A continuous read-out TPC for the ALICE upgrade

27th May 2015
Christian Lippmann

on behalf of the ALICE collaboration
The ALICE upgrade strategy
ALICE TPC overview
Operation from RUN1 to RUN3
GEM readout for the TPC
Ion backflow optimization
Prototype tests
Expected performance in RUN3
Read-out electronics
Summary and Outlook
The ALICE upgrade strategy
ALICE TPC overview
Operation from RUN1 to RUN3
GEM readout for the TPC
Ion backflow optimization
Prototype tests
Expected performance in RUN3
Read-out electronics
Summary and Outlook
ALICE upgrade strategy (1)

- **Motivation:** Focus on high-precision measurements of rare probes at low $p_T$
  - can not be selected with hardware trigger
  - need to record large sample of events
- **Strategy:** Read out all Pb–Pb interactions at maximum interaction rate of 50 kHz
- **When:** 2nd LHC Long Shutdown (LS2): 2018/19

- ALICE Upgrade LOI: [https://cds.cern.ch/record/1475243](https://cds.cern.ch/record/1475243)
- ALICE TPC Upgrade TDR: [https://cds.cern.ch/record/1622286](https://cds.cern.ch/record/1622286)
- Addendum to the TPC TDR: [https://cds.cern.ch/record/1984329](https://cds.cern.ch/record/1984329)
ALICE upgrade strategy (2)

- Example: Low mass di-leptons

Simulation: Current data rate

Simulation: Upgrade scenario

13th Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba (Italy)
May 24 - 30, 2015
ALICE TPC overview (1)

- Diameter: 5 m, length: 5 m
- Acceptance: $|\eta| < 0.9$, $\Delta \phi = 2\pi$
- Gas:
  - Ne–CO$_2$–N$_2$ 90–10(–5) in RUN1
  - Ar–CO$_2$ 90–10 in RUN2
- $v_d \approx 2.7$ cm/$\mu$s, max. drift time: 92 $\mu$s
ALICE TPC overview (2)

- Diameter: 5 m, length: 5 m
- Acceptance: $|\eta| < 0.9$, $\Delta\phi = 2\pi$
- Gas:
  - Ne–CO$_2$ (–N$_2$) 90–10(–5) in RUN1
  - Ar–CO$_2$ 90–10 in RUN2
- $v_d \approx 2.7$ cm/$\mu$s, max. drift time: 92 $\mu$s

- Read-out Chambers: 2 x 18 x 2
  - outer (OROC) and inner (IROC)
- Current detector (RUN1):
  - 557 568 cathode pads (sizes: 4 x 7.5, 6 x 10, 6 x 15 mm$^2$)
  - MWPC, gated grid operation
  - Rate limitation: ~1 kHz

Low mass, high precision field cage

Central drift electrode (100 kV)

Endplate

$E = 400$ V/cm

Inner, outer readout chambers (MWPCs)

13th Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba (Italy)
May 24 - 30, 2015
Gated operation in **RUN1**

Typical data taking with TPC in **RUN1**: Low luminosity Pb-Pb collisions

- Triggered operation with gated grid (max rate: few kHz)
- Maximum drift time of electrons in TPC: ~ 100us
- Additional gated grid closure time: 180us (to minimize ion backflow and drift distortions)
Continuous operation in **RUN3**

Typical data taking with TPC in **RUN3**: High luminosity Pb-Pb collisions

- Maximum drift time of electrons in TPC: ~100us
- Average event spacing: ~20us
- Event pileup
- Triggered operation does not make sense
- Minimize ion backflow (IBF) in different way

**Continuous read-out**

**Micro Pattern Gas Detectors**
• **Requirements** for read-out system:
  – IBF < 1% at effective gas gain 2000
  – Local energy resolution <12% (σ) for $^{55}\text{Fe}$
  – Stable operation under LHC condition
• **Requirements** for read-out system:
  - IBF < 1% at effective gas gain 2000
  - Local energy resolution <12% ($\sigma$) for $^{55}$Fe
  - Stable operation under LHC condition

• **Implementation:**
  - Replace MWPC read-out system with GEMs
    • low ion backflow (IBF)
    • high rate capability
    • no ion tail
    • continuous read-out possible
  - Gas with fast ion drift: Ne-CO$_2$
  - New read-out electronics
IBF optimized configuration (1)

