The NA62 Calorimeter Level 0 Trigger Operation and Performances

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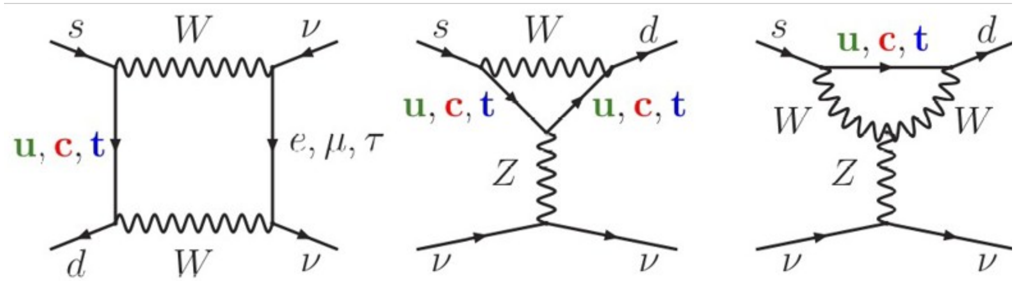
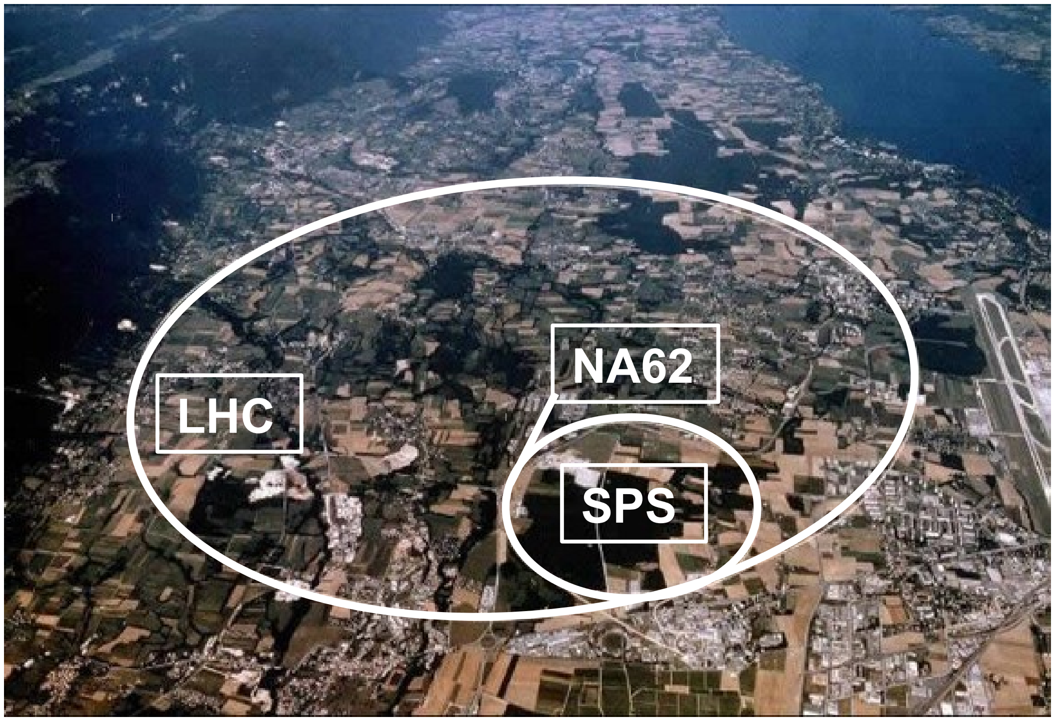
$K^+ \to \pi^+ \nu \bar{\nu}$



- Ultra-rare decays with the highest CKM suppression
- Very clean from the theoretical point of view
  - $BR_{SM}(K^+ \to \pi^+ \nu \bar{\nu}) = (8.4 \pm 1.0) \cdot 10^{-11}$
  - $BR_{SM}(K_L \to \pi^0 \nu \bar{\nu}) = (3.4 \pm 0.6) \cdot 10^{-11}$
- Very sensible to many NP models
- Almost unexplored from the experimental point of view
  - $BR(K^+ \to \pi^+ \nu \bar{\nu}) = (17.3^{+11.5}_{-10.5}) \cdot 10^{-11}$
  - $BR(K_L \to \pi^0 \nu \bar{\nu}) < 2.6 \cdot 10^{-8}$ (90% C.L.)
- See G. Ruggiero's talk: "Recent results from Kaon Physics"

The NA62 experiment at CERN SPS

Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, Lancaster, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP) , Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin, Vancouver (UBC)



Goal: O(10%) precision measurement of BR($K^+ \to \pi^+ \nu \bar{\nu}$)

- Statistics: O(100) events
- K decays 10^{12}
- Signal acceptance ~ 10%
- > 10^{12} background rejection

Broader Physics program:

- **G. Lanfranchi: Searching for hidden sectors particles at NA62**
- **M. Koval: New Limits on Heavy Neutrino from NA62**

