Central-forward correlation and One pion exchange

ideas for STAR-RHICf joint analysis

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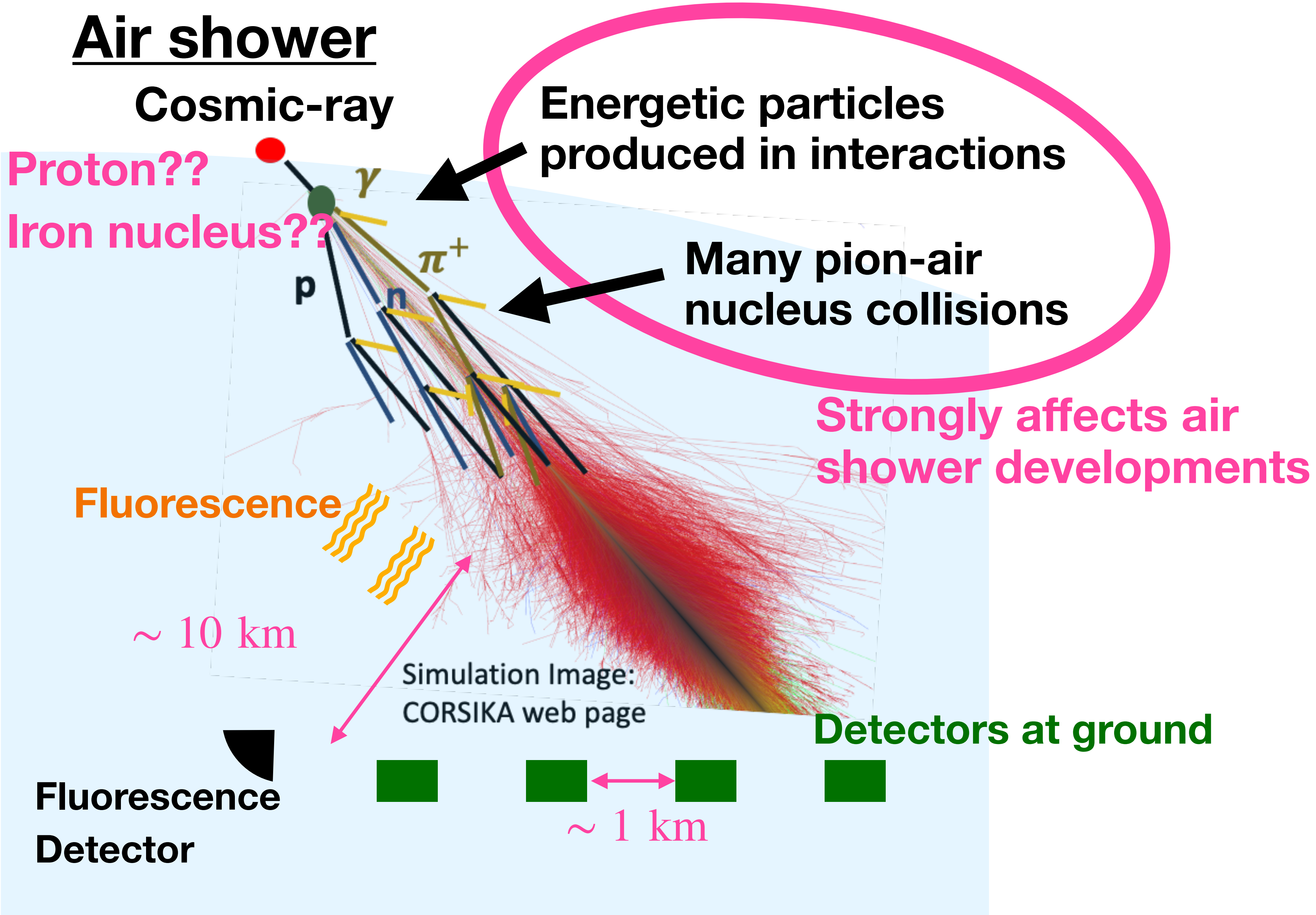
Contents

- Physics motivation
  - Diffractive dissociation
  - One pion exchange
  - Multi-parton interaction
- Idea for analysis
- Similar study at LHC (ATLAS-LHCf analysis)

Motivation : Air shower induced by cosmic ray



We need precise predictions of hadronic interactions for ultra-high energy cosmic rays

Energetic particles produced in interactions

Produced in very forward regions

Need to separate diffractive dissociation and others

Pion-air nucleus collisions

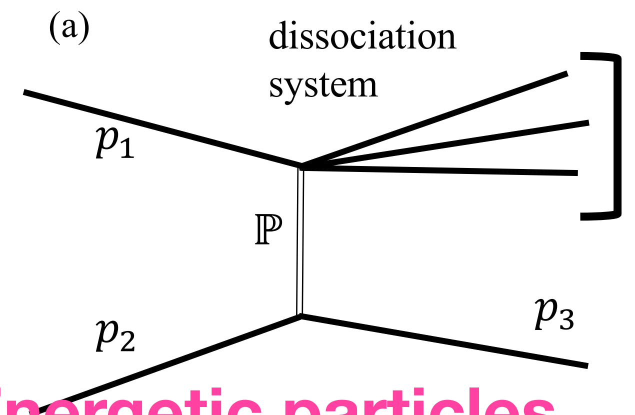
No colliders for pion collisions

Only low energy data are available

Importance of joint analysis of STAR/ATLAS and LHCf/RHICf

Joint analysis allow us several physics cases

Diffractive dissociation

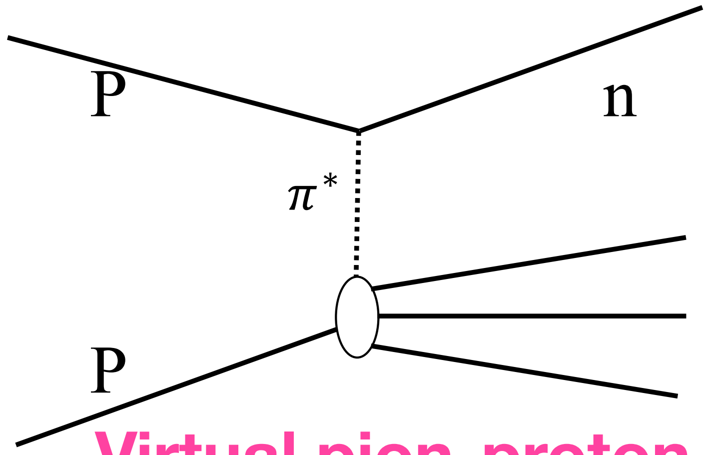


Energetic particles from diffractive dissociation

At LHCf/RHICf

photons (π^0) / neutrons

One pion exchange

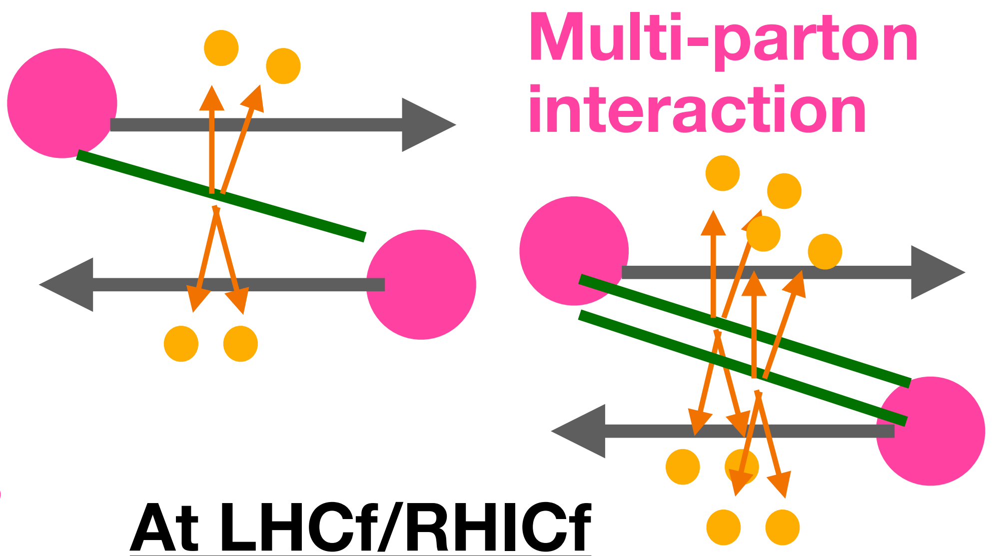


Virtual pion-proton collisions

At LHCf/RHICf

Neutrons

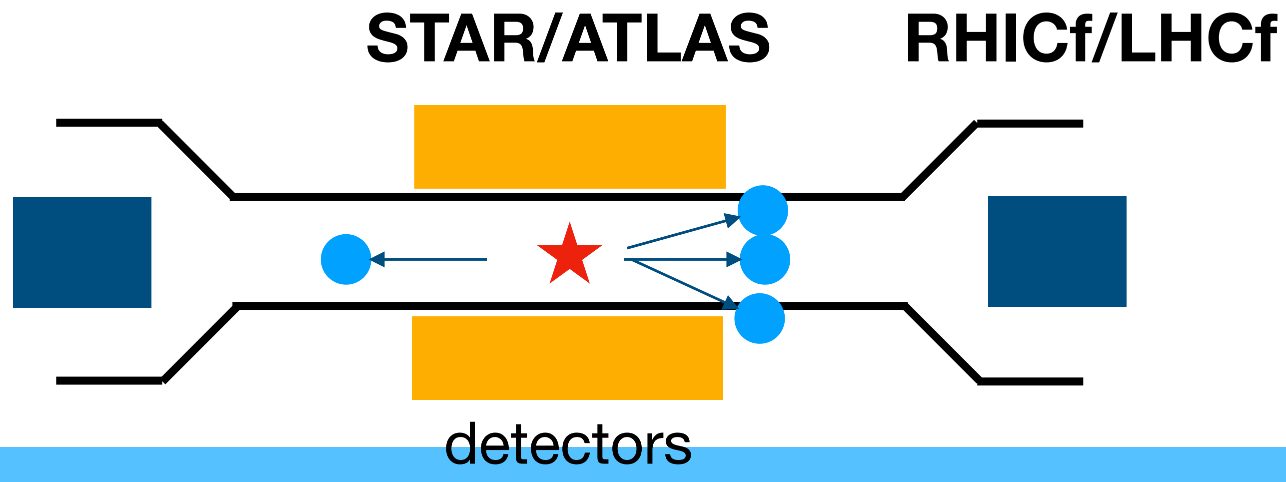
Others (Non-diffractive)



At LHCf/RHICf

photons (π^0) / neutrons

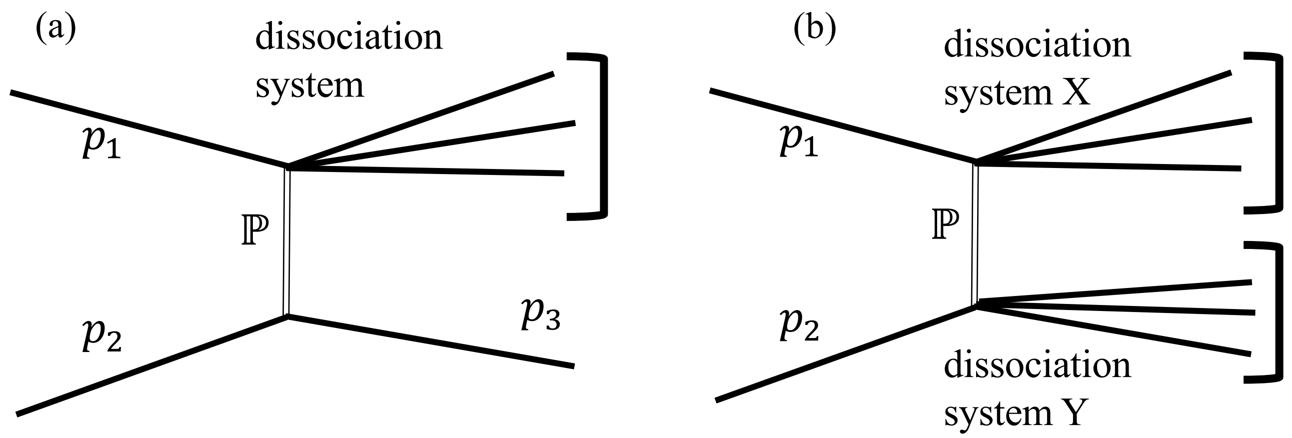
➡ **Separate these processes using central detectors**



