LHCC Open Session – 02 March 2016

LHCf
Report on the on-going activities and interest for a p+Pb run in 2016

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On behalf of the LHCf collaboration

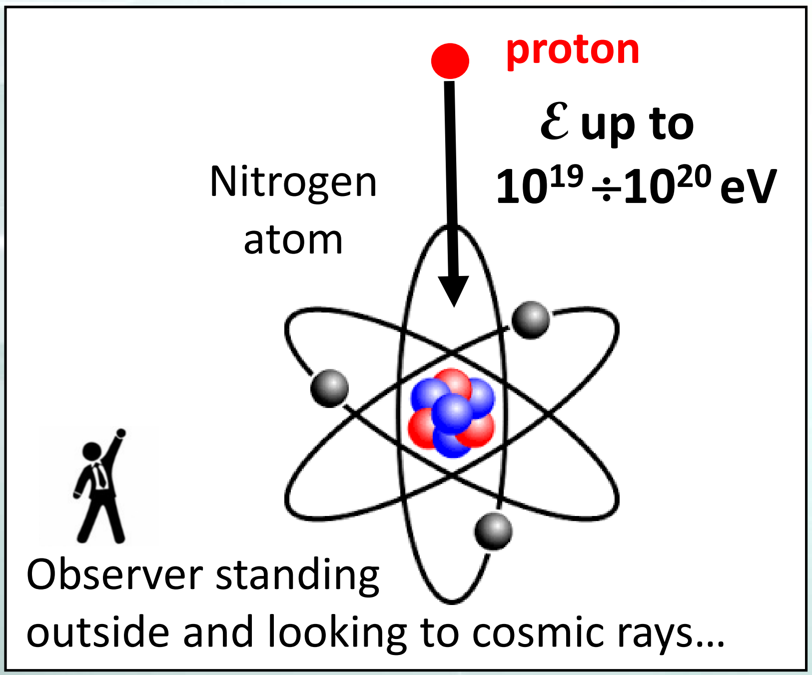
Outline

- Extremely quick introduction
  - The LHCf experiment
  - Achieved results
- Latest data analysis
  - p+p collisions at 13 TeV
- Interest for future activity
  - Proposal of a LHCf run in case of p+Pb collisions in 2016 at $\sqrt{s_{NN}} = 8.1\ \mathrm{TeV}$

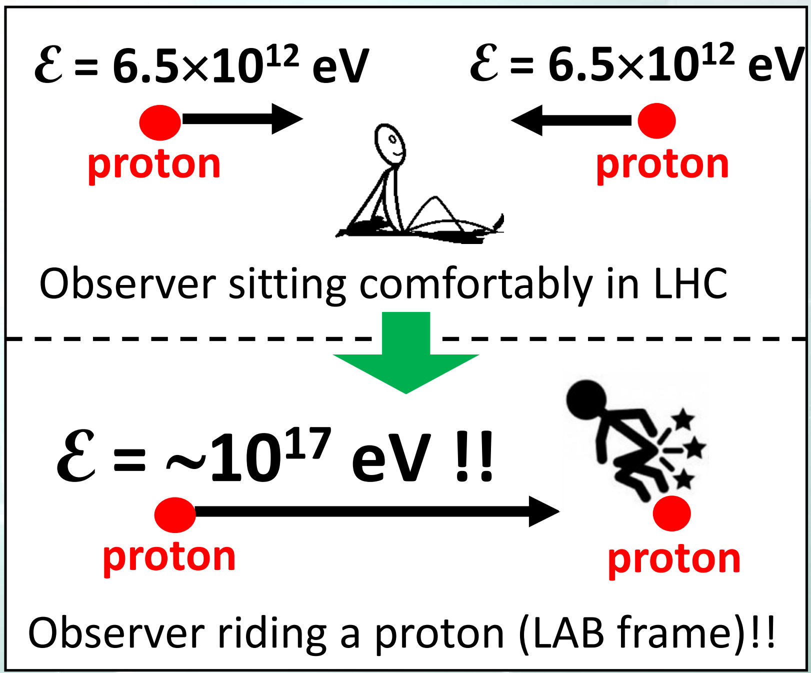
Introduction: LHCf and Cosmic Ray Physics

- Possibility to study particles in the **forward direction** at LHC (neutrals: γ, π^0, n)
  - Forward secondary particles carry a <u>great fraction of the primary energy</u>
- 6.5 TeV + 6.5 TeV in the LHC frame → **~10^{17} eV** in the laboratory frame (LAB)
- Calibration of **hadronic interaction models** used for the simulation of atmospheric showers

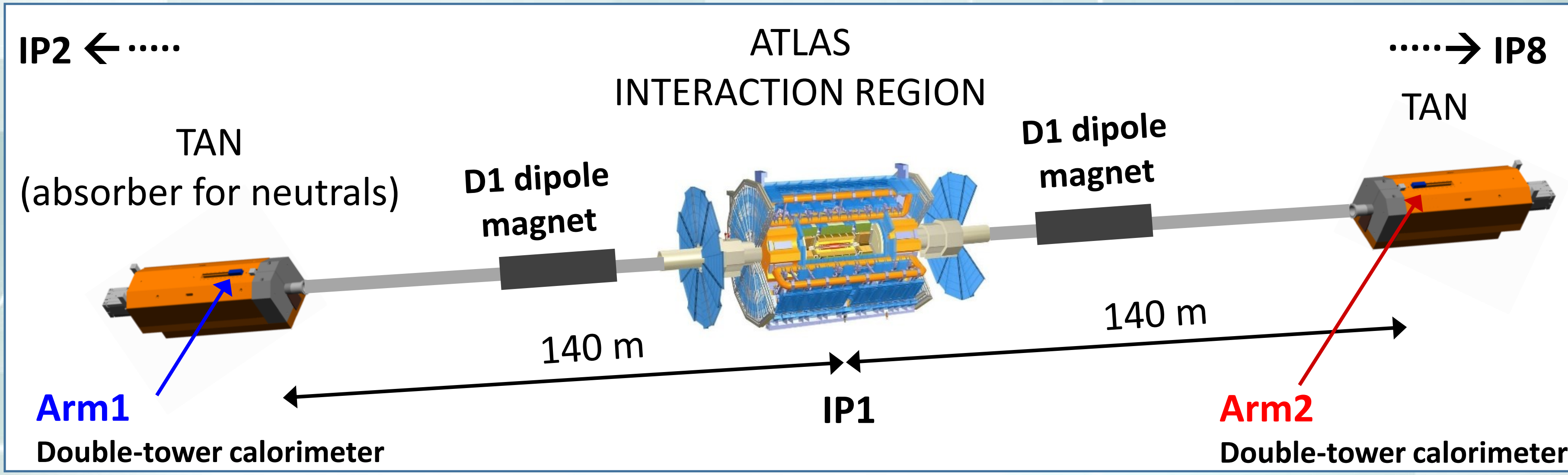
COSMIC RAYS



LHC



The experimental side



Position resolution: < 200 µm (Arm1) and 40 µm (Arm2)

Energy resolution: < 5% for photons; 30% for neutrons

Pseudo-rapidity range:

η > 8.7 @ zero X-ing angle

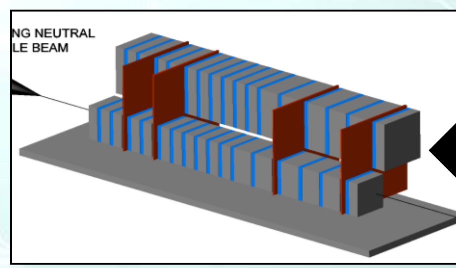
η > 8.4 @ 290 µrad (total)

Arm1 Detector

2cm x 2cm + 4cm x 4cm

GSO tiles (e.m. calo)

4 X-Y tracking layers (**GSO bars**)



Arm2 Detector

2.5cm x 2.5cm + 3.2cm x 3.2cm

GSO tiles (e.m. calor)

4 X-Y tracking layers (**silicon microstrip**)

44 X_0
~1.5 λ_{int}

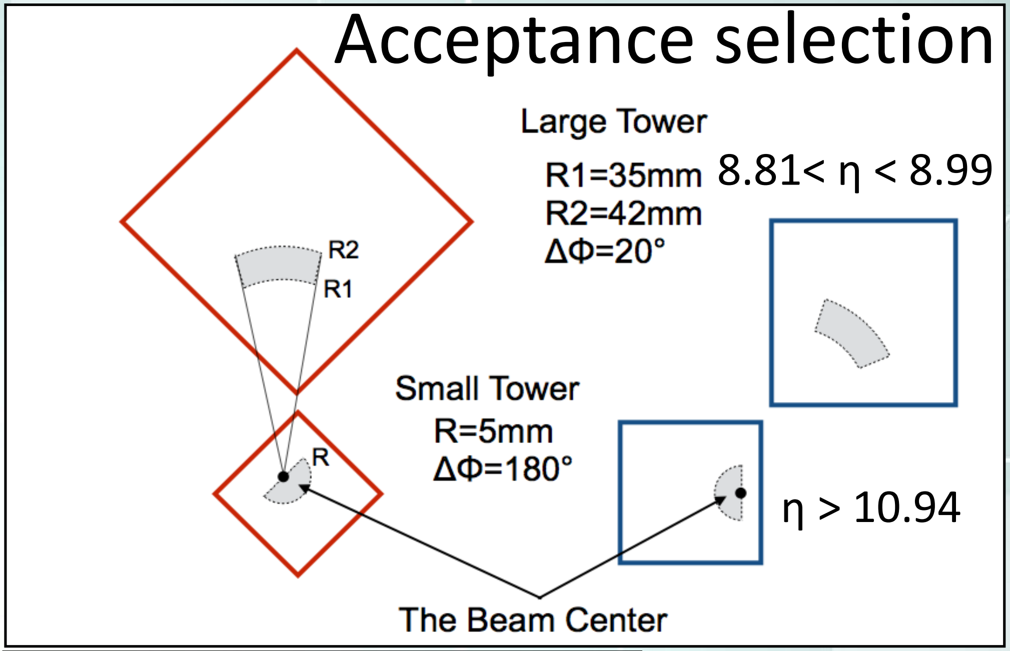
Achieved results & others

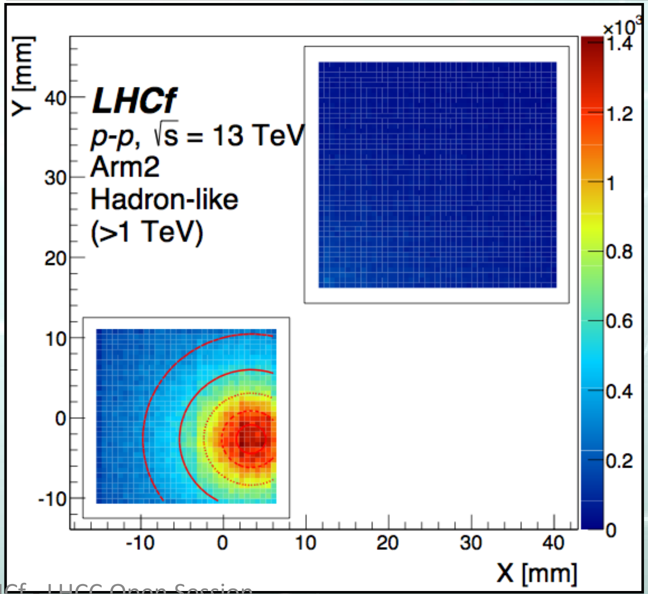
	Proton equivalent energy in LAB (eV)	γ	n	π^0
SPS test beam		NIM A, 671, 129 (2012)	JINST 9 P03016 (2014)	
p+p 900 GeV	4.3×10^{14}	Phys. Lett. B 715, 298 (2012)		
p+p 7 TeV	2.6×10^{16}	Phys. Lett. B 703, 128 (2011)	Phys. Lett. B 750 (2015) 360-366	Phys. Rev. D 86, 092001 (2012) + Submitted to Phys. Rev. D (Type-II)
p+p 2.76 TeV	4.1×10^{15}			Phys. Rev. C 89, 065209 (2014) + Submitted to Phys. Rev. D (Type-II)
p+Pb 5.02 TeV	1.4×10^{16}			
p+p 13 TeV	9.0×10^{16}	Data taken in June 2015 after the restart of LHC Analysis is on-going		
p+Pb 8.1 TeV	3.6×10^{16}	Letter of Intent just submitted to the LHC Committee…		

Single photon analysis for p+p 13 TeV

- Data set :
  - 12 July 22:32-1:30 (3 hours)
  - Fill # 3855, $\mu \sim 0.01$
  - $\int L dt = 0.19\ nb^{-1}$
  - $\sigma_{ine} = 73.1$ mb

- On-going analysis
  - Event Selection
    - Photon/hadron selection
    - Multi-Hit event rejection
  - Corrections
    - PID correction
    - Multi-Hit correction
    - Unfolding (to be done)
  - Combine Arm1 and Arm2 considering systematic





Beam center was estimated from the hit-map of high energy hadron events

Absolute energy scale uncertainty

The uncertainty of energy scale is the largest contribution to the systematic uncertainty of the final spectra. The energy scale of detector is checked by using $M_{\gamma\gamma}$ peak of π^0

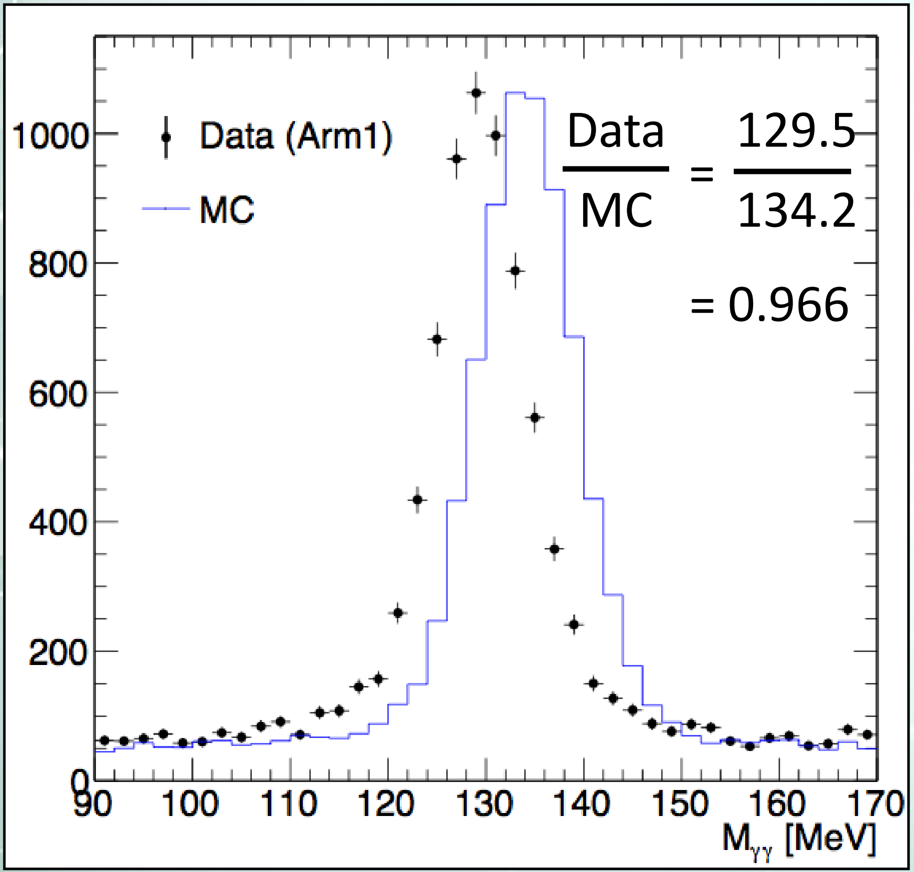


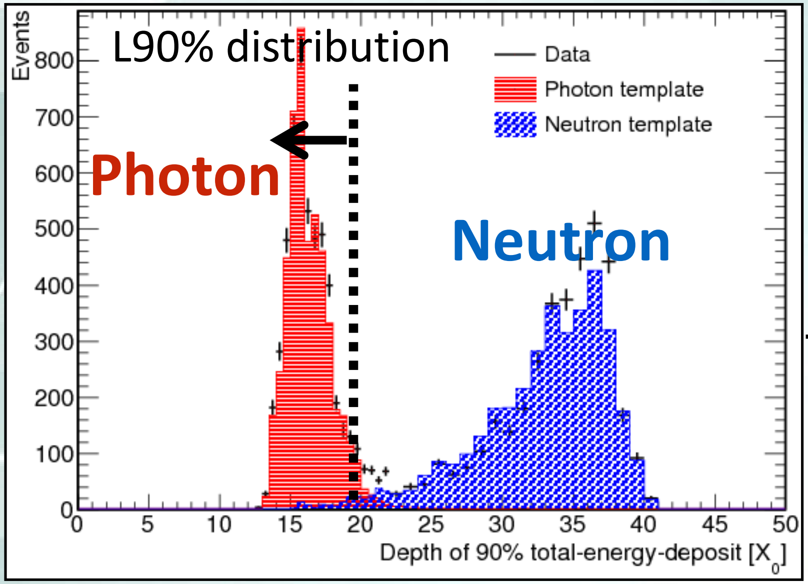
Table: shift of π^0 mass peak

	New detector	Old detector
Arm1	**-3.4%**	+7.8%
Arm2	**-2.1%**	+3.7%

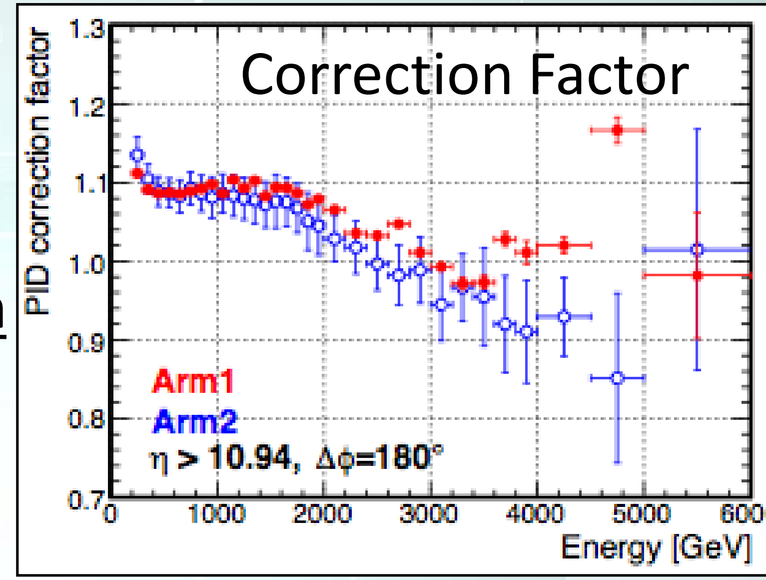
Thank to the careful energy-calibration of detector by the CERN-SPS beam test, the shift of π^0-mass-peak is reasonable compared to the uncertainty of calibration, 3.5%. The systematic error is expected to be smaller than at the previous result at √s=7TeV

