Performance of the continuous ions suppression TPC prototype for circular collider

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On behalf of TPC detector subgroup
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Outline

- Physics requirements
- Simulation of IBF at Z
- TPC prototype R&D
- Summary
**Three Detector Concepts (CEPC CDR)**

- **Baseline:** Silicon + TPC
- **FST:** all-silicon tracker
- **IDEA:** Silicon+Drift chamber (DCH)

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### Detector Parameters

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$L$ per IP $(10^{34} \text{ cm}^{-2} \text{s}^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H$</td>
<td>240</td>
<td>3</td>
</tr>
<tr>
<td>$W$</td>
<td>91.2</td>
<td>32 (*)</td>
</tr>
<tr>
<td>$W^+W^-$</td>
<td>158–172</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of IPs</td>
<td>2</td>
</tr>
<tr>
<td>Beam energy (GeV)</td>
<td>120</td>
</tr>
<tr>
<td>Circumference (km)</td>
<td>100</td>
</tr>
<tr>
<td>Synchrotron radiation loss/turn (GeV)</td>
<td>1.73</td>
</tr>
<tr>
<td>Crossing angle at IP (mrad)</td>
<td>$16.5 \times 2$</td>
</tr>
</tbody>
</table>

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**Detector Layout**

- **Detector length:** 1300 cm
- **Detector height:** 1100 cm
- **Magnet z:** ± 300 cm
- **Cal Rout:** 450 cm
- **Cal Rin:** 250 cm
- **DCH Rout:** 200 cm
- **DCH Rin:** 30 cm
- **VTX:**
- **Preshower:**
- **Silicon Wrapper:**
- **Yoke:** 100 cm

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**ArXiv:** 1811.10545
**Updated Parameters of Collider Ring since CDR**

<table>
<thead>
<tr>
<th></th>
<th>Higgs</th>
<th>Z (2T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CDR</td>
<td>Updated</td>
</tr>
<tr>
<td><strong>Beam energy (GeV)</strong></td>
<td>120</td>
<td>-</td>
</tr>
<tr>
<td><strong>Synchrotron radiation loss/turn (GeV)</strong></td>
<td>1.73</td>
<td>1.68</td>
</tr>
<tr>
<td><strong>Piwinski angle</strong></td>
<td>2.58</td>
<td>3.78</td>
</tr>
<tr>
<td><strong>Number of particles/bunch N_e (10^{10})</strong></td>
<td>15.0</td>
<td>17</td>
</tr>
<tr>
<td><strong>Bunch number (bunch spacing)</strong></td>
<td>242 (0.68\mu s)</td>
<td>218 (0.68\mu s)</td>
</tr>
<tr>
<td><strong>Beam current (mA)</strong></td>
<td>17.4</td>
<td>17.8</td>
</tr>
<tr>
<td><strong>Synchrotron radiation power/beam (MW)</strong></td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td><strong>Cell number/cavity</strong></td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td><em><em>β function at IP β_x</em> / β_y</em> (m)**</td>
<td>0.36/0.0015</td>
<td>0.33/0.001</td>
</tr>
<tr>
<td><strong>Emittance ε_x/ε_y (nm)</strong></td>
<td>1.21/0.0031</td>
<td>0.89/0.0018</td>
</tr>
<tr>
<td><strong>Beam size at IP σ_x/σ_y (\mu m)</strong></td>
<td>20.9/0.068</td>
<td>17.1/0.042</td>
</tr>
<tr>
<td><strong>Bunch length σ_z (mm)</strong></td>
<td>3.26</td>
<td>3.93</td>
</tr>
<tr>
<td><strong>Lifetime (hour)</strong></td>
<td>0.67</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Luminosity/IP L (10^{34} cm^{-2}s^{-1})</strong></td>
<td>2.93</td>
<td>5.2</td>
</tr>
</tbody>
</table>

**Luminosity increase factor:**  
- Higgs: $\times 1.8$  
- Z (2T): $\times 3.2$
Overview: physics requirements

TPC detector concept:

- Under 2-3 Tesla magnetic field (Momentum resolution: $\sim 10^{-4}$/GeV/c with TPC standalone)
- Large number of 3D space points ($\sim 220$ along the diameter)
- dE/dx resolution: $<5\%$
- $\sim 100$ µm position resolution in r$\phi$
  - $\sim 60$µm for zero drift, $<100$µm overall
- Systematics precision ($<20$µm internal)
- TPC material budget
  - $<1X_0$ including outer field cage
- Tracker efficiency: $>97\%$ for pT$>1$GeV
- 2-hit resolution in r$\phi$ : $\sim 2$mm
- Module design: $\sim 200$mm $\times$ 170mm
- Minimizes dead space between the modules: 1-2mm
Feasibility and limitations

TPC limitations for Z

- Ions back flow in chamber
- Calibration and alignment
- Low power consumption FEE ASIC chip

<table>
<thead>
<tr>
<th></th>
<th>ALICE TPC</th>
<th>CEPC TPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum readout rate</td>
<td>&gt;50kHz@pp</td>
<td>w.o BG?</td>
</tr>
<tr>
<td>Gating to reduce ions</td>
<td>No Gating</td>
<td>No Gating</td>
</tr>
<tr>
<td>Continuous readout</td>
<td>No trigger</td>
<td>Trigger?</td>
</tr>
<tr>
<td>IBF control</td>
<td>Build-in</td>
<td>Build-in</td>
</tr>
<tr>
<td>IBF*Gain</td>
<td>&lt;10</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Calibration system</td>
<td>Laser</td>
<td>NEED</td>
</tr>
</tbody>
</table>

Compare with ALICE TPC and CEPC TPC
Simulation of IBF effect

- Simulation
  - Re-established the model
  - Validated with 3 ions disks
  - Simulation of the multi ions disk in chamber under the continuous beam structure
  - Input from the full simulation data
  - IBF × Gain default as the factor of 5
  - Higgs run
  - Z pole run at the high luminosity
  - Without the charge of the beam-beam effects in TPC

Zhiyang Yuan
Simulation study at Z pole

- Goal:
  - Operate TPC at higher luminosity
  - No Gating options

- Simulation
  - IBF×Gain default as the factor of 5
  - 9 thousand Z to qq events
  - 60 million hits are generated in sample
  - Average hit density: 6 hits/mm²
  - Voxel size: 1mm × 6mm × 2mm
  - Average voxel occupancy: 1.33 × 10⁻⁸
  - Voxel occupancy at TPC inner most layer: ~2 × 10⁻⁷
  - Validated with 3 ions disks
  - Simulation of the multi ions disk in chamber under the continuous beam structure
  - Without the charge of the beam-beam effects in TPC
TPC module R&D
TPC detector module at IHEP

- Study with GEM-MM module
- New assembled module
- Active area: 100mm × 100mm
- X-tube ray and 55Fe source
- Bulk-Micromegas assembled from Saclay
- Standard GEM from CERN
- Avalanche gap of MM: 128μm
- Transfer gap: 2mm
- Drift length: 2mm ~ 200mm
- pA current meter: Keithley 6517B
- Current recording: Auto-record interface by LabView
- Standard Mesh: 400LPI
- High mesh: 508 LPI

Micromegas (Saclay) GEM (CERN)

DOI: 10.1088/1748-0221/12/04/P0401 JINST, 2017.4
DOI: 10.1088/1674-1137/41/5/056003, CPC, 2016.11
GEM+MM VS TPC@ALICE

For $e^+e^-$ machine
Primary $N_{\text{eff}}$ is small: $\sim 30$
Pad size: $1\text{mm} \times 6\text{mm}$

GEM+MM module:
Photo peak and escape peak are clear!
Good electron transmission.
Good energy resolution.

One option for ALICE TPC
GEM+GEM+MM
Gain of mid GEM: $\times 0.5$
GEM+MM VS DMM@USTC

Micronegas + GEM detector module
@IHEP

IBF of double mesh MM @USTC/Jianbei Liu

- IBF × Gain has the limitation ratio from the detector R&D at high gain.
- Lower gain and lower IBF ratio
Options #1: Pad TPC for collider

- Active area: $2 \times 10 \text{m}^2$
- One option for endplate readout:
  - GEM or Micromegas
  - $1 \times 6 \text{ mm}^2$ pads
  - $10^6$ Pads
  - 84 modules
  - Module size: $200 \times 170 \text{mm}^2$
  - Readout: Super ALTRO
  - Gain: 4000-6000
  - $\text{CO}_2$ cooling

TPC detector endplate concept
Option #2: Pixel TPC for collider

Benefits of Pixel readout:

- **Lower occupancy**
  - → 300 k Hits/s at small radii.
  - → This gives < 12 single pixels hit/s.
  - → With a read out speed of 0.1 msec (that matches a 10 kHz Z rate)
  - → the occupancy is less than 0.0012

- **Improved dE/dx**
  - → primary e- counting
  - Smaller pads/pixels could result in better resolution!
  - Gain <2000
  - Low IBF*Gain<2
  - CO$_2$ cooling

For Collider @cost:
But to readout the TPC with GridPixes:

- → 100-120 chips/module
- 240 modules/endcap (10 m$^2$)
- → 50k-60k GridPixes
- → 10$^9$ pixel pads
Pad and pixel TPC for collider

- Standard charge collection:
  - Pads of several mm²
  - Long strips (l~10 cm, pitch ~200 μm)
- Instead: Bump bond pads are used as charge collection pads

Smaller pads/pixels could result in better resolution!
- Gain <2000
- At Nikhef the GridPix was invented from 2003.

Benefits of GridPix readout:
- Lower occupancy → better track finding
- Improved dE/dx→ primary e- counting

For Collider @cost:
But to readout the TPC with GridPixes:
~100-120 chips/module
240 modules/endcap (10 m²)
→50k-60k GridPixes
Feasibility of Pixel TPC – Occupancies

- **Z rates** @ L = 32 10^34 cm^-2s^-1 and occupancies
  - Data is produced at a large rate of 300 k hits/s/chip (at R=40 cm)
  - In the test beam it has been demonstrated that the TPX3 can handle a rate that is a factor 10 higher
  - Occupancies are less than 1% at low radii

- Pattern recognition will be no problem
  - The occupancies in the pixel plane are low
  - The time between the Z interactions is large 120 μs. The time will be measured by each pixel.
  - The resolution is dominated by longitudinal diffusion. It amounts to less than about 20 nsec.
  - Different Z events can be easily separated in time.
Feasibility of Pixel TPC – Ions backflow

- Situation for a pixel TPC
  - Large potential in terms of rate capabilities
  - Pattern recognition high granularity works in high Z rate
  - Question: what is the IBF for our GridPix?
  - O(0.1%) It will be measured with IHEP and Nikehf’s collaborations.

- Can TPC apply in Z collisions?
  - High(est) luminosity CEPC  $L = 32-50 \ (17-32) \ 10^{34}\ \text{cm}^2\text{s}^{-1}$
  - CEPC Ring length 100 km with 12 000 bunches and a hadronic Z rate of $10-15 \ (5-10) \ \text{k Hz}$ (cross section 32 nb).
  - Beam structure rather continuous 14 ns spacing.
  - Note that this Luminosity gives about 60-120 (30-60) G Zs per running year
  - Time between Z interactions 120-60 (200-100) $\mu$s
  - TPC drift time takes -30 $\mu$s
  - Need IBF suppression and IBF*Gain $<2$
TPC prototype R&D
TPC prototype and FEE R&D

Main parameters

- Drift length: ~510mm, Readout active area: 200mm × 200mm
- Integrated the laser calibration with 266nm
- GEMs/Micromegas as the readout
- Amplifier (READY)
  - CASAGEM chip
  - 16Chs/chip
  - Shape time: 20ns
- DAQ (READY)
  - FPGA+ADC
  - 4 module/mother board
  - 64Chs/module
  - Sample: 40MHz
  - 1280chs

Diagram of the TPC prototype with the laser calibration system
Detector setup diagram

266nm laser device

266nm mirrors

Detector chamber

Setup and photo of the detector module
Energy spectrum and gain

Energy spectrum of 55Fe and the laser

Gain at T2K, P10, Ar/CO2
Laser track test@128chs

Drift length: 27mm
Pad row#4

Preliminary results of Laser tracker energy spectrum and tracker
Summary

Requirements and critical challenges for the high luminosity:

- High momentum resolution and position resolution
- IBF*Gain should be considered at the high luminosity
- It needs very sophisticated calibration in order to reach the desired physics performance at Z pole run
- Simulation and experiment studies give some parameters for the detector

TPC module and prototype R&D:

- TPC prototype has been designed with UV laser system and developed at IHEP and Tsinghua University.
- UV laser beam have been assembled and tested, some test parameters have been obtained.
- The beam test plan with TPC prototype under 1.0T magnetic field will be realized
Thank you for your attention!