Diffraction 2016

Santa Tecla, Acireale, September 2-8 2016

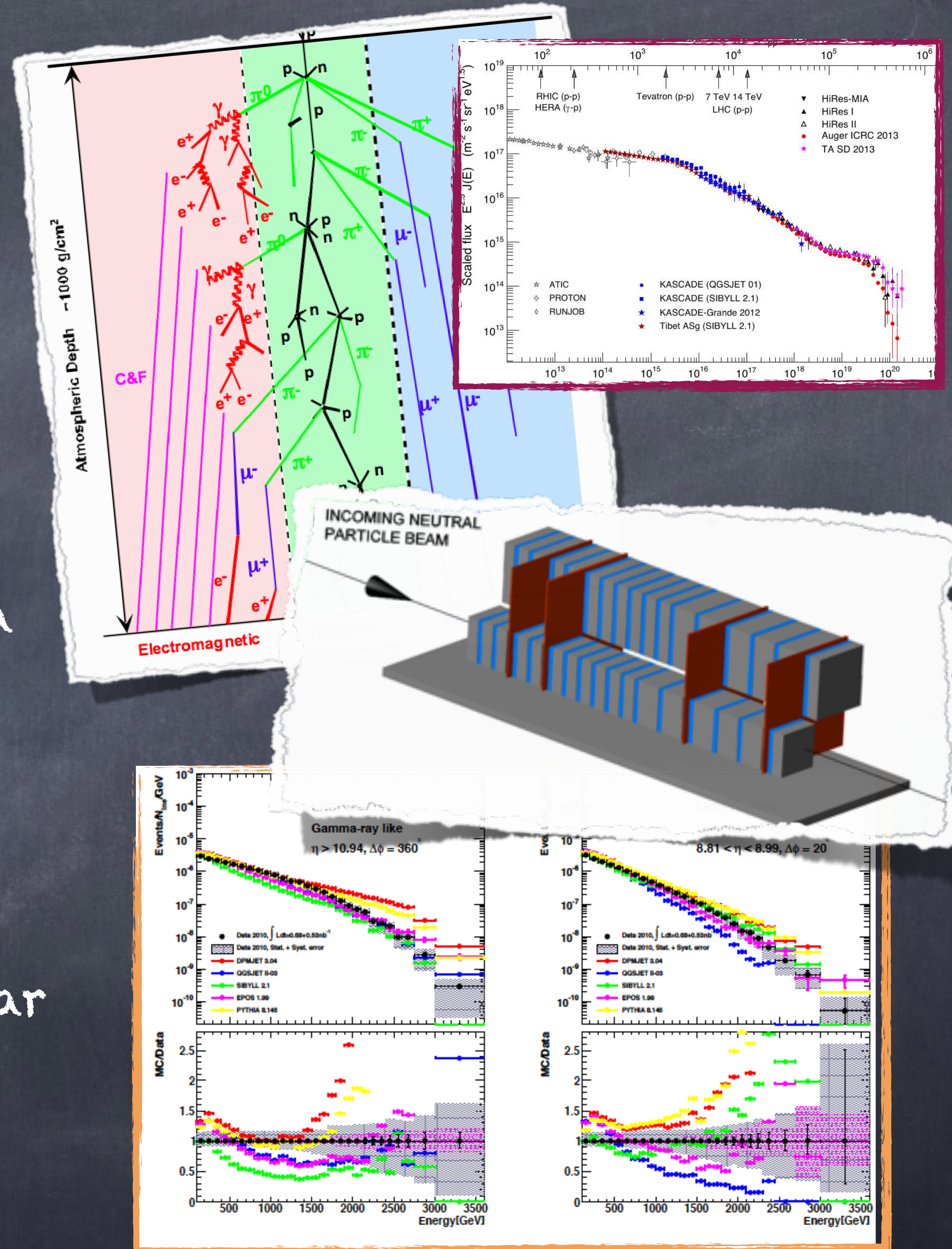
Hadronic Interaction Model Calibration with LHCf data at LHC

Alessia Tricomi

University and INFN Catania, Italy

Outline

- Physics Motivations
  - The link between HECR Physics and LHC
- The LHCf detectors
  - “Il vino buono sta nella botte piccola” or “good things comes in small packages”
- Physics Results
  - what we have done so far
- Future Plans
  - what’s next...



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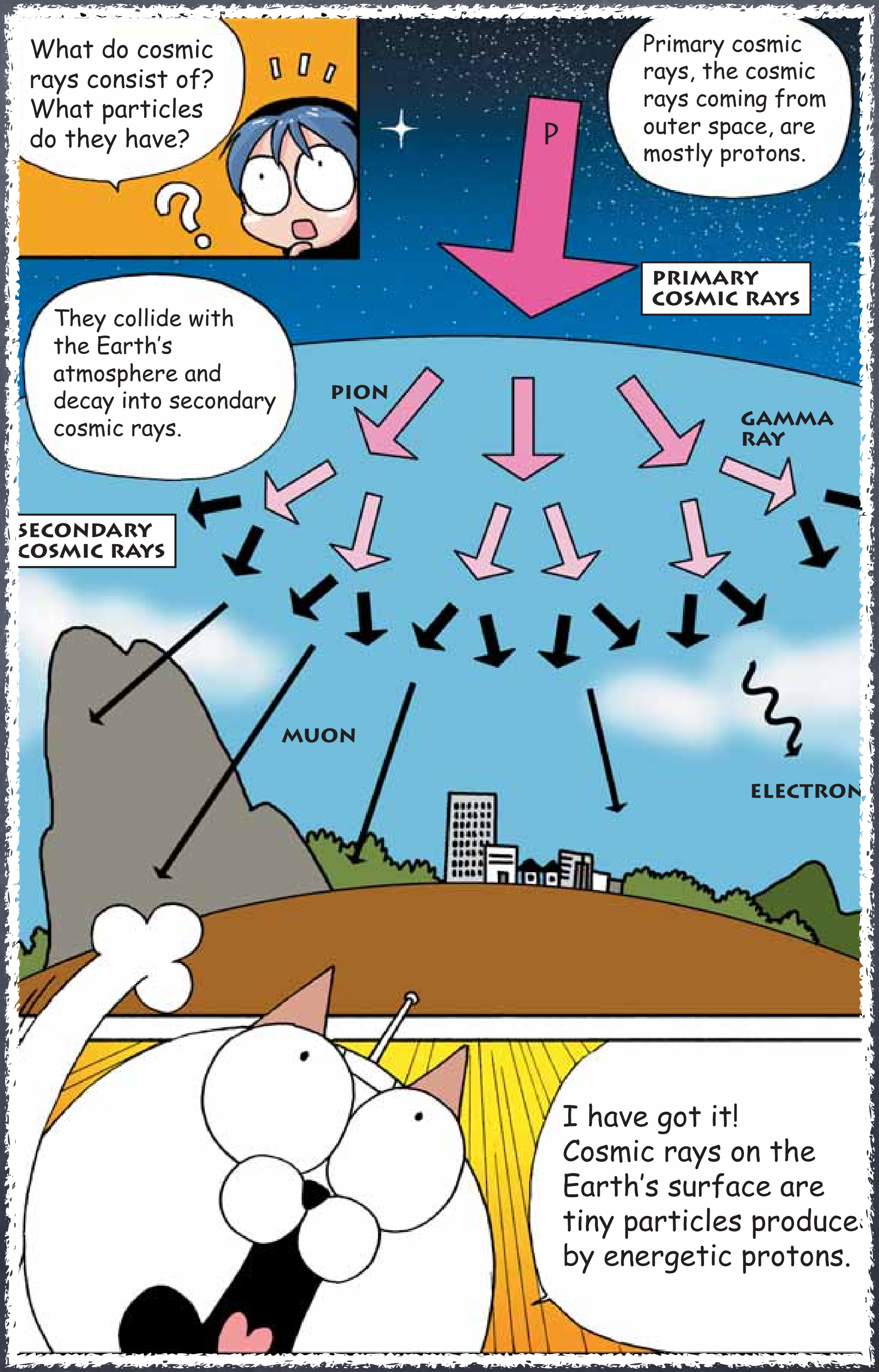


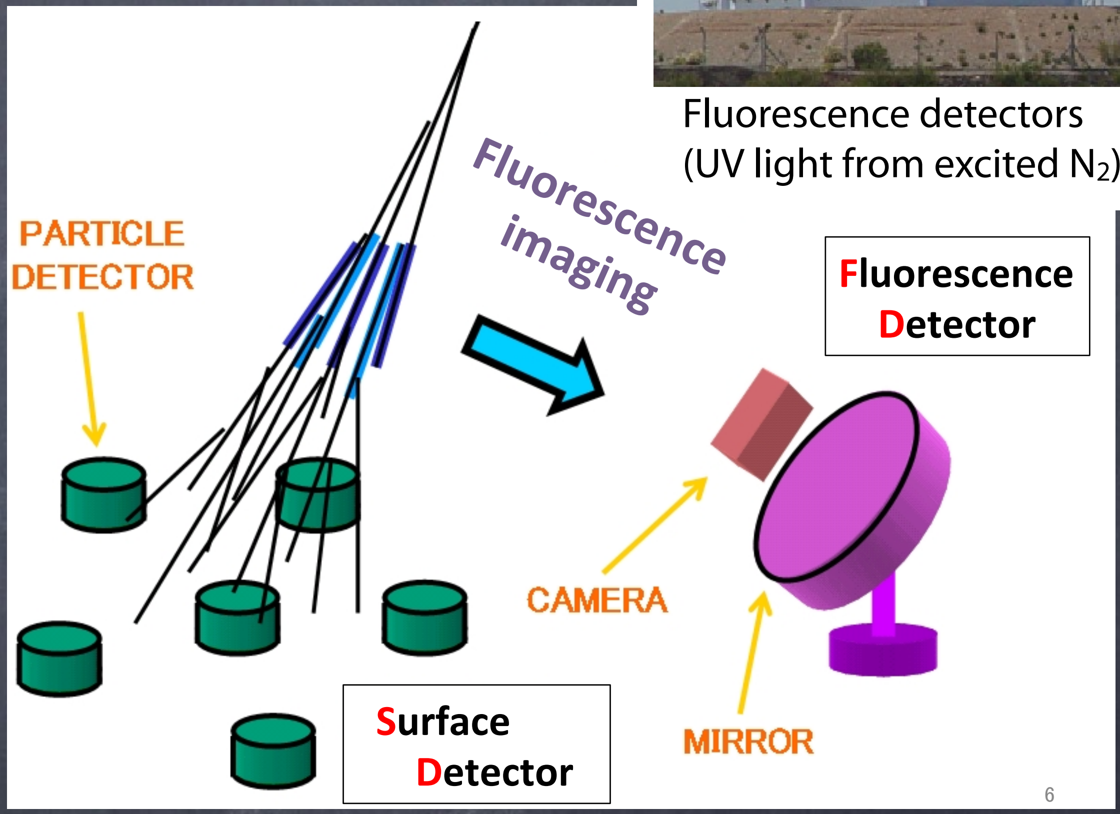
Ultra High Energy Cosmic Rays

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

+

MC Simulation to describe hadronic interaction with atmosphere

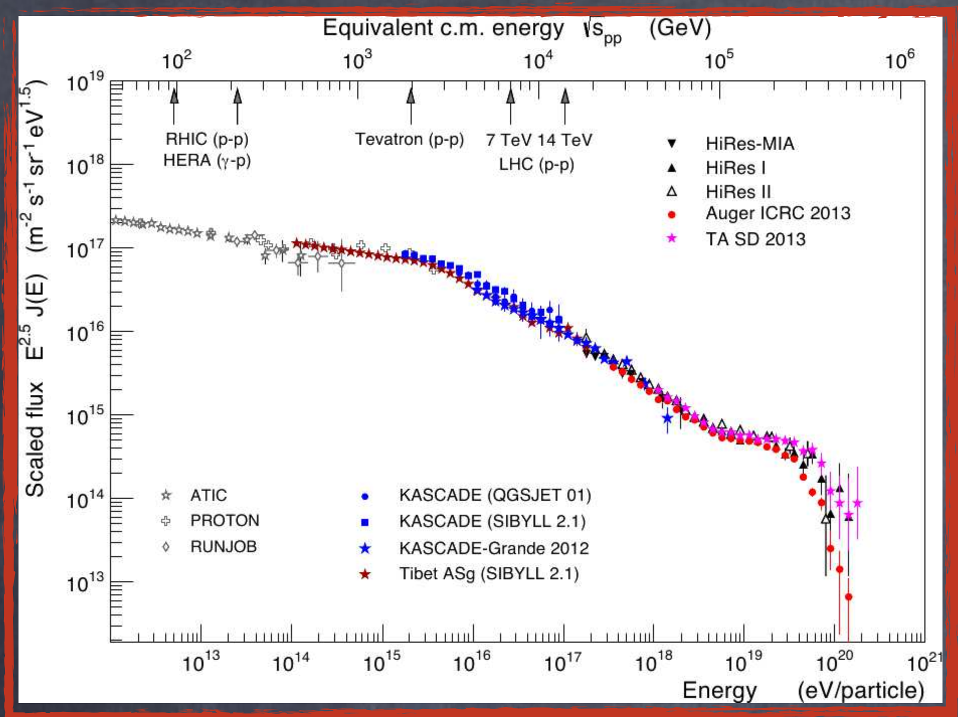
Fluorescence detectors (UV light from excited N_2)

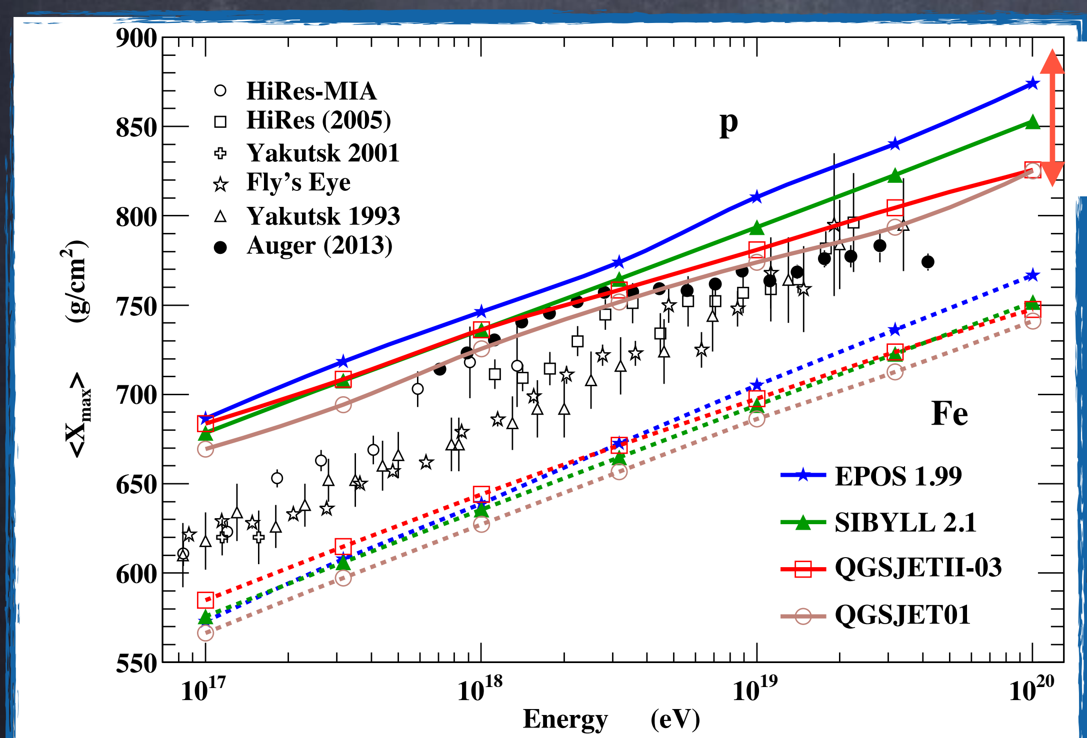


Surface detectors (charged+photon)

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

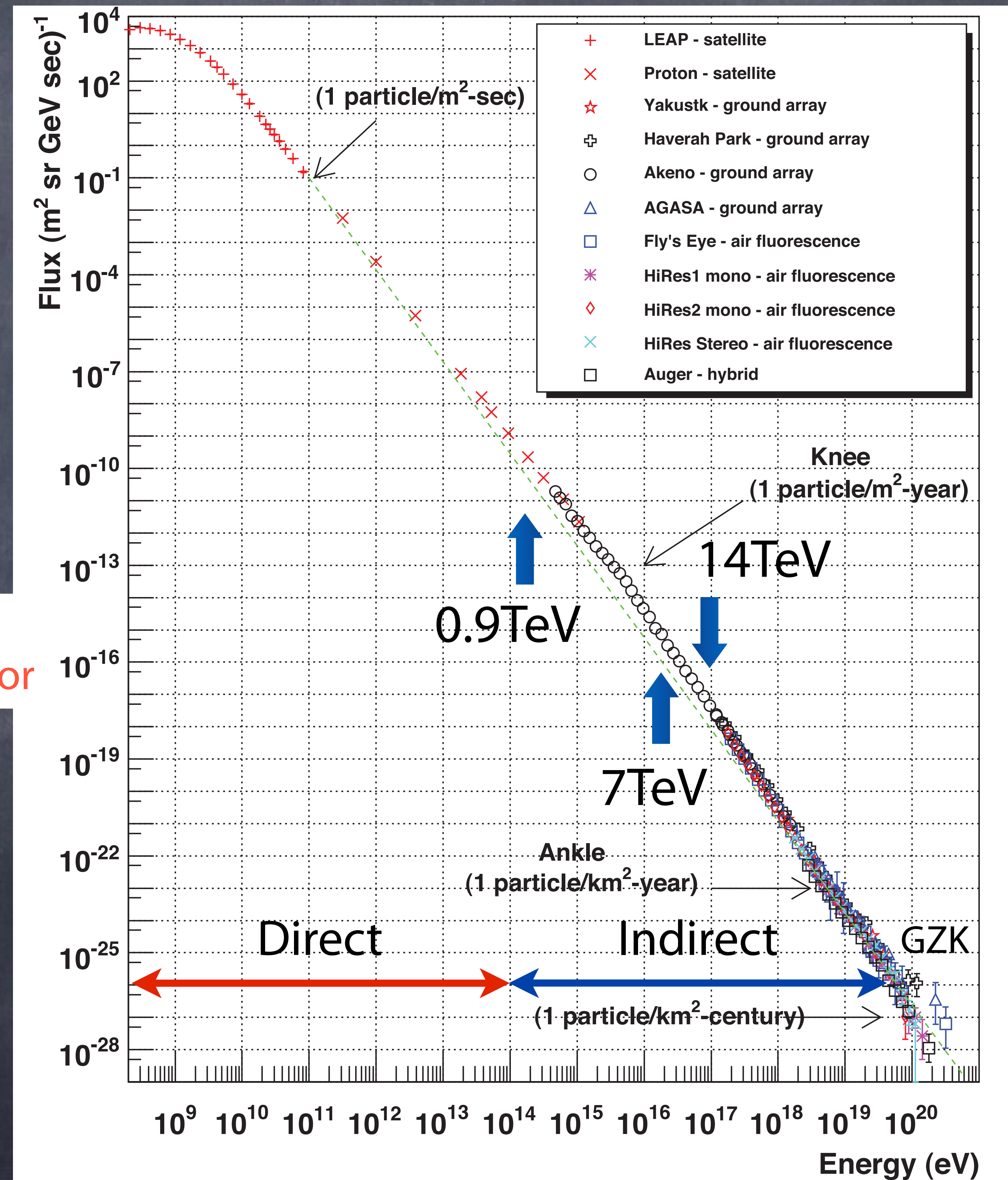
Observation of UHECR





Pre-LHC model error

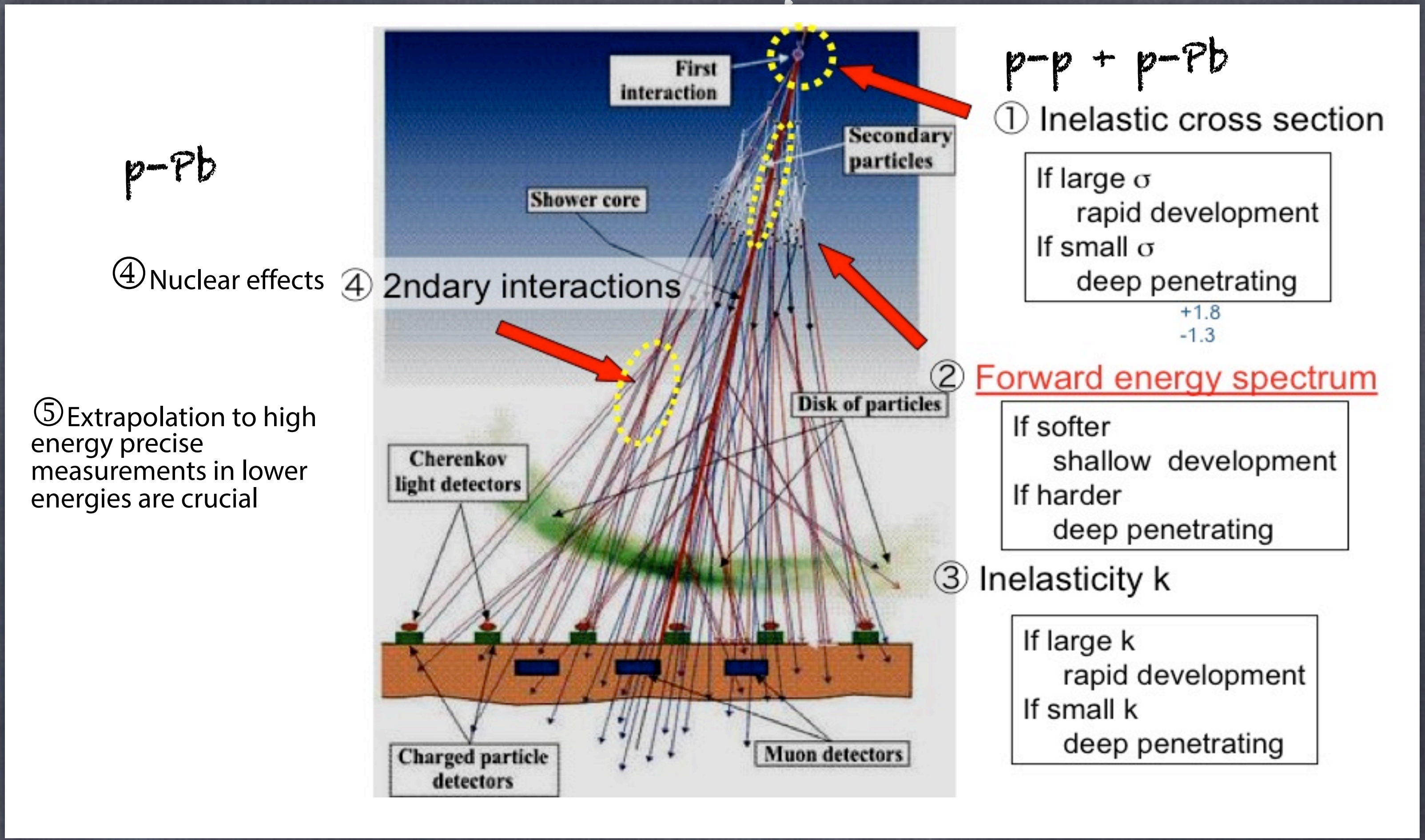
(Pierog 2013, 2014)

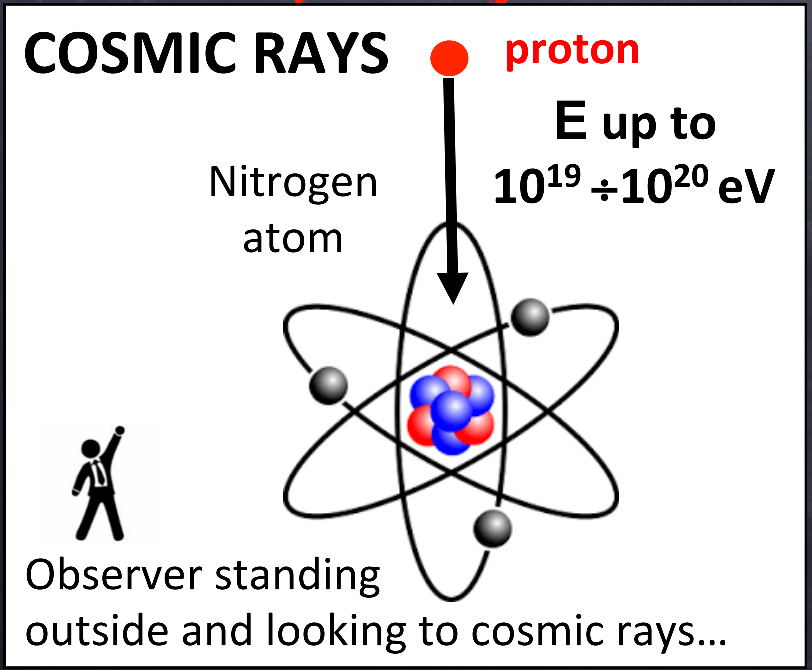


HECR Physics at LHC: LHCf Physics

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





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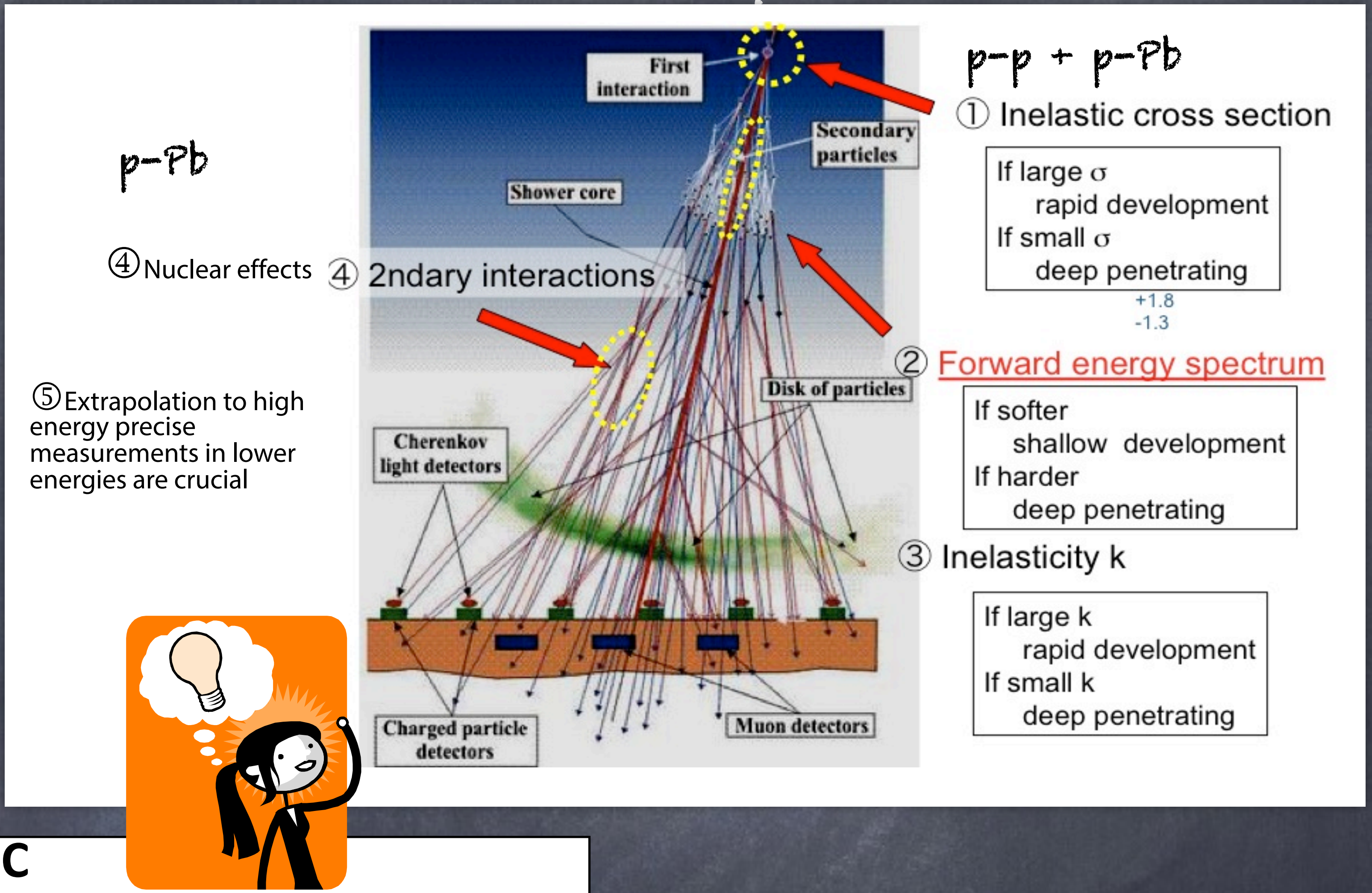

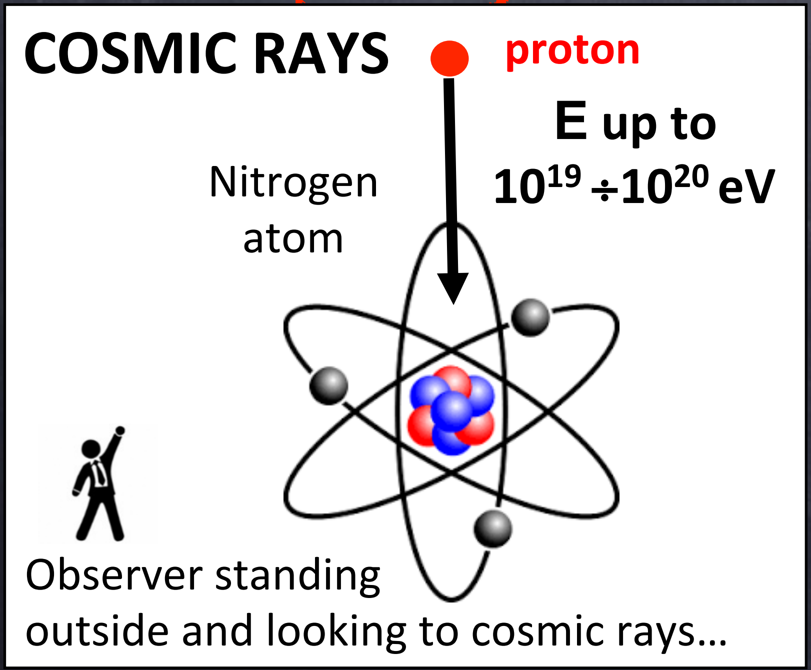

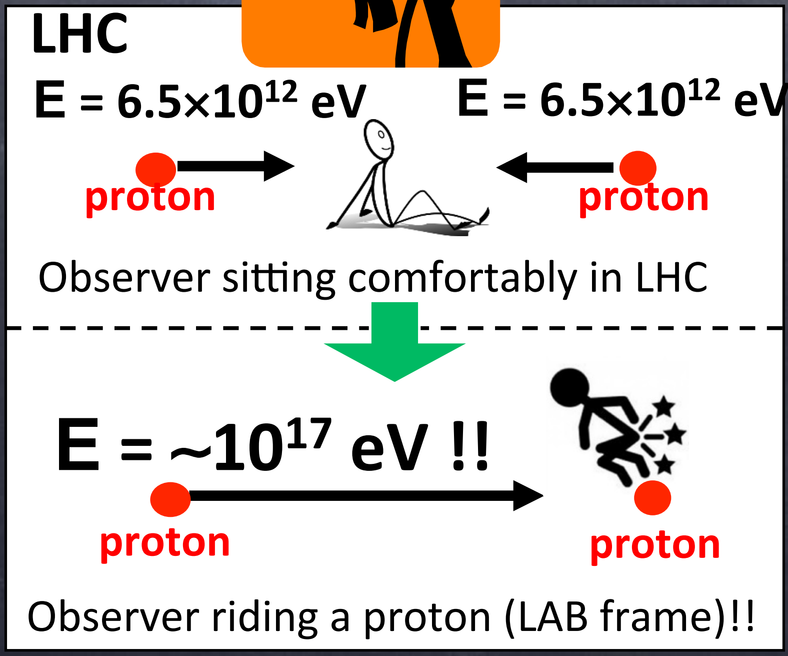

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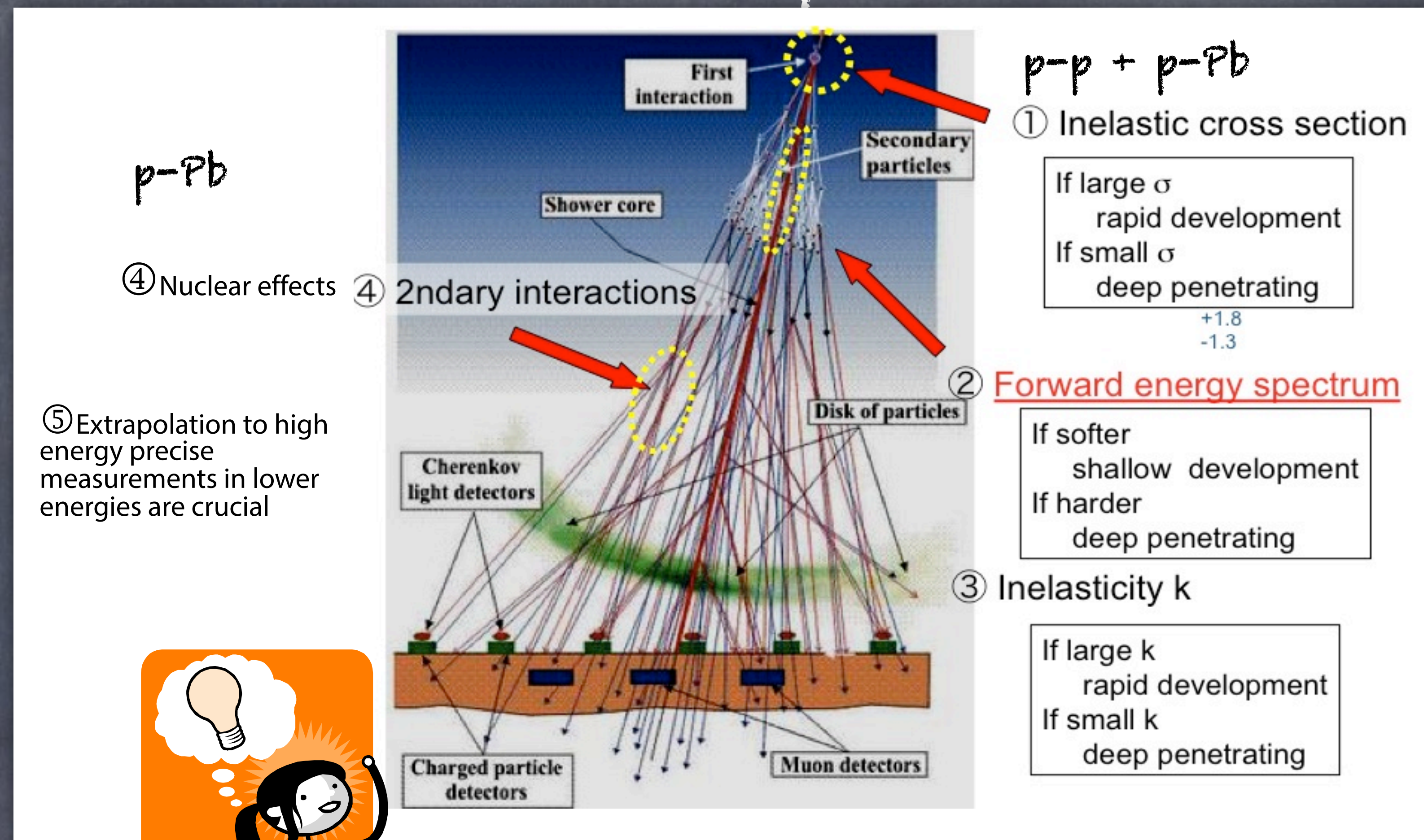
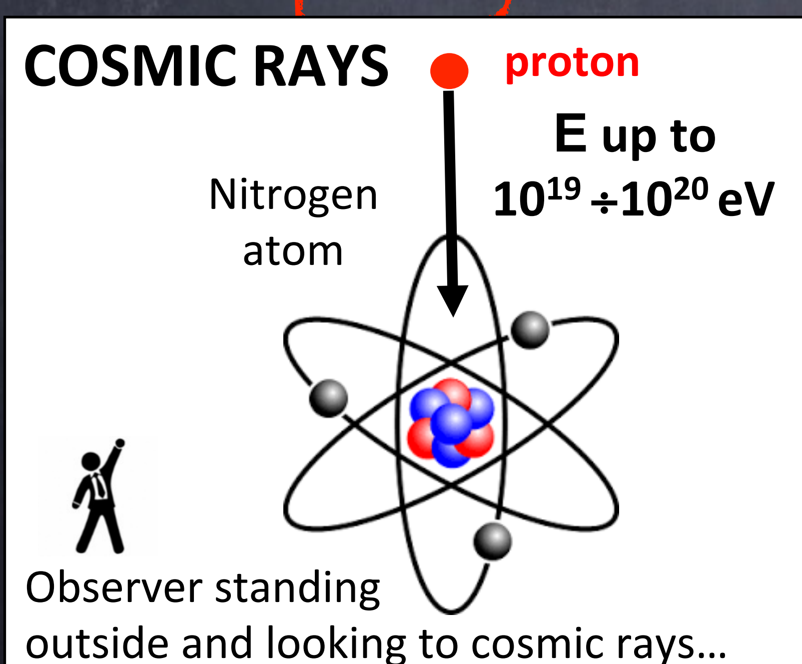
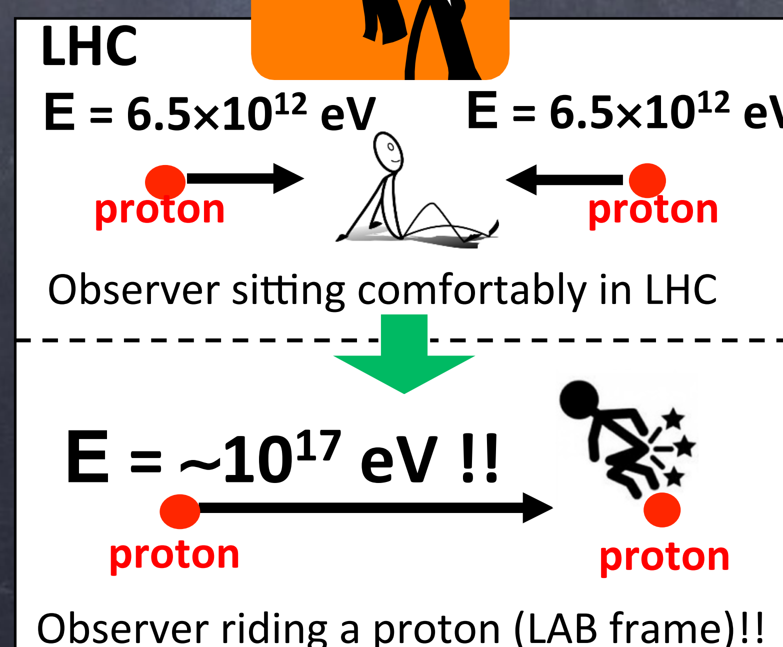






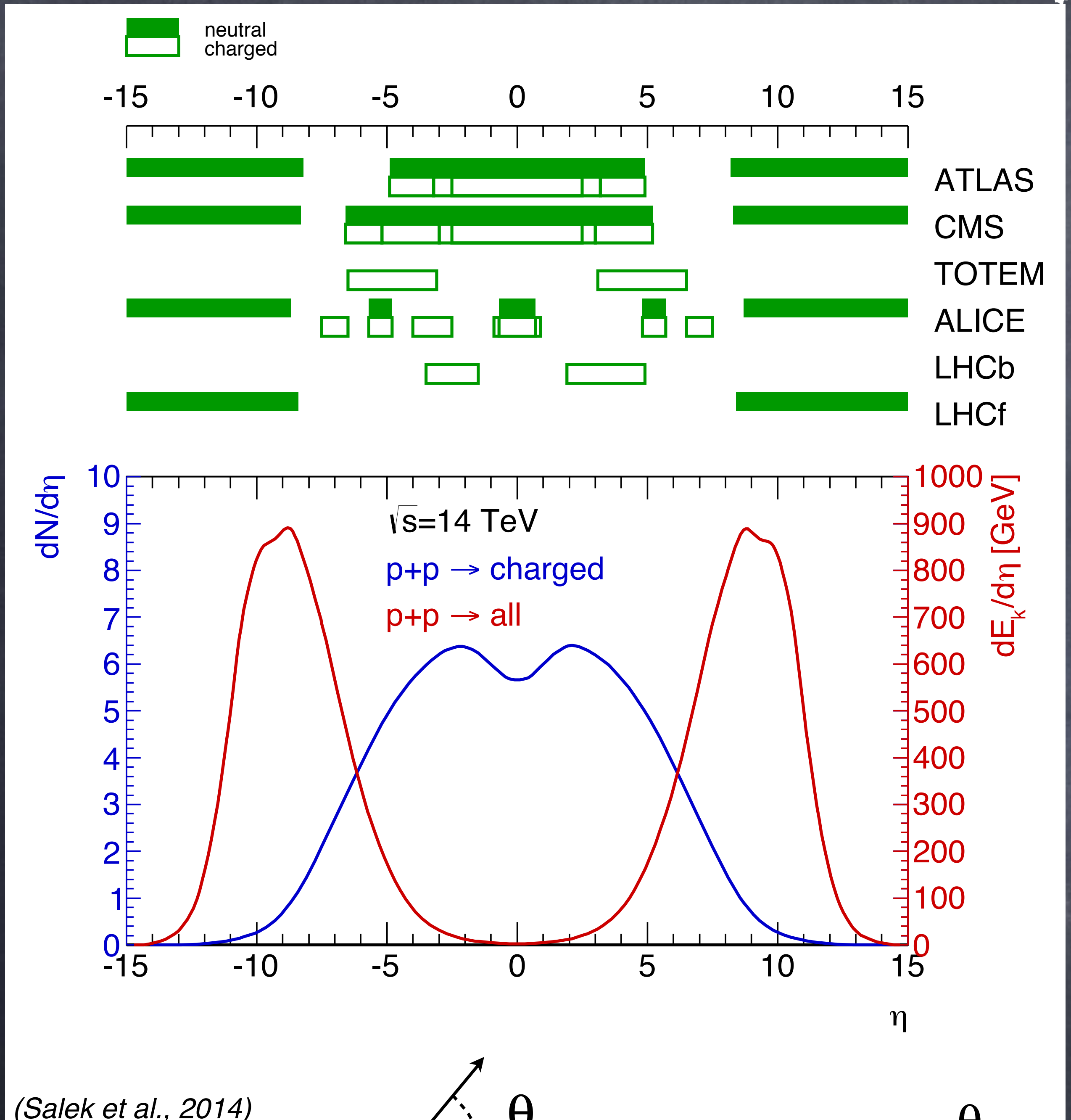
LHCf → use LHC

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

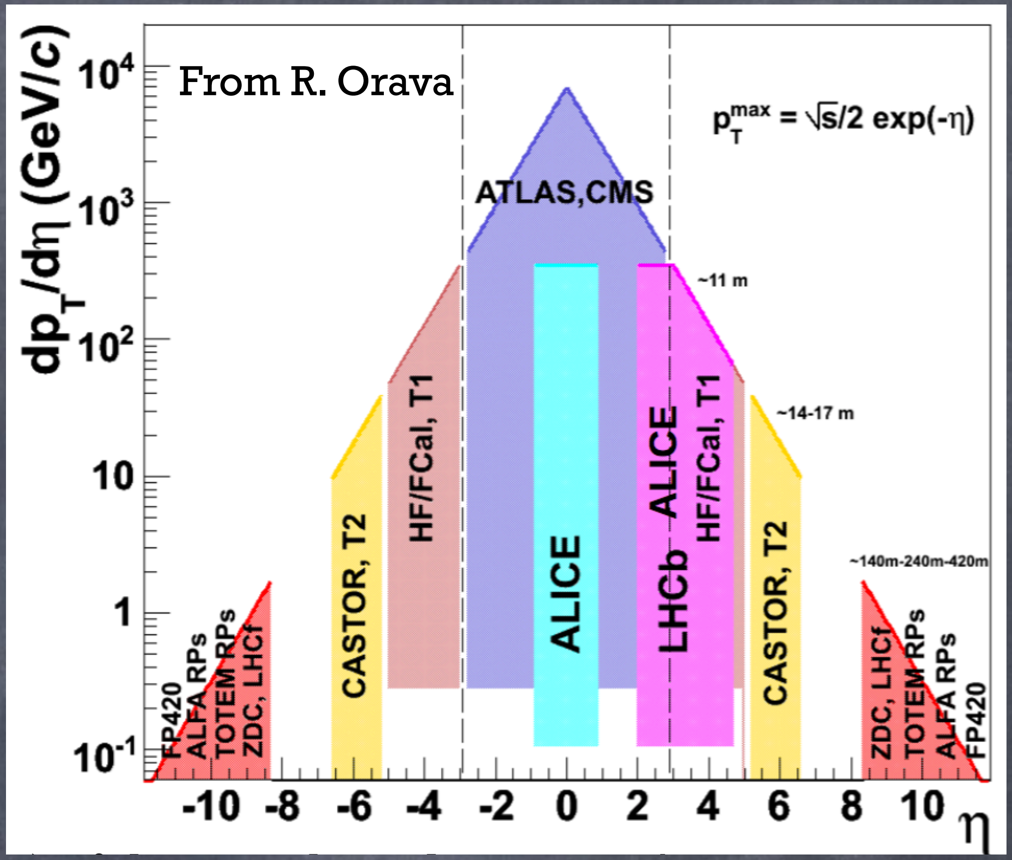
to calibrate MCs

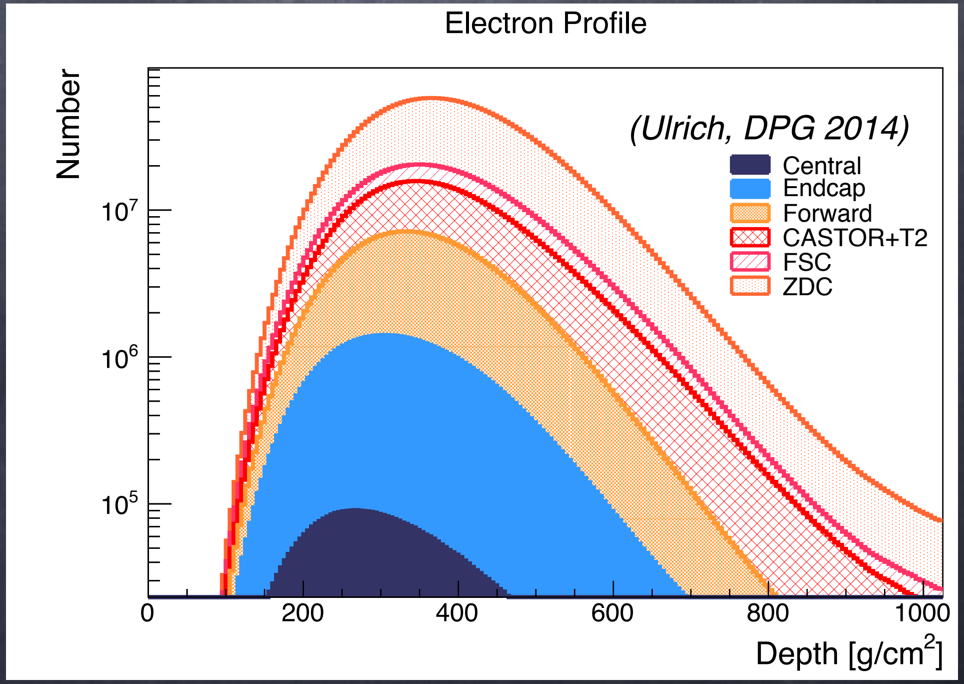
In addition: p-Pb collision at 5.02&8TeV to study nuclear effect

LHC Phase space coverage



$$\eta = -\ln\tan\frac{\theta}{2}$$





We are profiting of the broad coverage
but more than 50% of the shower from η>8
Dedicated fwd experiments crucial!

