Results of the LHCf experiment so far and future prospects

K.Kasahara for the LHCf collaboration.

Waseda Univ.

Jun. 9 2015 for √s=13 TeV@LHCf hut

Collaborators are always squeezable in a recognizable photo !

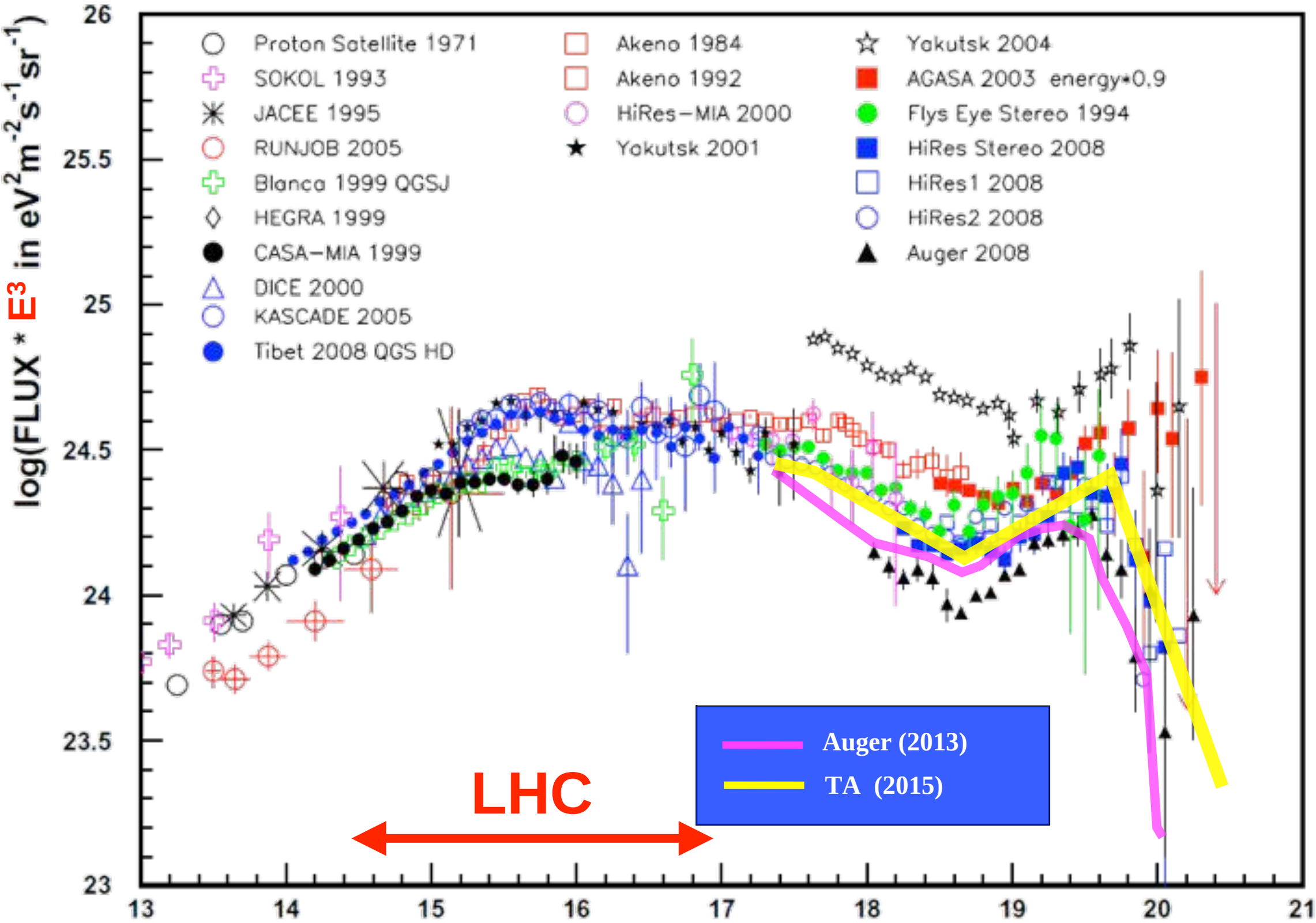
MPI workshop Nov. 23-27, 2015 @ Trieste,Italy

Physics motivation of the LHCf experiment

- To have better understanding of very high energy cosmic-rays

- Good hadronic interaction model(s) for M.C

- LHCf affords stuff for selecting good models or for tuning the models.



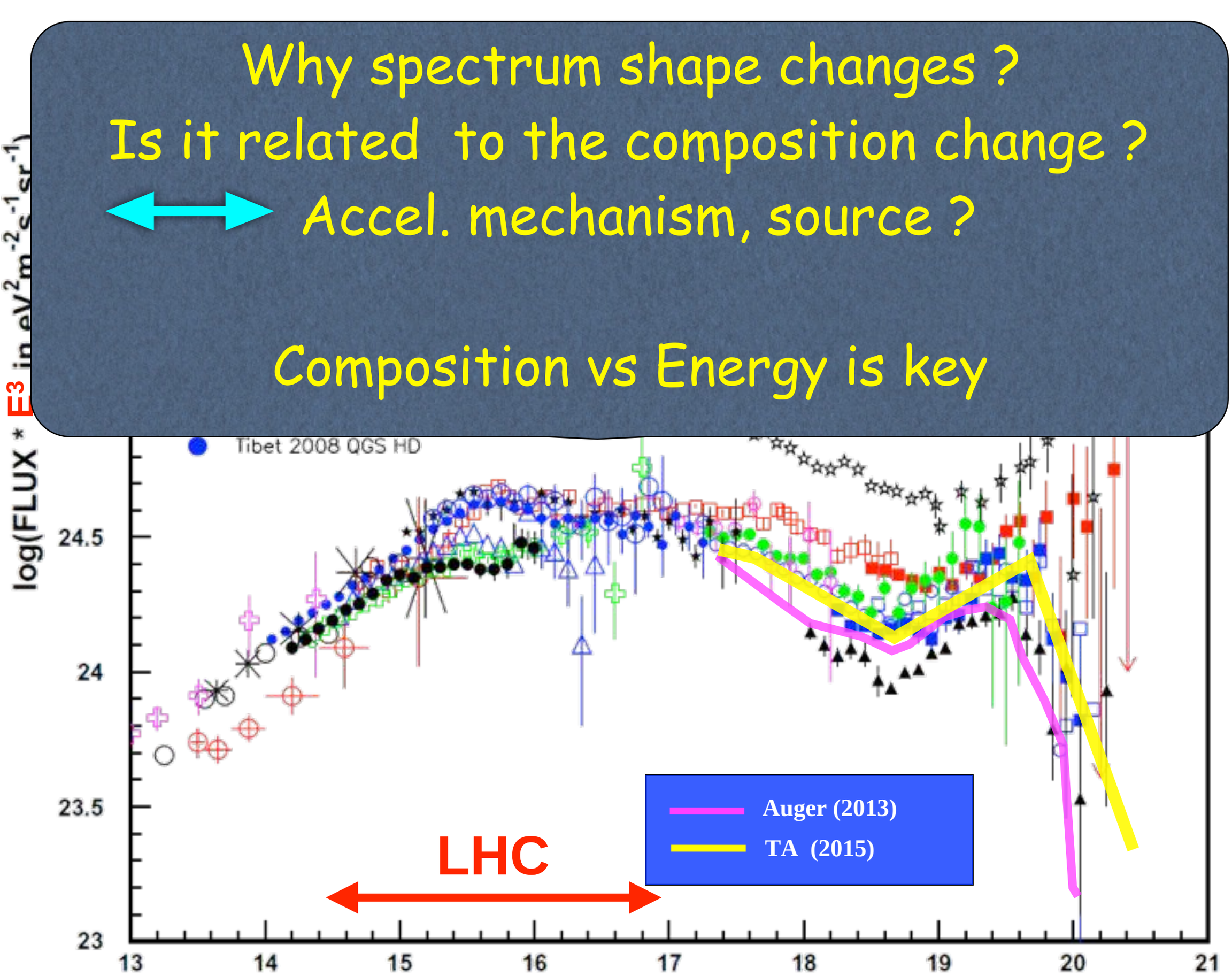
orm M.Nagano: New Journal of Physics 11 (2009)
+Recent Auger (2013) + TA(2015)

Why spectrum shape changes ?

Is it related to the composition change ?

⟷ Accel. mechanism, source ?

Composition vs Energy is key



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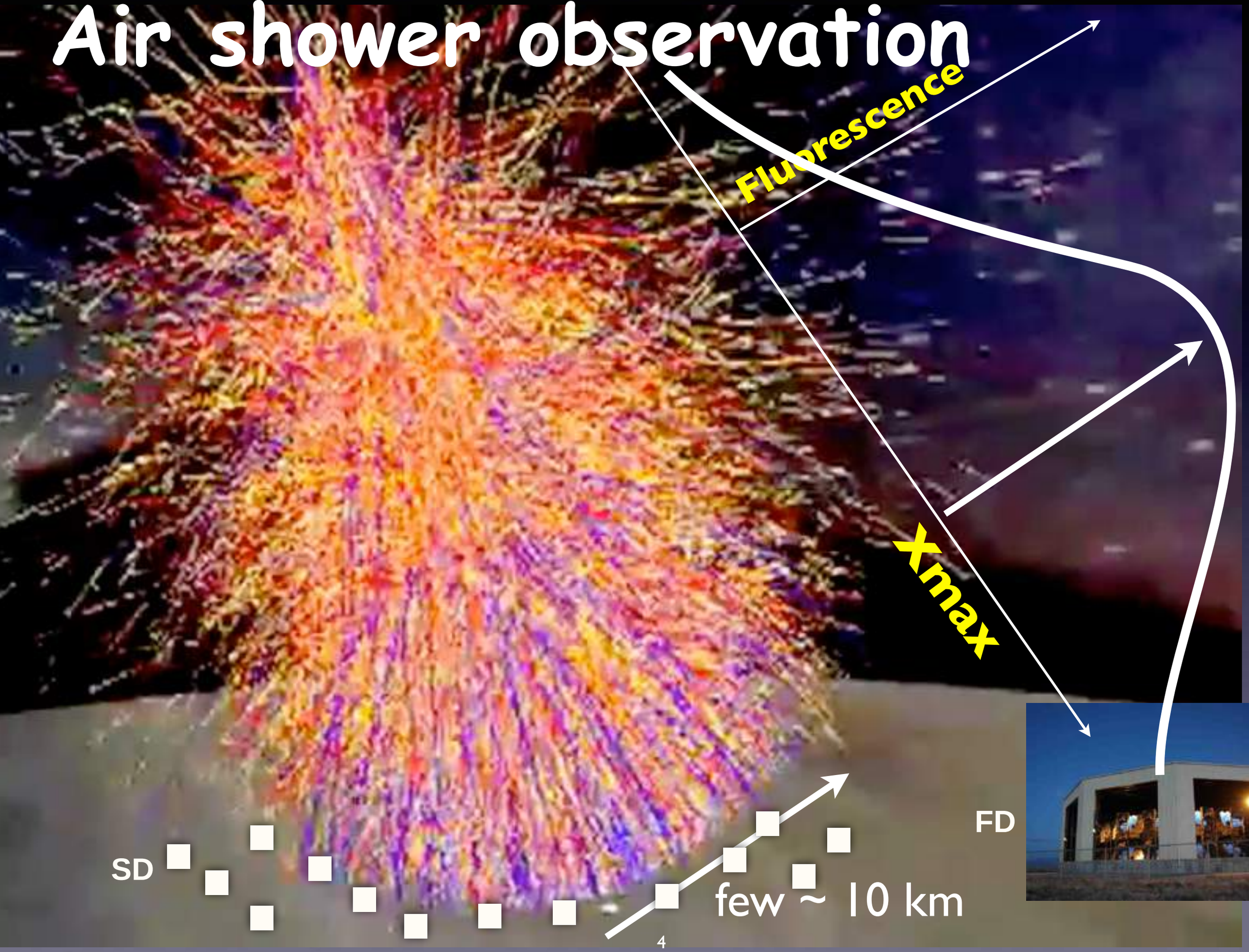
Air shower observation

