The future of NA48: $K^+ \to \pi^+ \nu\bar{\nu}$

Augusto Ceccucci/CERN

- We propose to measure the very rare $K^+ \to \pi^+ \nu \nu$ decay at the CERN SPS
- 10^{13} kaon decays by 2010 to measure $|V_{td}|$ to ~10%
- Compatible with the rest of the CERN programme
- By-products:
  1. Search for $K^+ \to \pi^+ X$
  2. Kaon and Pion(?) rare decays
  3. ? theorists, please suggest

Kaon Mini Workshop
April 13, 2005

Proposal to Measure the Rare Decay $K^+ \to \pi^+ \nu\nu$ at the CERN-SPS

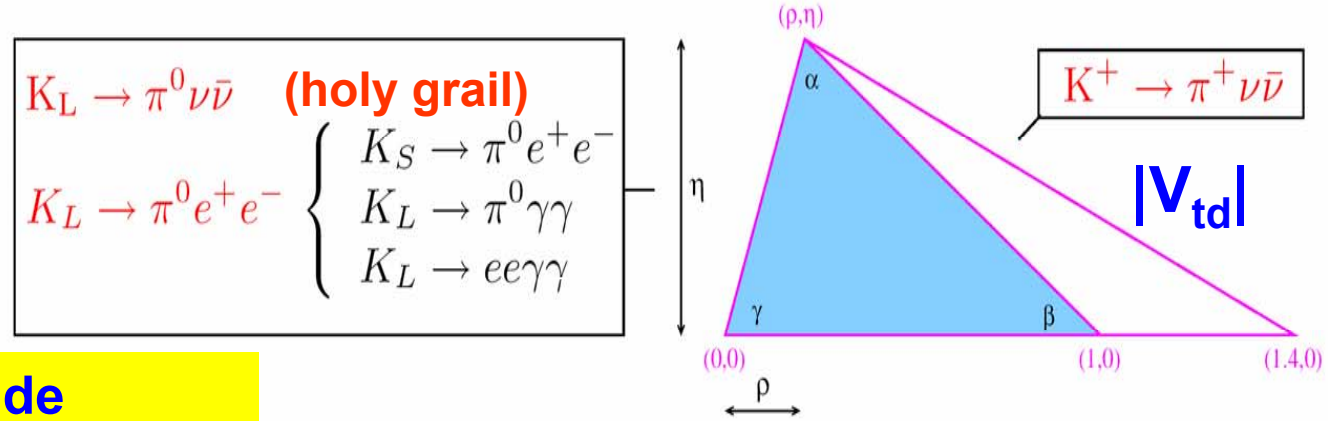
CERN-SPSC-2005-013
SPSC-P-326

CERN, Dubna, Ferrara,
Firenze, Frascati, Mainz, Merced, Moscow (INR), Napoli, Perugia,
Pisa, Protvino, Roma, Saclay, Sofia, Torino, + ??