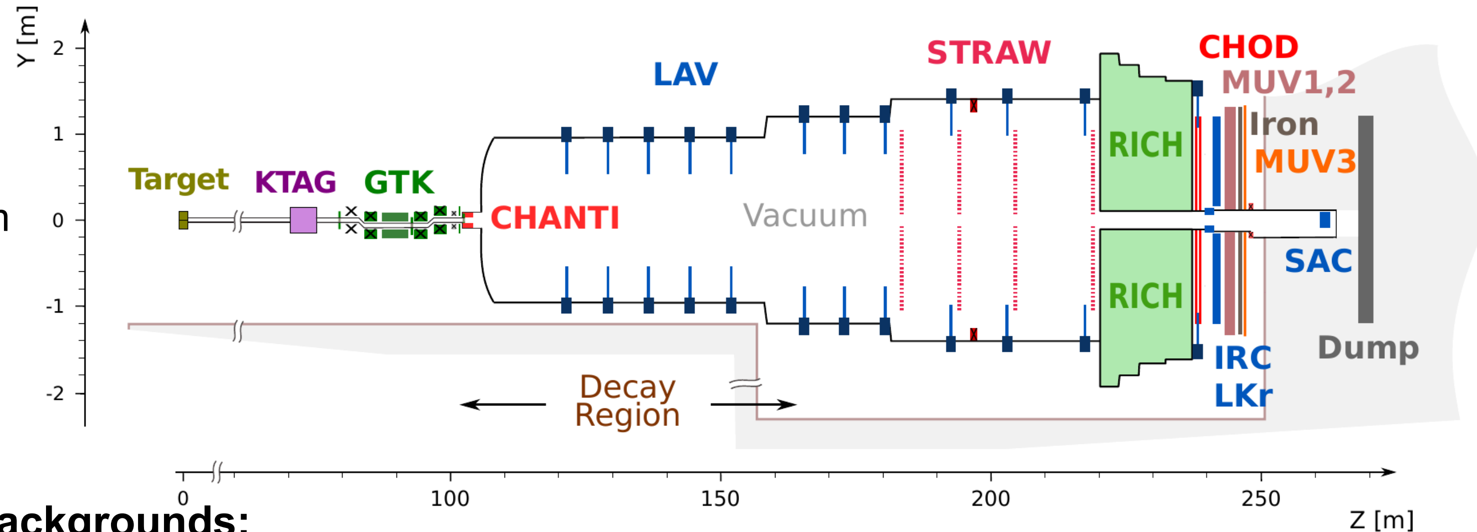
The NA62 experiment at CERN SPS

400 GeV/c
SPS protons

75 GeV/c
secondary beam

6% K^+

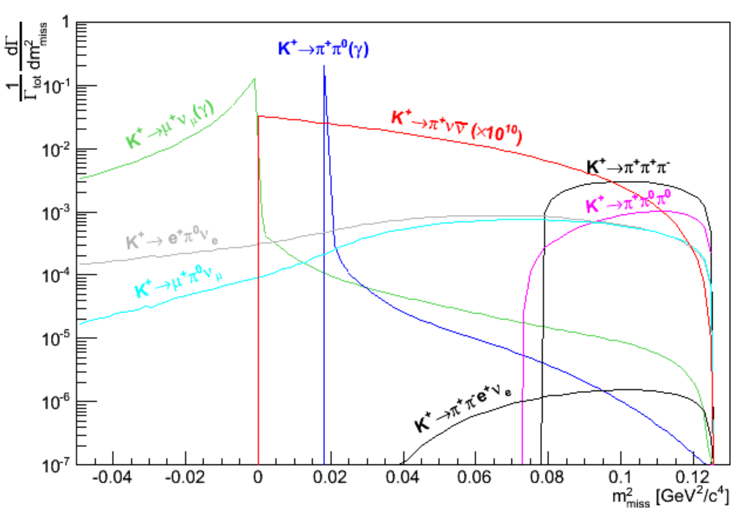
3.3 x 10^{12} ppp



Main backgrounds:

$K^+ \to \mu^+ \nu$ (~ 64 %)

$K^+ \to \pi^+ \pi^0$ (~ 21 %)



In flight kaon decay technique:

K tagging (CEDAR)

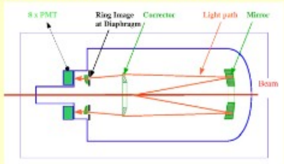
Cinematic rejection: K^+ momentum (GTK) and π^+ momentum (STRAW)

Particle ID and veto: CHANTI, γ veto(LAV,LKr,IRC,SAC), π/μ separation (RICH and muon detector), multi-track event veto (STRAW)

The NA62 detector

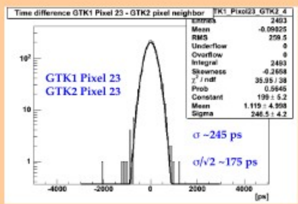
CEDAR

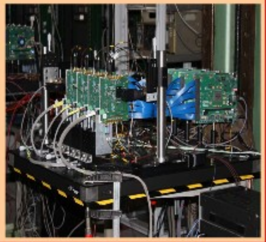
Gas differential Cerenkov counter (built for SPS beams) to tag beam kaon with $O(\sim100)$ ps time resolution



GTK 3 hybrid silicon pixel detector

stations ($<0.5\%$ X_0) with < 200 ps time resolution per station





LAV Large Angle photon Vetos

12 stations with 4/5 lead glass rings (blocks from OPAL @ LEP) in vacuum covering angular range 8.5 – 48 mrad

Detector setup

LKr 20T Liquid Krypton

calorimeter (from NA48) & new readout as forward photon veto in range 1-8.5 mrad

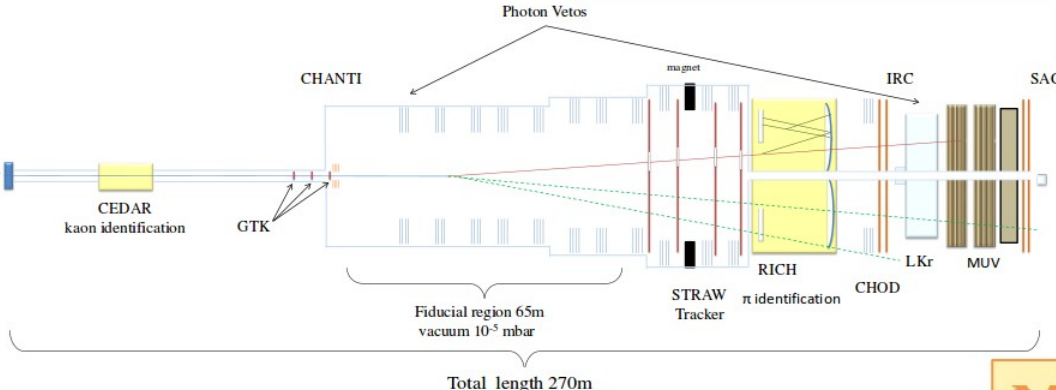
Beam

Primary SPS Beam:

- 400 GeV/c protons
- 3×10^{12} protons/pulse
- 4.8/16.8 s duty cycle

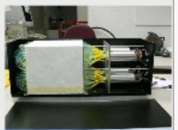
Secondary Beam: ~ 6% K^+

- p=75 GeV/c ($\Delta p/p \sim 1\%$)
- beam acc.: 12.7 mstr
- total rate: 750 MHz
- 4.5×10^{12} K^+decays/year



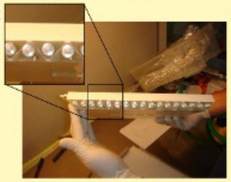
SAC/IRC

Small Angle / Inner Ring photon veto Calorimeters (lead-plastic scintillator) for angular region close to beam pipe below 1 mrad



CHANTI/CHOD

CHANTI: guard ring counters to veto beam induced inelastic interactions: triangular shape scintillators & SiPM readout

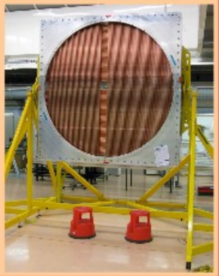


CHOD: scintillator hodoscope to

- trigger on single charged

STRAW

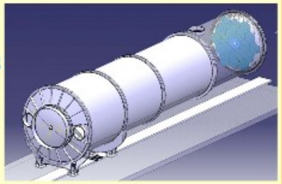
4 straw chambers (4 views each) operating in vacuum as tracker stations of the magnetic Spectrometer



RICH Neon gas Ring Imaging

Cerenkov counter, 18m long & 3m Ø

- segmented 17m focal length mirror
- ~2000 PM's
- time resolution better than 100 ps
- π/μ separation with <1% mis-ID

