Drell Yan Measurements at RHIC II

- **Strong Interaction Physics at BNL**

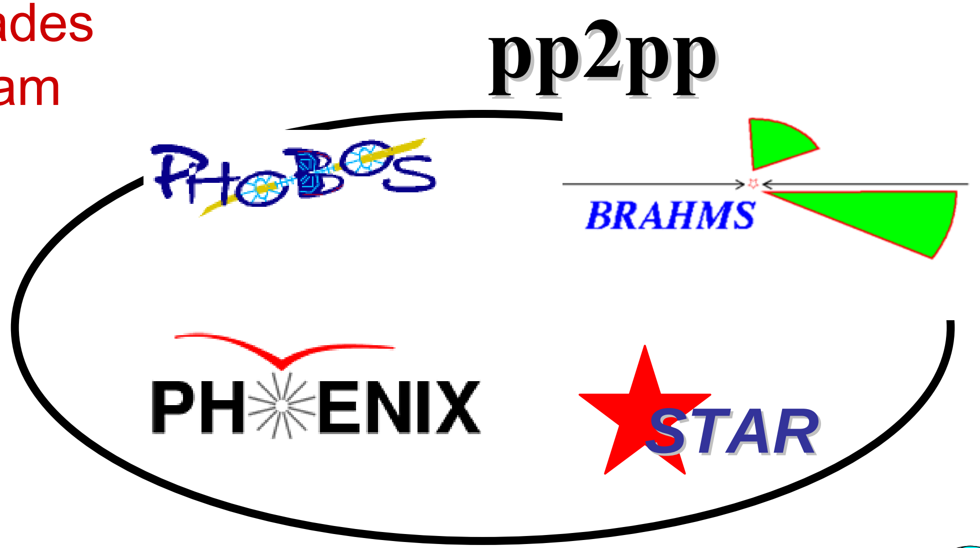
  RHIC ➔ RHIC II ➔ e-RHIC

- **RHIC II**

  Luminosity and Detector Upgrades
  Overview of the Physics Program

- **Transverse Spin Physics**

  Collins and
  Interference Fragmentation
  Drell Yan



Strong Interaction Physics at RHIC eRHIC RHIC II

- **Quark Matter at high Temperatures and Densities**

  ion-ion collisions (Cu-Cu, Au-Au: $\sqrt{s_{NN}}$=22.5, 62, 130, 200 GeV)

  10 x higher luminosity, detector upgrades

- **Proton Spin Structure**

  polarized proton-proton collisions (p-p: $\sqrt{s}$=62.4, 200, 500 GeV)

  $\int_{RHIC} L dt \rightarrow 2\ fb^{-1}$, high luminosity transverse spin running?

  polarized e-p

- **Low-x and high parton densities**

  ion-deuteron collisions (d-Au: $\sqrt{s_{NN}}$=200 GeV)

  high luminosity, forward detector upgrades

  e-A scattering

very active field:
> 90 PRL letters
in the first 6 years

RHIC II

RHIC II – Definition

(I) Electron Cooling in RHIC to increase luminosity for HI by factor 10

(II) Detector Upgrades in PHENIX and STAR

target date 2012

Scope and schedule are presently reviewed in context of the long range planning process

⇒ RHIC II upgrades will be carefully coordinated with the effort to build a electron ion collider
→ RHIC as "QCD Lab"

RHIC II: Luminosity Upgrade with Electron Cooling

(from Thomas Roser)

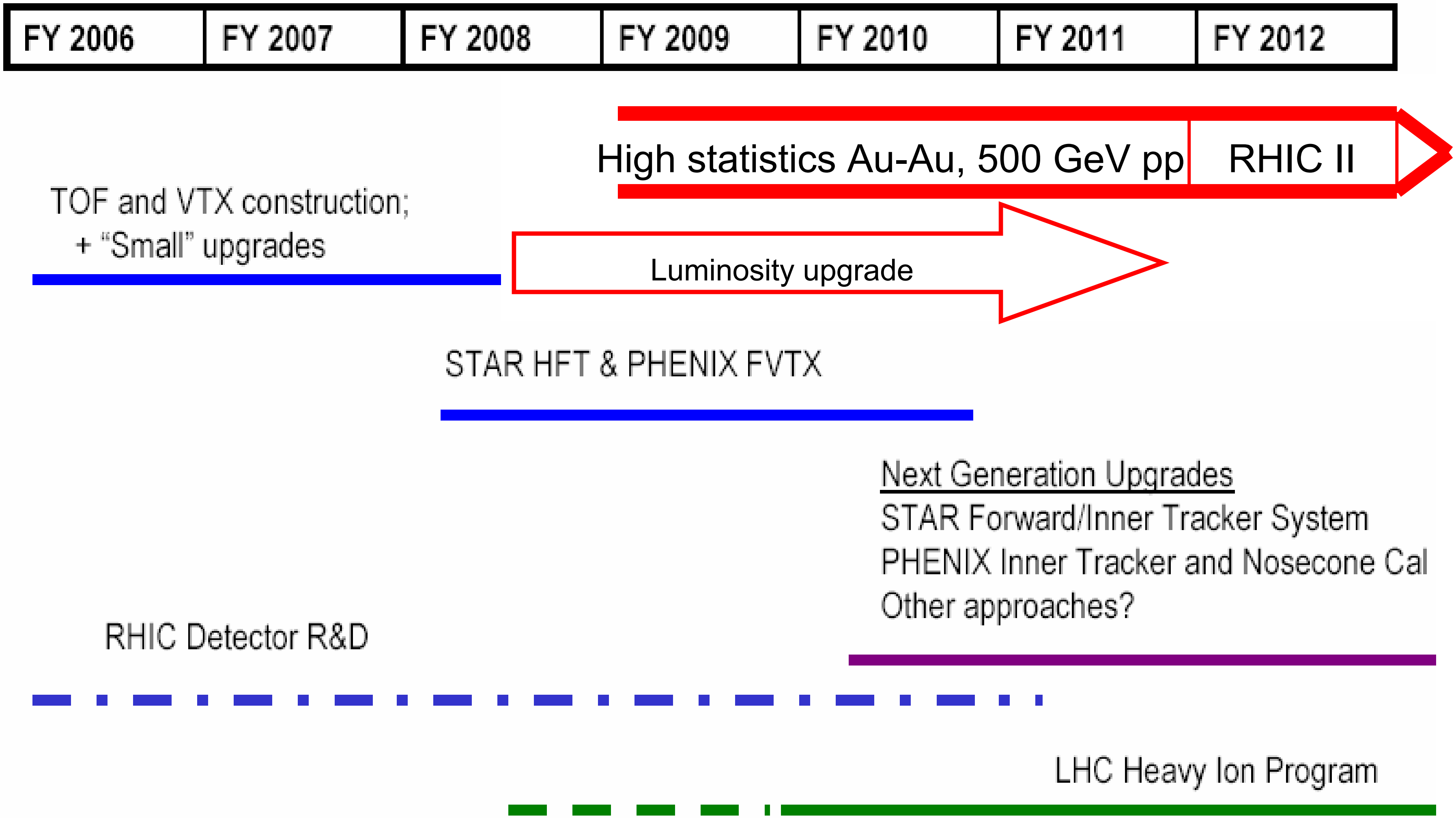
RHIC Luminosity Upgrade with Electron Cooling