Kaon Rare Decays and the SM

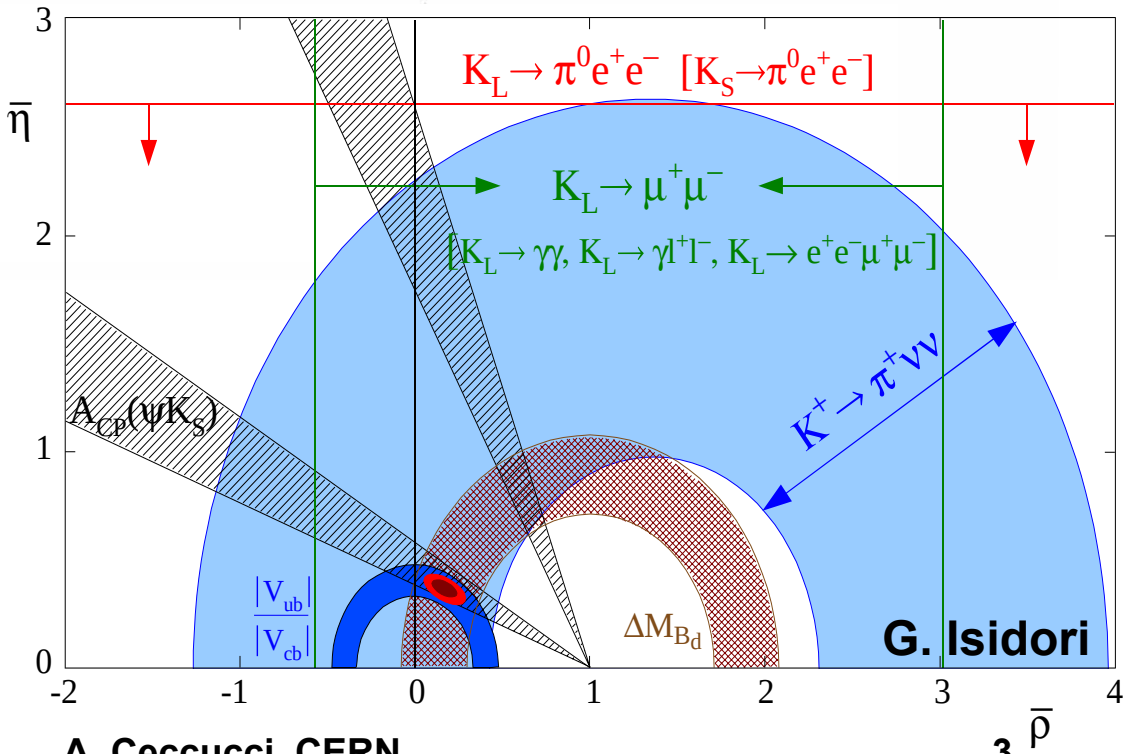
$K_L \to \pi^0 \nu\bar{\nu}$ **(holy grail)**

$K_L \to \pi^0 e^+ e^-$ { $K_S \to \pi^0 e^+ e^-$; $K_L \to \pi^0 \gamma\gamma$; $K_L \to ee\gamma\gamma$ }



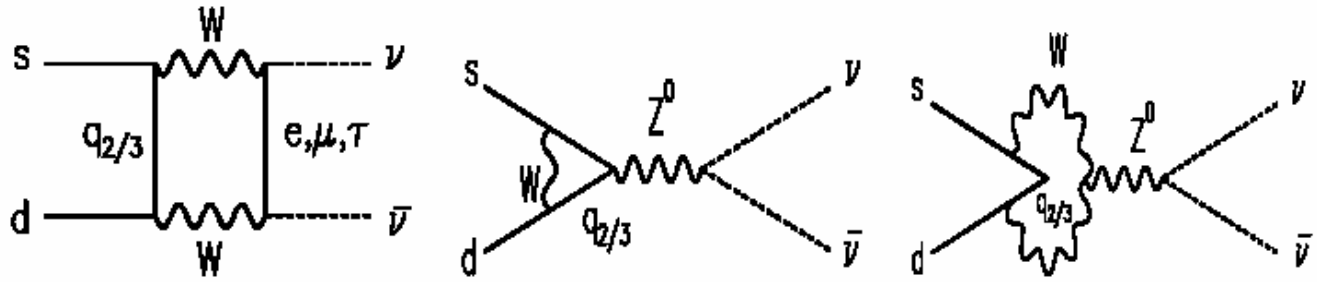
Kaons provide quantitative tests of SM independent from B mesons…

…and a large window of opportunity exists!



$$Im\ \lambda_t = A^2 \lambda^5 \eta$$
$$Re\ \lambda_t = A^2 \lambda^5 \rho$$

$K \to \pi \nu\nu$: Theory in Standard Model



$$B(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ \cdot \left[\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\mathrm{Re}\,\lambda_t}{\lambda^5} X(x_t) + \frac{\mathrm{Re}\,\lambda_c}{\lambda} P_c(X) \right)^2 \right]$$

$$B(K_L^0 \to \pi^0 \nu\bar{\nu}) = \kappa_L \cdot \left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2$$

charm contribution

top contributions

$$\lambda = V_{us}$$
$$\lambda_c = V_{cs}^* V_{cd}$$
$$\lambda_t = V_{ts}^* V_{td}$$

$$\kappa_+ = r_{K^+} \cdot \frac{3\alpha^2 Br(K^+ \to \pi^0 e^+ \nu)}{2\pi^2 \sin^4 \theta_W} \cdot \lambda^8$$

