Proposed Upgrades for the PHENIX Forward Spectrometers for Spin Physics

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Collaboration still forming!

How do quarks and gluons make up the proton spin?

- Quark spins?
- Quark angular momentum?
- Valence vs Sea?
- Gluon (spin+angular momentum)?
- Gluon ⇔ Sea Relationship
- Scale *Invariance* of (1/2)ħ

PHENIX Spin Structure Program

Using Polarized pp Scattering

- Polarized Gluon Distribution
  - Direct Photon production
  - Leading Pion production
  - Open Charm production
  - and more…
- Polarized Quark/AntiQuark Distributions
  - Polarized $W^{\pm}$ Production
- Transverse Distributions and Physics

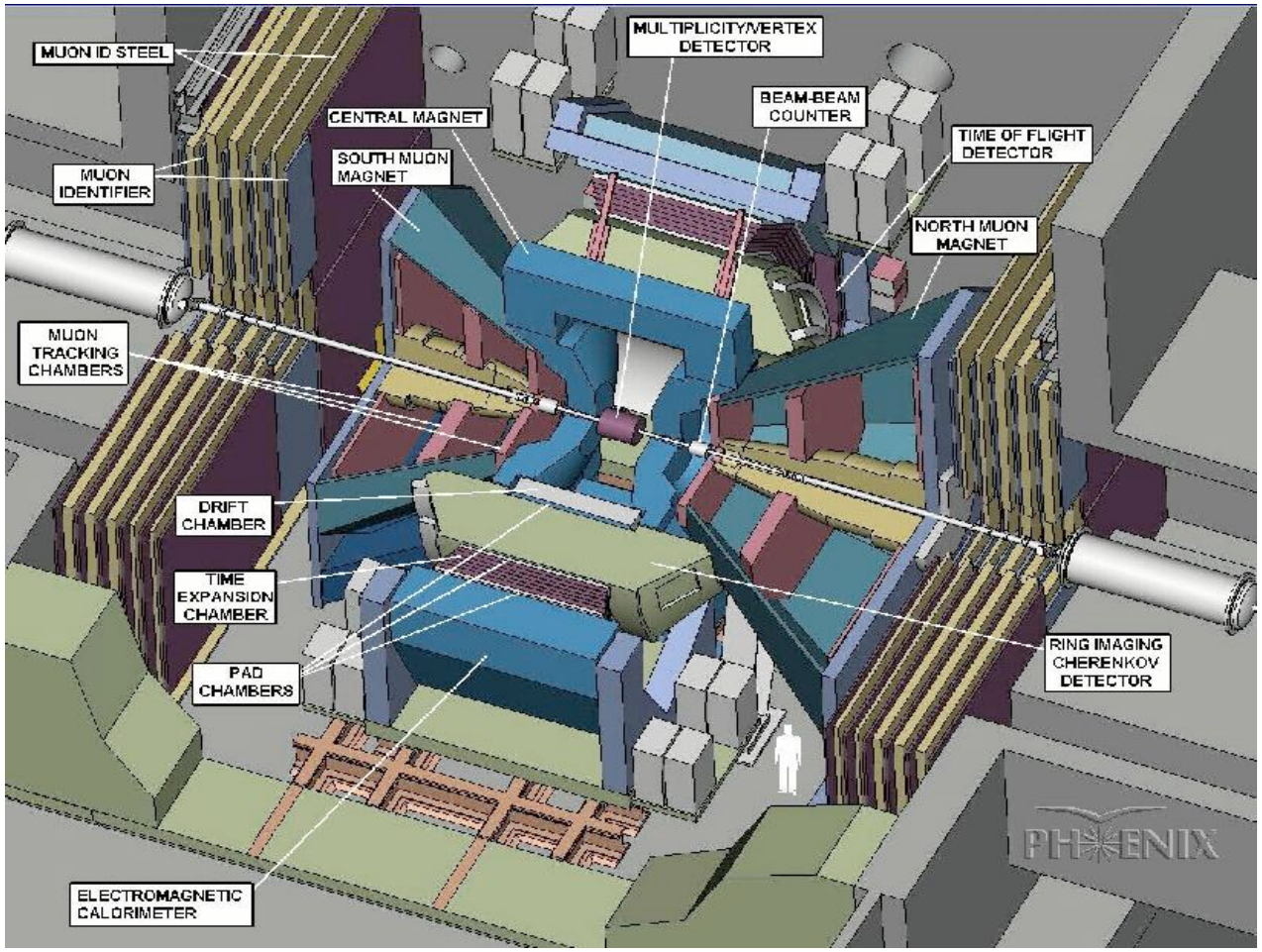
Spin Structure Motivations for PHENIX Forward Upgrade

- Greatly enhance capability to measure quark and anti-quark polarizations via W boson production
- Extend range of gluon polarization measurement to smaller x_{Bj} with additional photon/π^0 acceptance

Nuclear Physics Motivation for Forward Upgrade

- Study nucleon structure in nuclei at high parton densities in p+A collisions.
- Greatly extend acceptance for high p_T jet-photon measurements (jet tomography) in A+A.

The PHENIX Spectrometer



Muon Arms

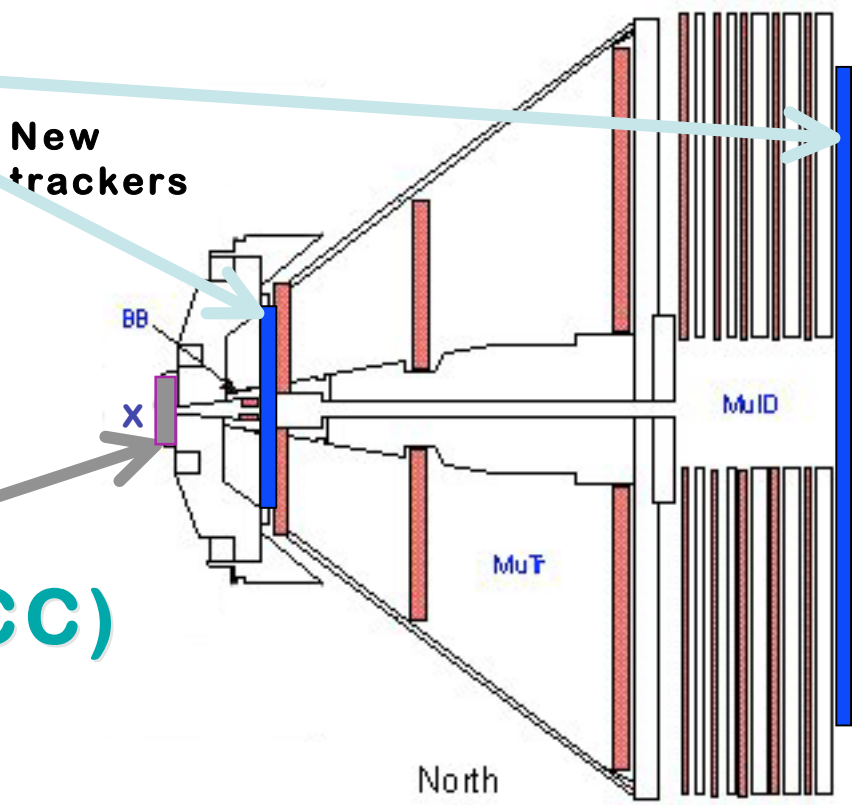
- Tracking + MuID
- $1.2 < |\eta| < 2.4$
- $\approx 2\pi$ Azimuthal Acceptance
- $p \geq 2\text{GeV}/c$

Central Arms

- Tracking + RICH + TOF+ EMCal
- $|\eta| < 0.35$
- $\approx \pi$ Azimuthal Acceptance
- $p_T \geq 0.2\text{GeV}/c$

