The kaon identification system in the NA62 experiment at CERN SPS

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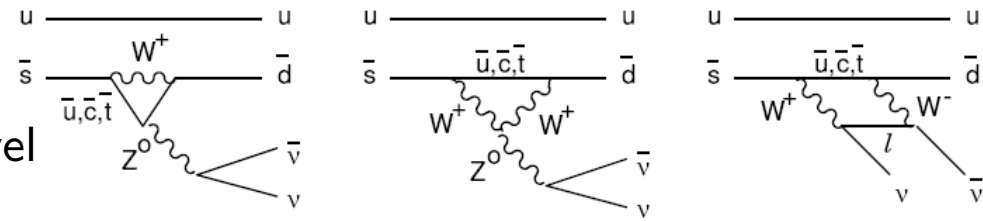
The 2015 International Conference on Applications of Nuclear Techniques Crete

$K \to \pi\nu\bar{\nu}$

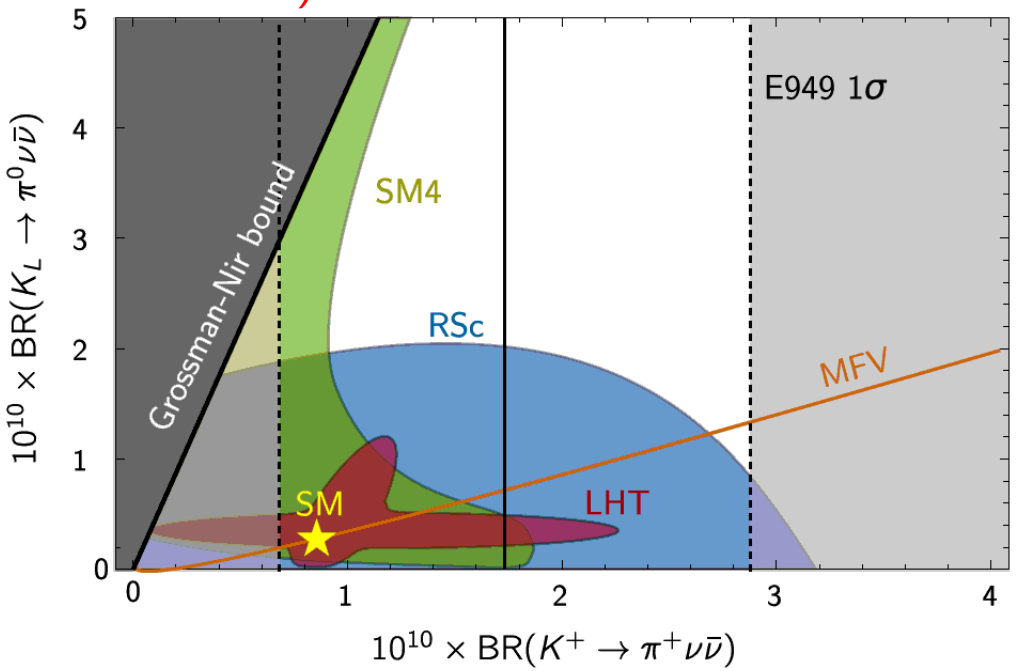


Ultra rare decay

- FCNC process forbidden at tree-level
- Very clean theoretical prediction:
  hadronic matrix element extracted from $BR(K \to \pi e\nu)$
- Golden modes:

	BR_{SM}	uncertainty (mostly from CKM)	arXiv:1503.02693
$K_L \to \pi^0\nu\bar{\nu}$	(3.00	$\pm 0.30)$	10^{-11}
$K^+ \to \pi^+\nu\bar{\nu}$	(9.11	$\pm 0.72)$	10^{-11}

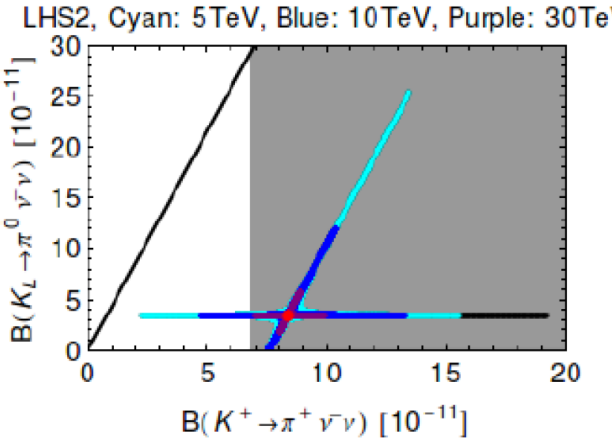
- Current existing measurement based on 7 events (E787/949): $(1.73^{+1.15}_{-1.05})10^{-10}$
- Lead to measurement of $V_{td} \approx 7\%$
- New Physics scenario $\to$

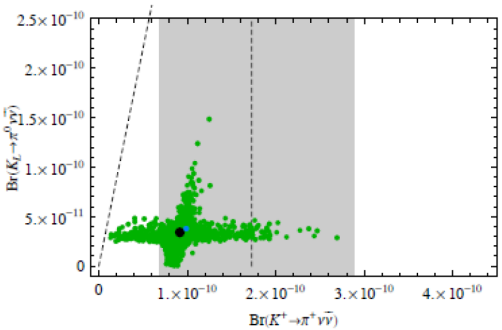


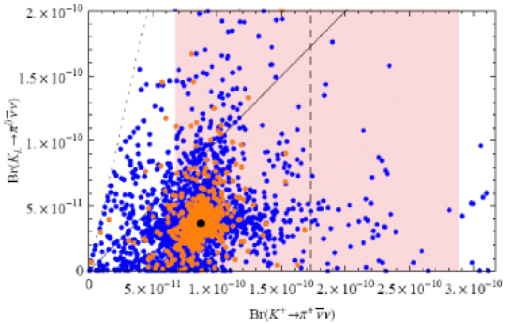
$K \to \pi\nu\bar{\nu}$ and New Physics

General model with new flavour structure:
Z gauge boson mediating FCNC at tree level
[A. Buras, F. De Fazio, J. Girrbach, JHEP 1302 (2013) 116]

K sensitive to mass scales beyond those explored by LHC (MZ > 5 TeV/c2)





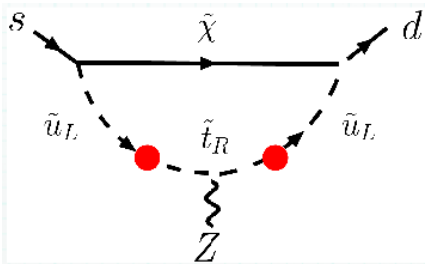


More specific NP models
Littlest Higgs with T-parity
Acta Phys. Polonica B41(2010)657
Custodial Randall-Sundrum
JHEP 0903 (2009) 108

Started to be probed at LHC, small effects in B physics

Best probe of MSSM non-MFV [JHEP 0608 (2006) 064]

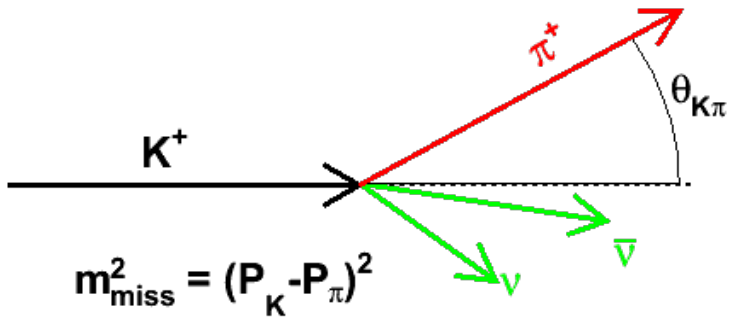
- E.g. non-MFV in up-squarks trilinear terms
- Still not excluded by the recent LHCb data



Measurement of $BR(K \to \pi\nu\bar{\nu})$

Measurement at 10% ($\approx$ SM prediction accuracy), 100 SM events

Missing mass



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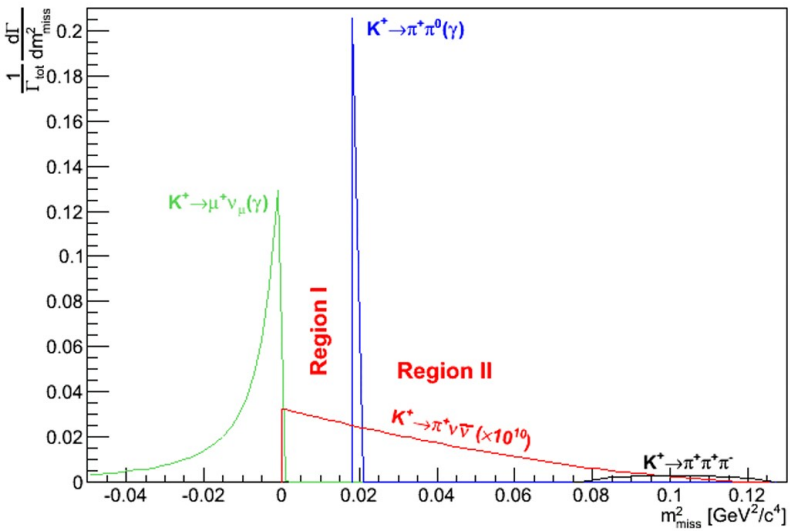

92% of K decays

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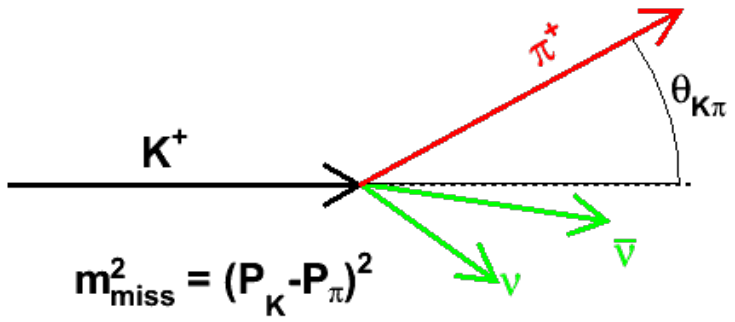

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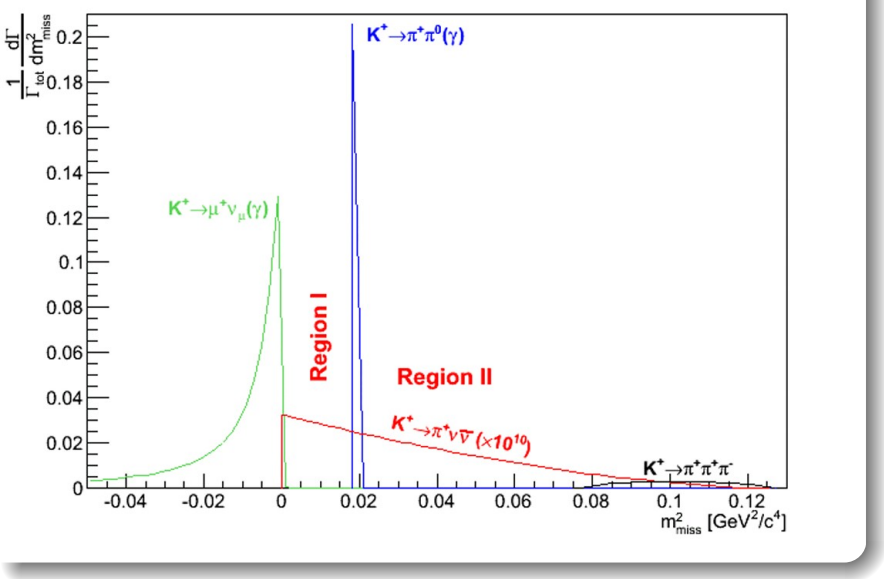

