The NA62 Calorimetric Level-0 trigger and readout electronics

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for the NA62 Level 0 Trigger Working Group

$K^+ \to \pi^+ \nu\bar{\nu}$ Branching ratio measurement with $\mathcal{O}(10\%)$ precision

SM prediction [Buras et al. JHEP 1511 (2015) 33] $BR(K^+ \to \pi^+ \nu\bar{\nu}) = (8.4 \pm 1.0) \cdot 10^{-11}$

Experimental status (E787, E949) $BR(K^+ \to \pi^+ \nu\bar{\nu}) = \left(17.3^{+11.5}_{-10.5}\right) \times 10^{-11}$

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Background Branching ratio

$K^+ \longrightarrow \pi^+\pi^0$	0.20
$K^+ \longrightarrow \mu^+\nu$	0.64
$K^+ \longrightarrow \pi^+\pi^+\pi^-$	0.06

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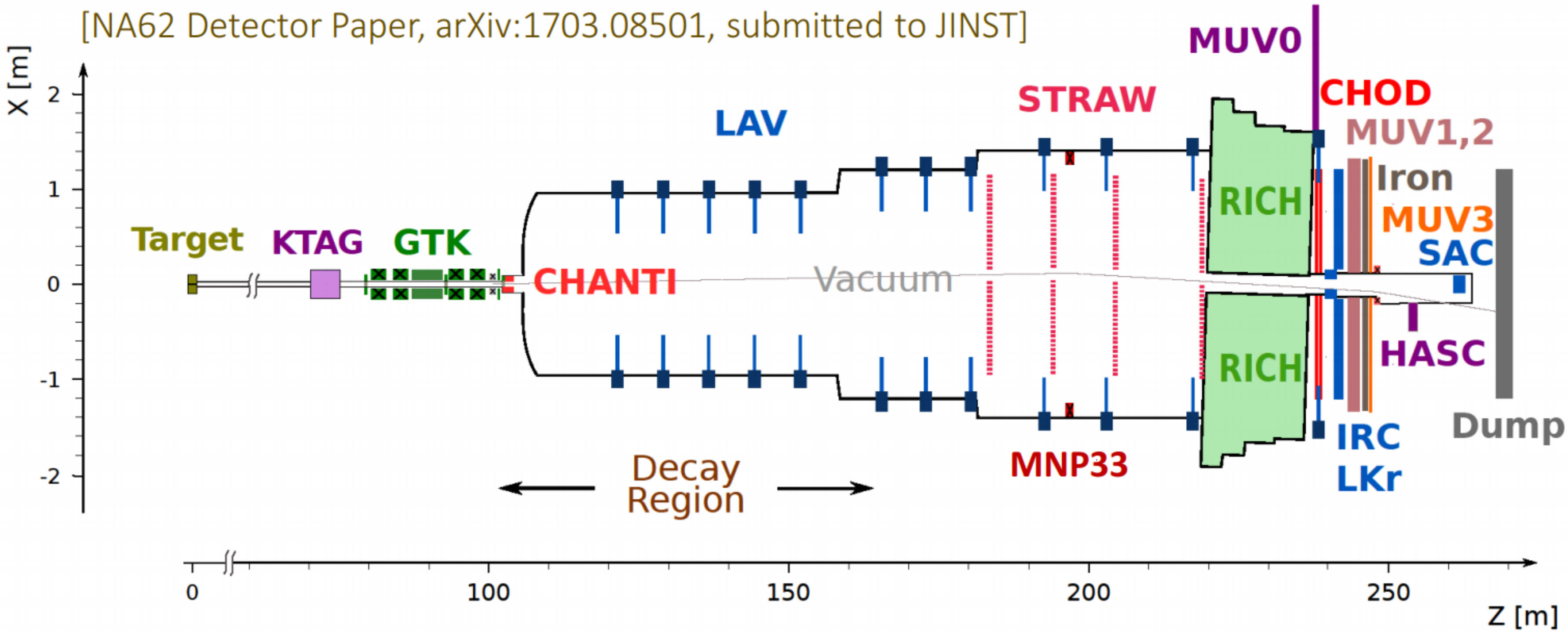
O(100 ps)	Timing between sub-detectors
$O(10^4)$	Background suppression from kinematics
$> 10^7$	Muon suppression
$> 10^7$	π^0 (from $K^+ \to \pi^+ \pi^0$) suppression

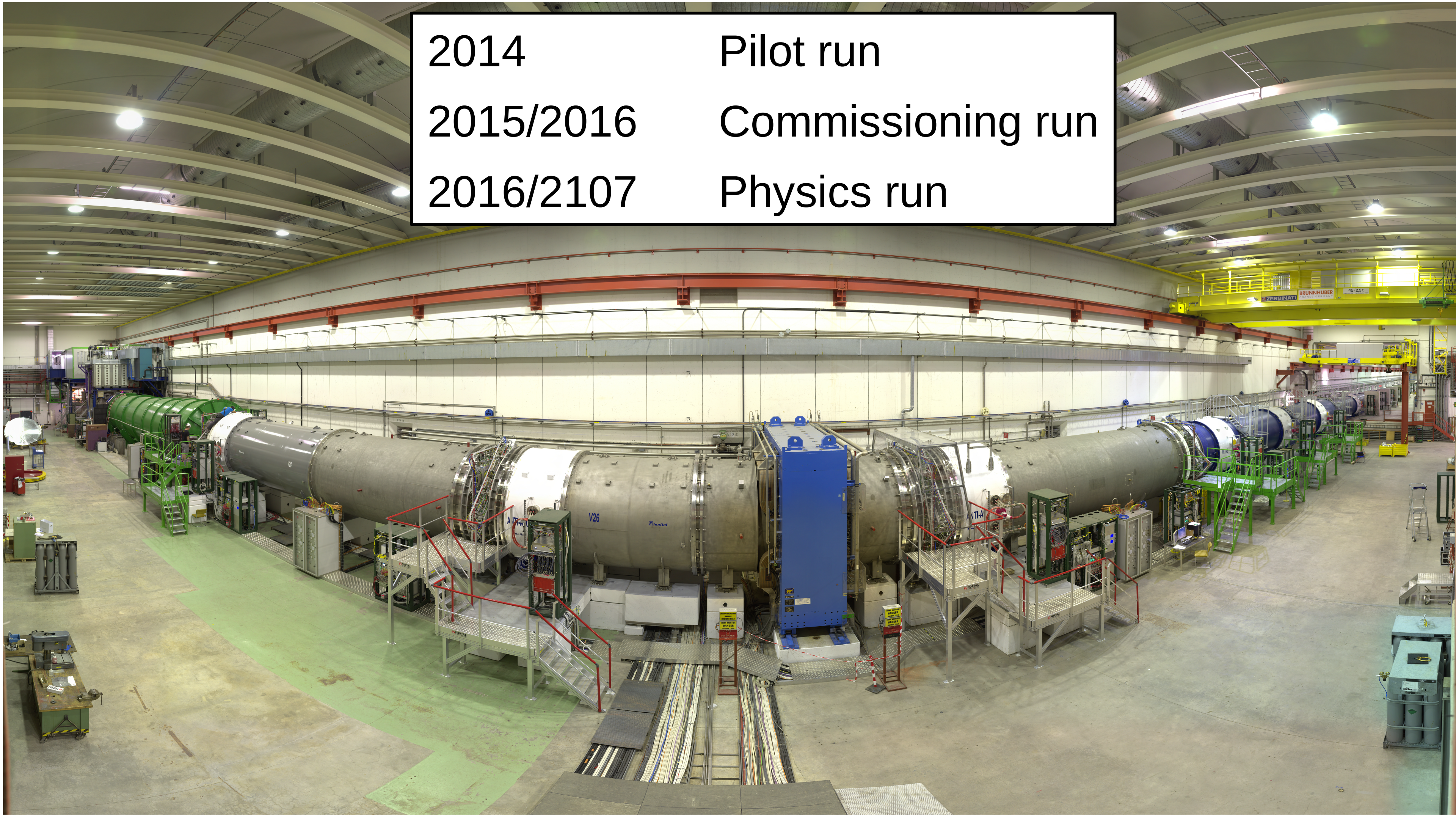
The NA62 experiment at CERN SPS

[NA62 Detector Paper, arXiv:1703.08501, submitted to JINST]



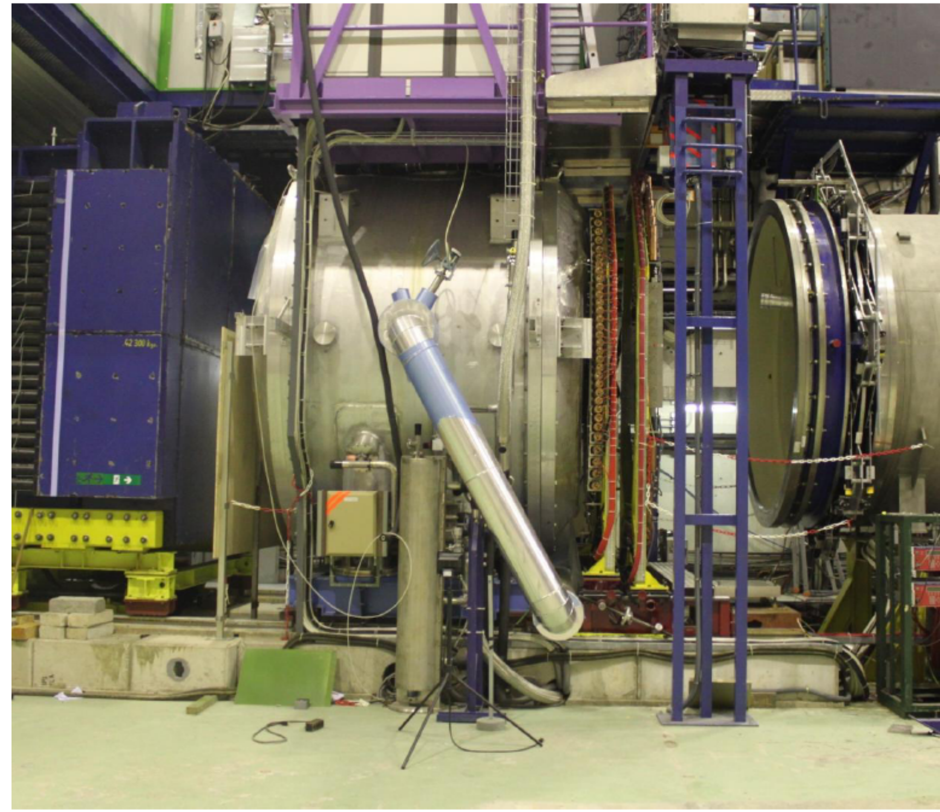
Secondary positive beam	
Momentum	75 GeV/c, 1% bite
Divergence (RMS)	100 μrad
Transverse Size	$60 \times 30\text{mm}^2$
Composition	$K^+(6\%)/\pi^+(70\%)/p(24\%)$
Nominal rate	33×10^{11} ppp on T10 (750 MHz at GTK3)

