The NA62 Experiment at CERN: Prospects for the $K^+ \to \pi^+ \nu\bar{\nu}$ Measurement

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on behalf of the NA62 Collaboration

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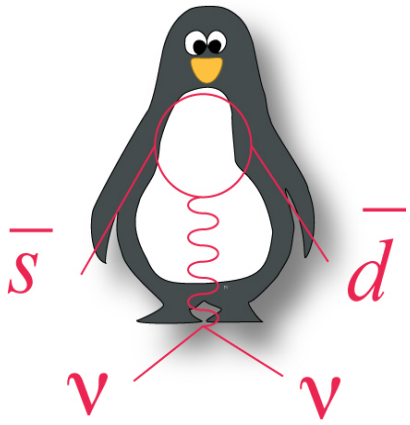
Outline

1. The $K^+ \to \pi^+ \nu\bar{\nu}$ decay (overview)

- Motivations & Theory
- Experimental Results
- New Physics

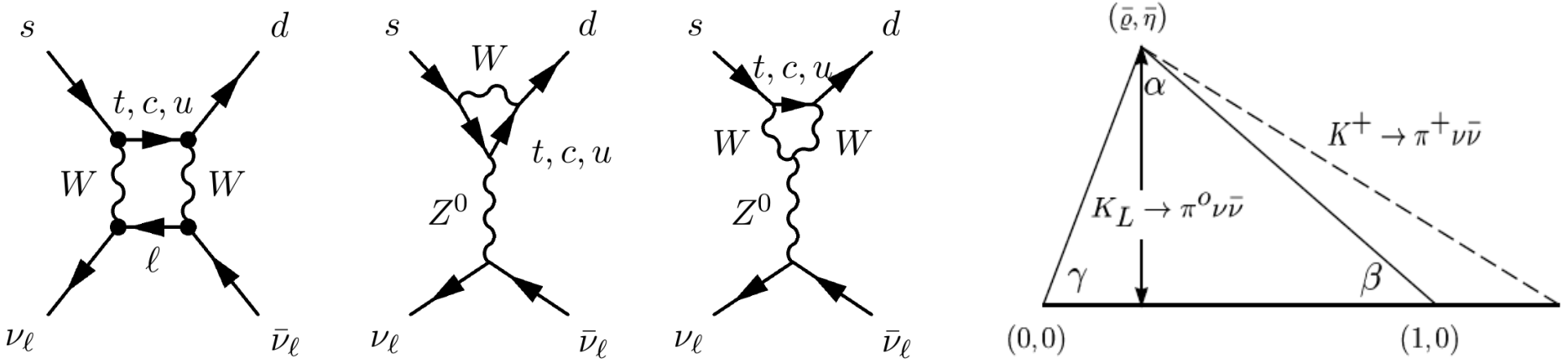


2. The NA62 experiment

- The NA62 timeline
- The main backgrounds
- The NA62 detector
- Physics Sensitivity

3. Conclusions

$K^+ \to \pi^+ \nu\bar{\nu}$: Motivations & Theory



- FCNC forbidden at tree level: 1-loop contributions as leading order
- Highly CKM suppressed: $BR(K^+ \to \pi^+ \nu\bar{\nu}) \sim |V_{ts}^* V_{td}|^2 \sim \lambda^{10}$

} high sensitivity to new physics

- Dominated by short-distance contribution (top quark)
- t quark contribution @ NLO QCD and 2-loop EW corrections, c quark @ NNLO QCD and 1-loop EW corrections
- Hadronic matrix element from $BR(K \to e\pi^0\nu)$

} high-precision theoretical prediction

- Measurement of $|V_{td}|$ complementary to those from $B–\bar{B}$ mixing or $B^0 \to \rho\gamma$
- Constraints on CKM unitary triangle

Parametric error
V_{cb}(56%), ρ(21%), m_c(8%) m_t(6%)

Pure theoretical error
(LD corrections)

SM prediction:

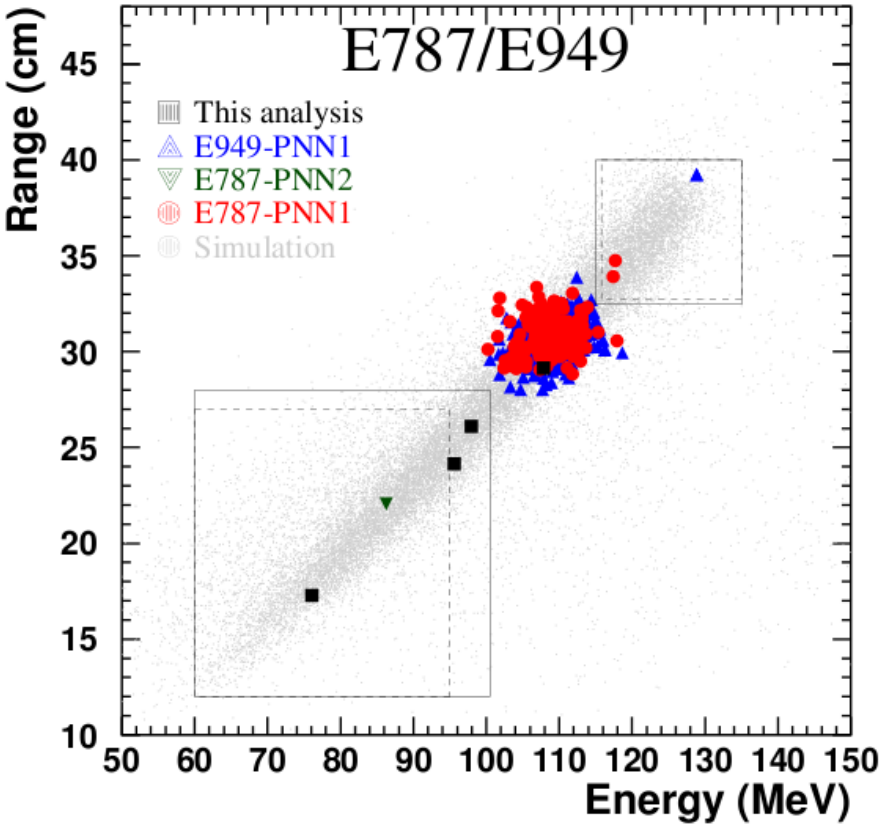
$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (0.781 \pm 0.075 \pm 0.029) \times 10^{-10}$

Brod Gorbahn Stamou PRD 83 (2011) 034030

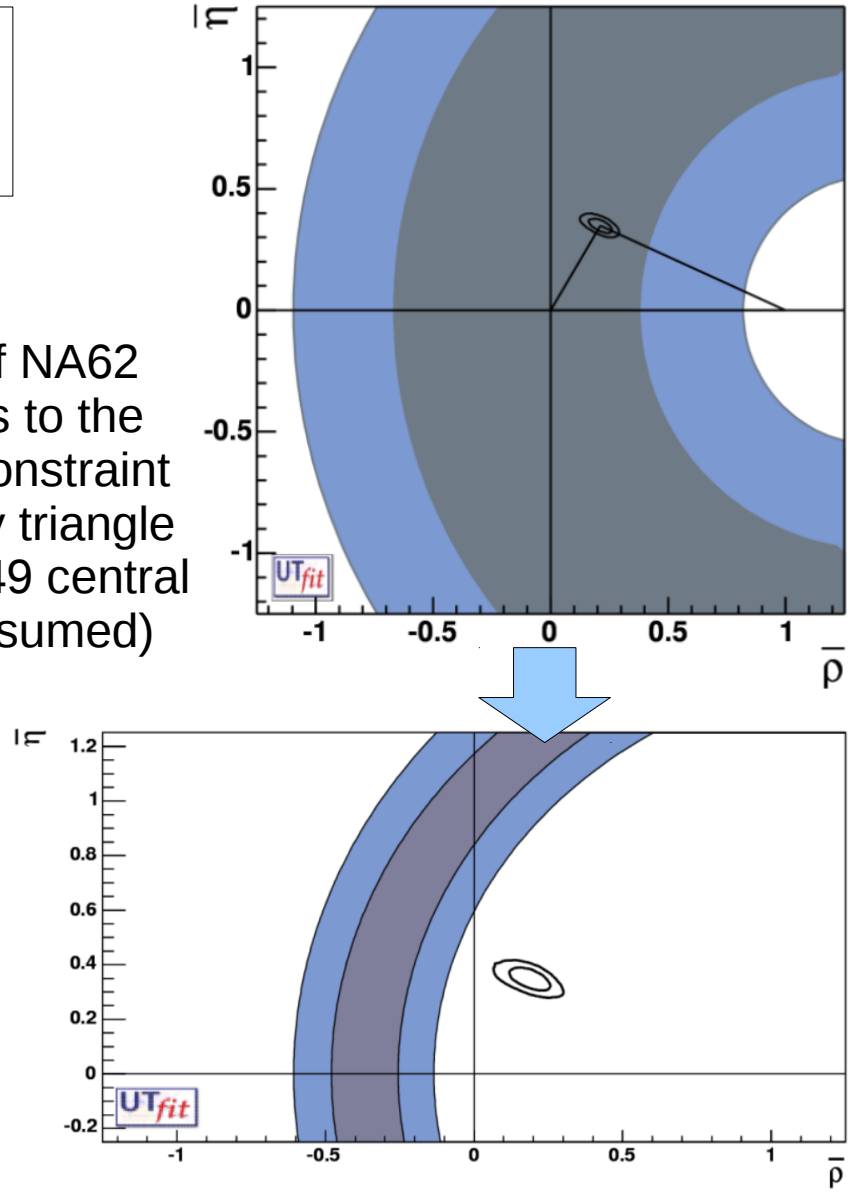
$K^+ \to \pi^+ \nu\bar{\nu}$: Experimental Results