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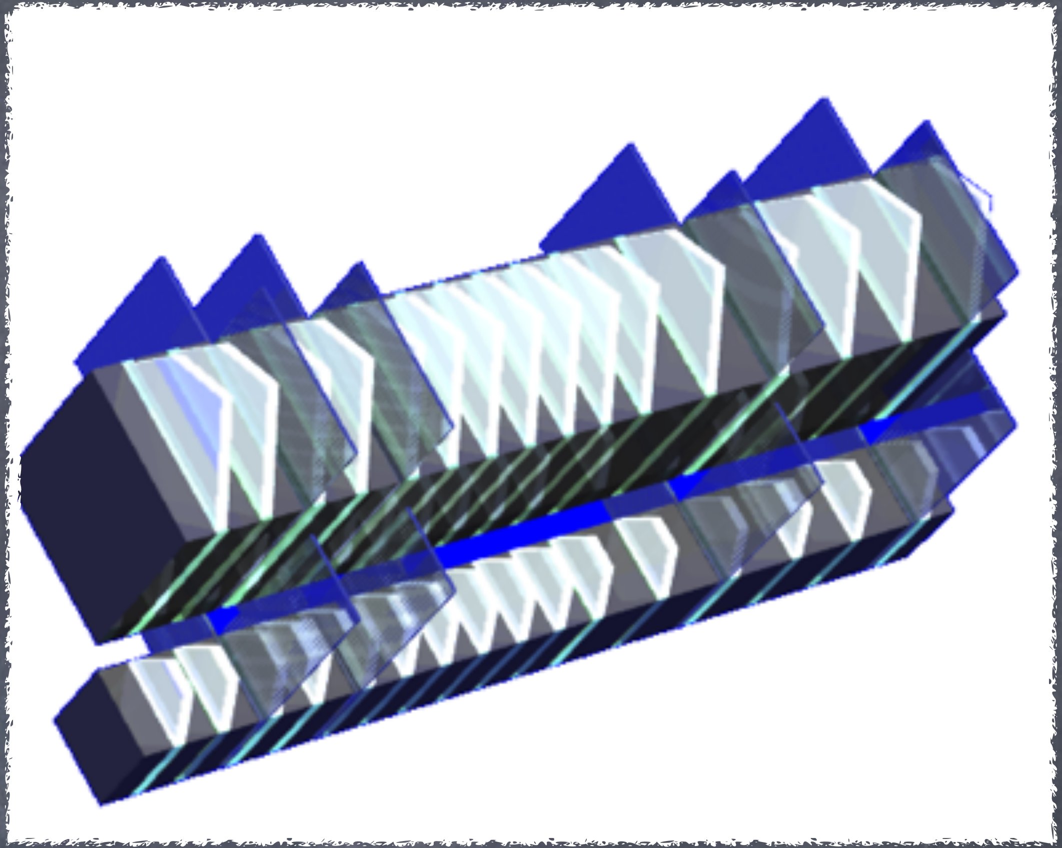
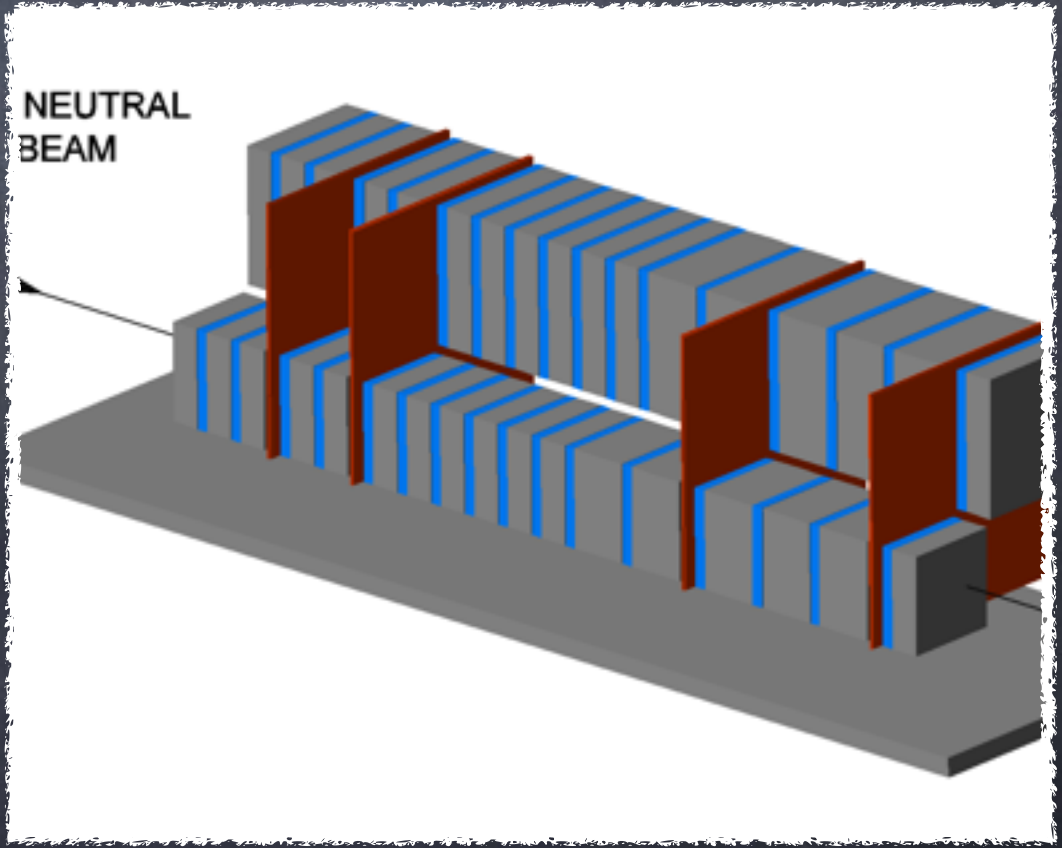
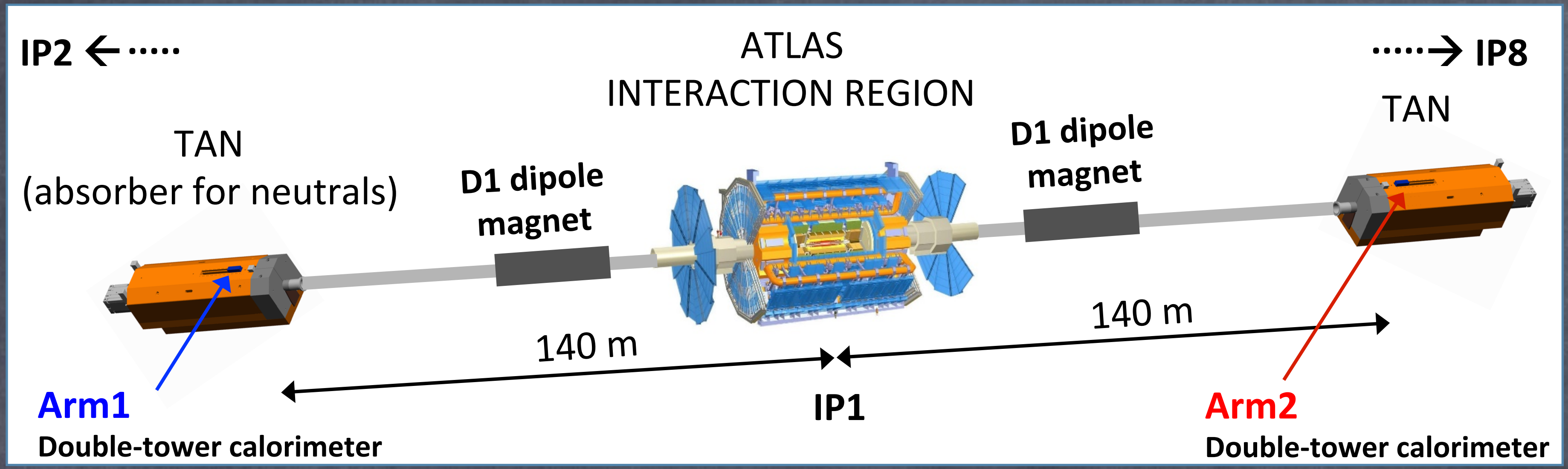
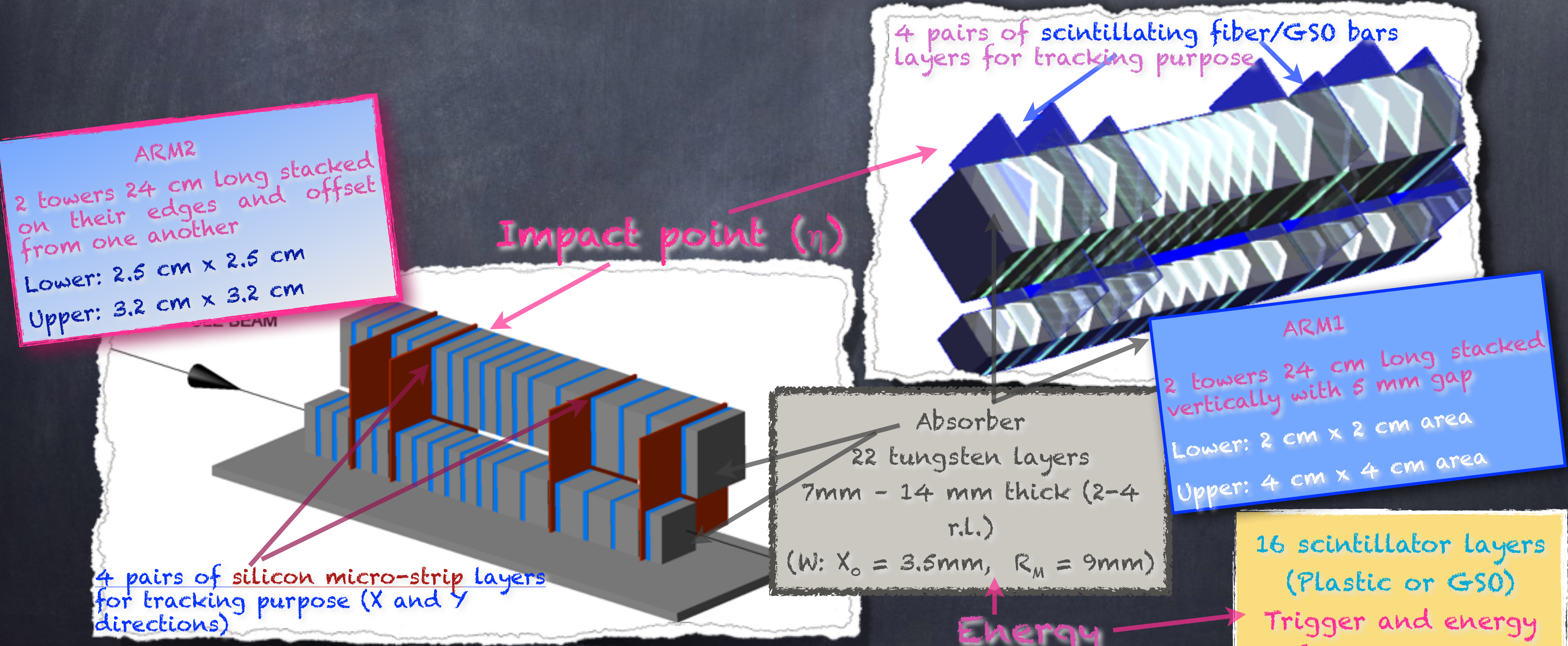


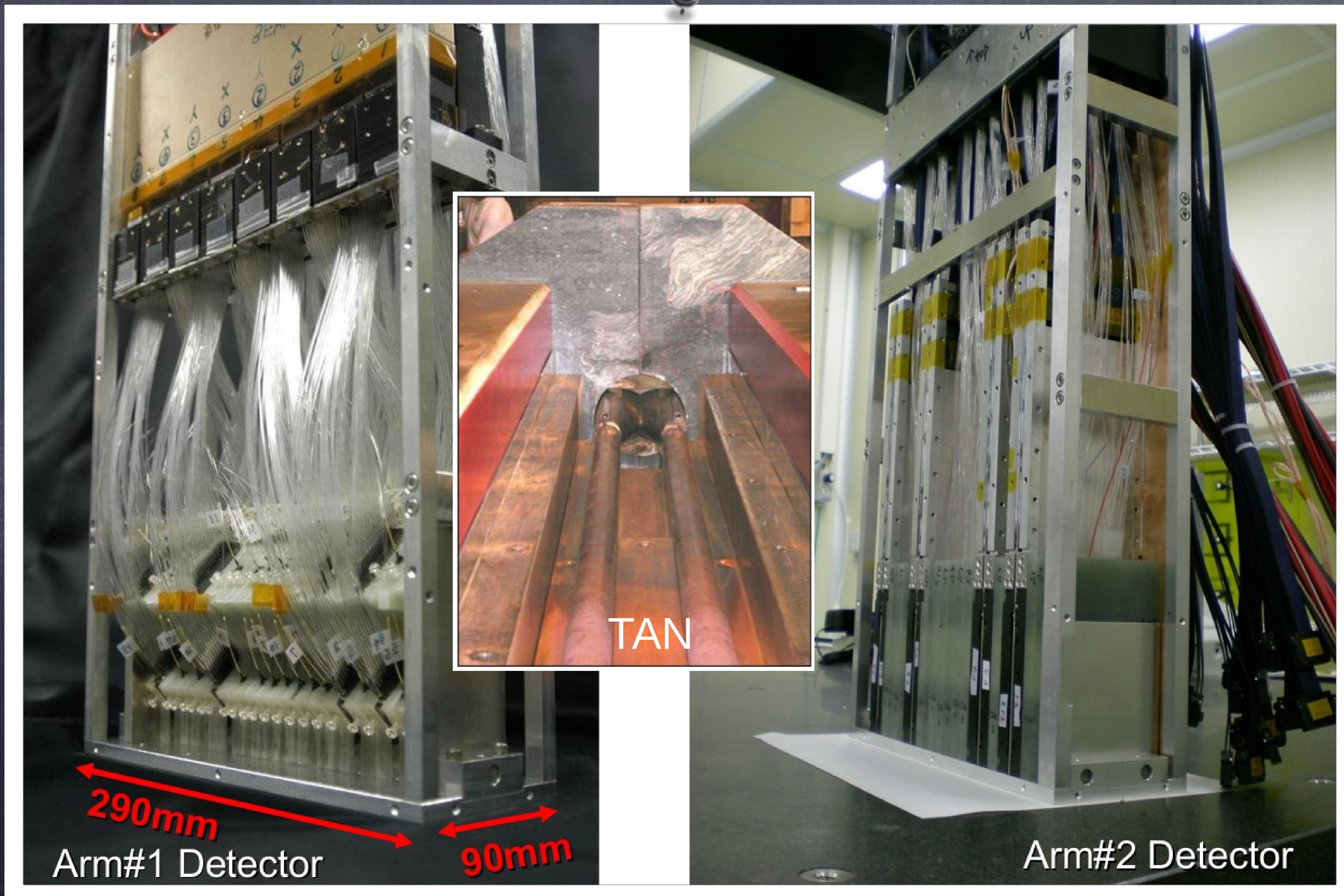


The LHCf Detector





From our photo album...



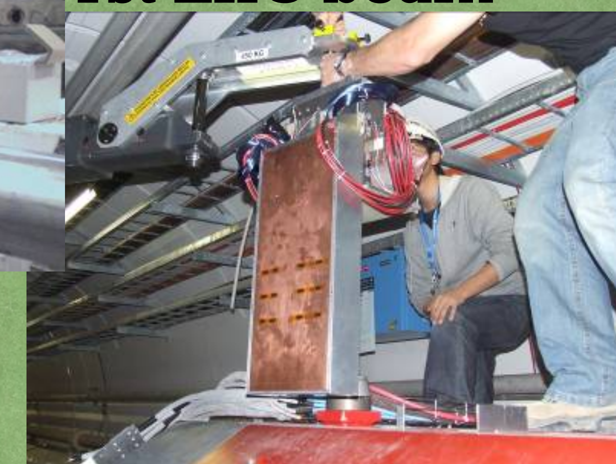
A brief LHCf photo-history

- 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

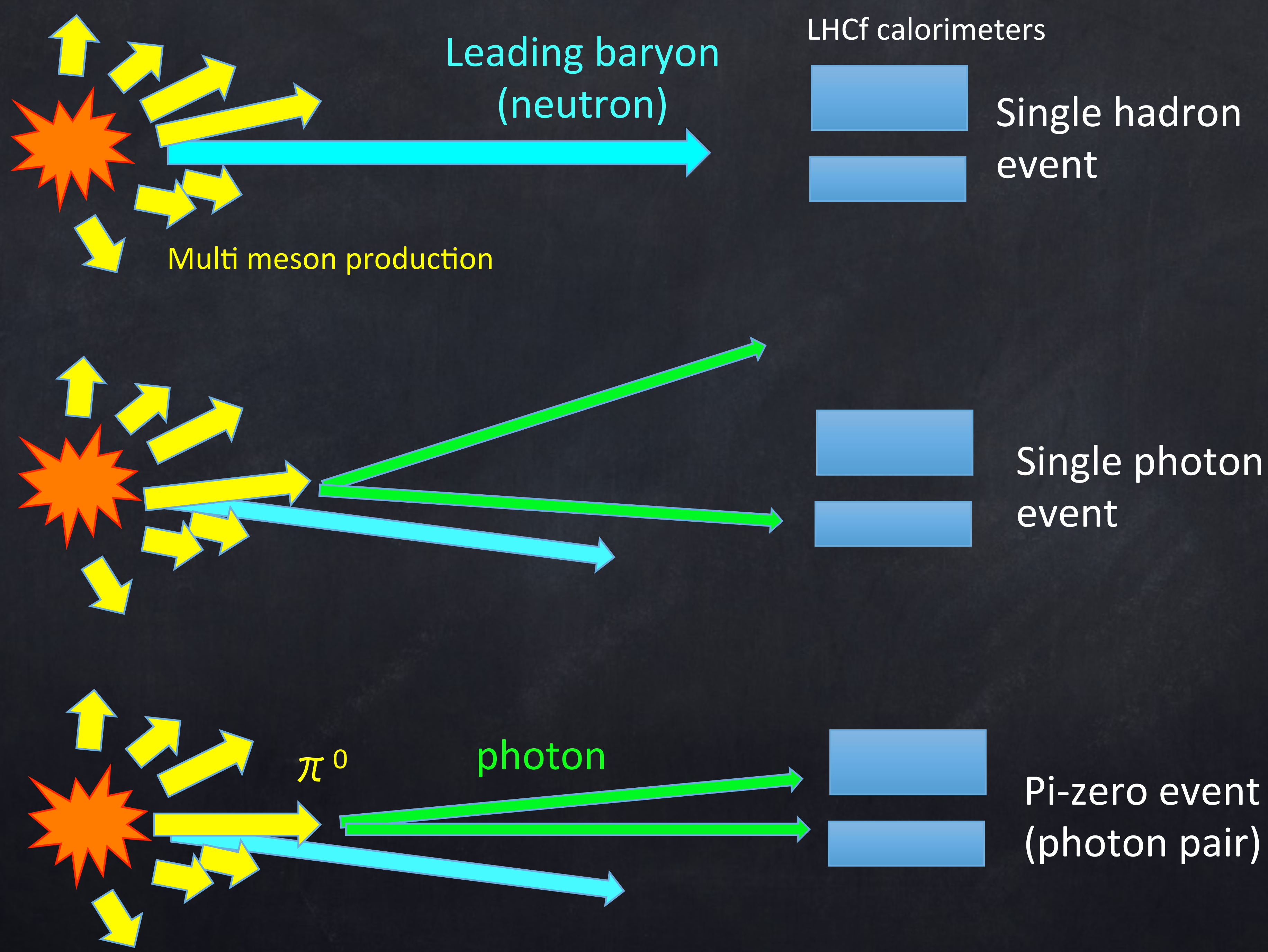


Dec- Jul 2010
0.9TeV& 7TeV pp
Detector removal

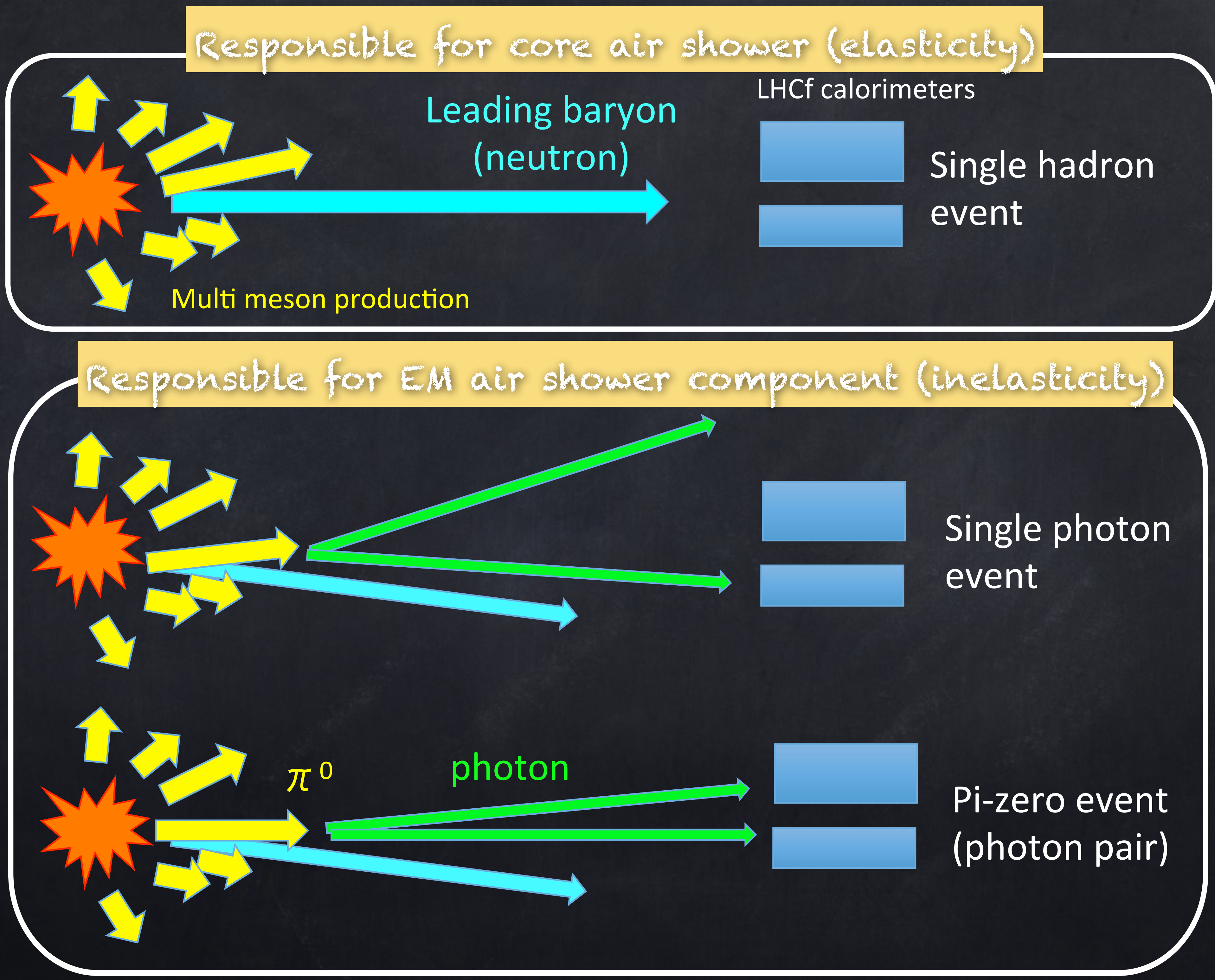
Dec 2012- Feb 2013
5TeV/n pPb, 2.76TeVpp
(Arm2 only)
Detector removal

May-June 2015
13 TeV dedicated pp
Detector removal

Event category in LHCf



Event category in LHCf



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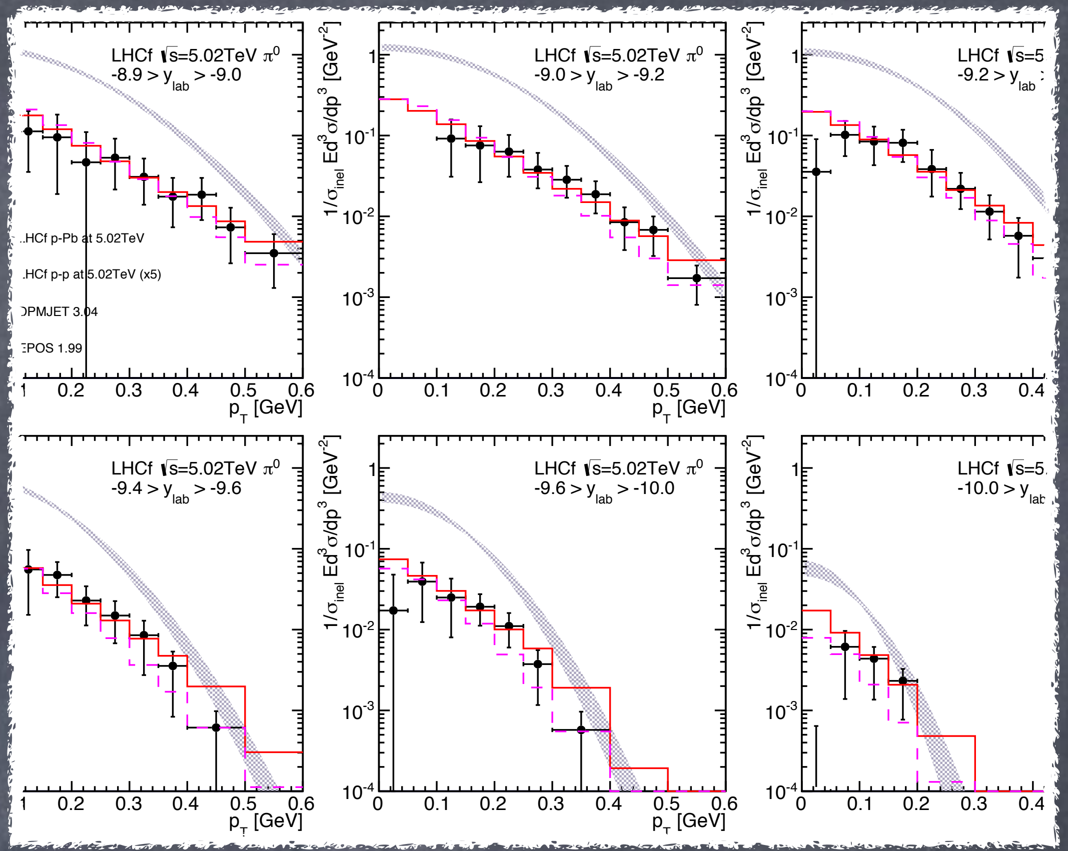
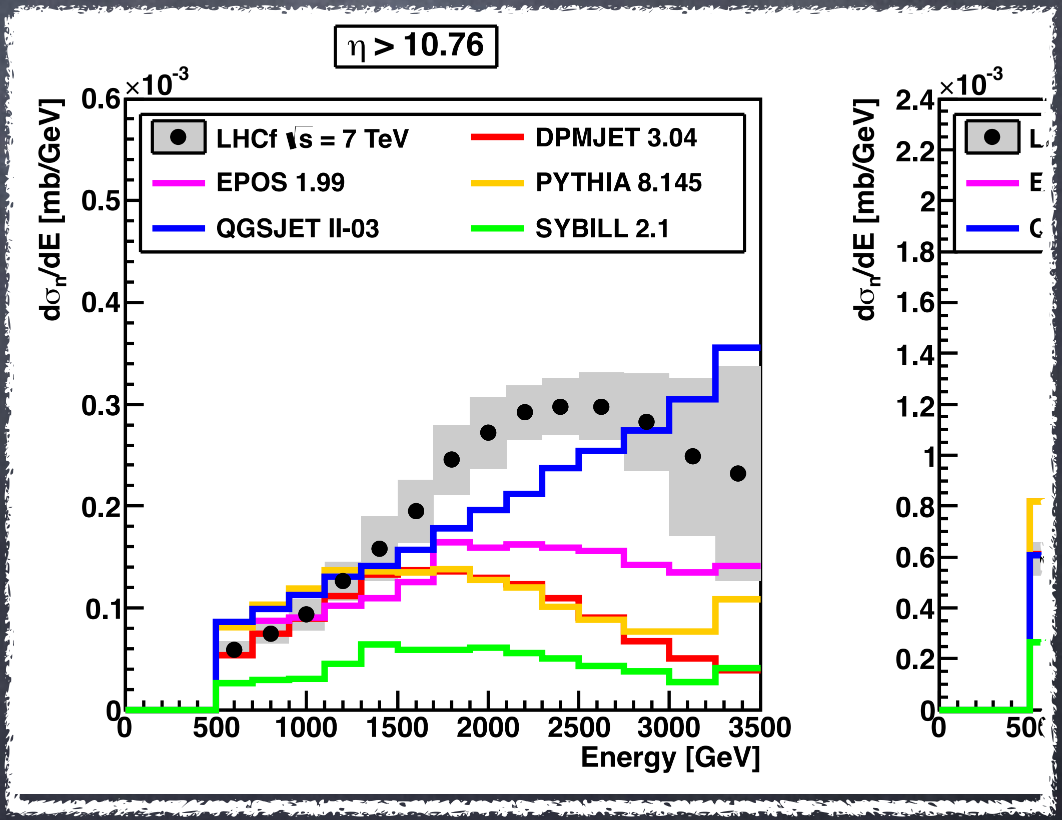


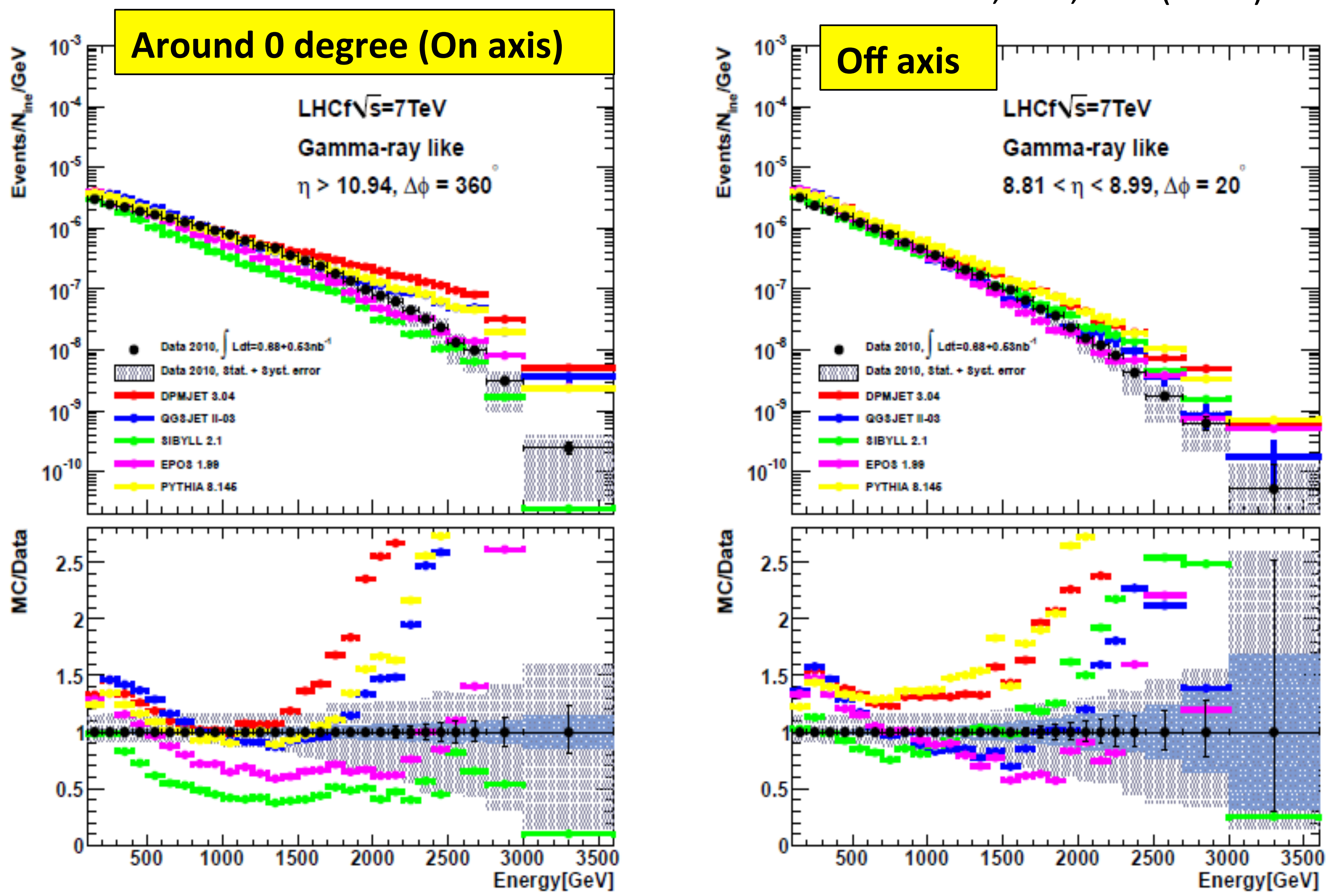


LHCf Data Taking and Analysis matrix

	Proton E	Photon (EM shower)	Neutron (hadron	π (EM shower)	
Test beam at SPS		NIM. A 671, 129-136 (2012)	JINST 9 (2014)P03016		
p-p at 900GeV	4.3x10	Phys. Lett. B 715, 298-303 (2012)			Run1
p-p at 7TeV	2.6x10	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	Run1
p-p at 2.76TeV	4.1x10			Phys. Rev. C 89, 065209 (2014)+ Phys. Rev. D 94, 032007(2016) Type II	Run2
p-Pb at 5.02TeV	1.3x10				Run2
p-p at 13TeV	9.0x10	Data taken in June 2015 dedicated run! Analysis activity ongoing...			Run3
p-Pb at 8.1 TeV	3.6x10	Letter of Intent submitted March 2016 — Approved!!!			Run4

LHCf @ pp 7TeV: Single photon spectra MC vs Data

Adriani et al., PLB, 703 (2011) 128-134

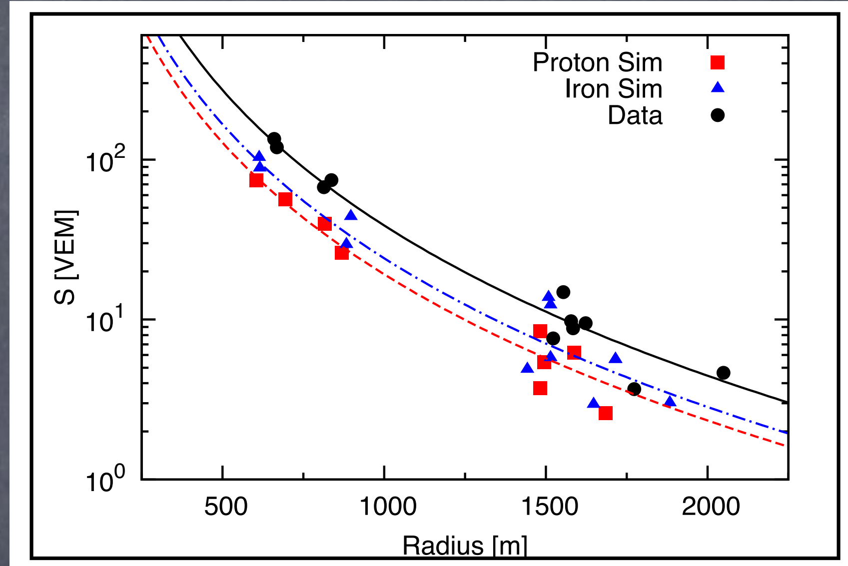


DPMJET 3.04 QGSJET II-03 SIBYLL 2.1 EPOS 1.99 PYTHIA 8.145

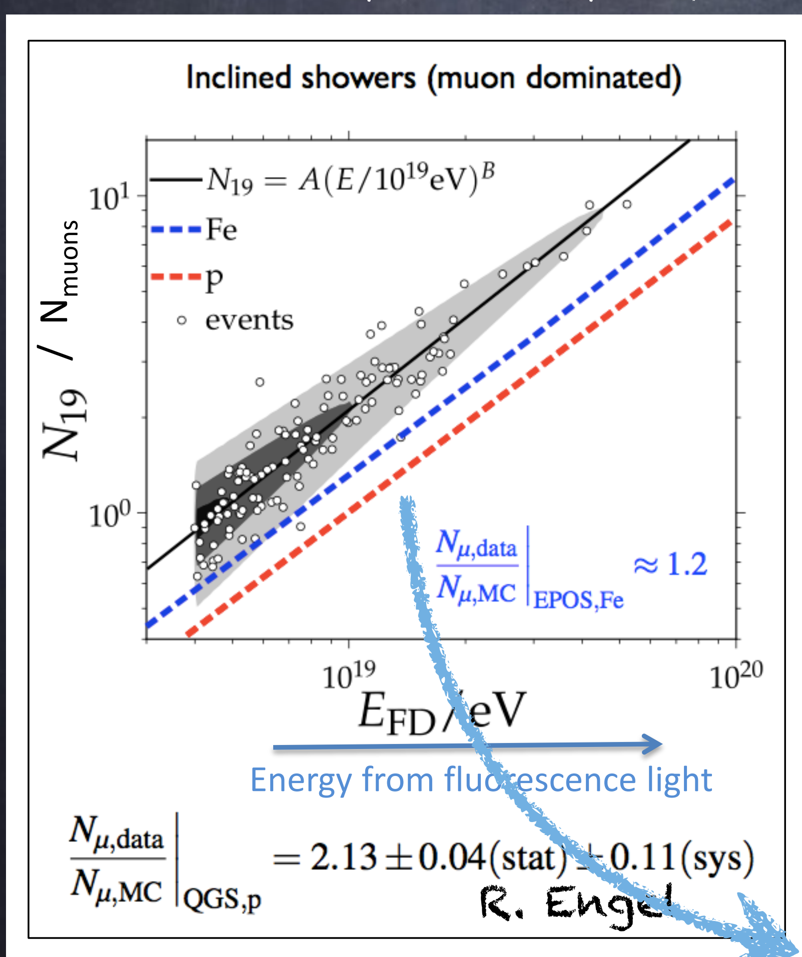
LHCf @ pp 7 TeV: neutron analysis

Motivations:

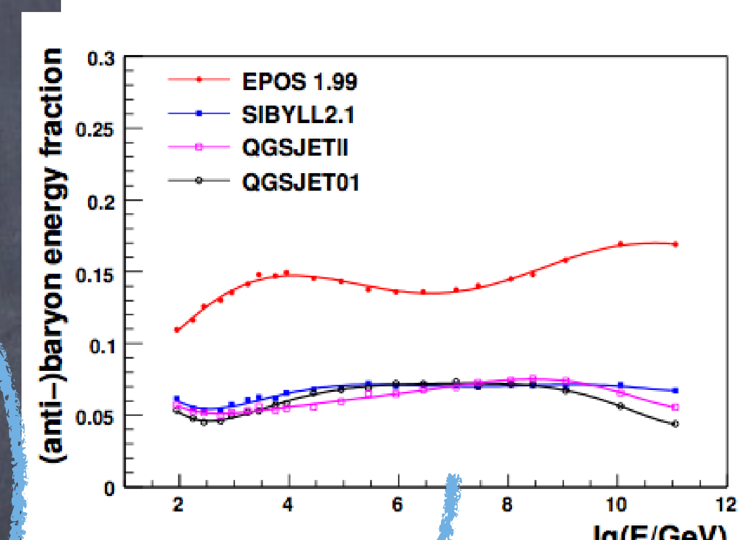
- Inelasticity measurement $k=1-p_{leading}/p_{beam}$
- Muon excess at Pierre Auger Observatory
  - cosmic rays experiment measure PCR energy from muon number at ground and florescence light
  - 20-100% more muons than expected have been observed



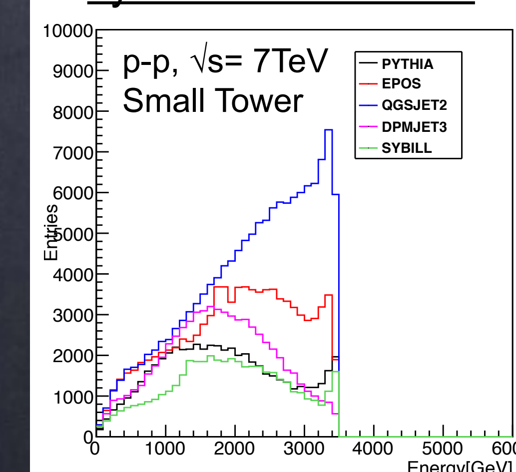
[J.Allen, et al. ICRC2011 Proceedings]



- Number of muons depends on the energy fraction of produced hadron
- Muon excess in data even for Fe primary MC
- EPOS predicts more muon due to larger baryon production

