Physics with Hard/Heavy Probes at sPHENIX/RHIC and Non-MIE Pre-Shower Detector

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July 30, 2013

s/ePHENIX Workfest at RIKEN
highlights via hard/heavy probes (mostly) at LHC
  - e.g. parton energy loss and redistribution
    - parton initial energy tagging

hard/heavy probes at RHIC: sPHENIX

physics prospects of sPHENIX with inner detectors
  - e.g. flavor differential energy loss and redistribution
  - e.g. QCD Debye screening

pre-shower detector

sPHENIX-J activities and prospects

summary
via high $p_T$ probes, e.g. jets, photon–jet correlation

recent highlights include:

- energy loss/redistribution of hard scattered parton
- photon–jet correlation: parton initial energy tagging
Jets at the LHC

- asymmetric di-jets and even mono-jets
- lost jet energy distributed very widely
  - $\Delta R > 0.8 \sim \pi/4$
  - enhancement at low $p_T$
Jet Energy Loss and Redistribution

- high $z_T$ suppression in narrow cone
  - no corresponding enhancement at low $z_T$
- low $z_T$ enhancement in wider cone

\[
\begin{align*}
I_{AA} &= \frac{\text{yield in Au+Au}}{\text{yield in p+p}} \\
\xi &= \ln(1/z_T) \\
z_T &= \frac{p_T^{\text{hadron}}}{p_T^{\text{photon}}} \\
|\Delta\phi - \pi| < \pi/6 & \quad |\Delta\phi - \pi| < \pi/3 & \quad |\Delta\phi - \pi| < \pi/2
\end{align*}
\]
- $\sigma(R=0.2)/\sigma(R=0.3)$ consistent with vacuum jets
  - both for peripheral and central collisions
- no sign of jet broadening
- good agreement with a model with energy loss
PHENIX and ALICE heavy flavor results consistent
  - charm+beauty decay electrons in semi-central collisions

next step: charm/beauty separation
charm and beauty mesons with compatible $<p_T>$
- open charm (average of $D^0$, $D^+$, $D^{*+}$), ALICE
- non-prompt $J/\Psi$ ($\leftarrow B$), CMS

indication of lower suppression of beauty
- cf. PHENIX VTX result?
Quarkonia – Sequentially Melting?

- $\Upsilon(2S)$ more suppressed than $\Upsilon(1S)$
- $\Upsilon(3S)$ even more suppressed
- No signature of sequential melting
- (feed down uncorrected)

CMS, PRL 109, 222301 (2012)
Forward Upsilon at ALICE

- forward $\Upsilon$ at ALICE $\sim$ mid-rapidity $\Upsilon$ at CMS
  - for both central and semi-peripheral collisions

- further systematic ALICE results awaited


- original sales points at higher energies
  - demonstrated very powerful at ALICE/ATLAS/CMS

- RHIC luminosity upgrade to give new opportunities
- more flexibility with EBIS and beam cooling

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**Hard/Heavy Probes at LHC vs. RHIC**

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Enhanced Design</th>
<th>Achieved</th>
<th>Next Upgrade ≥2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>particle energy $E$</td>
<td>GeV/n</td>
<td>— 100 —</td>
<td>— 111 —</td>
<td></td>
</tr>
<tr>
<td>no of bunches $N_b$</td>
<td>...</td>
<td>1.1</td>
<td>1.1</td>
<td>$1.0 \times 10^9$</td>
</tr>
<tr>
<td>bunch intensity $N_b$</td>
<td>...</td>
<td>1.0</td>
<td>0.75</td>
<td>0.5</td>
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<tr>
<td>IP envelope function $\beta^*$</td>
<td>m</td>
<td>2.5</td>
<td>2.8</td>
<td>2.5</td>
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<tr>
<td>rms emittance $\epsilon_n$</td>
<td>mm-mrad</td>
<td>0.5</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>rms bunch length $\sigma_s$</td>
<td>m</td>
<td>0.96</td>
<td>0.93</td>
<td>0.88</td>
</tr>
<tr>
<td>hourglass factor $h$</td>
<td>...</td>
<td>1.6</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>beam-beam parameter $\xi/IP$</td>
<td>$10^{-3}$</td>
<td>36</td>
<td>40</td>
<td>$55 \times 10^{26}$</td>
</tr>
<tr>
<td>peak luminosity $L_{peak}$</td>
<td>cm$^{-2}$s$^{-1}$</td>
<td>8</td>
<td>20</td>
<td>$40 \times 10^{26}$</td>
</tr>
<tr>
<td>average luminosity $L_{avg}$</td>
<td>cm$^{-2}$s$^{-1}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average polarization $P$</td>
<td>%</td>
<td>60</td>
<td>53</td>
<td>55</td>
</tr>
<tr>
<td>calendar time in store</td>
<td>%</td>
<td>300</td>
<td>650</td>
<td>1300 μb</td>
</tr>
<tr>
<td>integrated $L$ per week</td>
<td>...</td>
<td></td>
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</tr>
</tbody>
</table>

