Measurements of forward neutron and neutral pion productions with the LHCf detector

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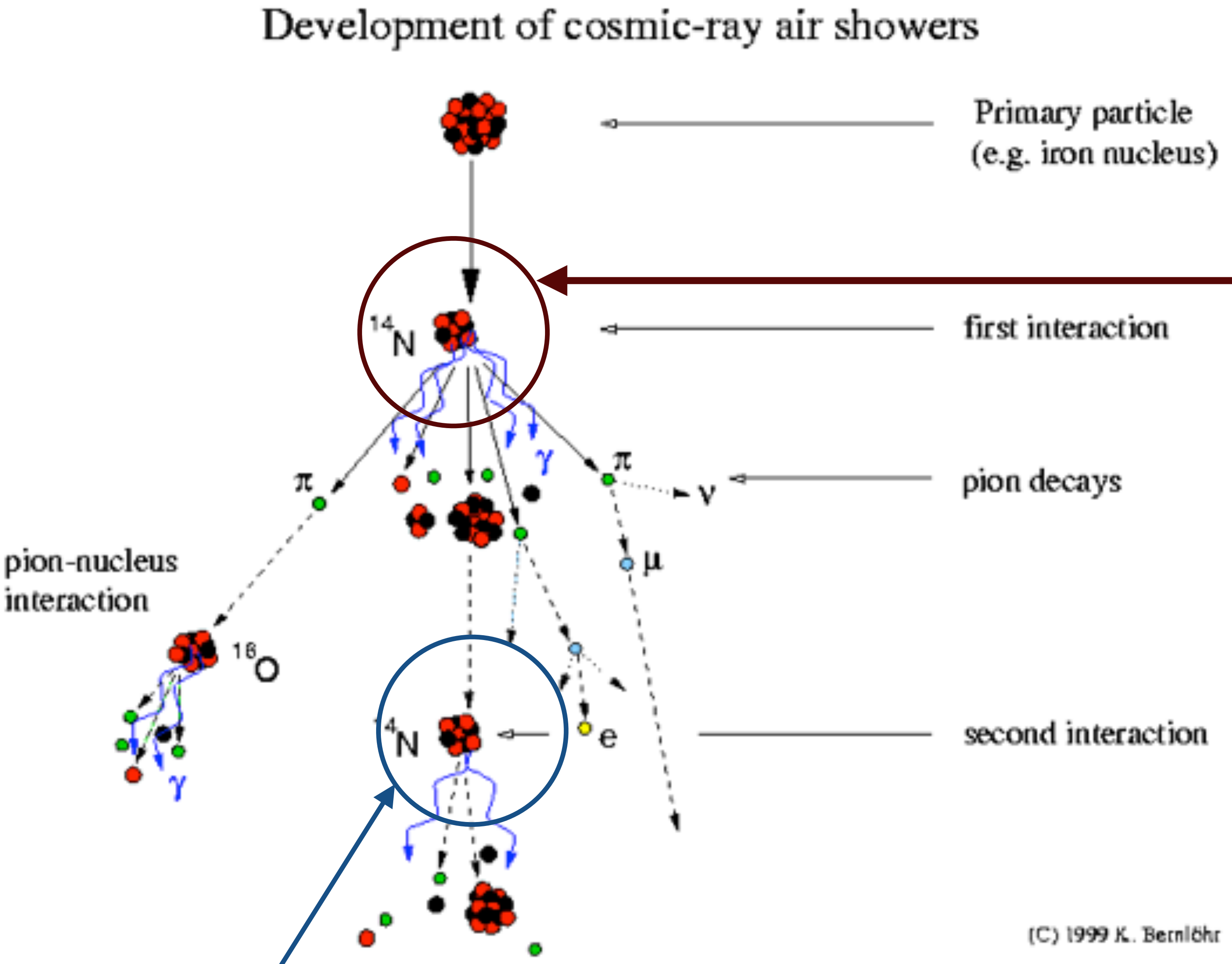
Outline

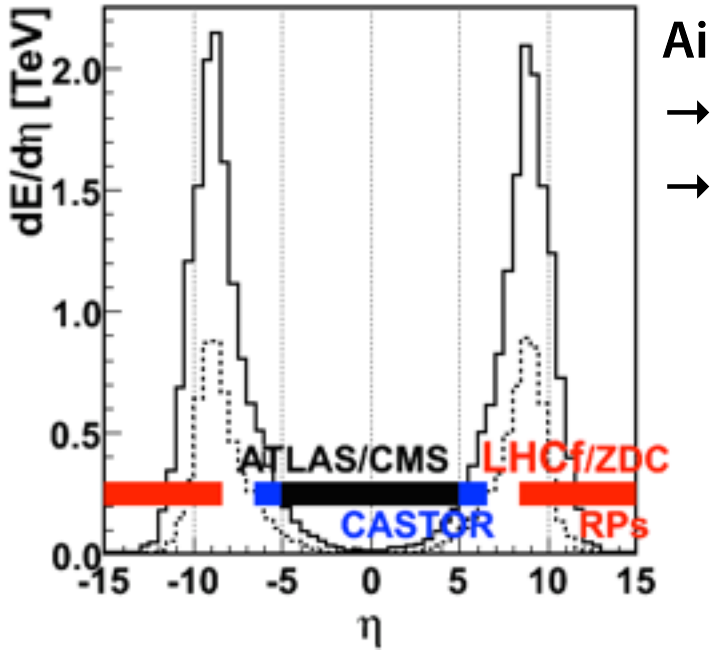
- Introduction and physics motivations
- The LHCf detector
- Selected physics results
  - π^0 p_T and energy spectra
  - Neutron energy spectra
- Upgrade of the LHCf detector towards 13 TeV
- Summary

Physics motivation (cosmic ray point of view)



1. **Charge ratio** (e.g. NA61)
2. **Multiplicity**
   number of muons in air shower sensitive to mass composition

1. **Inelastic cross section** large → rapid development small → deep penetrating	(by TOTEM)
2. **Inelasticity $k = 1 - p_{lead}/p_{beam}$** large → rapid development small → deep penetrating	neutron (~leading baryon)
3. **Forward energy spectrum** softer → rapid development harder → deep penetrating	photon or π^0
4. **Nuclear effects**	p-Pb collisions
5. **Extrapolation to high energy** precise measurements at lower energies are crucial	many data points



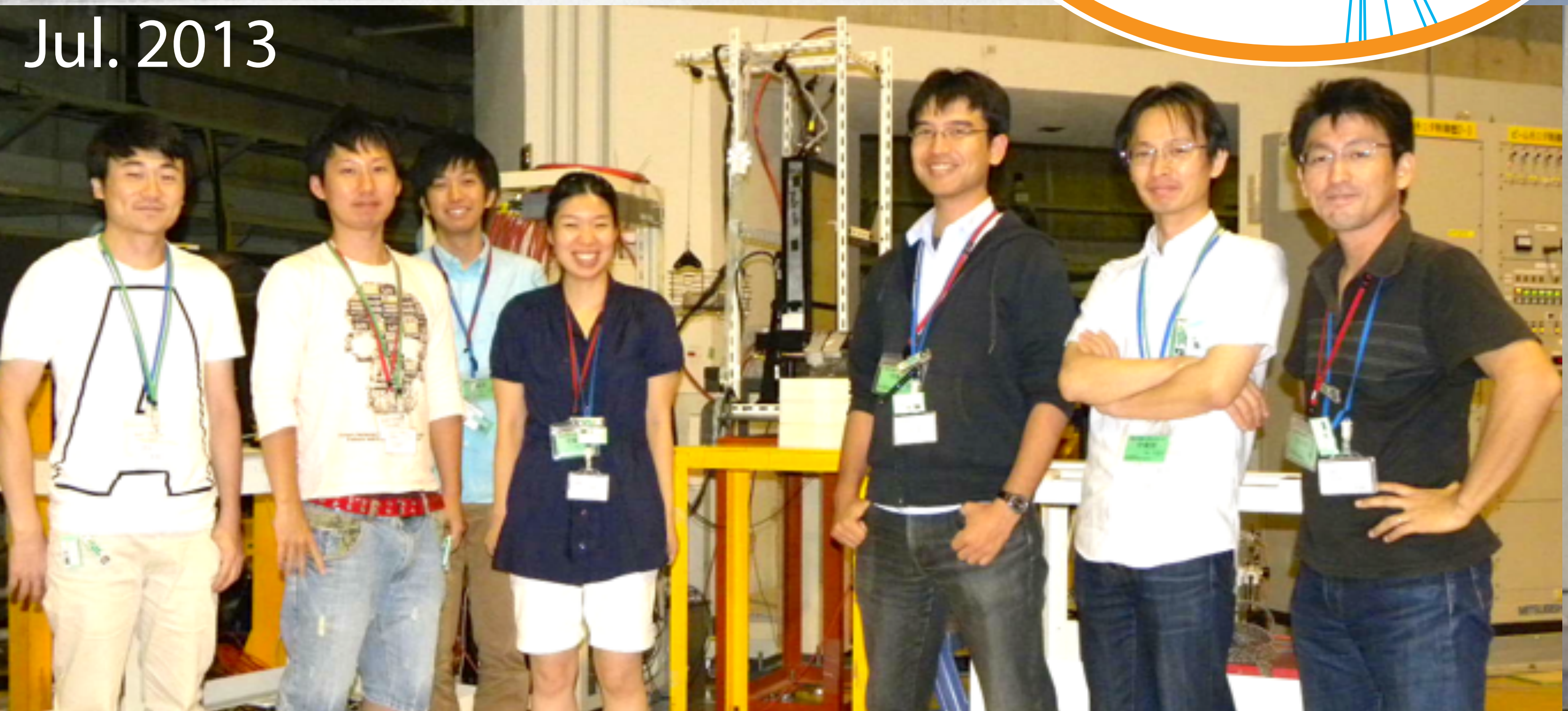
Air-shower production
→ proportional dE/dη
→ special importance in forward region

The LHCf collaboration

The LHCf collaboration involves ~30 members from 10 institutes.

