Lepton flavour universality and lepton flavour conservation tests in kaon decays at CERN
Measurement of the ratio of charged kaon leptonic decay rates
prospects for forbidden kaon and pion decay modes

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On behalf of the  collaboration

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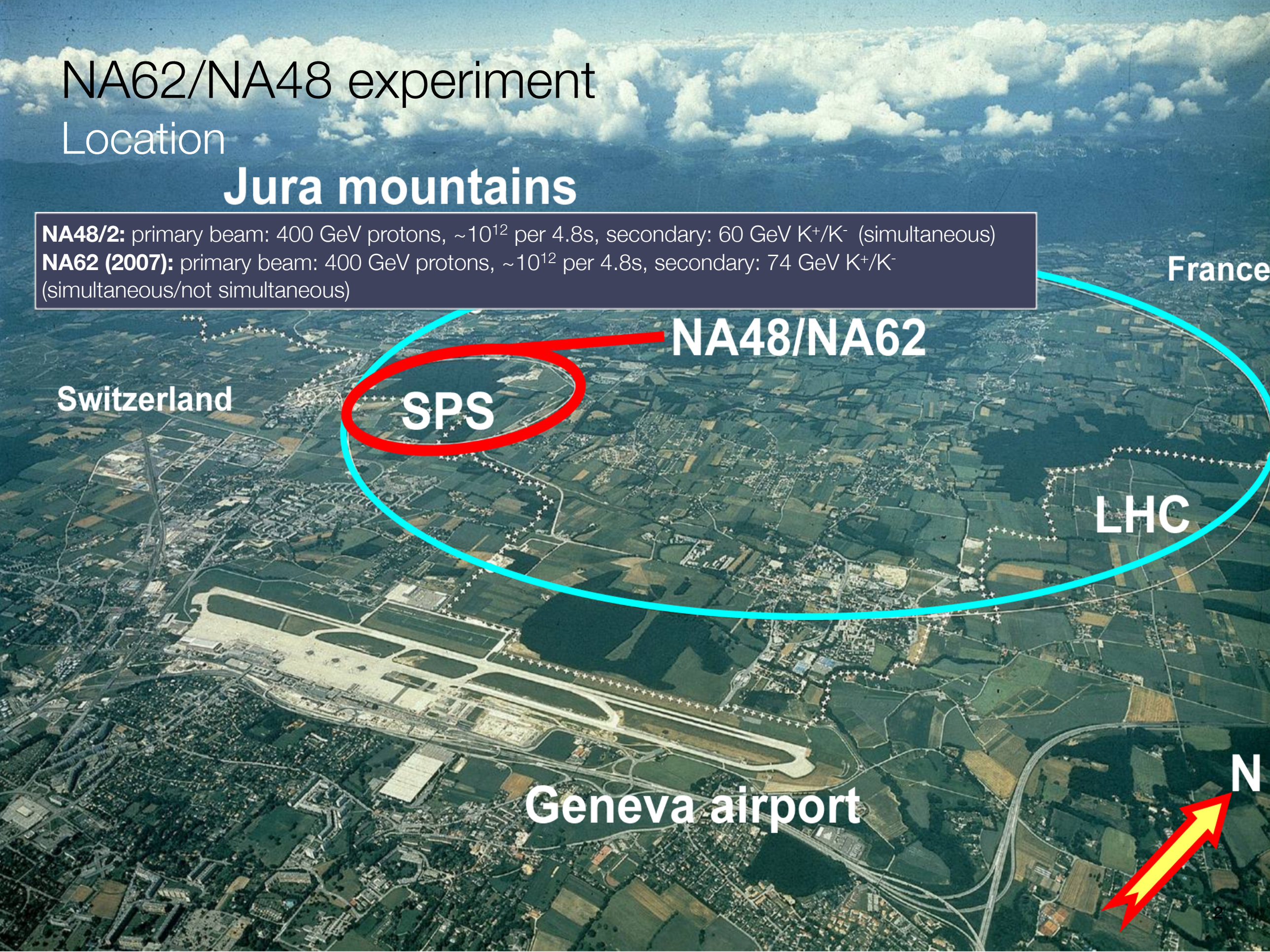
NA62/NA48 experiment

Location

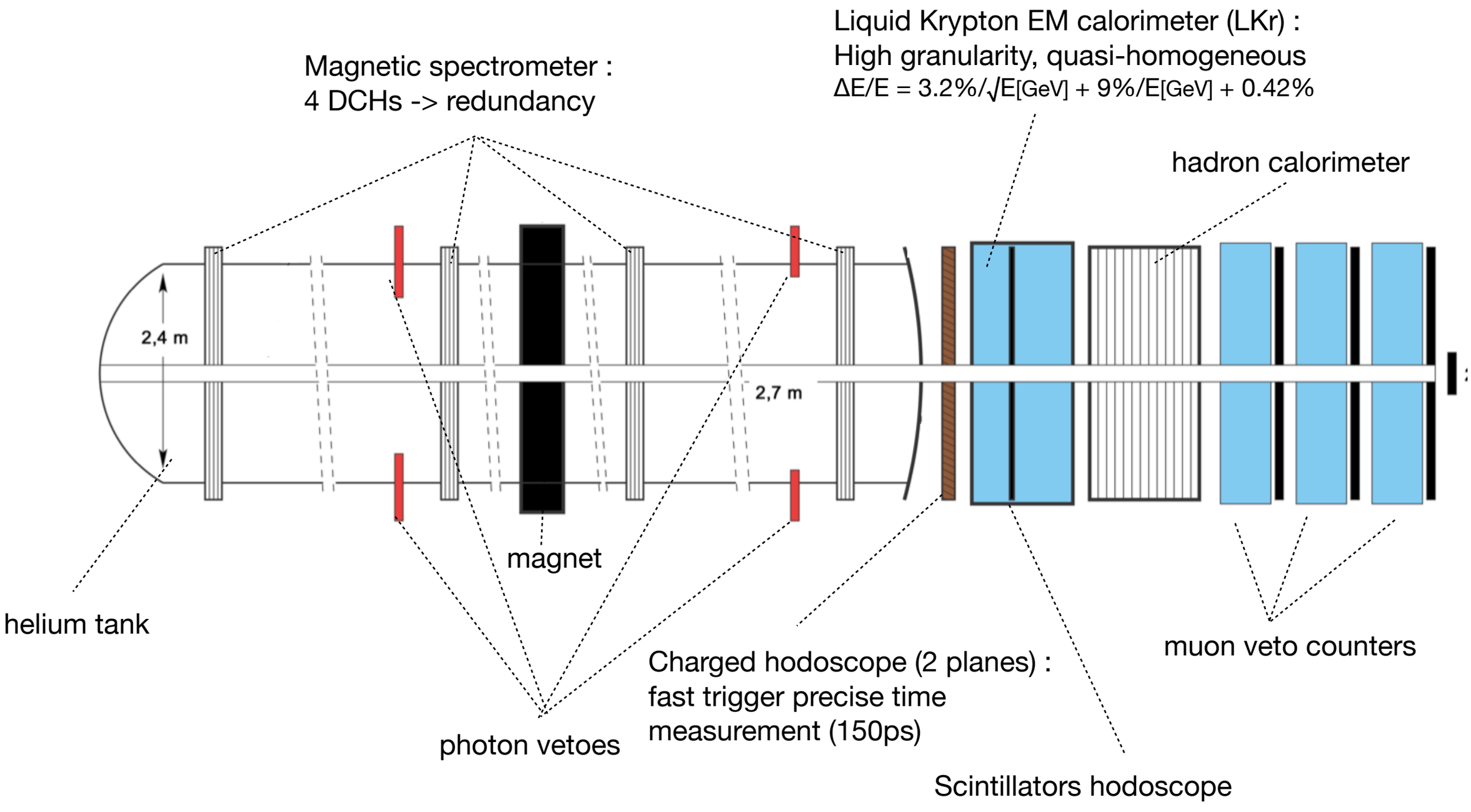
Jura mountains

NA48/2: primary beam: 400 GeV protons, ~10^{12} per 4.8s, secondary: 60 GeV K^+/K^- (simultaneous)
NA62 (2007): primary beam: 400 GeV protons, ~10^{12} per 4.8s, secondary: 74 GeV K^+/K^- (simultaneous/not simultaneous)



NA62/NA48 experiment

NA48/2 setup



Lepton flavour universality (R_k)
Motivation

Lepton flavour universality probe of SM

Sensitive to the NP (SUSY, MSSM, sterile neutrinos, 4-th generation of quarks)

$$R_K = \frac{\Gamma(K \to e\nu)}{\Gamma(K \to \mu\nu)}$$

Girrbach, Nierste, arXiv:1202.4906
A. Masiero et al. Phys.Rev. D74 (2006) 011701
H. Lacker and A. Menzel, JHEP 1007 (2010) 006
A. Abada et al., arXiv:1211.3052.