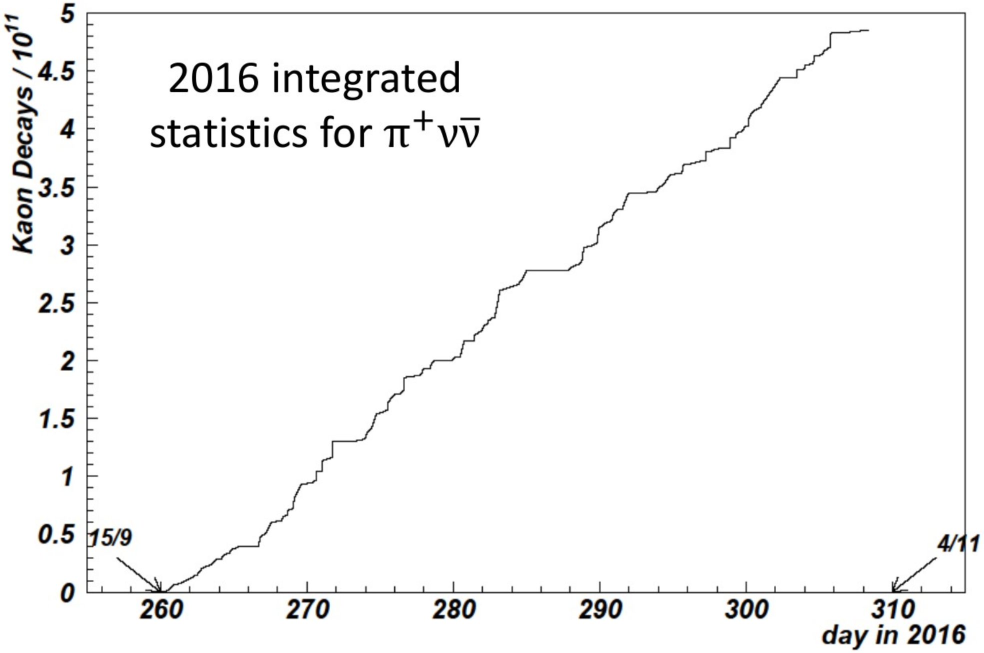


MUV Muon Veto system

MUV1 (25 layers)/MUV2 (23 layers, from NA48): iron-plastic scintillator calorimeters

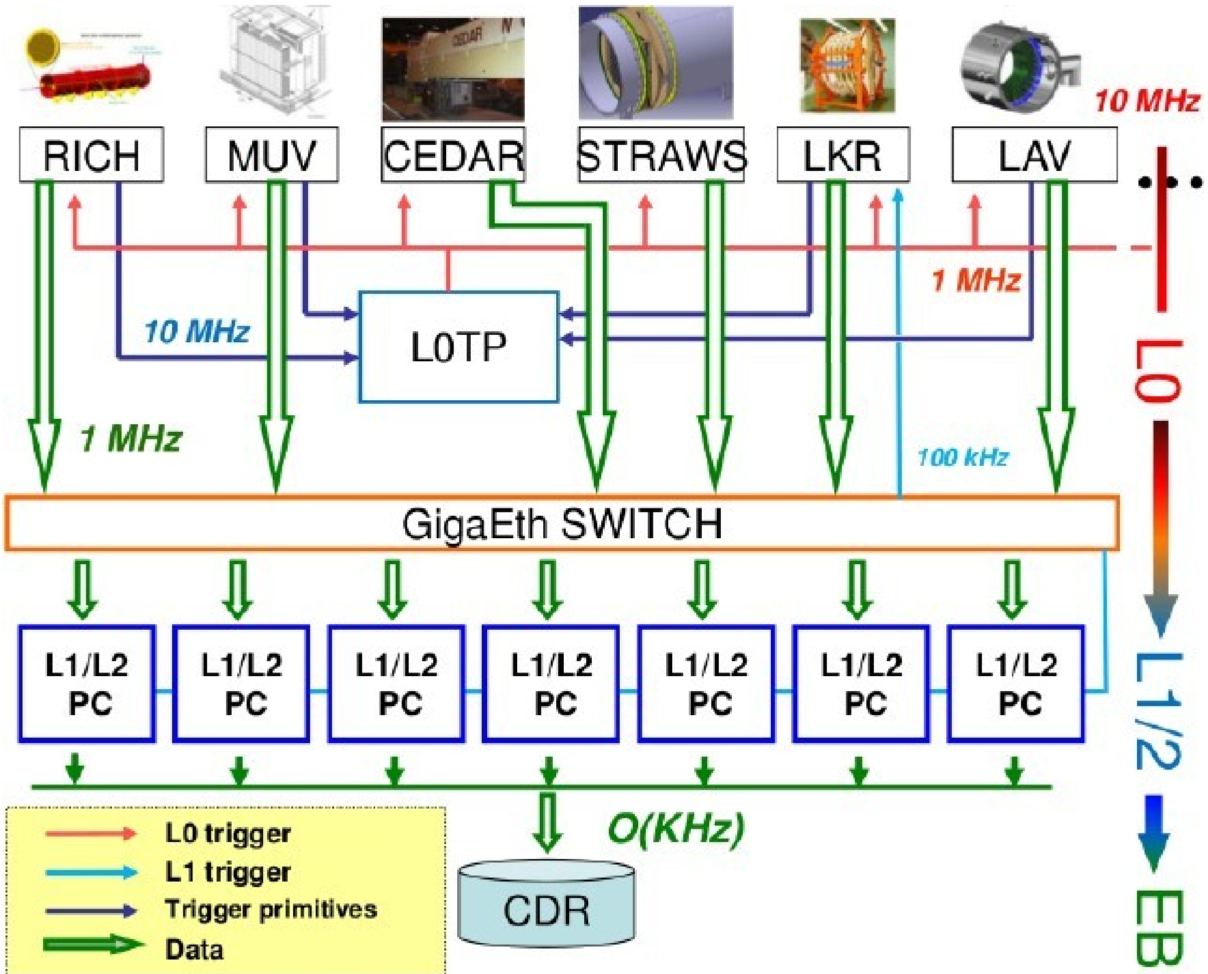
MUV3: after 80cm iron, 5cm thick single layer of scintillator tiles + PM readout, fast signal for trigger

NA62 status



- 2015: Commissioning run
- 2016: Commissioning + Physics Run (40% nominal intensity)
- 2017: Physics Run (55-60% nominal intensity)
- 2018: Physics Run
- SM Sensitivity with 2016 data

The Trigger and DAQ System



Three trigger levels:

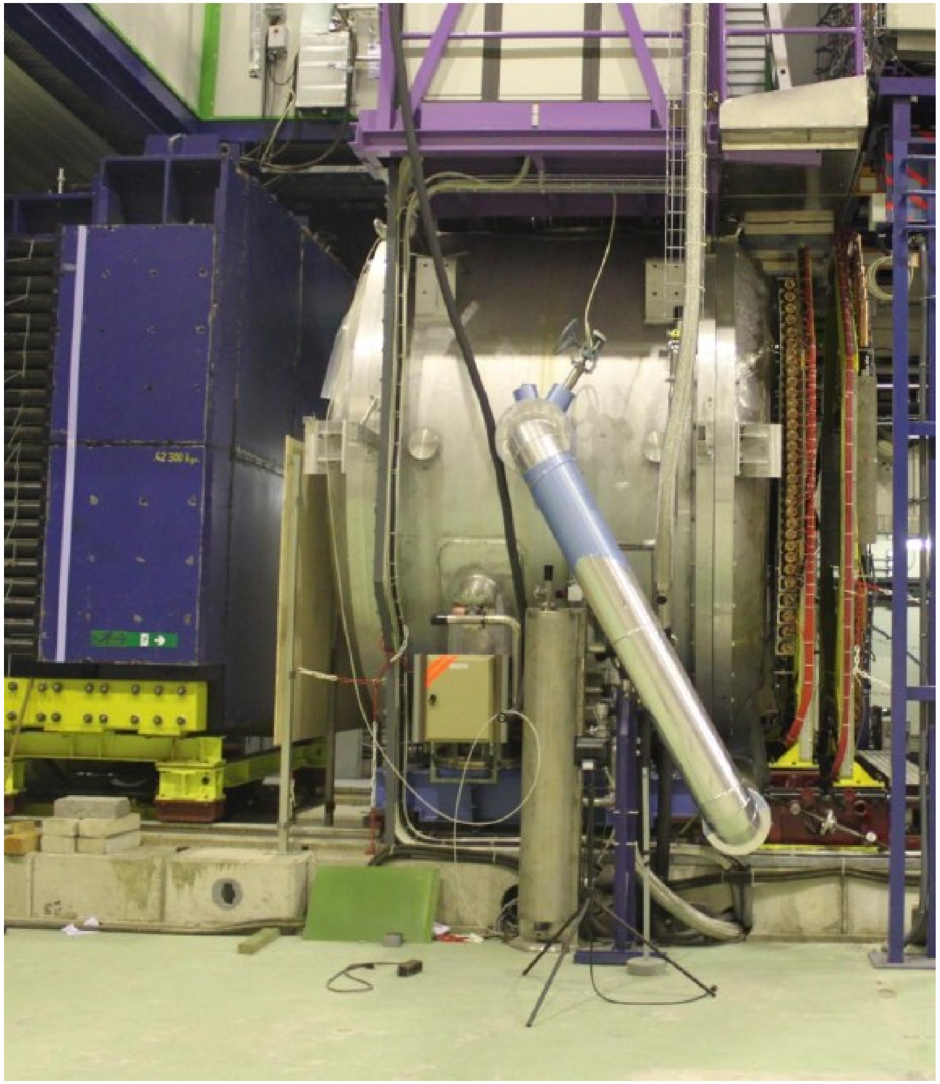
L0: Hardware synchronous level. 10 MHz to 1 MHz. Max latency: 1 ms.

L1: Software level. "Single detector". 1 MHz to 100 kHz. Max latency: O(1 s).

L2: Software level. "Complete events". 100 kHZ to O(kHz).Max latency: spill period O(10 s).

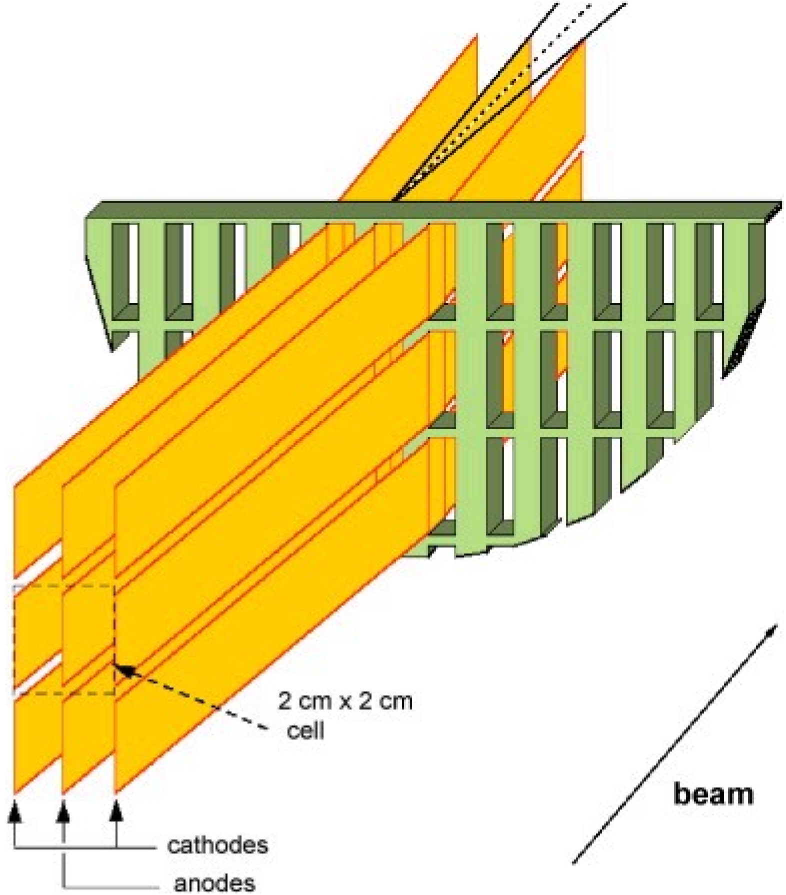
12 sub-detectors, ~ 80 000 channels, 25 GB/s raw data.

The NA48 Liquid Krypton electromagnetic calorimeter

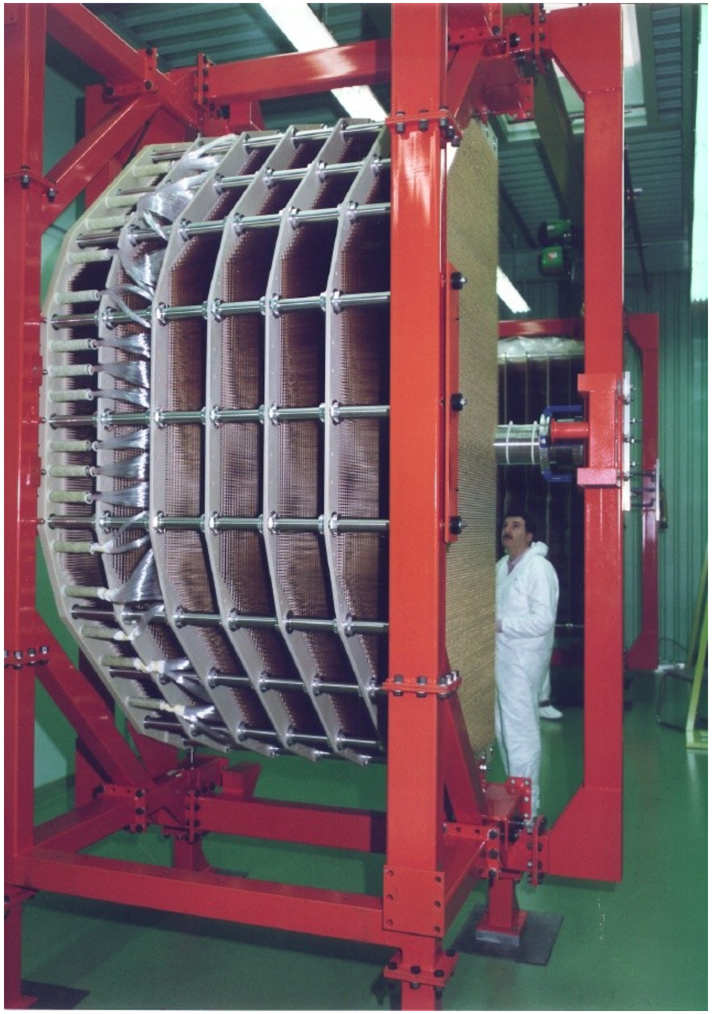


$K^+ \rightarrow \pi^+ \pi^0$ VETO

For $K^+ \rightarrow \pi^+ \pi^0$ decays in the decay fiducial region and for E_π < 35 GeV 80% of the photons are in the Lkr acceptance



