The NA62 GigaTracker and its upgrade

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on the behalf of the NA62 GTK Working Group

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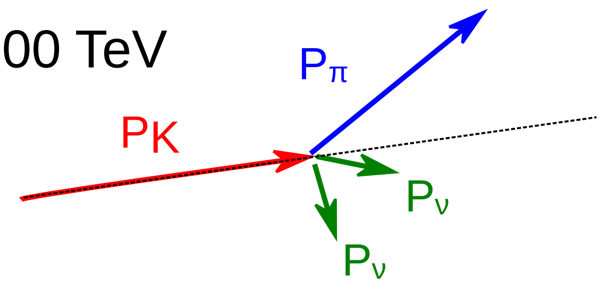
Outline

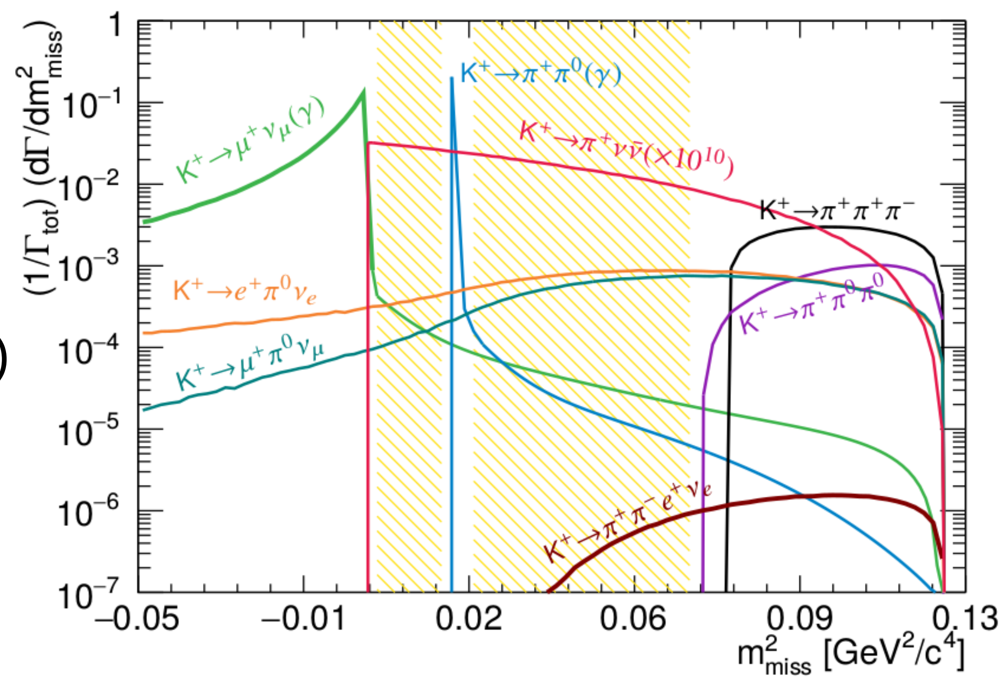
1. **NA62 and the GigaTracker**
   - Experiment goal
   - GigaTracker Specifications and Design
2. **HIKE: NA62 upgrade**
   - Specifications and ideas for the new GigaTracker
3. **Conclusions**

NA62 Experiment: measure $B(K^+ \to \pi^+ \nu\nu)$ with 10% precision



- Probe New Physics at energy scales as high as few 100 TeV
- Experimentally challenging:
  - 2 neutrinos in the final state
  - $B = (8.3 \pm 0.30) \times 10^{-11}$ if SM

- Kinematics is very important to control backgrounds, $m^2_{miss} = |p_K - p_\pi|^2$
- Previous dedicated experiments (BNL) used stopped beam (p_K=0)



The NA62 Experiement [JINST 12.5 (2017), P05025]

Decay in flight technique at CERN-SPS (proposed in 2005, 17 years ago!)

- **Continuous** beam 750 MHz (6% K + , 24% p, 70% π +) at 75 GeV/c
- Beam being **not bunched**, all detectors must provide **timing information**
- As K do not decay at rest, **p_K has to be measured** to compute m^2_{miss}

A (time resolved) **beam spectrometer is needed**: the GigaTracker (GTK)

