Cross Section and Asymmetry Measurement of Very Forward Neutral Particle Production at RHIC ~ RHICf Experiment ~

Spin 2014 in Beijing

October 24, 2014

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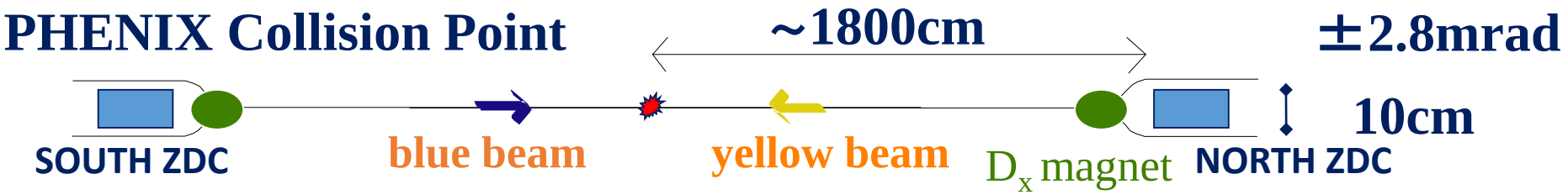
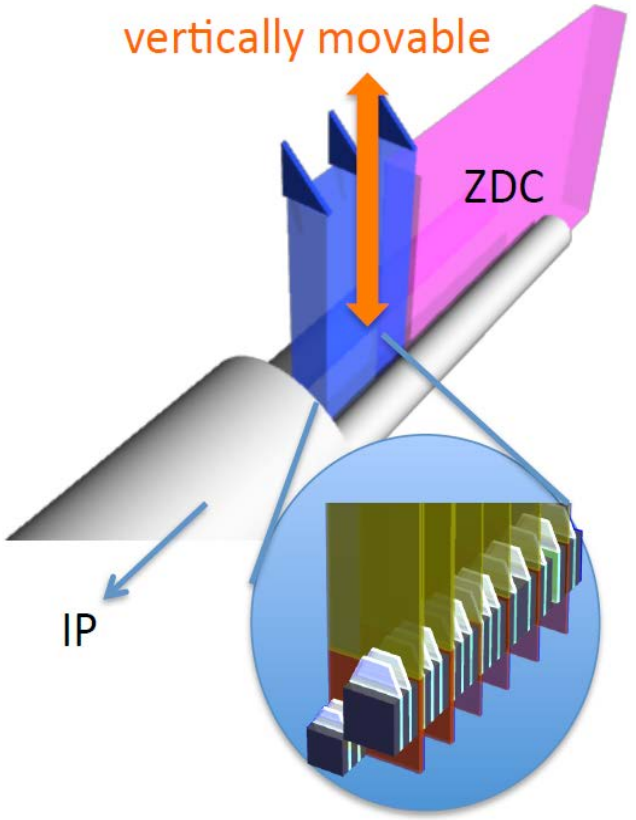
for the RHICf Collaboration

Overview of the RHICf experiment



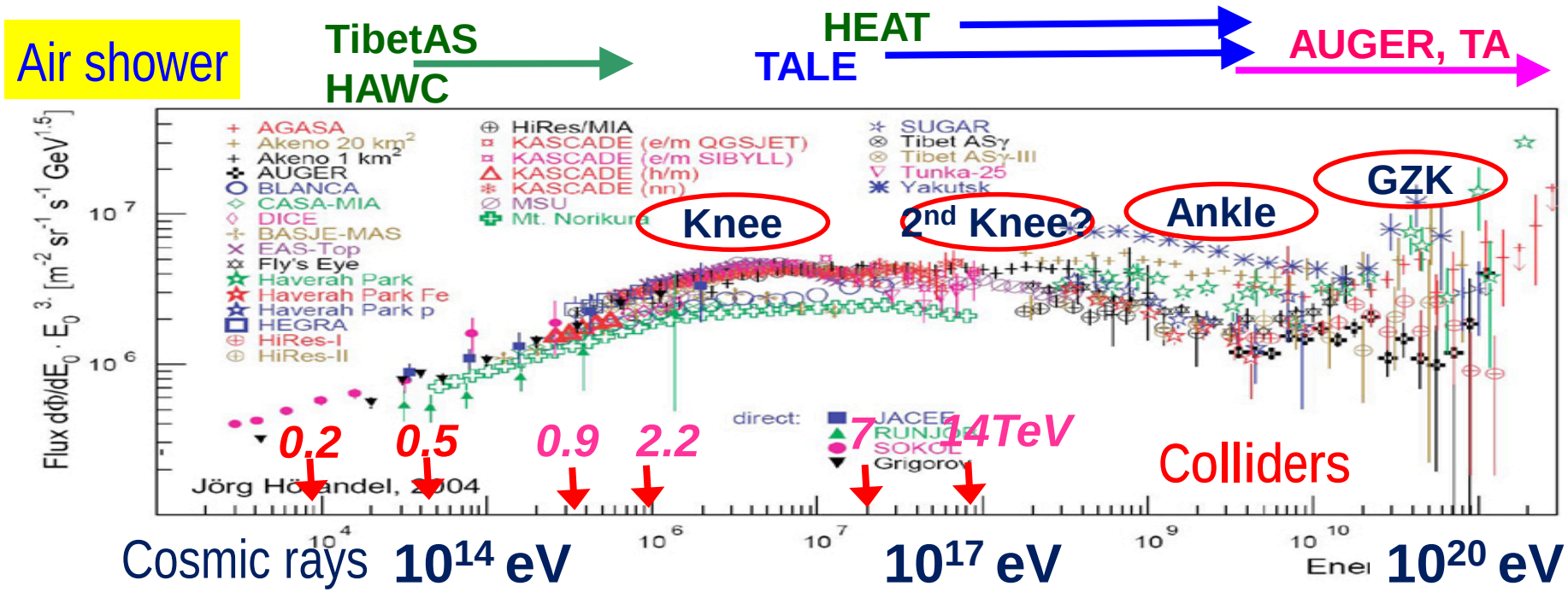
- A new experiment to measure neutral particle (i.e. γ, π^0, n) at very forward with a position-sensitive electromagnetic calorimeter in p+p collisions at $\sqrt{s}$ = 510 GeV (and p+A collisions at $\sqrt{s}$ = 200 GeV)
- One of LHCf calorimeter in front of ZDC of PHENIX
- Expect to run in 2016