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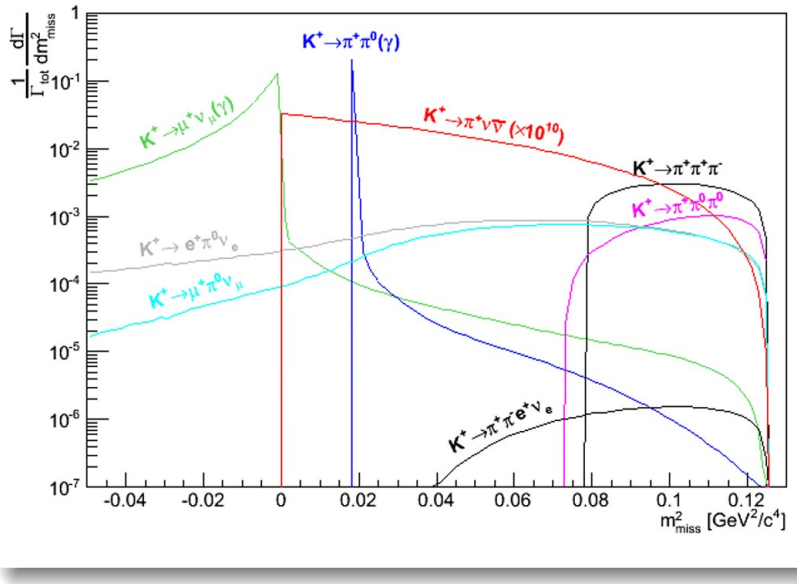

8% of K decays

Measurement of $BR(K \to \pi\nu\bar{\nu})$

Experimental strategy:

Requirements

- $O(10^{12-13})$ K decays
- Systematics $< 10\%$

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1. K momentum
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3. No other particle
4. No interaction
5. 1 day

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1. K ID & p_K
2. π ID & p_π
3. Veto efficiency
4. Low mass detectors
5. High intensity beam

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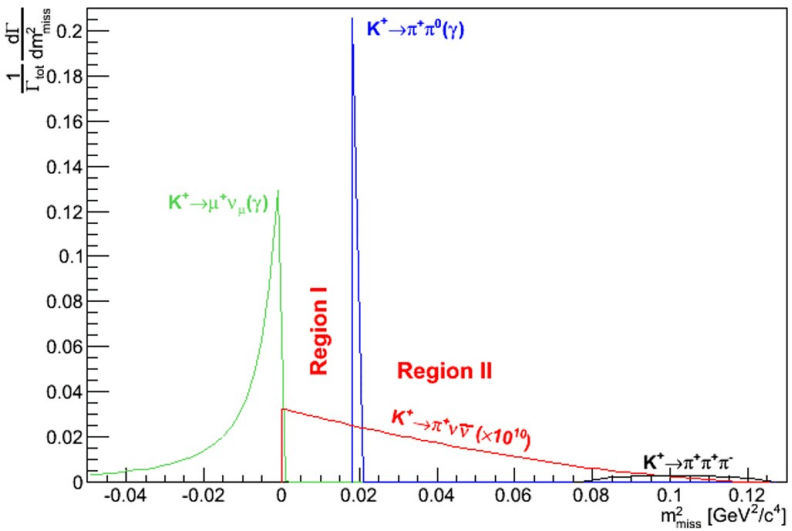
Real World

1. Efficiency, Resolution
2. Acceptance, Purity
3. High momentum
4. Gigatracker and Spectrometer in vacuum
5. Time resolution

Measurement of $BR(K \to \pi\nu\bar{\nu})$

Measurement at 10% ($\approx$ SM prediction accuracy), 100 SM events

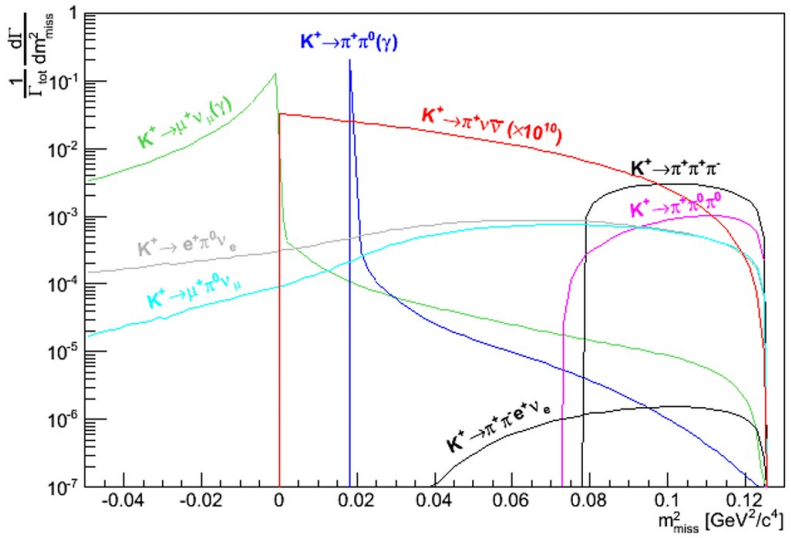
Constrained by closed kinematics



92% of K decays

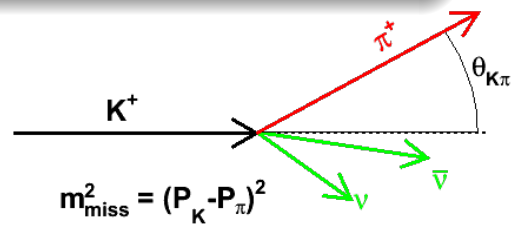
- 2 signal regions
- Minimize multiple scattering

Not constrained by closed kinematics



8% of K decays

- Particle ID
- Photon vetoes



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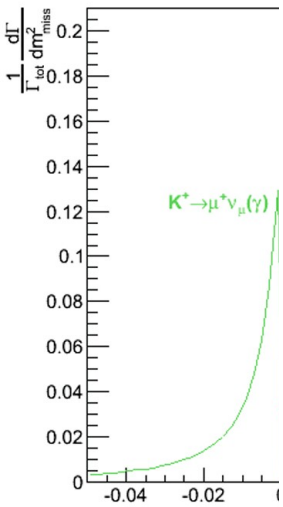
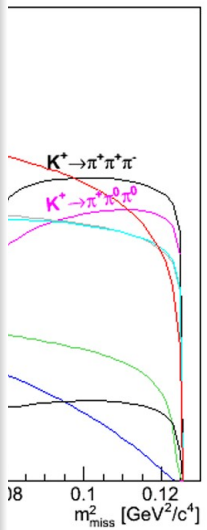
Background Rejection



- Main backgrounds:
  - $K^+ \to \mu^+\nu_\mu$ $(BR \approx 63\%)$
  - $K^+ \to \pi^+\pi^0$ $(BR \approx 21\%)$
- Rejection $\approx 10^{-12}$:
  - Kinematics $\approx 10^{-5}$
  - Vetoes $\approx 10^{-5}$
  - PID $\approx 5\ 10^{-3}$
- Time $K - \pi$:
  - Resolution $\approx 100ps$



92% of K dec

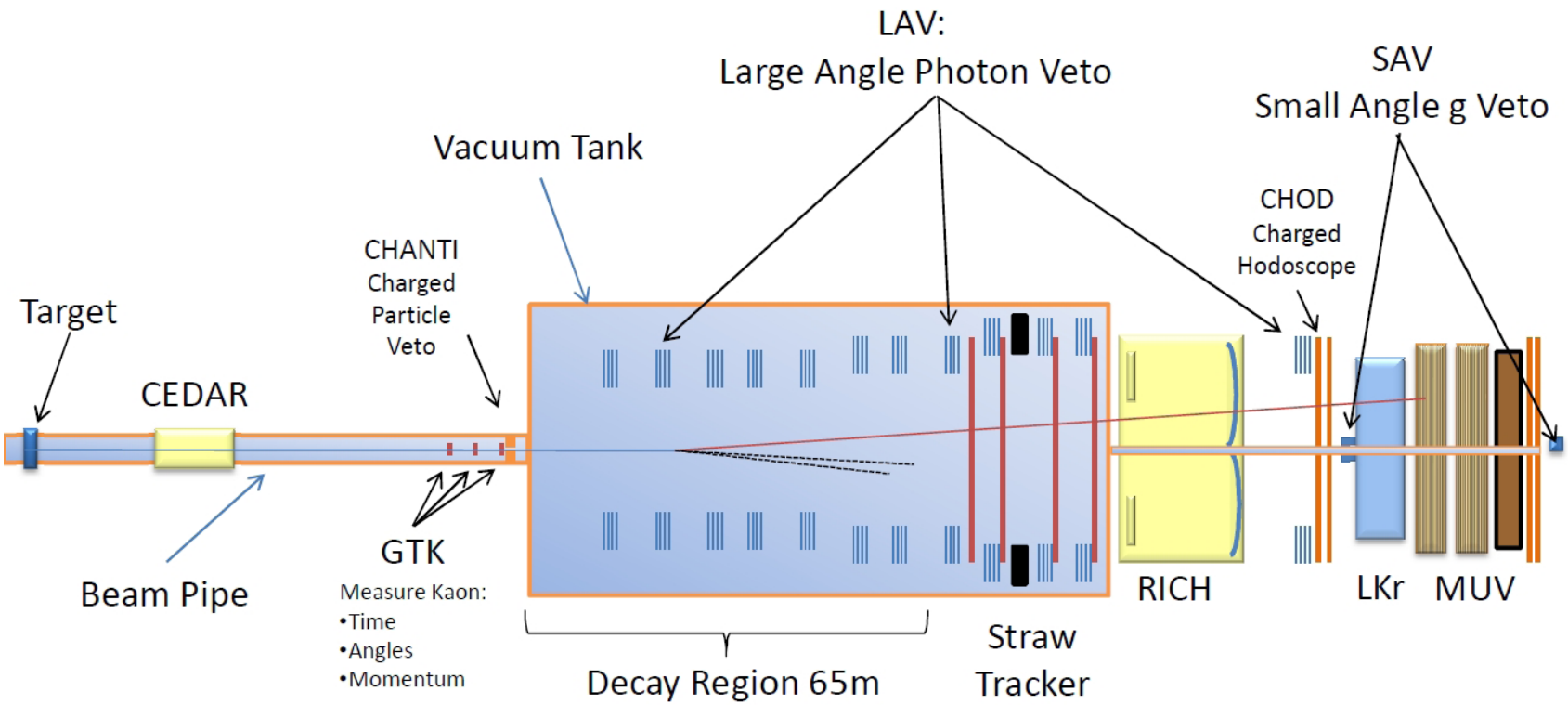
- 2 signal
- Minimize multiple scattering

- Photon vetoes

NA62: beam and experiment layout

State of the art detectors for new precision frontier down to 10^{-12}

- SPS primary protons @ 400 GeV/c
- 75 GeV/c ($\Delta P/P \approx 1\%$)
- Area @ beam tracker 16 cm^2
- Kaon decays/year 4.8×10^{12}
- Unseparated secondary charged beam
- $p/\pi/K$ (positron free, $K \approx 6\%$, $p \approx 23\%$)
- Integrated average rate @ beam tracker 750 MHz

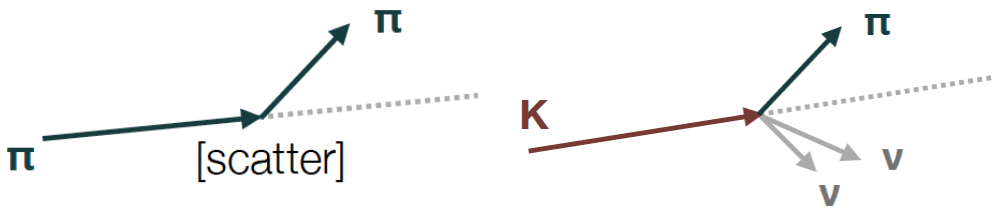


Technical Run (TR) in 2012, Pilot Run in 2014 and physics data taking in 2015-2017

Kaon identification for NA62

Problem:

- Interaction of beam particles in the residual gas in the decay volume: signature similar to signal



- Most beam particles are not K: "only" 50MHz out of 750MHz
- Time resolution required to be better than 100ps: accidental coincidence with a π at few %