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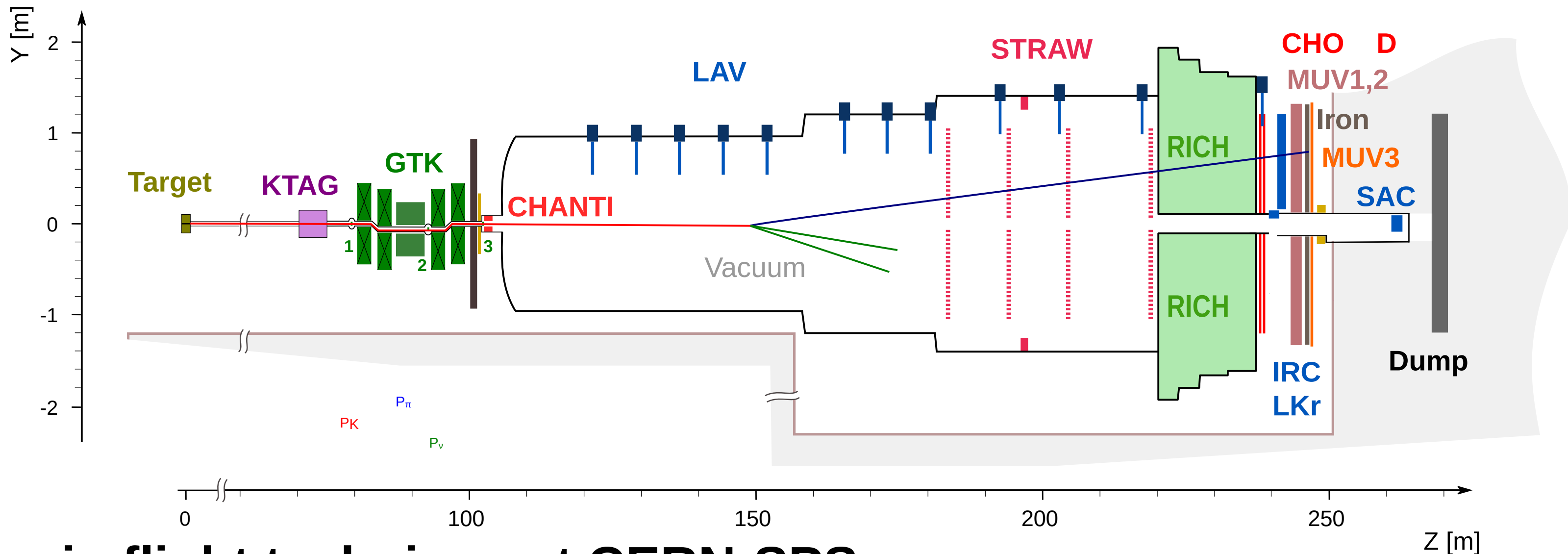

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The GigaTracker (GTK)

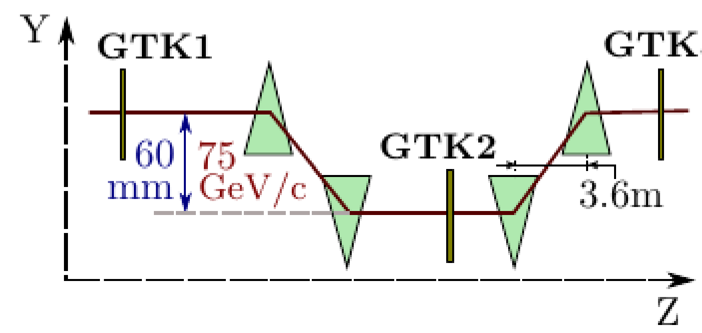
Beam Spectrometer

- Measures momentum, angle and time coordinate of all beam particles
- Sustains high particle flux
- Minimizes material budget

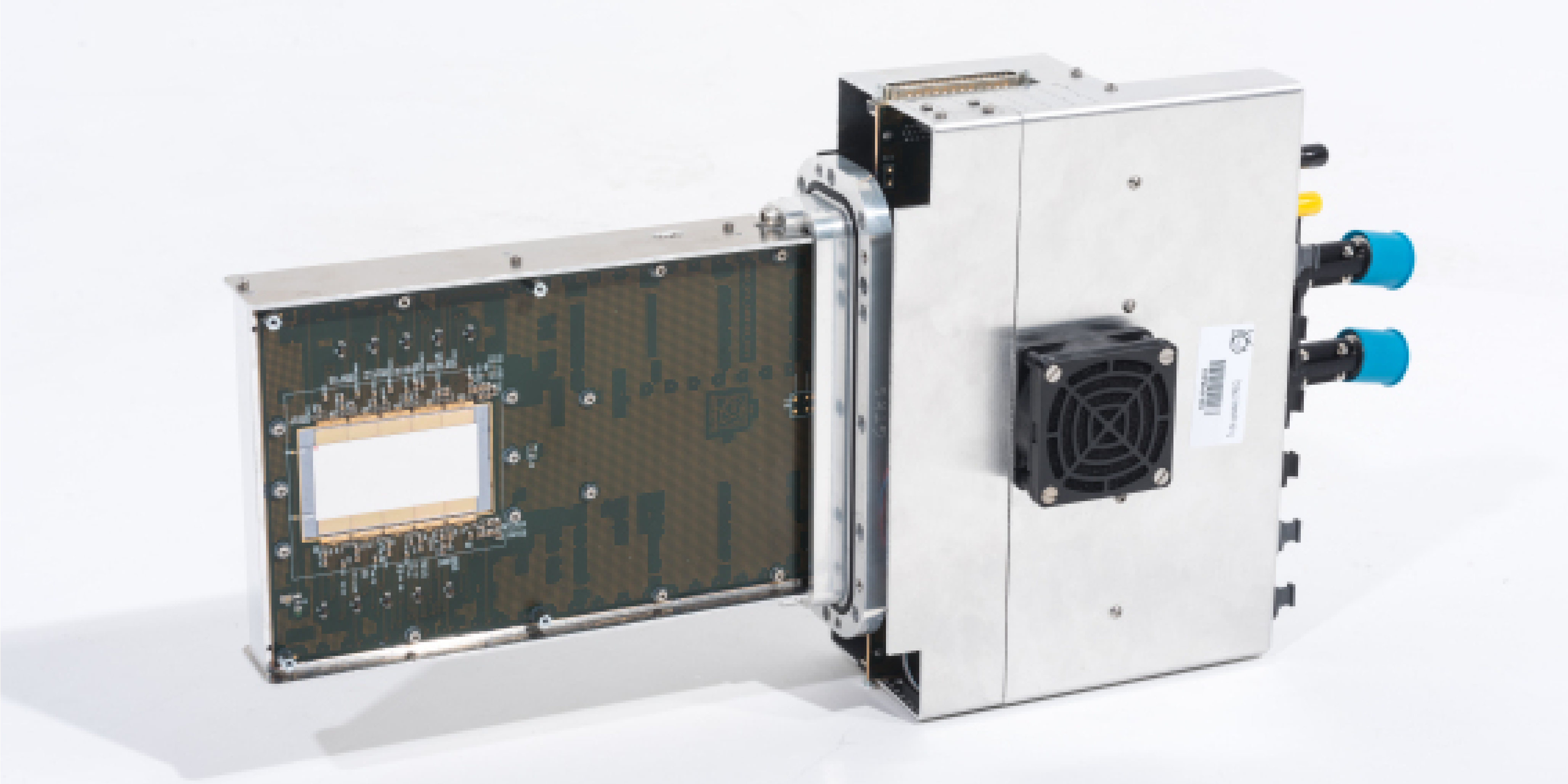
Beam Rate	750 MHz
Peak Flux	2.0 $\mathrm{MHz/mm^2}$
Peak Radiation	4.5×10^{14} 1MeV $\mathrm{n_{eq.}/cm^2}$ for 200 days
Efficiency	99%
Momentum Resol.	0.2%
Angular Resol.	16 μrad
Pixel Time Resol.	$<$ 200 ps RMS
Material Budget	0.5% X_0