Science cases of the RHICf experiment

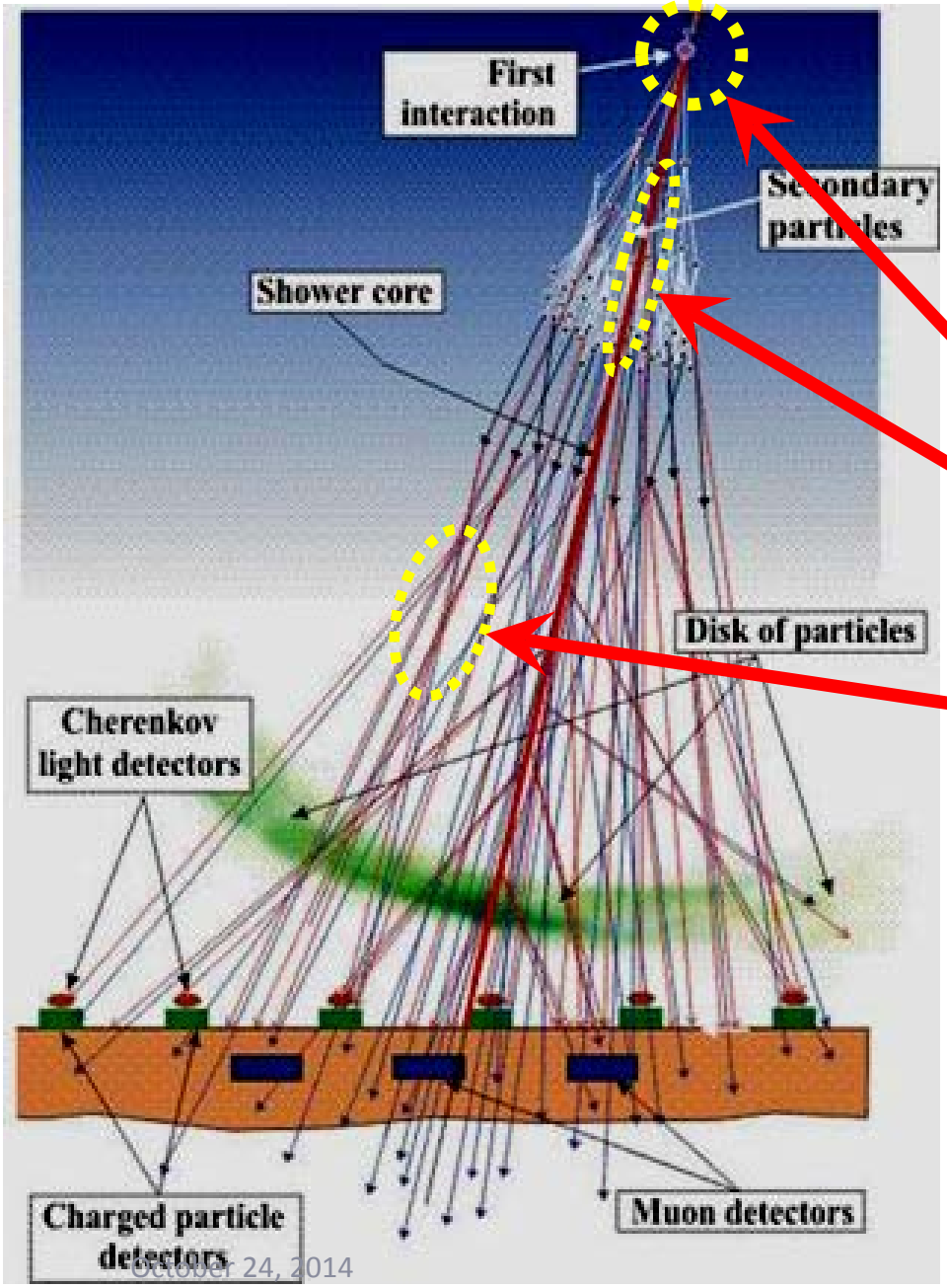
- Understanding hadron interaction
  - With cross section and asymmetry measurement of very forward neutral particle production
  - Based on QCD
- Origin of the ultra high energy cosmic ray
  - Air shower observation at the surface of the ground
  - Accelerator experiments to calibrate hadron interaction

Origin of the ultra high energy cosmic ray



- A 100 year-old problem since its discovery in 1912
  - Supernova remnant up to 10^{15} eV
  - Beyond 10^{15} eV, from our galaxy or extragalactic source?
  - Different experiments do not agree in absolute flux
- Need dedicated very forward measurement at hadron colliders
  - LHCf measured p+p (7, 2.76, 0.9 TeV) and p+Pb(5TeV/n)
  - RHIC data at the low end is important for extrapolation to 10^{20}eV
  - RHIC may be able to serve p + Light Ion (e.g. Nitrogen) collisions

Air shower observation at the surface

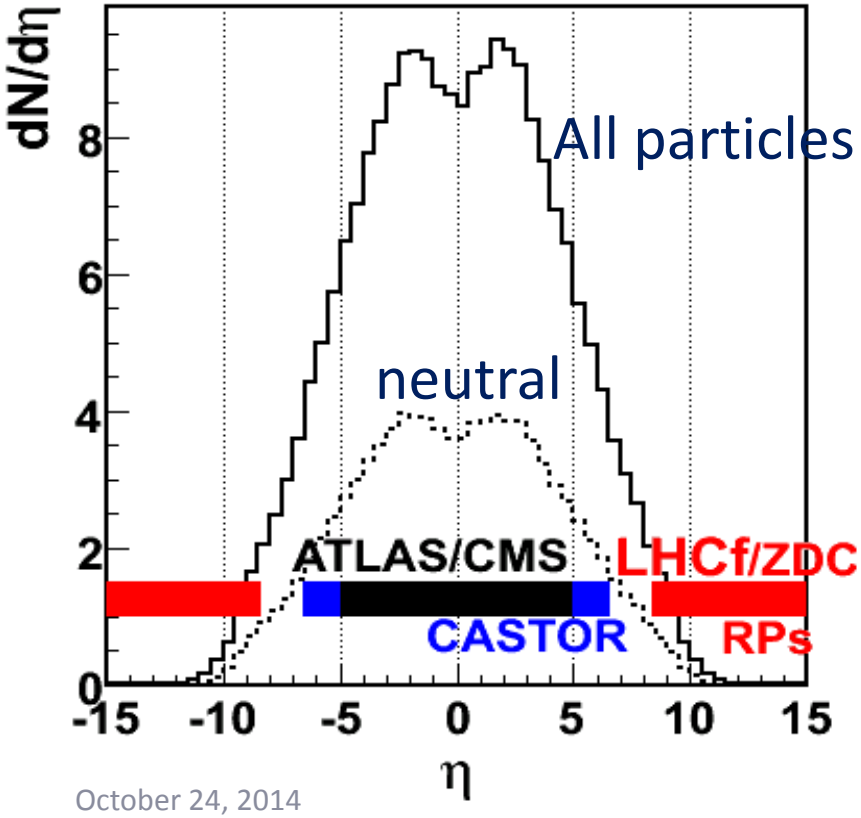


- Cosmic ray interaction
  - Rapid depelopment or deep penetration
- Inelastic cross section
- Forward energy spectrum
- Inelasticity
- secondary interactions

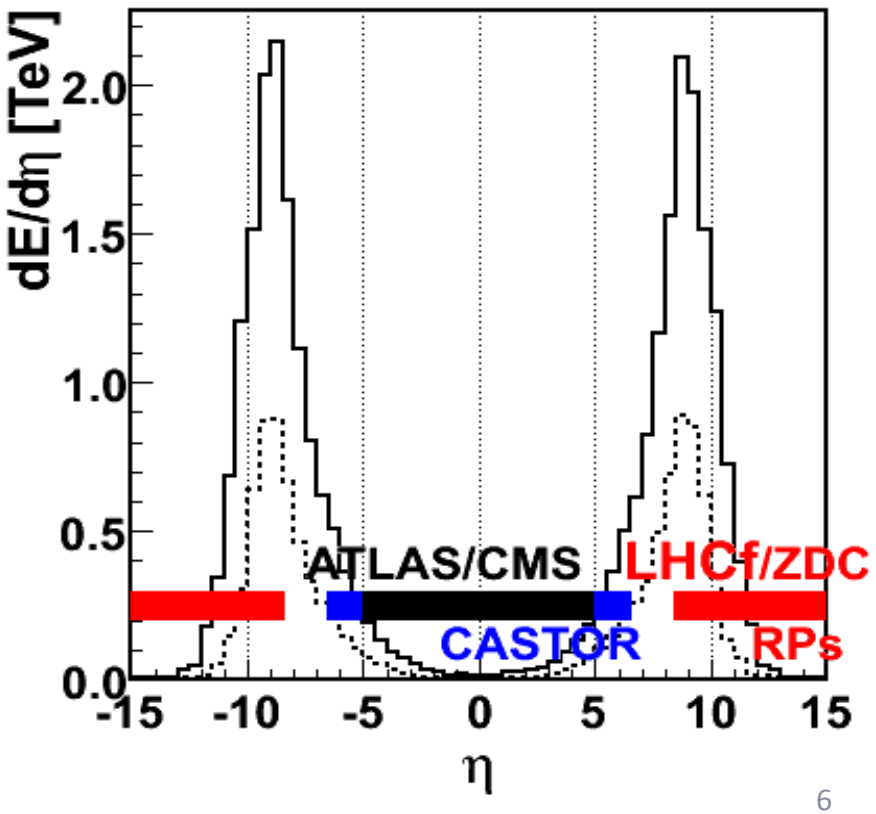
Forward energy spectrum

- From high energy accelerator experiments
- Majority of energy flow at very forward
  - LHCf / ZDC / Roman pots at LHC
  - Particles $x_F > 0.1$ gives 50% of shower particles

