RHIC II / LHC Comparisons

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Goals and scope

My first attempt to quantify and compare the size of the heavy flavor signals at RHIC II and at LHC.

Of course, because the energies are quite different, we hope to see different **physics effects** at RHIC II and LHC. But we should be able to estimate the size of the heavy flavor signals at the two colliders, to see which physics probes should be accessible.

There are many caveats on the numbers I will show - the detectors are complex, and in some cases do not exist yet. I have tried to include as much realism as possible in all estimates, often by assuming that PHENIX reality factors (which I am most familiar with) apply to all detectors.

I have not yet had time to understand capabilities for open heavy flavor to single leptonic and hadronic decay channels (eg. $D \rightarrow K\pi$), and **so will discuss only quarkonia**. I did not get ATLAS estimates done, so my apologies to ATLAS people.

RHIC II Assumptions and sources

RHIC II performance estimates by BNL CAD department:
http://rhicii-heavy.bnl.gov/doc/RHIC_II_Luminosity_Roser.xls

PHENIX acceptances and efficiencies from various PHENIX internal notes.

STAR acceptances and efficiencies from private communication by Thomas Ullrich.

“ New Detector” acceptances and efficiencies from **“Expression of interest for a comprehensive new detector at RHIC”, P. Steinberg et al. , August 2004.**

LHC Assumptions and sources

LHC performance estimates from: **“Luminosity Determination in ALICE”, Andreas Morsch, September 2002.**

ALICE acceptance and efficiency from: **hep-ph/0311048**

CMS acceptance and efficiency from:
Hard Probes in Heavy Ion Collisions at the LHC: Heavy Flavor Physics hep-ph/0311048 (chapter 9).

Cross sections

Main source is $d\sigma/dy$ vs energy predictions from CEM for J/ψ, ψ' and Υ: “Quarkonium production in heavy ion collisions”, R. Gavai et al., **hep-ph/9502270.**

I assumed:

α = 0.92 for charmonia
α = 1.0 for Upsilons

Detectors

PHENIX:

See talk by Vince Cianciolo on PHENIX RHIC II capabailities.

STAR:

See talk by Jamie Dunlop on STAR RHIC II capabilities.

RHIC New Detector:

See talk by Manuel Calderon on New Detector proposal for RHIC II

ALICE and CMS baseline detectors.

See: “Hard Probes in Heavy Ion Collisions at the LHC: Heavy Flavor Physics:” hep-ph/0311048

Coverages

Detector	Signal	η	p_T
PHENIX	e	-0.35 to 0.35	> 0.2 GeV/c
PHENIX	μ	1.2 to 2.2, -1.2 to -2.4	
STAR (barrel EMC)	e	-1.0 to 1.0	> 0.2 GeV/c ?
RHIC ND	e	-3.0 to 3.0	> 1.5 GeV/c
RHIC ND	μ	-3.0 to 3.0	> 1.5 GeV/c
ALICE	e	-0.9 to 0.9	> 5.2 GeV/c (ee)
ALICE	μ	2.5 to 4.0	
CMS barrel	μ	-0.8 to 0.8	> 3.5 GeV/c
CMS endcap	μ	-2.4 to 2.4	

Reality factors

There are no "unimportant details".

After we multiply the **geometric acceptance** by the **cross section** by the **delivered luminosity** by the **detector uptime**, we still have to add some **reality factors**. For example:

- Minimum bias trigger efficiency
  (0.75 in pp hard processes for PHENIX, 0.92 in AuAu for PHENIX)
- Collision vertex cut (0.8 of beam in central bucket at RHIC)
- Collision vertex cut (0.7 of central bucket for PHENIX VTX in +/- 10 cm)
- Level 1 trigger efficiency (typically 0.8)
- Pair reconstruction and PID efficiency (typically 0.8 in pp, 0.4 in AuAu).
- **Displaced vertex cut for open B (about 0.4 at 1 mm)**

Example reality factors:

0.75 x 0.8 x 0.7 x 0.8 x 0.8 x **0.4** = **0.11** for pp B $\rightarrow J/\psi$

0.92 x 0.8 x 0.7 x 0.8 x 0.4 x **0.4** = **0.07** for AuAu B $\rightarrow J/\psi$

0.92 x 0.8 x 0.7 x 0.8 x 0.4 = **0.16** for AuAu J/ψ

PHENIX / STAR / New RHIC Detector

12 week **p+p run at 200 GeV** at RHIC II - **238 pb^{-1}** sampled
Numbers are expected yields after background subtraction

Signal	**PHENIX**	$\lvert\eta\rvert$	**STAR**	$\lvert\eta\rvert$	**ND**	$\lvert\eta\rvert$
J/ψ → ee	55,000	< 0.35	1,598,00	< 1	5,094,500	< 3
J/ψ → μμ	470,000	1.2-2.4			5,094,500	< 3
ψ' → ee	990	< 0.35	28,812	< 1	92,000	< 3
ψ' → μμ	8,450	1.2-2.4			92,000	< 3
χ_c → eeγ	3,630	< 0.35	?		788,000	< 3
χ_c → μμγ	139,000	1.2-2.4			788,000	< 3
Y → ee	210	< 0.35	8,300	< 1	17,600	< 3
Y → μμ	530	1.2-2.4			17,600	< 3
B → J/y → ee	**369**	**< 0.35**	**19,000**	**< 1**	**34,000**	**< 3**
B → J/y → μμ	**3,689**	**1.2-2.4**			**34,000**	**< 3**