The NA48 Liquid Krypton electromagnetic calorimeter



13248 channels

27 X_0

$$\frac{\sigma_E}{E} = \frac{0.032}{\sqrt{E}} + \frac{0.09}{E} + 0.0042$$

$$\sigma_{X,Y} = \frac{0.42}{\sqrt{E}} + 0.06$$

$$\sigma_t = \frac{2.5}{\sqrt{E}}$$

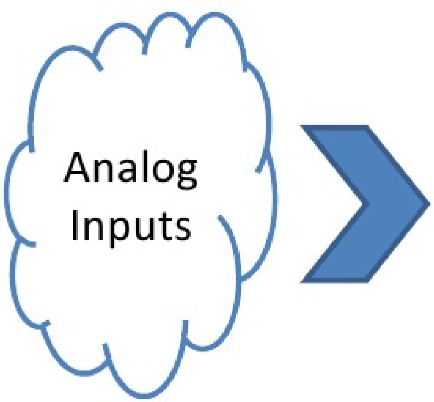
(GeV, cm and ns)

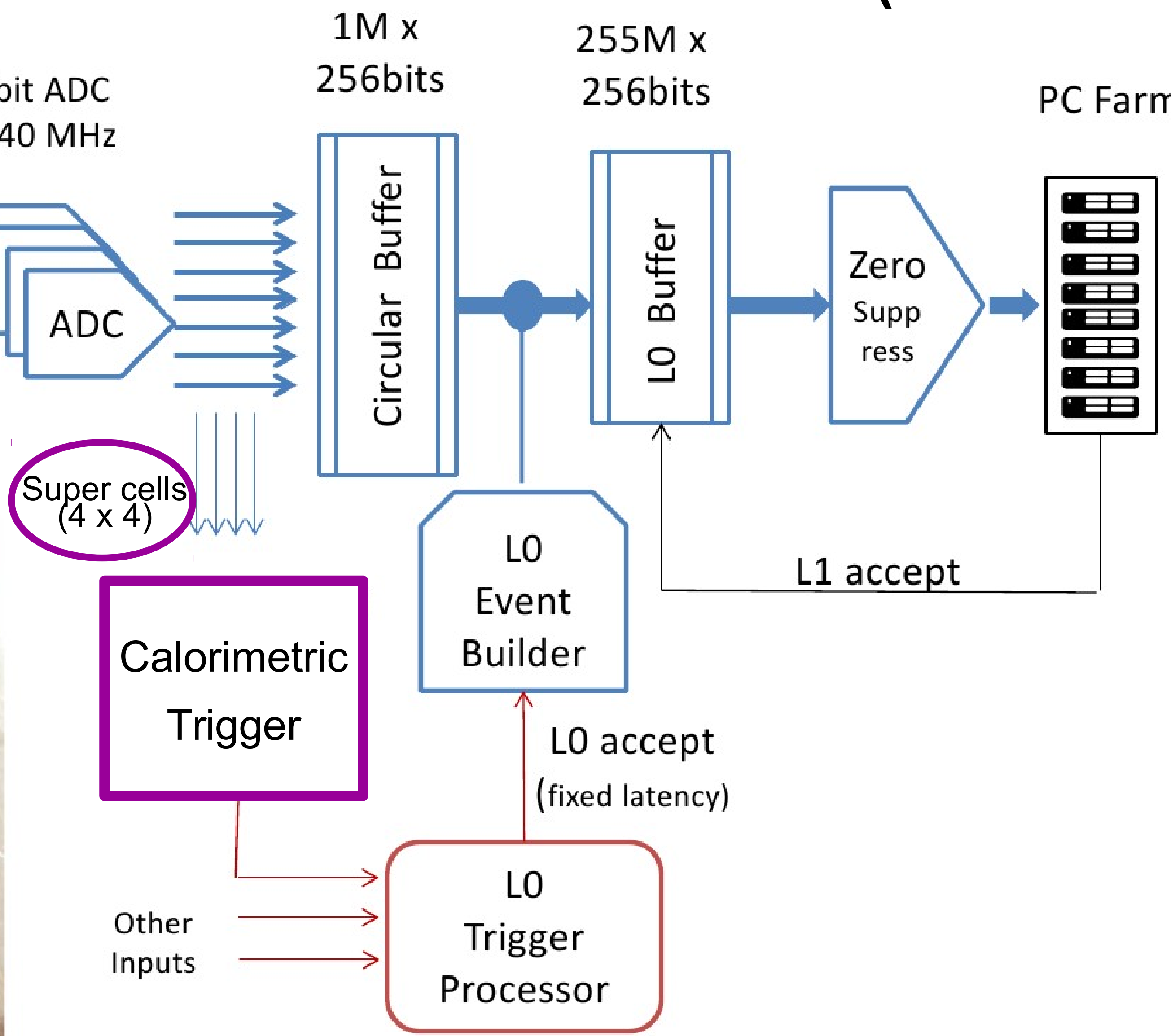
Photon veto in the angular decay region 1-8.5 mrad

For $K^+ \rightarrow \pi^+ \pi^0$ decays in the decay fiducial region and for $E_\pi < 35$ GeV 80% of the photons are in the Lkr acceptance

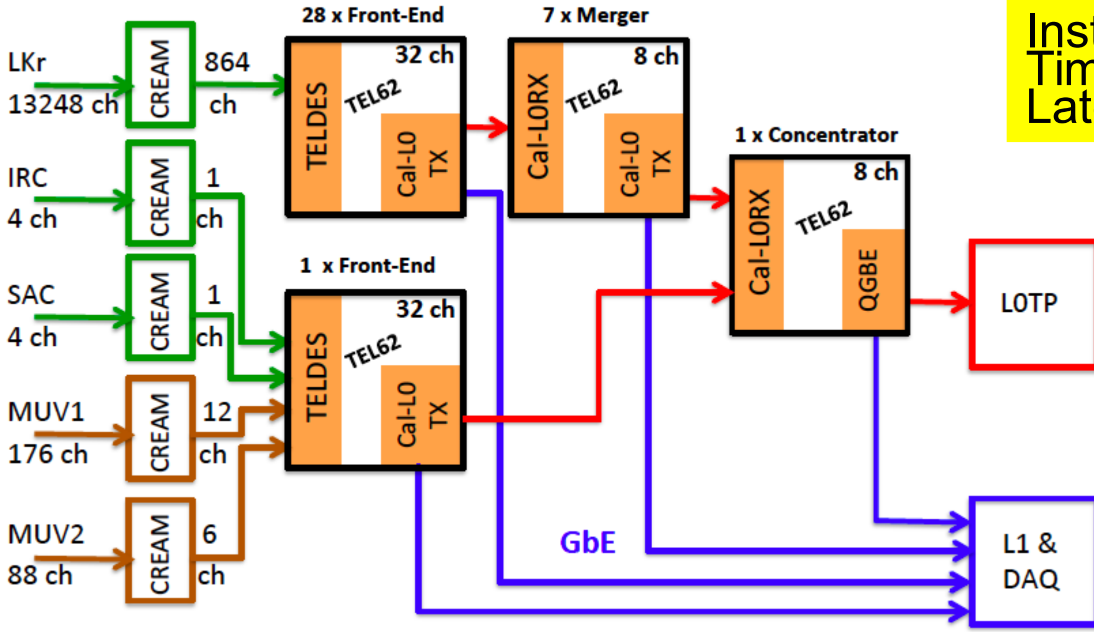
Inefficiency $< 10^{-5}$ for $E_\gamma > 10$ GeV

