# LHCf Status
# Letter of Intent for p/Pb run

Oscar Adriani
University of Florence & INFN Firenze
On behalf of the LHCf Collaboration

December 7th, 2011

# Introduction and Contents

- LHCf expression of interest for proton/Lead 2012 run
  - Presentation at the LPCC meeting on October 17th, 2011
  - Contact with Atlas management
- Letter of Intent submitted to LHCC on December 4th, 2011
  - CERN-LHCC-2011-015/LHCC-I-021 04/12/2011

**LHCf**

**Letter of Intent for a p-Pb run**

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**A precise study of forward physics in $\sqrt{s_{NN}} = 4.4$ TeV proton-Lead ion collisions with LHCf at the LHC**

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CERN-LHCC-2011-015 / LHCC-I-021
04/12/2011

- In this presentation:
- Expected performances and physics results
- Short summary on the status of the LHCf upgrade

# Few details about the LHCf Arm2 detector

## Sampling and imaging E.M. calorimeter

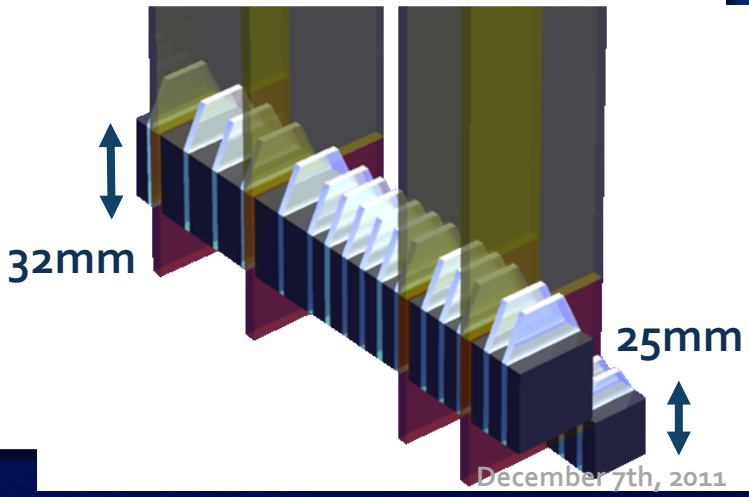
- Absorber: W (**44 r.l** , 1.55$\lambda_I$ )
- Energy measurement: plastic scintillator tiles
- 4 tracking layers for imaging:
  **XY-Silicon strip(Arm#2)**
- **Each detector has two calorimeter towers, which allow to reconstruct $\pi^0$**

**Performances**

Energy resolution (> 100 GeV):
**< 3% for 1 TeV photons and ~ 30% for neutrons**
Position resolution for photons:
**~ 40μm (Arm#2)**

## Front Counters

- thin scintillators 80x80 mm²
- **monitoring of beam condition**
- **Van der Meer scan**



# LHCf physics program for p-Pb run

WHY

Important information for the study of the **interaction of UHECR in the Earth atmosphere**

- Comparison with **hadronic interaction models**
- Study of the **Nuclear Modification Factor**
- Inelasticity

HOW

**Precise measurement of** of E, $\eta$ and $p_T$ distributions **for pseudo-rapidity $\eta$ > 8.4** both for p and Pb remnant

- **Single $\gamma$**
- **Neutral pions**
- **Neutrons**

# Global LHCf physics program

LHCf measurement for p-Pb interactions at 3.5TeV proton energy could be easily and finely integrated in the LHCf global campaign.

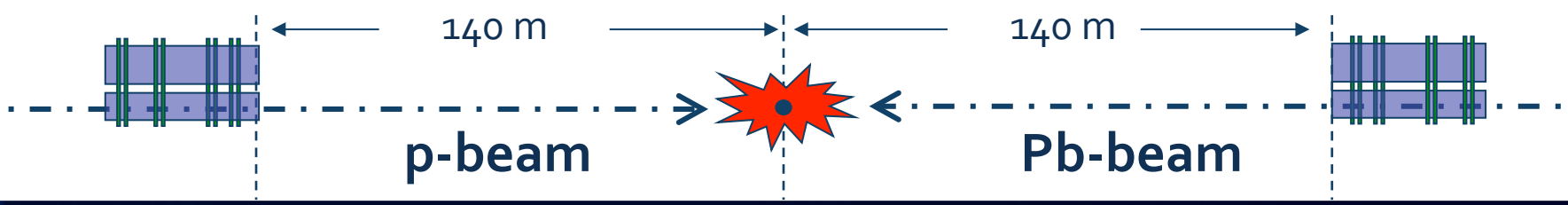
| Period | Type | Beam energy | LAB proton Energy (eV) | Detector |
|---|---|---|---|---|
| 2009 | p - p | 450+450 GeV | $4.3\ 10^{14}$ | Arm1+Arm2 |
| 2009/2010 | p - p | 3.5+3.5 TeV | $2.6\ 10^{16}$ | Arm1+Arm2 |
| 2012 | p – Pb | 3.5 TeV proton E | $10^{16}$ | Arm2 |
| 2014 | p - p | 7+7 TeV | $10^{17}$ | Arm1+Arm2 upgraded |

# What LHCf can measure in the p+Pb run (1)
# E, $p_T$, η spectra of neutral particles

- We are simulating protons with energy $E_p$ = 3.5 TeV
  - Energy per nucleon for ion is $E_N = \frac{Z}{A} E_p = 1.38\ \mathrm{TeV/nucleon}$
  - $\sqrt{s_{NN}} = 4.4\,\mathrm{TeV}$
- **"Arm2" geometry** considered on both sides of IP1 to study both p-remnant side and Pb-remnant side
- No detector response introduced yet (only geometrical considerations and energy smearing)
- $\sigma_{ine}$=2 barn, following Michelangelo suggestion

**"Pb-remnant side"**

**"p-remnant side"**



# Models used in the p/Pb simulations

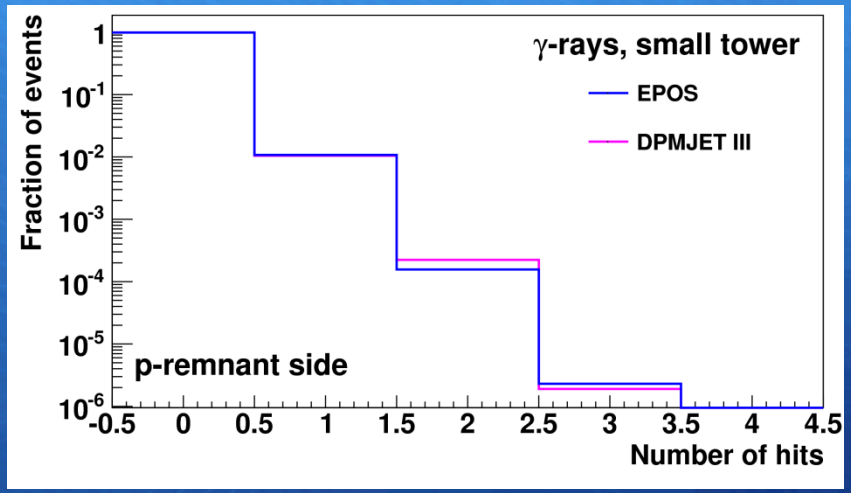
- Results are shown for **DPMJET 3.0-5** and **EPOS 1.99**
  - $10^7$ events each
- **EPOS 1.99** does not consider Fermi motion and Nuclear Fragmentation
  - Some caveat for the Pb remnant side results.....
- **QGSJET2** can be used for p/Pb collisions
  - Work in progress, coming soon....
- Public version of other models (Sybill, HIJING, Pythia etc.) can not be used for p/Pb collisions at TeV scale!

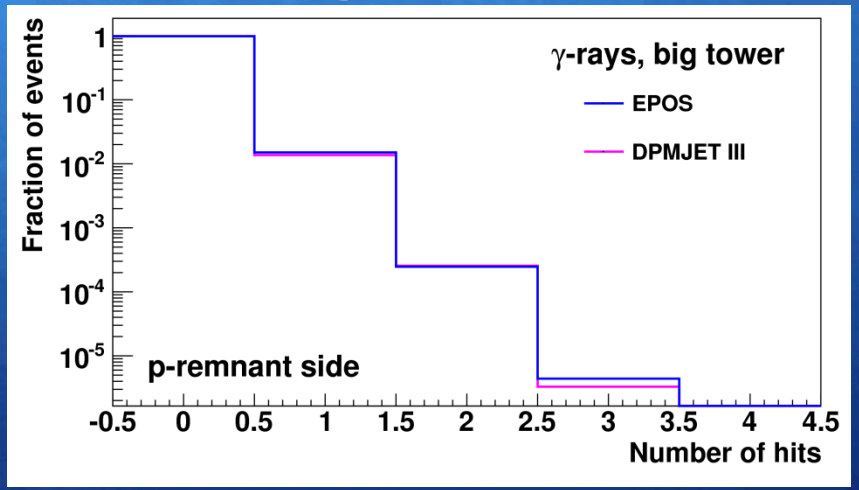
# Proton-remnant side - **multiplicity**

## Small tower

## Big tower

γ

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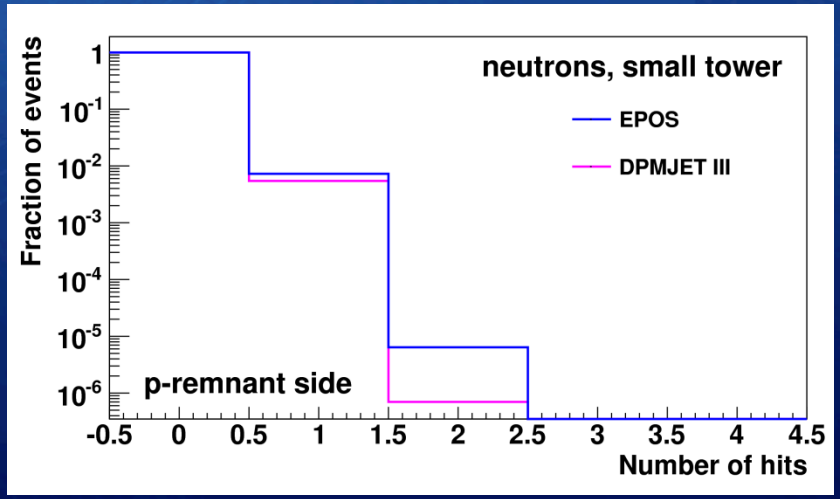
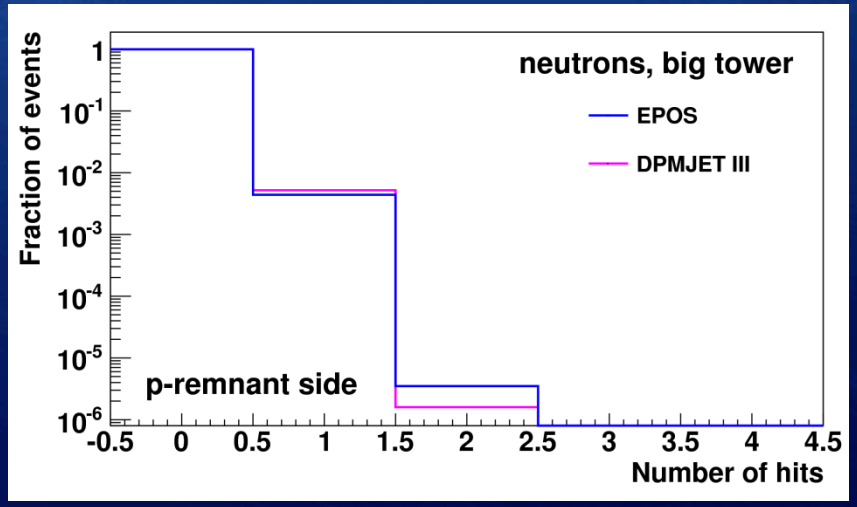
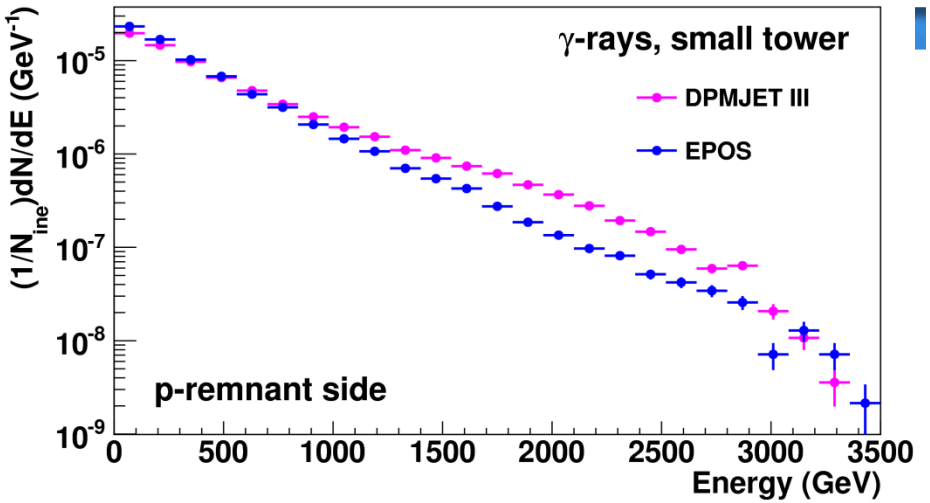


