Results from the LHCf calorimeter

Takashi Sako for the LHCf collaboration

ICRR, University of Tokyo

and RUN3 prospects

Results from the LHCf calorimeter

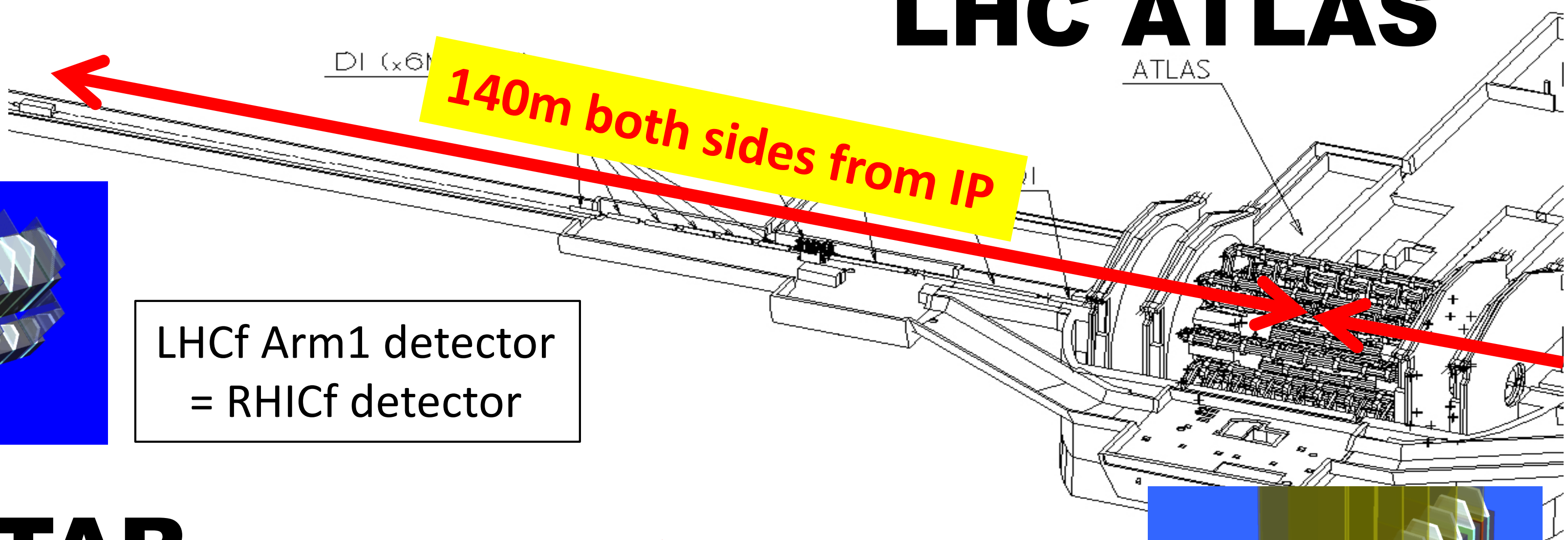
and RHICf

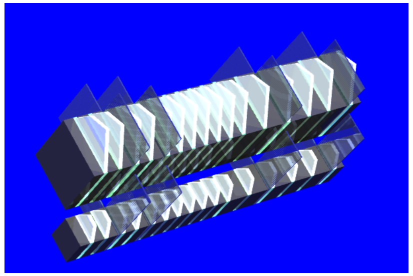
Takashi Sako for the LHCf collaboration

ICRR, University of Tokyo

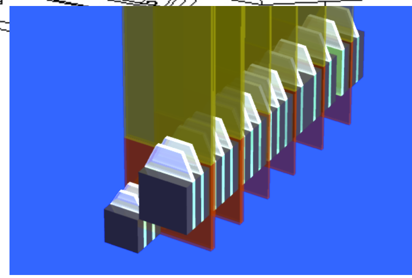
LHC forward and RHIC forward

LHC ATLAS



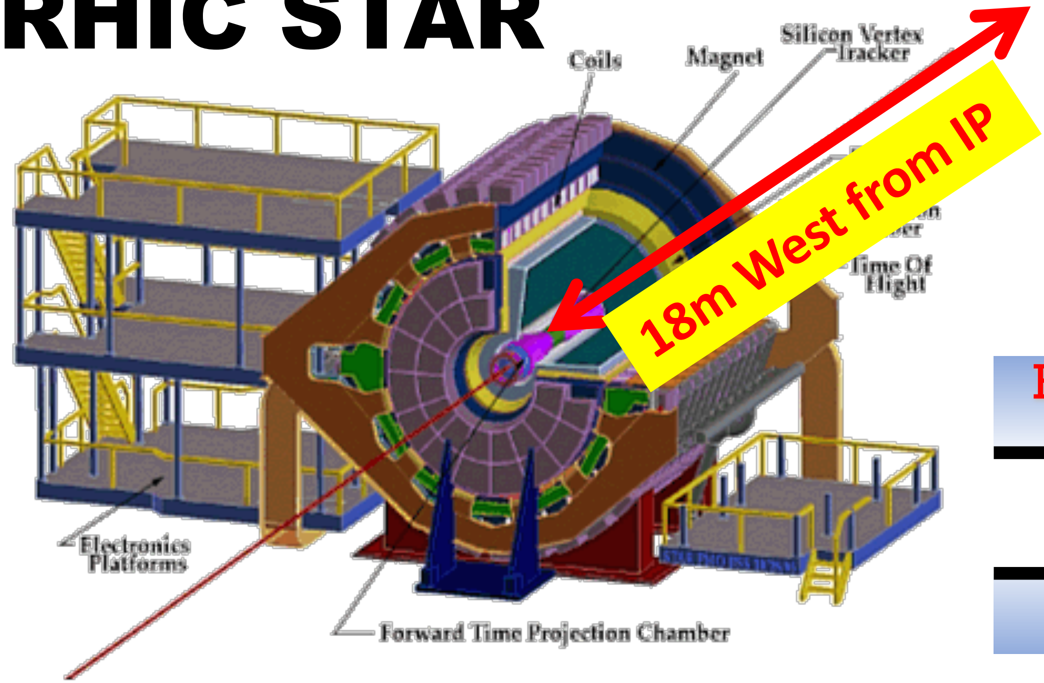


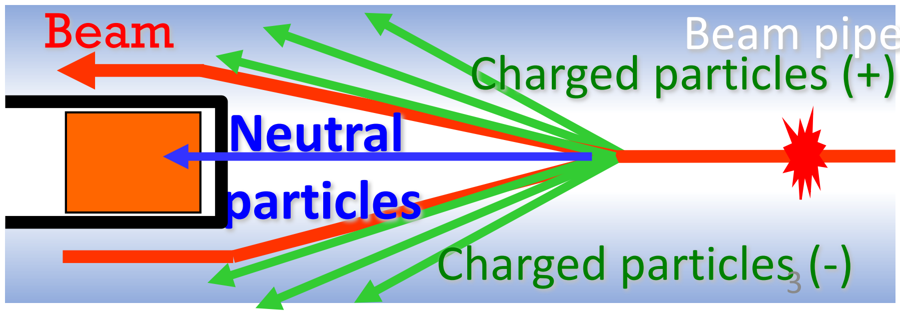
LHCf Arm1 detector
= RHICf detector



LHCf Arm2 detector

RHIC STAR





The LHCf collaboration

Y.Itow, K.Masuda, Y.Matsubara, H.Menjo, Y.Muraki, K.Ohashi, K.Sato, M.Ueno, Q.D.Zhou, T.Sako, K.Yoshida, K.Kasahara, S.Torii, Y.Shimizu, T.Tamura, N.Sakurai, M.Haguenauer, W.C.Turner, O.Adriani, E.Berti, L.Bonechi, M.Bongi, G.Castellini, R.D'Alessandro, P.Papini, S.Ricciarini, A.Tiberio, A.Tricomi

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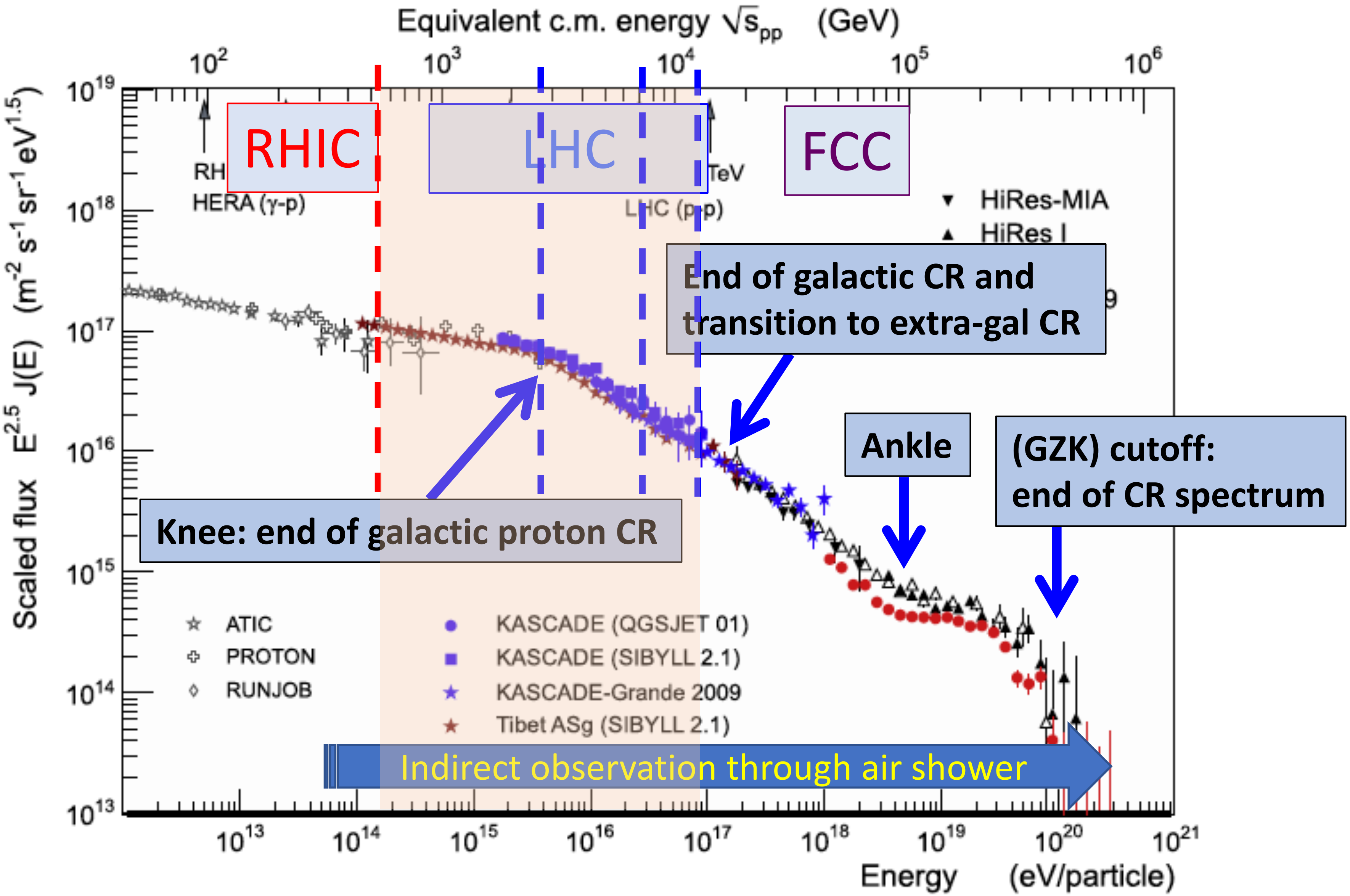
The RHICf collaboration

Y.Itow, H.Menjo, K/Ohashi, K.Sato, M.Ueno, Q.D.Zhou, T.Sako, Y.Goto, I.Nakagawa, R.Saidl, J.S.Park, M.H.Kim, K.Tanida, K.Kasahara, S.Torii, N.Sakurai, B.Hong, O.Adriani, E.Berti, L.Bonechi, R.D'Alessandro, A.Tricomi