Current Experimental result [from 7 events]:
BR($K^+ \to \pi^+ \nu\bar{\nu}$) = $(1.73^{+1.15}_{-1.05}) \times 10^{-10}$
E787/E949,Phys.Rev.Lett.101, 191802(2008)

Probability of all events being background ~ 10^{-3}



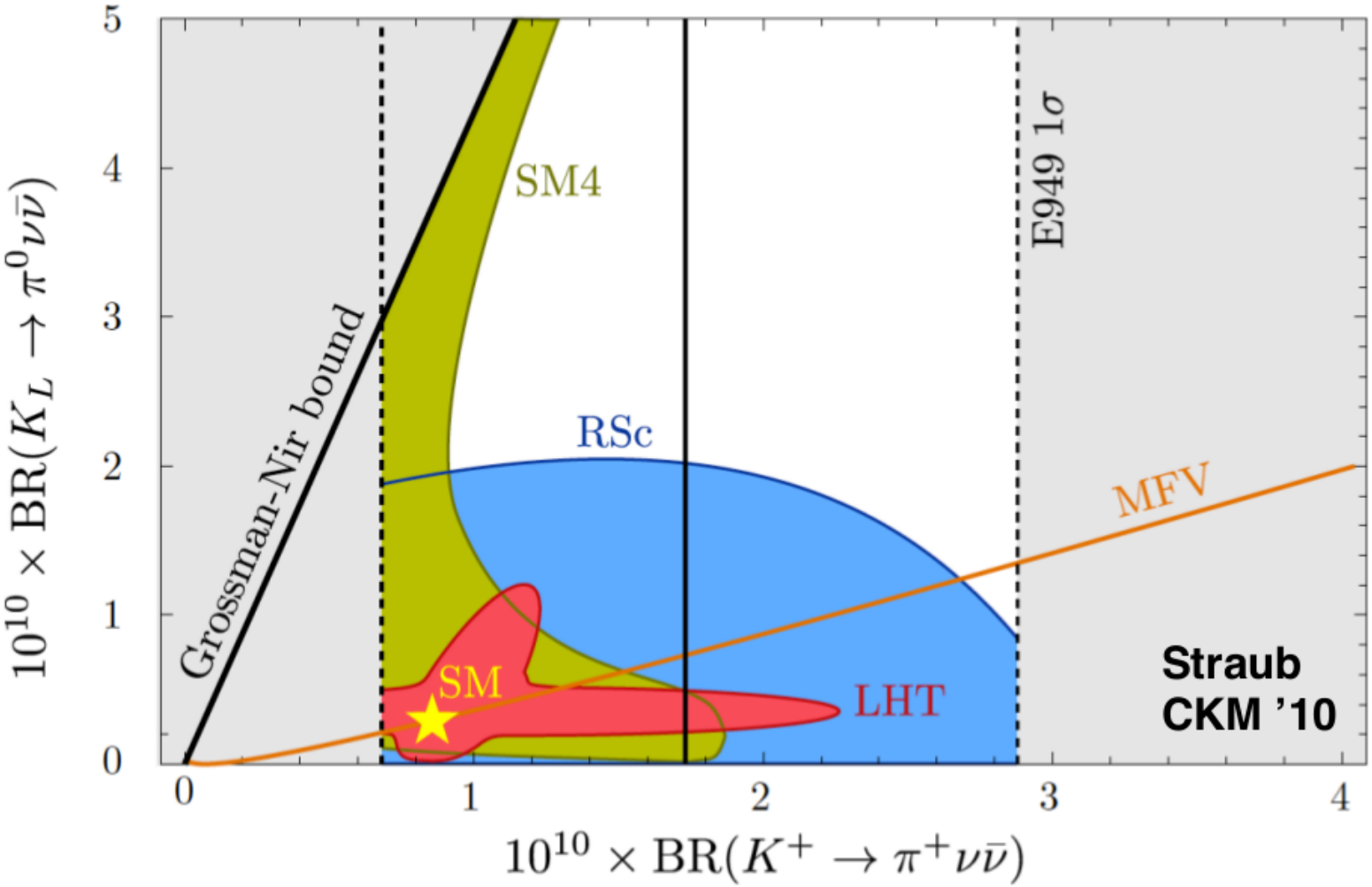
Effect of NA62 statistics to the current constraint on unitary triangle (E787/E949 central value assumed)



Future $K^+ \to \pi^+ \nu\bar{\nu}$ experiments: NA62 @ CERN (2014-2017), ORKA @ Fermilab (2020-2025)

$K^+ \to \pi^+ \nu\bar{\nu}$: New Physics

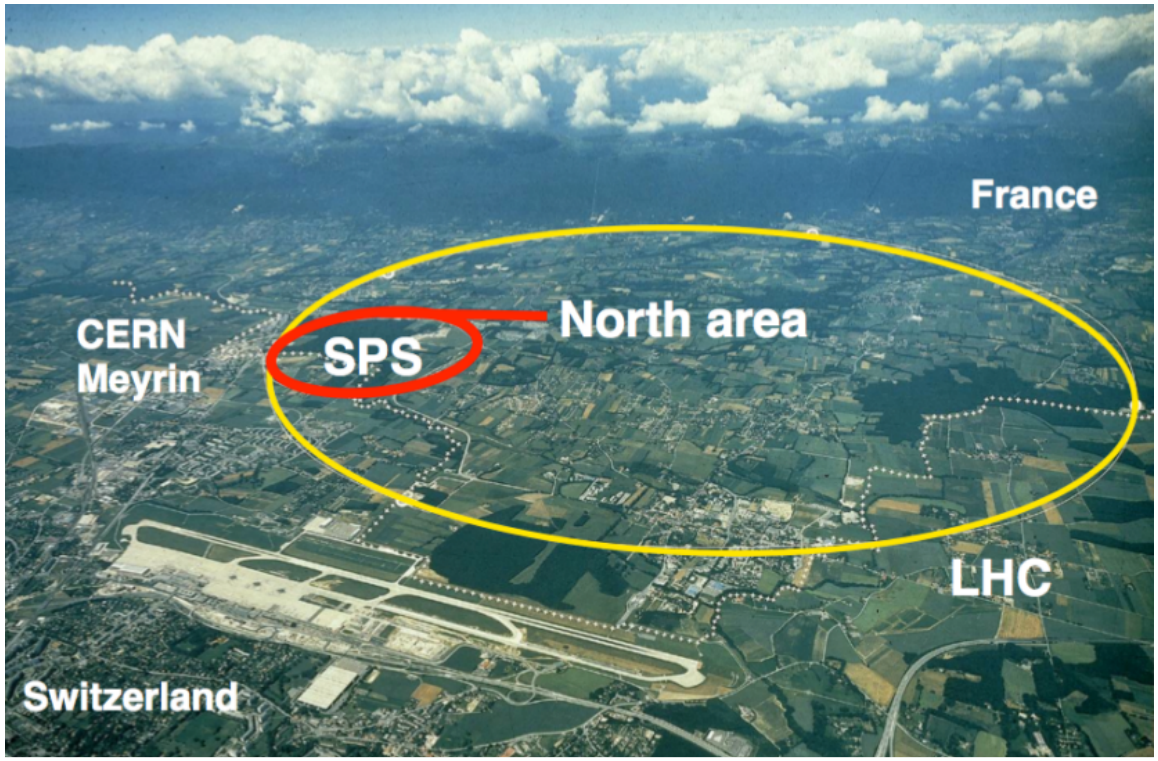
New physics affects BRs differently for different channels
Multiple measurements can discriminate among NP scenarios



SM4: SM with 4th generation (Buras et al. '10)
RSc: Custodial Randall-Sundrum (Blanke '09)
LHT: Littlest Higgs with T parity (Blanke '10)
MFV: Minimal flavor violation (Hurth et al. '09)

The NA62 experiment @ CERN

NA62 is the last from a long tradition of fixed-target Kaon experiments in the North Area (NA) @ CERN