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Solution:

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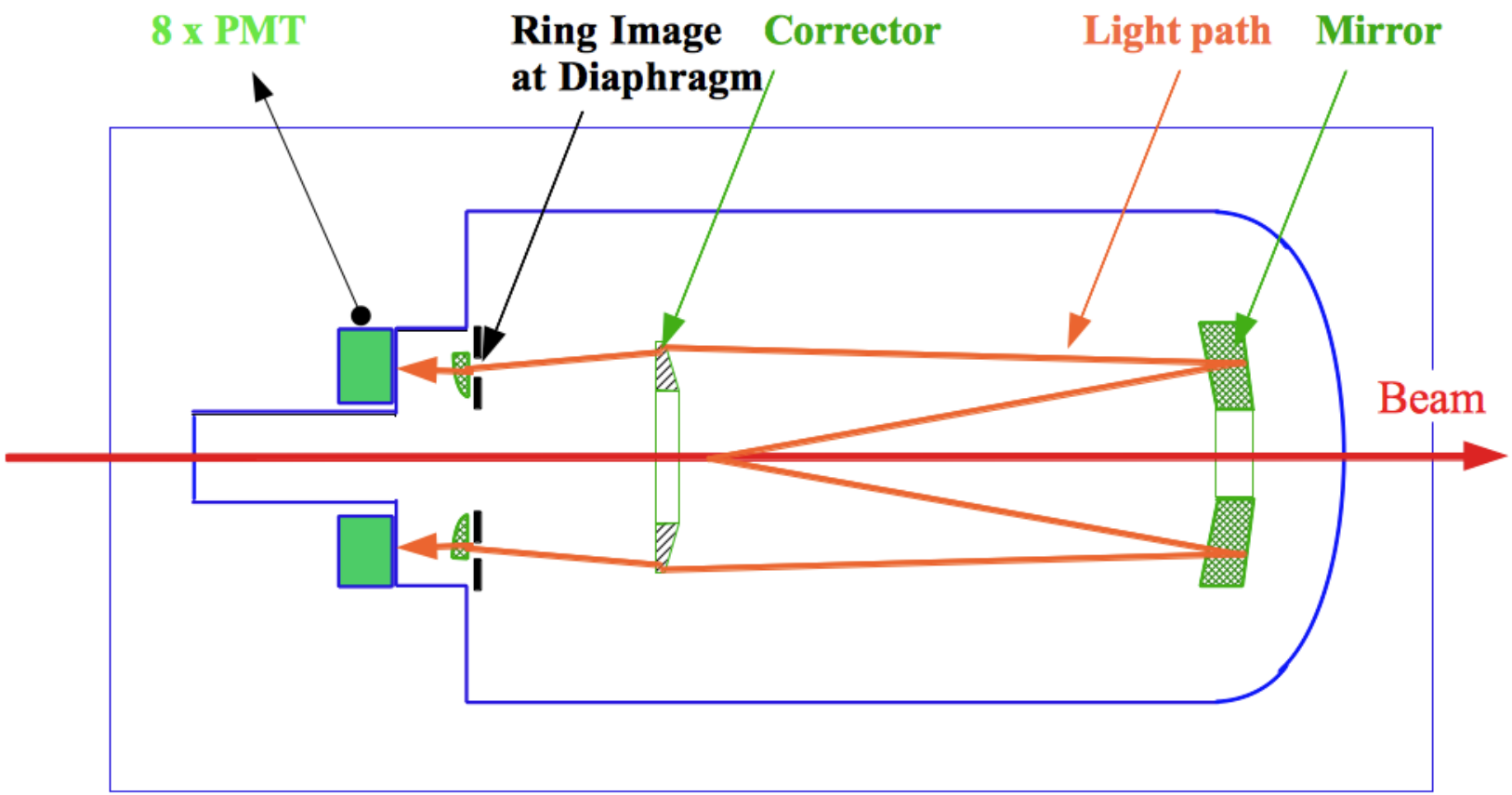

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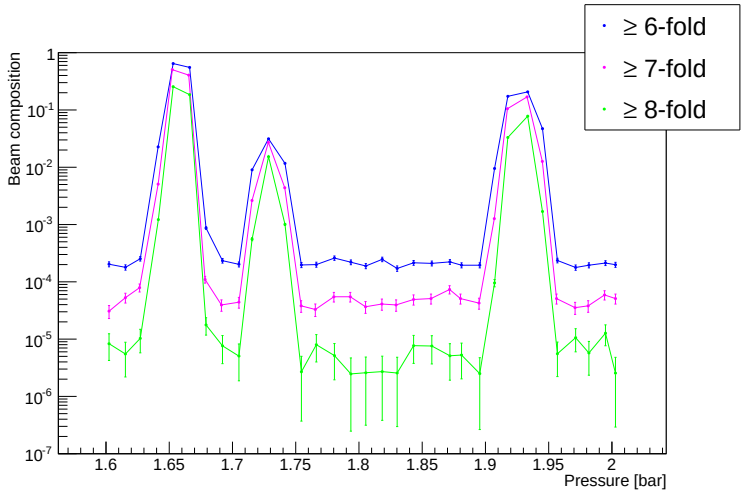
Solution:

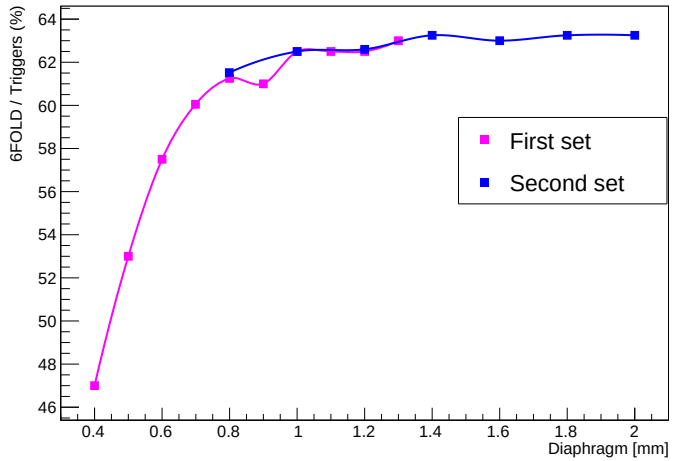
- Use a CEDAR to identify K within the unseparated beam
- The CEDAR was designed and built in the early '80s for CERN beamlines: limited rate capabilities
- Photo-detection system to be redesigned to fit NA62: 50MHz K rate and 100ps time resolution

Test Beam in 2011

Step 1: calibration and performance assessment

- The chosen CEDAR was placed on the H6 beam line at CERN
- Original design configuration: nitrogen
- Tuning:
  - Alignment on π: most abundant
  - Pressure scan: particle identification
  - Diaphragm scan: efficiency
  - Result: suitable performance

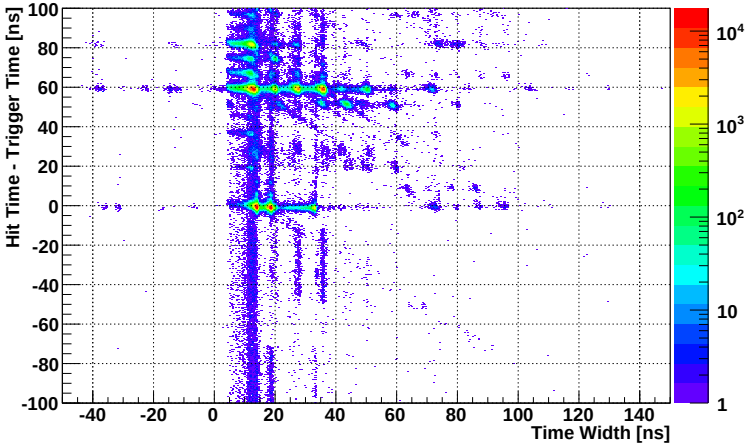




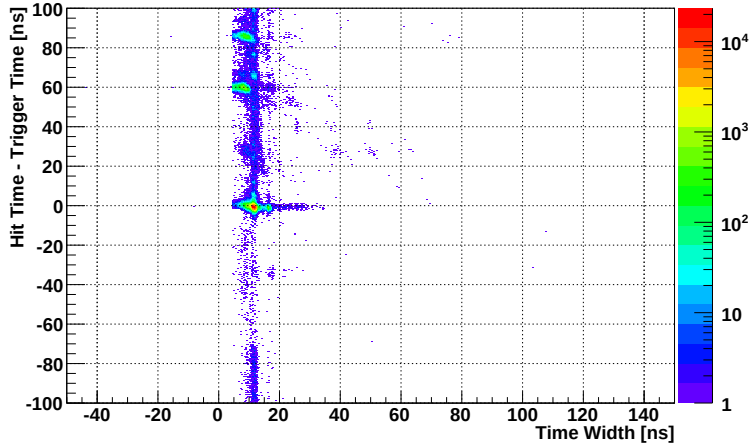
Test Beam in 2011

Step 2: test new Front-End electronics

- Split PMT signals to feed also new electronics
- Front-End based on NINO ASIC (differential input)
- 2 preamlifiers:
  - Newly designed unipolar to differential, radiation hard
  - Non radiation hard, developed for NA62 RICH, for comparison
- Read-out based on HPTDC and TELL1: intermediate development stage of the NA62 common TDAQ system (TEL62, TDCB)



Rad-hard preamp, too noisy



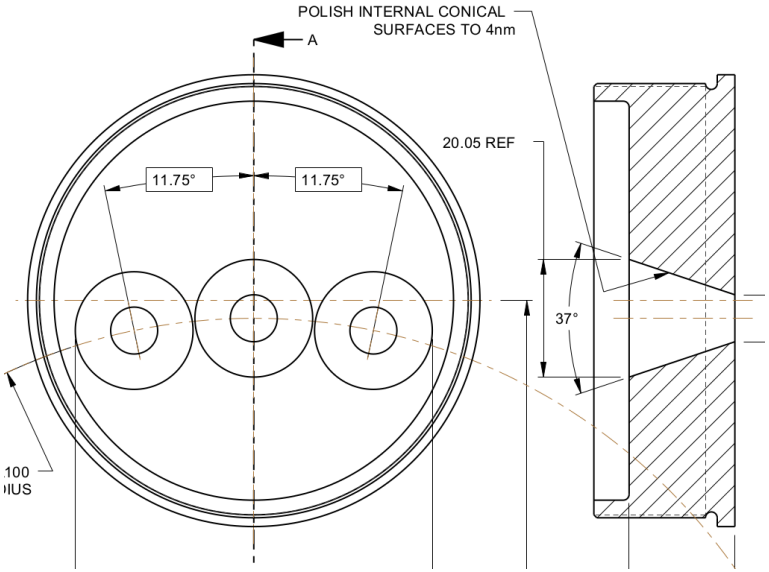
RICH preamp, reference

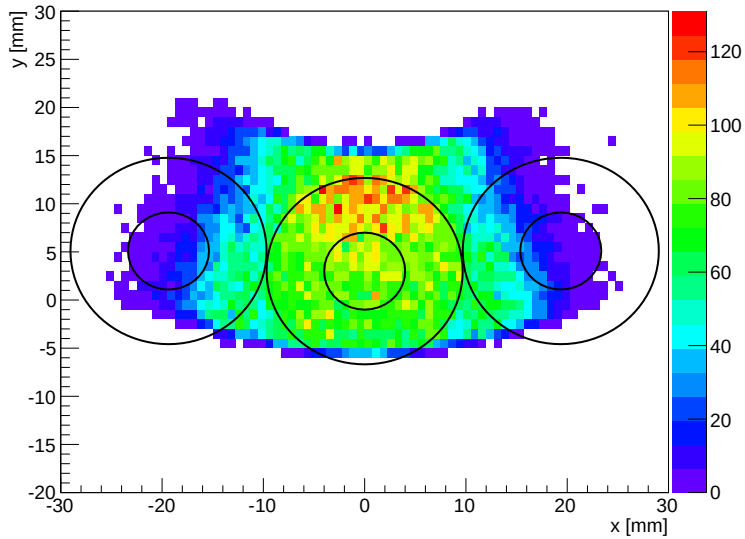
Decision: extract differential signal from PMT with custom voltage divider

