The NA62 GigaTracker Detector

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(Università di Ferrara and INFN Ferrara, Italy)

On behalf of the NA62 GigaTracker Working Group:
CERN, INFN Ferrara, INFN Torino, UCL Louvain

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The NA62 experiment

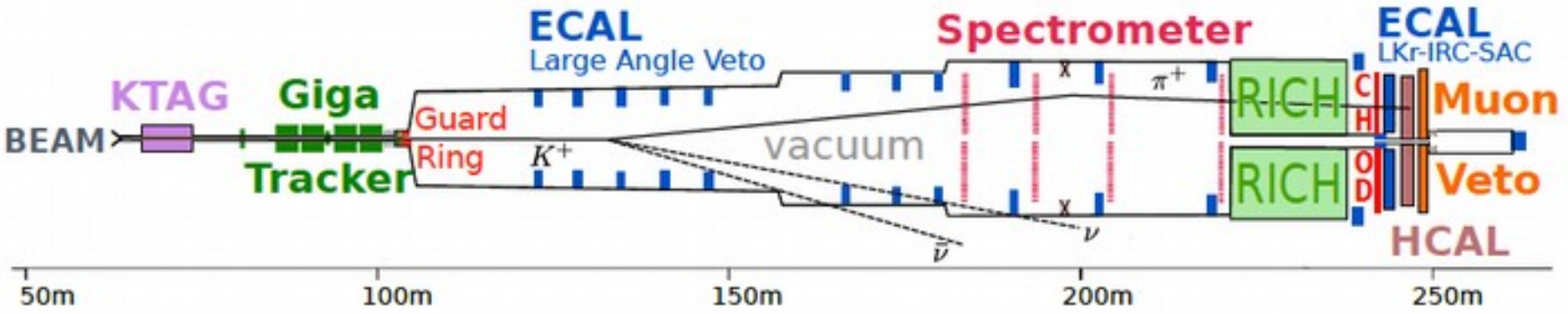
Fixed target experiment: precision kaon physics @CERN SPS

Ultra rare K decay $K^+ \to \pi^+ \nu\bar{\nu}$

How rare is it? $\lesssim$ 1 in 10^{10} particle decays

Aim to get O(100) event in 2-3 years

- Un-separated hadron beam (6% K, 23% p, 70% π)
- 75 GeV/c, Δp/p ~ 1%
- 0.75 GHz beam rate (~ 45 MHz K)



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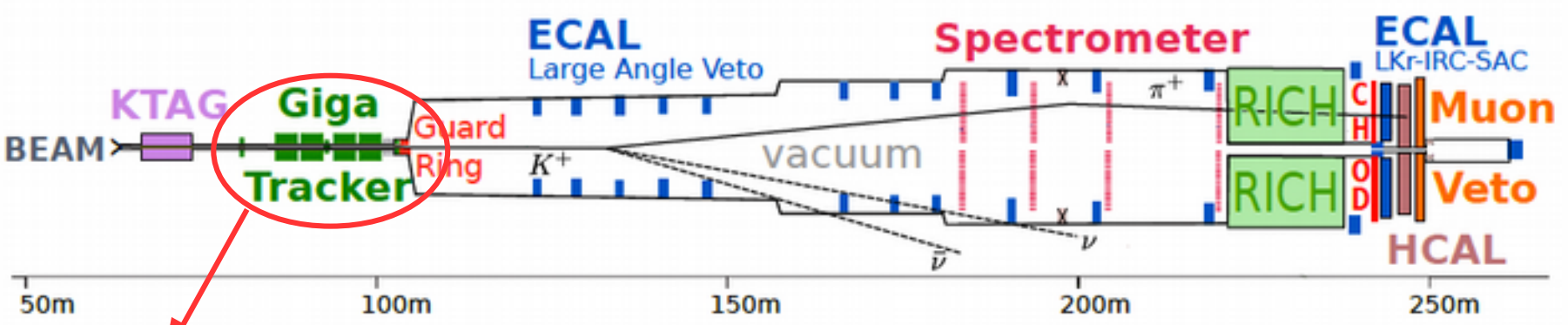

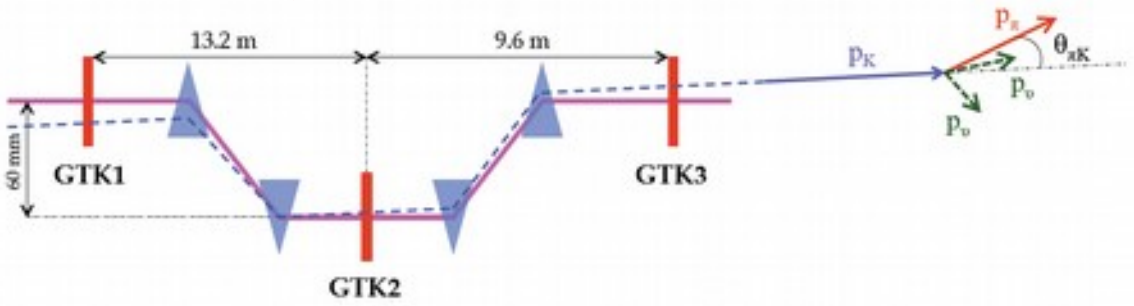

GTK measures initial state kinematics and arrival time

It sees the whole beam!

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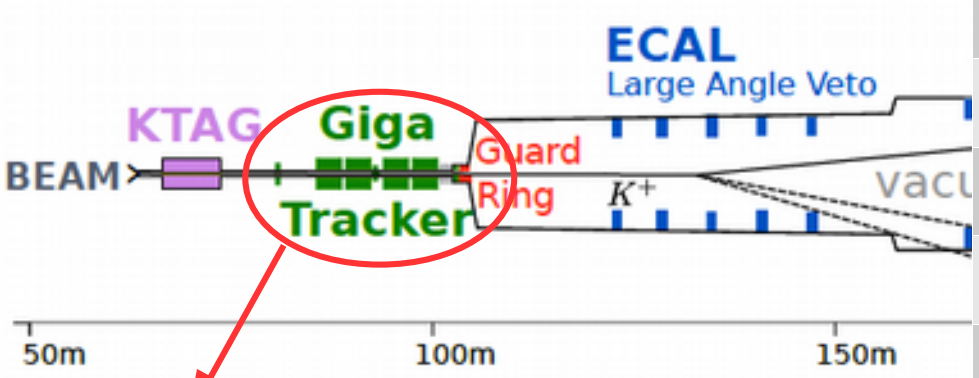
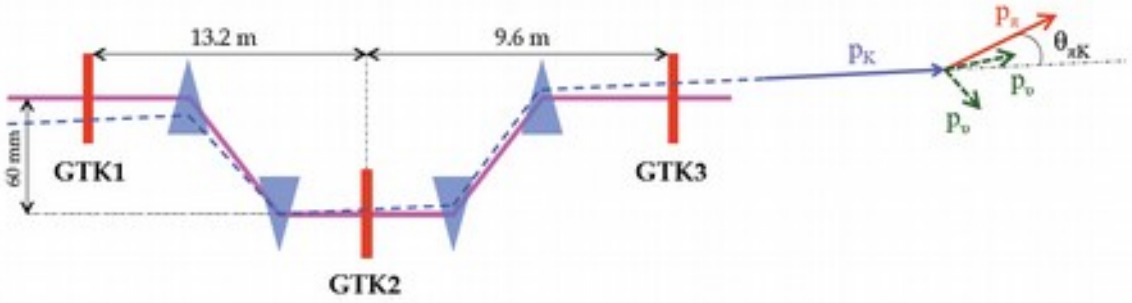
Beam rate	750 MHz total 1.3 Mhz/mm^2 center
Radiation	10^{14} 1MeV eq n/cm^2/y
Efficiency	99%
Momentum resolution	0.2%
Angular resolution	16 μrad
Hit time resolution	< 200 ps RMS
Material budget	3 x 0.5% X_0
Detector size	60 mm x 27 mm





