

Overview of Longitudinal Spin Physics at PHENIX

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The **R**elativistic **H**eavy **I**on **C**ollider at Brookhaven National Laboratory

R-HI

New state of matter

QGP

De-confinement

...

polarized proton

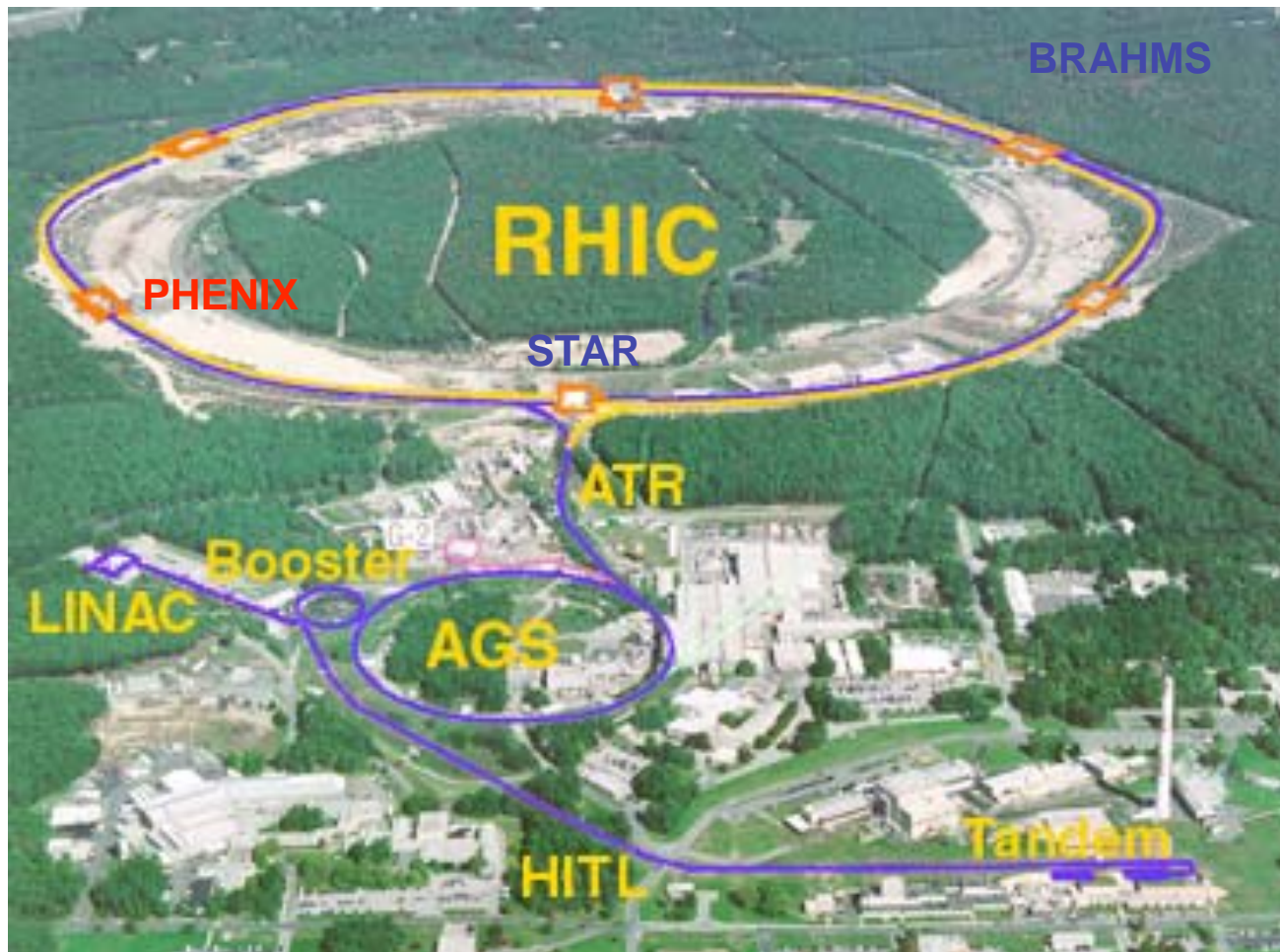
Nucleon Spin Structure

Spin Fragmentation

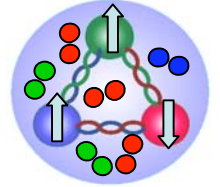
pQCD

...

RHIC is a QCD lab



RHIC-Spin Physics



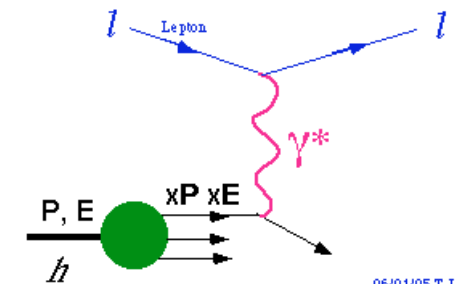
New Frontier of Nucleon Structure Research

- Proton Spin - a major puzzle from polarized DIS experiments
 - Proton Spin Decomposition

$$\frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + \Delta L_{q+g}$$

Experimentally \Rightarrow $\Delta\Sigma = 0.31 \pm 0.04$

Deep Inelastic Scattering
in Parton Model



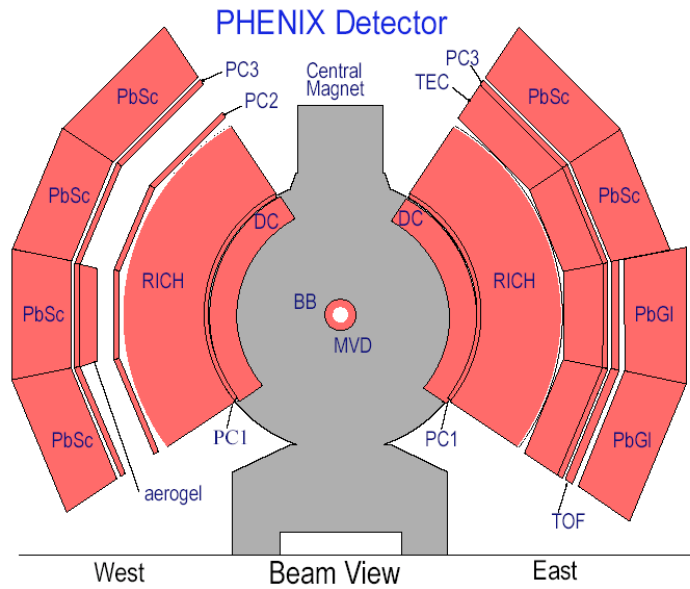
- Origin of Proton Spin:
 - gluon, sea quarks, orbital angular momentum ?
 - DIS can't directly probe gluons and anti-quarks @LO
- a new tool : RHIC-SPIN
 - a polarized proton collider
 - quark-gluon, quark-quark and gluon-gluon interactions
 - directly explore gluon and sea quark distributions

