

# Studying Proton Spin Structure with the PHENIX Upgrade Program



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*for the PHENIX Collaboration*

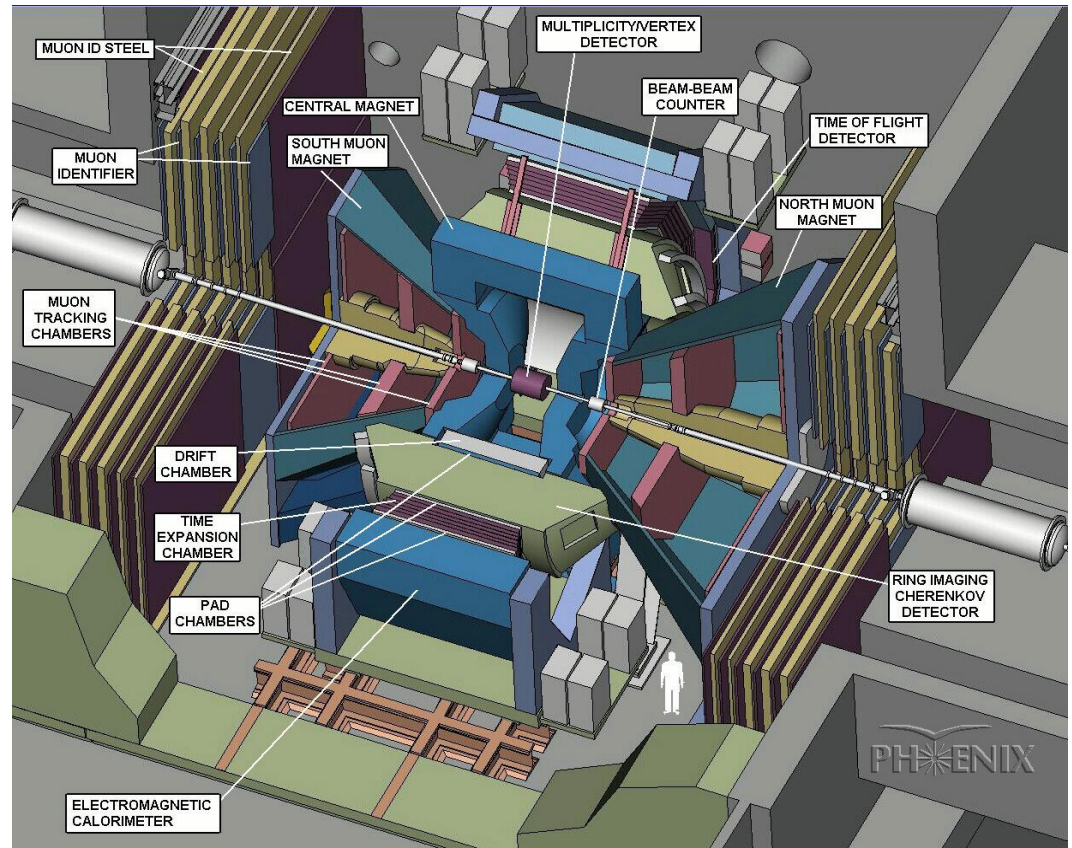
- The PHENIX Upgrades
  - Silicon Tracking
    - VTX and FVTX
  - Electromagnetic Calorimetry
    - NCC and MPC
  - Upgraded Muon Trigger Capabilities
- Spin Physics in the Upgrade Era
  - $\Delta G$  from heavy flavor, photon-tagged jets
    - Expanded reach in  $x$
  - Flavor separation of spin asymmetries
    - $W$  physics at 500GeV
  - Transverse Spin Physics

# PHENIX Spin Physics Program:

## $\Delta G$ , $\Delta q/q$ , $\Delta \bar{q}/\bar{q}$ , $\delta q$



- **2 central arms:**  
electrons, photons, hadrons
  - charmonium  $J/\psi$ ,  $\psi' \rightarrow e^+e^-$
  - vector meson  $\rho$ ,  $\omega$ ,  $\phi \rightarrow e^+e^-$
  - high  $p_T$   $\pi^0$ ,  $\pi^+$ ,  $\pi^-$
  - direct photons
  - open charm
  - hadron physics
- **2 muon arms:**
  - “onium”  $J/\psi$ ,  $\psi'$ ,  $Y \rightarrow \mu^+\mu^-$
  - open heavy flavor
  - $W \rightarrow \mu$  (500GeV)



Excellent trigger and DAQ capabilities: multiple trigger signature important for spin physics can be taken in parallel with high bandwidth!

# Key Spin Measurements



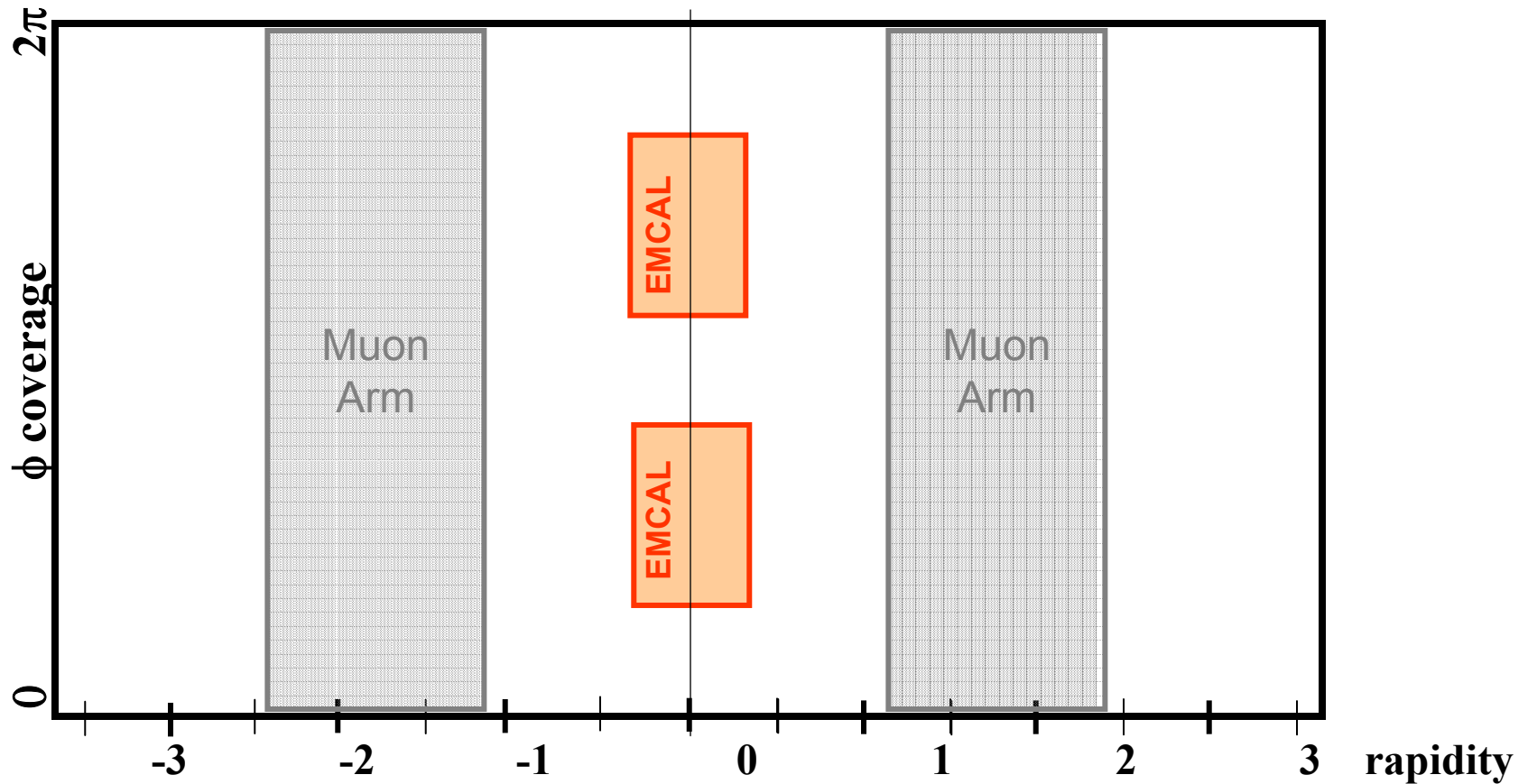
- $\Delta G$  through a variety of physical processes (double-spin asymmetries):
  - Inclusive pions  
 $a_{LL}(gg, gq \rightarrow \pi^{0,\pm} + X)$
  - Heavy Flavor  
 $a_{LL}(gg, gq \rightarrow \bar{c}c, \bar{b}b + X)$
  - Direct Photon + Jet  
 $a_{LL}(gg, gq \rightarrow \gamma + jet + X)$
- Flavor separation of quark/antiquark asymmetries:
  - $W^{+/-}$  production in polarized pp collisions at 500 GeV
- Transverse Spin Physics
  - Sivers (jets and heavy flavor)
  - Collins fragmentation function
  - Interference fragmentation

$$A_{LL} \sim \frac{\Delta a}{a} \frac{\Delta b}{b} a_{LL} (a + b \rightarrow c + d)$$

$$A_L^{W^+} \approx \frac{\Delta u(x_1, M_W^2)}{u(x_1, M_W^2)} \quad A_L^{W^+} \approx -\frac{\Delta \bar{d}(x_1, M_W^2)}{\bar{d}(x_1, M_W^2)}$$

