Stato e prospettive di misura dell'esperimento NA62

IFAE, L'Aquila 9th April 2014

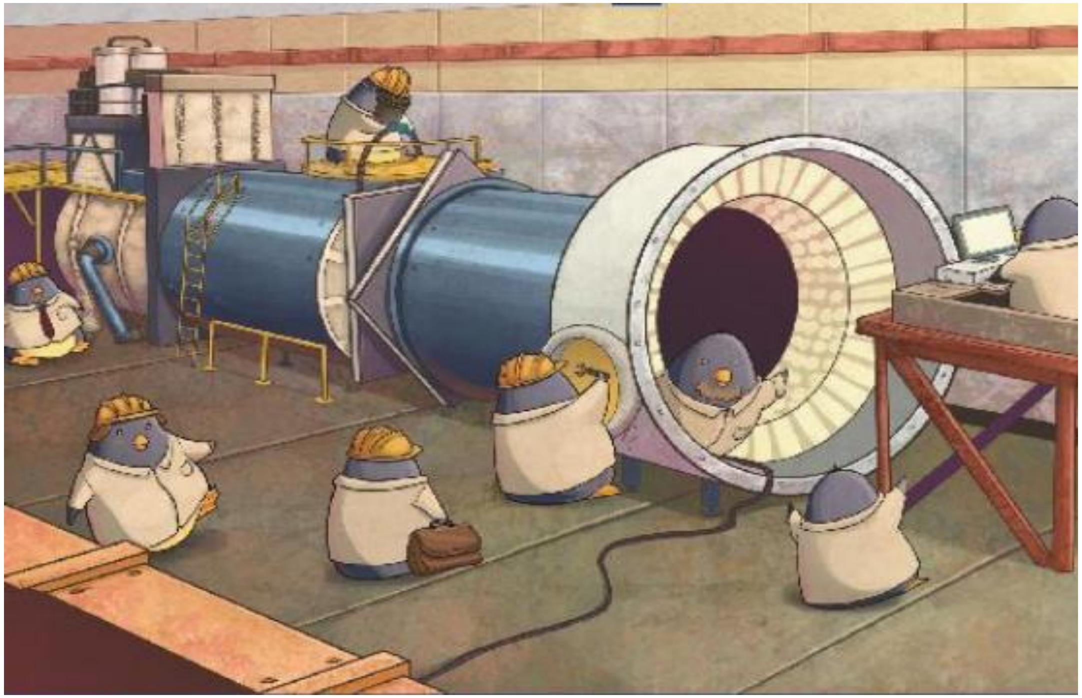
Marco Mirra – Università degli studi di Napoli Federico II and INFN Napoli

on behalf of the NA62 collaboration:

Birmingham, Bratislava, Bristol, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, Glasgow, Liverpool, Louvain, Mainz, Merced, Moscow, Napoli, Perugia, Pisa, Prague, Protvino, Roma I, Roma II, San Luis Potosi, Stanford, Sofia, Torino

Outline

- **NA48/2 and NA62 (R_K phase)**
- $K^+ \rightarrow \pi^+ \nu\nu$ **decay**
- **NA62 experimental apparatus**
- **NA62 expected results**



K_{e2} and $K_{\mu 2}$: motivations

- $K, \pi \rightarrow \ell\nu$ decays are helicity suppressed in SM

$$\Gamma^{SM}(P^{\pm} \rightarrow \ell^{\pm}\nu) = \frac{G_F^2 M_P M_\ell^2}{8\pi}\left(1 - \frac{M_\ell^2}{M_P^2}\right) f_P^2 \left|V_{qq'}\right|^2$$

- The ratio R_K accurately predicted within the SM

$$R_K^{SM} = \frac{\Gamma^{SM}(K^{\pm} \rightarrow e^{\pm}\nu_e)}{\Gamma^{SM}(K^{\pm} \rightarrow \mu^{\pm}\nu_e)} = \left(\frac{M_e}{M_\mu}\right)^2 \left(\frac{M_K^2 - M_e^2}{M_K^2 - M_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.477 \pm 0.001) \times 10^{-5}$$

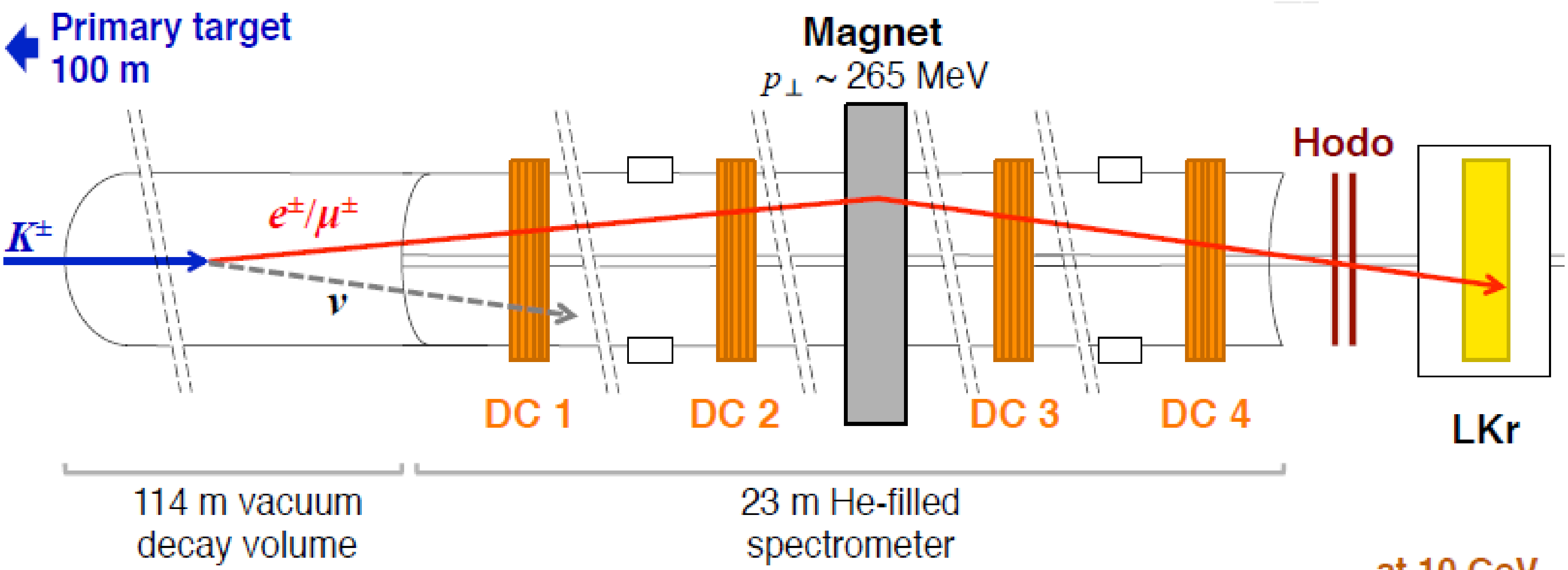
[V. Cirigliano and I. Rosell, JHEP 0710:005 (2007)]

- Cancellation of hadronic uncertainties

$$\left.\frac{\Delta R_K}{R_K}\right|_{SM} \sim 0.04\%$$

- A precise measurement probes $\mu - e$ universality and provides a stringent test of the SM

NA48/2 and NA62 (R_K phase) experimental setup

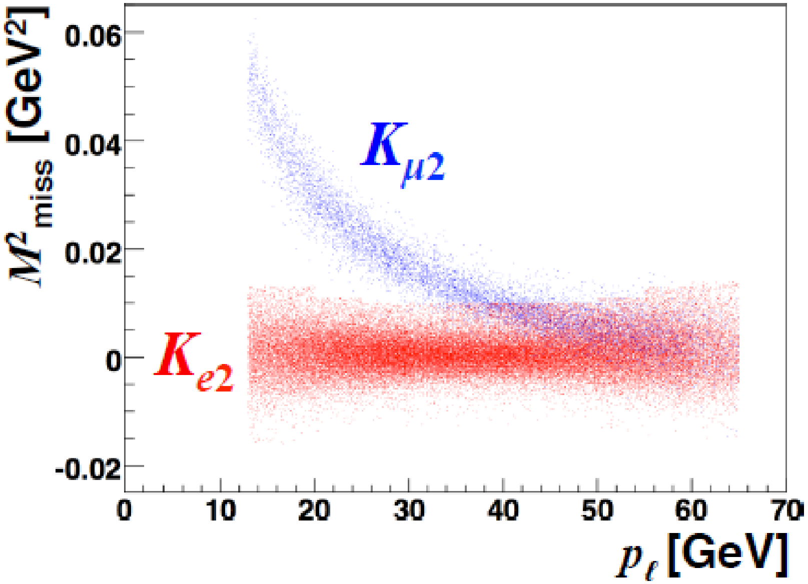


		at 10 GeV
Drift chambers	$\sigma(p)/p = 0.48\% \oplus 0.009\%\, p$ [GeV] $\sigma_{x,y} = 90$ µm	0.48%
LKr calorimeter	$\sigma_E/E = 3.2\%/\sqrt{E}$ [GeV] $\oplus$ $9\%/E$ [GeV] $\oplus$ 0.42% $\sigma_x = \sigma_y = 4.2$ mm$/\sqrt{E} \oplus 0.6$ mm	1.4% 1.5 mm
Hodoscope	Fast trigger, good time resolution (150 ps)	

R_K measurement strategy

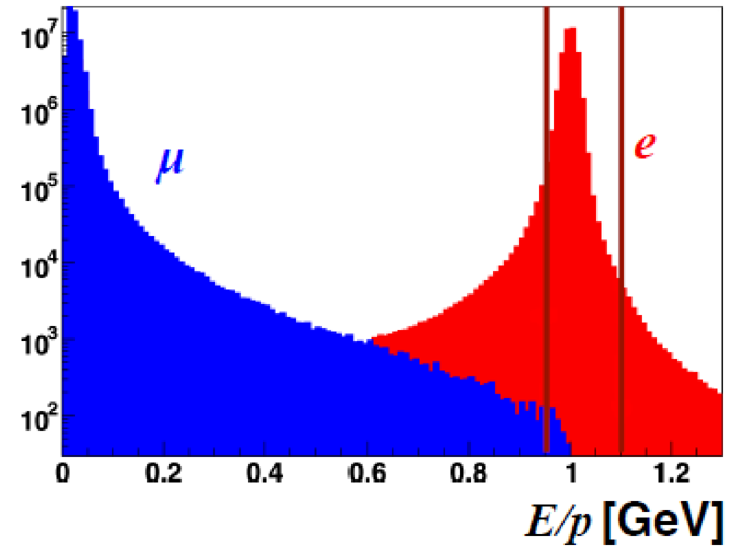
Common reconstruction:

- **1 Reconstructed Track**
- **Photon veto using LKr**
- **Track momentum 13 GeV/c < p < 65 GeV/c**
- **Good decay vertex reconstruction**



Kinematical separation :

- **Missing mass $M^2 = (p_K - p_l)^2$**
- **P_K : Average monitored with $K_{3\pi}$ decays**