Design

- Three planes of Si hybrid pixels
- Installed in beam pipe vacuum: 10^{-6} mbar
- Replaced after 1 year at full intensity



The GigaTracker



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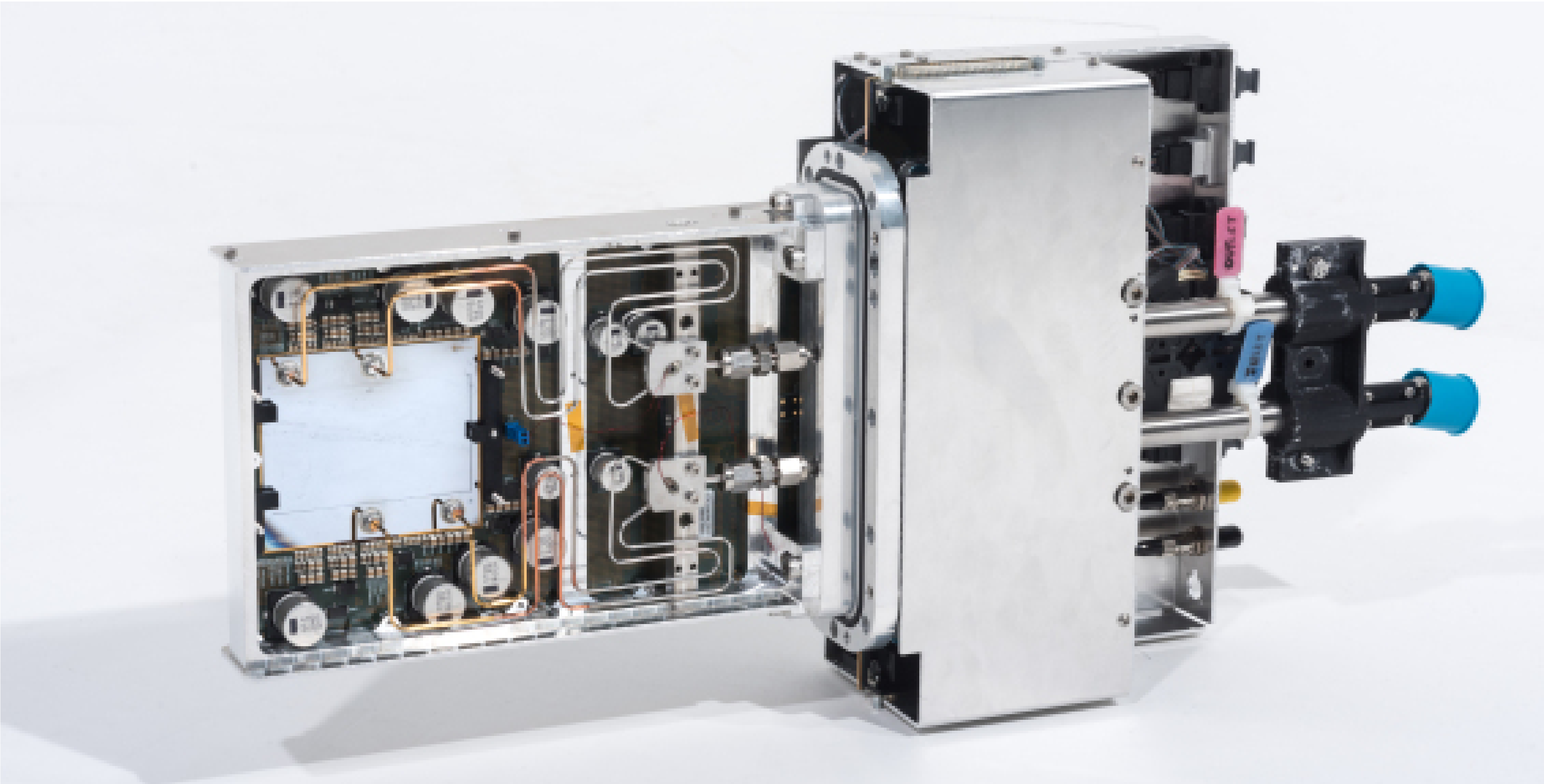

