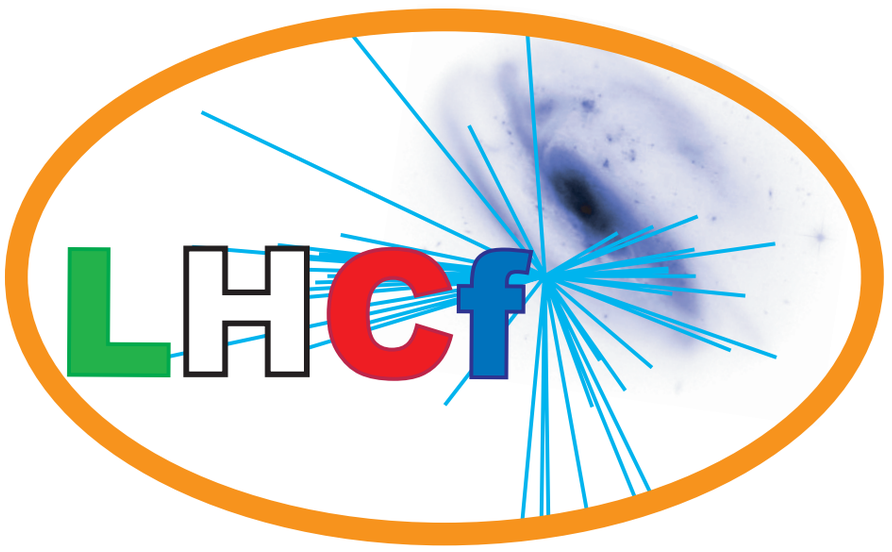


LHCf : Very forward measurement at LHC p-p and p-Pb

Hiroaki MENJO (Nagoya University, Japan)

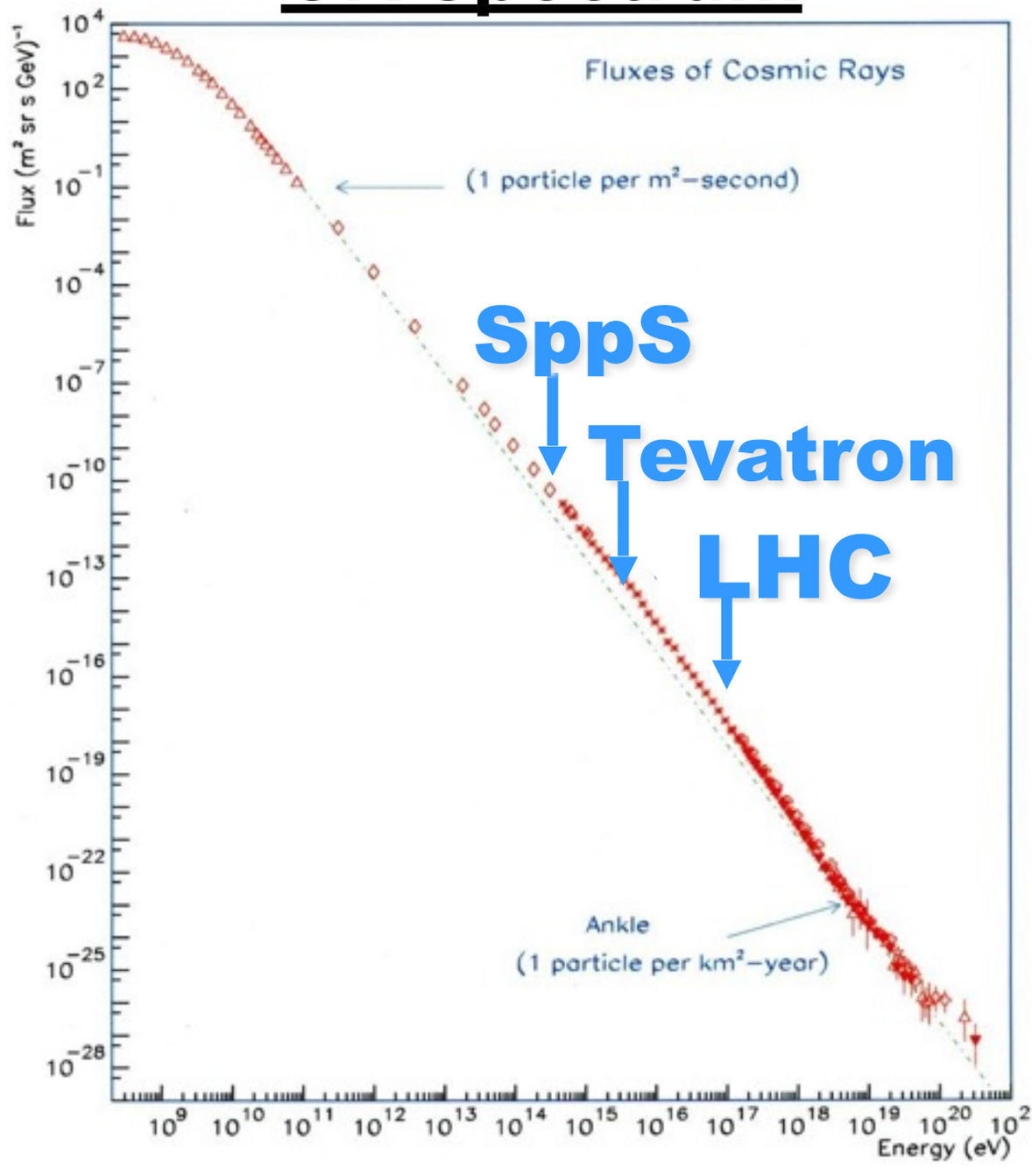
on behalf of the LHCf collaboration

-PANIC 2014, 25-30 Aug. 2014, Hamburg -

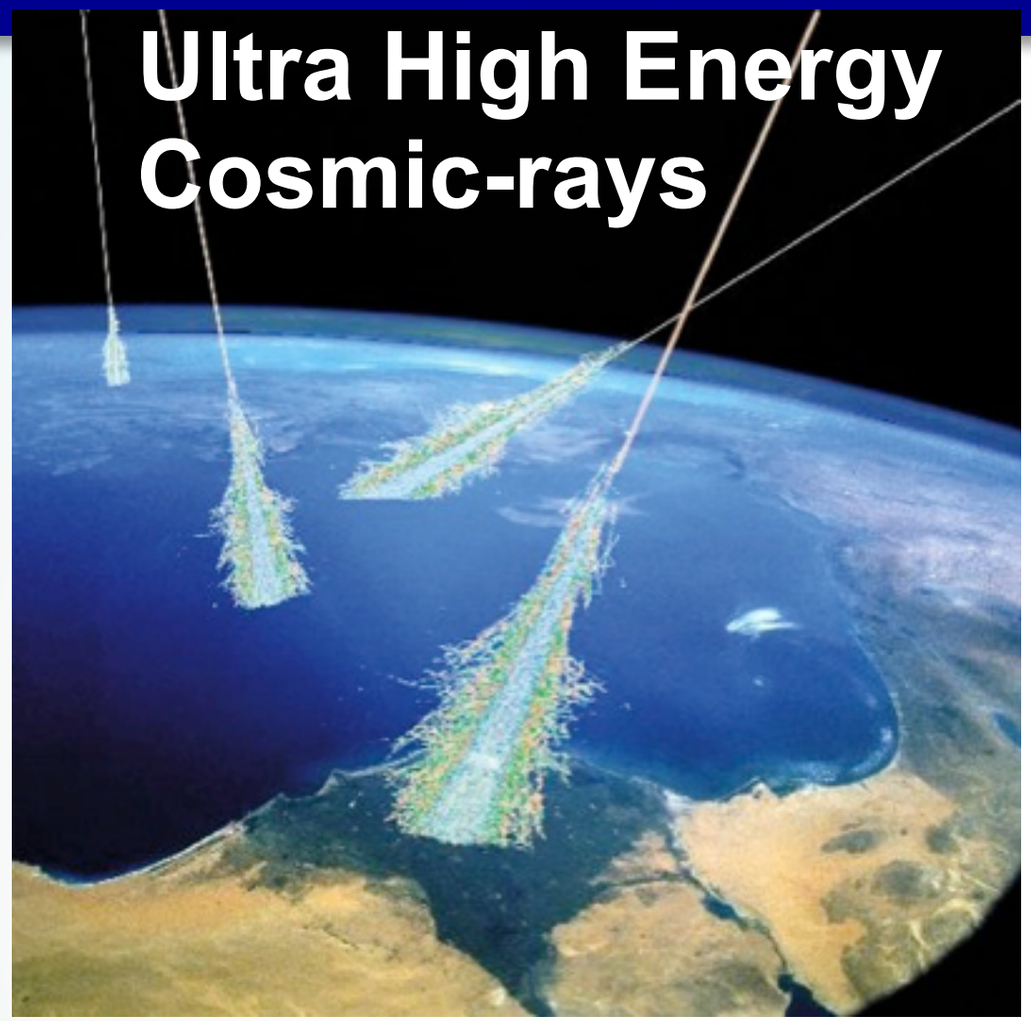
Contents

- Introduction
- LHCf experiment
  - LHC Forward expriment -
- Results from p-p, p-Pb
  - Neutron spectrum at p-p
  - Neutral pions at p-Pb
- Future prospects
- Summary

CR spectrum



Introductions : UHECR



Extensive air shower observation

- longitudinal distribution
- lateral distribution
- Arrival direction

Air shower development

Astrophysical parameters

- Spectrum
- Composition
- Source distribution

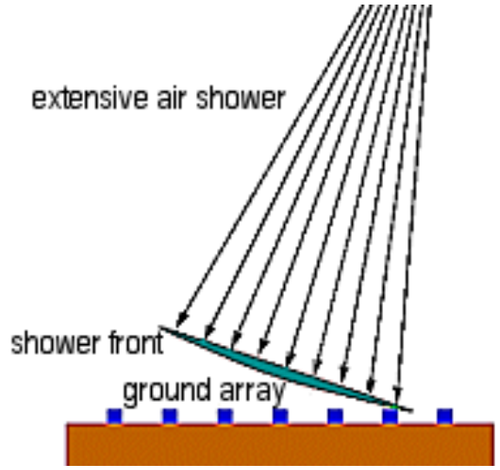
X_{max}
the depth of air shower maximum.
An indicator of CR composition

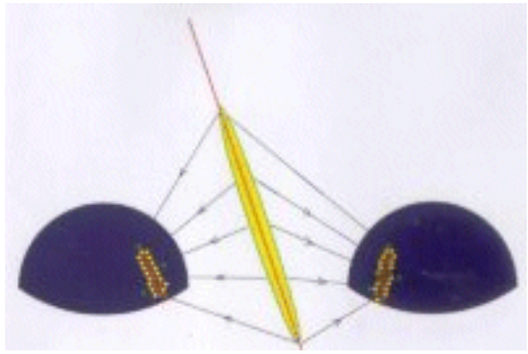
Uncertainty of hadron interaction models
V
Error of $<X_{max}>$ measurement

X_{max} distribution measured by AUGER

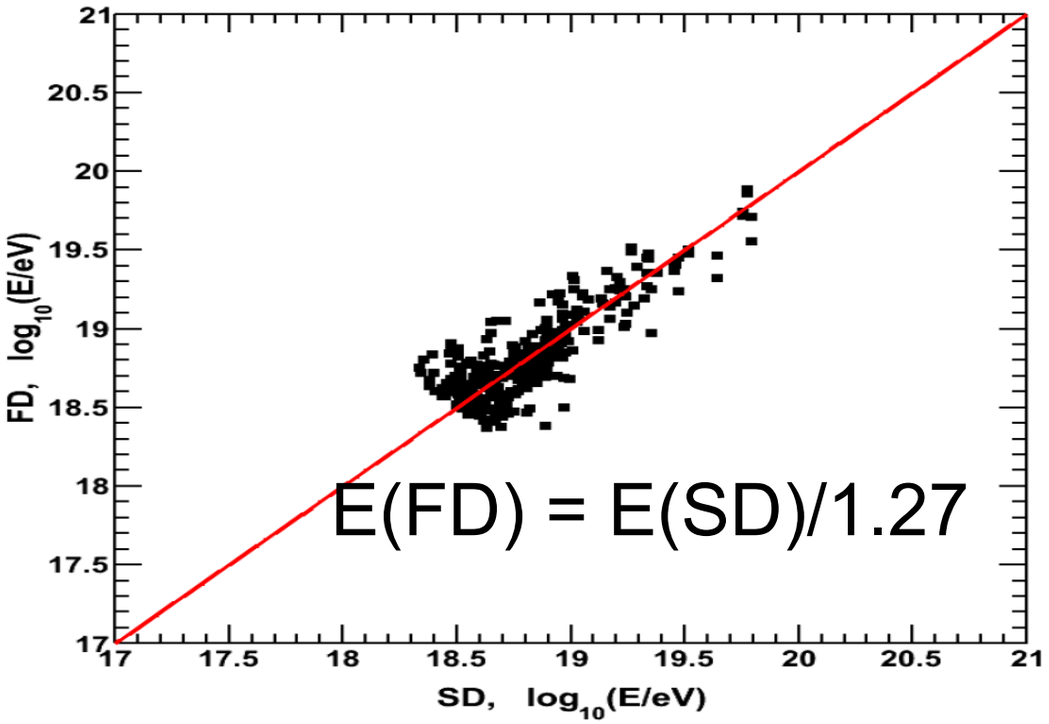
From UHECRs Observation

Air Shower technique :
AirShowers induced by UHECRs are observed by Florescence telescope (Calorimetric) and Surface detector array (Sampling on Ground)

