Letter of Intent
Precise measurements of very forward particle production at RHIC
(LHCf@RHIC = RHICf)

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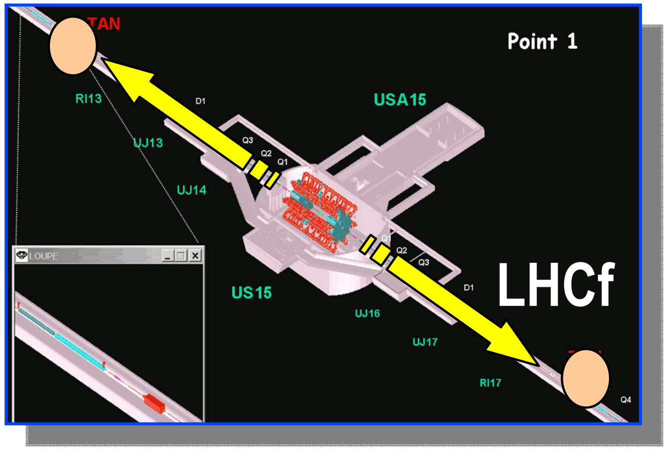
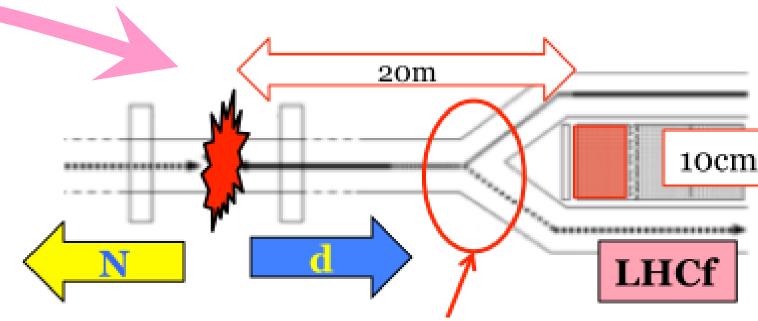
Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe

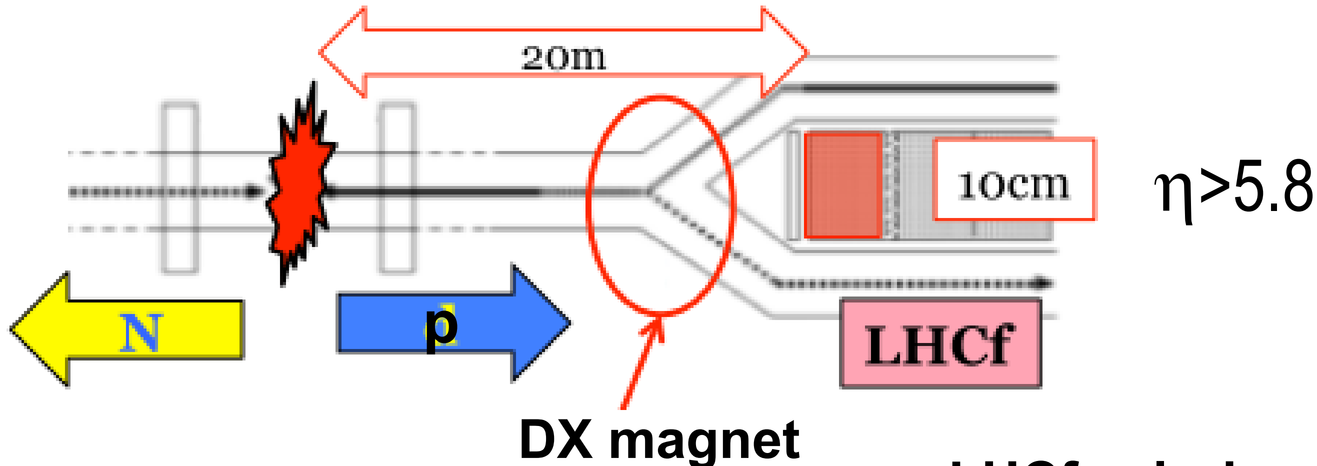
Outline of LHCf@RHIC “RHICf” proposal

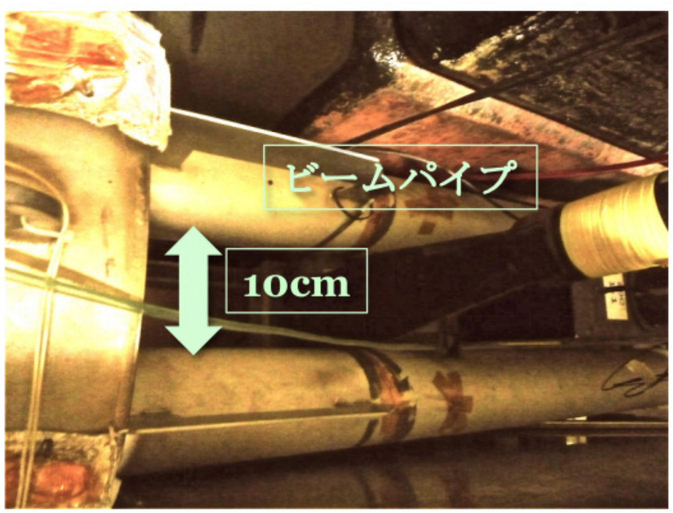


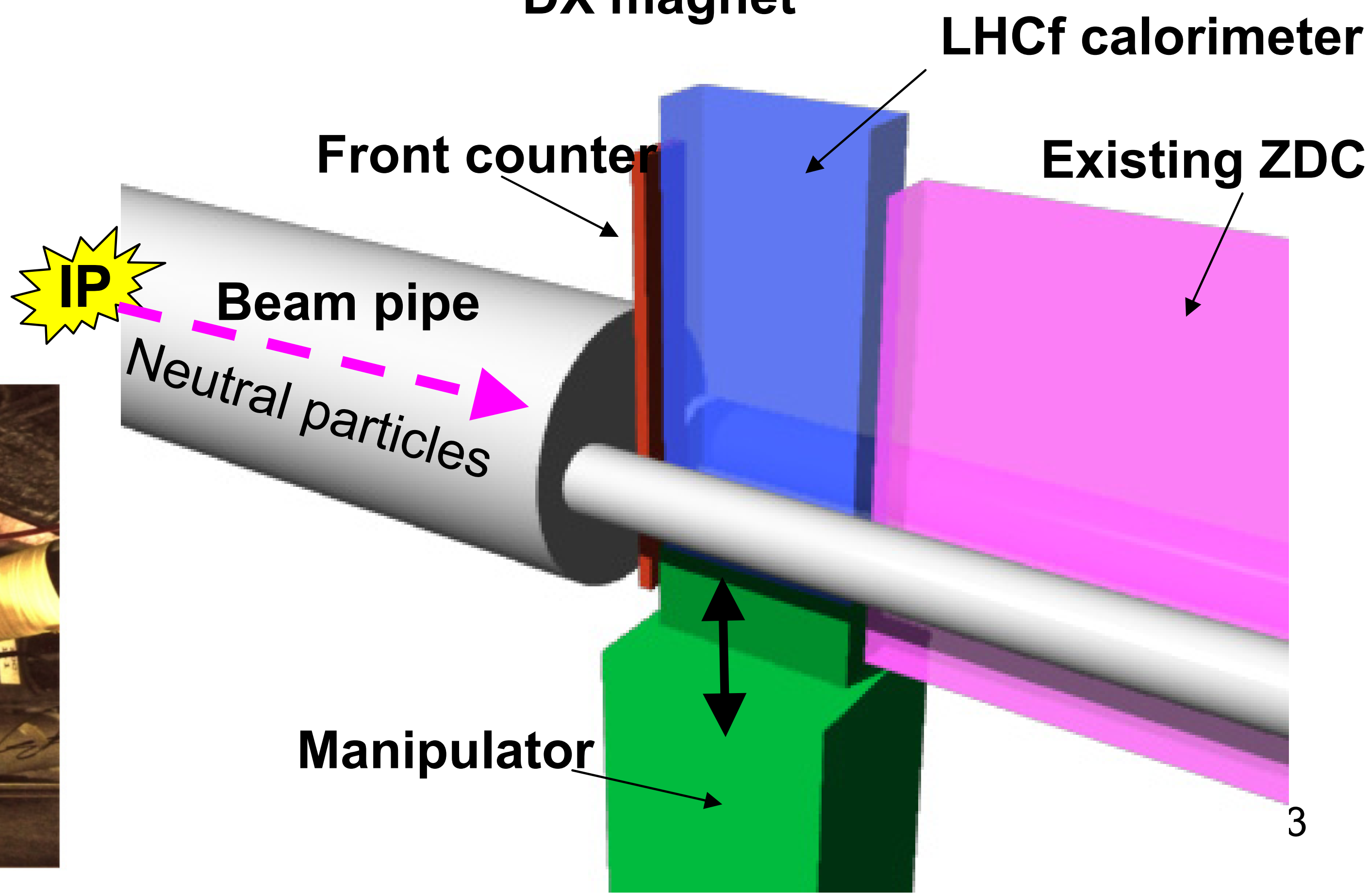


- Measurement of neutral particles (i.e. γ, π^0, n) at very forward with a position-sensitive small EM calorimeter.
- Install one of LHCf calorimeter in front of ZDC of either Phoenix or STAR IRs.
- Not a permanent detector. The detector will be supported by remotely-controlled manipulator to be inserted/retracted occasionally.
- 500GeV p↑p, 200GeV p↑p and 200GeV/n pN. Short time dedicated run (~a week) to prevent possible interference with ZDC.

RHICf experimental setup

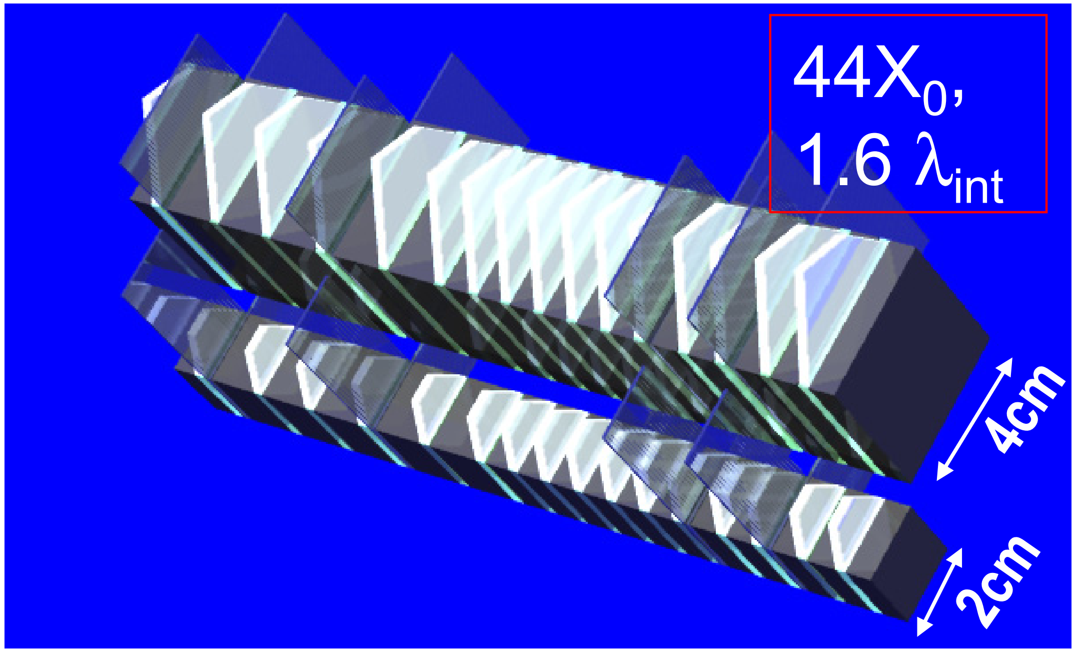






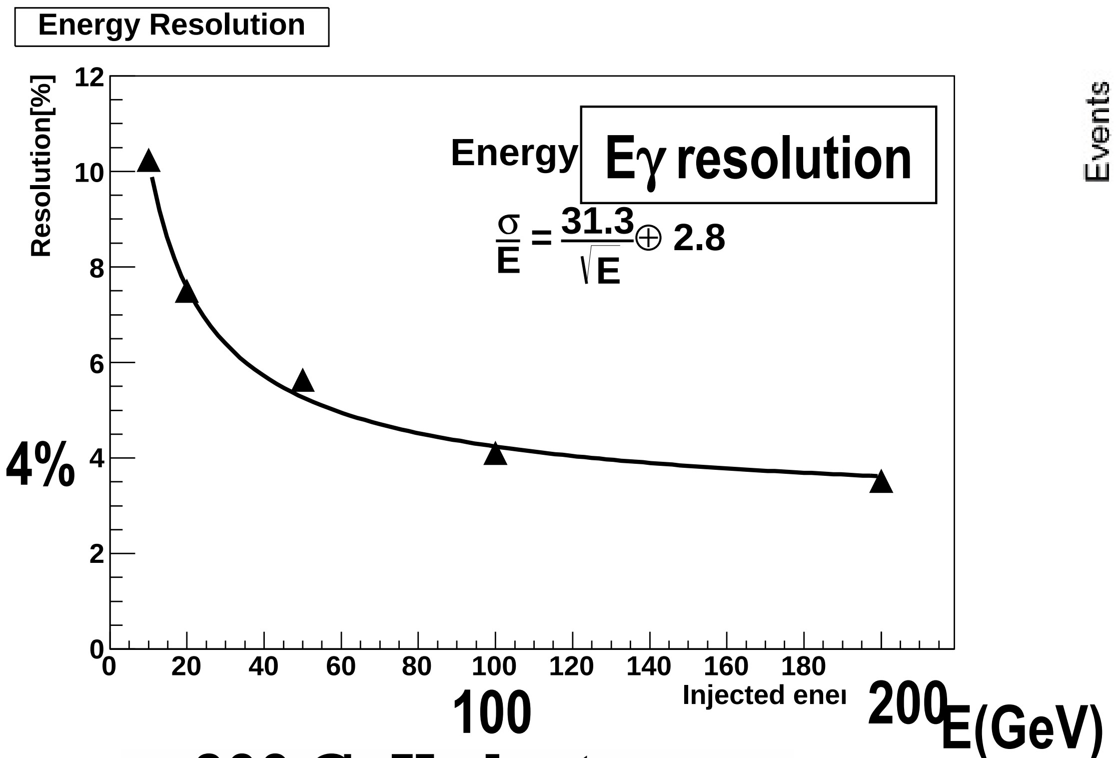
The LHCf detector (Arm1)

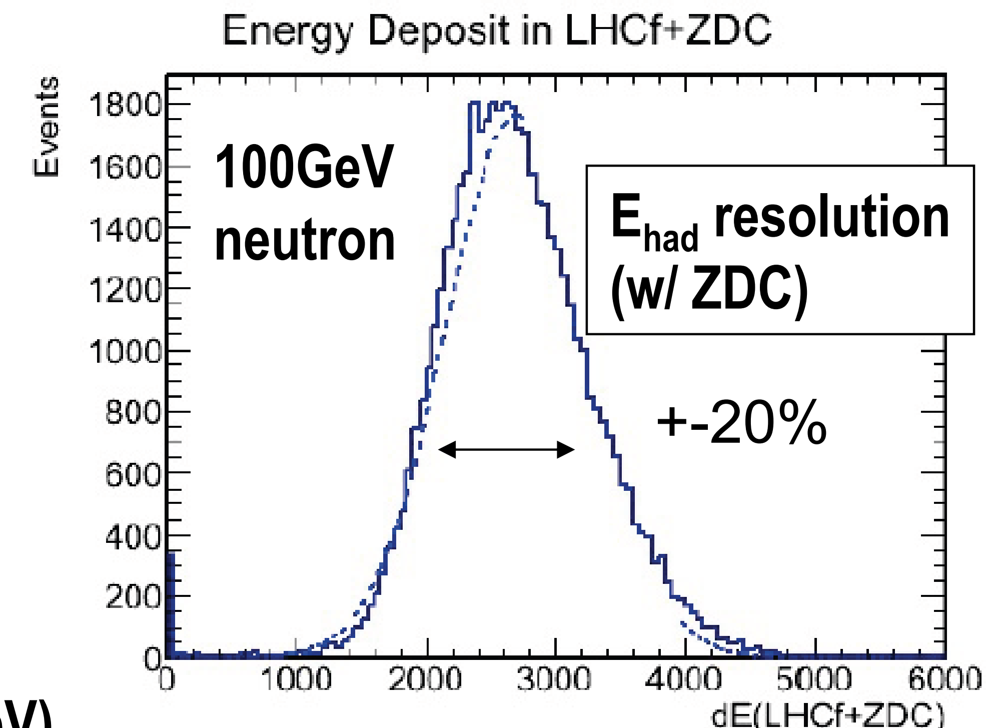
- A pair of cal with very small aperture
- Position sensitive EM calorimeter
- Clear π^0 reconstruction