→ The Hadronic Matrix Element is measured and isospin rotated (~10% correction)

Predictions in SM

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (8.0 \pm 1.1) \times 10^{-11}$$ (latest CKM workshop)

Error ~ 14% Mainly parametric

Theory error due to charm (Buras04):

$$P_c(X) = 0.389 \pm 0.033(m_c) \pm 0.045(\mu_c) \pm 0.010(\alpha_s)$$

Largest contribution from scale error. To be reduced by NNLO calculation

For long distance contribution see:"LIGHT-QUARK LOOPS IN K->PI NU NU" By G. Isidori, C.Smith, F.Mescia. e-Print Archive: hep-ph/0503107

$$BR(K_L^0 \to \pi^0 \nu\bar{\nu}) = (3.0 \pm 0.6) \times 10^{-11}$$ (Buras et al. 04)

The error is almost purely parametric

Possibly the Cleanest SM test

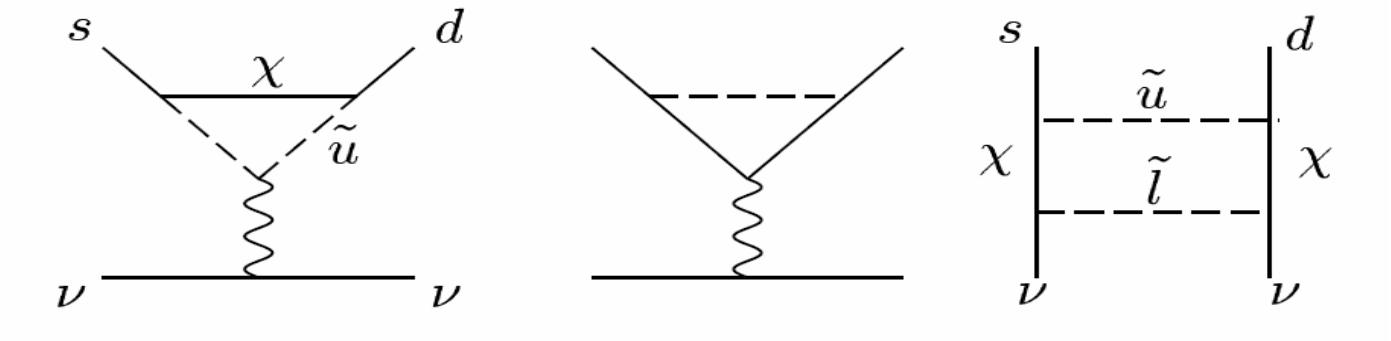
- In $K \to \pi\nu\bar{\nu}$ The phase β derives from Z^0 diagrams (ΔS=1) whereas in A(J/ψ K_S) originates in the $B_d^0 - \bar{B}_d^0$ box diagram (ΔB=2)
- Any non-minimal contribution to Z^0 diagrams would be signalled by a violation of the relation:

$$(\sin 2\beta)_{K\to\pi\nu\bar{\nu}} = (\sin 2\beta)_{B\to J/\psi K_S}$$

- A deviation from the predicted rates of SM would be a clear indication of new physics
- Complementary programme to the high energy frontier:
  - When new physics will appear at the LHC, the rare decays may help to understand the nature of it

