Future physics plan from RHICf

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on behalf of the RHICf II collaboration

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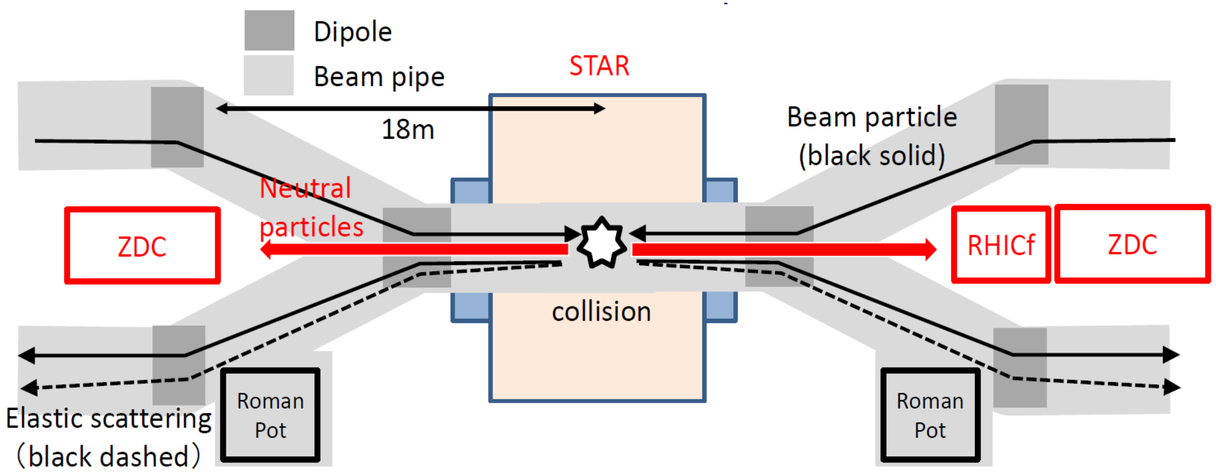
Institute for
Space–Earth Environmental Research

2021 RHIC/AGS Annual Users' Meeting, 8-11 June 2021

RHIC "*forward*"

