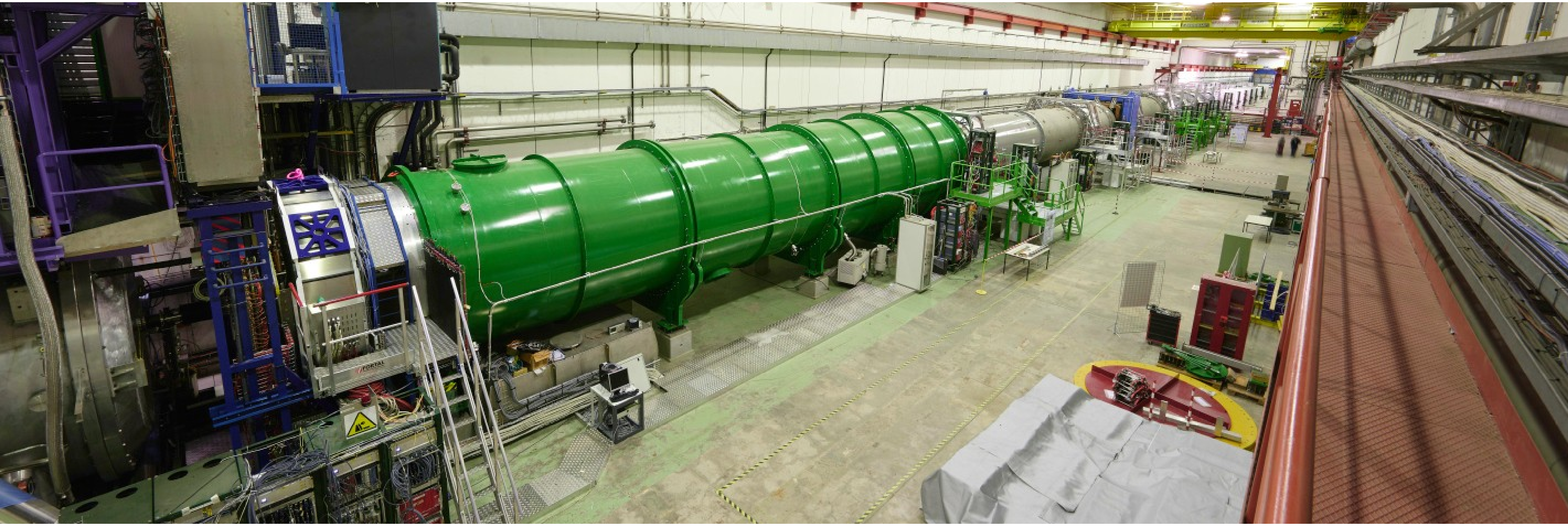
Triggers for Particle Physics

[Lecture 3] NA62: a non-LHC experiment



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MPAGS lectures

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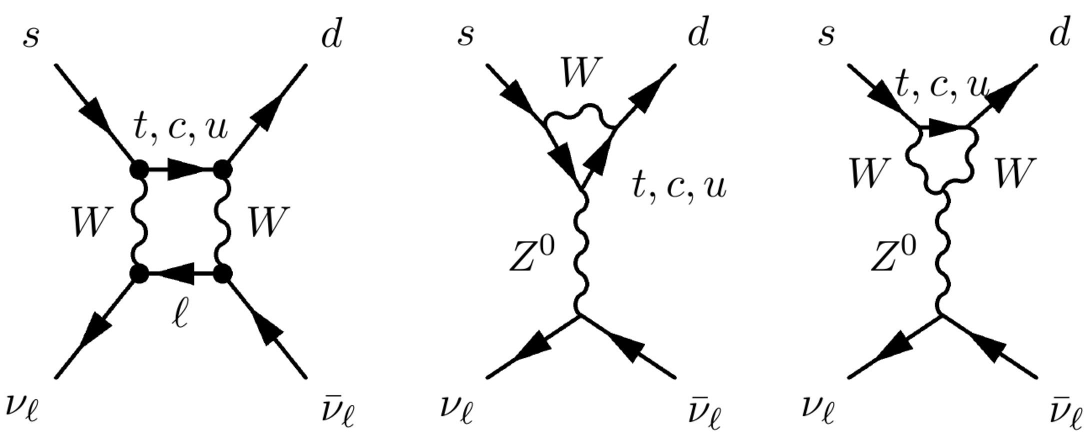
Why are we talking about NA62?

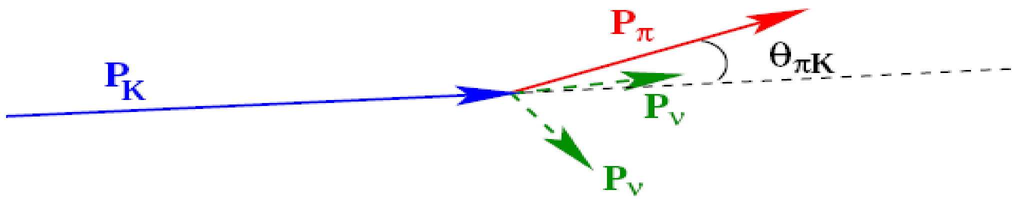
- **NA62 main physics goal:**
  measure the BR of the ultra-rare decay $K^+ \rightarrow \pi^+ \nu\nu$
  - Very clean theoretically, very sensitive to new physics
  - The Standard model expectation is **$BR(K^+ \rightarrow \pi^+ \nu\nu) = (8.4 \pm 1.0) \times 10^{-11}$**



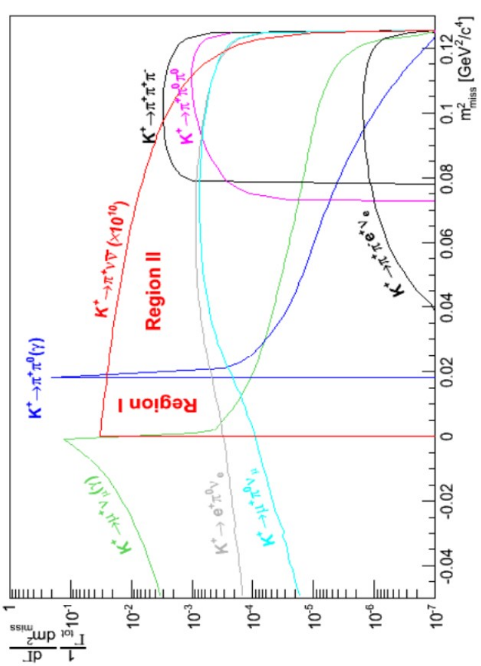
- **Trigger challenges:**
  - Needs high intensity kaon beam → very high rate wrt LHC
  - Huge background (~ 11 orders of magnitude higher than signal) to be rejected
  - Weak $K^+ \rightarrow \pi^+ \nu\nu$ signature: difficult to trigger on signal

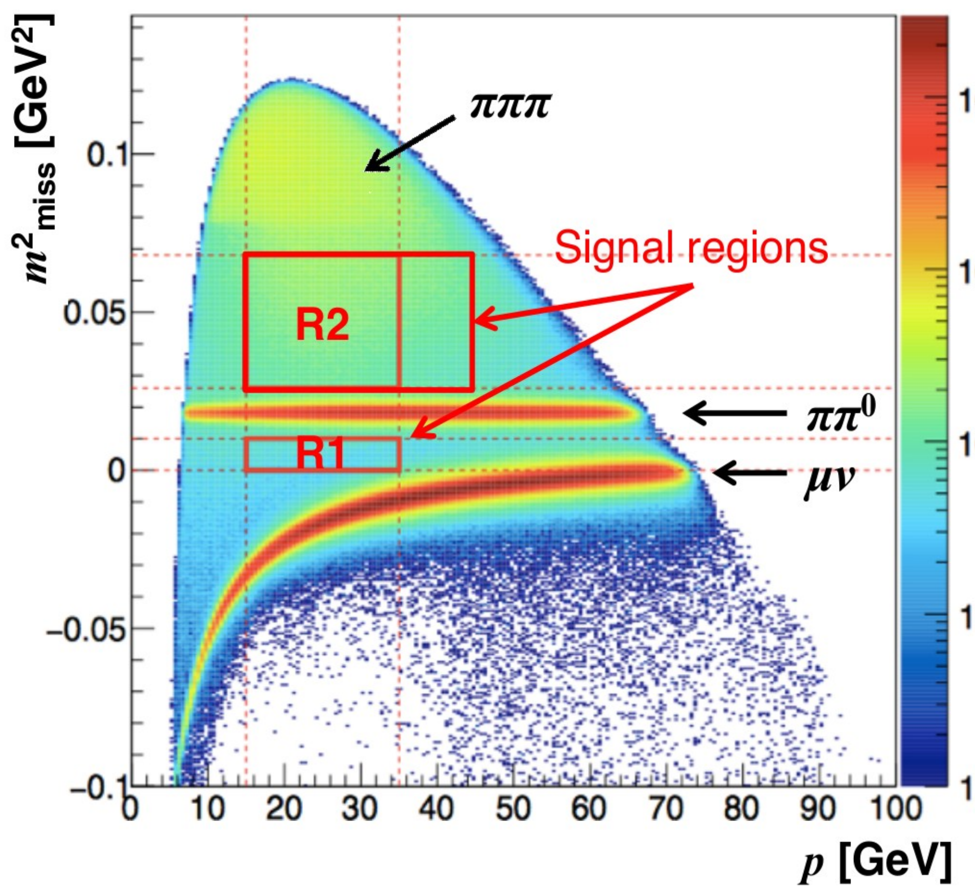
$K^+ \to \pi^+ \nu\bar{\nu}$ at NA62: strategy

$K^+ \to \pi^+ \nu\bar{\nu}$ signature:
Kaon track +
Pion track +
NOTHING ELSE



$$m^2_{miss} \approx m^2_K \left(1 - \frac{|p_\pi|}{|p_K|}\right) + m^2_\pi \left(1 - \frac{|p_K|}{|p_\pi|}\right) - |p_K||p_\pi|\theta^2_{\pi K}$$



