LHCf results and prospects

Takashi SAKO
(STE Lab/KMI, Nagoya University)
for the LHCf Collaboration

The LHCf Collaboration

[*,]Y.Itow, [*]K.Kawade, [*]Y.Makino, [*]K.Masuda, [*]Y.Matsubara, [*]E.Matsubayashi, [**]H.Menjo, [*]Y.Muraki, [*,**]T.Sako, [*]N.Sakurai, [*]Y.Sugiura, [*]Q.D.Zhou**

[*]Solar-Terrestrial Environment Laboratory, Nagoya University, Japan
[**]Kobayashi-Maskawa Institute, Nagoya University, Japan
[***]Graduate School of Science, Nagoya University, Japan

K.Yoshida — *Shibaura Institute of Technology, Japan*

K.Kasahara, Y.Shimizu, T.Suzuki, S.Torii — *Waseda University, Japan*

T.Tamura — *Kanagawa University, Japan*

M.Haguenauer — *Ecole Polytechnique, France*

W.C.Turner — *LBNL, Berkeley, USA*

O.Adriani, E.Berti, L.Bonechi, M.Bongi, G.Castellini, R.D'Alessandro, M.Delprete, M.Grandi, G.Mitsuka, P.Papini, S.Ricciarini, A.Tiberio — *INFN, Univ. di Firenze, Italy*

A.Tricomi — *INFN, Univ. di Catania, Italy*

J.Velasco, A.Faus — *IFIC, Centro Mixto CSIC-UVEG, Spain*

A-L.Perrot — *CERN, Switzerland*

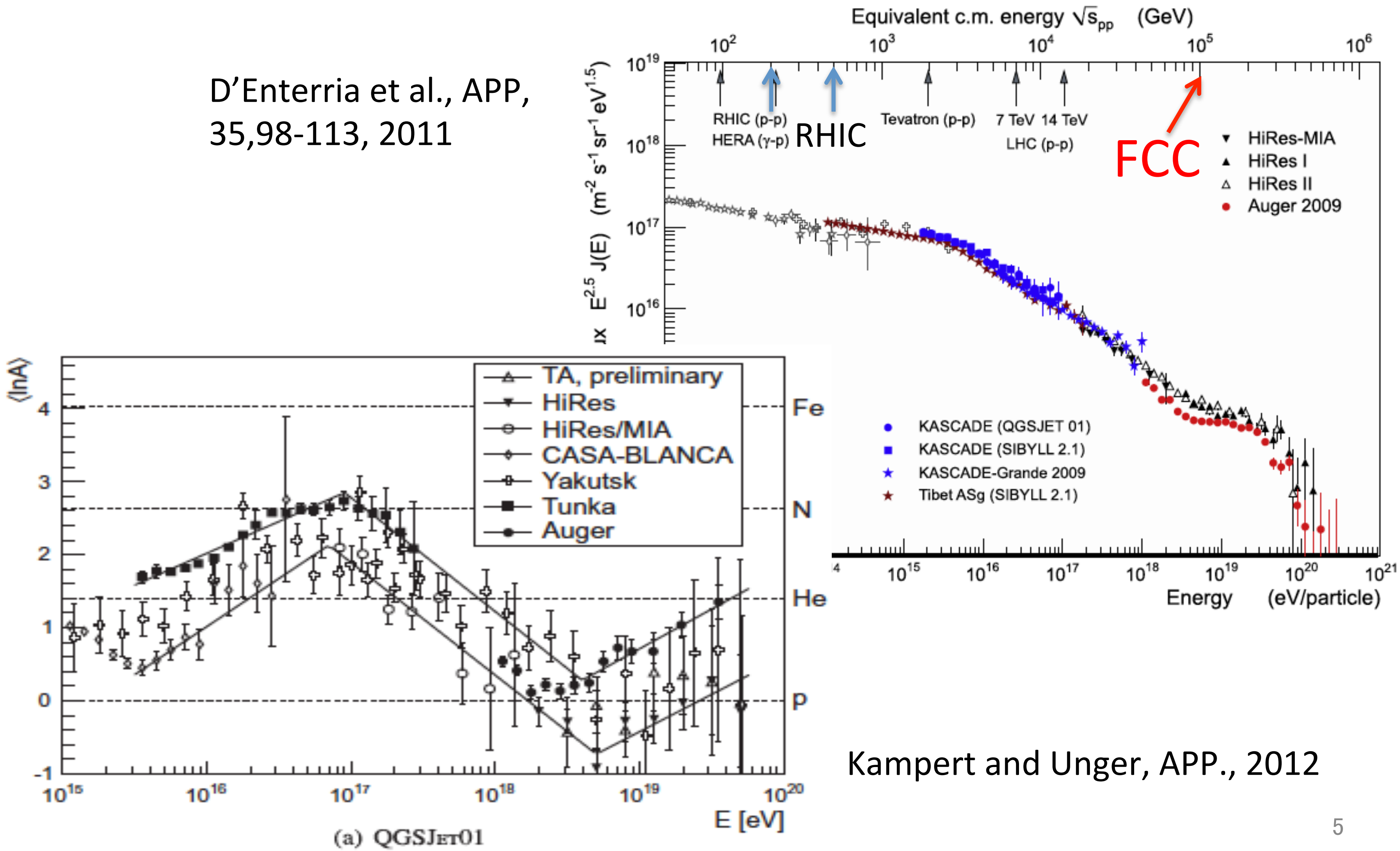
Outline

- ✓ Physics Motivation of LHCf - cosmic-ray physics -
- ✓ Experimental Setup
- ✓ Results
  - – photons at 900GeV, 7TeV pp
  - – neutral pions at 7TeV pp
  - – neutrons at 7TeV pp
  - – neutral pions at 5TeV pPb vs. pp
- ✓ Plans
  - – LHC Run2
  - – Etc.

Physics Motivation of LHCf

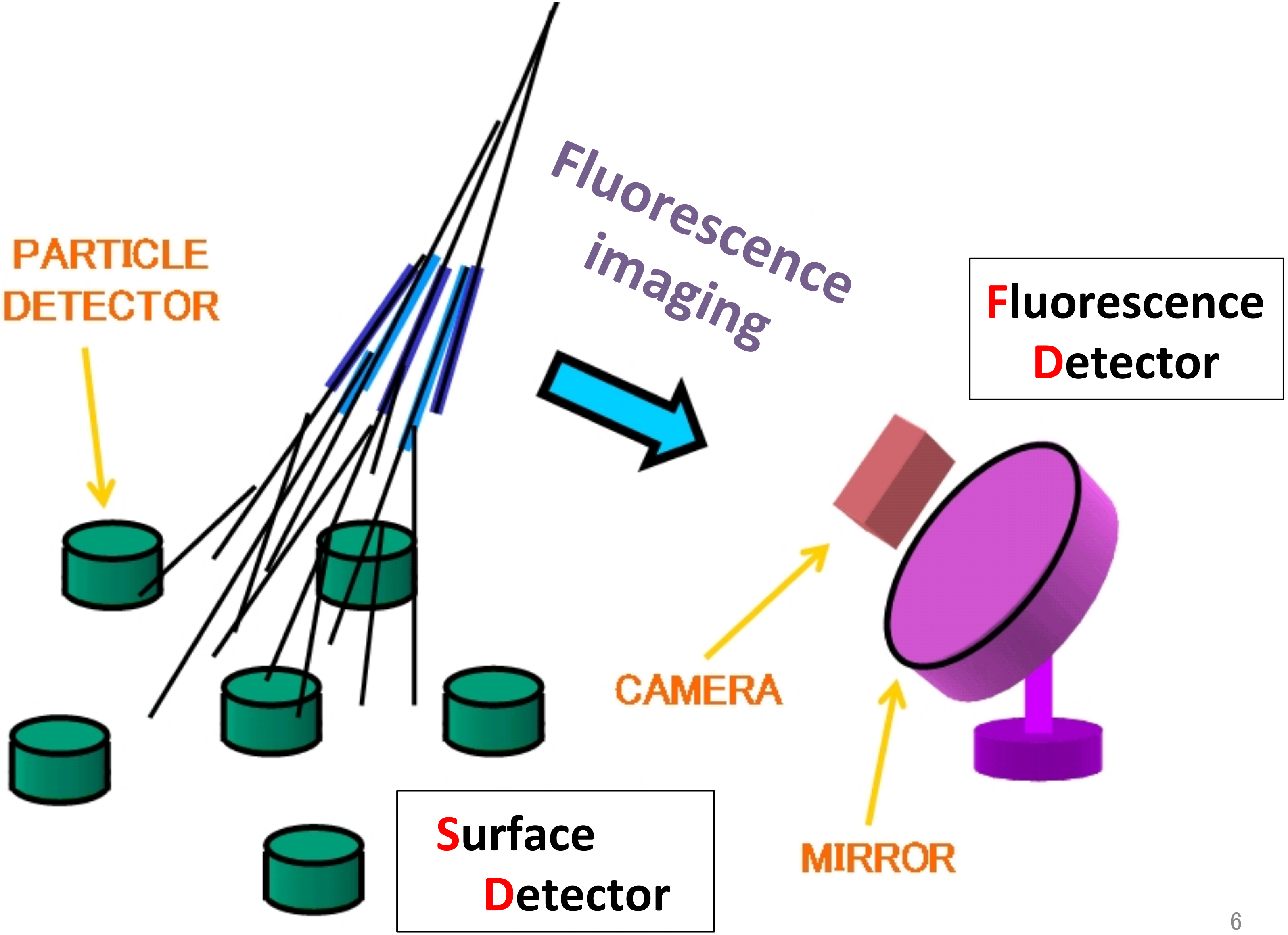
Recent progress on UHECR observation

D'Enterria et al., APP, 35,98-113, 2011



Kampert and Unger, APP., 2012

Observation of UHECRs



Problems in the CR data interpretation

Interpretation of AS observations needs help of MC simulation – hadronic interaction model

=> model-originated uncertainty or even discrepancy

✓ Energy

- $E_{SD} > E_{FD}$: discrepancy
- missing energy (μ,ν) in FD : uncertainty

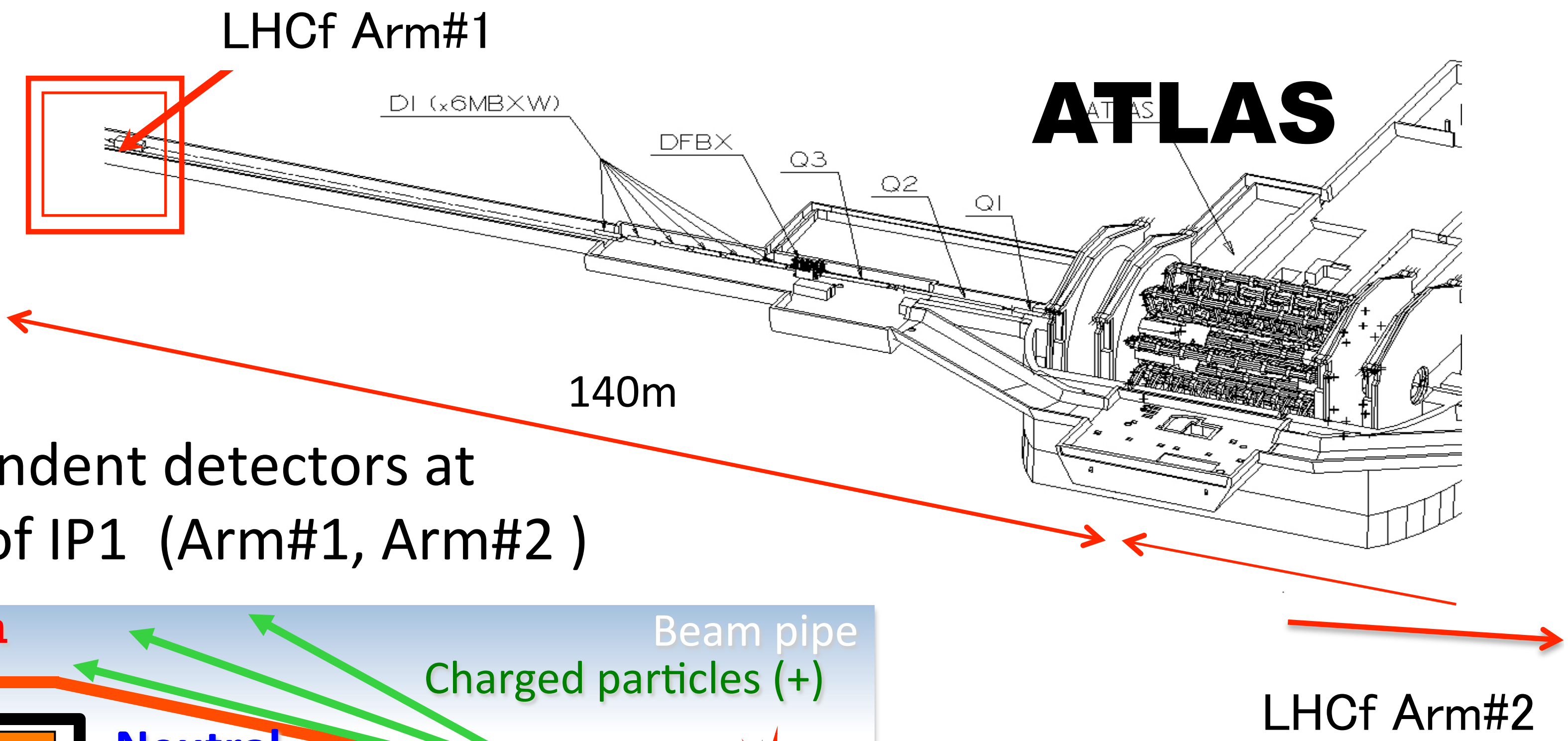
✓ Mass

- Mass vs. X_{max} in FD: uncertainty
- Mass vs. e/μ or μ excess in SD : discrepancy

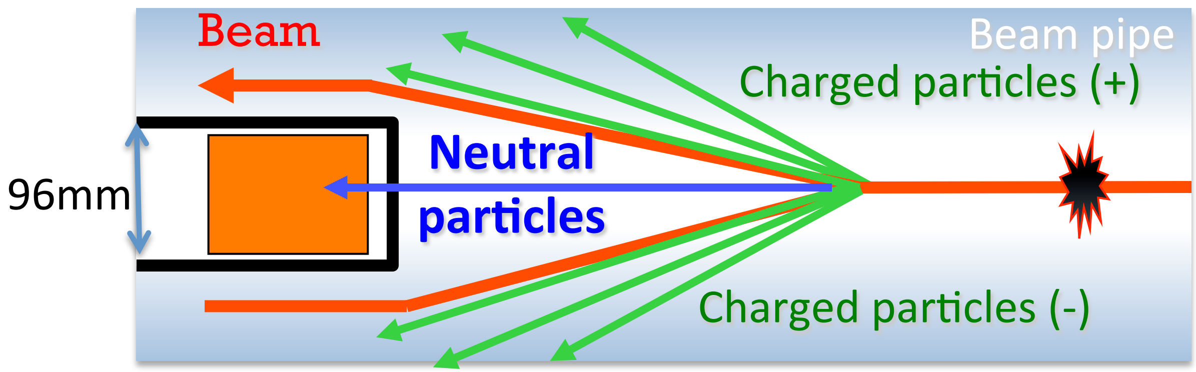
It is evident that our knowledge of hadronic interaction relevant to CR is missing something

Experimental Setup

The LHC forward experiment



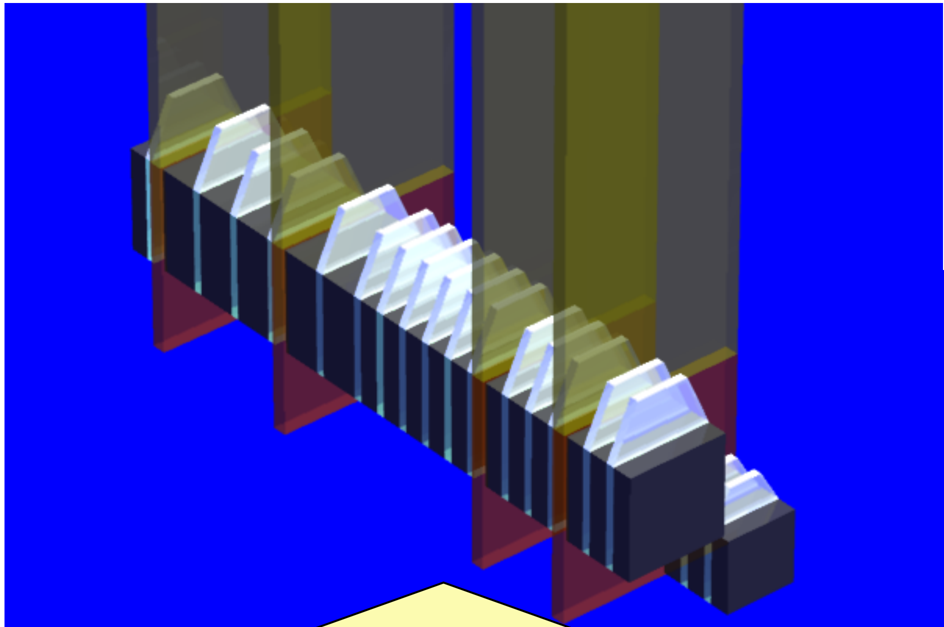
Two independent detectors at either side of IP1 (Arm#1, Arm#2)



