

NA62 readout

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Outline

1 Introduction

- $K \rightarrow \pi \nu \bar{\nu}$
- Experiments

2 NA62

- Strategy
- TDAQ

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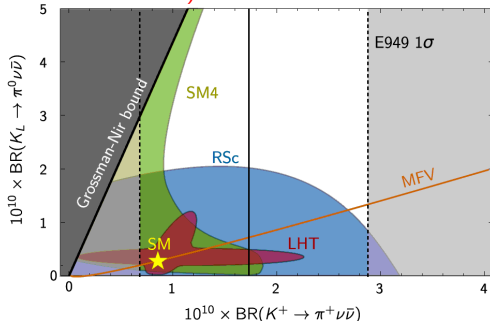
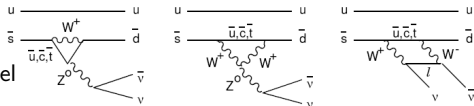
$K \rightarrow \pi \nu \bar{\nu}$

Ultra rare decay

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

	BR_{SM}	from CKM	from theory	
$K_L \rightarrow \pi^0 \nu \bar{\nu}$	(2.43	± 0.39	± 0.06)	10^{-11}
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$	(7.81	± 0.75	± 0.29)	10^{-11}

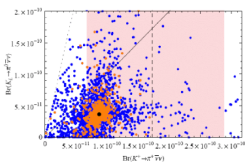
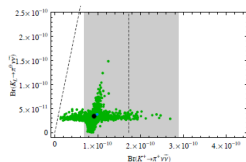
- Current existing measurement based on 7 events (E787/949):
 $(1.73^{+1.15}_{-1.05}) 10^{-10}$
- Lead to measurement of $V_{td} \approx 7\%$
- New Physics scenario $\rightarrow$



$K \rightarrow \pi \nu \bar{\nu}$ 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 ($M_Z > 5 \text{ TeV}/c^2$)

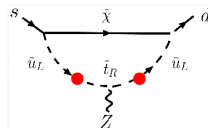
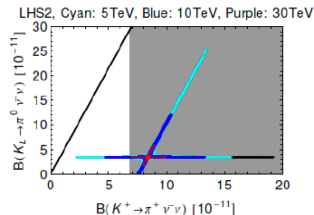


More specific NP models
 Littlest Higgs with T-parity
 Acta Phys. Polonica B41(2010)657
 Custodial Randall-Sundrum
 JHEP 0903 (2009) 108

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

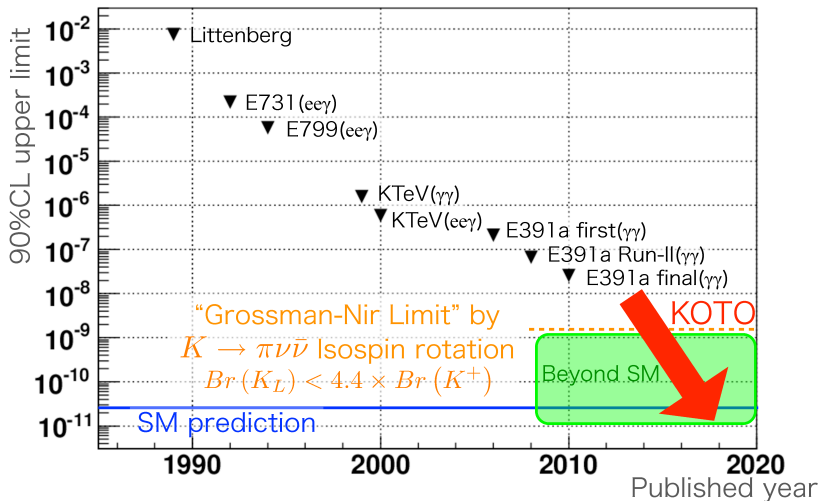
Best probe of MSSM non-MFV [JHEP 0608 (2006) 064]

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



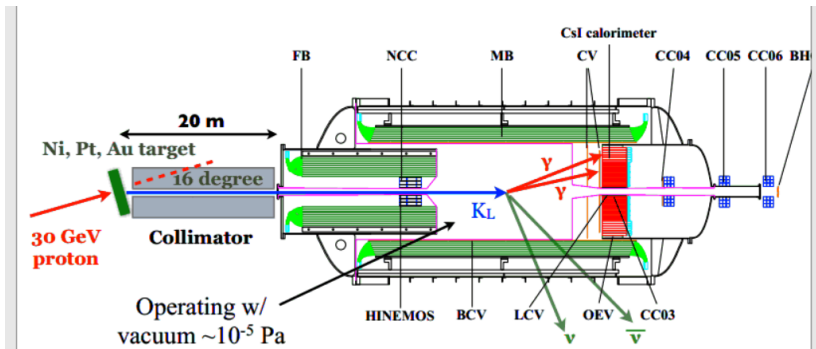
$K \rightarrow \pi \nu \bar{\nu}$ foreseen experiments

Expt	Primary beam	Intensity (ppp)	SM evts/yr	Start date + run yrs	Total SM evts
NA62	SPS 400 GeV	3 ± 10^{12}	45	2015+2	100
E14(KoTO)	JPARC-I 30 GeV	2 ± 10^{14}	1-2	2013+3	3-7
E14	JPARC-II 30 GeV	3 ± 10^{14}	30	2020+3?	100