Within SM:

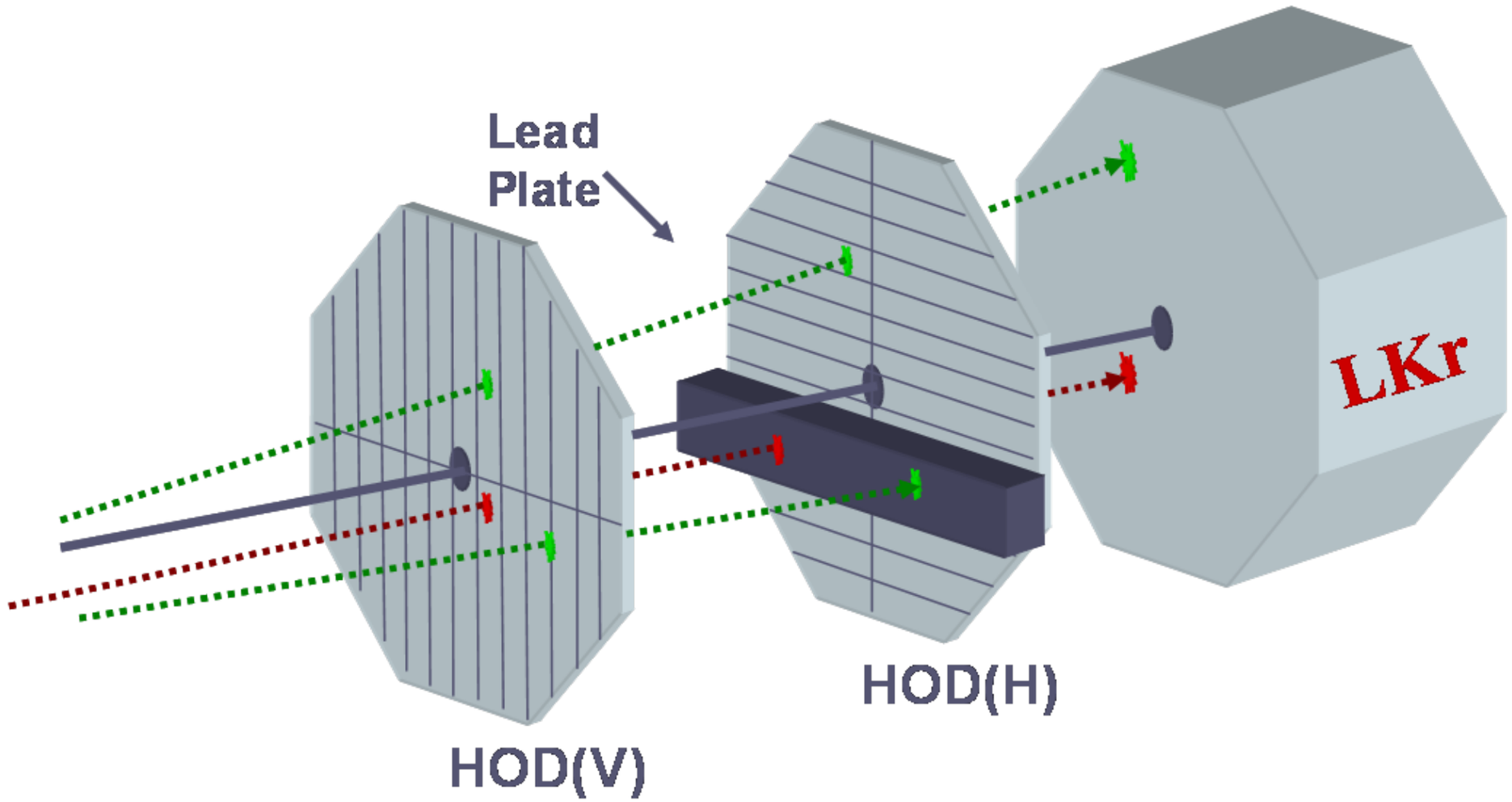
$$R_K^{\mathrm{SM}} = \frac{m_e^2}{m_\mu^2}\frac{(m_K^2 - m_e^2)^2}{(m_K^2 - m_\mu^2)^2}(1 + \delta R_{\mathrm{QED}}) = (2.477 \pm 0.001) \cdot 10^{-5}$$

Experimental value:

R_k = (2.493 ± 0.031)x10^{-5} (KLOE [EPJ C64 (2009) 627])
$\delta R_k/R_k \approx 1.3\%$

Lepton flavour universality (R_k)

Registration strategy



Trigger selection (data set of 2007):
Ke2 trigger: 1 trk (hodoscope) & 1-trk activity in DCH's & ELKr>10 GeV
Kμ2 trigger: 1 trk (hodoscope) & 1-trk activity in DCH's downscaled

Lepton flavour universality (R_k)
Reconstruction strategy

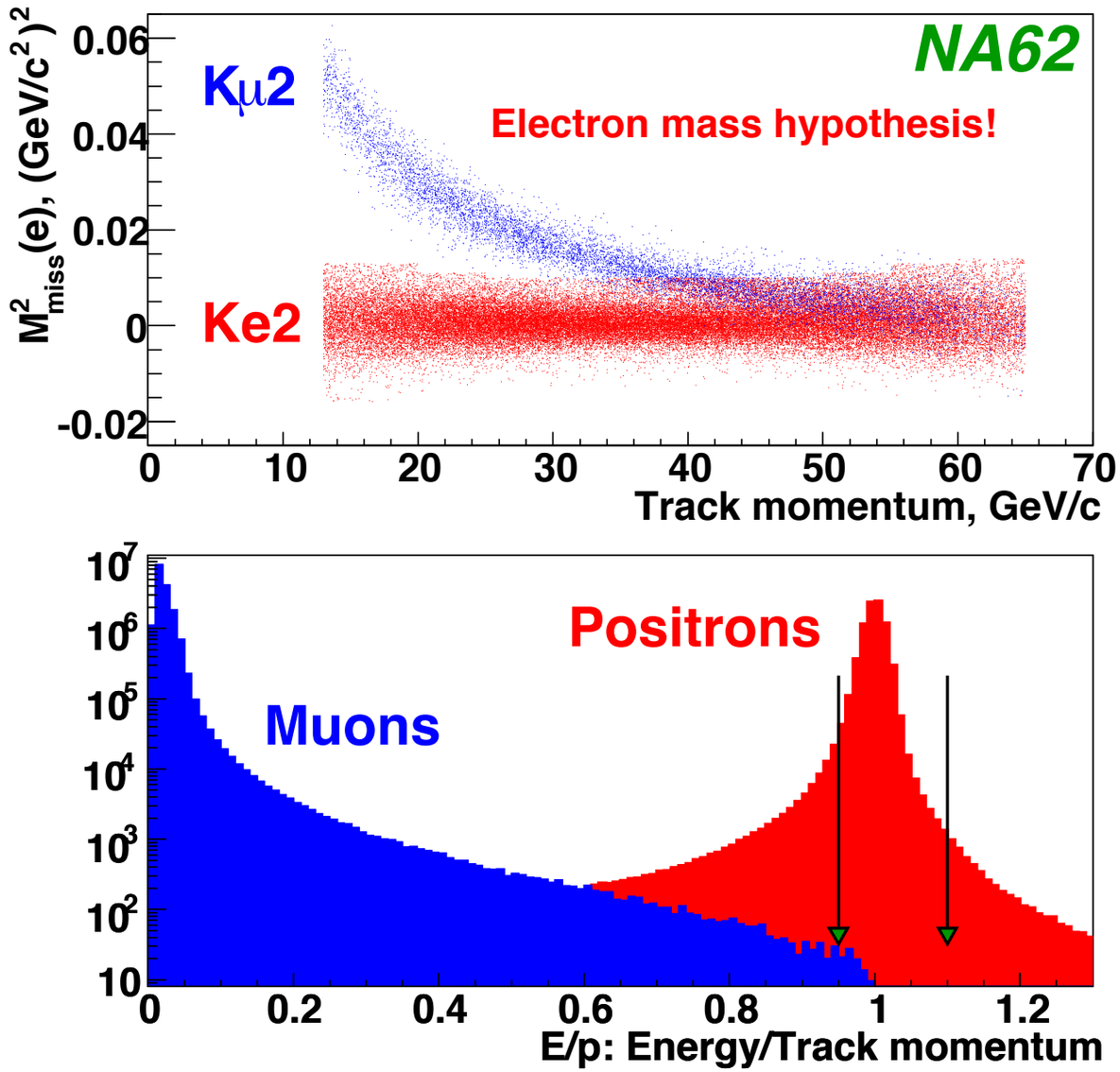
Offline reconstruction:
1 reconstructed track
geometrical acceptance
decay vertex reconstructed as intersection reconstructed track and beam axis

