Longitudinal double helicity asymmetry A_{LL} from direct photon, jet and charged pion production in polarized $\vec{p} + \vec{p}$ collisions

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Deep Inelastic Scattering 2021
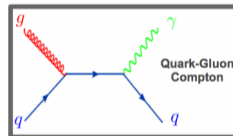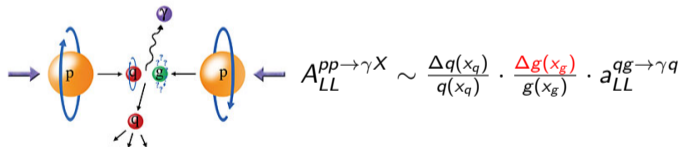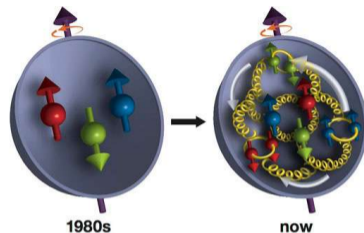
April 14, 2021

Probing the gluon spin inside the proton
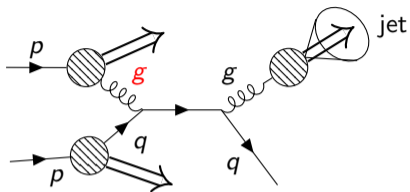

- The proton spin can be decomposed as

$$\frac{1}{2} = \frac{1}{2}\sum_q \Delta q + \Delta g + L_q + L_g$$

- Gluon spin Δg is important for the proton spin puzzle.

1980s   now

$$A_{LL}^{pp \to \gamma X} \sim \frac{\Delta q(x_q)}{q(x_q)} \cdot \frac{\Delta g(x_g)}{g(x_g)} \cdot a_{LL}^{qg \to \gamma q}$$
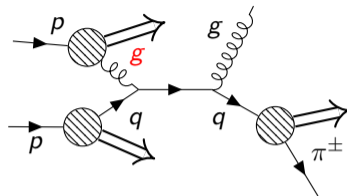
Quark-Gluon Compton

- $A_{LL} = \frac{\Delta\sigma}{\sigma} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$
- Little fragmentation contributions to direct photon production.
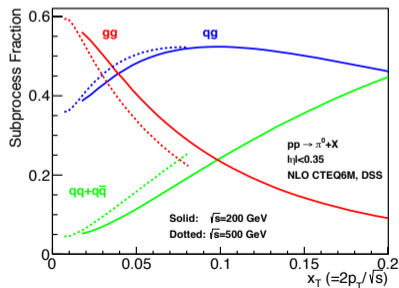
Jet and charged pion production


Jet production

Charged pion production

- Larger statistics: not suppressed by small QED coupling.
- $\pi^{\pm}$: separate u and d quark.
- RHIC 200 GeV data probe $0.05 < x < 0.2$.
- RHIC 510 GeV data probe $0.02 < x < 0.08$.

From A_{LL} to Δg

- Existing RHIC data mainly probe $0.05 < x_g < 0.2$.
- PHENIX π^0 A_{LL} at 510 GeV confirms a nonzero Δg and extend x_g to 0.01.
- STAR jet data clearly imply a polarization of gluons in this range.
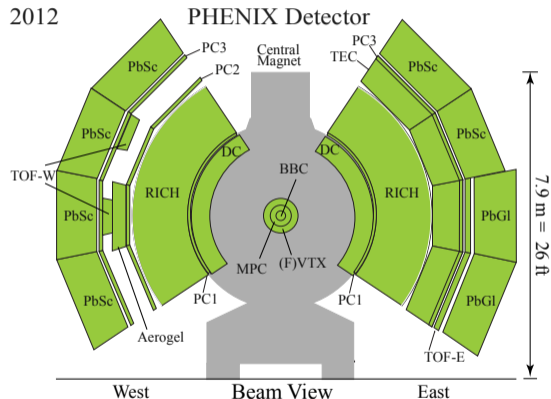- Results from γ, jet and $\pi^{\pm}$ will add additional independent constraints on the Δg.
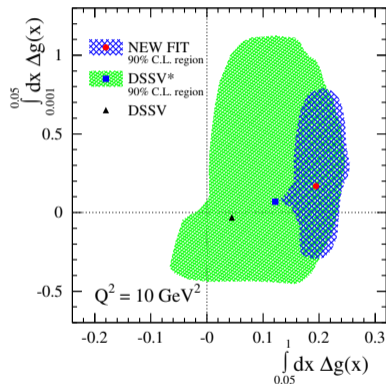
PRL 113, 012001 (2014)