Gold collisions (100 GeV/n x 100 GeV/n):	w/o e-cooling	with e-cooling
Emittance (95%) $\pi\mu m$	15 → 40	15 → 3
Beta function at IR [m]	1.0	1.0 → 0.5
Number of bunches	112	112
Bunch population [10^9]	1	1 → 0.3
Beam-beam parameter per IR	0.0016	0.004
Ave. store luminosity [10^{26} cm^{-2} s^{-1}]	8	70

Pol. Proton Collision (250 GeV x 250 GeV):		
Emittance (95%) $\pi\mu m$	20	12
Beta function at IR [m]	1.0	0.5
Number of bunches	112	112
Bunch population [10^{11}]	2	2
Beam-beam parameter per IR	0.007	0.012 ?
Ave. store luminosity [10^{32} cm^{-2} s^{-1}]	1.5	5.0

RHIC II Schedule: Detector Upgrades + Luminosity

Tom Ludlam



p-p Expectations for the RHIC II Luminosity Upgrade

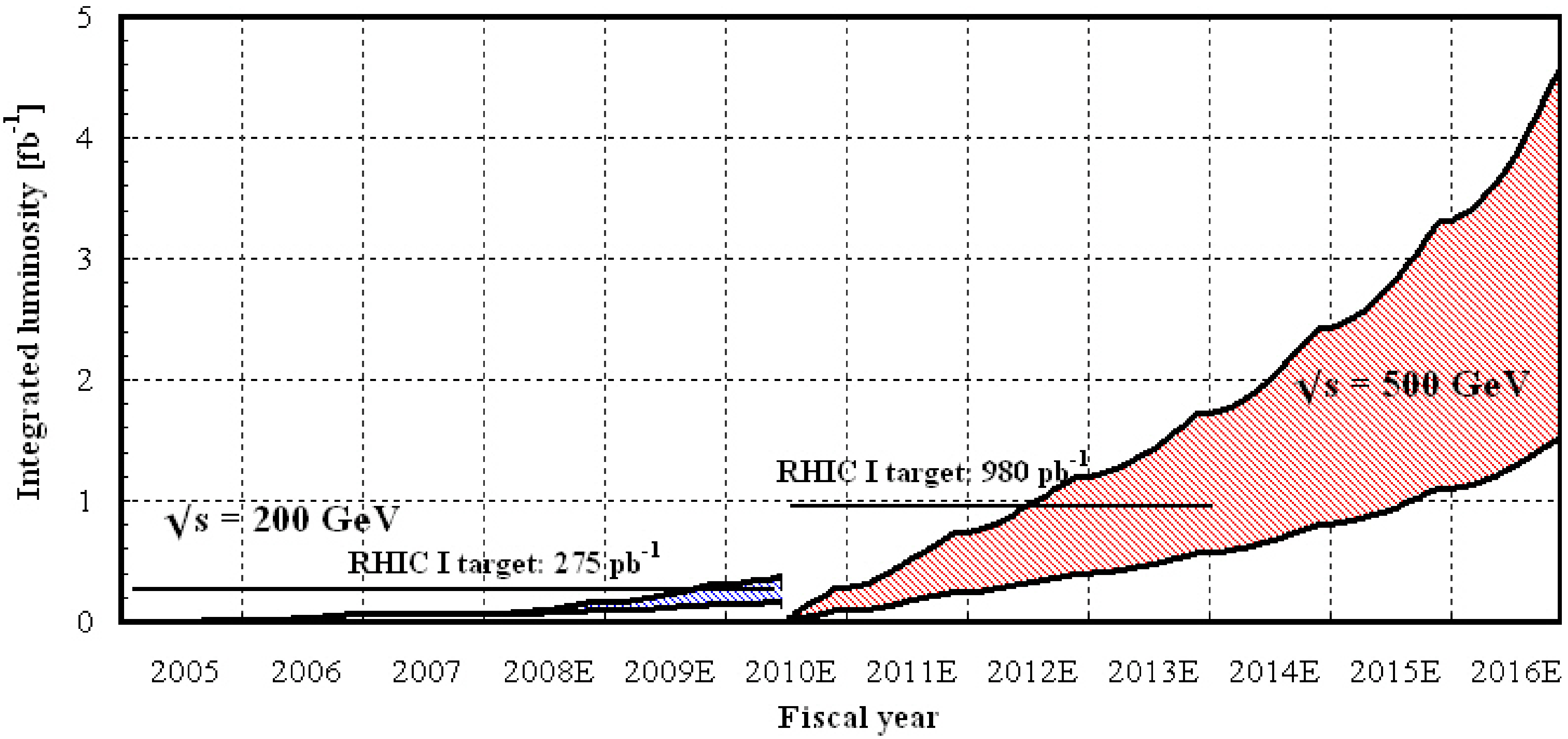
- Factor 2-3 increase in pp luminosity
- Small improvements in polarization
- Maximum energy $\sqrt{s}$ = 650 GeV
- Polarized $^3He^{2+}$ beams may be possible
- Mini-quads at the IRs might provide additional increase in luminosity.

In light of the ongoing discussion related to the long range plan new ideas for luminosity improvements and possibly polarized deuterons are being discussed.