Physics 1: diffractive dissociation

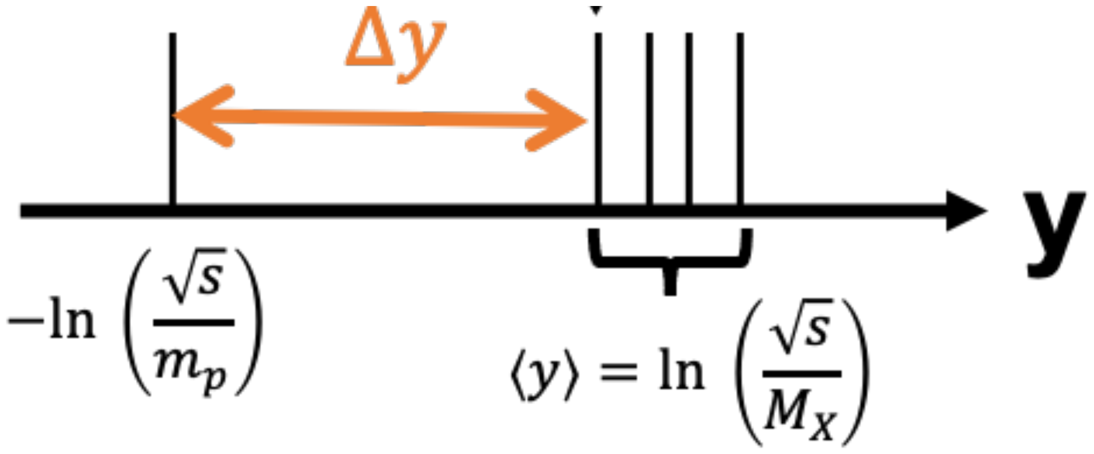
Diffractive dissociation

Particles produced in forward regions

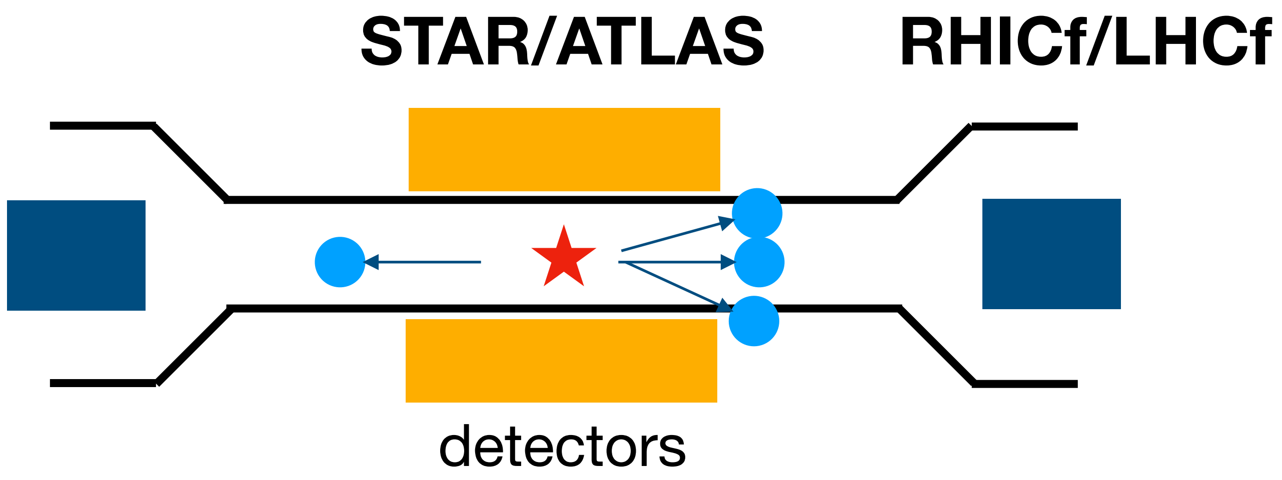


$$M_X^2 = (p_1 + p_2 - p_3)^2 \qquad \xi = M_X^2/s$$

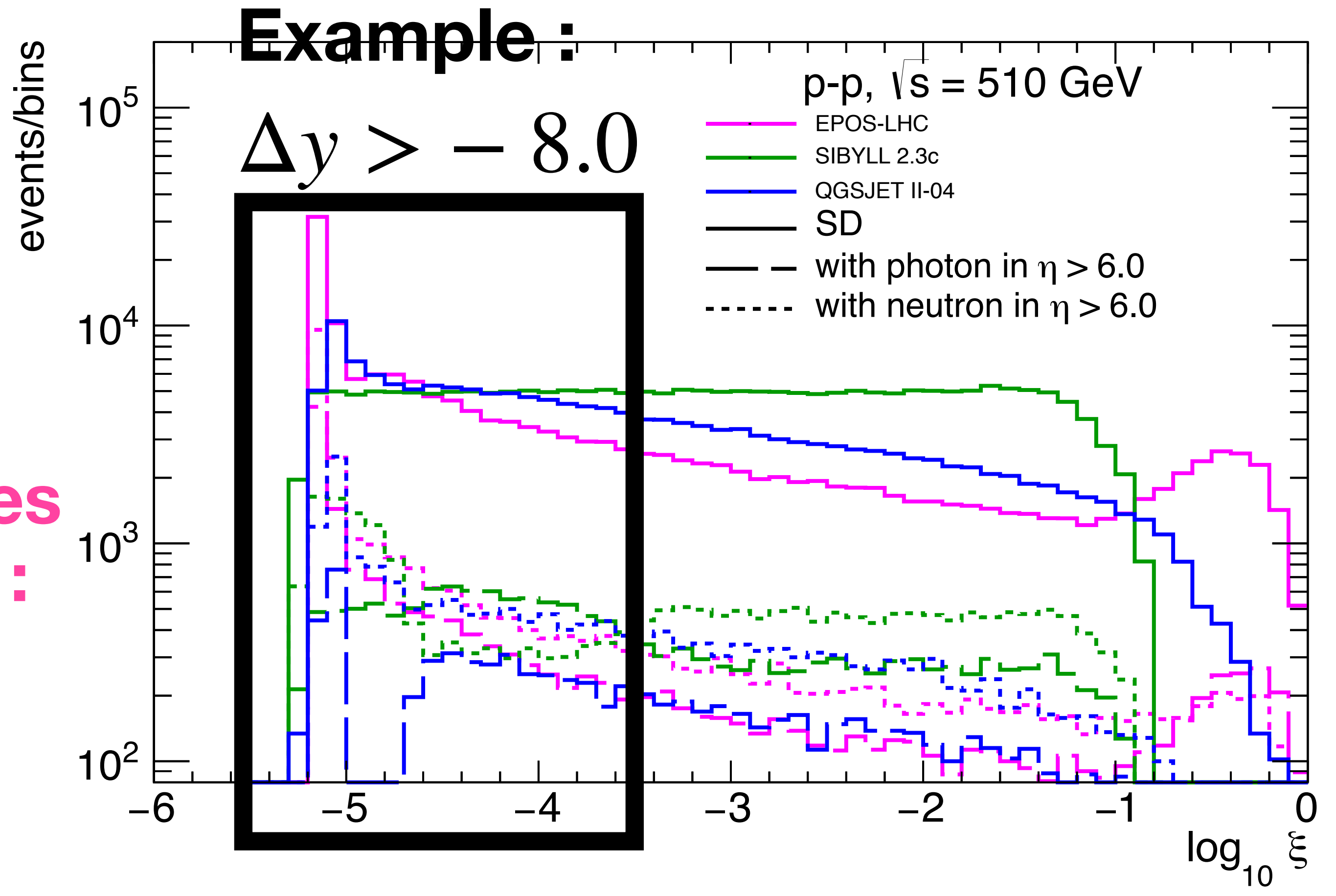
Large rapidity gap $\Delta y \approx \ln \xi$