Decay region	
Fiducial region	60 m
K^+ decay rate	~ 5 MHz
Vacuum	$\mathcal{O}(10^{-6})$ mbar



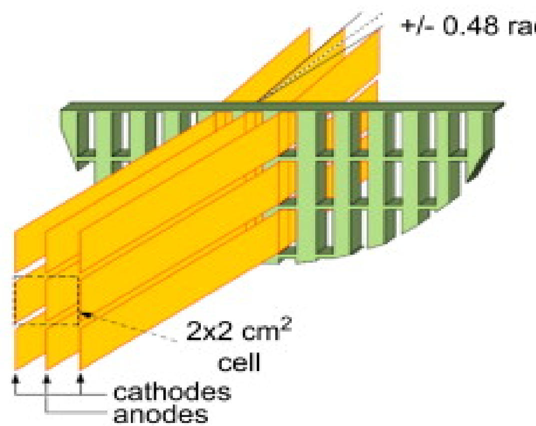
2014	Pilot run
2015/2016	Commissioning run
2016/2107	Physics run

THE NA48/62 LKr CALORIMETER



The detector

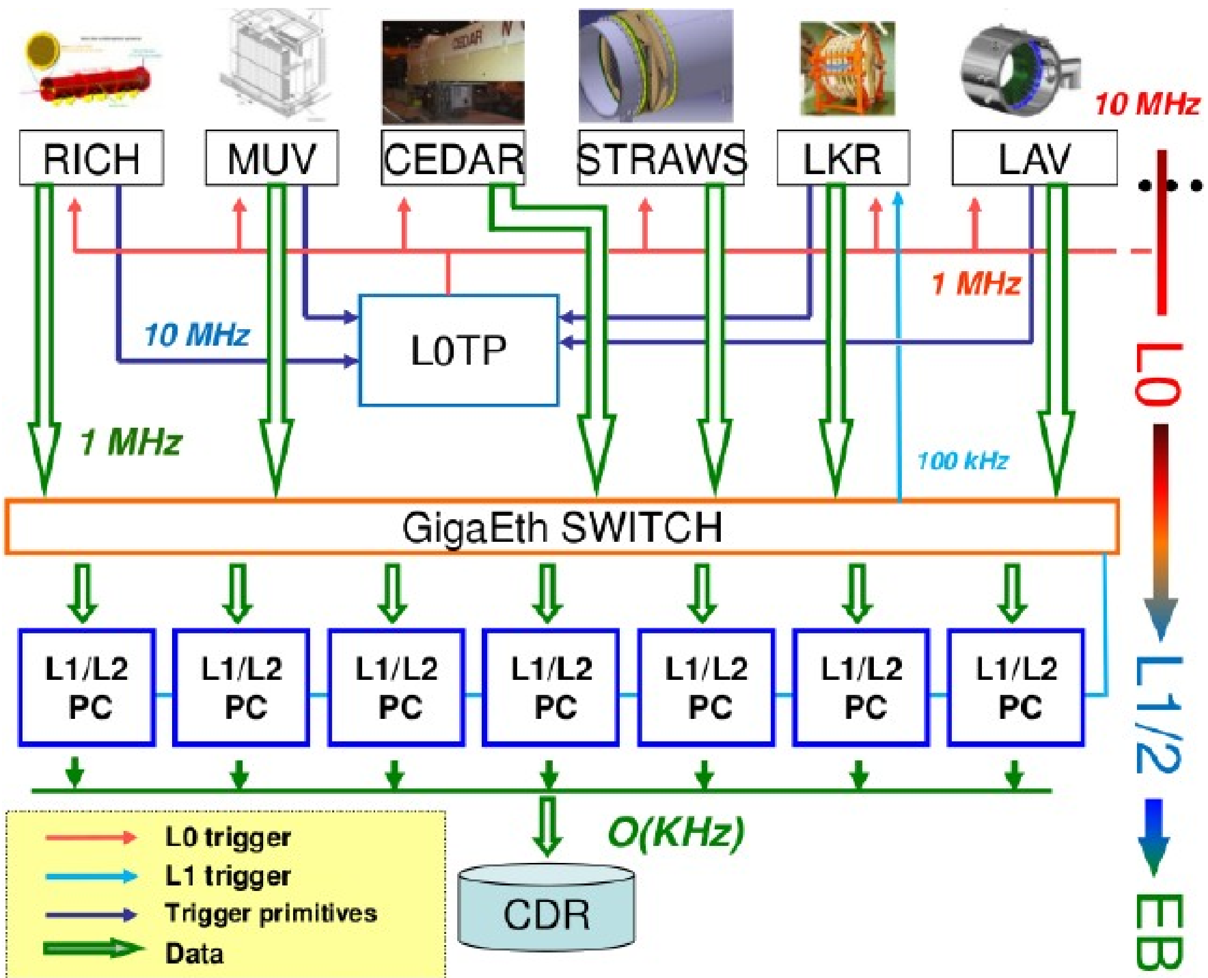
- 10 m^3 liquid Krypton calorimeter, 1.25 m deep (27 X_0)
- 13284 2x2 cm^2 cells, projecting geometry
- Preamplifiers inside the LKr tank
- Calibration system mounted on the LKr tank



Use

- Veto in the forward direction
- High-precision measurement of the electromagnetic energy deposit

The Trigger and DAQ System



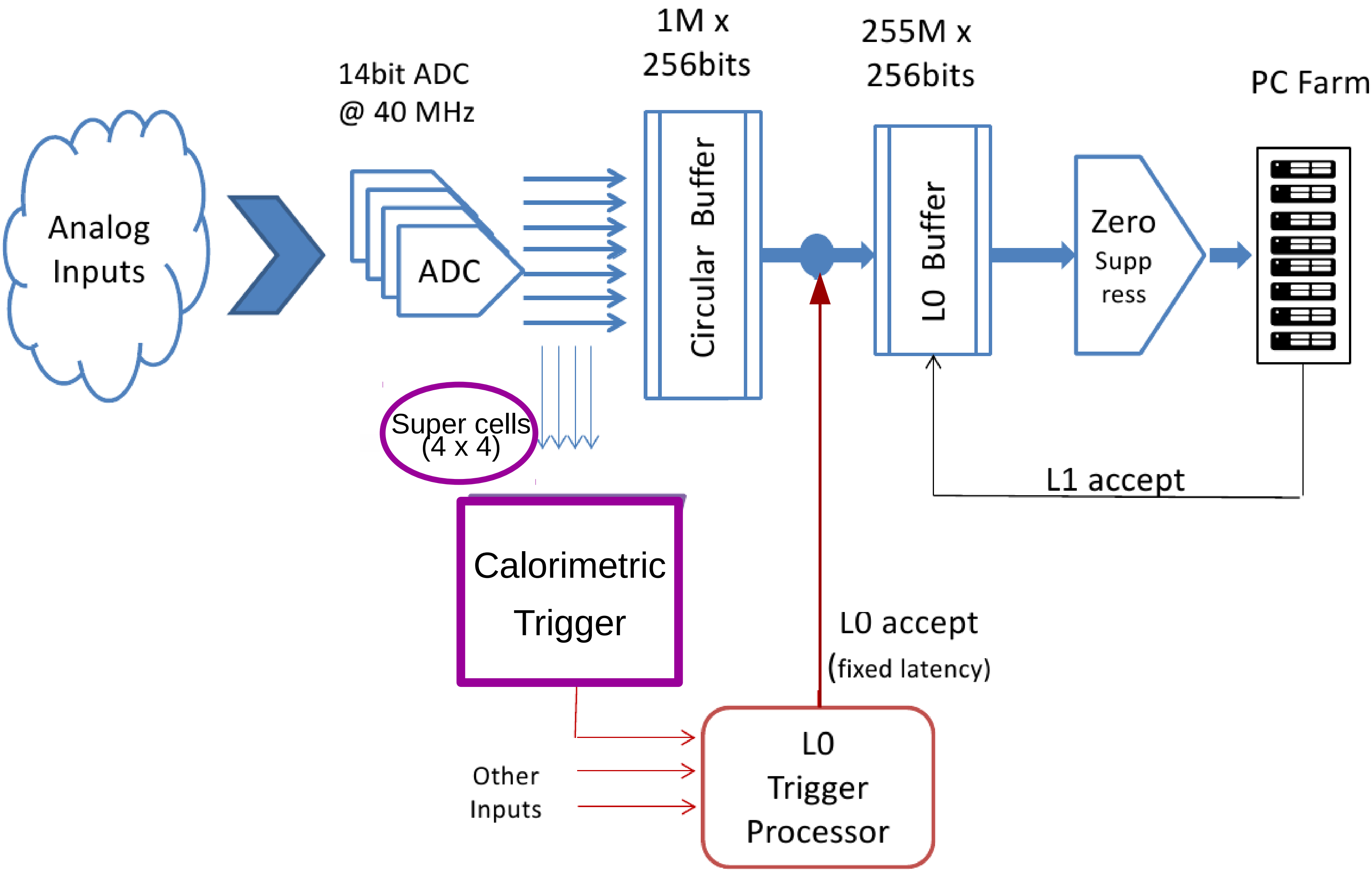
Trigger levels:

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

L1/L2: Software level. 1 MHz to O(kHz).