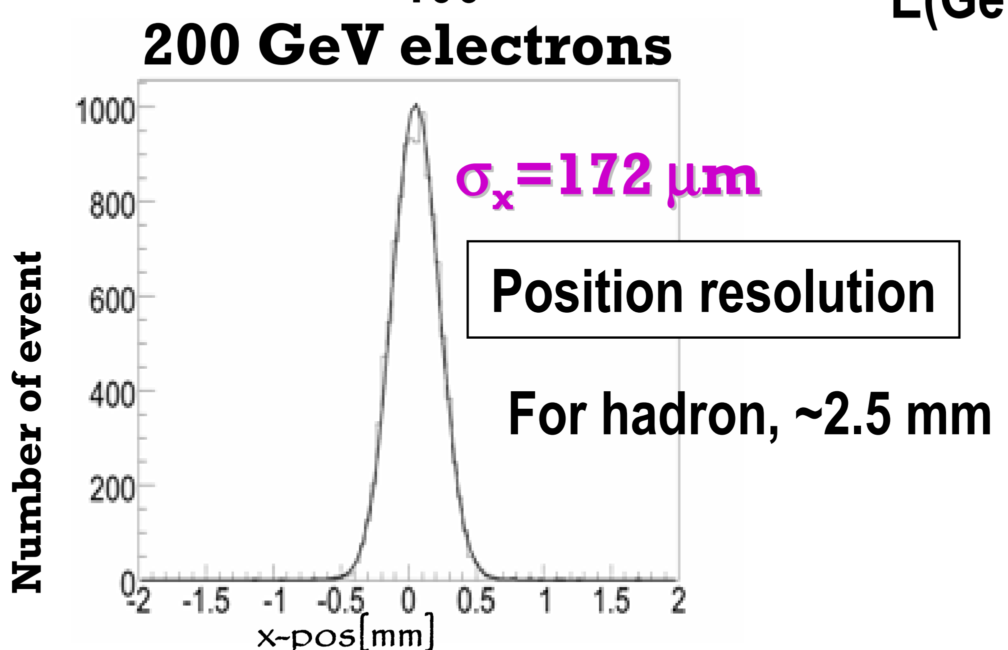


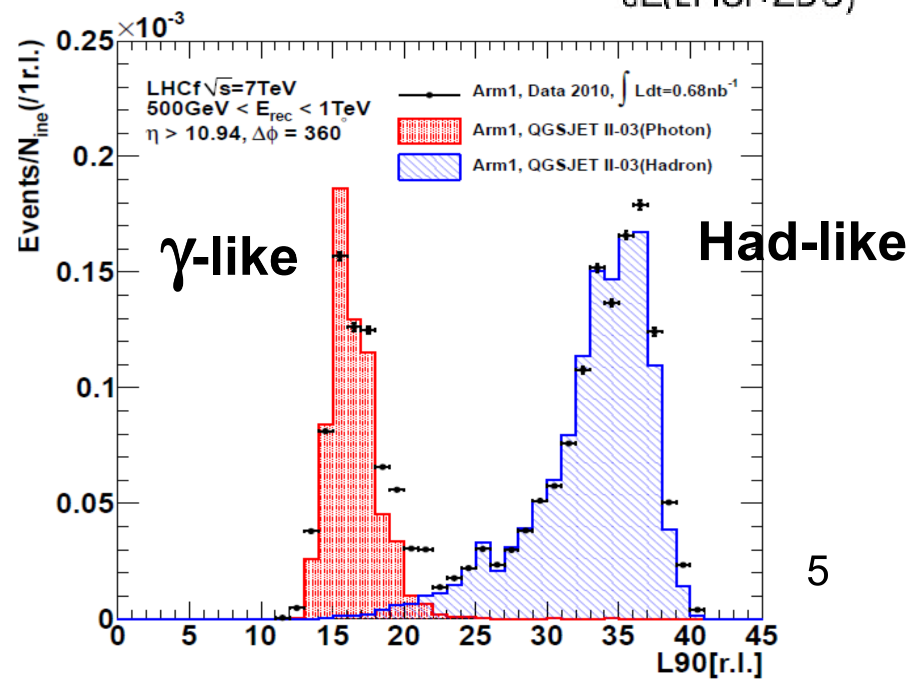
16 tungsten + GSO scinti. layers
20mmx20mm+40mmx40mm
4 1mm GSO hodoscope layers

Detector performance



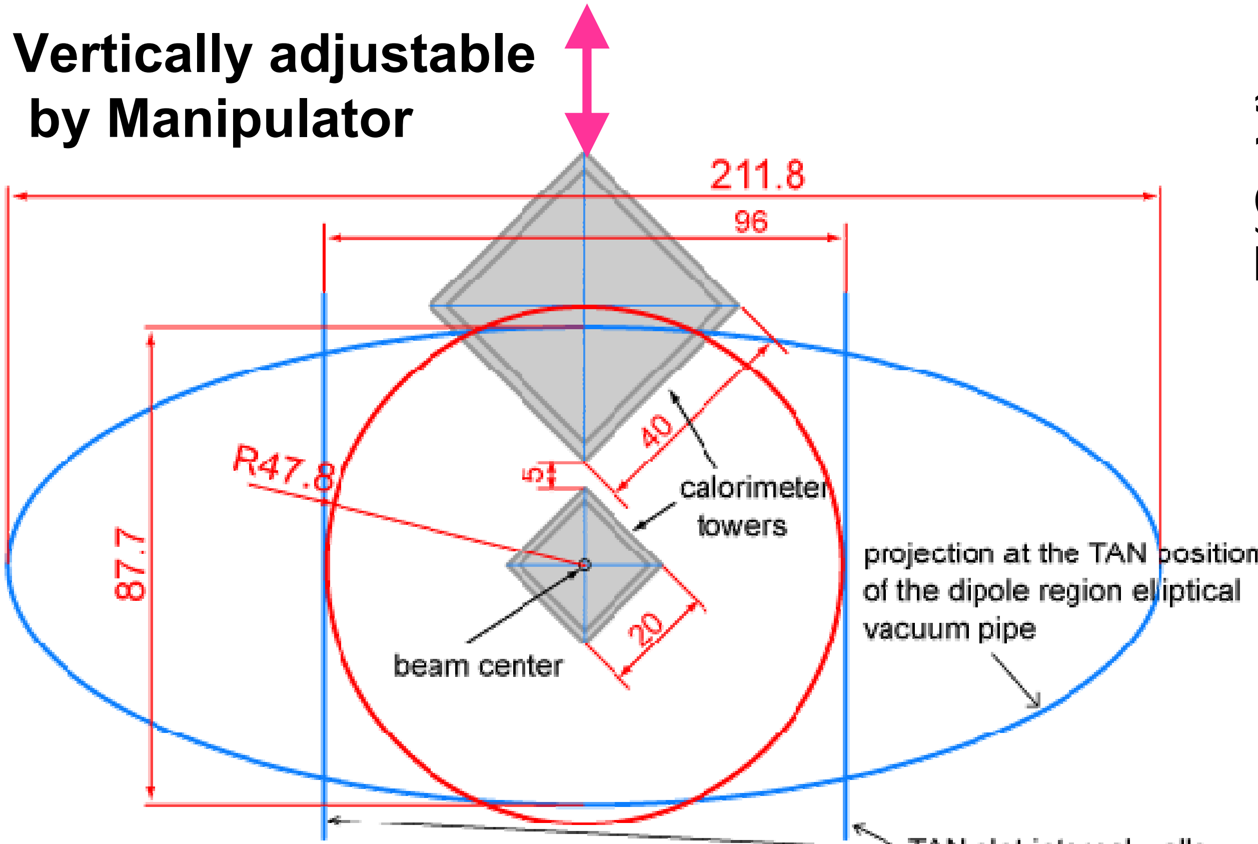




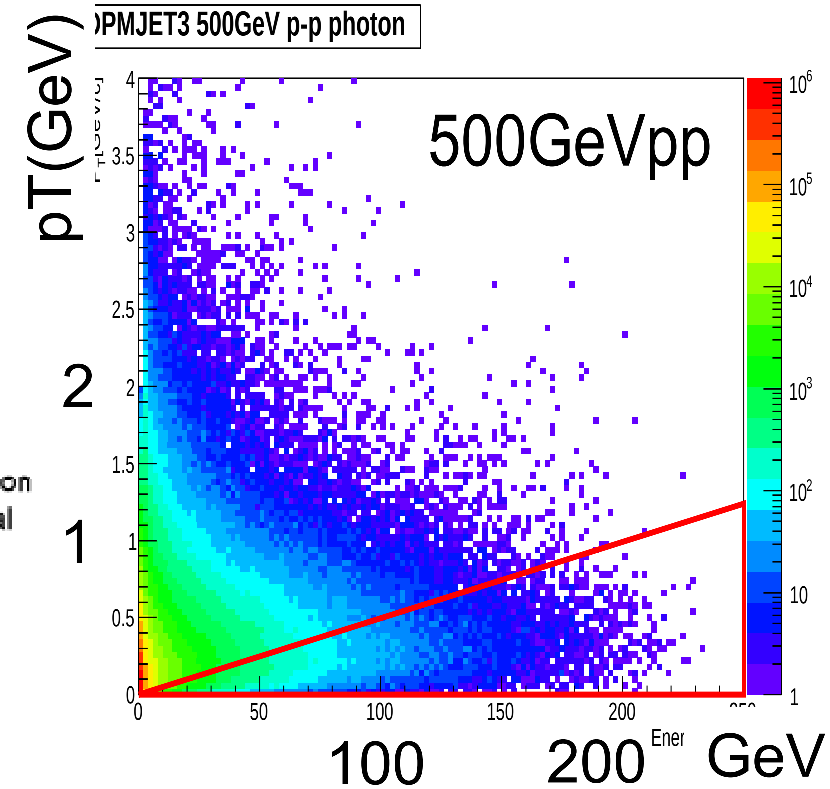


Detector acceptance

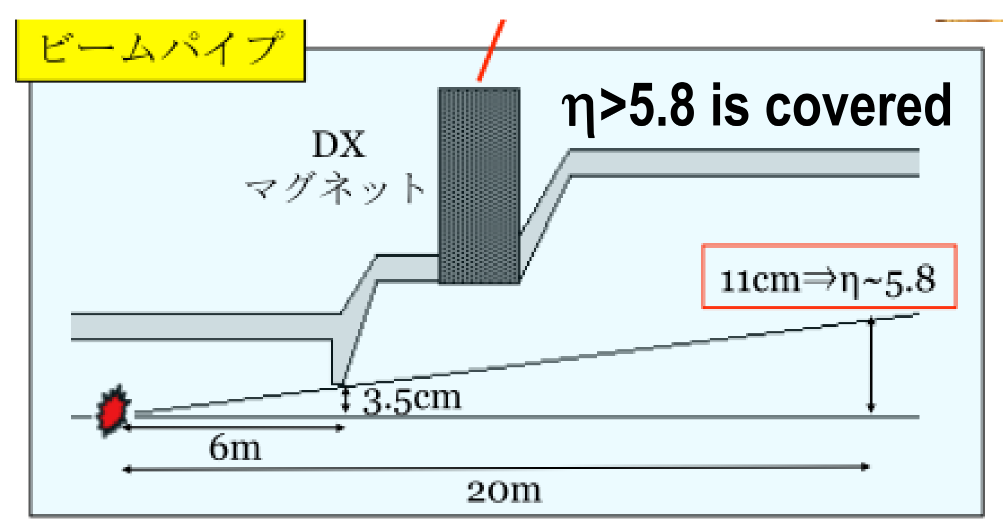
Vertically adjustable by Manipulator



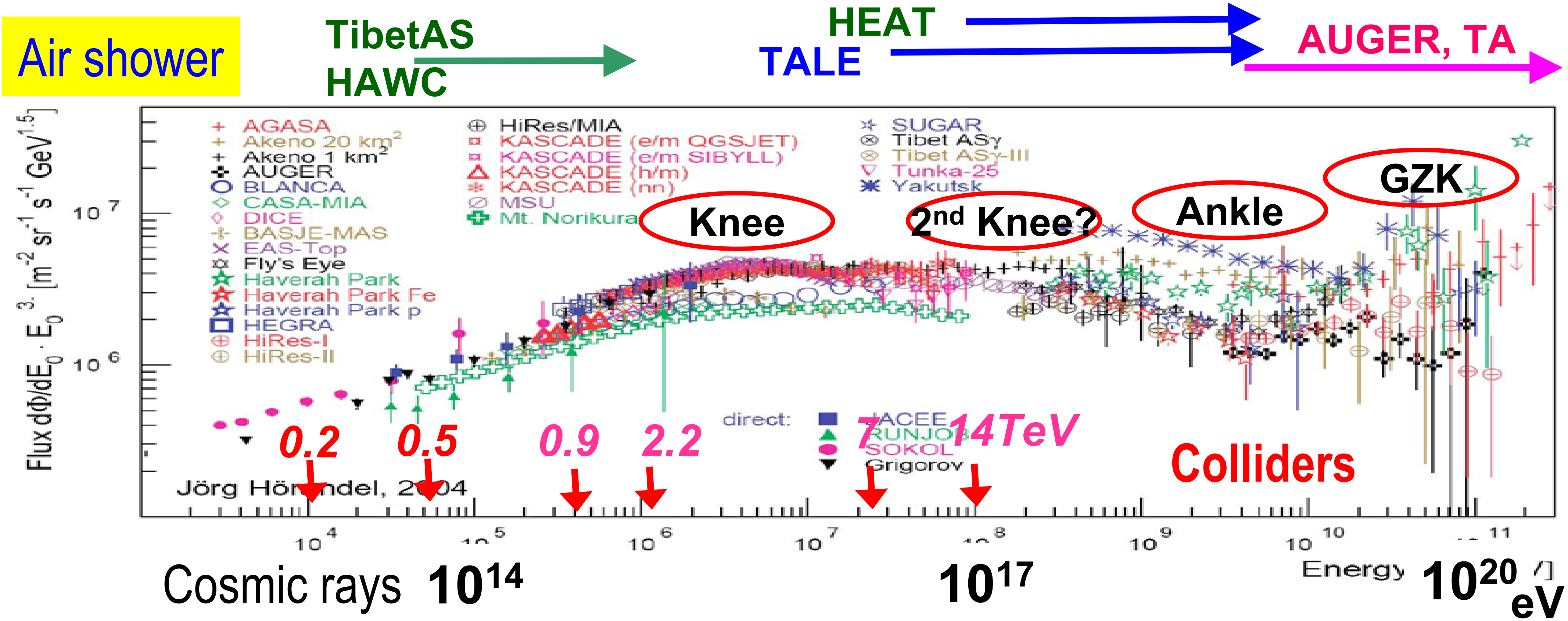
Viewed from IP



(*)This figure shows the case for LHC layout.
RHIC machine geometry will be confirmed.



Motivation 1: cosmic ray interactions



- Need dedicated very forward measurement at hadron colliders
- So far LHCf measured pp (7, 2.76, 0.9 TeV) and p-Pb(5TeV/n)
- RHIC data at the low end is important for extrapolation to 10^{20}eV
- RHIC can serve p-LI or LI-LI collisions (LI: light ion, ex, Nitrogen).

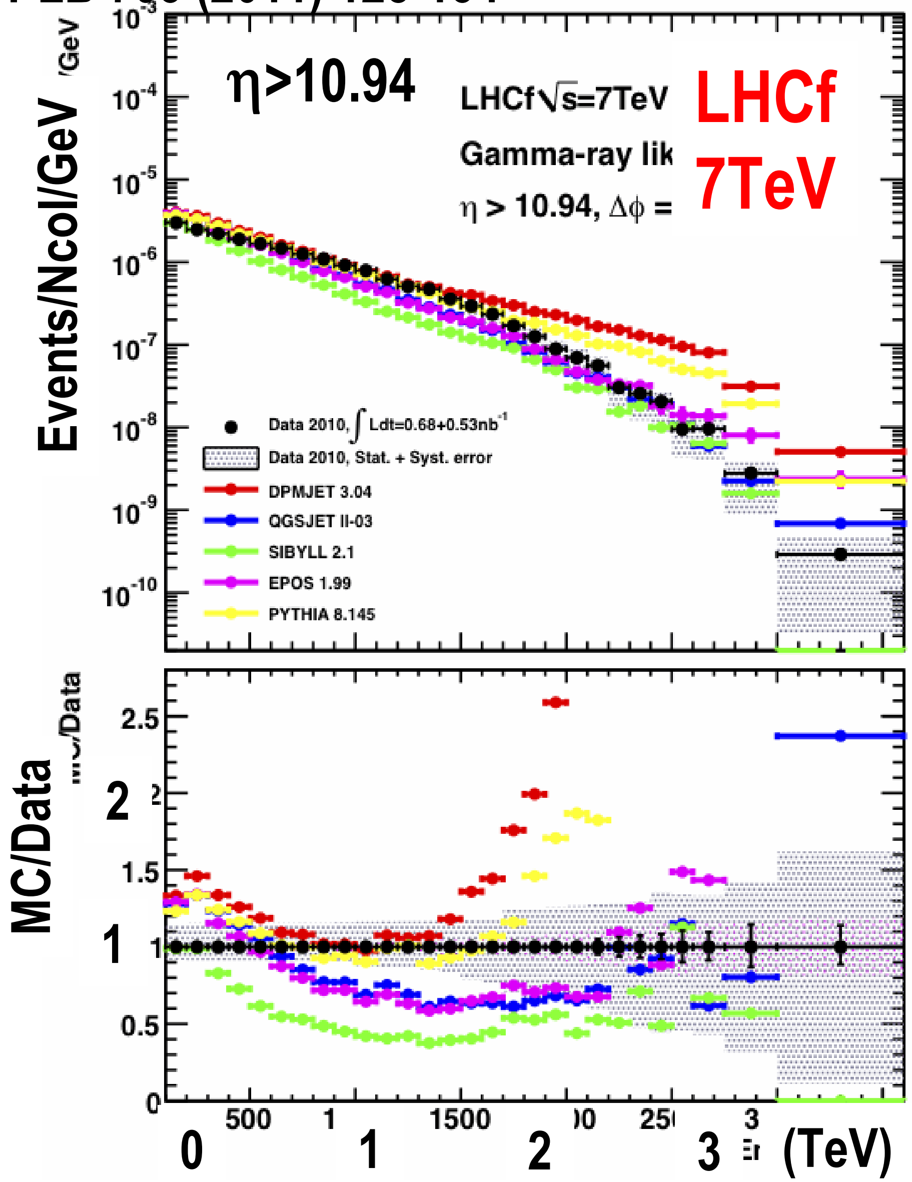
LHCf single γ spectra at 7TeV and 900GeV