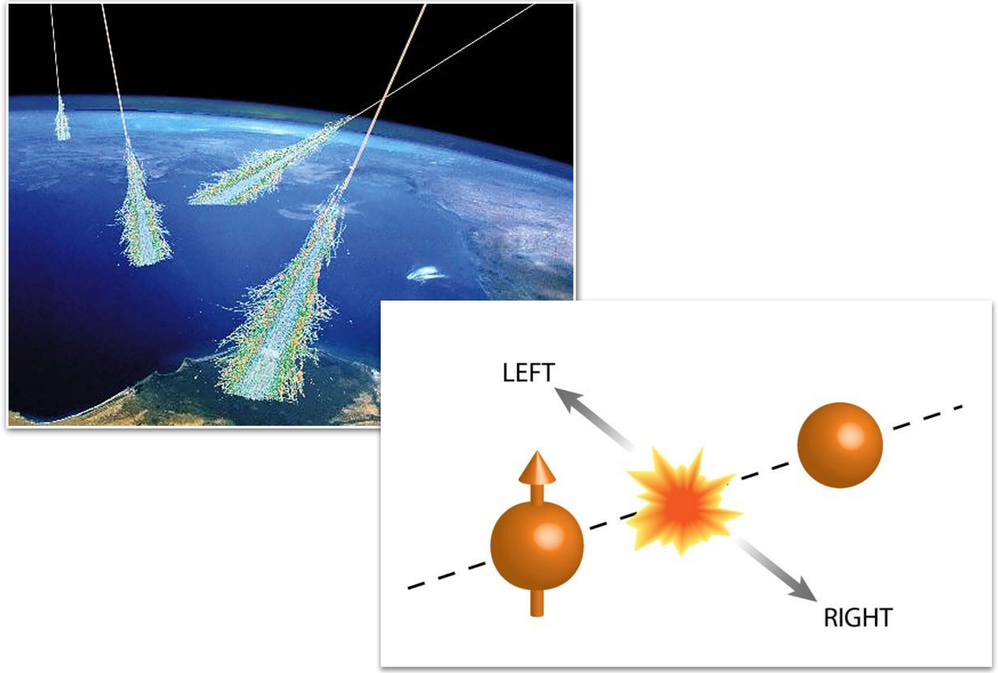


Physics at Very Forward including "Zero" degree of collisions

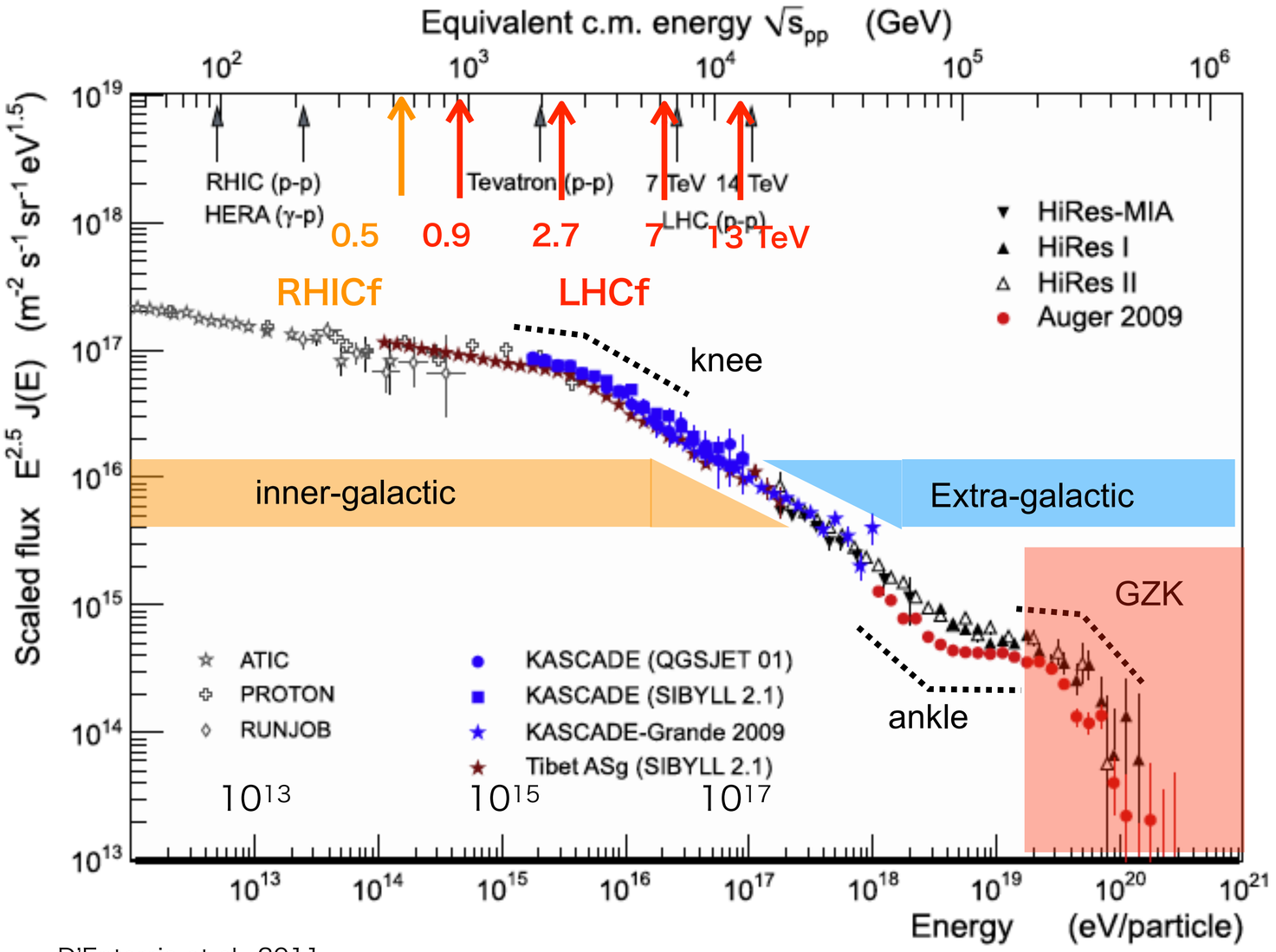
<u>Two main motivations</u>

- Cosmic-ray physics
  - Understand high energy collisions for precise measurement of high energy cosmic-rays

- Spin asymmetry measurement
  - To understand the hadronic collision mechanism based on QCD



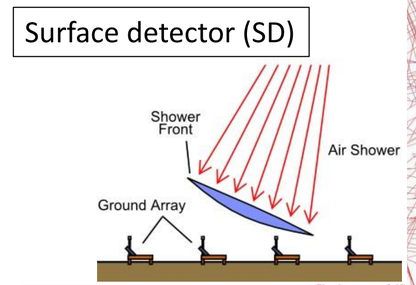
Motivation 1 - Cross-section measurement -

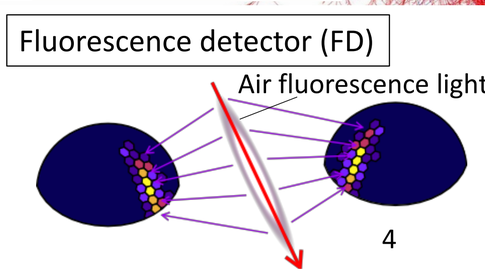


D'Enterria et al., 2011

High Energy CR observation
by Extensive Air Shower
E ~ 10^{15}eV

Studying the properties of primary CR relying on MC simulation.





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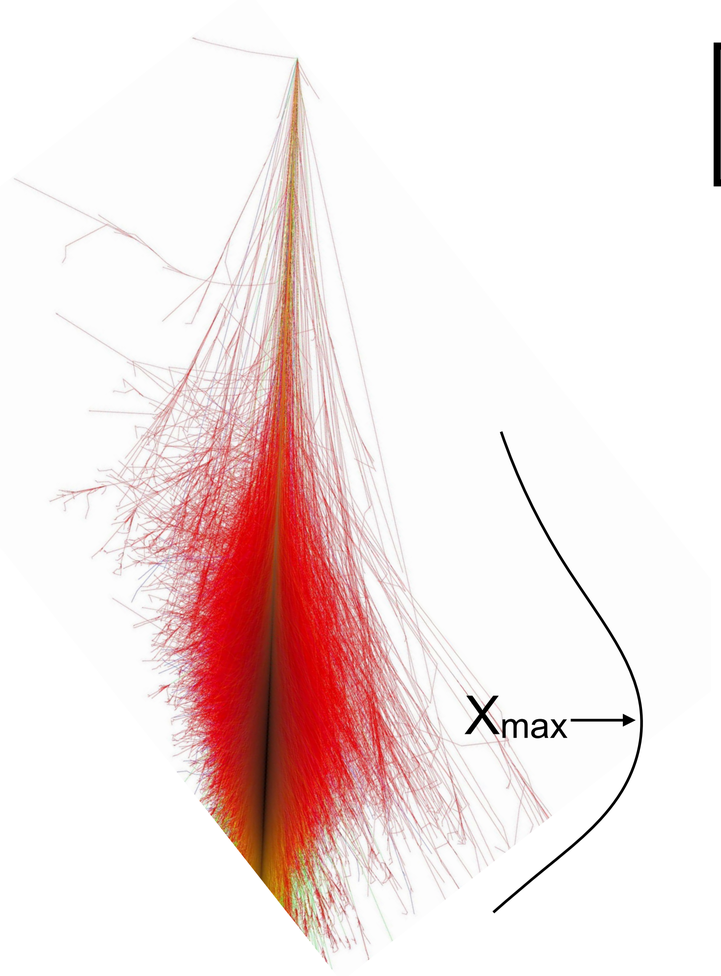
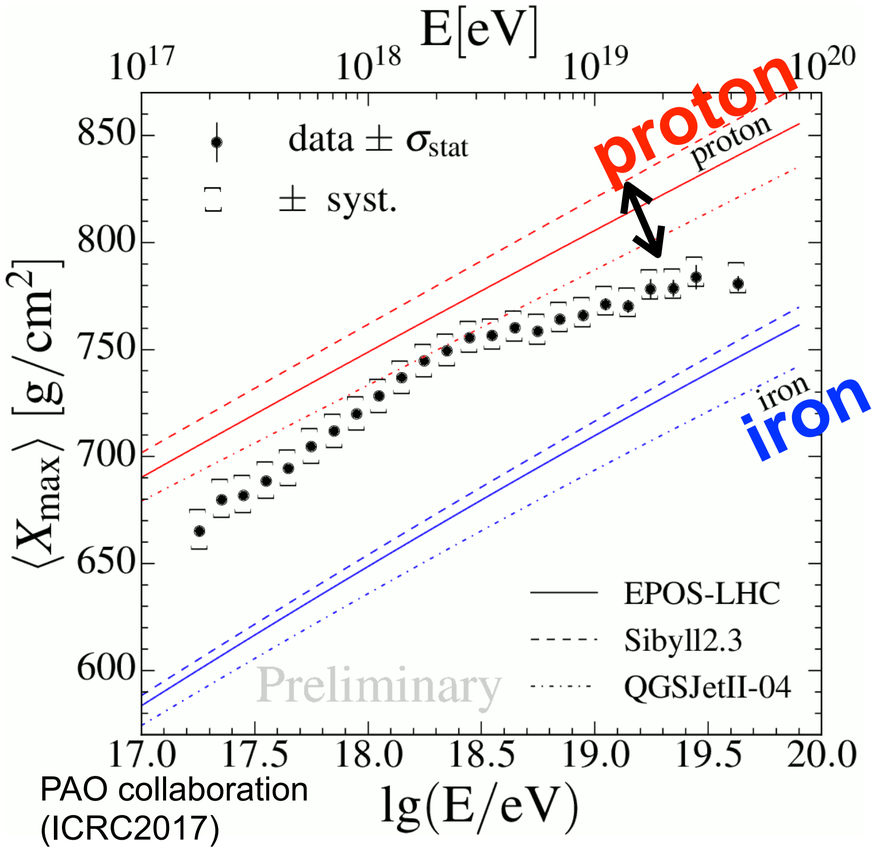
Issues on UHECR observations



