CEPC MDI Study Status

Haoyu SHI
On behalf of the CEPC MDI Working Group

Joint Workshop of the CEPC Physics, Software and New Detector Concept in 2022
2022.05.23, Beijing(Zoom)
Outline

• Introduction

• Current Study Status
  • Physics Design
    • Layout/Components/Parameters
    • Heat Deposition/Radiation Levels
  • Engineering effort
    • Mechanical Design of each components (beampipe, cryostat, connector... etc)
    • Integration/Installation Scheme (Refer to Songwen’s talk later today)

• Summary & Outlook
Introduction

• MDI stands for “Machine Detector Interface”
  • Interaction Region and other components
  • 2 IPs
  • 33 mrad Crossing angle

• Flexible optics design
  • Common Layout in IR for all energies
  • High Luminosity, low background impact, low error
  • Stable and easy to install, replace/repair

• For CEPC TDR, the interaction region is ±7 m from the IP
### Inputs – Accelerator Parameters

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Accelerator Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of IPs</td>
<td><img src="image" alt="Number of IPs" /></td>
</tr>
<tr>
<td>Beam energy (GeV)</td>
<td><img src="image" alt="Beam energy" /></td>
</tr>
<tr>
<td>Circumference (km)</td>
<td><img src="image" alt="Circumference" /></td>
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<tr>
<td>Synchrotron radiation loss (GeV)</td>
<td><img src="image" alt="Synchrotron radiation loss" /></td>
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<tr>
<td>Crossing angle at IP (rad)</td>
<td><img src="image" alt="Crossing angle" /></td>
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<tr>
<td>Proton angle</td>
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<tr>
<td>Particle bunch N (10^9)</td>
<td><img src="image" alt="Particle bunch N" /></td>
</tr>
<tr>
<td>Beam number</td>
<td><img src="image" alt="Beam number" /></td>
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<tr>
<td>Beam spacing (mm)</td>
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<tr>
<td>Beam current (mA)</td>
<td><img src="image" alt="Beam current" /></td>
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<tr>
<td>Synch radiation power (MW)</td>
<td><img src="image" alt="Synch radiation power" /></td>
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<tr>
<td>Bending radius (km)</td>
<td><img src="image" alt="Bending radius" /></td>
</tr>
<tr>
<td>Momentum compaction (10^7)</td>
<td><img src="image" alt="Momentum compaction" /></td>
</tr>
<tr>
<td>Beam function at IP $\beta_p, \gamma_p$ (GeV)</td>
<td><img src="image" alt="Beam function at IP" /></td>
</tr>
<tr>
<td>Emittance (x, y) (nm)</td>
<td><img src="image" alt="Emittance" /></td>
</tr>
<tr>
<td>Beam size at IP $\Delta x, \Delta y$ (mm)</td>
<td><img src="image" alt="Beam size at IP" /></td>
</tr>
<tr>
<td>Beam-beam parameters $\Delta / \gamma$</td>
<td><img src="image" alt="Beam-beam parameters" /></td>
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<tr>
<td>RF voltage @RF (GHz)</td>
<td><img src="image" alt="RF voltage @RF" /></td>
</tr>
<tr>
<td>RF frequency @ RF (GHz)</td>
<td><img src="image" alt="RF frequency @ RF" /></td>
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<tr>
<td>Harmonic number</td>
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<tr>
<td>Natural bunch length x (mm)</td>
<td><img src="image" alt="Natural bunch length x" /></td>
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<tr>
<td>Beam length y (mm)</td>
<td><img src="image" alt="Beam length y" /></td>
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<tr>
<td>Demagnification $\alpha$</td>
<td><img src="image" alt="Demagnification $\alpha$" /></td>
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<tr>
<td>Natural Chromaticity</td>
<td><img src="image" alt="Natural Chromaticity" /></td>
</tr>
</tbody>
</table>

#### 2018 CDR Baseline Design

- **Number of Ips**
- **Circumference [km]**
- **SR power per beam [MW]**
- **Half crossing angle at IP [rad]**
- **Bending radius [km]**
- **Energy [GeV]**
- **Energy loss per turn [GeV]**
- **Piwinski angle**
- **Bunch number**
- **Bunch population [10^10]**
- **Beam current [mA]**
- **Momentum compaction [10^7]**
- **Beta functions at IP (bx, by) [mm/μm]**
- **Emittance (ex/ey) [nm/μm]**
- **Beam size at IP (sx/sy) [mm/μm]**
- **Bunch length (SR/total) [mm]**
- **Energy spread (SR/total) [%]**
- **Energy acceptance (DA/RF) [%]**
- **Beam-beam parameters (ksix/kstv) [mm/μm]**
- **RF voltage [GV]**
- **RF frequency [MHz]**
- **HOM power per cavity (5/2cell[kw])**
- **Qc/Qv/Qvs**
- **Beam lifetime (bb/bs) [min]**
- **Beam lifetime [min]**
- **Hour glass Factor**
- **Luminosity per IP [1e34cm^-2s^-1]**