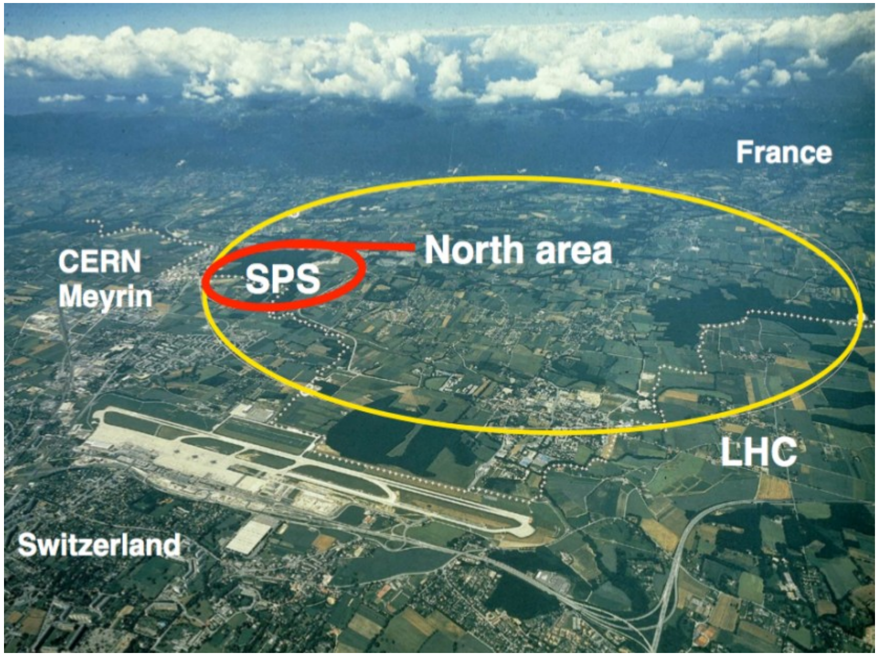


Main backgrounds:
$BR(K^+ \to \mu^+\nu) = 63.5\%$
$BR(K^+ \to \pi^+\pi^0) = 20.7\%$

NA62 Keystones:
- Precise tracking
- Photon rejection
- PID (in particular π/μ)
- Precise timing: O(100 ps)

Background rejection at ~ 10^{11} level

NA62: a fixed target experiment



Decay-in-flight technique

High energy kaons → Easier to veto additional particles (e.g. γ from $\pi^0 \rightarrow \gamma\gamma$, $\pi^\pm$ from $K^+ \rightarrow \pi^+\pi^+\pi^-$)

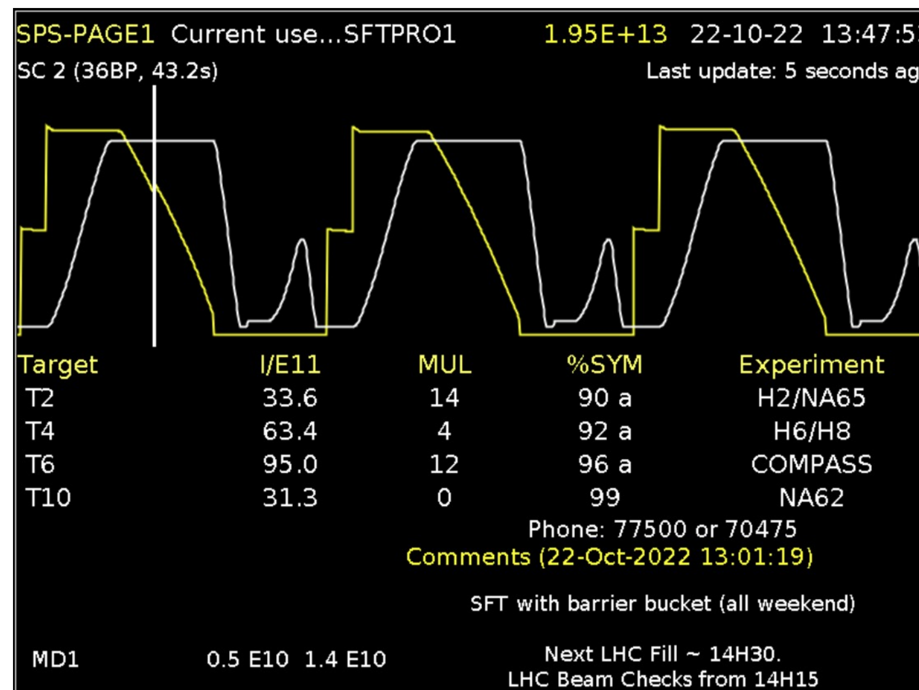
Fixed target experiment at CERN SPS

Secondary 75 GeV/c hadron beam (6% kaons) produced by 400 GeV/c primary SPS protons impinging on a Beryllium target

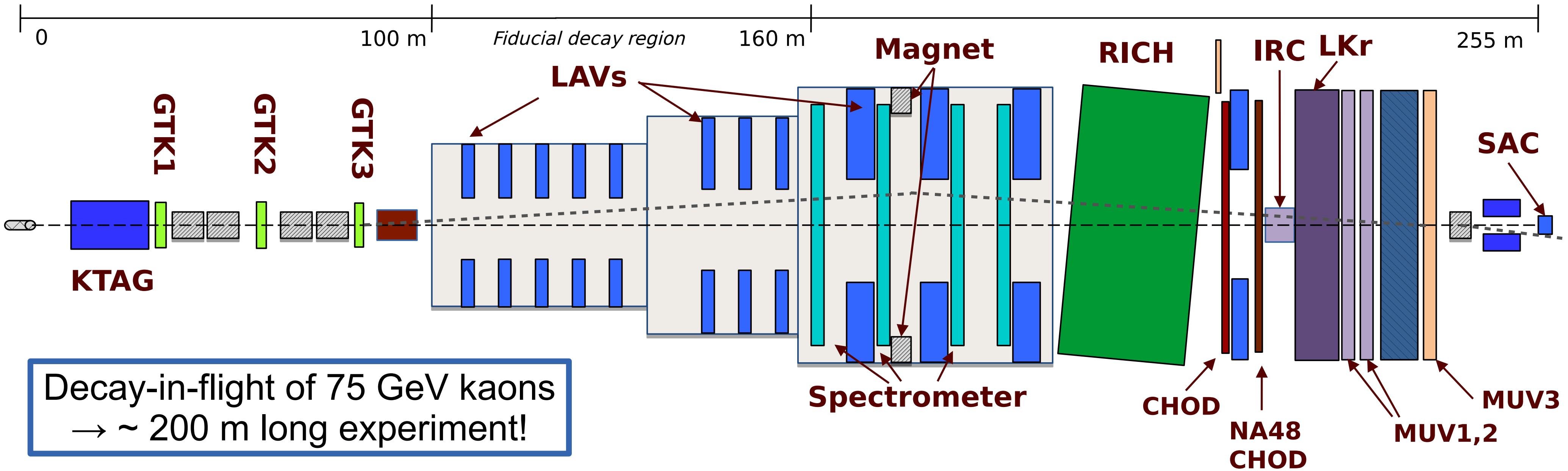
Very different environment wrt LHC:

- Continuous beam from SPS, bunched in spills of 4.8s
- Asynchronous trigger: no bunch crossing!
- High-intensity hadron beam (~ 750 MHz!)

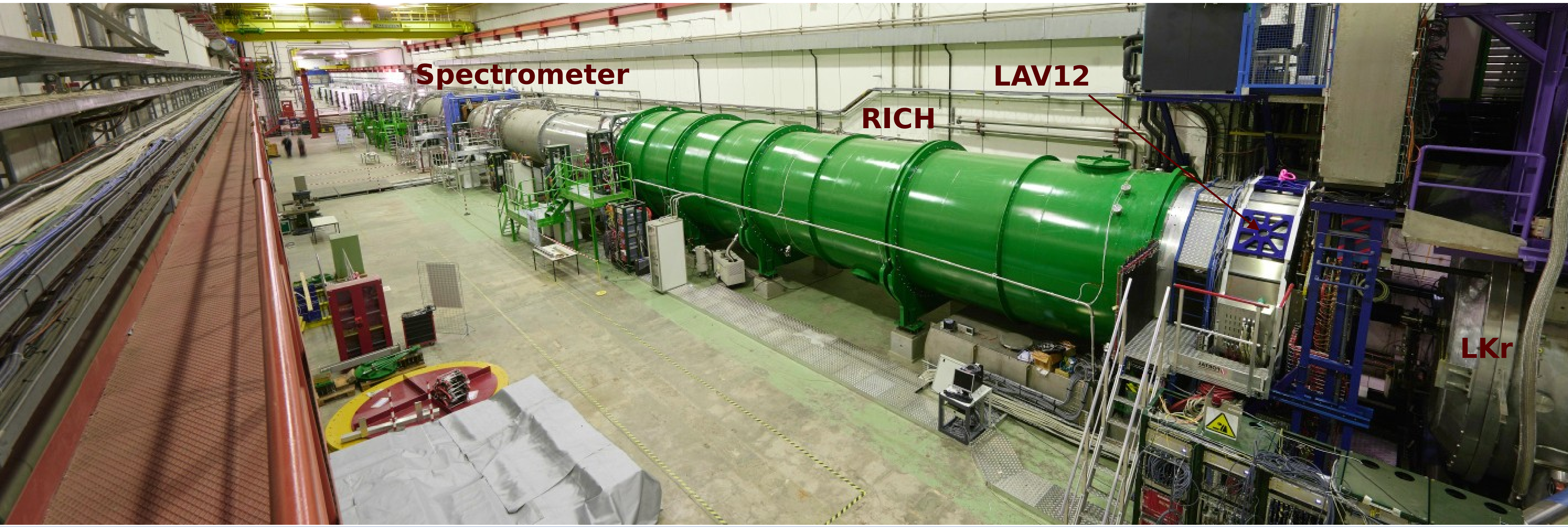
→ excellent time resolution (<1ns) needed at trigger level!