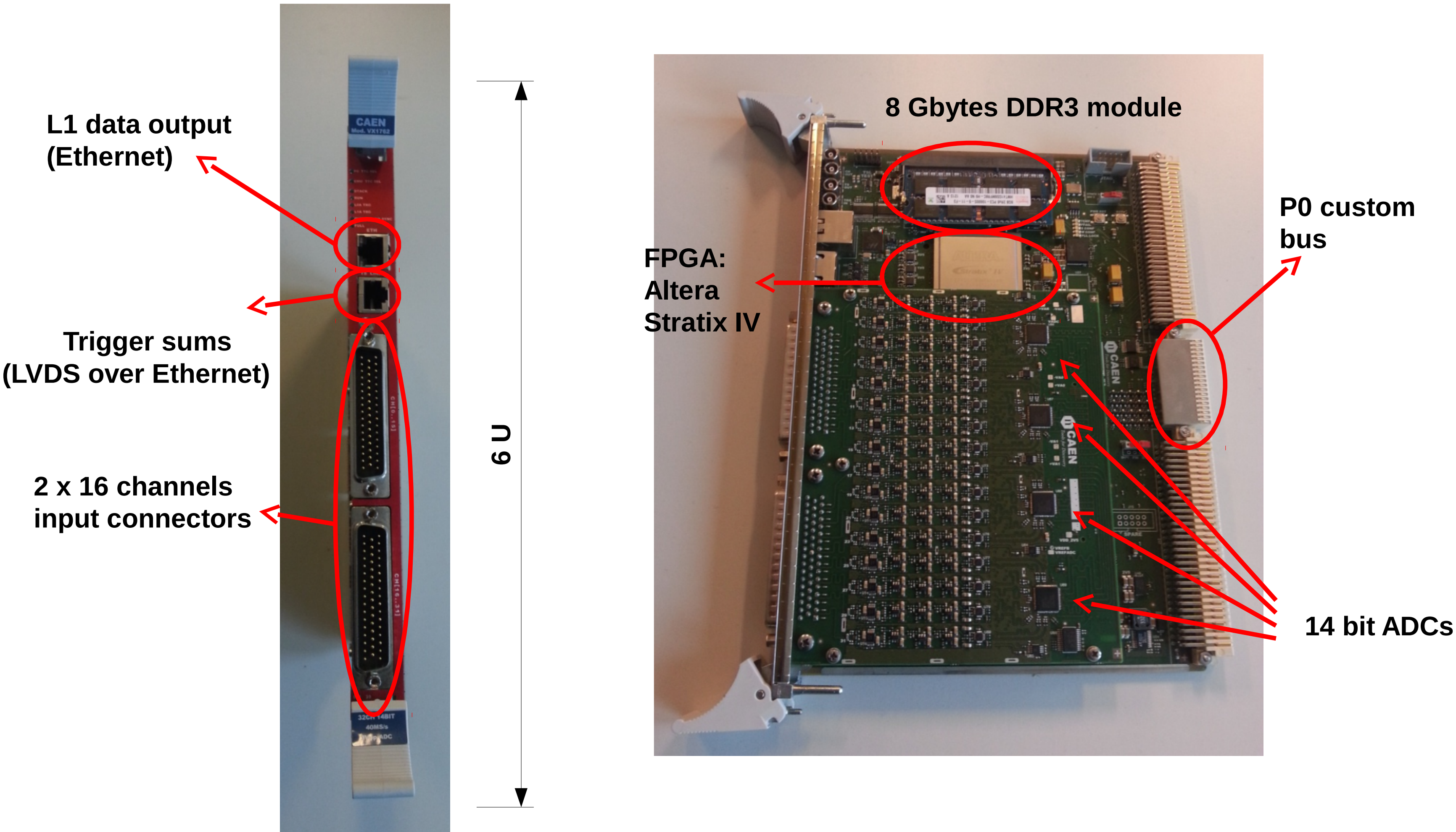
12 sub-detectors, ~ 80 000 channels, 25 GB/s raw data.

Calorimeter TDAQ

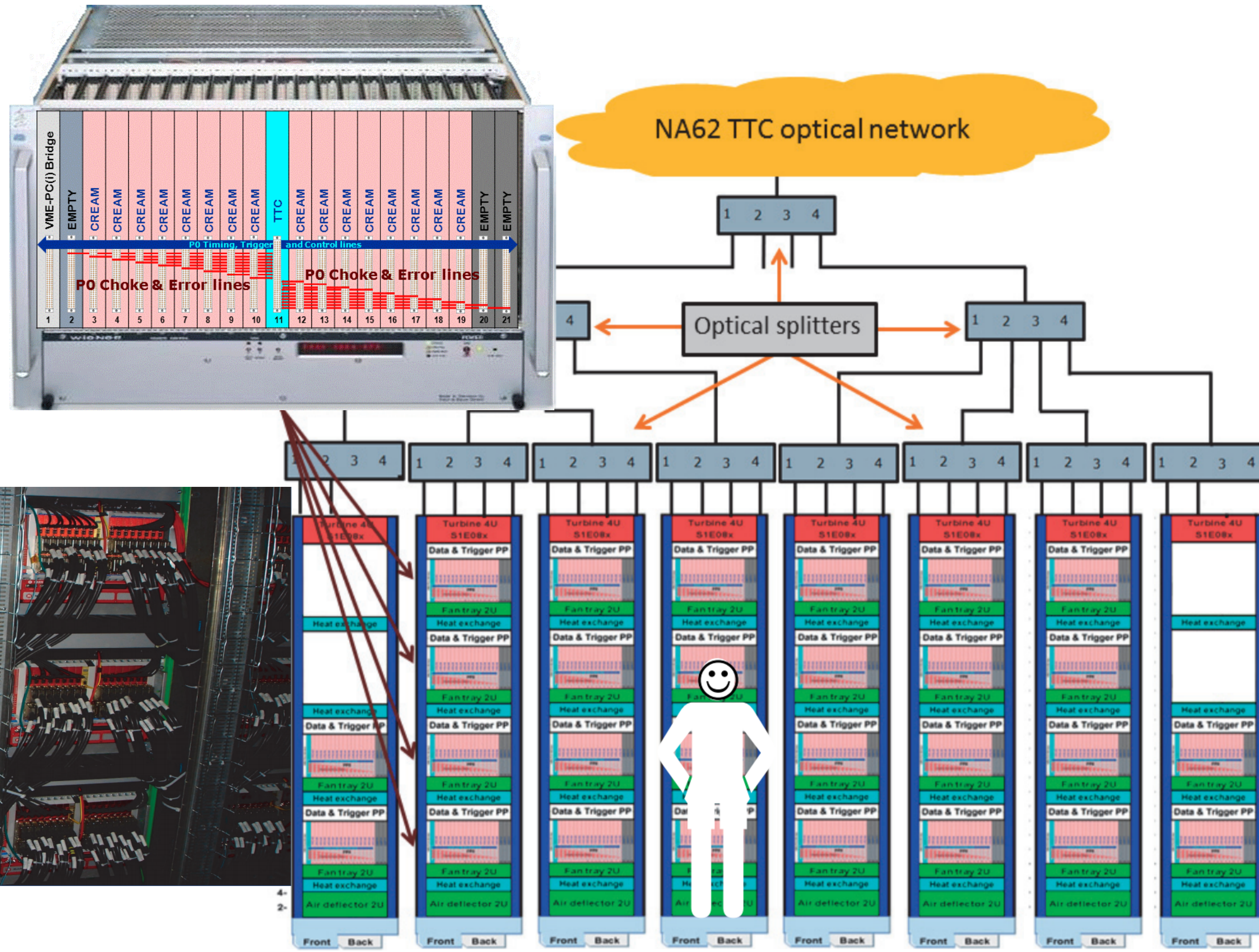


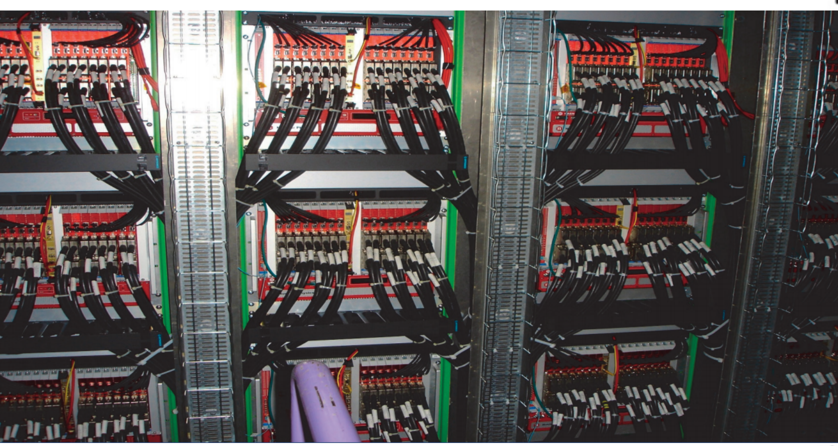
THE Calorimeter Readout Board (CREAM)

6U VME board developed by CAEN upon CERN specifications.

