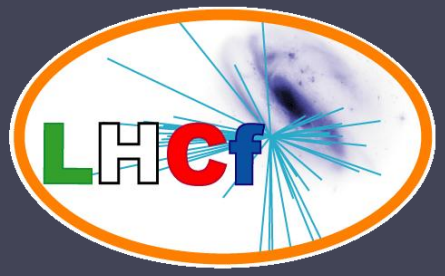


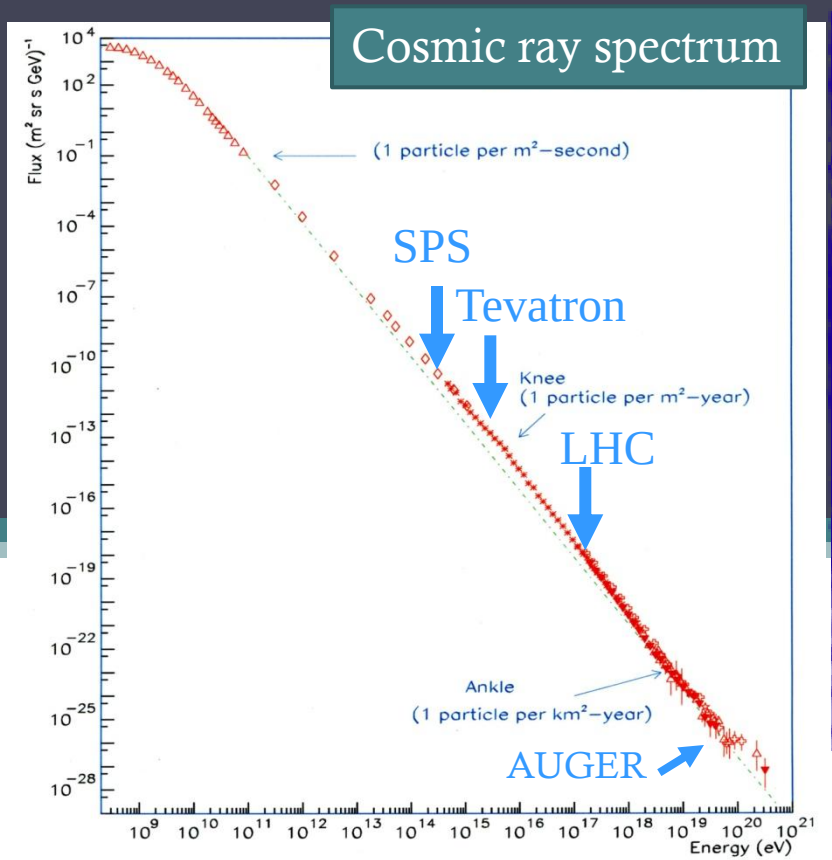
The LHCf experiment

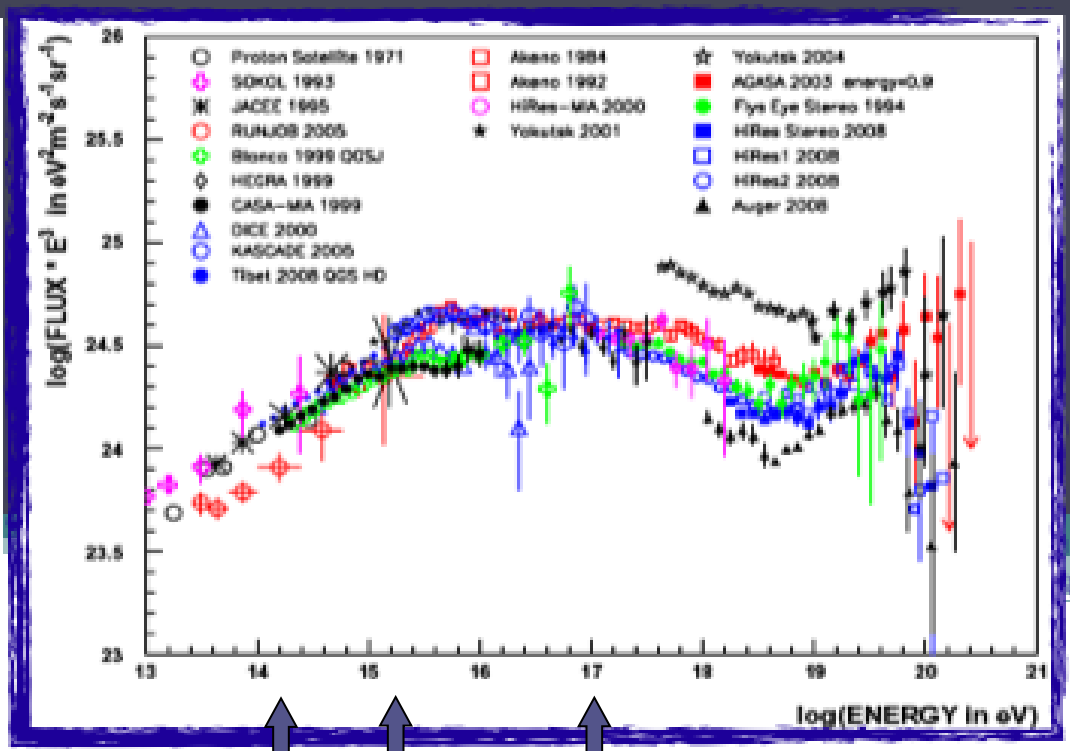
Koji Noda (INFN Catania)
on behalf of the LHCf Collaboration

18 June 2012

QCD@Work (Lecce, Italy)

Very-high-energy cosmic ray spectrum



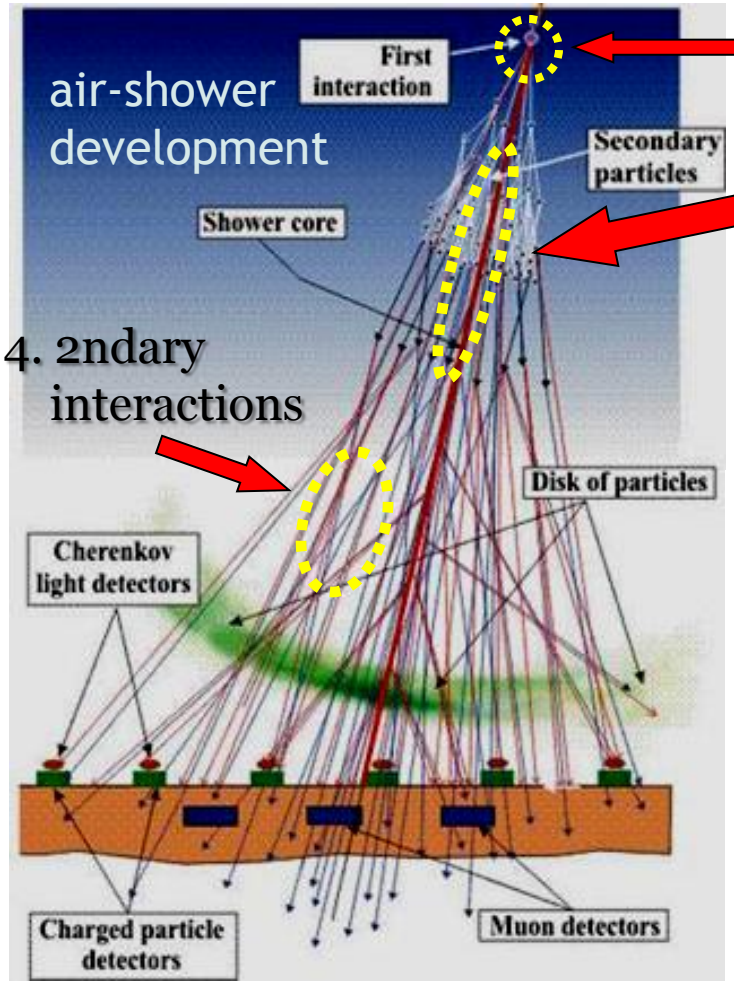


Spp̄S (UA7) Tevatron LHC

cm energy at LHC (7+7TeV) <=> 10^17eV CR (fixed target)
>10^15eV: detected with ***air-showers***, but many unknowns

Physics motivation of LHCf

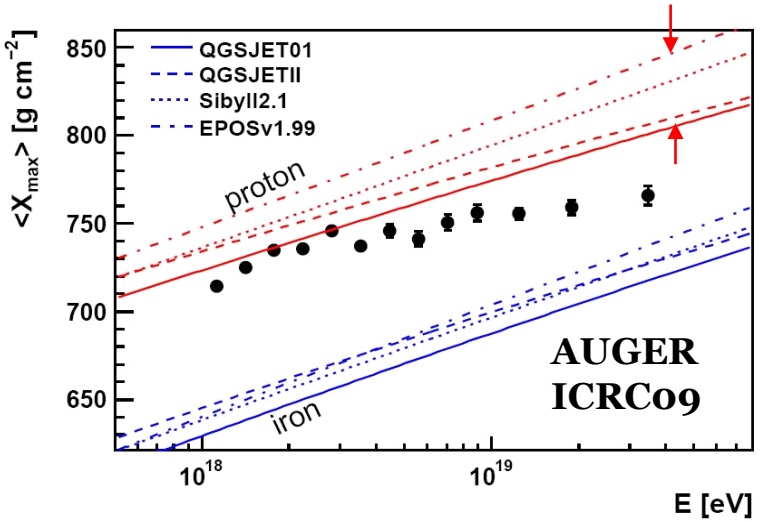
The air-shower development of ultra-high-energy cosmic-ray should be understood by the high-energy particle physics



1. Inelastic cross section (ex. by TOTEM)
2. Forward energy spectrum
3. Inelasticity

} large model dependence…

Large σ, soft, large k => rapid development
Small σ, hard, small k => deep penetrating



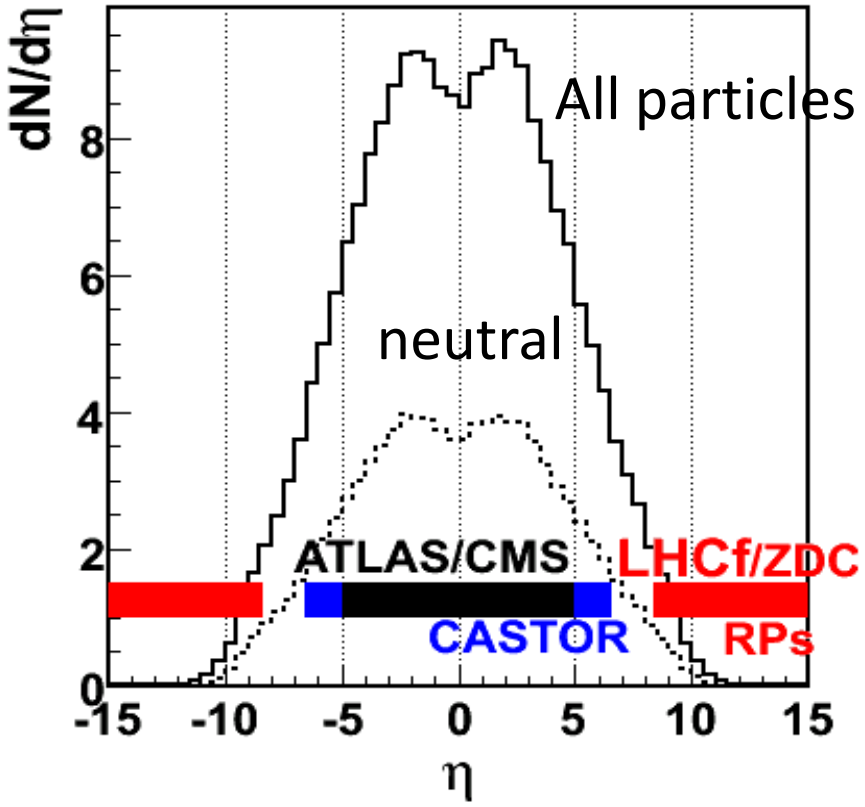
Chemical composition of CR has an uncertainty due to the large mode dependence

How forward?

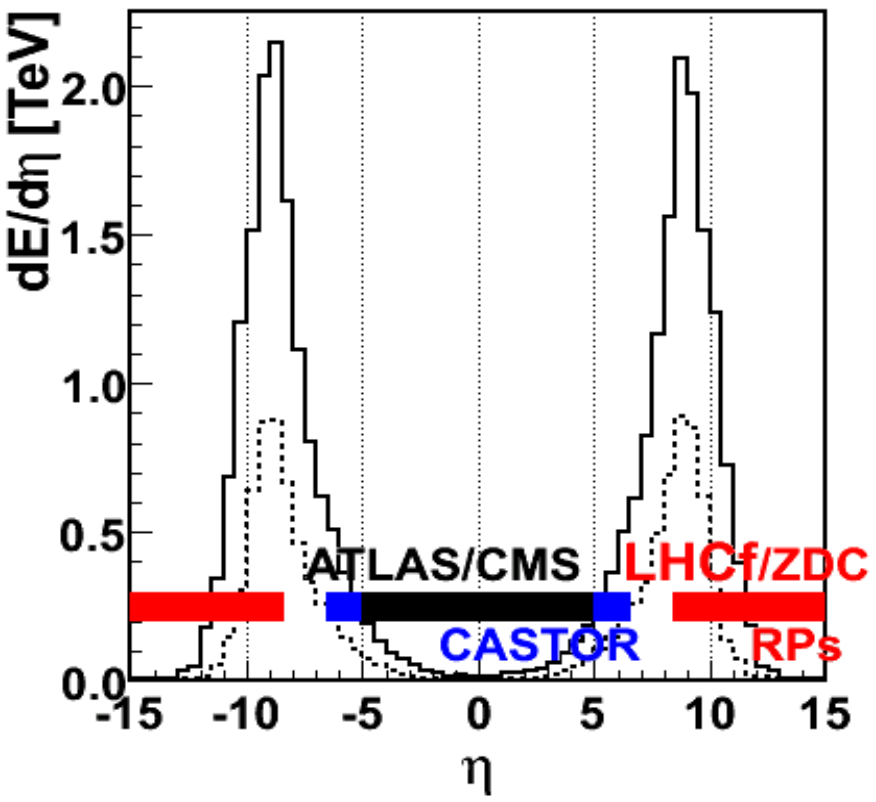
Multiplicity and energy flux at LHC 14TeV collisions

pseudo-rapidity; $\eta = -\ln(\tan(\theta/2))$

Multiplicity

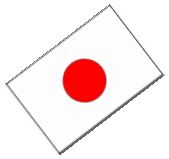


Energy Flux



Most of the energy flows into very forward

The LHCf Collaboration



K.Fukatsu, T.Iso, Y.Itow, K.Kawade, T.Mase, K.Masuda, Y.Matsubara, G.Mitsuka, Y.Muraki, T.Sako, K.Suzuki, K.Taki *Solar-Terrestrial Environment Laboratory, Nagoya University, Japan*