number of particles in central regions : Small or zero

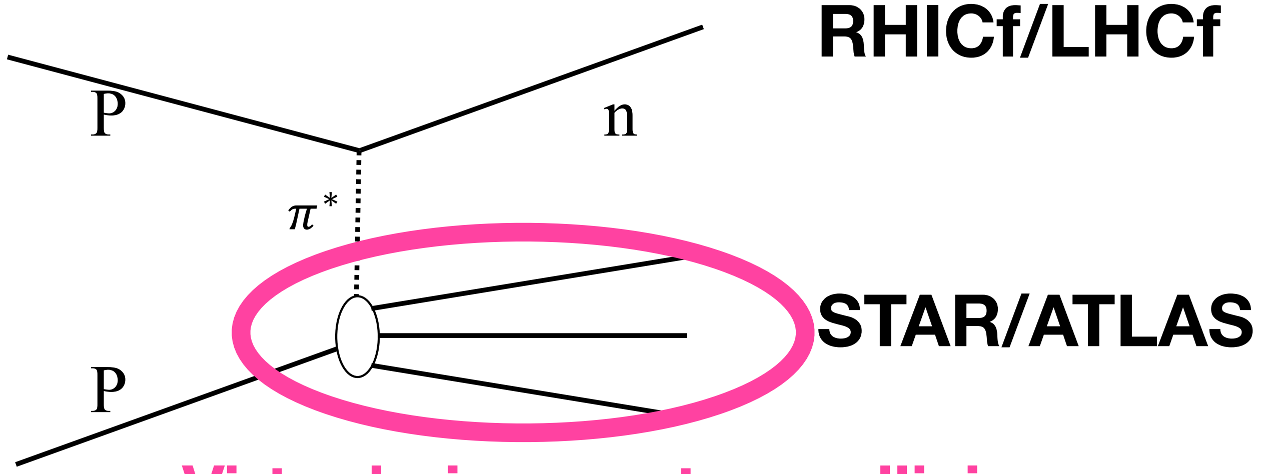


Detect rapidity gap using STAR/ATLAS

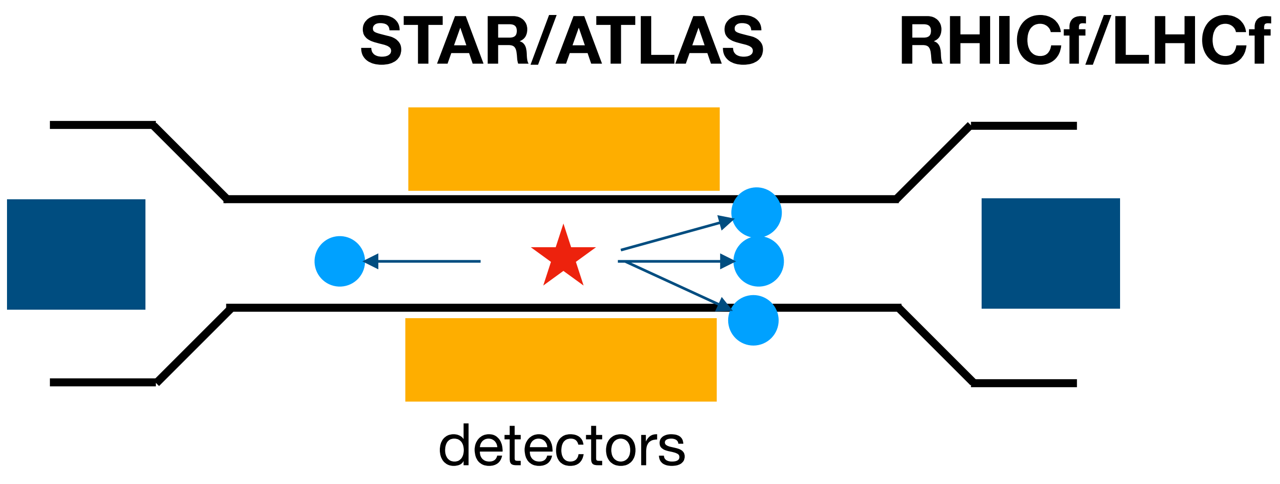


Physics 2: One pion exchange

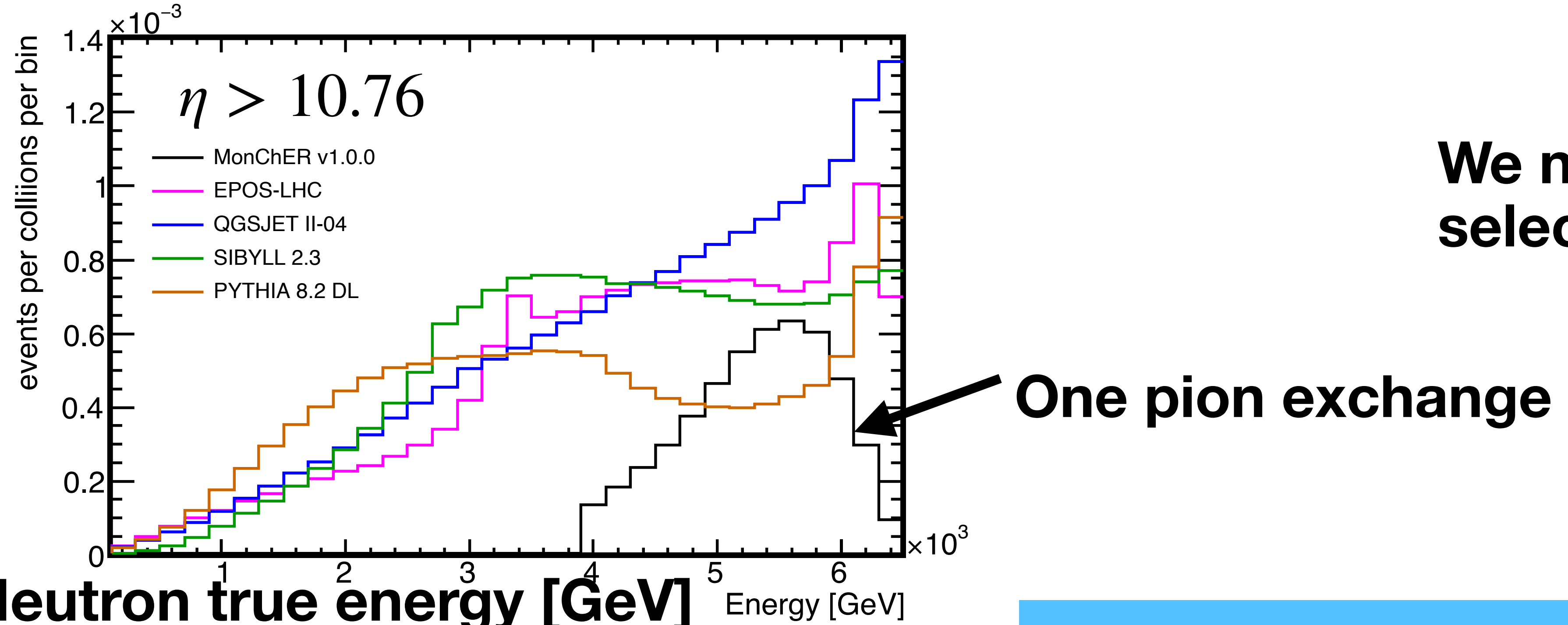
<u>One pion exchange</u>



Virtual pion-proton collisions



Simulation (LHC, p-p $\sqrt{s} = 13$ TeV)



Neutron true energy [GeV]

We need to develop a method to select one pion exchange…

Physics 3: Multi-parton interaction

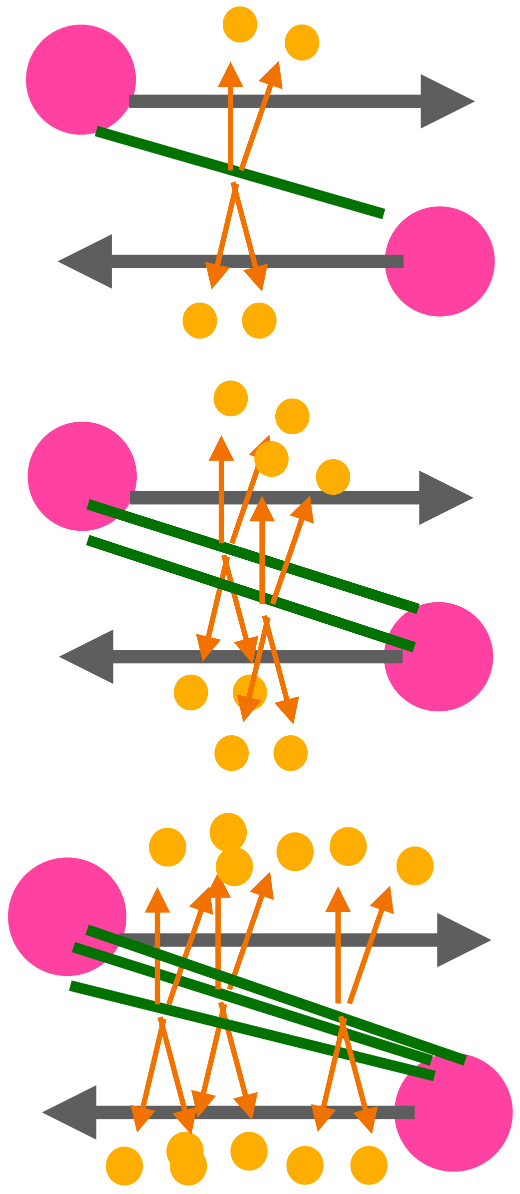
<u>Multi-parton interaction</u>

The number of multi-parton interaction

$N_{MPI} = 1$

$N_{MPI} = 2$

$N_{MPI} = 3$



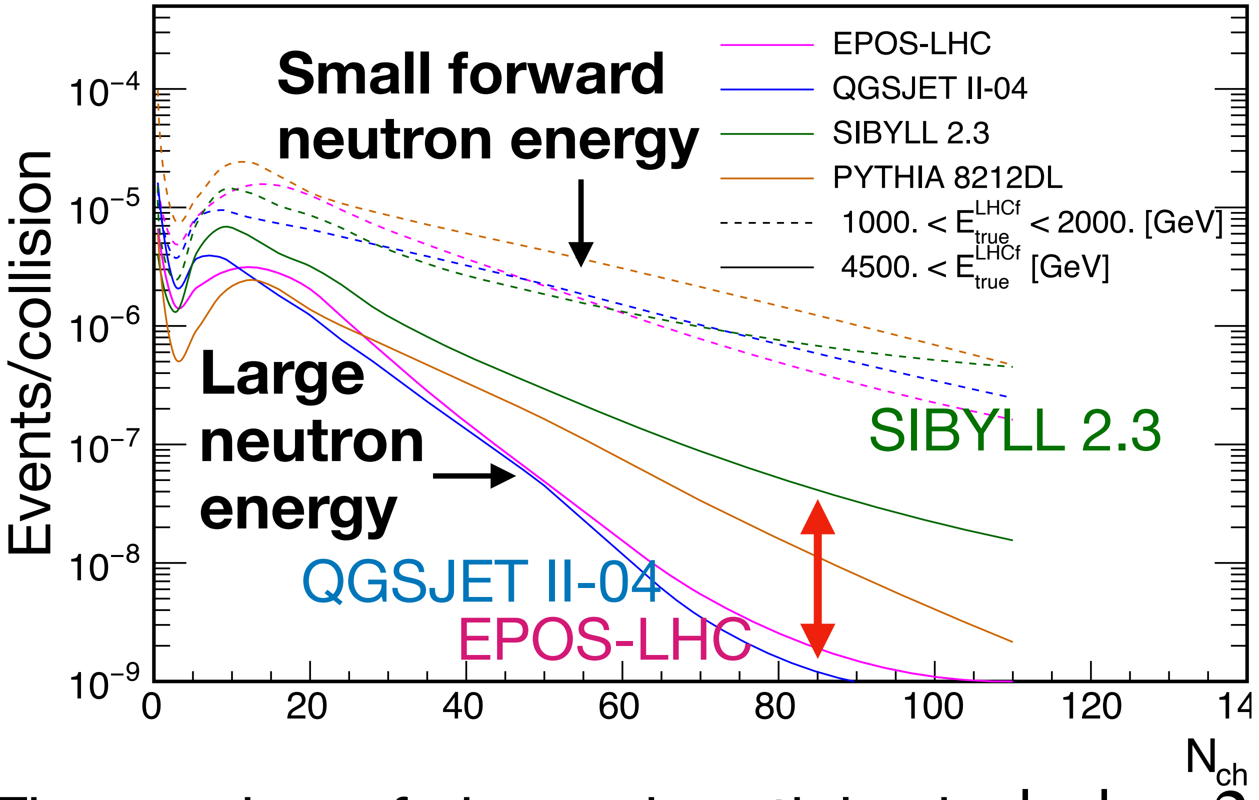
Energy of very forward neutron/ π^0

Large

Small

Large number of particles in central detectors ~ large N_{MPI}

Simulation (LHC, p-p $\sqrt{s} = 13$ TeV)



The number of charged particles in $|\eta| < 2.5$

Large difference among models

Modeling of MPI makes large difference for high neutron energy & high N_{MPI}

Multi-parton interaction

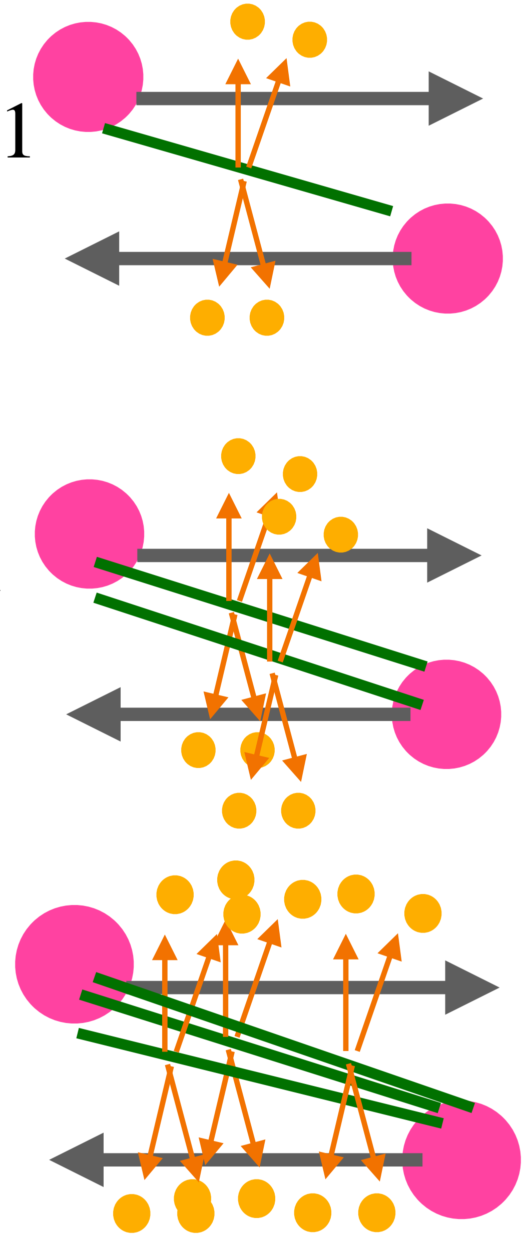
S. Ostapchenko et al,
Phys. Rev. D 94 114026