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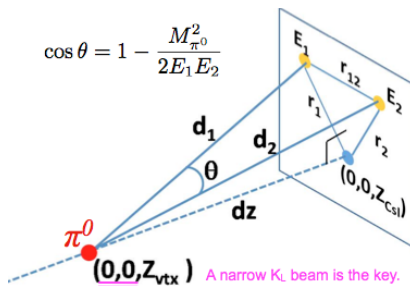
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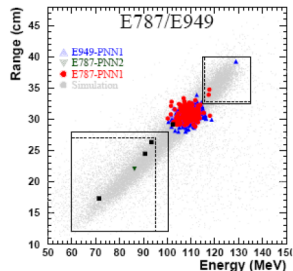
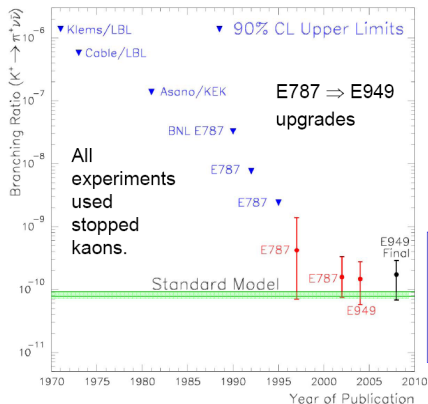
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$K \rightarrow \pi \nu \bar{\nu}$ foreseen experiments

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ History



E787/E949 Final: 7 events observed

$$B(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = 1.73^{+1.15}_{-1.05} \times 10^{-10}$$

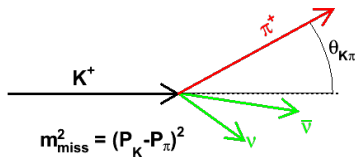
Standard Model:

$$B(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.85 \pm 0.07) \times 10^{-10}$$

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

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

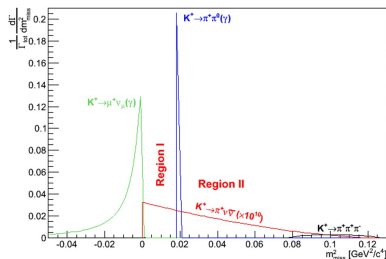
Missing mass



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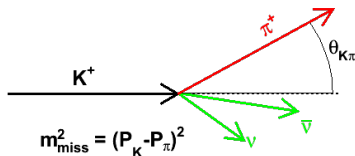
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Constrained by kinematics



92% of K decays

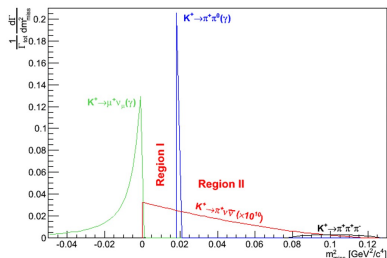
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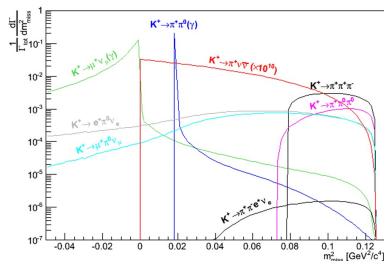
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92% of K decays

Not constrained by kinematics



8% of K decays

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

Experimental strategy:

Requirements

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

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Dream

- 1 K momentum
- 2 π momentum
- 3 No other particle
- 4 No interaction
- 5 1 day

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Concept

- 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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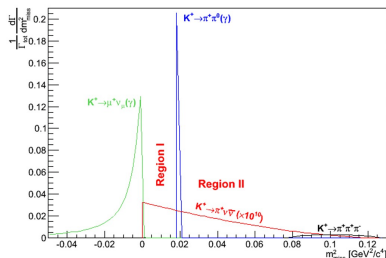
Real World

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

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

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

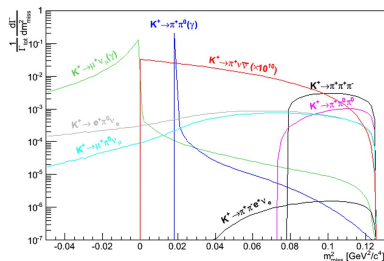
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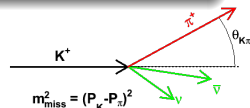
- 2 signal regions
- Minimize multiple scattering

Not constrained by kinematics



8% of K decays

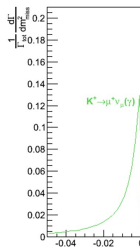
- Particle ID
- Photon vetoes



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

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

Background Rejection

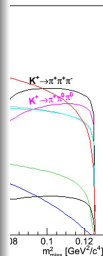


- Main backgrounds:
 - $K^+ \rightarrow \mu^+ \nu_\mu$ ($BR \approx 63\%$)
 - $K^+ \rightarrow \pi^+ \pi^0$ ($BR \approx 21\%$)
- Rejection $\approx 10^{-12}$:
 - Kinematics $\approx 10^{-5}$
 - Vetoes $\approx 10^{-5}$
 - PID $\approx 5 \cdot 10^{-3}$
- Time $K - \pi$:
 - Resolution $\approx 100ps$

