Incontri di Fisica delle Alte Energie 2010
Roma – 8 Aprile 2010

Kaon physics

(Fisica dei K: rassegna sperimentale)

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Outline of the talk:

- **"Vus saga" or "precise tests of SM from leptonic and semileptonic K decays"**
- **Measurement of $R_K = \Gamma(Ke2)/\Gamma(K\mu 2)$**
- **(Near) future plans**

Leptonic and semileptonic K decays

• Within the SM leptonic and semileptonic K decays can used to obtain the most accurate determination of the element Vus of the CKM matrix

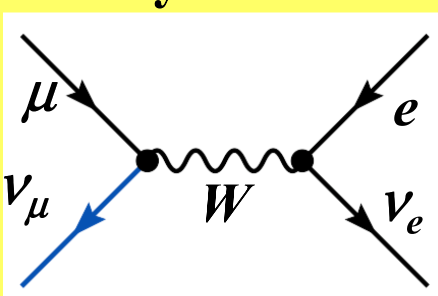
$$\Gamma(K_{\ell 3(\gamma)}) = \frac{G_F^2 m_K^5}{192\pi^3} C_K S_{\rm ew} |V_{us}|^2 f_+(0)^2 I_K^\ell(\lambda_{+,0}) \left(1 + \delta_{SU(2)}^K + \delta_{\rm em}^{K\ell}\right)^2$$

$$\frac{\Gamma(K^\pm_{\ell 2(\gamma)})}{\Gamma(\pi^\pm_{\ell 2(\gamma)})} = \left|\frac{V_{us}}{V_{ud}}\right|^2 \frac{f_K^2 m_K}{f_\pi^2 m_\pi} \left(\frac{1 - m_\ell^2/m_K^2}{1 - m_\ell^2/m_\pi^2}\right)^2 \times (1 + \delta_{\rm em})$$

• Test **unitarity of the quark mixing matrix** (V_{CKM}):

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 + \epsilon_{\rm NP} \qquad \epsilon_{\rm NP} \sim M_W^2/\Lambda_{\rm NP}^2$$

μ decay

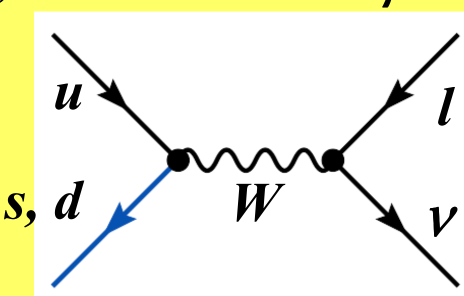


$$(g_\mu g_e)^2 / M_W^4 = G_F^2$$

?

=

***K*, π and nuclear *β* decays**



$$(g_q g_l)^2 \left(|V_{ud}|^2 + |V_{us}|^2\right) / M_W^4 = G_{CKM}^2$$

NP test from (semi)leptonic K decays

Study within a **model-independent effective theory approach** the implications of precise measurements of Kl2 and Kl3 decays for SM estension [Cirigliano, Gonzalez-Alonso, and Jenkins, arXiv:0908.1754 hep-ph]

Phenomenology in $U(3)^5$ flavor symmetry limit

• Taking into account all the Precision Electroweak constraints, the maximal deviation of $|\Delta_{CKM}|$ allowed is:

$$-9.5 \times 10^{-3} \leq \Delta_{CKM} \leq 0.1 \times 10^{-3};$$

$\rightarrow$ deviation from CKM unitarity at -1% level not ruled out by PEW tests.

• Even a % level test of CKM unitarity would provide information not available through other precision tests at low- and high-energy.

• δVus=0.5% combined with δVud=0.02% (nuclear beta decays) allow to probe NP effective scales of the order of 10 TeV.

NP test from (semi)leptonic K decays

Study within a **model-independent effective theory approach** the implications of precise measurements of Kl2 and Kl3 decays for SM [Cirigliano, Gonzalez-Alonso, and Jenkins, arXiv:0908.1754 hep-ph]

Beyond $U(3)^5$ limit.
Corrections to the $U(3)^5$ limit can be introduce within MFV and via generic flavor structures (pseudoscalar and tensor structures).
A high sensitive probe of $U(3)^5$ violating structures is provided by comparing the Vus value extracted by the helicity suppressed $K\mu 2$ decays and the helicity allowed Kl3 modes, using the ratio

$$R_{\mu 23} = \left| \frac{|V_{us}|}{|V_{ud}|} \frac{f_K}{f_\pi} \right|_{K_{\mu 2}} \frac{|V_{ud}|_{0^+ \to 0^+}}{(|V_{us}| f_+(0))_{K_{\ell 3}}}$$

(minimize impact of f_K and e.m. corrections)

Within SM, $R_{\mu 23}=1$; the inclusion of Higgs-mediated scalar currents leads to

$$R_{\ell 23} = \left| 1 - \frac{m^2_{K^+}}{M^2_{H^+}} \left(1 - \frac{m_d}{m_s}\right) \frac{\tan^2\beta}{1+\epsilon_0 \tan\beta} \right|$$


Vus saga

Determination of V_{us} from Kl2 decays

Within SM, the ratio of photon inclusive K_{l2} to π_{l2} decay rates is:

$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} = \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K}{f_\pi} \times \frac{M_K(1-m_\mu^2/M_K^2)^2}{m_\pi(1-m_\mu^2/m_\pi^2)^2} \times (1+\delta_{em})$$

Obtain $|V_{us}|$ from:

- measurements of the inclusive K_{l2} and π_{l2} decay widths;
- $|V_{ud}|$=**0.97425(22)** from super-allowed $0^+ \rightarrow 0^+$ nuclear beta decays
  [Hardy and Towner, Phys. Rev. C79(2009) 055502]

Use precise evaluation of long-distance e.m. corrections $\delta_{em} = -0.0070(18)$.

f_K/f_π not protected by the Ademollo-Gatto theorem: only lattice.

(lattice calculation of f_K/f_π and radiative corrections benefit of cancellations).

Determination of V_{us} from Kl3 decays

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2\, G_F^2 M_K^5}{192\pi^3} S_{EW}\, |V_{us}|^2\, |f_+(0)|^2\, I_{K,l}(\lambda)\, (1+\delta_K^{SU(2)}+\delta_{K,l}^{EM})^2$$

(with $K = K^+, K^0;\ l = e, \mu$ and $C_K^2 = 1/2$ for K^+, 1 for K^0)

	Theory			Experiment
Decay Rate				$\Gamma(K_{l3(\gamma)})$ BR and lifetimes
Form Factor	$f_+(0)$ Hadronic matrix element at zero momentum transfer			$I_{K,l}(\lambda)$ Phase space: λ param. form factor dependence on t
Corrections	S_{EW} short distance EW	$\delta_K^{SU(2)}$ strong SU(2) breaking	$\delta_{K,l}^{EM}$ long distance EM	

V_{us} estimate

- Present world data for K→πlν BR's quite satisfactory, determined by experiments with very different techniques:

KLOE@DaΦne: pure K beams, lifetimes, absolute BR
NA48@CERN: intense K^0, K^+ beams from SPS proton beam, ratio of BR's
KTeV@FermiLab: intense K_L beam from Tevatron proton beam, ratio of BR's
ISTRA+@IHEP (Protvino): ratio of K^+l3 BR's

- …and the **theoreticians**!
- **FlaviaNet Kaon Working Group: do the dirty job of putting all together…**

