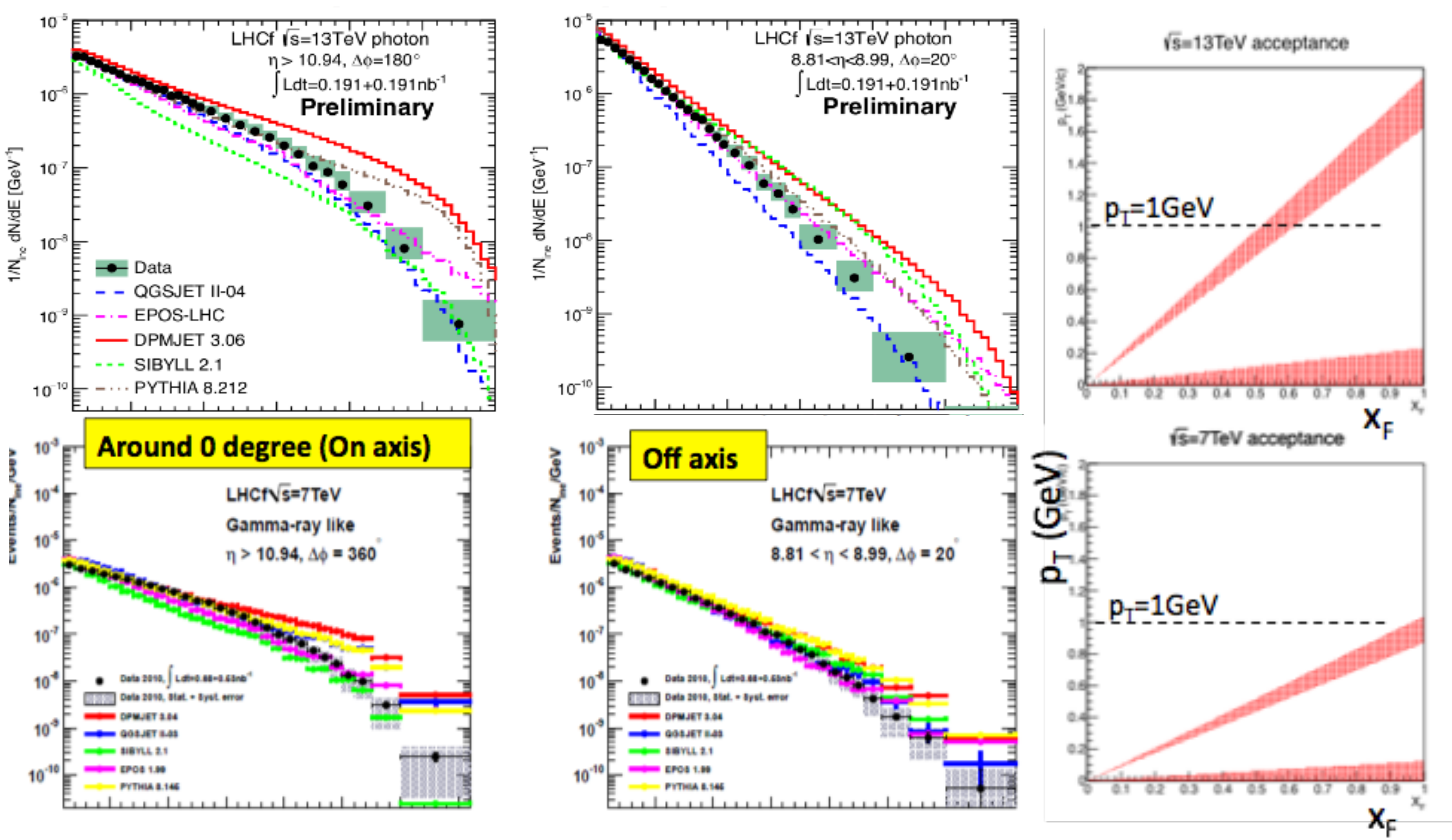
# Event category in LHCf



# LHCf Data Taking and Analysis matrix

| | Proton $E_{LAB}$ (Ev) | Photon (EM shower) | Neutron (hadron shower) | $\pi^0$ (EM shower) | |
|---|---|---|---|---|---|
| Test beam at SPS | | NIM. A 671, 129–136 (2012) JINST 12P03023(2017) | JINST 9 P03016 (2014) (2014)P03016 | | |
| p-p at 900GeV | $4.3x10^{14}$ | Phys. Lett. B 715, 298-303 (2012) | | | Run1 |
| p-p at 7TeV | $2.6x10^{16}$ | Phys. Lett. B 703, 128–134 (2011) | Phys. Lett. B 750, 360-366 (2015) | Phys. Rev. D 86, 092001 (2012)+ Phys. Rev. D 94, 032007(2016) Type II | |
| p-p at 2.76TeV | $4.1x10^{15}$ | | | Phys. Rev. C 89, 065209 (2014)+ Phys. Rev. D 94, 032007(2016) Type II | Run2 |
| p-Pb at 5.02TeV | $1.3x10^{16}$ | | | | |
| p-p at 13TeV | $9.0x10^{16}$ | Submitted to PLB | Preliiminary results | | Run3 |
| p-Pb at 8.1 TeV | $3.6x10^{16}$ | Run completed in November 2016 | | | Run4 |

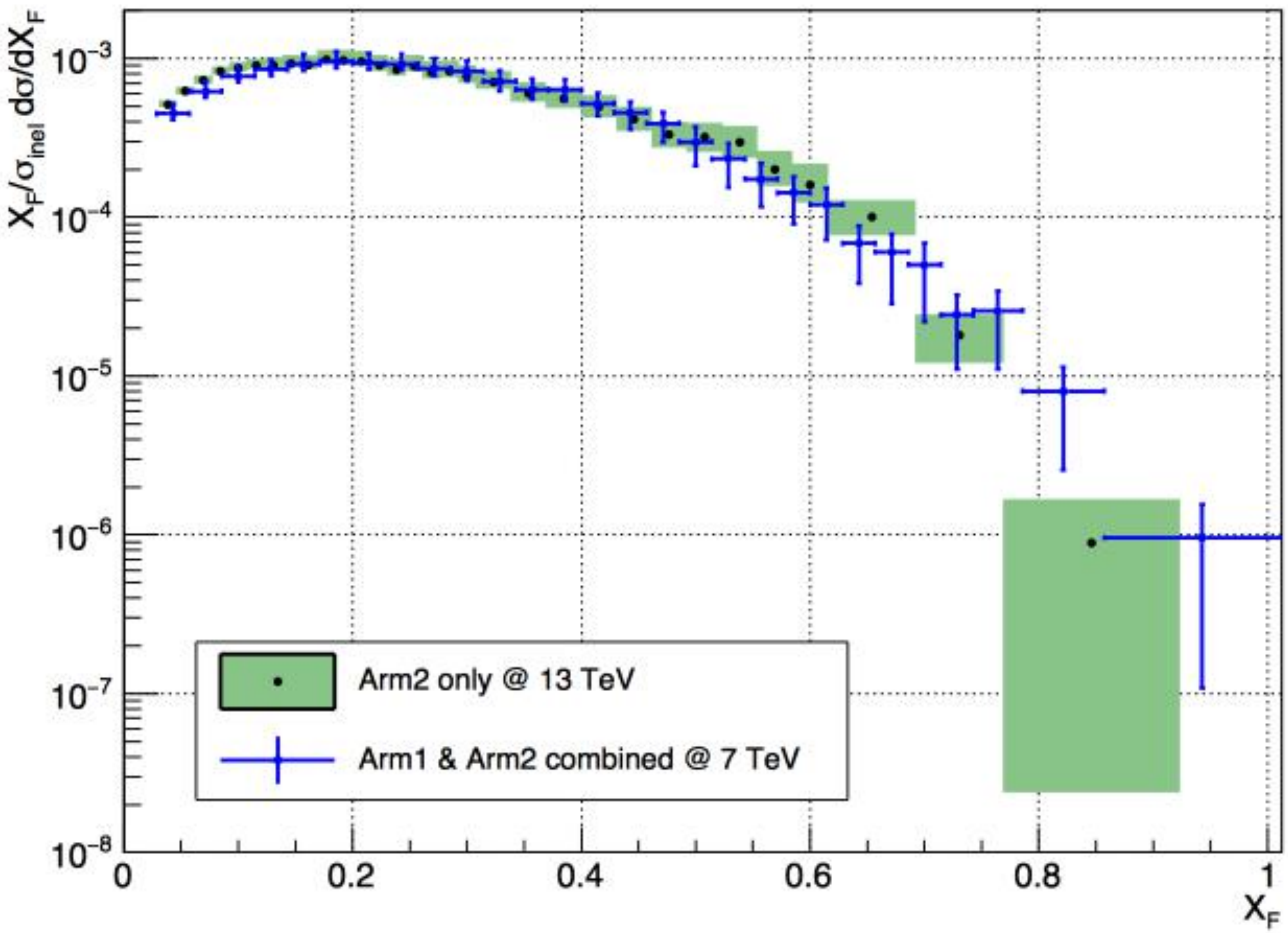
# γ energy spectra 7 vs 13 TeV




High energy data covers up to larger $p_T$

Similar trend in 7TeV and 13TeV, but differences look enhanced in 13TeV results

# Photon spectra – Feynman Scaling



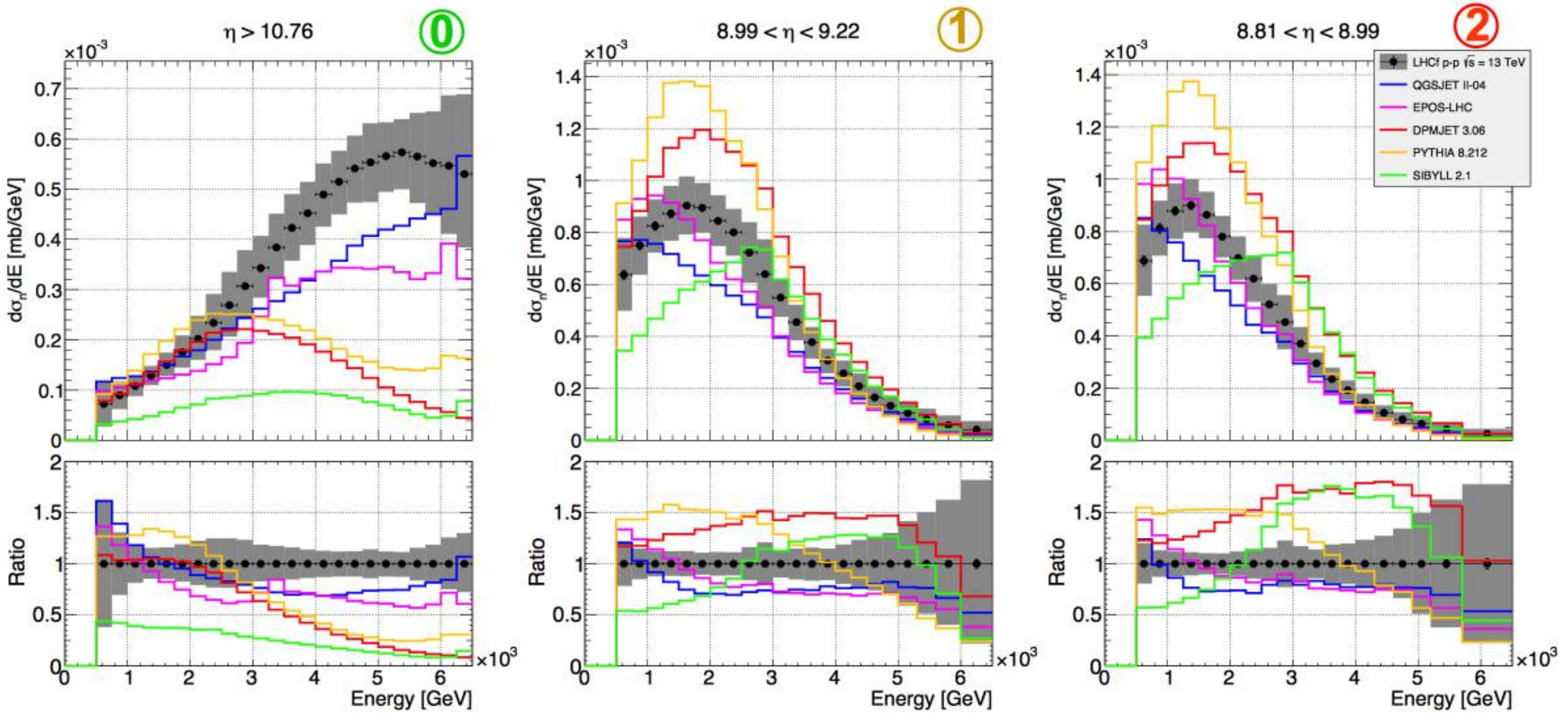

Feynman scaling: differential cross section as a function of $X_F$ independent of $\sqrt{s}$ for $X_F$

Feynman scaling holds within systematic uncertainties

# Preliminary ARM2 unfolded neutron spectra @ 13 TeV

**Differential production cross section**

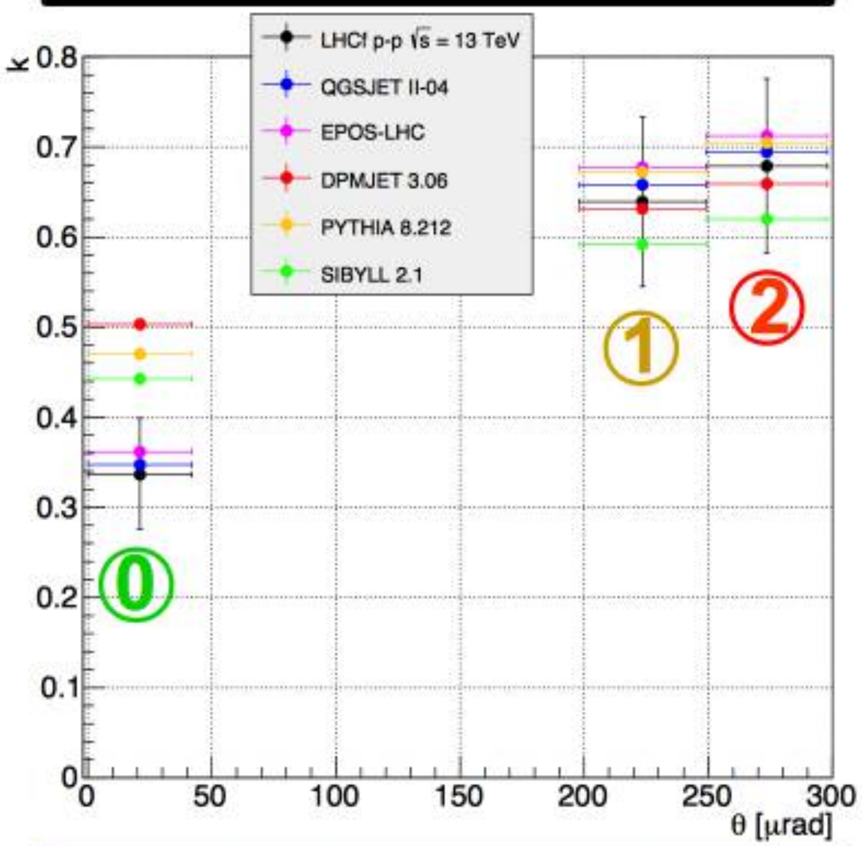
$$d\sigma_n/dE = \frac{dN(\Delta\eta,\Delta E)}{E}\frac{1}{L}\times\frac{2\pi}{d\varphi}$$




Only **QGSJET II-04** qualitatively reproduces behavior of data in η > 10.76
**EPOS-LHC** has similar shape in 8.81 < η < 9.22, but lower yield

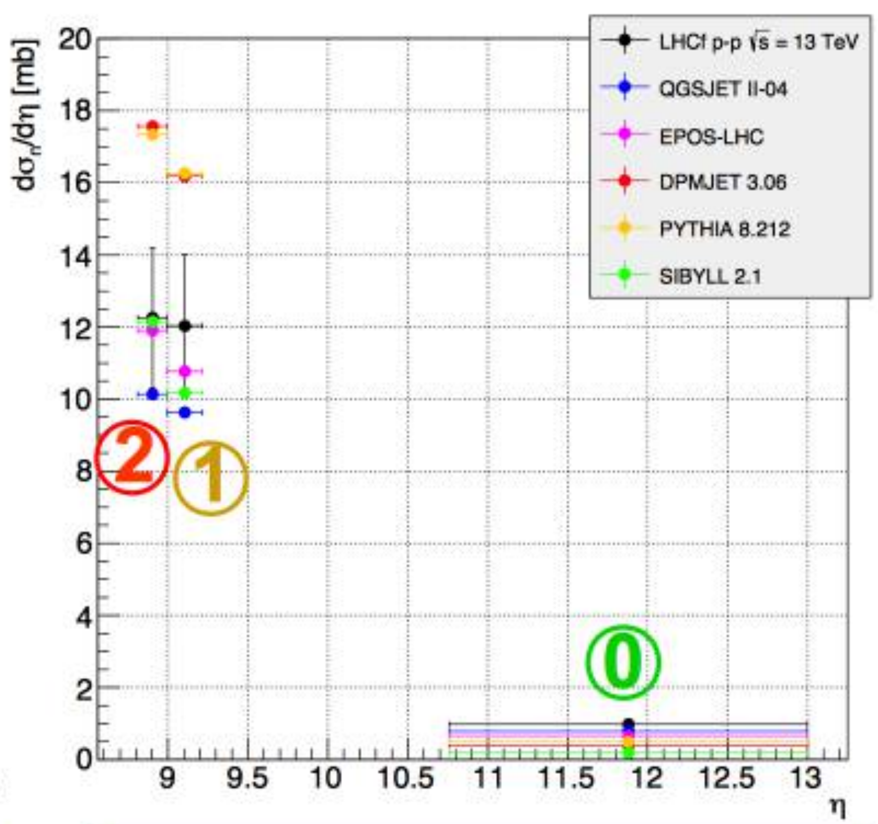
# Measurement of interesting quantities for CR Physics

## Inelasticity VS θ



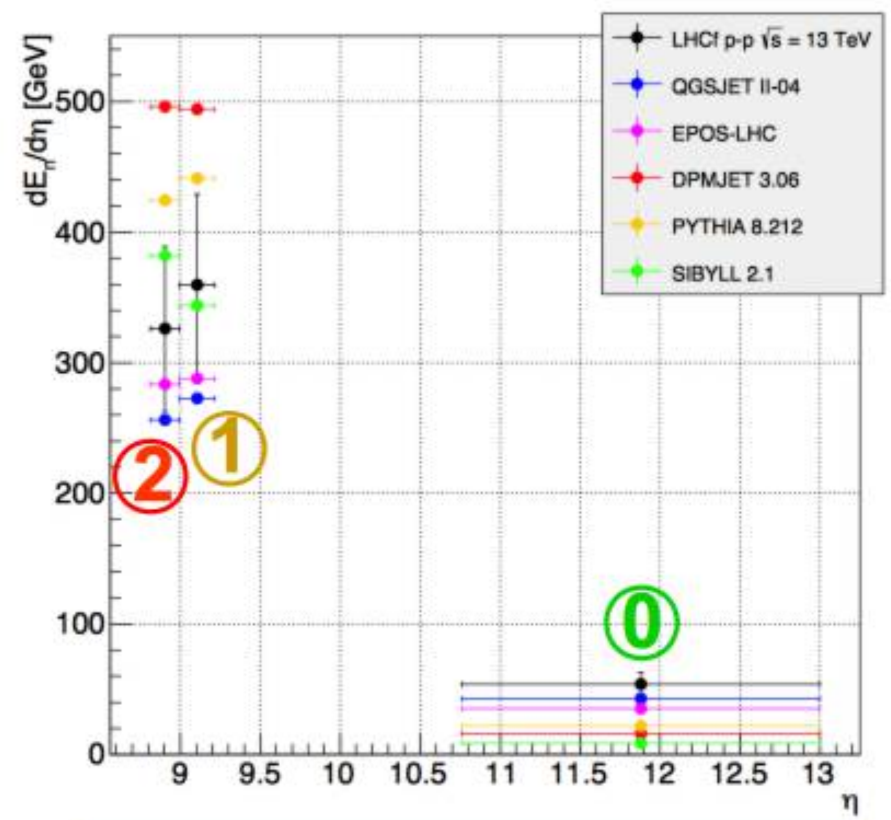

All models overestimate inelasticity in the most forward region even if **QGSJET II-04** and **EPOS-LHC** are consistent within the error bars

## dσ/dη VS η




**EPOS-LHC** and **SIBYLL 2.1** reproduce enough well the measured total differential cross section except in the most forward region

## dE/dη VS η

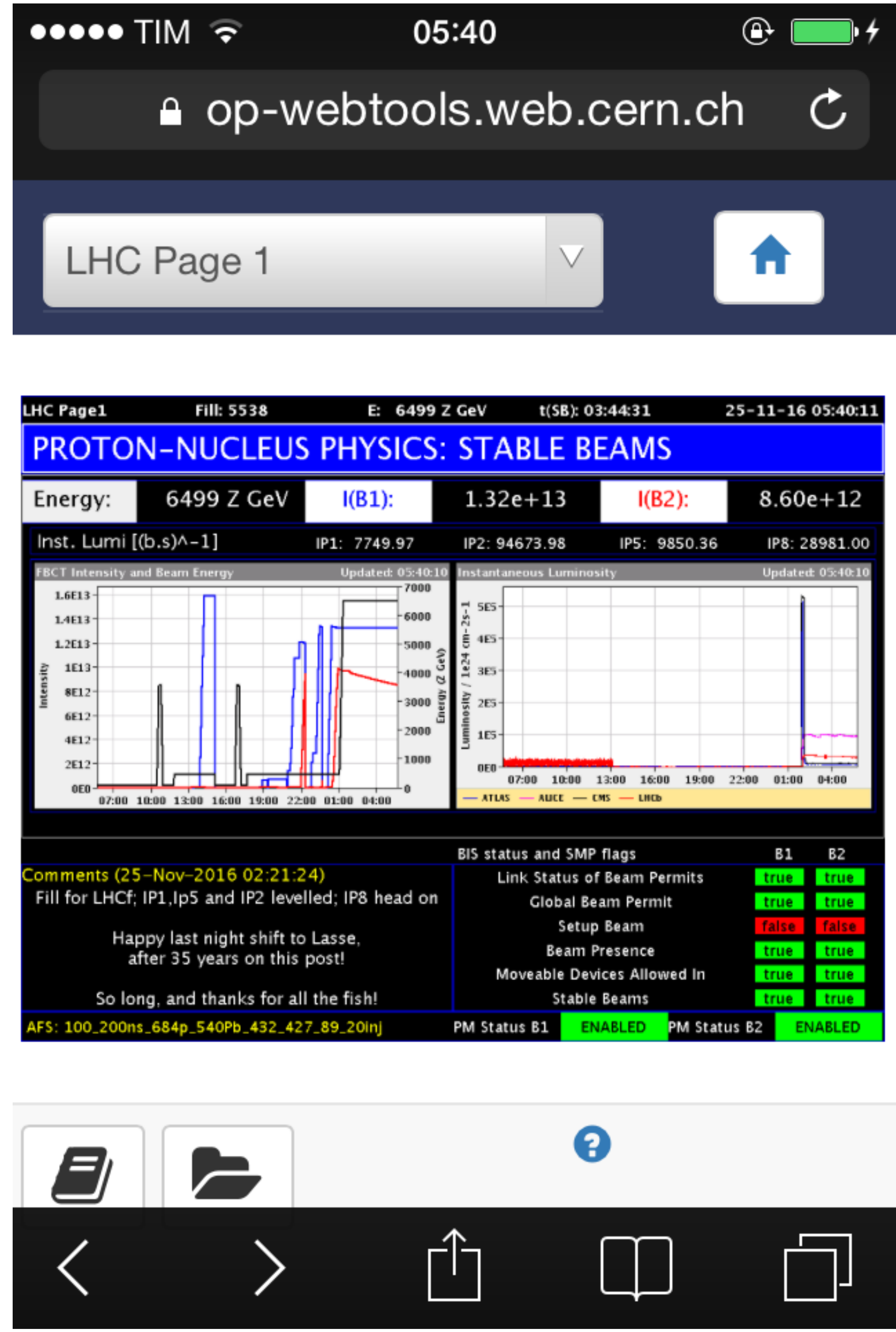



Where the energy flux is high, the agreement between experimental measurements and **SIBYLL 2.1**/**EPOS-LHC** is quite good

# Summary of the 5 & 8 TeV p-Pb run

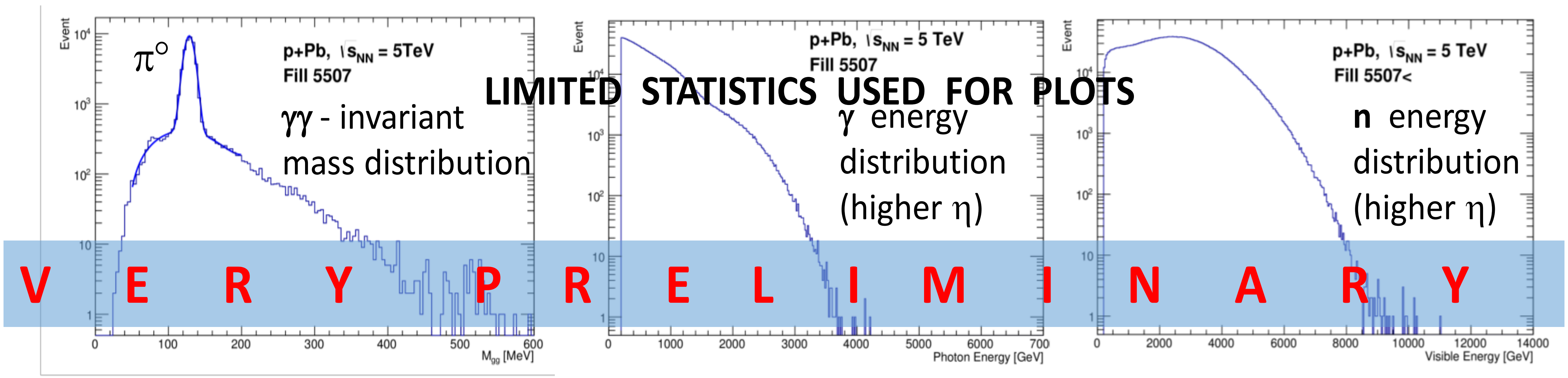
- Collected data sets at 5 TeV
  - Ideal running condition
  - Three different positions
    - Z=0, +8mm, +16mm
  - 26M common events (LHCf-ATLAS)

- Collected data sets at 8 TeV
  - Very good conditions
  - Two different positions
    - Z=0, +8mm
  - 20.5M common events (LHCf-ATLAS)