Corrections: particle ID and multiple hits

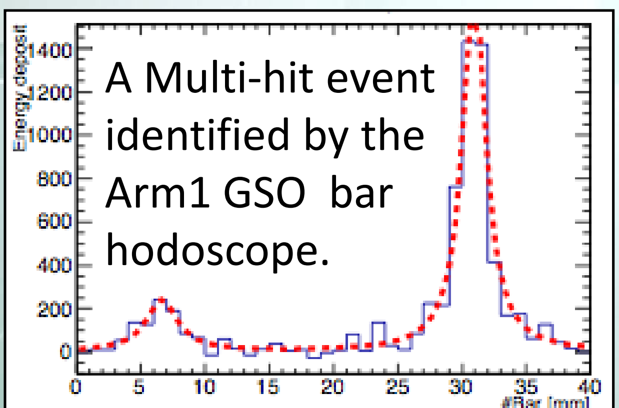
The correction factor was driven from the template fitting method of L90% distribution



PID correction

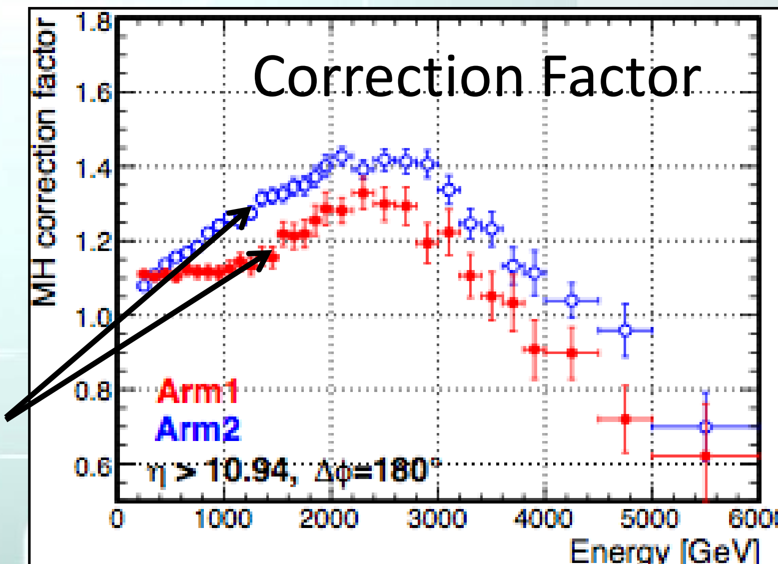


Effect of the multi-hit event cut is estimated based on MC with QGSJET2 model

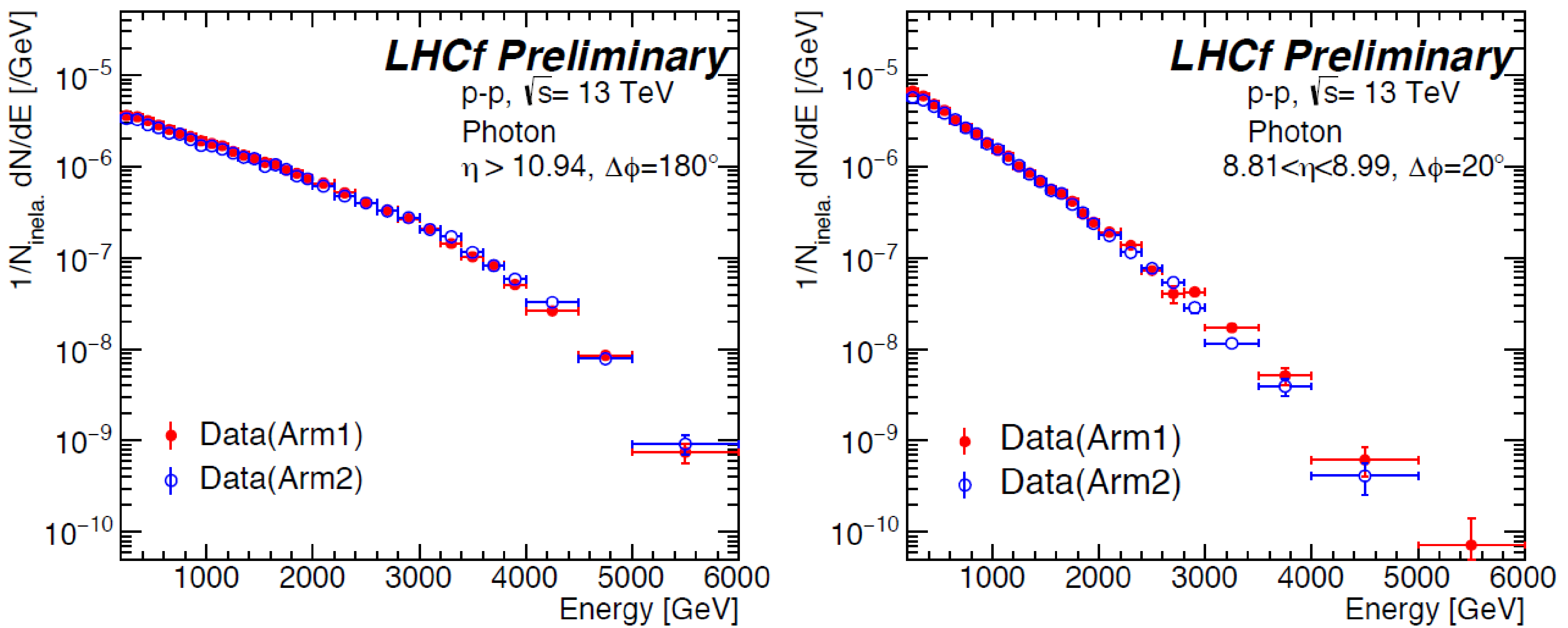


Multi-hit correction

Difference due to the different geometrical shape of calorimeters



Comparison Arm1/Arm2

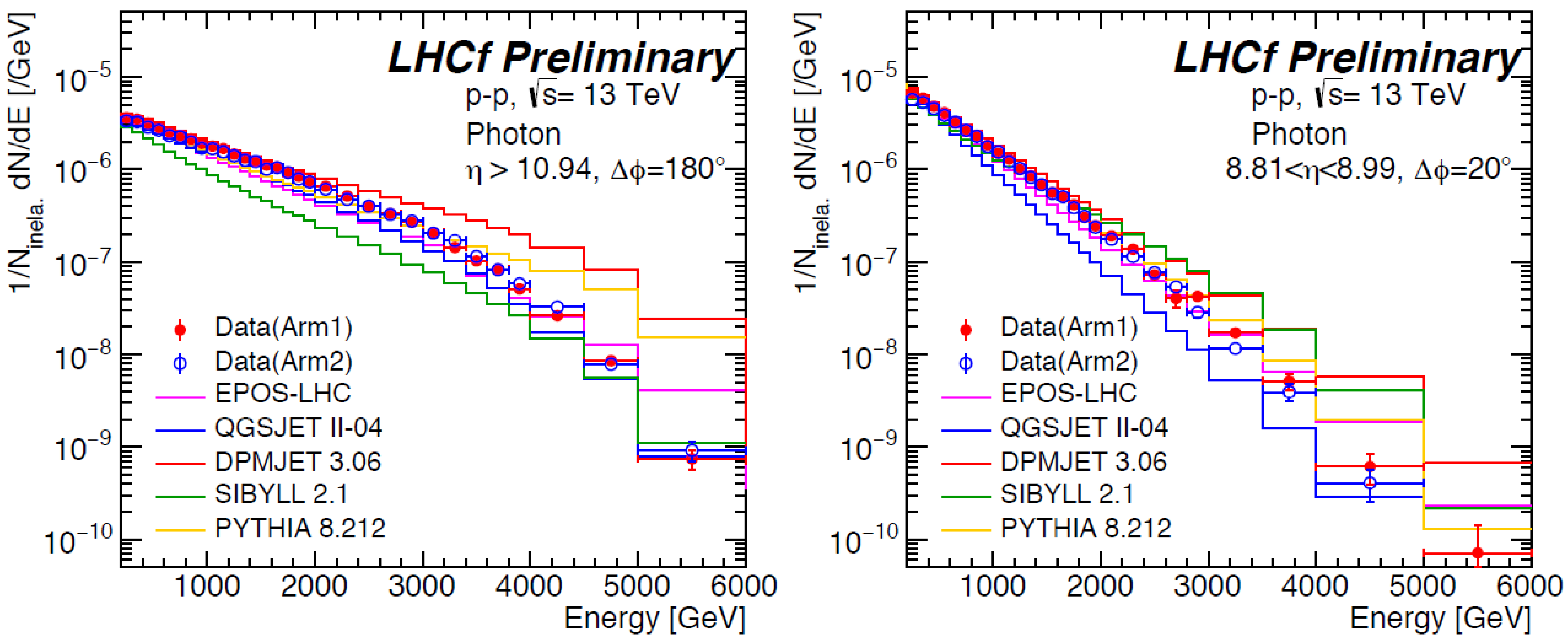


Error bars show only the statistical errors.

The evaluation of the systematic uncertainties is in progress

We would like to acknowledge the ATLAS collaboration for providing the measurement of the luminosity and of the cross section.

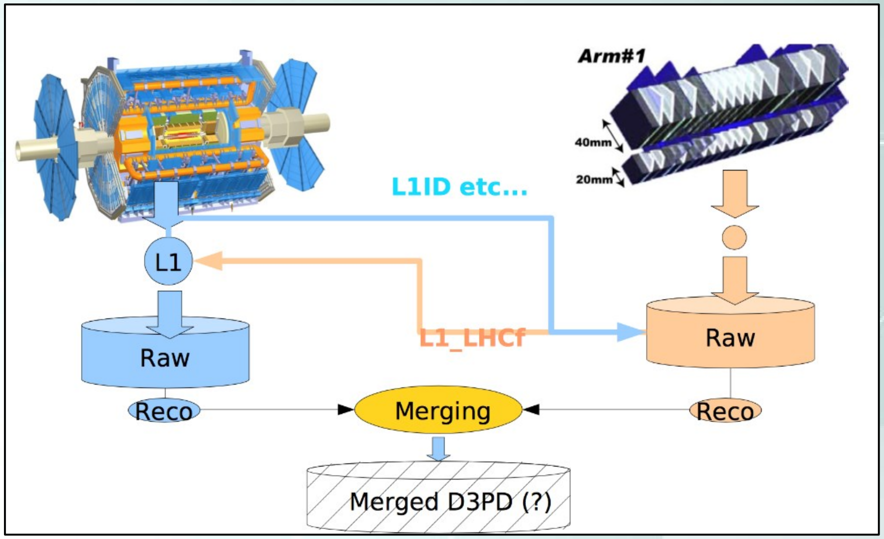
Preliminary comparison with models

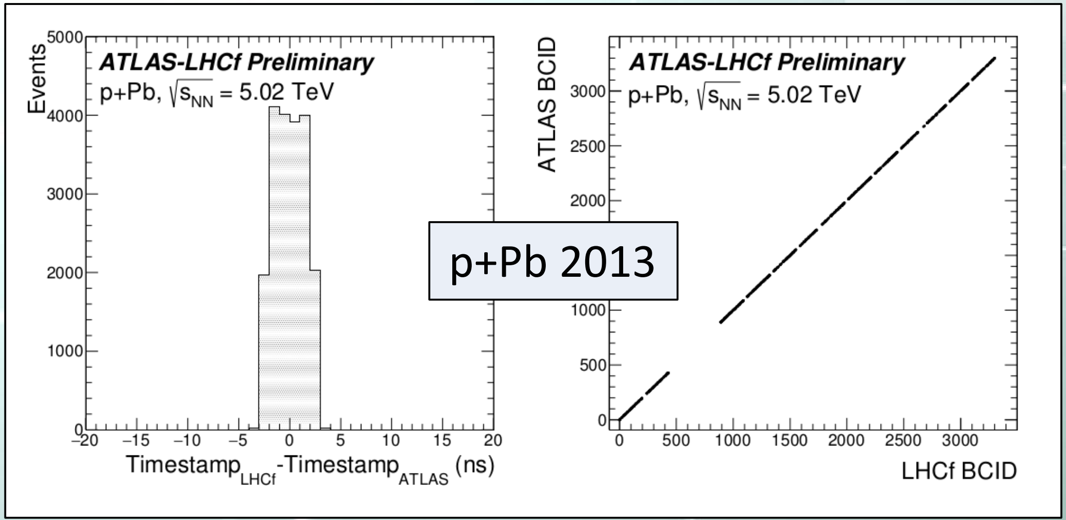


Error bars show only the statistical errors.

ATLAS-LHCf combined data analysis

- Trigger sharing with ATLAS at ~100 Hz in 2015 p+p (10 Hz in 2013 p+Pb)
- Off-line event matching
- **Status** (p+p 2015)
  - Event matching successfully verified
- Internal note (p+Pb 2013)
  - **ATL-PHYS-PUB-2015-038**
- Important to separate the contributions due to diffractive and non-diffractive collisions
  - It makes more easy improving the hadronic interaction models





+ A commonly triggered event

ATLAS LHCf NOTE

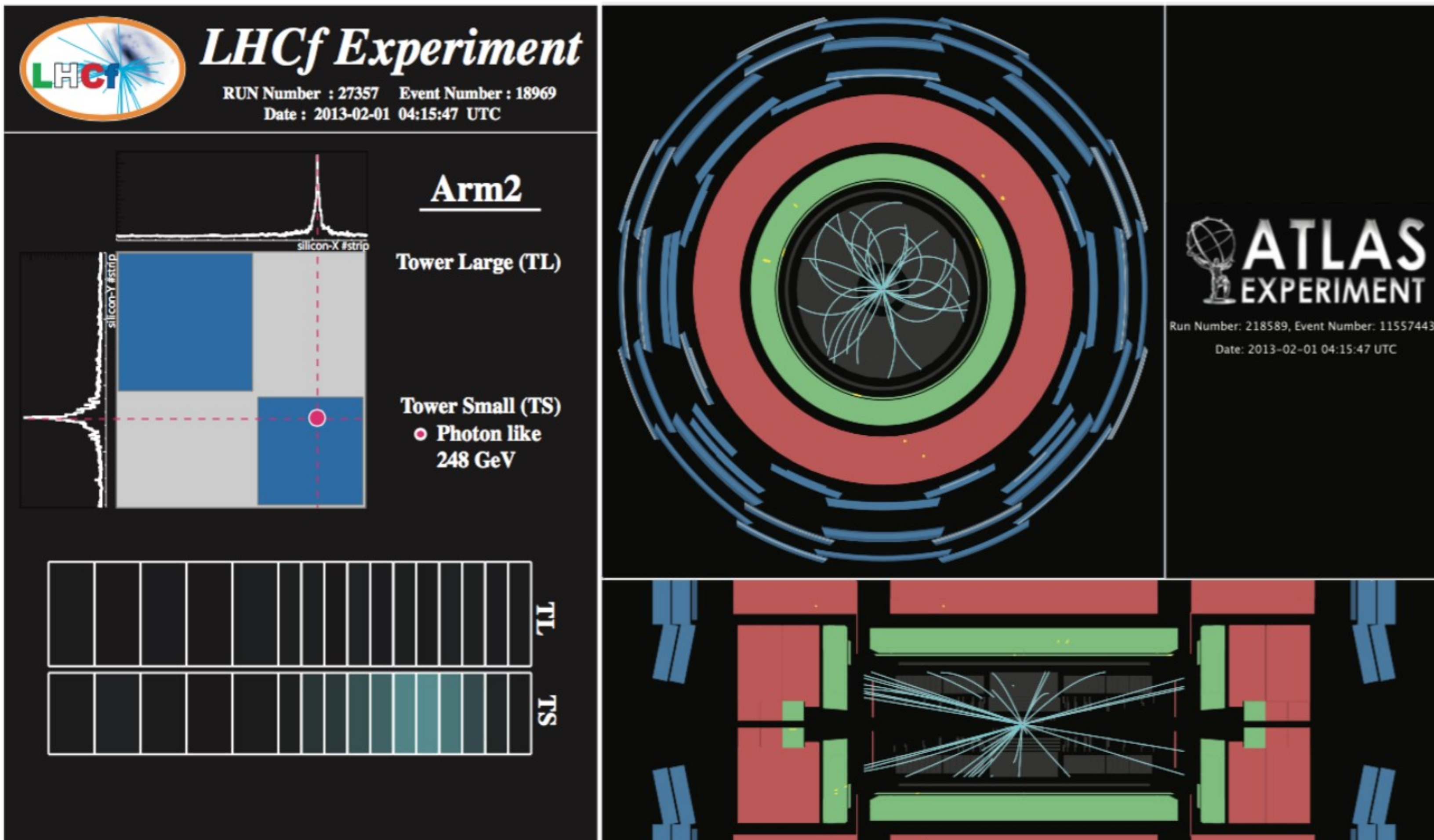
August 26, 2015

ATL-PHYS-PUB-2015-038

30 August 2015

Classification of Events in the Combined ATLAS-LHCf Data Recorded During the p+Pb Collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

The ATLAS and the LHCf Collaborations



Letter of Intent – p+Pb 2016 run

LHCf

Letter of Intent for a p-Pb run in 2016

Study of forward physics in $\sqrt{s_{\mathrm{NN}}} = 8.1$ TeV proton-Lead ion collisions with the LHCf detector at the LHC

JUST SUBMITTED !

