The LHCf experiment to verify UHECR interactions at LHC

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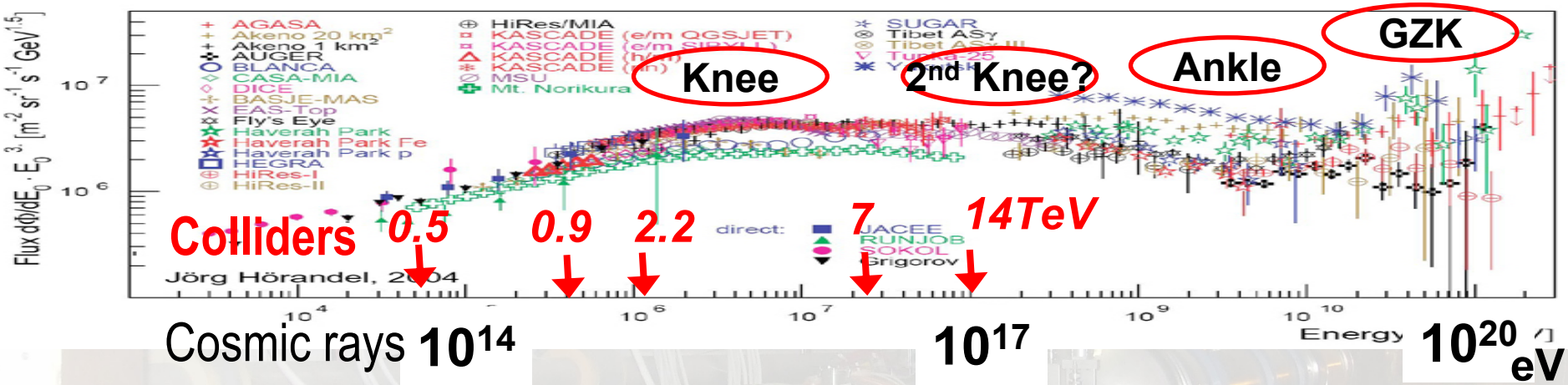
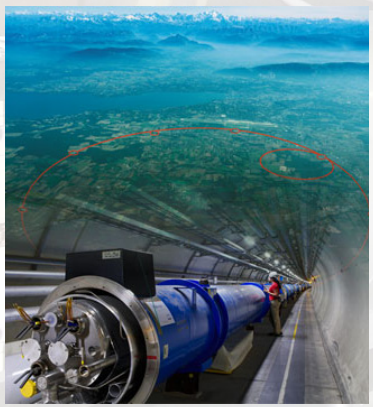
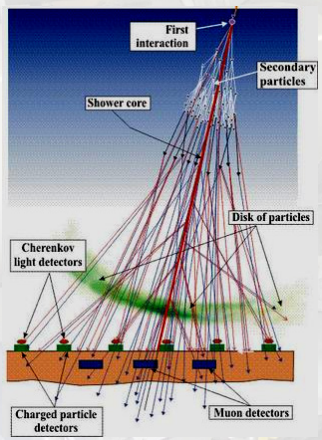
10^{17} eV :Crossroad of accelerator and UHECR

Air shower experiments HEAT TALE AUGER, TA



Cosmic rays 10^{14} 10^{17} 10^{20} eV

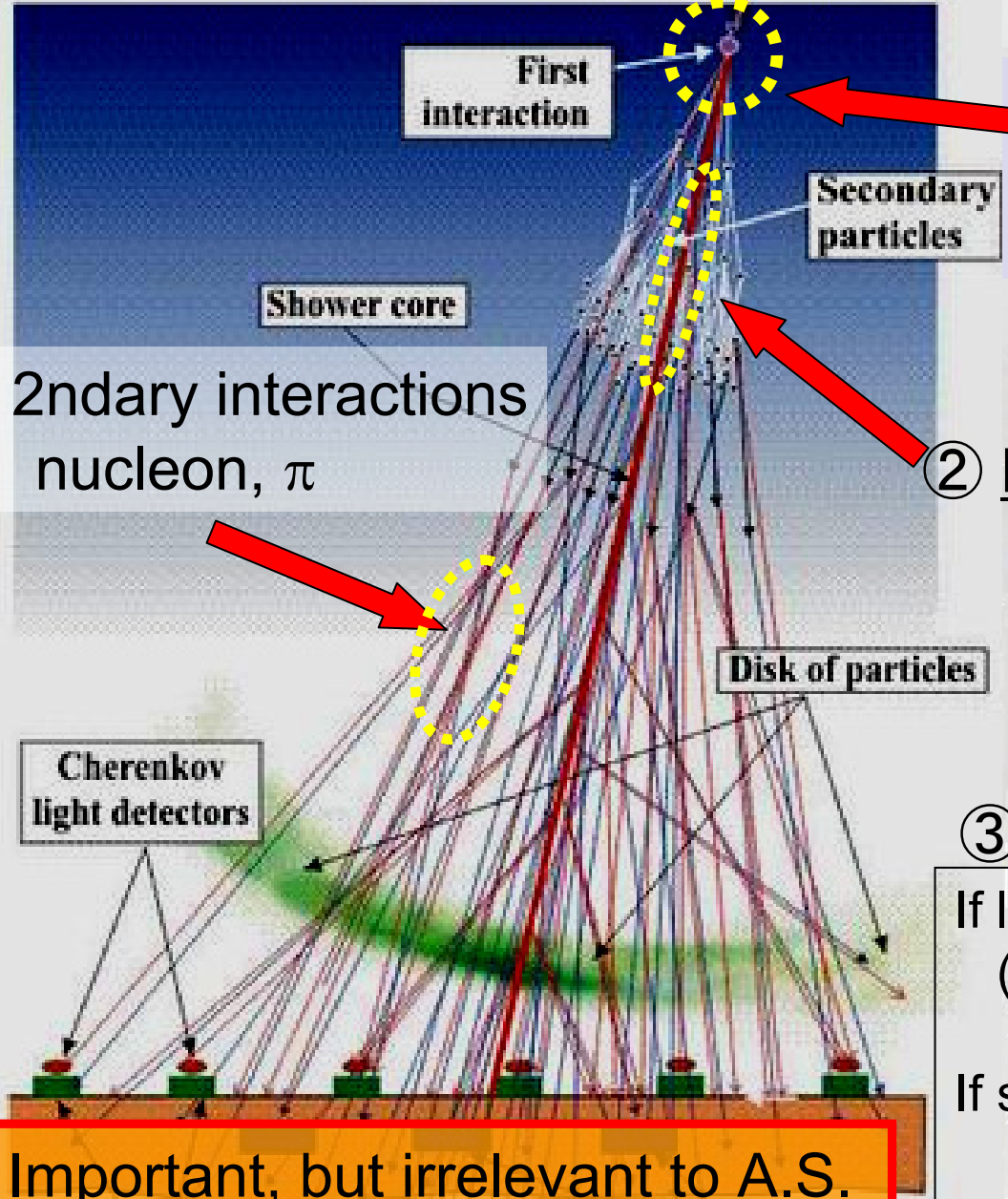




Problem in UHECR exp.

- Auger μ excess
- Tension in composition (Xmax) btw Auger / TA
- 20% diff of E scale btw TA SD / FD

- LHC can verify interactions at 10^{14} ~ 10^{17} eV
- Ongoing low E extension (TALE, HEAT) can verify 10^{17}eV shower



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= $1-p_{lead}/p_{beam}$

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

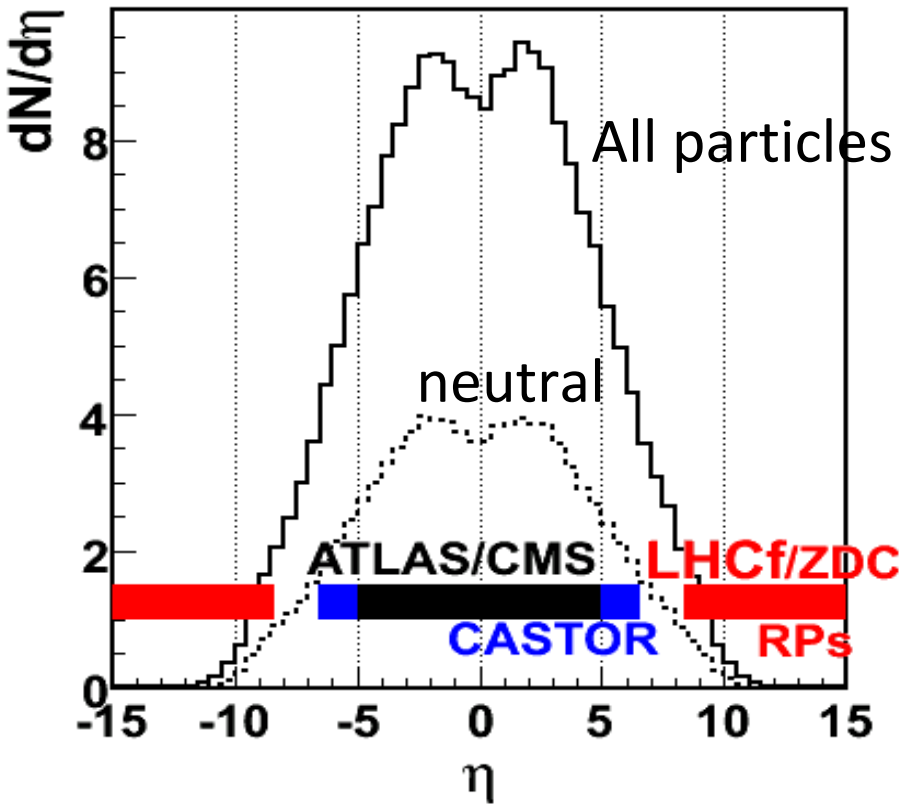
④ 2ndary interactions
nucleon, π

Important, but irrelevant to A.S.
⑤P_T
⑥multiplicity (relevant to N_μ)

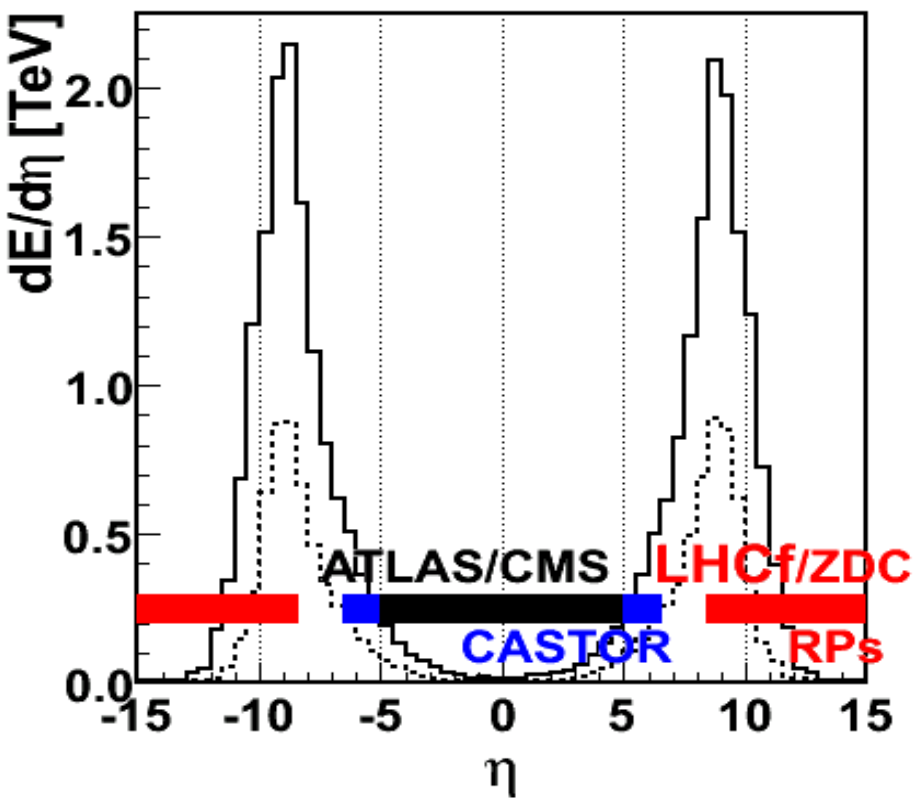
(relevant to N_μ^3)