$(y_W \gg 0) \qquad \qquad (y_W \ll 0)$

# Baseline Acceptance



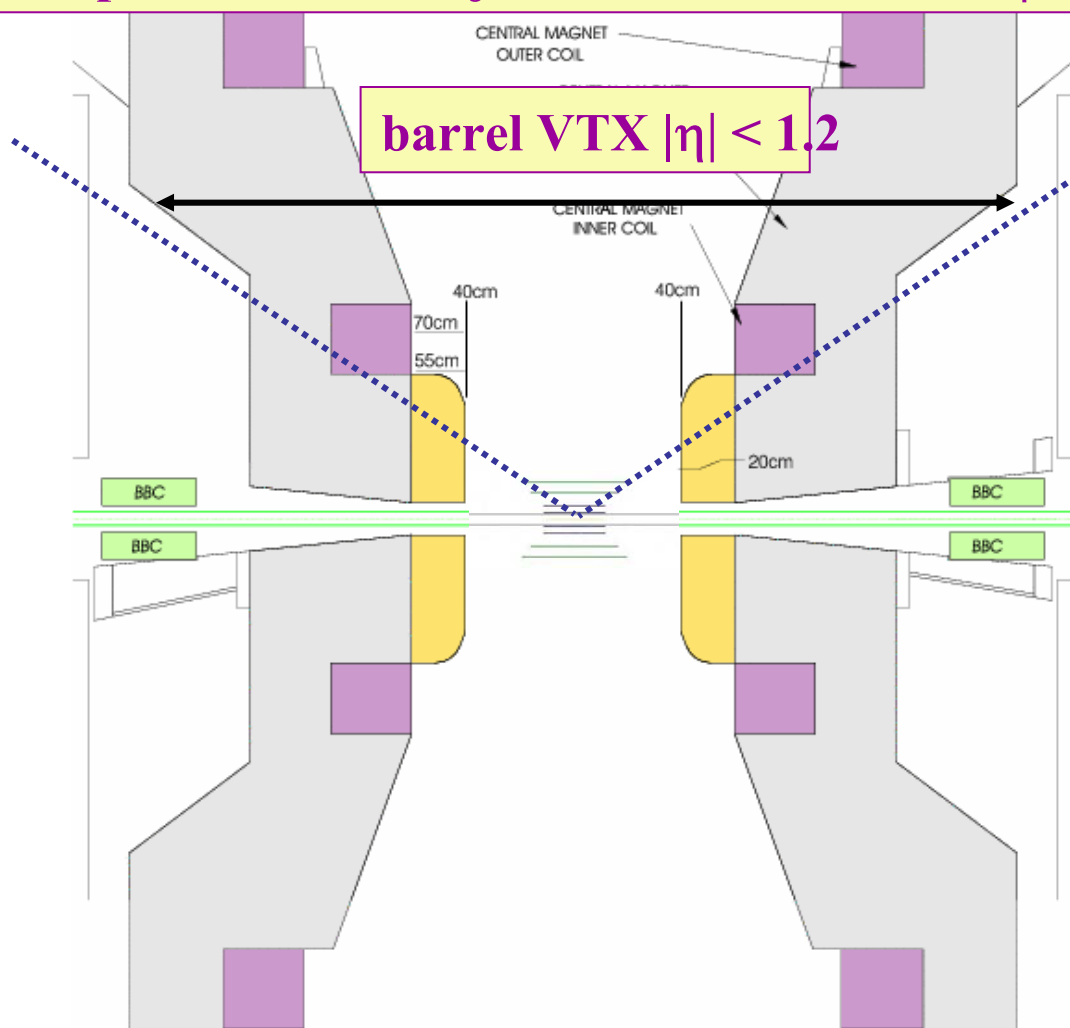
# Adding Silicon: The PHENIX VTX



Provides displaced vertex & jet measurement over  $\Delta\phi \sim 2\pi$

- Specifications:
  - Large acceptance ( $\Delta\phi \sim 2\pi$  and  $|\eta| < 1.2$ )
  - Displaced vertex measurement  $\sigma_{\text{DCA}} < 40 \mu\text{m}$
  - Charged particle tracking  $\sigma_p/p \sim 5\%$   $p$  at high  $p_T$
  - Detector must work for both of heavy ion and  $pp$  collisions.
- Technology Choice:
  - Hybrid pixel detectors developed at CERN for ALICE
  - Strip detectors, sensors developed at BNL with FNAL's SVX4 readout chip

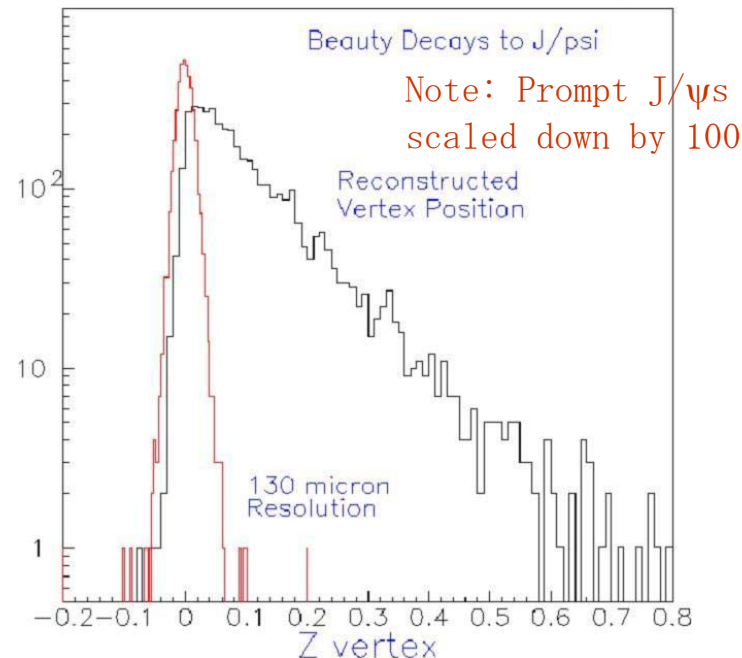
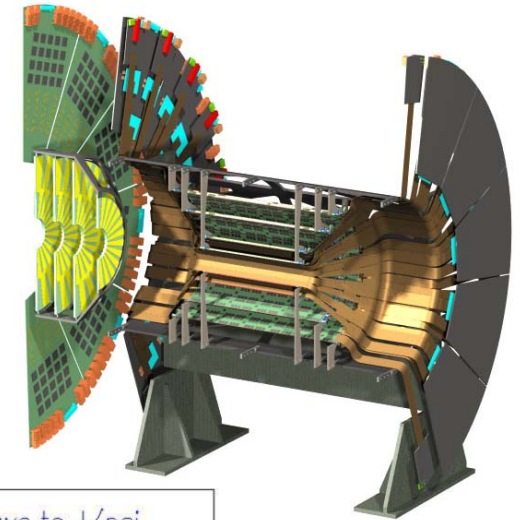
Construction Underway



# Forward Silicon: The FVTX

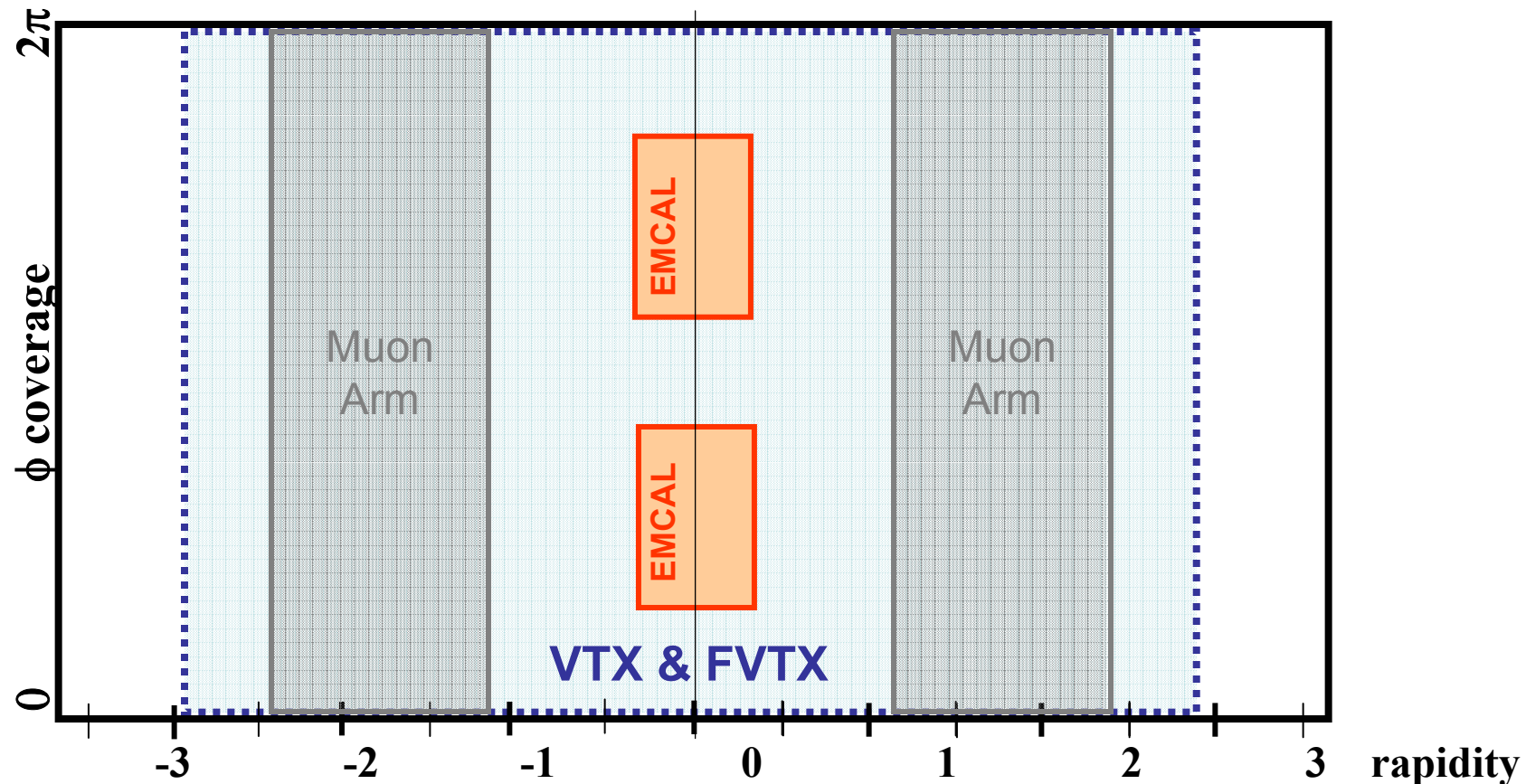


- **Detector:**
  - 4 layers
  - Vertical planes
  - 75  $\mu\text{m}$  radial pitch, 7.5°  $\phi$  segmentation (2 – 13 mm)
  - Maximize z and r extent to give good resolution and  $\geq 3$  hits/track as much as possible
  - 2\*600K channels
- **Status:**
  - Recently favorably reviewed for FY08 start
  - Bootstrapped by LANL LDRD funds to construct one octant prototype
  - Submitted proposal to DOE for FY08 funding start