- ✓ All charged particles are swept by dipole magnet
- ✓ Neutral particles (photons and neutrons) arrive at LHCf
- ✓ $\eta > 8.4$ (to infinity) is covered

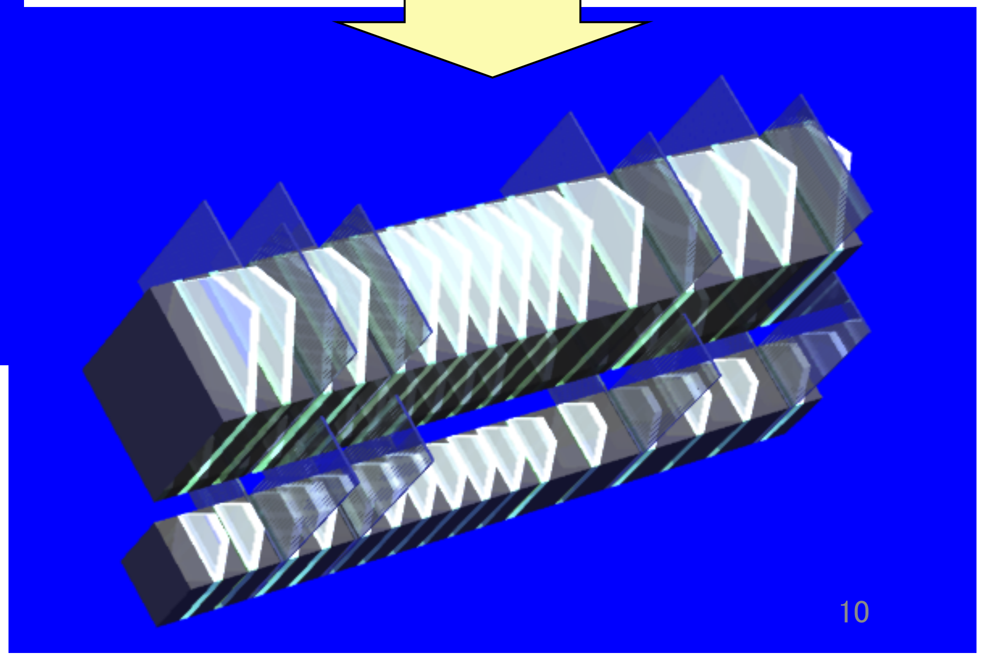
LHCf Detectors

- ✓ Imaging sampling shower calorimeters
- ✓ Two calorimeter towers in each of Arm1 and Arm2
- ✓ Each tower has 44 r.l. of Tungsten,16 sampling scintillator and 4 position sensitive layers

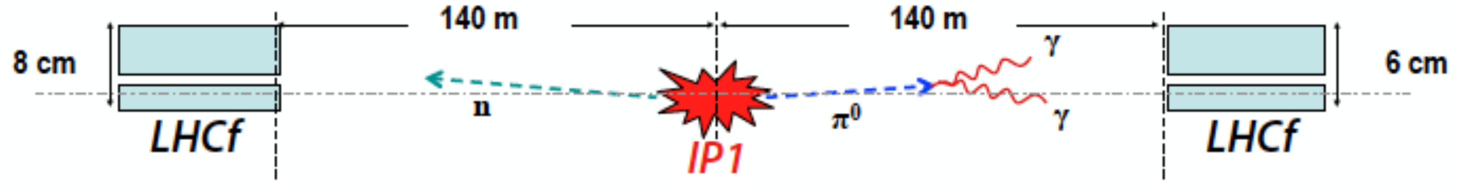


Arm#2 Detector
25mmx25mm+32mmx32mm
4 XY Silicon strip detectors

Arm#1 Detector
20mmx20mm+40mmx40mm
4 XY SciFi+MAPMT

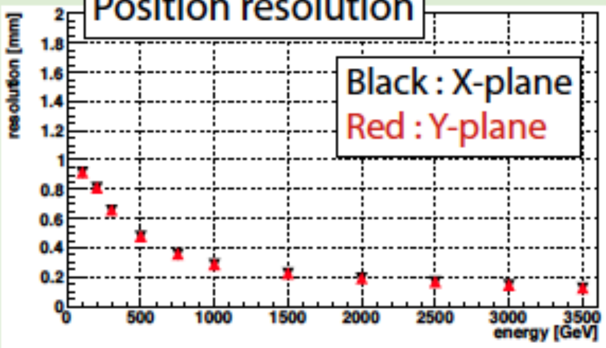


Detector performance

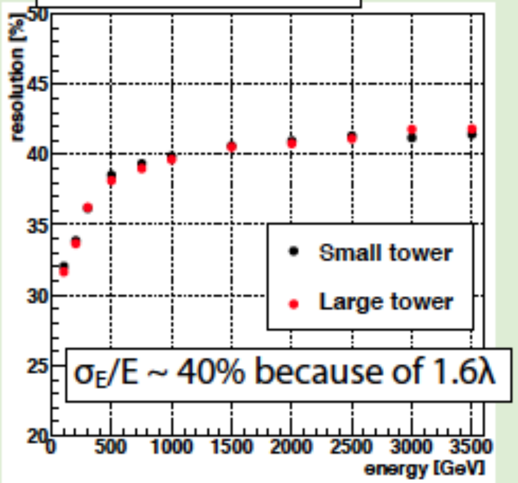


Hadronic shower (MC)

Position resolution



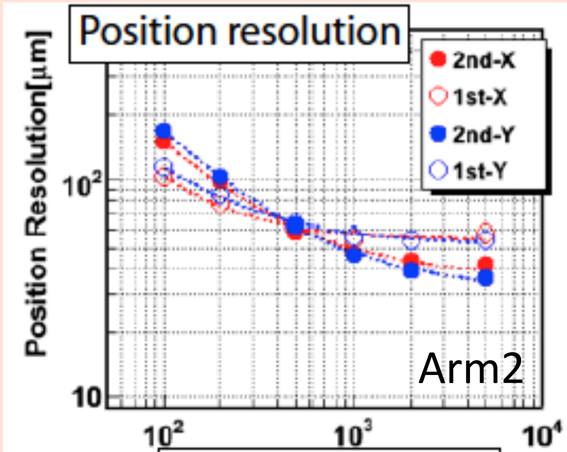
Energy resolution



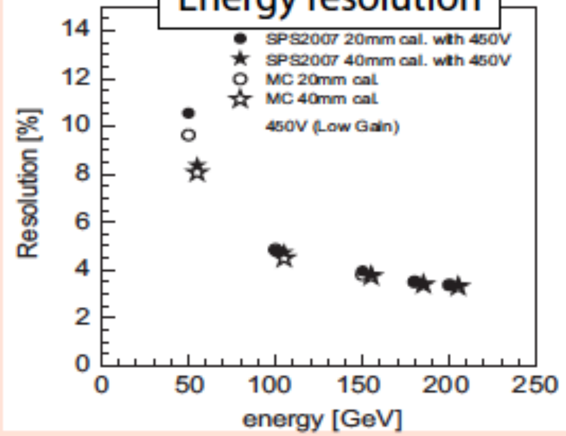
$\sigma_E/E \sim 40\%$ because of 1.6λ

EM shower (MC)

Position resolution



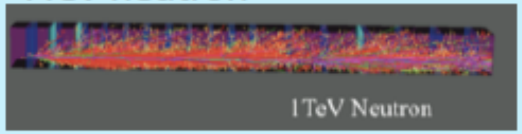
Energy resolution



PID technique

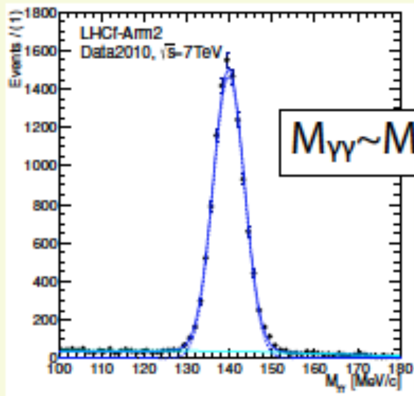
400GeV photon

1TeV neutron



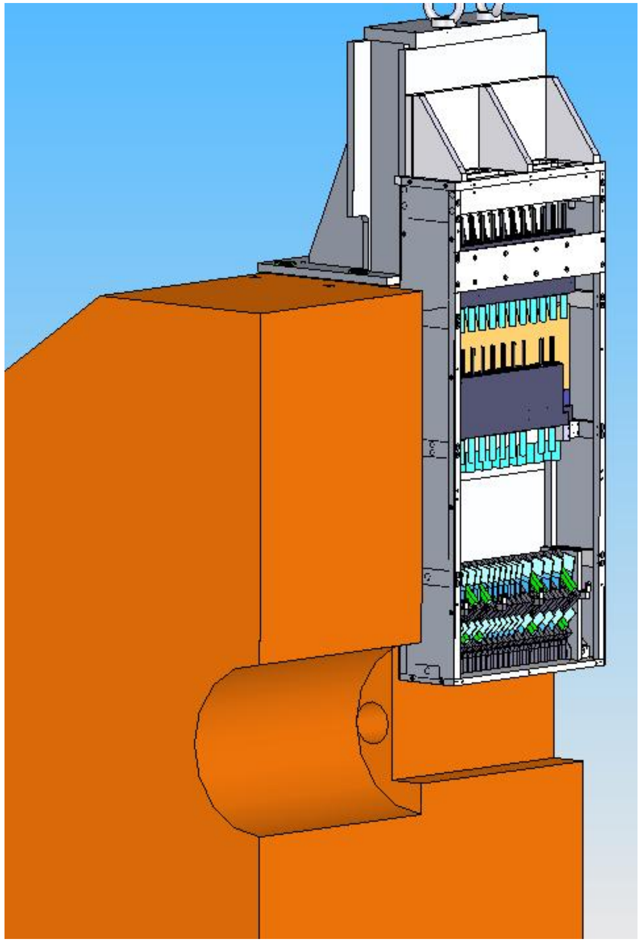
Identification of incoming particle by shower shape

π^0 reconstruction

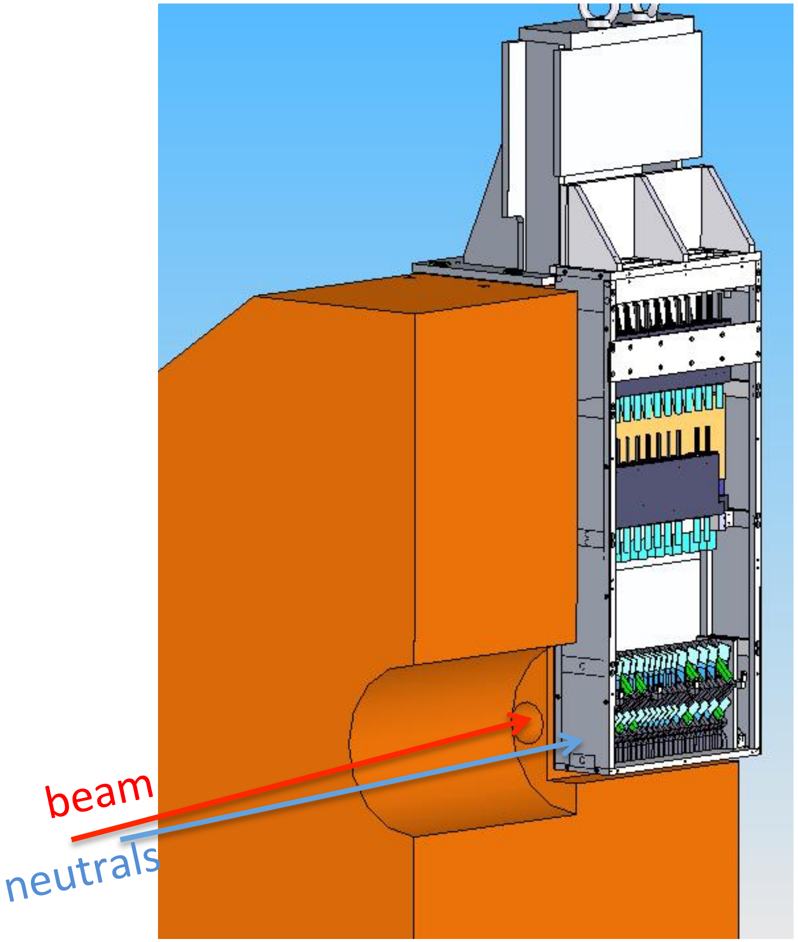


$M_{\gamma\gamma} \sim M_{\pi 0}$

Operation with manipulator



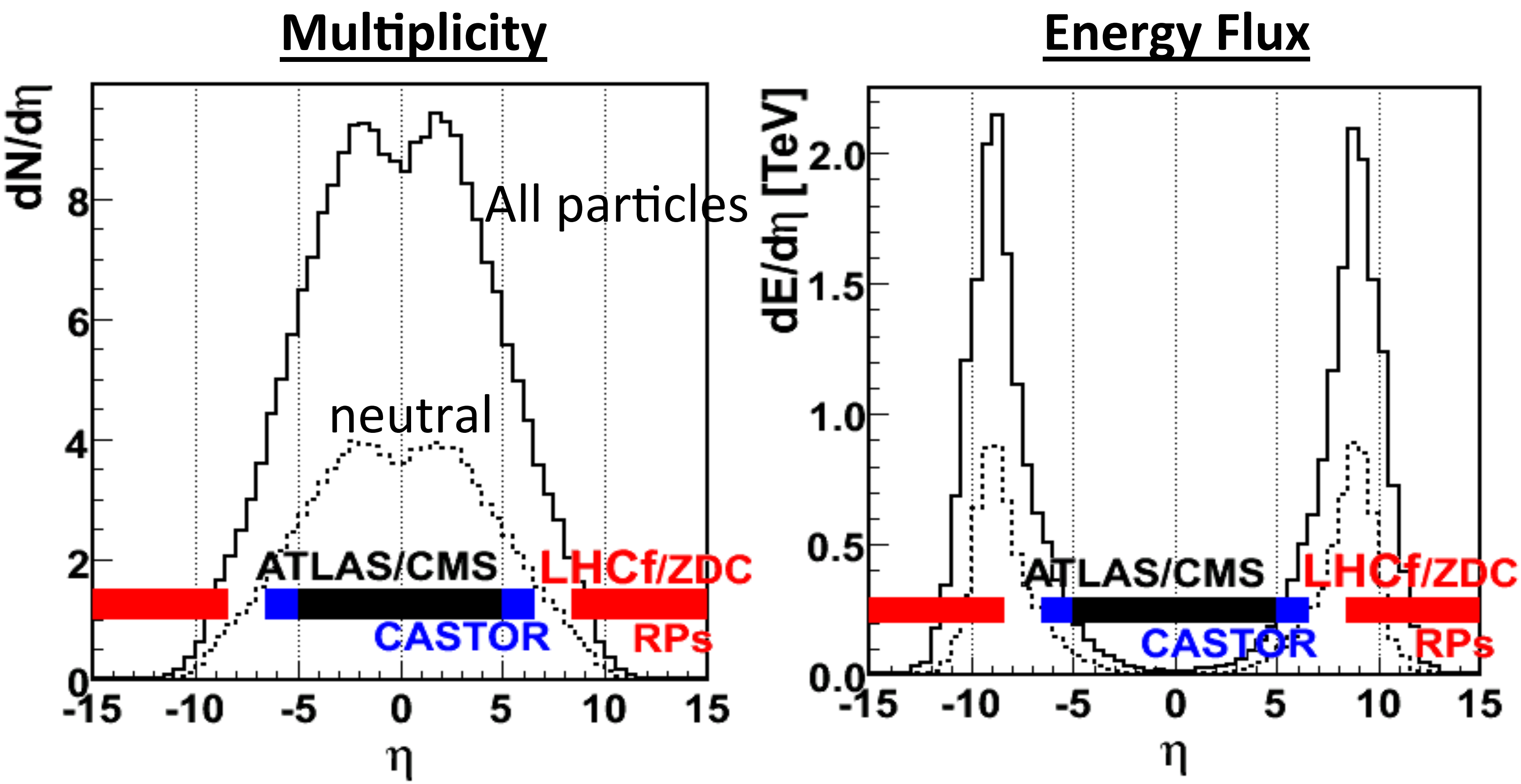
Garage position



Data taking position

2^{ry} particle flow at colliders

multiplicity and energy flux at LHC 14TeV collisions



- ✓ LHCf covers the peak of energy flow
- ✓ √s=14 TeV pp collision corresponds to $E_{lab}=10^{17}$eV