The number of multi-parton interaction

Forward particle energy

Charged tracks in central regions

$N_{MPI} = 1$



Large ↑ **Small**

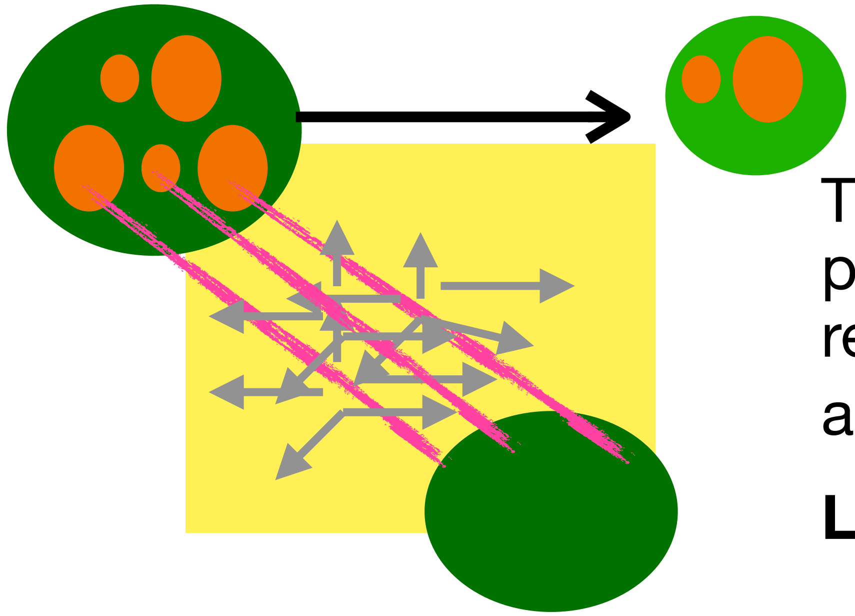
$N_{MPI} = 2$

$N_{MPI} = 3$

Small ↓ **Large**

Differences in modeling

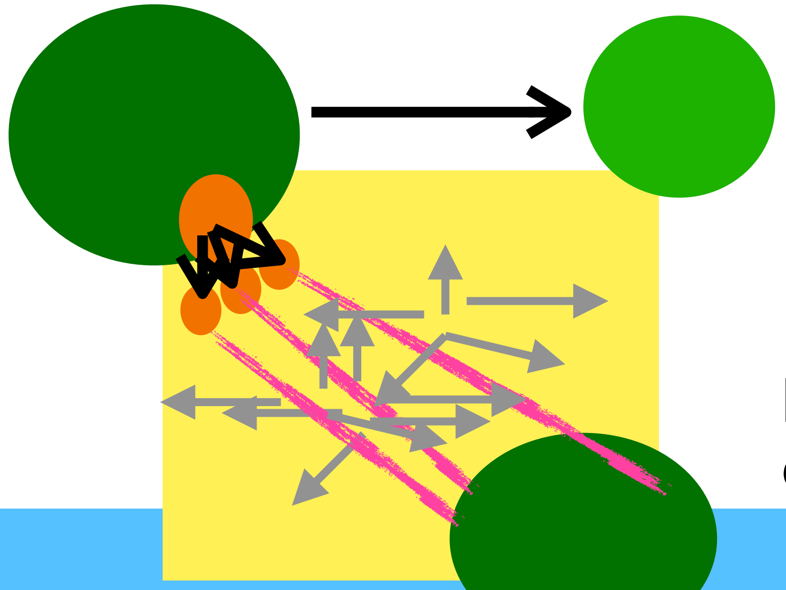
EPOS-LHC & QGSJET II-04



The number of partons in the remnants decreases as N_{MPI} increases

Large correlations

PYTHIA & SIBYLL



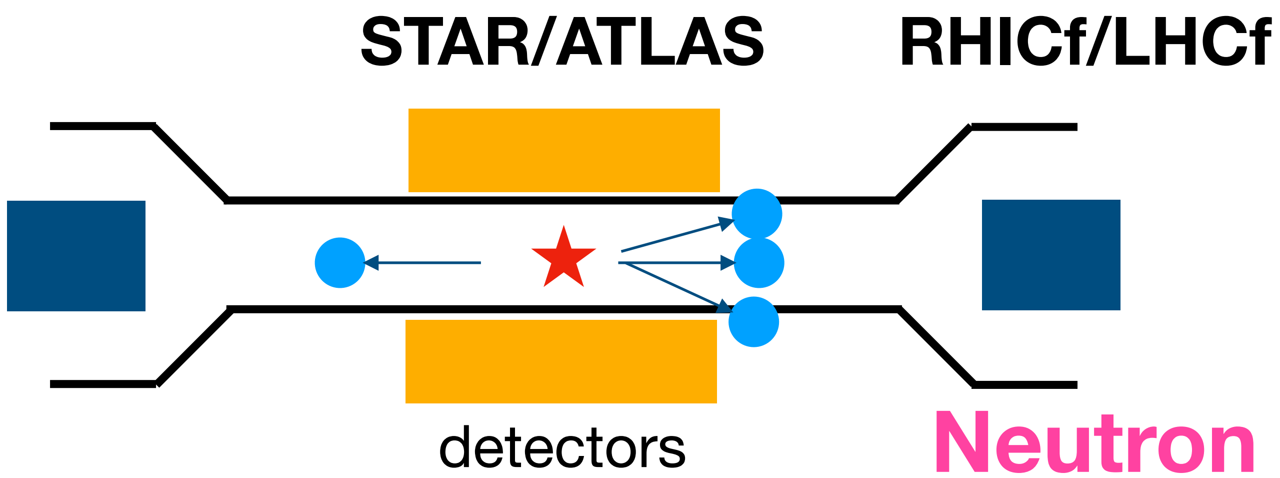
The parton cascades are considered in the model.

Relatively small correlations

Central-forward correlation with forward neutron

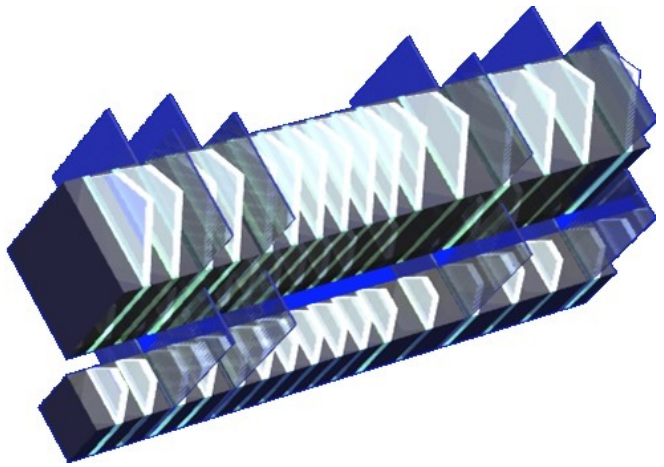
Physics targets

- **Energetic particles from diffractive dissociation**
- **Virtual pion-proton collisions using one-pion exchange**
- **Multi-parton interaction**



Number of charged particles in central detectors

Neutron at RHICf/LHCf



RHICf (LHCf-Arm1)

Problem : How to separate diffractive/ one-pion exchange/non-diffractive ?

<u>Key information to separate them :</u>

The number of charged particles in central detectors

p_{T} of forward neutrons

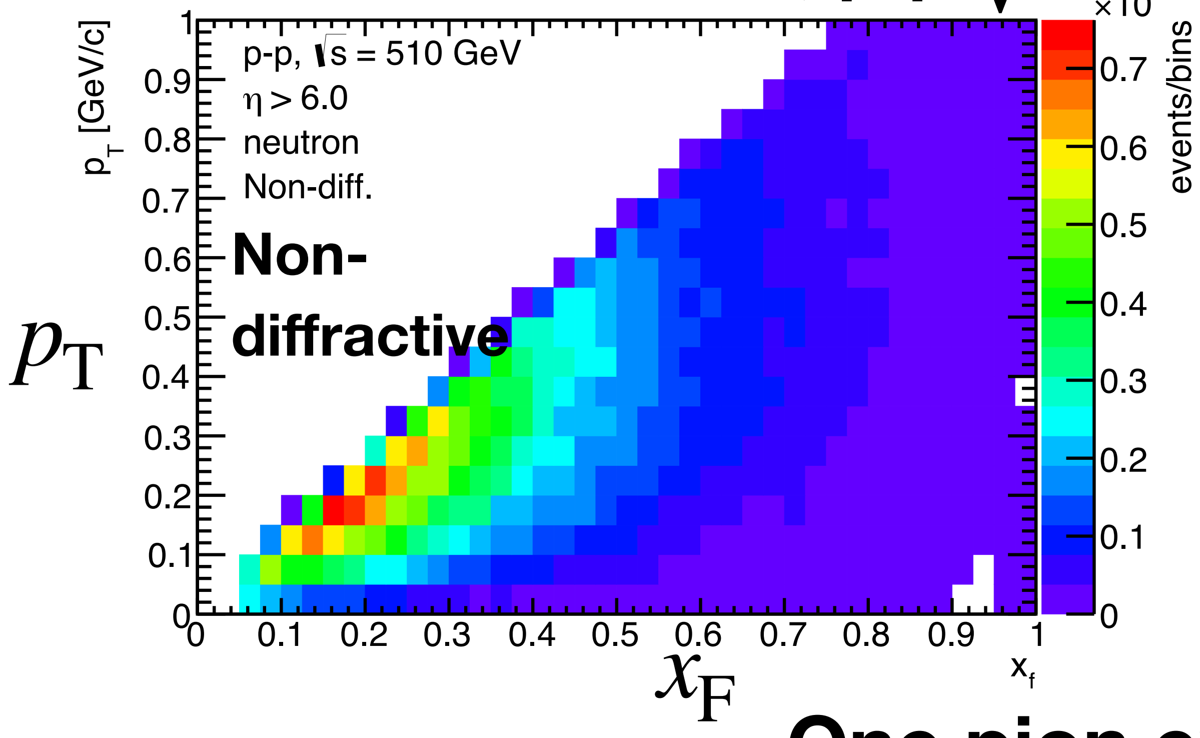
ATLAS-LHCf joint analysis for forward neutrons is on going…