Multiplicity

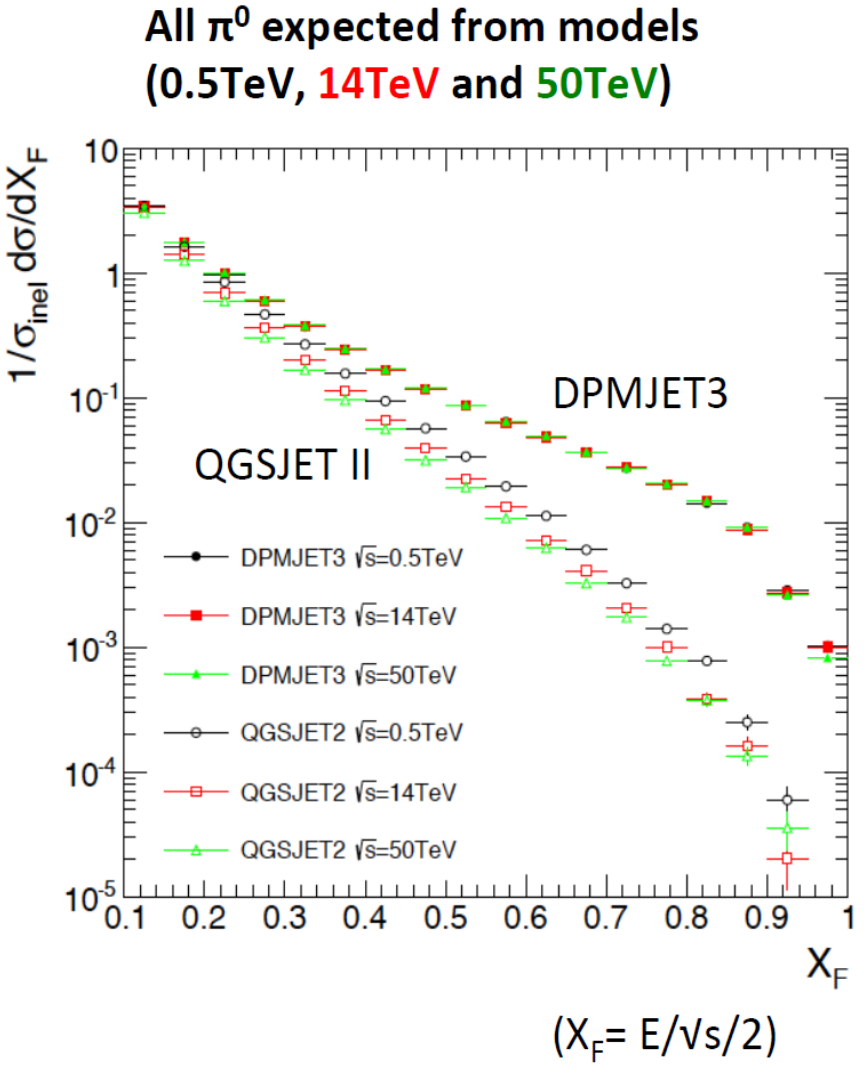


Energy Flux



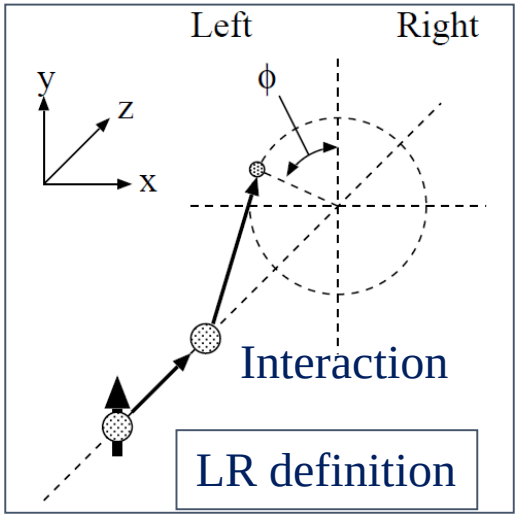
Forward energy spectrum

- Highest energy of the cosmic ray cannot be reached by accelerator experiments
- Scaling property?
  - Cross-section can be approximately given by x_F (E/E_{max}) and p_T (transverse momentum, << E)
  - Scaling violation should be checked with different energies
- Comparison at LHC and RHIC energies

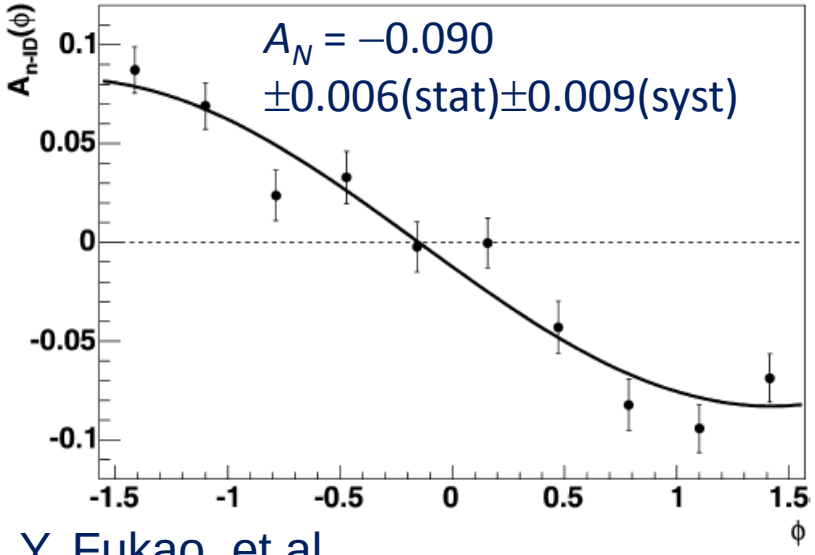


Understanding hadron interaction

- Asymmetry measurement of very forward neutron production with polarized proton collisions at RHIC
- Measurement at IP12 in Run2 (2001-02)
  - Very large left-right asymmetry (A_N) of very forward neutron was discovered
  - Used for local polarimeter to monitor polarization direction at the collision point



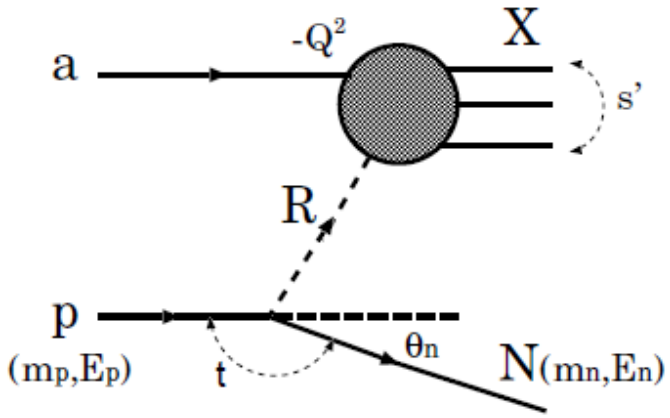
$$A_N \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}}$$

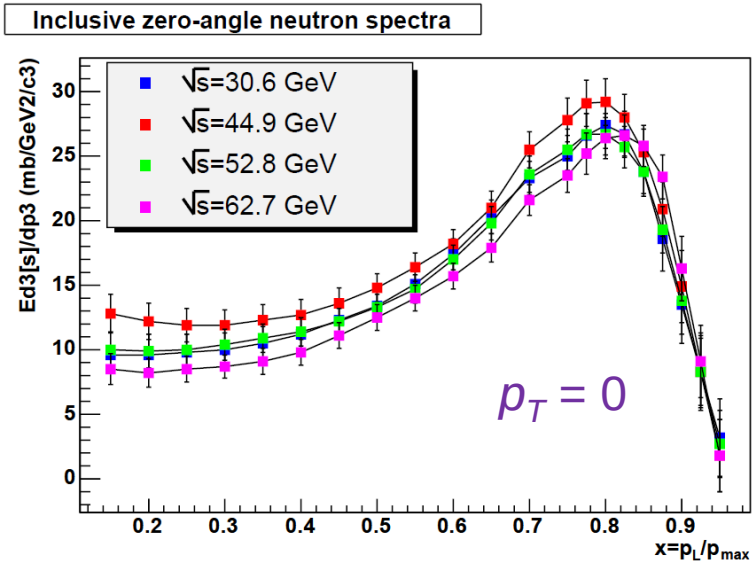


Y. Fukao, et al.,
Phys. Lett. B 650 (2007) 325.

Very forward neutron

- Cross section measurement at ISR/FNAL
  - Forward peak in the x_F distribution around $x_F \sim 0.8$
  - Only a small $\sqrt{s}$ dependence
- OPE (one-pion exchange) model gives a reasonable description
- Cross section measurement at HERA(e+p)/NA49(p+p)
  - $\sqrt{s}$ dependence indicated
  - Suppression of the forward x_F peak at high $\sqrt{s}$?