DPMJET 3.04 QGSJETII-03 SIBYLL 2.1 EPOS 1.99 PYTHIA 8.145

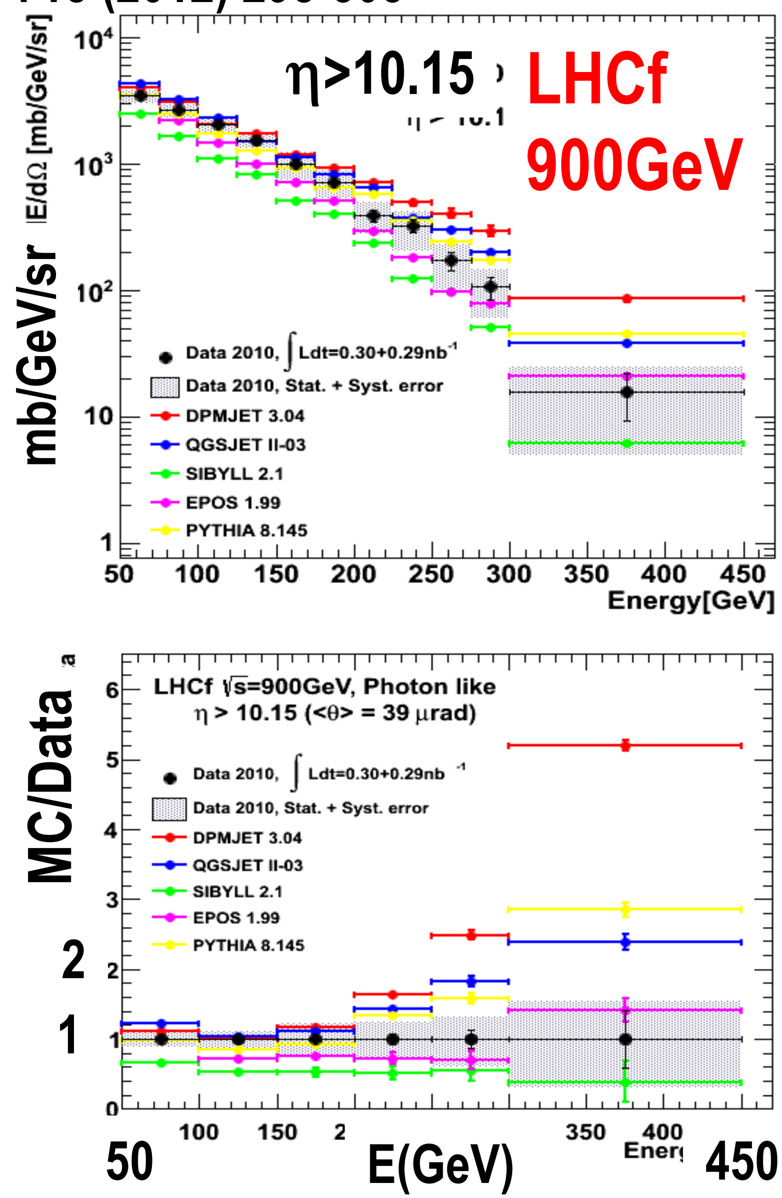
Gray hatch : Sys+stat errors

Magenta hatch: Stat errors of MC

PLB 703 (2011) 128-134



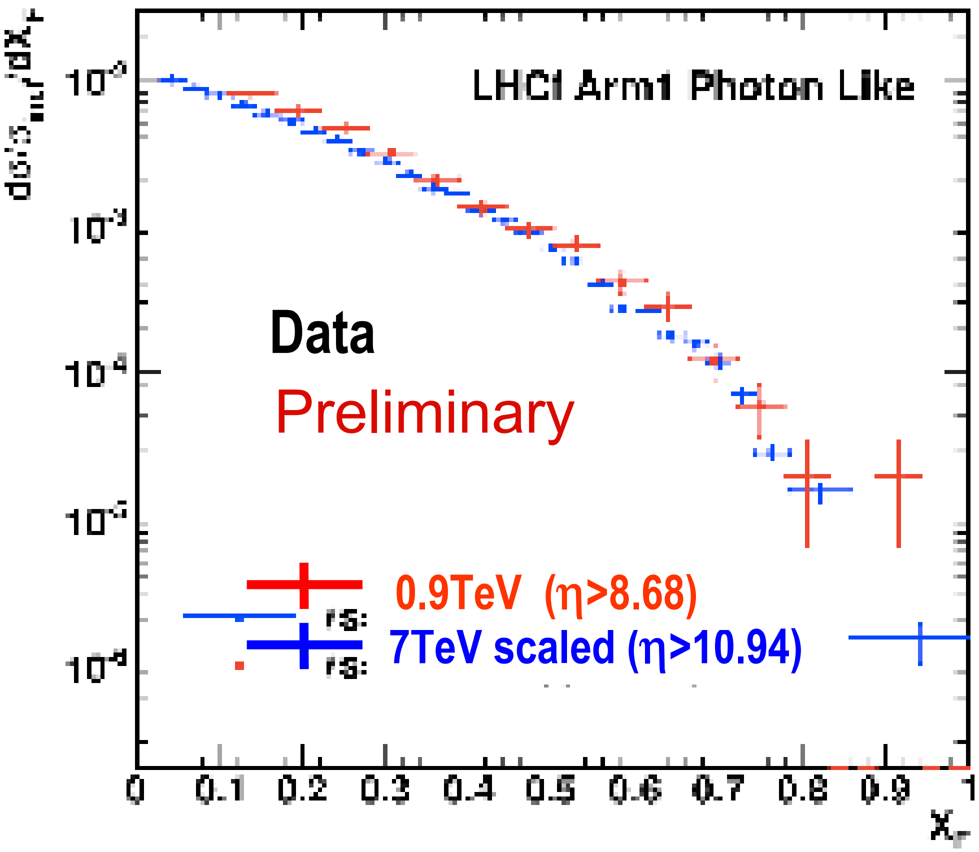
PLB 715 (2012) 298-303



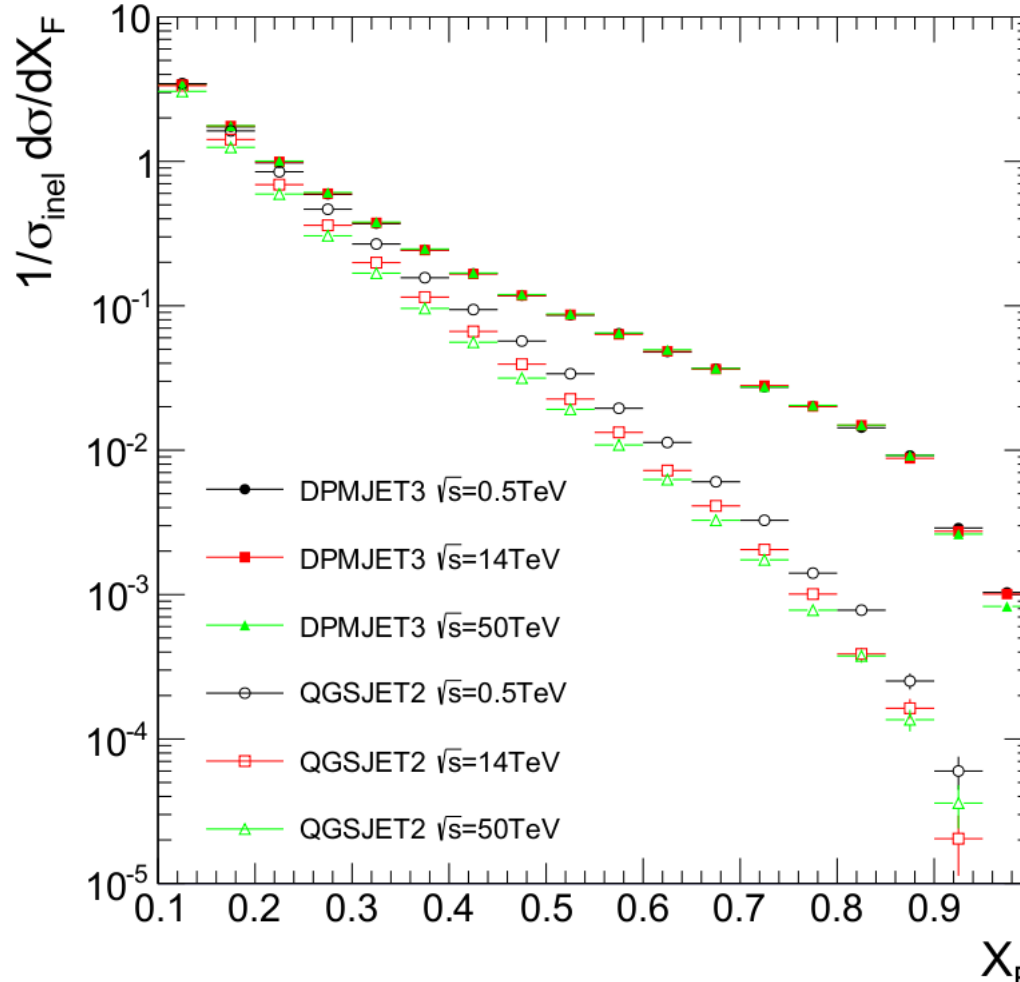
Do we see such big discrepancy even at 500GeV?

x_F scaling : a key for extrapolation

LHC single gamma data (900GeV pp / 7TeV pp)

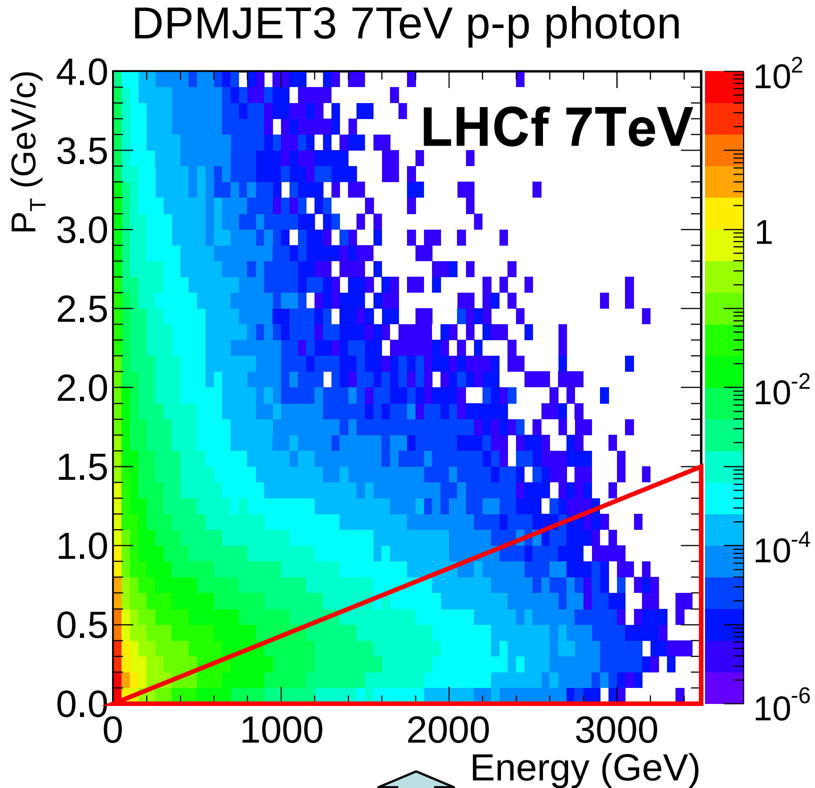


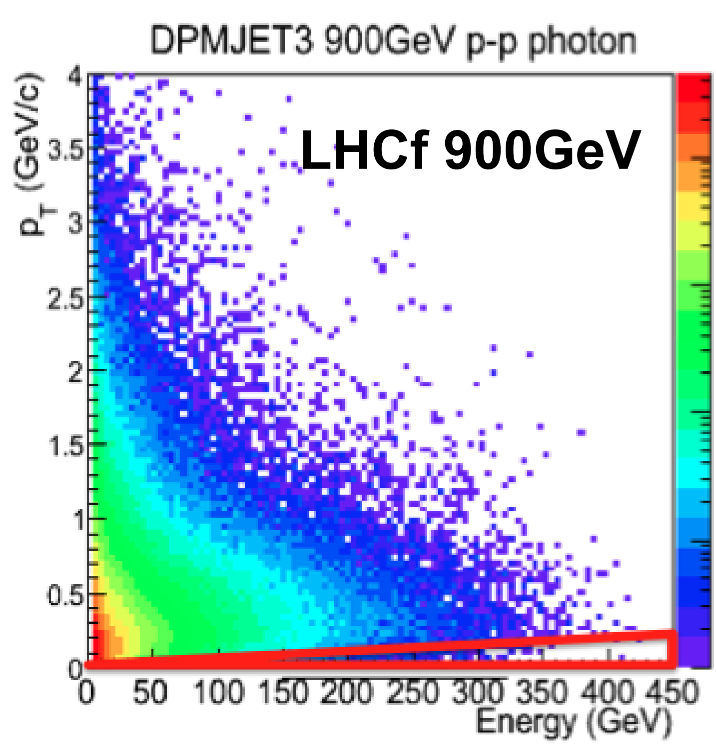
Expected from models (5TeV, 14TeV and 50TeV)

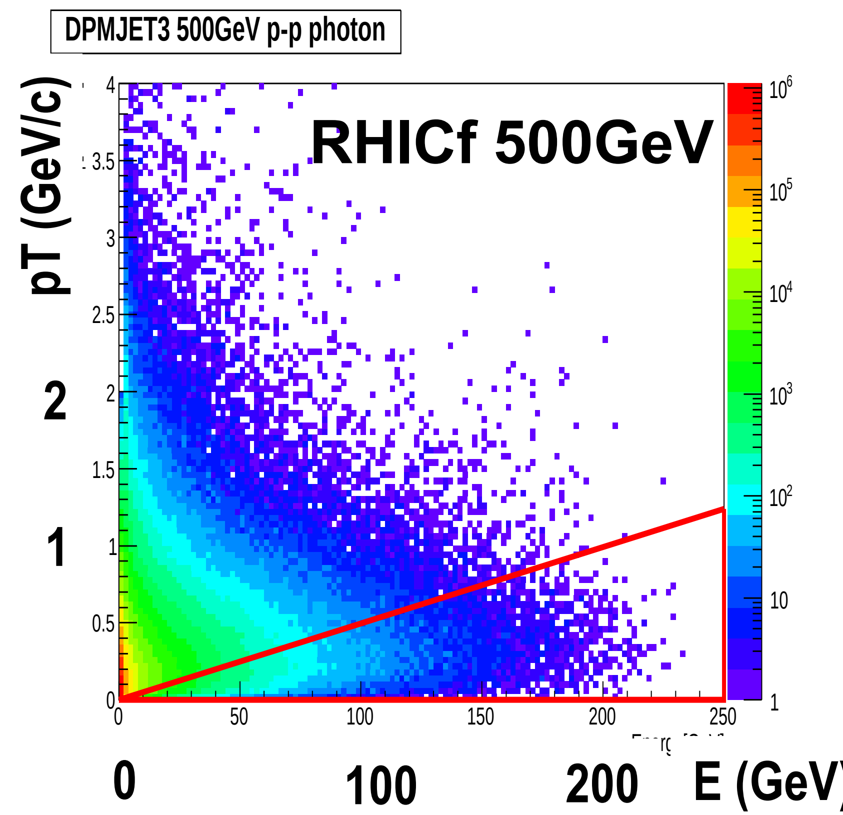


But this comparison done in very limited phase space..

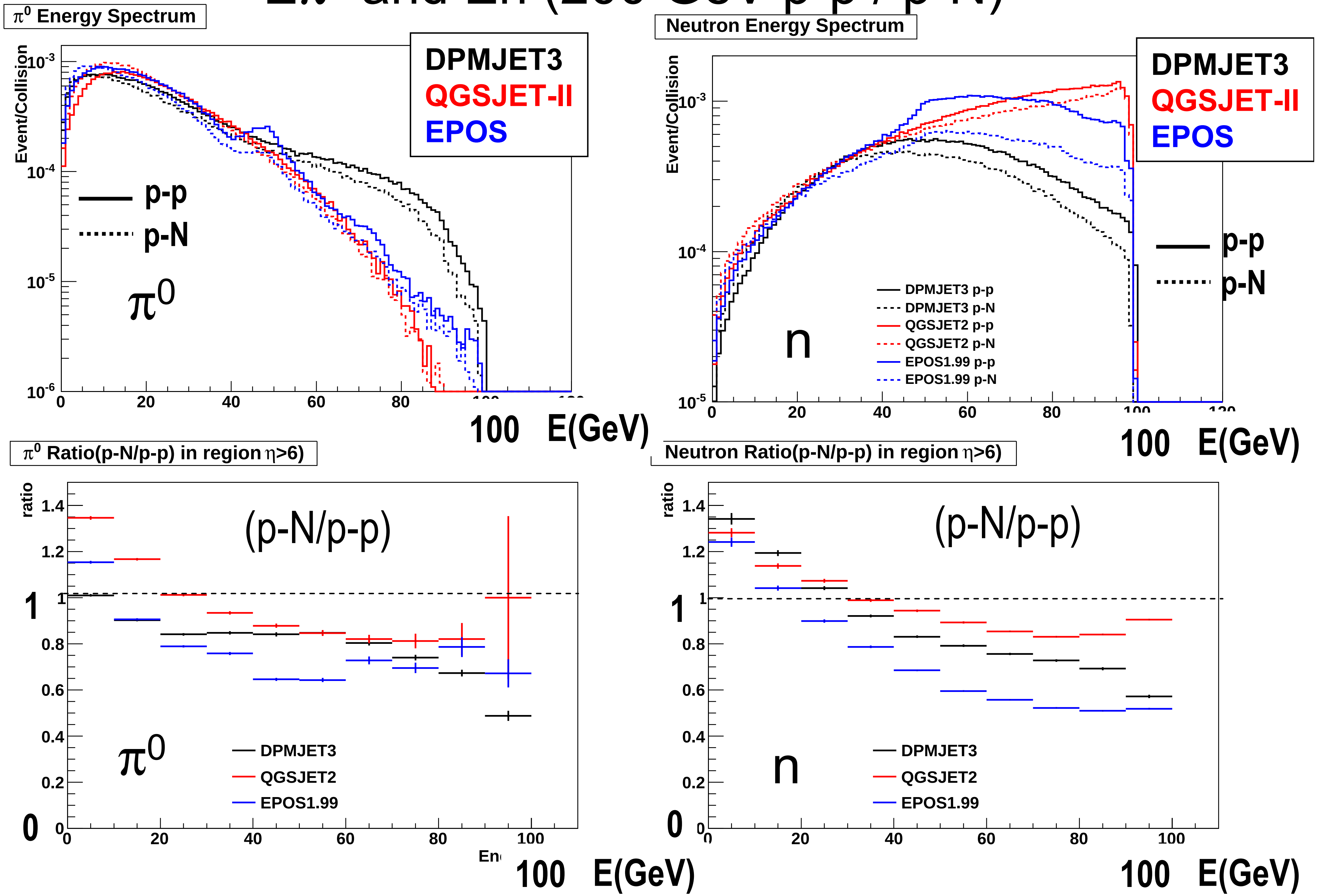
RHICf 500GeV Similar phase space to LHCf 7TeV







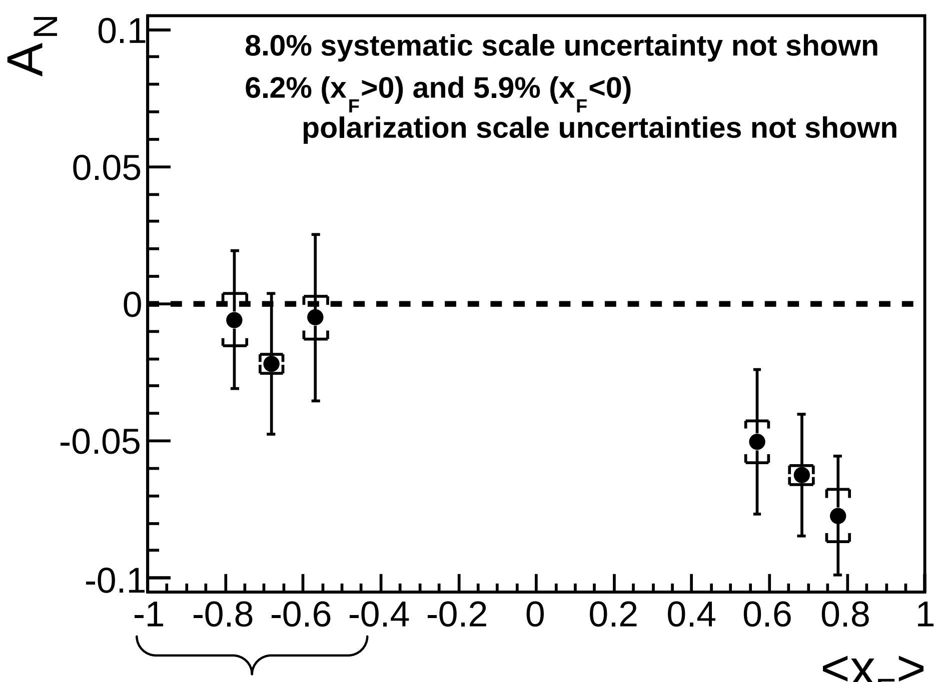
Nuclear modification factor $E\pi^0$ and En (200 GeV p-p / p-N)