H.Menjo *Kobayashi-Maskawa Institute, Nagoya University, Japan*

K.Yoshida *Shibaura Institute of Technology, Japan*

K.Kasahara, Y.Shimizu, T.Suzuki, S.Torii *Waseda University, Japan*

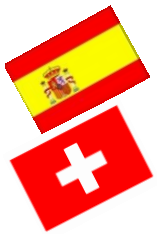
T.Tamura *Kanagawa University, Japan*

M.Haguenauer *Ecole Polytechnique, France*

W.C.Turner *LBNL, Berkeley, USA*

O.Adriani, L.Bonechi, M.Bongi, R.D'Alessandro, P.Papini, S.Ricciarini, G.Castellini *INFN, Univ. di Firenze, Italy*

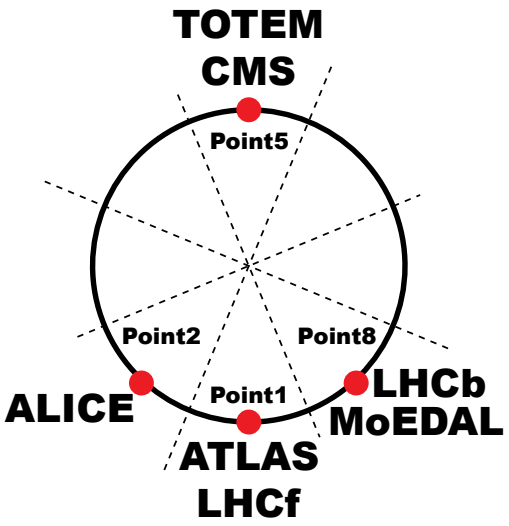
K.Noda, A.Tricomi *INFN, Univ. di Catania, Italy*

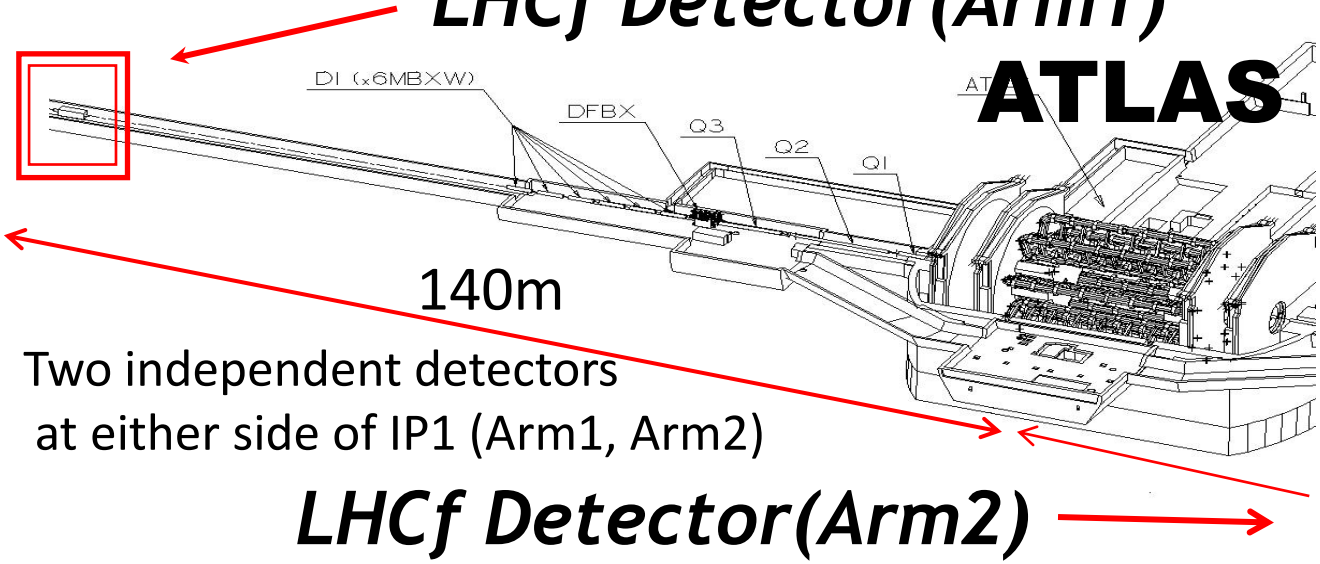


J.Velasco, A.Faus *IFIC, Centro Mixto CSIC-UVEG, Spain*

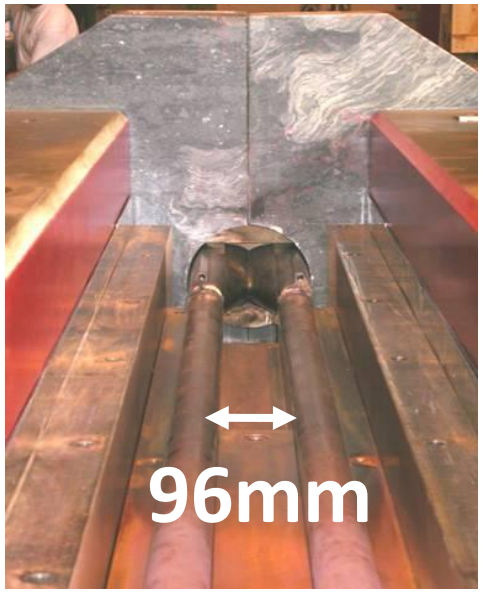
A-L.Perrot *CERN, Switzerland*

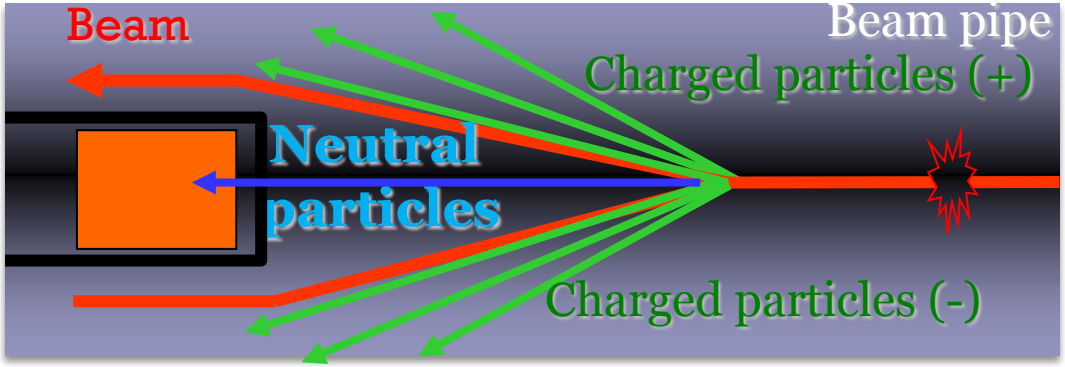
LHCf location





Two independent detectors
at either side of IP1 (Arm1, Arm2)



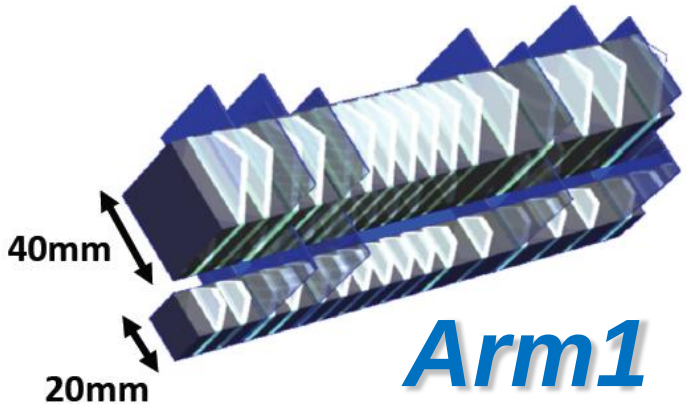


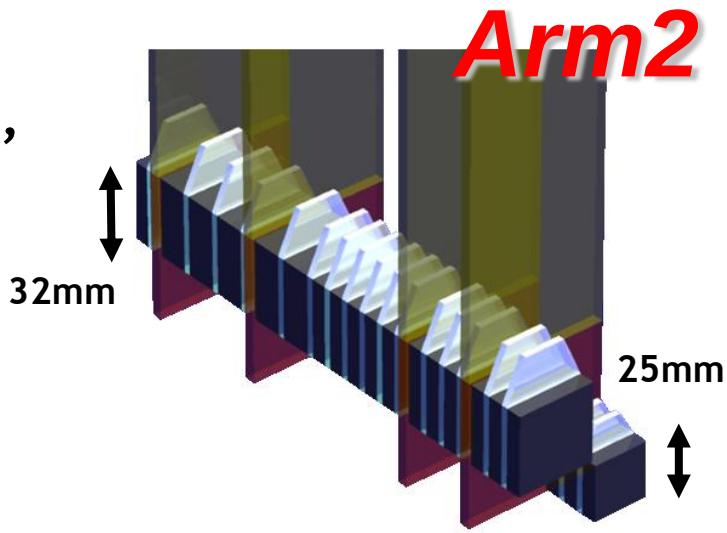
neutral particles, such as γ, π^0, n, with $\eta > 8.4$ enter into the detector slot

LHCf detectors

Sampling and imaging EM calorimeter

- Absorber: W (**44 r.l**, 1.55λ_I)
- Energy measurement: plastic scintillator tiles
- 4 tracking layers for imaging:
  XY-SciFi (Arm1) and XY-Silicon strip(Arm2)
- **Each detector has two calorimeter towers, which allow to reconstruct π^0**





Front Counters

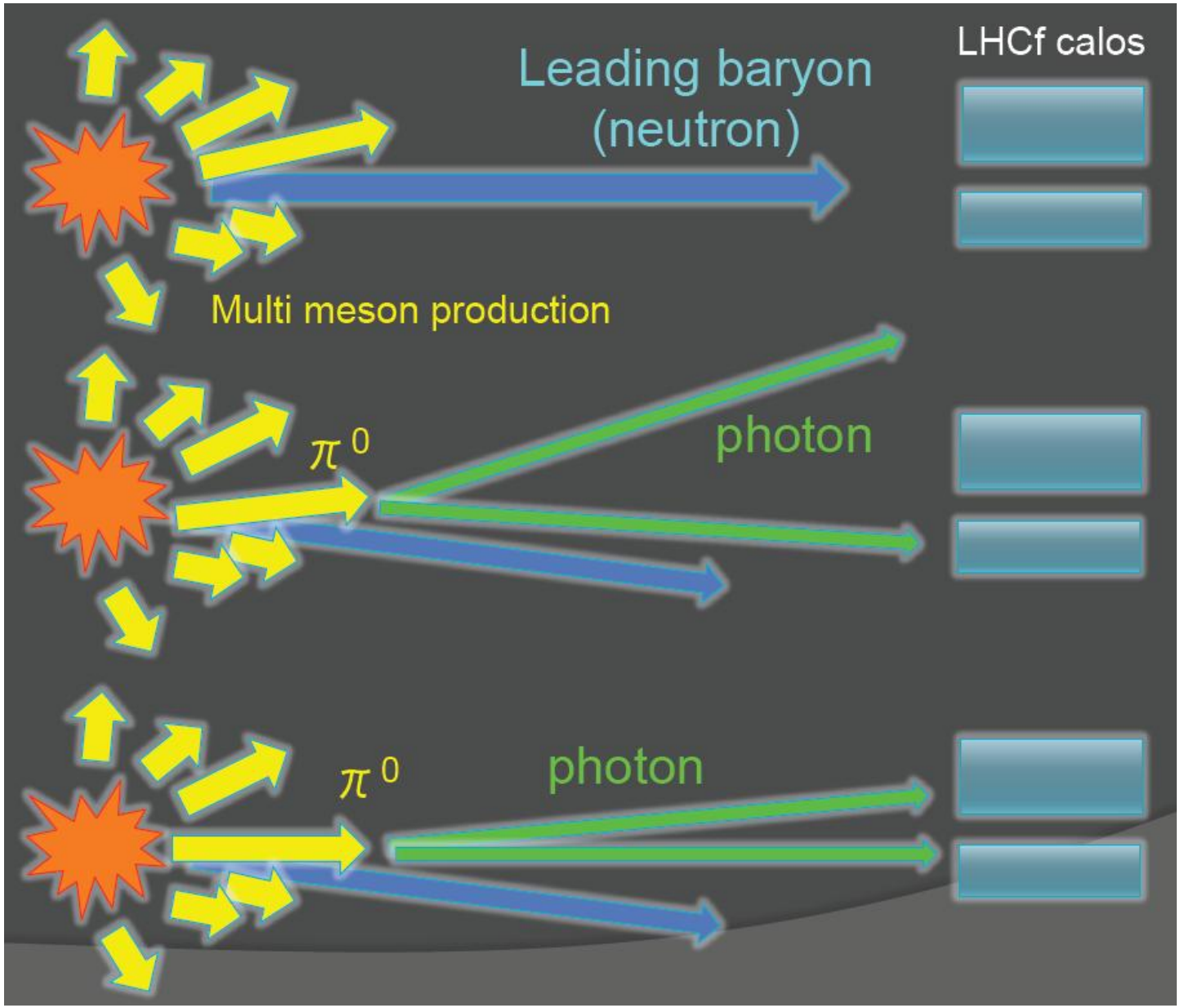
- thin scintillators 80x80 mm
- **monitors beam condition**
- **Van der Meer scan**