History of Spin Runs

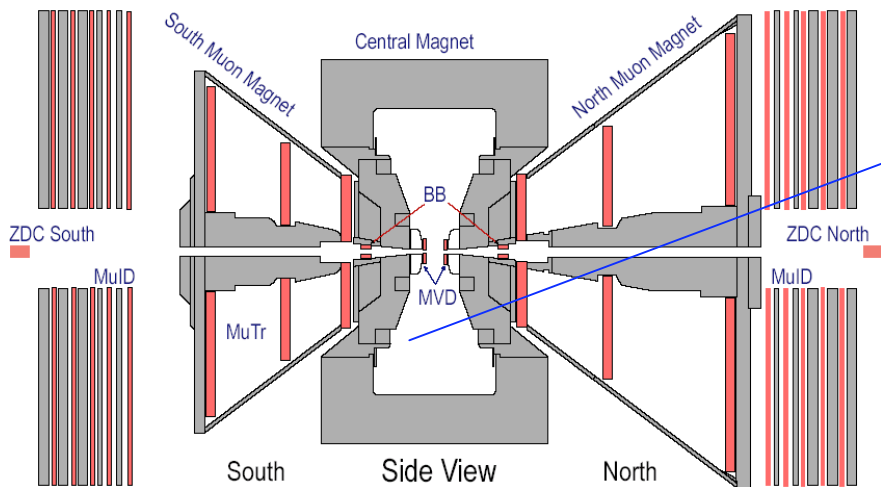
$\sqrt{s} = 200 \text{ GeV}$	Polarization	Recorded L	Recorded LP^4
<hr/>			
2001-2002 transverse-spin run	15%	0.15 pb ⁻¹	
first polarized proton collisions			
<hr/>			
2003 longitudinal-spin run	27%	0.35 pb ⁻¹	1.5 nb ⁻¹
spin rotators commissioned, AGS p-C CNI polarimeter			
<hr/>			
2004 commissioning run (longitudinal spin)	40%	0.12 pb ⁻¹	3.3 nb ⁻¹
AGS warm snake commissioned, gas-jet absolute polarimeter			
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2005 longitudinal-spin run (w/ short transverse run)	47%	3.8 pb ⁻¹	205 nb ⁻¹
AGS cold snake installed			
<hr/>			
2006 transverse and longitudinal spin run	60%	in progress	◆in progress

2005 – First “long” longitudinal-spin polarized-proton run: Figure of merit (LP^4) more than 40 times larger than that of previous runs

The PHENIX Detectors



- Philosophy
 - high resolution & high-rate at the cost of acceptance
 - trigger for rare events
- Central Arms
 - $|\eta| < 0.35$, $\Delta\phi \sim \pi$
 - γ , π^0 , e , π^{\pm} , ... – Identified
 - Momentum, Energy
- Muon Arms
 - $1.2 < |\eta| < 2.4$
 - Momentum (MuTr)



04/22/2006

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Experimental Observables

- Asymmetries

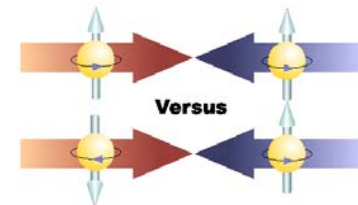
$$A_{LL} = \frac{\sigma(++)-\sigma(+-)}{\sigma(++)+\sigma(+-)}$$

Versus

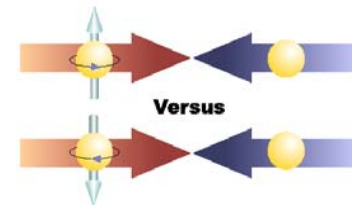
$$A_L = \frac{\sigma(+)-\sigma(-)}{\sigma(+)+\sigma(-)}$$

Versus

$$A_{TT} = \frac{\sigma(\uparrow\uparrow)-\sigma(\uparrow\downarrow)}{\sigma(\uparrow\uparrow)+\sigma(\uparrow\downarrow)}$$



$$A_T = \frac{\sigma(\uparrow)-\sigma(\downarrow)}{\sigma(\uparrow)+\sigma(\downarrow)}$$

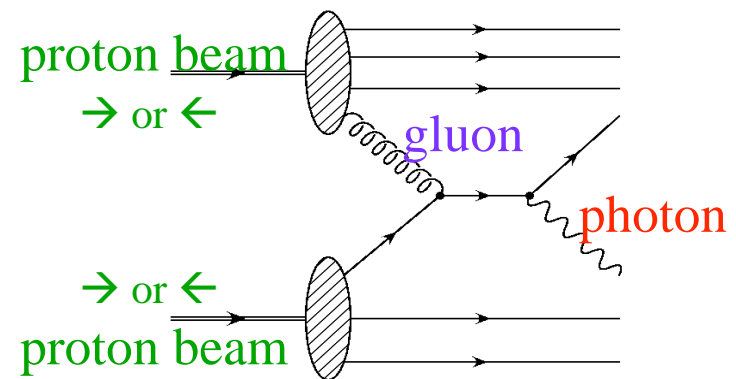
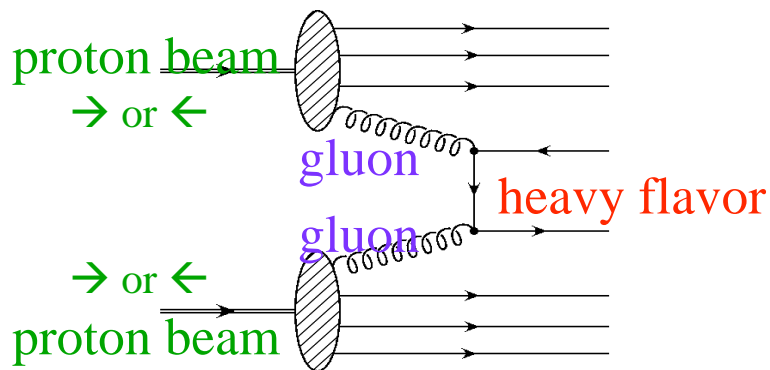
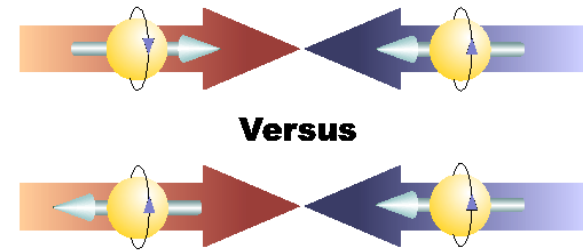


A_{LL} @ RHIC-SPIN

- Polarized hadron collisions
 - double longitudinal spin asymmetry

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \Delta f_A^a(x_a, Q^2) \otimes \Delta f_B^b(x_b, Q^2) \otimes \frac{d\Delta\sigma_{ab}^{cd}}{dt}$$

- leading-order gluon interactions
 - direct-photon production
 - heavy-flavor production
 - Other channels with light hadrons



Heavy Quark Production @RHIC

➤ Sensitive to gluon polarization: $\Delta g(x)$

➤ Gluon Fusion dominates at LO

PYTHIA estimate:

GeV	Charm	Beauty
200	95:5	85:15
500	97:3	92:8

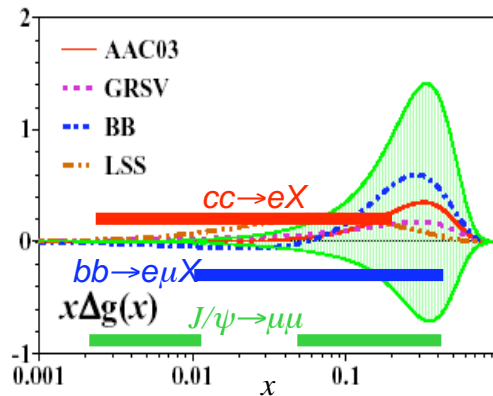
$$\sigma(gg \rightarrow Q\bar{Q}) : \sigma(q\bar{q} \rightarrow Q\bar{Q})$$

Double spin asymmetry:

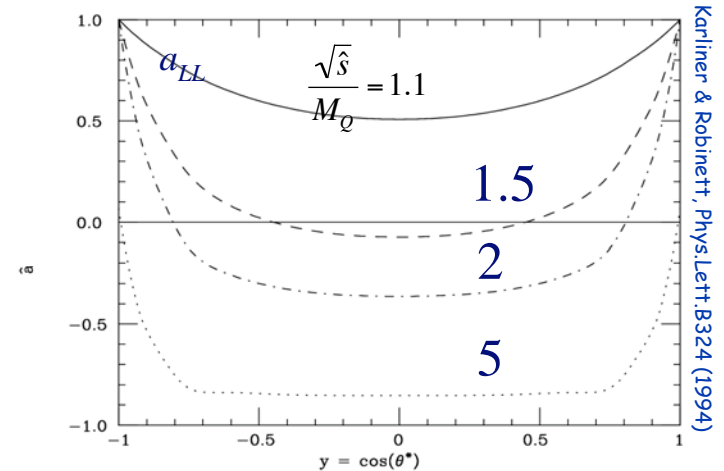
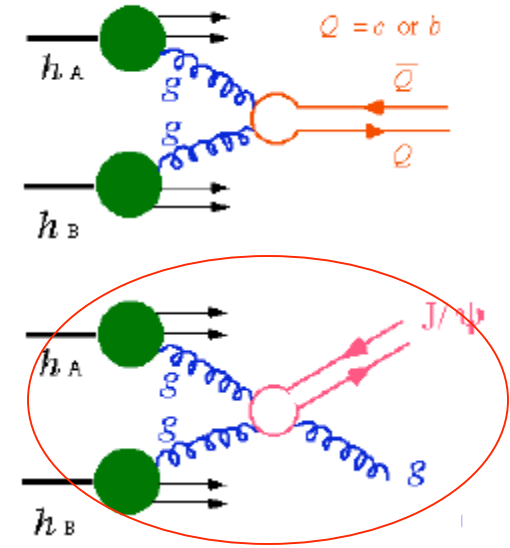
$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \frac{\Delta g(x_2)}{g(x_2)} a_{LL}^{gg \rightarrow Q\bar{Q}}$$

Decay modes:

e^+e^- , $\mu^+\mu^-$, $e\mu$, eX , μX

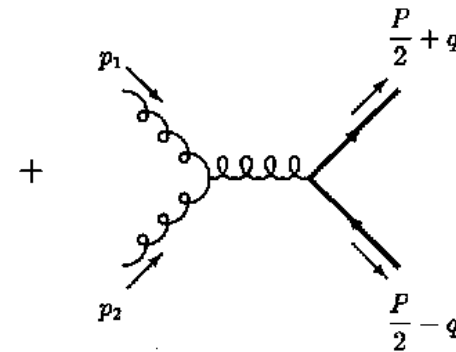
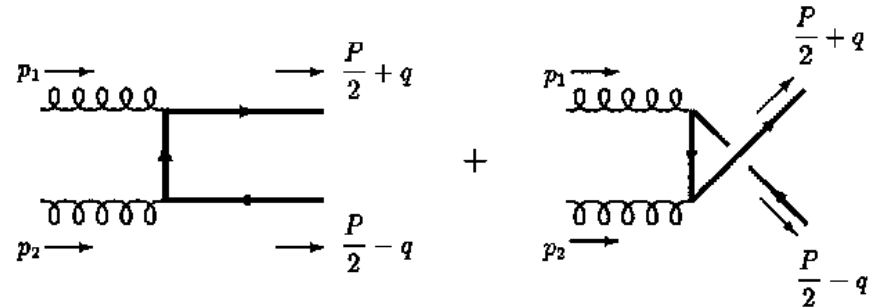
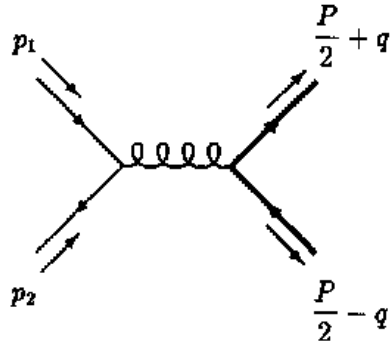


Gluon Fusion



J/ψ production mechanism

- LO NRQCD: $\sim \alpha_s^2$



$$\Delta\sigma_{(pp \rightarrow J/\Psi(\lambda))} \approx \frac{\pi^3 \alpha_s^2}{27 \cdot s \cdot m^2} \int_{4m^2/s}^1 \frac{dx_1}{x_1} \{$$

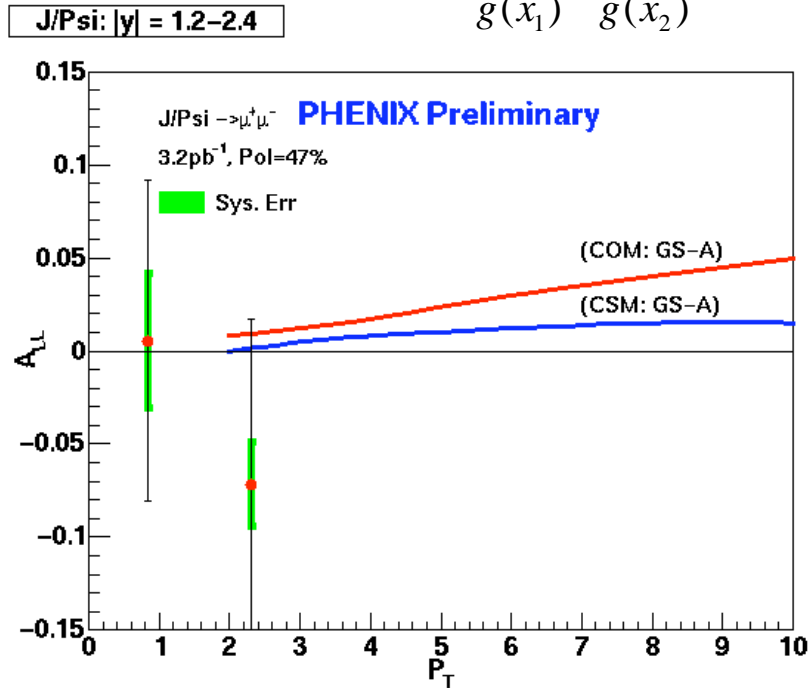
$$\Delta f_q(x_1, 2m) \cdot \Delta f_{\bar{q}}\left(\frac{4m^2}{x_1 \cdot s}, 2m\right) \times (\delta_{\lambda 0} - 1) \langle O_8^{J/\Psi(\lambda)}(^3S_1) \rangle$$

$$+ \frac{15}{32} \Delta f_g(x_1, 2m) \cdot \Delta f_{\bar{g}}\left(\frac{4m^2}{x_1 \cdot s}, 2m\right) \times \left[\frac{9}{m^2} \left(1 - \frac{1}{2} \delta_{\lambda 0}\right) \langle O_8^{J/\Psi(\lambda)}(^3P_0) \rangle - \langle O_8^{J/\Psi(\lambda)}(^1S_0) \rangle \right]$$