The LHCf collaboration

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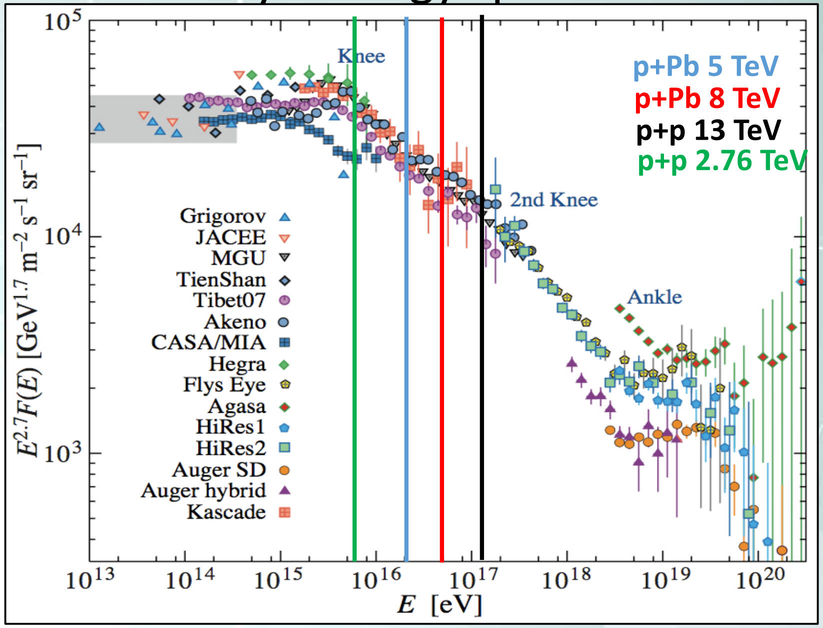
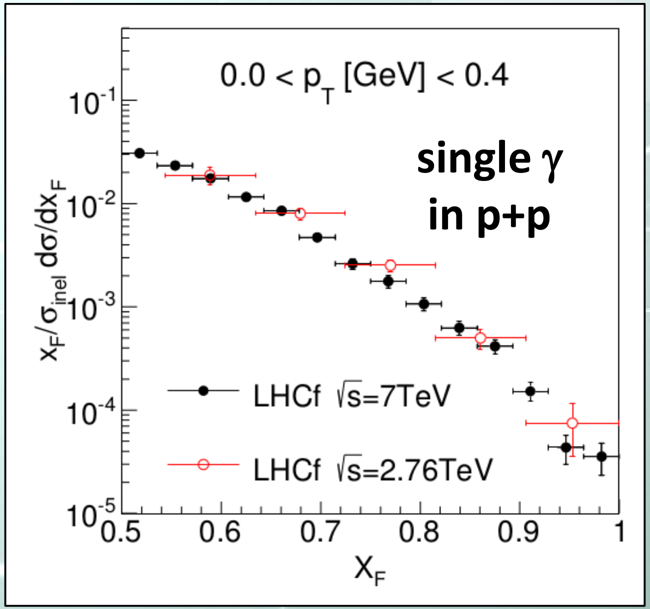
February 28, 2016

Motivations

- Energy
  - $\sqrt{s_{NN}} = 5.0\ \text{TeV} \rightarrow p_{LAB} = 1.4 \cdot 10^{16}\ \text{eV}$
  - $\sqrt{s_{NN}} = 8.1\ \text{TeV} \rightarrow p_{LAB} = 3.6 \cdot 10^{16}\ \text{eV}$
- Statistics
  - Measure π^0 with increased statistics wrt 2013
  - Possibility to detect the η meson
  - Combined ATLAS-LHCf data taking (very limited in 2013)
- Phase space
  - Extend the accessible phase space up to $p_t > 1$ GeV/c:
    - deviations from models are suggested from 2013 data at high p_t
    - Investigate a PQCD phase space region
- Scaling properties
  - Extrapolation at extreme CR energies
  - Feynman scaling: spectra in x_F

Cosmic Rays energy spectrum





Preliminary simulations

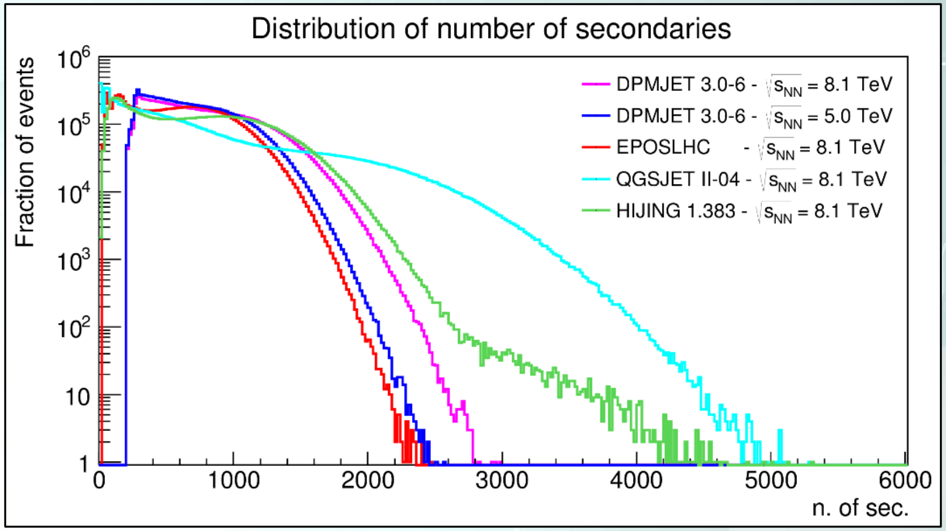
The **Cosmic Ray Monte Carlo** (CRMC)* framework has been used to simulate **10^7 collisions** with 4 different hadronic interaction models:

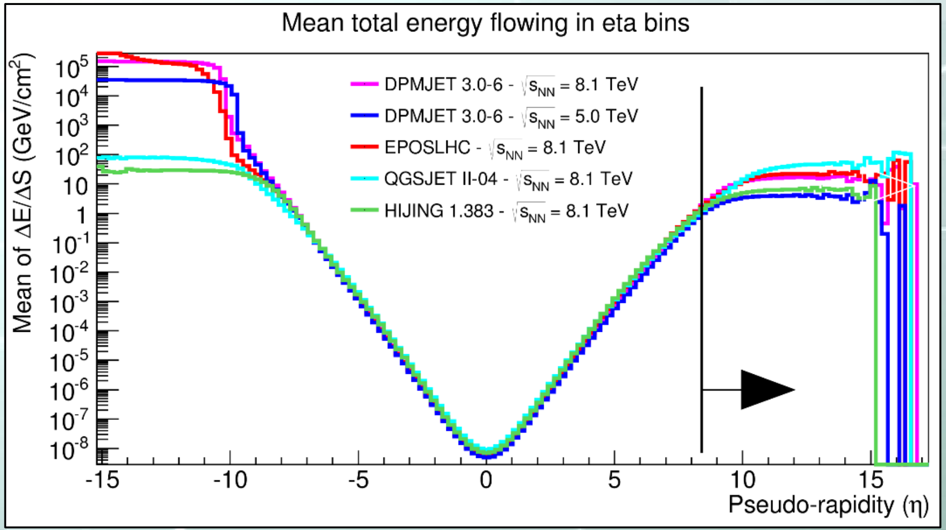
- **DPMJET 3.0-6 p+Pb**
- **EPOSLHC p+Pb**
- **QGSJET II-04**
- **HIJING 1.383**

$\sigma_{DPMJET} = 2.2\ \text{b}$

$L_{int} = 4.5 \cdot 10^{-3}\ \text{nb}^{-1}$ (simulated)

- Small calorimeter tower centered on the beam spot
- Only the proton-remnant side has been considered in the analysis





* **We acknowledge T. Pierog, C. Baus and R. Ulrich for support**

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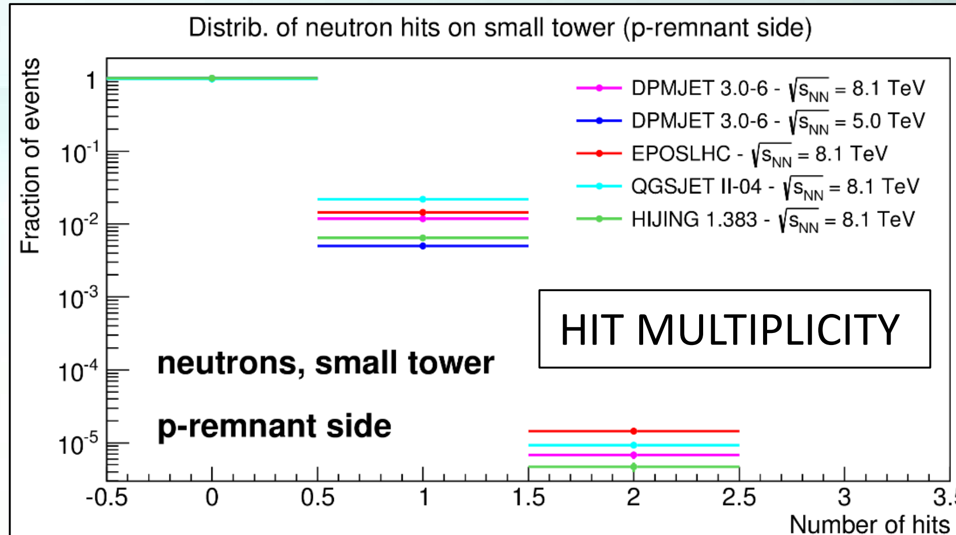

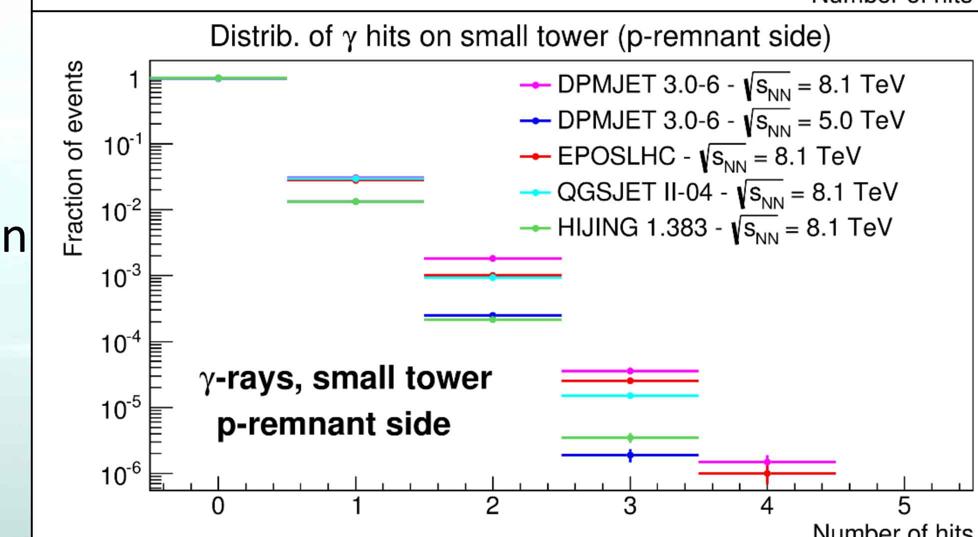

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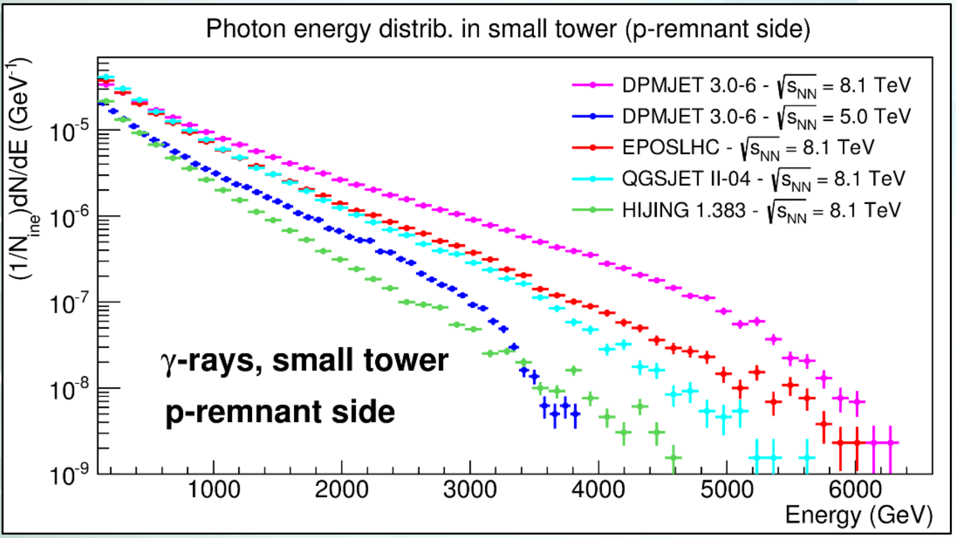
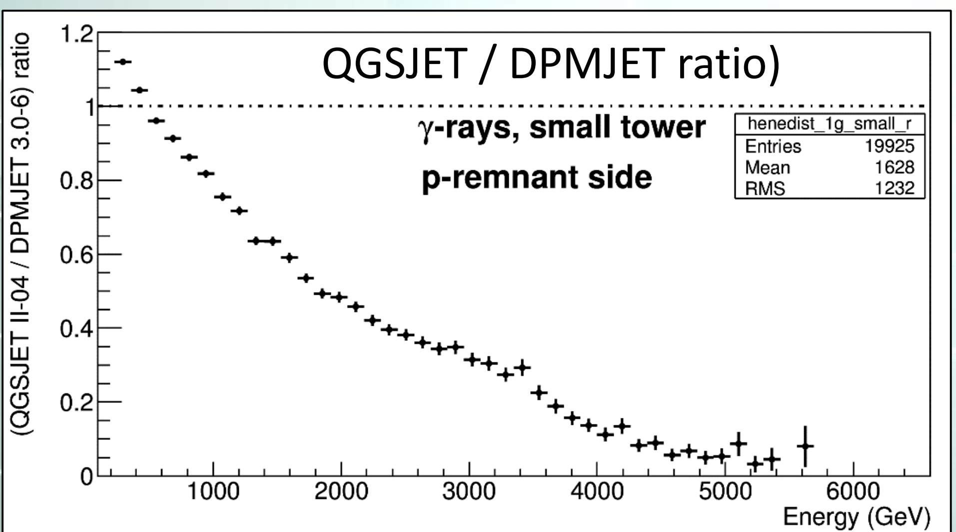
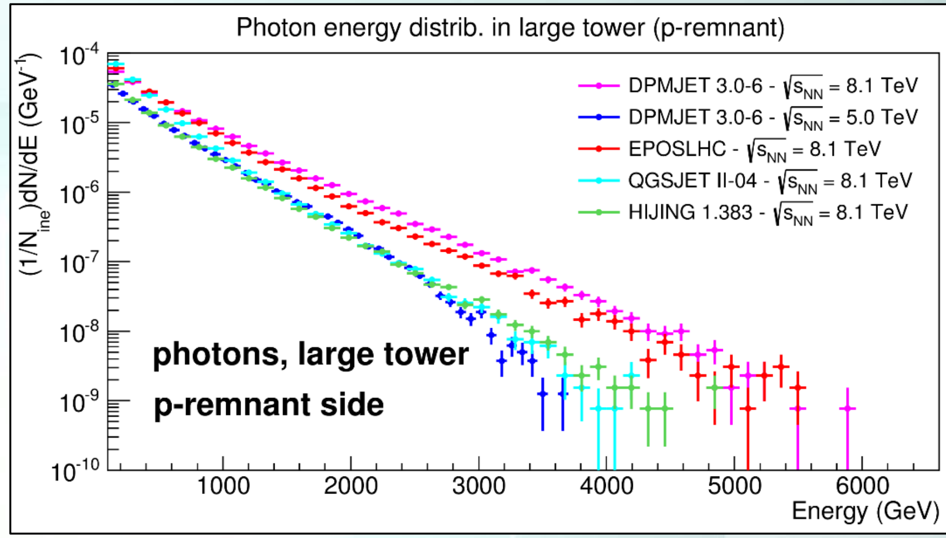
Single photon spectrum

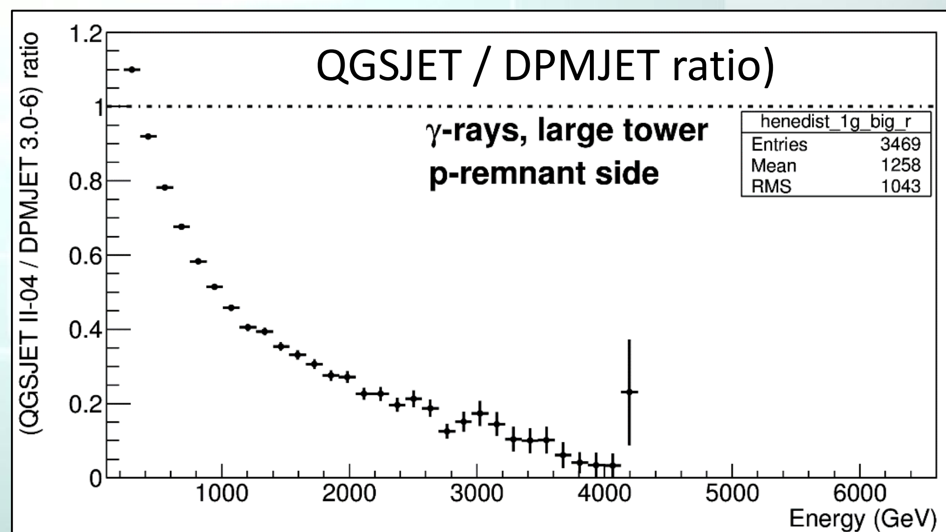
Small tower (Higher rapidity)





Large tower (Lower rapidity)

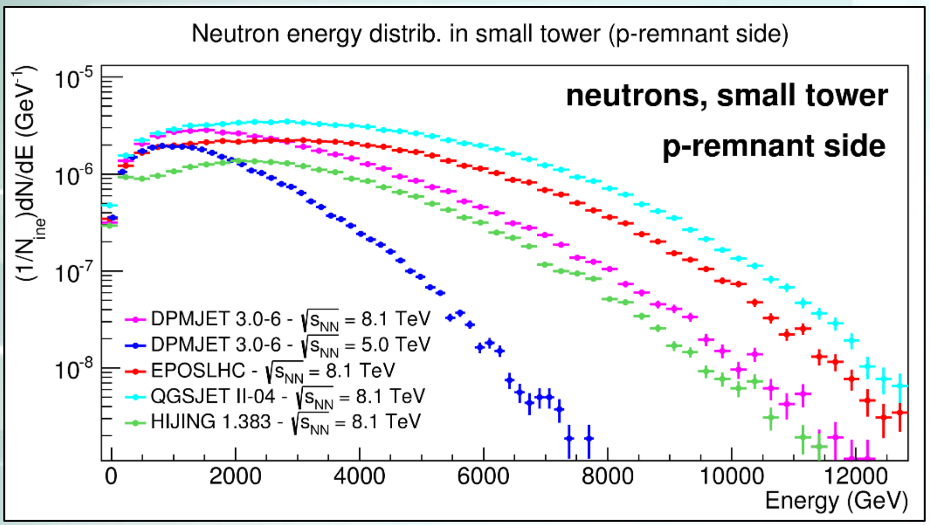




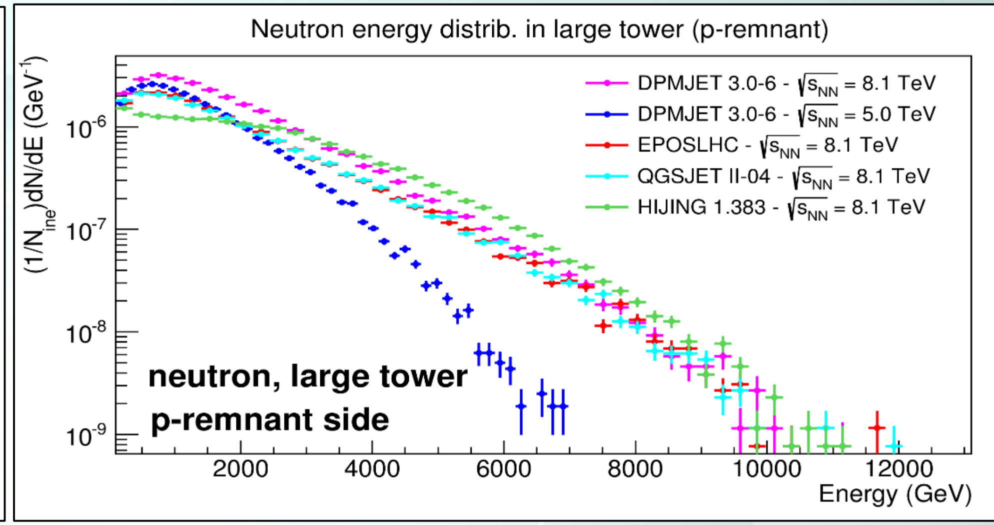
Single neutron spectrum

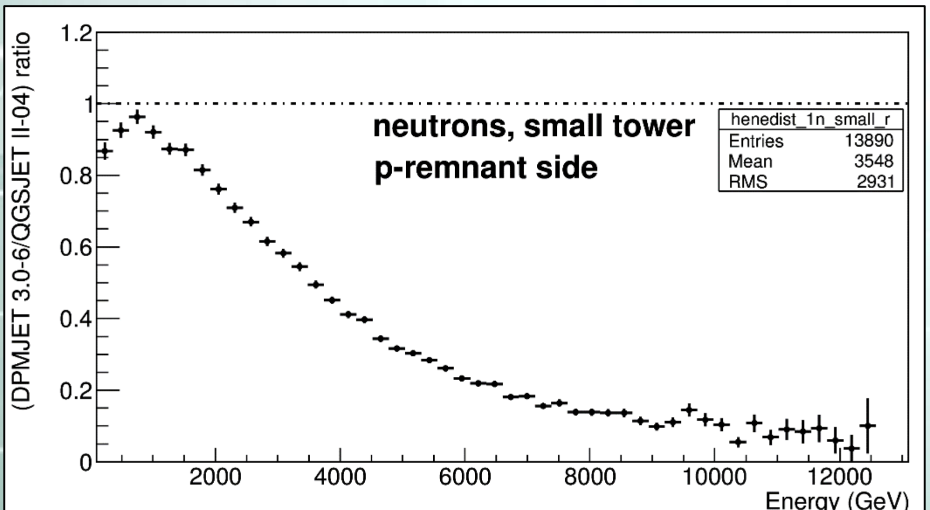
35% ENERGY RESOLUTION IS INCLUDED IN THESE PLOTS

