The PHENIX Future Physics Program

Axel Drees, Stony Brook University
NSCA review, 6/03/2004, BNL

Overview of physics goals

Overview of PHENIX upgrades required

Hard probes

- **PID**
- **Heavy flavor**
- **γ-jet**

Low mass dileptons

DAQ & 1st level trigger

Summary

- **Expected physics performance**
- **Budget requirements and time lines**
- **Conclusion**

Physics Beyond Reach of Current PHENIX

Provide key measurements so far inaccessible at RHIC in three broad areas:

- **Comprehensive study of QCD at high T with heavy ion, p-nucleus, and pp**
  - high p_T phenomena (identified particle, p_T>20 GeV/c and γ-jet tomography)
  - electron pair continuum (low masses to Drell-Yan)
  - heavy flavor production (c- and b-physics)
  - charmonium spectroscopy (J/ψ, ψ' , χ_c and Υ(1s),Υ(2s),Υ(3s))

requires highest AA luminosity

- **Extended exploration of the spin structure of the nucleon**
  - gluon spin structure (ΔG/G) with heavy flavor and γ-jet correlations
  - quark spin structure (Δq/q) with W-production
  - Transversity

requires highest polarization and luminosity

- **Dedicated p-nucleus program**
  - A-, p_T-, x-dependence of the parton structure of nuclei
  - gluon saturation and the color glass condensate at low x

Requires upgrades of PHENIX and RIHC II luminosity

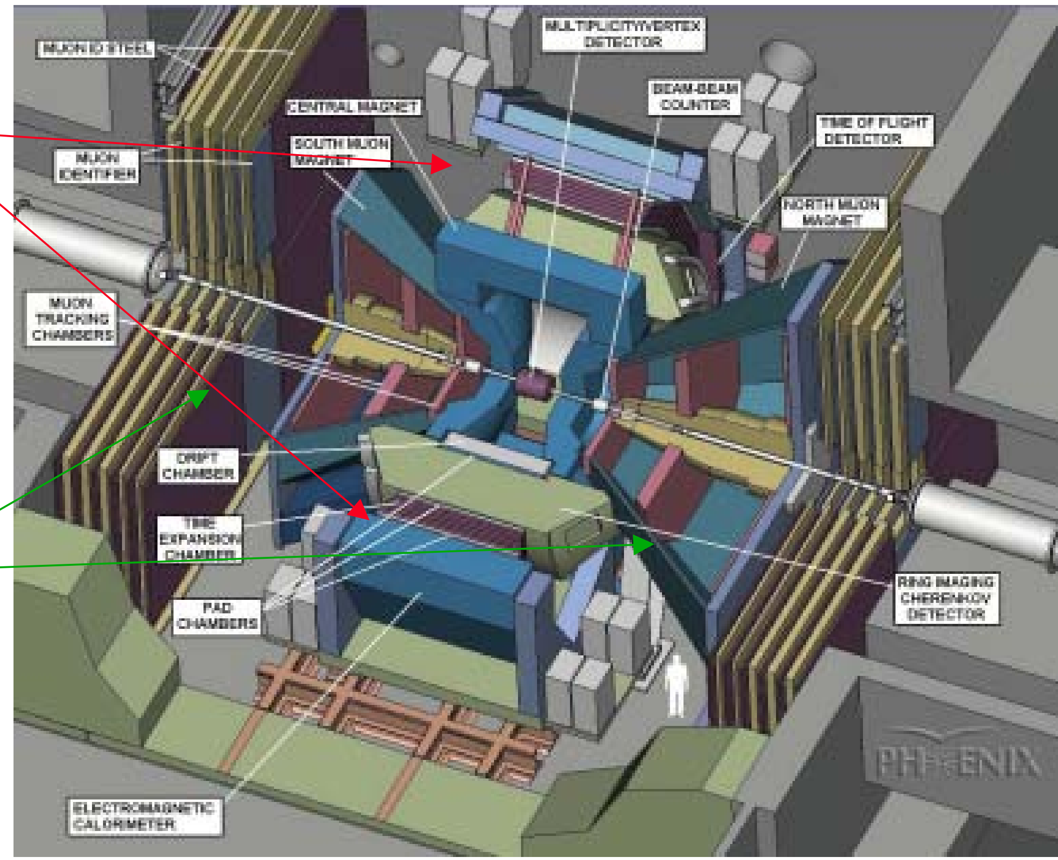
PHENIX Experiment

designed to measure rare probes:

Au-Au & p-p spin

+ high rate capability & granularity
+ good mass resolution and particle ID
- limited acceptance

- **2 central arms:**
  electrons, photons, hadrons
  - charmonium J/ψ, ψ' –> e^+e^-
  - vector meson ρ, ω, φ –> e^+e^-
  - high p_T π^o, π^+, π^-
  - direct photons
  - open charm
  - hadron physics

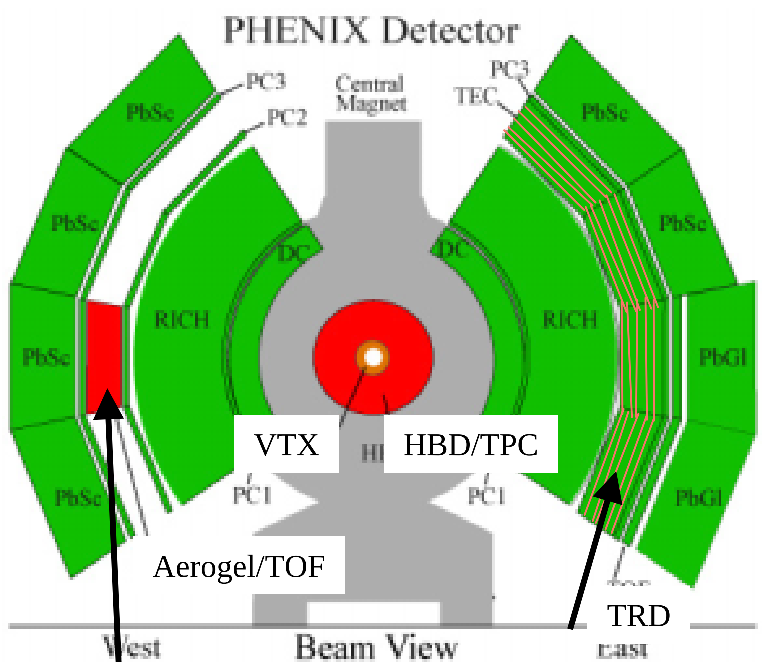


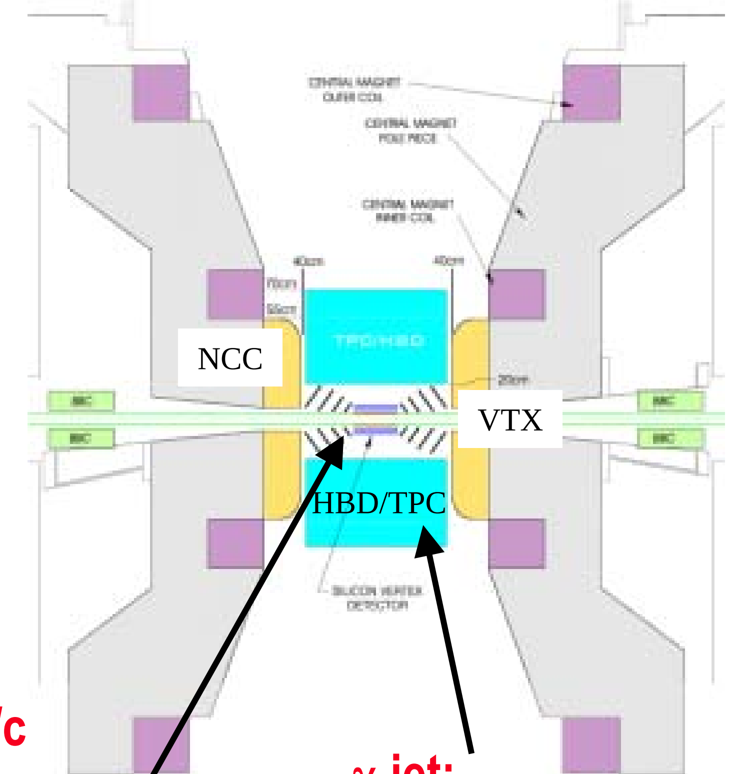
- **2 muon arms:** **muons**
  - "onium" J/ψ, ψ', Υ –> $\mu^+\mu^-$
  - vector meson φ –> $\mu^+\mu^-$
  - open charm

Discovery potential of PHENIX demonstrated in Run's 1-4
Upgrades aim at precision measurements

PHENIX Central Arm Upgrades

- **Enhanced Particle ID**
  - ✓ **TRD (east)**
  - **Aerogel/TOF (2006)**
- **Vertex Spectrometer**
  - ✓ **flexible magnetic field**
  - **VTX: silicon vertex tracker (2008)**
  - **HBD (2007) and TPC (2011)**