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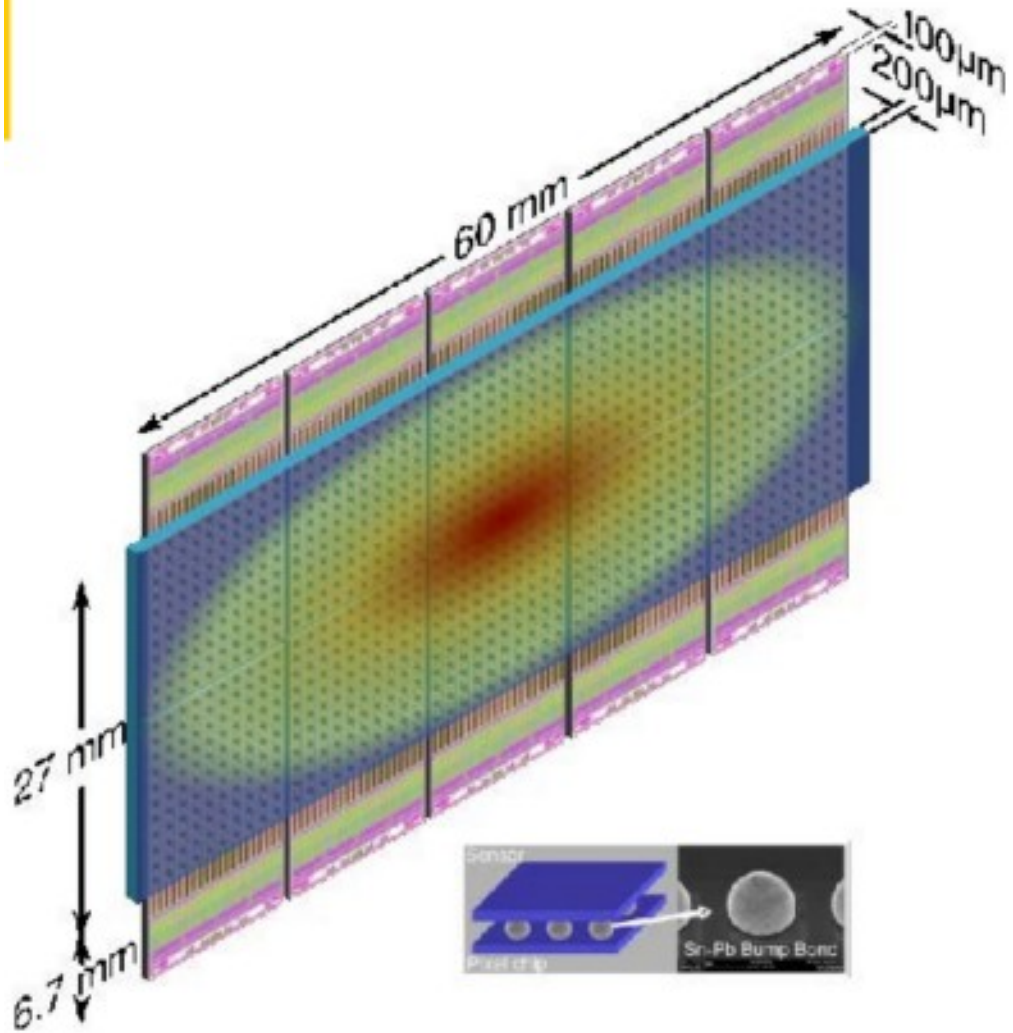
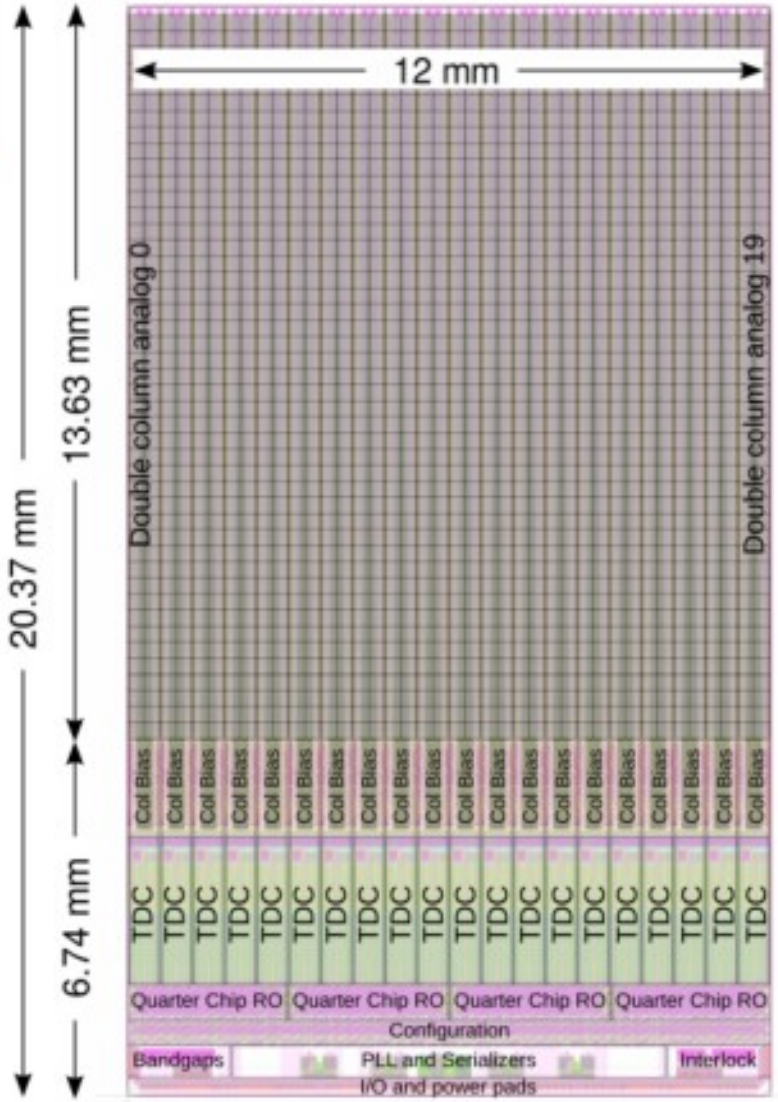
Sensor-Chip Assembly



- Hybrid pixel detector
  - 300 µm x 300 µm pixels
  - 1 sensor bump-bonded to 10 read-out chips
- Sensor [FBK, CIS]
  - Both p-in-n/n-in-p
  - Bias: 100 V – 300 V
  - Thickness: 200 µm
  - MPV Charge per MIP: 2.4 fC
- Bump-bonding Sn-Pb [IZM]
- 10 TDCPix chips/station:
  - 130 nm CMOS [IBM] thinned to 100 µm
- Detector replacement every 100 days of beam (radiation)

The Front-End Chip - TDCPix



- Design by CERN PH-ESE:
  - 1800 pixels (40col x 45row)
  - Each pixel (300 x 300) μm^2
  - Separate analog-digital: no high frequency clock to pixels

