PHENIX: Muon trigger upgrade and Nose Cone Calorimeter

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NSAC Subcommittee on Relativistic Heavy Ions
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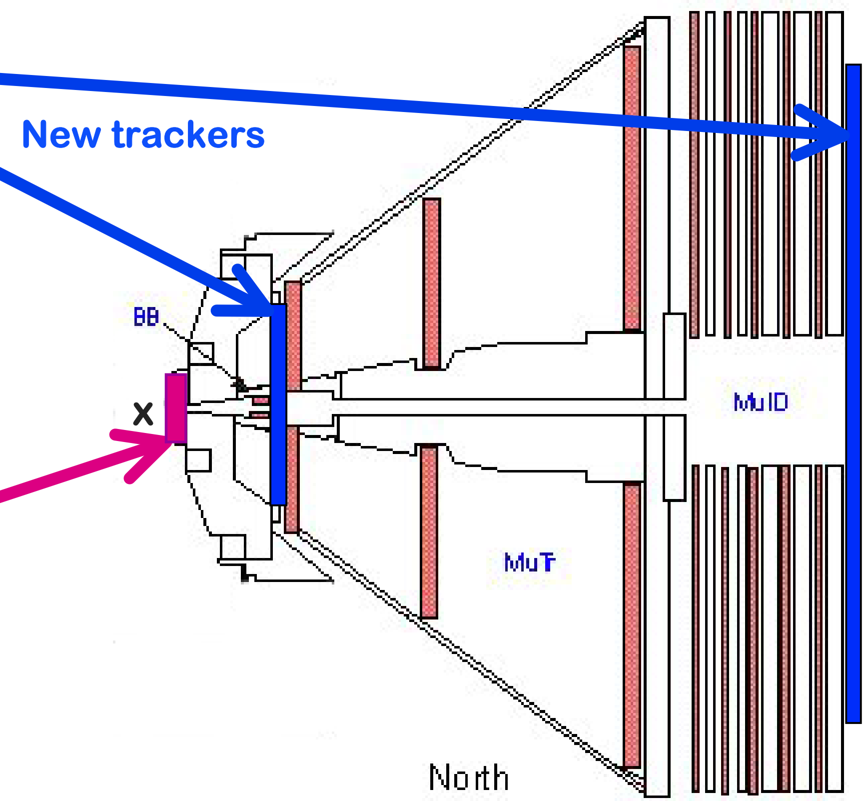
Add PHENIX's capabilities at forward rapidity in order to:

- probe nucleon structure through W production in polarized p+p.
- study nucleon structure in nuclei at high parton densities in p+A collisions.
- greatly extend acceptance high p_T jet-photon measurements (jet tomography) in A+A.

What is proposed?



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

Who is proposing?

Brookhaven National Laboratory:
- » Edward Kistenev, Peter Kroon, Mike Tannenbaum, Craig Woody

University of Colorado
- » Frank Ellinghaus, Ed Kinney, Jamie Nagle, Joseph Seele, Matt Wysocki

University of California at Riverside
- » Ken Barish, Stefan Bathe, Tim Hester, Xinhua Li, Astrid Morreale, Richard Seto, Alexander Solin

University of Illinois at Urbana Champaign
- » Mickey Chiu, Matthias Grosse Perdekamp, Hiro Hiejima, Alexander Linden-Levy, Cody McCain, Jen-Chieh Peng, Joshua Rubin, Ralf Seidel