Event selection:
Missing mass: $M^2_{miss} = (P_K - P_l)^2$
LKr as veto
track momentum 13 < p < 65 GeV

***μ/e* separation:**
E/p (energy in LKr/track momentum)

For electrons: 0.95 < E/p < 1.1
(electron ID efficiency: (98.28 ± 0.05)%

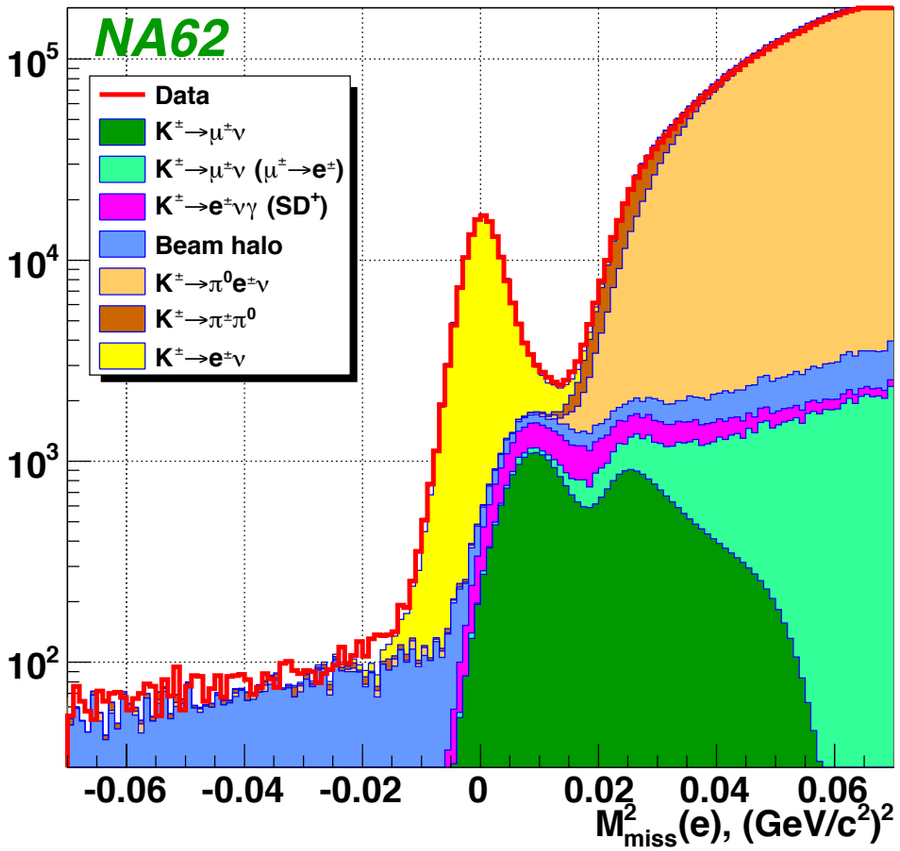
For muons: E/p < 0.85
Suppression of $\mu^\pm$ in $e^\pm$ sample by x10^6



Lepton flavour universality (R_k)

Results

$$R_K = \frac{1}{D} \cdot \frac{N(K_{e2}) - N_{\mathrm{B}}(K_{e2})}{N(K_{\mu 2}) - N_{\mathrm{B}}(K_{\mu 2})} \cdot \frac{A(K_{\mu 2})}{A(K_{e2})} \cdot \frac{f_\mu \times \epsilon(K_{\mu 2})}{f_e \times \epsilon(K_{e2})} \cdot \frac{1}{f_{\mathrm{LKr}}}$$



Source	B/(S+B)
$K \to \mu\nu_\mu$	(5.64 ± 0.20)%
$K_{\mu 2}$ ($\mu \to e$)	(0.26 ± 0.03)%
$Ke2\gamma$ (SD^+)	(2.60 ± 0.11)%
Beam halo	(2.11 ± 0.09)%
$K_{e3(D)}$	(0.18 ± 0.09)%
$K_{2\pi(D)}$	(0.12 ± 0.06)%
Wrong sign K	(0.04 ± 0.02)%
Total	**(10.95 ± 0.27) %**

