LHCf plans for pA data taking

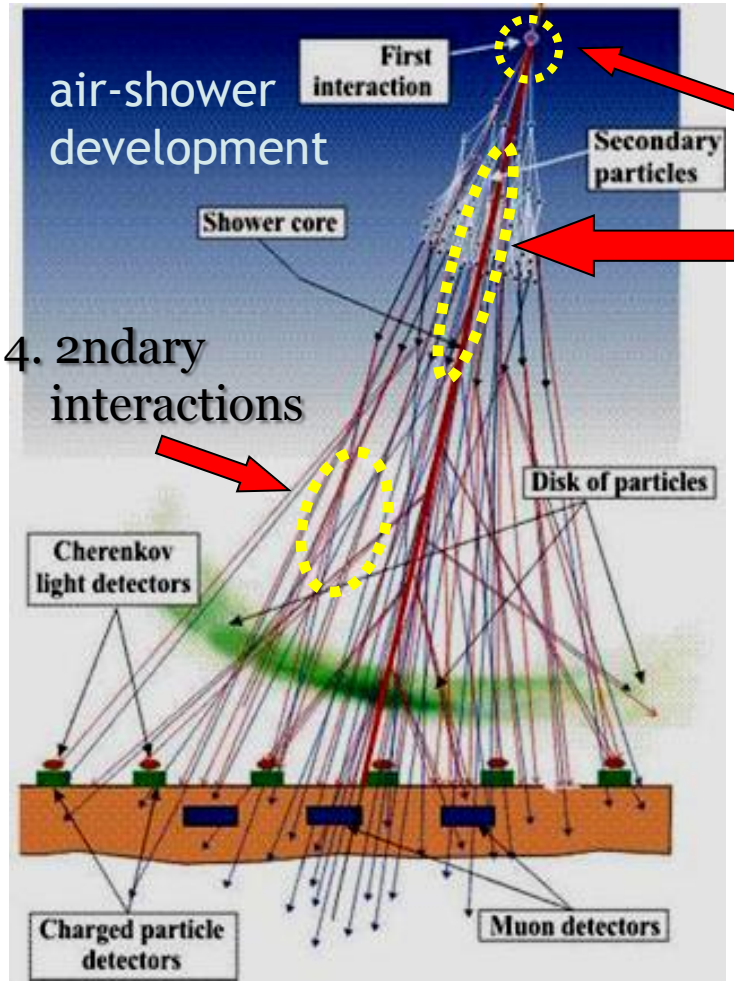
Koji Noda (INFN Catania)
for the LHCf Collaboration

04 June 2012

pA@LHC workshop @CERN

Introduction ~Physics motivation of LHCf~

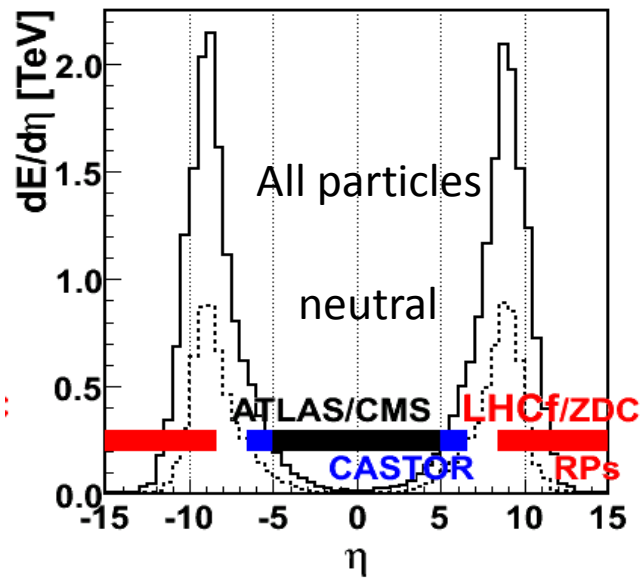
- **UHE cosmic-ray air-shower is initiated by <u>pA or AA interaction</u>**
- **Its development is to be understood by the HE particle physics**



sqrt(s)=14TeV ⟷ $E_{lab}=10^{17}$eV

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

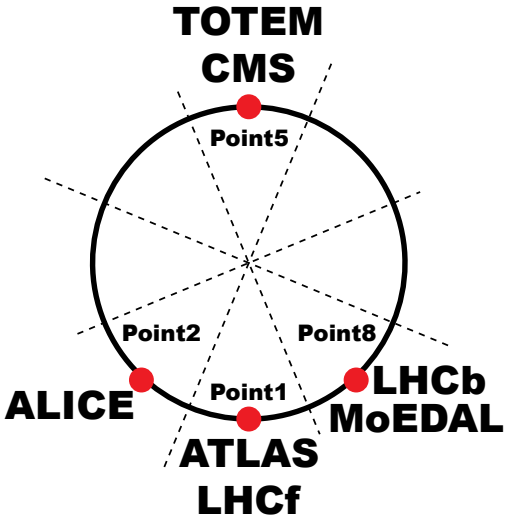
} large model dependence…

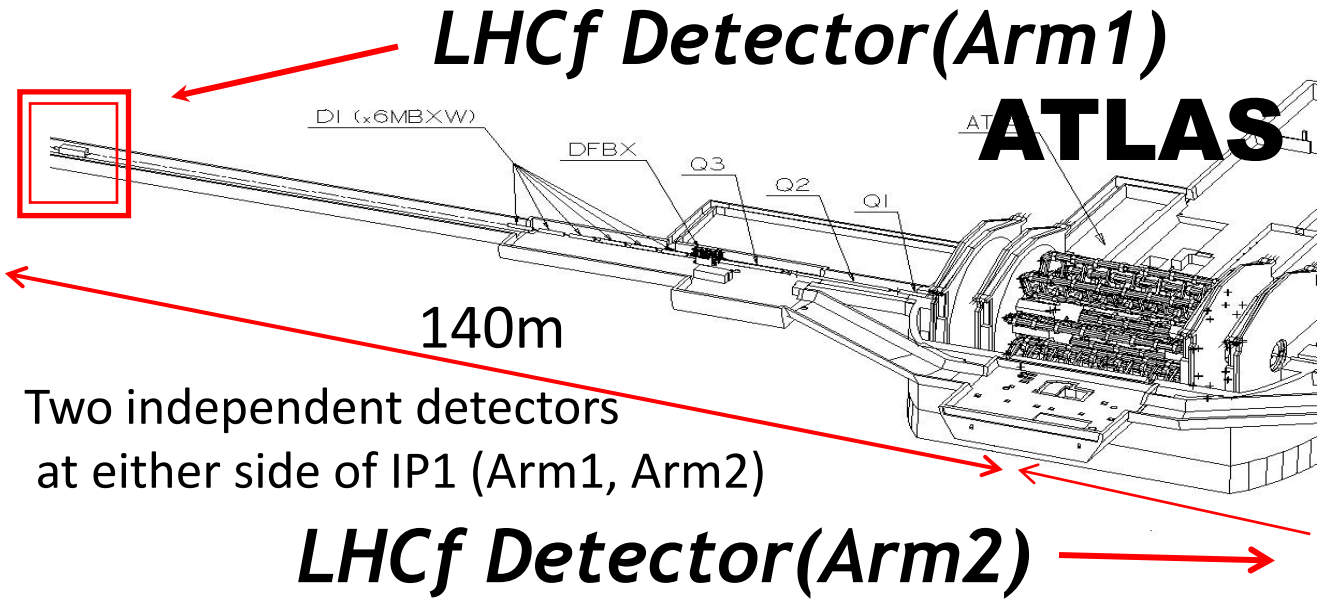


<= Energy flux at LHC 14TeV pp

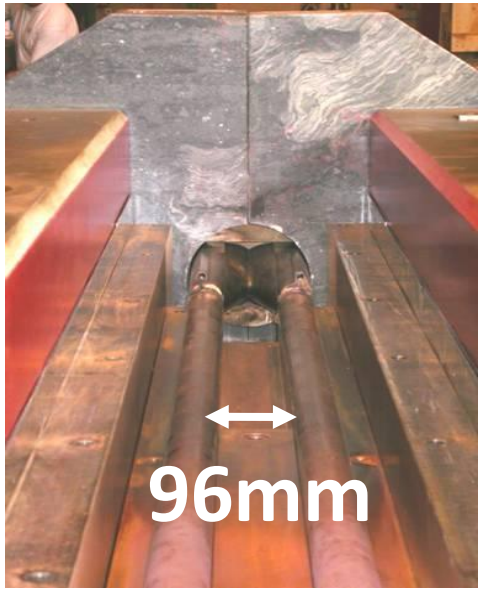
Most of the energy flows into very forward

