The NA62 GigaTracker

Mathieu Perrin-Terrin* on behalf of the GTK Working Group

*CERN, INFN Torino, INFN Ferrara, UCL Louvain

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Vienna, Austria
The GigaTracker in a nutshell

- an hybrid **time-resolved** pixel detector (60mm × 27mm)
- tracking all particles in a beam with a rate up to 1GHz
- providing hit time with a resolution better than 200 ps
- implementing **micro-channel cooling** (HEP world first)
Outlines

1. Detector Purpose and Specifications
2. The TDCPix ASIC Assembly
3. The Detector Integration
4. Performance
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The NA62 Aim: Measuring $\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$

- **Ultra-rare** decay, $\mathcal{B} \sim 10^{-10}$, difficult final state

- GTK measures initial state kinematics and arrival time

| Beam Rate | 800 MHz - 1GHz  
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td></td>
<td>1.3 MHz/mm$^2$</td>
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<table>
<thead>
<tr>
<th>Radiation</th>
<th>$10^{14}$ 1MeV eq. n/cm$^2$/y</th>
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<tbody>
<tr>
<td>Efficiency</td>
<td>99%</td>
</tr>
<tr>
<td>Momentum Resolution</td>
<td>0.2%</td>
</tr>
<tr>
<td>Angular Resolution</td>
<td>16 $\mu$rad</td>
</tr>
<tr>
<td>Hit Time Resolution</td>
<td>200 ps RMS</td>
</tr>
<tr>
<td>Material Budget</td>
<td>$3 \times 0.5%X_0$</td>
</tr>
<tr>
<td>Detector Size</td>
<td>60mm $\times$ 27mm</td>
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</tbody>
</table>

More on NA62: talks by N. Lurkin, L. Pontisso and poster by D. Soldi

mathieu.perrin-terrin@cern.ch (CERN) The NA62 GigaTracker 14th VCI 4/20
A challenging concept started in 2007
made real in 2013!
Outlines

1. Detector Purpose and Specifications
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3. The Detector Integration
4. Performance
The Full Pixel Matrix

- **Sensor** [FBK, CIS]
  Both p-in-n/n-in-p
  Bias: 300-600V
  Thickness: 200 µm
  MPV Charge per MIP: 2.4 fC

- **Bump-bonding** Sn-Pb [IZM]

- 10 TDCPix chips / station:
  130 nm CMOS [IBM]
  Thinned at 100 µm

- Detector replaced every 100 days of run (radiation)
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Some key numbers:
- 1800 pixels (40×45)
- 720 TDCs with 100ps bin
- 12.8 Gb/s output data
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  - discriminator
  - DAC threshold trim
  - configuration register

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End of column (EoC) integrates:
- time-to-digital converters (TDC)
- data serialisers
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- **Power** consumption: 3.5W (mostly EoC)
End-Of-Columns

- Digital signal from 5 pixels in a column are sent to a multiplexer (HitArbiter)
End-Of-Columns

- **Digital signal** from 5 pixels in a column are sent to a *multiplexer* (HitArbiter)

- To each HitArbiter corresponds a **TDC pair** measuring leading and trailing edges → in total 360 TDC pair/chip
End-Of-Columns

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- TDC have 100ps bins.
- Self triggered architecture.
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- To each HitArbiter corresponds a **TDC pair** measuring leading and trailing edges → in total 360 TDC pair/chip

- **TDC** have 100ps bins

- **Self triggered** architecture

- Data sent out with four 3.2 Gbits/s serialisers
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Mechanical Integration

- **Detector** glued on 130µm (currently 210µm) Silicon Cooling Plate

![Diagram of mechanical integration](image)
Mechanical Integration

- **Detector** glued on 130µm (currently 210µm) Silicon Cooling Plate

![Diagram showing detector integration mechanics]

- Cooling Plate is clamped onto PCB (isostatic)
- PCB is glued into frame and flange
- Flange closes the vacuum vessel
- Detector replaced every 100 days of run
Mechanical Integration

- Detector glued on 130μm (currently 210μm) Silicon Cooling Plate
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Mechanical Integration

- **Detector** glued on 130\(\mu\text{m}\) (currently 210\(\mu\text{m}\)) Silicon Cooling Plate