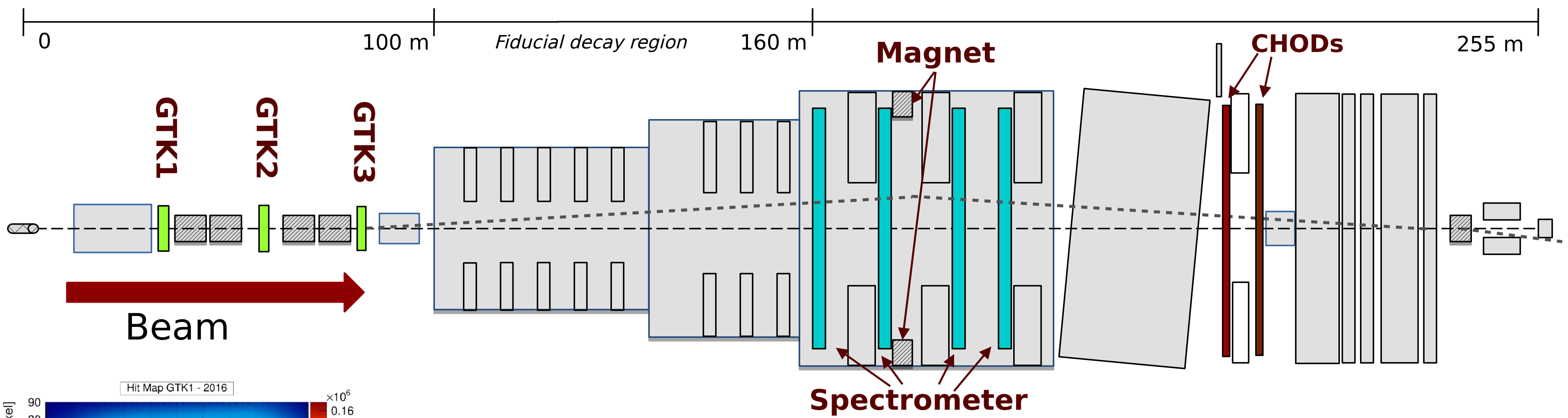
The NA62 experiment

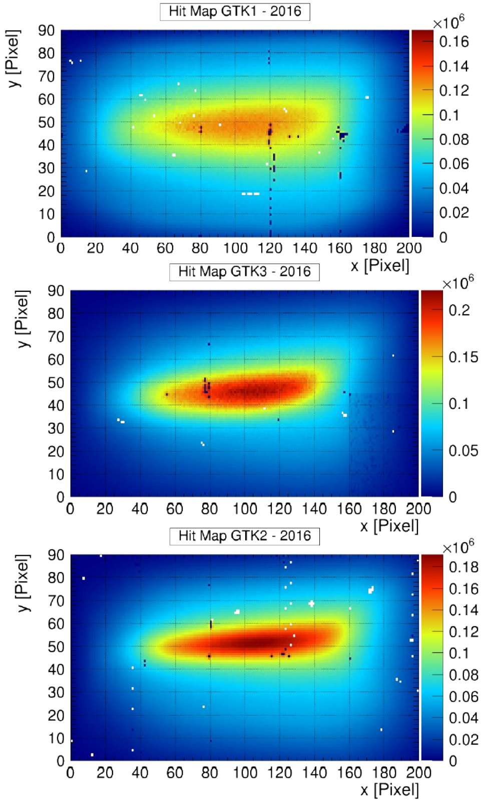


Decay-in-flight of 75 GeV kaons
→ ~ 200 m long experiment!



The NA62 experiment – Precise tracking





Beam Spectrometer (GigaTracker - GTK):

- 3 stations of Silicon pixel detectors inside an achromat;
- Time : σ ≈ 130 ps per station;

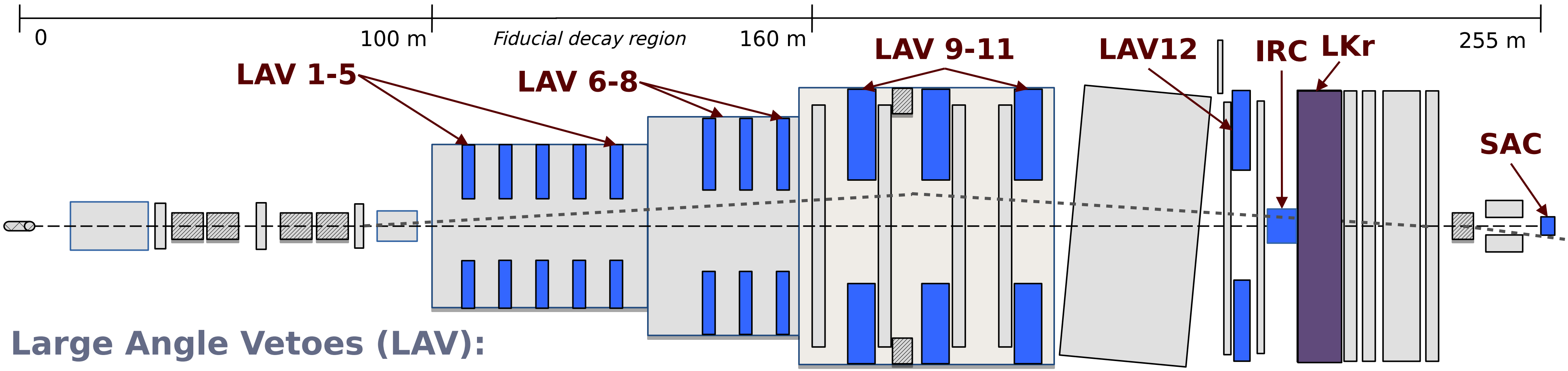
Direction: $\sigma_{dx,dy} \approx 0.016$ mrad
Momentum: $\Delta P/P < 0.4\%$;

Straw Spectrometer:

- 4 straw chambers in vacuum;
- Each chamber measuring 4 coordinates (views);
- High accuracy: 130 μm/view;
- Straws participate to level-1 trigger selection.

STRAW4 installation

The NA62 experiment – Photon rejection

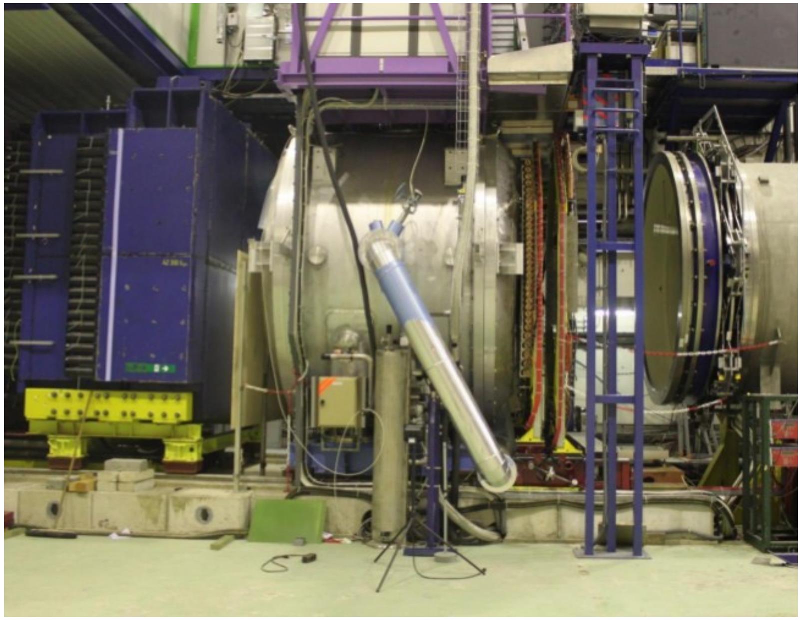


Large Angle Vetoes (LAV):

- 12 stations along the vacuum tank
- Coverage: 8.5 – 50 mrad

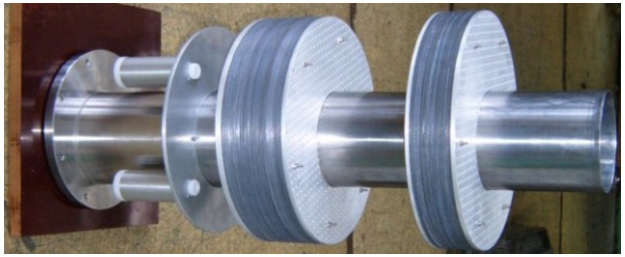
Liquid Krypton Calorimeter (LKr):

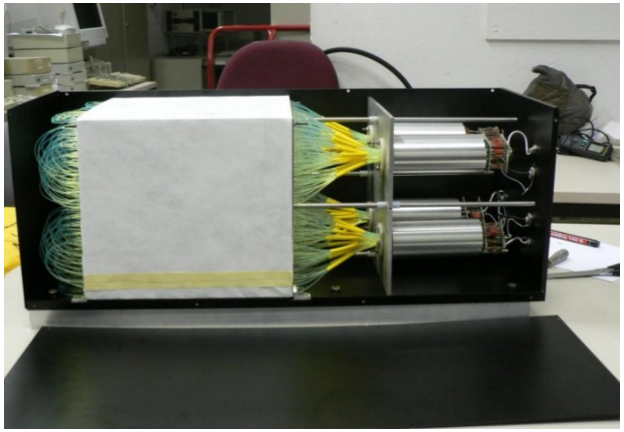
- Electromagnetic calorimeter
- Coverage: 1 – 8.5 mrad



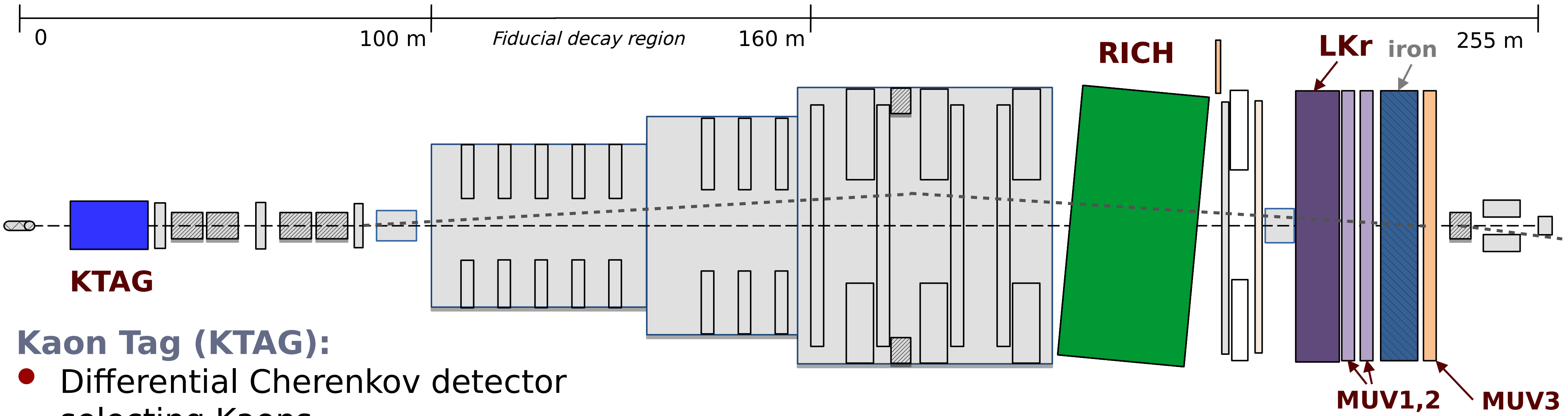
Small Angle Vetoes (SAV):