Calorimeter REAdout Modules (CREAMs)





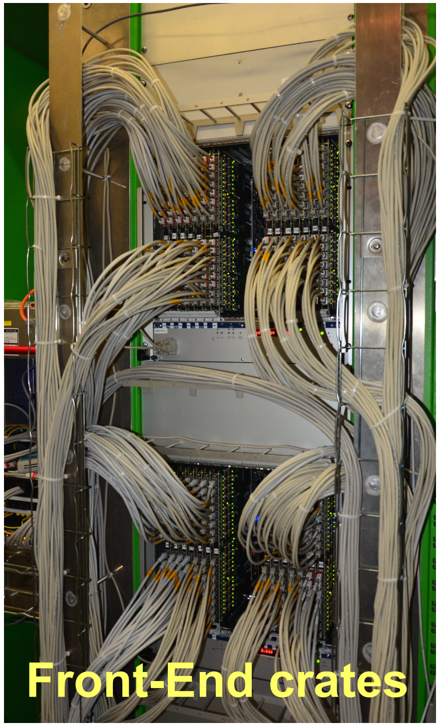
The NA62 Calorimeter L0 trigger

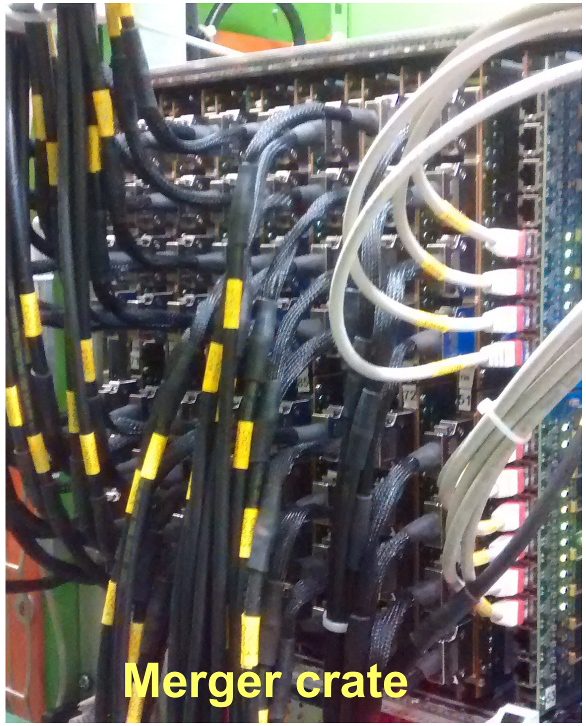


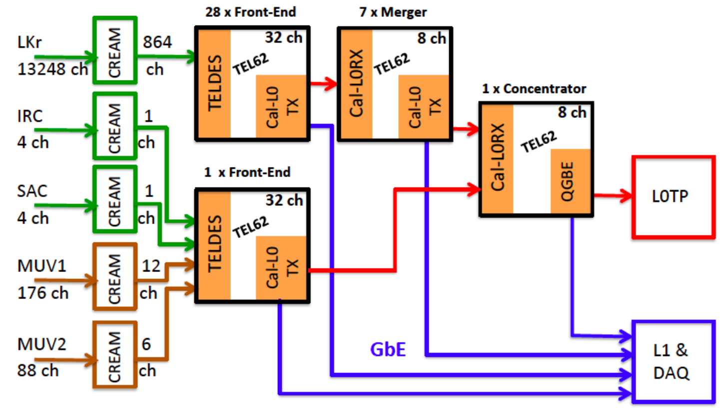
Inst. hit rate: 30 MHz
Time resolution: 2.5 ns
Latency < 100 us

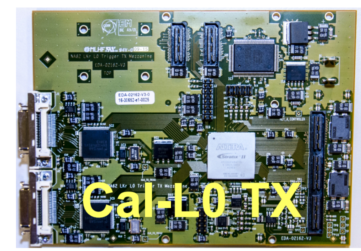
- Pixel based trigger processor with 4x4 calorimeter cell tiles
- Identifies electromagnetic clusters in the calorimeter and prepares a time-ordered list of reconstructed clusters (time, position and energy) for the L0 Trigger Processor
- Low granularity readout independent from CREAMs full granularity readout
- Fast readout for L1 software triggers and/or Region of Interest for the Lkr full granularity readout at L1