Precision tests of the Standard Model with leptonic and semileptonic kaon decays

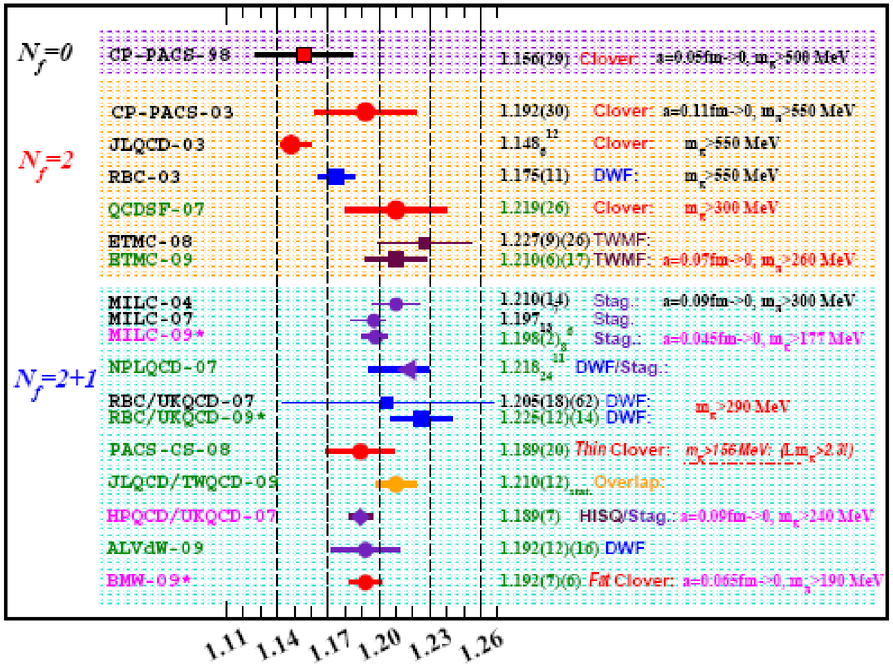
The FlaviaNet Kaon Working Group*†‡

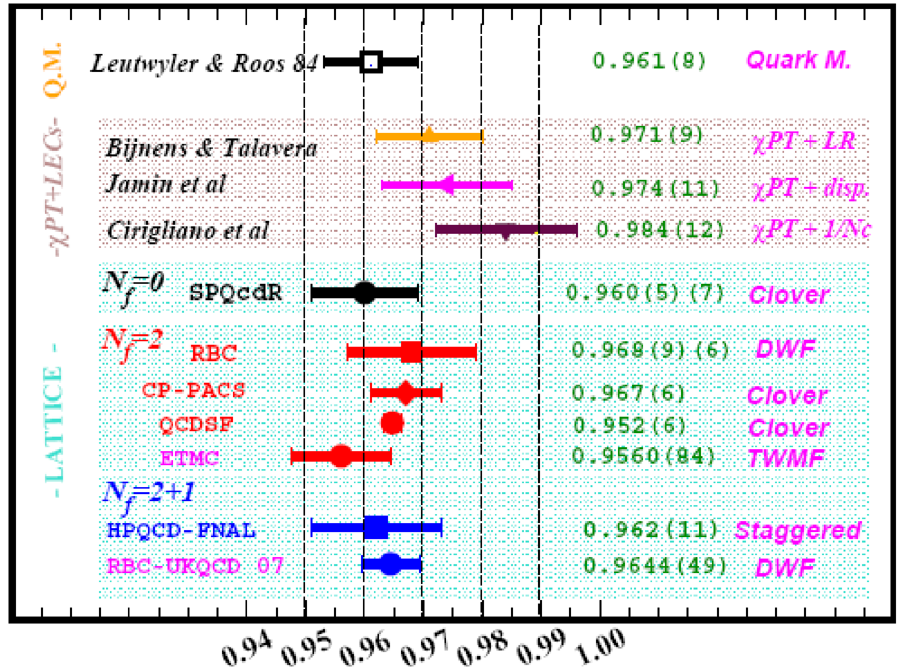
FlaviaNet Kaon WG note: arXiv:0801.1817.

Final updated version available on arXiv in few days!

All results presented are from the final updated version.

Theoretical estimate of f_K/f_π and $f_+(0)$





Waiting for FLAG FlaviaNet WG results, we use:

f_K/f_π: average of results with analysis of all systematics [BMW, MILC09, HPQCD/UKQCD]. Av. with stat. err. only + smalles syst. err: **1.193(6)**.

$f_+(0)$: the only available N_f=2+1 result: **0.9644(49)** [RBC/UKQCD]

Note on BR and lifetime data set

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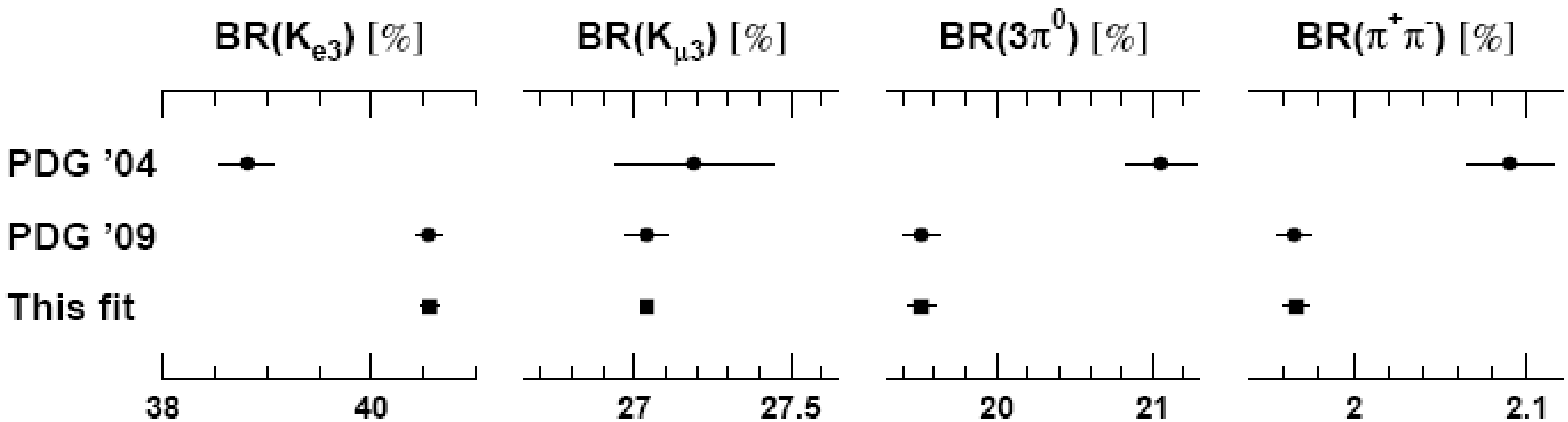
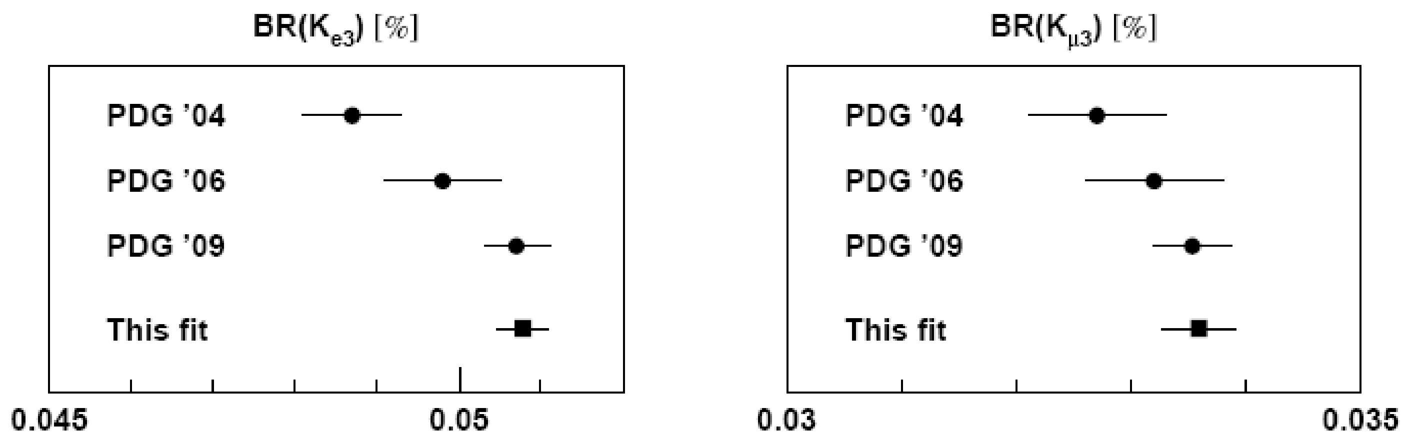
Careful reading of the original papers → definition of different data set and/or parameters wrt to PDG