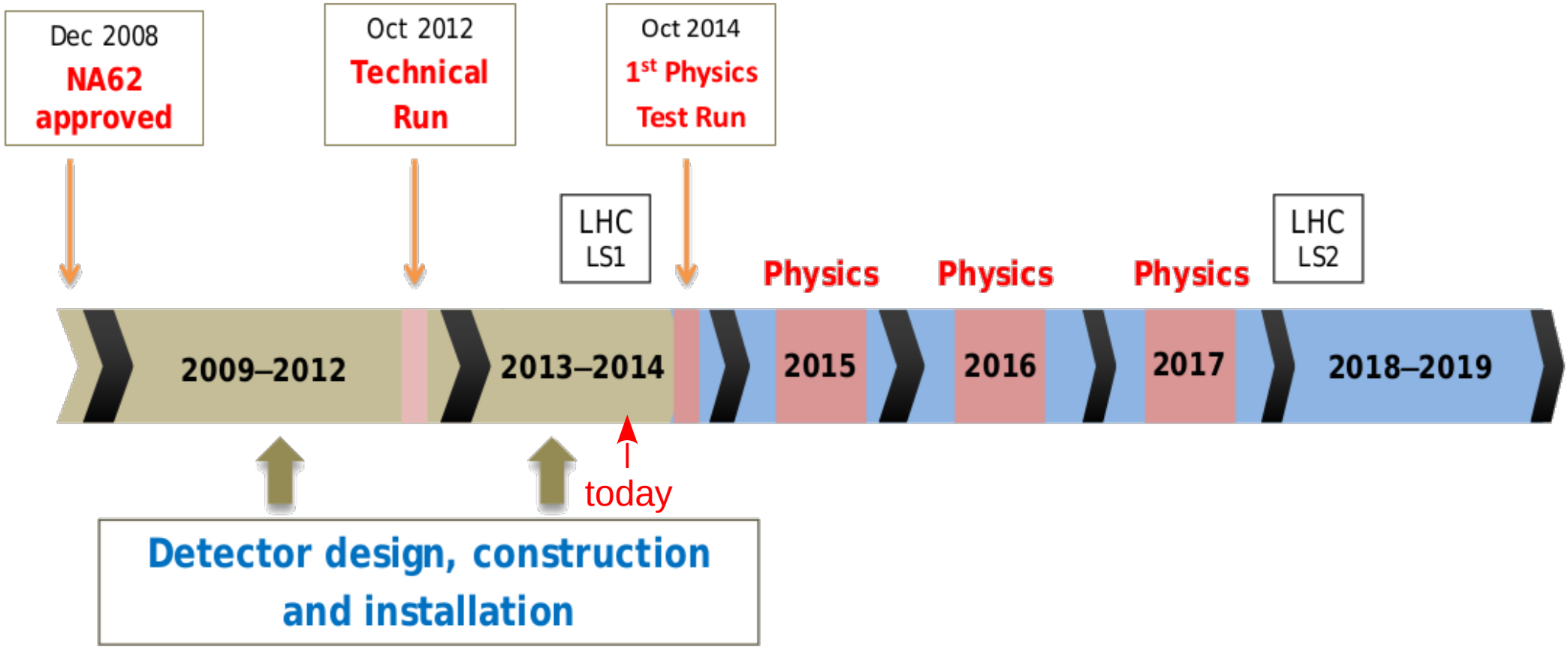


Birmingham, Bratislava, Bristol, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Glasgow, IHEP Protvino, INR Moscow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Naples, Padua, Perugia, Pisa, Prague, Rome I, Rome II, San Luis Potosí, SLAC, Sofia, Turin

Recent history of NA experiments		
1997 ↓ 2001	NA48 (K_S/K_L)	Re ε′/ε **Discovery of direct CPV**
2002	NA48/1 (K_S/hyperons)	Rare K_S and hyperon decays
2003 ↓ 2004	NA48/2 (K^+/K^-)	Direct CPV, Rare K^+/K^- decays
2007 ↓ 2008	NA62 R_K-phase (K^+/K^-)	$R_K = K^{\pm}_{e2}/K^{\pm}_{\mu 2}$
2009 ↓ 2017	NA62 (K^+)	$K^+ \to \pi^+ \nu\bar{\nu}$, Rare K^+ and π^0 decays

NA62 GOAL: measure the BR of the ultra-rare Kaon decay $K^+ \to \pi^+ \nu\bar{\nu}$ with 10% accuracy collecting ~ 100 events in 3 years of data taking

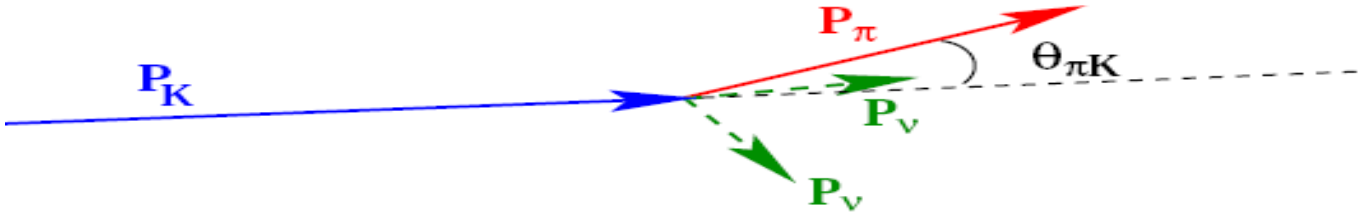
The NA62 timeline



- 5 years of construction
- Technical Run (October 2012) with partial detector
- First Run with full detector in 2014
- 3 years of data-taking before LHC Long Shutdown 2 (LS2)

$K^+ \to \pi^+ \bar{\nu}\nu$: Main Backgrounds

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

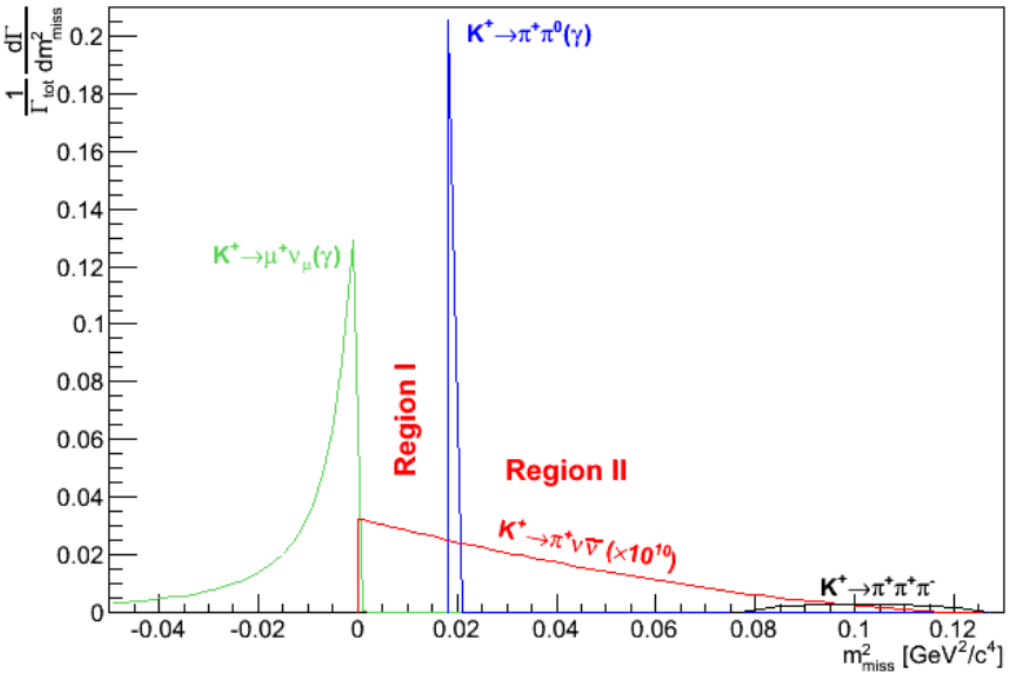


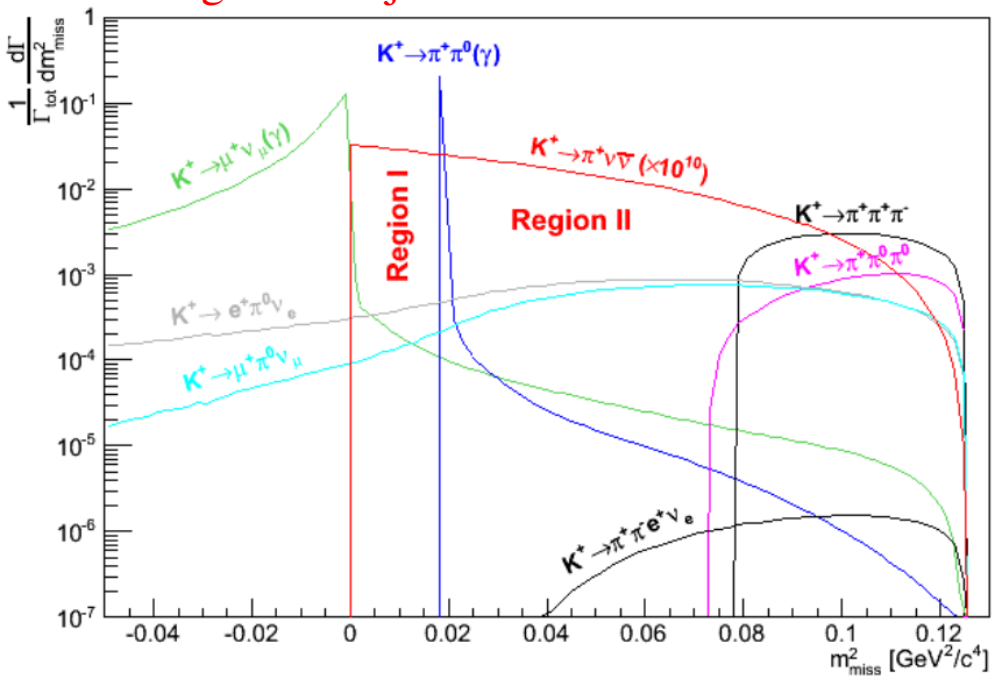
$$m^2_{miss} \cong m^2_K\left(1-\frac{|P_\pi|}{|P_K|}\right)+m^2_\pi\left(1-\frac{|P_K|}{|P_\pi|}\right)-|P_K||P_\pi|\theta^2_{\pi K}$$

Backgrounds rejection cutting on the M^2_{miss} ~ 92%

Correct K-π association is ESSENTIAL to reject them!