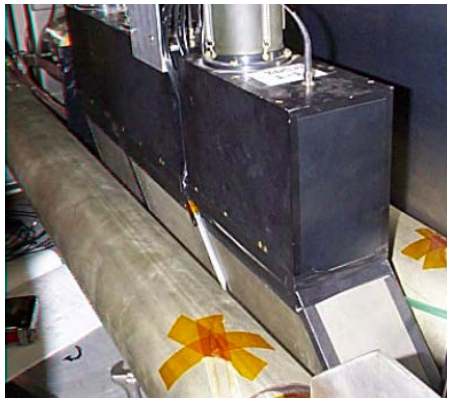


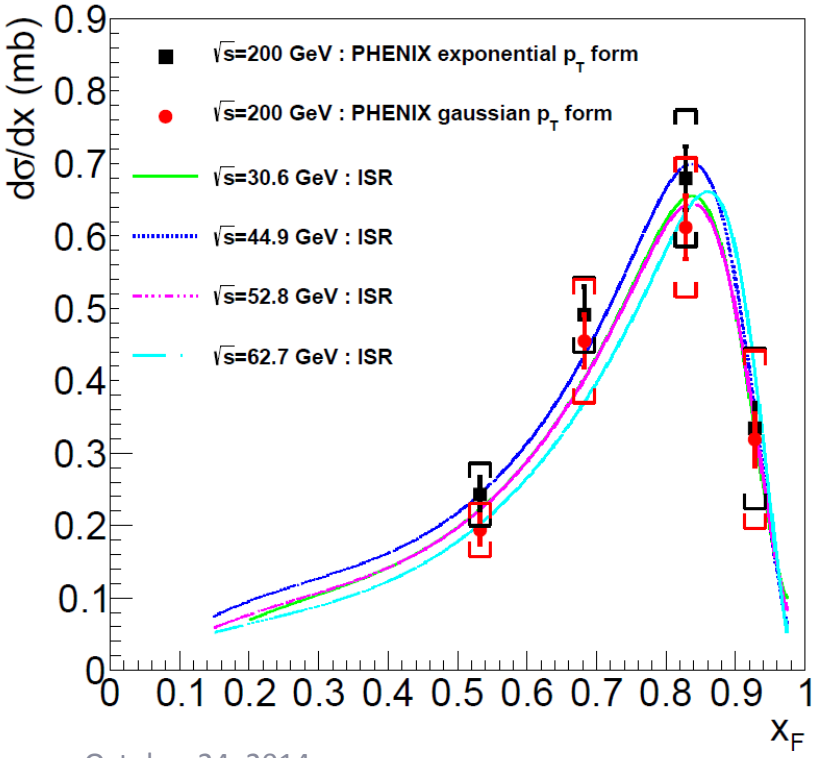


No cross section measurement performed at IP12 experiment → measurement at PHENIX

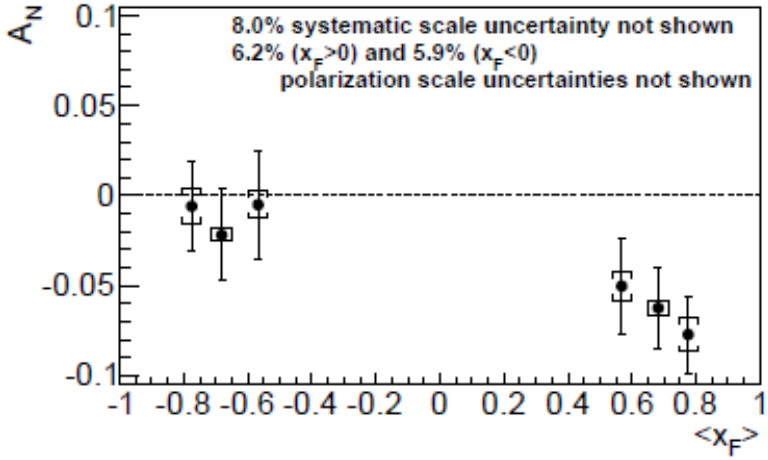
Very forward neutron at RHIC

- PHENIX ZDC + SMD Phys. Rev. D88 (2003) 032006.
- Cross section
  - Consistent with x_F scaling from ISR results
- Asymmetry
  - x_F dependence