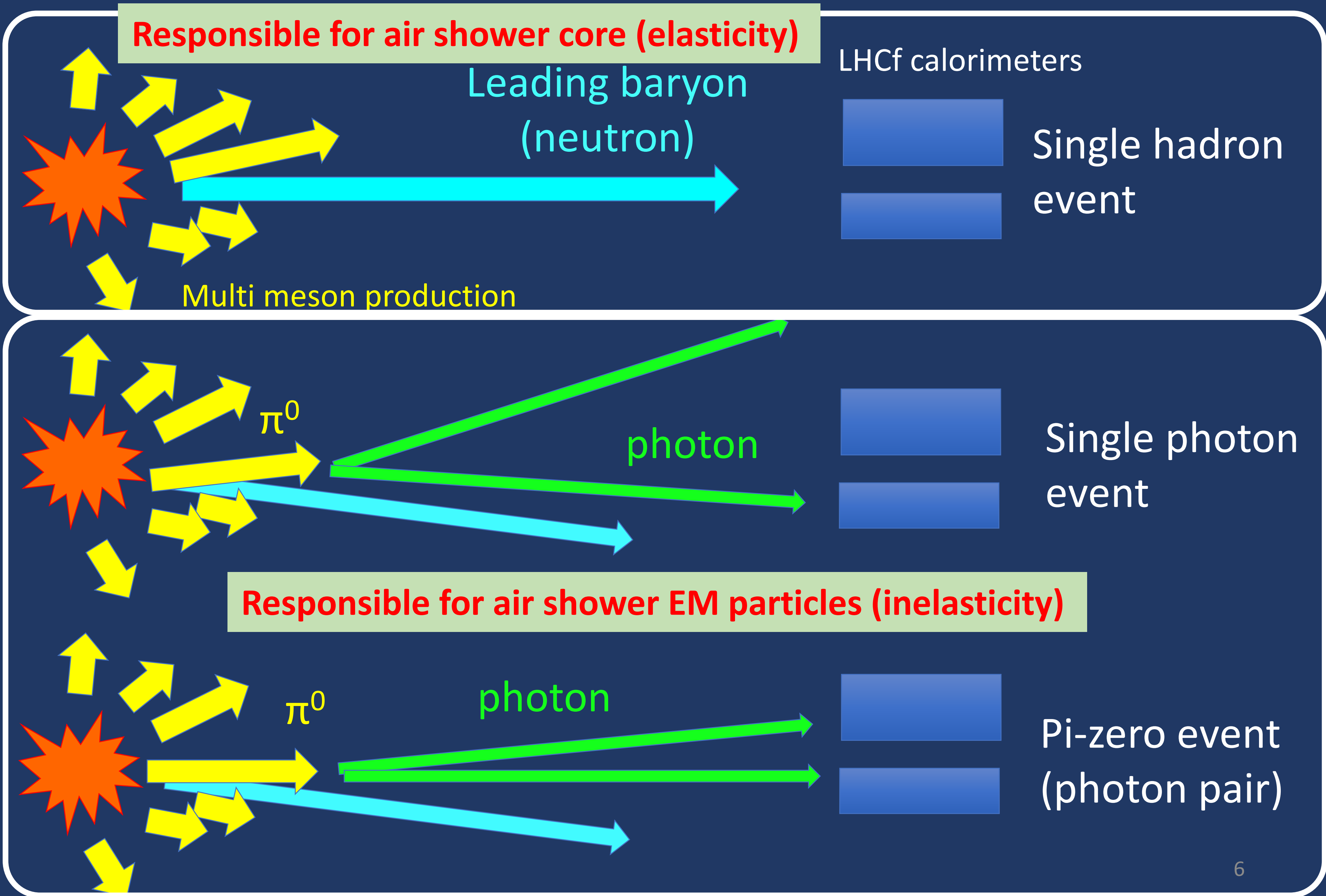
Institute for Space-Earth Environmental Research, Nagoya University, Kobayashi-Maskawa Institute, Nagoya University, Graduate School of Science, Nagoya University, ICRR, University of Tokyo, Riken/Riken BNL Research Center, JAEA, Waseda University, Tokushima University, Japan, Seoul National University, Korea University, Korea, INFN, Univ. di Firenze, INFN, Univ. di Catania, Italy

Cosmic-ray spectrum and collision energy

（D’Enterria et al., APP, 35,98-113, 2011 ）

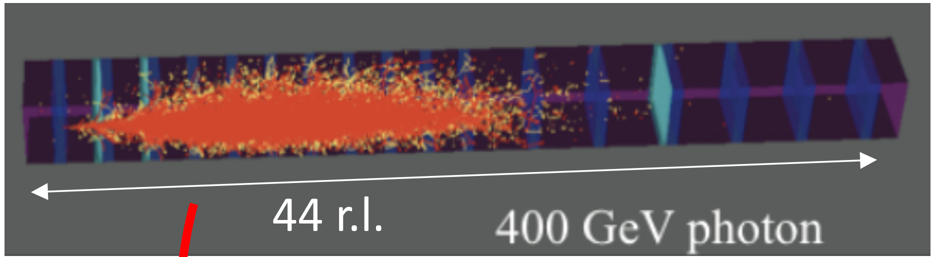


Event categories of LHCf/RHICf

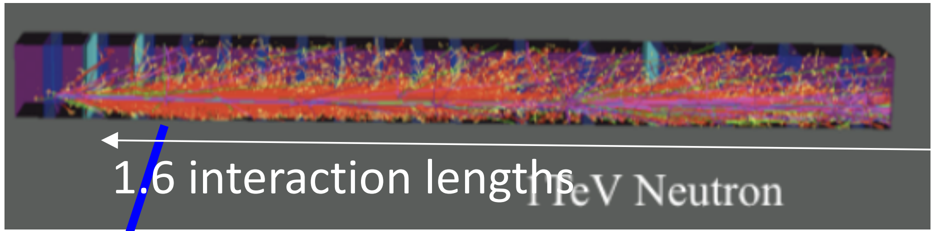


Particle ID (PID)

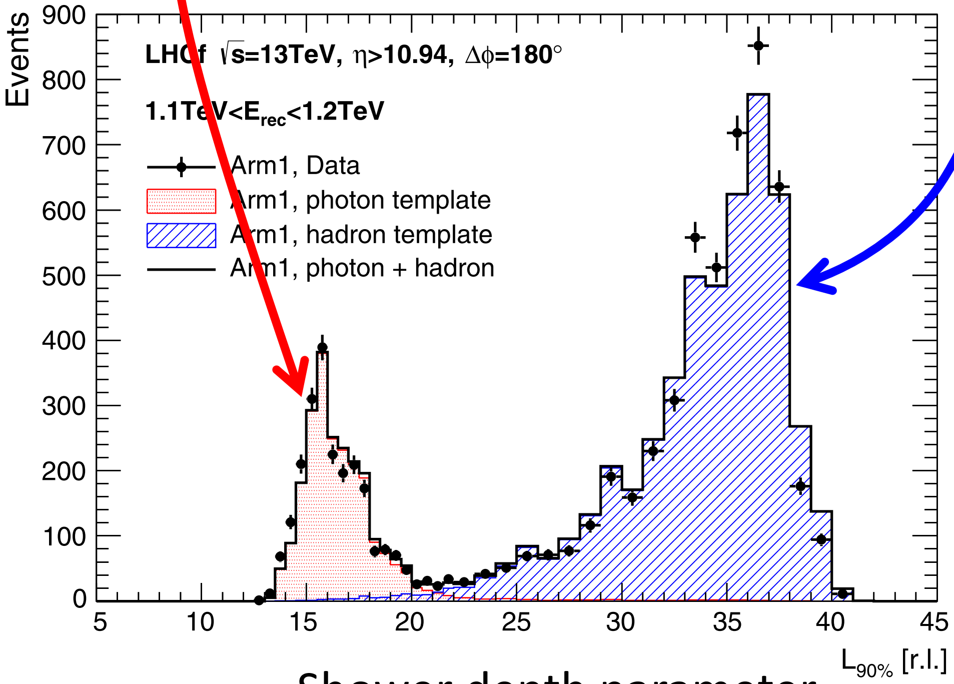
Photon event



Neutron event

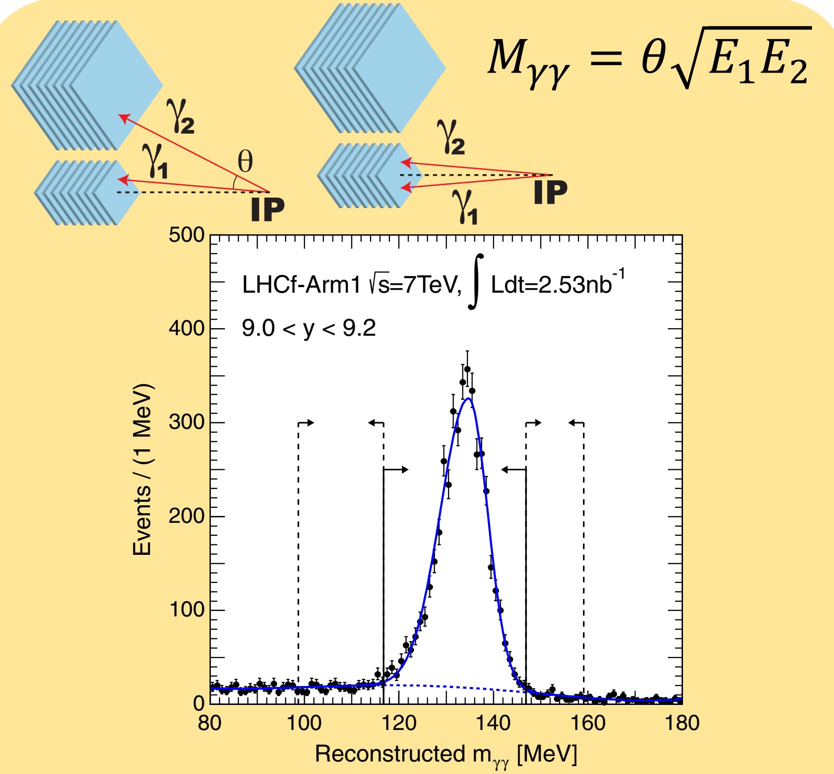


(Adriani et al., PRD, 2012)



Shower depth parameter

(Adriani et al., PLB, 2018)