92% of K dec

- 2 signal

- Minimize multiple scattering

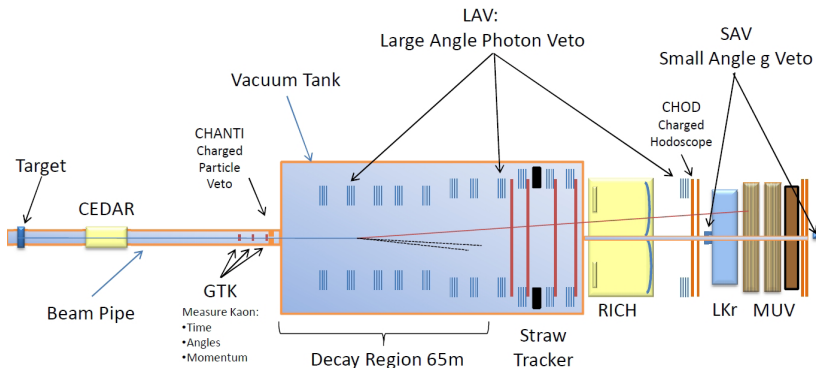


- Photon vetoes

NA62: beam and experiment layout

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

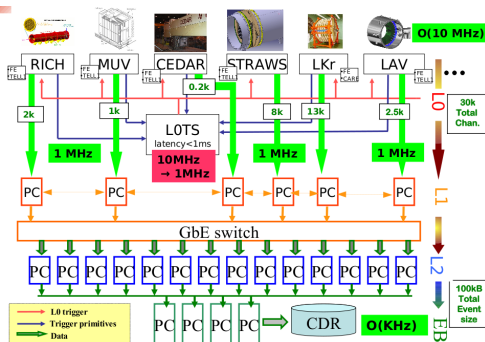
- SPS primary protons @ 400 GeV/c
- 75 GeV/c ($\Delta P/P \approx 1\%$)
- Area @ beam tracker 16 cm²
- Kaon decays/year 4.8×10^{12}
- Unseparated secondary charged beam
- $p/\pi/K$ (positron free, $K \approx 6\%$, $p \approx 23\%$)
- Integrated average rate @ beam tracker 750 MHz



Pilot Run in 2014 and physics data taking in 2015-2018

Integrated Trigger and DAQ

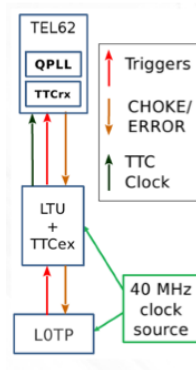
- High trigger efficiency ($> 95\%$)
- Low random veto ($< 1\%$)
- Fully digital after FE



- Level 0:
 - 10MHz $\rightarrow$ 1MHz
 - FPGA based, 1ms max latency
 - Digital primitives from fast detectors
- Level 1:
 - 1MHz $\rightarrow$ 100kHz
 - PC based, few ms latency
 - Data from all detectors but LKr
- Level 2:
 - 100kHz $\rightarrow$ 10kHz
 - PC based, few ms latency
 - All data used

Clock and L0 Trigger distribution

- Clock:
 - 40MHz (LHC standard)
 - QPLL on each RO device
 - Jitter $\ll 100$ ps
- LTU:
 - LTU (Local Trigger Unit); refit from ALICE
 - Receives synchronization signals and triggers
 - Encodes and dispatch them to TTCE_x
- TTCE_x:
 - CERN development
 - Encoder laser transmitter
 - 10 optical output



DAQ

Common to most of the detectors:

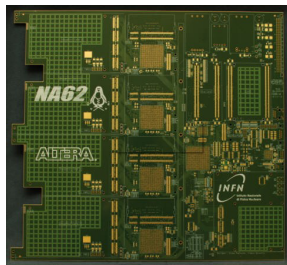
- Time measurement
- Time-Over-Threshold measurement for time walk corrections
- FE provides LVDS signals
- TDC daughter board (128ch)
- TEL62 hosts 4 TDC boards

Detectors with special solutions:

- Gigatracker (too high rate)
- LKr (too much data)
- Straw (cheaper solution)



TDCBoard based on HPTDC



TEL62 refit of TELL1(LHCb)

L0 Trigger processor

Input:

- 8 GbE
- Digital trigger primitives (up to 13.3MHz)
- Synchronization signals

Processing:

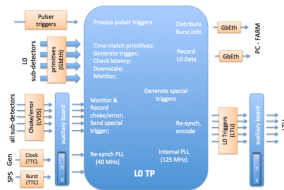
- Up to 16 trigger masks
- Control trigger
- Pseudo-random
- Programmable latency (up to few ms)
- 8 programmable time windows

Output:

- Up to 1MHz
- 75 ns dead time (from TTC)
- Trigger decision data to pcfarm
- Finetime down to 100 ps

