New experimental conditions in the near future at RHIC and LHC

David Morrison
Brookhaven National Laboratory

Initial Stages 2016
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Defining “near future”

LHC schedule through Run 3

Pb+Pb @ $\sqrt{s_{NN}} = 5.5$ TeV
peak collision rate $\approx 50$ kHz

←past now far future→
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past now far future→
### BNL’s plan for the same time period

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What are “new experimental conditions”? 

- Changes to beam conditions
  - novel collision systems
  - new collision energies
  - higher luminosity

- Changes to experimental equipment
  - higher DAQ rates
  - improved triggering capabilities
  - adding, improving, or replacing subdetectors or even whole experiments

Every single one of these things is happening over the next years
Final PHENIX data is being taken now. Three weeks to go.
Run-16 Small-System (d + A) Beam Energy Scan beam use proposal

FIGURE 3.14: Shown are predictions for d + Au collisions at collision energies = 7.7, 20, 39, 62, 200 GeV from the superSONIC hydrodynamic model for $v_2$ (left) and $v_3$ (right) as a function of transverse momentum.

FIGURE 3.15: Shown are predictions two-particle, rapidity-separated correlations for d + Au collisions at collision energies = 20, 39, 62, 200 GeV from the AMPT model.

32 AMPT calculations of d + Au
superSONIC calculations of d + Au

Discussion of pre-flow at IS2014
J. Orjuela-Koop’s talk IS2016

d + Au beam energy scan: recorded 1.1B events at 200 GeV, successful 62.4 GeV just completed, switching to 20 GeV today!

d + Au @ 200 GeV – 20x 2008 data
improved event plane via endcap silicon detectors

role of pre-equilibrium flow,
time spent in low viscosity sQGP phase – $v_3$ provides additional sensitivity
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Future RHIC Run Plans: The plan for RHIC runs before the BES-II has recently been refined to include independent runs in 2017 and 2018. The change is driven by the desire to permit a sufficiently long run with transversely polarized p+p collisions at 510 GeV in Run-17 (up to 19 cryo-weeks depending on budgetary constraints) to “test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic scattering” (NP Milestone HP13), and the plan to collide isobars ($^{96}$Zr+$^{96}$Zr and $^{96}$Ru+$^{96}$Ru) at 200 GeV in Run-18 (13 cryo-weeks) as a critical test of the contribution from the possible Chiral Magnetic Effect to the various observed charge separation effects.

BNL ALD Berndt Mueller – two weeks ago

If observed effects are due to CME, should scale with $Z^2$
widely separated correlations now needed to be established at very early times
STAR upgrades for $\eta$ coverage, EP determination

Event plane detector (BES II):
$1.8 < \eta < 4.2$

Opportunities for Exploring Longitudinal Dynamics in Heavy Ion Collisions at RHIC
RBRC workshop at BNL, January 2016
Event plane detector for STAR in the BES II

- Expected Performance and Status
  - Event plane resolution studied as a function of centrality and for different EPD setups
  - Optimum reached for \( \geq 12 \) azimuthal segments
  - Factor 2F4 difference for first harmonic EP resolution compared to BBC
  - R&D currently ongoing
  - Proposal by end FY15
  - Built and ready for run FY18

EPD details
- Pie shape detector setup is optimal → symmetry, \( \eta \) segmentation
  - Large area to be covered → plastic scintillator (fast, efficient, cheap)
  - Silicon PhotoMultiplier (SiPM) for readout → cheap, equivalent to standard photomultiplier
  - Detector will be optimized for a limited amount of different tile shapes for cost efficiency

F. Videbaek WWND’15
design driven by LHCb primary physics goals: very welcome “side benefit” excellent forward & backward capability in p+Pb
LHCb: moderating occupancy effects with granularity

Current detector

- UTbX
- UTbV
- UTaU
- UTaX
- Y
- X
- Z

Figure 2.7: Overview of UT geometry looking downstream. The different sensor geometries are colour coded.

- 1526 mm in X and 1336 mm in Y, corresponding to \( \pm 317 \) mrad, and \( \pm 279 \) mrad. The UTbX plane covers wider in X of 1717 mm. Its angular coverage is \( \pm 314 \) mrad and \( \pm 248 \) mrad in X and Y directions, respectively.

The radius of the circular cutout in the innermost sensors is determined by the size of the beam-pipe, the thickness of thermal insulation layer, and the clearance required. The outer radius of the existing beam-pipe at UTbX is 27.4 mm. The current design of thermal insulation, presented in Ref. [19] is 3.5 mm thick aerogel heat shield. We allow for 2.5 mm clearance. These considerations lead to an inner radius of the silicon sensor of 33.4 mm. Due to the 0.8 mm guard ring, the active area starts at 34.2 mm. The central hole leads to an acceptance starting at roughly 14 mrad for straight tracks from the centre of the interaction region. We have verified by simulation that for the typical B decay of interest, we lose only about 5% of the events because one track is in the beam-pipe hole, when compared with tracks reconstructed in the VELO and the outer tracker.