Very forward : Majority of energy flow ($\sqrt{s}$=14TeV)

Multiplicity



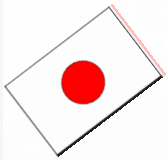
Energy Flux



Most of the energy flows into very forward

(Particles of $X_F > 0.1$ contribute 50% of shower particles)

The LHCf collaboration



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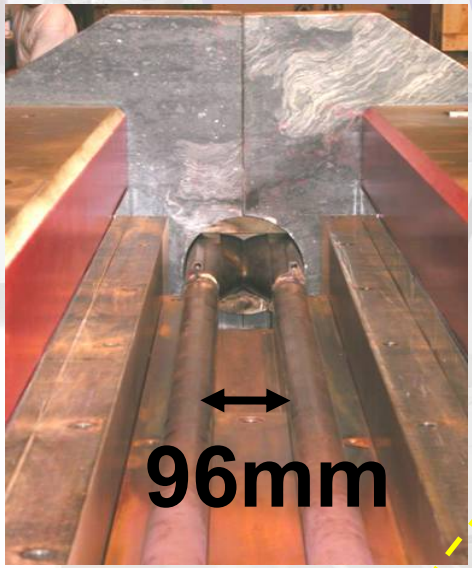
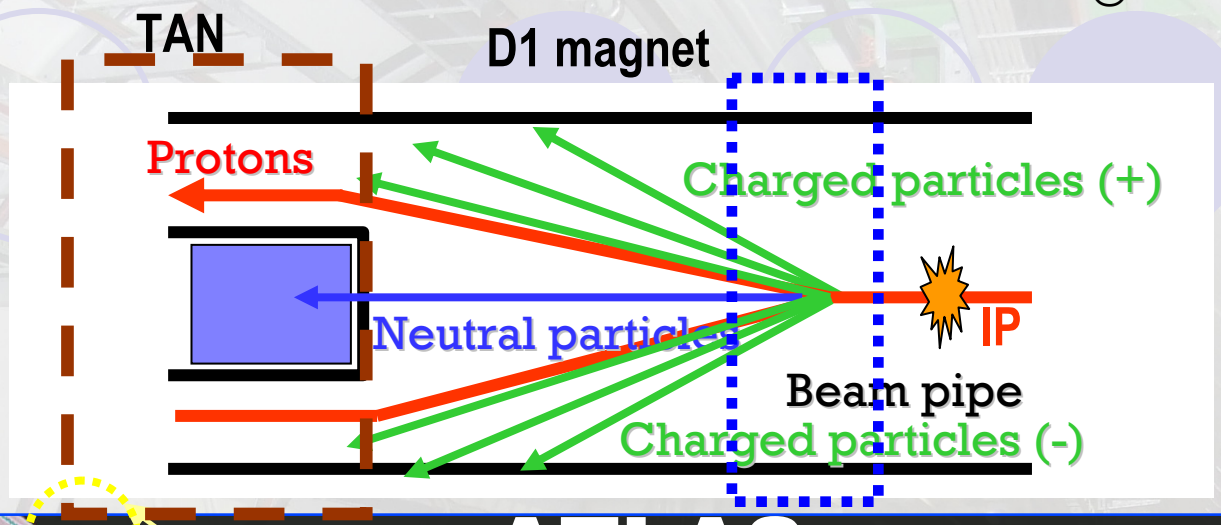
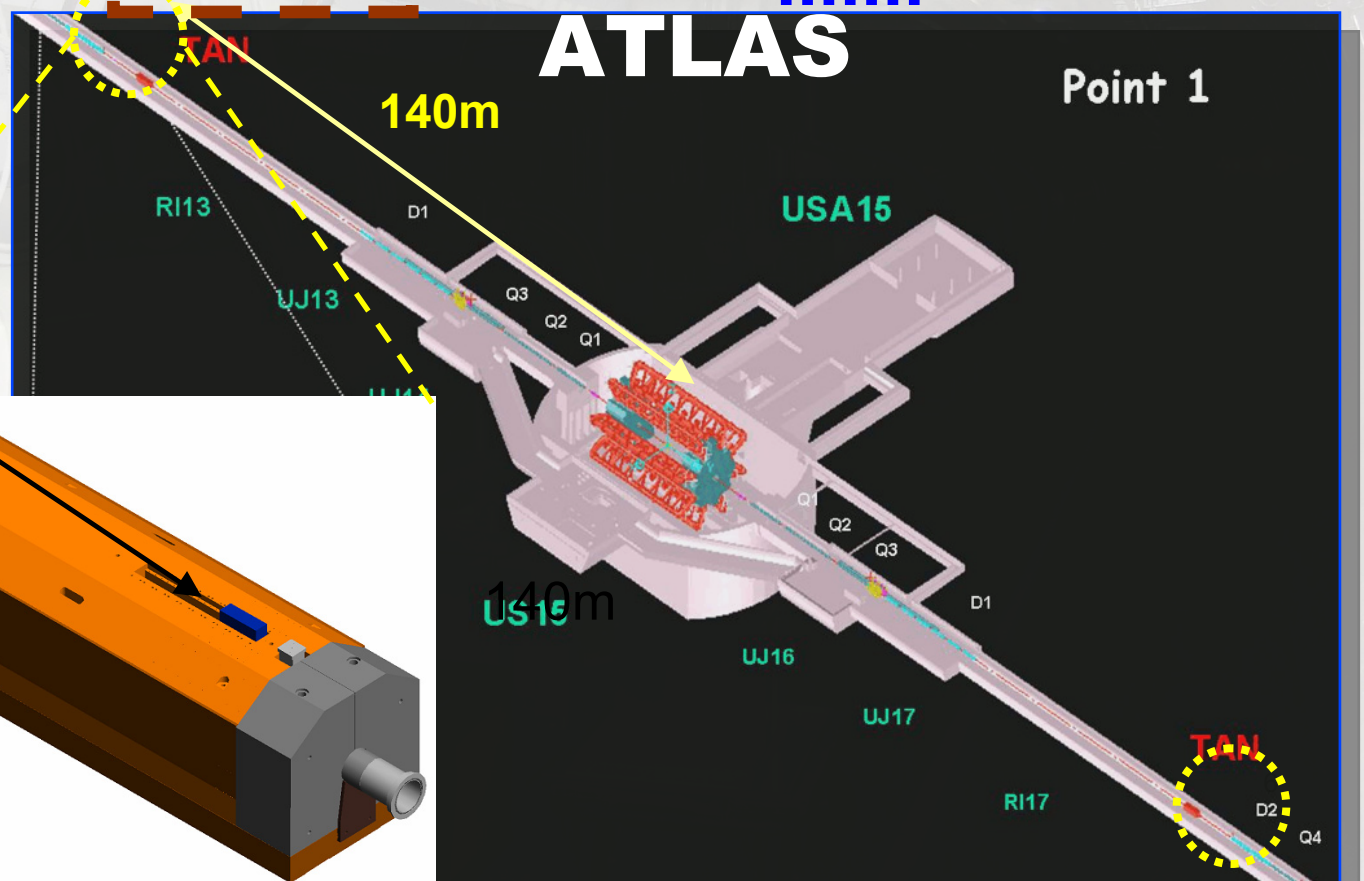
LHCf site