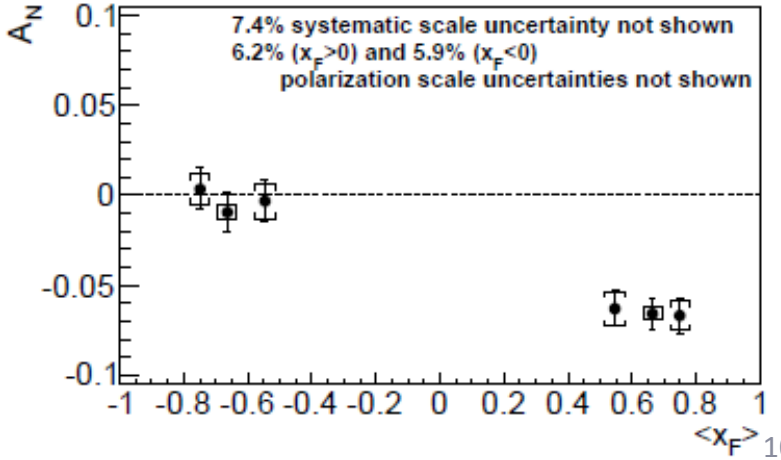




Inclusive neutron



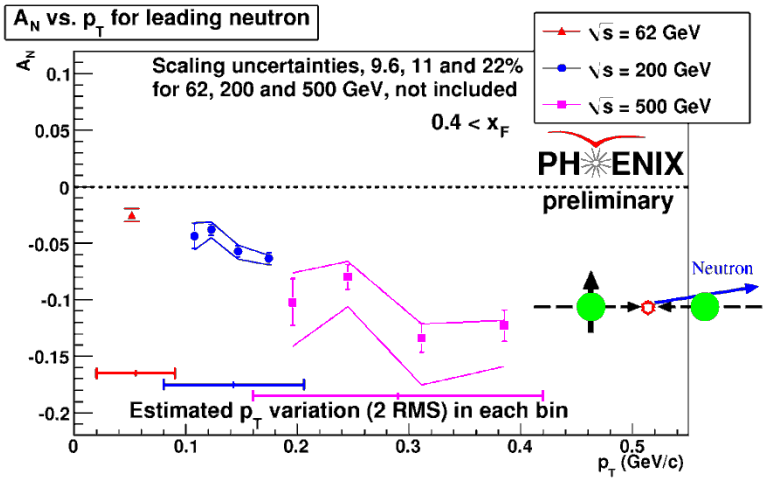
Neutron with charged particles



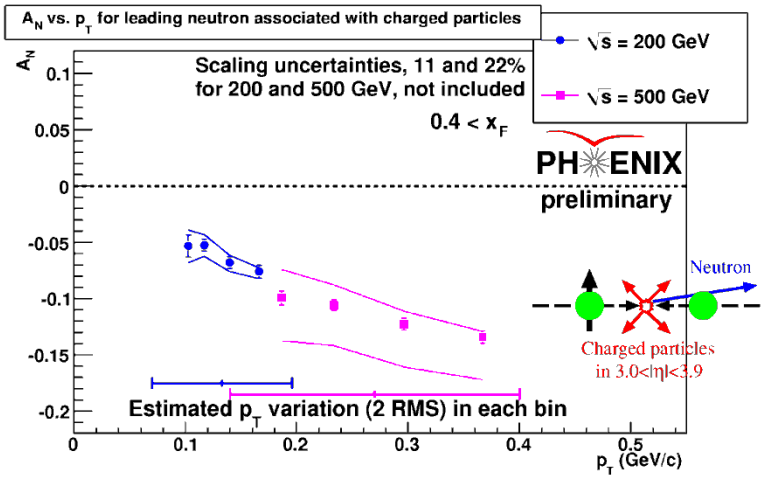
Very forward neutron at RHIC

- $\sqrt{s}$ dependence

Inclusive neutron



Neutron with charged particles



- Interference between spin-flip and non-flip with a relative phase

$$A_N \approx \frac{2\,\mathrm{Im}\left(fg^*\right)}{|f|^2+|g|^2}$$

f : spin non-flip amplitude
g : spin flip amplitude

- Pion exchange
  - Kopeliovich, Potashnikova, Schmidt, Soffer: Phys. Rev. D 78 (2008) 014031.
  - Spin-flip amplitude and non-flip amplitude have the same phase
  - No single transverse-spin asymmetry can appear
- Interference with other Reggeons
  - Kopeliovich, Potashnikova, Schmidt, Soffer: Phys. Rev. D 84 (2011) 114012.
  - a_1 axial-vector meson

Very forward neutron at RHIC

- Pion-a_1 interference: results
  - π-ρ in 1^+S state instead of a_1
  - exchanges with spin-non-flip amplitude, even if they are small amplitudes
  - The data agree well with independence of energy
- The asymmetry has a sensitivity to presence of different mechanisms, e.g. Reggeon

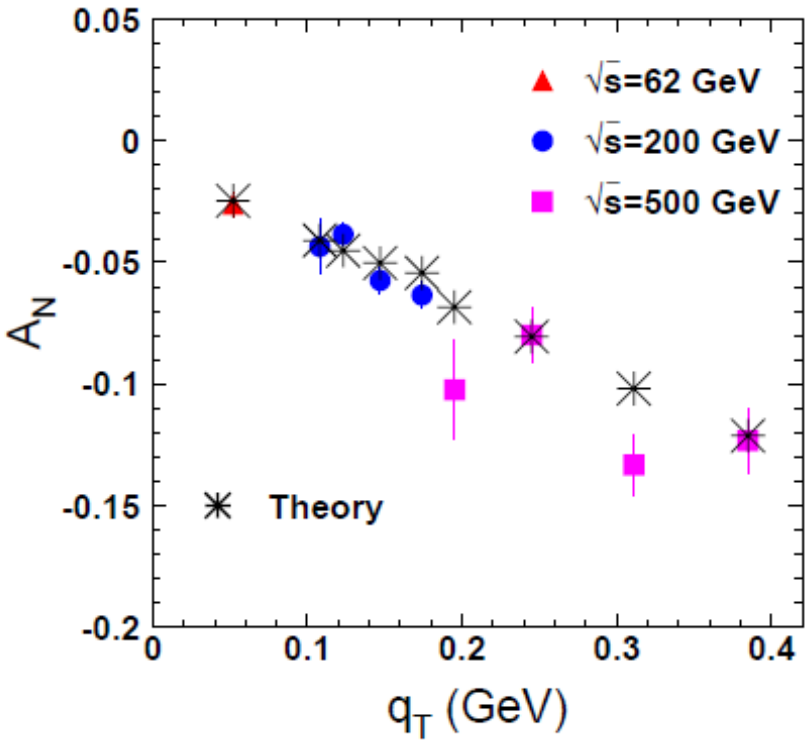
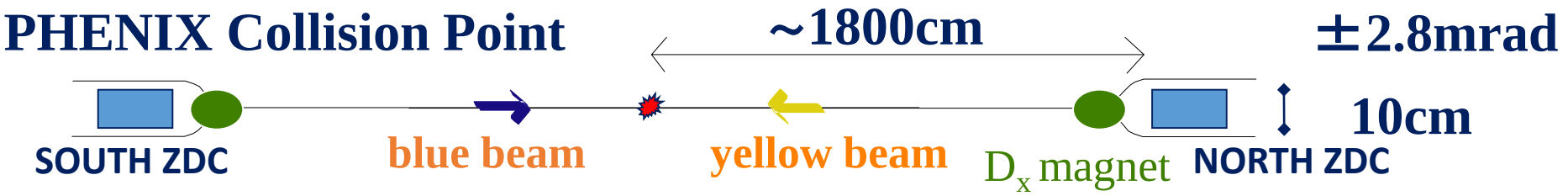
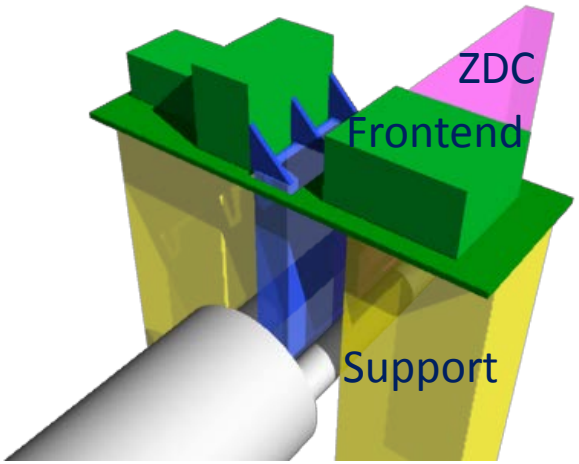


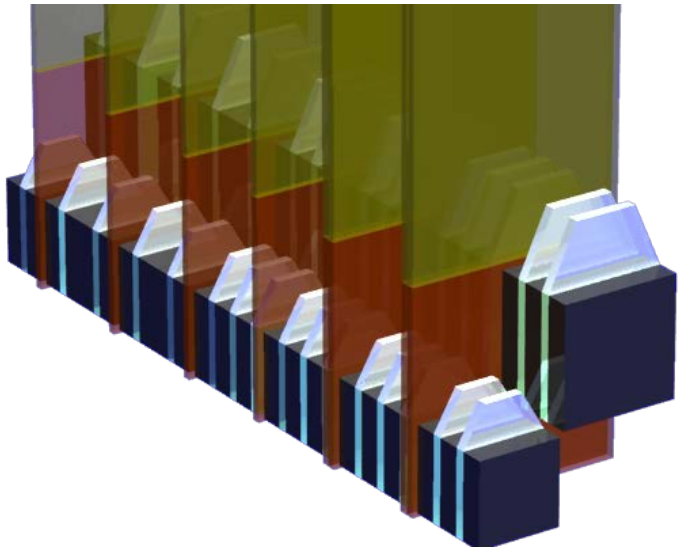
FIG. 1: (Color online) Single transverse spin asymmetry A_N in the reaction $pp \to nX$, measured at $\sqrt{s} = 62,\ 200,\ 500\,\text{GeV}$ [1] (preliminary data). The asterisks show the result of our calculation, Eq. (38), which was done point by point, since each experimental point has a specific value of z (see Table I).