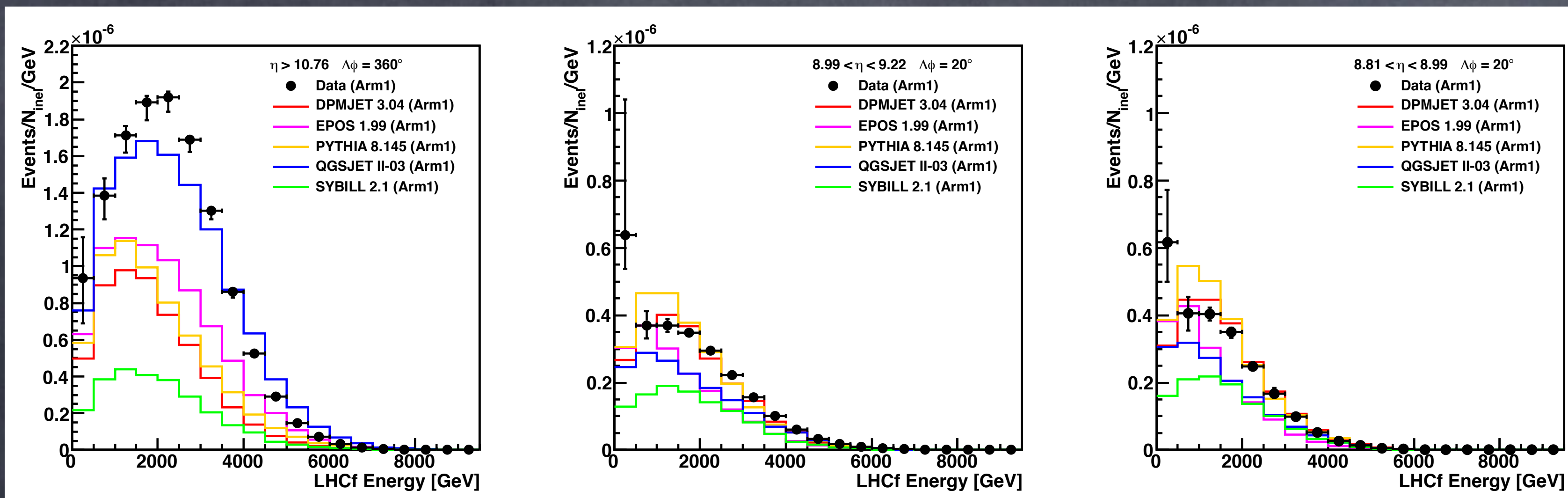


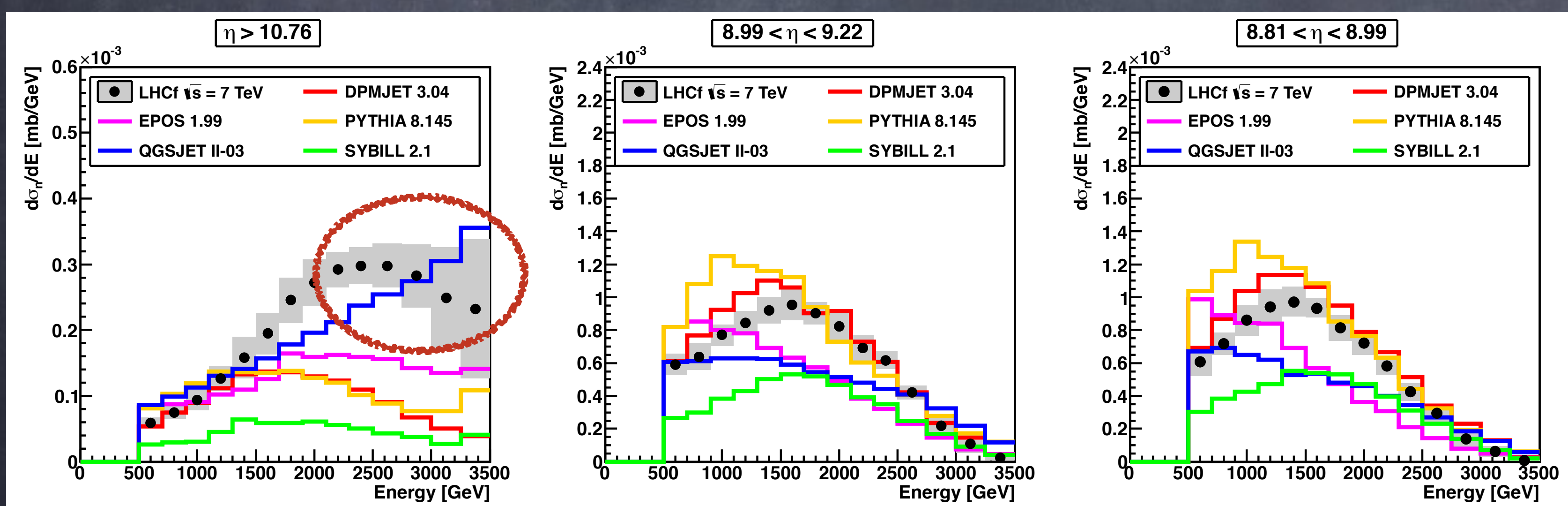
Neutron spectra predicted by interaction models



importance of baryon measurement

LHCf @ pp 7 TeV: neutron spectra





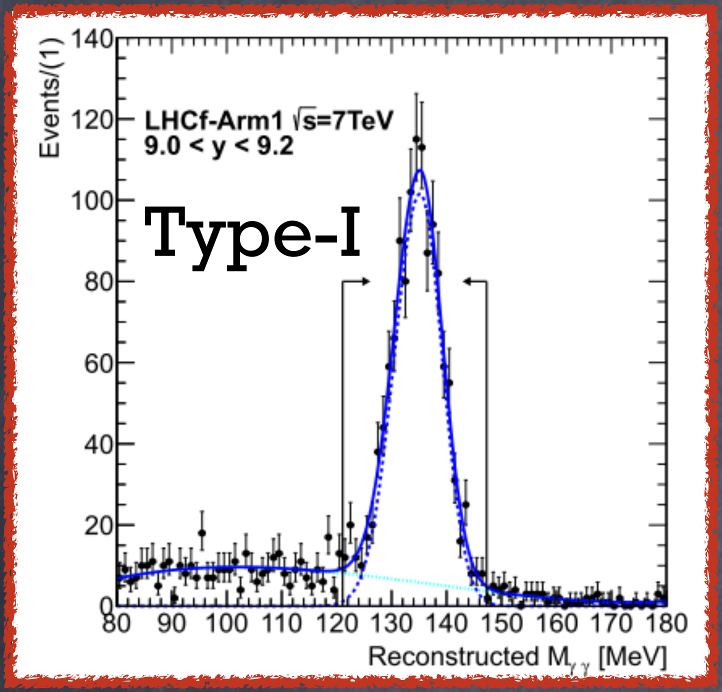
n/γ ratio

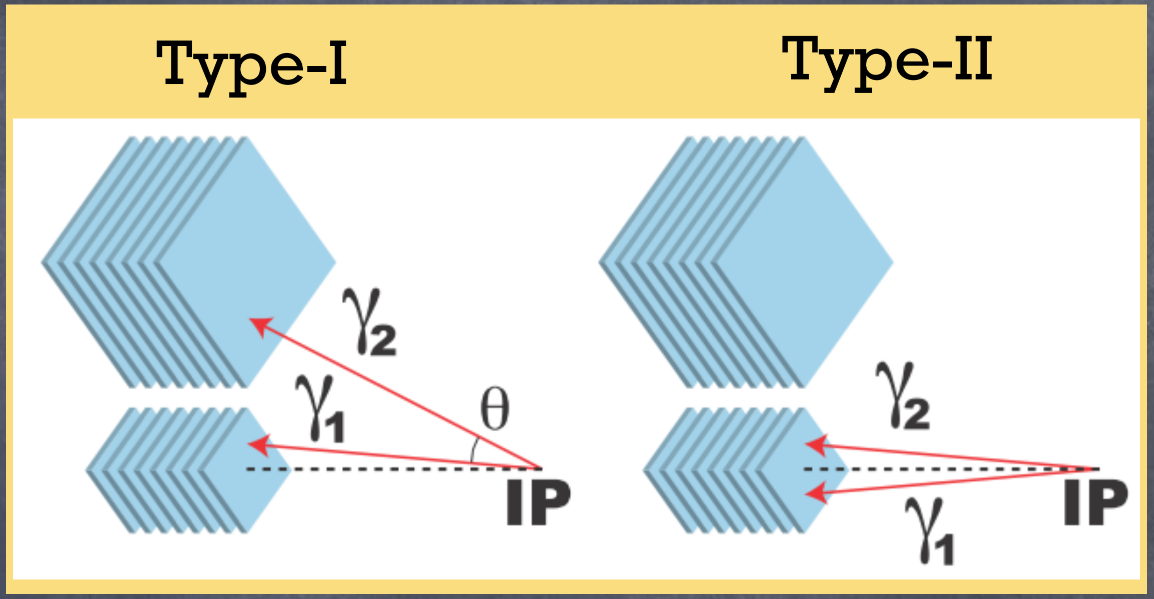
Data (	3.05±0.19
DPMJET3.04	1.05
EPOS 1.99	1.80
PYTHIA 8.145	1.27
QGSJET II-03	2.34
SYBILL 2.1	0.88

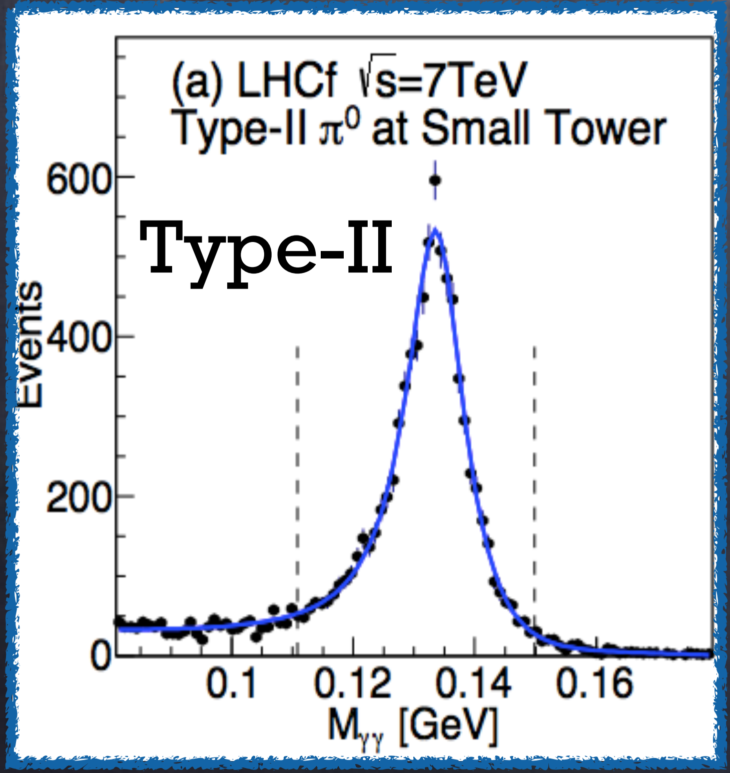
Data (8.99<	1.26±0.08
DPMJET3.04	0.76
EPOS 1.99	0.69
PYTHIA 8.145	0.82
QGSJET II-03	0.65
SYBILL 2.1	0.57

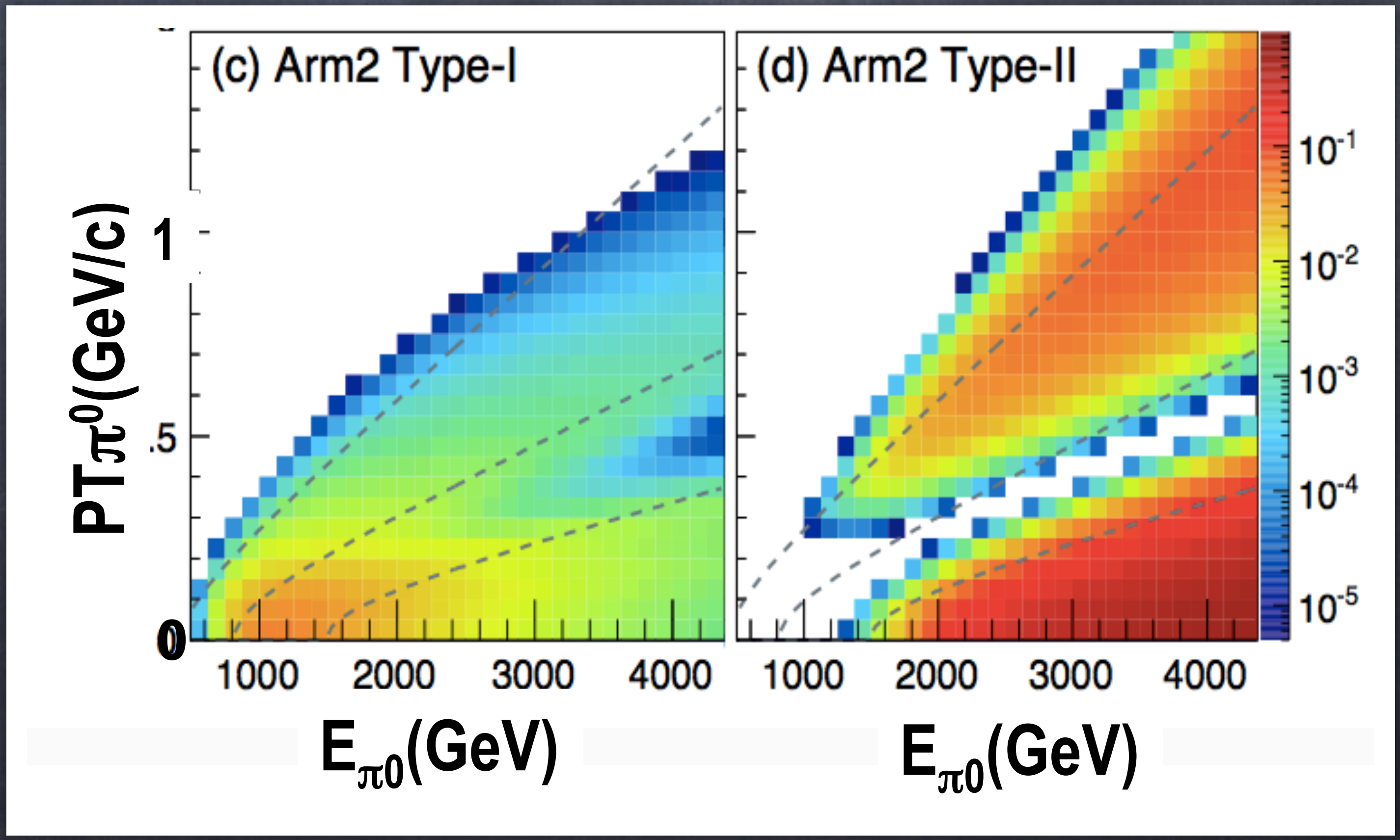
- LHCf Arm1 and Arm2 agree with each other within systematic error, in which the energy scale uncertainty dominates.
- In η>10.76 huge amount of neutron exists. Only QGSJET2 reproduces the LHCf result.
- In other rapidity regions, the LHCf results are enclosed by the variation of models.

LHCf Type I and Type II π°analysis

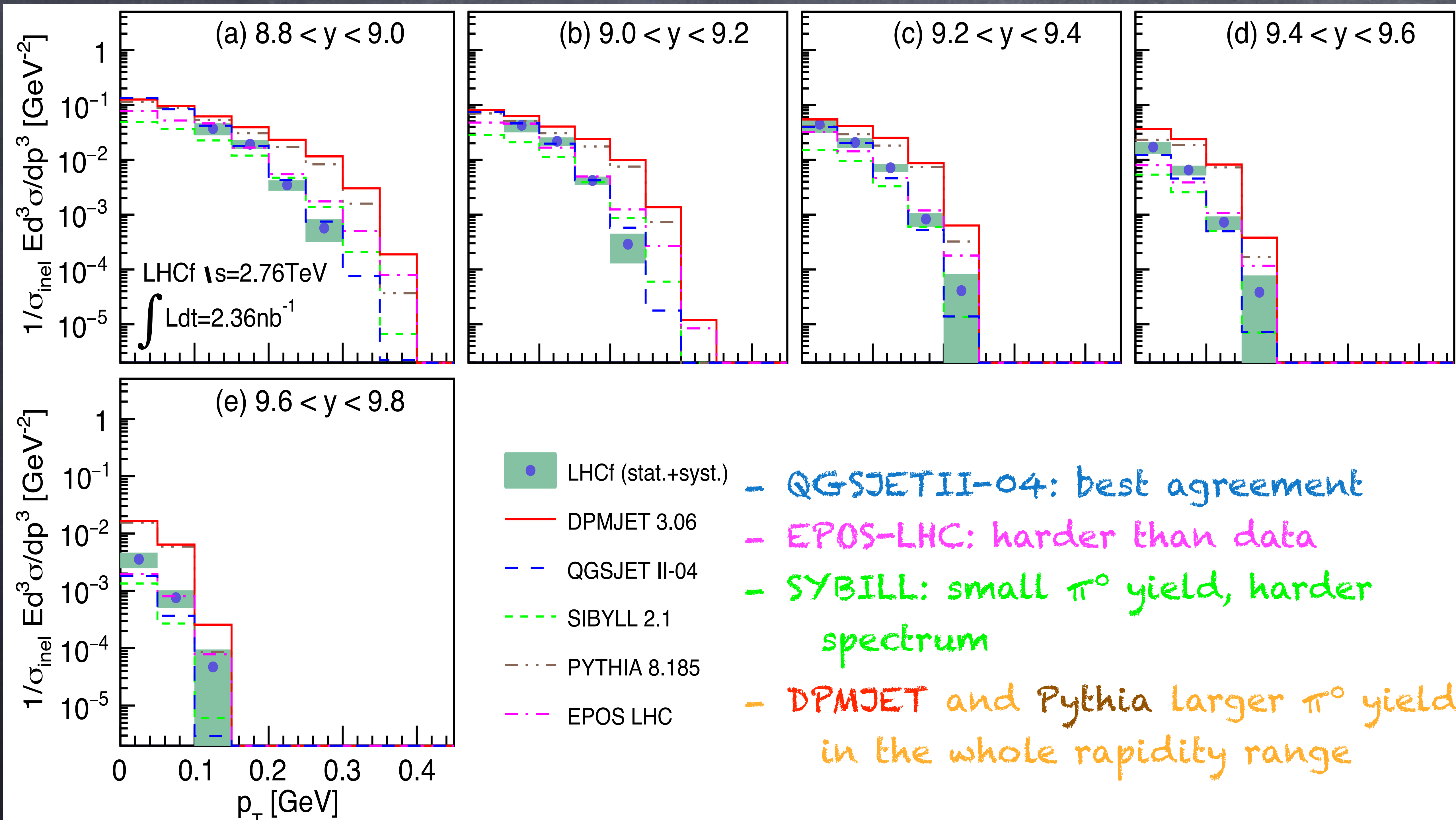






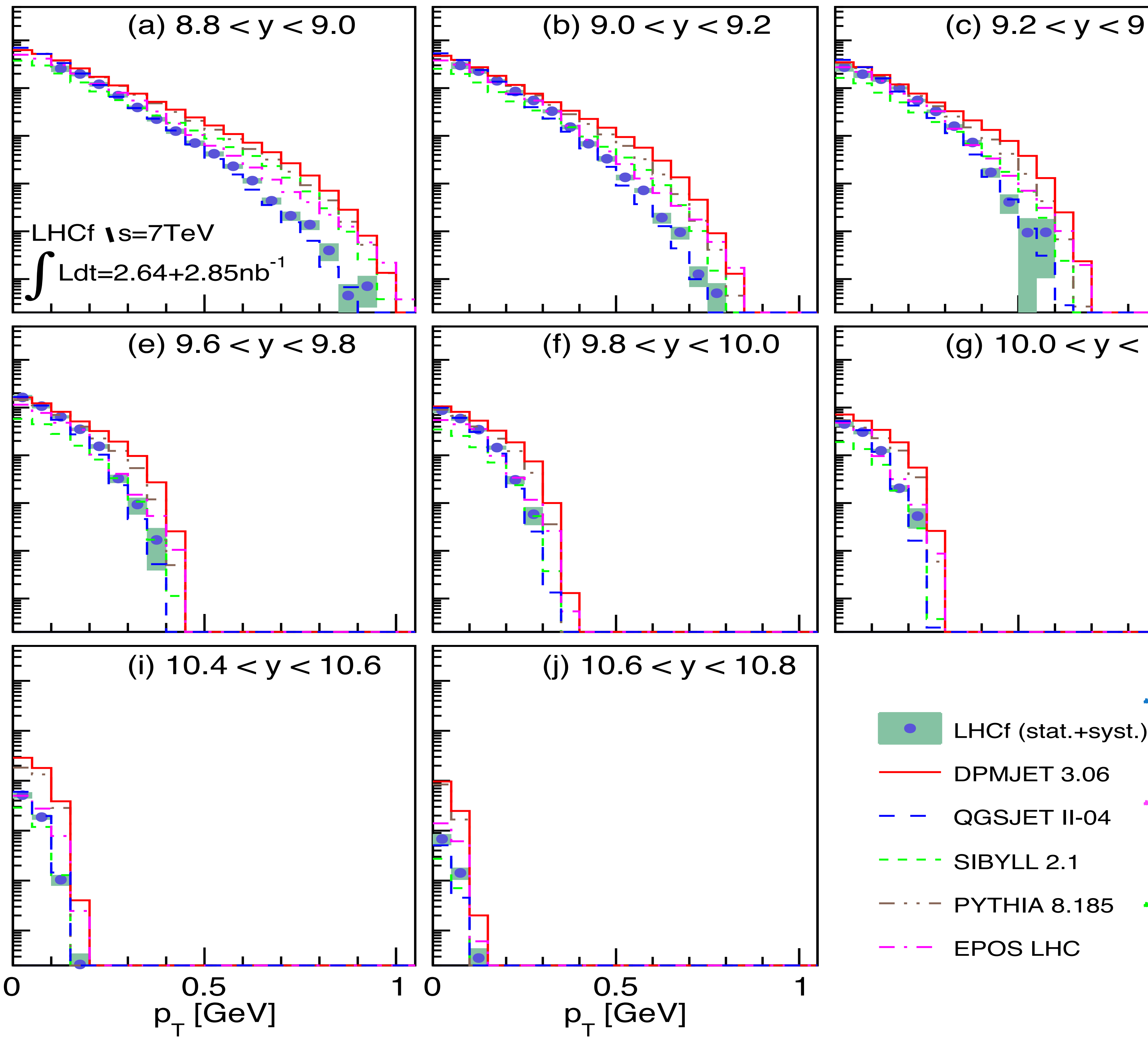


LHCf @ pp 2.76 TeV: π^0 p_T spectra



- QGSJETII-04: best agreement
- EPOS-LHC: harder than data
- SYBILL: small π^0 yield, harder spectrum
- DPMJET and Pythia larger π^0 yield in the whole rapidity range

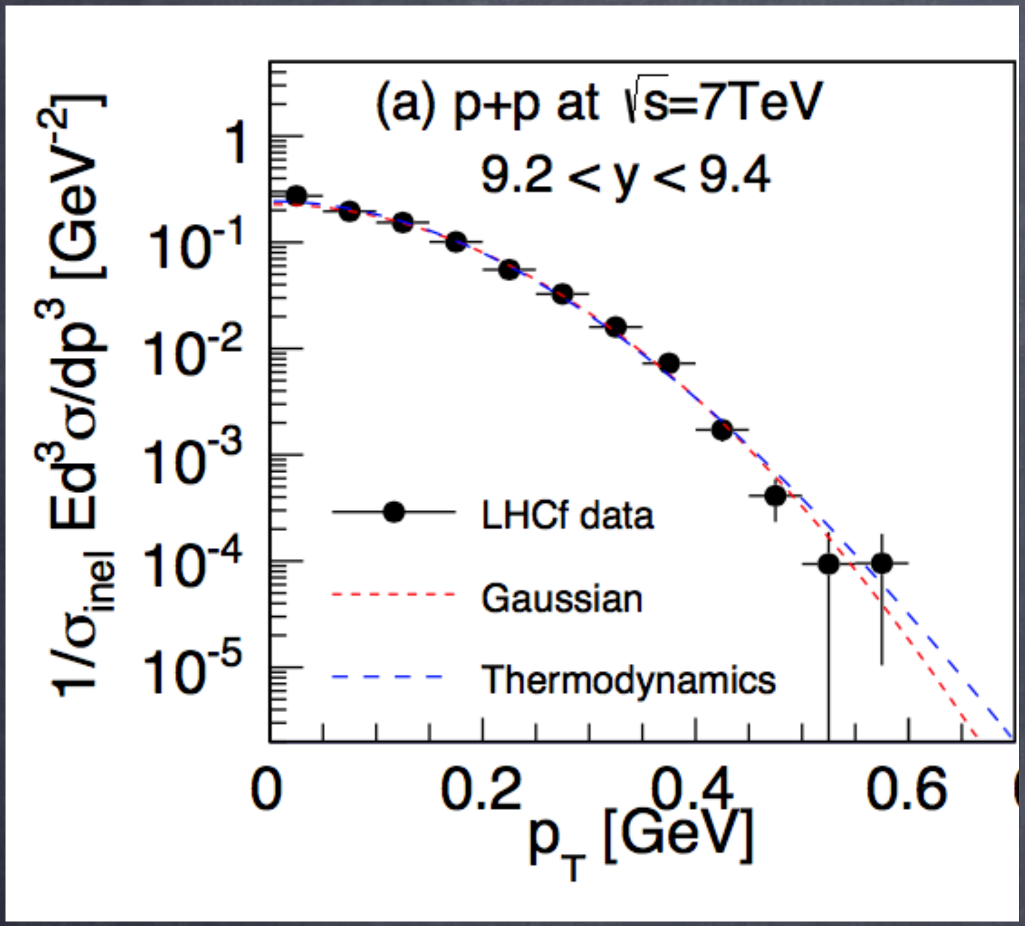
LHCf @ pp 7 TeV: π^0 p_T spectra



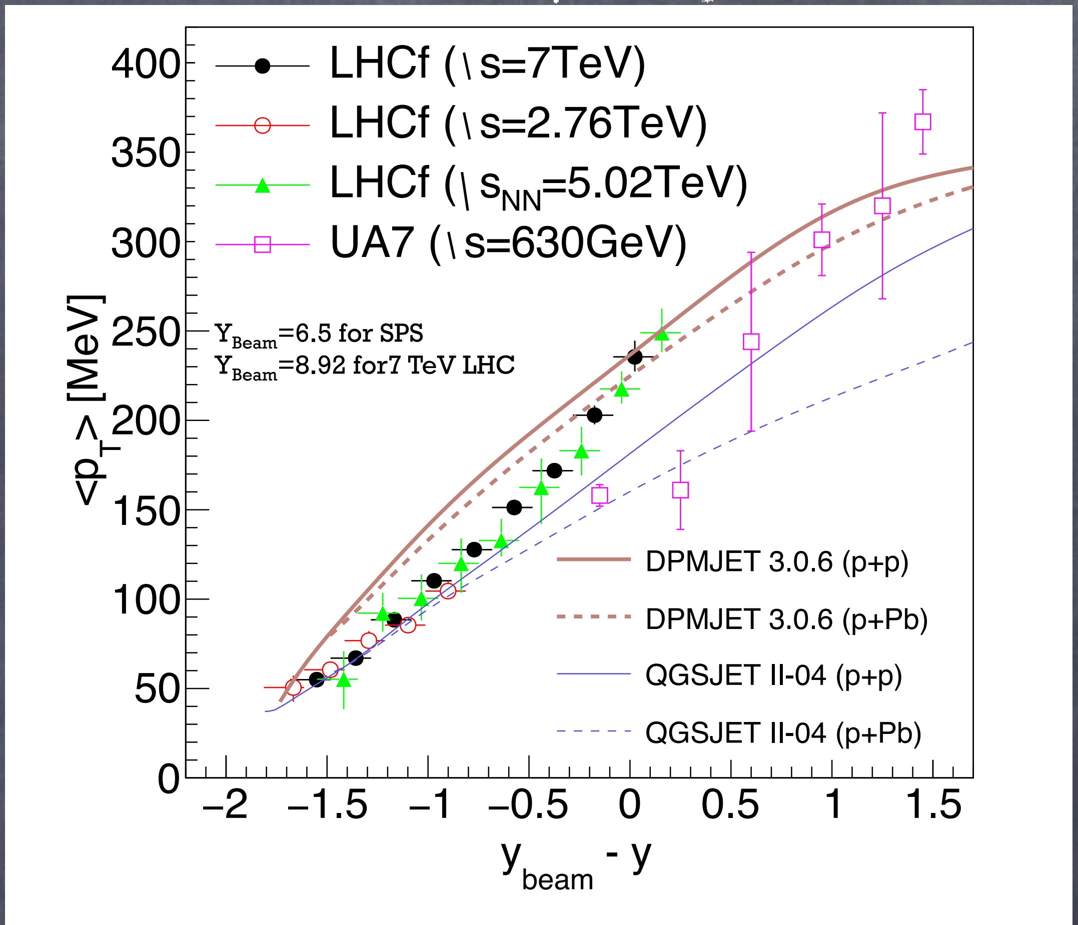
- QGSJETII-04: best agreement
- EPOS-LHC: harder than data for large p_T
- SYBILL: good agreement only for small y

π^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

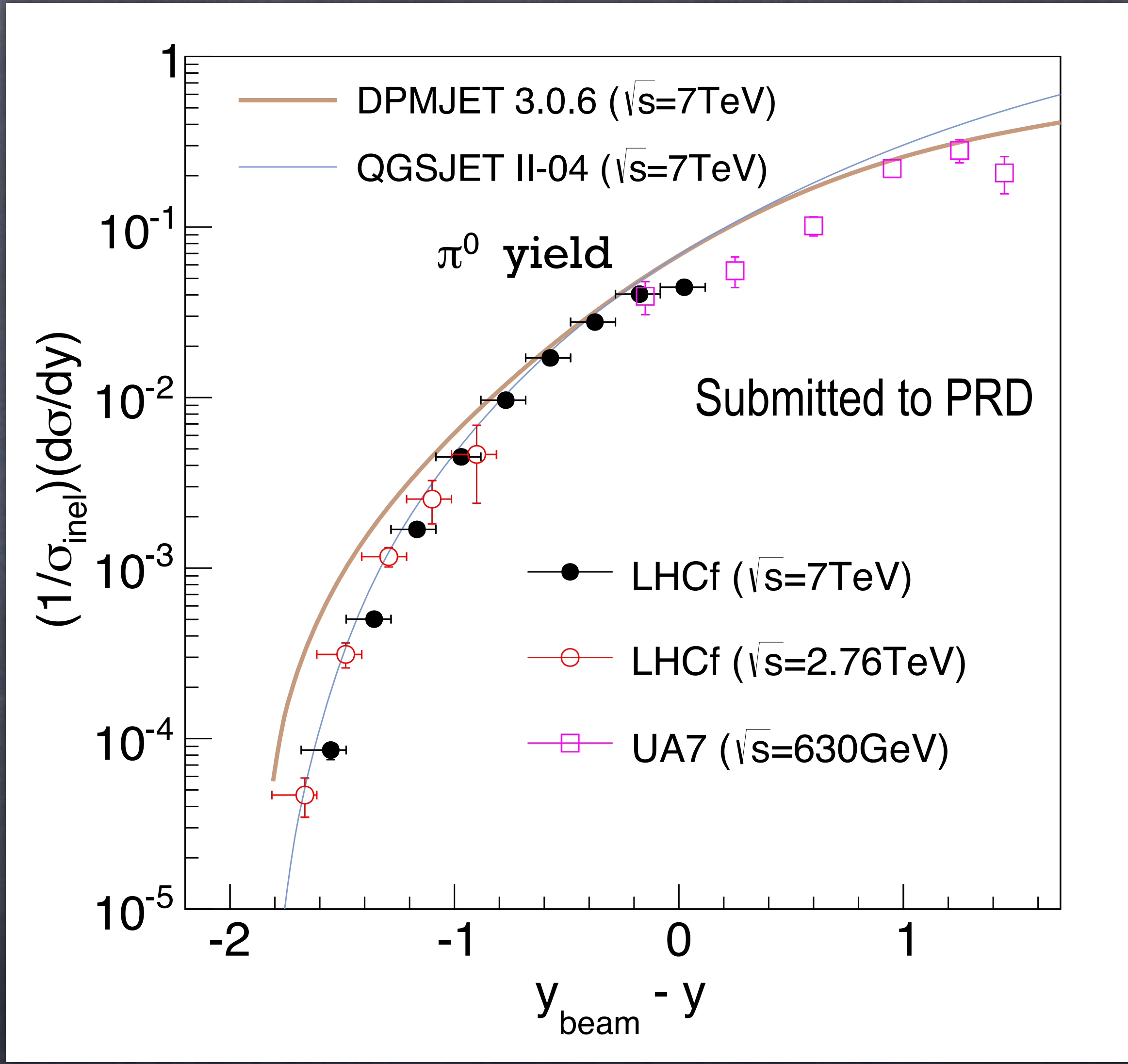
From scaling considerations (projectile fragmentation region) we can expect that <p_T> vs rapidity loss should be independent from the c.m. energy

Reasonable scaling can be inferred from the data

Limiting fragmentation in forward π^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.

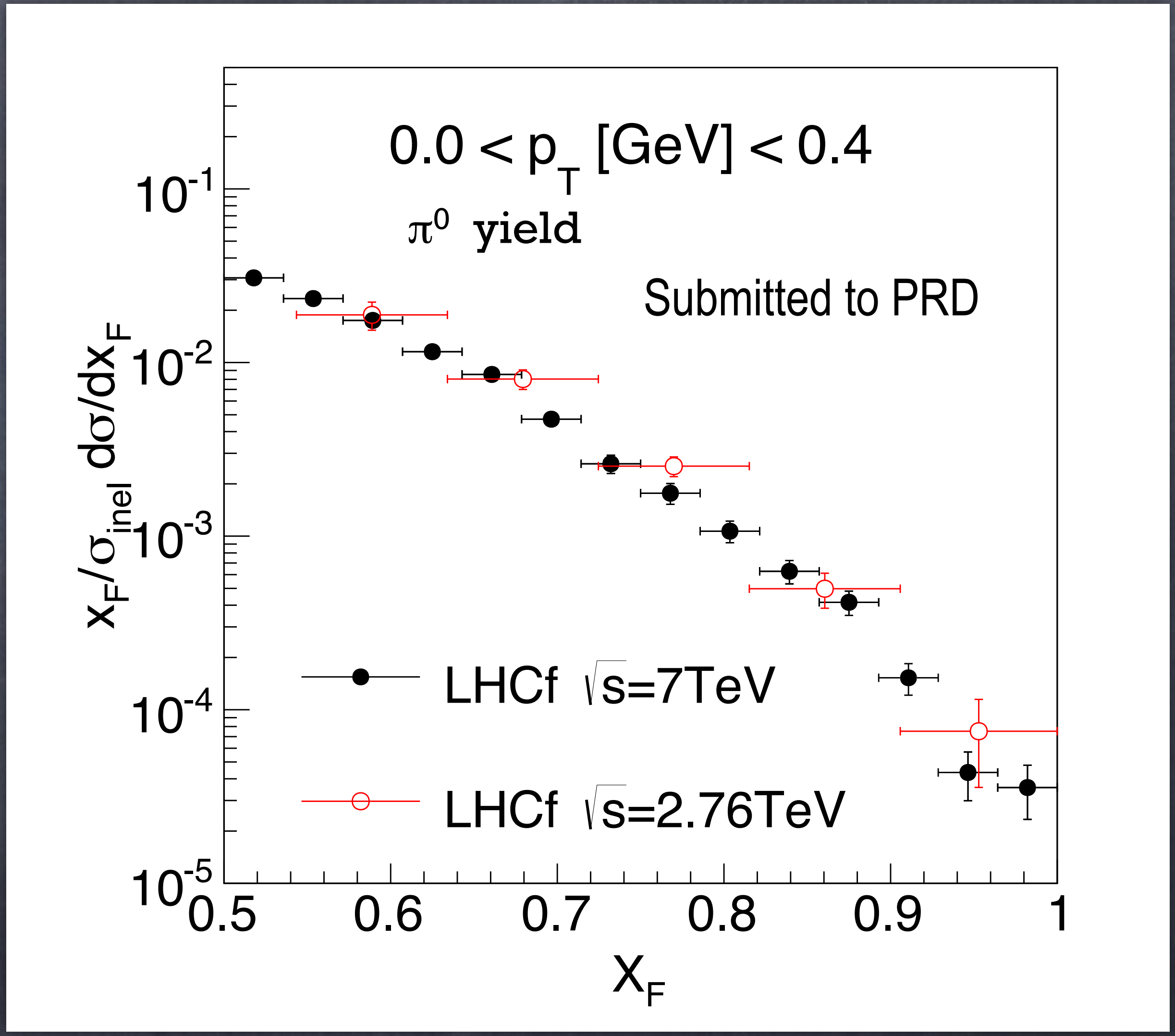
This hypothesis for π^0 is true at the level of ±15%



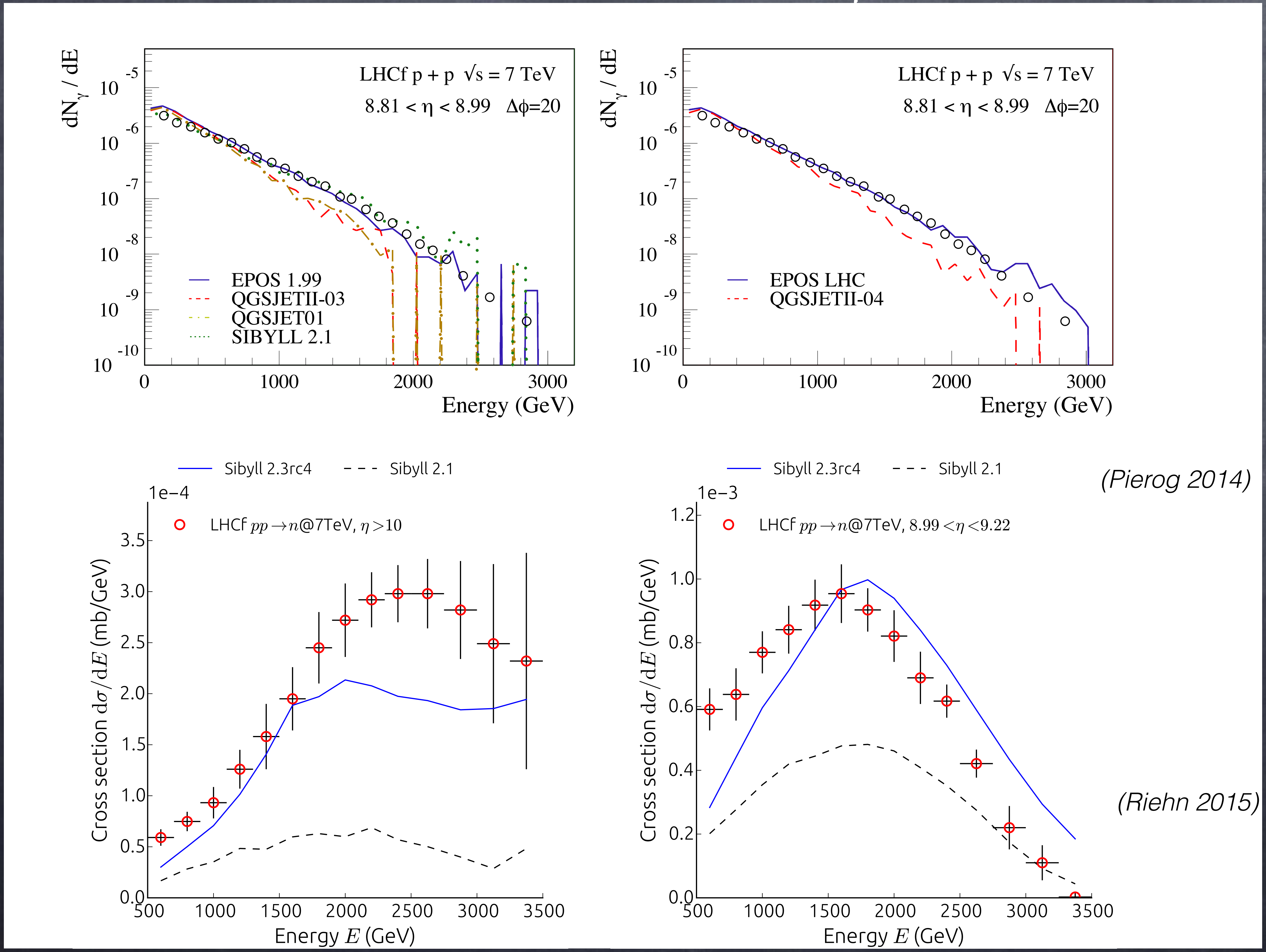
Feynman scaling in forward π^0 production

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 π^0 is true at the level of ±20%

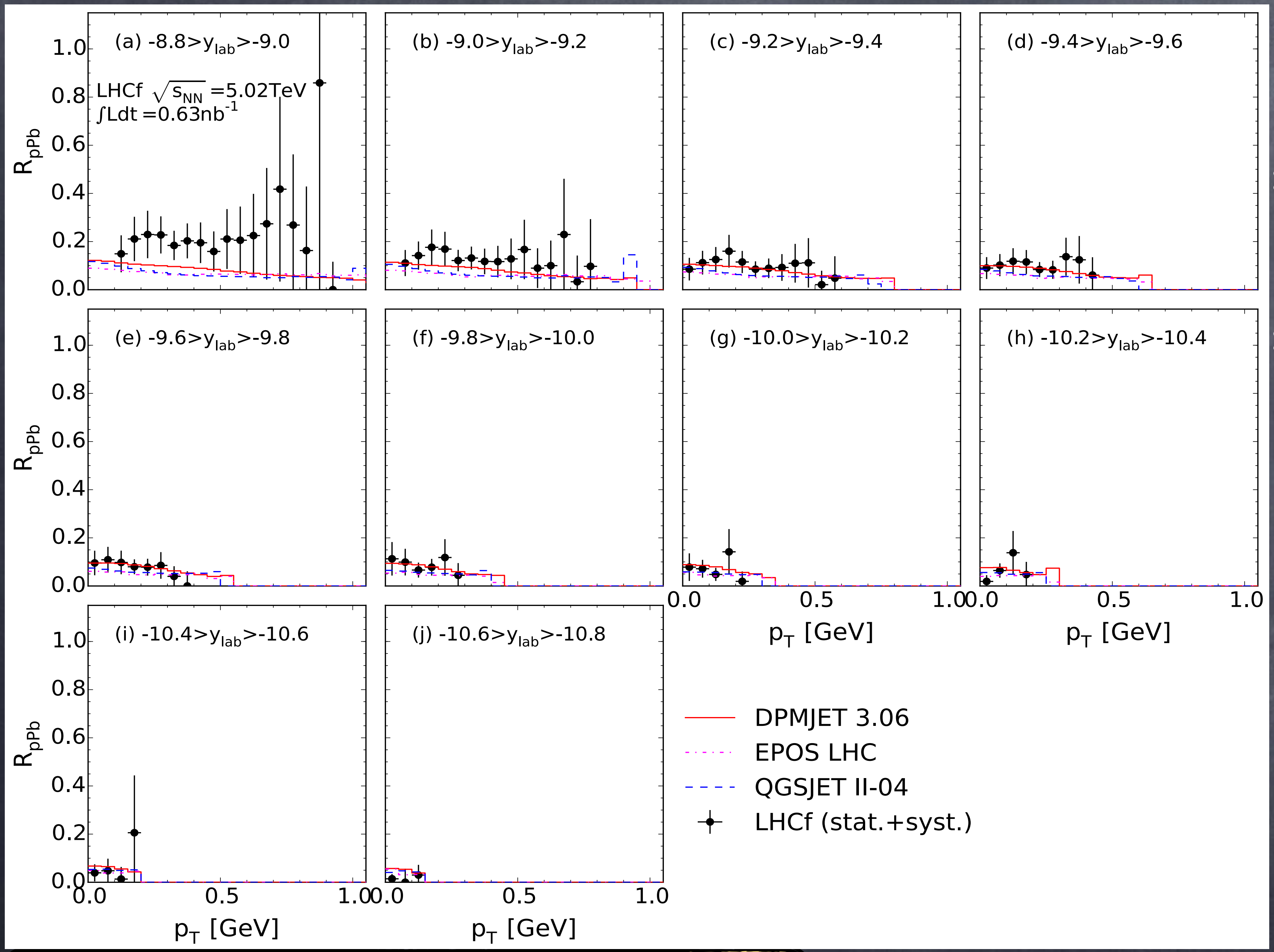


Tuning of hadronic interaction model with LHCf data

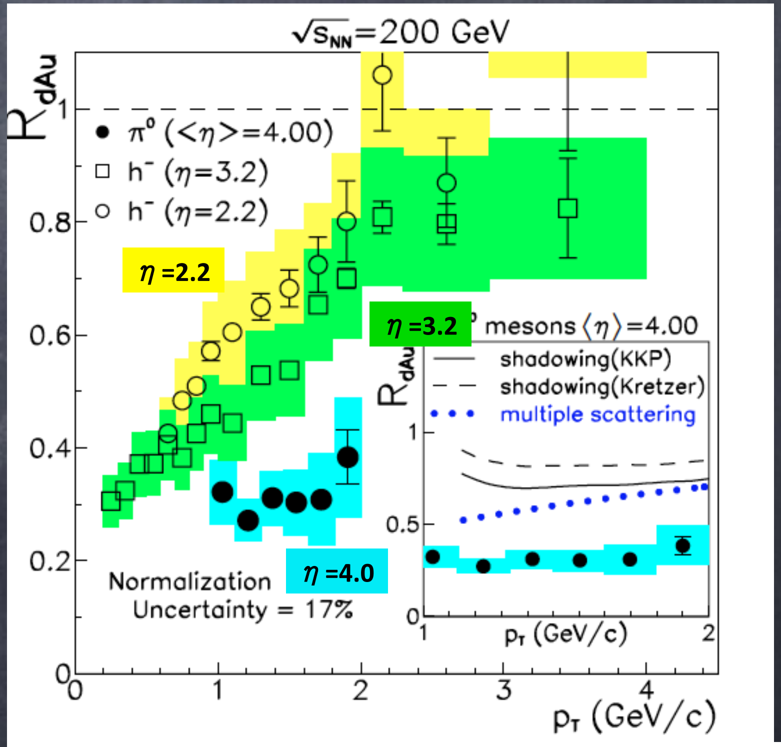


R. Engel
CRIS2016

LHCf @ pPb 5.02 TeV: Nuclear modification factor



- LHCf show strong suppression in pPb wrt pp collisions
- Good agreement with the models

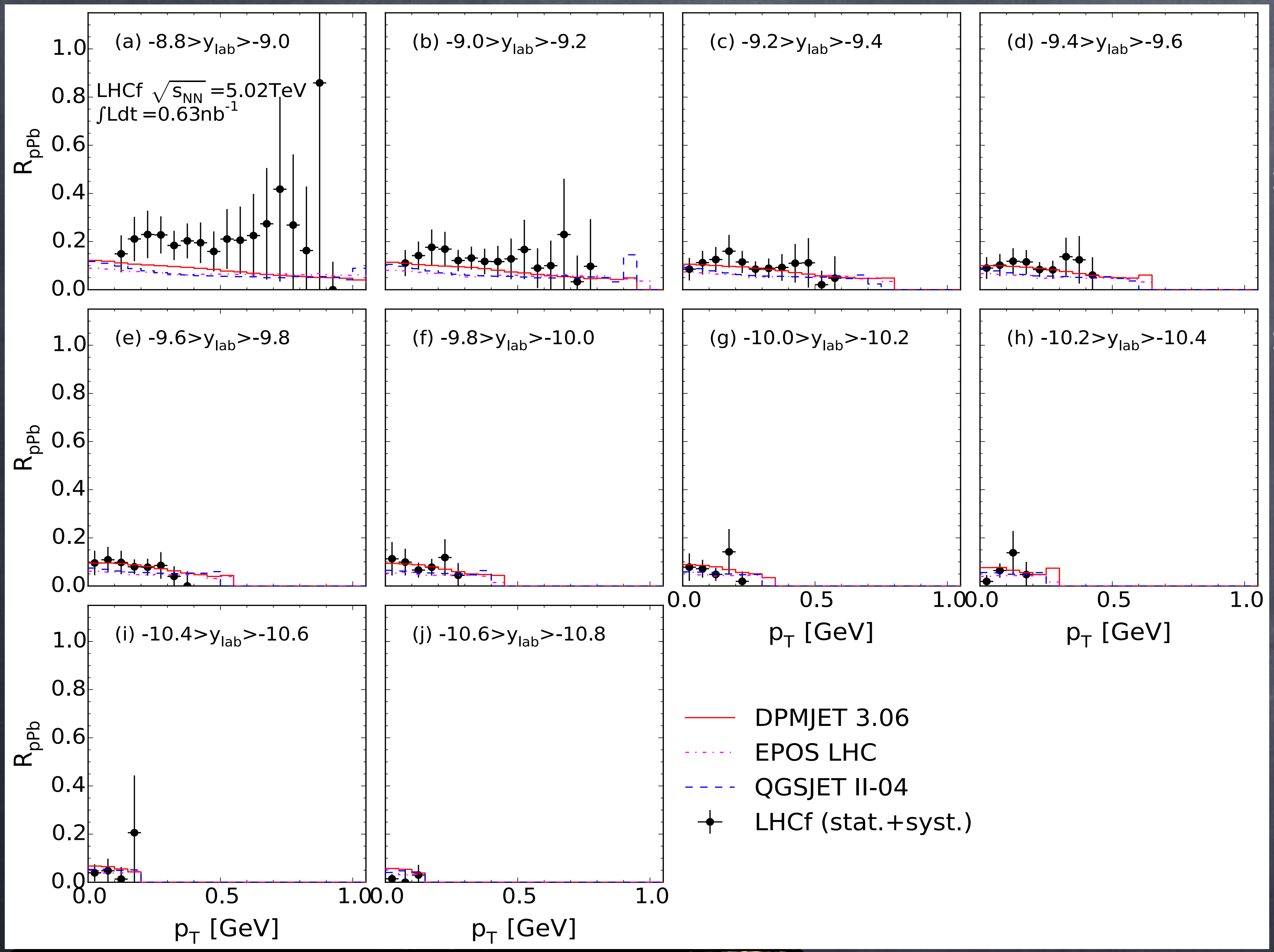


RHIC 200GeV d-Au, STAR Collaboration
Adams et al., PRL 97 (2006) 152302.