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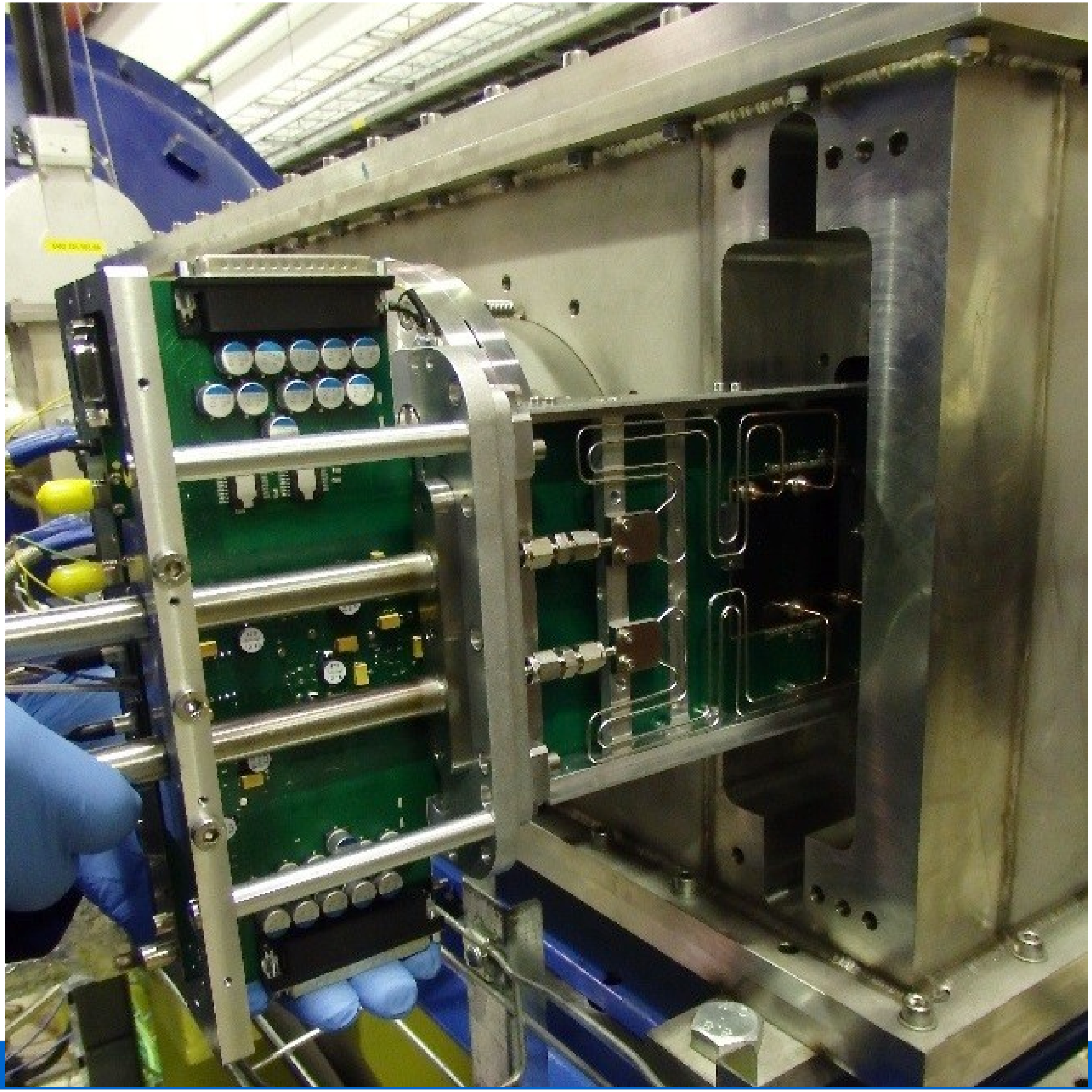
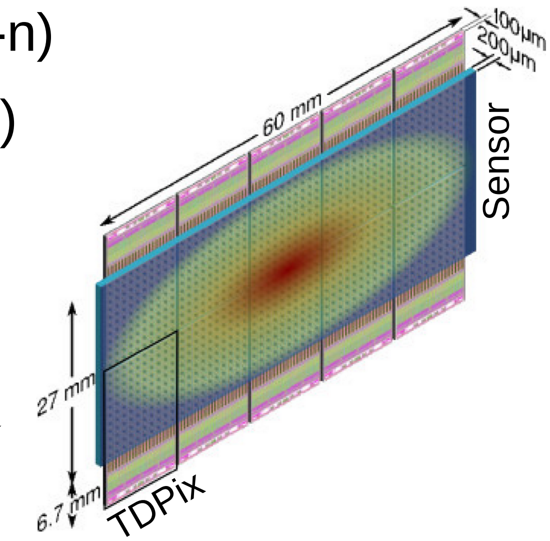
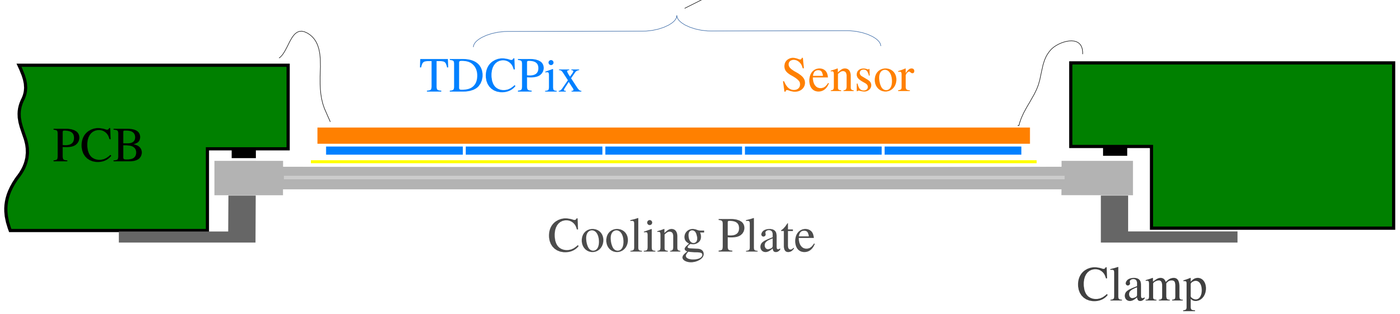