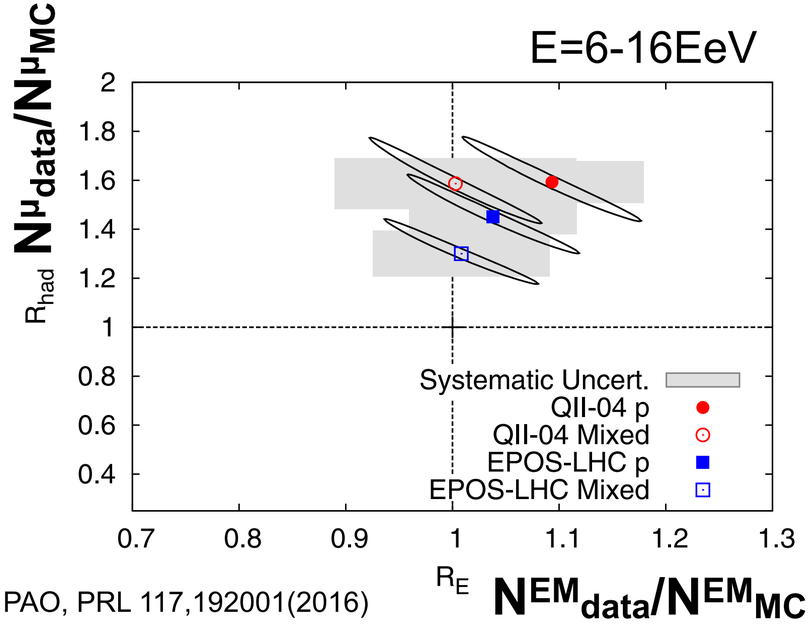
N^{μ}: Number of muons on the ground

Large model dependency of UHECR composition measurement



PAO collaboration (ICRC2017)

Muon excess $N^{\mu}_{data} > N^{\mu}_{MC}$



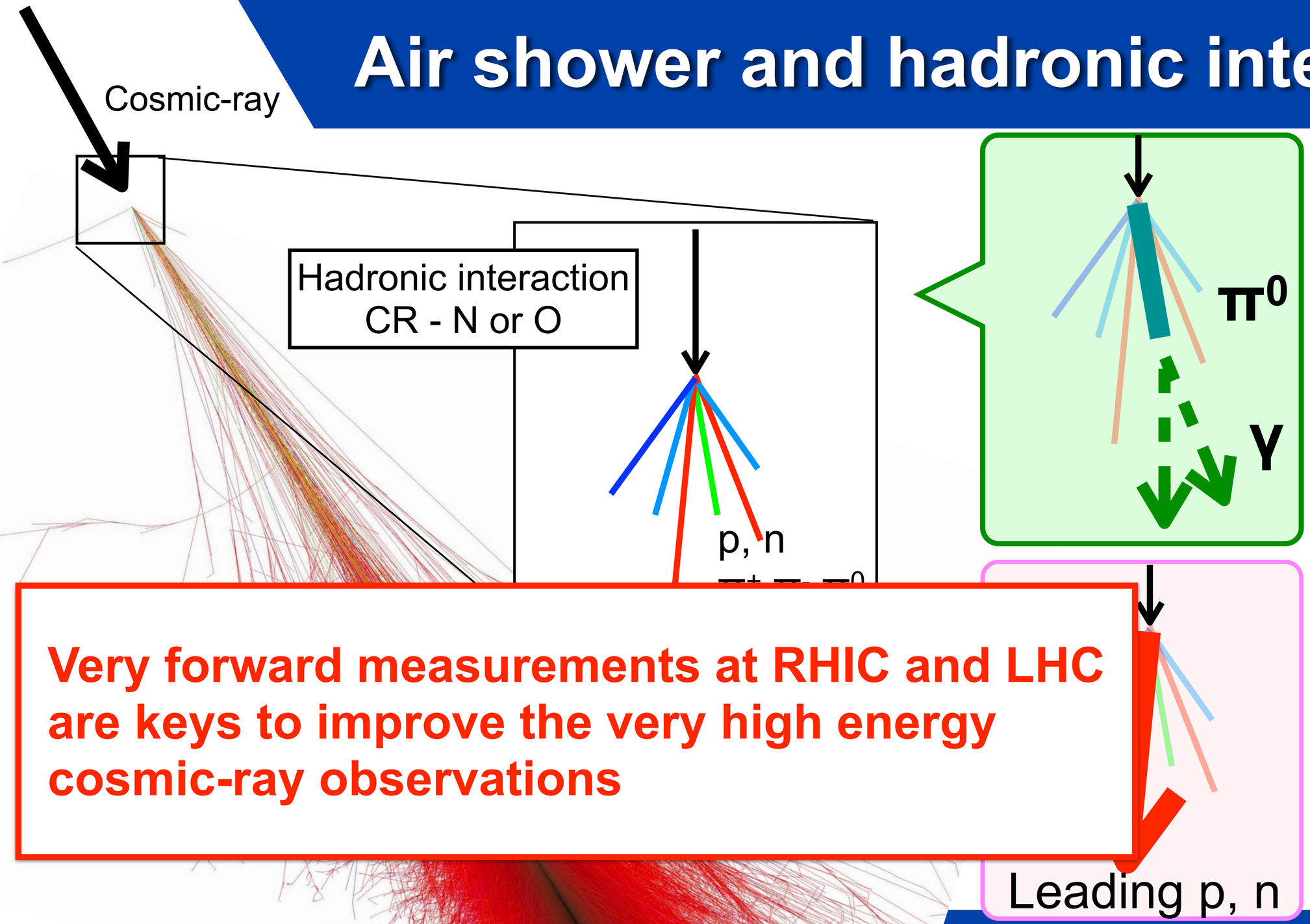
PAO, PRL 117,192001(2016)

Sensitive $E^{\pi 0}/E^{had}$ for a collision

Several ideas to solve it

- Strange particles
- Vector meson productions
- QGP

Air shower and hadronic interaction



Neutral pions

- $\pi^0 \rightarrow 2\gamma$
- Induce electromagnetic showers

Leading baryons

- bring the energy to next collisions
- Inelasticity: fraction of energy used for particle productions

  $k = 1 - E_{leading}/E_{CR}$

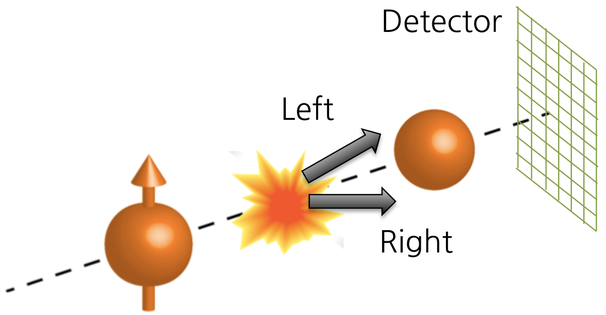
Very forward measurements at RHIC and LHC are keys to improve the very high energy cosmic-ray observations