LHCf Status

- ✓ Done
  - 0.9, 2.76, 7 TeV pp collision, 5 TeV pPb collision data taking
  - Photon spectra at 0.9 and 7TeV published
  - π^0 spectra at 7 TeV published
  - Performance at 0.9 and 7TeV published
  - π^0 and UPC spectra at 5TeV pPb submitted to PRC (public on arXiv and CDS)
- ✓ On going
  - Neutron spectra at 7TeV (to be published soon)
  - Rad-hard detector upgrade for 13 TeV pp
- ✓ Plan
  - 13TeV pp collision in 2015
  - 0.5TeV pp at RHIC (LOI submitted => operation with PHENIX under discussion)
  - Discussions for light ion collision at RHIC and LHC

Results

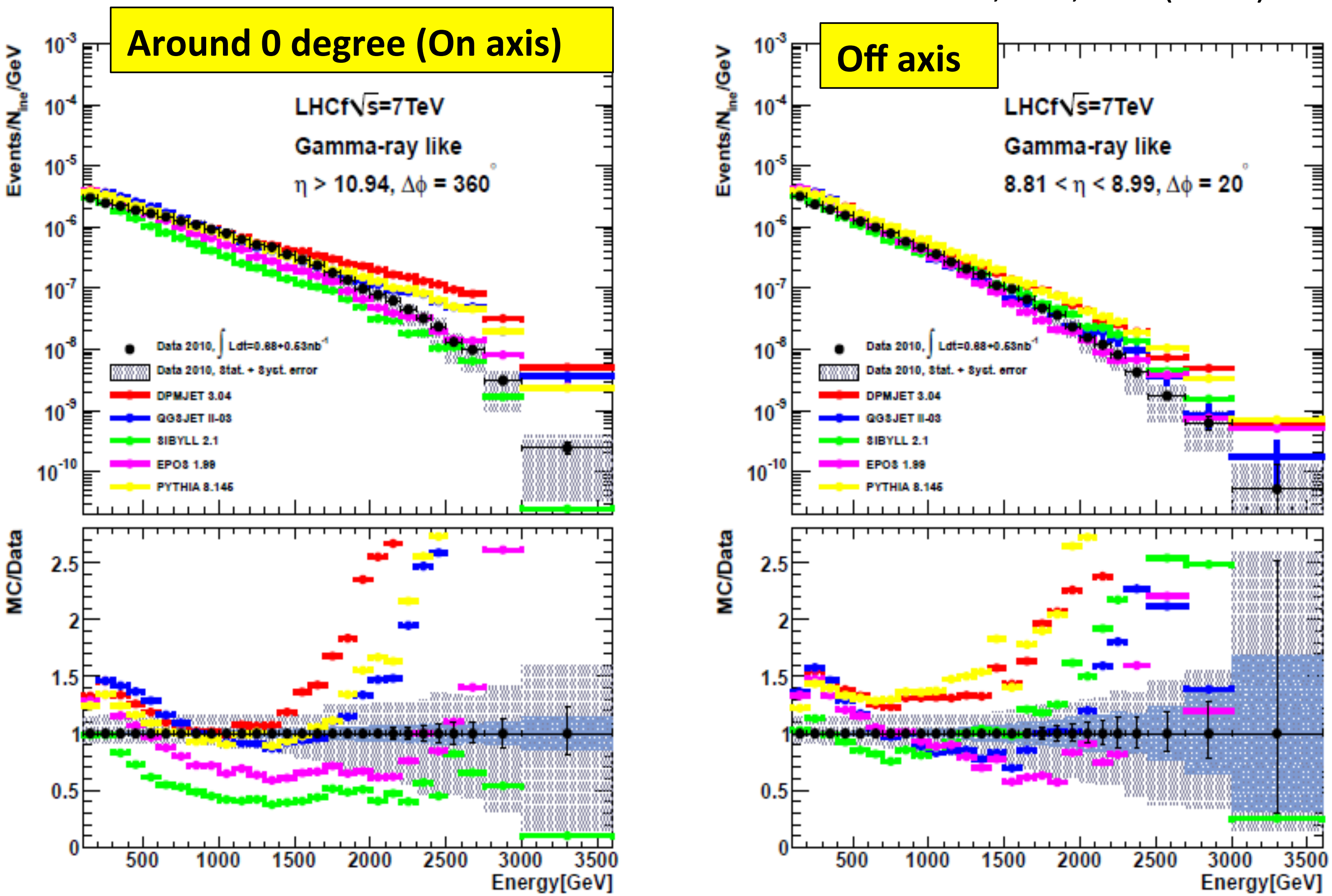
Publication Summary

	Photon (EM shower)	Neutron (hadron shower)	π (EM shower)
Test beam at SPS	NIM. A 671, 129–136 (2012)	**JINST, 9, P03016 (2014)**	
p-p at 900GeV	Phys. Lett. B 715, 298-303 (2012)		
p-p at 7TeV	Phys. Lett. B 703, 128–134 (2011)	**to be submitted soon**	Phys. Rev. D 86, 092001 (2012)
p-p at 2.76TeV			**arXiv:1403.7845 [nucl-ex](2014)**
p-Pb at 5.02TeV			

LHCf 7TeV pp photon

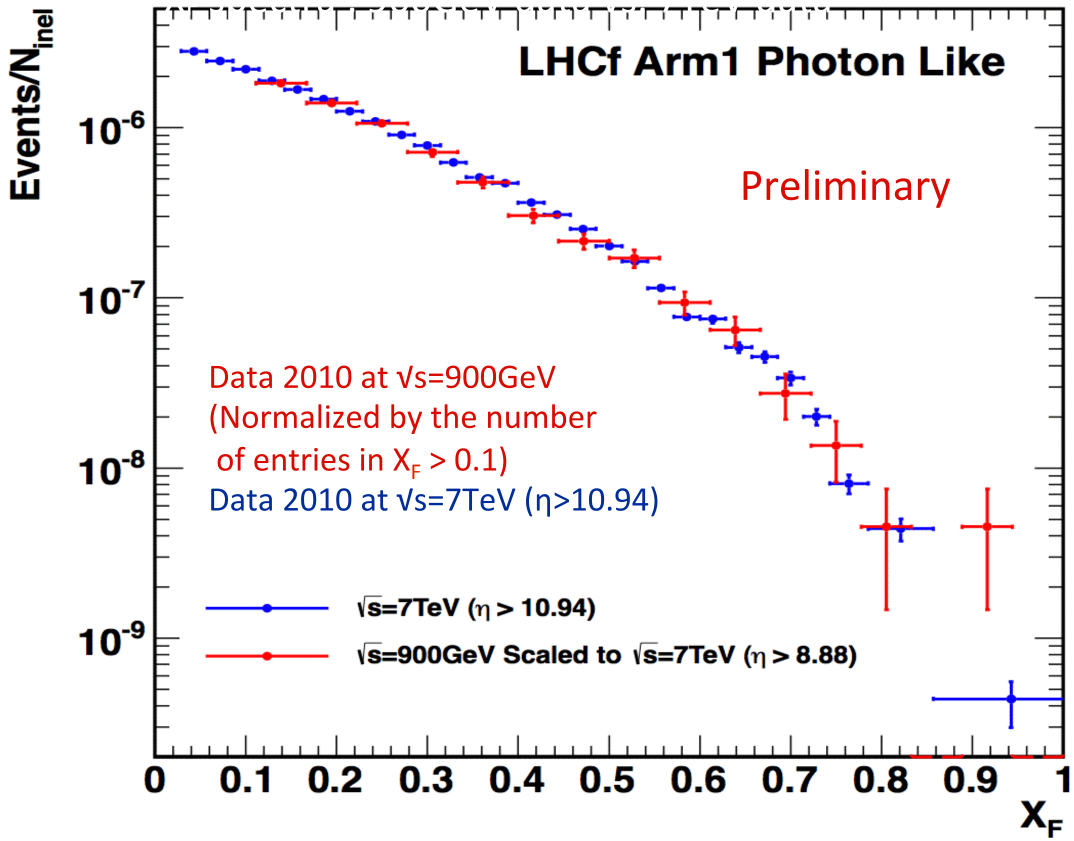
Photon spectra @ 7TeV (Data vs. Models)

Adriani et al., PLB, 703 (2011) 128-134



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

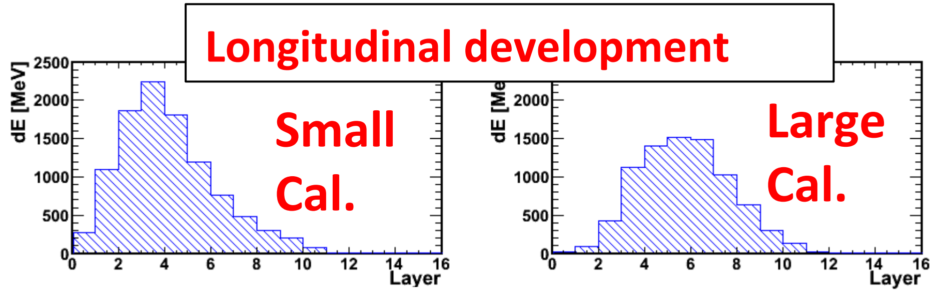
900GeV vs. 7TeV

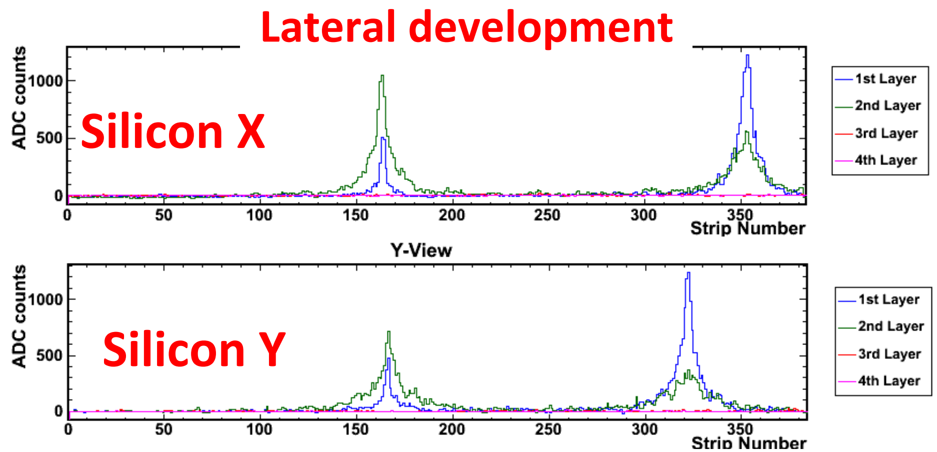


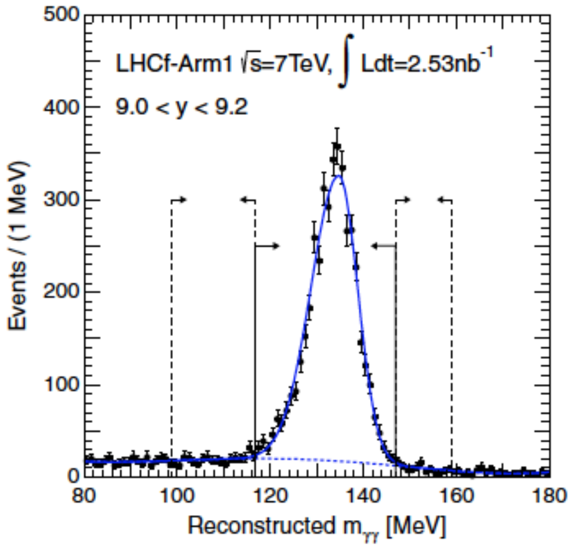
- ✓ Comparison in the same p_T range (pT<0.13x_F GeV/c)
- ✓ Normalized by # of events $X_F > 0.1$
- ✓ Statistical error only
- ✓ Comparison with 2.76TeV, 13TeV (and RHIC 500GeV) are planned

LHCf 7TeV pp π^0

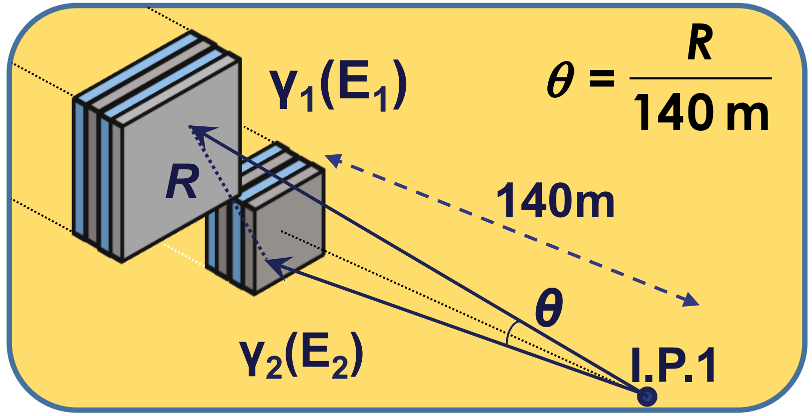
π^0 analysis

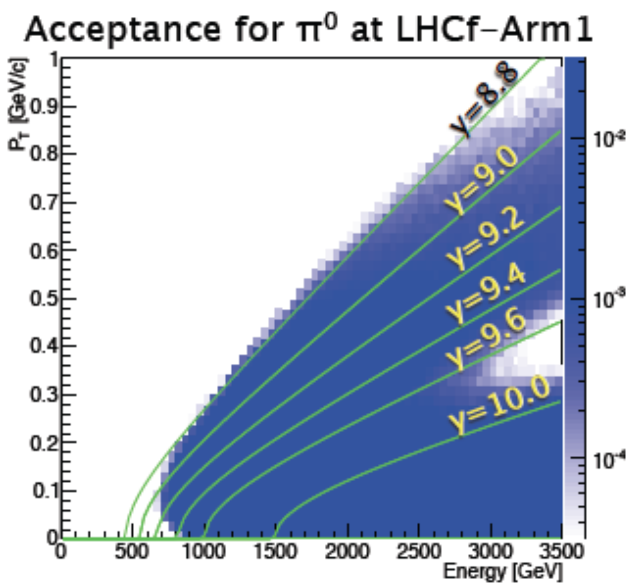






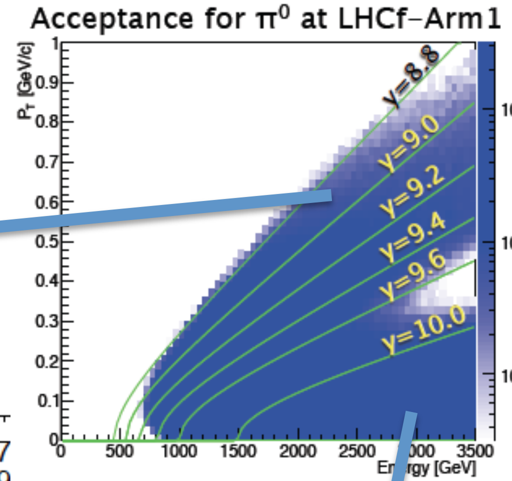
- π^0 candidate
- 599GeV & 419GeV photons in 25mm and 32mm tower, respectively
- $M = \theta\sqrt{(E_1 \times E_2)}$