charm/beauty:
TRD e/π above 5 GeV/c

High p_T phenomena:
π, K, p separation to 10 GeV/c

charm/beauty:
displaced vertex

γ-jet:
large acceptance
e+e- continuum:
Dalitz rejection

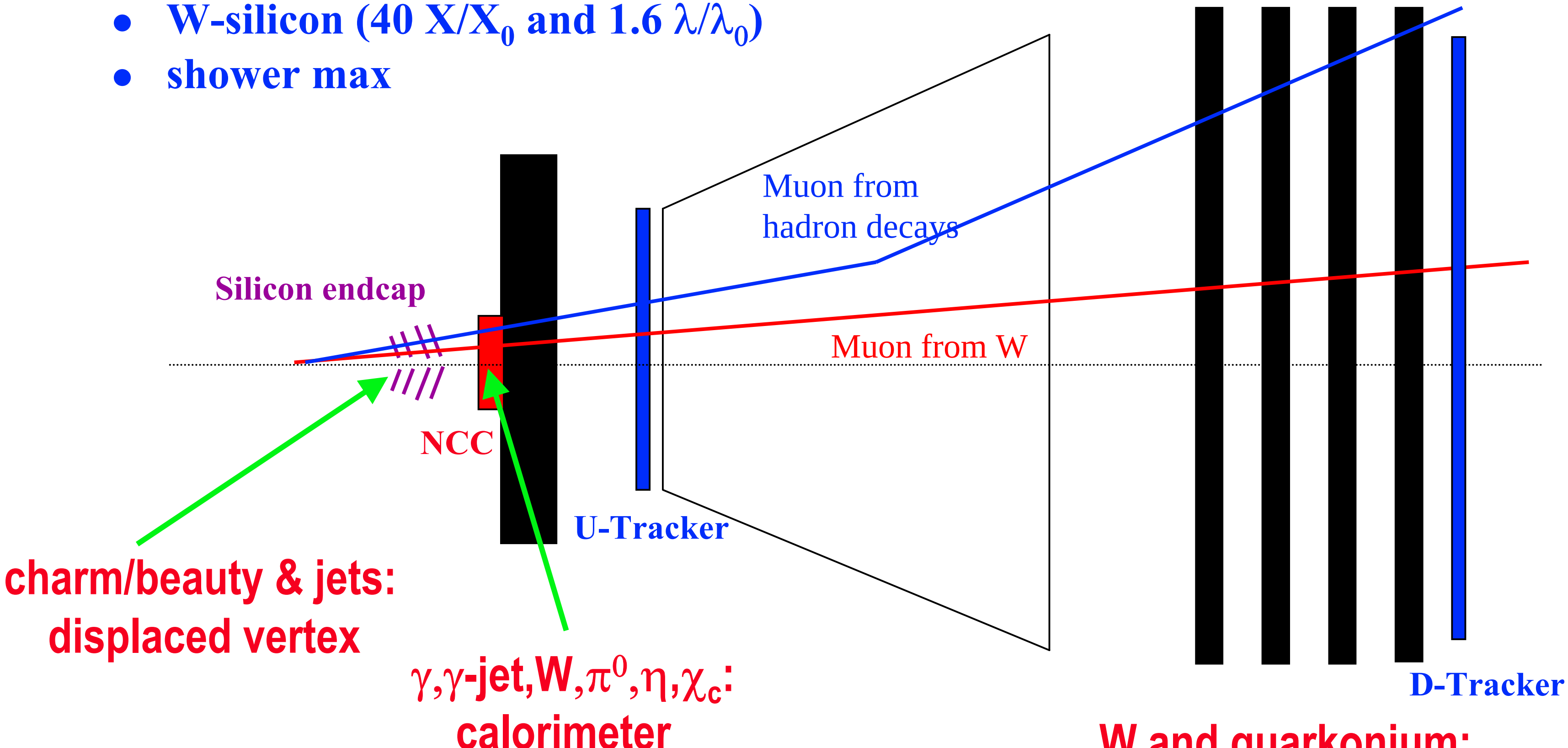
Staged implementation 2005++

PHENIX

Axel Drees

PHENIX Forward Upgrade Components

- **Forward Silicon Vertex Tracker (2009)**
  - **silicon pixel detectors**
- **NCC: EM & hadron Calorimeter (2010)**
  - **W-silicon (40 X/X_0 and 1.6 λ/λ_0)**
  - **shower max**
- **Muon trigger (2007)**
  - **U-tracker (MuTr or new)**
  - **D-tracker (timing with RPC's)**



**W and quarkonium:
improved μ-trigger rejection**

Staged implementation

Ongoing PHENIX Upgrades Program

Discovery potential of PHENIX demonstrated in Run's 1-4

- **All upgrades utilize full strength of PHENIX experiment**
  - **Central arms & muon arms & DAQ/trigger**

- **Upgrades will be implemented in a staged approached**
  - **Implement upgrades year by year**
  - **Maintaining yearly operation and full physics output**

Run 1	→ Run 2 1st μ-arm	→ Run 3 completed	→ Run 4 Aerogel & TRD
DAQ	20 MB/s		→ 500 MB/s

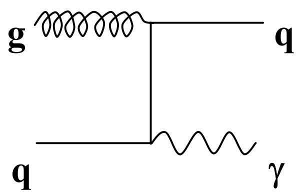
Realistic basis for future planning

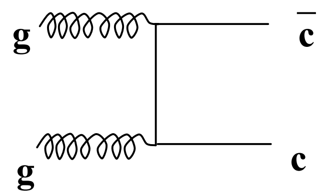
- **Actively recruiting new expert groups to PHENIX & RHIC**

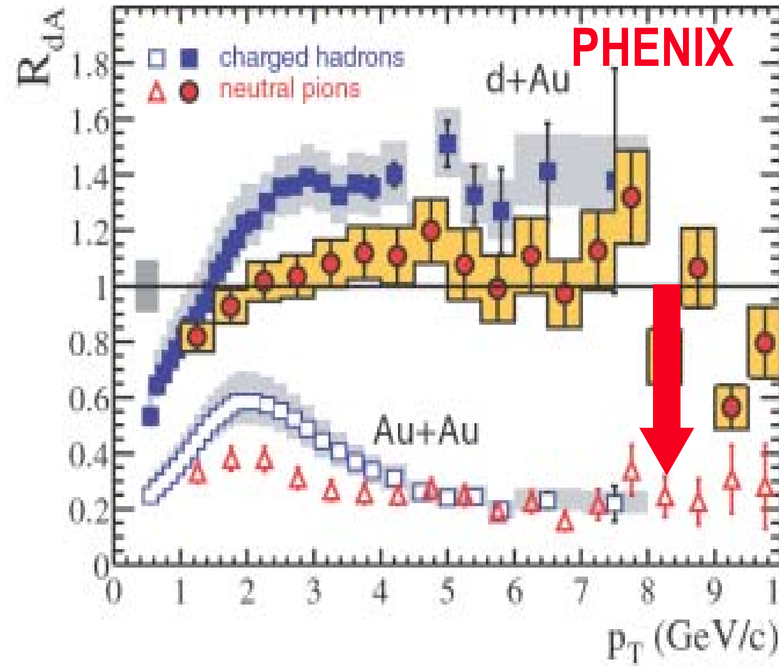
Probing Dense Matter with Hard Probes

Great potential of hard scattering shown by discovery of jet quenching:
opaque and dense matter created in AuAu

Future detailed studies with hard probes:
γ-jet and heavy flavor production







Future steps to gain more detailed insight:

- high momentum PID K, π, p p_T range to 10 GeV/c → Aerogel/ToF
- heavy flavor c, b → VTX
- J/ψ, ψ', χc, Υ(1s),Υ(2s),Υ(3s) → RHIC II & VTX, & μ-trigger
- γ-jet tomography → RHIC II & TPC & NCC

PHENIX

High p_T Particle Identification

		Pion-Kaon separation	Kaon-Proton separation
TOF	σ~100 ps	0 - 2.5	- 5
RICH	n=1.00044 γth~34	5 - 17	17 -
Aerogel	n=1.01 γth~8.5	1 - 5	5 - 9

Combination of three PID detectors
RICH with CO_2 γ_{th} ~ 34
Aerogel Č, γ_{th} ~ 8.5
TOF σ ~ 100 ps

π, K, p separation out to ~ 10 GeV/c

coverage ~ 4 m^2 in west arm

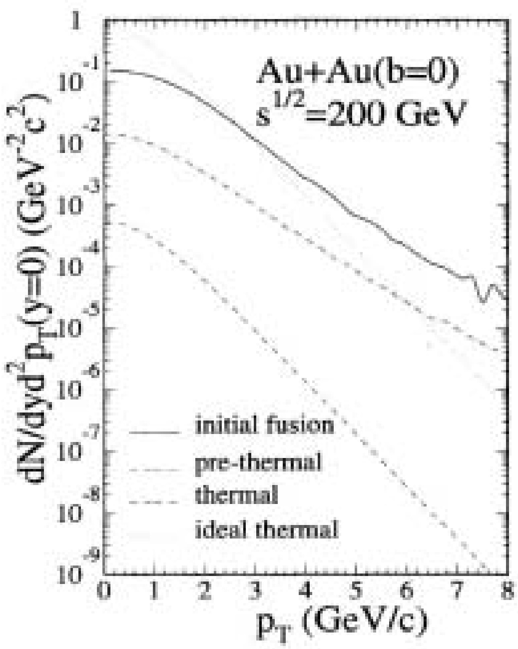
- **Scope of PID upgrade:**
  - Ongoing construction project
  - KEK, Tokyo, Vanderbilt, Dubna, BNL
  - 2 m^2 Aerogel Cherenkov installed 2004
    completion 2005
  - New TOF detector based on RPC's
    prototypes under construction
    full installation by 2006

Axel Drees

Physics from Precise Charm Measurements in Au-Au

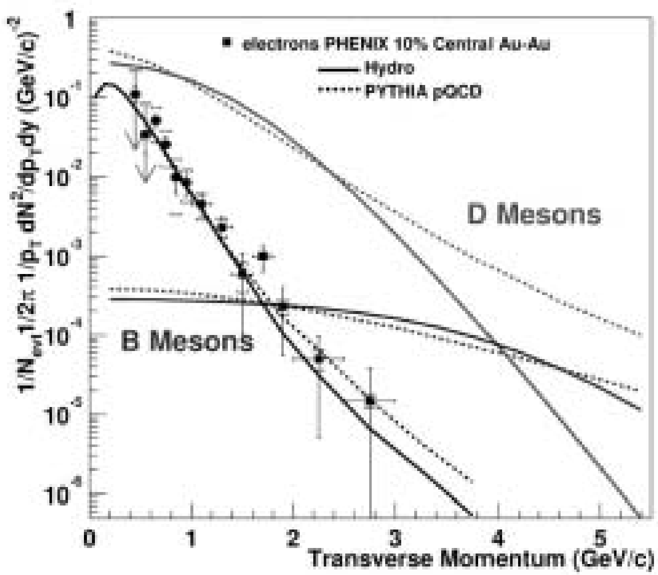
Are there medium modifications for heavy quarks?

Is there pre-thermal charm production?



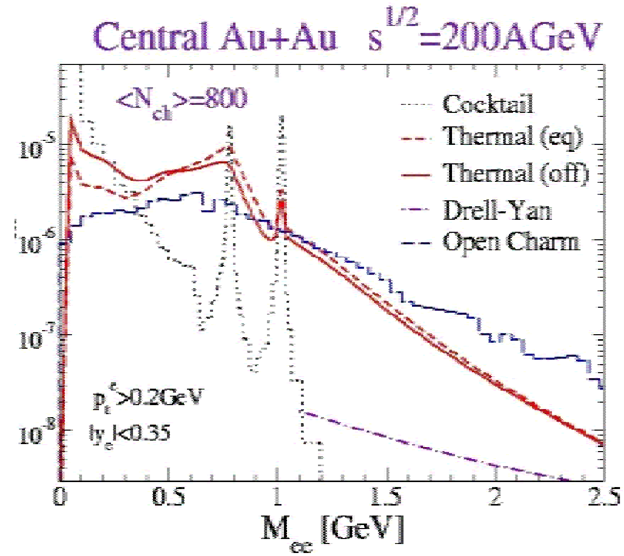
Precision measurement

Does charm flow? Does charm suffer energy loss?