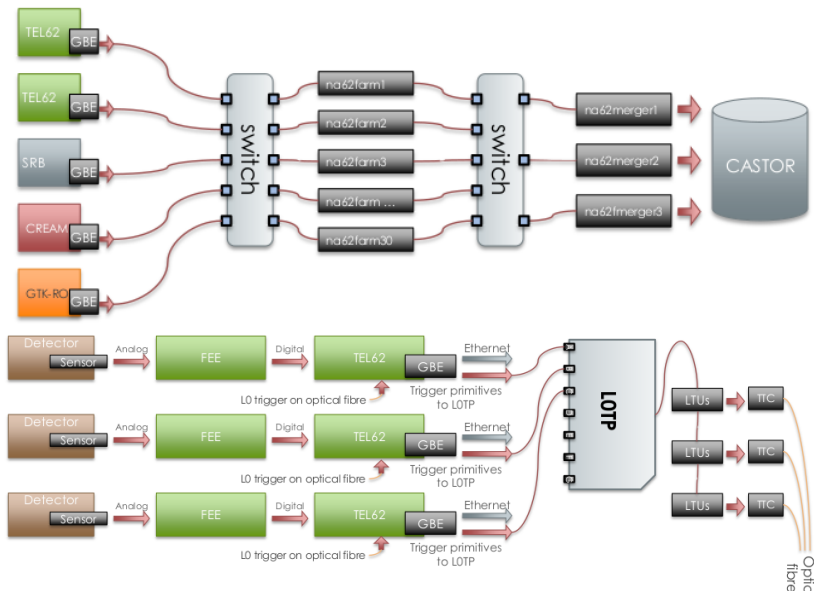


Implemented on an Altera DE4



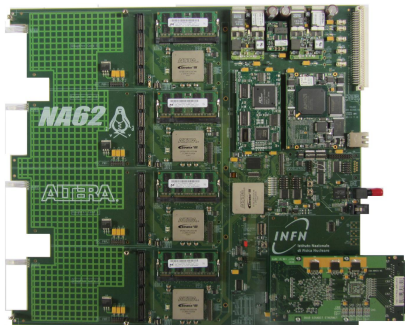
Firmware diagram

Data and L0 Trigger flow



TEL62

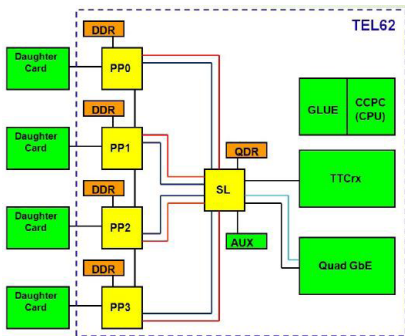
- Developed in Pisa (from TELL1)
- 8x processing power, 20x memory buffer
- O(100) installed



- 4 PP-FPGA:
 - Stratix III
 - DDR2 (2 GB)
 - Processing 1 daughter card data each
 - Digital L0 trigger primitives generation
- 1 SL-FPGA:
 - Stratix III
 - Merging data from PPs
 - Synchronization and trigger interface
 - Event building
- Output:
 - Custom GbE card
 - 4x1 GbE links
 - Choke/Error lines (backpressure)
- Control:
 - CreditCard PC
 - I2C, JTAG, ECS via PCI
 - TTCRx (Clock and L0 Trigger input)

TEL62

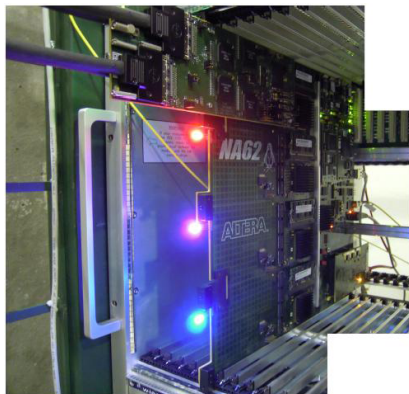
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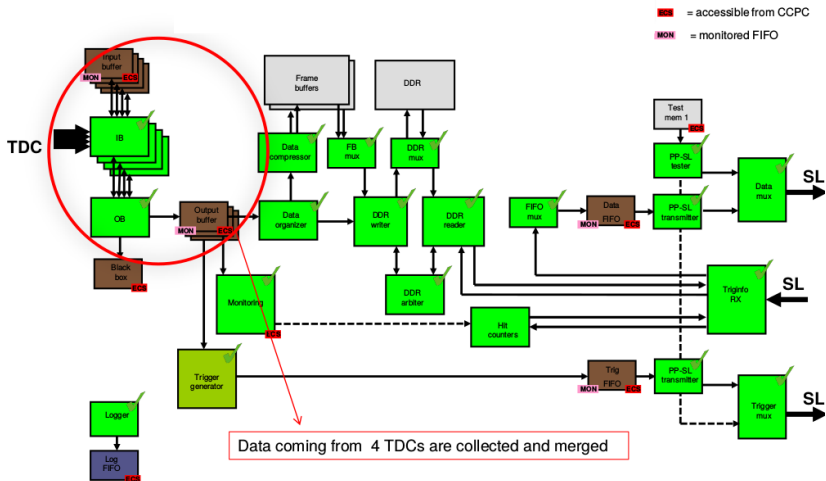
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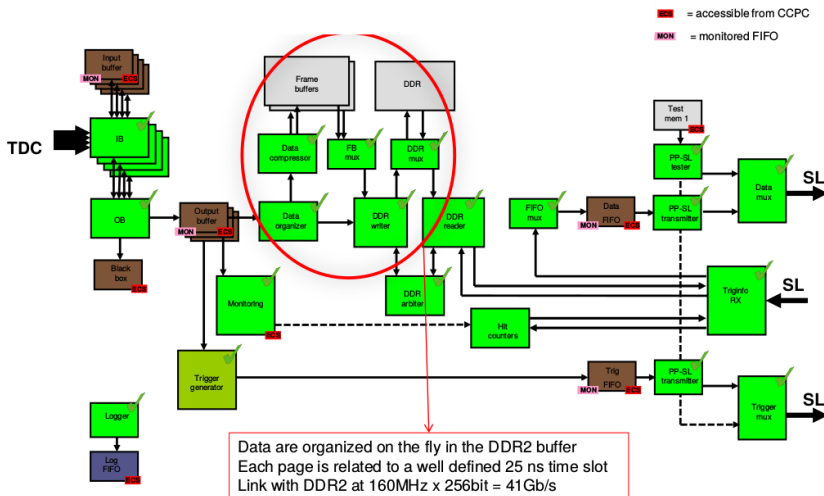
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TEL62 Firmware