Test Beam in 2011

Step 3: test new optical detection components and refine MC simulation

- Replaced 1 PMT with a prototype with 3 new PMTs
- Mesurements in several configurations, varying:
  - Rotation angle
  - Distance from CEDAR quartz window

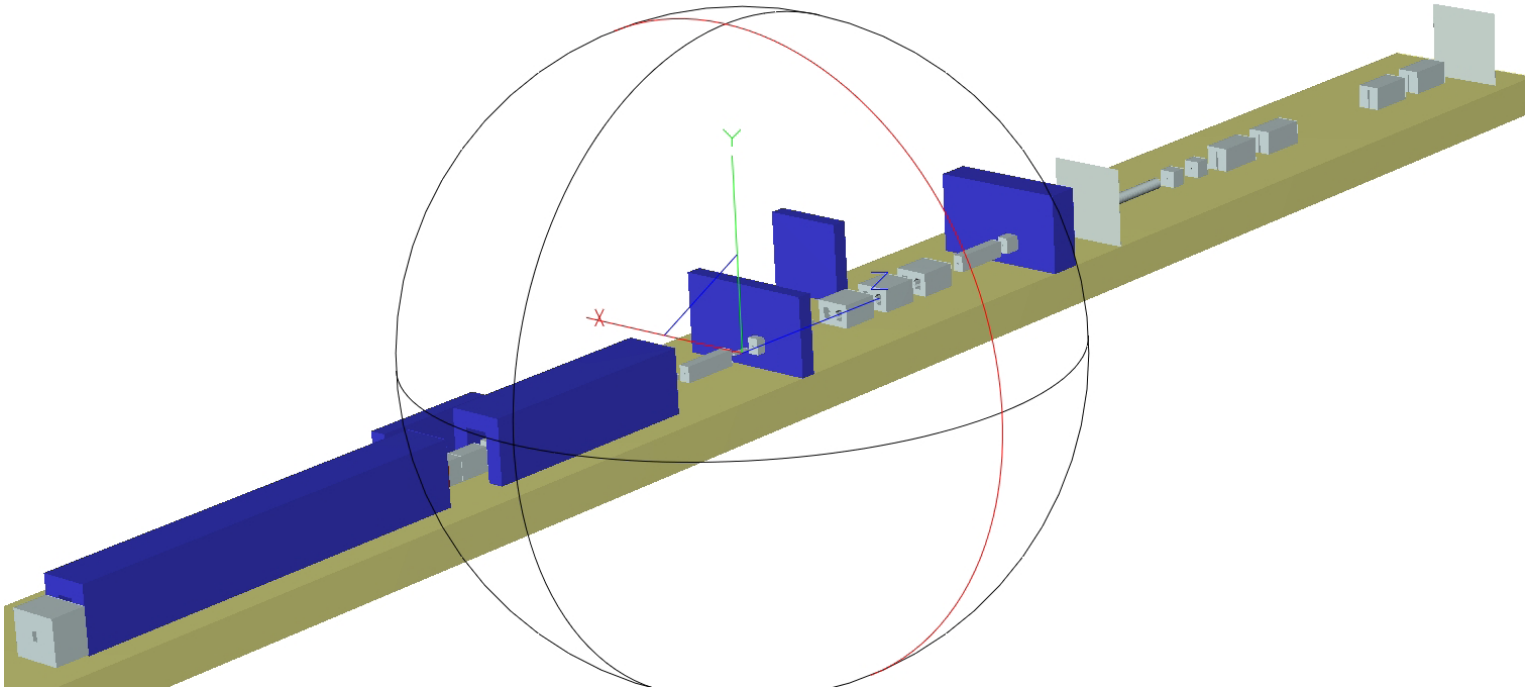




Final design

Ingredients:

- FLUKA simulation: 0.4Gy/year



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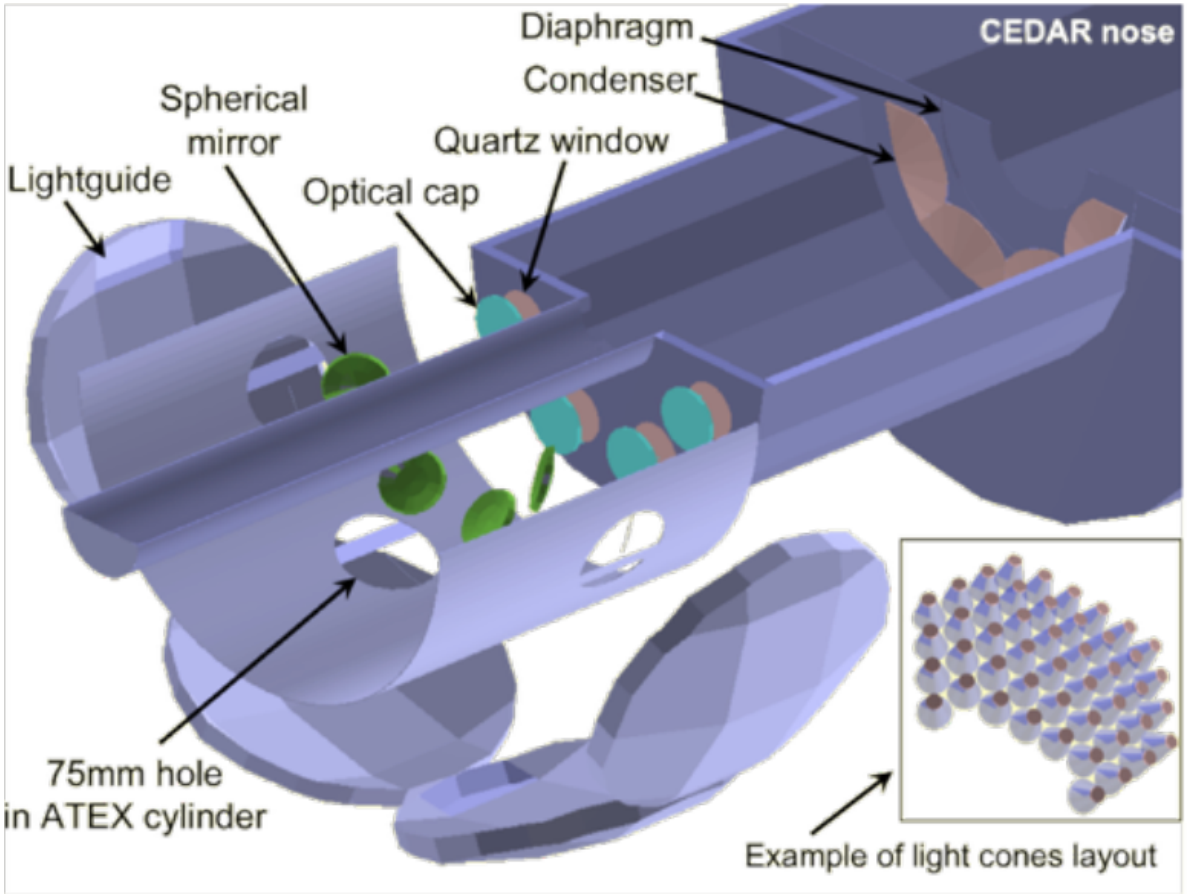
- GEANT4 simulation: photon rates on the NA62 beam line (few MHz/mm^2)



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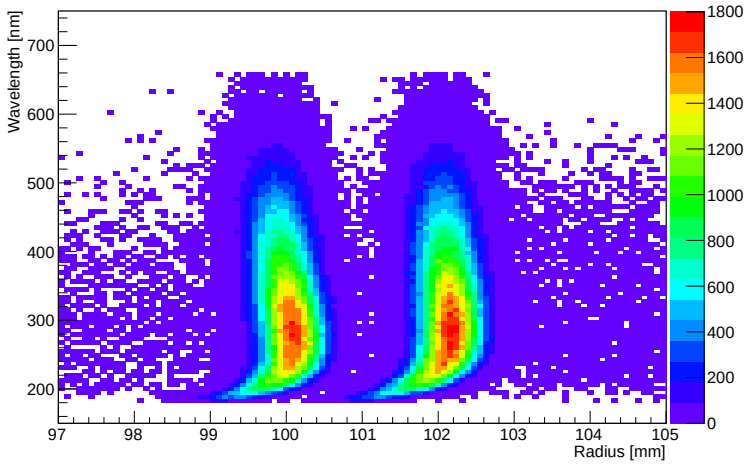

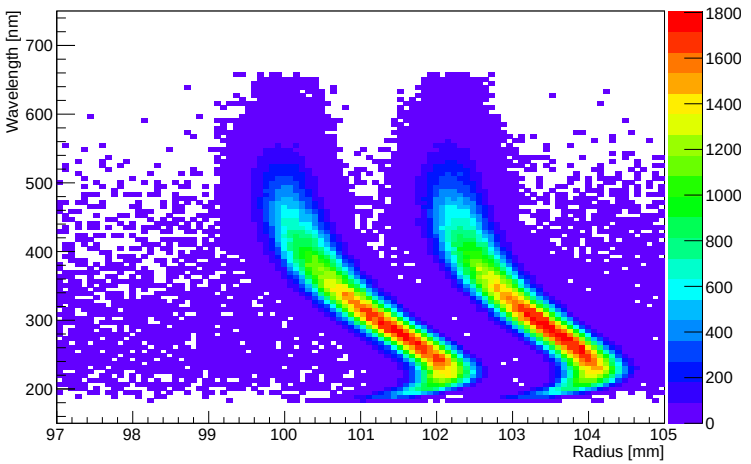

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- Efficiency and time resolution requirements translate in at least 18 hits per K
- HPTDC hits rate limited to 5MHz/channel and 15MHz/group of 8 channels

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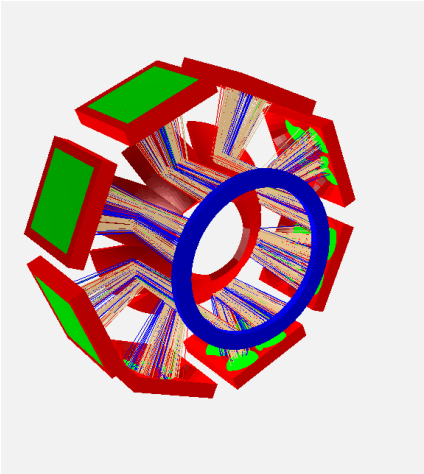

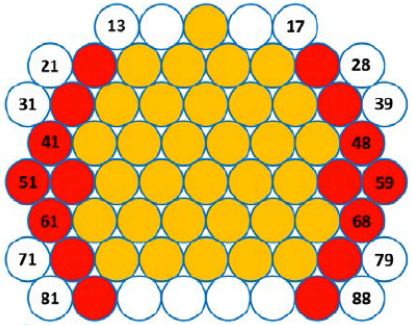

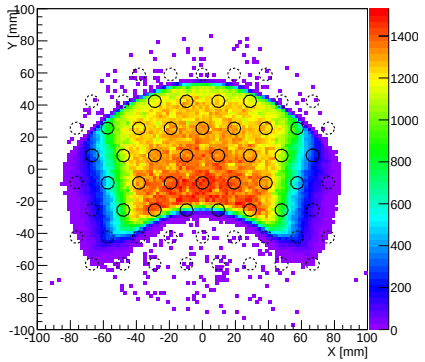

Recipe:

- Spread light over 8x48 PMTs (Hamamatsu, 16 R7400U-03 and 32 R9880U-110)