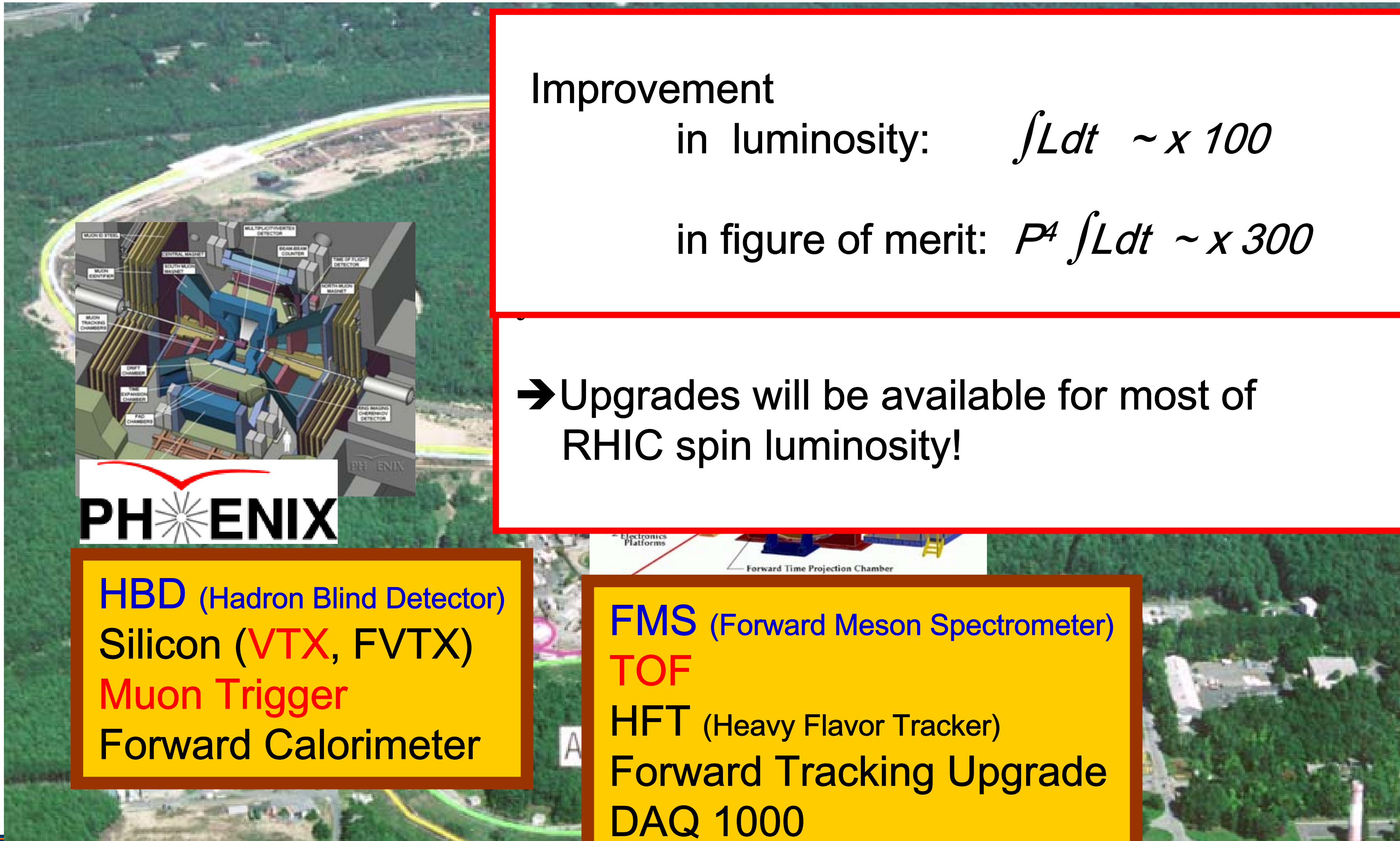
Luminosity Projection

(electron cooling only, no mini-quads)

Wolfram Fischer



RHIC II: Upgrades in STAR and PHENIX



Improvement

in luminosity: $\int L dt \sim x\ 100$

in figure of merit: $P^4 \int L dt \sim x\ 300$

➔Upgrades will be available for most of RHIC spin luminosity!

PHENIX

HBD (Hadron Blind Detector)
Silicon (VTX, FVTX)
Muon Trigger
Forward Calorimeter

FMS (Forward Meson Spectrometer)
TOF
HFT (Heavy Flavor Tracker)
Forward Tracking Upgrade
DAQ 1000

RHIC II Science Workshops: Spin Physics

BNL, October 7-8, 2005

Transverse spin physics: S. Menzel (Bochum), L. Gamberg (Penn State), J. Soffer (Marseille), M. Burkardt (New Mexico), F. Yuan (RBRC), M. Radici (Pavia)

Hyperons : Z. Liang (Shandong), Q. Xu (Shandong+LBL), K. Sudoh (KEK)

W-physics: P. Nadolsky (Argonne), K. Sudoh (KEK), J. Soffer (Marseille)

Beyond the SM: J. Soffer (Marseille), D. Maitre (Zurich)

Talks at http://rhicii-science.bnl.gov/spin/ Organizers: Ernst Sichterman, Marco Stratmann, MGP

RHIC II white paper
http://www.bnl.gov/physics/rhicIIscience/docs/rhic2_wp_draft_dec30.pdf

Spin working group report
http://rhicii-science.bnl.gov/spin/rhicii-spin-20060127.pdf

Drell Yan white paper (input to the long range planning effort)
http://thy.phy.bnl.gov/~vogelsan/drellyan1/dy_final.ps

Physics Channels for RHIC II

(RHIC II Spin Working Group.)

Precision measurement of the proton helicity structure

- o $\Delta G(x)$ and $\Delta q(x)$, $\Delta \bar{q}(x)$ with high luminosity in multiple channels with available detector upgrades. Extend measurements to ^{3}He → neutron.

  ➔ minimize errors and increase x-coverage of $\Delta G(x)$ for precision measurement of the first moment of the spin-dependent gluon distribution $\Delta G = \int \Delta G(x) dx$:

  minimize errors in $$L_z = \frac{1}{2} - \frac{1}{2}\Delta\Sigma - \Delta G$$

  ➔ global QCD analysis for best knowledge of polarized nucleon structure + pdfs

Precision cross section measurements + QCD analysis

- o Measure cross sections in direct photon production, inclusive jet + hadron production as input to QCD analysis to improve knowledge of

  ➔ G(x) at large x
  ➔ Gluon fragmentation function

Physics Channels for RHIC II

(RHIC II Spin Working Group.)