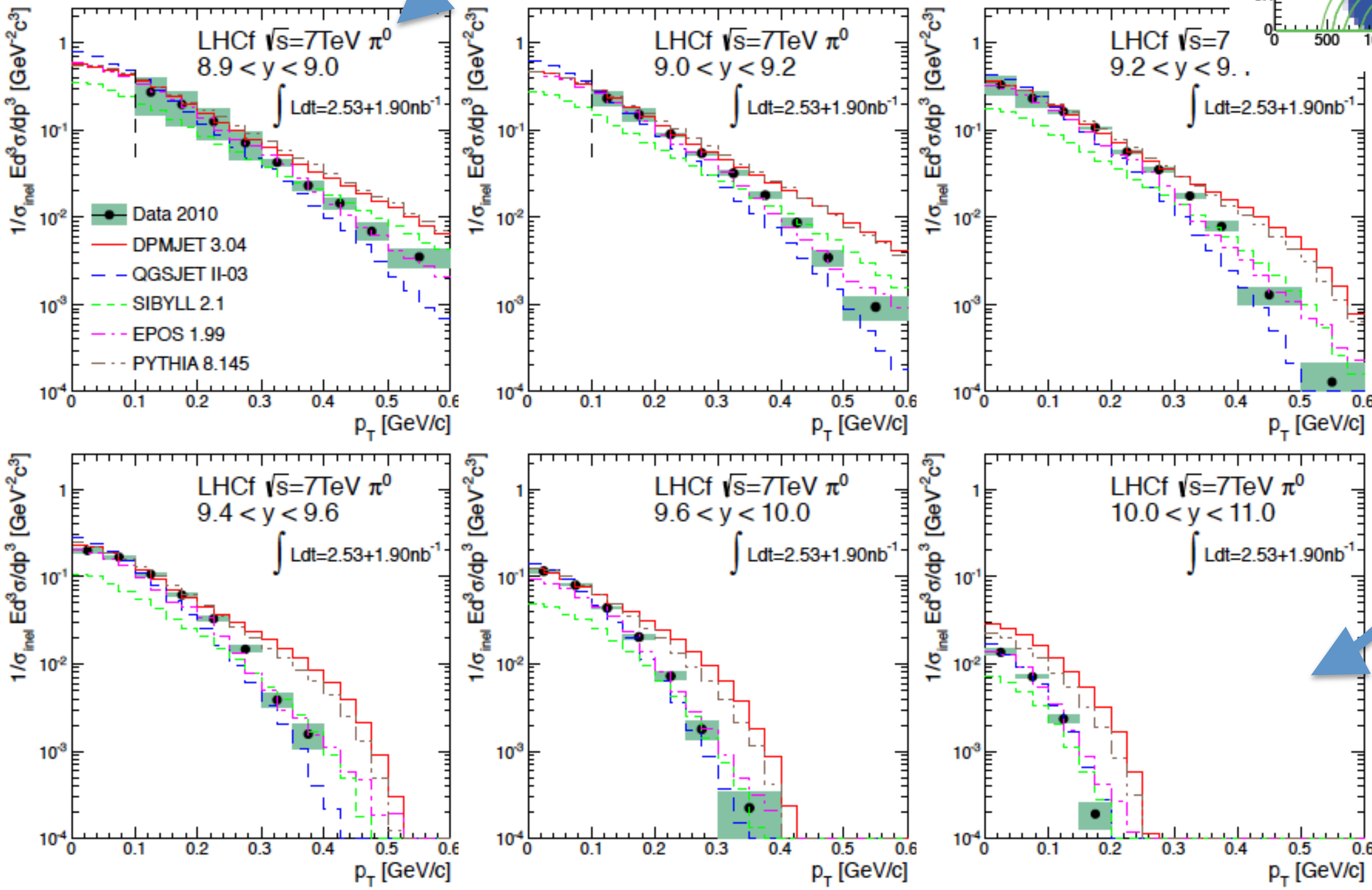


LHCf 7TeV pp π^0

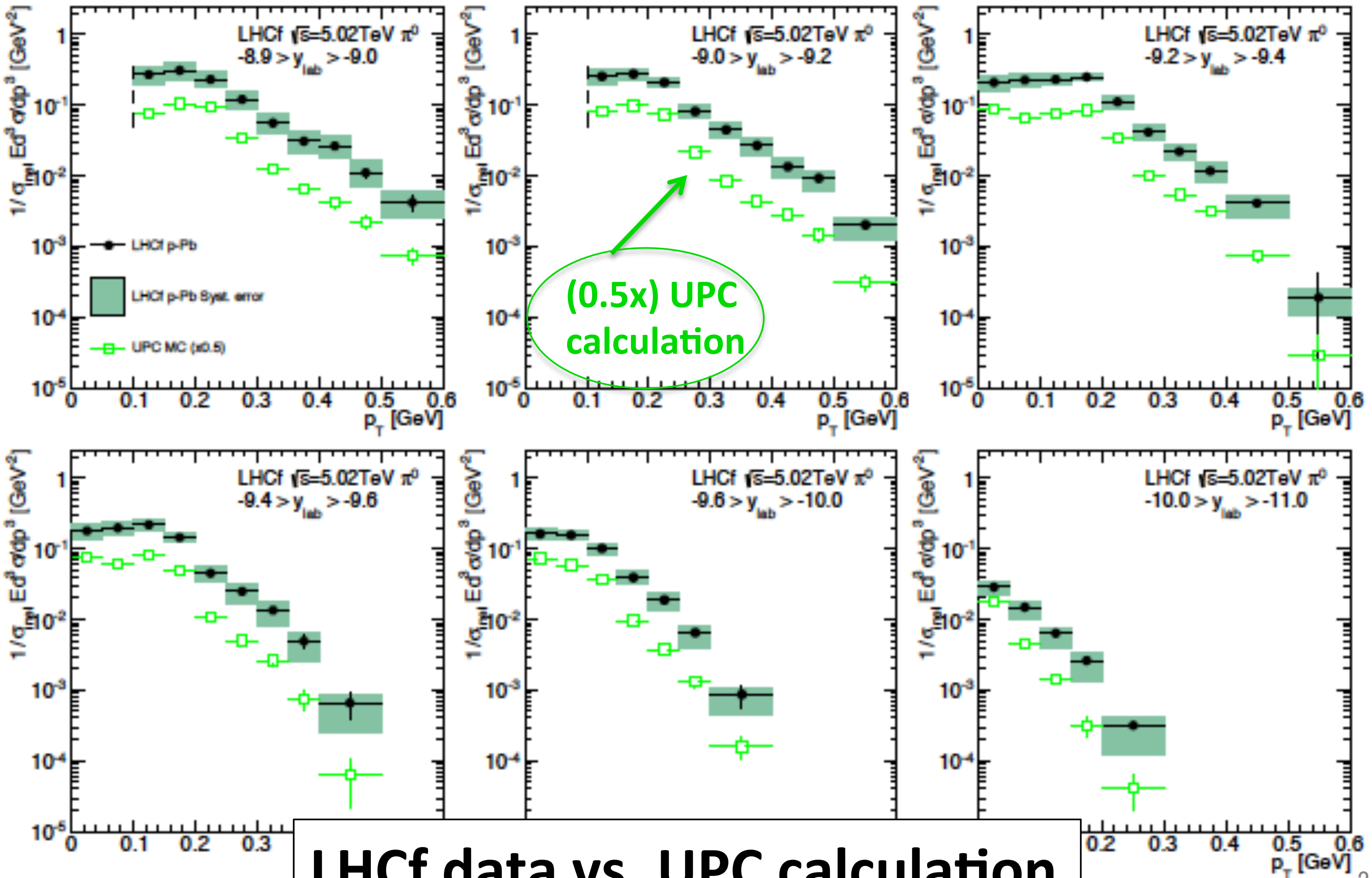
π^0 p_T distribution in different rapidity (y) ranges



Adriani et al., PRD, 86, 092001 (2012)



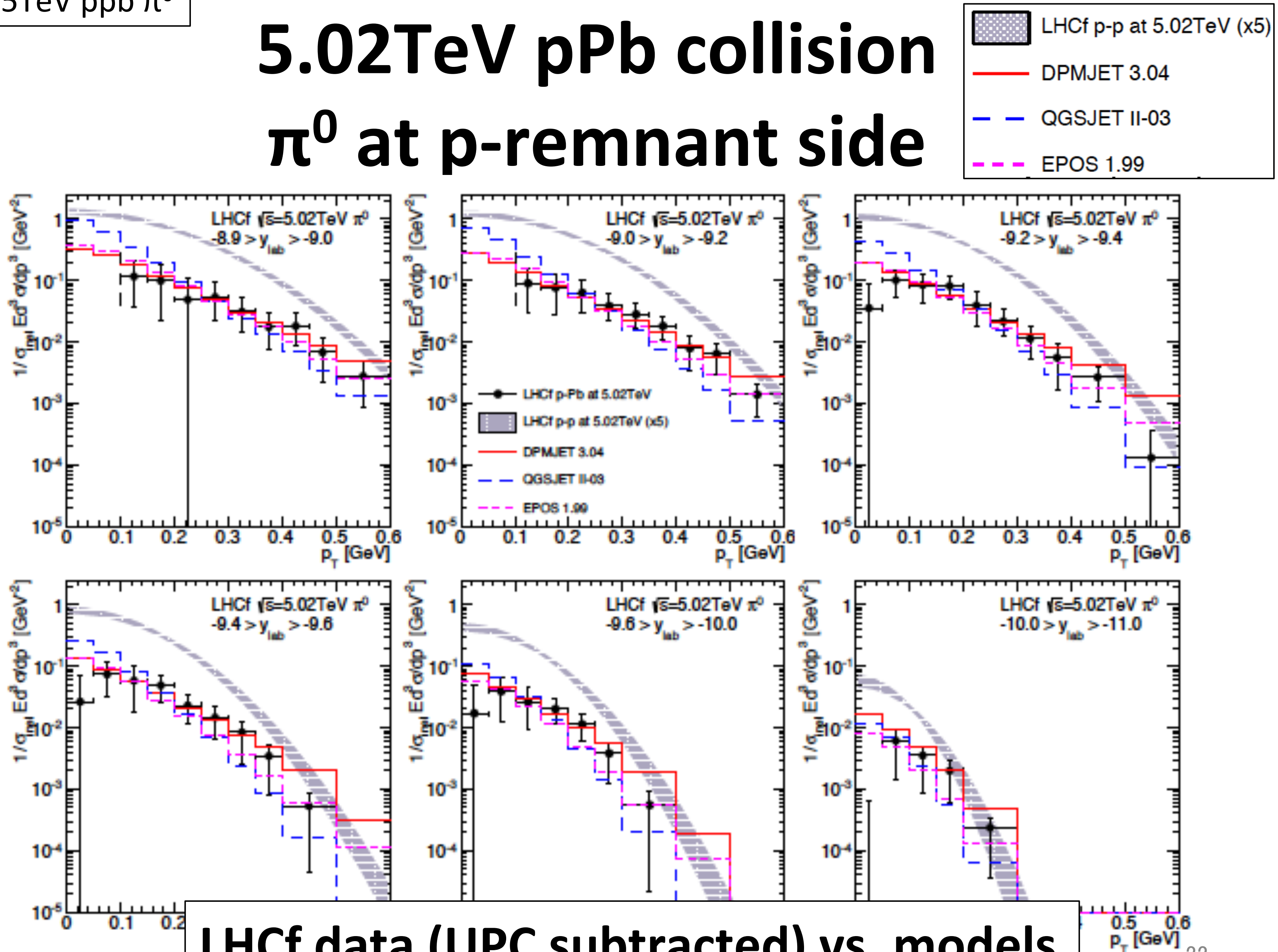
5.02TeV pPb collision
π^0 at p-remnant side



LHCf data vs. UPC calculation

LHCf 5TeV ppb π^0

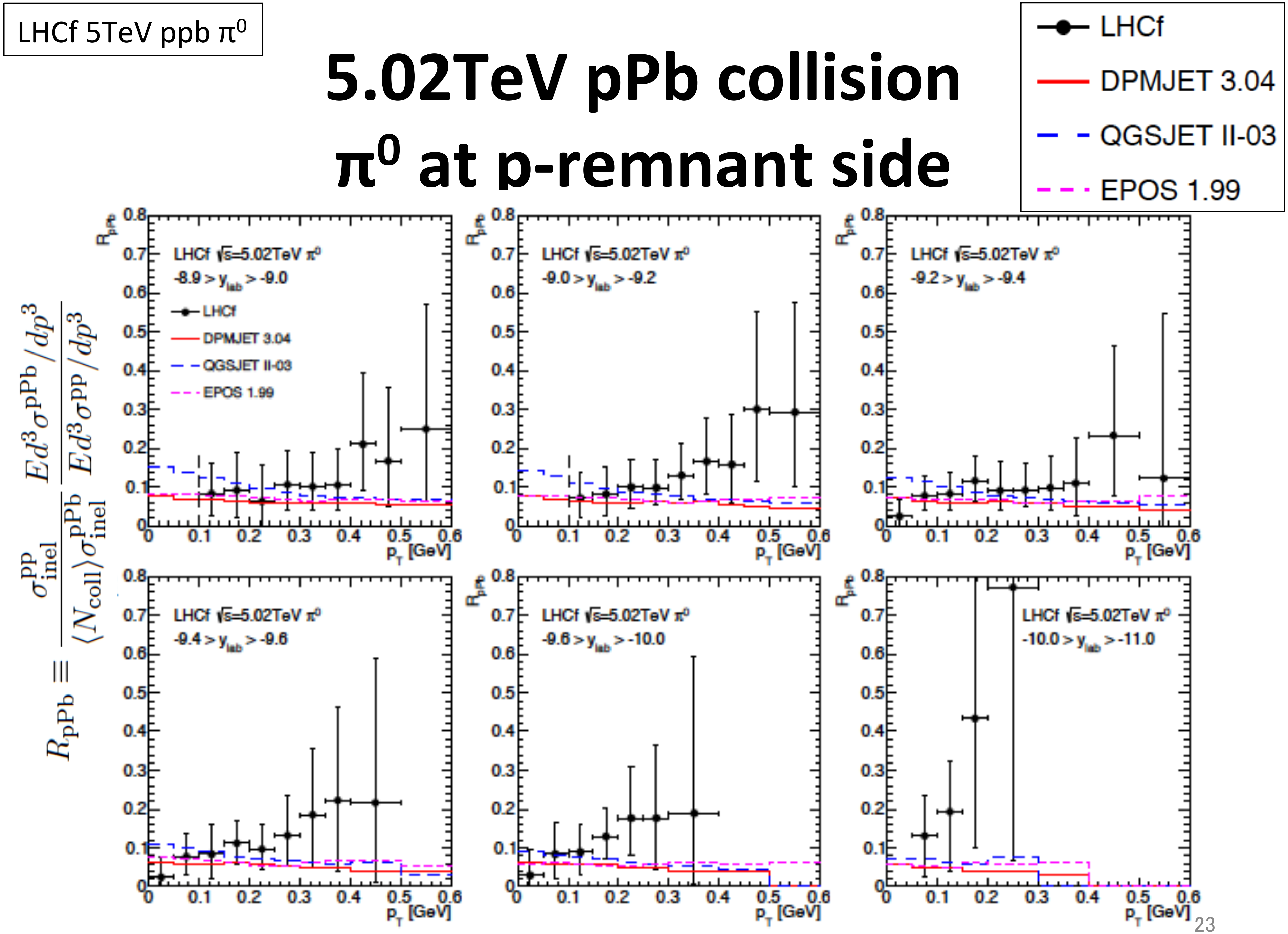
5.02TeV pPb collision
π^0 at p-remnant side