Motivation 2: Spin asymmetry A_N for very forward neutron production

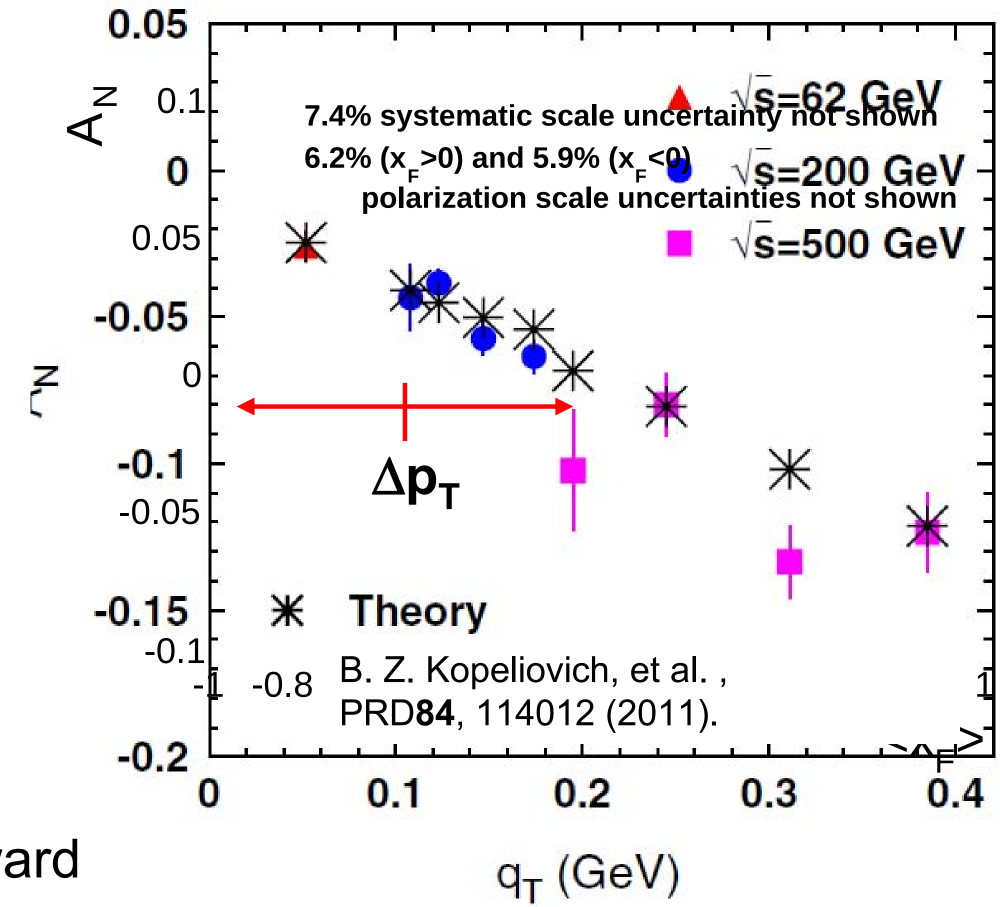
Y. Fukao *et al.*, Phys. Lett. **B650**, 325-330 (2007). [hep-ex/0610030].

Polarized p↑p at 62, 200 500 GeV



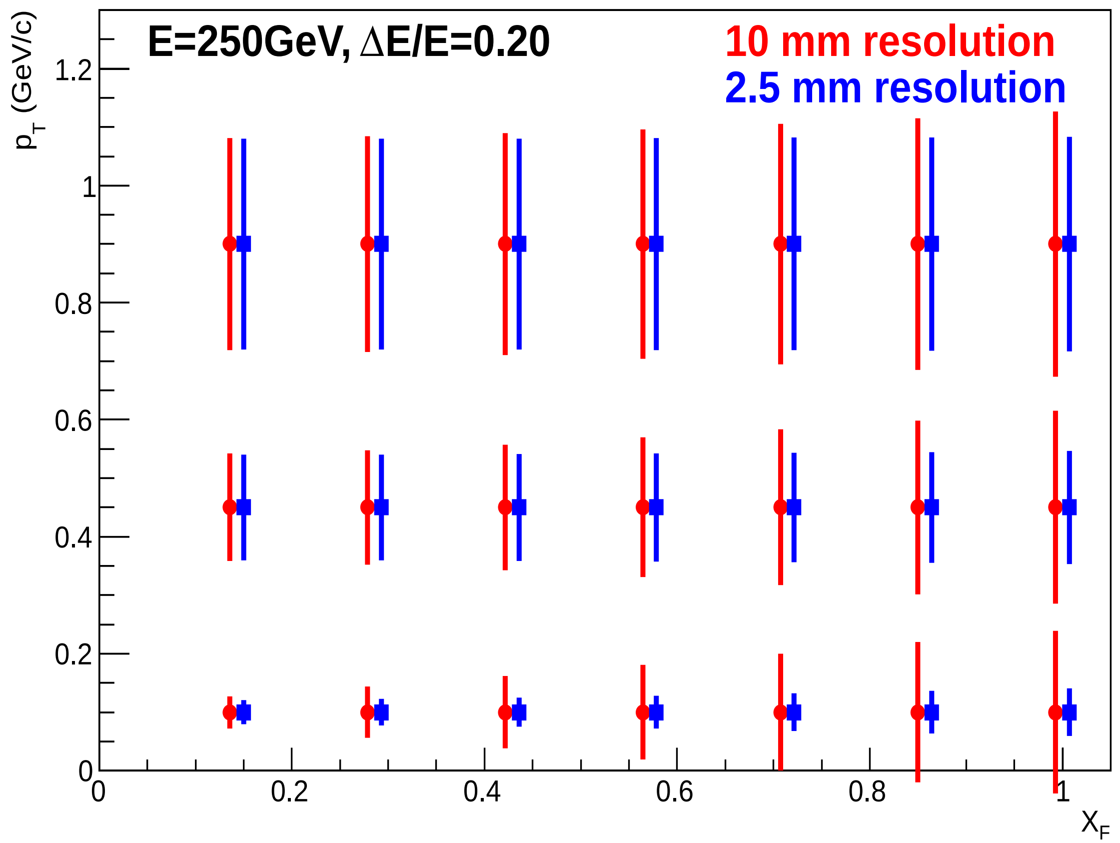
No A_N at backward

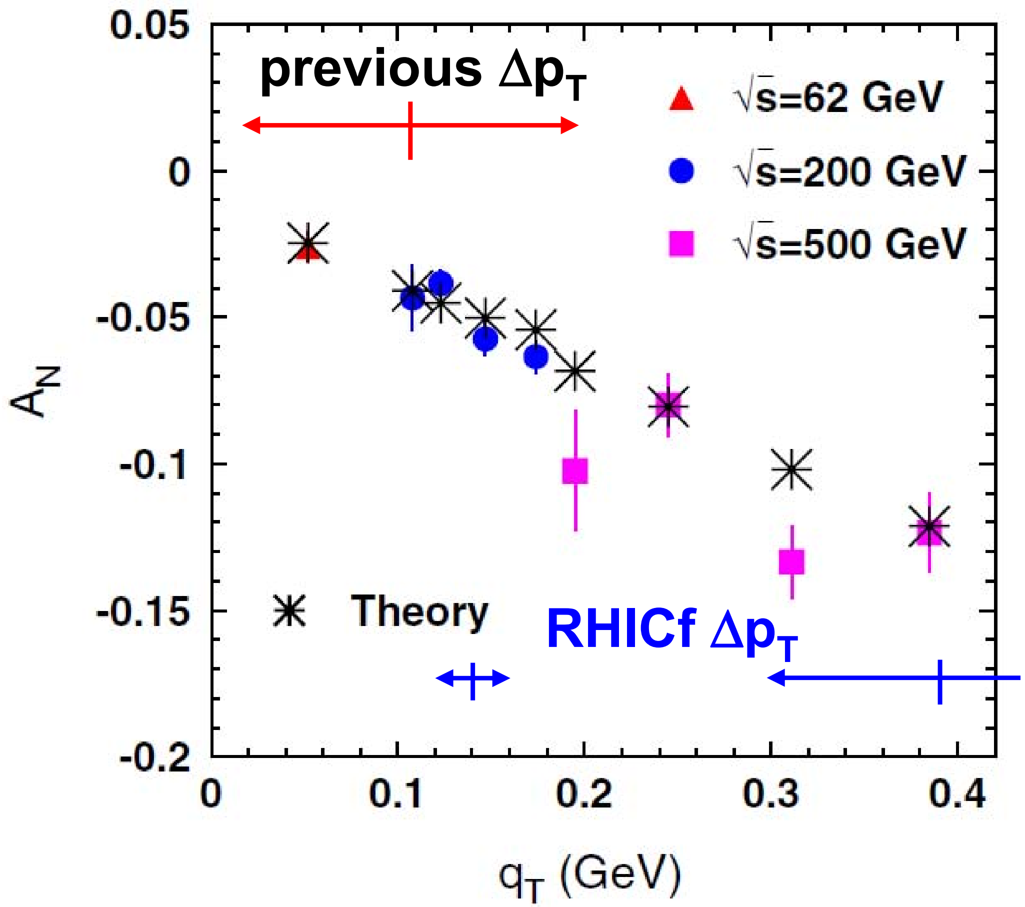
A_N only at very forward



Need finer pT resolution !

Expected pT resolution (w/ ZDC, 20% ΔE_{had})





2.5 mm incident position resolution of RHICf is essential to improve $\Delta\, p_T$ at low p_T, large x_F

RHICf running scenario

- 500 GeV p↑p
  - E_{CR}=~10^{14}eV
  - A_N of forward neutrons
- 200 GeV p↑p and 200 GeV/n pN runs
  - Nuclear effects (N can be C, O, or other LI)
  - A_N of forward neutrons
- One data set (10^6 events) requires a few hour data taking. Repeat for several different settings (different pT coverage, PMT HV, etc..)

For A_N measurement, higher trigger threshold runs are being considered to enhance data taking rate for the region of interest (i.e. X_F>0.4)

Request for machine parameters, trigger, etc. (RHICf point of view)

- **Good Δp_T needs precise "0degree" determination. Need large β^* >10m with good emittance (<20mmrad) to obtain <1mm accuracy of "0 degree" at the detector.**
- **DX magnet arrangement for p-A needs to realize that "0-degree" at the center of LHCf small calorimeter.**
- Current DAQ for GSO tracker requires 2μs interval for shaping time. 6-bunches operation is preferable. But we can cope with ~100 bunches by rejecting overlapped events.
- Current DAQ rate is limited by 1kHz. A few hundreds Hz trigger rate is preferable.
- Needs any beam-synchronized signals for DAQ. Common data taking w/ ZDC or BBC.

RHICf preferable parameters in LOI (To give "1kHz" trigger rate)

	p-p 500GeV	p-p 200GeV	p-N (p-side) 200GeV
RHICf acceptance	3.2e-2	5.9e-4	4.5e-4
Beam emittance (mm rad)	20	<20	<20
Beta* (m)	10	>10	>10
Number of bunches	6	6	6
Expct'd Lumiosity ($10^{30}cm^{-2}s^{-1}$)	0.63	42	6.7
RHICf event rate(Hz)	1000	1000	1000
Events per bunch xing	0.065	3.6	4.7
Number of collisions(required)	0.31e8	17e8	22e8
Integrated luminosity (nb-1)	0.63	42	6.7
Total time (sec)(*)	1000	1000	1000

(*)DAQ deadtime (0.64) not included here

For standard beam parameters (cope with “RHIC Collider Projections”)

	p-p↑ 500GeV	p-p↑ 200GeV	p-N (p-side) 200GeV
RHICf acceptance	3.2e-2	5.9e-4	4.5e-4
Beam emittance (mm rad)	20	<20	<20
Beta* (m)	10	>10	>10
Number of bunches	6	100	100
Expct'd Lumiosity ($10^{30}cm^{-2}s^{-1}$)	0.62	3.0	0.5
RHICf event rate(Hz)	1000	71	74
Events per bunch xing	0.065	0.015	0.021
Events overlap in 2μs	n/a	1.8e-4	1.9e-4
Number of collisions(required)	0.31e8	17e8	22e8
Integrated luminosity (nb-1)	0.63	42	6.7
Total time (hour)	0.77(*)	4.3	4.1

(*)DAQ deadtime (0.64) considered here

Schedule

- LHC 13 TeV preparation / run is scheduled at the end of 2014 ~ early 2015.
- RHICf likes to run after LHC 13TeV runs, i.e. late 2015 due to limitation of detector/ budget / man power. But it should depend on LHC situation and we should be flexible.
- The detector can be modified/optimized for lower energy once after LHC13TeV finishes.

Summary

- RHICf :Measurement of neutral particle productions (i.e. γ, $\pi 0$, n) at very forward with a position-sensitive small EM calorimeter.
  - Reuse of existing LHCf detector, installed in front of ZDC.
  - Important calibration of cosmic ray MC (E_{CR}~10^{14}eV) and first check of nuclear effect in LI.
  - New study of forward neutron A_N w/ fine p_T resolution
- 500GeV p↑p, 200GeV p↑p and 200GeV/n pN. Short time dedicated run (~ a week).
  - Requested beam parameters should be flexible .
  - Further discussion with experts on DX magnet for p-A.
- Decision of IR, organization, collaboration w/ existing experiments will be fixed with further discussions.

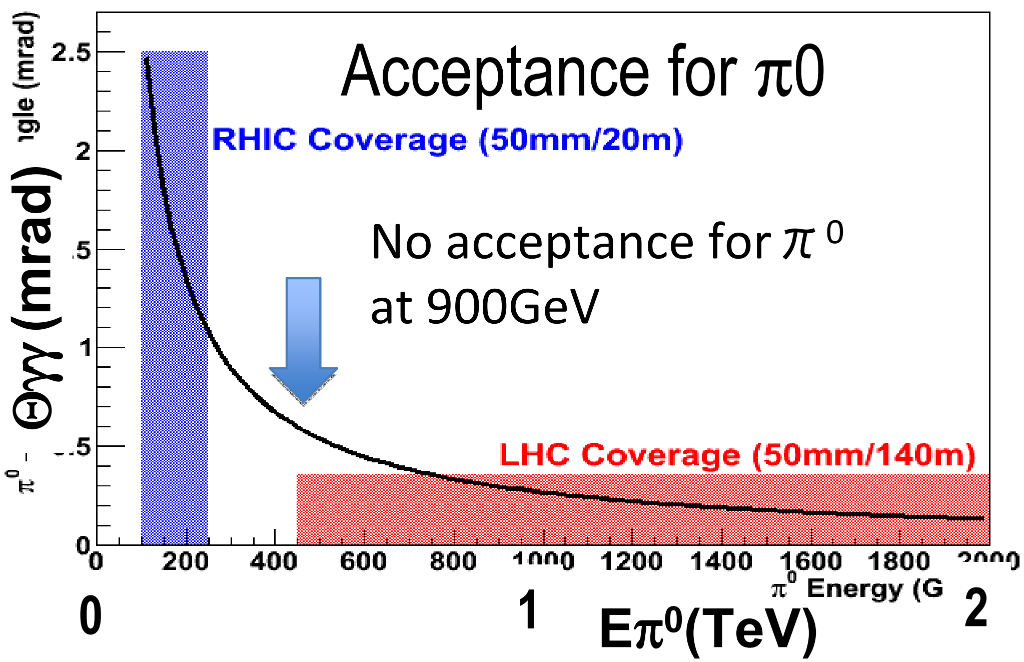
Backup

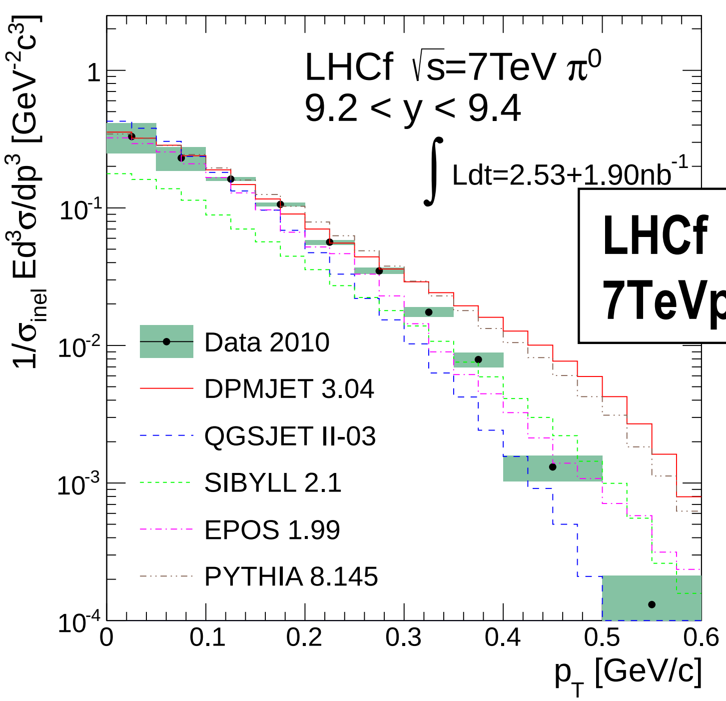
Other logistics to be considered

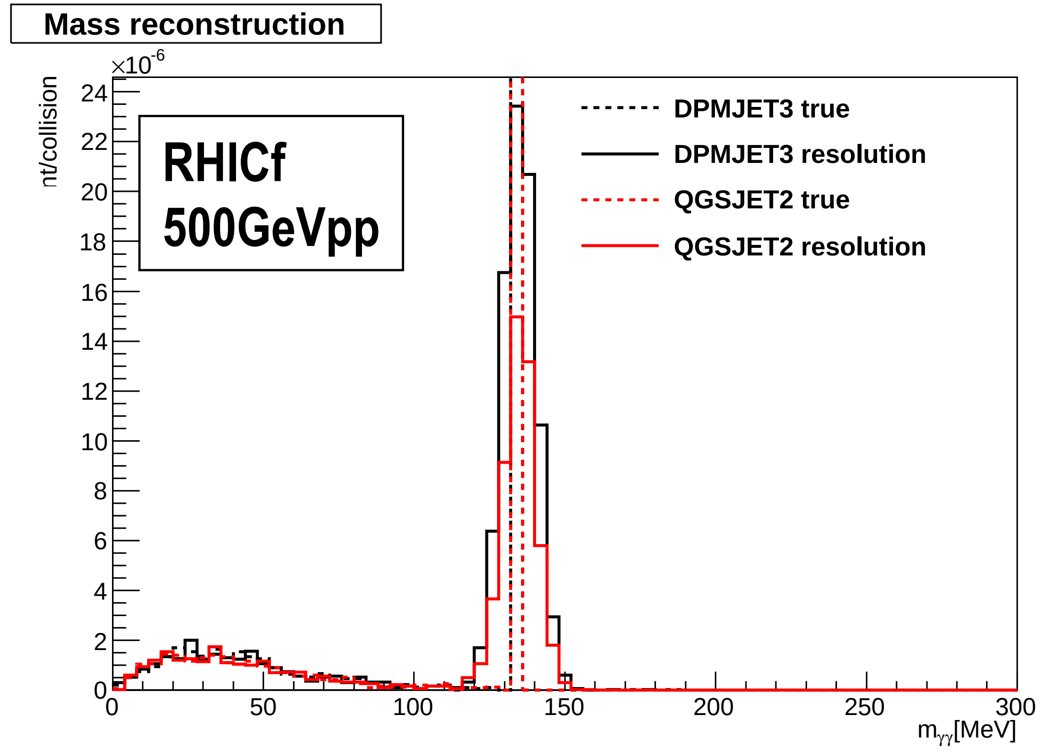
- Location for DAQ electronics should be fixed. Depending on a hosting experiment, cabling, radiation issues.
- So far the standalone DAQ system used in LHCf is considered. Newly development of DAQ integrated to a hosting experiment can be an option.
- IP location, a hosting experiment will be determined by further discussion for possible enhancement of physics case.