K_L



$K^{\pm}$



Wrt to PDG09: minor differences on the fit results

Parameterization of form factors

$|V_{us}f_+(0)|$ extraction needs calculation of the phase space integrals:

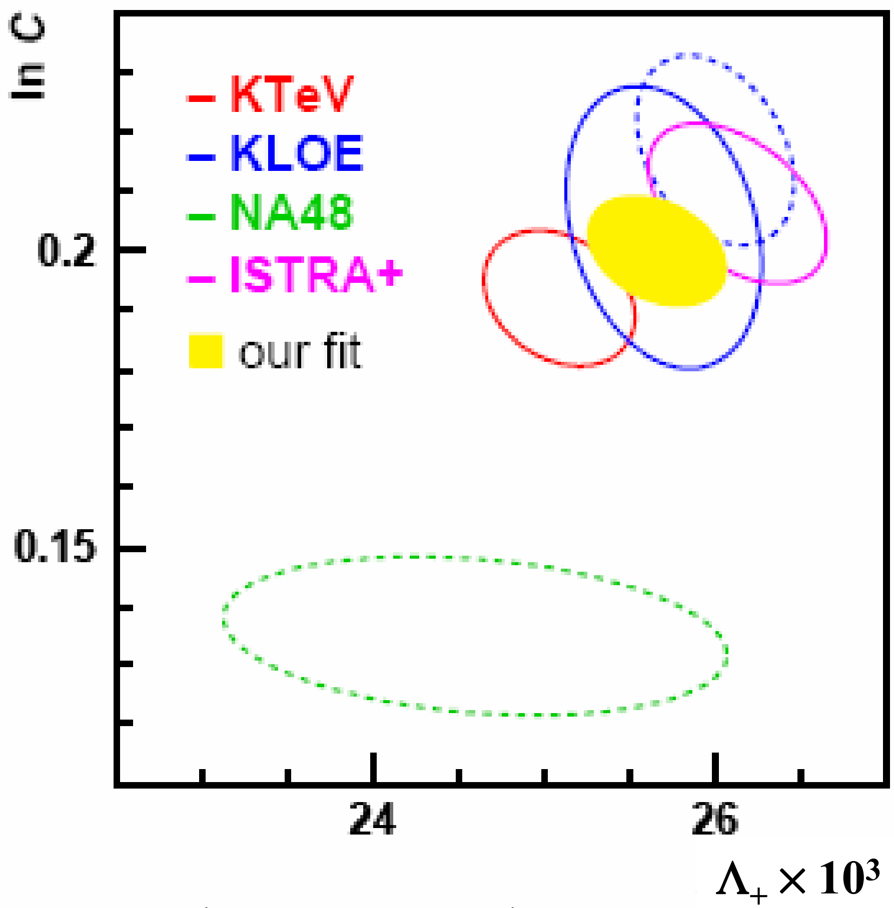
$$I_K^\ell = \int_{m_\ell^2}^{t_0} dt\, \frac{1}{m_K^8}\, \lambda^{3/2} \left(1+\frac{m_\ell^2}{2t}\right) \left(1-\frac{m_\ell^2}{2t}\right)^2 \left(\bar{f}_+^2(t) + \frac{3m_\ell^2 \Delta_{K\pi}^2}{(2t+m_\ell^2)\lambda} \bar{f}_0^2(t)\right)$$

• **Class II**: based on a systematic mathematical expansion (e.g. Taylor, "z-par.")
- freedom to determine high-order terms from data
- strong par. correlation → no sensitivity to high order terms (λ_0'') **[PoS 2008(KAON)002]**
- accurate description in physical region needs at least 2nd Taylor exp. **[PLB638(2009)480]**
- test of low-energy dynamics involving Callan-Treiman th. needs orders>2nd.

• **Class I**: to reduce the number of parameters, impose additional physical constraints
- **pole**: dominance of single resonance $M_{V,S}$ (one free parameter)
  vector: K*(892) ok; scalar: no obvious dominance.
- **dispersive**: ff analytic (except real $t>(m_K+m_\pi)^2$) functions in the complex t-plane.
  vector: numerically similar to pole (K*(892) dominance);
  scalar: necessary without dominant one-particle intermediate state.

Form factors: dispersive approach

Results from **KTeV** **KLOE** **ISTRA+** **NA48** **This fit**



$$\Lambda_+ \times 10^3 = \mathbf{25.66 \pm 0.41}$$
$$\ln C = \mathbf{0.2004(91)}$$
$$\rho(\Lambda_+, \ln C) = -0.33$$
$$\chi^2/\text{ndf} = 5.6/5\ (34\%)$$

Dashed lines show **NA48*** and **preliminary KLOE** data **not in fit**

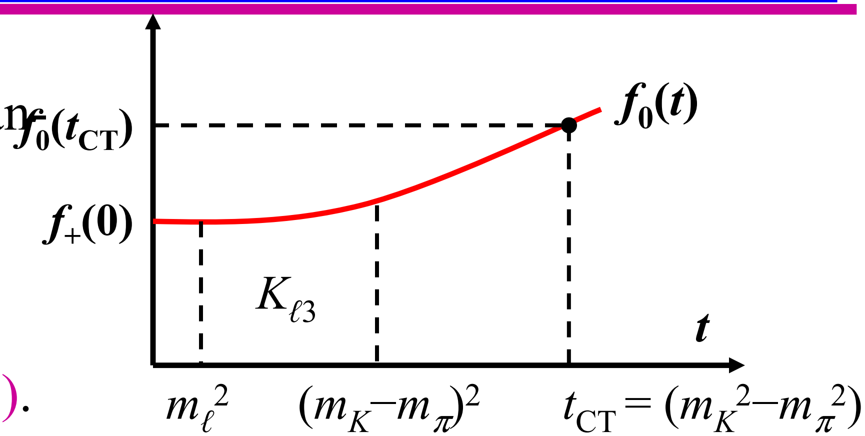
Integrals		
Mode	Quad-lin	Disp
K^0_{e3}	0.15457(20)	**0.15476(18)**
K^+_{e3}	0.15894(21)	**0.15922(18)**
$K^0_{\mu3}$	0.10266(20)	**0.10253(16)**
$K^+_{\mu3}$	0.10564(20)	**0.10559(17)**

Maximum change 0.2% if same data used as for quad-lin fits

$K\mu 3$ scalar ff: test of χPT

Dispersive parameterization for f_0(t) plus Callan-Treiman relation

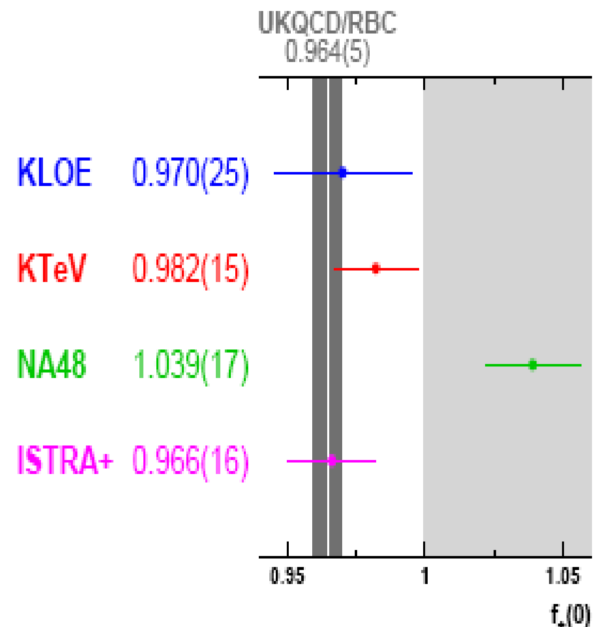
$$C \equiv \tilde{f}_0(\Delta_{K\pi}) = \frac{f_K}{f_\pi}\frac{1}{f_+(0)} + \Delta_{CT}$$



Assuming a f_K/f_π value, obtain a value for $f_+(0)$.

Consistency test between scalar ff measurement and lattice calculations.