PHENIX / STAR / New RHIC Detector

12 week **d+Au run at 200 GeV** at RHIC II - **446 nb^{-1}** sampled
Numbers are expected yields after background subtraction

Signal	**PHENIX**	$\|\eta\|$	**STAR**	$\|\eta\|$	**ND**	$\|\eta\|$
$J/\psi \to ee$	30,000	< 0.35	880,000	< 1	1,560,000	< 3
$J/\psi \to \mu\mu$	248,000	1.2-2.4			1,560,000	< 3
$\psi' \to ee$	540	< 0.35	15,900	< 1	28,100	< 3
$\psi' \to \mu\mu$	4,650	1.2-2.4			28,100	< 3
$\chi_c \to ee\gamma$	1,970	< 0.35	?		241,000	< 3
$\chi_c \to \mu\mu\gamma$	76,300	1.2-2.4			241,000	< 3
$Y \to ee$	185	< 0.35	8,200	< 1	8,700	< 3
$Y \to \mu\mu$	470	1.2-2.4			8,700	< 3
$B \to J/y \to ee$	**330**	**< 0.35**	**14,100**	**< 1**	**33,600**	**< 3**
$B \to J/y \to \mu\mu$	**4,390**	**1.2-2.4**			**33,600**	**< 3**

PHENIX / STAR / New RHIC Detector

12 week **Au+Au run at 200 GeV** at RHIC II - **18 nb^{-1}** sampled
Numbers are expected yields after background subtraction
STAR charmonium from minbias only (100 Hz)

Signal	**PHENIX**	$\|\eta\|$	**STAR**	$\|\eta\|$	**ND**	$\|\eta\|$
$J/\psi \rightarrow ee$	44,600	< 0.35	8,000	< 1	4,290,000	< 3
$J/\psi \rightarrow \mu\mu$	395,000	1.2-2.4			4,290,000	< 3
$\psi' \rightarrow ee$	800	< 0.35	140	< 1	77,300	< 3
$\psi' \rightarrow \mu\mu$	7,100	1.2-2.4			77,300	< 3
$\chi_c \rightarrow ee\gamma$	2,930	< 0.35	?		663,000	< 3
$\chi_c \rightarrow \mu\mu\gamma$	116,800	1.2-2.4			663,000	< 3
$\Upsilon \rightarrow ee$	400	< 0.35	16,400	< 1	34,600	< 3
$\Upsilon \rightarrow \mu\mu$	1,040	1.2-2.4			34,600	< 3
$B \rightarrow J/y \rightarrow ee$	**720**	**< 0.35**	**100**	**< 1**	**66,000**	**< 3**
$B \rightarrow J/y \rightarrow \mu\mu$	**7,320**	**1.2-2.4**			**66,000**	**< 3**

Aside: 500 GeV p+p at RHIC II

12 week **p+p run at 500 GeV** at RHIC II - **1195 pb^{-1}** sampled
Numbers are expected yields after background subtraction
Dramatic increases due to higher cross sections **and** luminosity!

Signal	**PHENIX**	$\lvert\eta\rvert$
$J/\psi \rightarrow ee$	609,000	< 0.35
$J/\psi \rightarrow \mu\mu$	5,483,000	1.2-2.4
$\psi' \rightarrow ee$	11,000	< 0.35
$\psi' \rightarrow \mu\mu$	99,000	1.2-2.4
$\chi_c \rightarrow ee\gamma$	103,000	< 0.35
$\chi_c \rightarrow \mu\mu\gamma$	3,980,000	1.2-2.4
$Y \rightarrow ee$	3,030	< 0.35
$Y \rightarrow \mu\mu$	7,700	1.2-2.4
B → J/y → ee	**9,840**	**< 0.35**
B → J/y → $\mu\mu$	**98,440**	**< 0.35**

ALICE / CMS

1 month **p+p run at 5500 GeV** at LHC - **3 pb^{-1}** sampled
Numbers are expected yields after background subtraction
ALICE p+p luminosity limited by rate. **CMS p+p luminosity?**

Signal	**ALICE**	$\|\eta\|$	**CMS**	$\|\eta\|$
$J/\psi \rightarrow ee$	> 5.2 GeV/c	< 0.9		
$J/\psi \rightarrow \mu\mu$	135,900	2.5-4.0	17,219	< 2.4
$\psi' \rightarrow ee$	> 5.2 GeV/c	< 0.9		
$\psi' \rightarrow \mu\mu$	2,450	2.5-4.0	310	< 2.4
$\chi_c \rightarrow ee\gamma$	> 5.2 GeV/c	< 0.9		
$\chi_c \rightarrow \mu\mu\gamma$	?	2.5-4.0	?	
$Y \rightarrow ee$	830	< 0.9		
$Y \rightarrow \mu\mu$	520	2.5-4.0	3,010	< 2.4
B → J/y → ee	> 5.2 GeV/c	**< 0.9**		
B → J/y → μμ	**3,580**	**2.5-4.0**	**573**	**< 2.4**