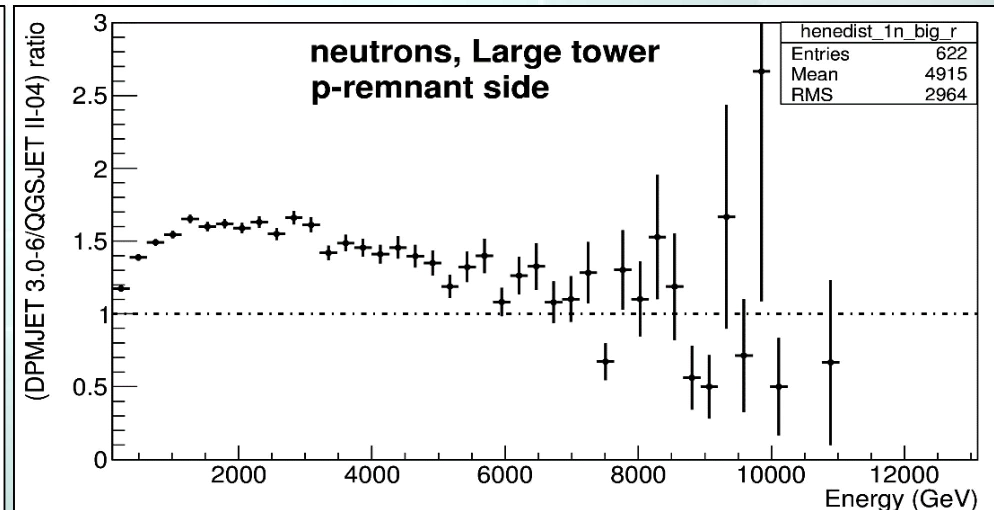
Small tower



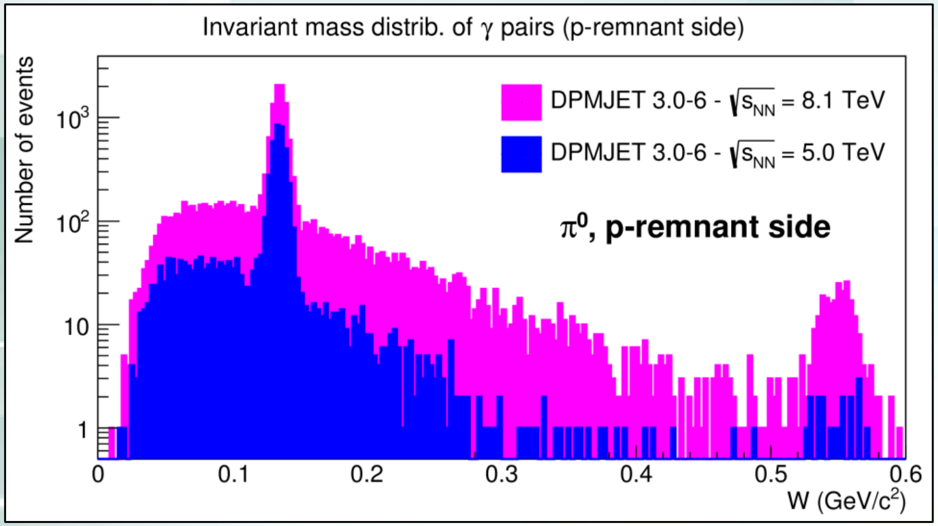
Large tower

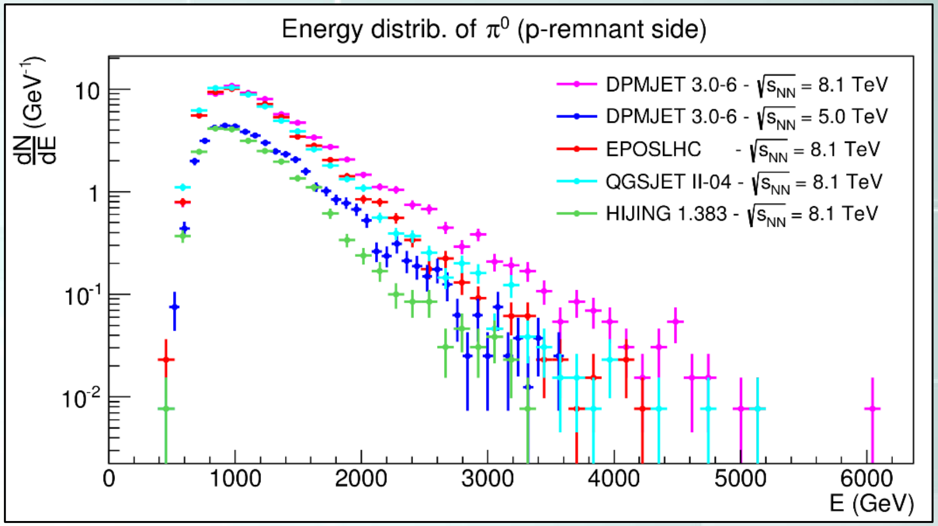




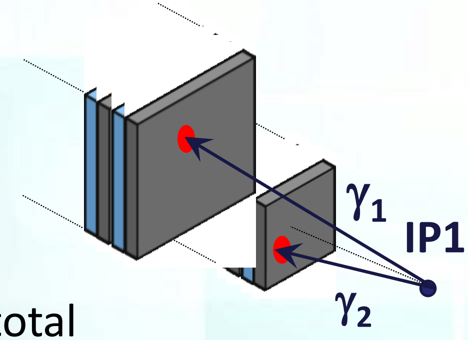


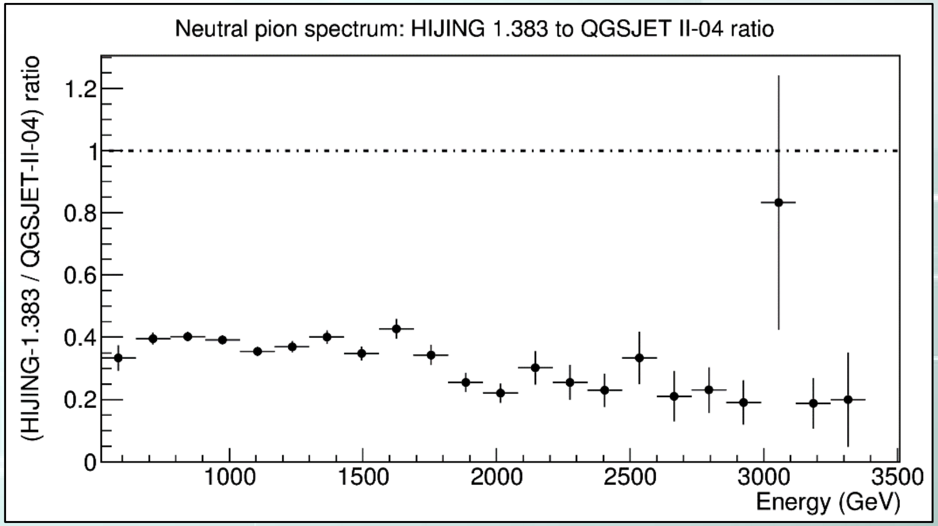
Neutral pions





Type-I

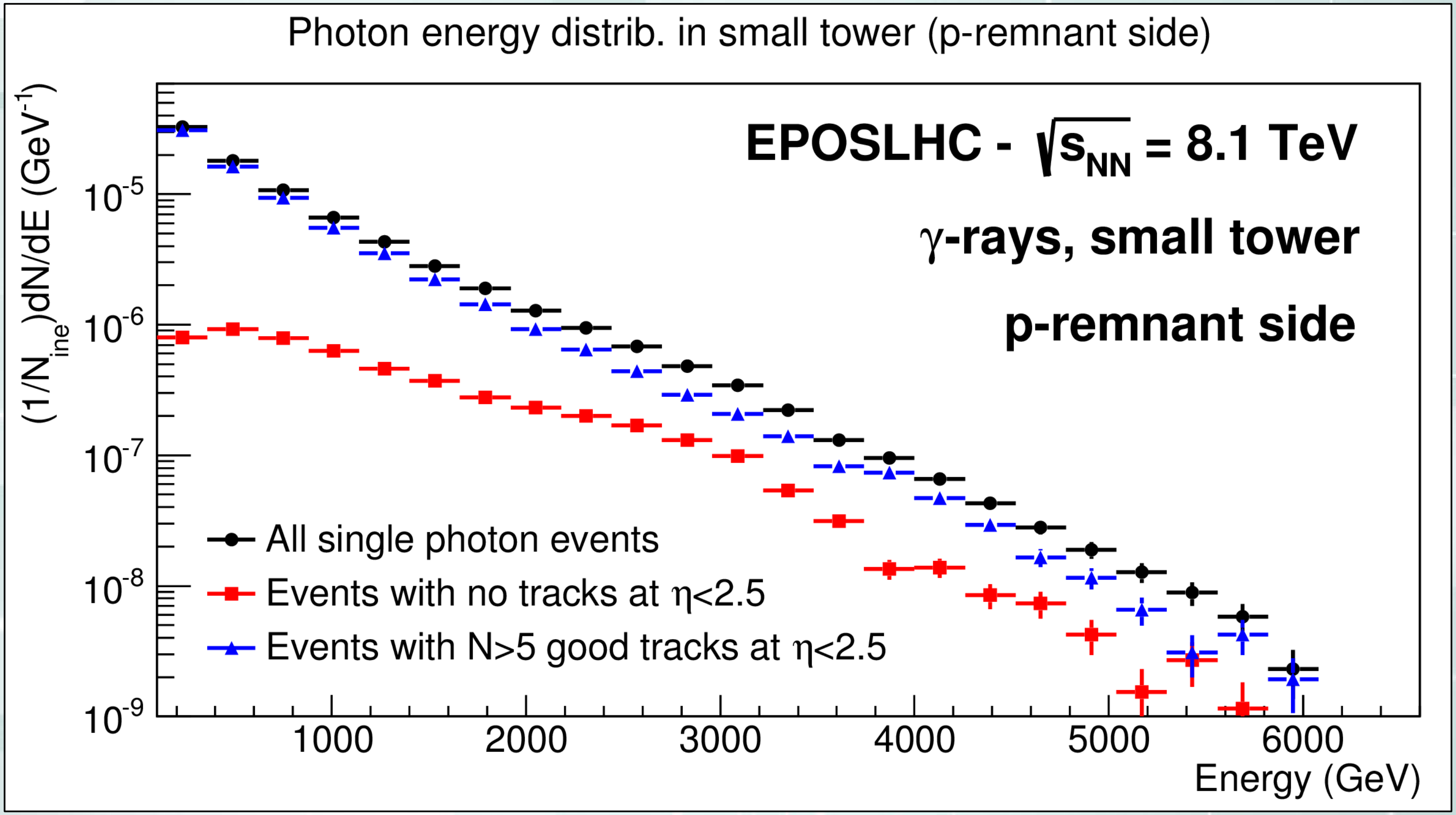




- 10^7 collisions in total
- 4 times more pions wrt 2013 run
  - Acceptance $\sim 10^{-3}$ (DPMJET)
- Evidence for η meson
  - Acceptance $\sim 2.3 \cdot 10^{-5}$ (DPMJET)

Important to run at 8.1 TeV to measure neutral pions and η meson!!!

ATLAS-LHCf combined analysis



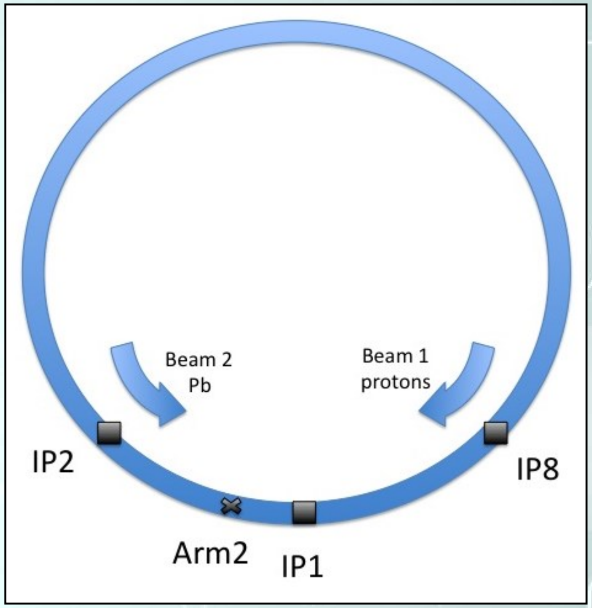
Information from the ATLAS central region is essential to separate the contributions due to diffractive and non-diffractive collisions.

Realistic running conditions

- Basic idea
  - Reduce as much as possible the impact of the LHCf run on the HI 2016 program
  - Minimal requests on the allocated time and NO further optimization of the machine parameters
  - Main request: low luminosity to reduce pile-up and radiation damage, easily reachable by means of beam separation (no special dedicated optic setup)
- Machine parameter
  - $\mathcal{L} = 10^{28}\ \mathrm{cm^{-2}s^{-1}}$
  - Beam crossing angle: up to 370 urad (ideal: downward going beams at IP1)
  - $\beta^* = 0.4 \div 0.5\ \mathrm{m}$
- Minimum physics program (based on simulations)
  - Minimum integrated luminosity to detect $4 \cdot 10^4\ \pi^0$ **ATLAS-LHCf common events** for physics and energy calibration
  - Data acquisition time depends on the bandwidth allowed by ATLAS for common data taking
  - 100 Hz common rate → 1 day
  - **400 Hz common rate → ~ 12 h taking data in two different acceptance region**

Technical details

- Installation
  - Arm2 detector only (to minimize the interference with the ATLAS ZDC)
    - Better spatial resolution than Arm1 (silicon microstrip)
    - Faster shaping time (front-end electronics)
  - Location
    - LSS1R (between IP1 and IP2)
    - Installation during TS3 2016 with remote handling system
  - Evaluation of radioprotection issues
    - Contacts with dr. C. Adorisio (DGS/RP)
    - New evaluations based on previous docs + 2016 Chamonix
    - 300 μSv max expected → ALARA level 2



- Limiting conditions for the measurement
  - Low luminosity (10^{28} $cm^{-2}s^{-1}$)
    - At 10^{29} : pile-up, signal overlap and radiation damage (400 Gy/day)
  - Bunch spacing > 150 ns
    - Limit of trigger logic
  - p-remnant side only
    - Protons in Beam 1
    - Lead in Beam 2