Feb. 2009

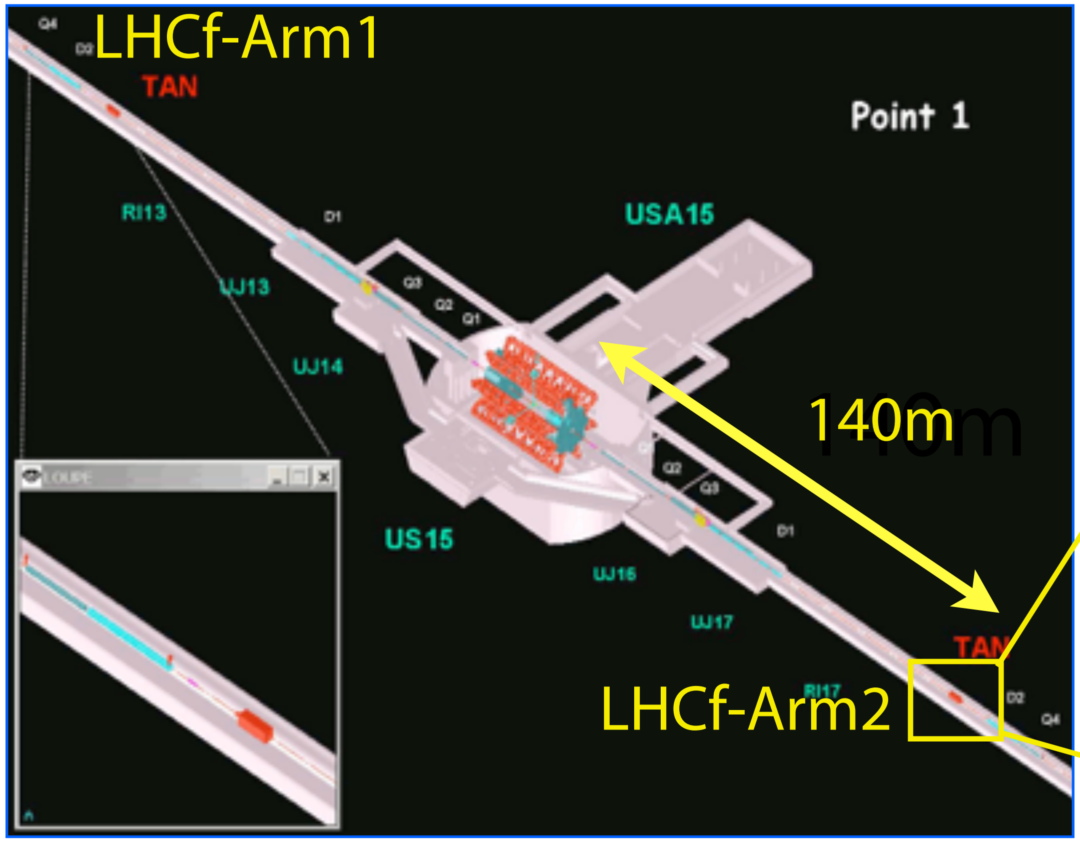
Jul. 2011



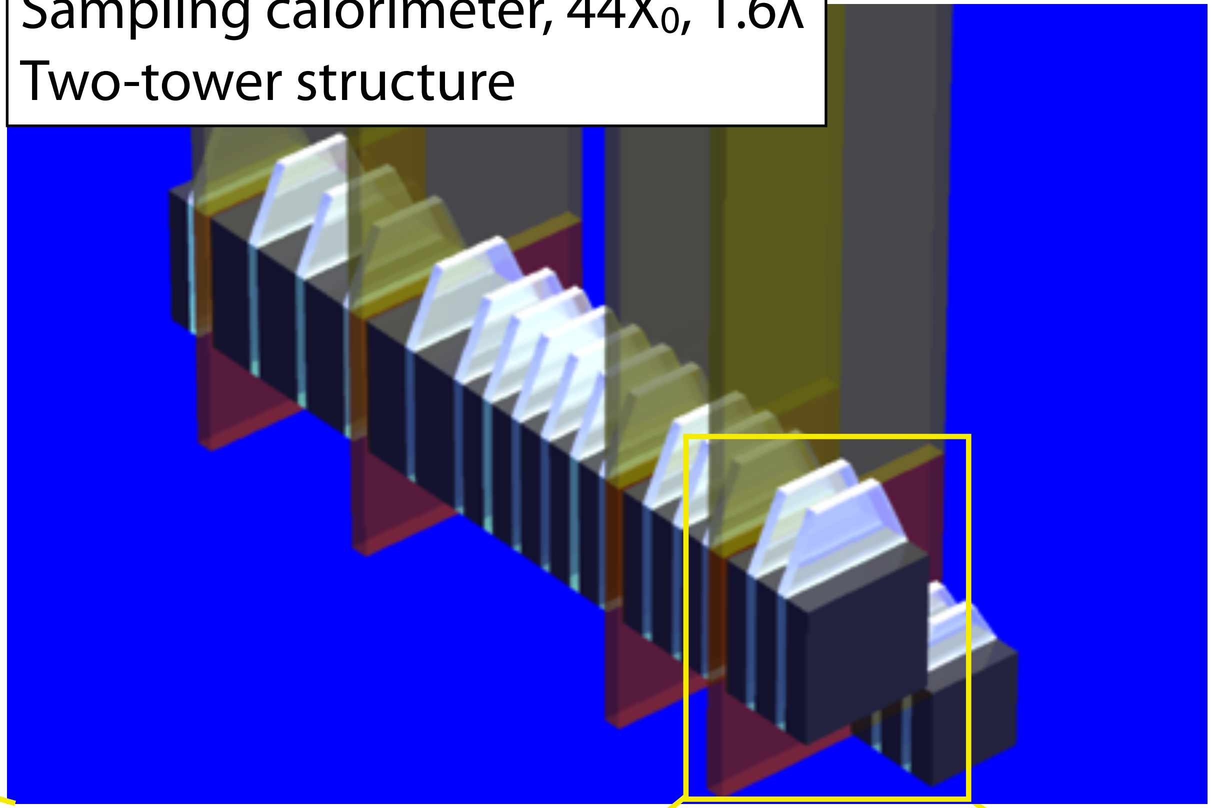
Jul. 2013

Apr. 2013

The LHCf detectors

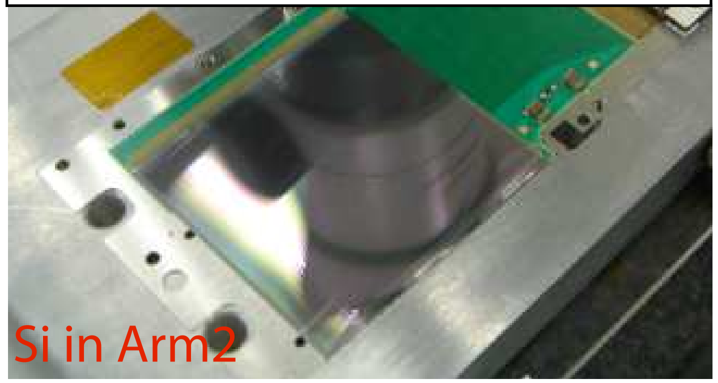


10(W)cm x 10cm(H) x 30cm(D)
Sampling calorimeter, $44X_0$, 1.6λ
Two-tower structure

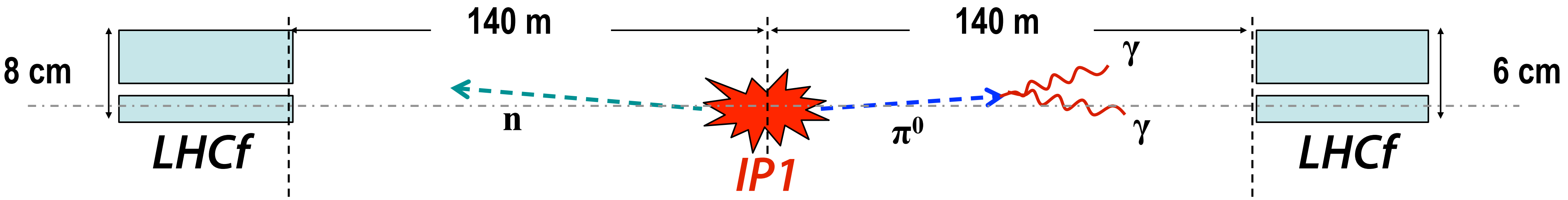


- Two independent detectors (Arm1 and Arm2) are located in TAN to measure the ***very forward particles***:
  - $\eta>8.7$ w/o crossing angle and $\eta>8.4$ with crossing angle
  - $p_T<1$GeV at $\sqrt{s}=7$TeV.
- Sampling calorimeter + position sensitive detector.
- Charged particles are swept away due to the D1 magnet, so we can only observe neutral particles (photon and neutron).
- Same detectors have been used since 2009.

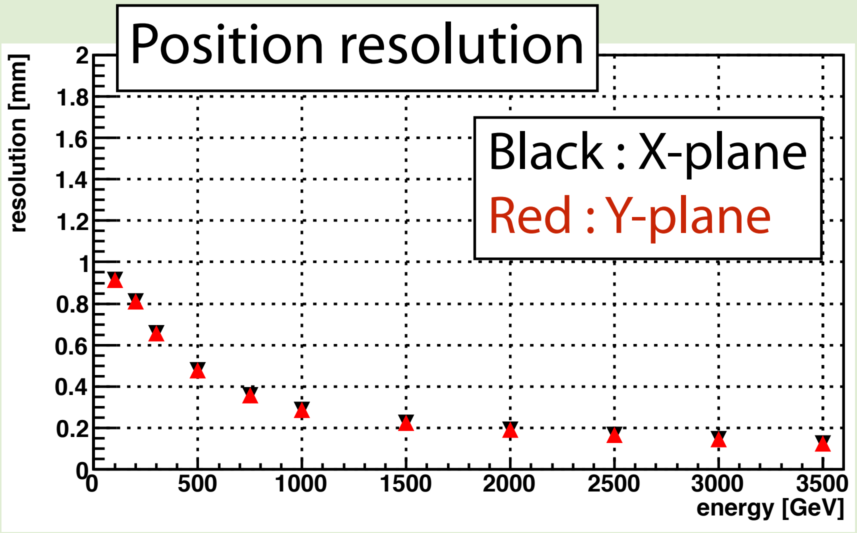
Position sensitive detector
Arm1 : Scintillation fibers
Arm2 : Silicon strip detector

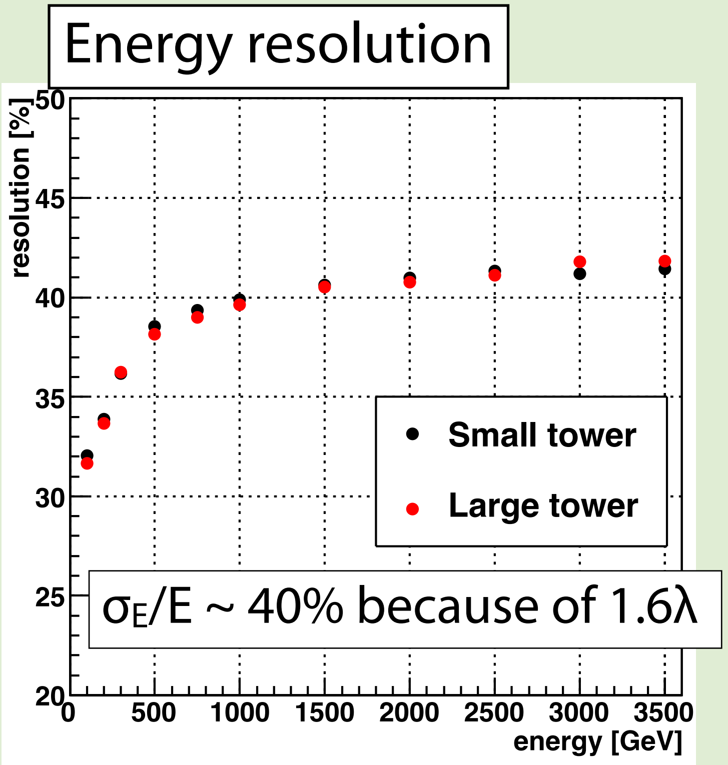


Detector performances (2009-2013)



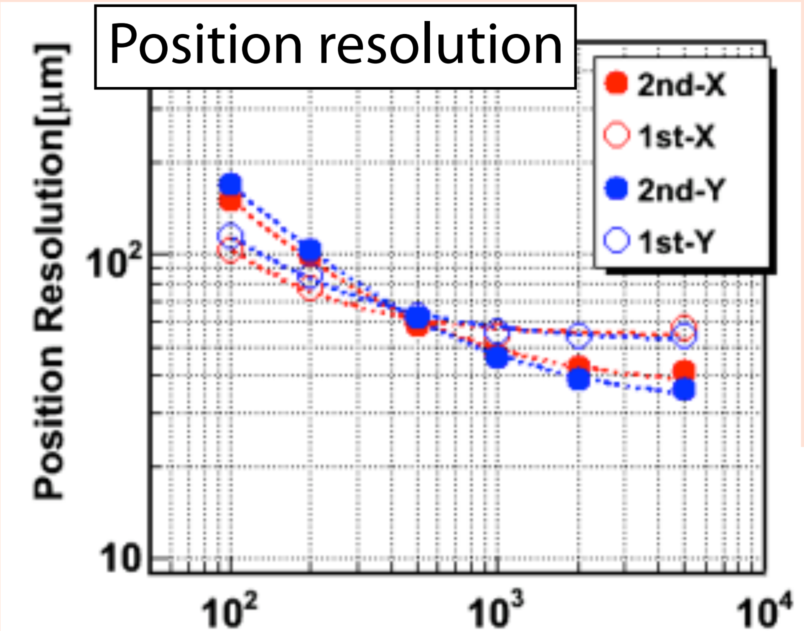
Hadronic shower (MC)

