Recent results from NA62 experiment

16th Lomonosov conference
Moscow, 22-28.08.2013

Viacheslav Duk, INFN Perugia
For the NA62 collaboration

Plan

1. NA62 biography
2. Rare kaon decays
3. Results from 2007-2008 run
4. $K \to \pi\nu\nu$ decay
5. Experimental setup
6. Beyond the baseline
7. Conclusions

NA62 biography

1997-2002 **NA48, NA48/1**
Simultaneous K_S, K_L beams
Re ε'/ε, rare K_S and hyperon decays

2003-2004 **NA48/2**
Simultaneous K^+, K^- beams
Direct CP violation, rare $K^\pm$ decays

2007-2008 **NA62** (using NA48/2)
$R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$

NA62 main goal:
measure $K^+ \to \pi^+ \nu\nu$ decay
(~100 events with S/B~10)

Beyond the baseline:
- ✓ Decays with LFV
- ✓ Heavy neutrinos
- ✓ π^0 decays

NA62 collaboration:
Birmingham, Bratislava, Bristol, CERN, JINR 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, Sofia, Stanford, Turin

Rare kaon decays

Do we still need kaon physics in the LHC era?

Towards the Identification of New Physics through Correlations between Flavour Observables

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IAS TUM Institute for Advanced Study

erc

EPS-HEP Stockholm
July 2013

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Rare kaon decays

Message from A.Buras for NA62 and others

Important Messages on K Physics

1. Many Models (SUSY, 4G, LHT, RS) can still accommodate

$$Br\left(K^+ \to \pi^+ \nu\bar{\nu}\right) \sim 2Br\left(K^+ \to \pi^+ \nu\bar{\nu}\right)_{SM}$$

$$Br\left(K_L \to \pi^0 \nu\bar{\nu}\right) \sim 3Br\left(K_L \to \pi^0 \nu\bar{\nu}\right)_{SM}$$

2. Even if no significant New Physics would be seen in B-decays large effects in $K \to \pi\nu\bar{\nu}$ are possible.

3. LHCb opened the road for large effects in LHT, RSc.

4. ε'/ε very important provided QCD Penguin hadronic matrix under control

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Results from 2007-2008 run

R_K = BR(Ke2(γ)) / BR(Kμ(γ)) measurement:

Motivation: Lepton flavor universality test

- ✓ Best statistics (145958 events of Ke2 decay)
- ✓ ~0.4% accuracy achieved
- ✓ Result: $R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5}$

(in accordance with SM predictions)

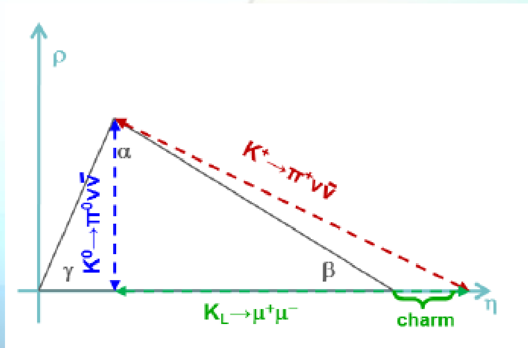
K→πγγ decay:

Motivation: ChPT tests

- ✓ Best statistics (~300 events, combined with 2003-2004 run)
- ✓ Result: ChPT $O(p^4)$ and $O(p^6)$ cannot be distinguished
- ✓ Model-independent BR measurement with accuracy <10%
- ✓ Details: see talk by Andrea Bizzeti on August 27

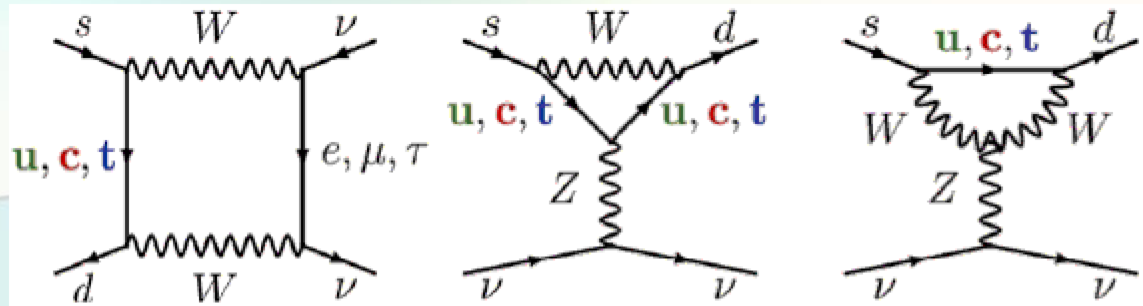
$K\to\pi\nu\nu$ decay

Golden kaon modes



FCNC process:

- Forbidden at tree level
- Box and penguin diagrams
- Small BR (λ^5 suppression)



- ✓ Theoretically clean (~10%)
- ✓ Main contribution from Short Distance
- ✓ 2-loop EW corrections below 1%
- ✓ Hadronic matrix elements related to well known decay $K^+\to e^+\nu\pi^0$
- ✓ Sensitive to New Physics

SM branching ratios

(Brod, Gorbahn, Stamou; PRD83 (2011) 034030)

Mode	$BR_{SM}\times10^{11}$
$K^+\to\pi^+\nu\bar{\nu}(\gamma)$	$7.81\pm0.75\pm0.29$
$K_L\to\pi^0\nu\bar{\nu}$	$2.43\pm0.39\pm0.06$

Parametric error
(V_{cb}, ρ measurements)

theoretical error
(LD corrections)

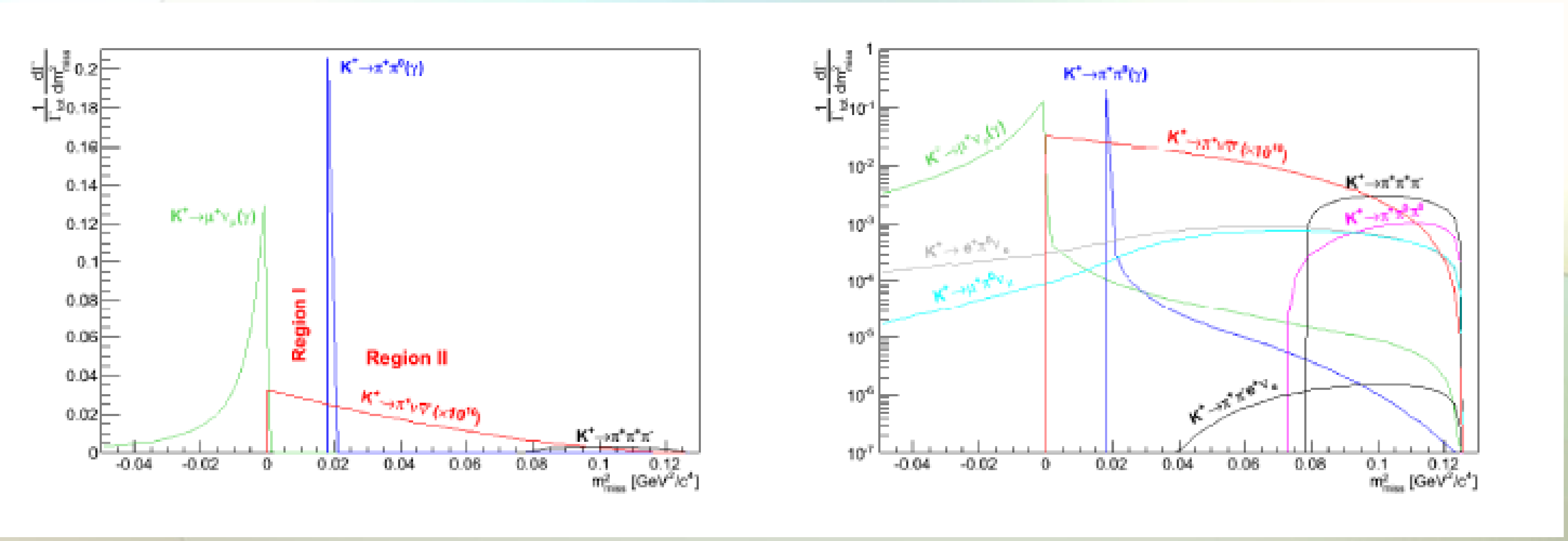
Experimental result:
E787/E949 (BNL)