PHENIX detector

- $|\eta| < 0.35$ and π coverage for ϕ.
- EMCal: primary detector for photons.
- EMCal trigger: select high energy particles.
- DC: measure charged particles.
- PC3: track matching.
- RICH: PID from Čerenkov light.

2012 PHENIX Detector

West   Beam View   East
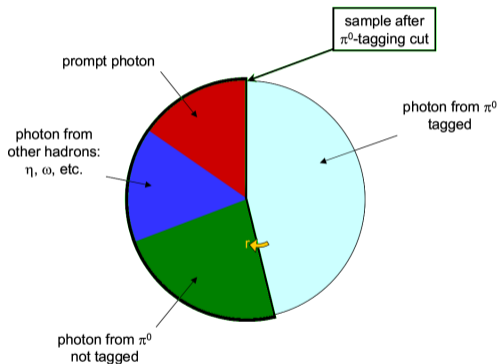
Direct photon identification

Source of direct photon:

- Compton scattering: $g + q \rightarrow \gamma + q$.
- Annihilation: $q + \bar{q} \rightarrow \gamma + g$.
- Parton fragmentation to photon.
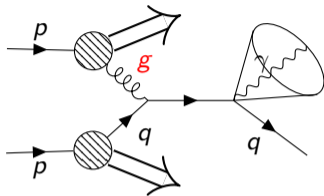- Quark bremsstrahlung.

Source of direct photon background:

- Decay photons from hadrons (π^0, η, ω, η').

Direct photon yield:

- $\gamma_{direct} = \gamma_{all} - \gamma_{decay}$

sample after π^0-tagging cut

prompt photon

photon from other hadrons: η, ω, etc.

photon from π^0 tagged

photon from π^0 not tagged
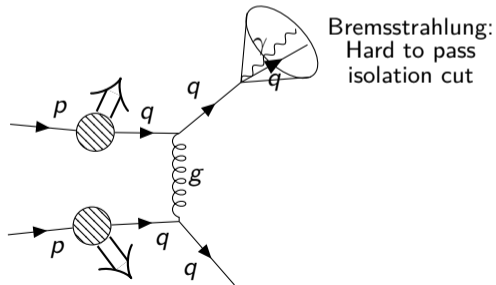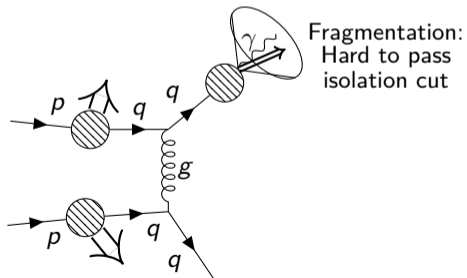
Isolation cut for direct photon

$$r_{cone} = \sqrt{(\delta\eta)^2 + (\delta\phi)^2} = 0.5$$

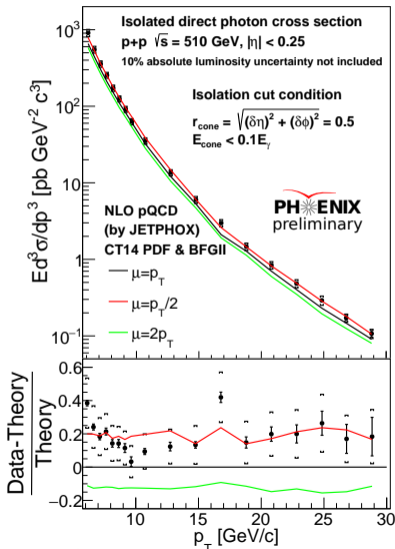Isolation cut requirement:

$$\sum E_{in\,cone} < 0.1 E_\gamma$$

Quark-gluon Compton scattering: Easy to pass isolation cut

Fragmentation:
Hard to pass
isolation cut

Bremsstrahlung:
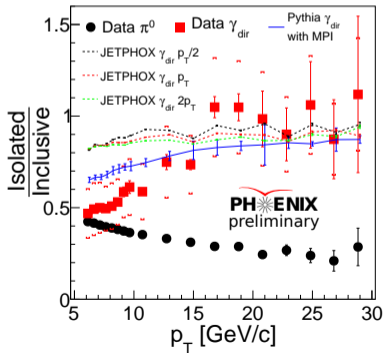Hard to pass
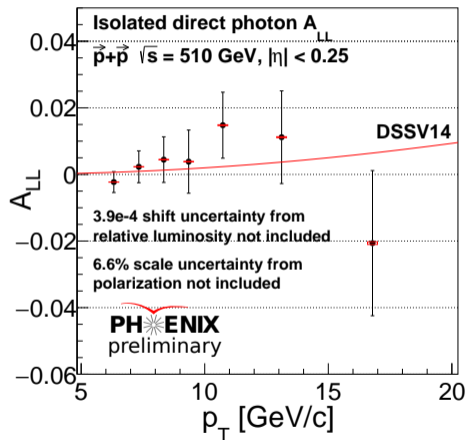isolation cut

Direct photon cross section

- Consistent with NLO pQCD.
- MPI and parton shower are important for inclusive direct photon production.
- Constrain unpolarized gluon PDF.

Direct photon A_{LL}

- Consistent with NLO DSSV14.
- Will be the first published direct photon A_{LL}.
- Constrain polarized gluon PDF Δg.

Isolated direct photon A_{LL}
$\vec{p}+\vec{p}$ $\sqrt{s}$ = 510 GeV, $|\eta|$ < 0.25
DSSV14
3.9e-4 shift uncertainty from relative luminosity not included
6.6% scale uncertainty from polarization not included
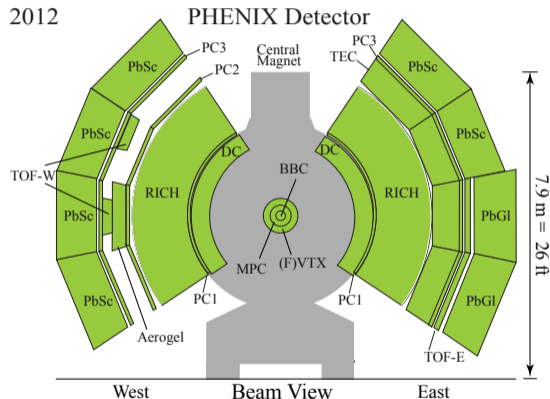PH☆ENIX preliminary

Jet identification

- BBC and EMCal trigger.
- DC match in PC3 or EMCal.
- EMCal energy > 1 GeV.
- Time of flight < 10 ns.
- Cluster-track matching.
- Only keep the jet with the largest p_T.
- Algorithm: anti-k_T.
- Unfolding: Bayes iteration method implemented by RooUnfold
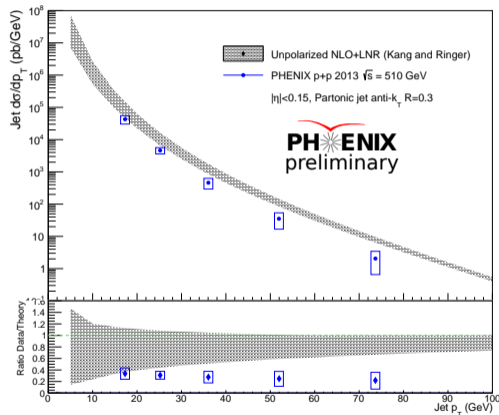 $N(p_T^{reco}) = \boldsymbol{R}(p_T^{reco}, p_T^{truth}) N(p_T^{truth})$