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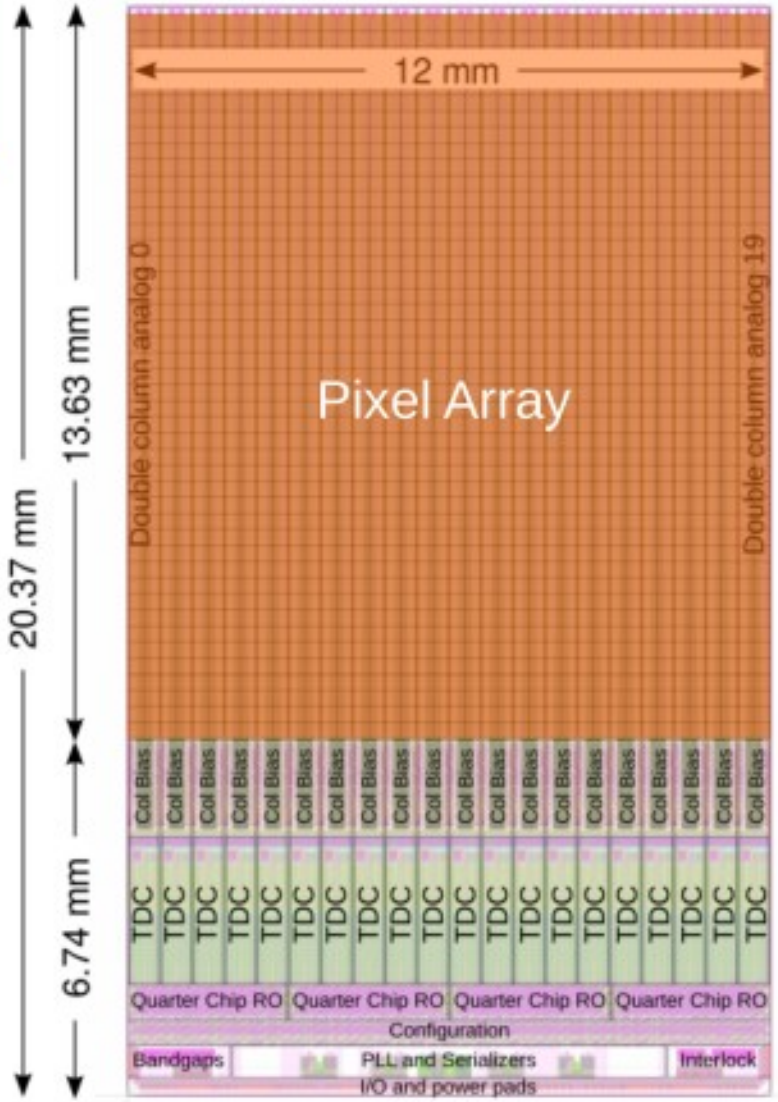

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  - Amplifier (65 mV/fC, 5 ns peak time)
  - Discriminator
  - 5 bit DAC threshold trim
  - Configuration register

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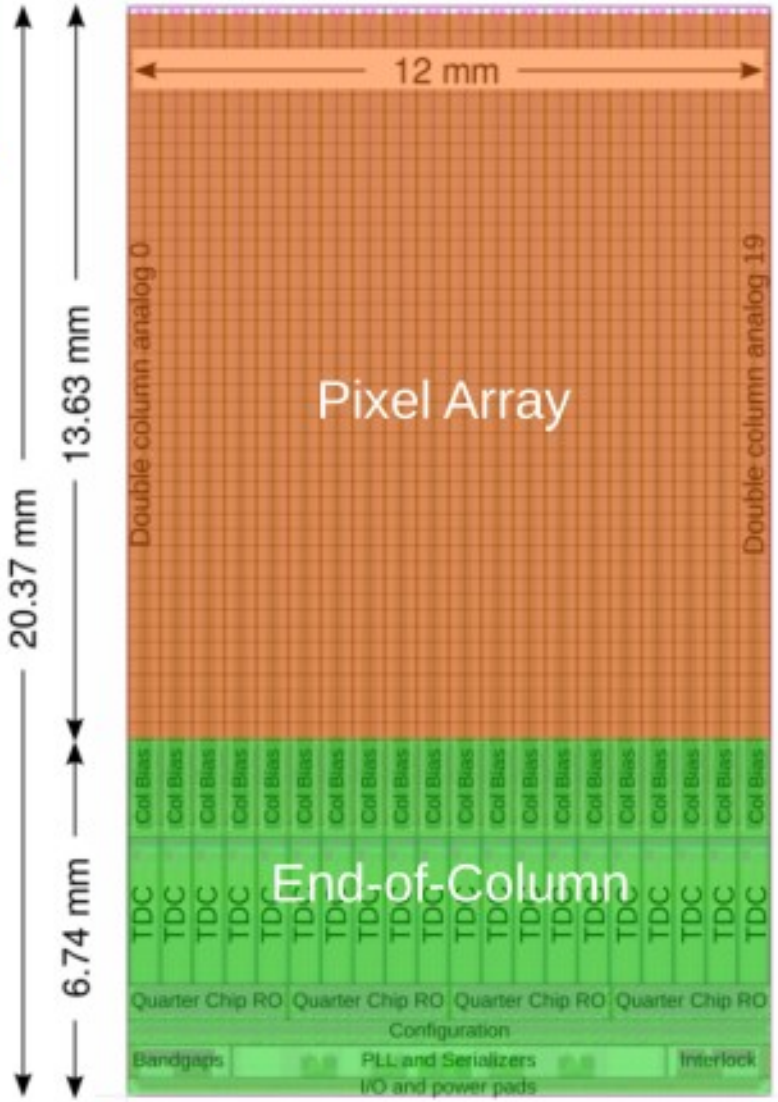

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- End of column (EoC) integrates:
  - Time-to-digital converters (TDC)
  - Data serializers

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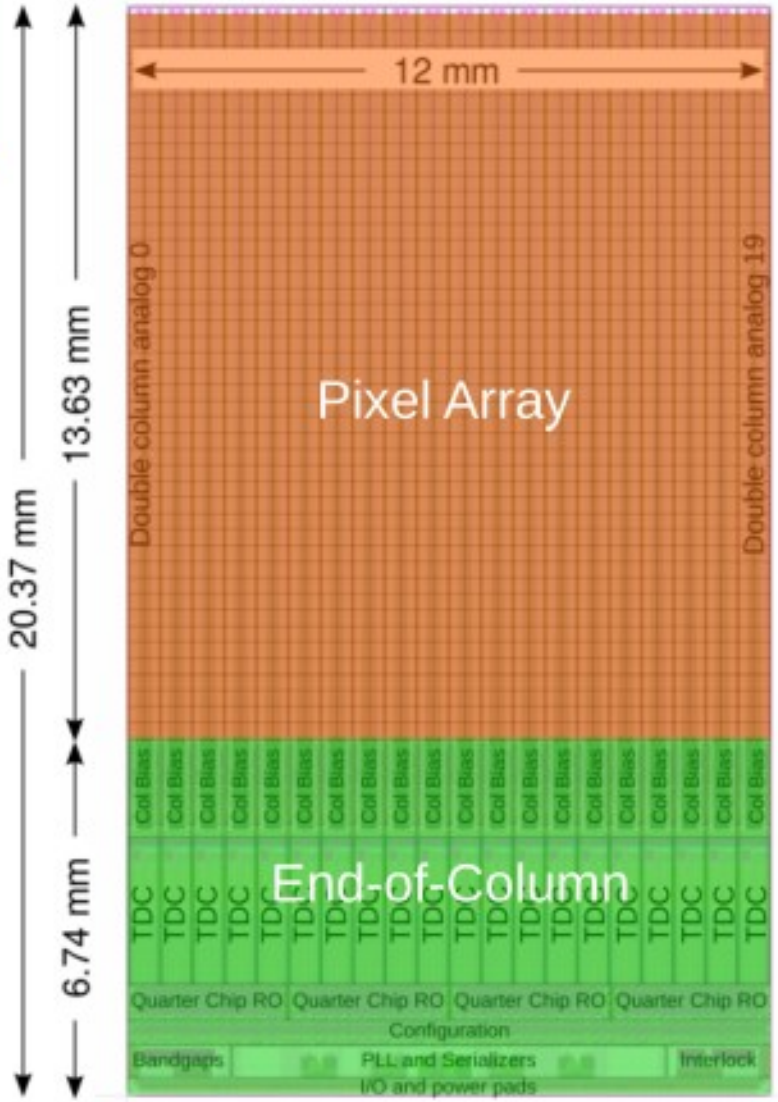