$$BR=(1.73\,^{+1.15}_{-1.05})\times10^{-10}$$

K→πνν decay: measurement principles

main kinematic variable:

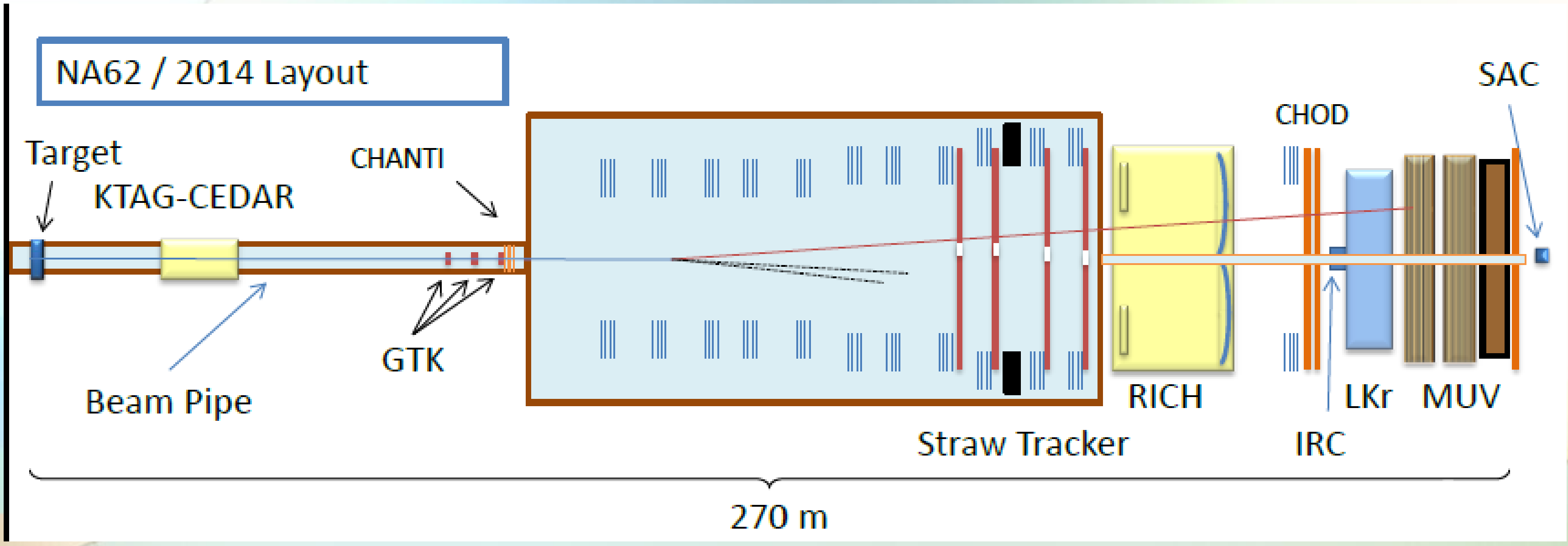
$M_{miss}^2 = (P_K - P_\pi)^2$

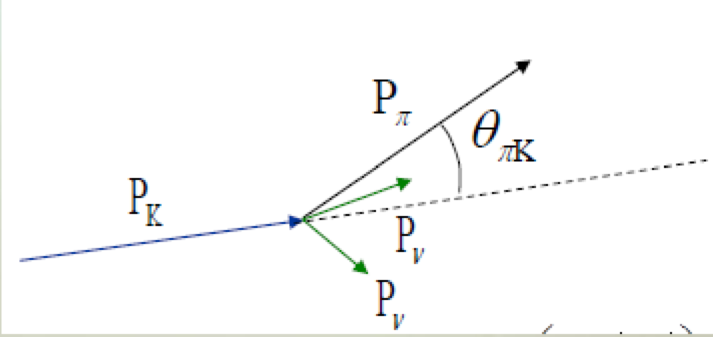


2 signal regions split by the Kπ2 peak:

- ✓ 92% background decays outside kinematical region
- ✓ 8% background should be rejected by vetoes and PID