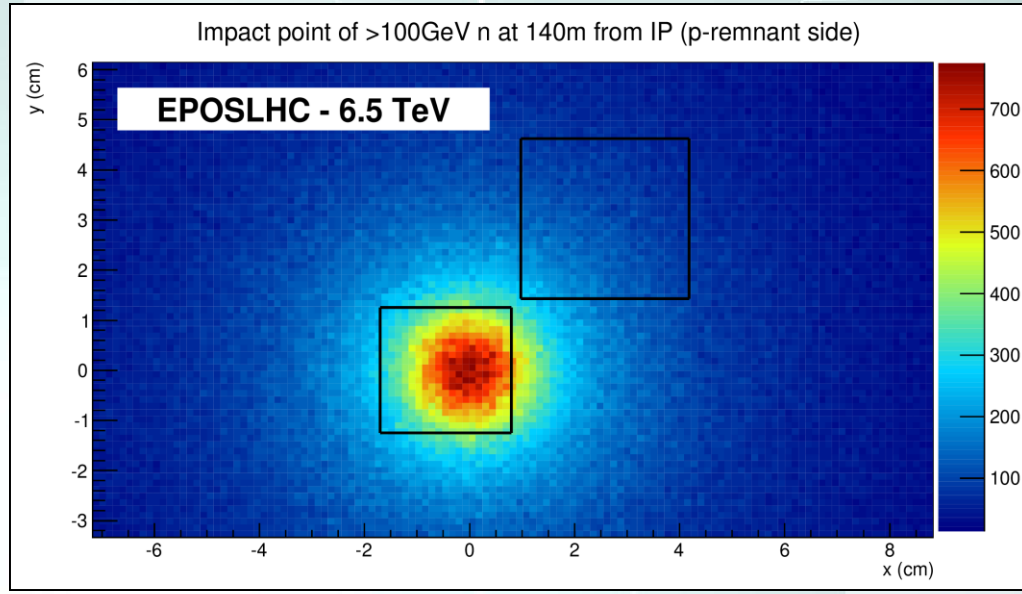
Conclusions

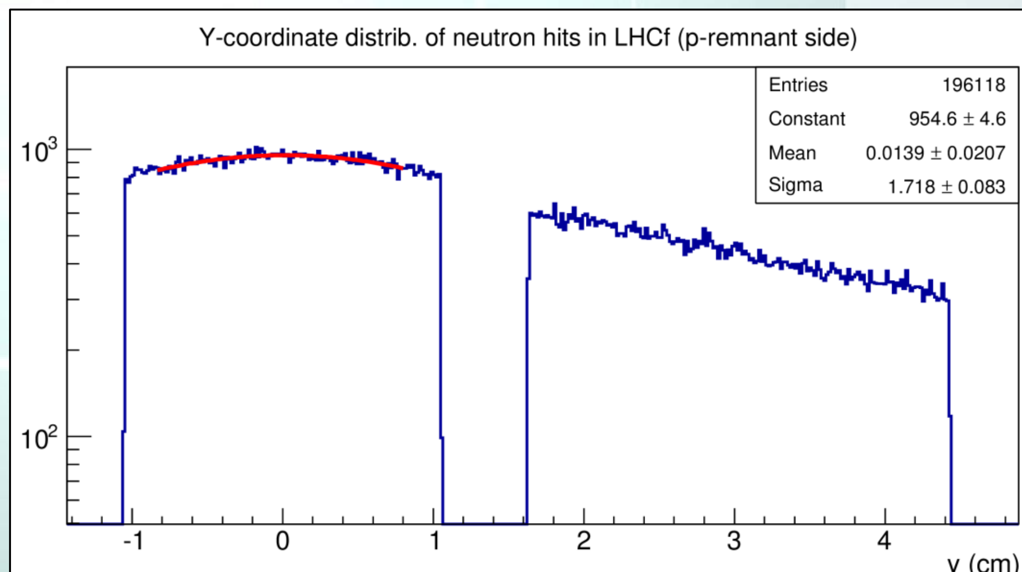
- 13 TeV p+p analysis on-going (LHCf only)
  - Preliminary photon spectrum has been presented
  - Neutron analysis is on the way
- 13 TeV p+p LHCf + ATLAS joint analysis is starting
  - Event matching has been successfully verified
- Letter of Intent for p+Pb 2016 has been submitted
  - CERN-LHCC-2016-003 (LHCC-I-027)
  - Half day running at $L=10^{28}$ Hz/cm^2 to collect 40000 π^0 in common with ATLAS
  - Technical issues related to installation and radioprotection have been considered
- Light Ion (LI) future collisions
  - Please keep in mind that LHCf is still interested in running in a possible future p+LI and LI+LI run ☺

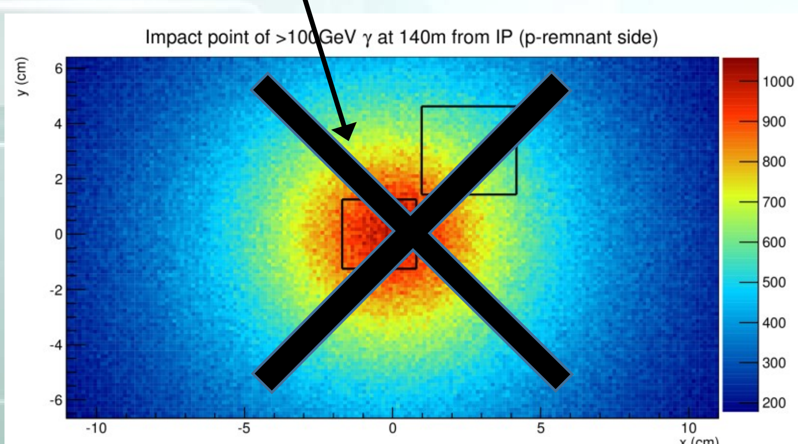
BACKUP

Determination of beam center

- Exploiting the hit-map of <u>high energy hadrons</u>
- Contribution of UPC: well peaked at 0 deg
- 2D or 1D fit
- Not easy with <u>photons</u>







Pile-up and signal overlap

frev	11235,95506	
nbunches	400	
sigma QCD	2,20E-24	
sigma UPC	5,50E-25	
L	2,00E+28	
mu	0,00979	0,01
mu con UPC	0,0122375	
accettanza	0,163	
accettanza con	0,326	

Collision prob. senza UPC	
p0	9,9005E-01
p1	9,9005E-03
p2	4,9502E-05
p3	1,6501E-07

Collision prob. con UPC	
p0	9,8784E-01
p1	1,2089E-02
p2	7,3967E-05
p3	3,0173E-07

prob. good	0,00162
prob. bad	0,00001
pbad/pgood	0,00352

Pile-up without UPC	
pile-up probability	4,9668E-05
pile-up fraction	0,00499

Pile-up with UPC	
pile-up probability	7,4270E-05
pile-up fraction	0,00611

SIGNAL OVERLAP without UPC	
Overlap in case of 2 additional b.c.	
overlap prob.	0,00324
Overlap in case of 3 additional b.c.	
overlap prob.	0,00486

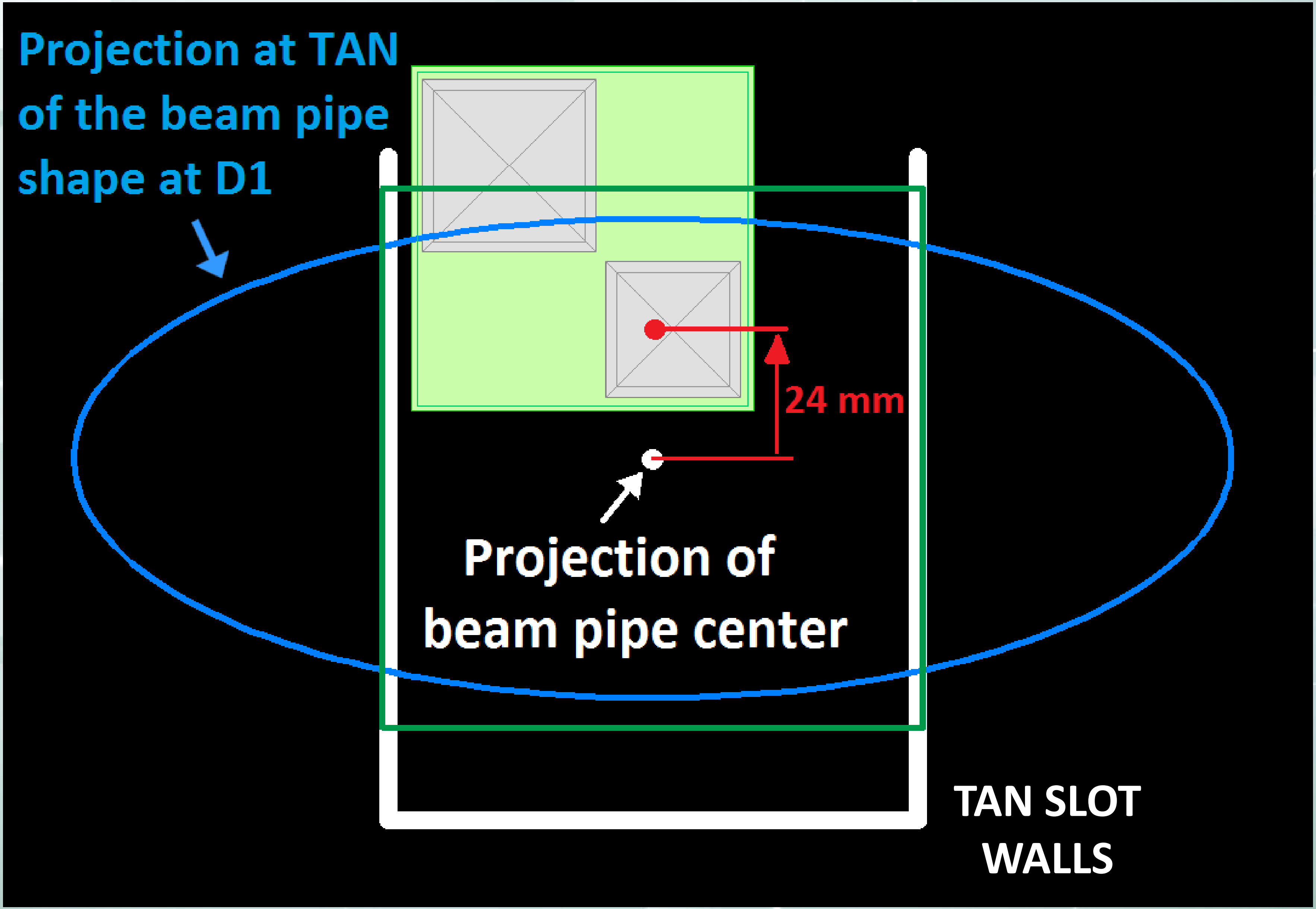
SIGNAL OVERLAP with UPC	
Overlap in case of 2 additional b.c.	
overlap prob.	0,00791
Overlap in case of 3 additional b.c.	
overlap prob.	0,01185

Minimum physics program

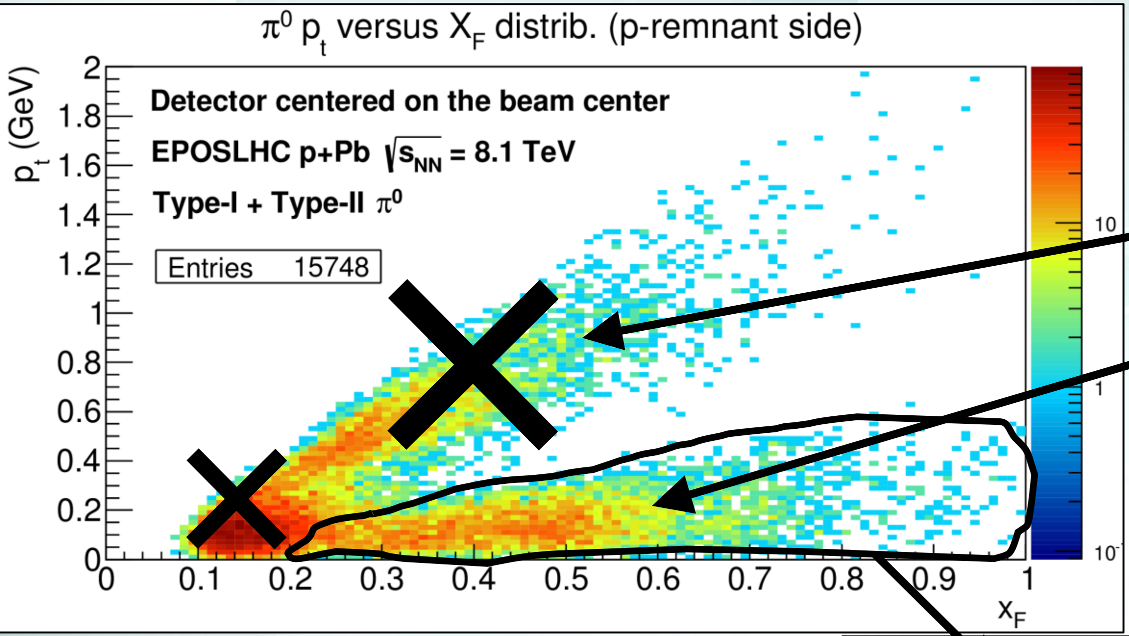
n. trigger QCD	n. trigger with UPC	acceptance for pi0	collision rate QCD	total LHCf acceptance	dead time
3,00E+06	6,00E+06	0,0133	2,20E+04	6,60E-02	1,50E-03
n. pi0 expected			LHCf QCD hit rate	LHCf hit rate with UPC	LHCf trigger rate
3,99E+04			1,45E+03	2,90E+03	5,42E+02
Lumi	sigma qcd		ATLAS-LHCf trigger rate	DAQ time LHCf-ATLAS (h)	TOTAL DAQ time +20% (h)
1,00E+28	2,20E-24		400	4,17	5,00
			100	16,67	20,00
					TOTAL DAQ (2 positions) (h)
					10

- **NEXT SLIDES: neutral pions**
  - Beam crossing angle = 340 urad
  - Upward going beams at IP1
  - A distance > 1.5 mm between the impact points of the two photons is required for neutral pion reconstruction

Problems with the 2016 "beam flip"

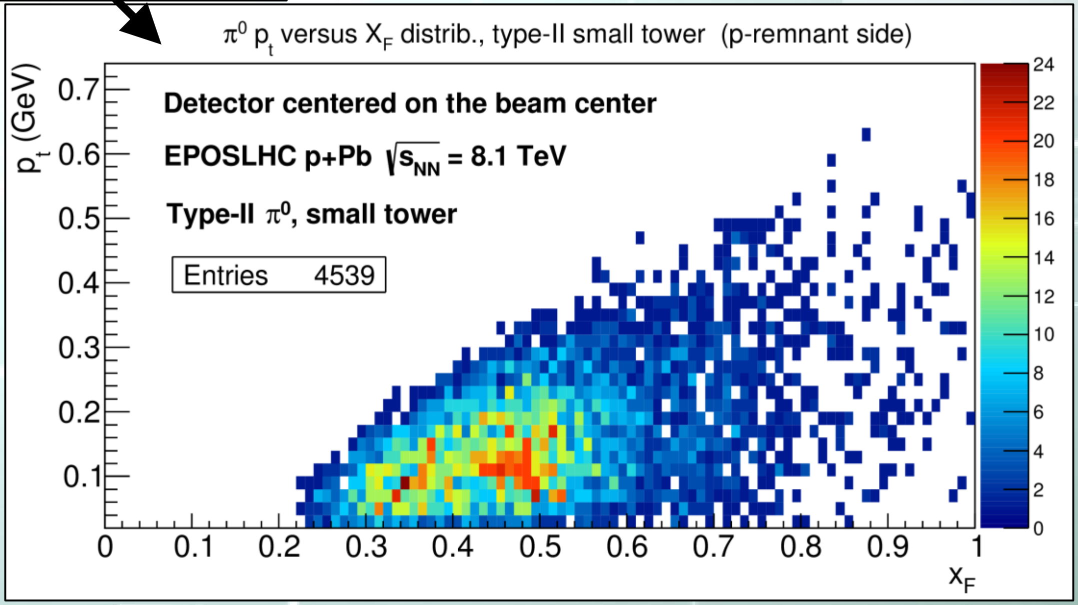


Visible contributions in the p_t-x_F plane



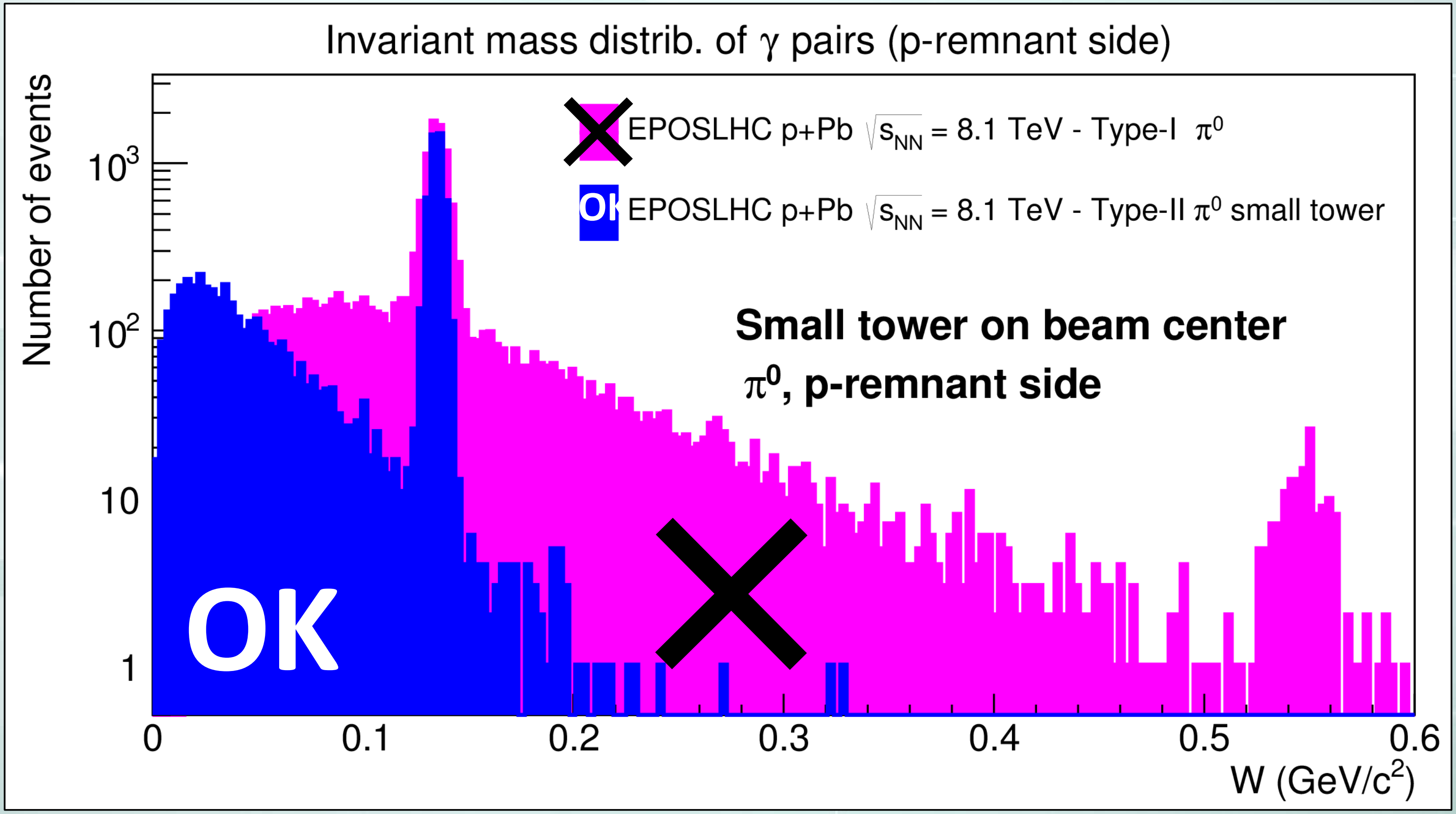
Arm2 large tower is hidden behind the beam pipe shadow. The **small tower** is positioned on the beam line to measure Secondary particles at extreme pseudo-rapidity and determine also the beam center.