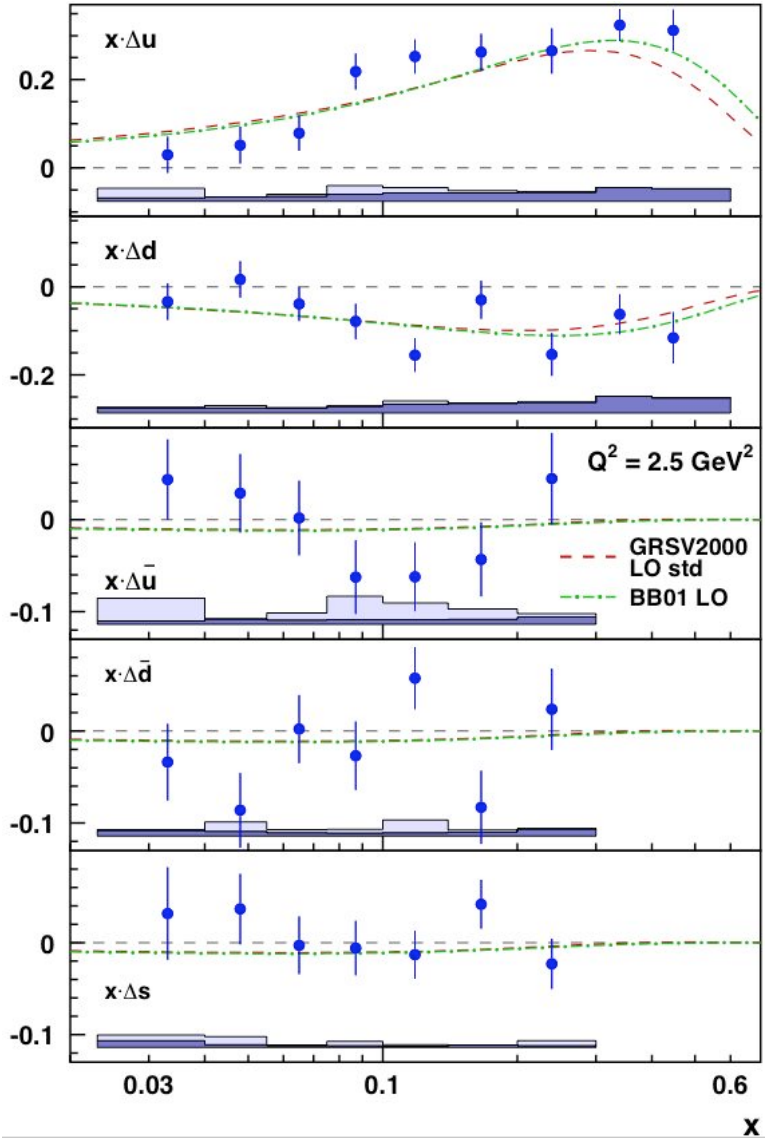
Upgrade Components

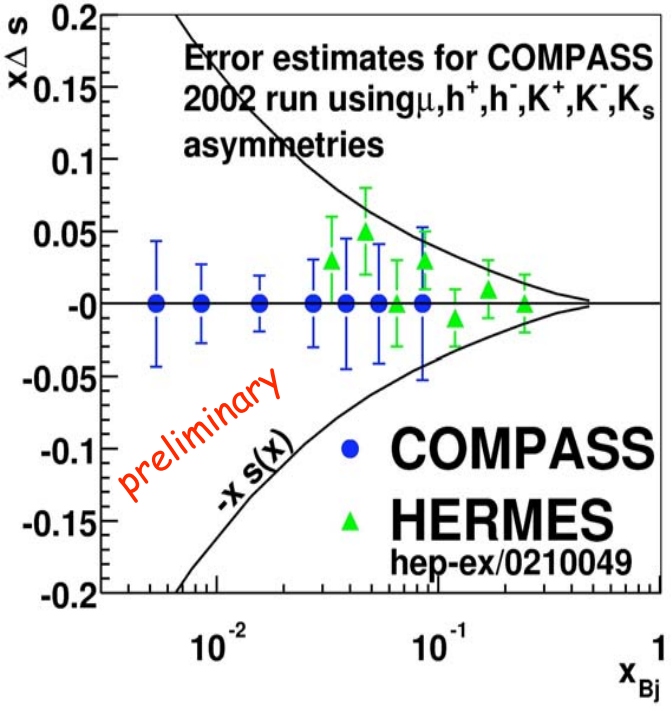
- **Upgraded muon trigger**
  - Add momentum information into muon trigger for highest luminosities in p-p, d-A and A-A
  - Gives robustness against beam and collision related backgrounds.
- **Nose cone calorimeter (NCC)**
  - $0.9 < |\eta| < 3.0$
  - Tungsten-Silicon sampling calorimeters
  - Electromagnetic and shallow hadronic compartment
  - Expands PHENIX's kinematical coverage for jets, inclusive neutral pions, electrons, and photons to forward rapidity
  - For p-p, d-A and A-A collisions.



Upgraded muon trigger and NCC also on South side

Flavor decomposition with SIDIS

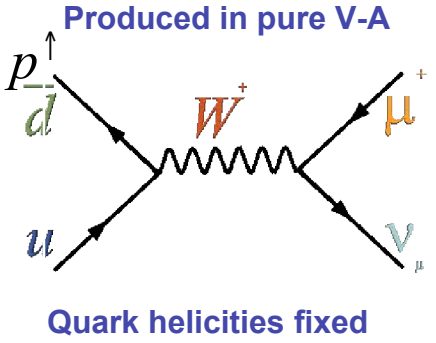




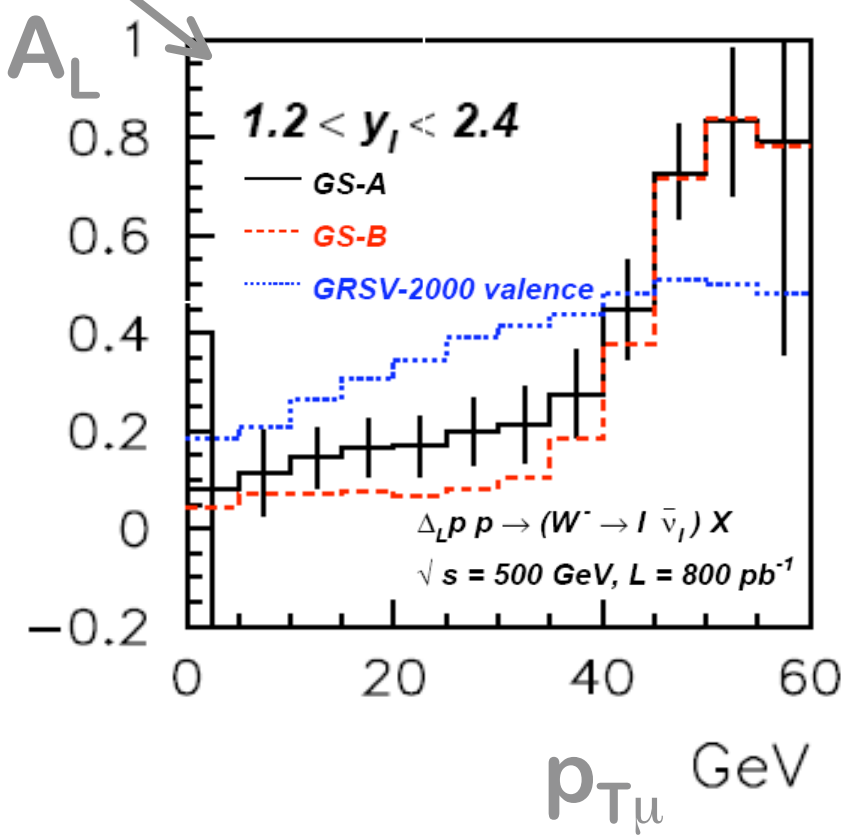
- Depends on knowledge of FFs
- Difficult to apply full NLO analysis
- u quark dominance "hides" d and s