WA for ln C gives: $f_+(0) = 0.974(12)$



NA48 value is inconsistent with theoretical expectations: $f_+(0)<1 \rightarrow$ exclude NA48 $K\mu 3$ ff from averages used for V_{us}.

WA exp. data on ln C alone gives $f_K/f_\pi / f_+(0) = 1.225(14)$ completely independent of any information from lattice estimates

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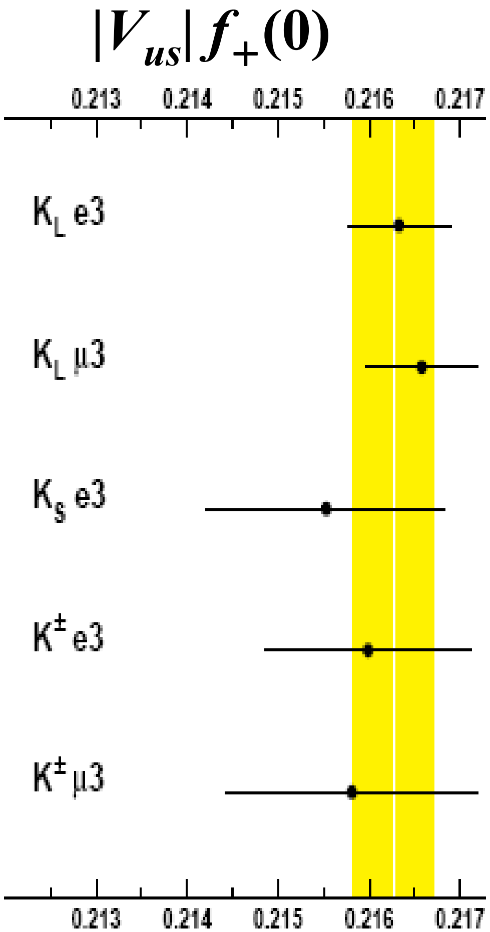
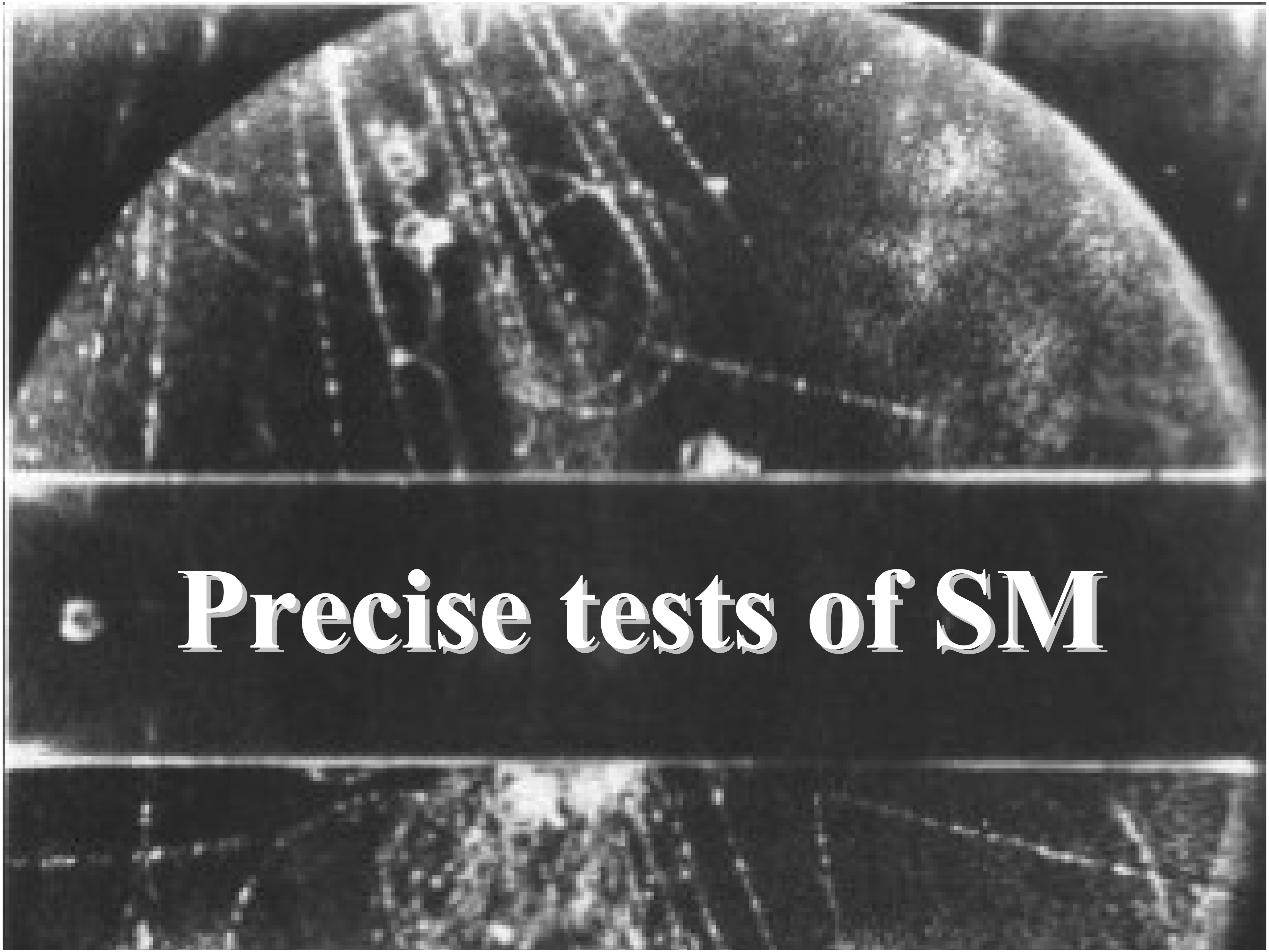
$|V_{us}| f_+(0)$ from K_{l3} data



		% err	Approx. contrib. to % err from: BR	τ	Δ	Int
K_Le3	0.2163(6)	0.26	0.09	0.20	0.11	0.06
$K_L\mu3$	0.2166(6)	0.29	0.15	0.18	0.11	0.08
K_Se3	0.2155(13)	0.61	0.60	0.03	0.11	0.06
$K^{\pm}e3$	0.2160(11)	0.52	0.31	0.09	0.40	0.06
$K^{\pm}\mu3$	0.2158(14)	0.63	0.47	0.08	0.39	0.08

Average: $|V_{us}| f_+(0) = 0.2163(5)$ $\chi^2/\mathrm{ndf} = 0.77/4$ (94%)


Precise tests of SM

Accuracy of SU(2)-breaking corrections

Fit 5 modes with separate values of $|V_{us}| f_+(0)$ for $K^{\pm}$ and $K_{L,S}$ modes; $K^{\pm}$ modes modes are corrected for the isospin-breaking using $\delta^{SU(2)}{}_{\text{theory}} = 2.9(4)\%$.

When fit performed without $SU(2)$ corrections for $K^{\pm}$ modes; from ratio of neutral- charged-modes, obtains an **experimental estimate of $\delta^{SU(2)}$**:

$$\delta^{SU(2)}{}_{\text{exp}} = 2.7(4)\%$$

- Check of the $\delta^{SU(2)}$ estimate from χPT; the uncertainty on $\delta^{SU(2)}{}_{\text{theory}}$ contributes significantly on the overall uncertainty of $|V_{us}| f_+(0)$ from charged modes.

- Since $\delta^{SU(2)}$ can be expressed in terms of the quark mass ratio (at LO):

$$\delta_{\mathrm{SU(2)}}^{K^{\pm}\pi^0} = \frac{3}{4}\frac{1}{R}\ , \ \text{with} \quad R = \frac{m_s - \widehat{m}}{m_d - m_u}$$

its phenomenological determination can be **used to derive constraints on the ratio of quark masses**.