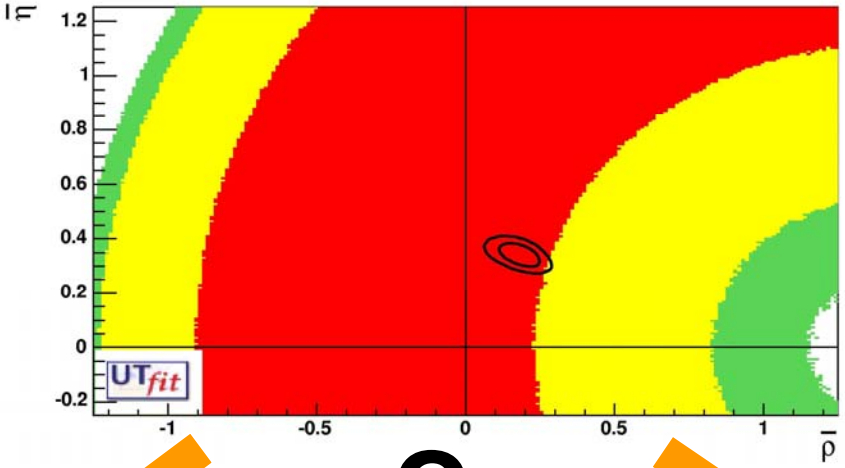
Beyond Standard Model Predictions

	$BR(K^+ \to \pi^+ \nu\bar{\nu}) \times 10^{-11}$	$BR(K_L^0 \to \pi^0 \nu\bar{\nu}) \times 10^{-11}$
SM	**8.0 ± 1.1**	**3.0 ± 0.6**
MFV hep-ph/0310208	**19.1**	**9.9**
EEWP NP B697 133	**7.5 ± 2.1**	**31 ± 10**
EDSQ hep-ph/0407021	**15**	**10**
MSSM hep-ph/0408142	**40**	**50**



Setting the bar for the next generation of $K^+ \to \pi^+ \nu\nu$ experiments

Current constraint on ρ,η plane



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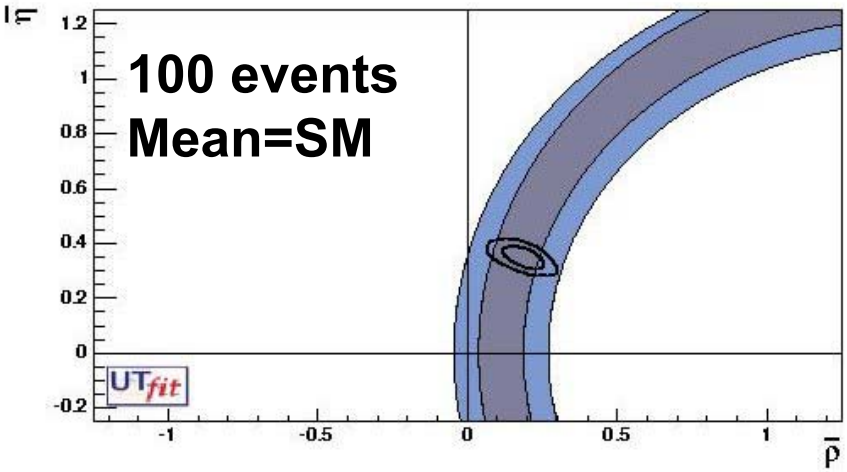
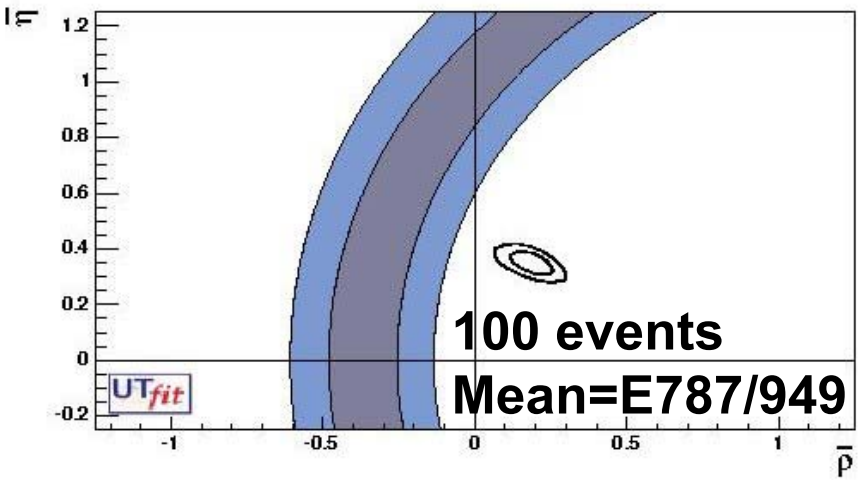