Particle Identification => Muon suppression ~10^{-6}

- **E/p = (LKr energy deposit/track momentum)**

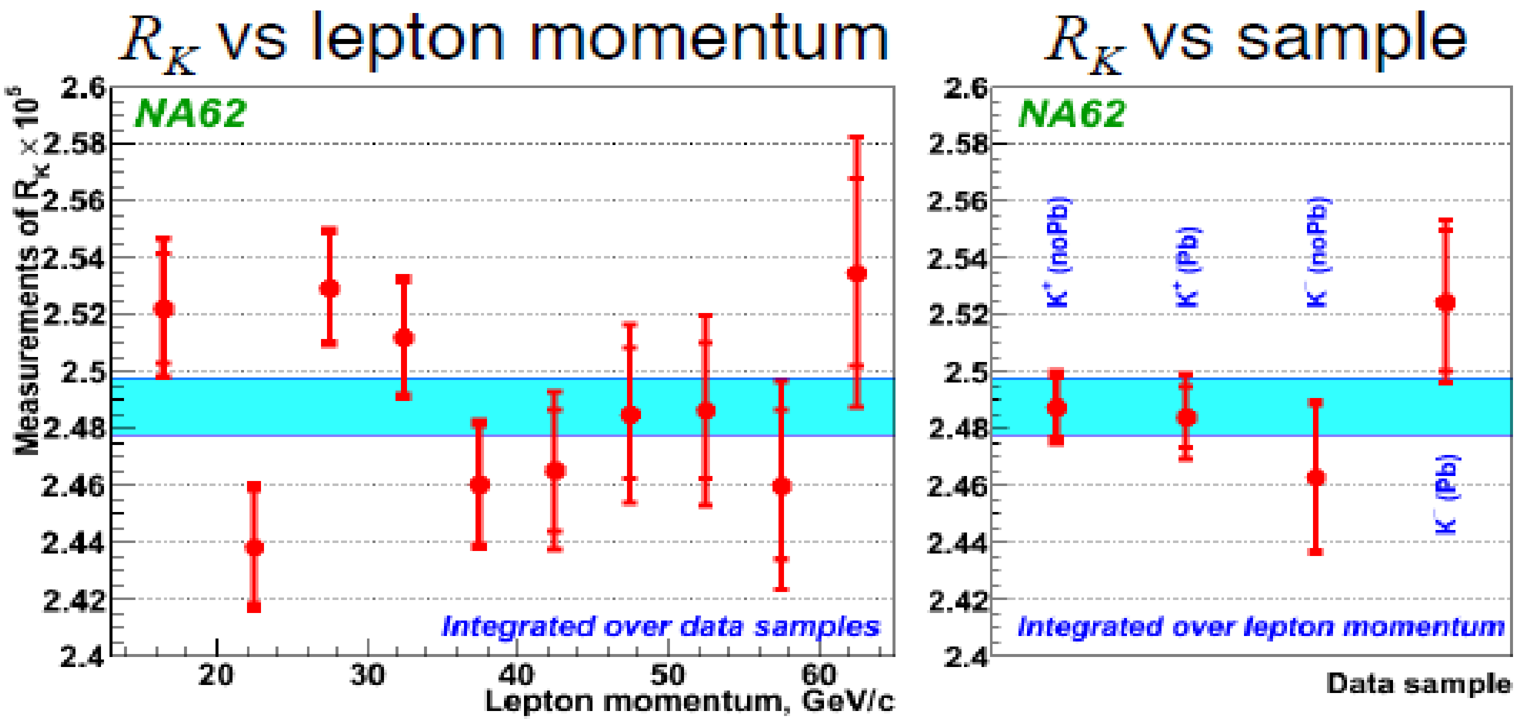
0.90<E/p<1.10 for electrons with P≤25GeV
0.95<E/p<1.10 for electrons with P>25 GeV
E/p<0.85 for muons

R_K final result

0.4% accuracy reached (cfr. PDG2008 4.5%)!

But theoretical error still 1 order of magnitude smaller …

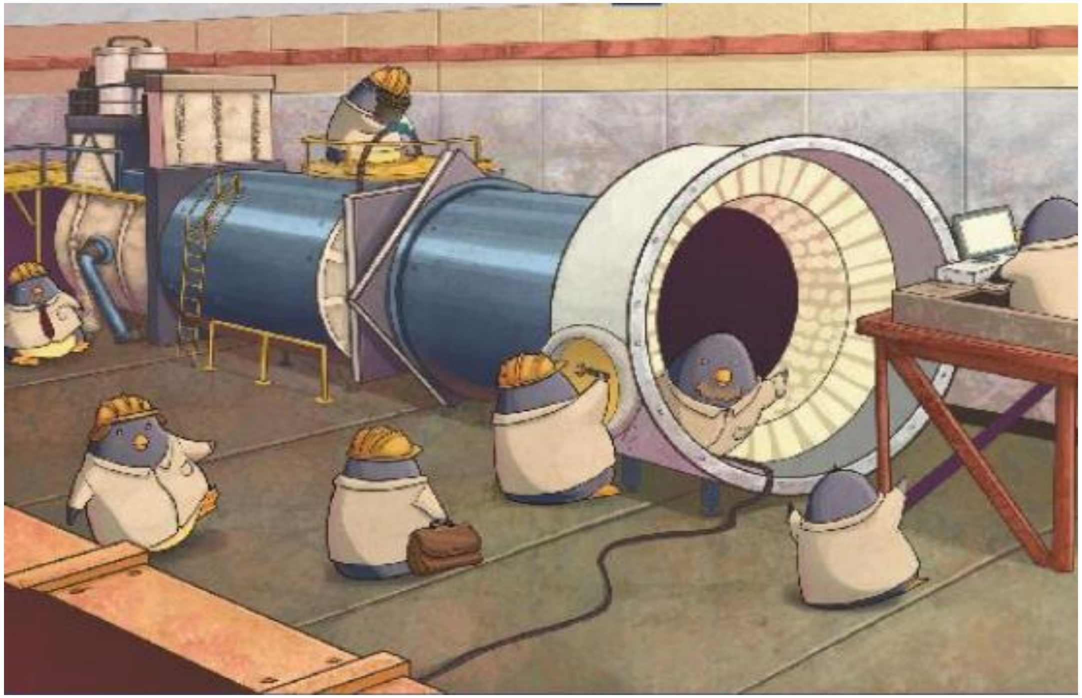
$R_K = 2.488(7)_{stat}(7)_{syst}10^{-5}$ [PLB 719 (2013) 326]



Fit over 40 independent measurements, 10 lepton momentum bins × 4 configurations:
χ^2 / Nd.o.f. = 47/39 (P = 18%)

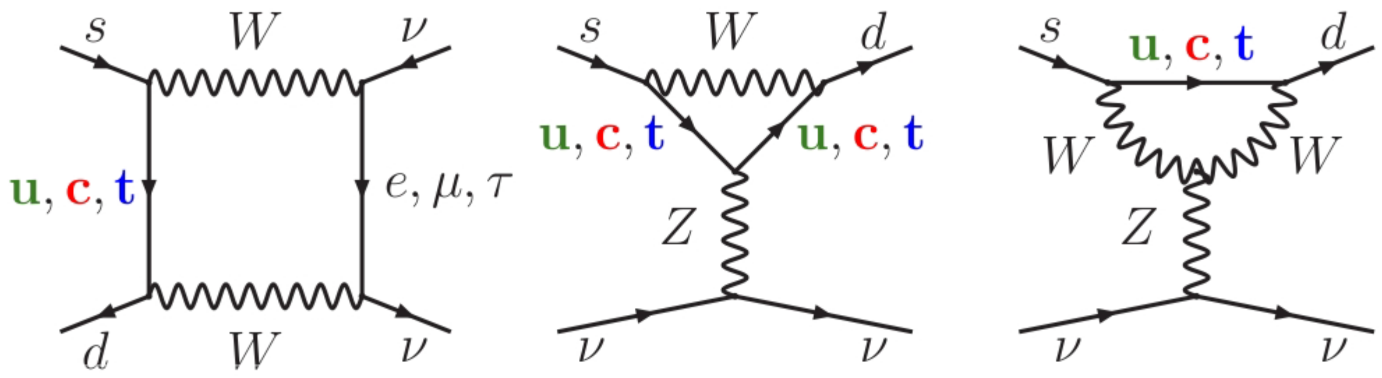
Outline

- NA48/2 and NA62 (R_K phase)
- **$K^+ \rightarrow \pi^+ \nu\nu$ decay**
- NA62 experimental apparatus
- NA62 expected results



$K^+ \to \pi^+ \nu \bar{\nu}$ decay in SM

- **FCNC loop processes: s→d coupling and highest CKM suppression**



- **Very clean theoretically:**
  - **SD contribution dominate** $A_q \sim \frac{M_q^2}{M_W^2} V_{qs}^* V_{qd}$
  - **Hadronic matrix element related to the precisely measured BR** $(K^+ \to \pi^0 e^+ \nu_e)$

- **BR proportional to** $|V_{ts}^* V_{td}|^2$

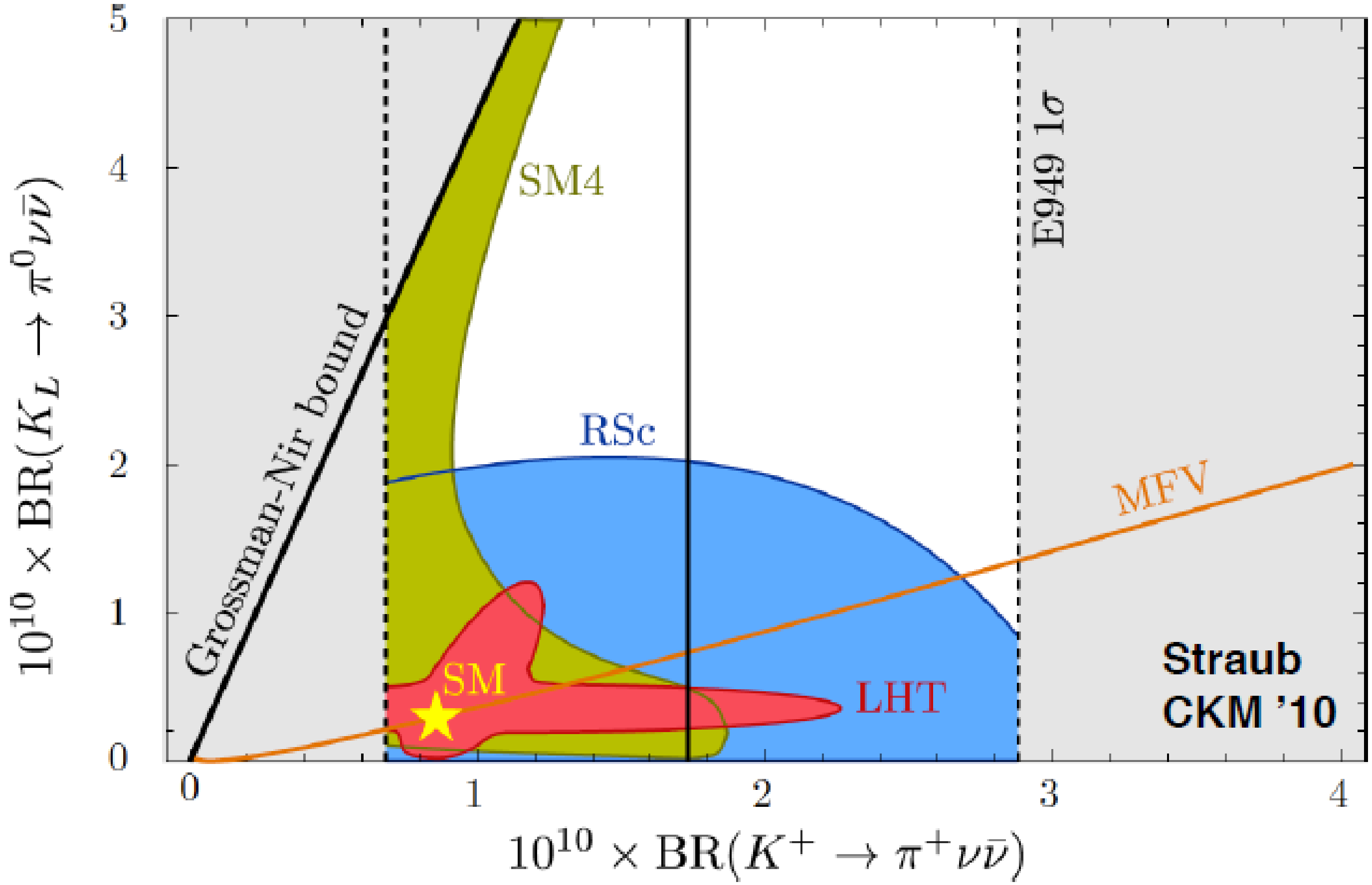
- **SM prediction [Brod, Gorbahn and Stamou 2011 and refs therein]**

$$\mathrm{BR}(K^+ \to \pi^+ \nu \bar{\nu}) = (7.81 \pm 0.75 \pm 0.29)\times 10^{-11}$$