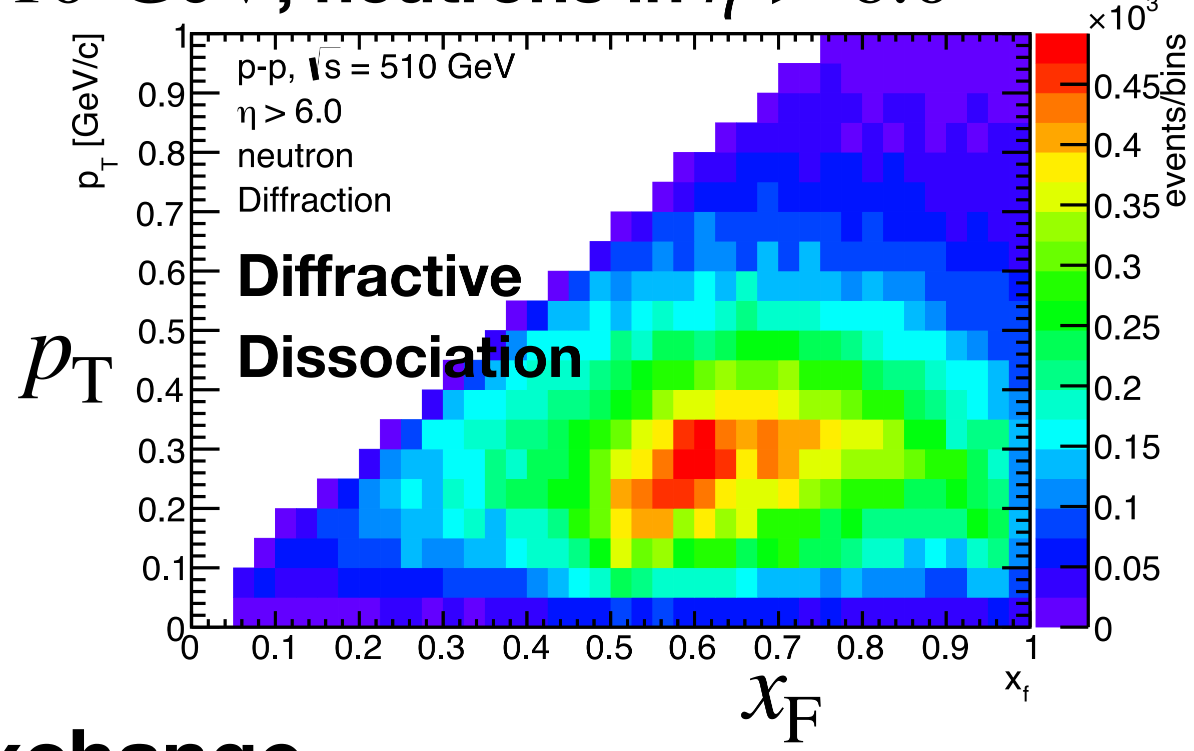
From next slide, I show simulation studies for joint analysis

Distributions for each cases

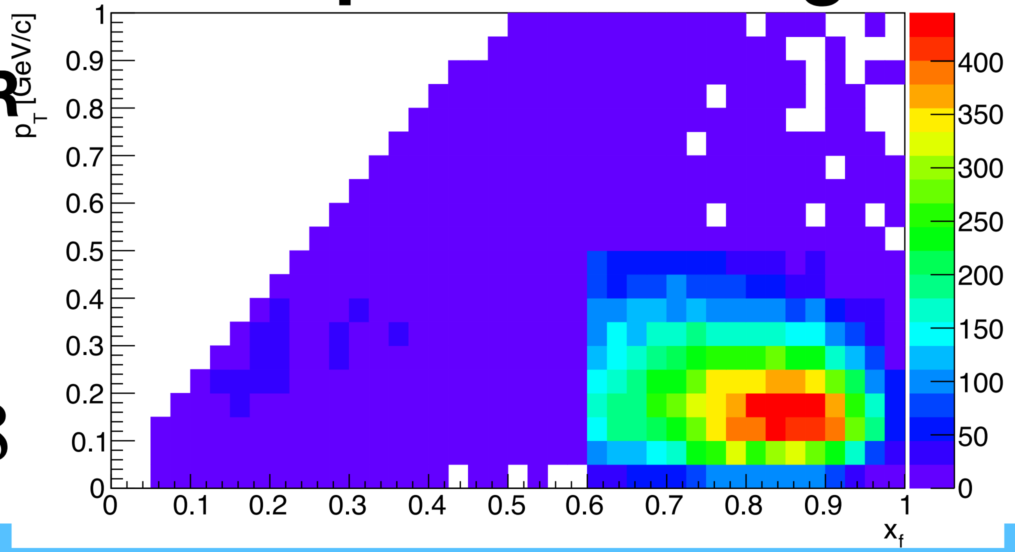
Distributions of forward neutrons

EPOS-LHC, p-p $\sqrt{s} = 510$ GeV, neutrons in $\eta > 6.0$





One pion exchange



simulated by MonChER
(arXiv: 1106.2076)

p-p $\sqrt{s} = 13$ TeV

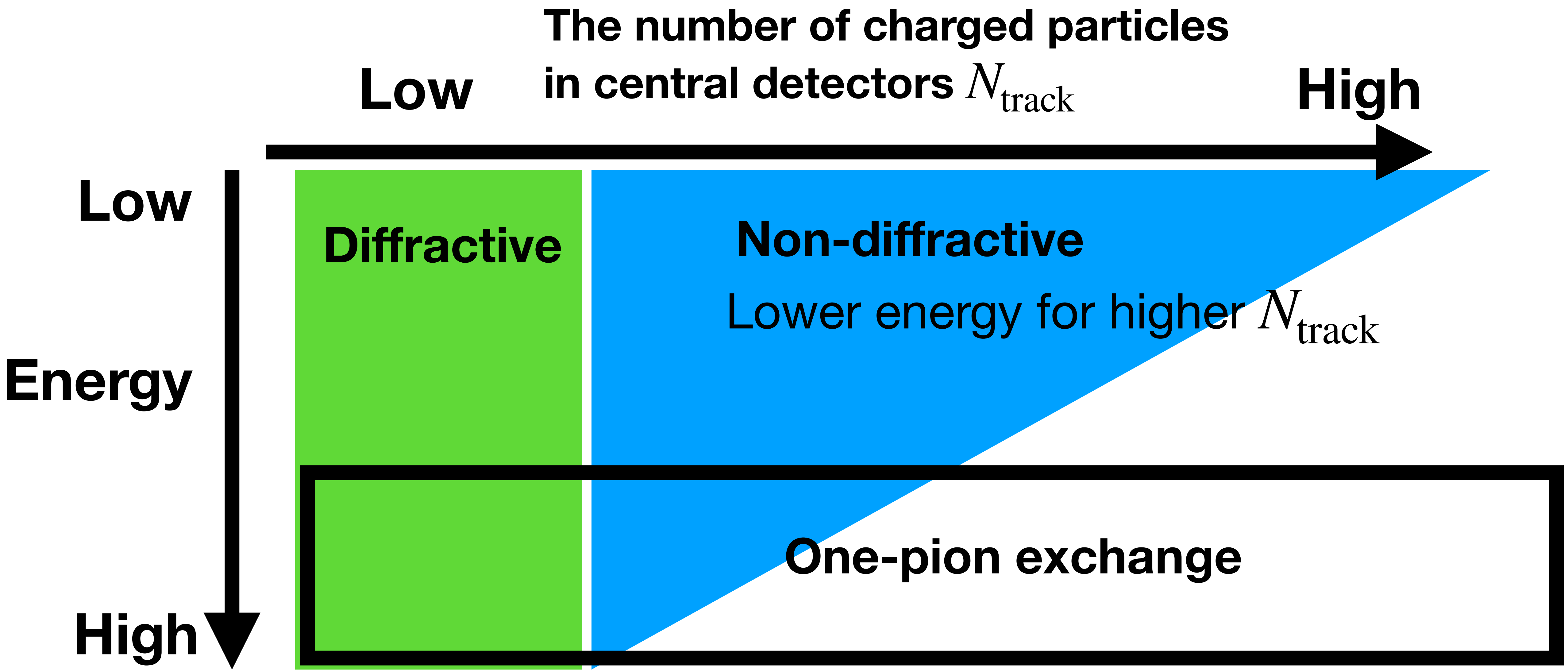
Neutrons in $\eta > 8.8$

For example, for ATLAS-LHCf,
most of neutrons from OPE are in $\eta < 9.5$.

