Lorenzo Pezzotti
Università degli Studi di Pavia & INFN

on behalf of the
INFN RD_FA Collaboration

Updates on IDEA

FCC Week 2019, Bruxelles 26/6/2019
FCCee physics drivers

- Higgs physics

<table>
<thead>
<tr>
<th>To measure</th>
<th>Critical Detector</th>
<th>Required Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgs mass, Cross section</td>
<td>Tracker</td>
<td>$\Delta(1/p_T) \approx 2 \times 10^{-5} \pm 1 \times 10^{-3}/(p_T \sin \theta)$</td>
</tr>
<tr>
<td>Branching ratios</td>
<td>Vertex</td>
<td>$\sigma_{r\phi} \approx 5 \pm 10/(p \sin^{3/2} \theta) \mu m$</td>
</tr>
<tr>
<td>Branching ratios</td>
<td>Calorimeter (ecal + hcal)</td>
<td>$\sigma/E_{\text{jet}} \approx (30 - 40) % / \sqrt{E}$</td>
</tr>
<tr>
<td>Branching ratio</td>
<td>Calorimeter (ecal)</td>
<td>$\sigma/E_{\gamma} \approx 16 % / \sqrt{E} \pm 1 %$</td>
</tr>
</tbody>
</table>

- Z, W, top physics mostly covered with the above requirements
FCCee IDEA Detector

**Beam pipe:** $r \sim 1.5$ cm

**Vertex:** 5 MAPS layers  
$r = 1.7$-34 cm

**Drift Chamber:** 4 m long, $r = 35$-200 cm

**Outer Silicon Layers:** strips

**Superconducting solenoid coil:** 2 T, $r \sim 2.1$-2.4 m  
0.74 $X_0$, 0.16 $\lambda$ @ 90°

**Preshower:** $\sim 1 \, X_0 \, \mu$-RWELL MPGD

**Dual-Readout Calorimeter:** 2 m / 8 $\lambda_{int}$

**Yoke + Muon chamber:** $\mu$-RWELL MPGD
Muon chambers

Features

- Large areas: \( \sim 77 \, m^2 \) in the barrel region, \( \sim 37 \, m^2 \) in the endcap and \( \sim 900 \, m^2 \) divided in 3 stations for the muon spectrometer (assuming 2-dimensional readout).
- High granularity preshower (for \( n^0 \) ID near charged hadrons and acceptance definition for \( \gamma \) @ level of \( \mu m \)).

MPGD Detector

- High rate capability > 1 MHz/cm\(^2\), space resolution easily < 200 \( \mu m \), signal creation time \( \sim 100 \, ns \).

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... how to deal with spikes?

The micro-Resistive WELL, *made of*

- Cathode
- u-RWELL PCB: a Well patterned Apical foil acting as amplification stage, a resistive layer for discharge suppression, a readout PCB

2D spatial resolution tunable for muon chambers and preshower up to 40 \( \mu m \)
Features
Jet energy resolution of 3-4% for jets of 100 GeV, good particle ID capability ($\varepsilon(e) \sim 99\%$, $\sim 2\%$ π-mis-ID) and electromagnetic energy resolution of $\approx 11\%/\sqrt{E} \oplus 1\%$
… in a single calorimeter calibrated at the electromagnetic scale.

Excellent 2D spatial resolution by reading out each fiber with a dedicated SiPM.
IDEA Dual-Readout Calorimeter

**Features**

Jet energy resolution of 3-4% for jets of 100 GeV, good particle ID capability ($\varepsilon(e) \sim 99\%$, ~2% $\pi^{-}$ mis-ID) and electromagnetic energy resolution of $\approx 11\% / \sqrt{E} \oplus 1\%$

... in a single calorimeter calibrated at the electromagnetic scale.

Excellent 2D spatial resolution by reading out each fiber with a dedicated SiPM.