#### 2021 Improved Design

- **Number of Ips**
- **Circumference [km]**
- **SR power per beam [MW]**
- **Half crossing angle at IP [rad]**
- **Bending radius [km]**
- **Energy [GeV]**
- **Energy loss per turn [GeV]**
- **Piwinski angle**
- **Bunch number**
- **Bunch population [10^10]**
- **Beam current [mA]**
- **Momentum compaction [10^7]**
- **Beta functions at IP (bx, by) [mm/μm]**
- **Emittance (ex/ey) [nm/μm]**
- **Beam size at IP (sx/sy) [mm/μm]**
- **Bunch length (SR/total) [mm]**
- **Energy spread (SR/total) [%]**
- **Energy acceptance (DA/RF) [%]**
- **Beam-beam parameters (ksix/kstv) [mm/μm]**
- **RF voltage [GV]**
- **RF frequency [MHz]**
- **HOM power per cavity (5/2cell[kw])**
- **Qc/Qv/Qvs**
- **Beam lifetime (bb/bs) [min]**
- **Beam lifetime [min]**
- **Hour glass Factor**
- **Luminosity per IP [1e34cm^-2s^-1]**
Inputs – Detector Designs

- Particle Flow Approach (ILD-like)
- Full Silicon Tracker (FST) concept
- IDEA concept (also proposed for FCC-ee)
- 4th Detector concept

Diagram showing:
- DR Calorimeter
- 2T Magnet
- Drift chamber
- Si Vertex, Si + TPC, PFA ECal & HCal
- Full Silicon Tracker (FST) concept

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Physics Design

• Interaction Region Layout/Parameters
  • $L^* = 1.9\text{m} / \text{Detector Acceptance} = 0.99$

• Estimation of the Radiation Level/Heat Deposition
The length of Interaction Region is -7m~7m on TDR Phase
New Beampipe Design – Detector Beampipe

Symmetry Design with increasing aperture
New Beampipe Design – Half Detector pipe

- Central Beampipe
- Extended Beampipe

**Be**
- Cylindrical
- Inner Diameter: 20mm
- Thickness: 0.15% X$_0$ (CDR)

**Al**
- Cylindrical
- Inner Diameter: 20mm

**Racetrack Cone**
- Inner Diameter at Y Axis: 20mm
- Inner Diameter at X Axis: 20-35mm

We are also checking the elliptical cross-section.
The range between 2 cryostat chambers would be -1.11m~1.11m
• We plan to have at least a pair of double electrodes BPM

• But above setting could only measure the timing/position at Y axis

• If we want to have more, we may need octo-electrodes BPM, and the position optimization was required.
Interfaces between pipe and LumiCal

With LumiCal:

• Will not be putted at detector beampipe region.
  • Therefore, the material of extended beam pipe could be changed.
• The material and thickness(material budget) of the flange&bellow needs to be calculated.

Please refer to Ivan’s talk later today, and Suen’s talk tomorrow.
Heat Deposition

We are considering to change the material beyond bellows to Al due to demands of LumiCal, it wouldn’t affect heat deposition to much.
Background Estimation

- Simulate each background separately
- Whole-Ring generation for single beam BGs
- Multi-turn tracking (50 turns)
  - Using built-in LOSSMAP with one step ahead output
  - SR emitting/RF on
  - Radtaper on
  - No detector solenoid
- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- 2 IR considered
- We are also updating our toolkit to latest version.
- Plan to study the photon bg generated during BGB/BTH/RBB...