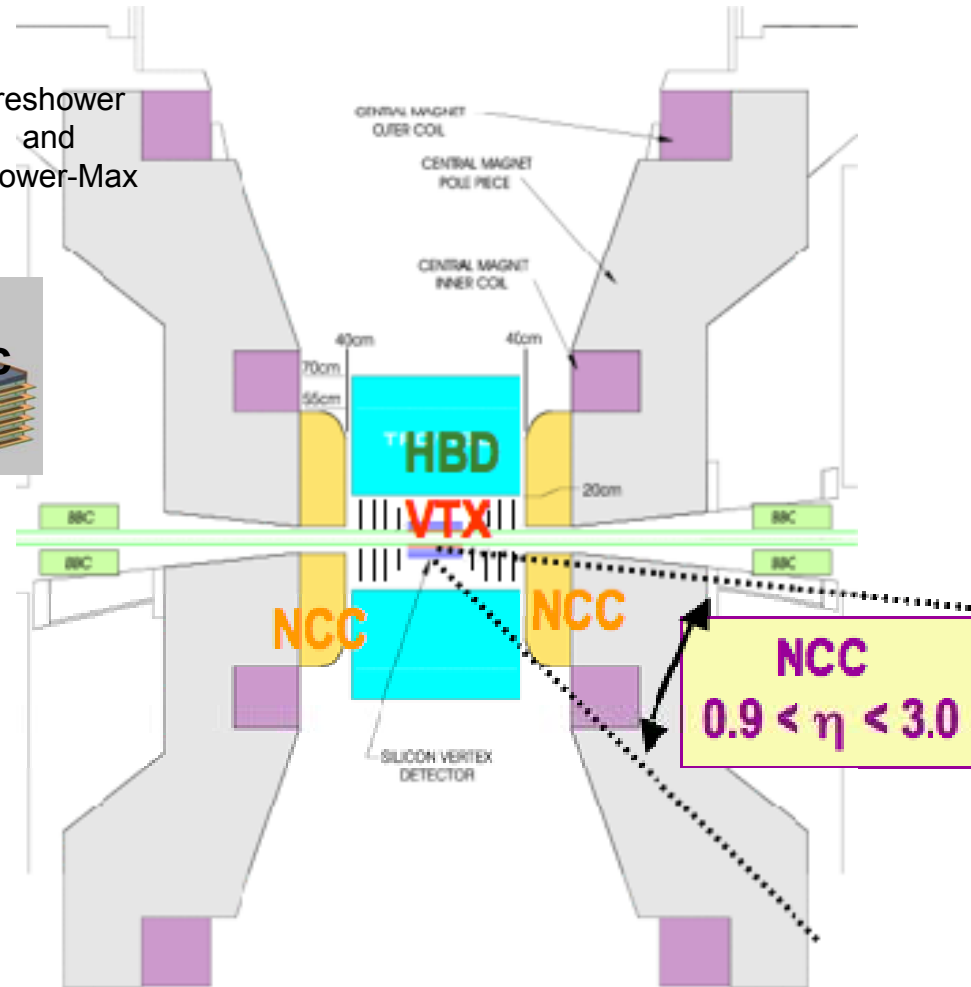
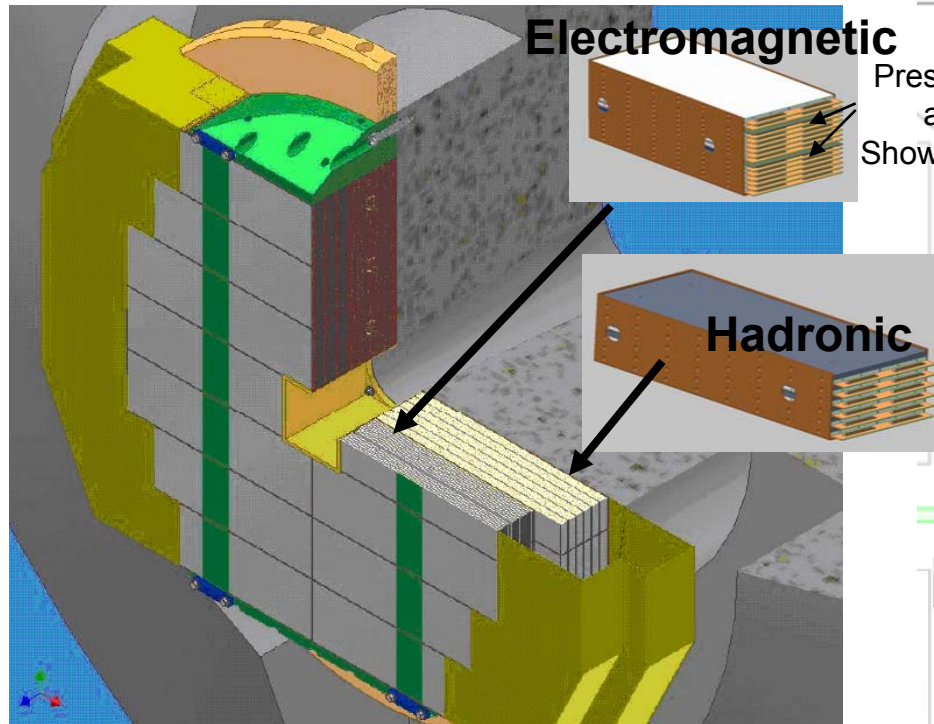


# Expanded Acceptance I



**VTX and FVTX add charged particle tracking close to the event vertex over a wide kinematic range.**

# The PHENIX NoseCone Calorimeter (NCC)



- $\gamma + e$  identification
- $\gamma - \pi^0$  separation
- $e/\mu$  isolation
- jet identification
- $e/\gamma/\text{jet}$  triggers

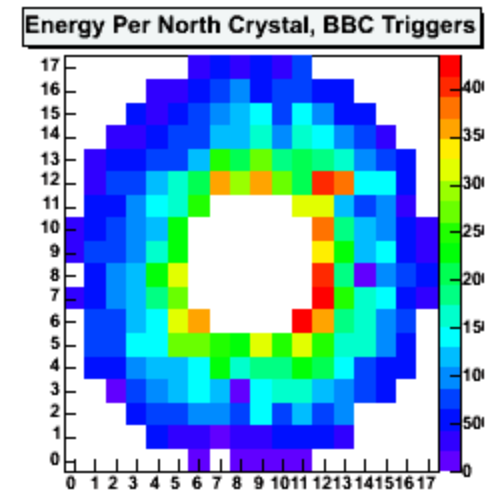
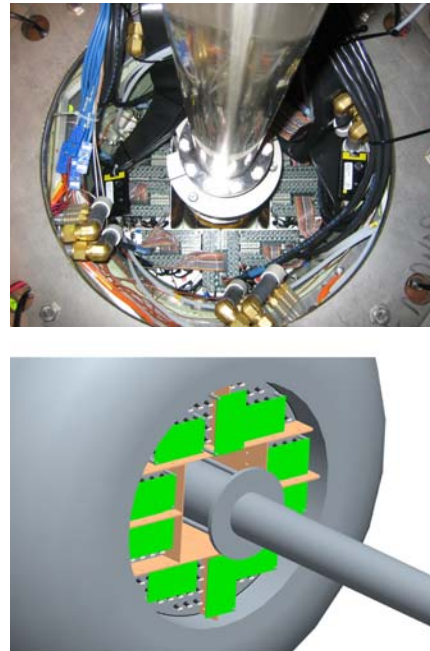
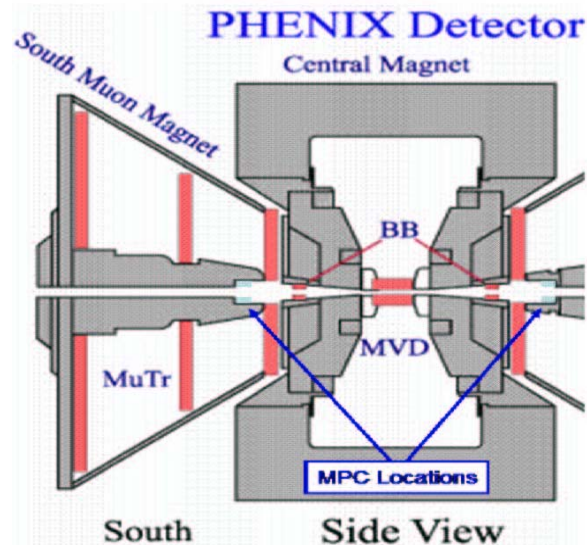


# Muon Piston Calorimeter I



- Array of  $\text{PbWO}_4$  crystals mounted inside a recess in the Muon magnet pistons.
- 412 crystals covering  $3.1 < |\eta| < 3.7$
- Physics motivation:
  - Spin asymmetries in forward region

Installed and  
taking data!