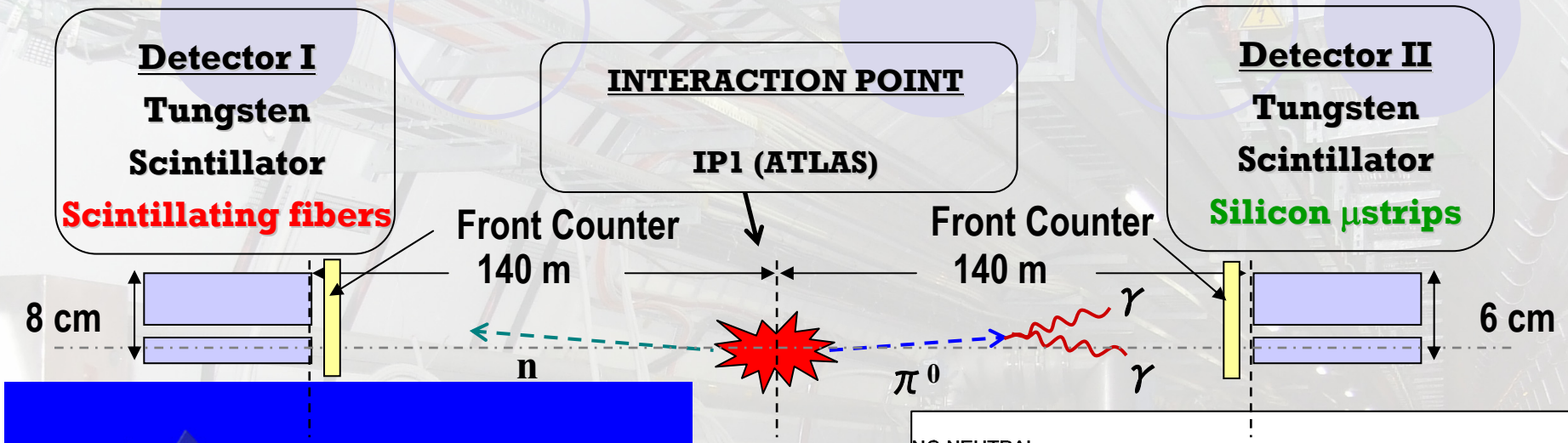


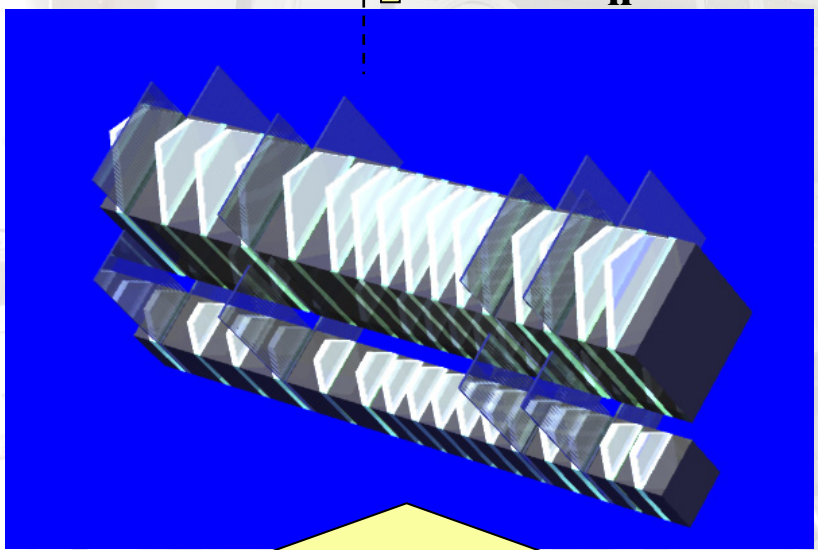


LHCf/ZDC

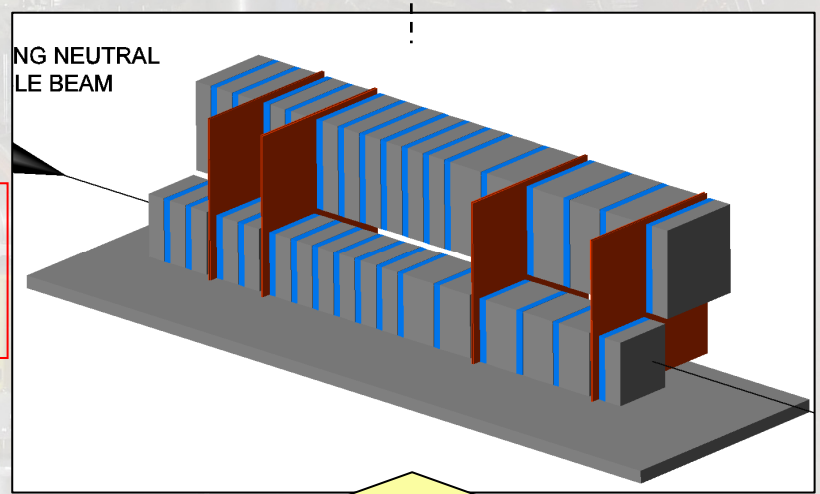
TAN absorber

LHCf: location and detector layout





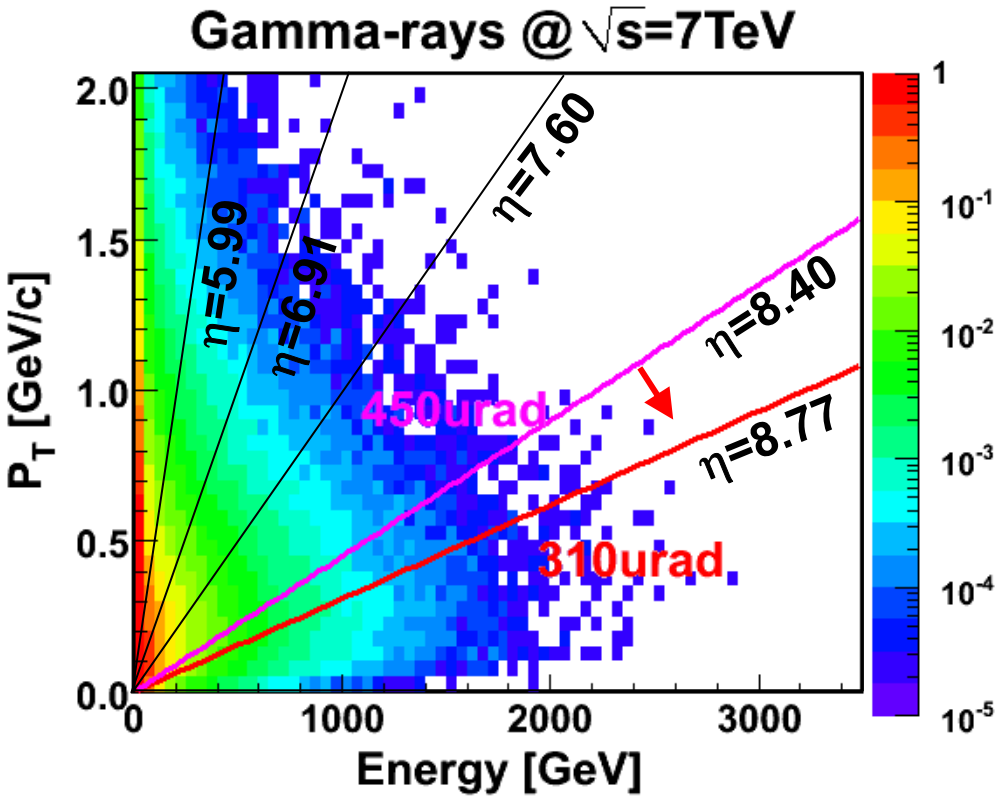
$44X_0$,
$1.6\ \lambda_{int}$

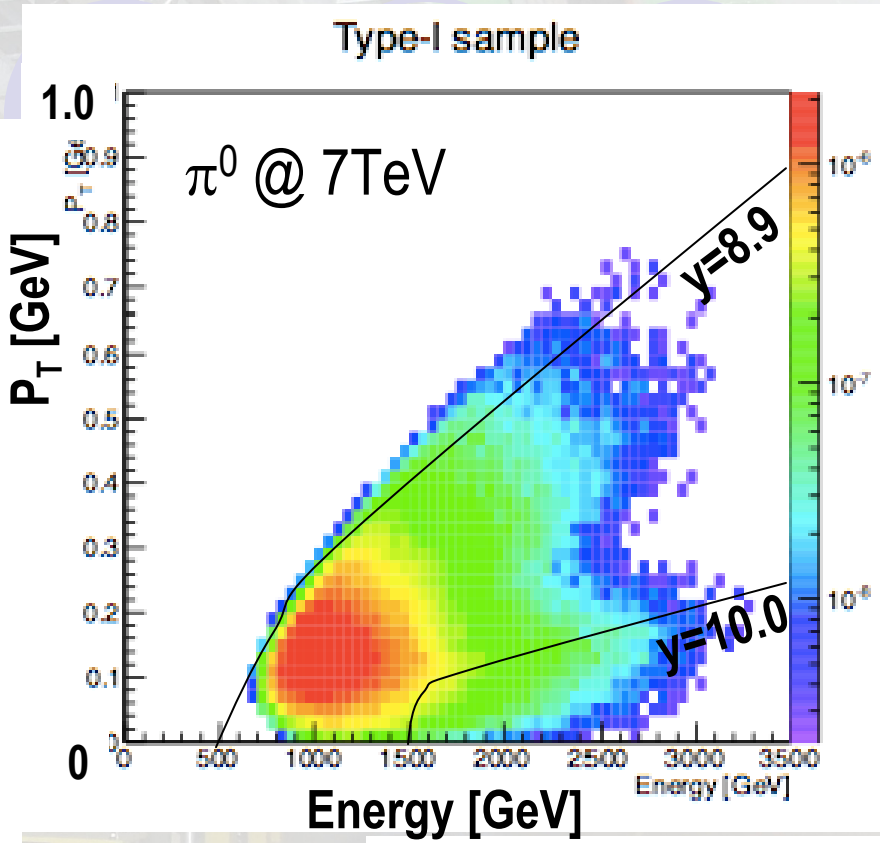


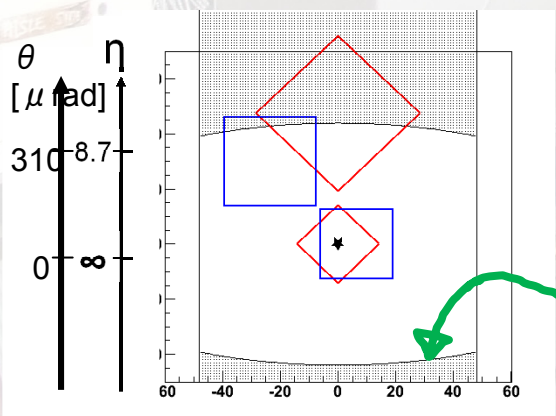
Arm#1 Detector
20mmx20mm+40mmx40mm
4 SciFi tracking layers

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

LHCf γ / π^0 measurement



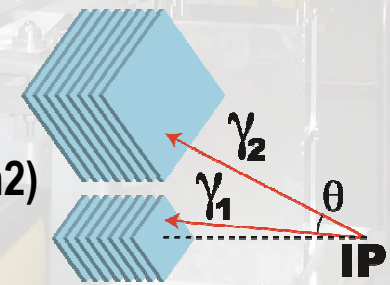


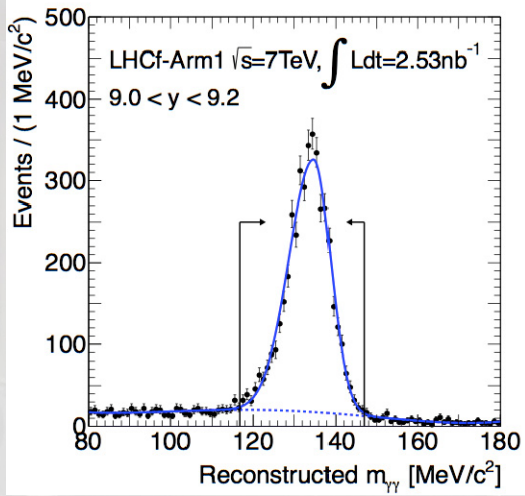


Viewed from IP1
(red:Arm1, blue:Arm2)

Projected edge of beam pipe

$\pi^0 \rightarrow \gamma\gamma$





LHCf single γ spectra at 7TeV

Phys.Lett. B703 (2011) 128-134

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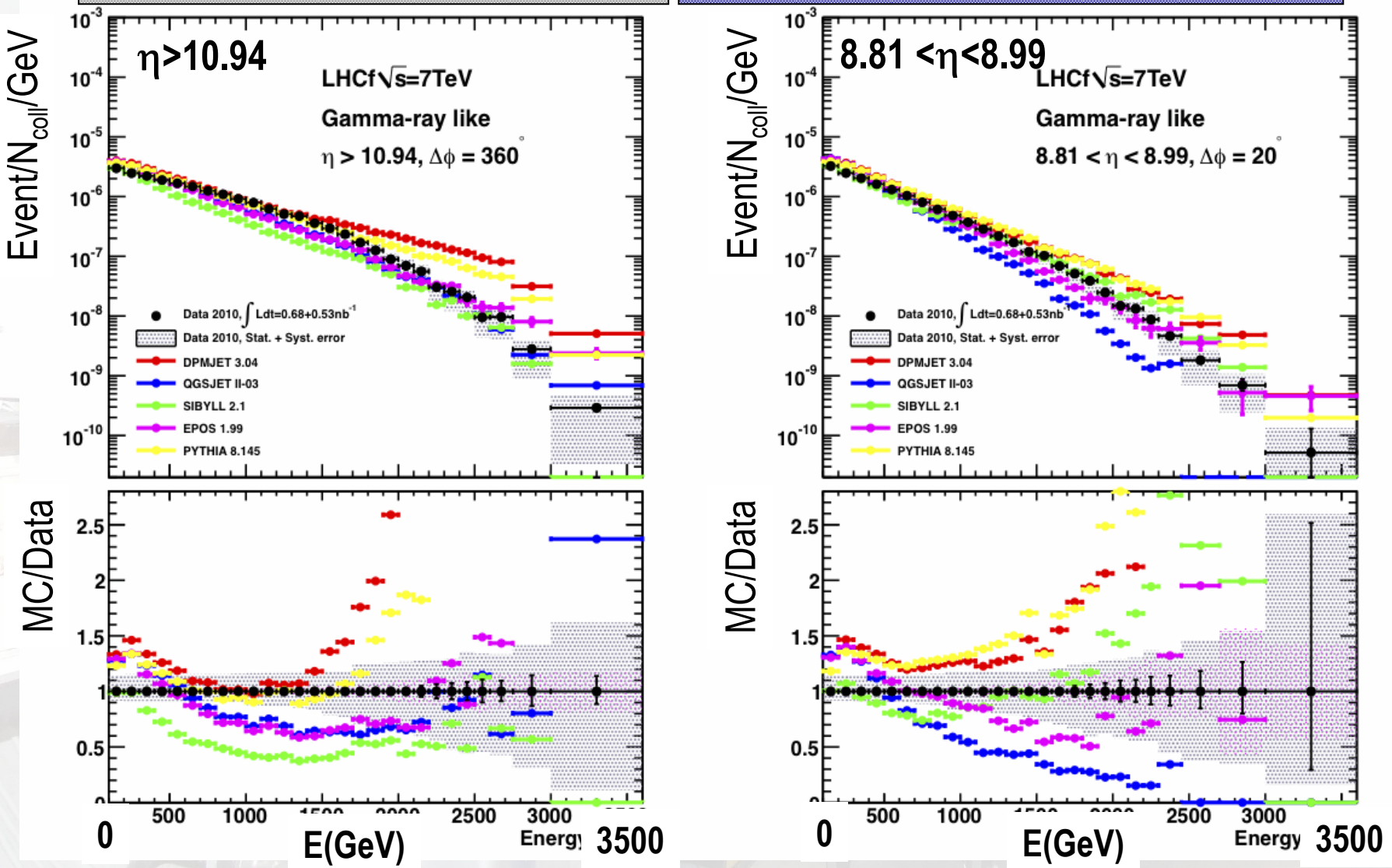
Gray hatch : Systematic Errors **Blue hatch: Statistics errors of MC**



LHCf single γ spectra at 900 GeV (submitted to PLB)