Flavor decomposition via W's with PHENIX

- **The measurement of inclusive single spin muon asymmetries (from W's) is a new unbiased way to probe $\Delta\bar{q}/\bar{q}$, $\Delta q/q$.**
  - Complete theoretical treatment from first principles by Nadolsky and Yuan using re-summation and NLO techniques [NuclPhysB 666(2003) 31].
  - Does not suffer from scale uncertainties



- **Experimentally clean measurement .**
  - A_L is parity violating - no false physics asymmetries.
  - Does not rely on knowledge of fragmentation functions
- **Highest luminosity p+p running at 500GeV required.**
  - Prescale factor of 20-50 required without muon trigger upgrade.
  - Significance would go down by $\sqrt{\text{prescale factor}}$

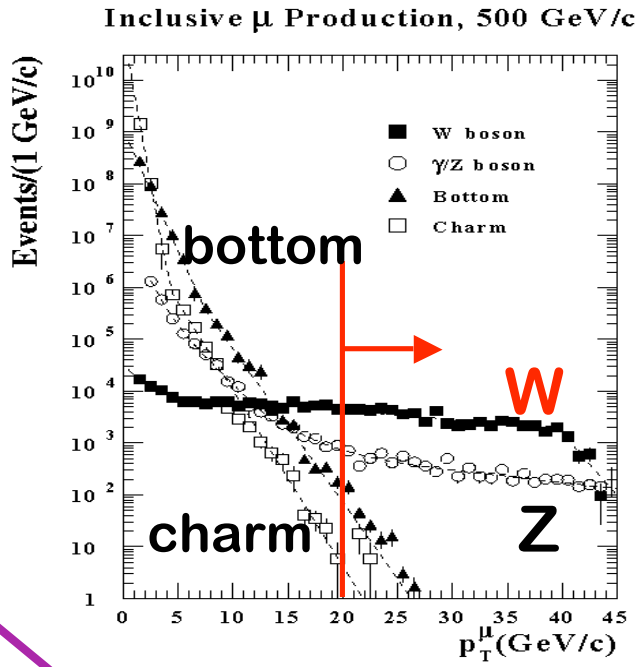


Upgraded muon trigger for W's

» **Current muon trigger:**
- 2.3GeV "deep" muon
- Factor of 20-50 rejection and robustness to background required for p+p at highest luminosities

» **Upgrade needed to add momentum information to trigger:**
- RPC's for new chambers
  - Even modest timing information help remove beam related background.
- Instrument muTR with triggering electronics

» **Detailed simulations with lookup-table algorithms give specifications:**
- Upstream tracker granularity 10x10cm^2 into look-up table
- Downstream tracker granularity 30x30cm^2 into look-up table
- ϕ resolution = 1°

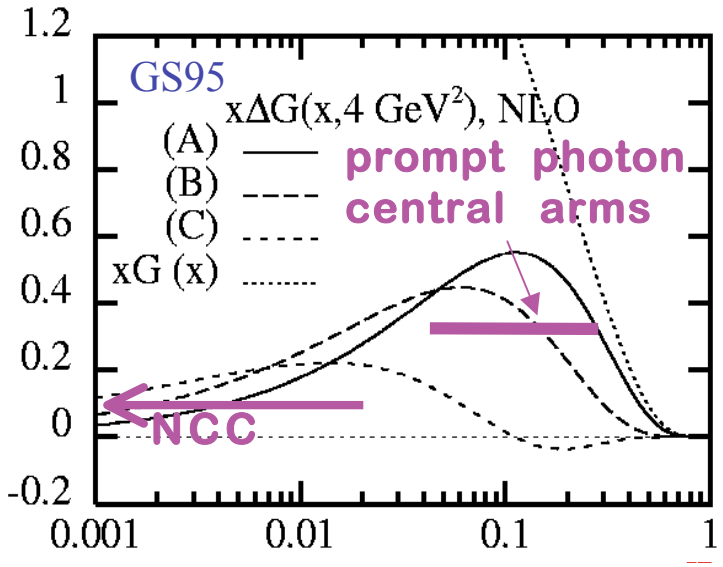


➢ RPC R&D at UIUC and RBRC prototype for run 5.
➢ Tests/studies at Kyoto and UNM to instrument muTR

ΔG using the NCC

- **Detection of both hadron jet and final state photon is possible with the NCC and new central arm tracking detectors.**
  - **Allows the determination of x_G of the gluon on an event-by-event basis (used in conjunction with silicon vertex)**

- **Significantly extends the range of x_G for the prompt-γ measurement down to ~0.001 at $\sqrt{s}$ =200 GeV**
  - **Channel with highest analyzing power for gluon polarization in polarized p+p.**
  - **Sensitivity to shape of polarized gluon distribution over a large x range (important input to extrapolation of ΔG to low x)**



- **ΔG with NCC at low-x through jet-γ, π^0, e-μ, open charm.**

Nose Cone Calorimeter

Requirements:

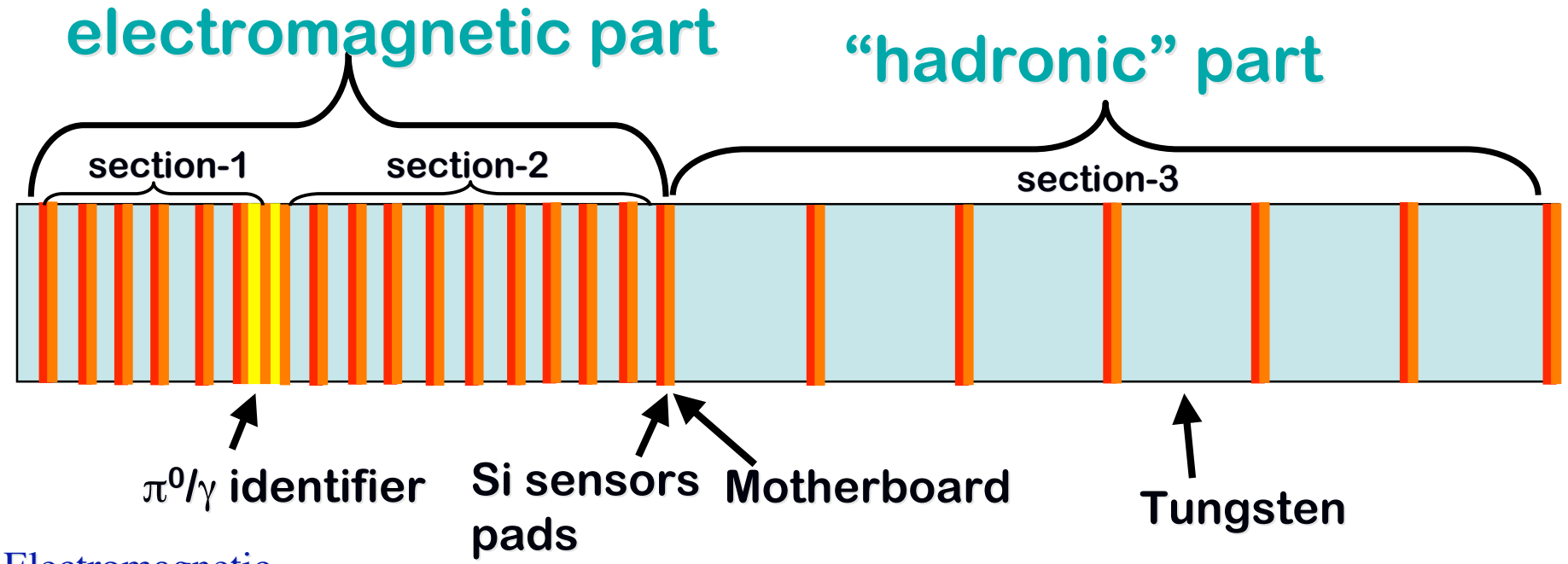
- Good photon measurements
- Reasonable jet measurements
- Triggering capability

Constraints:

- 40 cm from collision point => Silicon pixels
- 20 cm of space is available => Tungsten small Molière R
- Photon / π^0 separation => Silicon strip layers

Challenging technical requirements, but devices with similar specifications have been built for balloon based experiments and are being developed for ALICE.