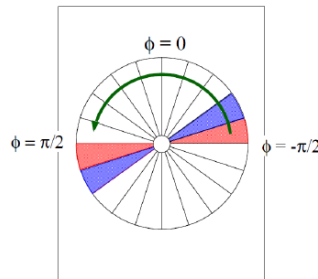


# Muon Piston Calorimeter II



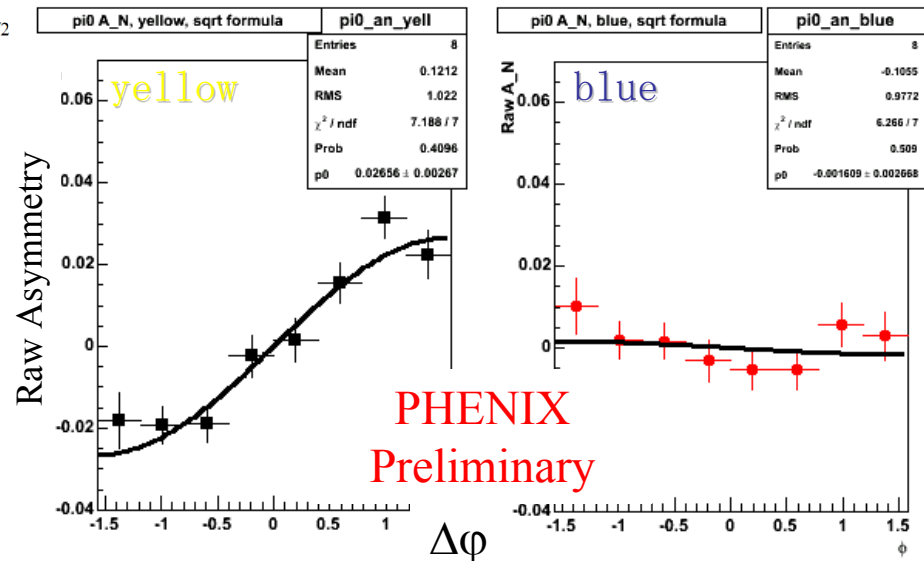
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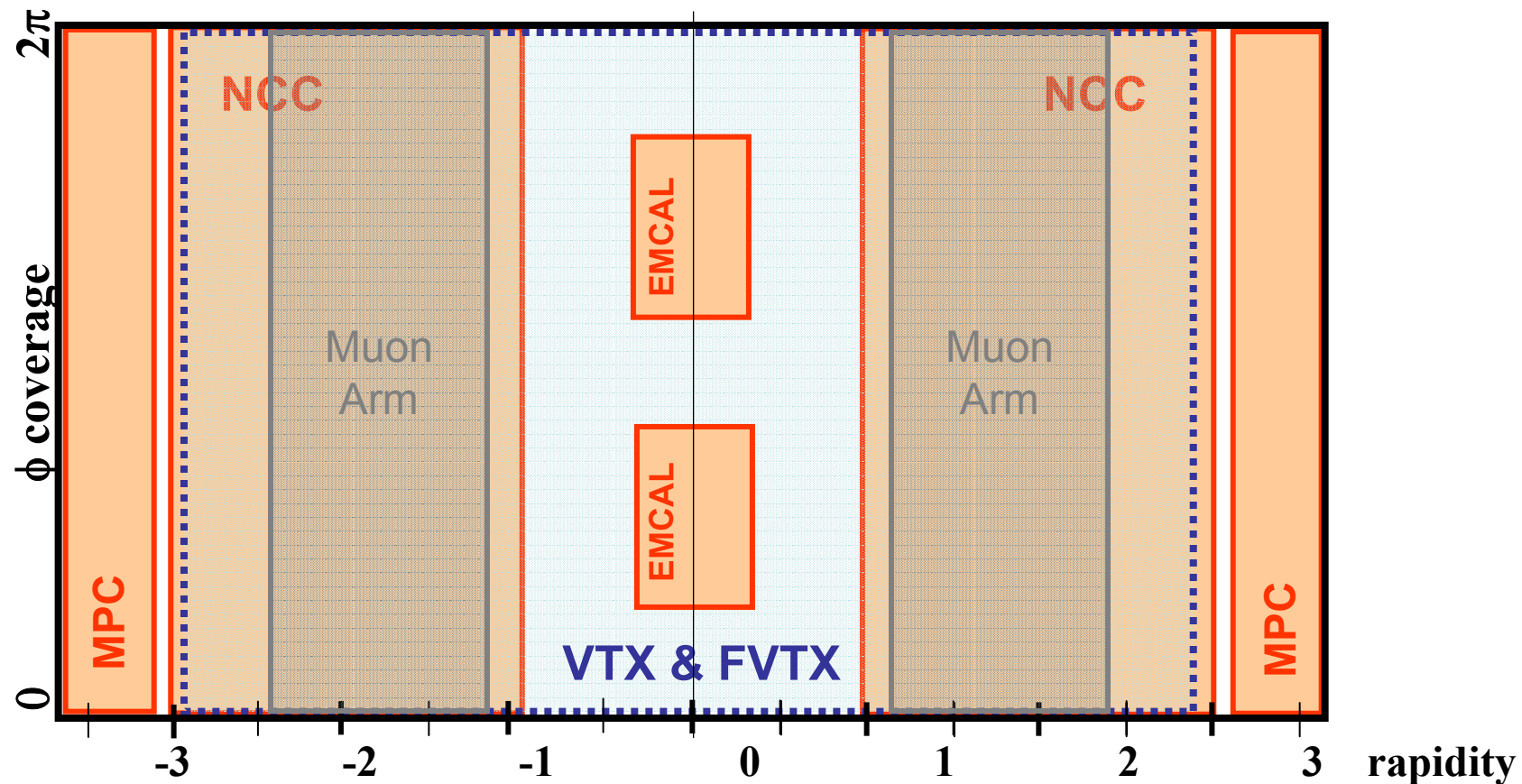


Raw asymmetry seen for positive  $x_F$  (yellow), but not for negative  $x_F$  (blue), as expected (62 GeV Transverse)

$$RawA_N \equiv \varepsilon_N \equiv \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} \approx \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$