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

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

LHCf @ pPb 5.02 TeV: Nuclear modification factor



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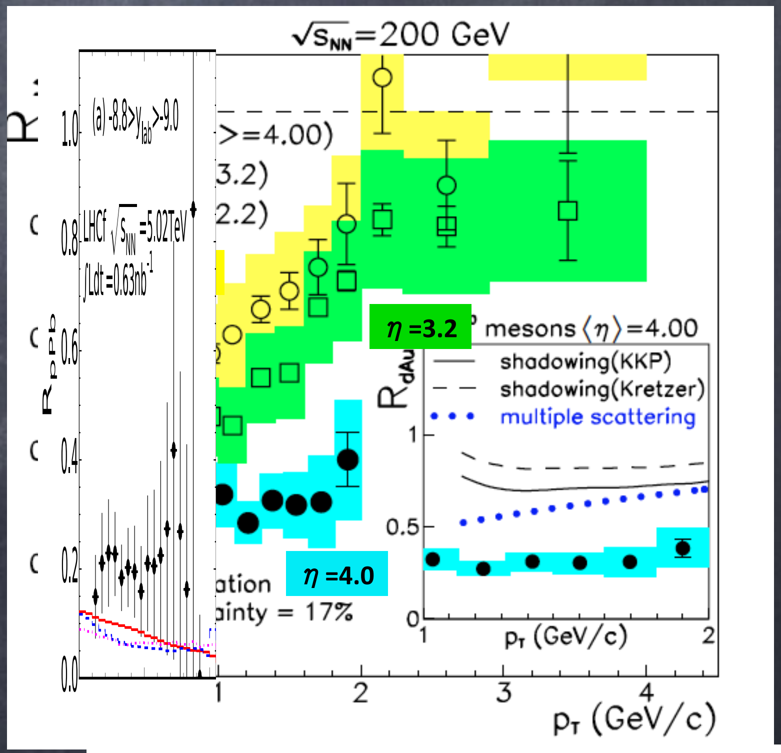
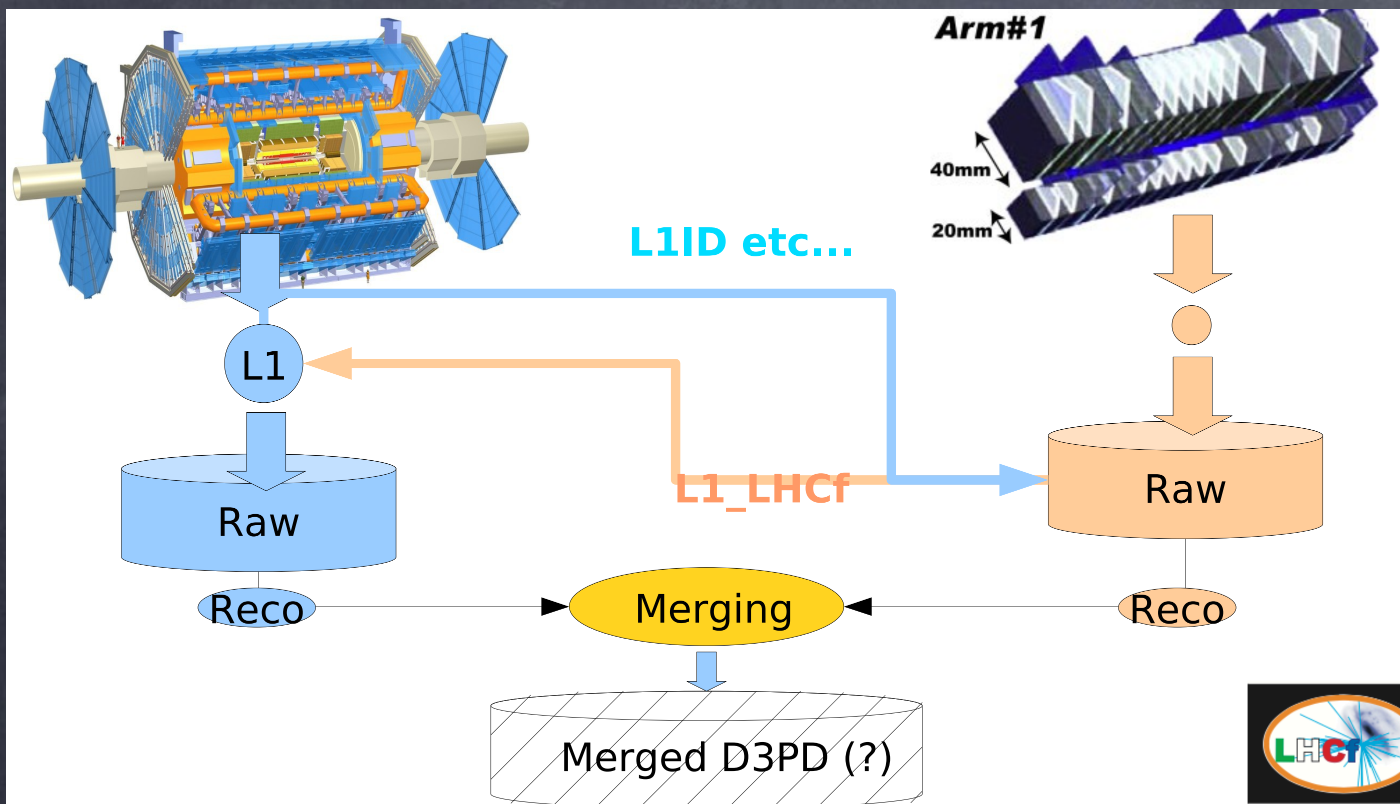
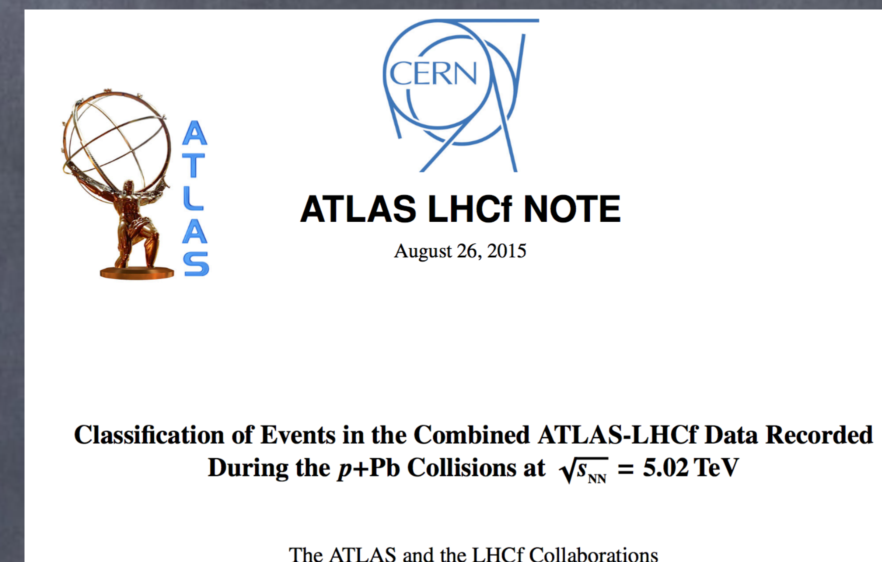


RHIC 200GeV d-Au, STAR Collaboration Adams et al., PRL 97 (2006) 152302.

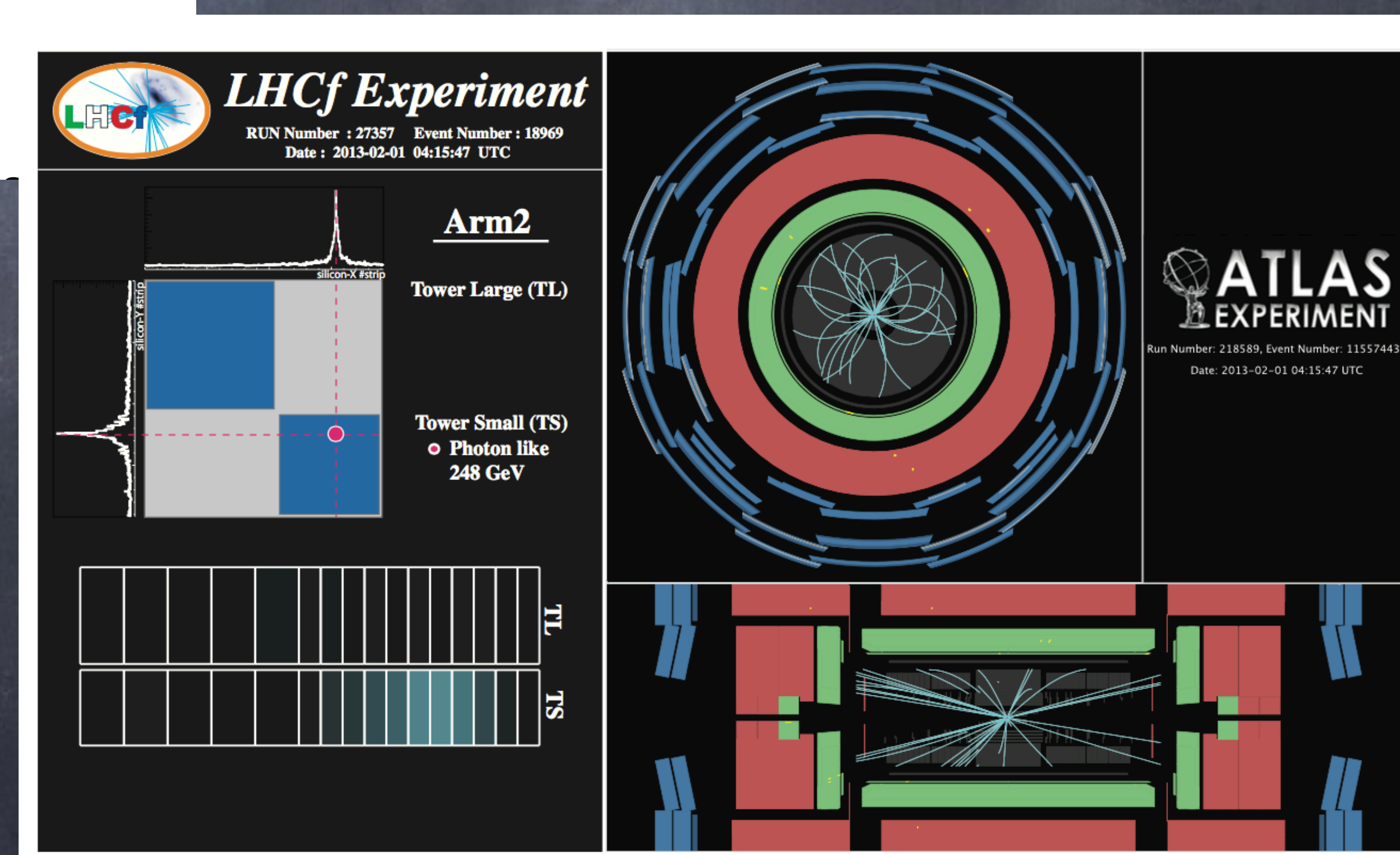
Common trigger with ATLAS




ATLAS
CERN
ATLAS LHCf NOTE
August 26, 2015

Classification of Events in the Combined ATLAS-LHCf Data Recorded During the *p*+Pb Collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

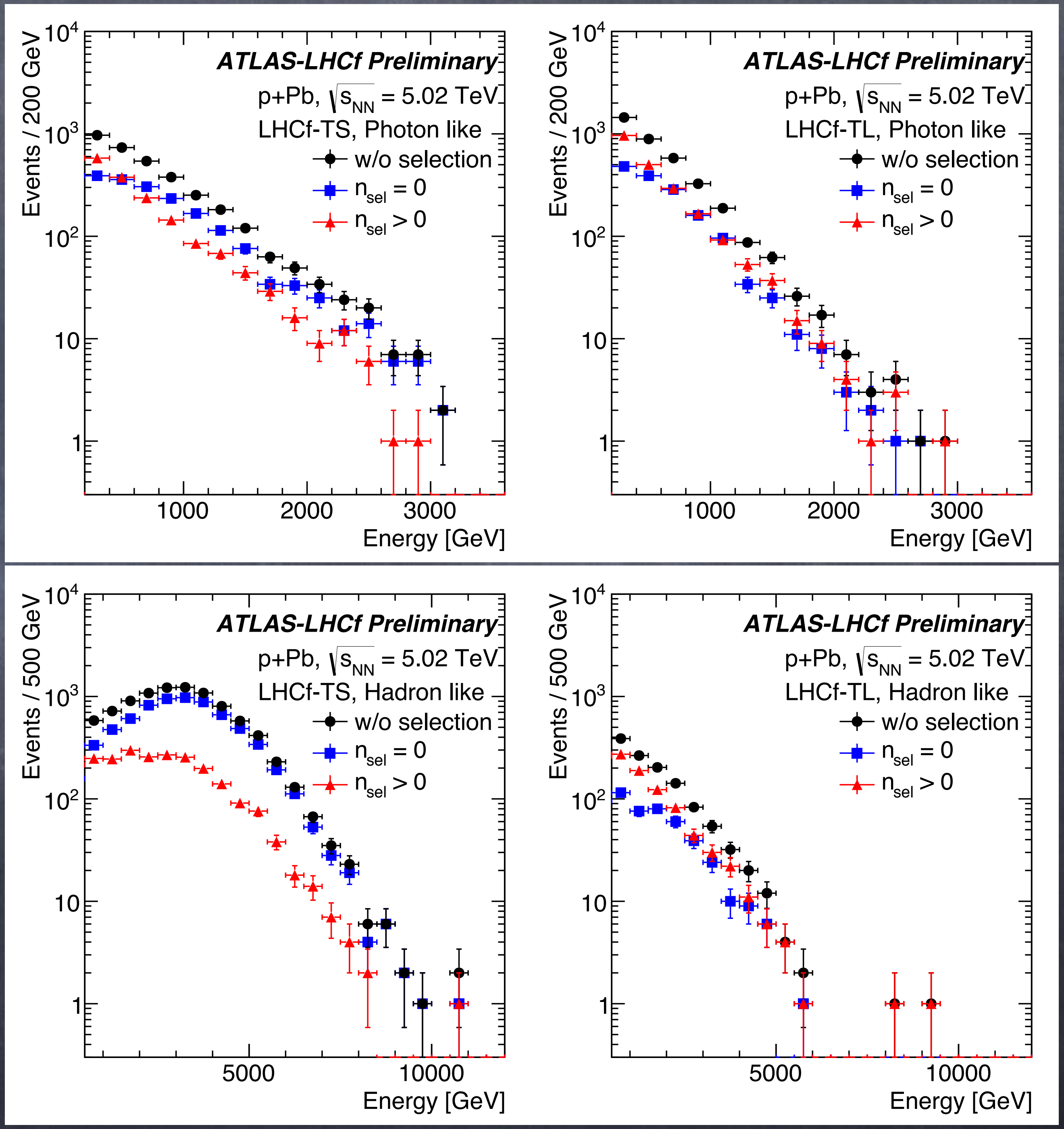
The ATLAS and the LHCf Collaborations



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

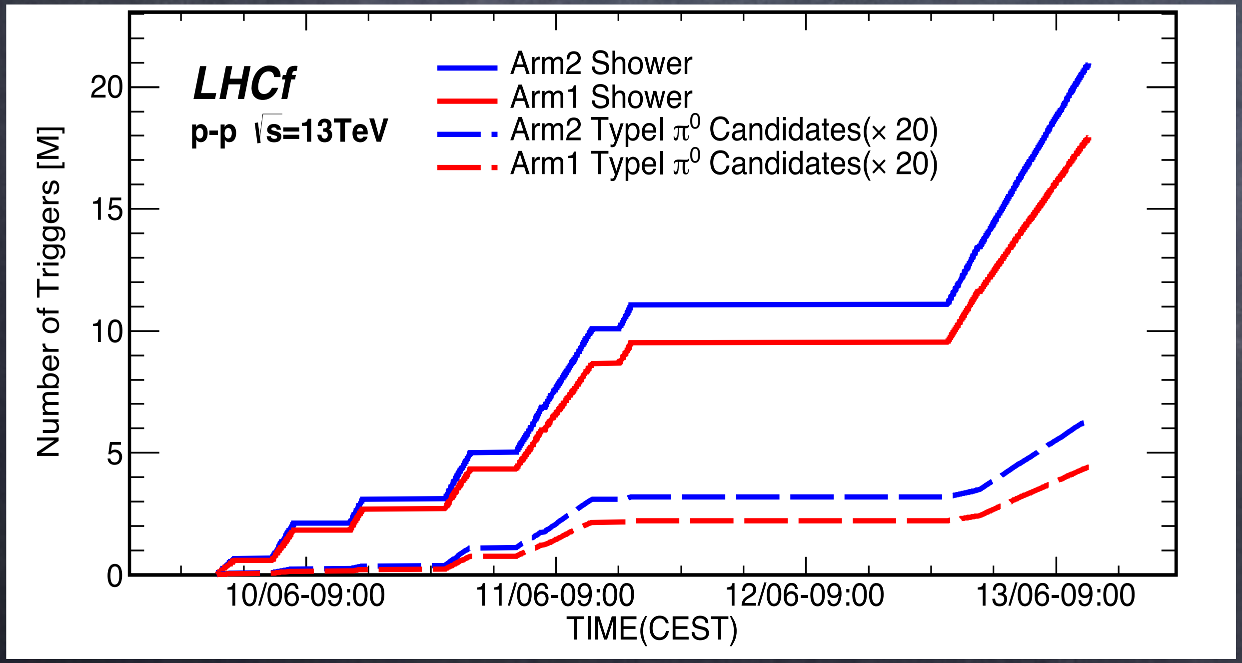
Nsel:
number of good charged ATLAS tracks
- $p_T > 100$ MeV
- vertex matching
- $|\eta| < 2.5$.

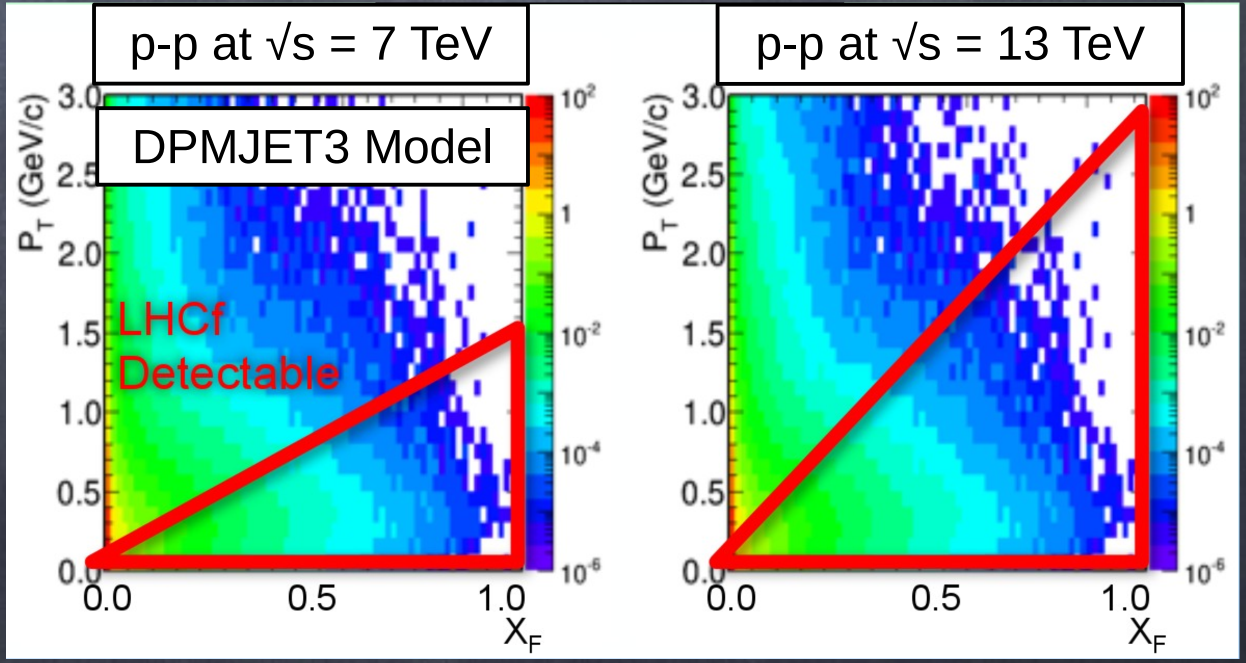
Significant UPC contribution in the very forward region with $N_{sel}=0$



LHC 13 TeV Run

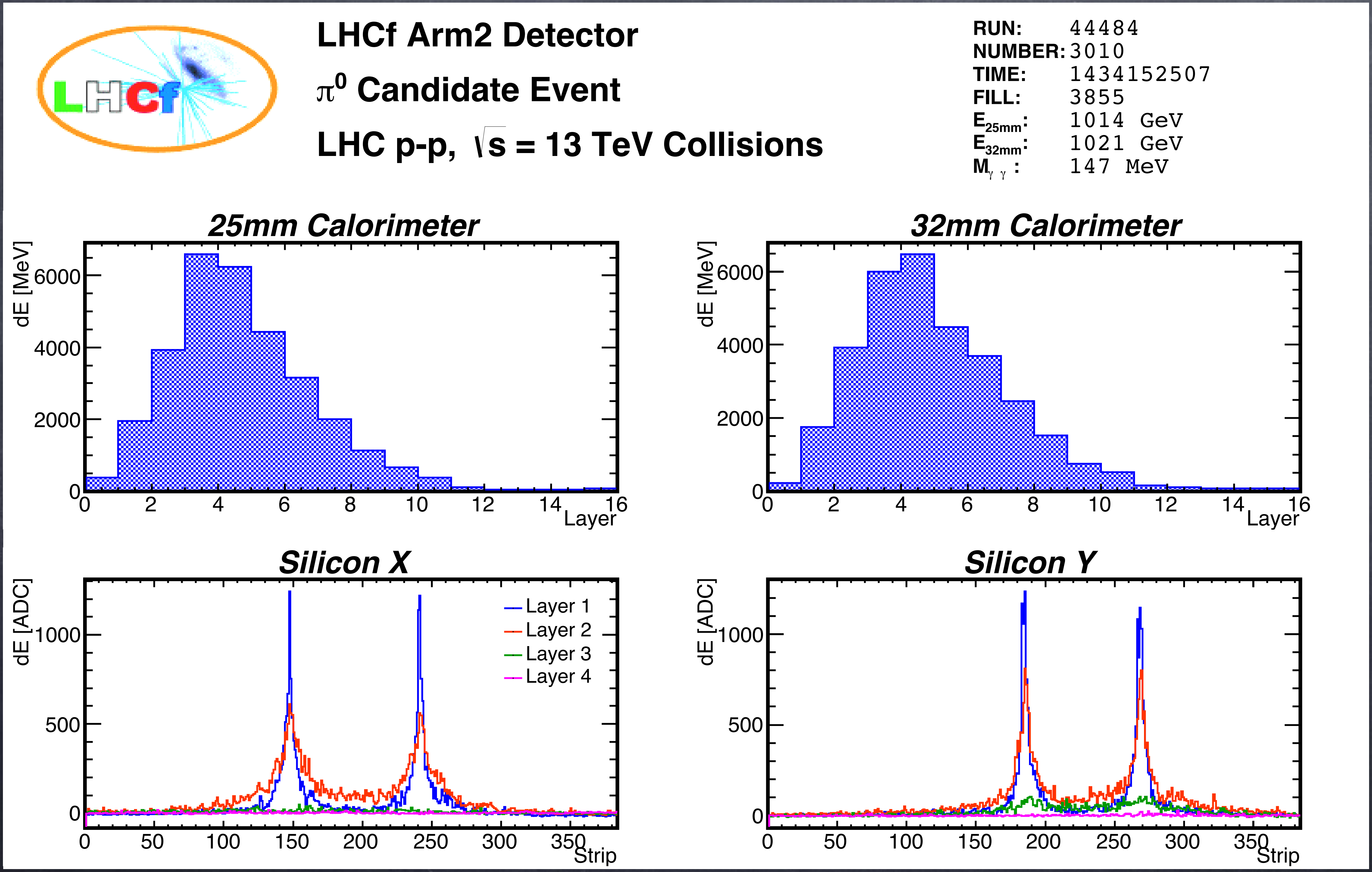
- During Week 24, June 9-13, LHCf dedicated low-lumi run
- Total 26.6 hrs with $L=0.5\sim1.6 \cdot 10^{29}\ cm^{-2}s^{-1}$ ($16\ nb^{-1}$)
- ~39 M showers, 0.5 M π^0 obtained
- Trigger exchange with ATLAS
- Detector removal on June 15th during TS1
- Run was very successful!!!!



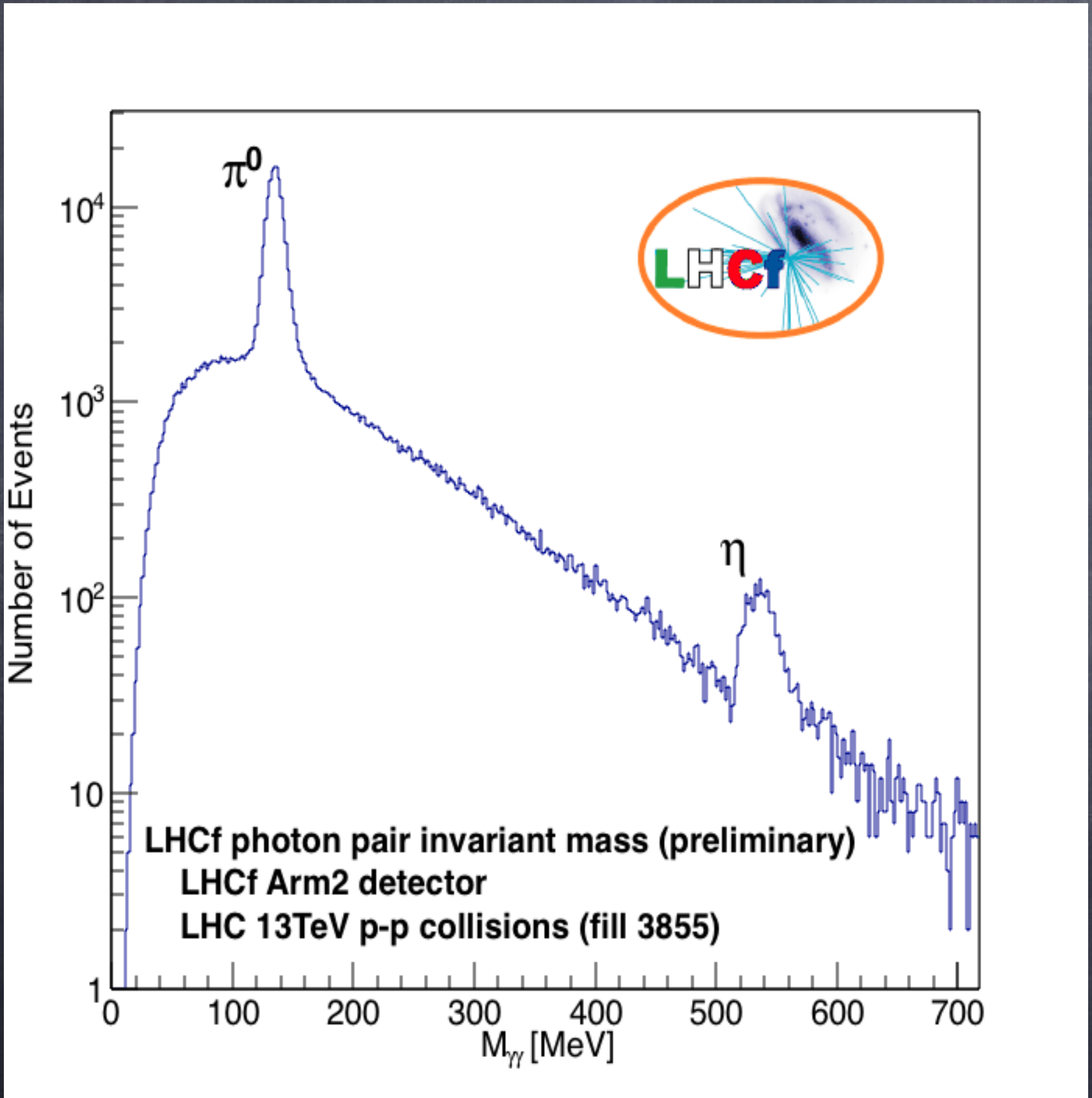


Significant improvement in phase-space acceptance

An impressive high energy π°

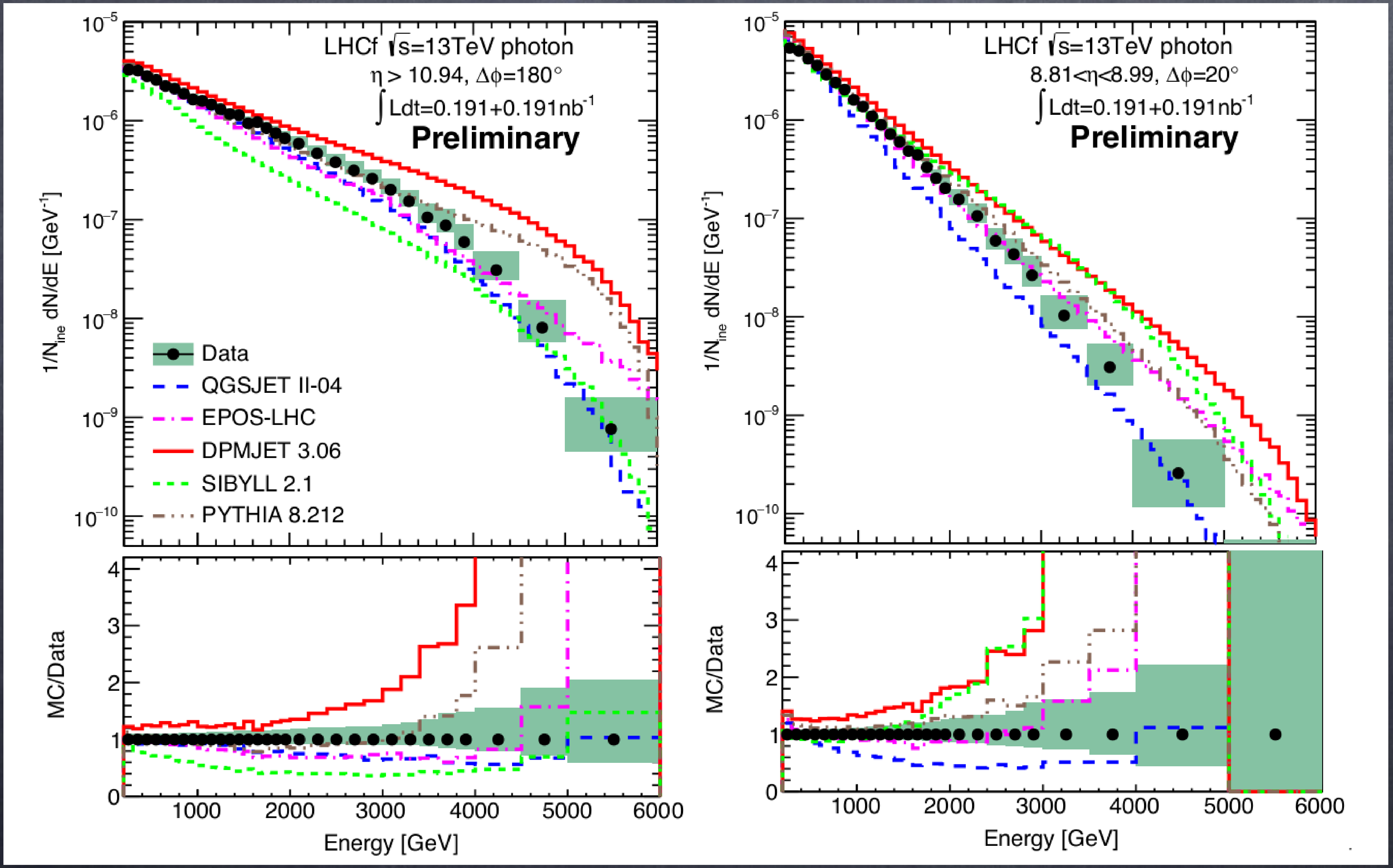


First look at 13 TeV data

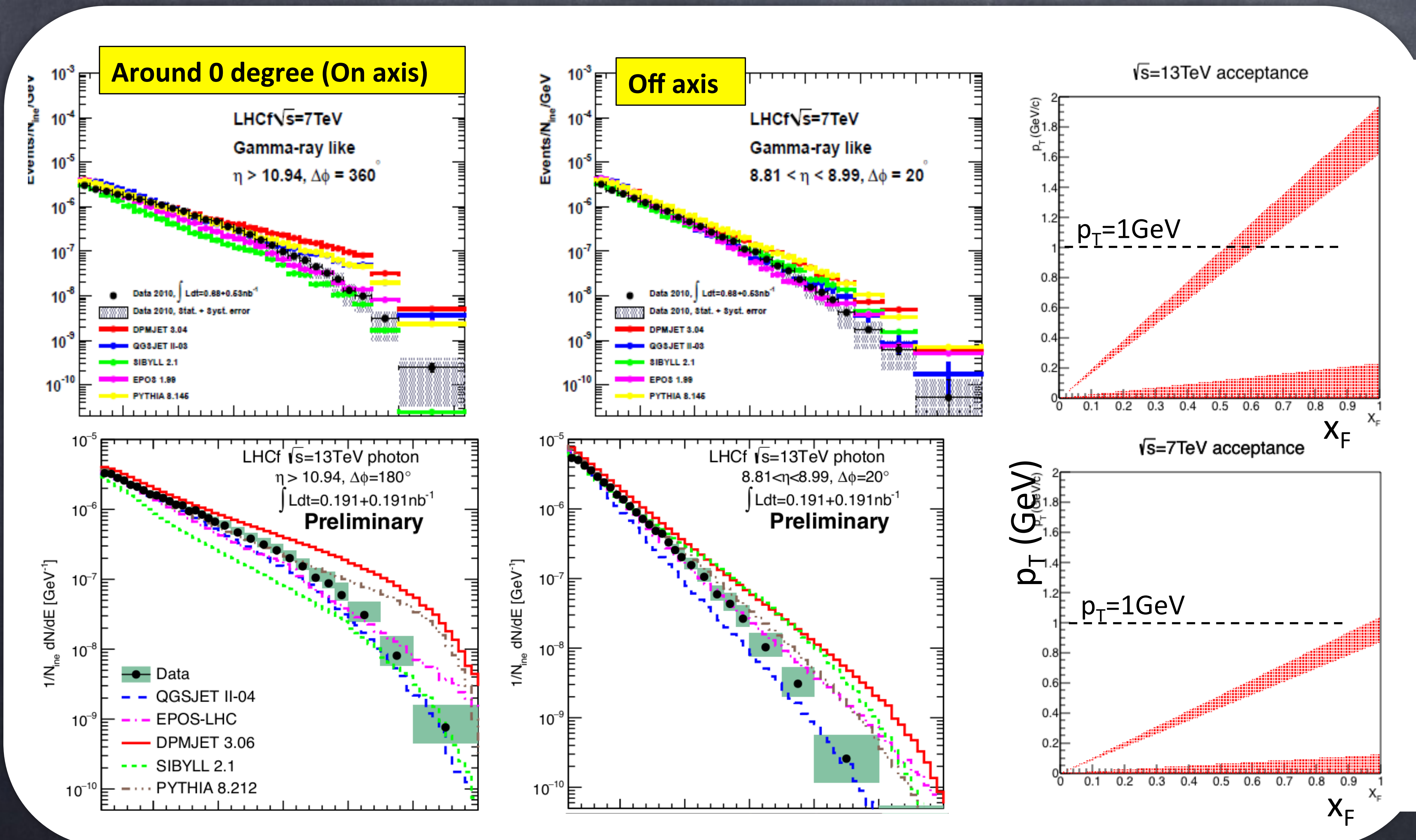


Mandatory tool for energy scale calibration

Preliminary γ energy spectra at 13 TeV



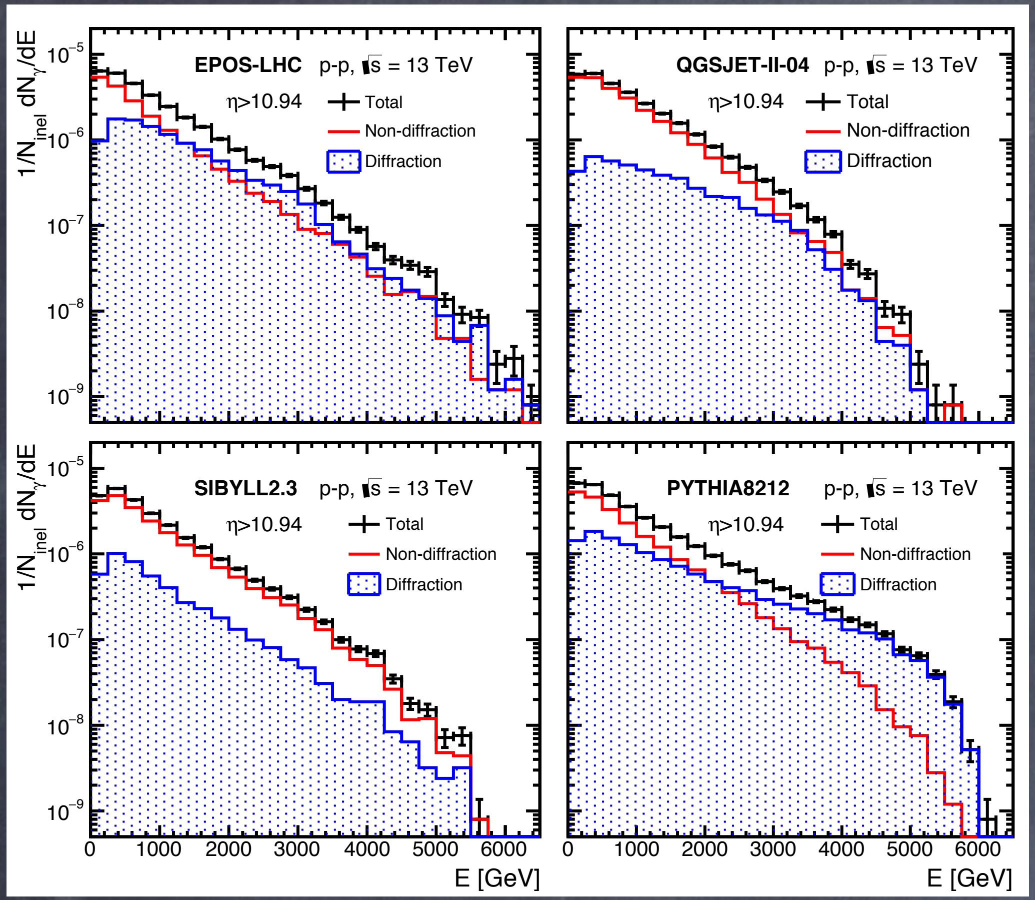
γ energy spectra 7 vs 13 TeV

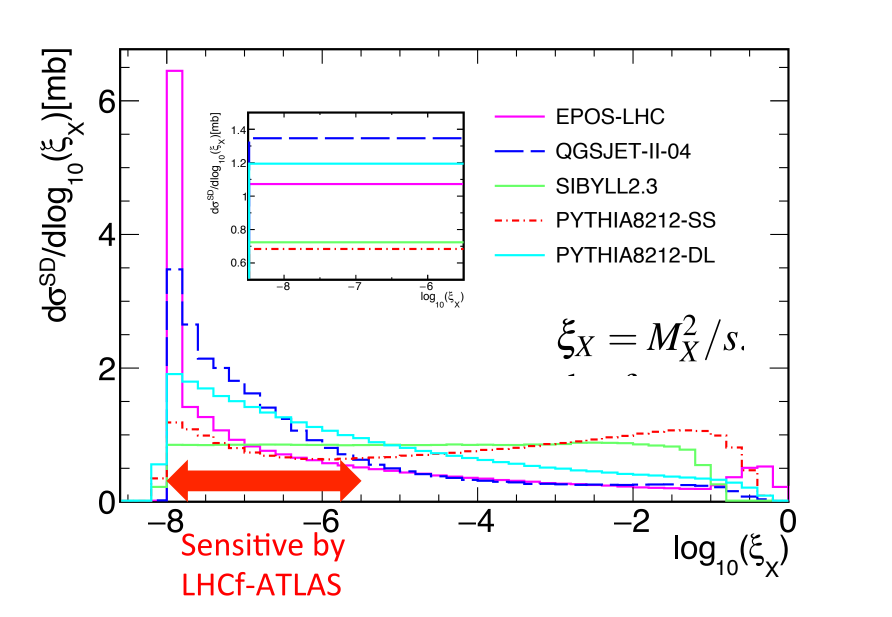


High energy data covers up to larger p_T

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

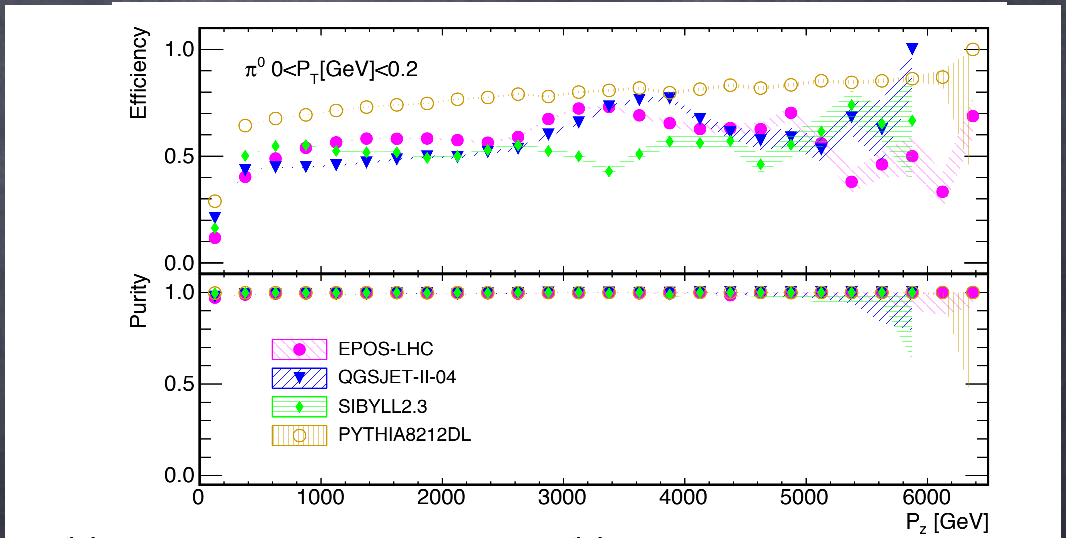
Origin of the differences





Single diffraction cross sections

- ~half of LHCf detected particles are produced in diffractive dissociation
- Fraction and shape of diffraction/non-diffraction are model dependent
- By classifying LHCf events with ATLAS track information, LHCf can select pure diffractive samples in never explored mass range (ξ_X)