Calorimeter L0 trigger implementation



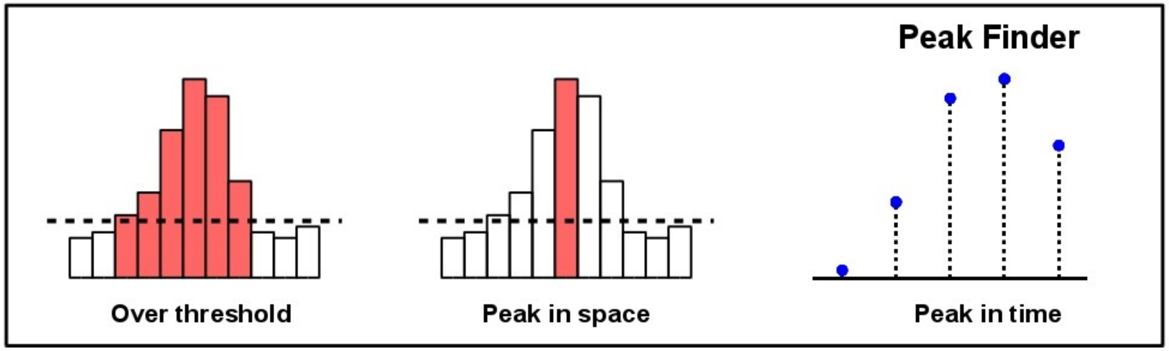


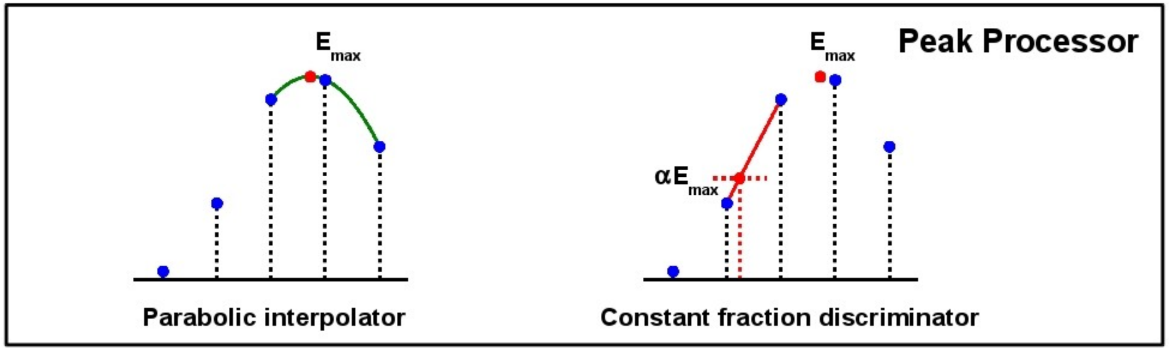


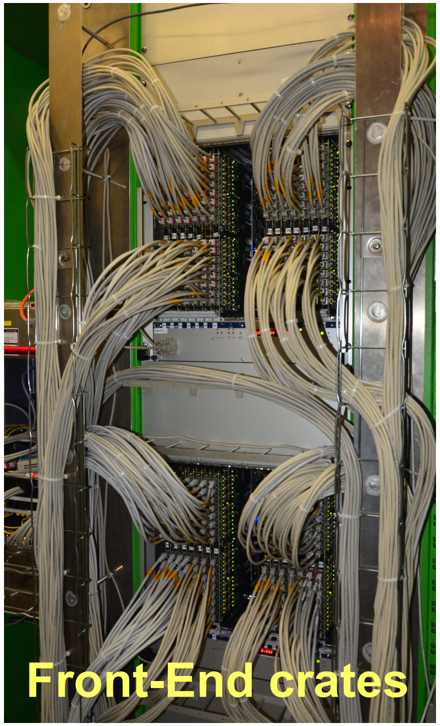


- 37 9U TEL62 electronics modules + 111 dedicated mezzanines installed in 3 crates
- 864+20 input channels (tiles), 16 bit @ 40 MHz per tile from the calorimeter readout modules (CREAM) over 15 meters high quality Ethernet cables (**560 Gbps**)
- 1 trigger output channel (Gbit Ethernet) to the L0 Trigger Processor
- 29 raw data + 7 reconstructed clusters readout channels to L1 and DAQ
- Less than 100 μs output latency

Peak reconstruction



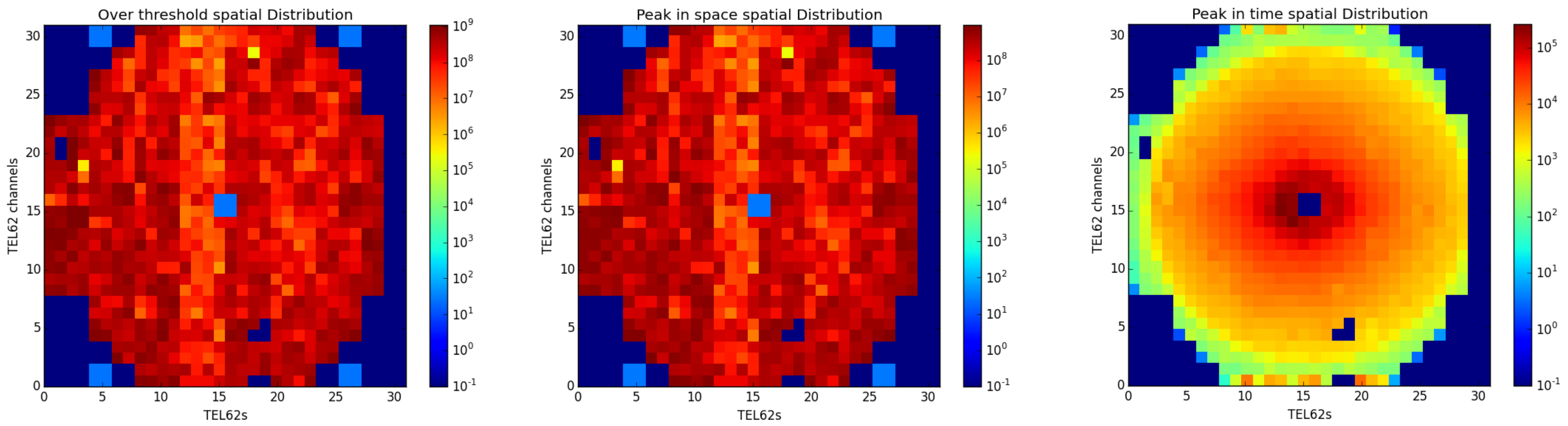


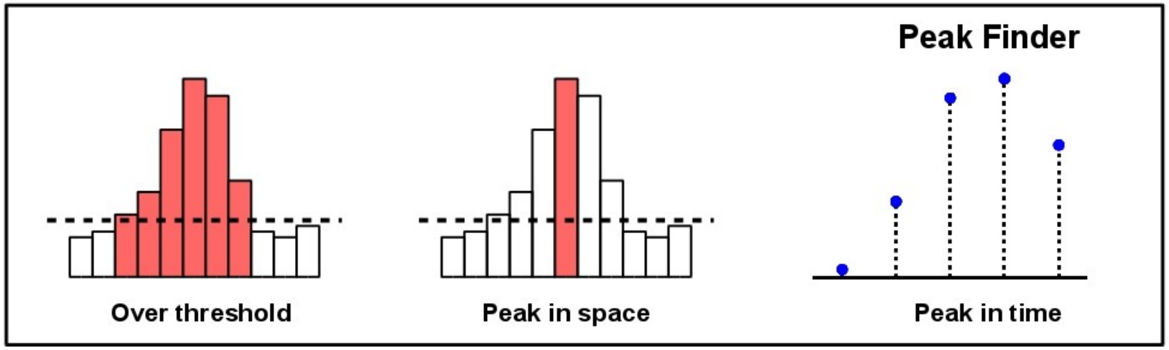


For each input channel:

- Threshold check: $E_i[n] > E_{th}$
- Peak in space: $E_{i-1}[n] < E_i[n]$ AND $E_i[n] > E_{i+1}[n]$, E ADC count, i tile number, n sample number
- Peak in time: $E_i[n-2] < E_i[n-1] < E_i[n]$ AND $E_i[n] > E_i[n+1]$
- Parabolic interpolation in time around maximum
- Constant fraction discriminator with linear interpolation between samples n-2 and n-1