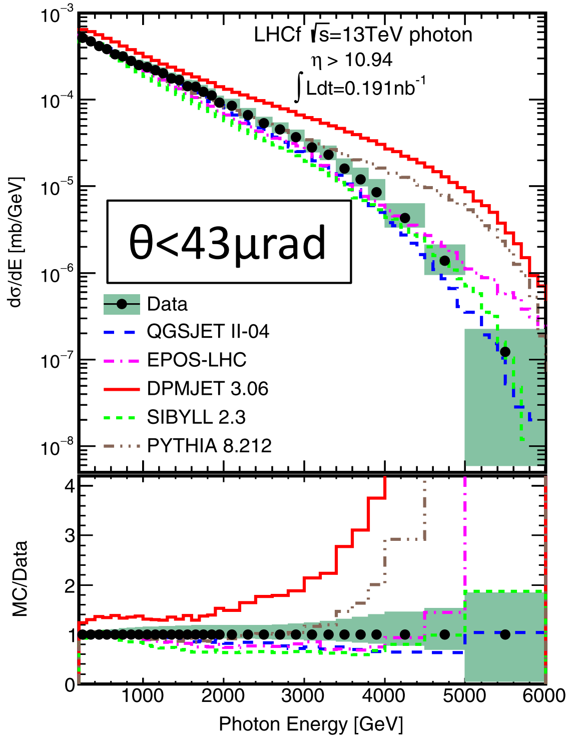


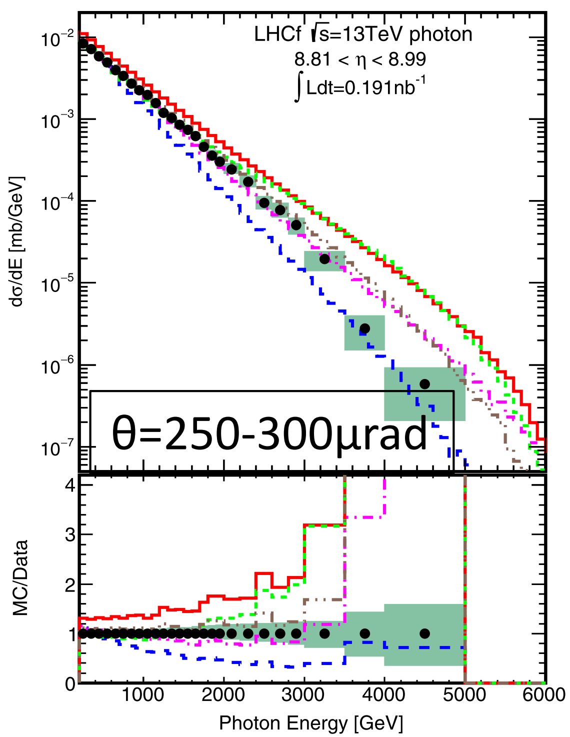
Invariant mass of photon pair

Peak @ 135MeV from π^0 decay events

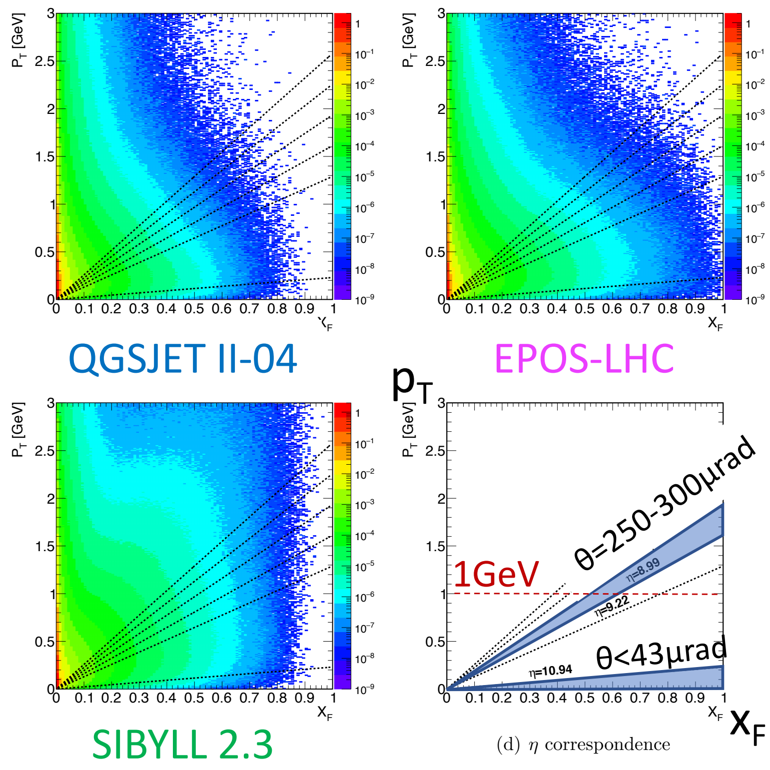
Photon ($\pi^0 \rightarrow 2\gamma$) production cross section in LHC 13TeV p-p collision

PLB, 780 (2018) 233-239

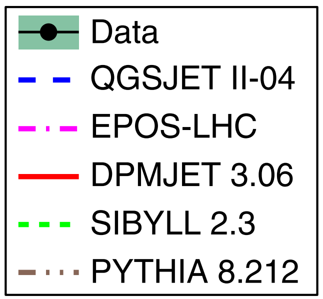




Predictions in x (=E_γ/E_p) vs. p_T

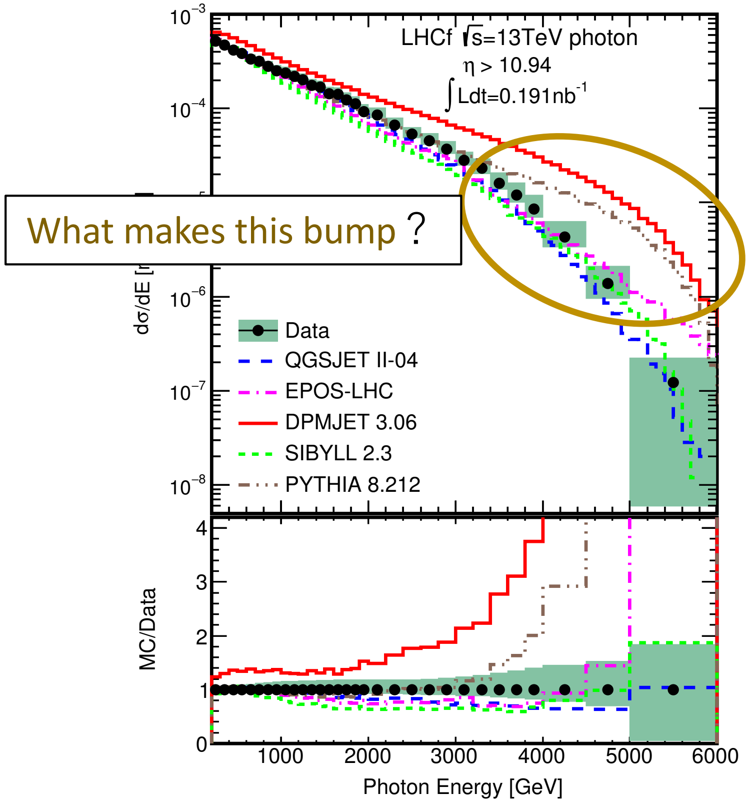


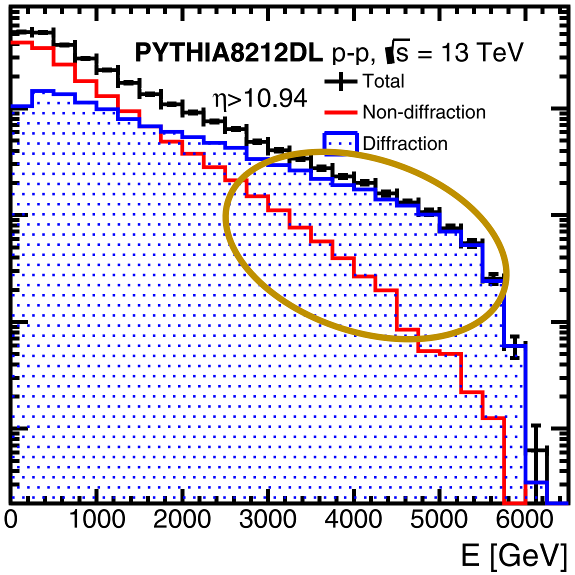
Y. Makino, PhD thesis（2017） CERN-THESIS-2017-049



- PYTHIA8, DPMJET3 overestimate
- SIBYLL2.3 under(over) estimates at small (large) angle
- QGSJET II-04 underestimates
- EPOS-LHC shows best agreement (slight overestimate near maximum energy)

Origin of photons

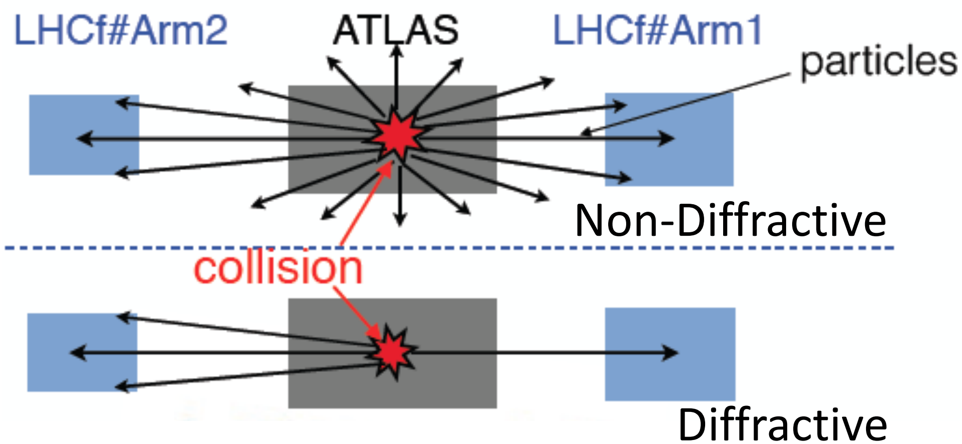




Zhou, Itow, Menjo and Sako, EPJC (2017) 77:212

Diffractive

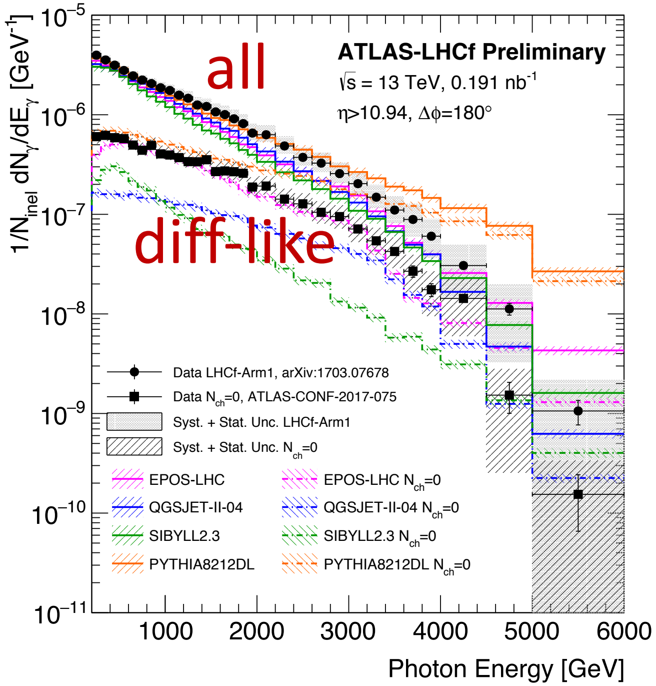
Non-diffractive

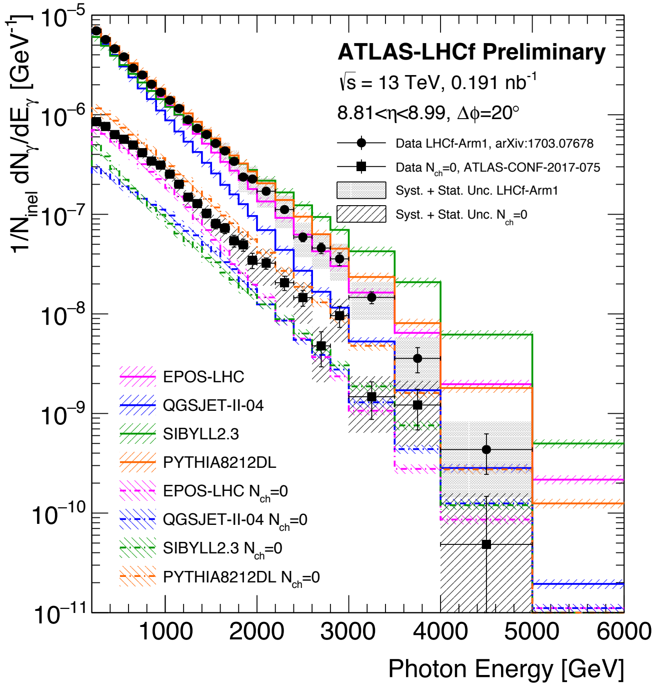


- PYTHIA predicts different spectra between diffractive and non-diffractive interactions
- ATLAS inner tracker enables to categorize events in diffractive-like and non-diffractive-like

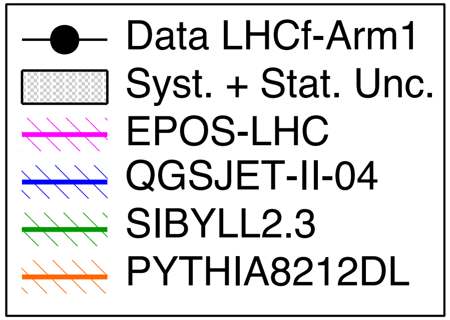
ATLAS-LHCf joint analysis

LHCf (all; ● +solid lines), LHCf diffractive-like (■ +dashed lines)

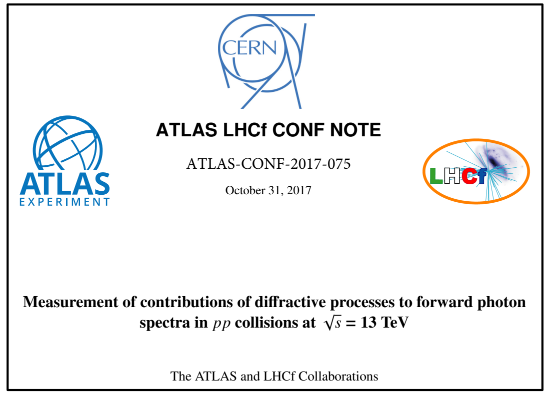




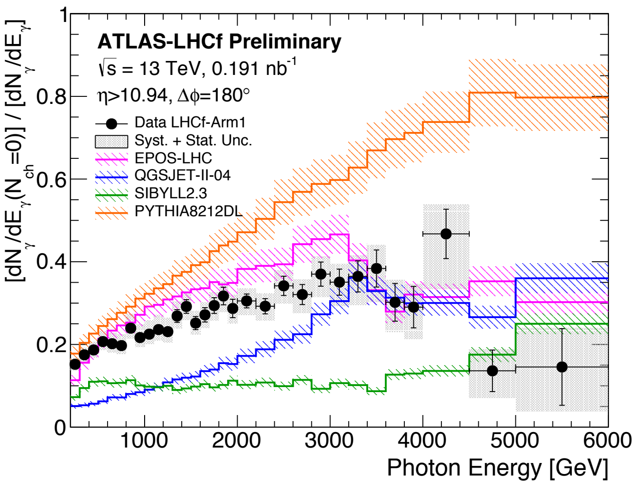
- Use ATLAS N_{ch}=0 to define diffractive-like events
- Applied to LHCf photon cross sections