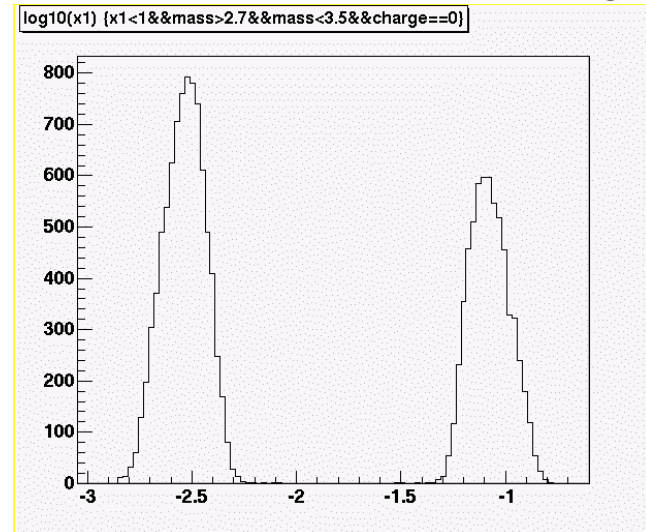
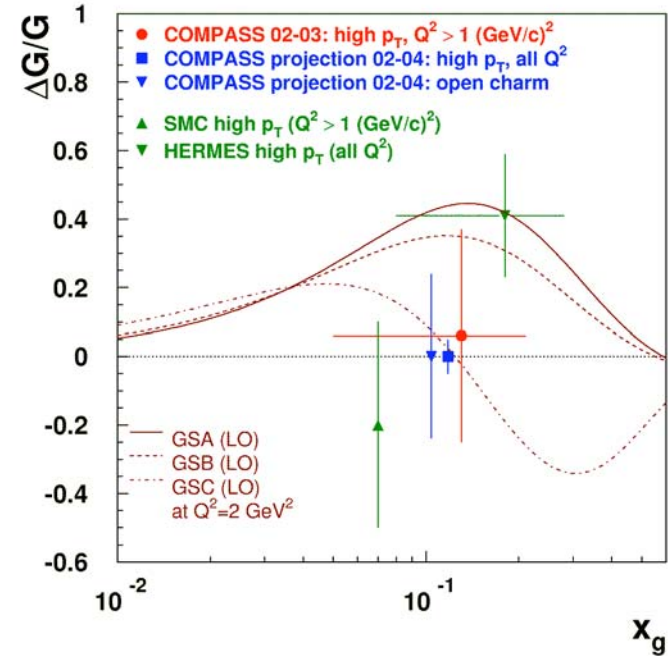
mix of various processes

A_{LL} vs p_T

$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \frac{\Delta g(x_2)}{g(x_2)} a_{LL}^{gg \rightarrow J/\Psi + X}$$



- J/ ψ : produced via almost pure gluon fusion
- sensitive to gluon polarization
- expect x100 improvement in the future

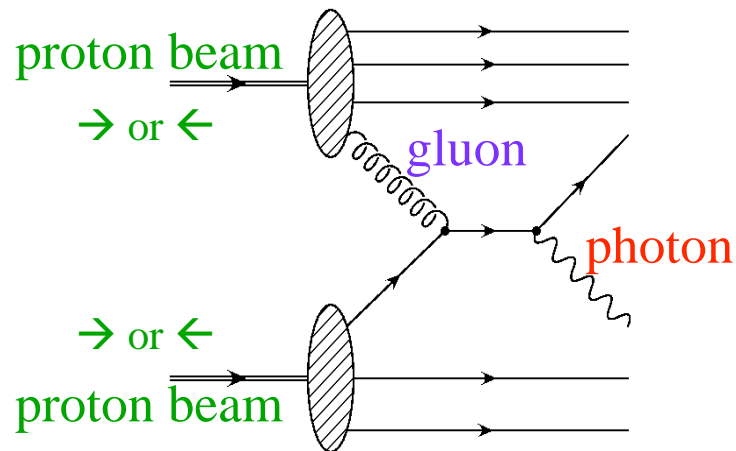


Direct Photon

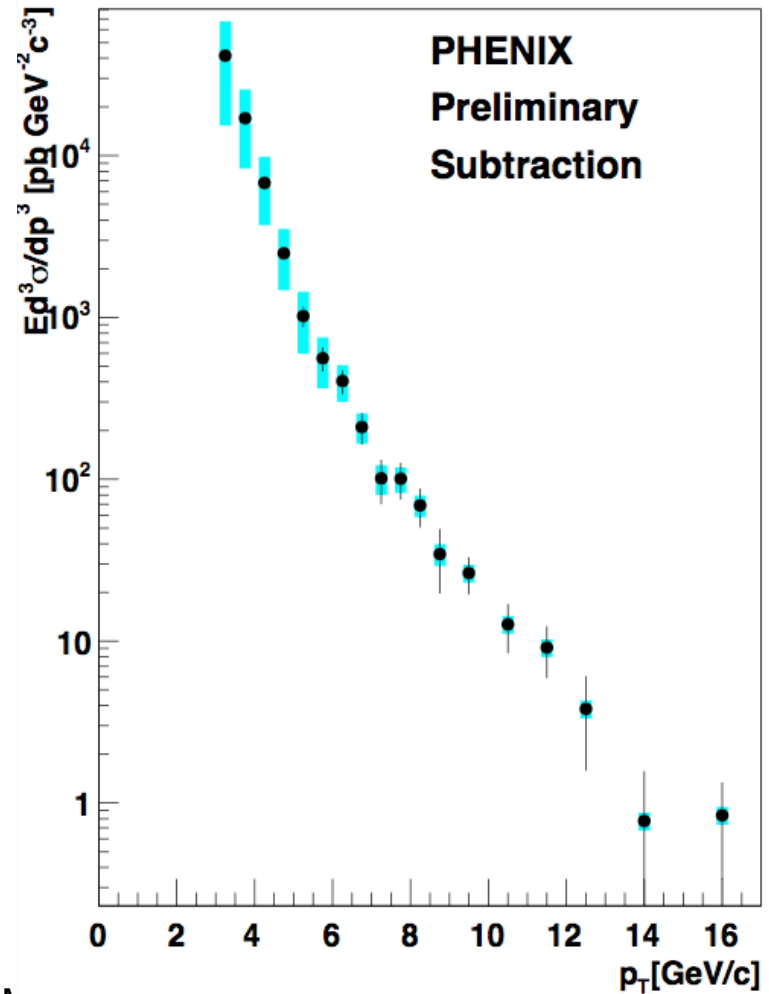
- A Golden channel

- Sign and magnitude(x)