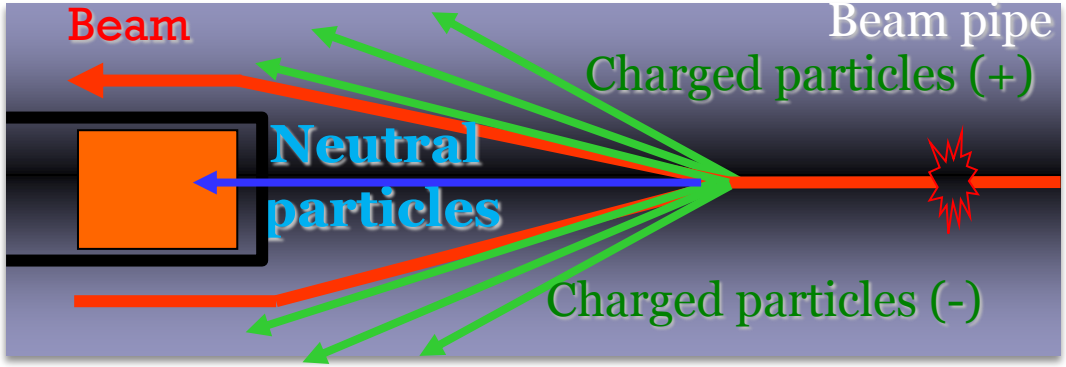
LHCf experiment





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



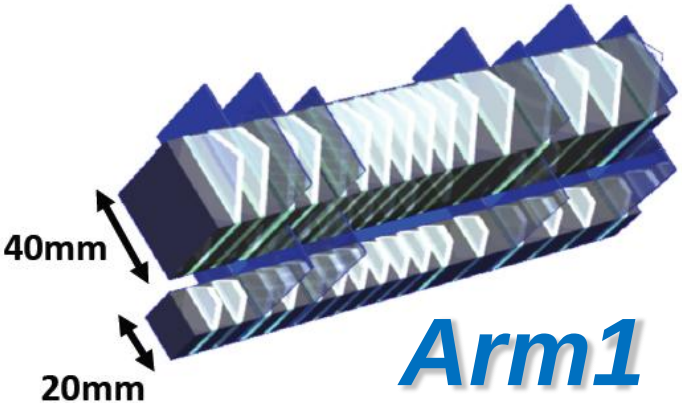


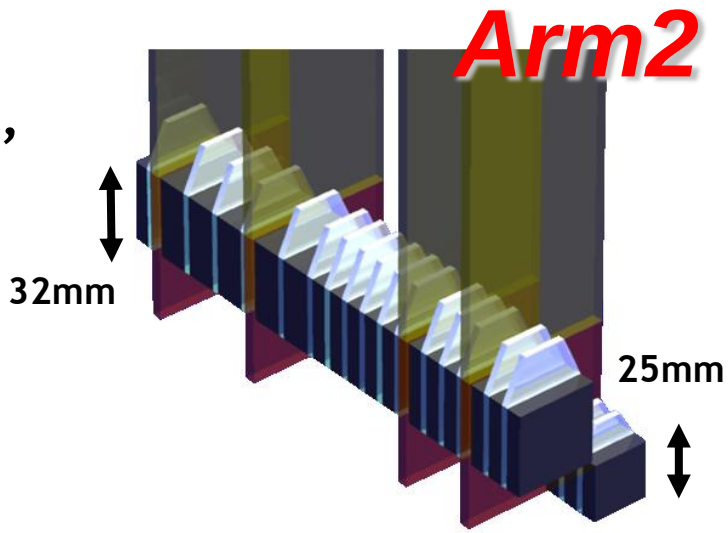
neutral particles, such as γ, π^0, n, with $\eta > 8.4$ enter into the detector slot

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

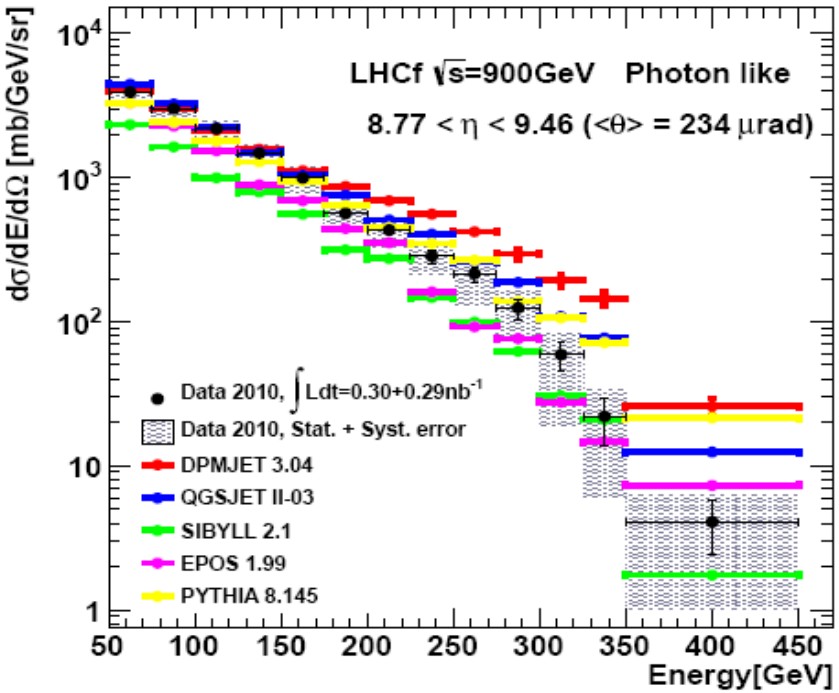
Energy resolution (> 100 GeV): **< 3% for 1 TeV γ & ~ 30% for n**

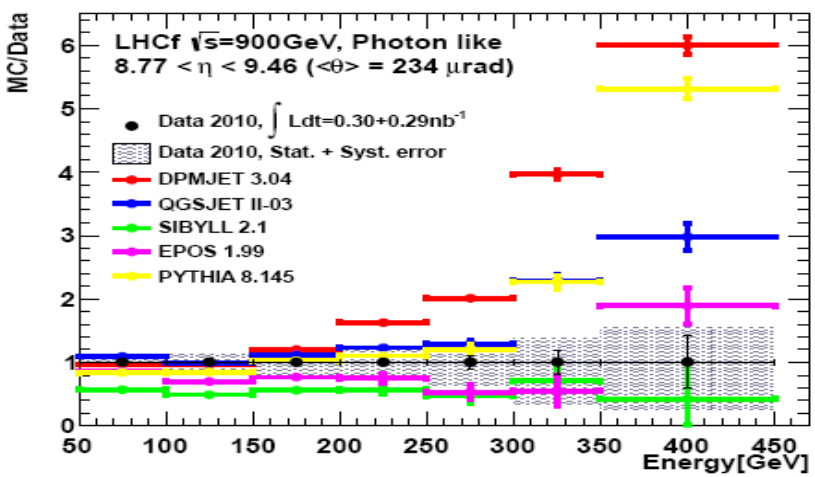
Position resolution for photons: **~ 40 μm (Arm2)**

Operations & status

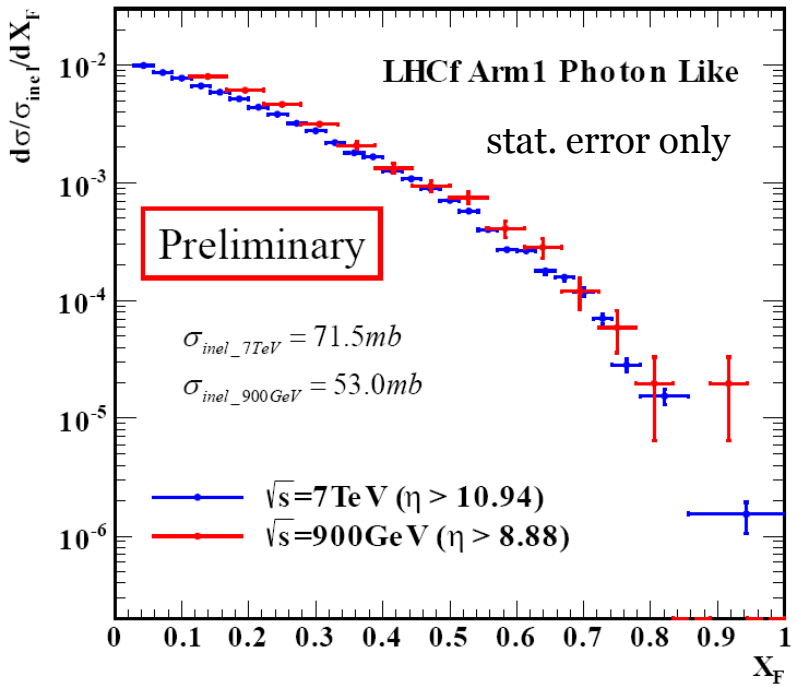
Period	Type	Beam energy	LAB proton Energy (eV)	Detector
2009/2010	p - p	450+450 GeV	$4.3\ 10^{14}$	Arm1+Arm2
2010	p - p	3.5+3.5 TeV	$2.6\ 10^{16}$	Arm1+Arm2
now	detectors were detached from the tunnel			
Nov 2012	p - Pb	3.5 (4.0) TeV proton E	10^{16}	Arm2
2014-2015	p - p	6.5+6.5 TeV	$9.0\ 10^{16}$	Arm1+Arm2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