Charm out to p_T > 4 GeV/c

Thermal dileptons from the QGP

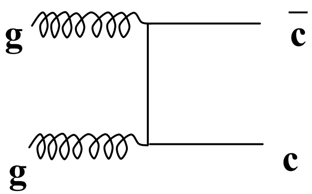


Accurate measurement of correlated e+e- pairs

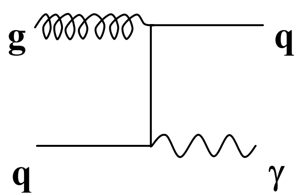
These measurements are not possible or very limited without the precise vertex tracking

Spin and pA Physics with Vertex Tracking

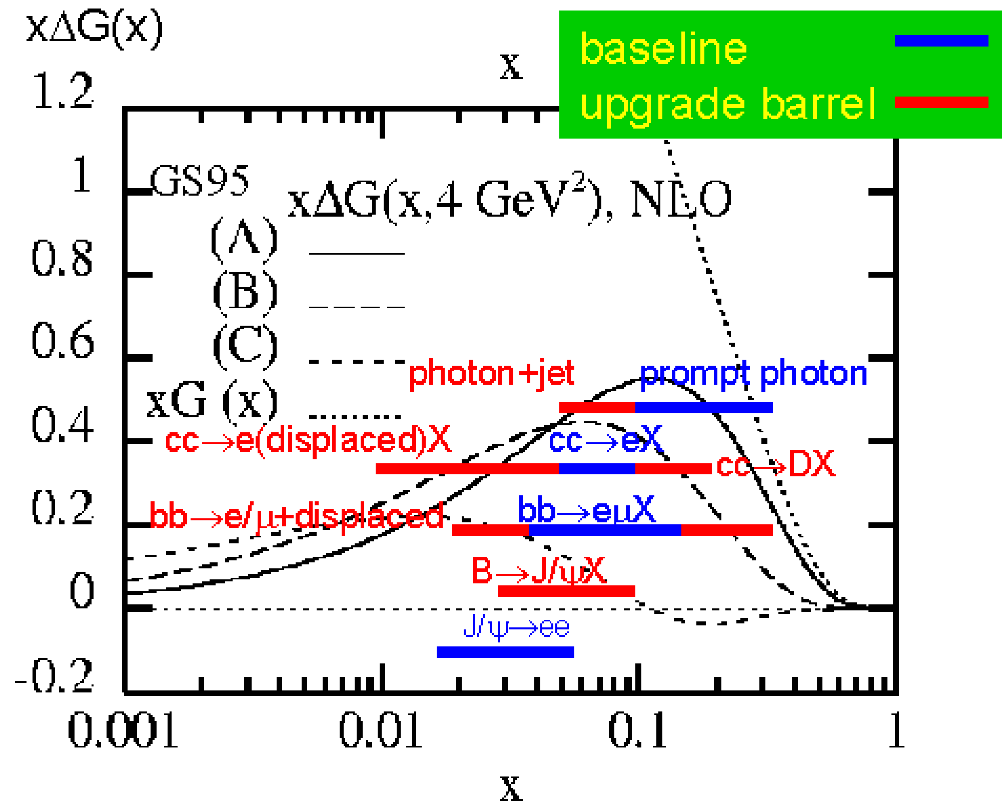
- **Measurement of gluon polarization**
  - **by heavy flavor production**



  - **Through γ-jet**
    (jet reconstruction in VTX)



gluon polarization



- **Extracting gluon structure function in nuclei, shadowing**

Barrel VTX Detector Proposal Submitted to BNL

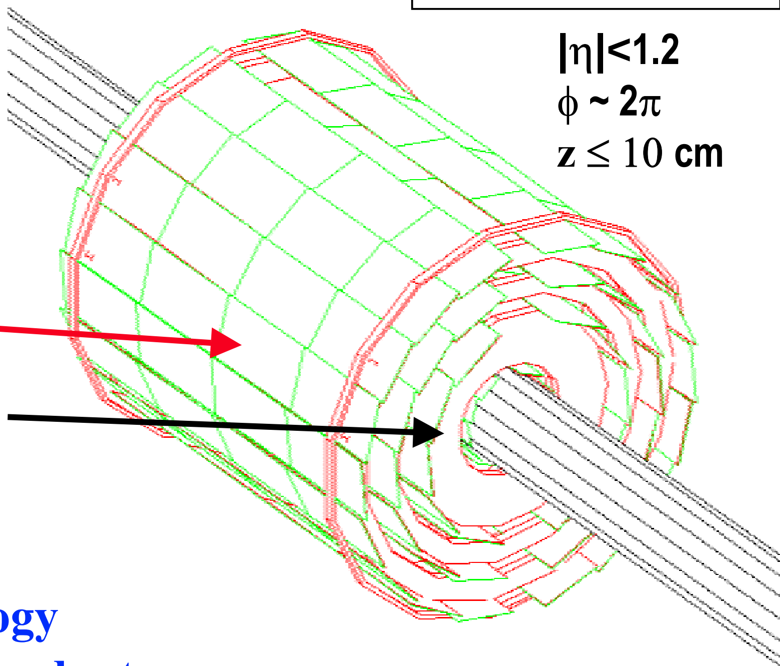
- **Specifications:**
  - **Large acceptance ($\Delta\phi \sim 2\pi$ and $|\eta| < 1.2$)**
  - **Displaced vertex measurement $\sigma < 100\ \mu m$**
  - **Charged particle tracking $\sigma_p/p \sim 5\%\ p$**

GEANT model

$|\eta|<1.2$
$\phi \sim 2\pi$
$z \leq 10$ cm

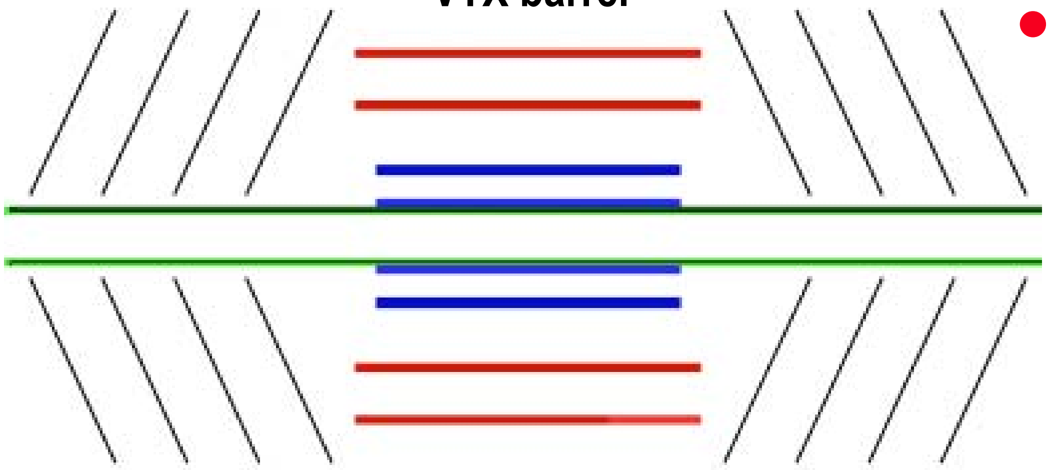
Strip Detectors (80 μm x 3 cm) at R ~ 10 & 14 cm

Hybrid Pixel Detectors (50 μm x 425 μm) at R ~ 2.5 & 5 cm



- **VTX project**
  - **Detector system based on established technology**
    ALICE Pixel detector & strips with SVX4 readout
  - **Extensive R&D program mostly completed**
  - **Cost sharing DOE ~$ 5.5M and RIKEN ~$ 3M**
  - **Seek DOE construction funds FY06 through FY07**
  - **Proposal to BNL 65 authors from 14 institutes**
    (4 presently not members of PHENIX)

Completion of Vertex Tracker with Endcaps



- **Technology option:**
  - **"mini" strips (~0.1 x 1 m^2)**
  - **R&D effort with FNAL initiated**
  - **Expect ~1-2 year development**
  - **requires sufficient R&D funds**

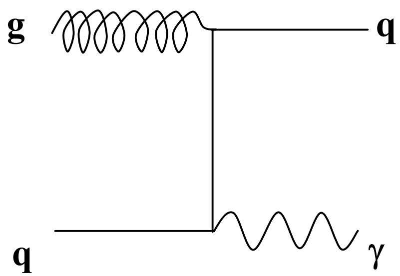
  - **Proposal by early 2006**
  - **Construction start FY07 or FY08**
  - **Scope ~ $6 M for two endcap's**

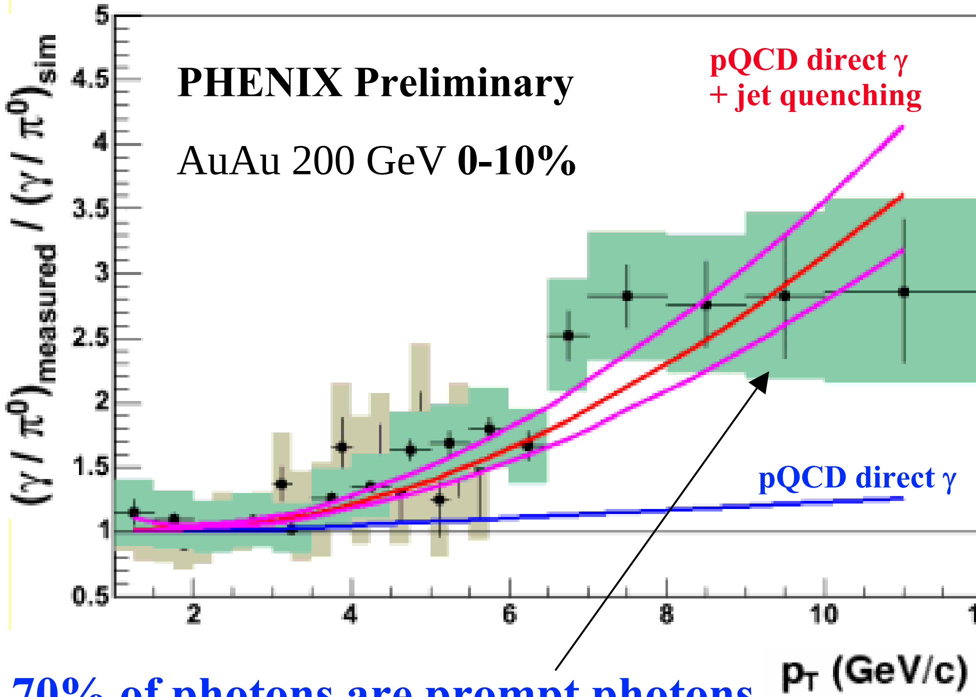
Heavy flavor detection in PHENIX:

- **Beauty and low p_T charm via displaced e and/or μ** — $-2.7<\eta<-1.2$, $|\eta|<0.35$, $2.7<\eta<1.2$
- **Beauty through displaced $J/\psi \rightarrow ee$ ($\mu\mu$)** — $-2.7<\eta<-1.2$, $|\eta|<0.35$, $2.7<\eta<1.2$
- **High p_T charm through $D \rightarrow \pi K$** — $|\eta|<0.35$

Jet Tomography of Quark Matter

Quark gluon Compton scattering:





γ-energy fixes jet energy
γ & Jet direction fix kinematics

measure ΔE as function of:
E, "L", flavor

70% of photons are prompt photons

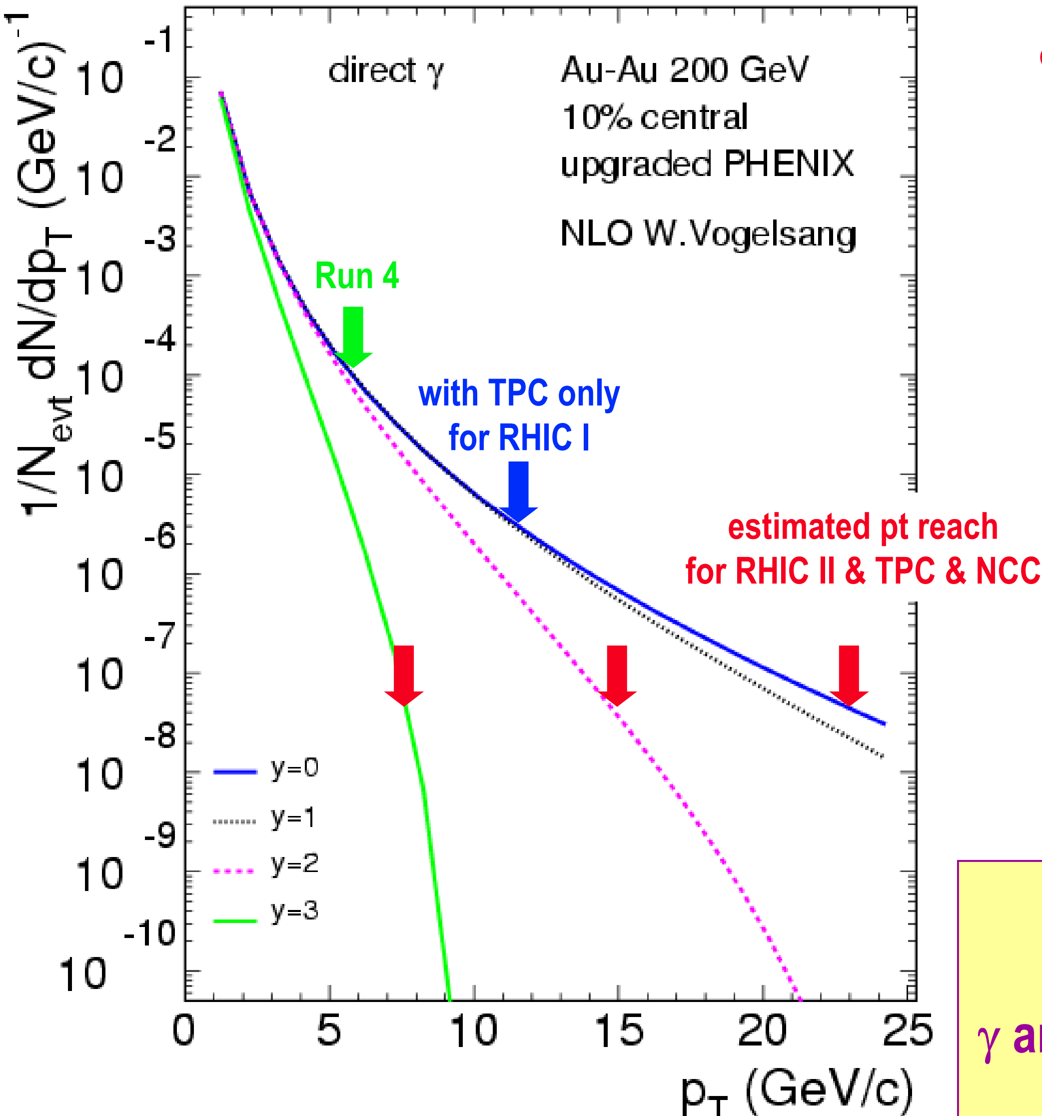
Promising measurement in PHENIX:

- **present setup: excellent γ-measurement at mid rapidity**
- **future TPC: large acceptance for recoil jet**
- **future NCC: extends rapidity coverage to |y|<3**

PHENIX

Axel Drees

Rate Estimates for γ-jet Tomography



- **Rapidly falling cross section with rapidity:**
  - Assume ~ 1000 events required for statistical γ-jet correlation
  - RHIC II luminosity
  - PHENIX acceptance (TPC & NCC)

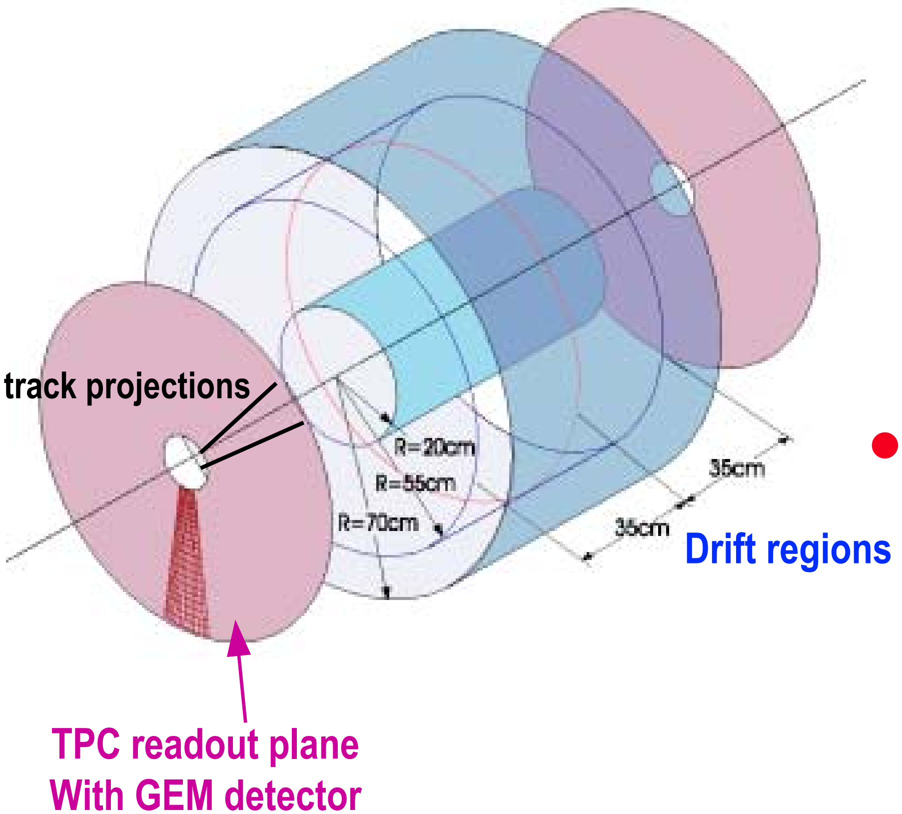
y	max γ-p_T (GeV)
0	23
1	21
2	15
3	8

γ-jet tomography at RHIC requires
RHIC II luminosity
γ and jet reconstruction in central region
(-2 < η < 2)

Axel Drees

Large Acceptance Tracker (TPC)

$\Delta\phi \sim 2\pi, \ |\eta| < 1.0$



- **Inner tracker with fast, compact TPC**
  - **Large acceptance tracker**
  - **Excellent momentum resolution**
    - □ $\delta p/p \sim 1\%\ p$
  - **May be combined with HBD**
- **Status of TPC project**
  - **Ongoing R&D with STAR and LEGS**
  - **Need sufficient funding to complete R&D**
  - **Expect proposal by 2007**
  - **Construction ~2-3 years starting FY09 depending on funding**
  - **Rough cost estimate ~$6 M**

Nosecone Calorimeter (NCC)

- **Forward physics with PHENIX**
  - **Large acceptance calorimeter**
  - **EM calorimeter ~40 X/X_o**
  - **hadronic section (1.6 λ/λ_0)**
  - **Tungsten with Silicon readout**

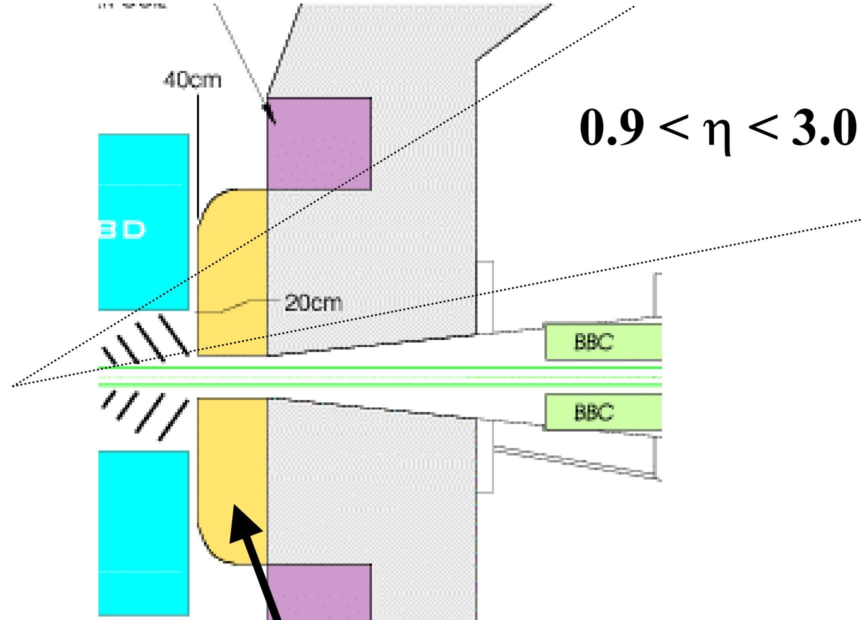
- **Extended physics reach with NCC**
  - **Extended A-A program**