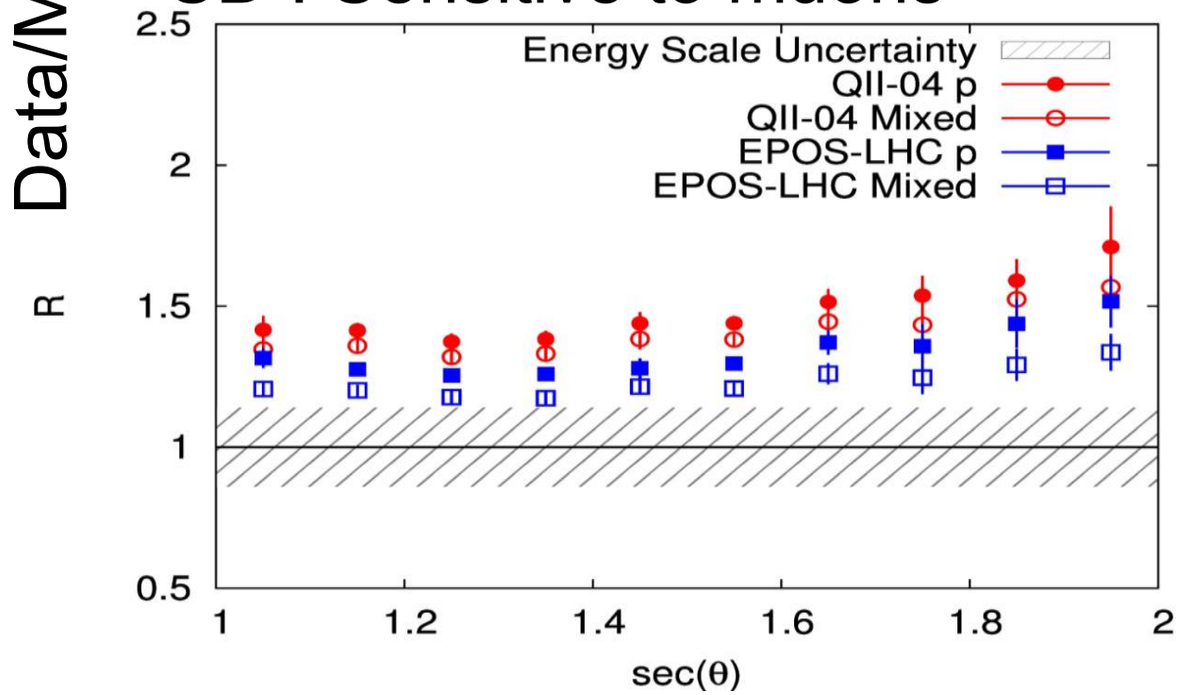




From Telescope Array
SD : Sensitive to EM



From Pierre Auger Observatory
SD : Sensitive to muons

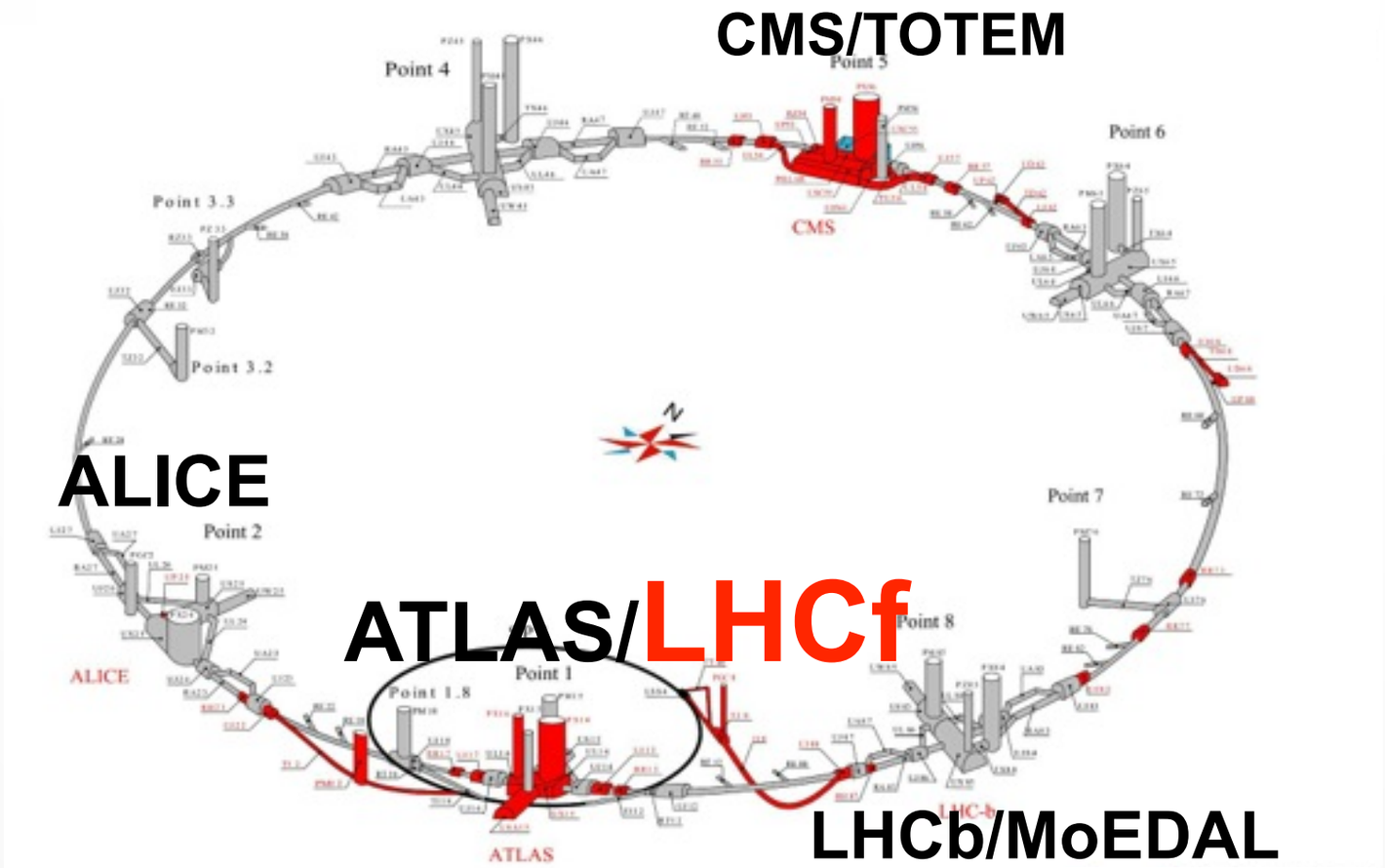


30% much EM components
30-50% much muons on ground

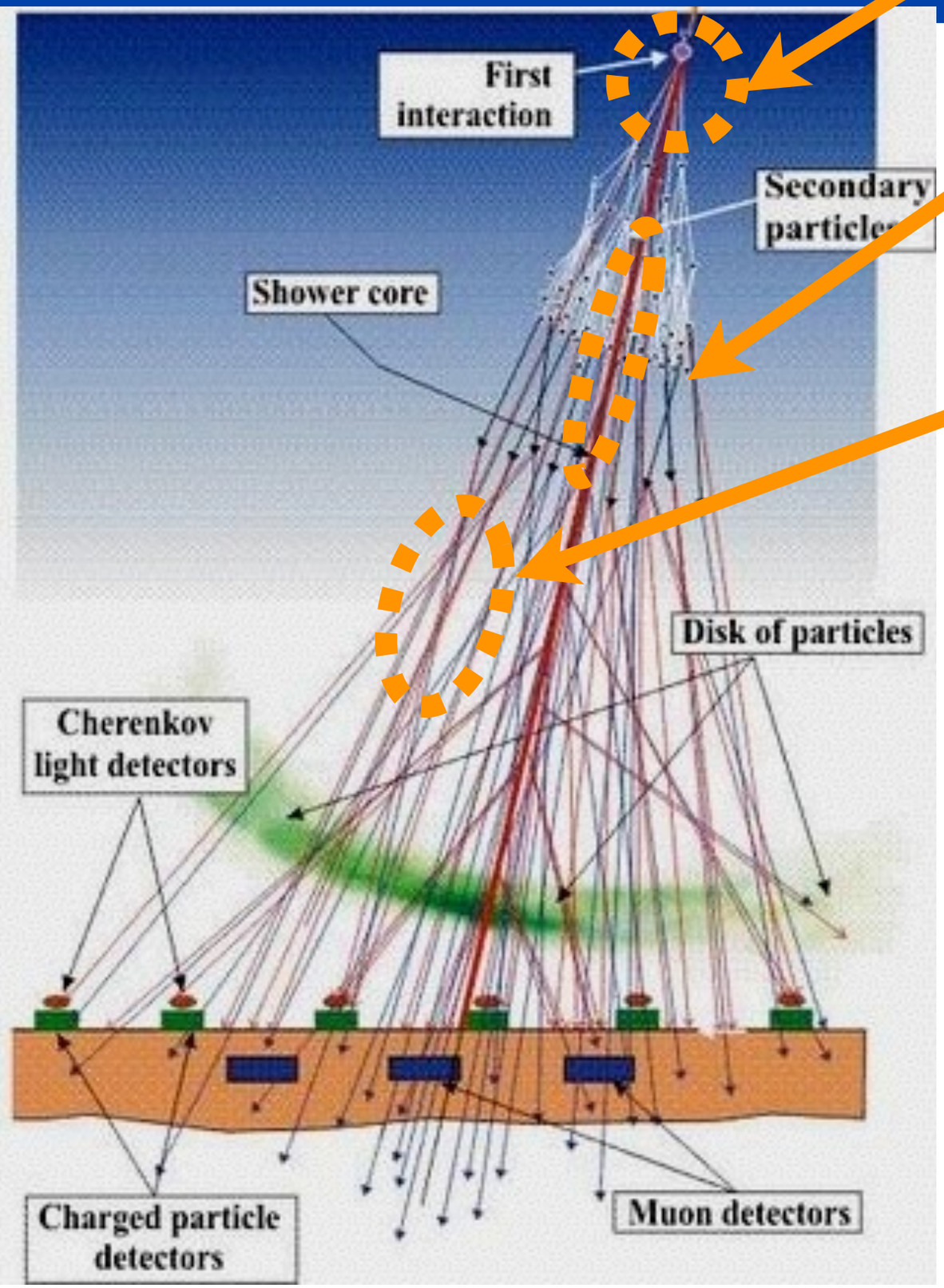
New Physics @ √s > 50TeV ??

The Large Hadron Collider (LHC)

pp $\sqrt{s}$ = 13TeV	**→ E_{lab} = 0.9x10^{17}eV**	**2015-**
pp $\sqrt{s}$ = 7TeV	**→ E_{lab} = 2.6x10^{16}eV**	2010-2011
pp $\sqrt{s}$ = 0.9TeV	**→ E_{lab} = 2x10^{14}eV**	2009,2010
pp $\sqrt{s}$=2.76TeV, 8TeV		2012
PbPb $\sqrt{s_{NN}}$=2.76TeV		2011
p-Pb $\sqrt{s_{NN}}$=5TeV		2013



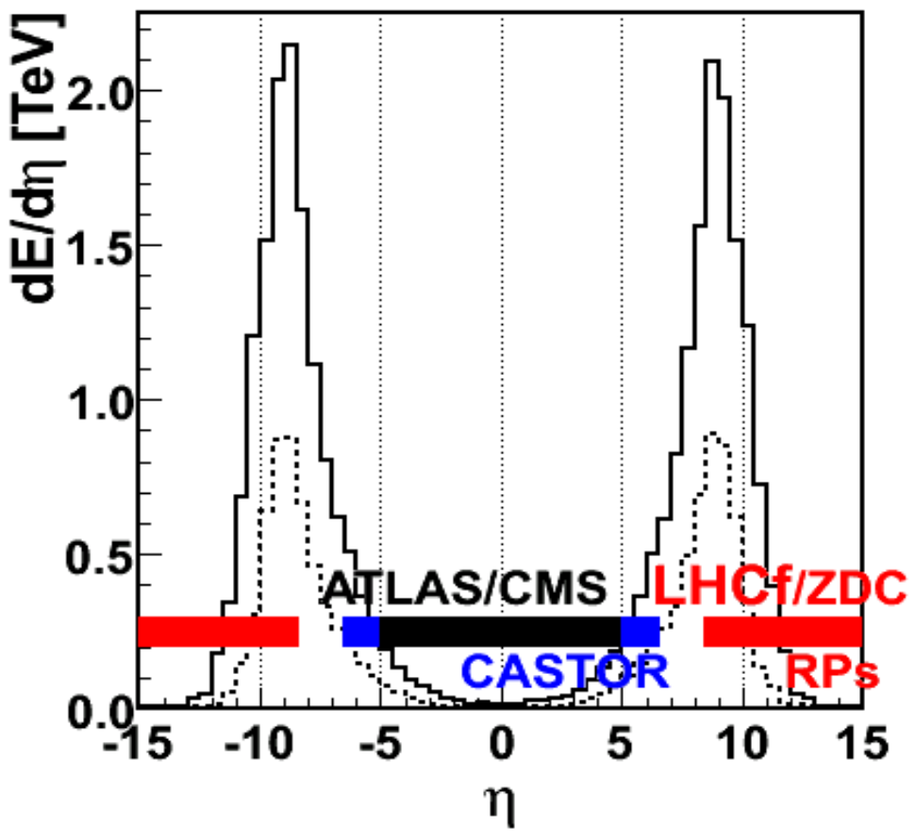
Key parameters for Air Showers



- Inelastic Cross Section
  →TOTEM, ATLAS, CMS,ALICE
- Forward Energy Spectrum
  →**LHCf**, ZDC and etc.
- Inelasticity k= 1-p_{lead}/p_{beam}
  →**LHCf**, ZDC and etc.
- Multiplicity
  →Central detectors

+Nuclear Effect @ CR-Air

Energy flux @ p-p, 14TeV



The LHCf collaboration

The LHCf collaboration involves
~30 members at 10 institutions.

Feb. 2009

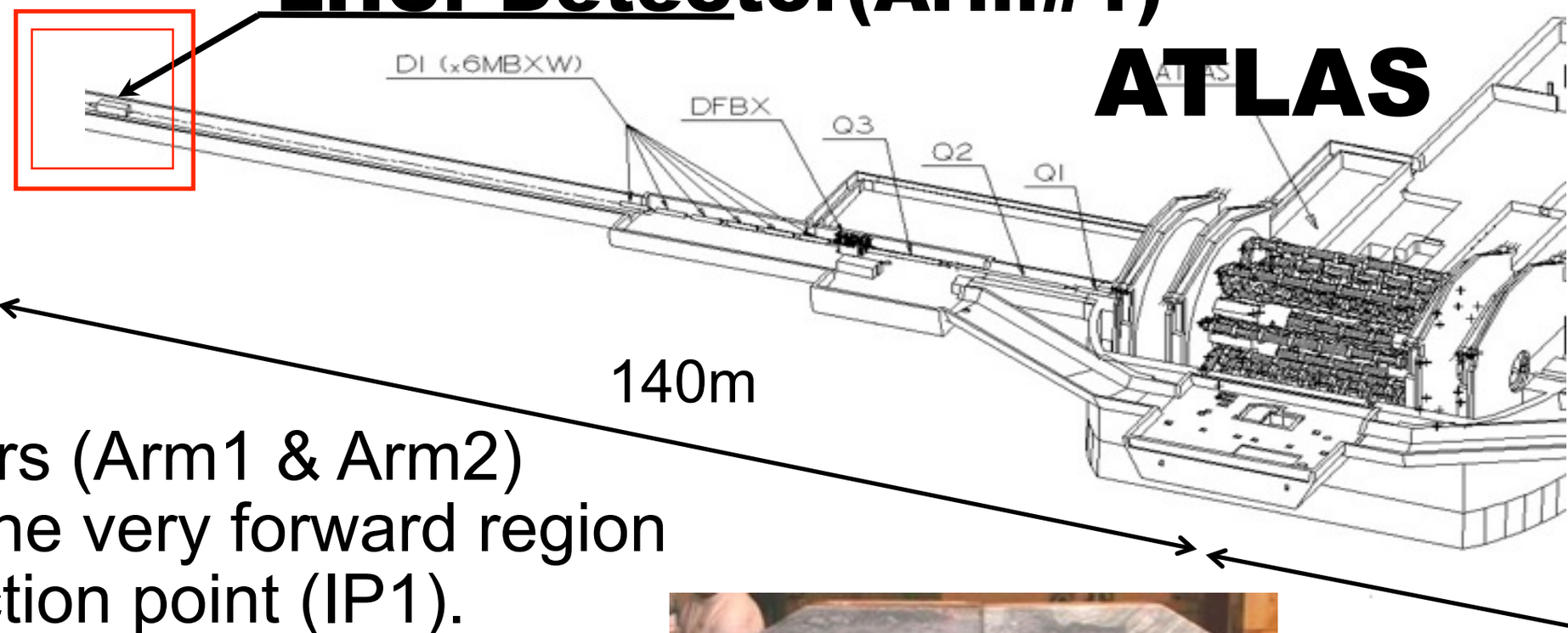
Jul. 2011

Jul. 2013

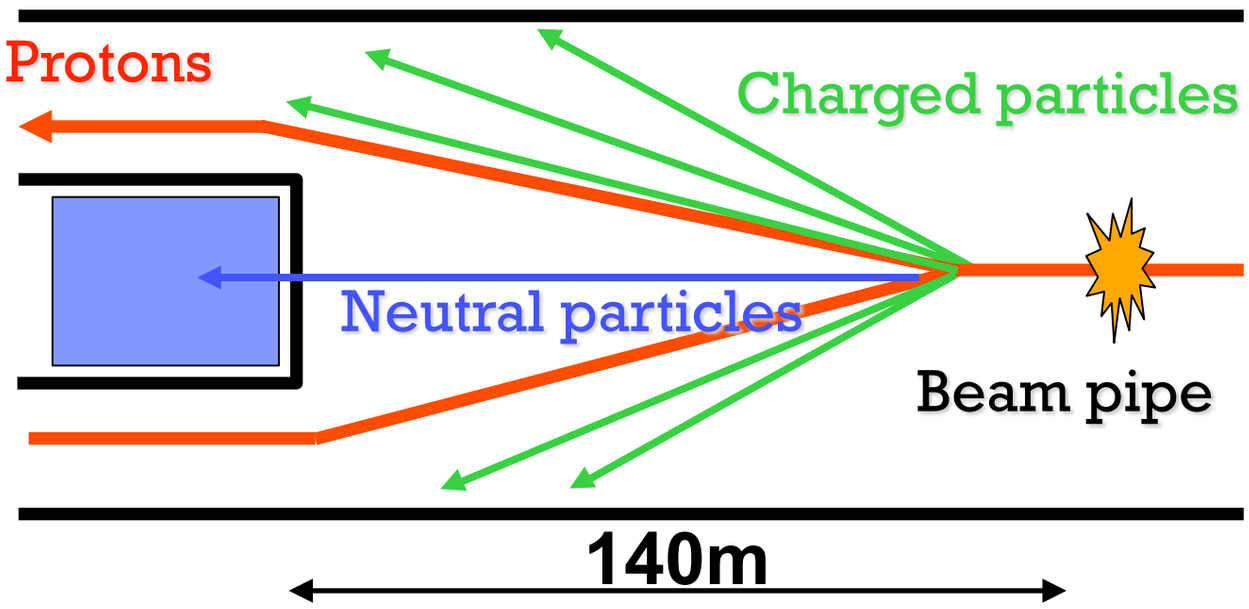
Apr. 2013

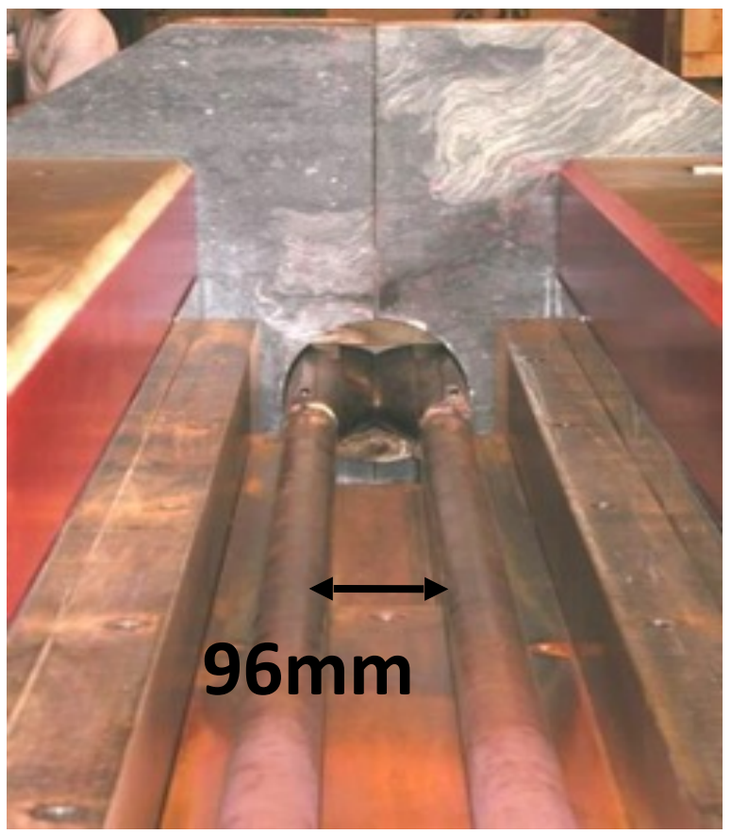
LHCf Experiment

LHCf Detector(Arm#1)



Two LHCf detectors (Arm1 & Arm2) are installed into the very forward region of the LHC interaction point (IP1). LHCf can measure neutral particles (γ, n) at the rapidity range **η > 8.4.**