Coverage: <1 mrad





The NA62 experiment – Particle ID

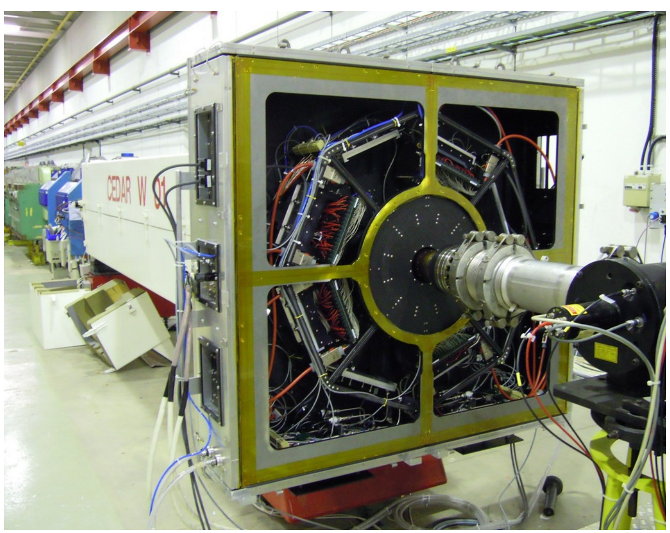


Kaon Tag (KTAG):
- Differential Cherenkov detector selecting Kaons
- ~80 ps time precision

RICH:
- Cherenkov detector filled with Neon
- 70 ps of time resolution

Hadronic Calorimeters MUV1/MUV2:
- Readout with LKr electronics

MUV3: Muon Veto
- Placed after an iron wall
- Rate: > 10 MHz muons.



NA62 Trigger & Data acquisition system

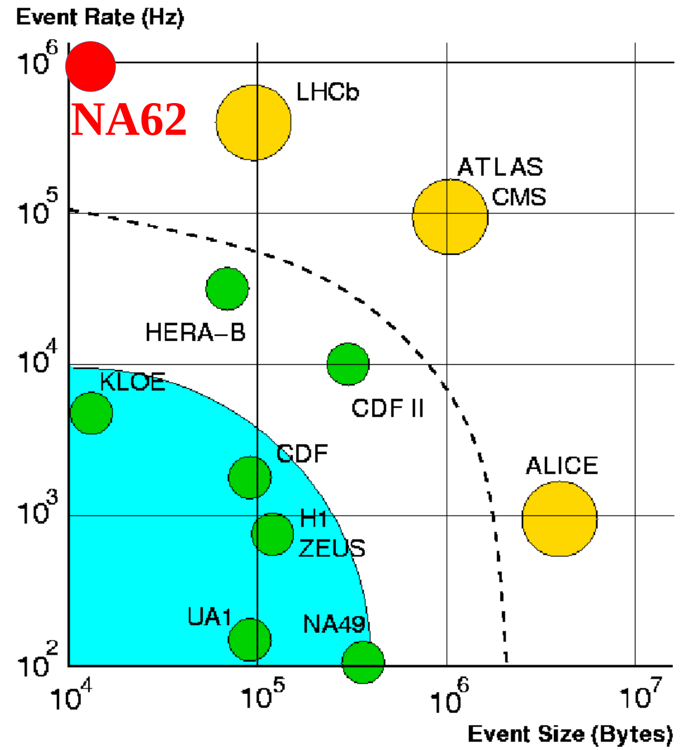
NA62 Trigger and Data Acquisition (TDAQ) system

NA62: extreme rate environment
Trigger rate higher than Hi-Lumi ATLAS/CMS!

<u>2 trigger levels:</u>

– **Hardware (L0)**, based on custom programmable electronics

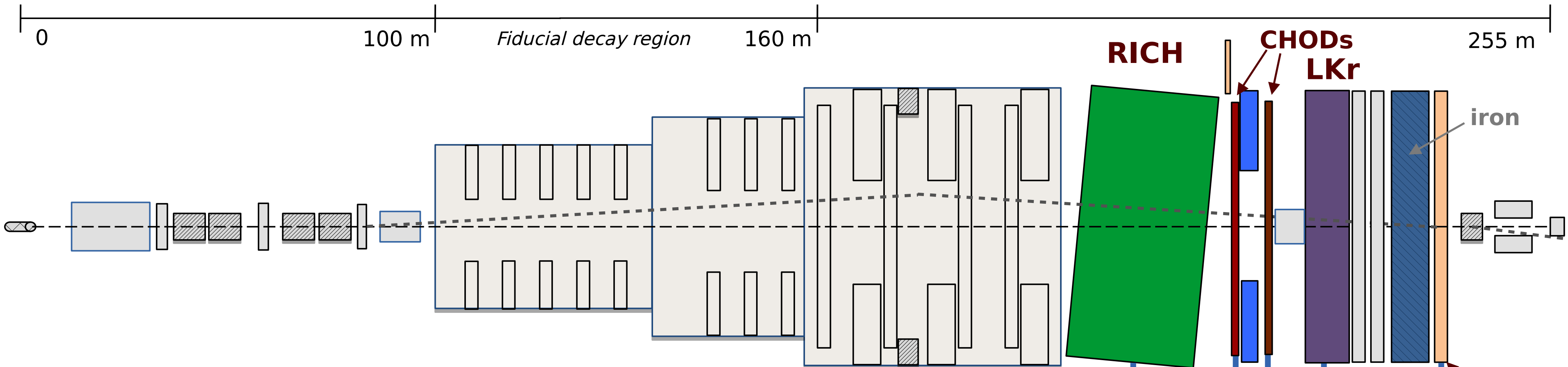
– **Software (L1),** running on a dedicated data-acquisition (DAQ) computing cluster



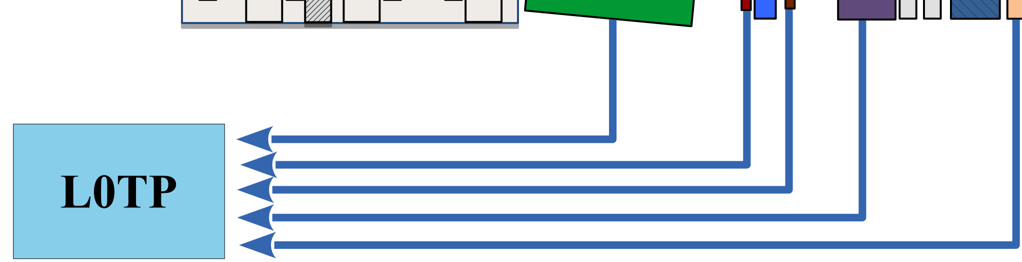
NA62 PC Farm: 30 PCs for HLT and event building
+ 4 mergers for raw data file building

NA62 L0 Trigger Processor (L0TP)

NA62 Trigger and Data flow



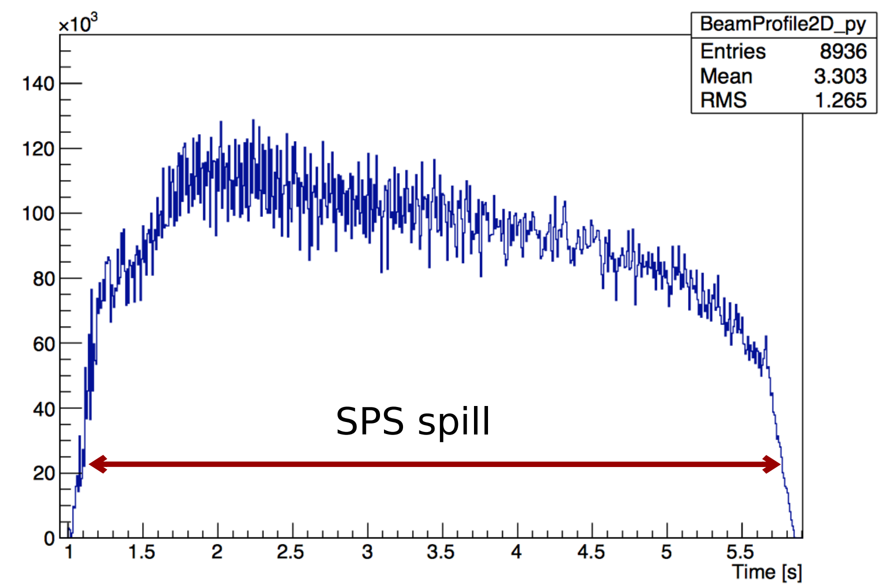
Each L0 detector has its own logic
Whenever a primitive is produced,
it gets sent to L0TP