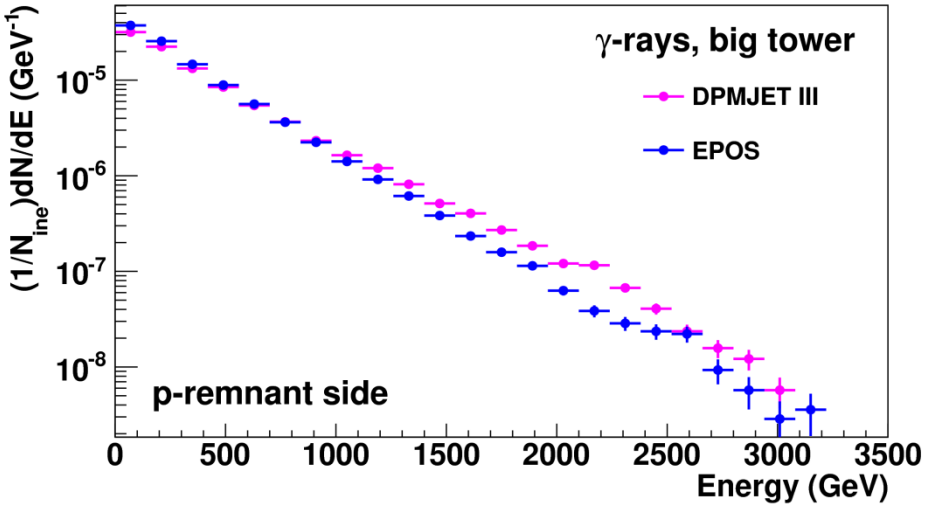



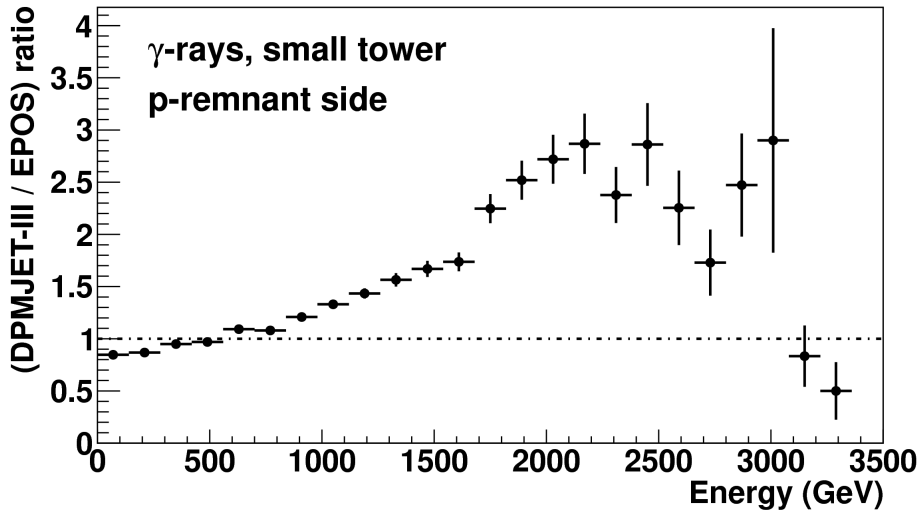
# Proton-remnant side – **photon spectrum**

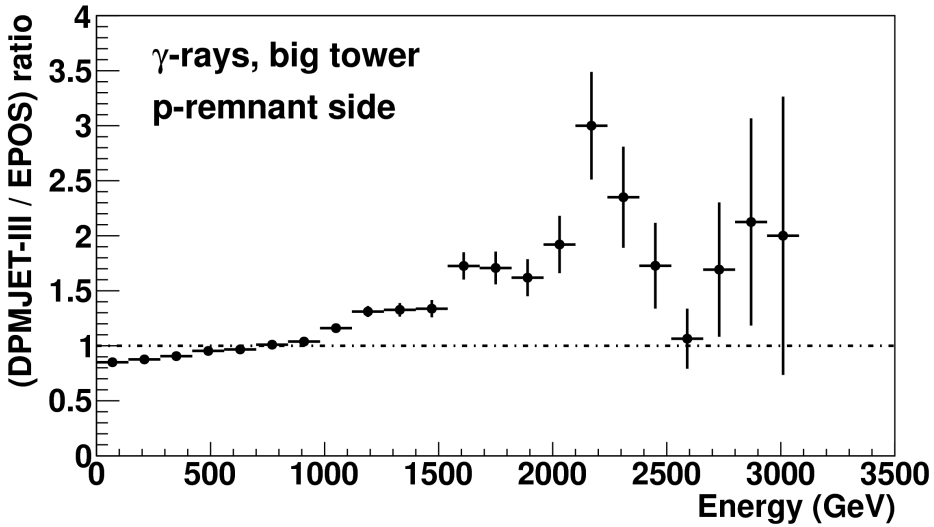
## Small tower




## Big tower



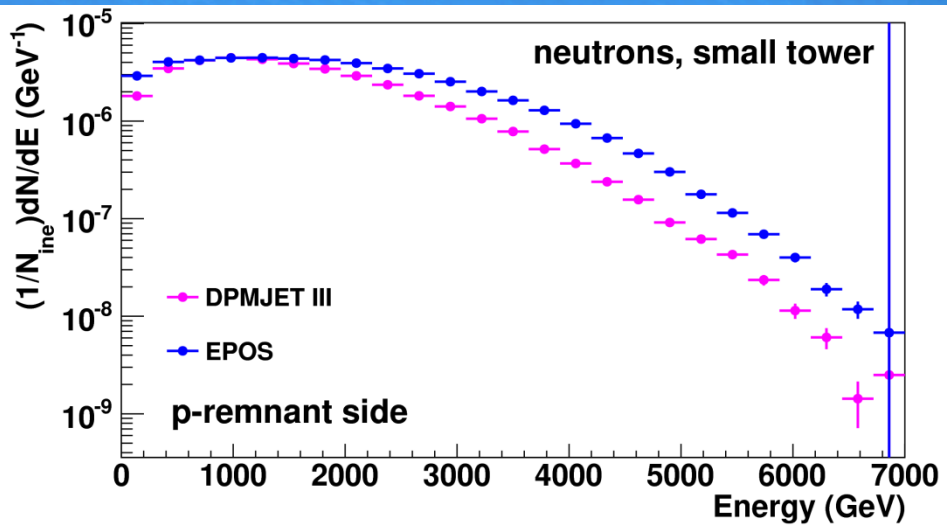



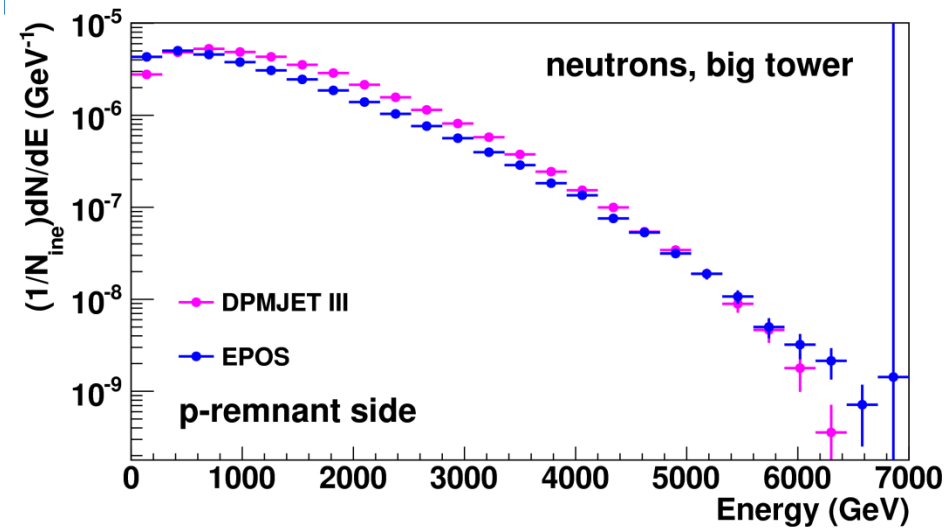



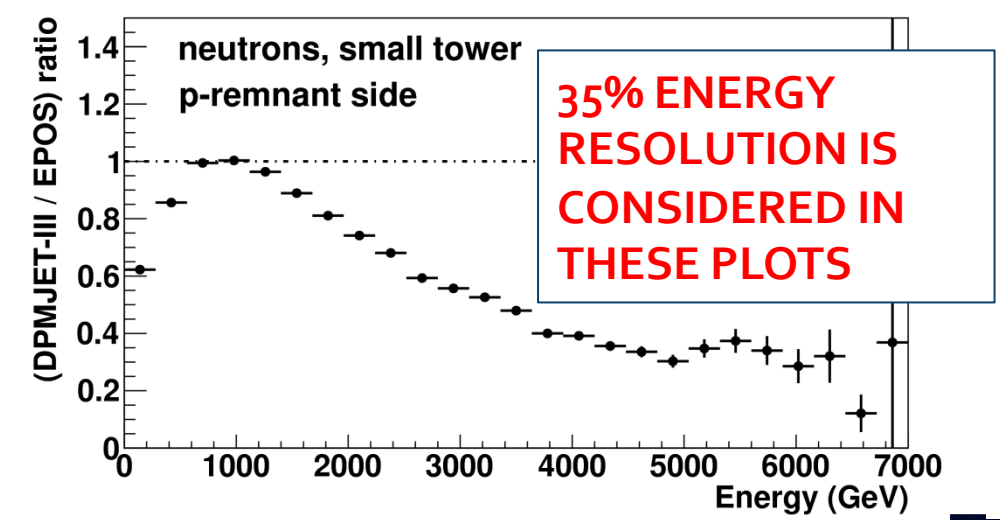
# Proton-remnant side – **neutron spectrum**