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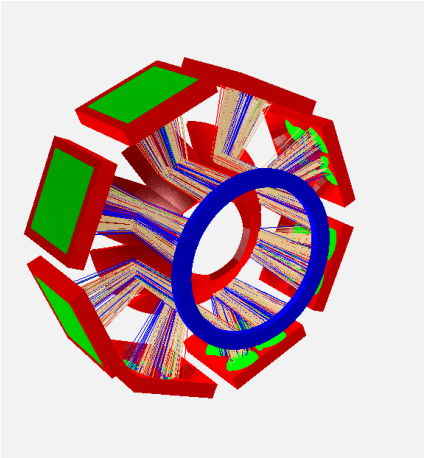

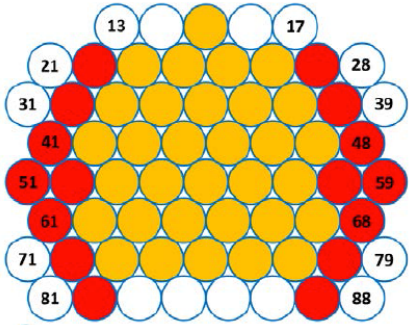

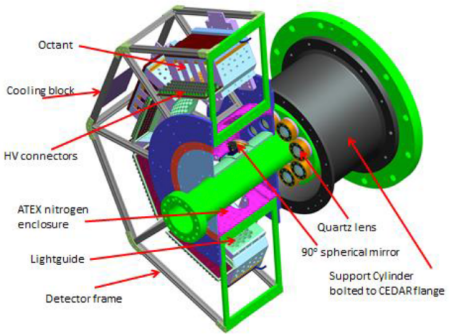

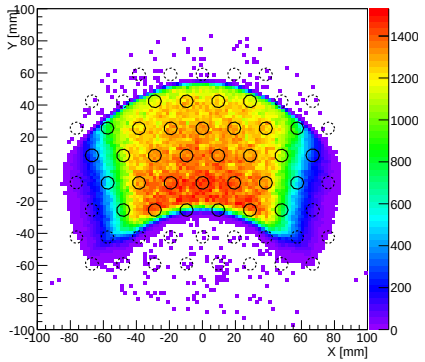

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- Tuned spherical mirrors and lenses

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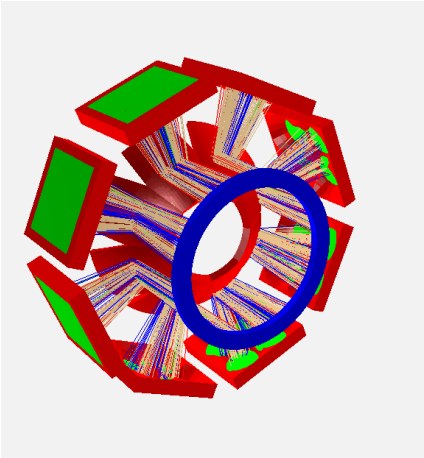

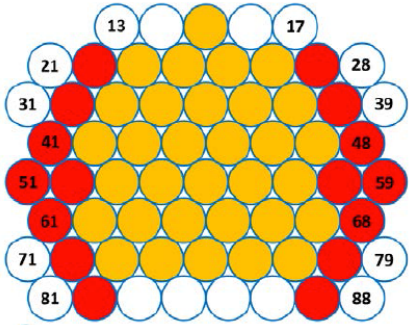

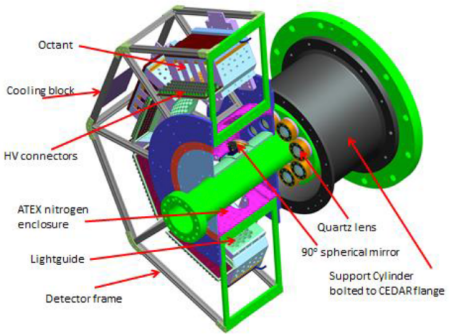

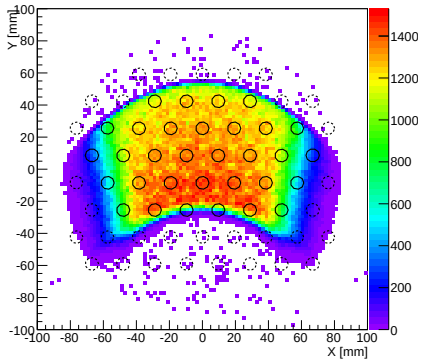

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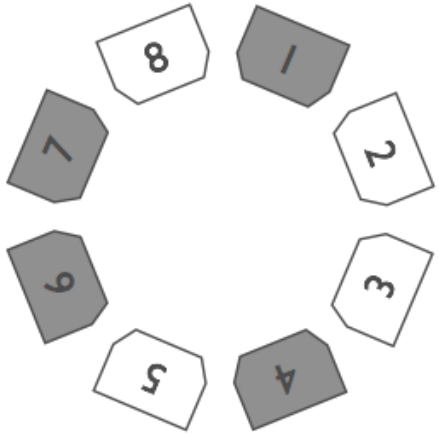
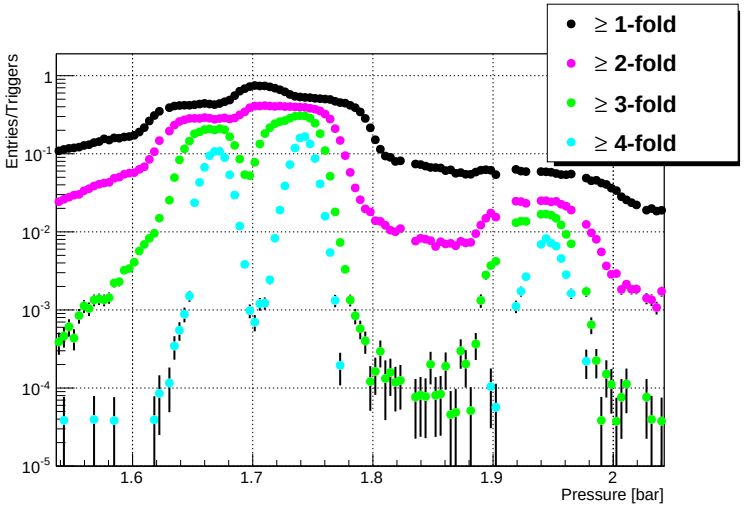
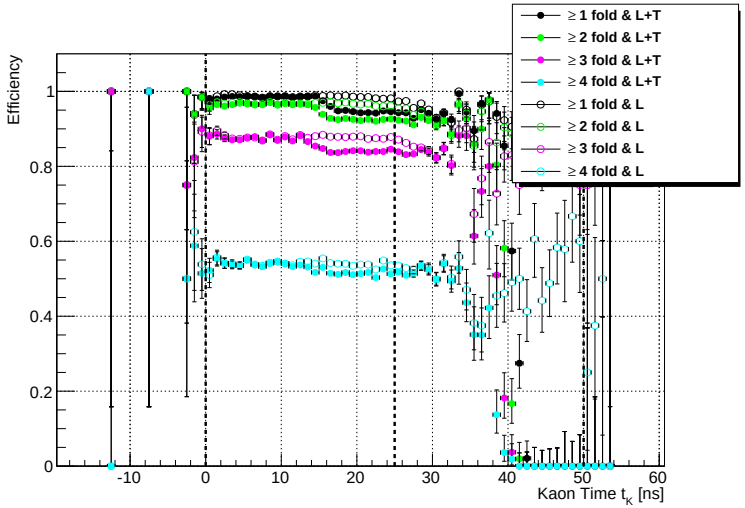
- Tuned spherical mirrors and lenses
- Splitter boards to balance Read-Out load

NA62 Technical Run 2012

- Final beam line, at 1% of the design intensity
- Partial installation of NA62 detectors
- 4 octants of CEDAR-KTAG equipped with 32 R7400-U03 each
- Results:
  - Time resolution 100ps
  - Efficiency as expected

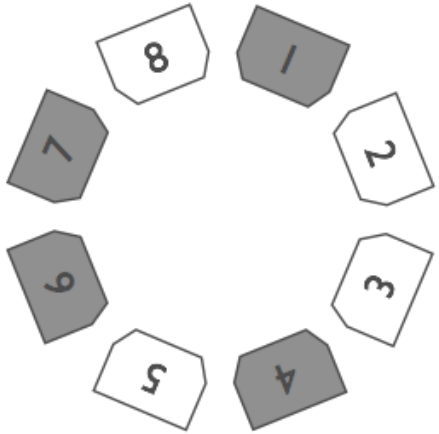


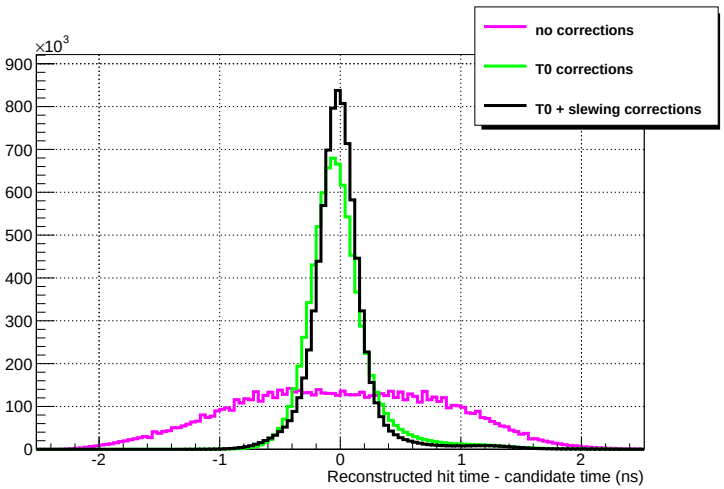


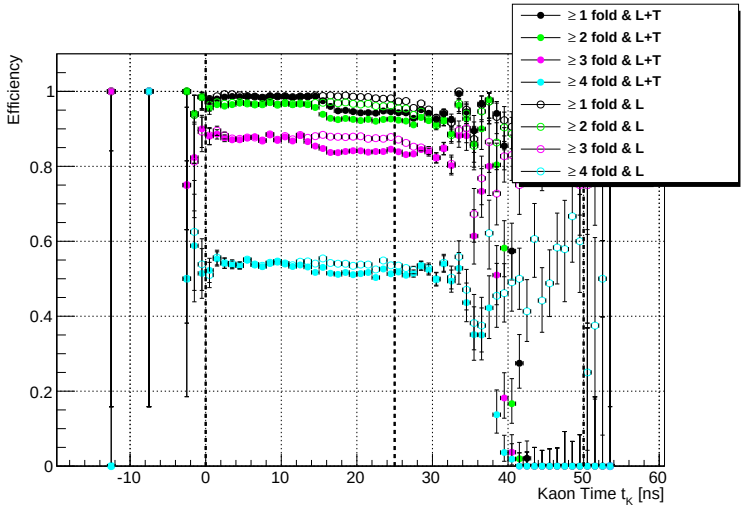


NA62 Technical Run 2012

- Final beam line, at 1% of the design intensity
- Partial installation of NA62 detectors
- 4 octants of CEDAR-KTAG equipped with 32 R7400-U03 each
- Results:
  - Time resolution 100ps
  - Efficiency as expected

