The STAR iTPC Upgrade

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For the STAR Collaboration
Beam Energy Scan – Phase I Results:

• Seen the turn-off of QGP signatures.
• Seen suggestions of the first order phase transition.
• Not seen conclusive evidence of a critical point.

The most promising region for refining the search is in the lower energies ➔ 19.6, 15, 11.5, 7.7, and lower.

The iTPC Upgrades strengthen the BES II physics program, and enables new key measurements:

• Rapidity dependence of proton kurtosis
• Dilepton program (sys. errors and intermediate mass region)
• Enables the internal fixed target program to cover 7.7 to 3.0 GeV
The STAR Upgrades and BES Phase II

**iTPC Upgrade:**
- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends $\eta$ coverage from 1.0 to 1.5
- Lowers $p_T$ cut-in from 125 MeV/c to 60 MeV/c

**EndCap TOF Upgrade:**
- Rapidity coverage is critical
- PID at $\eta = 0.9$ to 1.5
- Improves the fixed target program
- Provided by CBM-FAIR

**EPD Upgrade:**
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics

Daniel Cebral
18-Jun-2015
RHIC Program Advisory Meeting
Brookhaven National Laboratory
Slide 3 of 40
What is the Current TPC?

- 24 sectors
- 12 on each side
- Large pads for good dE/dx resolution in the Outer sector
- Small pads for good two track resolution in the inner sector

Inner sector 1/12

- 32 Rows
  - 6.2 X 19.5 mm
  - 3940 pads
- 13 Rows
  - 2.85 X 11.5 mm
  - 1750 pads
Current Inner Sector Limitations

• Staggered readout
  – Only 13 maximum possible points
    • Issues in Tracking: recognition and resolution
  – Only reads ~20% of possible gas path length
    • Inner sectors essentially not used in dE/dx

• Essentially limits TPC effective acceptance to $|\eta|<1$
What is the iTPC Upgrade?

Rebuild the readout regions for the inner sectors:
- Pad Planes
- Wire Planes
- Electronics

- 13 Rows
  - 2.85 x 11.5 mm
  - 1750 Pads

- 32 Rows
  - 6.2 x 19.5 mm
  - 3940 Pads

- 40 Rows
  - 4.5 x 15.5 mm
  - 3370 Pads
Pad plane

- Increase coverage. Higher density FEE
- Prototype has been produced and tested
The TPC inner sector upgrade is important for three reasons:

1) It extends the accessible rapidity range

2) It reduces the low $p_t$ cut-in threshold

3) Improves $dE/dx$ resolution

4) Also improves the momentum resolution
Simple Geometry $\Rightarrow$ $\eta$ acceptance

What determines if a track is accepted?
20 hits... fraction of possible > 50%... Enough $dE/dx$ hits

$\eta=0$

- **Outer Sectors**
  - 32 pad rows

- **Inner Sectors**
  - 13 or 40 pads rows

$\eta=0.9$

$\eta=1.0 \Rightarrow$ Current TPC “limit”

$\eta=1.2$

$\eta=1.3$

$\eta=1.5 \Rightarrow$ iTPC “limit”

$\eta=1.9$

$L_T$ cm

- 0
- 15
- 40
- 60
- 120
- 130
- 200

$\eta$
Simple Geometry $\xrightarrow{\text{p}_T}$ $\text{p}_T$ acceptance

STAR Low $\text{p}_T$ acceptance is dependent on the track quality cuts.

Quality tracks require at least 20 hits.

Current TPC low $\text{p}_T$ limit is 125 MeV/c

iTPC low $\text{p}_T$ limit is 60 MeV/c
Do we have any such low $p_T$ tracks?