## Small tower

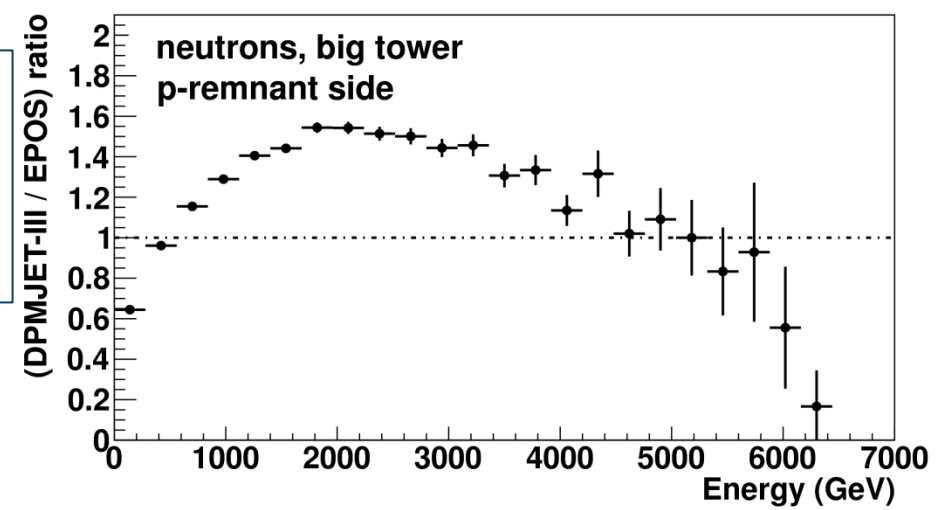
## Big tower



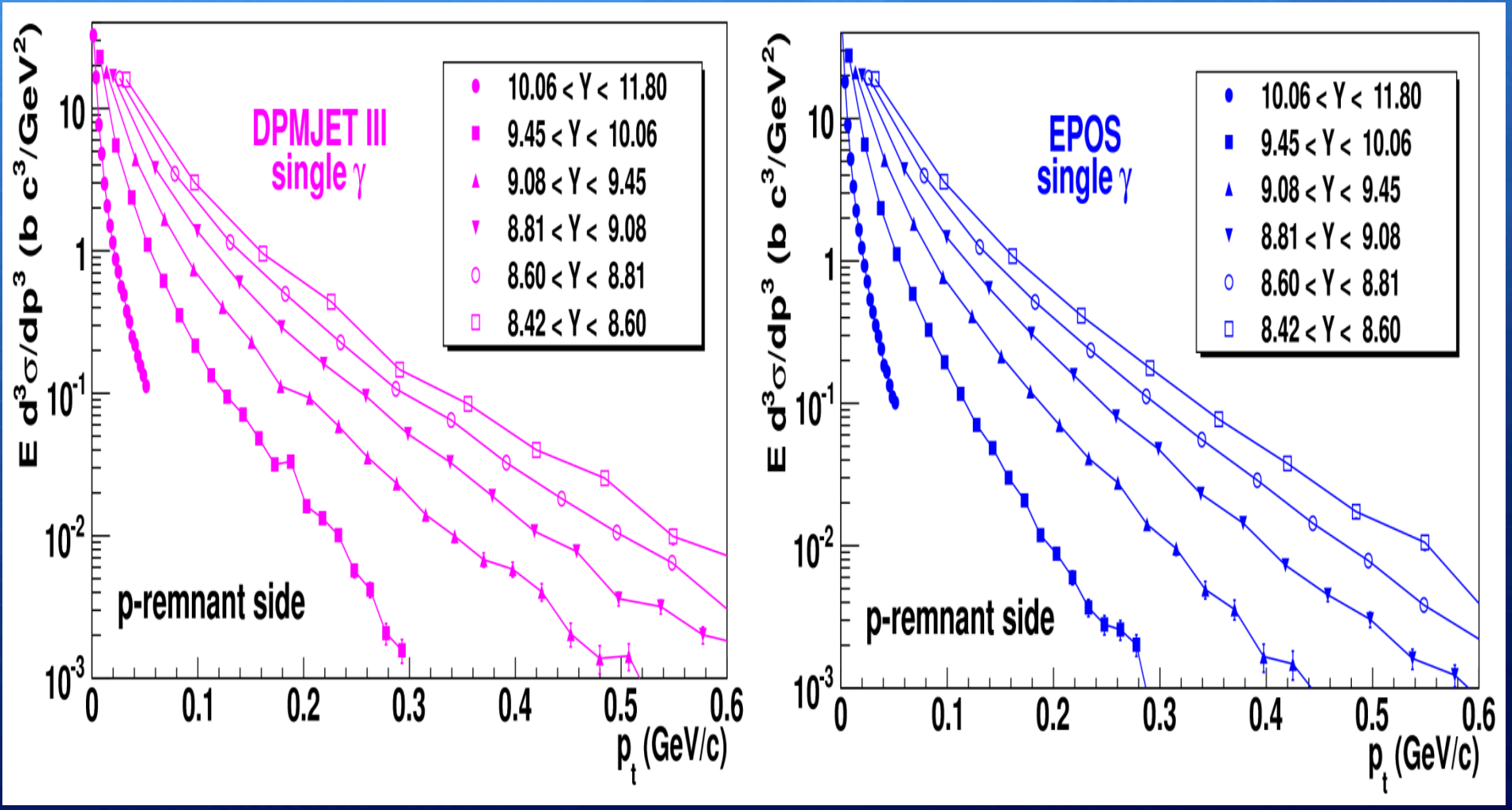



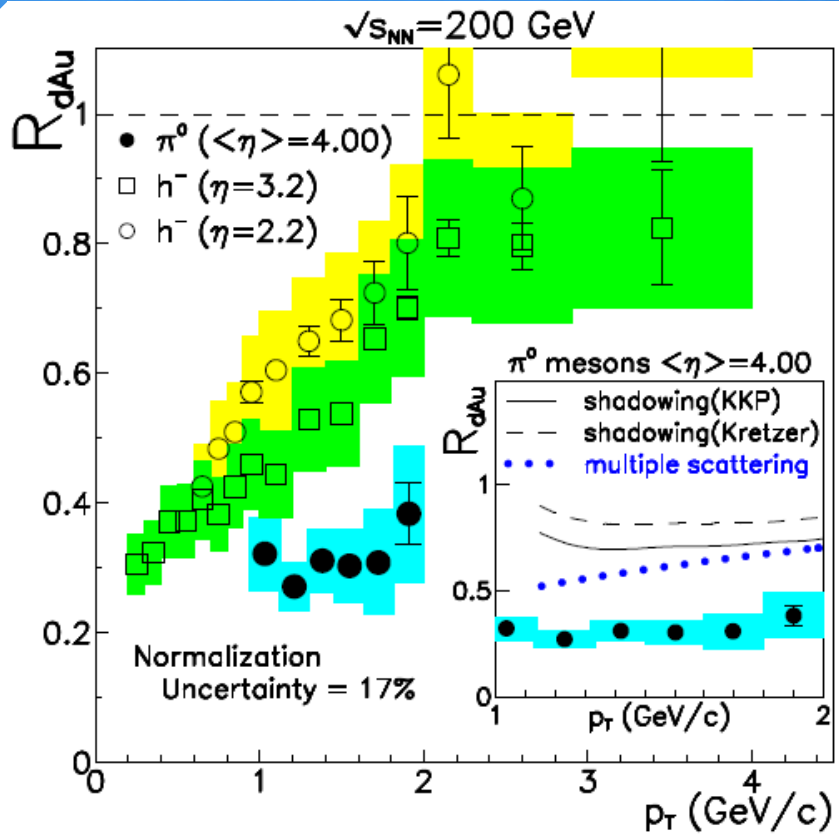

35% ENERGY RESOLUTION IS CONSIDERED IN THESE PLOTS



# Proton remnant side –
# **Invariant cross section for isolated γ-rays**



# What LHCf can measure in the p+Pb run (2)
# Study of the Nuclear Modification Factor



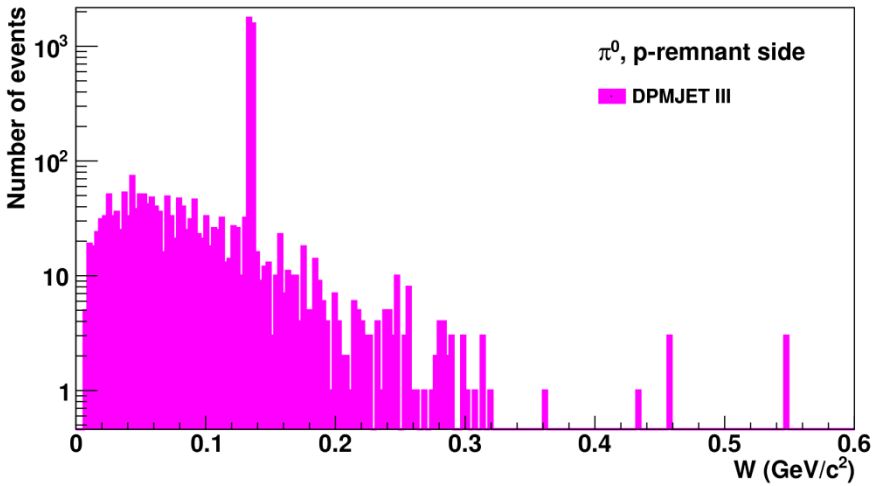

<u>Nuclear Modification Factor</u> measured at **RHIC** (production of $\pi^0$): strong suppression for small $p_t$ at **<η>=4**.