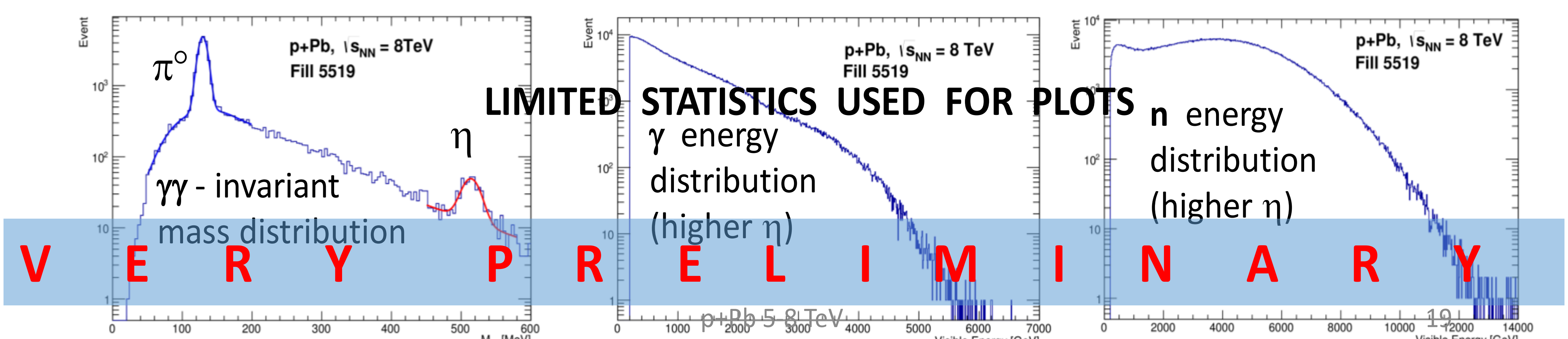


# Very preliminary overview of the p-Pb run

- **5 TeV**
  - Fills 5007 and 5010 (100_200ns_702p_548Pb_81_389_54_20inj)
    - 26M common events (LHCf-ATLAS)



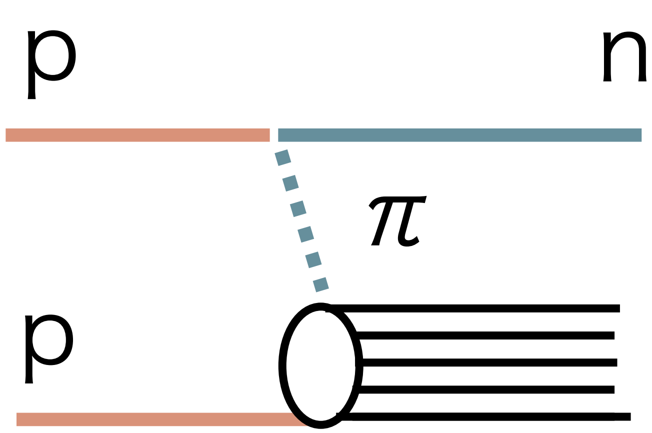

- **8 TeV**
  - Fill 5519 (Single_20p_20Pb_10_10_9_1non_coll) → 5.5M events (LHCf-ATLAS)
  - Fill 5538 (100_200ns_684p_540Pb_432_427_89_20inj) → 15M events (LHCf-ATLAS)



# Physics cases with ATLAS joint taken data

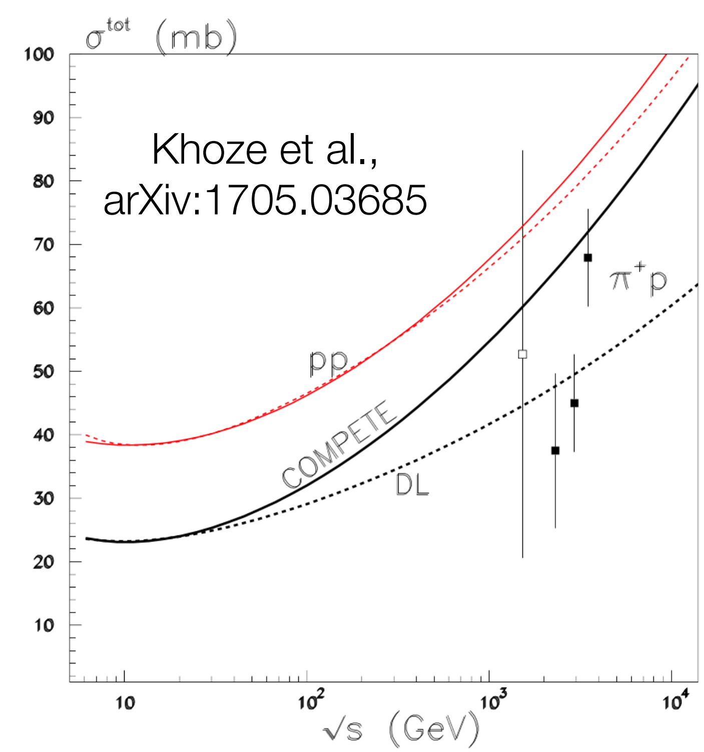
- In p+p collisions
  - Forward spectra of Diffractive/ Non-diffractive events
  - Measurement of proton-π collisions

Both are important for precise-understanding of CR air shower development




*p-π measurement at LHC*

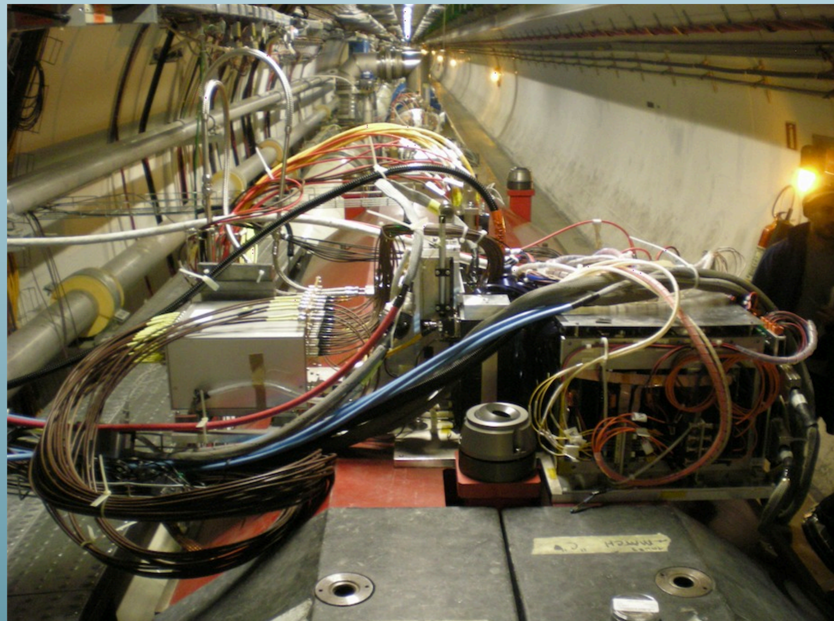
Leading neutron can be tagged by LHCf detectors
-> total cross section
multiplicity measurement



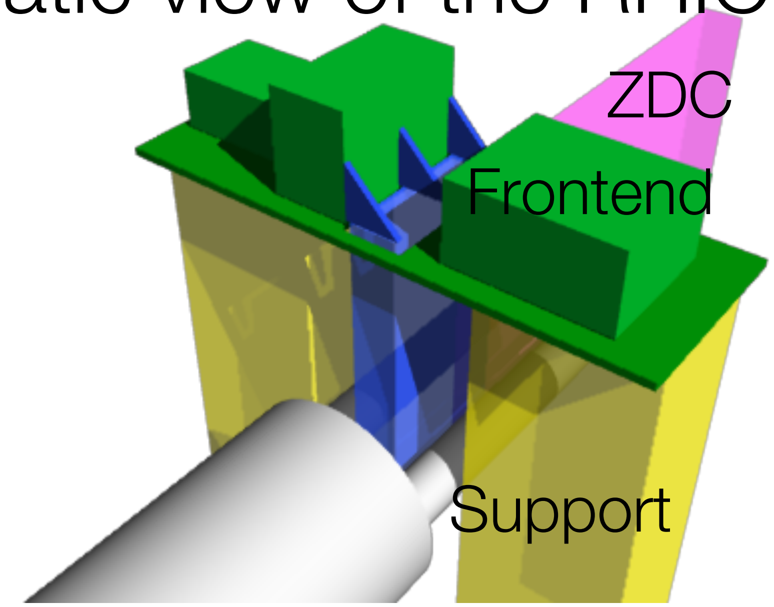

- In p+Pb collisions
  - Measurement of UPC in the forward region.

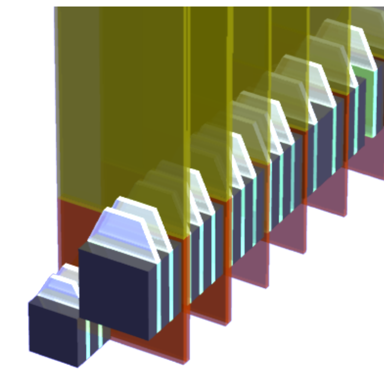
# From the LHC to RHIC

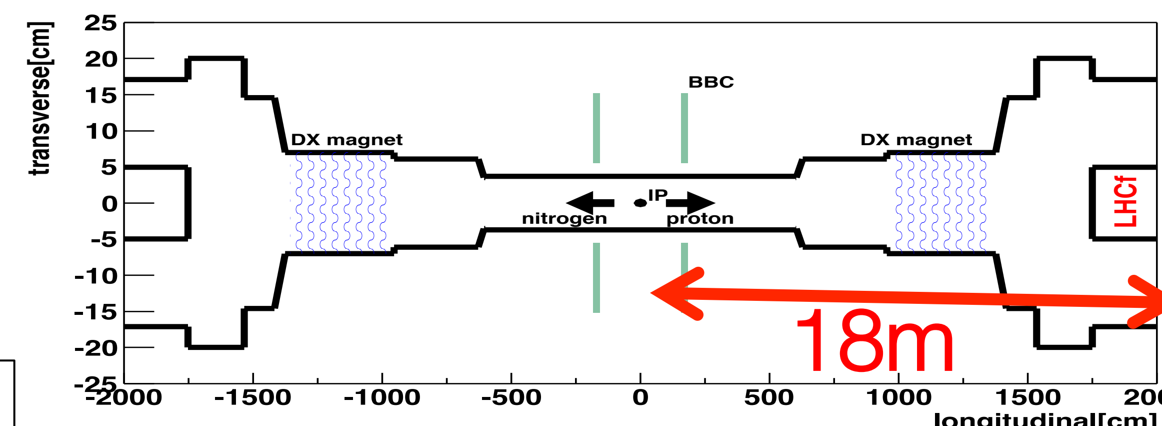
LHCf Arm2 detector in the LHC tunnel



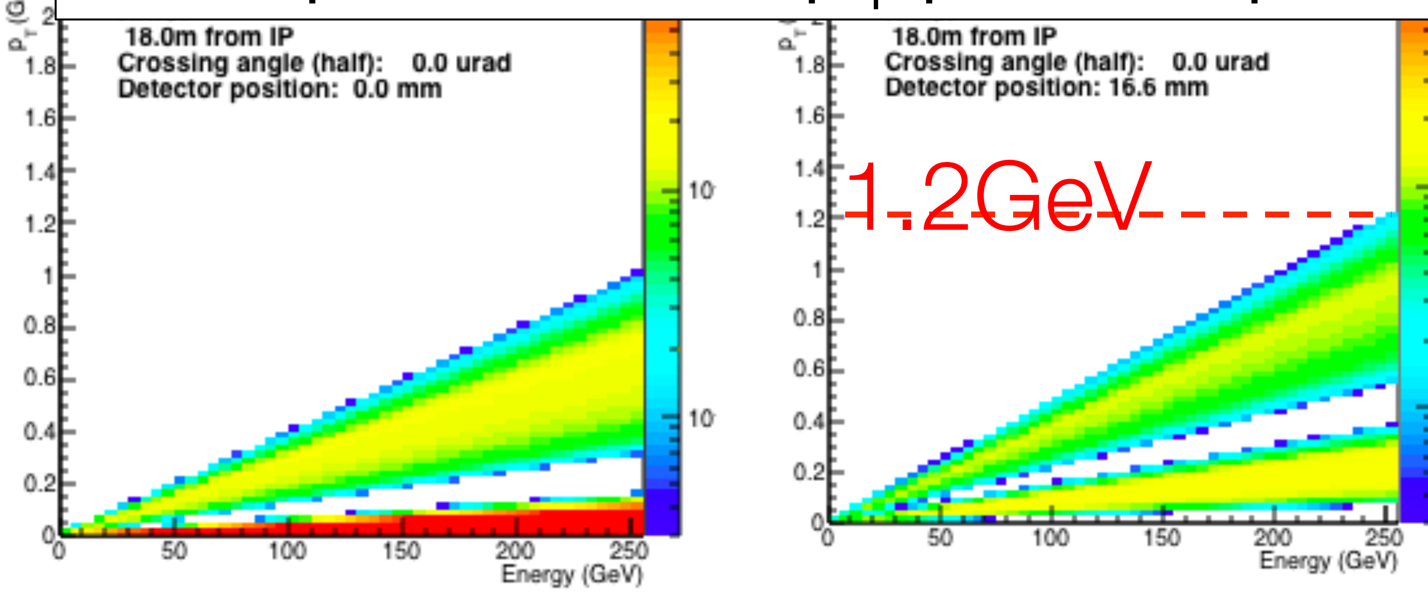
## Schematic view of the RHICf installation

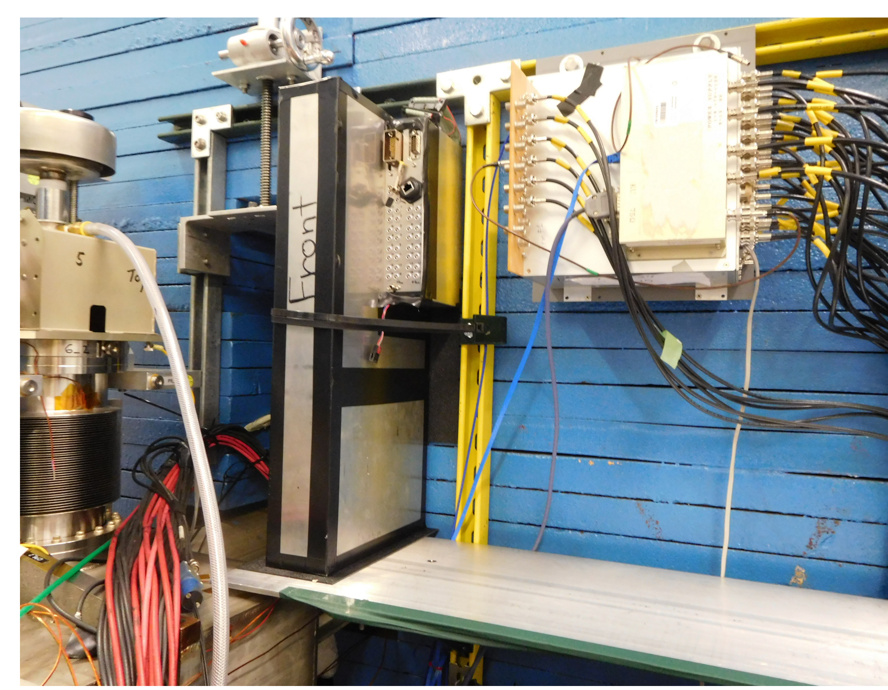




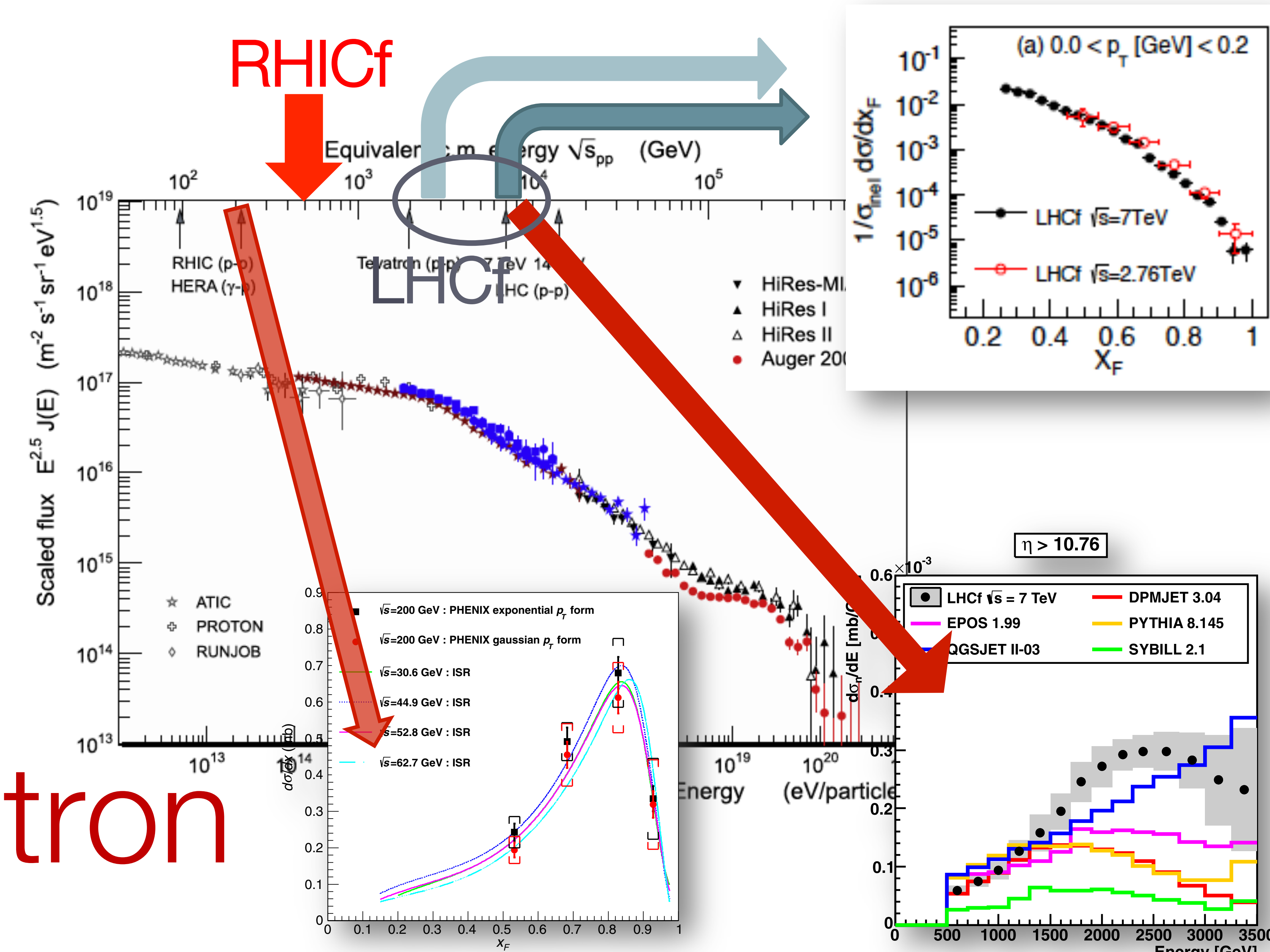

## Acceptance in E-$p_T$ phase space



# √s scaling, or breaking?

LHCf 2.76TeV and 7TeV data
shows scaling of forward $\pi^0$



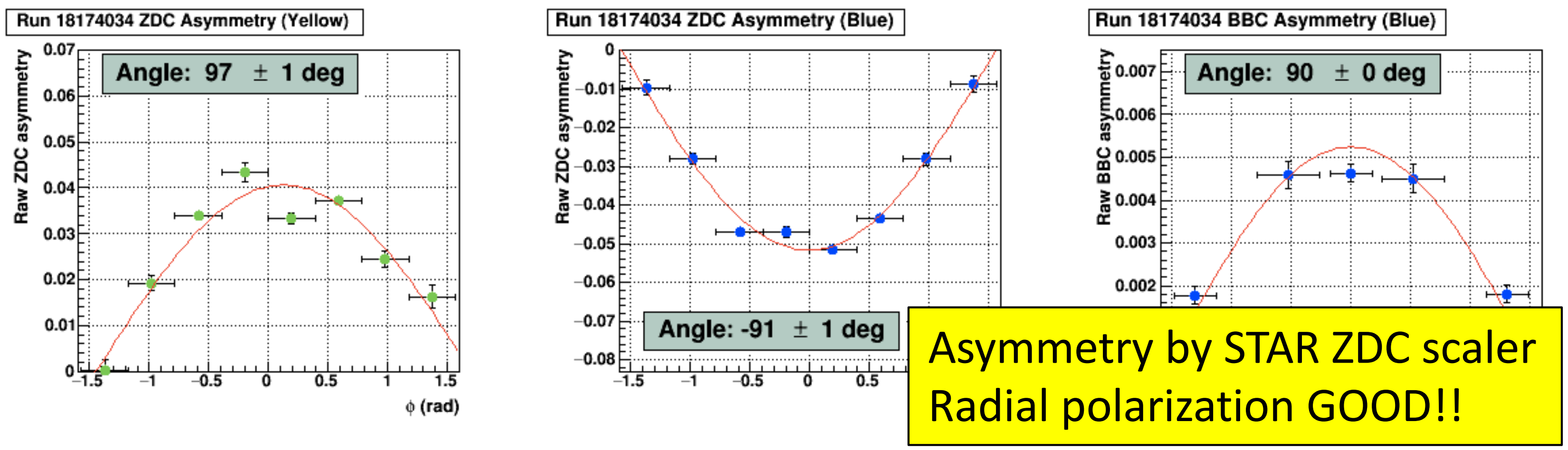

$\pi^0$

neutron

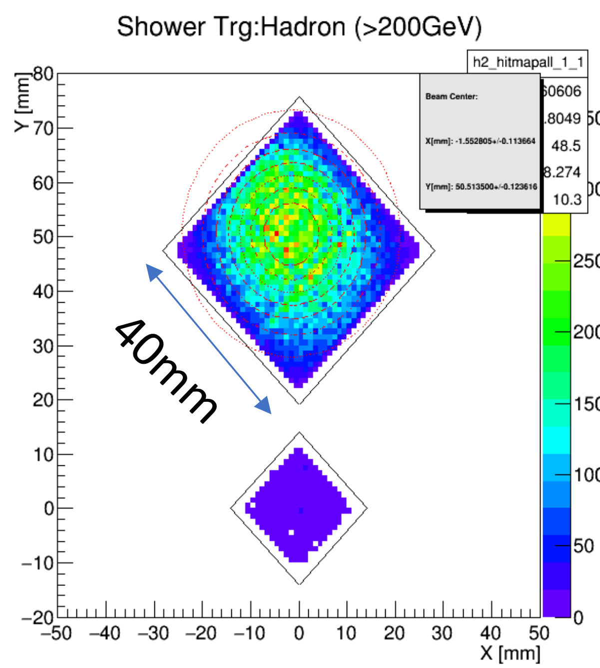
ISR (30-60GeV), PHENIX (200GeV) and LHCf (7TeV)
data indicate scaling ***breaking*** of forward neutrons

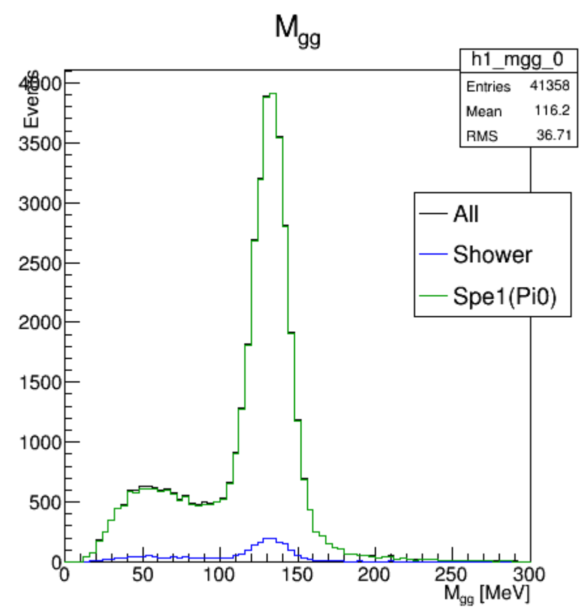
# Very preliminary overwiew of the RHICf run

24 June 2017!!!

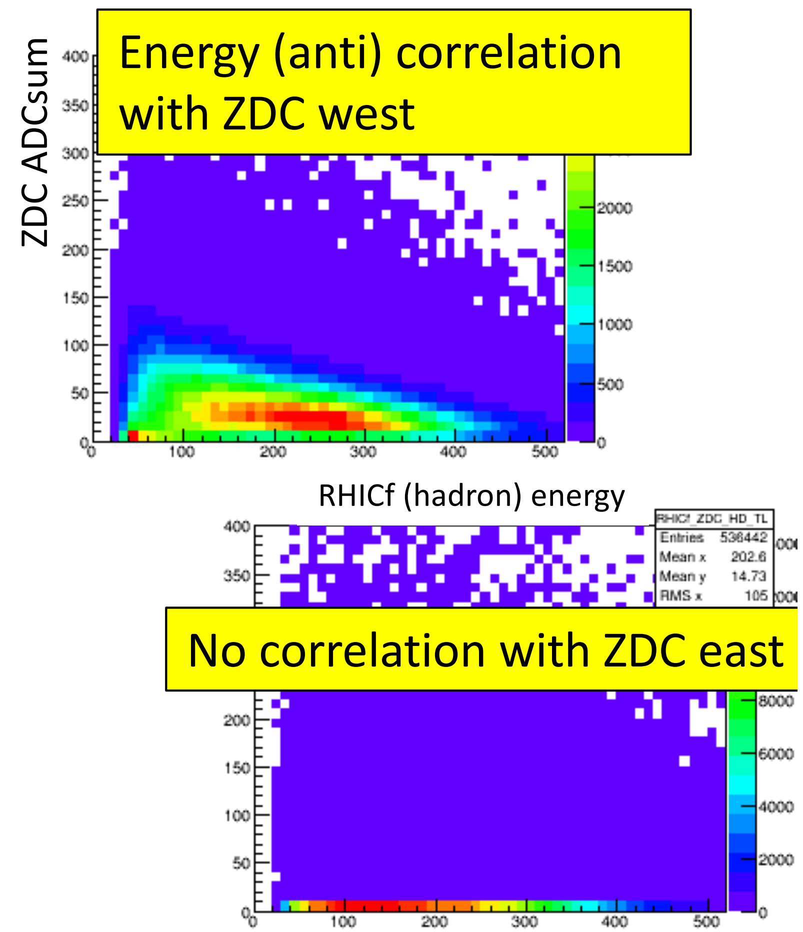



Hadron shower hitmap
0 degree well defined!



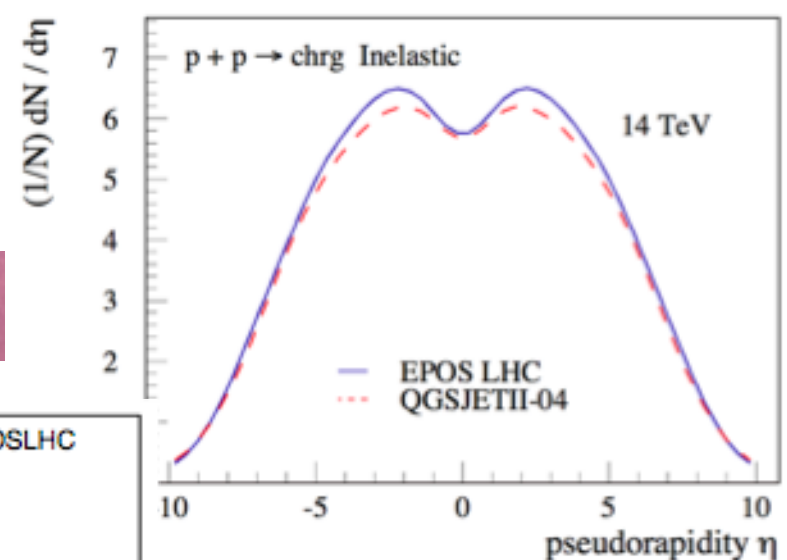



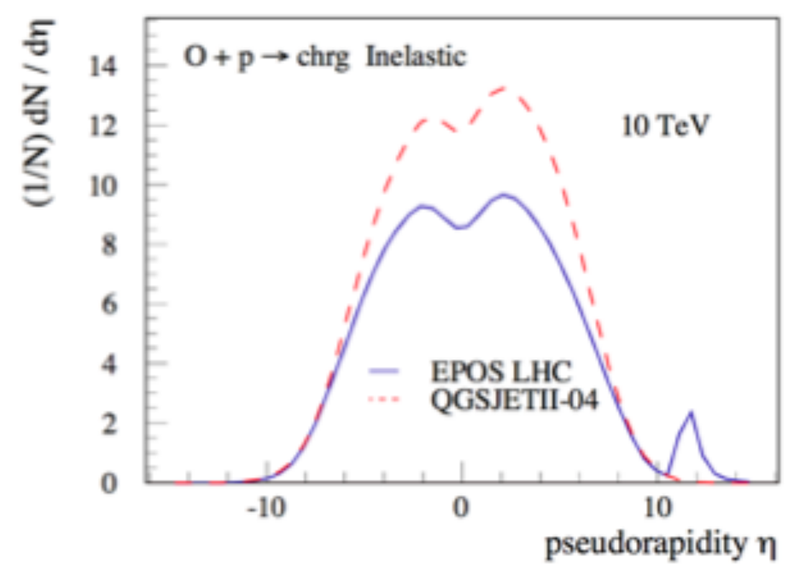

Invariant mass of $2\gamma$
Peak by $\pi^0$ !!