125 MeV/c track

160 MeV/c tracks

60 MeV/c tracks

Not found

120 MeV/c

160 MeV/c

125 MeV/c track

This is an actual event
Increased rapidity coverage

Increased efficiency for $|\eta| < 1$ mostly due to lower $p_T$ cut-in values
Increased efficiency for $|\eta| < 1.5$ mostly due to tracks exiting the end cap
<table>
<thead>
<tr>
<th>11.5 GeV</th>
<th>Total</th>
<th>Standard TPC</th>
<th>Inner Upgrade</th>
<th>p_T &lt; 60 MeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pions</td>
<td>234</td>
<td>152</td>
<td>+17%</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Kaons</td>
<td>25.3</td>
<td>12.4</td>
<td>+30%</td>
<td>4%</td>
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<td>6%</td>
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<tr>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pions</td>
<td>435</td>
<td>283</td>
<td>+21%</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Kaons</td>
<td>47</td>
<td>22.9</td>
<td>+35%</td>
<td></td>
</tr>
<tr>
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<td>Protons</td>
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<td></td>
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<tr>
<td>Pions</td>
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<td>&lt;20%</td>
<td></td>
<td>90%</td>
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</tr>
<tr>
<td>Protons</td>
<td>&lt;20%</td>
<td>&lt;20%</td>
<td></td>
<td>90%</td>
</tr>
</tbody>
</table>

Additional Tracks Available for Physics

Combining Improved inner tracking AND half field could have even more impact.
Improvements to dE/dx

- dE/dx resolution vs track length from the primary vertex to the edge of the TPC for $|\eta| < 1$ and $p_T > 0.5$ GeV/c.

- dE/dx resolution vs track length for $|\eta| > 1$ and $p_T > 0.5$ GeV/c.

Comparing the iTPC Upgrade with the Existing TPC.
Goals of BES I:
1) Turn–off of QGP
2) Onset of Deconfinement
3) Critical Point

Goals of BES II:
1) Onset of Deconfinement
2) Critical Point

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>µB (MeV)</th>
<th>Events (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.6</td>
<td>205</td>
<td>150</td>
</tr>
<tr>
<td>15.0</td>
<td>255</td>
<td>150</td>
</tr>
<tr>
<td>11.5</td>
<td>315</td>
<td>50</td>
</tr>
<tr>
<td>7.7</td>
<td>420</td>
<td>70</td>
</tr>
<tr>
<td>5.0</td>
<td>550</td>
<td>TBD</td>
</tr>
</tbody>
</table>
## Statistics Needed in BES phase II

<table>
<thead>
<tr>
<th>Collision Energies (GeV):</th>
<th>7.7</th>
<th>9.1</th>
<th>11.5</th>
<th>14.5</th>
<th>19.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Potential (MeV):</td>
<td>420</td>
<td>370</td>
<td>315</td>
<td>260</td>
<td>205</td>
</tr>
<tr>
<td>Observables</td>
<td>Millions of Events Needed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{CP}$ up to $p_T$ 4.5 GeV</td>
<td>NA</td>
<td>NA</td>
<td>160</td>
<td>92</td>
<td>22</td>
</tr>
<tr>
<td>Elliptic Flow of $\phi$ meson ($v_2$)</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td>Local Parity Violation (CME)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Directed Flow studies ($v_1$)</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>asHBT (proton-proton)</td>
<td>35</td>
<td>40</td>
<td>50</td>
<td>65</td>
<td>80</td>
</tr>
<tr>
<td>net-proton kurtosis ($\kappa\sigma^2$)</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>Dileptons</td>
<td>100</td>
<td>160</td>
<td>230</td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td><strong>Proposed Number of Events:</strong></td>
<td>100</td>
<td>160</td>
<td>230</td>
<td>300</td>
<td>400</td>
</tr>
</tbody>
</table>
Elliptic Flow

Elliptic flow results are improved

\[ \left( \frac{v_2(X) - \langle v_2(X) \rangle}{v_2(X)} \right)_Y \]

\[ \sqrt{s_{NN}} \] (GeV)

Centrality (%)
Directed flow of net protons is one of the key BES-I results.
Directed Flow

Open questions remain about the rapidity dependence of the directed flow.

iTPC dramatically improves the results above \( y = 1.0 \).
Directed Flow

The added reach of the iTPC allows a significant measurement of $v_1$ for most centralities.