Note: this generator only support for $\sqrt{s}$ = 900-14000 GeV

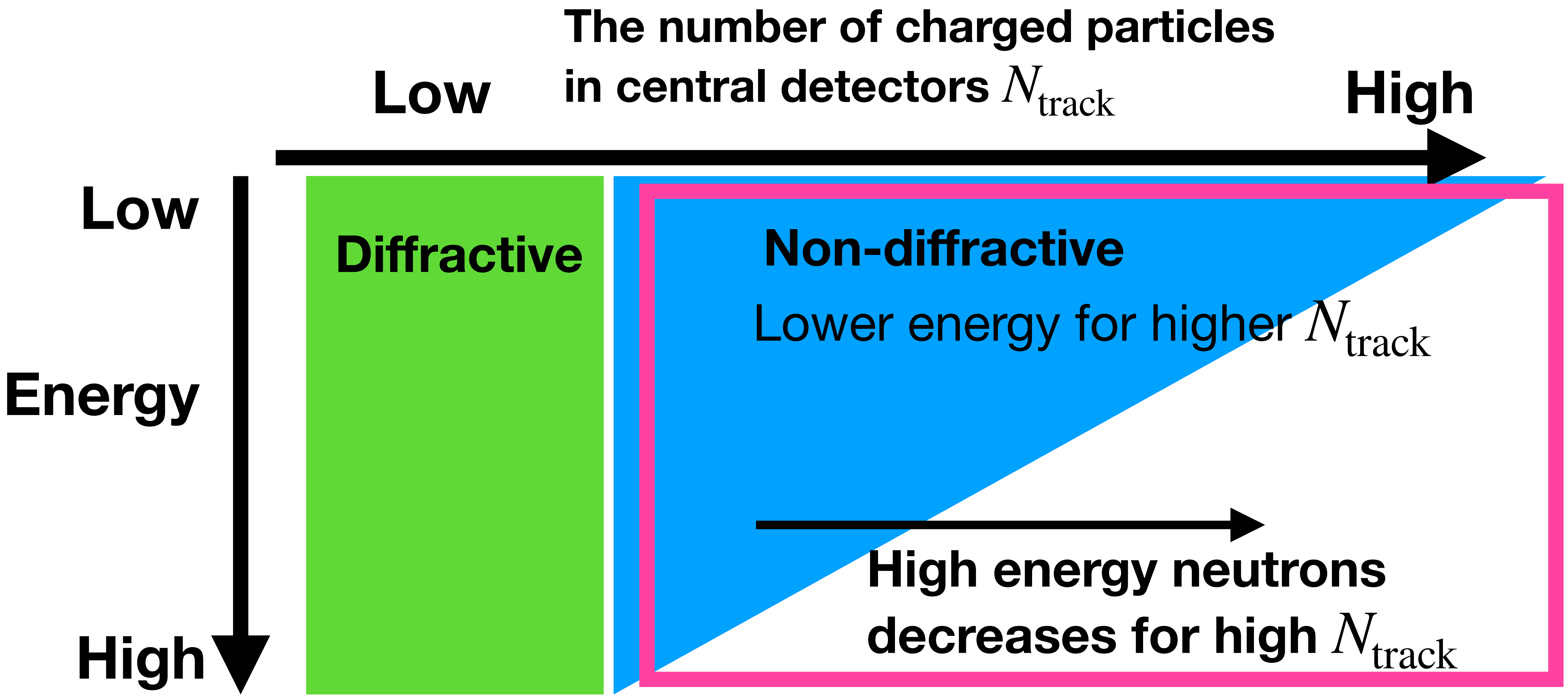
Concept to separate each process

If we focus on zero degree…



Concept to separate each process

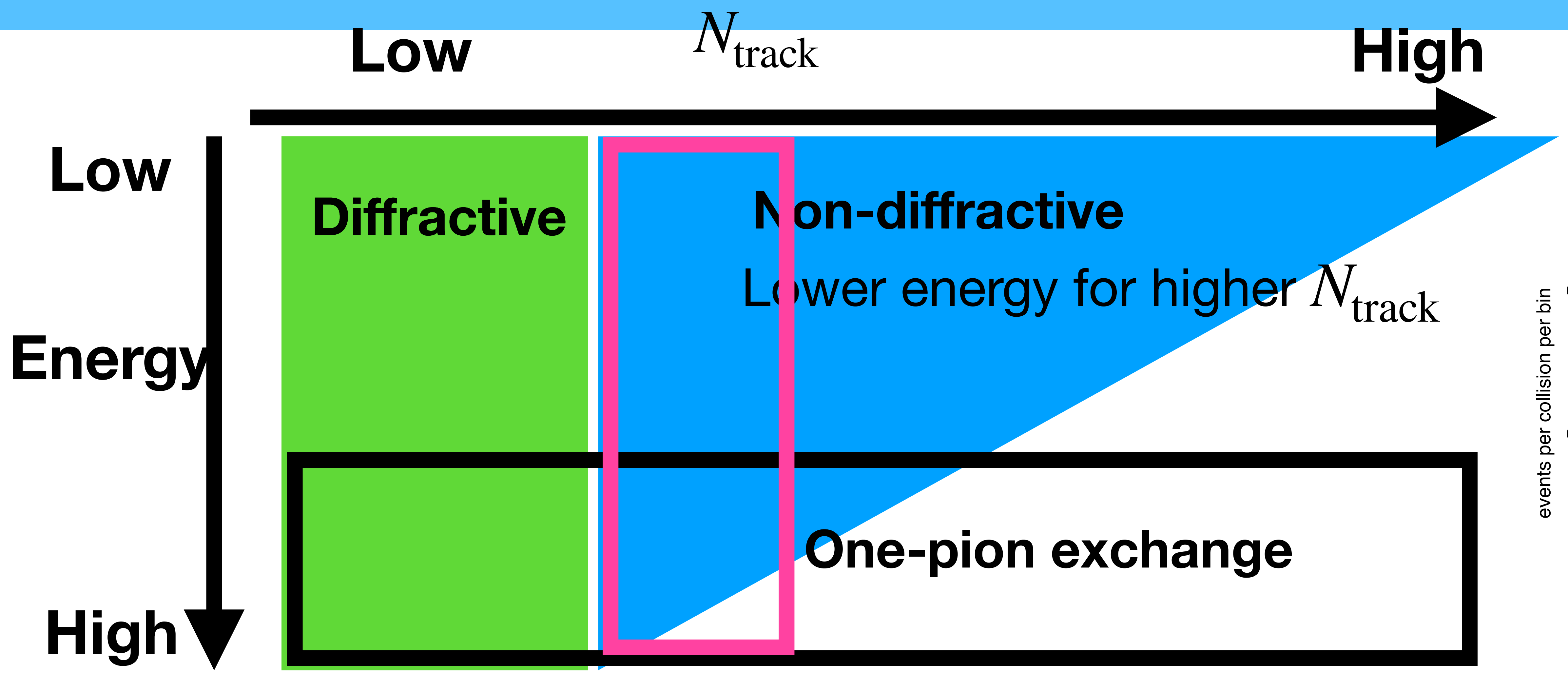
If we focus on off-axis, ($\eta < 9.5$ for ATLAS-LHCf)



This effect depends on the modeling of MPI in each model.

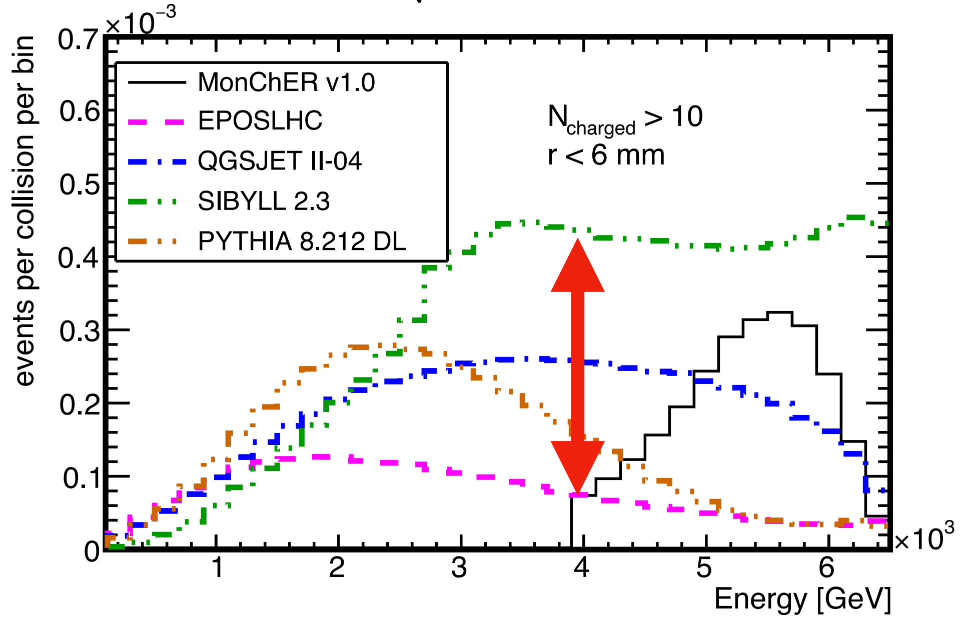
Central-forward correlation for MPI study

Concept to separate one-pion exchange



Simulation

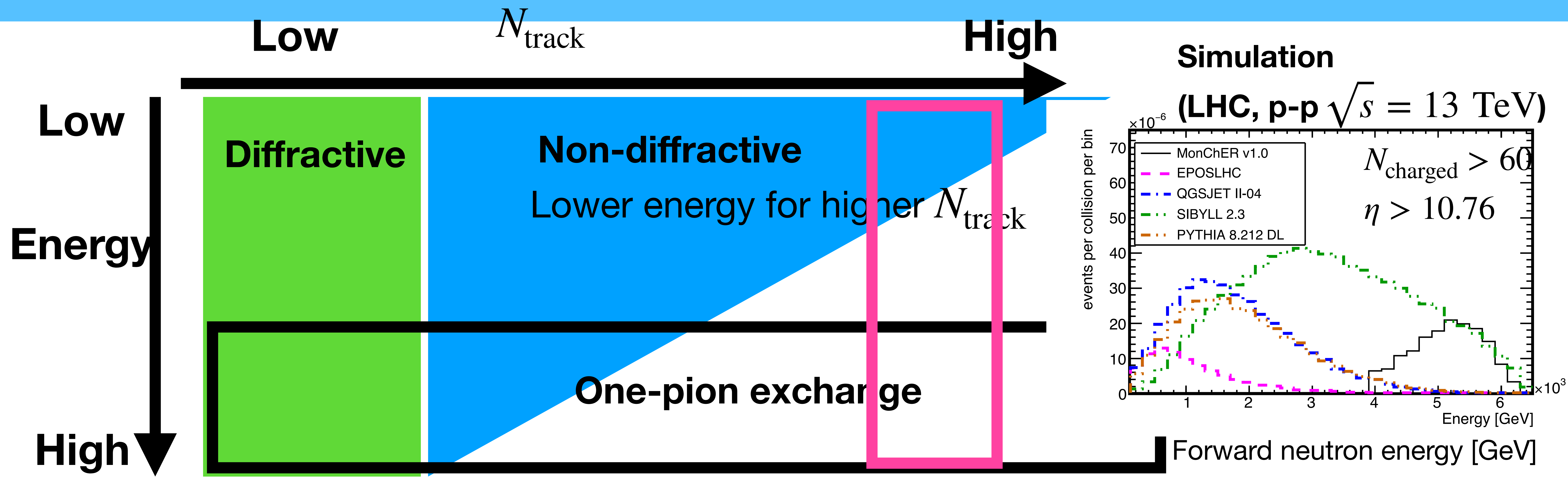
(LHC, p-p $\sqrt{s} = 13$ TeV**)**



<u>Very large uncertainties in background estimations</u> by models

=> Difficult to understand one-pion exchange contributions.

Concept to separate one-pion exchange



<u>Two peaks in true energy distributions.</u>

=> We can select neutrons from one-pion exchange and non-diffractive despite very large differences in predictions.

(if energy resolutions for neutrons is good.)

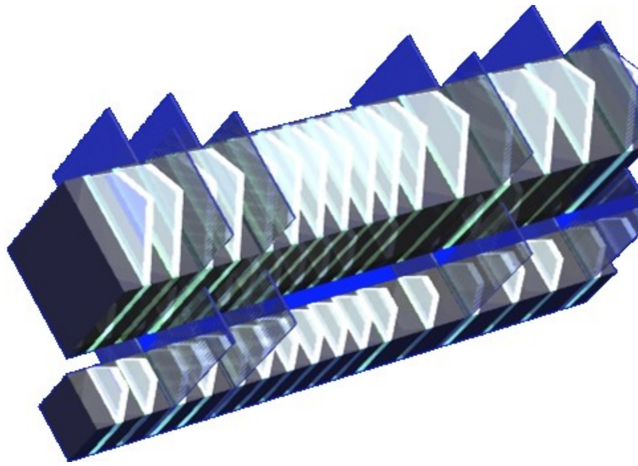
At LHC : ATLAS-LHCf joint analysis

Analysis is on going…

Analysis : simple extension using N_{track}

A simple extension of LHCf/RHICf stand alone analysis works well.

Two dimensional analysis with neutron energy and N_{track}



RHICf (LHCf-Arm1

Some problems in analysis… (ATLAS-LHCf analysis)

Contaminations of kaons and lambda, and their decay products depends on process/models

Large differences in predictions for diffractive dissociation

Multi-hit, two or more particles hit in a calorimeter tower, depends on process/models

Large differences in predictions for diffractive dissociation and for neutrons around beam center

Summary

- For comic-ray air shower, predictions of energetic particles and pion-proton collisions in hadronic interactions are important.
- Forward neutron analysis using central detectors and LHCf/RHICf detectors can measure
  - energetic particles produced in diffractive dissociation
  - virtual pion-proton collisions in one pion exchange process
  - Central-forward correlations for non-diffractive collisions to constrain the modeling of multi-parton interaction.
- I presented some idea to separate each process.

Back up

MonChER arXiv: 1106.2076

A generator for one-pion exchange process

- https://moncher.hepforge.org
- Exchange of pion, rho, and a2 are considered.
- Developed by R.A. Ryutin, A.E. Sobol, V.A. Petrov (Serpukhov, IHEP)
- Related references
  - “LHC as πp and ππ collider “ : Eur. Phys. J. C (2010) 65: 637–647 DOI 10.1140/epjc/s10052-009-1202-0
  - “Total $\pi^+ p$ cross section extracted from the leading neutron spectra at the LHC “ PHYSICAL REVIEW D 96, 034018 (2017)
- Only support 900-1400 GeV (LHC energy)
- No update since 2011. No maintenance??