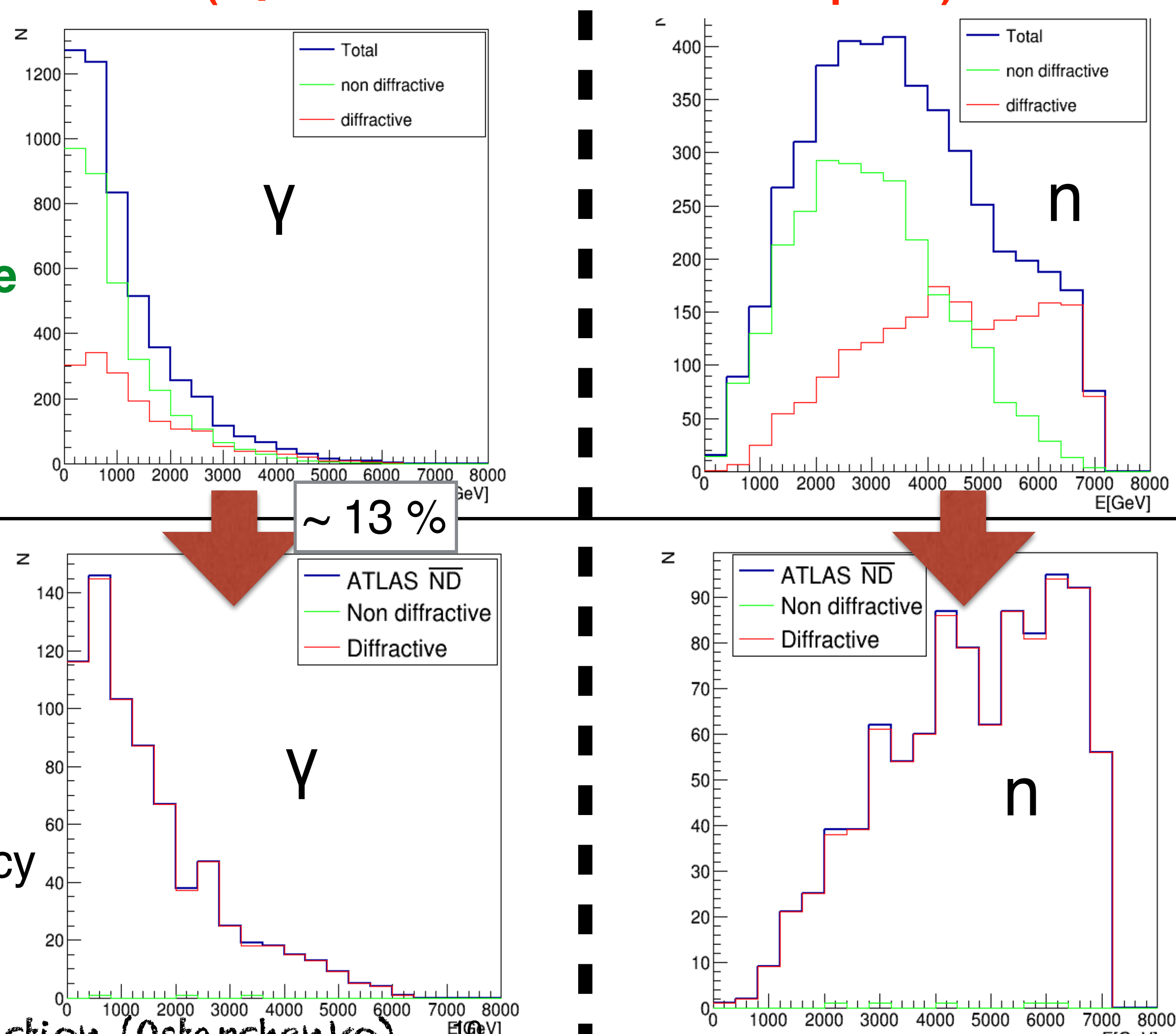
Diffraction selection efficiency and purity

Impact of common ATLAS-LHCf trigger

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

All events

in MC true,
Non-diffractive
Diffractive



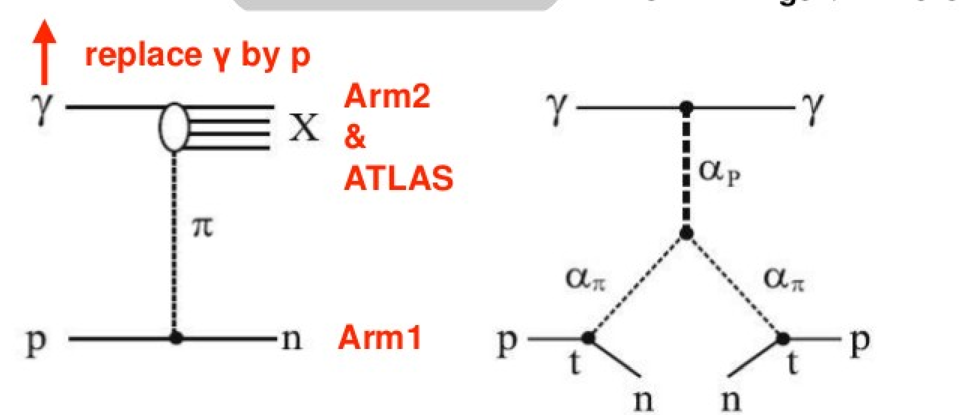
w/ event selection (not ND)

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

key: low mass diffraction (Ostapchenko)

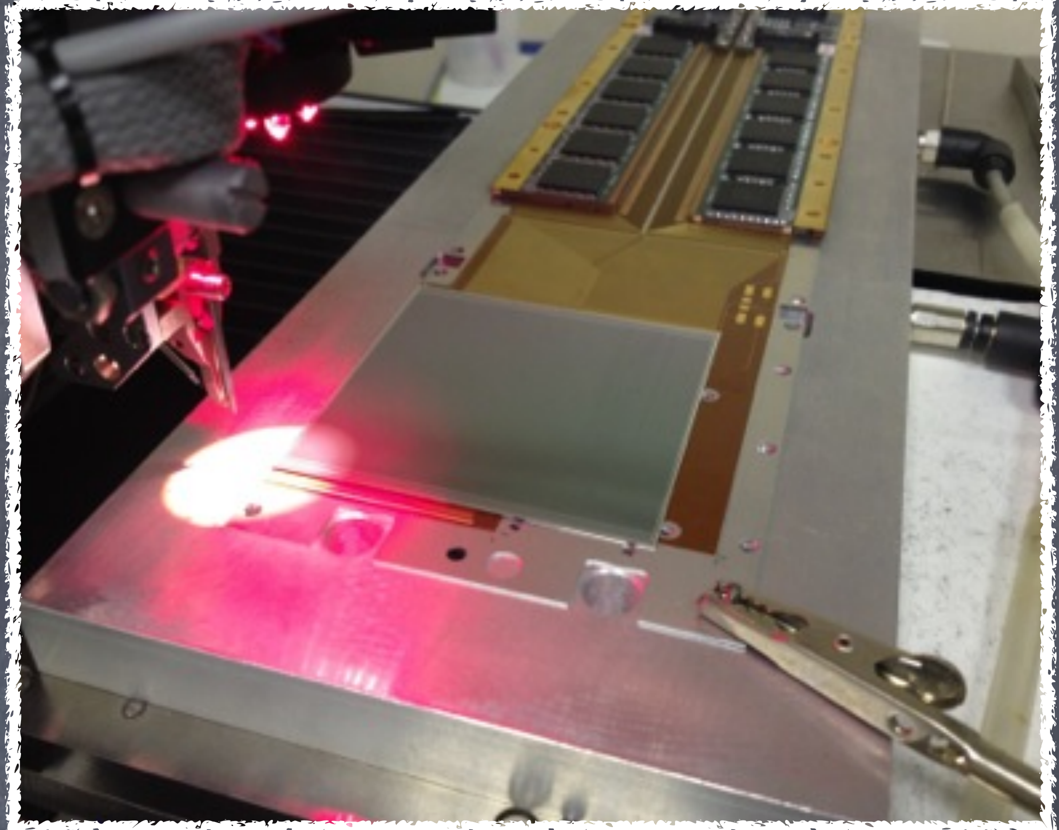
Use neutron tag in LHCf to measure π+p in ATLAS

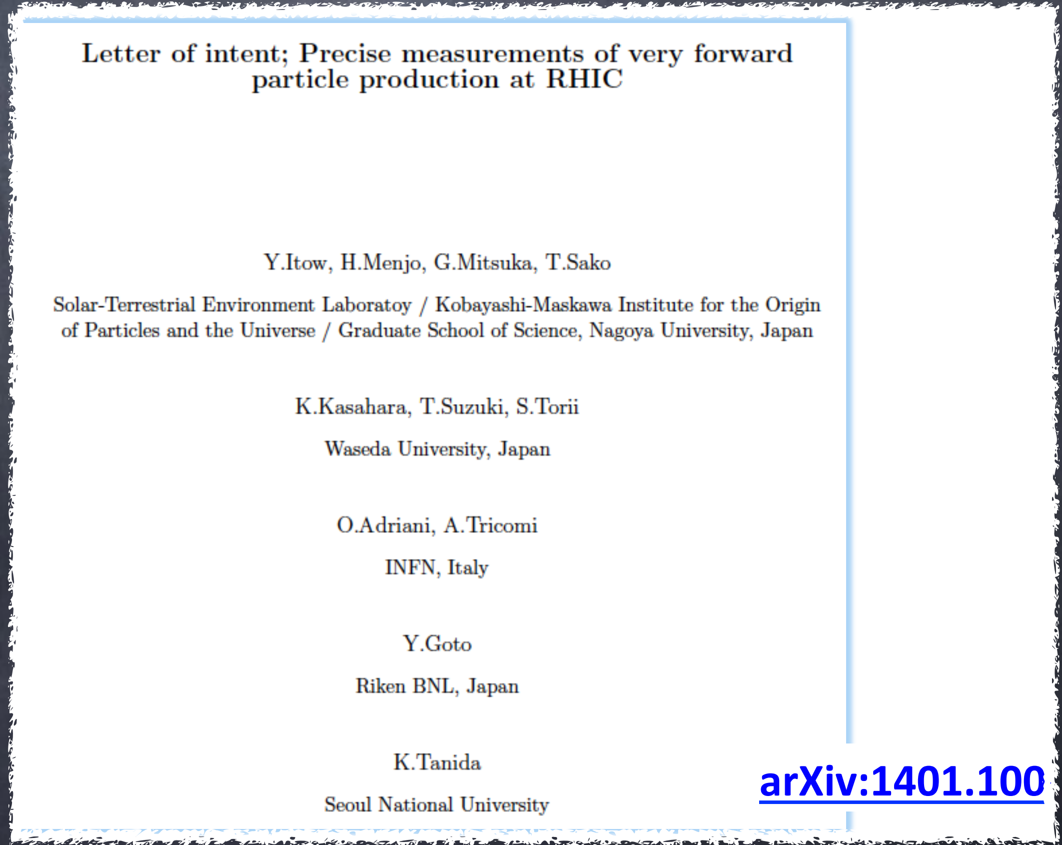
From R. Engel / T. Pierog



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)

- Physics Motivations
  - The link between HECR Physics and LHC
- The LHCf detectors
  - “Il vino buono sta nella botte piccola” or “good things comes in small packages”
- Physics Results
  - what we have done so far
- **Future Plans**
  - **what’s next…**





Letter of intent; Precise measurements of very forward particle production at RHIC

Y.Itow, H.Menjo, G.Mitsuka, T.Sako

Solar-Terrestrial Environment Laboratoy / Kobayashi-Maskawa Institute for the Origin of Particles and the Universe / Graduate School of Science, Nagoya University, Japan

K.Kasahara, T.Suzuki, S.Torii

Waseda University, Japan

O.Adriani, A.Tricomi

INFN, Italy

Y.Goto

Riken BNL, Japan

K.Tanida

Seoul National University

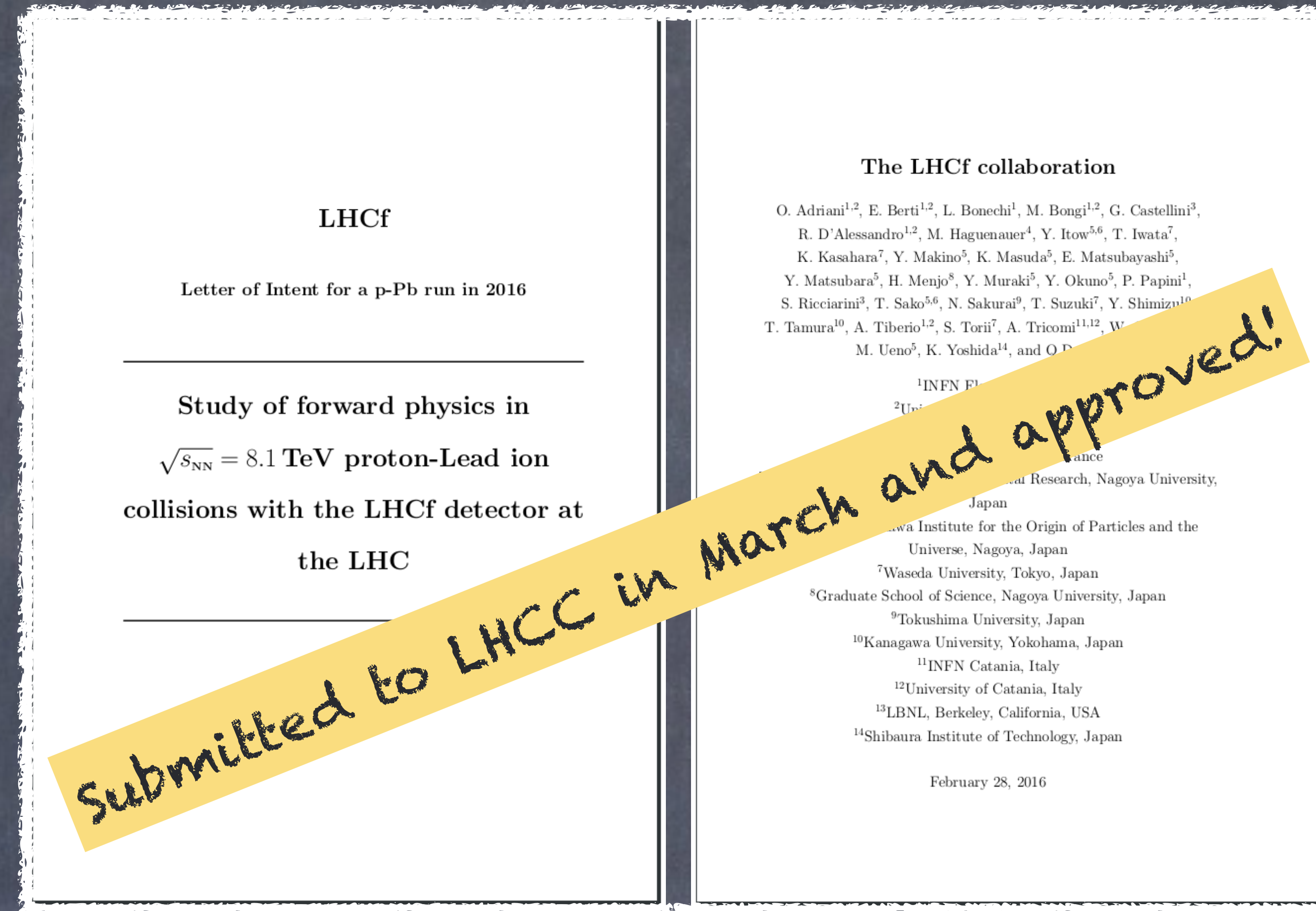
arXiv:1401.100

p-Pb at 8.1 TeV

Ony ARM2 Detector

Motivations:

* Statistics:
  - Measure π0 with increased statistics wrt 2013 run
  - Possibility to detect the η meson
  - Combined ATLAS-LHCf data take (very limited in 2013)
* Phase space
  - extend up to p_T>1 GeV/c
    - deviations from models suggested from 2013 data at high p_T
    - investigate pQCD phase-space region
* Scaling properties
  - Extrapolation at extreme CR energies
  - Feynman scaling: spectra in x_F


LHCf

Letter of Intent for a p-Pb run in 2016

Study of forward physics in $\sqrt{s_{NN}} = 8.1$ TeV proton-Lead ion collisions with the LHCf detector at the LHC

The LHCf collaboration

O. Adriani[1,2], E. Berti[1,2], L. Bonechi[1], M. Bongi[1,2], G. Castellini[3], R. D'Alessandro[1,2], M. Haguenauer[4], Y. Itow[5,6], T. Iwata[7], K. Kasahara[7], Y. Makino[5], K. Masuda[5], E. Matsubayashi[5], Y. Matsubara[5], H. Menjo[8], Y. Muraki[5], Y. Okuno[5], P. Papini[1], S. Ricciarini[3], T. Sako[5,6], N. Sakurai[9], T. Suzuki[7], Y. Shimizu[10], T. Tamura[10], A. Tiberio[1,2], S. Torii[7], A. Tricomi[11,12], W. ... M. Ueno[5], K. Yoshida[14], and Q. D...

[1]INFN Fi...

[2]Uni...

...ance

...Research, Nagoya University, Japan

...wa Institute for the Origin of Particles and the Universe, Nagoya, Japan

[7]Waseda University, Tokyo, Japan

[8]Graduate School of Science, Nagoya University, Japan

[9]Tokushima University, Japan

[10]Kanagawa University, Yokohama, Japan

[11]INFN Catania, Italy

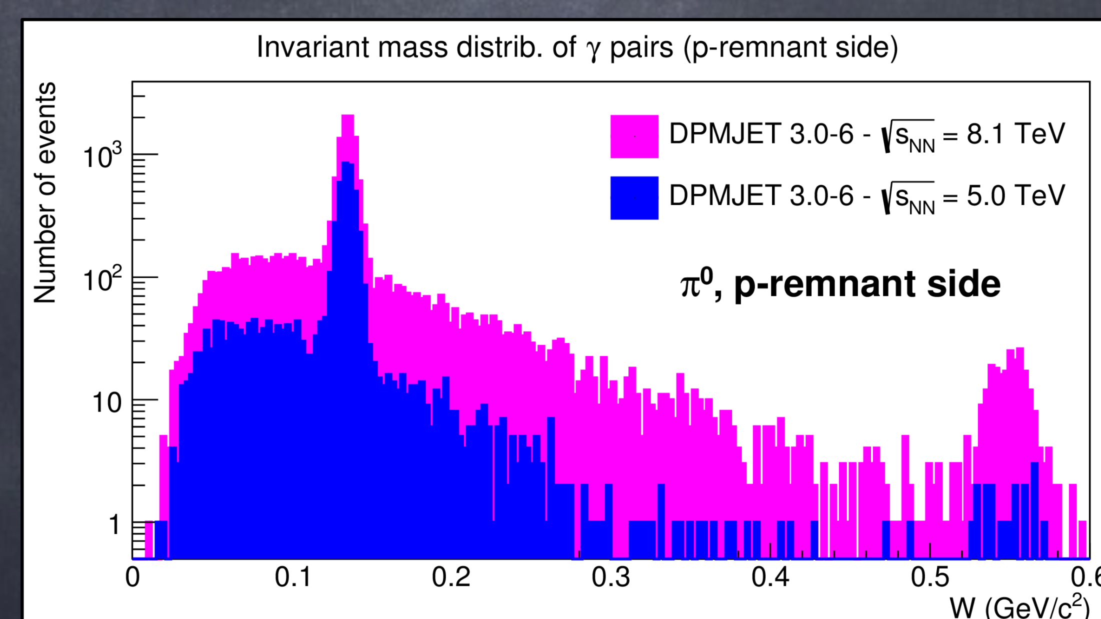
[12]University of Catania, Italy

[13]LBNL, Berkeley, California, USA

[14]Shibaura Institute of Technology, Japan

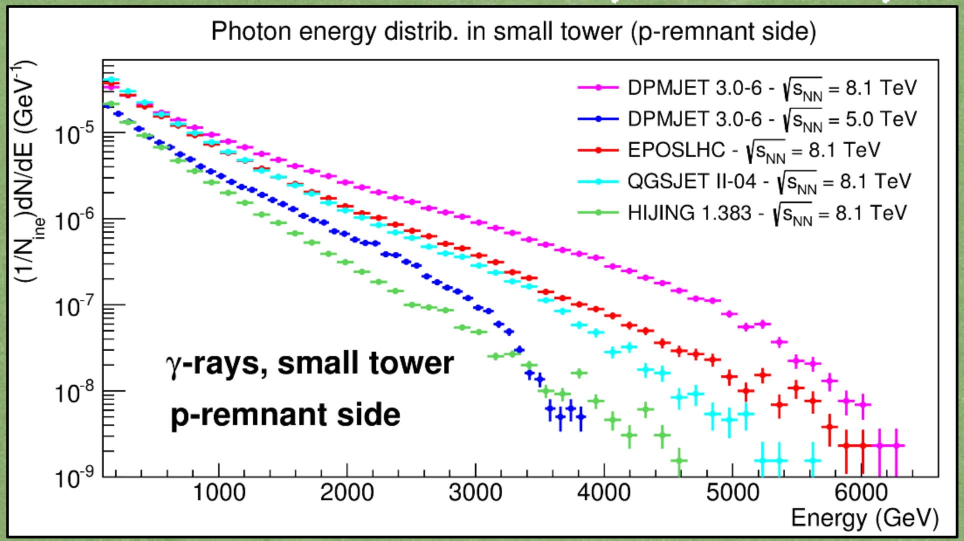
February 28, 2016

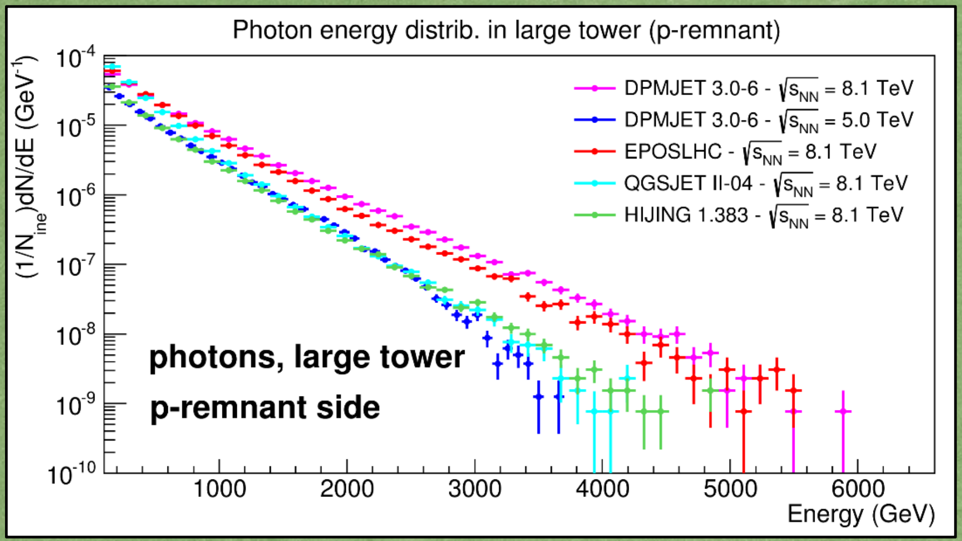
Submitted to LHCC in March and approved!



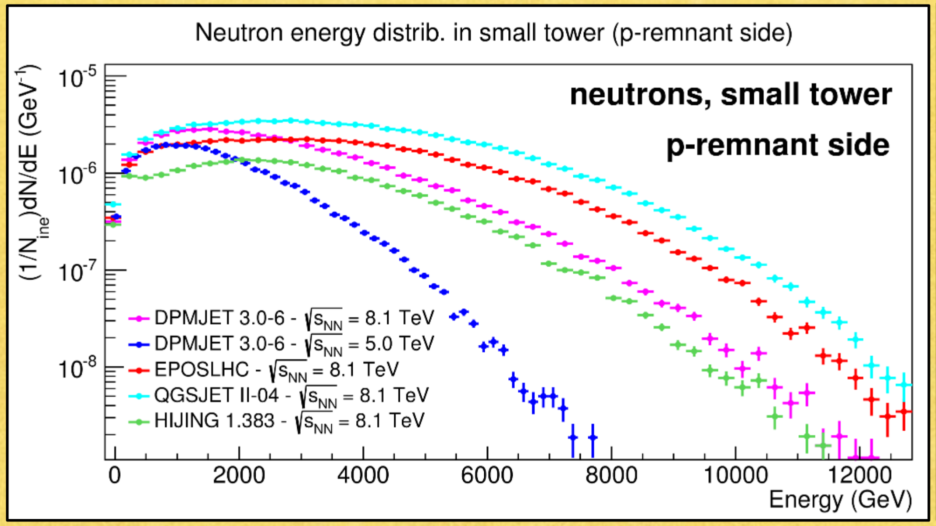
p-Pb at 8.1 TeV: γ & n spectra

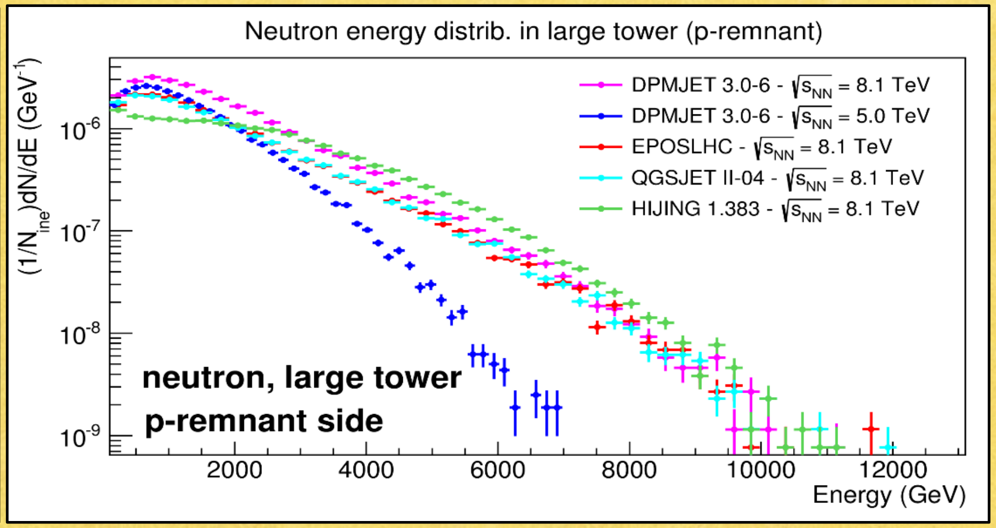
Expected photon distribution





Expected neutron distribution (35% energy resolution)





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

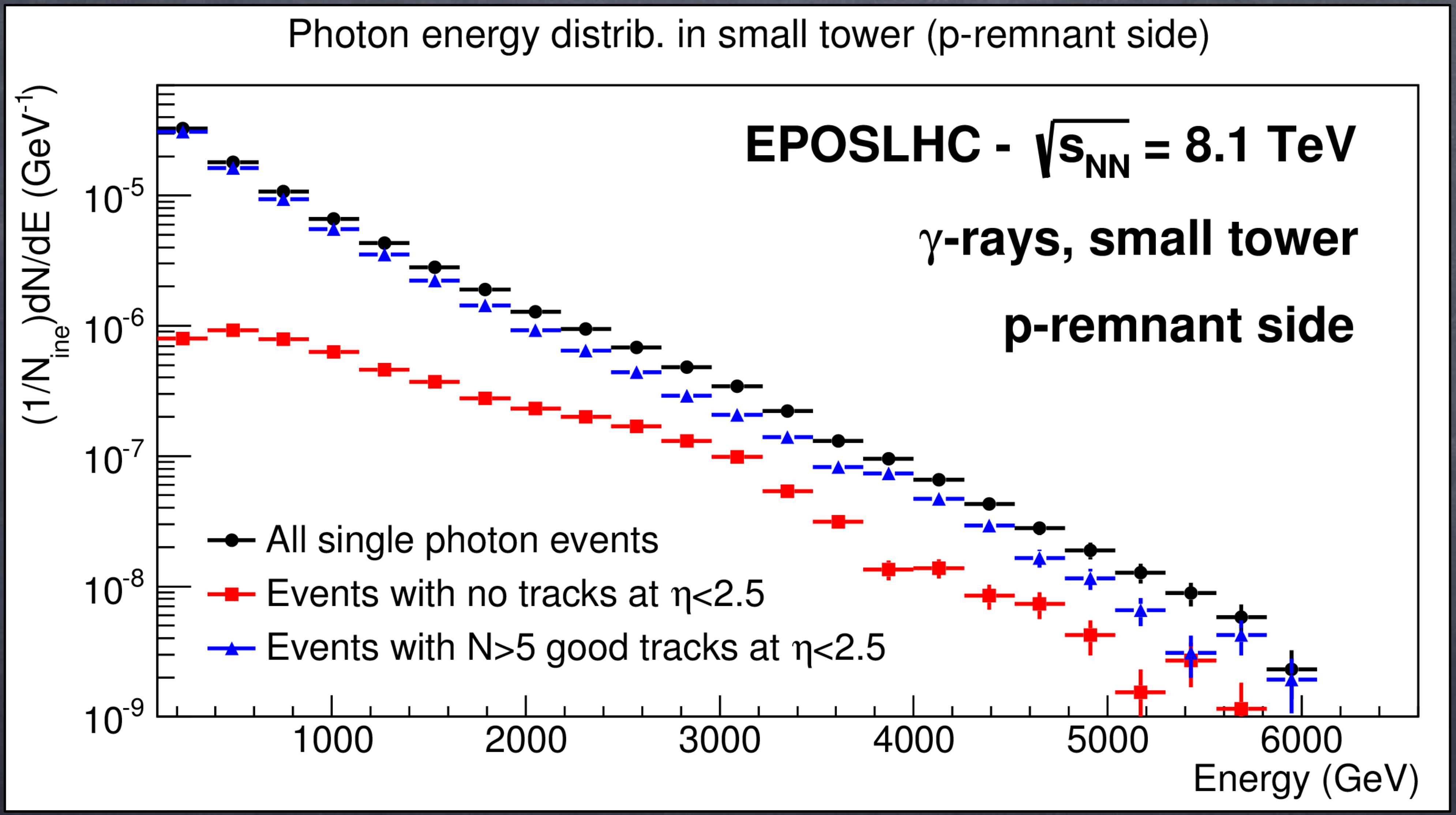
- DPMJET 3.0-6 p+Pb
- EPOSLHC p+Pb
- QGSJET II-04
- HIJING 1.383

Small calorimeter tower centered on the beam spot

Only p-remnant side considered

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

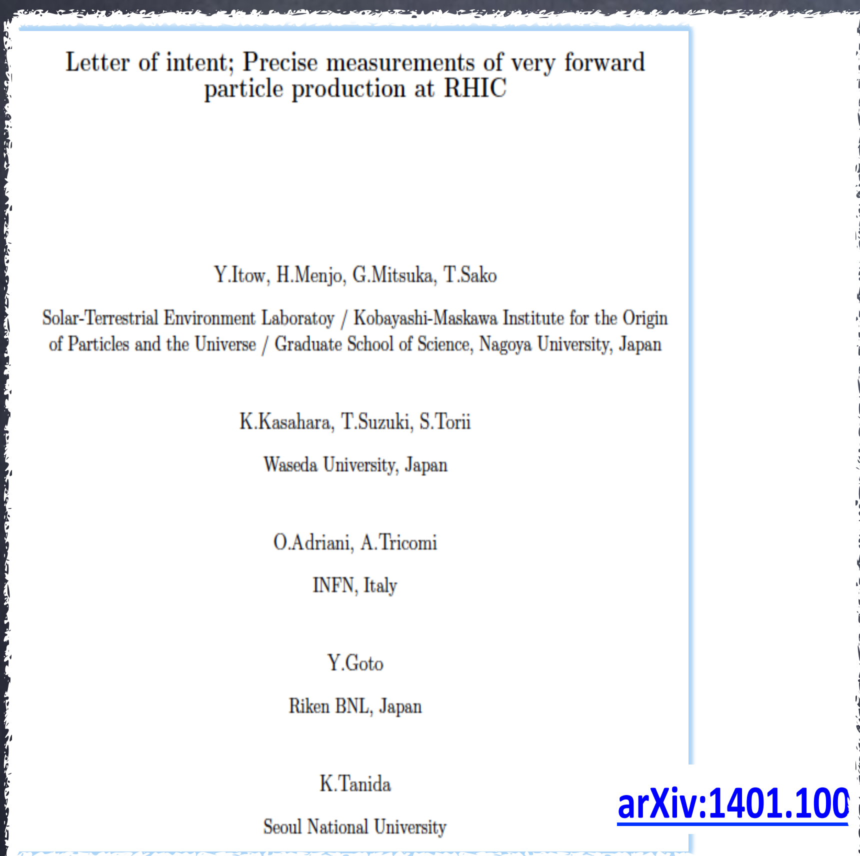
p-Pb at 8.1 TeV: perspective for ATLAS-LHCf combined analysis



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

From LHCf to RHICf

p-p at $\sqrt{s}$=510 GeV with ARM1 in 2017
Extend $\sqrt{s}$ coverage for the test of Feynman scaling



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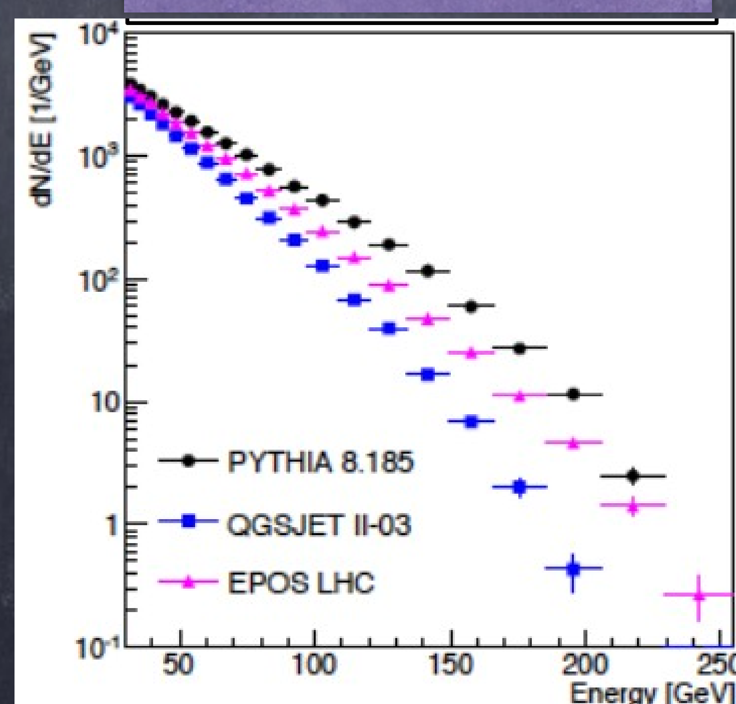
Riken BNL, Japan

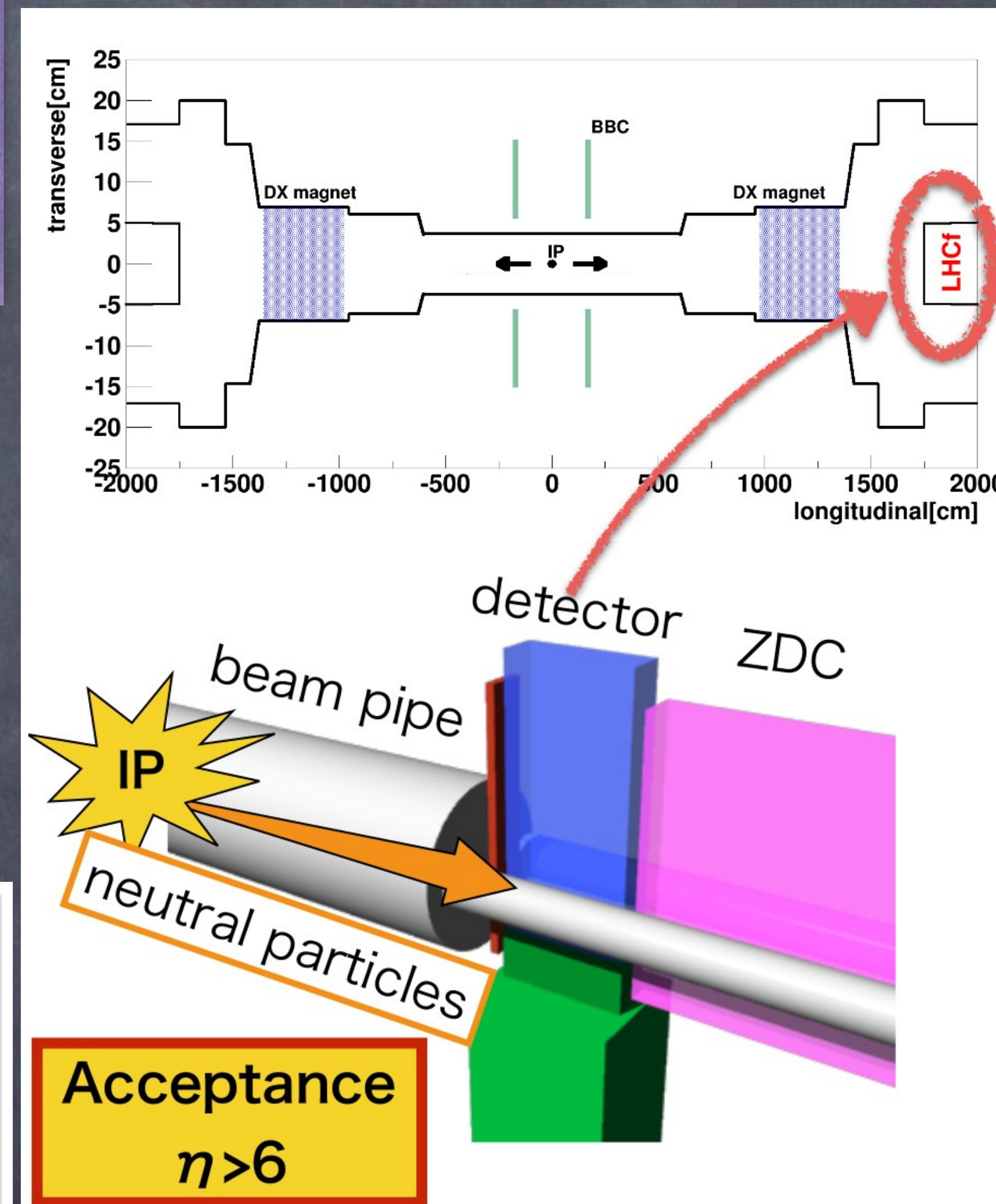
K.Tanida

Seoul National University

arXiv:1401.100

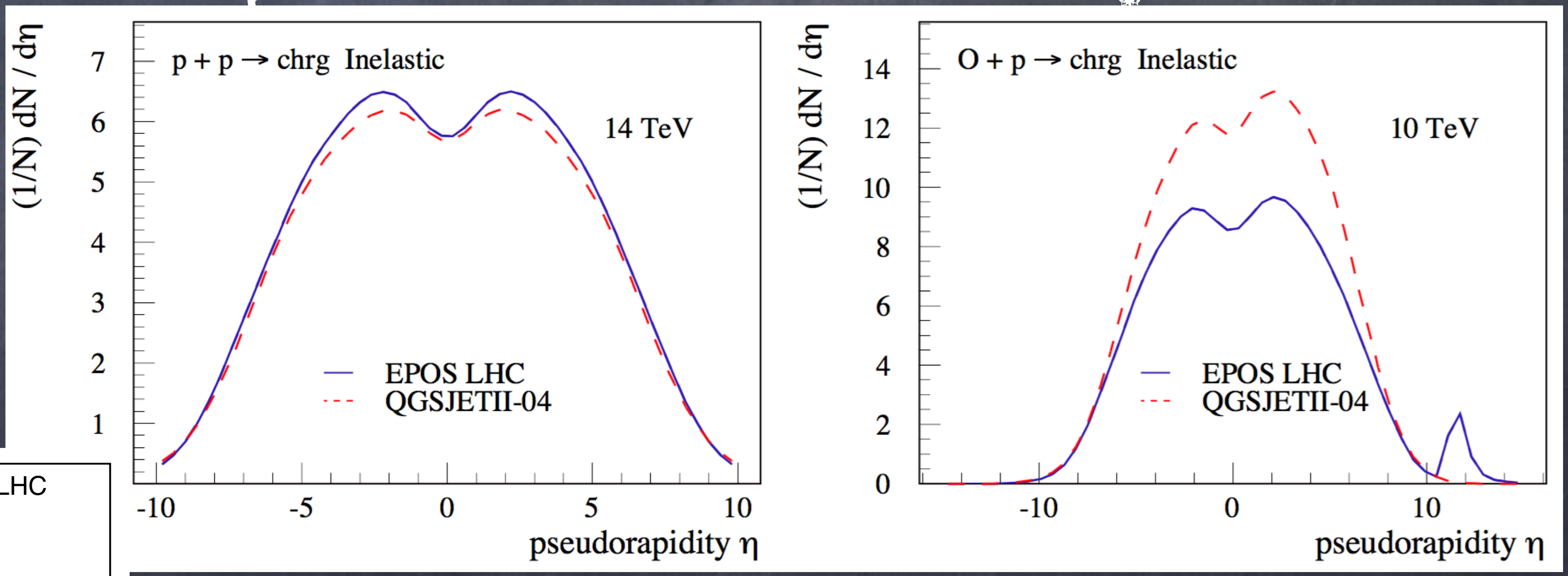
Photons



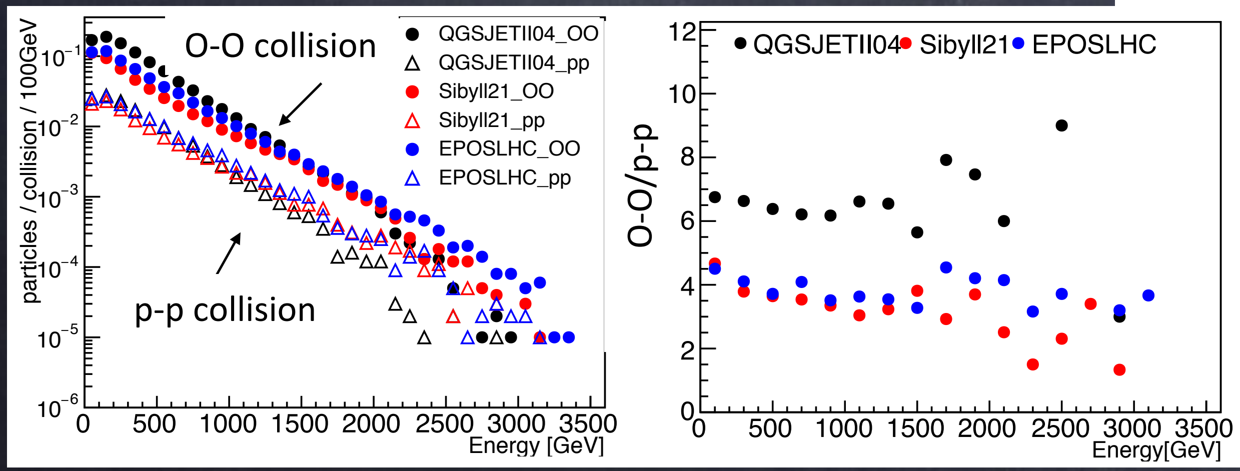


The Far Future at LHC

- 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



Photon spectra p-p vs. O-O



Y. Okuno, Master thesis
Nagoya university (2016)

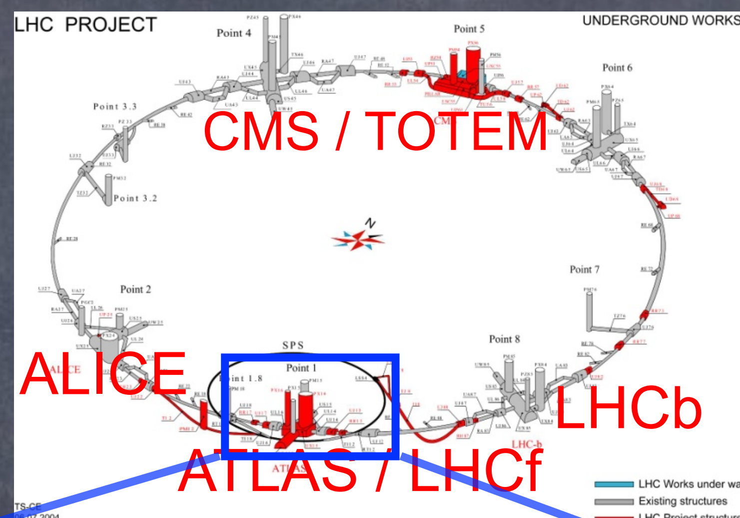
Summary

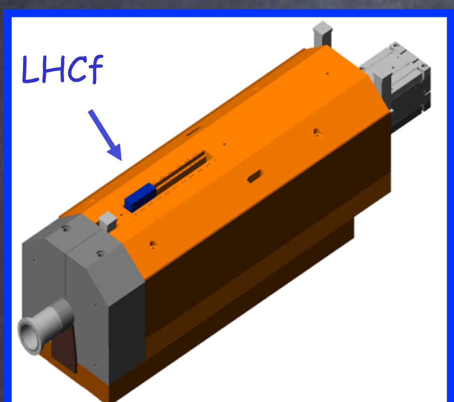
- Very forward γ, n and π0 production in p-p and p-Pb collision have been precisely measured by LHCf at $E_{CM} \leq 7$ TeV
    - LHCf zero degree results are significantly contributing to improve our knowledge of hadronic interaction model for HECR Physics
    - New results with hadrons are particularly interesting to understand the muon excess
    - p-Pb results give important hints to understand nuclear medium effect
- Very successful 13 TeV pp run has been done in June 2015
    - Analysis is on going
- An intensive 2016-2017 program is waiting for us
    - 8.1 TeV and 5 TeV p-Pb collisions at LHC in November 2016
    - 510 GeV p-p with polarized beam at RHIC in February 2017
- Still a lot of results will come in the next years... while waiting for p-Light Ion run at LHC
- So... stay tuned!