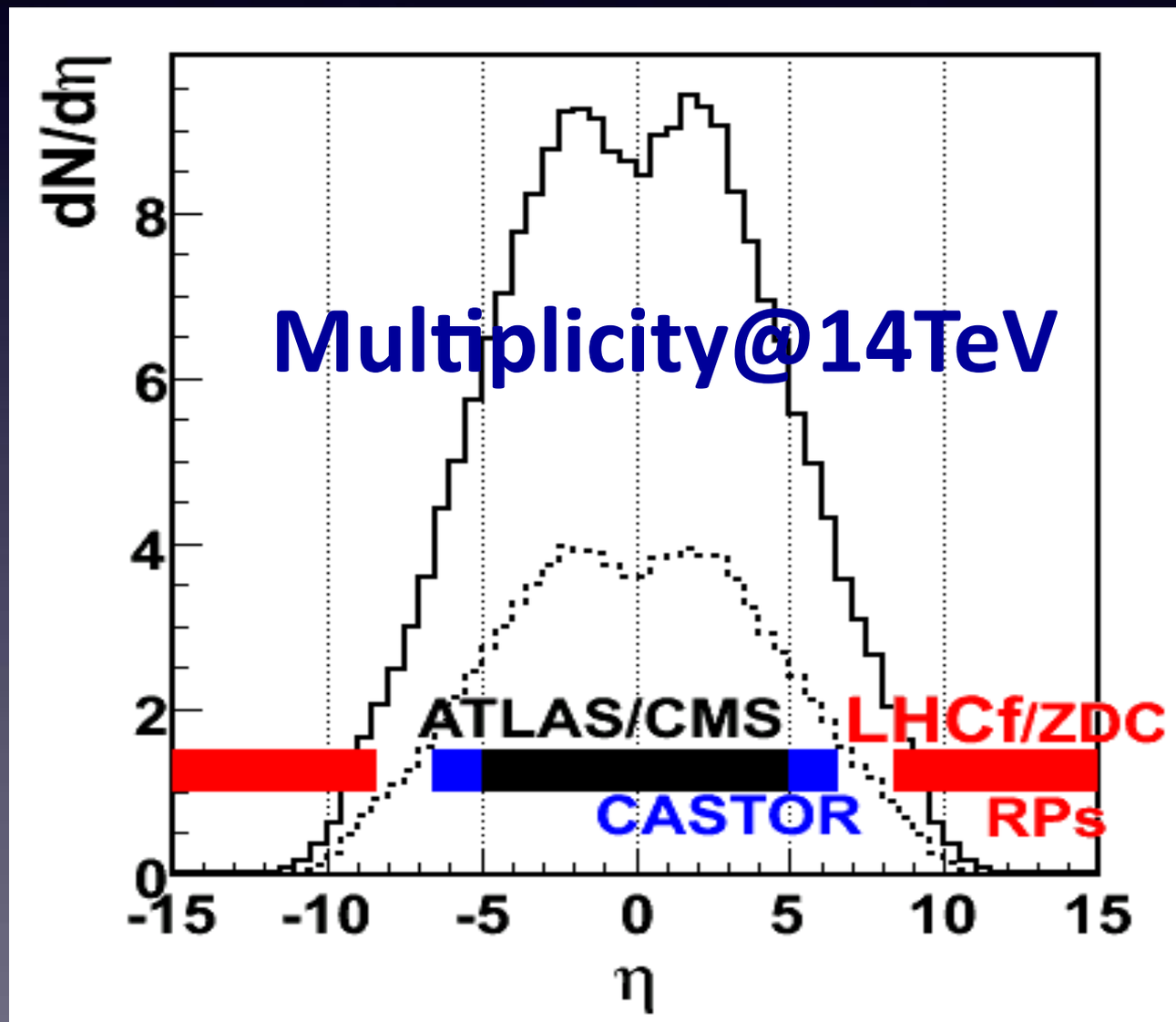


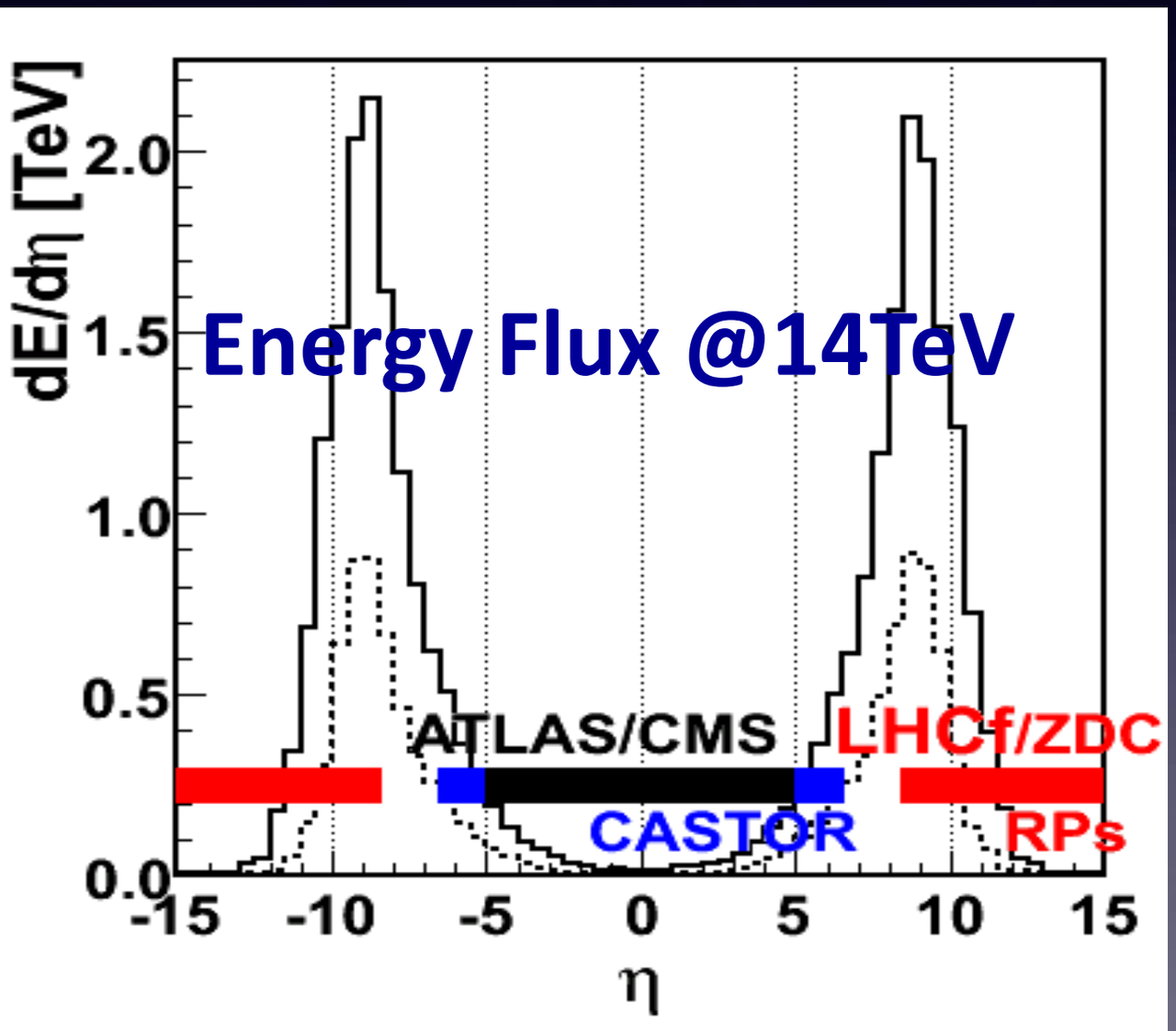
- Xmax: F(E0, Iry type, interaction model)

- Several interaction models in the cosmic ray field
  - qgsjetII
  - EPOS
  - sibyll
  - dpmjet3
  - pythia (H.E field)

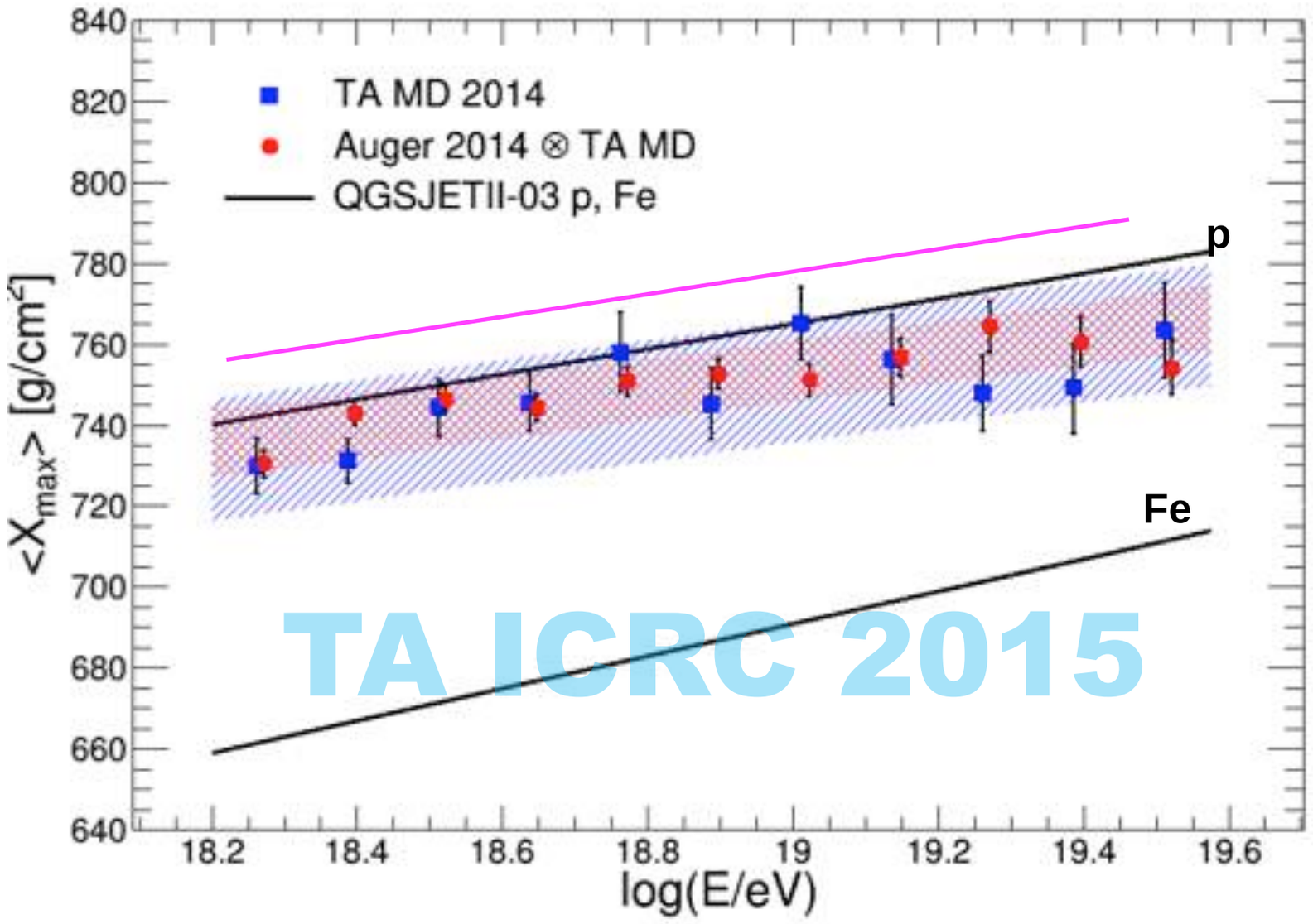
- **Pre-LHC, no reliable info. about what is happening at > 10^{15} eV. But we have been using them even at 10^{20} eV !**

η-distribution:In terms of number and energy in CMS





Meta-analysis: Composition WG

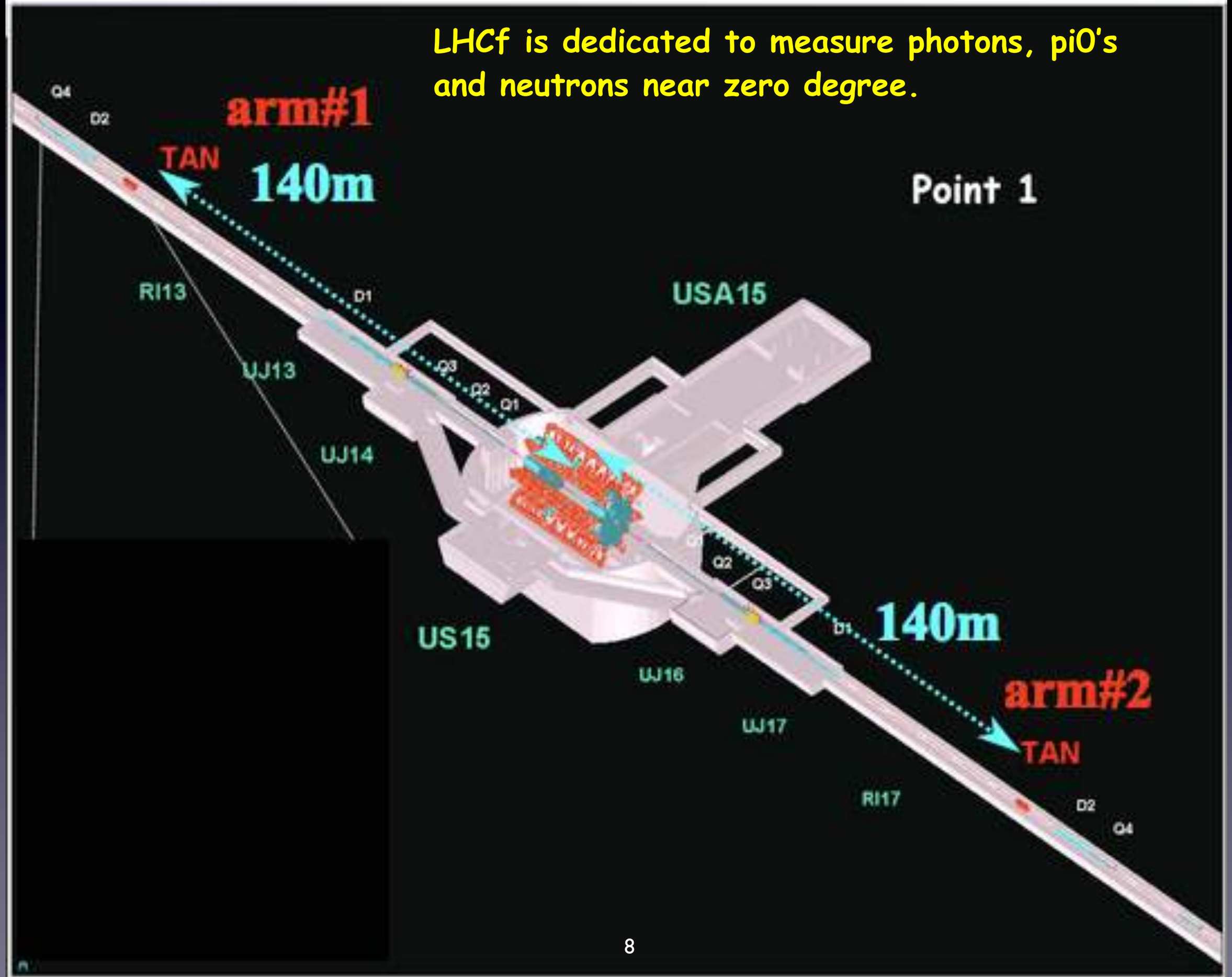


[618 - PoS 307]
Parallel CR07 EAS mass
Track: CREX, Presented by
Michael UNGER
on 31 Jul 2015 at 14:00
Unger et al, PoS 307