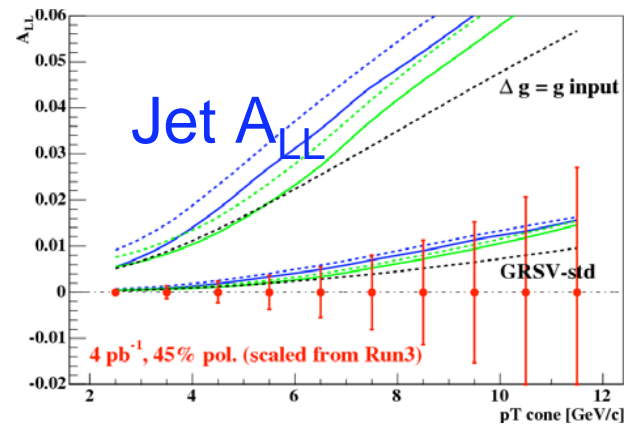
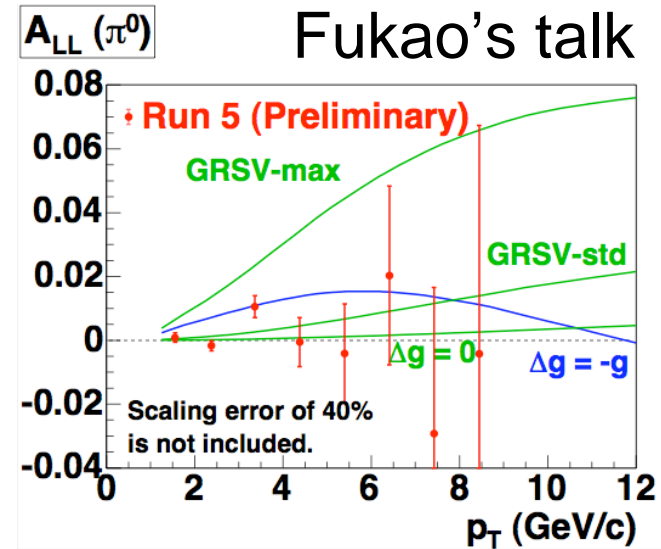
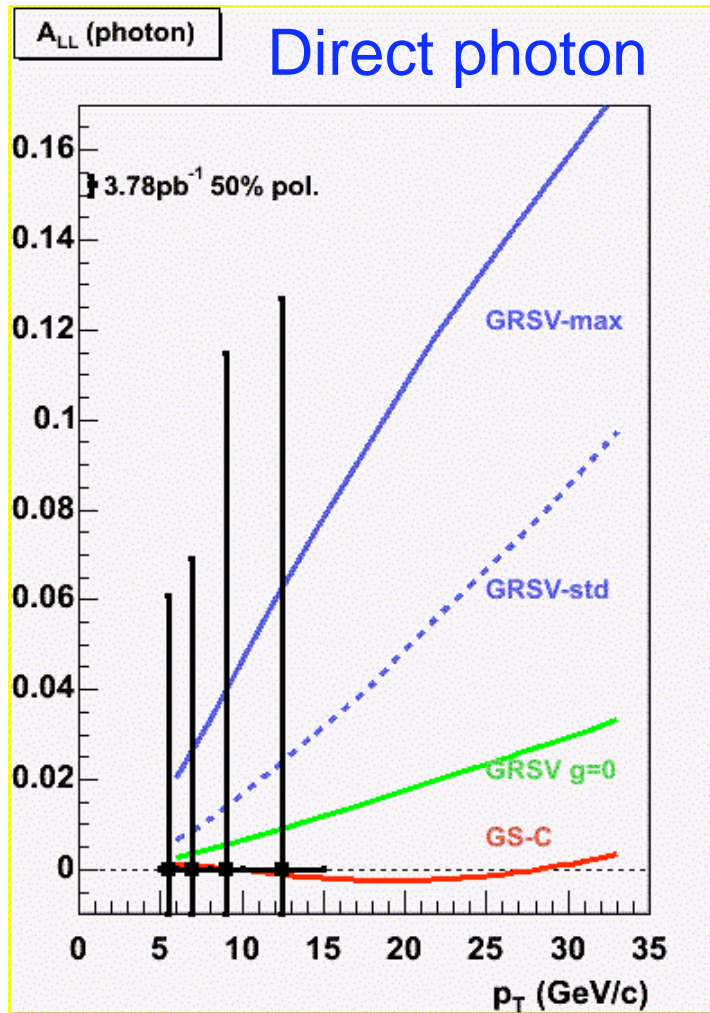
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \sim \frac{\Delta G}{G} \cdot \frac{\Delta q}{q}$$



Spectra (Subtraction)



More on A_{LL}



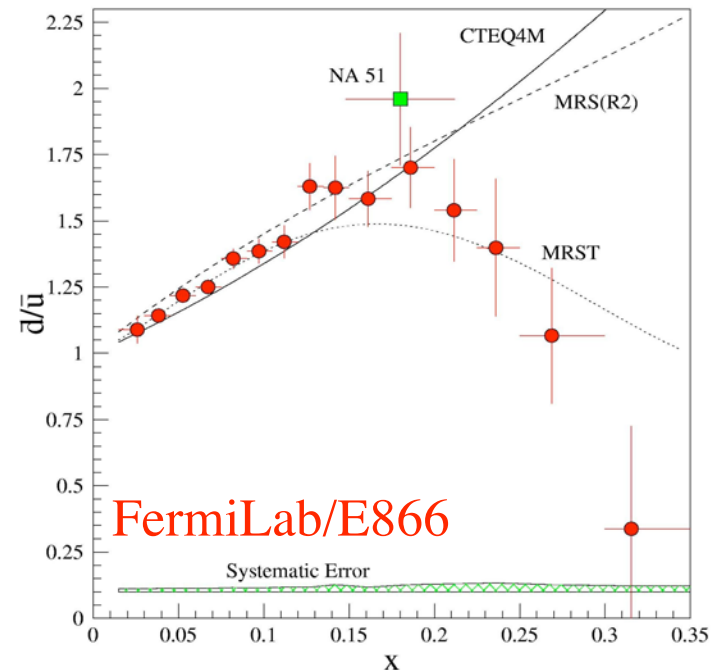
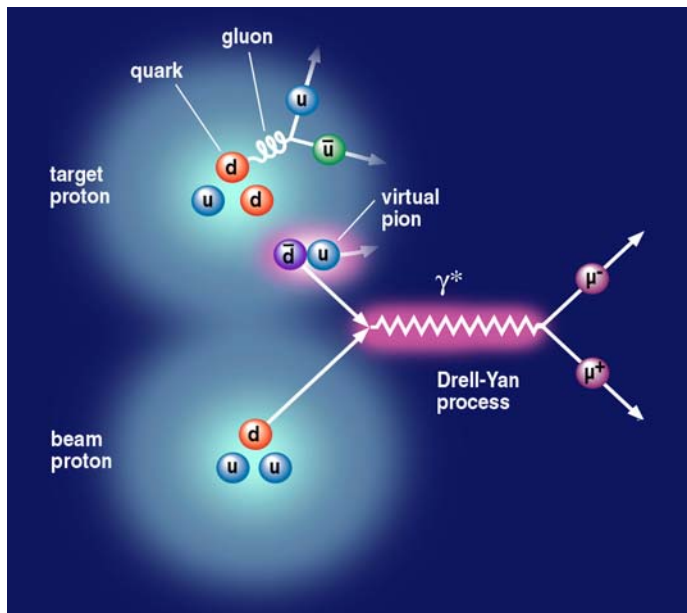
$\eta, h^\pm, \text{electron}, \mu, \Lambda, \dots$