2012   PHENIX Detector

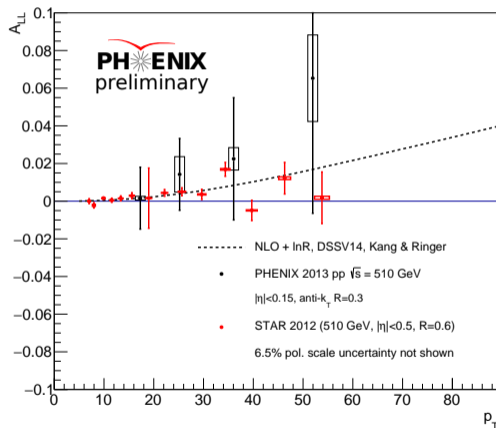7.9 m = 26 ft

West   Beam View   East

Jet cross section

- Calculation from NLO + ln(R) resummation overestimates data.
- The calculation is at partonic level: MPI and parton shower are important.
- Similar observation from CMS, for small R anti-k_T.

Jet A_{LL}

- Consistent with DSSV14 at NLO + ln(R) resummation.
- Independent constraint on polarized gluon PDF Δg.
- Uncertainty are correlated due to unfolding.

PH✱ENIX preliminary

NLO + lnR, DSSV14, Kang & Ringer

PHENIX 2013 pp √s = 510 GeV

|η|<0.15, anti-k$_T$ R=0.3

STAR 2012 (510 GeV, |η|<0.5, R=0.6)

6.5% pol. scale uncertainty not shown

Charged pion identification

- Preselection rule: $0.2 < E/p < 0.8$.
- Logical OR of EMCal triggers.
- Matching track in DC with EMCal.
- >1 photomultiplier in RICH ($E_\pi \gtrsim 4.9$ GeV).
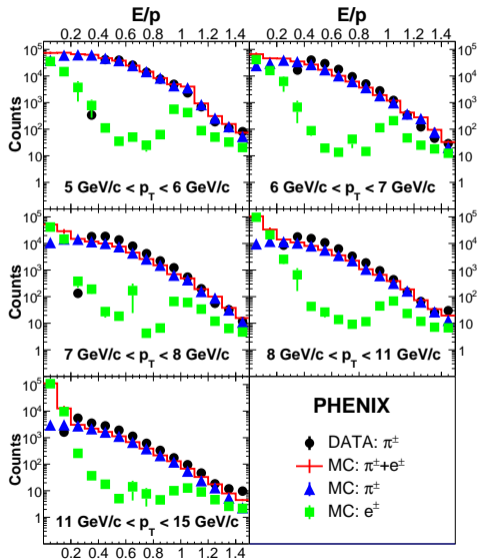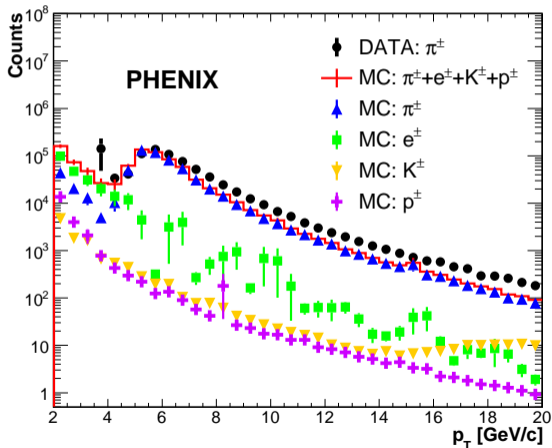- EM shower shape probability < 0.1.
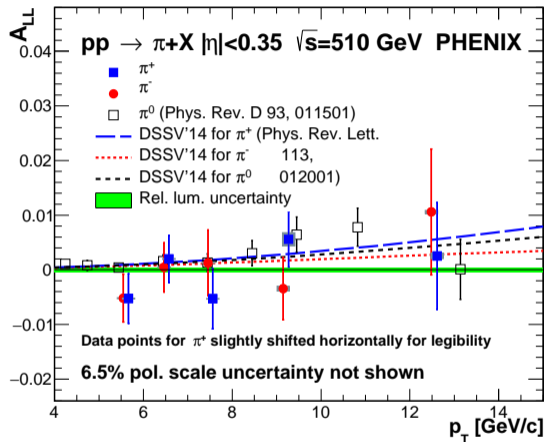- PRD 102, 032001 (2020)
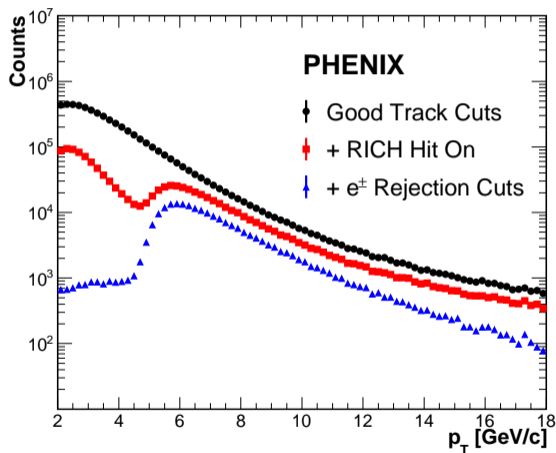
Charged pion background