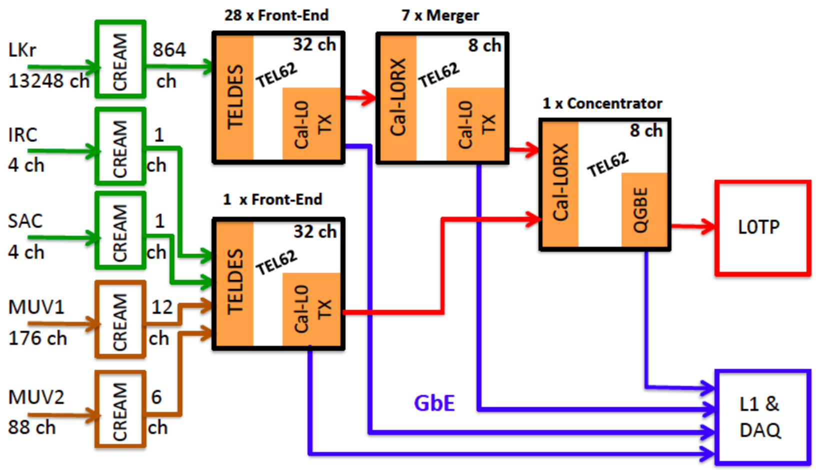
Peak reconstruction

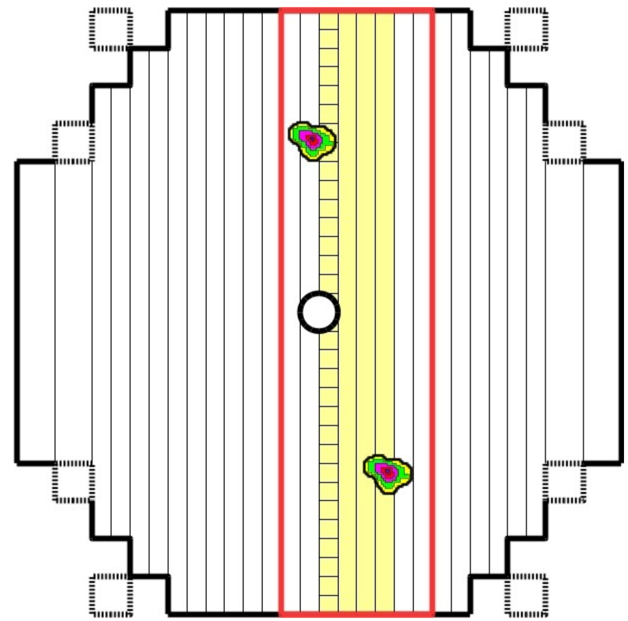




2015 commissioning run: one missing FE board, one broken Ethernet cable, one broken channel

Liquid Kripton Calorimeter

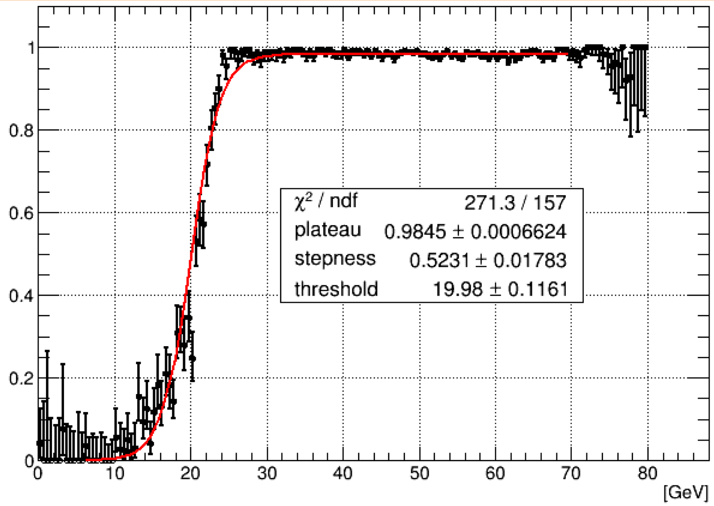




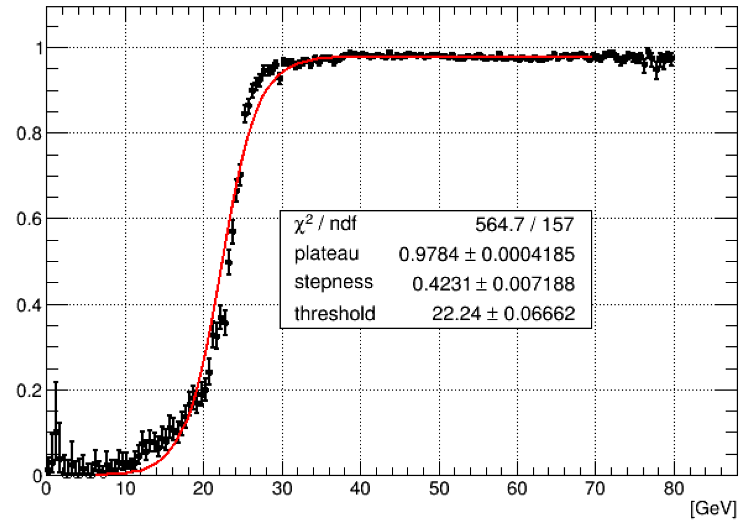
- 1 D + 1 D pixel based algorithm: LKr divided in slices parallel to the y axis.
- Front-End boards (28): peaks in space and time **indipendently** searched in each vertical slice: digital constand fraction discriminator + linear interpolator for fine timing.
- Merger boards (7): peaks close in space and time merged and assigned to the same electromagnetic cluster. **Overlap resolution** to avoid double counting: only clusters with maximum along x axis in the yellow area are reconstructed.

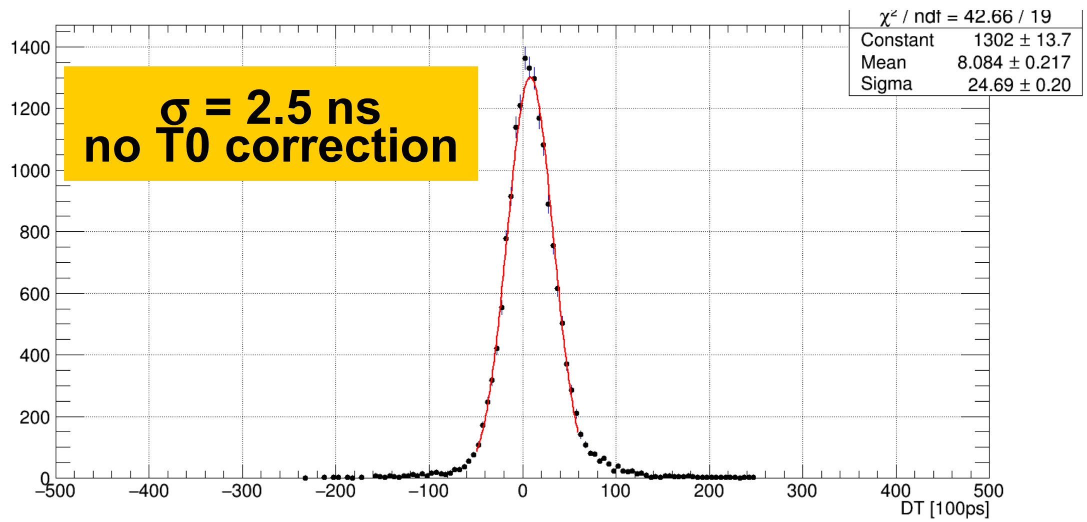
Calorimetric trigger performances

280 MeV - 5% of intensity



560 MeV - 35% of intensity





Conclusions

The NA62 calorimetric trigger processor (for $K^+ \rightarrow \pi^+ \pi^0$ rejection) has been designed, installed, commissioned and is taking data.

Instantaneous hit rate: 30 MHz

Time resolution: 2.5 ns

Latency: < 100 μs

2016: Commissioning + Physics run (SM sensitivity)

2017-2018: Physics runs

Thanks a lot for your attention!