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$K_{\ell 3}$ data and lepton universality

For each state of kaon charge, evaluate:

$$r_{\mu e} = \frac{(R_{\mu e})_{\rm obs}}{(R_{\mu e})_{\rm SM}} = \frac{\Gamma_{\mu 3}}{\Gamma_{e3}} \cdot \frac{I_{e3}\,(1+\delta_{e3})}{I_{\mu 3}\,(1+\delta_{\mu 3})} = \frac{[|V_{us}|\,f_+(0)]^2_{\mu 3,\,\rm obs}}{[|V_{us}|\,f_+(0)]^2_{e3,\,\rm obs}} = \frac{g_\mu^2}{g_e^2}$$

Modes	2004 BRs*	World data
$K_{L,S}$	**1.040(13)**	**1.003(5)**
$K^{\pm}$	**1.013(12)**	**0.998(9)**
Avg	**1.034(10)**	**1.002(5)**

*Assuming current values for form-factor parameters and Δ^{EM}; K_S not included

As statement on lepton universality

Compare to results from world data:

$\pi \to l\nu$ **$(r_{\mu e})$ = 1.0042(33)**

Ramsey-Musolf, Su & Tulin ’07

$\tau \to l\nu\nu$ **$(r_{\mu e})$ = 1.000(4)**

Davier, Hoecker & Zhang ’06

As statement on calculation of δ^{EM}

Highly successful

Results confirmed at per-mil level

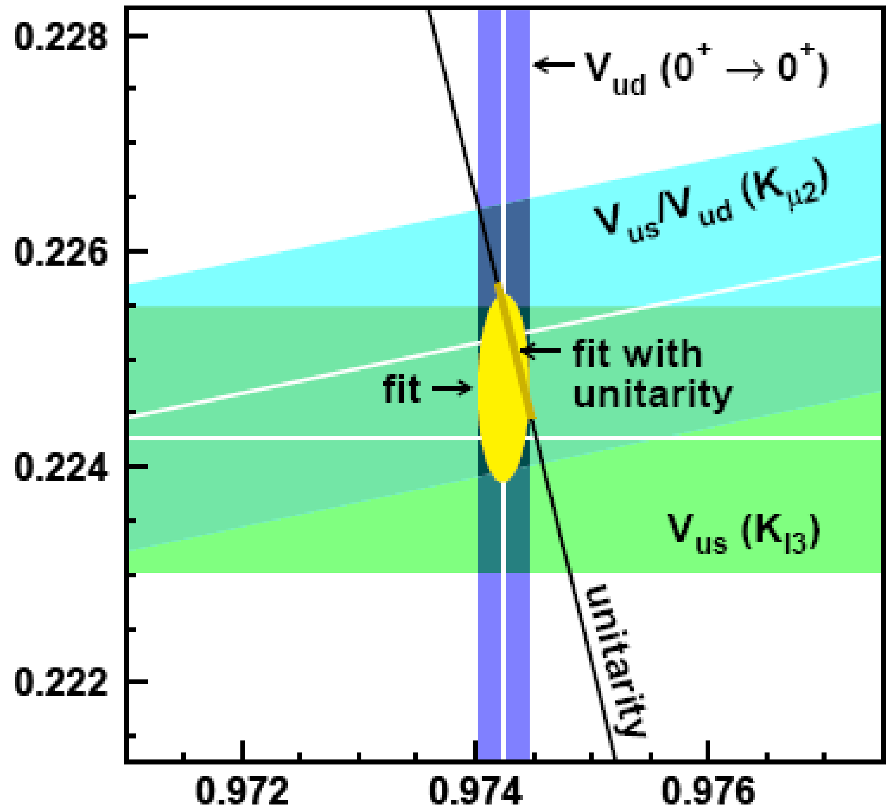
Test of CKM unitarity

Determine $|V_{us}|$ and $|V_{ud}|$ from a fit to the results:

$|V_{us} f_+(0)|=0.2163(5)$, $f_+(0)=0.964(5)$;

$|V_{us}|/|V_{ud}| f_K/f_\pi=0.2758(5)$, $f_K/f_\pi=1.193(6)$

$$|V_{us}| = 0.2243(12) \qquad [K_{\ell 3} \text{ only}],$$
$$|V_{us}|/|V_{ud}| = 0.2312(13) \qquad [K_{\ell 2} \text{ only}].$$



Adding $|V_{ud}|=0.97425(22)$, obtains (χ^2/ndf=0.29/1, P=59%, negligible correlation between V_{us} and V_{ud}):

$$|V_{ud}| = 0.97425(22),$$
$$|V_{us}| = 0.2247(9) \qquad [K_{\ell 3}, K_{\ell 2}, 0^+ \to 0^+],$$

Including in the fit the unitairty constraint, obtains (χ^2/ndf=0.60/2, P=74%):

$$|V_{us}| = \sin\theta_C = \lambda = 0.2251(6) \qquad [\text{with unitarity}]$$

Test of CKM unitarity

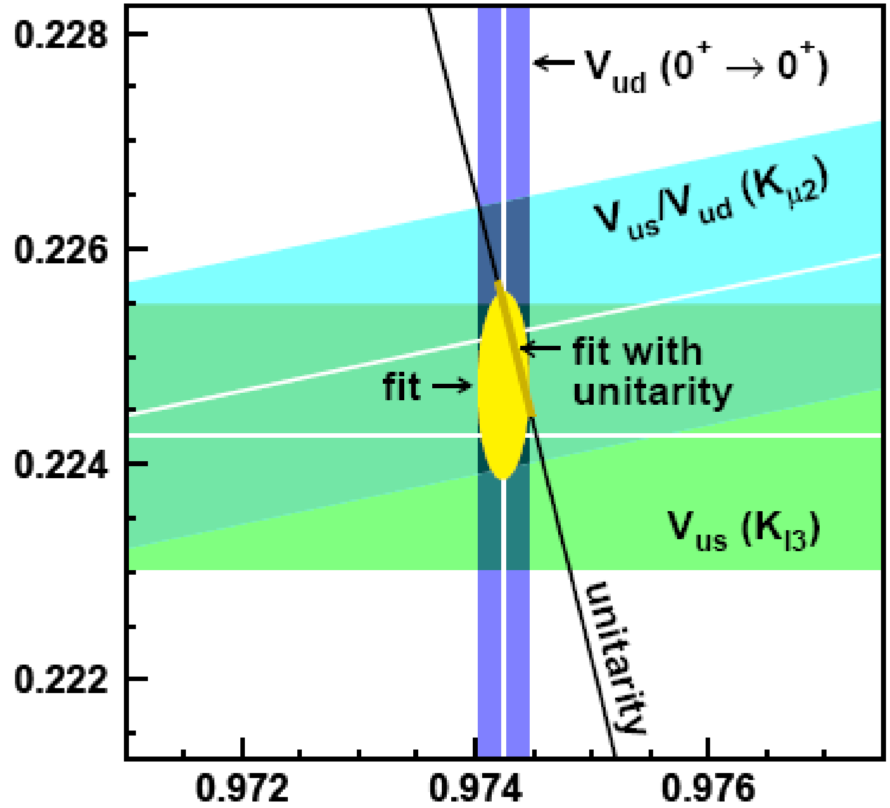
Using the current WA value $|V_{ub}|$=0.00393(36), the first-row unitarity sum is Δ_{CKM}=–0.0003(6), in agreement within 0.5σ with unitarity hypothesis.

Allow to set bounds on the effective scale of the operators that parametrize NP contributions to Δ_{CKM}:

if $\Delta_{CKM}<0$, $\Lambda >$ 9.7 TeV (90% C.L.);

if $\Delta_{CKM}>0$, $\Lambda >$13.3 TeV (90% C.L.).