**Concept:** Do not reach $h/e=1$ by construction, but measure both components in each event.

Cherenkov signal

$$C = E[fem + \left( \frac{h}{e} \right)_c (1 - fem)]$$

Scintillation signal

$$S = E[fem + \left( \frac{h}{e} \right)_s (1 - fem)]$$

The correct energy value is given by

$$E = \frac{S - \chi C}{1 - \chi}$$

$$\chi = \frac{1 - (h/e)_s}{1 - (h/e)_c}$$

Data from RD52 Collaboration

EM resolution, measured

$$\sigma/E = 11\% / \sqrt{E} \oplus 1\%$$

Had resolution, Geant4 expected

$$\sigma/E = (30 - 40\%) / \sqrt{E}$$
Design of the fully projective fiber solution

Tower segmentation: $\Delta \theta = 1.125^\circ$, $\Delta \phi = 10.0^\circ$
Total number of towers in barrel: $40 \times 2 \times 36 = 2880$
Total number of towers per endcap: $35 \times 36 = 1260$
Theta coverage up to $\sim 0.100$ rad

Implemented in Geant4 simulation
Design of the fully projective fiber solution

Barrel: Inner length: 5m - Outer diameter: 9 m @ 90°
2 m long copper based towers: ~ 8.2 λ
36 rotation around z axis

Implemented in Geant4 simulation
Main advantage of keeping the sampling fraction constant:

- Scintillation response uniform within 1.5% from $\theta=90^\circ$ to $\theta=5.7^\circ$
- Cherenkov response uniform better than 1.0% from $\theta=90^\circ$ to $\theta=5.7^\circ$
Updates on IDEA DR Calorimeter

**Calorimeter event displays**

For both C/S fibers: 1 mm diameter, 0.5 mm absorber in between. Total number of fibers: \(\sim 131 \, M\).

Fibers starting at different depths to keep the sampling fraction constant.

![Fiber length distribution](image)
Calorimeter event displays

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Fibers starting at different depths to keep the sampling fraction constant.

40 GeV π⁻

S signal (MeV)
Barrel towers
θ: -45-45 deg, φ: 0-360 deg
Updates on IDEA DR Calorimeter

Calorimeter event displays

For both C/S fibers: 1 mm diameter, 0.5 mm absorber in between. Total number of fibers: ~131 M.

Fibers starting at different depths

40 GeV $e^-$

40 GeV $\pi^0$

S signal (MeV)

S signal (MeV)
Calorimeter event displays

Fiber length distribution

40 GeV π^0

S signal (MeV)
SiPM readout

SiPMs enable an unprecedented 2D spatial resolution but…
a single fiber can carry up to 10% of the total signal!

Achieved SiPM response linearity

By filtering the scintillation light

- it is possible to operate at 22% PDE and a light yield of 93 Spe/GeV with no saturation effects, with 25 µm pixel sensors.

Photor statistics fluctuations will become negligible going to 10 µm pixels.
What about longitudinal segmentation?

For a better separation of em and hadronic clusters a longitudinal segmentation might be needed. The first DR staggered module was tested at the CERN SPS beam line:

- $9.2 \times 9.2 \times 230 \text{ cm}^3$
- Half fibers (C and S) start at ~ 20 $X_0$ from the front face
- Short fibers only sensitive to hadrons
- Long - Short fibers’ signals define an em compartment
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For a better separation of em and hadronic clusters a longitudinal segmentation might be needed. The first DR staggered module was tested at the CERN SPS beam line:
- 9.2 x 9.2 x 230 cm³
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- Long - Short fibers’ signals define an em compartment

Short/long fiber signal ratio

![Graph showing short/long fiber signal ratio with entries and mean and std dev values]
Updates on IDEA 2018 test beam

**Scintillation and Cherenkov channel - 60 GeV n**

As it is possible to estimate the difference in the responses between short and long fibers,

- it is possible to use the dual-readout principle in a longitudinally segmented fiber calorimeter.

... what about timing?

As light in fibers travels at \( c/n \), it is possible to discriminated between electrons and hadrons with the signals’ time of arrival.

- to be studied with SiPMs!