<table>
<thead>
<tr>
<th>Background</th>
<th>Generation</th>
<th>Tracking</th>
<th>Detector Simu.</th>
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</thead>
<tbody>
<tr>
<td>Synchrotron Radiation</td>
<td>BDSim</td>
<td>BDSim/Geant4</td>
<td></td>
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<tr>
<td>Beamstrahlung/Pair Production</td>
<td>Guinea-Pig++</td>
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<tr>
<td>Beam-Thermal Photon</td>
<td>PyBTH[Ref]</td>
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<tr>
<td>Beam-Gas Bremsstrahlung</td>
<td>PyBGB[Ref]</td>
<td></td>
<td>SAD</td>
</tr>
<tr>
<td>Beam-Gas Coulomb</td>
<td>BGC in SAD</td>
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<td></td>
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<tr>
<td>Radiative Bhabha</td>
<td>BBBREM</td>
<td></td>
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</tbody>
</table>

A. Natochii

Injection BG

Photon BG

Beam Loss BG
• The SR must be dealt with high priority when designing the circular machine. At CEPC, there would be no SR photons hitting the central beam pipe directly in normal conditions.
• However, some secondaries generated within QD would hit the detector beampipe, even the beryllium part. Therefore, the mitigation methods must be studied. We compared several methods based on CDR, and we believe the results can also be used on TDR with optimization.
Mitigation of the BG - Collimator

- Beam stay clear region: $18 \sigma_x + 3\text{mm}$, $22 \sigma_y + 3\text{mm}$
- Impedance requirement: slope angle of collimator $< 0.1$
- 4 sets of collimators were implemented per IP per Ring (16 in total)
  - 2 sets are horizontal (4mm radius), 2 sets are vertical (3mm radius).
- One more upstream horizontal collimator sets were implemented to mitigate the Beam-Gas background

<table>
<thead>
<tr>
<th>name</th>
<th>Position</th>
<th>Distance to IP/m</th>
<th>Beta function/m</th>
<th>Horizontal Dispersion/m</th>
<th>Phase</th>
<th>BSC/2/m</th>
<th>Range of half width allowed/m</th>
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</thead>
<tbody>
<tr>
<td>APTX1</td>
<td>D11.785</td>
<td>44611</td>
<td>20.7</td>
<td>0.12</td>
<td>164.00</td>
<td>0.006</td>
<td>1~6</td>
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<tr>
<td>APTX2</td>
<td>D11.788</td>
<td>44680</td>
<td>20.7</td>
<td>0.12</td>
<td>164.25</td>
<td>0.006</td>
<td>1~6</td>
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<td>APTY1</td>
<td>D11.791</td>
<td>44745</td>
<td>105.37</td>
<td>0.12</td>
<td>165.18</td>
<td>0.0036</td>
<td>0.156~3.6</td>
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<td>APTY2</td>
<td>D11.794</td>
<td>44817</td>
<td>113.83</td>
<td>0.12</td>
<td>165.43</td>
<td>0.0036</td>
<td>0.156~3.6</td>
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<tr>
<td>APTX3</td>
<td>D10.5</td>
<td>1729.66</td>
<td>20.7</td>
<td>0.06</td>
<td>6.85</td>
<td>0.00182</td>
<td>1~6</td>
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<tr>
<td>APTX4</td>
<td>D10.8</td>
<td>1798.24</td>
<td>20.7</td>
<td>0.12</td>
<td>7.10</td>
<td>0.00182</td>
<td>1~6</td>
</tr>
<tr>
<td>APTY3</td>
<td>D10.10</td>
<td>1832.52</td>
<td>20.7</td>
<td>0.26</td>
<td>7.22</td>
<td>0.00182</td>
<td>0.069~3.3</td>
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<td>D10.14</td>
<td>1901.1</td>
<td>20.7</td>
<td>0.25</td>
<td>7.47</td>
<td>0.00182</td>
<td>0.069~3.3</td>
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<td>APTX5</td>
<td>DMBV01IR-U0</td>
<td>56.3</td>
<td>196.59</td>
<td>0</td>
<td>362.86</td>
<td>0.01178</td>
<td>2.9~11.78</td>
</tr>
</tbody>
</table>

S. Bai

Beam Lost Particle Distribution

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TDR Estimation – with safety factor of 10

• For fast estimation, we try to perform some scaling based on CDR results according to Luminosity.
• We also performing the full-TDR simulation. But it takes time.
• We plan to have double check on detector simulation(Mokka/CEPCSW/FLUKA)
  • We learn that the background impact on LumiCal must be studied.