- Satisfactory performance could not be achieved with 3 GEM stack
- Best results in terms of IBF and energy resolution:
  - 4 GEM stack
IBF optimized configuration (2)

- Satisfactory performance could not be achieved with 3 GEM stack
- Best results in terms of IBF and energy resolution:
  - 4 GEM stack
  - S-LP-LP-S configuration
  - S: standard GEM foils
  - LP: large hole pitch foils
  - Optimized V settings: $V_{\text{GEM}}, E_T$ (transfer fields)
### IBF optimized configuration (3)

- **IBF optimized settings:**
  - high $E_{T1}$ & $E_{T2}$
  - low $E_{T3}$
  - $V_{GEM1} \approx V_{GEM2} \approx V_{GEM3} < V_{GEM4}$

<table>
<thead>
<tr>
<th>Drift Field</th>
<th>= 0.4 kV/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential at top of GEM 1</td>
<td>$\Delta U_{GEM1}$ = $U_{1\text{top}}$ - $U_{1\text{bot}}$ = 270 V</td>
</tr>
<tr>
<td>Transfer Field 1 ($E_{T1}$)</td>
<td>= $(U_{1\text{bot}} - U_{2\text{top}})/0.2\ \text{cm}$ = 4.0 kV/cm</td>
</tr>
<tr>
<td>Potential at top of GEM 2</td>
<td>$\Delta U_{GEM2}$</td>
</tr>
<tr>
<td>Transfer Field 2 ($E_{T2}$)</td>
<td>= $(U_{2\text{bot}} - U_{3\text{top}})/0.2\ \text{cm}$ = 2.0 kV/cm</td>
</tr>
<tr>
<td>Potential at top of GEM 3</td>
<td>$\Delta U_{GEM3}$</td>
</tr>
<tr>
<td>Transfer Field 3 ($E_{T3}$)</td>
<td>= $(U_{3\text{top}} - U_{4\text{bot}})/0.2\ \text{cm}$ = 0.1 kV/cm</td>
</tr>
<tr>
<td>Potential at top of GEM 4</td>
<td>$\Delta U_{GEM4}$</td>
</tr>
<tr>
<td>Collection/Induction Field ($E_{\text{ind.}}$)</td>
<td>= $U_{4\text{bot}}/0.2\ \text{cm}$ = 4.0 kV/cm</td>
</tr>
</tbody>
</table>
IBF optimized configuration (4)

- Achieved performance:
  - \(0.63\%\) IBF at \(\sigma(5.9\text{ keV}) \approx 11.3\%\)

- Typical voltage settings are shown above (eff. gas gain is always 2000)

IBF optimized settings:
- high \(E_{T1} \& E_{T2}\)
- low \(E_{T3}\)
- \(V_{\text{GEM1}} \approx V_{\text{GEM2}} \approx V_{\text{GEM3}} < V_{\text{GEM4}}\)
IBF optimized configuration (3)

- Electron transport properties for IBF optimized voltage settings
- $\varepsilon_{\text{coll}} =$ collection efficiency
- $\varepsilon_{\text{extr}} =$ extraction efficiency

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{\text{coll}}$</th>
<th>$n_{\text{e,in}}$</th>
<th>$M$</th>
<th>$n_{\text{e-ion}}$</th>
<th>$\varepsilon_{\text{extr}}$</th>
<th>$n_{\text{e,out}}$</th>
<th>$G$</th>
<th>$n_{\text{ion,back}}$</th>
<th>fraction of total IBF (sim.)</th>
<th>fraction of total IBF (meas.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEM1 (S)</td>
<td>1</td>
<td>1</td>
<td>14</td>
<td>13</td>
<td>0.65</td>
<td>9.1</td>
<td>9.1</td>
<td>3.6 (28%)</td>
<td>40%</td>
<td>31%</td>
</tr>
<tr>
<td>GEM2 (LP)</td>
<td>0.2</td>
<td>1.8</td>
<td>8</td>
<td>12.7</td>
<td>0.55</td>
<td>8</td>
<td>0.88</td>
<td>3.3 (26%)</td>
<td>37%</td>
<td>34%</td>
</tr>
<tr>
<td>GEM3 (LP)</td>
<td>0.25</td>
<td>2</td>
<td>53</td>
<td>104</td>
<td>0.12</td>
<td>12.7</td>
<td>1.6</td>
<td>1.3 (1.3%)</td>
<td>14%</td>
<td>11%</td>
</tr>
<tr>
<td>GEM4 (S)</td>
<td>1</td>
<td>12.7</td>
<td>240</td>
<td>3053</td>
<td>0.6</td>
<td>1830</td>
<td>144</td>
<td>0.84 (0.03%)</td>
<td>9%</td>
<td>24%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3183</td>
<td>1830</td>
<td>1830</td>
<td>9 (0.28%)</td>
<td></td>
</tr>
</tbody>
</table>
IBF optimized configuration (4)