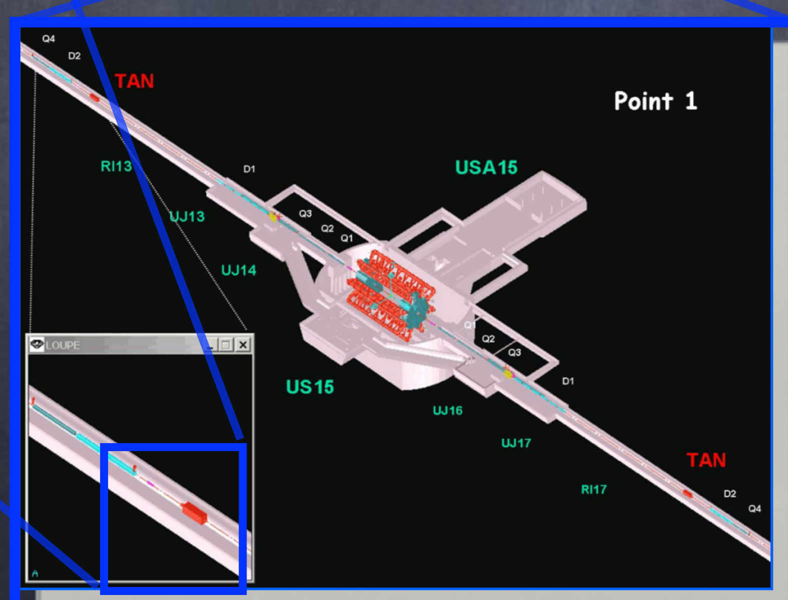
Back up slides

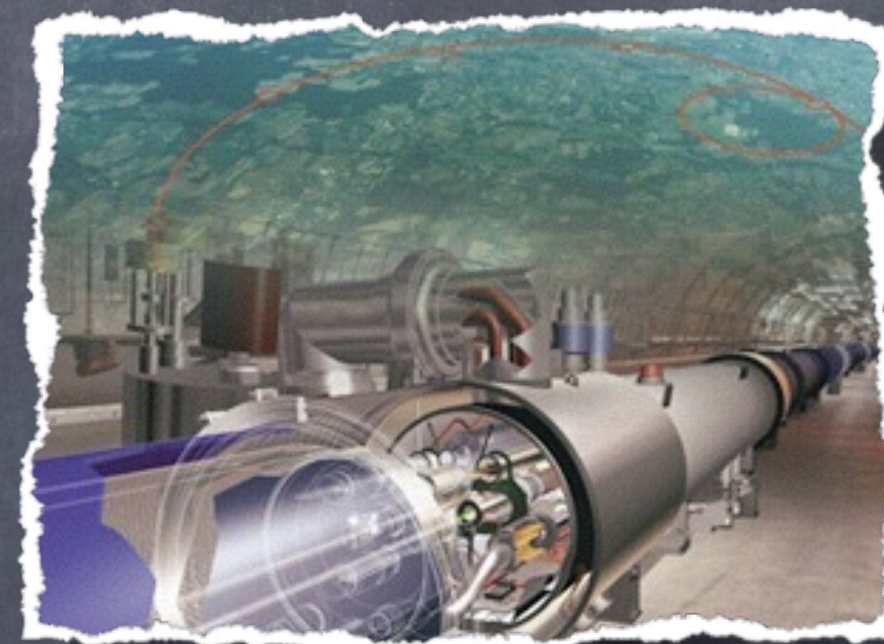
The LHC-forward experiment

- Two independent electromagnetic calorimeters equipped with position sensitive layers, on both sides of IP1







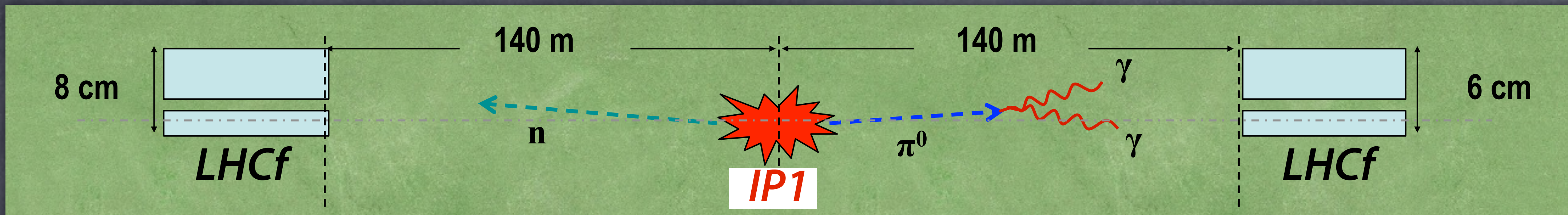


7 TeV + 7 TeV proton collisions at LHC correspond to $E_{LAB} = 10^{17}$ eV

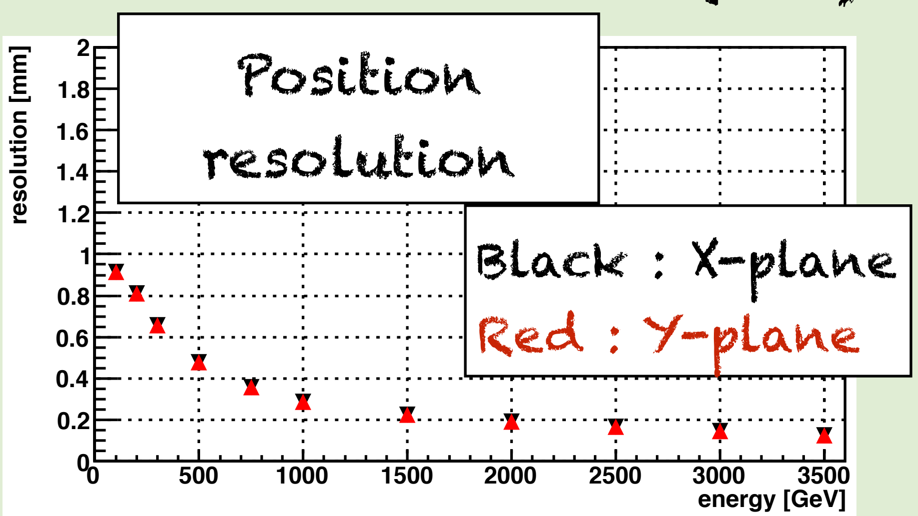
- Measure energy and position for $|\eta|>8$ of γ from π^0 decays and neutrons produced in pp interaction at LHC

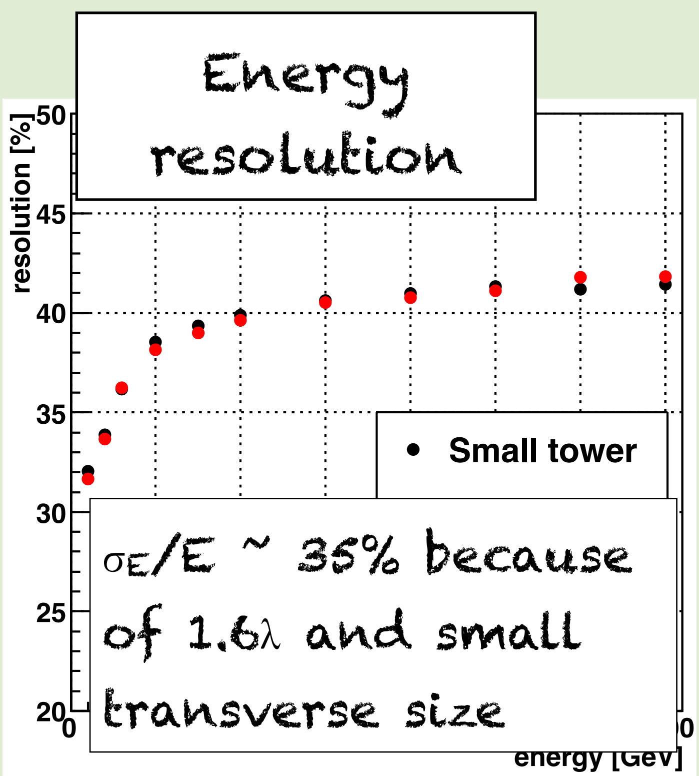
- International Collaboration mainly Japan-Italy (about 30 members)

Detector Performance

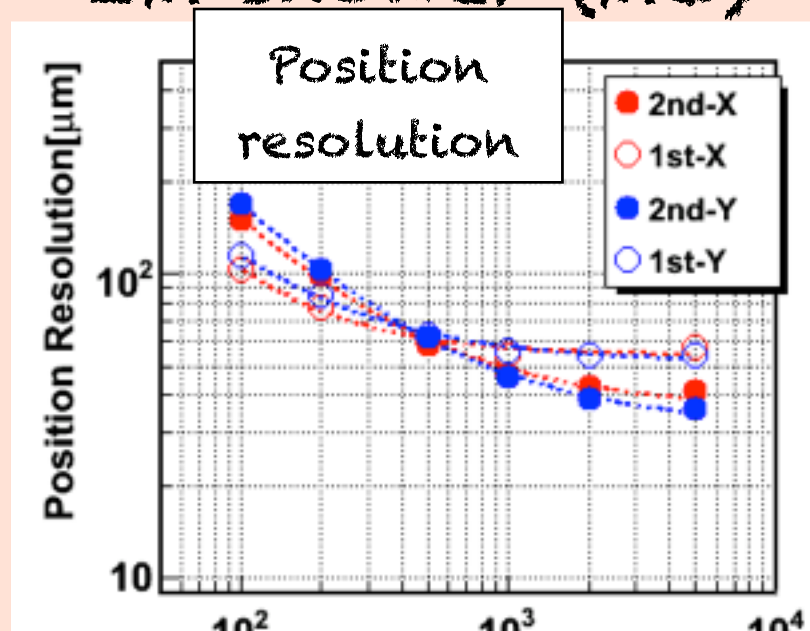


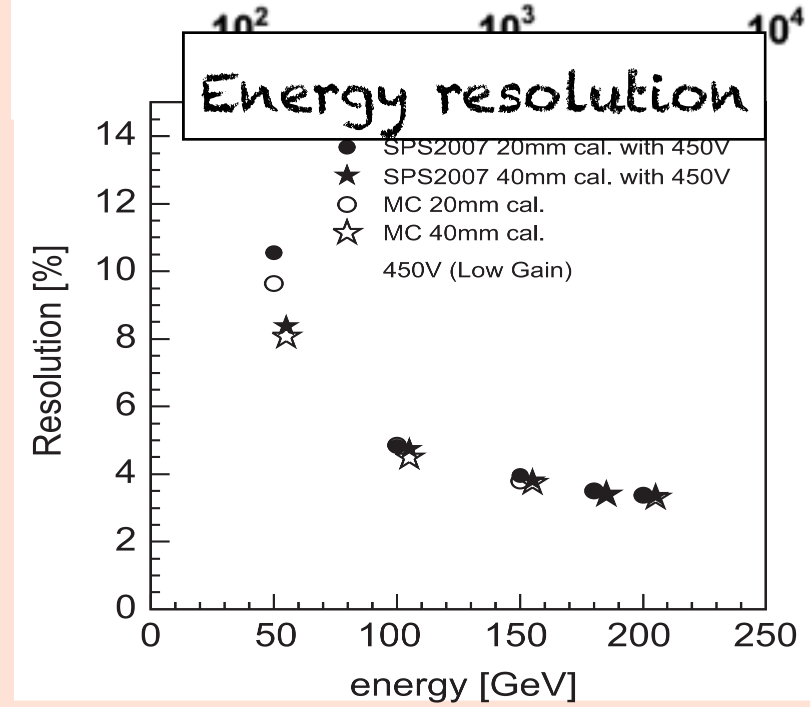
Hadronic shower (MC)





EM shower (MC)

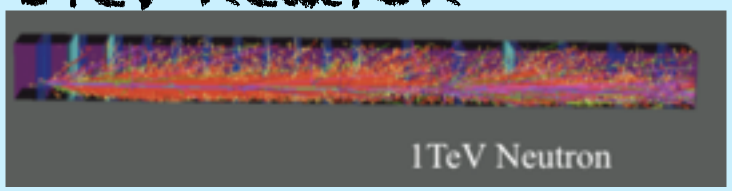




PID technique

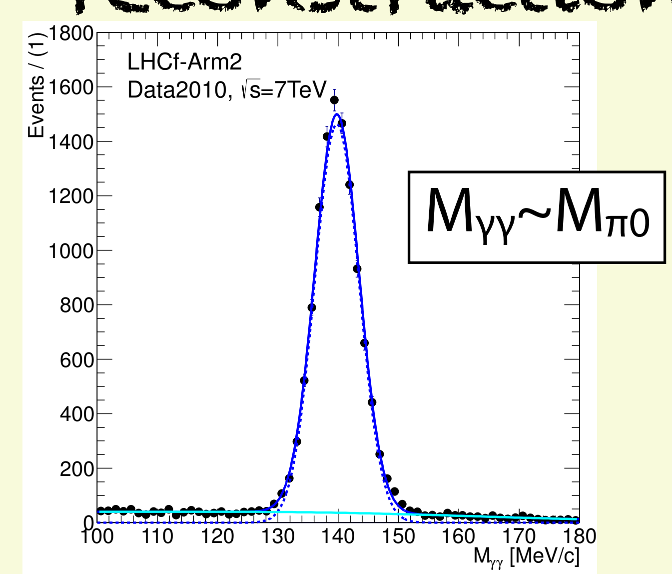
400GeV photon

1TeV neutron



Identification of incoming particle by shower shape

π^0 reconstruction

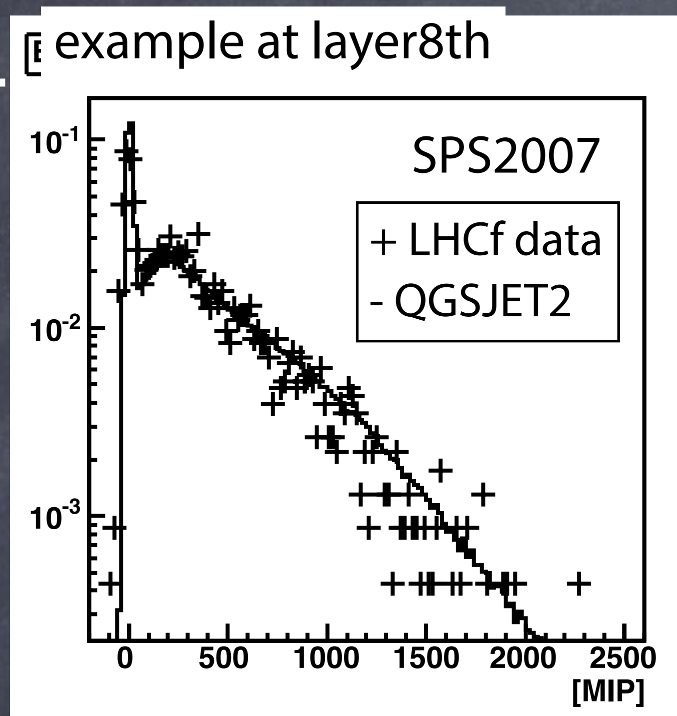


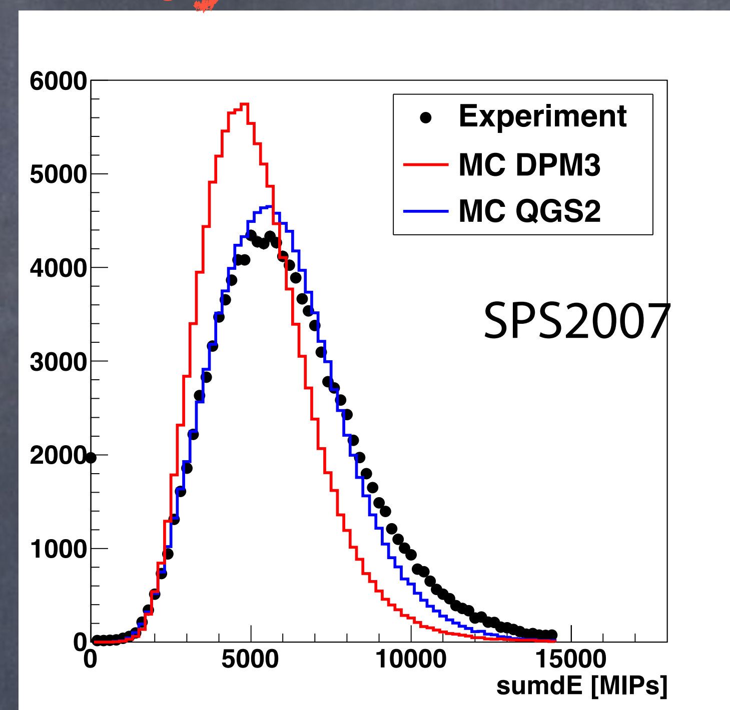
LHCf @ pp 7 TeV: neutron analysis

Neutron energy reconstruction

JINST 9 (2014)P03016

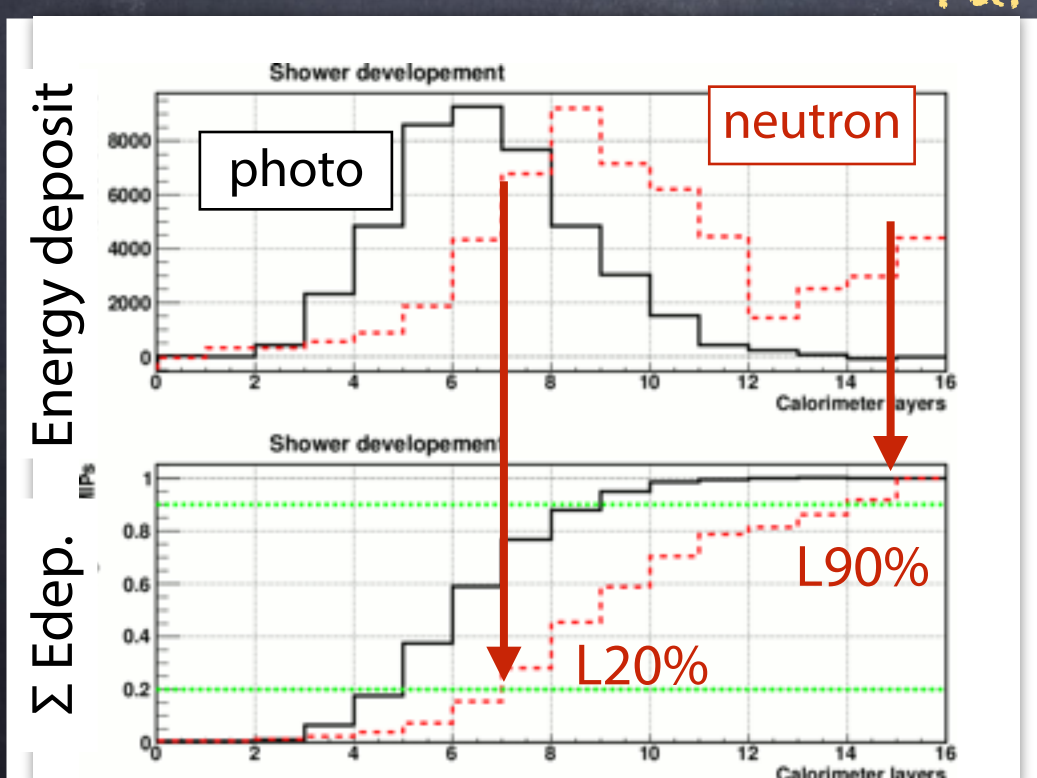
$$\sum_{l=2}^{15} \left[\right] =$$

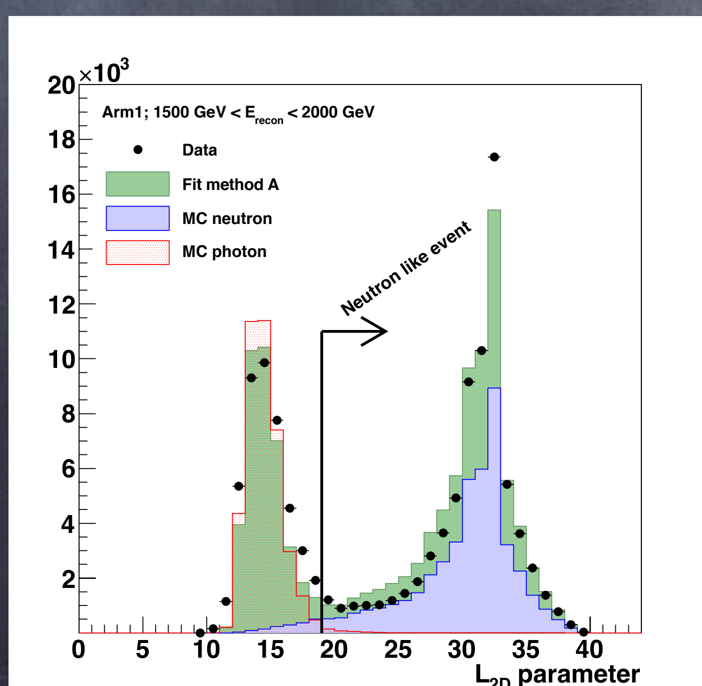




- Neutron energy is reconstructed by a sum of energy deposits.
- Detector simulation based on QGSJET2 for hadronic shower reproduces the test beam data better than that on DPMJET3.
- Difference between QGSJET2 and the test beam data is taken into account as a systematic error in the latter analysis.

Particle identification

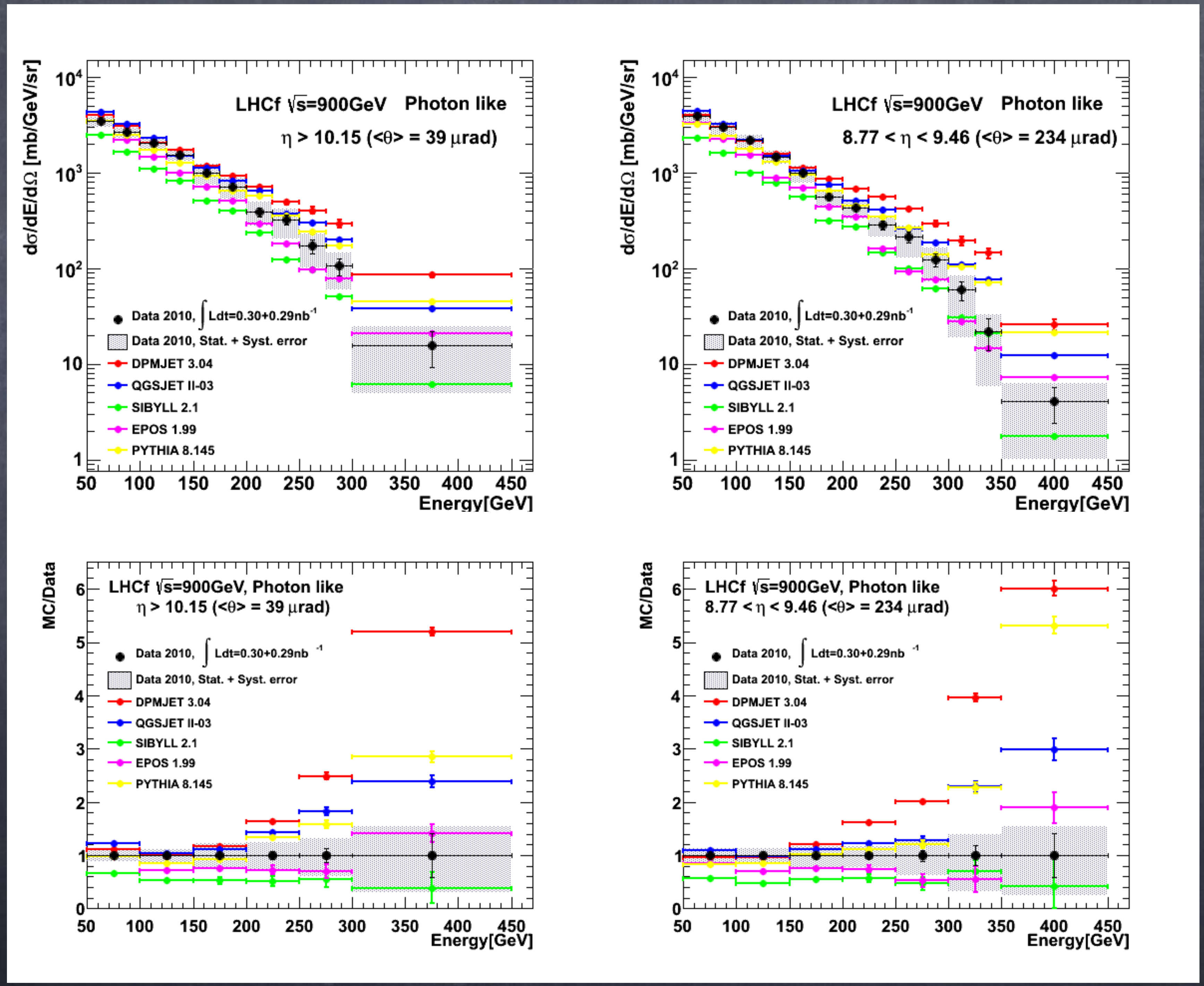




L_{2D} = L90%−0.25*L20%

- With two variables, L90% and L20%, PID performance is improved to reduce the photon contamination in neutron events.
- PID efficiency and purity are >90%.
- Energy spectra are corrected for PID inefficiency and BG contamination.

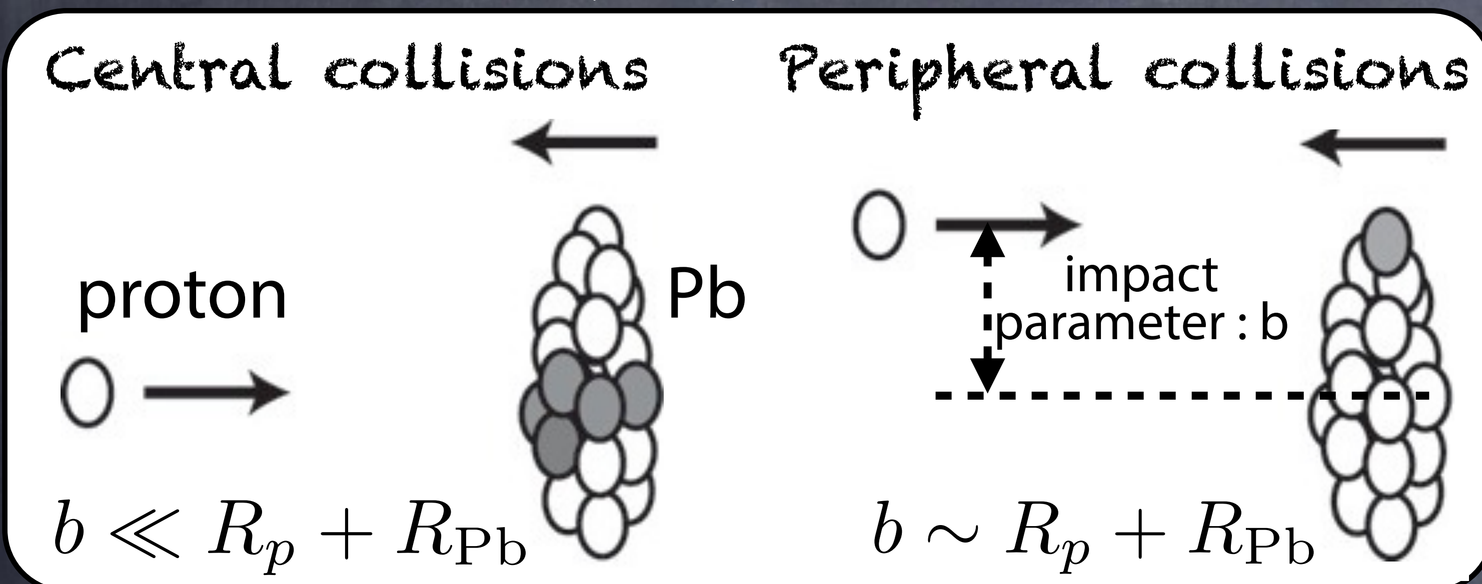
LHCf @ pp 900 GeV: Single photon spectra MC vs Data

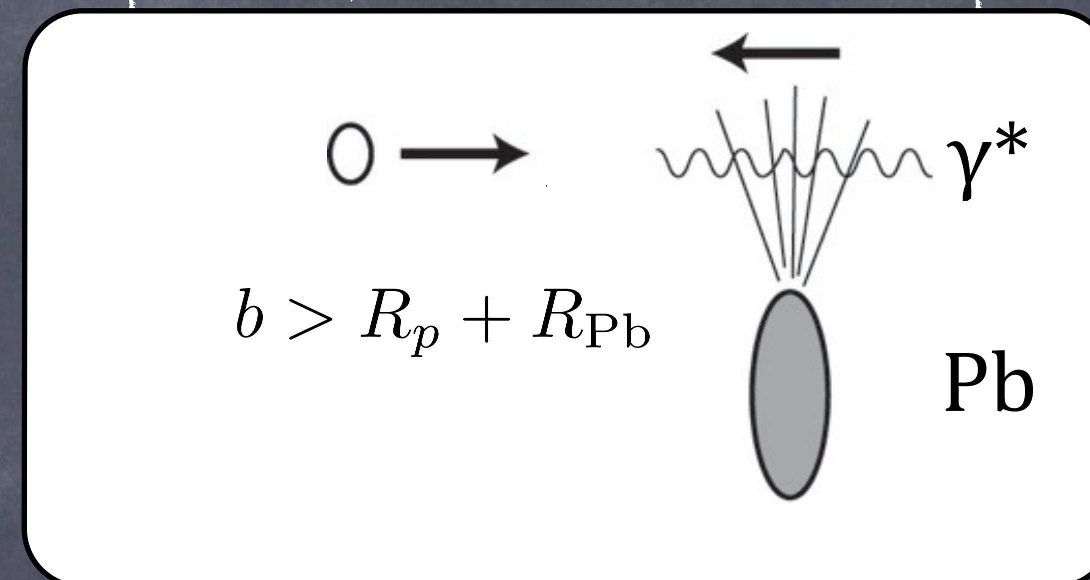


LHCf @ pPb 5.02 TeV: π^0 analysis

(Soft) QCD :
central and peripheral collisions

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





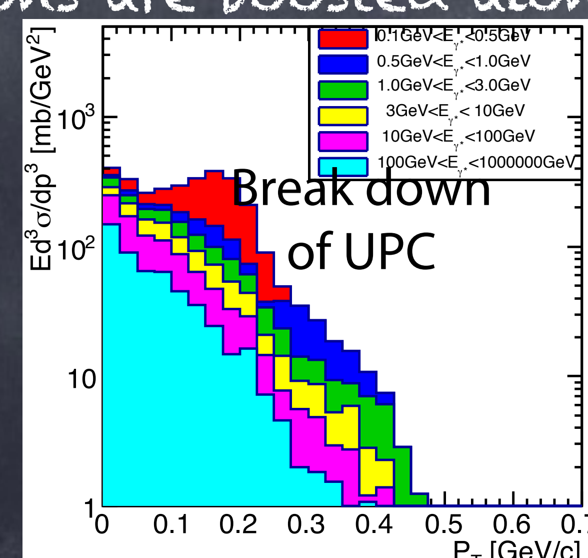
Momentum distribution of the UPC induced secondary particles is estimated as] proton rest frame

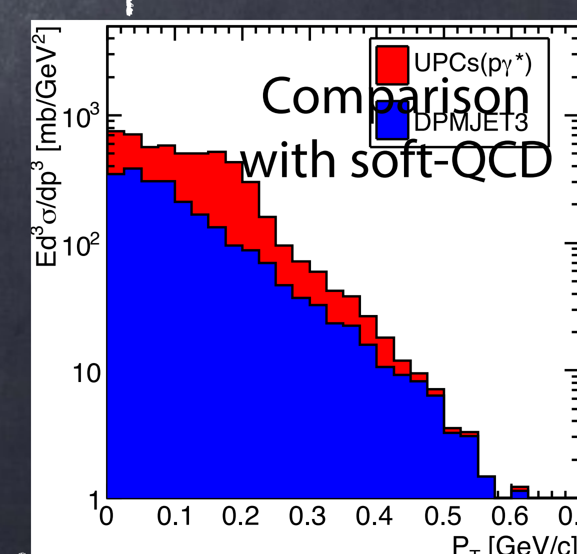
1. energy distribution of virtual photons is estimated by the Weizsacker Williams approximation.
2. photon-proton collisions are simulated by the SOHIA model (E_γ > pion threshold).
3. produced mesons and baryons by γ-p collisions are boosted along the proton beam.

Dominant channel to forward π^0 is

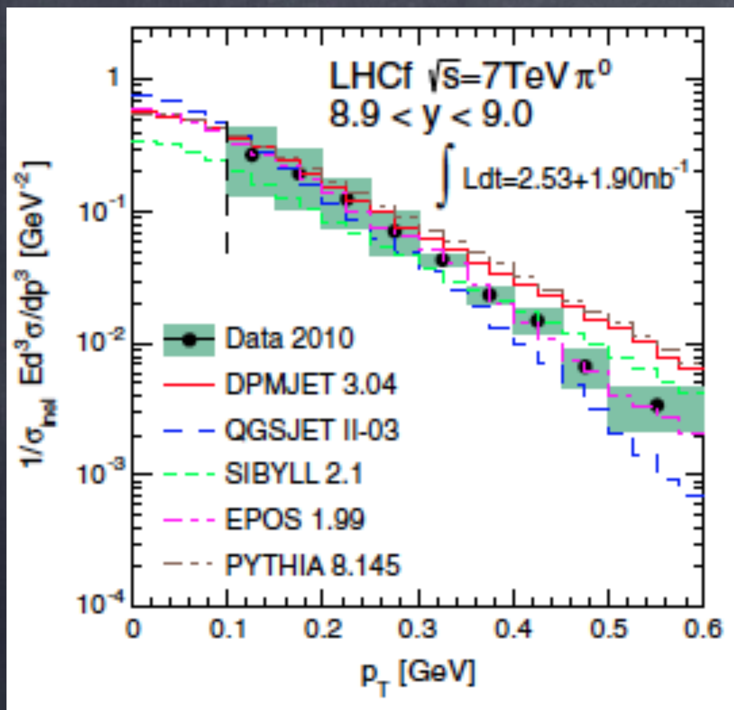
$$\gamma + p \rightarrow \Delta(1232) \rightarrow p + \pi^0$$

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

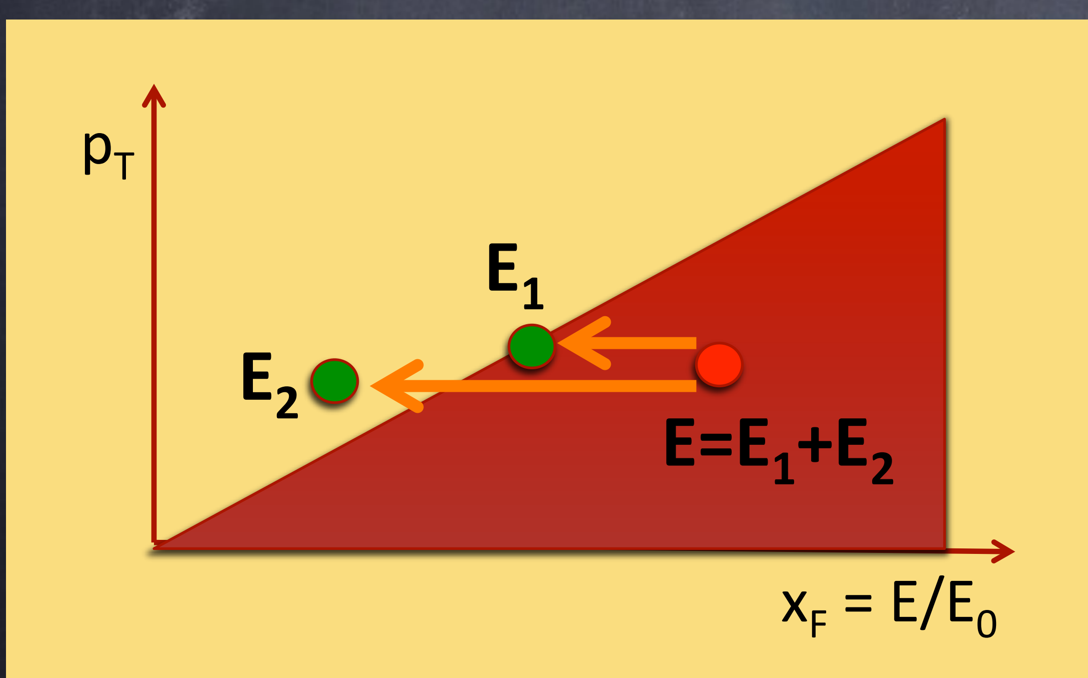


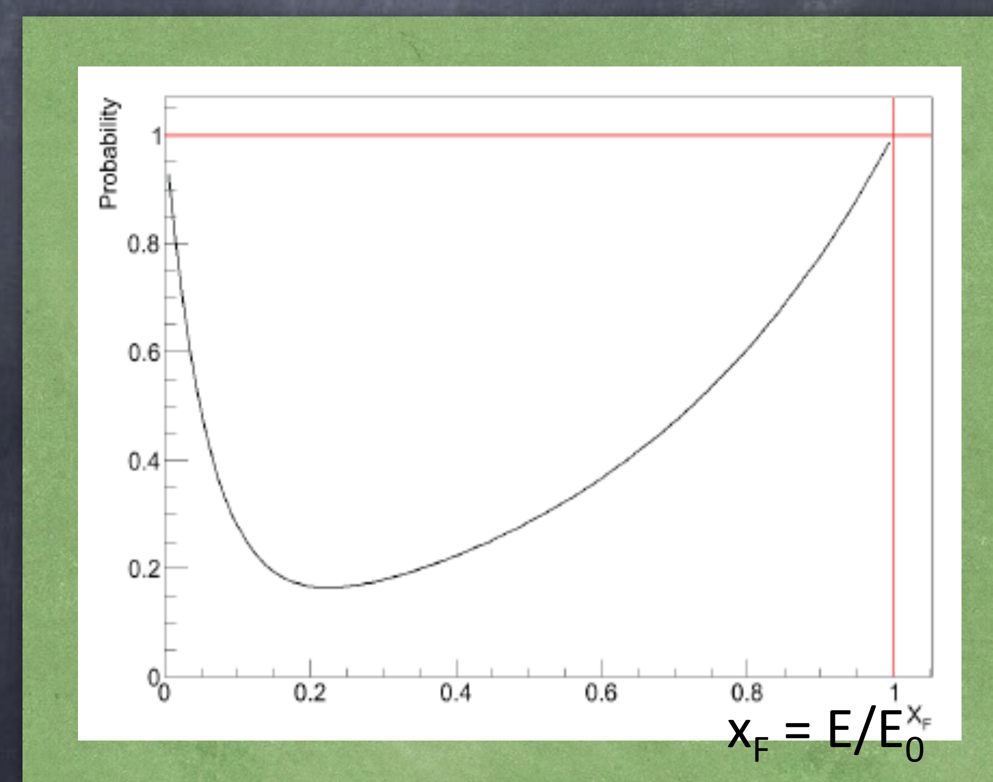


Playing a game with air shower - effect of forward meson spectra

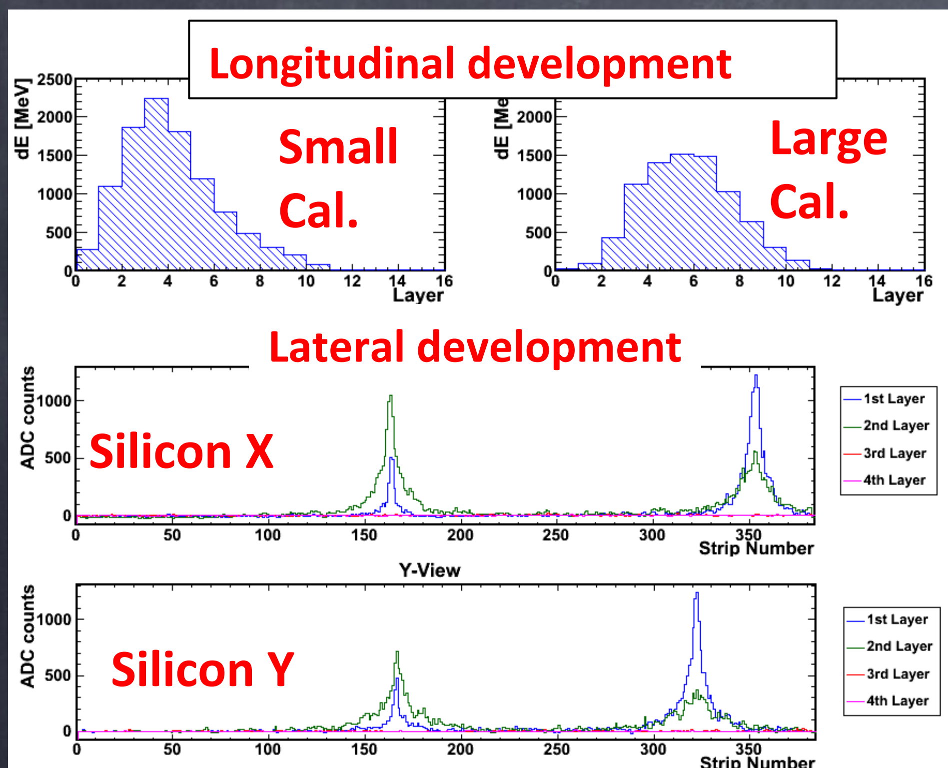


- DPMJET3 always over-predicts production
- Filtering DPMJET3 mesons
  - according to an empirical probability function, divide mesons into two with keeping p_T
  - Fraction of mesons escape out of LHCf acceptance
- This process
  - Holds cross section
  - Holds elasticity/inelasticity
  - Holds energy conservation
  - Changes multiplicity
  - Does not conserve charge event-by-event

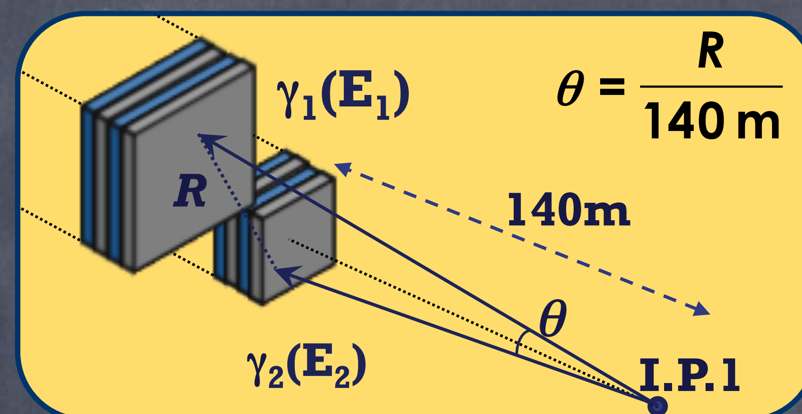




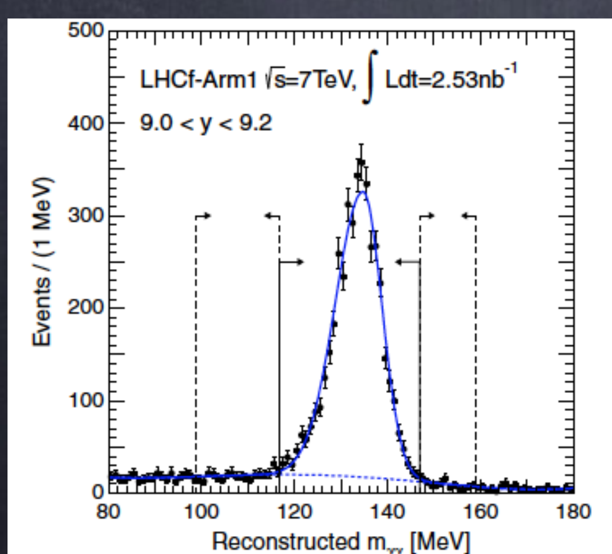
LHCf @ pp 7 TeV & p-Pb 5 TeV: π^0 analysis



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



$$M_{\pi^0} = \sqrt{E_{\gamma 1} E_{\gamma 2} \theta^2},$$
$$E_{\pi^0} = E_{\gamma 1} + E_{\gamma 2},$$
$$P_{T\pi^0} = P_{T\gamma 1} + P_{T\gamma 2}$$



Analysis Procedure

Standard photon reconstruction

Event selection

- one photon in each calorimeter
- reconstructed invariant mass

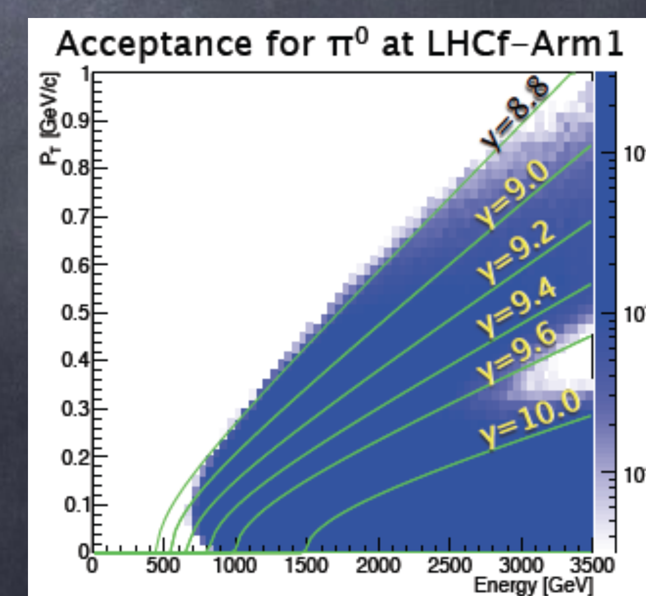
Background subtraction

by using outer region of mass peak

Unfolding for detector response.