Transverse Spin Physics

- o Extract transversity quark distributions from precision measurements of asymmetries in Collins- and interference fragmentation.
- o Measure Sivers- and transversity-distributions in Drell Yan
- o A_N in direct photon production

➔ direct measurements with good statistical resolution
➔ explore origin of transverse spin phenomena in QCD
➔ study transverse proton spin structure
➔ unique test of factorization & universality for k_T-dependent distribution functions
➔ possible connection to orbital angular momentum

Polarization of the strange sea

- o Access $\Delta s(x)$ through inclusive anti-Lambda production and charm associated W-production (very luminosity hungry)

➔ study polarization of the strange sea
➔ verify Δs from DIS (spin crisis!), neutrinos

Transverse Spin Physics at RHIC with Large ∫Ldt

Transversity : correlation between transverse proton spin and quark spin

$$A_{TT} \propto \delta q(x_1)\delta q(x_2)$$

Collins and Interference FF
∫Ldt > 30 pb^{-1}

Drell Yan
∫Ldt > 1000 pb^{-1}

Sivers : correlation between transverse proton spin and quark transverse momentum

$$A_T \propto q(x_1) \cdot \bar{f}_{1T}^{\perp q}(x_2, k_\perp^2) \cdot \frac{(\hat{P} \times \vec{k}_T) \cdot \vec{S}_P}{M}$$

A_T in Drell Yan
∫Ldt ~ 250 pb^{-1}

Boer/Mulders: correlation between transverse quark spin and quark transverse momentum

$$N(\phi) \propto h_1^{\perp q}(x_1, k_\perp^2) \cdot \frac{(\hat{P} \times \vec{k}_\perp) \cdot \vec{S}_q}{M} \cdot h_1^{\perp \bar{q}}(x_2, \bar{k}_\perp^2) \cdot \frac{(\hat{P} \times \vec{\bar{k}}_\perp) \cdot \vec{S}_{\bar{q}}}{M}$$

A(φ_0) Drell Yan
?, not studied

Transversity, Sivers and Boer Mulders in the Proton Wavefunction

Transversity : correlation between transverse proton spin and quark spin $\delta q(x_2)$

$S_p - S_q$ – coupling ?

Sivers : correlation between transverse proton spin and quark transverse momentum $\bar{f}_{1T}^{\perp q}(x_2, k_\perp^2)$

S_p - L_q – coupling ??

Boer/Mulders: correlation between transverse quark spin and quark transverse momentum $h_1^{\perp q}(x_1, k_\perp^2)$

S_q - L_q – coupling ??

Transverse spin program at RHIC is luminosity limited

Physics channel	Luminosity?
A_N	yes, very good
A_N(back-to-back)	good
A_T (Collins FF)	fair
A_T (Interference FF)	limited
A_{TT} (Jets)	not studied experimentally
A_T (Drell Yan)	
A_{TT}(Drell Yan)	
Direct photons, Ws (A_N,A_T(CFF, IFF))	---

➔ Dedicated Drell Yan experiment for transverse spin physics at RHIC ?

RHIC by 2009 at 200 GeV

$\int Ldt$ ~275pb^{-1} delivered

$\int Ldt$ ~100pb^{-1} accepted (eg. PHENIX: vertex cut, trigger efficiencies, duty factor)

➔ $\int Ldt$ ~25 pb^{-1} transverse

RHIC II

Transversity from spin dependent fragmentation

A_T in p-p and in SIDIS

Collins and IFF asymmetries from e+e-

Global QCD analysis

(for a discussion of the Collins effect see Feng Yuan's talk from yesterday)

Transversity + Tensor Charge from a Global Analysis of e-p, p-p and e^+e^-

SIDIS $\Rightarrow$
- transversity $\times$ Collins
- transversity $\times$ IFF
- HERMES, COMPASS, JLAB, EIC

Factorization
+
Universality ?!

e^+e^- $\Rightarrow$ Collins x Collins
Interference FF x Interference FF

Belle

RHIC / GSI

pp $\Rightarrow$
- A_N for inclusive hadrons, Jets
- A_T in Jets : transversity $\times$ Collins
- transversity $\times$ IFF

GSI
- A_{TT} Drell Yan : transversity $\times$ transversity

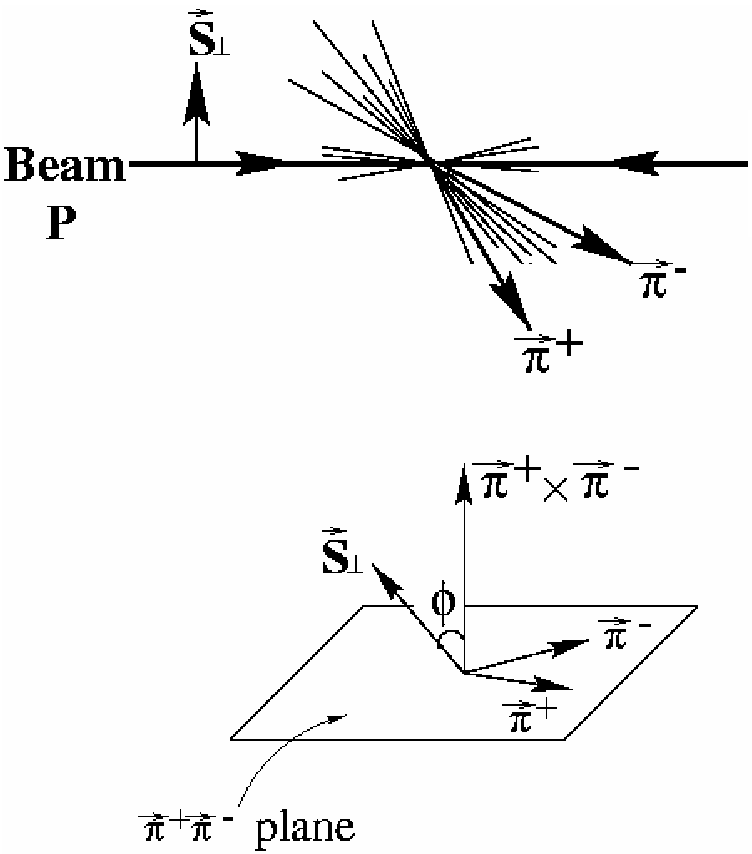
Transversity
Tensor Charge

Theory

Lattice QCD: Tensor Charge

Transverseity from Inter-ference Fragmentation in pp

(Efremov, Collins, Heppelman, Ladinsky, Atru, Jaffe, Jin, Tan, Radici, Jacob, Bacchetta)