- Electron transport properties for IBF optimized voltage settings
- $\varepsilon_{\text{coll}} = \text{collection efficiency}$
- $\varepsilon_{\text{extr}} = \text{extraction efficiency}$
- $M = \text{gas multiplication factor}$
- $G = \varepsilon_{\text{coll}} \times M \times \varepsilon_{\text{extr}} = \text{effective gain}$

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{\text{coll}}$</th>
<th>$n_{e,\text{in}}$</th>
<th>$M$</th>
<th>$n_{e-\text{ion}}$</th>
<th>$\varepsilon_{\text{extr}}$</th>
<th>$n_{e,\text{out}}$</th>
<th>$G$</th>
<th>$n_{\text{ion,back}}$</th>
<th>$\frac{\text{fraction of total IBF (sim.)}}{}$</th>
<th>$\frac{\text{fraction of total IBF (meas.)}}{}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEM1 (S)</td>
<td>1</td>
<td>1</td>
<td>14</td>
<td>13</td>
<td>0.65</td>
<td>9.1</td>
<td>9.1</td>
<td>3.6 (28%)</td>
<td>40%</td>
<td>31%</td>
</tr>
<tr>
<td>GEM2 (LP)</td>
<td>0.2</td>
<td>1.8</td>
<td>8</td>
<td>12.7</td>
<td>0.55</td>
<td>8</td>
<td>0.88</td>
<td>3.3 (26%)</td>
<td>37%</td>
<td>34%</td>
</tr>
<tr>
<td>GEM3 (LP)</td>
<td>0.25</td>
<td>2</td>
<td>53</td>
<td>104</td>
<td>0.12</td>
<td>12.7</td>
<td>1.6</td>
<td>1.3 (1.3%)</td>
<td>14%</td>
<td>11%</td>
</tr>
<tr>
<td>GEM4 (S)</td>
<td>1</td>
<td>12.7</td>
<td>240</td>
<td>3053</td>
<td>0.6</td>
<td>1830</td>
<td>144</td>
<td>0.84 (0.03%)</td>
<td>9%</td>
<td>24%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3183</td>
<td>1830</td>
</tr>
</tbody>
</table>

13th Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba (Italy)
May 24 - 30, 2015
IBF optimized configuration (5)

- Electron transport properties for IBF optimized voltage settings
- $\varepsilon_{\text{coll}} = \text{collection efficiency}$
- $\varepsilon_{\text{extr}} = \text{extraction efficiency}$
- $M = \text{gas multiplication factor}$
- $G = \varepsilon_{\text{coll}} \times M \times \varepsilon_{\text{extr}} = \text{effective gain}$
- $n_{\text{e-ion}} = \text{number of produced e-ions pairs}$

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{\text{coll}}$</th>
<th>$n_{e,\text{in}}$</th>
<th>$M$</th>
<th>$n_{e-\text{ion}}$</th>
<th>$\varepsilon_{\text{extr}}$</th>
<th>$n_{e,\text{out}}$</th>
<th>$G$</th>
<th>$n_{\text{ion,back}}$</th>
<th>fraction of total IBF (sim.)</th>
<th>fraction of total IBF (meas.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEM1 (S)</td>
<td>1</td>
<td>1</td>
<td>14</td>
<td>13</td>
<td>0.65</td>
<td>9.1</td>
<td>9.1</td>
<td>3.6 (28%)</td>
<td>40%</td>
<td>31%</td>
</tr>
<tr>
<td>GEM2 (LP)</td>
<td>0.2</td>
<td>1.8</td>
<td>8</td>
<td>12.7</td>
<td>0.55</td>
<td>8</td>
<td>0.88</td>
<td>3.3 (26%)</td>
<td>37%</td>
<td>34%</td>
</tr>
<tr>
<td>GEM3 (LP)</td>
<td>0.25</td>
<td>2</td>
<td>53</td>
<td>104</td>
<td>0.12</td>
<td>12.7</td>
<td>1.6</td>
<td>1.3 (1.3%)</td>
<td>14%</td>
<td>11%</td>
</tr>
<tr>
<td>GEM4 (S)</td>
<td>1</td>
<td>12.7</td>
<td>240</td>
<td>3053</td>
<td>0.6</td>
<td>1830</td>
<td>144</td>
<td>0.84 (0.03%)</td>
<td>9%</td>
<td>24%</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>12.7</td>
<td>240</td>
<td>3183</td>
<td>0.6</td>
<td>1830</td>
<td>1830</td>
<td>9 (0.28%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
IBF optimized configuration (6)