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Data from RD52 Collaboration, PMTs readout fiber calorimeter

**Starting time PMT signal**

- electron
- pion
Updates on IDEA 2018 test beam

The IDEA vertical slice combined test beam

To study the combined performances of IDEA we tested in series:

- a drift chamber
- two GEM detectors (+ lead slabs as preshower)
- the RD52 lead Dual Readout calorimeter
- 2 GEM detectors (muon trackers)
Updates on IDEA 2018 test beam

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Effect of budget material on the electromagnetic performances

GEM detectors clearly indicate the effect of upstream radiation in front of the calorimeter, however

- The electromagnetic energy resolution was not spoiled.
  Strong point for having the coil inside the calorimeter!
IDEA Drift Chamber

**Features**

Large solid angle coverage ($|\cos\vartheta| = 0.99$), high granularity and high transparency detector.

Good momentum resolution at level of $\sigma_{p_t}/p_t \simeq 10^{-5} p_t$ (a factor 10 better than LEP).
### IDEA Drift Chamber

#### Features
Large solid angle coverage (|cosθ| = 0.99), high granularity and high transparency detector.

Good momentum resolution at level of \( \sigma_{pt}/p_t \simeq 10^{-5} p_t \) (a factor 10 better than LEP).

#### Caveat
Emittance preservation at the IR constraints the B field to be at the 2T level

\[
\frac{\Delta p_t}{p_t} = \frac{8\sqrt{5} \sigma_{xy}}{0.3 B R_{out}^2 \sqrt{N} p_t} \oplus \frac{0.0523}{\beta B L} \sin \theta \sqrt{\frac{L}{X_0}}
\]

... but stay light and large!

Short bunch spacing @ Z-pole (20-30 ns) stay fast!
IDEA Drift Chamber

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Large solid angle coverage ($|\cos \theta| = 0.99$), high granularity and high transparency detector.

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**Caveat**
Emittance preservation at the IR constraints the \( B \) field to be at the 2T level

\[
\Delta p_t / p_t \leq \frac{8 \sqrt{5} \sigma_{xy}}{0.3 B R_{out}^2 \sqrt{N}} p_t \sin \theta \sqrt{L / X_0} \]

... but \( \Delta p_t / p_t \leq \frac{0.0523}{\beta B L} \) stay light and large!

Short bunch spacing @ Z-pole (20-30 ns) stay fast!

- \( L = 400 \text{ cm}, R = 35-200 \)
- Gas: 90% He - 10% iC\(_4\)H\(_{10}\)
- Drift length: 1 cm \( \rightarrow \) drift time: 350 ns

Spatial res: \( \sigma_{xy} < 100 \text{ µm}, \sigma_z < 1000 \text{ µm} \)
56448 squared drift cells of 12 - 13.5 mm
Layers: 112
Boundary conditions

- Detector specific: $\sigma_{ip} = a \oplus \frac{b}{p \sin^{3/2} \theta}$ towards $\sigma_{ip} \approx 5 \oplus \frac{10}{p \sin^{3/2} \theta} \mu m$

- Beam induced background: @ H pole 1-10 hits/cm$^2$/BX

... but air cooling namely works up to a power density of $\sim$ 20 mW/cm$^2$

But, as of today, there is NO SENSOR featuring:

- single point resolution at the 3 $\mu$m
- level thickness at the 0.1% $X_0$ level
- power dissipation not exceeding 20 mW/cm$^2$
- being read-out in less than 80 $\mu$s/cm$^2$
- scaled-up to “reticle size” areas
Boundary conditions

- Detector specific: $\sigma_{ip} = a \oplus \frac{b}{p \sin^{3/2} \theta}$ towards $\sigma_{ip} \approx 5 \oplus \frac{10}{p \sin^{3/2} \theta} \mu m$

- Beam induced background: @ H pole 1-10 hits/cm²/BX

- to limit the occupancy at 1% level

- readout $\Delta t < 80 \mu s$

- “burn” energy and “grow in mass”