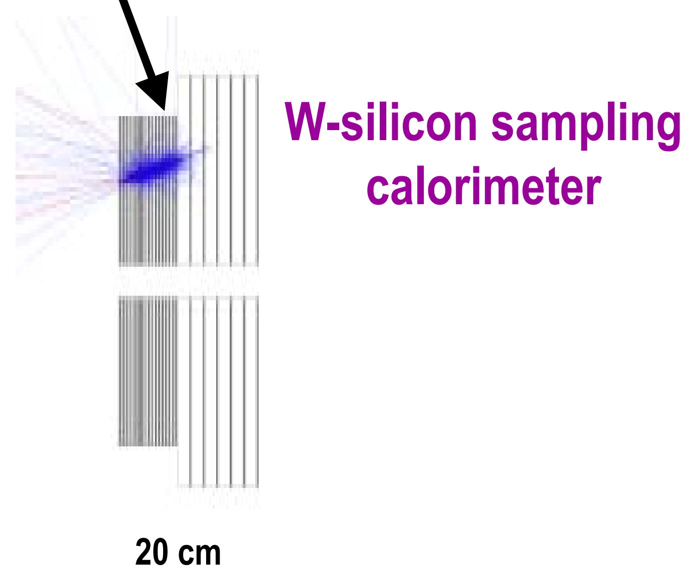
    high p_T phenomena: π^0 and γ-jet

    $\chi_c \rightarrow J/\psi + \gamma$
  - **Small x-physics in d-A**

- **Scope**
  - **Recently proposed to PHENIX collaboration**
  - **New expert groups join R&D**

    (MSU, Triest, Prag)
  - **Construction FY08 – FY09**

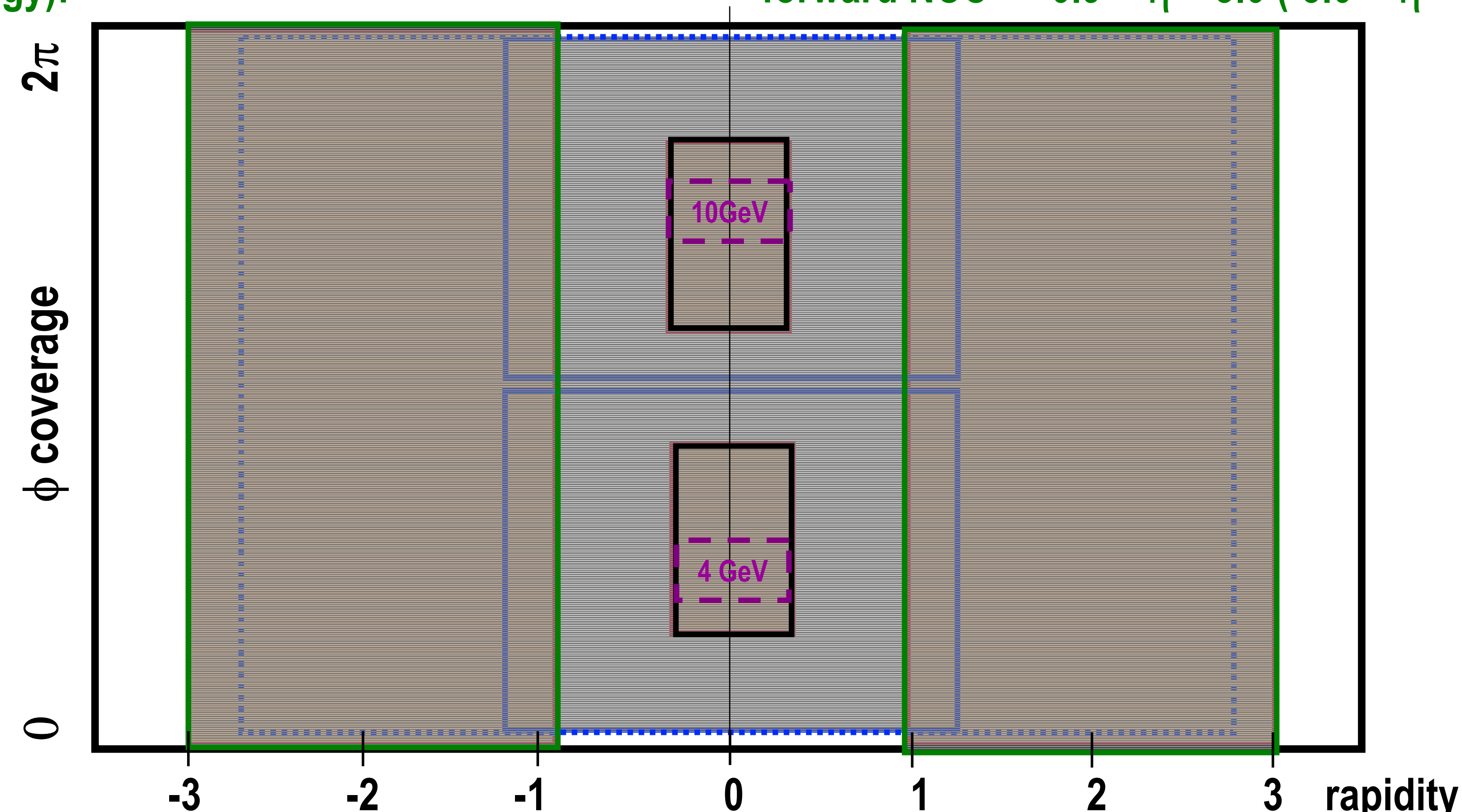




More details in K. Barish's talk

PHENIX Acceptance for γ-jet Measurement

Prompt photons:	central EMCal	$|y| < 0.35$	forward NCC	$0.9 < y < 3.0$ $(-3.0 < y < -0.9)$
Jet (charged):	central TPC + VTX	$|\eta| < 1.2$	forward silicon	$1.2 < \eta < 2.7$ $(-2.7 < \eta < -1.2)$
Jet (energy):			forward NCC	$0.9 < \eta < 3.0$ $(-3.0 < \eta < -0.9)$

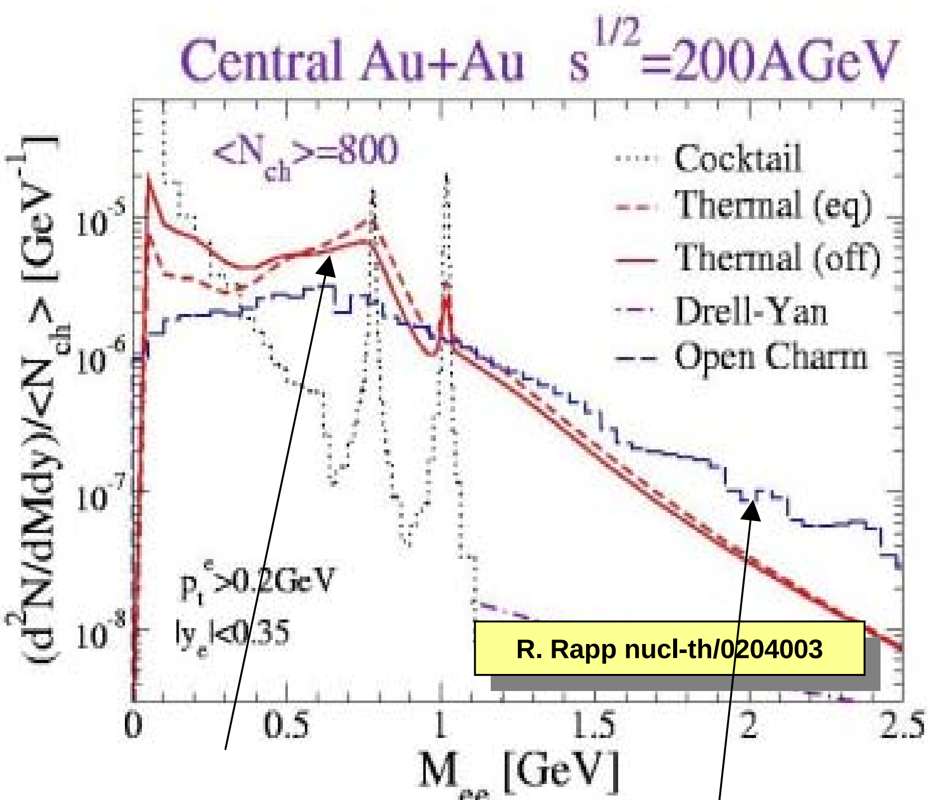


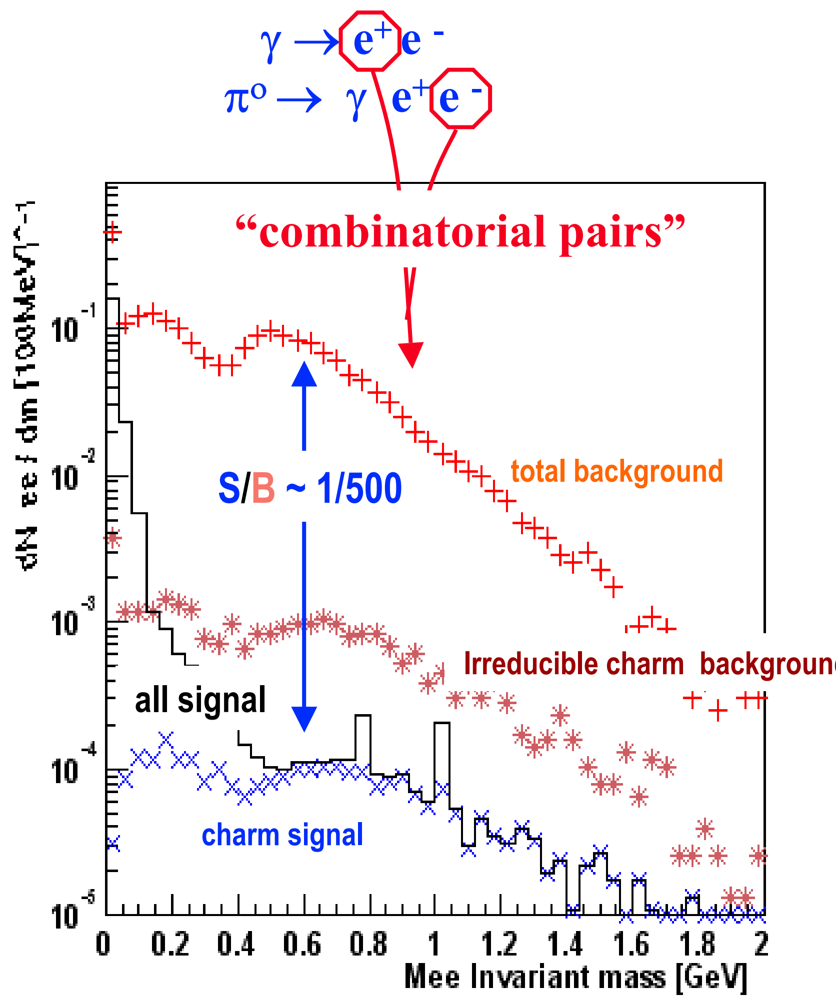
Large acceptance for γ-jet tomography:
expect measurements out to $E_{jet} > 20$ GeV
Large acceptance for flavor tagging
Limited acceptance for p – meson separation