Motivation 2 - A_N measurement -

- A_N (transverse single-spin asymmetry) measurement
  - Azimuthal angle modulation

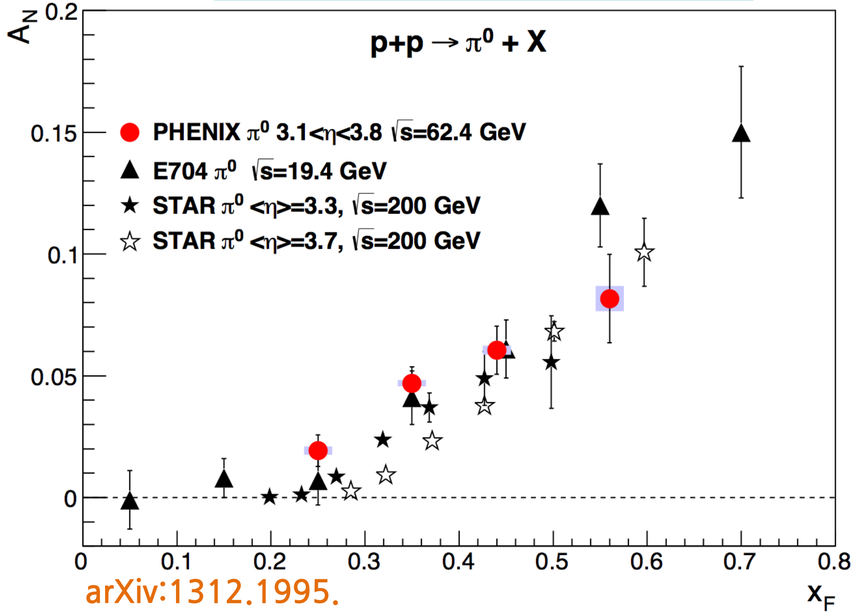
- Large A_N for forward hadron production
  - π^0 $1 < \eta < 4$, X_F dependent
    $\leftrightarrow$ RHICf coverage: $\eta > 6$
  - Neutron asymmetry at zero degree.

- The mechanism is not understood yet.



$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}} = \frac{\sigma_L^{\uparrow} - \sigma_L^{\downarrow}}{\sigma_L^{\uparrow} + \sigma_L^{\downarrow}}$$

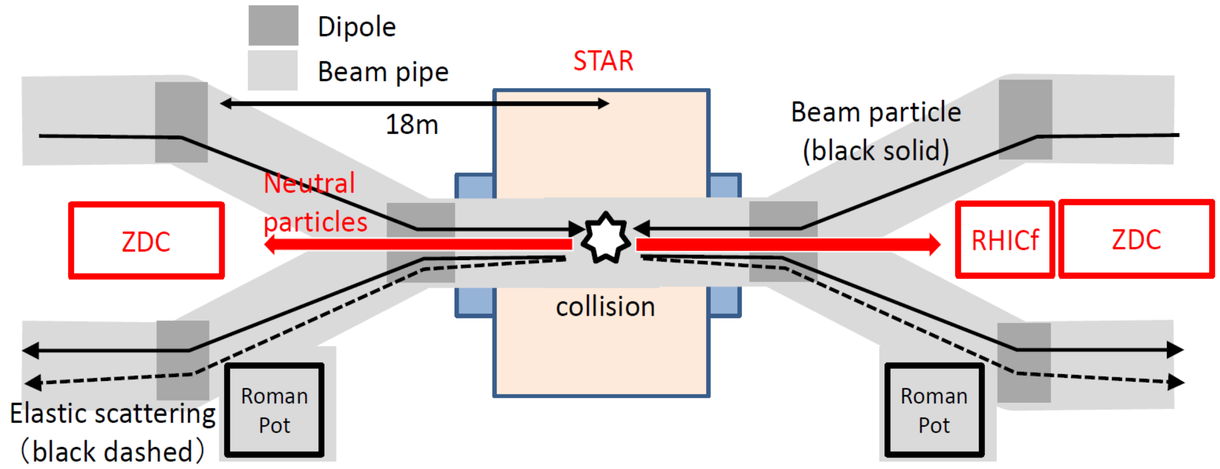
$2 < \eta < 4, p_T > 1$ GeV/c

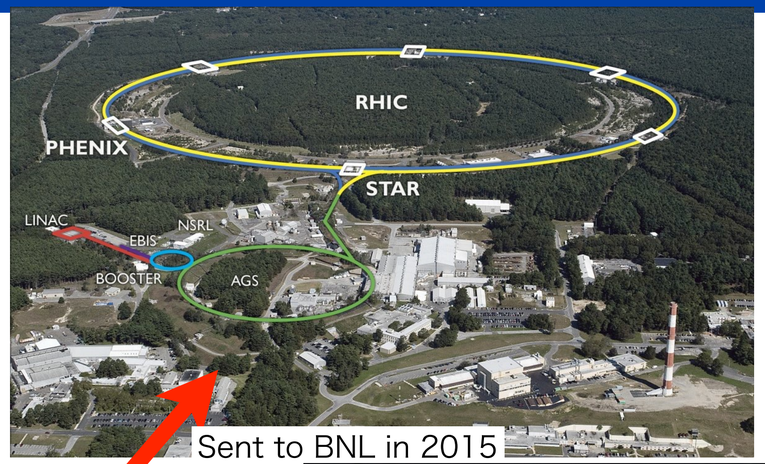


arXiv:1312.1995.

Operation in Run 17

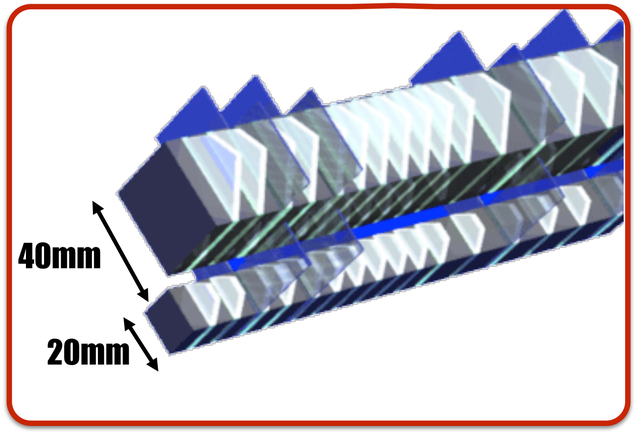
- RHICf detector (LHCf-Arm1) installed in front of STAR-ZDC