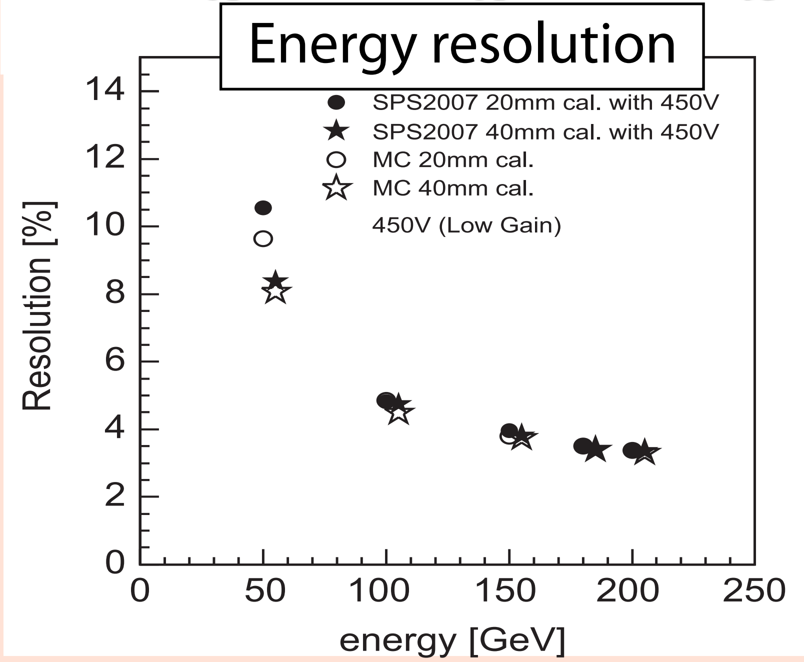




σ_E/E ~ 40% because of 1.6λ

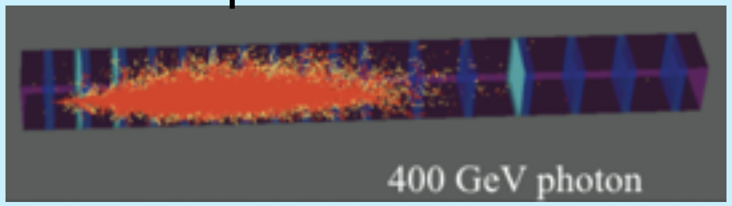
EM shower (MC)



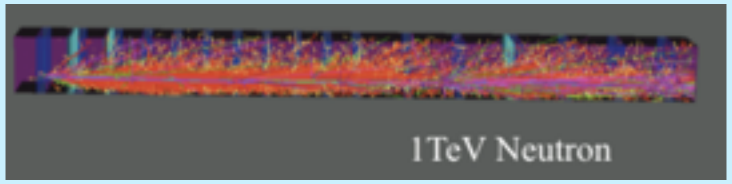


PID technique

400GeV photon

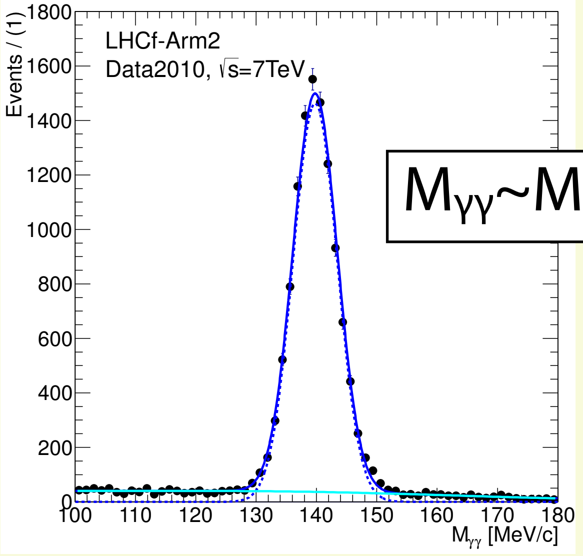


1TeV neutron



Identification of incoming particle by shower shape

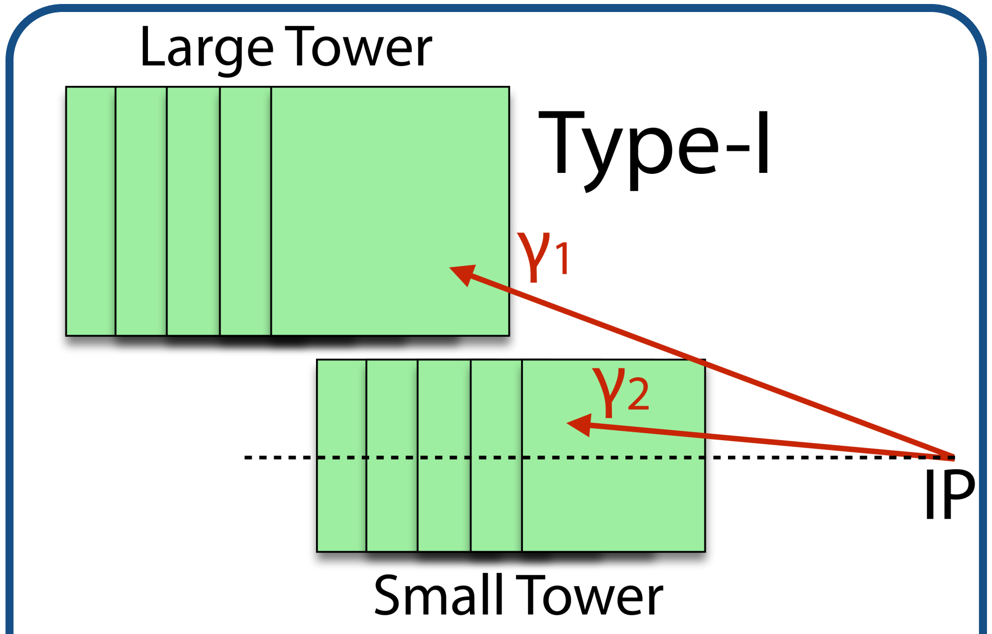
π^0 reconstruction



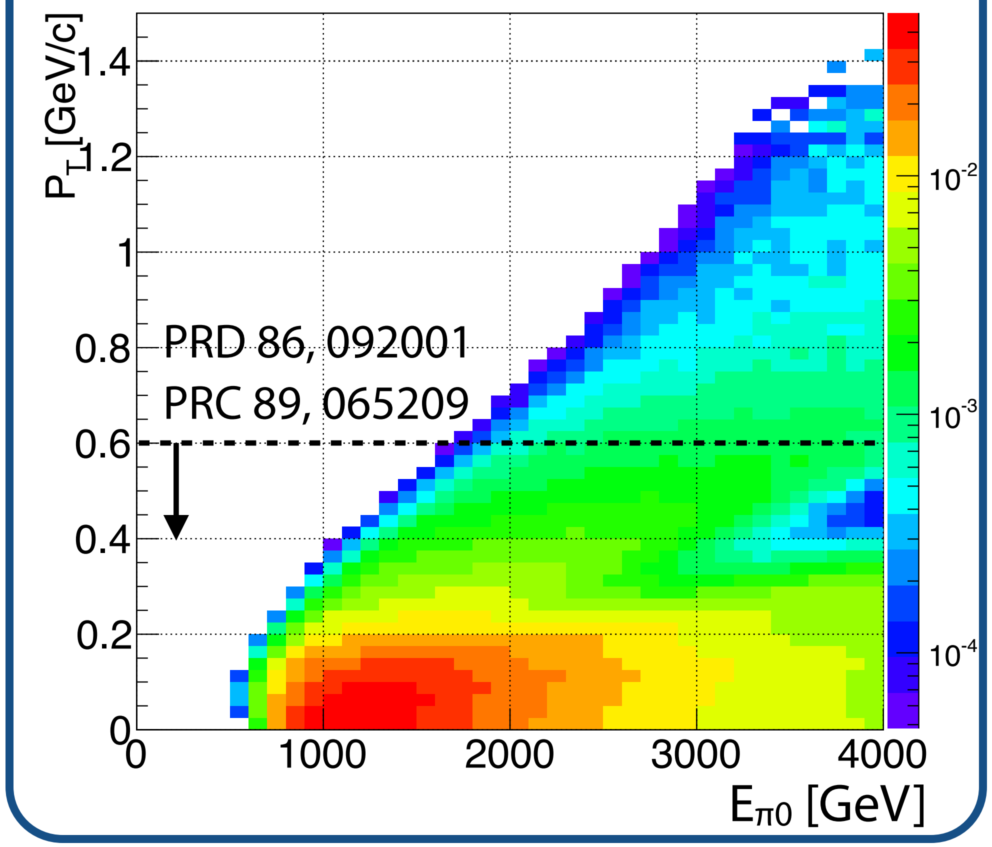
$M_{\gamma\gamma} \sim M_{\pi 0}$

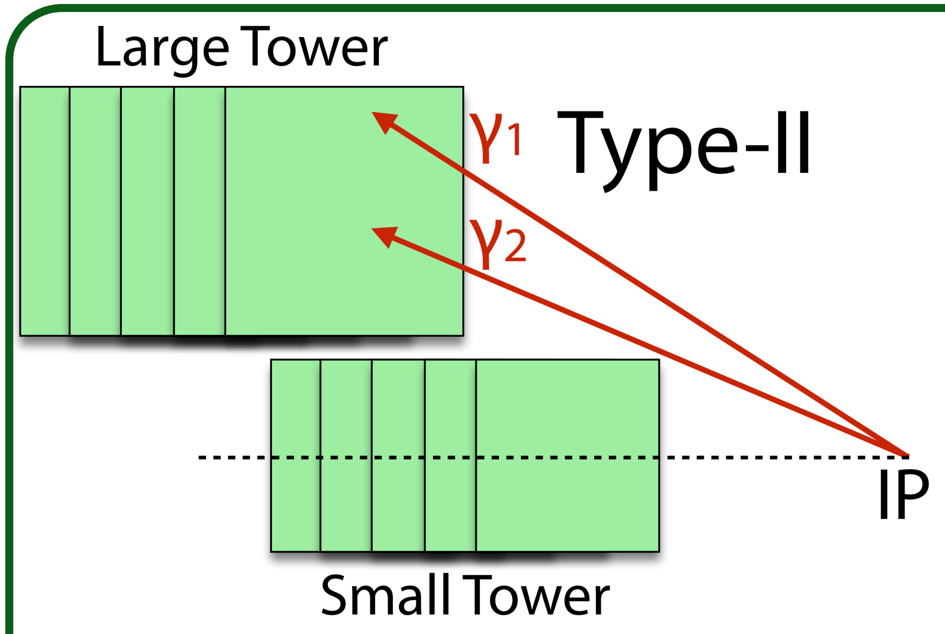
Update of π^0 analysis

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.