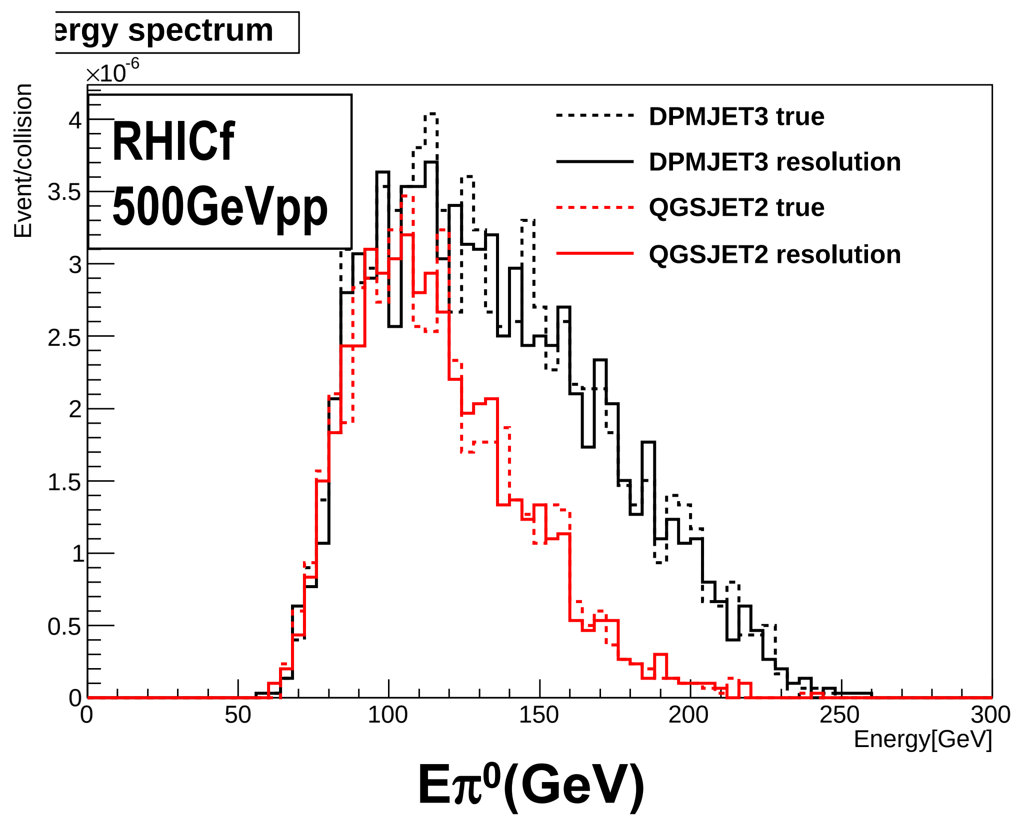
Y.Itow, LHCf @ RHIC

RHICf 500GeVpp π^0

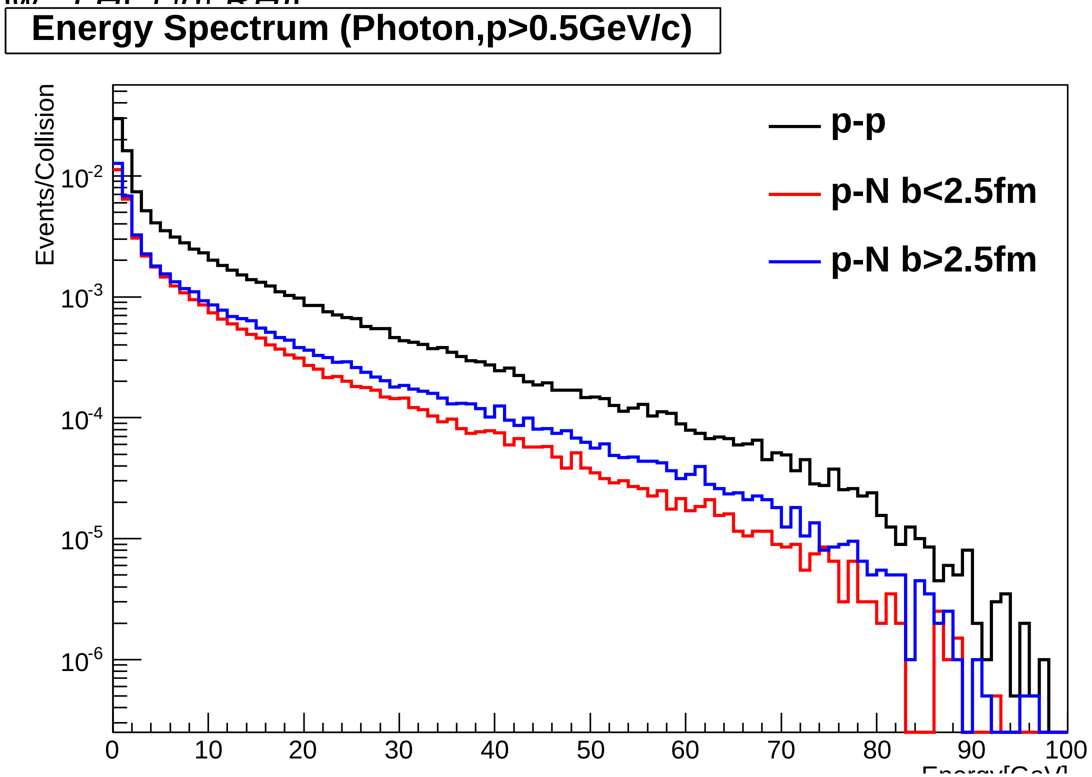


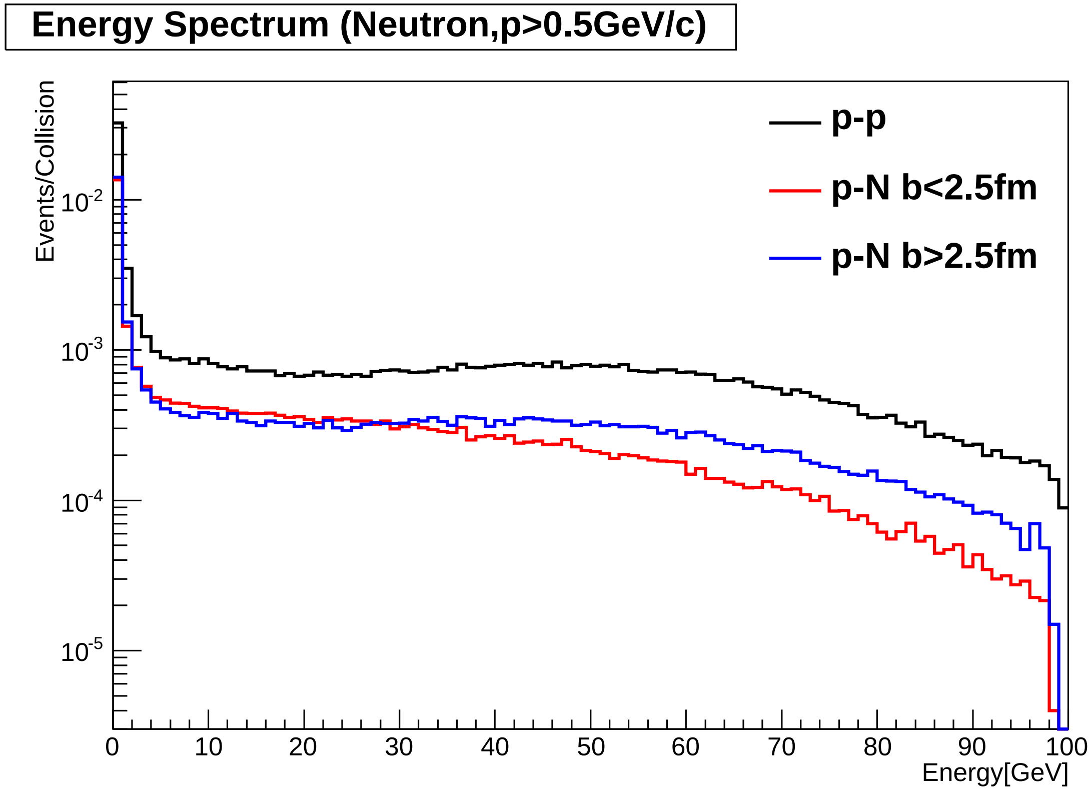






Impact parameter "b" dependence





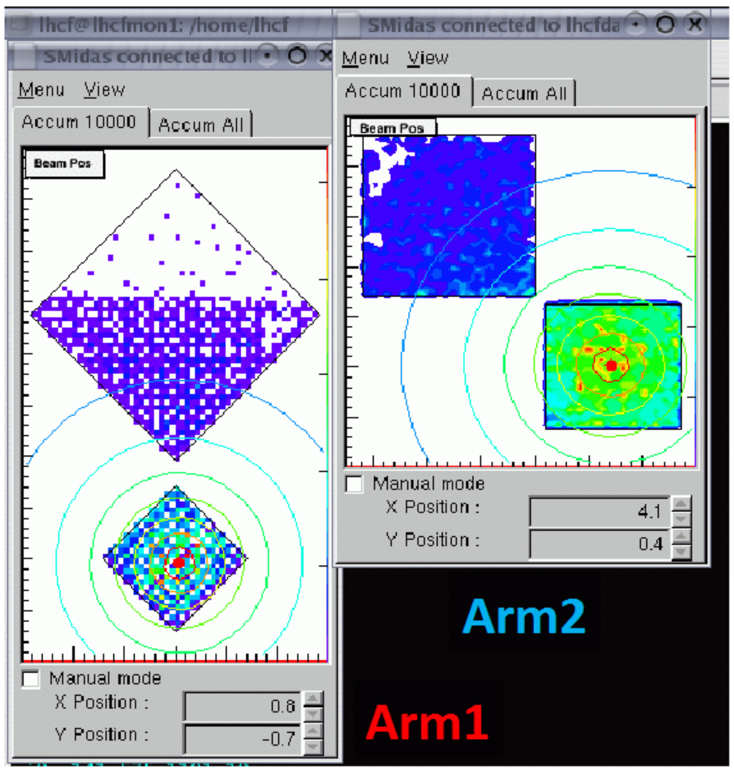
Statistical errors for A_N (0.1pb)

	neutron		photon		π^0	
p_T (GeV/c)	N(x10^3)	δA	N(x10^3)	δA	N(x10^3)	δA
0.1 – 0.2	4,790	0.0007	450	0.0021	200	0.0032
0.2 – 0.3	7,030	0.0005	1,220	0.0013	120	0.0041
0.3 – 0.4	10,290	0.0004	1,290	0.0013	160	0.0035
0.4 – 0.5	7,870	0.0005	600	0.0018	150	0.0037
0.5 – 0.6	4,520	0.0007	150	0.0037	70	0.0055
0.6 – 0.7	1,990	0.0010	50	0.0067	20	0.0097

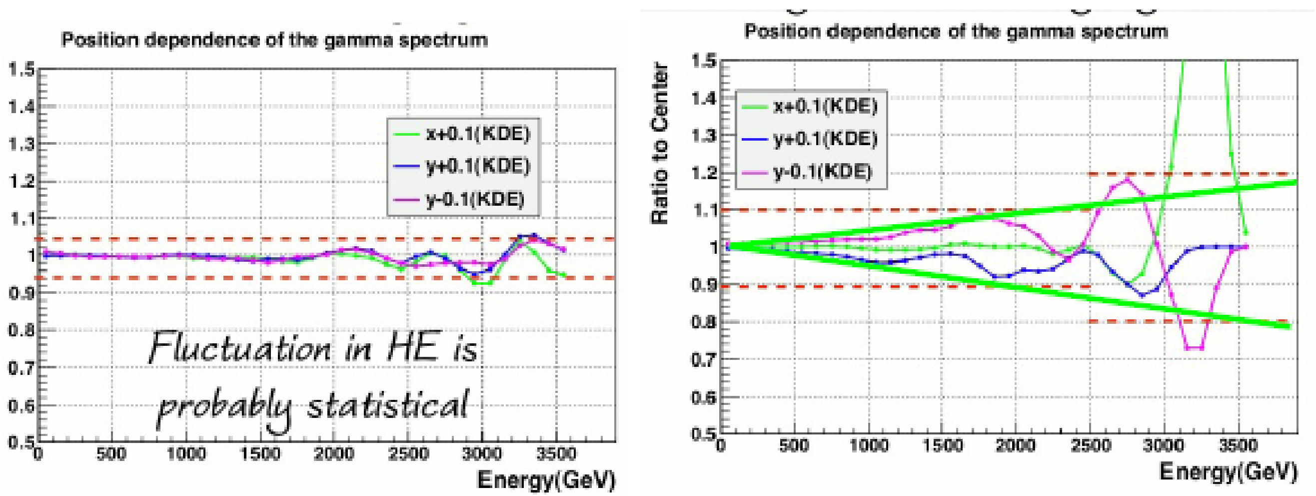
Where is zero degree at RHICf ?

$$\Delta\theta = 136\,\mu rad \times \sqrt{\frac{(\epsilon^*/20\,mm\,mrad)}{(E/100\,GeV)(\beta^*/10\,m)}}$$

c.f. 1mm /18m = 56 μrad

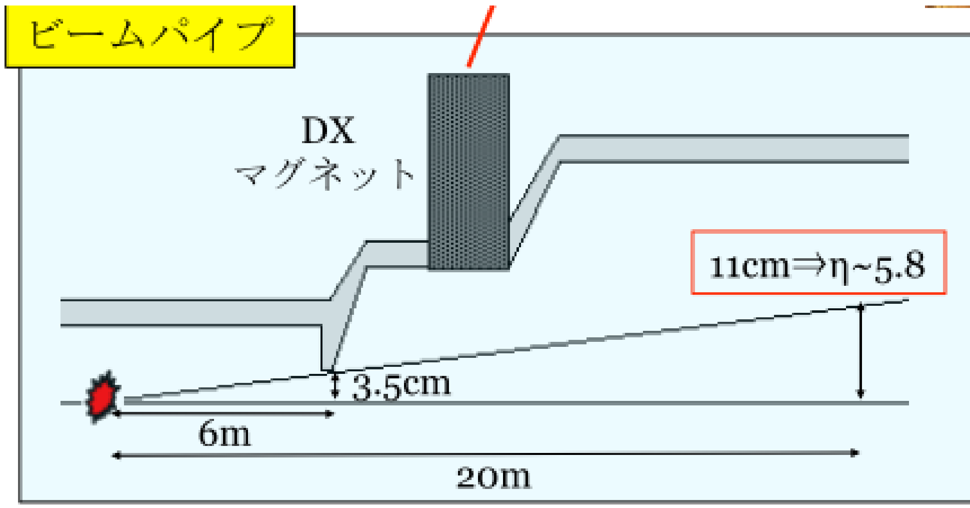


LHCf online hit-map monitor

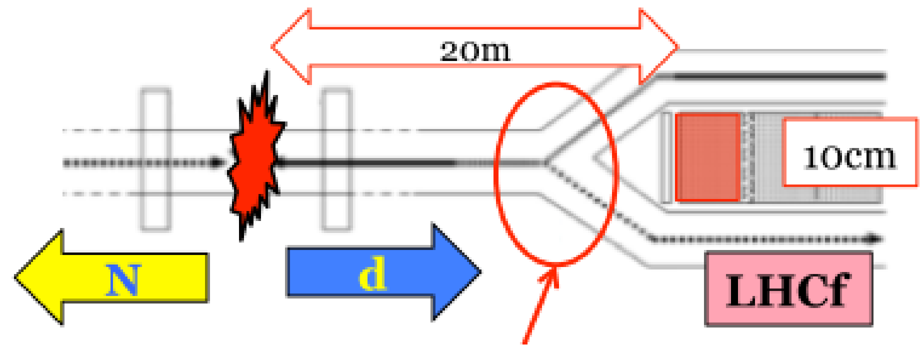


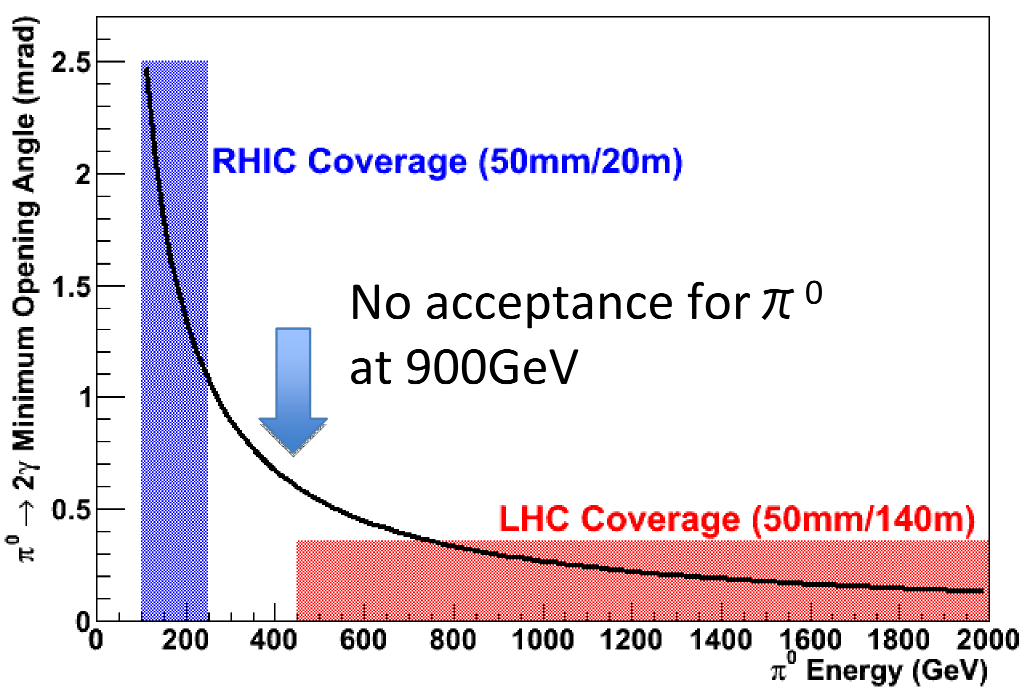
Effect of 1mm shift in the final spectrum (LHCf case)