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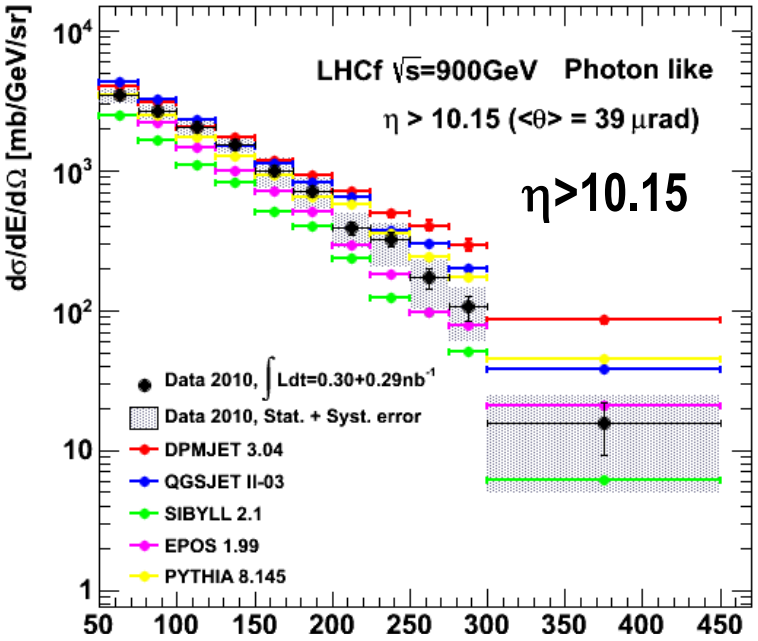
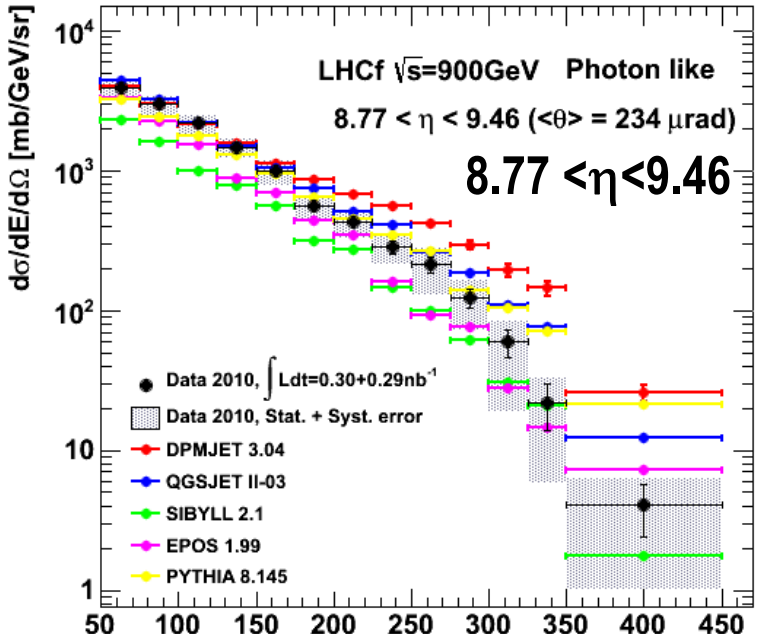
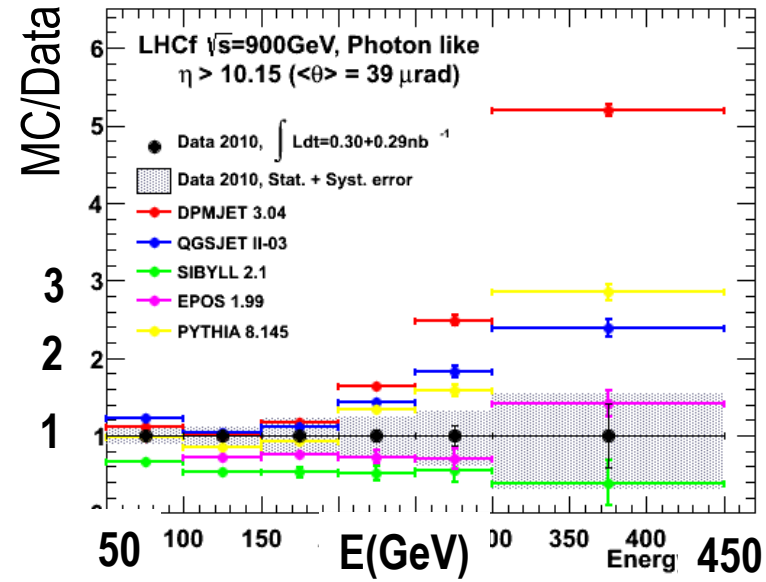
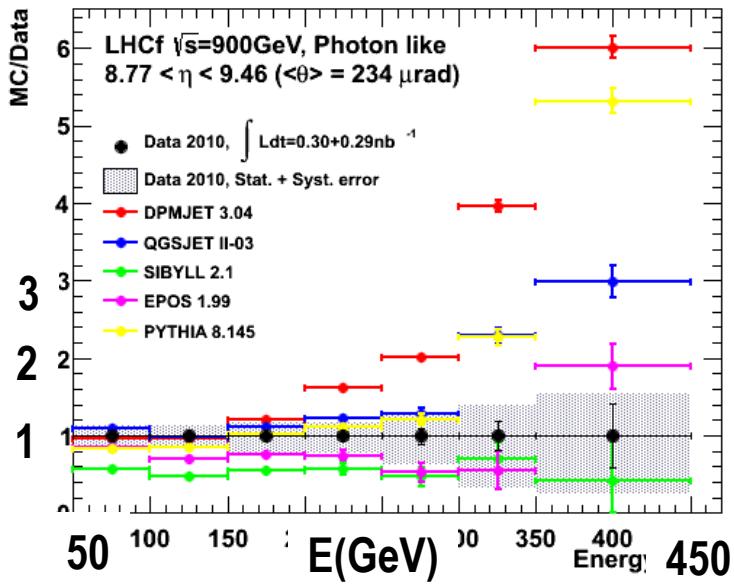
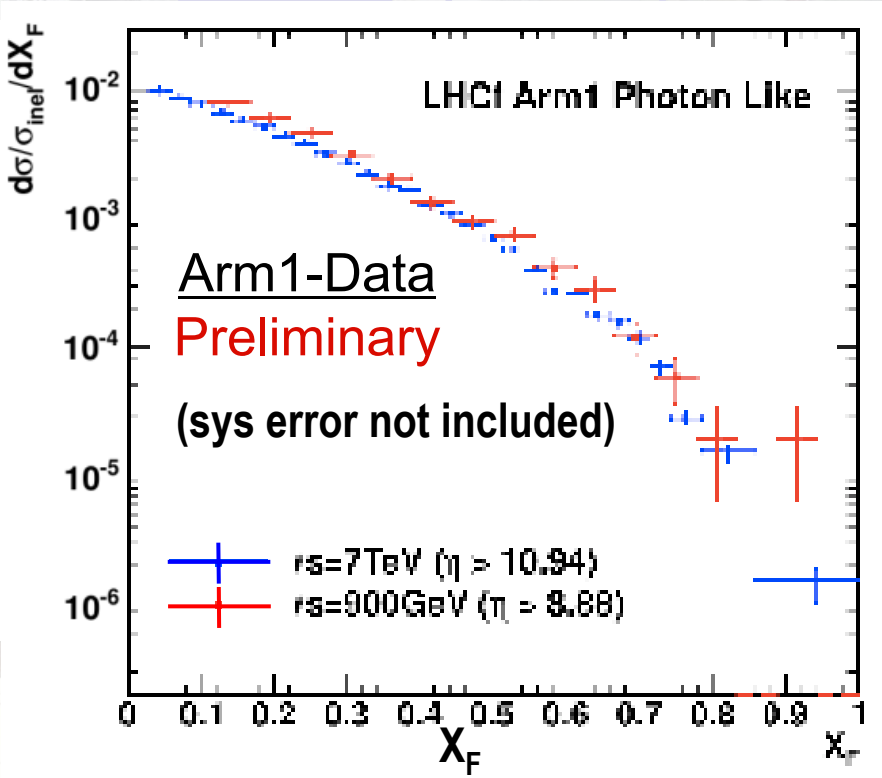