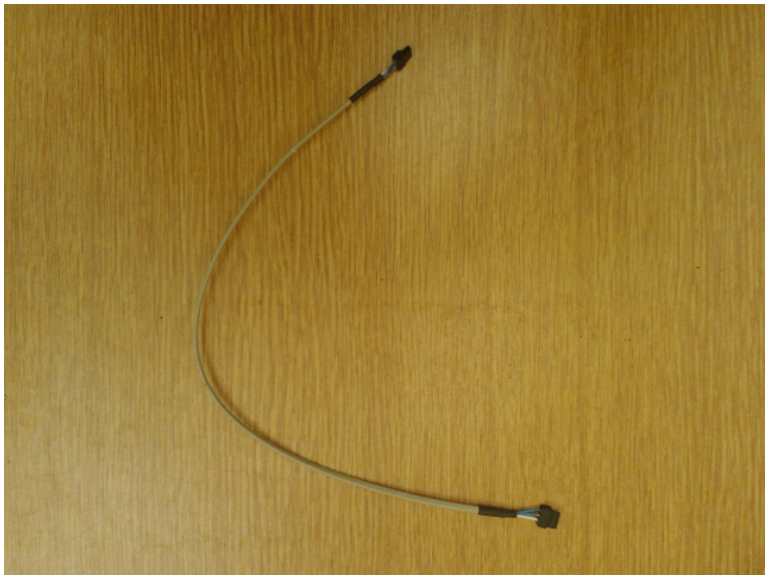


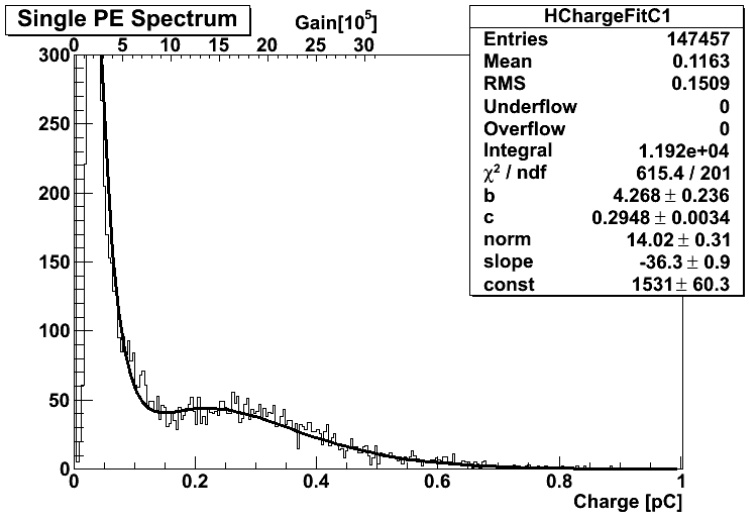




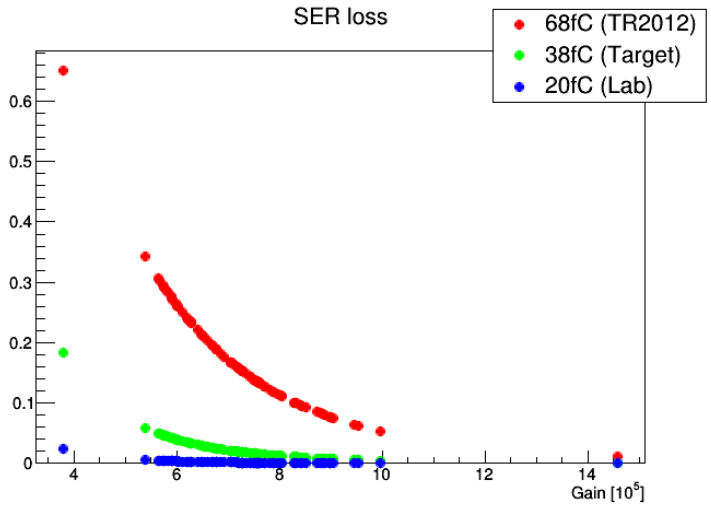
Final design details (2013)

- Studied the effect of the threshold
- Tested R9880U-110 before procurement
- Dry Runs in NA62 (integration)
- Analog differential cabling:
  - Halogen free (very stiff) twinax
  - Improved strain relief
  - Tried alternatives





R7400



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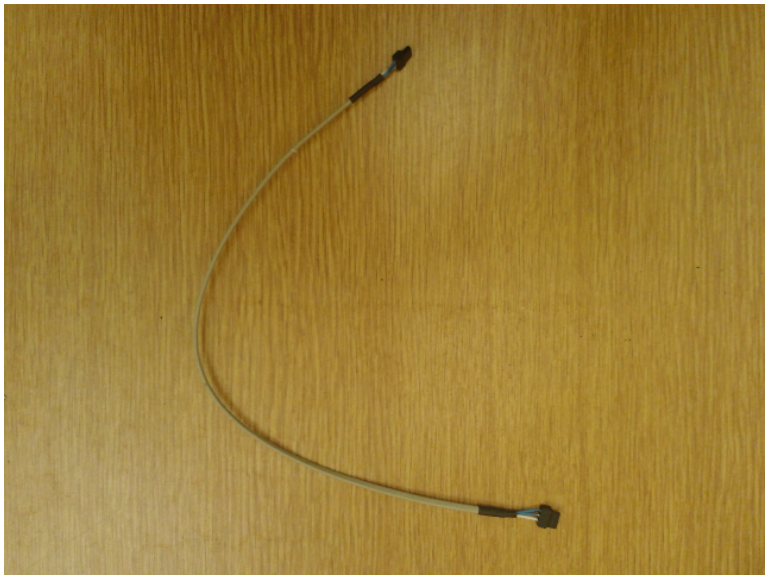
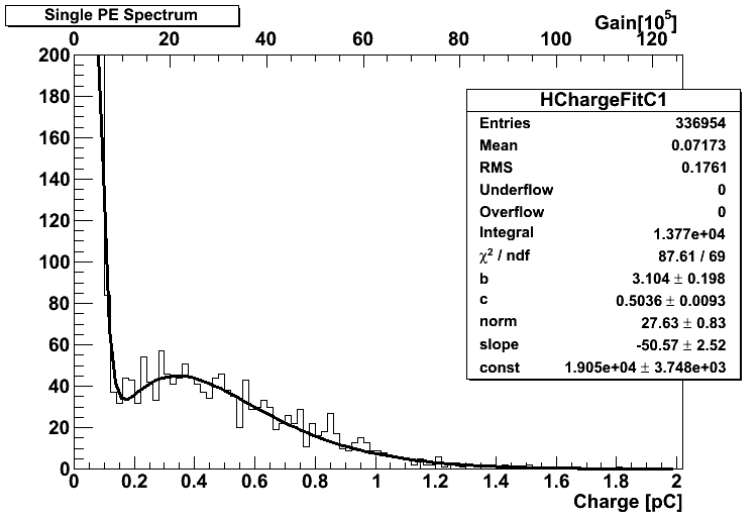
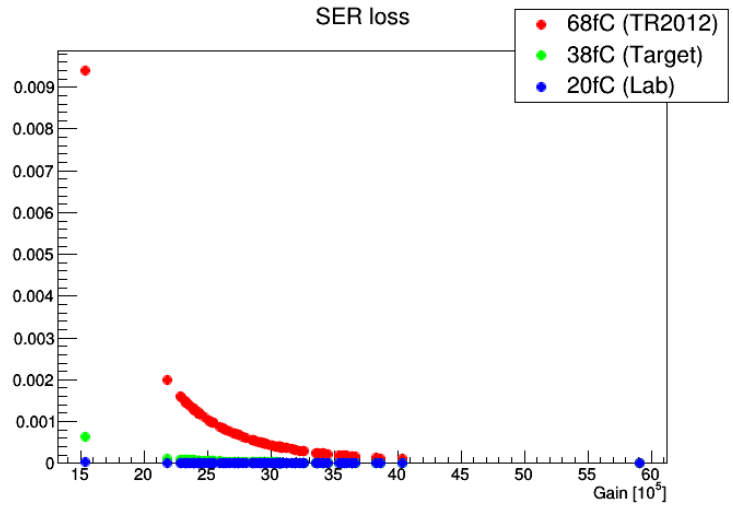




R9880



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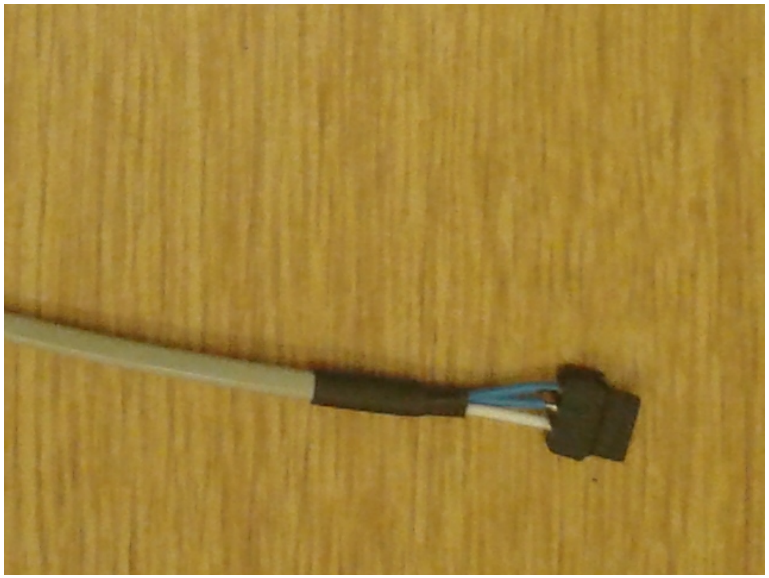

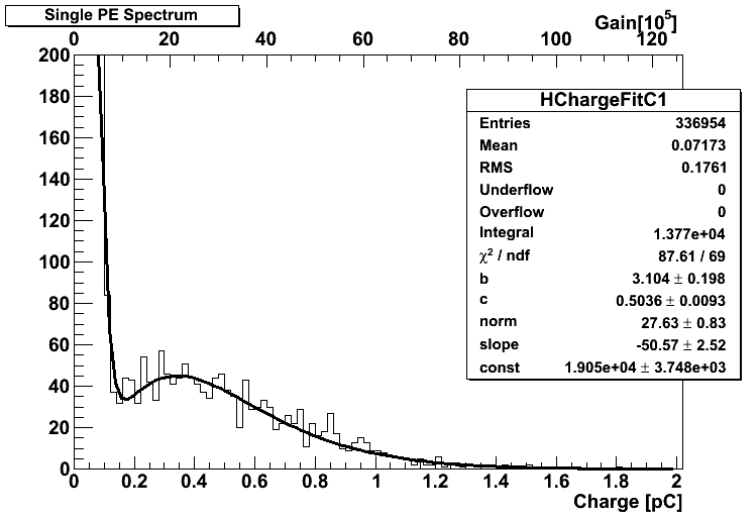

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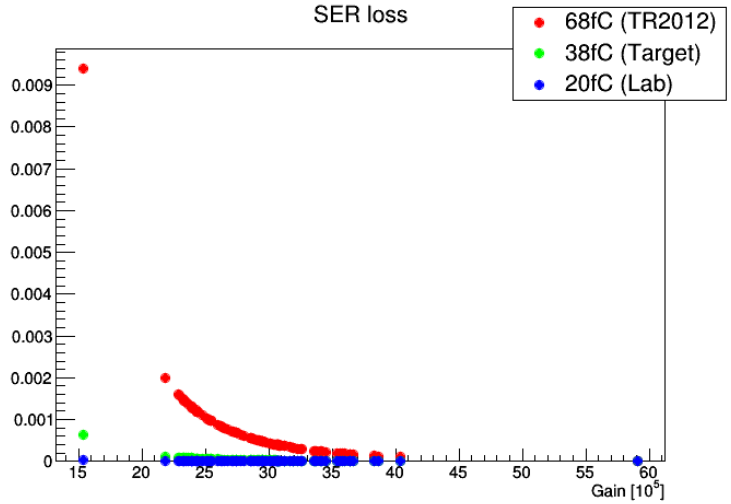
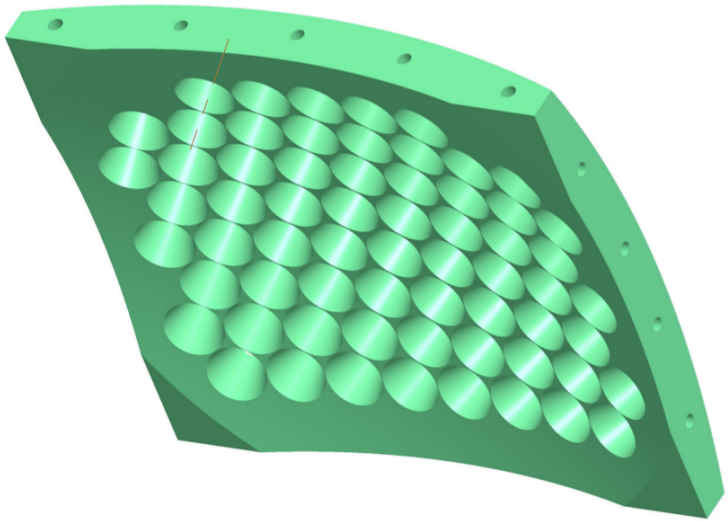
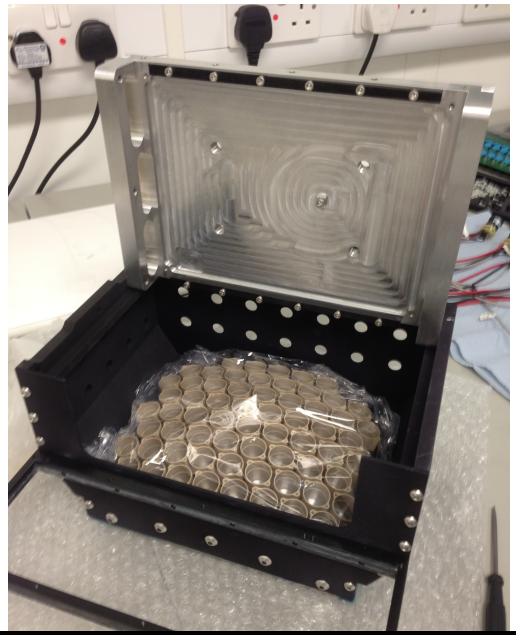


