VTX detector physics reach

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This is an attempt to summarize the physics reach that will be obtained by PHENIX after the VTX barrel and endcap are installed.

Heavy Ion heavy flavor physics topics

Heavy flavor physics measurements that are enabled by, or improved by, the offset vertex capability include almost the entire program:

$B \to J/\psi \to ee, \mu\mu$	Open beauty at all pT
	b quark energy loss
	Nontrivial prompt J/ψ background
$D \to e, \mu$	σ_{cc} baseline
	c quark energy loss (indirect)
	Open charm v_2
$B \to e, \mu$	σ_{bb} baseline
	b quark energy loss (indirect)
$D \to K\pi$	c quark energy loss (direct)
$Y \to ee, \mu\mu$	Separation of Y, Y', Y'' masses
$\psi' \to ee$	Separation of J/ψ and ψ' masses
DD correlations	Background for IM dilepton measurement

Spin physics topics

Spin structure function measurements that benefit from the VTX:

γ + jet	Increased jet acceptance
$c \rightarrow e, \mu$	Increased x range
$b \rightarrow e, \mu$	Increased x range
$B \rightarrow J/\psi \rightarrow ee, \mu\mu$	Possible only with VTX

Assumptions

RHIC I luminosity (circa 2008) from Roser in "2003-0909 RHIC collider projections.pdf".

RHIC II luminosity conditions from Roser in "RHIC II Machine Plans", presented at the Dec 2003 Open Planning Meeting.

$\sqrt{s}$ = 500 GeV is included for p-p.

5+14 week runs at constant peak luminosity.

Integrated luminosities assume exponential decay of stores (stores 4 exponential lifetimes long for RHIC I, 0.2 lifetimes for RHIC II).

RHIC uptime 60%, PHENIX uptime 60%.

Assume that we will be able to archive data at (before compression) 1.2 GB/s for RHIC I and 3.6 GB/s for RHIC II.

RHIC I luminosity (~ 2008)

Assumptions:

5+14 week run
Max. DAQ throughput 6 KHz by ~ 2008
RHIC Z vertex σ = 20 cm, 80% in central peak
Maximum archiving rate 1200 MB/s (before compression)
σ_{BBC}(p-p) = 21.8 mb, σ_{mVTX}(p-p) = 42 mb 20% higher at 500 GeV

Species	Peak RHIC luminosity	Trigger	Z-cut (cm)	Peak MB rate	------Integrated luminosity--------- Total	DAQ	max archived
Au-Au	32×10^{26}	BBC	30	14 KHz	1.70 nb^{-1}	1.32 nb^{-1}	1.18 nb^{-1}
Fe-Fe	1.0×10^{28}	BBC	30	54 KHz	14.4 nb^{-1}	4.80 nb^{-1}	4.80 nb^{-1}
Si-Si	1.33×10^{28}	BBC	30	212 KHz	70.7 nb^{-1}	7.70 nb^{-1}	7.70 nb^{-1}
p-p(200)	0.89×10^{32}	BBC	30	1.3 MHz	47.3 pb^{-1}	0.84 pb^{-1}	0.84 pb^{-1}
p-p(200)	0.89×10^{32}	BBC	**10**	0.6 MHz	21.2 pb^{-1}	0.84 pb^{-1}	0.84 pb^{-1}
p-p(200)	0.89×10^{32}	**mVTX**	**10**	1.15 MHz	21.2 pb^{-1}	0.44 pb^{-1}	0.44 pb^{-1}
p-p(500)	1.5×10^{32}	BBC	30	2.7 MHz	80.9 pb^{-1}	0.70 pb^{-1}	0.70 pb^{-1}
p-p(500)	1.5×10^{32}	BBC	**10**	1.2 MHz	35.8 pb^{-1}	0.70 pb^{-1}	0.70 pb^{-1}
p-p(500)	1.5×10^{32}	**mVTX**	**10**	2.3 MHz	35.8 pb^{-1}	0.37 pb^{-1}	0.37 pb^{-1}

RHIC II luminosity (FEMS not demultiplexed)

Assumptions:

5+14 week run
Max. DAQ throughput 8 KHz by RHIC II
RHIC Z vertex σ = 20 cm, 80% in central peak
Maximum archiving rate 1200 MB/s (before compression)
σ_{BBC}(p-p) = 21.8 mb, σ_{mVTX}(p-p) = 42 mb   20% higher at 500 GeV