Performances

Energy resolution (> 100 GeV): **< 3% for 1 TeV γ & ~ 30% for n**

Position resolution for photons: **~150 μm (Arm1) & ~40 μm (Arm2)**

Event category of LHCf



Single hadron event

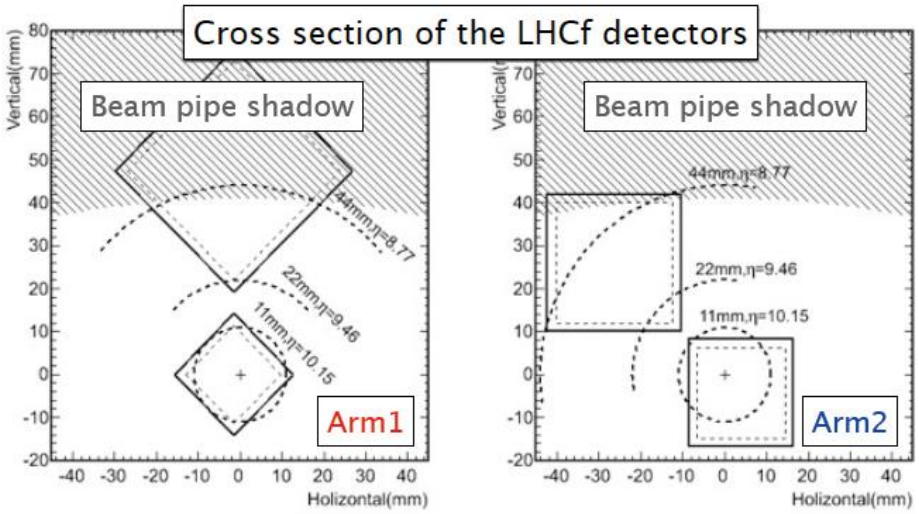
Single photon event

Pi-zero event (photon pair)

Operations & status

Period	Type	Beam energy	LAB proton Energy (eV)	Detector
2009/2010	p - p	450+450 GeV	$4.3\ 10^{14}$	Arm1+Arm2
2010	p - p	3.5+3.5 TeV	$2.6\ 10^{16}$	Arm1+Arm2
now	detectors were detached from the tunnel			
Nov 2012	p - Pb	3.5 (4.0) TeV proton E	10^{16}	Arm2
2014-2015	p - p	6.5+6.5 TeV	$9.0\ 10^{16}$	Arm1+Arm2 upgraded

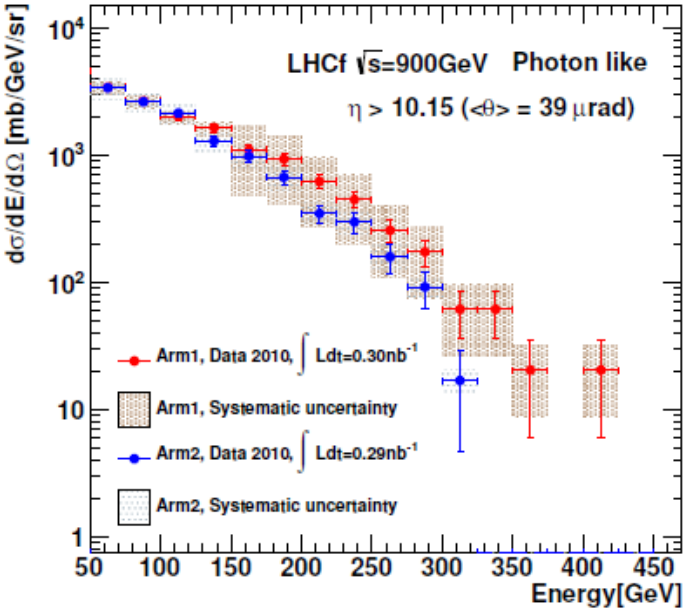
Results: 900 GeV photons

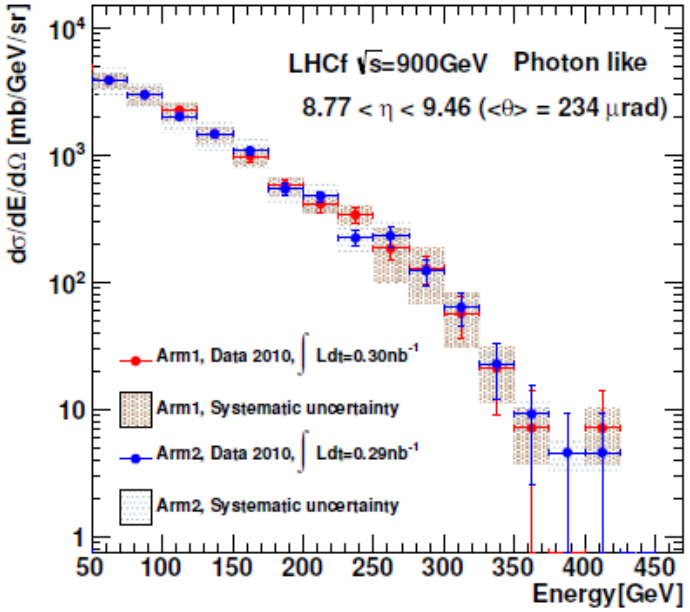


Submitted to PLB

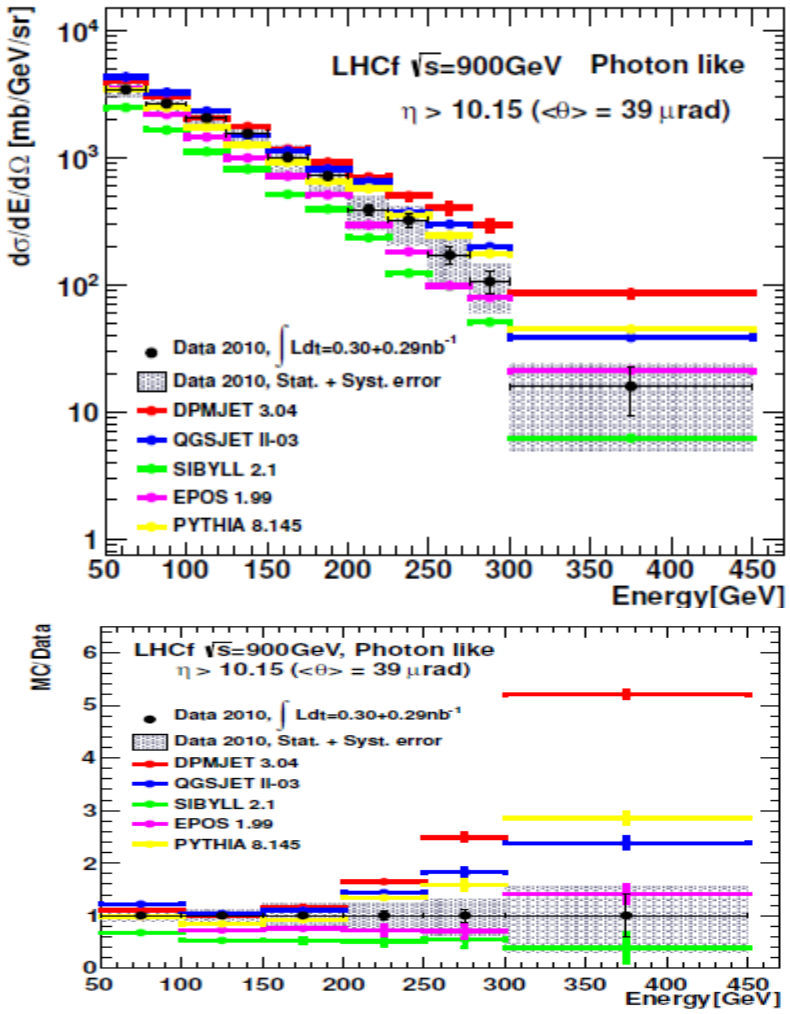
- two pseudo-rapidity ranges: $\eta>10.15$ & $8.77<\eta<9.46$
- Integral luminosity ~ $0.3nb^{-1}$, and its uncertainty is 21%
- Efficiency and purity in PID are corrected in each bin.

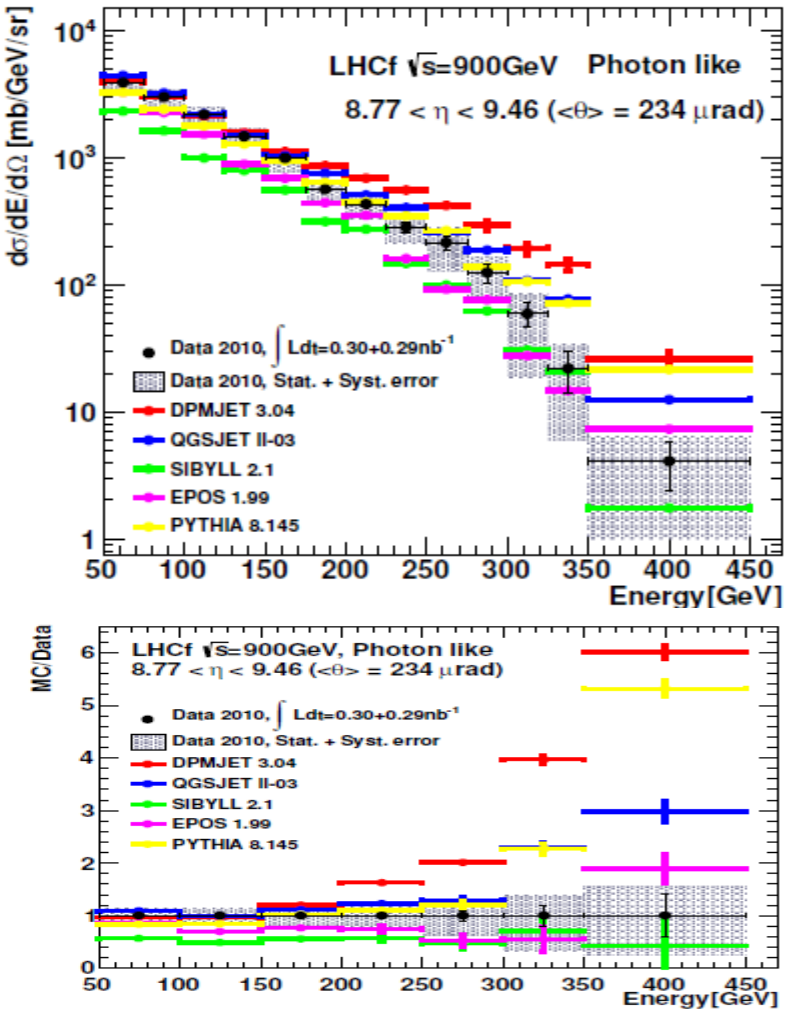
Independent analyses show a good agreement within their syst. errors





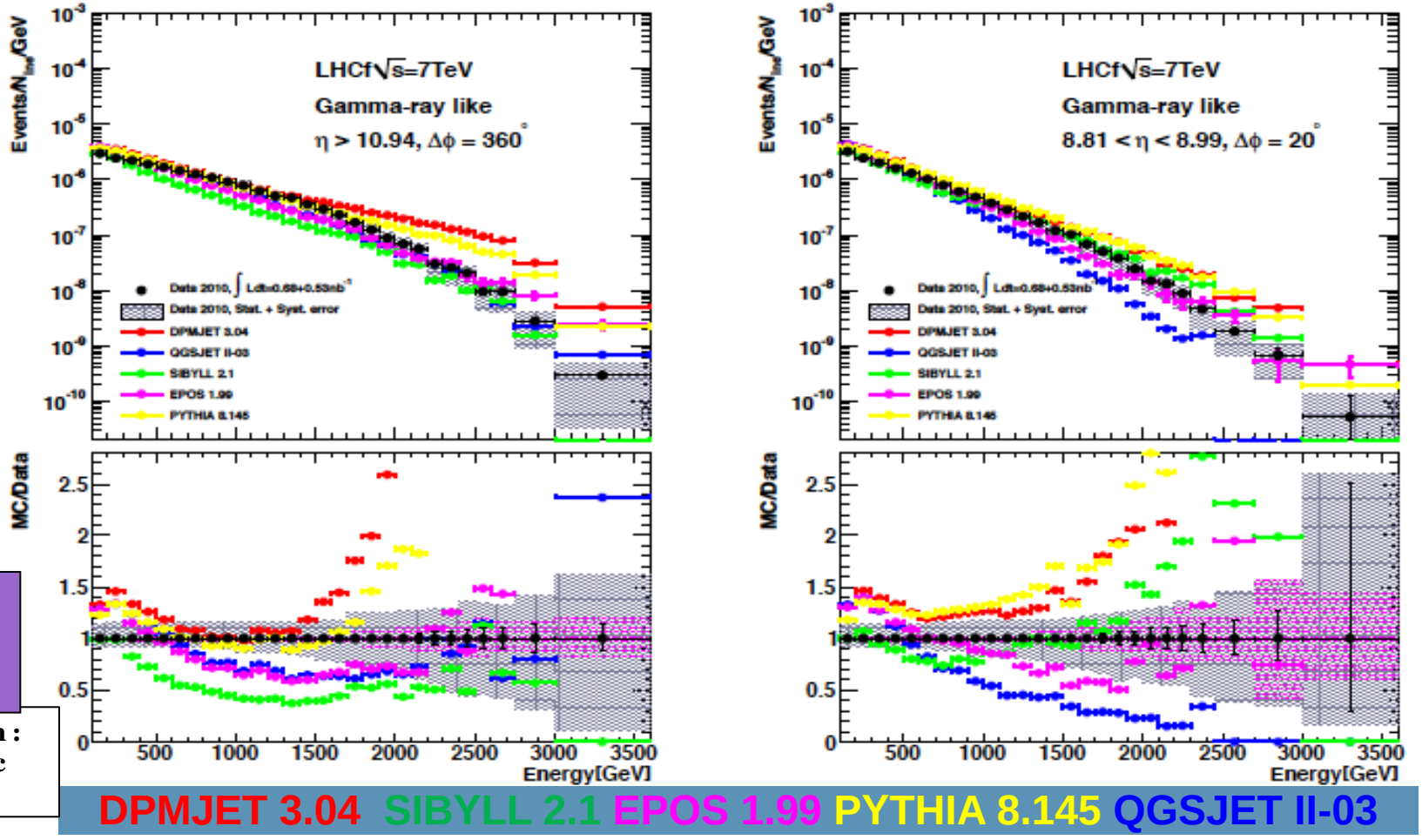
DATA vs. MCs





- None of the models perfectly describe the data,
- EPOS and SIBYLL show a reasonable agreement with the LHCf data.
- *Quite similar tendency to the 7 TeV results.*

Cf.) 7 TeV (PLB 703, 128, 2011)