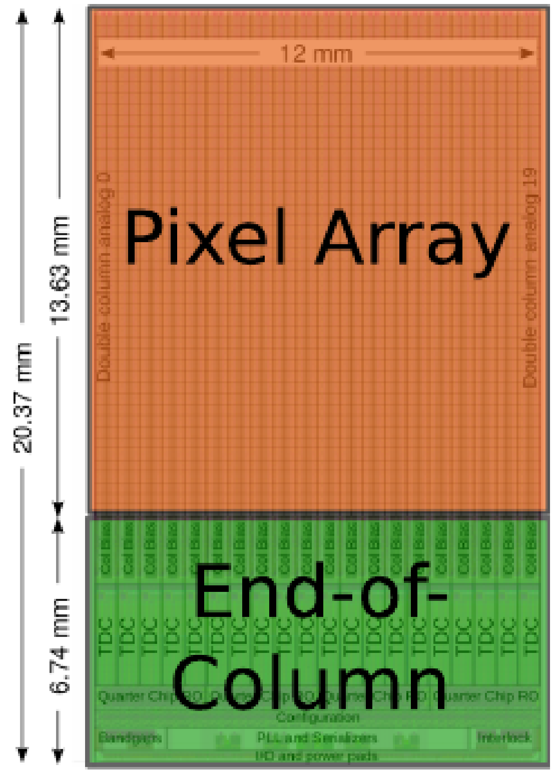
Module Design

- A single 27x60 mm² large planar sensor (200μm, p-in-n)
- Readout by 2x5 custom made ASICs (100μm TDCPix)
- Mechanical and thermal integration using a silicon microchannel cooling plate (200μm)
- Wirebonds to PCB at chips edge for power, config, clock and data transfer





TDCPix



Specifications

Time Resol	$< 200\,\mathrm{ps}$
TDC bin	97 ps
Peaking Time	$5\,\mathrm{ns}$
Peak Dose	$15\,\mathrm{MRad/y}$
Max Pixel Hit Rate	$180\,\mathrm{kHz}$
Chip Max. Hit Rate	$212\,\mathrm{MHz}, 130\,\mathrm{MHz/cm^2}$
Data Ouput Rate	$12.8\,\mathrm{Gb/s}$
Power	$4.1\,\mathrm{W}$
	$4.8\,\mathrm{W/cm^2}$ in EoC
	$0.32\,\mathrm{W/cm^2}$ in Px Array
Dynamic Range	$0.6 - 10\,\mathrm{fC}$
Efficiency	$> 99\%$