One pion exchange selections

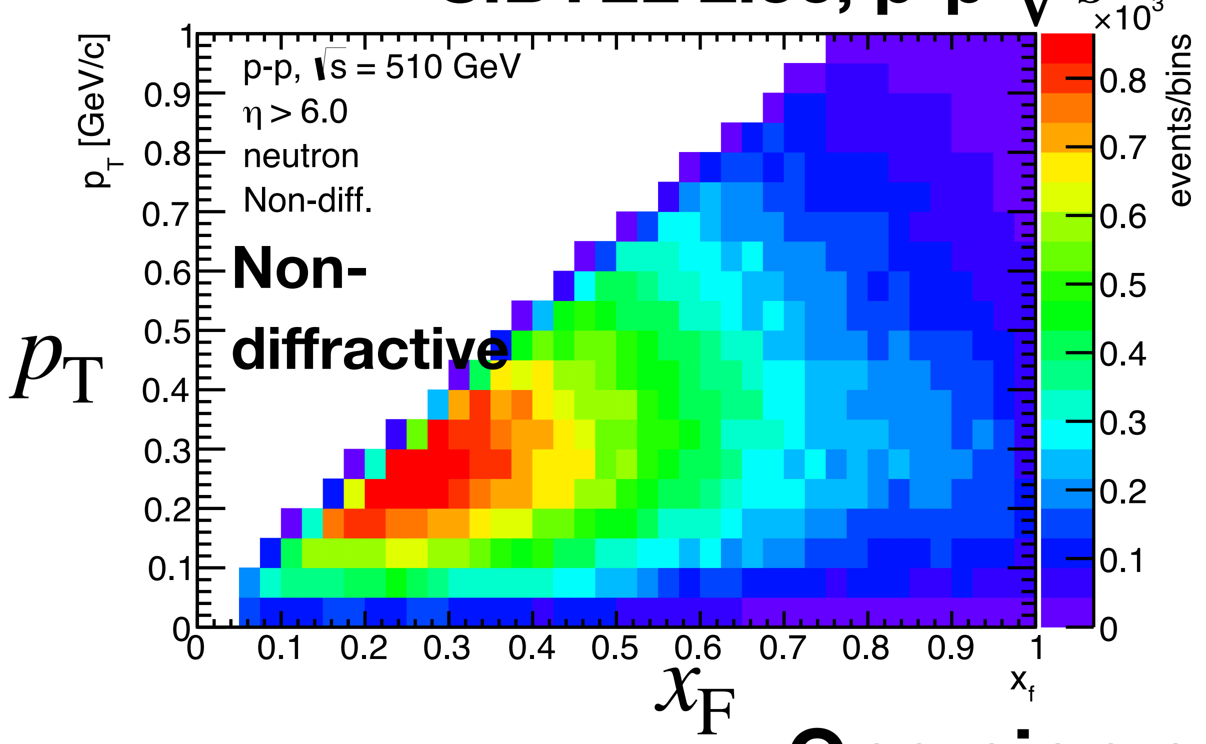
Can we separate neutrons from diffractive and one pion exchange?

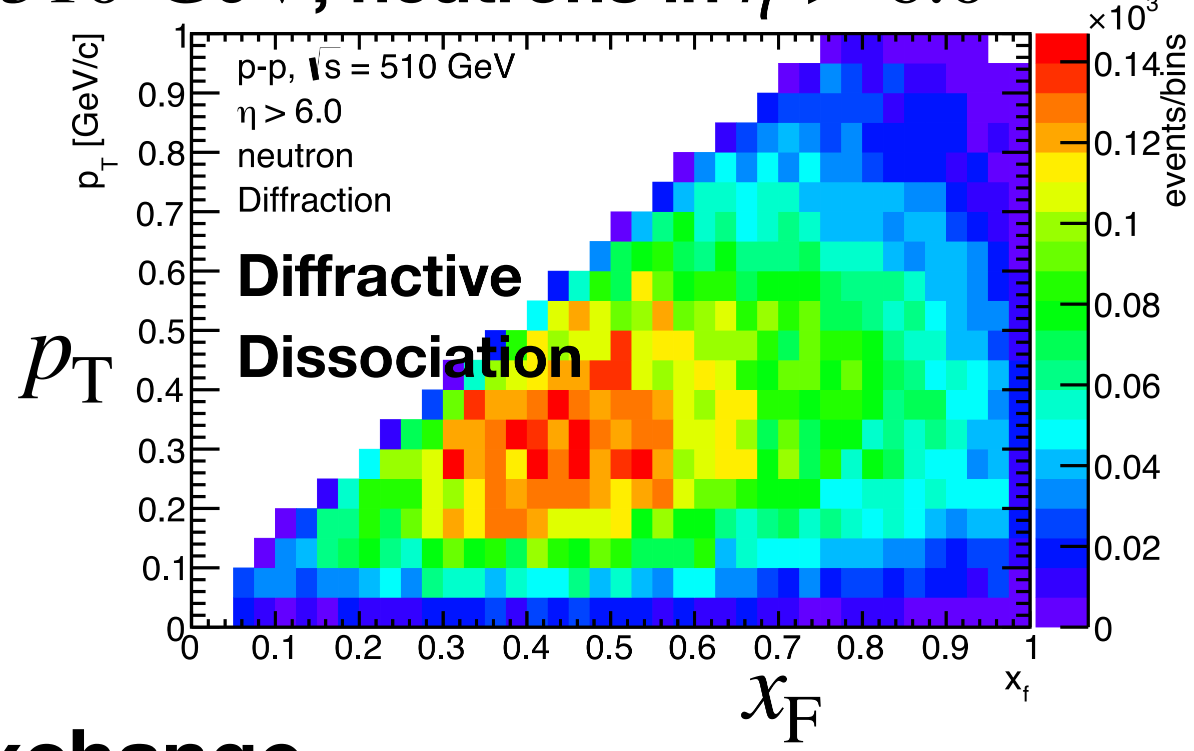
- Several cases are (partially) considered
  - Using distributions in central detectors
    - Using true level information from generators
    - No differences between Non-diff. and One pion exchange
  - Using Roman pot detectors
    - Simple calculation only.
    - No idea to separate single diffractive and one pion exchange with elastic π^+-p collisions
  - Using hit information in two LHCf/RHICf detector
    - Hit in beam center and another hit in another calorimeter tower
    - It is difficult to select one pion exchange…
- No clear idea to separate diffractive dissociation and one pion exchange for the moment…

Distributions for each cases

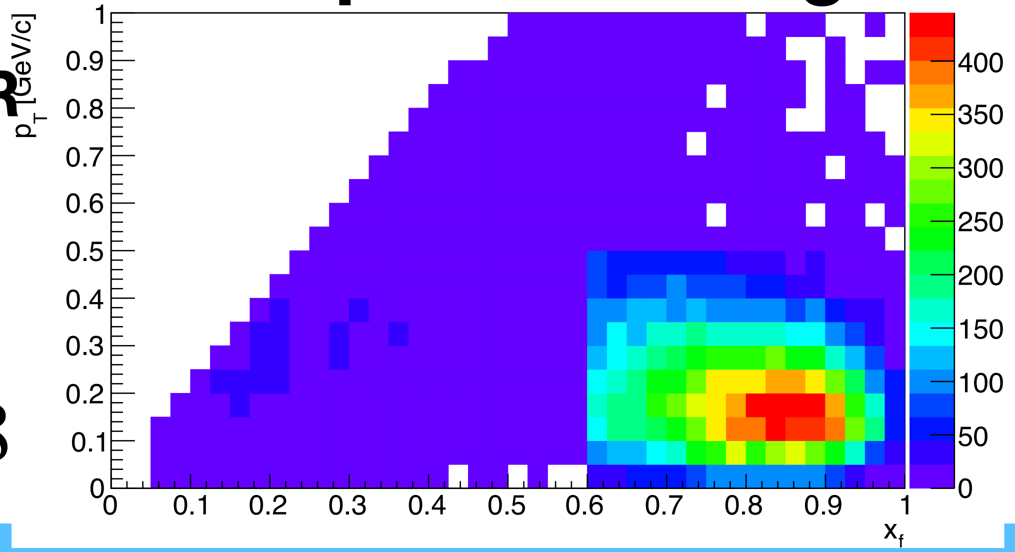
Distributions of forward neutrons

SIBYLL 2.3c, p-p $\sqrt{s} = 510$ GeV, neutrons in $\eta > 6.0$





One pion exchange



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Distributions for each cases