![Graph showing $v_1$ vs centrality for different pseudorapidity ranges with iTPC and TPC data points.](image)

$1.3 \leq |\eta| \leq 1.4$
Rapidity Density Widths

The Width of the pion rapidity distribution have been suggested to be sensitive to the speed of sound.

Added acceptance of the iTPC allows a measurement of the rapidity widths.
Published STAR results for beam energy dependence of $\kappa\sigma^2$ (top panels) and $S\sigma$/Skellam (lower panels for net protons in Au+Au collisions. The left panel illustrate the effect of $p_T$ selections while the right panels indicate the effects of rapidity selections.
Fluctuation Analysis

The iTPC brings significant new physics with the rapidity dependence of the net-proton kurtosis.

This panel shows the effects of rapidity selections on the $k_s^2$ signal and the projected errors for BESII.
Di-lepton program

- The dominate systematic error on the di-electron experiment is the purity of electrons. The added pad-rows will improve $dE/dx$.

The expected purity for electrons as a function of transverse momentum.

Di-electron program in the Intermediate mass region is now possible with the iTPC.

The expected systematic uncertainty of dielectron excess mass spectrum with the iTPC upgrade compared to the current TPC case.
## Fixed Target Program

<table>
<thead>
<tr>
<th>Collider Energy (GeV)</th>
<th>Fixed-Target Energy</th>
<th>Center-of-mass Rapidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>62.4</td>
<td>7.7</td>
<td>2.10</td>
</tr>
<tr>
<td>39</td>
<td>6.2</td>
<td>1.87</td>
</tr>
<tr>
<td>27</td>
<td>5.2</td>
<td>1.68</td>
</tr>
<tr>
<td>19.6</td>
<td>4.5</td>
<td>1.52</td>
</tr>
<tr>
<td>14.5</td>
<td>3.9</td>
<td>1.37</td>
</tr>
<tr>
<td>11.5</td>
<td>3.5</td>
<td>1.25</td>
</tr>
<tr>
<td>9.1</td>
<td>3.2</td>
<td>1.13</td>
</tr>
<tr>
<td>7.7</td>
<td>3.0</td>
<td>1.05</td>
</tr>
</tbody>
</table>
Target Design 2014 and 2015

Target design:
- Gold foil
- 1 mm Thick
- ~1 cm High
- ~4 cm Wide
- 210 cm from IR

2014: Passive tests
2015: Beams steered to target
Run 14 and 15 Setup

iTPC allows FXT at 7.7, 6.2, and 5.2

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<th>Center-of-mass Rapidity</th>
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<td>1.25</td>
</tr>
<tr>
<td>3.2</td>
<td>1.13</td>
</tr>
<tr>
<td>3.0</td>
<td>1.05</td>
</tr>
</tbody>
</table>
Identifying Target Events

2014 Passive tests using the beam halo

Lots of background, but the target events are evident.

Three weeks of running at 14.5 GeV resulted in a few thousand central Au+Au events.
Au + Au Fixed Target 4.5 GeV

- May 20th 2015 – Test run with lowered beam
- 1.25 millions triggers, ~100k central events

Online Event Display

Data from a 10 minute run through full production

Beam Pipe
Flange

Fixed Target

PrimaryVertices.mPosition.mX3

myHisto
Entries 87965
Mean 127.7
RMS 81.62
Pion Acceptances are good from target to mid-rapidity for all BES II energies.

Proton Acceptances have low $p_T$ acceptance threshold. An iTPC would greatly improve the acceptance reach here.

$iTPC$ allows a physics program from 7.7 to 3.0 GeV in the Fixed target mode.