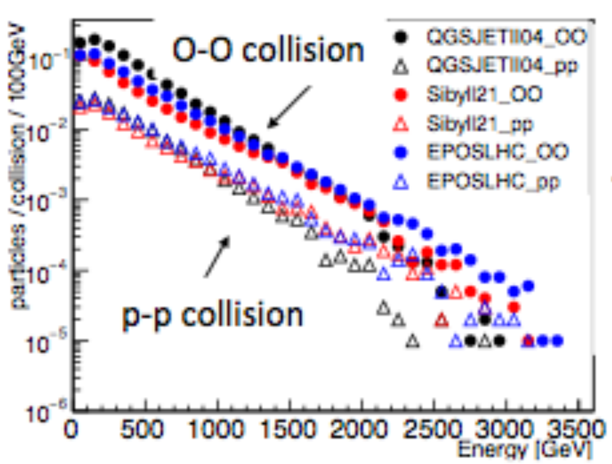
# The Near-Far Future at LHC

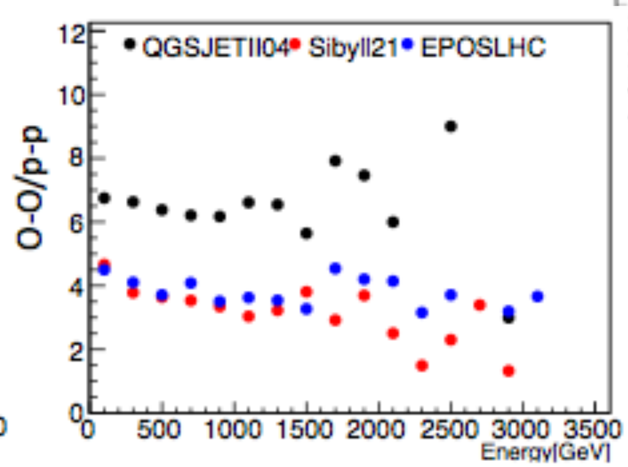
- The most promising future at LHC for LHCf involve the proton-light ion collisions
- To go from p-p to p-Air is not so simple….
- Comparison of p-p, Pb-Pb and p-Pb is useful, but model dependent extrapolations are anyway necessary
- Direct measurements of p-O or p-N could significantly reduce some systematic effects
- Still make sense to take data if intermediate ion (like Ar) will be available




Photon spectra p-p vs. O-O




Y. Okuno, Master thesis
Nagoya university (2016)

# Summary

LHCf zero degree results are significantly contributing to improve our knowledge of hadronic interaction model for HECR Physics

- Analysis of 13 TeV p-p run in a good shape
  - New results with hadrons are particularly interesting to understand the muon excess
- 8.1 TeV and 5 TeV p-Pb collisions at LHC done in November 2016
  - Analysis of p-Pb to be started
- 510 GeV p-p with polarized beam at RHIC just done few days ago

- Still a lot of results will come in the next years… while waiting for p-Light Ion run at LHC
- So… stay tuned!

Slide back-up

# A brief LHCf photo-history

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

Jul 2006
construction

Aug 2007
SPS beam test

Jan 2008
Installation
Sept
1st LHC beam

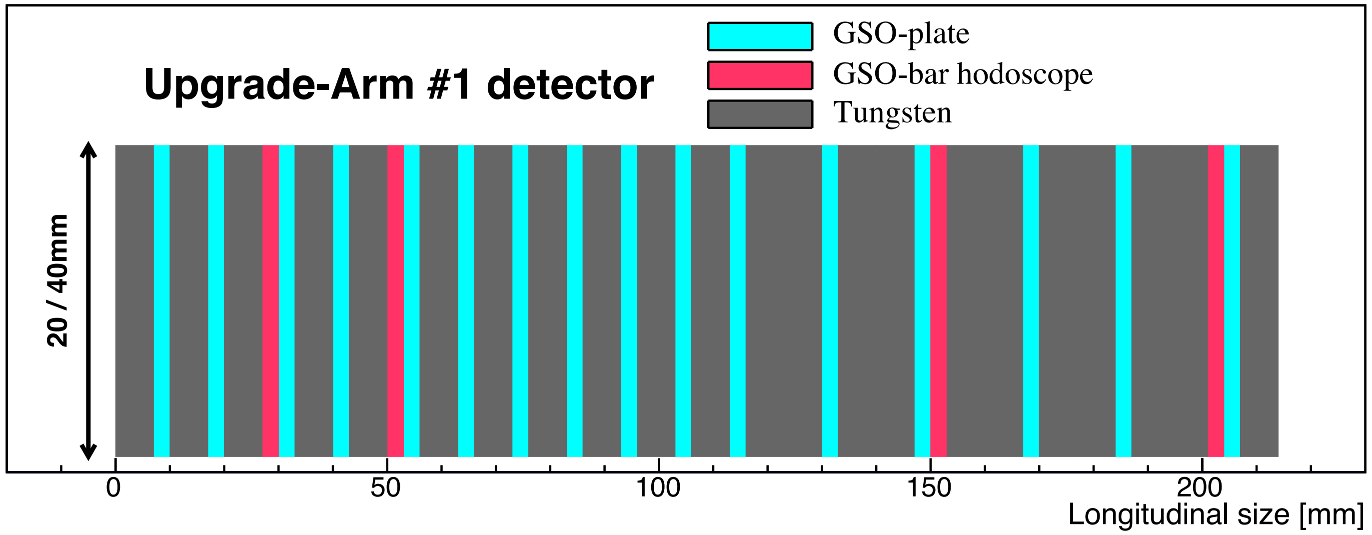
Dec- Jul 2010
0.9TeV& 7TeV pp
Detector removal

Dec 2012- Feb 2013
5TeV/n pPb, 2.76TeVpp
(Arm2 only)
Detector removal

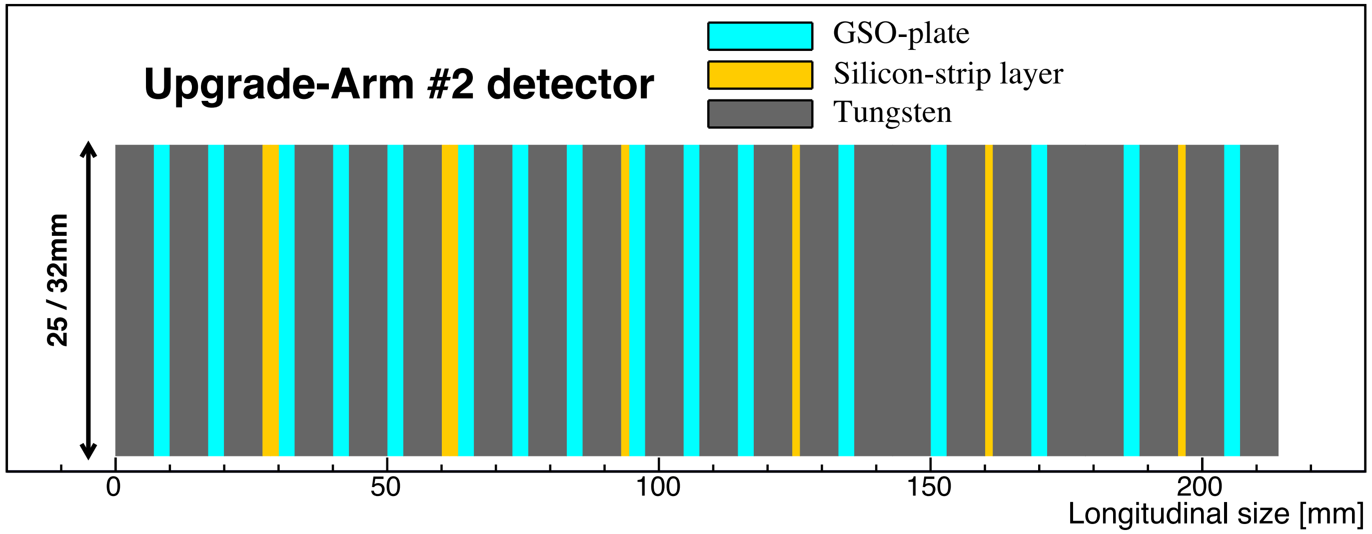
May-June 2015
13 TeV dedicated pp
Detector removal

November 2016
8 Tev p-Pb

# LHCf @ 13 TeV




**(a)** Arm1

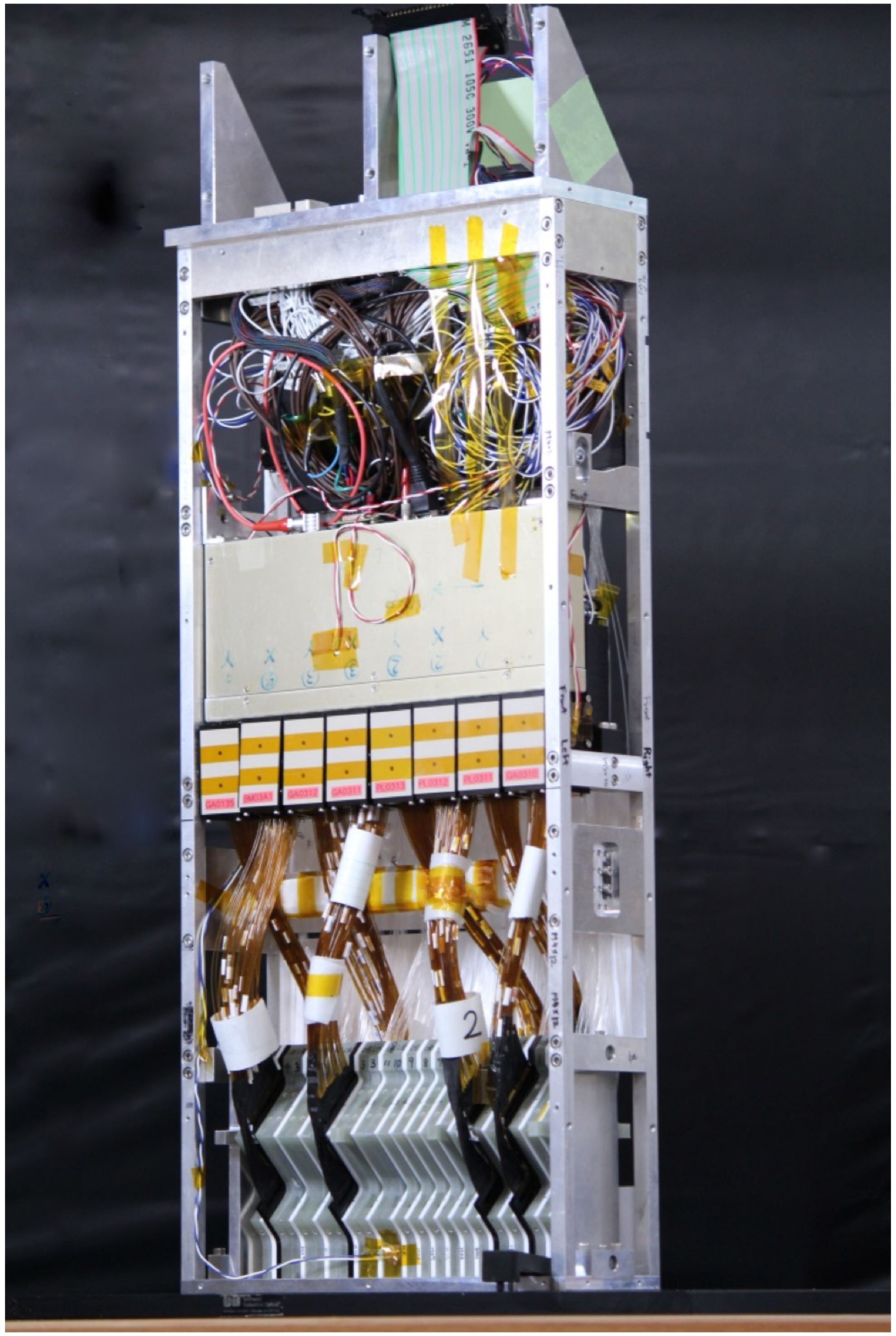



**(b)** Arm2

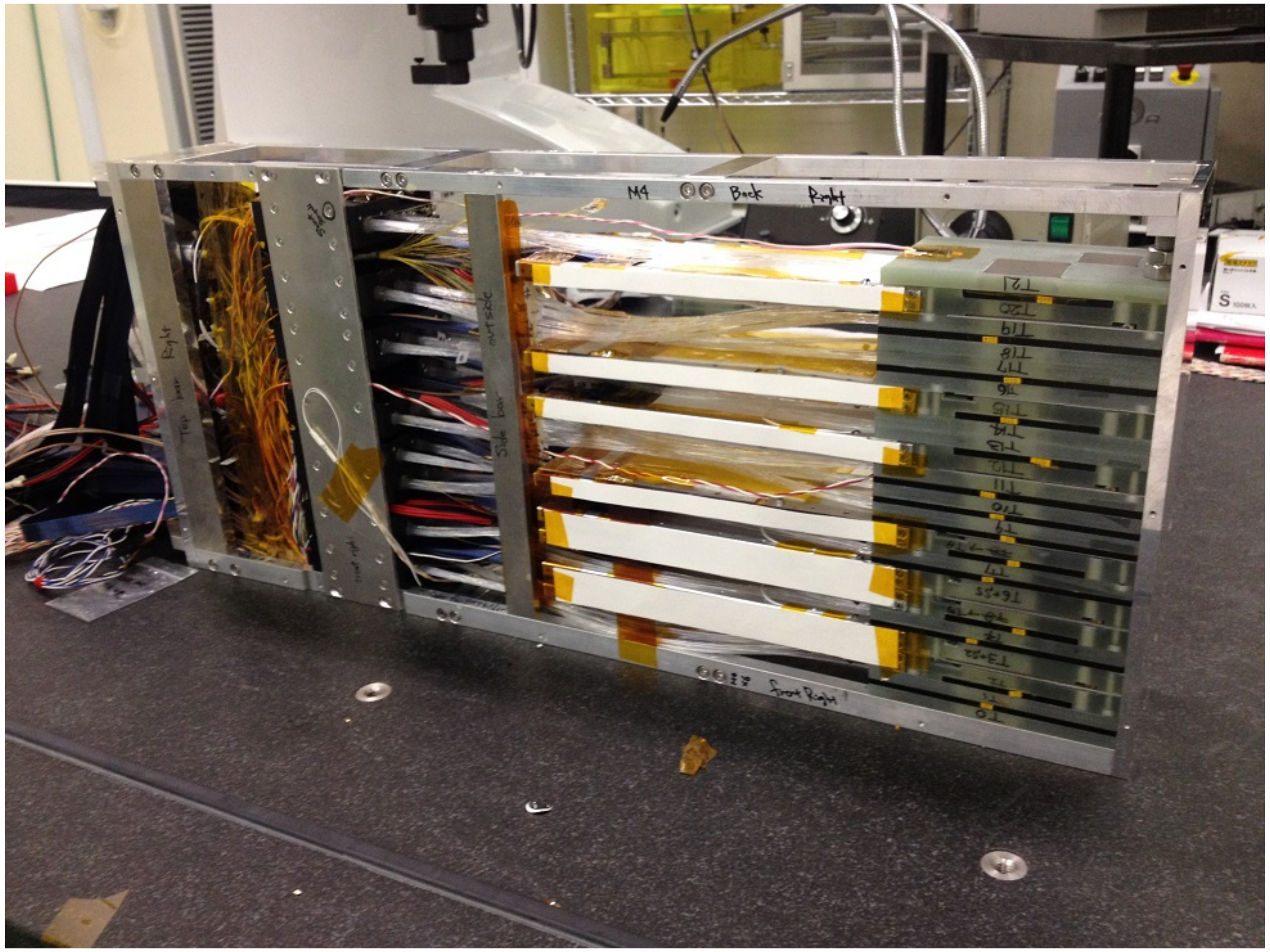
- Sampling layers
  - EJ-260 is replaced with GSO
  - 3mm (EJ-260) -> 1mm (GSO)
- Position sensitive layers
  - Arm1
    - SciFi is replaced with GSO-bar hodoscope
  - Arm2
    - Longitudinal configuration is changed
    - Grounding for not-used strips

# LHCf at 13 TeV

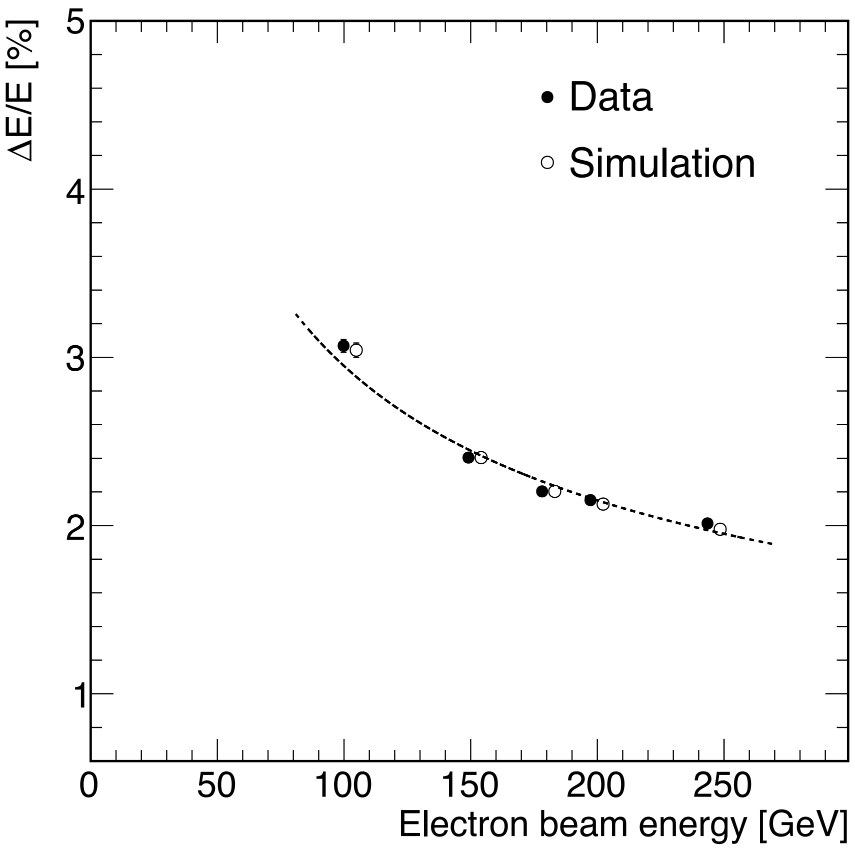
Arm1



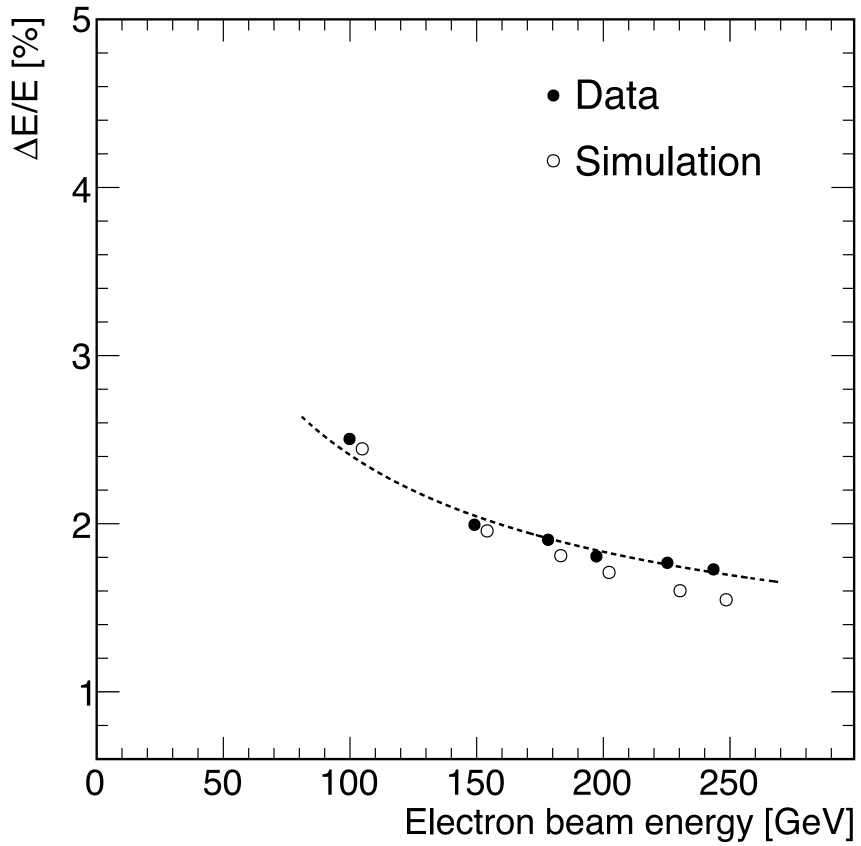
Arm2



# Performance of the upgraded detector




**Arm1 20 mm cal.**




**Arm2 25 mm cal.**

JINST 12 P030023 (2017)

Published by IOP Publishing for Sissa Medialab

Received: *November 17, 2016*
Revised: *January 13, 2017*
Accepted: *February 24, 2017*
Published: *March 21, 2017*

**Performance study for the photon measurements of the upgraded LHCf calorimeters with $Gd_2SiO_5$ (GSO) scintillators**

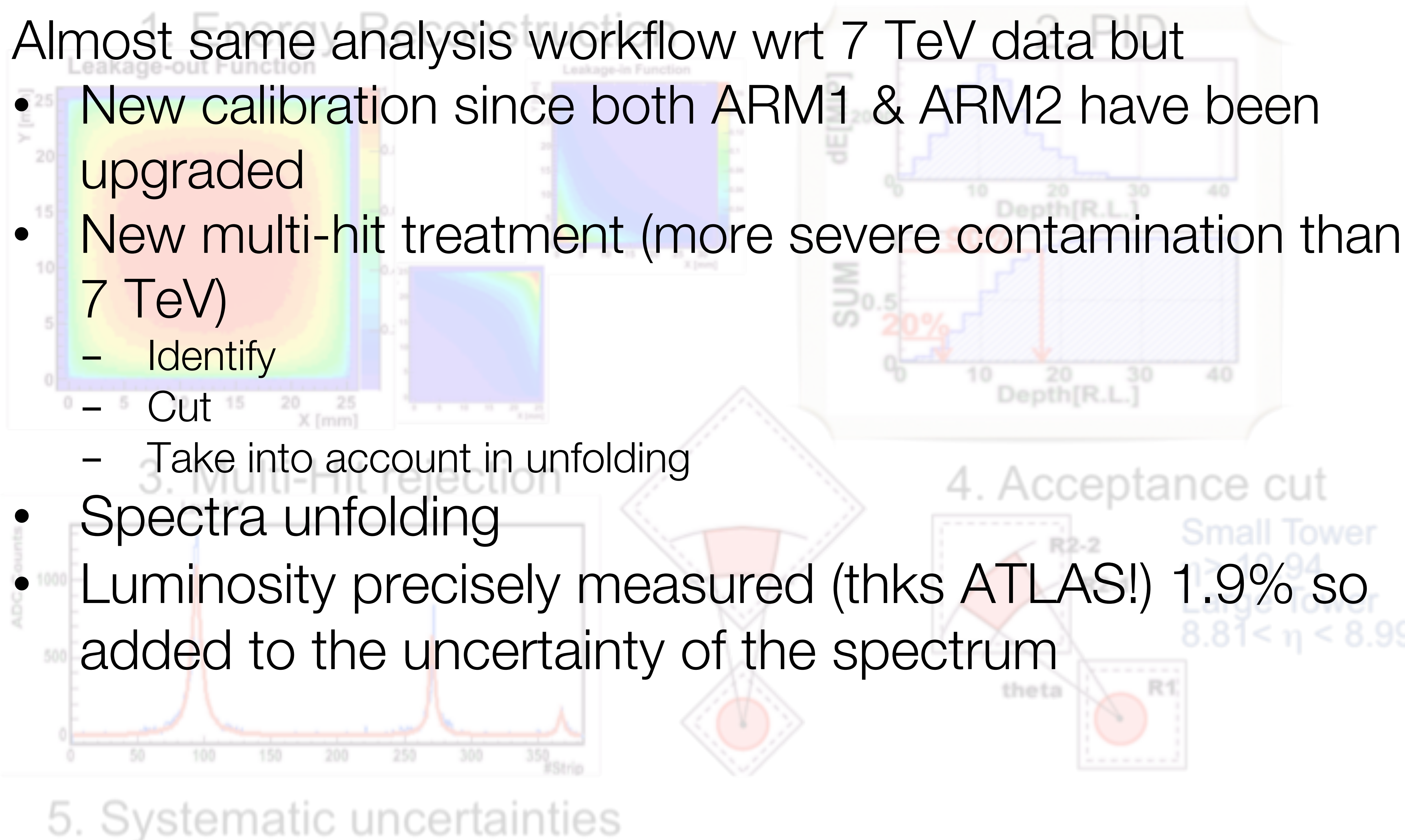
Y. Makino,[a,1] A. Tiberio,[b,c] O. Adriani,[b,c] E. Berti,[b,c] L. Bonechi,[b] M. Bongi,[b,c] Z. Caccia,[d] R. D'Alessandro,[b,c] M. Del Prete,[b,c] S. Detti,[b] M. Haguenauer,[e] Y. Itow,[a,f] T. Iwata,[h] K. Kasahara,[h] K. Masuda,[a] E. Matsubayashi,[a] H. Menjo,[i] G. Mitsuka,[c,2] Y. Muraki,[a] P. Papini,[b] S. Ricciarini,[b,g] T. Sako,[a,f] N. Sakurai,[j] T. Suzuki,[h] T. Tamura,[k] S. Torii,[h] A. Tricomi,[d,l] W.C. Turner,[m] M. Ueno[a] and Q.D. Zhou[a]

[a] *Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan*
[b] *INFN Section of Florence, Florence, Italy*
[c] *University of Florence, Florence, Italy*
[d] *INFN Section of Catania, Catania, Italy*
[e] *Ecole-Polytechnique, Palaiseau, France*
[f] *Kobayashi-Maskawa Institute for the Origin of Particles and the Universe, Nagoya University, Nagoya, Japan*