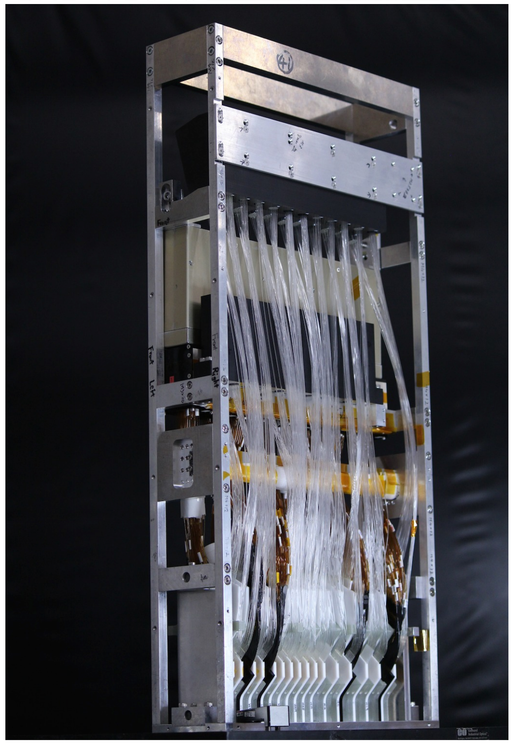




Sent to BNL in 2015

LHCf-Arm1

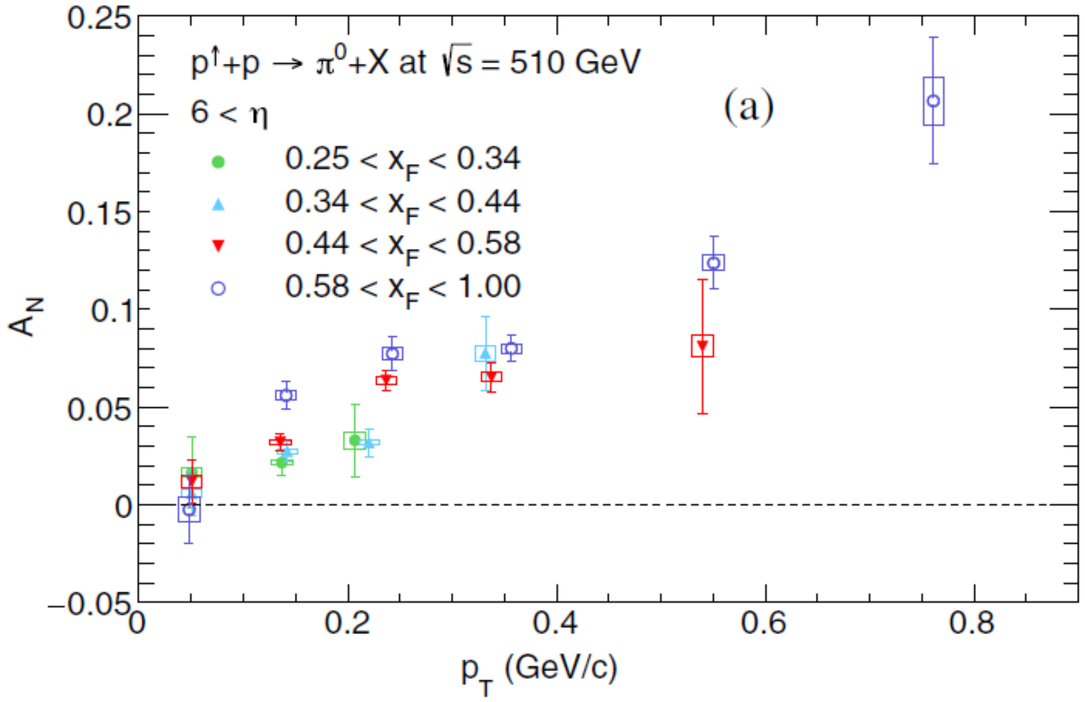


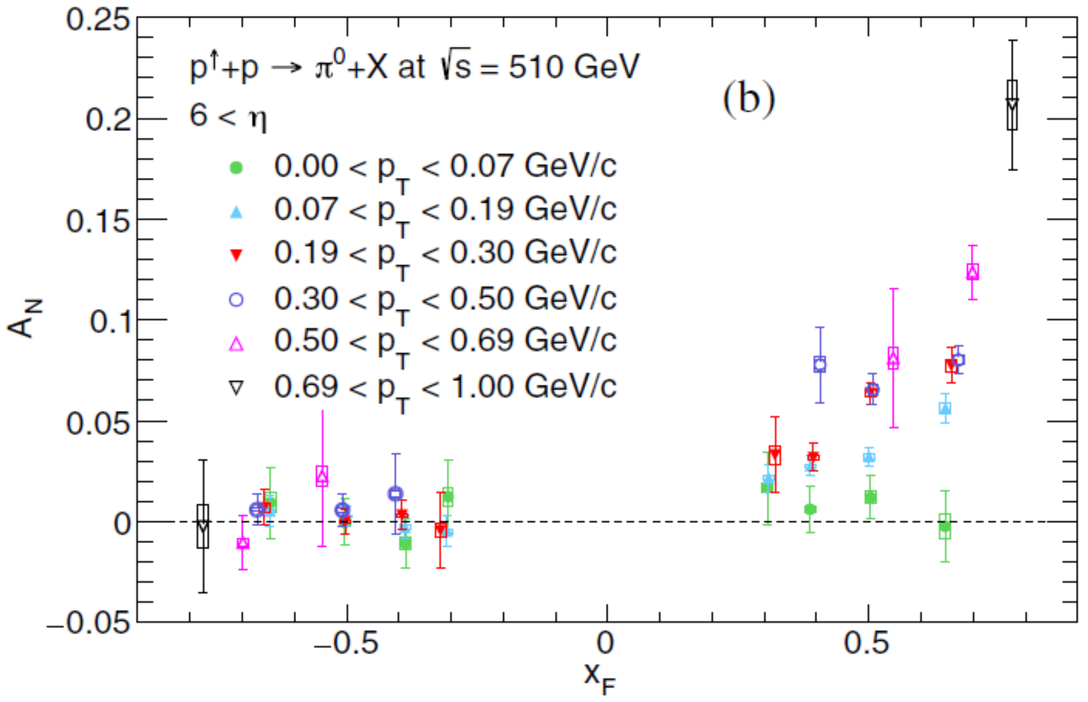


- Two position-sensitive calorimeters
  - Small tower: 20mm x 20mm
  - Large tower: 40mm x 40mm
  - Tungsten 44 radiation
  - 16 GSO scintillator plates for shower sampling
  - 4 XY GSO bar hodoscopes