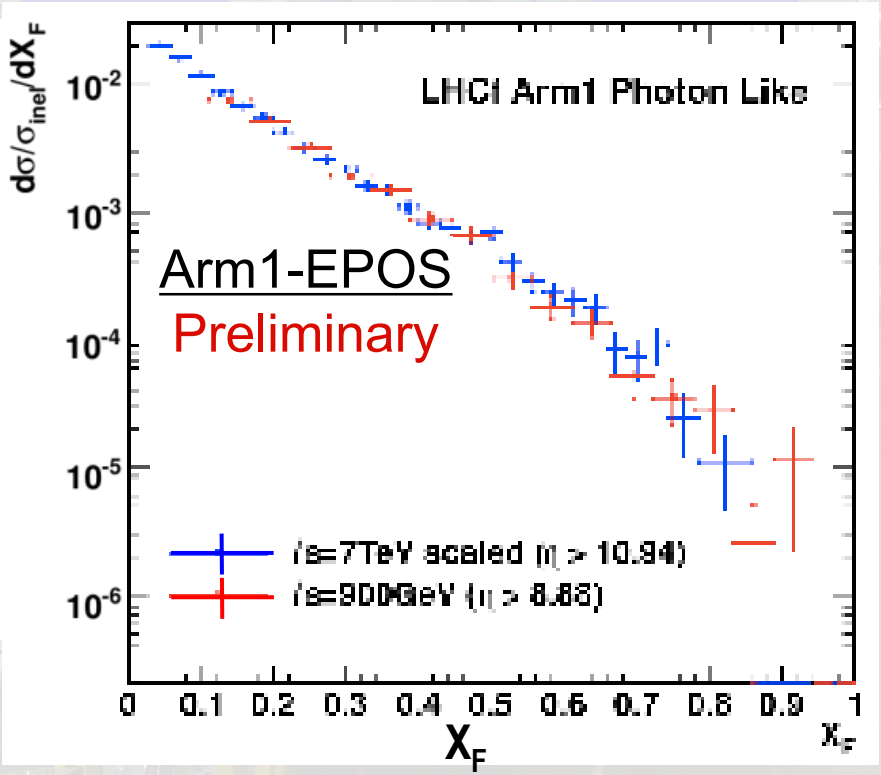






Single γ X_F spectra : 900GeV/ 7TeV comparison





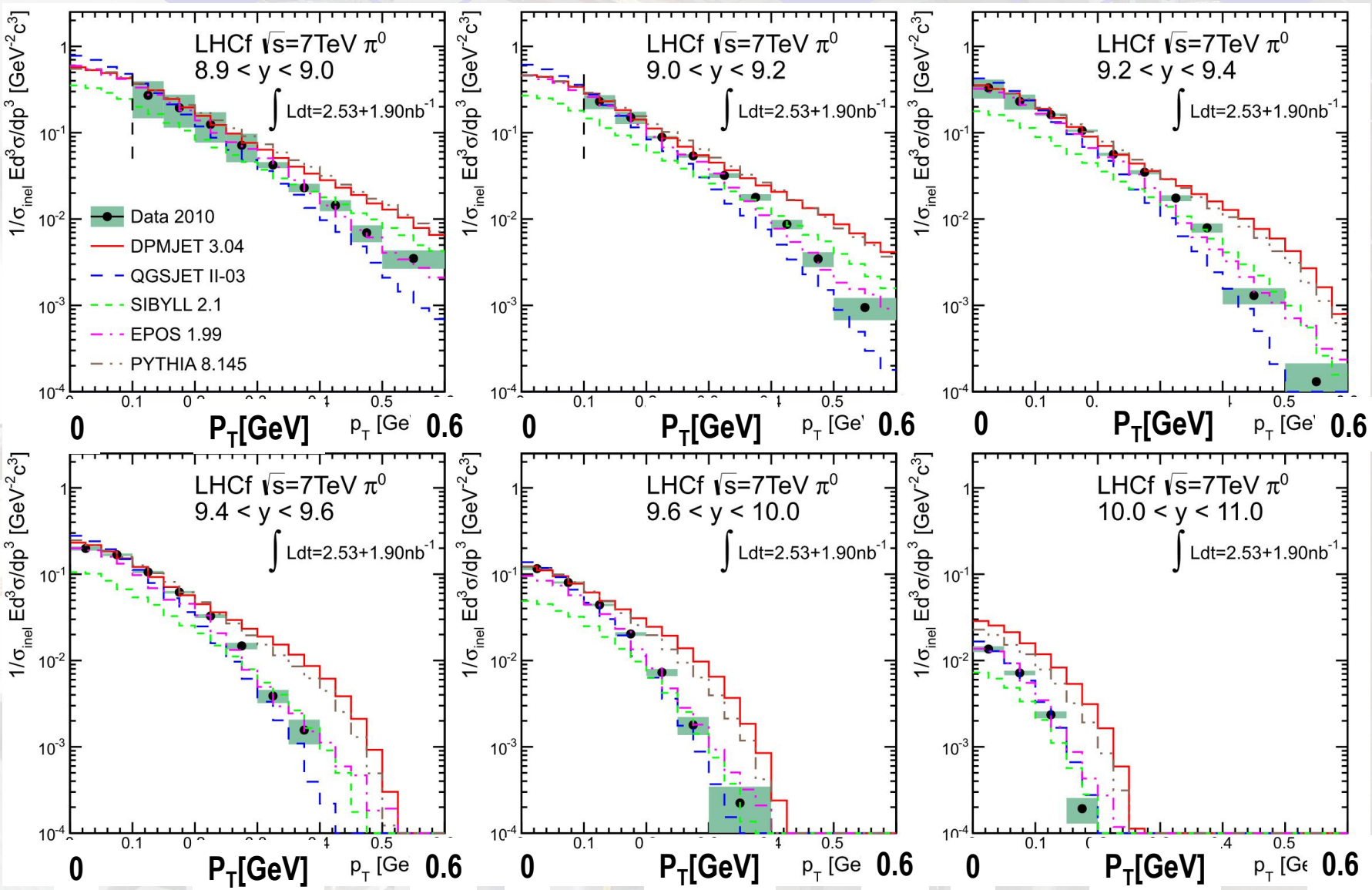
$$\left.\frac{1}{\sigma_{\rm inel}}\frac{d\sigma_\gamma}{dX_{\rm F}}\right|_{\eta<\rm limited} \propto \frac{1}{\sigma_{\rm inel}}\frac{d\sigma_\gamma}{p_{\rm T}dp_{\rm T}dX_{\rm F}}\langle p_{\rm T}\rangle dp_{\rm T}$$

- Comparing X_F for common P_T region at two collision energies.
- Less root-s dependence of P_T for X_F ?

LHCf π^0 P_T spectra at 7TeV

Submitted to PRD (arXiv:1205.4578).

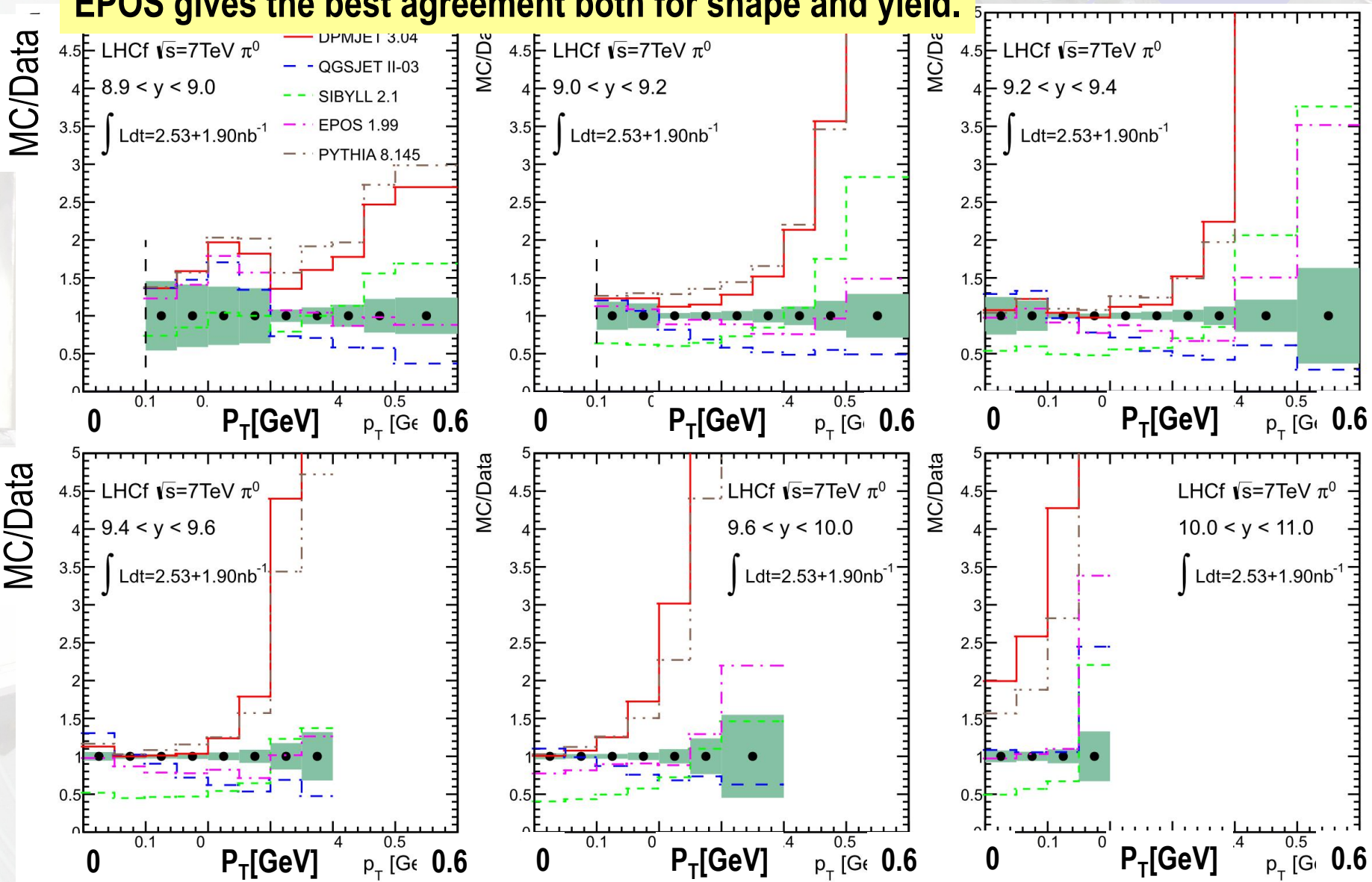
DPMJET 3.04 **QGSJETII-03** **SIBYLL 2.1** **EPOS 1.99** **PYTHIA 8.145**



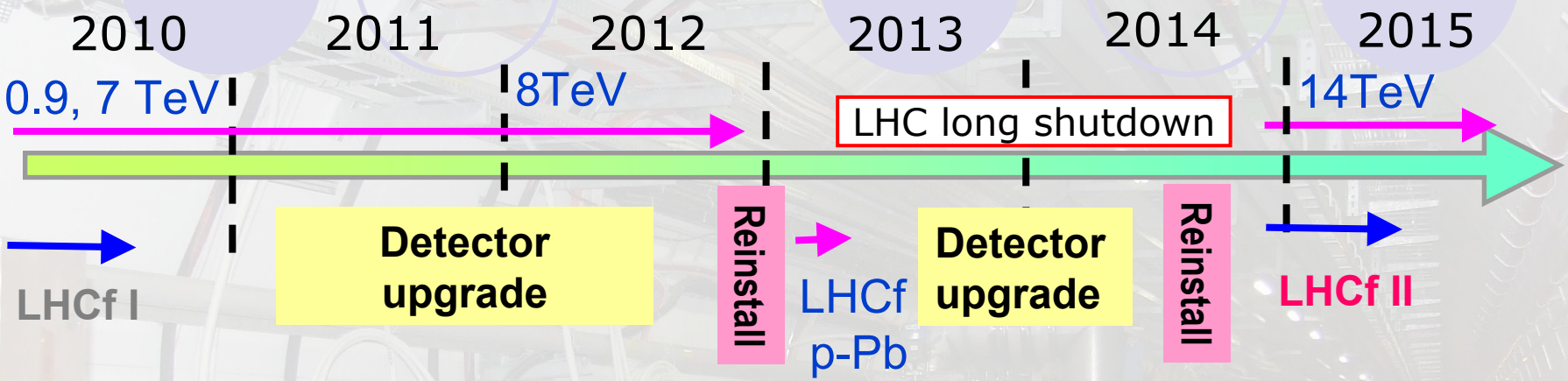
LHCf π^0 P_T spectra at 7TeV (data/MC)

DPMJET 3.04 **QGSJETII-03** **SIBYLL 2.1** **EPOS 1.99** **PYTHIA 8.145**

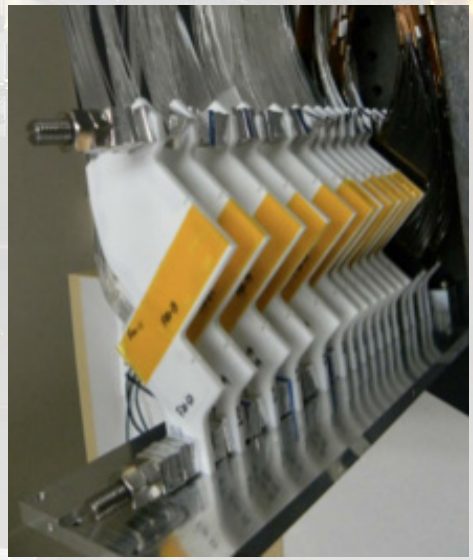
EPOS gives the best agreement both for shape and yield.



LHCf future plan



- Analysis ongoing for 2010 data
  - Neutron energy spectra → inelasticity.
- Reinstall Arm2 for p-Pb in early 2013
  - Very important information for nuclear effect.
  - Under discussion of common triggers for combined analysis w/ ATLAS detector.
- Reinstall Arm1+2 for 14TeV in 2014
  - Now upgrading detectors w/ rad-hard GSO.
- A new measurement at RHIC 0 degree
  - Under discussions for 500GeV p+p and d + light-A .



Summary

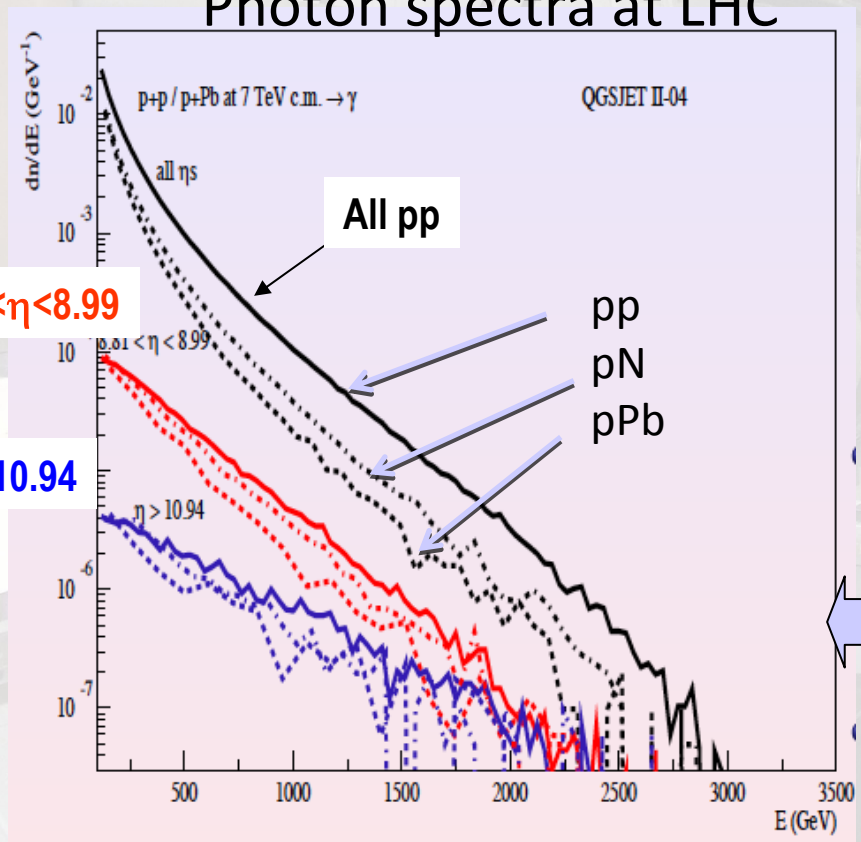
- LHCf : Dedicated measurements of neutral particles at 0 deg of LHC IP1 to verify UHECR interactions up to 10^{17}eV.
- Phase-I run successfully completed. Analysis on-going.
  - E spectra for single gamma at 7TeV and at 900GeV. Agreement is “so-so”, but none of models really agree.
  - PT spectra for 7TeV pi0. EPOS gives nice agreement.
- Future plan
  - Reinstall LHC at 2013 p-Pb run to study nuclear effect.
  - Revisit LHC for “14TeV” at ~2014 with a rad-hard detector.
  - Possible future RHIC run is under discussion.