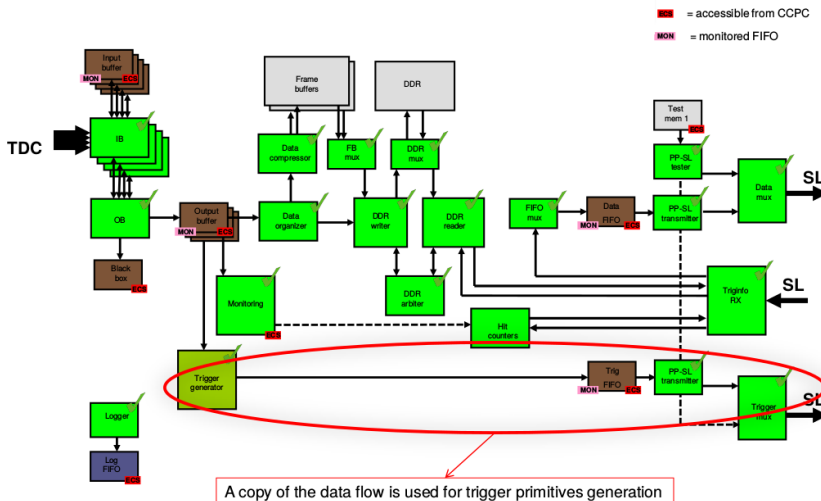
Courtesy of B. Angelucci

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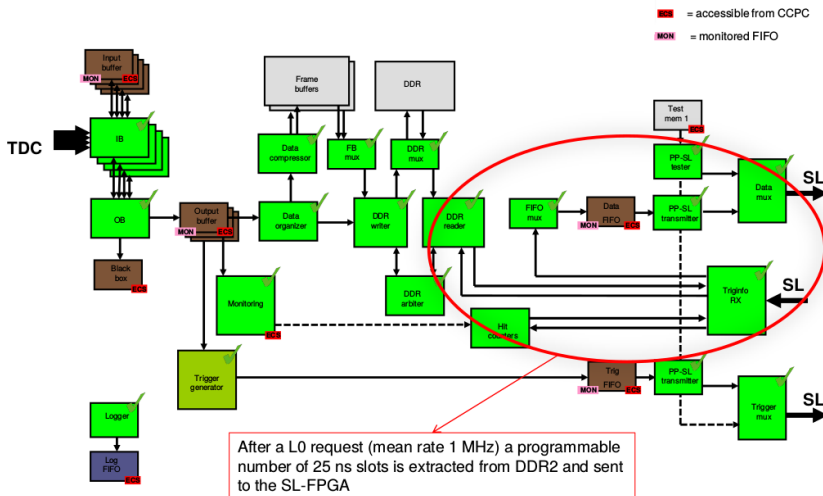
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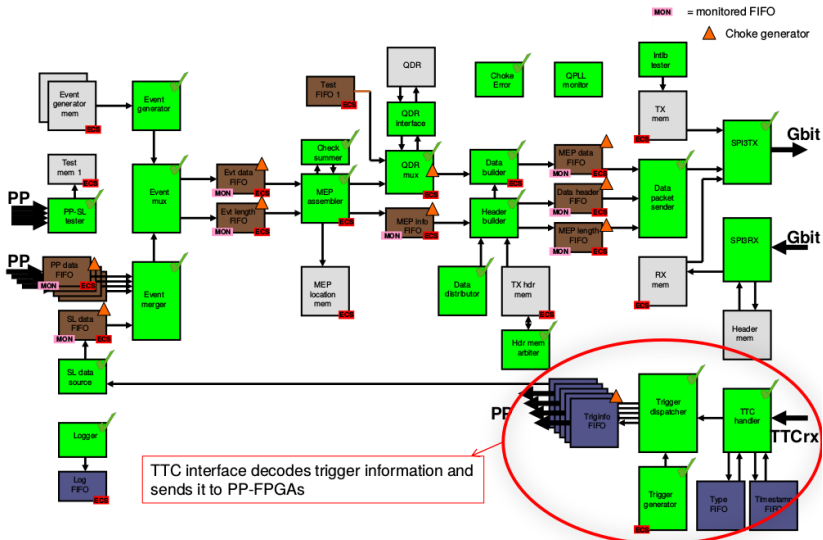
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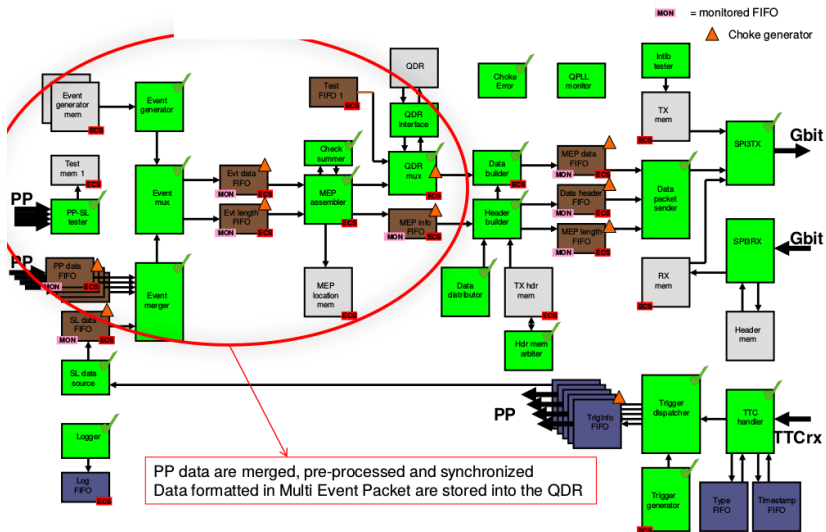
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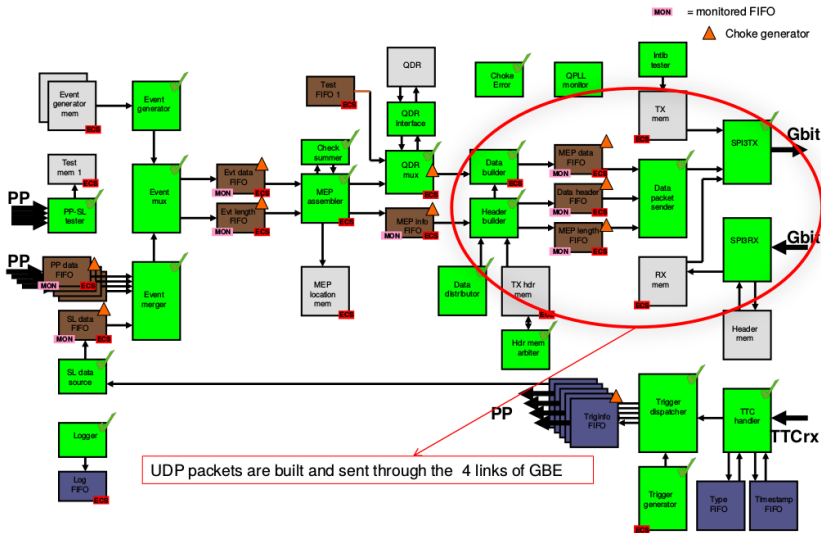
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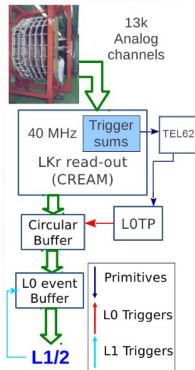
Calorimeter ReadOut and L0 Trigger