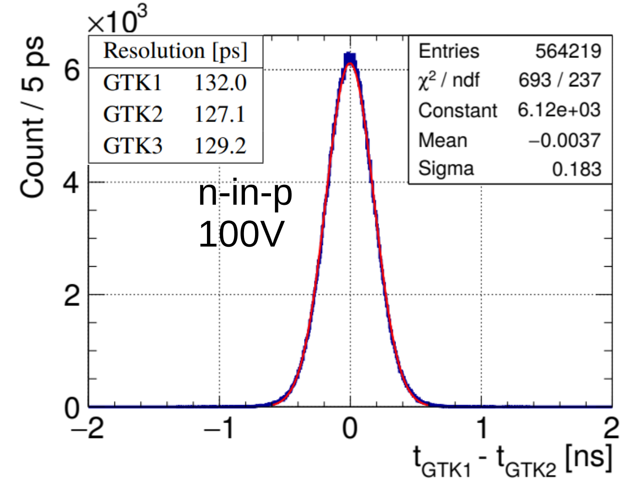
Architecture

- IBM 130nm CMOS technology
- Digital logic fit in EoC to reduce digital switching noise in pixel array

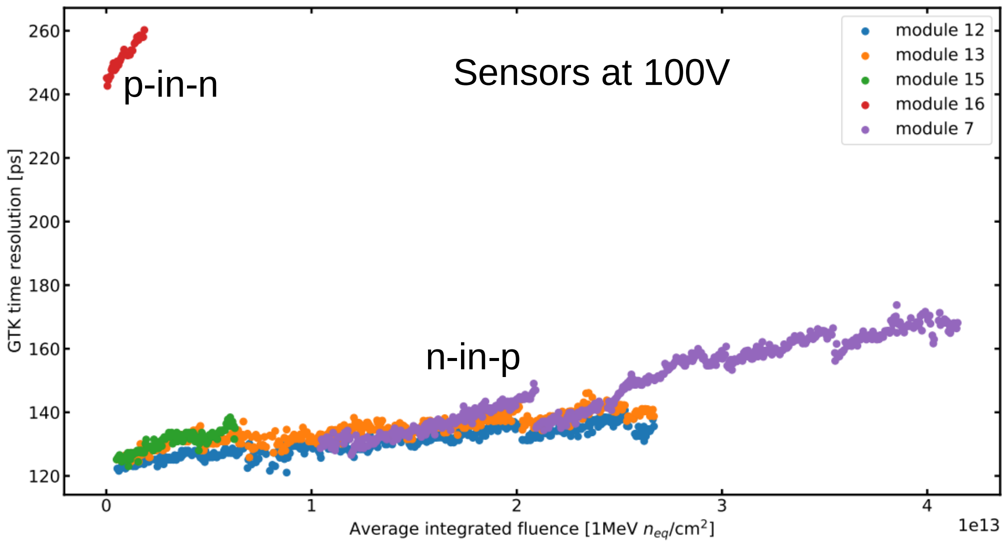
GTK Performance in a nutshell

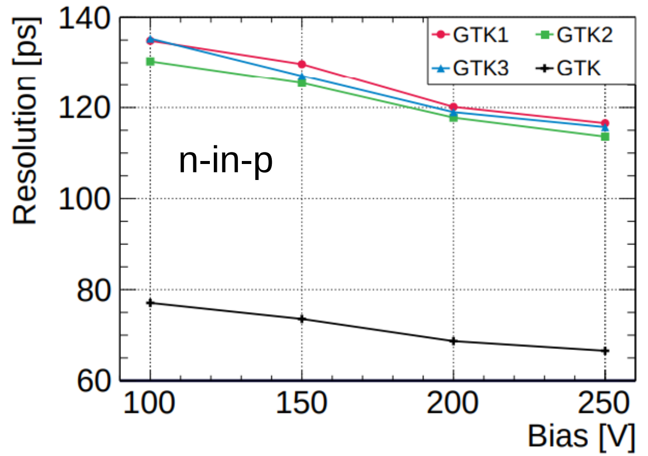
G. Aglieri Rinella et al 2019 JINST 14 P07010

- Time resolution of 130 ps with new n-in-p sensors @100V
- Resolution improves when bias is increased
- Marginal degradation of the time resolution with radiation which can be compensated by increasing the bias



A. Kleimenova, PhD thesis, Sep. 2021, UCLouvain





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HIKE: High Intensity Kaon Experiement

- **Main focuss** of NA62 is $B(K^+ \rightarrow \pi^+\nu\nu)$
  - short range process in SM very **sensitive to new physics** (cf $B_s \rightarrow \mu\mu$)
  - extremely **rare** and **precise** prediction

$$B(K \rightarrow \pi\nu\nu) = (8.30 \pm 0.30)\ 10^{-11} \text{ in SM}$$

- By **LS3**, NA62 will measure $B(K \rightarrow \pi\nu\nu)$ with **O(10)% precision**

- **Upgrade's** main goal is to reach the **irreducible theoretical precision** for $B(K \rightarrow \pi\nu\nu)$: 5%
  - Need to collect about **400 $K \rightarrow \pi\nu\nu$** (if SM) between 2029 and 2034
  - with current beam intensity NA62 collects ~20 $K \rightarrow \pi\nu\nu$ / year
- To collect 400 $K \rightarrow \pi\nu\nu$ in 5 years **beam intensity has to be scaled by 4**

Hike Beam Tracker (HTK)