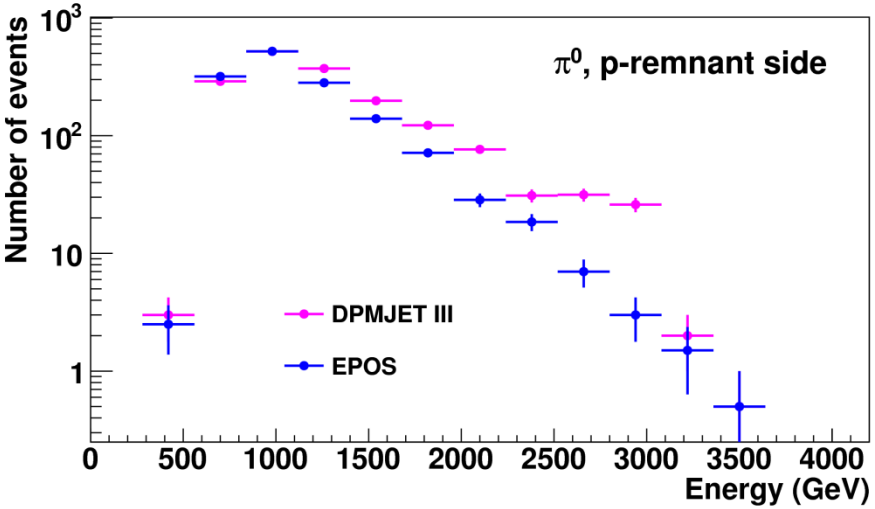
**Phys. Rev. Lett. 97 (2006) 152302**

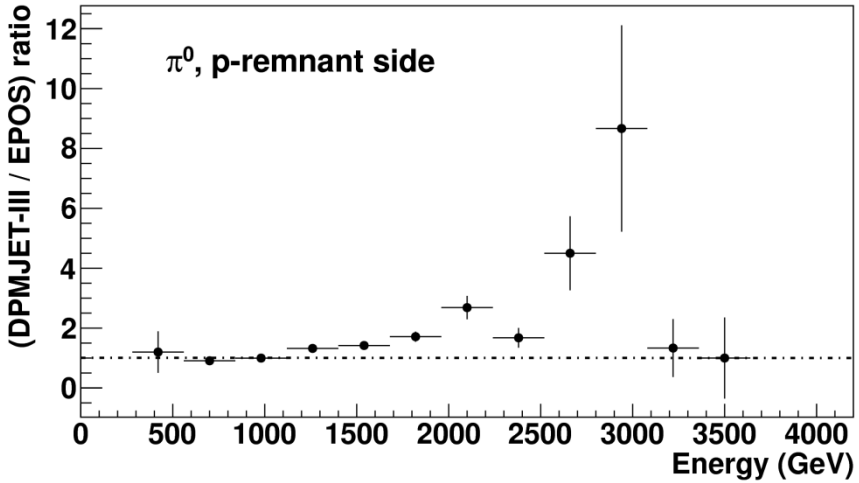
**LHCf** can extend the measurement at higher energy and for **η>8.4**
**Very important for CR Physics**

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

# Proton-remnant side – $\pi^0$




We can detect $\pi^0$!
Important tool for energy scale
And also for models check.....

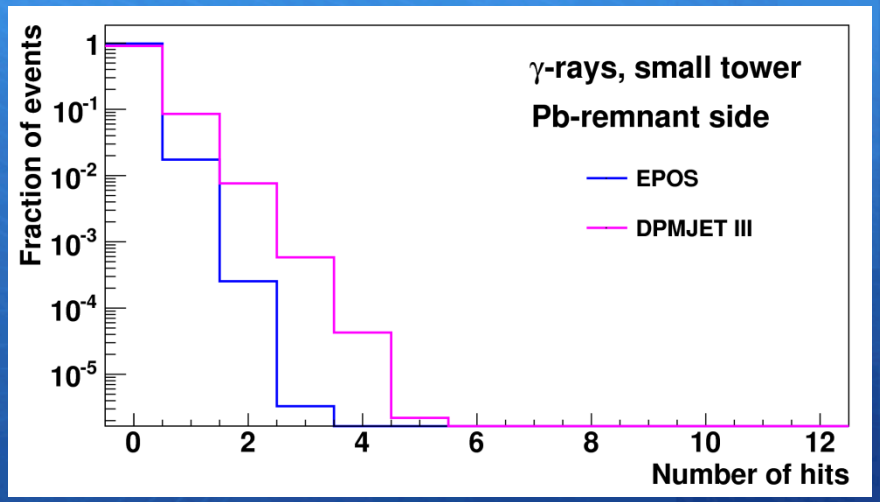
# Lead-remnant side – **multiplicity**

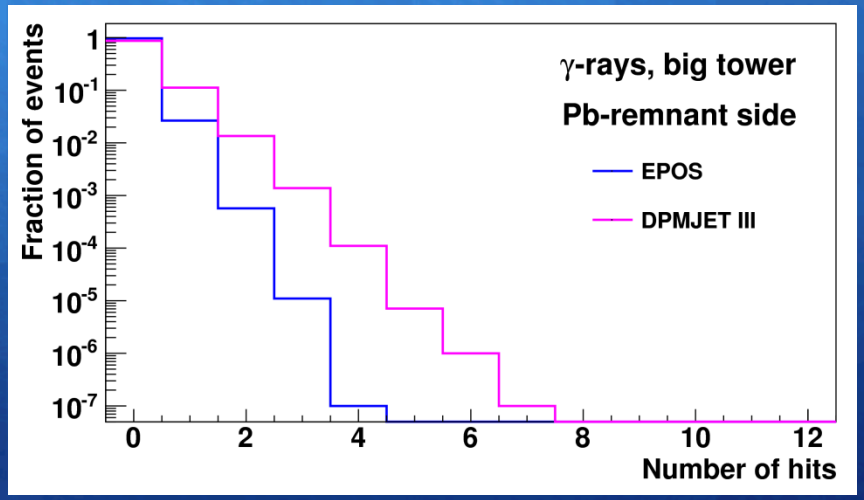
**Please remind that EPOS** does not consider Fermi motion and Nuclear Fragmentation

## Small tower

## Big tower

γ

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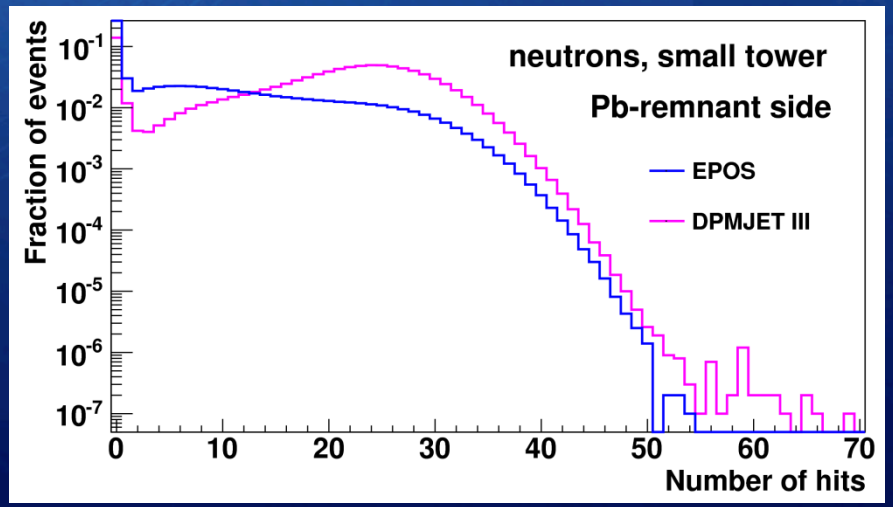
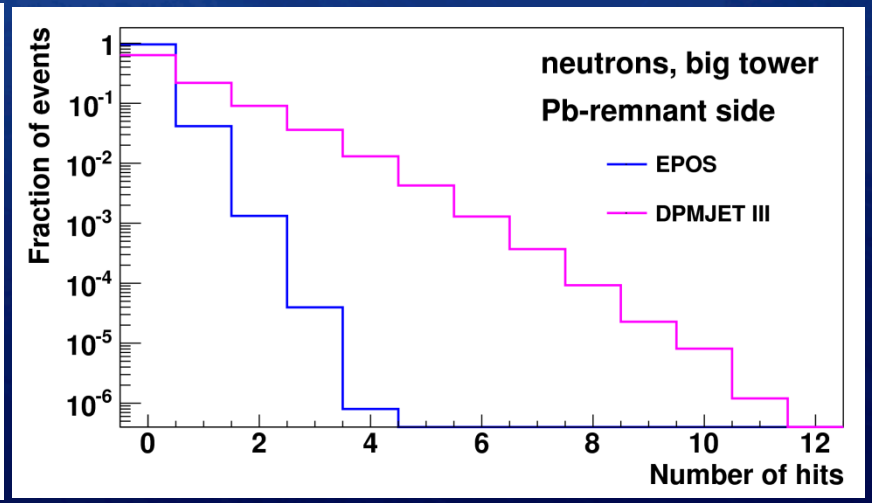
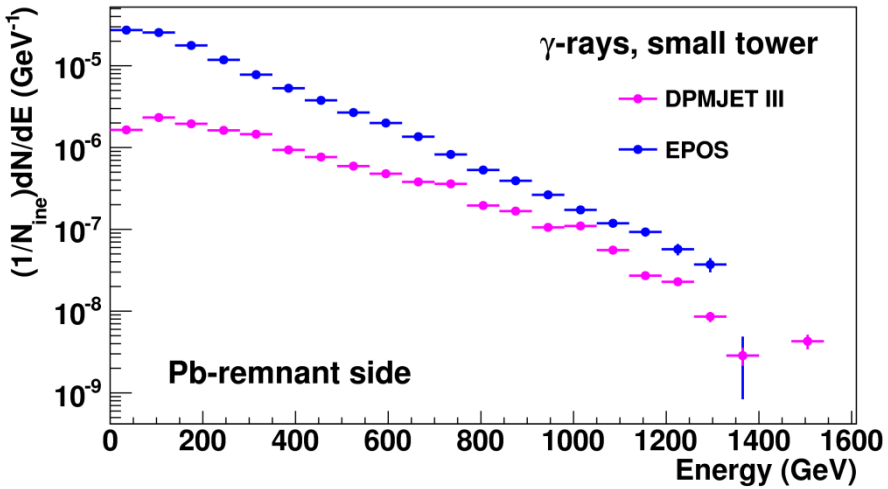


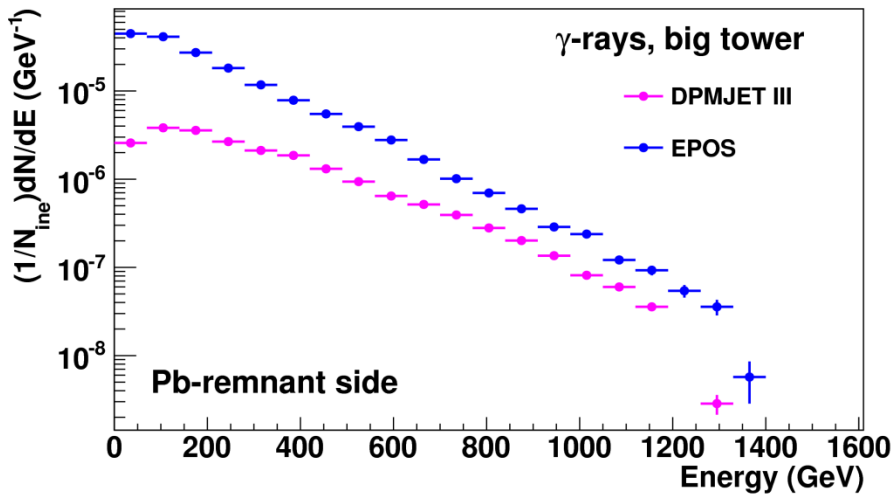



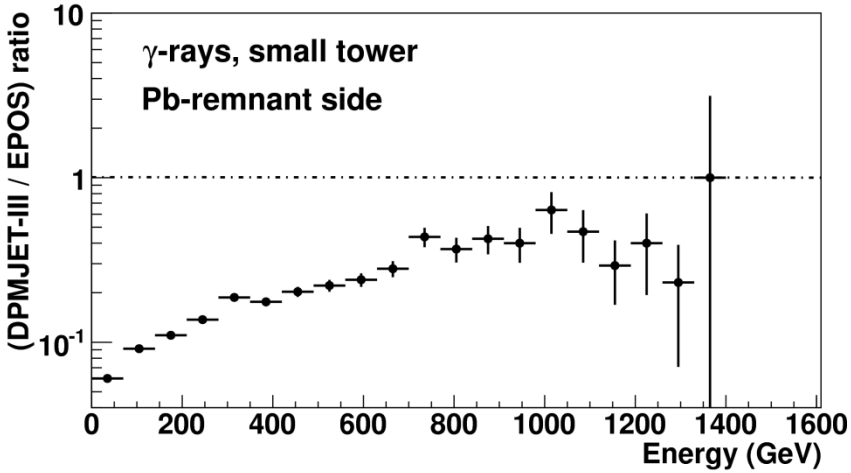
# Lead-remnant side – **photon spectrum**