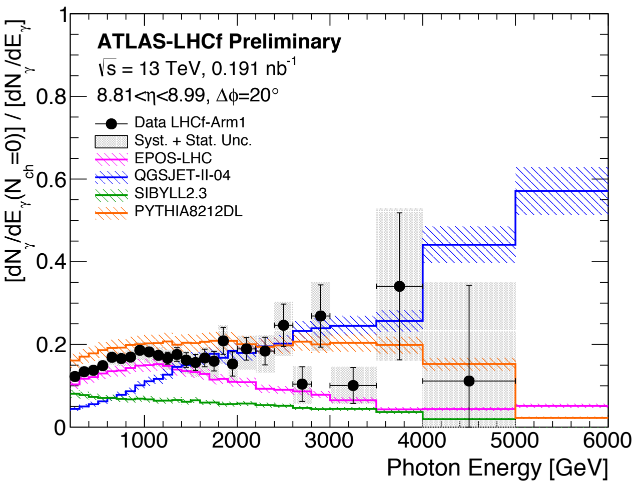


ATLAS-CONF-2017-075



diffractive-like/ all

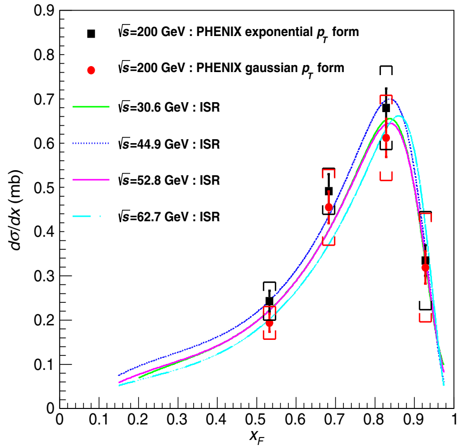




SD, DD separation with MBTS in progress for publication

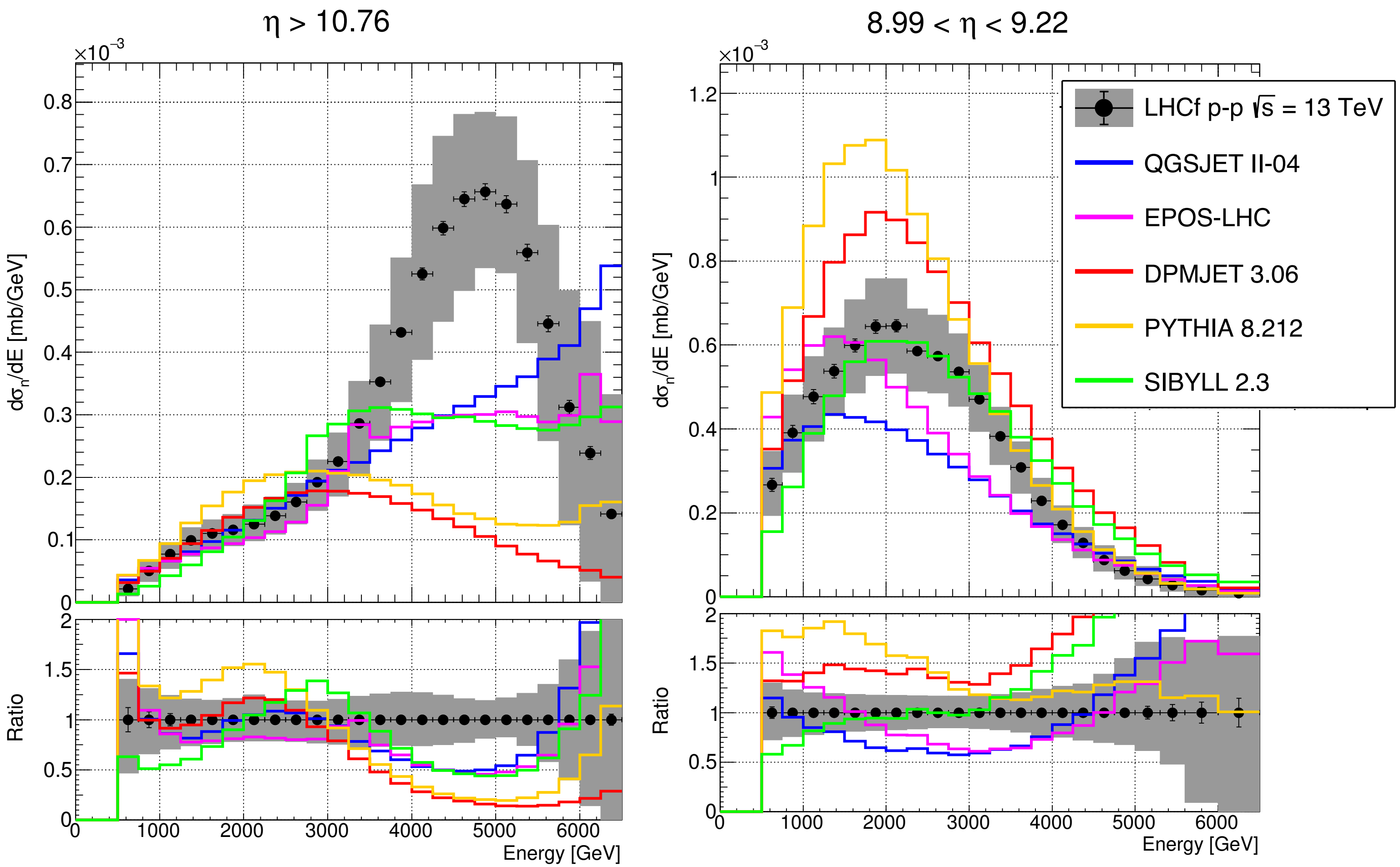
Neutron in 13TeV p-p collisions

JHEP11 (2018) 073



ISR, RHIC(PHENIX)

NOTE:p_T range is not same



- Peak structure around 0 degree is similar to the previous results

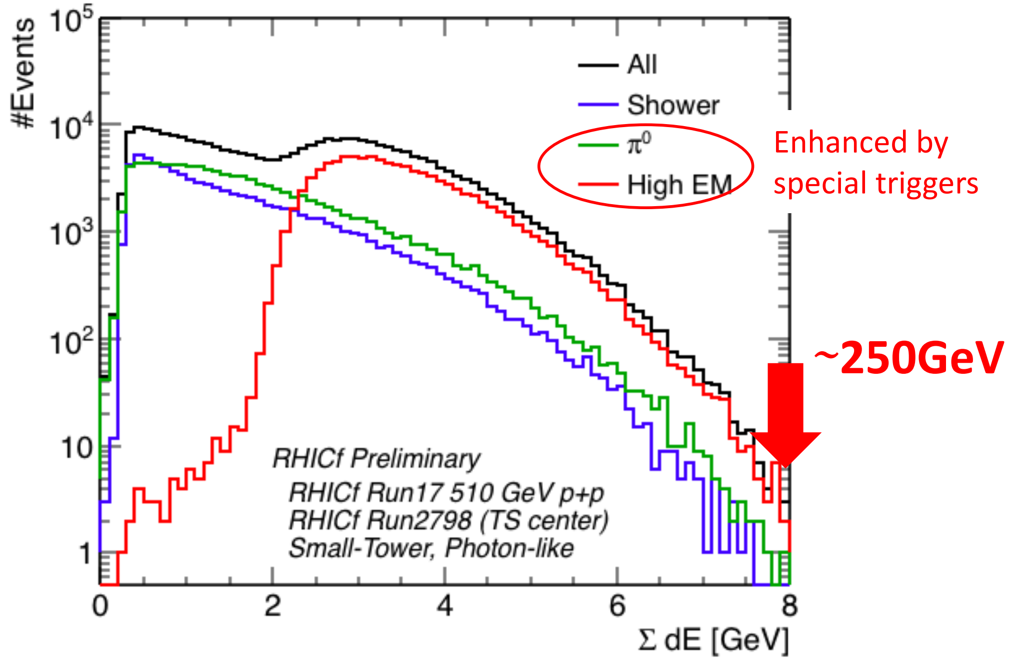
  (NOTE: p_T range is wider than the previous analyses. Analysis for direct comparison in progress.)

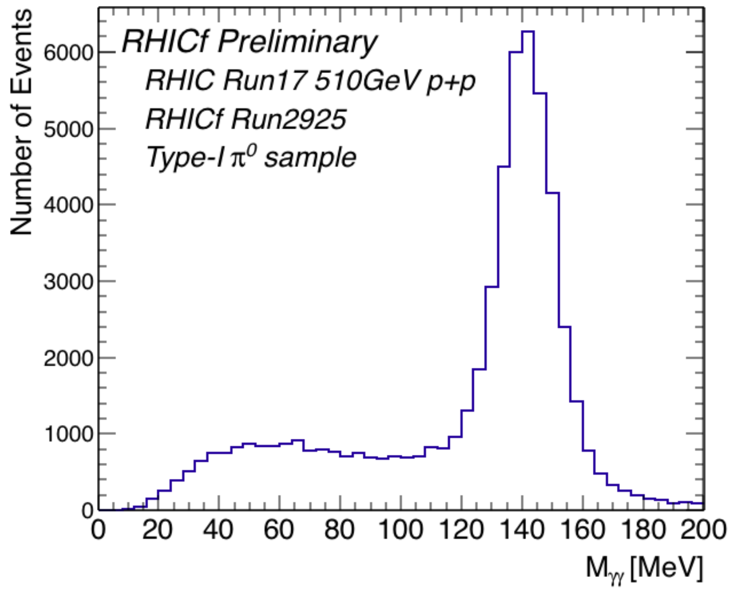
- Effect of 40% energy resolution is unfolded

RHICf: Successful operation in 2017

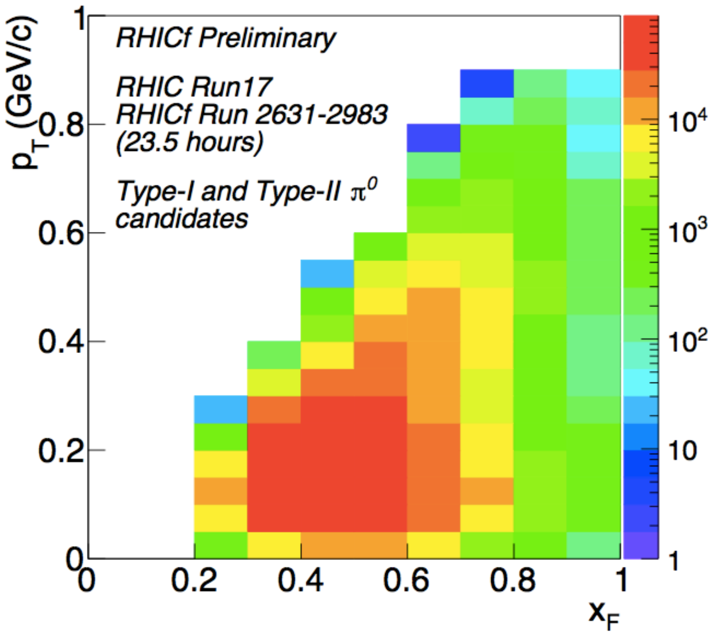
$\sqrt{s}$ = 510GeV p+p => 1.4 × 10^{14} eV CR

- Energy spectrum of EM−like showers in a 30 minutes run
- High−energy EM showers and π^0 were selectively triggered to compensate the limited DAQ speed.