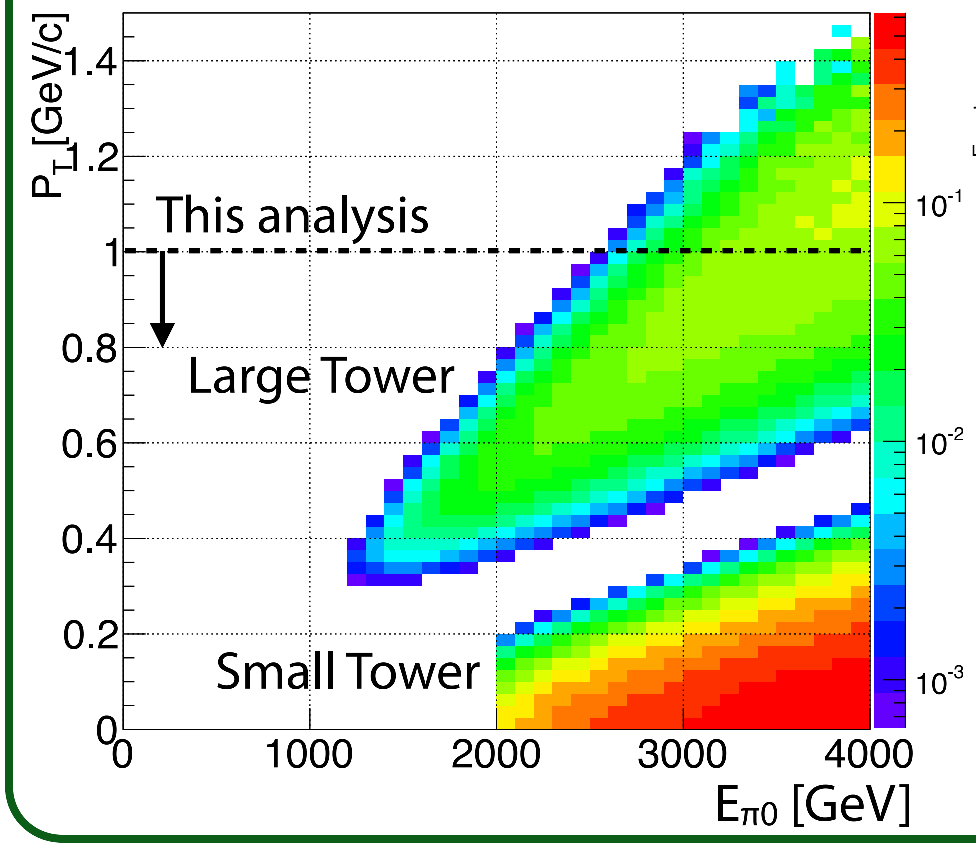
Arm2 acceptance for Type-I π^0

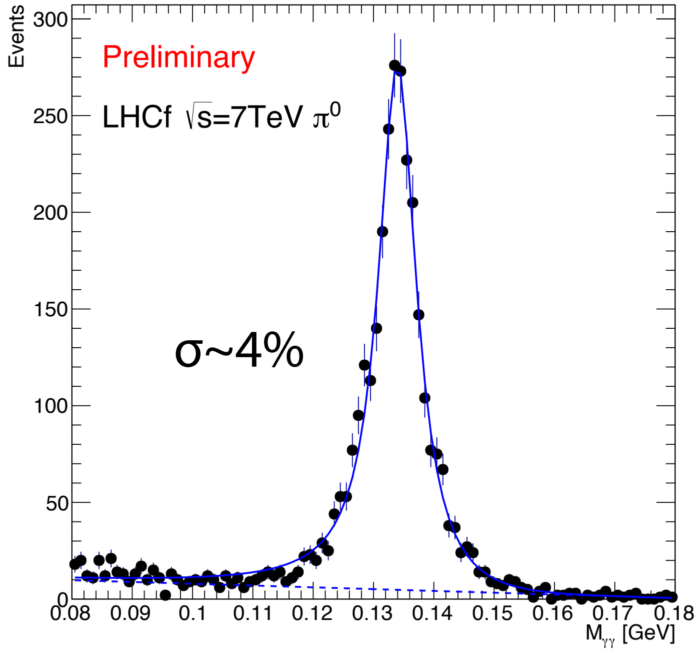




Motivation of Type-II
- extended p_T range
- applicable to Λ and K
- di-hadron.

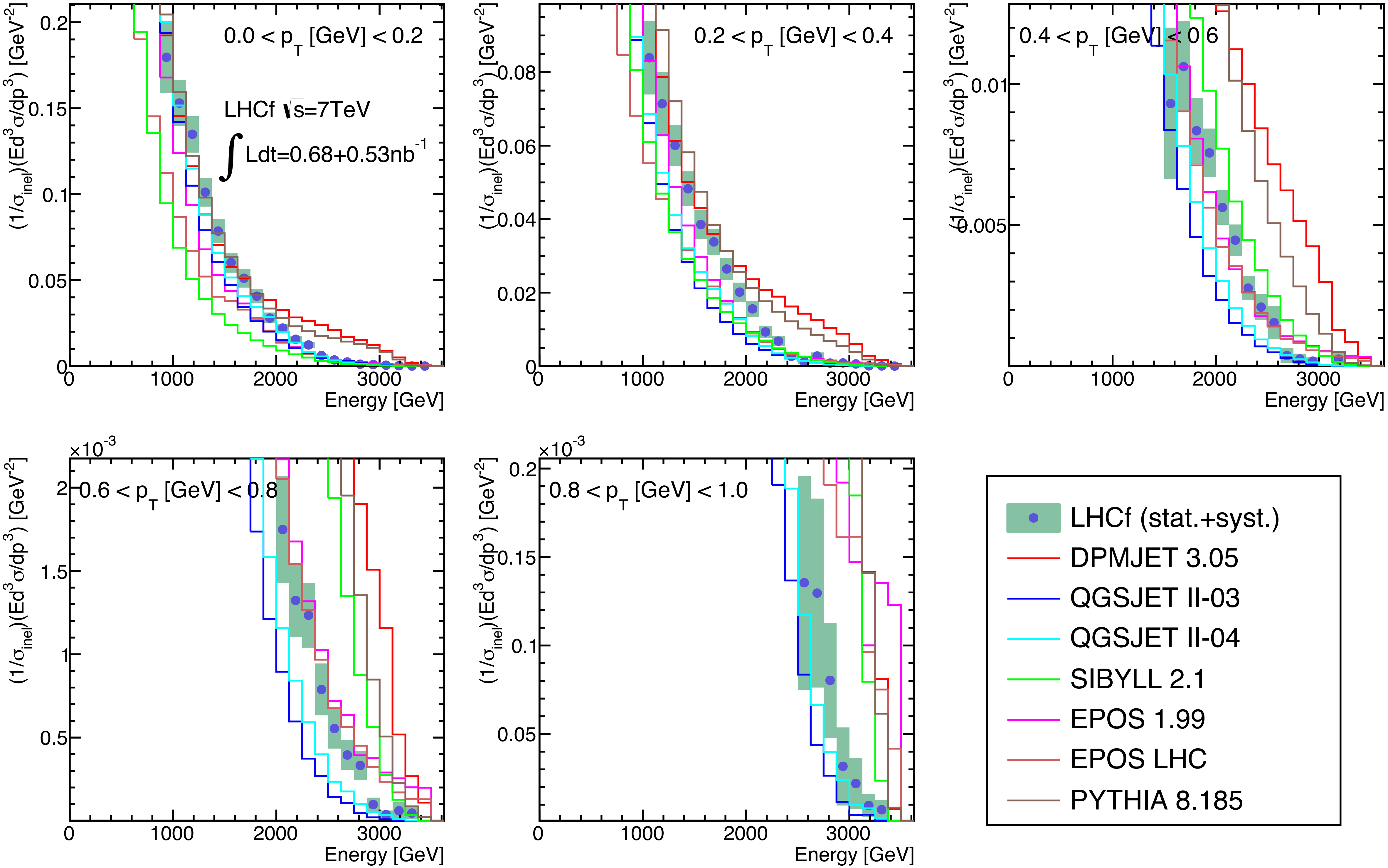
Arm2 acceptance for Type-II π^0





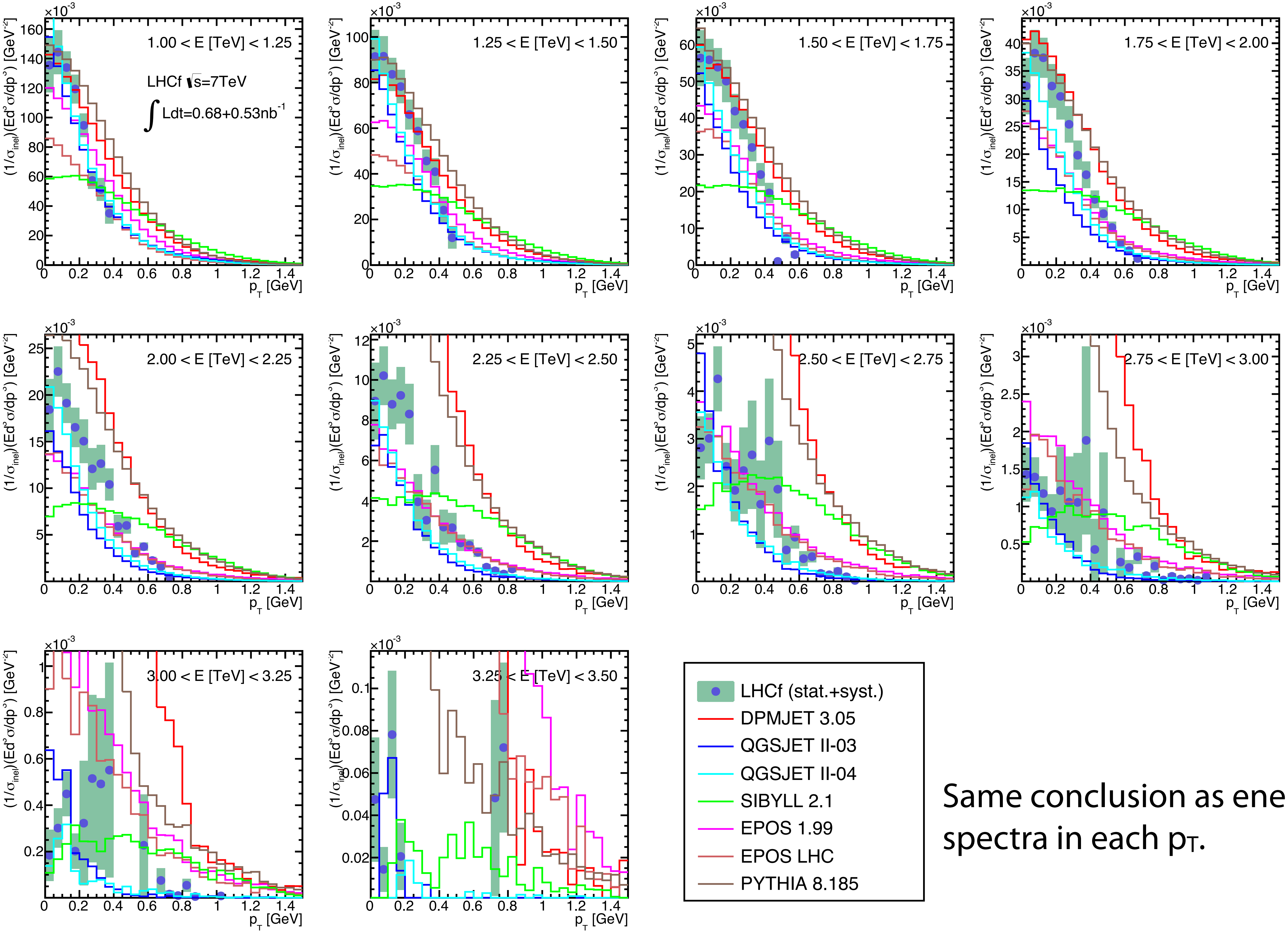
Neutral pion energy spectra (in each p_T)

Preliminary



- 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.