Results: photons

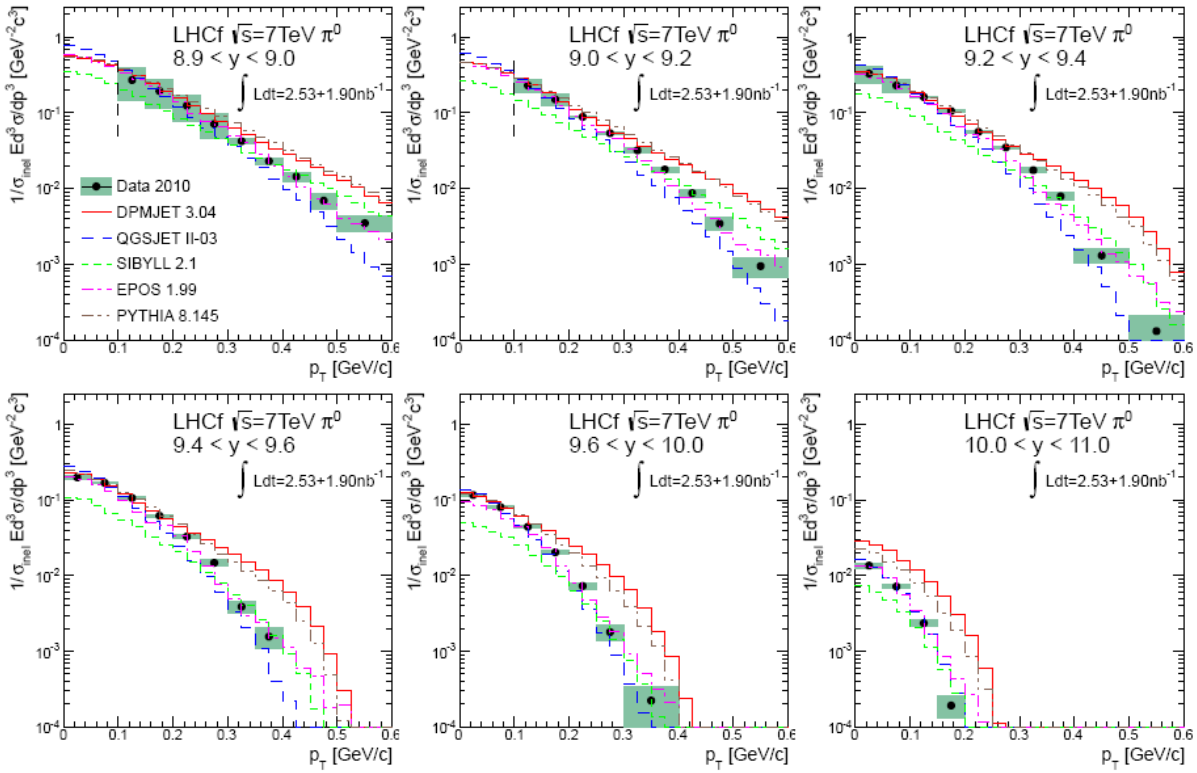


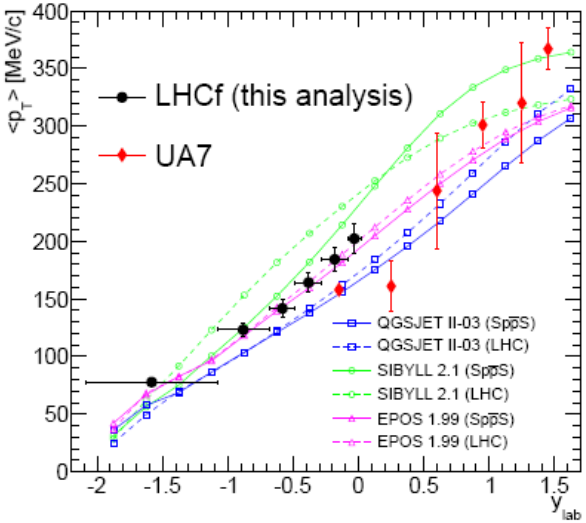


- 7 TeV: PLB 703, 128, 2011
- 900 GeV: submitted, *quite similar tendency to the 7 TeV*. Compared with 7 TeV (Arm1, the same p_T region selected) *Spectral shape is common*



Results: neutral pions





Averaged p_T for the 6 y region in the left plots

- Submitted (arXiv:1205.4578)
- EPOS shows the best agreement in the p_T distribution
- Next: neutron, γ full paper (p_T) ,,,

LHCf in pA runs: Letter of Intent

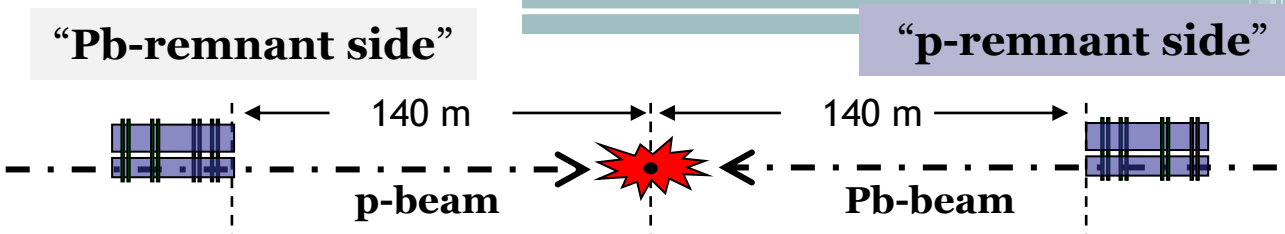
CERN-LHCC-2011-015 / LHCC-I-021

- Physics goals
  - model discrimination with a cosmic-ray point of view, by photons, neutral pions & neutrons
  - nuclear modification factor
  - inelasticity and others?

  How much data will be required?
- Also, 1 detector has only 2 calorimeter pads, so the particle *multiplicity* should be checked

=> Monte Carlo simulation study

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>

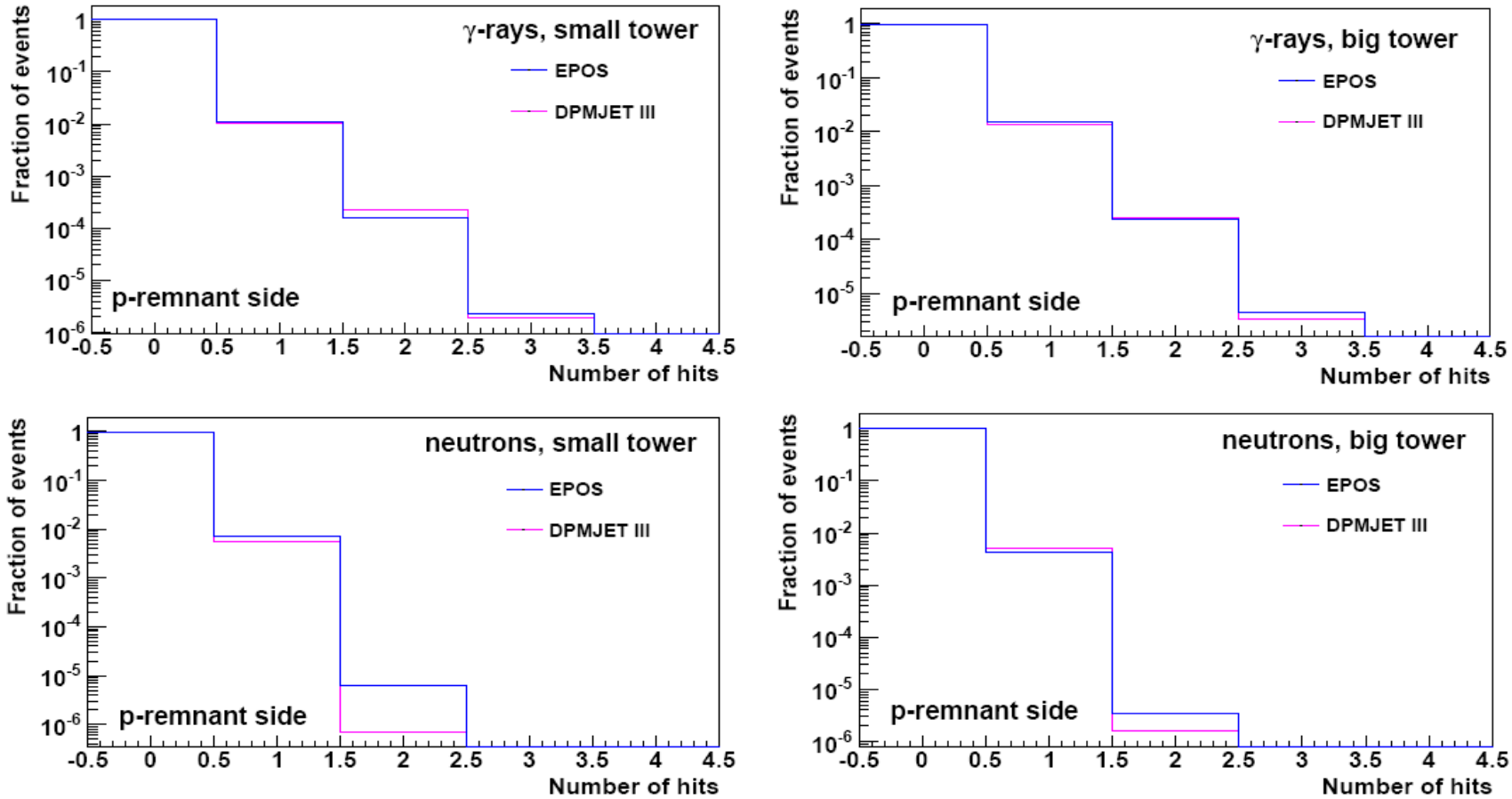
- Results are shown for DPMJET 3.0-5 and EPOS 1.99
- EPOS 1.99 does not consider Fermi motion and Nuclear Fragmentation. Be careful for the Pb-remnant side results
- QGSJET2 can be used for p-Pb collisions. Works in progress.
- Public version of other models (Sybill, HIJING, Pythia etc.) cannot be used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