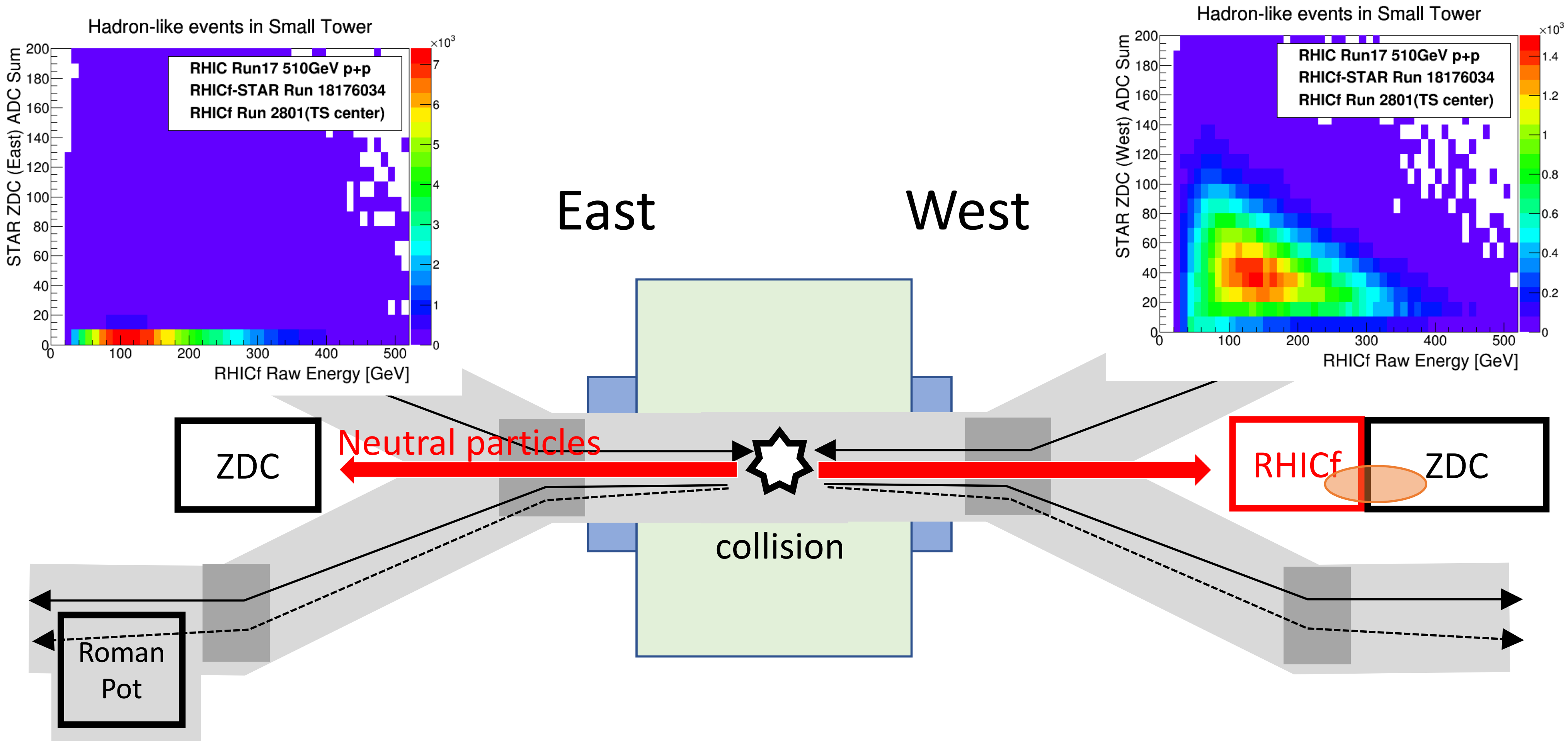


Invariant mass of photon pairs
=> 135MeV peak by π^0



Number of reconstructed π^0 candidates

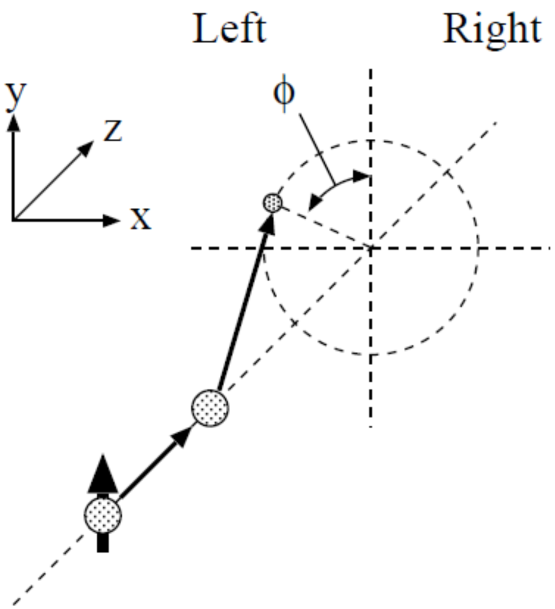
RHICf: common run with STAR

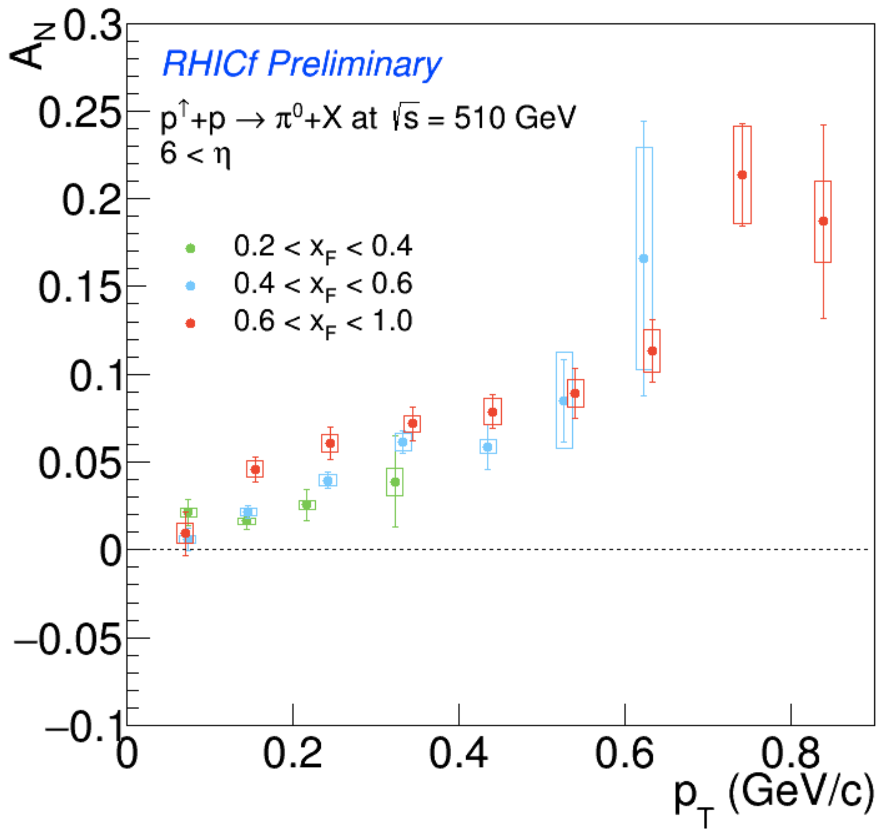


- Hadron-like (deep penetrating) showers were selected
- Anticorrelation between the RHICf raw (folded) energy and ZDC measured energy (in ADC unit) is confirmed
- (Anti)correlation only with West ZDC as expected => correct event matching

RHICf: π^0 single spin asymmetry

arXiv:1902.0785





LHCf Run3

LHCf

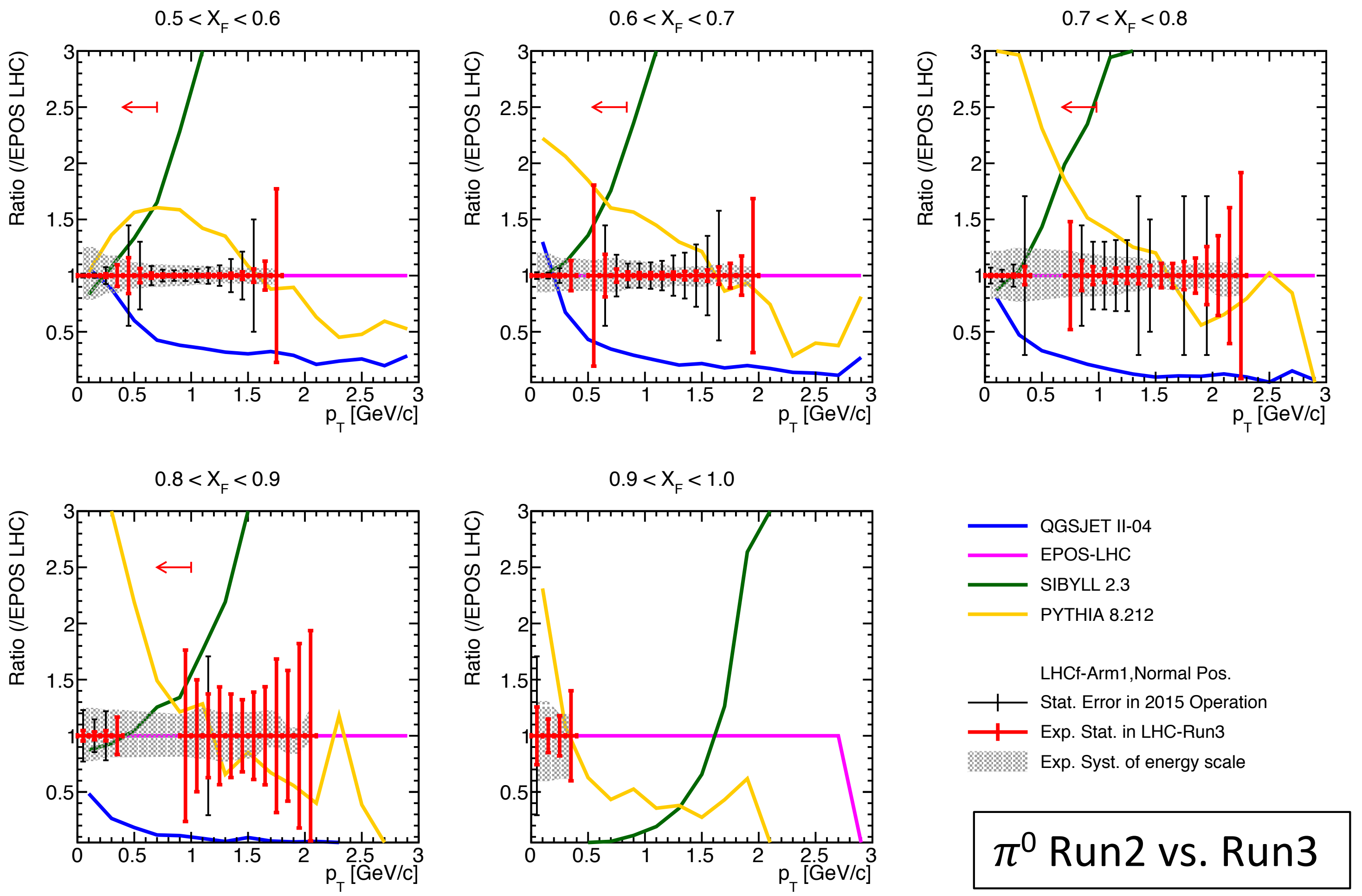
Technical Proposal for the LHC Run3

Addressing Cosmic Ray physics with forward measurements in proton–proton and proton–light nuclei collisions at LHC