Acceptance correction.

Dedicated part for π^0 analysis



LHCf @ pp 7 TeV: π^0 p_T spectra

dpmjet 3.04 & pythia 8.145

overall agreement with LHCf data for 9.2<y<9.6 and p_T <0.25 GeV/c

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

the expected π^0 yield is generally small

qgsjet II-03

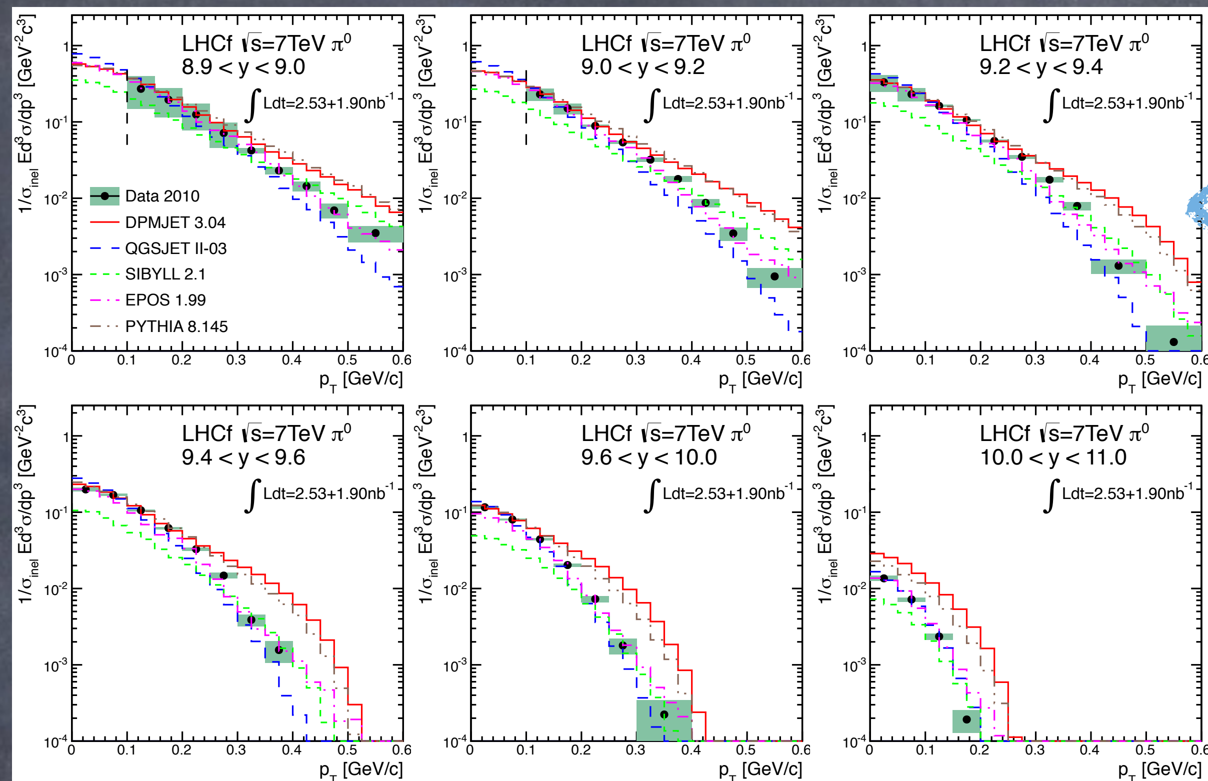
predicts π^0 spectra softer than LHCf data

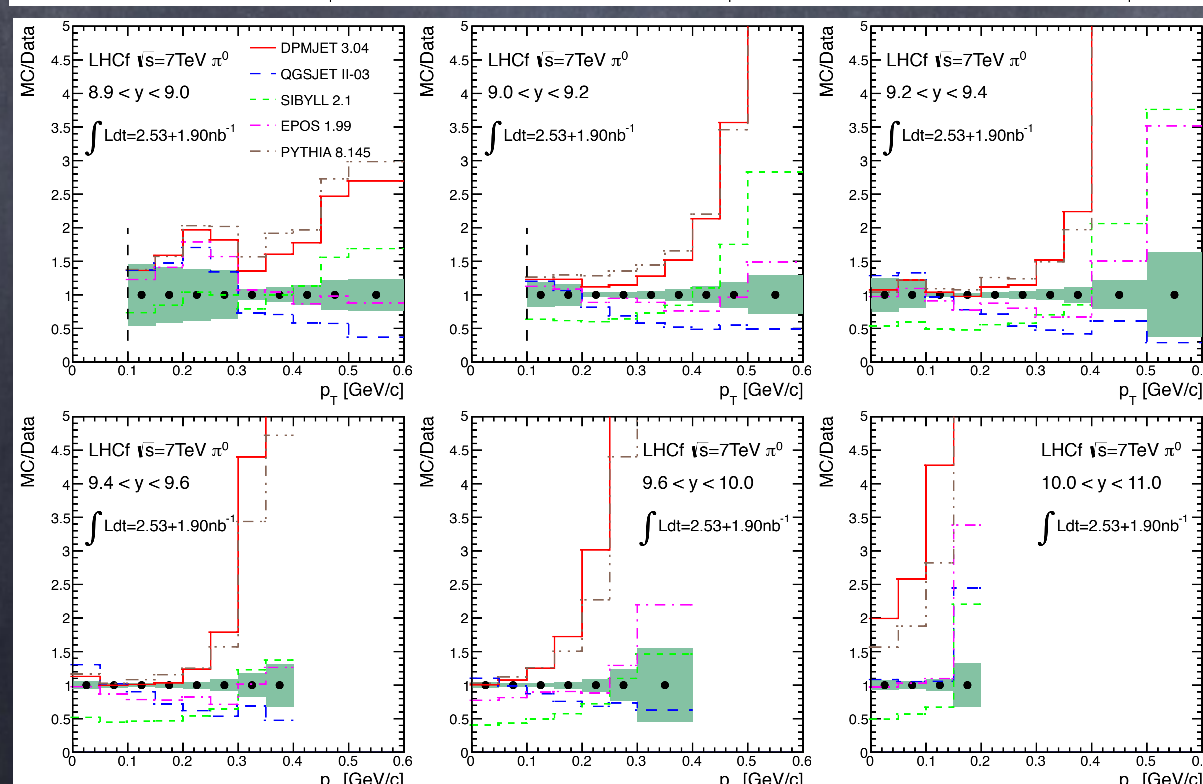
epos 1.99

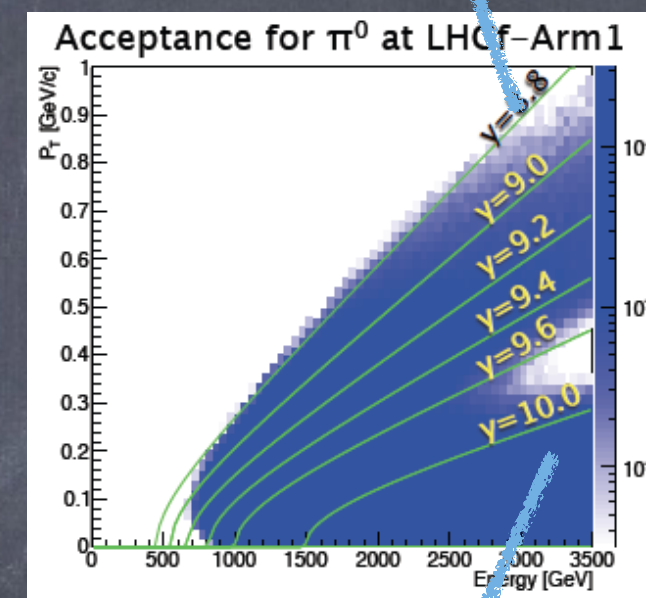
shows the best overall agreement with the LHCf data:

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.

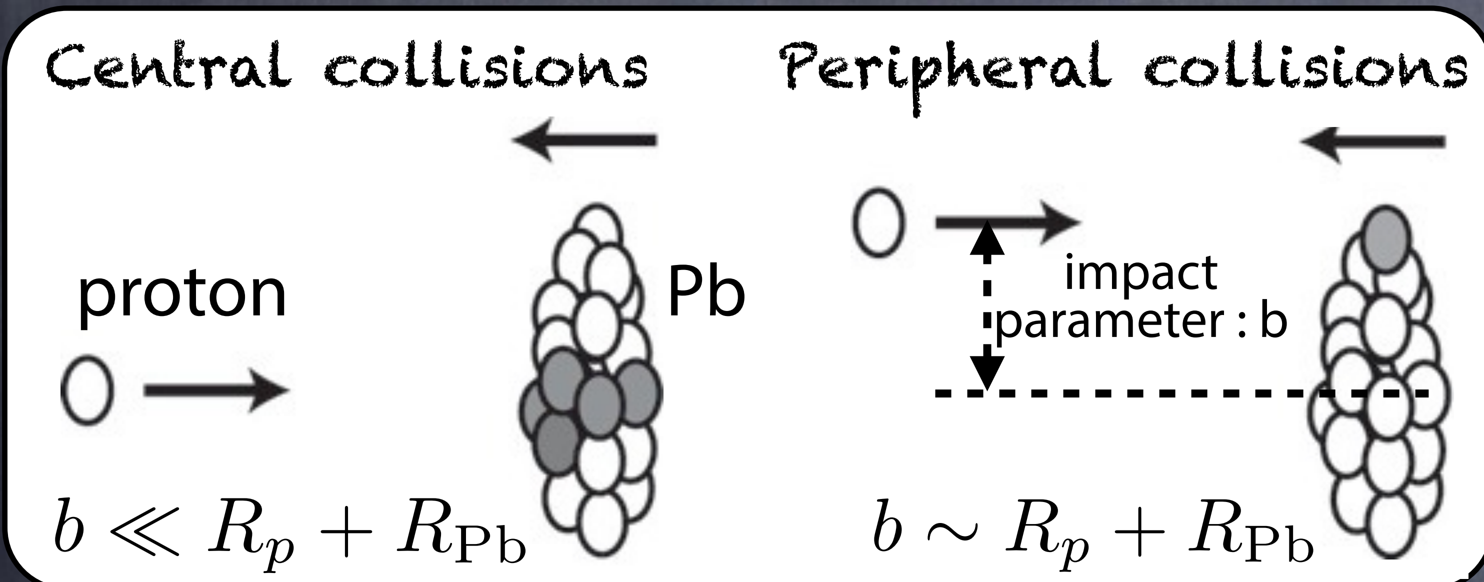




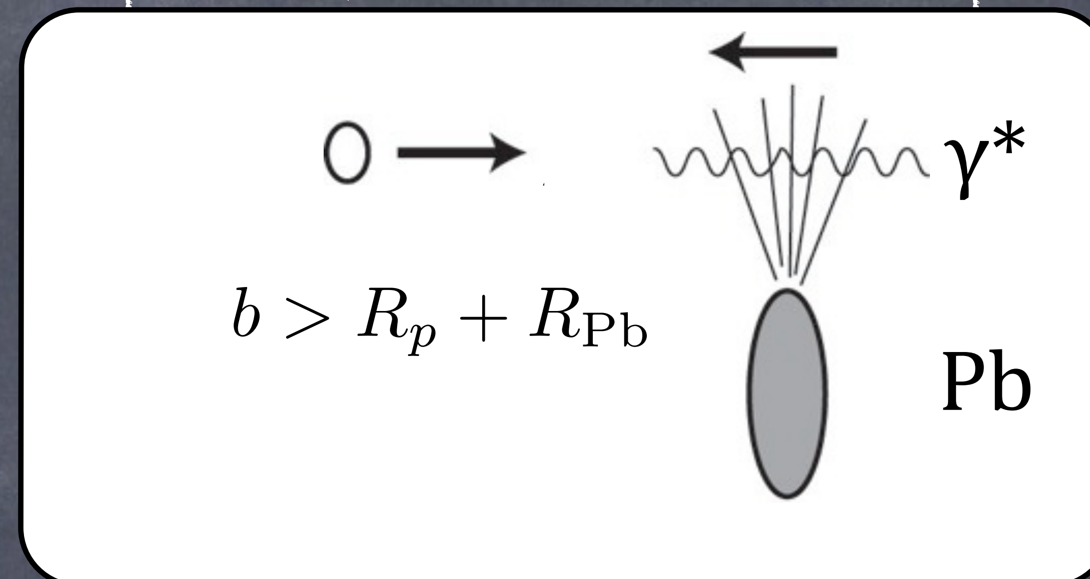


LHCf @ pPb 5.02 TeV: π^0 analysis

(Soft) QCD :
central and peripheral collisions



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

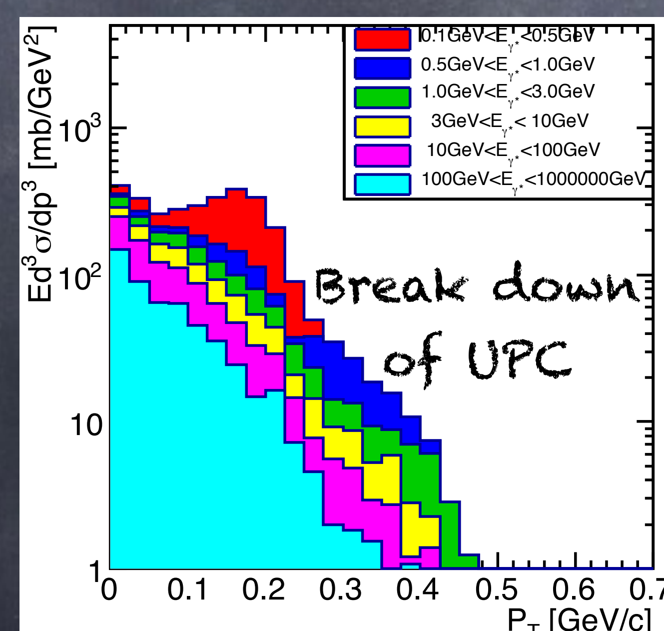


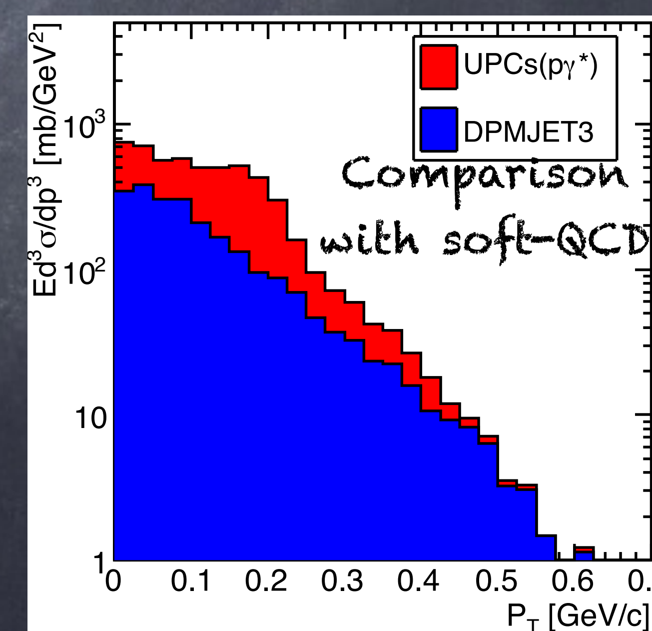
Dominant channel to forward π^0 is

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

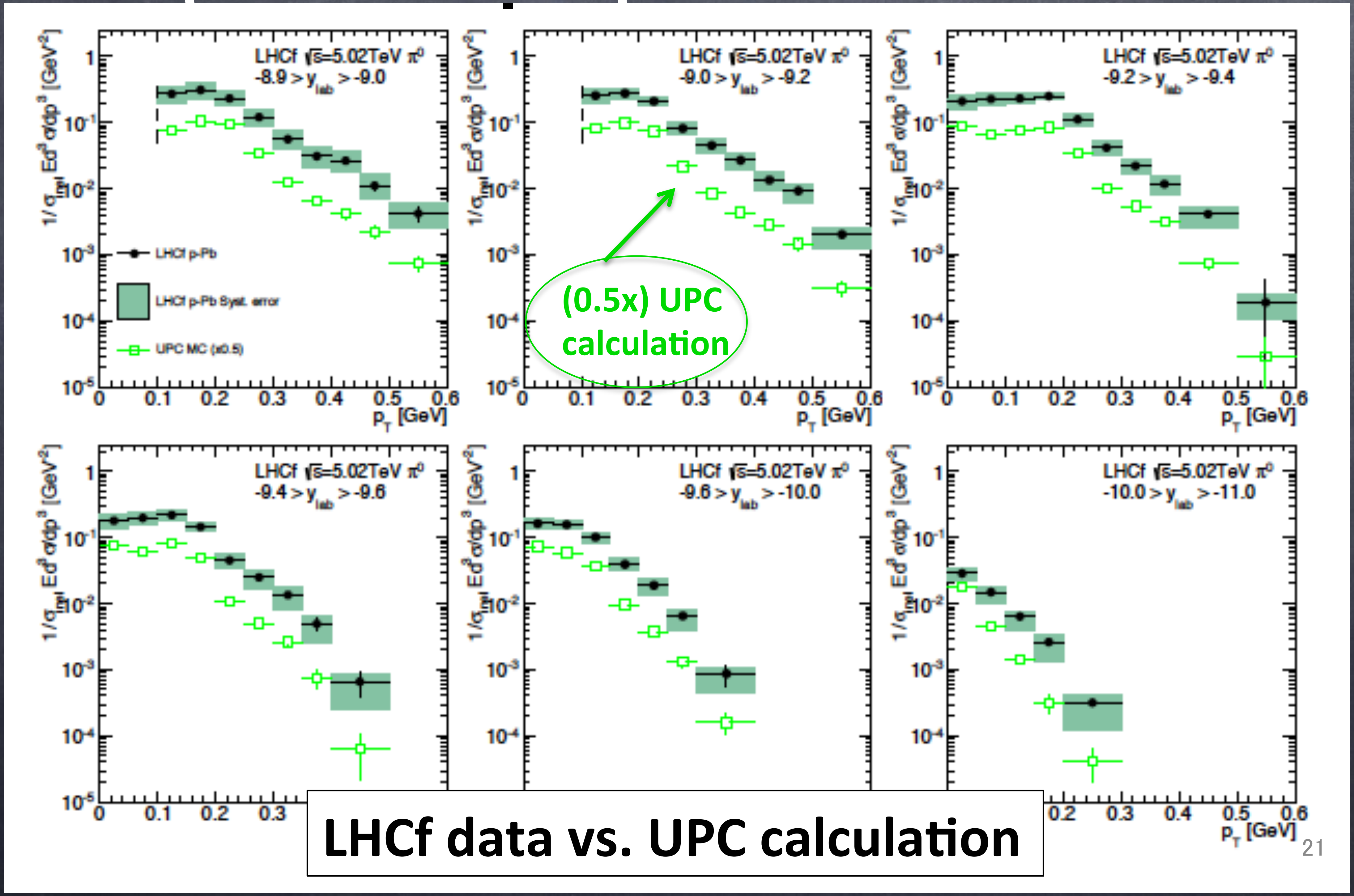
About half of the observed π^0 may originate in UPC, another half is from soft-QCD

Need to subtract UPC component

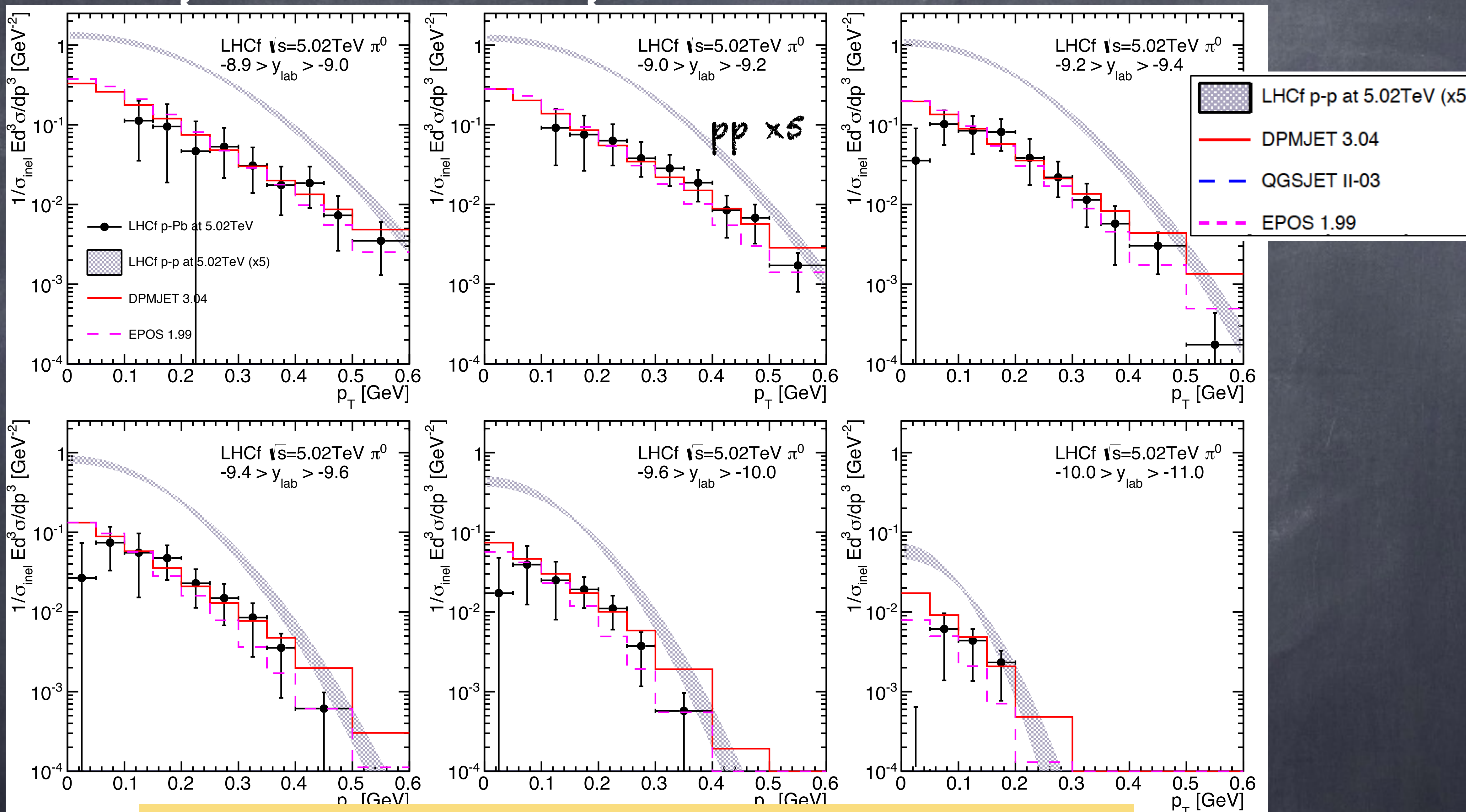




LHCf @ pPb 5.02 TeV: π^0 spectra @ p-remnant side



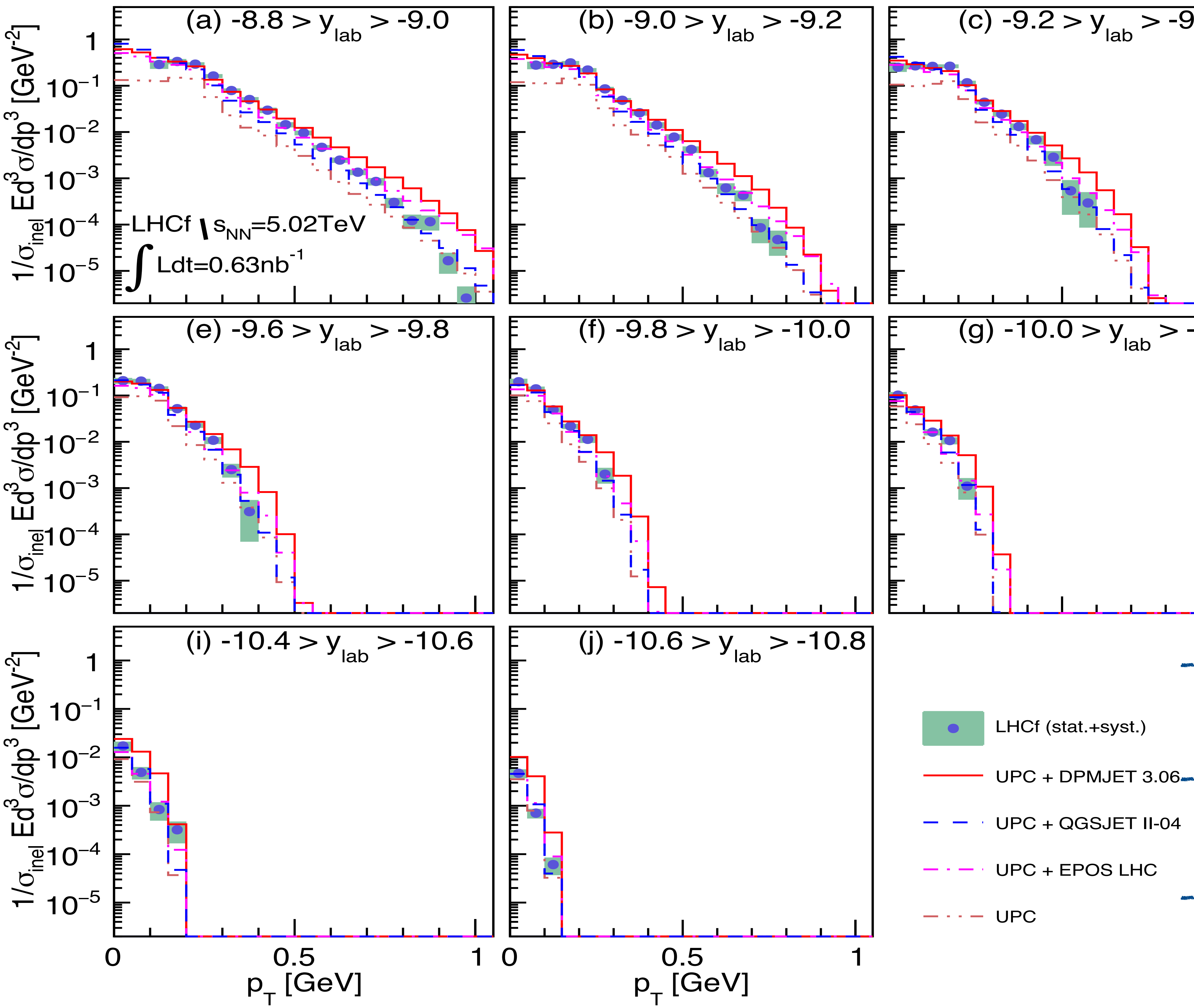
LHCf @ pPb 5.02 TeV: π^0 spectra @ p-remnant side



LHCf Data (UPC subtracted) vs Models

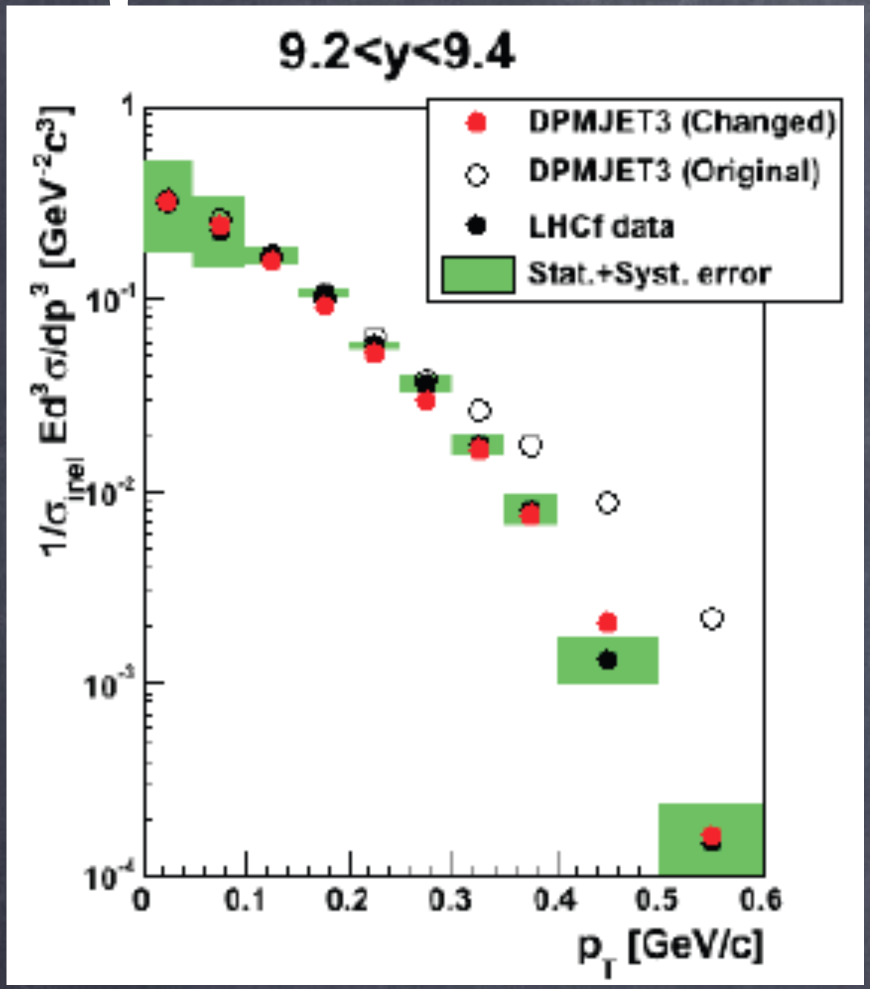
- The LHCf results in p-Pb (filled circles) show good agreement with DPMJET and EPOS.
- The LHCf results in p-Pb are clearly harder than the LHCf results in p-p at 5.02TeV (shaded area) which are interpolated from the results at 2.76TeV and 7TeV.

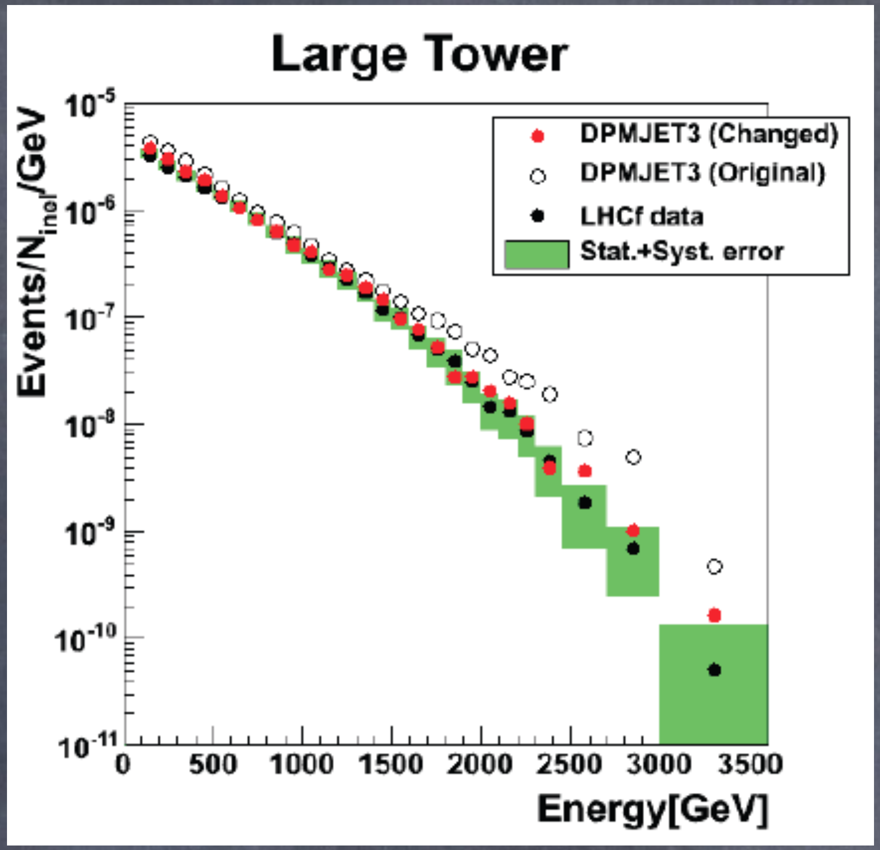
LHCf @ pPb 5.02 TeV: π^0 p_T spectra



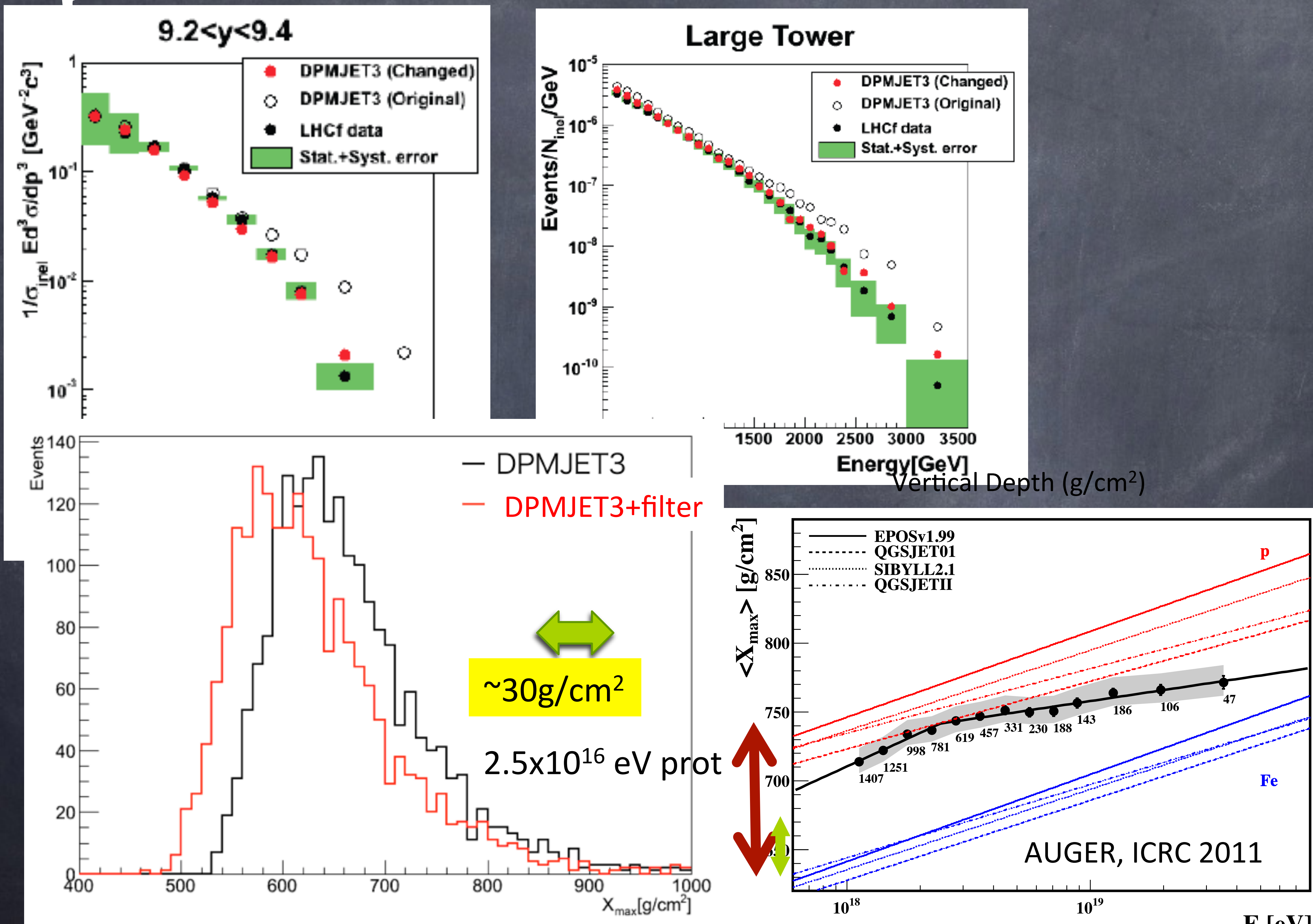
- QGSJETII-04 and EPOS-LHC: similar, good agremeent for pT>0.4 GeV
- DPMJET: good agreement for -8.8 > ylab > -10.0 and p_T < 0.3 GeV
- Characteristic bump at y > -9.6 and p_T ~ 0.2GeV: Ultra Peripheral Collisions

Impact of LHCf measurement





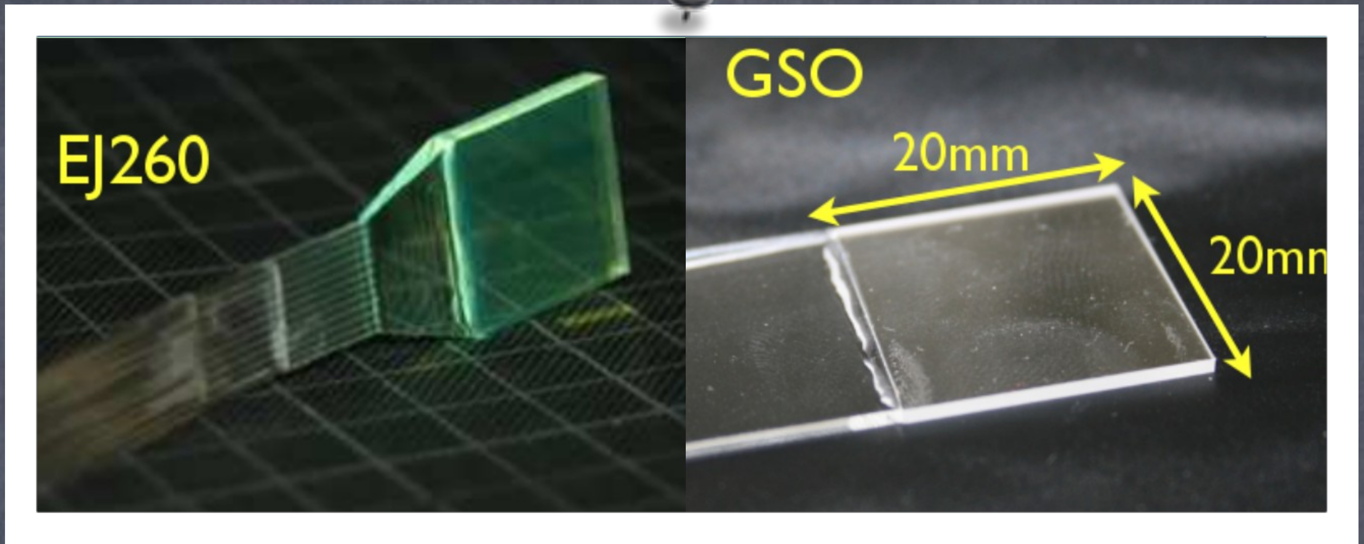
Impact of LHCf measurement



LHCf @13 TeV

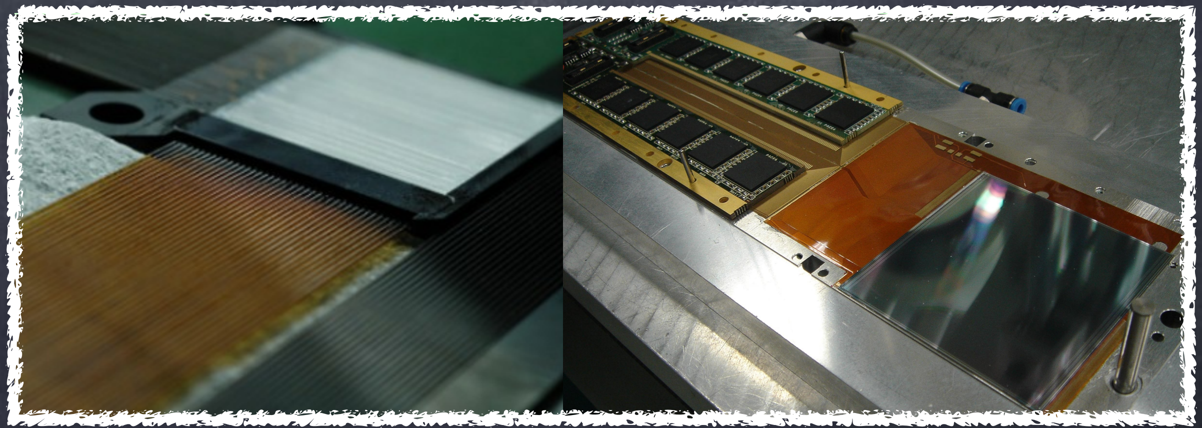
Detector Upgrade:

- Plastic Scintillator EJ260 (10^2Gy) replaced by GSO scintillator (10^6Gy) for both ARM1 & ARM 2 => Improve radiation hardness for high dose rate expected at 13 TeV (30 Gy/nb^{-1})