LHCf data (UPC subtracted) vs. models

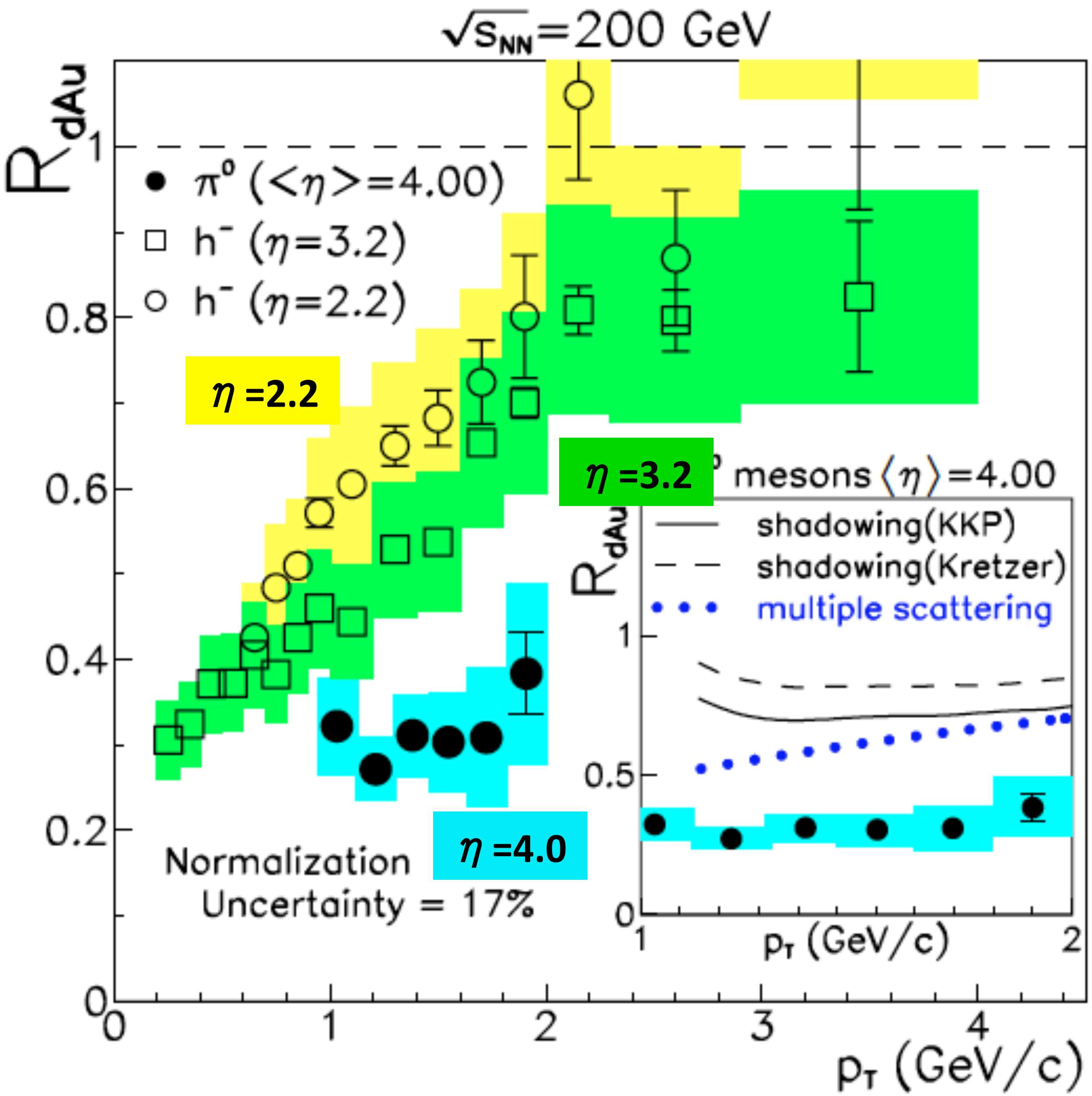
LHCf 5TeV ppb π^0

5.02TeV pPb collision
π^0 at p-remnant side



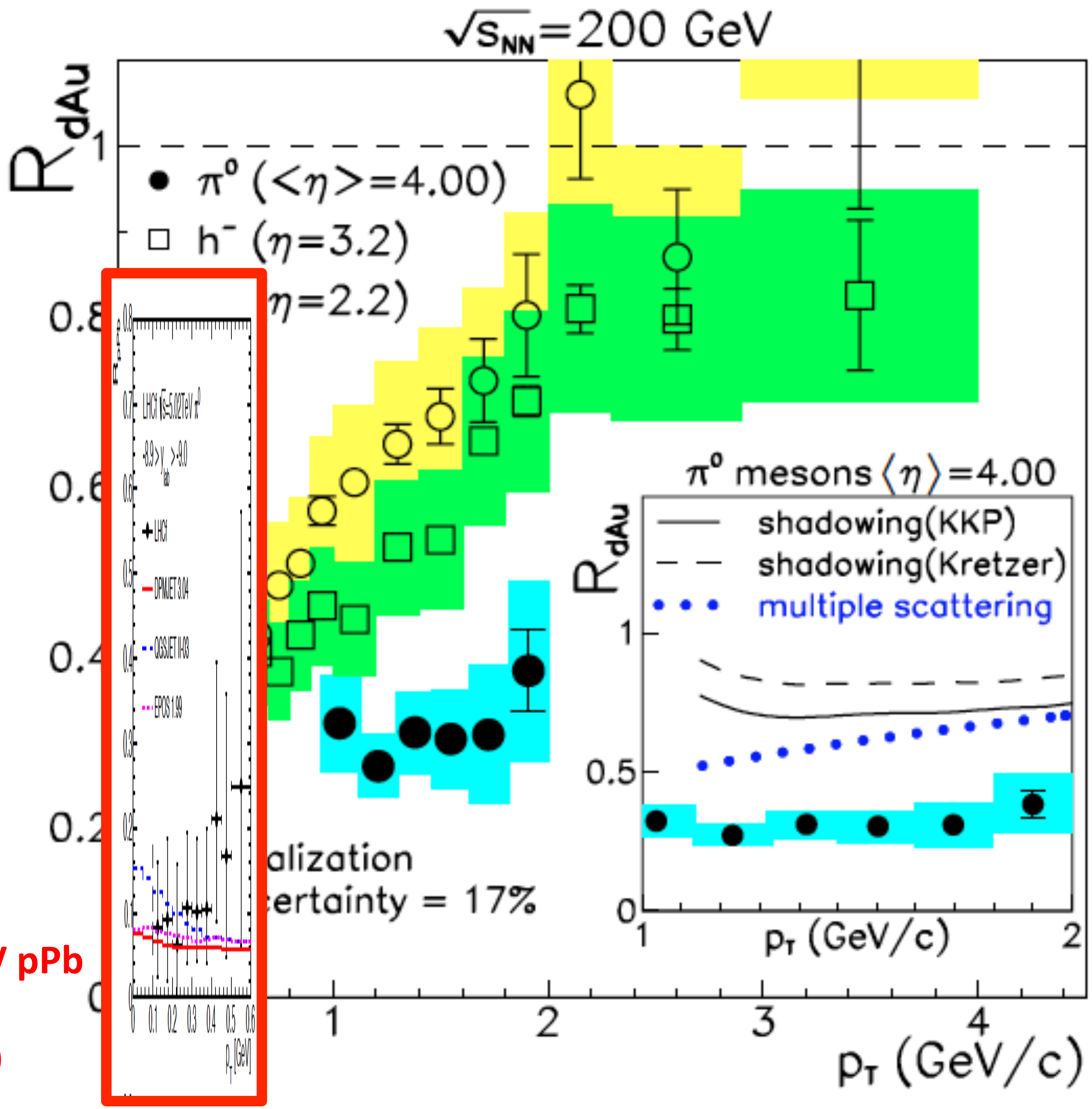
LHCf 5TeV ppb π^0

RHIC 200GeV d-Au, STAR Collaboration
Adams et al., PRL 97 (2006) 152302.



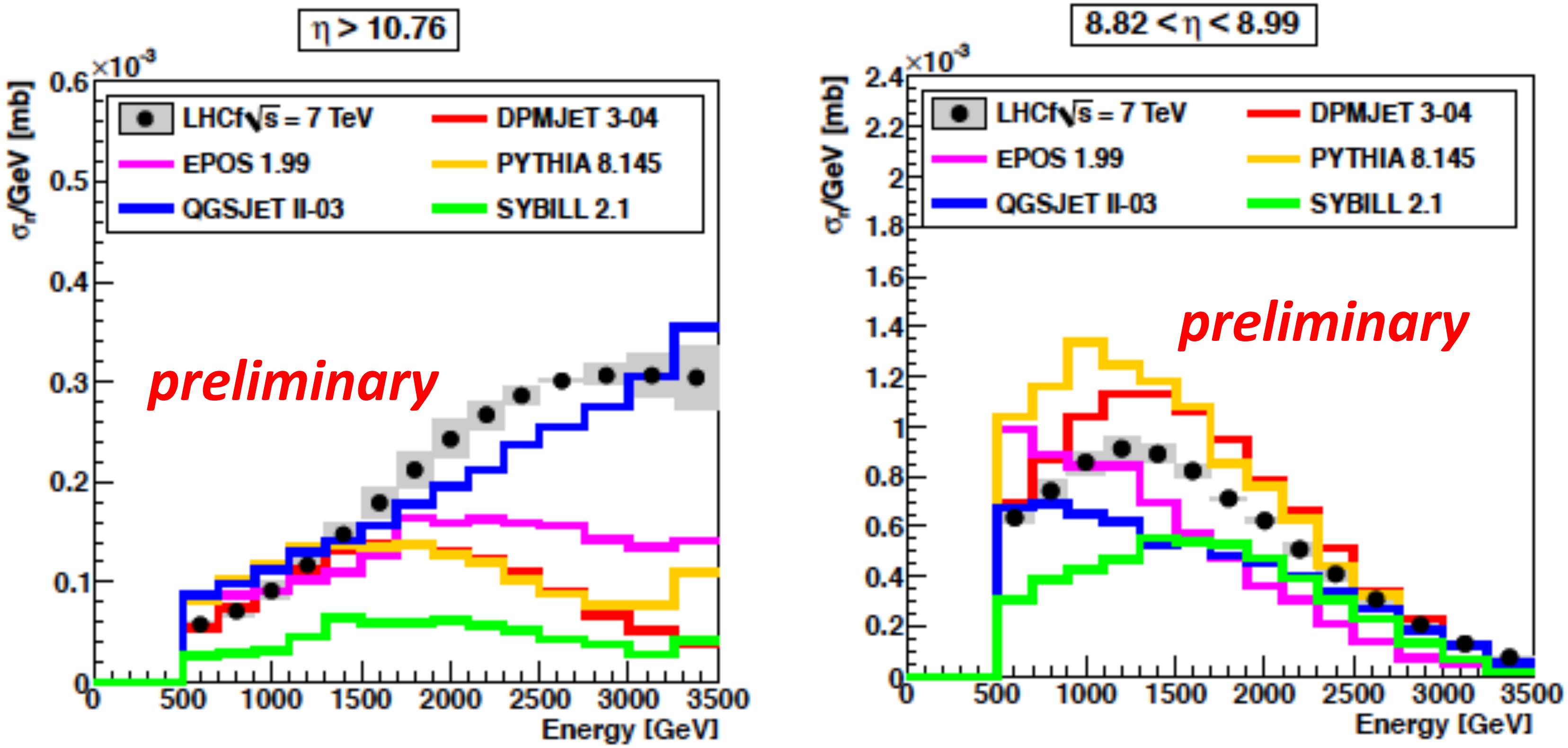
LHCf 5TeV ppb π^0

RHIC 200GeV d-Au, STAR Collaboration
Adams et al., PRL 97 (2006) 152302.



LHCf 5TeV pPb
π^0 R_{pPb}
8.9<η<9.0

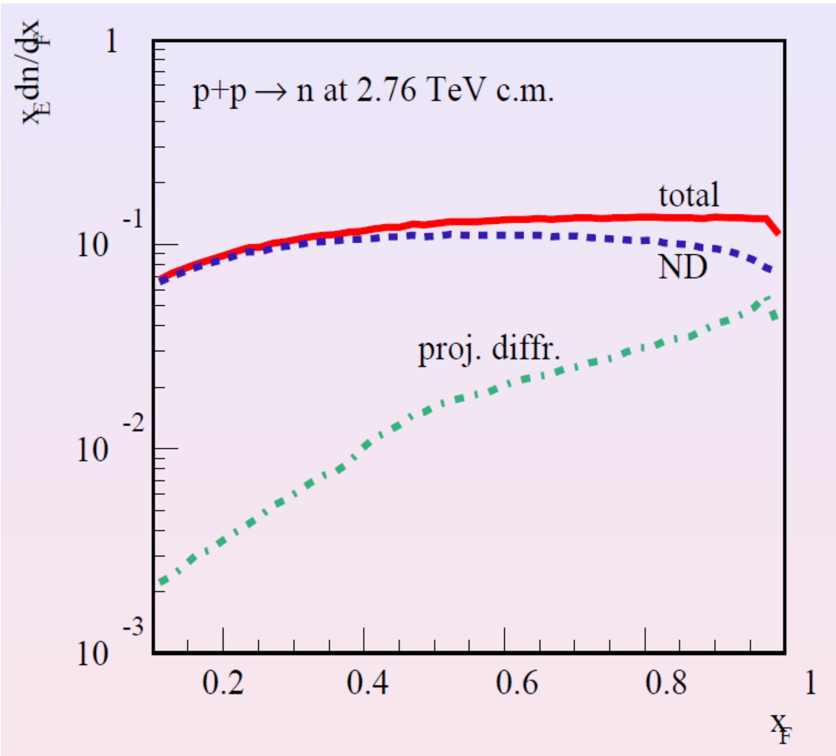
7TeV pp neutron



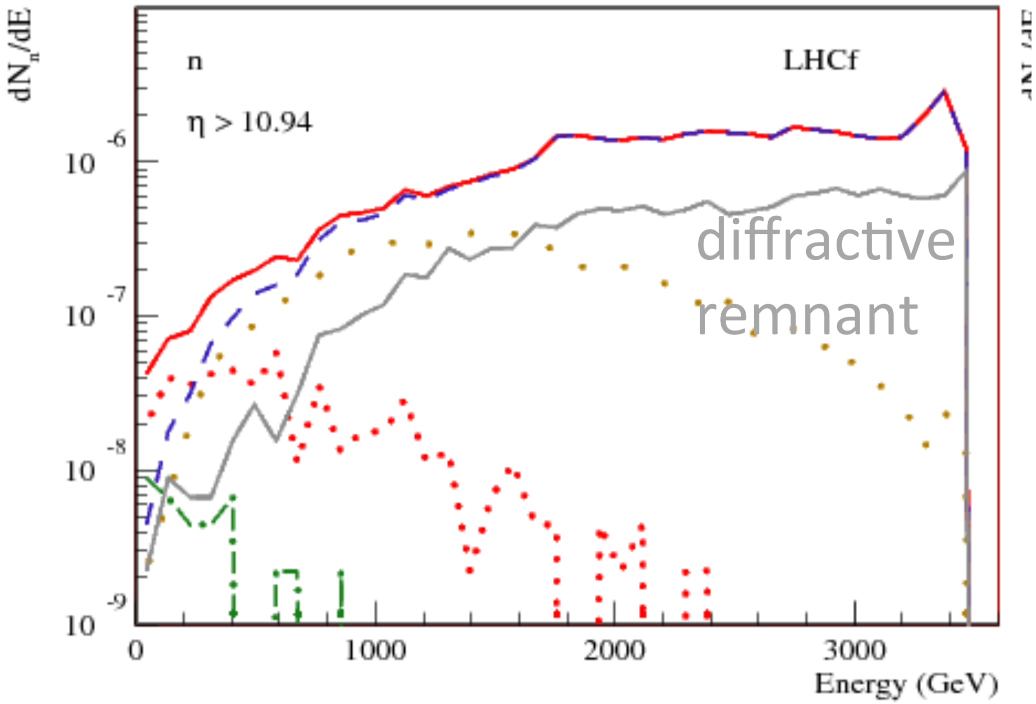
- ✓ Sys-error to be updated
- ✓ Energy resolution 40%, position resolution 0.1-1 mm are unfolded
- ✓ Detection efficiency, PID efficiency, purity are corrected