Error on input parameters (V_{cb}, ρ, ..) and other theory errors (mostly LD correction)

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

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

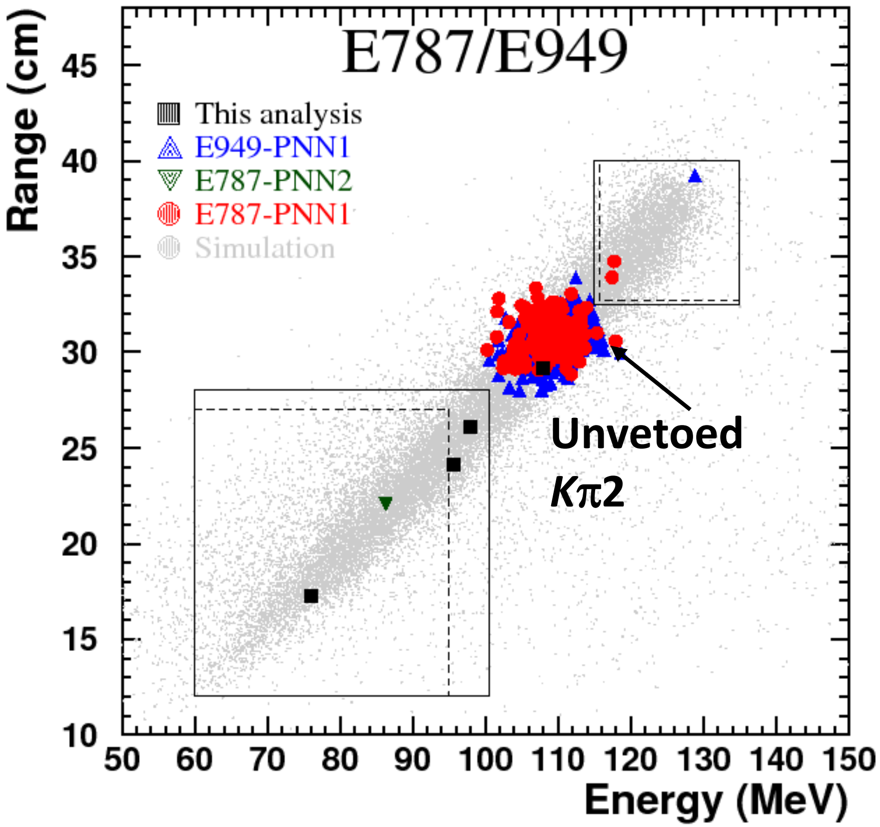


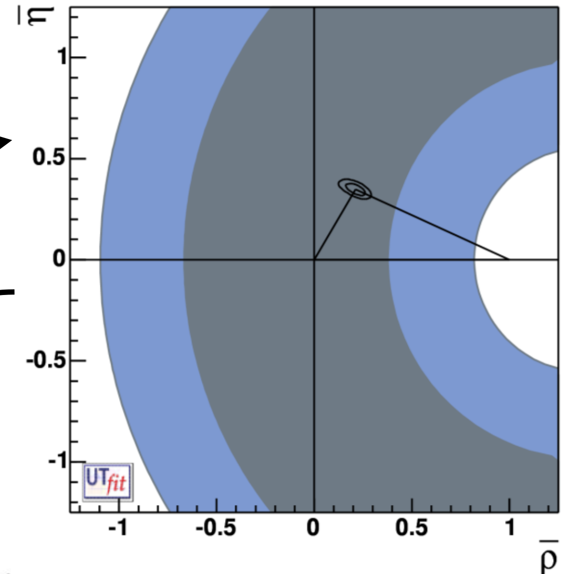
SM4: SM with 4th generation (Buras et al. '10)
LHT: Littlest Higgs with T parity (Blanke '10)
RSc: Custodial Randall-Sundrum (Blanke '09)
MFV: Minimal flavor violation (Hurth et al. '09)

$K^+ \to \pi^+ \nu\bar{\nu}$ decay: experimental status

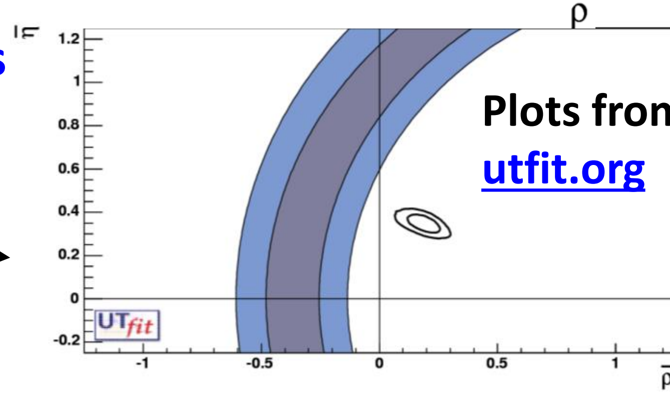
In 2008, combine E787 (1995-8 runs) & E949 (12-weeks run in 2001) results

$BR(K^+ \to \pi^+ \bar{\nu}\nu) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$





Same central value, 100 evts

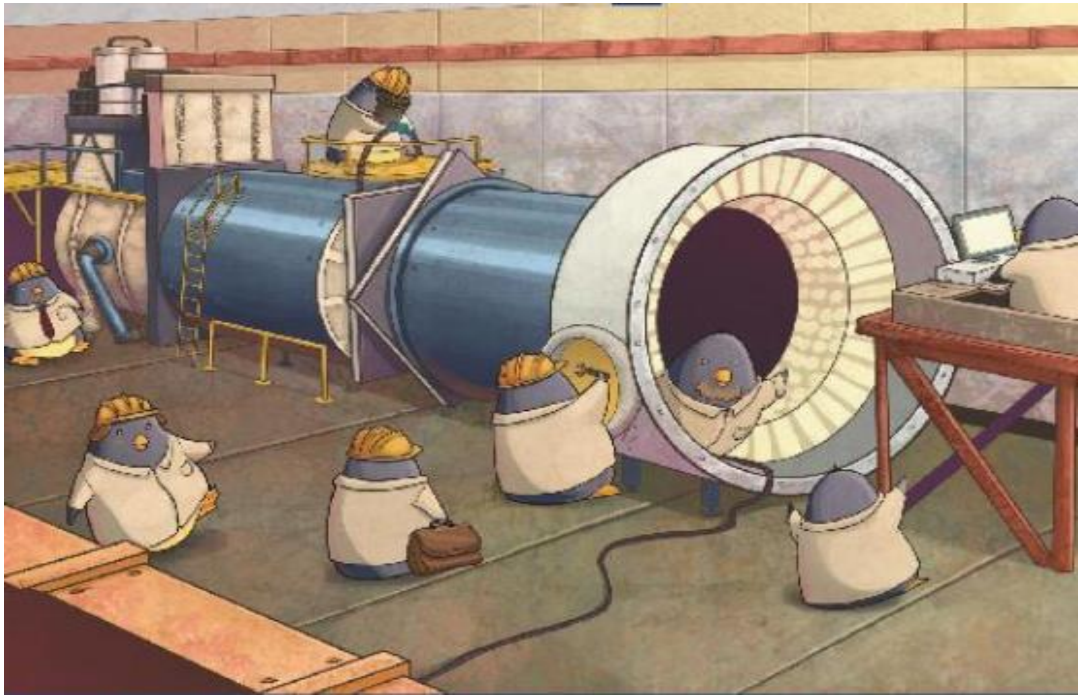


Plots from utfit.org

Expected bkg 2.6 events, prob. all 7 obs. evts are bkg is ~10^{-3}

Outline

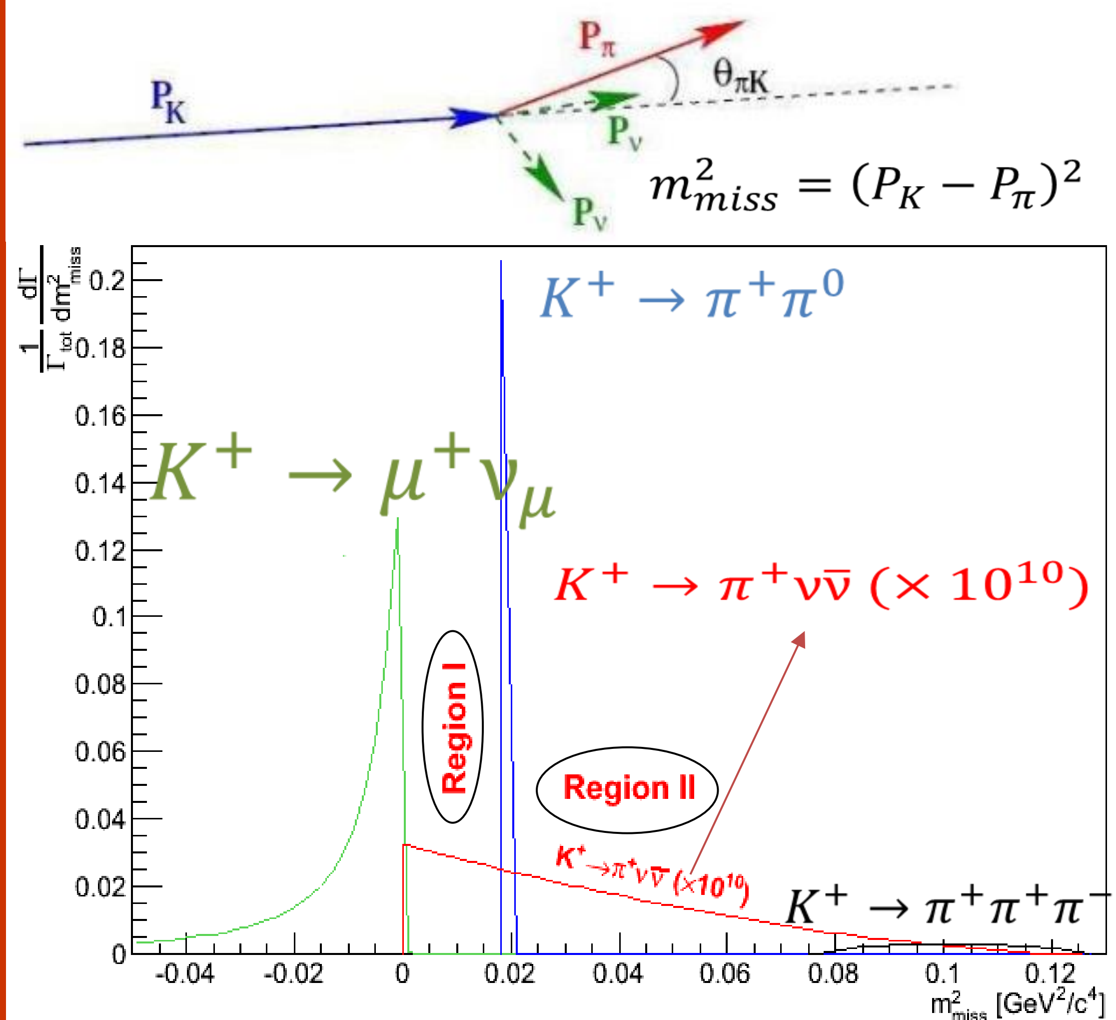
- NA48/2 and NA62 (R_K phase)
- $K^+ \rightarrow \pi^+ \nu\nu$ decay
- **NA62 experimental apparatus**
- NA62 expected results