Iowa State University
- » John Lajoie, John Hill, Gary Sleege

Kyoto University
- » Kazuya Aoki, Ken-ichi Imai, Naohito Saito, Kohei Shoji

Moscow State University
- » Mikhail Merkin, Alexander Voronin

Nevis Laboratory
- » Cheng Yi Chi

University of New Mexico
- » Doug Fields

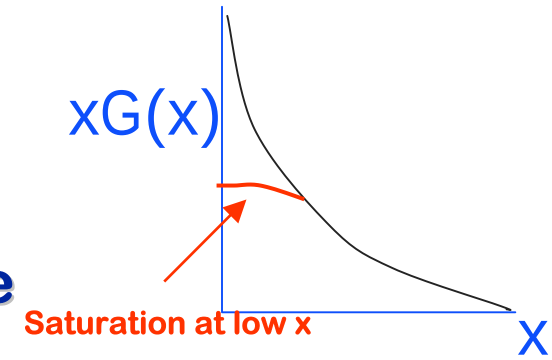
RIKEN
- » Atsushi Taketani

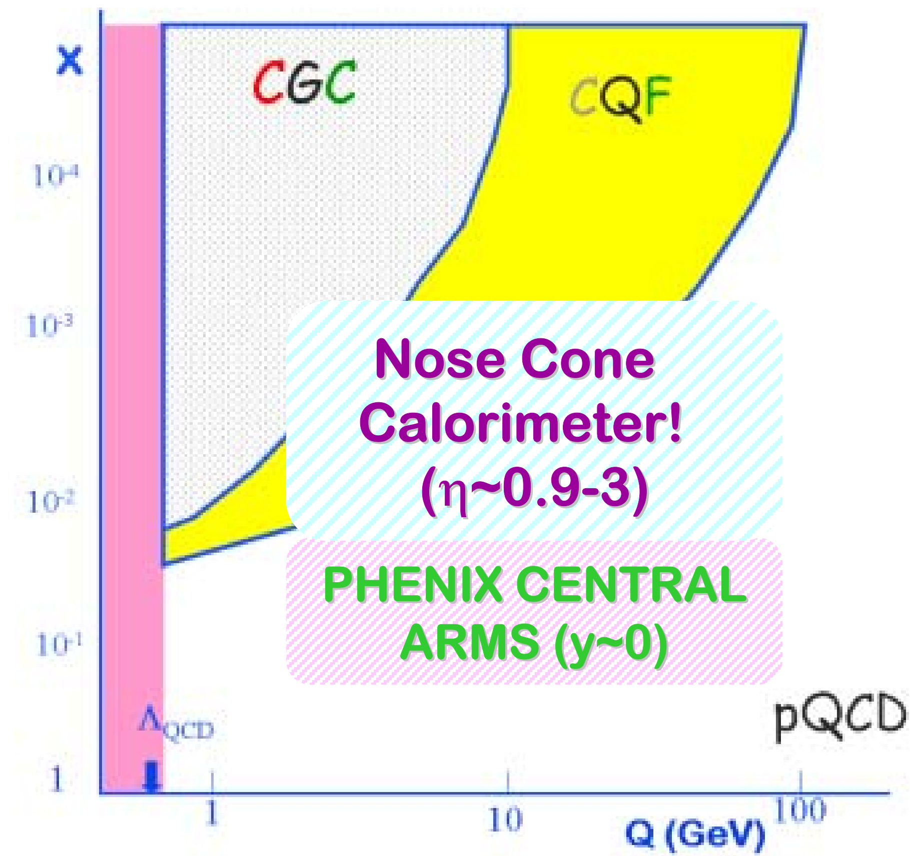
RBRC
- » Gerry Bunce, Wei Xie

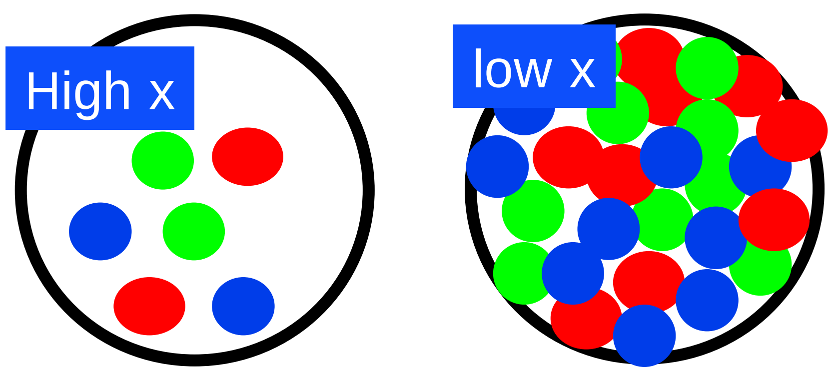
University of Tennesee
- » Vasily Dzhordzhadze, Ken Read

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
    - – $Q_s^2 \alpha A^{1/3} \sim (1\text{-}2\ \text{GeV})^2$ at RHIC
  - » Is this the correct theory at RHIC?
  - » Where are the boundaries?







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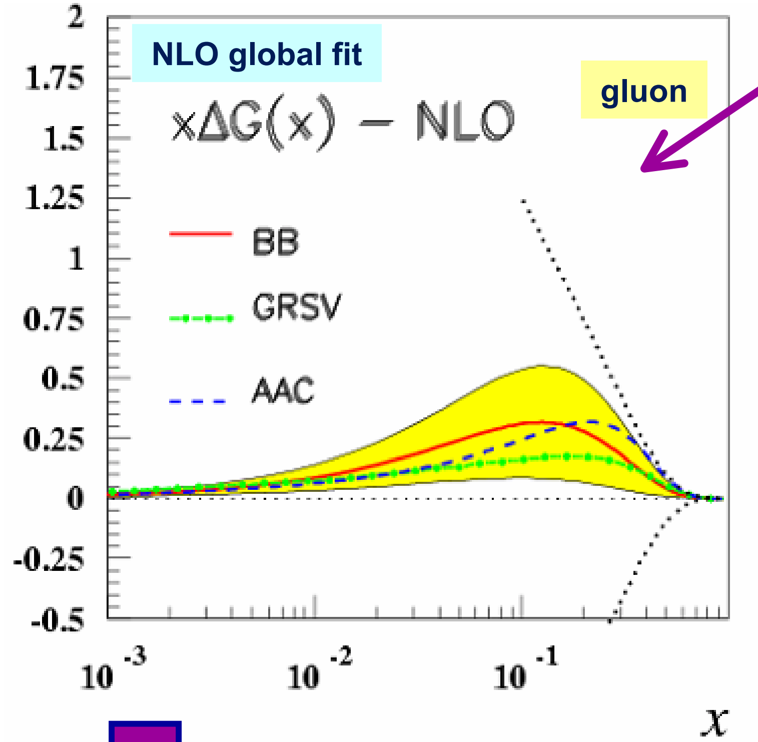
Understanding proton spin structure

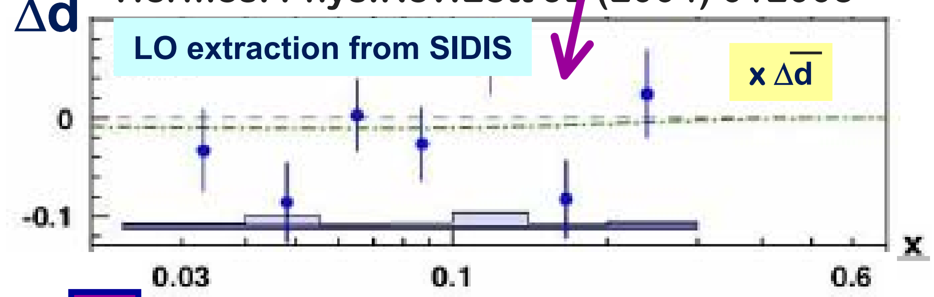
» Pressing issues to understand dynamics of the nucleon spin:

- Contribution of gluons to proton spin - $\Delta G(x)$
- Flavor separation of quark polarization - measure $\Delta\bar{q}(x)/\bar{q}(x)$ and $\Delta q(x)/q(x)$

x ΔG Blümlein and Böttcher



x Δd Hermes: Phys.Rev.Lett 92 (2004) 012005



W trigger upgrade!

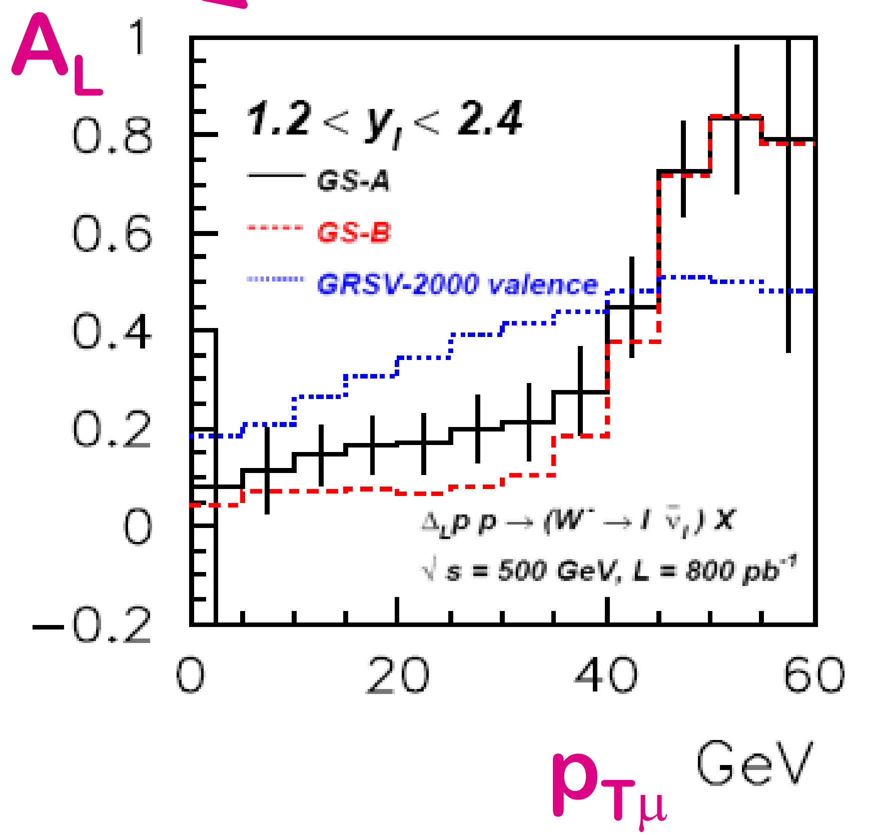
$\Delta G(x)$ and $\Delta q(x)/q(x)$, $\Delta\bar{q}(x)/\bar{q}(x)$ are currently poorly constrained