Prospects in K rare decays

- $K^0_L \to \pi^0 \nu\nu$
  - Large window of opportunity exists.
  - Upper limit is 4 order of magnitude from the SM prediction
  - Expect results from data collected by E391a (proposed SES~3 10^{-10})
  - Next experiment KOPIO@ BNL (currently under Review)
- $K^0_L \to \pi^0 ee(\mu\mu)$
  - Long distance contributions under better control
  - Measurement of K_S modes by NA48/1 has allowed SM prediction
  - K_S rates to be better measured (KLOE?)
  - Background limited (study time dep. Interference?)
  - 100-fold increase in kaon flux to be envisaged
- $K^+ \to \pi^+ \nu\nu$
  - The situation is different: 3 clean events are published
  - Experiment in agreement with SM
  - Next round of exp. need to collect O(100) events to be useful
  - Move from stopped to in flight experiments (NA48)

Prospects on $K^+ \to \pi^+ \nu\nu$

- **Decays at rest:**
  - Window of opportunity to accumulate more data at BNL until 2010 (before KOPIO data taking starts)
  - Ideas to pursue stopped kaon decays in Japan
  - Established technique…
  - …but hard to extrapolate to O(100) events
- **Decays in flight**
  - Large acceptances, good photon rejection
  - Separated beam: (FNAL-CKM cancelled)
    - Limited to about P_K<30 GeV/c
  - Un-separated beam: CERN-NA48/3
    - Limited by rate in beam trackers

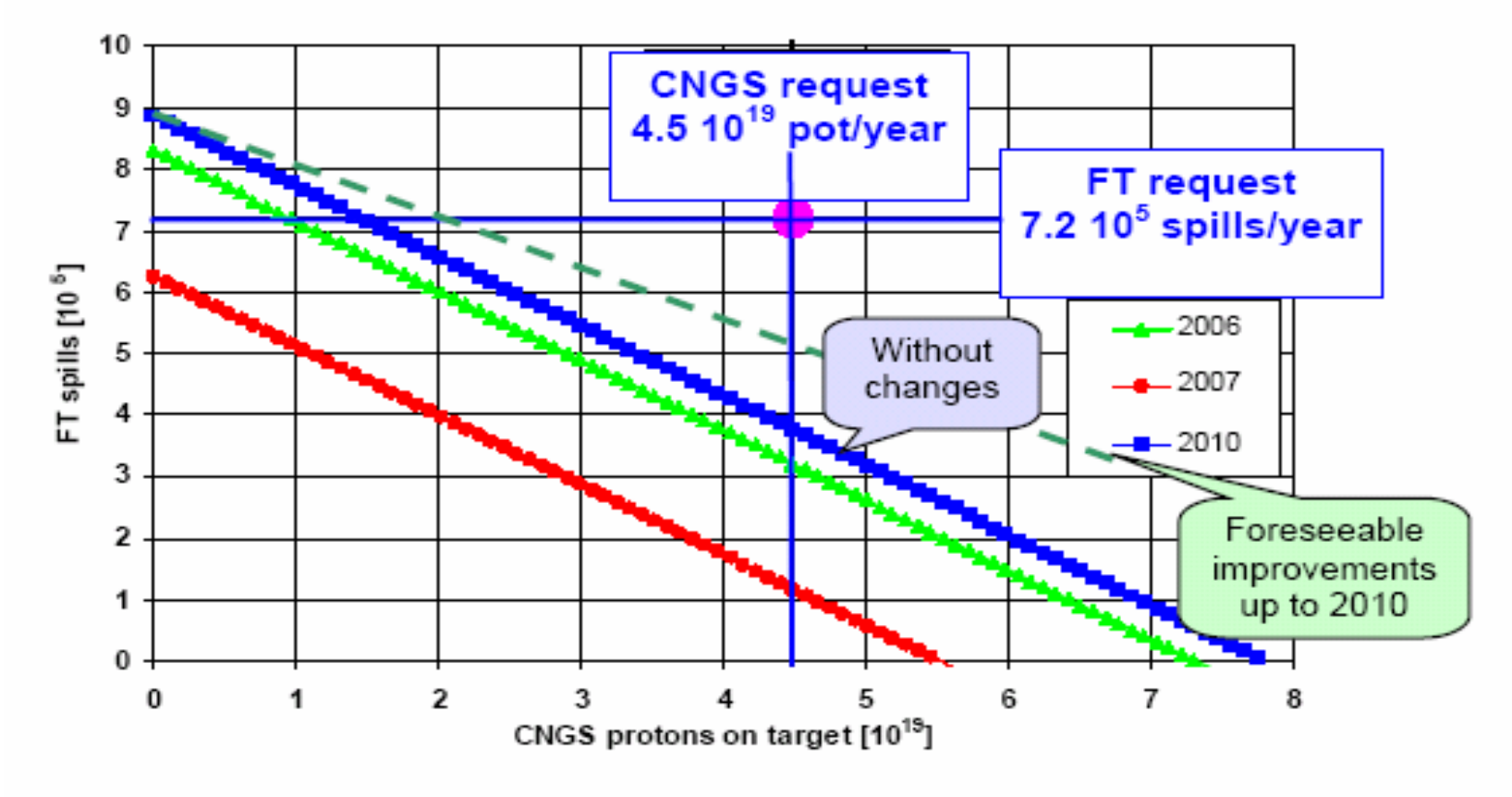
Message from the CERN Director General to the staff (Jan 05)