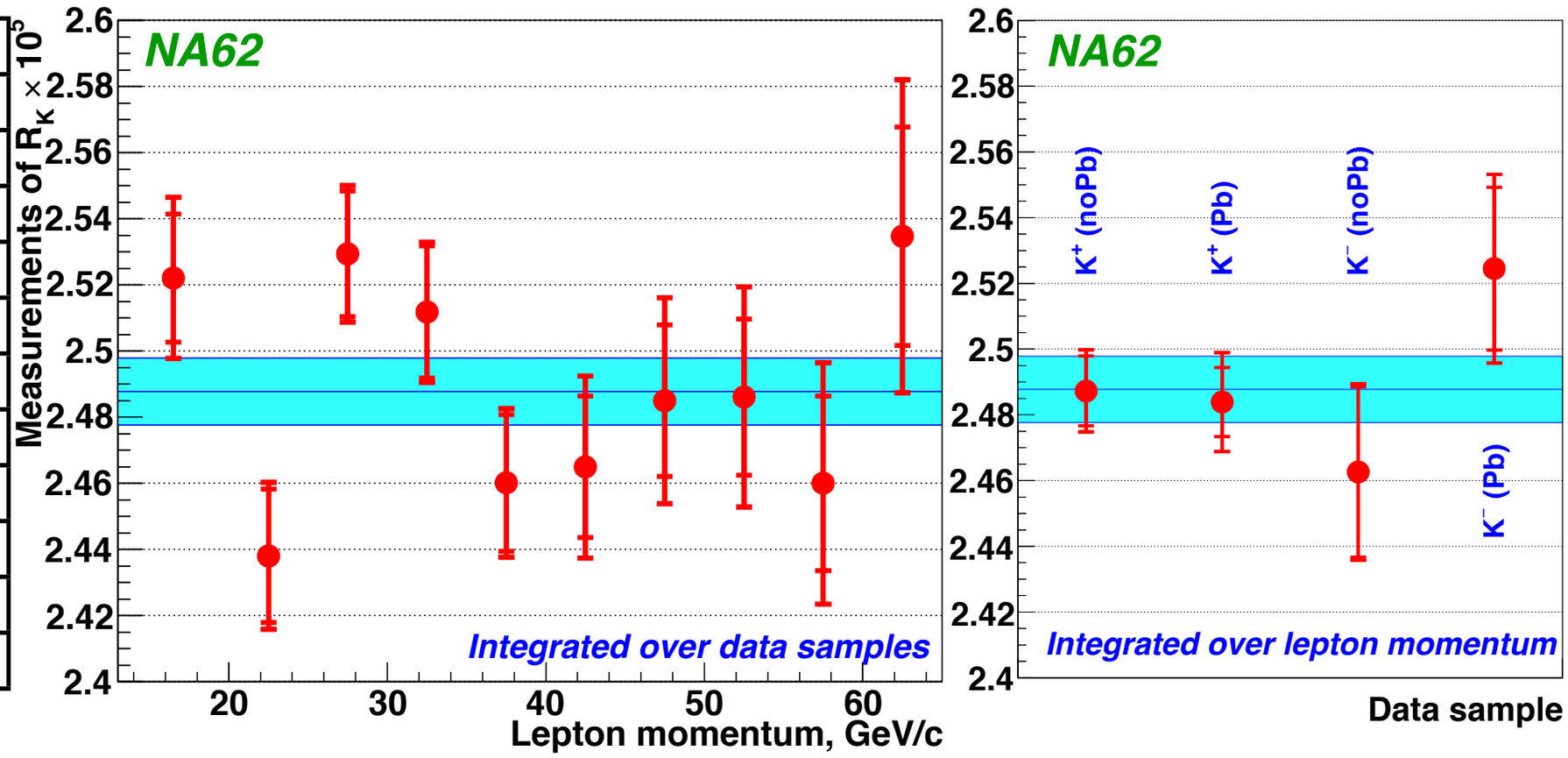
145958 Ke2 candidates selected

Lepton flavour universality (R_k)

Results

Uncertainties

Source	δRk x 10^5
Statistical	0.007
$K \to \mu\nu_\mu$	0.004
$K \to e\nu_e\gamma(SD^+)$	0.002
$K \to \pi^0 e\nu_e\gamma$, $K \to \pi\pi^0$	0.003
Beam halo	0.002
Matter composition	0.003
Acceptance	0.002
Positron ID	0.001
DCH alignment	0.001
1-track trigger	0.001
Total	**0.010**



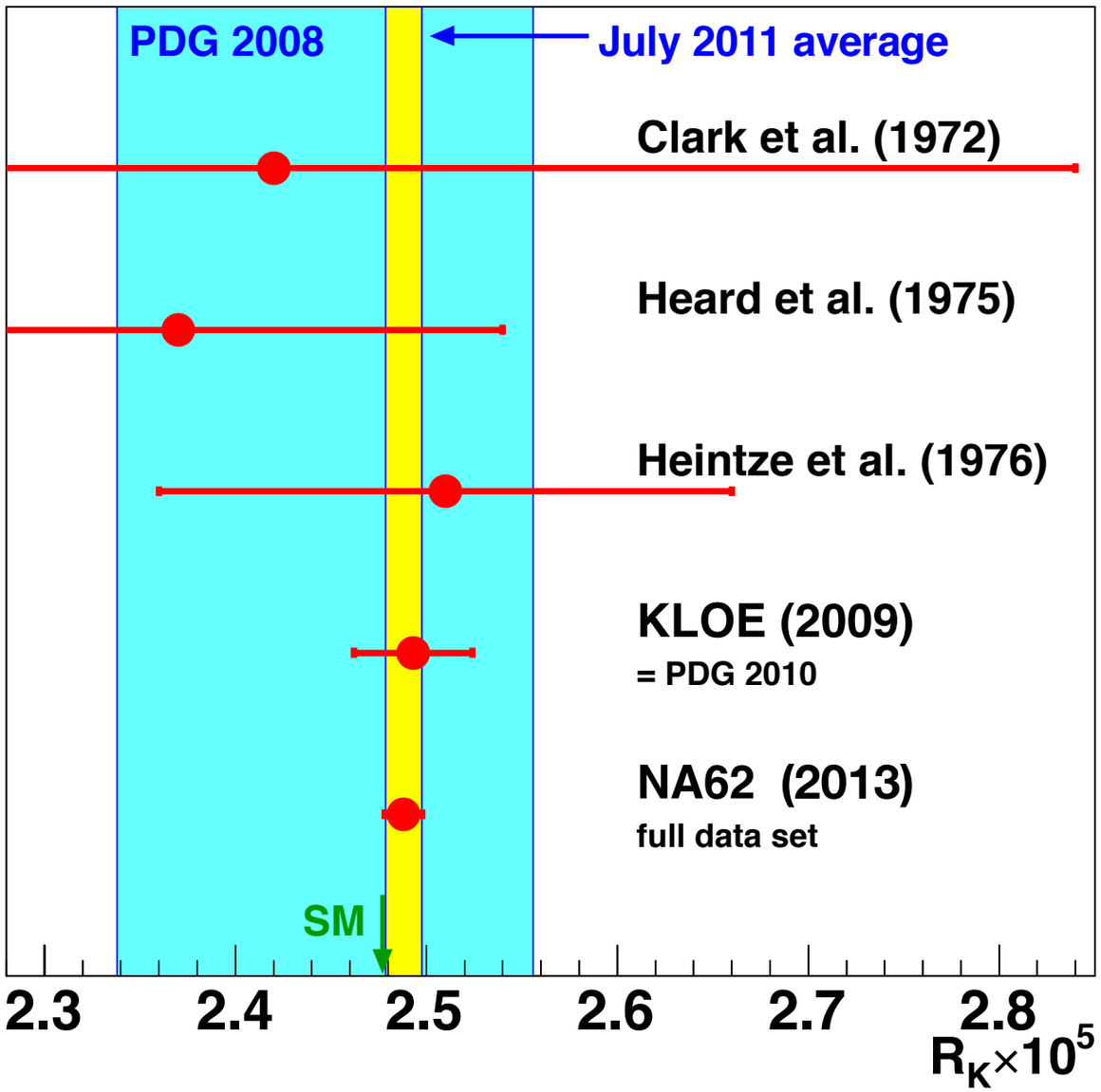
Fit over 40 independent measurements, 10 lepton momentum bins × 4 configurations:

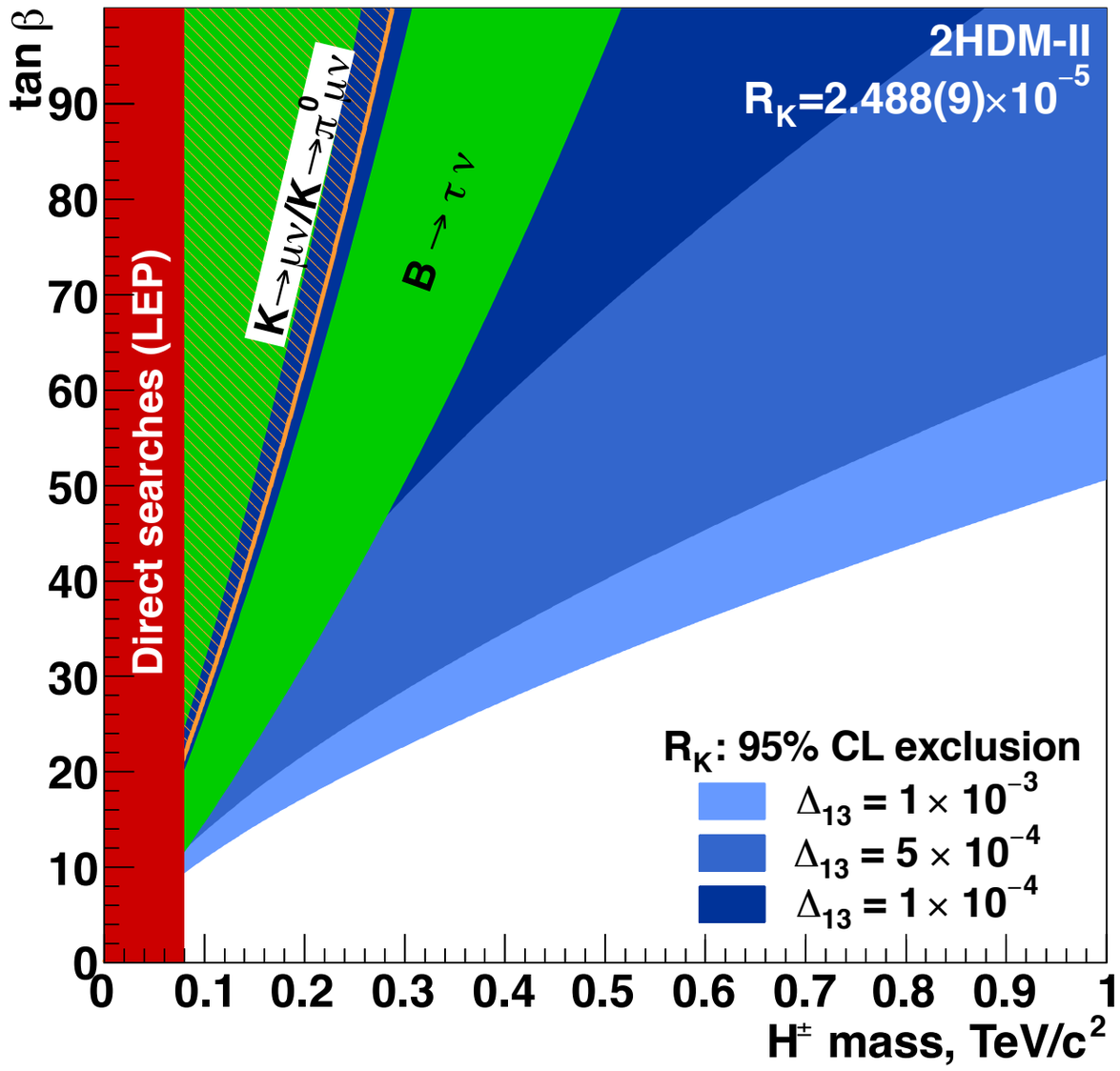
χ^2 / Nd.o.f. = 47/39 (P = 18%)