<table>
<thead>
<tr>
<th></th>
<th>CDR</th>
<th>TDR(30MW)</th>
<th>TDR(50MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgs (3T)</td>
<td>2.93</td>
<td>5.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Z (2T)</td>
<td>32.1</td>
<td>115.0</td>
<td>184.0</td>
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</tbody>
</table>

Scaling Results on 1\textsuperscript{st} layer of vertex detector

<table>
<thead>
<tr>
<th></th>
<th>Hit Density($cm^{-2} \cdot BX^{-1}$)</th>
<th>TID(krad \cdot yr^{-1})</th>
<th>NIEL($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertex</td>
<td>2.3</td>
<td>5360</td>
<td>120.4</td>
</tr>
<tr>
<td>TPC</td>
<td>2.59e-2</td>
<td>387.09</td>
<td>42.503</td>
</tr>
<tr>
<td>Ecal Barrel</td>
<td>1.16e-3</td>
<td>31.56</td>
<td>8.002</td>
</tr>
<tr>
<td>Ecal EndCup</td>
<td>1.36e-3</td>
<td>14.175</td>
<td>6.128</td>
</tr>
<tr>
<td>Hcal Barrel</td>
<td>2.78e-5</td>
<td>1.450</td>
<td>0.9326</td>
</tr>
<tr>
<td>Hcal EndCup</td>
<td>1.32e-3</td>
<td>26.31</td>
<td>6.351</td>
</tr>
</tbody>
</table>

TDR Pair-Production Distribution

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Mechanical Design of the detector beam pipe

- Coolant might be paraffin or water.
  - If water was chosen, then the corrosion on Be must be studied.

- At CDR phase, the thermal analysis with 5kw heat deposition rate and 28mm inner diameter has been studied. The latest case is under analysis.

Outer Be Layer: 0.15mm
Gap: 0.35mm
Inner Be Layer: 0.2mm
Thickness: ~0.2%$X_0$

Please refer to Junsong’s talk tomorrow
Summary & Outlook

• We are moving our design to TDR phase.
  • Layout & Physics design has been updated.
  • The heat deposition calculation was done.
  • The estimation of radiation level caused by BG is under simulation.
  • The mechanical design is updating, including the thermal analysis based on the deposited heat.
  • We plan to have a preliminary whole TDR MDI design before next CEPC workshop.

• The optimization and validation of current design is always needed.
  • The BESIII backgrounds experiment was done last summer. We hope we could have another run this summer.
  • Validate our BG simulation codes using BEPCII and SuperKEKB.

Thank You
Backup
Physics Gains for 20mm Be

- First estimates made with fast simulation and scaling

\[
\frac{\delta \mu}{\mu} \propto \frac{\sqrt{S + B}}{S} \propto \frac{1}{\sqrt{\epsilon \cdot p}}
\]

\[
\sigma_{\text{tot}}^2 = \sigma_{\text{geom}}^2 + \sigma_{\text{MS}}^2 = \left(\frac{\sigma_{\text{res}}^2}{\sigma_{\text{res}}^2 - \sigma_{\text{MS}}^2}\right)^2 + \left(\frac{\sigma_{\text{res}}^2}{\sigma_{\text{res}}^2 - \sigma_{\text{MS}}^2}\right)^2 + \sum_{j=1}^{n_{\text{scatt}}} (R_j \Delta \theta_j)^2
\]

- Implement the geometry in simulation and run a full analysis to estimate the physics gains

Q. Ruan & Z. Wu

H. Zeng

G. Li
Map of the MDI Study

Accelerator
- IP Feedback
- BG Simulation
- LumiCal
- Vacuum Chamber
- SR Masks
- QD0/QF1
- Anti-Solenoid
- Cryostats
- BPMs
- Instability & Impedance
- Cooling
- Shielding
- Assembly & Supporting
- Alignment
- Connecting System
- Vacuum pumps
- Last Bending Magnet
- Collimators
- Control

Detector
- Central Beam Pipe
- Vertex Detector
- LumiCal
- Silicon Tracker
- TPC
- Hcal
- Ecal
- Solenoid
- Yoke
- Muon Detector
- Hall
- BG Simulation & Shielding
- Software Geometry
- Alignment & Assembly
- Electronics
- Cryogenic
- Radiation Protection
- Booster

Last Bending Magnets

Collimators
Thermal Analysis - CDR

- **Pressure drop:**
  - Be pipe: 19.8 kPa
  - Al pipe: 19.3 kPa

- **TEMP rise:**
  - Be pipe: 3.2 °C (between the inlet and the outlet)
  - Transition: 13.3 °C
  - Al pipe: 6.3 °C