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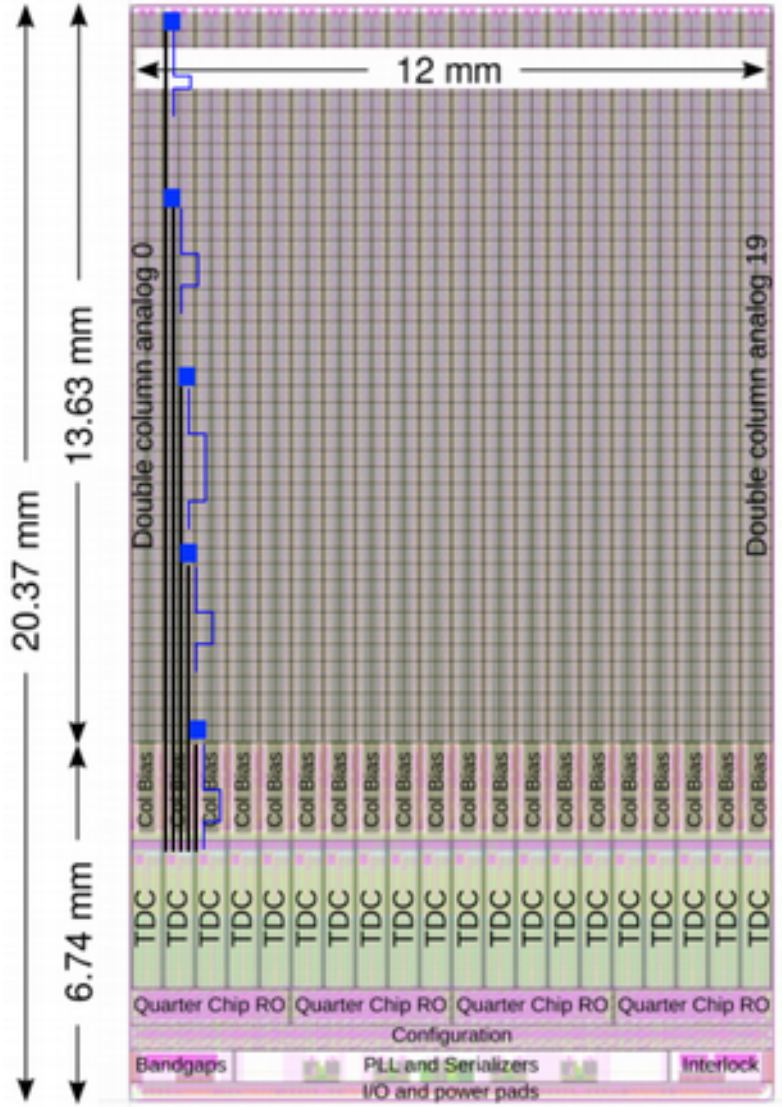
- End of column (EoC) integrates:
  - Time-to-digital converters (TDC)
  - Data serializers
- Power consumption: ~ 3.5 W, mostly EoC

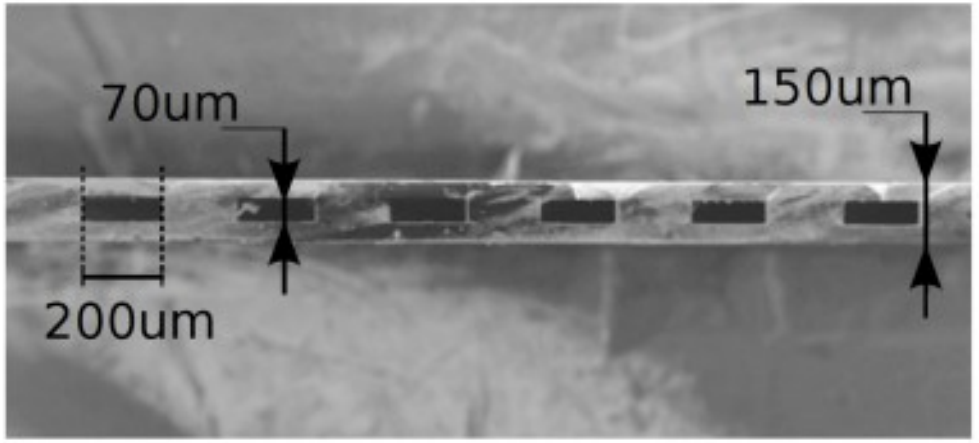
TDCPix End of Columns

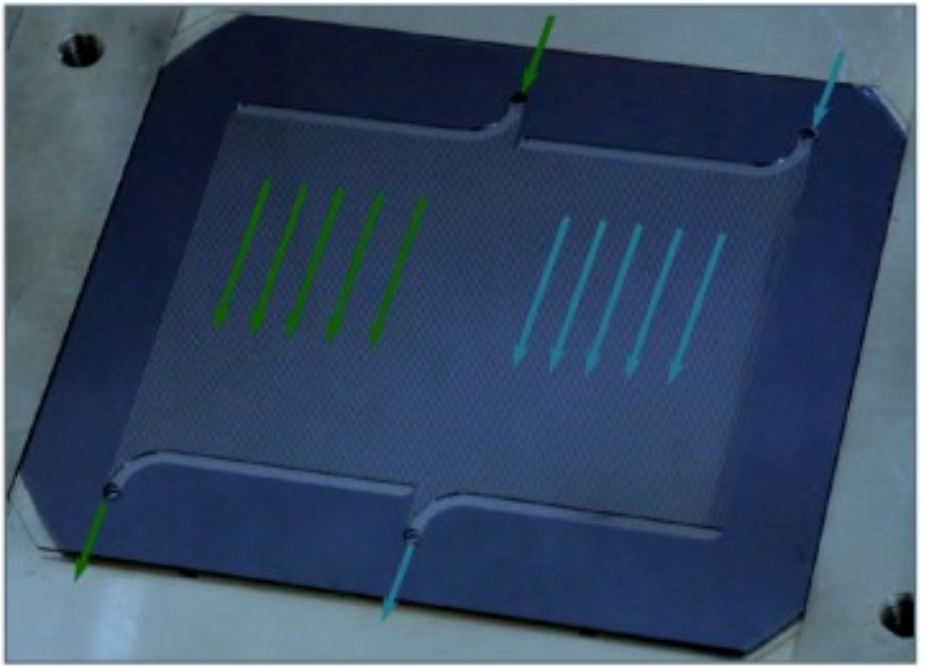


- Signals from 5 pixels in a column are sent to a multiplexer (HitArbiter)
- Each HitArbiter has a TDC pair measuring leading and trailing edges
  → 360 TDC pair/chip
- TDC bin size ~ 98 ps
- Self triggered operation:
  - rate 210 Mhits/s
- Data sent out using 4 x 3.2 Gb/s serializers

Micro-channel cooling

- Physics performance requires to minimize the material budget
- Detector is in vacuum
- Need to dissipate ~ 35 W/station



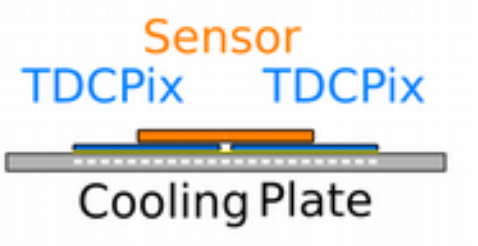


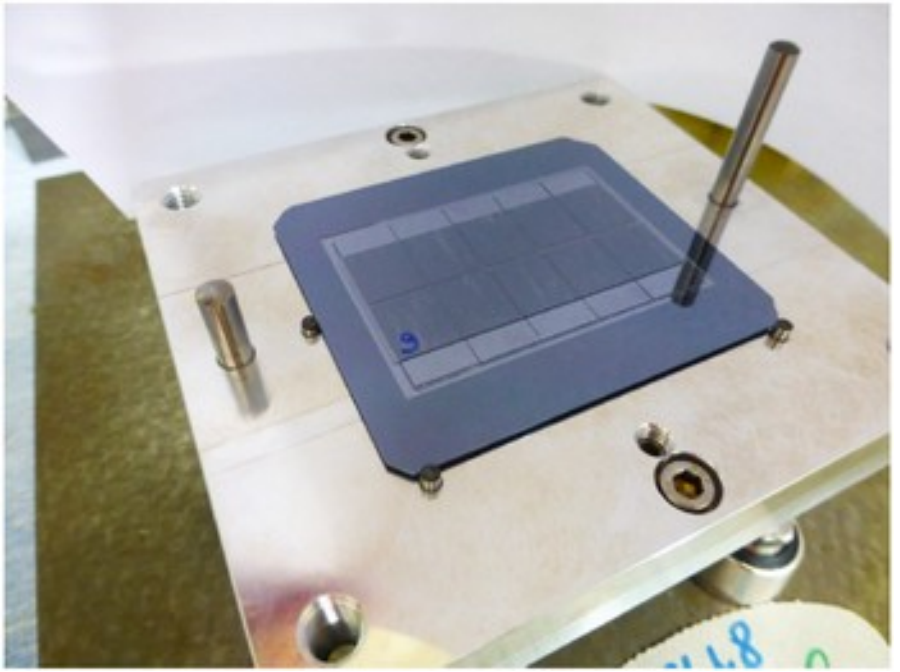
Micro-channel cooling matches the constrains:

- Designed by CERN PH-DT group
- Silicon-silicon assembly, (200 x 70) μm^2 channels
- Low material budget: 150 µm of silicon (< 0.15% X_0)

Mechanical integration

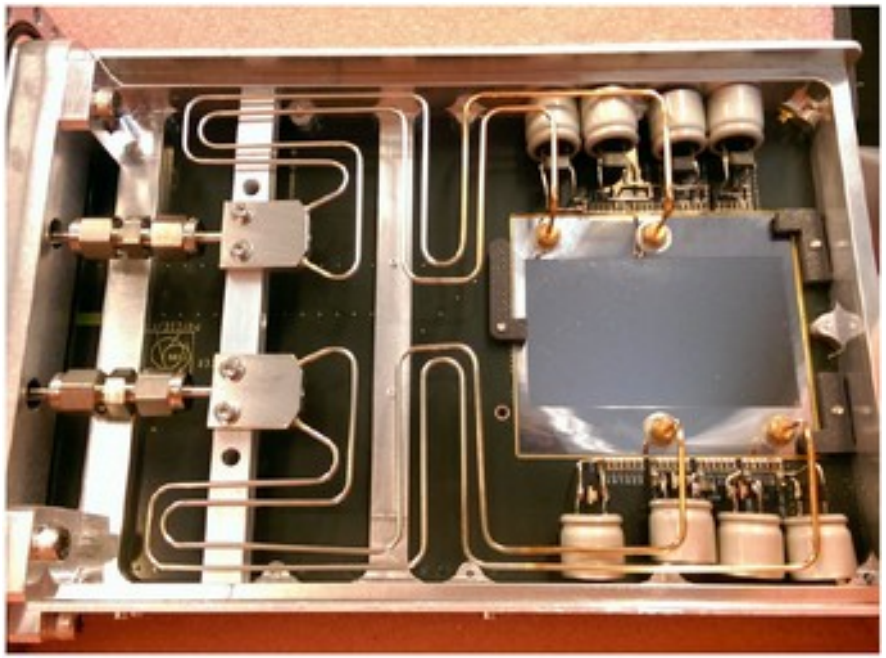
- Bump-bonded assembly glued on 150 µm silicon cooling plate





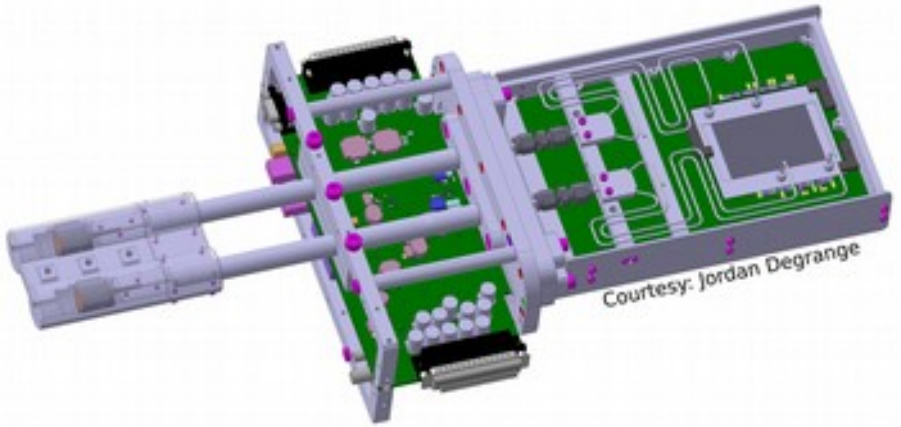
Mechanical integration

- Bump-bonded assembly glued on 140 µm silicon cooling plate
- Cooling plate is clamped onto PCB



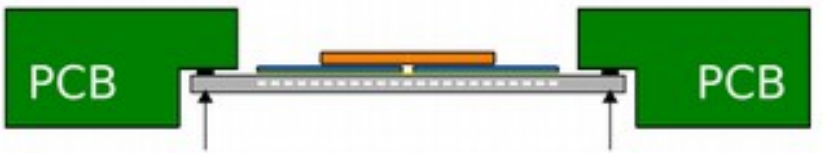
Mechanical integration

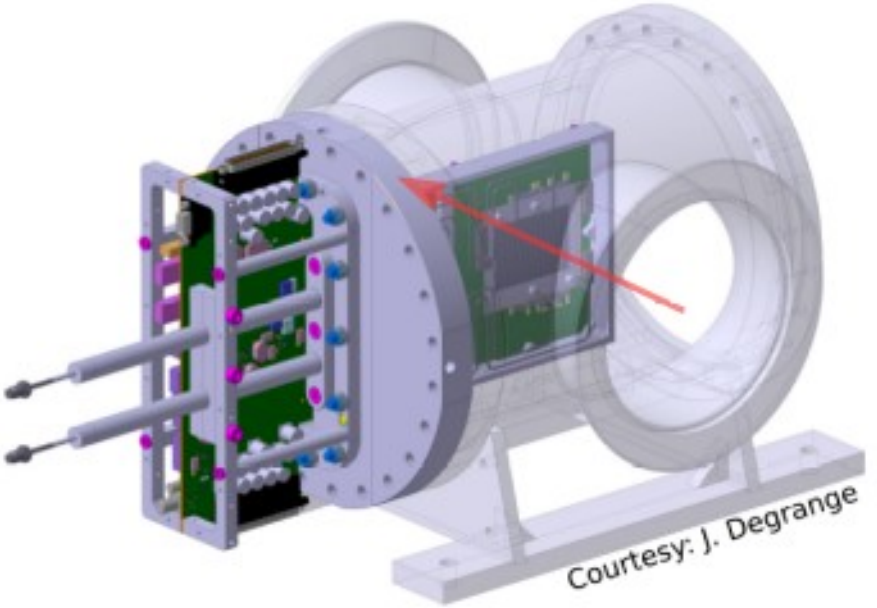
- Bump-bonded assembly glued on 140 µm silicon cooling plate
- Cooling plate is clamped onto PCB
- PCB is glued into frame + flange



Mechanical integration

- Bump-bonded assembly glued on 140 µm silicon cooling plate
- Cooling plate is clamped onto PCB
- PCB is glued into frame + flange
- Flange closes the vacuum vessel
- Easy access for intervention and detector exchange

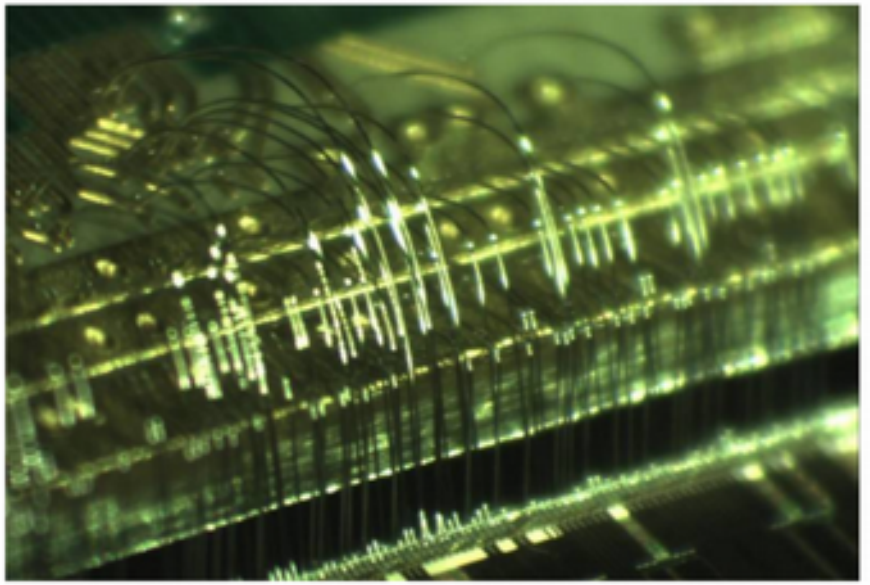




Electrical integration

- TDCPix wired bonded to PCB: dense wire-bonding scheme (73 µm pitch on chip)