$$\mathbf{R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \cdot 10^{-5}}$$

Lepton flavour universality (R_k)

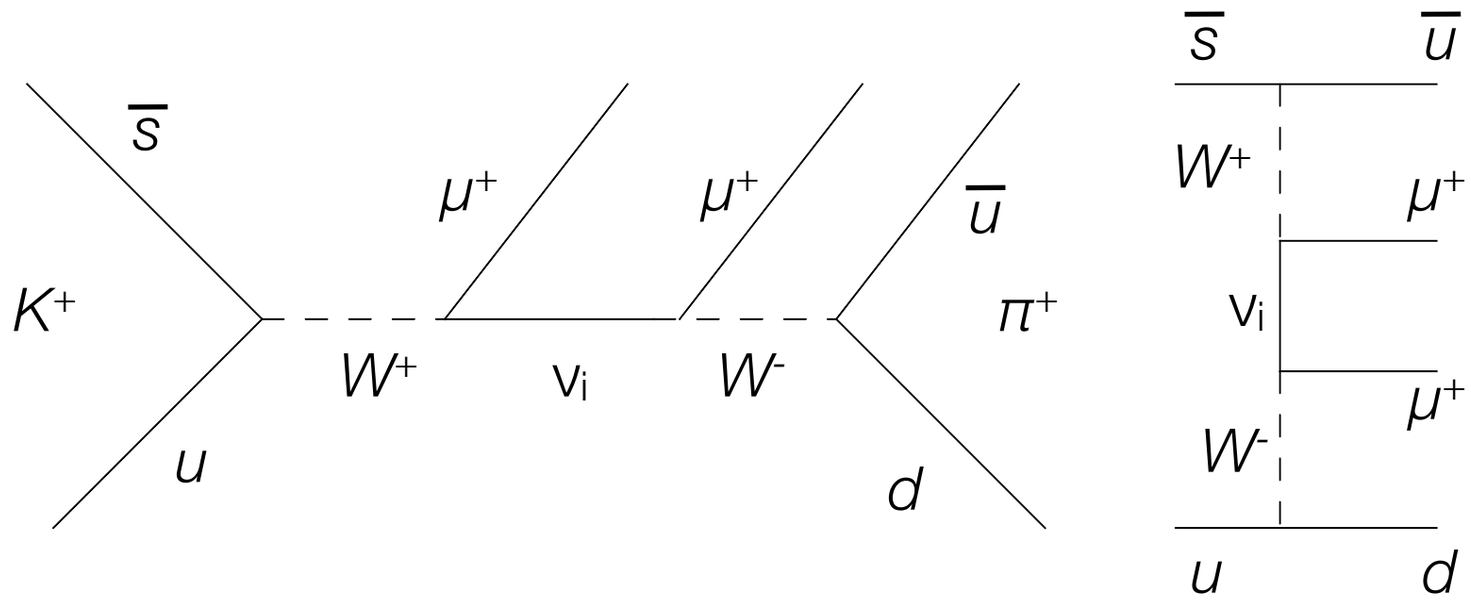
Results





R_k consistent with SM predictions. Precision ~10 time larger then SM estimations

Probing of lepton number violation in $K^+ \to \pi^- \mu^+ \mu^+$
Motivation



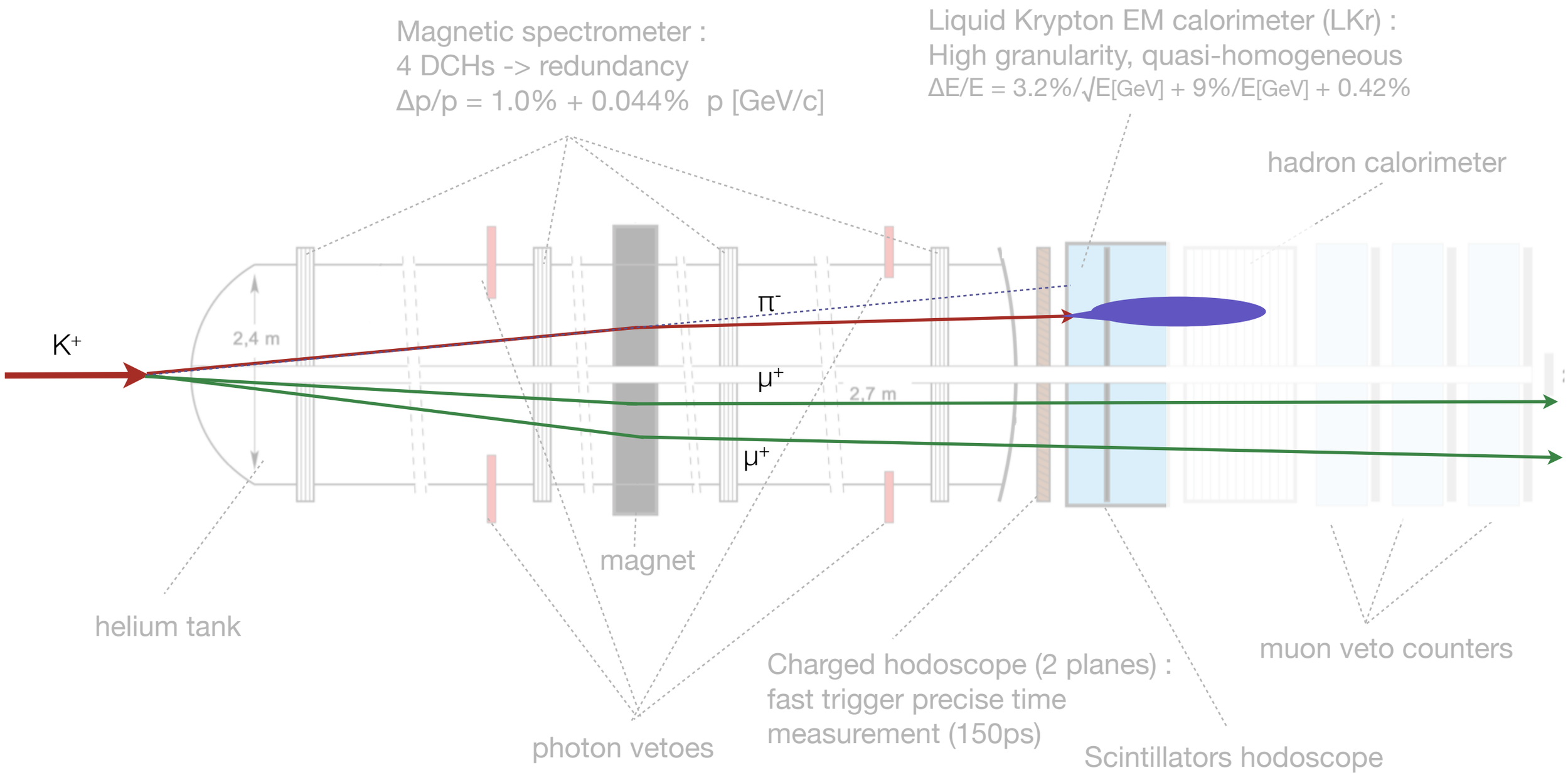
Feynman diagrams in lowest order contributing to the $K^+ \to \pi^- \mu^+ \mu^+$ decay proceed via a Majorana neutrino exchange

measurement of Br($K^+ \to \pi^- \mu^+ \mu^+$) apply restrictions on $< m_{\mu\mu} >$