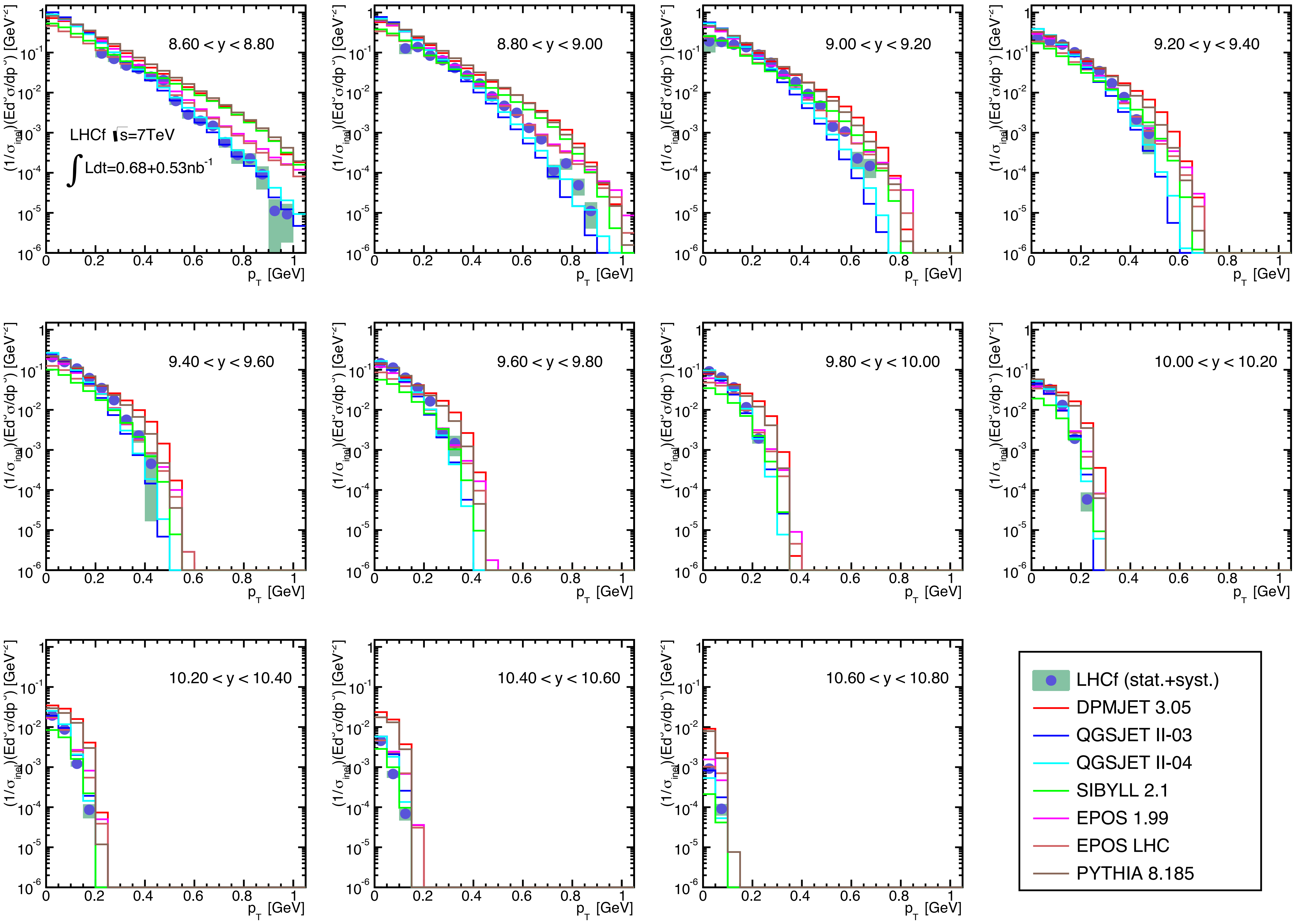
Neutral pion p_T spectra (in each energy) Preliminary



Same conclusion as energy spectra in each p_T.

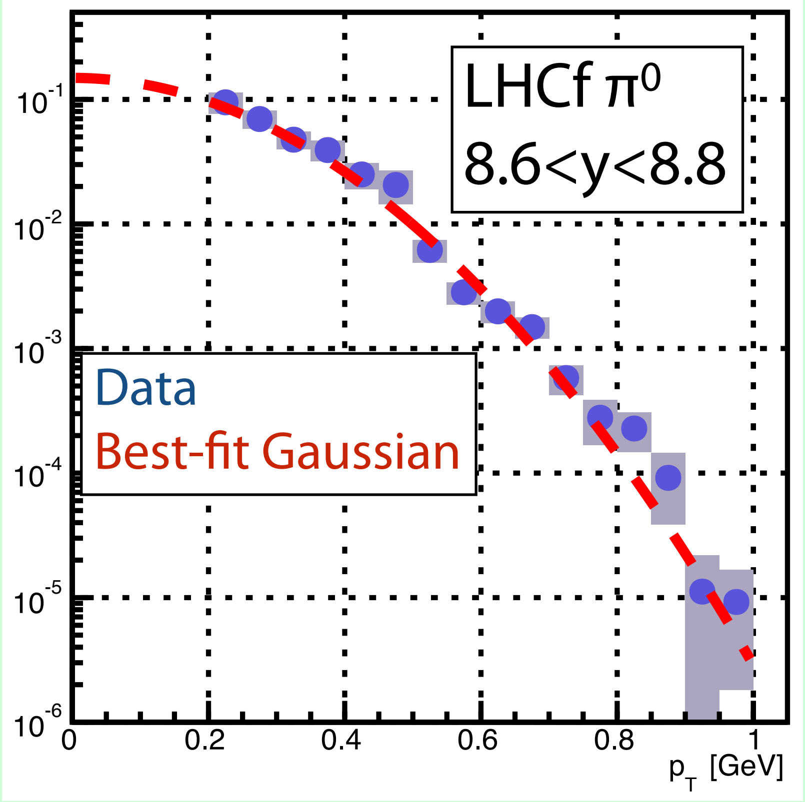
Neutral pion p_T spectra (in each y)

Preliminary



Average p_T and limiting fragmentation

Preliminary



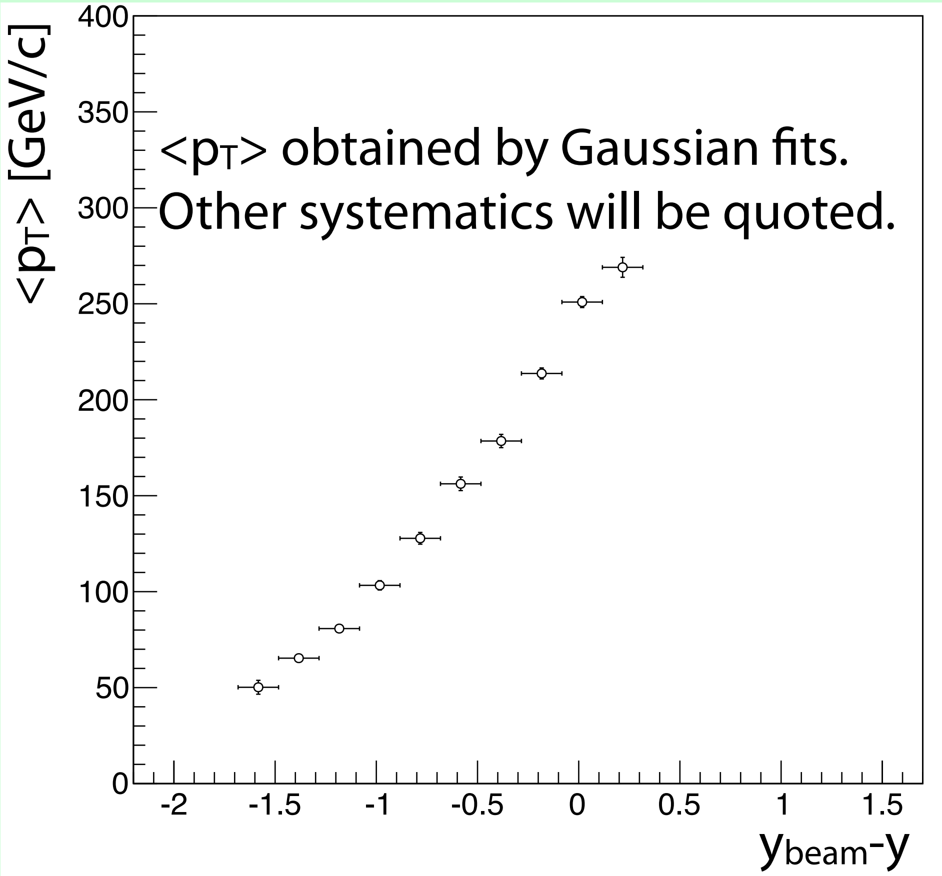
p_T spectra can be fitted by a Gaussian shape:

$$\frac{1}{\sigma_{\rm inel}} E\frac{d^3\sigma}{dp^3} = A\frac{\exp(-p_{\rm T}^2/\sigma_{\rm Gauss}^2)}{\pi\sigma_{\rm Gauss}^2}.$$

Then the average p_T $\langle p_T \rangle$ is obtained by

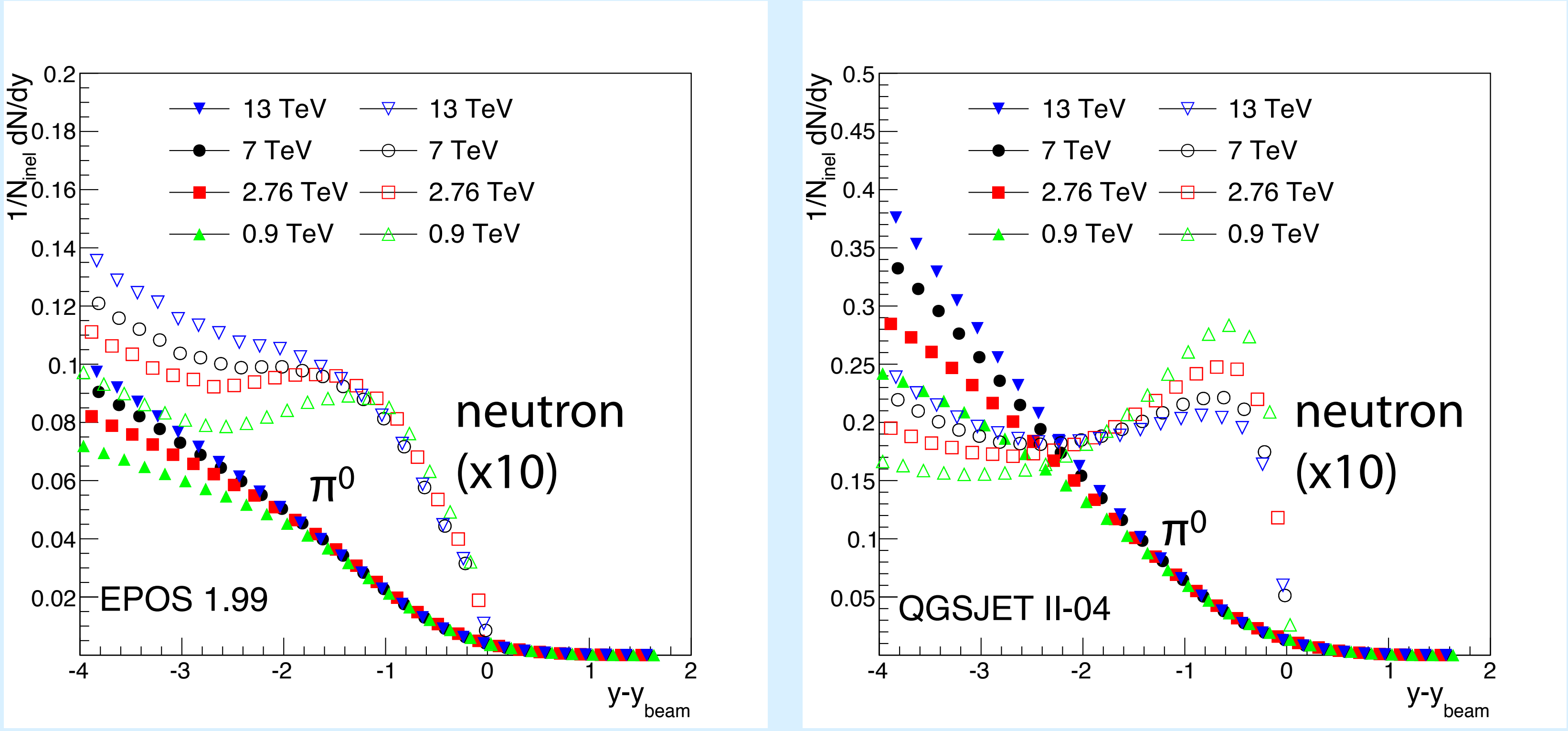
$$\langle p_{\rm T}\rangle = \frac{\int 2p_{\rm T}^2 f(p_{\rm T})dp_{\rm T}}{\int 2p_{\rm T} f(p_{\rm T})dp_{\rm T}} = \frac{\sqrt{\pi}}{2}\sigma_{\rm Gauss},$$

(Exponential and Tsallis fail to fit the LHCf data.)