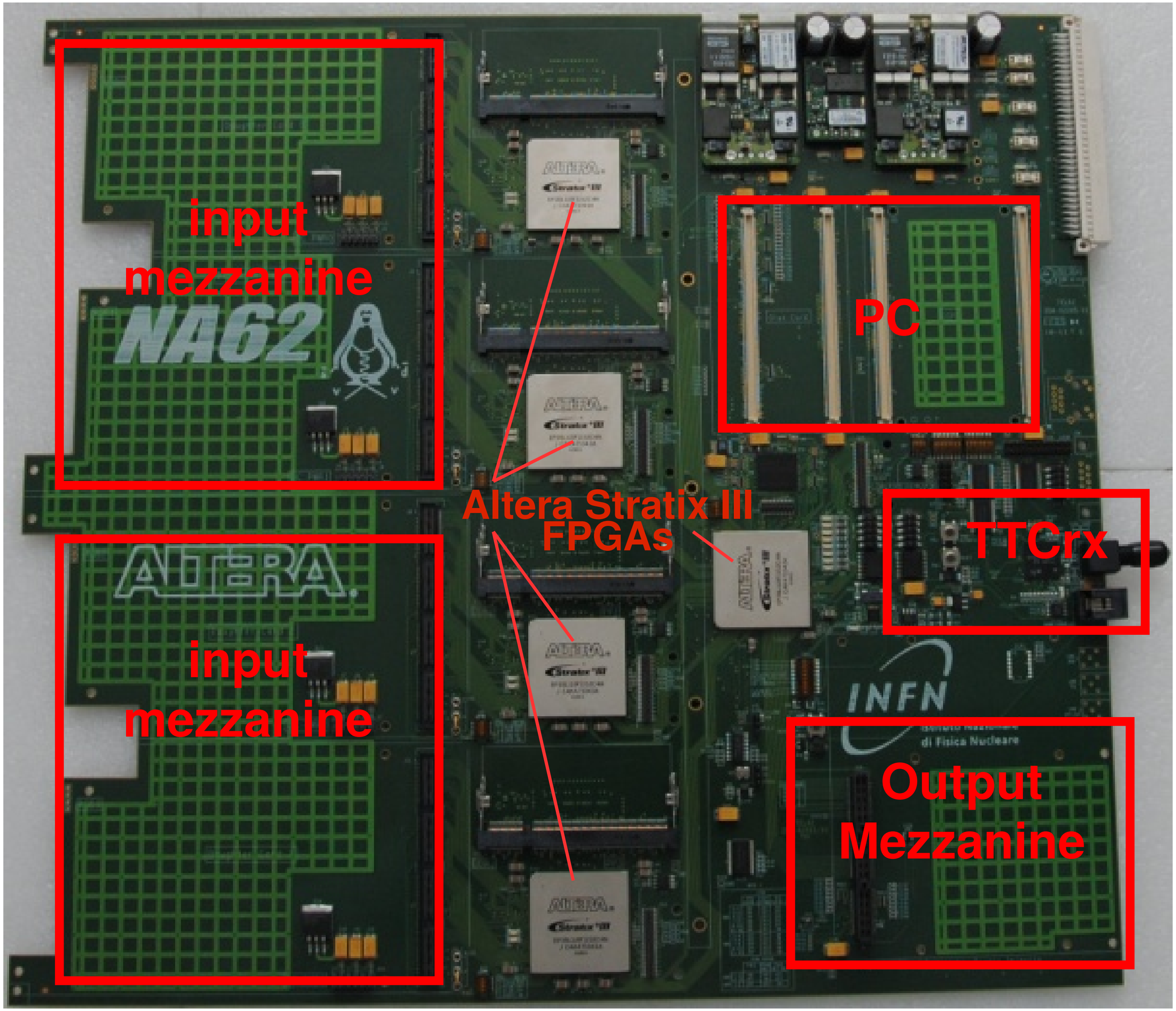


16 CREAMs per crate.
28 CREAM crates in 8 racks.
TTC-LKr board handles Timing, Trigger and Control.

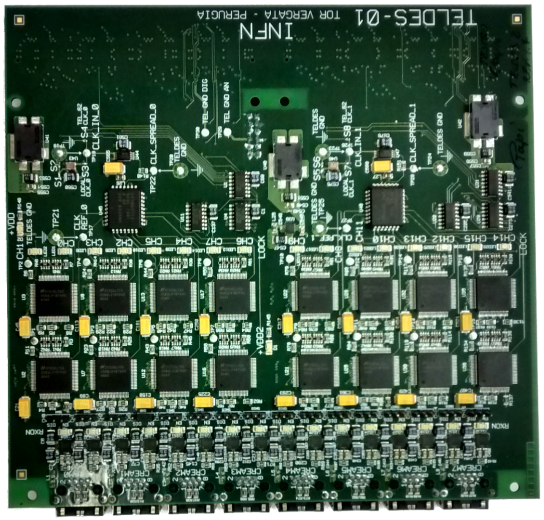




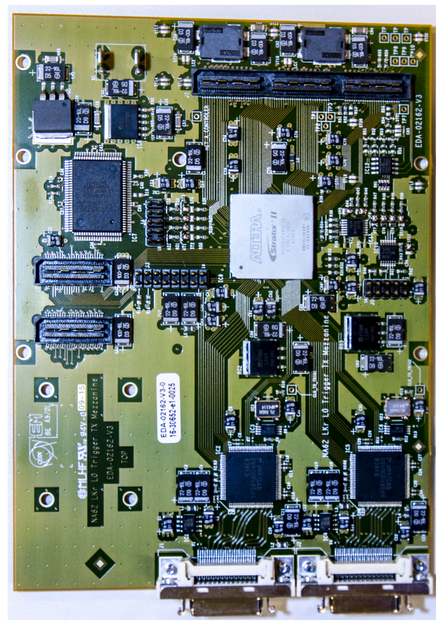
TEL62: the NA62 TDAQ motherboard



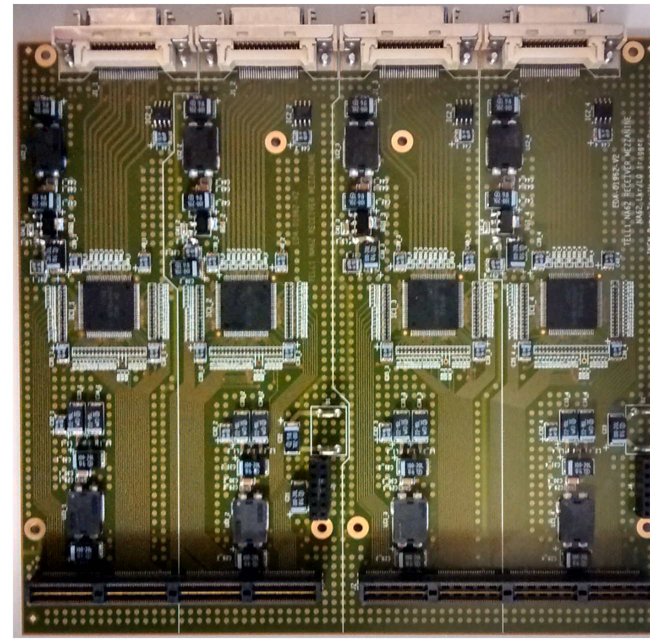
TEL62/L0Calo: I/O Mezzanines



TELDES
16 ch
(16 bit @ 40 MHz)
LVDS over
Ethernet

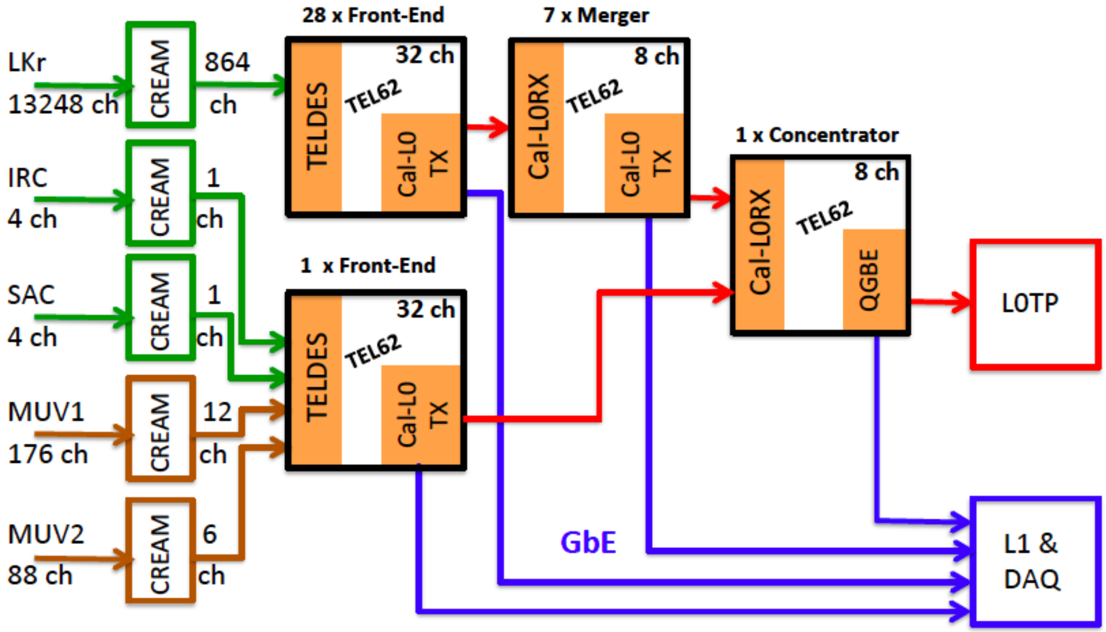


Internal TX board
2 ch
(48 bit @ 70 MHz)



Internal RX board
4 ch
(48 bit @ 70 MHz)

The NA62 Calorimeter L0 trigger

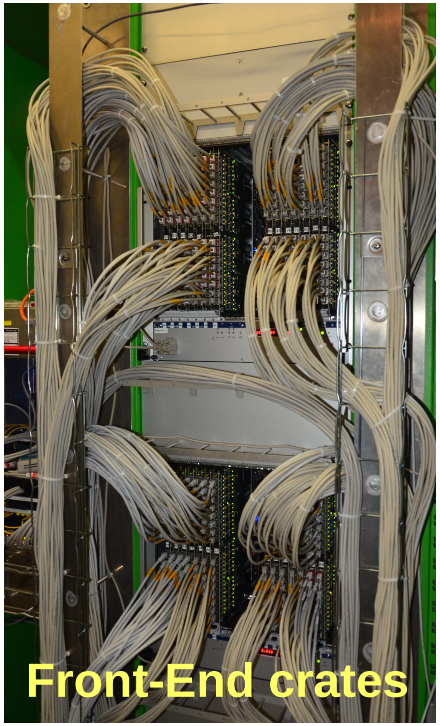


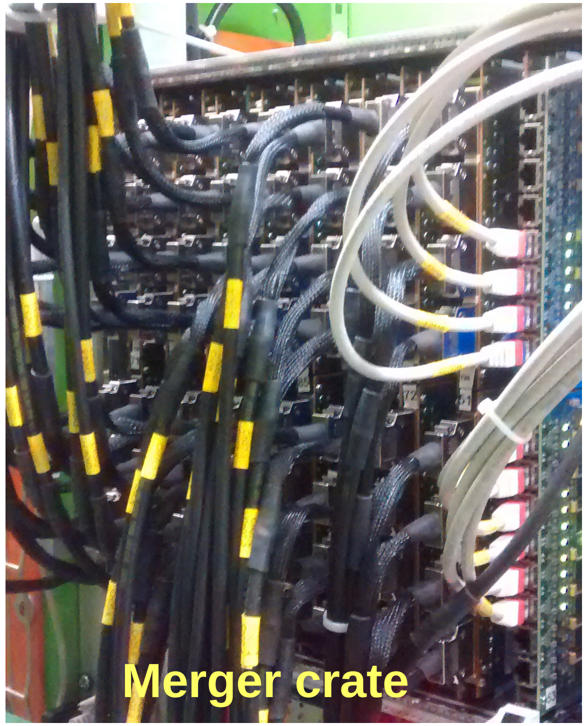
<u>3D trigger information</u>: time, position, energy of reconstructed clusters.

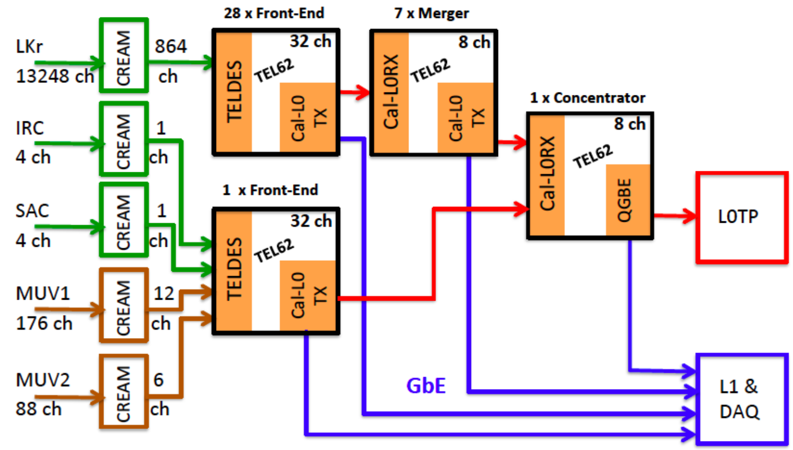
<u>Independent</u> from CREAMs readout.