TA data cannot distinguish between mix and QGSJETII-03 protons at this level of systematic uncertainty.

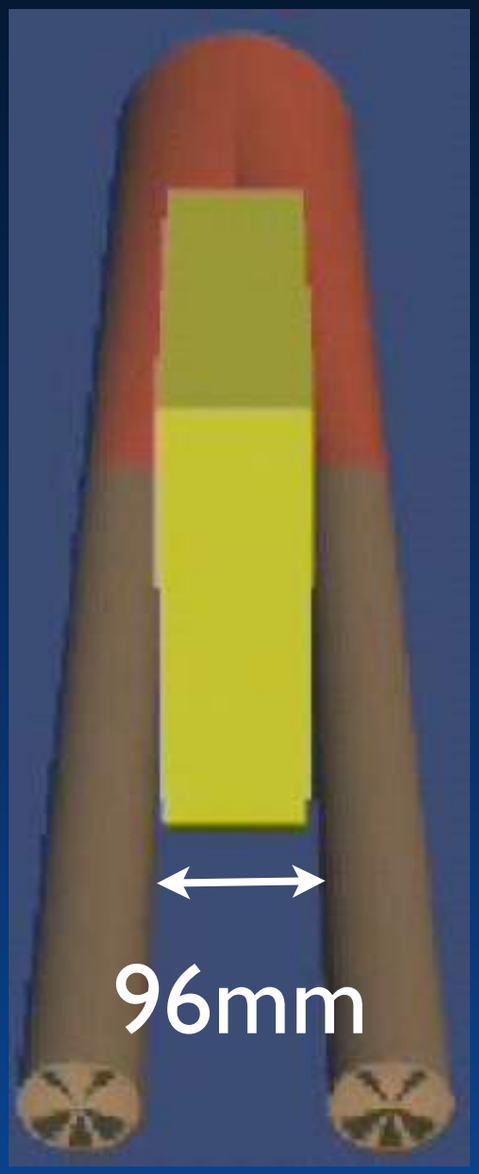
From talk by Fukushima

LHCf is dedicated to measure photons, pi0's and neutrons near zero degree.



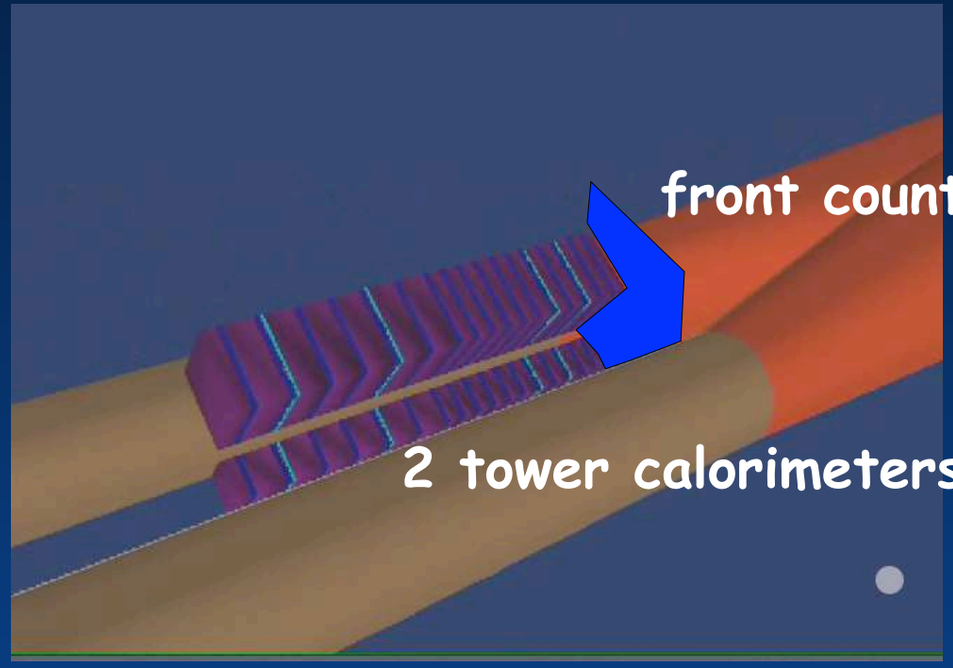
TAN area

neutral particles



Sampling calorimeter
W of 44 X0, 1.7λc
Plastic scinti. → GSO plates
4 pos. sensitive layers:
Arm1: SciFi → GSO bars
Arm2: Si strip

From 2014



Large tower

Small tower

Summary of the LHCf experiment

Year	Beam $\sqrt{s_{NN}}$ Detectors	Equiv. proton lab. E (eV)	γ	Neutron	π^0
2007,10,12, 14	SPS beam test Arm1,2		NIM A, 871, 129 (2012)	JINST 9 P03016 (2014)	
2009	pp 900 GeV Arm1,2	4.3×10^{14}	PLB 715, 298(2012)		
2009/10	pp 7 TeV Arm1,2	2.6×10^{16}	PLB 703, 128 (2011)	PLB 750(2015)	PRD 86, 092001 (2012)
2013	pp 2.76 TeV Arm2	4.1×10^{15}			PRC 89, 065209 (2014)
2013	pPb 5.02 TeV Arm2	1.3×10^{16}	First trial of common TRG with ATLAS. Some preliminary results		
2015	pp 13 TeV Arm1,2	9.0×10^{16}	**Our main target. Data taken in June 2015 after the LHC restart!**		
2015	SPS beam test Arm1,2		Post LHC calibration		