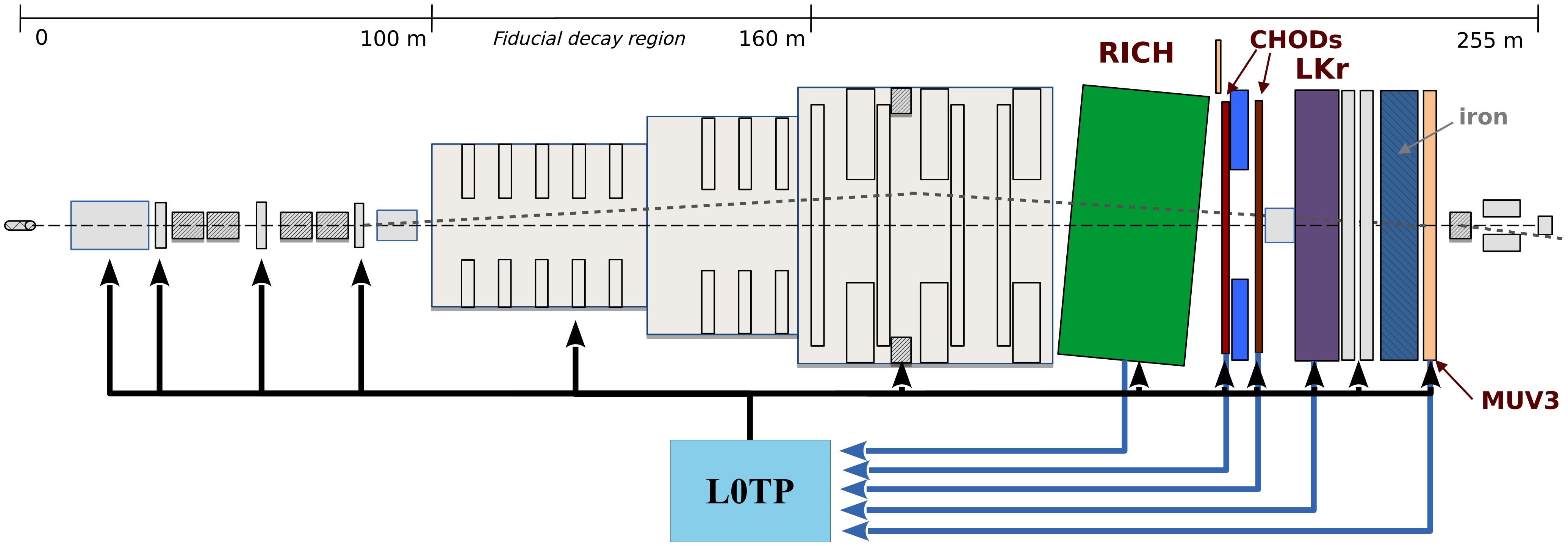
L0 Primitive format (64 bits):

- Primitive ID (16 bits): encodes the detector information (Energy, multiplicity, position);
- Timestamp(32 bits): primitive time in units of 25 ns
- Fine Time (8 bits): primitive fine time in units of 100 ps.

L0 primitive rates @ 100% intensity
RICH/CHODs/MUV3 ~ 10 MHz
LKr ~ 3 MHz



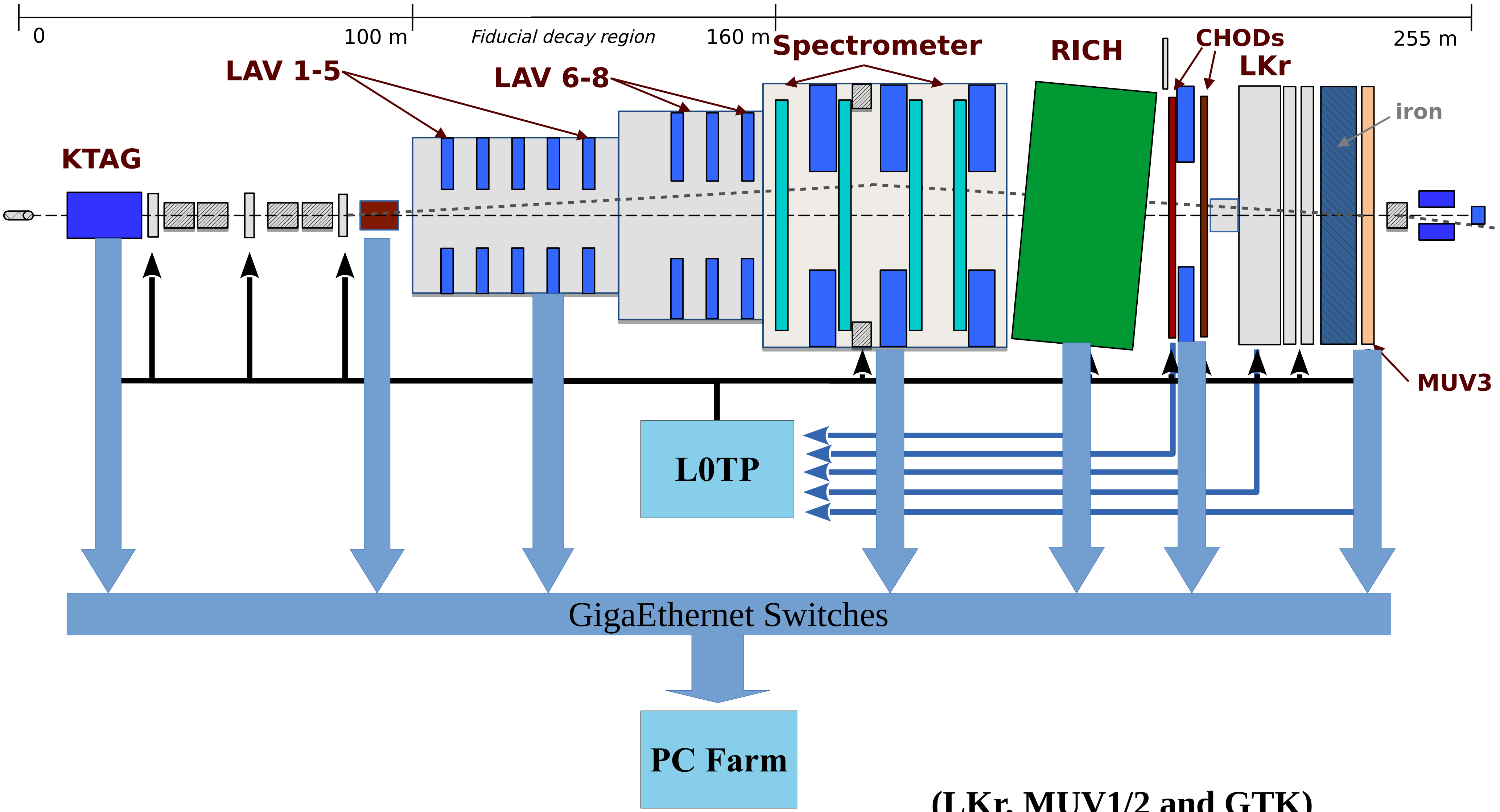
NA62 Trigger and Data flow



If primitives received in a certain time interval satisfy any of the implemented L0 trigger conditions, a L0 trigger is produced by L0TP and is sent to ALL detectors [Maximum latency: 1 ms]

L0 input: 10 MHz → **L0 output:** 1 MHz

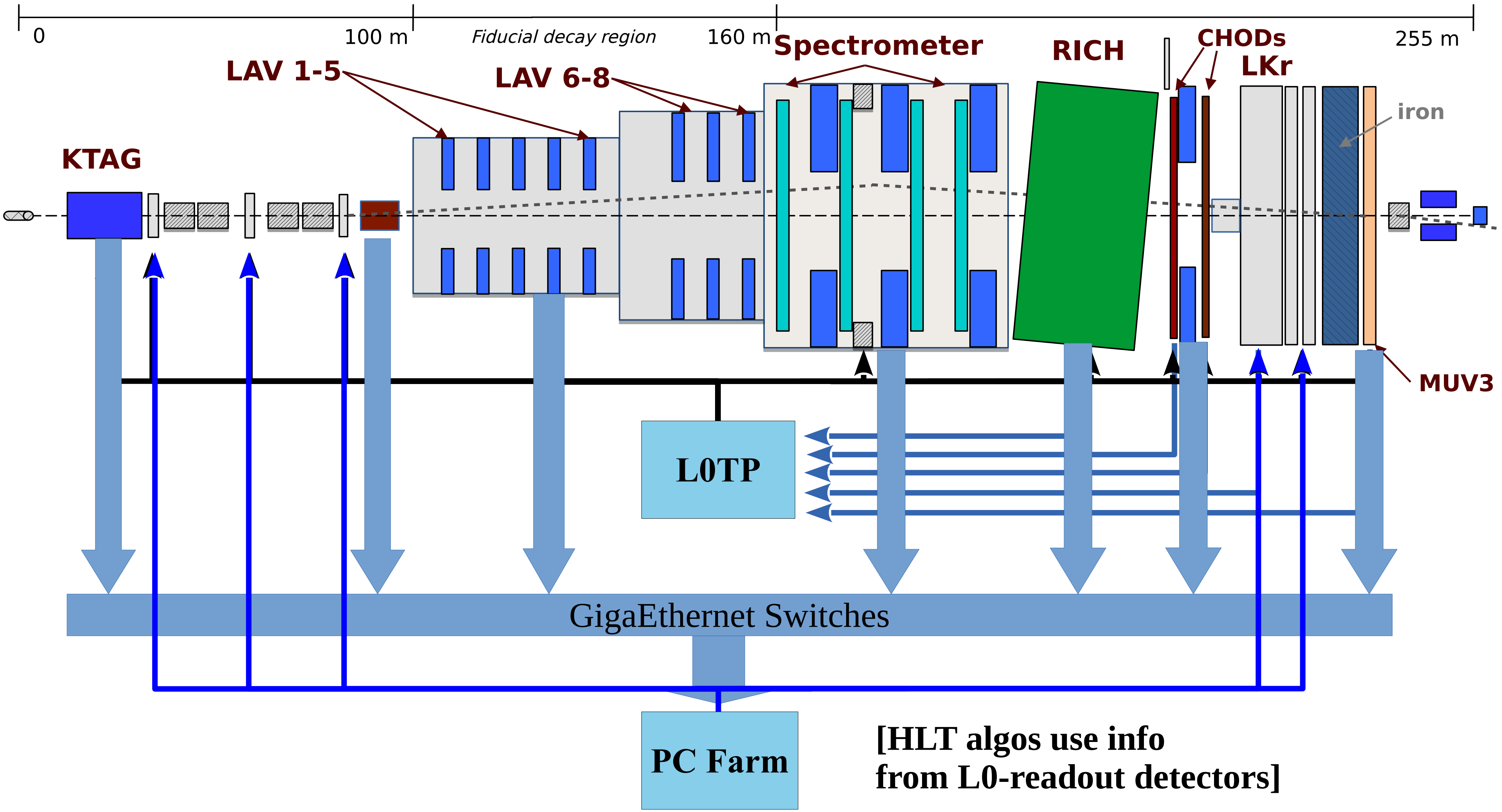
NA62 Trigger and Data flow



(LKr, MUV1/2 and GTK)

All detectors except for <u>L1-readout detectors</u> send data to the PC Farm [L1-readout detectors store the data for each L0 trigger internally]