Experimental setup



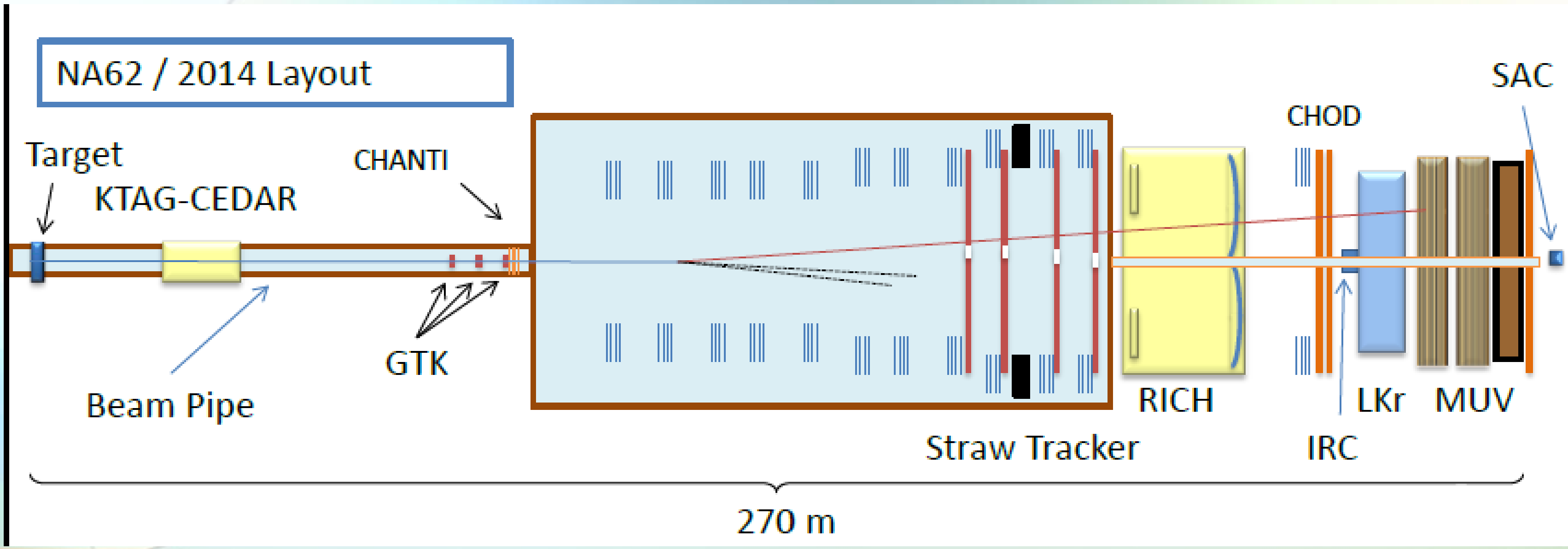


Basic principles:

- ✓ Decays-in-flight technique (60m decay volume, ~10% decayed kaons)
- ✓ High intensity, fast timing
- ✓ Kinematic reconstruction
- ✓ particle ID
- ✓ Efficient veto
- ✓ ~10% acceptance

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

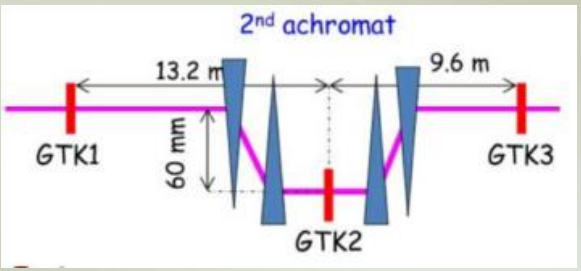
Experimental setup: kaon measurement



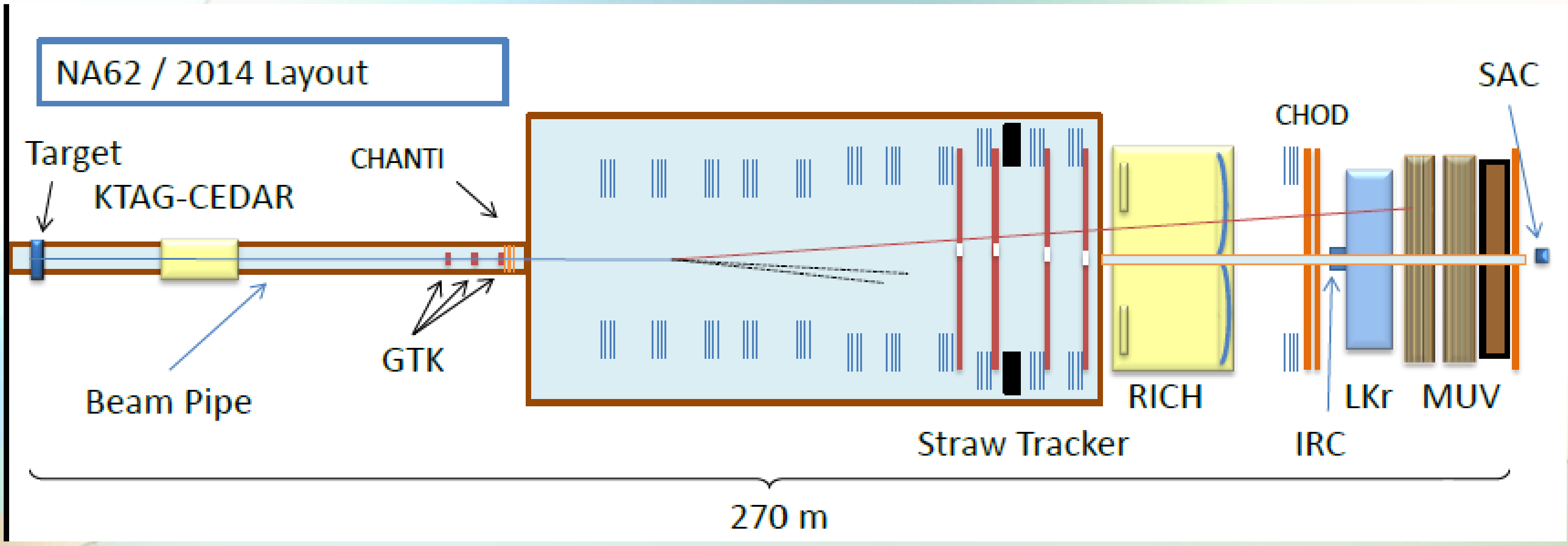
Beam:
- ✓ 400 GeV/c protons from SPS
- ✓ 3 x 10^{12} protons per pulse on target
- ✓ 75 GeV/c secondary beam
- ✓ ~6% of K^+ (unseparated beam)
- ✓ 750MHz @ beam tracker
- ✓ 10MHz downstream
- ✓ 4.8 x 10^{12} kaon decays per year

KTAG/Cedar:
- ✓ Differential Cherenkov counter for kaon ID
- ✓ High rate environment
- ✓ H_2 at 3.6 bar
- ✓ ~100ps time resolution

GTK:
- ✓ 3 Si pixel stations
- ✓ 300 x 300 μm pixels
- ✓ Very thin (~0.5X_0 per station)
- ✓ Δp/p ~ 0.2%
- ✓ 200ps per station time resolution