• Calorimeter REAdout Module (CREAM):

- Outsourced to CAEN
- 32 analog inputs
- 14 bits 40MS/s flash ADC
- 10 ms circular buffer
- 16 channels sums to L0 primitive generation
- 1MHz (L0 trigger) data storage up to 10 s
- Data requested at L1

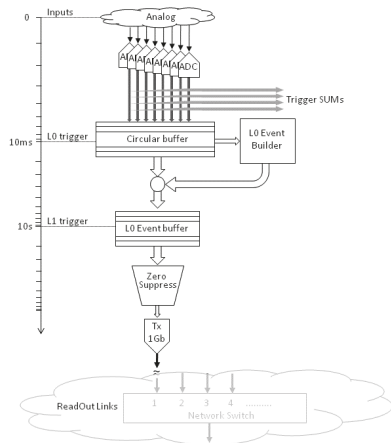
• L0 Trigger primitives:

- TEL62 based (TELDES mezzanines)
- Parabolic fit of digital sums (16ch)
- Funneling and merging
- Total energy, cluster counting



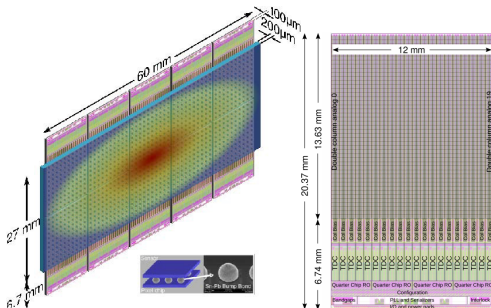
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GigaTracker ReadOut

- Exposed to $\approx 1\text{GHz}$ of particles
- 1 MHz L0 requirement
- Several ms max latency



- TDCpix:
 - CERN development
 - 12mm x 20 mm (1800 channels)
 - Time over threshold discriminator
 - 100 ps LSB TDC
- Links:
 - 4 x 6 Gb/s serial links
 - 200 m
- ReadOut board:
 - Developed in Ferrara
 - Stratix IV
 - 2 x DDR2

GigaTracker ReadOut

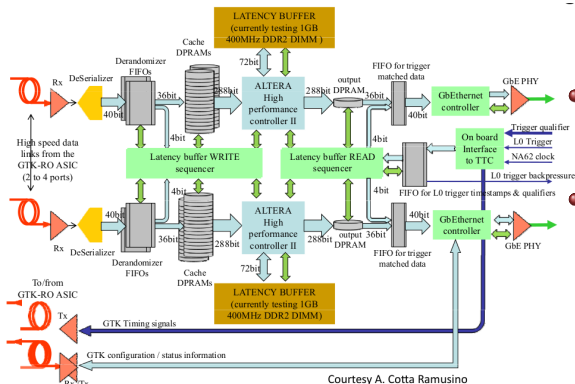
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Courtesy A. Cotta Ramusino

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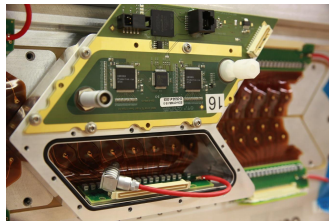
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STRAW Spectrometer ReadOut

FrontEnd:

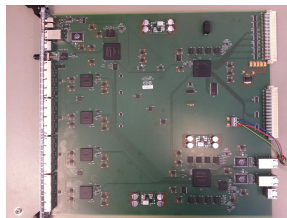
- CERN development
- Based on CARIOCA
- Part of the gas manifold
- 16 channels
- FPGA-based TDC (0.23 ns LSB)
- Cyclone III



Front-end board

Straw Readout Board (SRB):

- CERN development
- 16 high speed serial links to FrontEnd
- Cyclone V
- 2 ms circular buffer (QDR)
- 2 x GbE output
- Controlled via VME SBC



SRB (9U VME)