# LHCf @ pp 13 TeV: γ energy spectra analysis workflow

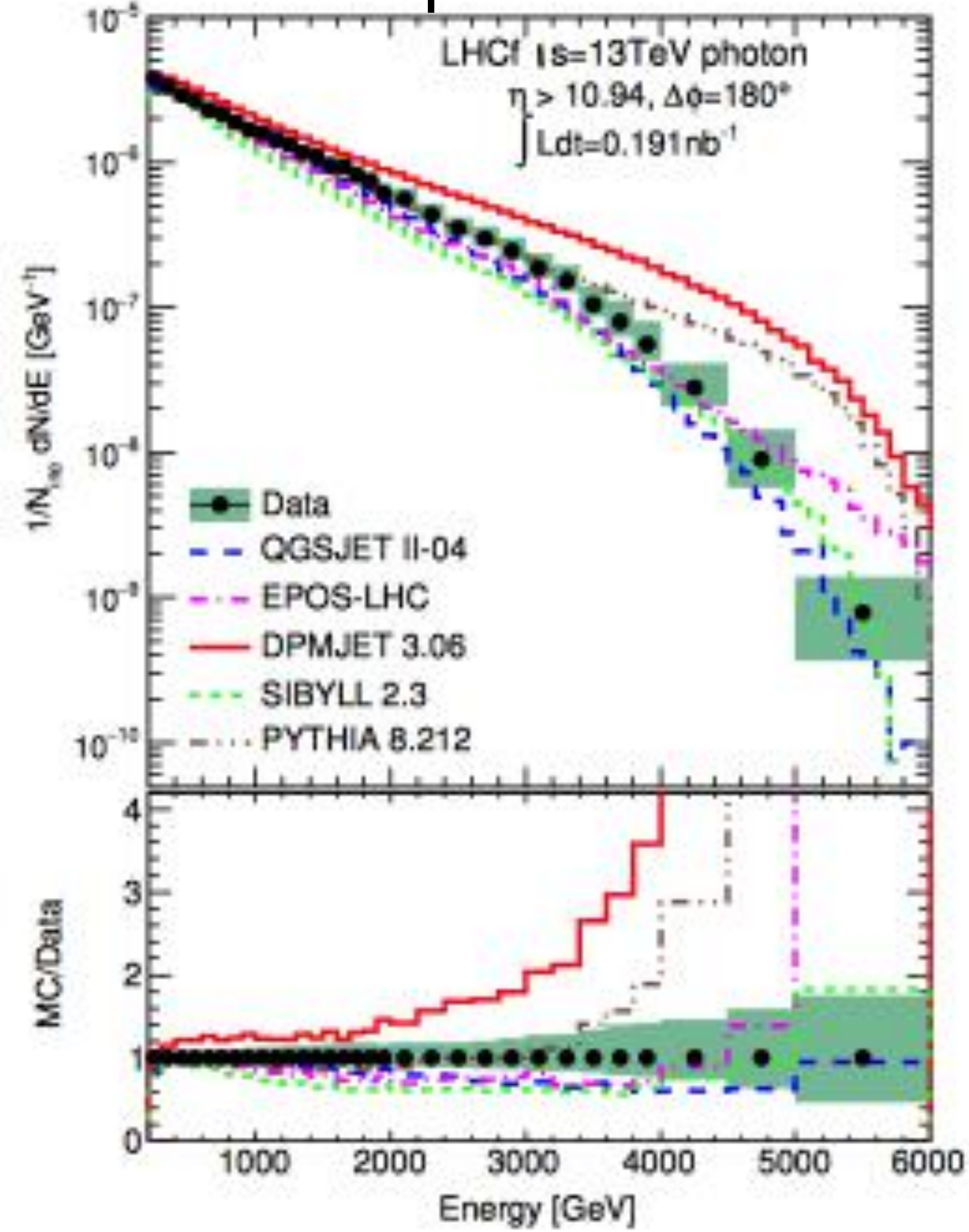
Almost same analysis workflow wrt 7 TeV data but

- New calibration since both ARM1 & ARM2 have been upgraded
- New multi-hit treatment (more severe contamination than at 7 TeV)
  - Identify
  - Cut
  - Take into account in unfolding
- Spectra unfolding
- Luminosity precisely measured (thks ATLAS!) 1.9% so added to the uncertainty of the spectrum



# γ energy spectra in p-p collisions @ 13 TeV

η>10.94




QGSJET II-04: overall good agreement

EPOS-LHC: overall good agreement

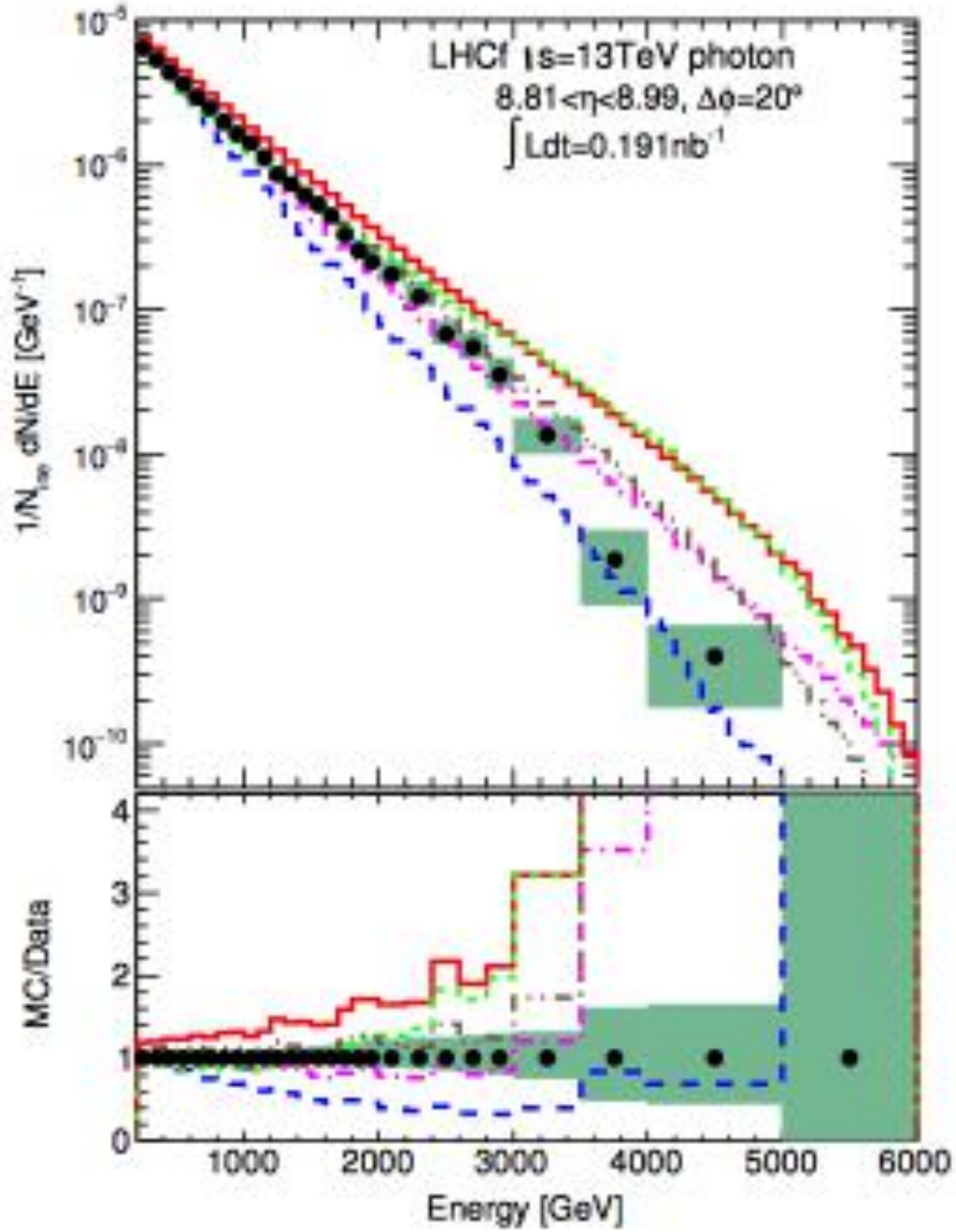
DPMJET 3.06: overall higher flux

SIBYLL 2.3: overall lower flux

PYTHIA 8.212: higher flux above 3 TeV

# γ energy spectra in p-p collisions @ 13 TeV

8.81<η<8.99




QGSJET II-04: overall lower flux

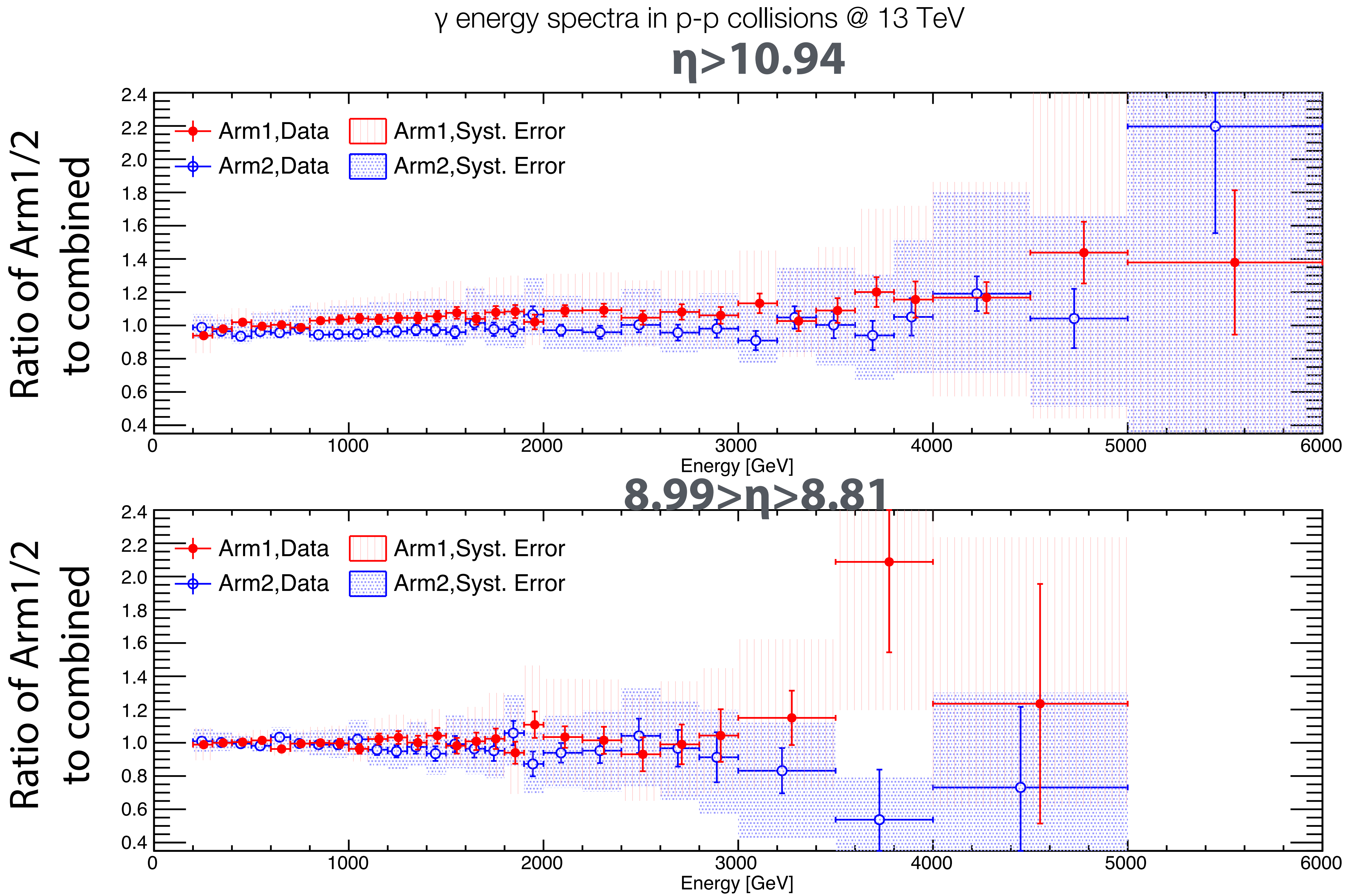
EPOS-LHC: higher flux above 3-4 TeV

DPMJET 3.06: overall higher flux

SIBYLL 2.3: higher flux above 2 TeV

PYTHIA 8.212: higher flux above 3 TeV

# Ratio of ARM1-ARM2 wrt combined spectrum



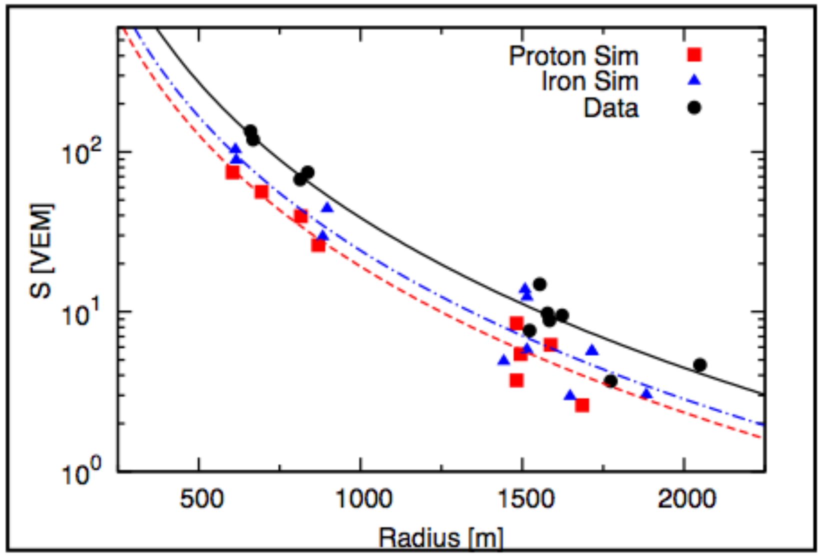

Arm1 and Arm2 are consistent within the uncertainties

# LHCf neutron analysis: motivations

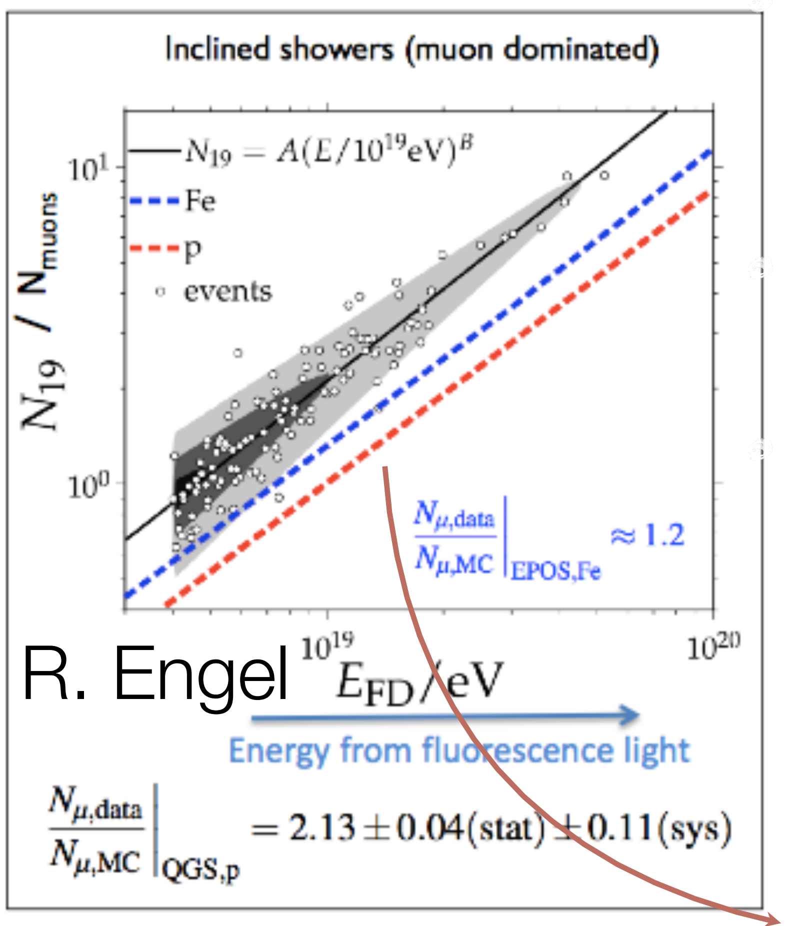
Inelasticity measurement $k=1-p_{leading}/p_{beam}$

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



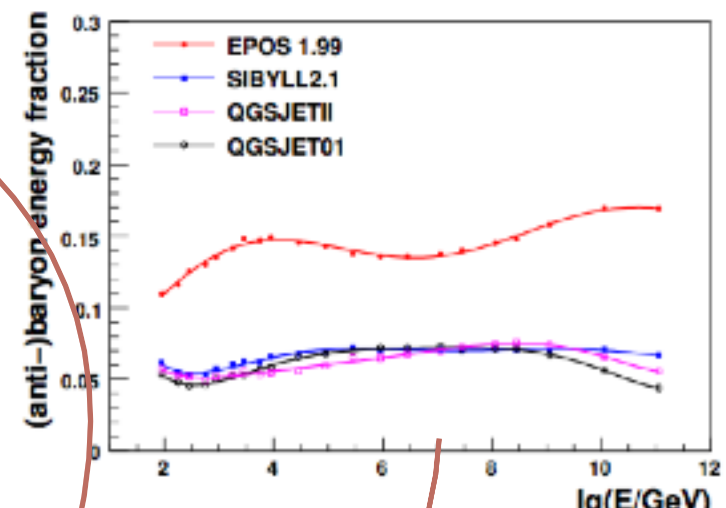

[ J.Allen, et al. ICRC2011 Proceedings]



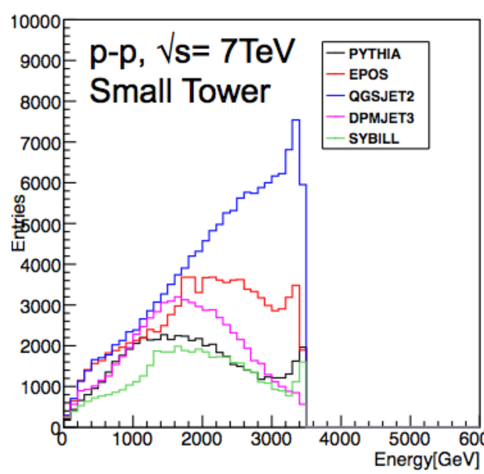

Number of muons depends on the energy fraction of produced hadron

Muon excess in data even for Fe primary MC

EPOS predicts more muon due to larger baryon production




Neutron spectra predicted by interaction models




importance of baryon measurement

# Analysis of hadron production in p-p collisions at 13 TeV

Data set

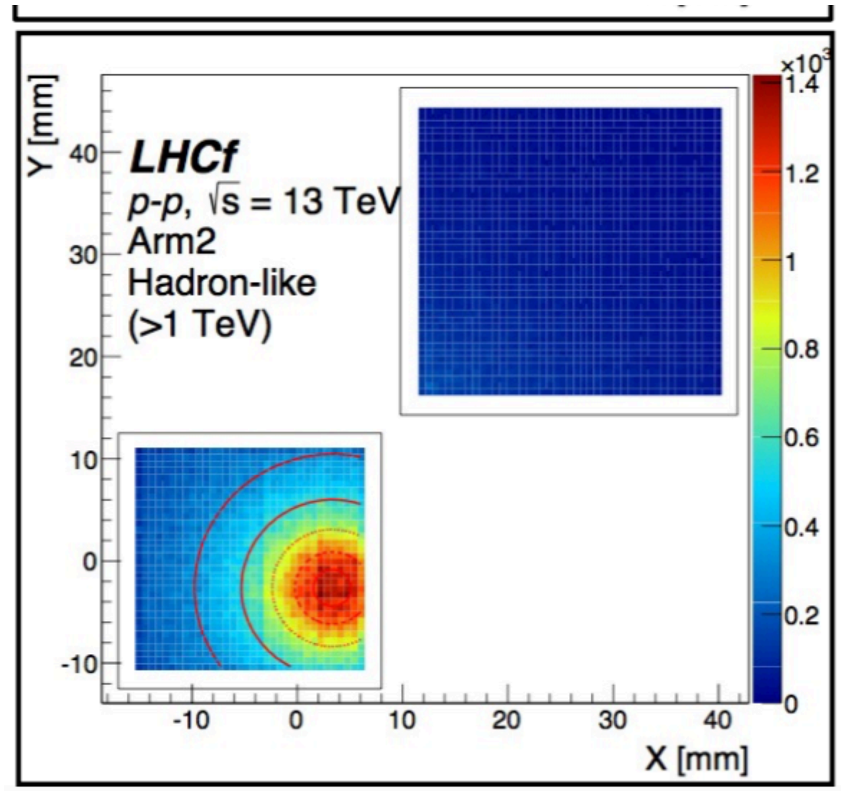
12 July 2015, 22:32-1:30 (3 hours)

Fill # 3855

$\mu = 0.01$

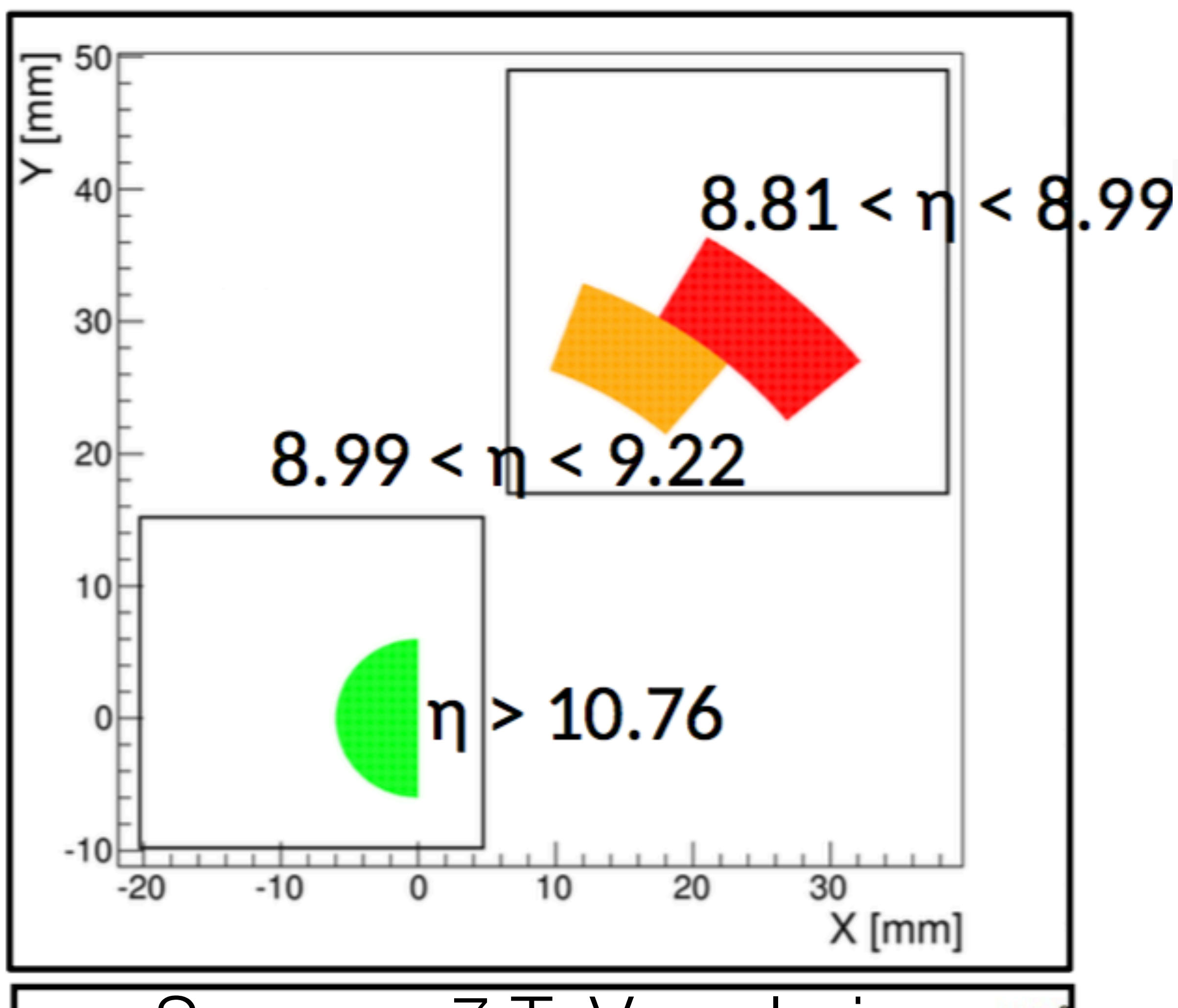
$\int L dt = 0.19\ nb^{-1}$

$\sigma_{ine} = 78.53\ mb$




Beam Center

Estimated using 2D fit on high energy ha dron hitmap distribu tion




Same as 7 TeV analysis
PLB 750 (2015) 360-366

Event selection criteria:

software trigger

at least 3 consecutive layers with deposit above threshold $dE>dE^{thr}$

PID selection

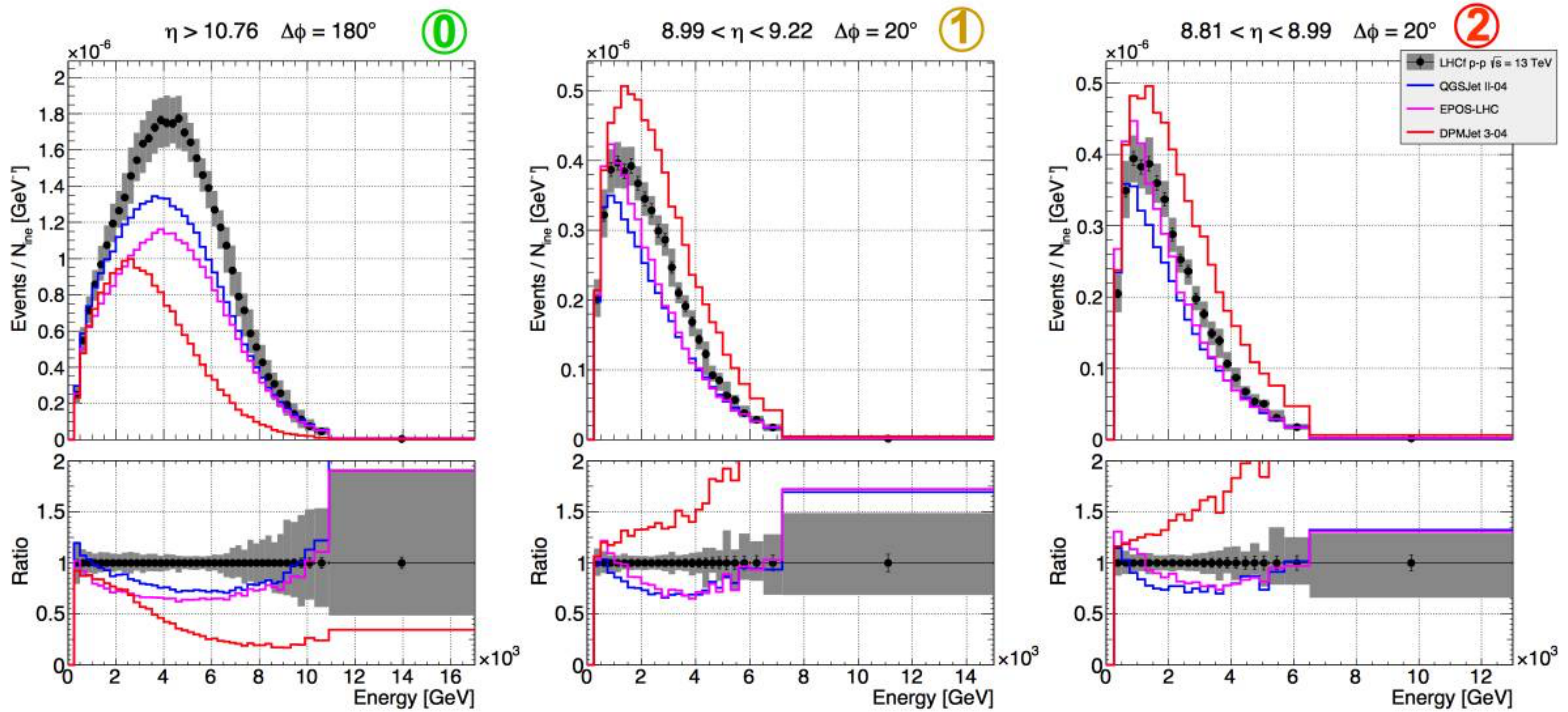
$L_{2D}>L_{2D}^{thr}$ where $L_{2D}$ is a variable related to shower longitudinal profile