Nose Cone Calorimeter!

Flavor decomposition via W's with PHENIX

- **The measurement of inclusive single spin muon asymmetries (from W's) is the least biased 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 $\sqrt{\text{prescale factor}}$

$$A_L = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$



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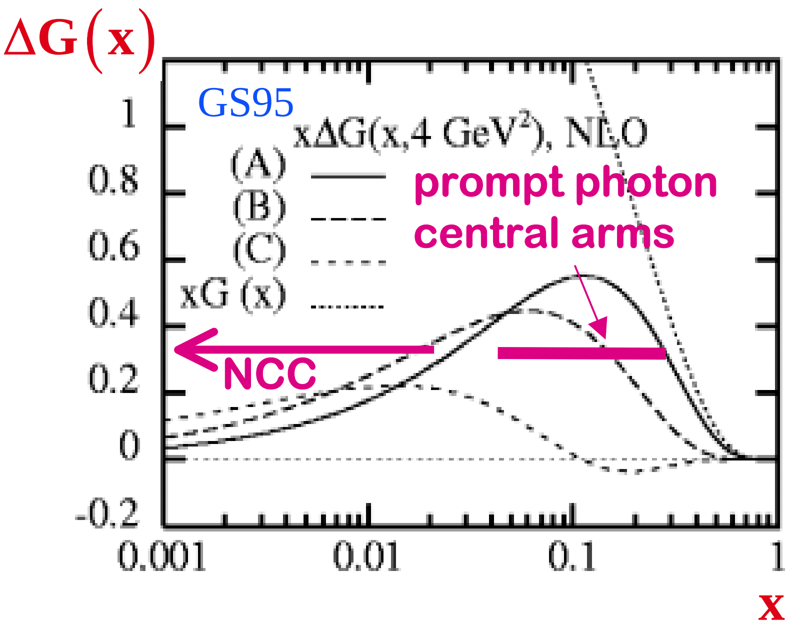
ΔG using the NCC

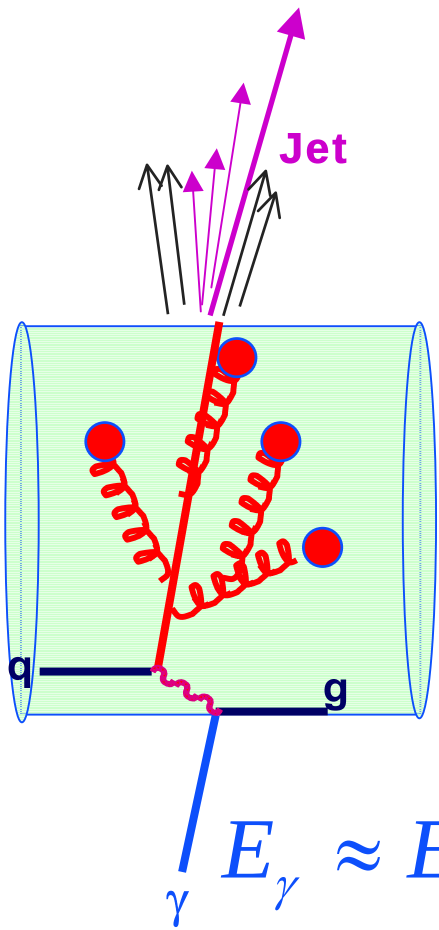
- Detection of both hadron jet and final state photon is possible with the NCC and new central arm tracking detectors.
  - Allows the determination of x_G of the gluon on an event-by-event basis (used in conjunction with silicon vertex)
- Significantly extends the range of x_G for the prompt-γ measurement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