- Each UT sensors is composed of 250 µm thick silicon and a 10 µm metalisation layer.
- The sensors positions are shown as coloured squares in Fig. 2.7. In the central area the track density is very high. To deal with the high density, sensors of thinner strips, and also shorter lengths are used. Sensors shaded in yellow have nominal length, and 95 µm pitch, half that of the nominal sensor. Sensors shaded in pink have both half the nominal pitch and the half nominal length, being about 5 cm long in Y direction. Thus, the central two staves have sixteen sensors each, instead of fourteen. Each of these fine pitch sensors 140 µm – 95 µm

Conclusions & Outlook

LHCb took part in proton-lead data taking

- Cold nuclear matter effects from \( J/\psi \) in proton-lead and lead-proton collisions
- CNM effects from \( (2S) \) in pA and Ap data
- CNM effects from \( (1S) \) in proton-lead collisions
- CNM effects from open charm production in pA collisions
- First observation of the 'ridge' effect in forward region

LHCb took part in the PbPb running as well

- Analysis of Pb-Pb data commencing
- Expected centrality reach at around 50%

Pb+p configuration puts high multiplicity into acceptance

- Analysis of Pb-Pb data commencing
- Expected centrality reach at around 50%

In parallel, inject different gasses in VeLo

- Data available with proton-Argon collisions, with neon gas
- Also: lead-argon collisions

First promising preliminary publicity plots from fixed target mode at LHCb

Much more to come...

– Johan Blouw IS2016
ALICE upgrades: strategy for exploiting luminosity

MAPS-based inner tracker (ITS and MFT)
very low mass, very fast, very precise
ITS: read out Pb+Pb > 100 kHz
40 μm [z,rφ] at low \( p_T = 500 \text{ MeV/c} \)

capability to employ heavy flavors down to low \( p_T \) in manner analogous to light flavors: \( v_n, R_{AA} \)

TPC: read out Pb+Pb ~ 50 kHz
Example: Low mass di-electrons

- Increase statistics
- Suppress combinatorial background ($\pi^0$ Dalitz decays, photon conversion)
- Reduce systematic uncertainty from semi-leptonic charm decays
  - Improved secondary vertex resolution

**ALICE Simulation**

*Current data rate*

*New ITS*

*dedicated low-field run (B=0.2T)*

**ALICE Simulation**

*High data rate*

*New ITS*

*dedicated low-field run (B=0.2T)*
CMS and ATLAS: employing complex triggers

approach to selecting desired events builds on trigger infrastructure developed for p+p being employed very successfully in Pb+Pb and p+Pb

- Uses $L_{\text{int}} = 515 \mu b^{-1}$ of data with a special UPC muon trigger
  - Loose muon L1 trigger
  - Limit of total $E_T < 50$ GeV at L1
  - Maximum of 1 hit in both MBTS inner rings
  - At least one track with 400 MeV measured by high-level trigger tracking algorithm

“At L1, the triggers relied on minimum bias and jet seeds. At HLT, the D meson trigger ran global track reconstruction, including the reconstruction of displaced tracks of secondary origin. Events were saved if the mass of the D-meson candidates were compatible with the expected mass.”

– Kaya Tatar and Krisztián Krajczár (MIT) poster at LHCC meeting March 2016
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Paraphrasing G M, “I think we’re collecting all the charm that’s being delivered.”
Initial stages physics via triggering in p+p, p+Pb

gluon nPDFs through dijet $\eta$ distribution, vector bosons ($W/Z/\gamma$) and di-b-jets