Sea Quark Polarization & Flavor Asymmetry

- Nucleon is a complex system
- Sea quarks and gluons correlated
- QCD dynamics

$$\bar{d}(x) \neq \bar{u}(x)$$

$$\Delta \bar{d}(x) \stackrel{?}{=} \Delta \bar{u}(x)$$



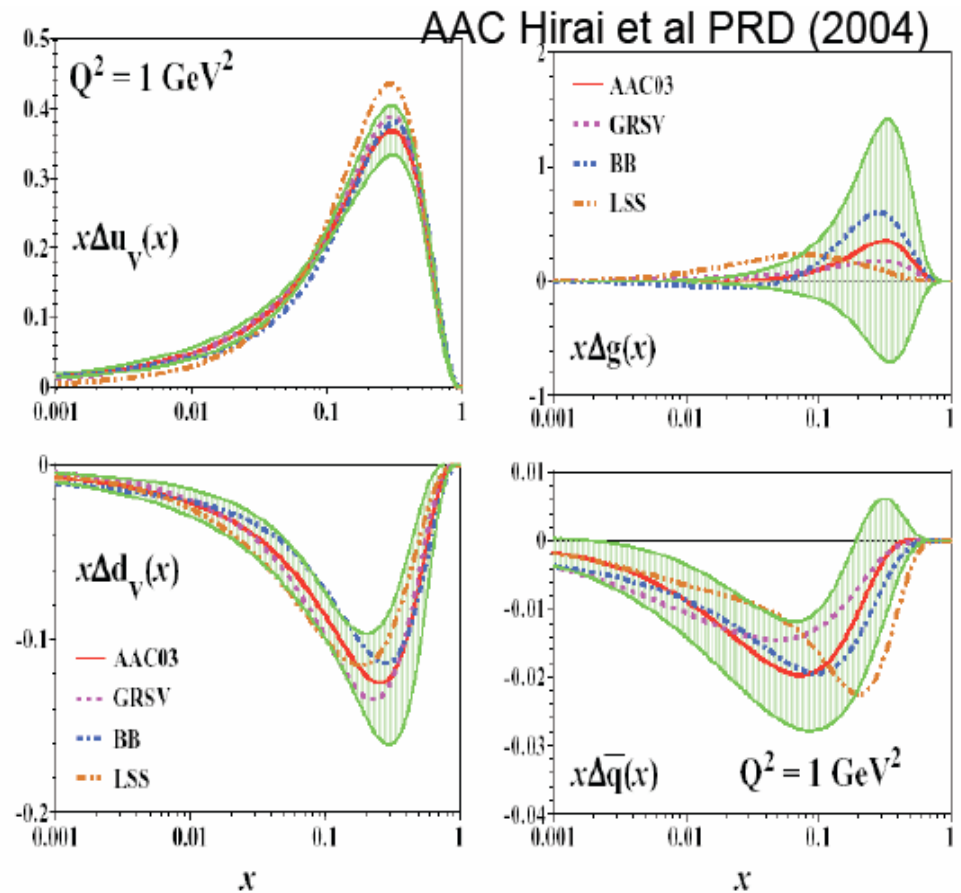
Sea Quark Polarization

- Pion cloud model:

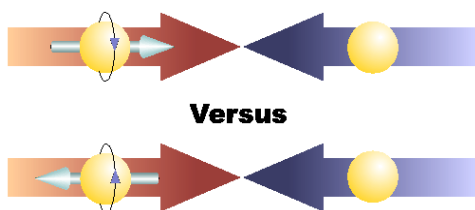
$$\Delta\bar{u} - \Delta\bar{d} = 0$$

- Chiral soliton model:

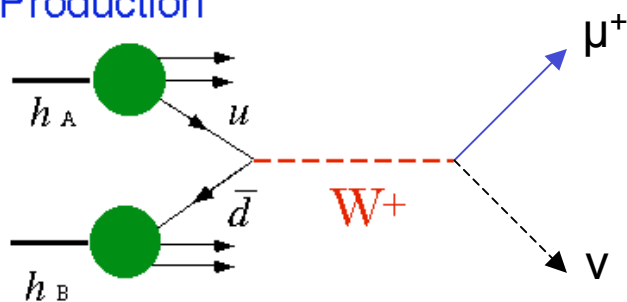
$$\Delta\bar{u} - \Delta\bar{d} \sim N_C (\bar{u} - \bar{d})$$