- Electron transport properties for IBF optimized voltage settings
- $\varepsilon_{\text{coll}} = \text{collection efficiency}$
- $\varepsilon_{\text{extr}} = \text{extraction efficiency}$
- $M = \text{gas multiplication factor}$
- $G = \varepsilon_{\text{coll}} \times M \times \varepsilon_{\text{extr}} = \text{effective gain}$
- $n_{\text{e-ion}} = \text{number of produced e-ions pairs}$
- $n_{\text{ion,back}} = \text{number of ions drifting back into the drift volume}$

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{\text{coll}}$</th>
<th>$n_{\text{e, in}}$</th>
<th>$M$</th>
<th>$n_{\text{e-ion}}$</th>
<th>$\varepsilon_{\text{extr}}$</th>
<th>$n_{\text{e, out}}$</th>
<th>$G$</th>
<th>$n_{\text{ion, back}}$</th>
<th>Fraction of total IBF (sim.)</th>
<th>Fraction of total IBF (meas.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEM1 (S)</td>
<td>1</td>
<td>1</td>
<td>14</td>
<td>13</td>
<td>0.65</td>
<td>9.1</td>
<td>9.1</td>
<td>3.6 (28%)</td>
<td>40%</td>
<td>31%</td>
</tr>
<tr>
<td>GEM2 (LP)</td>
<td>0.2</td>
<td>1.8</td>
<td>8</td>
<td>12.7</td>
<td>0.55</td>
<td>8</td>
<td>0.88</td>
<td>3.3 (26%)</td>
<td>37%</td>
<td>34%</td>
</tr>
<tr>
<td>GEM3 (LP)</td>
<td>0.25</td>
<td>2</td>
<td>53</td>
<td>104</td>
<td>0.12</td>
<td>12.7</td>
<td>1.6</td>
<td>1.3 (1.3%)</td>
<td>14%</td>
<td>11%</td>
</tr>
<tr>
<td>GEM4 (S)</td>
<td>1</td>
<td>12.7</td>
<td>240</td>
<td>3053</td>
<td>0.6</td>
<td>1830</td>
<td>144</td>
<td>0.84 (0.03%)</td>
<td>9%</td>
<td>24%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
IBF optimized configuration (7)

- Electron transport properties for IBF optimized voltage settings
- $\varepsilon_{\text{coll}} = \text{collection efficiency}$
- $\varepsilon_{\text{extr}} = \text{extraction efficiency}$
- $M = \text{gas multiplication factor}$
- $G = \varepsilon_{\text{coll}} \times M \times \varepsilon_{\text{extr}} = \text{effective gain}$
- $n_{\text{e-ion}} = \text{number of produced e-ions pairs}$
- $n_{\text{ion,back}} = \text{number of ions drifting back into the drift volume}$

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{\text{coll}}$</th>
<th>$n_{\text{e,in}}$</th>
<th>$M$</th>
<th>$n_{\text{e-ion}}$</th>
<th>$n_{\text{e, out}}$</th>
<th>$G$</th>
<th>$n_{\text{ion, back}}$</th>
<th>fraction of total IBF (sim.)</th>
<th>fraction of total IBF (meas.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEM1 (S)</td>
<td>1</td>
<td>1</td>
<td>14</td>
<td>13</td>
<td>9.1</td>
<td>9.1</td>
<td>3.6 (28%)</td>
<td>40%</td>
<td>31%</td>
</tr>
<tr>
<td>GEM2 (LP)</td>
<td>0.2</td>
<td>1.8</td>
<td>8</td>
<td>12.7</td>
<td>0.55</td>
<td>8</td>
<td>0.88 (26%)</td>
<td>37%</td>
<td>34%</td>
</tr>
<tr>
<td>GEM3 (LP)</td>
<td>0.25</td>
<td>2</td>
<td>53</td>
<td>104</td>
<td>0.12</td>
<td>12.7</td>
<td>1.6 (1.3%)</td>
<td>14%</td>
<td>11%</td>
</tr>
<tr>
<td>GEM4 (S)</td>
<td>1</td>
<td>12.7</td>
<td>240</td>
<td>3053</td>
<td>0.6</td>
<td>1830</td>
<td>144 (0.03%)</td>
<td>9%</td>
<td>24%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>3183</td>
<td>1830</td>
<td>1830</td>
<td>9</td>
<td>9 (0.28%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13th Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba (Italy)
May 24 - 30, 2015
Prototype beam tests: PID