For three operators (ll, ϕl, ϕq), constraint at the same level as Z-pole measurements; **for the 4-fermion operator (lq), improves LEP2 bounds by one order of magnitude.**

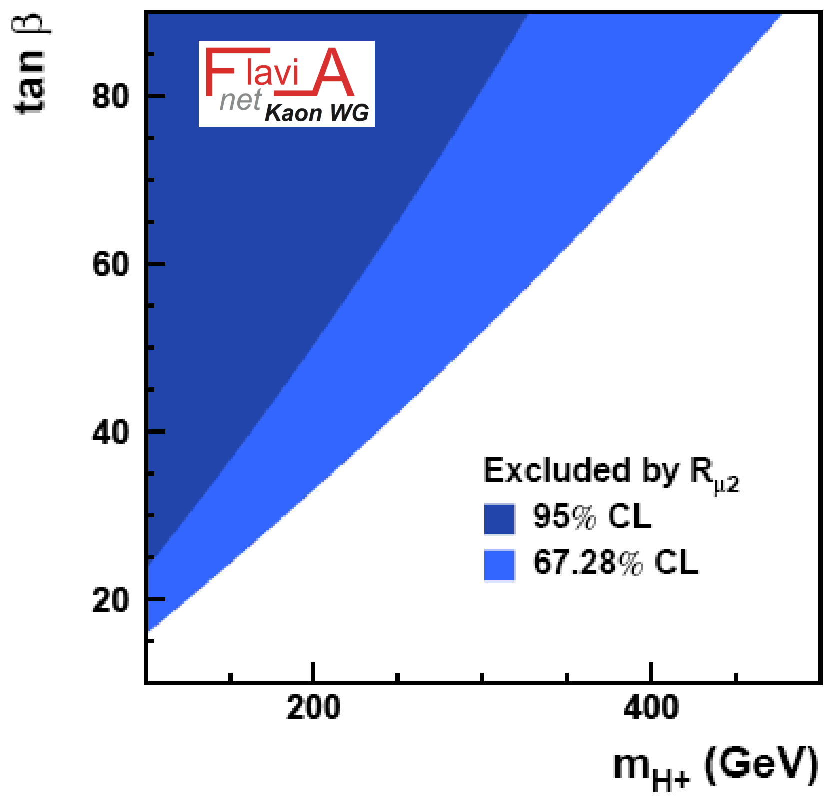


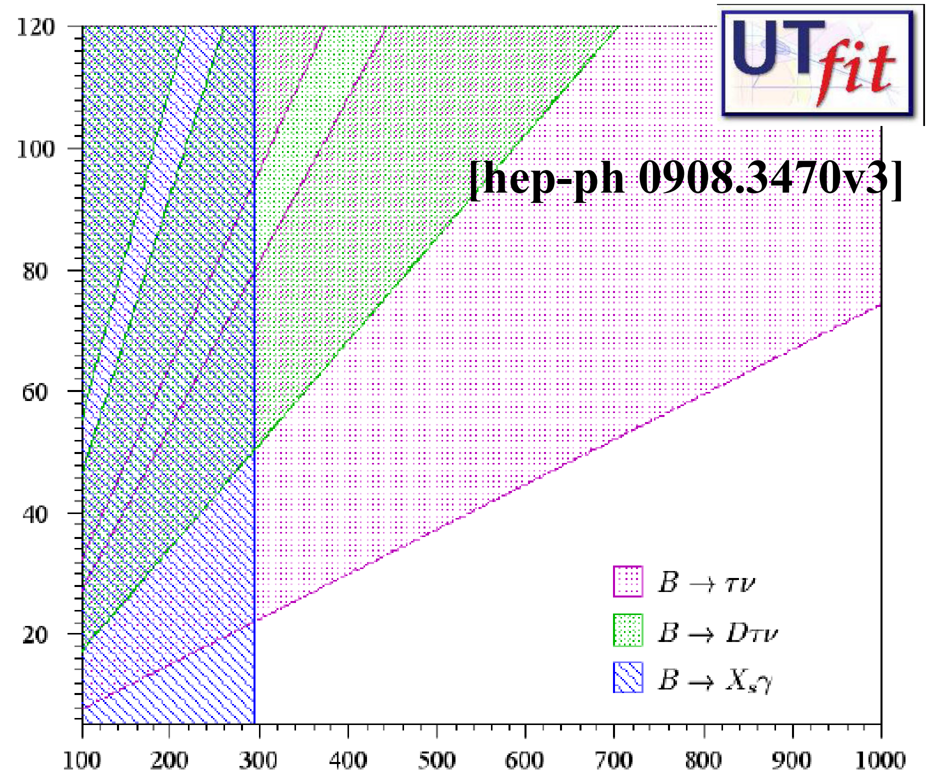
Bounds on non helicity-suppressed amps

With a 3-parameter fit (V_{us} from Kl3, V_{us}/V_{ud} from Kμ2, V_{ud}) with 1 constraint:
$[V_{us}(K_{l3})]^2+[V_{ud}(0^+\to 0^+)]^2+[V_{ub}]^2 = 1$, obtains ($\chi^2$/ndf=0.57/1 P=45%, ρ= –0.54):

$$|V_{us}| = 0.2250(7) \qquad [K_{\ell 3}, 0^+ \to 0^+, \text{unitarity}],$$
$$\mathbf{R}_{\mu 23} = 1.001(7) \qquad [K_{\mu 2}].$$

this excludes the region at low m_{H+} and large tg β favoured by B→τν.





$f_+(0)$ and f_K/f_π: straight calculation

$$Q_{\ell 2} = \frac{(|V_{us}| f_+(0))^2}{|V_{ud}|^2} \times \frac{1}{f_+(0)^2} \times \frac{f_K^2}{f_\pi^2}$$

From decay rates and rad. corr. — From nucl. β-decay — From K13

Straight calculation from Kμ2/πμ2 relation and assuming SM:

- Use $Q_{\ell 2} = \frac{\Gamma_{K^\pm_{\ell 2(\gamma)}}}{\Gamma_{\pi^\pm_{\ell 2(\gamma)}}} \frac{1}{(1+\delta_{\rm em})}$ = 0.07604(26)
- Obtain $f_K/f_\pi / f_+(0)$ = **1.242(4)**

depends on decay rate data, radiative corrections; unitarity not assumed, although V_{us} equality in Kμ2 and K13 decays is

- using $f_+(0)$ = 0.965(4) obtain f_K/f_π = **1.198(7)**
- using f_K/f_π = 1.193(6) obtain $f_+(0)$ = **0.960(6)**

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$f_+(0)$ and f_K/f_π: fit assuming unitarity

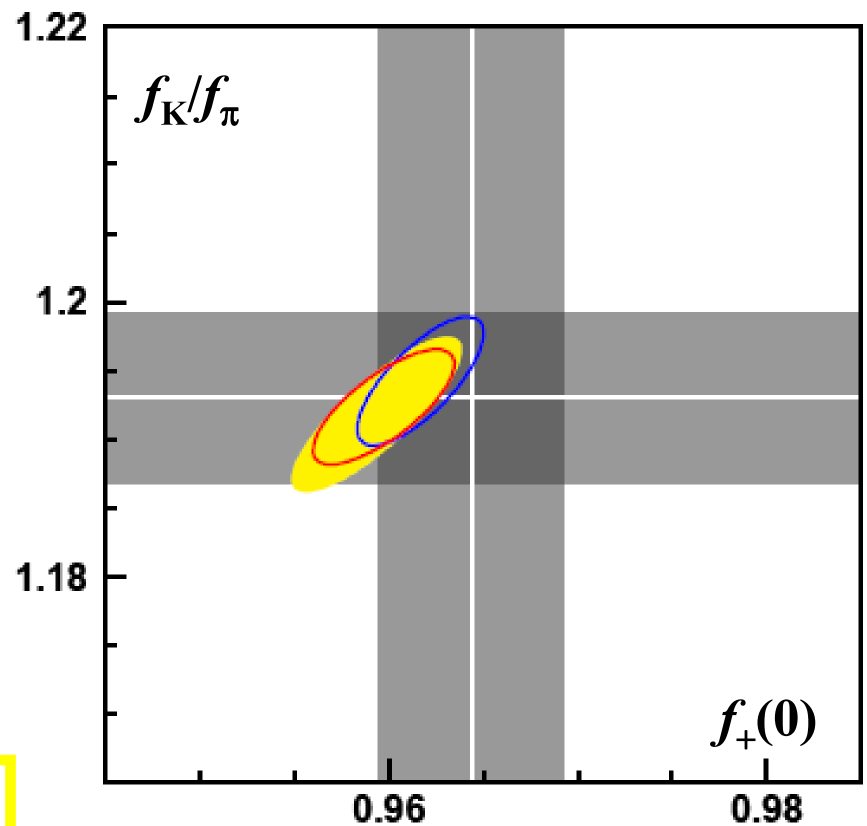
$$Q_{\ell 2} = \frac{(|V_{us}| f_+(0))^2}{|V_{ud}|^2} \times \frac{1}{f_+(0)^2} \times \frac{f_K^2}{f_\pi^2}$$