Table

<table>
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<tr>
<th>Process</th>
<th>$N_{\text{evts}}$ at 5.02 TeV</th>
<th>$N_{\text{evts}}$ at 8.16 TeV</th>
<th>Gain</th>
<th>Reference</th>
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<tr>
<td>$Z$ bosons</td>
<td>3 900</td>
<td>24 000</td>
<td>6.1</td>
<td>[5]</td>
</tr>
<tr>
<td>$W$ bosons</td>
<td>21 000</td>
<td>130 000</td>
<td>6.1</td>
<td>[6]</td>
</tr>
<tr>
<td>$J/\psi$ ($p_T &gt; 8.5$ GeV)</td>
<td>13 000</td>
<td>93 000</td>
<td>7.2</td>
<td>[4, 7]</td>
</tr>
<tr>
<td>$\psi(2s)$ ($p_T &gt; 8.5$ GeV)</td>
<td>500</td>
<td>3 600</td>
<td>7.2</td>
<td>[7]</td>
</tr>
<tr>
<td>$\Upsilon(1s)$ ($p_T &gt; 0$ GeV)</td>
<td>4 500</td>
<td>32 000</td>
<td>7.1</td>
<td>[8]</td>
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<td>$\Upsilon(2 + 3s)$ ($p_T &gt; 0$ GeV)</td>
<td>2 000</td>
<td>14 000</td>
<td>7.0</td>
<td>[8]</td>
</tr>
<tr>
<td>DPS: $W + 2$ jets ($p_T &gt; 20$ GeV)</td>
<td>980</td>
<td>7 000</td>
<td>7.1</td>
<td>[9, 10]</td>
</tr>
<tr>
<td>Drell–Yan ($p_T^1 &gt; 9$ GeV, $p_T^2 &gt; 6$ GeV)</td>
<td>700</td>
<td>4 000</td>
<td>5.7</td>
<td>[11]</td>
</tr>
<tr>
<td>$\gamma\gamma$ ($p_T^1 &gt; 25$ GeV, $p_T^2 &gt; 22$ GeV)</td>
<td>150</td>
<td>1 000</td>
<td>6.7</td>
<td>[12]</td>
</tr>
<tr>
<td>4 jets ($p_T^1 &gt; 100$ GeV, $p_T^{2,3,4} &gt; 64$ GeV)</td>
<td>–</td>
<td>190 000</td>
<td>–</td>
<td>[13]</td>
</tr>
<tr>
<td>$tt$–bar</td>
<td>7</td>
<td>90</td>
<td>13.3</td>
<td>[14, 15]</td>
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Complex events – e.g. 4-jet sensitivity to MPI
Blok, Strikman, Wiedemann, EPJ C, 73(6):1, 2013
Meanwhile, at RHIC in the 2020s …

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Color screening for different quarkonia  
Forward spin & initial state physics                  | sPHENIX  
Forward upgrades ?                                    |
| 2024-22 |                                                                      |                                                                                                       |                                                                                    |
| ≥ 2023 ?| No Runs                                                                          |                                                                                                       | Transition to eRHIC                                                            |
sPHENIX: A fantastic high-rate capable detector at RHIC IP8, built around the former BaBar 1.5 T superconducting solenoid, with full electromagnetic and hadronic calorimetry and precision tracking and vertexing, with a core physics program focused on light and heavy-flavor jets, direct photons, Upsilon and their correlations in p+p, p+A, and A+A to study the underlying dynamics of the QGP – physics delivered by 22 weeks of Au+Au, 10 weeks each of p+p and p+A (@ 200 GeV).

*full disclosure: co-spokespersons G. Roland, D. Morrison
sPHENIX in one plot

Initial hard scattered parton virtuality in units of $1$/fm as a function of the local temperature of the QGP medium.

**Jet Virtuality Evolution**
- RHIC $E_T = 20-80$ GeV
- RHIC QGP Medium Influence
- LHC $E_T = 100-1000$ GeV
- LHC QGP Medium Influence

**Temperature [MeV]**
- 100
- 150
- 200
- 250
- 300
- 350
- 400
- 450
- 500
- 550
- 600

**Scale [1/fm]**
- 10

- RHIC
- LHC


Upsilon family 1S, 2S, 3S establish fixed locations in this space.

Vacuum virtuality evolution initially, with medium influence becoming significant as virtuality of parton shower and medium become comparable.
sPHENIX reach exploits RHIC luminosity

for measurements able to use full vertex range
– can sample 0.6 trillion events
RHIC luminosity: more differential measurements

direct photons, charged hadrons

statistical uncertainties based on sPHENIX run plan
RHIC/LHC measurements in 2020s

R_{AA}

Hadrons

Jets

D Mesons

B Mesons

b Jets

X+Jet

Ensemble-based measurements and x+hadron correlations add low p_T reach

Dijets (p_{T,1})

γ+Jets (p_{T,γ})

Z^0+Jets (p_{T,Z})

Double b-Tag (p_{T,1})
Looking forward to the near future

• detectors: as you’d hope, lower mass, higher granularity, larger \( \eta \) coverage, faster readout – but these represent major technical accomplishments

• triggering: much more complex decisions possible – utility is already on display

• fully exploiting luminosity – complementary strategies being pursued, high throughput readout and/or highly complex triggering

• physics relevant to initial stages particularly benefits from these developments

• PHENIX ending data taking; sPHENIX preparing to move in