Approved by Research Board

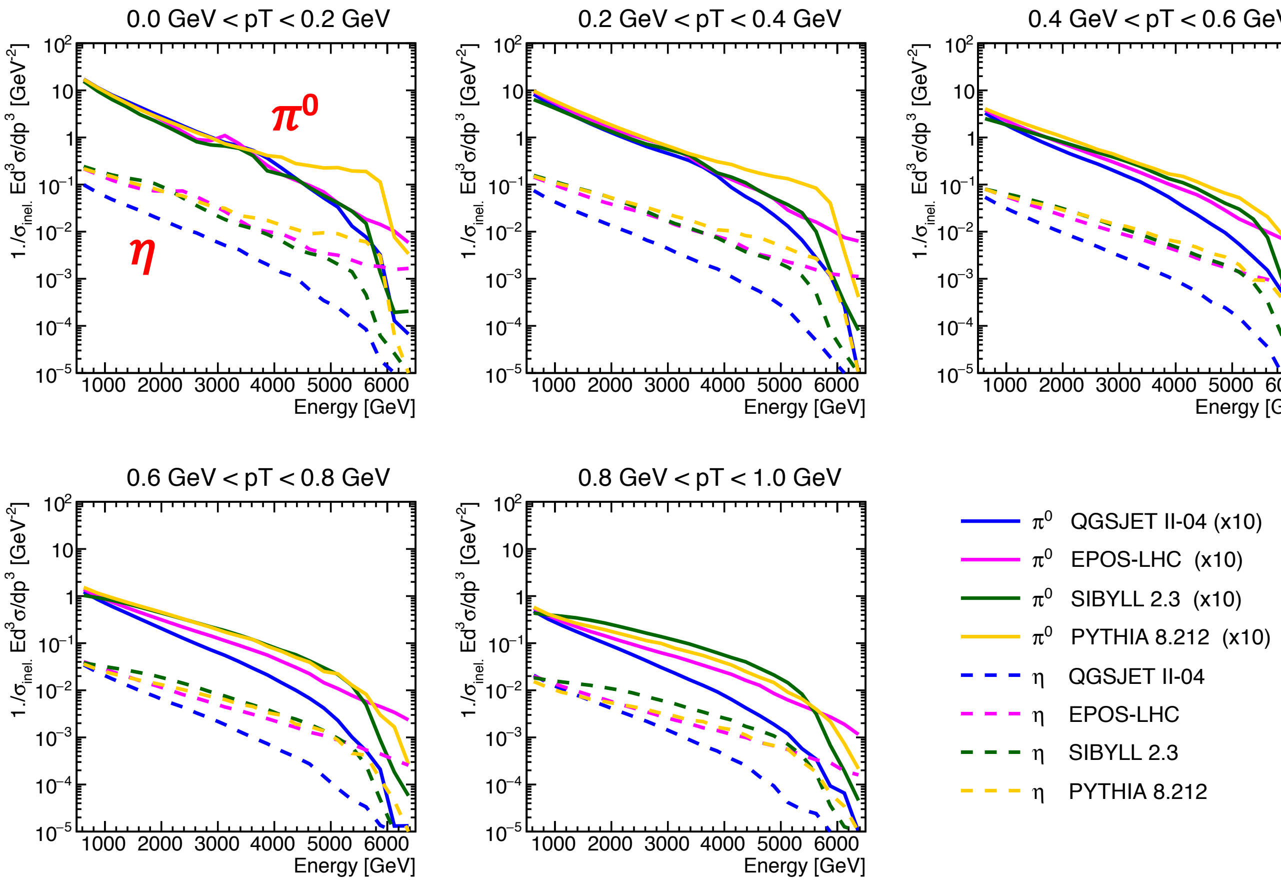
Contents

p+p: Operation under higher luminosity



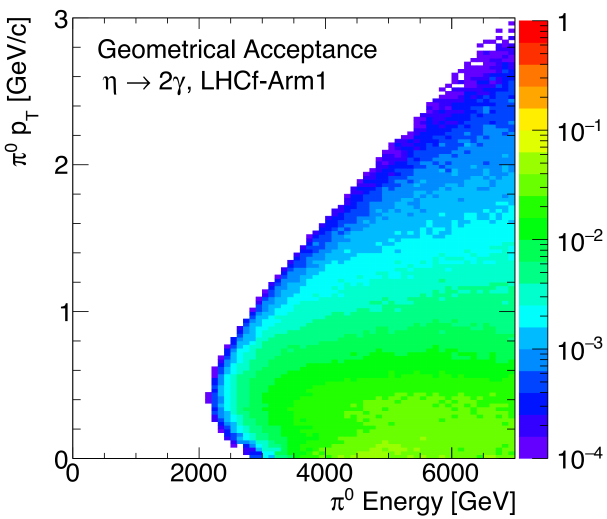
π^0 Run2 vs. Run3

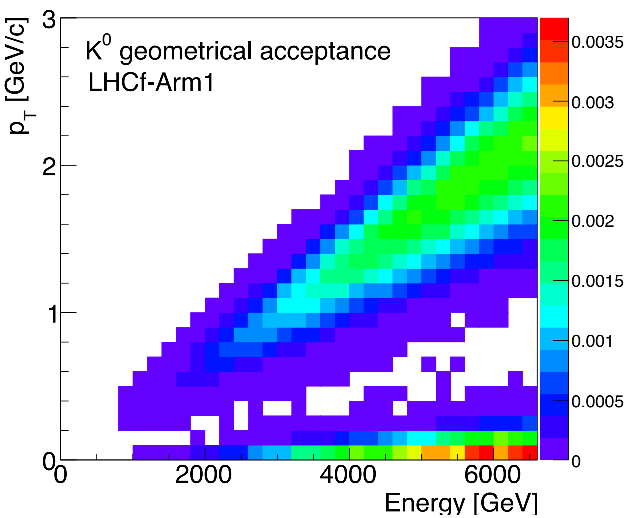
- Sophisticated trigger and faster DAQ read out allow
  - More π^0
  - More η
  - Possibly K^0



π^0 vs. η

η, K^0 acceptance

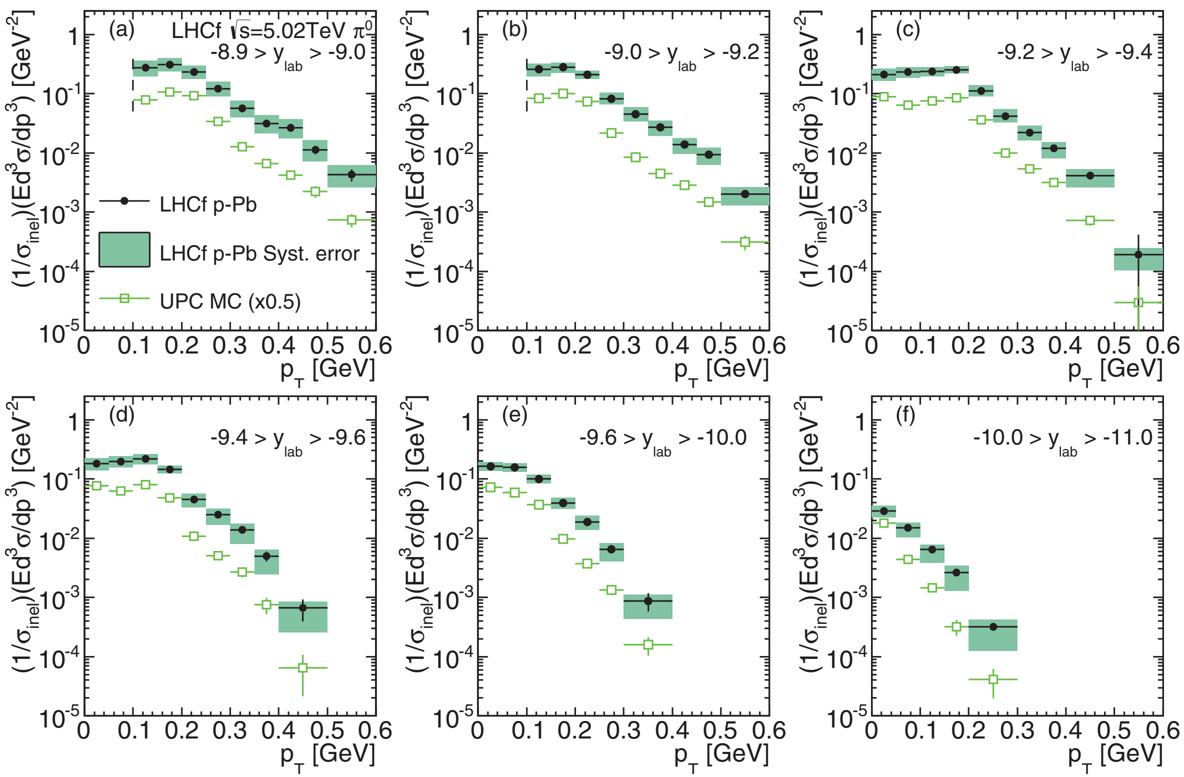




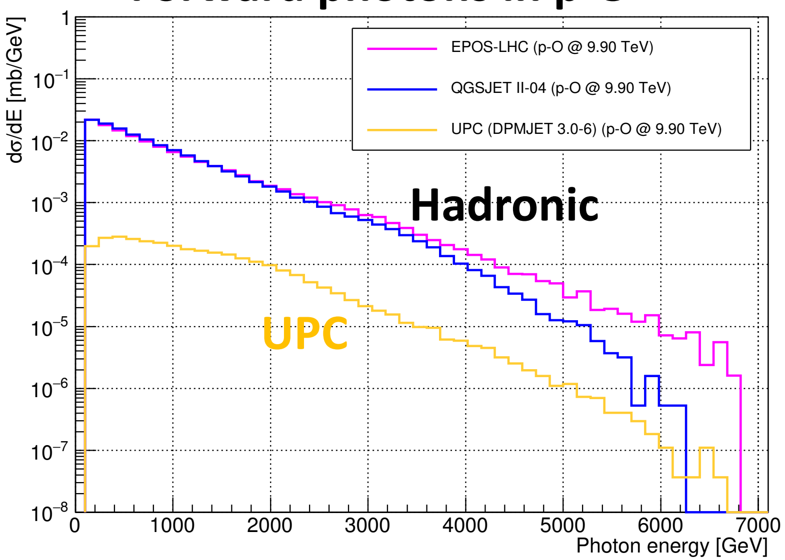
Oxygen, finally…

- Not only more atmosphere-like…
- π^0 measured by LHCf in p-Pb collision
- Half of events comes from UPC, not relevant for atmospheric air shower

Forward photons in p-Pb (LHCf) PRC 89, 065209 (2014)



Forward photons in p-O



- Forward photons in LHC p-O collisions
- Less systematic uncertainty to study hadronic interaction than p-Pb

First discussion of light ion collisions at CERN

30-Aug-2012

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Dear all,
                 here's a summary of our discussion, corrections/comments welcome.
Cheers
                     Django
==============================================================
Preliminary discussion on the feasibility of N-N, p-N and Fe-N collisions in the LHC

Present:
Sako, Hannes, Detlef, Simone, John, Reine, Michaela, Django.

Introduction by Sako:
The experiment LHCf is motivated to understand the interaction between cosmic-rays and atmosphere, and hence the origin of the cosmic-ray
particles up to 10^20 eV.  The p-p and p-Pb collisions at LHC give important fundamental information for this study.  However, clearly, in
the atmosphere the target of the interaction is light nuclei like Nitrogen and Oxygen.  The direct measurements of p-N,
N-N to Fe-N are very interesting to understand the nuclear effect in the interaction but there are no such experiment carried out using
colliders. LHCf is interested in using the LHC as a light ion collider in the future.
Of course, these collisions are not prime target of the LHC science.  But is it technically possible? And what is necessary to realize such
experiments in future?

Discussion:
- As there is only one ion source at present, only p-N and N-N can be considered in the near future.
- Production of nitrogen in the ECR source is not a problem as it is a gas, neither is Fe as there are techniques to produce it easily
(MIVOC). But afterwards the source needs several weeks to repliably produce Pb in a stable manner.
- LHCf does not need a lot of running time, only a few days, and since it is looking at high cross-section events, the luminosity does not
need to be very high.
- ALICE is not interested in other ions than Pb, but an N-N ion run would not take many days out of the LHC programme. It would, however,
use a lot of resources from the injectors team. In fact the schedule would be dominated by the setting up and commissioning in the
injectors, not by the collisions. Preparation of a N-N run would also take a lot of time from the regular fixed target programme.
- One can imagine to start preparing the source with N in early January, commission the circular accelerators, and have a N-N or p-N run in
autumn, before switching to Pb. But then it would take too long for the source to stabilise to have a Pb-Pb run before Xmas. This would
only work during a year where there is no Pb-Pb run, or when it is postponed to after Xmas like this year.
- Oxygen on the other hand is also abundant in the atmsophere and could be a viable alternative. It is used in the ECR as a support gas for
Pb production. One can consider tuning the source and transport systems for oxygen while preparing for a Pb run, still using Pb in order to
keep conditions optimal. A short O-O or p-O run could be compatible with a "normal" collider schedule, possibly in 2020.
- Nitrogen could be used as support gas too, but would be less efficient for Pb production so the idea is not retained.
- In the longer term future, if the medical facility is approved, a switchyard and a second source, able to provide any ion from p to Ne,
will be built. It should then be possible to collide Pb-N, or even Fe-N, after 2022.
- As a conclusion, there is no technical show-stopper, and LHCf can go ahead with a letter of intent.