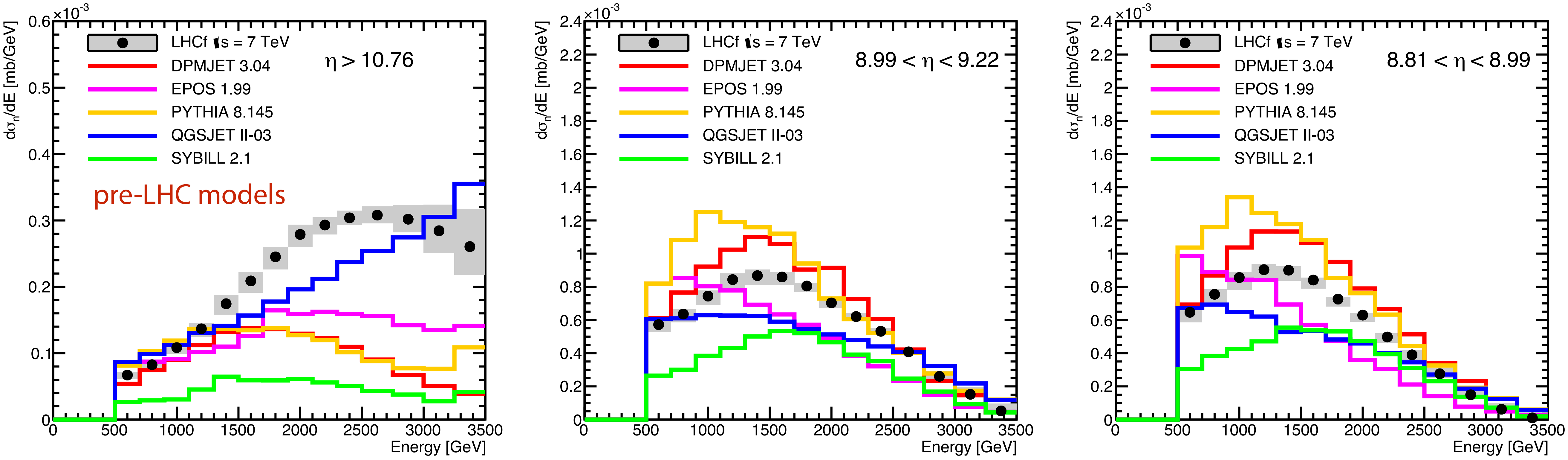
$\langle p_T \rangle$ obtained by Gaussian fits.
Other systematics will be quoted.

LHCf provides a unique opportunity to test a limiting fragmentation (analysis ongoing but limited rapidity…)

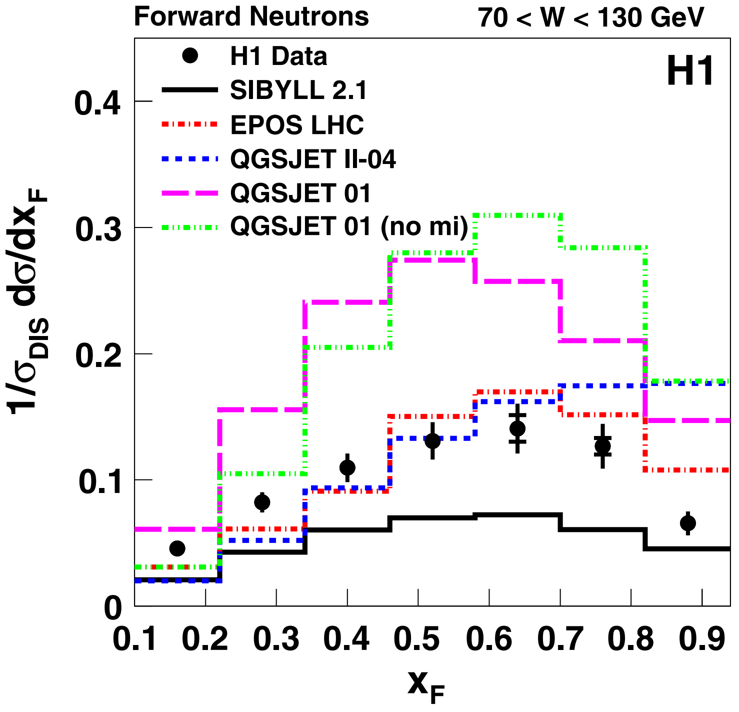


Neutron energy spectra

Preliminary

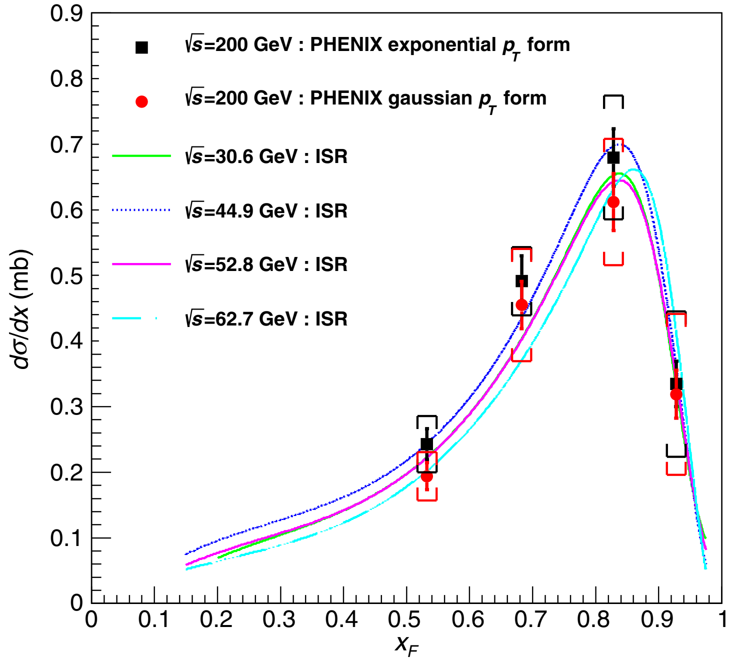


(e+p at HERA)



(H1, Eur. Phys. J. C 74 2915 (2014))

(p+p at RHIC)



(PHENIX, Phys. Rev. D 88 032006 (2013))

Focusing on the extreme forward region η>10.76

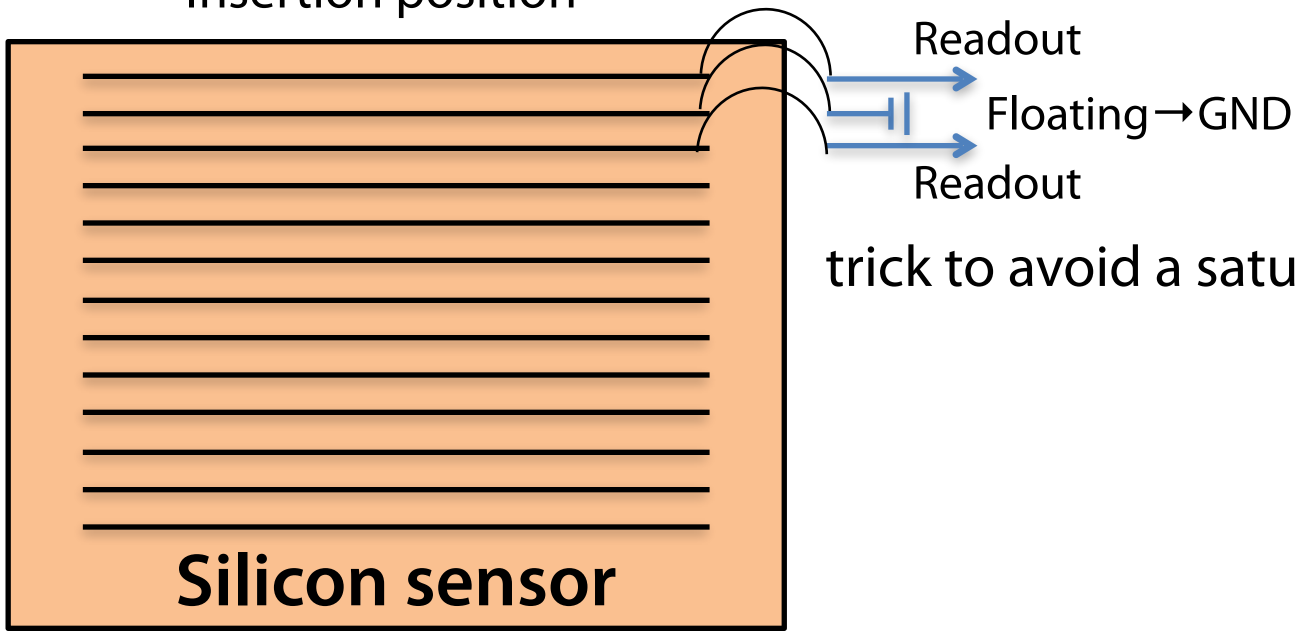
- only QGSJET II-03 reproduces LHCf (more or less). Is this a signature of low-mass diffraction ?
- a similar shape with HERA, RHIC, and ISR data which can be explained by a pion exchange. Can LHCf be also explained by a pion exchange ?

Investigation in more wider rapidity and energy ranges is needed to answer this question.

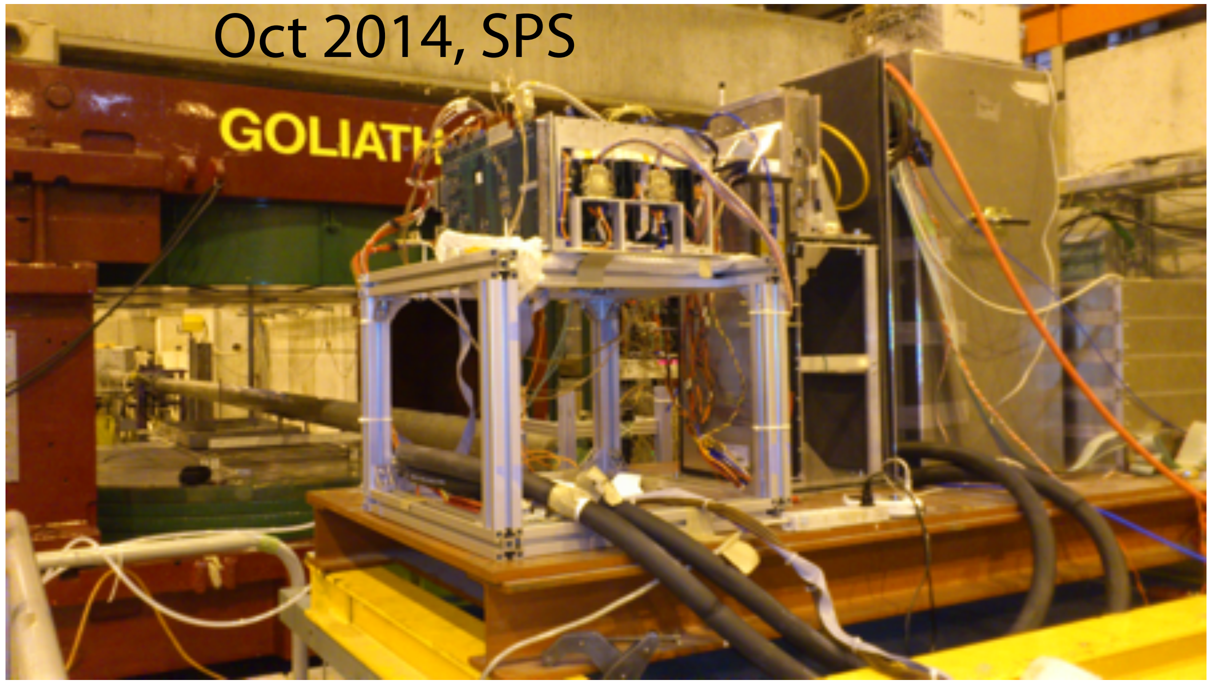
Upgrade of the LHCf detector

Preliminary

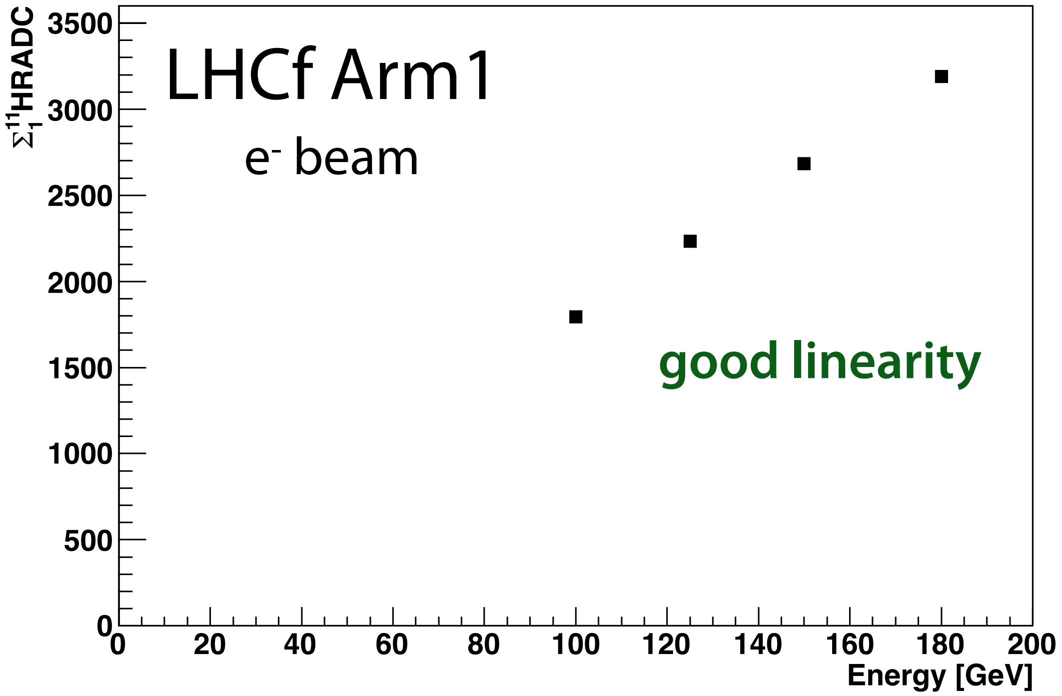
Main features of the upgrade LHCf detector
- GSO scintillator
- GSO hodoscope (Arm1)
- Update of Si-strip sensor (Arm2)
  - Bonding scheme
  - Insertion position