multiplicity: p-remnant side

small tower | large tower

γ

n



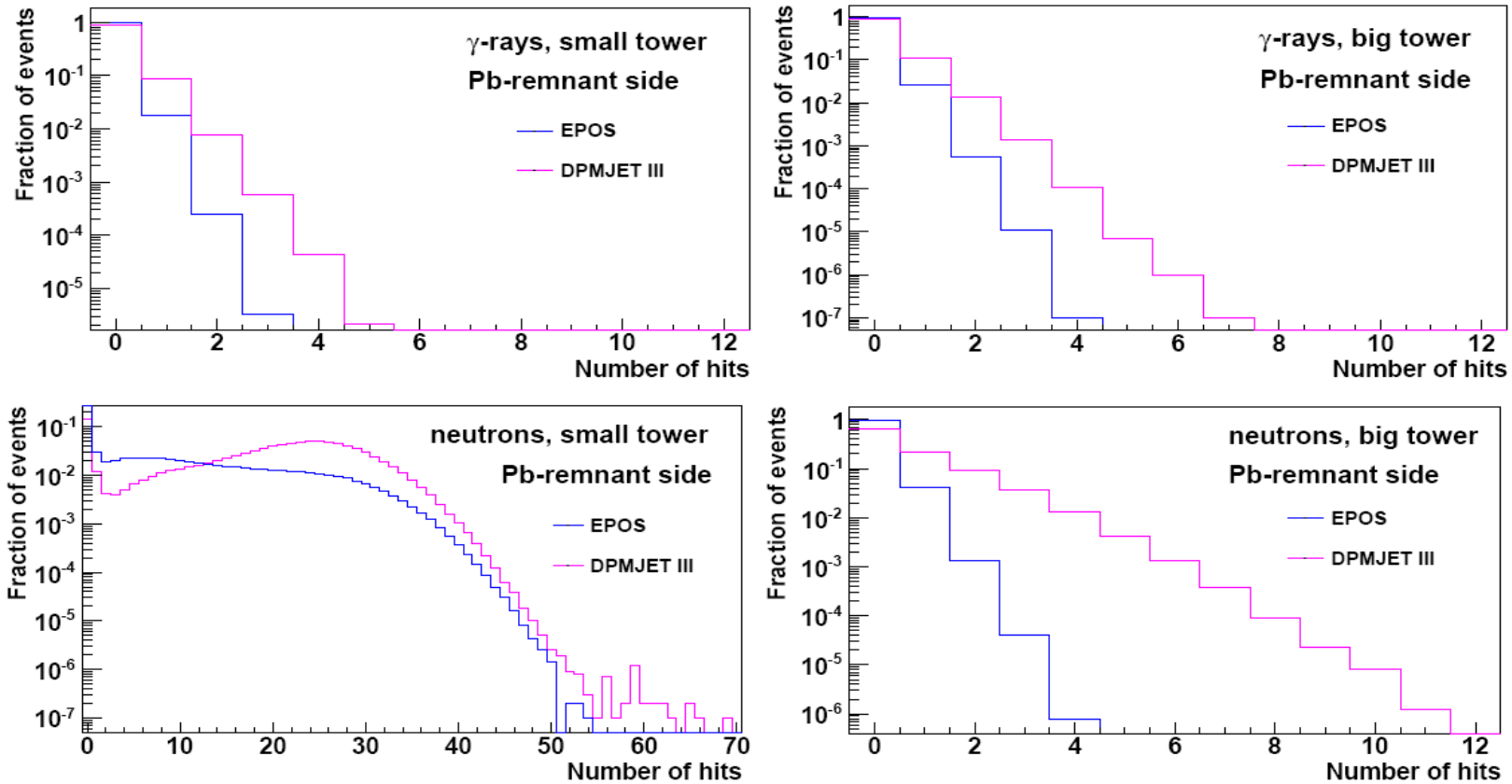
- multi-hit events are <~1% of single events

multiplicity: Pb-remnant side

small tower | large tower

γ

n



possibility of "(too) many neutrons" =>

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

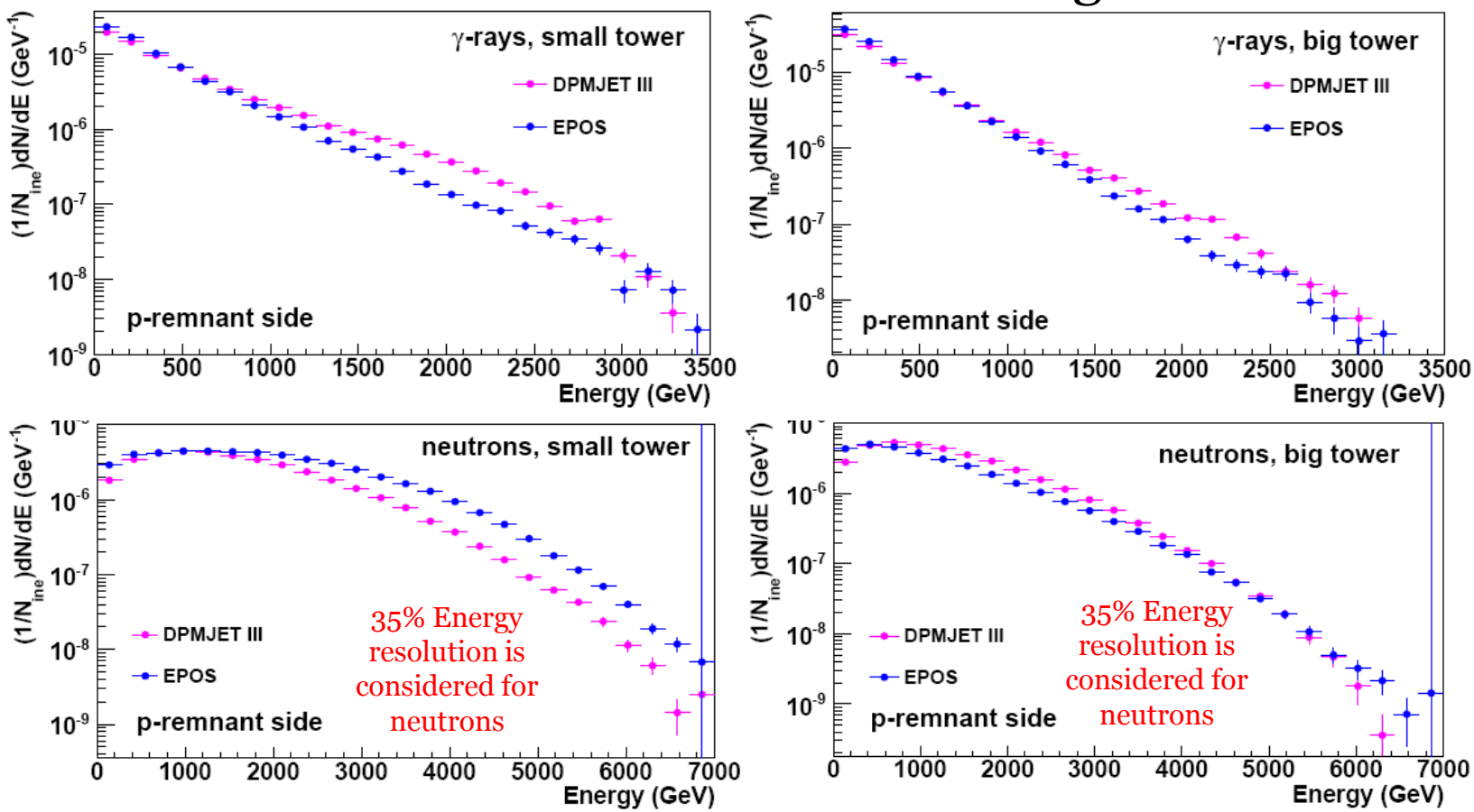
(no strong need to install both of the two detectors)