Experimental status:
Br($K^+ \to \pi^- \mu^+ \mu^+$) < 3.0×10^{-9} (90% C.L.) (E865 collaboration PRL85(2000)2877)

Probing of lepton number violation in $K^+ \rightarrow \pi^- \mu^+ \mu^+$

Detection principle

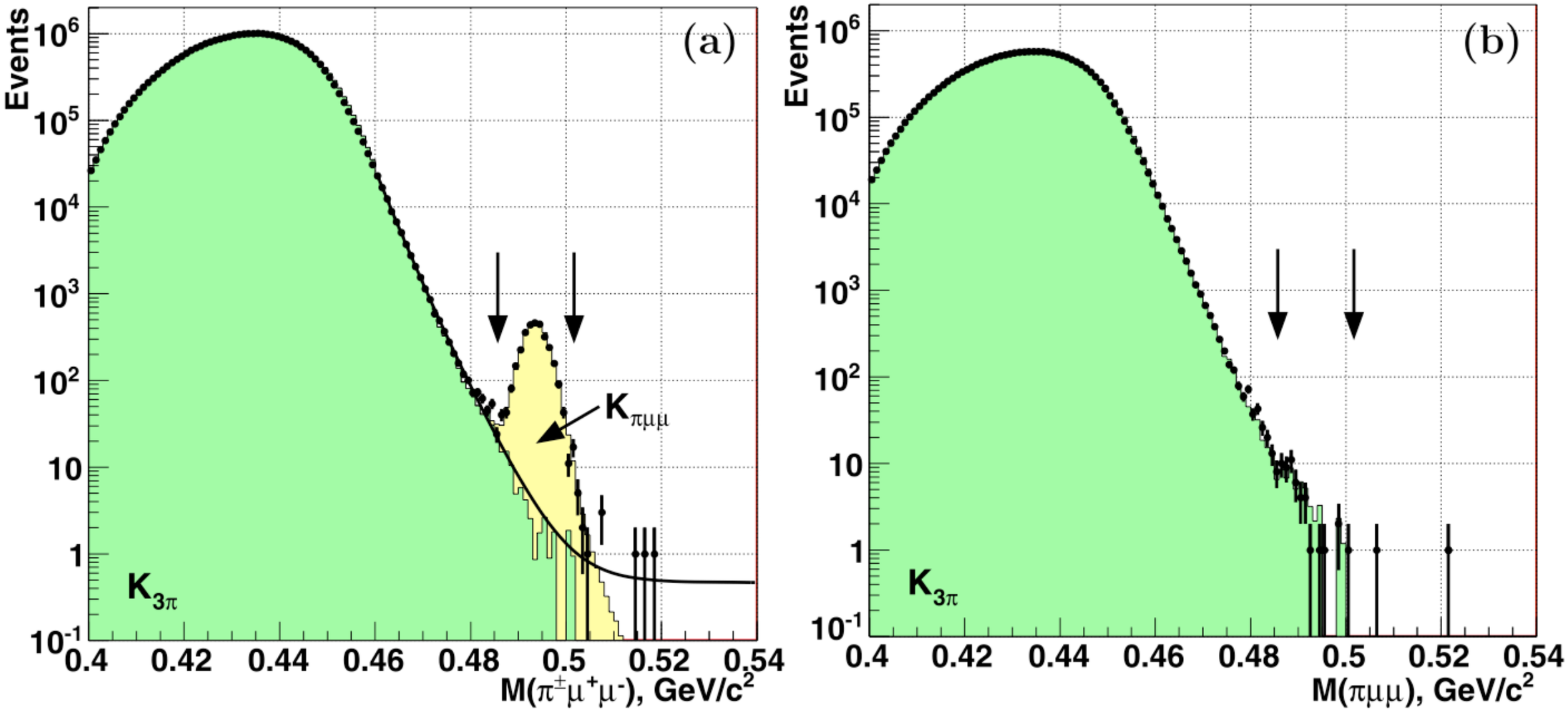


3 tracks, π,μ tracks ⇒ Z_{vertex}, total charge, total momentum, Pt, ΔM

Statistics accounted in 2003/2004

Probing of lepton number violation in $K^+ \to \pi^- \mu^+ \mu^+$

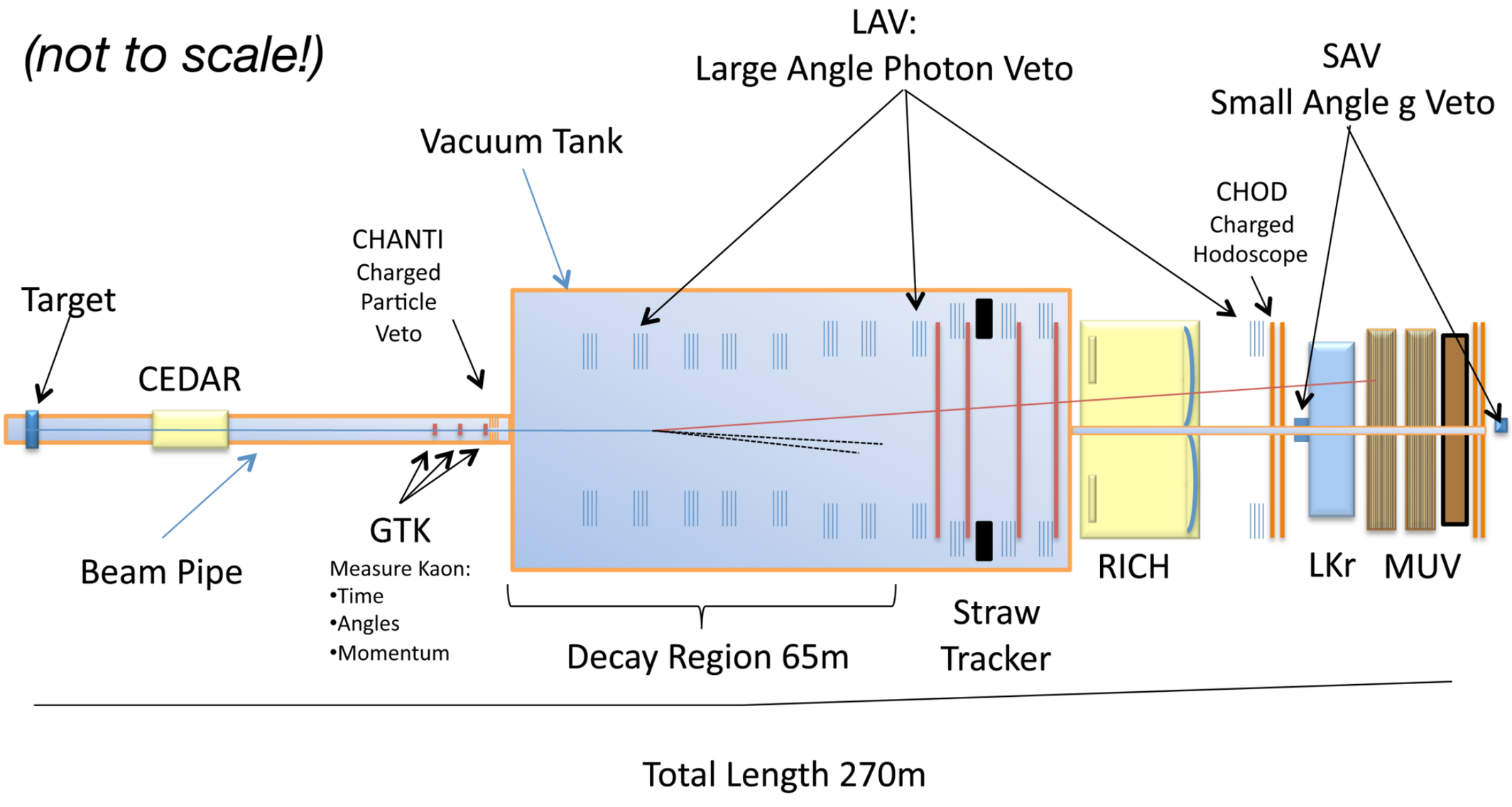
Results



Ndataws=52, NMCws=52.6±19.8, BR($K^+ \to \pi^- \mu^+ \mu$) < 1.1×10^{-9} (90%CL)