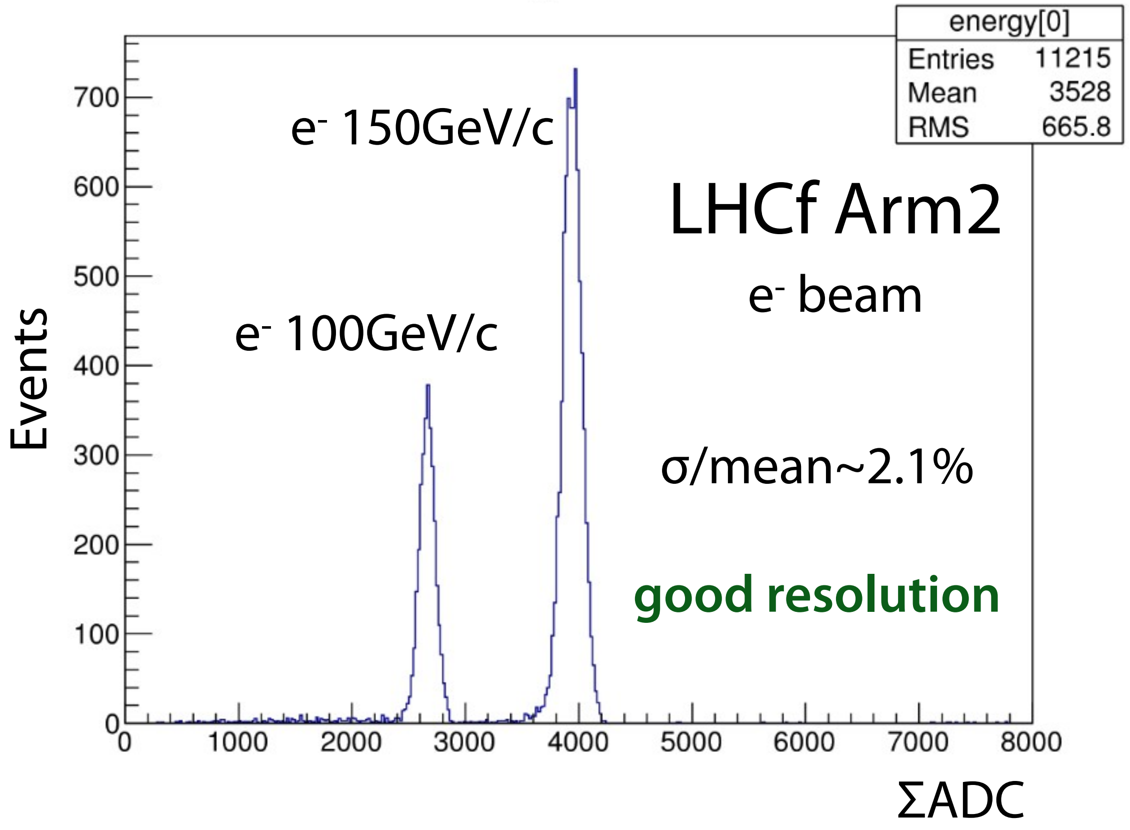


trick to avoid a saturation.



Oct 2014, SPS





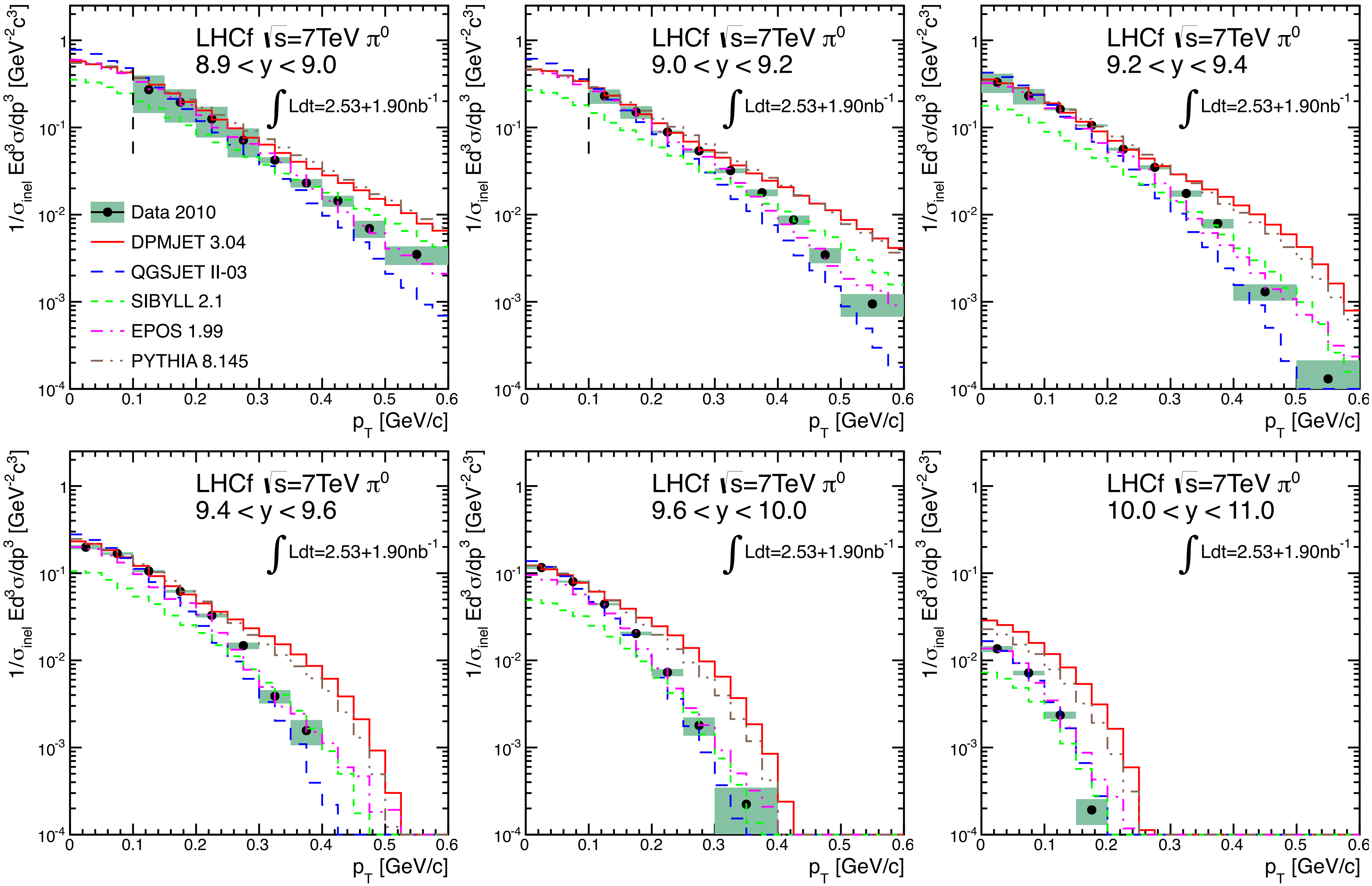
Summary

- Extended p_T range in the π^0 analysis provides a more reliable benchmark for hadronic interaction MC and theoretical model (CGC?).
- Large amount of neutron yield is found in extreme forward rapidity which may be a signature of low-mass diffraction or pion exchange. Need exhaustive analysis.
- The upgraded LHCf detectors were calibrated by the SPS test beam. They show a good and expected performance.

Backup

Phys. Rev. D 86, 092001 (2012)

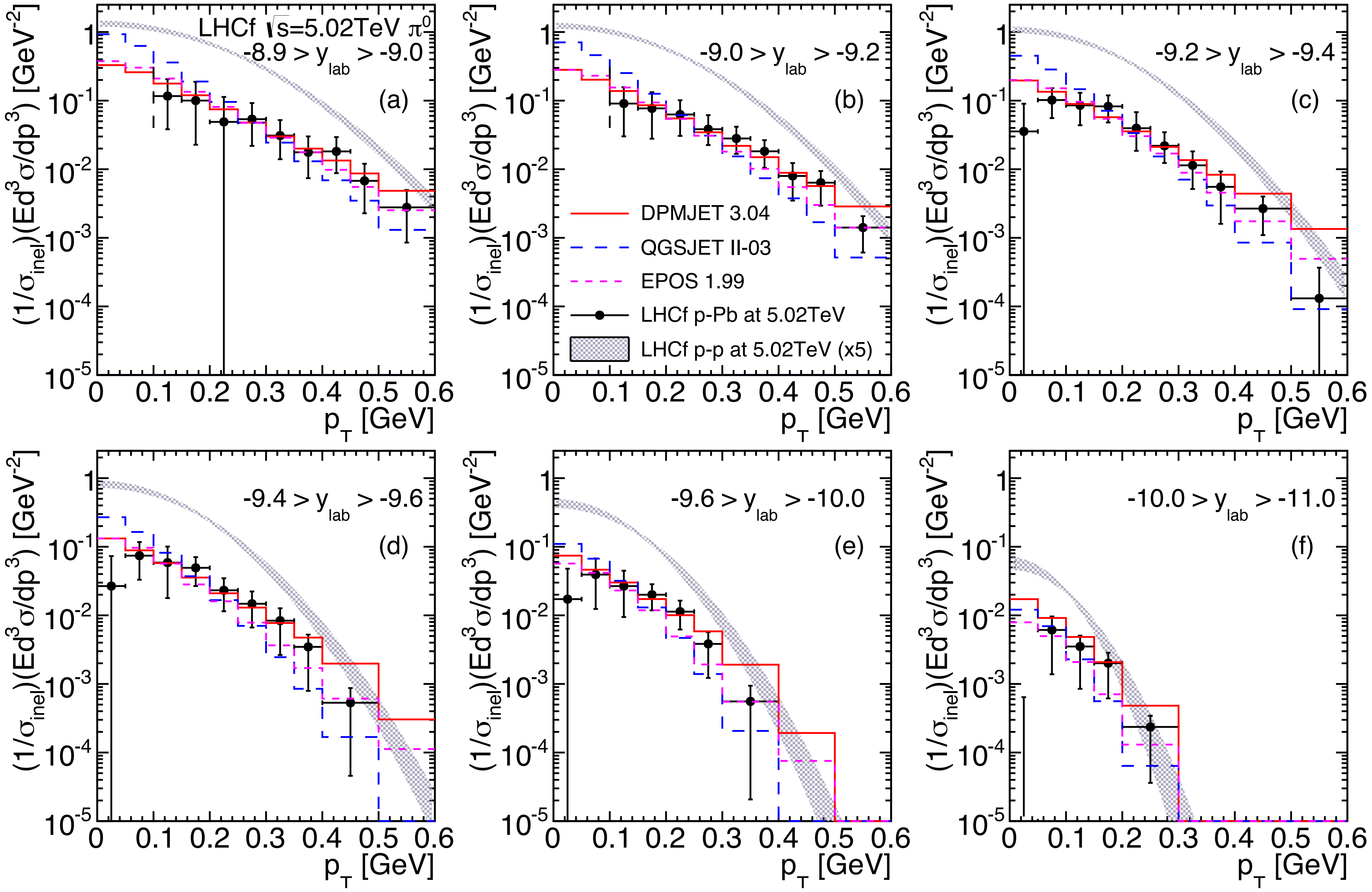
Inclusive π^0 p_T spectra in p-p at 7TeV



- LHCf data are mostly bracketed among hadronic interaction models.
- DPMJET, SIBYLL(x2) and PYTHIA are apparently harder, while QGSJET2 is softer.