"RHICf" : η acceptance for 100GeV/n d-N MC

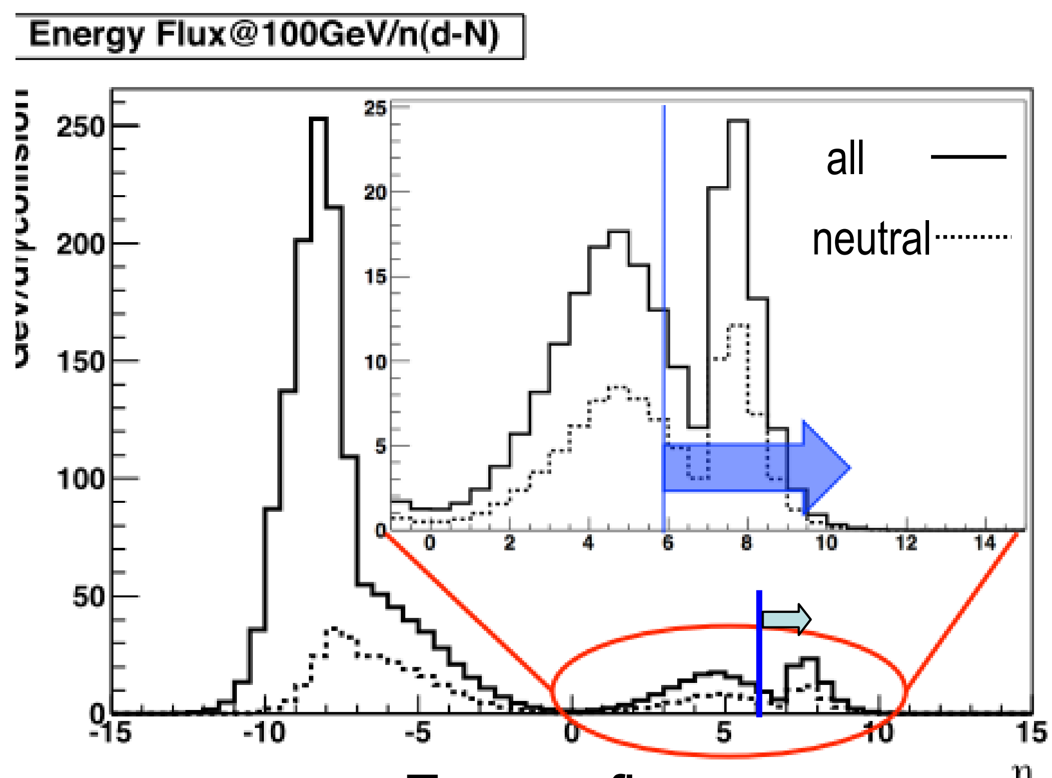


η>5.8 is covered





Acceptance for π0

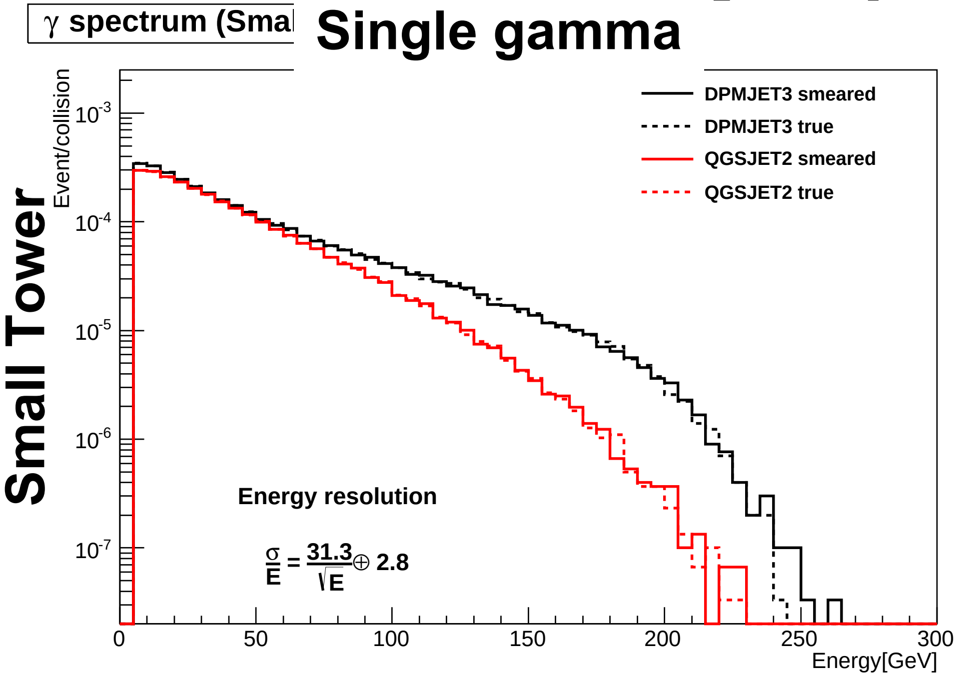


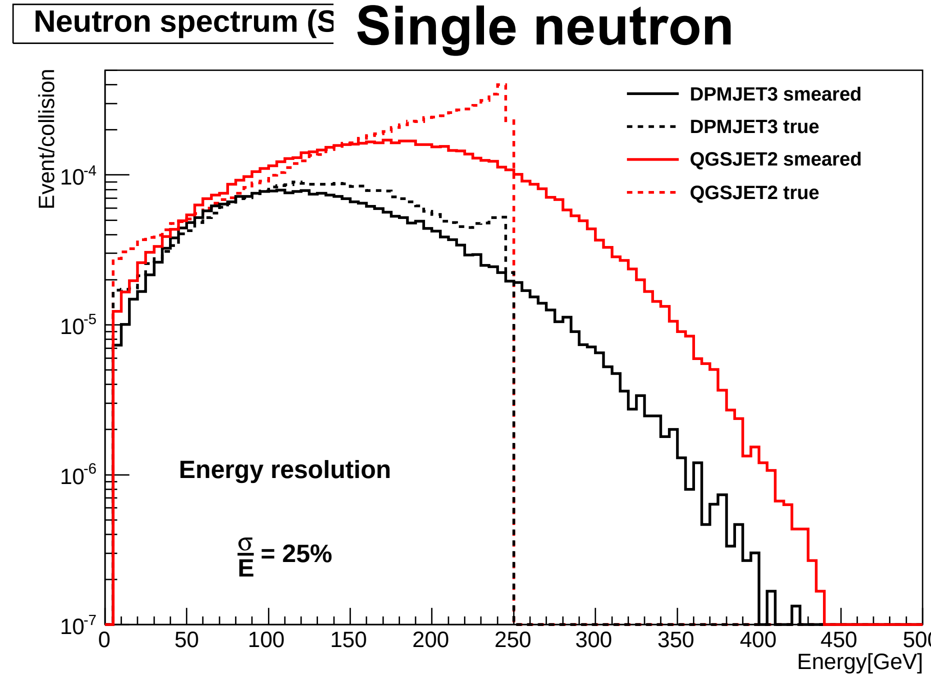
Energy flow

Raw energy spectra (500GeV pp)

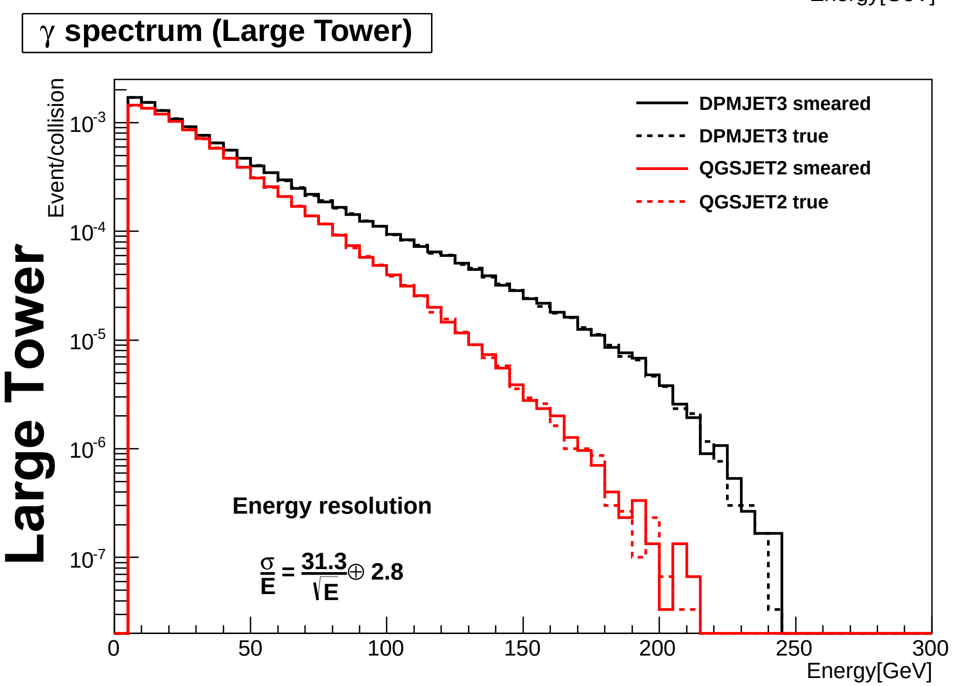
Single gamma **Single neutron**

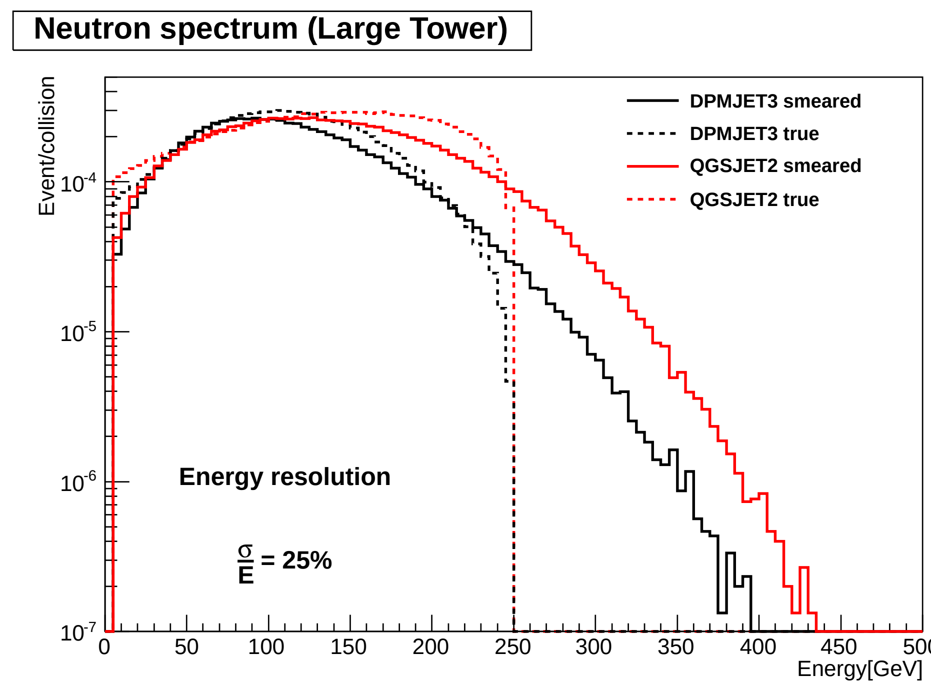
Small Tower



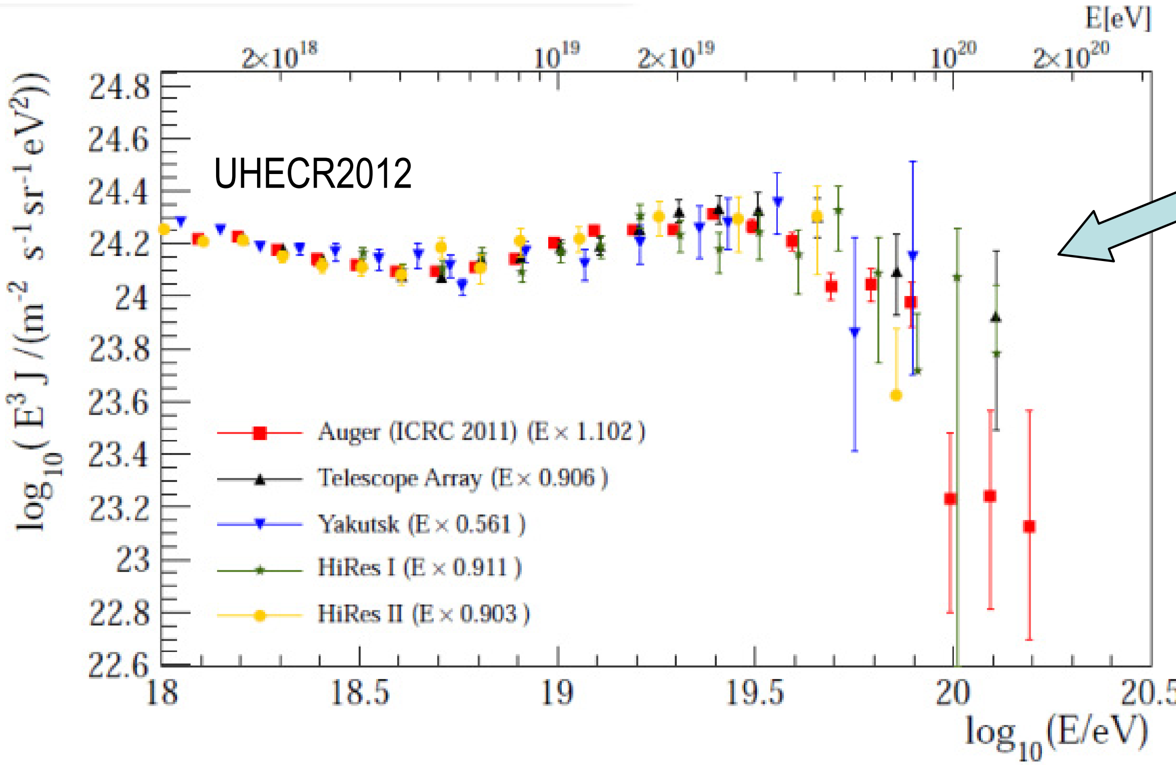


Large Tower





GZK cut-off confirmed ? But…

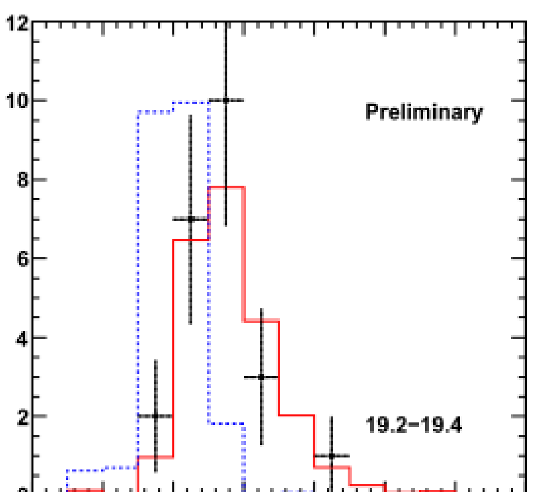


GZK cut off ?

$$\boxed{p + CMB\gamma \rightarrow \Delta}$$

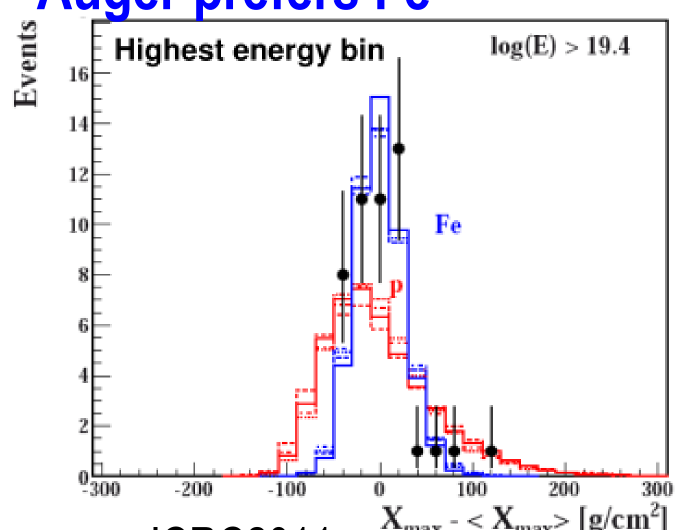
Need identify UHECR is "proton"