pseudorapidity acceptance

3 different pseudorapidity regions

# Reconstructed ARM2 hadron energy spectra

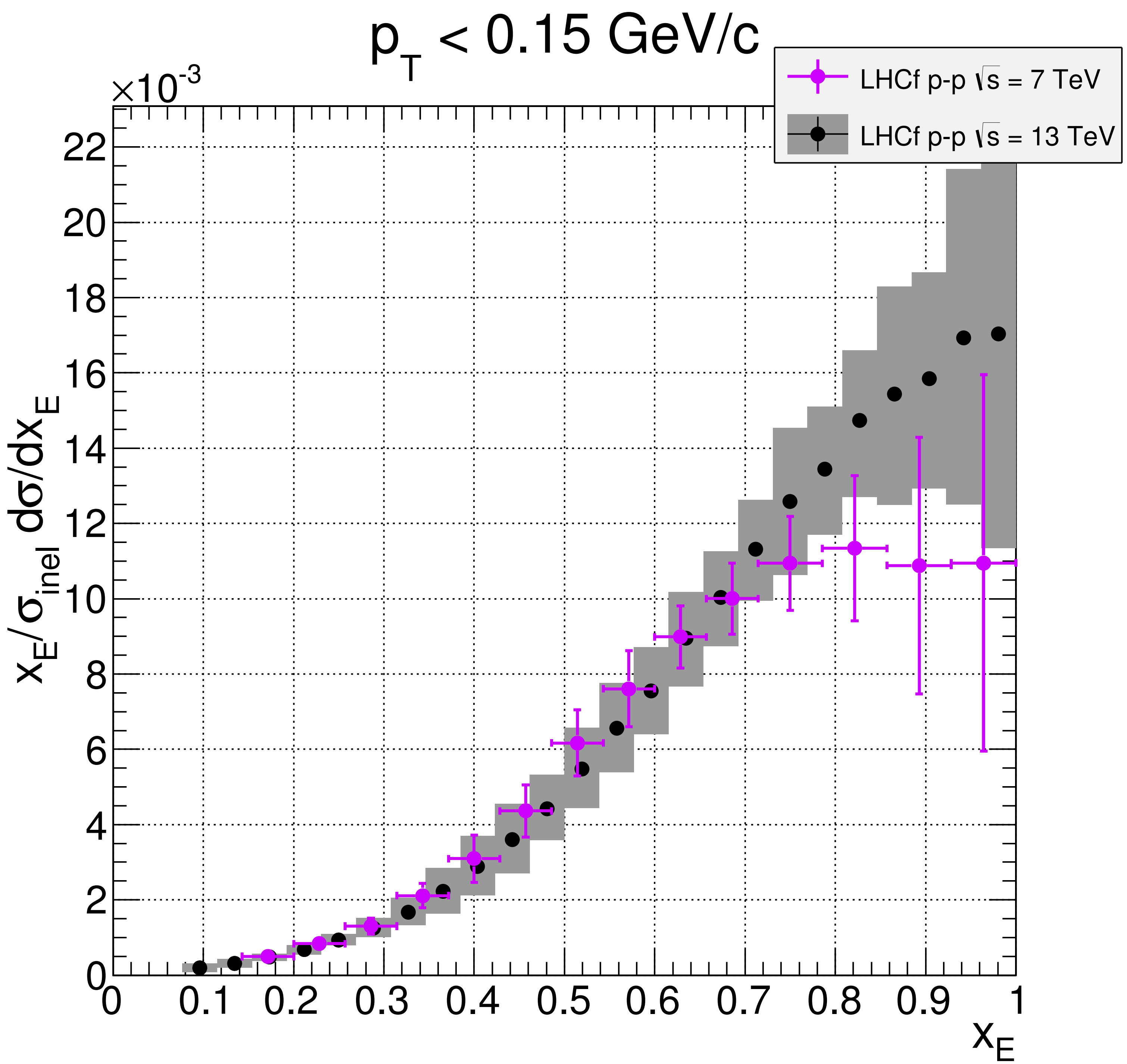
**Events / $N_{ine}$ / dE**




**QGSJET II-04** and **EPOS-LHC** have similar shape but lower yield

**DPMJET 3.04** have very different shape and yield

# Feynman scaling in neutron production cross-section

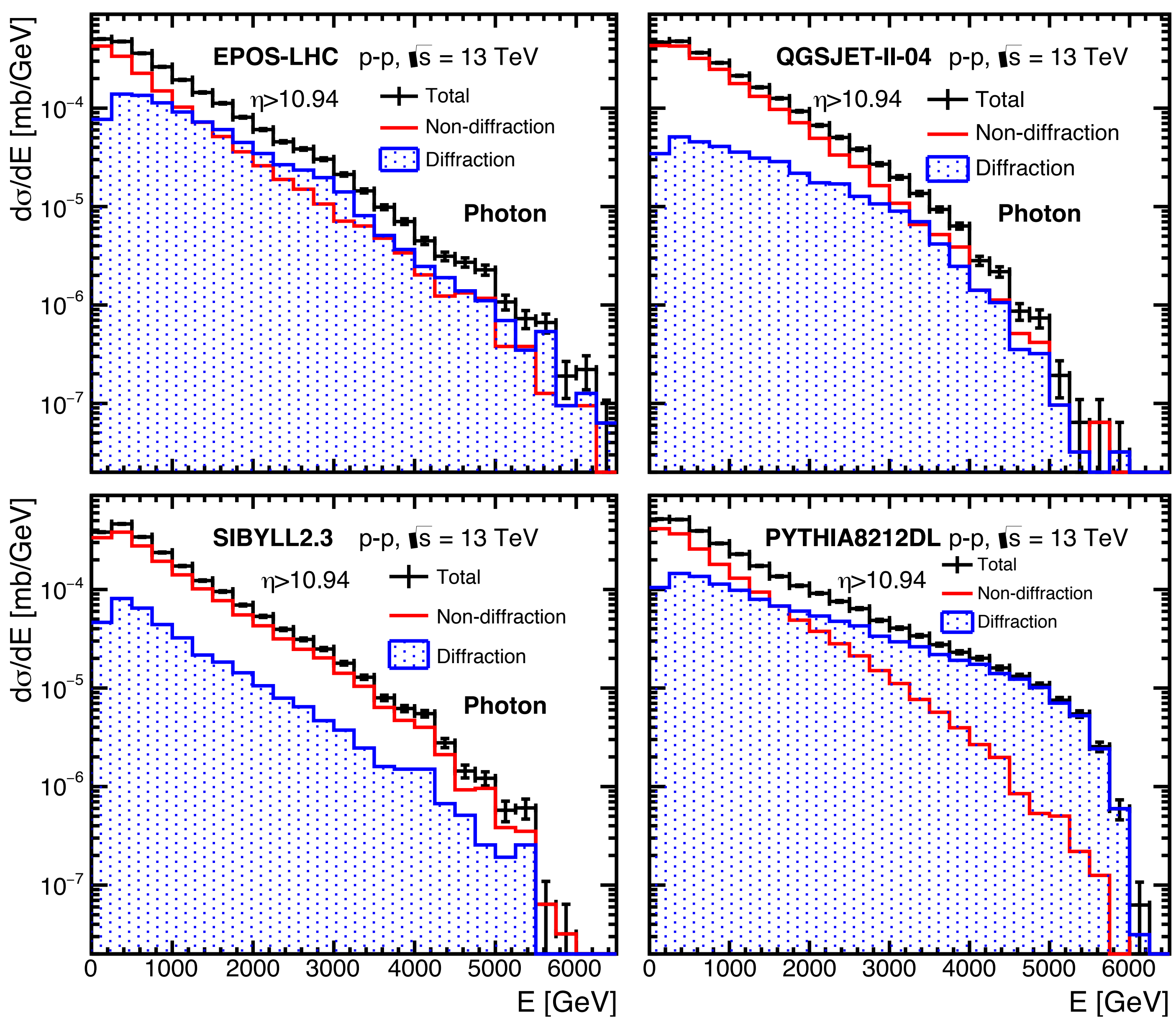



Feynman scaling hypothesis holds within the error bars

Consistency is good especially in the region $0.2 < x_F < 0.75$

# Diffractive studies

- MC studies
  - Contributions on forward photon/ neutron spectra from diffractive/non-diffractive collisions.
  - Event-selection by the central particle production to separate these events




Very forward photon energy spectra predicted by four models with **total/** diffractive/non-diffractive

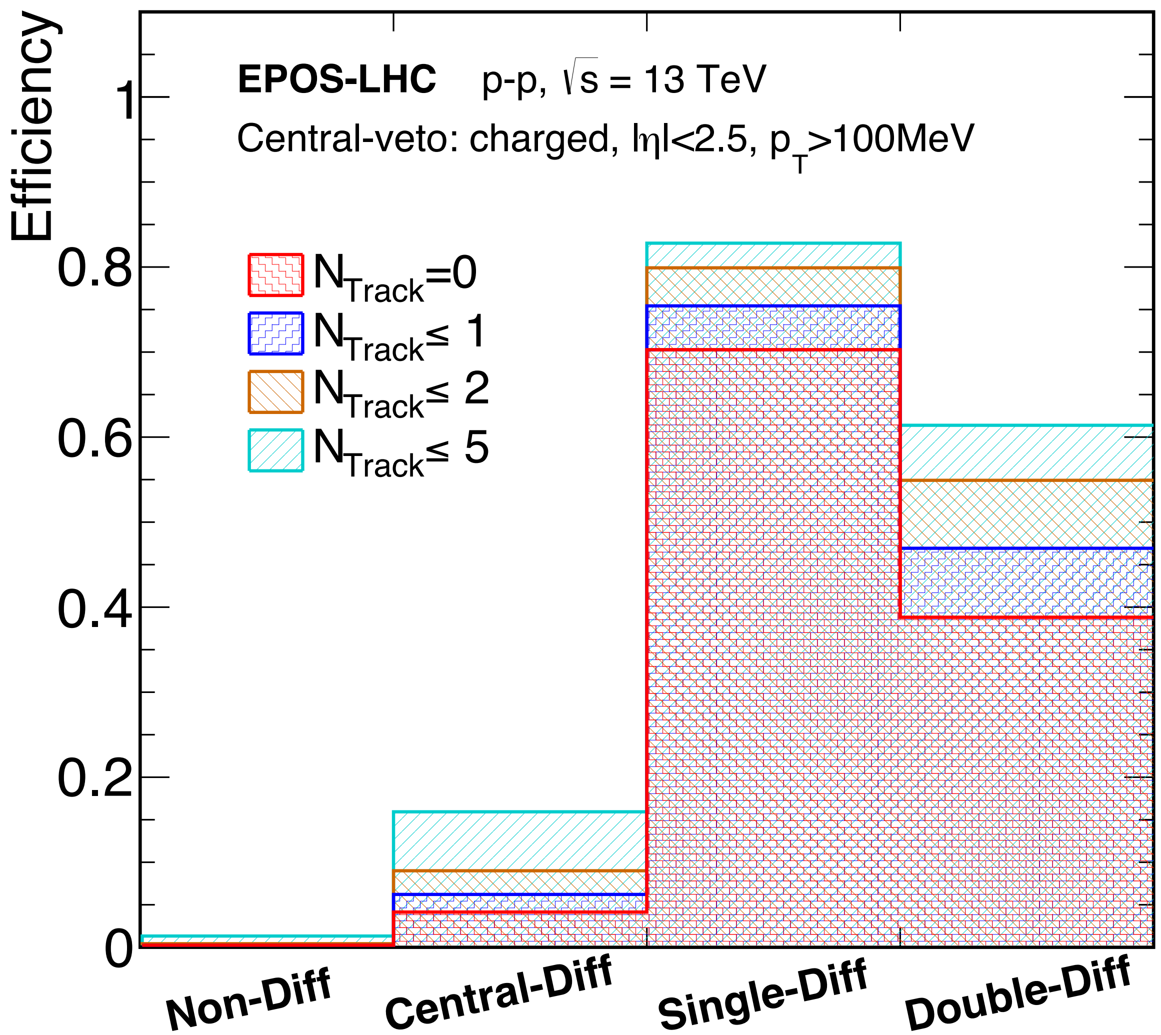
- Total: Very similar spectra in EPOS,QGSJET and SIBYLL (LHCf alone)
- Diffractive/Non-diffractive: Very big difference between models (ATLAS-LHCf)

# Diffractive studies

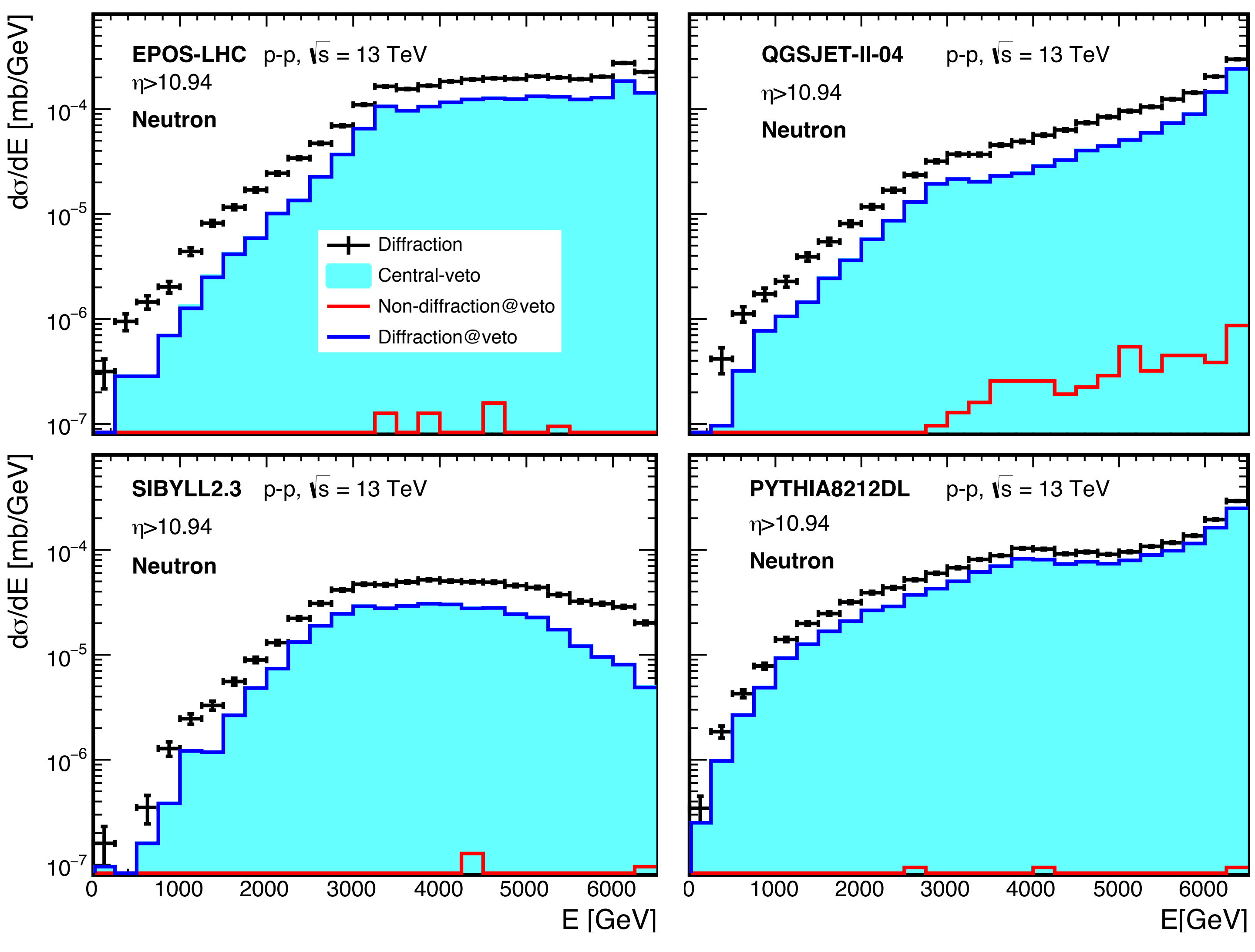
- Event selection for Diffractive/ Non-diffractive by using $N_{charged}$ with $p_T$>100MeV in |η|<2.5

By using ATLAS-tracker information, We can separate diffractive/non-diffractive events with high efficiency and purity

## Expected efficiencies

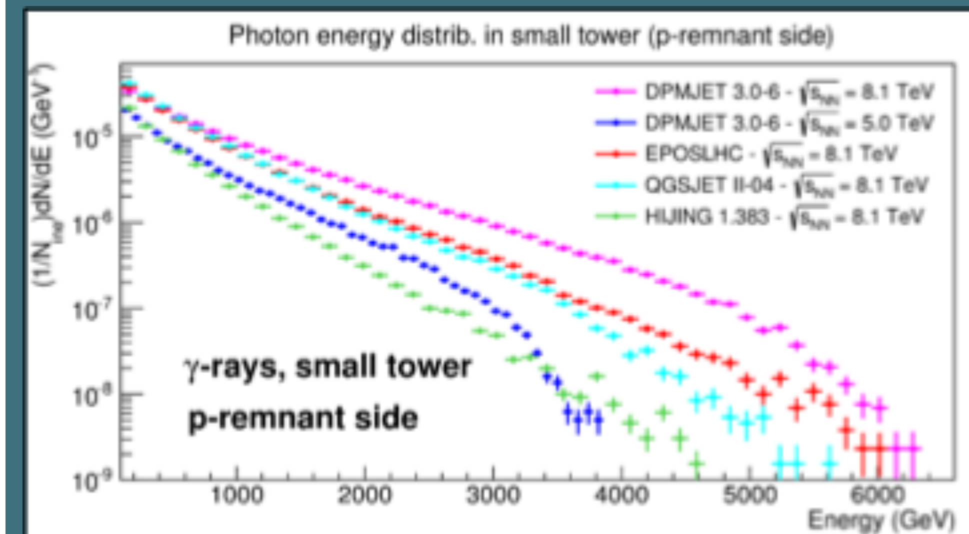


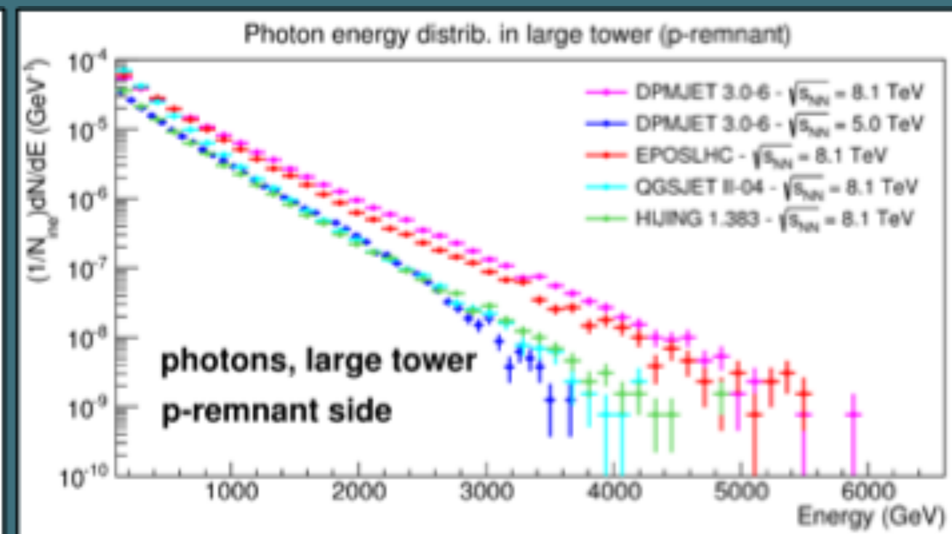

## Forward neutron spectra



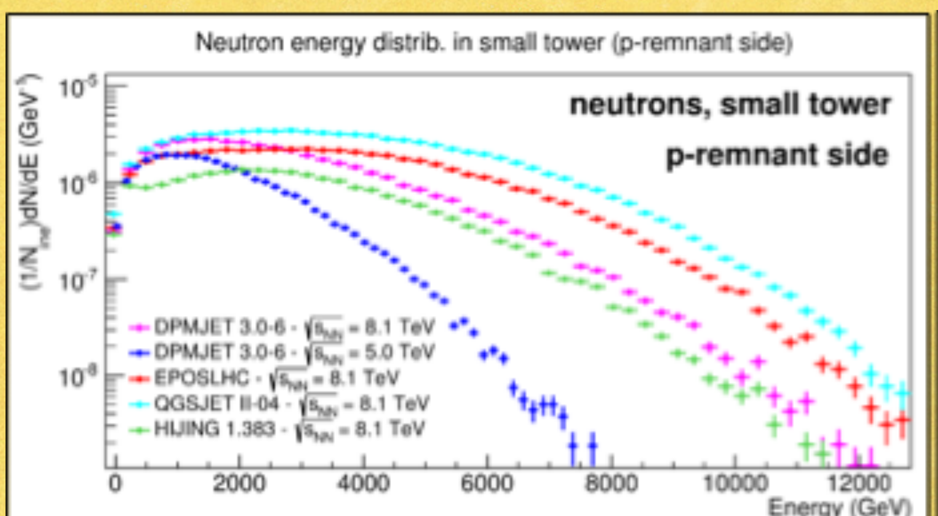
# p-Pb at 8.1 TeV: γ & n spectra

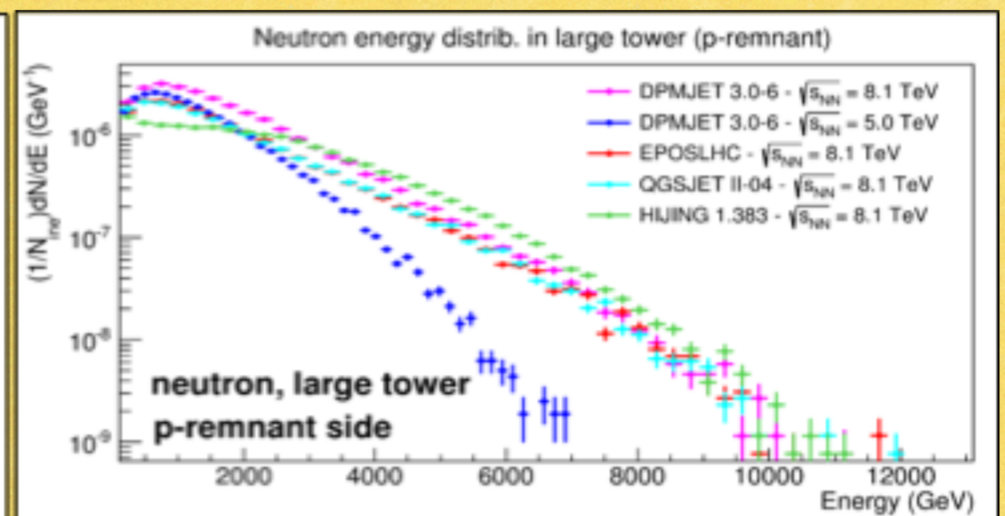
## Expected photon distribution




## Expected neutron distribution (35% energy resolution)




(CRMC)* framework has been used to simulate $10^7$ collisions with 4 different hadronic interaction models:

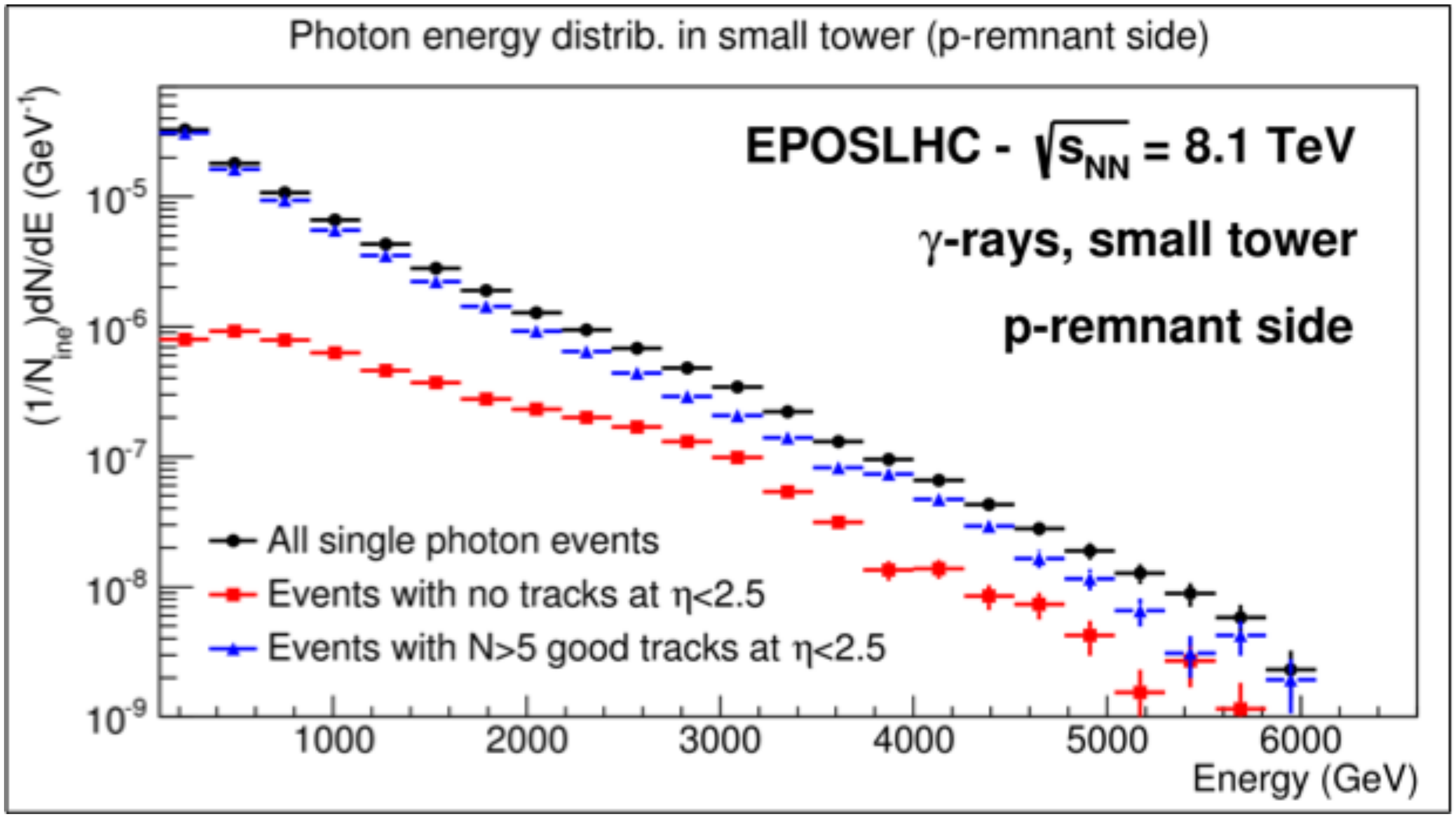
- DPMJET 3.0-6 p+Pb
- EPOS-LHC p+Pb
- QGSJET II-04
- HIJING 1.383