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Mechanical Integration

- **Detector** glued on 130\(\mu m\) (currently 210\(\mu m\)) Silicon Cooling Plate

- **Cooling Plate** is clamped onto **PCB** (isostatic)

- **PCB** is glued into frame and flange

- **Flange** closes the **vacuum vessel**

- **Detector** replaced every 100 days of run
Electrical Integration

- TDCPix **wired bonded** to PCB serving power, clock, config and receiving data
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- TDCPix \textit{wired bonded} to PCB serving power, clock, config and receiving data

- A \textbf{challenging} PCB:
  - 14 layers
  - 40 differential 3.2 Gb/s signals over 30cm
Electrical Integration

- TDCPix **wired bonded** to PCB serving power, clock, config and receiving data

- A **challenging** PCB:
  - 14 layers
  - 40 differential 3.2 Gb/s signals over 30cm
  - dense wire-bonding scheme (73µm pitch on chip)
Trigger and Data Acquisition

- Every hit in TDCPix is sent out
- Each TDCPix connects to one DAQ board through 4 optical links (one per TDCPix 3.2 Gb/s serializer)
- DAQ Board buffers data for 1ms..
- .. and retrieves 75ns slices upon each trigger request
Detector Cooling

Constraints

- Physics performances require to minimise material budget
- Detector in vacuum
- 35W power is dissipated per station
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Micro-channel cooling matches the constraints

- Etch channels in a 130 µm thin Si plate glued on TDCPix
- Circulate coolant (C₆F₁₄) in micro-channels (pressure 3.5 bars, flow 3 g/s, temp. ambient to -25C)
- First time implemented in HEP
Cooling Plates

- Fabricated by CEA Leti
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- 200µm × 70µm channels
Cooling Plates

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- $200\mu m \times 70\mu m$ channels
- Two cooling circuits
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- Fluid brought in with capillaries
- Kovar connectors soldered onto cooling plate
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- $200\mu m \times 70\mu m$ channels
- Two cooling circuits
- Fluid brought in with capillaries
- Kovar connectors soldered onto cooling plate
- Infra-red picture
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Time Resolution - TDCPix Demonstrator

Charge Injection

- **Laser** pulse shined at pixel centre
- Time resolution: **70 ps RMS** for charged injected equivalent to MIP

![Mean T0 RMS Jitter](image)

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M. Noy
J. Instrum. 6 (2011) C01086
```
**Time Resolution - TDCPix Demonstrator**

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**Beam Test**
- $\pi^+$ at 10GeV/c at CERN PS in 2012
- Time resolution: 200 ps RMS
Time Resolution - TDCPix Demonstrator

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Difference Beam/Laser

- Weighting field and charge straggling
Performance  Time Resolution

Time Resolution - TDCPix Demonstrator

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Time Resolution - Final TDCPix

- NA62 runs in 2014 and 2015
- Time Walk Correction
- $\sigma_t \approx 215 \text{ ps } @ \text{ 300V}$

$\chi^2 / \text{ndf} = 62.3 / 80$
$p0 = 4.47 \pm 0.02096$
$p1 = -0.5391 \pm 0.003927$
$p2 = 0.01083 \pm 0.0001706$

$\times 10^3$

Count / 10 ps

$\sigma_t = 232 \text{ ps}$

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Time Resolution - Final TDCPix

- NA62 runs in 2014 and 2015
- Time Walk Correction
- $\sigma_t \approx 215 \text{ ps} @ 300V$
- In agreement with previous results

![Graph showing time resolution data with bias and time resolution values for test beam runs in 2014 and 2015.](image-url)
Conclusions

Summary

- GTK is essential to measure $\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ at NA62
- Provides momentum, angles, and time for 1GPart/s
- 200 ps RMS time resolution has been achieved
- First implementation of micro-channel cooling in HEP

Prospects

- Run restarts on April 25th 2016
- Study effect of radiation damage on the timing performance
Conclusions

SPARES
GTK Kinematics in 2015

Without GTK
Full $p$ range

With GTK
Full $p$ range

Preliminary Data 2015

$K^+ \rightarrow \pi^+ \pi^0$

$K^+ \rightarrow \mu^+ \nu$

$K^+ \rightarrow \pi^+ \pi^+ \pi^-$

$|p_K - p|^2 [\text{GeV}^2/c^4]$