$y_{cm} = 0$

$7.7$ GeV
Particle Identification using \( \frac{dE}{dx} \) and TOF

Lots of light nuclei

\( \alpha \)   \( h \)

Expanded Y axis
iTPC Pictures
Strong back

Prototype – original drawings

Only modify position of FEE openings. No reduction in thickness. Pure construction project, no engineering and design - but lots of retrieving old knowledge.
Electronics

- FEE based on current FEE, but using ALICE SAMPA chip
- Twice channels per FEE
- RDO similar to existing
- Developments over several years by BNL electronics group

Pre-prototype iFEE (ppFEE) electronic card shown plugged into the padplane
Work in Shandong

- Prototype work; going through all the steps of assembly, winding, gluing and testing
Sector Insertion Tooling

- Concept based on ALICE design
- Cartesian coordinates
• Sector Installation Platform – It is a platform that consists of extension slides that brings the sector manipulation tool into the position for the sector to be installed in the end-wheel.
Conclusions

• iTPC improves the reach of all BES II observables
• iPTC brings significant new physics
  – Radipity dependence of net-proton kurtosis
  – Di-electron program in the Intermediate mass region
  – Internal fixed target program covering 7.7 to 3.0 GeV
• The prospect of getting E-TOF for BESII will also be a boost for the physics.
• The project has made significant progress and has a dedicated team – for both and data analysis
Backup Slides
Simplified Production Plan

- Pad planes at BNL
- Strong backs at UT and/or commercial
- Joining of strong back and pad planes at LBNL
- Wire-winding, mounting at Shandong
- Insertion tooling at BNL
- FEE and RDO,DAQ at BNL
Path forward

• Proposal has been updated since submitted in Feb. New version is now available
• It was realized that project cannot be done for below 2M, and that the insertion tooling is a critical item and should be included
• Review BNL – DOE summer fall 2015
• Most production in FY17,18 – important procurements in FY16
### Planned Cost to DOE

<table>
<thead>
<tr>
<th>WBS</th>
<th>Mgt</th>
<th>FY15</th>
<th>FY16</th>
<th>FY17</th>
<th>FY18</th>
<th>Conting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mgt</td>
<td>92.0</td>
<td>180.5</td>
<td>185.9</td>
<td>125.9</td>
<td>111.5</td>
<td>695.7</td>
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<tr>
<td>2</td>
<td>Electronics</td>
<td>53.3</td>
<td>602.8</td>
<td>38.9</td>
<td>727.8</td>
<td>268.3</td>
<td>1,691.1</td>
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<tr>
<td>3</td>
<td>Mechanics</td>
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<td>423.4</td>
<td>381.4</td>
<td>4.9</td>
<td>173.6</td>
<td>1,053.6</td>
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<td>4</td>
<td>Insertion tooling</td>
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<td>406.2</td>
<td>82.8</td>
<td>0.0</td>
<td>106.1</td>
<td>653.1</td>
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<td>5</td>
<td>Installation</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total DOE</td>
<td>273.7</td>
<td>8</td>
<td>688.9</td>
<td>858.6</td>
<td>659.4</td>
<td>4,093.5</td>
<td></td>
</tr>
</tbody>
</table>

The total planned cost to DOE is $4,093,500.
Wire arrangement

- A sub group has studied wire arrangements to optimize pad layout and looked at ways to reduced grid leak
Elliptic Flow of the \( \phi \) meson

\[
\begin{align*}
(1) \quad \sqrt{s_{NN}} &= 7.7 \text{ GeV} \\
(2) \quad \sqrt{s_{NN}} &= 11.5 \text{ GeV}
\end{align*}
\]
Pion Acceptances

$\gamma_{cm} = 0$
- 2.5 GeV
- 3.0 GeV
- 3.5 GeV
- 4.0 GeV
- 4.5 GeV

$p_T$ (GeV)