Magenta hatch: MC Statistical errors

Gray hatch : Systematic Errors

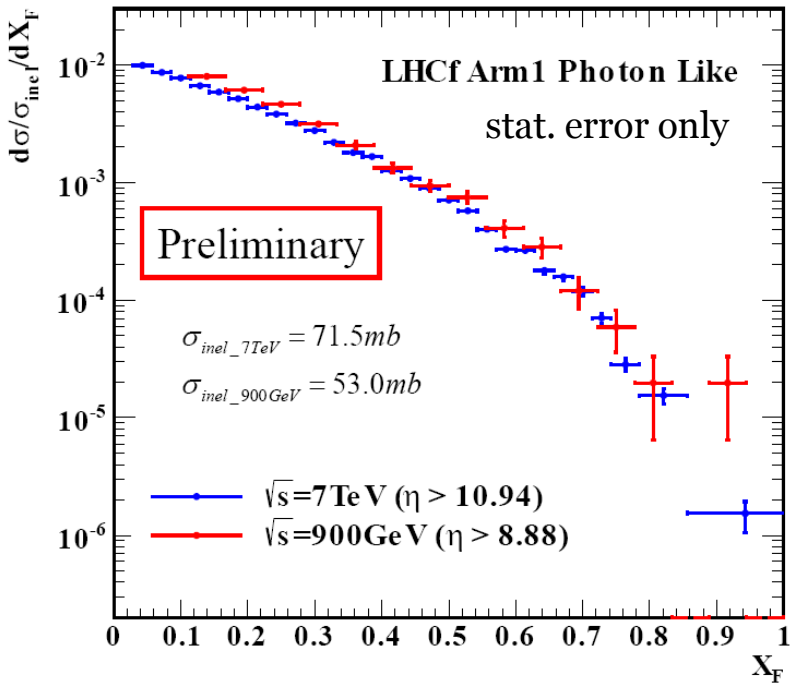
DPMJET 3.04 SIBYLL 2.1 EPOS 1.99 PYTHIA 8.145 QGSJET II-03

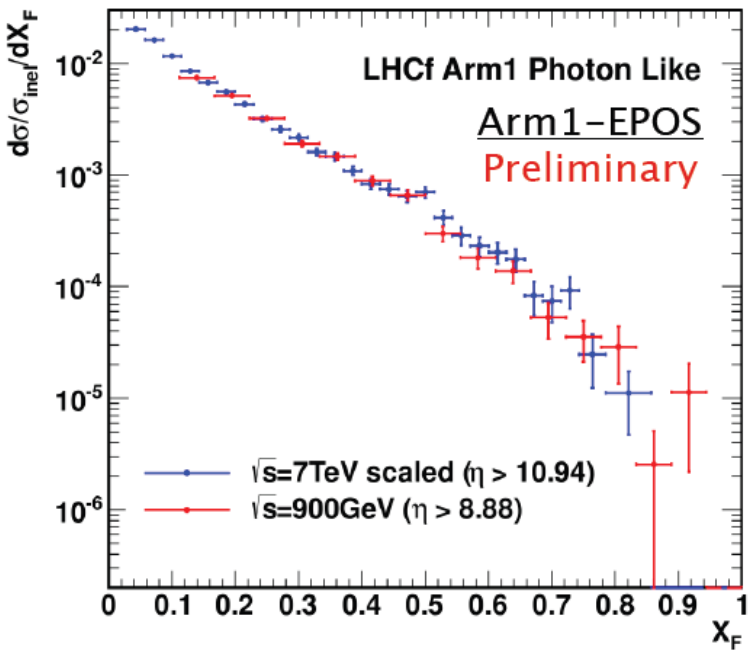
- **None of the models nicely describe the LHCf data in the whole energy range (100 GeV – 3.5 TeV).**
- **A big discrepancy in the high energy region**

Comparison btw 900 GeV & 7 TeV

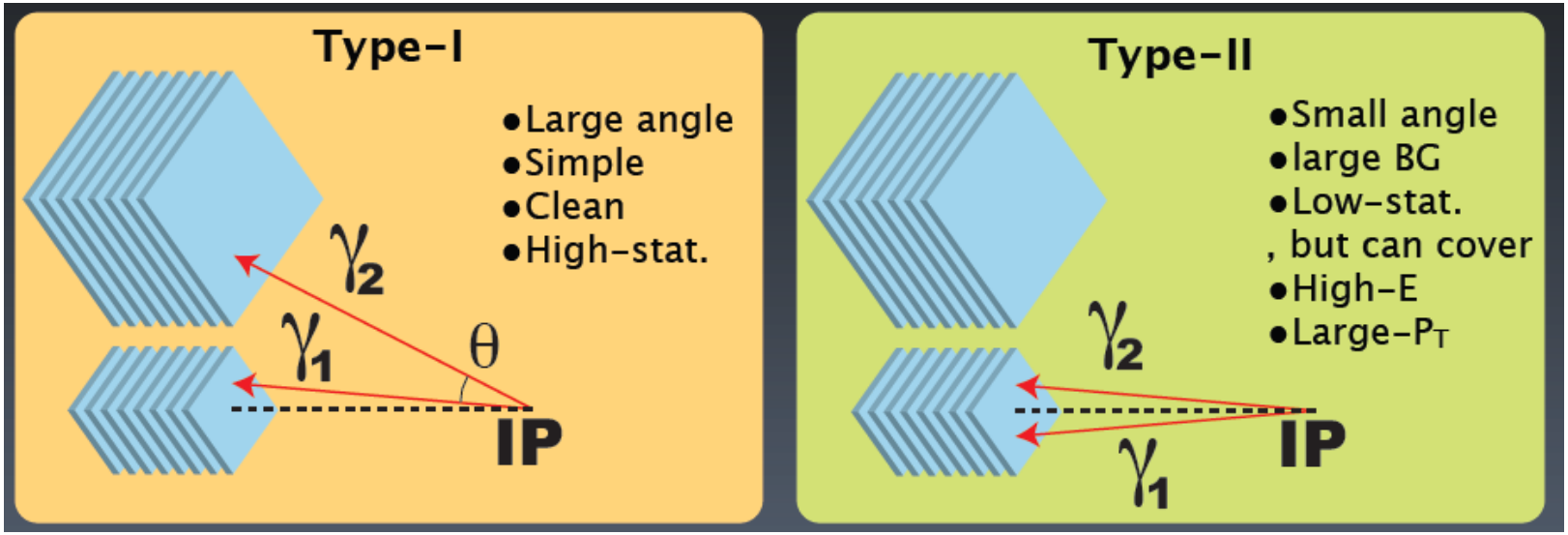
- Only Arm1, the same p_T region selected
  ϕ=5 mm circle for 7 TeV, while 39mm for 900 GeV
- *Spectral shape is common.*
  Small <p_T> dependence on E_{cm}

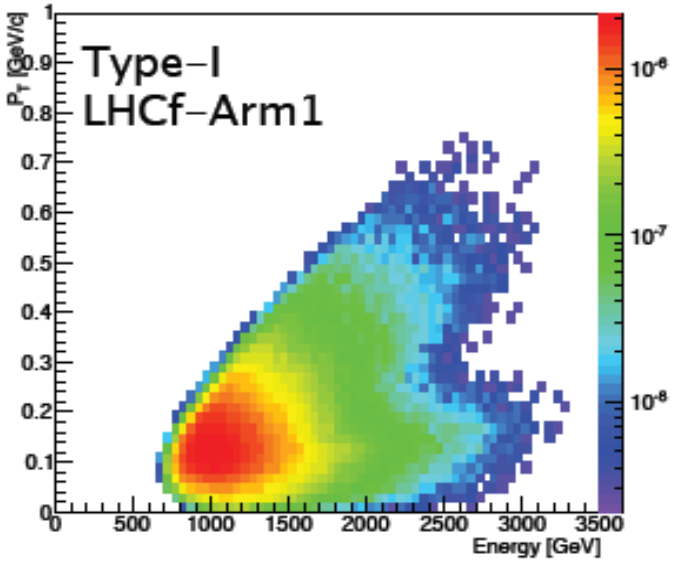
$$\left.\frac{1}{\sigma_{\mathrm{inel}}}\frac{d\sigma_\gamma}{dX_F}\right|_{\eta<\mathrm{limited}} \propto \frac{1}{\sigma_{\mathrm{inel}}}\frac{d\sigma_\gamma}{p_T dp_T dX_F}\langle p_T\rangle dp_T$$





Results: neutral pions



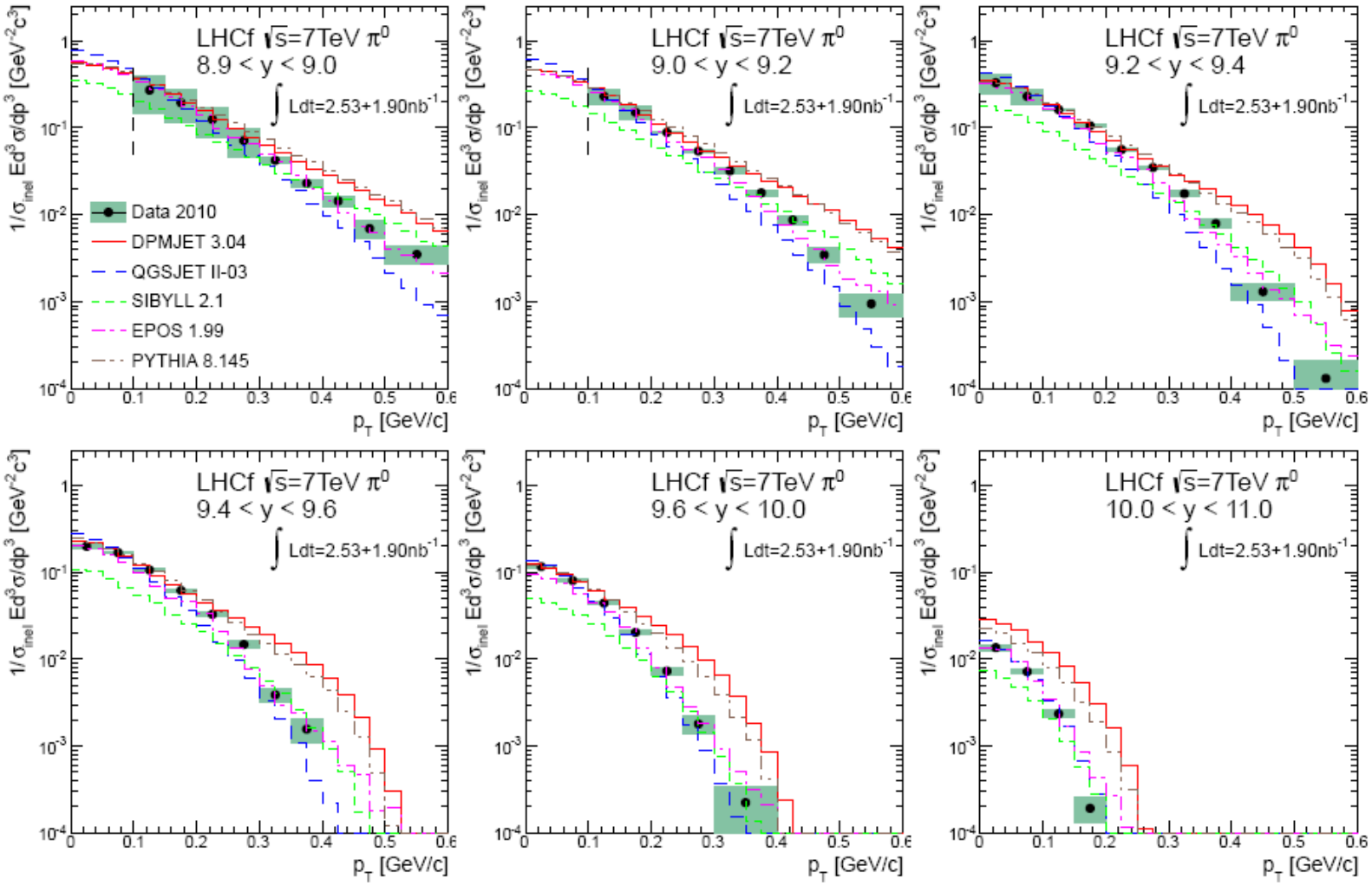


- Type-I only. p_T range: 0~0.6 GeV, limited by detector configuration
- 6 rapidity bins (8.9 - 11.0)
- BG estimation w/ rec. mass
- Unfolding for detector response

Submitted (arXiv:1205.4578)