Experimental setup: pion measurement

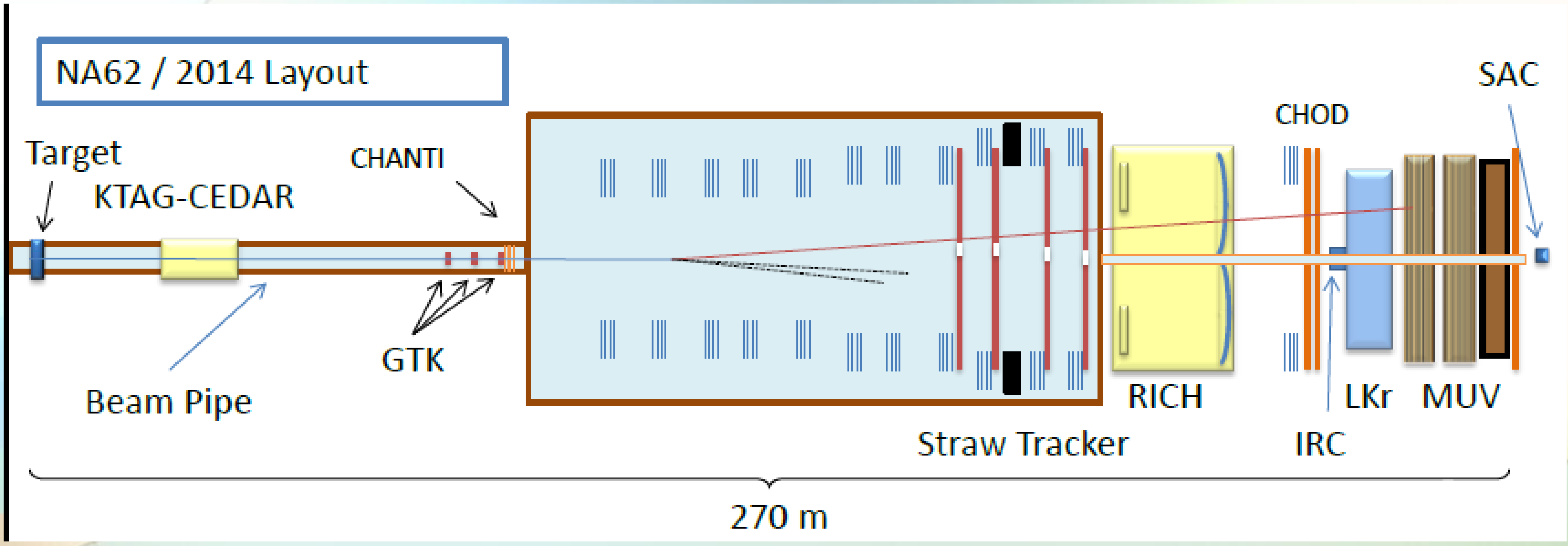


Straw:
- ✓ 4 straws in vacuum
- ✓ Spectrometer magnet (256 MeV/s kick)
- ✓ $\Delta p/p < 1\%$
- ✓ $\Delta\theta\pi \leq 66$ μrad

RICH:
- ✓ Ne at atmospheric pressure
- ✓ μ-π separation at ~1% for 15 < P < 35 GeV/c
- ✓ Time resolution ~100 ps
- ✓ L0/L1 trigger signals

CHOD:
- ✓ 2 planes with 128 scintillator slabs read by PMs
- ✓ L0 trigger signal

Experimental setup: photon veto systems



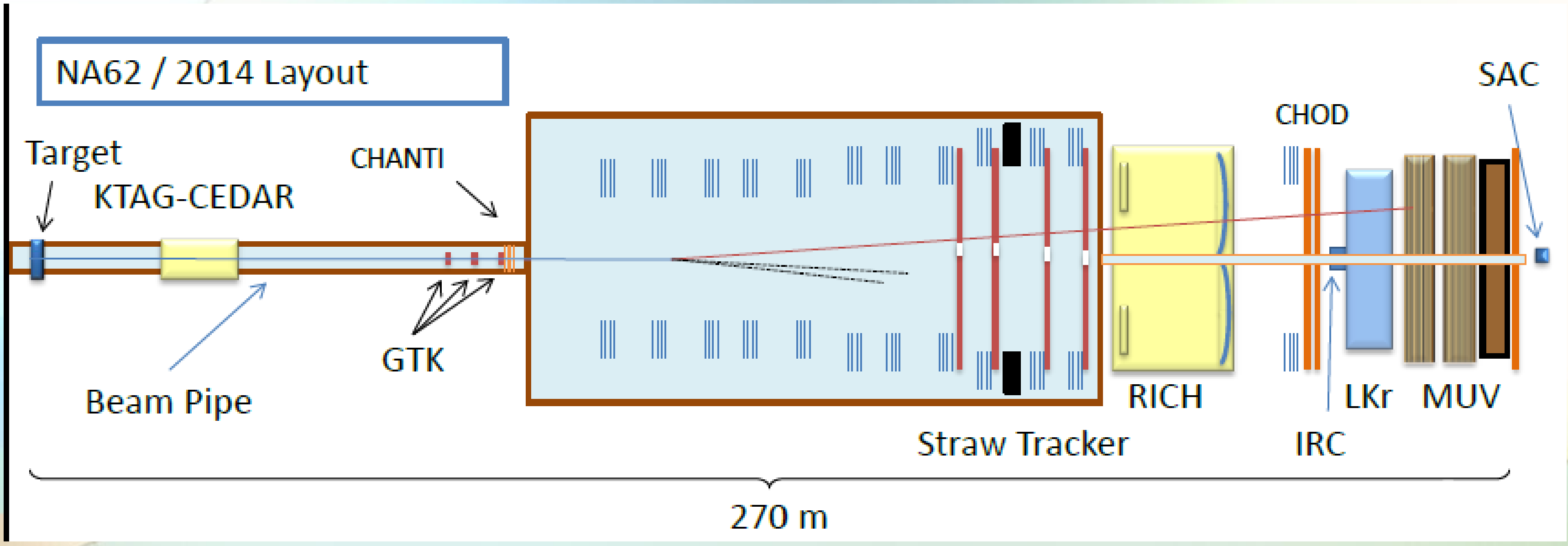
LAV:
- ✓ 12 stations in vacuum
- ✓ Cover 8.5 to 50 mrad
- ✓ OPAL lead glass read by PMs
- ✓ ~18.6 X_0

LKr:
- ✓ NA48/2 em calorimeter
- ✓ Cover 1 to 8.5 mrad
- ✓ ~27 X_0
- ✓ γ detection inefficiency for E>10 GeV: $(1-\varepsilon) < 8\times10^{-6}$
- ✓ 100ps time resolution

IRC & SAC:
- ✓ Small angle calorimeters
- ✓ Cover <1 mrad

LAV+LKr+IRC+SAC:
~10^8 rejection of $\pi^0\to\gamma\gamma$

Experimental setup: veto systems



CHANTI:
- ✓ 6 stations after GTK3
- ✓ Identify upstream inelastic interactions
- ✓ Identify muon halo

MUV1 & MUV2:
- ✓ Iron/scintillator sandwich calorimeter

MUV3:
- ✓ Iron wall + scintillator
- ✓ Light read by PMs
- ✓ Fast trigger signals