Nose Cone Longitudinal Segmentation



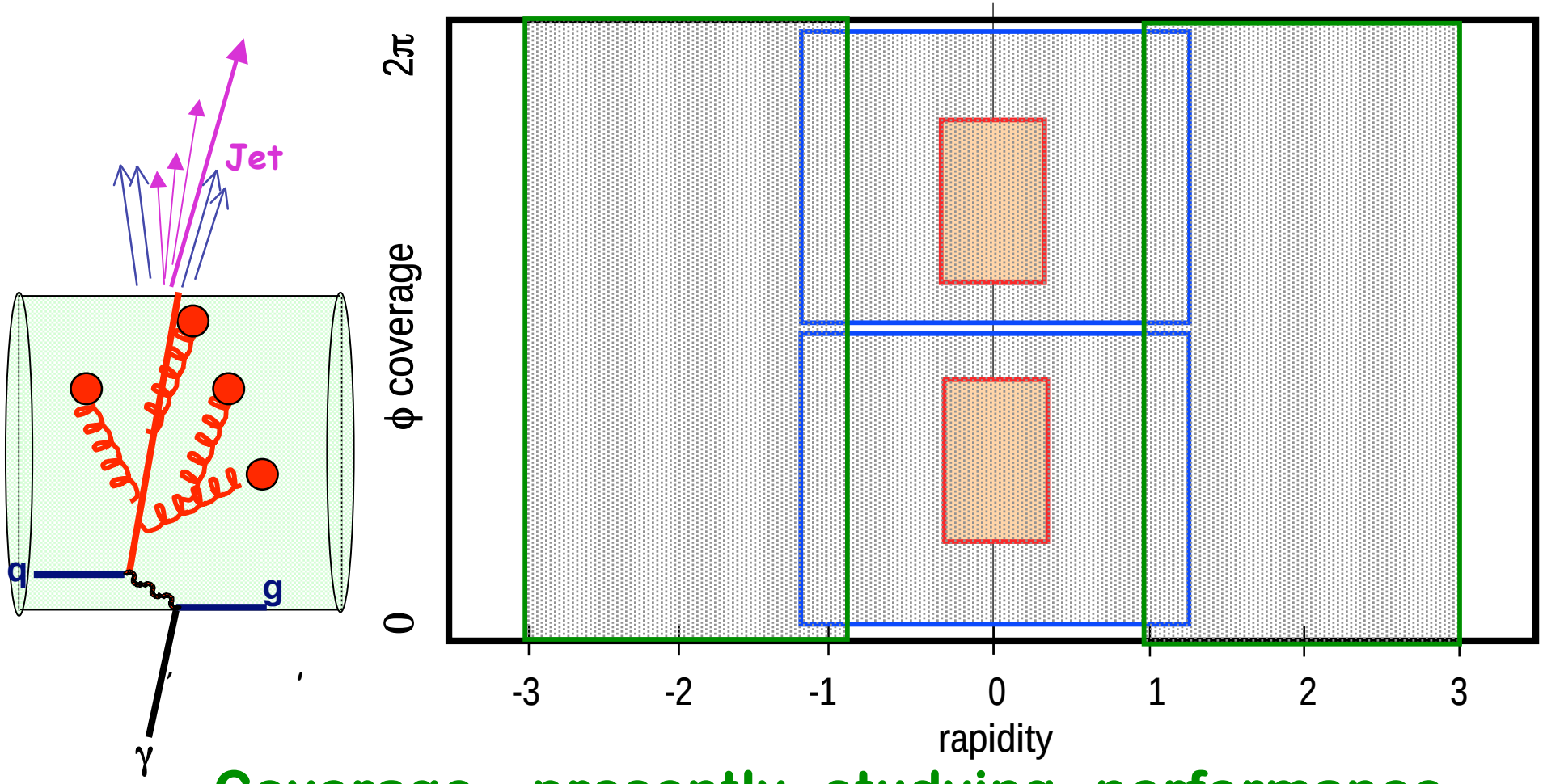
- Electromagnetic
  - 16 layers of W 2.5 mm thick ➔ $10X_0$
  - Si 1.5 cm x1.5 cm pads
- π^0/γ identifier
  - 2 layers Si , 1.9 mm x 6 cm strips
  - after $4.3X_0$
- Hadronic
  - 6 layers W16.6 mm thick
  - Si 1.5 cm x 1.5 cm pads
  - Total (em+had) $40X_0$ 1.5 λ_0

Readout in 3 longitudinal sections
Molière radius~1.3 cm
EM Energy resolution ~ 20%/√E
Hadronic Energy res ~ 100%/√E (?)
2 γ "2 track resolution" ~ 4mm (?)

X_0(tungsten)=3.5mm
λ_0=9.5 cm

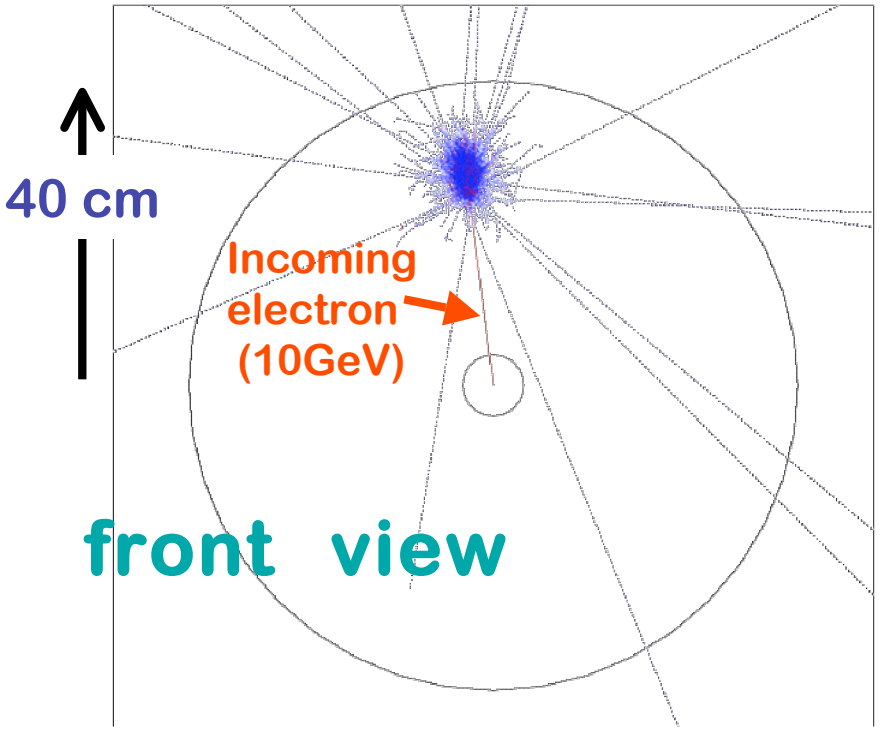
NCC adds kinematic reach for γ-jet measurements