# Expanded Acceptance II

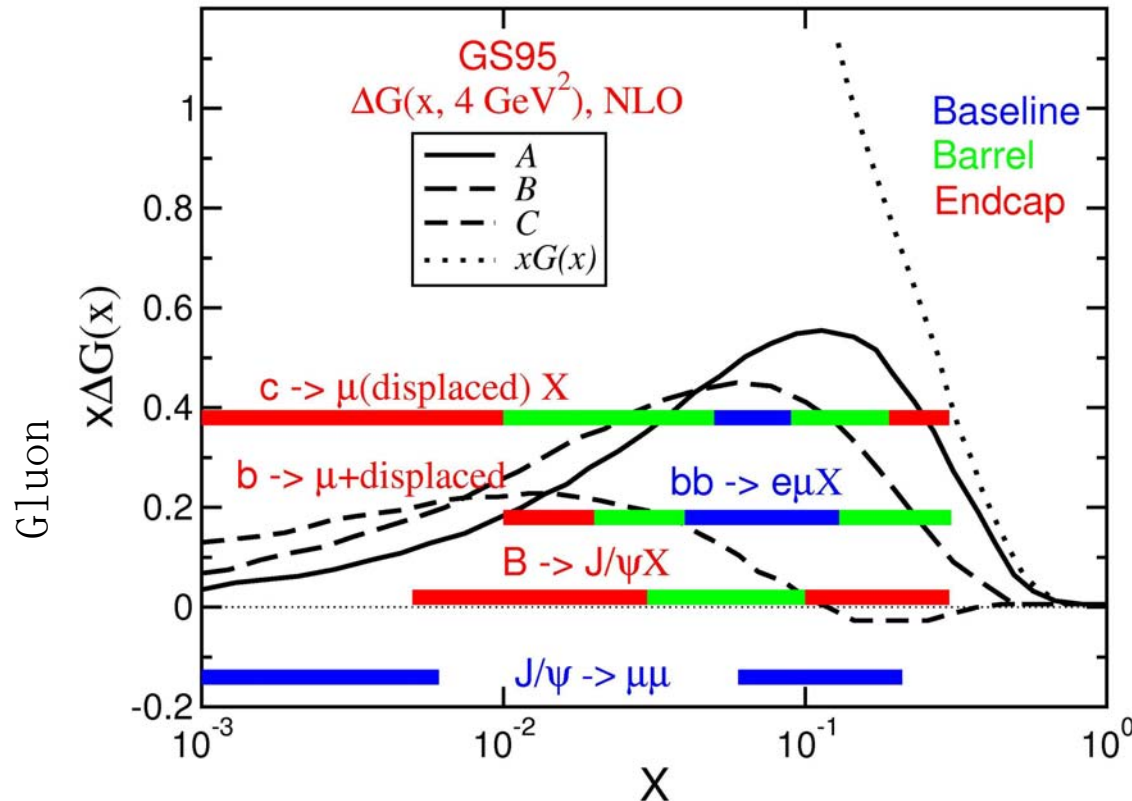


**NCC and MPC add EM Calorimetry in the forward direction.**

# Gluon polarization $\Delta G$ (Heavy Flavor)



Polarized p+p collisions



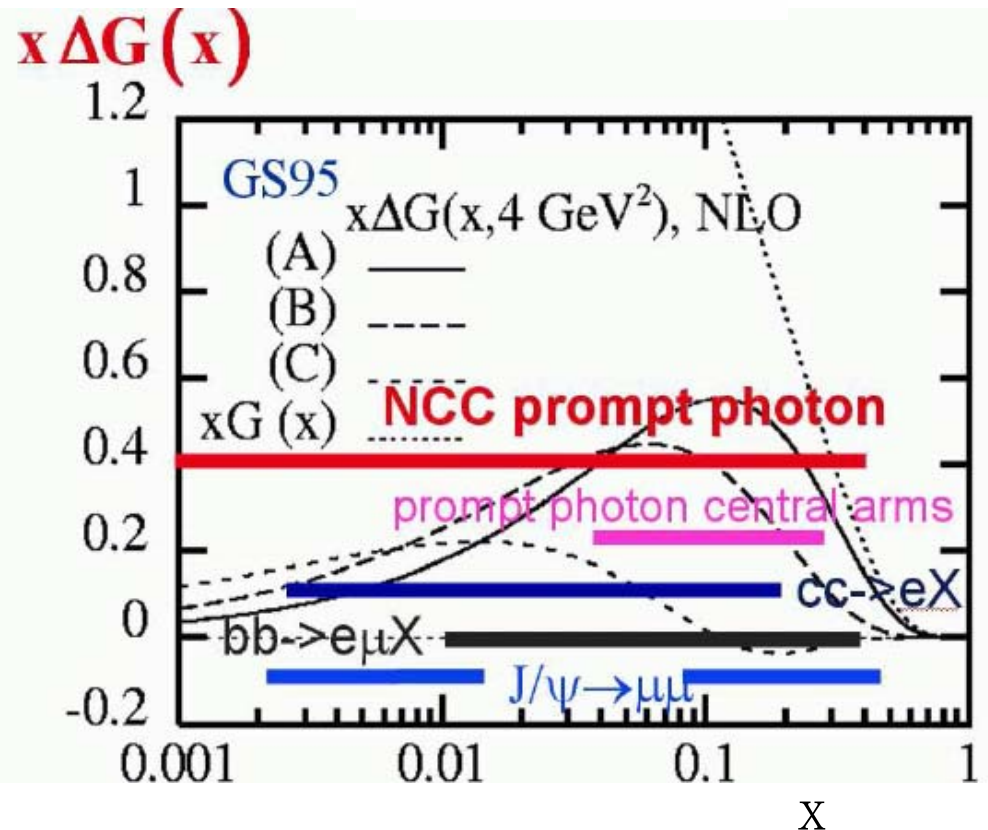
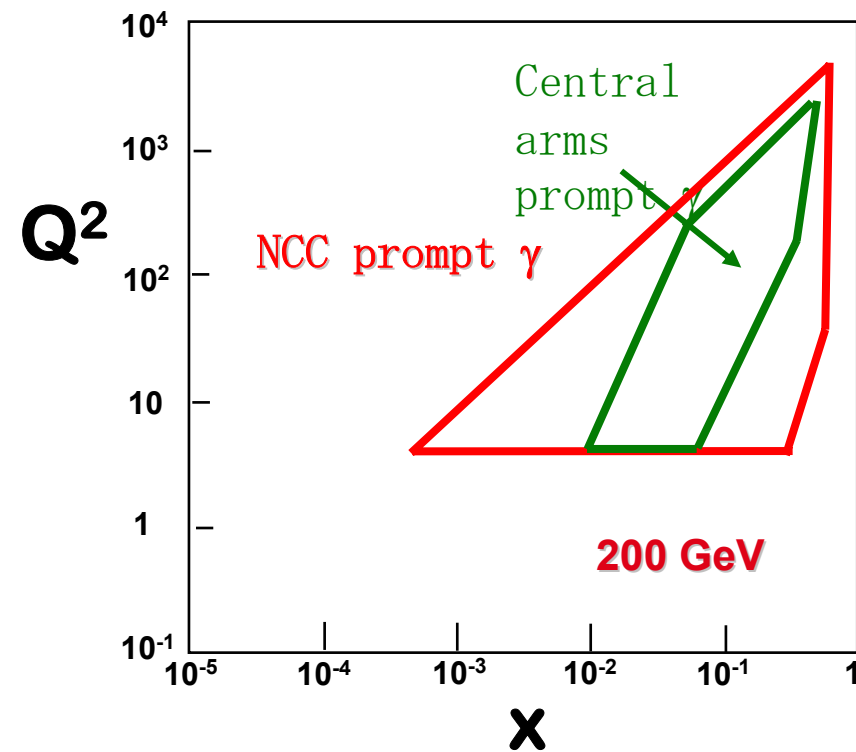
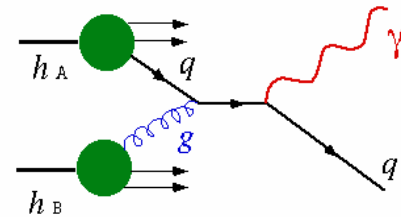
Gluon polarization can be measured by double-spin asymmetry  $A_{LL}$ .

- charm and bottom identification by displaced vertex
- Jet identification with larger acceptance

# Gluon polarization $\Delta G(x)$ (Direct Photons)

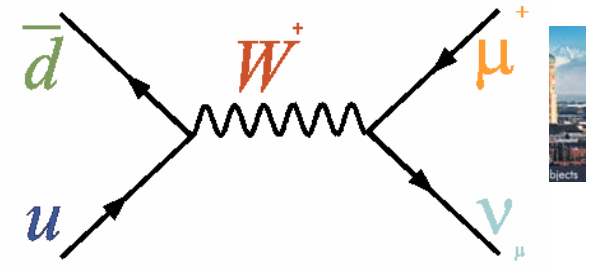


- $\gamma$ -jet is:
  - Very clean way to measure the gluon
  - Measuring the angle of the jet gives you access to  $x_{\text{gluon}}$





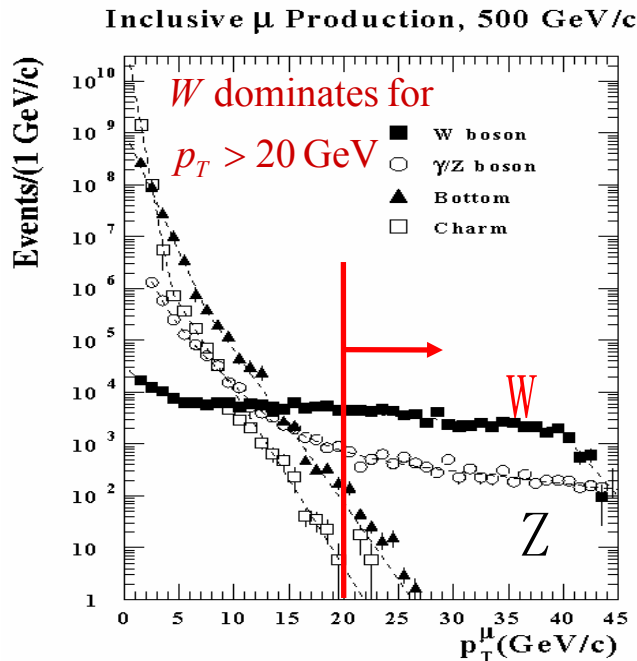
# Flavor separation of the spin dependent quark and anti-quark distributions in pp collisions @500GeV



$$\left. \begin{aligned} A_L^{W^+} &\approx \frac{\Delta u(x_1, M_W^2)}{u(x_1, M_W^2)}, \quad x_1 > x_2 \quad (y_W \gg 0) \\ A_L^{W^+} &\approx -\frac{\Delta \bar{d}(x_1, M_W^2)}{\bar{d}(x_1, M_W^2)}, \quad x_1 < x_2 \quad (y_W \ll 0) \end{aligned} \right\}$$

For  $W^-$  interchange  $u$  and  $d$ .

Parity violation of the weak interaction in combination with control over the proton spin orientation gives access to the flavor spin structure in the proton!



## Experimental Requirements:

- ➔ tracking at high  $p_T$
- ➔ good rejection of backgrounds in analysis.
- ➔ event selection for muons difficult due to background muons from hadron decays and beam backgrounds

# Trigger Rate and Rejection ( $W$ Physics)



## Design Luminosity

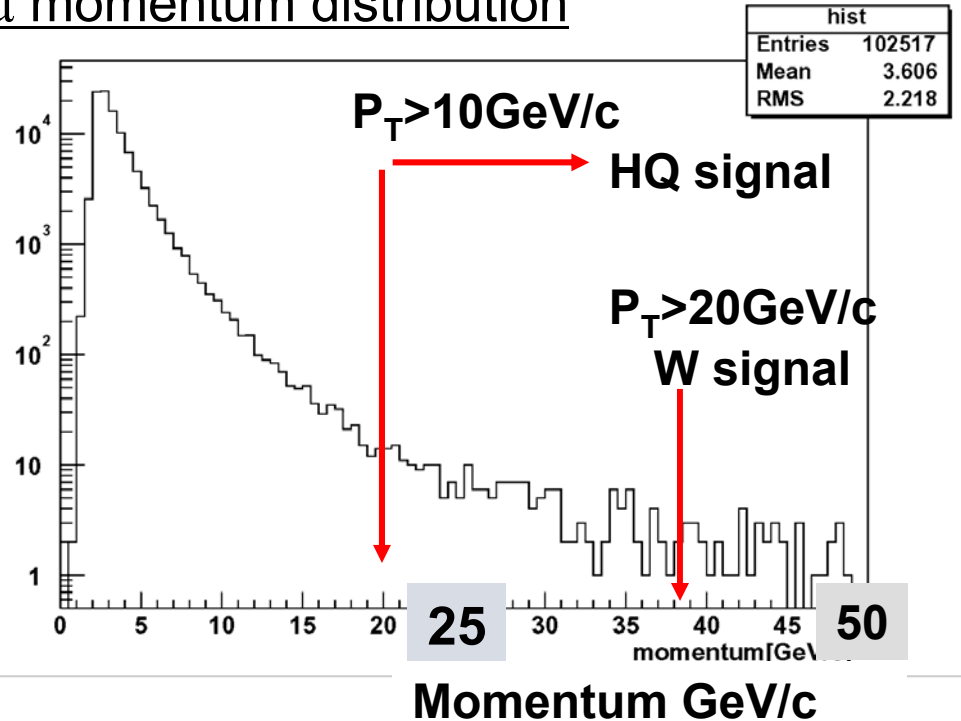
$$\sqrt{s} = 500 \text{ GeV} \quad \sigma = 60 \text{ mb}$$
$$L = 2 \times 10^{32} / \text{cm}^2 / \text{s}$$

Total X-sec rate = **12 MHz**

DAQ LIMIT  
= **1-2 kHz** (for  $\mu$  arm)

Required RF  
 **$\sim 10,000$**

## $\mu$ momentum distribution



Need Momentum Selectivity in the LVL-1 Trigger!