ALICE / CMS

1 month **p+Pb run at 5500 GeV** at LHC - **110 nb^{-1}** sampled
Numbers are expected yields after background subtraction
ALICE p+Pb luminosity limited by rate. **CMS p+Pb luminosity?**

Signal	**ALICE**	$\|\eta\|$	**CMS**	$\|\eta\|$
$J/\psi \rightarrow ee$	> 5.2 GeV/c	< 0.9		
$J/\psi \rightarrow \mu\mu$	676,432	2.5-4.0	85,700	< 2.4
$\psi' \rightarrow ee$	> 5.2 GeV/c	< 0.9		
$\psi' \rightarrow \mu\mu$	66,202	2.5-4.0	1,550	< 2.4
$\chi_c \rightarrow ee\gamma$	> 5.2 GeV/c	< 0.9		
$\chi_c \rightarrow \mu\mu\gamma$	?		?	
$Y \rightarrow ee$	6,326	< 0.9		
$Y \rightarrow \mu\mu$	3,954	2.5-4.0	22,960	< 2.4
B → J/y → ee	> 5.2 GeV/c	**< 0.9**		
B → J/y → μμ	**27,300**	**2.5-4.0**	**4,370**	**< 2.4**

ALICE / CMS

1 month **Pb+Pb run at 5500 GeV** at LHC - 500 μb^{-1} sampled
Numbers are expected yields after background subtraction
Luminosity limit from Alice rate for Pb+Pb. **CMS luminosity higher?**

Signal	**ALICE**	$\|\eta\|$	**CMS**	$\|\eta\|$
$J/\psi \to ee$	> 5.2 GeV/c	< 0.9		
$J/\psi \to \mu\mu$	208,600	2.5-4.0	26,400	< 2.4
$\psi' \to ee$	> 5.2 GeV/c	< 0.9		
$\psi' \to \mu\mu$	3,760	2.5-4.0	480	< 2.4
$\chi_c \to ee\gamma$	> 5.2 GeV/c	< 0.9		
$\chi_c \to \mu\mu\gamma$	?		?	
$\Upsilon \to ee$	2,990	< 0.9		
$\Upsilon \to \mu\mu$	1,870	2.5-4.0	10,800	< 2.4
B → J/y → ee	> 5.2 GeV/c	**< 0.9**		
B → J/y → $\mu\mu$	**12,900**	**2.5-4.0**	**2,060**	**< 2.4**

Comments

LHC detectors will also have p+p measurements at 14 TeV. Remember that CMS and ATLAS could run at higher luminosity than Alice.

I have not attempted to quantify the signal/background ratios for the various quarkonia signals. The S/B ratio is best for PHENIX at RHIC II in central arms, but PHENIX also has the smallest signals. All signals are expected to be statistically usable, but the significance will be reduced by background pairs in some cases.

Y yields are large and mass resolution good for ALICE, CMS and ND.
Y yields are large but mass resolution not as good for STAR.
Y yields are smaller and mass resolution good for PHENIX (with VTX).

Charmonium yields are as good or better at RHIC II as in Alice or CMS.
B decay backgrounds will be much larger at LHC.

It should be possible to do quarkonium physics at RHIC II and LHC.

Conclusions - RHIC

We must have the RHIC II luminosity upgrade to get usable statistics for:

- χ_c yields vs η - charmonium ratios
- Upsilonium yields - bottomonium baseline at RHIC temperature
- $B \rightarrow J/\psi$ measurements - critical (background for prompt high p_T J/ψ, open b)
- High statistics charmonium (& open charm) correlations - flow, thermal.
- High statistics charmonium (& open charm) at high p_T - recombin. (E loss)
- ψ' yields - charmonium ratios

We must complete detector upgrades at RHIC in addition to the luminosity upgrades so that we can do:

- χ_c yields vs η - charmonium ratios
- Upsilonium yields - bottomonium baseline at RHIC temperature
- $B \rightarrow J/\psi$ measurements - critical (background for prompt high p_T J/ψ, open b)
- High statistics charmonium (& open charm) correlations - flow, thermal.
- High statistics charmonium (& open charm) at high p_T - recombin. (E loss)

Conclusions - RHIC and LHC - my impression

RHIC II with detector upgrades

Very good J/ψ yields

Can do χ_c decays and ψ'

Can do open charm well

Enough bottomonium for baseline measurement of Υ

Can do baseline open bottom measurement

LHC with ALICE/CMS/ATLAS

Good Υ yields

Can do χ_b decays?

Can do open bottom well

Enough charmonium for baseline measurement

Can do baseline open charm measurement

Different energy = different temperature = physics differences