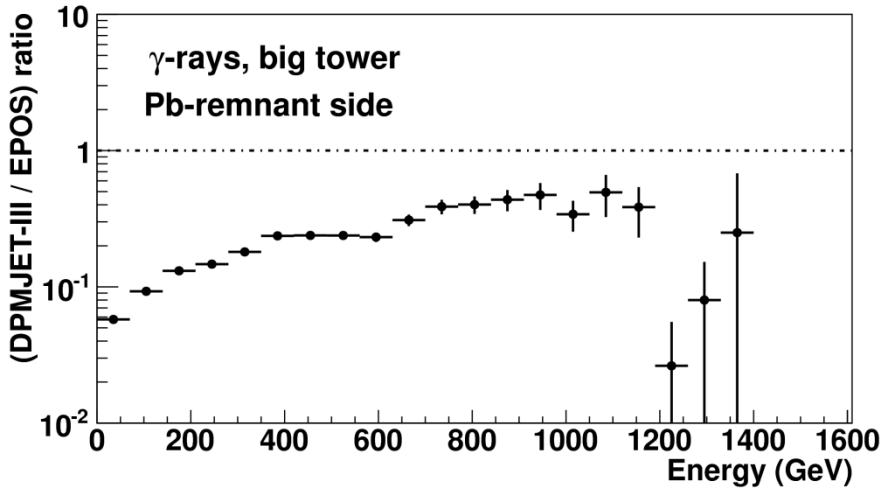
## Small tower

## Big tower



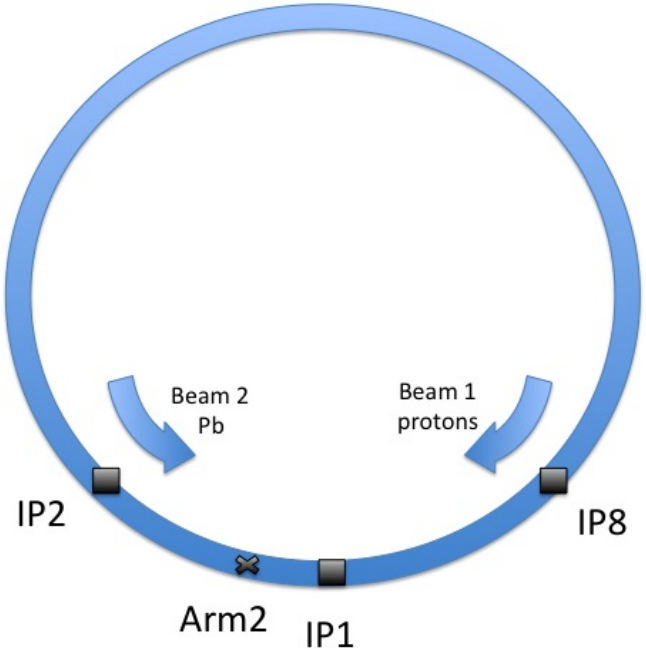



# LHCf plans for the p/Pb run

- We require to run with **only one detector**
  - Arm2 (W/scint. e.m. calorimeter + μ-strip silicon)
  - Only on one side of IP1 (on IP2 side, compatible with the preferred machine setup: Beam1=p, Beam2=Pb)
    - Minimal interference with Atlas
    - Installation during the technical shutdown at the end of the p/p 2012 run
    - Technical details to be agreed with Atlas, LHC, Radio-protection etc.



# Some estimations based on reasonable machine parameters….

- Considering machine/physics parameters:
  - Number of bunches, **n = 590** (150 ns spacing)
  - Luminosity up to **$10^{28}$ $cm^{-2}s^{-1}$**
  - Interaction cross section **2 barn**
- **PILE-UP** effect
  - Around **$3\times10^{-3}$ 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
- **Beam gas** first estimation indicate no problem
  - Beam Gas/Beam Beam = $3.10^{-4}$

# … and required statistics to complete the p/Pb physics run

- Minimum required number of collision: **$N_{coll}$ = $10^8$ (factor 10 more statistics wrt shown plots)**
  - Integrated luminosity **$L^{int}$ = 50 $\mu b^{-1}$**
    - **$2\times10^6$ single photons expected on p-remnant side**
    - **35000 $\pi^0$ expected on same side**

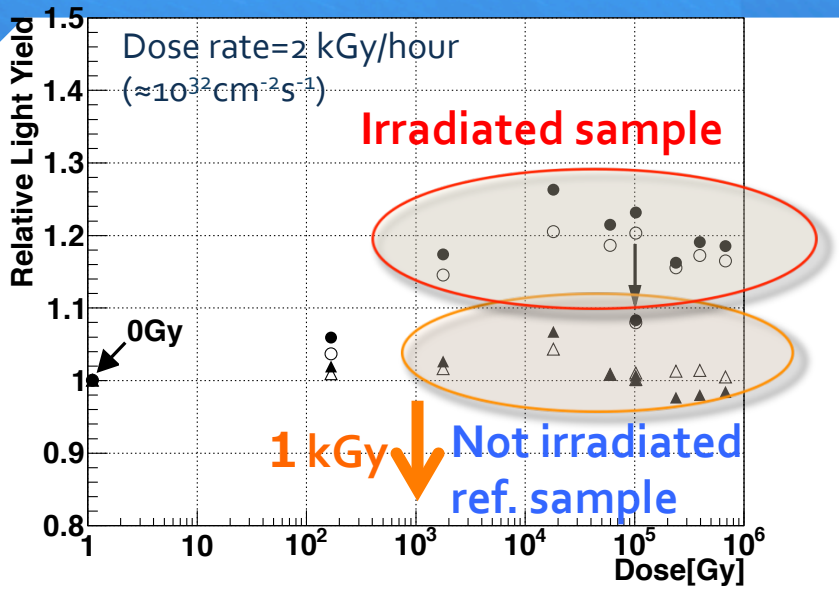
- Assuming a pessimistic scenario with luminosity **L = $10^{26}$ $cm^{-2}s^{-1}$** :
  - Minimum running time for physics **t = 140 h (6 days)**

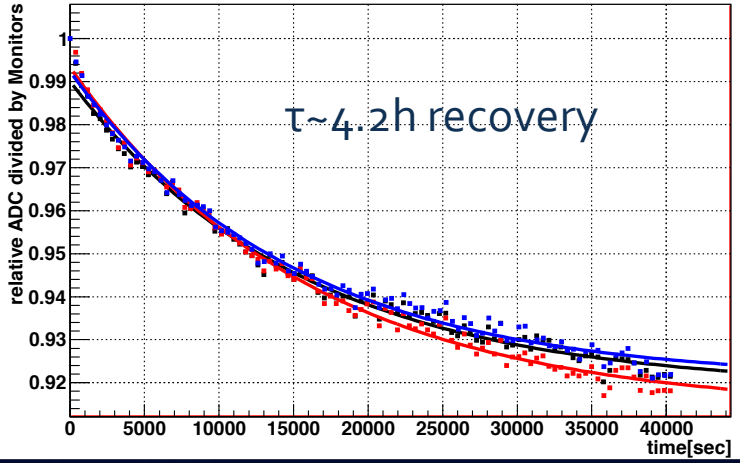
# Status of the LHCf upgrade

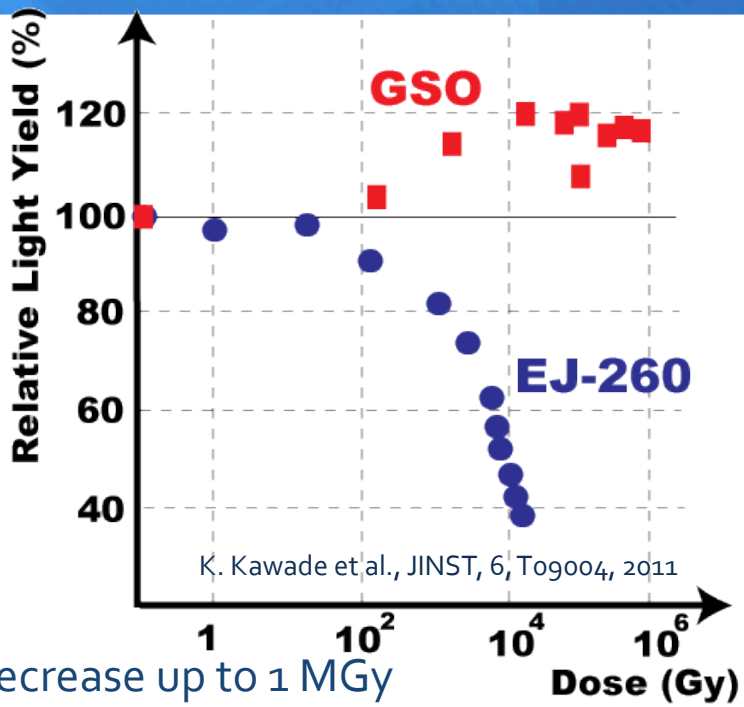
# LHCf Upgrade for the 14 TeV p-p run

- Calorimeter radiation hardening by replacing plastic scintillator with GSO
  - Scintillator plates
    - 3 mm → 1mm thick scintillators
    - Acrylic → quartz light guides
      → construction and light yield uniformity test carried out in Japan
  - SciFi
    - 1 mm square fibers → 1 mm GSO square bars
    - No clad-core structure (GSO bar)
      → Attenuation and cross talk test carried out
    - Acrylic light guide fiber → quartz light guide fibers
      → Construction and light yield test carried out
- Fast install and uninstall of the detectors from TAN region under study
- Upgrade of the silicon positioning measurement system
  - Rearranging Silicon layers for independent precise energy measurement
  - Increase the dynamic range to reduce saturation effects