- **The top priority is to maintain the goal of starting up the Large Hadron Collider (LHC) in 2007**

- **"…Meanwhile, the natural break we have in the fixed-target programme in 2005 is already allowing the community to develop a well-focused programme for the future"**

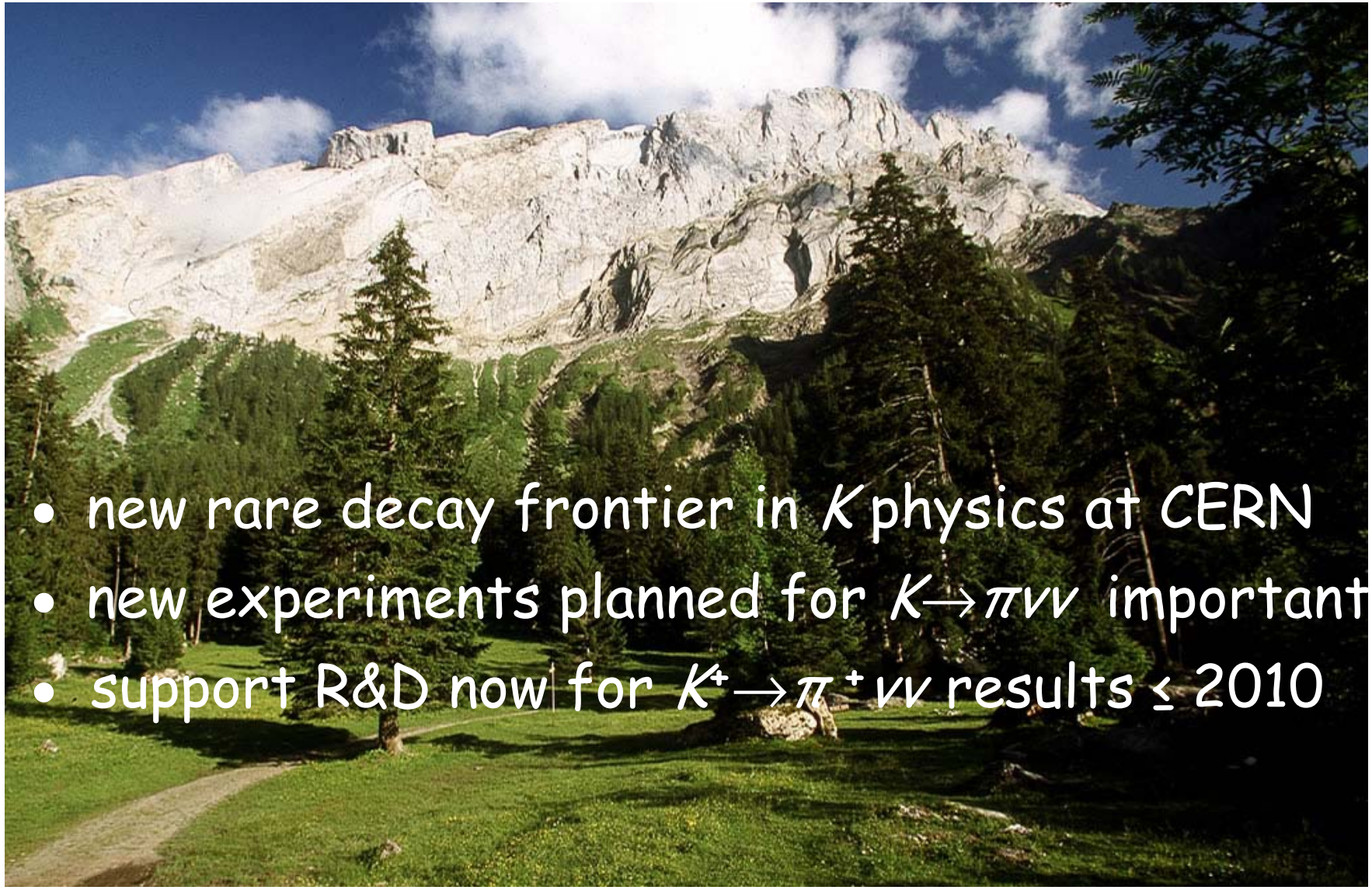
The possible Non-LHC Future Programme was reviewed by the SPSC in Villars (September 22-27, 2004)