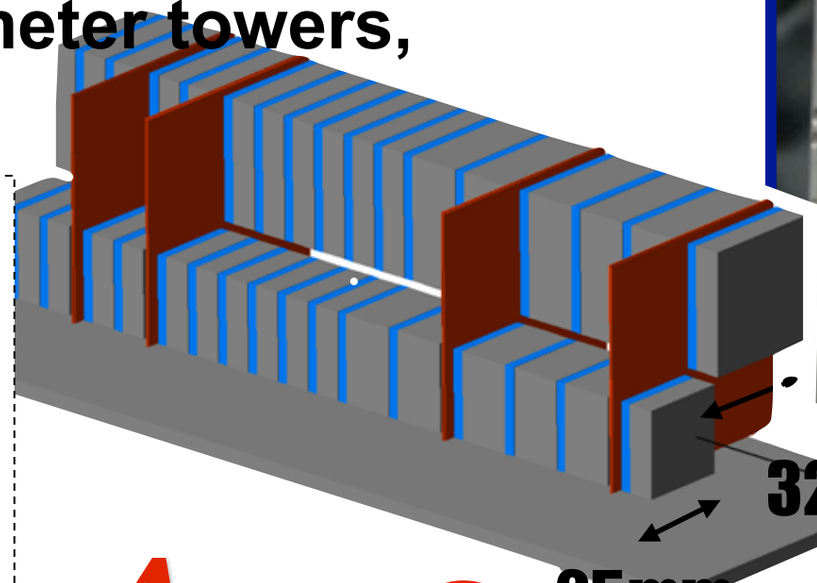




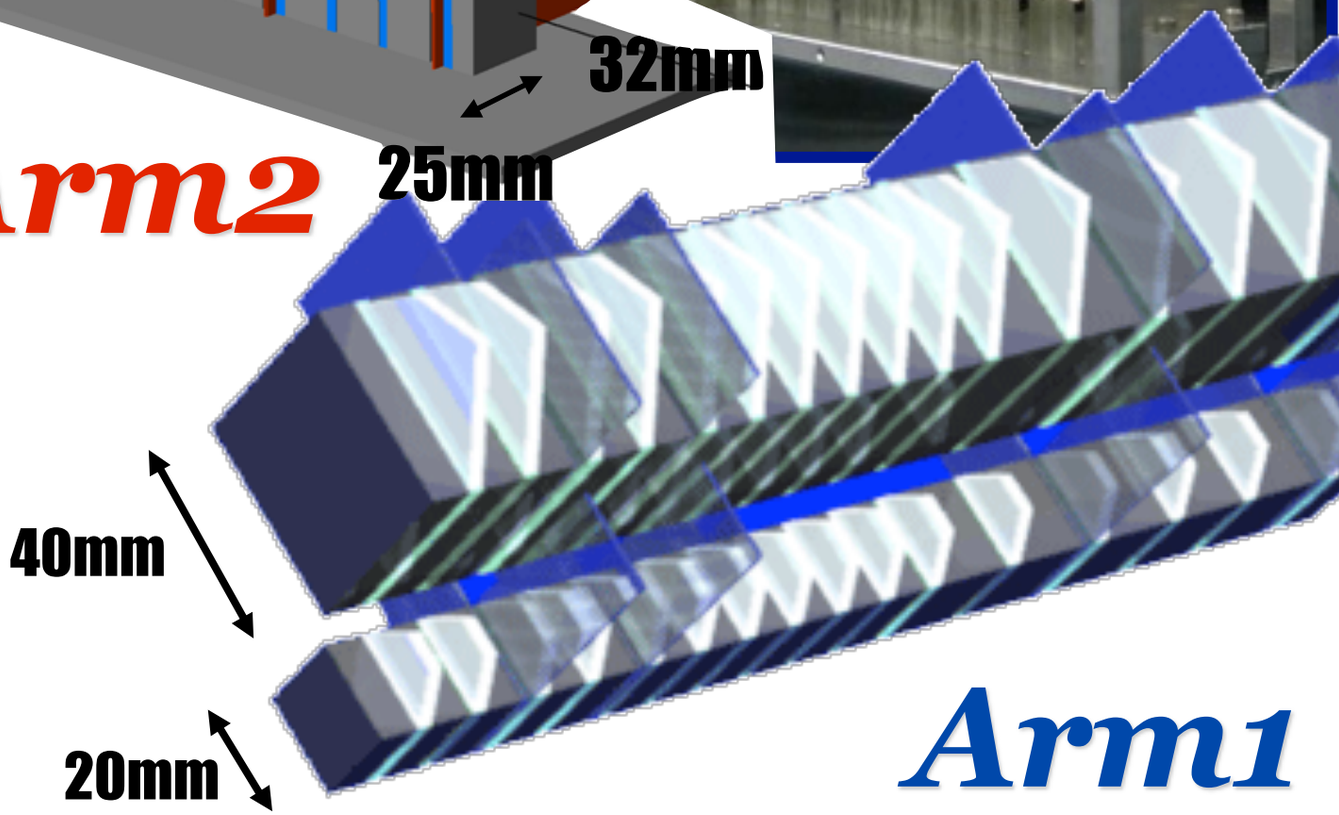
The LHCf detectors

Sampling and Positioning Calorimeters

- W (44 r.l , 1.7λ_I) and Plastic Scintillator x 16 Layers
- 4 positioning layers
  XY-SciFi (Arm1) and XY-Silicon strip(Arm#2)
- **Each detector has two calorimeter towers, which allow to reconstruct π^0**



Arm2



Arm1

Expected Performance

Energy resolution (> 100GeV)

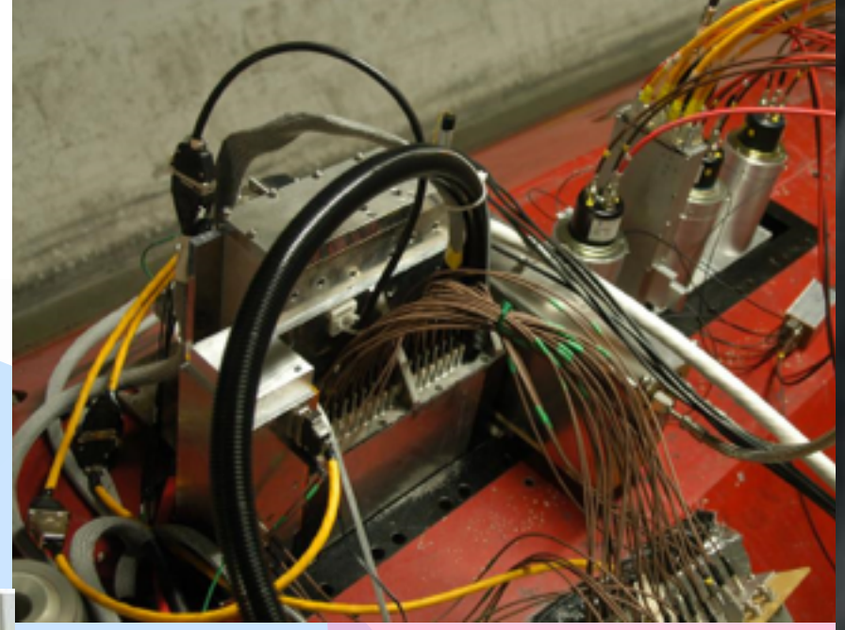
< 5%	for Photons
40%	for Neutrons

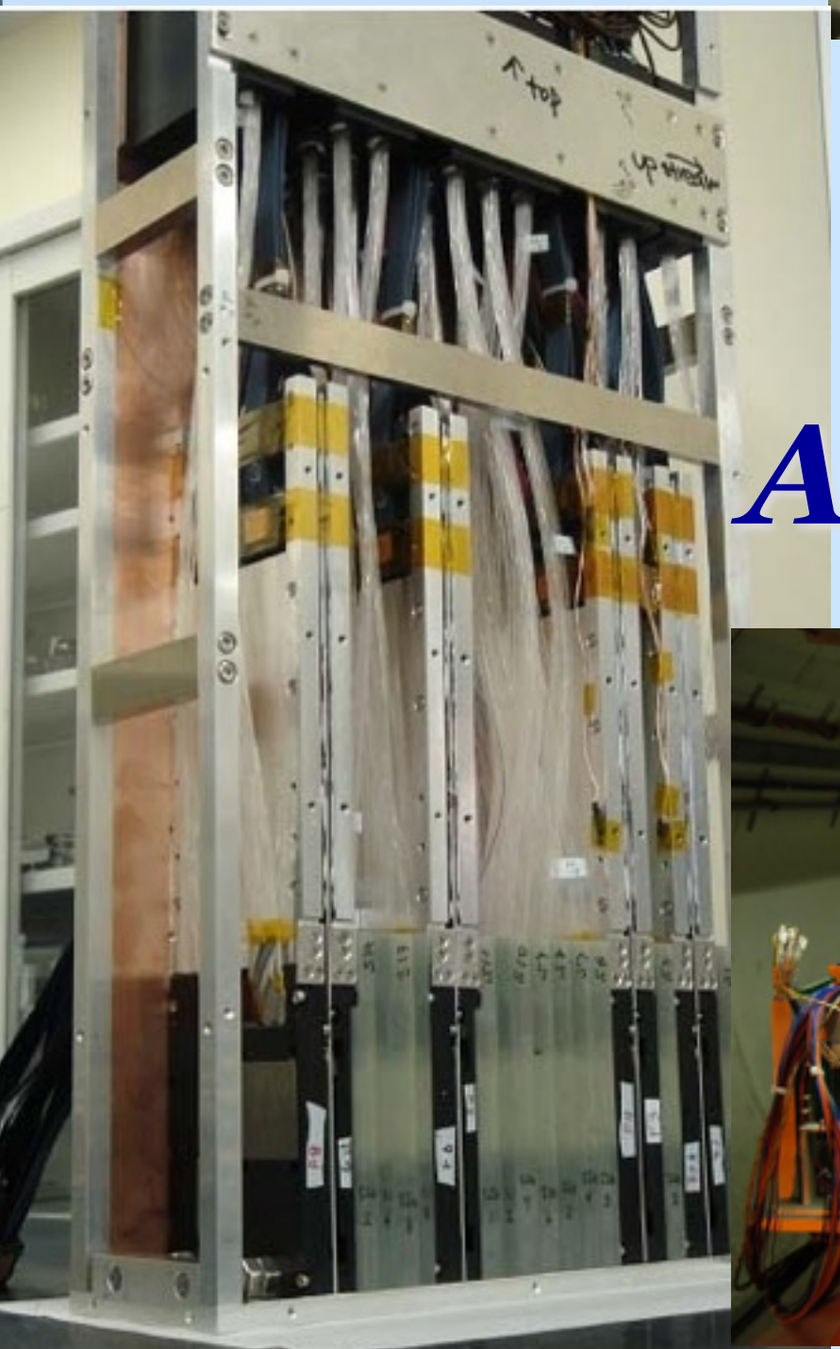
Position resolution

< 200μm	for Photons
a few mm	for Neutrons

Front Counter

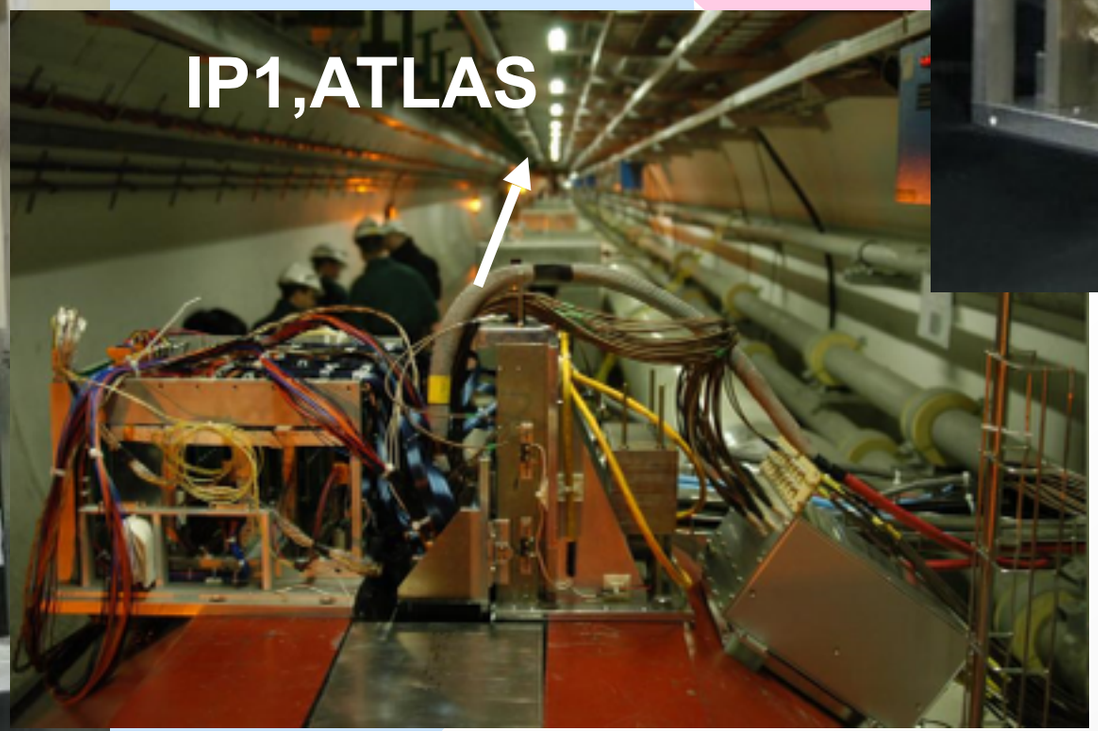
- thin scintillators with 80x80mm^2
- **To monitor beam condition.**
- **For background rejection of beam-residual gas collisions by coincidence analysis**





Arm1

Arm2



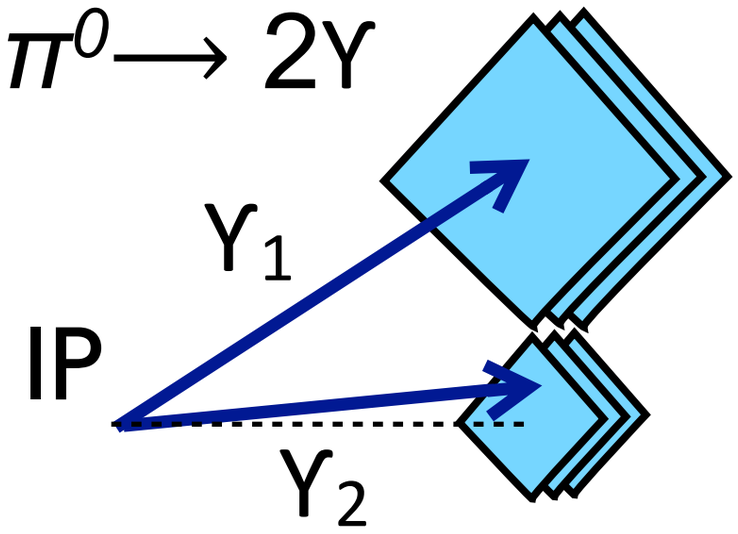
Operations and Results

- **p-p, $\sqrt{s}$ = 0.9 TeV (Dec. 2009 and May 2010)**
  - Photon spectra (PLB 715 (2012) 298)
- **p-p, $\sqrt{s}$ = 7.0 TeV (Apr.-July 2010)**
  - Photon spectra (PLB 703 (2011) 128)
  - Neutral pion spectra (PRD 86 (2012) 092001)
  - **Neutron spectra (submit quite soon)**
    → Forward baryons relating to "Inelasticity"

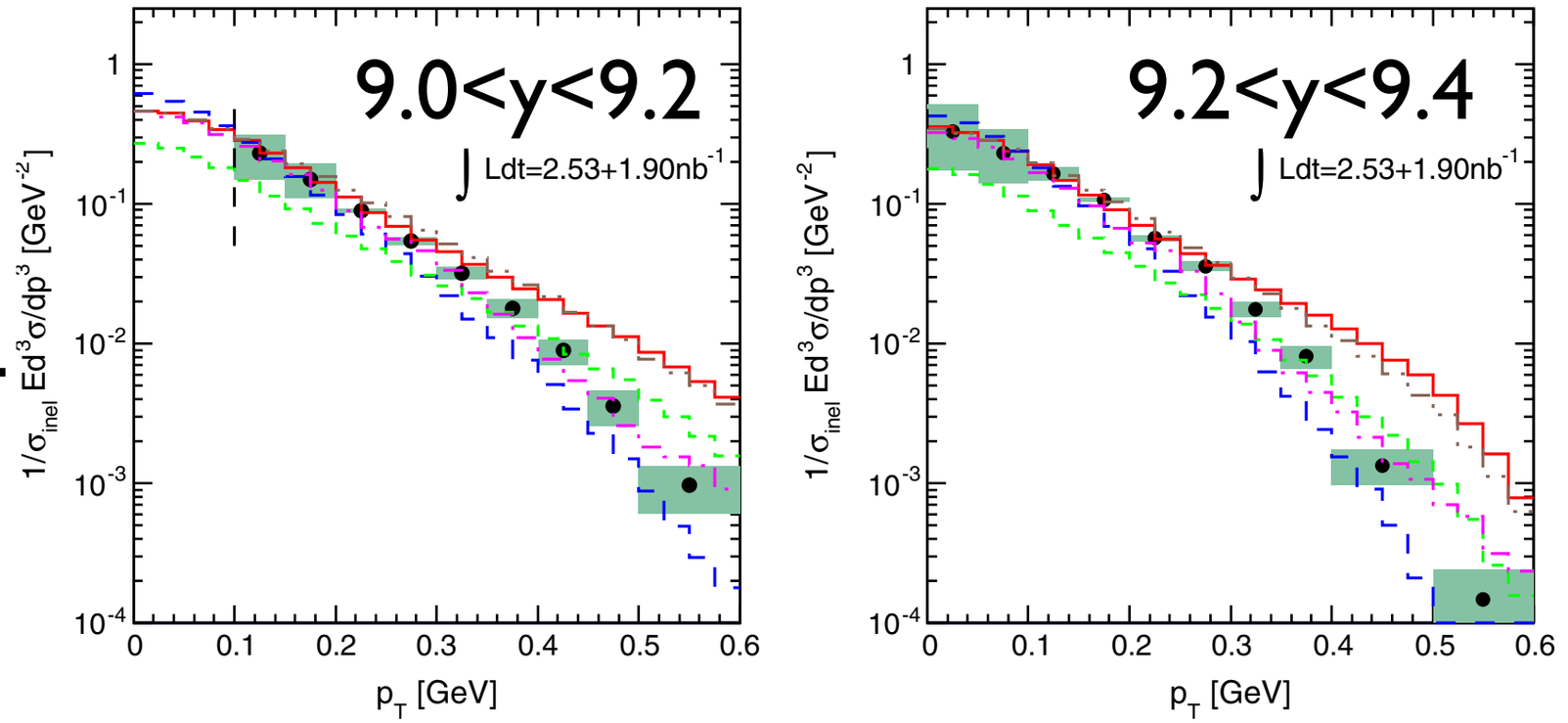
Electromagnetic components

- **p-Pb, $\sqrt{s_{NN}}$=5TeV (Jan.-Feb. 2013)**
  - **Neutral pion spectra (PRC 89 (2014) 065209)**
    → Nuclear effect at the very forward region.