LHCf toward solving the current UHECR observation problem.
Also UHECR data may hint UHE interactions at beyond-LHC energy.
LHCf gives firm basement to understand what happens at 10^{17}eV.

LHCf for p-Pb collisions

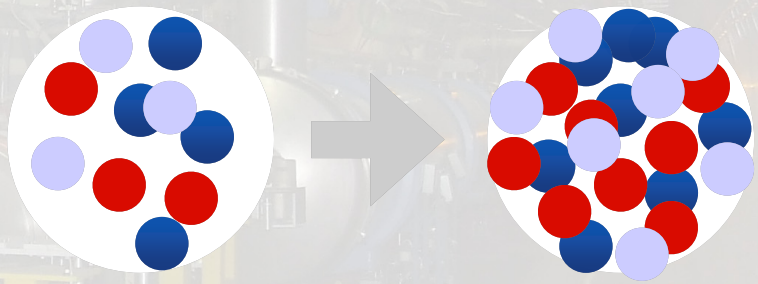
- Air shower MC needs p-N (or Fe-N) interactions !
- Important first information for nuclear effect

Photon spectra at LHC



By S.Ostapchenko

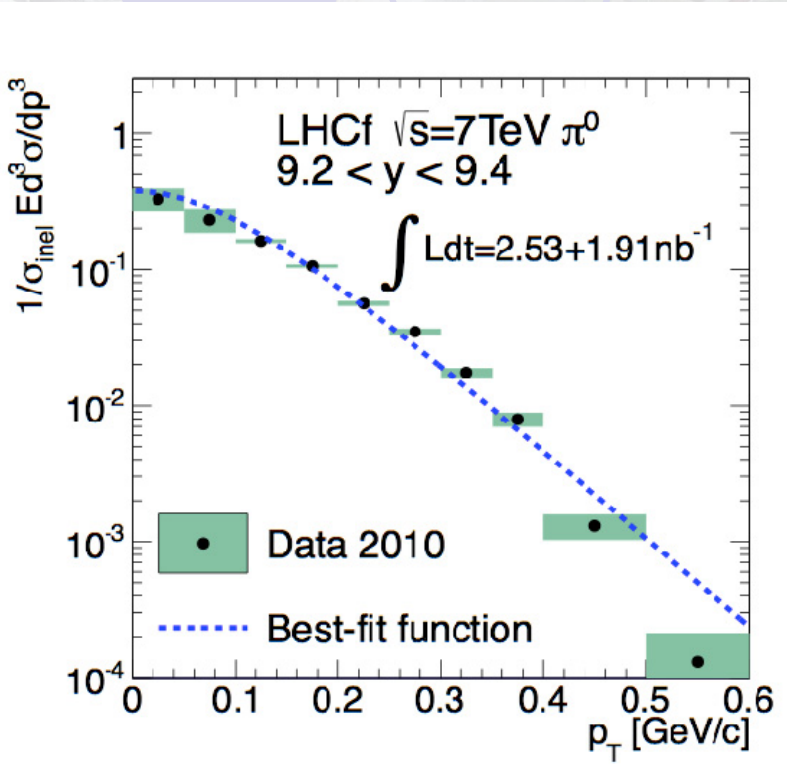
Saturation effects ?

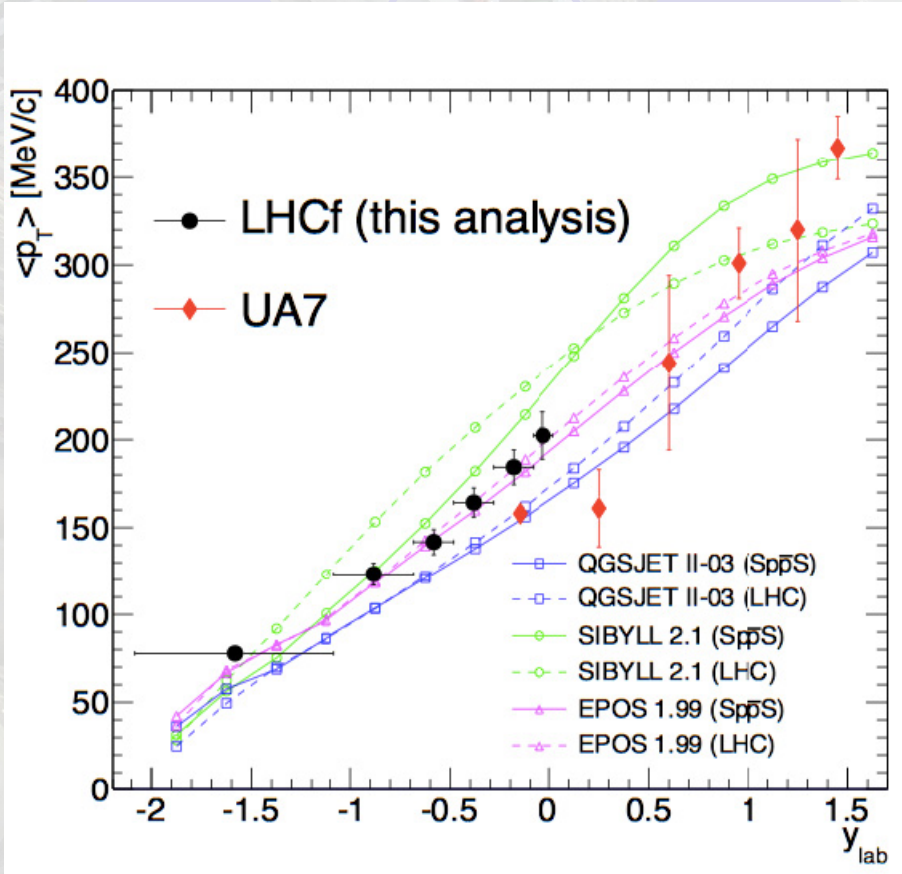


Low-E High-E

Softening of photon energy spectra due to nuclear effect may be seen !

Average P_T of π^0





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

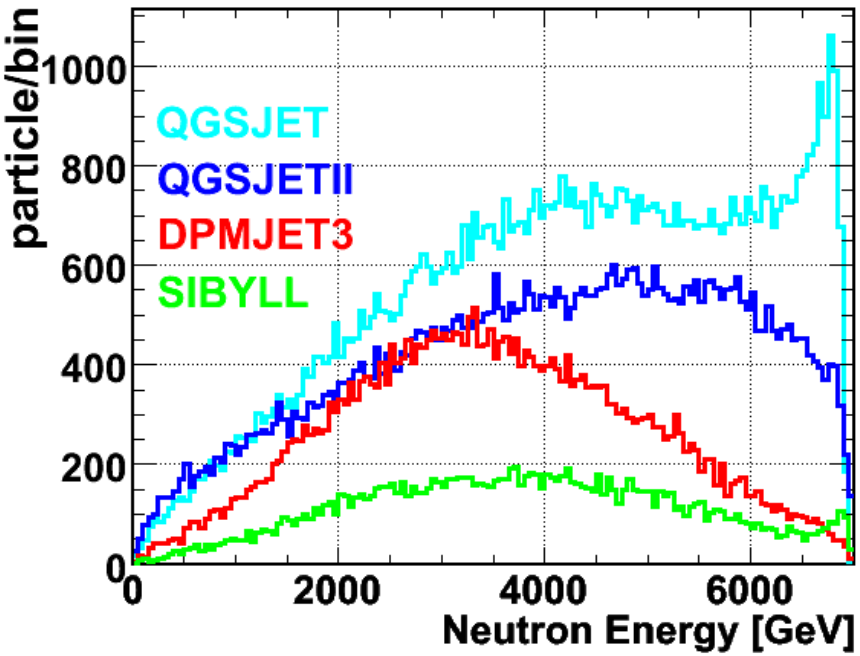
$$\frac{1}{\sigma_{\rm inel}} E\frac{d^3\sigma}{dp^3} = A\cdot\exp(-\sqrt{{p_{\rm T}}^2c^2+m_{\pi^0}^2c^4}/T)$$

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

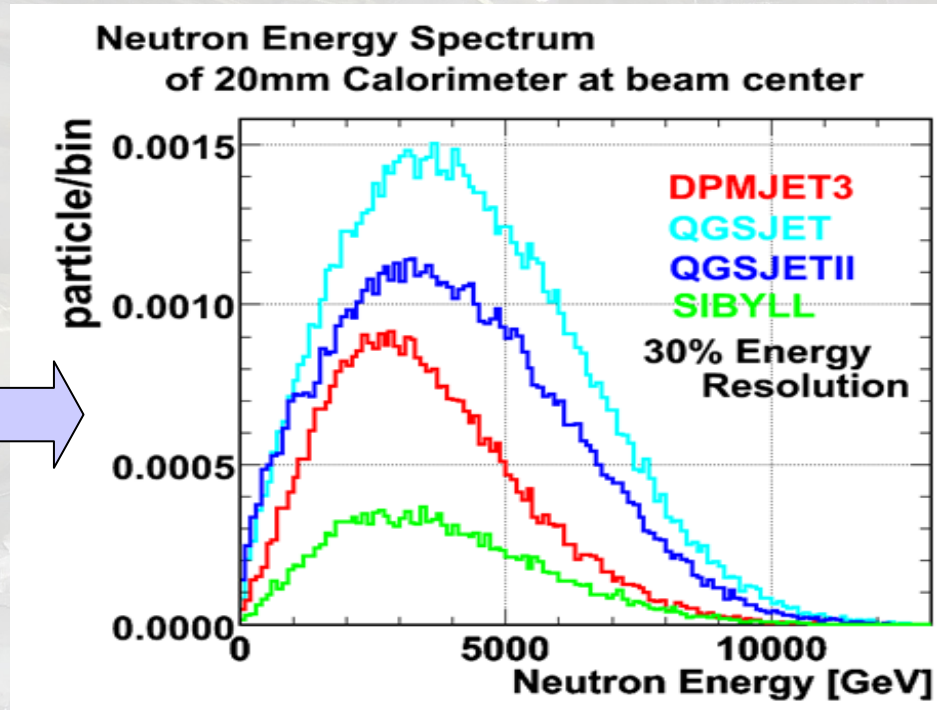
- Comparison w/ UA7@630GeV
- Extend to higher η regions
- Less energy dependence of <PT>?