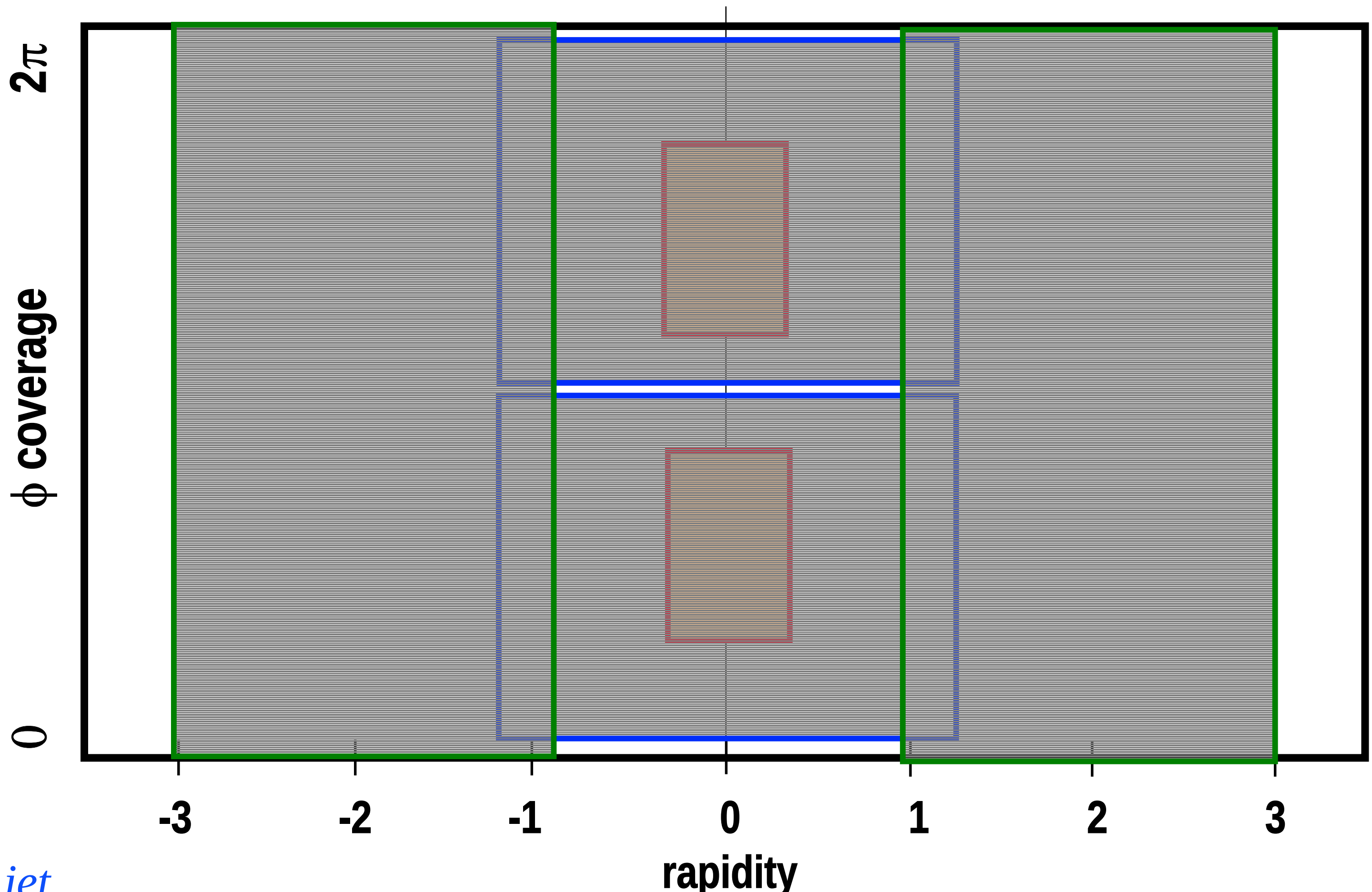
- ΔG with NCC at low-x through jet-γ, π^0, e-μ, open charm.

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)	$0.9 < \|\eta\| < 3.0$



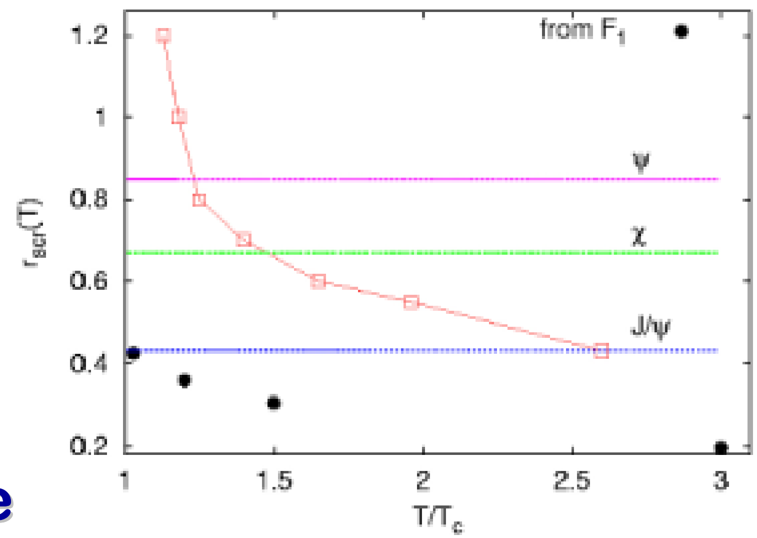
$$E_\gamma \approx E_{jet}$$



Coverage, presently studying performance

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.