Inst. hit rate: 30 MHz
Time resolution: 2.5 ns
Latency ~ 20 us

Calorimeter L0 trigger implementation

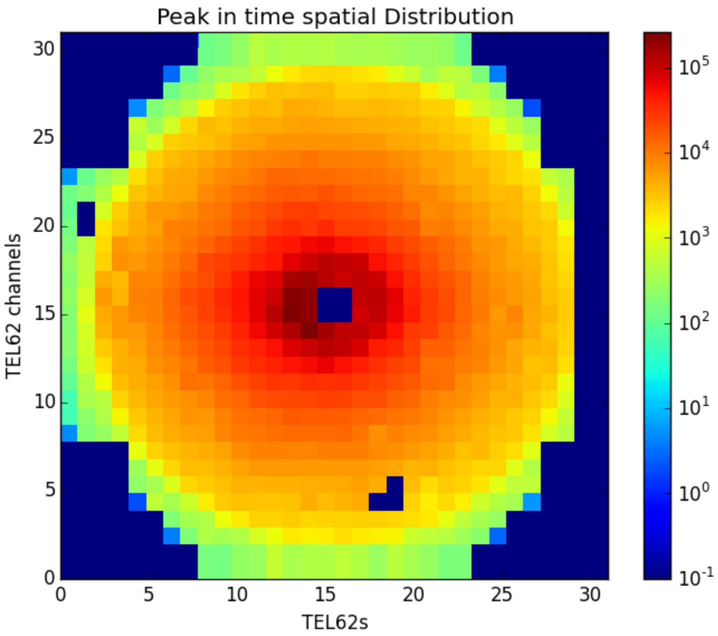


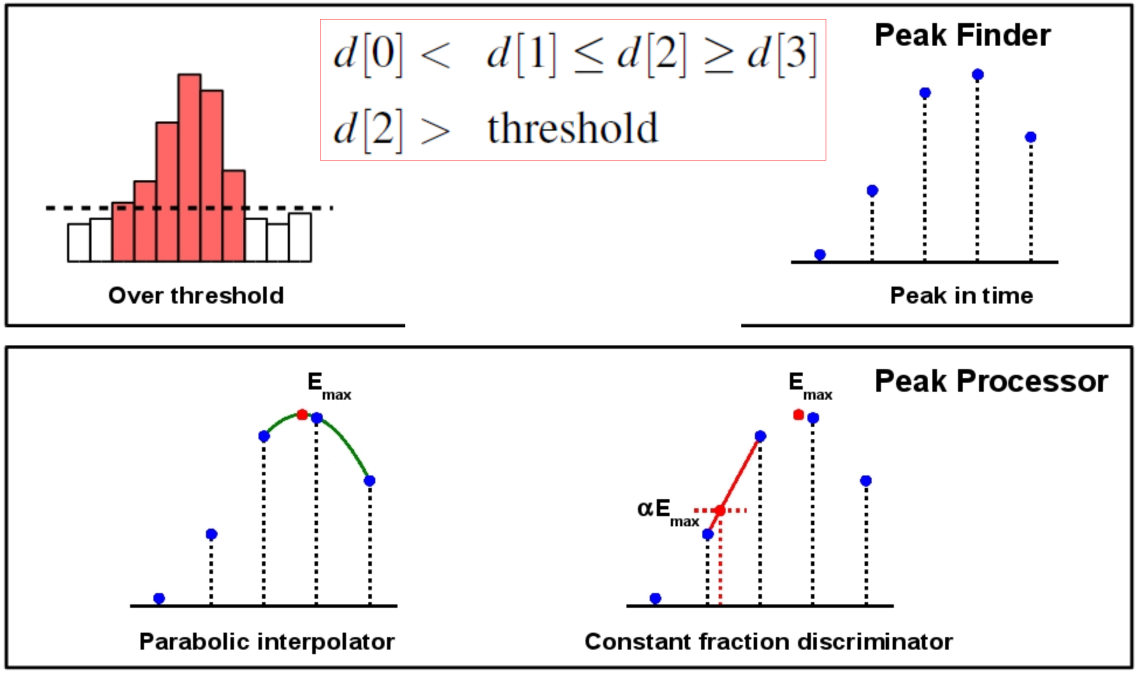




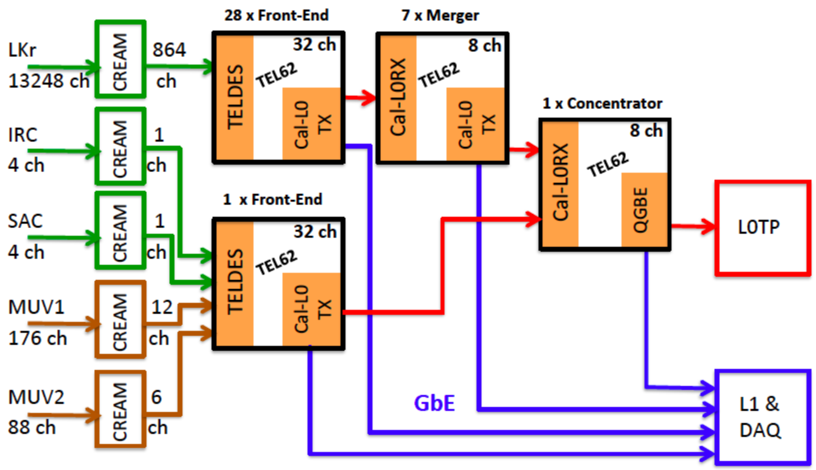
- 37 9U TEL62 electronics modules
- 111 dedicated mezzanines
- 884+20 input channels, 16 bit @ 40 MHz over Ethernet LVDS
- 1 trigger output channel (Gbit Ethernet) to the L0 Trigger Processor

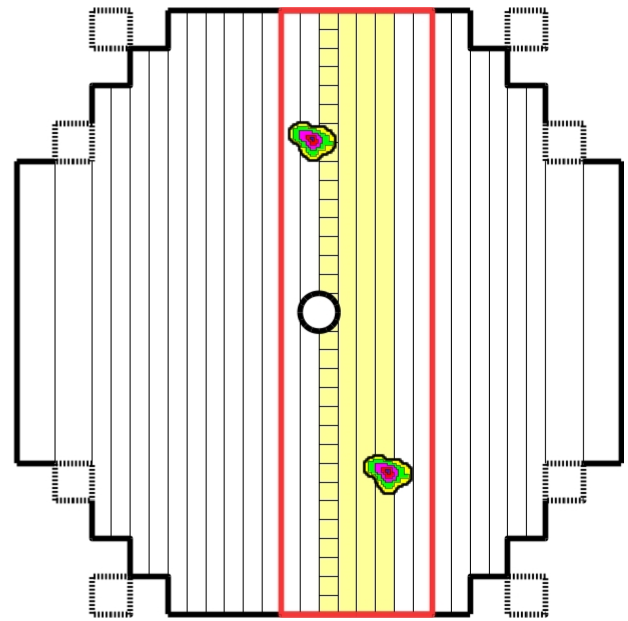
Peak reconstruction (parallel on all channels)





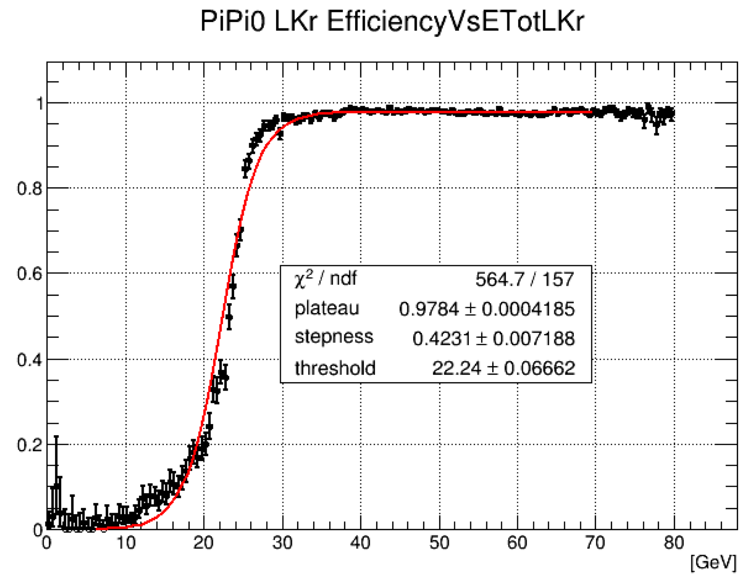
Liquid Kripton Calorimeter



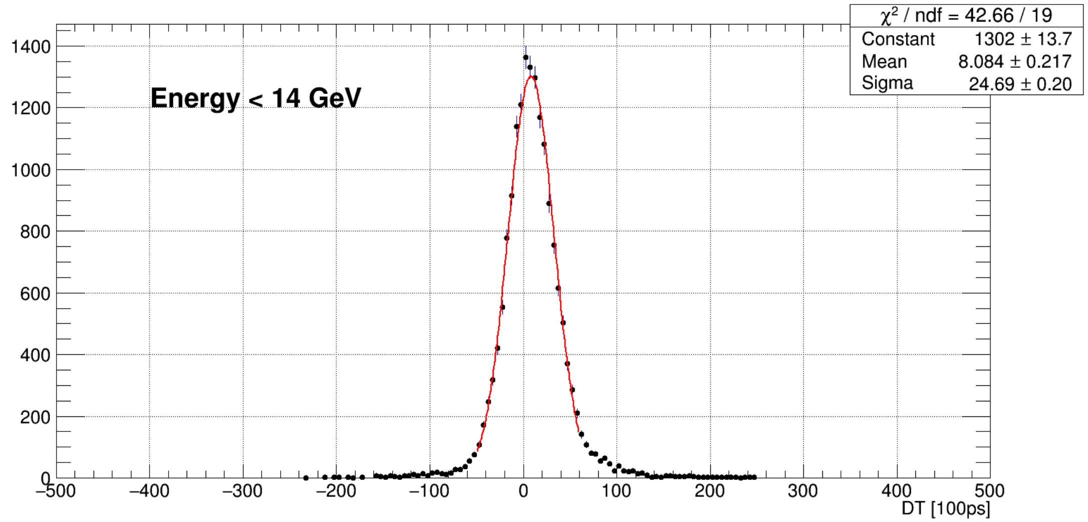


- 1 D + 1 D pixel based algorithm: LKr divided in slices parallel to the y axis.
- Front-End boards (28): peaks in space and time **indipendently** searched in each vertical slice: digital constand fraction discriminator + linear interpolator for fine timing.
- Merger boards (7): peaks close in space 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



Efficiency 98%
for Etot(LKr) > 20 GeV



σ = 2.5 ns

Conclusions

The NA62 calorimetric trigger and readout are performing as by specifications and taking data.