... but air cooling namely works up to a power density of ~ 20 mW/cm²

**ARCADIA** (Advanced CMOS Architectures with Depleted Integrated sensor Arrays)

- INFN CSNV Call Project targeting a full-size system-ready demonstrator of a low-power high-density pixel matrix CMOS monolithic sensor featuring

  1. Active sensor thickness in the 50-500 µm range
  2. Operating in full depletion fast charge collection by drift
  3. Scalable readout architecture with ultra-low power capability $O(10 \text{ mW/cm}^2)$
Updates on the IDEA Drift Chamber

Estimates of the full tracker material budget

5% $X_0$ - barrel region

< 15% $X_0$ - forward and backward regions
Full tracking performances (vertex + drift chamber + Si wrapper)

@ 90°, asymptotic behavior

\[ \frac{\sigma_{p_t}}{p_t} \approx 2.2 \times 10^{-5} p_t \]

IDEA

\[ \frac{\sigma_{p_t}}{p_t} \approx 5.7 \times 10^{-5} p_t \]

IDEA no Si wrapper

Cluster counting for improved particle identification:

\[ \frac{dN_{cl}}{dx} \sim 2\% \ vs \ \frac{dE}{dx} \sim 4\% \]

No ion back-flow & short drifting time.
Updates on the IDEA Drift Chamber

IDEA/CLD Comparison

Run @Higgs pole, assuming 0.136% beam spread

Higgs recoil mass

Di-muon invariant mass
Conclusions

The IDEA Detector is specifically intended for e⁺e⁻ high luminosity circular colliders, featuring:

- A Dual-readout calorimeter for excellent hadronic and jet energy resolution
- An ultra-light drift chamber for superior momentum resolution in the envisaged energy range and excellent particle identification capabilities
- and an ultra-light solenoid coil inside the calorimeter.

Several AIDA++ EOI’s to be submitted both on hardware and software sides.
THANK YOU!
Drift chamber tracking performances

- Geant4
  - ROOT based simulation
 Updates on the IDEA Drift Chamber

Tracking performances

@ 90°, $p_t > 30$ GeV

IDEA

$$\frac{\sigma_{p_t}}{p_t} = 0.7 \times 10^{-3} + 2.2 \times 10^{-5} p_t$$

IDEA no Si wrapper

$$\frac{\sigma_{p_t}}{p_t} = 0.5 \times 10^{-3} + 5.7 \times 10^{-5} p_t$$

IDEA, Multiple Scattering only

$$\frac{\sigma_{p_t}}{p_t} = 0.25 \times 10^{-3}$$

CLD, Multiple Scattering only

$$\frac{\sigma_{p_t}}{p_t} = 2.5 \times 10^{-3}$$
Updates on the IDEA Drift Chamber

**Particle Identification**

Excellent K/π separation except 0.8<p<1.5 GeV

PID with TOF might become marginal, *if not needed at all*.
**Updates on IDEA 2018 test beam**

**Scintillation channel - 60 GeV π⁻**

**Signal in long fibers**

<table>
<thead>
<tr>
<th>Tower2_scinlong</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Std Dev</td>
</tr>
</tbody>
</table>

**Signal in short fibers**

<table>
<thead>
<tr>
<th>Tower2_scinshort</th>
</tr>
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<tr>
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**Short/long fiber signal ratio**

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</table>
Updates on u-RWELL

From low rates to high rates: the silver grid solution

Single Resistive Layer (SRL): 2-D current evacuation scheme based on a single resistive layer with a conductive grounding all around the perimeter.

A simplified high rate scheme on a single resistive layer with the implementation of a 2-D grounding based on conductive strip lines realized on the DLC layer.

<table>
<thead>
<tr>
<th>Pitch (um)</th>
<th>Dead area (um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SG1</td>
<td>6</td>
</tr>
<tr>
<td>SG2</td>
<td>12</td>
</tr>
<tr>
<td>SG2++</td>
<td>12</td>
</tr>
</tbody>
</table>

Rate Capability @ 90% (MHz/cm²)

Average Resistance (MΩ)

Gain

Efficiency

Ar/CO2/CF4=45/14/40 & Beam spot ~ 4 cm²

5000±10%