RHICf experiment



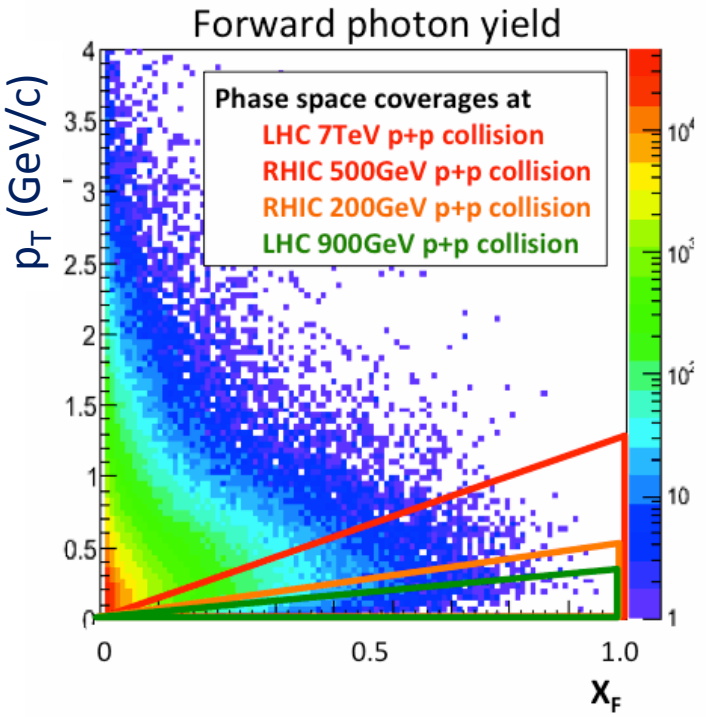
- One of LHCf EM calorimeter in front of ZDC of PHENIX
- Two calorimeter towers
  - 25mm×25mm + 32mm×32mm
- Each tower has 44 radiation length of Tungsten,16 sampling scintillators and 8 (4XY pairs) silicon strip sensors





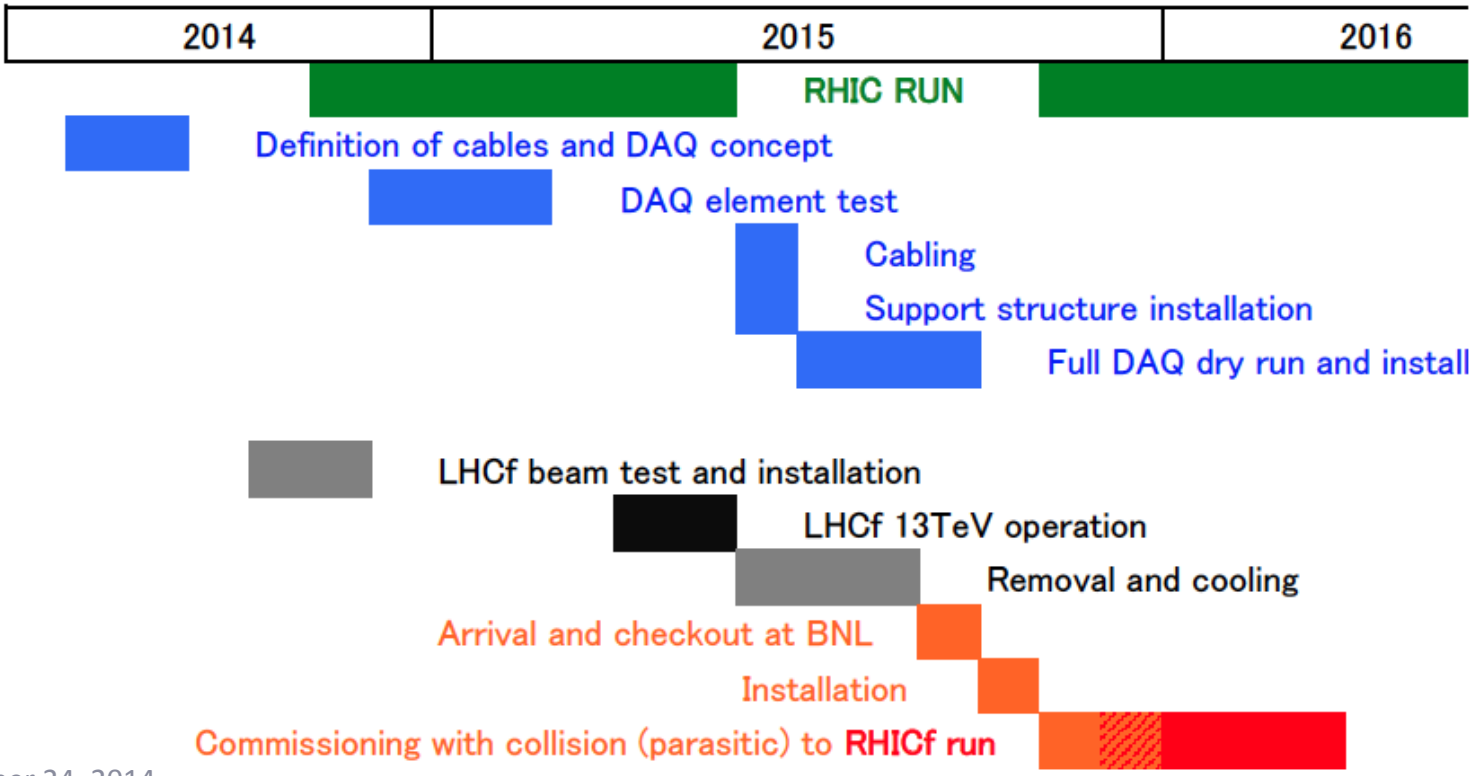
RHICf experiment

- Comparison at LHC and RHIC energies for scaling property
- Similar kinematic coverage at LHC 7 TeV and RHIC 510 GeV
  - Narrow kinematic coverage at LHC low energy



Run plan of the RHICf experiment

- LHCf Arm2 detector will be removed from LHC in June 2015
  - Weak radioactivation expected
- Detector will arrive at BNL in 2015 autumn
- RHICf run expected in 2016
  - 1 week dedicated run with 510 GeV polarized p+p collisions



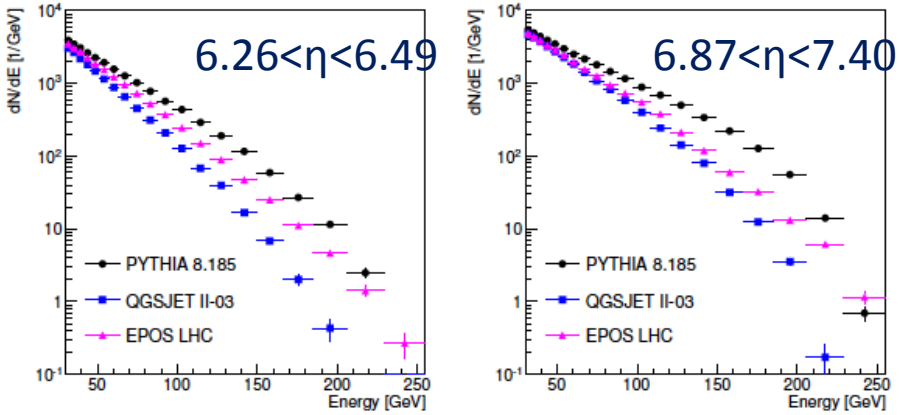
Collaboration

- RHICf Collaboration
  - *Nagoya University (Japan)*
  - *Waseda University (Japan)*
  - *INFN/University of Firenze (Italy)*
  - *INFN/University of Catania (Italy)*
  - *RIKEN/RIKEN BNL Research Center (Japan)*
  - *Seoul Natioanl University (Korea)*
- PHENIX Collaboration