SPS Protonomics



John Dainton
Villars 2004
October 7th 2004
CERN seminar

SPSC@Villars



From the Villars Report…

CERN-SPSC-2005-010
SPSC-M-730
Febbruary 28, 2005

3.3 Flavour Physics

There is a strong physics case for pursuing an ambitious program of kaon physics at CERN, exploiting the high-energy proton beams available at the SPS for rare K-decay in-flight measurements. Building on its expertise in high-intensity neutral and charged kaon beams and on the outstanding physics achievements of the NA48, NA48/1 and NA48/2 experiments in the last decade, CERN should remain in the future a major laboratory for kaon physics at the sensitivity frontier.

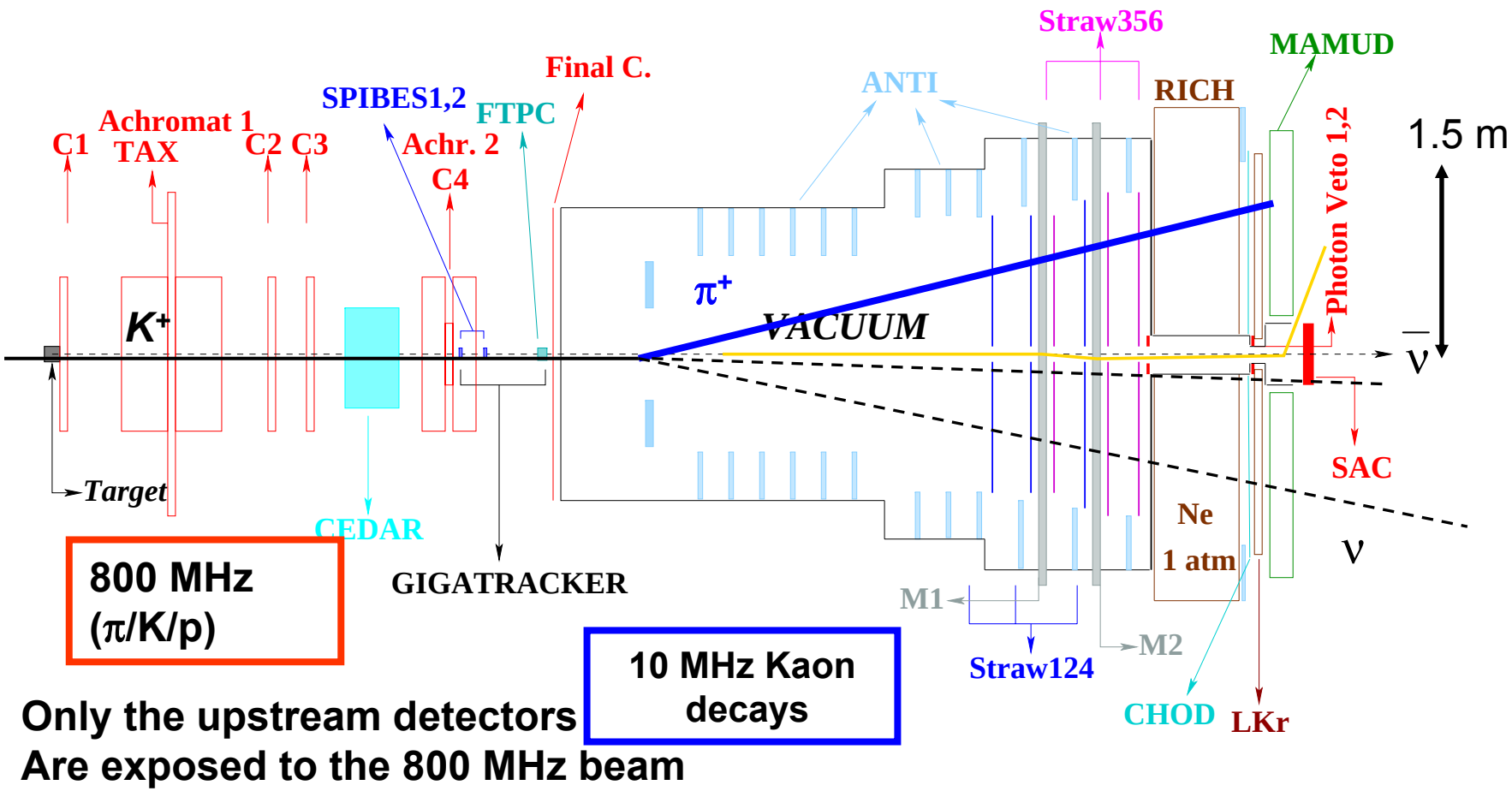
The possibility of a precise measurement of the $K^+ \to \pi^+ \nu\nu$ transition is exciting. The goal is to detect more than 100 signal events over two years starting in 2009. The challenge is for experimental sensitivity to a K-decay BR of order 10^{-11}. A major upgrade of the present NA48/2 set-up would be necessary and the required R&D and detector developments should be supported. According to present studies this measurement appears globally competitive.

New high-intensity K^+ beam for NA48/3

Already Available