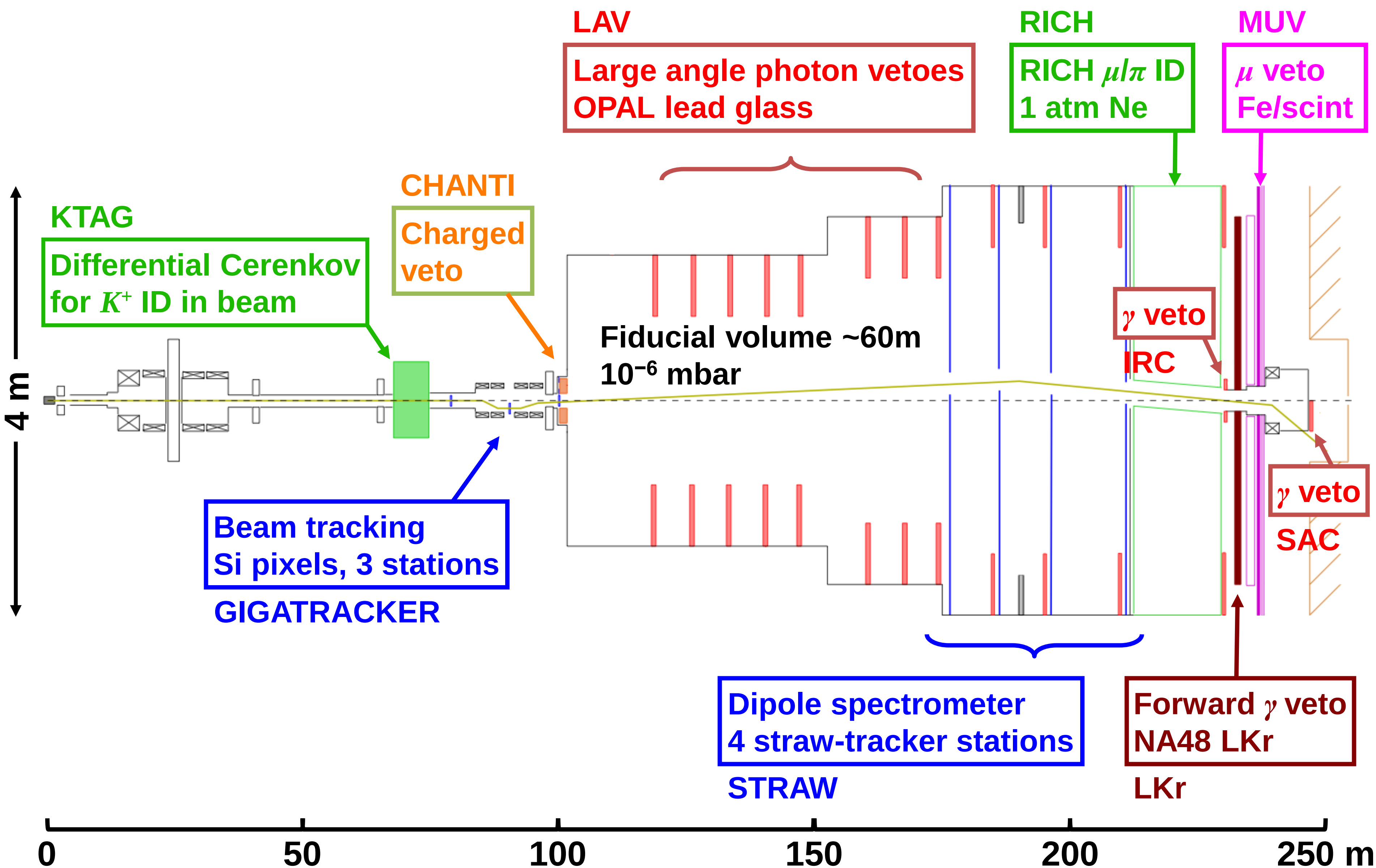
NA62 experimental strategy

Main goal: Detect ~100 SM $K^+ \to \pi^+ \nu\bar{\nu}$ decays with O(10%) precision BR measurement

- High K momentum (in flight technique)
- Kinematical rejection w lightweight spectrometers (GTK, STRAW)
- Low π momentum to allow enough «missing» energy to be detected by hermetic veto detectors (LAV,IRC,SAC,LKr)
- Particle identification (RICH, MUV)
- Beam particle identification and inelastic event suppression (KTAG, CHANTI)



NA62 setup



LAV
Large angle photon vetoes
OPAL lead glass
RICH
RICH μ/π ID
1 atm Ne
MUV
μ veto
Fe/scint
CHANTI
Charged
veto
KTAG
Differential Cerenkov
for K+ ID in beam
Fiducial volume ~60m
10−6 mbar
γ veto
IRC
γ veto
SAC
4 m
Beam tracking
Si pixels, 3 stations
GIGATRACKER
Dipole spectrometer
4 straw-tracker stations
STRAW
Forward γ veto
NA48 LKr
LKr
0
50
100
150
200
250 m

NA62 beam

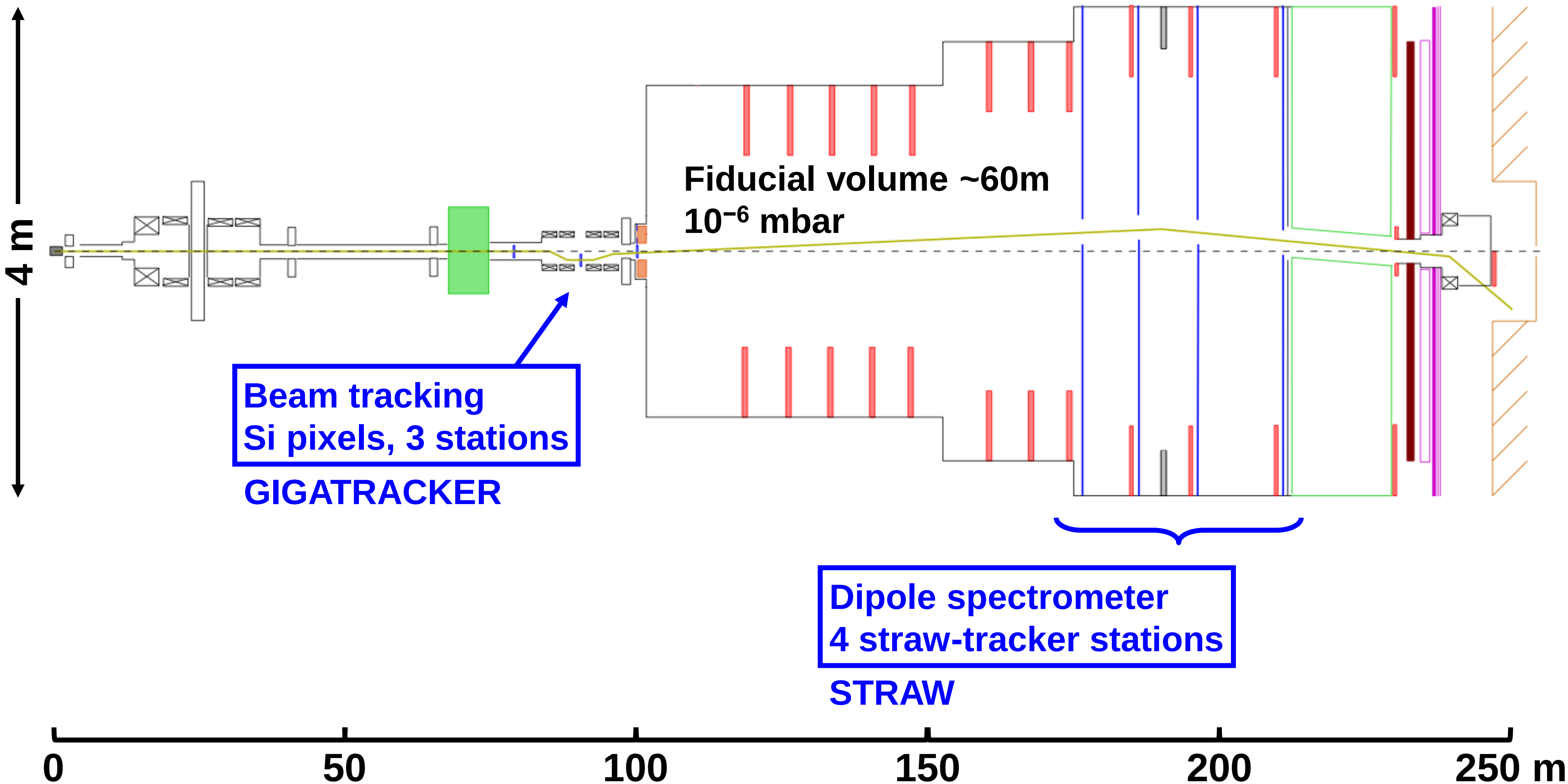
Primary SPS proton beam:
- p = 400 GeV protons
- Proton on target 1.1×10^{12} /s
- Simultaneous beam delivery to LHC

High-intensity, unseparated secondary beam
- Momentum selection chosen to optimize K decays
- p = 75 GeV/c (1.4× more K^+ than NA48/2)
- $\Delta p/p \sim 1\%$ (3× smaller than NA48/2)

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

Decay volume
- 60m long, starting at 102m from target
- 10% of K^+ decay in FV ($\beta\gamma c\tau = 560m$)
- 4.5×10^{12} K^+ decays/yr = 45 × NA48/2