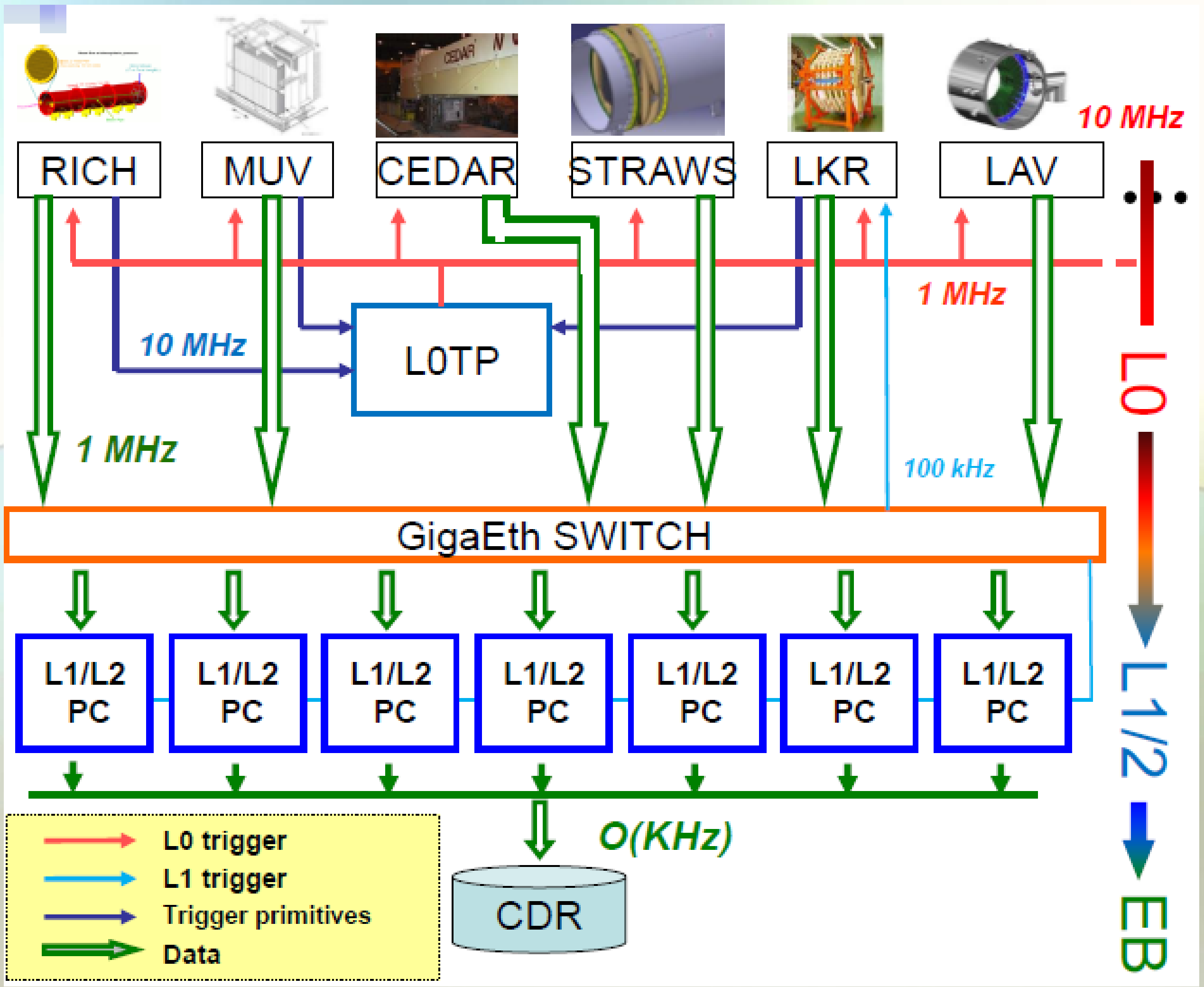
MUV+RICH:
~10^7 muon rejection

Experimental setup: trigger

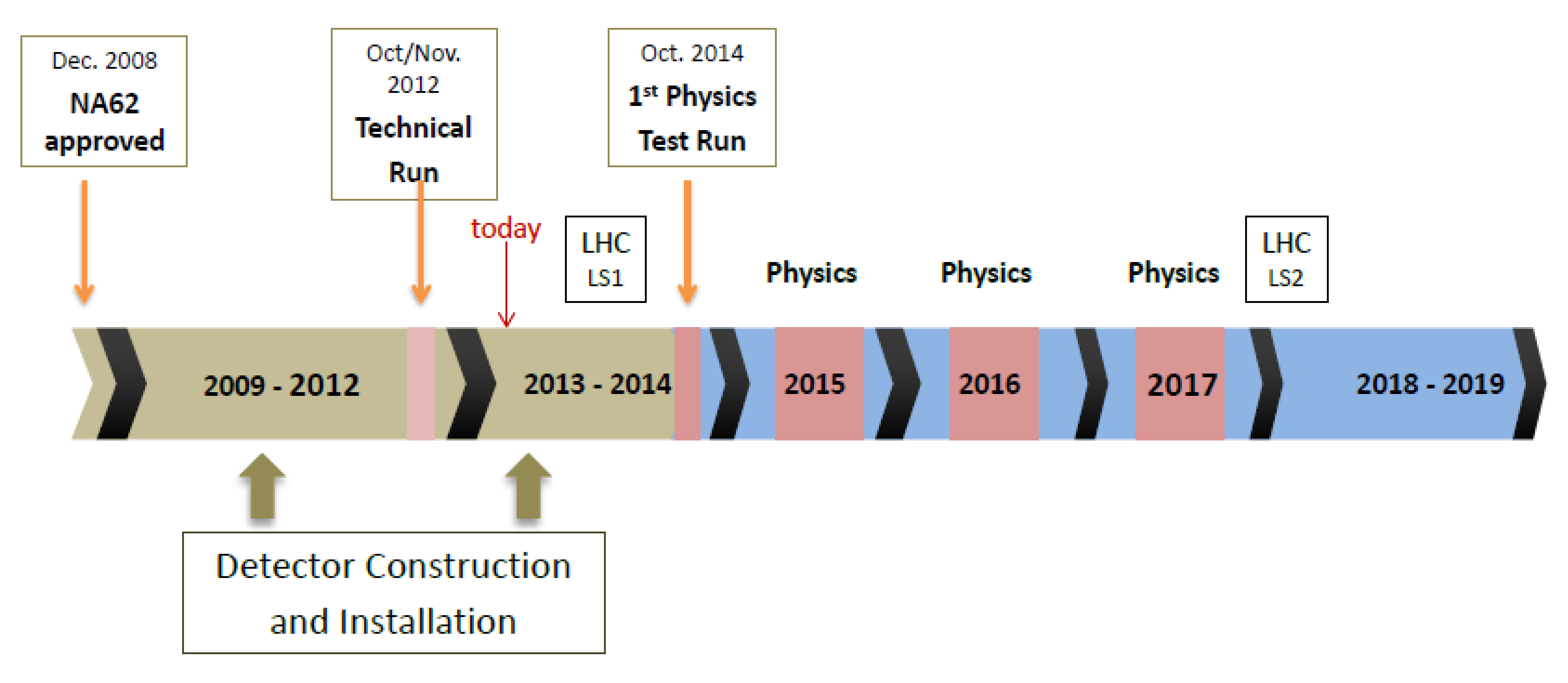
L0:
- ✓ Hardware trigger
- ✓ RICH+CHOD+!LKr+ !MUV3

L1:
- ✓ Software trigger
- ✓ “single detector”

L2:
- ✓ Software trigger
- ✓ Correlations between detectors



Status of the experiment

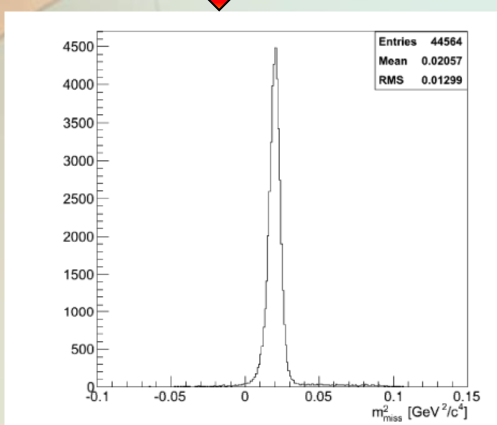


- 5 years of construction interleaved with a Technical Run in fall 2012
- In 2014 a first Run with full detector
- Plan 3 years of Physics data taking before LHC Long Shutdown 2 (LS2)