2016: Commissioning + Physics run (SM sensitivity)

2017-2018: Physics runs

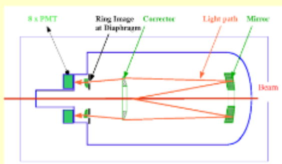
Radiation induced effects on the electronics are being observed and managed.

Thanks!

The NA62 detector

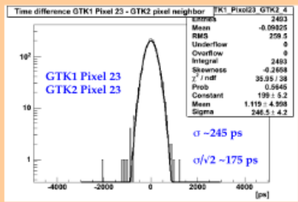
CEDAR

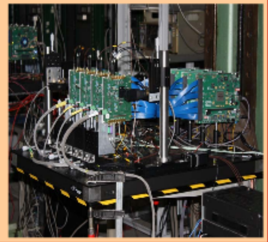
Gas differential Cerenkov counter (built for SPS beams) to tag beam kaon with $O(\sim100)$ ps time resolution



GTK 3 hybrid silicon pixel detector

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





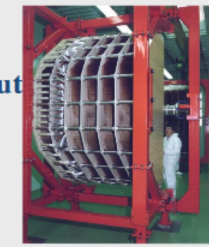
LAV Large Angle photon Vetos

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



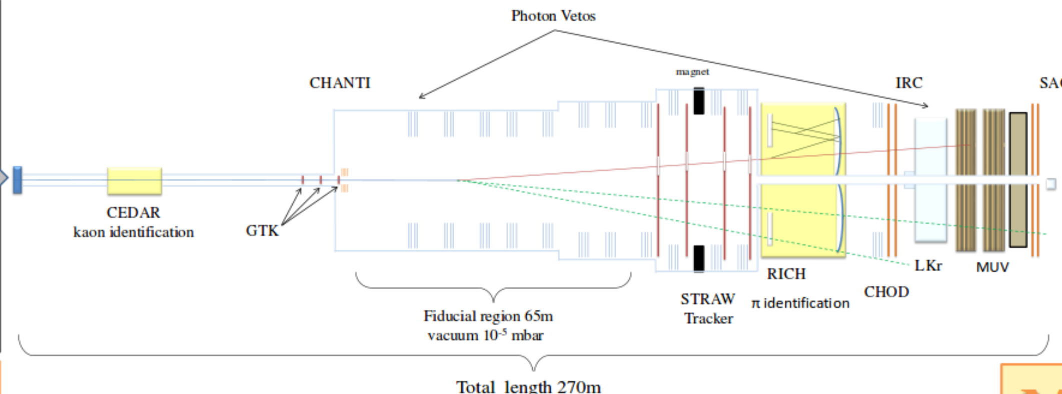
Beam

Primary SPS Beam:

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

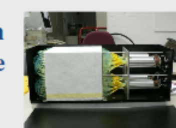
Secondary Beam: ~ 6% K^+

- p=75 GeV/c ($\Delta p/p\sim1\%$)
- beam acc.: 12.7 mstr
- total rate: 750 MHz
- 4.5×10^{12} K^+decays/year



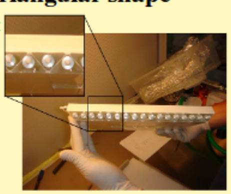
SAC/IRC

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

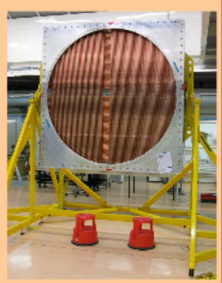


CHOD: scintillator hodoscope to

- trigger on single charged

STRAW

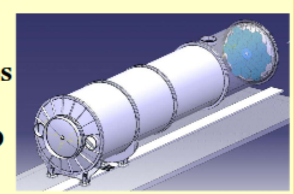
4 straw chambers (4 views each) operating in vacuum as tracker stations of the magnetic Spectrometer



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

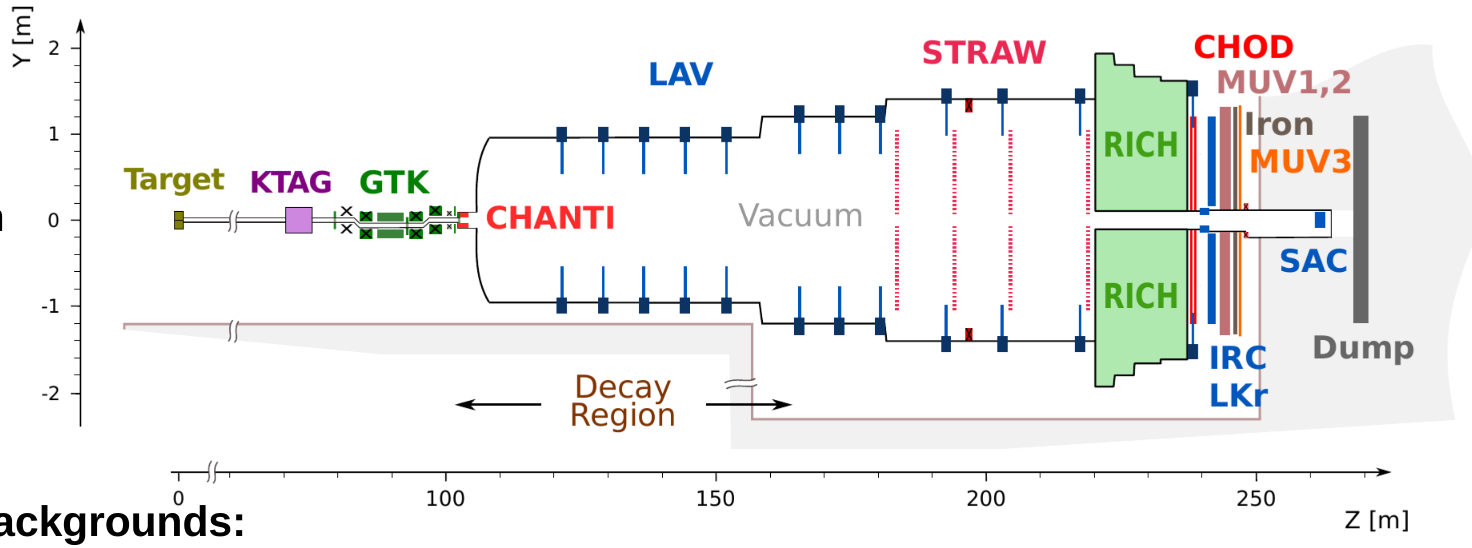
The NA62 experiment at CERN SPS

400 GeV/c
SPS protons

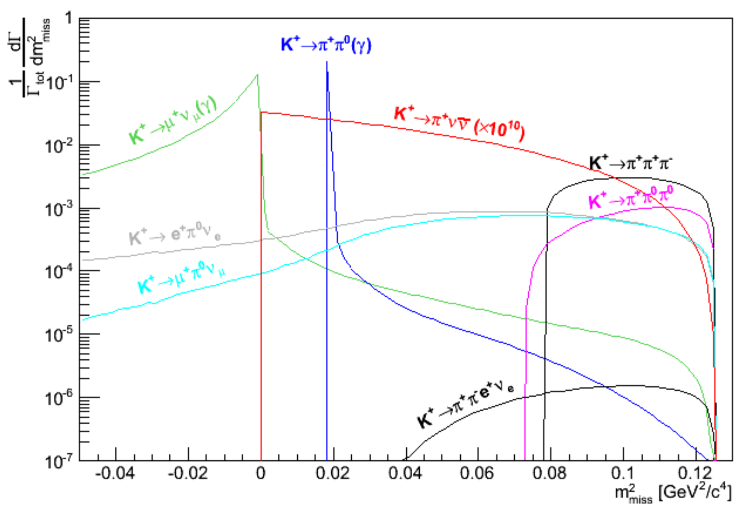
75 GeV/c
secondary beam

6% K^+

3.3 x 10^{12} ppp



Main backgrounds:
$K^+ \rightarrow \mu^+ \nu$ (~ 64 %)
$K^+ \rightarrow \pi^+ \pi^0$ (~ 21 %)



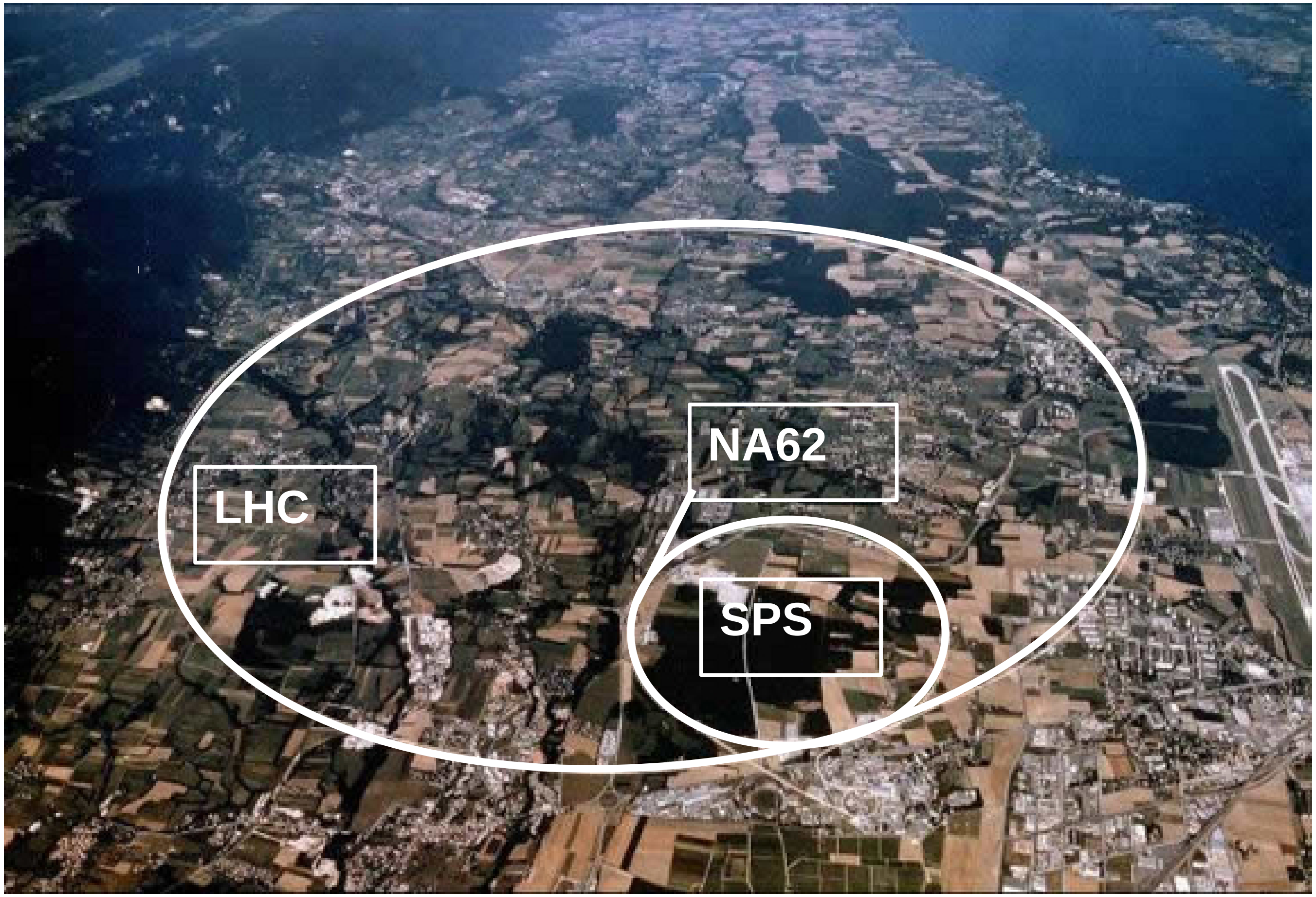
In flight kaon decay technique:

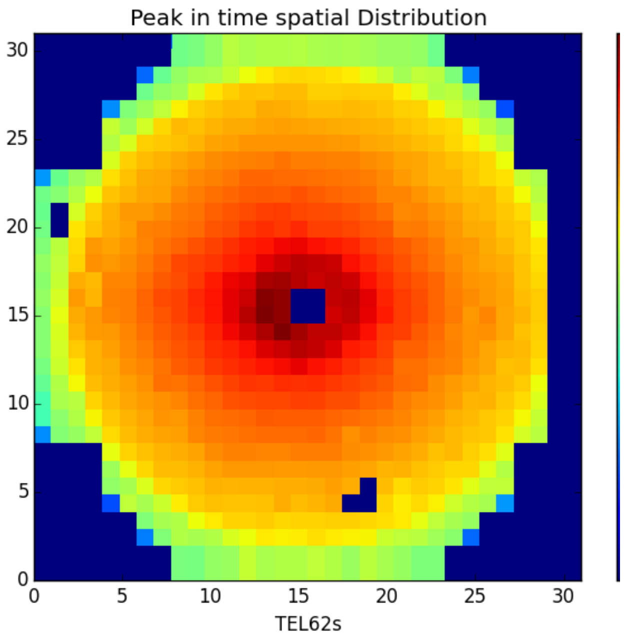
K tagging (CEDAR)

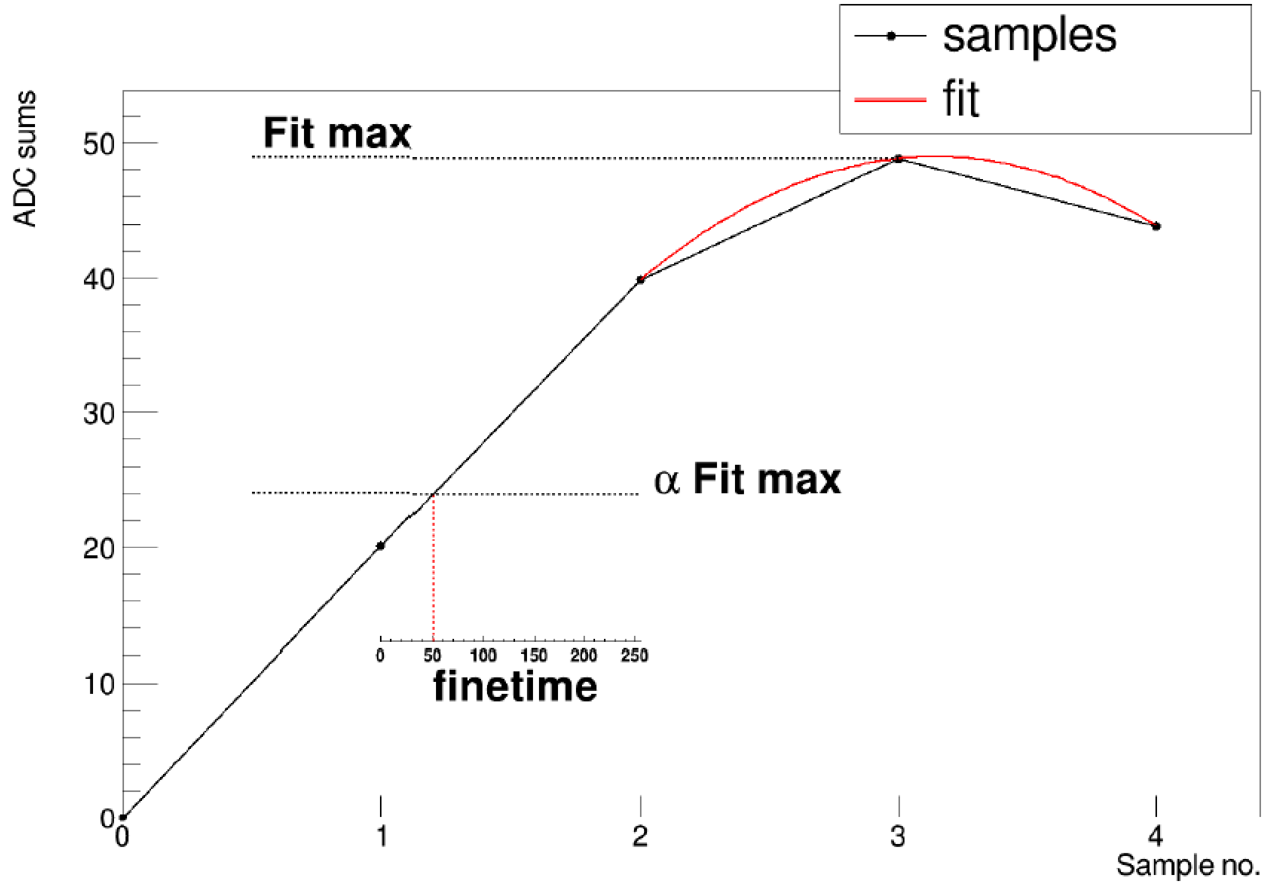
Cinematic rejection: K^+ momentum (GTK) and π^+ momentum (STRAW)

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 experiment at CERN SPS







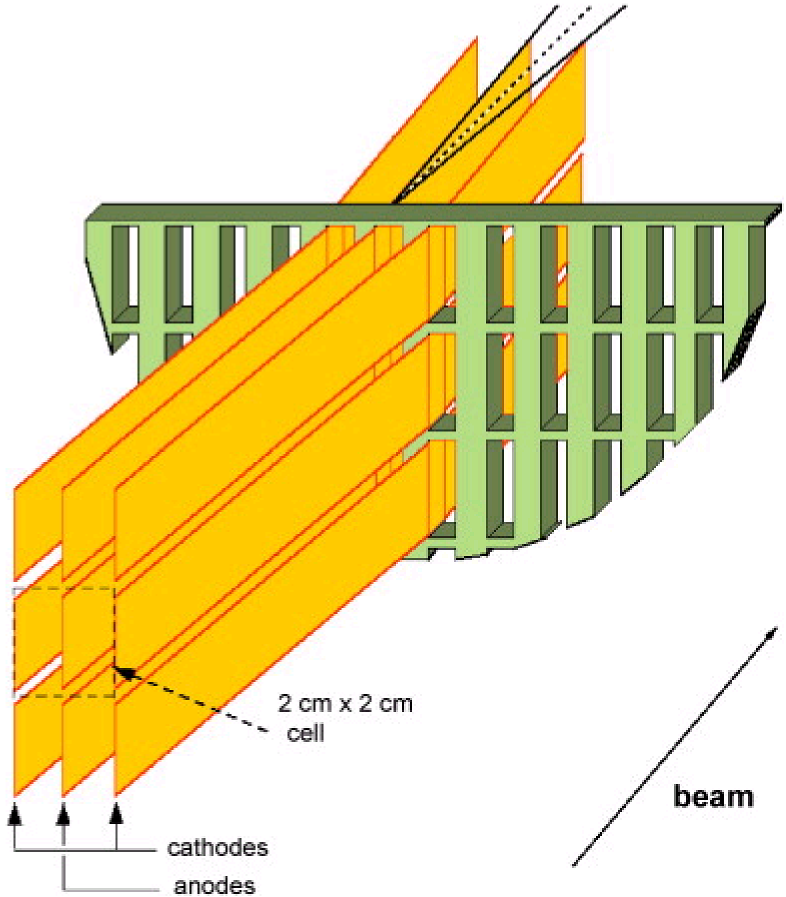
$$d[0] < \quad d[1] \leq d[2] \geq d[3]$$

$$d[2] > \quad \text{threshold}$$

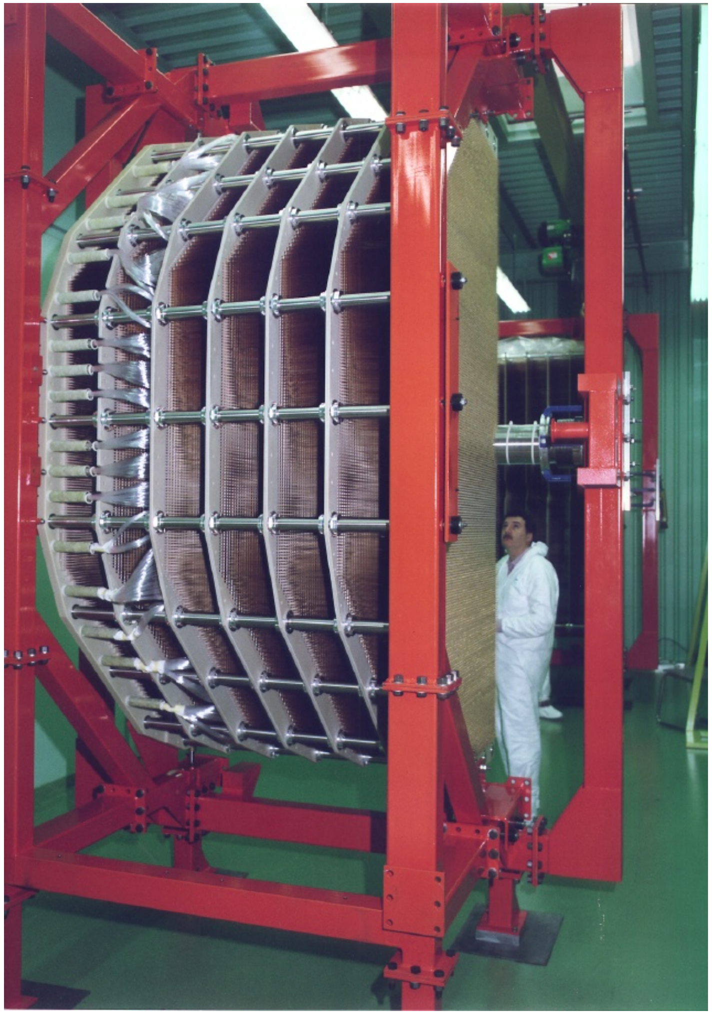
The NA48 Liquid Krypton electromagnetic calorimeter