- Key Specifications

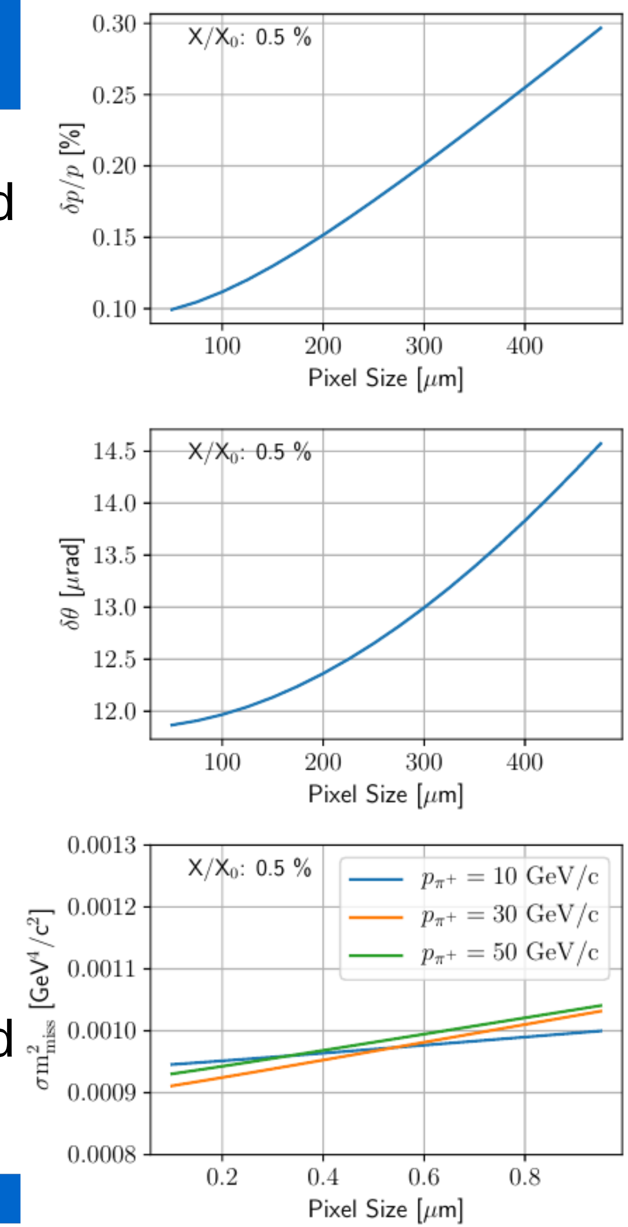
	HTK	GTK
Pixel Size	$\lesssim$ 300×300μm²	300×300μm²
Hit Time Resolution	$\lesssim$ 50 ps RMS	200 ps RMS
Peak Hit Rate	8 MHz/cm²	2 MHz/mm²
Pixel Efficiency	>99%	>99%
Beam Size	3x6cm²	3x6cm
Dose / year*	$48 \cdot 10^4$ Gy/year $2.4 \cdot 10^6$ Gy	$12 \cdot 10^4$ Gy
Fluence / year*	$1.6 \cdot 10^{15}$ 1MeV n_{eq}/cm²/year $5 \cdot 10^{15}$ 1MeV n_{eq}/cm²	$4 \cdot 10^{14}$ 1MeV n_{eq}/cm²/year

* 1 year corresponds to 200 days of beam
HIKE will run 5 years, if pixel technology has not enough radition tolerance, yearly station exchange could be envisaged (as for current GTK)

Pixel Size

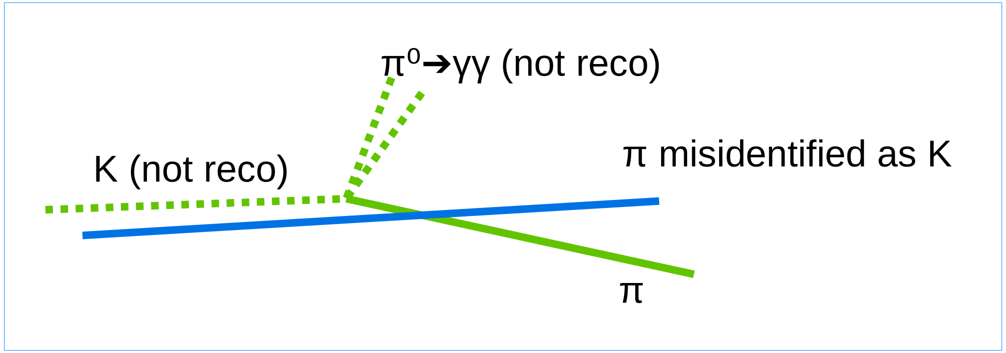
- **Physics** wise, the GTK/HTK performance are determined by the **material budget** and **pixel pitch**
- Most technologies feature **pitches smaller than GTK**
- A smaller pitch would:
  - strongly enhance the momentum resolution
  - marginally enhance the angular resolution
  - marginally increase the hit size (more addresses needed?)
- However, the figure of merit is the m^2_{mass} resolution which is dominated by the performances of another detector