Combined spectra vs. MCs

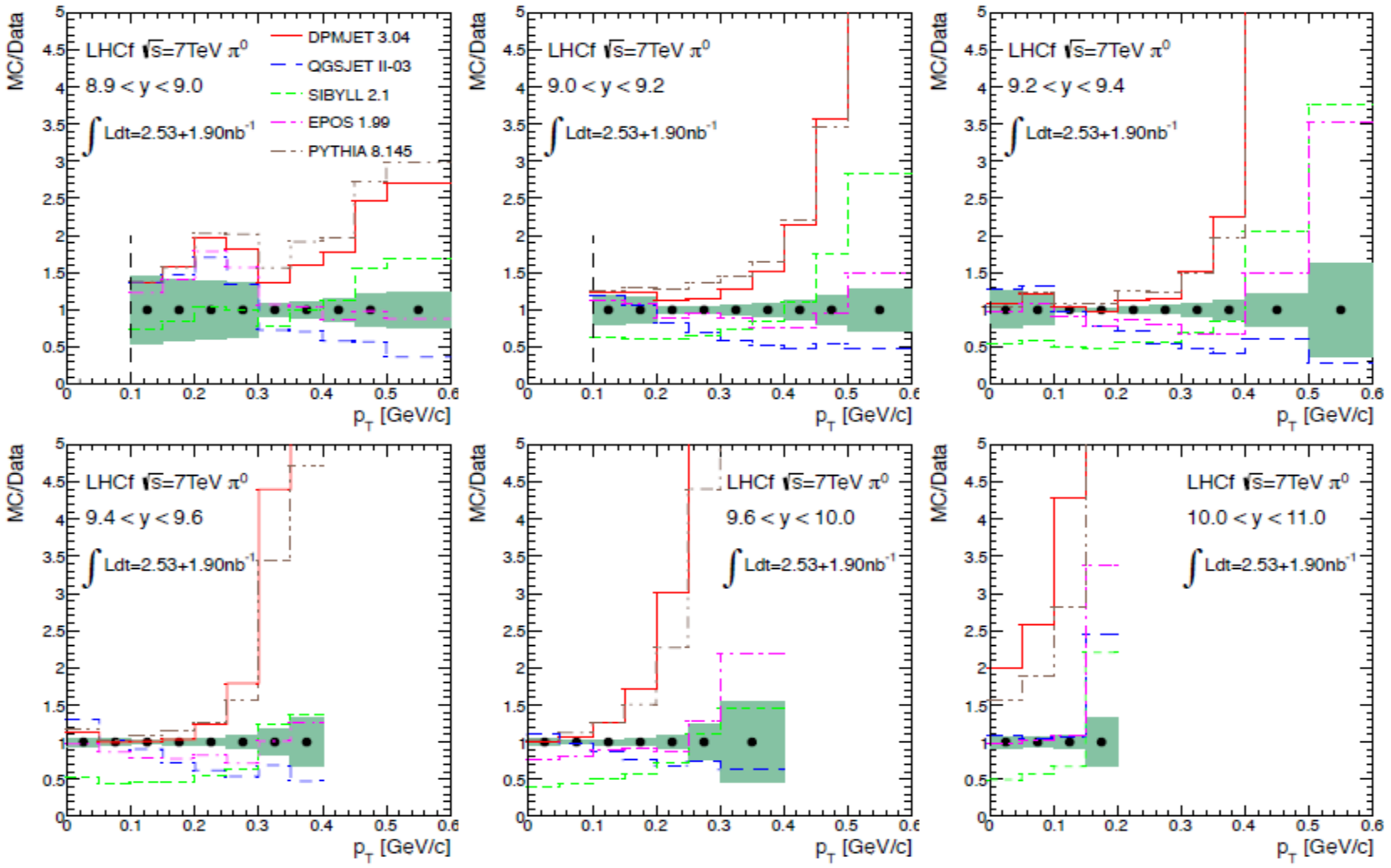
arXiv:1205.4578



LHCf data are mostly bracketed among hadronic interaction models

MCs / Data

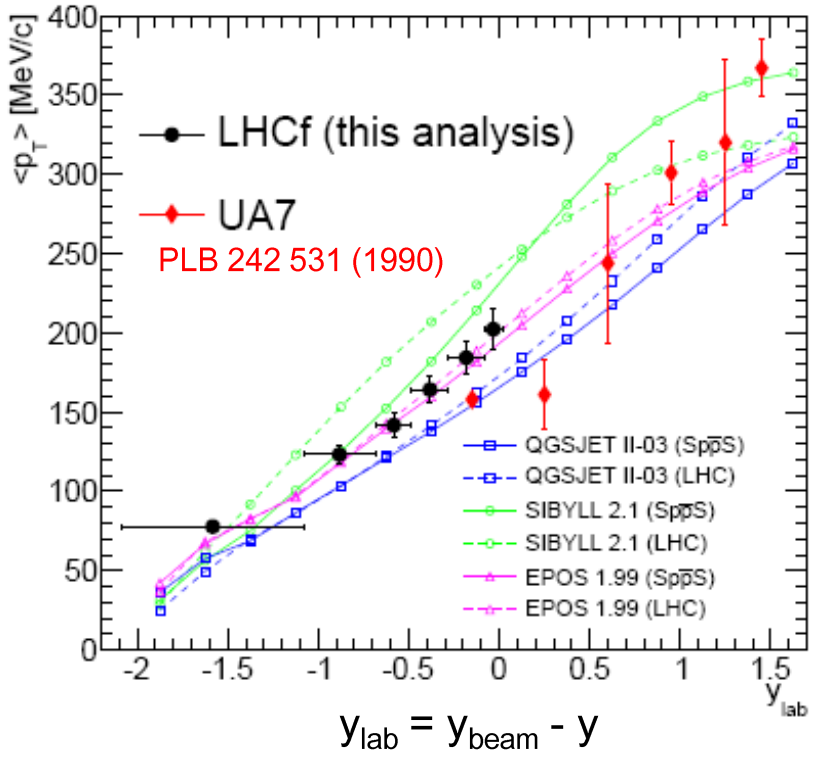
arXiv:1205.4578



EPOS shows the best agreement in the p_T distribution

Averaged p_T comparison

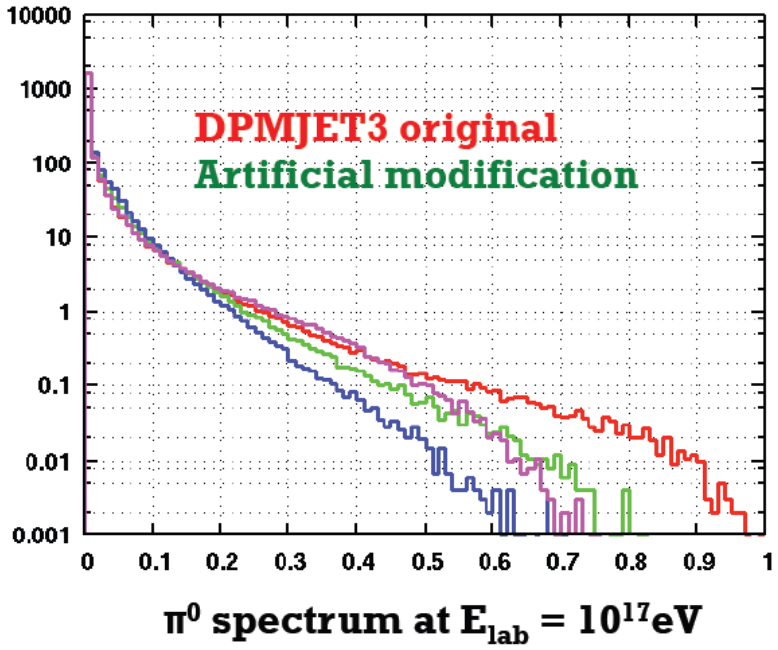
arXiv:1205.4578

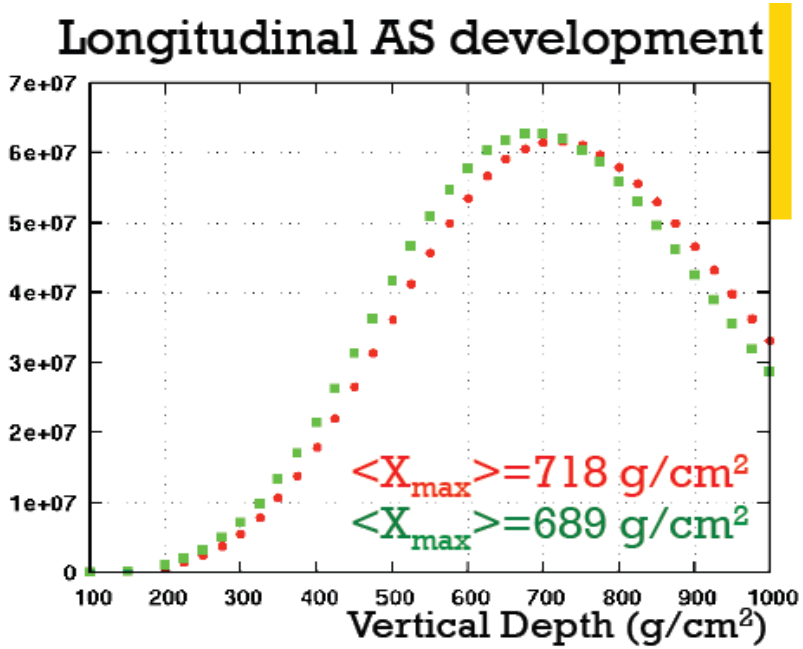


- Estimate $\langle p_T \rangle$ for the 6 rapidity regions to compare with the UA7
- Roughly, the data by the 2 experiments lie on a common curve => Small $\langle p_T \rangle$ dependence
- EPOS is consistent with the data, also for UA7

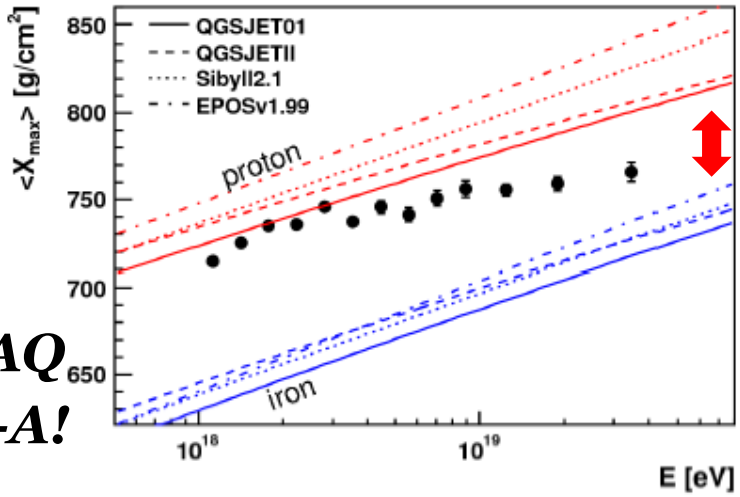
Indication for QCD: small $\langle p_T \rangle$ dependence on E_{cm}
(γ: LHCf 900 GeV - 7 TeV, π^0: UA7 630 GeV - LHCf 7 TeV)
EPOS1.99 describes the dependence well.

Impact on the CR physics





- ✓ Artificial modification of meson spectra
- ✓ Δ Xmax (p-Fe) ~ 100 g/cm²
- ✓ The effect ~30 g/cm²



Next: analyses for neutrons, and DAQ at pA run. CR interactions are p(A)-A!

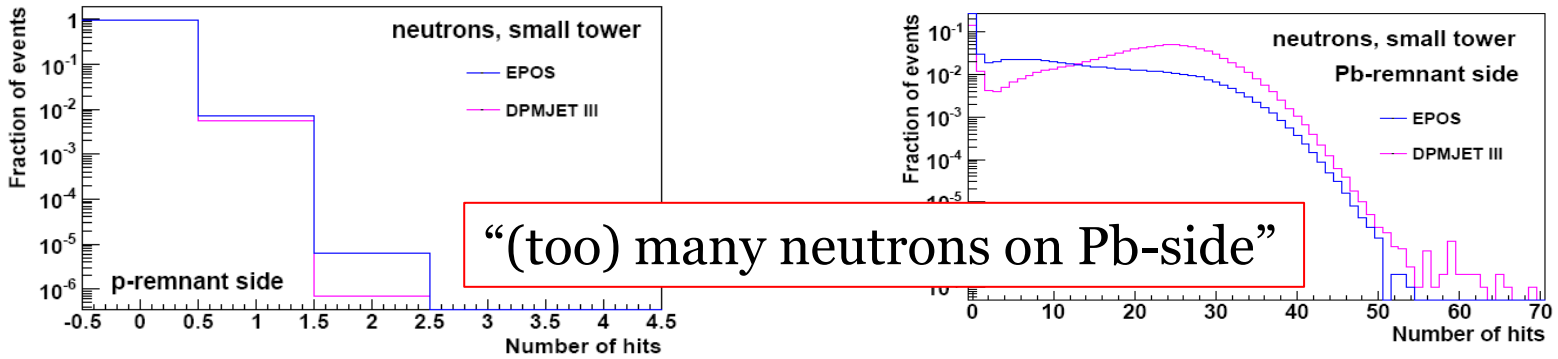
DAQ at pA runs in Nov. 2012

LOI: CERN-LHCC-2011-015 / LHCC-I-021

- Hadron model discrimination with a CR point of view, by photons, neutral pions & neutrons
- Nuclear modification factor, etc.

⇒MC study: Multiplicity should be checked

(p energy = 3.5 TeV, 10^7 collisions, DPMJET3 & EPOS1.99)

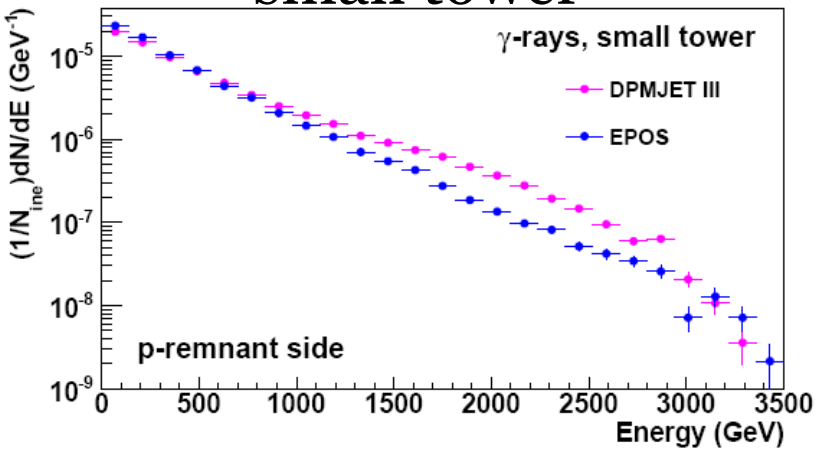


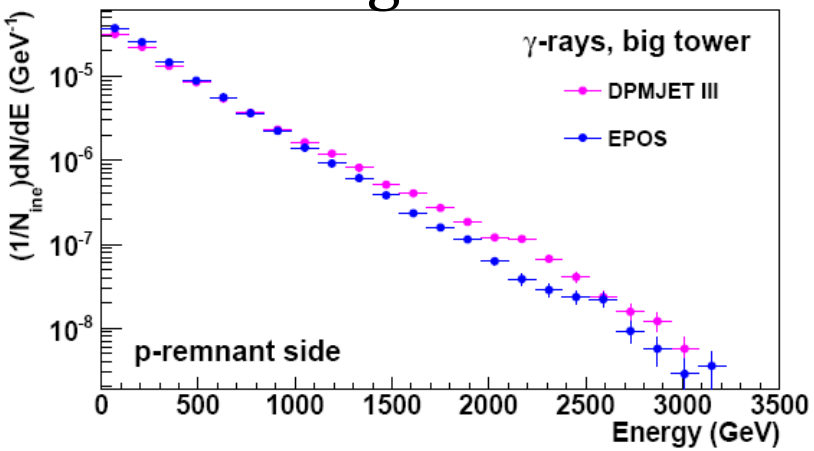
- **Only Arm2, which has the finer Si μ-strip detectors**
- **First p-remnant side, then Pb-side by swapped beam**