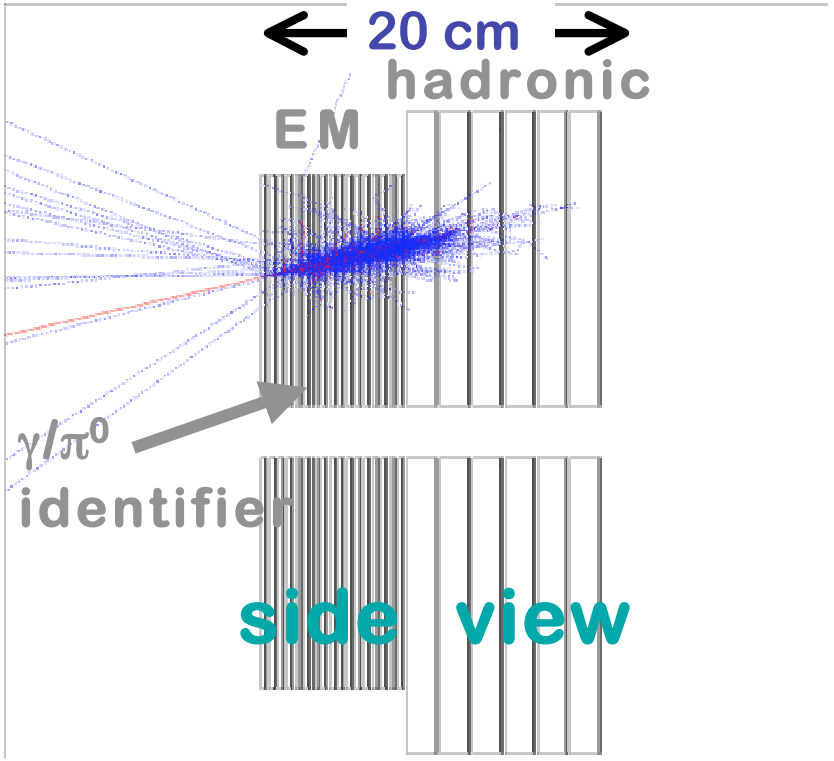
Prompt photons:	central EMCal	$\|y\| < 0.35$	forward NCC	$0.9 < \|\eta\| < 3.0$
Jet	central TPC + VTX (charged)	$\|\eta\| < 1.2$	forward NCC (energy)	$0.9 < \|\eta\| < 3.0$



Coverage, presently studying performance

10 GeV electron in NCC

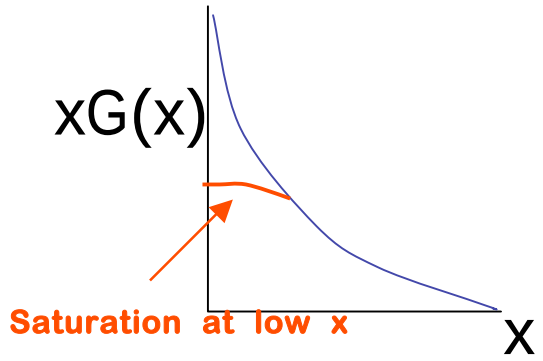




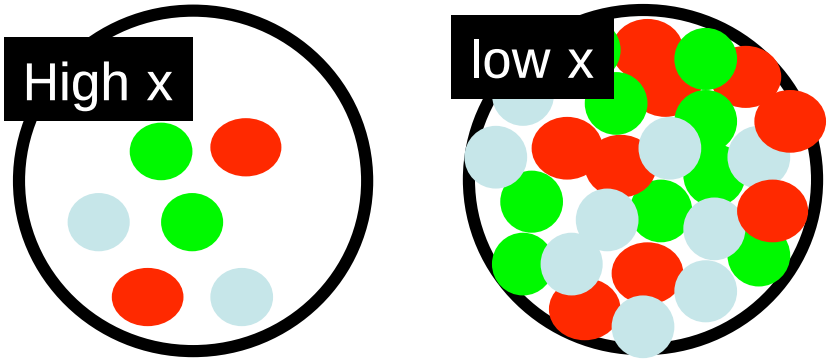
- First 10cm: 22 layers of Tungsten (2.5 mm), Si(0.3 mm), G10(0.8 mm), Kapton (0.2 mm) and Air(1.2 mm).
  - After first 6 layers there is a 0.5mm thick double layer of Si,G10,Kapton,Air (this is the γ/π^0 identifier).
- Second half has a 6 layers with same sequence of materials, only thickness of Tungsten 16.6 mm.

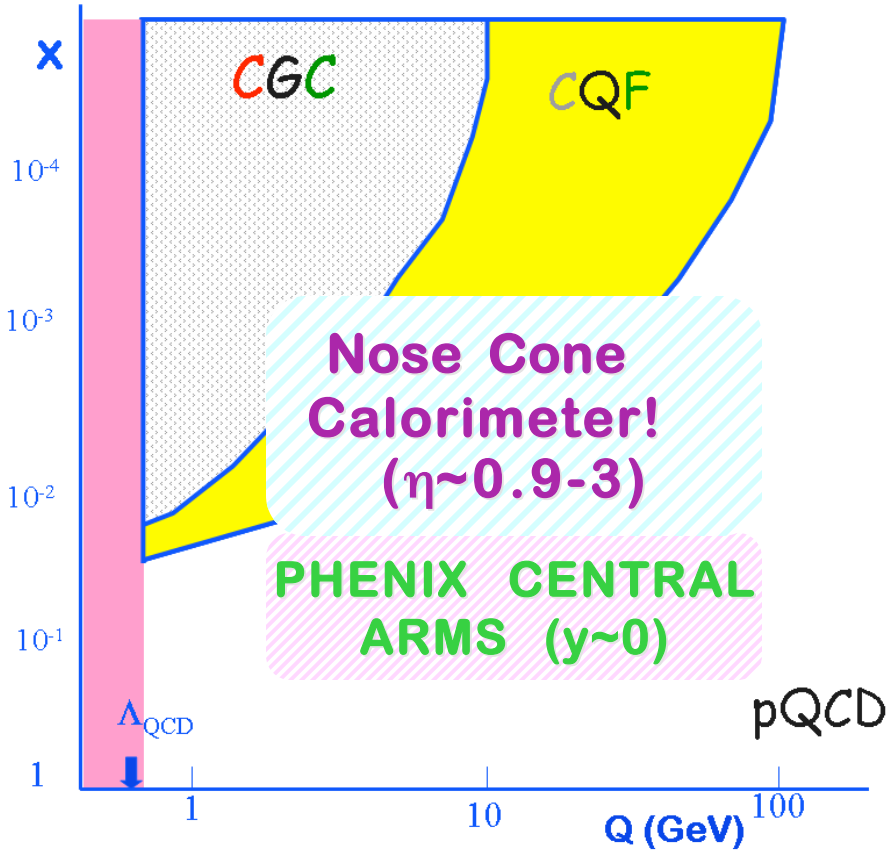
High parton densities in nuclear matter

- ✓ **QCD - High Gluon Densities at low-x**
  - Onset of gluon saturation?
  - Initial conditions in Au+Au?