LHCf 7TeV pp neutron

Origin of 0 degree neutrons



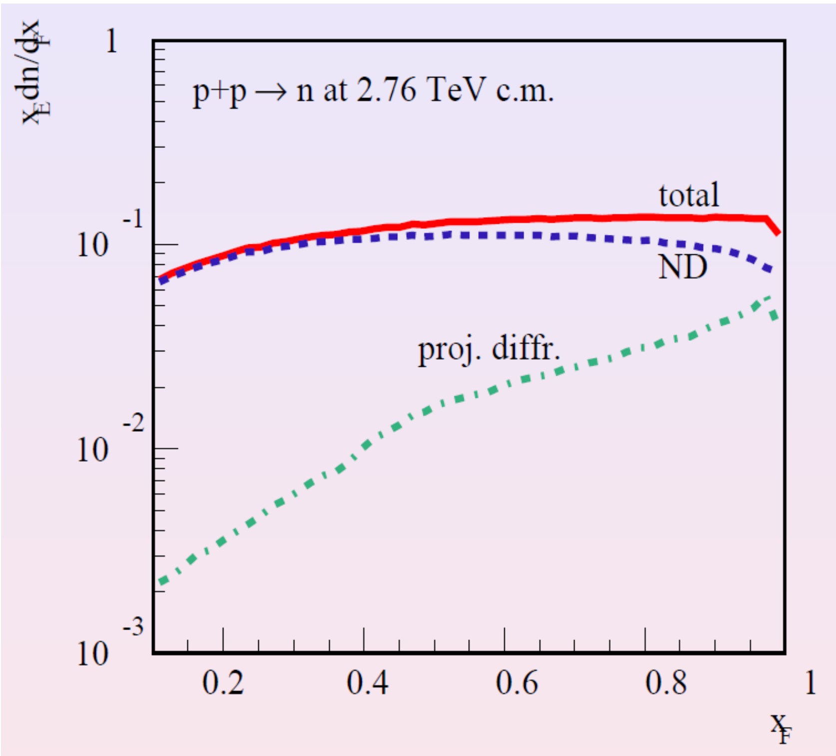
Ostapchenko, QGSJET II

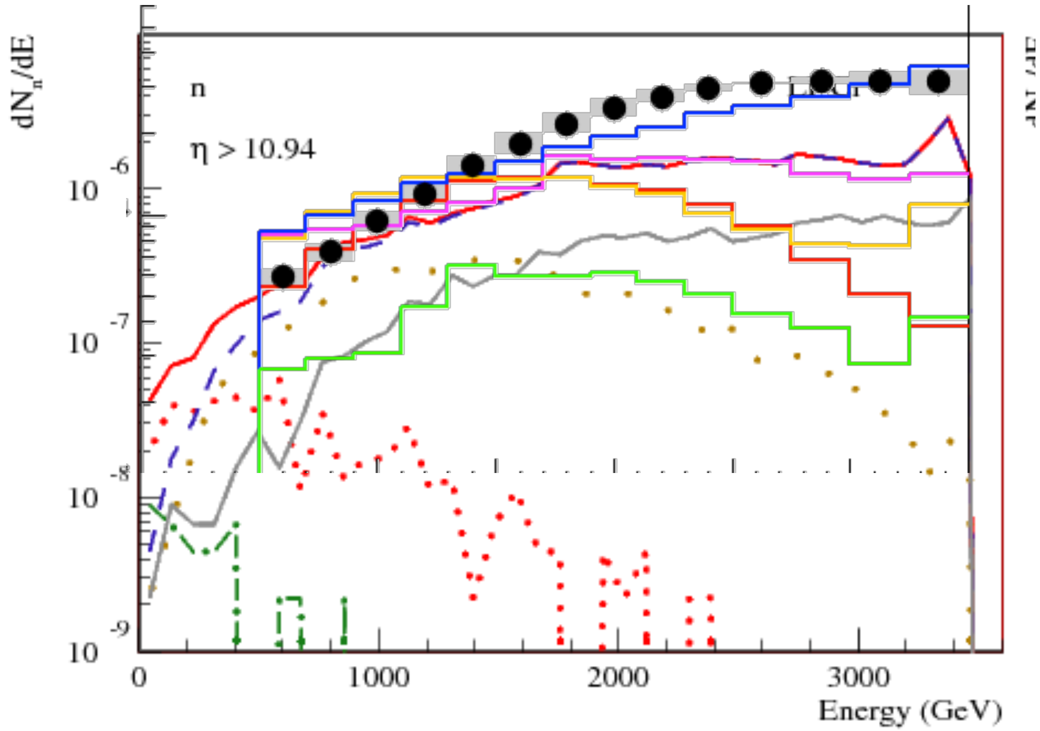


Pierog, EPOS

LHCf 7TeV pp neutron

Origin of 0 degree neutrons





LHCf data
EPOS total
EPOS diffractive

Plan

LHC RUN2

Other considerations: first rough vdM Scan + LHCf

- Combined run for vdM and LHCf at 19 m β^* early 2015

LHCf:

- 40 low intensity bunches ~ 1 x 10^{10}, low luminosity (6 x 10^{28} $cm^{-2}s^{-1}$)
- Integrate 5 – 20 nb^{-1}
- Pilot run a week before the main run
- Runs at different energies: 13 TeV, 7 TeV and 3.5 TeV

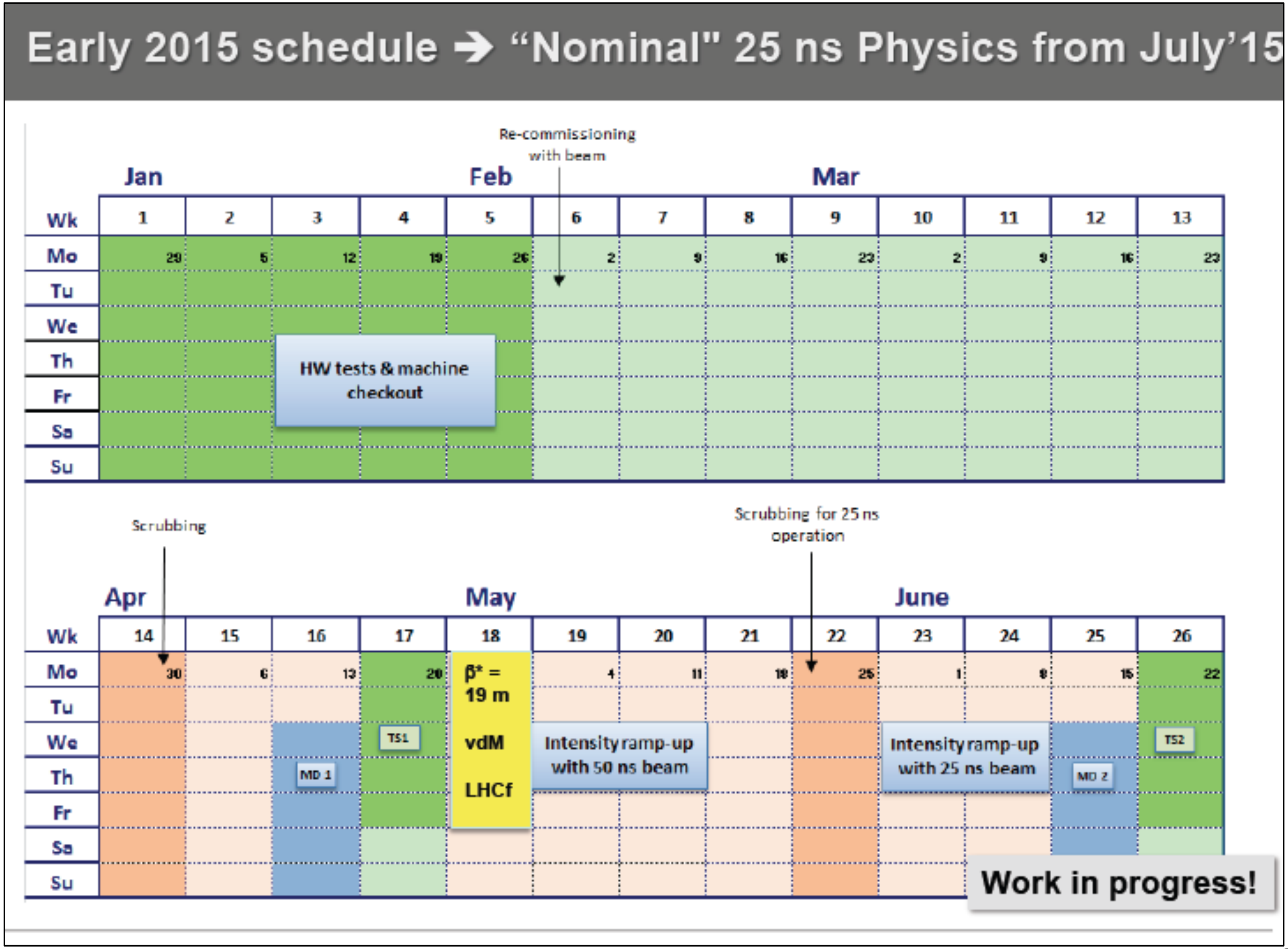
vdM Scan:

- ~ 2 fills at 19 m β^*

- ➔ Will commission 19 m β^* unsqueeze during initial beam commissioning

slide discussed in the LHC Machine Committee on 11 Dec 2013

LHC RUN2



slide discussed in the LHC Machine Committee on 11 Dec 2013

Future Circular Collider Study Kickoff Meeting

UNIVERSITÉ DE GENÈVE

CERN

FCC hh ee he

12-15 February 2014
University of Geneva - UNI MAIL
Europe/Zurich timezone

Search

Webcast: Please note that this event will be available live via the Webcast Service.

Futur… udy Kickoff Meeting

CERN | FCC hh ee he

EDMS NO.	REV.
1342402	

Date : 2014-02-11

…pecification

Any messages from forward physics?
From cosmic-ray physics, of course, YES!

Future Circular Collider Study

Hadron Collider Parameters

WBS PATH

1.2.1.2

ABSTRACT:

The goal of the hadron collider designed in the scope of the Future Circular Collider study is to provide proton-proton collisions at a centre-of-mass energy of 100 TeV. The machine is compatible with ion beam operation. Assuming a nominal dipole field of 16 T, such a machine would have a circumference of the order of 100 km. The machine is designed to accommodate two main proton experiments that are operated simultaneously. The machine delivers a peak luminosity of 1 - 5 x 10^{34} $cm^{-2}s^{-1}$. The layout should allow for two

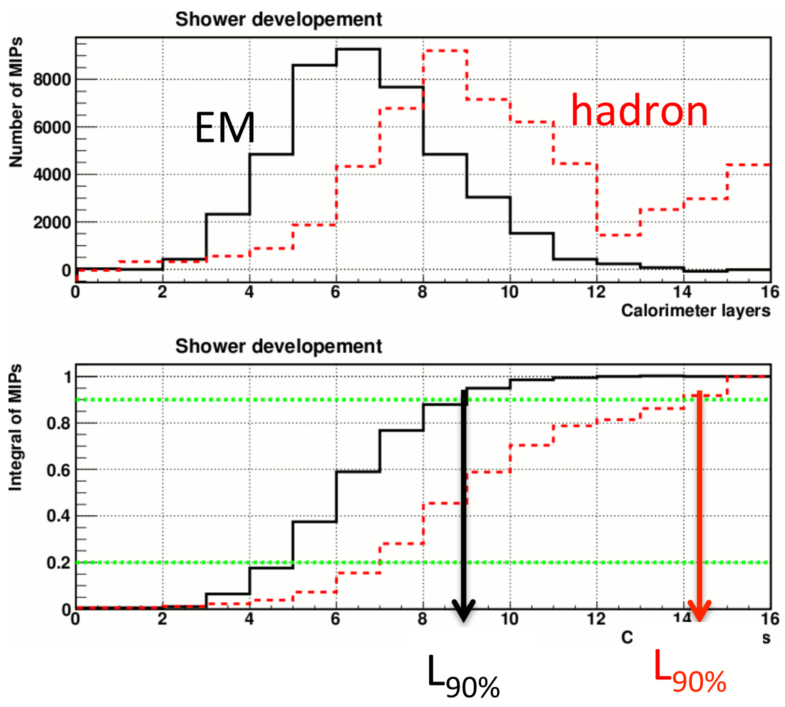
Summary

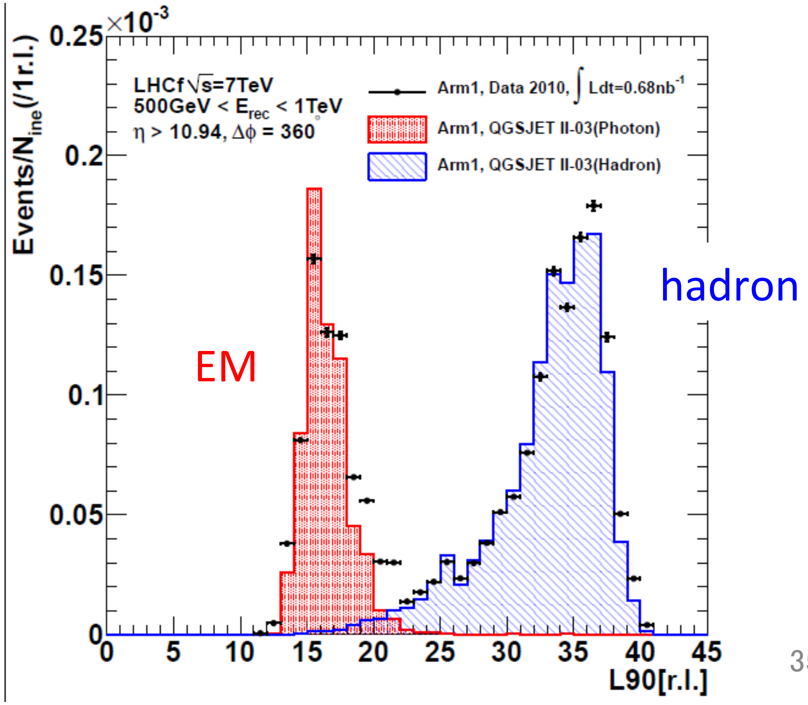
- ✓ LHCf is dedicated to measure 0 degree neutral particles at LHC IP1 to improve the cosmic-ray AS modeling
- ✓ LHCf succeeded data taking at LHC 0.9, 2.76 and 7TeV pp, and 5TeV pPb collisions
- ✓ Following results were published (or soon published)
  - photons at 0.9 and 7TeV pp collisions
  - π^0 at 7TeV pp collisions
  - neutrons at 7TeV pp collisions
  - π^0 at 5TeV pPb collisions and nuclear modification factor
- ✓ √s dependence of spectra is important to extrapolate beyond the LHC (13TeV pp and RHICf)
- ✓ Special low luminosity run (with vdM scan) is planned at the early phase of RUN2
- ✓ Light ion collisions at LHC and FCC are clearly interesting future for CR physics.

Backup

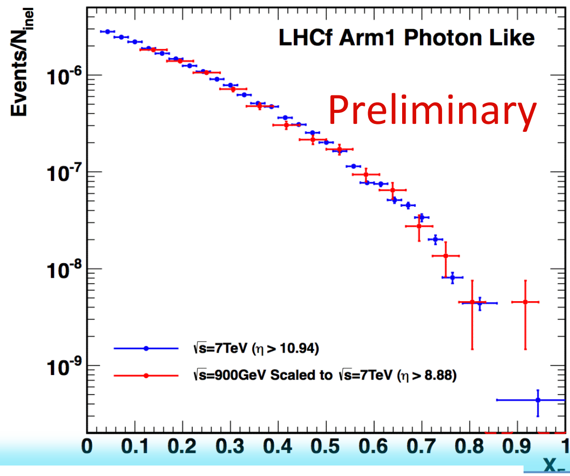
Particle Identification

- ✓ PID (EM shower selection)
  - Select events $<L_{90\%}$ threshold and multiply P/ε
    ε (photon detection efficiency) and P (photon purity)
  - By normalizing MC template $L_{90\%}$ to data, ε and P for certain $L_{90\%}$ threshold are determined.