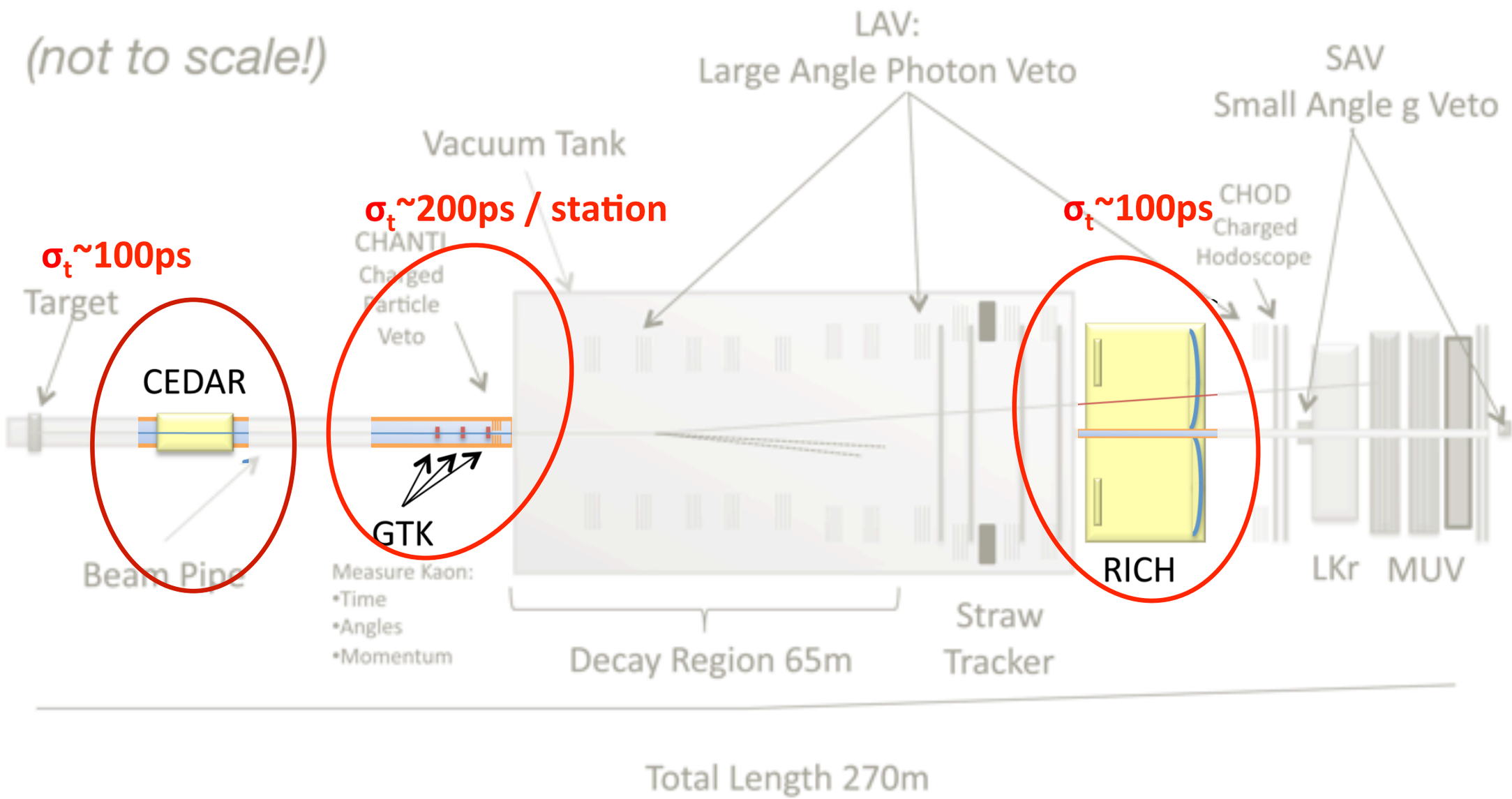
Improvement by factor 3, < mμμ > ≲ 300 GeV/c^2

NA62 is a high sensitive laboratory for studying K decays: overview



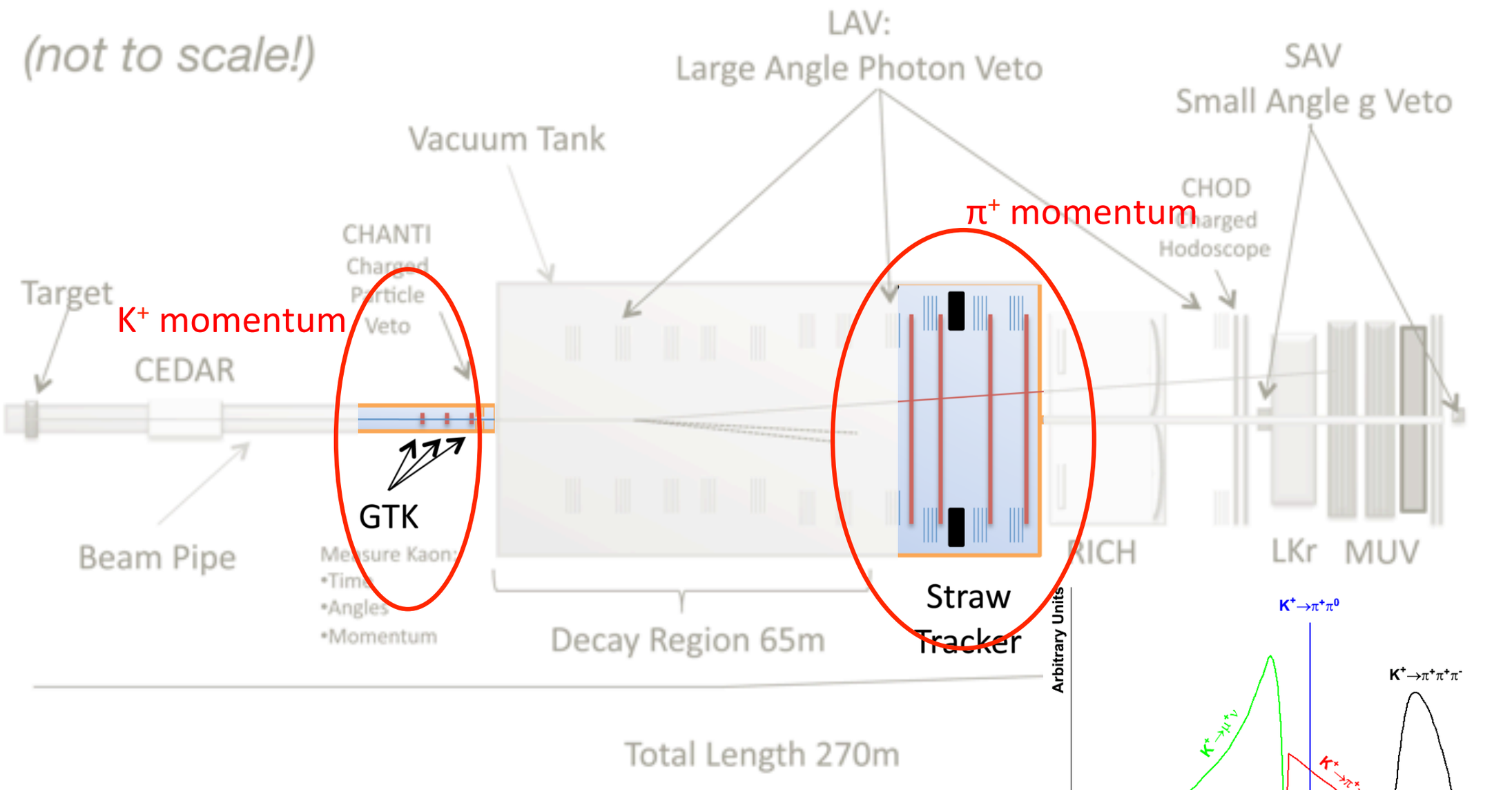
details of the detector are at A.Cassese talk