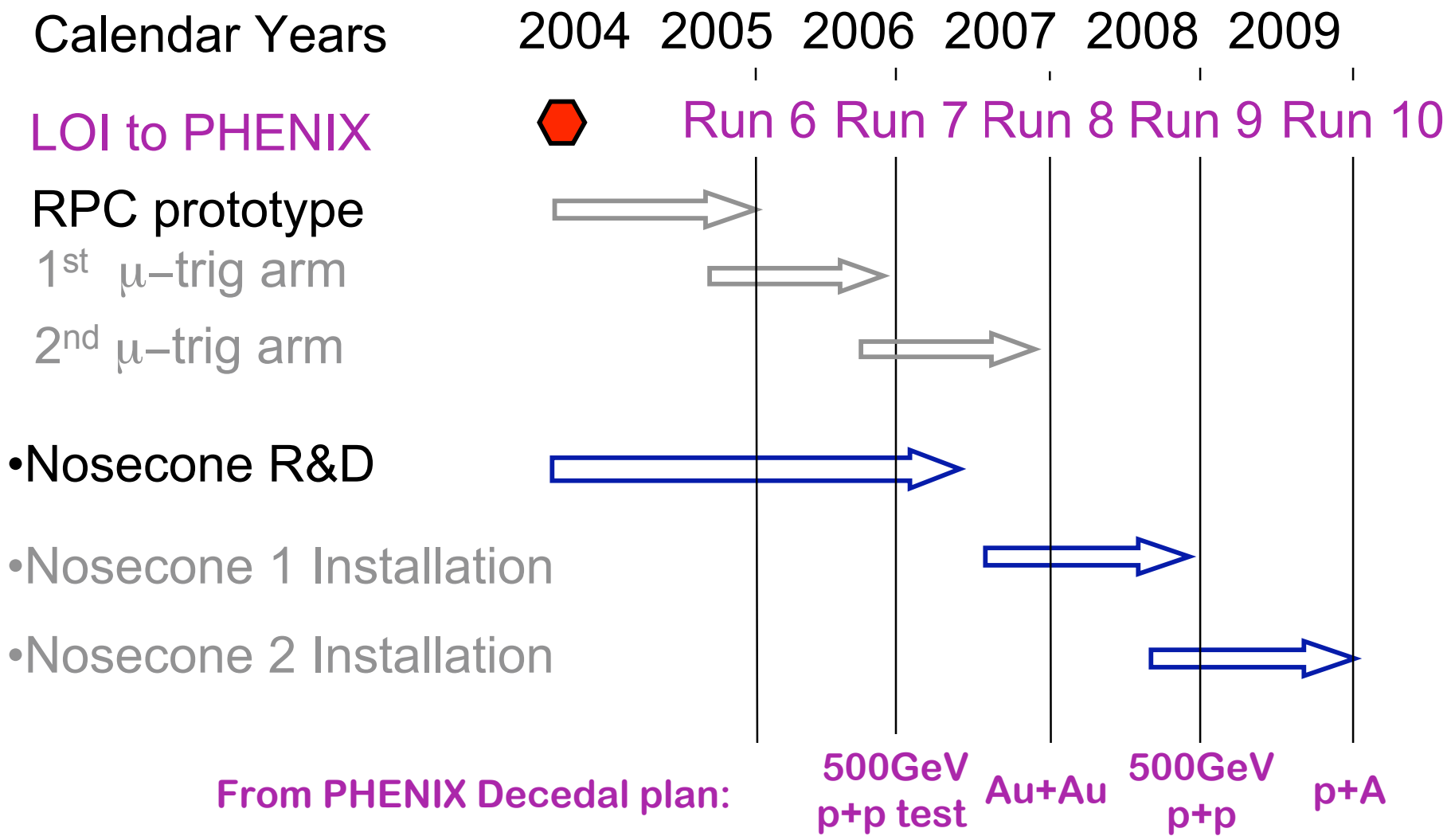


- ✓ **Classical Approx → Color glass condensate**
  - McLerran, Venugopalan, et al.
  - Depends on a single scale
    - $Q_s^2 \propto A^{1/3} \sim$ (1-2 GeV)^2 at RHIC
  - Is this the correct theory at RHIC?
  - Where are the boundaries?





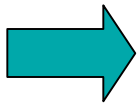
Schedule



Initial cost estimates: muon trigger ($2M), NoseCone ($5M/2-arm)

Summary and Outlook

- Upgrades significantly increase scope of PHENIX spin physics program
- Endorsed in recent NSAC review
- Detailed design/prototyping presently under development
- Installation in time for first 500 GeV production run in 2009
- New collaborators welcome!



Informational meeting Wednesday evening

Extra slides …

Expected γ/π^0 separation

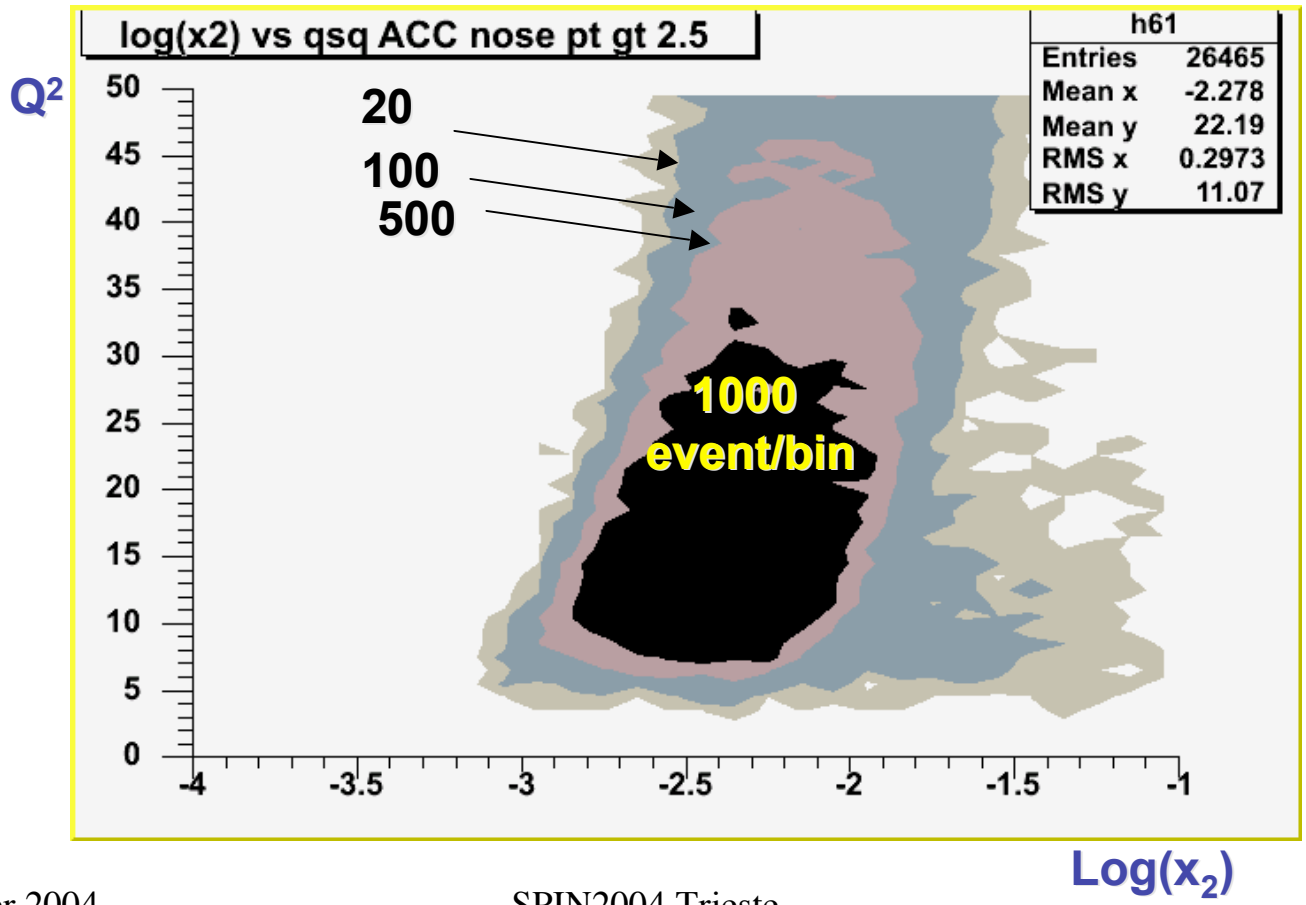
- **Extrapolating PHENIX EMC experience of γ/π^0 separation with central arm EMC to NoseCone EMC:**
  - **PHENIX today has a brute-force pattern recognition that works up to around 15 GeV/c π^0 energy**
  - **NCC is x10 closer to production vertex**
    - **1.5 GeV/c**
  - **x10 better lateral granularity and x3 smaller Moliere radius resulting in x 3.5 two photon separation**
    - **5 GeV/c**
  - **With 2 mm strips in the silicon layers we can separate two close photons down to ~4 mm compared to ~ 2 cm assumed for NCC itself**
    - **~20 GeV/c**