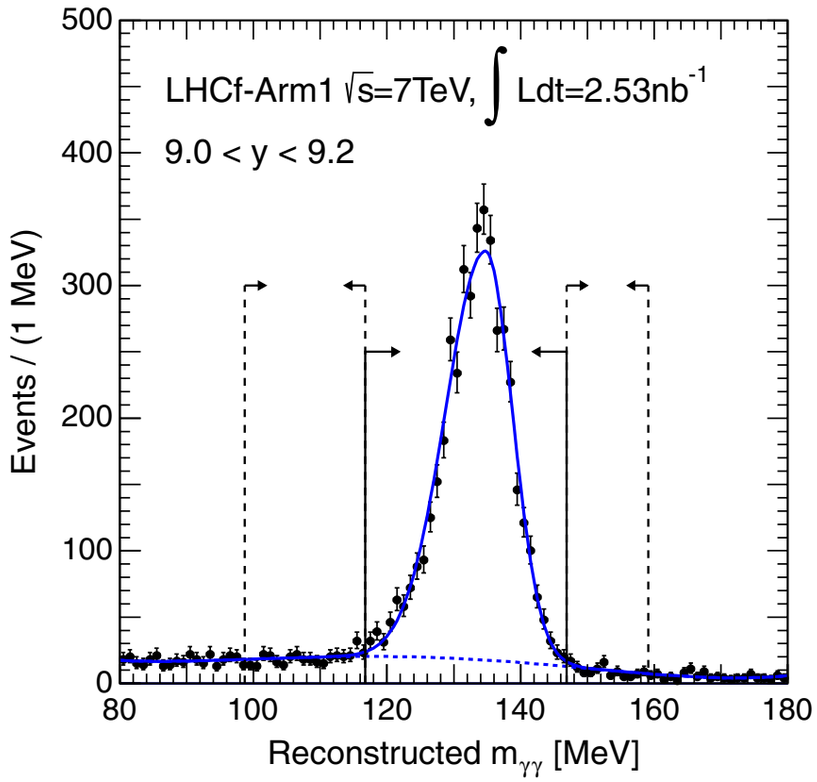
Neutral Pions at 7TeV p-p



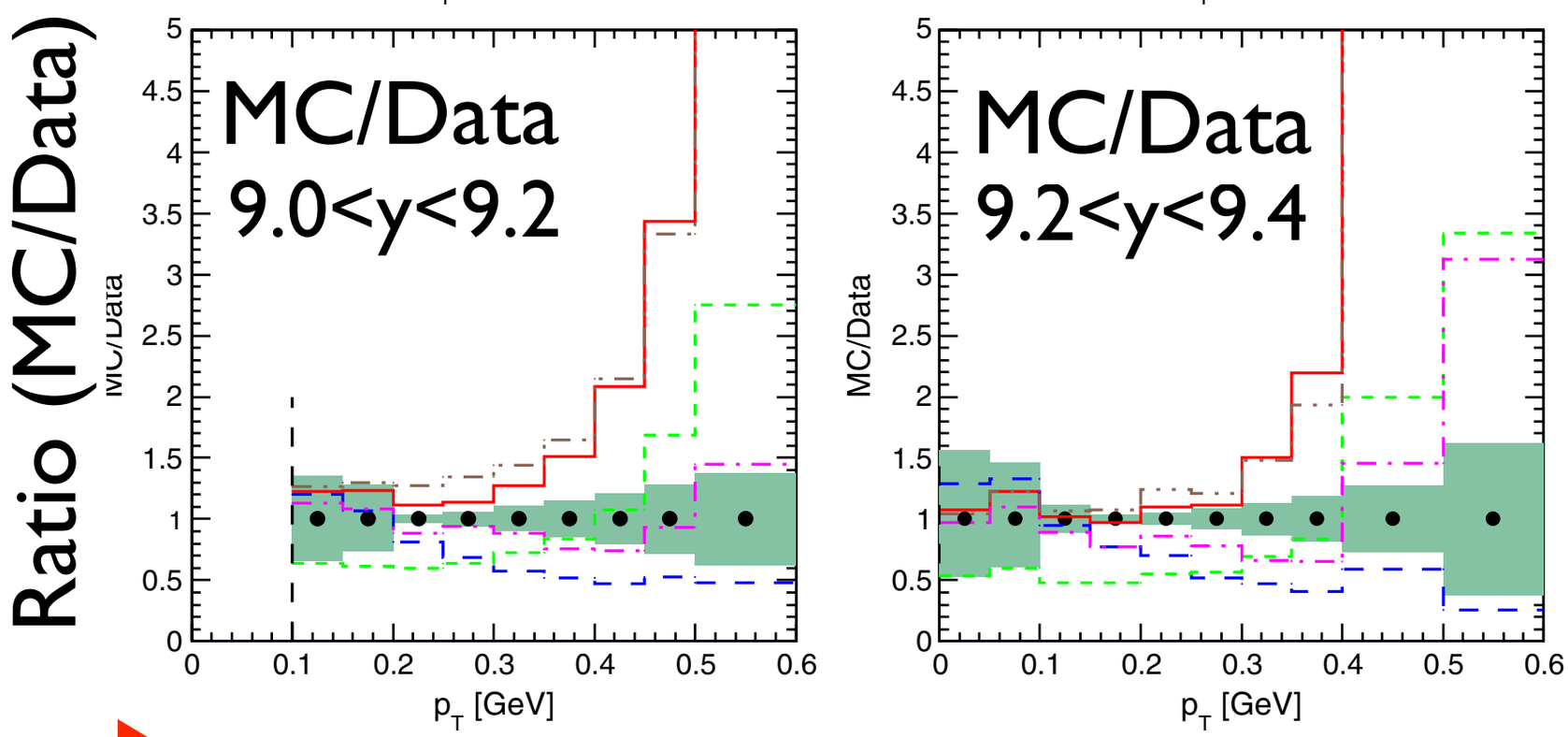
P_T spectra



Reconstructed Mass



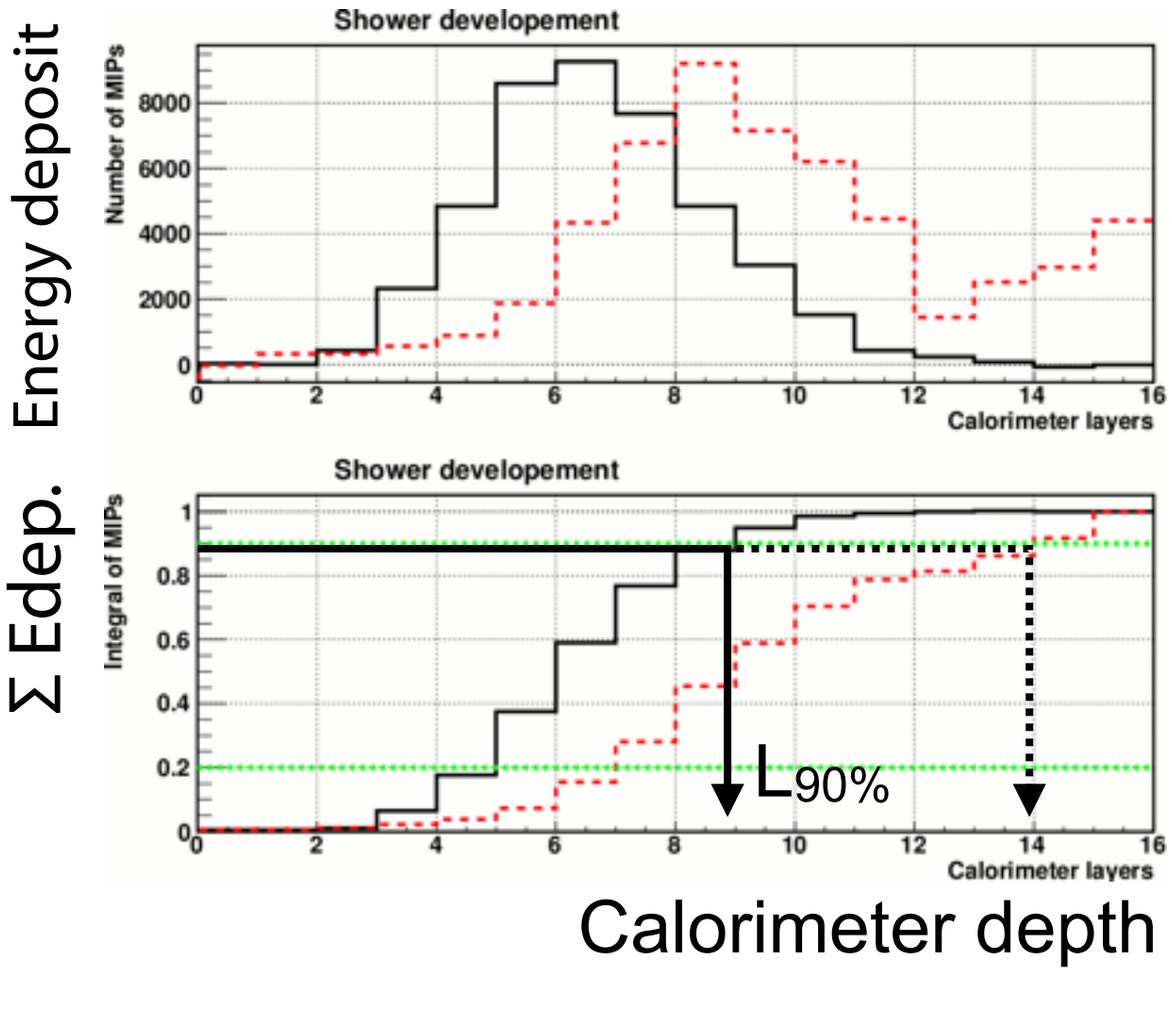
Ratio (MC/Data)

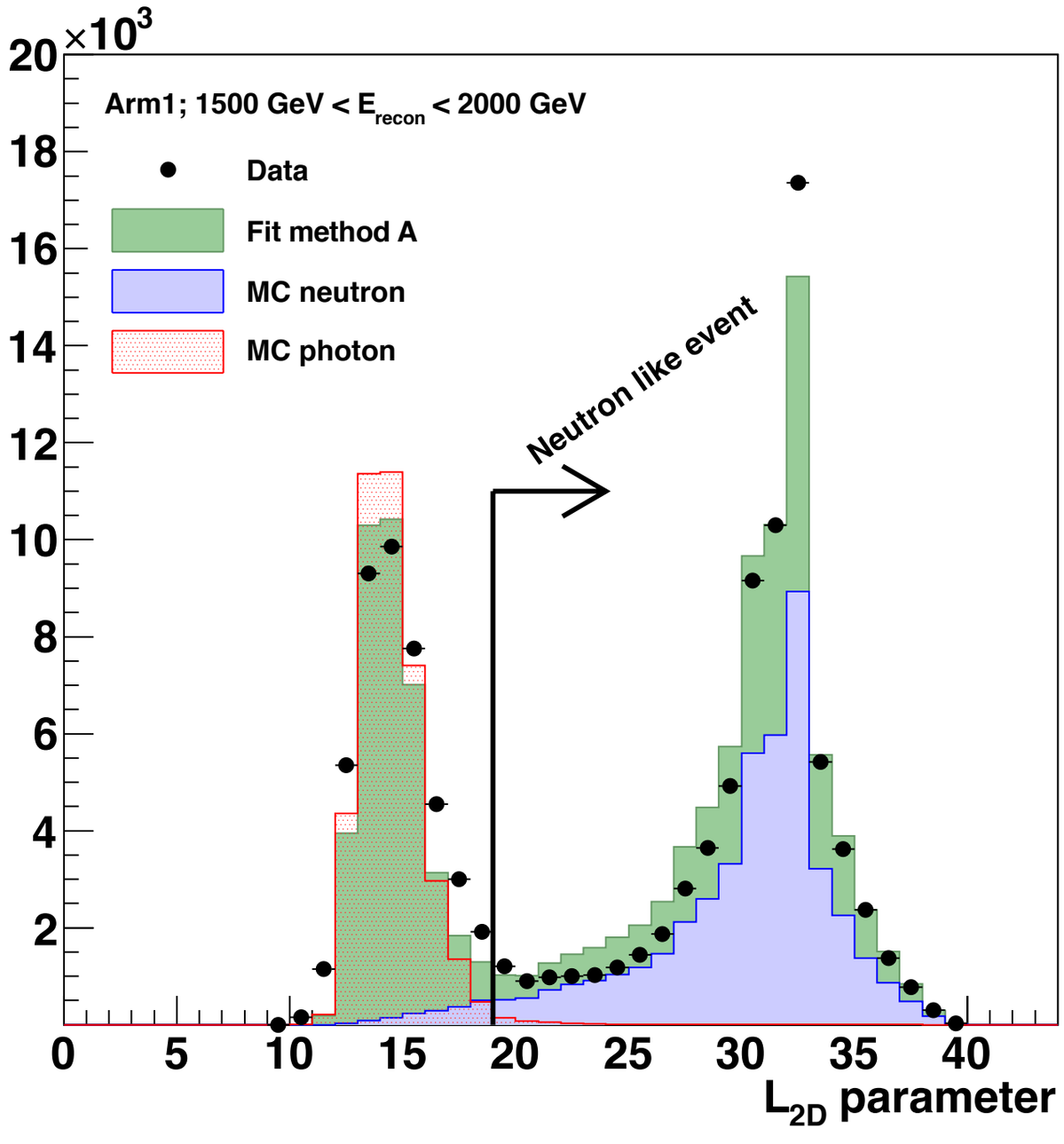


Data favors EPOS1.99

PID method

Detector thickness is
EM : 44 radiation length
→ Thick enough to contain all showers.
Hadron : 1.7 interaction length
→ Thin. Showers develop at deeper part