Inelasticity~ 0 degree neutron spectra

- Important for X_{max} and also N_{μ}
- Measurement of inelasticity at LHC energy

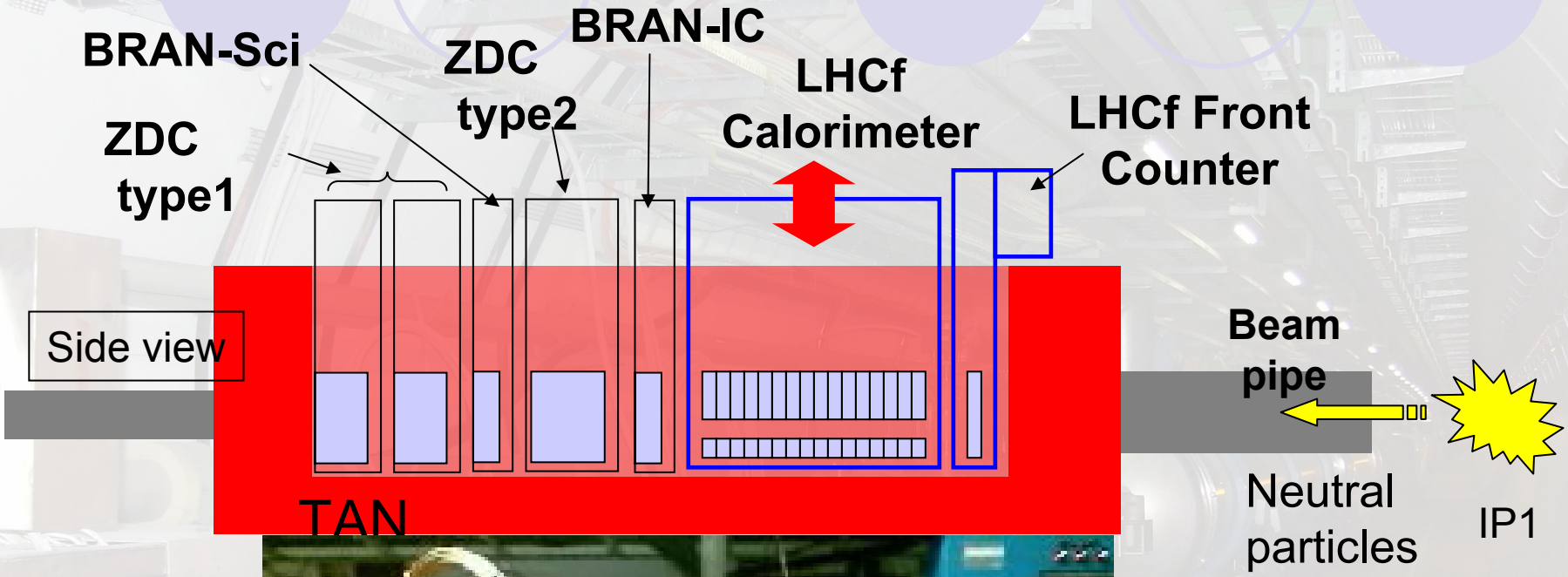


Neutral hadrons at 14 TeV
(LHCf acceptance, no resolution)



Neutral hadrons at 14 TeV
(LHCf acceptance, 30% resolution)

Setup in IP1-TAN (side view)

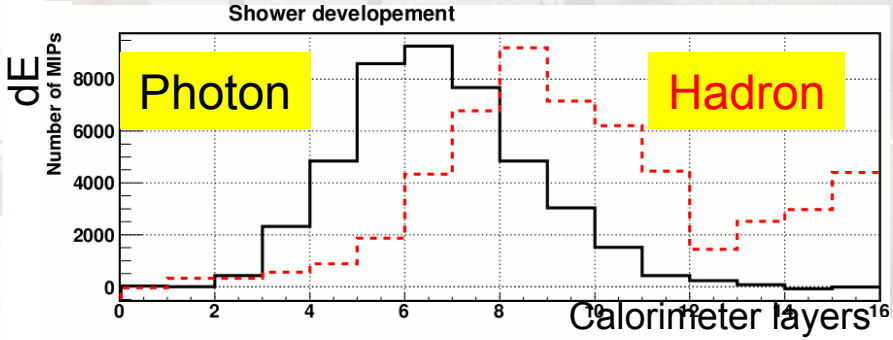


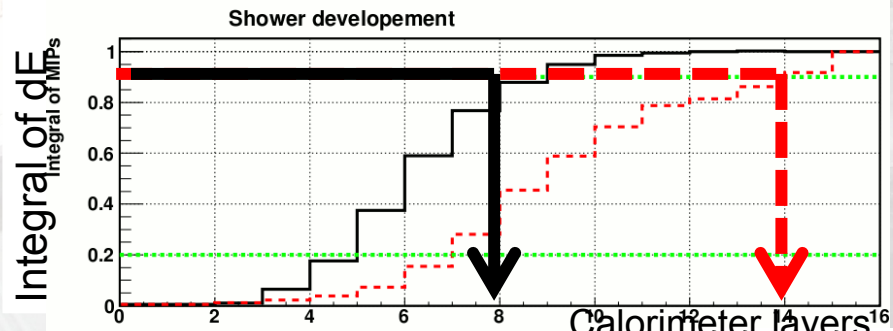
Particle Identification

Calorimeter Depth

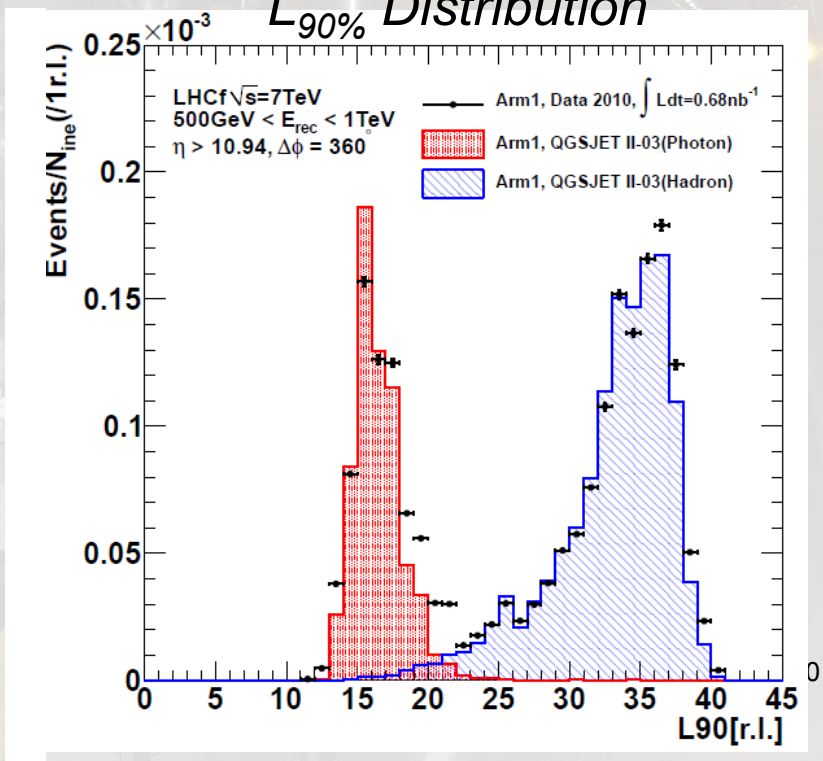
Elemag: 44r.l.
Hadronic: 1.7 λ

- Event selection and correction
  - Select events <$L_{90\%}$ threshold and multiply P/ ε
    ε (photon detection efficiency) and P (photon purity)
  - By normalizing MC template $L_{90\%}$ to data,
    ε and P for certain $L_{90\%}$ threshold are determined.