- PCB routes power, clock, control and signal lines to/from the off-detector electronics



- Complex PCB:
  - 14 layers
  - 40 differential 3.2 Gb/s signals over 30 cm

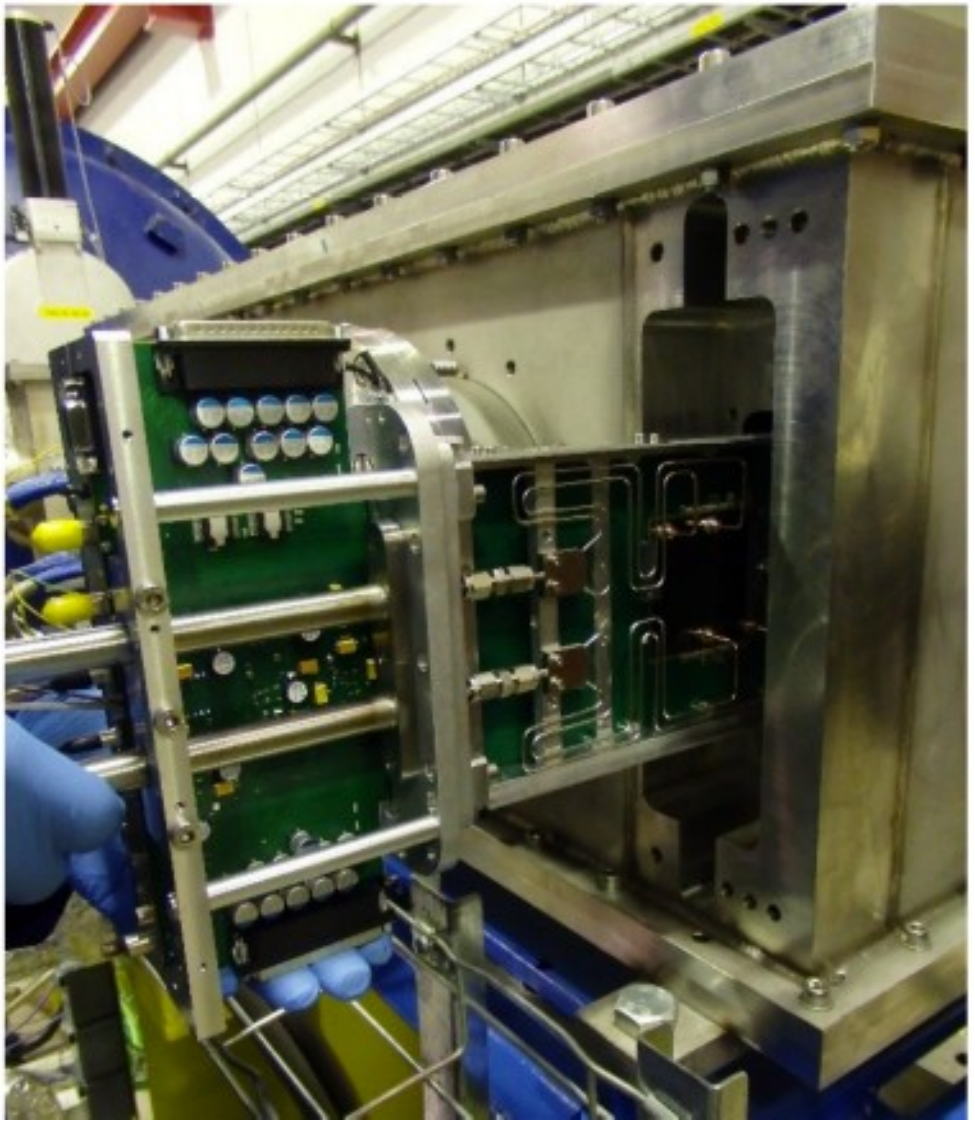
Data acquisition: GTK-RO

- TDCPix sends out every hit → trigger matching needed
- GTK-RO built using FPGA (Altera Stratix GX110)

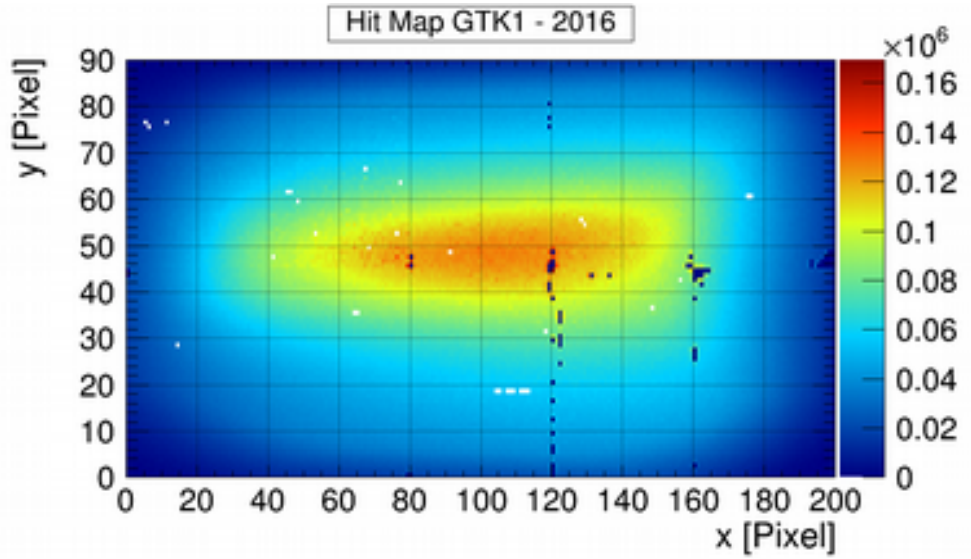
- Each TDCPix is connected to one DAQ board (GTK-RO) through 4 optical links (one per 3.2 Gb/s serializer) + 2 configuration links.
- The GTK-RO board must
  - Buffer data, waiting for level-0 trigger decision (max trigger latency is 1 ms)
  - Retrieve hits in a 75 ns time window upon each trigger request, and send them to the sub-detector PC using UDP
- 6 x sub-detector PCs
  - assemble data from several GTK-ROs and send it to online PC farm
  - Configure both GTK-ROs and TDCPix