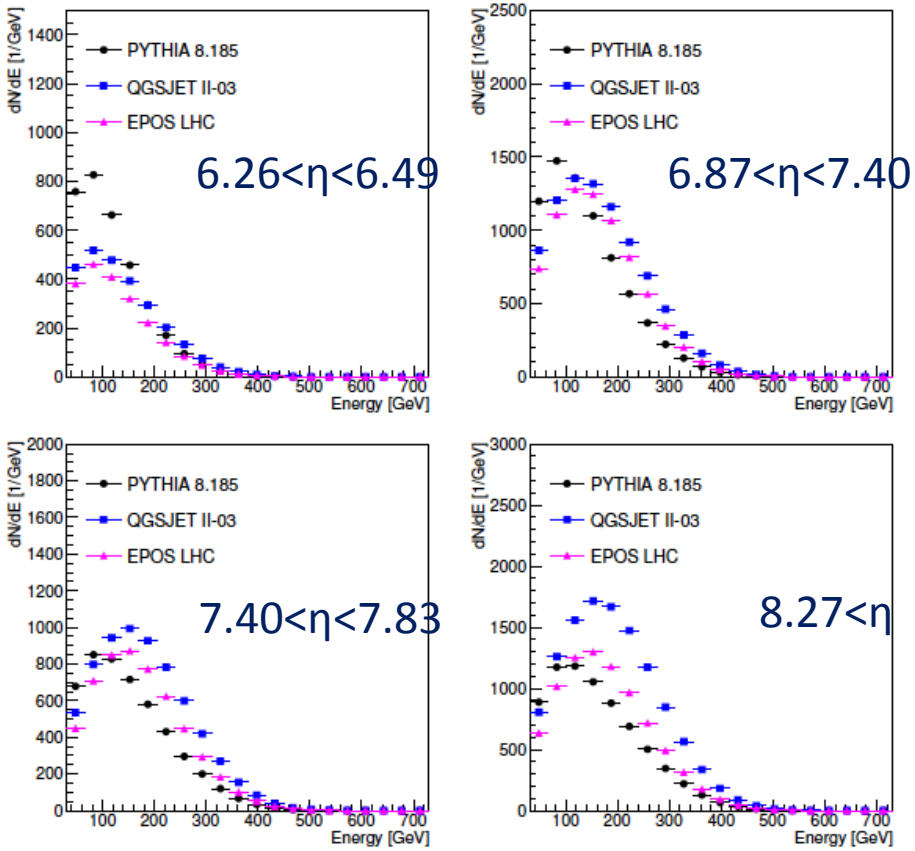
Expected yield of inclusive γ and neutron

- 12 hours statistics
  - 12 nb^{-1} effective luminosity; 360nb^{-1} delivered
- Statistical error is almost negligible

Inclusive photons

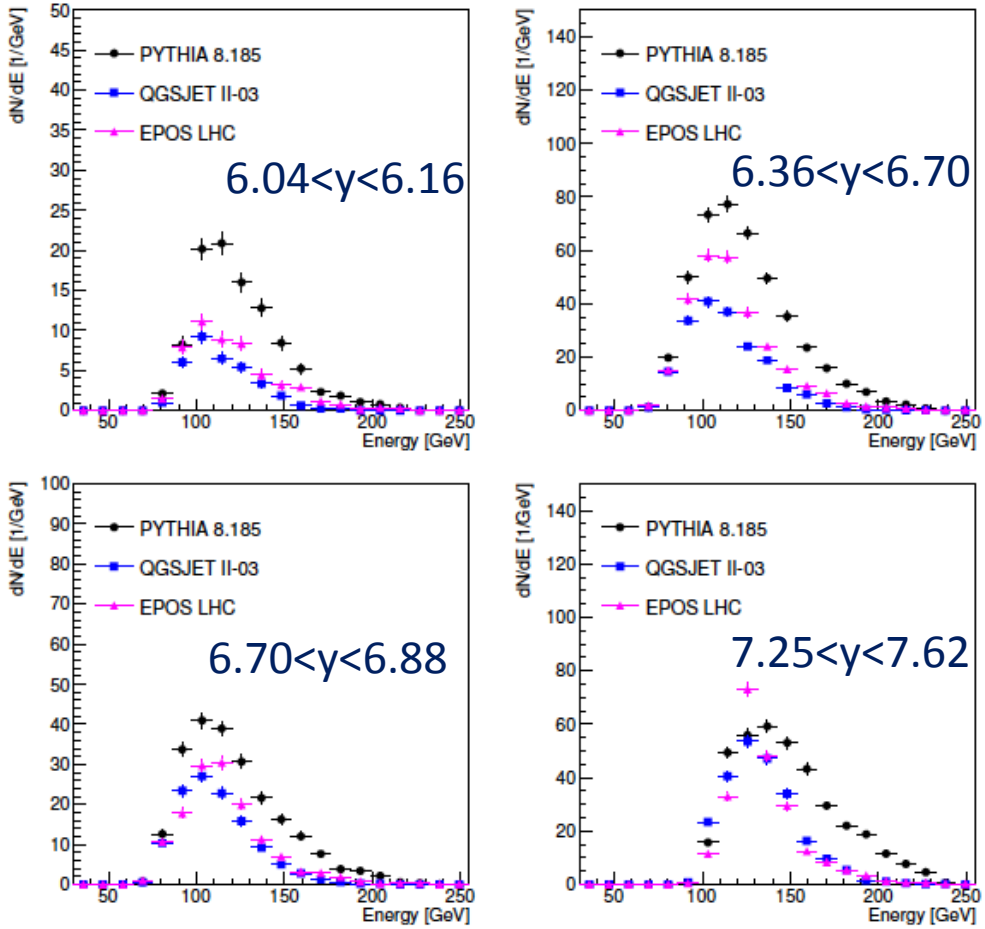


Inclusive neutrons

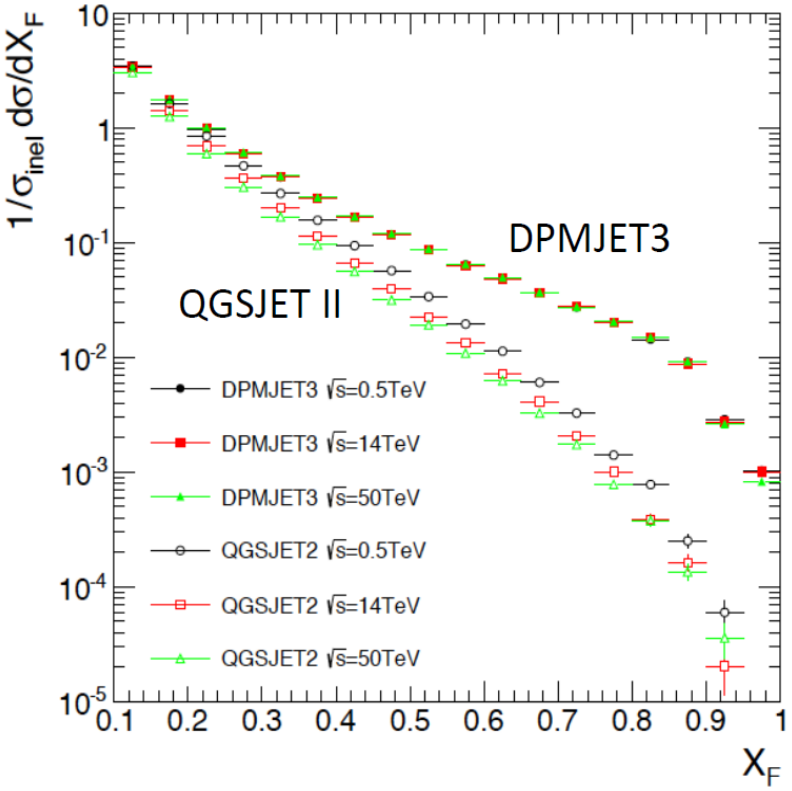


Expected yield of inclusive π^0

- < 60GeV not detectable due to large opening angle of $\gamma\gamma$
- 24 min statistics (12 nb^{-1} effective luminosity; 12 nb^{-1} delivered)
- Statistical error will be negligible with a reasonable run time