Technical Run 2012

Partial setup:
LKr, Cedar/KTAG, CHOD, MUV2, MUV3

TR goals:
- ✓ Tests of readout electronics, detector, infrastructure
- ✓ Kπ2 reconstruction

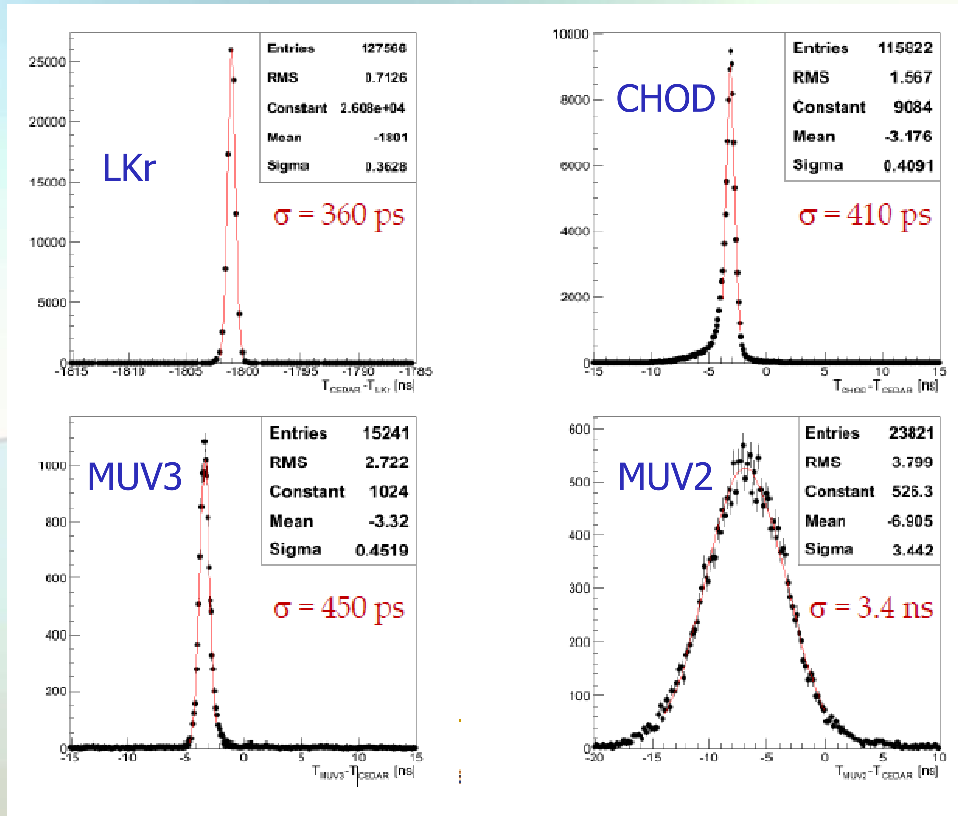


$$m^2_{miss} = (P_K - P_{\pi^0})^2$$

$$m^2_{miss} = 0.0198 \pm 0.0003\, GeV^2/c^4$$

(PDG : 0.0195)

Time distirbutions wrt Cedar/KTAG



detector	Resolution (ps)
Cedar/KTAG	150
LKr	350
CHOD	400 (240 after time corrections)
MUV3	450

Beyond the baseline: search for LFNV decays

π^0 tagged from $K\pi 2$ decay

2 years of data taking:
1.2×10^{13} K^+ decays
2.5×10^{12} π^0 decays

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	
$K^+ \to \pi^-\mu^+e^+$	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%
$\pi^0 \to \mu^+e^-$	3.8×10^{-10}	KTeV	~2%
$\pi^0 \to \mu^-e^+$	3.4×10^{-9}		

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

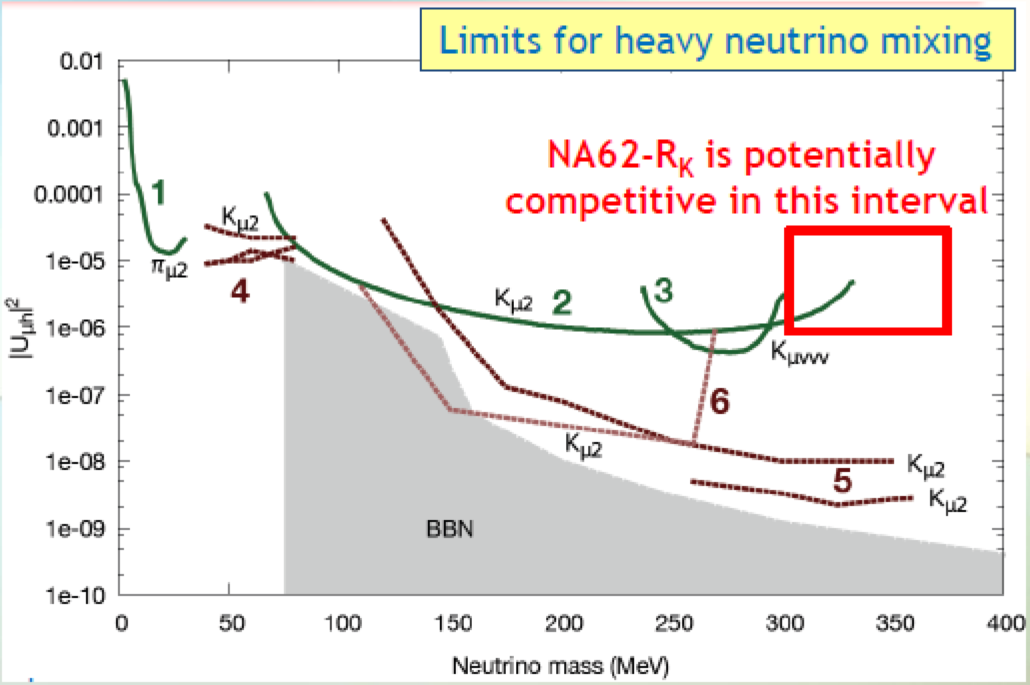
NA62 single-event sensitivities: **~10^{-12} for K^+ decays**
~10^{-11} for π^0 decays

Beyond the baseline: heavy ν

Search for heavy ν: peak in $K\to\mu N$ decay

NA62:

- ✓ 18M Kμ2 data sample (2007-2008 run)
- ✓ UL if no backgrounds: $|U_{\mu N}|^2 < 10^{-7}$
- ✓ Sensitivity limited by background subtraction
- ✓ Prospects for high masses



Peak searches (long-lived ν_h)
1. PSI, PLB 105 (1981) 263.
2. KEK, PRL 49 (1982) 1305.
3. LBL, PRD 8 (1973) 1989.