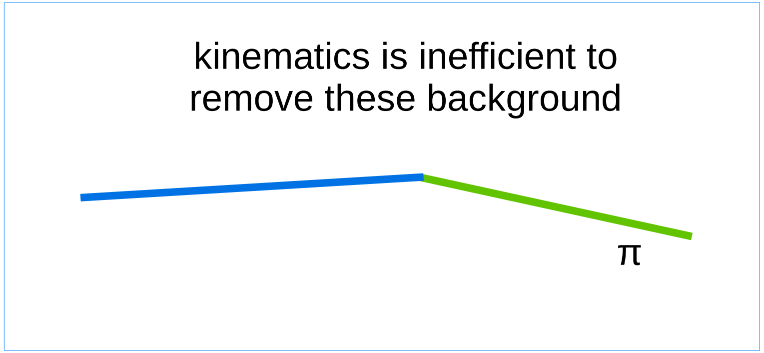
- **Conclusion:**
  GTK/HTK can use pixel pitch <300μm but it is not needed



Efficiency

- Small number of tracking planes (low mat. budget) imposes high efficiency
- Tracking **inefficiency increases background**

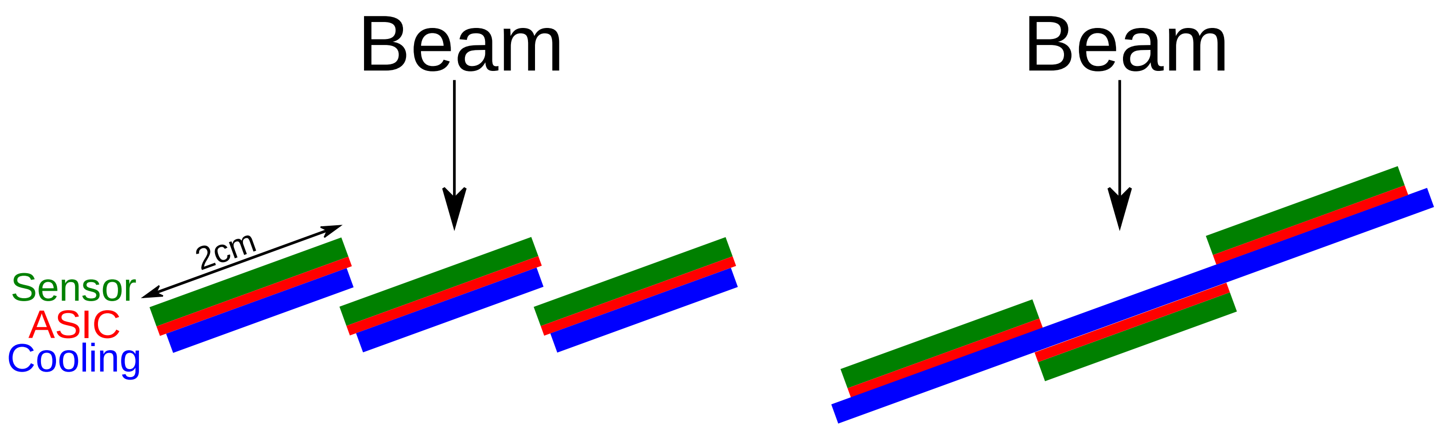




- Including fill factor and all readout effects, efficiency per pixel should be >99%

Efficiency and dead regions

- Sensor technology featuring **dead region** (implants) would need to be operated tilted (luckily NA62 beam is very parallel)
- Beam spot size ($3x6cm^2$) is quite large compared to advanced sensor size ($2x2cm^2$). Avoiding dead region at sensor edges would require stitching or tiling



Some perspectives

- Other experiments aims for similar performances

Requirement	LHCbU2 Option 1	LHCbU2 Option 2	NA62X4
Pixel pitch [µm]	≤ 55	≤42	≤300
Time resolution RMS [ps]	≤30	≤30	≤50
Loss of hits [%]	≤1	≤1	≤1
TID lifetime [MGy]	>24	>3	>2.4
Data BW per ASIC [Gbps]	>250	>94	>55

- Several R&D projects are aligned with the needs of HTK (see yesterday)
  - TimeSpot
  - LGAD community

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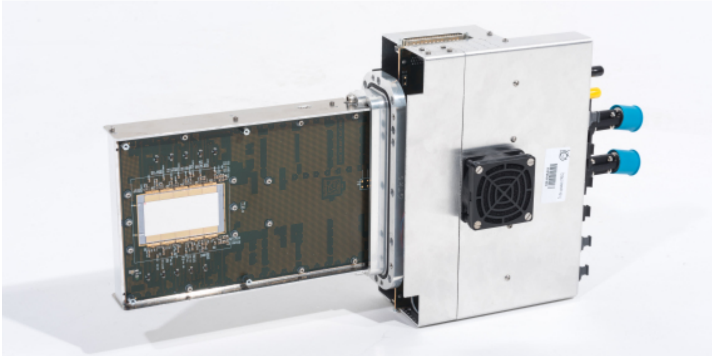
Conclusion

- NA62 has been pioneer on 4D tracking with the GTK (started in ~2007)



- A new step is ahead of us with the NA62 upgrade which should be able to operate a 4 times the current beam intensity by 2029
- Specifications have been presented and are in-line with the ones of other experiments and R&D project.
- Critical points are the >99% efficiency on a large area and <50ps time resolution