Expected spectra: p-remnant side

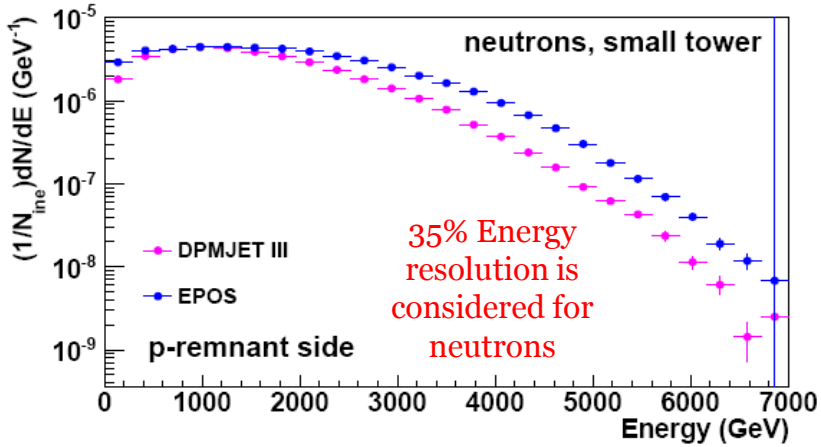
small tower | large tower

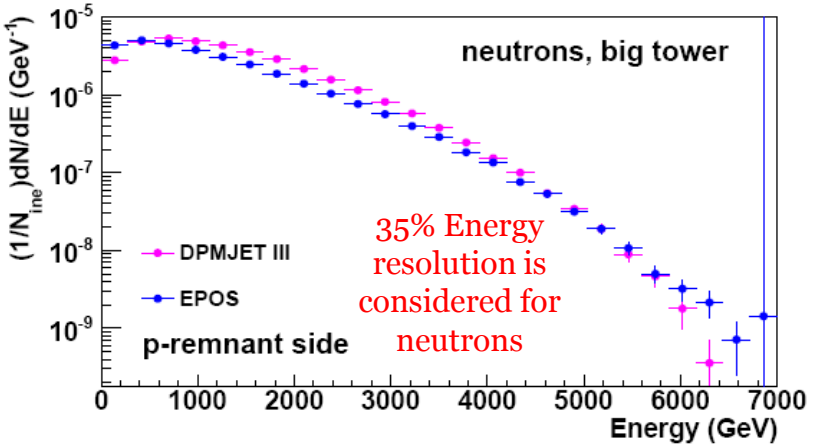
γ





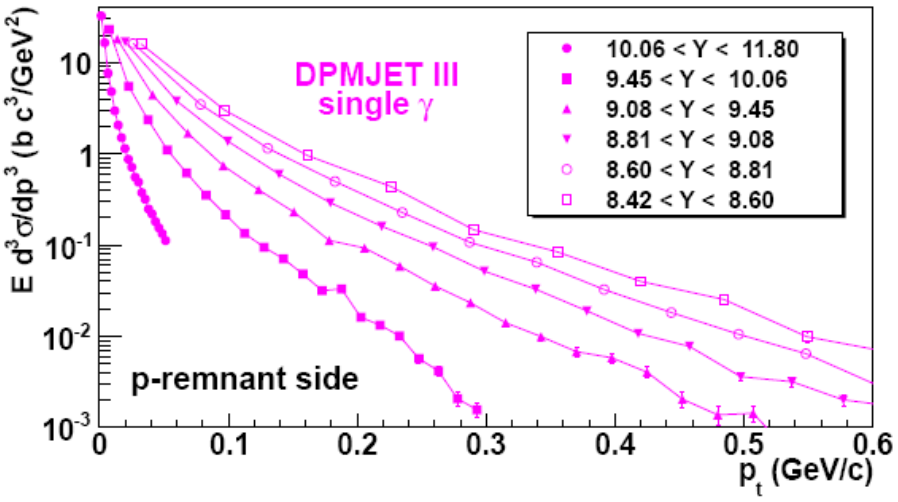
n

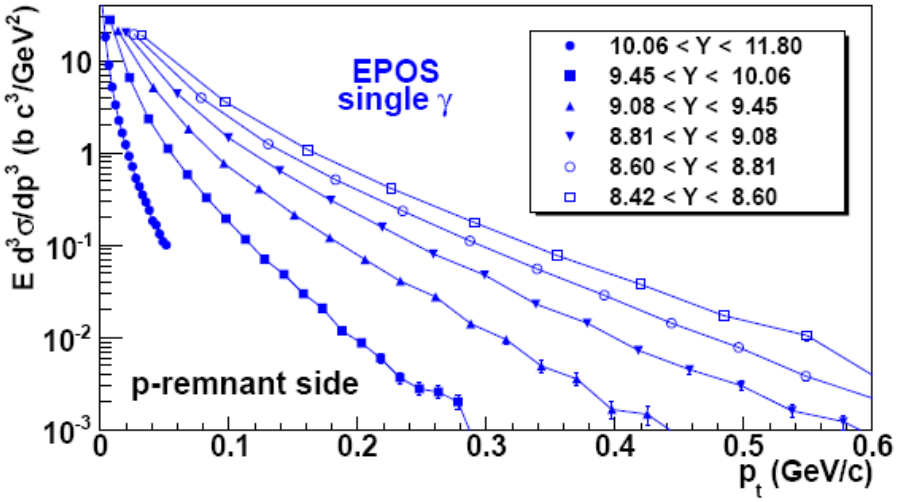




- **γ: 10^7 collisions (<14hrs) is enough**
- n: introduced ΔE=35% is dominant, but still has a certain power for the model discrimination

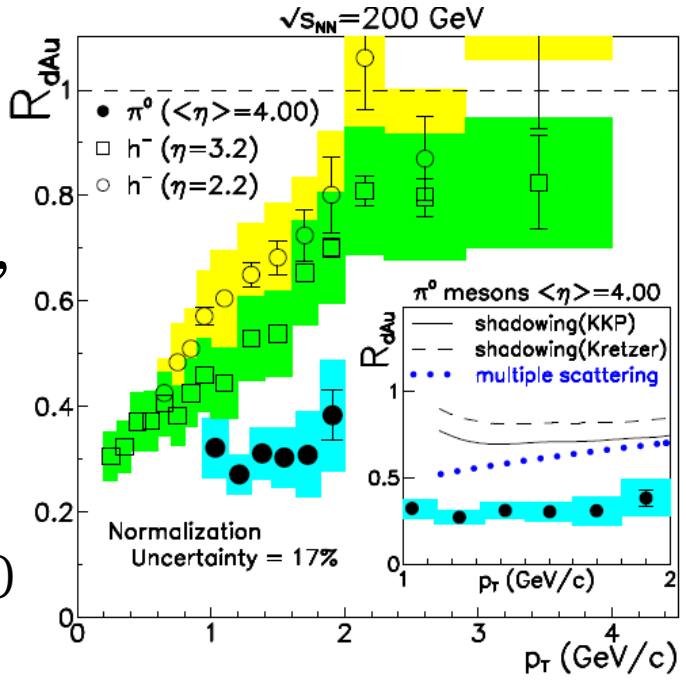
γ invariant cross section: p-remnant side





- Smooth enough with the same stat
- If the γ spectrum in 4.4 TeV pp collisions is measured (or estimated), we can derive the nuclear modification factor for η >8.4
- A big suppression reported for η=4

cf.) NMF by STAR@RHIC (PRL97, 152302, 2006)

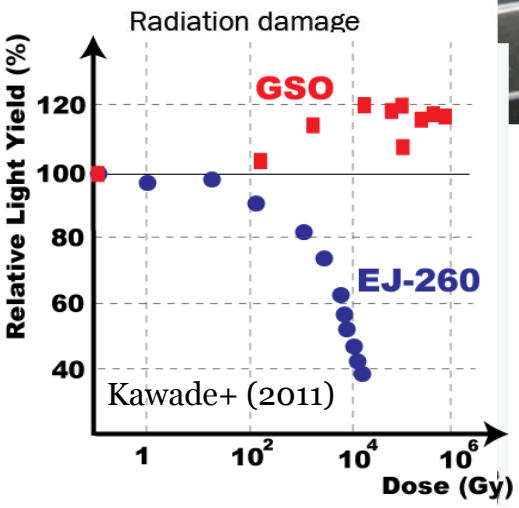


Upgrade for 14 TeV pp runs

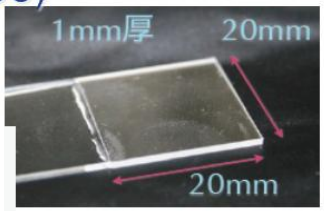
Rad-hardness

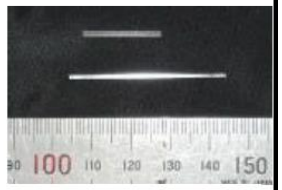
higher luminosity is expected

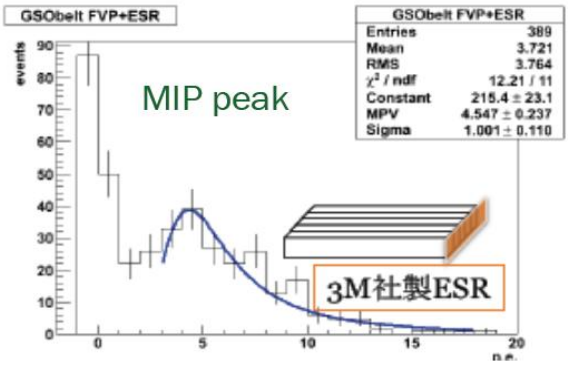
Plastic scintillators (EJ260)
⇒ GSO scintillators



Scintillating Fibers
⇒ GSO bars

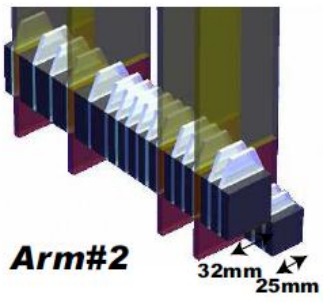


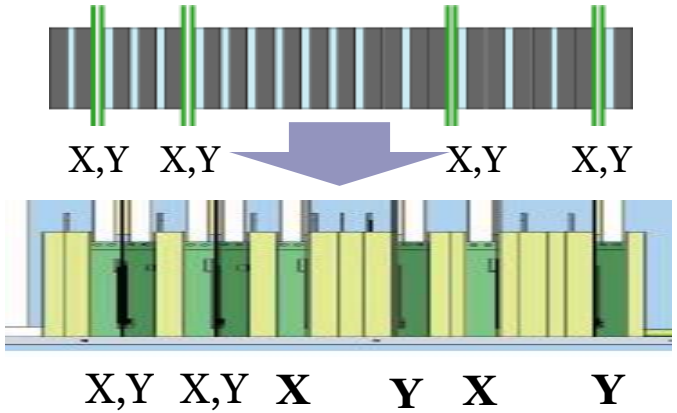


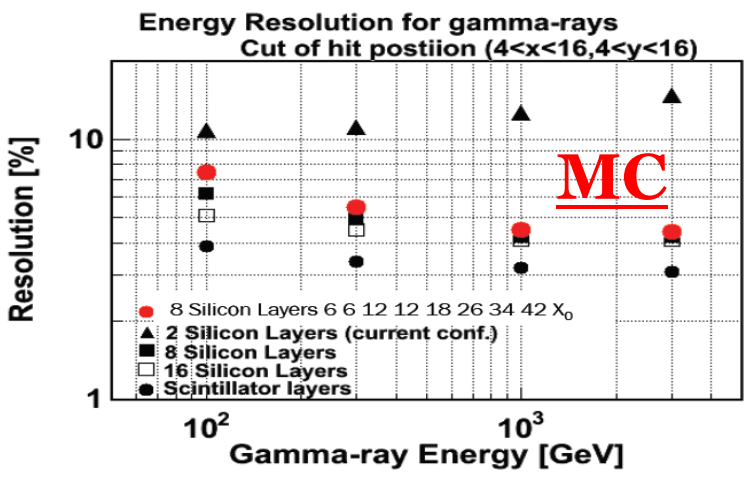


Improvement of energy reconstruction

Silicon layer positions in Arm2 detector







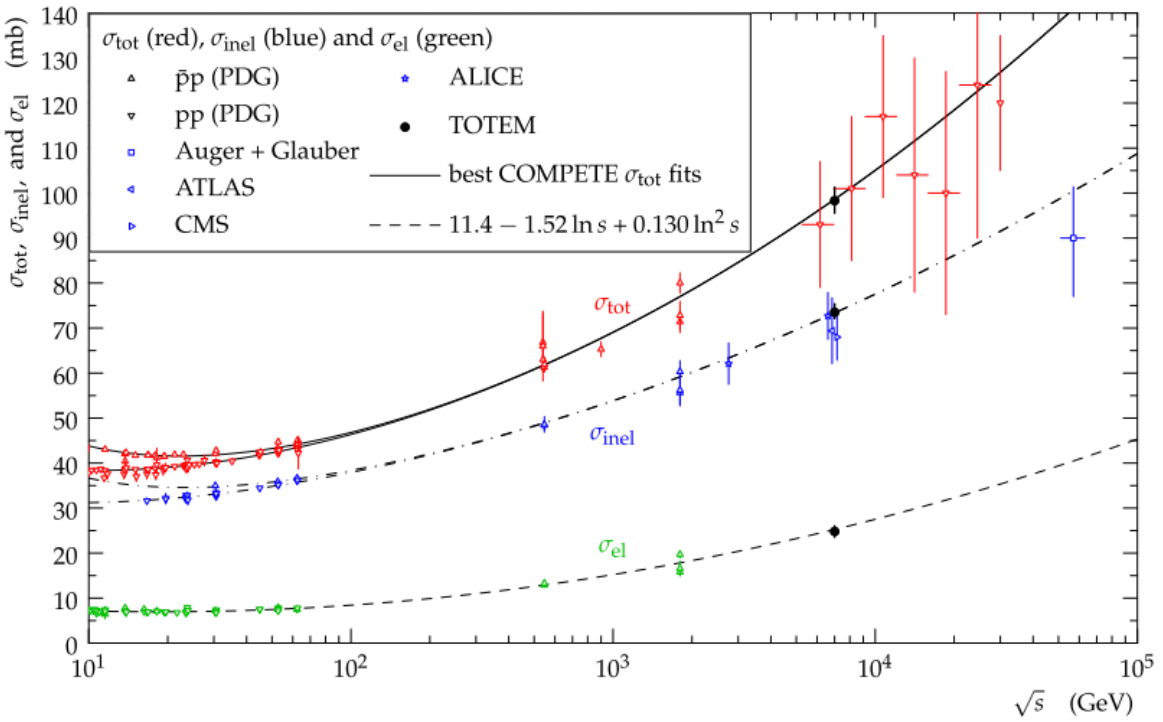
Better energy reconstruction with upgraded scintillators & Si detectors