From decay rates and rad. corr. — From nucl. β-decay — From Kl3

Assuming SM

- f_K/f_π and $f_+(0)$ values from a fit.
- 5 parameters: V_{ud}, $V_{us} f_+(0)$, Q_{l2}, f_K/f_π, and $f_+(0)$.
  - 3 inputs: V_{ud}, $V_{us} f_+(0)$, Q_{l2}
  - 2 constraints: $\Gamma(K\mu 2)/\Gamma(\pi\mu 2)$ relation and Unitarity
- Obtain (correlation ρ=0.83) :

$$f_+(0) = 0.959(4),$$
$$|f_K/f_\pi| = 1.192(6) \qquad \text{[with unitarity]}$$



Lattice estimations

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$f_+(0)$ and f_K/f_π: fit assuming unitarity

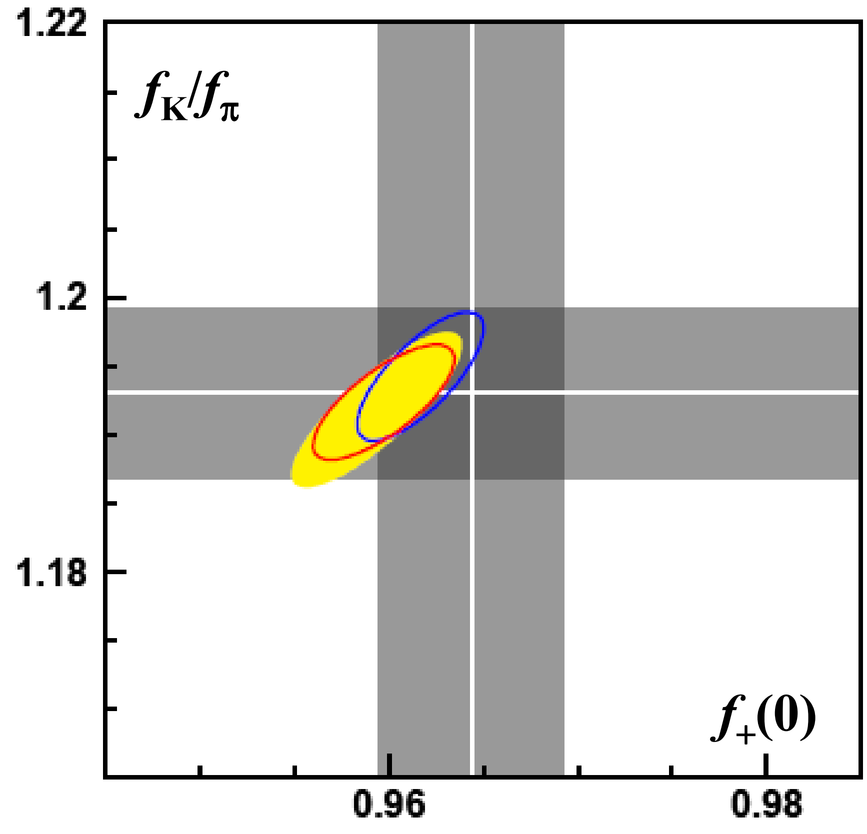
$$Q_{\ell 2} = \frac{(|V_{us}| f_+(0))^2}{|V_{ud}|^2} \times \frac{1}{f_+(0)^2} \times \frac{f_K^2}{f_\pi^2}$$

From decay rates and rad. corr.

From nucl. β-decay

From K13

Assuming SM



Lattice estimations

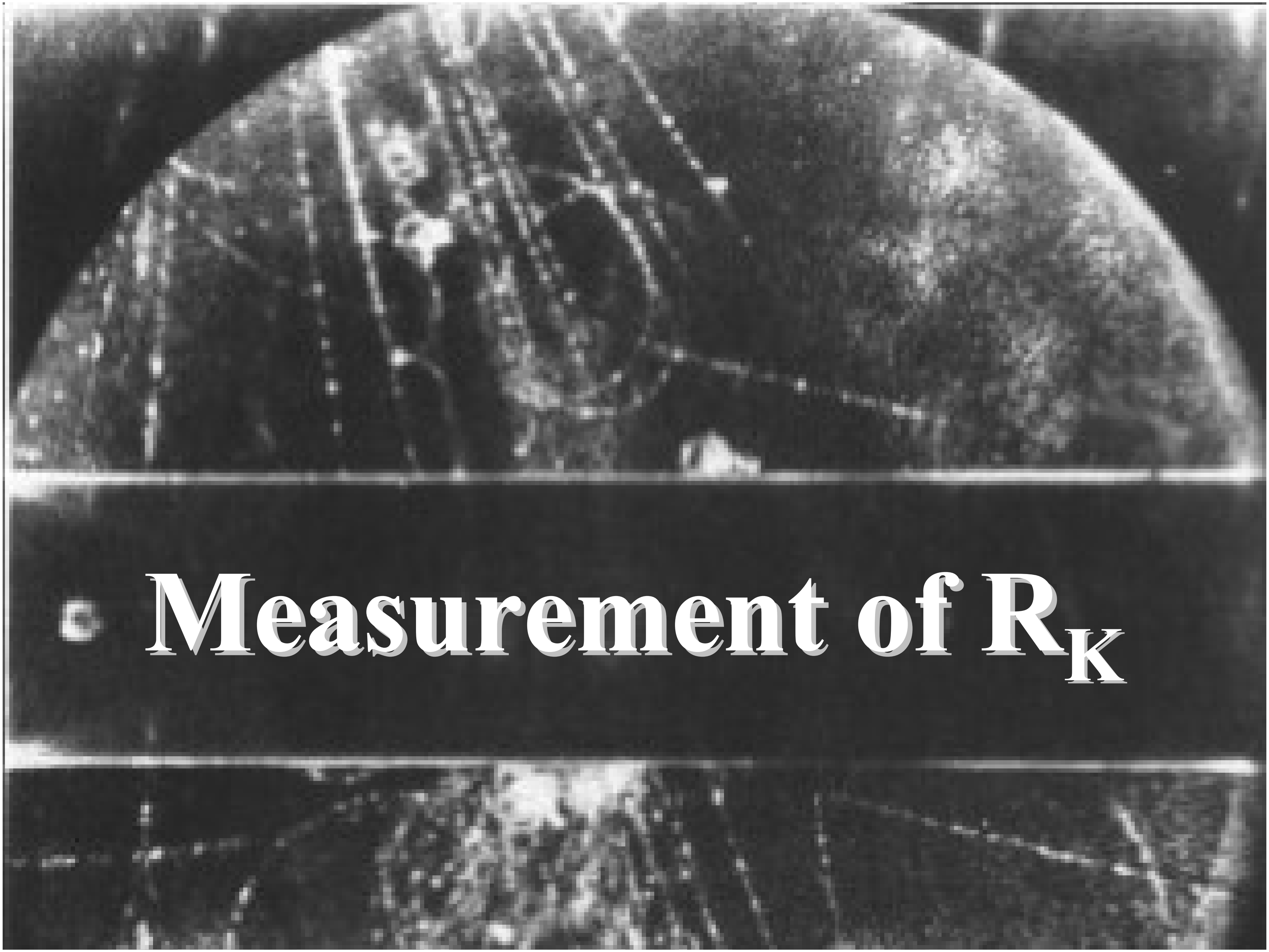
With either of reference values of f_K/f_π or $f_+(0)$ as an **additional** input:

- with input $f_+(0)$=0.964(5), obtain **$f_+(0)$=0.962(3) and f_K/f_π = 1.194(5)**

- with input f_K/f_π = 1.193(6), obtain **$f_+(0)$=0.960(4) and f_K/f_π = 1.192(4)**.