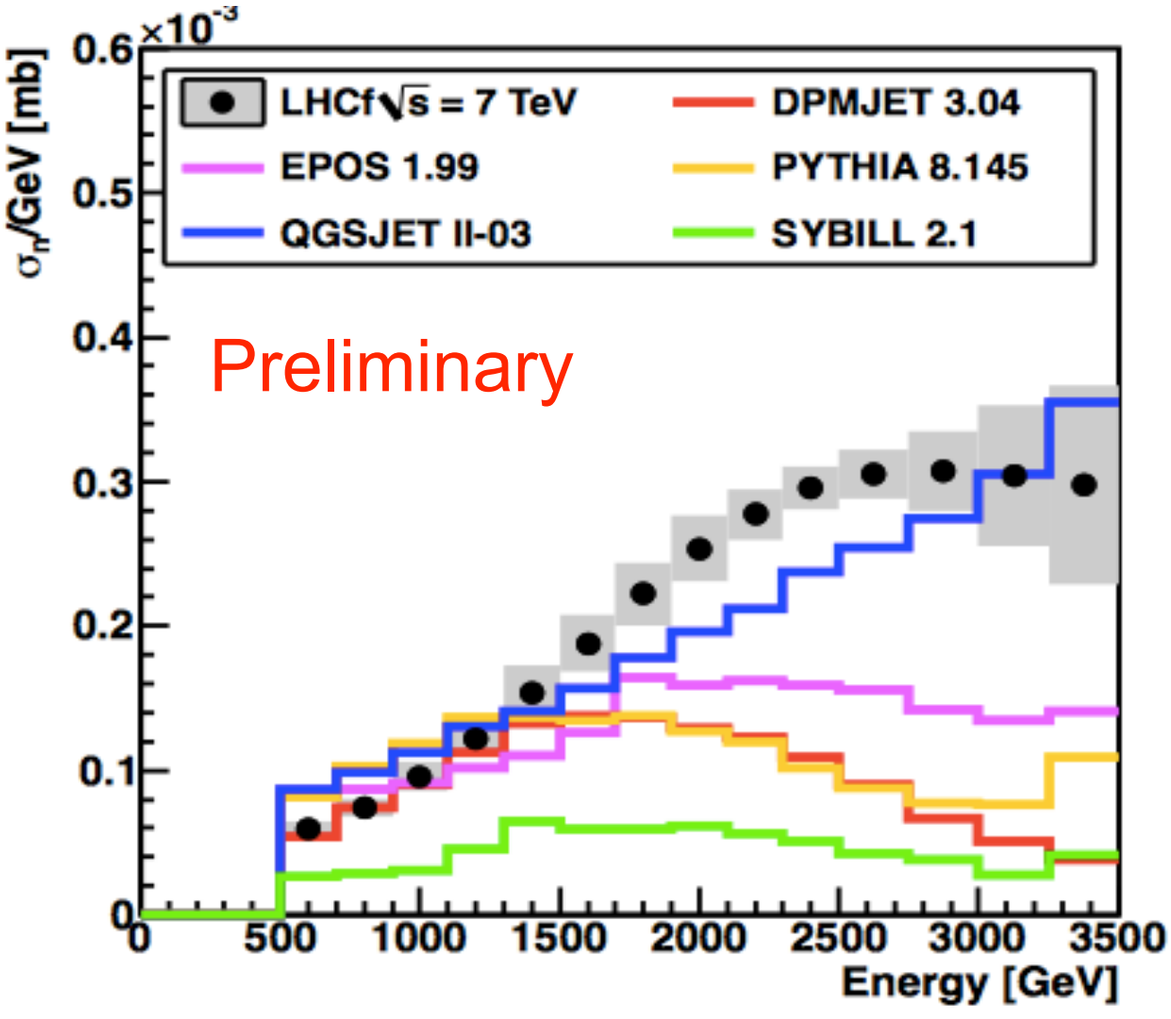


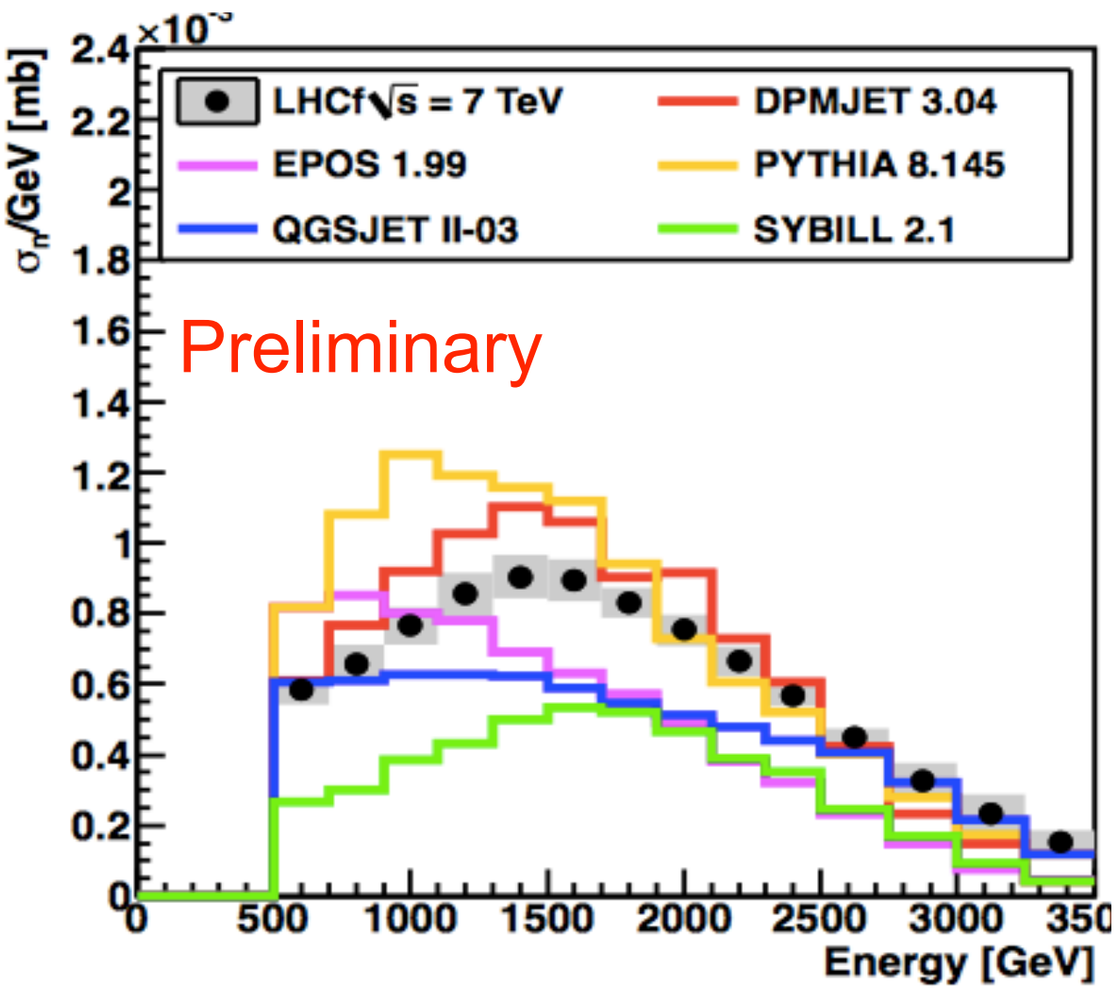


$L_{2D} = L_{90\%} - 0.25 * L_{20\%}$

Neutron results at p-p 7TeV

- In η>10.76 huge amount of neutron exists.
- Only QGSJET2 reproduces the LHCf result.
- In other rapidity regions,
  the LHCf results are enclosed by the variation of models.

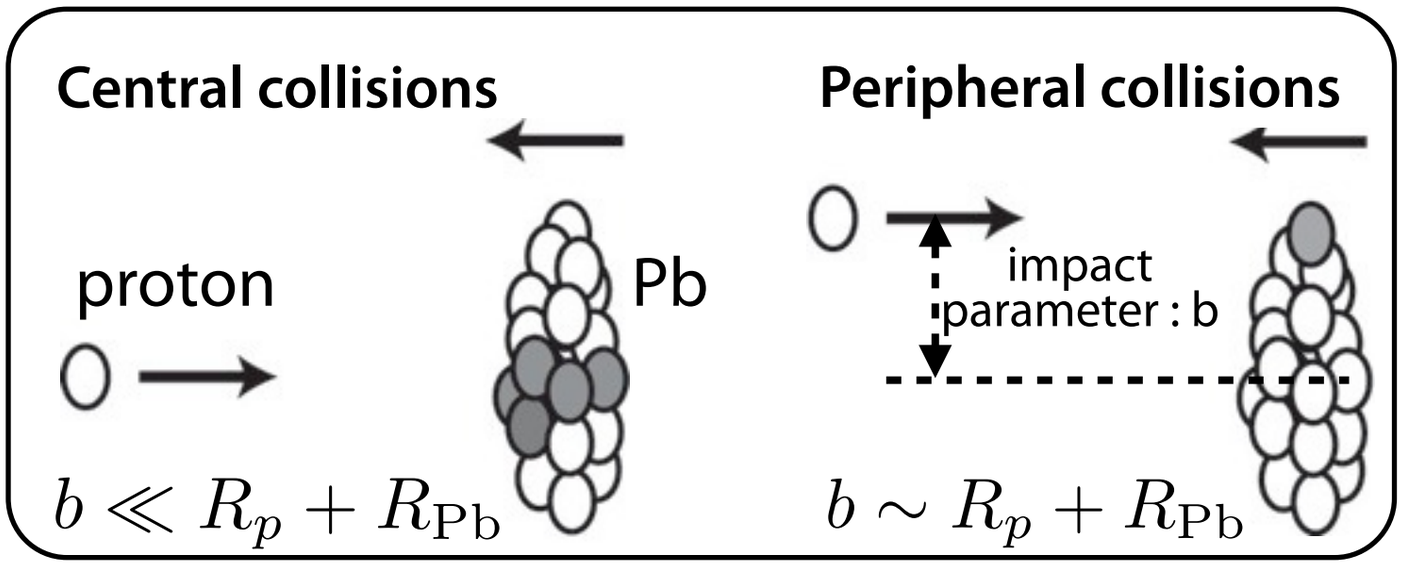


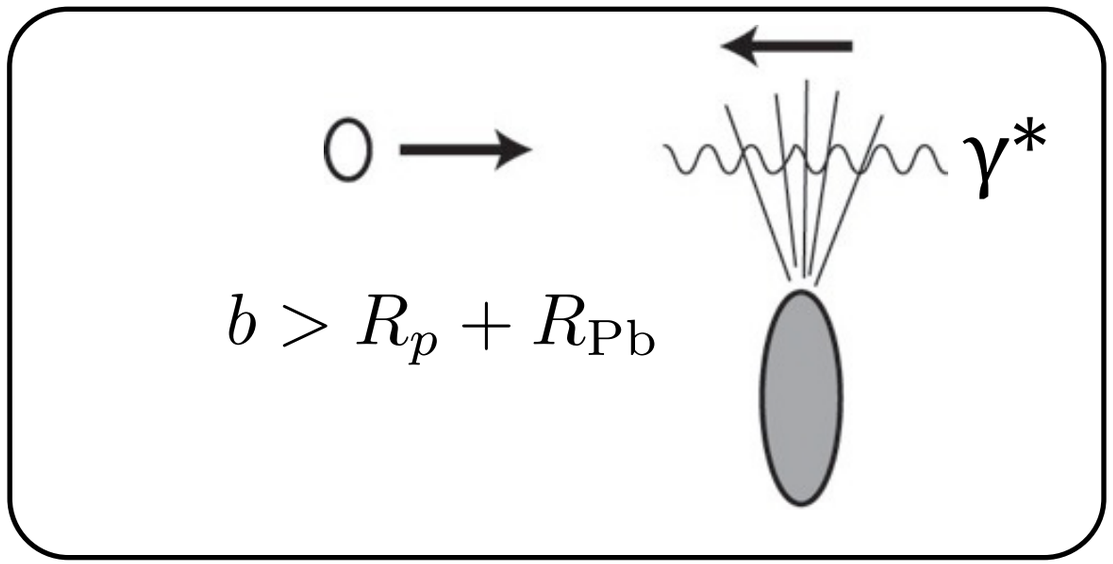


π^0 event analysis in p-Pb collisions

(Soft) QCD :
central and peripheral collisions

Ultra peripheral collisions :
virtual photon from rel. Pb collides a proton.





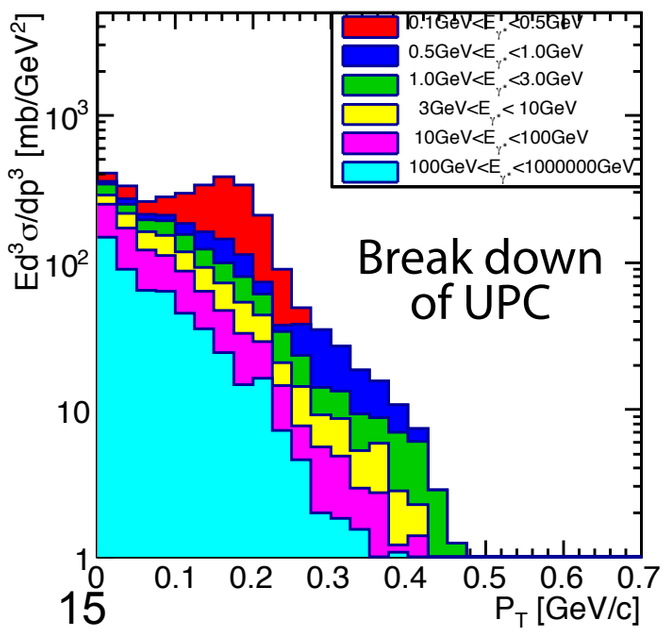
Momentum distribution of the UPC induced secondary particles is estimated as
1. energy distribution of virtual photons is estimated by the Weizsacker Williams approximation.
2. photon-proton collisions are simulated by the SOHIA model (E > pion threshold).
3. produced mesons and baryons by γ-p collisions are boosted along the proton beam.

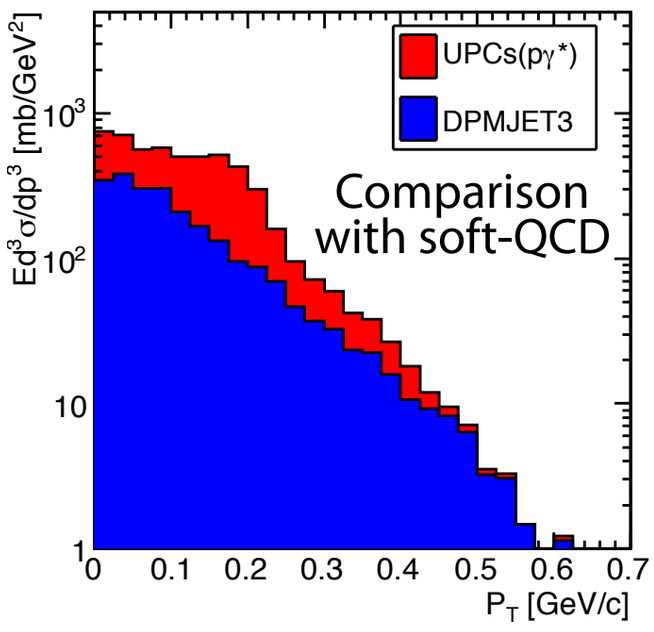
] proton rest frame

Dominant channel to forward π^0 is

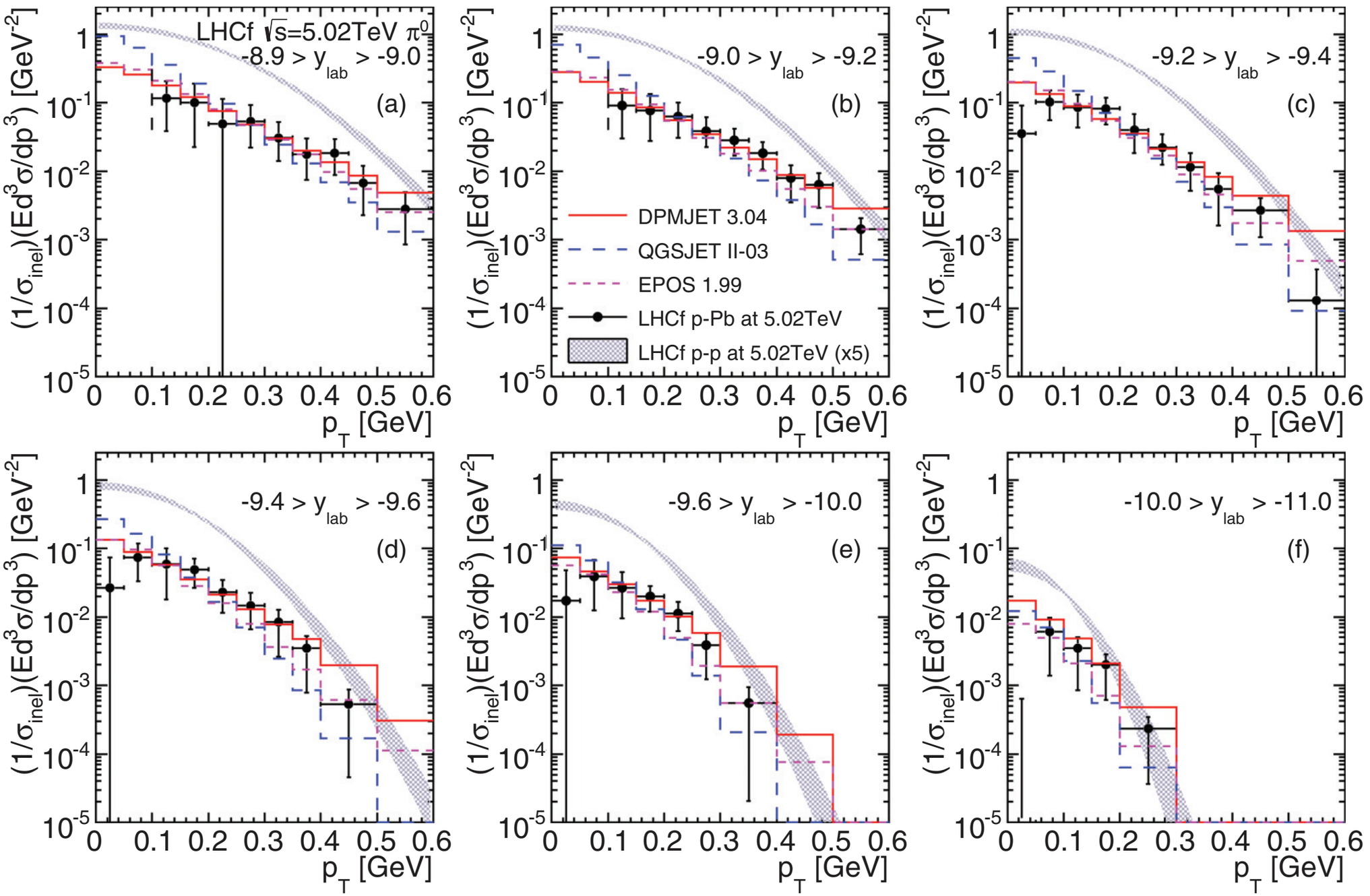
$$\gamma + p \rightarrow \Delta(1232) \rightarrow p + \pi^0$$

About half of the observed π^0 may originate in UPC, another half is from soft-QCD.