Combined analysis paper: submitted to PRD

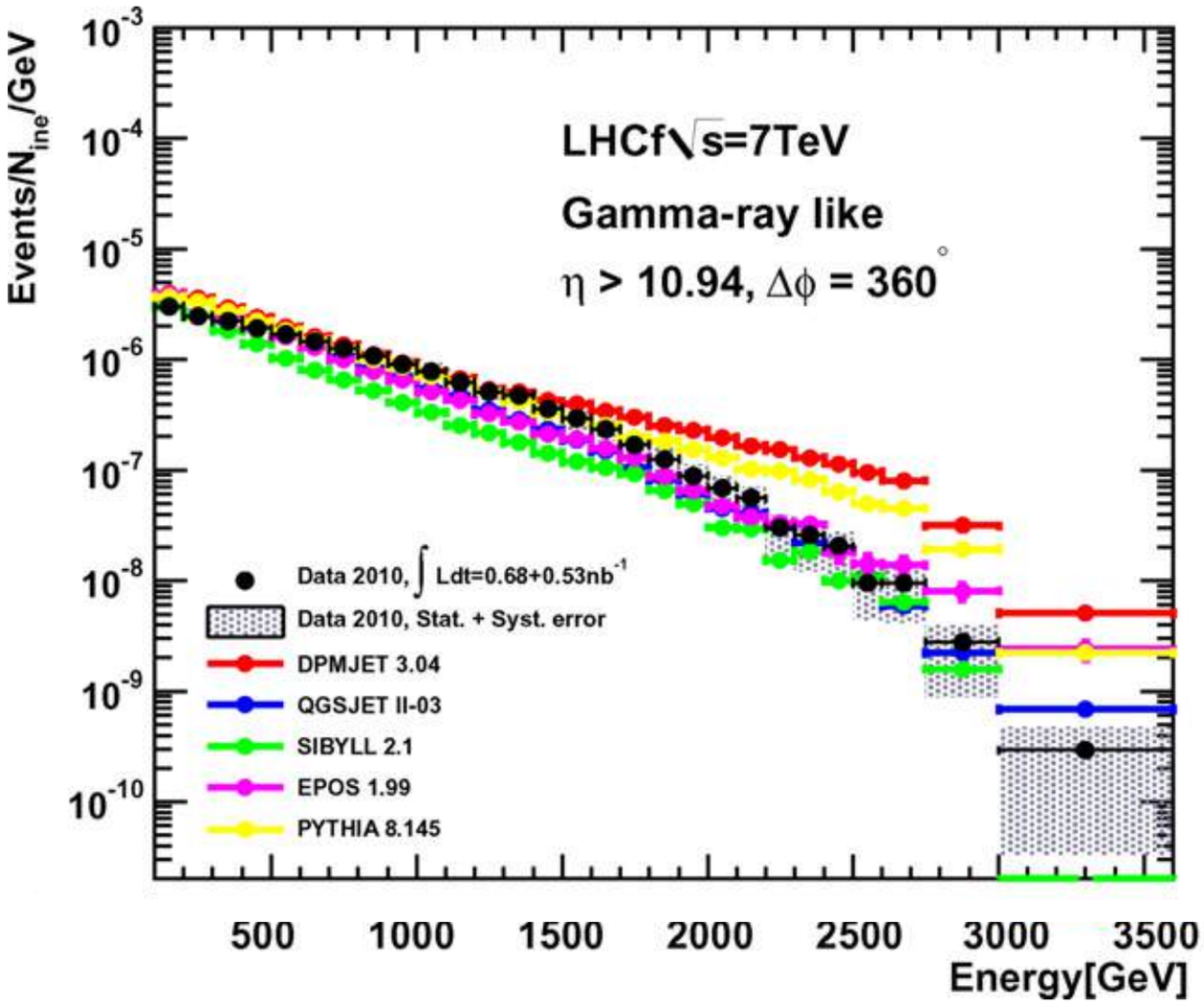
Quick Report

Results

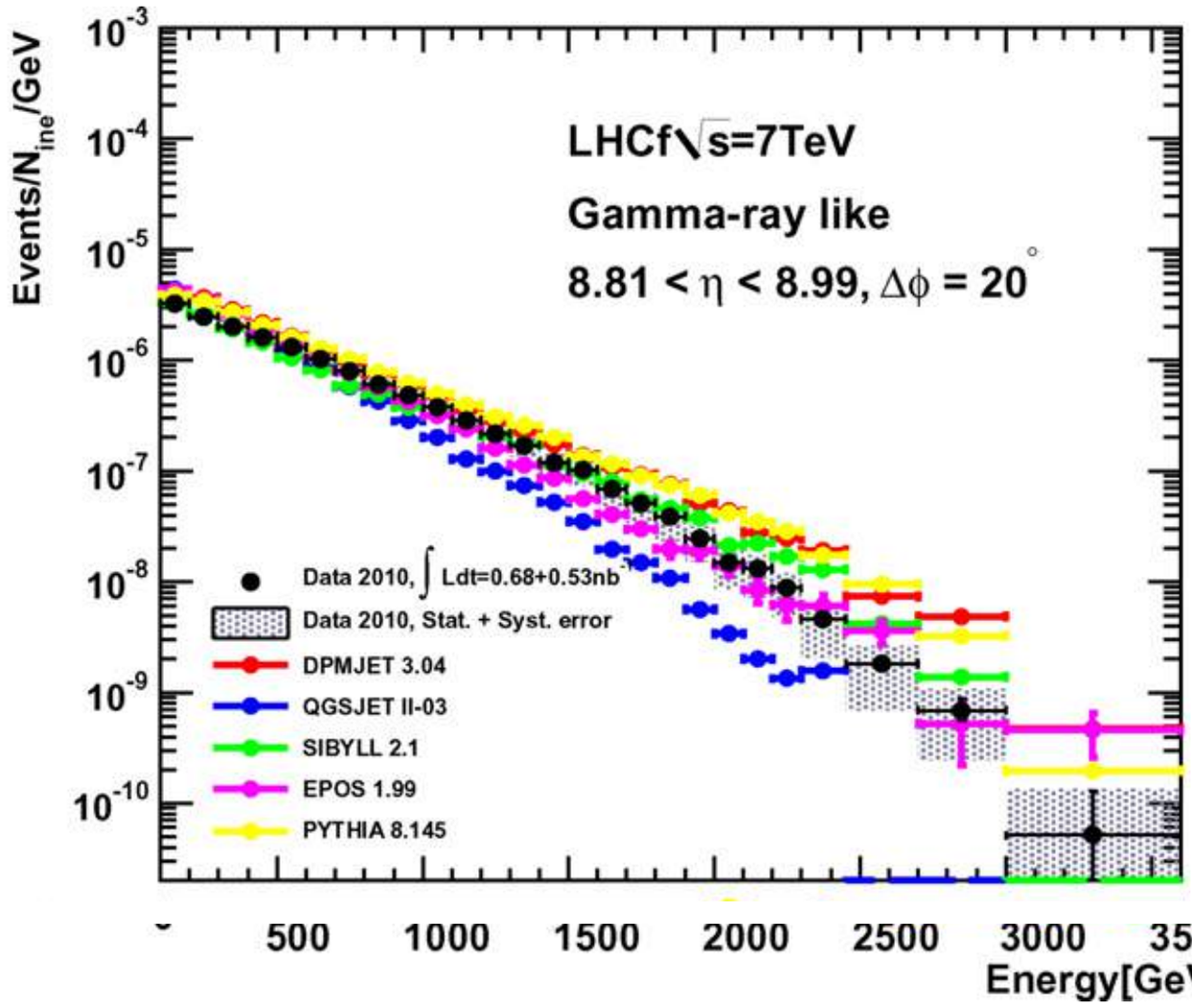
photon spectrum @√S= 7 TeV

Comparison with M.C predictions

Small Tower; eta >10.94



Large Tower; 8.81<eta<8.99



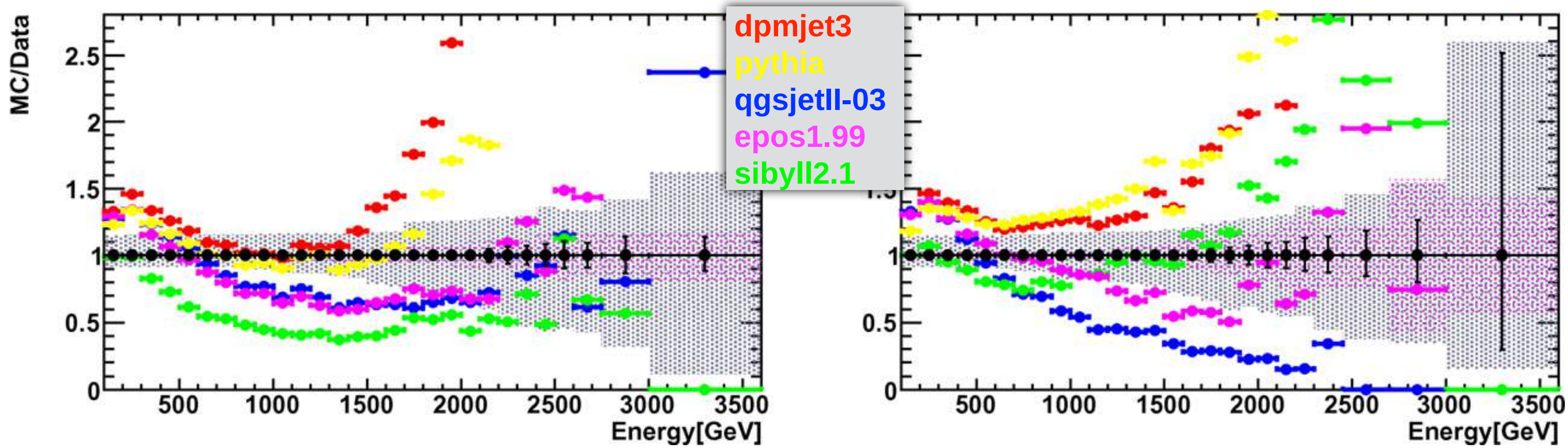
photon spectrum @√S= 7 TeV

Comparison with M.C predictions

MC/Data

Small Tower; eta >10.94

Large Tower; 8.81<eta<8.99



No model is perfect but not too bad

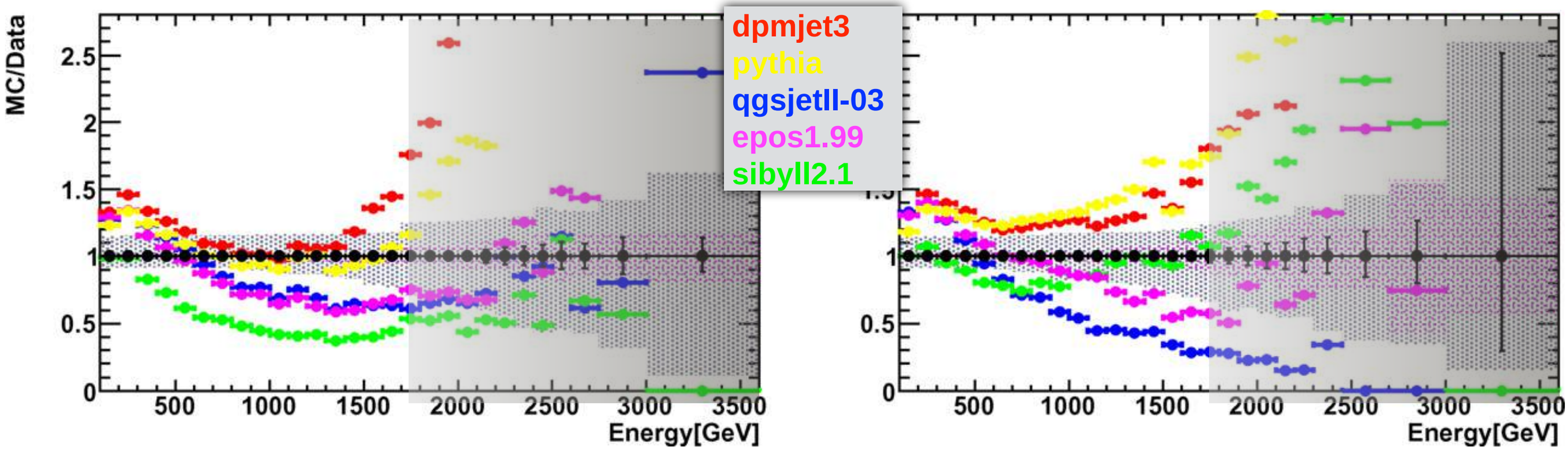
LHC-tuned EPOS and QGSJETII show bit harder spectra and MC/Data will be improved a bit

photon spectrum @√S= 7 TeV

Comparison with M.C predictions

MC/Data

Small Tower; eta >10.94 | **Large Tower; 8.81<eta<8.99**

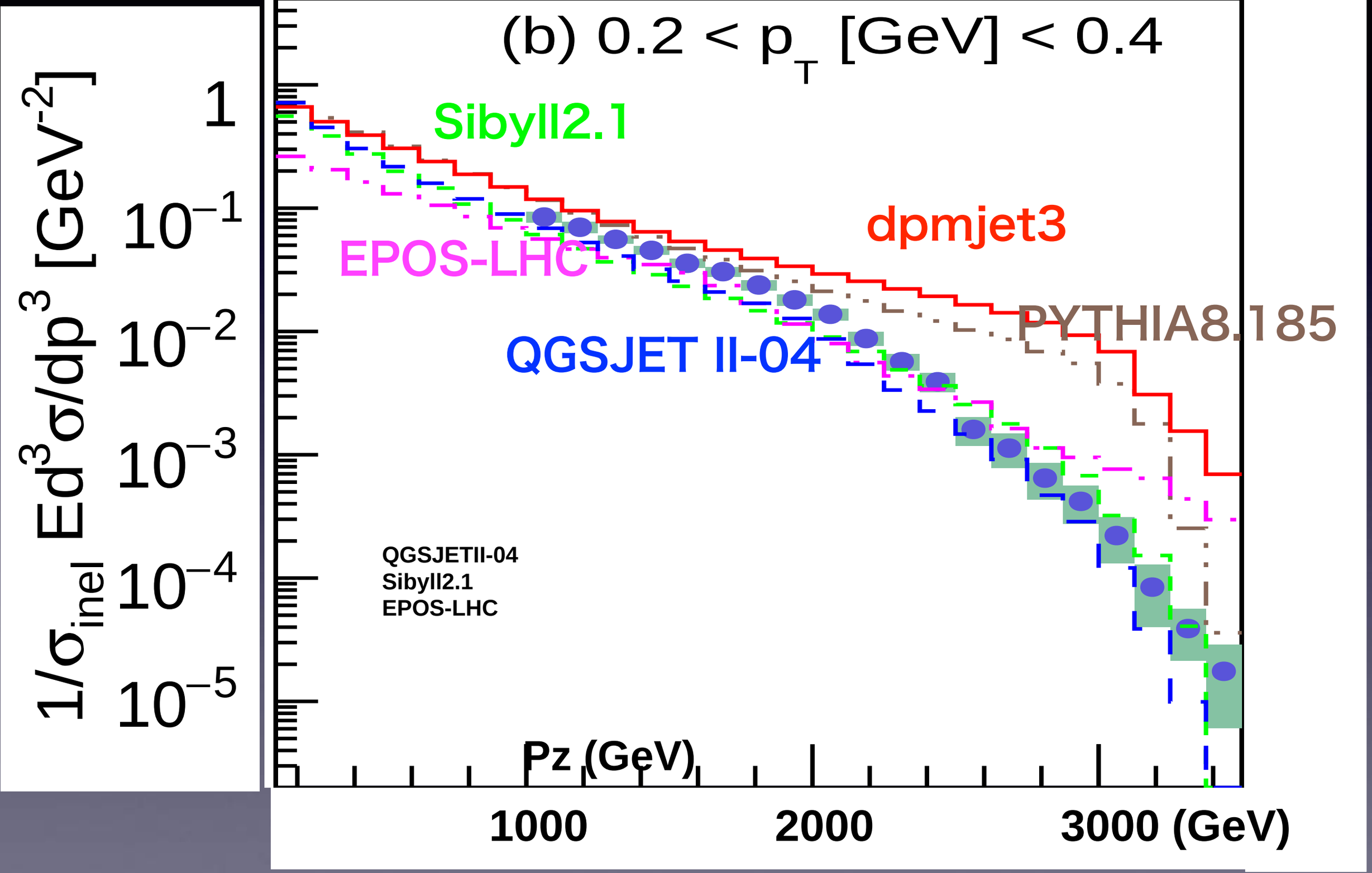


No model is perfect but not too bad

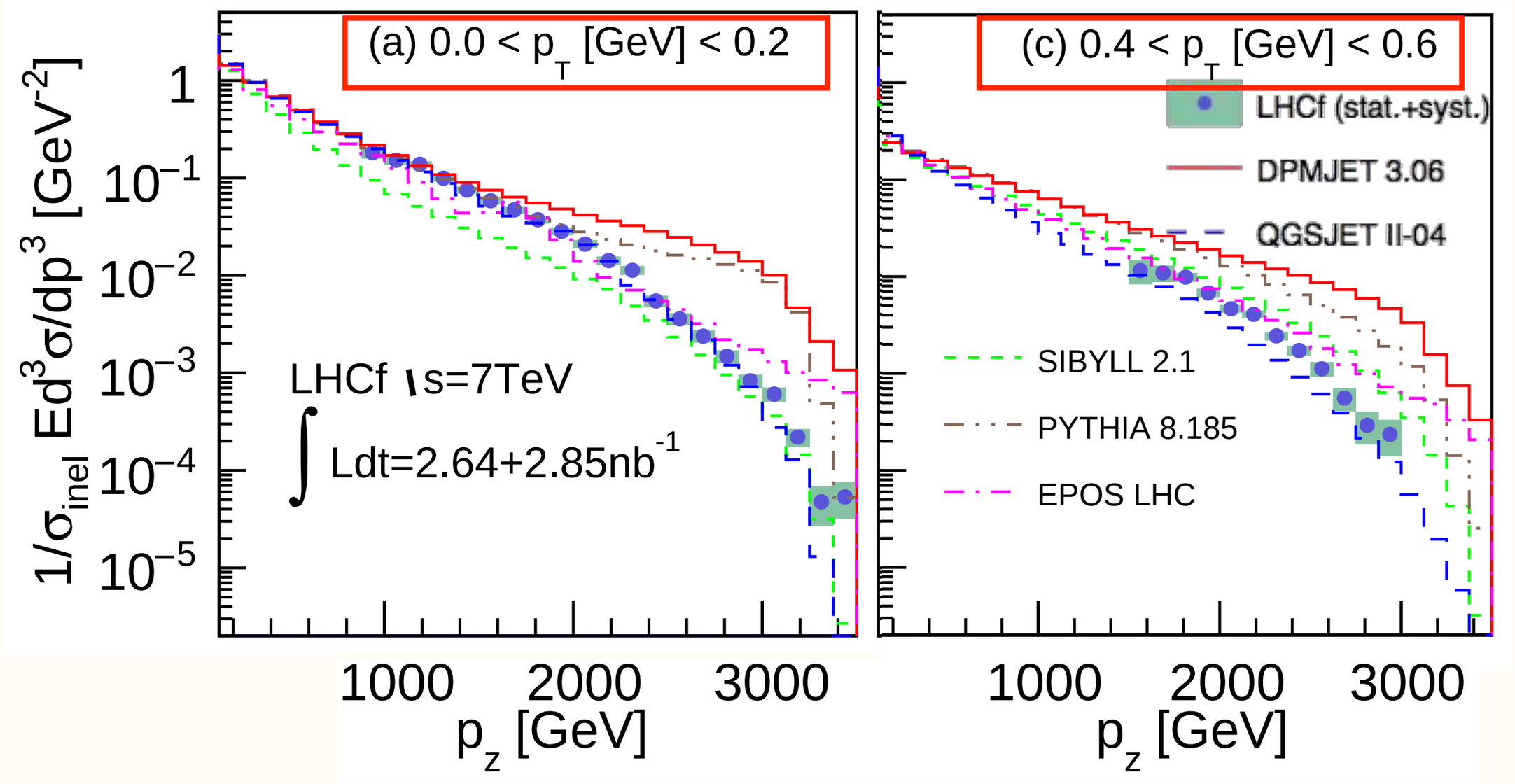
LHC-tuned EPOS and QGSJETII show bit harder spectra and MC/Data will be improved a bit