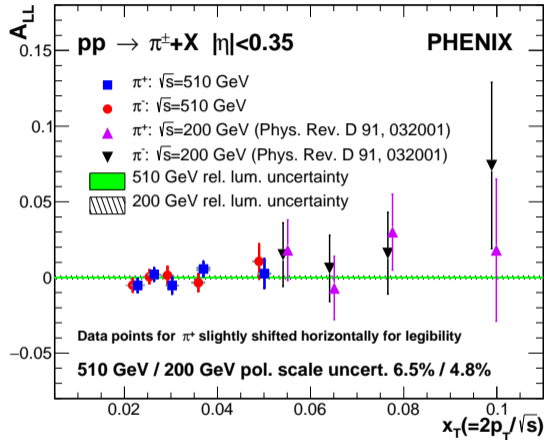- 4.9 to 17.3 GeV: electrons are main BG.
- $0.2 < E/p < 0.8$: best S/B ratio.

Charged pion A_{LL}

- PRD 102, 032001 (2020)
- Consistent with DSSV14.

- 510 GeV data probe low x range.
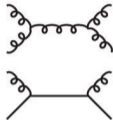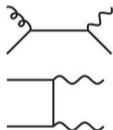- Not enough statistics to decide $\pi^\pm$ order.
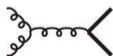
Summary