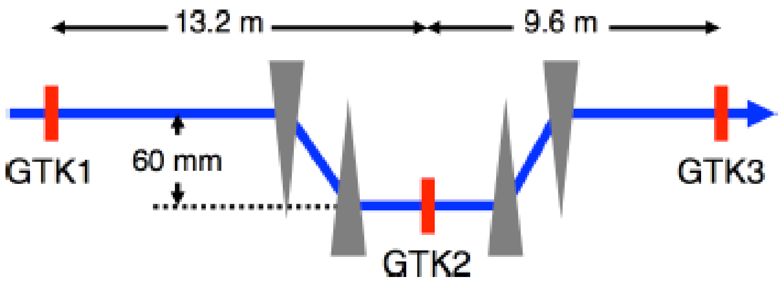
NA62 setup: Gigatracker and Straw tracker



NA62: Gigatracker and Straw tracker

Gigatracker

Tracks particles in the unseparated beam with 3 planes of hybrid Si pixel detectors



On site bump bonded readout chip 0.13 µm CMOS tech (200+100 µm ~ 0.5% X_0)
Pixel size 300x300µm^2 , σ_p/p ~ 0.2%, σ_θ = 16 µrad

The installation of the 3 stations will be completed in October 2014

Straw-tracker

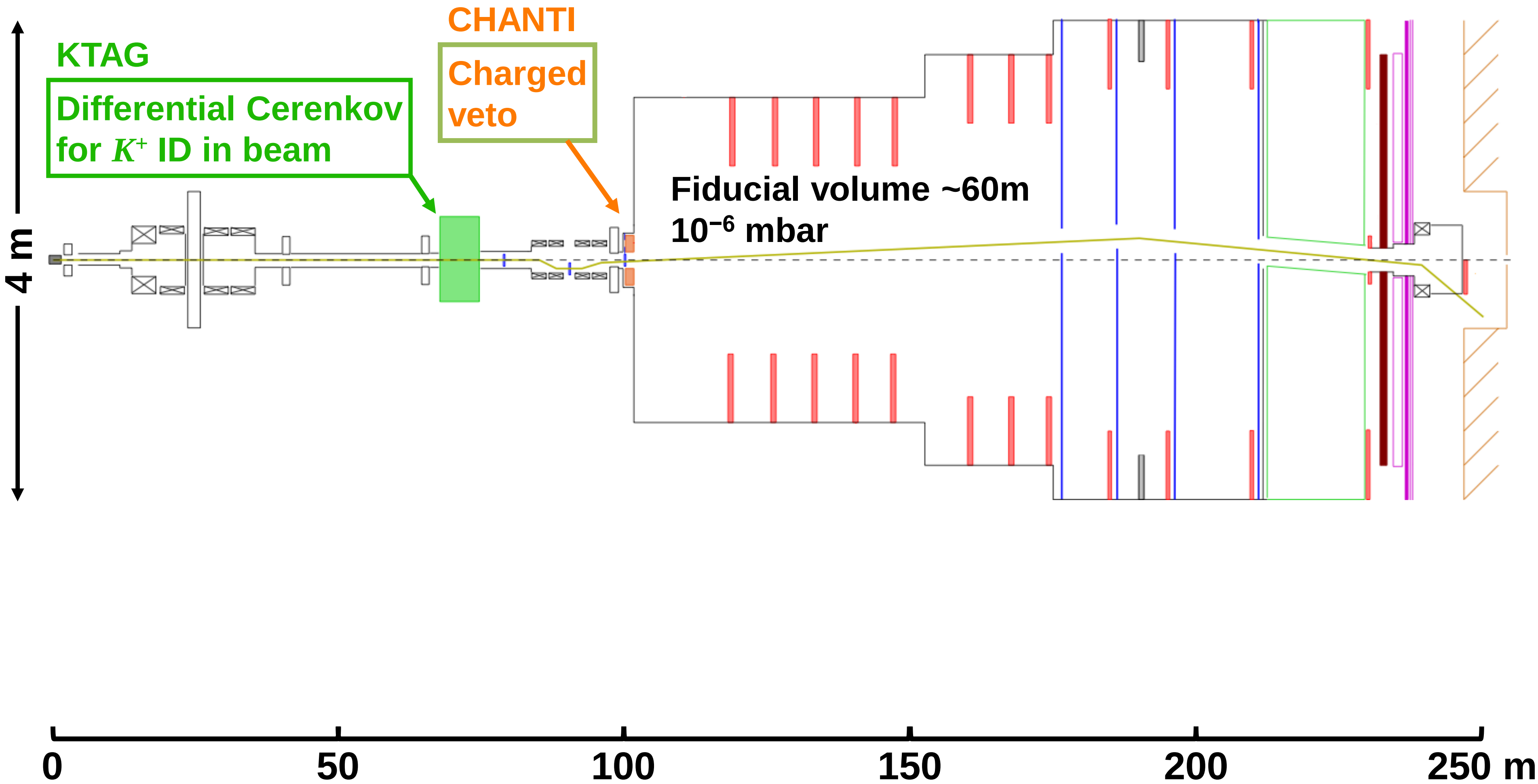
4 chambers, 2.1 m in diameter
16 layers (4 views) of straws per chamber

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

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

1 chamber already installed, another module is expected to be at CERN in June 2014

NA62 setup: KTAG and CHANTI



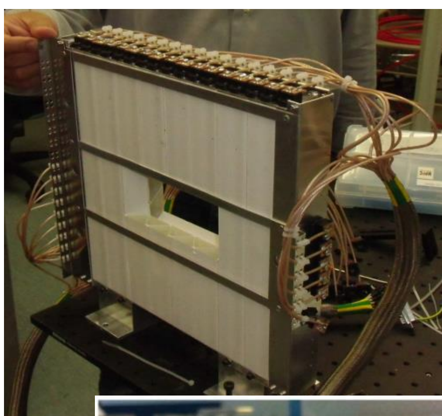
NA62 beam identification and inelastic interaction

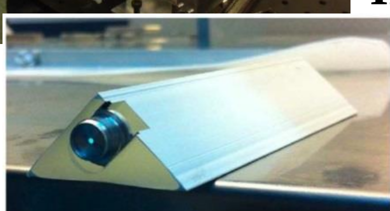
KTAG

Identifies 45 MHz of K^+ in 750 MHz of unseparated beam
Running with H2 at 3.85 bar
Completely new, high segmentation readout
Requirements: K tagging @ 10^{-3} level, σ_t~100 ps

CERN CEDAR reused, it will be completed by the end of August 2014

CHANTI

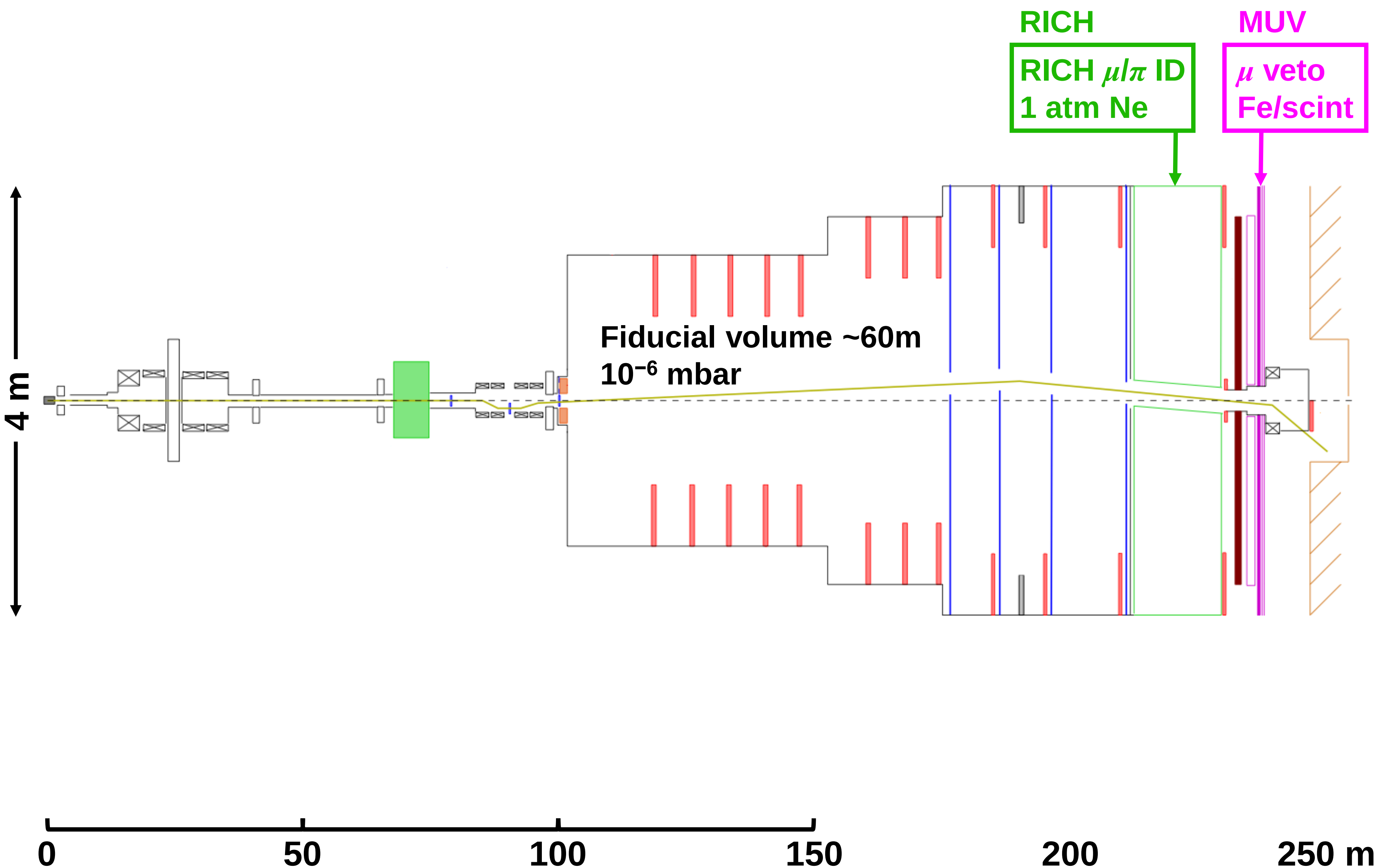




Detection of particles from inelastic interactions(IIs) in GTK3 mimicking a pion in time with a kaon
6 stations hermetic to charged particles between 49 mrad and 1.31 rad
Each station is made of 24 scintillation bars in each view (X & Y)
WLS fibers inside each bar, readout by SiPM on one side only(other is mirrored)
IIs happen every $5/10^4$ (GEANT studies)

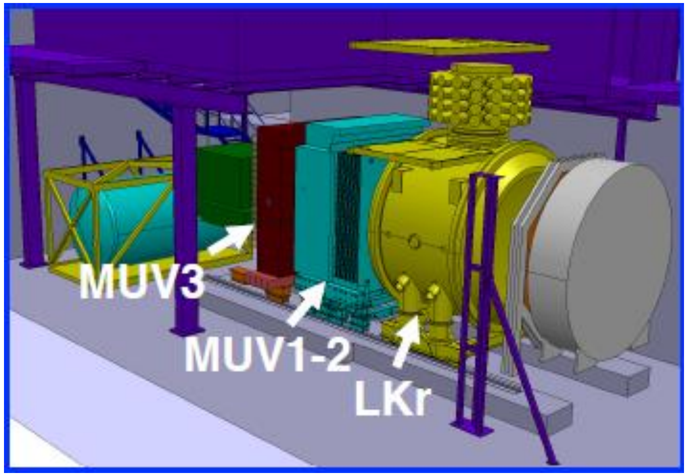
Installation will be completed in June 2014