- Temperature rise and pressure drop are in a safe range
Deformation Calculation

Refer to Haijing’s Talk

Detailed Beampipe Design

Cone structure

Ladder structure

Structural comparison design drawing

Streamline comparison chart

Old

New

Old

New
Updates on BG Simulation

• The detector simulation (with a safety factor of 10 for TID/NIEL):

  • Detector Impacts, Vertex : CDR $\rightarrow$ TDR(Scale)

<table>
<thead>
<tr>
<th></th>
<th>Higgs</th>
<th>Z</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>CDR</td>
<td>TDR-30</td>
</tr>
<tr>
<td>Hit Density($cm^{-2} \cdot BX^{-1}$)</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>TID($k-rad \cdot yr^{-1}$)</td>
<td>930</td>
<td>1490</td>
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<tr>
<td>NIEL($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)</td>
<td>2.2</td>
<td>3.5</td>
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• Detector Impacts, TPC : CDR $\rightarrow$ TDR(Scale)

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<td>TDR-30</td>
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<tr>
<td>Hit Density($cm^{-2} \cdot BX^{-1}$)</td>
<td>2.59e-2</td>
<td>2.59e-2</td>
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<tr>
<td>TID($k-rad \cdot yr^{-1}$)</td>
<td>4.385</td>
<td>7.483</td>
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<tr>
<td>NIEL($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)</td>
<td>0.4519</td>
<td>0.7712</td>
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</table>
Updates on BG Simulation

• The detector simulation (with a safety factor of 10 for TID/NIEL):
  • Detector Impacts, Ecal Barrel : CDR→TDR(Scale)

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<td>TDR-30</td>
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<tr>
<td>Hit Density(cm⁻²⋅BX⁻¹)</td>
<td>1.162e-3</td>
<td>1.162e-3</td>
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<tr>
<td>TID(krad ⋅ yr⁻¹)</td>
<td>0.319</td>
<td>0.544</td>
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<tr>
<td>NIEL(nₑq×10¹² cm⁻²⋅yr⁻¹)</td>
<td>0.1285</td>
<td>0.2193</td>
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• Detector Impacts, Ecal Endcup: CDR→TDR(Scale)

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<td>CDR</td>
<td>TDR-30</td>
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<tr>
<td>Hit Density(cm⁻²⋅BX⁻¹)</td>
<td>1.356e-3</td>
<td>1.356e-3</td>
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<tr>
<td>TID(krad ⋅ yr⁻¹)</td>
<td>0.2841</td>
<td>0.4848</td>
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<tr>
<td>NIEL(nₑq×10¹² cm⁻²⋅yr⁻¹)</td>
<td>0.1248</td>
<td>0.2130</td>
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Updates on BG Simulation

• The detector simulation (with a safety factor of 10 for TID/NIEL):
  • Detector Impacts, HCal Barrel: CDR→TDR(Scale)

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<td>TDR-30</td>
</tr>
<tr>
<td>Hit Density ((cm^{-2} \cdot BX^{-1}))</td>
<td>2.778e-5</td>
<td>2.778e-5</td>
</tr>
<tr>
<td>TID ((krad \cdot yr^{-1}))</td>
<td>7.603e-3</td>
<td>12.974e-3</td>
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<tr>
<td>NIEL ((n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}))</td>
<td>0.0116</td>
<td>0.198</td>
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• Detector Impacts, HCal Endcup: CDR→TDR(Scale)

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<td></td>
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<td>TDR-30</td>
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<td>Hit Density ((cm^{-2} \cdot BX^{-1}))</td>
<td>1.321e-3</td>
<td>1.321e-3</td>
</tr>
<tr>
<td>TID ((krad \cdot yr^{-1}))</td>
<td>0.284</td>
<td>0.485</td>
</tr>
<tr>
<td>NIEL ((n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}))</td>
<td>0.159</td>
<td>0.271</td>
</tr>
</tbody>
</table>
SR from solenoid combined field

- Horizontal trajectory will couple to the vertical
- Due to the sol+anti-sol field strength quite high, maximum~4.24T, transverse magnetic field component is quite high.
- SR from vertical trajectory in sol+anti-sol combined field should be taken into account.

- SR fan is focused in a very narrow angle from -116urad to 131urad
- SR will not hit Berryllium pipe, and no background to detector.
- SR will hit the beam pipe ~213.5m downstream from IP
- Water cooling is needed.

**Vertical SR critical energy distribution**

- Maximum: 670keV

**Vertical SR power distribution**

- Maximum: 31W