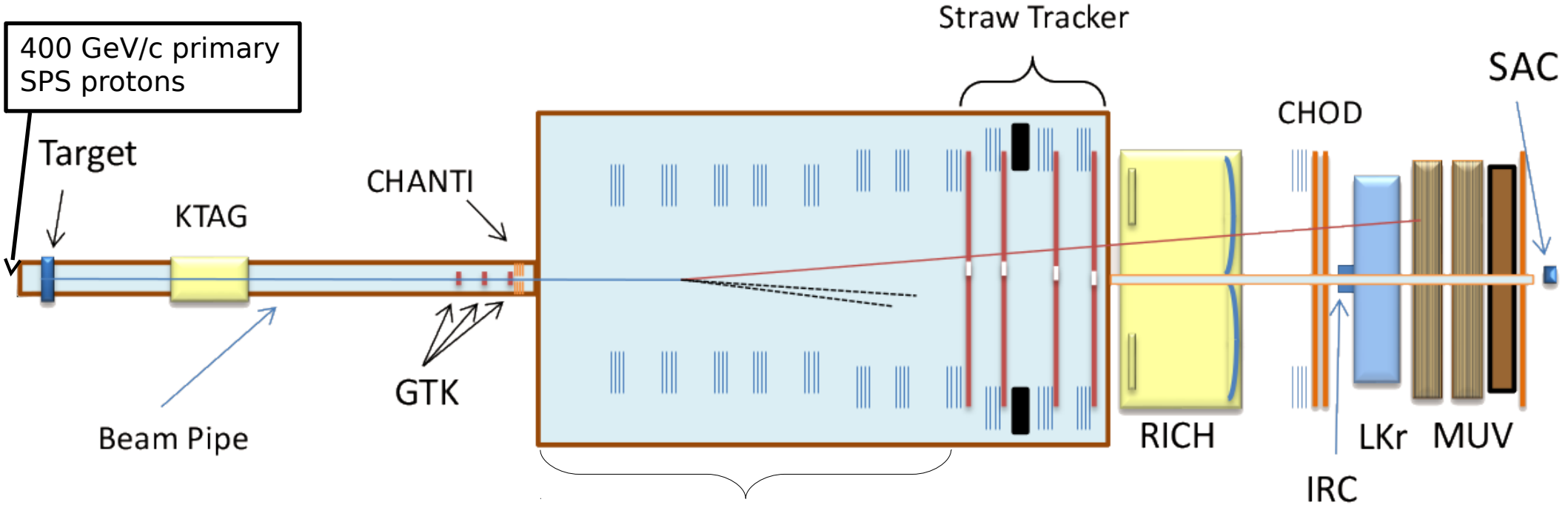
Required Photon veto inefficiency ~ 2×10^{-4}
Required Muon mis-ID probability ~ 10^{-7}
Background rejection at ~ 10^{11} level





The NA62 detector

75(±1%) GeV/c unseparated secondary hadron (K / p / π) beam
Kaon decays in flight technique
750 MHz beam; 45MHz Kaons (~6%); ~10 MHz L0 rate



The K12 high-intensity K^+ beam line

Primary SPS proton beam:

p = 400 GeV protons

3×10^{12} protons/pulse ($3 \times$ NA48/2)

Duty factor ~ 0.3

Expected similar to 4.8s/16.8s duty cycle for NA48/2

Simultaneous operation of LHC and fixed target experiments

High Intensity, unseparated secondary beam:

Momentum selection chosen to optimise K decays

P = 75 GeV (1.4 × more K^+ than NA48/2 at same proton beam intensity)

$\Delta p/p$ ~ 1% ($3 \times$ smaller than NA48/2)

Total Rate 750 MHz
- 525 MHz π
- 170 MHz p
- 45 MHz K

Beam Timing and Kaon Identification

Gigatracker (750 MHz) ← Must precisely match events → Downstream detectors (~10 MHz)

GigaTracker:	$\sigma_t < 200$ ps/station
KTAG:	$\sigma_t < 100$ ps
RICH:	$\sigma_t < 100$ ps

Mismatch probability < 1%

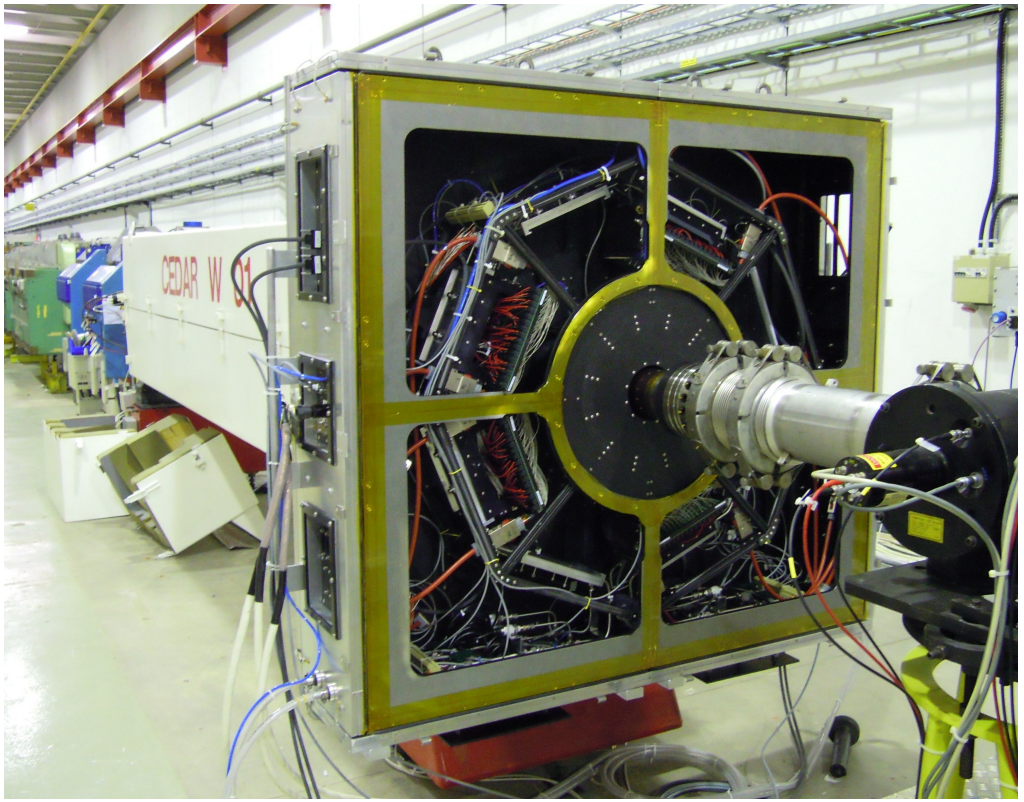
Wrong matching → 3 × increase in $\sigma(m_{miss})$

CEDAR/KTAG characteristics:

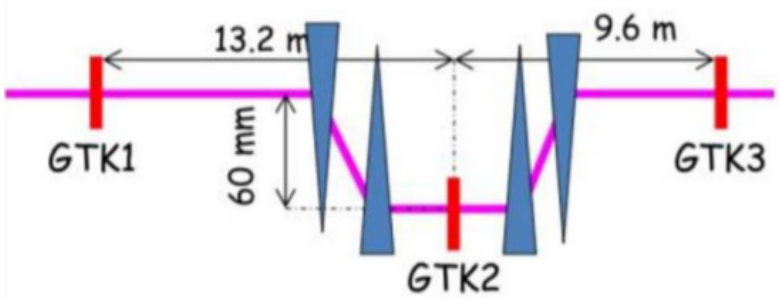
- Differential Cherenkov, 1.1 m^3 of Hydrogen @ 3.7 bar as radiator
- 8 light boxes with 48 PMTs each
- Kaon Time resolution < 100 ps
- Kaon Tagging efficiency > 95%
- Pion Mis-ID probability < 0.001

CEDAR/KTAG working conditions:

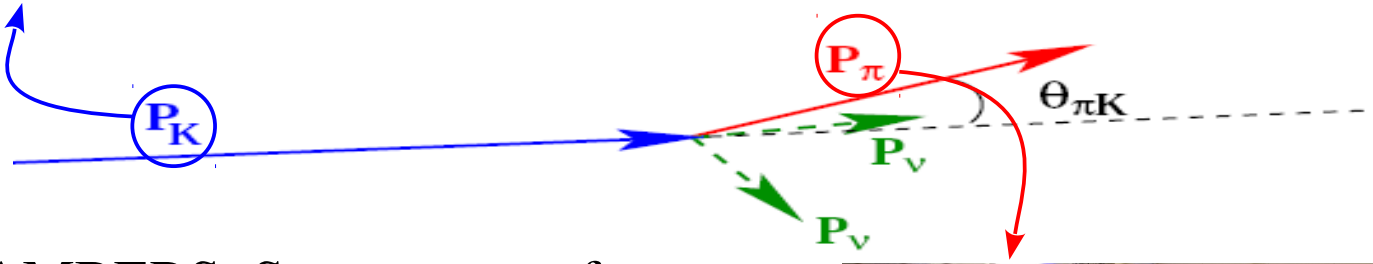
- Kaon Rate (average) ~ 45 MHz
- Rate on single PMT ~ 4 MHz



The Tracking detectors



GIGATRACKERS: Beam spectrometer for Kaon momentum, time and angular measurements, based on 3 Silicon sensors with $300\times300\mu m^2$ pixels ($\sigma_p/p \sim 0.2\%$, $\sigma_\theta = 16$ μrad)