# Radiation hardness of GSO

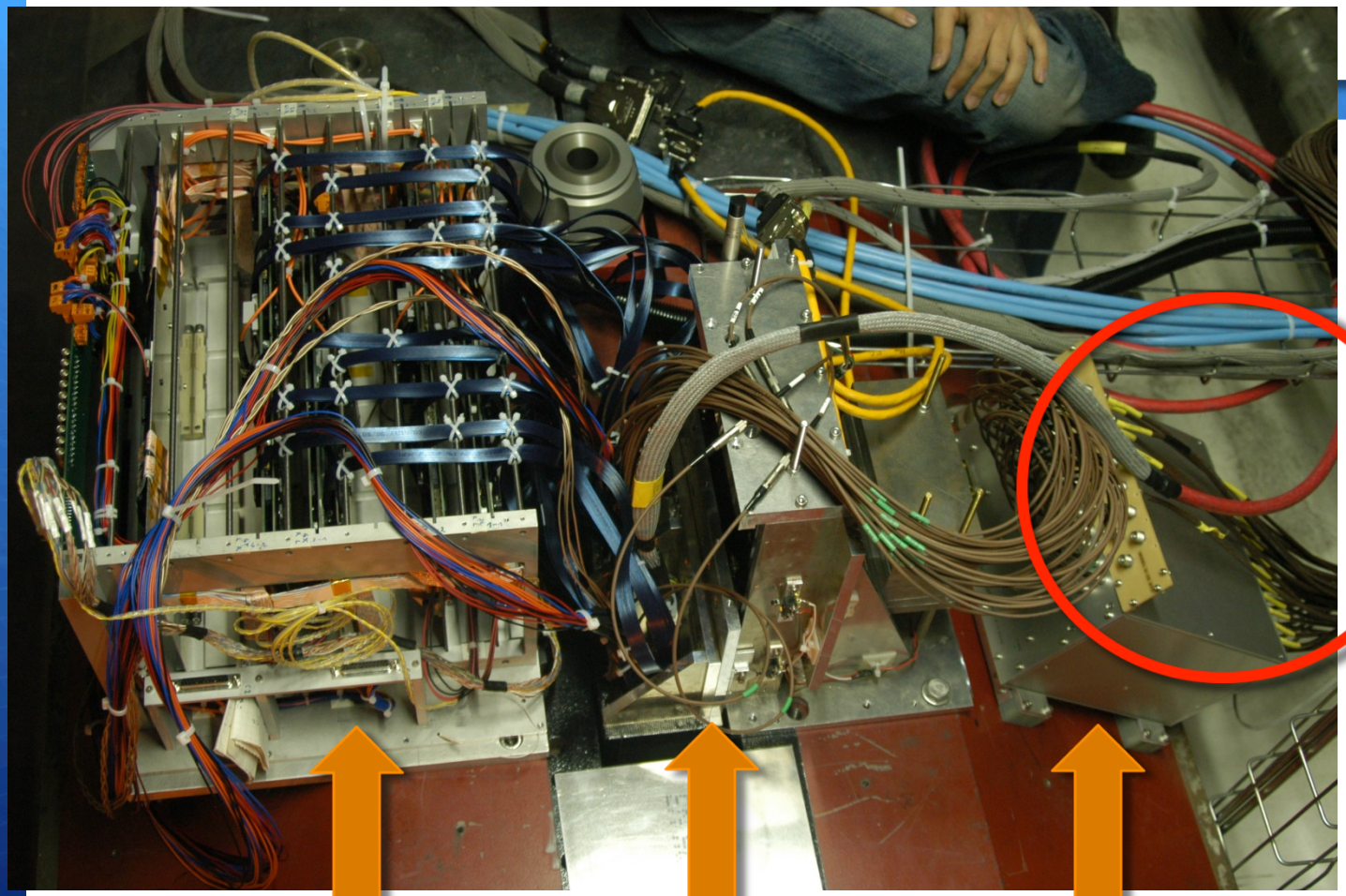



- No decrease up to 1 MGy
- +20% increase over 1 kGy (τ=4.2h recovery)
- 2 kGy is expected for 350nb$^{-1}$ @ 14TeV pp)

# Fast install/uninstall



Now 35 BNC connections in the tunnel

**To be packed in 2-3 Harting multipoles connectors**

Silicon strip FE electronics

LHCf main detector

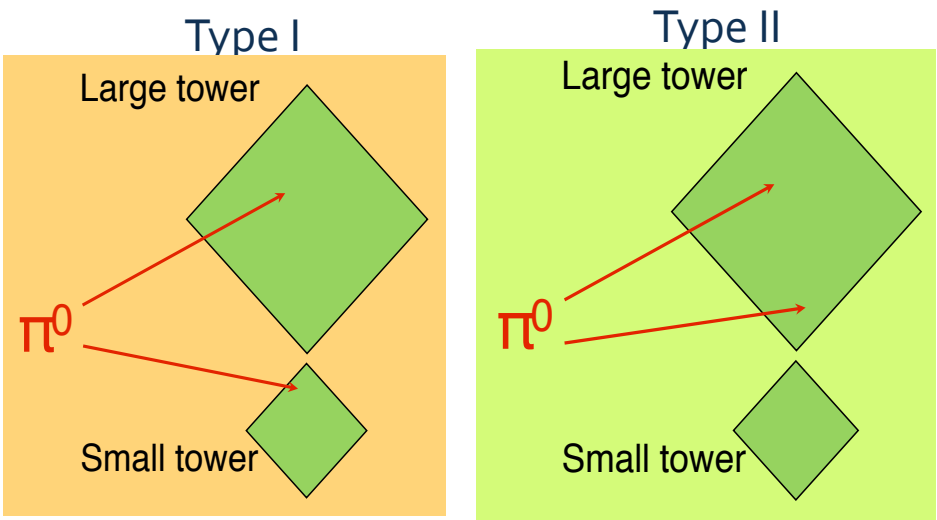
Calorimeters amplifier

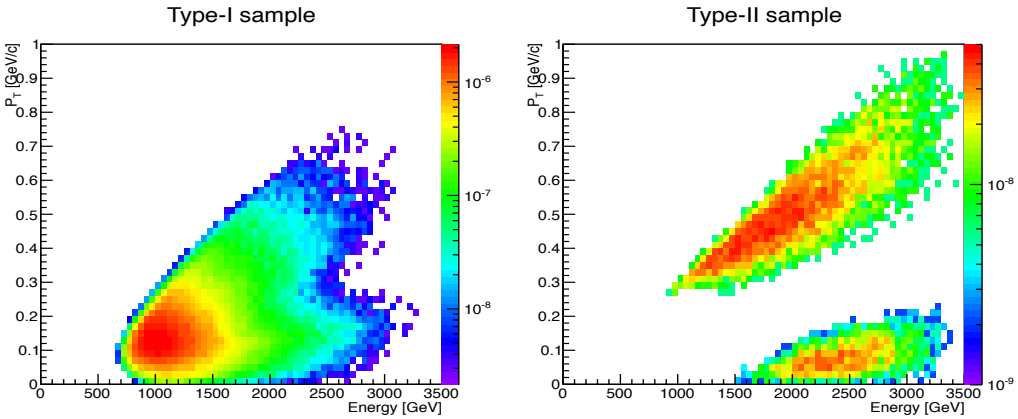
Now 3 main structures installed separately

**To be assembled in a single structure**

# LHCf on going analysis of the p-p data

- 900 GeV single photon spectrum
  - Analysis completed, paper submitted soon
- $\pi^0$ energy and $P_T$ spectra for Type I and II $\pi^0$
  - Analysis almost finished, draft circulating
- Hadron spectra
- $\eta$, $K^0$, $\Lambda$ ?