- Gluon spin is important for proton spin decomposition and the proton spin puzzle.
- Direct photon production have little fragmentation contributions.
- Jet and $\pi^{\pm}$ production have larger statistics.
- $\pi^{\pm}$ measurement can separate u and d quark contributions.
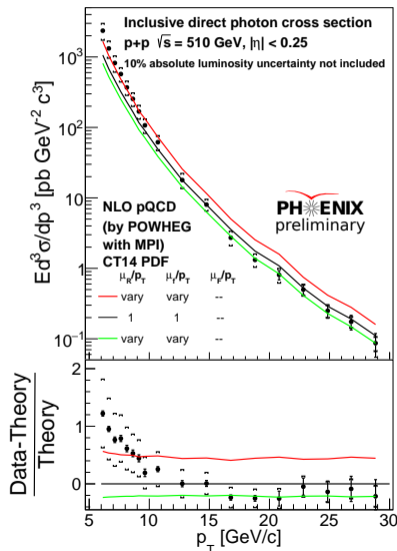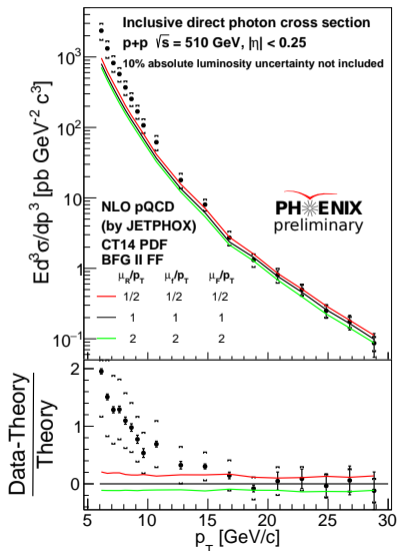- Contribute to future global analysis together with forward cluster and forward/central η A_{LL}.
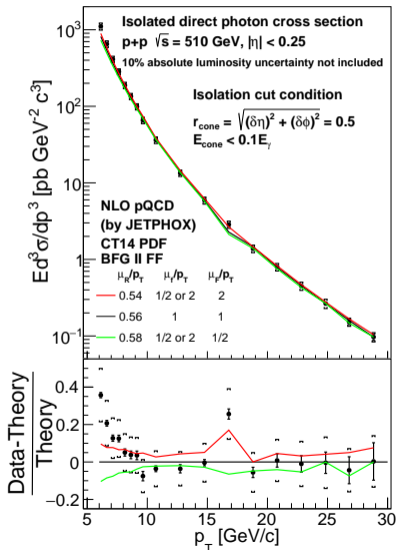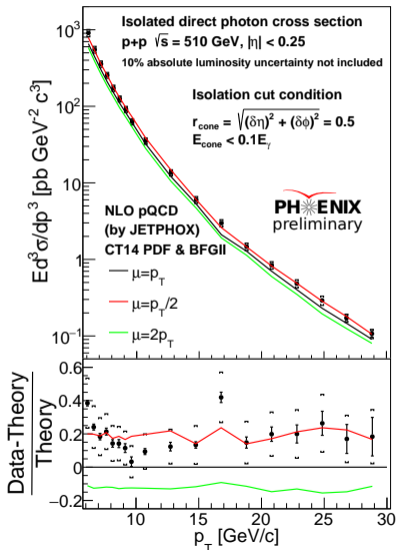
Backup

Processes

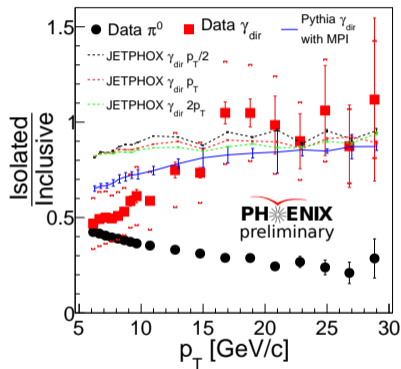| Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \to \pi + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	
$\vec{p}\vec{p} \to \text{jet(s)} + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	(as above)
$\vec{p}\vec{p} \to \gamma + X$ $\vec{p}\vec{p} \to \gamma + \text{jet} + X$ $\vec{p}\vec{p} \to \gamma\gamma + X$	$\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{\bar{q}} \to \gamma\gamma$	Δg Δg $\Delta q, \Delta \bar{q}$	
$\vec{p}\vec{p} \to DX, BX$	$\vec{g}\vec{g} \to c\bar{c}, b\bar{b}$	Δg	

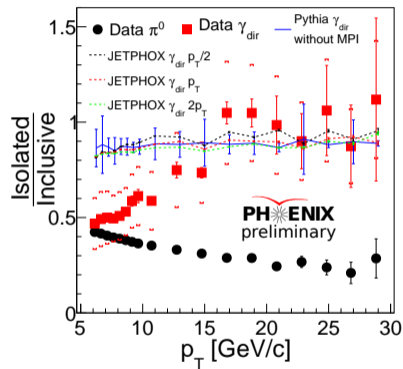# Inclusive direct photon cross section

Isolated direct photon cross section

Isolated/Inclusive direct photon ratio

With MPI

Without MPI