Expected spectra: p-remnant side

small tower | large tower

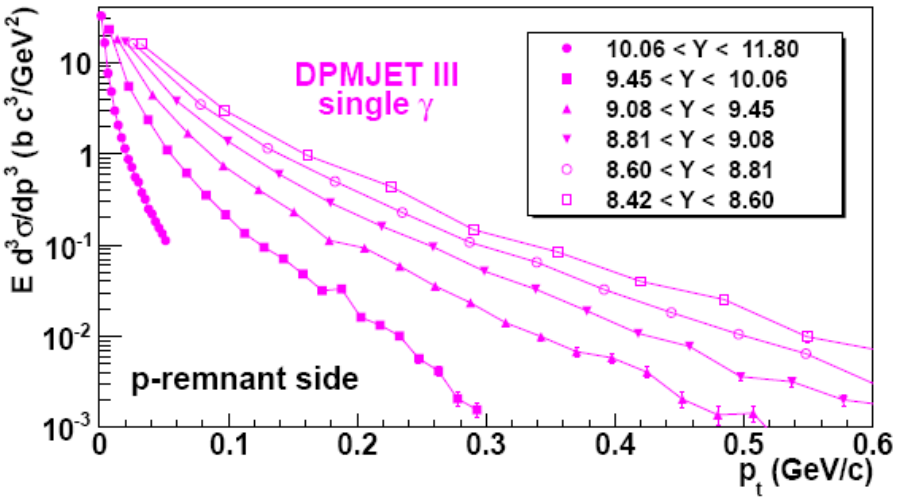
γ

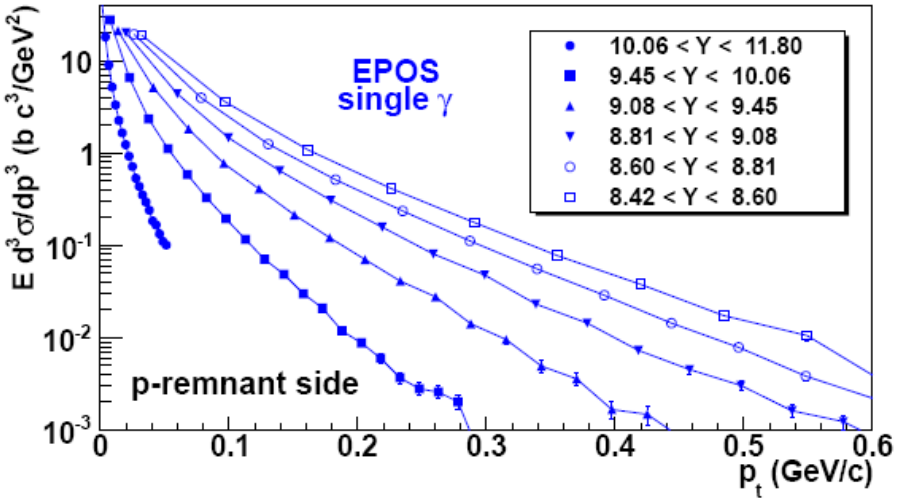
n



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

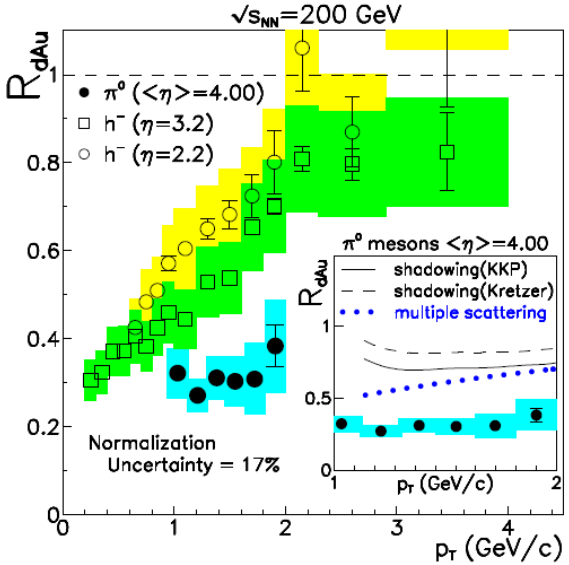
γ invariant cross section: p-remnant side



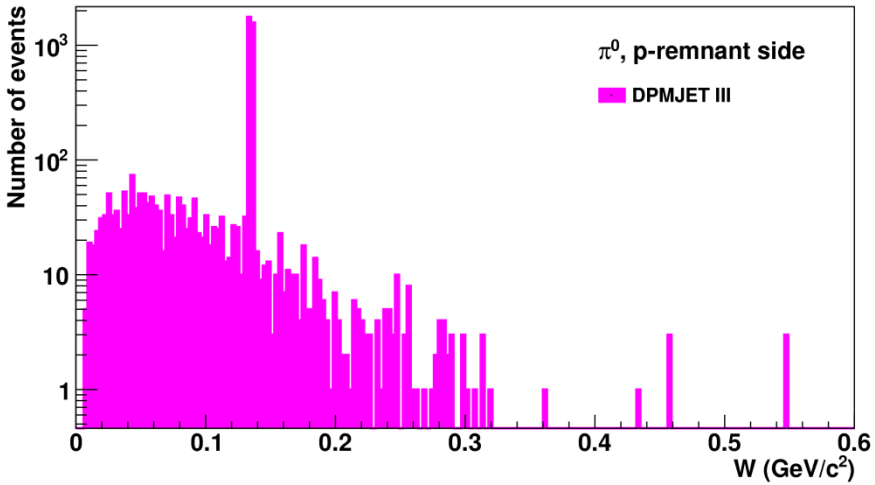


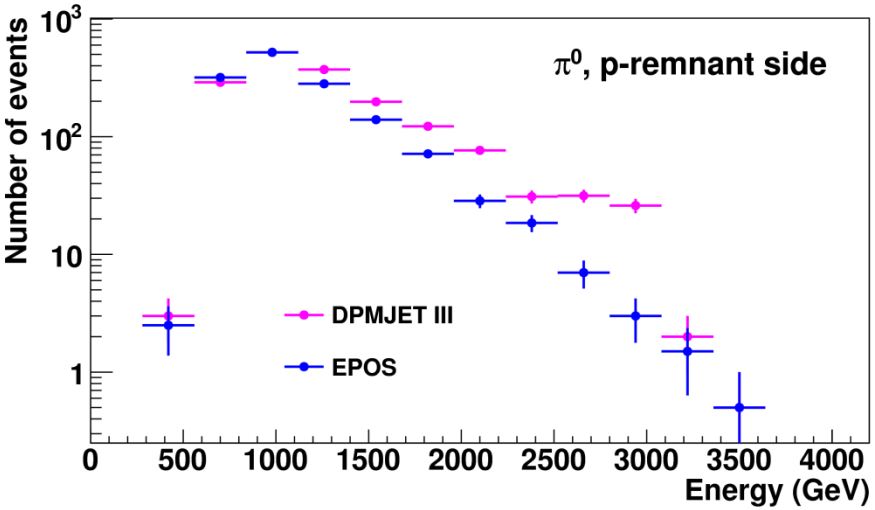
- Smooth enough with the same stat
- If the γ spectrum in 4.4 TeV pp collisions is measured (or estimated), we can derive the nuclear modification factor for η >8.4
- A big suppression reported for η=4

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

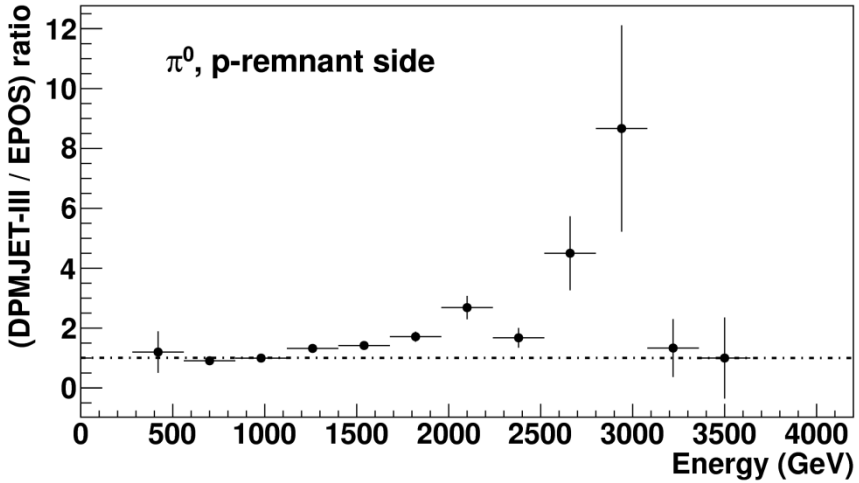


Neutral pions





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

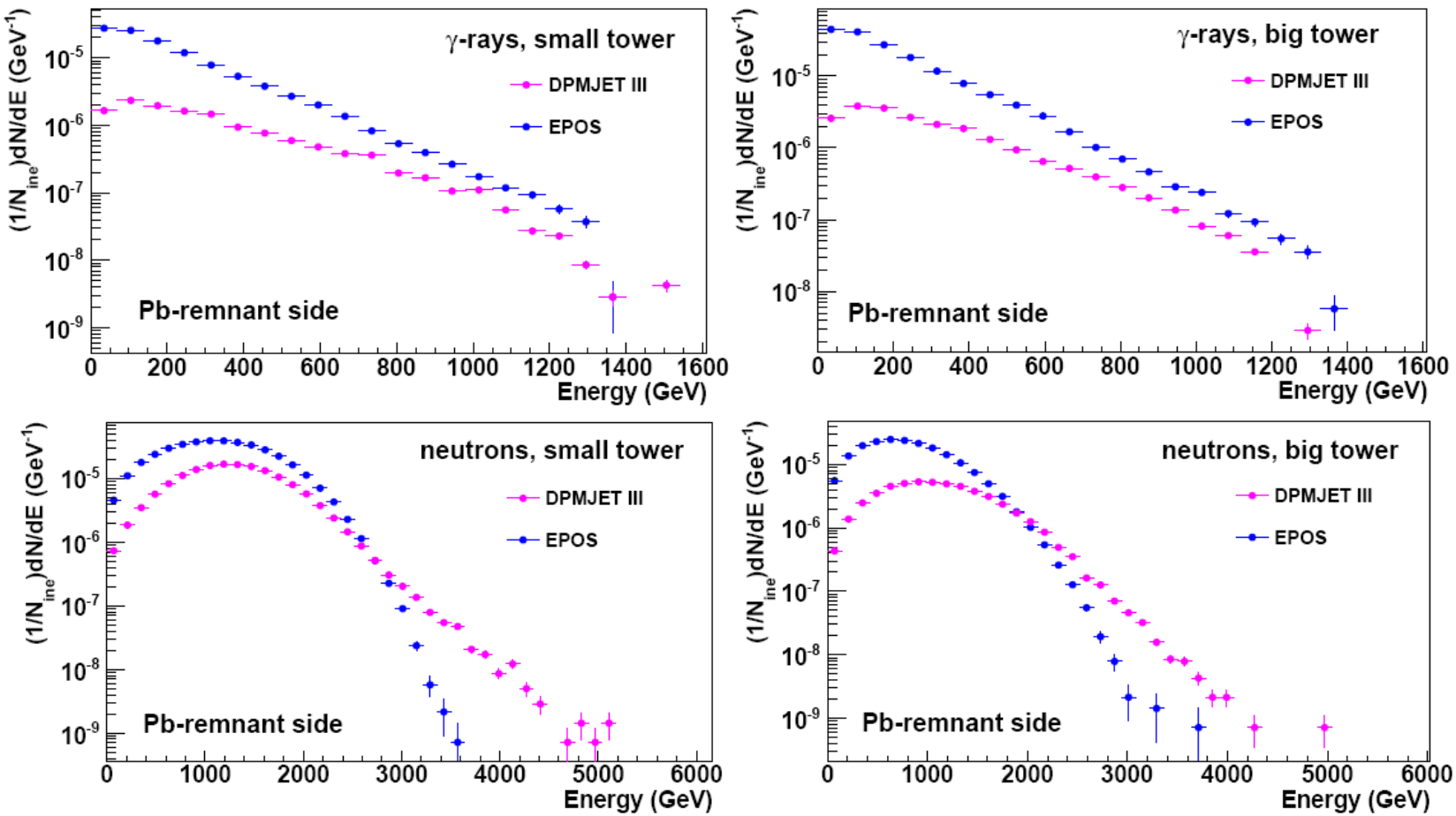


Expected spectra: Pb-remnant side

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!