NA62 Trigger and Data flow

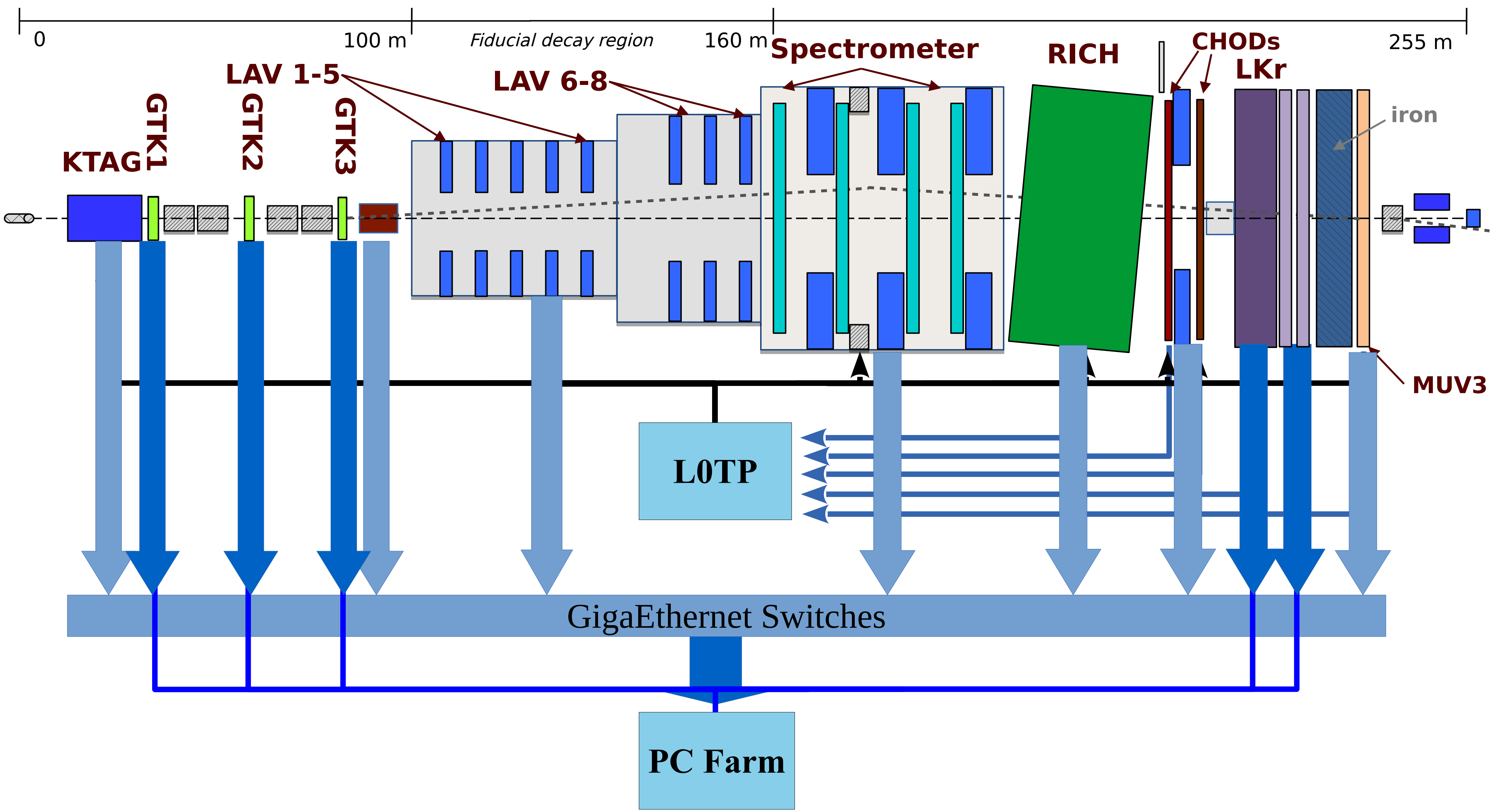


[HLT algos use info from L0-readout detectors]

If a certain L1 trigger condition is satisfied, a L1 trigger is sent to the L1-readout detectors

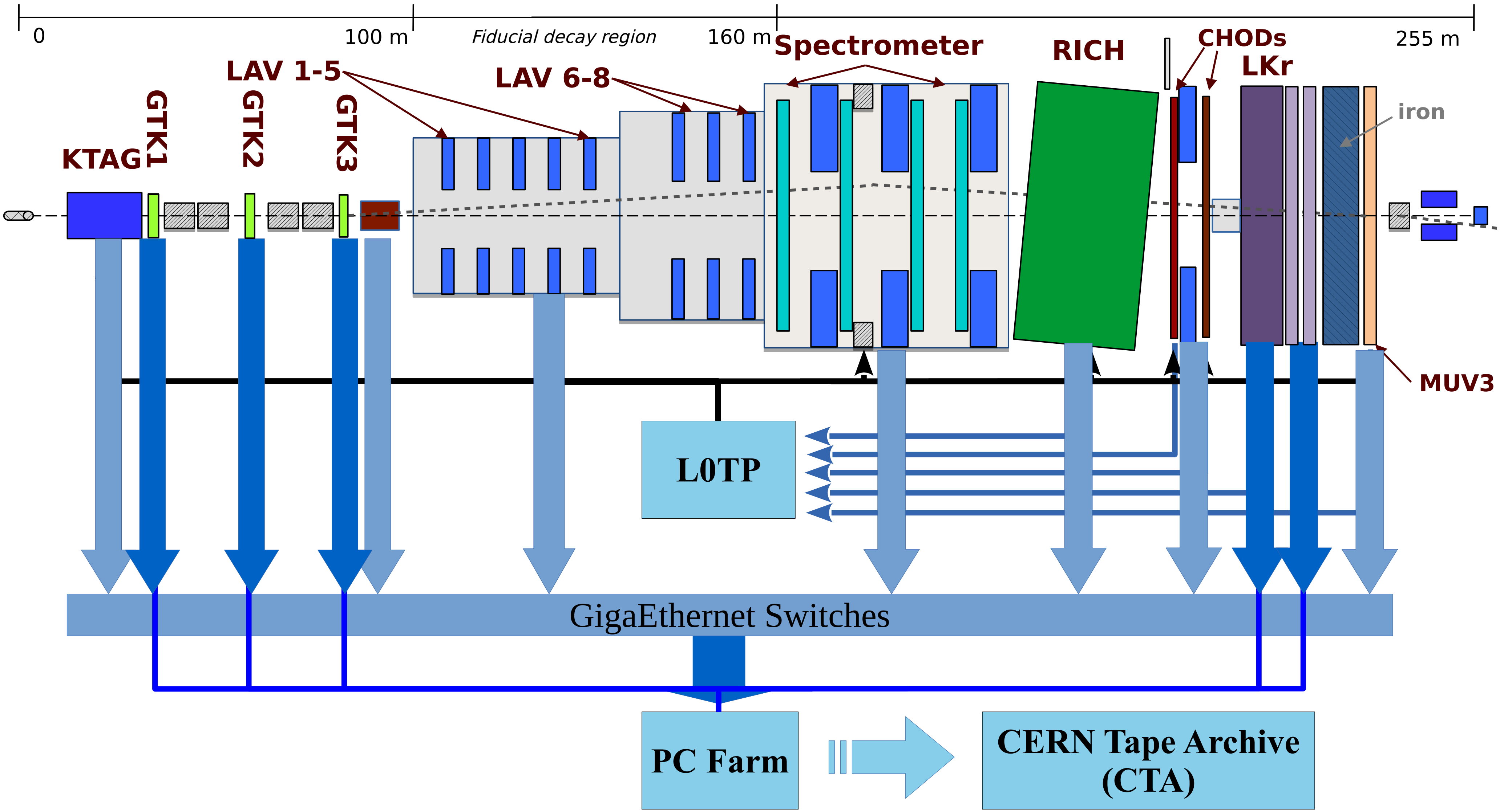
L1 input: 1 MHz → **L1 output:** < 100 kHz

NA62 Trigger and Data flow



L1-readout detectors send the selected event data to the PC Farm

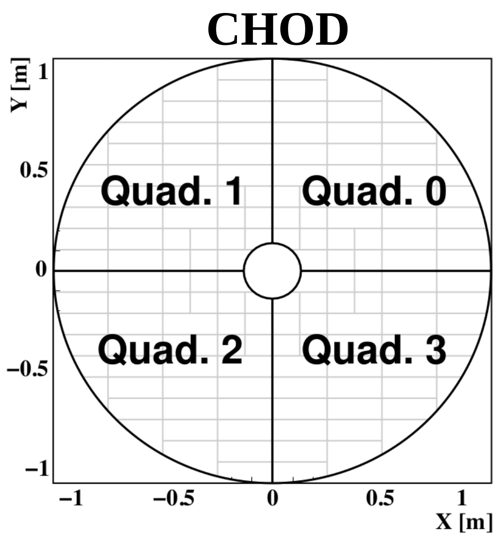
NA62 Trigger and Data flow

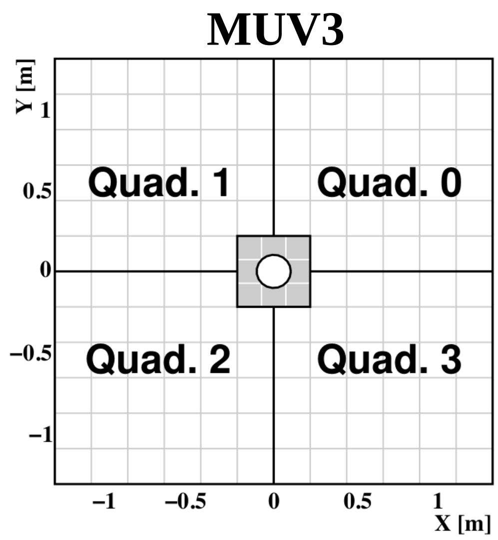


Once the complete event is received, it gets added to the raw data file by the mergers. Once closed, raw files get copied asynchronously to the permanent storage (CTA)