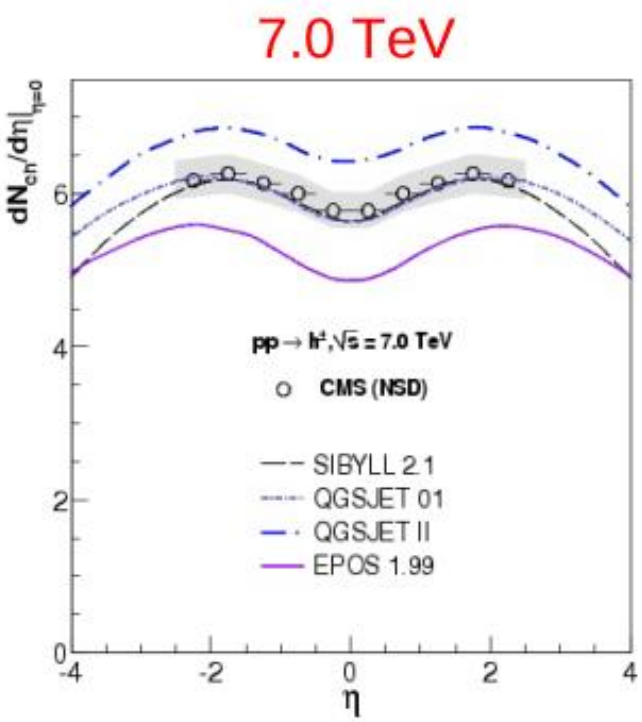
Summary

- LHCf: experiment for measurement of very forward neutral particles (γ, π^0,n), for the cosmic-ray physics
- Analyses show:
  - Smooth curves = a good detector performance
  - Small $<p_T>$ dependence on E_{cm} both for γ & π^0
  - EPOS shows the best agreement among models
  - The above are consistent with the past data
- We will be back to LHC for:
  - the coming pA runs in this year with Arm2 detector
  - the 14 TeV pp runs in 2014 with the upgraded detectors

backup

Recent input from LHC data



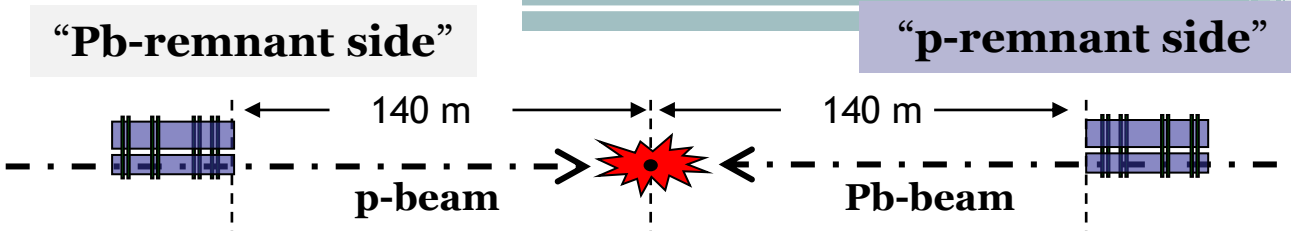


Inelastic cross section

Charged hadron multiplicity

Missing part: spectra of forward neutral particles

MC setups



- Protons with energy E_p = 3.5 TeV, and Pb with

$$E_N = \frac{Z}{A} E_p = 1.38\ \text{TeV/nucleon} \Rightarrow \sqrt{s_{NN}} = 4.4\text{TeV}$$

- Detector responses are not introduced, but the geometrical config. and a realistic E-smearing of Arm2 are considered
- 10^7 collisions (~ 2*10^5 photon events in total)

<about hadronic models>

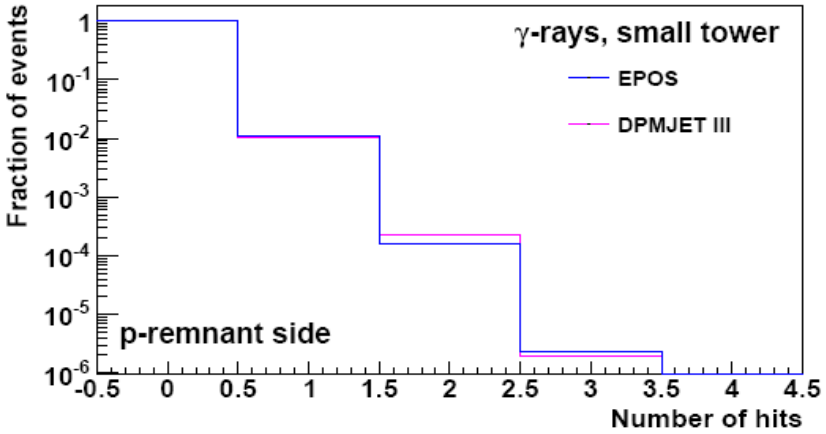
- Results are shown for DPMJET 3.0-5 and EPOS 1.99
- EPOS 1.99 does not consider Fermi motion and Nuclear Fragmentation. Be careful for the Pb-remnant side results
- QGSJET2 can be used for p-Pb collisions. Works in progress.
- Public version of other models (Sybill, HIJING, Pythia etc.) cannot be used for p-Pb collisions

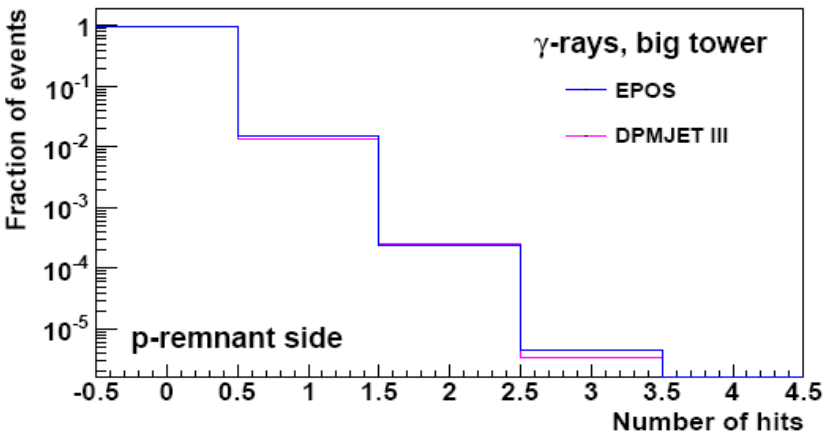
multiplicity: p-remnant side

small tower

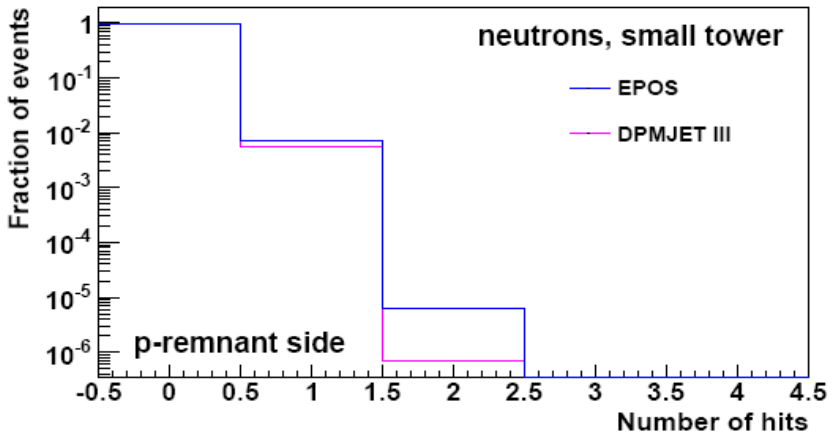
large tower

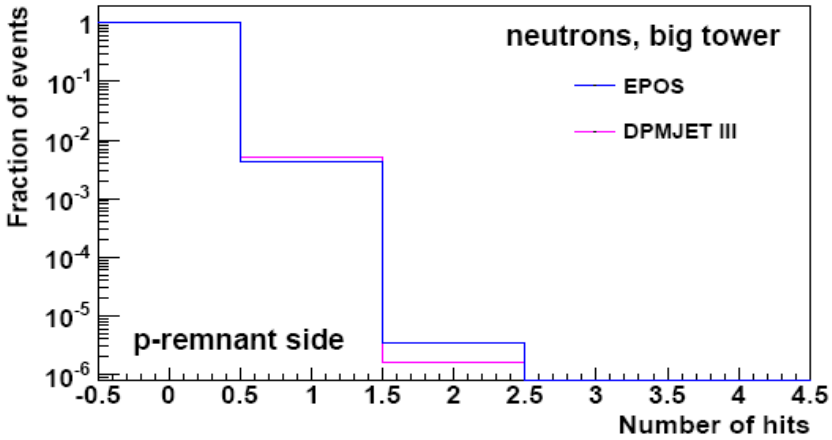
γ





n





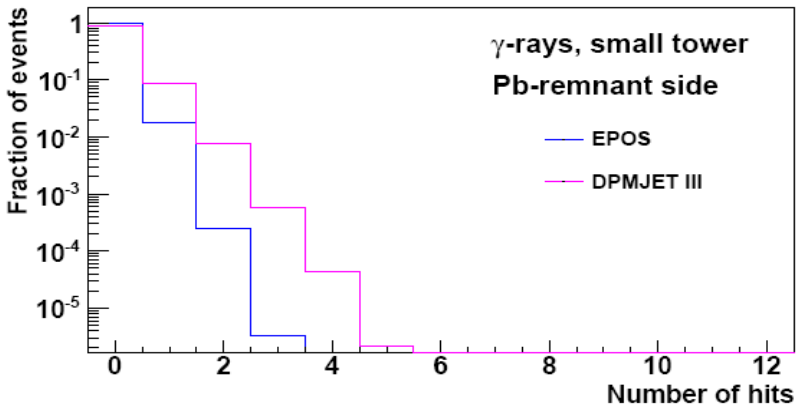
- multi-hit events are <~1% of single events

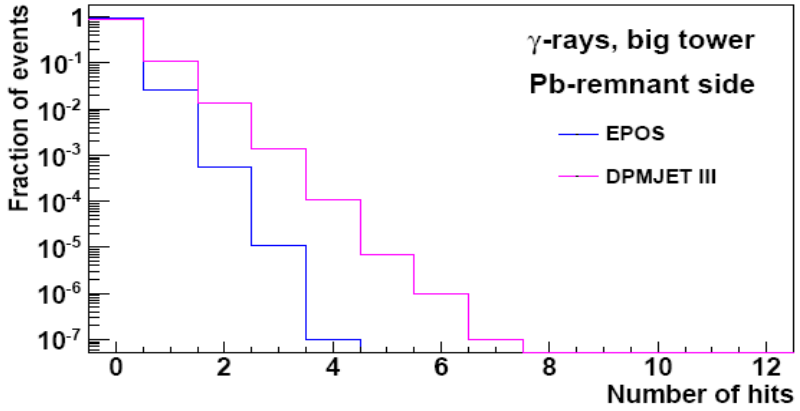
multiplicity: Pb-remnant side

small tower

large tower

γ





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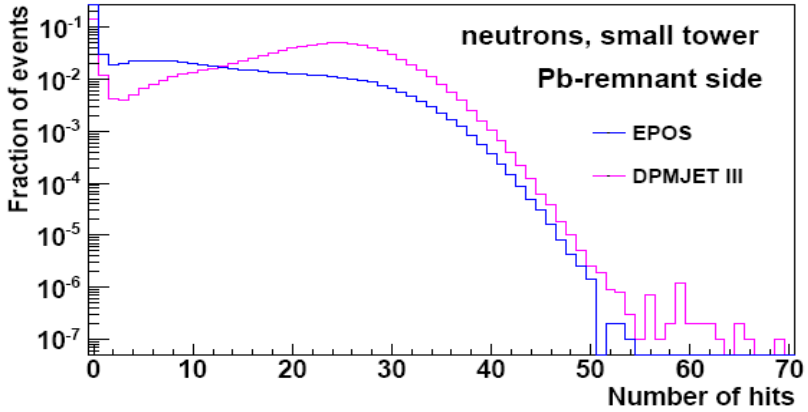
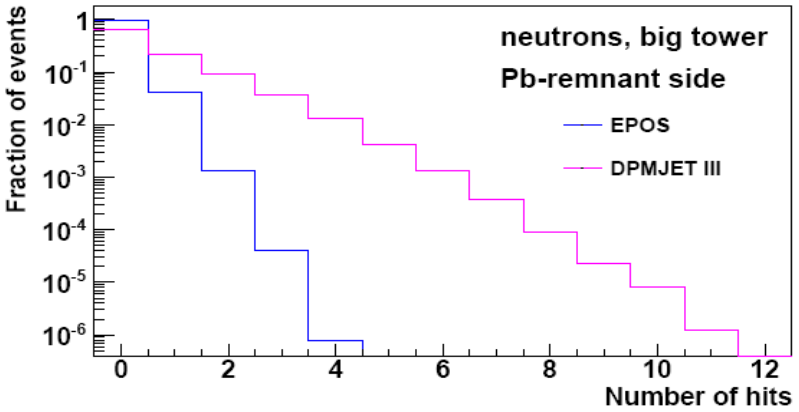


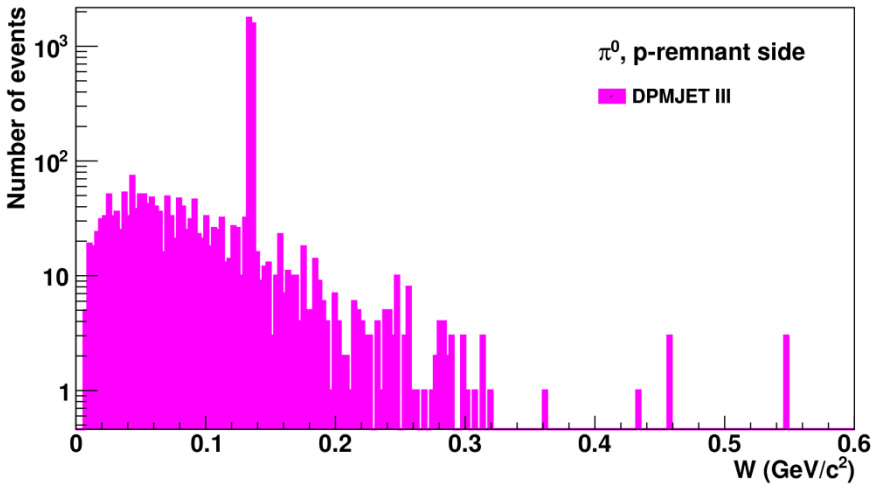


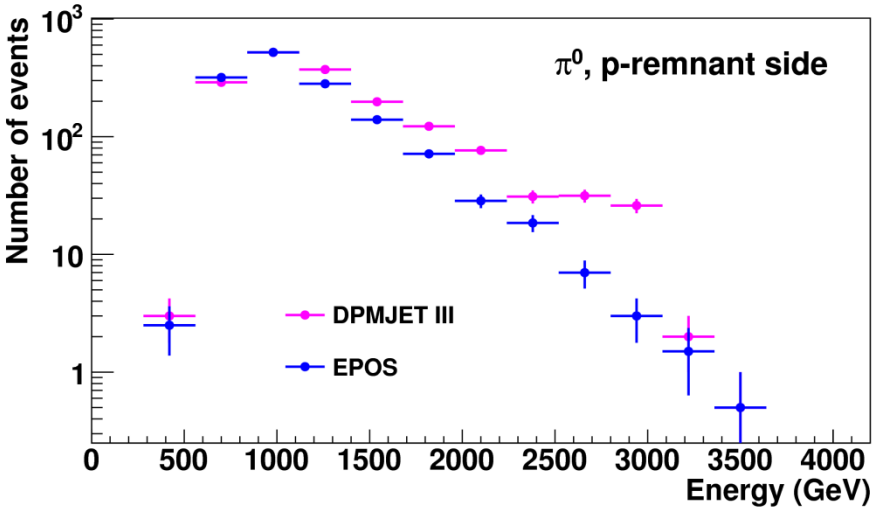
possibility of "(too) many neutrons" =>

- **Arm2, which has the finer Si μ-strip detectors**
- **First p-remnant side, then Pb-side by swapped beam**