Decay searches (short-lived ν_h)
4. ISTRA+, PLB 710 (2012) 307.
5. CERN-PS191, PLB 203 (1988) 332
6. BNL-E949, preliminary

conclusions

- ✓ NA62 is a challenging kaon experiment
- ✓ The main goal is to measure $K^+ \rightarrow \pi^+ \nu\nu$ with 10% precision
- ✓ Other goals: LFNV searches in K^+ and π^0 rare decays
- ✓ Extensive setup tests were performed during Technical Run 2012
- ✓ NA62 will start data taking in the end of 2014

THANK YOU!

Spares

Background budget

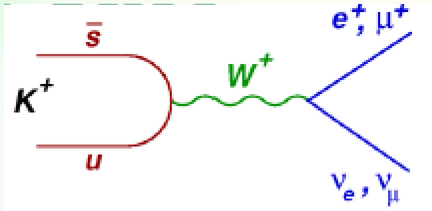
Decay	BR
$K^+ \to \mu^+ \nu$ ($K_{\mu 2}$)	63.5%
$K^+ \to \pi^+ \pi^0$	20.7%
$K^+ \to \pi^+ \pi^+ \pi^-$	5.6%
$K^+ \to \pi^+ \pi^0 \pi^0$	1.8%
$K^+ \to \pi^0 \mu^+ \nu$ ($K^+_{\mu 3}$)	3.3%
$K^+ \to \pi^0 e^+ \nu$ (K^+_{e3})	5.1%

Decay	evt/year
$K^+ \to \pi^+ \nu\nu$ [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 tracks decays	< 1
$K^+ \to \pi^+ \pi^0 \gamma$(IB)	1.5
$K^+ \to \mu^+ \nu \gamma$(IB)	0.5
$K^+ \to \pi^0 e^+ (\mu^+) \nu$, others	negligible
Total background	< 10

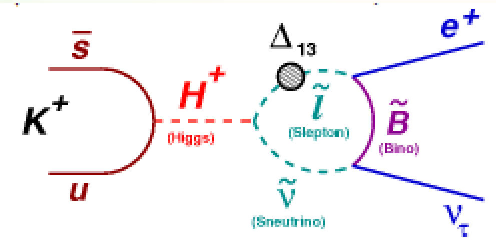
Simple cut and count estimation with no optimization
Background to be evaluated on data to reach the 10% accuracy

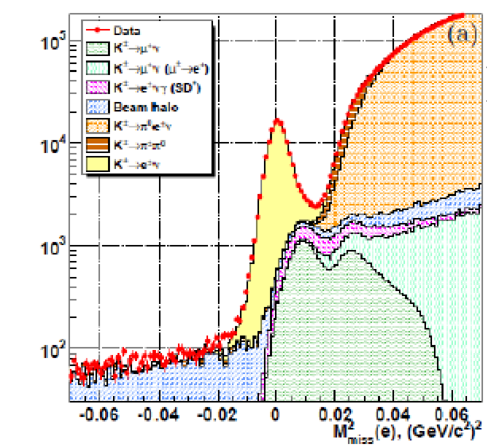
RK measurement

SM: $$R_K = \frac{\Gamma(K^\pm \to e^\pm \upsilon)}{\Gamma(K^\pm \to \mu^\pm \upsilon)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot \left(1 + \delta R_K^{\text{rad.corr.}}\right)$$



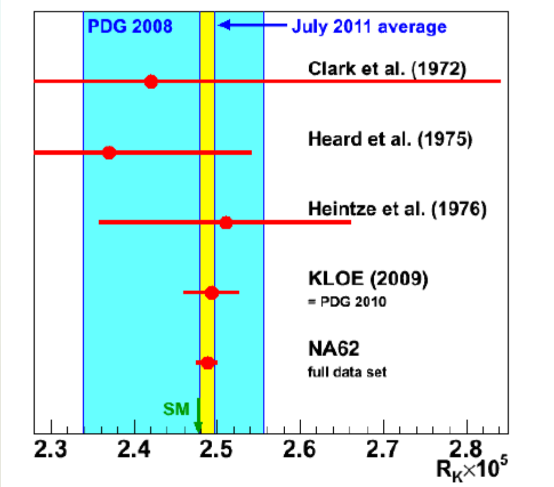
NP: $$R_K^{MSSM} = R_K^{SM} \cdot \left[1 + \left(\frac{m_K^4}{m_{H^\pm}^4}\right) \cdot \left(\frac{m_\tau^2}{m_e^2}\right) \cdot |\Delta_{13}|^2 \cdot \tan^6 \beta\right]$$