Axel Drees

Low-Mass e^+e^- Pairs at RHIC

Sensitive to the chiral transition and thermal radiation





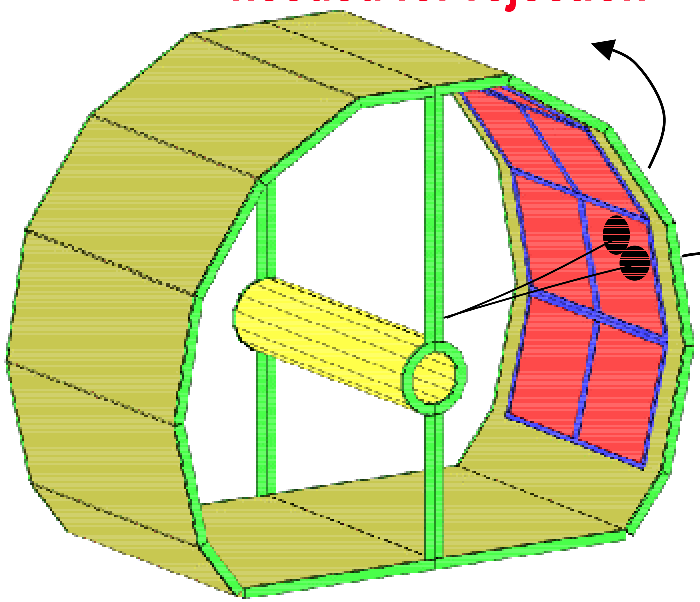
Strong enhancement of low-mass pairs persists at RHIC

Significant contribution from open charm

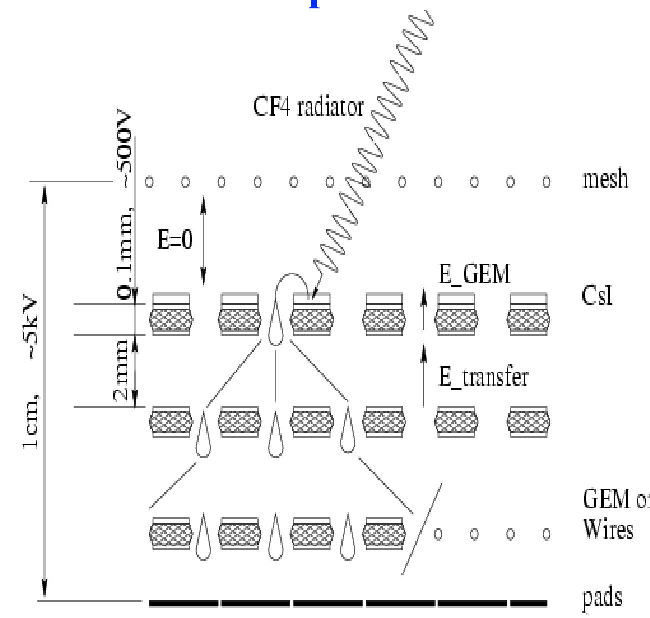
Need Dalitz rejection & accurate charm measurement

PHENIX

Dalitz Rejection with a Hadron Blind Detector



- **Dalitz rejection via opening angle**
  - **Identify electrons in field free region**
  - **Veto signal electrons with partner**



- **HBD concept:**
  - **windowless CF_4 Cherenkov detector**
  - **50 cm radiator length**
  - **CsI reflective photocathode**
  - **Triple GEM with pad readout**
- **scope**
  - **Extensive R&D over past 1-2 years**
  - **Collaboration Weizmann Inst., BNL, Tokyo, USB**
  - **Cost estimate ~ 1.2 M$**
  - **Construction FY05/06**

R&D highlights
- test beam KEK 5/04
- GEM + CsI work with CF_4
- sufficient gain $\sim 10^4$
- hadron blind e/h > 100

PHENIX

Axel Drees

Interaction Rates and DAQ Requirements

Au-Au at 200 GeV	Run 4	RHIC I	RHIC II
<L> ($cm^{-2}\ s^{-1}$)	$4\ 10^{26}$	$8\ 10^{26}$	$70\ 10^{26}$
interaction rate	2 kHz	4 kHz (max 12 kHz)	40 kHz

p-p polarized	Run 4	RHIC I (200)	RHIC I (500)	RHIC II
<L> ($cm^{-2}\ s^{-1}$)	$7\ 10^{30}$	$6\ 10^{31}$	$1.5\ 10^{32}$	$5\ 10^{32}$
Interaction rate (MHz)	0.2	2.0	6.0	20

PHENIX DAQ bandwidth: 8 kHz event rate (FEE limited)
option to upgrade to ~ 20 kHz event by
requires demultiplexing FEE; total cost $1 M

Required rejection at 1st level trigger:	RHIC I	RHIC II
Au-Au	none	2 - 5
pp (500)	250 – 800	800 - 2500

Replacement of some FEE may be required after 2010
Cost estimate ~ $4 M

PHENIX

Axel Drees

Example for First Level Triggering in the RHIC II Era

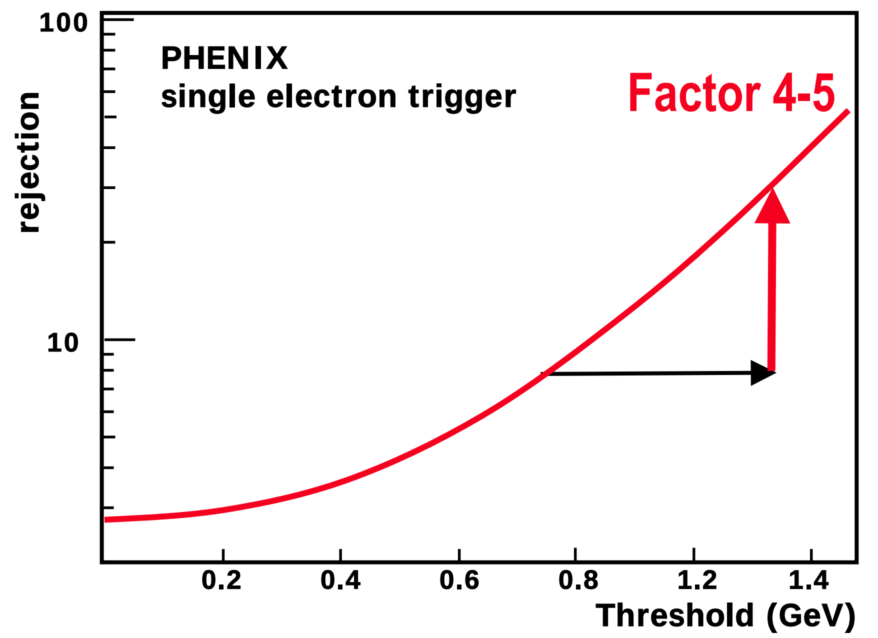
- Main physics goals: rare probes → high momentum → easy to trigger
- RHIC II luminosity: 1st level trigger rejection ~ 20 for 4 1st level triggers

- Example: Single electron trigger

  Now threshold 0.8 GeV rejection 6

  Increase threshold → 1.2 GeV
  Rejection 6 → ~25-30

  Physics reach:
  All single electrons $p_t > 2$ GeV
  All Υ's
  70% of J/ψ trigger
  (efficiency loss at low pt)

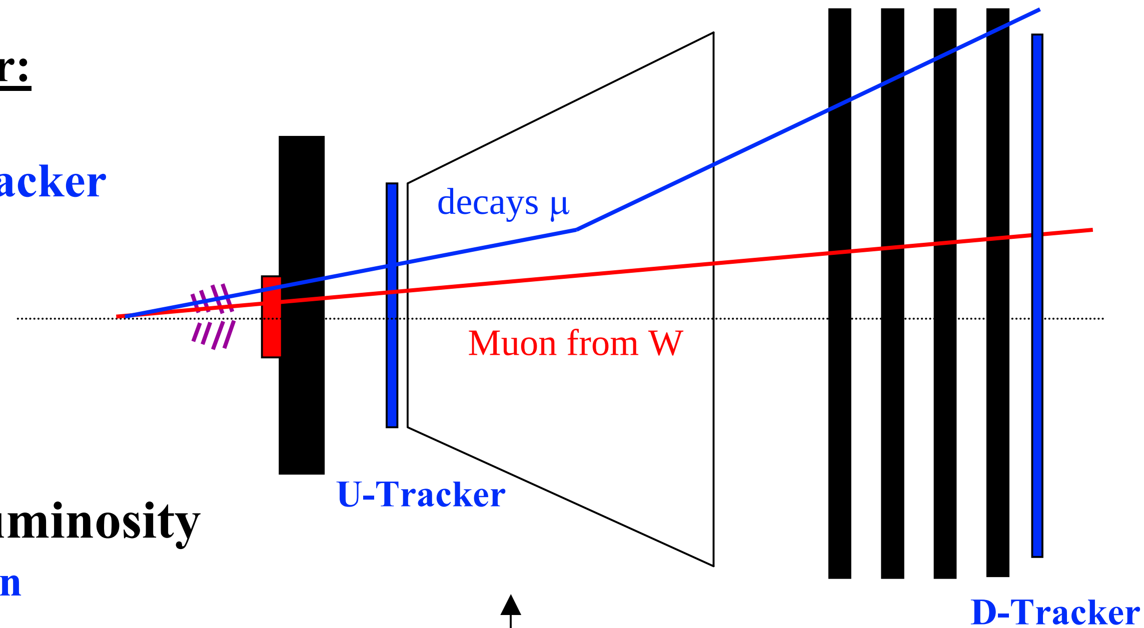


PHENIX & PHENIX upgrades operational at RHIC II luminosities

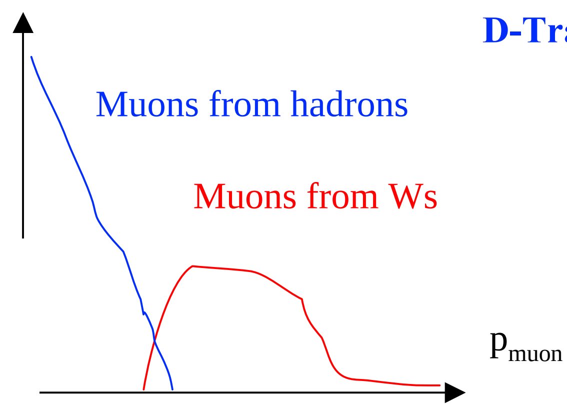
Improved Muon Trigger

Enhanced first level muon trigger:

p-Cut: U-Tracker + D-Tracker
Timing: D-Tracker



- **First level trigger for high luminosity**
  - Increased background rejection
  - W production in p-p 500 GeV/c
  - Upsilon production with RHIC II luminosity



- **Project Schedule**
  - Recently proposed to PHENIX collaboration
  - Proposal to NSF in FY05
  - Estimated cost $2 M
  - Construction 2005/2006
  - Completed for first 500 GeV pp run

More details in K. Barish's talk

PHENIX Physics Potential with RHIC I & II

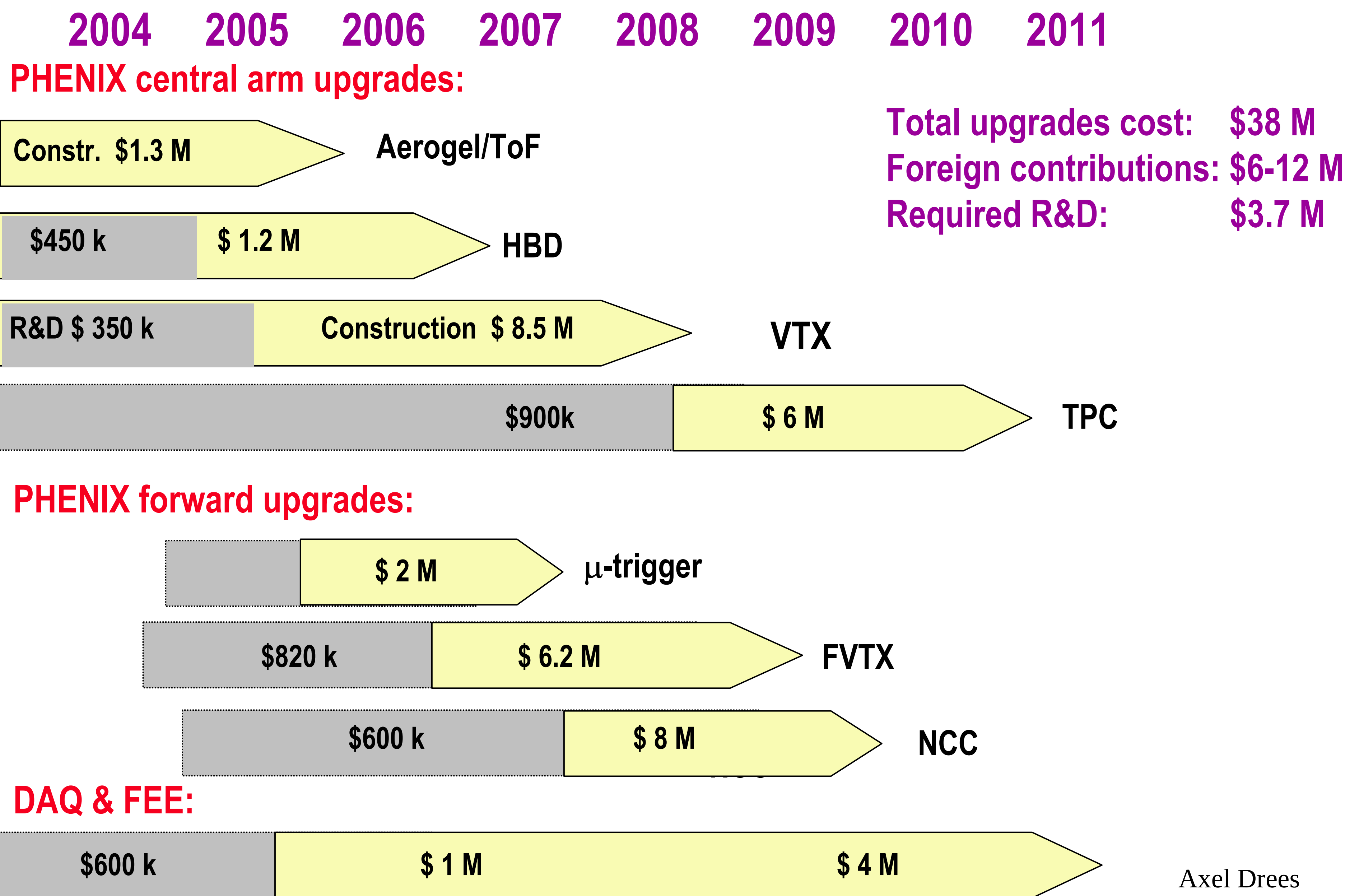
RHIC II Au-Au luminosity increase 10x (lifetime) + 2x (bunch length)

Physics topic		RHIC I ($1.5\ nb^{-1}$)	RHIC II ($\sim 30 nb^{-1}$)	
High p_T	inclusive π^0	$p_T < 20$ GeV	$p_T > 25$ GeV	
	γ-jet (charged)	$E_\gamma \sim 10$ GeV	$E_\gamma > 20$ GeV	TPC/ VTX
	γ-jet (energy)	$E_\gamma \sim 10$ GeV	$E_\gamma > 20$ GeV	NCC/ FVTX
Open heavy flavor	$c \to e,\mu$	$1 < p_T < 6$ GeV		
	$b \to e,\mu$	$1 < p_T < 6$ GeV	$p_T > 6$ GeV	VTX/FVTX
	$D \to \pi k$	$p_T < 4$ GeV	$p_T > 6$ GeV	μ-trigger
Charmonium	$J/\psi \to ee$	2800	56000	
	$\psi' \to ee$	100	2000	
	$Y \to ee$	8	155	VTX/ TPC
	$J/\psi\ (\psi') \to \mu\mu$	38000 (1400)	760000 (28000)	
	$\chi \to \mu\mu$	38000	760000	NCC
	$Y \to \mu\mu$	35	700	μ-trigger
	$B \to J/\psi \to \mu\mu$	2000	30000	FVTX
Lepton pairs	LMR	75000 HBD		
	ρ,ω,ϕ	6000-8000 each	>50000 each	

Luminosity upgrade necessary
Provides precision measurement

Requires PHENIX upgrades

Time Line for PHENIX Upgrades (Technology Driven)



Axel Drees

Conclusion

- RHIC is a world class QDC laboratory
  - High temperature QCD
  - Spin physics
  - Dedicated p-A program
- RHIC II upgrade will allow to fully unfold physics potential
- PHENIX ready to exploit these opportunities in timely a manner
  - Comprehensive upgrades program in place
  - Provide key measurement currently not accessible in all areas

  - Proposed detector upgrades are cost-effective
  - Sufficient R&D funds required in next 3 years
  - Staged implementation while maintaining strong physics output
  - Program has attracted many new groups to PHENIX & RHIC

BACKUP Slides

Questions of the Committee:

- Compare the physics reach with/without detector upgrades.
  Compare the physics reach of the baseline with/without luminosity upgrade.
  Summarize the physics payoff of each upgrade.
  What physics drives the higher luminosity for PHENIX?
  ⇒ Answers compiled on summary slide 23

- R&D required for upgrades.
  When needed compared to construction start?
  ⇒ Time schedule & costs on summary slide 24

HBD:	readout electronics	FY04 (ongoing)
VTX:	strip readout with SVX4	FY04/05
FVTX:	mini strip readout chip	FY05/06
TPC:	GEM & readout electronics	next 3+ years to maintain collaboration
NCC:	Sensors, readout electronics	next 3 years to maintain collaboration
DAQ:	match new detectors	FY04 - FY08

Questions of the Committee:

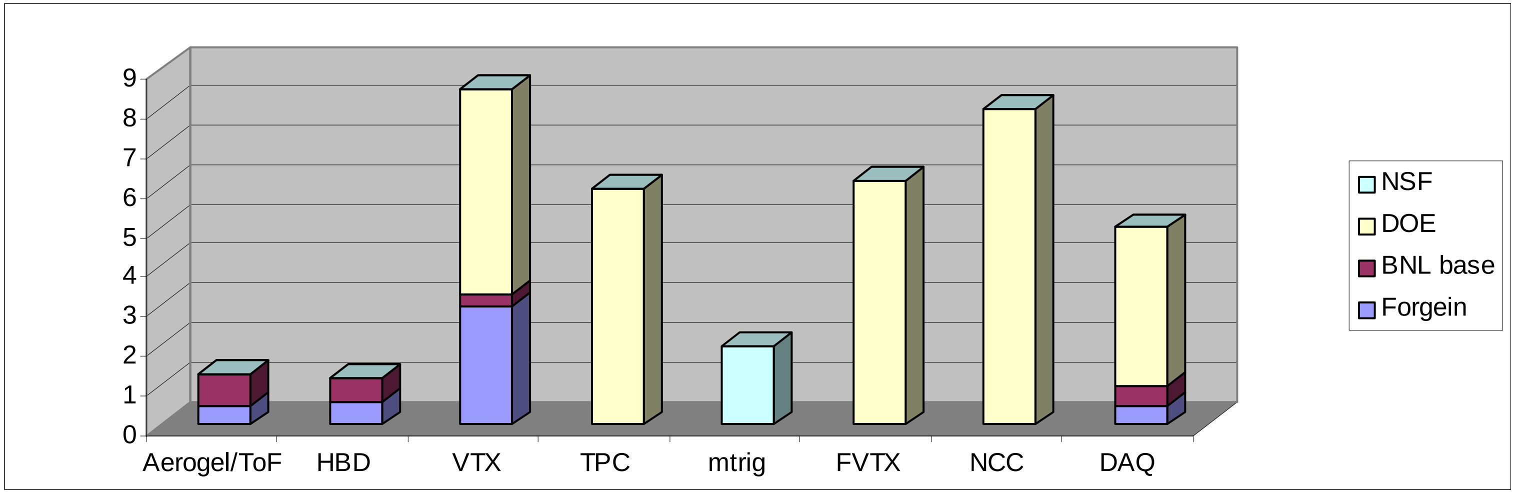
- How long does it makes sense to run without a luminosity upgrade?
  - ⇒ …. difficult question …
  - ⇒ without the baseline program will stretch out > 2015 (see PHENIX decadal plan)
  - ⇒ my personal opinion: till ~2008-10 when LHC becomes productive