$\pi^-$ Rapidity
Clearly, to achieve the physics goals, we need to improve the forward tracking.
Au + Al Results: Spectra and ratios

Paper has been signed off by the working group. Ready for God Parent Committee

Spectra fit with Bose-Einstein Functions

Ratios fit with Coulomb Functions
Pion Ratio and Coulomb Potential Comparison

STAR Preliminary

Paper has been signed off by the working group. Ready for God Parent Committee
Fixed Target Tests
May 2015
The Inner Sector Pads are too small

- The **outer** sector pad size was chosen to match the diffusion limit of P10
  - Width (pitch) in the outer sector is 6.7 mm
  - Tonko has measured an average of 3 pads hit per cosmic ray track
- The inner sector pads were deliberately made smaller (for no good reason except that people expected it, HW)
  - Width (pitch) in the inner sector is 3.35 mm
    - note different pad plane to anode wire spacing & gain (2 mm vs 4 mm)
  - Tonko has measured an average of 4 pads hit per cosmic ray track
- It seems quite reasonable to increase the size of the inner sector pads so that an average of 3 pads are hit per cosmic ray track
  - Note, this does not mean 6.7 mm pitch is best ... due to different gain and wire geometries in the inner and outer sectors
  - Real simulations are required ... but

---

**Outer subsector:**

Roy Bossingham’s simulations of the old pad geometry (3σ) agree with Tonko (~2σ)
TPC Sector Detail – Aging of the Anode Wires

- Gating Grid
- Ground Shield
- Anode
  - 4 mm pitch, no field wires
  - Spacing: inner ≠ outer
- Pad Plane

Sector Operation for 20:1 signal to noise

<table>
<thead>
<tr>
<th>Sector</th>
<th>anode voltage</th>
<th>gas gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>inner</td>
<td>1170</td>
<td>3770 ± 10%</td>
</tr>
<tr>
<td>outer</td>
<td>1390</td>
<td>1230 ± 10%</td>
</tr>
</tbody>
</table>
Pad Size: Constraints & possibilities ...

*Numbers, not science*

- The outer sectors are **6.7 mm x 20 mm** (pitch)
- The inner sectors are **3.35 mm x 12 mm** (pitch)
- The full range of possibilities for the new inner pad plane
  - Height from 12 mm to 20 mm (nb: 0.5 mm gap on all edges)
    - Note: only 12, 16 and 20 mm match anode wire spacing (3x, 4x, 5x)
  - Width from 3.35 to 6.7 mm

  Limited choices in the vertical dimension

  Horizontal dimension will be determined by physics and engineering

- Translate to number of electronic channels
  - 6,650 channels if 3.35 by 12 mm (50 rows)
  - 2,000 channels if 6.7 by 20 mm (30 rows)
    - Currently 1,750 channels in 13 rows (widely spaced at ~5 cm)
  - Range is from 1 to 4x number of channels (for hermetic coverage)
    - 1x would accommodate 6.7 x 20 pad pitch (87% coverage, 30 rows)
    - 2x would accommodate 4.8 x 16 pad pitch (100% coverage, 40 rows)
    - 3x would accommodate 4.2 x 12 pad pitch (100% coverage, 50 rows)

  For reference, ALICE uses 4x7 pads, but note that Neon-CO2 has better diffusion characteristics so we expect smaller pads in their case.

Optimize this number for performance cost and engineering factors.
Implications for $dE/dx$

This one shows $\sigma_{dE/dx}/(dE/dx)=8\%$ at $L=76$ cm
- $\sim 1.5\sigma$ $K-\pi$, $2.5\sigma$ $p-\pi$: $1\sigma$ $K-p$ for $p>5$ GeV/c
- Has gotten better since then: now more like 6\%
- Need TOF for $K-p$ in the region 2-4 GeV

- Scales as $1/\sqrt{L}$: with 130-180 cm, more like $<5.5\%$ everywhere
  - Something like $1.5\sigma$ $K-p$