STRAW CHAMBERS: Spectrometer for position and momentum measurements of charged decay products, based on 4 straw chambers, 2.1 m in diameter
[16 layers (4 views) of straws per chamber]

MNP33 dipole: 0.36T ($p_\perp = 270$ MeV)

$\sigma \leq 130$ μm (1 view)
0.45 X_0 per chamber

$\sigma_p/p = 0.32\% \oplus 0.008\%p$
$\sigma_{\theta(K\pi)} = 20\text{-}50$ μrad

The Photon Veto System

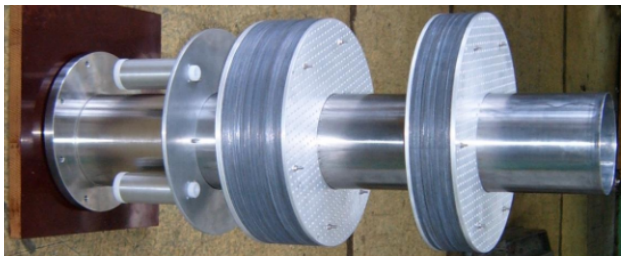
Hermetic Photon Vetoes up to 50 mrad

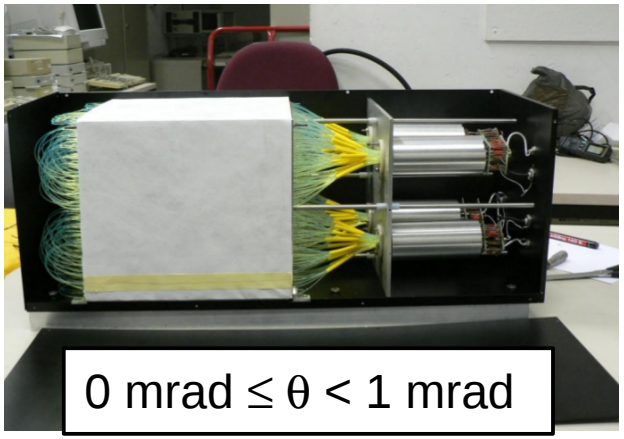
LAV: 12 counters surrounding the vacuum tank providing full coverage for photons at large angles

LKR: Electromagnetic calorimeter built for the NA48 experiment for the photon veto in the forward region

IRC/SAC: Photon veto at small angles

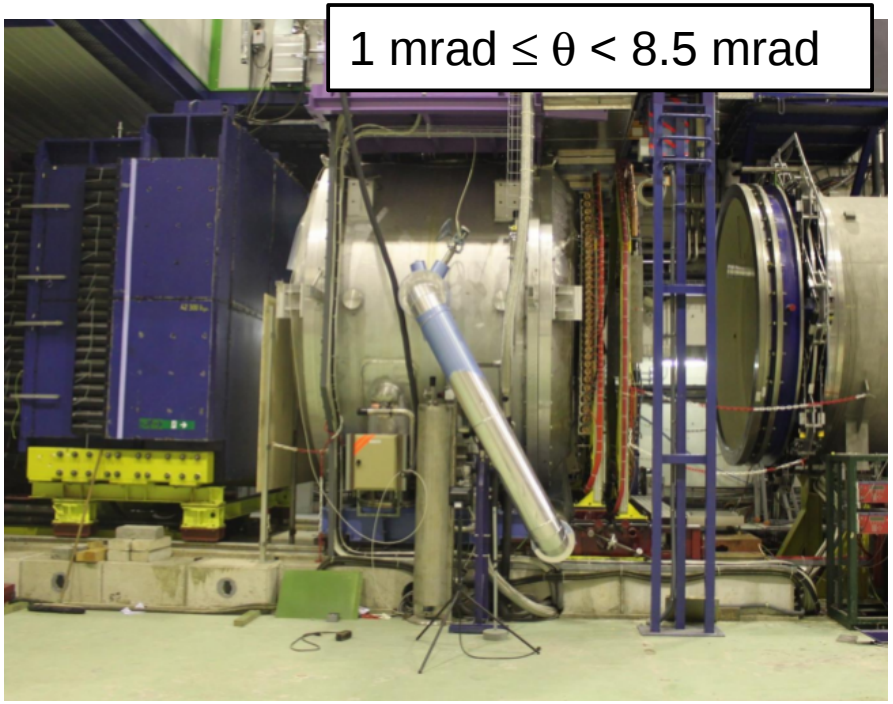
8.5 mrad ≤ θ < 50 mrad





0 mrad ≤ θ < 1 mrad

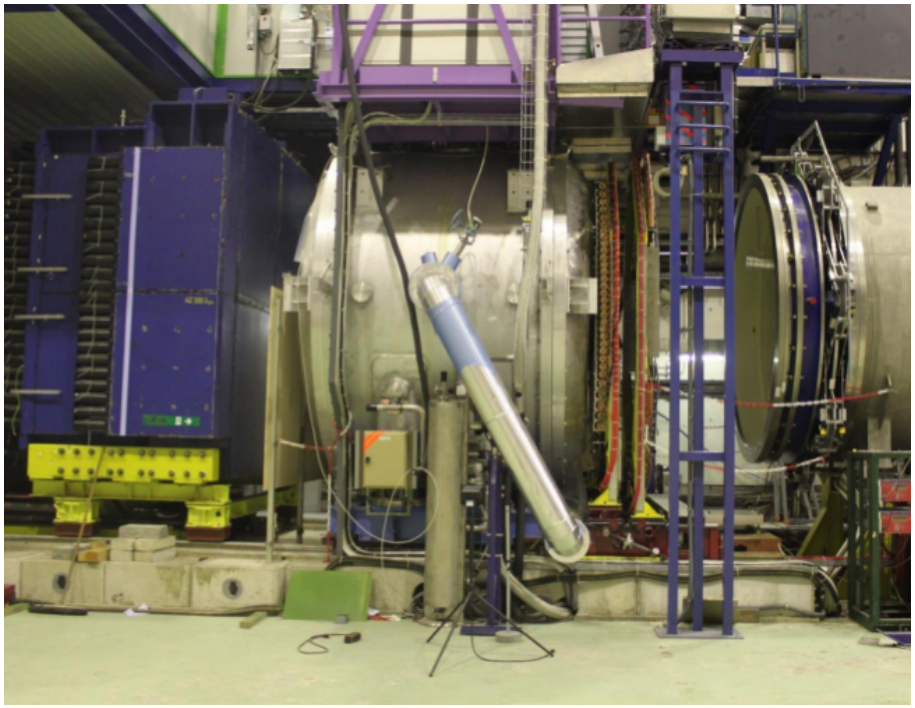
1 mrad ≤ θ < 8.5 mrad



$K^+ \to \pi^+\pi^0$ Photons:

81.2%: 2 in LKr/SAC
18.6%: 1 in LKr/SAC + 1 in LAV
0.2%: 1 in LAV + 1 lost (θ>50mrad)

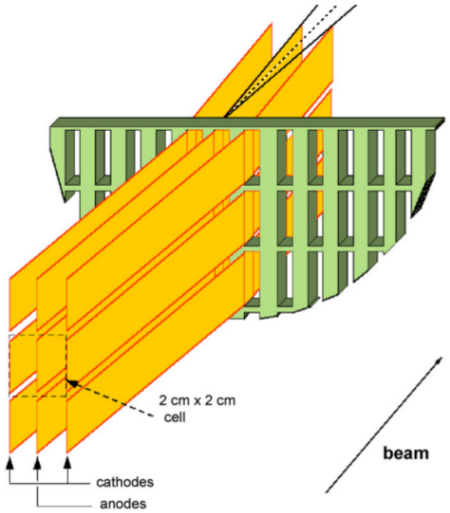
The LKr calorimeter

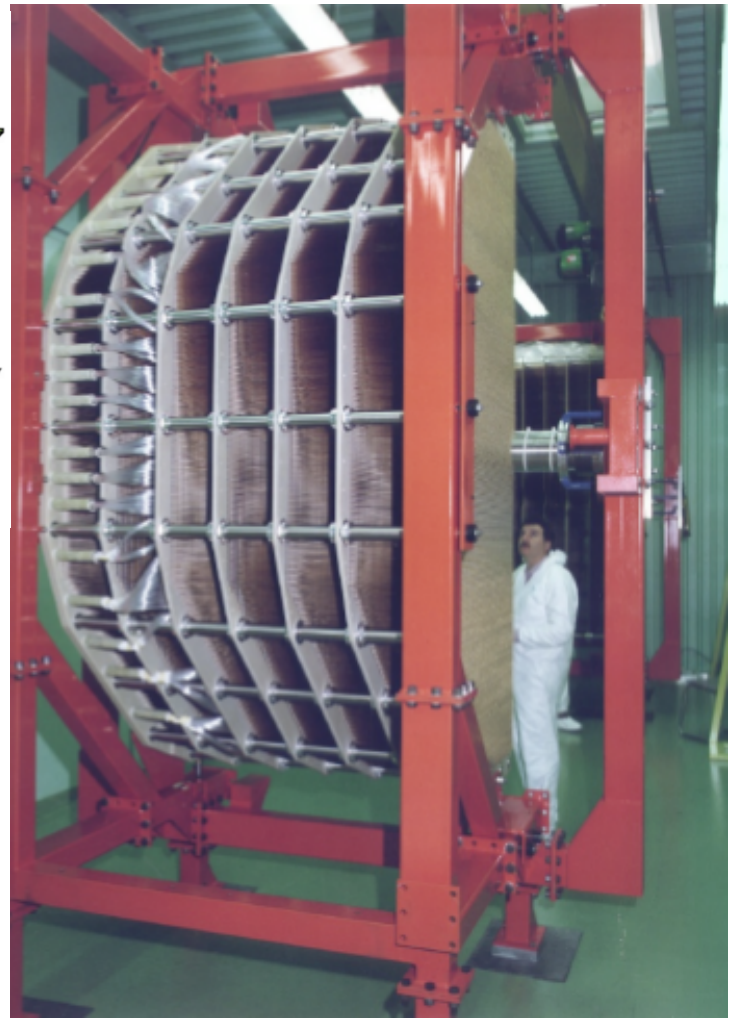


Quasi-homogeneous ionisation calorimeter

Readout towers 2×2cm^2 = 13248 channels

Depth 127 cm = 27 X_0





Photon Inefficiency ($E\gamma > 10$ GeV) < 8×10^{-6}

$$\frac{\sigma_E}{E} = \frac{3.2\%}{\sqrt{E(GeV)}} \oplus \frac{9\%}{E(GeV)} \oplus 0.42\%$$

$$\sigma_{x,y} = \frac{4.2\text{mm}}{\sqrt{E(GeV)}} \oplus 0.6\text{mm} \quad [= 1.5 \text{ mm @ } 10 \text{ GeV}]$$