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

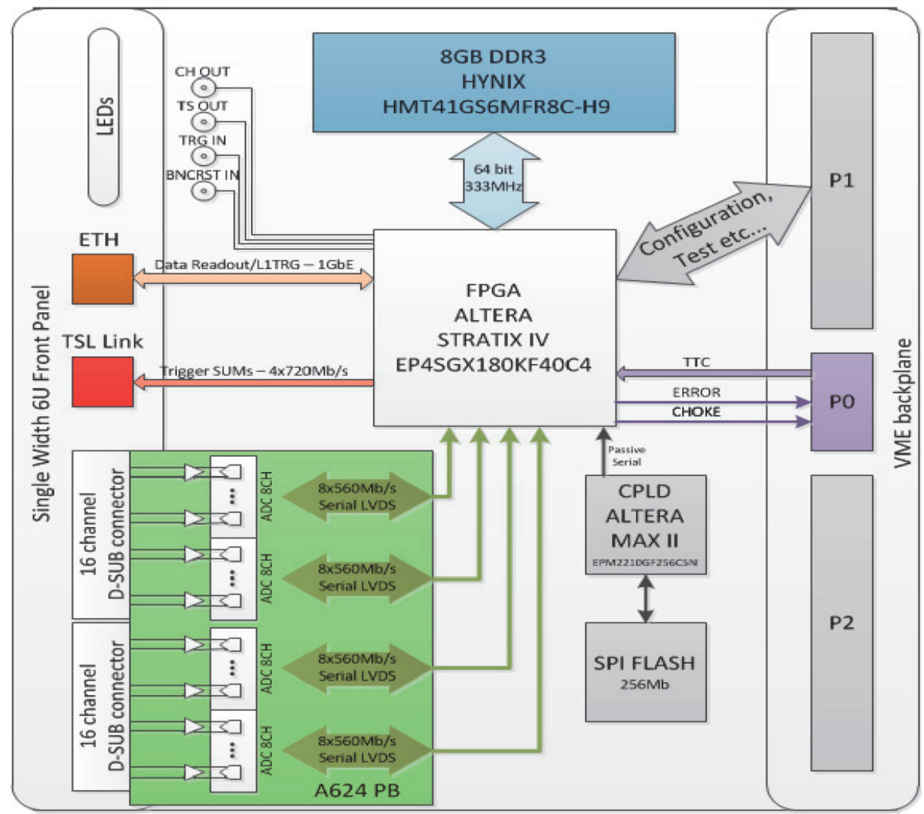
Photon veto in the angular decay region 1-8.5 mrad

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

Inefficiency < 10^{-5} for E_γ > 10 GeV

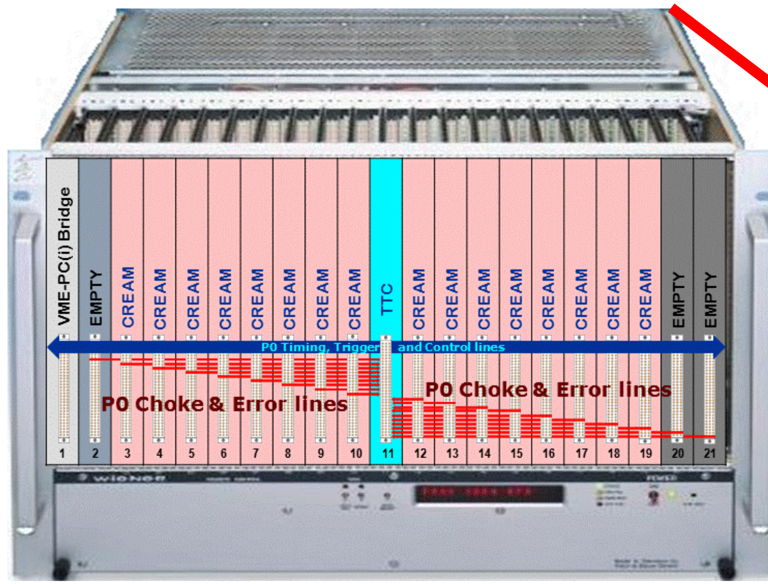
THE CREAM BOARD FUNCTIONS

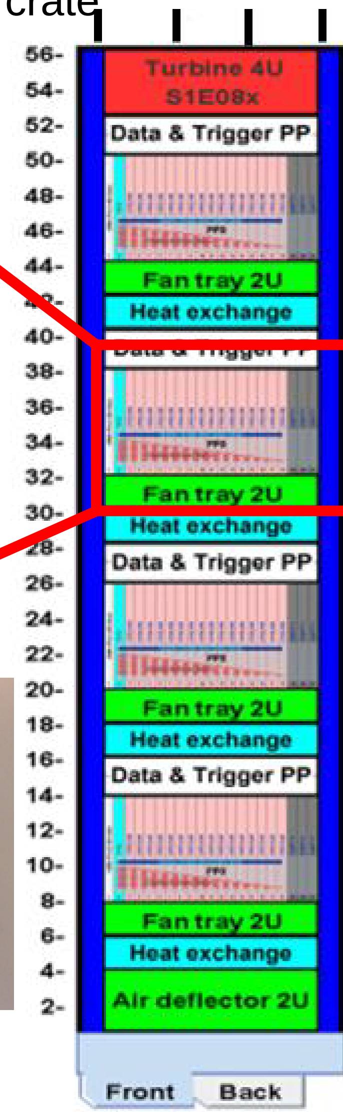
- **INPUT SIGNAL SHAPING**: the 2.7 μs long triangular signal from LKr channels is shaped into a 70 ns FWHM pseudo-Gaussian signal
- **DIGITISATION**: shaped signals are digitised @ 40 MHz by octal 14 bit ADCs and copied in a circular buffer
- **FIRST TRIGGER LEVEL (L0T):** upon reception of the L0T signal through the custom P0 VME backplane, data is moved from the circular buffer to the L0 buffer
- **SECOND TRIGGER LEVEL (L1T):** when a L1T signal is received through a Multiple request UDP packet (MRP) data is sent to the PC farm
- **TRIGGER SUM LINKS**: the sums of the digitised samples from two groups of 16 channels each are serialized inside the FPGA and sent to the LKr L0 processor



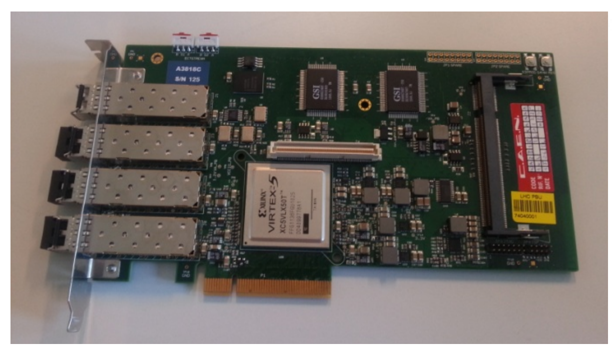
CREAM CRATE ORGANIZATION

- 16 CREAMs will be housed in a VME crate
- 28 CREAM crates, organised in 8 racks, will readout the whole calorimeter
- The TTC-LKr board is placed in the 11th slot of each crate

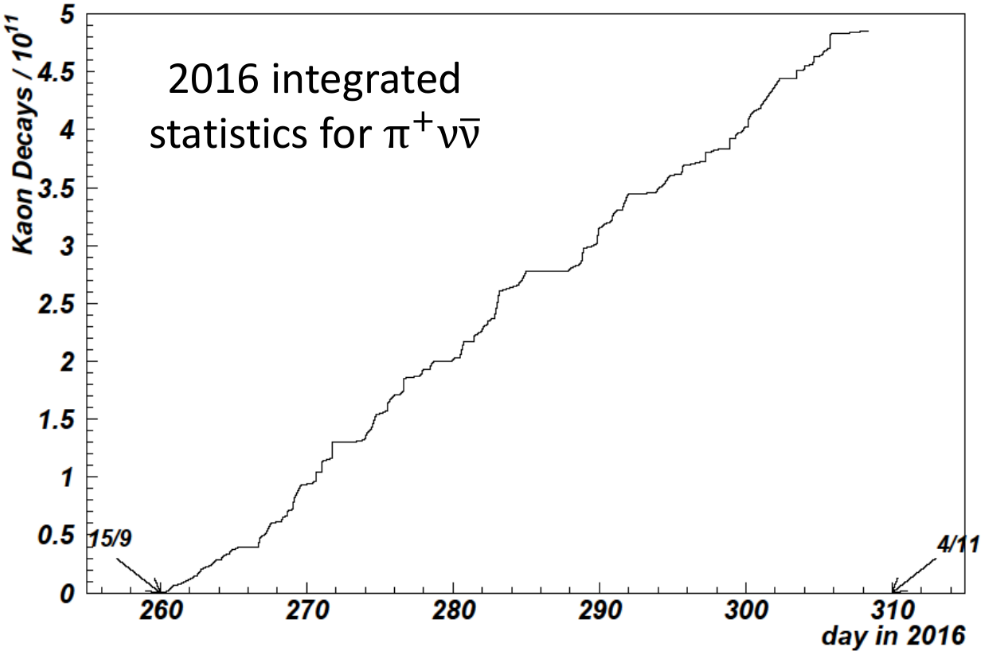




SLOW CONTROL: up to 8 bridges (CAEN VX2718) daisy chained, four links controlled by a single A3818 PCIe card



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