• 4GEM IROC prototype tests: $dE/dx$ resolution measurements at CERN PS

- Excellent $dE/dx$ resolution: ~10% (IROC only)
- Performance equal to existing MWPC IROCs
Prototype beam tests: Stability

- **Discharge tests at CERN SPS**

- **Discharge probability:** $(6.4\pm3.7)\times10^{-12}$ per hadron

- Additional lab measurements with $\alpha$ and $\beta$ particles

- Performance similar to standard triple GEMs

- Odd voltage settings compensated by addition of 4$^{th}$ GEM foil

- Expected number of discharges in full TPC per typical yearly heavy-ion run at 50 kHz
  - 4.5 discharges per GEM stack, 650 discharges for the whole TPC
  - Not expected to create any damage to the GEM detectors

13$^{th}$ Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba (Italy)
May 24 - 30, 2015
• 2015: First OROC prototype built, all institutes that will be involved in the ROC mass production took part
• Largest GEM detector built so far!
Space charge distortions

- See poster by M. Ljunggren (Performance simulation studies for the ALICE TPC GEM Upgrade)
- Even with required IBF = 1% there will still be considerable space charge!
  - For 50kHz Pb-Pb collisions ion pile-up from on average 8000 events ($t_{\text{ion}}=160\text{ms}$)
- Expect distortions on the cm level
- Corrections to few $10^{-3}$ to achieve final resolution ($\sigma(r\phi) \approx 200\ \mu\text{m}$)
- 2 stage calibration and reconstruction scheme
Expected performance (1)

- See poster by M. Ljunggren (Performance simulation studies for the ALICE TPC GEM Upgrade)
- Influence of **space charge distortions**: Track matching efficiency and transverse momentum resolution are retained up to twice the design IBF (2%; $\varepsilon=40$)

![Graphs showing track matching efficiency and inverse momentum resolution with and without space charge distortions.](image-url)
Expected performance (2)

- **Influence of track density**: Track matching efficiency and transverse momentum resolution deteriorate only for interaction rates >100 kHz (design 50 kHz)
Front-end Electronics

- New FE ASIC: **SAMPA**
  - Continuous or triggered read-out
  - Positive or negative input
  - Programmable conversion gains and peaking times

- **Digital filters** for baseline correction (common mode effect in GEM ROCs)

- Aim for a system **noise** of $670 \text{ e}^{-}$ as currently achieved

- Use CERN–developed **GBT** and Versatile Link components for readout (radiation hard)

- Average data output for 50 kHz Pb–Pb collisions: 1 Tbyte/s

---

13\textsuperscript{th} Pisa Meeting on Advanced Detectors
La Biodola, Isola d'Elba (Italy)
May 24 - 30, 2015
Summary and outlook

• Major upgrade of the ALICE experiment for installation in 2018/19
• **Continuous TPC read-out** to inspect 50 kHz Pb-Pb collisions
• New read-out chambers based on **4 GEM stacks**
• Required **ion backflow, energy resolution** and **stability** achieved
• New electronics for continuous read-out
• 2-stage **reconstruction scheme** able to retain **physics performance**
• Technical Design Report endorsed
• Successfully tested ROC prototypes
• GEM foil production starts in August
• ROC assembly starts next year
More slides
TPC upgrade R&D program

• Extensive studies started in 2012
  1. characterization of 3 or 4-GEM configurations and of other MPGD technologies
  2. technology choice
  3. optimisation of operational voltages and IBF suppression
  4. gain stability
  5. discharge probability
  6. large-size prototypes, single mask technology
  7. electronics R&D
  8. Garfield++ simulations
  9. physics and performance simulations: Remaining drift-field distortions must be calibrated