Run 17 result: π^0 A_N measurement

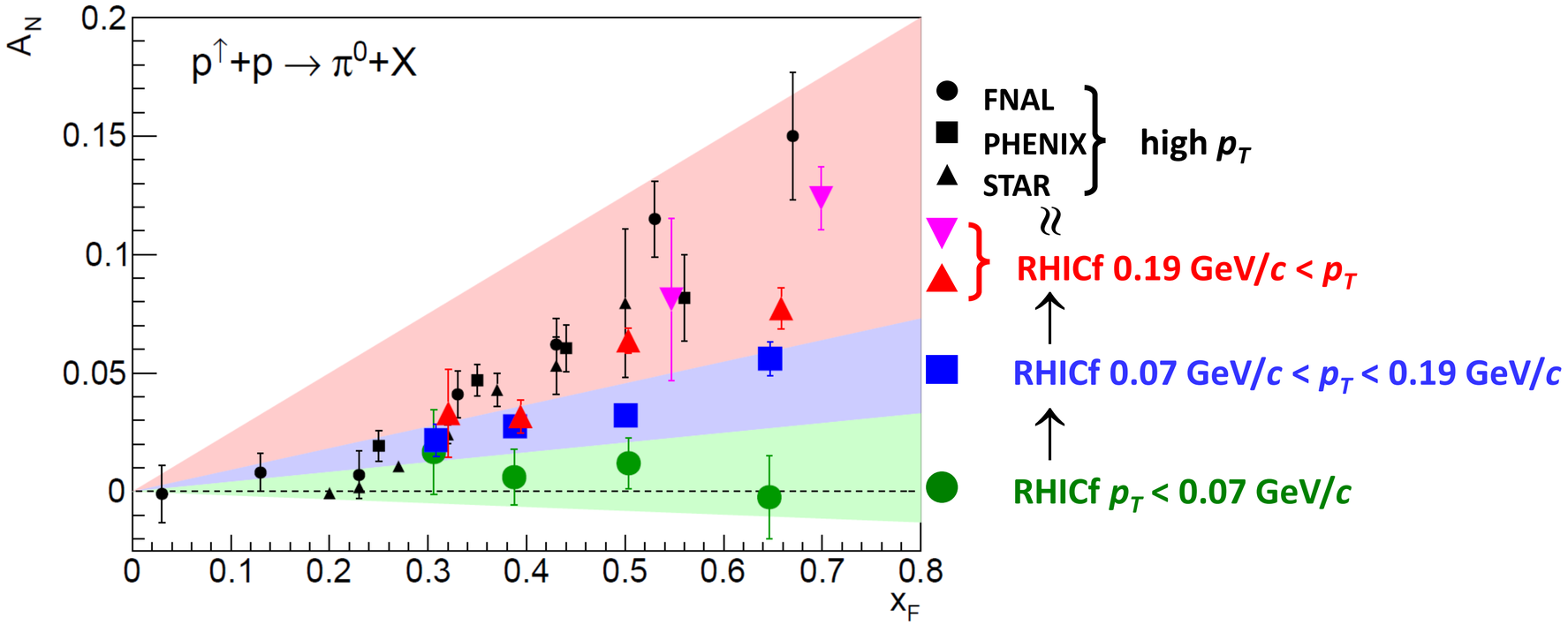
- Transverse single-spin asymmetry for very forward neutral pion production in polarized p+p collisions at $\sqrt{s}$ = 510 GeV
  Phys. Rev. Lett. 124, 252501 (2020)
- Zero asymmetry in backward and forward $p_T < 0.07$ GeV/c
- Clear p_T dependency





Run 17 result: π^0 A_N measurement

- Comparison with high p_T data of past experiments
  - Nearly the same large asymmetry is reached at low $p_T < 0.2$ GeV/c
  - Contribution of other mechanisms, diffraction and resonance, may provide a hint to the mystery



On-going analyses

- Production cross-section measurement
  - Forward photon differential cross-section
  - (π^0 and neutron)
- A_N measurement
  - Neutron A_N measurement ($\Delta E/E \sim 40\%$, $\Delta p = 1$mm)

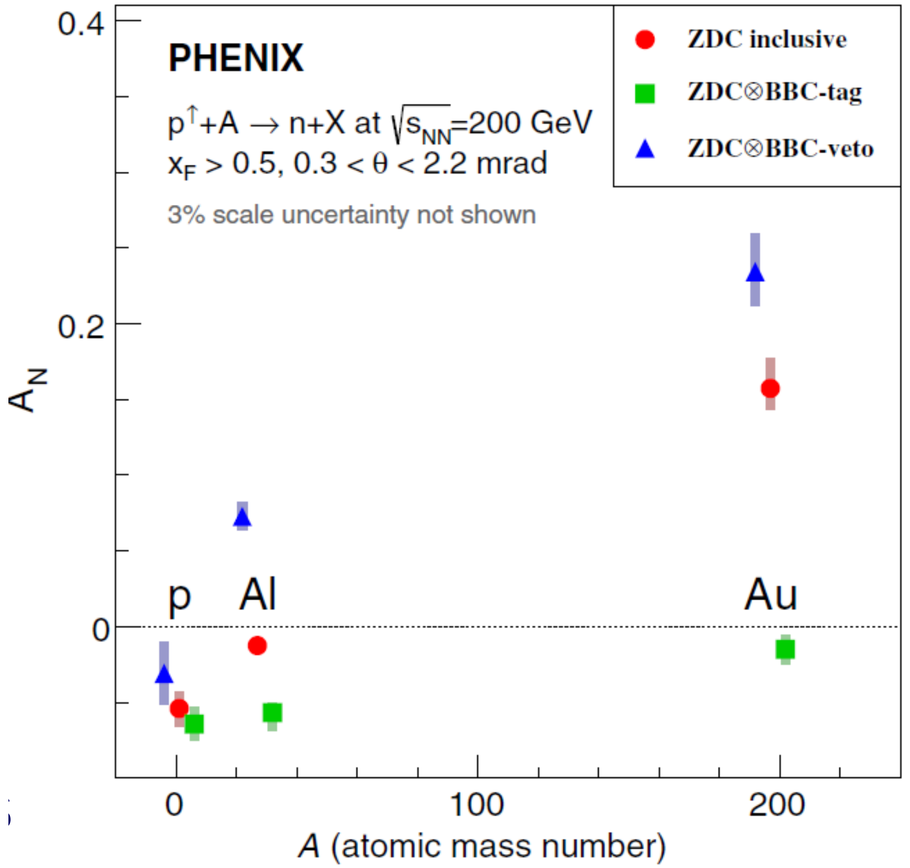
- Combined analyses with STAR in future
  - A_N measurement with separating diffractive and non-diffractive events
    Diffractive sample with selection of no activity in the central region.
  - Improvement of neutron energy resolution from 40% to 20%

Future plan “RHICf II”

Motivation for RHICf II

- Increase statistics of high-X_F π^0
- Measurement of strange hadrons at 0 degree
  - $K^0_S \rightarrow 2\pi^0 \rightarrow 4\gamma$ (B.R. 30.7%)
  - $\Lambda \rightarrow n+\pi^0 \rightarrow n+2\gamma$ (B.R. 35.9%)
    For Air shower physics and Atm. neutrino flux (next page)

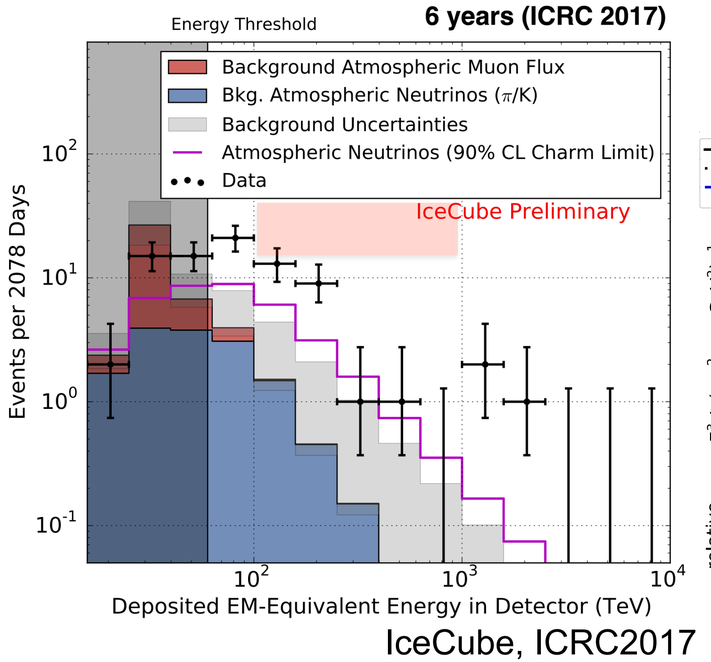
- p + A collisions
  - A-dependence of A
    - Strong A-dependence of Neutron by PHENIX (Pays. Rev. Lett 120, 022001 (2018))
    - A-depedence of very forward π^0
  - p + light ion collisions for Cosmic-rays
    - Ideal condition for CR-Air interaction studies