PHENIX Forward Upgrade Components

Nosecone Calorimeter

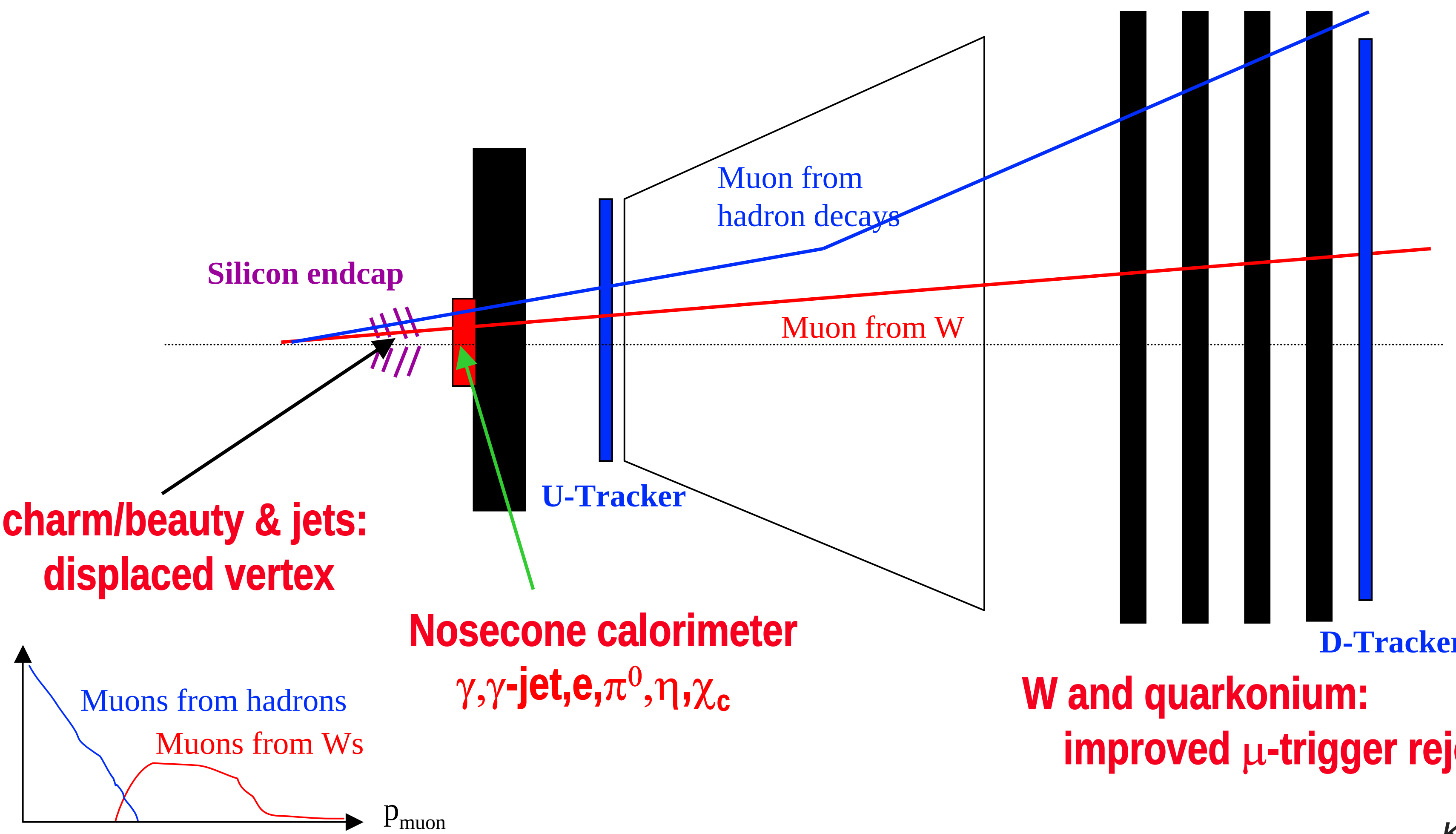
» Sampling Tungsten-Silicon

» Silicon photon / π^0 identifier layers

Muon trigger

» Upstream tracker (RPC or MuTr)

» Downstream tracker (RPC's)



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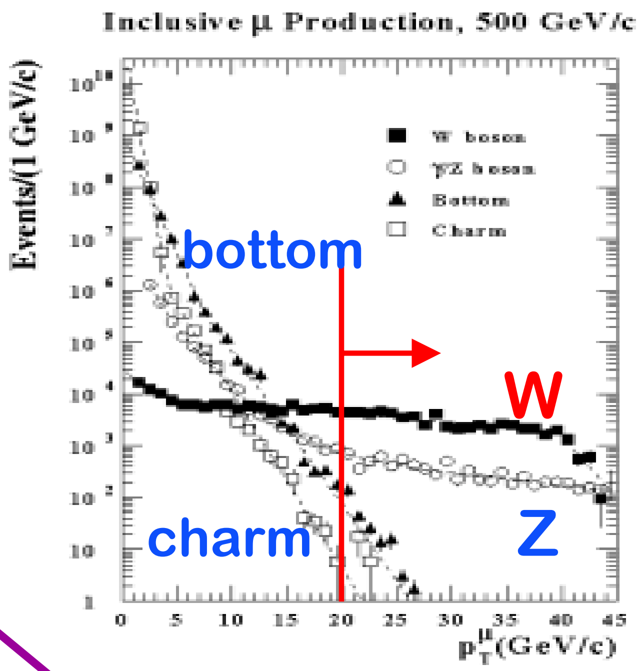
Upgraded muon trigger for W's

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

» **Two new tracking chambers add momentum information to trigger.**
- RPC's are the preferred solution
  - Even modest timing information help remove beam related background.
- Instrumenting muTR also a possibility



» **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^o

RPC R&D at UIUC and RBRC prototype for run 5.

Nose Cone Calorimeter

Constraints:

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

Requirements:

- Good photon measurements
- Reasonable jet measurements
- Triggering capability

14 cm of W absorber

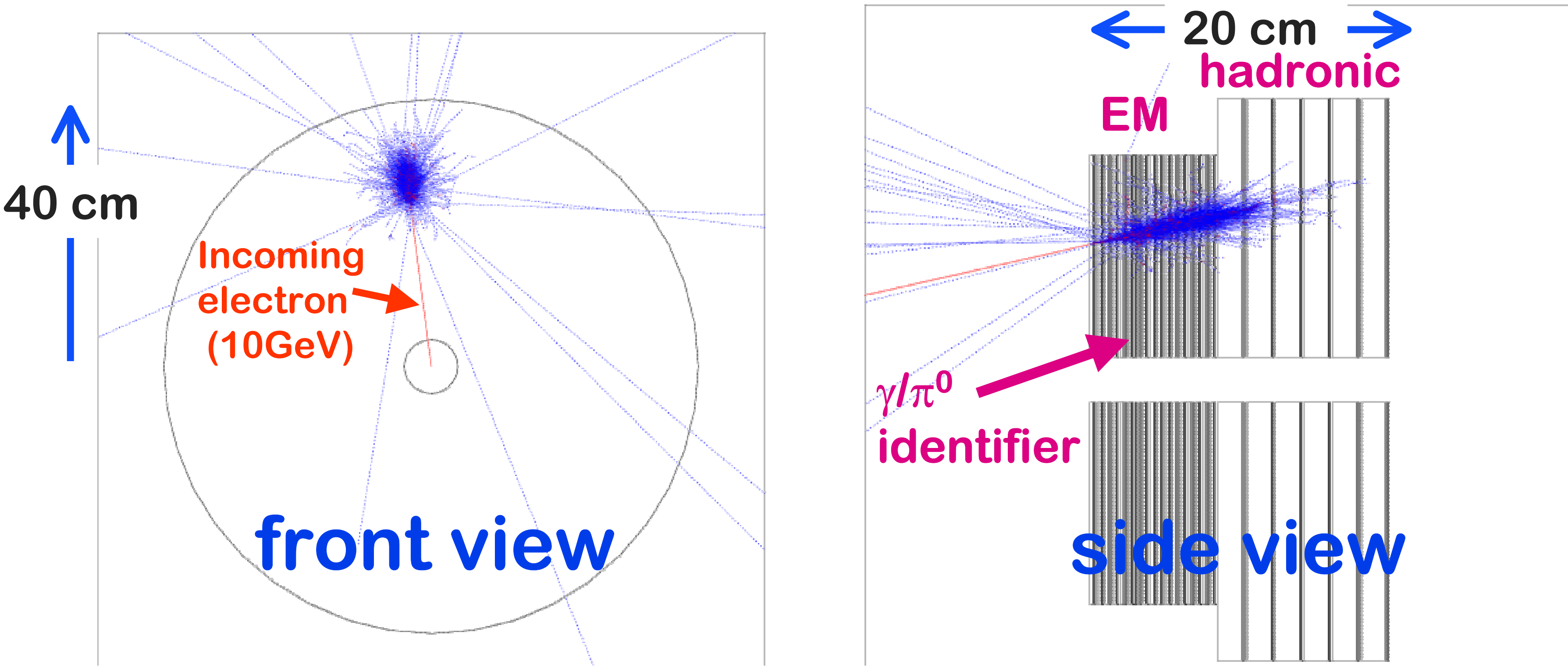
+

6 cm Si readout

Calorimeter:	**~40 L_{rad} / 1.6 L_{abs}**
Lateral seg.	**1.5 x 1.5 cm^2**
EM section:	**11.4 L_{rad}**
γ/π^0 identifier:	**at a depth 4.3 L_{rad} (two layers of ~2x60 mm^2 silicon strips)**

Challenging technical requirements, but devices with similar specifications have been built for balloon based experiments (new Moscow State group in PHENIX brings experience, INFN-Trieste and Prague are also contributing to the R&D).