NA62



Summary

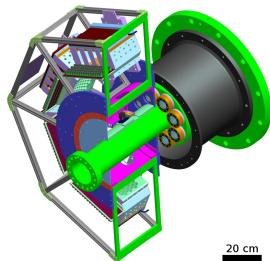
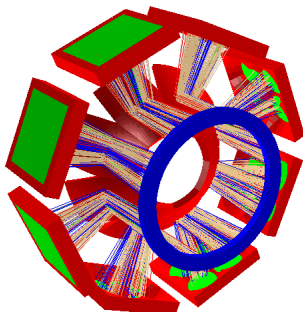
- NA62 construction was completed for 2015 run
- We are learning how to exploit the new detector to its full potential
- Trigger and DAQ
 - Designed for:
 - 10 MHz (events) triggerless data input rate
 - High latency for L0 trigger decision (up to few ms)
 - 1 MHz L0 trigger
 - Less than 10^{-8} untagged inefficiency
 - Not working at peak performance yet ($\approx 50\%$)
 - Improving
- Data taking is currently ongoing

Spares

Kaon Tracking

Cedar-KTAG: kaon tagger

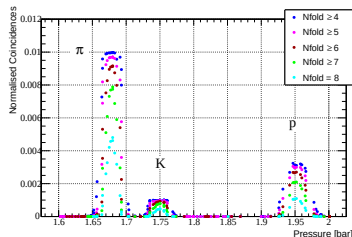
- 384 PMs, $\approx 4\text{MHz/PM}$
- K @ 50MHz
- Filled with H_2 or N_2
- $\sigma_t < 100\text{ps}$
- Sub-percent π mis-tagging for K
efficiency $> 95\%$



Kaon Tracking

Cedar-KTAG: kaon tagger

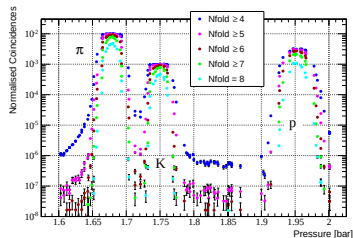
- 384 PMs, $\approx 4\text{MHz/PM}$
- K @ 50MHz
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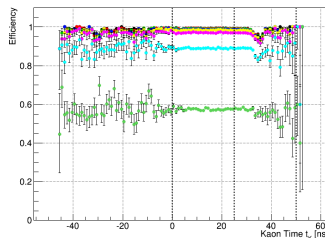
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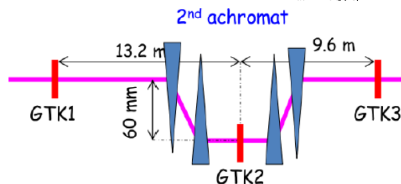
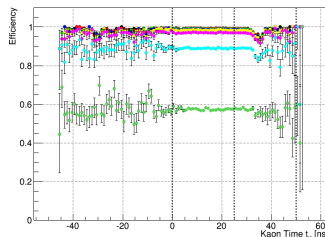
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GigaTracker: beam tracker @ 750MHz

- Si μ -pixel ($300\mu\text{m} \times 300\mu\text{m}$)
- $< 3 \times 0.5\% X_0$ ($< 1\text{mm}$)
- $> 99\%$ efficiency
- $\sigma_p/p \approx 0.2\%$
- $\sigma_\theta \approx 16\mu\text{rad}$
- $\sigma_t < 200\text{ps/station}$ (test beam)



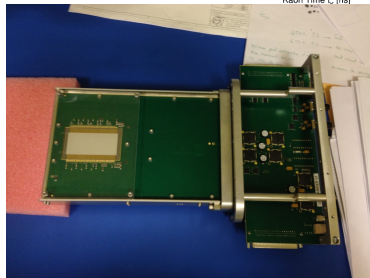
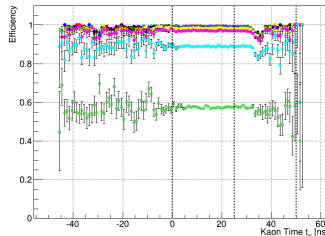
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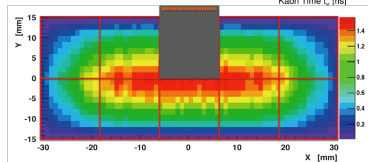
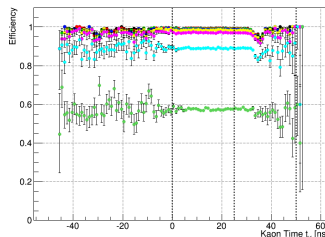
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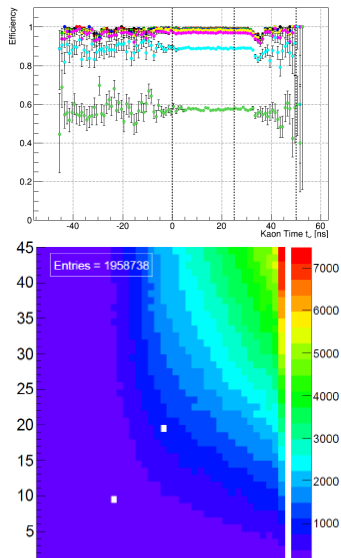
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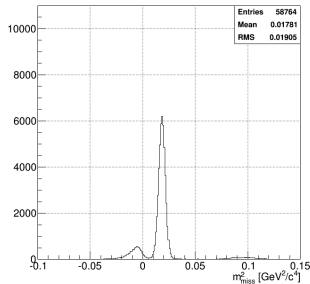
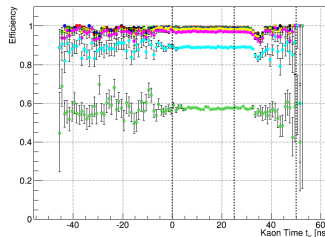
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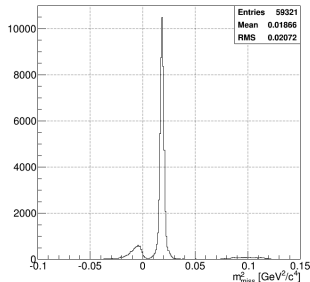
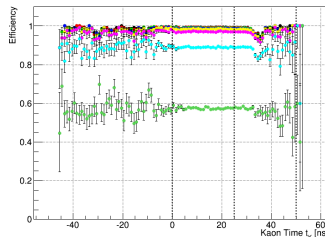
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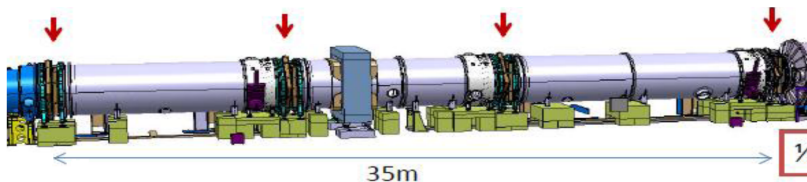
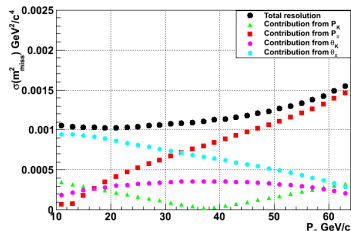
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Decay Tracking