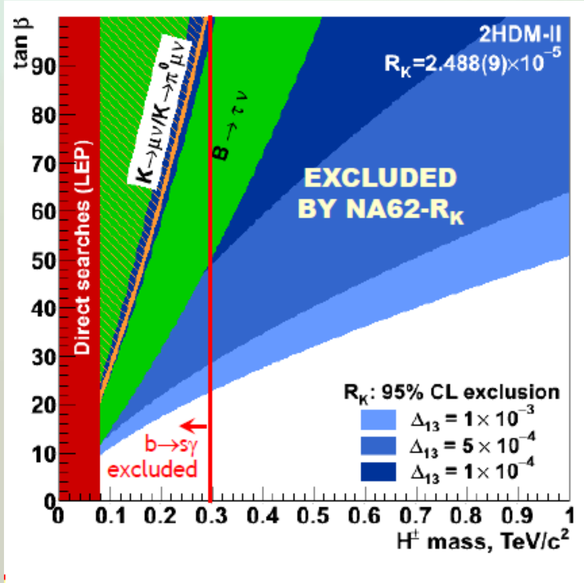




Ke2 sample

Full 2007 data sample analyzed: 145'958 K_{e2}

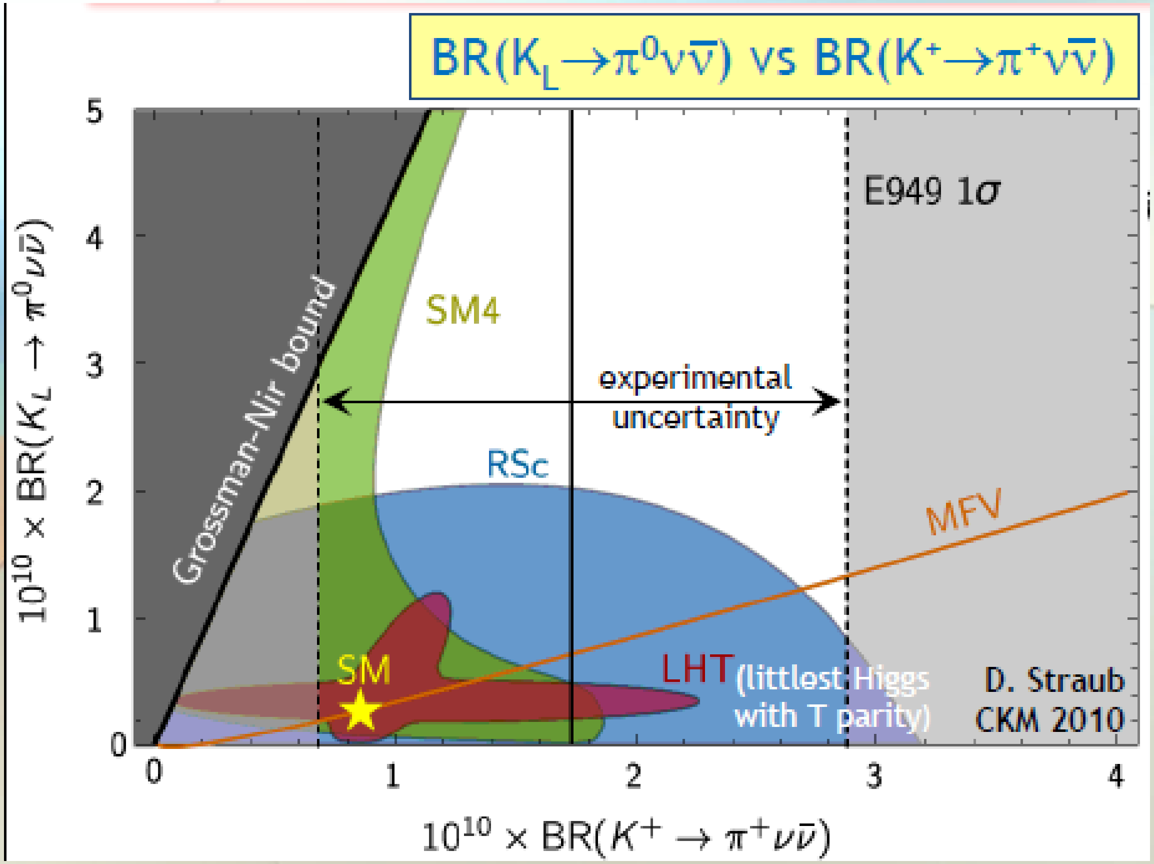




$R_K = (2.488 \pm 0.007_{stat.} \pm 0.007_{syst.}) \times 10^{-5} = (2.488 \pm 0.010) \times 10^{-5}$

[Phys. Lett. B 719 (2013) 326]

K→πνν decay: NP contributions



SM4: SM with 4th generation (Buras et al. '10)

RSc: Custodial Randall-Sundrup (Blanke '09)

LHT: Littlest Higgs with T parity (Blanke '10)

MFV: Minimal flavor violation (Hurth et al. '09)!

π^0 decays: U boson search

New, light vector gauge boson with weak couplings to charged SM fermions

Could mediate interactions of dark-matter constituents

Not pure speculation, could explain e.g.:

- PAMELA e^+ excess
- DAMA/LIBRA, CoGent dark-matter signals
- 3.6σ discrepancy in $a_\mu = (g-2)/2$

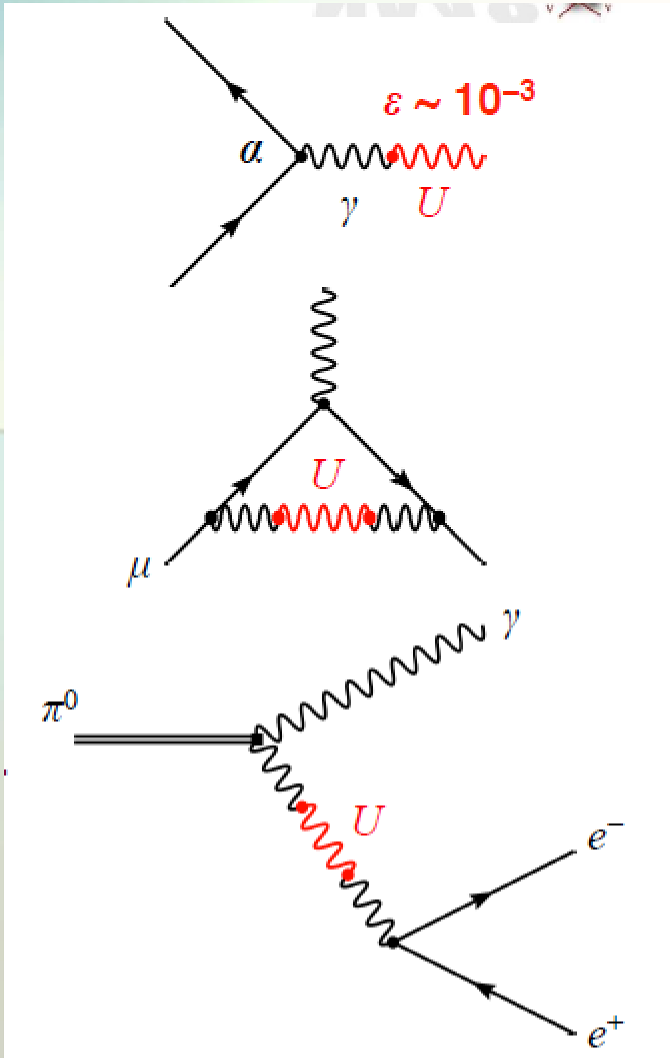
Search for U boson in $\pi^0 \to e^+e^-\gamma$ decay:

MC studies indicate acceptable rate and good efficiency can be obtained with multi-track trigger with $e^\pm$ PID: $Q_2 \cdot LKR_2(10)$

Expect to collect ~10^8 $\pi^0 \to e^+e^-\gamma$ decays/year

Mass resolution $M_{ee} \sim 1$ MeV, even before kinematic fit

Potential for ~100× improvement in BR limit for $30 < M_U < 100$ MeV



Forbidden pion and kaon decays in NA62 – M. Moulson (Frascati) – KAON 2013 – Ann Arbor, MI – 29 April 2013

π^0 decays: $\pi^0 \rightarrow$ invisible

$$\text{BR}(\pi^0 \rightarrow \nu\bar{\nu}) = 3 \times 10^{-8}\, k \left(\frac{m_\nu}{m_{\pi^0}}\right)^2 \left[1 - 4\left(\frac{m_\nu}{m_{\pi^0}}\right)^2\right]^{1/2} \qquad k = \begin{cases} 1 \text{ if Dirac type} \\ 2 \text{ if Majorana type} \end{cases}$$

Direct experimental limit:

$\text{BR}(\pi^0 \rightarrow \text{inv}) < 2.7 \times 10^{-7}$ 90%CL — **BNL 949 (2005)**

Limit from ν_τ mass measurement:

$m_{\nu\tau} < 18.2$ MeV 95%CL — **ALEPH (1998)**

Implies $\text{BR}(\pi^0 \rightarrow \nu\bar{\nu}) < 5 \times 10^{-10}$

Limits from astrophysics/cosmology:

$\text{BR}(\pi^0 \rightarrow \nu\bar{\nu}) < 3 \times 10^{-13}$

$m_{\nu\tau} \sim 400$ keV

Potential — **Limit $\text{BR}(\pi^0 \rightarrow \text{invisible})$ to less than 10^{-9}**

~100× better than present limits