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W. Fischer, IPAC’10
- highest energy ≠ optimum physics condition
- RHIC: dedicated to heavy ion (and spin) programs
  - wide collision energy range
    - $10 < \sqrt{s_{NN}} < 200$ GeV
    - phase boundary; transition regime
  - variety of collision systems including asymmetric
    - $\text{Au+Au, Cu+Cu, U+U, Cu+Au, d+Au, p+p, \ldots}$
  - high luminosity
    - average $30 \times 10^{26}$ cm$^{-2}$s$^{-1}$ (2011, Au+Au 200 GeV)
    - cf. LHC peak $5 \times 10^{26}$ cm$^{-2}$s$^{-1}$ (2011, Pb+Pb 2.76 TeV)
  - good time allocation for heavy ion program
    - ave. 9.6 weeks (+ ave. 7.0 weeks of p+p) /year (runs 1–13)
Strategy Feedback from LHC to RHIC

- high $p_T$ probes
- full jet reconstruction
  - electro-magnetic + hadronic calorimeters
- $e^\pm$ and $\gamma$ ID
- large acceptance
- high luminosity
- fast data collection

Questions:
- Quarks strongly coupled interaction mechanisms
- Quasiparticles in medium
- Screening Length
- Thermal Behavior

Observables:
- Jets, Dijets, $\gamma$ - Jet (FF, radiation)
- Charm/Beauty Jets
- $J/\psi$ at multiple energies
- Upsilon (all states)
- Direct $\gamma'$ flow

Needs:
- Large Acceptance
- High Rate
- Electron ID
- Photon ID
- Excellent Jet Capabilities (HCAL)
sPHENIX Basic Strategies

- **PHENIX**
  - fast, selective, precise
  - mid/low $p_T$
  - limited acceptance

- **sPHENIX**
  - fast, (selective,) precise
  - high/mid $p_T$
  - large acceptance

Detectors by US-Japan
Non-MIE Inner Detectors

- precise measurement of charged particles
  - inside magnet/calorimeters
  - tracking
  - particle ID

- electron/hadron ID

- single/double photon ID
transverse and longitudinal jet modifications

→ energy loss and fragmentation
  - comparison between RHIC and LHC
  - model prediction of stronger effects at RHIC

- measurement in wide $p_T$ range
tracking → heavy flavor jets

- charm/beauty hadron and tagged jet
- energy loss and fragmentation of heavy flavor
  - additional exams to models
light (u, d, s), charm, and beauty quarks

- vertex + tracking + electron ID

→ mass hierarchy question
precise $\Upsilon$ measurement separating excited states
→ binding energy (average radius) dependence
→ function of temperature (color Debye length) ?
  – comparison between RHIC and LHC

ref. X.He, this afternoon
rejection of double $\gamma$ from hadron decay

$\rightarrow$ direct $\gamma$ tagged jet: ultimate jet measurement

$\rightarrow$ direct $\gamma$: QCD reference process

- wide $p_T$ range from below 15 GeV/c to above 30 GeV/c
Double $\gamma$ ID $\rightarrow$ High $p_T$ Neutral Mesons

- very high $p_T \pi^0$ suppression
  - present RHIC data up to 20 GeV/c $\rightarrow$ ~ 40 GeV/c
  - constraints on energy loss models
  - check if different behavior at RHIC and LHC
design/simulation/R&D/prototyping
- ongoing/planned activities in Japan, as well as in US
  - ref. Y.Akiba 7/29; K.Nagashima, E.Kistenev, this afternoon
  - cf. PHENIX MPC-EX
    - ref. J.Lajoie, 7/31
  - cf. sPHENIX internal Si tracker
    - ref. Y.Kwon, E.Mannel, this afternoon; A.Taketani, 7/31

especially simulation studies in Japan
- K.Nagashima (Hiroshima U.), this afternoon
  - “naga” = long, “shima” = island
  - many thanks to C.Pinkenburg
- GEANT4 based simulation studies of pre-shower
Pre-Shower Design Parameters

- full azimuth, $|\eta| < 1$, radius ~ 65 cm (?)
  - between inner trackers and EM calorimeter
  - area ~ 6.2 m²
- tungsten absorber (~ 2 $X_0$)
- 1 (or 2?) layer(s) of Si pad/pixel
- in case of 1 layer of 2 ($\phi$) $\times$ 50 (z) mm² at 65 cm
  - $\Delta\phi = 0.003$, $\Delta\eta = 0.08$ (at $\eta = 0$) – 0.05 (at $|\eta| = 1$)
  - ~ 62 k readout channels
- all parameters are very preliminary
- performance study and optimization needed
most of current PHENIX-J group
- Hiroshima U. (Shigaki et al.), U. Tsukuba (Esumi et al.)
- CNS Tokyo (Gunji et al.), Tsukuba U. of Tech. (Inaba), ...

open minded technical collaborations
- RIKEN Nishina Center (PHENIX VTX, sPHENIX tracker)
- T.Ohsugi (spec. appoint. prof., Hiroshima U.)
  - world-class silicon detector expert

funding efforts
- (continuing)
- US-DoE CDO would be very helpful
hard/heavy probes demonstrated more and more

sPHENIX: strategy feedback from LHC to RHIC
- RHIC: optimum facility to explore heavy ion physics
- keeping basic PHENIX strategies: fast, (selective,) precise
- plus: higher $p_T$, larger acceptance

strong physics case via high $p_T$ electron/photon
- to attack most interesting topics now at LHC/RHIC
- highly regarded; aimed at sPHENIX day-1

pre-shower detector for $e^\pm / h^\pm / \gamma / \pi^0$ identification
- activities in Japan toward design/R&D/prototyping
- ref. K.Nagashima, GEANT4 simulation, this afternoon