                                                                                  Minutes by Django
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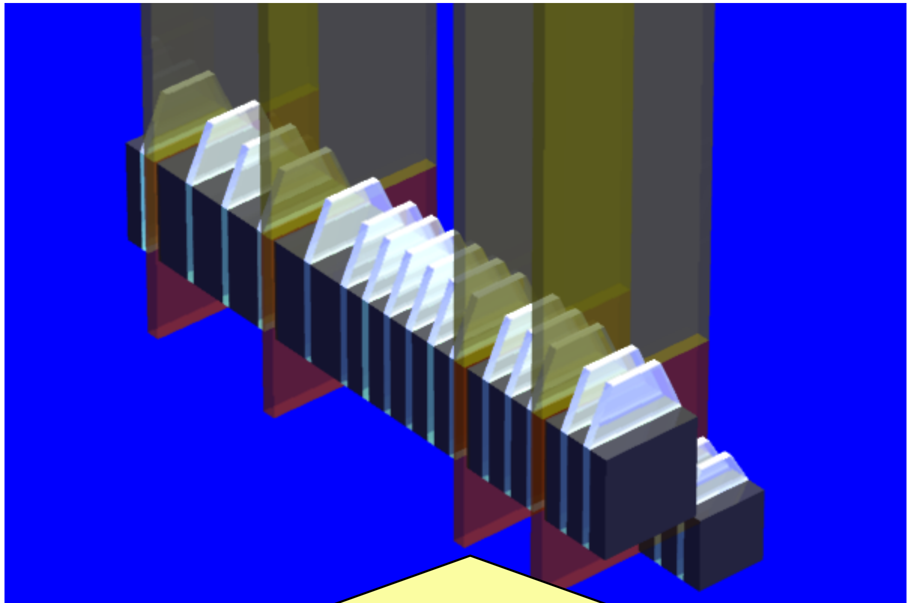
Summary

- LHCf and RHICf cover CR energy from 10^{14}eV to 10^{17}eV, important for air shower studies and for interpolation/extrapolation
- LHCf and RHICf demonstrated unique measurements at zero degrees
  - Forward photons, neutrons and π^0's
  - Combination with other detectors, central, roman pots,…
  - ZDC, having wider acceptance and good hadron energy resolution, is an interesting opportunity!!
- LHC Run3, from 13TeV to 14TeV…
  - Not a repeat of Run2
  - More exclusive measurements help model improve
  - Oxygen!!!

Backup

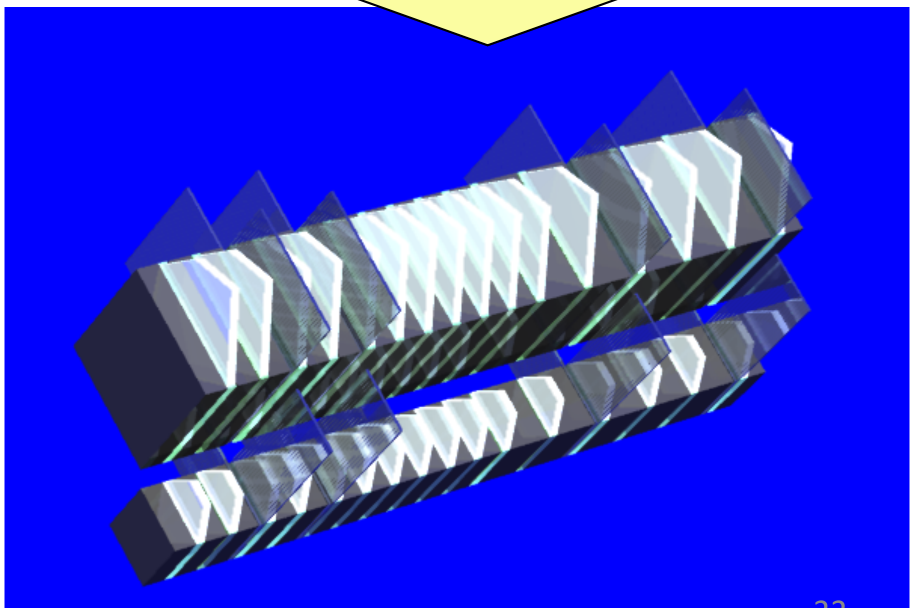
LHCf/RHICf Detectors

- ✓ Imaging sampling shower calorimeters
- ✓ Two calorimeter towers in each of Arm1 and Arm2
- ✓ Each tower has 44 r.l. (1.6λ) of Tungsten,16 sampling scintillator and 4 position sensitive layers
- ✓ Plastic scintillators => GSO scintillators, SciFi => GSO bars in Run2 (13TeV p-p, 8.16TeV p-Pb)

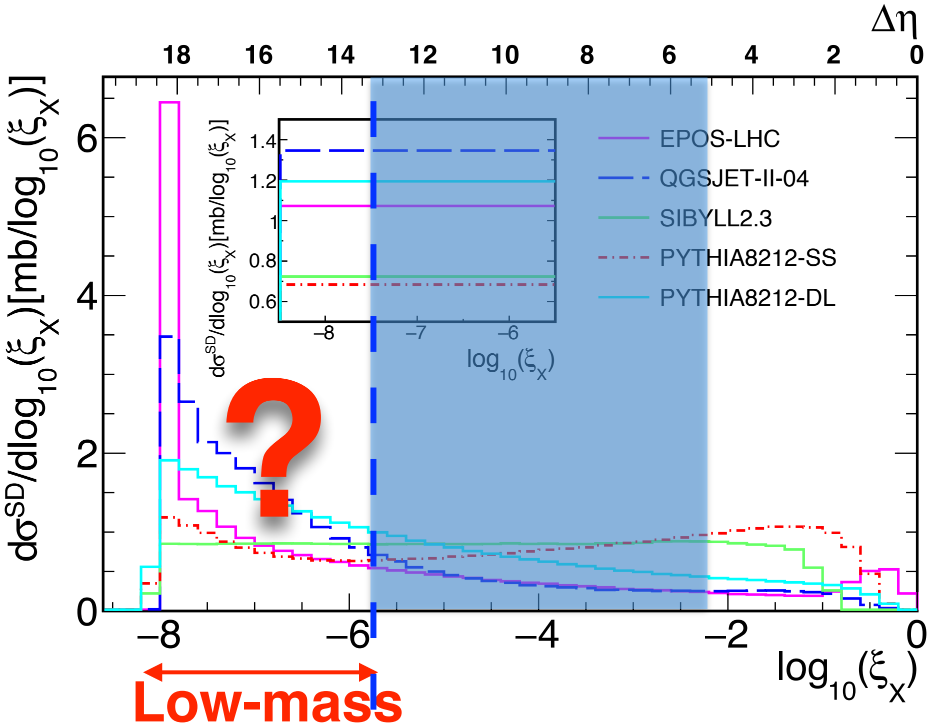


LHCf Arm#2 Detector
25mmx25mm+32mmx32mm
4 XY Silicon strip detectors

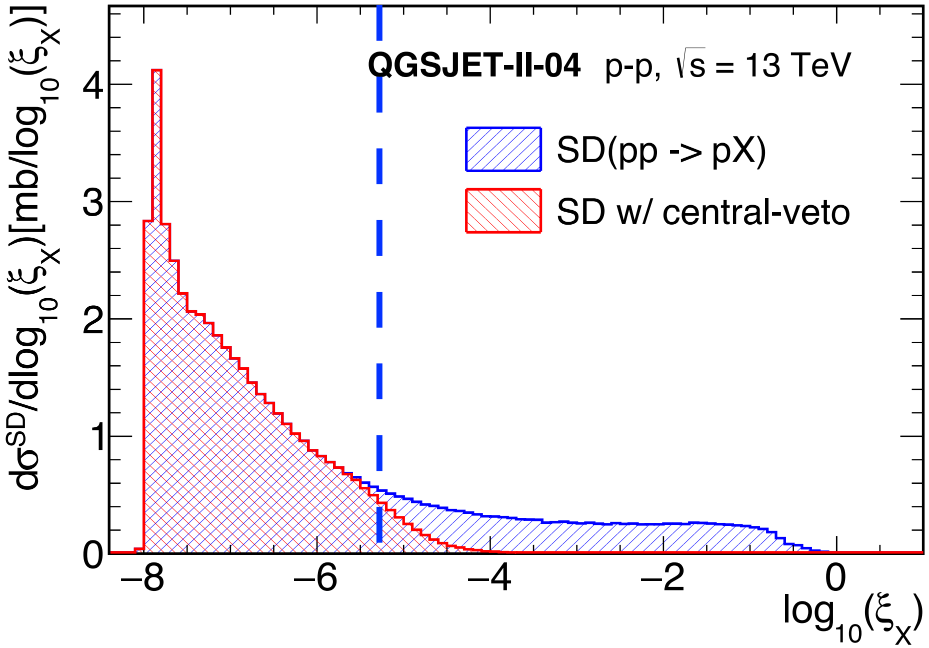
LHCf Arm#1 Detector = RHICf
20mmx20mm+40mmx40mm
4 XY SciFi+MAPMT

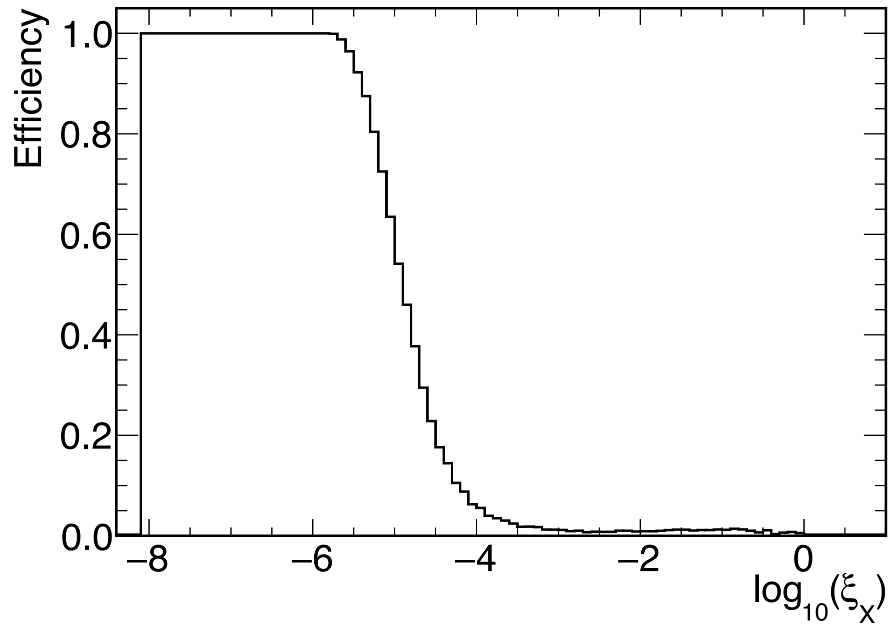


low-mass diffraction事象の感度



- Central-veto は low-mass diffraction ($\log_{10}(\xi_x) < -6.0$)に対して約**100%**の検出効率がある。
- ATLAS-LHCf連動実験によるこれまで測定例のないlow-mass diffraction事象の選別方法を確立。