Small calorimeter tower centered on the beam spot

Only p-remnant side considered

* We acknowledge T. Pierog, C. Baus and R. Ulrich for support

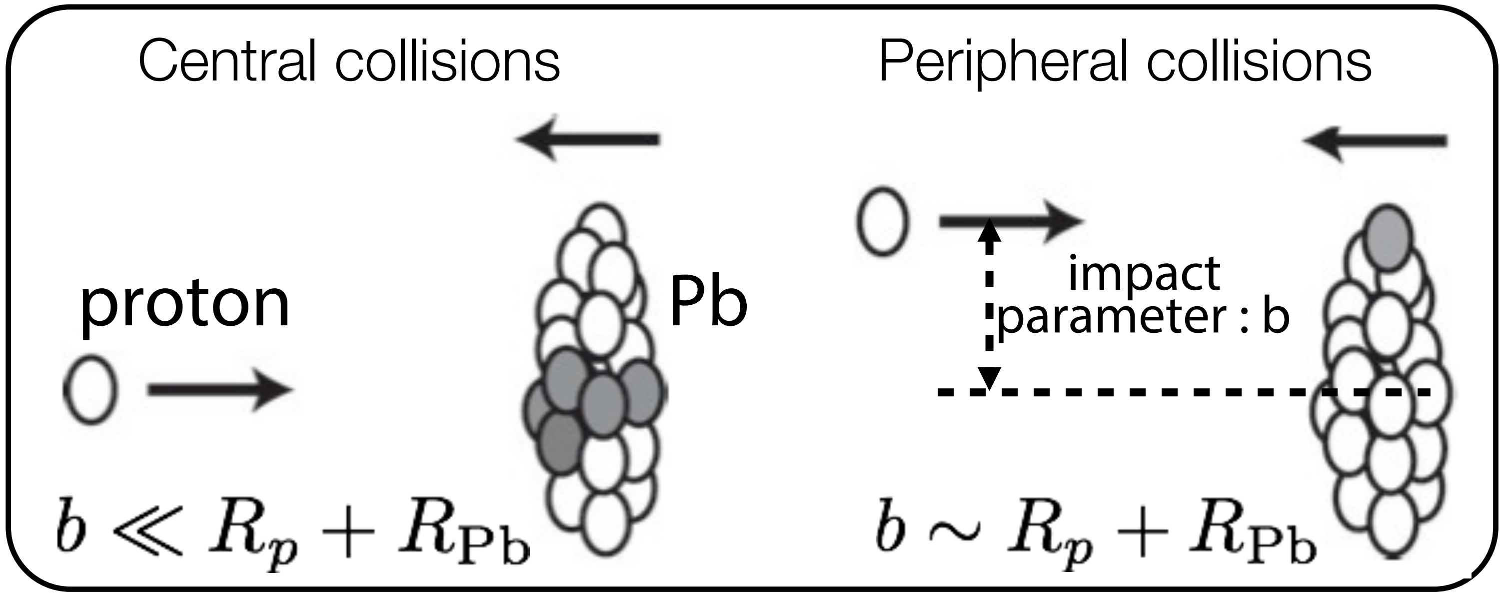
# p-Pb at 8.1 TeV: perspective for ATLAS-LHCf combined analysis



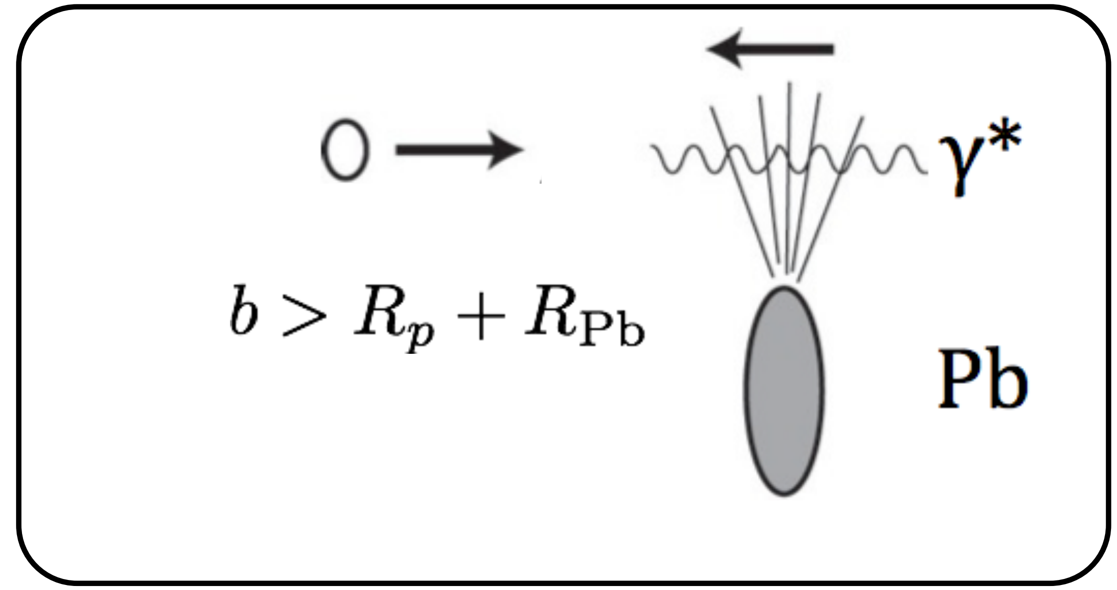

Information from the ATLAS central region is essential to separate the contributions due to diffractive and non-diffractive collisions.

# LHCf @ pPb 5.02 TeV: $\pi^0$ analysis

## (Soft) QCD :
central and peripheral collisions




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




Momentum distribution of the UPC induced secondary particles is estimated as

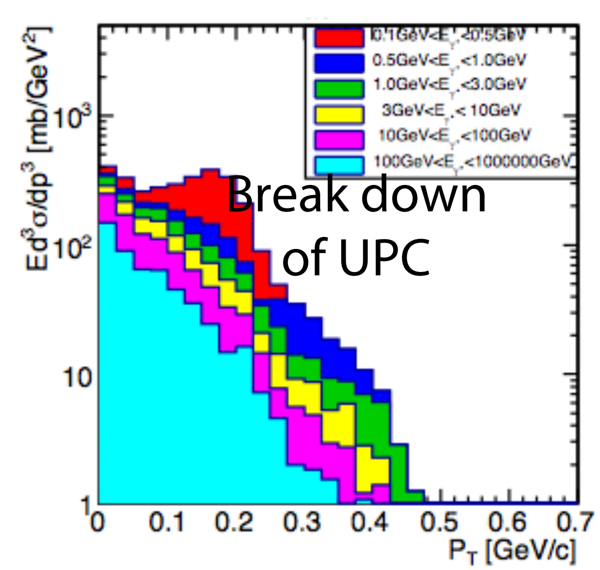
1. energy distribution of virtual photons is estimated by the Weizsacker Williams approximation.
2. photon-proton collisions are simulated by the SOHIA model ($E_\gamma$ > pion threshold).
3. produced mesons and baryons by γ-p collisions are boosted along the proton beam.

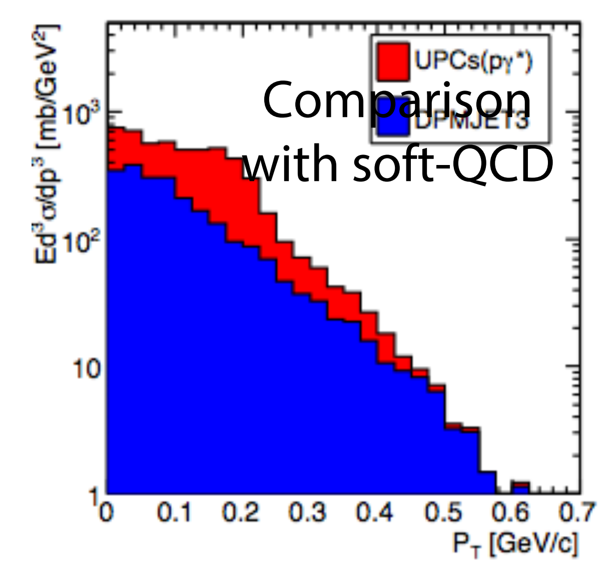
proton rest frame

Dominant channel to forward $\pi^0$ is

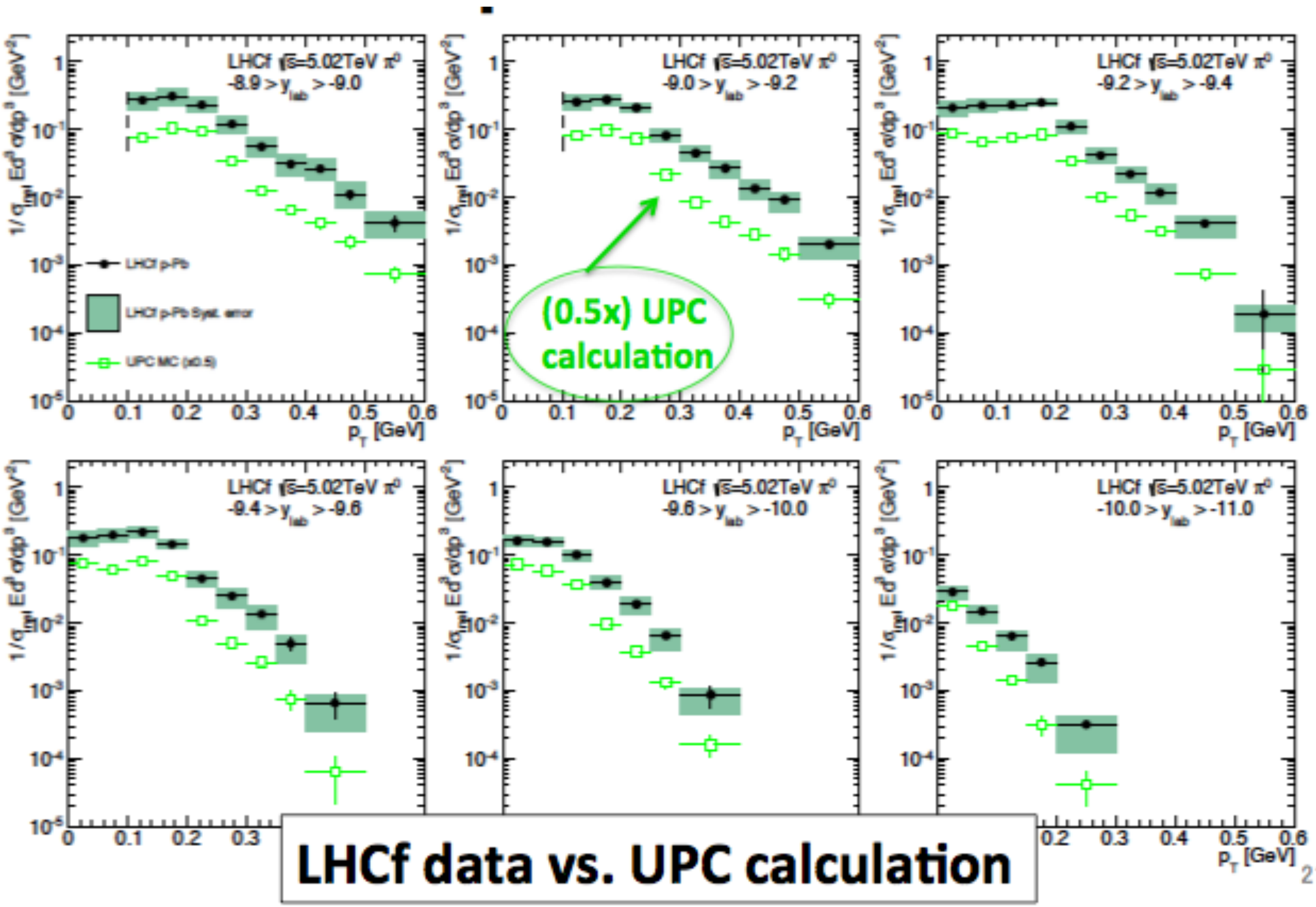
$$\gamma + p \rightarrow \Delta(1232) \rightarrow p + \pi^0$$

About half of the observed $\pi^0$ may originate in UPC, another half is from soft-QCD.

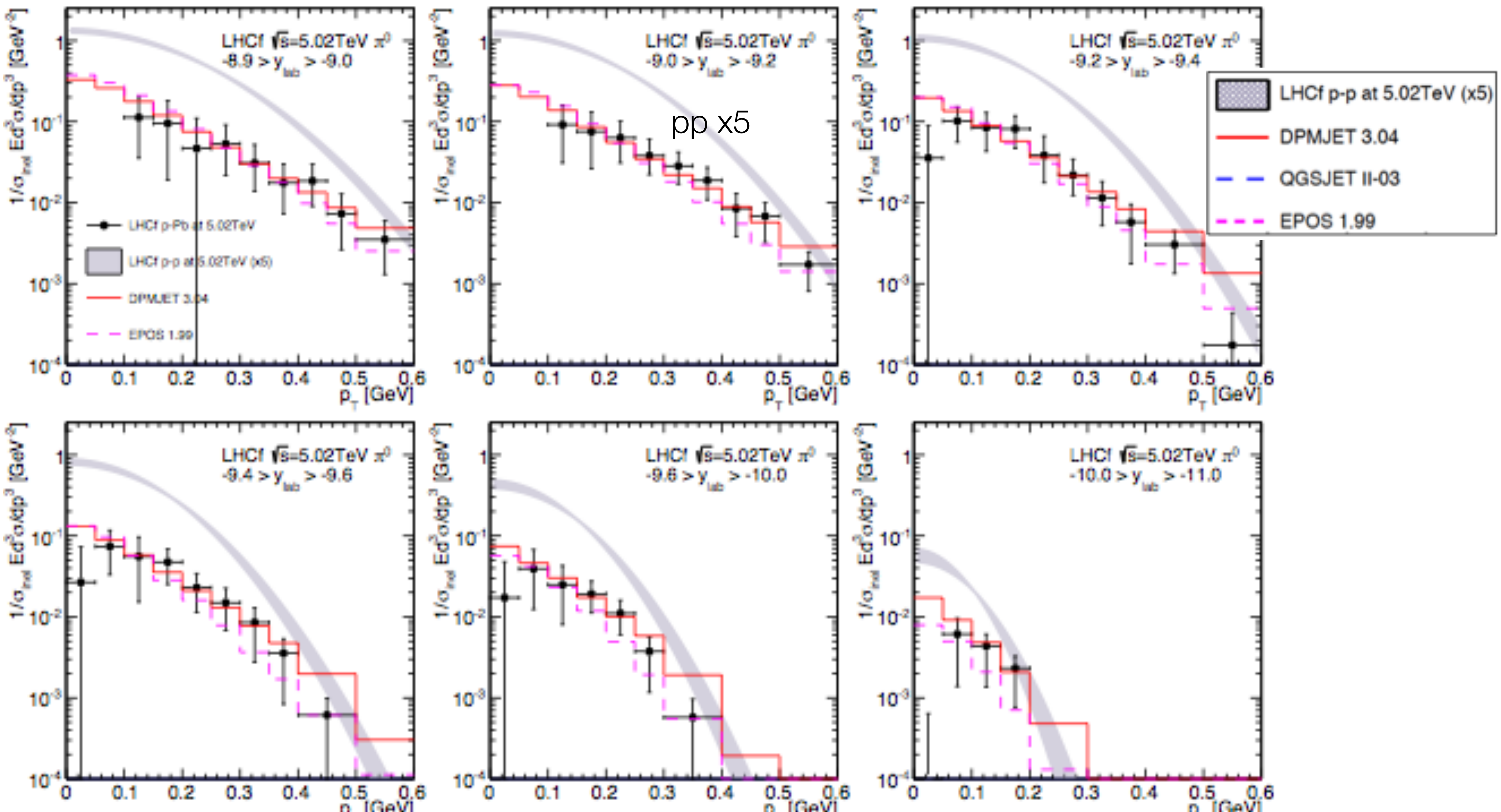


# LHCf @ pPb 5.02 TeV: $\pi^0$ spectra @ p-remnant side



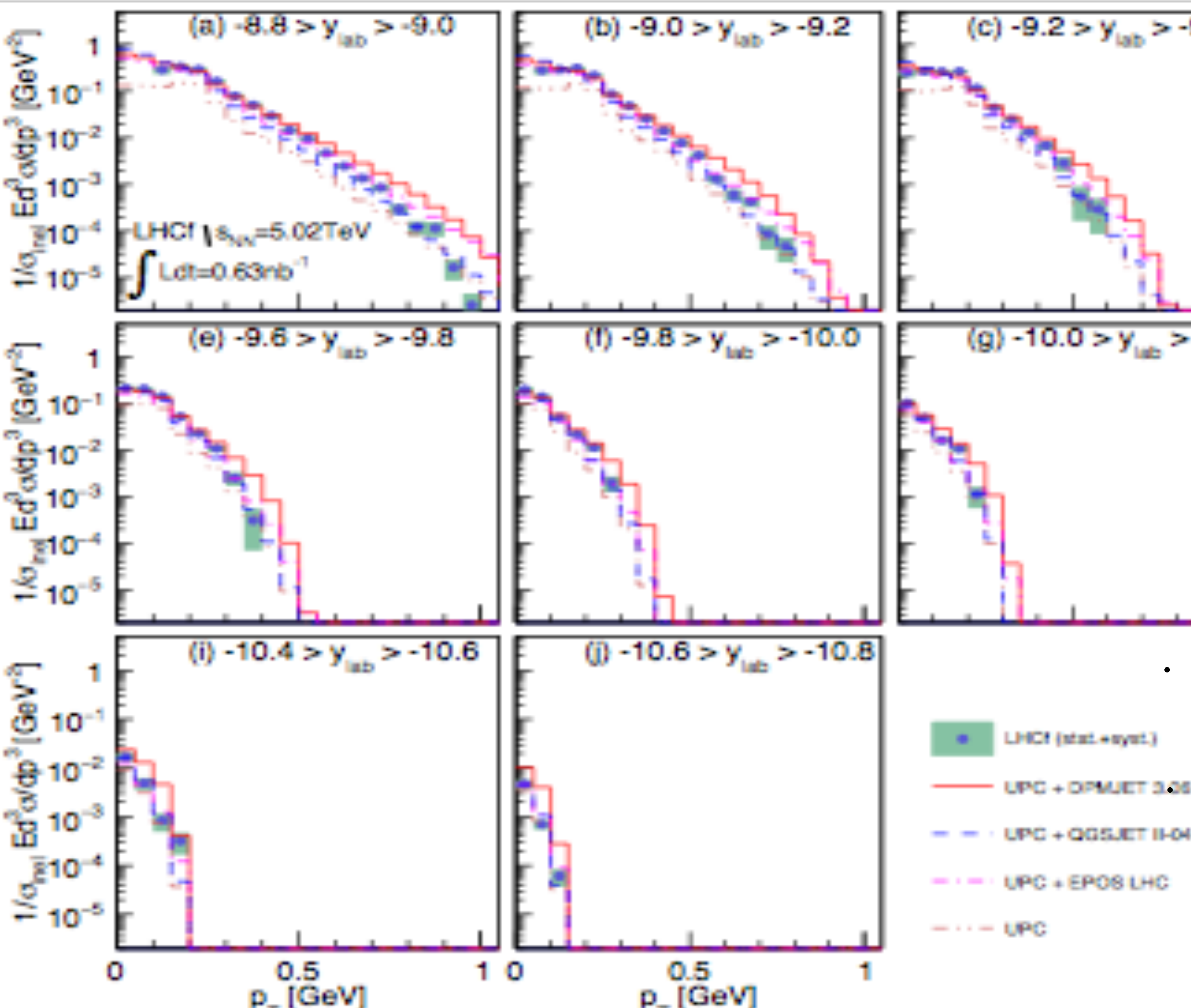
LHCf @ pPb 5.02 TeV:
$\pi^0$ spectra @ p-remnant side




LHCf Data (UPC subtracted) vs Models

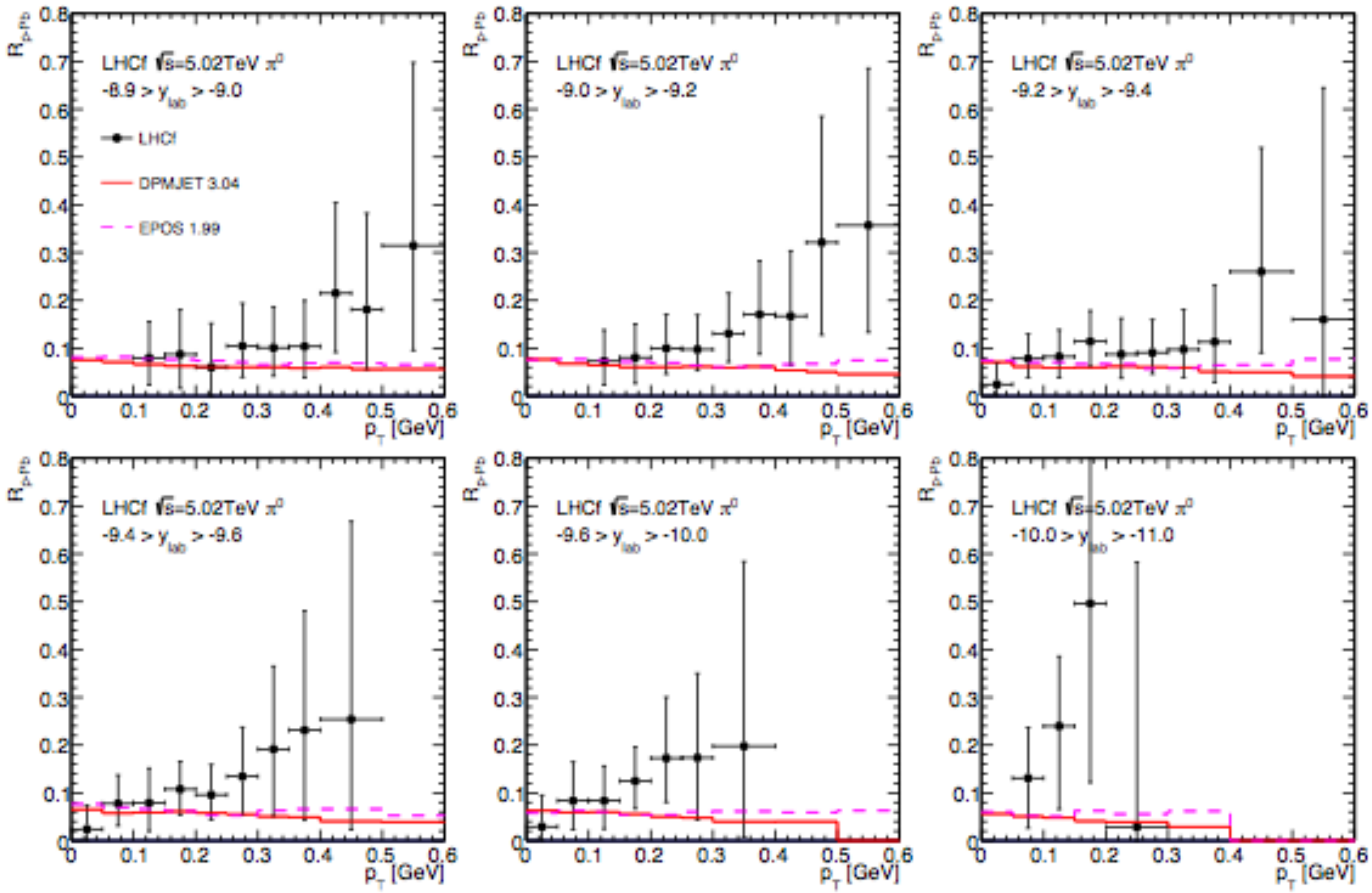
- The LHCf results in p-Pb (filled circles) show good agreement with DPMJET and EPOS.
- The LHCf results in p-Pb are clearly harder than the LHCf results in p-p at 5.02TeV (shaded area) which are interpolated from the results at 2.76TeV and 7TeV.