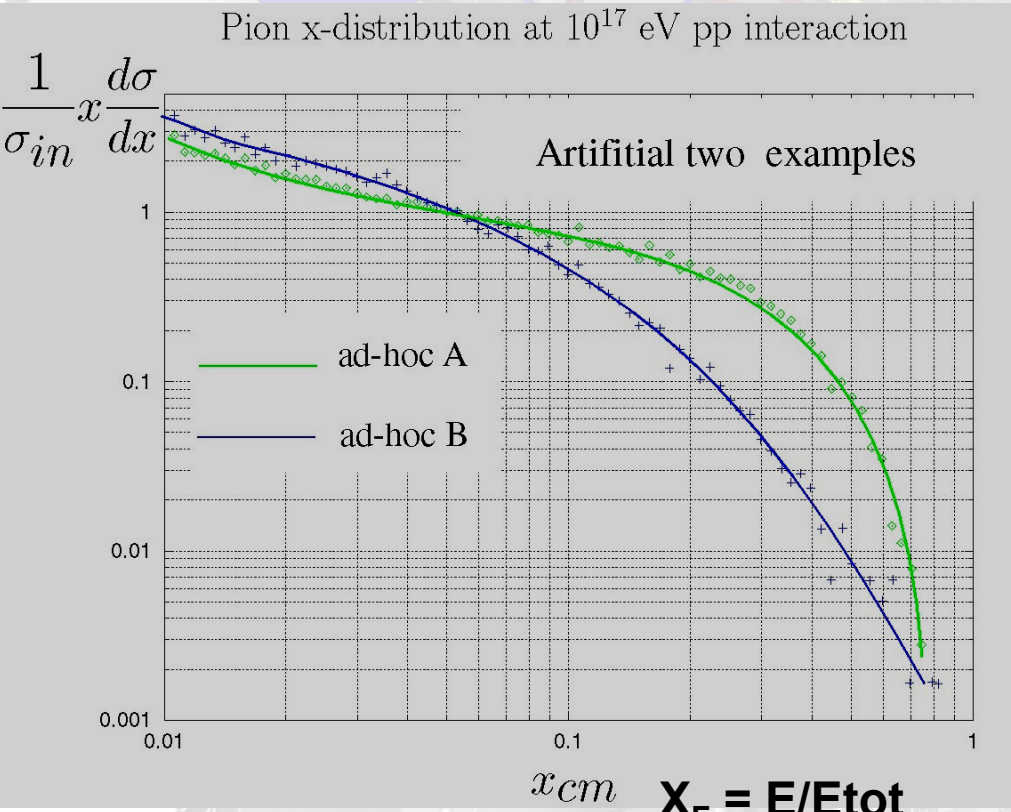




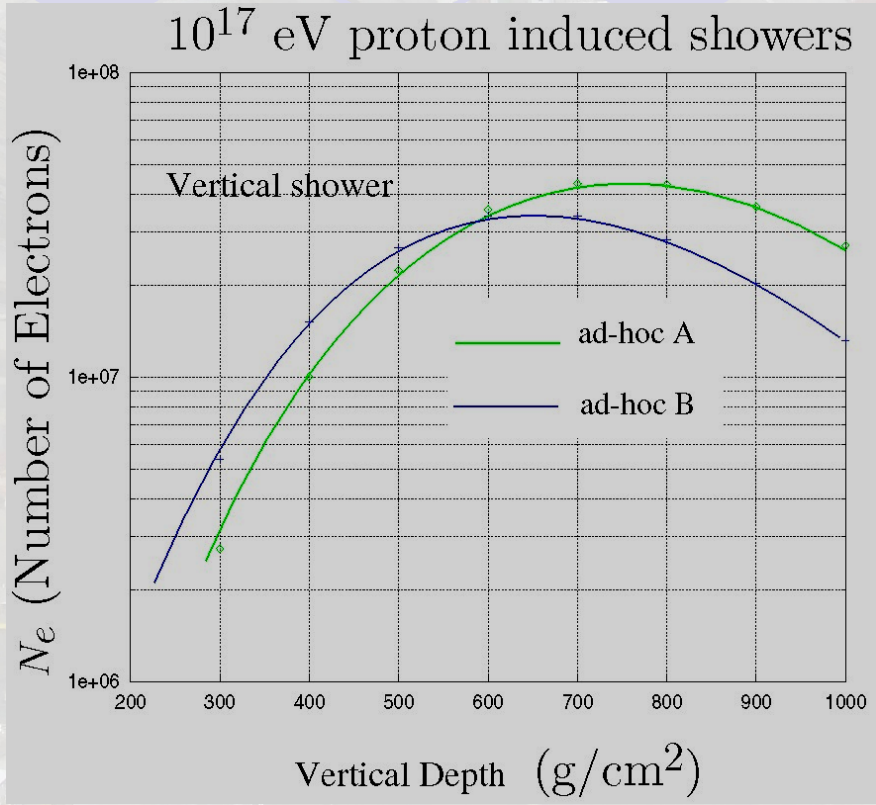
$L_{90\%}$ *Distribution*



Forward production spectra vs Shower curve



X_F = E/Etot



Half of shower particles comes from large X_F γ

Measurement at very forward region is needed

LHCf 900GeV single γ spectra: Data/MC

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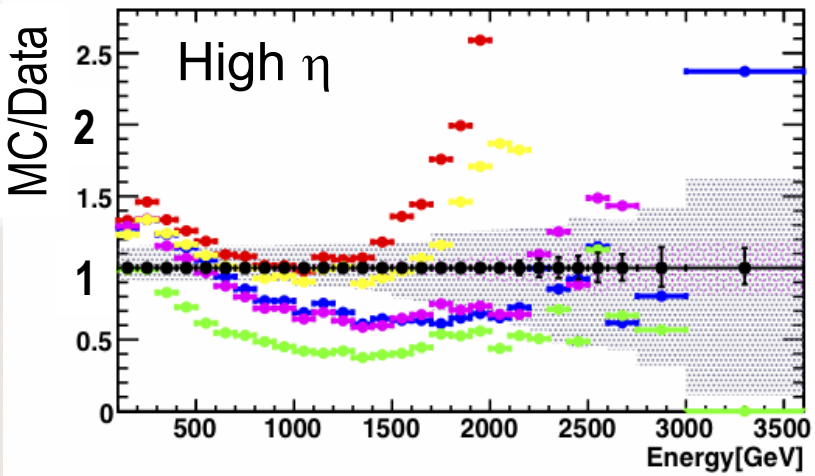
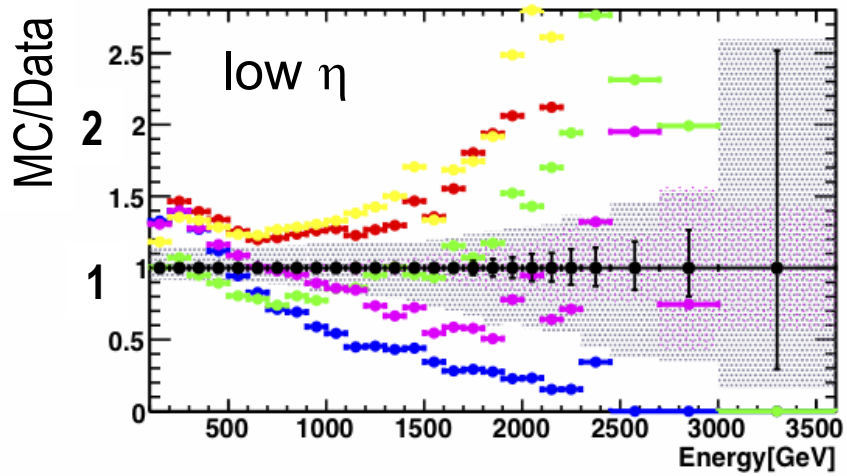
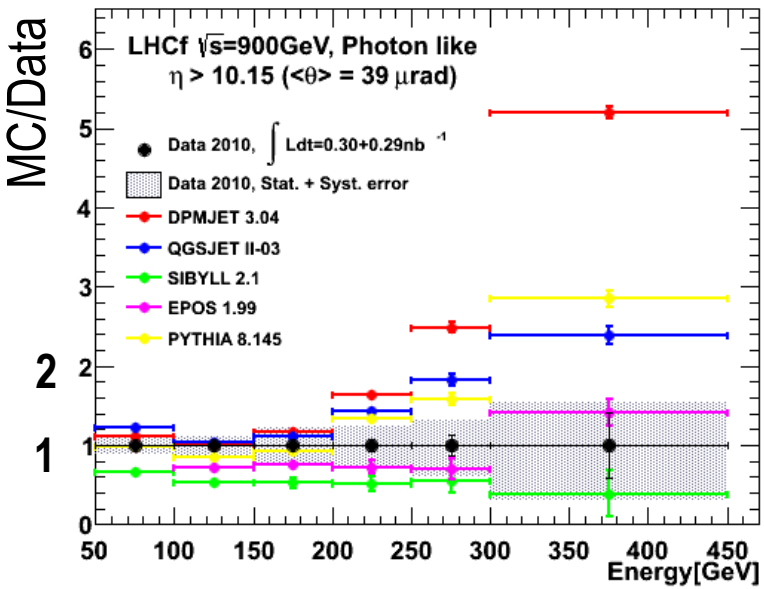
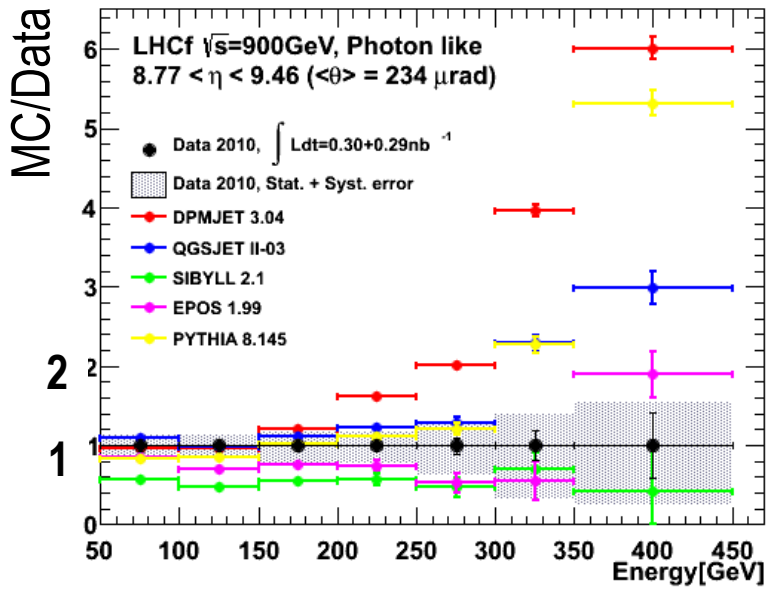
7TeV





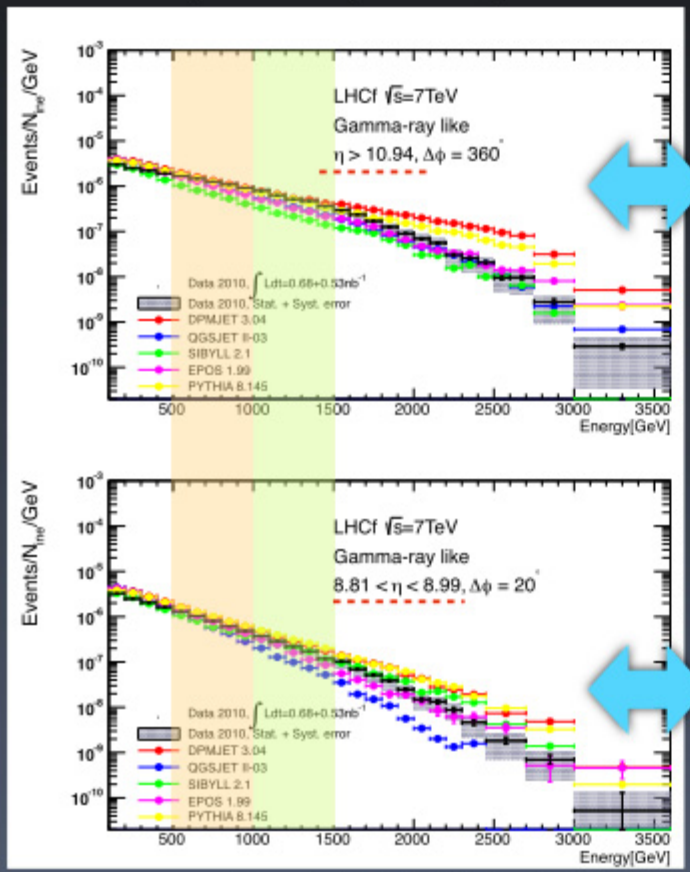
900GeV



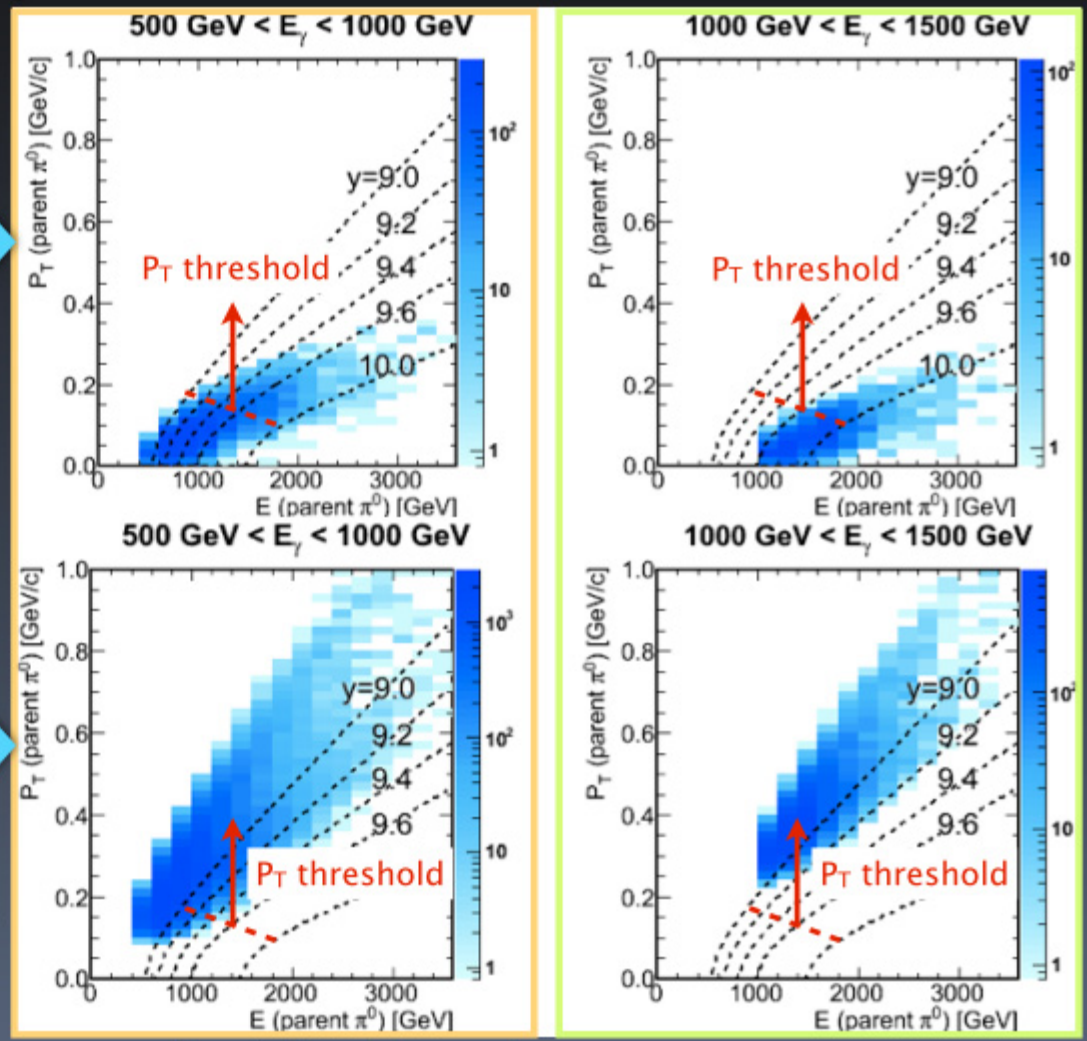


7TeV π^0 analysis

7TeV photon spectra by LHCf



(Phys. Lett. B 703 128-134 (2011))



- Photon analysis and π^0 analysis compensate each missing information.
  - High energy photon originates from large P_T π^0 events.
  - Photon spectrum includes a contribution from other hadrons/baryons.

→ Photon P_T analysis can connect each measurement.