Straw spectrometer:

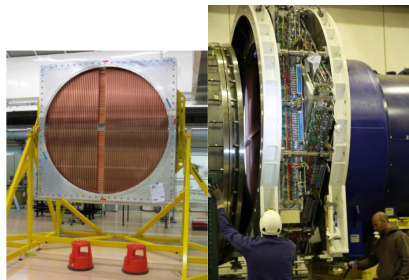
- In vacuum ($< 10^{-6}$ mbar)
- 7168 mylar straws
- ArCO₂ 70%:30%
- $< 4 \times 0.5\% X_0$
- $\sigma_p/p = 0.32\% \oplus 0.008\% \times p[\text{GeV}/c]$
- $\sigma_\theta < 60 \mu\text{rad}$
- $\geq 99\%$ hit efficiency
- leakrate $< 10^{-1}$ mbar l/s



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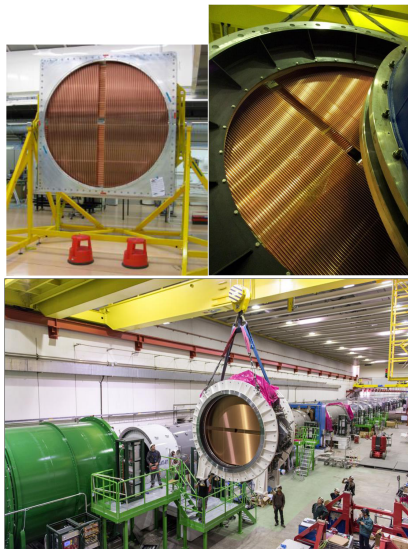
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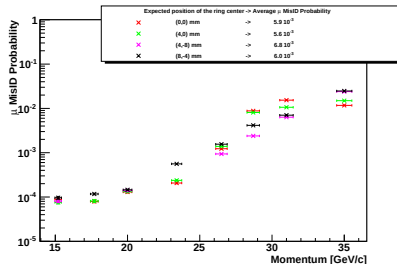
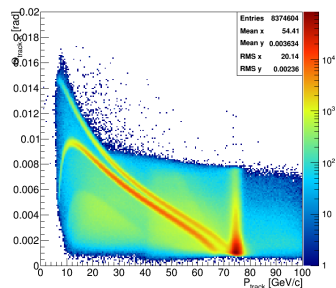
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RICH: β_{trk} @ 10MHz

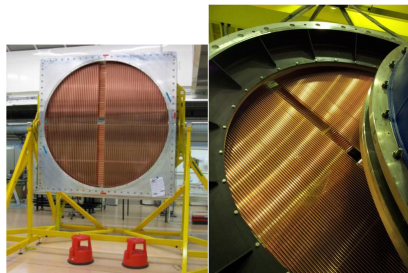
- Ne @ 1 atm ($\approx 5\% X_0$)
- 20 mirror segments ($\approx 20\% X_0$)
- $15 < \frac{p_{tr}}{\text{GeV}/c} < 35$
- Contamination of $\mu < 1\%$ (test beam)
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- $\sigma_t < 100 \text{ ps}$



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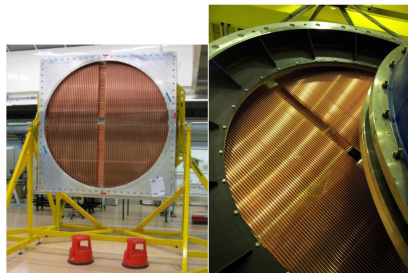
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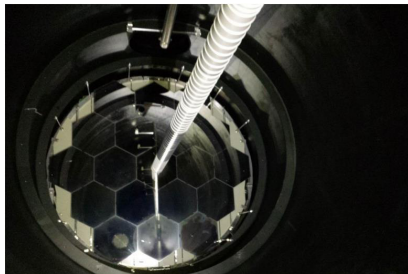
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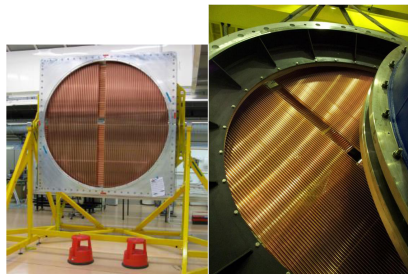
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