# PHENIX Muon Trigger Upgrade



## (I) Three dedicated trigger RPC stations (CMS design):

R1(a,b):  $\sim 12\text{mm}$  in  $\phi$ ,  $4 \times \theta$  pads

R2:  $\sim 5.4\text{mm}$  in  $\phi$ ,  $4 \times \theta$  pads

R3:  $\sim 6.0\text{mm}$  in  $\phi$ ,  $4 \times \theta$  pads

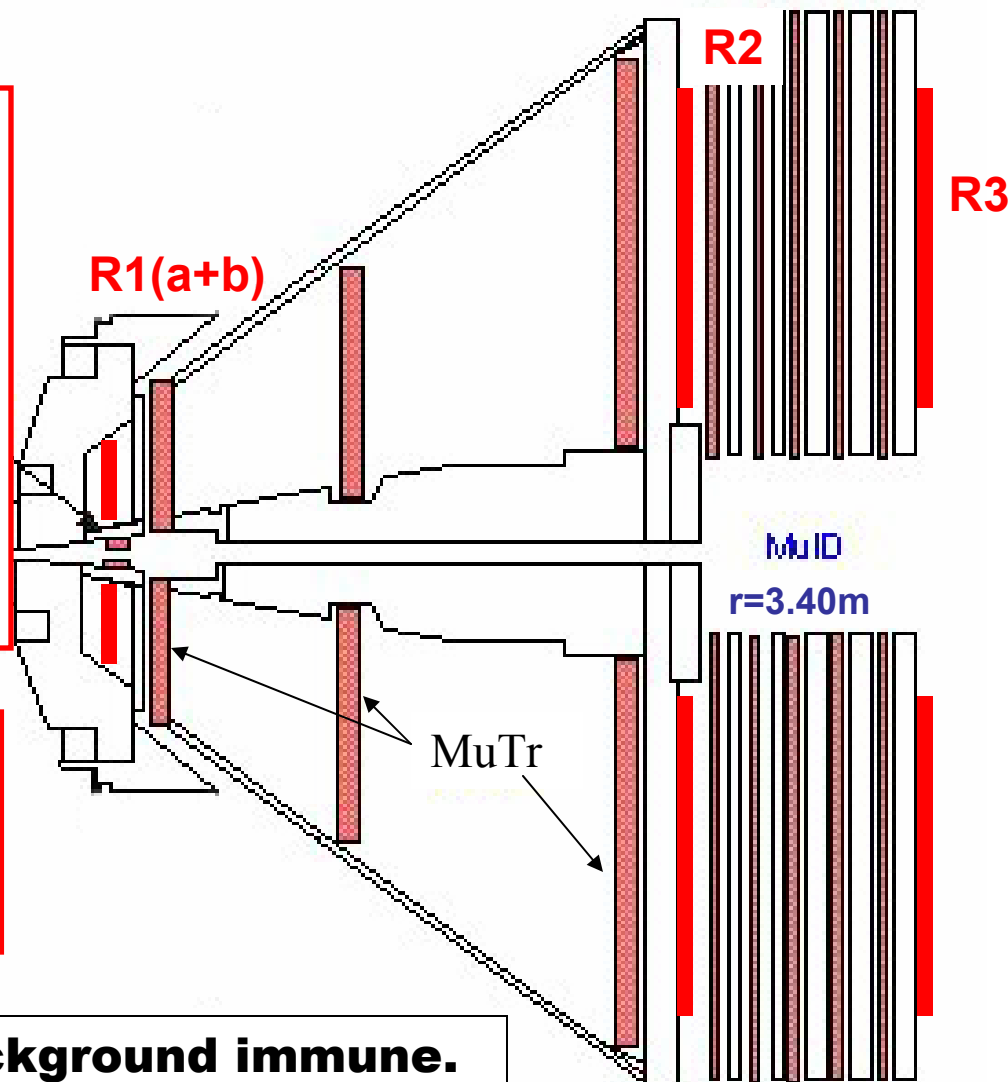
(Trigger only – offline segmentation higher)

**NSF (Funded)**

## (II) MuTr front end electronics

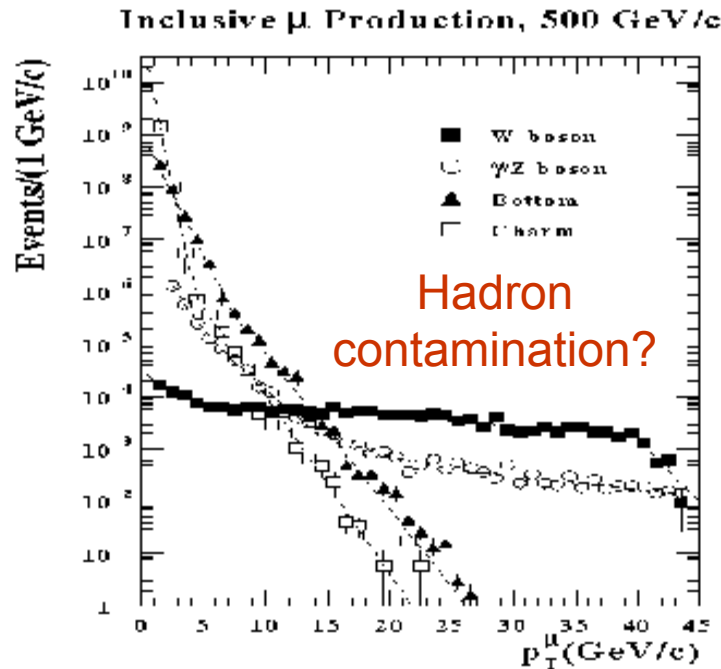
Upgrade to allow LL1 information

**JSPS (Funded)**

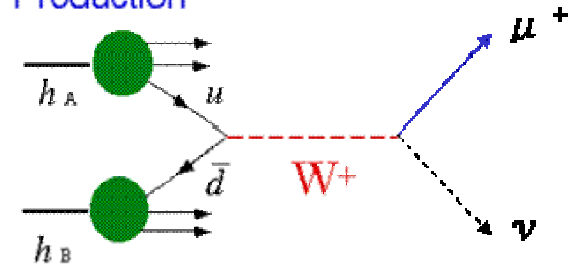


**Rejection  $\sim 12,000$ , beam background immune.**

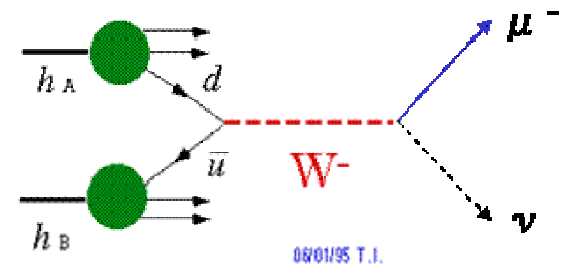
# Upgrades Combine to Improve $W^{+/-}$ Measurement



$W^+$  Production



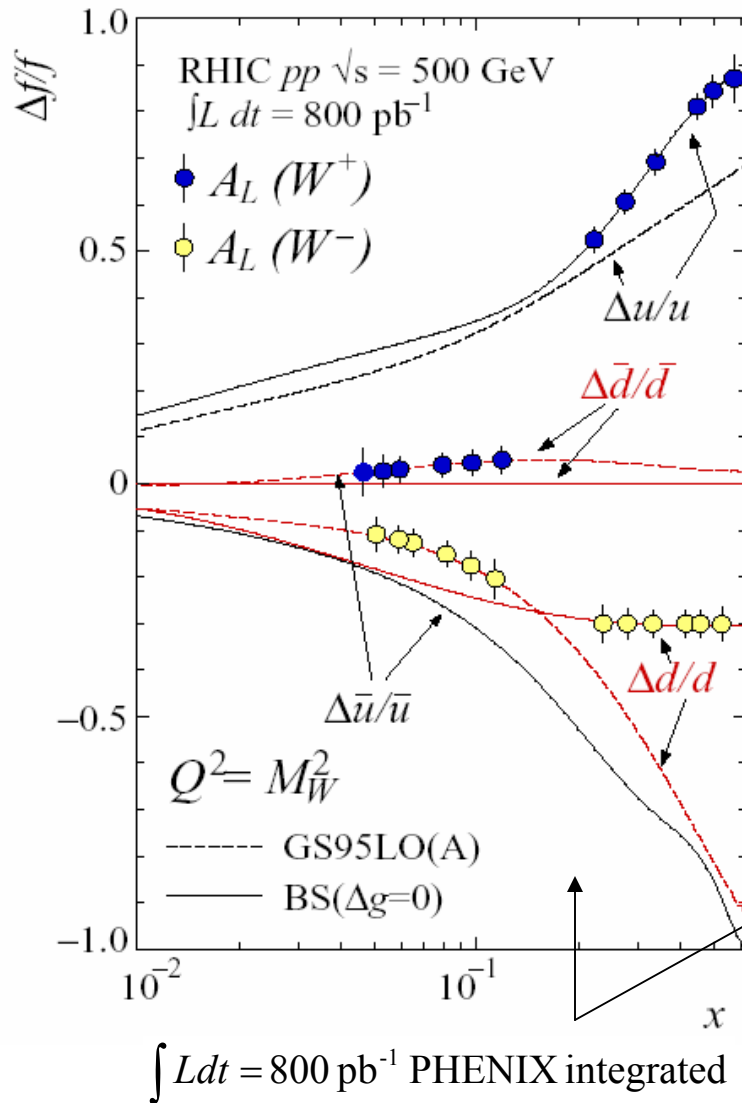
$W^-$  Production



$W^{+/-}$  measurement in polarized pp collisions to get at sea quark contributions to proton spin:

- Isolation cut with FVTX/NCC detectors could be used to suppress hadron background to  $W^{+/-}$  signal.