NA62 setup: particle identification



NA62 particle identification

MUV system: π/μ identification & trigger



MUV1-2: Fe/scintillator hadron calorimeter

- **Used offline to provide principal veto for $K \to \mu\nu$**
- **Rejects μ to 10^{-5}**

MUV3: Fast μ identification for trigger

- **Vetoes μ online at 10 MHz with $\sigma_t < 1$ ns**

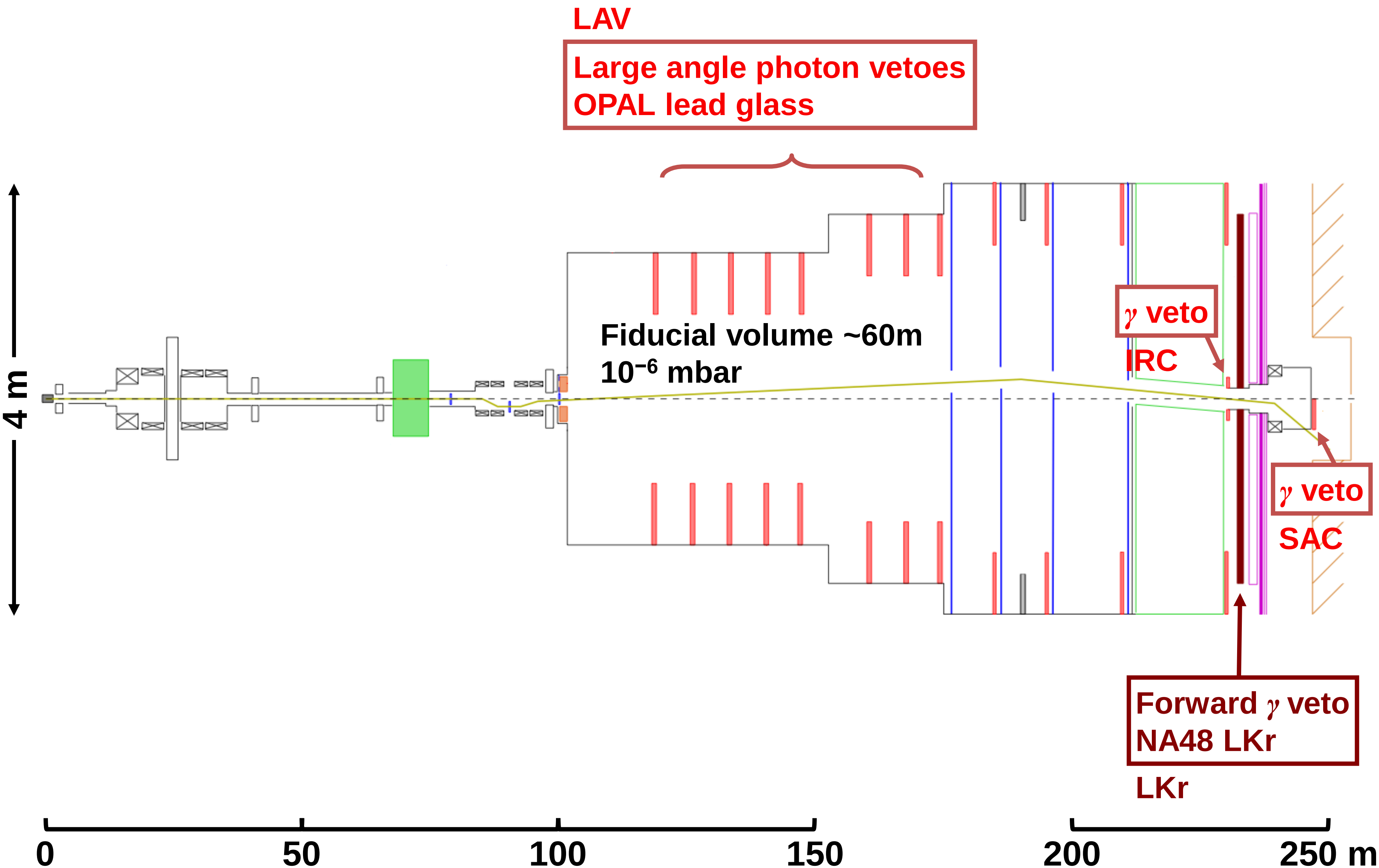
MUV2 & 3 installed, MUV1 is being assembled

RICH provides additional 10^{-2} μ rejection to exclude $K \to \mu\nu$

μ/π separation better than 1% for $15 < p < 35$ GeV
Measures π crossing time with $\sigma_t < 100$ ps
Provides L0 trigger for charged particles
Ne gas at 1 atm $p_{thresh} = 12$ GeV for π
2000 8-mm PMTs on upstream flanges

RICH vessel installed; installation will be completed in September 2014

NA62 setup: photon veto detectors



NA62 photon veto detectors

Large angles vetoes (LAV) $8.5 < \theta < 50$ mrad

12 stations at intervals of ~10m along decay volume
Each station has 4-5 rings/station of lead glass blocks
$1-\varepsilon$ for e^- at 200 MeV: $(1\pm1) \times 10^{-4}$

LAV 1 to 9 installed, LAV 10+11 already at CERN, LAV 12 in construction

Liquid krypton calorimeter (LKr) $1 < \theta < 8.5$ mrad

Quasi-homogeneous ionization calorimeter
Readout towers 2×2 cm^2 - 13248 channels
Depth 127 cm = 27 X_0
$1-\varepsilon$ for γ with $E > 10$ GeV: $< 8 \times 10^{-6}$

LKr from NA48 setup

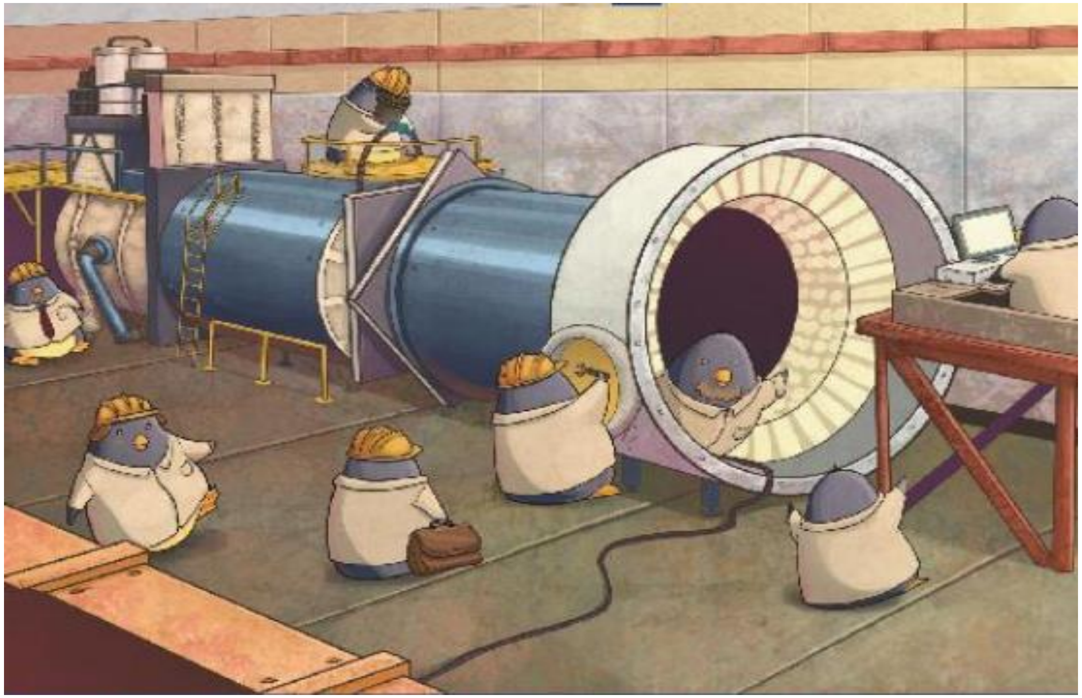
SAC & IRC: very small angle veto Shashlik calorimeters

SAC: γ detection along the beamline (after beam deflection)
IRC: detection of photons at very low angle in front of the LKr, radial coverage 7 cm < R< 14 cm
WLSs+PMTs used for both detectors

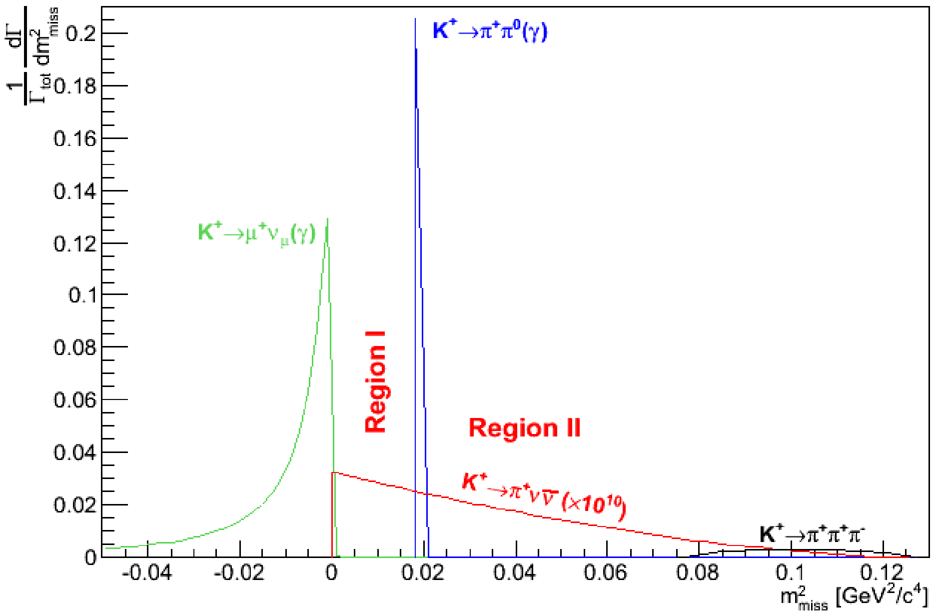
SAC is installed, IRC installation in July

Outline

- NA48/2 and NA62 (R_K phase)
- $K^+ \to \pi^+ \nu\nu$ decay
- NA62 experimental apparatus
- **NA62 expected results**



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



Acceptance: ~12%

3% in Region I

9% in Region II

50% loss from momentum cut

Detector inefficiencies included

45 signal events/yr

- **1 track with $15<p_\pi<35$ GeV and π PID in RICH**
- **No γ in LAV, LKr, IRC, SAC**
- **No μ in MUV**
- **1 beam particle in Gigatracker with K PID by KTAG**
- **No activity on CHANTI**
- **Z_{vtx} in 60m fiducial region**

Expected backgrounds	
$K^+ \to \pi^+\pi^0$	11%
$K^+ \to \pi^+\pi^0\gamma_{IB}$	3%
$K^+ \to \mu^+\nu$	2%
$K^+ \to \mu^+\nu\gamma_{IB}$	1%
$K^+ \to \pi^+\pi^+\pi^-$	< 2%
K^+_{e4}, other 3 track decays	< 2%
K^+_{e3}, $K^+_{\mu3}$	negligible
Total	**< 20%**