The Pion ID detectors

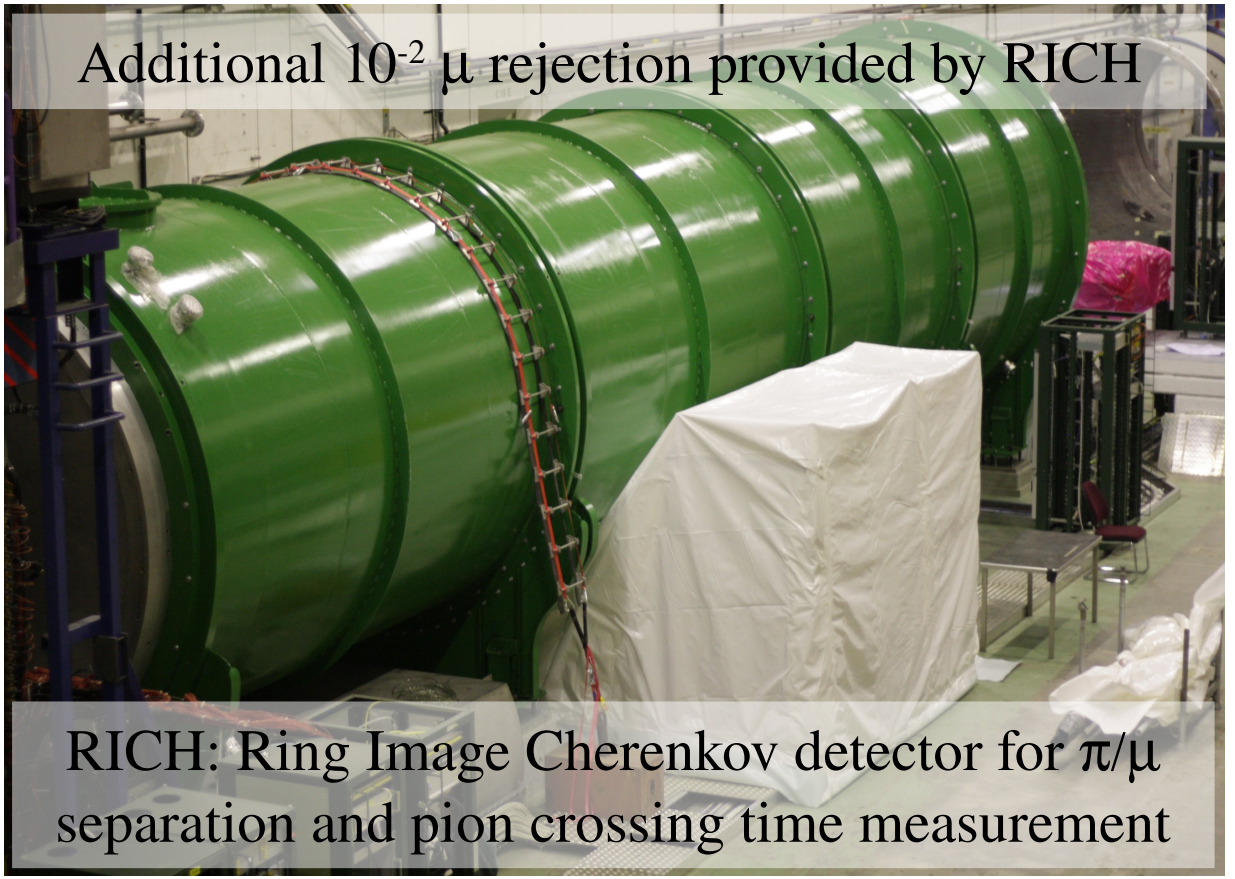
Primary π/μ separation from downstream muon vetoes (MUV)

MUV1-2: Fe/scintillator hadron calorimeter

Used offline to reject μ up to 10^{-5} level

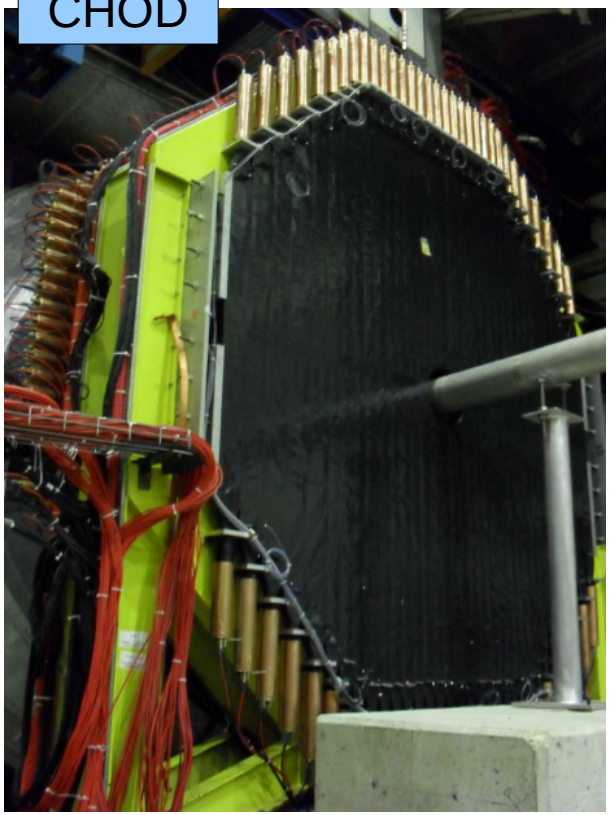
MUV3: Fast μ identification for trigger

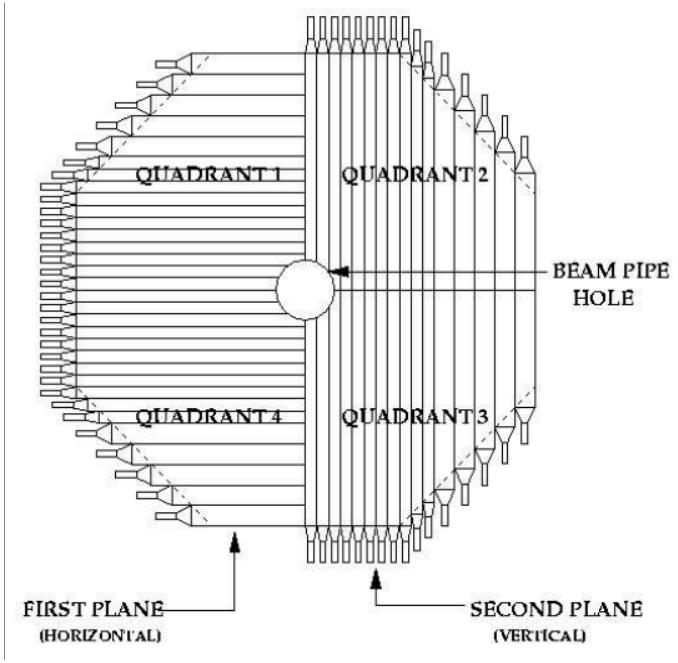
Vetoes μ online @ 10 MHz with $\sigma_t < 1$ ns



The Hodoscope (CHOD) and the CHANTI

CHOD





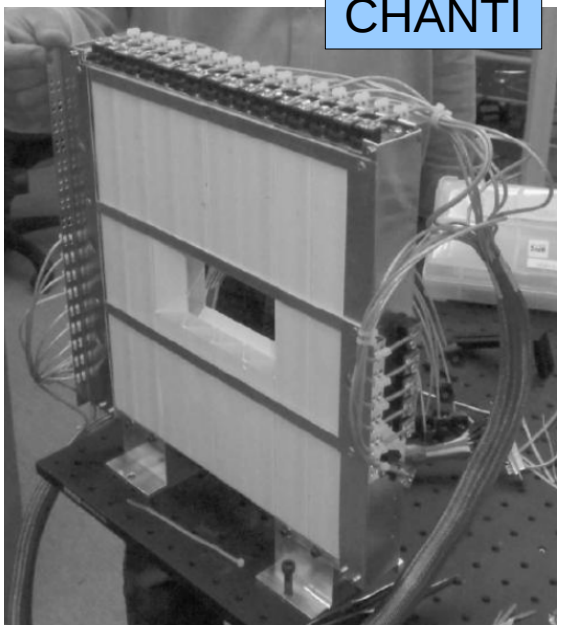
2 planes (horizontal + vertical) of 64 plastic scintillator strips each