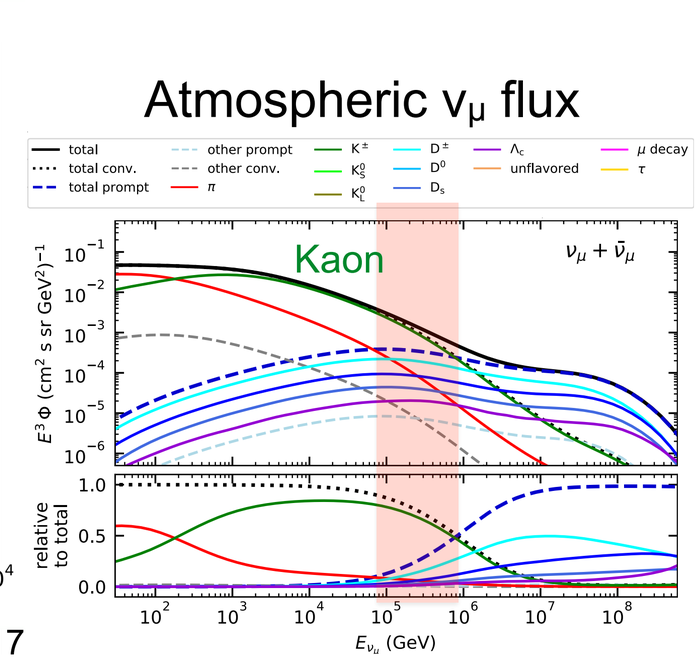


Kaons in Air showers

- Muon excess issue
  - If higher Kaon production in high energy
    → increase the muon number on the ground.
    - A high energy π^0 decays immediately →EM component,
    - A high energy K^0 collides air before its decay→ Hadronic component
  - Large K/π ratio in QGP

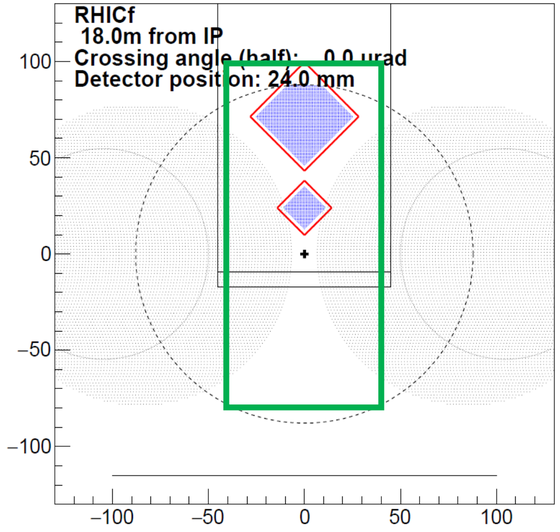
- Impact on Atm. ν flux
  - Hot topics:
    Astro-neutrino detection by IceCube
  - large uncertainty on
    background estimation of Atm. ν
  - Kaons are dominant source of
    ν_μ in E_ν <~ 10^{15}eV

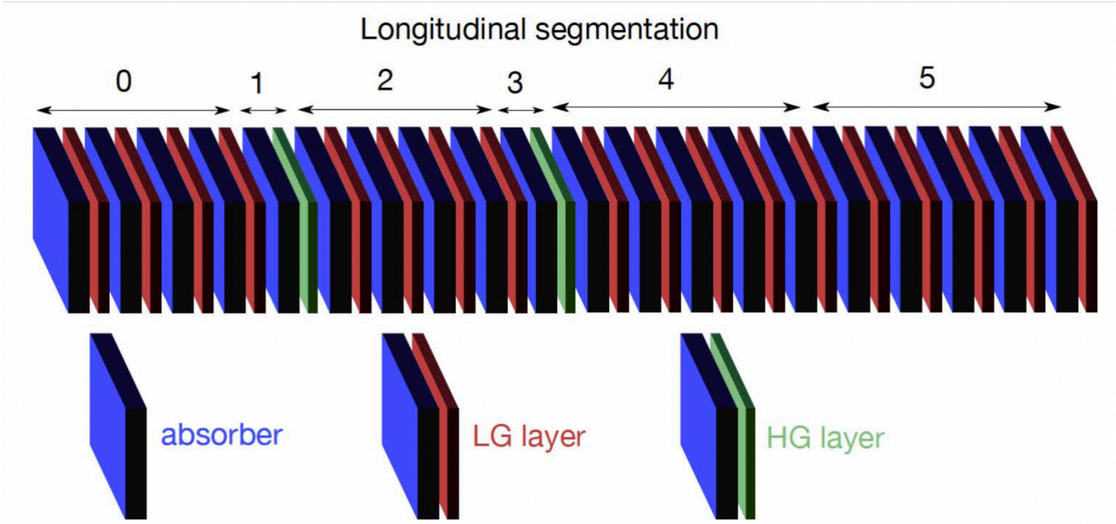


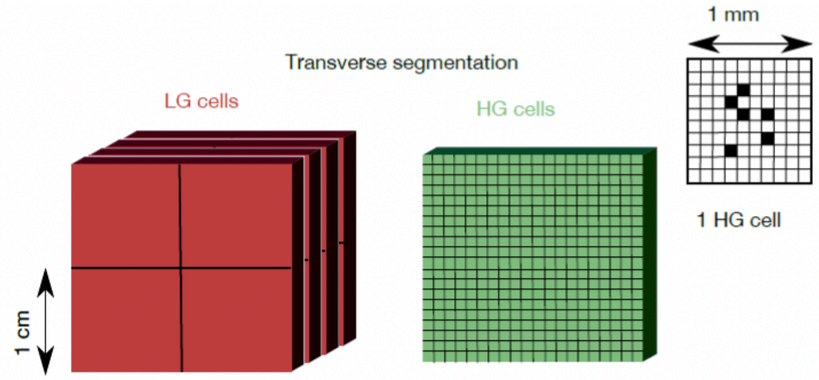


New detector for RHICf II

- Develop a completely NEW detector
  - W + Silicon Pad & Pixel calorimeter from ALICE FoCal technology
  - Wide acceptance detector of 8 cm^W x 18 cm^H
  - Optimization for ~ 100 GeV photons
    Expected energy resolusion: $\sigma_E/E=25\%/\sqrt{E(GeV)}\oplus 2\%$
- Readout electronics based on HGCROC ASIC (CMS)