$N^{\rightarrow}$: Pion Pair Yield

$\delta q(x)$: Transversity quark DFs

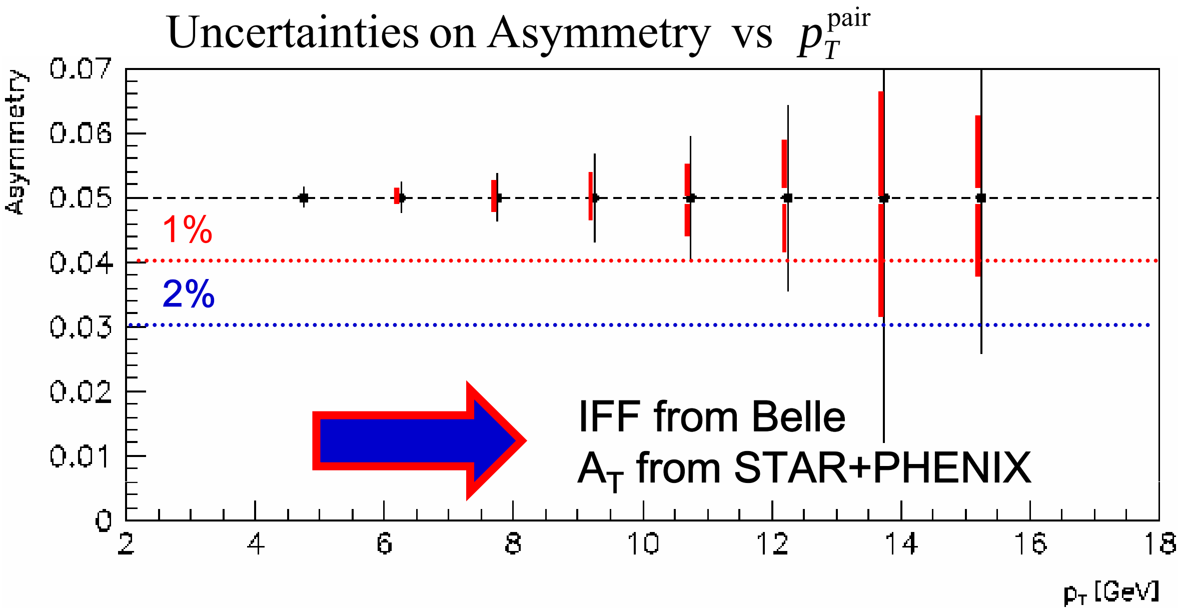
$\delta\hat{q}(z)$: Pol. Fragmentation Func.

$$A_T = \frac{1}{P_{beam}} \frac{N^{\rightarrow} - N^{\leftarrow}}{N^{\rightarrow} + N^{\leftarrow}}$$

QCD analysis of Belle IFF and RHIC A_T in IFF to extract transversity

Projected Errors at for $\int Ldt = 125\ pb^{-1}$ at RHIC II

Projected statistical errors in one invariant mass bin 800 MeV < m < 950 MeV



Sivers in SIDIS vs Drell Yan

- Important test at RHIC of the fundamental QCD prediction of the_non-universality of the Sivers effect!

- requires very high luminosity (~ 250pb^{-1})

DY vs SIDIS, what do we learn?

The Sivers effect arises from soft gluon interactions in the final state (SIDIS) or initial state (Drell Yan).

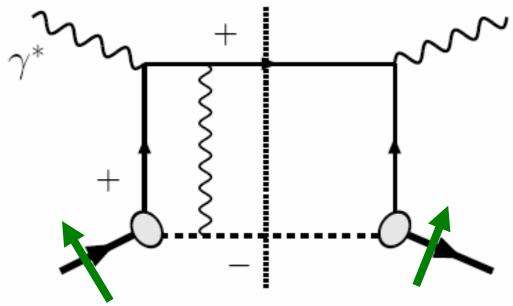
Need to modify naïve concepts of factorization which reduce hard scattering to partonic processes and neglect soft gluon interactions in the initial or final state: hard scattering matrix elements are modified with gauge link integrals that account for initial and final state soft gluon exchange.

A modified concept of universality has been obtained which shows how the presence of initial or final state interactions can impact transverse momentum dependent distribution; eg. the Sivers function changes sign between SIDS and Drell Yan!

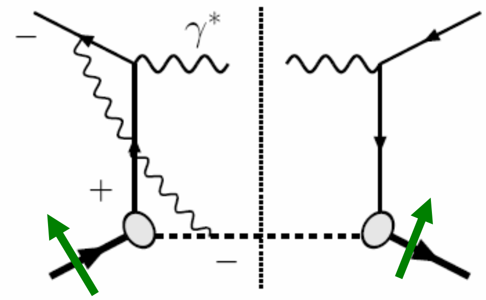
There may be exciting applications elsewhere, eg. other transverse momentum dependent effects or the understanding nuclear effects in hard scattering.

Non-universality of Sivers Asymmetries: Unique Prediction of Gauge Theory !

Simple QED example:



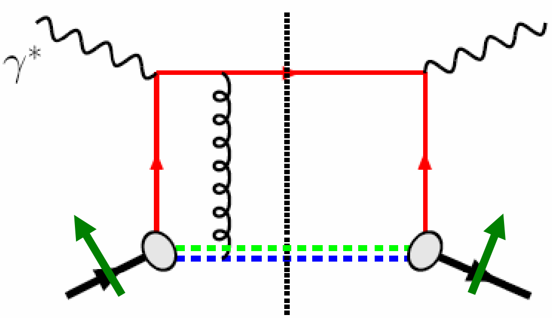
DIS: attractive

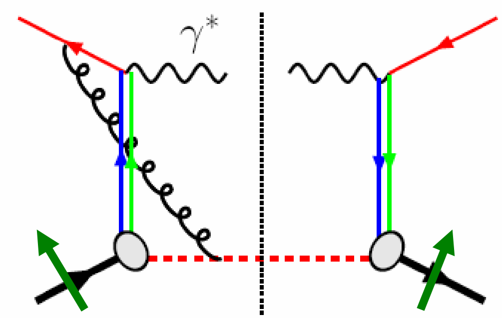


Drell-Yan: repulsive

Same in QCD:

from Werner Voglesang





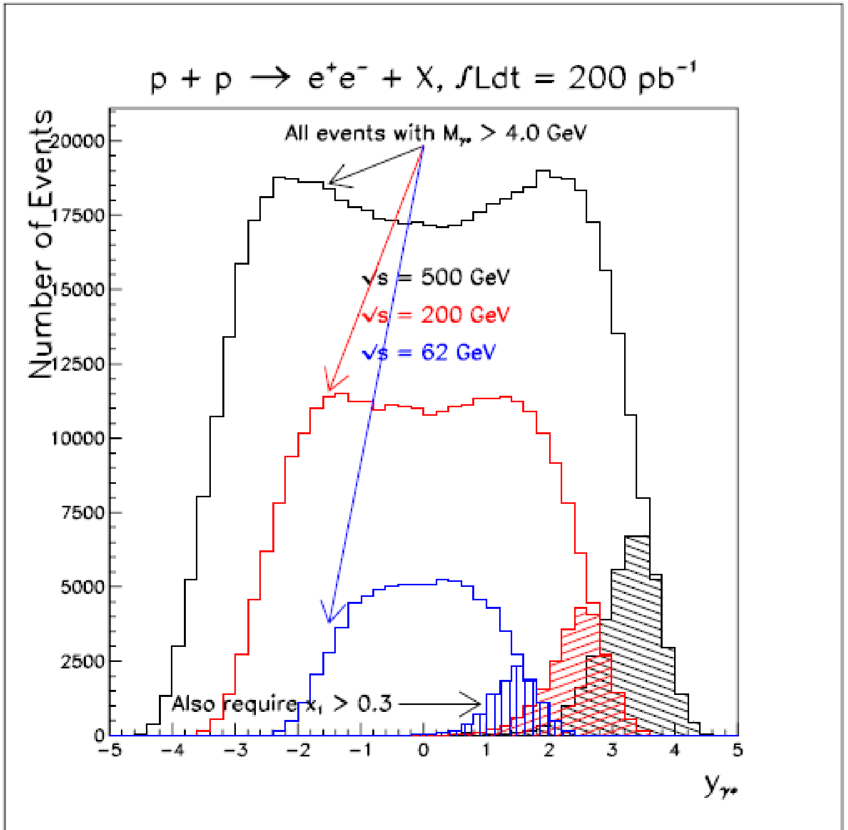
As a result:

$$\text{Sivers}|_{\text{DIS}} = -\text{Sivers}|_{\text{DY}}$$

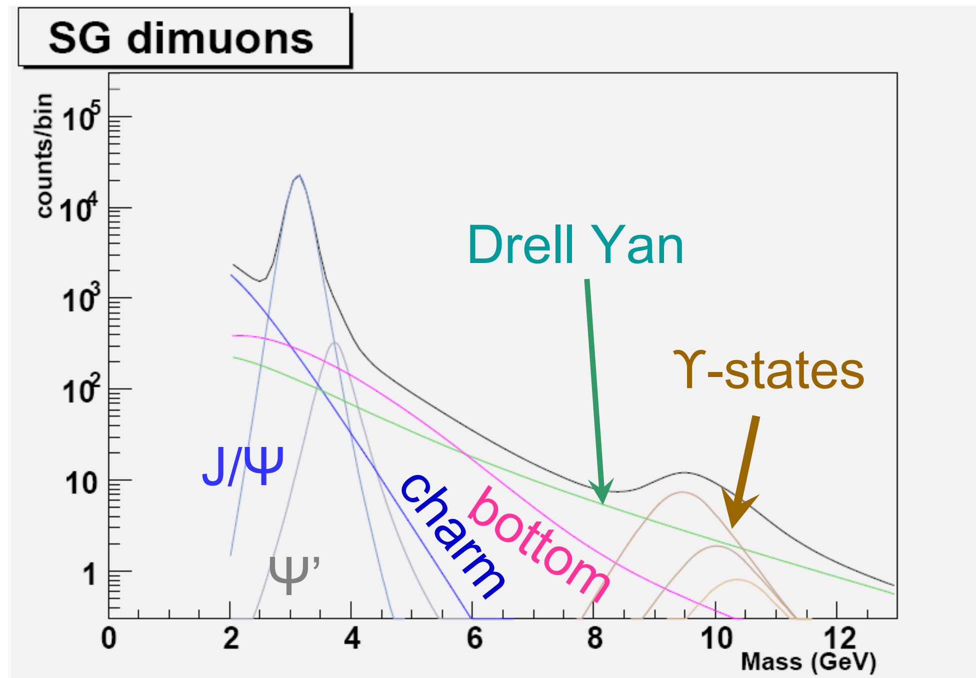
Drell Yan at RHIC

http://thy.phy.bnl.gov/~vogelsan/drellyan1/dy_final.ps

Large x → forward rapidity (Les Bland)



Heavy flavor background (Ming Liu)