π^0 analysis

Pz spectrum at $\sqrt{s}$ = 7 TeV (Arm1,2 combined)

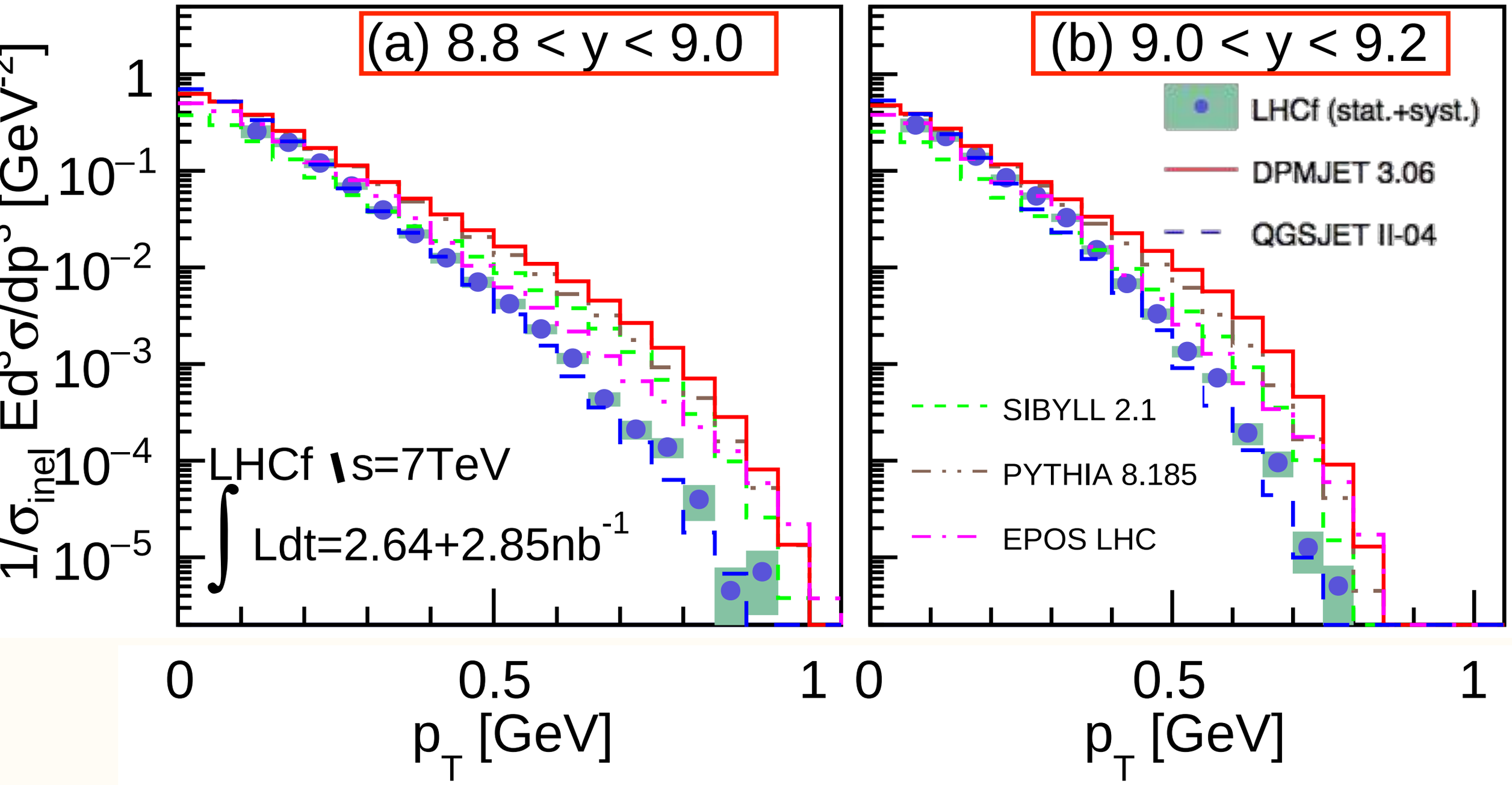


Pz spectrum of π^0 (Arm1,2 combined) at $\sqrt{S}$ = 7 TeV



In these Pt regions, Sibyll2.1 deviates from the data.
How about Pt dist.?

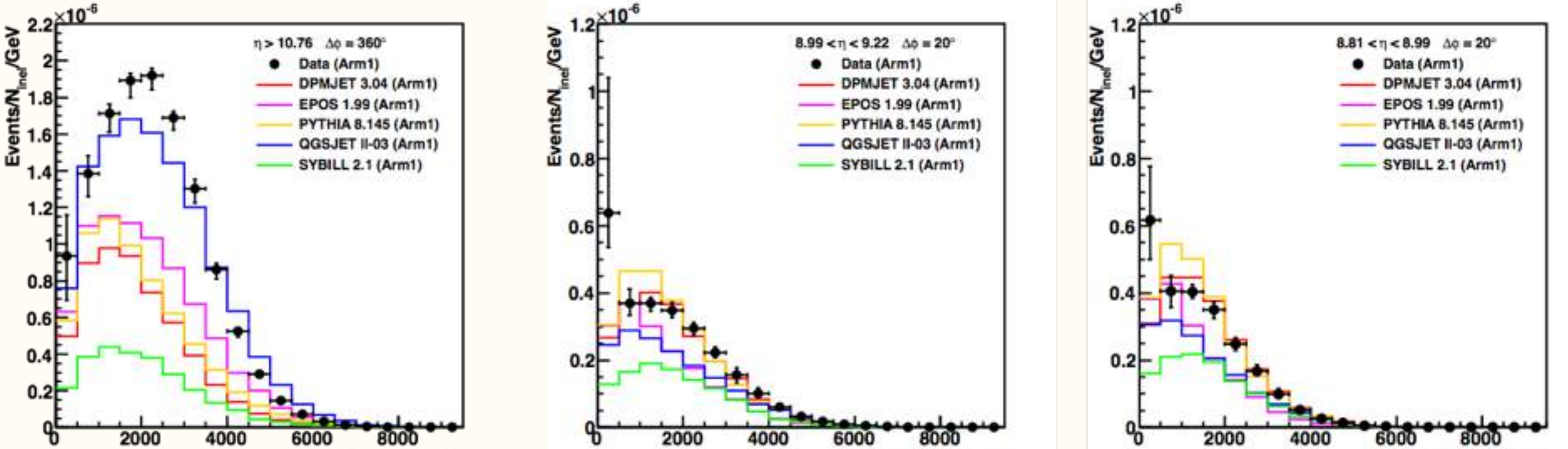
Pt spectrum of π^0 (Arm1,2 combined) at $\sqrt{S}$ = 7 TeV



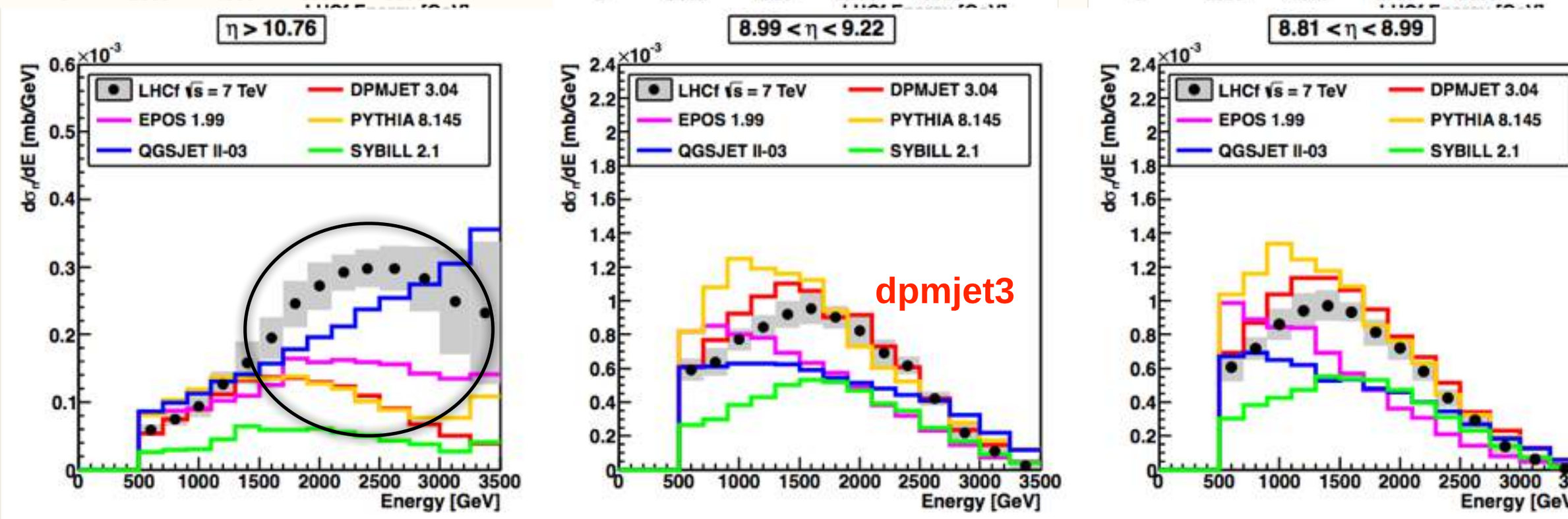
Neutral hadron (neutron) Energy Spectrum @ √S=7 TeV

η>10.76 **8.99<η<9.22** **8.81<η<8.99**

folded



unfolded



Phys. Lett. B 750 (2015) 360-366

p+Pb at $\sqrt{s_{NN}} = 5.02$ TeV

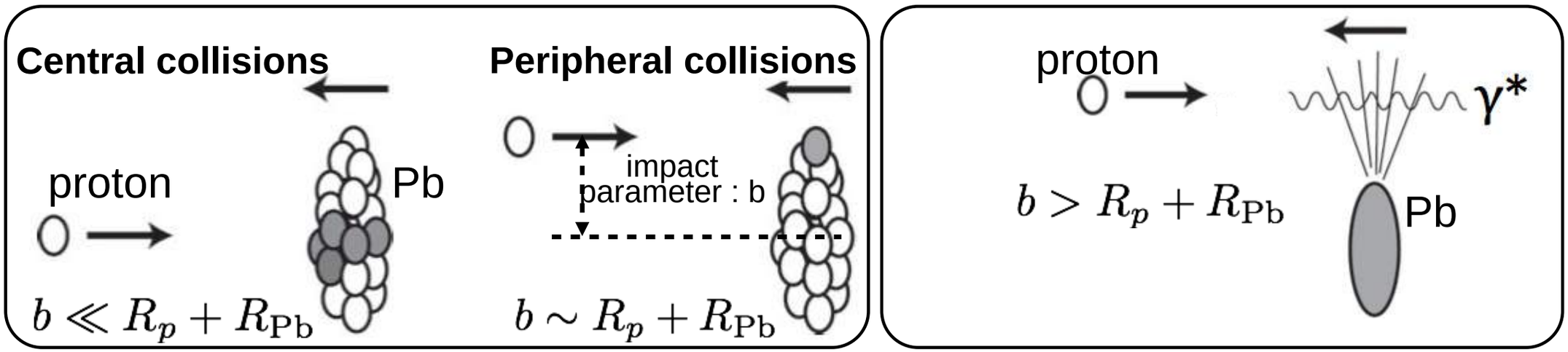
Arm2 only

UPC+QCD, Nuc.Mod.Fac.