Fast charged particles signal for trigger

σ_t ~ 300 ps (after impact point corrections using track extrapolation)

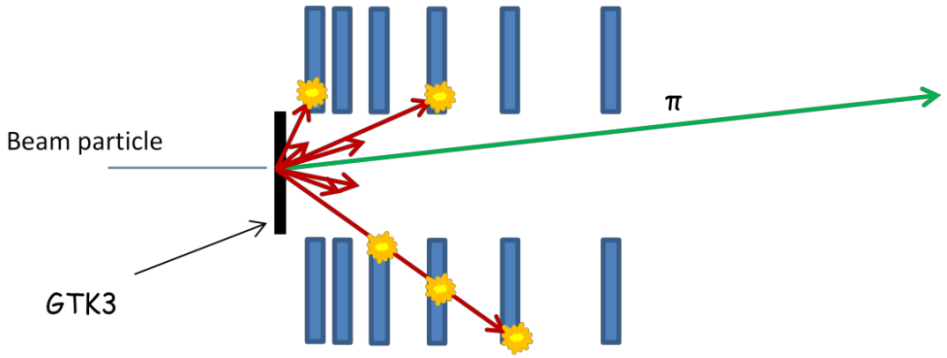
A new CHOD is foreseen from 2015
Old CHOD will be used only in 2014

CHANTI



Veto for charged particles from inelastic interactions in GTK3

6 scintillator stations hermetic between 1.31 and 49 mrad



Physics Sensitivity

Decay	Events/year
$K^+ \to \pi^+ \nu\bar{\nu}$ [SM] (flux 4.5×10^{12})	45
$K^+ \to \pi^+\pi^0$	5
$K^+ \to \mu^+\nu$	1
$K^+ \to \pi^+\pi^+\pi^-$	<1
$K^+ \to \pi^+\pi^-e^+\nu$ + other 3-trks decays	<1
$K^+ \to \pi^+\pi^0\gamma$ (IB)	1.5
$K^+ \to \mu^+\nu\gamma$ (IB)	0.5
$K^+ \to \pi^0e^+(\mu^+)\nu$ + others	negligible
Total background	**<10**

Cut & count analysis without any optimization

e.g. Use of the m^2_{miss} shape to add further signal/background discrimination

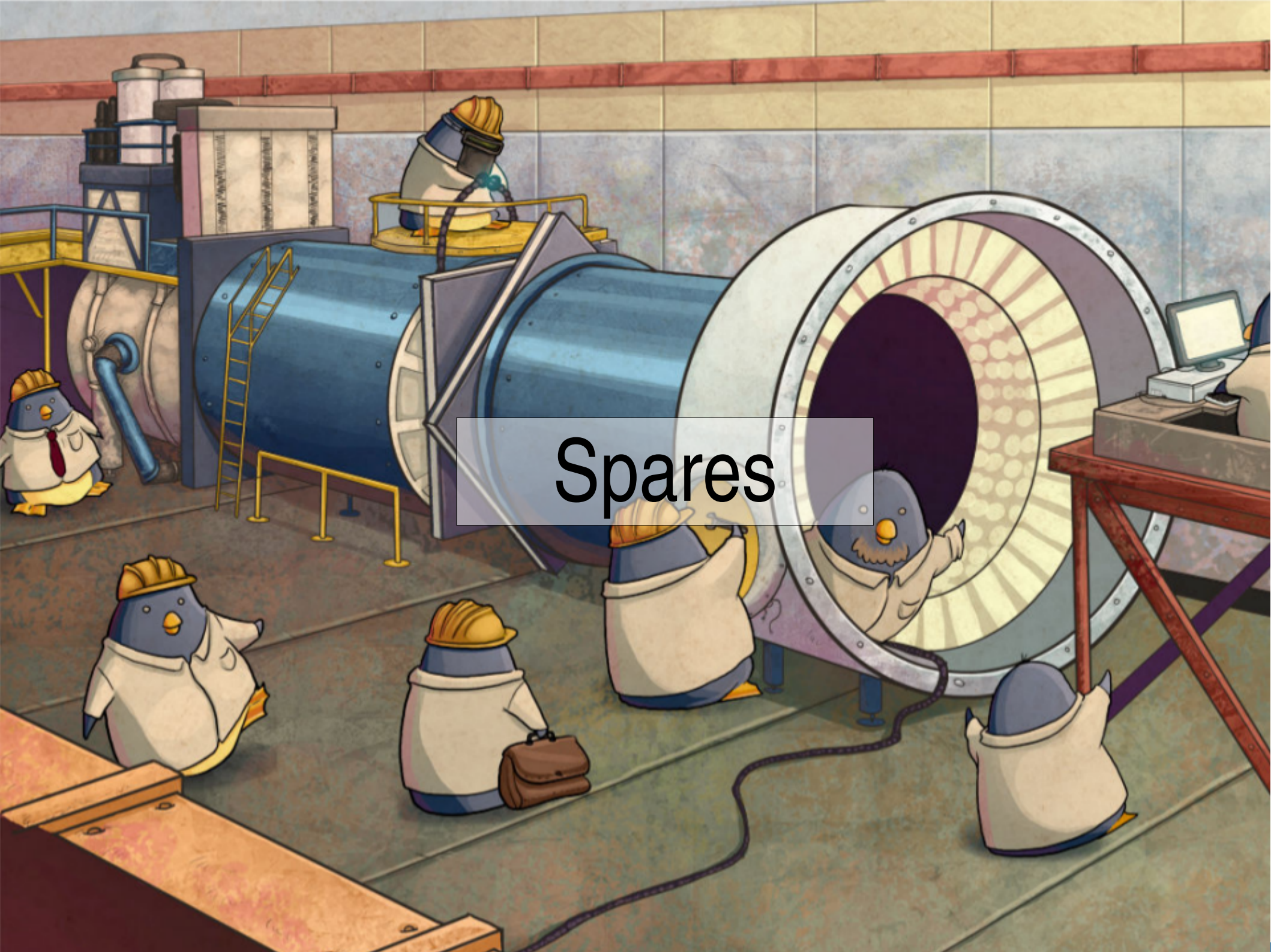
The background must be measured with at least 10% precision

→ Background evaluation to be done on data

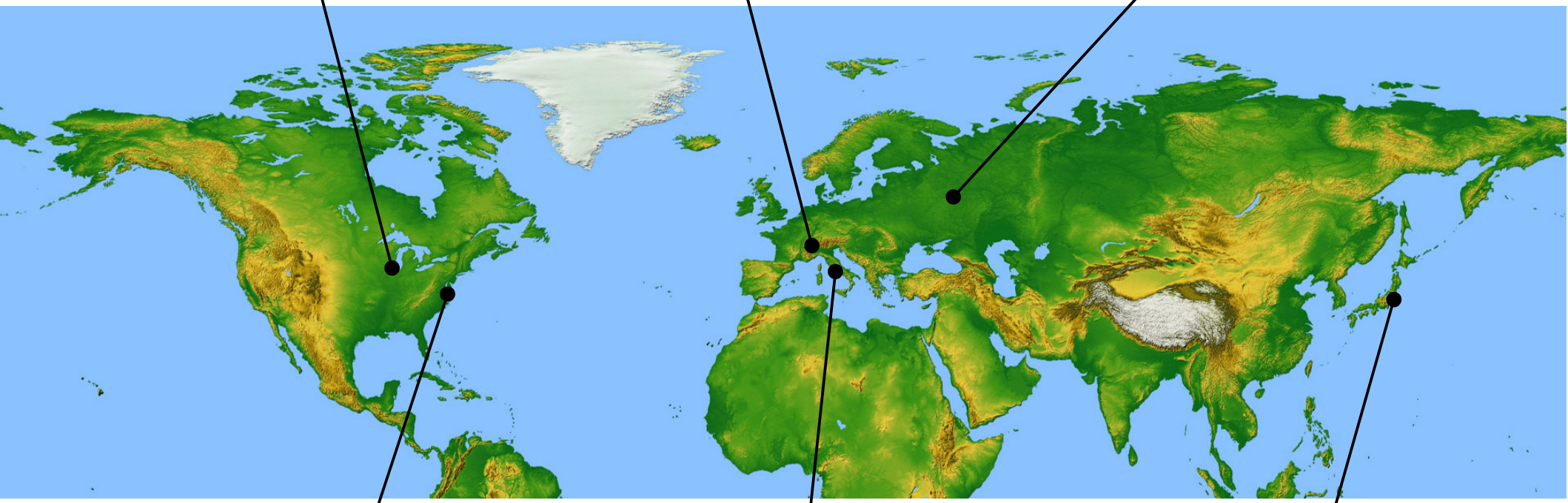
Conclusions

- The $K^+ \to \pi^+ \nu\bar{\nu}$ decay is a sensitive probe of the Flavour Sector of the Standard Model
- The NA62 experiment aims to improve the precision on the BR($K^+ \to \pi^+ \nu\bar{\nu}$) of one order of magnitude
- The NA62 detector installation is in progress, many detectors are already in place
- First Physics Run foreseen for October 2014 (SPS restart)

We look forward to the 2014 data!


Spares

Kaon Physics Facilities



FNAL:
KTeV, ORKA, Project X?