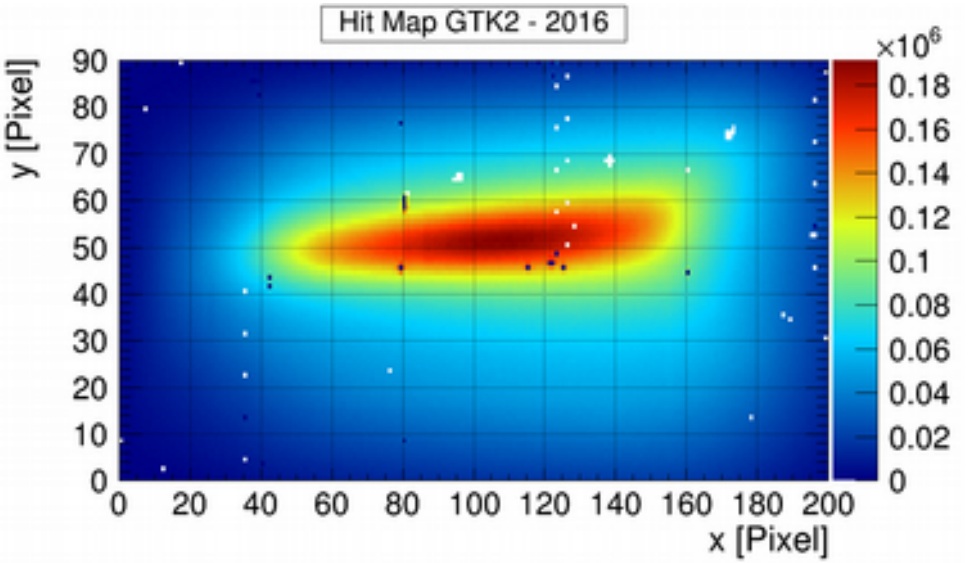
Installation in NA62

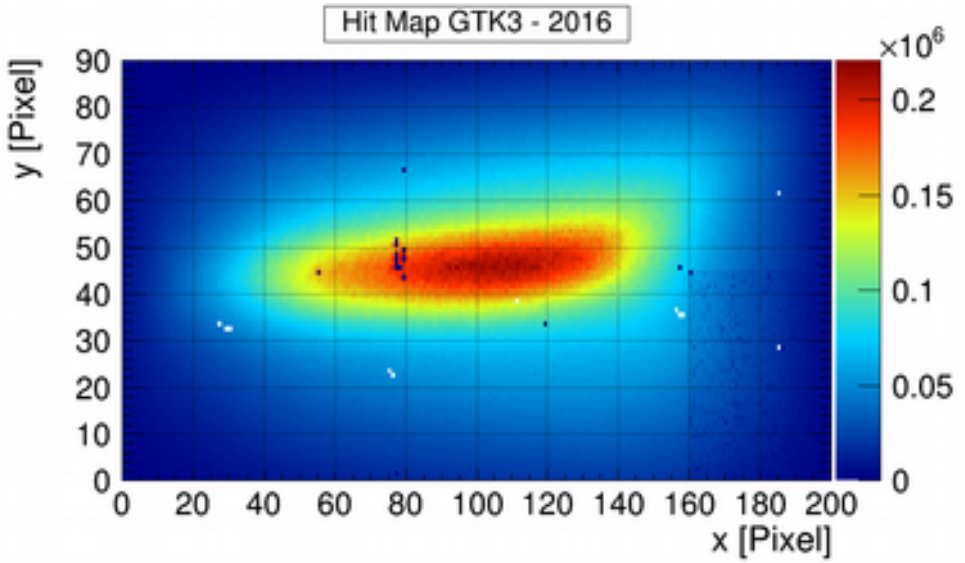
- All stations and infrastructure installed in 2014/2015
- Gigatracker commissioned in 2014/2015
  - GTK cooled at 0 to -10 °C
  - Thresholds set to 0.7 fC
  - Bias voltage set to 100-300 V depending on running periods
  - 70% read-out chip yield…
- Complete in 2016!



Hit maps

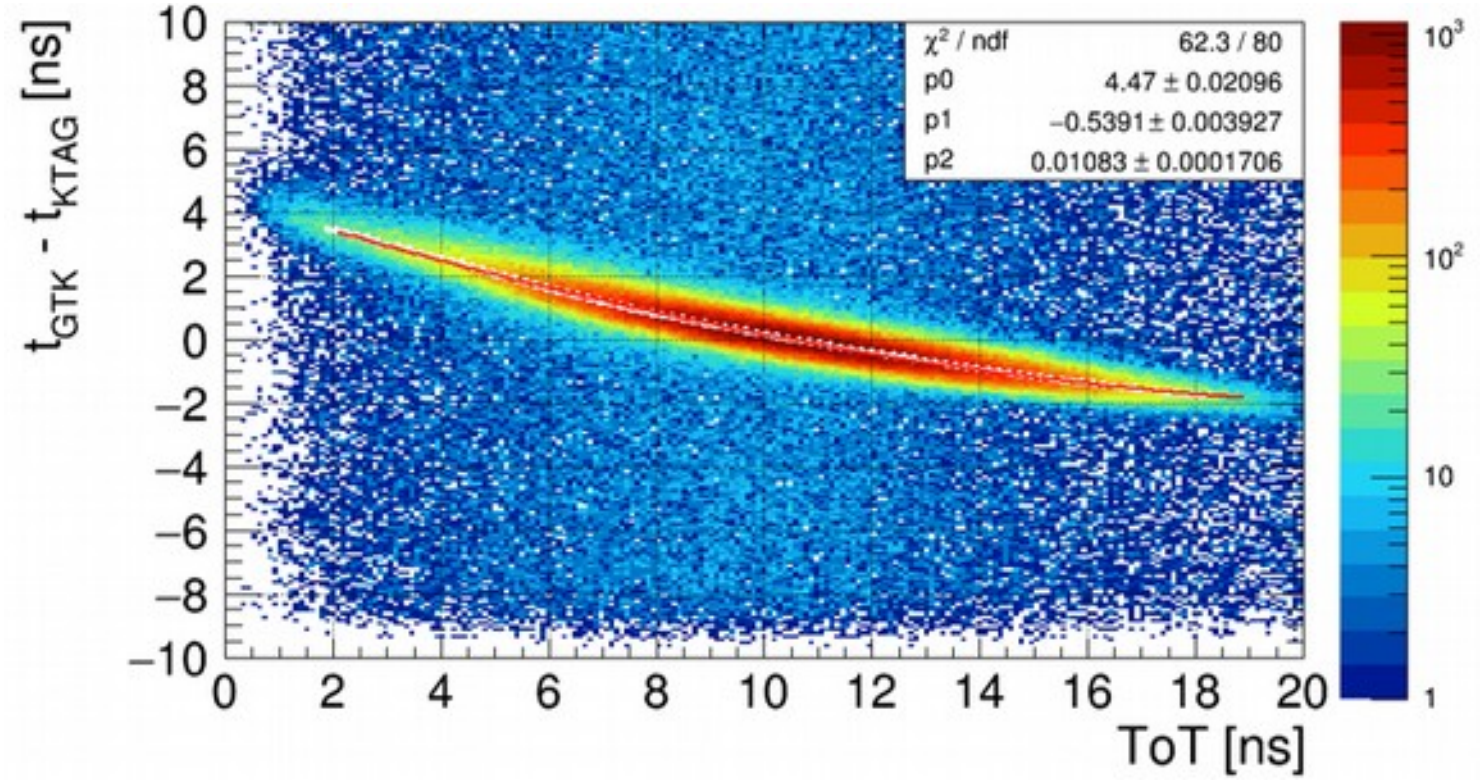

Hit Map GTK1 - 2016
y [Pixel]
x [Pixel]
×10^6
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0


Hit Map GTK2 - 2016
y [Pixel]
x [Pixel]
×10^6
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0


Hit Map GTK3 - 2016
y [Pixel]
x [Pixel]
×10^6
0.2
0.15
0.1
0.05
0

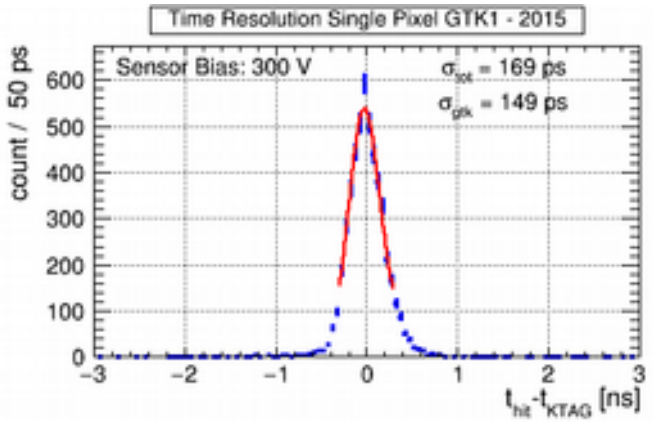
Time resolution

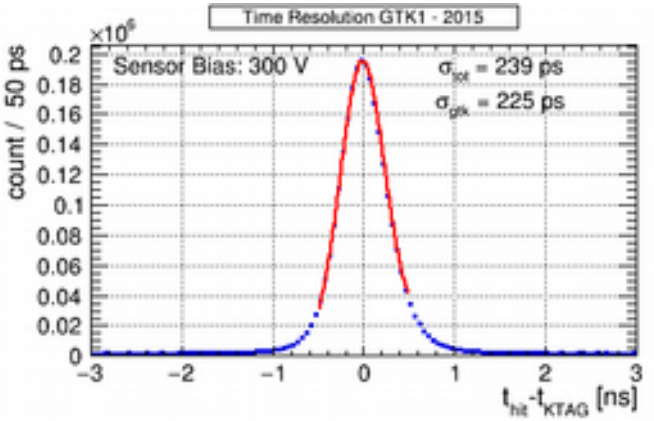
- Preliminary results from 2015 data
  - Paper on NA62 detector and beam line performance is under preparation
- Time walk correction using KTAG as timing reference