π^0 event categories in p-Pb collisions

(Soft) QCD :
central and peripheral collisions

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



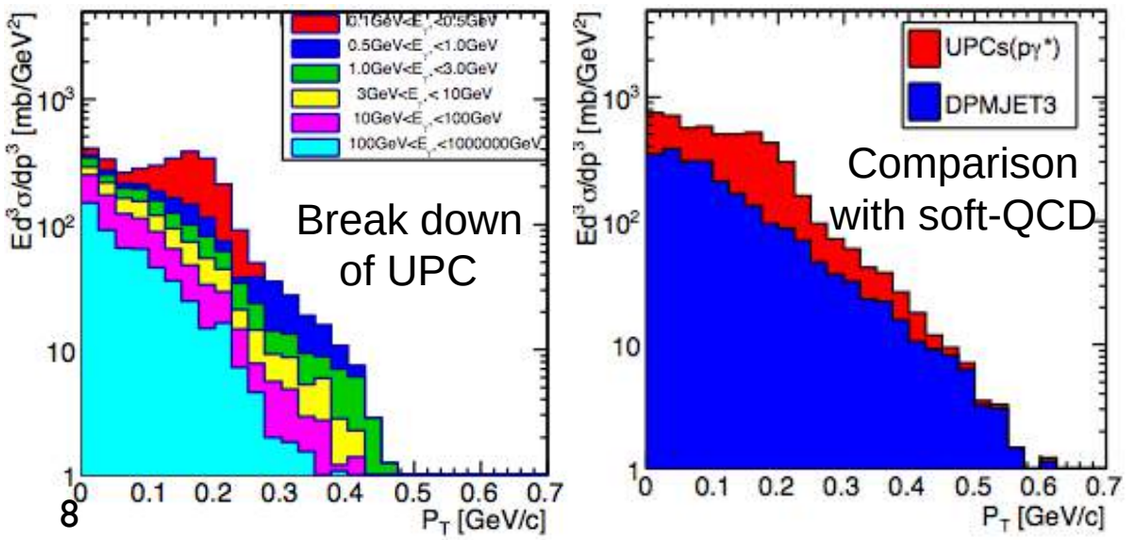
Momentum distribution of the UPC induced secondary particles is estimated as

1. energy distribution of virtual photons is estimated by the Weizsacker Williams approximation.] proton rest frame
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.

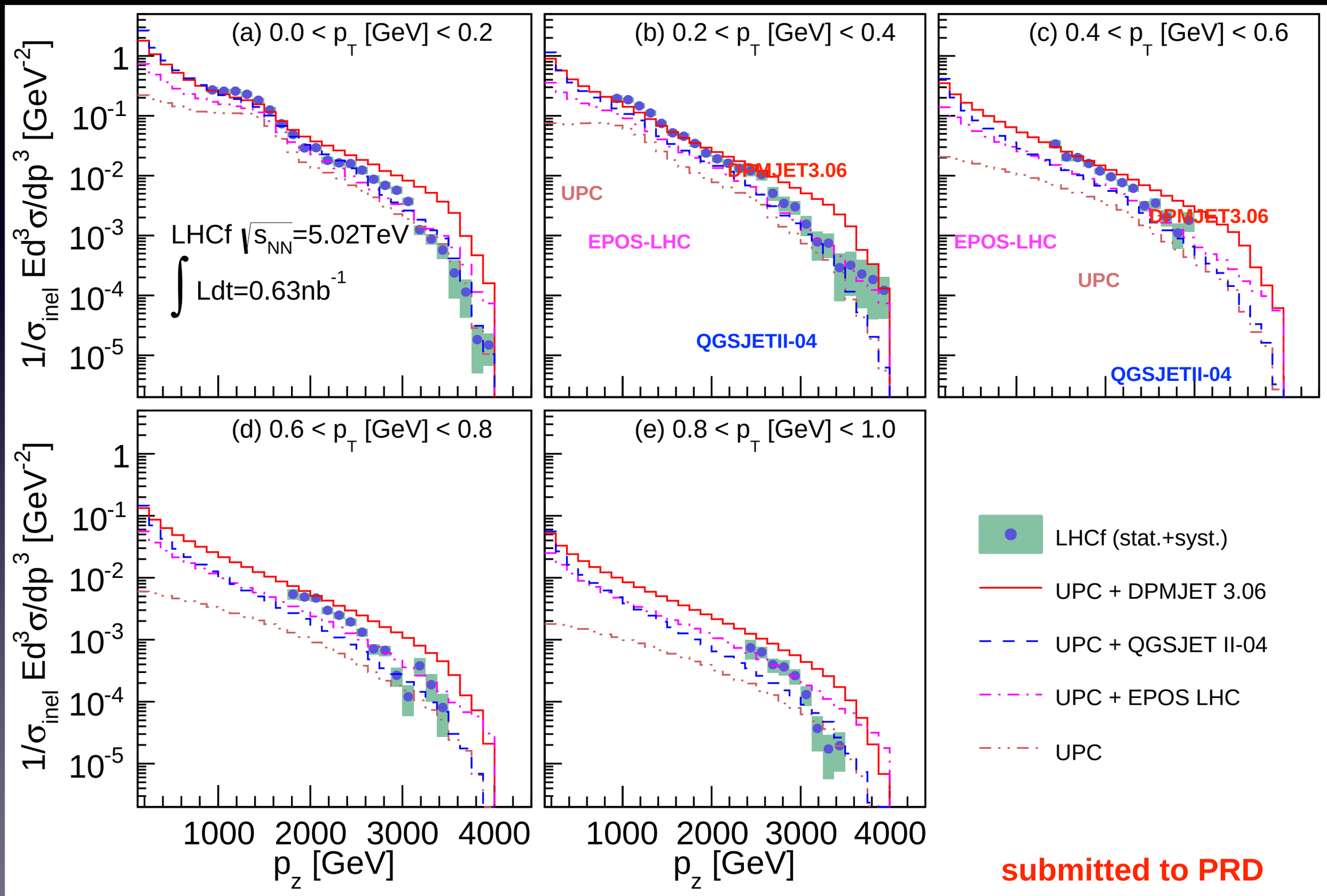
Dominant channel to forward π^0 is

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

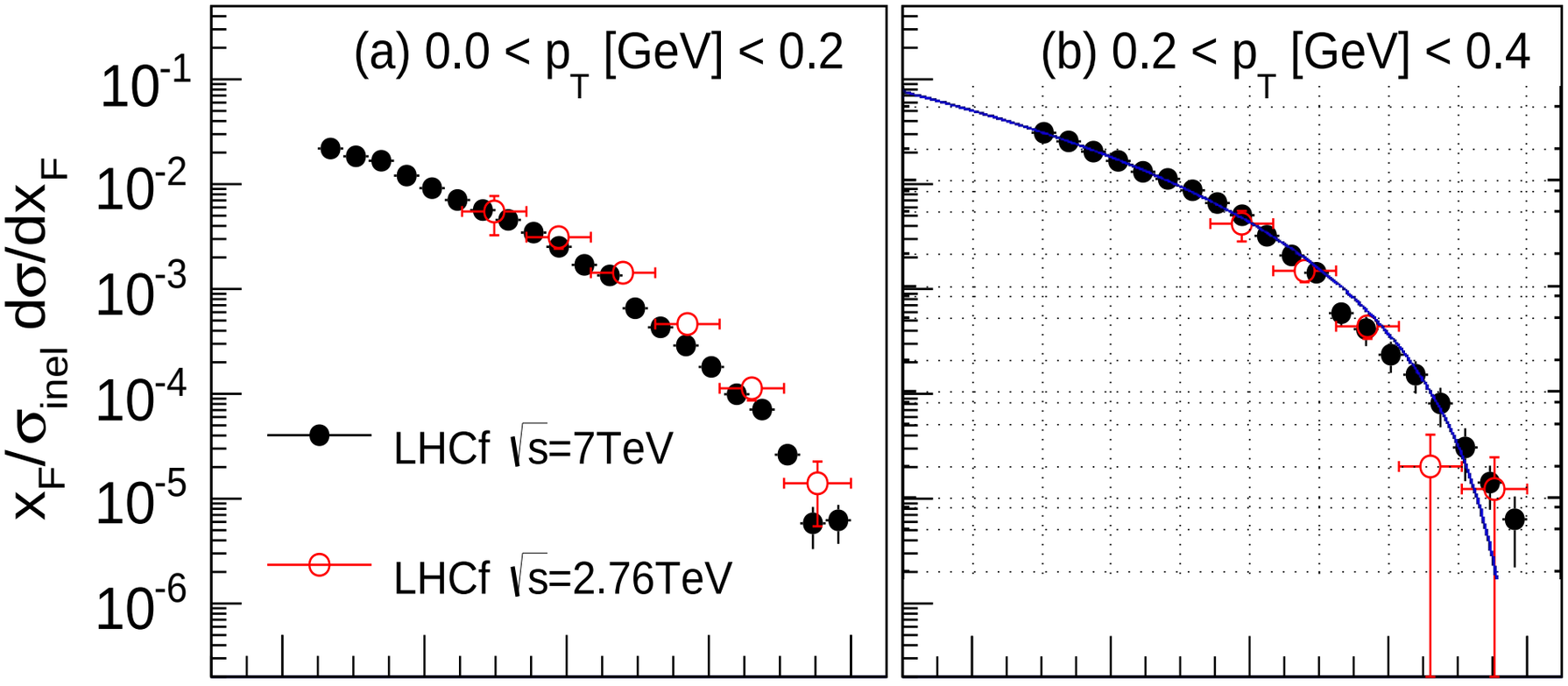
About half of the observed π^0 may originate in UPC, another half is from soft-QCD.

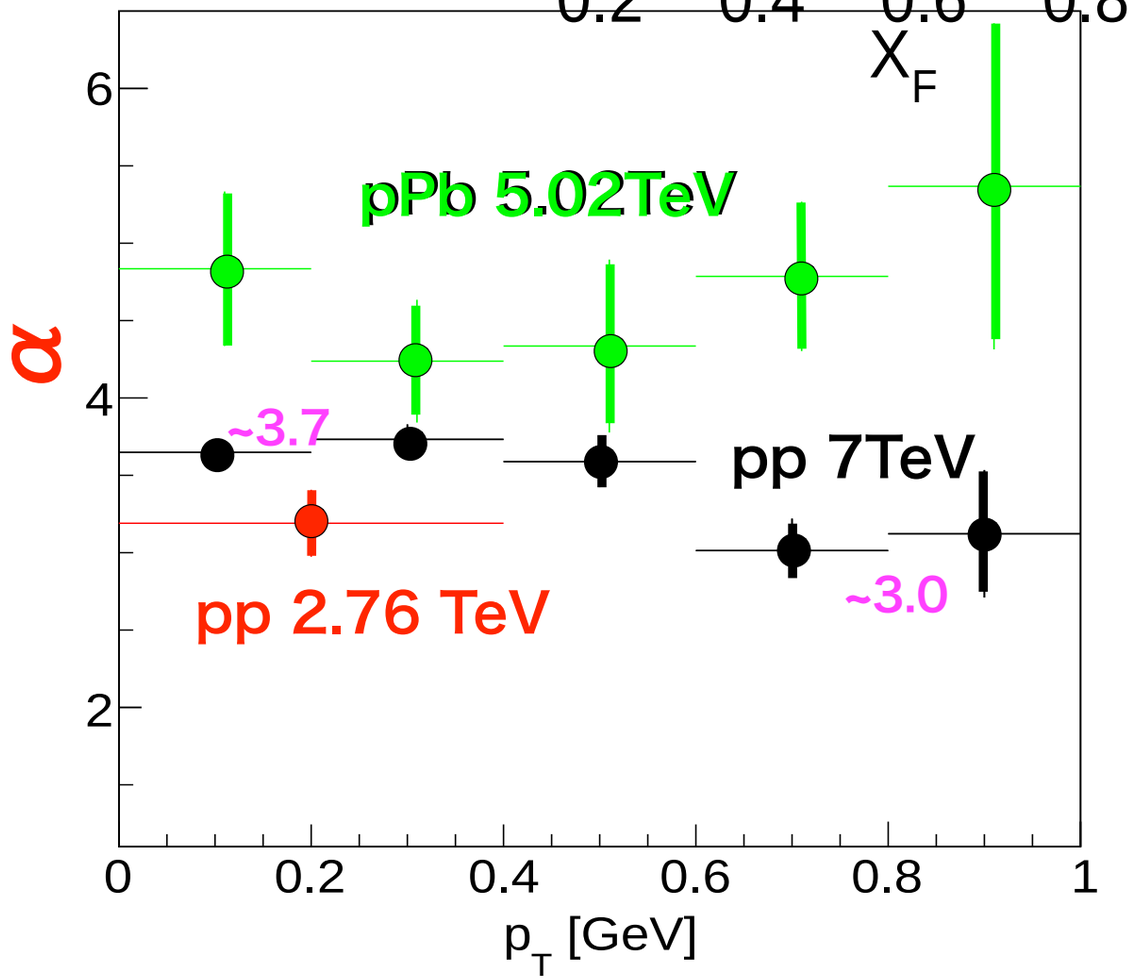


P_z spectrum of π^0 in p+Pb at $\sqrt{s_{NN}}$=5.02 TeV
Exp. data vs model (both include UPC)