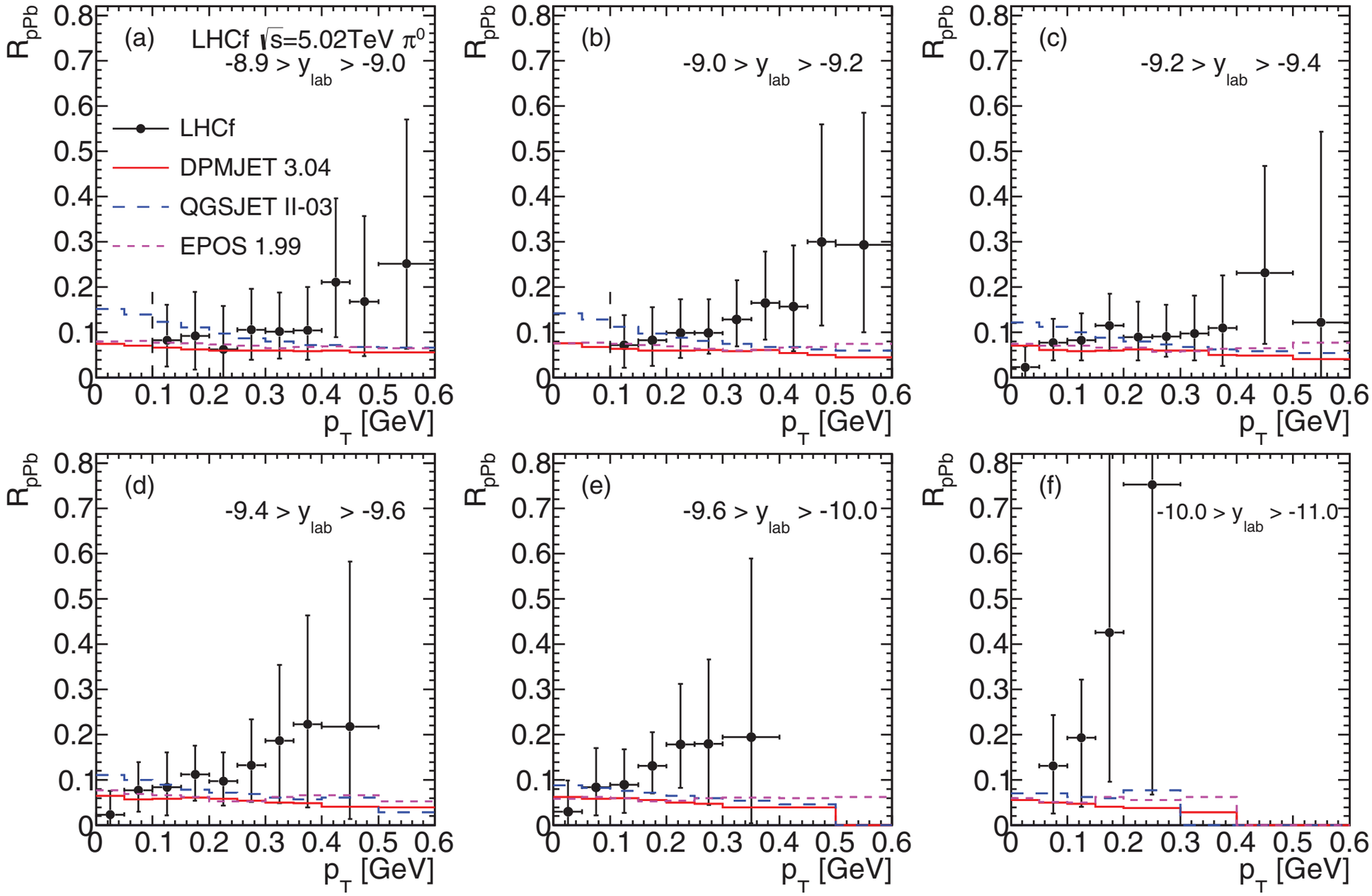


π^0 p_T spectra at p-Pb



- The LHCf results in p-Pb (filled circles) show good agreement with MC predictions.
- The LHCf results in p-Pb are clearly harder than the LHCf results in p-p at 5.02TeV (shaded area) which are interpolated from the results at 2.76TeV and 7TeV.

Nuclear modification factor



$$R_{\mathrm{pPb}}(p_{\mathrm{T}}) \equiv \frac{d^2 N_{\pi^0}^{\mathrm{pPb}}/dydp_{\mathrm{T}}}{\langle N_{\mathrm{coll}}\rangle d^2 N_{\pi^0}^{\mathrm{pp}}/dydp_{\mathrm{T}}}$$

$\langle N_{coll} \rangle = 6.9$

- Both LHCf and MCs show strong suppression.
- But LHCf grows as increasing p_T, understood by the softer p_T spectra in p-p at 5TeV than those in p-Pb.

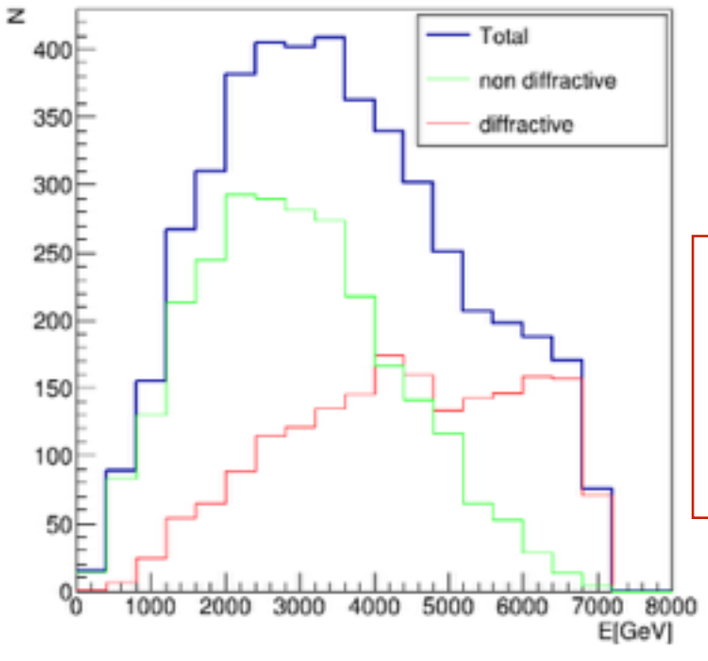
Future Operations

- **LHC p-p $\sqrt{s}$ = 13 TeV**
  - Operation for about 1 week in **May 2015** with low luminosity collisions.
    - **• Test of Energy scaling**
    - **• Enlarge the LHCf acceptance**
    - **• Measurement with Event Categorization**

thank to the common operation with ATLS

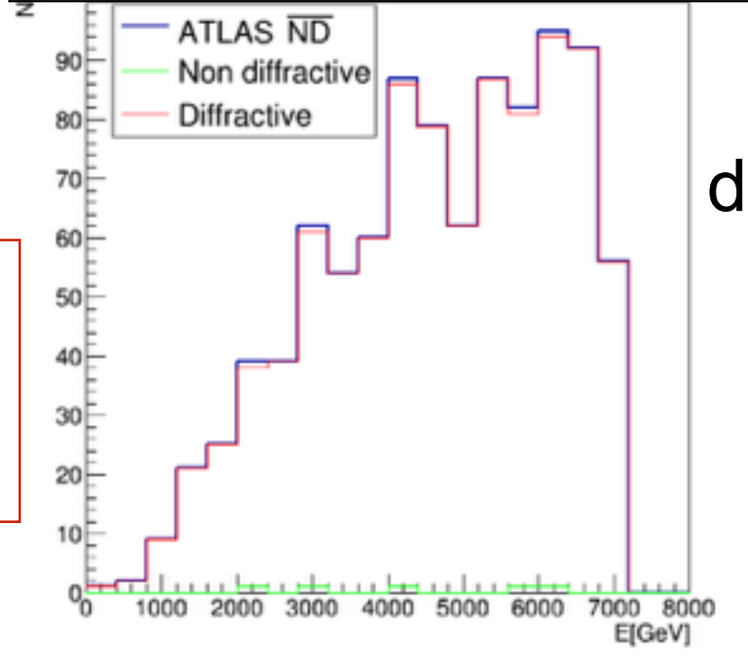
n @ Arm1-TS

All Events



0 charged particle with > 100MeV/c in $|\eta| < 2.5$

w/ Event selection by ATLS



99% Pure diffractive events with ~40% eff.

Future Operations

- **LHC p-p $\sqrt{s}$ = 13 TeV**
  - Operation for about 1 week in **May 2015** with low luminosity collisions.
    - **Test of Energy scaling**
    - **Enlarge the LHCf acceptance**
    - **Measurement with Event Categorization thank to the common operation with ATLS**
- **Operation at RHIC, p-p $\sqrt{s}$ = 0.5 TeV**
  - Bring LHCf detectors to RHIC
    Proposing to the committee
    - **Test of interaction at lower energy**

Future Operations

- **LHC p-p $\sqrt{s}$ = 13 TeV**
  - Operation for about 1 week in **May 2015** with low luminosity collisions.
    - **Test of Energy scaling**
    - **Enlarge the LHCf acceptance**
    - **Measurement with Event Categorization**

      thank to the common operation with ATLS
- **Operation at RHIC, p-p $\sqrt{s}$ = 0.5 TeV**
  - Bring LHCf detectors to RHIC
    Proposing to the committee
    - **Test of interaction at lower energy**
- **p-light A collisions**
  - Under discussion

  → **• Simulate CR-Air collisions at LHC !!**

Summary

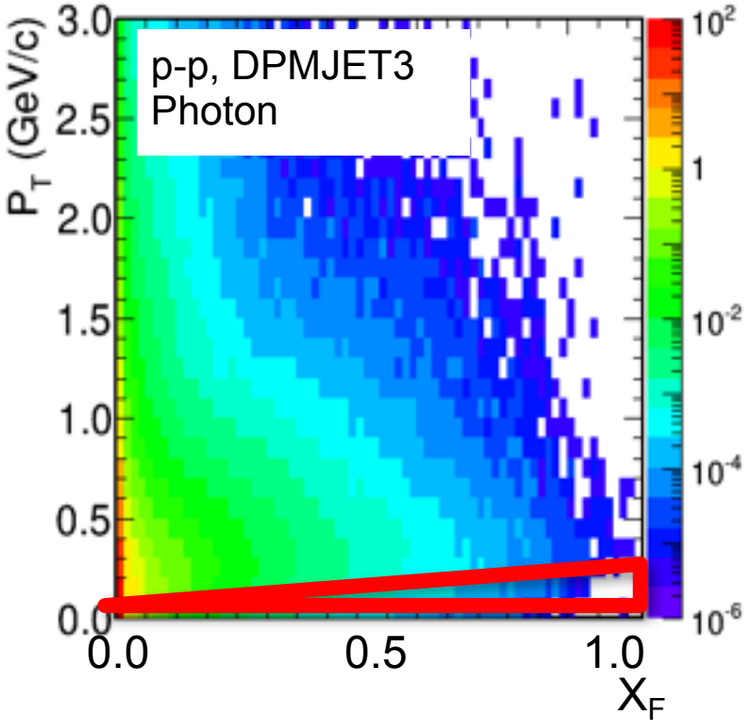
- LHCf is a forward experiment at LHC and had operations at p-p with $\sqrt{s}$=0.9,7 TeV and with p-Pb at $\sqrt{s_{NN}}$=5 TeV.
- The data of EM components (photon and neutral pions) at the forward region at p-p collisions seems to be reproduced by EPOS model well however Neutron data was well consistent with the prediction of QGSJET II-03.
- LHCf measured the nuclear factor of 0.1 at for forward neutral pions. The small factor is well reproduced by the interaction models.
- LHCf provides the critical data for testing interaction models.

Backup

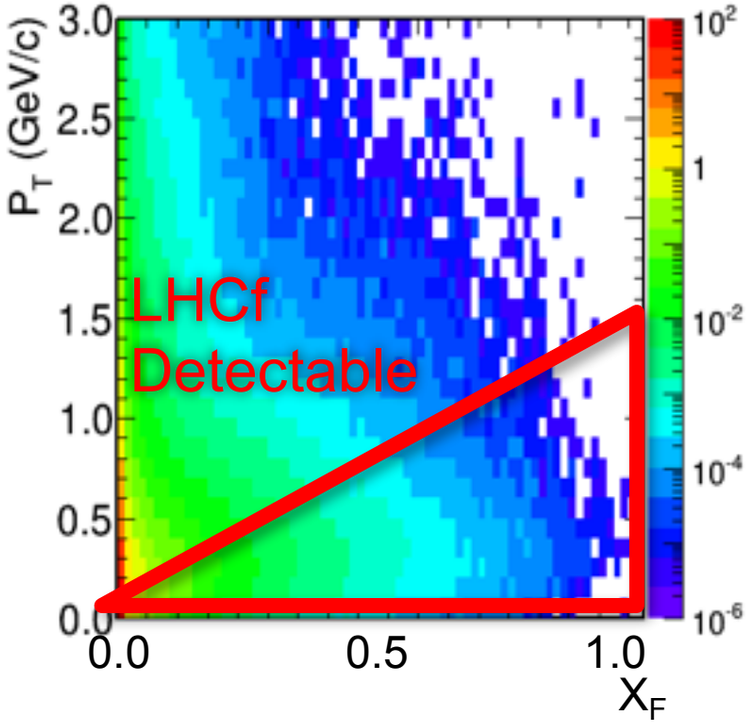
Future Operations

- **LHC p-p $\sqrt{s}$ = 13 TeV**
  - Operation for about 1 week in **May 2015** with low luminosity collisions.
    - **Test of Energy scaling**
    - **Enlarge the LHCf acceptance**

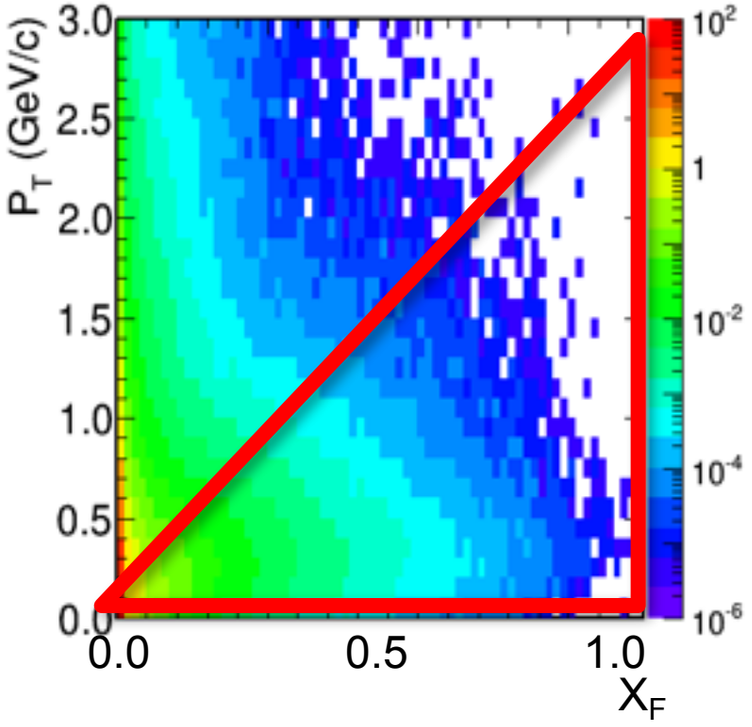
$\sqrt{s}$=900GeV



$\sqrt{s}$=7TeV

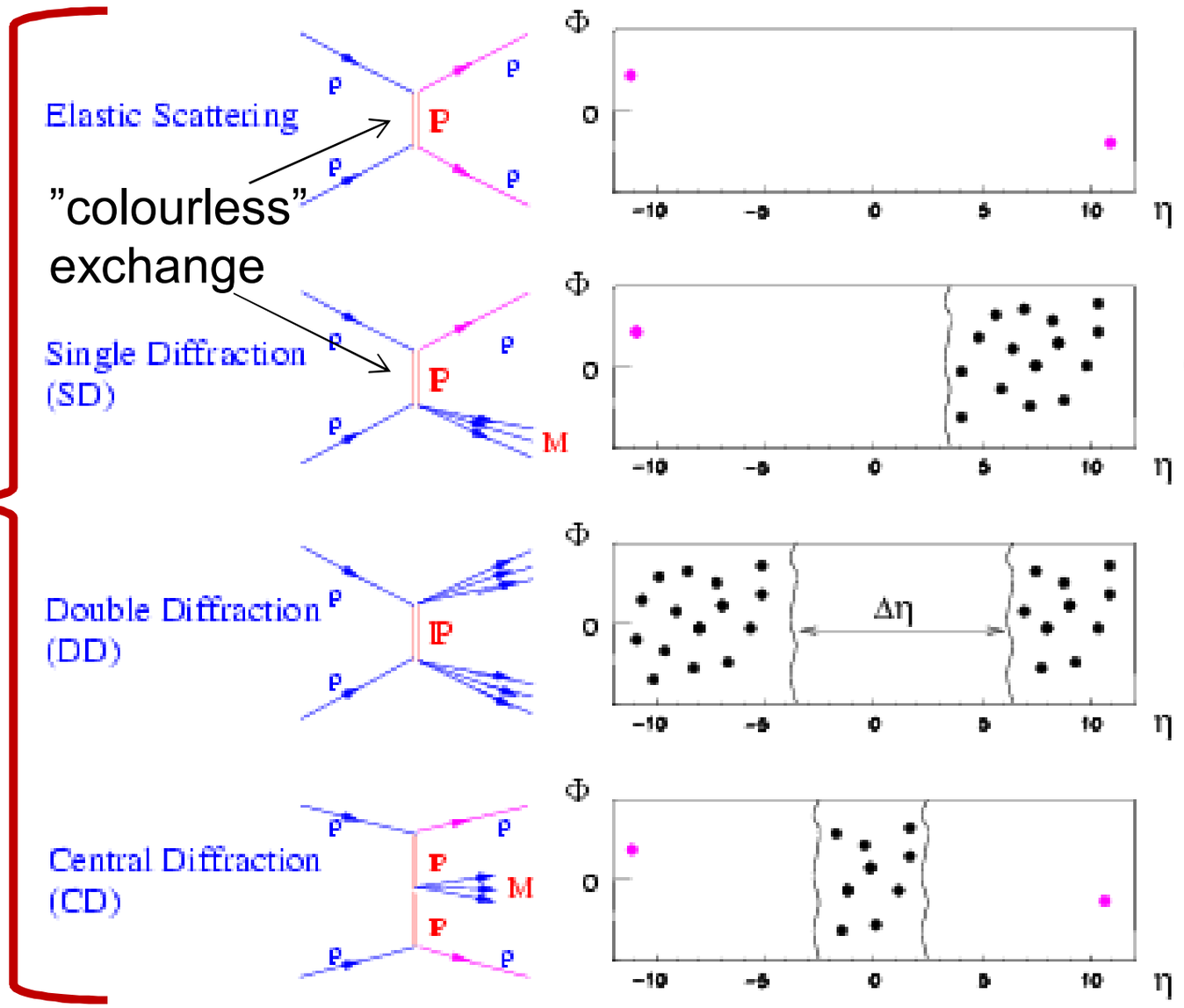


$\sqrt{s}$=13TeV



Soft pp processes

Diffraction a large fraction of total pp cross-section !!