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.

NCC Prototype schedule

MSU	*Prototyping - sensors*	
	DC coupled sensors (TESLA design) for proof of principle prototype (30 samples)	8/2004
	AC coupled sensors (TESLA design), 5 samples for the bench testing	10/2004
	Decision on AC sensor	1/2005
	Preproduction sensors for the prototype and bench testing (30 samples)	5/2005
	Ready for production	1/2006

Prototyping - cables

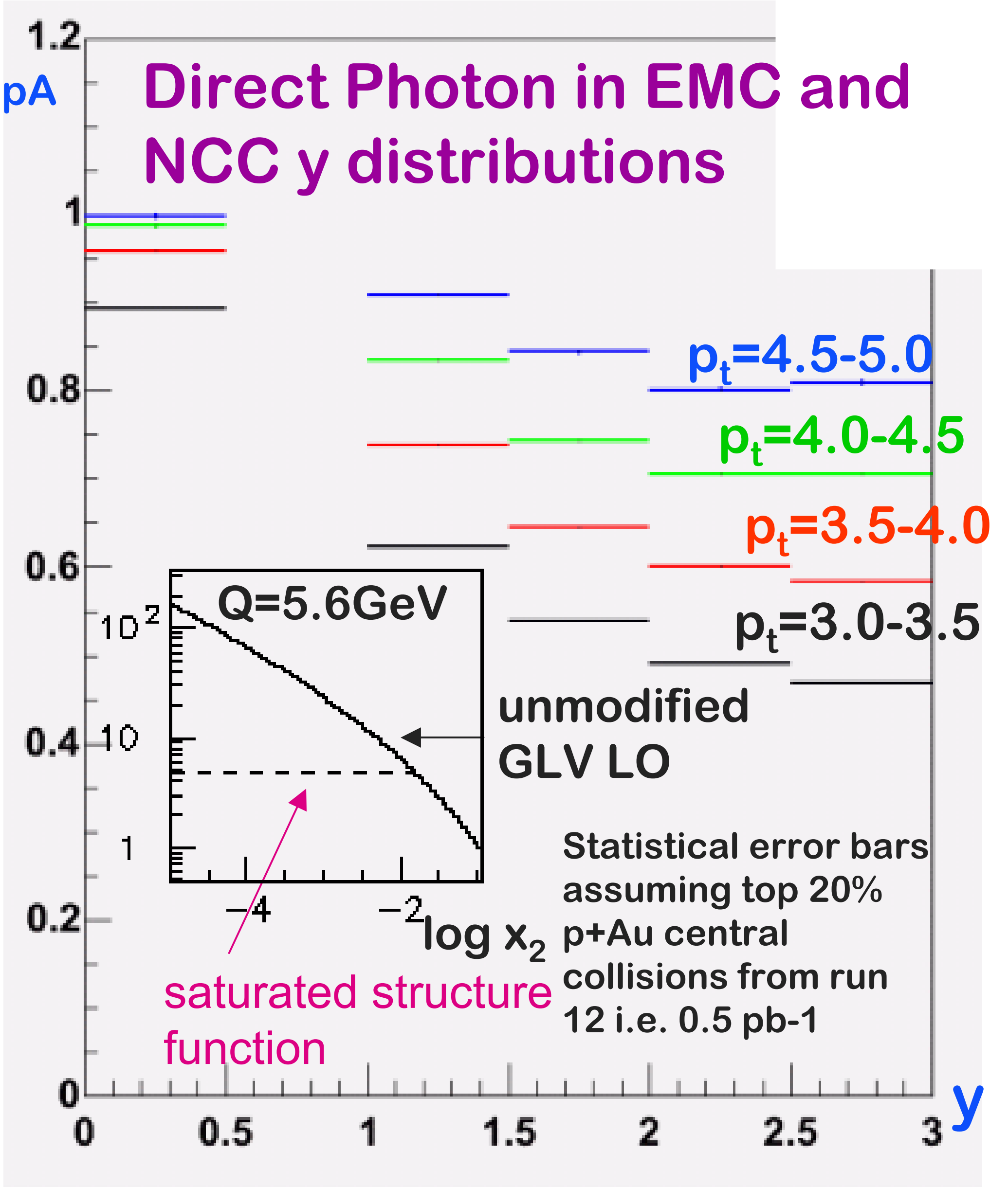
MSU	Samples expected end of summer 2004 if funding available

Prototyping – mother board

MSU, BNL, Trieste	Footprint for the sensor (MSU)	6/2004
	Footprint for the packaged preamp (Trieste)	6/2004
	Footprint for unpackaged preamp (Trieste)	6/2004
	Signal packaging proposal (BNL, MSU)	7/2004
	Board design (BNL)	8/2004
	Board design (MSU)	8/2004
	Test boards production , staffing and testing (BNL, MSU)	10/2004
	Boards for DC sensor based prototype	1/2005
	Boards for refurbishing prototype with preproduction sensors	