Scaling or Limiting Fragmentation





Scaling: 2.76 ~ 7.0 TeV ~20 %

13 TeV & RHICf experiment

$$\frac{1}{\sigma_{in}} x_F \frac{d\sigma}{dx_F} \sim (1 - x_F)^{\alpha}$$

Premature to discuss saturation Effect ? (Strikman)

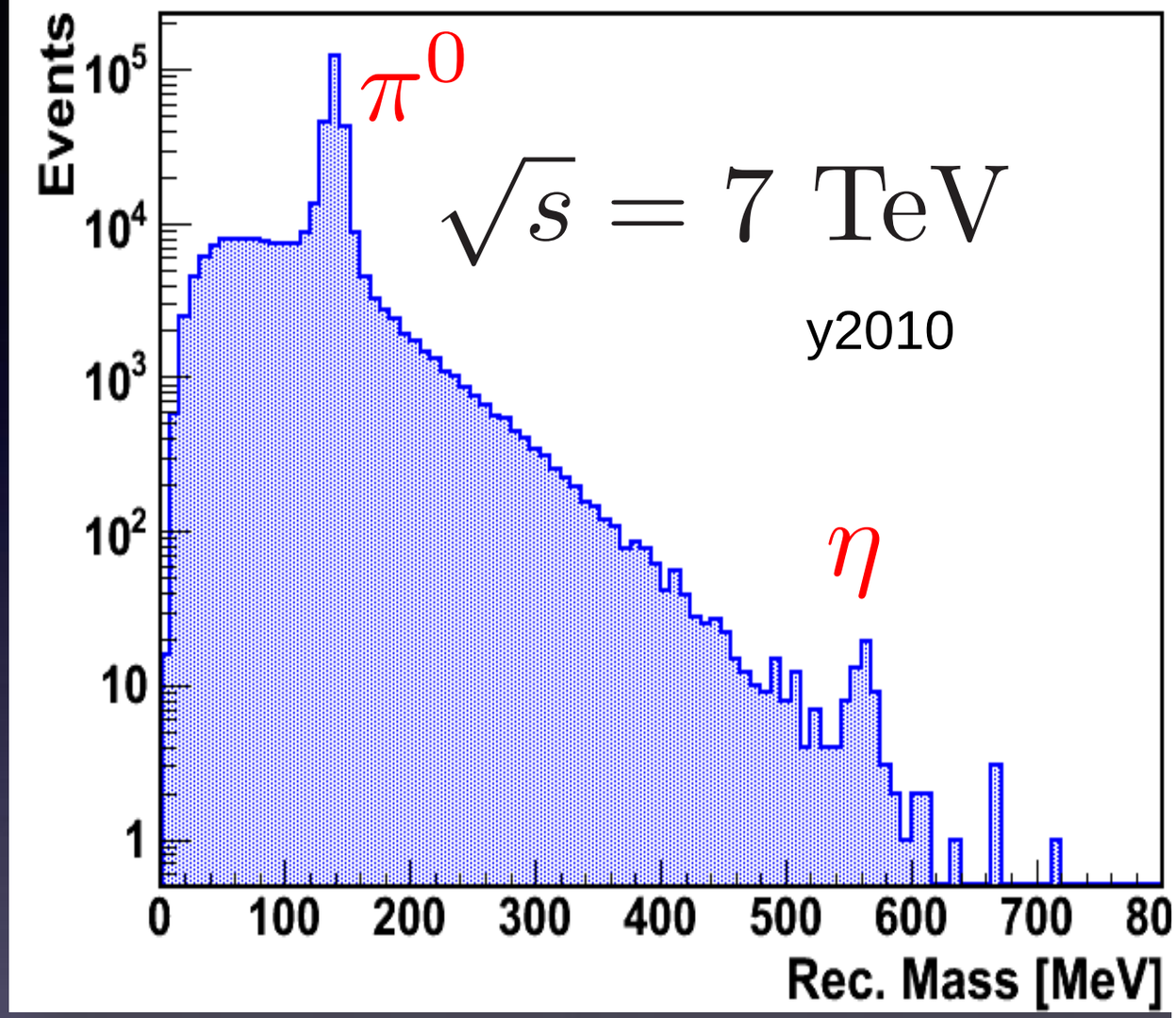
13 TeV with ATLAS info.

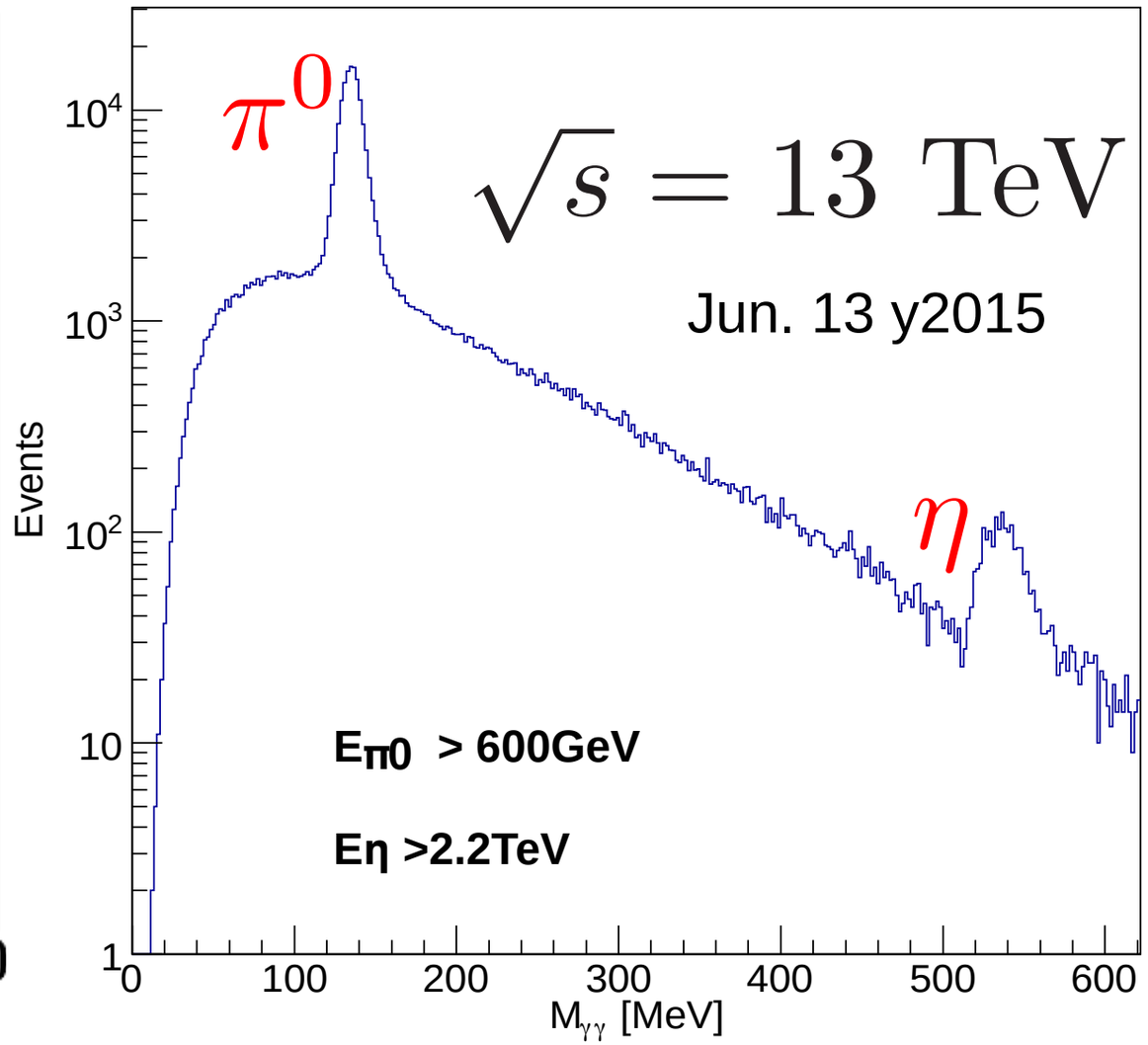
√s=13 TeV

Our main target

Data taking: Early Jun. 2015

Analysis on-going





At 13 TeV, larger acceptance for η

η itself is insensitive to the A.S development;

However, $N_{\pi 0}/N_\eta$ depends on interaction models.

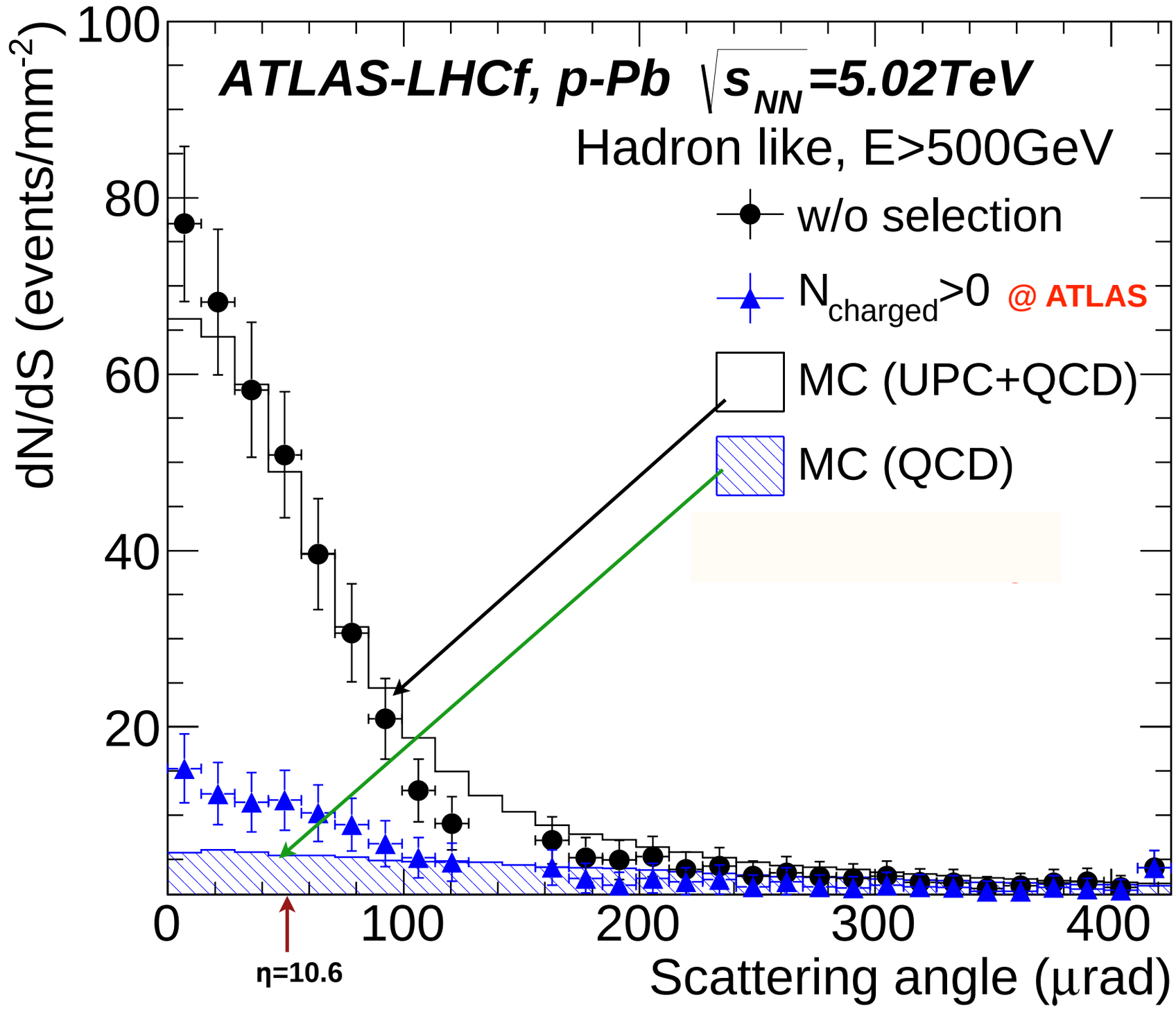
√s=13 TeV data will tell it.

Common DAQ with ATLAS

39M events (E>100GeV)

Info. related to single/double diffraction will be obtained.