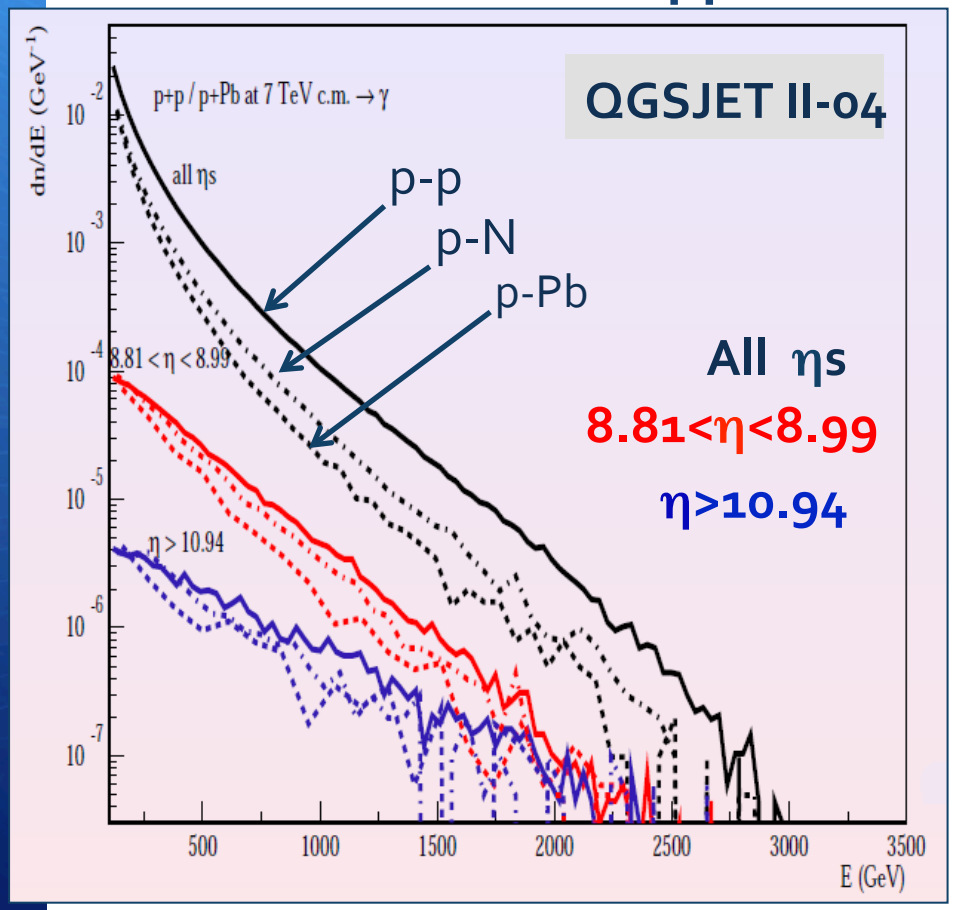
# Conclusions

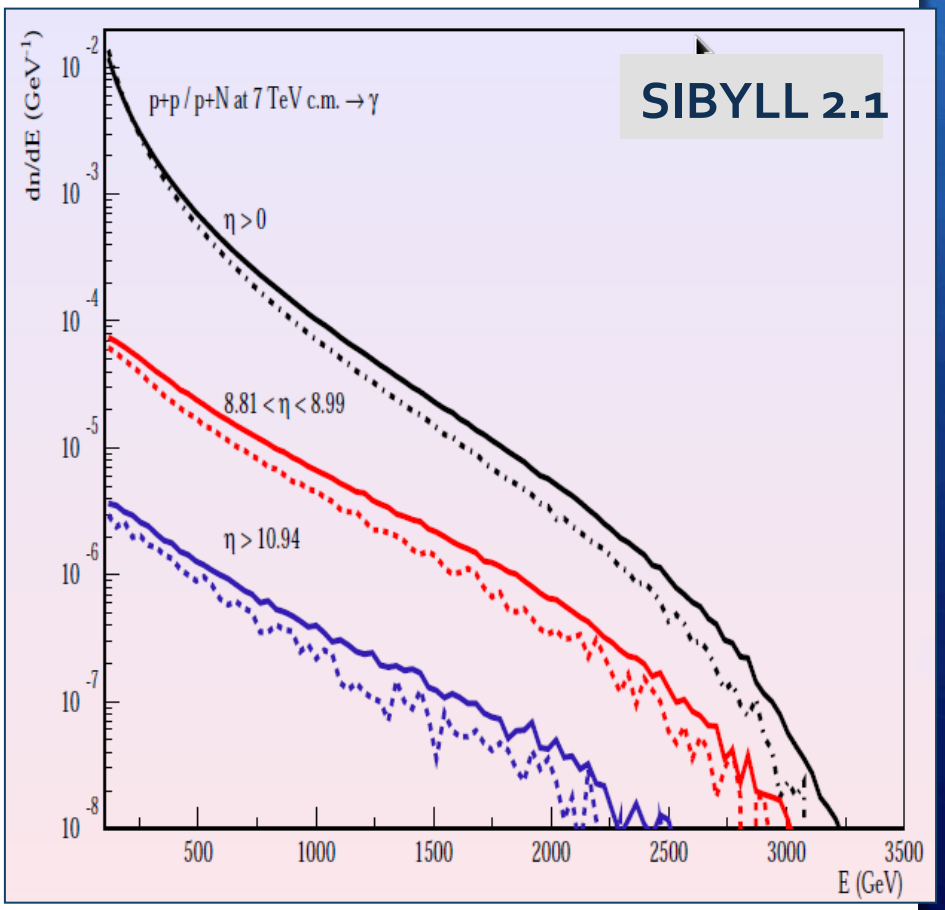
- Letter of Intent for the p/Pb run submitted to LHCC
- Interesting physics case can be investigated by LHCf
  - Most clean measurement on proton remnant side, but we can work also on Pb remnant side
  - Photon and neutron spectra and invariant cross section can be precisely measured in the $\eta$>8.4 rapidity range
- Operating conditions look promising
  - The machine expected conditions well fit the LHCf characteristics and good statistics can be collected in few days of data taking
  - Technical details for the installation/removal, radioprotection, radiation dose etc. will be addressed in the near future
- Meanwhile the upgrade program for 14TeV run and the 900 GeV+7 TeV p-p analyses are on-going

# Spares slides

# Photons on the proton remnant side

- Photon energy distrib. 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**



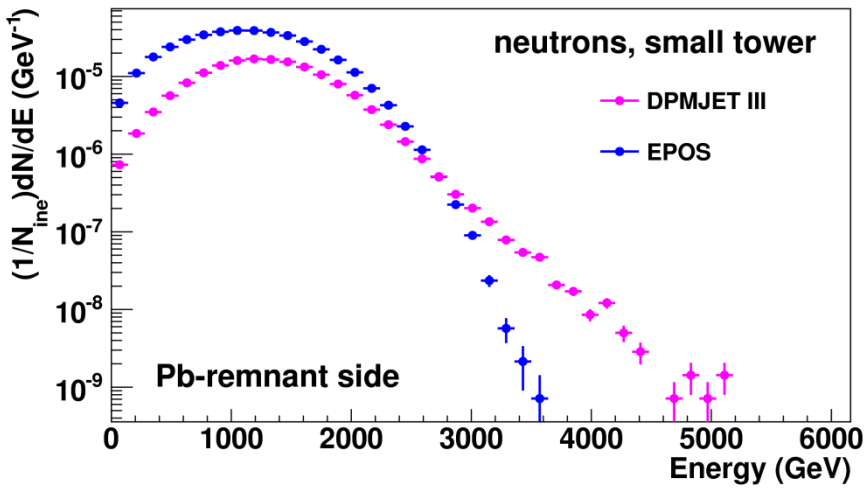



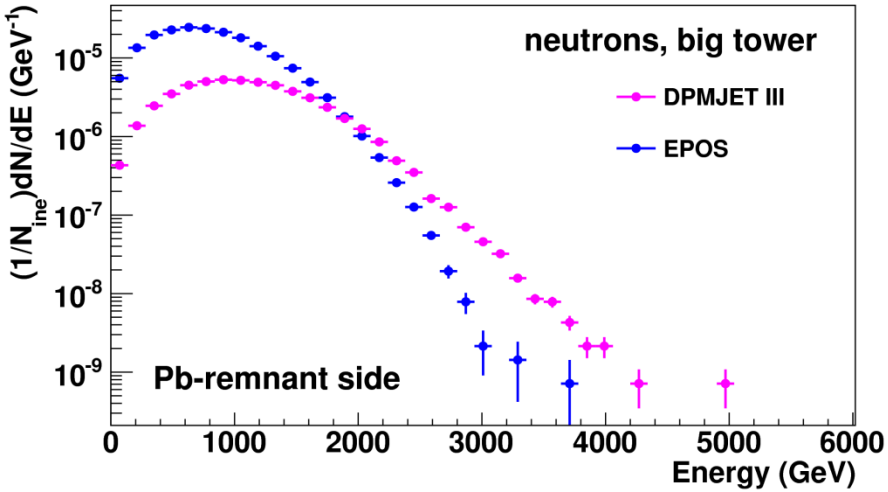

Courtesy of S. Ostapchenko

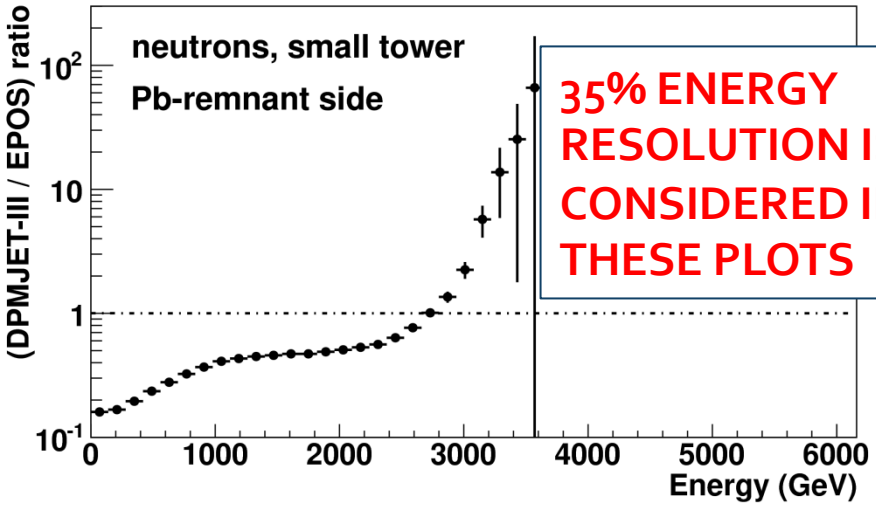
# Lead-remnant side – **neutron spectrum**

## Small tower

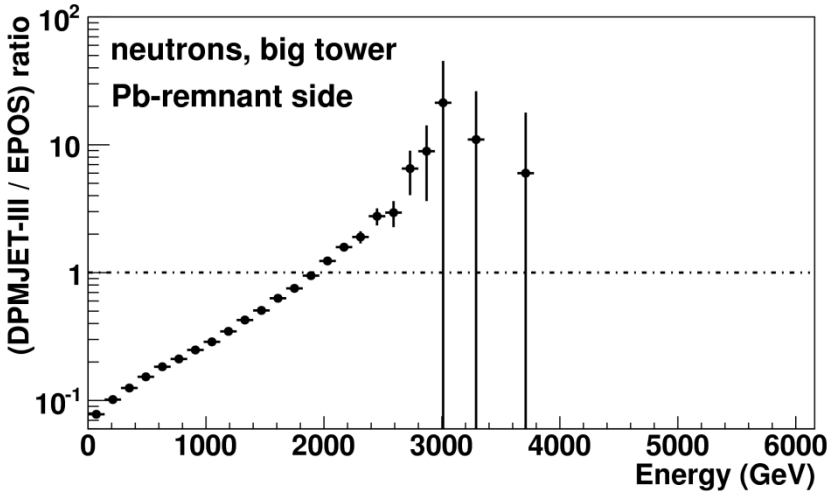
## Big tower




35% ENERGY RESOLUTION IS CONSIDERED IN THESE PLOTS



# CERN CPU

- Due to the East Japan spring earthquake and subsequent electrical power reduction, CPU service at ICRR, Univ. of Tokyo was strongly reduced, and is still reduced.
- During the last LHCC meeting, LHCf required to use CERN CPU service.
- We now routinely produce MC datase twith 200 job limitation by help of Bernd Panzer-Steindel (we will ask to increase job limit ☺)

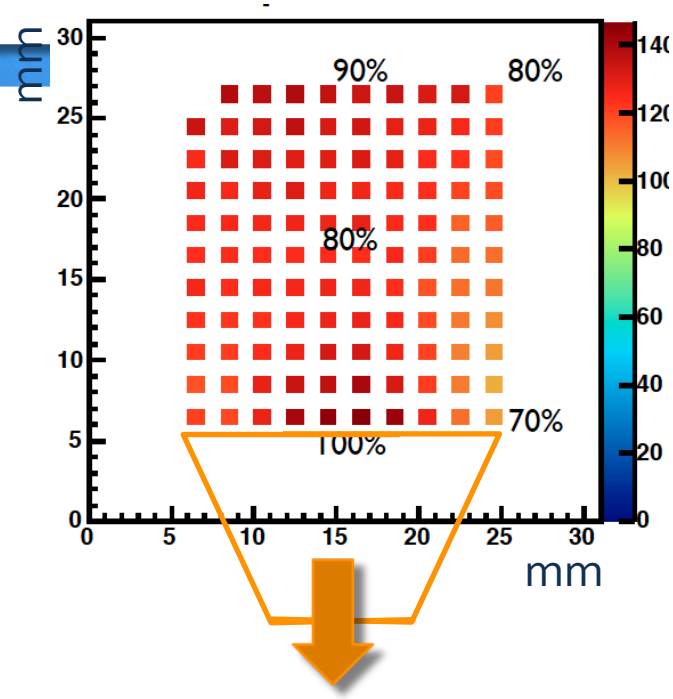
MANY TANKS FOR THE SUPPORT!!!!!!