Coverage of NCC at 200 GeV

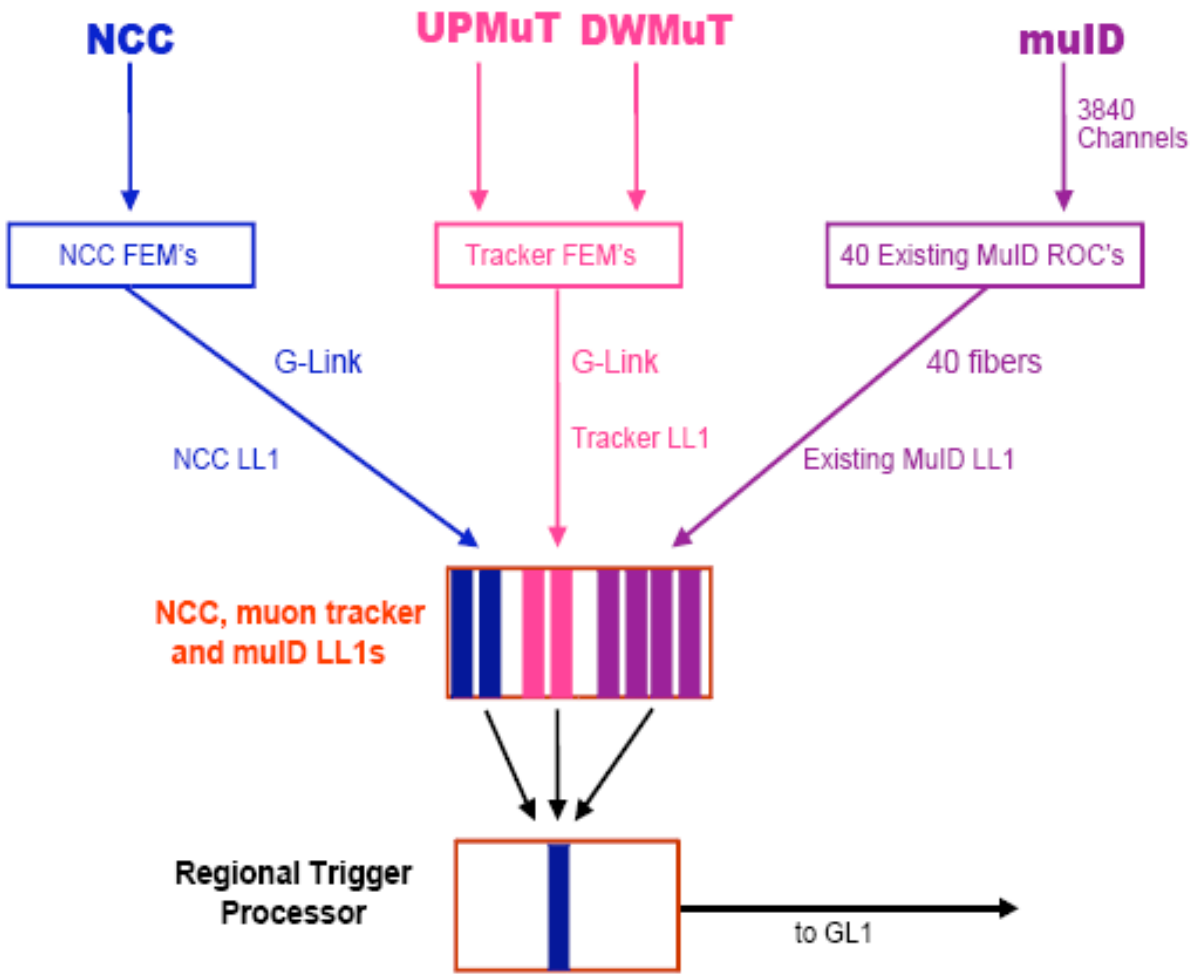
0.5 pb^{-1} pAu (run 12)

$\Delta\log(x_2)$ ΔQ^2=0.1x1 GeV^2

Direct photon

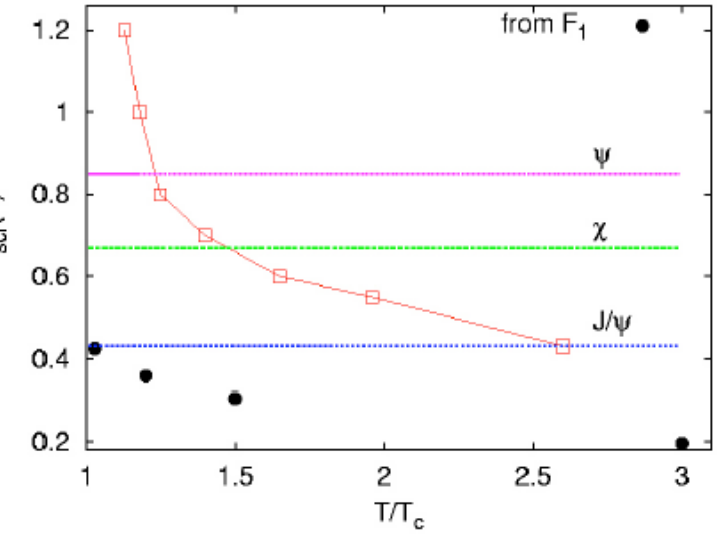


Level-1 triggering scheme



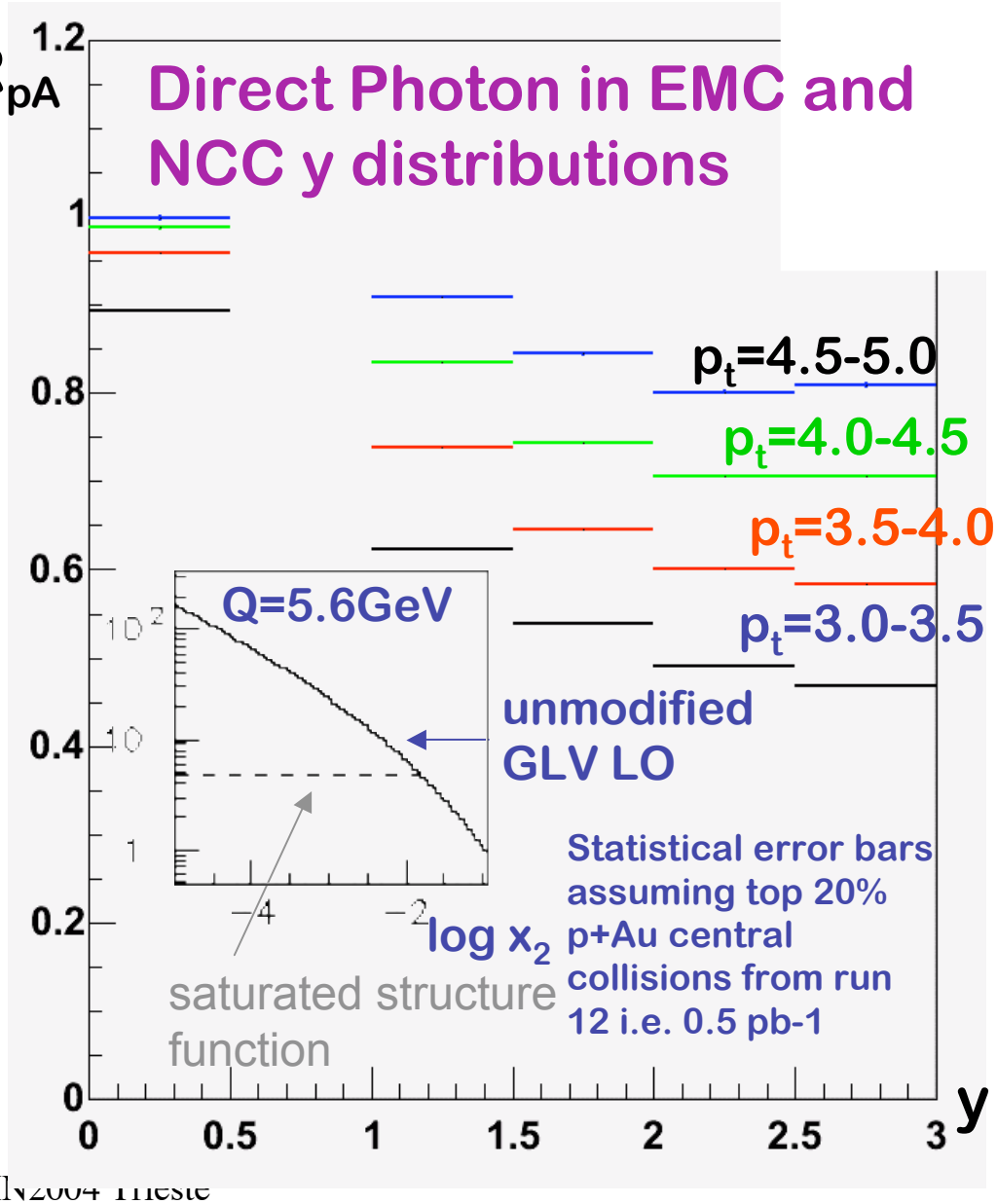
Quarkonium (χ_c & Ψ with NCC & muon trig)