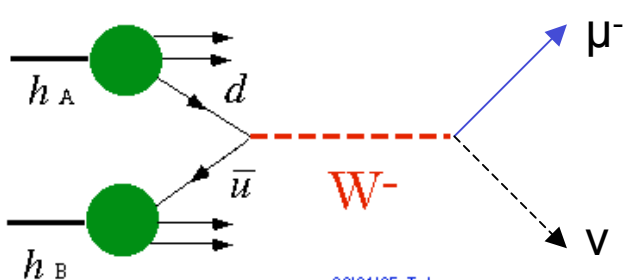
W Production and A_L @500GeV



W^+ Production

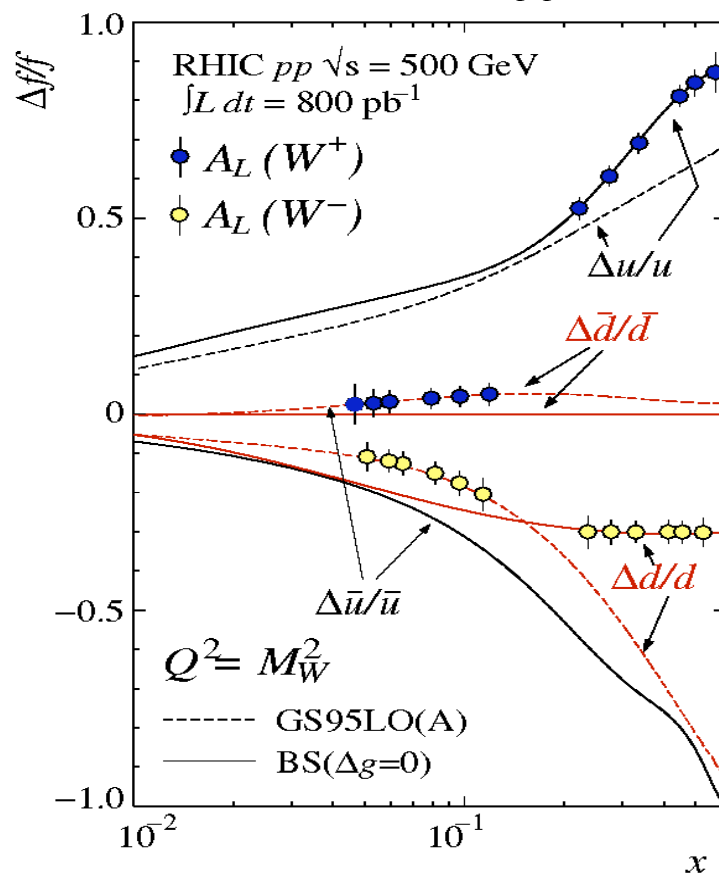


W^- Production



08/01/95 T.I.

Bunce G. et al, hep-ph/0007218



Summary and Outlook

- Very rich physics program with longitudinally polarized beams
 - Spin Puzzle
 - Polarized gluon distribution
 - Flavor-dependent polarized quark distributions
 - Excellent QCD test ground with polarized partons
- Latest news from PHENIX:
 - Light hadron production: π , η , Λ , ...
 - Heavy quark production: J/Psi, open charm ...
 - Explore orbital angular momentum: jet correlation?
 - Run6 500GeV test run: first W events @RHIC
- Where does the nucleon get its spin?
 - Still don't know ... but RHIC-SPIN will help us to find the answer
 - and we will learn a lot more about the nature of strong interactions

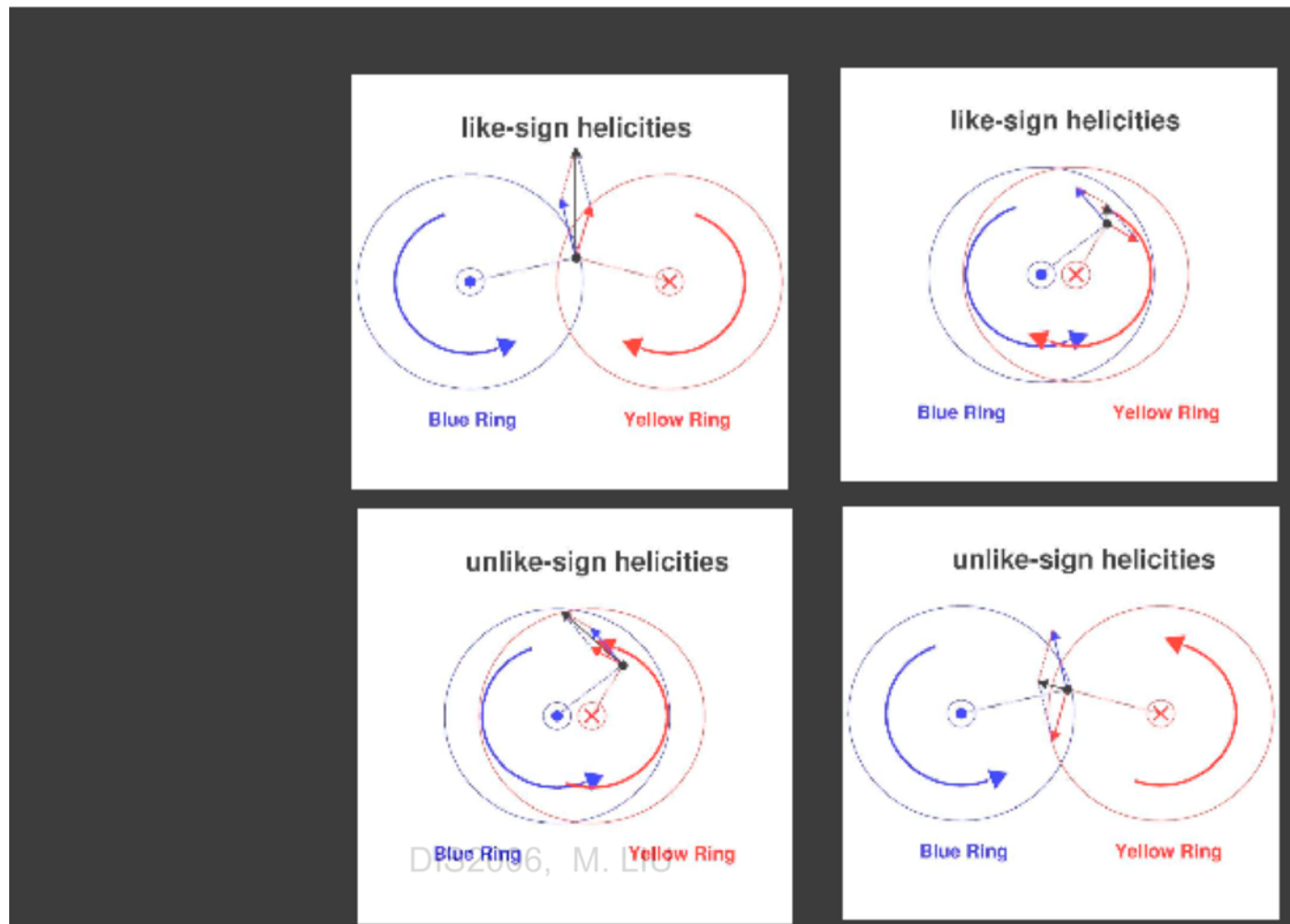
Backup

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Orbital Angular Momentum

- Back-to-back jet correlation



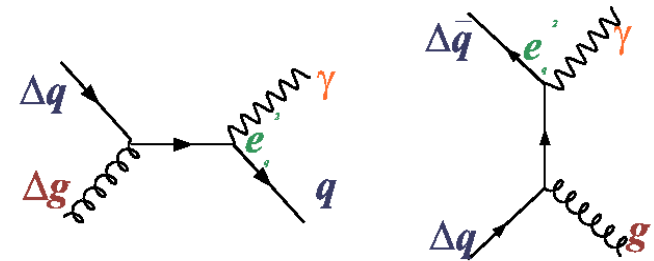
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What do we learn from A_{LL} ?