Distributions of forward photon

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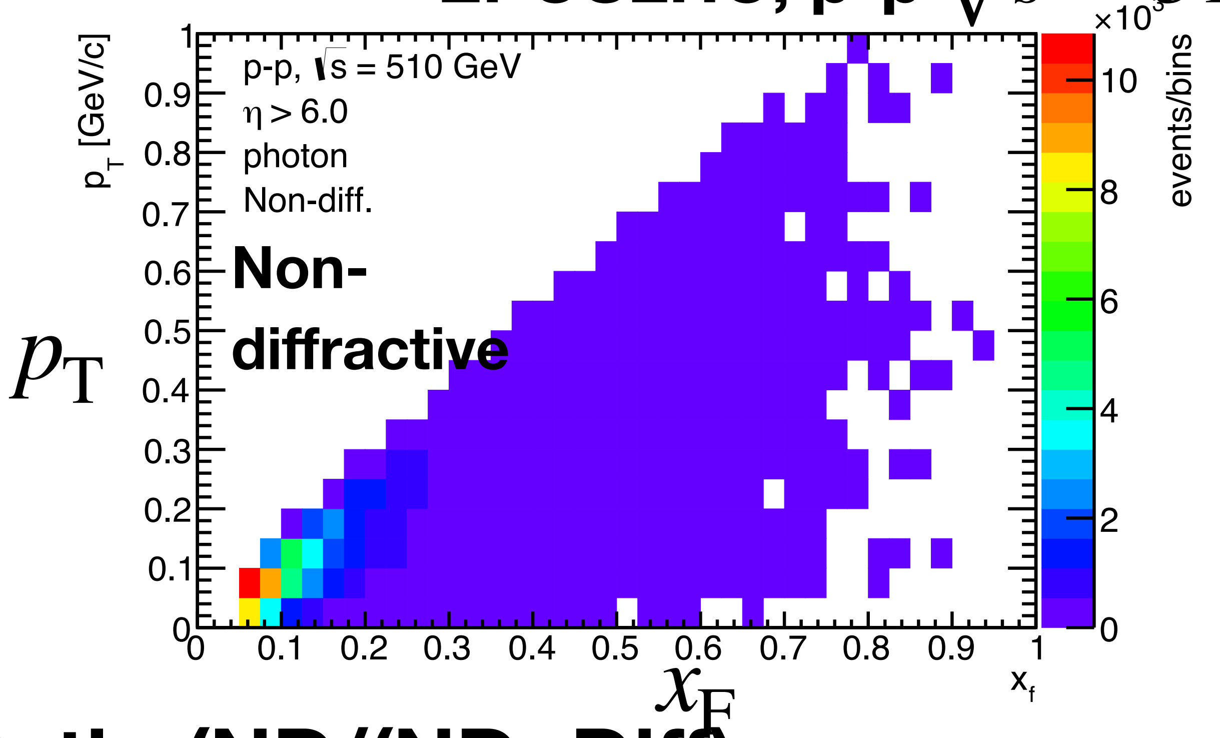
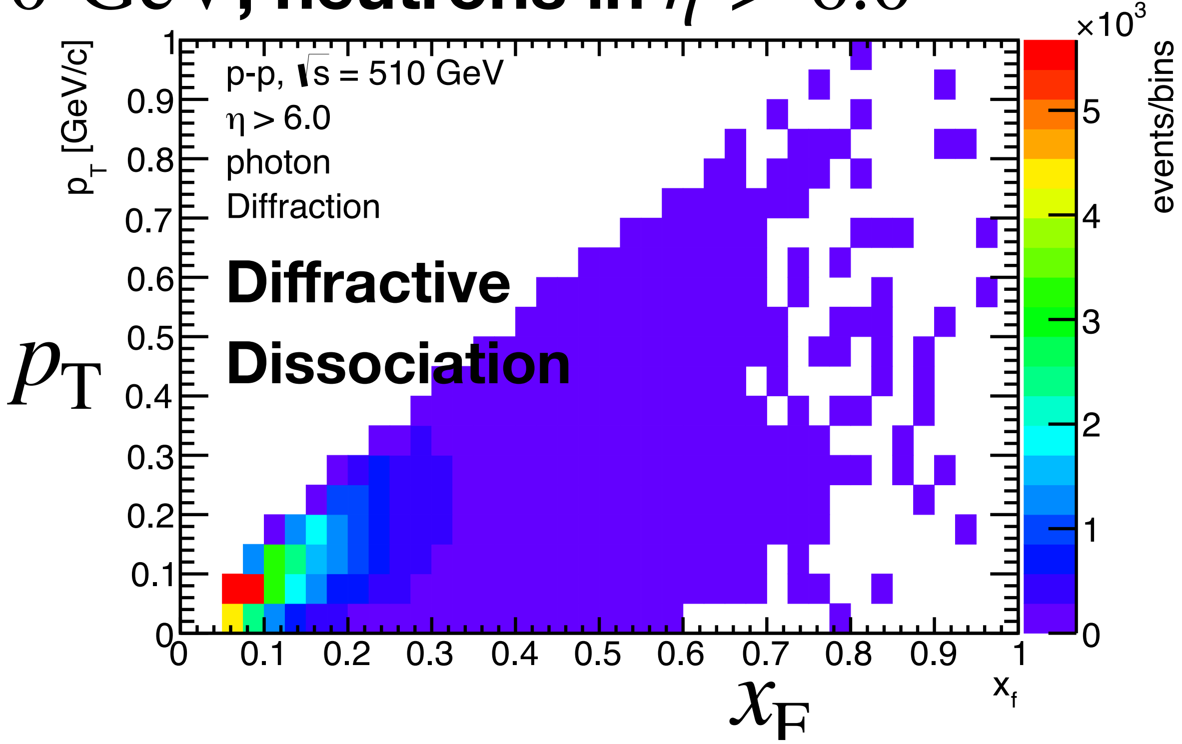
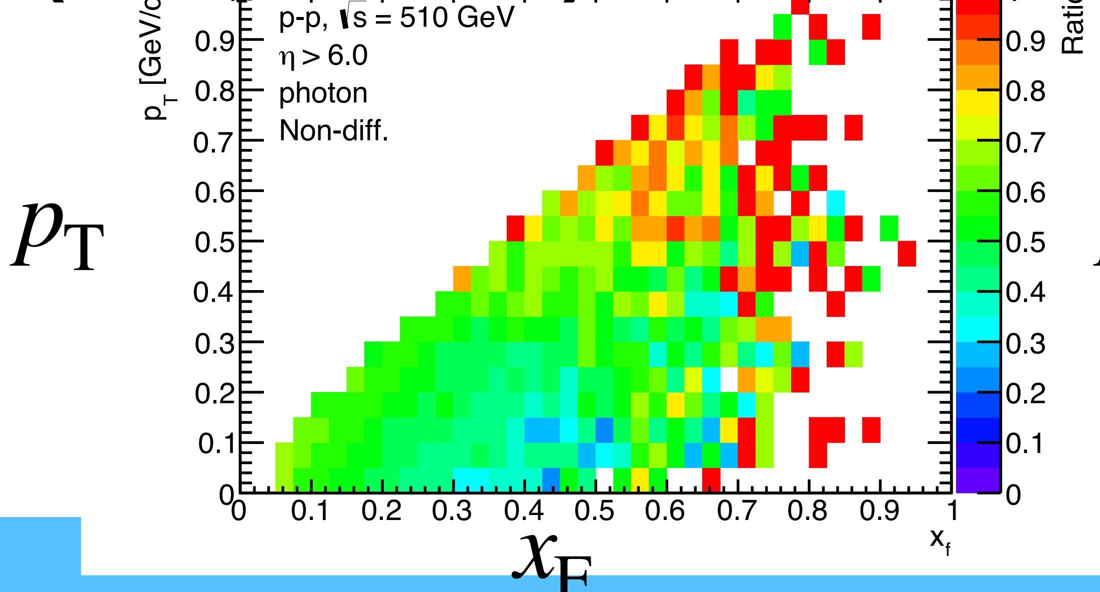
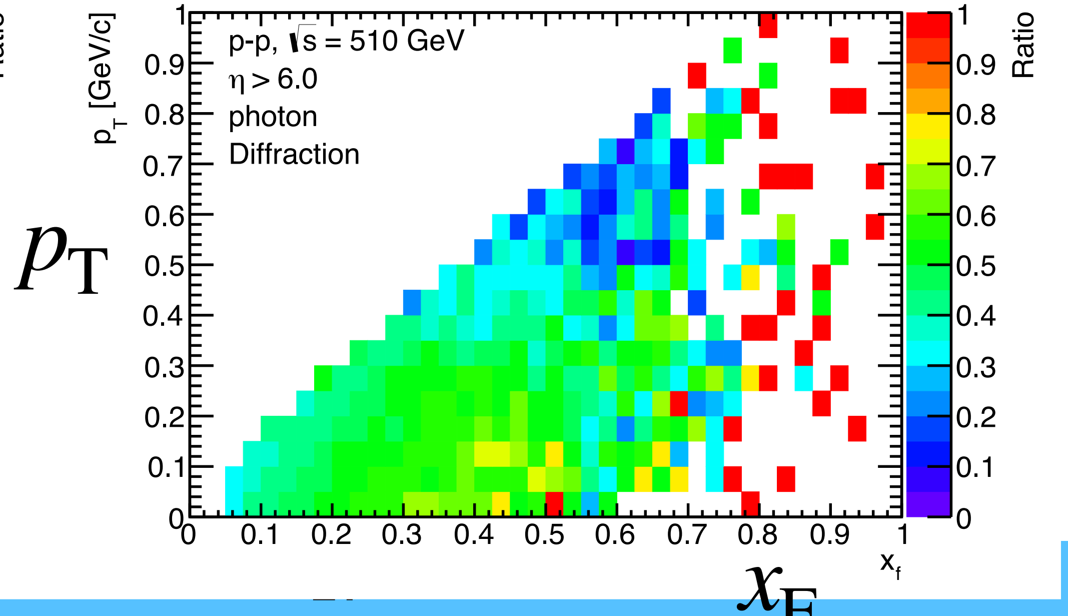




Ratio (ND/(ND+Diff))





Distributions for each cases

Distributions of forward photon

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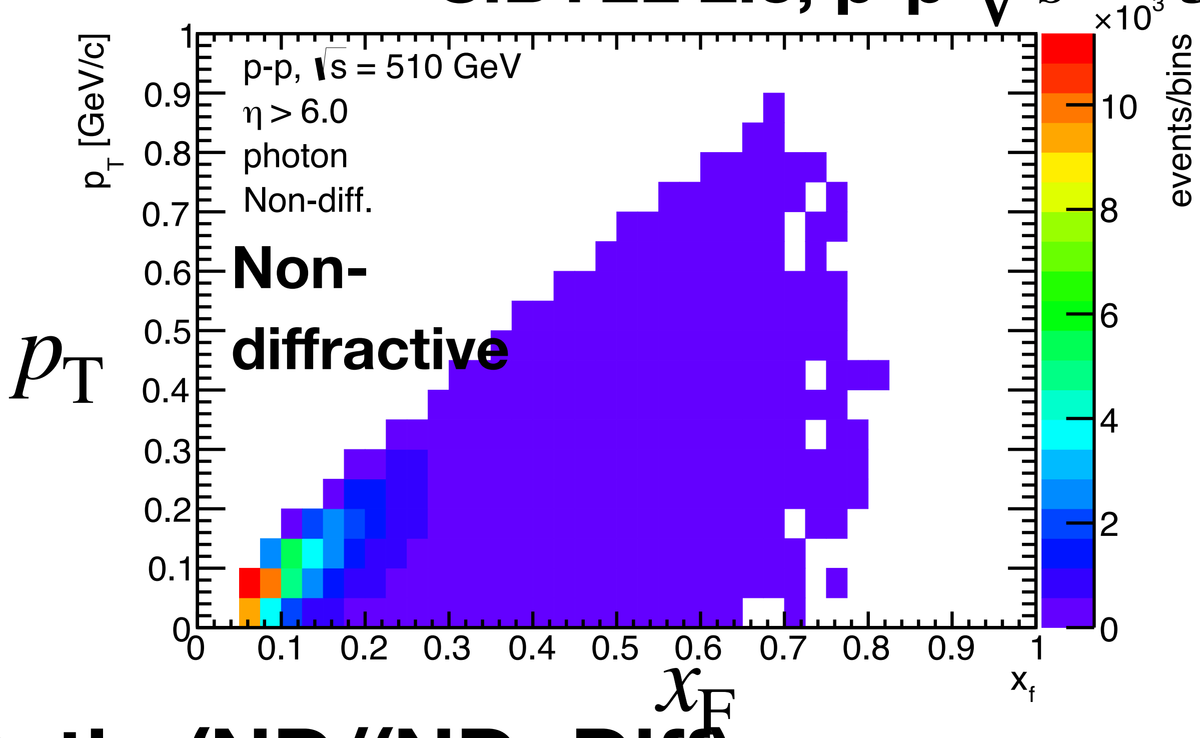

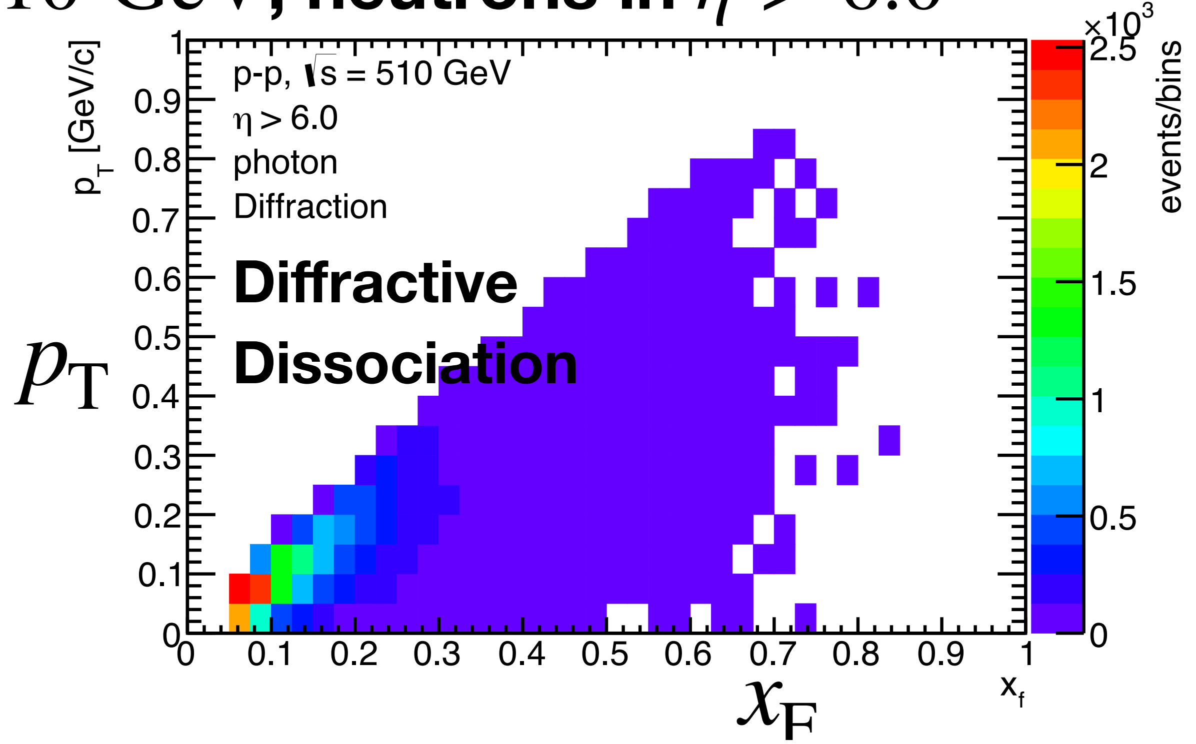

Ratio (ND/(ND+Diff)