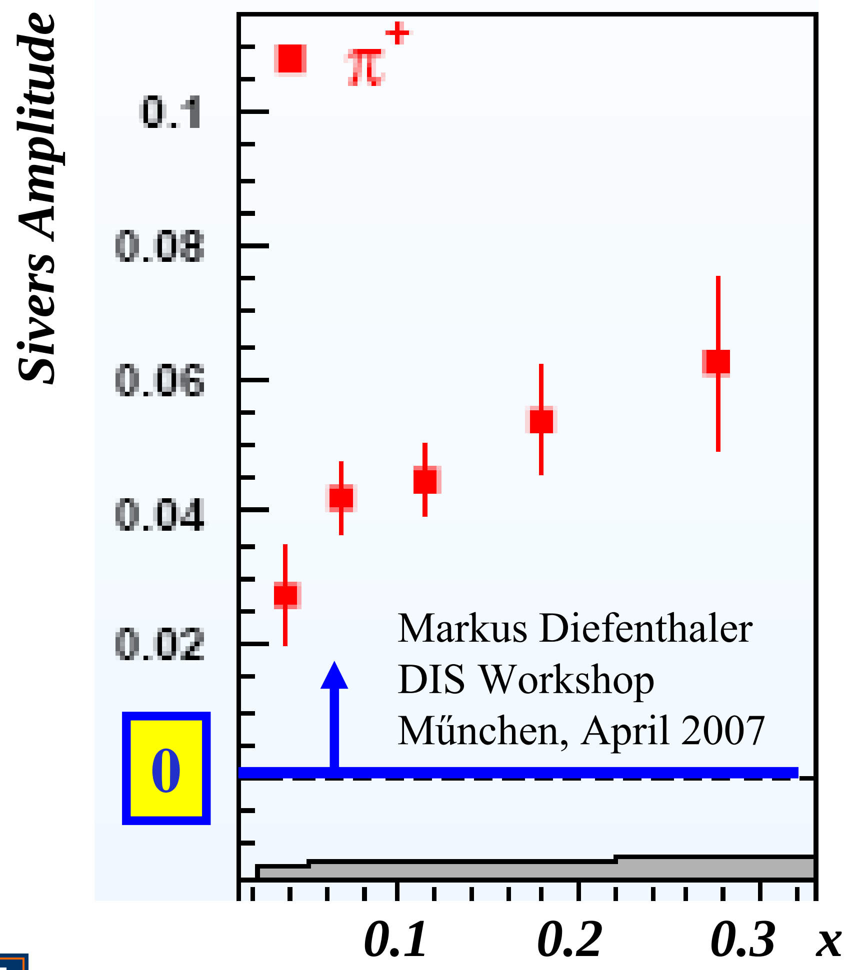
➔4 GeV < Q < 10 GeV

b-background: use FVTX

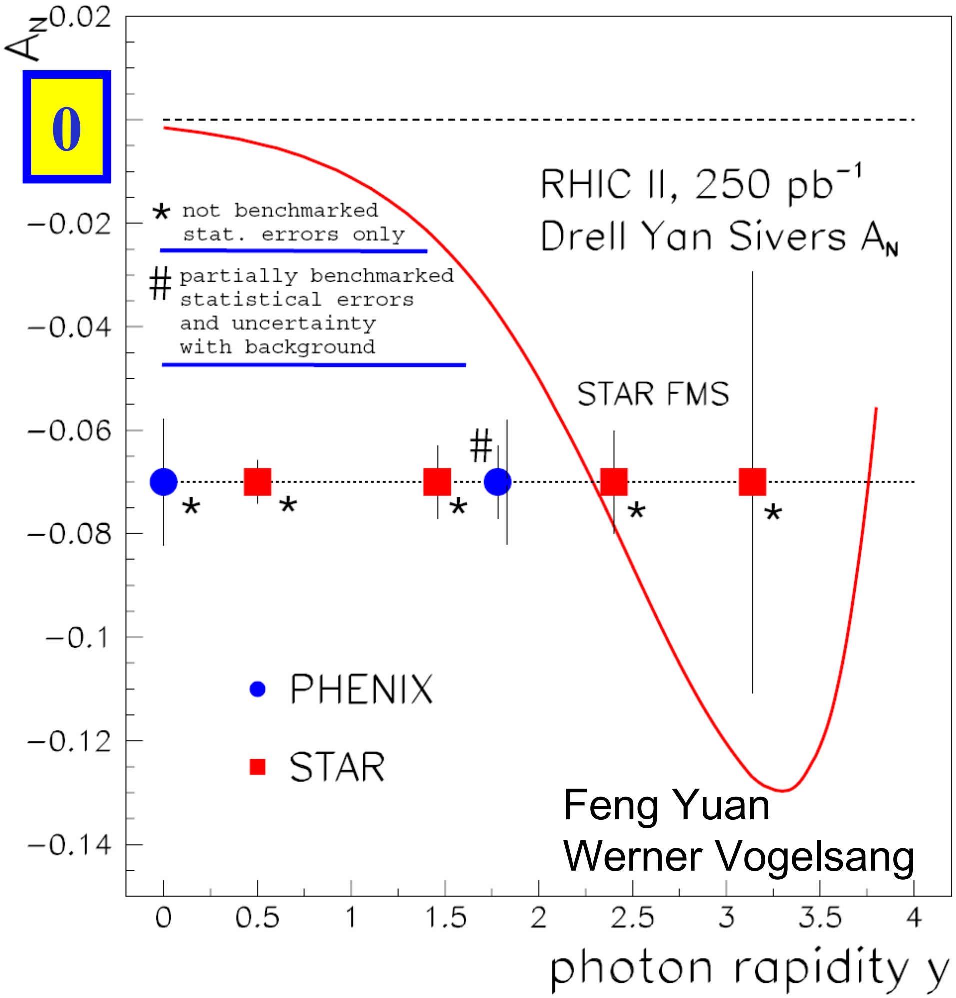
Experiment SIDIS vs Drell Yan: $\text{Sivers}|_{DIS} = -\,\text{Sivers}|_{DY}$

*** Test QCD Prediction of Non-Universality ***

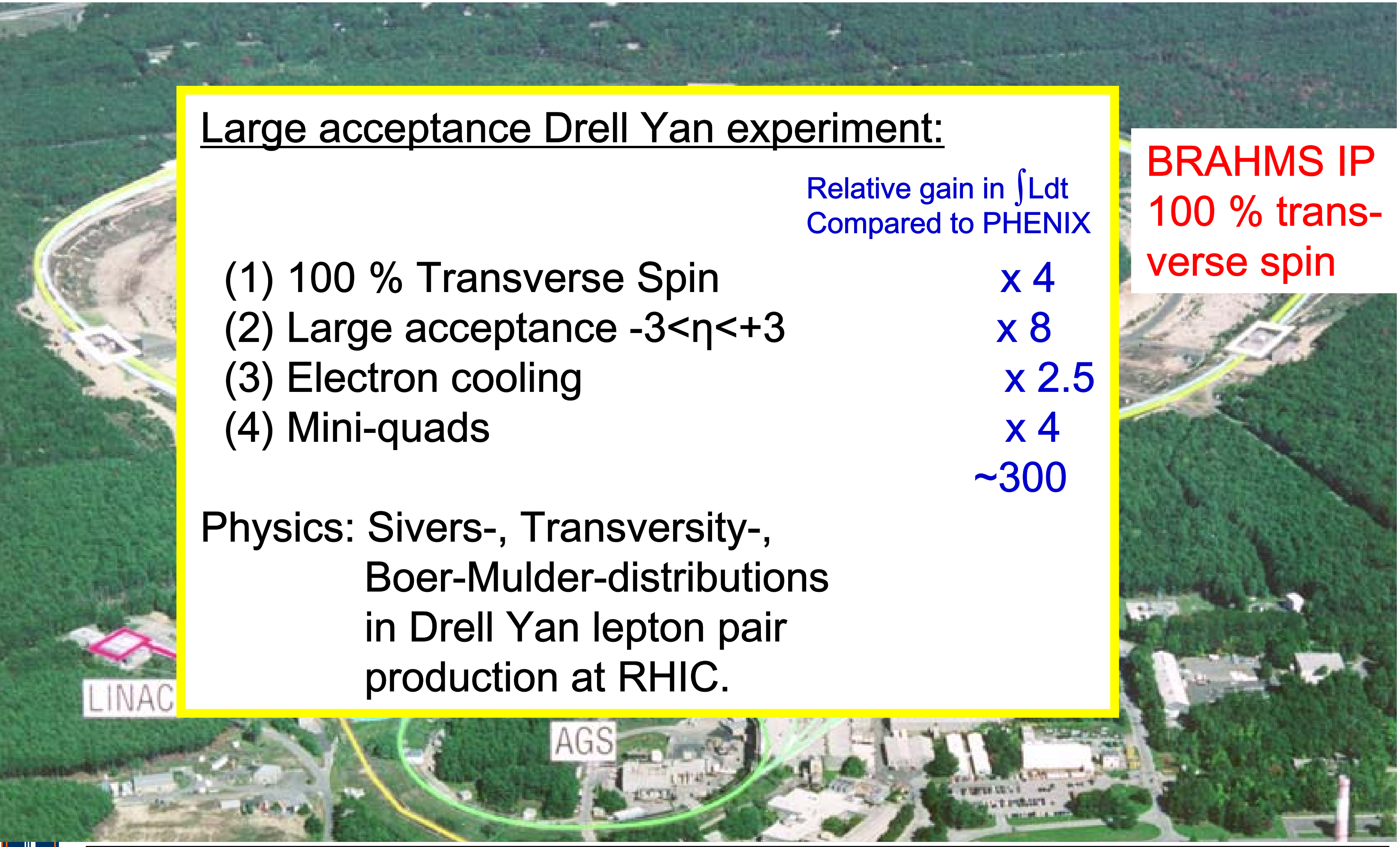
HERMES Sivers Results



RHIC II Drell Yan Projections



RHIC II: Dedicated Drell Yan Experiment ?