Arm2 small tower is centered on the beam line



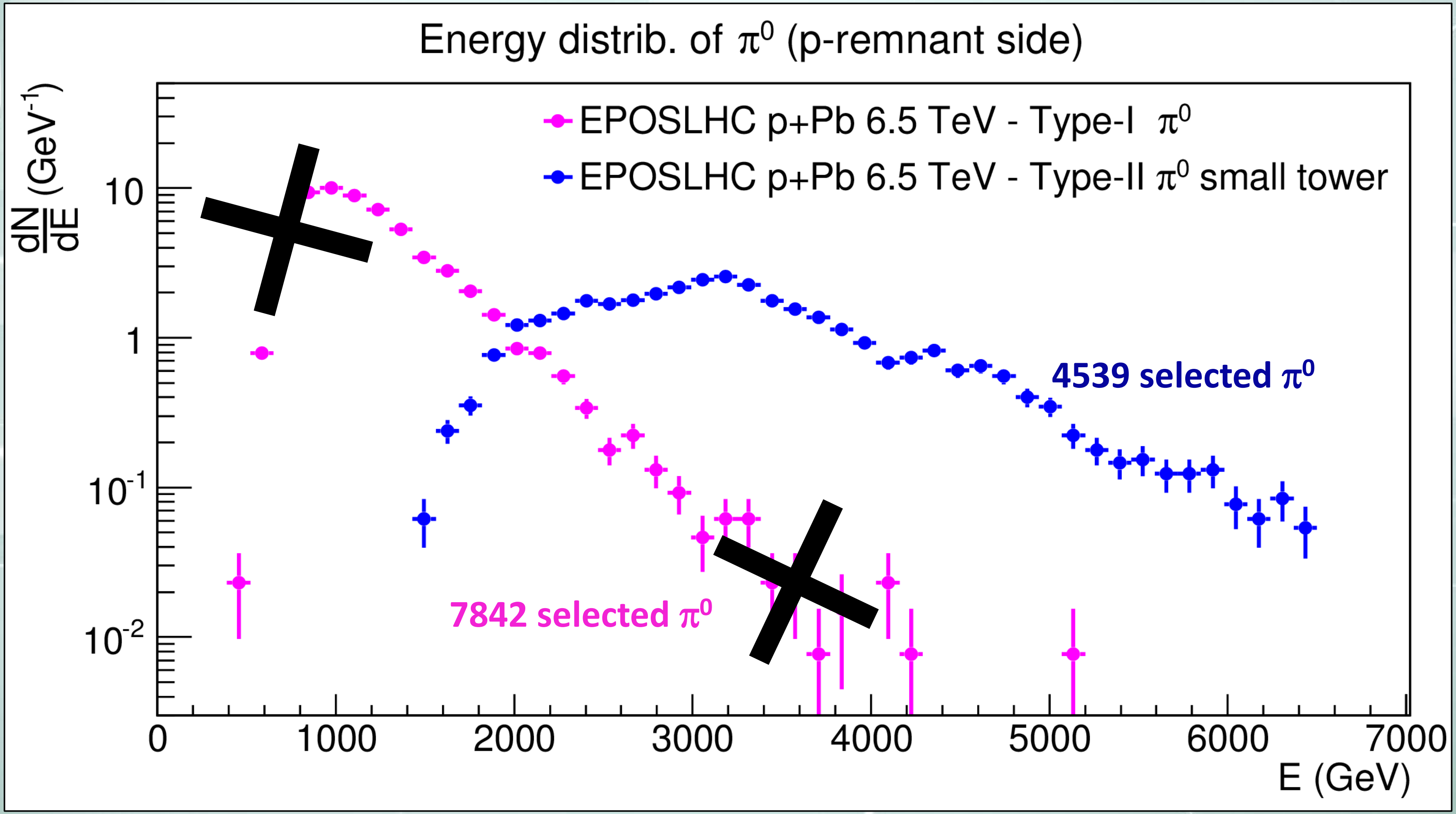
Upward going beams

- The small tower is “centered” on the beam center
  - Simulation for BCA = 340 μrad



Upward going beams

- The small tower is "centered" on the beam center
  - Simulation for BCA = 340 μrad



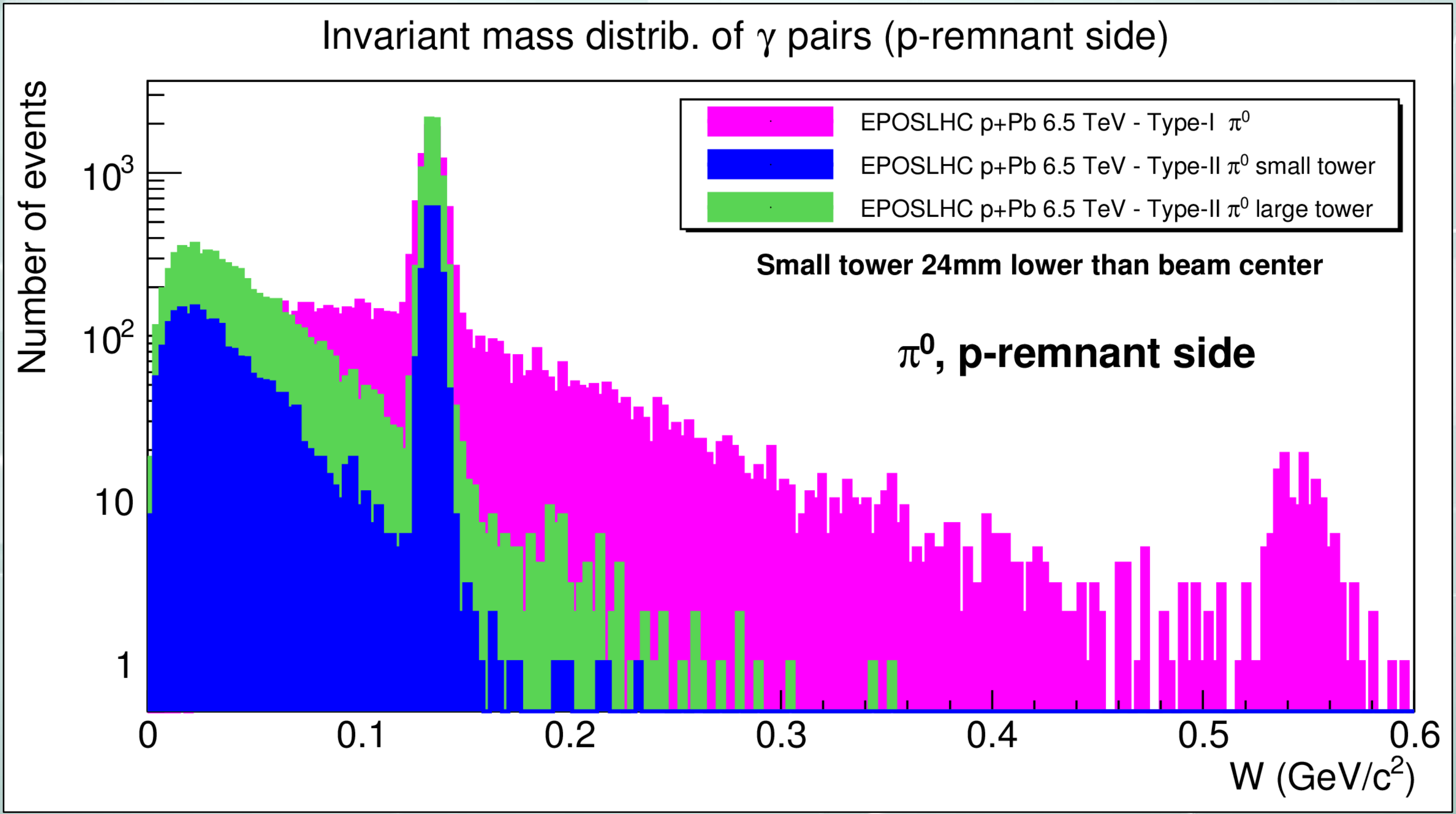
Upward going beams

Tentative solution

- We can somewhat workaround the problem by moving the detector down, but …
  - The measurement with the small tower on the beam line center remains the most important part, to measure at extreme pseudo-rapidity and to determine the beam line position
  - We loose high-p_t secondary particles
  - We loose type-I π^0s
  - Not negligible inefficiency in an eventual low duration run

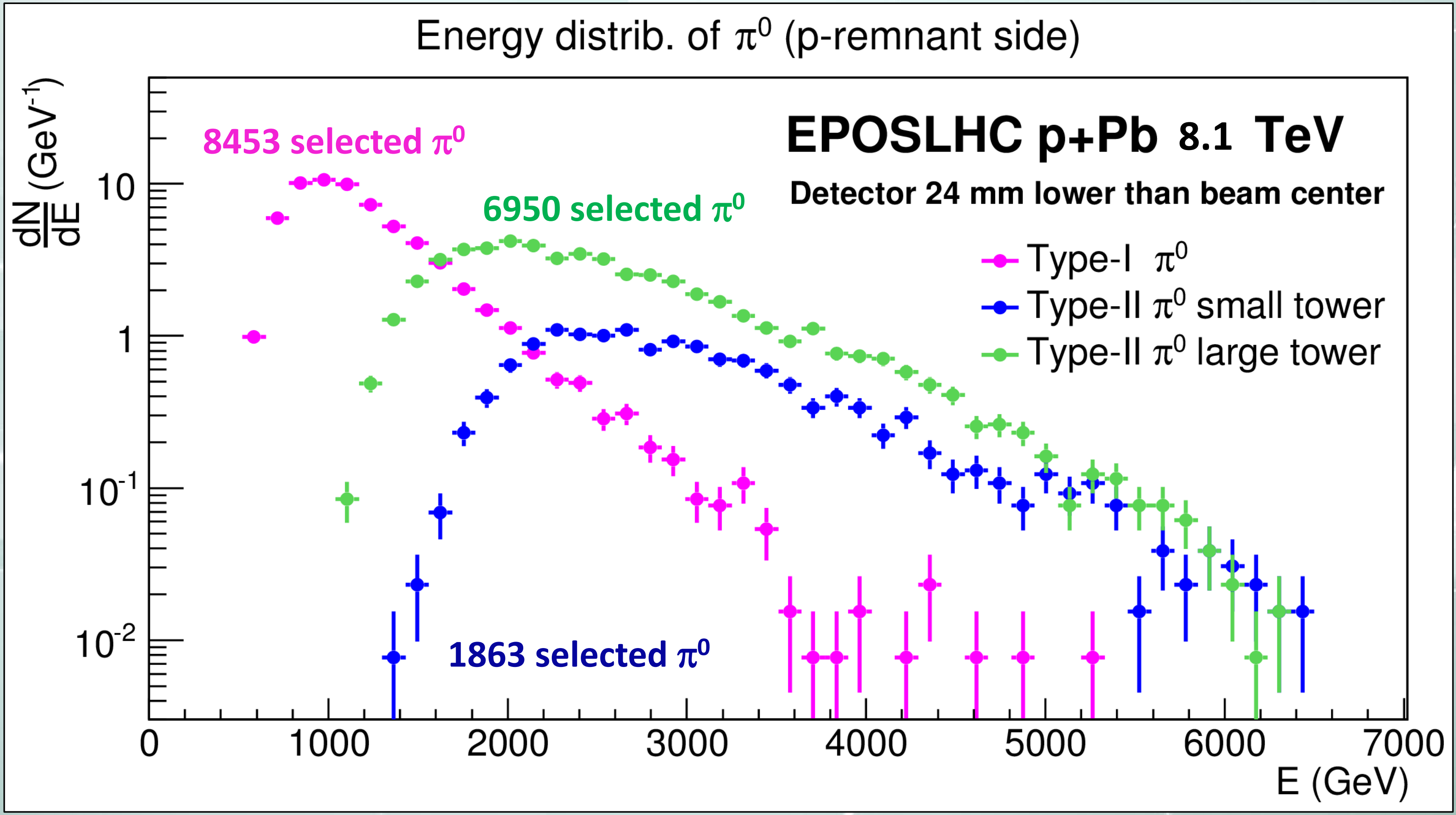
Upward going beams

- Moving detector down 24 mm (the calorimeter does not cover the beam center anymore)



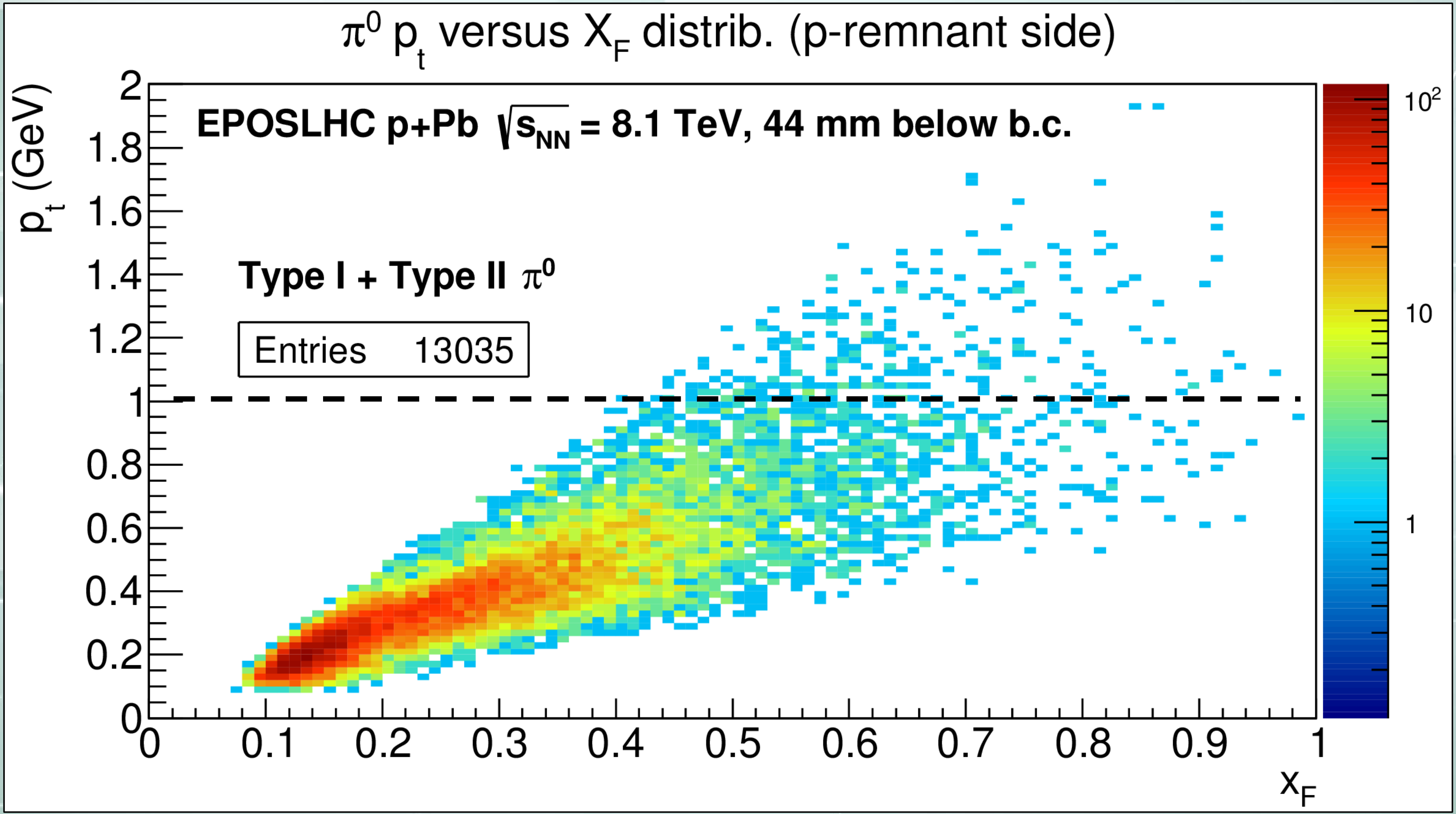
Upward going beams

- Moving detector down (the calorimeter does not cover the beam center)



Upward going beams

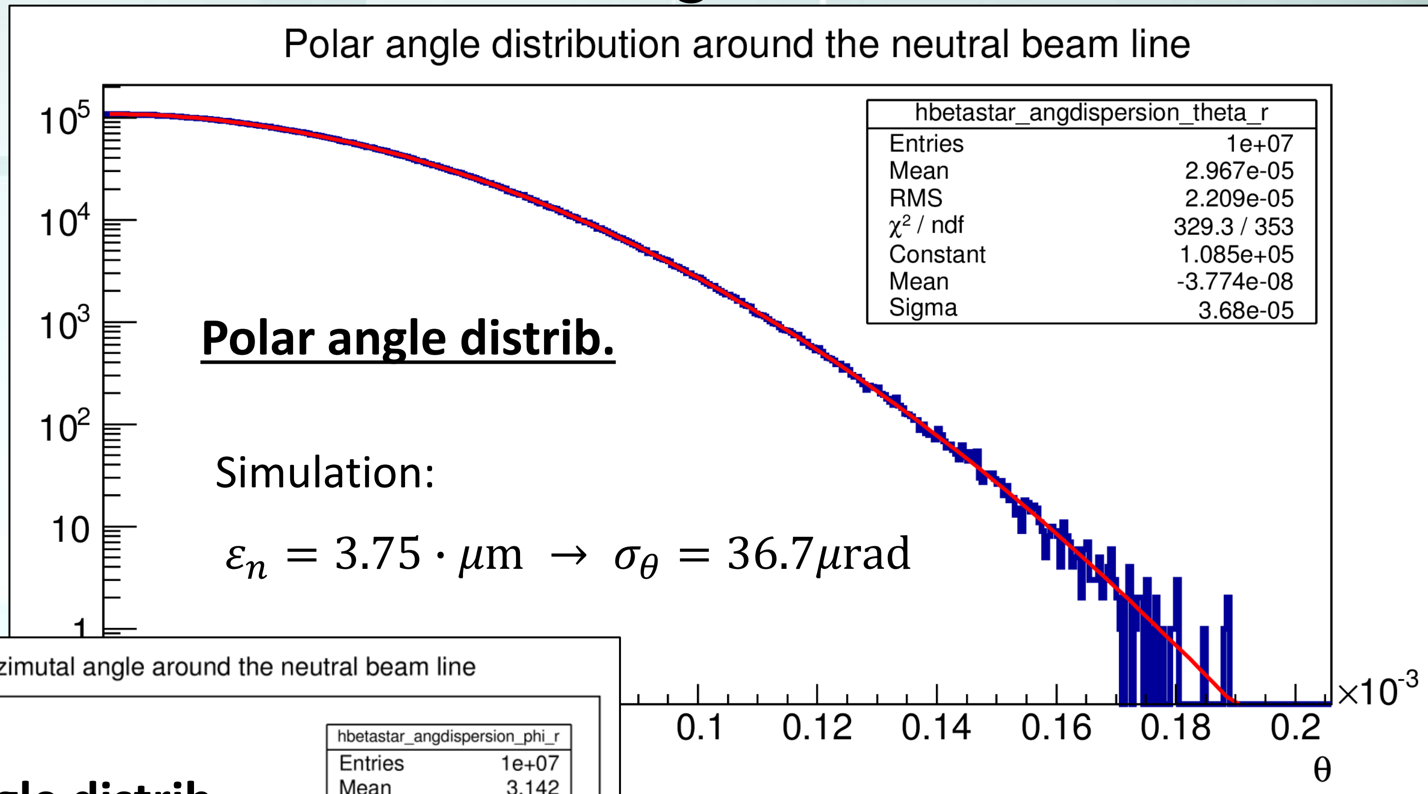
Measurements of neutral pions in a different position



Considering small beta values…*

- DPMJET 3.0-6
  - Same simulated data analyzed in two different ways:
    - Assuming no angular dispersion
    - Assuming the angular dispersion due to β^* = 0.4 m
      → rotating momenta of all secondary particles for each event
- Comparison of p_t spectra

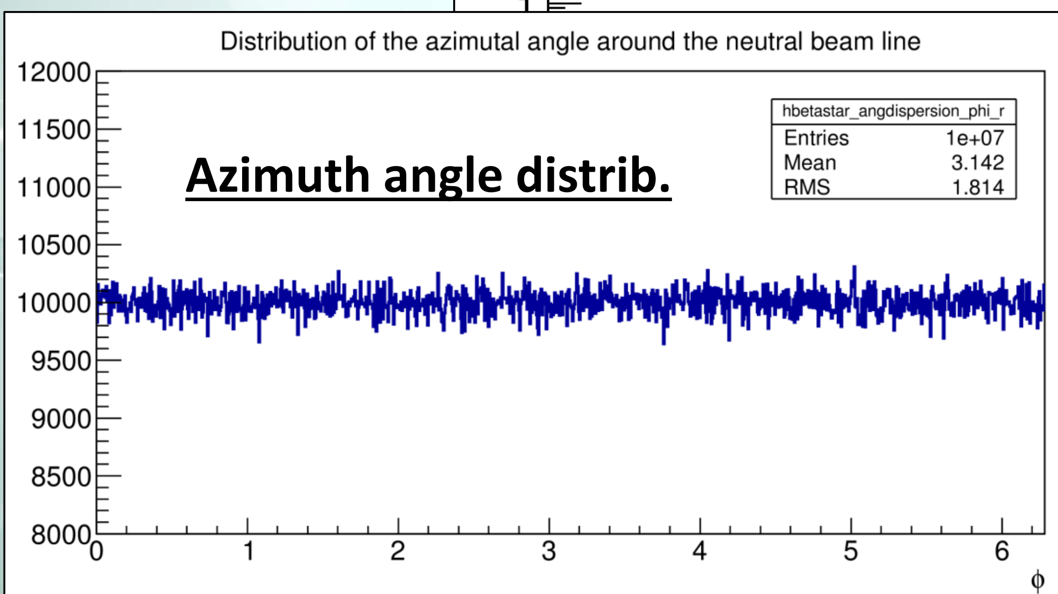
Considering small bSimulated angular distributions



Polar angle distrib.