TA prefers proton



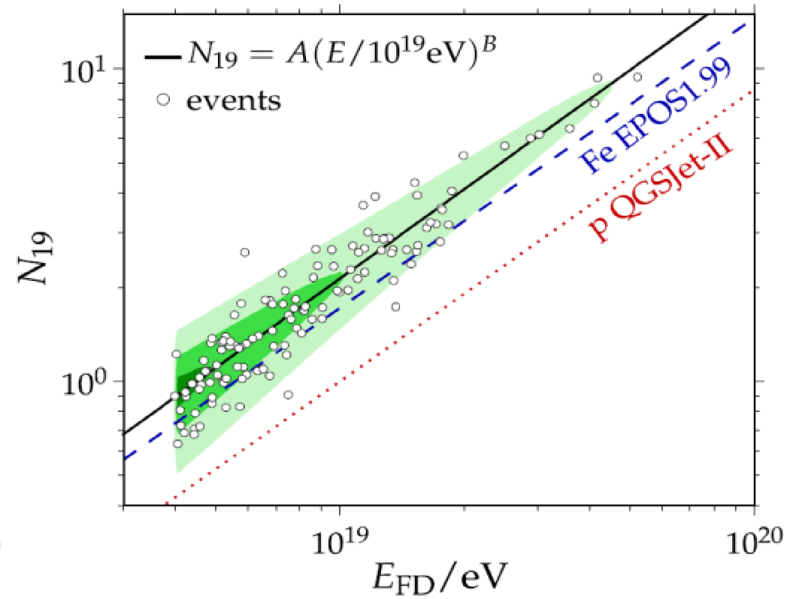
ICRC2011

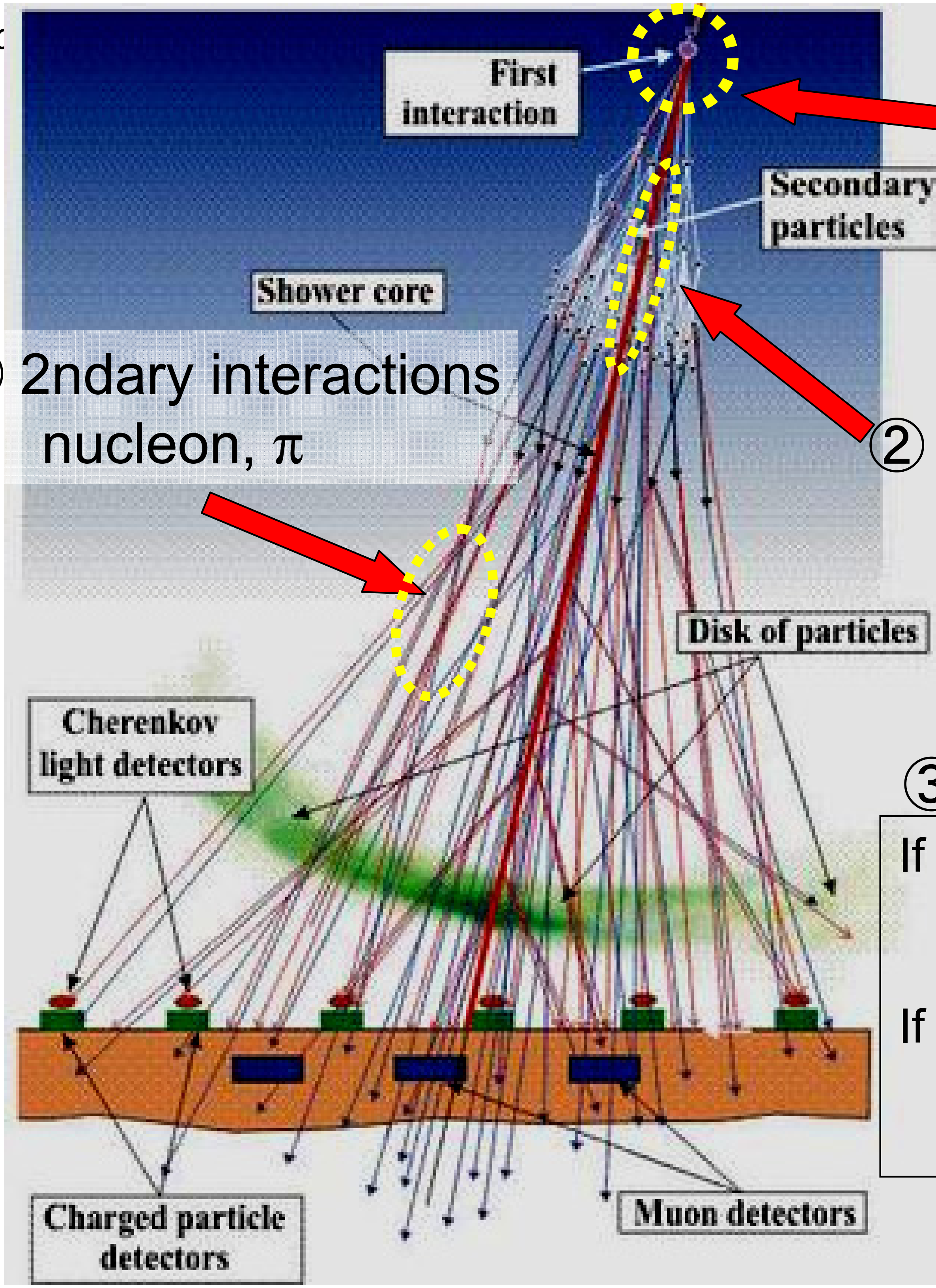
Auger prefers Fe



ICRC2011

Too many μs @ Auger, if proton





① Inelastic cross section

If large σ
rapid development
If small σ
deep penetrating

② Forward energy spectrum

If softer
shallow development
If harder
deep penetrating

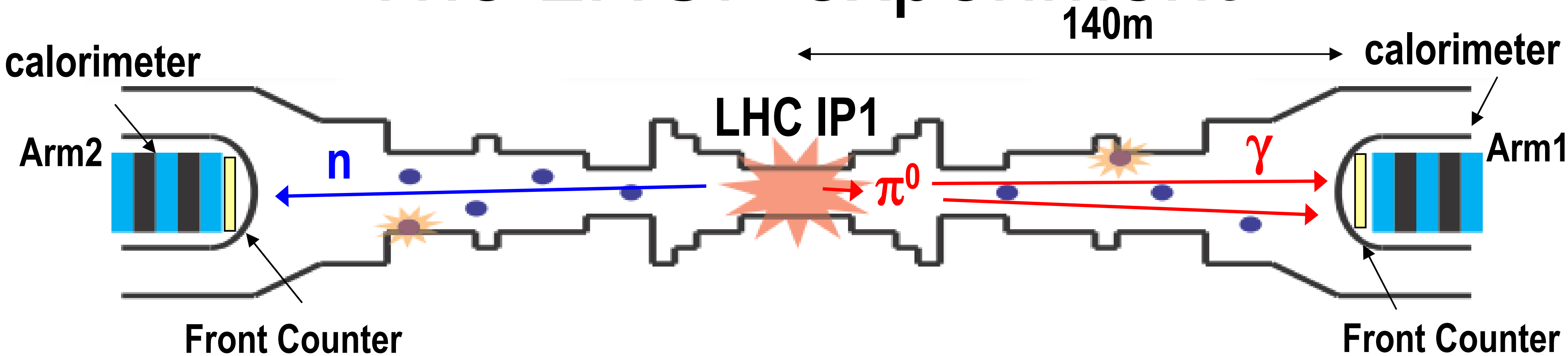
③ Inelasticity $k = 1 - p_{lead}/p_{beam}$

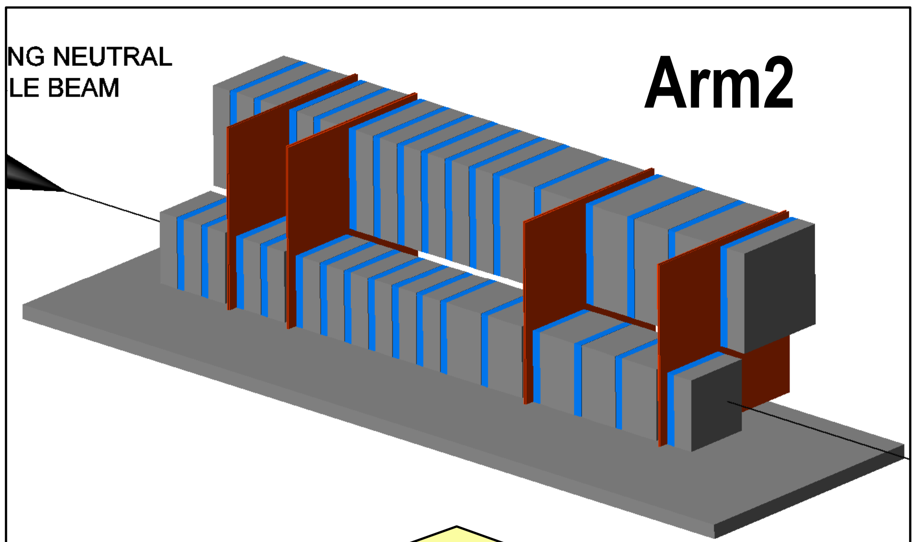
If large k
(π^0s carry more energy)
rapid development
If small k
(baryons carry more energy)
deep penetrating

④ 2ndary interactions
nucleon, π

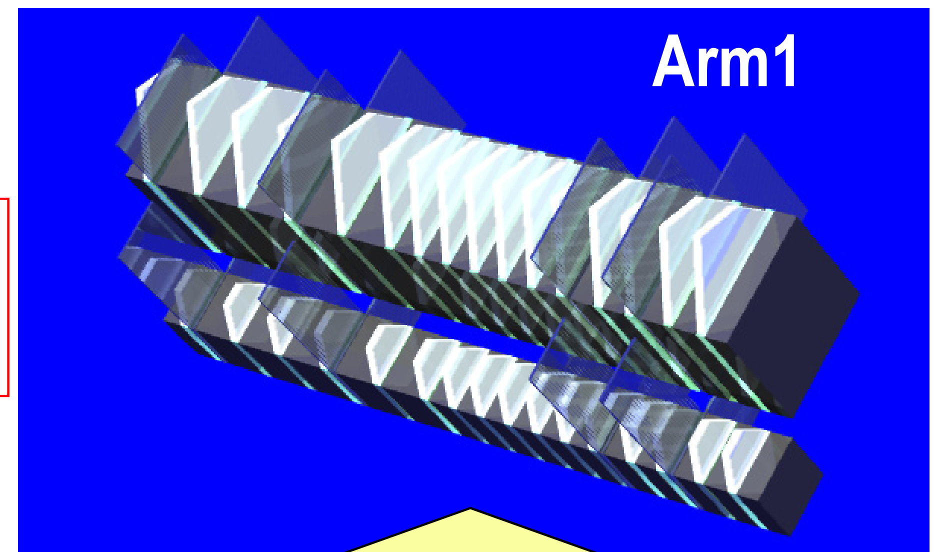
(relevant to N_μ)

The LHCf experiment





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

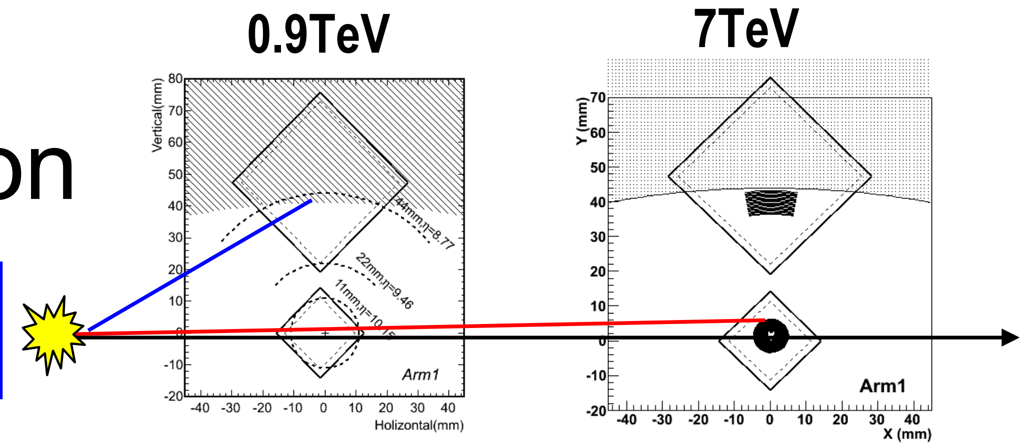


16 tungsten + pl.scinti. layers
25mmx25mm+32mmx32mm
4 Silicon strip tracking layers

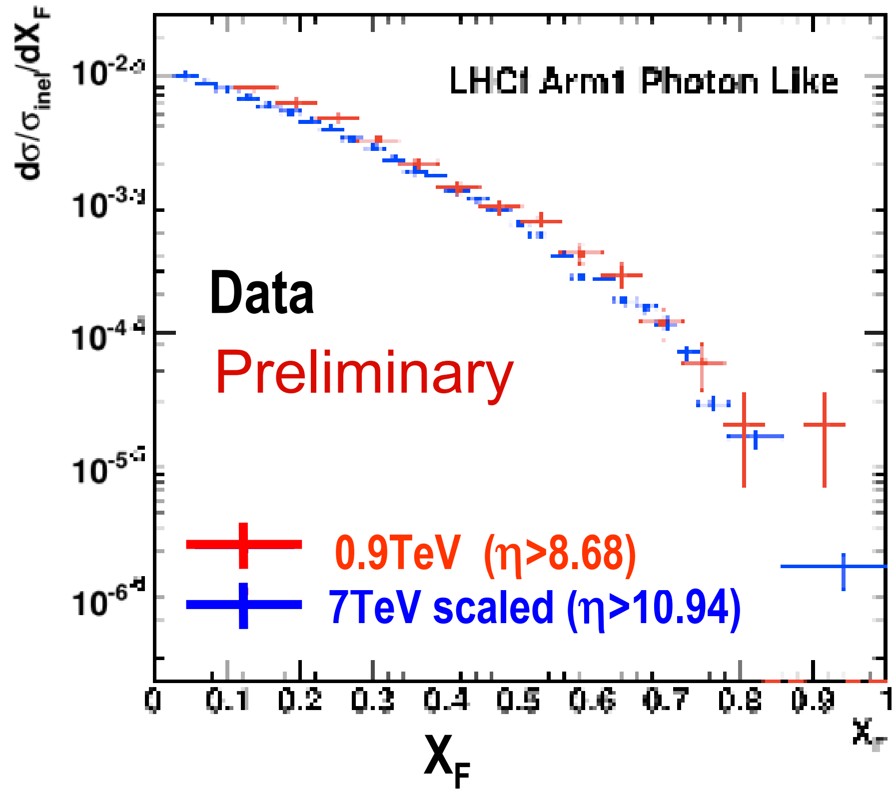
16 tungsten + pl.scinti. layers
20mmx20mm+40mmx40mm
4 SciFi tracking layers

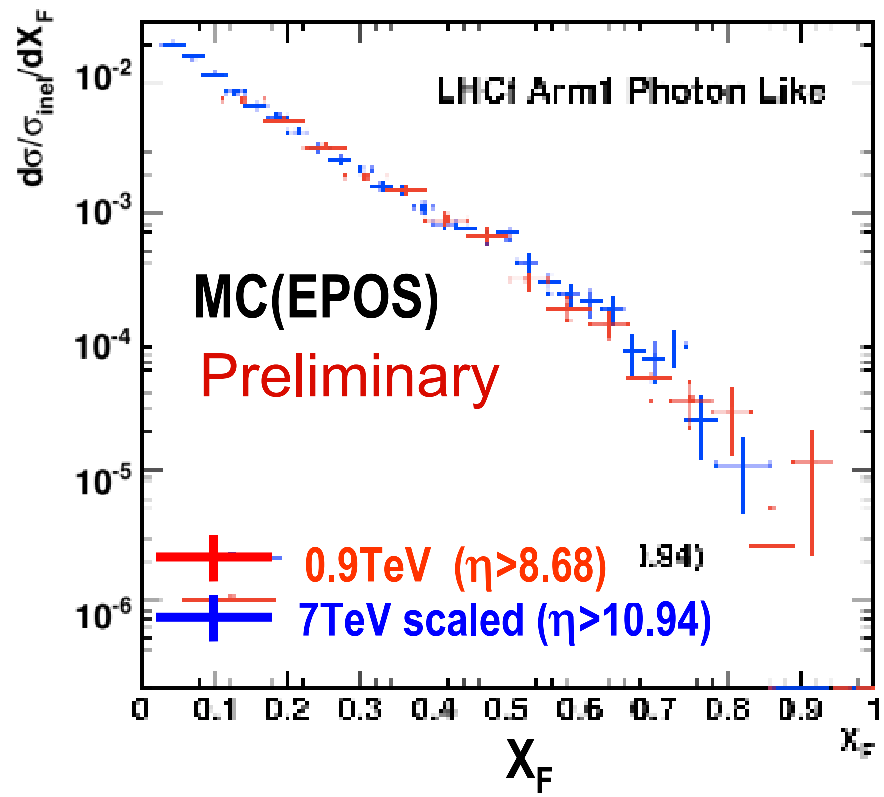
X_F spectra for single γ: 900GeV/ 7TeV comparison

$$\frac{1}{\sigma_{\mathrm{inel}}}\frac{d\sigma_\gamma}{dX_{\mathrm{F}}}\Big|_{\eta<\mathrm{limited}} \propto \frac{1}{\sigma_{\mathrm{inel}}}\frac{d\sigma_\gamma}{p_{\mathrm{T}}dp_{\mathrm{T}}dX_{\mathrm{F}}}\langle p_{\mathrm{T}}\rangle dp_{\mathrm{T}}$$



(sys error not included)



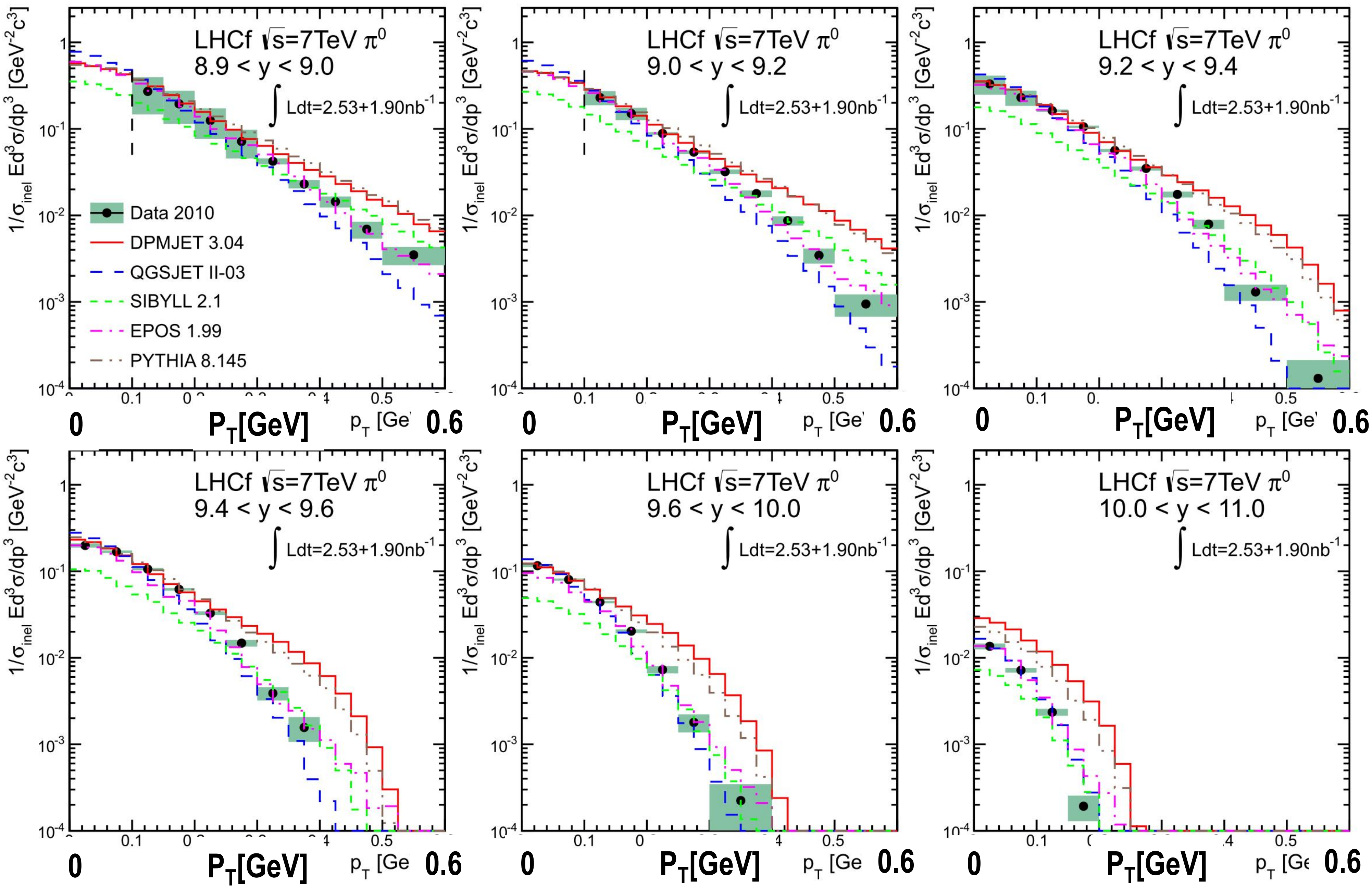


- Comparing X_F for common P_T region at two collision energies.
- Less root-s dependence of P_T for X_F ?