• Collaboration with RD51 at CERN
TPC: Garfield Simulations

- Garfield++/Magboltz simulations for different 4GEM setups (S-LP-LP-S)
  - Field calculation by ANSYS
  - IBF quantitatively well described by simulations using Garfield++
Alignment (1)

The IBF is related to hole alignment and thus optical transparency

Effect of slight rotation of foils

Randomization of the relative hole positions after rotation of one foil by 90°
• Garfield++ simulation: Gas gain (left) and ion backflow (right) in a double GEM system vs GEM hole offset between the two layer

Need random misalignment between holes \( \Rightarrow \text{turn foils by } 90^\circ \)
TPC: IBF – Rate Dependence

Poisson equation:

\[ \Delta \varphi(\mathbf{r}) = -\frac{\rho(\mathbf{r})}{\varepsilon \varepsilon_0} \]

For homogenous space charge density and parallel plate boundary conditions:

\[ E(z) = E_{\text{drift}} - \frac{\rho d}{2 \varepsilon \varepsilon_0} + \frac{\rho z}{\varepsilon \varepsilon_0} \]

Expected after LS2: 5000 fC/cm²
Run3 reconstruction scheme

- Two stage reconstruction scheme
  1. Cluster finding and cluster-to-track association in the TPC
     - data compression by factor 20: 1 TB/s → 50 GB/s
     - use scaled average space-charge distortion map
  2. Full tracking with matching to inner and outer detectors (ITS and TRD)
     - full space-charge distortion calibration
     - use high resolution space-charge map (time interval ~5 ms)
### Front-end Electronics

- **FE parameters for current ALICE TPC FEE and for SAMPA (upgrade)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RUN 1 (measured)</th>
<th>RUN 3 (requirement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal polarity</td>
<td>Pos</td>
<td>Neg</td>
</tr>
<tr>
<td>Detector capacitance (range)</td>
<td>12 – 33.5</td>
<td>12 – 33.5</td>
</tr>
<tr>
<td>$S/N$ ratio for MIPs (IROC)</td>
<td>14:1</td>
<td>20:1</td>
</tr>
<tr>
<td>(OROC 6×10 mm$^2$ pads)</td>
<td>20:1</td>
<td>30:1</td>
</tr>
<tr>
<td>(OROC 6×15 mm$^2$ pads)</td>
<td>28:1</td>
<td>30:1</td>
</tr>
<tr>
<td>MIP signal (fC)</td>
<td>$1.5 - 3^{14}$</td>
<td>2.4 – 3.2</td>
</tr>
<tr>
<td>System noise (at 18.5 pF, incl. ADC)</td>
<td>670 e</td>
<td>670 e</td>
</tr>
<tr>
<td>PASA conversion gain (at 18 pF)</td>
<td>12.74</td>
<td>20 (30)</td>
</tr>
<tr>
<td>PASA return to baseline (ns)</td>
<td>&lt; 550</td>
<td>&lt; 500</td>
</tr>
<tr>
<td>PASA average baseline value (mV)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>PASA channel-to-channel baseline variation ($\sigma$) (mV)</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>PASA shaping order</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>PASA peaking time (ns)</td>
<td>160</td>
<td>160 (80)</td>
</tr>
<tr>
<td>PASA crosstalk</td>
<td>&lt; 0.1 %$^{15}$</td>
<td>&lt; 0.2 %</td>
</tr>
<tr>
<td>PASA integrated non-linearity</td>
<td>0.2 %</td>
<td>&lt; 1 %</td>
</tr>
<tr>
<td>ENC (PASA only, at 12 pF)</td>
<td>385 e</td>
<td>385 e</td>
</tr>
<tr>
<td>ADC voltage range (differential)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>ADC linear range (differential)</td>
<td>160</td>
<td>100 (67)</td>
</tr>
<tr>
<td>ADC number of bits</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>ADC sampling rate (MHz)</td>
<td>10 (2.5, 5, 20)</td>
<td>10 (20)</td>
</tr>
<tr>
<td>Power consumption (analog &amp; digital)</td>
<td>35</td>
<td>&lt; 35</td>
</tr>
</tbody>
</table>

---

**13th Pisa Meeting on Advanced Detectors**
La Biodola, Isola d'Elba (Italy)
May 24 - 30, 2015