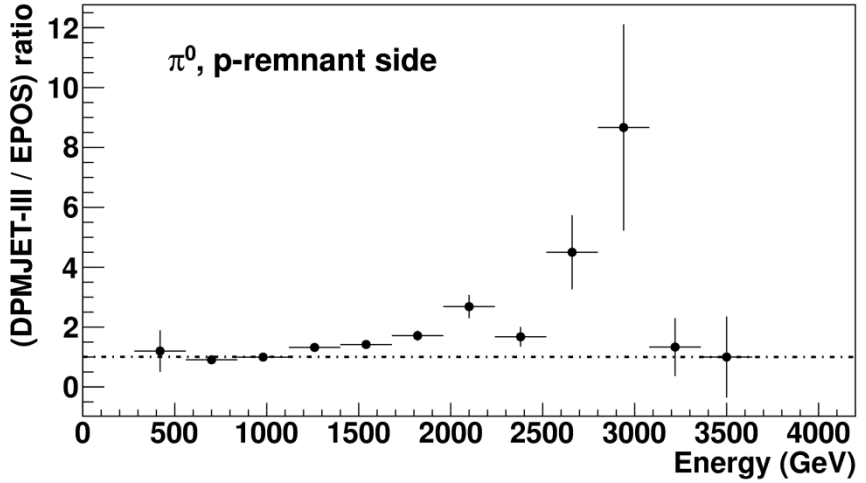
(no strong need to install both of the two detectors)

Neutral pions





- We can detect neutral pions
- Complementary for the model discrimination
- Important info to check the detector performance

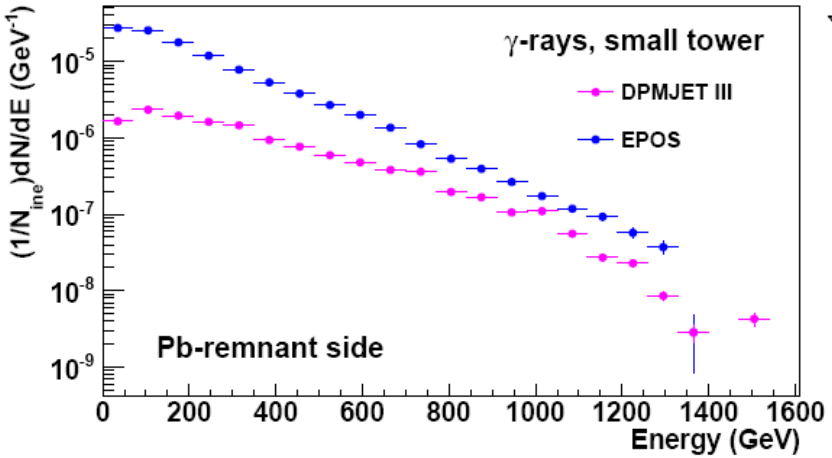


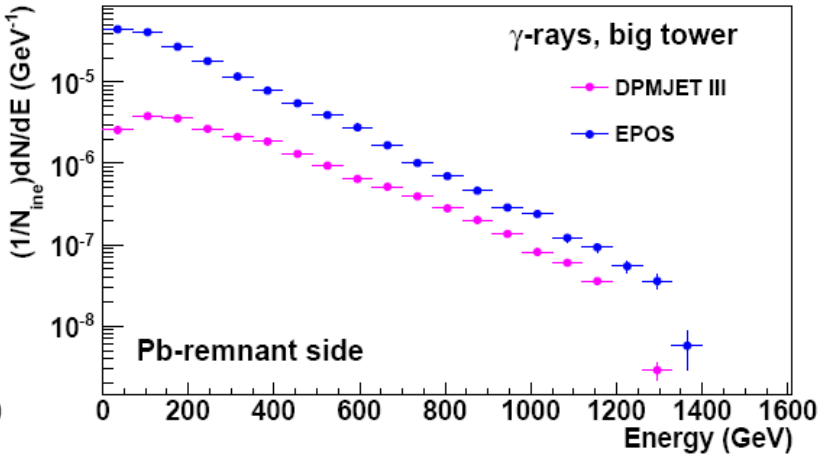
Expected spectra: Pb-remnant side

small tower

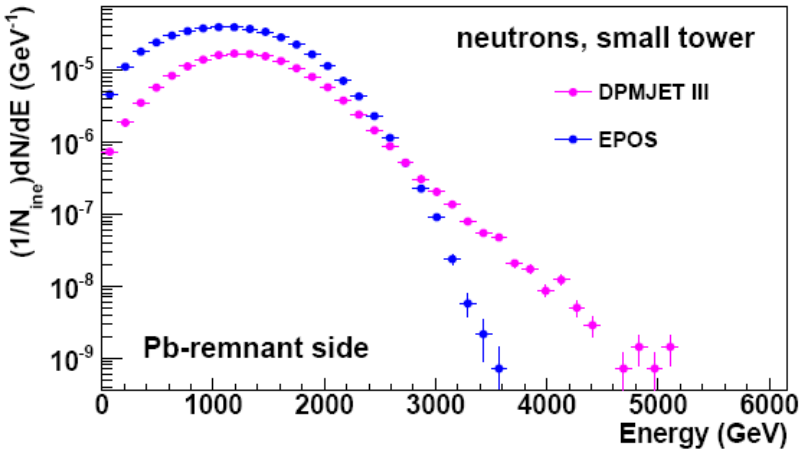
large tower

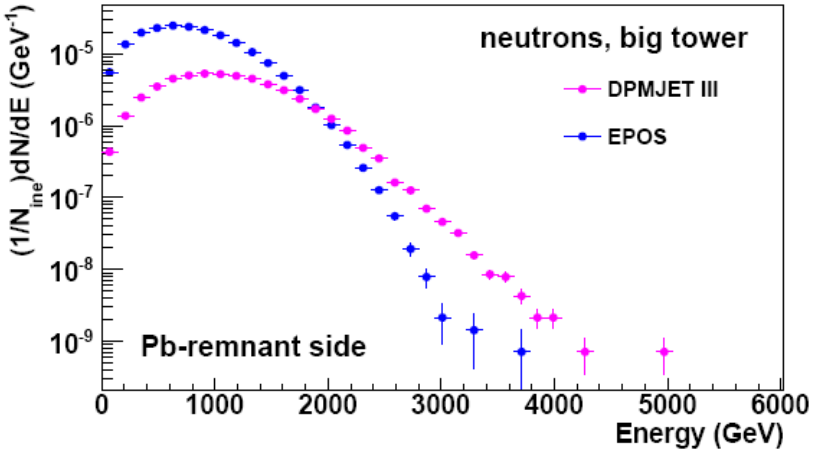
γ





n





Large difference among models.
Interesting if we can solve the large multiplicity

Plans for DAQ

1. Only Arm2 will be installed in a short TS in Oct

   Radiation, transportation, cabling, etc. are all ok.

2. DAQ first in p-remnant side, then in Pb side

   Arm2 was installed in this side in 2010. No big change.

3. Required min. # events: 10^8 collisions (2*10^6 γ)

   Beam parameters : #bunch=590, Luminosity<$10^{28}cm^{-2}s^{-1}$, σ=2b

   (pile-up is negligible for the max. luminosity)

   Assuming that the luminosity is only $10^{26}cm^{-2}s^{-1}$,

   the min. running time for physics is **140 hours (6 days)**

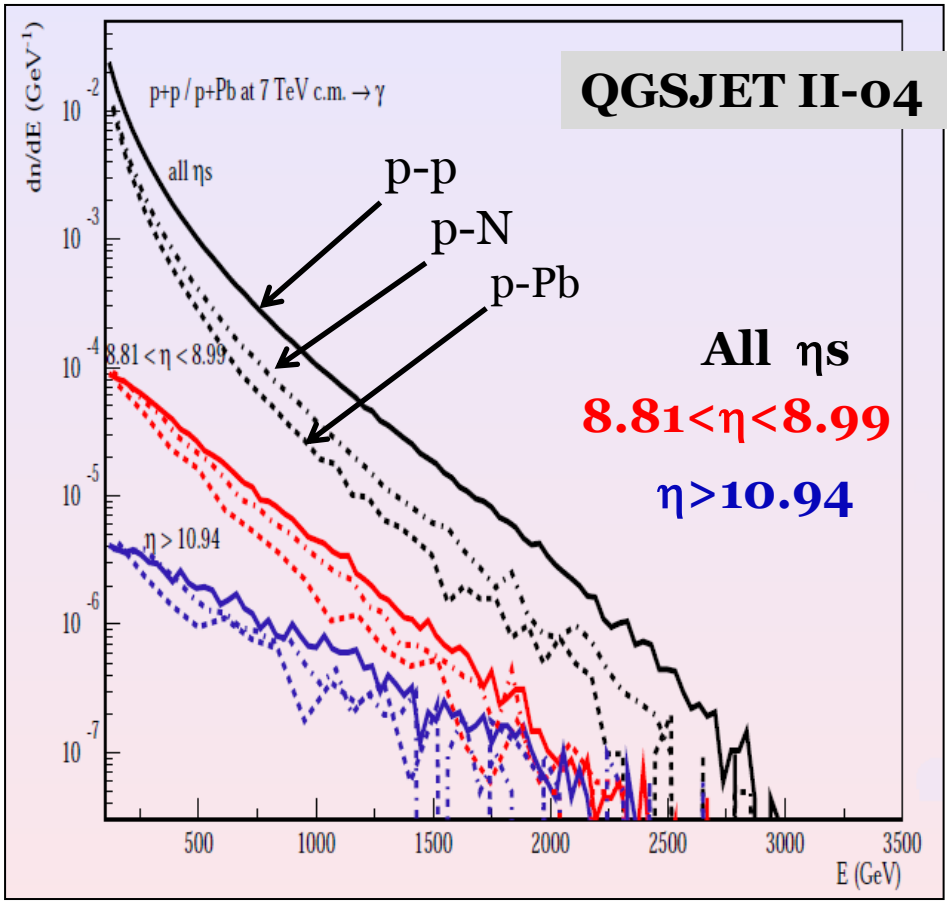
Presented in LPCC (10/2011),

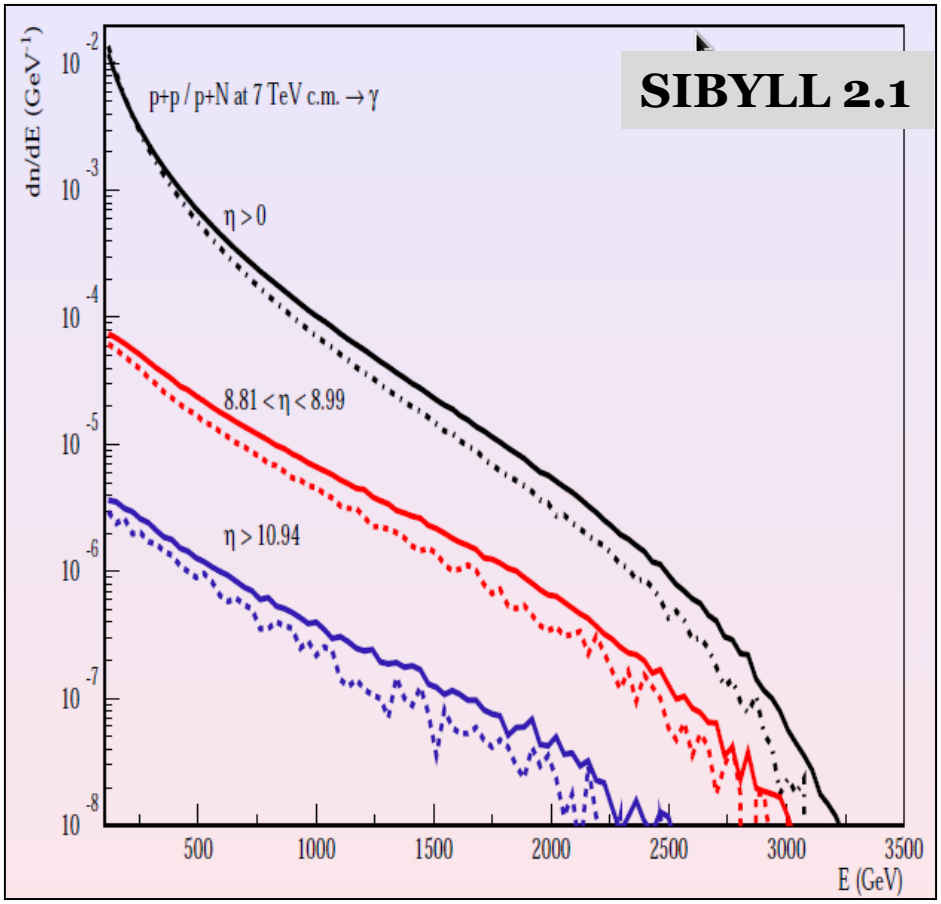
then approved in LHCC (12/2011 & 03/2012)

We will be back in this autumn!

pPb is still useful for CR

- γ spectrum (p-remnant) in different η intervals at $\sqrt{s_{NN}}$ = 7 TeV
- Comparison of p-p / p-N / p-Pb
- **Enhancement of suppression for heavier nuclei case**





Courtesy of S. Ostapchenko

Discussions ~physics with ATLAS?~

- In hardware level a common trigger with ATLAS is hard to be implemented in this pA run.
- **An ATLAS event ID is recorded in our data. Event reconstruction with ATLAS can be done in offline.**

- Thus, the point is the # fraction of common events, i.e., the trigger efficiencies of each experiments.
  If the beam luminosity is not high, they would be similar.
- Which detector of ATLAS?
  It would be relatively easy to combine the ZDC data with our data, compared with data of the central detectors.
- Max. trigger rate?