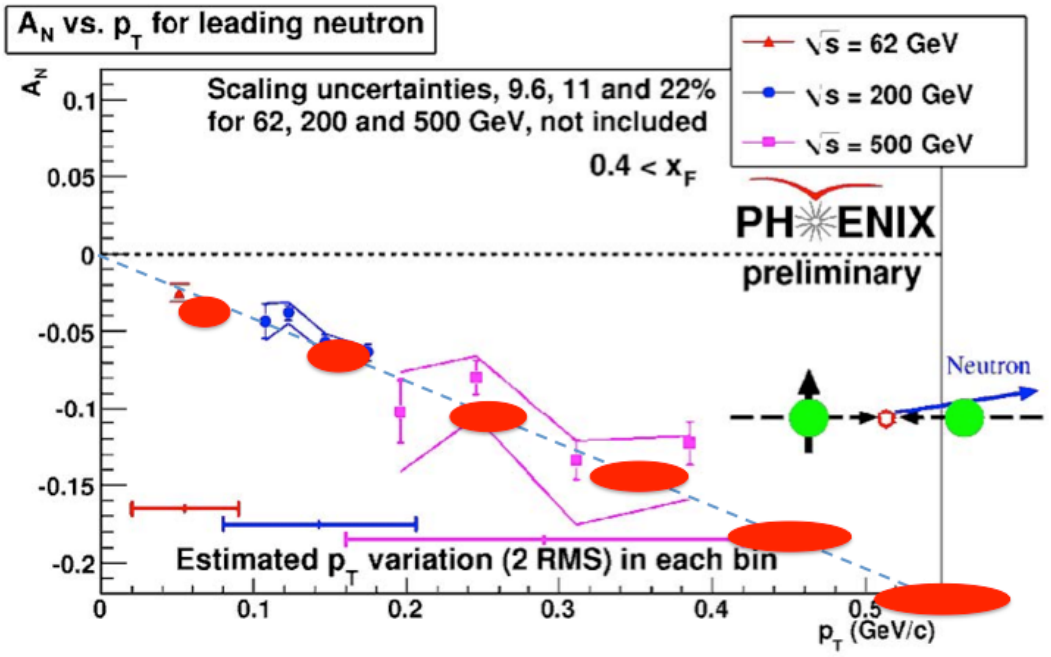
All π^0 expected from models (0.5TeV, 14TeV and 50TeV)



(X_F= E/√s/2)

Expected single-spin asymmetries

	neutron		photon		π^0	
p_T (GeV/c)	$N(\times 10^3)$	δA	$N(\times 10^3)$	δA	$N(\times 10^3)$	δA
0.0 – 0.1	660	0.0025	110	0.0060	100	0.0063
0.1 – 0.2	920	0.0021	120	0.0058	130	0.0055
0.2 – 0.3	820	0.0022	110	0.0060	89	0.0067
0.3 – 0.4	670	0.0024	79	0.0071	58	0.0083
0.4 – 0.5	450	0.0030	43	0.0096	37	0.010
0.5 – 0.6	250	0.0040	18	0.015	14	0.017
0.6 – 0.8	170	0.0049	8	0.022	8	0.022
0.8 – 1.0	29	0.012	1	0.063	1	0.063



- statistics expected by PYTHIA8
- 12 hours for inclusive photons and neutrons
- 4 hours for π^0
- RHICf+ZDC p_T resolution and ±1% errors are plotted over PHENIX result

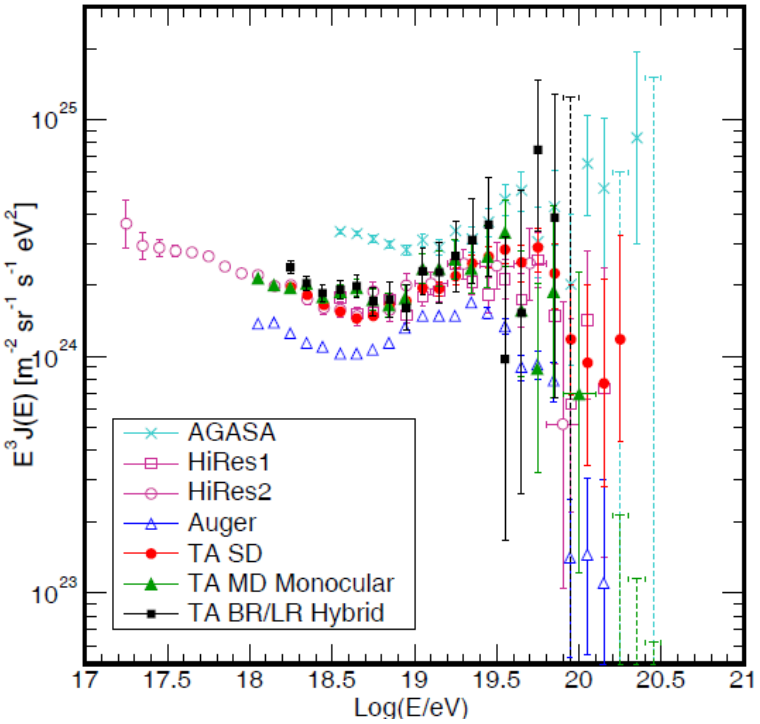
Summary

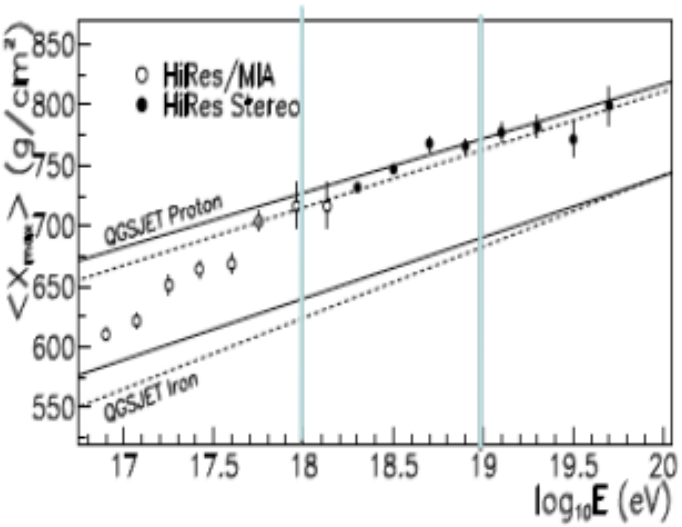
- RHICf experiment
  - position sensitive EM calorimeter in front of the PHENIX ZDC
  - 1 week dedicated run expected in 2016 with 510 GeV polarized p+p collisions
- Cross section and asymmetry measurement of very forward neutral particle production
  - Understanding hadron interaction
- Origin of the ultra high energy cosmic ray
  - Air shower observation at the surface of the ground
  - Accelerator experiments to calibrate hadron interaction
- More physics topics with combined use of PHENIX data

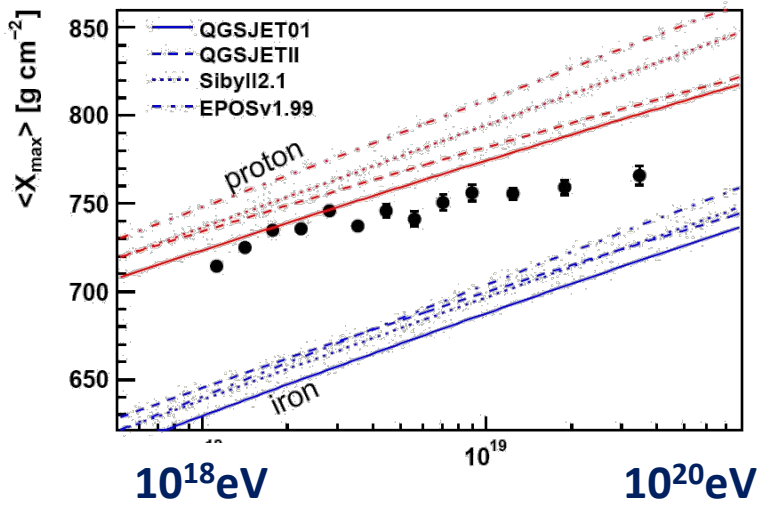
Backup Slides

Origin of the ultra high energy cosmic ray

- Different experiments do not agree in absolute flux
  - calibration issue
  - ~20% energy uncertainty
  - ~40% flux uncertainty
- Analysis of the same events by SD/FD shows 27% difference
  - Air shower development is not well understood
- Proton or heavier nuclei, up to Fe?







Accelerator experiments

- LHC experiments
  - Total/elastic/inelastic cross section from TOTEM/ATLAS/CMS/ALICE
  - Charged hadron multiplicity from CMS