Large acceptance Drell Yan experiment:

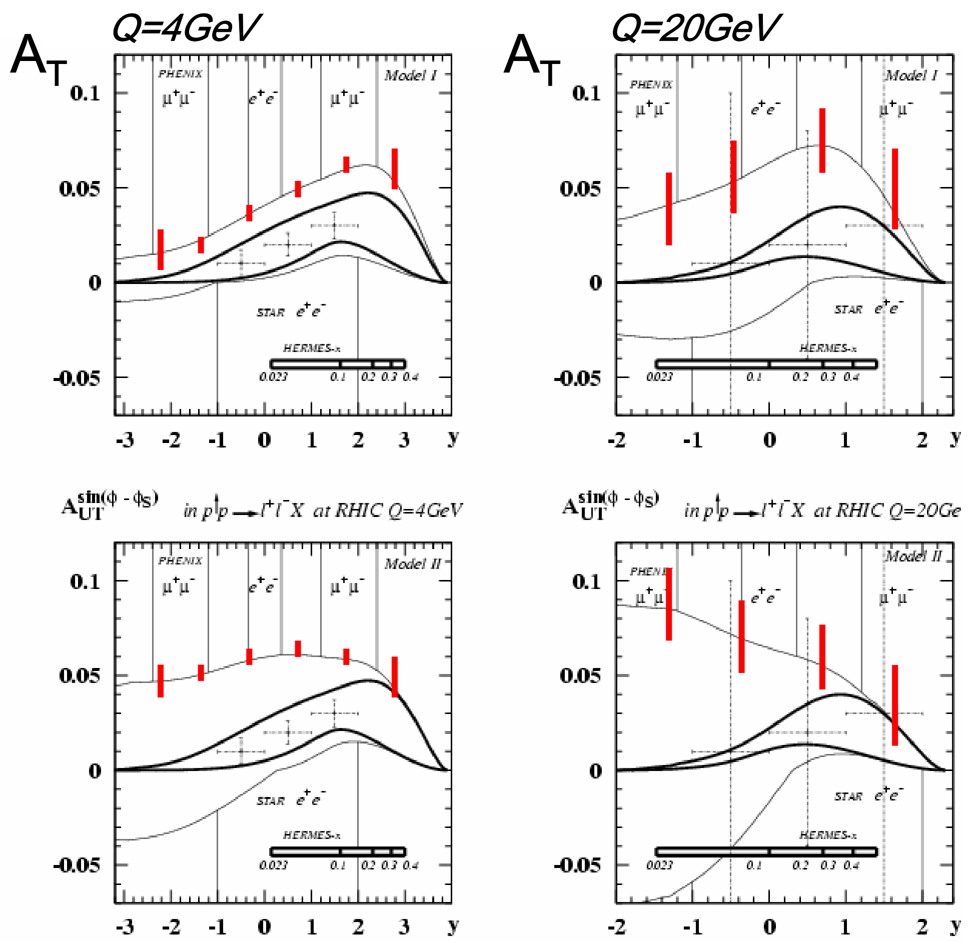
	Relative gain in $\int Ldt$ Compared to PHENIX
(1) 100 % Transverse Spin	x 4
(2) Large acceptance $-3<\eta<+3$	x 8
(3) Electron cooling	x 2.5
(4) Mini-quads	x 4
	~300

Physics: Sivers-, Transversity-,
Boer-Mulder-distributions
in Drell Yan lepton pair
production at RHIC.

BRAHMS IP
100 % trans-
verse spin

Sivers-Asymmetries, A_T in Drell Yan (J. Collins et al.)

Large Acceptance
DY experiment
With $\int Ldt=1250\ pb^{-1}$

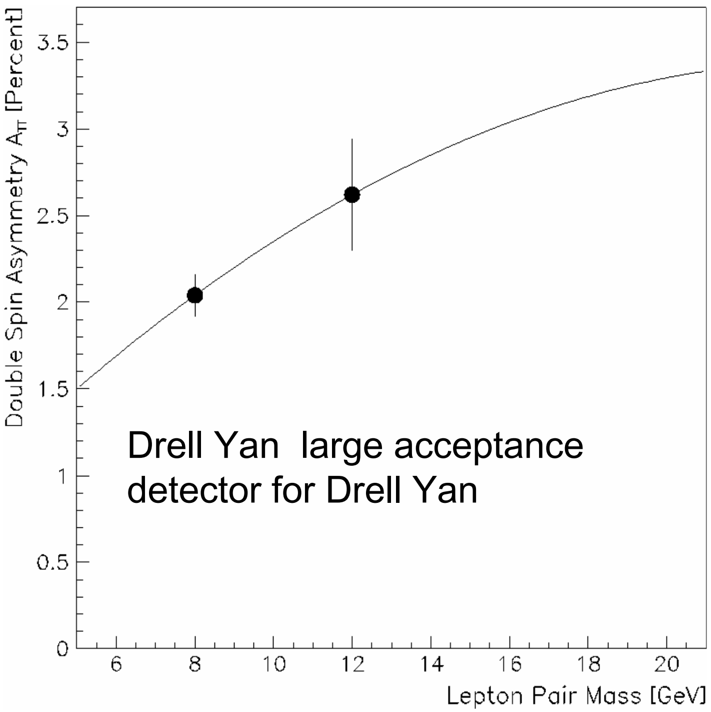


Precision measurement of Sivers distributions ?

Transversity?

A_{TT} for Drell Yan with dedicated DY detector

$$\frac{d\delta\sigma}{dM\,dy\,d\phi} = \sum_q \tilde{e}_q^2 \int_{x_1^0}^{1} dx_1 \int_{x_2^0}^{1} dx_2 \left[\delta q(x_1,\mu_F^2)\delta\bar{q}(x_2,\mu_F^2) + \delta\bar{q}(x_1,\mu_F^2)\delta q(x_2,\mu_F^2)\right] \frac{d\delta\hat{\sigma}}{dM\,dy\,d\phi}$$



coarse estimate for 1250pb^{-1} of running for large acceptance DY-E, “RHIC II ∫Ldt” and 5-10% higher polarization. The estimate was based on Martin, Schaefer, Stratmann, Vogelsang, Phys.Rev.D57:3084-3090,1998.

Summary

Future running of polarized protons at RHIC will lead to data samples a factor 100 larger then the present sample. Assuming a polarization of P=0.7 this will make it possible to increase the figure of merit by more Than two orders of magnitude for longitudinal and transverse spin measurements.

In combination with detector upgrades in STAR and PHENIX this enables a rigorous transverse spin program

(I) Precision measurements of asymmetries in Collins- and Interference-Fragmentation to map out quark transversity distributions.

(II) Access to direct photons

(III) Measurement of the Sivers function in Drell Yan