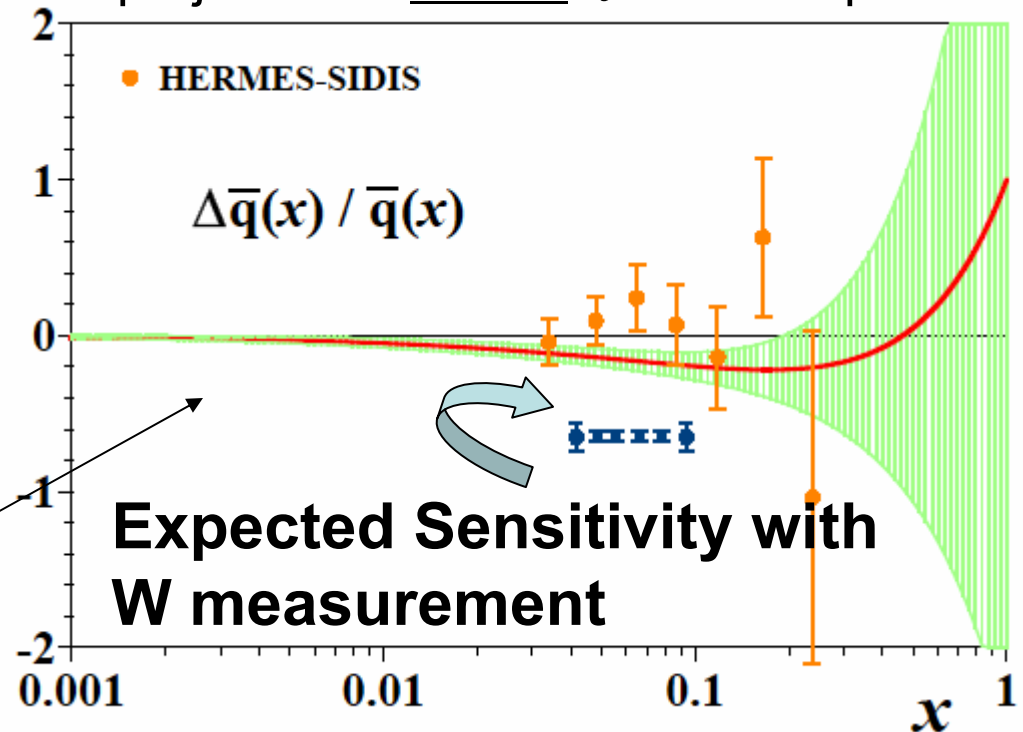
# PHENIX $A_L^{W^{+/-}}$ Sensitivity



## ➤ Machine and detector requirements:

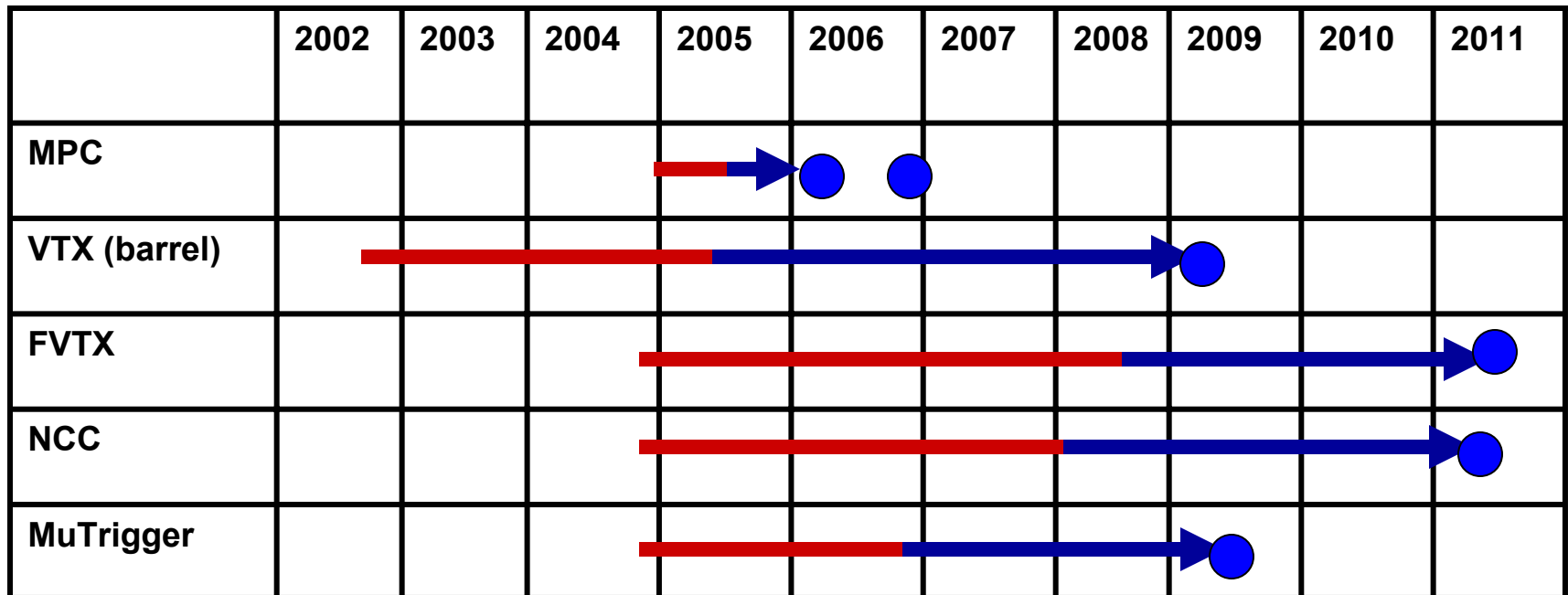
- PHENIX  $\int L dt = 800 \text{ pb}^{-1}$ ,  $P=0.7$
- Muon trigger upgrade!

2009 to 2012 running at  $\sqrt{s}=500 \text{ GeV}$   
 is projected to deliver  $\int L dt \sim 980 \text{ pb}^{-1}$





# Upgrade Schedule



 R&D Phase
  Construction Phase
  Ready for Data

# Physics Timeline



see Spin report to DOE <http://spin.riken.bnl.gov/rsc/>

$$L = 1 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$$

$$6 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$$

$$1.6 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$$

$$P = 0.5 \quad 0.6 \quad 0.7 \quad \dots$$

$$\sqrt{s} = \dots 200 \text{ GeV} \dots 500 \text{ GeV}$$

2005

2006

2007

2008

2009

....

2012 (RHIC II)

10 pb<sup>-1</sup>

→ 275 pb<sup>-1</sup> | @ 200 GeV

980 pb<sup>-1</sup> | @ 500 GeV

**Inclusive hadrons + Jets**

~ 25% **Transverse Physics**

**Charm Physics**

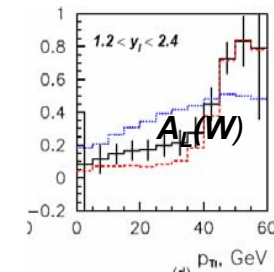
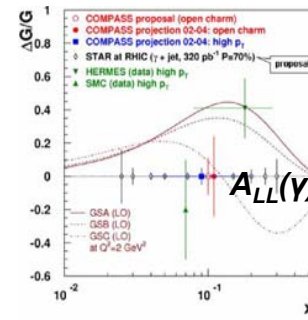
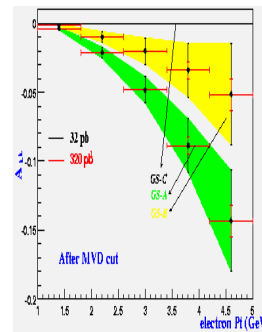
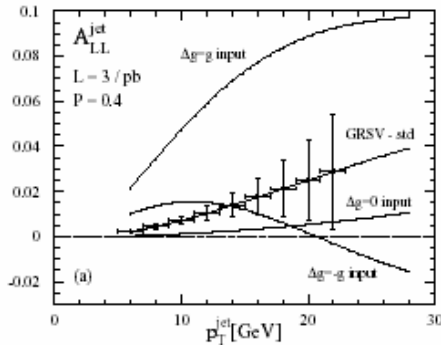
**direct photons**

**bottom physics**

**W-physics**

$A_{LL}(\text{hadrons, Jets})$

$A_{LL}(\text{charm})$



# Summary



- PHENIX is pursuing a rich program of spin physics at RHIC!
  - The polarized gluon distribution function  $\Delta G$  will be measured through a variety of processes
    - Inclusive hadrons, heavy flavor, photon-tagged jets
  - The polarized proton program at RHIC will address the flavor dependent quark and antiquark spin distribution functions.
  - Transverse spin will be explored (Sivers, Collins, etc.)
- The PHENIX upgrade will provide the event detection and selection necessary to access this physics:
  - Silicon Tracking
    - VTX and FVTX
  - Electromagnetic Calorimetry
    - NCC and MPC
  - New Level-1 Trigger Capabilities
    - Muon Trigger Upgrade
      - RPC tracking chambers

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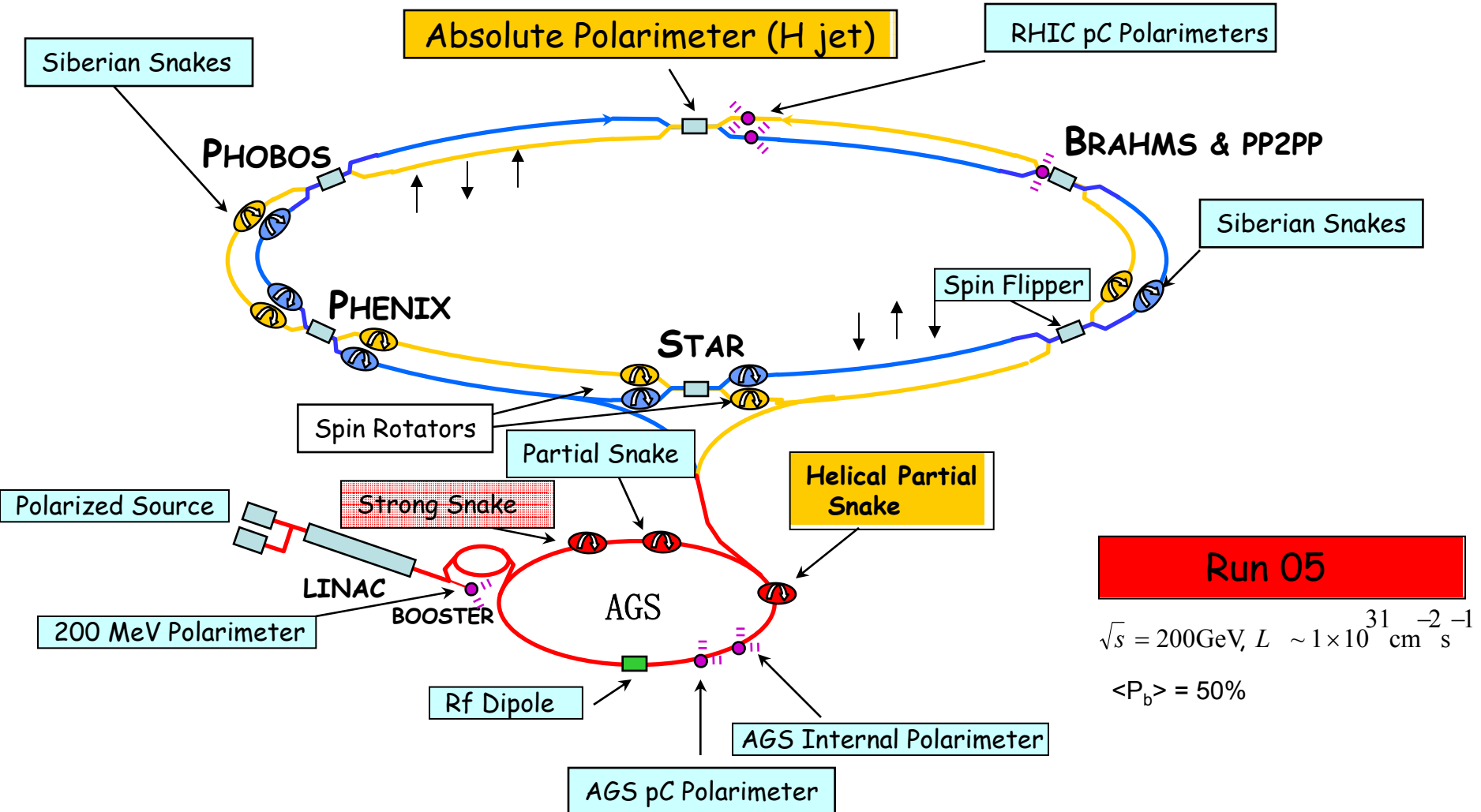
**Stay Tuned....**