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?

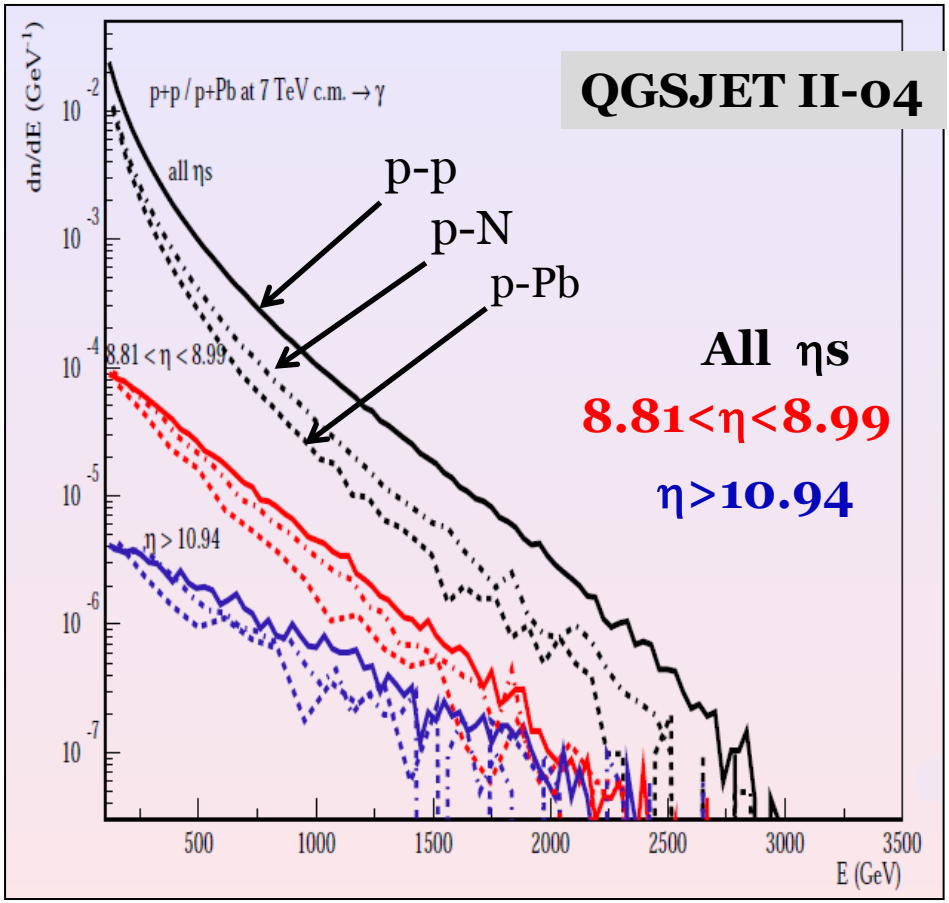
Summary

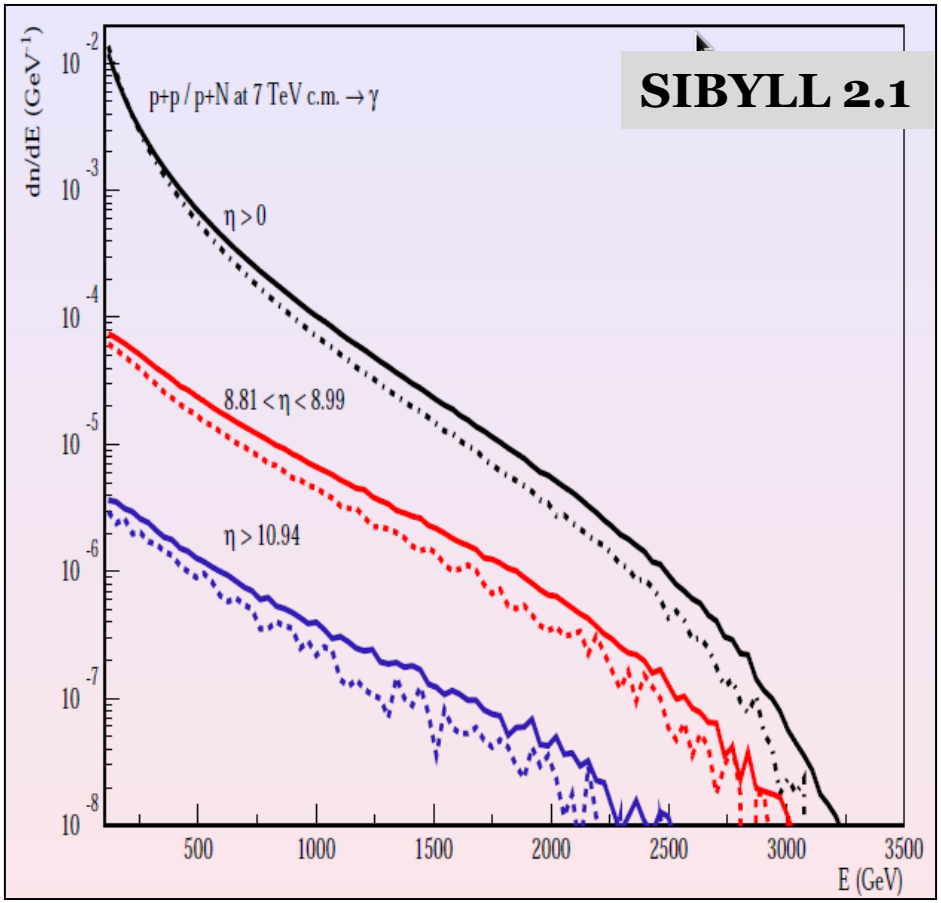
- LHCf: experiment for measurement of very forward neutral particles (γ, π^0,n), for the cosmic-ray physics
- Analyses show smooth spectra and the capability of discrimination of the models used in the CR MCs
- For pA runs, we will be back to take data:
  - for the model discrimination, and also for the other physics, such as NMF, inelasticity, etc.
  - by one detector (Arm2)
  - First in the p-remnant side, then in the Pb-side
- A possibility of the offline analysis combined with the ATLAS information is also discussed