Species	Peak RHIC luminosity	Trigger	Z-cut (cm)	Peak MB rate	------Integrated luminosity-------		
					Total	DAQ	max archived
Au-Au	90 x 10^{26}	BBC	30	39 KHz	17.0 nb^{-1}	3.48 nb^{-1}	2.31 nb^{-1}
p-p(200)	5.0 x 10^{32}	BBC	30	7.4 MHz	946 pb^{-1}	1.12 pb^{-1}	1.12 pb^{-1}
p-p(200)	5.0 x 10^{32}	BBC	**10**	3.3 MHz	424 pb^{-1}	1.12 pb^{-1}	1.12 pb^{-1}
p-p(200)	5.0 x 10^{32}	**mVTX**	**10**	6.4 MHz	424 pb^{-1}	0.58 pb^{-1}	0.58 pb^{-1}
p-p(500)	5.0 x 10^{32}	BBC	30	9.0 MHz	946 pb^{-1}	1.12 pb^{-1}	0.94 pb^{-1}
p-p(500)	5.0 x 10^{32}	BBC	**10**	4.0 MHz	424 pb^{-1}	0.94 pb^{-1}	0.94 pb^{-1}
p-p(500)	5.0 x 10^{32}	**mVTX**	**10**	7.7 MHz	424 pb^{-1}	0.49 pb^{-1}	0.49 pb^{-1}

RHIC II luminosity (FEMS are demultiplexed)

Assumptions:

5+14 week run
Max. DAQ throughput 16 KHz by RHIC II
RHIC Z vertex σ = 20 cm, 80% in central peak
Maximum archiving rate 3600 MB/s (before compression)
σ_{BBC}(p-p) = 21.8 mb, σ_{mVTX}(p-p) = 42 mb   20% higher at 500 GeV

Species	Peak RHIC luminosity	Trigger	Z-cut (cm)	Peak MB rate	Integrated luminosity: Total	Integrated luminosity: DAQ	Integrated luminosity: max archived
Au-Au	90 x 10^{26}	BBC	30	39 KHz	17.0 nb^{-1}	7.68 nb^{-1}	6.91 nb^{-1}
p-p(200)	5.0 x 10^{32}	BBC	30	7.4 MHz	946 pb^{-1}	2.24 pb^{-1}	2.24 pb^{-1}
p-p(200)	5.0 x 10^{32}	BBC	**10**	3.3 MHz	424 pb^{-1}	2.24 pb^{-1}	2.24 pb^{-1}
p-p(200)	5.0 x 10^{32}	**mVTX**	**10**	6.4 MHz	424 pb^{-1}	1.16 pb^{-1}	1.16 pb^{-1}
p-p(500)	5.0 x 10^{32}	BBC	30	9.0 MHz	946 pb^{-1}	1.88 pb^{-1}	1.88 pb^{-1}
p-p(500)	5.0 x 10^{32}	BBC	**10**	4.0 MHz	424 pb^{-1}	1.88 pb^{-1}	1.88 pb^{-1}
p-p(500)	5.0 x 10^{32}	**mVTX**	**10**	7.7 MHz	424 pb^{-1}	0.98 pb^{-1}	0.98 pb^{-1}

Implications for triggering

Era	Species	Trigger	Z cut	Luminosity available	% at max MB/s	% archived as minbias	trigger rejection
RHIC I	Au-Au	BBC	30	1.7 nb^{-1}	69	69	-
	Fe-Fe	BBC	30	14.4 nb^{-1}	33	16.5	6
	Si-Si	BBC	30	70.7 nb^{-1}	11	5.5	18
	p-p	BBC	30	47.3 pb^{-1}	1.8	0.9	110
	p-p	BBC	10	21.2 pb^{-1}	4.0	2.0	50
	p-p	mVTX	10	21.2 pb^{-1}	2.0	1.0	100
RHIC II	Au-Au	BBC	30	17.0 nb^{-1}	13.6	6.8	15
	p-p	BBC	30	946 pb^{-1}	0.12	0.06	1700
	p-p	BBC	10	424 pb^{-1}	0.26	0.13	760
	p-p	mVTX	10	424 pb^{-1}	0.14	0.07	1460
RHIC II (demuxed)	Au-Au	BBC	30	17.0 nb^{-1}	41	20	5
	p-p	BBC	30	946 pb^{-1}	0.24	0.12	830
	p-p	BBC	10	424 pb^{-1}	0.53	0.26	380
	p-p	mVTX	10	424 pb^{-1}	0.27	0.14	730

The “mVTX” trigger is a 100% efficient minbias trigger. It records ~ twice as many **events** for the same integrated luminosity. For all cases except RHIC I AuAu, assume we use **50% of the bandwidth** to archive minbias data.