NA62 sensitivity for LFNV decays

High fluxes and PID/veto capabilities of NA62 well suited to look for Lepton Flavor/ Lepton Number Violation modes in both kaon and pion decays:

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

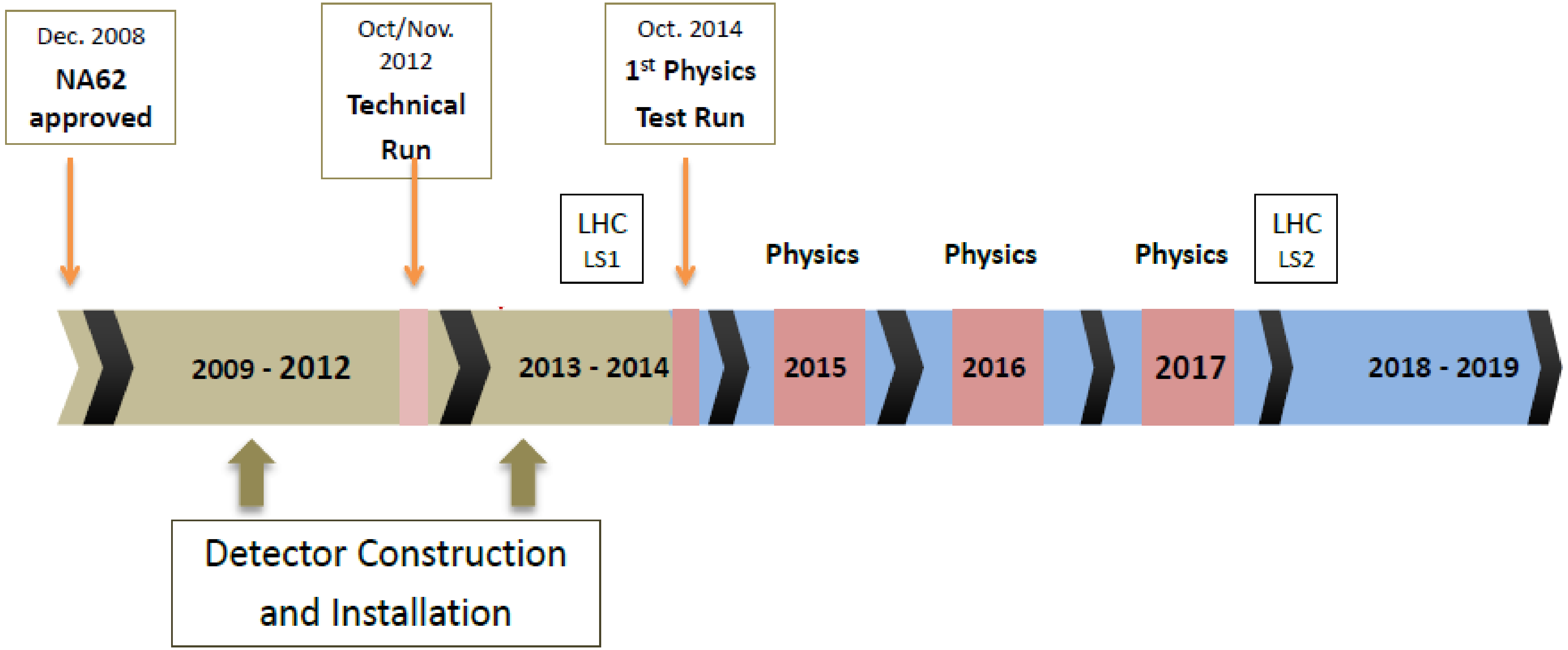
Single-event sensitivity 1/(decays × acceptance)

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	
$K^+ \to \pi^-\mu^+e^+$	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^{-10}	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

NA62 timeline



- 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)

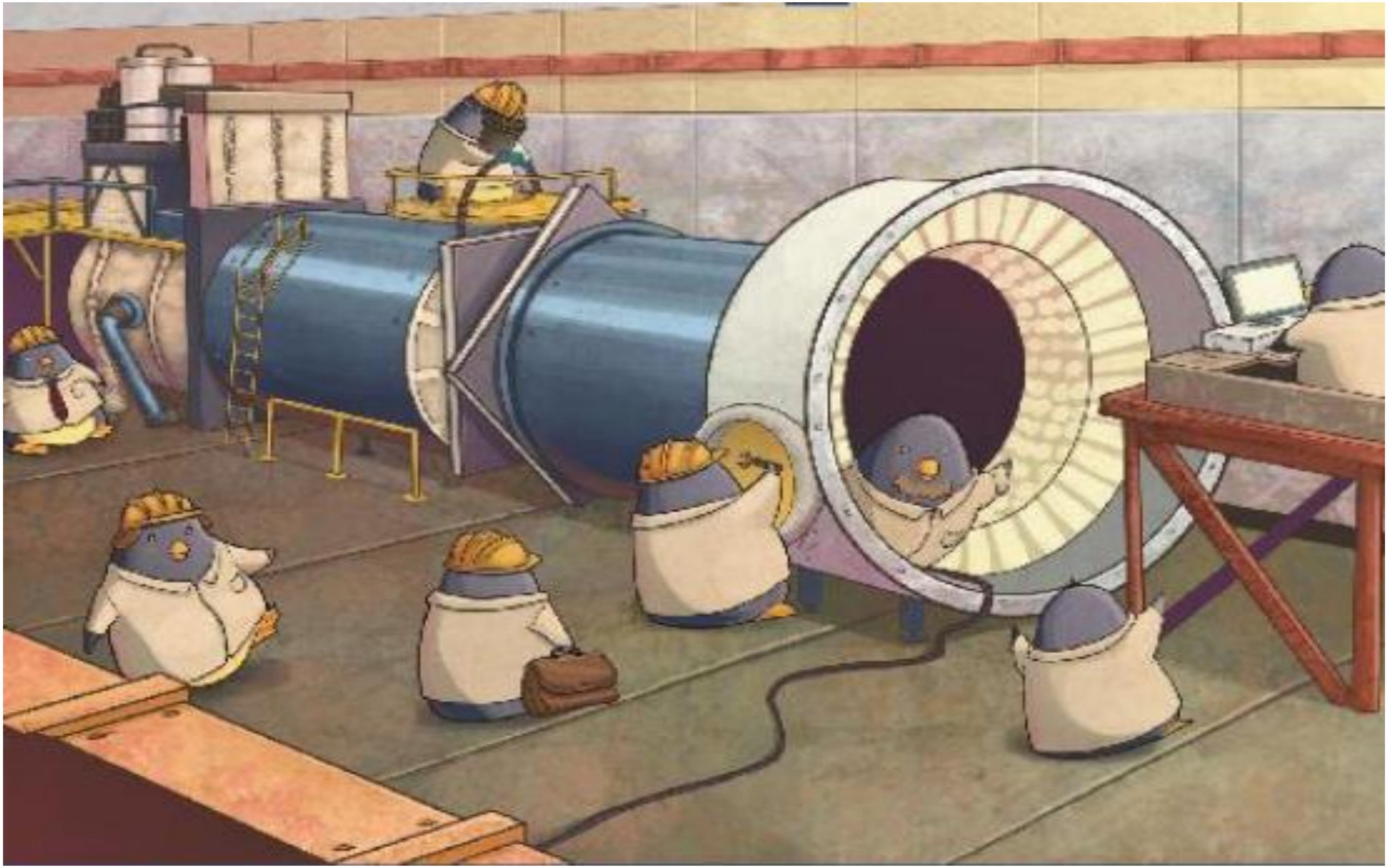
Conclusion

- **More than 60 years after their discovery kaons provide a unique playground for testing our ideas on fundamental physics**

- **NA62 collaboration is analyzing data taken in past years and producing very precise results for both leptonic, non-leptonic and semileptonic kaon decays.**

- **But the best is yet to come, with the new generation NA62 apparatus: it will collect an unprecedented statistics and exploit its powerful detector features to push further our knowledge of rare (and forbidden) kaon decays.**

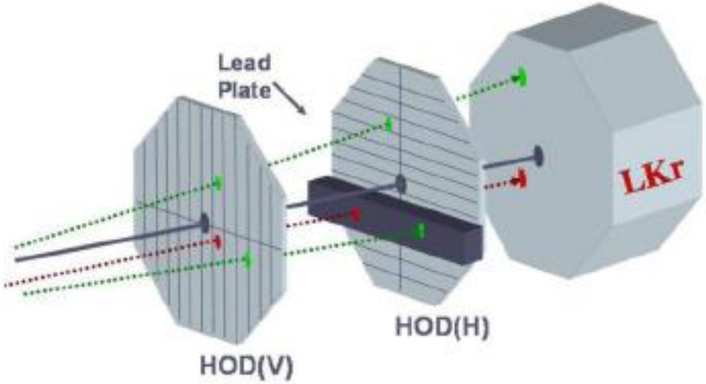
NA62 will begin data taking at the end of this year, so stay tuned …



Ke2: μ background

Subsample of data (55%) taken with a $9.2\text{-}X_0$ Pb in fornt of LKr in order to measure *on data* the μ mis-ID

Four samples analyzed independently:
K^+(Pb) ; K^+ (NoPb); K^-(Pb) ; K^- (NoPb)



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

Data sample	K^+(noPb)	K^+(Pb)	K^-(noPb)	K^-(Pb)
K_{e2} candidates	59813	63282	10530	12333
Muon halo	$(1.11 \pm 0.09)\%$	$(1.51 \pm 0.10)\%$	$(4.61 \pm 0.18)\%$	$(7.86 \pm 0.23)\%$
$K_{\mu 2}$	$(6.11 \pm 0.22)\%$	$(5.33 \pm 0.19)\%$	$(5.76 \pm 0.20)\%$	$(4.87 \pm 0.17)\%$
$K_{\mu 2}$ ($\mu \to e$ decay)	$(0.26 \pm 0.04)\%$	$(0.27 \pm 0.04)\%$	$(0.31 \pm 0.09)\%$	$(0.19 \pm 0.07)\%$
$K^\pm \to e^\pm \nu \gamma$ (SD$^+$)	$(1.07 \pm 0.05)\%$	$(4.01 \pm 0.18)\%$	$(1.25 \pm 0.06)\%$	$(3.95 \pm 0.17)\%$
$K^\pm \to \pi^0 e^\pm \nu$	$(0.05 \pm 0.03)\%$	$(0.28 \pm 0.14)\%$	$(0.09 \pm 0.05)\%$	$(0.37 \pm 0.17)\%$
$K^\pm \to \pi^\pm \pi^0$	$(0.05 \pm 0.03)\%$	$(0.18 \pm 0.09)\%$	$(0.06 \pm 0.03)\%$	$(0.18 \pm 0.09)\%$
Opposite sign K	–	$(0.04 \pm 0.01)\%$	–	$(0.25 \pm 0.03)\%$
Total background	$(8.65 \pm 0.25)\%$	$(11.62 \pm 0.33)\%$	$(12.08 \pm 0.29)\%$	$(17.67 \pm 0.39)\%$

NA62: 2014 Physics Goal

➢ Assumptions:

- 60 days of data taking
- 10% of the nominal Intensity x data taking efficiency

$$N_K = 0.06 \times \left(4.5 \times 10^{12}\right) = 2.7 \times 10^{11}$$

$$N_{\pi\nu\bar{\nu}}^{selected} = N_K \cdot BR(\pi\nu\bar{\nu}) \cdot A_{\pi\nu\bar{\nu}} = \left(2.7 \times 10^{11}\right) \cdot \left(0.8 \times 10^{-10}\right) \cdot 0.1$$

$$N_{\pi\nu\bar{\nu}}^{selected} \approx 2.2(SM)$$

➢ Aiming to reach the SM sensitivity:

- may provide a BR measurement competitive with the existing one...
- ...or find out what is still missing to do so...