backup

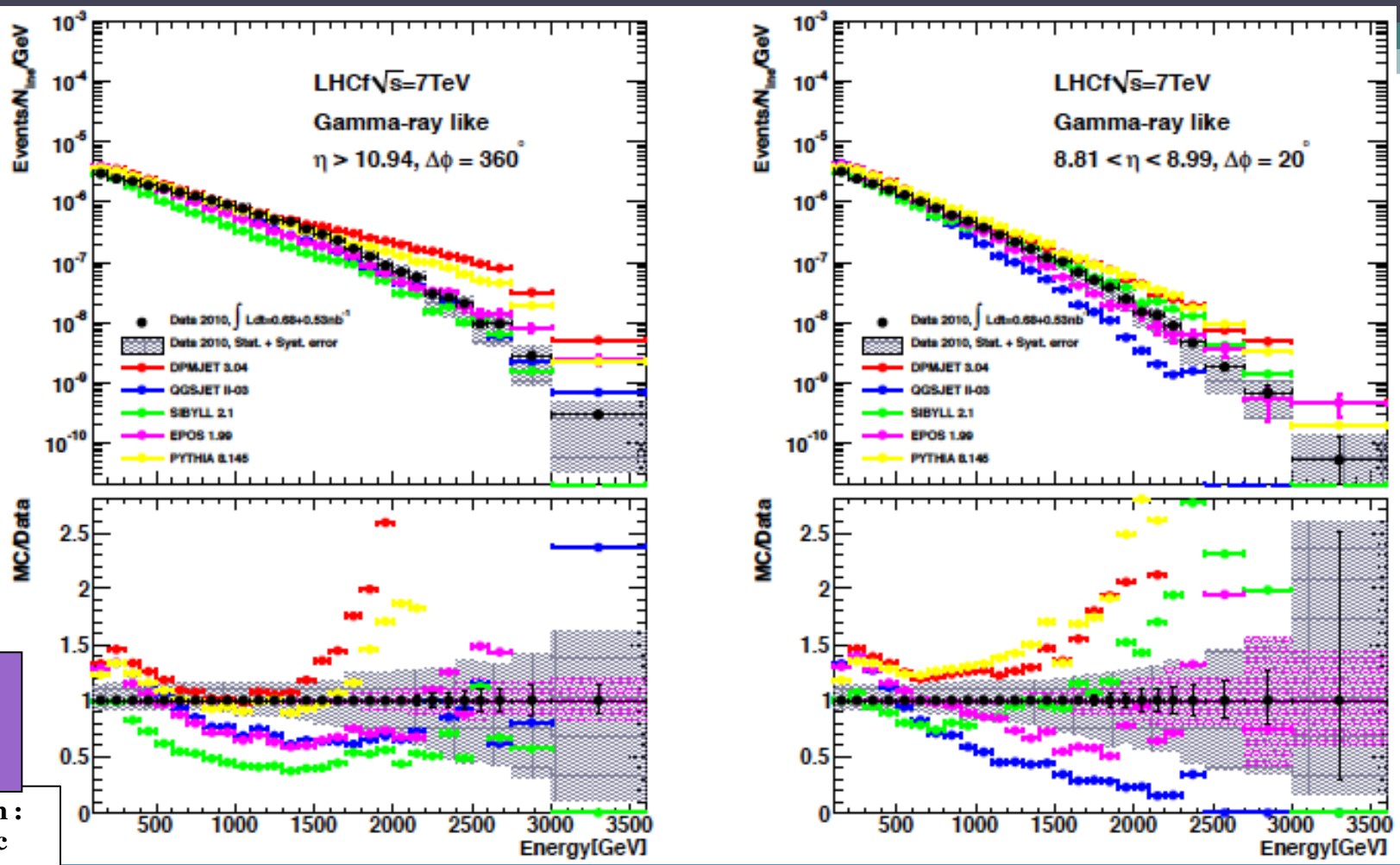
pPb is still useful for CR

- <u>γ spectrum</u> (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



Magenta hatch: MC Statistical errors

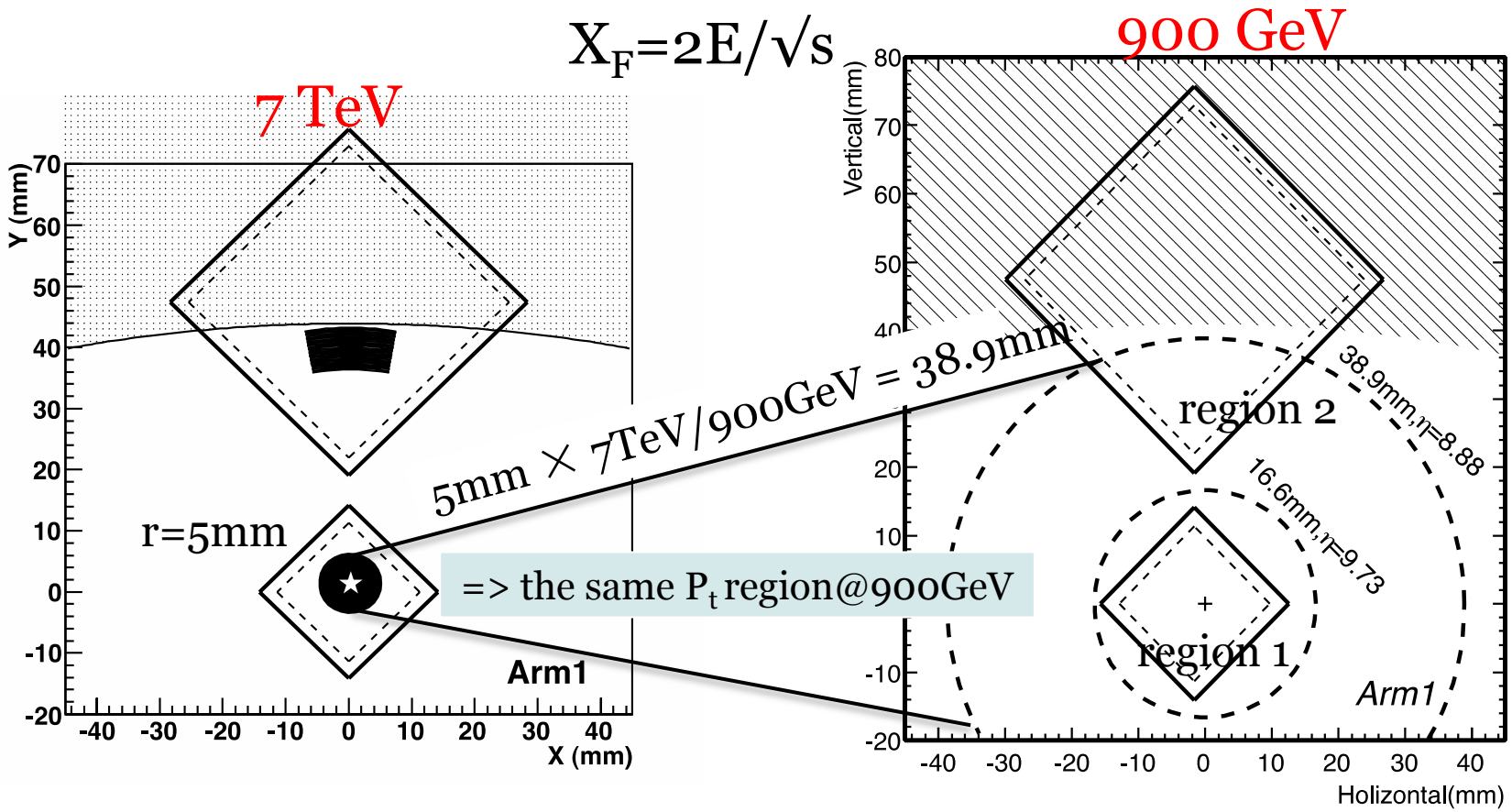
Gray hatch : Systematic Errors

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).**
- **Very big discrepancy in the high energy region**
- **Significant improvement of the models is possible by model developers**