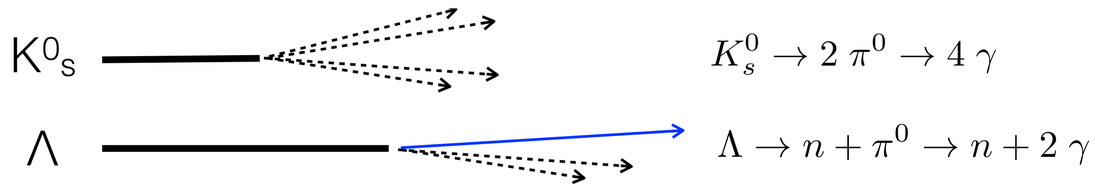




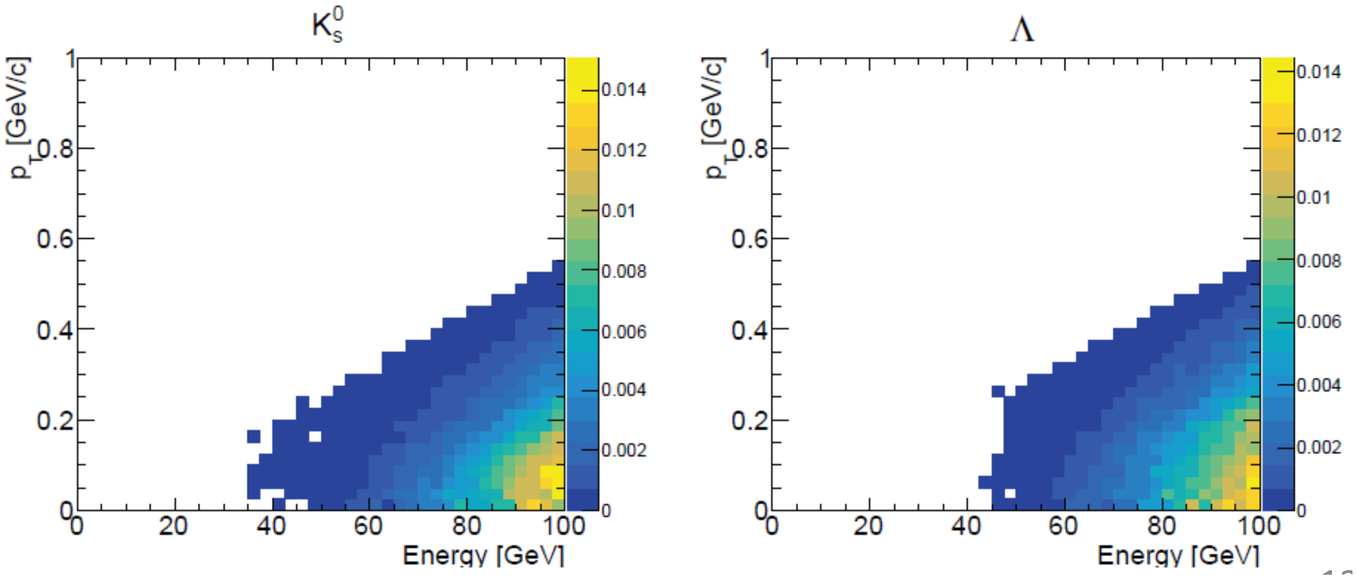


K^0_s and Λ measurement at RHICf II

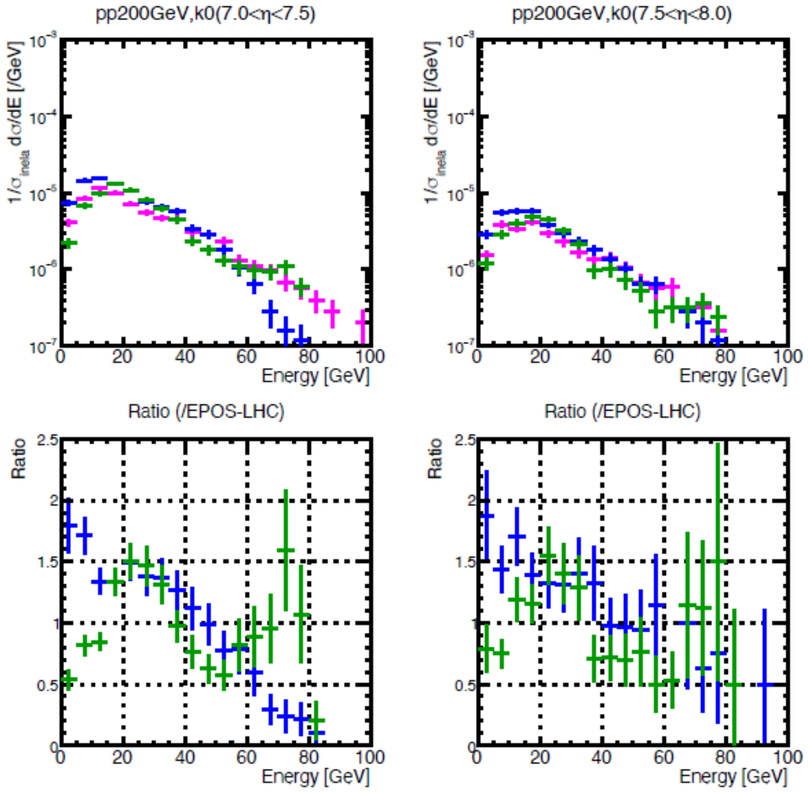
- 4 γ for K^0_s and n+2γ for Λ detection simultaneously



- Geometrical accettante



Large discrepancy of model predictions @ *pp*, √s=100GeV



Operation strategy

- Target of the operation in Run 24
- Parasitic operation with other programs
  - *No request of a dedicated beam time*
  - *No special beam condition except pol. direction*
    - Enough radiation hardness for long operation with nominal luminosity
    - No position scan thanks to the wide acceptance detector.
      Impact on ZDC will be stable during the operation
    - Radial polarization to maximize p_T acceptance
      Not all the time of the operation
      ~ 1 shift for setup
- Operation site
  - Under discussion.

Status & Schedule

- *"Letter of Intent"* has been submitted to PAC in September 2020

- Detector R&D (as ALICE-FoCal R&D) are ongoing
  - Confirmation of radiation hardness of Silicon Pad by accelerator
  - Beam tests of each components in
  - A beam test of Prototype detector at CERN-SPS

- Detector construction;
  - Fix the design in 2021
  - Construction in 2022 and 2023
  - Beam test at CERN-SPS before the operation in Run 24

Summary

- RHICf is an experiment at zero degree measurement at RHIC
  - Single spin asymmetry measurement of very forward π^0 and neutrons.
    Large and clear pT dependent asymmetry was found.
  - Differential cross-section analyses of photons, π^0s and neutrons are on-going.

- Another operation with a new detector is planed
  for Run 24 (RHICf II)
  - High statistics of high energy π^0 events
  - Strange hadrons, K^0_S and Λ, measurement with wide acceptance detector
  - Parasitic operation with other experiments