The sPHENIX TPC Project

KLAUS DEHMELT
FOR THE sPHENIX COLLABORATION

MPGD2017

TEMPLE UNIVERSITY
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The sPHENIX Experiment

- sPHENIX is a new proposed experiment at RHIC, plans to begin taking data in 2022

- Goal
  - Determine temperature dependence of Quark-Gluon Plasma
  - Measuring
    - Jets
    - Jet correlations
    - Upsilon states

- Required ingredients for these measurements
  - Electromagnetic/Hadronic calorimetry
  - High resolution, low mass tracking system
  - High data acquisition system to handle an estimated peak collision rate of 200 kHz and ~15 kHz “trigger” rate
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M. Connors

![Diagram of sPHENIX Experiment](https://example.com/sPHENIX_diagram.png)
## The sPHENIX Experiment

<table>
<thead>
<tr>
<th>Physics Goal</th>
<th>Detector Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragmentation Functions</td>
<td>Excellent Momentum Resolution: ( \frac{dp}{p} \sim 0.2% ) for ( p ) to ( &gt; 40 \text{ GeV/c} )</td>
</tr>
<tr>
<td>Jet Substructure</td>
<td>Excellent track pattern recognition</td>
</tr>
<tr>
<td>Distinguish Upsilon States</td>
<td>Mass resolution: ( \sigma_{M} &lt; 100 \text{ MeV/c}^{2} )</td>
</tr>
<tr>
<td>Heavy Flavor jet tagging</td>
<td>Precise DCA resolution ( \sigma_{DCA} &lt; 100 \mu m )</td>
</tr>
<tr>
<td>High Statistics Au+Au 200 GeV</td>
<td>Handle multiplicity and full RHIC luminosity</td>
</tr>
</tbody>
</table>

- Accomplished by
  - 3-layer Si-pixel detector (MAPS)
  - 4-layer Si-strip detector (Intermediate tracker)
  - Compact Time-Projection Chamber (TPC)
- TPC \( \rightarrow \) continuous readout, small space charge distortion
- Barrel solenoid magnet (Babar) dictates dimension of TPC
  - \( 20 \text{ cm} < \text{radius} < 75 \text{ cm}, 2\pi \text{ azimuthal coverage} \)
  - \( \text{Total length} = 211 \text{ cm} \rightarrow |\eta| < 1.1 \text{ polar coverage} \)

Poster: sPHENIX TPC simulation studies by S. Tarafdar

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K. Dehmelt  
Stony Brook University  
The State University of New York

M. Connors
**The sPHENIX TPC**

- **Novel TPC concept developed by ALICE**
  - No-gate option due to continuous, high rate readout requirement
  - Can only be achieved with MPGD readout → combat Ion Back Flow

1.6 m

2.11 m

72 modules
2(z), 12(φ), 3(r)
Field Cage

- Hybrid between STAR and ILD

Disassemble spokes to release field cage.

NOTE: Thicknesses not to scale

Poster: Mechanical Construction of the field cage of sPHENIX TPC by N. Ram
Field Cage

P. Garg (SBU) using ANSYS & GARFIELD

- Mechanical/electrostatic tolerance studies
  - Module tilt
  - Membrane tilt
  - Shifted field cage
  - Rotated field cage
  - Resistor tolerance

Poster: R&D and related Simulation Studies for the sPHENIX Time Projection Chamber by P. Garg
Field Cage

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Readout Modules

- Module design

72 modules
2(z), 12(ϕ), 3(r)

Quad-GEM Gain Stage
Operated @ low IBF
Readout Modules

B. Azmoun
Readout Modules

B. Azmoun
Readout Modules

B. Azmoun

- Module design

Scan across chevron pads with collimated X-ray source

Scan Distance: 4mm in 100um steps

2mm pitch/0.1mm period

- Ideally, looking for flat correction fcn, so that no correction is required

- Interleaving pads can obtain better than 100um resolution with 2mm pitch

Universal Correction for DNL

Position Resolution

\[ \sigma_{\text{Uncorrected}} = 132\mu m \]

\[ \sigma_{\text{Corrected}} = 98\mu m \]
Readout Modules

B. Azmoun

- Electron cloud: 2D Gaussian profile
- Generate N electrons according to gain
- Constant 2% N/S per pad

- Collect electrons onto pads assuming uniform field
- (field distortion will be added soon)
- Cross talk at level of 5% added, but unfolded