# GSO property

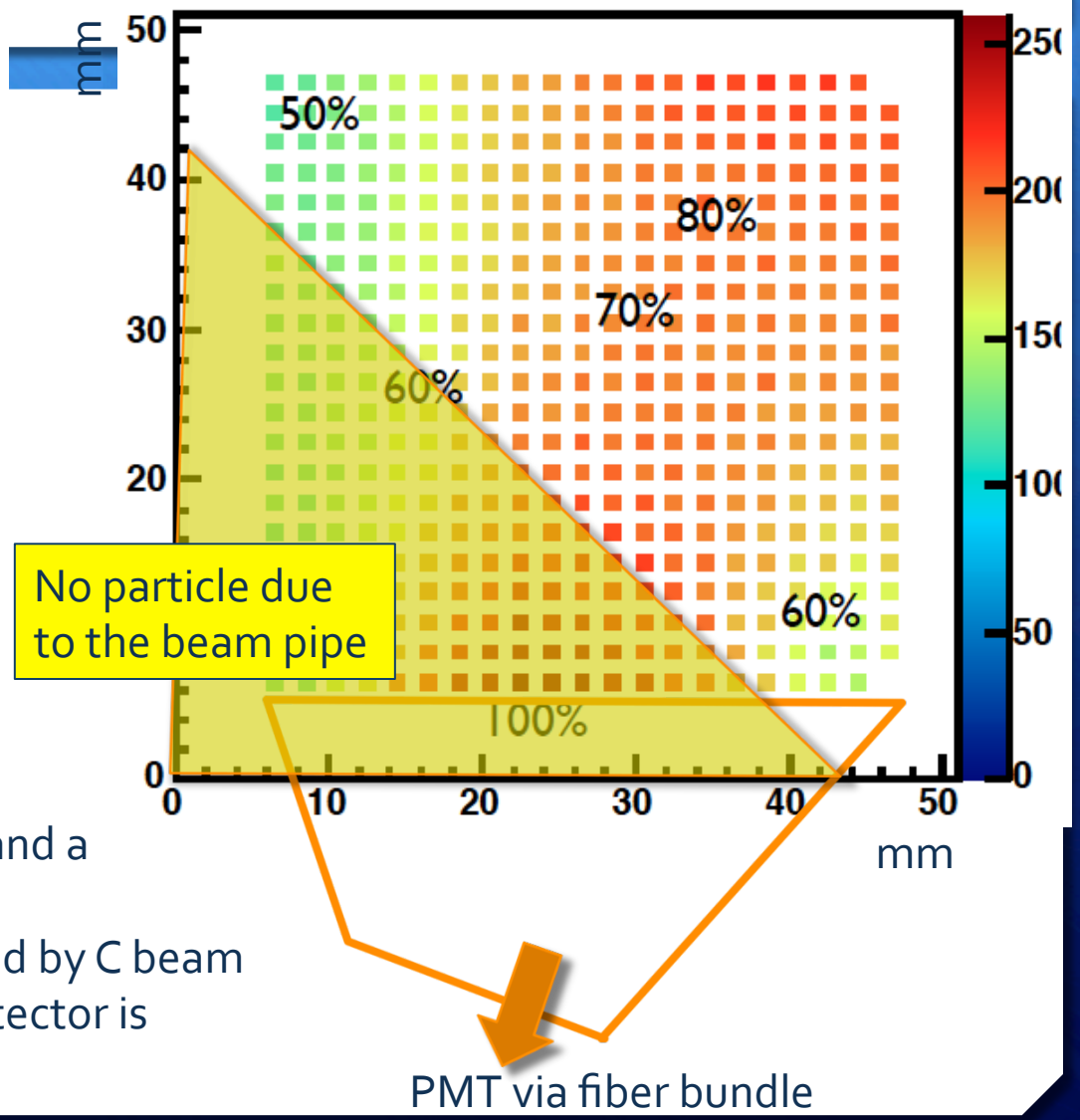
(EJ260: plastic scintillator used in the current LHCf detectors)

| | GSO | EJ-260 | |
|---|---|---|---|
| density(g/cm3) | 6.71 | 1.023 | Heavy; reason to reduce 3->1mm |
| r.l.(cm) | 1.38 | 14.2 | |
| decay time(ns) | 30-60 | 9.6 | Fast among inorganic scintillators |
| Fluorescence(NaI=100) | 20 | 19.6 | Identical to the current scintillators |
| $\lambda$ em(nm) | 430 | 490 | Similar to the current scintillators |
| Refractive(@ $\lambda$ em) | 1.85 | 1.58 | Light collection may differ |
| tolerance(Gy) | $10^6$ | 100 | Best in the known scintillators |
| melting point(°C) | 1950 | — | |

# Uniformity test using C beam at HIMAC (preliminary results from quick analysis)




PMT via fiber bundle



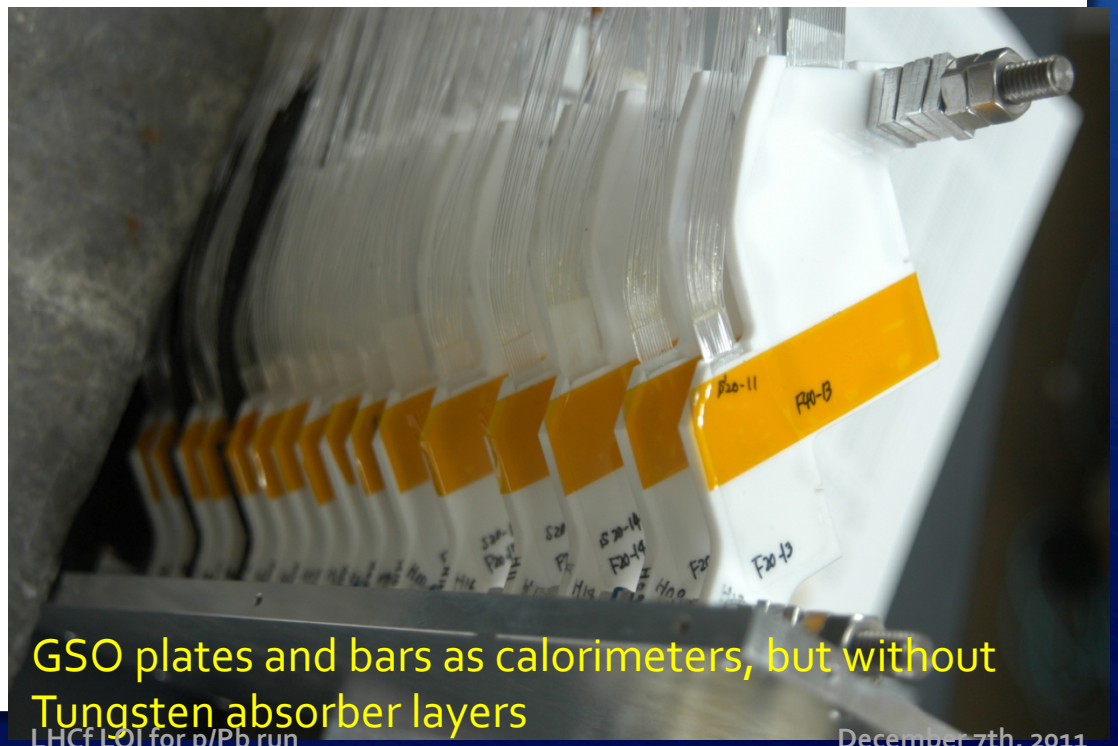

PMT via fiber bundle

- Scan examples for a 20mmx20mm and a 40mmx40mm GSO plates
- All scintillators of Arm1 were mapped by C beam
- Similar uniformity to the current detector is obtained

# New structure

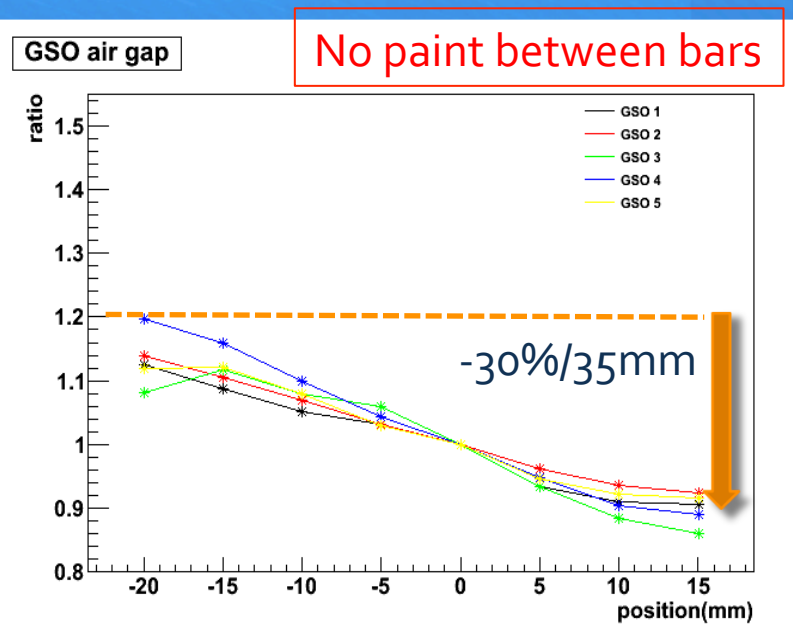
GSO plate and light guide packed in a new holder

GSO bar bundle and quartz fiber light guide

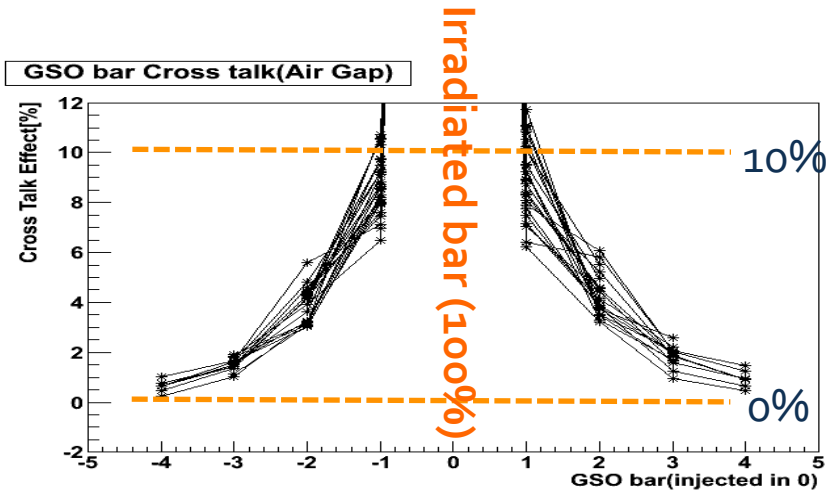


GSO plates and bars as calorimeters, but without Tungsten absorber layers

# GSO bars cross talk and attenuation




Attenuation along the longest 40mm bar




Cross talk

- Attenuation and cross talk are acceptable to determine the position of single particle shower and multihit identification
- For multihit analysis, further study is necessary
- Paint between the bars reduces cross talk, but worsens attenuation and its bar-to-bar variation

# Estimation of Beam Gas background

- Input from p-p collisions (Data set used for the photon paper).
  - Luminosity per bunch (L/n) : $2x10^{28}$ $cm^{-2}s^{-1}$/bunch
  - Intensity per bunch (I/n) : $2x10^{10}$ protons/bunch
  - Total detected events in 25mm tower at non-bunch crossing : 101 photon events (for non crossing bunches)
  - DAQ live time : ~ $8x10^{3}$ sec
  - -> Event rate of beam gas per bunch = 101/8000/3 = 0.004 Hz
- Inputs from p-Pb (assumptions)
  - Luminosity per bunches (L/n) : $1.7x10^{25}$ $cm^{-2}s^{-1}$/bunch ($L=10^{28}$, n=590)
  - Inelastic cross section : 2 barn
  - Expected collision rate : 34 Hz
  - Expected photon detection rate in 25mm : 0.34 Hz (assuming acceptance=0.01)
- Estimation of beam-gas background for p-Pb
  - Assuming as the optics for p-Pb is same as one for p-p (same beta, same emittance), the relative intensity is estimated by using L/n.
  - $(I/n)_{pPb} / (I/n)_{pp} \sim 0.03$
  - The beam-gas background rate should be proportional to the intensity per bunc, so it is estimated as 0.03 x 0.004 Hz = $10^{-4}$ Hz
- As conclusion, the N/S in p-Pb is estimated as $10^{-4}$ / 0.34 = $3x10^{-4}$ → Negligible!!!!