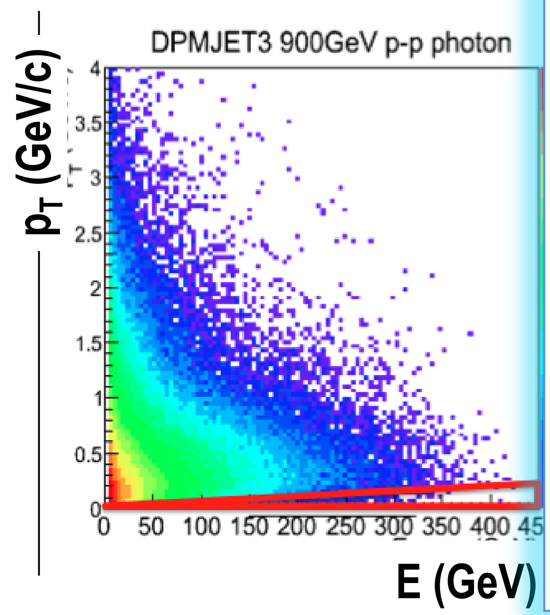


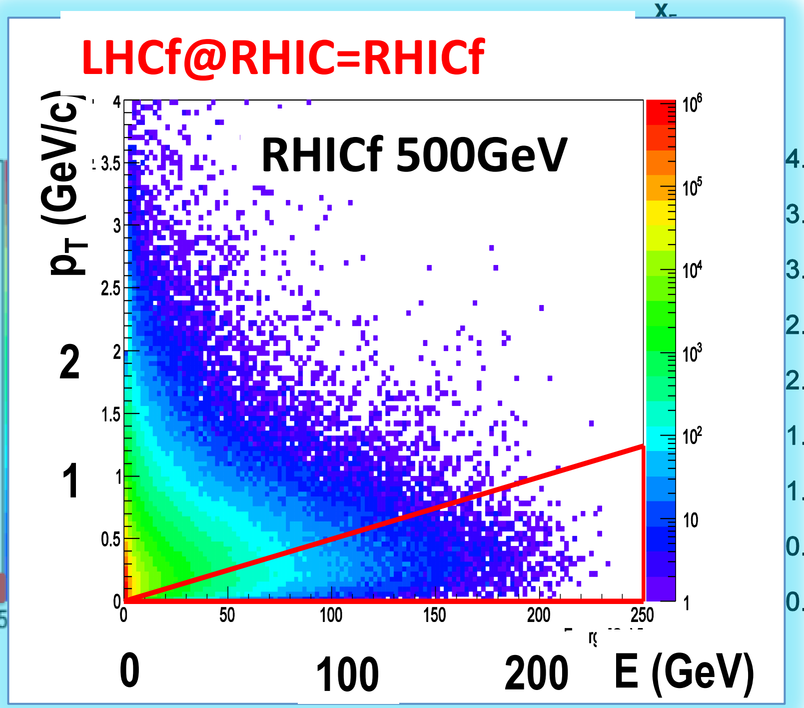
Confirmation of x_F scaling



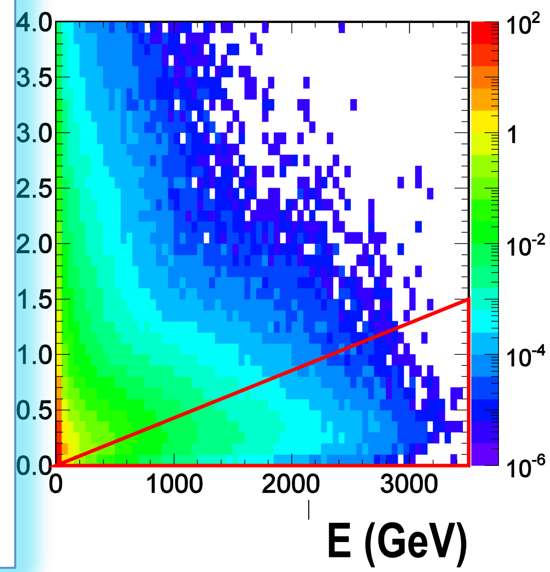
Events selected from very narrow phase space to compare with 900GeV result

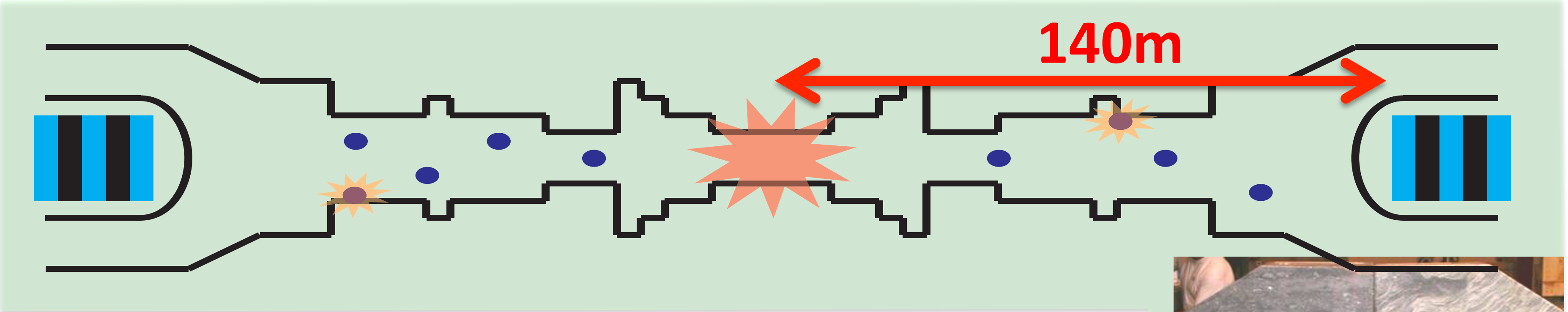
Phase space of LHC 900GeV data





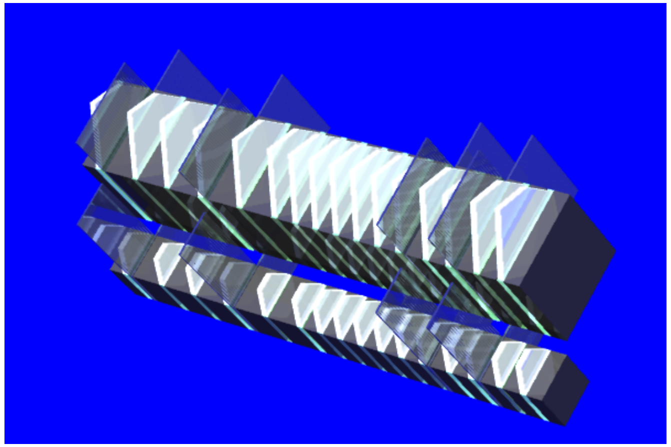
Phase space of LHC 7TeV data

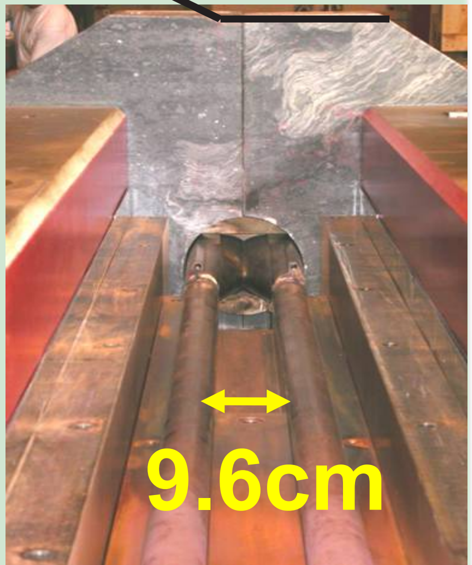




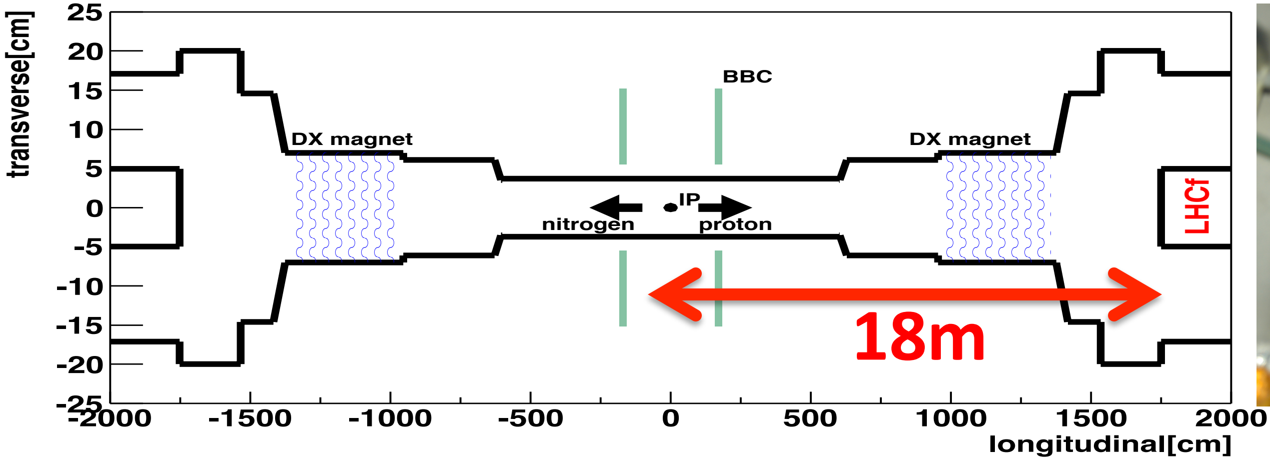
LHC

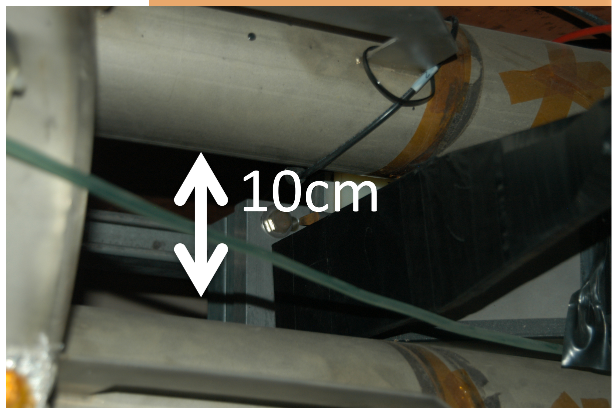
Why RHIC?





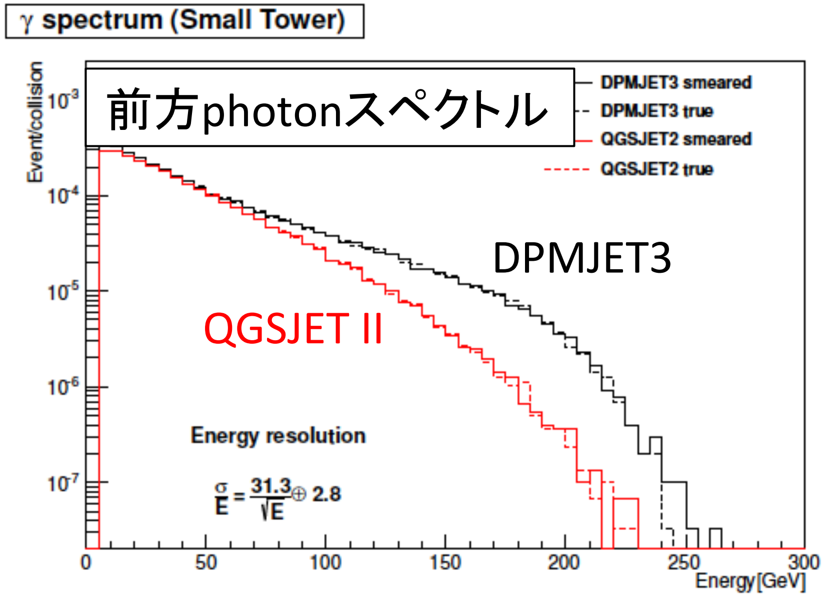
RHIC

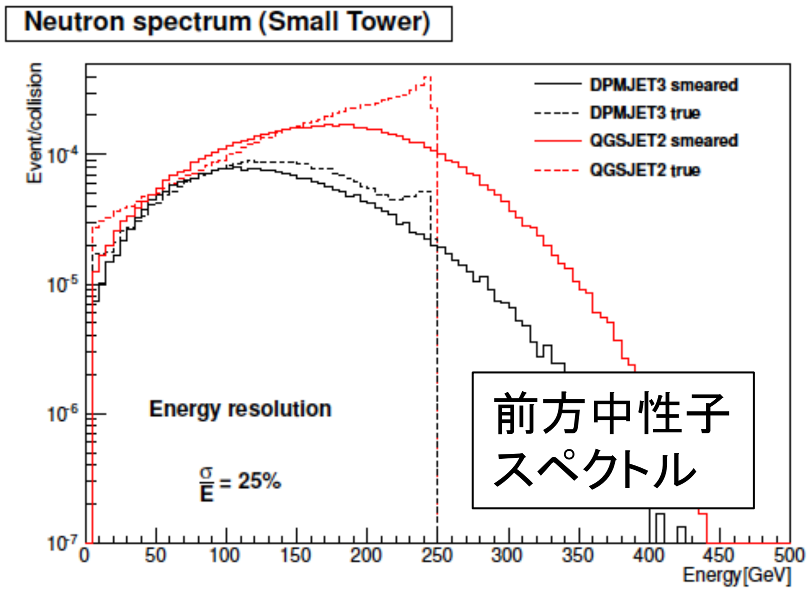


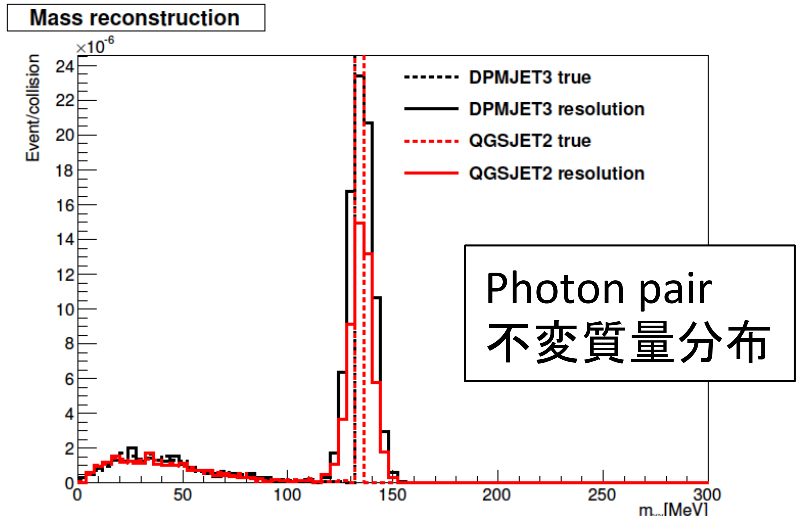


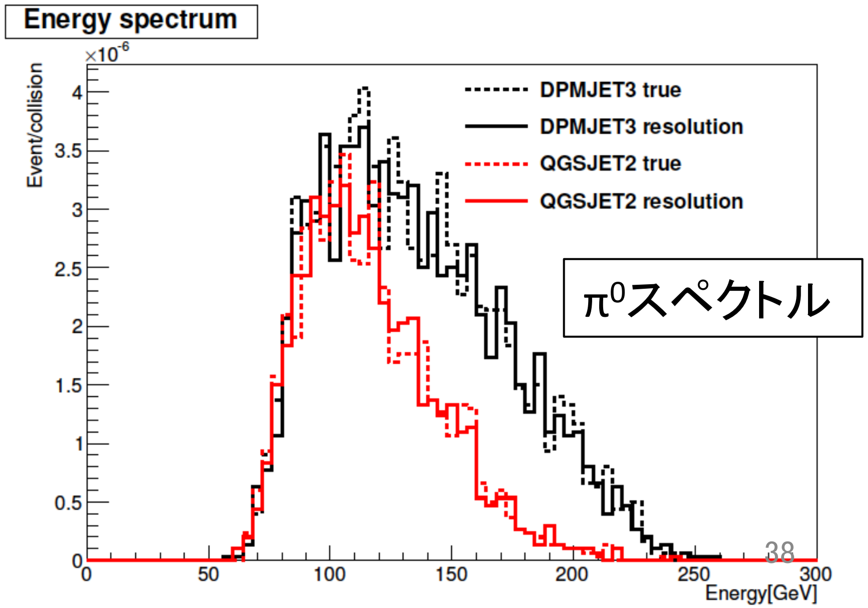
RHICfで期待される結果

- RHIC 500GeV pp collision
- 3x10^7 inelastic collisions (DAQのinefficiencyを考えて15分の測定)
- 現行LHCf検出器を使った場合









Letter of intent; Precise measurements of very forward particle production at RHIC

Y.Itow, H.Menjo, G.Mitsuka, T.Sako

Solar-Terrestrial Environment Laboratoy / Kobayashi-Maskawa Institute for the Origin of Particles and the Universe / Graduate School of Science, Nagoya University, Japan