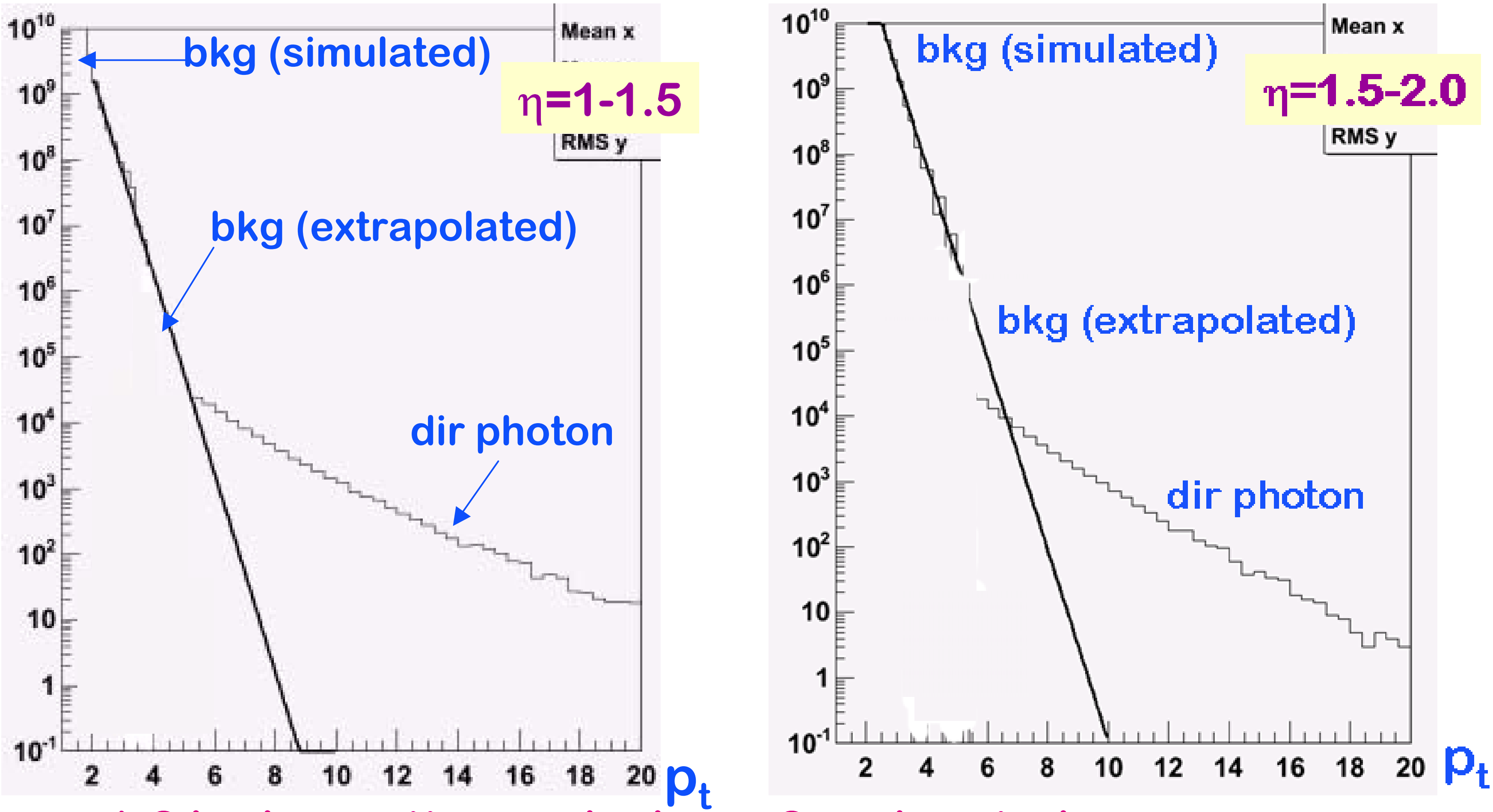
Gluon distribution function

- 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,



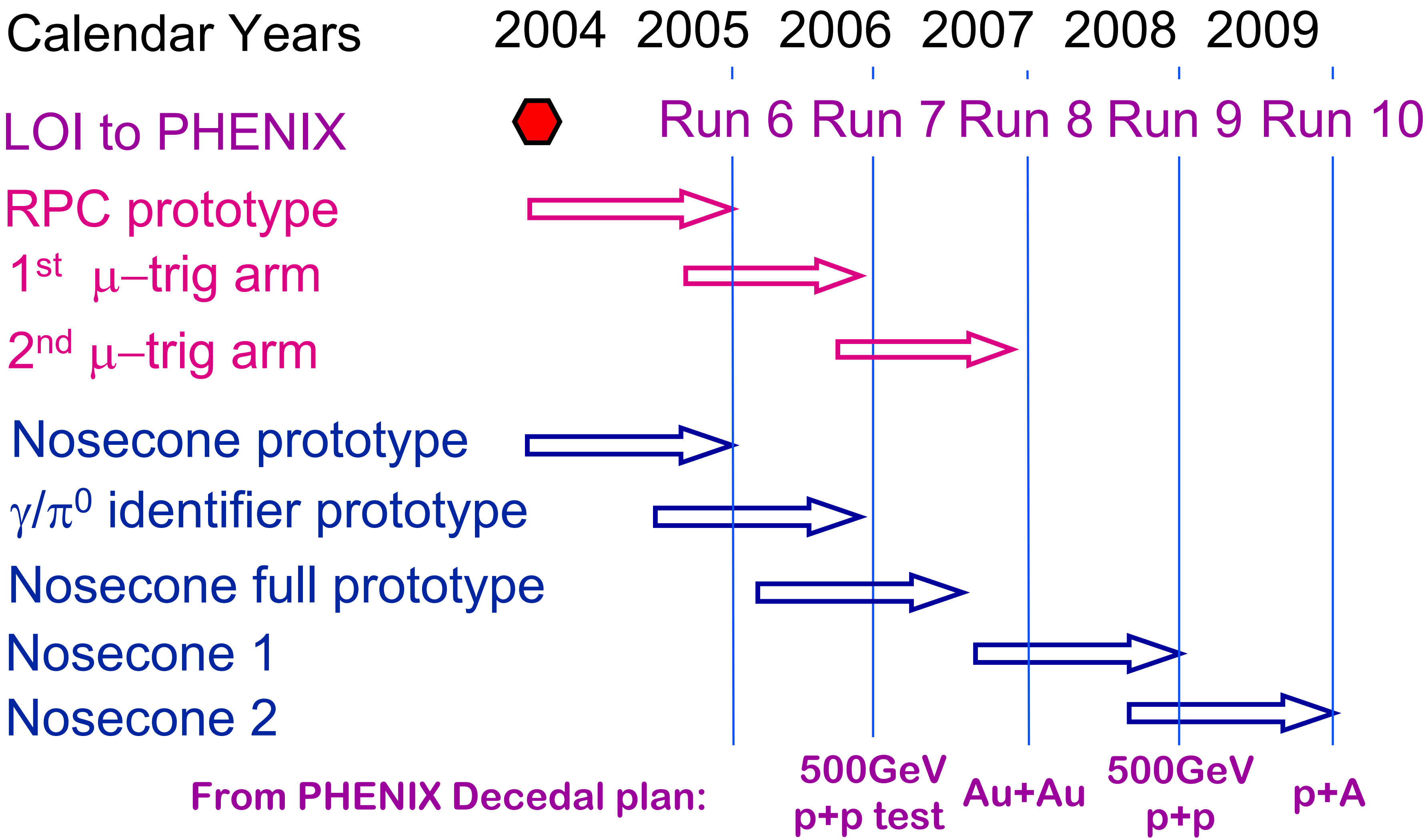
NCC in central Au+Au

- 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.