σ @ LHC

~25 mb

~10 mb

~5 mb

~1 mb

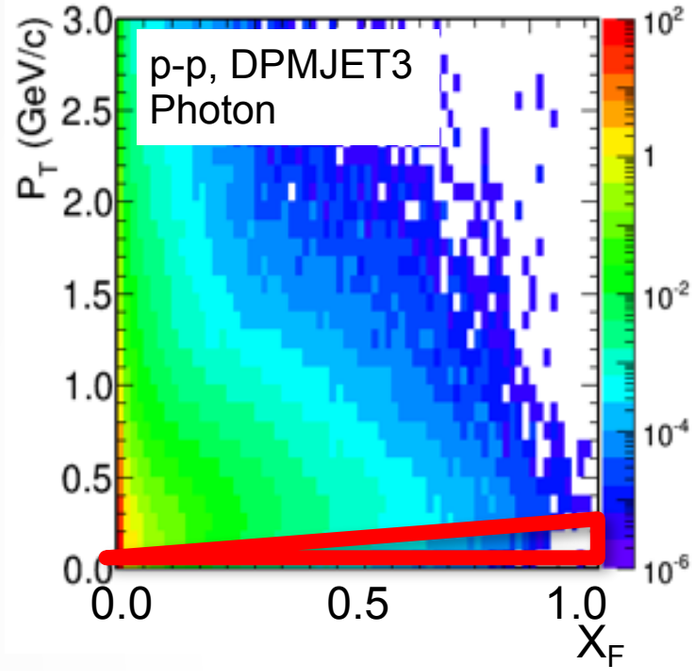
~60 mb

Measure $\sigma_{tot}(M,\xi,t)$

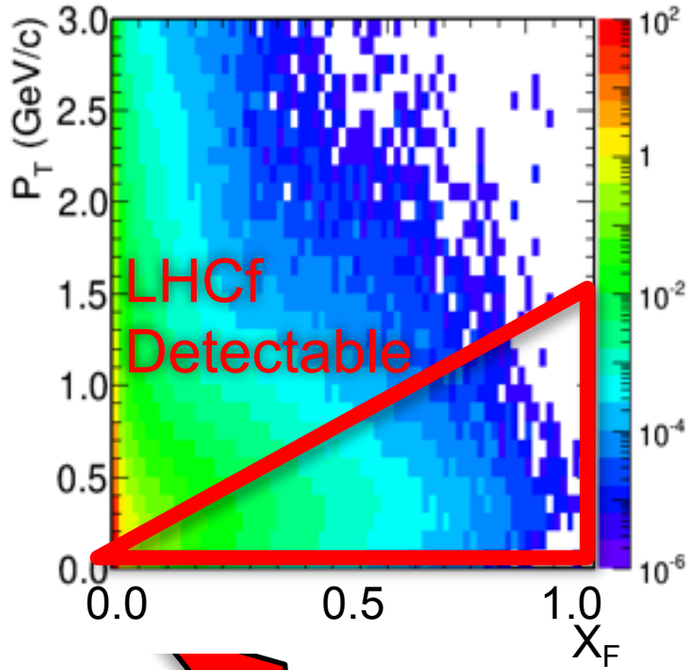
Energy Scan at LHC and RHIC

@LHC η>8.4

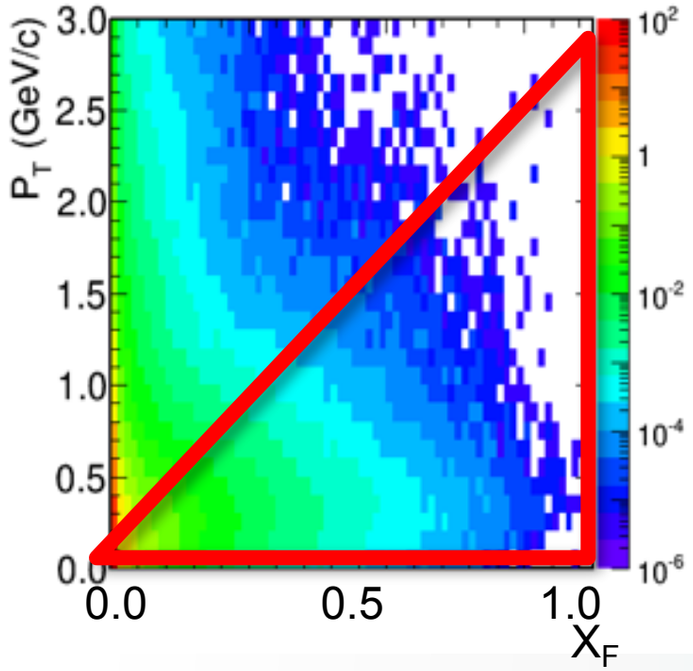
√s=900GeV



√s=7TeV

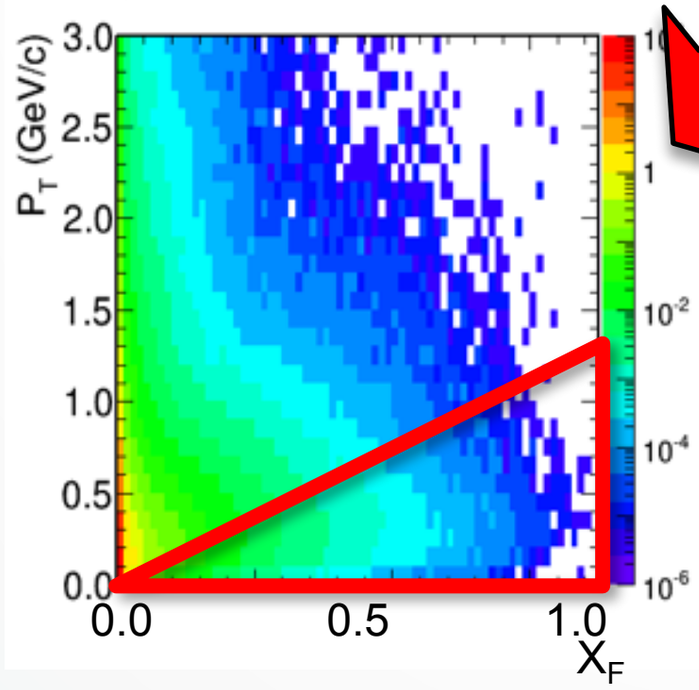


√s=13TeV

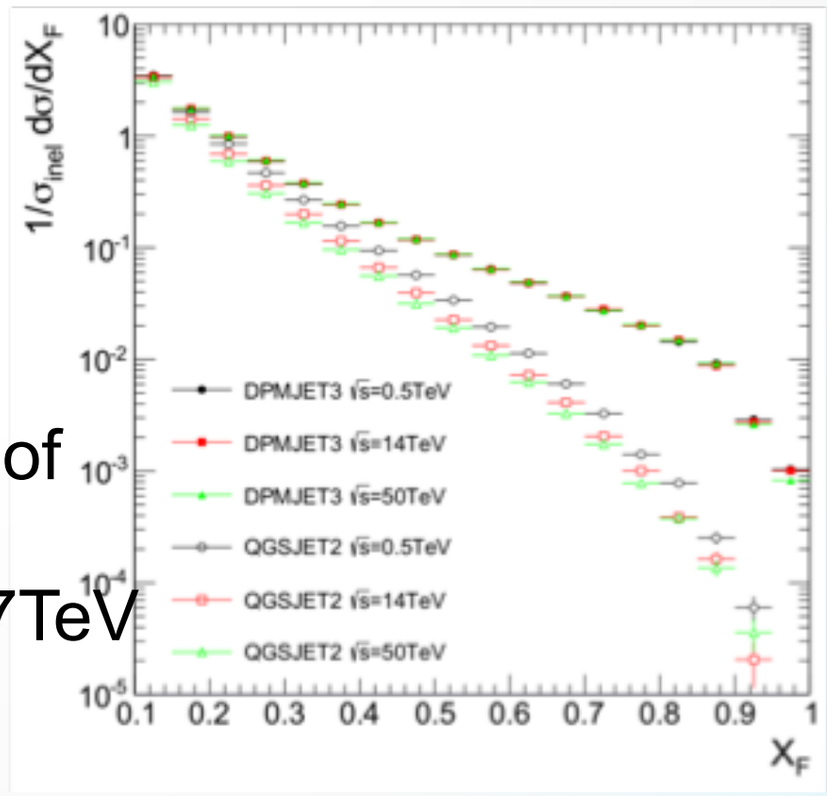


@RHIC η>6

√s=500GeV

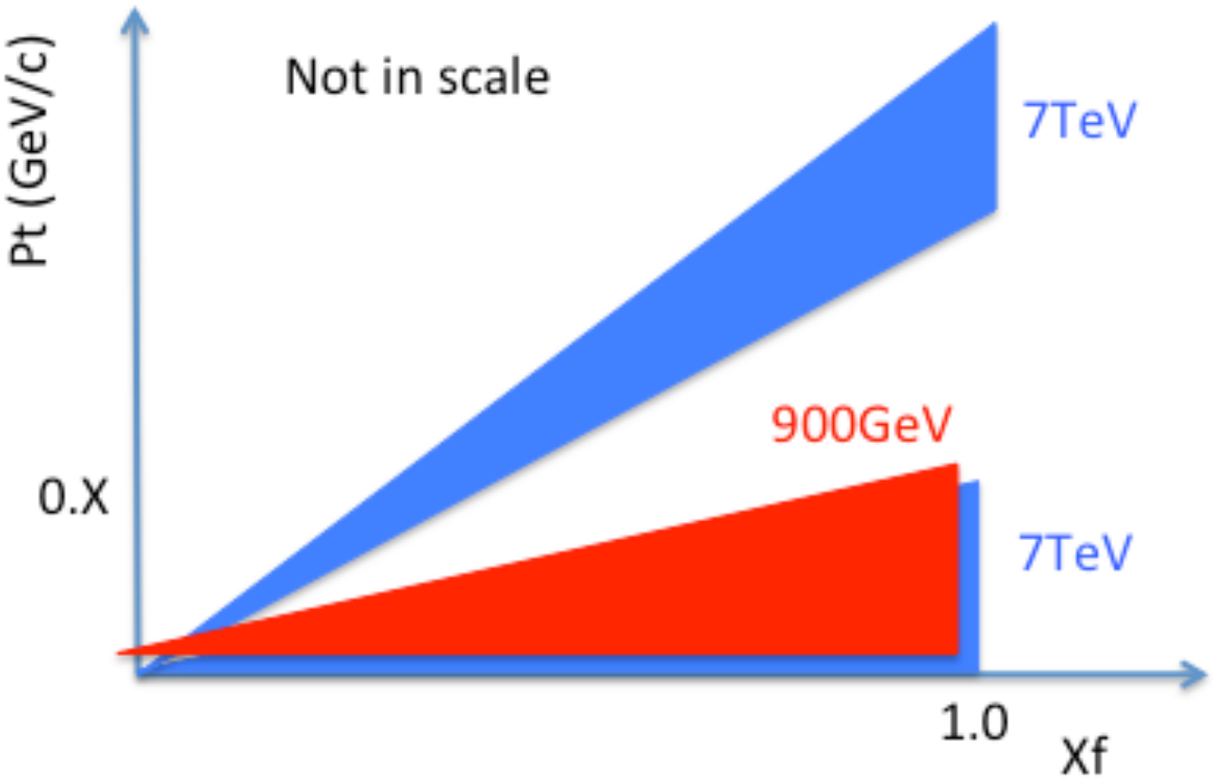


Comparison of
π^0 spectra
at 0.5TeV and 7TeV

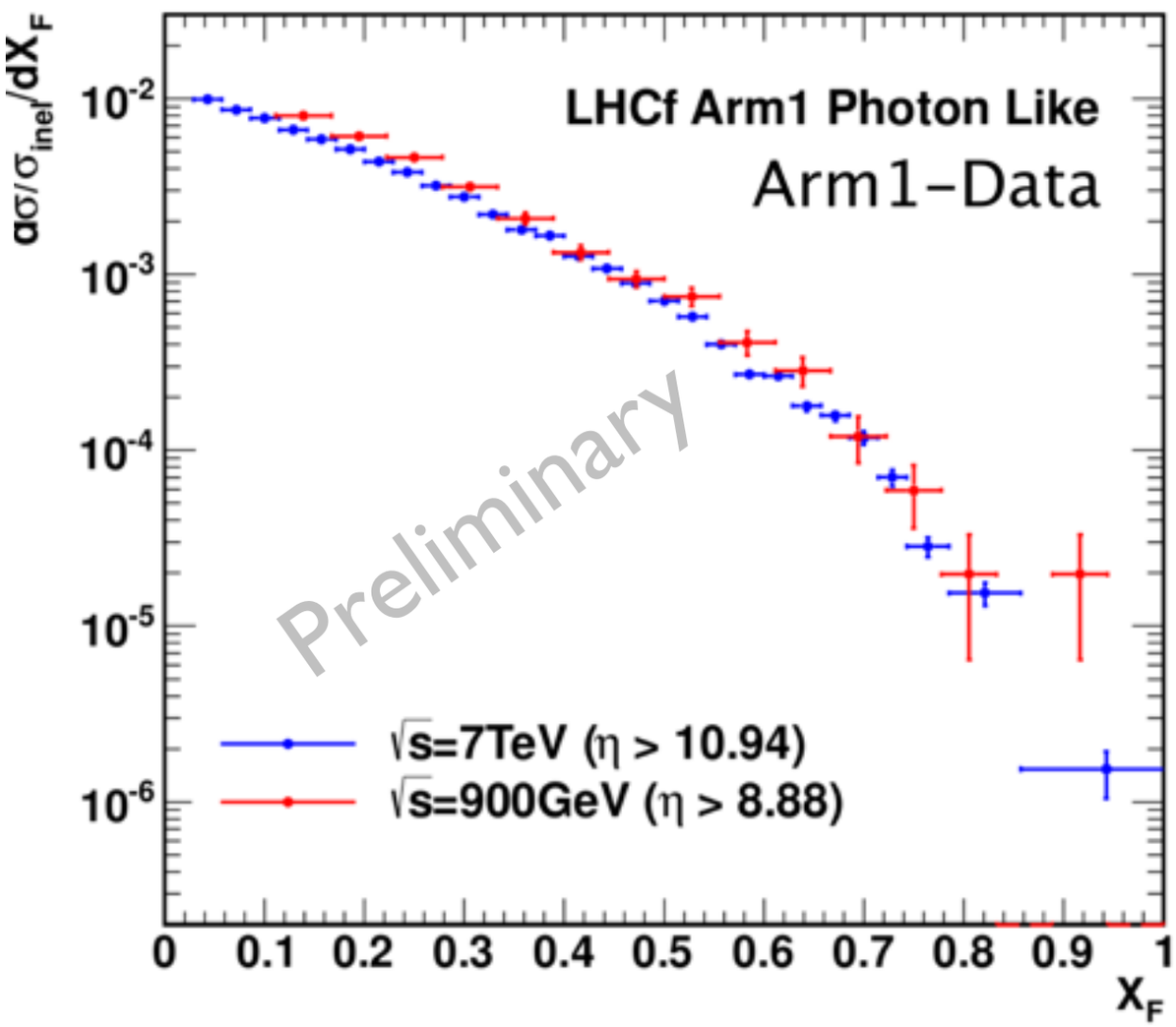


Photons at 900GeV p-p

Coverage of 900GeV and 7TeV results in Feynman-X and P_T



X_F spectra : 900 GeV data vs. 7 TeV data

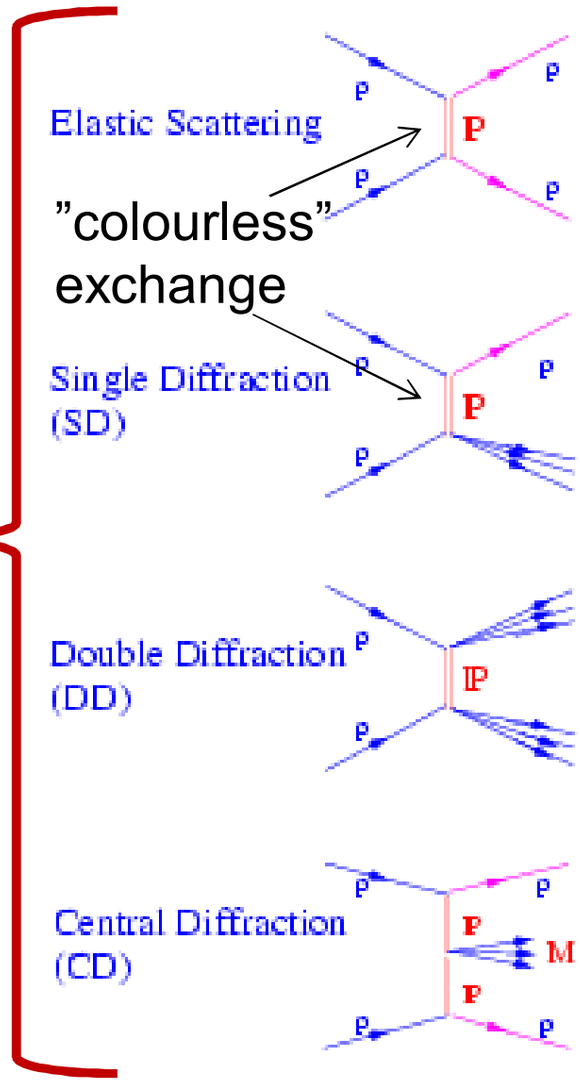


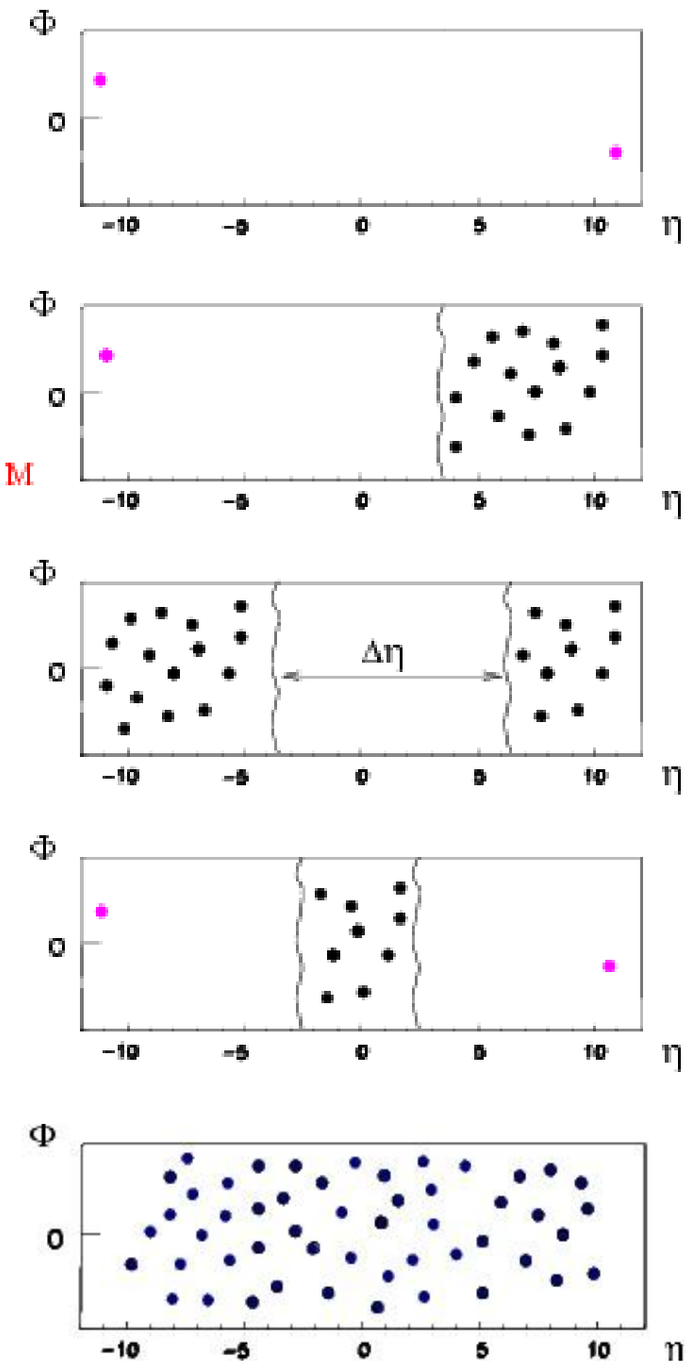
Good agreement of X_F spectrum shape between 900 GeV and 7TeV.
➔weak dependence of $<p_T>$ on E_{CMS}

Note : No systematic error is considered in both collision energies yet. 21% of the luminosity determination error allows vertical shift.

Soft pp processes

Diffraction a large fraction of total pp cross-section !!