LHCf π^0 P_T spectra at 7TeV

PRD 86 (2012) 092001

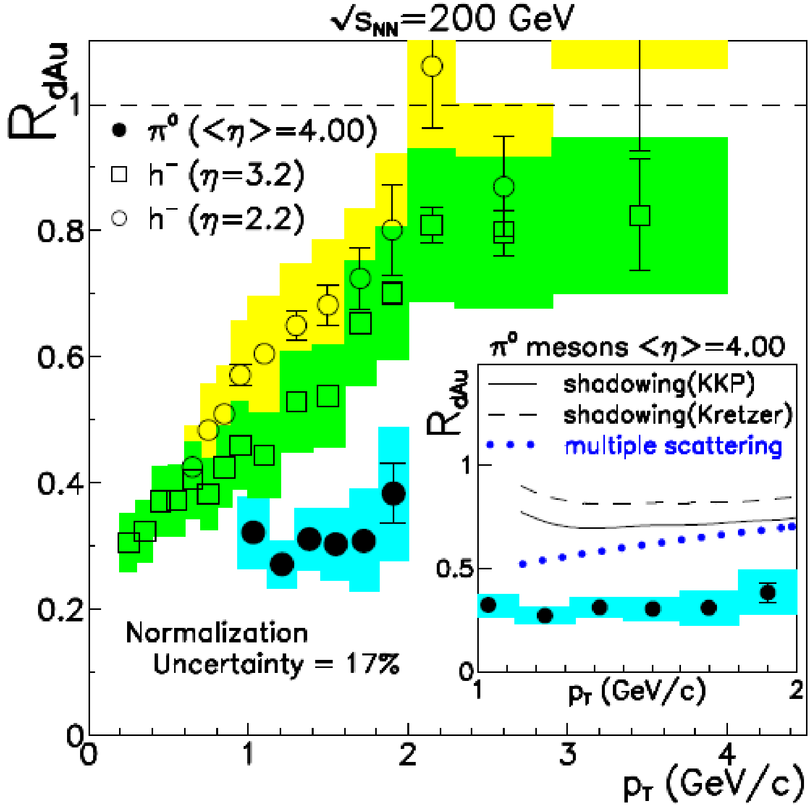
DPMJET 3.04 QGSJETII-03 SIBYLL 2.1 EPOS 1.99 PYTHIA 8.145



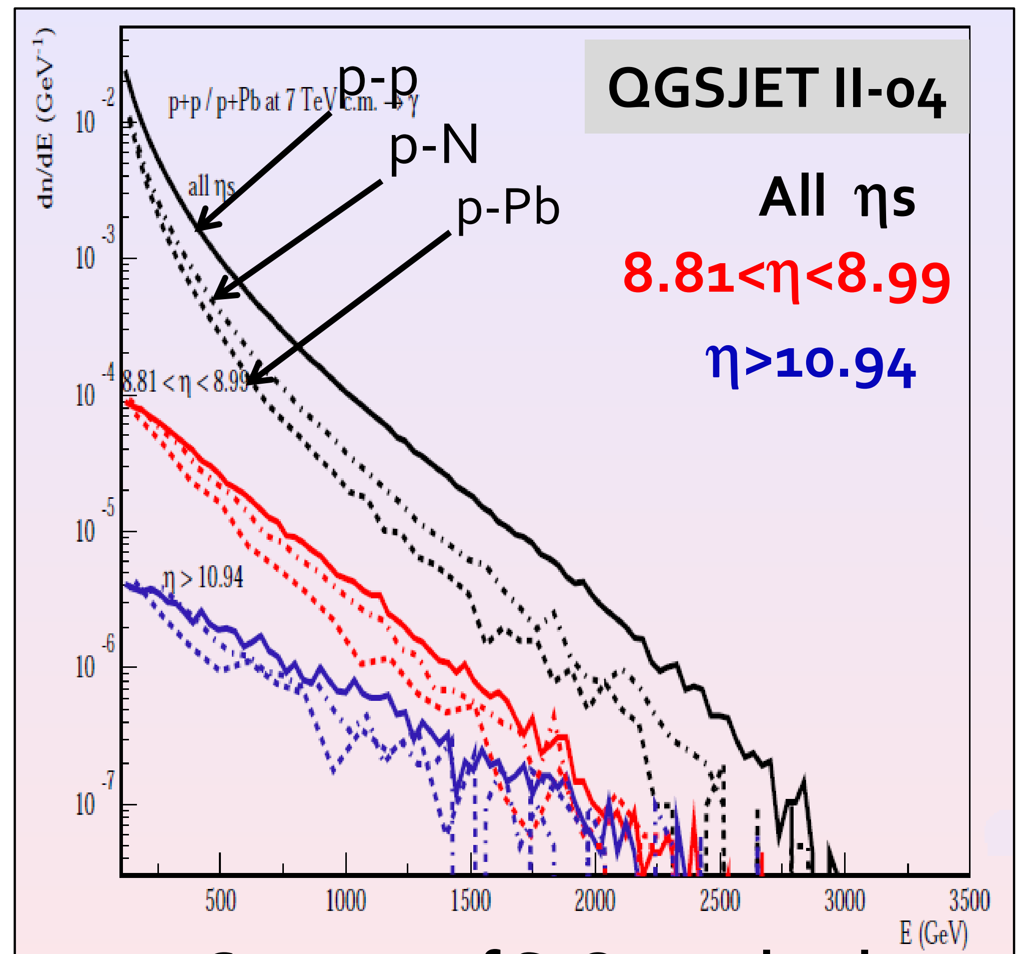
Nuclear effects for very forward region

- Air showers take place via p-N or Fe-N collisions !
  - Nuclear shadowing, final state interaction, gluon saturations
  - Nuclear modification factor at 0 degree may be large.

Phys. Rev. Lett. 97 (2006) 152302



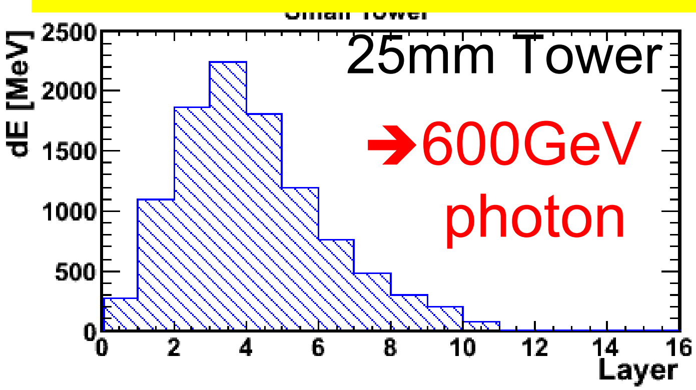
$$R^{Y}_{\mathrm{dAu}} = \frac{\sigma^{pp}_{\mathrm{inel}}}{\langle N_{\mathrm{bin}}\rangle \sigma^{dAu}_{\mathrm{hadr}}} \frac{E\, d^3\sigma/dp^3(d + Au \to Y + X)}{E\, d^3\sigma/dp^3(p + p \to Y + X)}$$

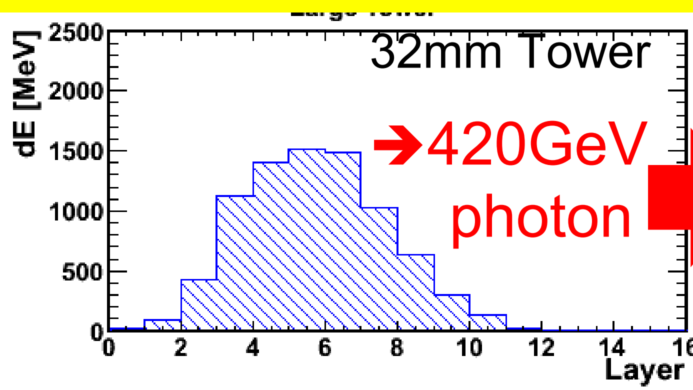


Courtesy of S. Ostapchenko

Event sample ($\pi^0 \rightarrow 2\gamma$)

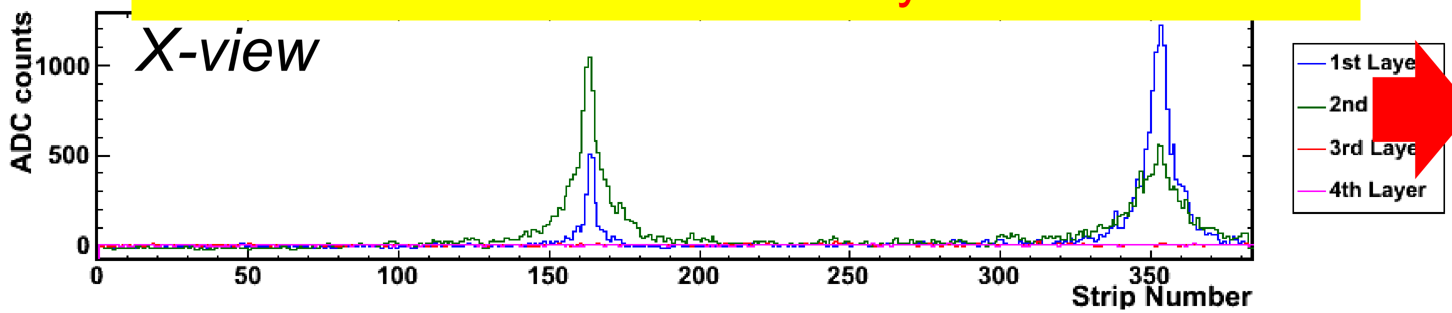
Longitudinal development measured by scintillator layers



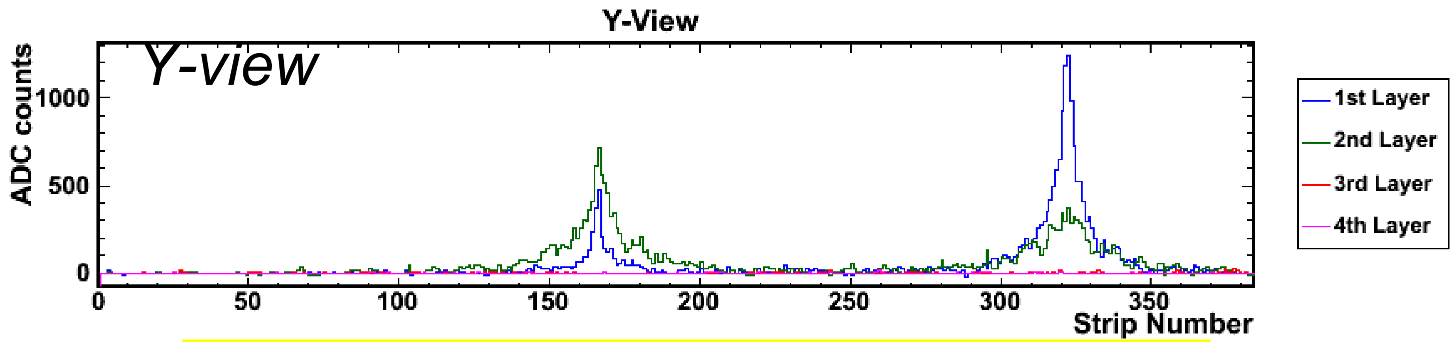


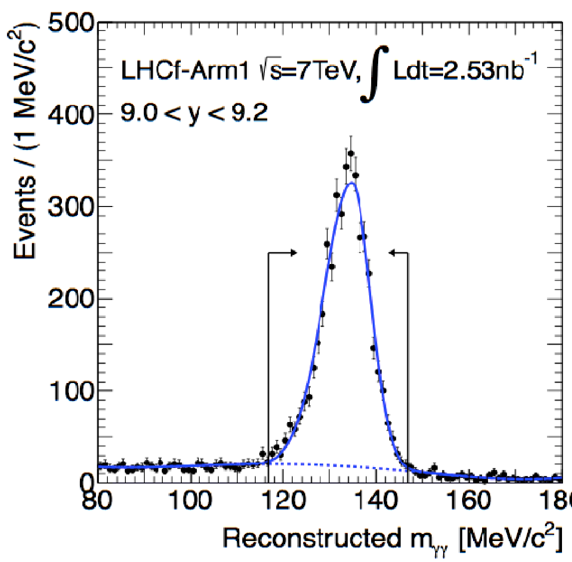
Total Energy deposit
➔Energy
Shape
➔PID

Lateral distribution measured by silicon detectors



Hit position,
Multi-hit search.



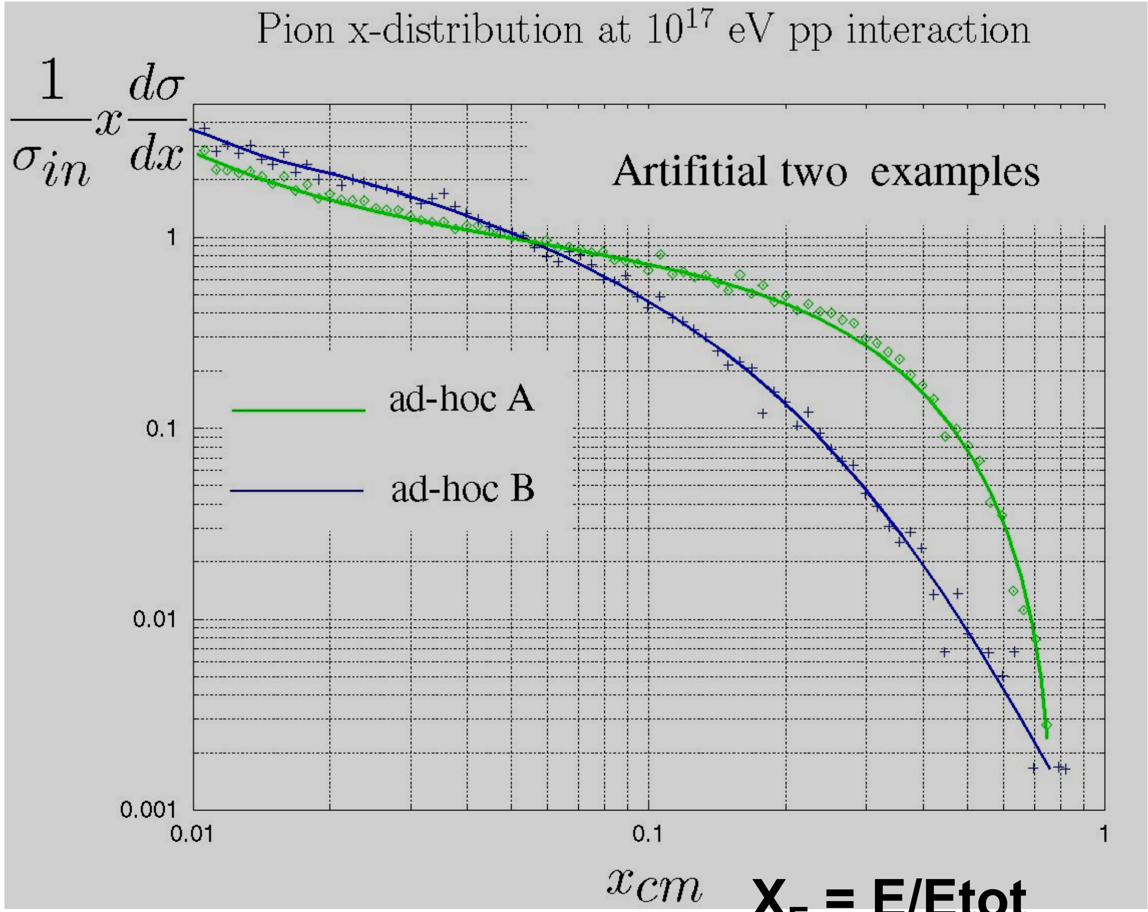


π^0 mass reconstruction from two photon.

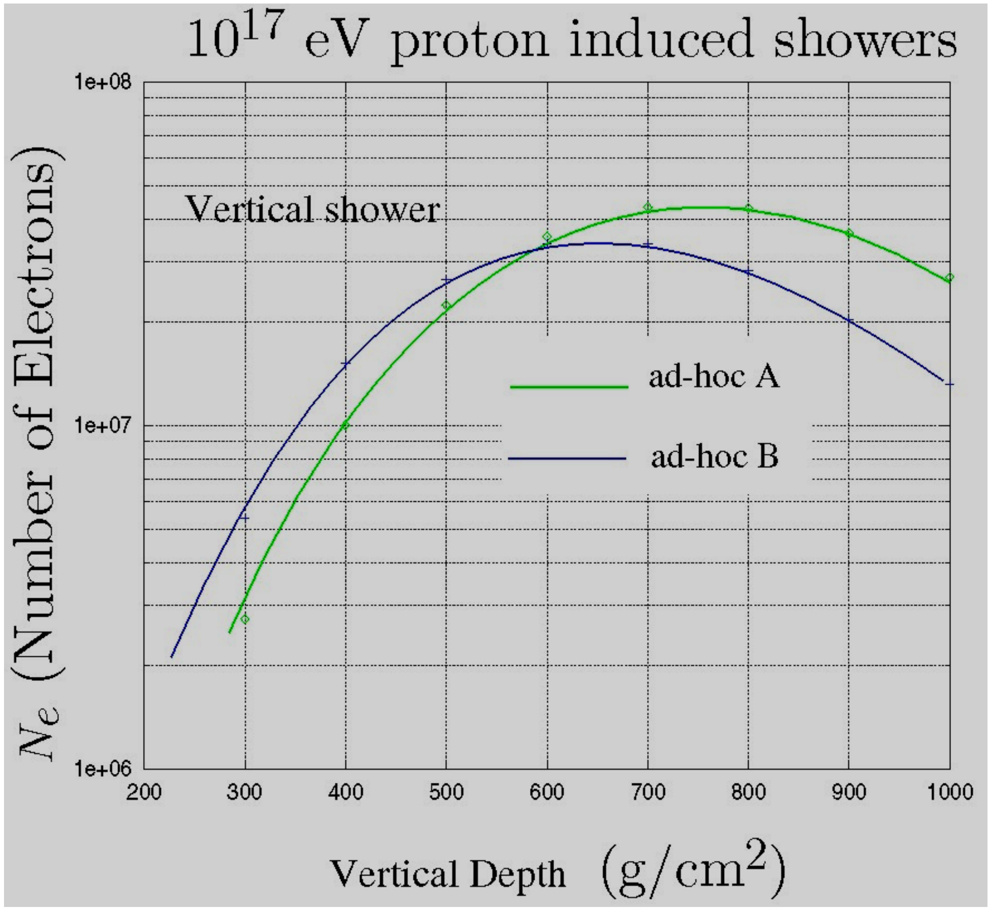
$$M_{\pi 0} = \sqrt{E_{\gamma 1} E_{\gamma 2}} \cdot \theta$$

Systematic studies

Forward production spectra vs Shower curve



X_F = E/Etot



Half of shower particles comes from large X_F γ

Measurement at very forward region is needed