# BACKUP



# Polarized p-p at RHIC

## A New Experimental Method for the Study of Proton Structure

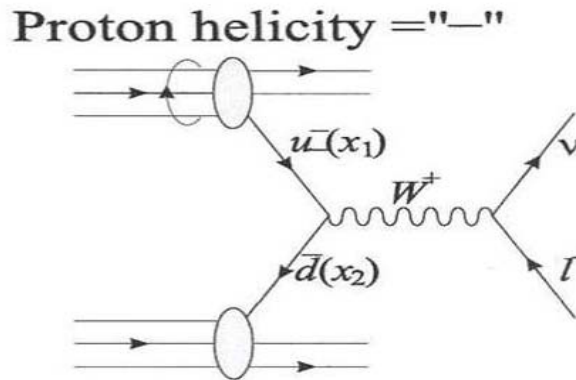
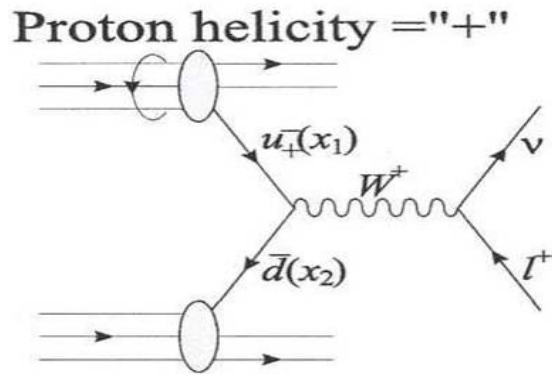


# $W^+$ Production in p + p Collisions



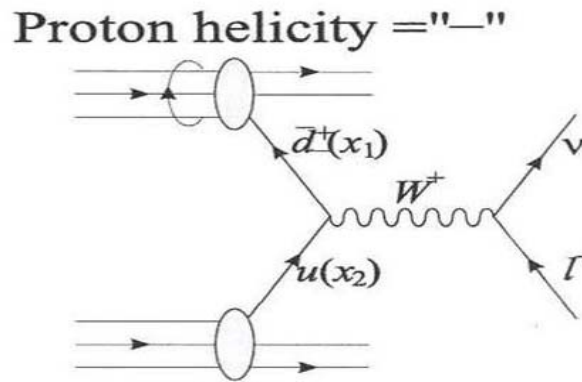
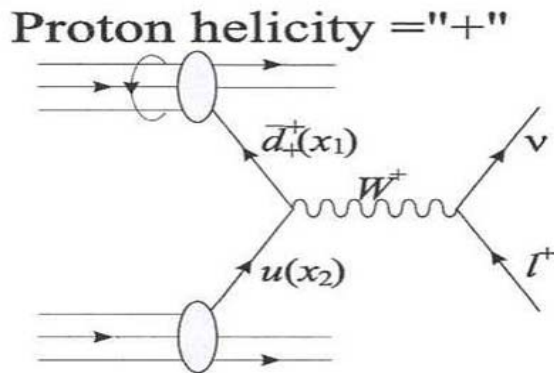
Weak interaction violates parity – quark/antiquark helicities fixed!

(left-handed quarks)



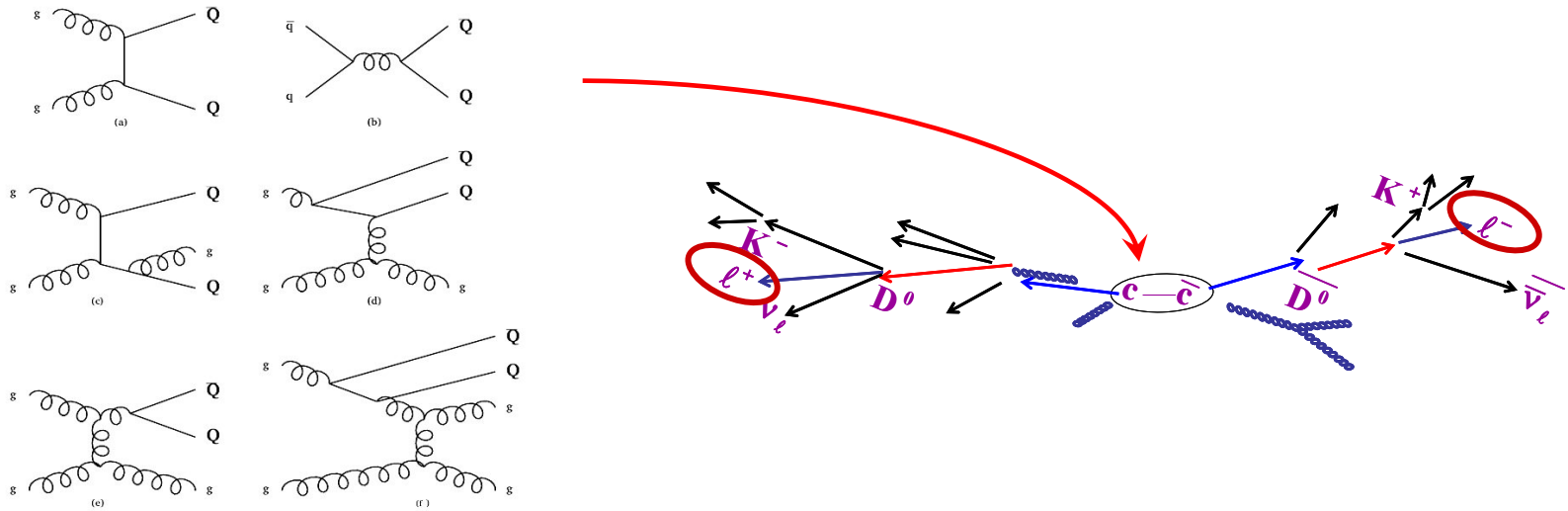
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(right-handed antiquarks)



$$A_L^{W^+} = - \frac{\Delta \bar{d}(x_1, M_W^2)}{\bar{d}(x_1, M_W^2)} \quad (y_W \ll 0)$$

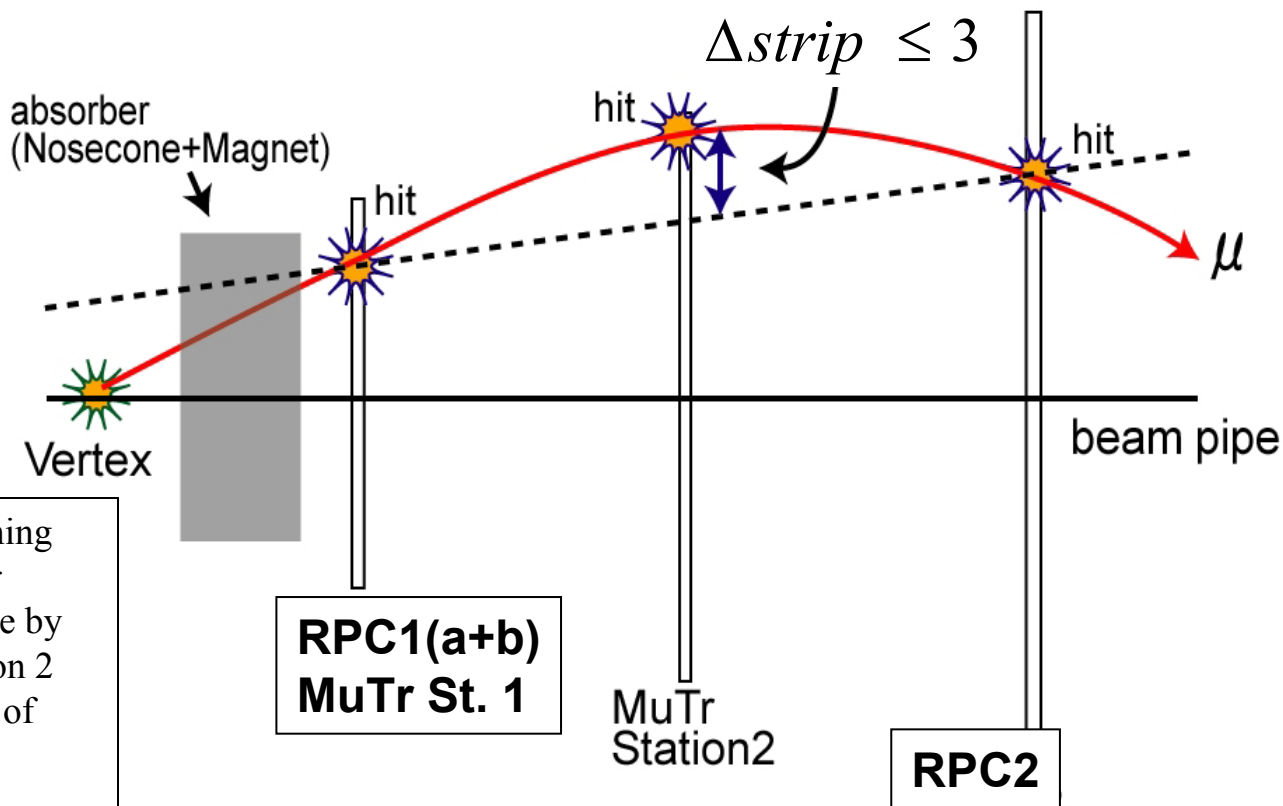
# Open Heavy Flavor at Forward Rapidity



## Open Heavy Flavor Physics Interests:

- What is the total cross section for charm/beauty in all collision systems?
- Does asymmetry measurement in polarized pp collisions indicate contribution of gluons to proton spin?
- Is there modification of charm production in cold nuclear matter: gluon saturation,...
- Is there modification of charm production in heavy-ion collisions: energy loss in medium
- Do heavy quarks flow?

# Trigger Algorithm



Candidates found by matching RPC1/2 hits within angular range. Momentum cut made by matching hit in MuTr station 2 within three cathode strip2 of RPC projection.

(MuID LL1 1D Trigger also required.)

(RPC3 hit also required in three inner theta rings)