Beam:	Present K12 (NA48/2)	New HI K^+ > 2006	Factor wrt 2004
SPS protons per pulse on T10	1×10^{12}	3×10^{12}	3.0
Duty cycle (s./s.)	4.8 / 16.8		1.0
Solid angle (μsterad)	≈ 0.40	≈ 16	40
Av. K^+momentum $\langle p_K \rangle$ (GeV/c)	60	75	Total : 1.35
Mom. band RMS: ($\Delta p/p$ in %)	≈ 4	≈ 1	~0.25
Area at Gigatracker (cm^2)	≈ 7.0	≈ 20	≈ 2.8
Total beam per pulse (x 10^7)	5.5	250	~45 (~27)
per Effective spill length MHz	18	800	~45 (~27)
MHz/cm^2 (gigatracker)	2.5	40	~16 (~10)
Eff. running time / yr (pulses)	3* x 10^5	3.1 * 10^5	1.0
K^+ decays per year	1.0×10^{11}	4.0×10^{12}	≈ 40

(Latest) NA48/3 Detector Layout



Time Schedule

- 2005
  - Launch R&D
  - Vacuum tests
  - Evaluate straw tracker
  - Complete realistic cost estimation
  - Complete analysis of beam-test data
  - Submit proposal to SPSC (P326 NOW!)
- 2006-2008
  - Costruction, Installation and beam-tests
- 2009-2010
  - Data Taking

Conclusions

- We have found a fortunate combination where a compelling physics case can be addressed with an existing accelerator, employing the infrastructure (i.e. civil engineering, hardware, some sub-systems) of an existing experiment

- We stress that this initiative in not a mere continuation of NA48

- We are seeking new Collaborators!