- Asymmetries

$$E \frac{d^3 \Delta \sigma}{dp^3} \propto \Delta f_A^a(x_a, Q^2) \otimes \Delta f_B^b(x_b, Q^2) \otimes \frac{d\Delta \sigma_{ab}^{cd}}{dt}$$

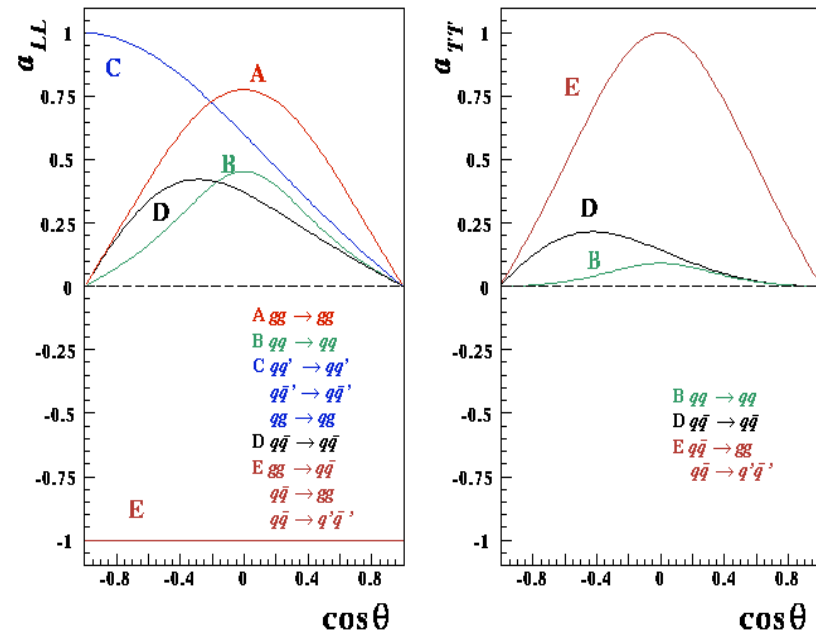


- Polarized Quark and Gluon Distributions

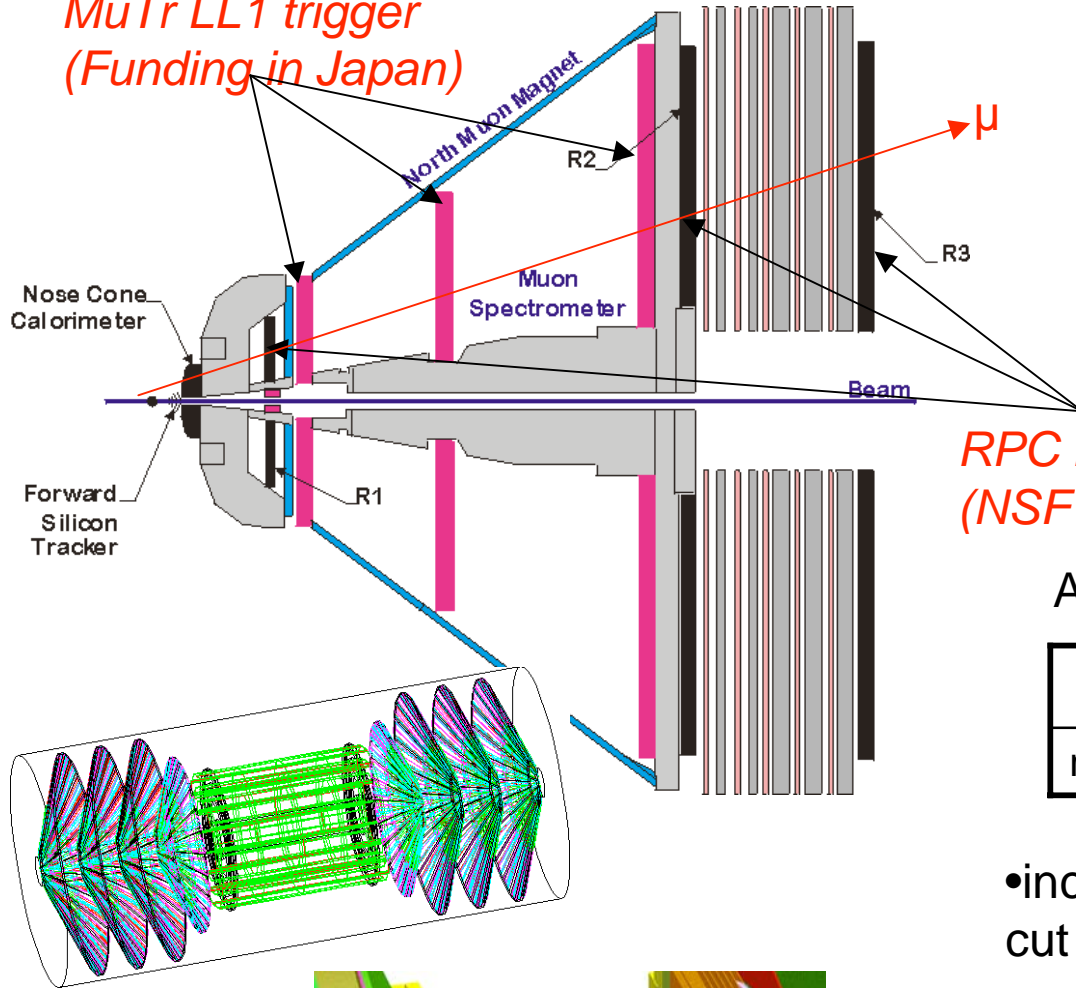
$$\Delta f(x) = f_{\uparrow}(x) - f_{\downarrow}(x)$$

$$\Delta f \equiv \int_0^1 \Delta f(x) dx$$

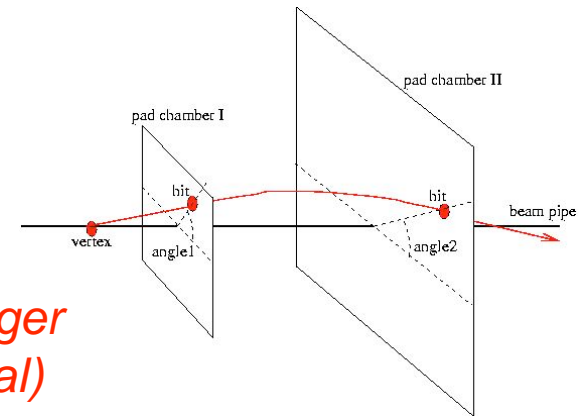
- Proton Structure
 - QCD dynamics



*MuTr LL1 trigger
(Funding in Japan)*



PHENIX forward upgrade

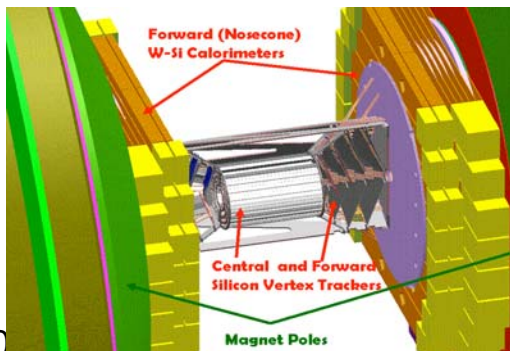


*RPC LL1 trigger
(NSF proposal)*

Achieved enough trigger rejection

$\delta(\phi)$ deg	<0.7	<1.0	<2.0
rejection	36000	19980	10090

- increase of pion rejection via isolation cut
- possible background rejection via reconstructing W transverse mass.
- possible improve of momentum resolution with well defined determined vertex.



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