K.Kasahara, T.Suzuki, S.Torii

Waseda University, Japan

O.Adriani, A.Tricomi

INFN, Italy

Y.Goto

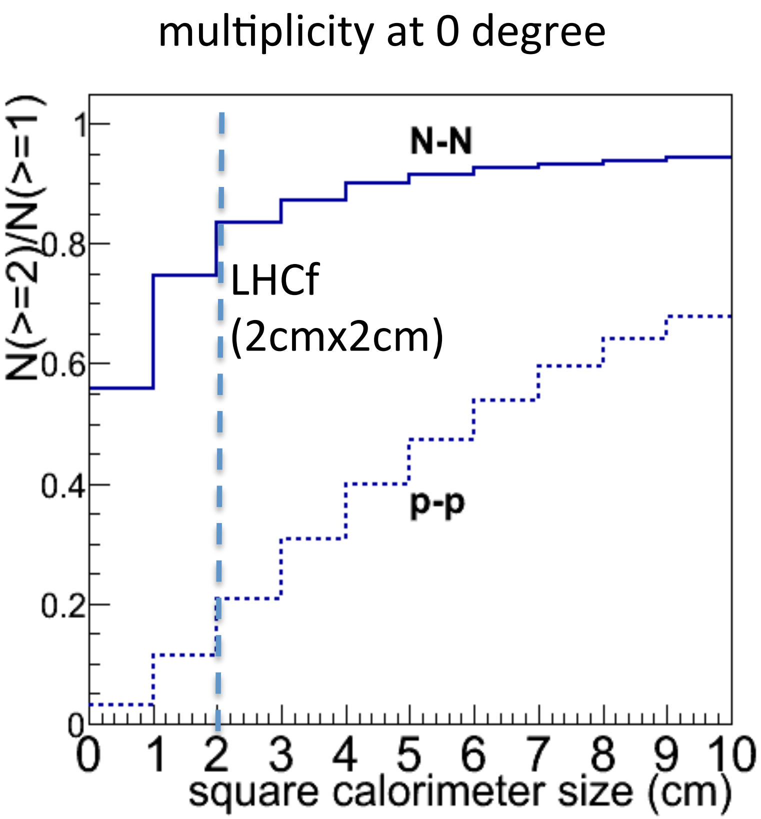
Riken BNL, Japan

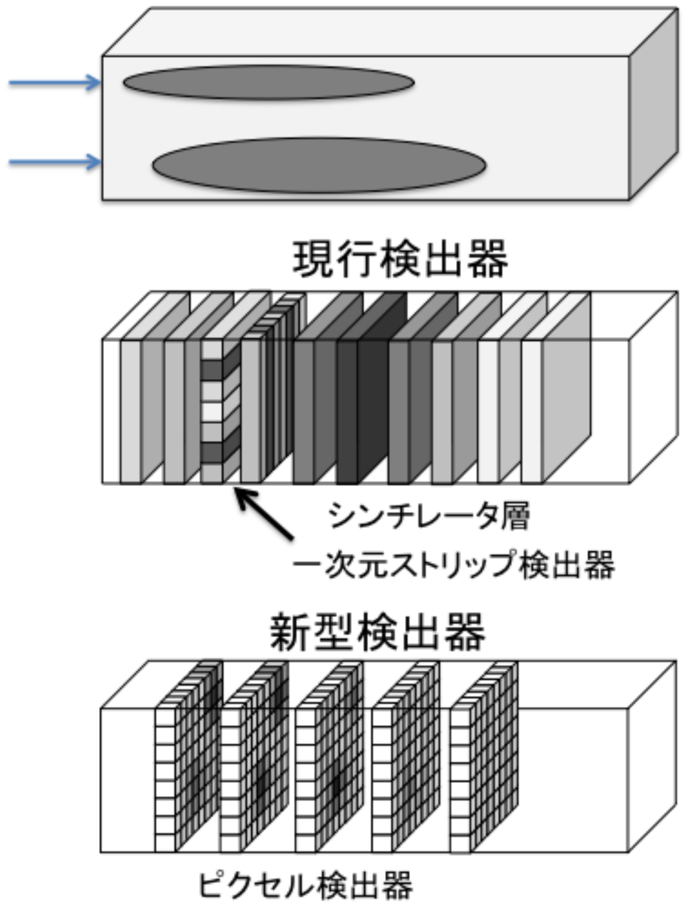
K.Tanida

Seoul National University

arXiv:1401.1004

High multiplicity calorimeter by Silicon pad



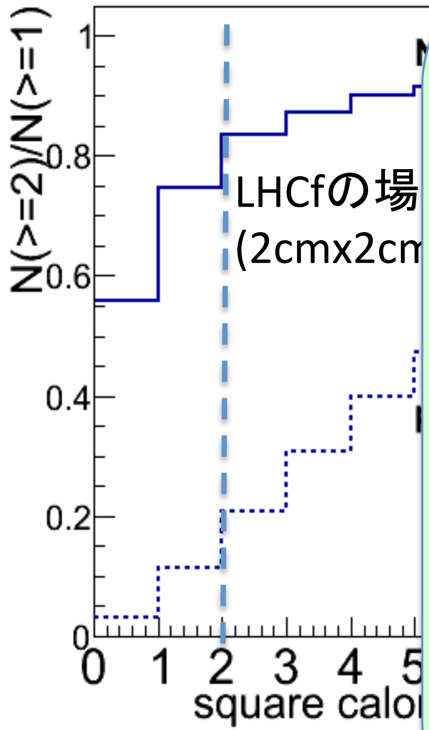


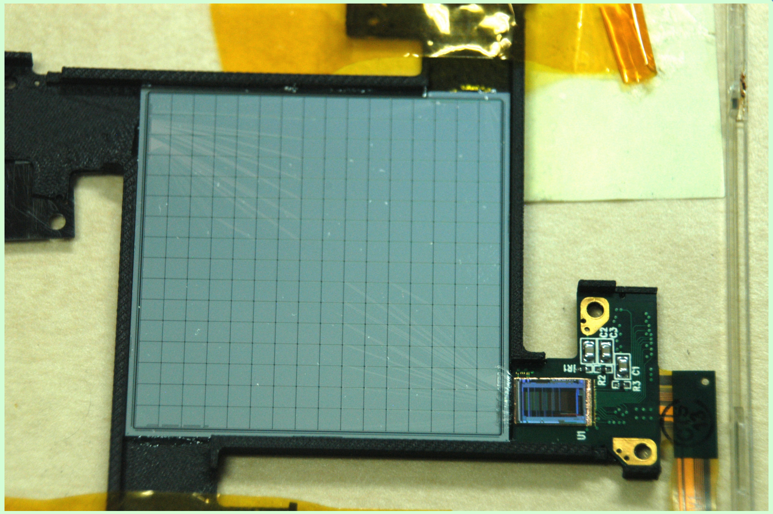
原子核衝突では、小型カロリーメータでも多重入射は避けられない

カロリーメータの「ピクセル化」で多重入射の測定を可能にする

High multiplicity calorimeter by Silicon pad

超前方カロリーメータにおける多重度

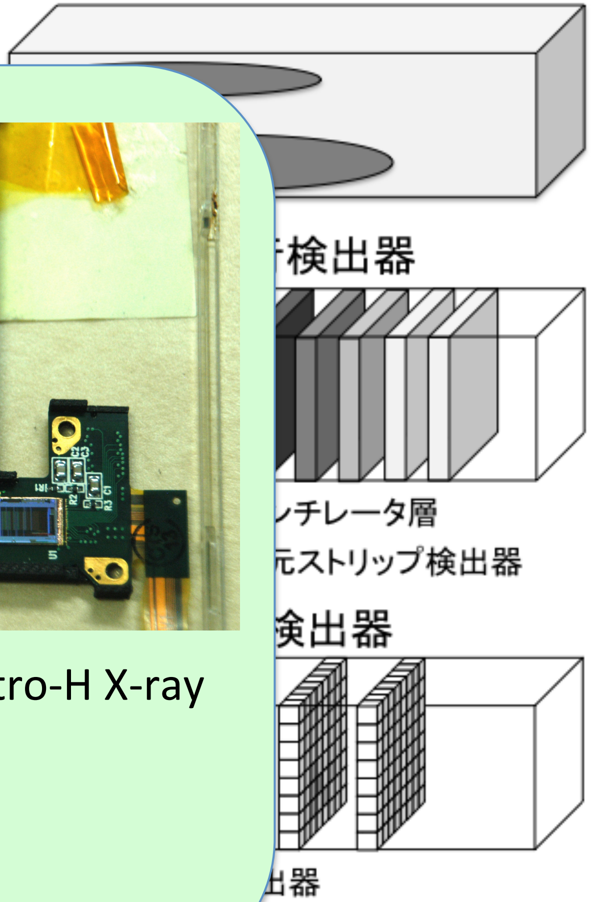




Silicon pad used in the Astro-H X-ray satellite, SDG detector

↓

R&D ongoing



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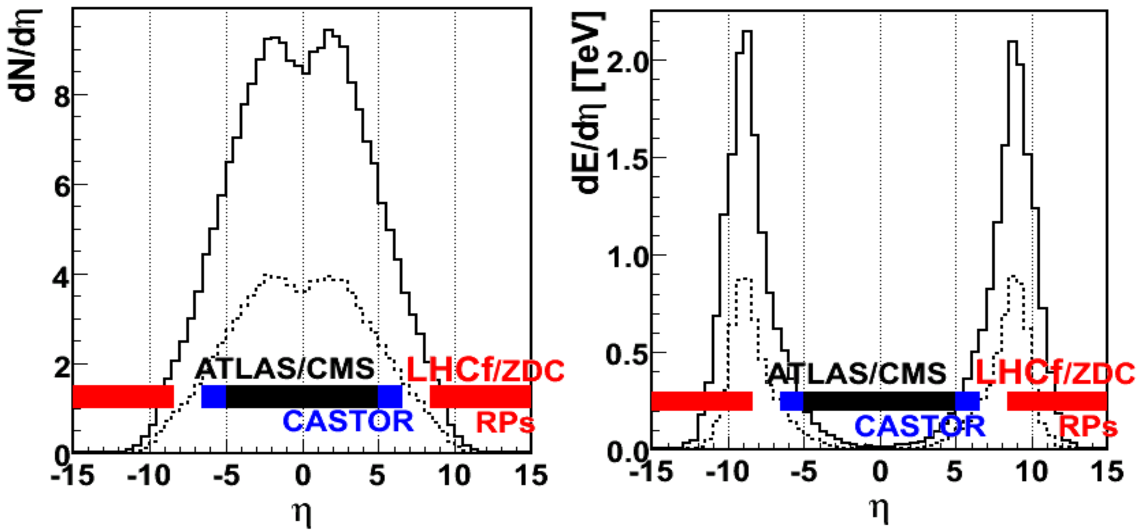
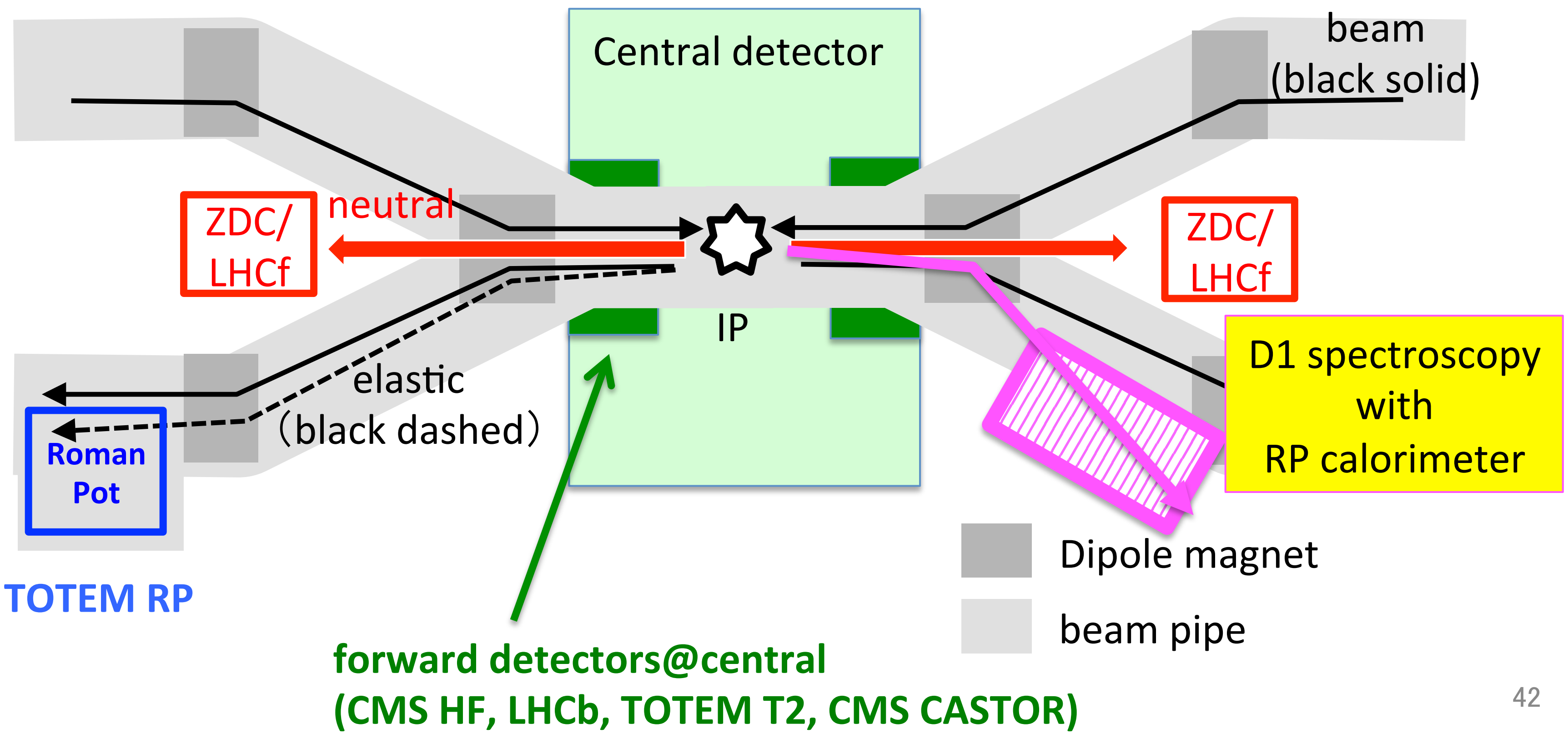
Covering η gap

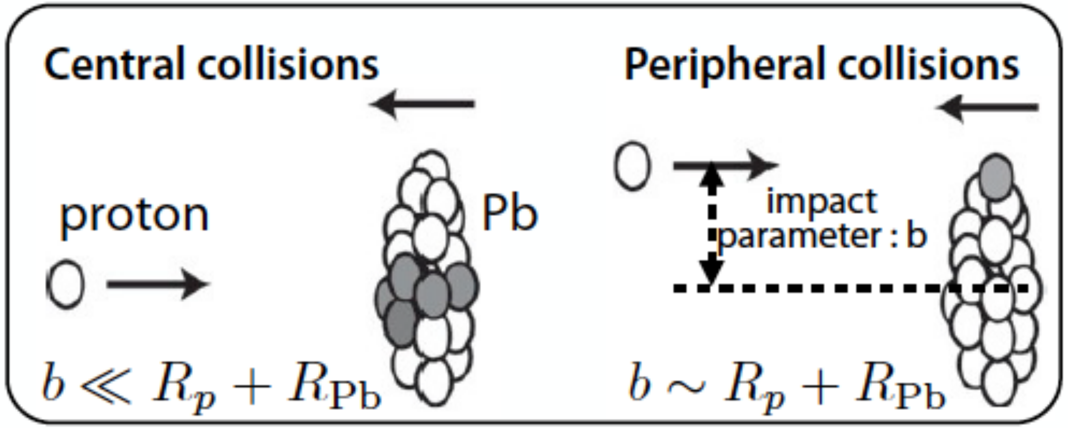


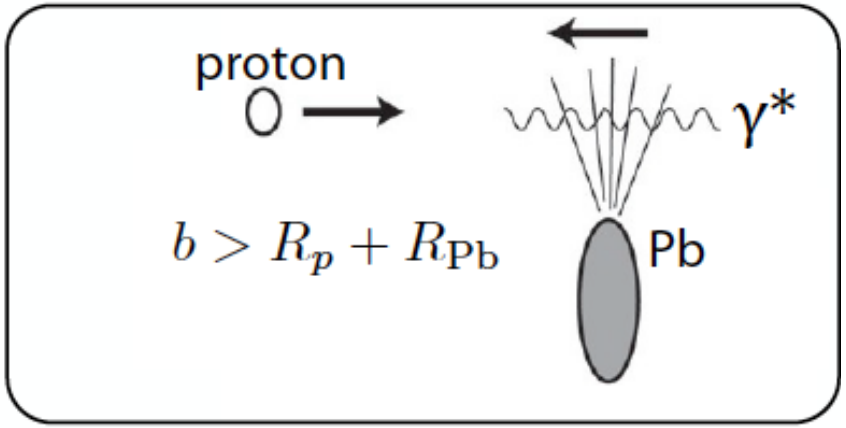


π^0 event analysis in p-Pb collisions

(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_γ > pion threshold).
3. produced mesons and baryons by γ-p collisions are boosted along the proton beam.

(1. and 2.: proton rest frame)

Dominant channel to forward π^0 is
$\gamma + p \to \Delta(1232) \to p + \pi^0$
About half of the observed π^0 may originate in UPC, another half is from soft-QCD.