Trial of common DAQ with ATLAS in pPb 5.02 TeV case

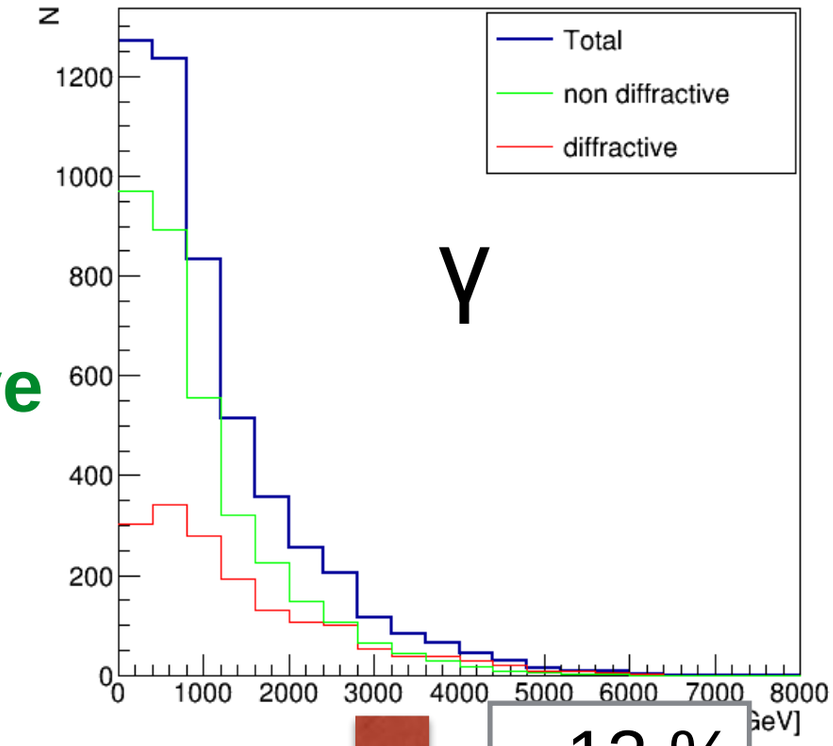


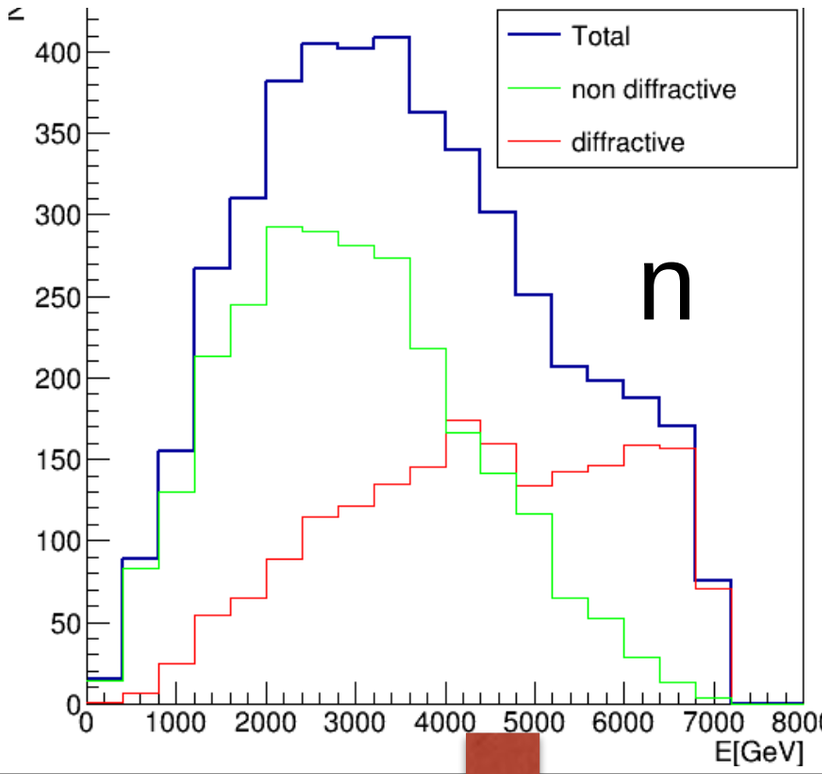
Nch >0 @ ATLAS drops most of UPC @LHCf

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

All events

in MC true,
Non-diffractive
Diffractive

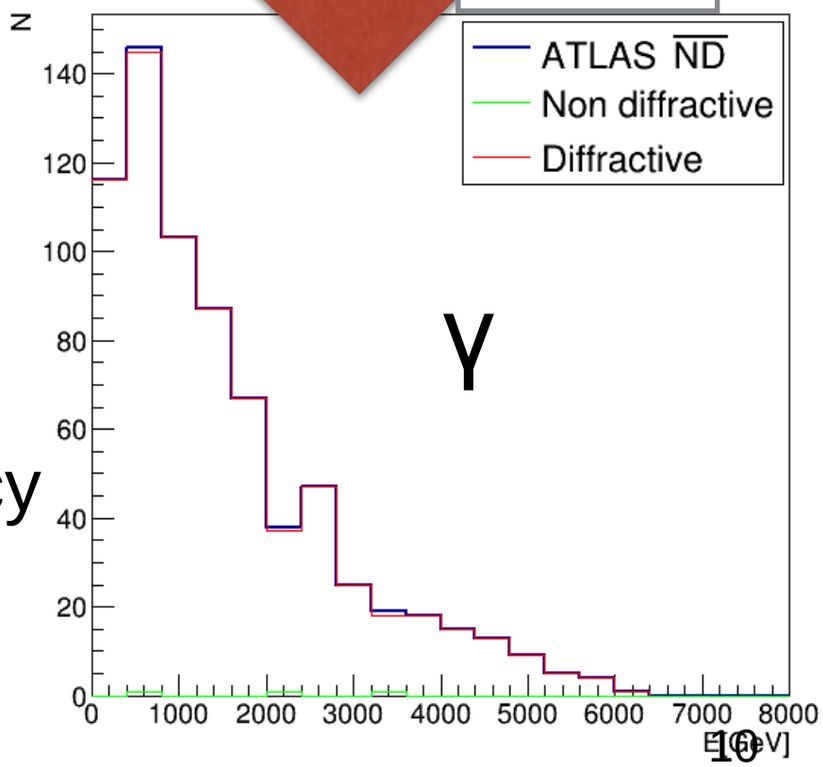


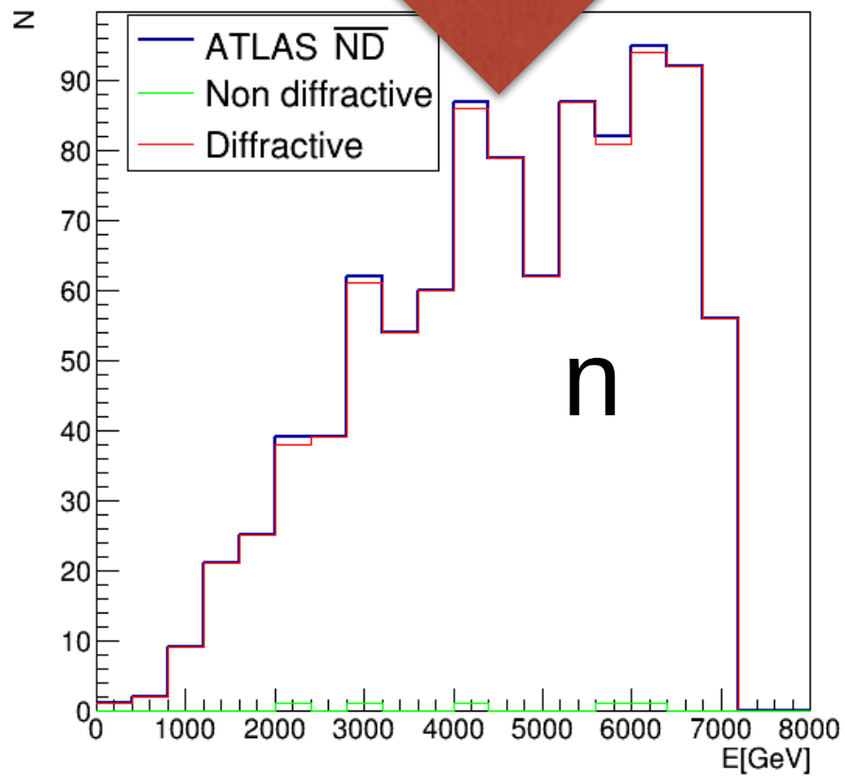


~ 13 %

w/ event selection (not ND)

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





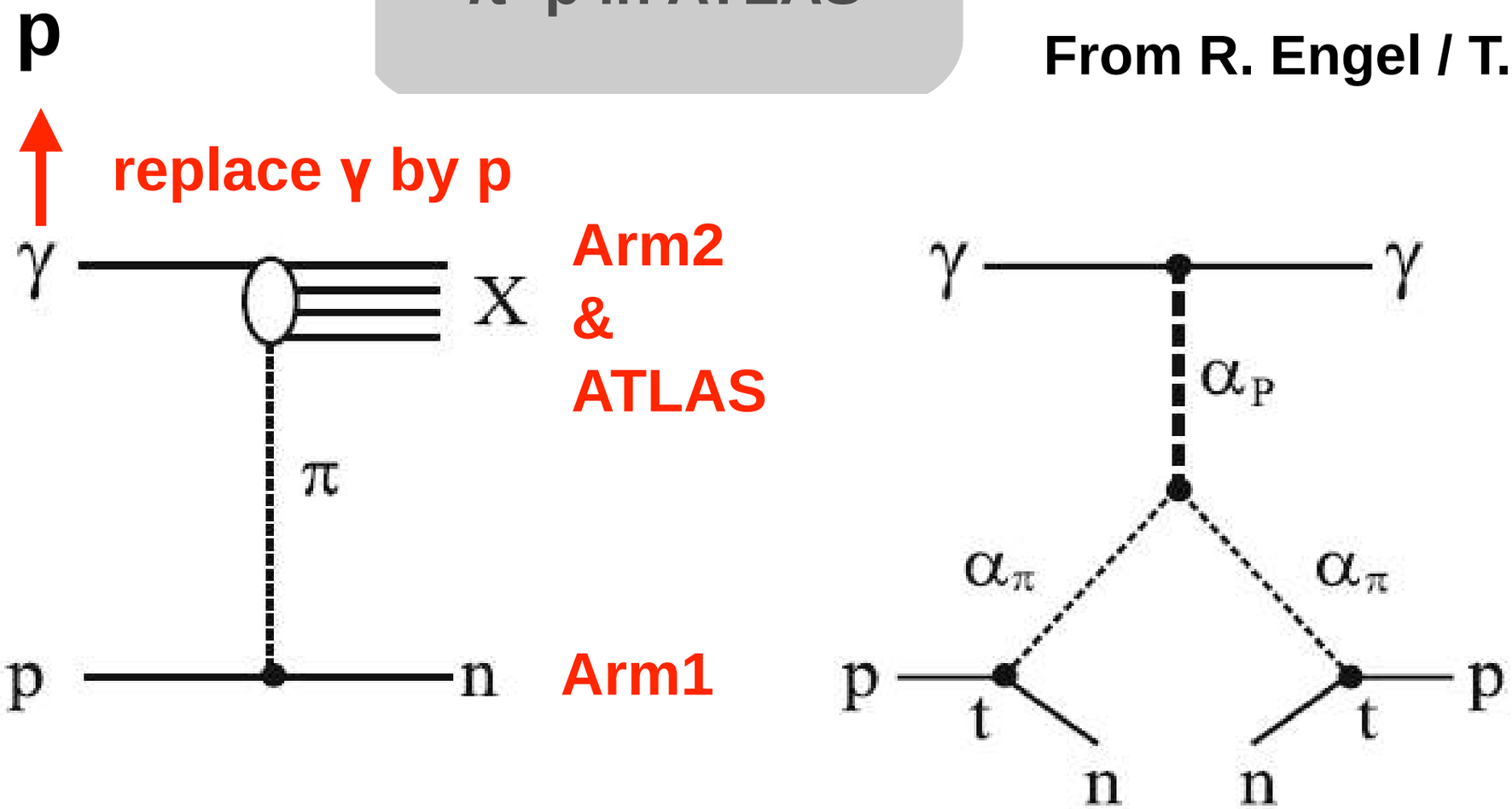
key: low mass diffraction (Ostapchenko)

By Menjo

Pi + P info. at higher energies could be obtained:

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)

Summary

- Cosmic ray people, more or less, on the rails. i.e,
  - ★ Models not perfect but not so bad.
  - ★ PiO and photon
    - LHC-tuned QGSJETII-4 and EPOS-LHC are fairly good
    - DPMJET3: too hard 2ry (PYTHIA too)
      - ✱ But at X < 0.5 (important for A.S) fairly good. pPb case: such tendency increases
  - ★ Leading neutron
    - Very forward region: ~qgsjetII. Others too small yeild
    - Larger angle region: dpmjet3 fairly good.
  - ★ Some hint for model construction

Summary (cont)

- UHECR Composition: further refined model selection or further model tuning.
  - ★ √S=13 TeV data
    - +ATLAS: (low M) diff. Pion int.
  - ★ LHCf data + η< 8.4: e.g CASTOR. Future SAS (Mike Albrow)
  - ★ RHICf: test scaling feature
  - ★ Nucleus effect (Air is not p). pA AA' at LHC ?