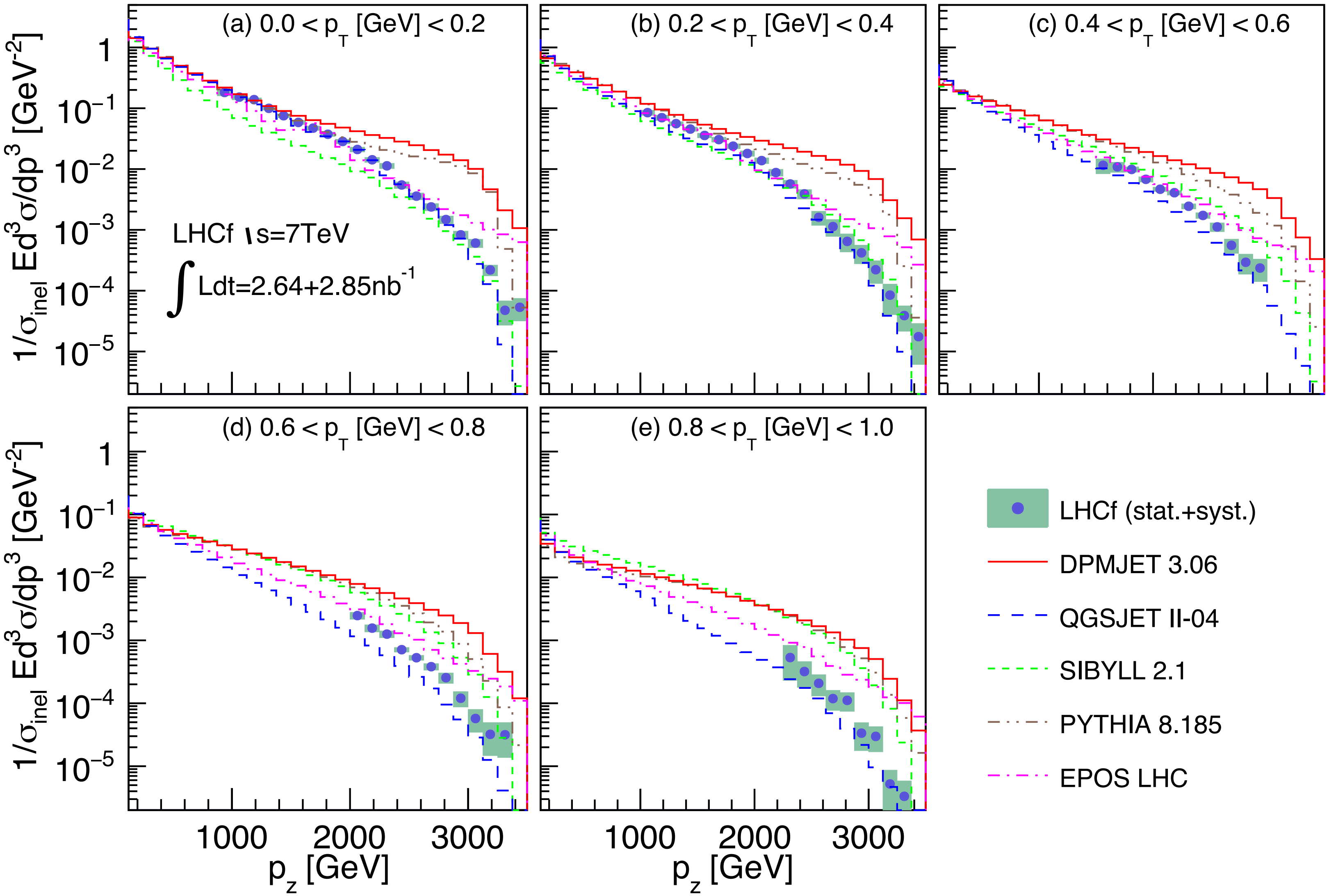




X

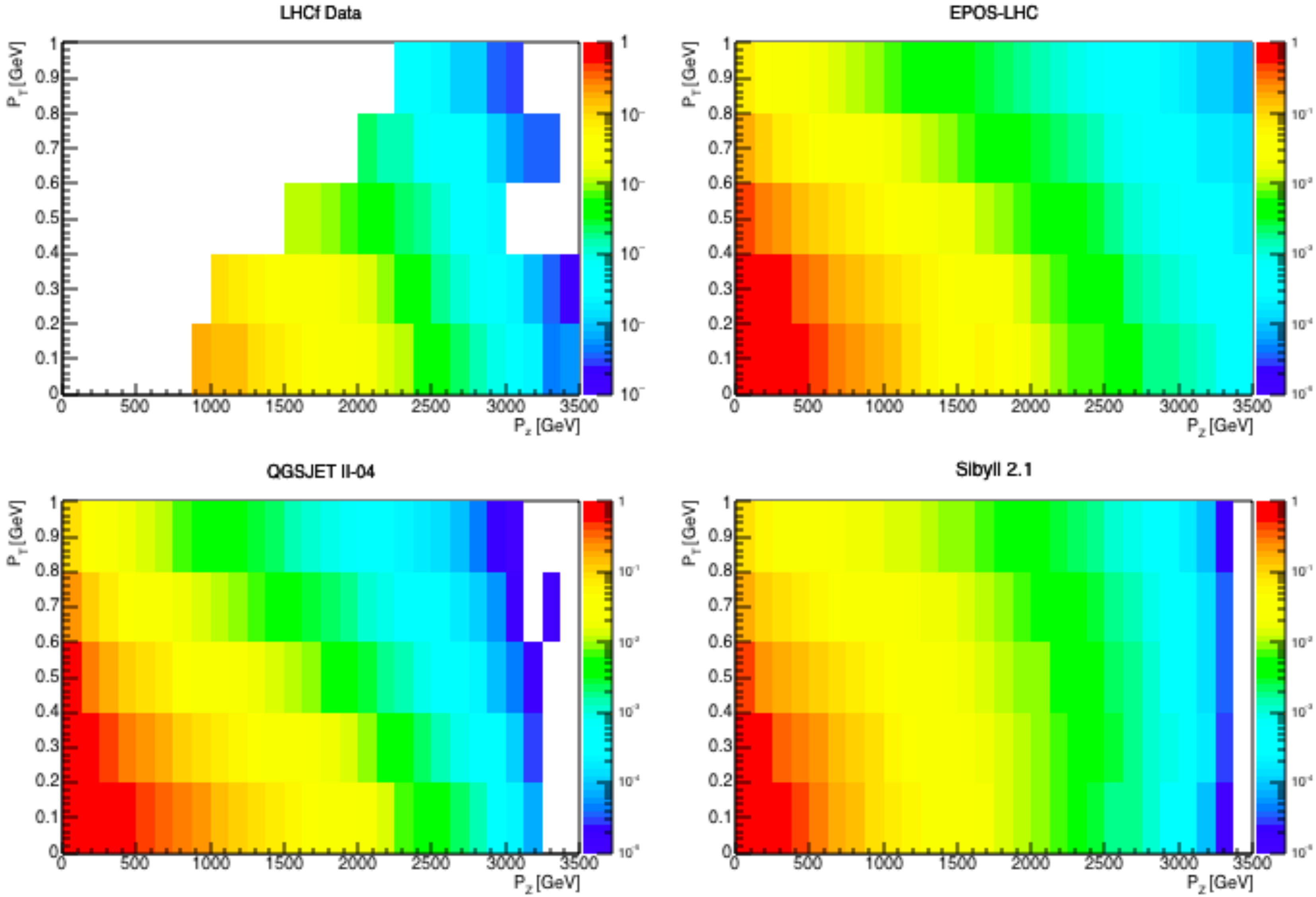
π^0 p_z spectra in 7TeV p-p collisions

(PRD, 94 (2016) 032007)

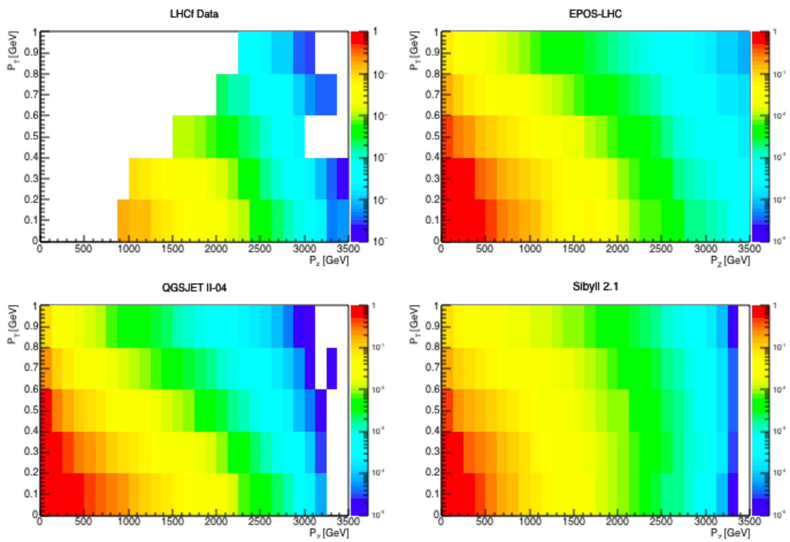


✓ DPMJET3 and PYTHIA8 overestimate over all E-p_T range

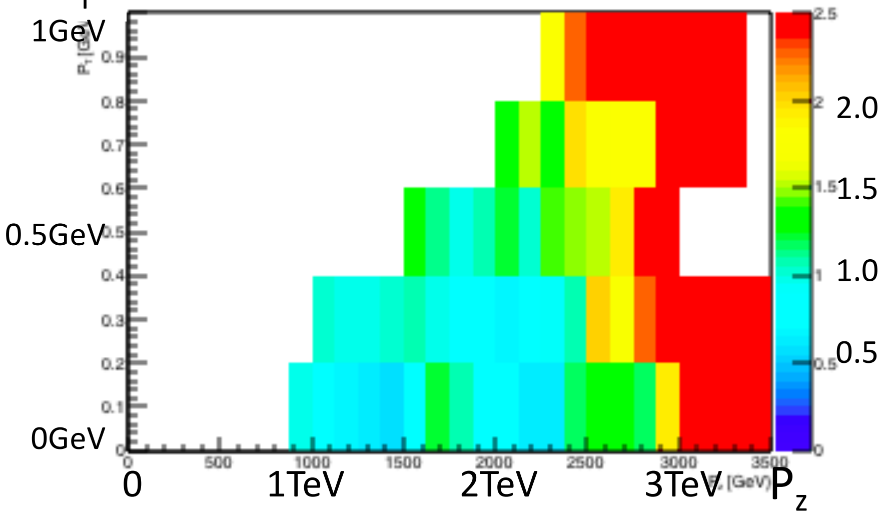
π^0 in 7TeV p-p collision
LHCf and models



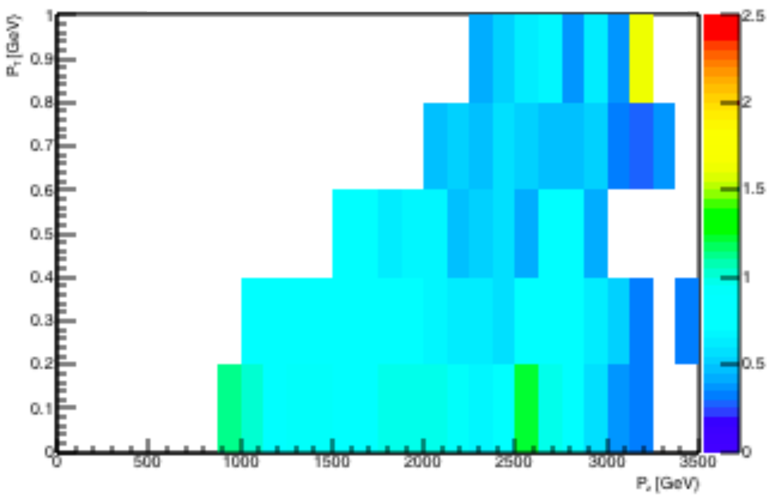
π^0 in 7TeV p-p collision
LHCf and models (ratio to data)



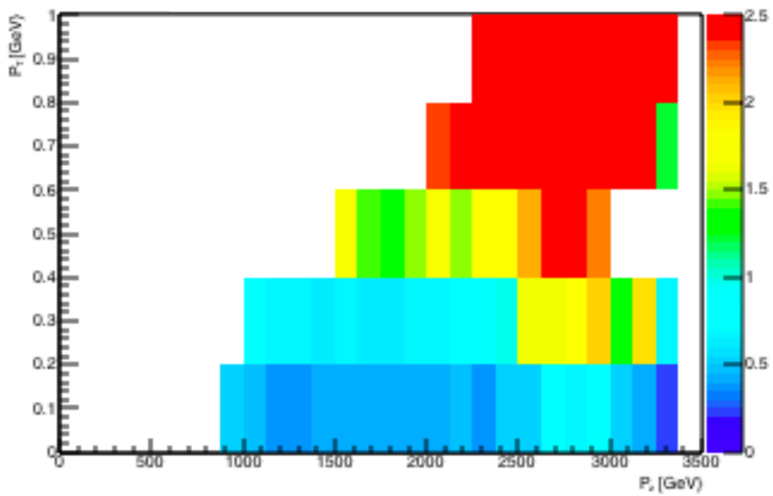
EPOS-LHC/LHCf data



QGSHET II-04/LHCf data



SIBYLL 2.1/LHCf data



√s scaling ; π^0

- ✓ Scaling is essential to extrapolate beyond LHC
- ✓ (630GeV –) 2.76TeV – 7TeV
  good scaling within uncertainties
- ✓ Wider coverage in y and p_T with 13TeV data
- ✓ Wider √s coverage with RHICf experiment in 2017 at √s=510GeV