Physics Reach Au+Au (from Craig Ogilvie)

Observable	Trigger	RHIC-I counts/run	RHIC-II counts/run
D =>e pt >1 GeV/c + DCA	e-PID	200K	2M
D =>μ	μ -PID	>10M	>100M
D=>Kπ pt >2 GeV/c + DCA	Min-bias	15K	75K
B =>e pt >2 GeV/c + DCA	e-PID	7K	70K
B =>DCA J/ψ =>μ+μ–	μ -PID	800	8K
Υ =>e+e-	e-PID	16	160
Υ =>μ+μ–	μ -PID	43	430

These are available yields, assuming that we trigger somehow!

Trigger Issues

RHIC I

AuAu: No problems, take all data as minbias

pp: Want better minbias trigger (with Z vertex cut)
May raise 2x2 ERT threshold some?
Need $D \rightarrow K\pi$ trigger (see below)

RHIC II

AuAu: Raise 2x2 ERT threshold to 1.2 GeV → x 30 rejection
- J/ψ efficiency drops at low pT (~ 70%) - but OK
- Photon, Y, high p_T electron - all OK

$D \rightarrow K\pi$ - get enough from minbias?
muon arm trigger rejection OK?

pp: Want better minbias trigger (with Z vertex cut)
Raise 2x2 ERT threshold to 1.2 GeV → rejection increase enough?
- J/ψ, photon, Y, high pT electron

Need $D \rightarrow K\pi$ trigger
- can use recoil electron trigger in other arm, VTX tracks for K, π?
- kaon trigger?

muon arm trigger rejection OK?

It appears the VTX mass will not have a large effect on central arm trigger rejection.
Will we use a 10 cm minbias Z vertex cut when the VTX is in?

c-quark fragmentation fractions

See hep-ph/0312054

c-quark fragmentation functions from γ-p data from ZEUS at HERA (for D, Λ p_T > 3.8 GeV/c, η < 1.6). Agrees quite well with other HERA data for e+e- collisions:

$$f(c \to D^+) = 0.249 \pm 0.014 + 0.004 - 0.008$$
$$f(c \to D^0) = 0.557 \pm 0.019 + 0.005 - 0.013$$
$$f(c \to D_s^+) = 0.107 \pm 0.009 \pm 0.005$$
$$f(c \to \Lambda_c^+) = 0.076 \pm 0.020 + 0.017 - 0.001$$
$$f(c \to D^{*+}) = 0.223 \pm 0.009 + 0.003 - 0.005$$

These may differ for hadroproduction, and **surely** could be different in HI collisions!

So about 45% of c quarks end up as a D^0. This is the basis of Yasuyuki Akiba's suggestion that we use the recoil open charm electron trigger to trigger on events containing a D^0, and use the large acceptance of the VTX to see the K and π tracks. **Needs to be quantified**.

Charmed baryon/meson ratio?

Here are the c-quark fragmentation fractions given on the previous page again:

$f(c \to D^+) = 0.249 \pm 0.014 + 0.004 - 0.008$

$f(c \to D^0) = 0.557 \pm 0.019 + 0.005 - 0.013$

$f(c \to D_s^+) = 0.107 \pm 0.009 \pm 0.005$

$f(c \to \Lambda_c^+) = 0.076 \pm 0.020 + 0.017 - 0.001$

$f(c \to D^{*+}) = 0.223 \pm 0.009 + 0.003 - 0.005$

About 6% of c-quarks end up as a Λ_c - ie. a **charmed baryon**. The obvious question to ask is: could we measure the Λ_c to D^0 ratio vs p_T in Au-Au and p-p? This has to be a revealing ratio!

If we could do it, it would be because the VTX gave us increased acceptance and probably also the displaced vertex measurement to cut background.

Finally

Demultiplexing the FEM's for RHIC II would help considerably with needed trigger rejection. Using a 30 cm Z vertex cut for all collisions would “help” even more. Should we?

The discussion about central arm triggering on May 19 was very useful. Raising the ERT threshold may work in Au-Au and p-p. Quantitative studies are still needed for $D \rightarrow K\pi$ triggering in p-p, to see if using the recoil $D \rightarrow eX$ electron and reconstructing tracks in VTX works.

I would like to understand if the Λ_c measurement is feasible in PHENIX with the VTX capability.

We need a better minbias trigger for p-p.

Muon arm triggering still needs to be looked at in detail for RHIC II.