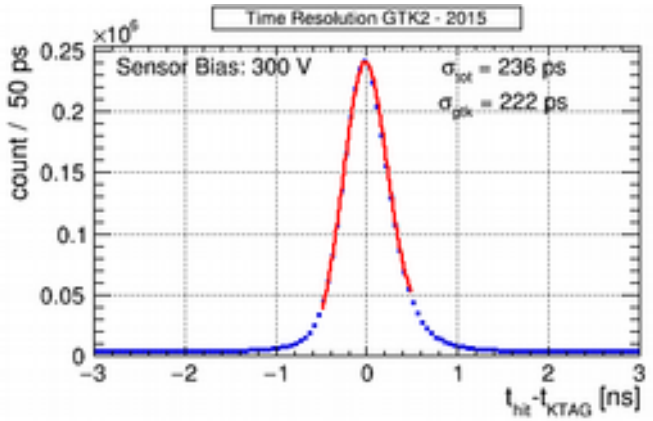


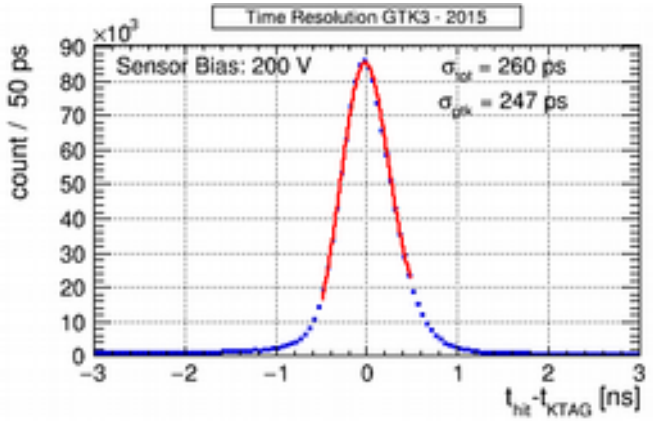
Time resolution

- Time resolution measured using 2015 data
  - 300 V bias voltage except for GTK3 (200 V)





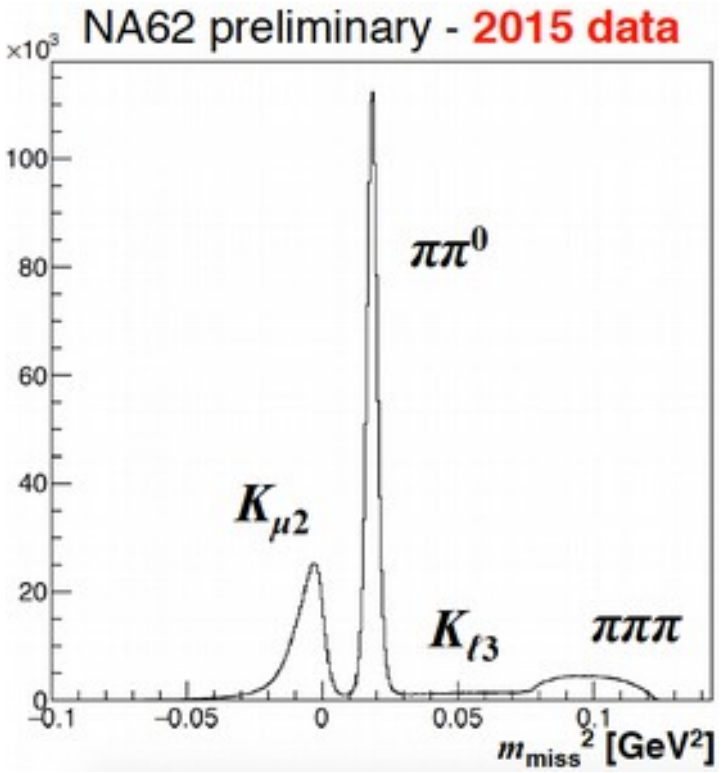


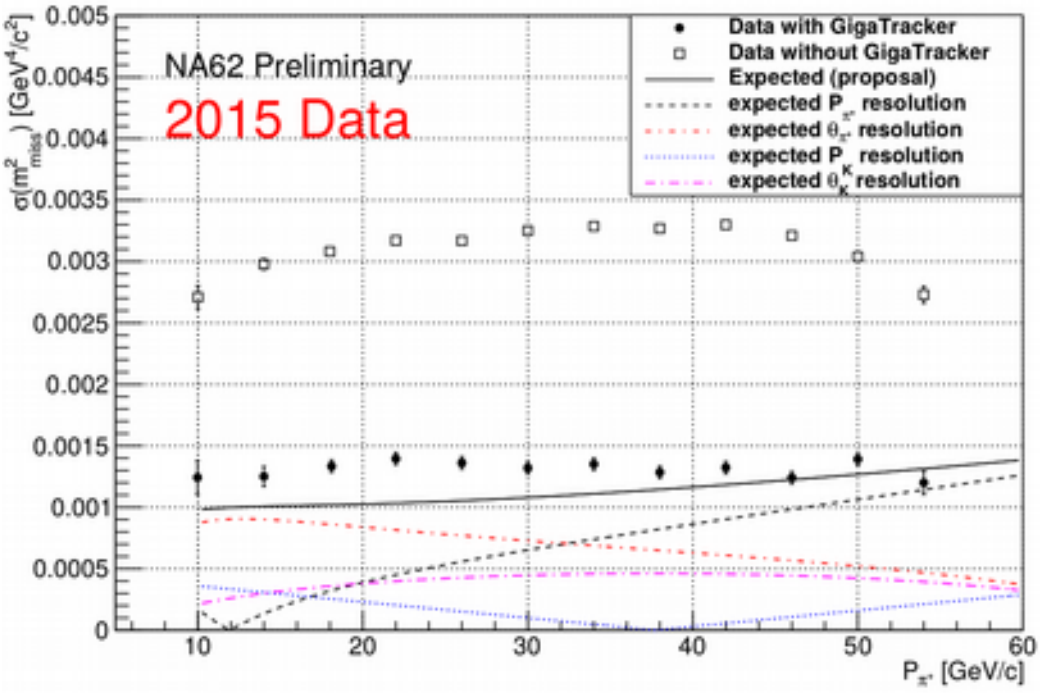


- Further calibrations and data analysis needed to exploit the full potential of the detector

m_{miss}^2 resolution

- Important contribution of the Gigatracker to improve missing mass resolution
  - Preliminary results from 2015 low intensity data





Conclusions

- The Gigatracker detector is essential to measure BR($K^+ \to \pi^+ \nu\bar{\nu}$) at NA62
- Detector fully commissioned
- Excellent timing performance measured on thin hybrid pixel detectors (200 μm planar sensors) with a very high density of channels (18000 per sensor) in vacuum
  - High over-depletion necessary
- Innovative and very-low mass cooling plate based on micro-channels
  - First implementation in HEP experiment
- Analysis of full 2015 and 2016 data sets is on-going
  - Monitoring radiation damage effects on performance