CERN:
NA48, NA62

IHEP:
ISTRA+, OKA

BNL:
E777, E787, E865, E949

LNF:
Kloe, Kloe2

KEK/J-PARC:
E391a, KOTO, TREK

A variety of experimental techniques:
K decay-in-flight (CERN, FNAL), stopped K (BNL, IHEP, JPARC) and a φ factory (LNF)

NA62: Kaon and π^0 factory

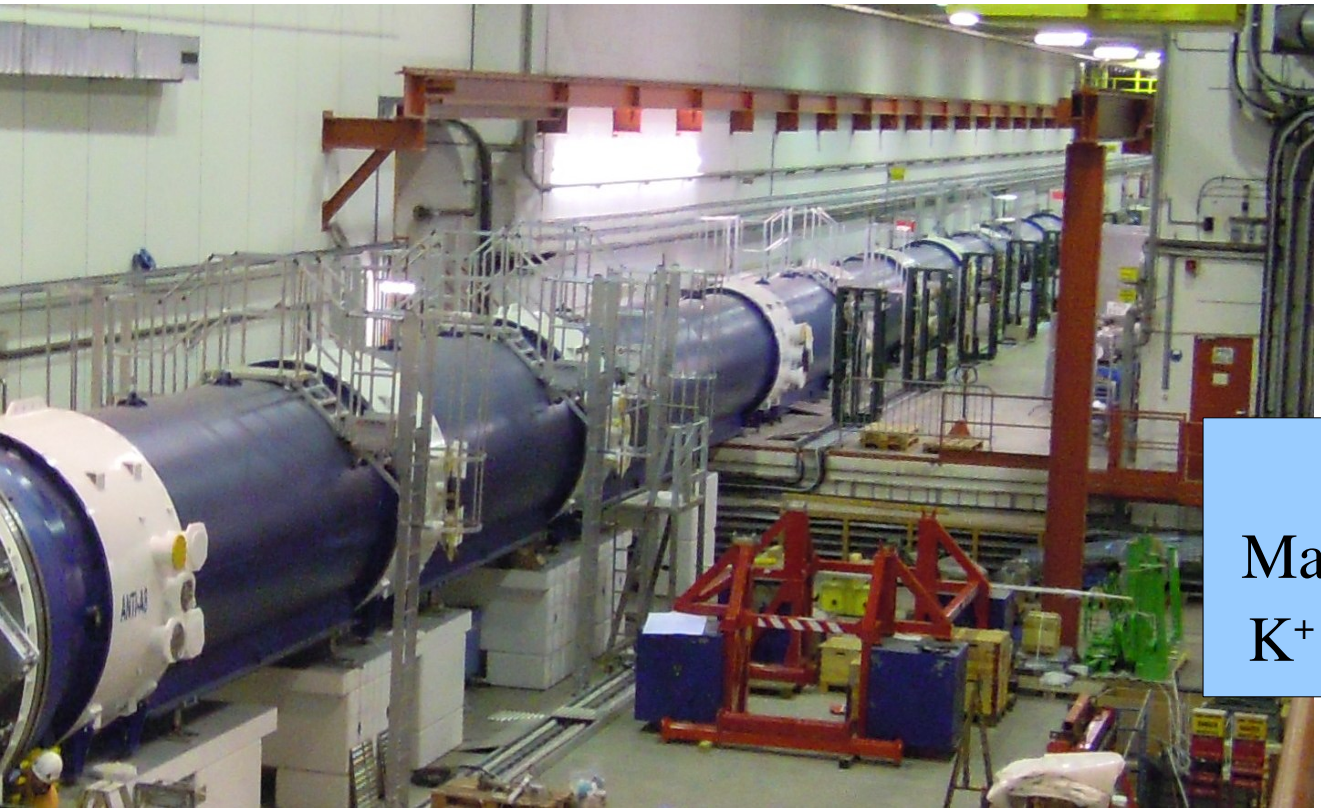
Decay Volume

65m long, starting at z = 102 m from target

10% of K^+ decay in FV ($\beta\gamma c\tau$ = 560 m)

4.5×10^{12} K^+ decays/yr = 45 × NA48/2

10^{12} $K^+ \to \pi^+\pi^0$ decays → π^0 tagging



Single Event Sensitivity (SES):

~ 10^{-12} for Kaon decays

~ 10^{-11} for π^0 decays

Not only $K^+ \to \pi^+\nu\bar{\nu}$!

Many others rare (or forbidden)

K^+ and π^0 decays can be studied

NA62: Kaon and π^0 LFNV decays

Decays in FV in 2 years of data: 1×10^{13} K^+ decays; 2×10^{12} π^0 decays

Single-event sensitivity 1/(decays × acceptance)

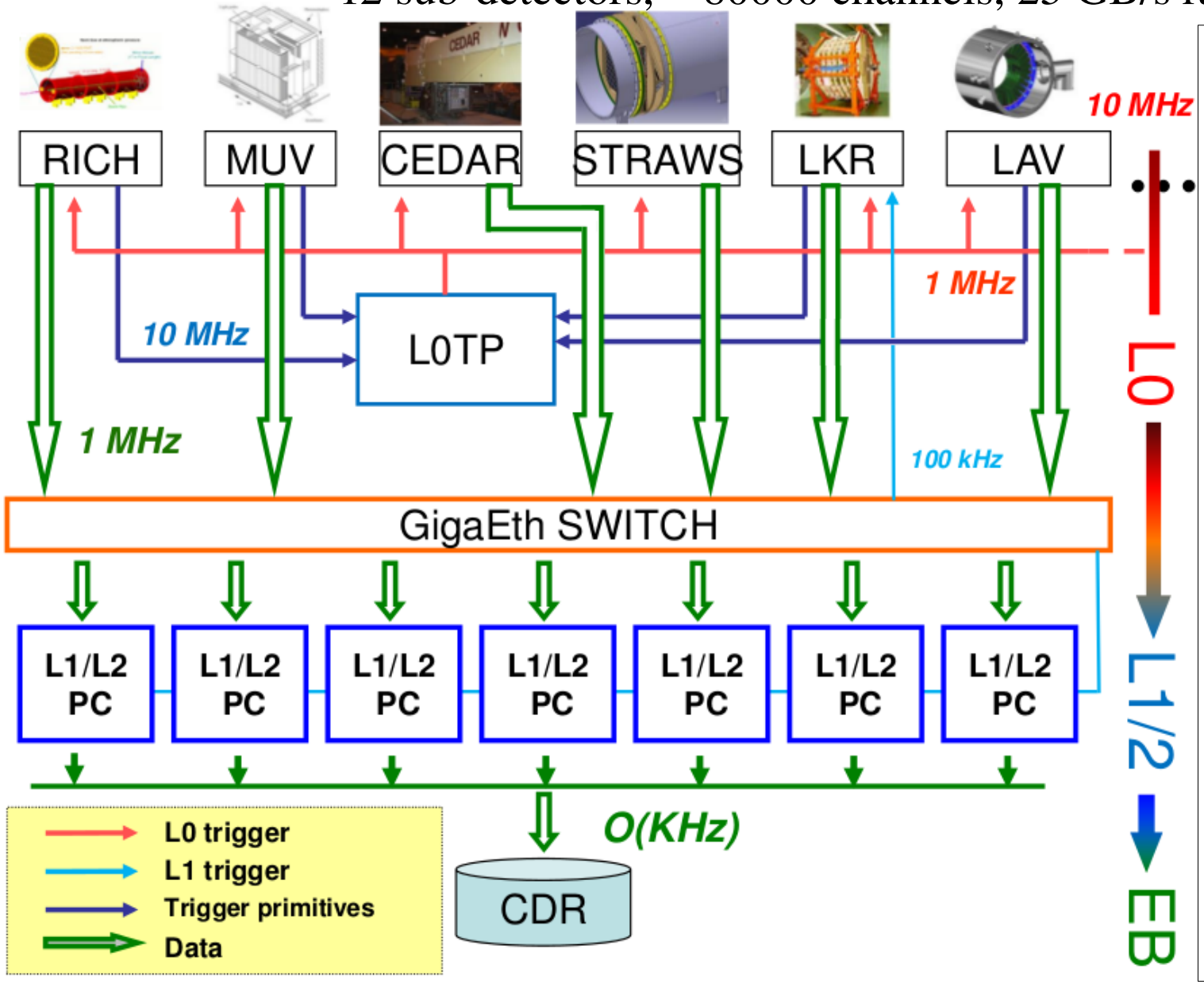
Mode	UL at 90% CL	Experiment	NA62 acceptance*
$K^+ \to \pi^+\mu^+e^-$	1.3×10^{-11}	BNL 777/865	~10%
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}	BNL 865	~10%
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}	BNL 865	~10%
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10}	BNL 865	~5%
$K^+ \to \pi^-\mu^+\mu^+$	1.1×10^{-9}	NA48/2	~20%
$K^+ \to \mu^-\nu e^+e^+$	2.0×10^{-8}	Geneva Saclay	~2%
$K^+ \to e^-\nu\mu^+\mu^+$	no data		~10%
$\pi^0 \to \mu^+e^-$	3.6×10^{-6}	KTeV	~2%
$\pi^0 \to \mu^-e^+$			

* From fast Monte Carlo simulation with flat phase-space distribution. Includes trigger efficiency.

NA62 single-event sensitivities: ~10^{-12} for K^+ decays; ~10^{-11} for π^0 decays

Trigger and Data Aquisition (TDAQ) system

12 sub-detectors, ~ 80000 channels, 25 GB/s raw data



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 information".
100 kHz to 10 kHz.
Max latency O(30 s).