Simulation:

$$\varepsilon_n = 3.75 \cdot \mu\text{m} \rightarrow \sigma_\theta = 36.7\mu\text{rad}$$

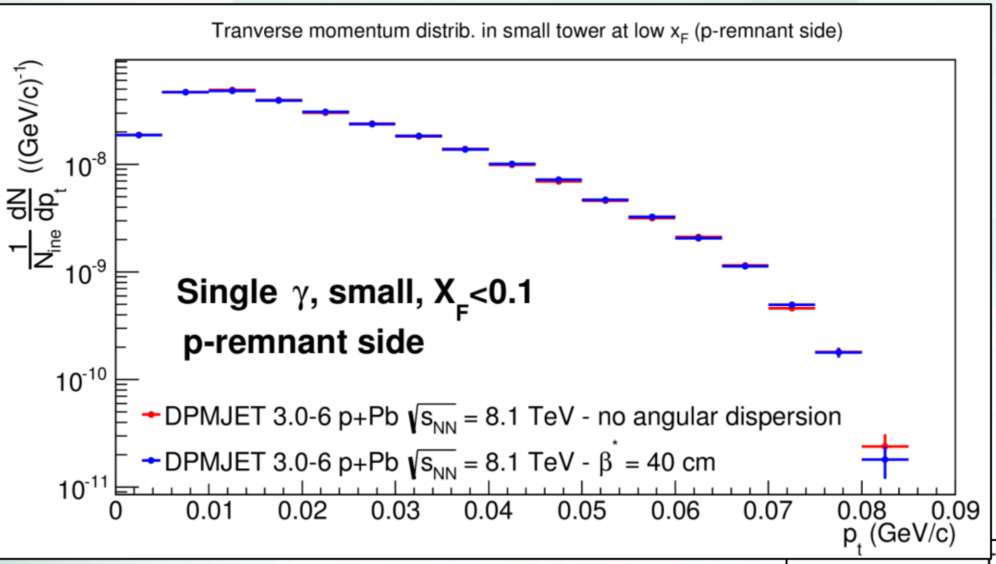


Azimuth angle distrib.

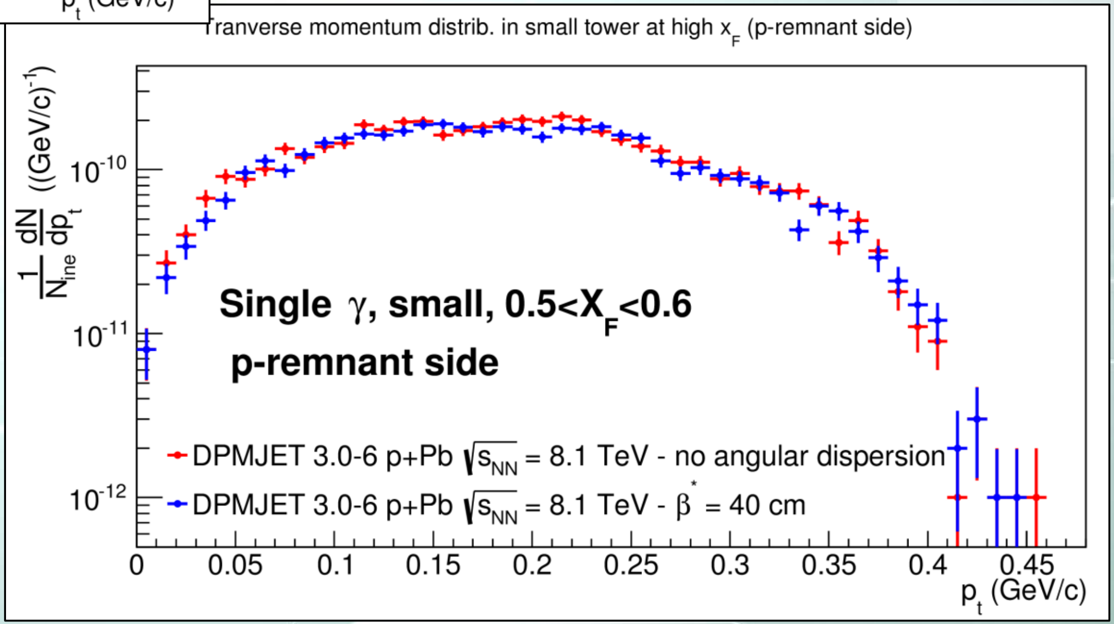
New positive info by John Jowett (from the hospital after an accident during skiing):

$$\boldsymbol{\varepsilon_n \approx 2\ \mu\text{m} \rightarrow \sigma_\theta \approx 24\ \mu\text{rad}}$$

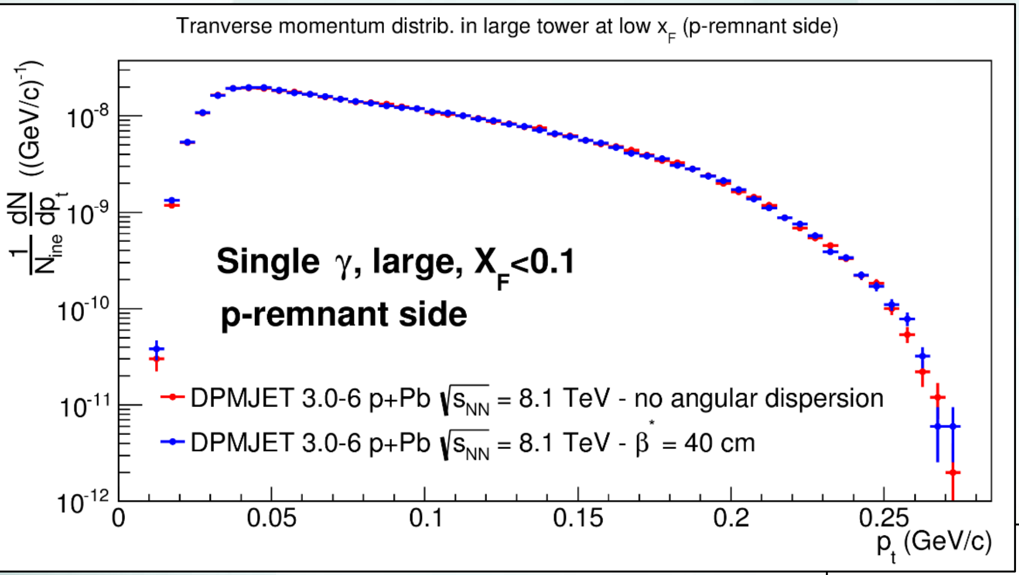
Single photon pt spectra at different energy



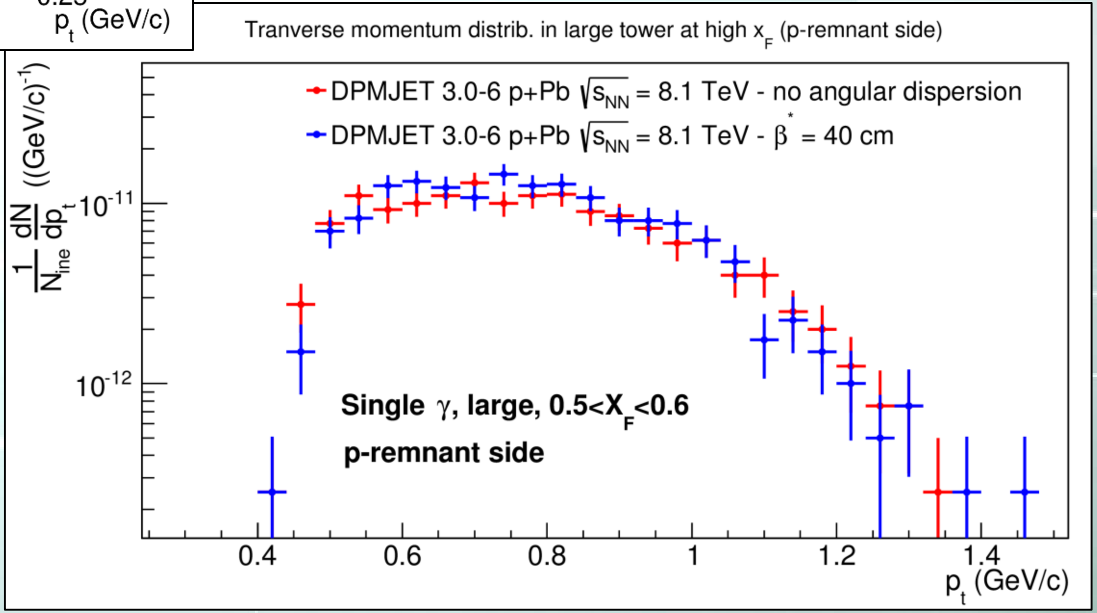
SMALL TOWER



Single photon pt spectra at different energy



LARGE TOWER



LHCf RE-INSTALLATION — XMAS TS

CERN

HSE
Occupational Health & Safety and Environmental Protection Unit

1 week cooling time

	Operation	Time (min)	Required Personnel	Position	Individual Dose (mSv)	Collective Dose (mSv)
-2	Bring downstairs the detectors and the tooling needed for the installation	10	2 physicists from LHCf	PM15-> UL16	0	0
-1	Bring downstairs electrical cupboard, camera and desktop	20	2 operators from EN/HE	PM15-> UL16	0	0
0	Radiation Survey	15	1 technician DGS/RP	UJ16/TAN	13	13
1	Prepare/check mini-cranes for operation	45	2 operators from EN/HE	TAN and between TAN and UJ16	6	12
2	Bring the shielding box	10	2 operators from EN/HE	Bunker in UJ17 ->TAN	0	0
3	Bring the detector to the TAN	5	2 physicists from LHCf	UJ17 -> TAN	0	0
4	Remove Cu bar and place it in the appropriate shielding box	10	2 operators from EN/HE	UJ16 Behind the shielding wall	0	0
5	Install detector	10	2 operators from EN/HE	UJ16 Behind the shielding wall	0	0
6	Remove bar shielding box	10	2 operators from EN/HE	TAN-> bunker in UJ17	0	0
7	Remove electrical cupboard and cameras from TAN	5	2 operators from EN/HE	TAN	5	10
8	Bring upstairs electrical cupboard, camera and desktop	20	2 operators from EN/HE	UJ16 -> PM15	0	0

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LHCf RE-INSTALLATION – XMAS TS

HSE
Occupational Health & Safety
and Environmental Protection Unit

1 week cooling time

	Operation	Time (min)	Required Personnel	Position	Individual Dose (mSv)	Collective Dose (mSv)
9	Screwing (no fine positioning)	15	2 physicists from LHCf	On top of the TAN	26	52
10	Installation of the Front Counter	10	2 physicists from LHCf	On top of the TAN and behind it on the footbridge	18	36
11	Cabling for preamp and FC	5	2 physicists from LHCf	On top of the TAN and behind it on the footbridge	9	18
12	Additional cabling for the electronics box	10	2 physicists from LHCf	On top and side of the TAN	18	36
13	Survey	*4 h*	2 technicians from BE/ABP	Around the TAN region	62	124
14	Electronics commissioning	*(8 h)* 60	2 physicists from LHCf	This test is performed from USA15. In case of problems 2 physicists from LHCf will have to work on top of the TAN for a period which depends on the kind of problem (typically 15-60 min)	105	210
15	Mechanical commissioning (manipulator)	*(8 h)* 30	2 physicists from LHCf	Test performed mainly from USA15. One physicist is required to stay on top of the TAN for 30 minutes maximum	27	54
16	Bring back detector shielding boxes	10	1 physicists from LHCf	TAN->PM15	0	0
17	Exit the zone	10	2 physicists from LHCf	TAN->PM15	0	0

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LHCf RE-INSTALLATION – XMAS TS

HSE
Occupational Health & Safety
and Environmental Protection Unit

Summarizing (1 week cooling time):

Concerned Person	Individual Dose (mSv)
1st LHCf physicist	158
2nd LHCf physicist	98
3rd LHCf physicist	150
DGS/RP technician	13
1st operator from EN/HE	11
2nd operator from EN/HE	11
1st operator from BE/ABP	62
2nd operator from BE/ABP	62
Collective Dose	***565mSv***

- The estimated dose are done considering the maximum dose rate at the position of the worker (TAN aisle, TAN top or side on contact).
- The individual dose for two of the LHCf physicists falls into the ALARA level II.
- Collective dose falls into ALARA level II.

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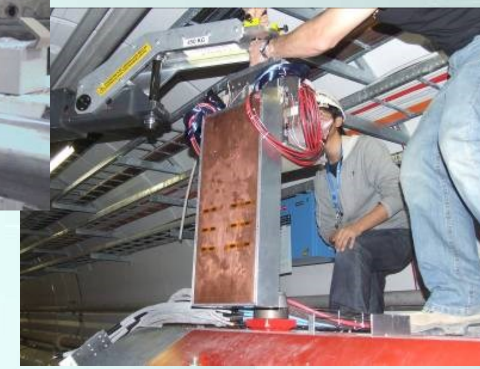
BRIEF HISTORY OF LHCf

- May 2004 LOI
- Feb 2006 TDR
- June 2006 LHCC approved

Jul 2006
construction

Aug 2007
SPS test beam

Jan 2008
installation
Sep 2008
1st LHC beam



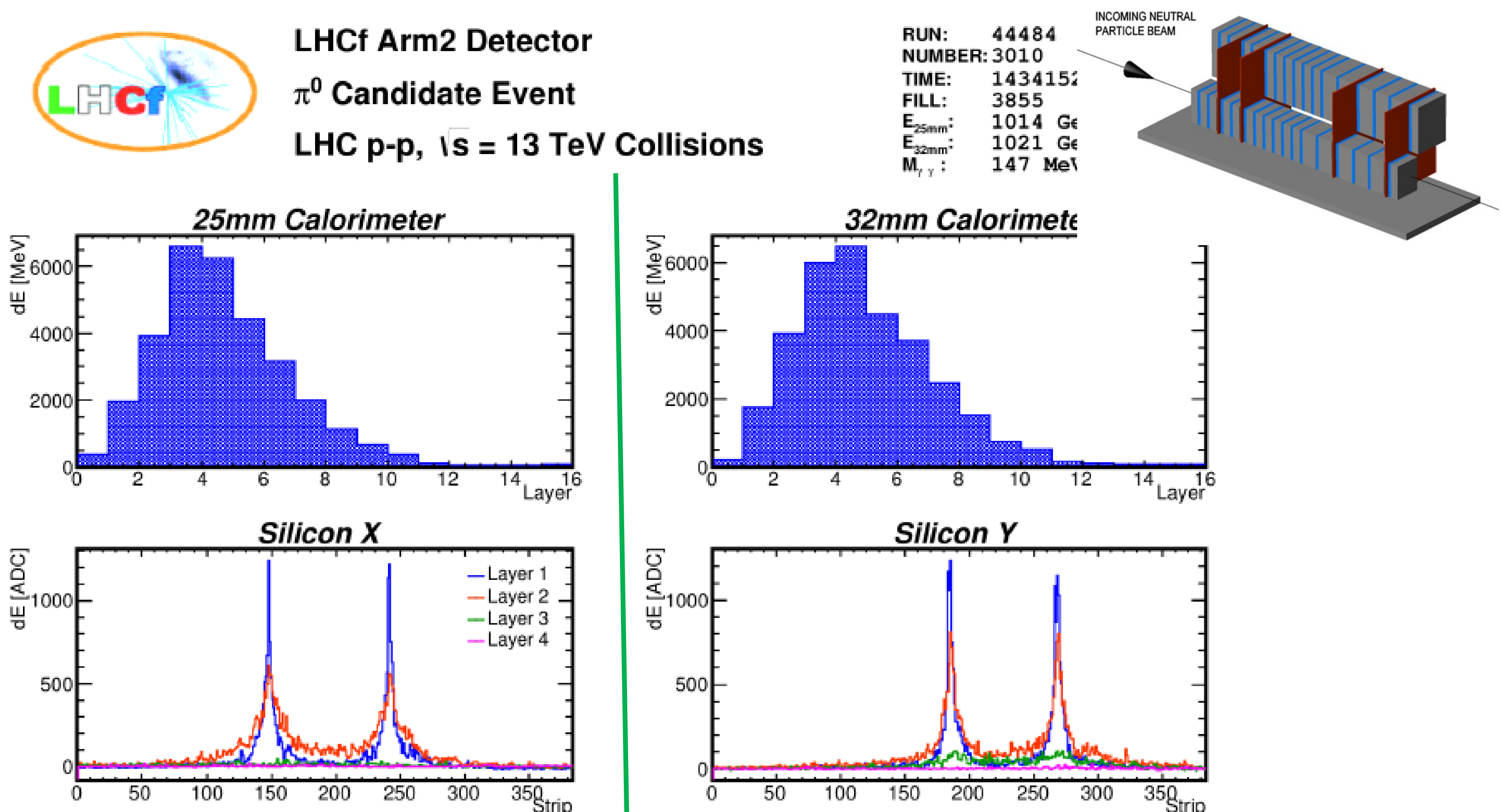
Dec 2009 - Jul 2010
0.9TeV & 7TeV pp,
detector removal