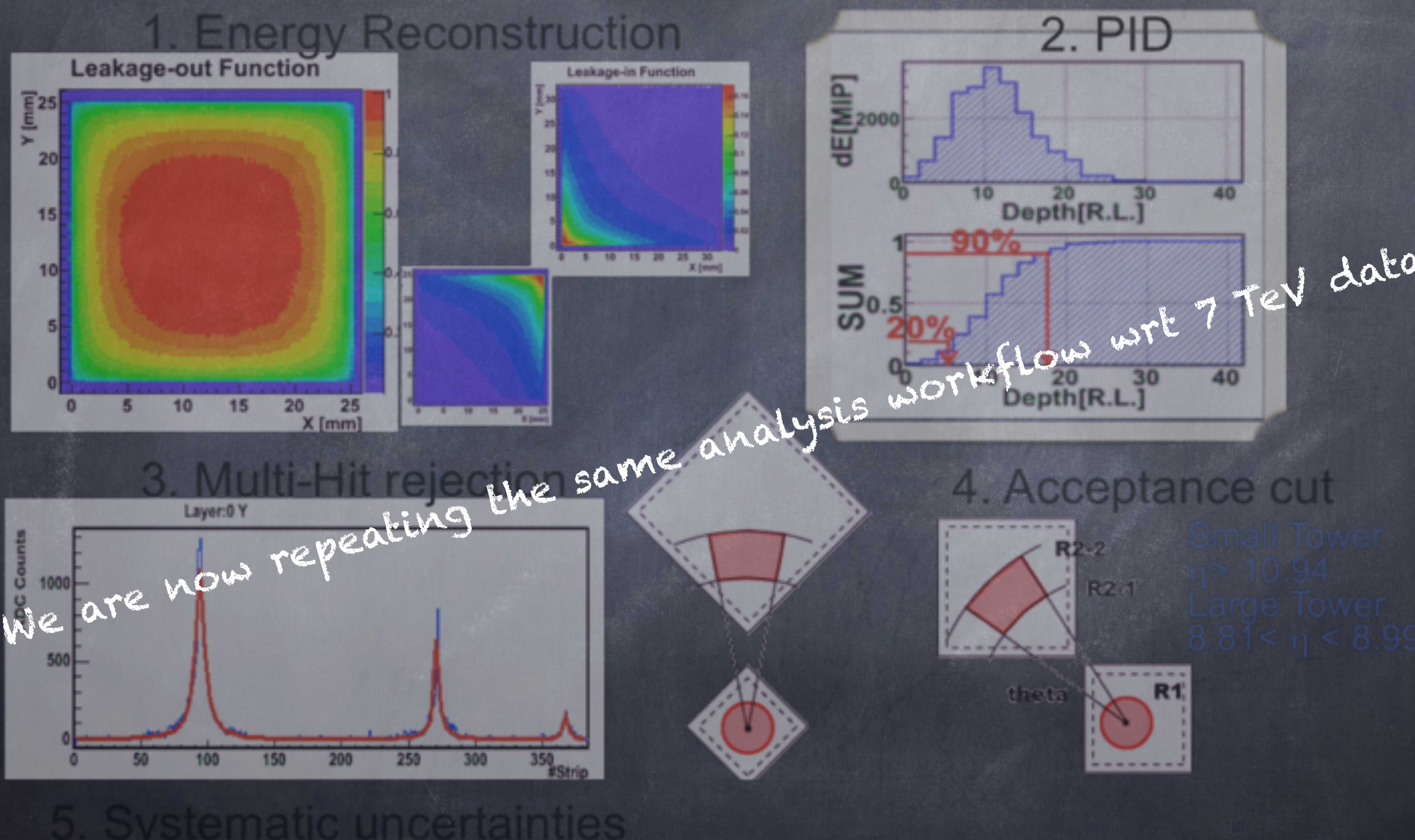


Detector Upgrade:

- ARM1:
  - SciFi layers replaced by GSO bars hodoscope
- ARM2:
  - modified the bonding of the silicon microstrip detector to improve the dynamic range
  - modified the silicon layer position to optimize the stand-alone energy reconstruction

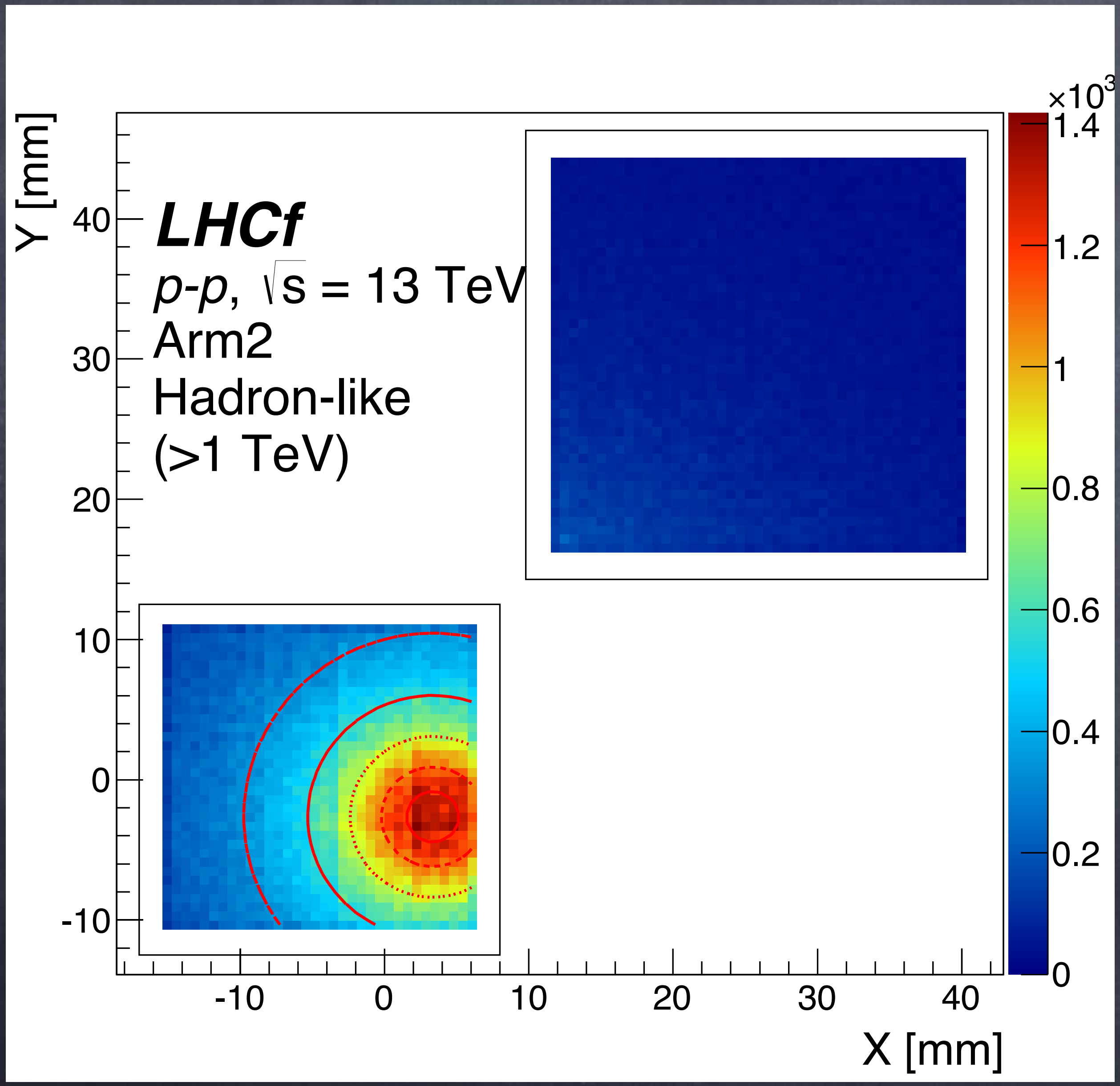


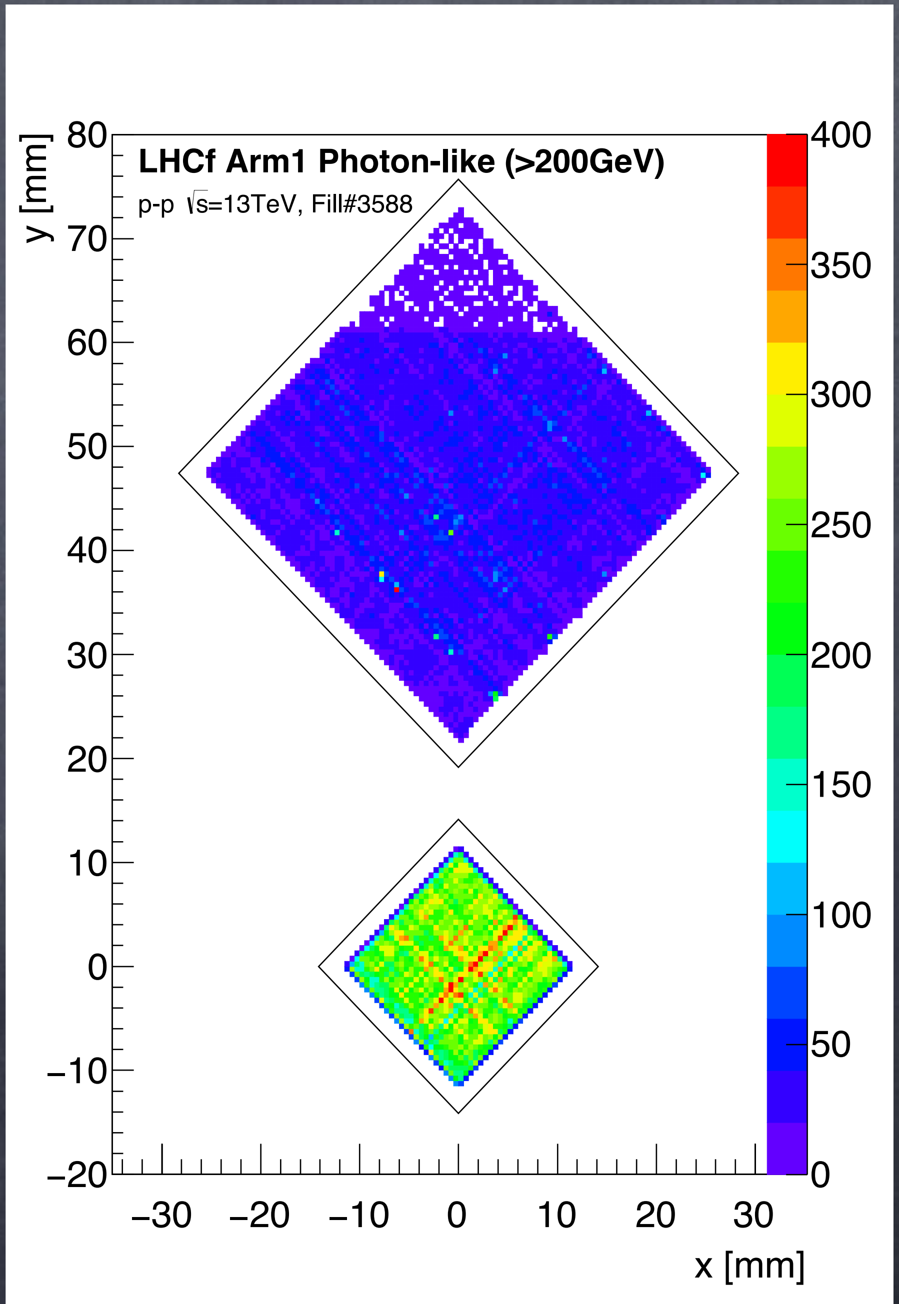
Analysis workflow



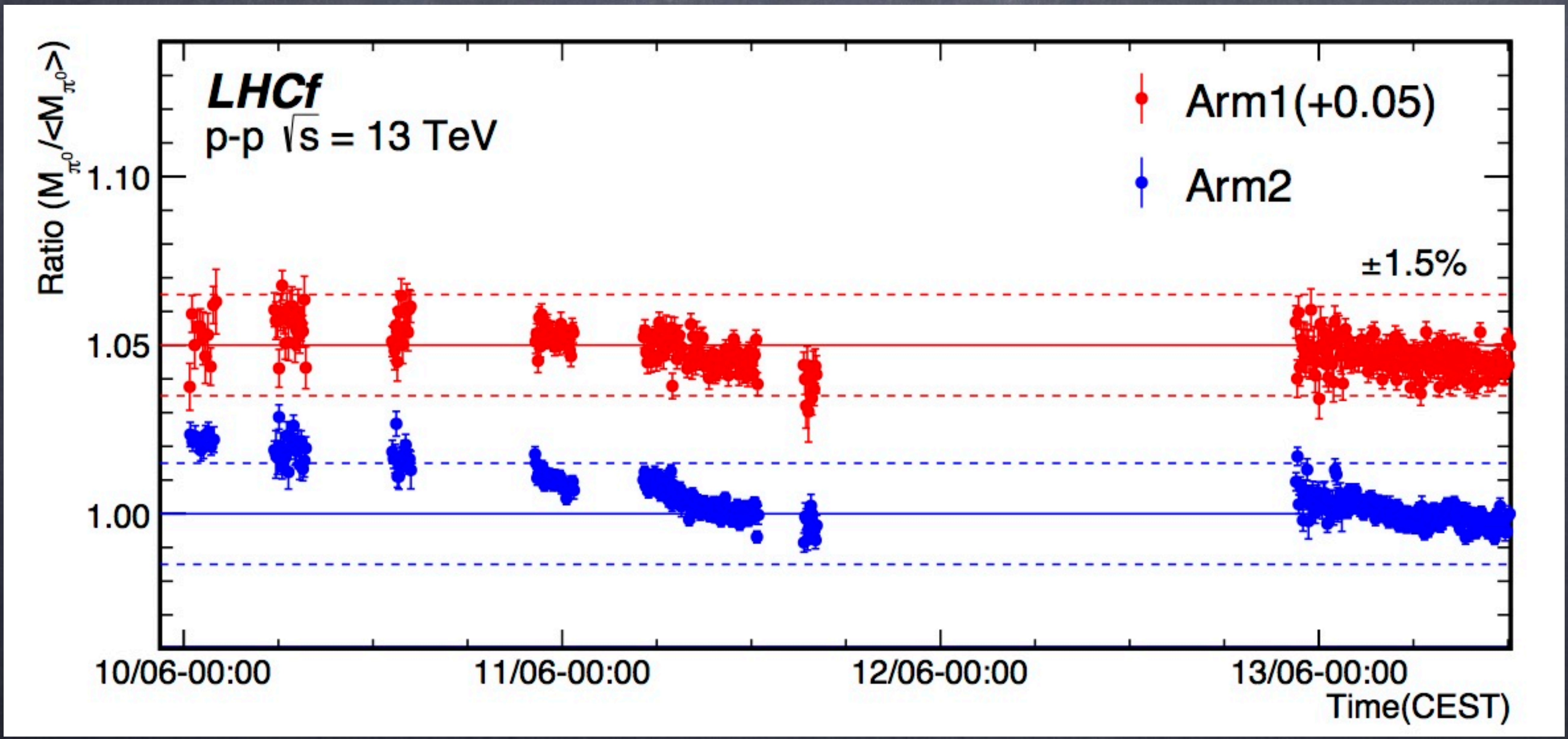
We are now repeating the same analysis workflow wrt 7 TeV data

Analysis workflow: determination of the beam center

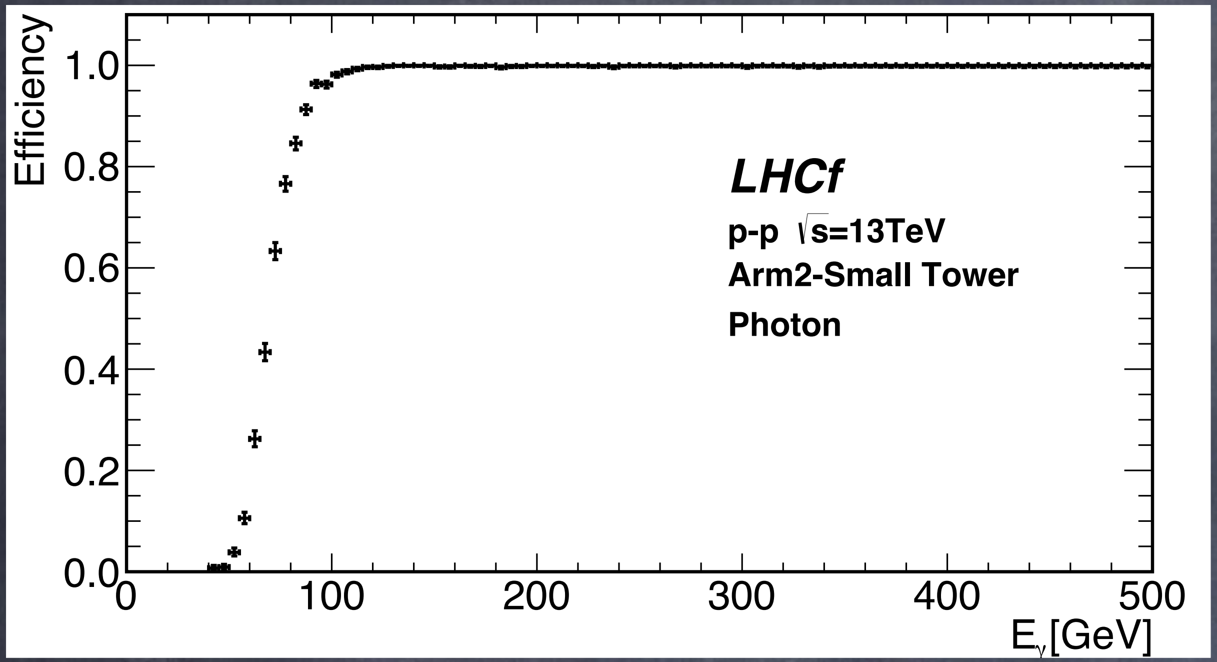




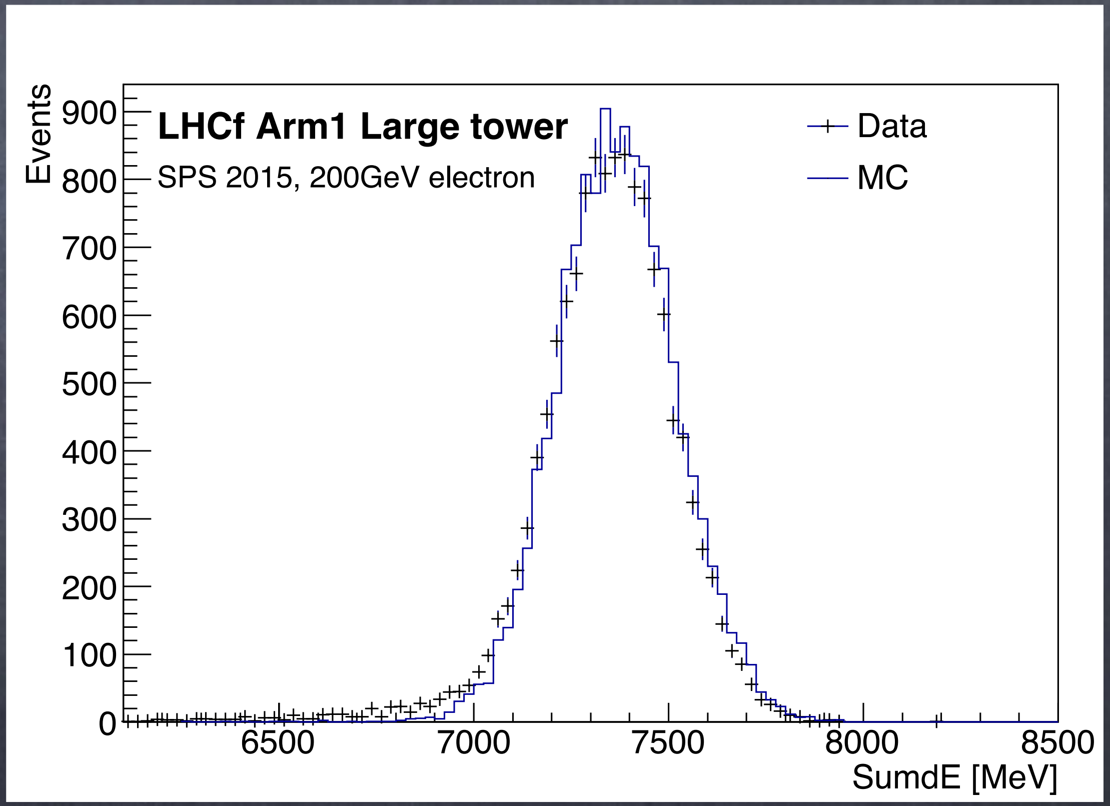
π^0 mass stability



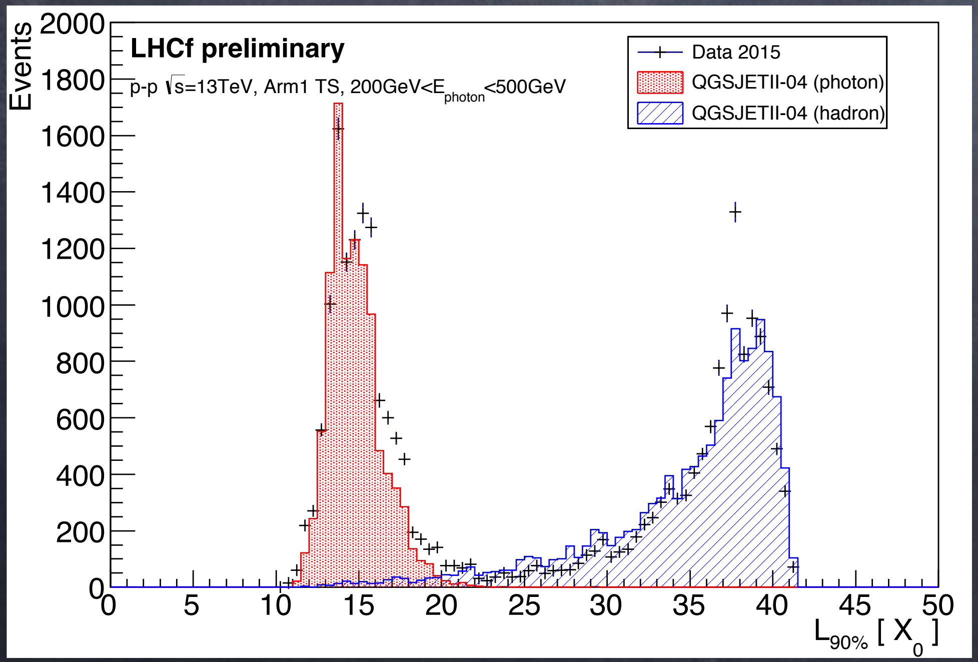
Analysis workflow: selections and reconstructions



Trigger efficiency:
Fully efficient for E>100 GeV

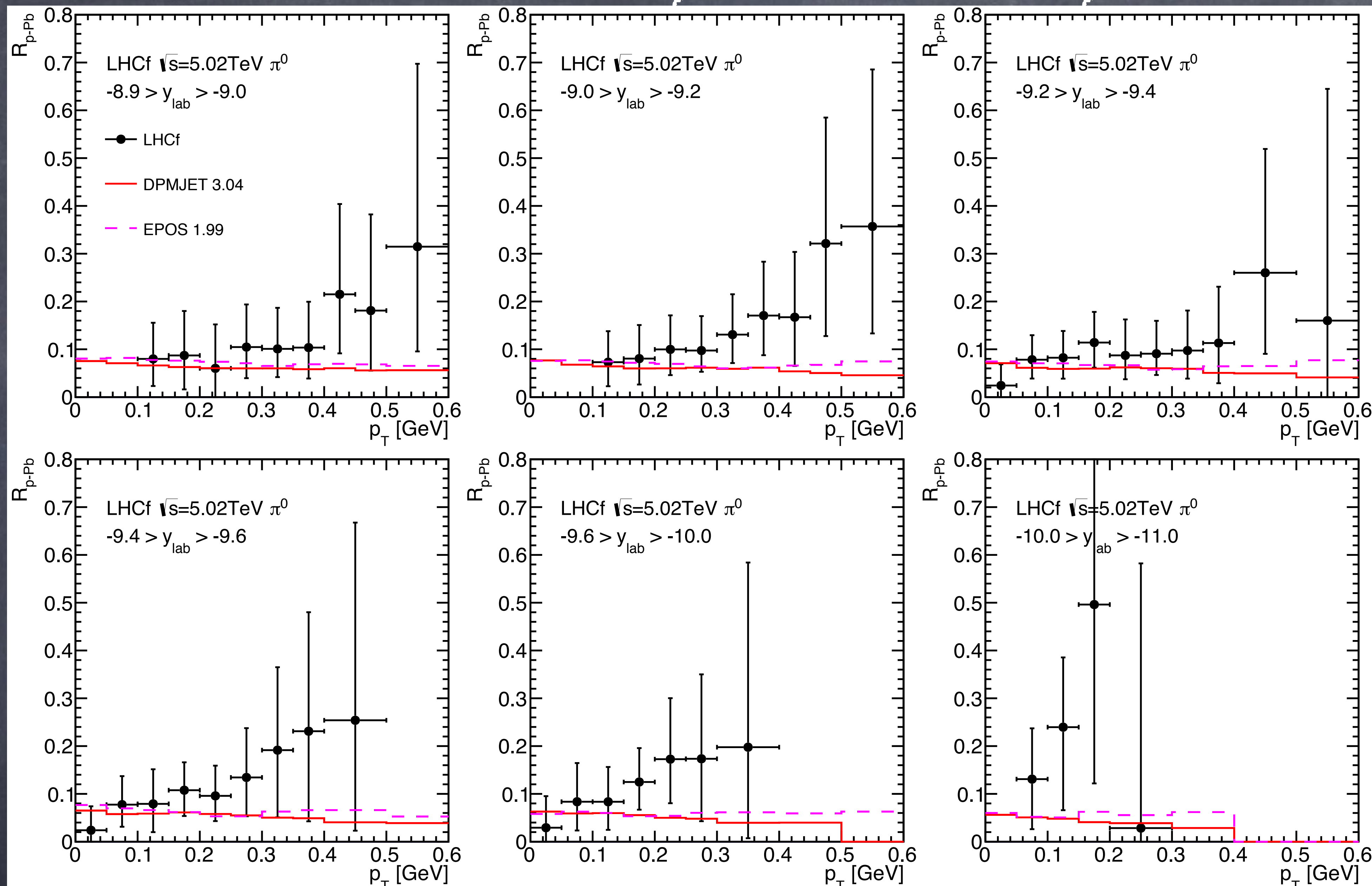


Energy calibration based on SPS beam test



PID based on longitudinal profile distribution ($L_{90\%}$)

LHCf @ pPb 5.02 TeV: Nuclear modification factor

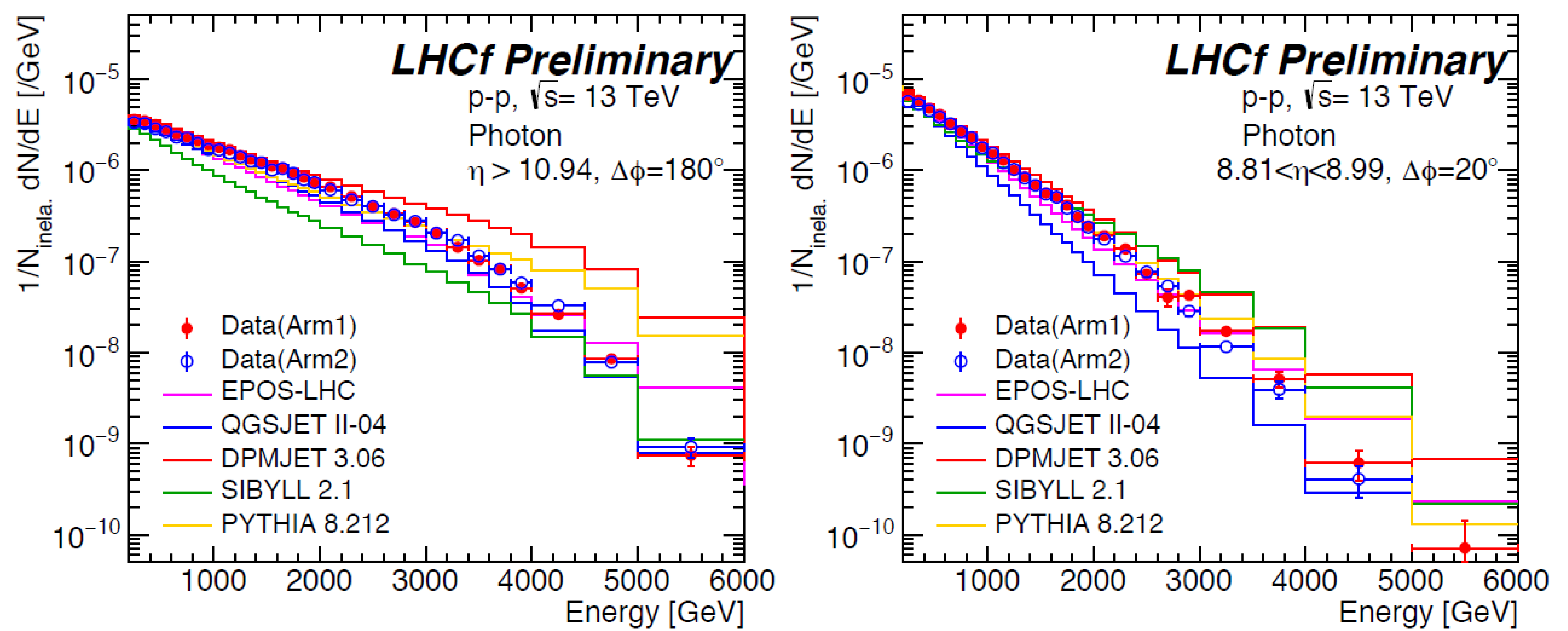


$$R_{\mathrm{pPb}}(p_{\mathrm{T}}) \equiv \frac{d^2N_{\pi^0}^{\mathrm{pPb}}/dydp_{\mathrm{T}}}{\langle N_{\mathrm{coll}}\rangle d^2N_{\pi^0}^{\mathrm{pp}}/dydp_{\mathrm{T}}}$$

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

- 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.

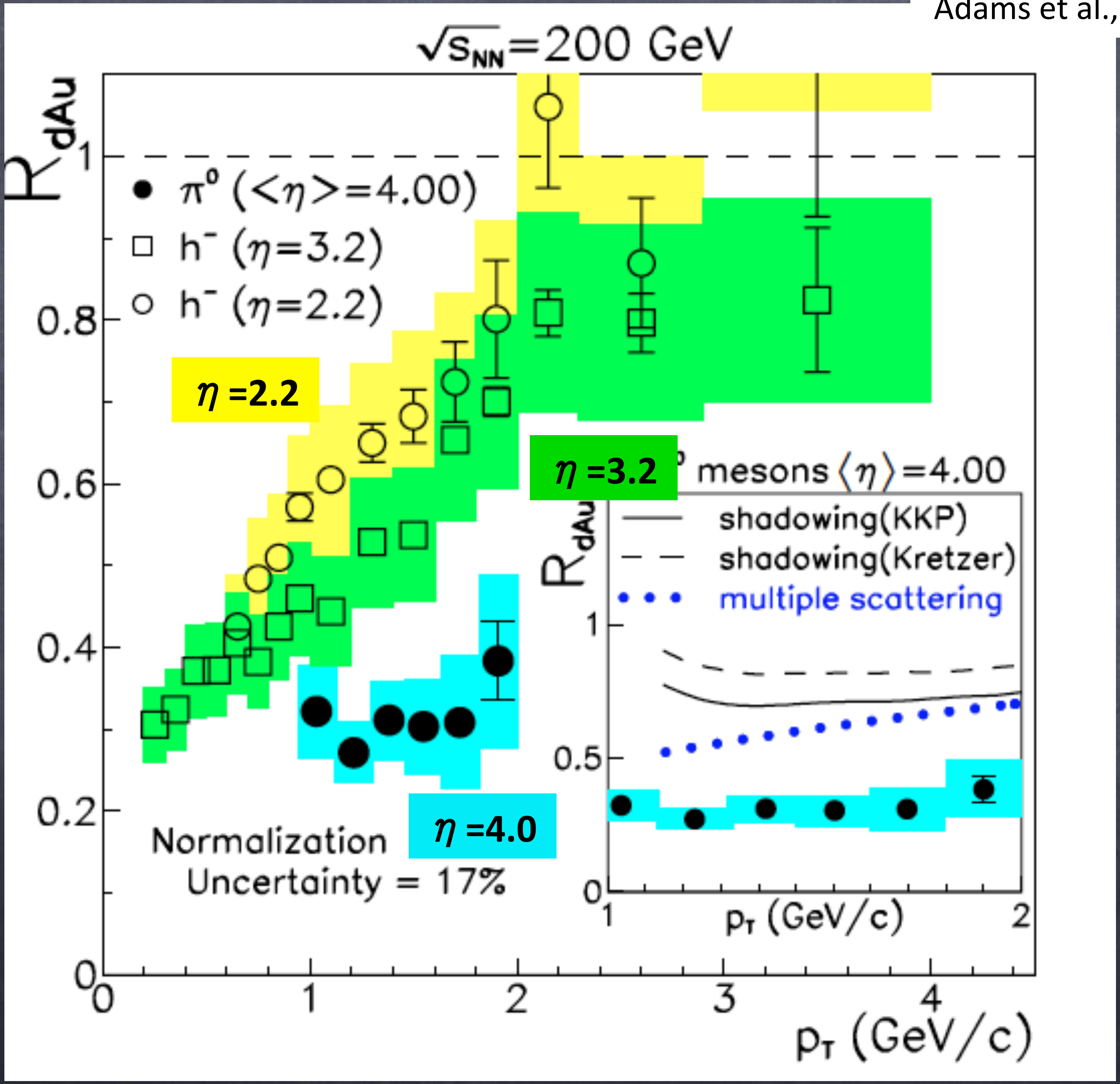
Preliminary γ energy spectra at 13 TeV



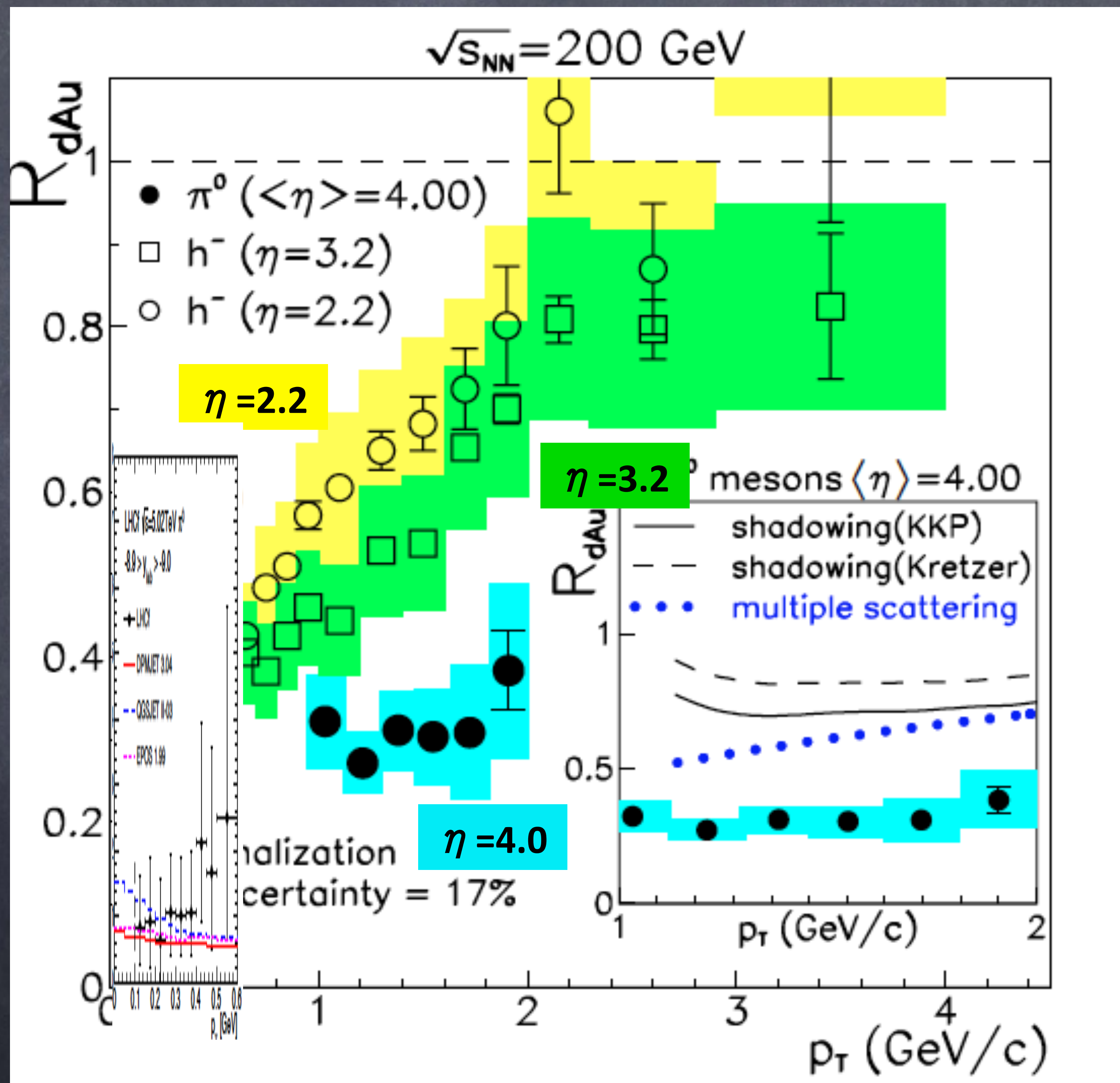
Error bars show only the statistical errors.

Nuclear modification factor

RHIC 200GeV d-Au, STAR Collaboration
Adams et al., PRL 97 (2006) 152302.



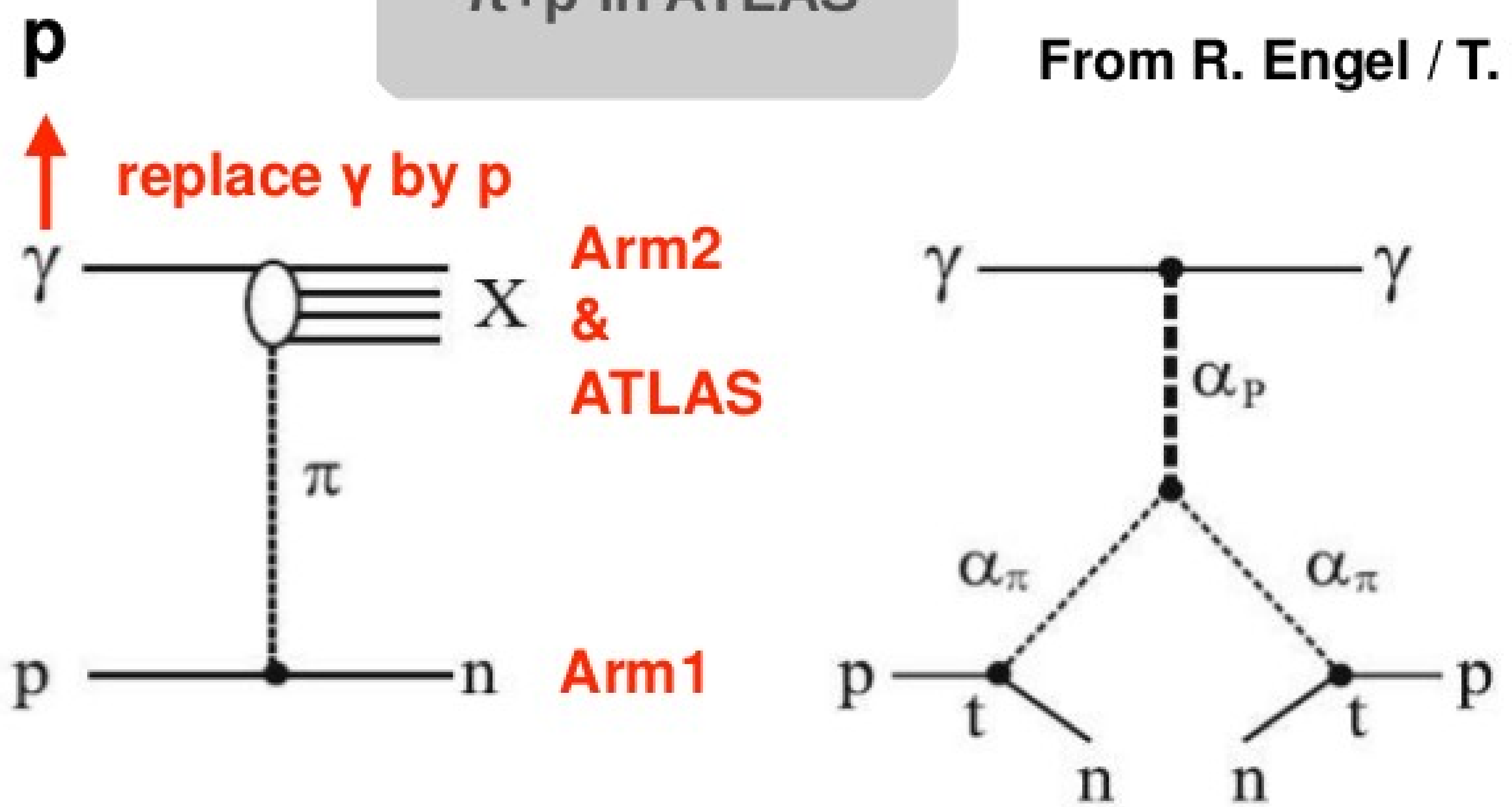
LHCf @ pPb 5.02 TeV vs RHIC: Nuclear modification factor



ATLAS Triggered by LHCf

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

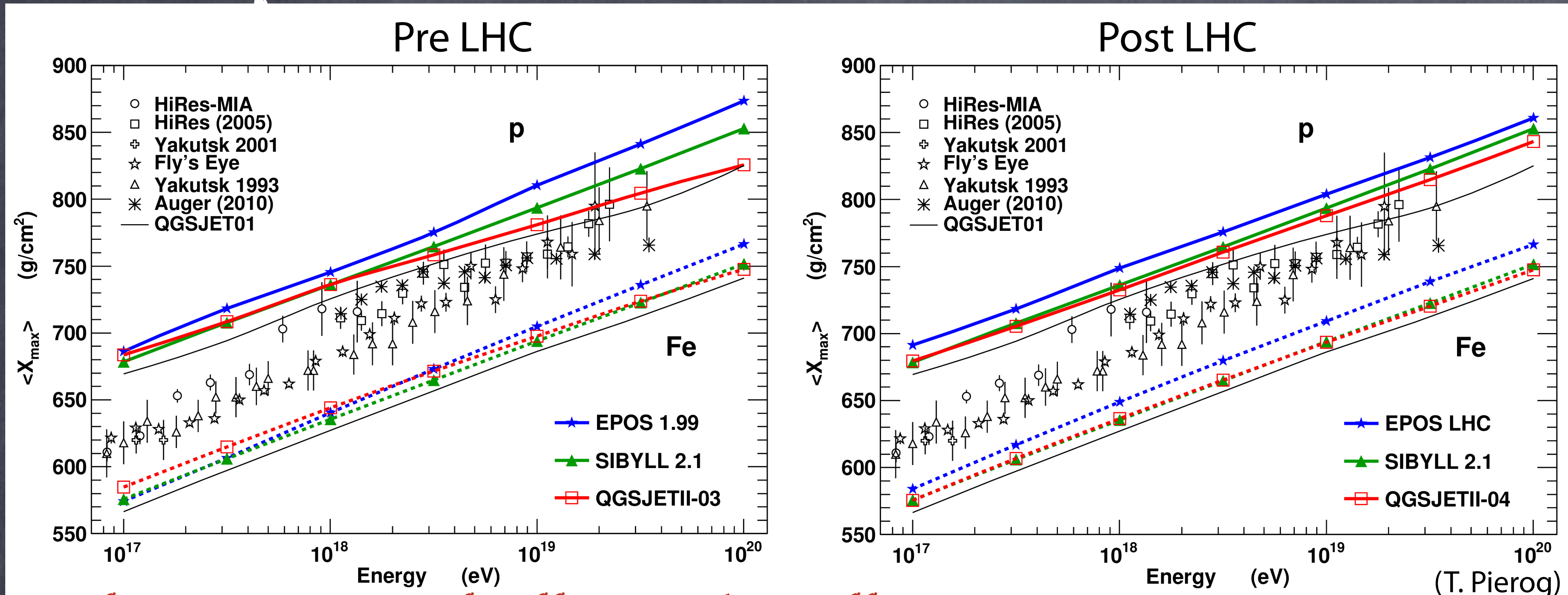
From R. Engel / T. Pierog



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)

The impact of LHC measurements

Mean depth of shower maximum



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

Number of muons on ground