Phys. Rev. C 89, 065209 (2014)

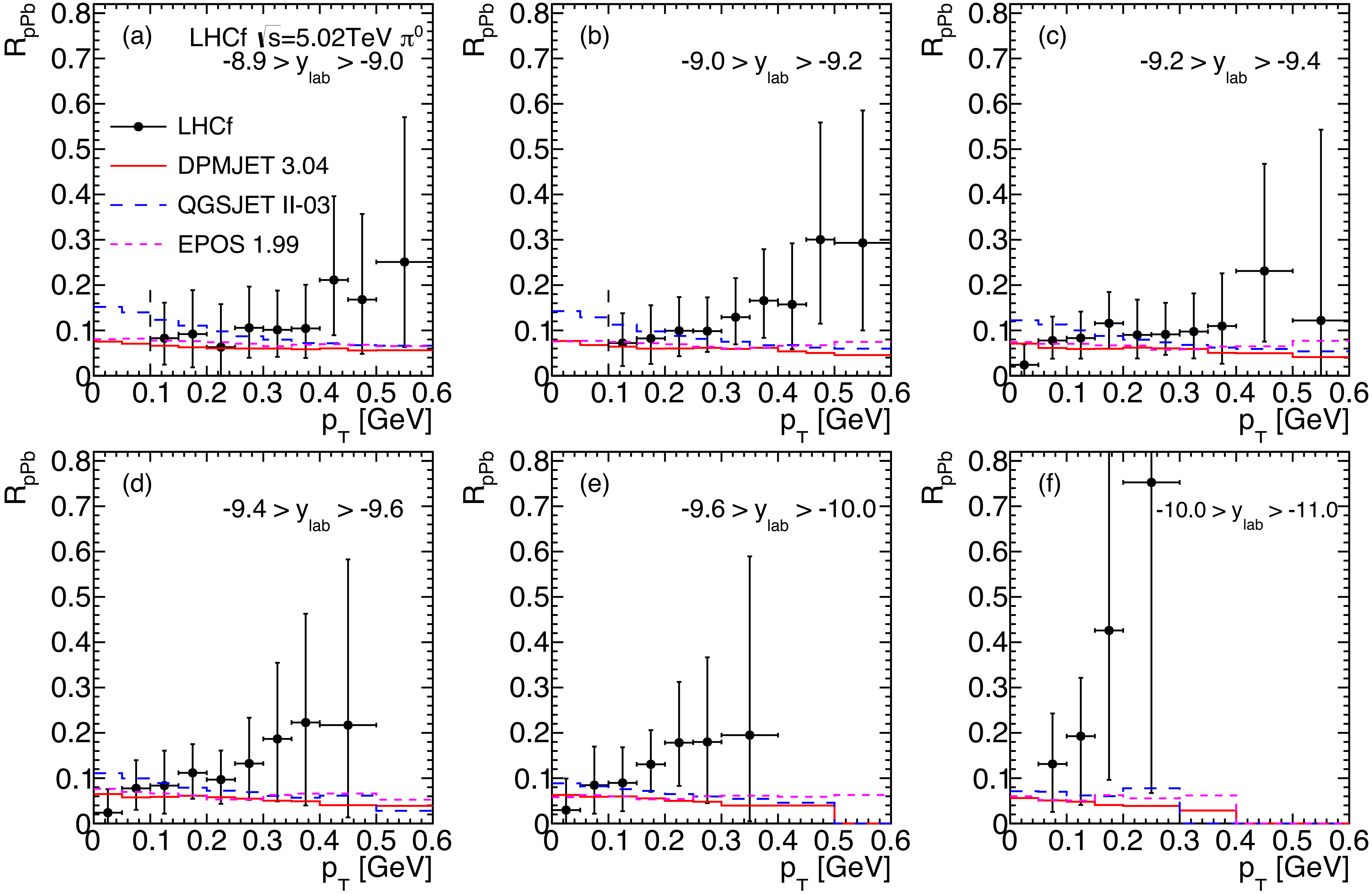
Inclusive π^0 p_T spectra in p-Pb at 5.02TeV



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

Phys. Rev. C 89, 065209 (2014)

Nuclear modification factor in p-Pb at 5.02TeV



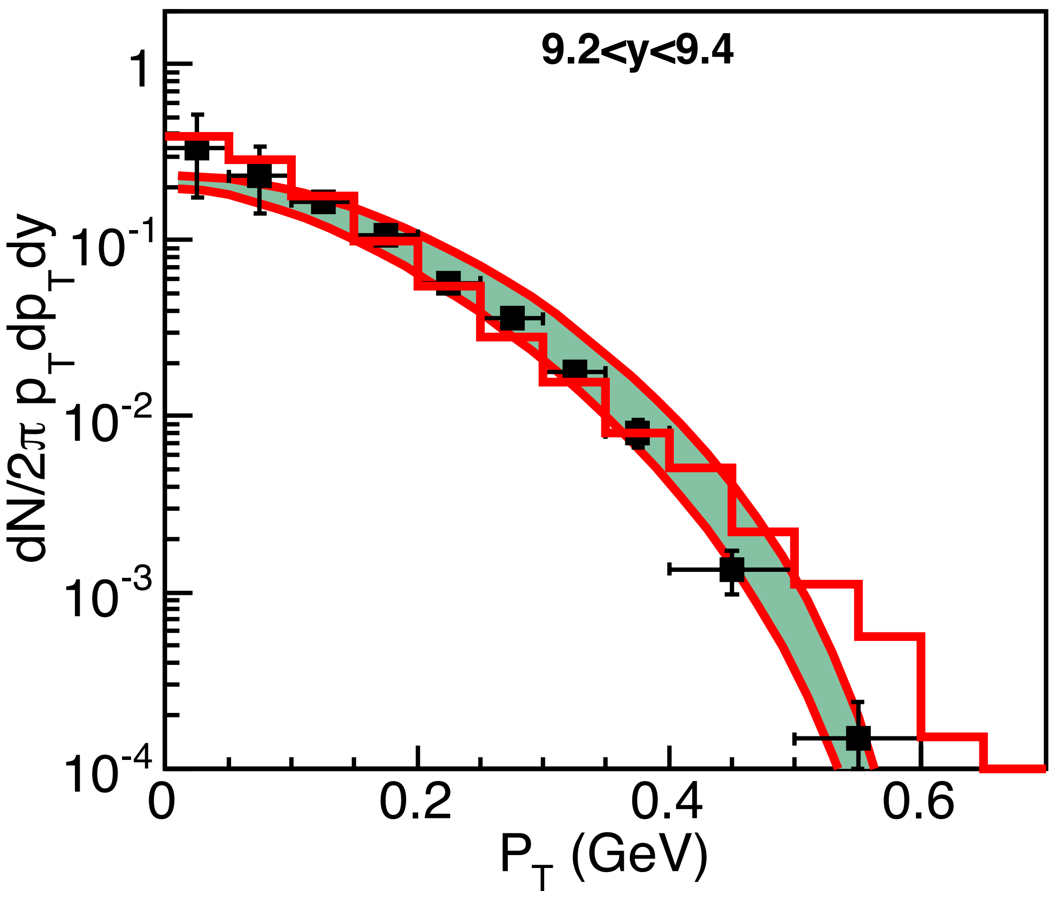
$$R_{\rm pPb}(p_{\rm T}) \equiv \frac{\sigma_{\rm inel}^{\rm pp}}{\langle N_{\rm coll}\rangle \sigma_{\rm inel}^{\rm pPb}} \frac{Ed^3\sigma^{\rm pPb}/dp^3}{Ed^3\sigma^{\rm pp}/dp^3}$$

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

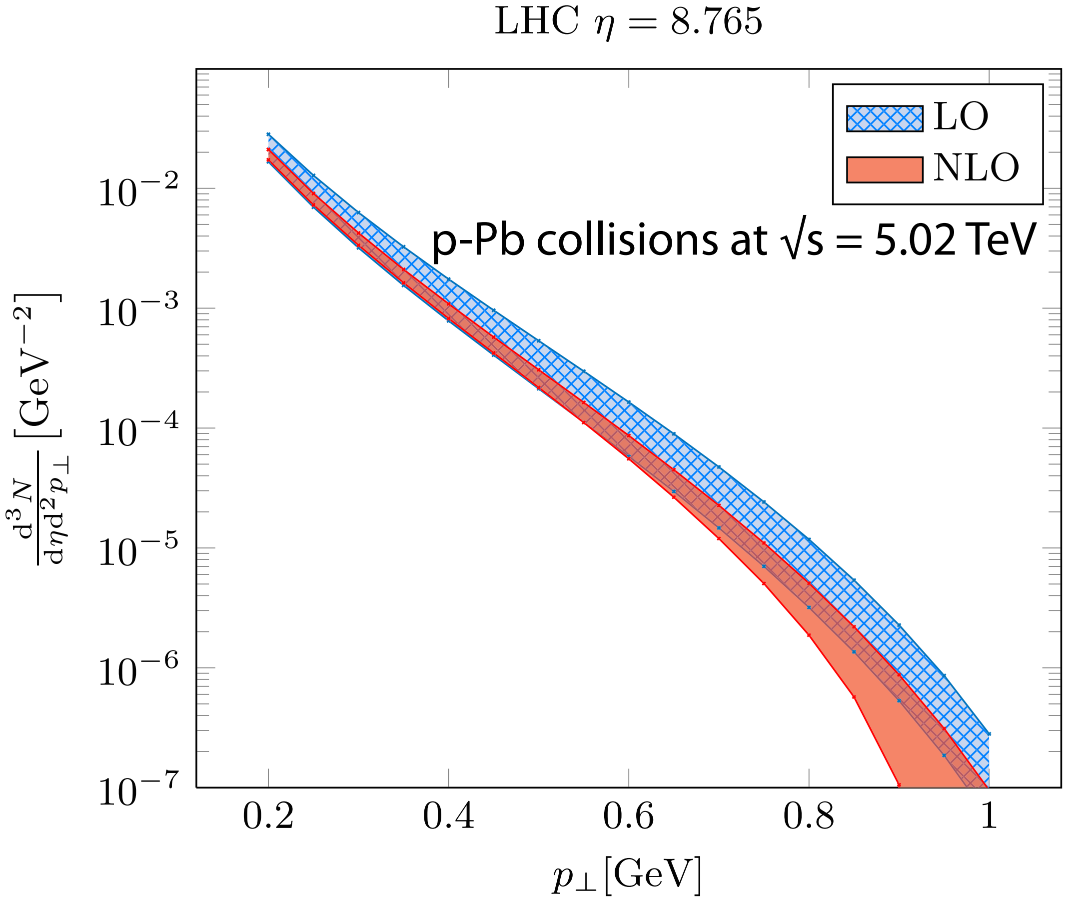
- Both LHCf and MCs show strong suppression.
- LHCf grows as increasing p_T, which is understood by the softer p_T spectra in p-p at 5TeV than those in p-Pb.

Color Glass Condensate

p-p collisions at √s = 7 TeV



(W.-T. Deng et al., 1410.2018)



p-Pb collisions at √s = 5.02 TeV

(A. M. Stasto et al., PRL 112 012302 (2014))