Guiding principle: develop design with as close to linear response as possible (ie minimize need for correction functions, like DNL)
- The zigzag design above ensures that the charge sharing is directly proportional to hit position
- No DNL; constant resolution as a function of hit position
- Pad pitch and zigzag period are nicely matched to size of charge cloud (400-600um)
  → No single pad hits (ie, avoid low position sensitive regions)
- No beating artifacts as a function of Y (since Y-zigzag period is small compared to cloud size)
- No strip collects more than 85% of charge
- This design is almost independent of charge cloud size (from 200-600um)
- More exotic designs needed to address real life constraints like gap width and trace thickness limitations, and field distortions
TPC & Space Charge

ALICE w/50 kHz PbPb: charge density in fC/cm³ vs radius and z (in m)

w/o IBF @gain = 2k

w/ 1% IBF @gain = 2k
Distortions can be ENORMOUS

- STAR: 10 cm peak distortion corrected to 400 μm (0.4 %)
  - Corrects for primary charge only (gated TPC ~ no IBF from gain stage)
  - Analytical phi-symmetric correction driven by current luminosity
- ALICE: 20 cm distortion corrected to 200 μm (0.1 %)
  - IBF = 20x larger than primary charge
  - Continuous readout determines INSTANTANEOUS space charge (every 5 ms)
  - 3D correction since IBF determined by GAIN

Advantages in sPHENIX

- Only the physics of the effect is given
- Appropriate design can minimize the impact
Distortions can be ENORMOUS

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Poster: sPHENIX Compact TPC for Tracking and Particle Identification by C.E.P. Perez Lara
Focusing on computation of the space charge using as initial density a simulation of hijing+geant4 and bunch crossings for the sPHENIX case
Several ways to combat Space Charge

1. Make the ions fast through mass
2. Choose the largest drift field possible
3. Optimize amplification device’s operating point
4. Update design of field cage informed by current experience
5. Improve amplification device
   i. Remove “gain fluctuation” before amplification
   ii. Increase number of amplification stages
6. Multi-layer gating grid
7. Accelerator parameters
8. Don’t let ions be created
Several ways to combat Space Charge

1. Make the ions fast through mass

\[ \nu_{ion} = K \cdot E \]

with

- \( K \): ion mobility
- \( E \): Electric field

\[ \frac{1}{K_{tot}} = \frac{f_1}{K_1} + \frac{f_2}{K_2} + \frac{f_3}{K_3} + \ldots \]

→ Choose primary gas component with low mass: Ne-based (Ne-CF\(_4\) 90-10)

\[ \mu \text{ (mobility)} \text{ vs mass} \]
Several ways to combat Space Charge

2. Choose the largest drift field possible

<table>
<thead>
<tr>
<th>Gas</th>
<th>$K \left( \frac{cm^2}{Volt \cdot sec} \right)$</th>
<th>$v_D \left( E = 130 \frac{V}{cm} \right)$</th>
<th>$v_D \left( E = 400 \frac{V}{cm} \right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar</td>
<td>1.51</td>
<td>196</td>
<td>604</td>
</tr>
<tr>
<td>Ar-CH$_4$ 90:10</td>
<td>1.56</td>
<td>203 (STAR)</td>
<td>624</td>
</tr>
<tr>
<td>Ar-CO$_2$ 90:10</td>
<td>1.45</td>
<td>189</td>
<td>582</td>
</tr>
<tr>
<td>Ne</td>
<td>4.2</td>
<td>546</td>
<td>1680</td>
</tr>
<tr>
<td>Ne-CH$_4$ 90:10</td>
<td>3.87</td>
<td>503</td>
<td>1547</td>
</tr>
<tr>
<td>Ne-CO$_2$ 90:10</td>
<td>3.27</td>
<td>425</td>
<td>1307 (ALICE)</td>
</tr>
<tr>
<td>He</td>
<td>10.2</td>
<td>1326</td>
<td>4080</td>
</tr>
<tr>
<td>He-CH$_4$ 90:10</td>
<td>7.55</td>
<td>981</td>
<td>3019</td>
</tr>
<tr>
<td>He-CO$_2$ 90:10</td>
<td>5.56</td>
<td>722</td>
<td>2222</td>
</tr>
<tr>
<td>T2K</td>
<td>1.46</td>
<td>190 (ILC)</td>
<td>584</td>
</tr>
</tbody>
</table>
Combatt Space Charge

- Several ways to combat Space Charge

3. Optimize amplification device’s operating point
   Gain on first GEM determines desired properties $\rightarrow$ compromise between energy resolution and IBF

Quad-GEM Solution for ALICE

R. Majka
Several ways to combat Space Charge

3. Optimize amplification device’s operating point
   Gain on first GEM determines desired properties \(\rightarrow\) compromise between energy resolution and IBF