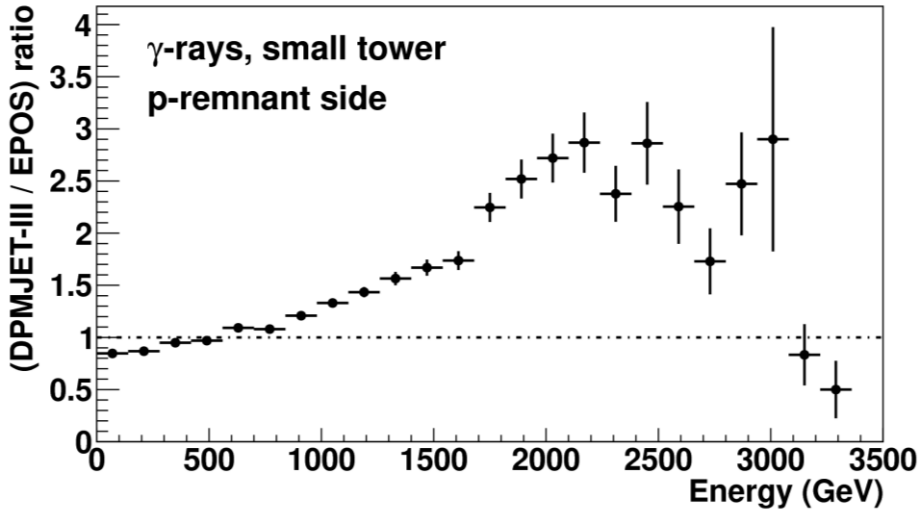
900 GeV - 7 TeV comparison

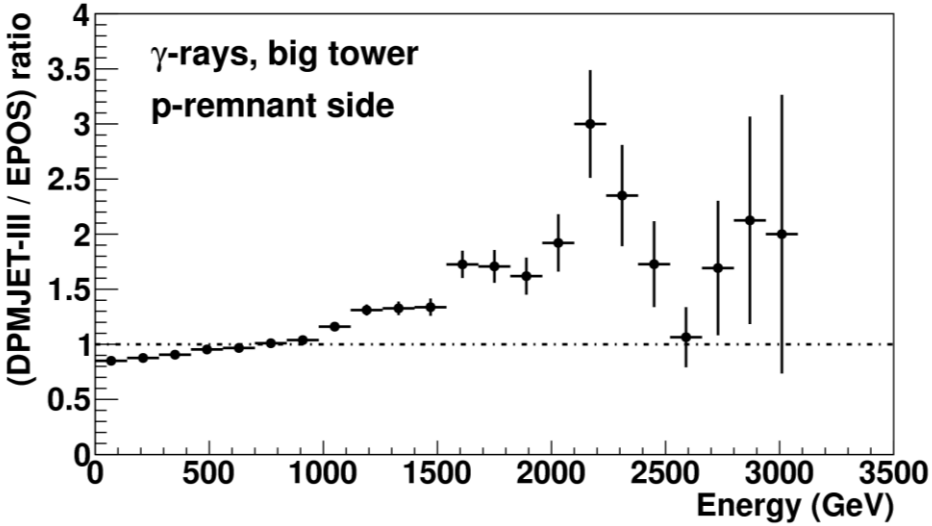
$X_F = 2E/\sqrt{s}$

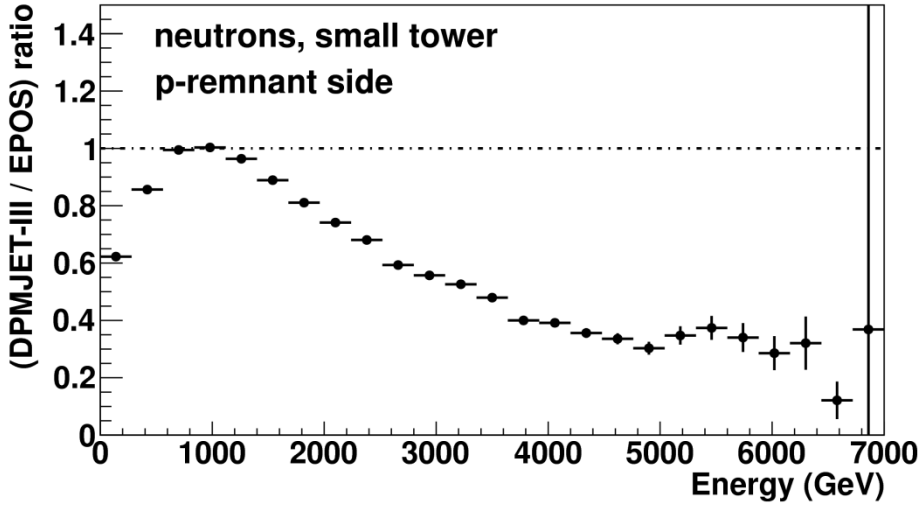


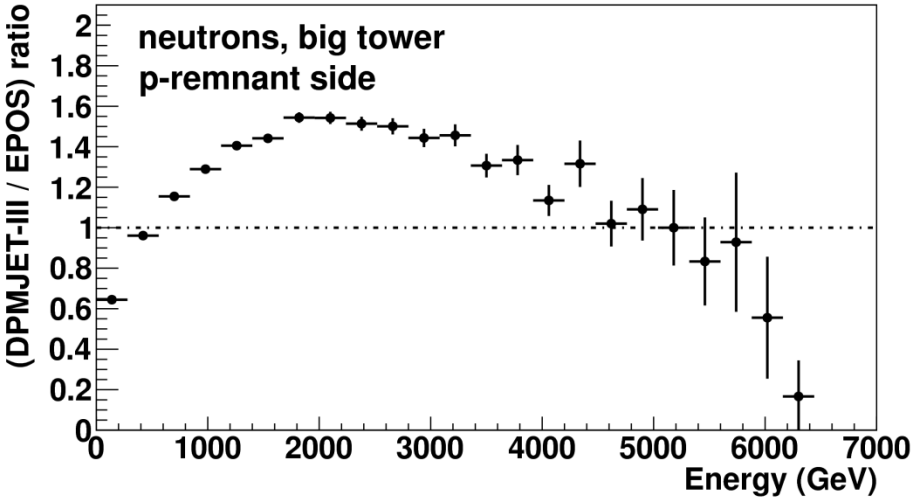
7TeV: only small tower ⟺ 900GeV:
(large ->region2)+(small -> region1)

Ratio plots: p-remnant

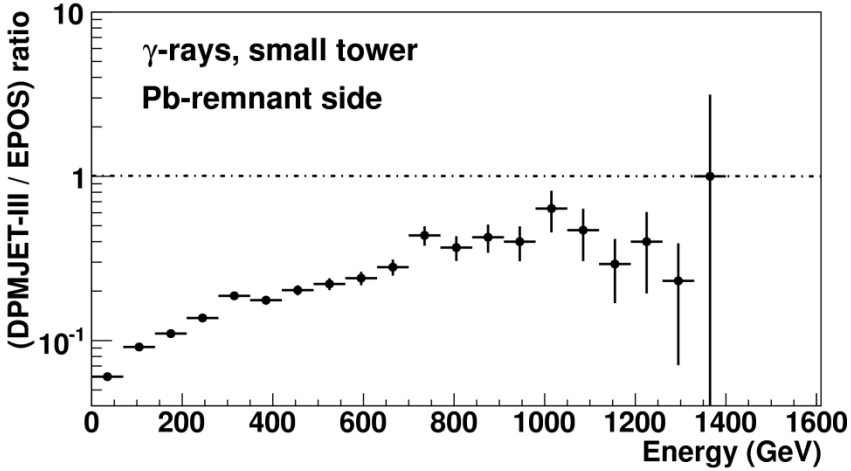


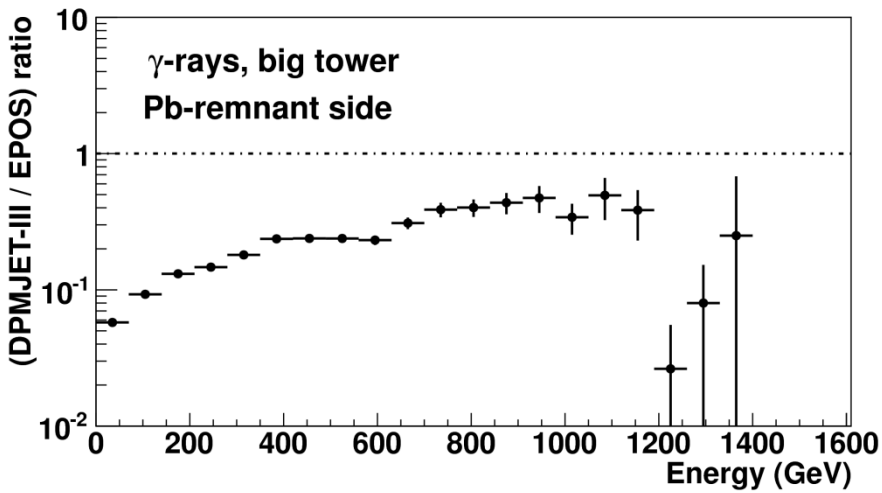


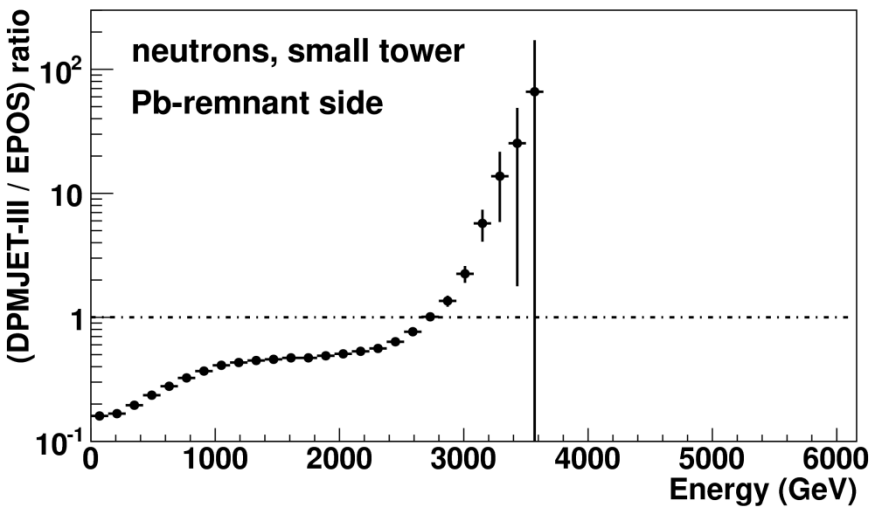


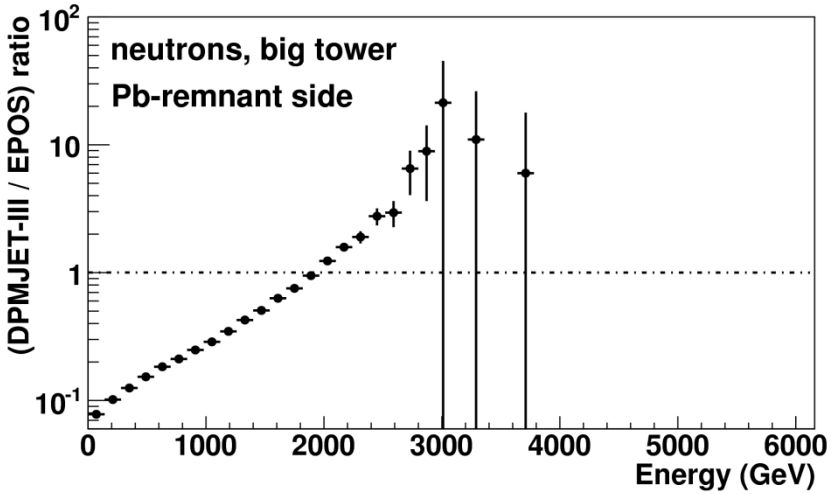


Ratio plots: Pb-remnant









misc

- PILE-UP effect
  - Around 3*10^-3 interactions per bunch crossing
  - 1% probability for one interaction in 500 ns (typical time for the development of signals from LHCf scintillators, after 200 m cables from TAN to USA15)
  - Some not interacting bunches required for beam-gas subtraction
- Radiation: <175 μSv per person (LTEX meeting, confId=188469 on the CERN indico)
- Max. Trigger rate: LHCf ~1KHz
- formula of NMF

$$R^{Y}_{\mathrm{dAu}} = \frac{\sigma^{pp}_{\mathrm{inel}}}{\langle N_{\mathrm{bin}} \rangle \sigma^{dAu}_{\mathrm{hadr}}} \frac{E\, d^3\sigma/dp^3(d + Au \rightarrow Y + X)}{E\, d^3\sigma/dp^3(p + p \rightarrow Y + X)}$$