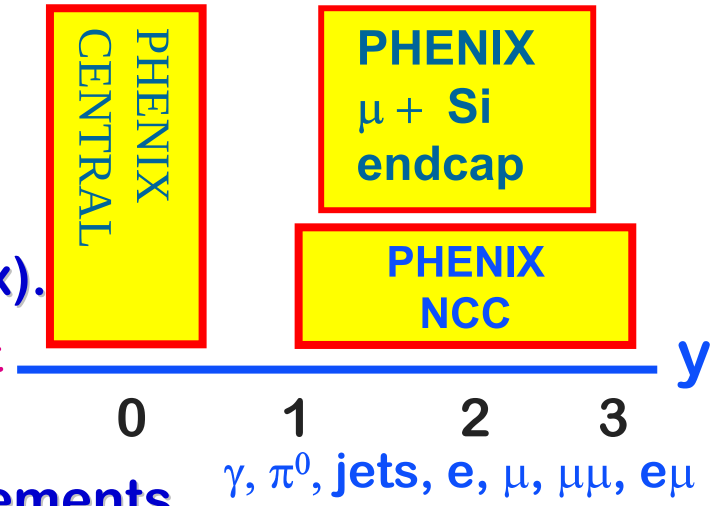
Schedule & Cost



Initial cost estimates: muon trigger ($2M), NoseCone ($4M/arm)

Summary

- High parton densities in nuclear matter
  - Saturation? CGC?
  - Initial conditions in Au+Au
  - Gluon distribution function forward rapidities $\Rightarrow$ NCC
- Flavor decomposition $\Delta\bar{q}(x)/\bar{q}(x)$ & $\Delta q(x)/q(x)$.
  - via $W \rightarrow \mu\nu$ theoretically clean measurement
  - Upgraded μ trigger required



- Extend kinematical reach of $\Delta G(x)$ measurements
  - prompt photon down to $x_g \sim 10^{-3} \Rightarrow$ NCC
- Extend jet tomography to $\eta \sim 2.5$.
  - photon-jet measurement $\Rightarrow$ NCC (photon or jet in NCC)
- Expand the physics with quarkonia to new states and high luminosity
  - Requires enhanced muon trigger for $\Psi \rightarrow \mu\mu \Rightarrow \mu$ trigger
  - Measurement of $\chi_c \rightarrow J/\psi + \gamma$ may be possible $\Rightarrow$ NCC

Physics requires highest luminosity p+p, p+A, A+A

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

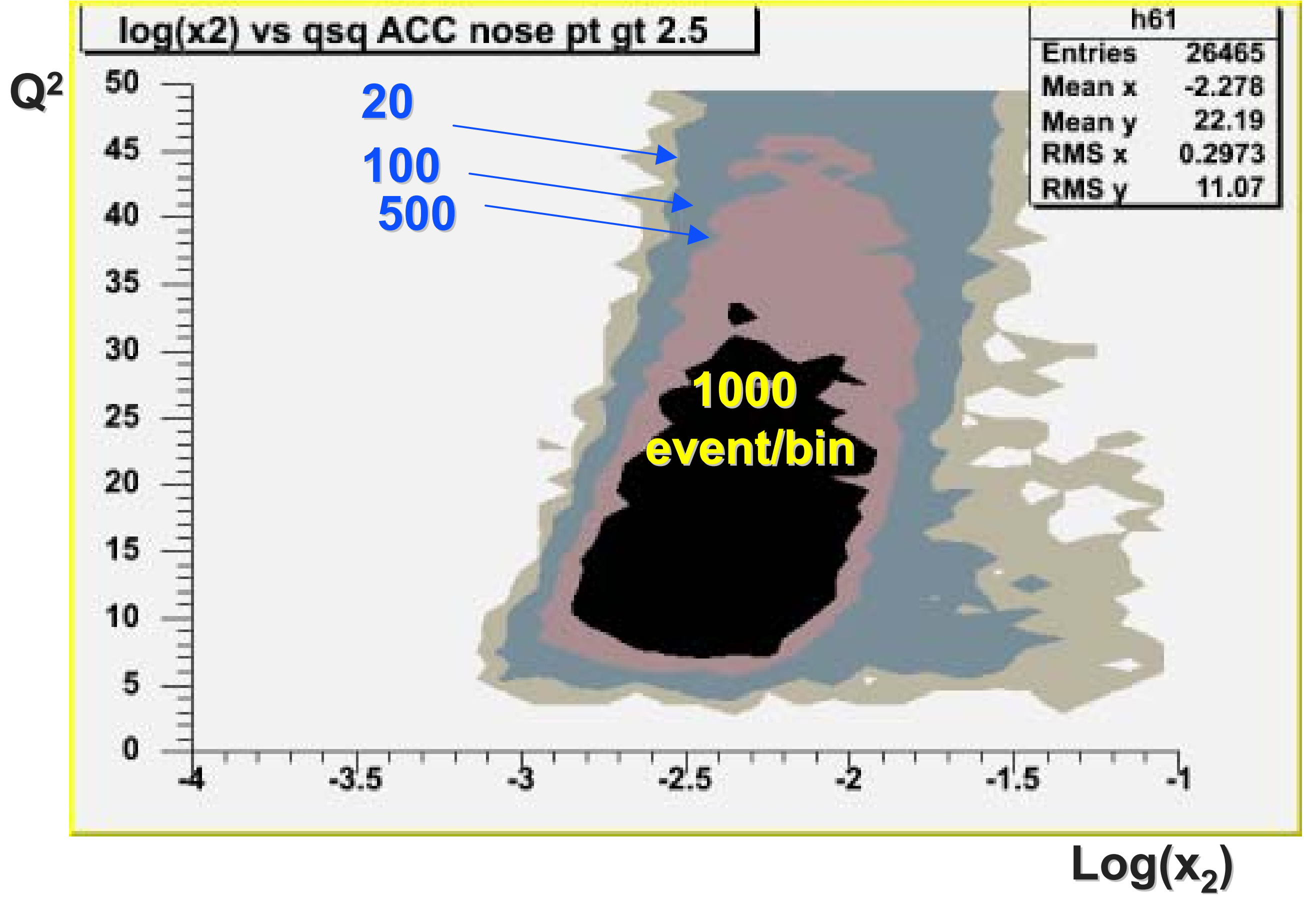
~20 GeV/c

Coverage of NCC at 200 GeV

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

$\Delta log(x_2)\ \Delta Q^2 = 0.1 x 1\ GeV^2$

Direct photon



Level-1 triggering scheme