- **Onium system as thermometer**
  - p_T Dependence
  - x_F Dependence
  - Study vs system size and energy
- **Upgraded muon trigger gives rejection needed for $\Psi \rightarrow \mu\mu$ measurements at highest Au+Au luminosities.**
- **Measurement of $\chi_c \rightarrow J/\psi + \gamma$, where the NCC measures γ, is under investigation.**
  - 58% of J/ψ that are accepted in muon arms have photon in NCC.
  - However, the photon is soft, so it will be difficult to measure especially in A+A.



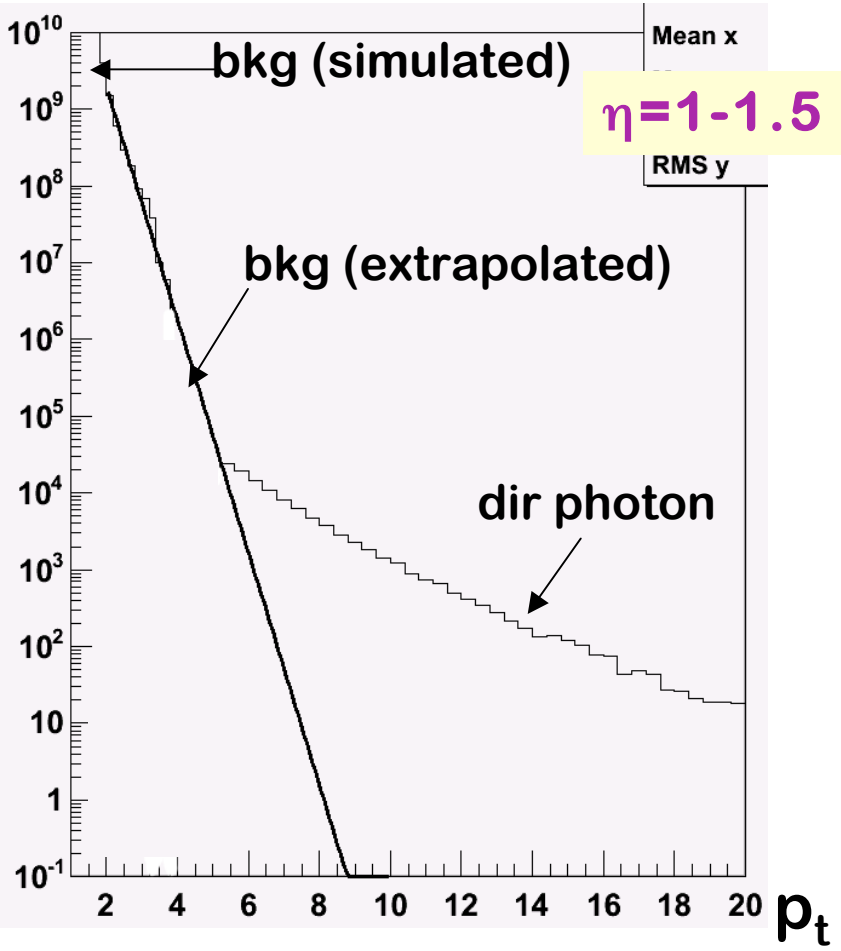
Gluon distribution function

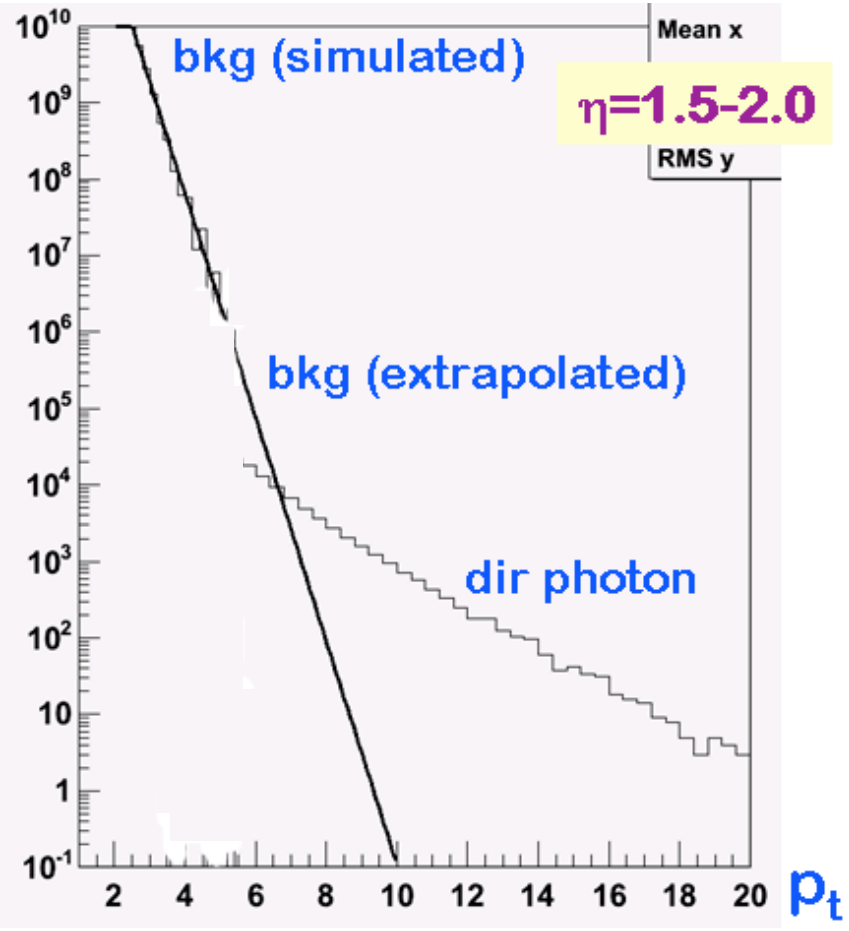
- Pythia input : normal structure function (p+p) and parameterized saturated structure function (p+A) that fit RHIC data.
- Can constrain gluon structure function by making measurements over rapidity and p_t
- Many other observables:
  - E.g. photons jet correlations
    - Constrain kinematics to obtain gluon structure function.
    - Intrinsic k_t.
    - Jet broadening,



NCC in central Au+Au

- Problem is pile up faking a photon
- Problem worst at high η since the effective segmentation is larger





- y=1-2 looks pretty good, above 2 under study.

PHENIX Forward Upgrade Components

- **Nosecone Calorimeter**
  - Sampling Tungsten-Silicon
  - Silicon photon / π^0 identifier layers
- **Muon trigger**
  - Upstream tracker (RPC/ MuTr)
  - Downstream tracker (RPC's)