Dec 2012 - Feb 2013
5.02 TeV/n pPb & 2.76TeV
pp (Arm2 only),
detector removal

- 2013-2015 detector upgrade
- Several test beams

May - June 2015
13 TeV pp (dedicated run),
detector removal

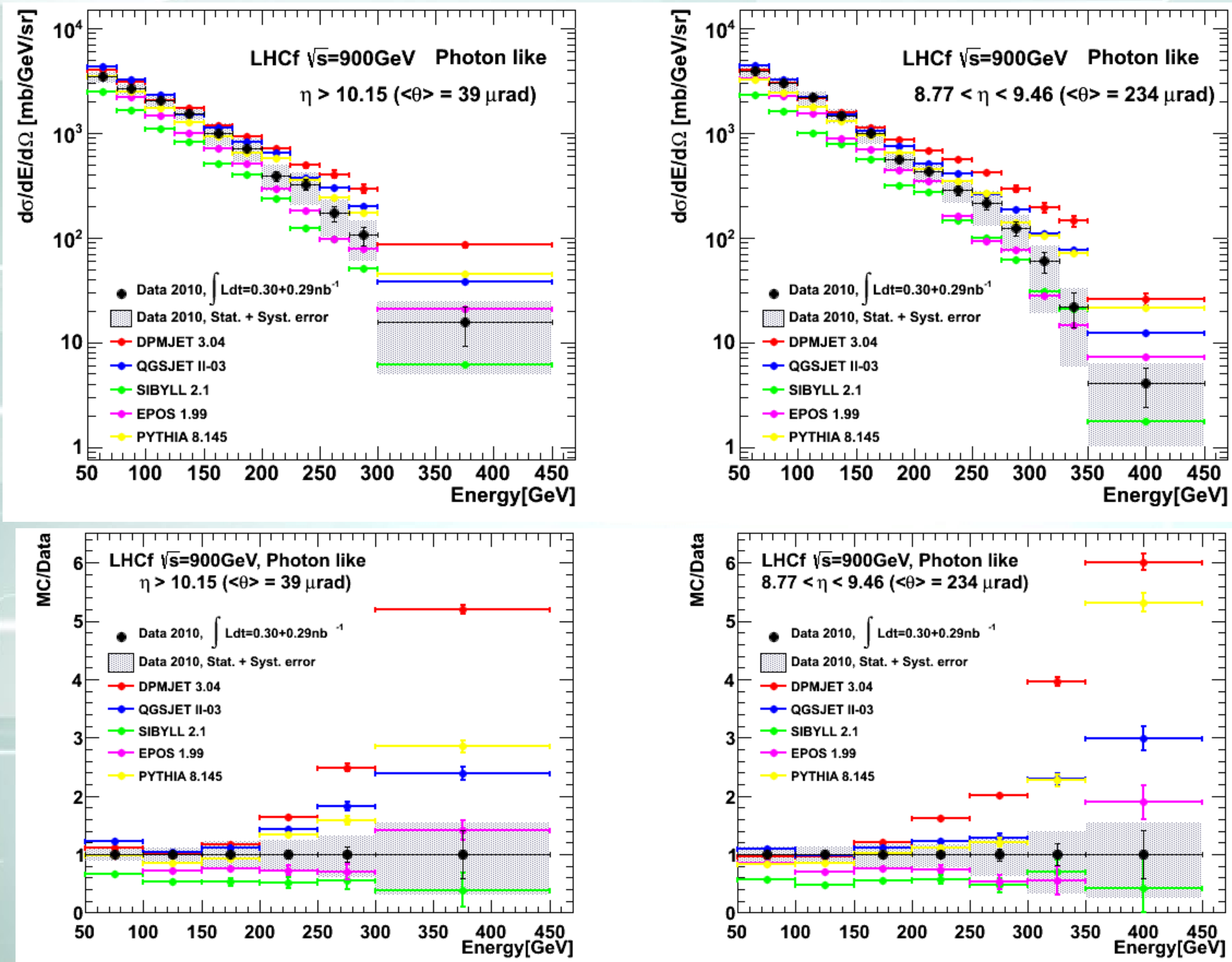
An impressive high energy p^0



SMALL TOWER

LARGE TOWER

Inclusive photon spectra (900 GeV pp)



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

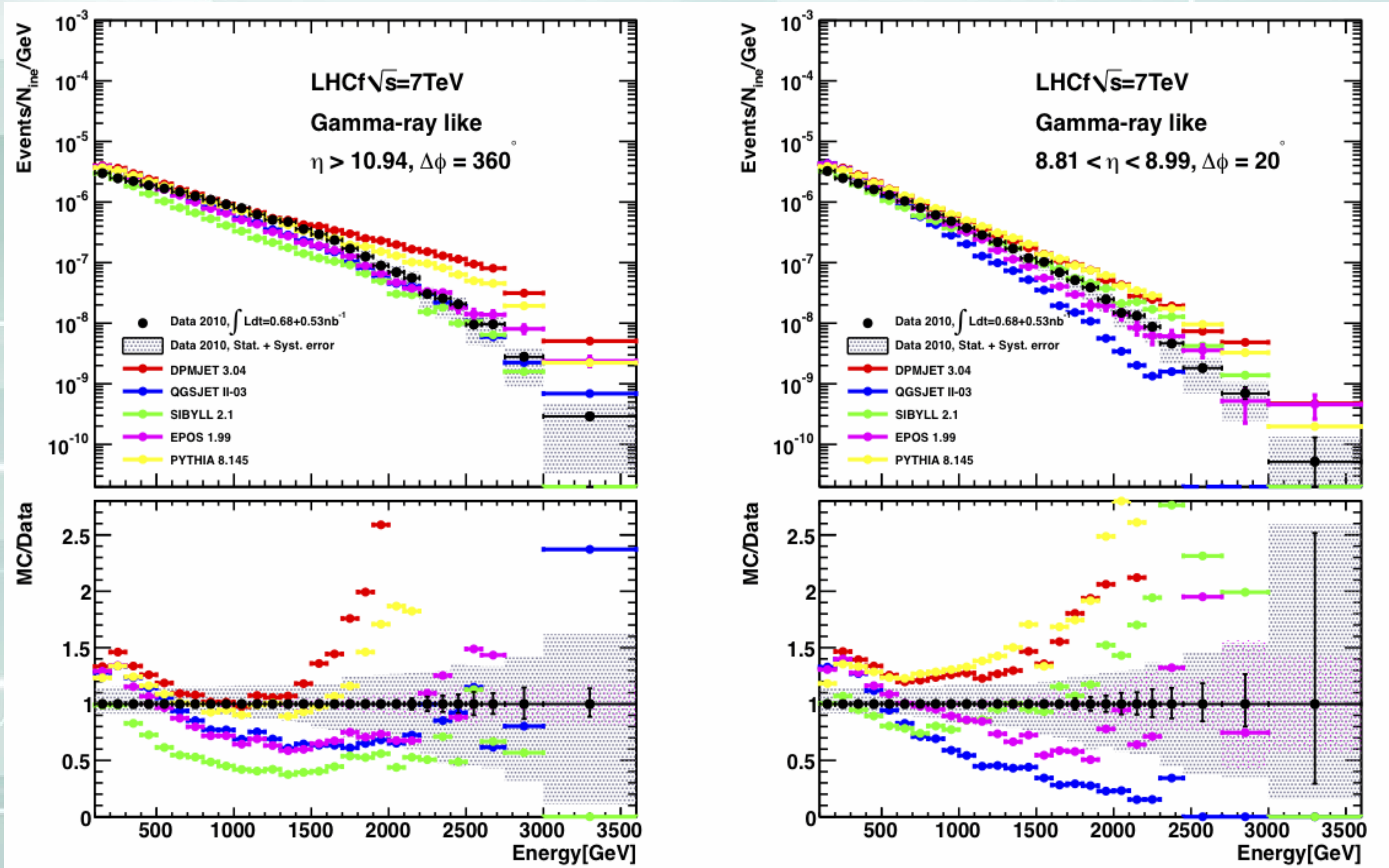
Syst.+Stat.

No strong evidence of η-dependence

DPMJET and **SYBILL** show reasonable agreement of shape

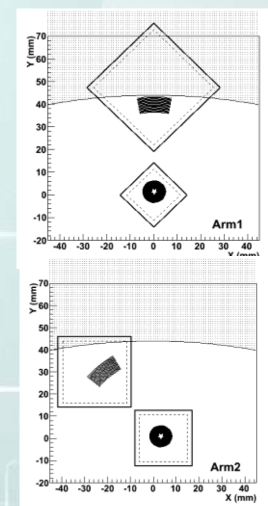
None of the models reproduces the data within the error bars

Inclusive photon spectra (7 TeV pp)



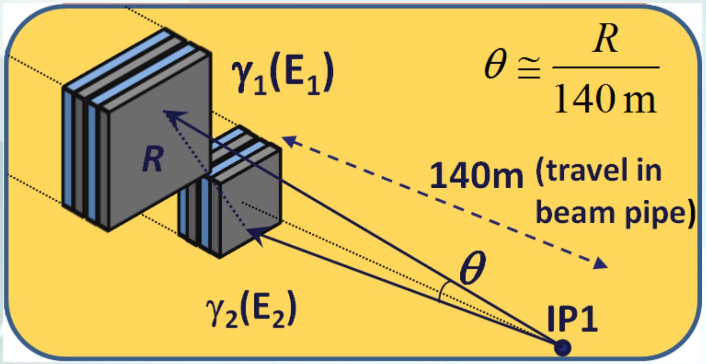
DATA
DPMJET 3.04
QGSJET II-03
SIBYLL 2.1
EPOS 1.99
PYTHIA 8.145

Syst.+Stat.

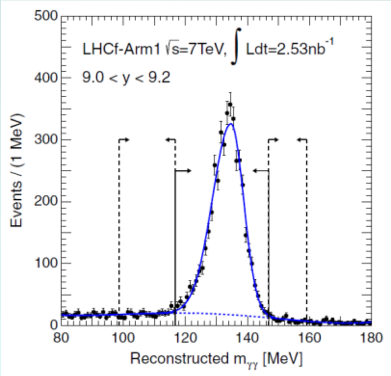


- No model can reproduce the **LHCf data** perfectly.
- **DPMJET** and **PYTHIA** are in good agreement at high-η for E_γ<1.5TeV, but harder in E>1.5TeV.
- **QGSJET** and **SIBYLL** shows reasonable agreement of shapes in high-η but not in low-η
- **EPOS** has less η dependency against the LHCf data.

π^0 cross section (7 TeV pp)

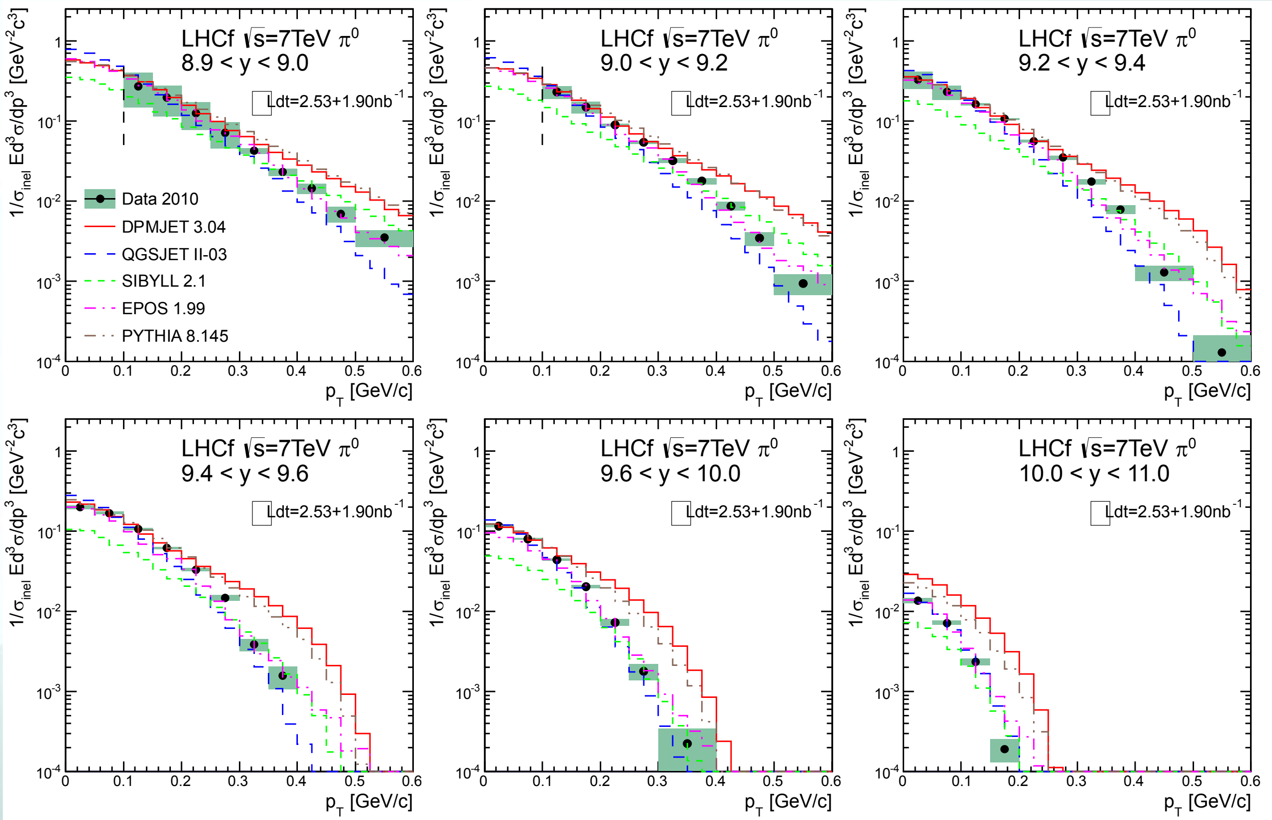


Reconstruction of the invariant mass of two-photon events

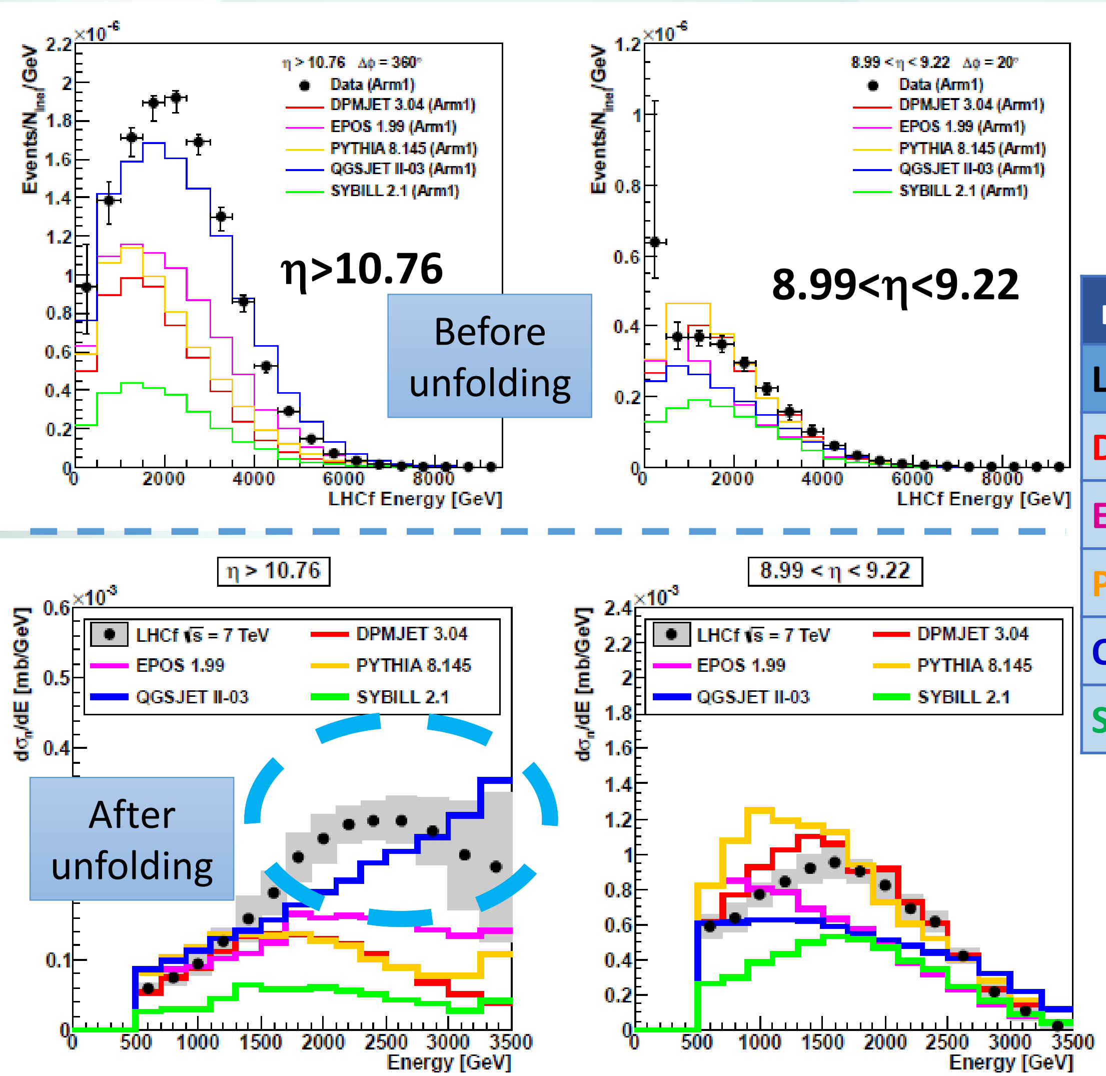


Identification of events with two particles hitting the two towers

- **EPOS1.99** show the best agreement with data in the models.
- **DPMJET** and **PYTHIA** have harder spectra than data ("popcorn model")
- **QGSJET** has softer spectrum than data (only one quark exchange is allowed)



Inclusive neutron spectra (7 TeV pp)



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

n / γ ratio	η>10.76	8.99<η<9.22
LHCf data	3.05±0.19	1.26±0.08
DPMJET3.04	1.05	0.76
EPOS 1.99	1.80	0.69
PYTHIA 8.145	1.27	0.82
QGSJET II-03	2.34	0.65
SYBILL 2.1	0.88	0.57

More abundant neutron yield wrt photons, not expected from MC

Large high-energy peak in the η>10.76 region (predicted only by QGSJET)
→ small inelasticity in the very forward region