The NA62 Trigger logic

L0 Primitives





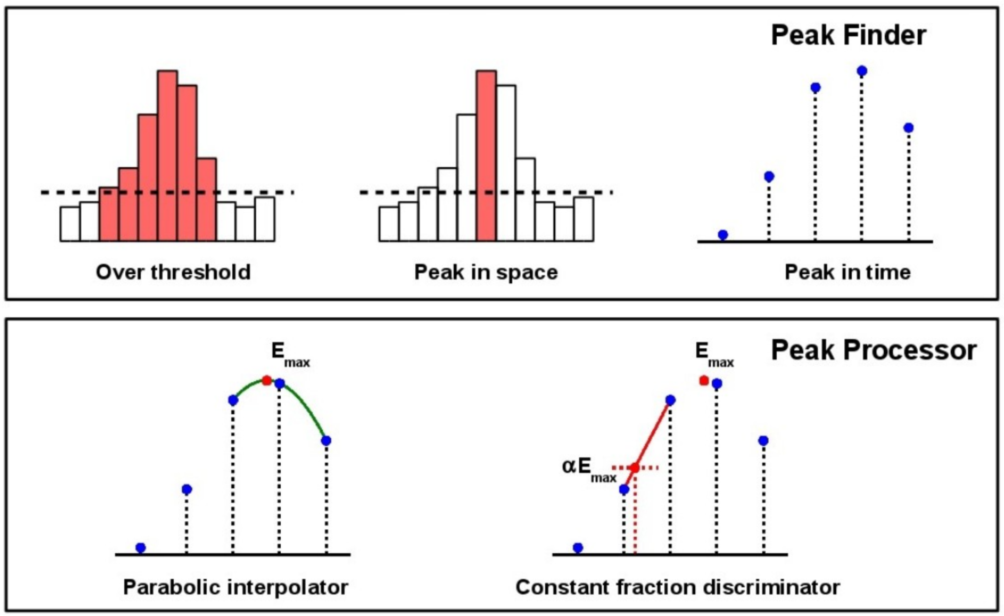
Example of L0 conditions:

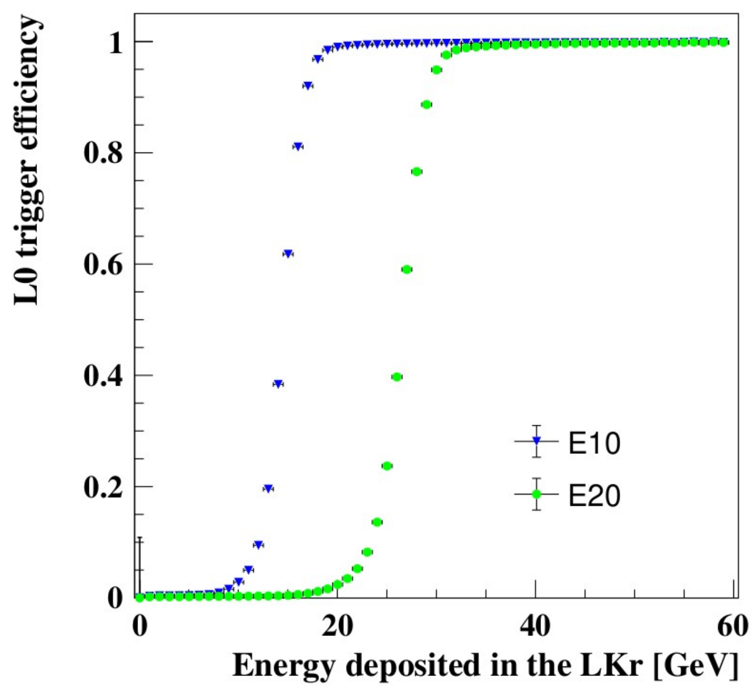
Q1 = at least a hit in a CHOD quadrant
Q2 = at least 2 quadrants with Q1
QX = at least 2 opposite quadrants

MO1 = same as Q1, for MUV3
MOQX = same as QX, for MUV3

E10 = at least 10 GeV in the LKr
E30 = less than 30 GeV in the LKr
C2E5 = at least 2 LKr clusters with E>5 GeV
LKr30 = E30 || C2E5

LKr energy reconstruction at L0





L1 algorithms

Full data available for L0-readout detectors – only constraint is the max latency O(1s)

Raw-decoder implemented in online software
Selection algorithms inspired to those used offline
(simpler, so faster but slightly less accurate)
Example: STRAW momentum resolution
– with L1 STRAW algorithm = 1%
– with full offline reco = 0.3%

Example of L1 algos:
KTAG = at least a kaon signal within 5 ns from the trigger time

LAV = at least a hit in the LAVs within 5 ns from the trigger time

STRAW = At least a positive track with momentum < 60 GeV/*c*,
with closest distance of approach (CDA) of the track to the nominal beam axis below 200 mm and reconstructed vertex with $z < z_{STRAW1}$
STRAW-1TRK = At least a positive track with momentum < 65 GeV/*c*
STRAW-EXO = At least one negatively-charged track

NA62 Run1 Trigger masks

Trigger line	L0 trigger conditions	L1 trigger conditions
PNN	RICH $\cdot$ Q1 $\cdot$ UTMC $\cdot$ $\overline{\text{QX}}$ $\cdot$ $\overline{\text{M1}}$ $\cdot$ $\overline{\text{LKr30}}$	KTAG $\cdot$ $\overline{\text{LAV}}$ $\cdot$ STRAW
Non-μ	RICH $\cdot$ Q1 $\cdot$ $\overline{\text{M1}}$	KTAG $\cdot$ STRAW-1TRK
MT	RICH $\cdot$ QX	KTAG $\cdot$ STRAW-Exo
2μMT	RICH $\cdot$ QX $\cdot$ MO2	KTAG $\cdot$ STRAW-Exo
eMT	RICH $\cdot$ QX $\cdot$ E20	KTAG $\cdot$ STRAW-Exo
μMT	RICH $\cdot$ QX $\cdot$ MO1 $\cdot$ E10	KTAG $\cdot$ $\overline{\text{LAV}}$ $\cdot$ STRAW-MT
DV-μ	RICH $\cdot$ Q2 $\cdot$ MO1 $\cdot$ E10	$\overline{\text{KTAG}}$ $\cdot$ STRAW-DV
DV-2μ	RICH $\cdot$ Q2 $\cdot$ MO2 $\cdot$ $\overline{\text{E10}}$	STRAW-DV
Neutrino	RICH $\cdot$ Q1 $\cdot$ MOQX $\cdot$ $\overline{\text{Q2}}$	KTAG $\cdot$ $\overline{\text{LAV}}$ $\cdot$ STRAW-1TRK
Control	NA48-CHOD	None

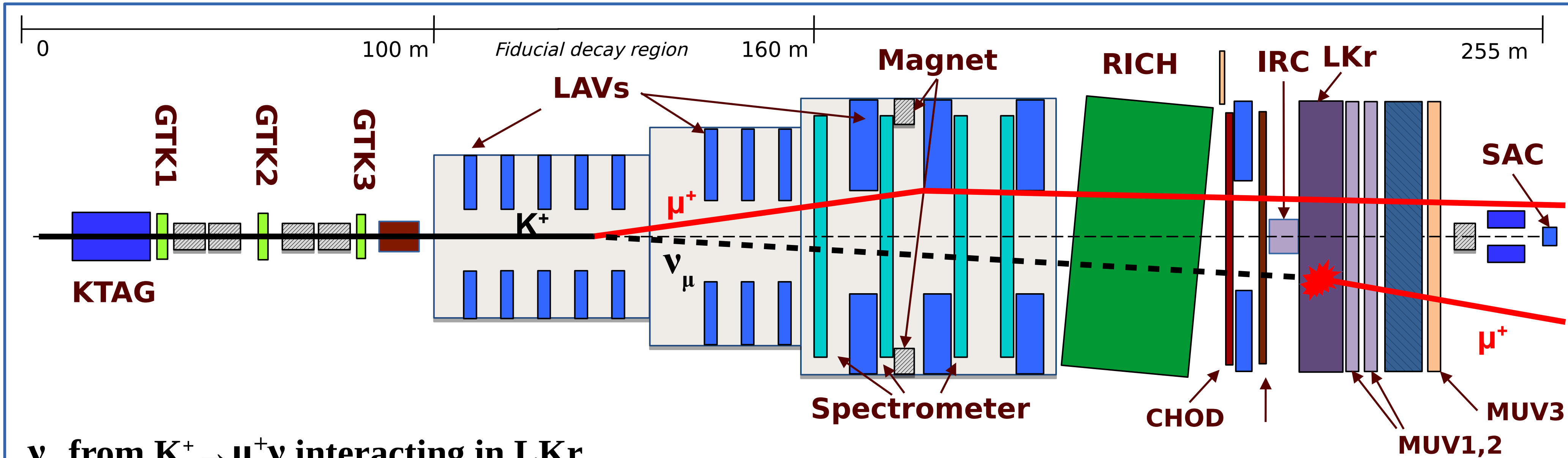
NA62 Run1 Trigger masks

Masks needed for $K^+ \rightarrow \pi^+ \nu\nu$

Trigger line	L0 trigger conditions	L1 trigger conditions
PNN	$\mathrm{RICH} \cdot \mathrm{Q1} \cdot \mathrm{UTMC} \cdot \overline{\mathrm{QX}} \cdot \overline{\mathrm{M1}} \cdot \overline{\mathrm{LKr30}}$	$\mathrm{KTAG} \cdot \overline{\mathrm{LAV}} \cdot \mathrm{STRAW}$
Non-μ	$\mathrm{RICH} \cdot \mathrm{Q1} \cdot \overline{\mathrm{M1}}$	KTAG · STRAW-1TRK
MT	RICH · QX	KTAG · STRAW-Exo
2μMT	RICH · QX · MO2	KTAG · STRAW-Exo
eMT	RICH · QX · E20	KTAG · STRAW-Exo
μMT	RICH · QX · MO1 · E10	$\mathrm{KTAG} \cdot \overline{\mathrm{LAV}} \cdot \mathrm{STRAW\text{-}MT}$
DV-μ	RICH · Q2 · MO1 · E10	$\overline{\mathrm{KTAG}} \cdot \mathrm{STRAW\text{-}DV}$
DV-2μ	$\mathrm{RICH} \cdot \mathrm{Q2} \cdot \mathrm{MO2} \cdot \overline{\mathrm{E10}}$	STRAW-DV
Neutrino	$\mathrm{RICH} \cdot \mathrm{Q1} \cdot \mathrm{MOQX} \cdot \overline{\mathrm{Q2}}$	$\mathrm{KTAG} \cdot \overline{\mathrm{LAV}} \cdot \mathrm{STRAW\text{-}1TRK}$
Control	NA48-CHOD	None

Many other masks for a broader physics programme:
$K^+ \rightarrow \pi^+\mu^+\mu^-$, $K^+ \rightarrow \pi^+e^+e^-$, $K^+ \rightarrow \pi^+\mu^+e^-$...