# LHCf @ pPb 5.02 TeV: $\pi^0$ $p_T$ spectra




- QGSJETII-04 and EPOS-LHC: similar, good agreement for pT>0.4 GeV
- DPMJET: good agreement for $-8.8 > ylab > -10.0$ and $p_T < 0.3$ GeV
- Characteristic bump at $y > -9.6$ and $p_T \sim 0.2$GeV: Ultra Peripheral Collisions

# LHCf @ pPb 5.02 TeV:
# Nuclear modification factor

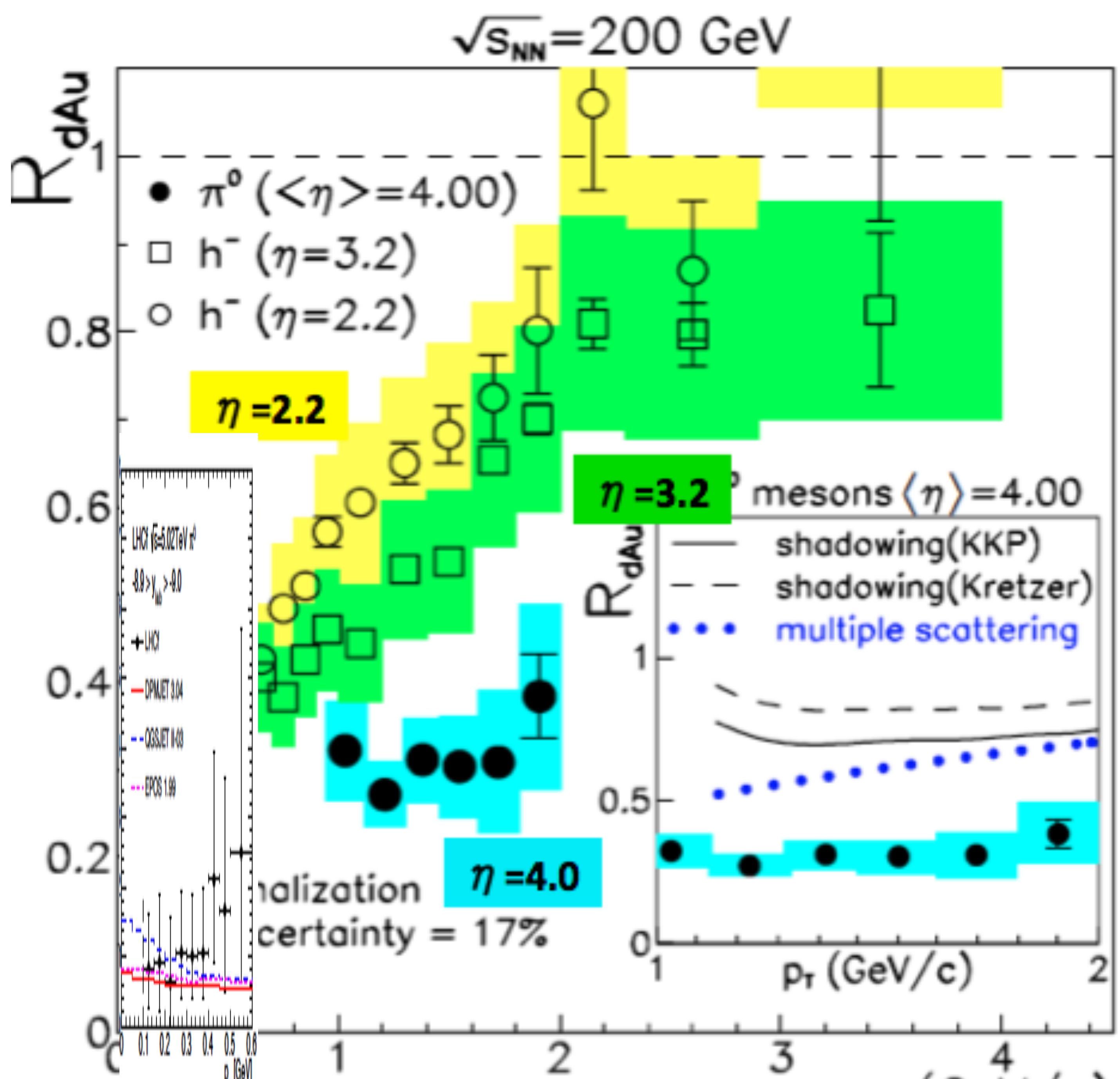



$$R_{\mathrm{pPb}}(p_{\mathrm{T}}) \equiv \frac{d^2N^{\mathrm{pPb}}_{\pi^0}/dydp_{\mathrm{T}}}{\langle N_{\mathrm{coll}}\rangle d^2N^{\mathrm{pp}}_{\pi^0}/dydp_{\mathrm{T}}}$$

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

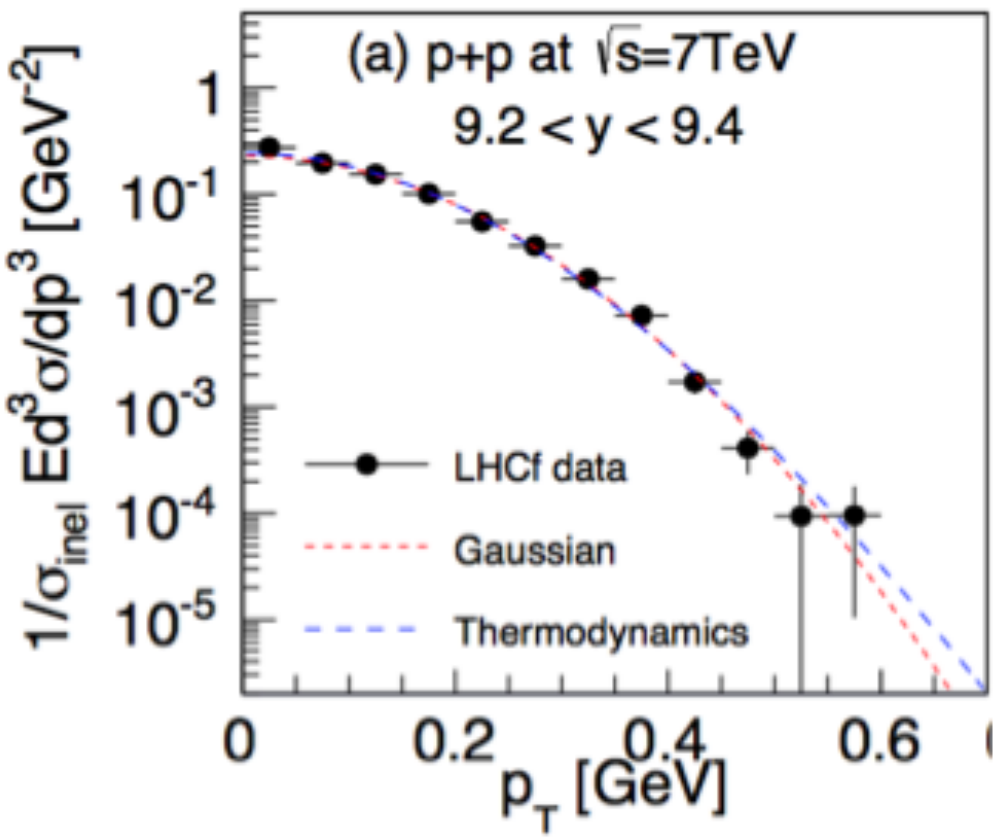
Both LHCf and MCs show strong suppression
But LHCf grows as increasing $p_T$, understood by the softer $p_T$ spectra in p-p at 5TeV than those in p-Pb.

# LHCf @ pPb 5.02 TeV vs RHIC:
# Nuclear modification factor

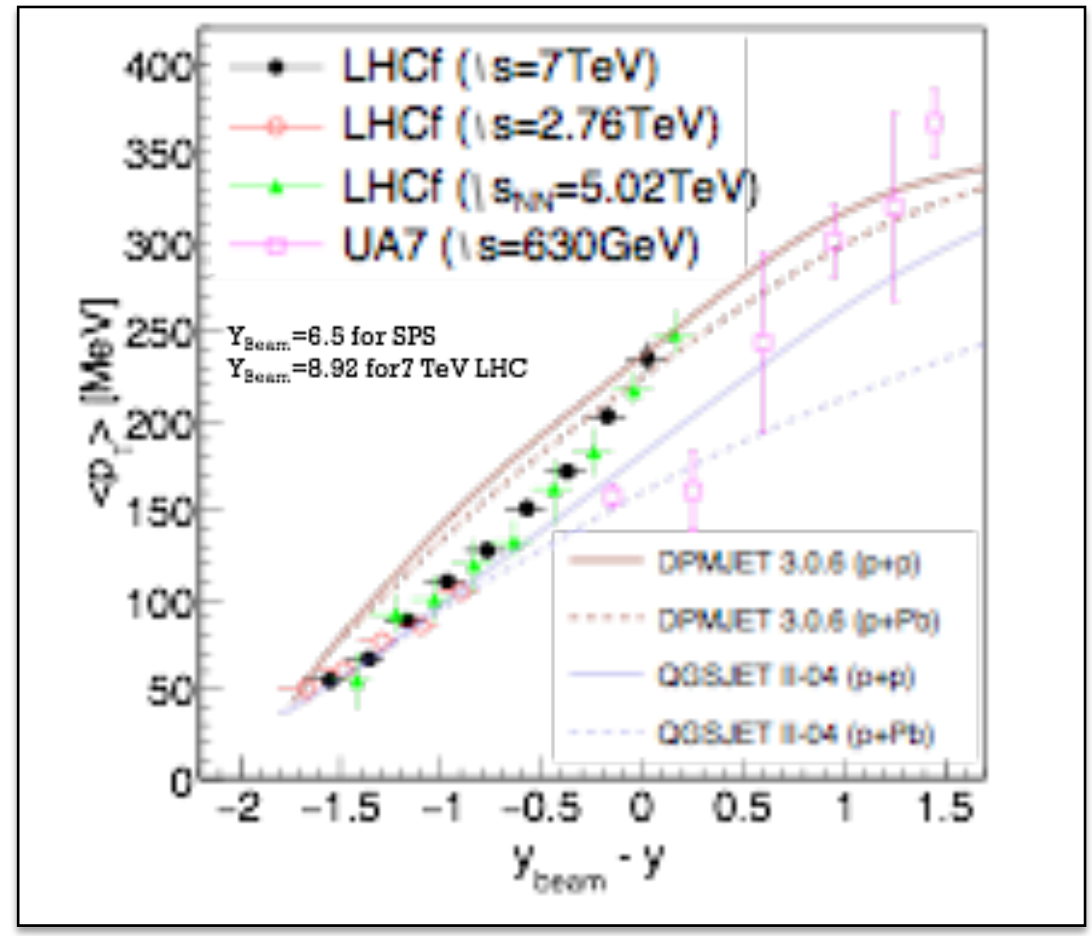


# $\pi^0$ average $p_T$ for different cm energies

## $p_T$ spectra vs best-fit function




## Average $p_T$ vs $y_{lab}$




$<p_T>$ is inferred in 3 ways:

1. Thermodynamical approach
2. Gaussian distribution fit
3. Numerical integration up to the histogram upper bound

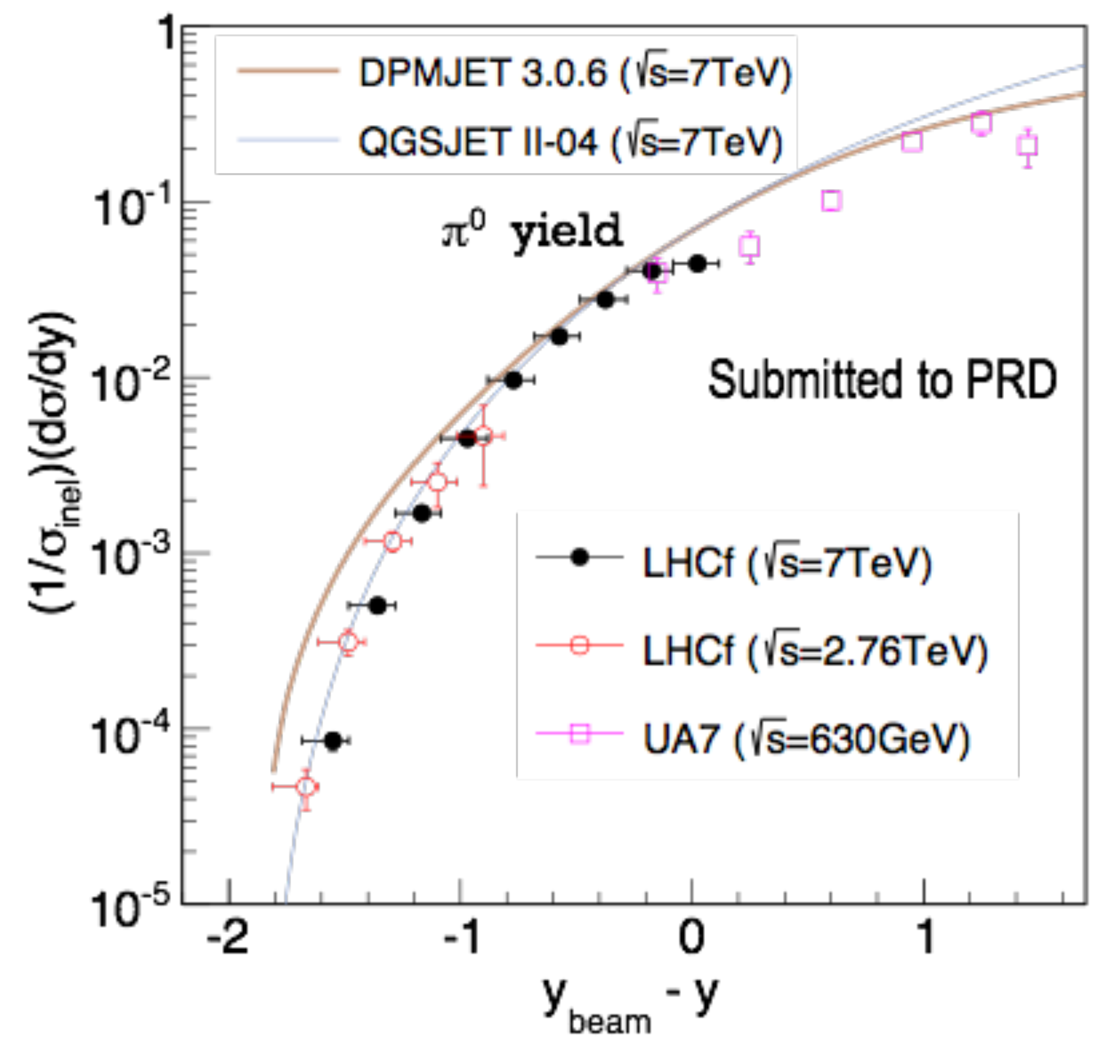
From scaling considerations (projectile fragmentation region) we can expect that $<p_T>$ vs rapidity loss should be independent from the c.m. energy

Reasonable scaling can be inferred from the data

# Limiting fragmentation in forward $\pi^0$ production

Limiting fragmentation hypothesis: rapidity distribution of the secondary particles in the forward rapidity region (target's fragment) should be independent of the center-of-mass energy.

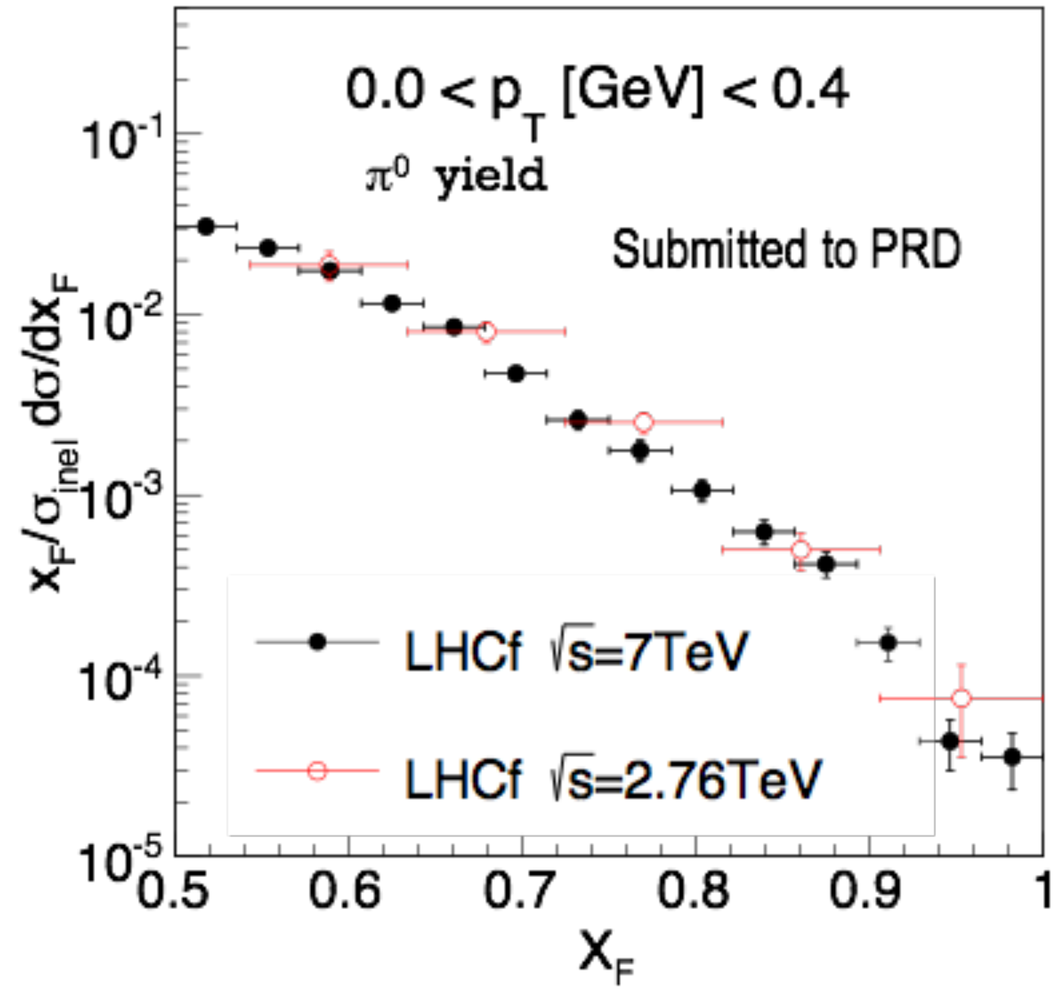
This hypothesis for $\pi^0$ is true at the level of ±15%



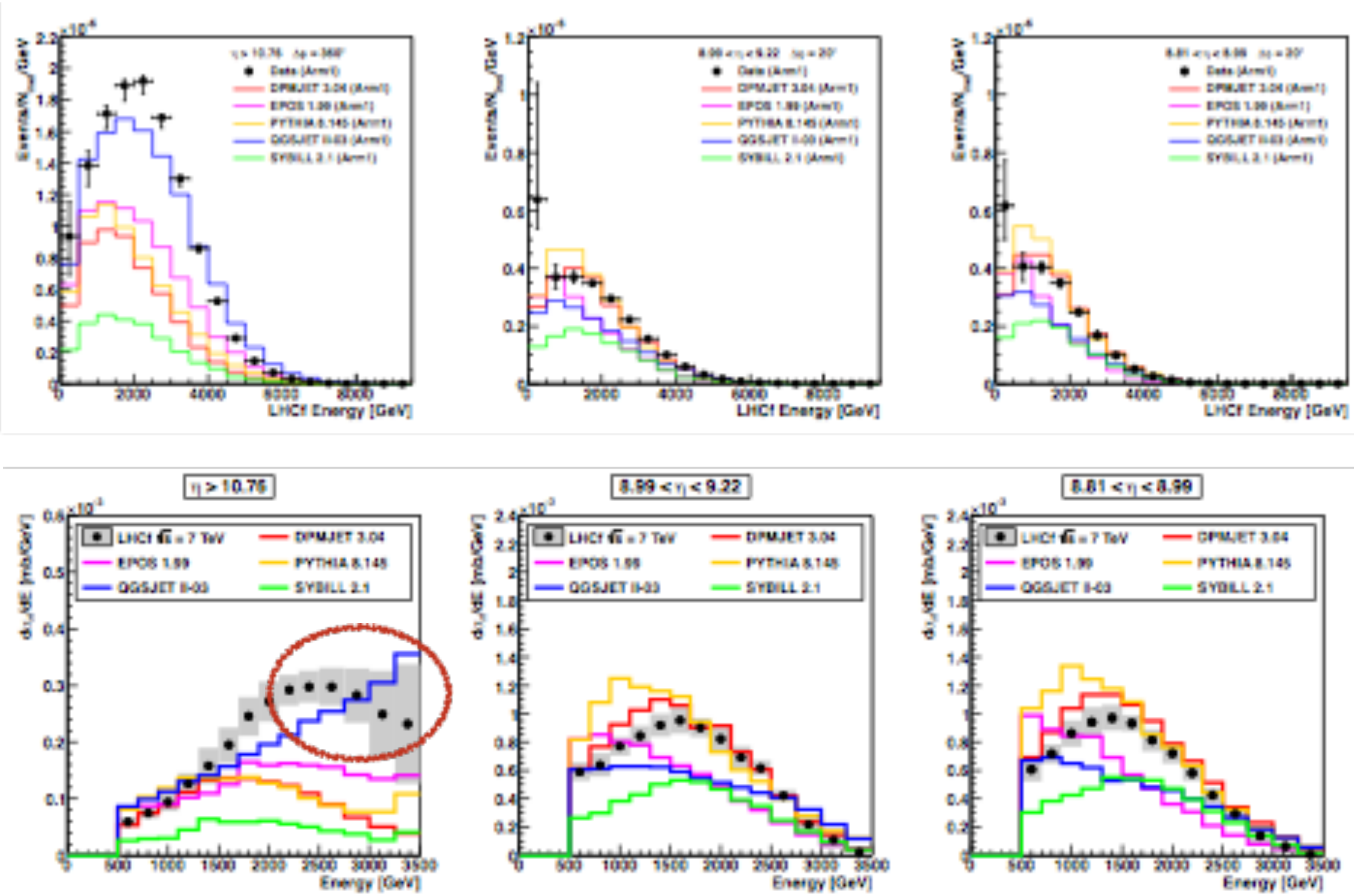
# Feynman scaling in forward $\pi^0$ production

Feynman scaling hypothesis: cross sections of secondary particles as a function of $x_F \equiv 2p_z/\sqrt{s}$ are independent from the incident energy in the forward region ($x_F > 0.2$).

This hypothesis for $\pi^0$ is true at the level of ±20%



# LHCf @ pp 7 TeV: neutron spectra




n/γ ratio

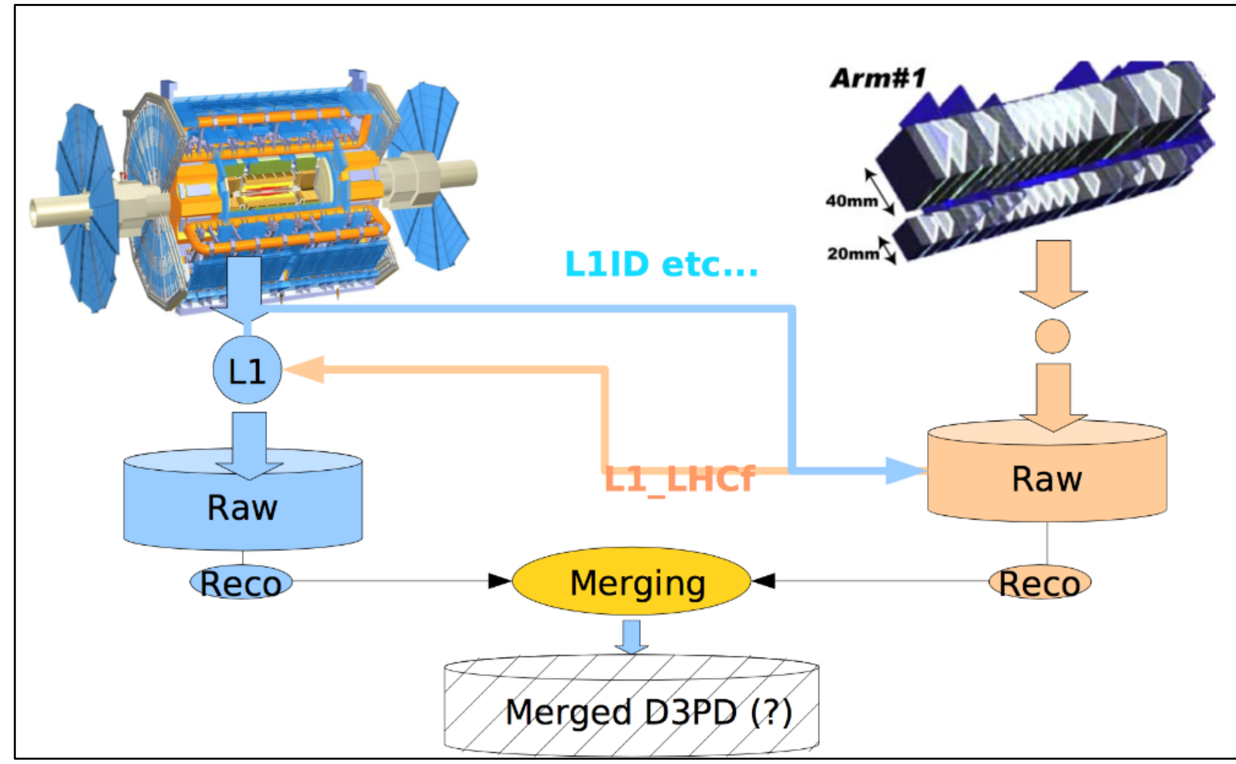
| Data (η>10.76) | 3.05±0.19 |
|---|---|
| DPMJET3.04 | 1.05 |
| EPOS 1.99 | 1.80 |
| PYTHIA 8.145 | 1.27 |
| QGSJET II-03 | 2.34 |
| SYBILL 2.1 | 0.88 |

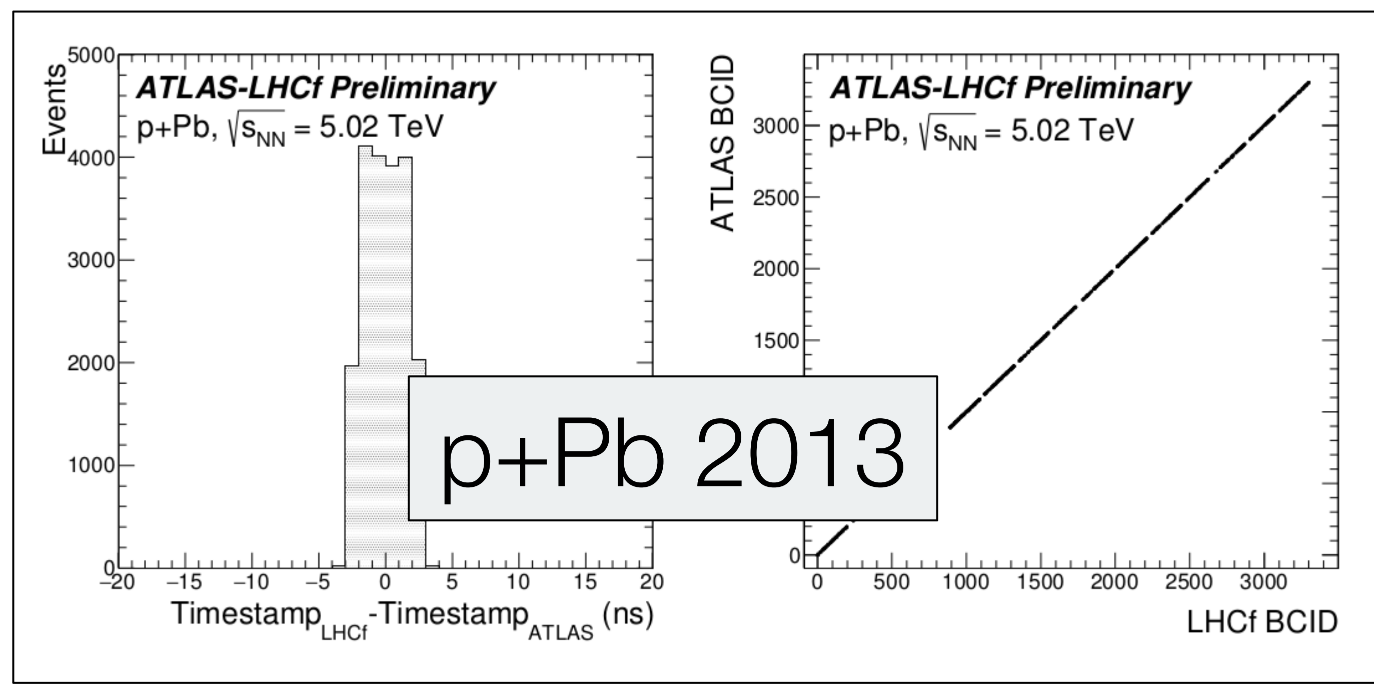
| Data (8.99<η<9.22) | 1.26±0.08 |
|---|---|
| DPMJET3.04 | 0.76 |
| EPOS 1.99 | 0.69 |
| PYTHIA 8.145 | 0.82 |
| QGSJET II-03 | 0.65 |
| SYBILL 2.1 | 0.57 |

- LHCf Arm1 and Arm2 agree with each other within systematic error, in which the energy scale uncertainty dominates.
- In η>10.76 huge amount of neutron exists. Only QGSJET2 reproduces the LHCf result.
- In other rapidity regions, the LHCf results are enclosed by the variation of models.