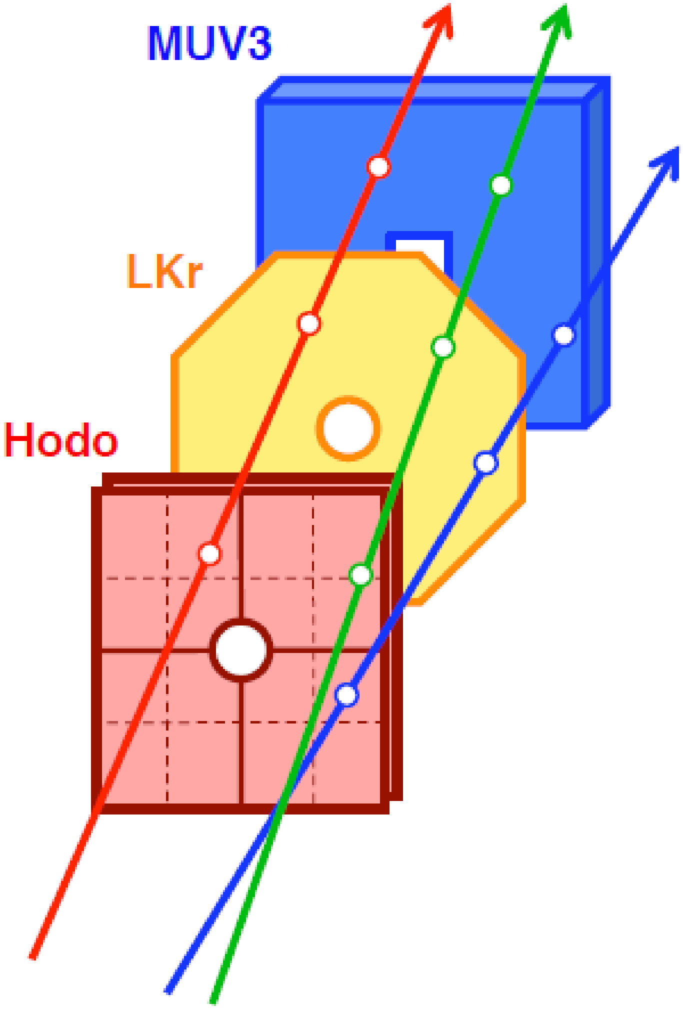
Rare π^0 decays in NA62

2×10^{12} π^0 decays in FV in 2 years of data will allow substantial improvement of results in many channels

Mode	Current knowledge	Experiment	Expectation in SM	Physics interest
Neutral modes				
$\pi^0 \to 3\gamma$	$BR_{90CL} < 3.1\times10^{-8}$	Crystal Box	Forbidden	Violates C
$\pi^0 \to 4\gamma$	$BR_{90CL} < 2\times10^{-8}$	Crystal Box	$BR \sim 10^{-11}$	Scalar states $\pi^0 \to SS$
$\pi^0 \to$ inv	$BR_{90CL} < 2.7\times10^{-7}$	BNL 949	$BR < 10^{-13}$ (cosm. limit)	N_ν, LFV
Charged modes				
$\pi^0 \to e^+e^-e^+e^-$	$BR = 3.34(16)\times10^{-5}$	KTeV	$3.26(18) \times10^{-5}$	Off-shell vectors
$\pi^0 \to e^+e^-\gamma$	$BR_{95CL}(\pi^0 \to U\gamma)$: $< 1\times10^{5}$, $M_U = 30$ MeV $< 3\times10^{6}$, $M_U = 100$ MeV	WASA/COSY	Null result	Dark forces

Trigger for LFN modes in NA62

640 kHz 3-track decays upstream of trigger hodoscope **vs. ~1 MHz** design rate for L0 trigger



Definitions of level-0 trigger primitives:

$\mathbf{Q}_n$	Hits in at least n Hodo quadrants
$\mathbf{LKR}_n(x)$	At least n LKr clusters with energy $E > x$ GeV
$\mathbf{MUV}_n$	Hits in at least n MUV3 pads

Level-0 triggers for LFNV searches:

ee pair	$Q_2 \cdot LKR_2(15)$
$e\mu$ pair	$Q_2 \cdot LKR_1(15) \cdot MUV_1$
$\mu\mu$ pair	$Q_2 \cdot MUV_2$

Total rate ~few × 10 kHz

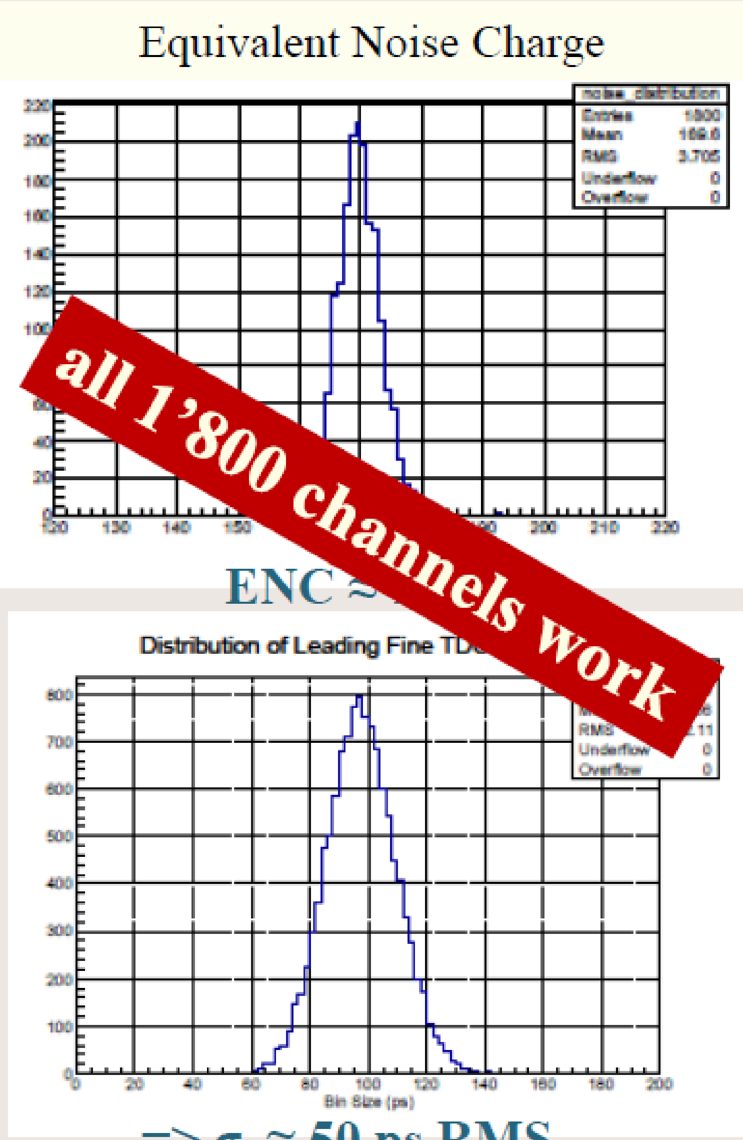
Dominantly from $K_{\pi 3}$, $K \to \pi\pi^0{}_D$

KTAG

- Go for 64 PMT's per octant (512 in total)/ 48 in 2014
- Hamamtsu R7400 replaced by successor R9980 (better in some respect higher gain and QE)
- Hybrid solution 16x R7400 and 48x R9980 per octant
- Use increased number of HPTDC boards to optimize rate capabilities.

- The ASIC tests show that the chip is working as expected.
- GTK carrier board designed, a prototype is ordered
- The chip thinning and bump bonding has been successfully tested on dummy chips.

The remaining work is on a tight time plan, but the most difficult technical issues have been mastered



=> $\sigma_t \approx$ 50 ps RMS

Straw Chambers

- Straw Module Assembly:
  - At CERN: 4/4 modules are completed
  - AT JINR: 3/4 modules completed, the last module will be finished in June).
- Dressing and Stacking of Modules:
  - i.e. attaching all services (HV,LV and gas patch panels) to the chambers is in full swing.
- Electronics:
  - The frontend electronics were all produced and successfully tested.
  - The SRB (back-end electronics) development is coming to the end and the production of a pre-series is expected to be available in June 2014

Estimation of the $K^+ \to \pi^+\pi^0(\gamma)$ background

Branching Ratio = ~21%

- Evaluation of the effect of the kinematic cuts using the simulation
- Evaluation of the single γ detection efficiency:
  - Intrisinc inefficiencies of the calorimeters from test-beam and NA48/NA62 data
  - Effect of the material in front of the calorimeter studied on simulation
  - Separation between π^+ cluster and γ cluster @ LKr taken into account
- Evaluation of the π^0 rejection power:
  - Single γ detection inefficiency applied parametrically to the γ's of $\pi^+\pi^0$ events
- Factorization of the kinematic and photon rejection
- Contribution from the radiative tails:
  - Evaluated by considering only the gaussian resolution of the tracking systems

- Result: 10% + 3% (radiative) (cut & count analysis without any optimization)
- Method to measure on data the γ detection efficiency from $K^+ \to \pi^+\pi^0$
- Kinematic rejection can be measured on data from $K^+ \to \pi^+\pi^0$ reconstructed by using the LKr
- Strongly momentum and Z vertex dependent.

Estimation of the $K^+ \to \mu^+ \nu\ (\gamma)$ background

Branching Ratio = ~64%

- Evaluation of the effect of the kinematic cuts using the simulation
- Calorimeters for π^+ identification and $\mu - \pi$ separation
- RICH for $\mu - \pi$ separation
- Factorization of the Kinematic rejection factor, the Particle ID from Calorimetry and Particle ID from RICH assumed.
- Contribution from the radiative tails evaluated

- Result: 2.2% + 1% (radiative) (cut & count analysis without any optimization)
- The RICH (Calorimeters) can be used to select a pure sample of $K^+ \to \mu^+ \nu$ in order to measure on data the rejection power from the Calorimeters (RICH).
- The RICH can be used to cross – check the momentum measured in the spectrometer

Estimation of the $K^+ \to \pi^+\pi^+\pi^-$ background

Branching Ratio = ~5.6%

- Evaluation of the effect of the kinematic cuts using the simulation
- Evaluation of the effect of the cuts against extra charged particles in the final state
  - RICH
  - LAVs
  - Forward calorimeters (LKr, MUV1,2, IRC)
  - Straws
- Factorization of the cut on m^2_{miss} and the multiplicity cuts.

- Result: 1 - 2% (cut & count analysis without any optimization)
- High level of redundancy in the multplicity analysis

- Similar study performed for $K^+ \to \pi^+\pi^- e^+ \nu$ (Branching Ratio ~4.3×10^{-5})
- Contribution <2%.