Quad-GEM Solution for ALICE

- 1. GEM: low gain
- 1. GEM: high gain
Several ways to combat Space Charge

3. Optimize amplification device’s operating point
   Gain on first GEM determines desired properties → compromise between energy resolution and IBF

Quad-GEM Solution for sPHENIX

R. Majka
Several ways to combat Space Charge

3. Optimize amplification device’s operating point
   Gain on first GEM determines desired properties $\rightarrow$ compromise between energy resolution and IBF

Quad-GEM Solution for ePHENIX

Recover $dE/dx$ when environment allows
Several ways to combat Space Charge

4. Update design of field cage informed by current experience

Space charge distortions at maximum where space charge density has discontinuity → FC entrance windows

Analytical 3-D model based on work for ALICE TPC revealed large distortions close to inner FC

Set \( r = 20 \text{ cm} \)

but make volume at \( r > 30 \text{ cm} \) active
Several ways to combat Space Charge

5. Improve amplification device
   i. Remove “gain fluctuation” before amplification
Combat Space Charge

- FC design includes a “termination grid” to ensure uniformity of the field in the drift volume
- Multiple simulations:
  - Wire mesh,
  - Photo-etched
  - Square/Round Hole
- Single conclusion:
  - Tune the field ratio surrounding the mesh to block many positive ions
Combat Space Charge

• Several ways to combat Space Charge

  5. Improve amplification device
     i. Remove “gain fluctuation” before amplification
     ii. Increase number of amplification stages → Quintuple GEM?
  6. Multi-layer gating grid
  7. Accelerator parameters → Crossing angle?
  8. Don’t let ions be created → Electroluminescence

5. – 8. require (significant) R&D
GEM Amplification and IBF Studies

P. Garg (SBU) using ANSYS & GARFIELD
GEM Amplification and IBF Studies

Stage 3

Stage 4
Alternative IBF Stopper

R. Majka

- Standard Pitch not rotated
- Large Pitch rotated
- Large Pitch not rotated
- Standard Pitch rotated

Iodine Backflow current / Anode Current (%)

400 V/cm drift field

$\Delta V = 270 \text{ V}$
$\Delta V = 800 \text{ V}$
$\Delta V = 230 \text{ V}$
$\Delta V = 800 \text{ V}$
$\Delta V = 288 \text{ V}$
$\Delta V = 800 \text{ V}$
$\Delta V = 359 \text{ V}$
$\Delta V = 800 \text{ V}$

$90-10-5 \text{ Ne-CO}_2-\text{N}_2$
Alternative IBF Stopper

- Dual-GEM + MicroMeGas Solution from Yale

See talk by N. Smirnov: 25 May 2017, 16:10
Electronics/DAQ

- \(\text{SAMPA} = \text{CSA} + \text{Shaper} + \text{ADC} + \text{DSP}\)
  - 32 channels input

- Prototype chip is available now (Aug 2016)
  - Final version SAMPA will be available in late 2018

Figure 6.4: Schematic of the SAMPA ASIC for the GEM TPC readout, showing the main building blocks.
**Electronics/DAQ**

**Input data stream:**
- 600 4-Gbps fibers total
- Max continuous: 2.87 Gbps / fiber
- Average continuous: 1.43 Gbps x 600 fibers

**Clock/Trigger input:**
- Fiber, protocol TBD
- Clock = 9.4 MHz
- Trigger Rate = 15 kHz

**Output data stream to buffer box:**
- N x 10 Gbps Ethernet via fiber (N=10-50)
- Total continuous limit: <120 Gbps (?)
- i.e. 3x (Transfer rate to RCF ~ 40 Gbps)

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**Structure/GEM L3 Scopes**

- **FEE L3 Scope**
- **Possible TPC DAM L3 Scope**

**TPC DAM L3 Scope**

- **X**

**FEE**
- 256 channels / iFEE
- 400 FEEs

**TPC**

**Data Aggregation Module (DAM)**

- Trigger
- Slow control system
- Timing distributor

**Event Buffering and Data Compressor (EBDC)**

**Buffer box**
- DAQ L2 Scope

**Transfer to RCF ~ 40 Gbps continuous**
Summary & Conclusion

- Aggressive schedule for TPC completion
  - Mechanical design well defined
  - Prototype v1 will contain full size Field Cage
  - Operating parameters to be determined, following existing applications
  - Simulations promising, will be followed by experimental verification
  - IBF as main issue to be solved

- sTPC well on track

- Possible compromises to be made

- Alternative IBF solutions being looked into