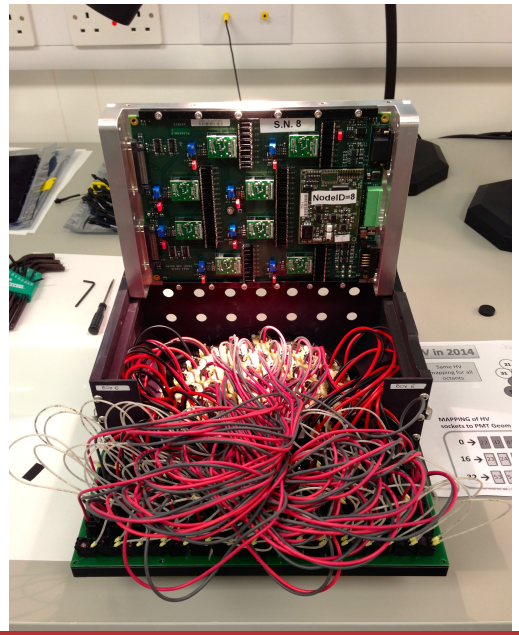
LightBox

Aluminium case:

- Light guide
- Heatsink
- Front-End board
- PMTs and voltage dividers
- High voltage patch panel

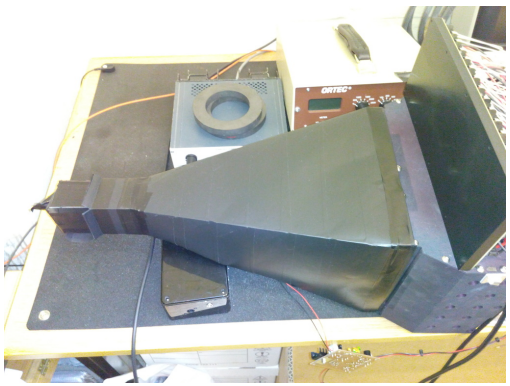


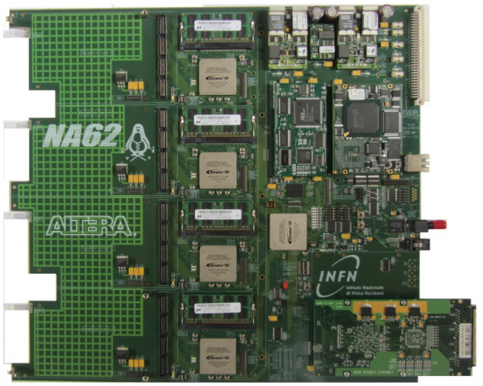




Commissioning of the LightBoxes (2014)

- 405nm laser with 30ps FWHM
- Light diffused over the full light guide (10% uniformity)
- Single photo-electron regime
- Read-out via TDCB and TEL62
- Remote control (ELMB) via OPC server
- Data analysis using the official NA62 reconstruction and analysis software





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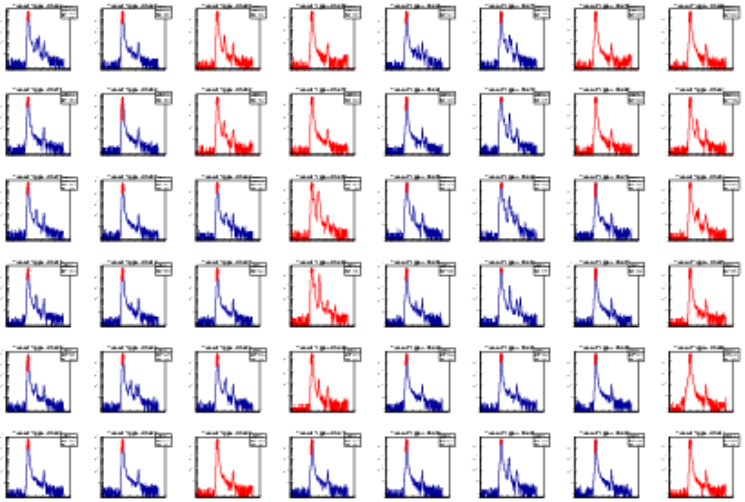

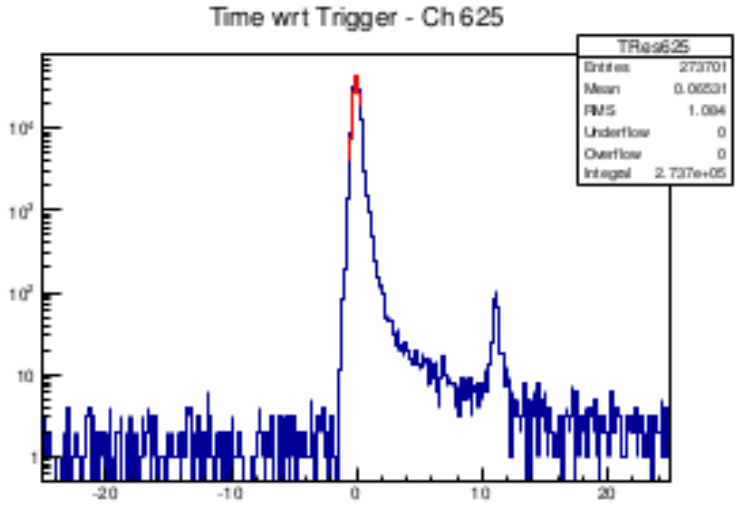

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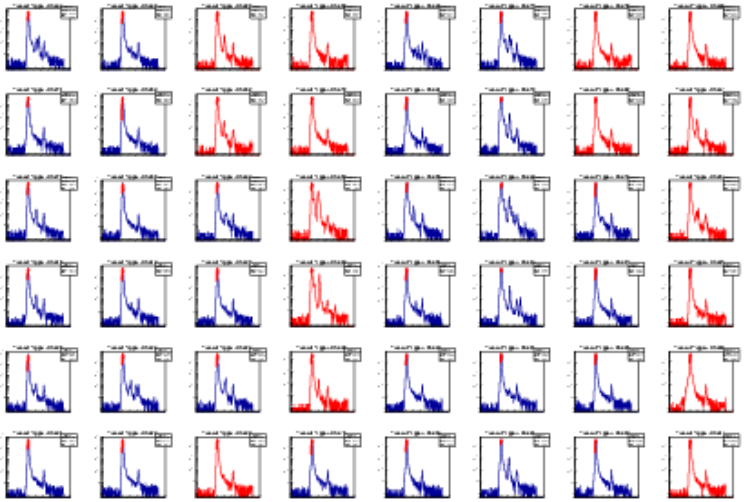
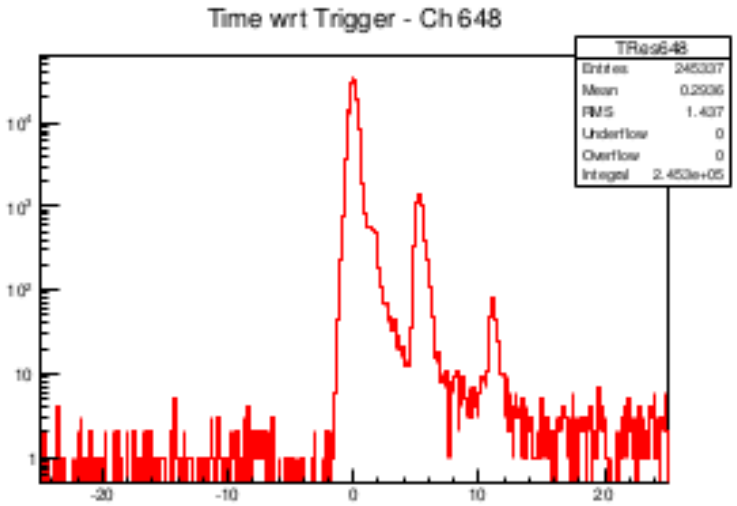
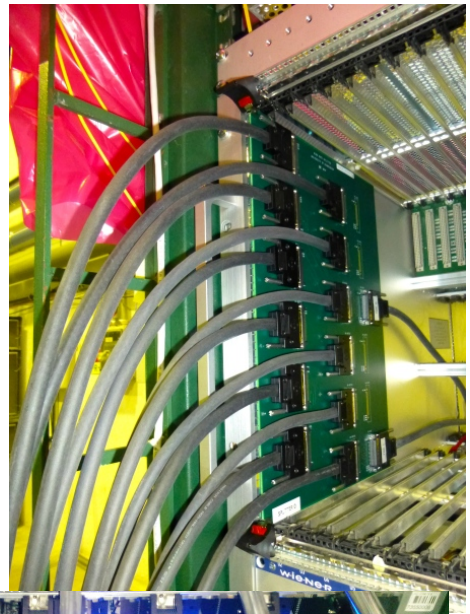
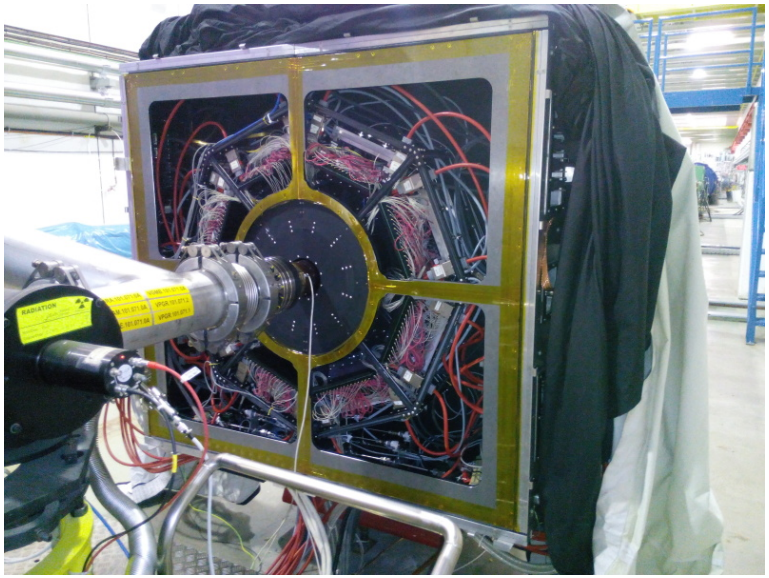




Installation (2014)

- Complete setup
- 100% channels working
- Noise as expected (better than needed)
- Full integration (DCS, DAQ ..)
  - Front-End, Read-Out, LV, HV
  - Gas pressure
  - Aligment motors





NA62 Pilot Run 2014

Most detectors installed, beam intensity 5-10% of nominal

CEDAR-KTAG:

- Filled with nitrogen
- Partial tuning:
  - Aligment
- Reference detector

NA62 Pilot Run 2014

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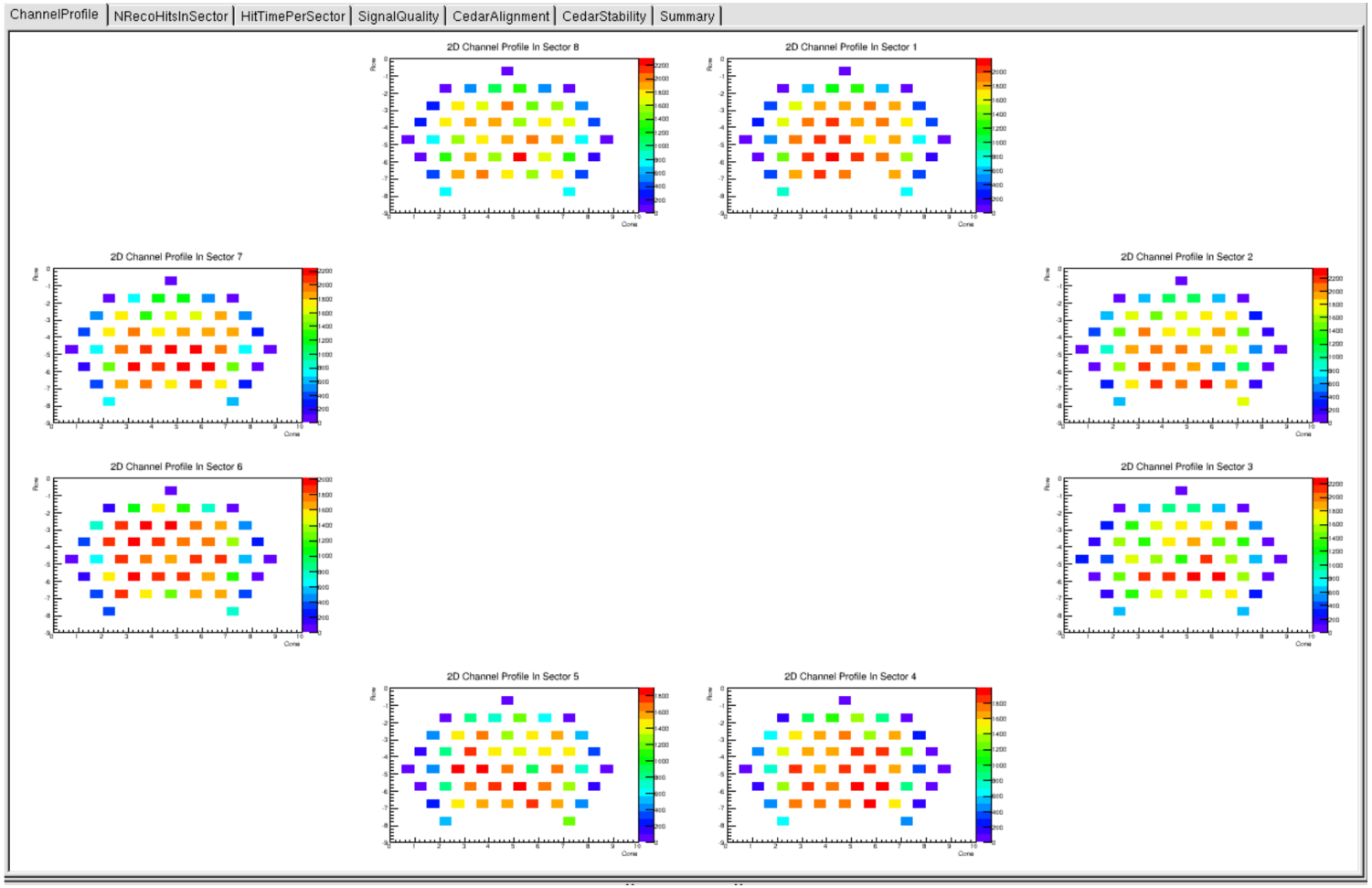
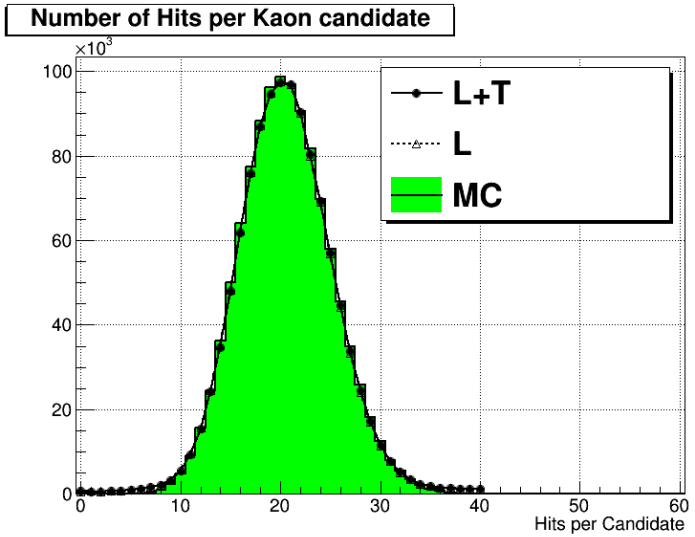
CEDAR-KTAG: Online Monitor

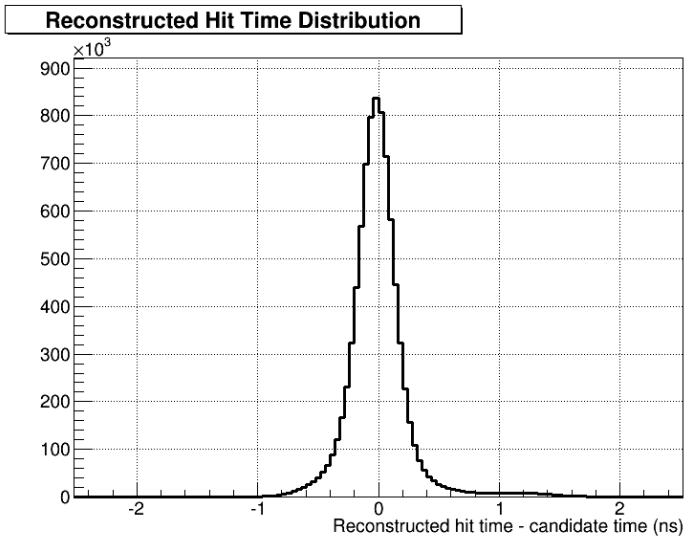


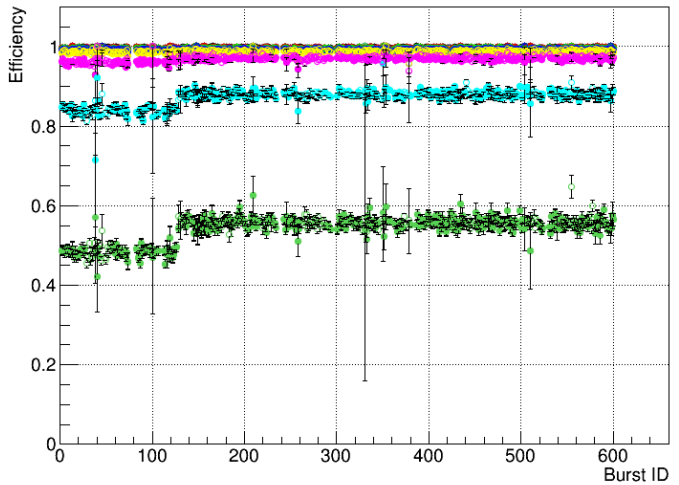
NA62 Pilot Run 2014 (Preliminary)

Most detectors installed, beam intensity 5-10% of nominal
CEDAR-KTAG:

- Filled with nitrogen
- Partial tuning:
  - Aligment
- Reference detector
- 20 hits/K
- Time resolution 70 ps
- Efficiency 95%







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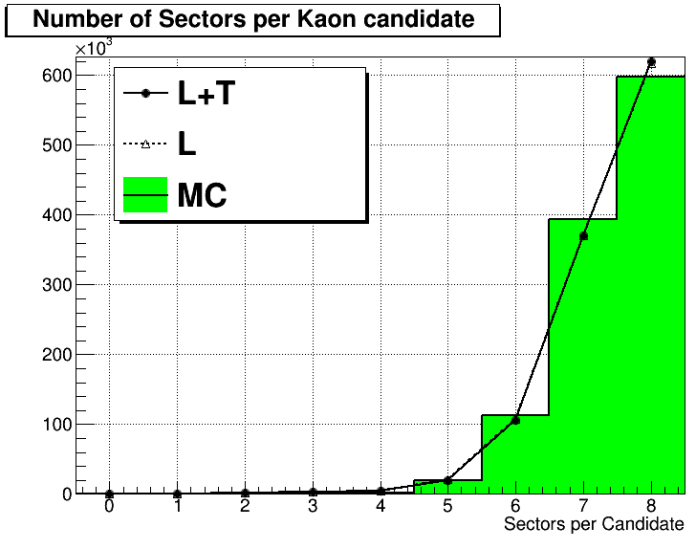

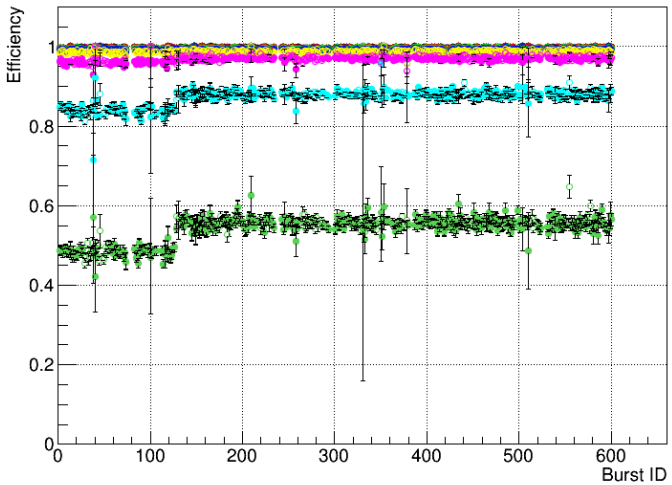

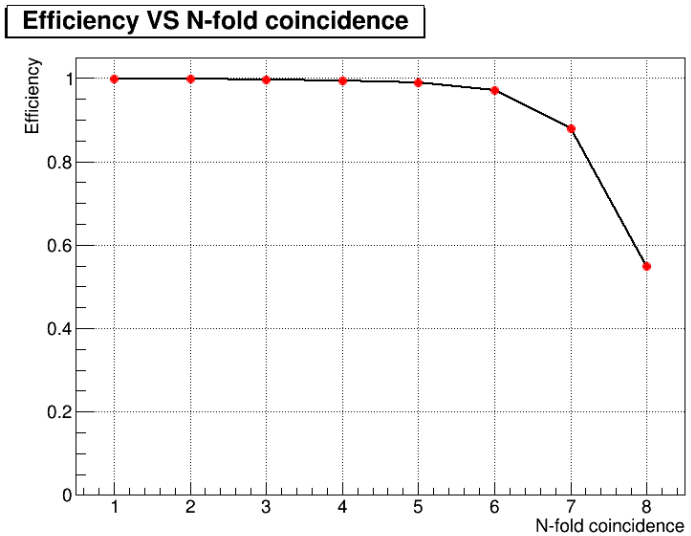

Summary and prospects

- Development of CEDAR-KTAG:
  - 2011 test beam provided information essential to finalized the design
  - MC simulations revealed limitations and provided estimates to fulfil requirements
- 2012 Technical Run proved the design was successful
- Detector fully installed and commissioned in 2014
- Preliminary performance evaluation within expectation
- CEDAR-KTAG in the NA62 Physics Run 2015:
  - Perform the full tuning procedure:
    - Aligment
    - Pressure scan
    - Diaphragm scan
  - Assessment of the final performance
  - Reference detector