NA62 Run1 Trigger masks



ν_μ from $K^+ \rightarrow \mu^+ \nu$ interacting in LKr

μMT	$\mathrm{RICH} \cdot \mathrm{QX} \cdot \mathrm{MO1} \cdot \mathrm{E10}$	$\mathrm{KTAG} \cdot \overline{\mathrm{LAV}} \cdot \mathrm{STRAW\text{-}MT}$
DV-μ	$\mathrm{RICH} \cdot \mathrm{Q2} \cdot \mathrm{MO1} \cdot \mathrm{E10}$	$\overline{\mathrm{KTAG}} \cdot \mathrm{STRAW\text{-}DV}$
DV-2μ	$\mathrm{RICH} \cdot \mathrm{Q2} \cdot \mathrm{MO2} \cdot \overline{\mathrm{E10}}$	STRAW-DV
Neutrino	$\mathrm{RICH} \cdot \mathrm{Q1} \cdot \mathrm{MOQX} \cdot \overline{\mathrm{Q2}}$	$\mathrm{KTAG} \cdot \overline{\mathrm{LAV}} \cdot \mathrm{STRAW\text{-}1TRK}$
Control	NA48-CHOD	None

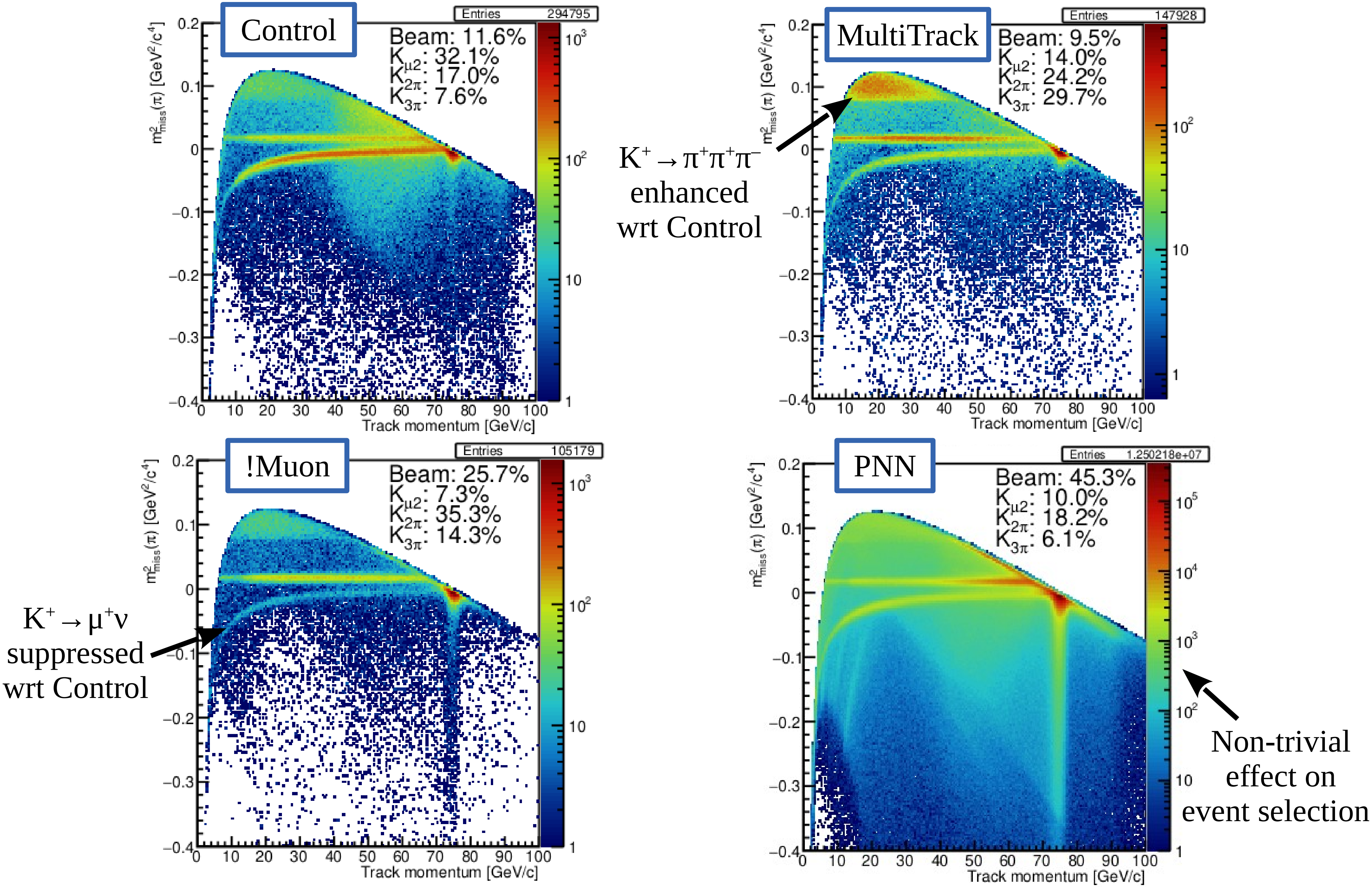
NA62 Run1 Trigger masks

[counts measured at 60% beam intensity]

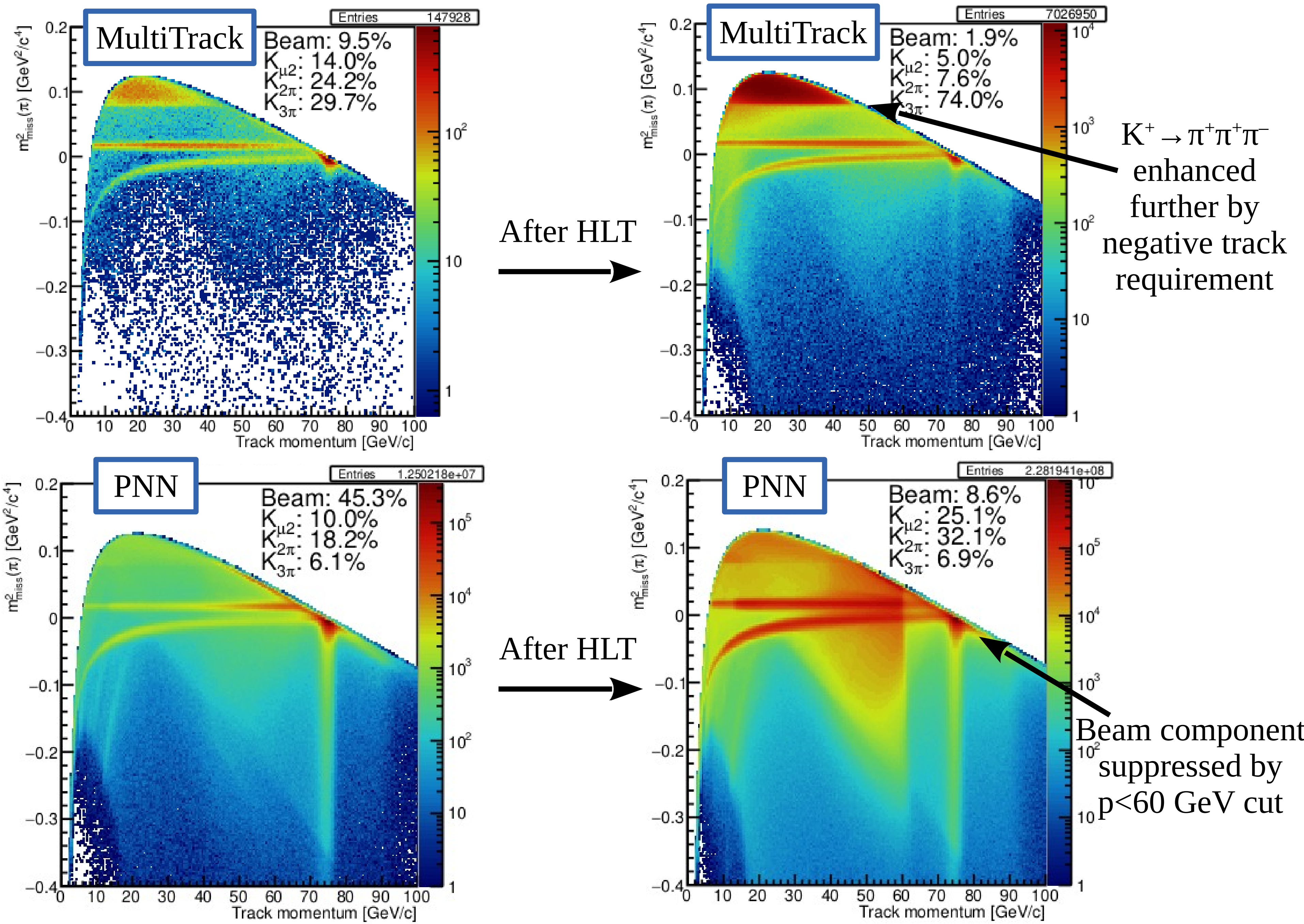
Trigger line	Downscaling	L0 triggers [10^3]	L1 triggers [10^3]
PNN	1	1540	74
Non-μ	200	30	12
MT	100	39	4
2μMT	2	150	30
eMT	8	193	22
μMT	5	99	10
DV-μ	5	140	0.3
DV-2μ	3	160	5
Neutrino	15	10	3
Control	400	94	94
Total:	–	2455	254.3

Corresponds to ~ 1 MHz L0 and ~ 100 kHz L1 at 100% beam intensity

Event population / mask after L0



Event population / mask after L1



Conclusions

The NA62 TDAQ system is quite different with respect to collider trigger systems:

- Good time resolution is essential already at the level-0 trigger in order to reject the high background.
- All the systems involved in the trigger have a level-0 time-resolution < 2.5 ns.
- NA62 is able to handle ~10 MHz of decay-products, reducing the rate to 1 MHz after level-0 and to 100 kHz after level-1 triggers.
- Multiple trigger logic conditions (masks) to perform a broad physics programme