# ATLAS-LHCf combined data analysis

- Operation in 2013
  - p+Pb, $\sqrt{s_{NN}}$ = 5TeV
    - ➔ about 10 M common events.
- Operation in 2015
  - p+p, $\sqrt{s}$ = 13TeV
    - ➔ about 6 M common events.
- Operation in 2016
  - p+Pb, $\sqrt{s_{NN}}$ = 5TeV
    - ➔ about 26 M common events
  - p+Pb, $\sqrt{s_{NN}}$ = 8TeV
    - ➔ about 16 M common events




Off-line event matching

Important to separate the contributions due to diffractive and non-diffractive collisions

WG active meeting every 2 weeks

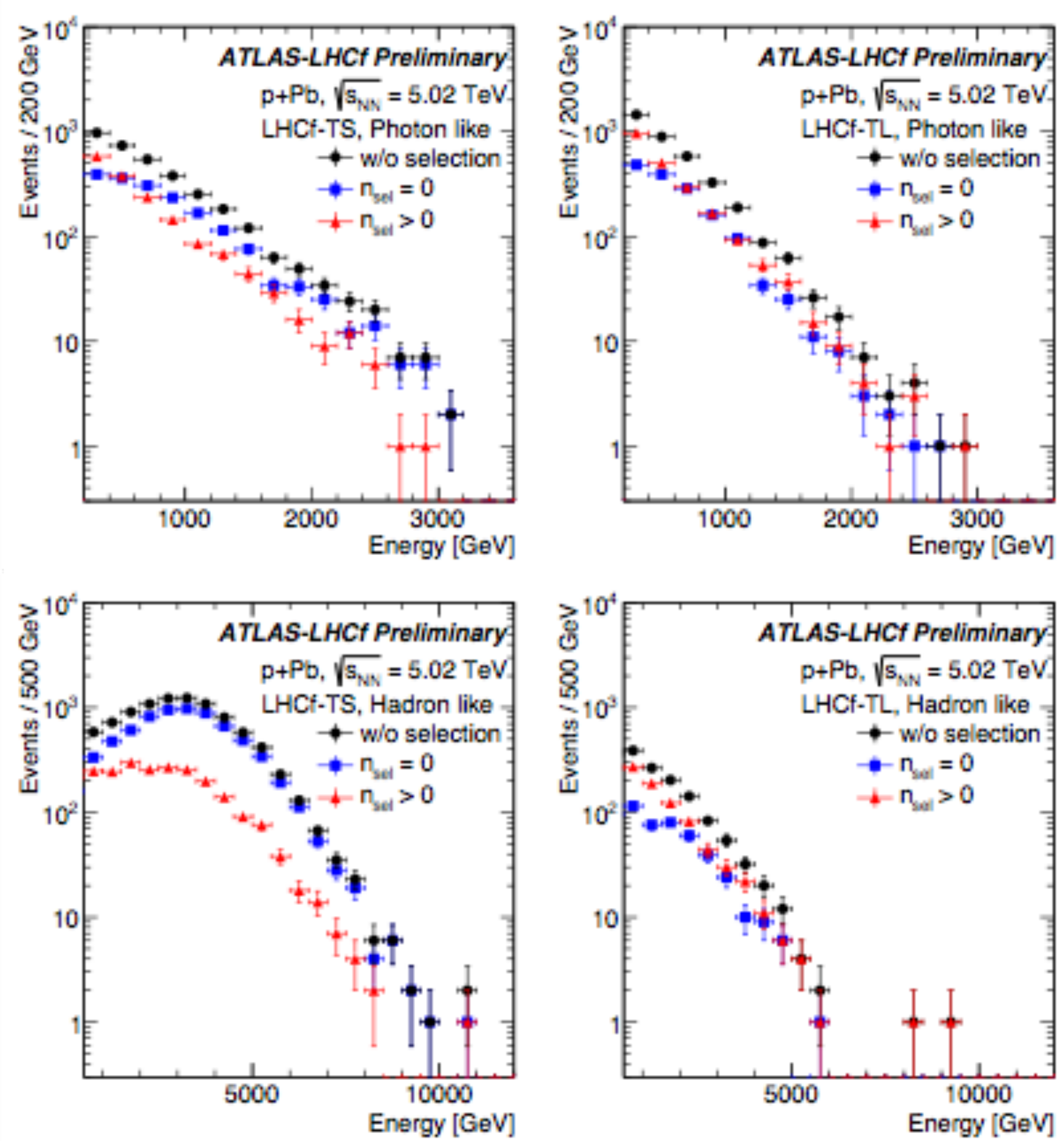
# LHCf spectra in p-Pb collisions with Atlas tagging on tracks

Nsel:

number of good charged ATLAS tracks

- $p_T > 100$ MeV
- vertex matching
- $|\eta| < 2.5$.

Significant UPC contribution in the very forward region with $N_{sel}=0$



# Impact of common ATLAS-LHCf trigger

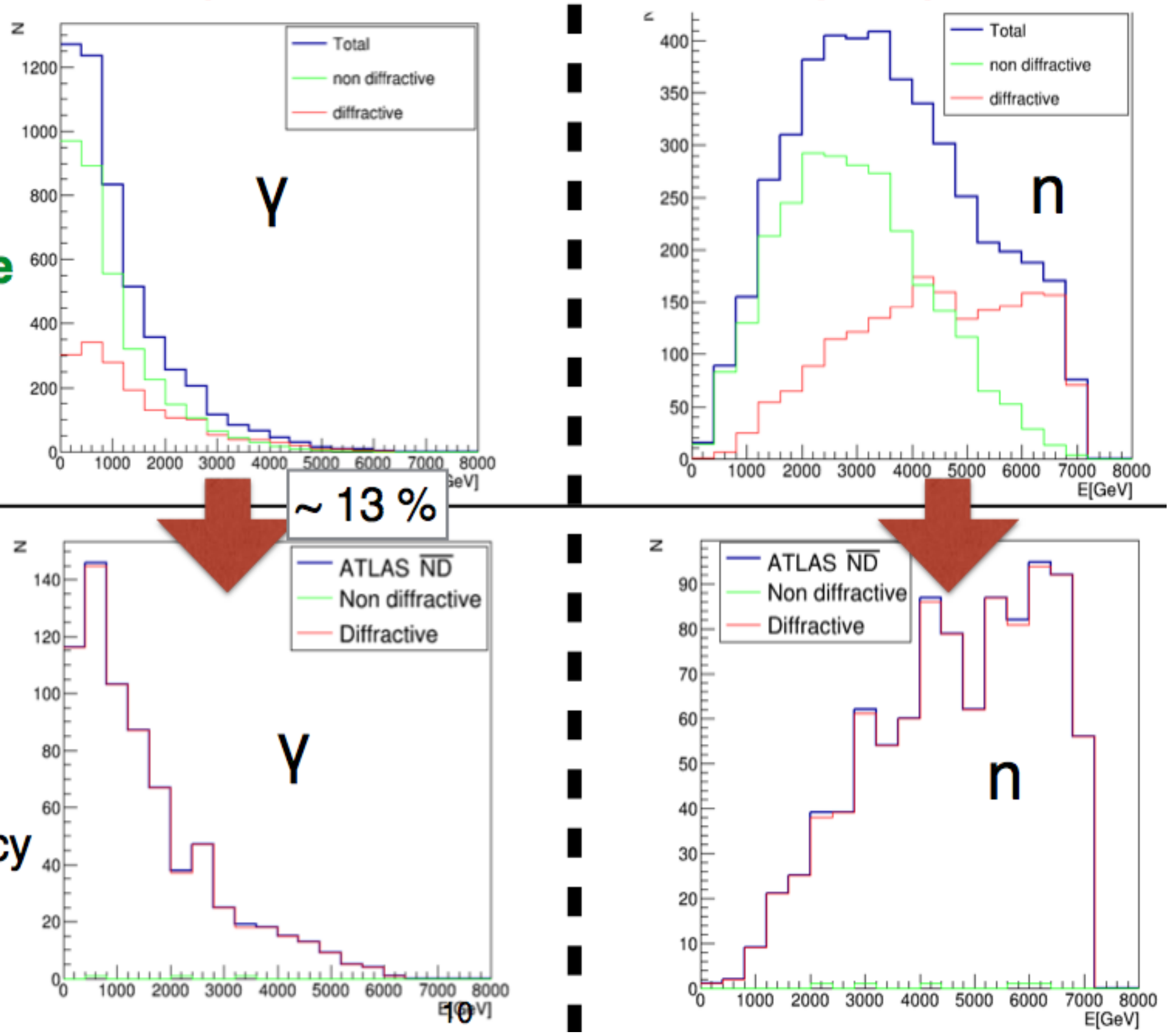
**PYTHIA MC study @ 14 TeV. Diffractive event selection efficiency and purity:dropping events with (PT > 100 MeV/c & Nch>1 in Iηl<2.5) @ATLAS**

All events

**in MC true,**
**Non-diffractive**
**Diffractive**

w/ event selection (not ND)

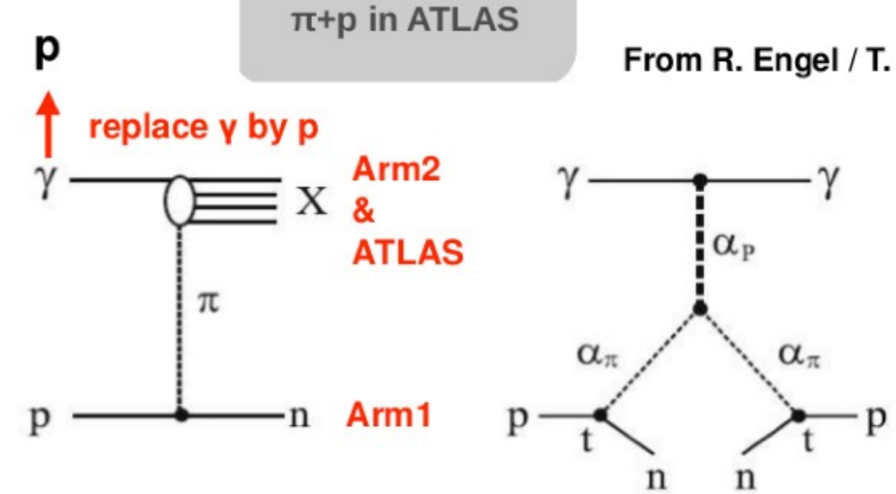
For diff. events,
35-40% efficiency
99 % purity




key: low mass diffraction (Ostapchenko)

**Use neutron tag in LHCf to measure π+p in ATLAS**

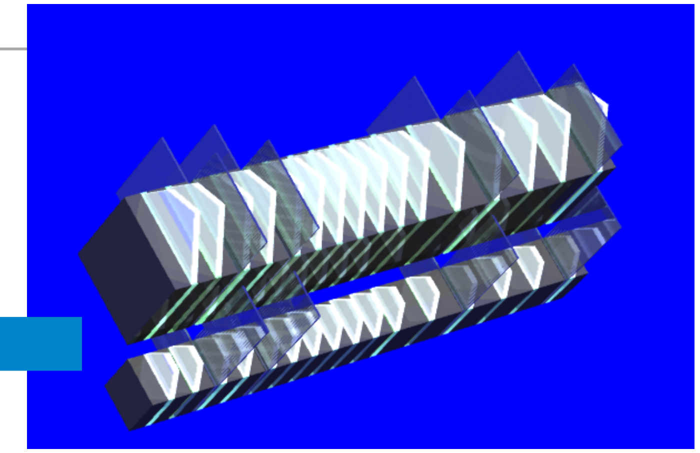
**From R. Engel / T. Pierog**

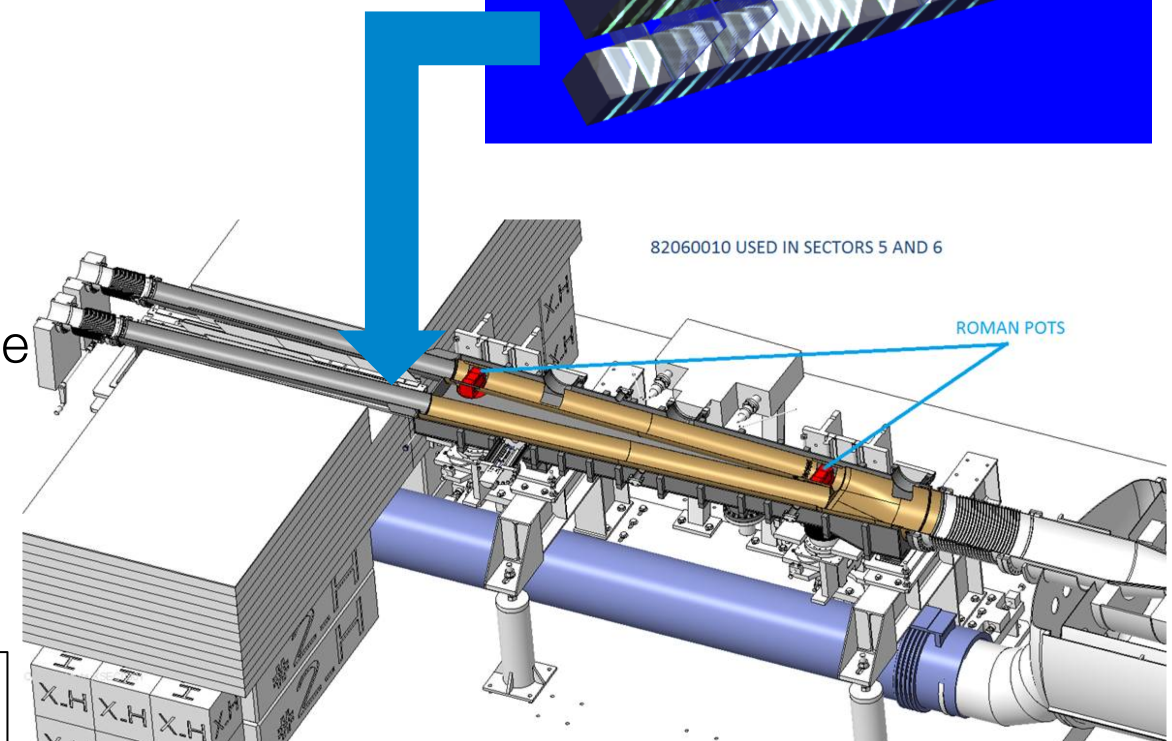



Physics discussed in detail for HERA (H1 and ZEUS) measurements
*(see, for example, Khoze et al. Eur. Phys. J. C48 (2006), 797 and Refs. therein)*

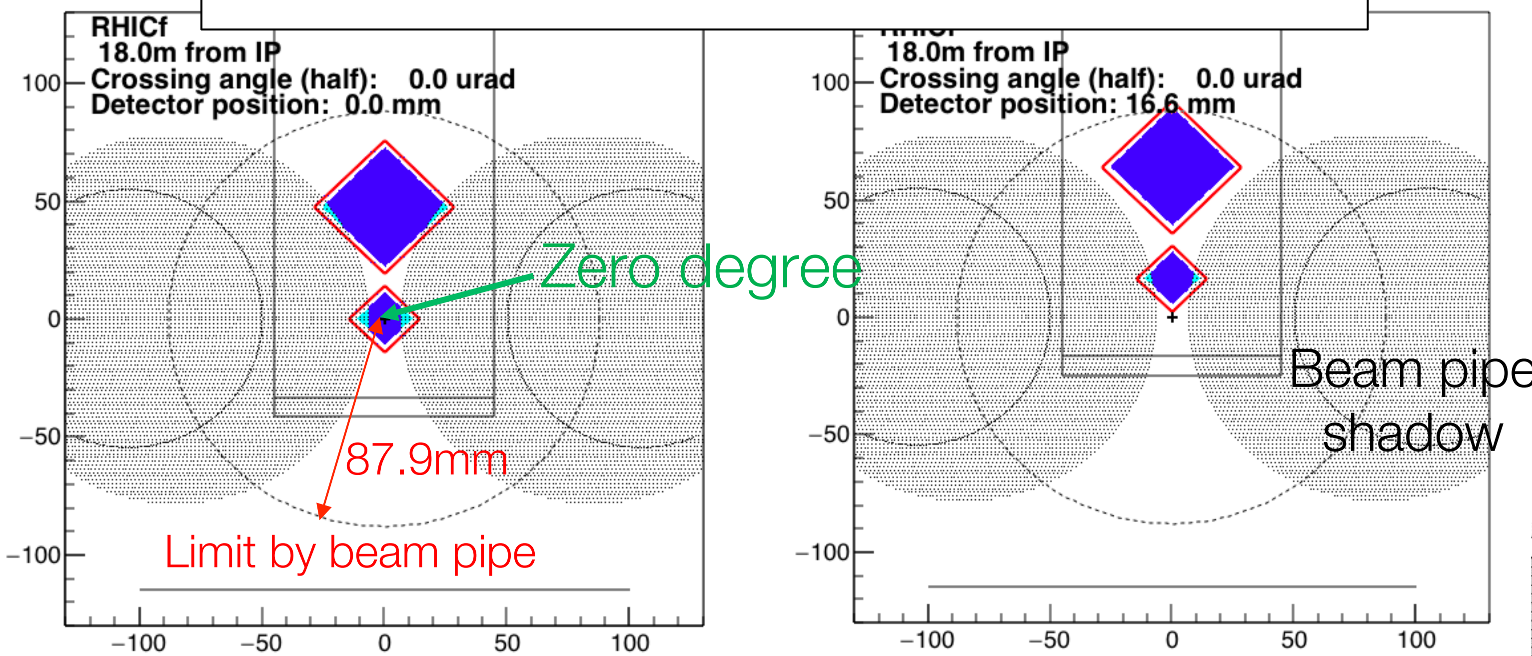
# RHICf detector acceptance

Compact double calorimeters (20mmx20mm and 40mmx40mm)

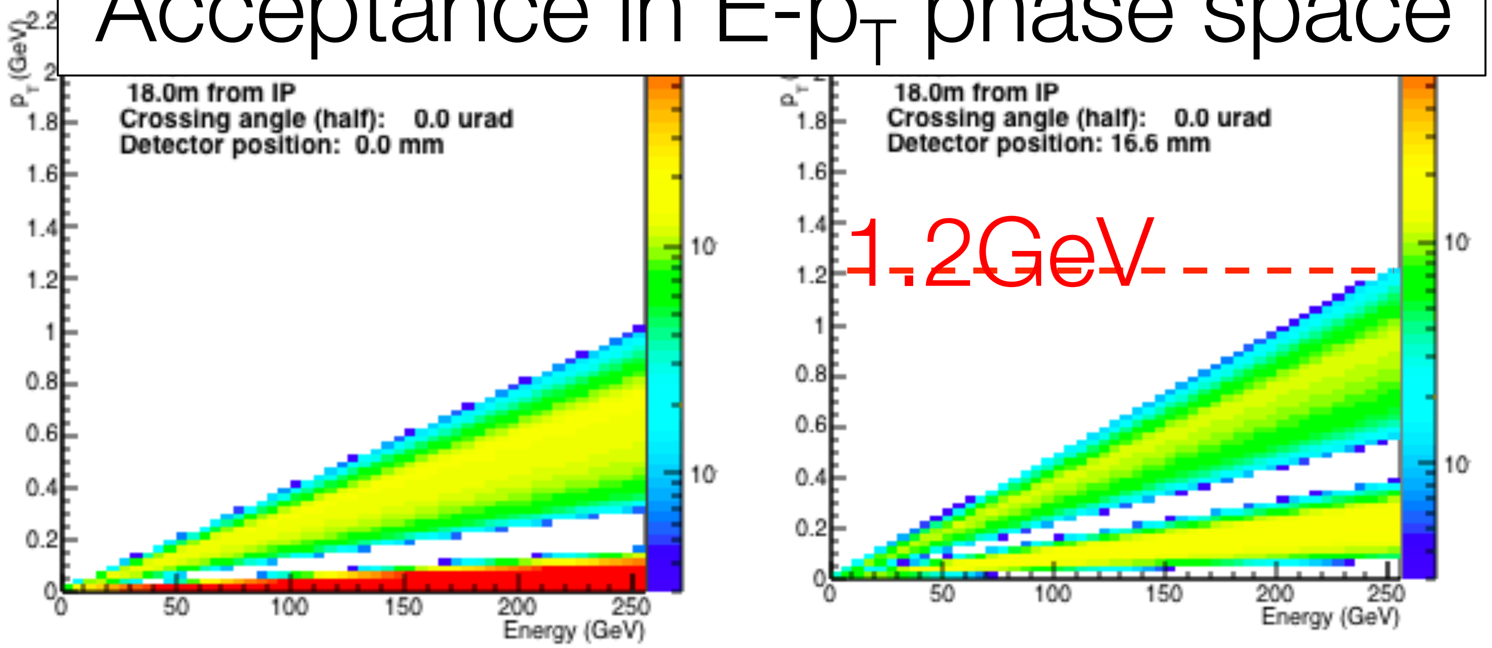





Cross section view from IP

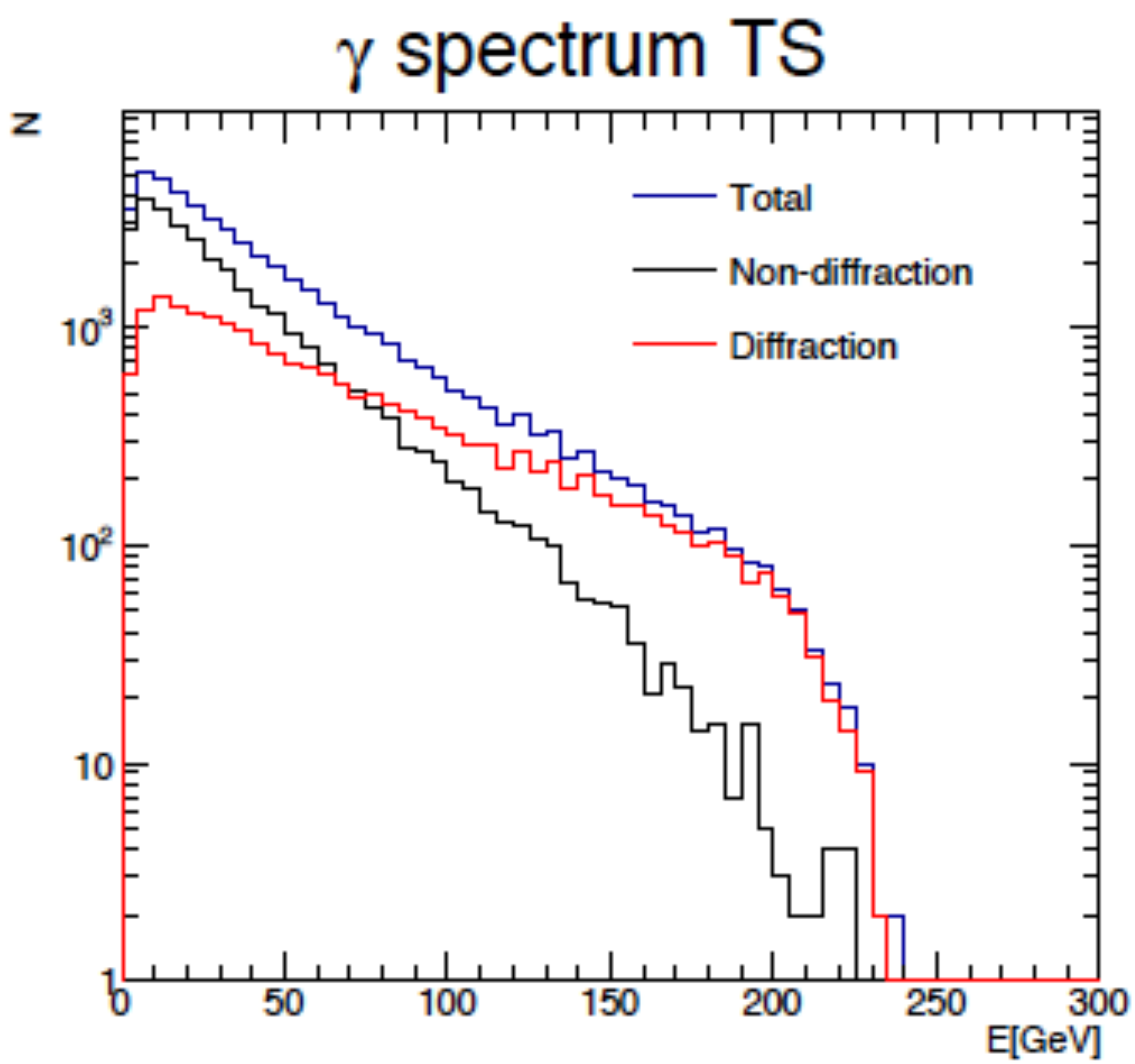


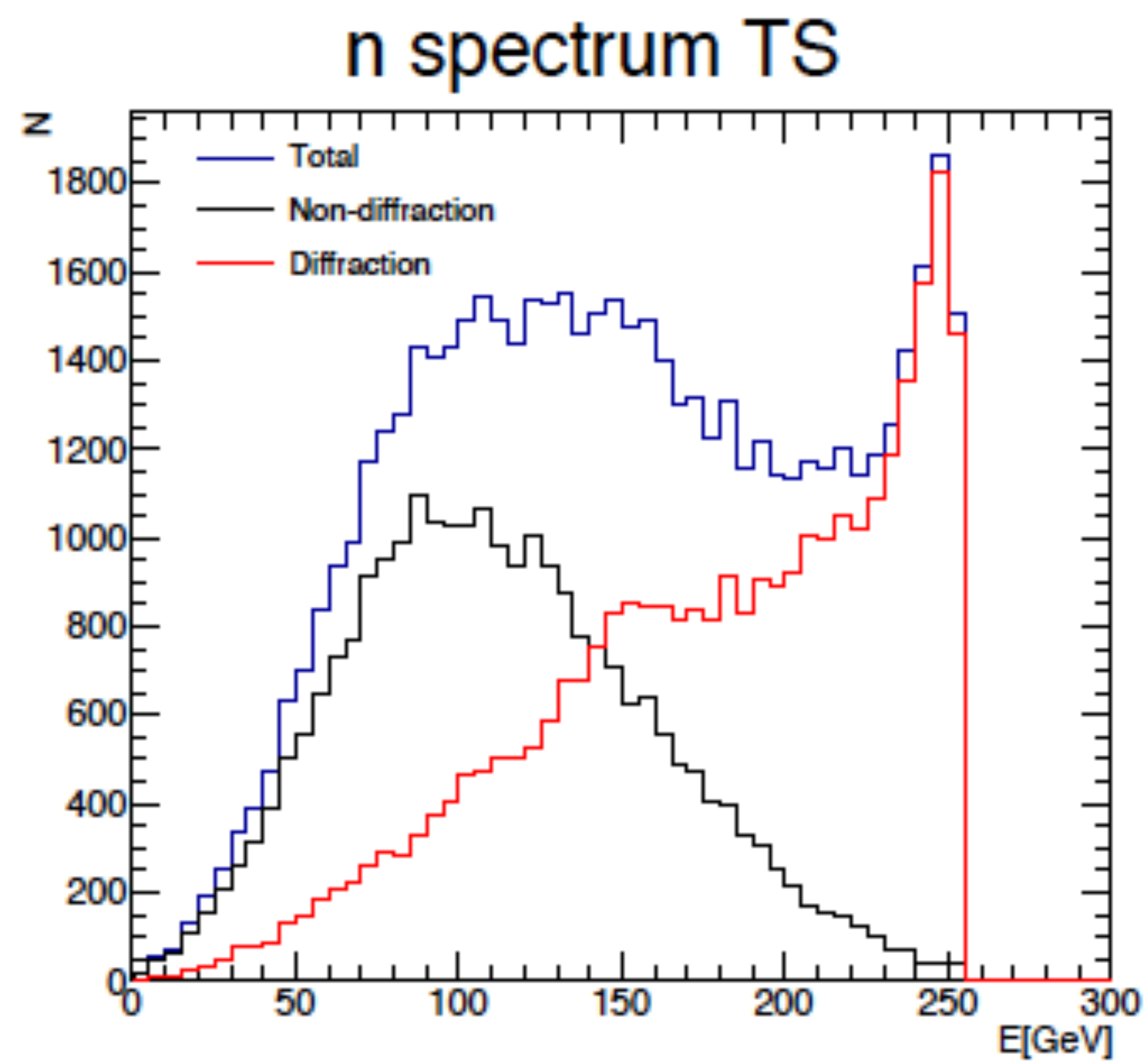

Acceptance in E-$p_T$ phase space




- ✓ Widest and gapless $p_T$ coverage is realized by moving the vertical detector position.
- ✓ Beam pipes obscure photons but not neutrons.

# Diffractive vs. non diffractive at η>8.2 with √s=510GeV p+p collisions




PYTHIA 8 simulation

BLUE: inclusive spectra expected by RHICf only

RED: diffractive only (“RHICf + no central track in STAR” will be similar => TBC)

BLACK: non diffractive (“RHICf + >=1 central track in STAR” => TBC )