σ @ LHC

~25 mb

~10 mb

~5 mb

~1 mb

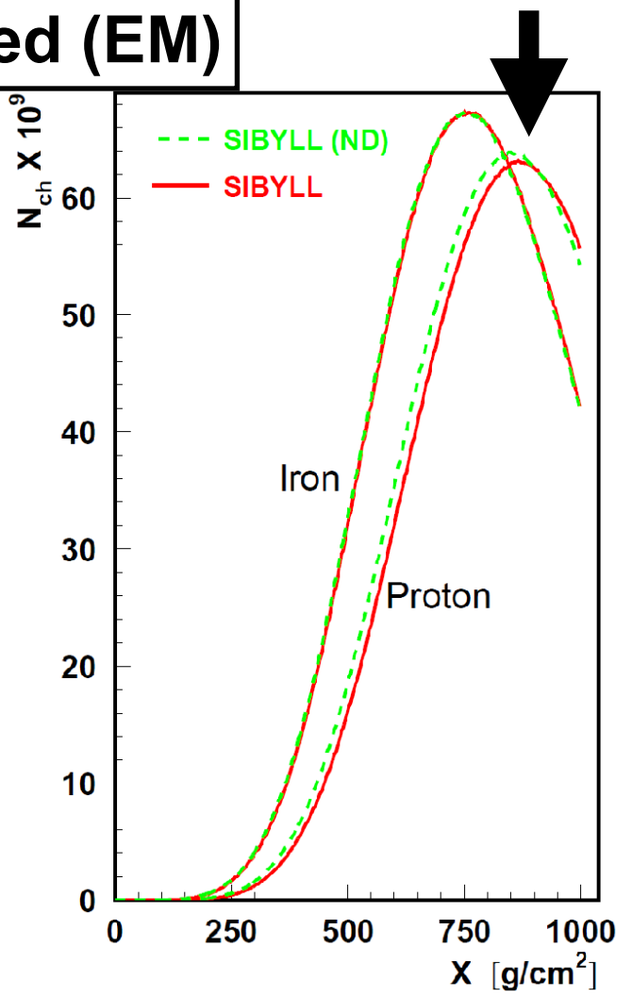
~60 mb

Measure σ (M,ξ,t)

Diffraction @ CR-AS

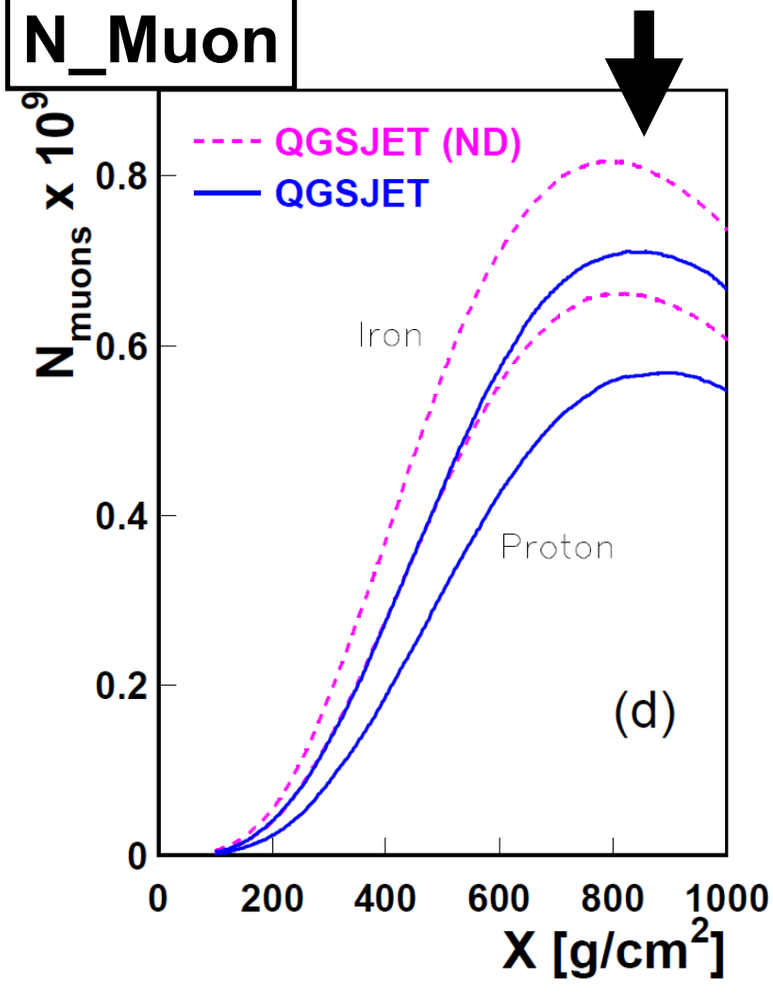
Small difference ΔX_{max}~ 2%

N_Charged (EM)



Large difference of flux ~15%

N_Muon



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- Cross section fraction differs largely in models (~10^11eV → 10^20eV)
  - Sibyll: 12% → 1%
  - QGSJet 13% → 16%
  - DPMJet 1% → 5% (but rising at mid energies)

C.Baus @ Seminar in Nagoya

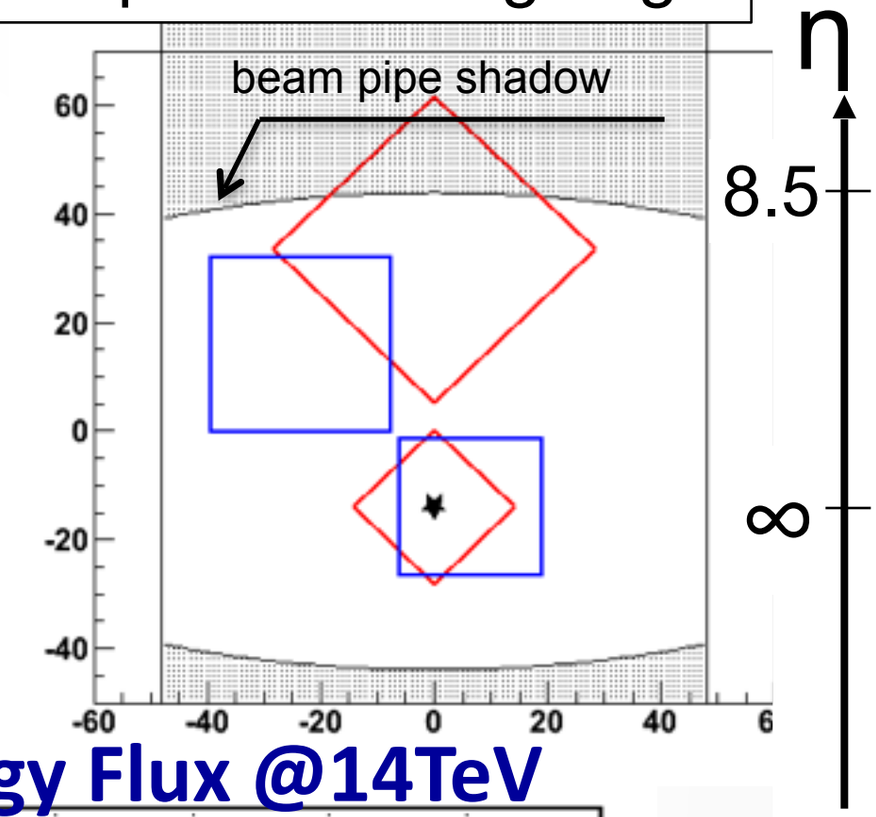
LHCf can measure

Energy spectra and
Transverse momentum distbution of

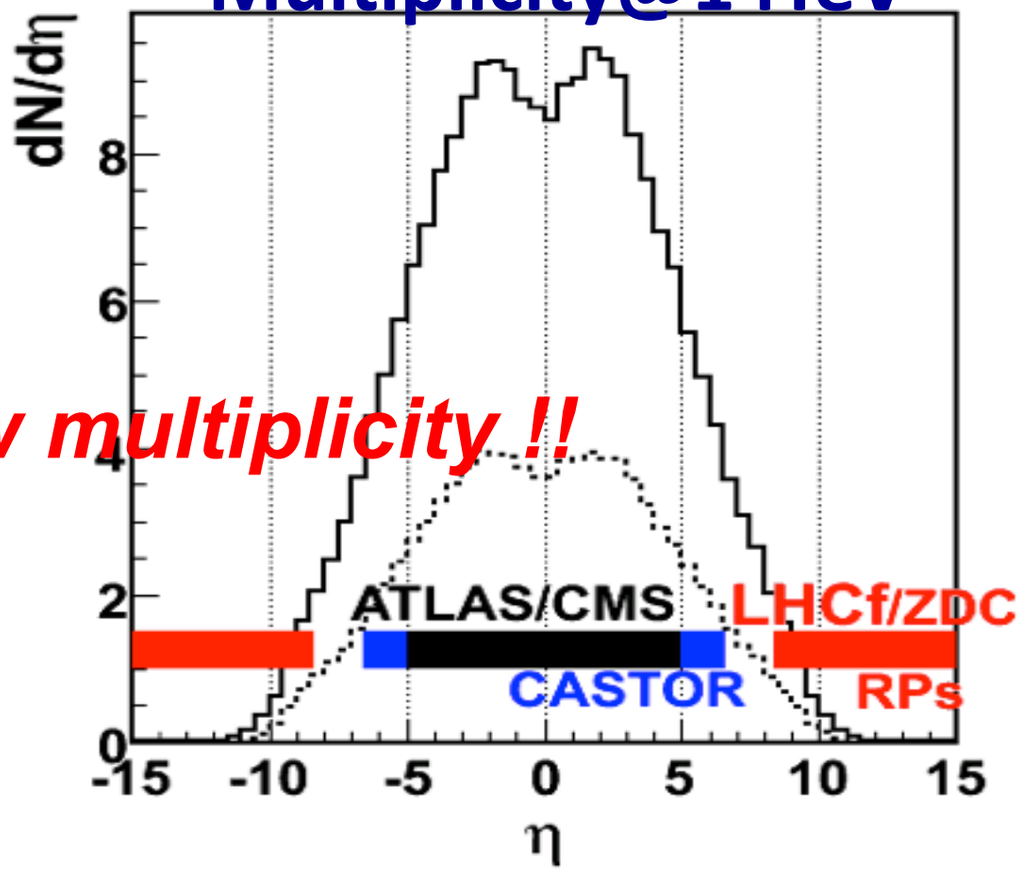
- **Gamma-rays (E>100GeV,dE/E<5%)**
- **Neutral Hadrons (E>a few 100 GeV, dE/E~30%)**
- **π^0 (E>600GeV, dE/E<3%)**

at pseudo-rapidity range >8.4

Front view of calorimeters
@ 100μrad crossing angle

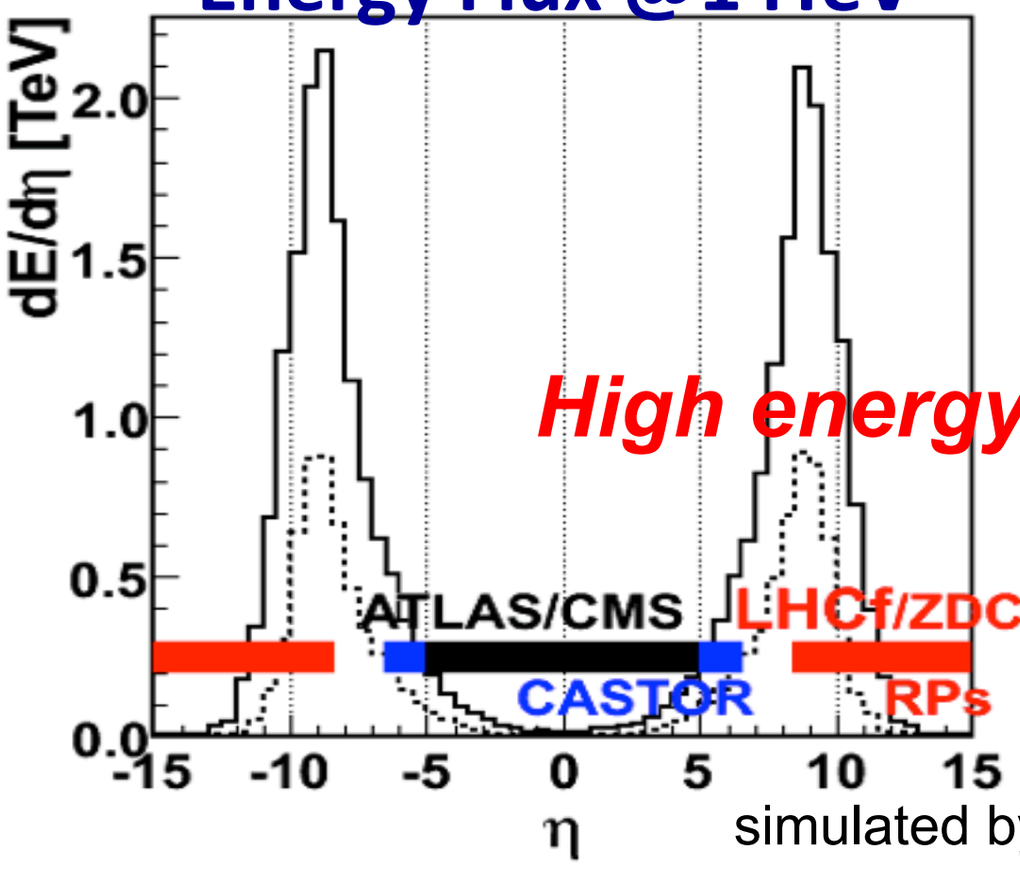


Multiplicity@14TeV



Low multiplicity !!

Energy Flux @14TeV



High energy flux !!

simulated by DPMJET3