- If the luminosity upgrade were advanced by two years, would that give RHIC more physics impact?
  - ⇒ definitely, but trade off with detector upgrades
  - ⇒ PHENIX can run at RHIC II luminosity today
  - ⇒ Much more time effective RHIC operation
  - ⇒ precision quarkonium physics (though limited resolution of Y-states)
  - ⇒ all detector upgrades will profit immediately

- Which upgrades are optimized for (or compatible with) Au+Au vs p+p running?
  - ⇒ HBD specifically for heavy ion program
  - ⇒ μ-trigger mandatory for spin physics with W's
  - ⇒ all other upgrades address AA, pp and p-A physics

Funding Profile of PHENIX upgrades

Funding sources for different upgrades



Project cost: ~$38 M + $5 M R&D (>6 years)

BNL base: $2.5 M + $1.5 M R&D
HBD, Aerogel/ToF, (VTX), DAQ

DOE: ~$24-30 M including R&D
VTX, TPC, FVTX, DAQ, NCC

NSF: $2 M
μ-trigger

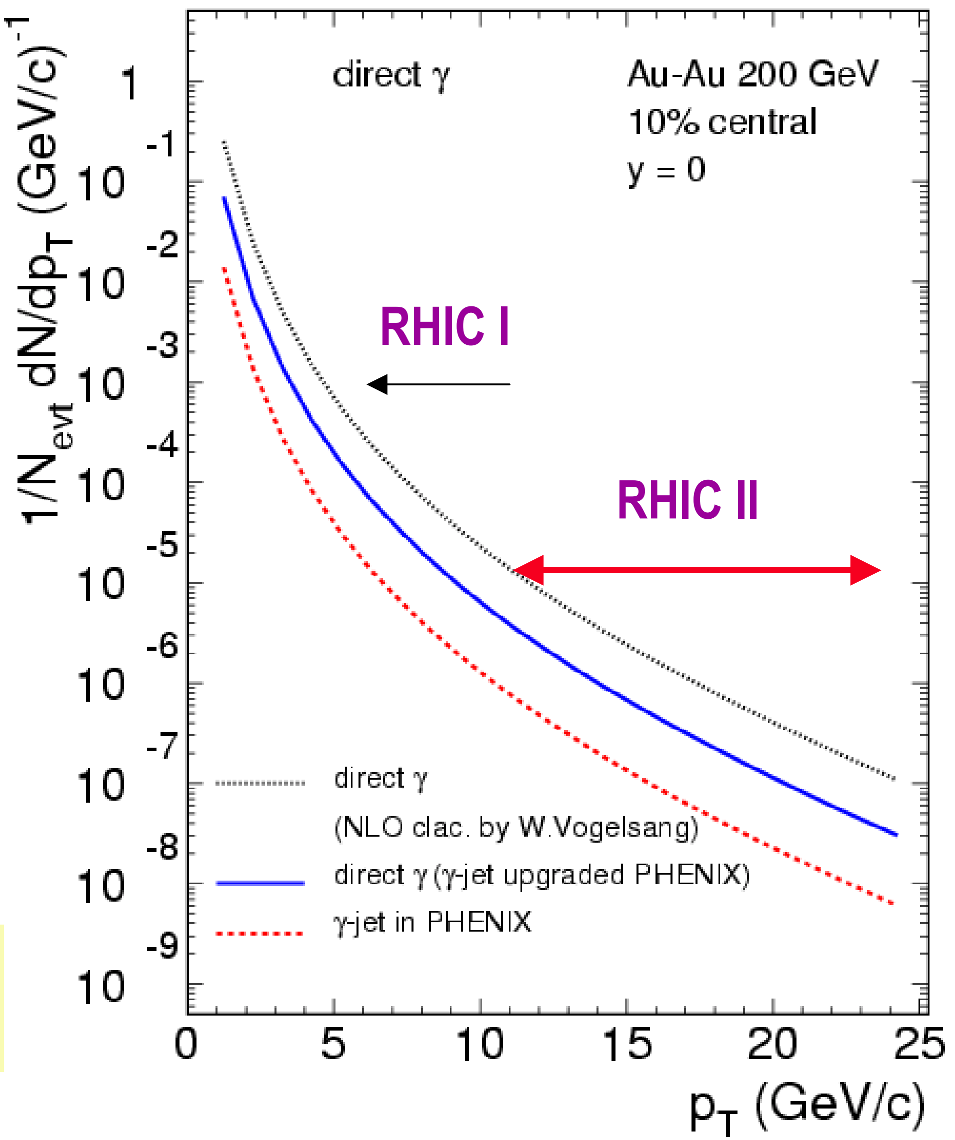
Foreign contributions: $ 4-10 M
Aerogel: US-Japan ~$500k
VTX: RIKEN: $3 M + 0.5 M R&D

Seeking foreign funding for HBD, NCC, & DAQ

PHENIX

PHENIX Rate Estimates for γ-jet tomography

- **Inclusive direct γ**
  - **Run 4 (on tape) out to >20 GeV (assume more than 10 event/bin)**
- **γ-jet rates**
  - **Need N_γ > 1000/pt-bin for statistical jet-correlation**
  - **Run 4** **E_γ~6 GeV** **(jet in central arm acceptance)**
  - **Ultimate RHIC I** **E_γ~12 GeV**
  - **RHIC II** **E_γ~23 GeV**
    - **10x Luminosity**
    - **2x IR diamond size**
    - **5x TPC acceptance**



Breakthrough to jet tomography requires RHIC II

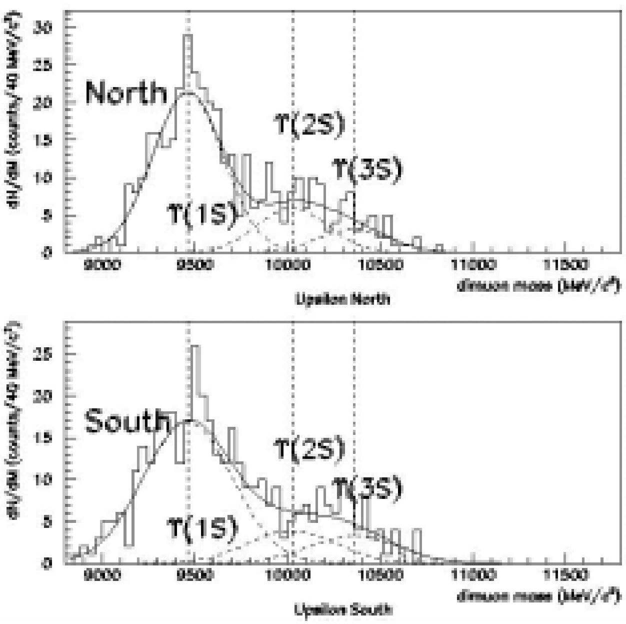
PHENIX

Upsilon Spectroscopy with RHIC II Luminosity

Assume RHIC II run with 30 nb^{-1}
& run 2 based reconstruction efficiency

Upsilon	mass (GeV)	Br(μμ) %	relative cross section	relative Br σ
Υ(1S)	9.460	2.48	1	1
Υ(2S)	10.023	1.31	0.36	.19
Υ(3S)	10.355	1.81	0.25	.18

- **Muon arms:**



total of ~ 700 $\Upsilon \rightarrow \mu\mu$ reconstructed decays

north muon arm: $\sigma_m \sim 190$ MeV

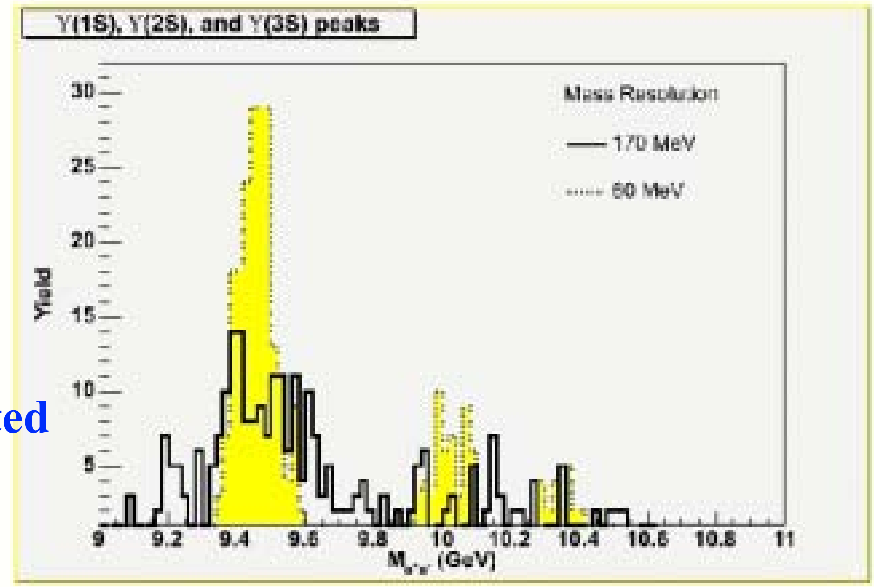
south muon arm $\sigma_m \sim 240$ MeV

- **Central arms:**

total of ~ 150 $\Upsilon \rightarrow ee$ decays reconstructed

original setup $\sigma_m \sim 170$ MeV

upgraded setup $\sigma_m \sim 60$ MeV



PHENIX