NA62 is a high sensitive laboratory for studying K decays: excellent time resolution



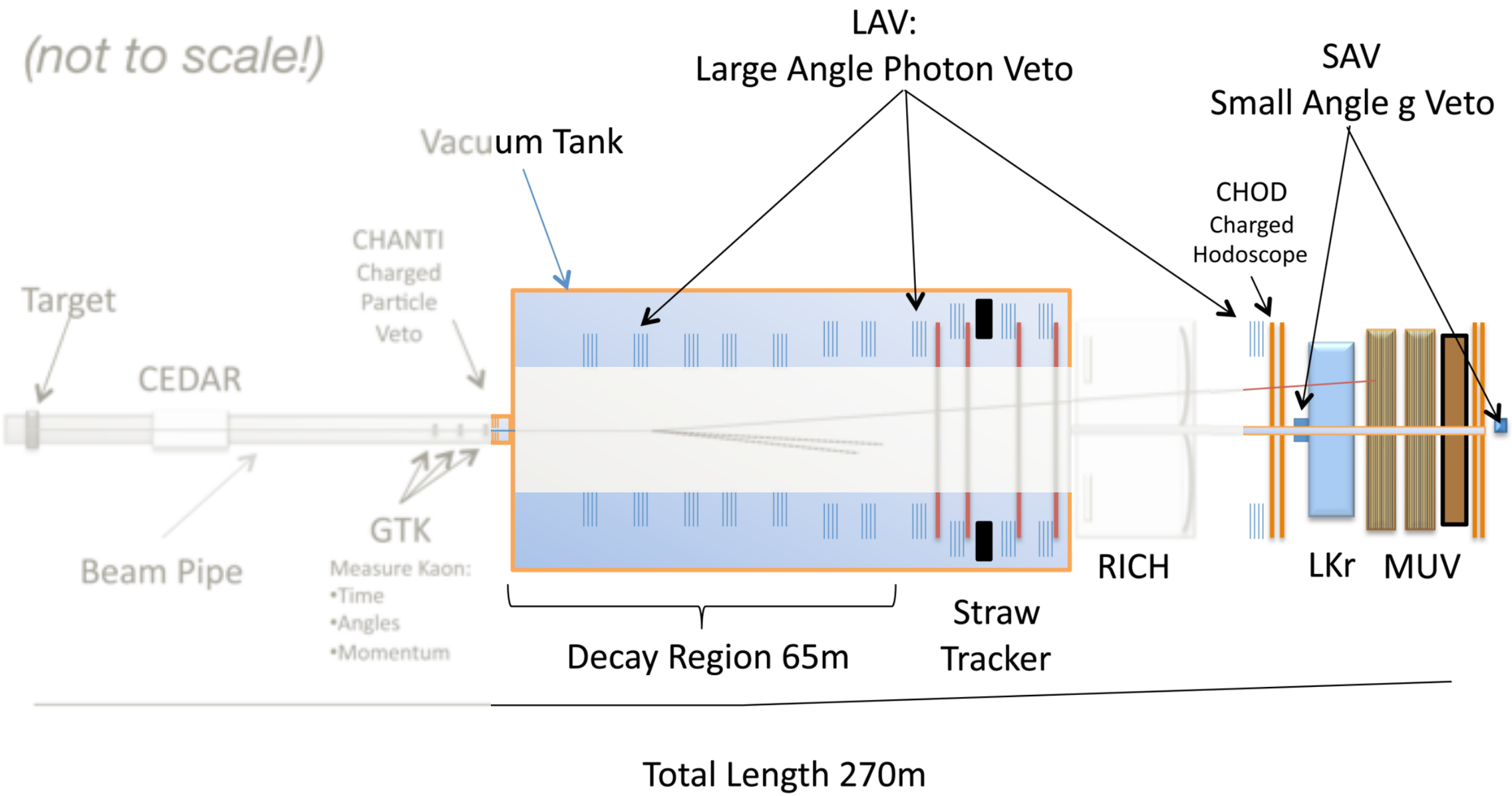
details of the detector are at A.Cassese talk

NA62 is a high sensitive laboratory for studying K decays: excellent charged tracks measurement



details of the detector are at A.Cassese talk

NA62 is a high sensitive laboratory for studying K decays: excellent photon veto



details of the detector are at A.Cassese talk

NA62 is a high sensitive laboratory for studying K decays: excellent opportunities

LFV modes:

Mode	UL at 90% CL	Experiment	Reference
$K^+ \to \pi^+\mu^+e^-$	1.3×10^{-11}	E777/E865	PRD 72 (2005) 012005
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}	E865	PRL 85 (2000) 2877
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}		
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10}		
$K^+ \to \pi^-\mu^+\mu^+$	1.1×10^{-9}	NA48/2	PLB 697 (2011) 107
$K^+ \to \mu^-\nu e^+e^+$	2.0×10^{-8}	Geneva-Saclay	PL 62B (1976) 485
$K^+ \to e^-\nu\mu^+\mu^+$	no data		

4.5×10^{12} well controlled K decays/year ⇒ possible SES 10^{-12}

R_K is also could be improved providing
a new constraints for searching the NP

NA62 is a high sensitive laboratory for studying π decays: excellent opportunities

Mode	Observable	Present exp. knowledge	SM expectation	Physics interest
		Neutral decay modes		
$\pi^0 \to 3\gamma$	BR	BR$< 3.1 \times 10^{-8}$, 90% CL [Crystal box at LAMF, 1988]	forbidden	NP, C violation
$\pi^0 \to 4\gamma$	BR, kinematics	BR$< 2 \times 10^{-8}$, 90% CL [Crystal box at LAMF, 1988]	10^{-11}	NP from $\pi^0 \to SS$, $S \to \gamma\gamma$
$\pi^0 \to$ inv.	BR	BR$< 2.7 \times 10^{-7}$, 90% CL [E949 at BNL, 2005]	BR$< 10^{-13}$ (cosm. lim.)	N_ν; NP LFV
		Charged decay modes		
$\pi^0 \to \mu^\pm e^\mp$	BR	BR$< 3.6 \times 10^{-10}$ KTeV, 2008	forbidden	LFV
$\pi^0 \to e^+e^-e^+e^-$	kinematics	BR$= 3.34(16)10^{-5}$ [KTeV, 2008, 3×10^4 events]	$3.26(18)10^{-5}$	NP off-shell vectors
$\pi^0 \to e^+e^-\gamma$	kinematics	BR$(\pi^0 \to U\gamma) < 1(0.3)10^{-5}$, 95% CL, $M_U = 30(100)$ MeV [WASA at COSY, 2013, 5×10^5 events]	No U boson in the SM	NP dark forces

4.5×10^{12} well controlled K decays/year ⇒ 1.3×10^{11} π^0's from K-> $\pi\pi^0$

Excellent event reconstruction gives possibility for high sensitive measurements of forbidden and rare π^0 decay modes

Conclusion

- Precision on RK value is highly improved (1.3% (KLOE) -> 0.4% (NA62))
  - Consistent with SM prediction
  - The error is still 10 times larger then the SM provides
- The new upper limit of BR($K^+ \rightarrow \pi^- \mu^+ \mu$) is 1.1×10^{-9} (NA48)
- Rich physics program is foreseen for forbidden kaon and pion decay modes in next few years.