Reference values nicely consistent with data (assuming SM)

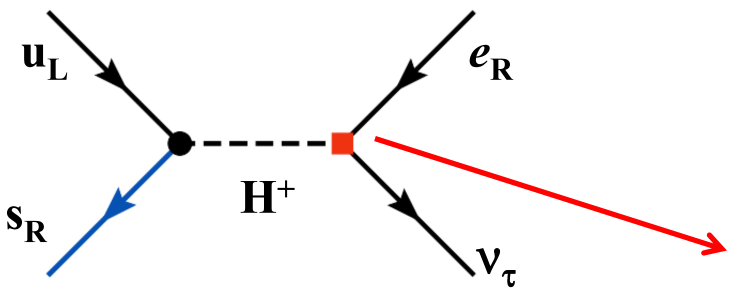
Measurement of R_K



NP potential of $R_K = \Gamma(K^{\pm}_{e2})/\Gamma(K^{\pm}_{\mu 2})$

• SM prediction with 0.04% precision, benefits of cancellation of hadronic uncertainties (no f_K): **R_K=2.477(1)×10^{-5}** [*Cirigliano Rosell arXiv:0707:4464*].

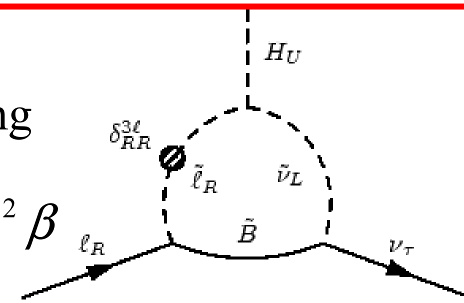
• Helicity suppression can boost NP [*Masiero-Paradisi-Petronzio PRD74(2006)011701*].



$$R_K^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \approx \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}$$

LFV from loop generates an effective $eH^+\nu_\tau$ coupling

$$eH^+\nu_\tau \to \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_R^{31} \tan^2\beta$$



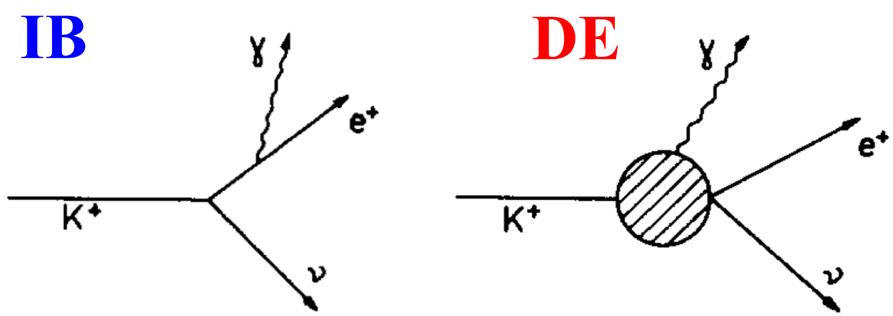
$$R_K^{LFV} \approx R_K^{SM}\left(1 + \frac{m_K^4}{m_H^4}\frac{m_\tau^2}{m_e^2}\left|\Delta_R^{31}\right|^2 \tan^6\beta\right)$$

LFV can give **O(1%) deviation from SM (Δ_R^{31}~5×10^{-4}, tanβ ~40, m_H ~ 500 GeV)**

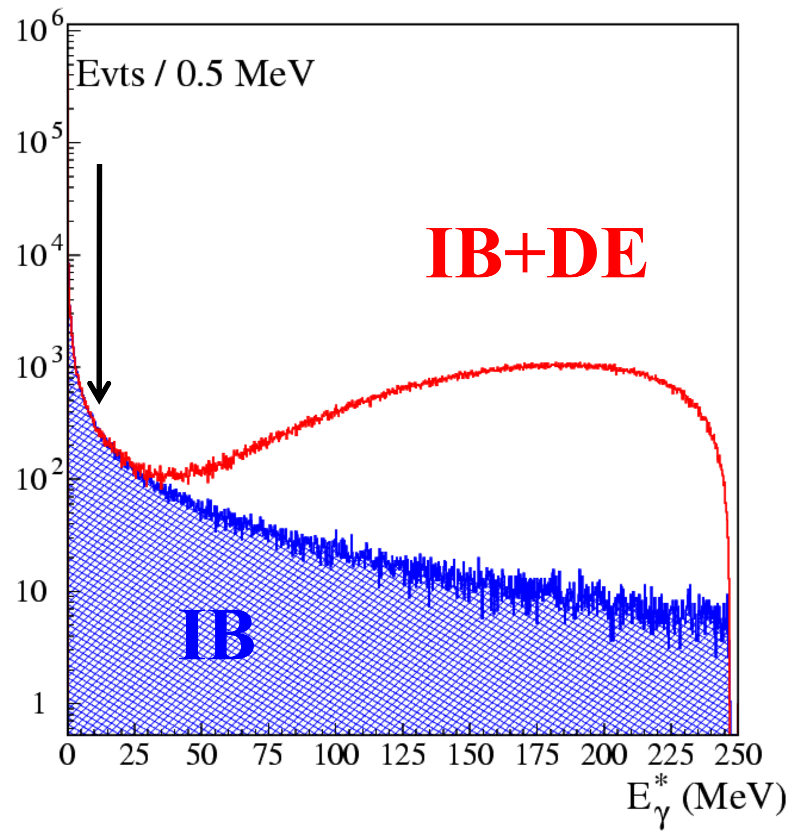
• Experimental accuracy on R_K (before KLOE and NA62 results) at 5% level.
• Measurements of R_K can be very interesting, **if error at 1% level or better**.

Ke2(γ): signal definition

SM prediction is defined to be inclusive of **IB** (ignoring **DE** contributions).



From theory (ChPT) expect **DE** ~ **IB** for Ke2, but experimental knowledge is poor: **δDE/DE~15%**

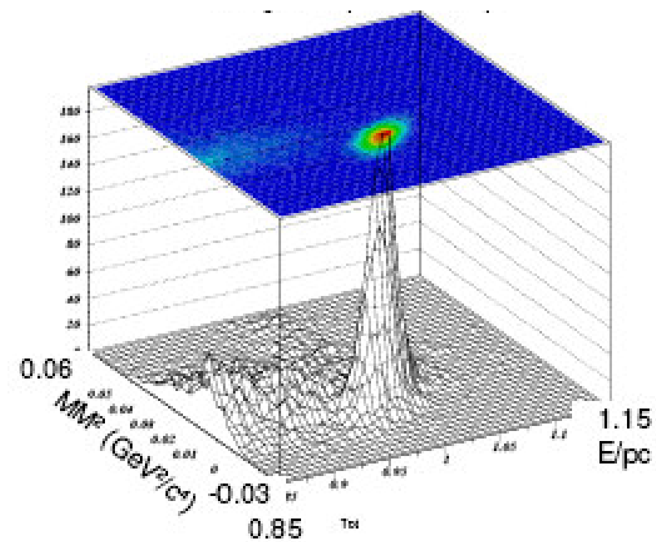


- **Define as "signal" events with E_γ<10 MeV**.
- Evaluating **IB** spectrum (O(α)+resummation of leading logs) obtain a 0.0625(5) correction for the IB tail.
- Under 10 MeV, the **DE** contribution is expected to be negligible.

$R_K = \Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$ @ PIC 2006

NA48/2: unseparated, simultaneous $K^\pm$ highly collimated beams, designed to precisely measure $K^\pm \to \pi^{+,0}\pi^{-,0}\pi^\pm$ dalitz-plot density

- 2003 data set
  $K^\pm_{e2}$ signature: E/p=1 & m_ν^2=0
  N_{TOT} = 5329 (73); Bkg = 659 (26)
  N_{SIG} = 4670 (77)$(^{+29}_{-8})_{SYST}$
- Preliminary (EPS05) NA48/2 measurement.



	$R_K \times 10^5$
PDG average	**2.45 (11)**
SM prediction	**2.472 (1)**
NA48/2 (2003)	**2.416 $(43)_{STAT}(24)_{SYST}$**

Future:
- **NA48/2** 2004 statistics: about ×2 of 2003
- **KLOE** complete data set (2.5 fb^{-1})

- Result: slight discrepancy between R_K measurement and the SM prediction

First useful data in 2003/4 NA48/2 runs, preliminary results for R_K (now obsolete…)

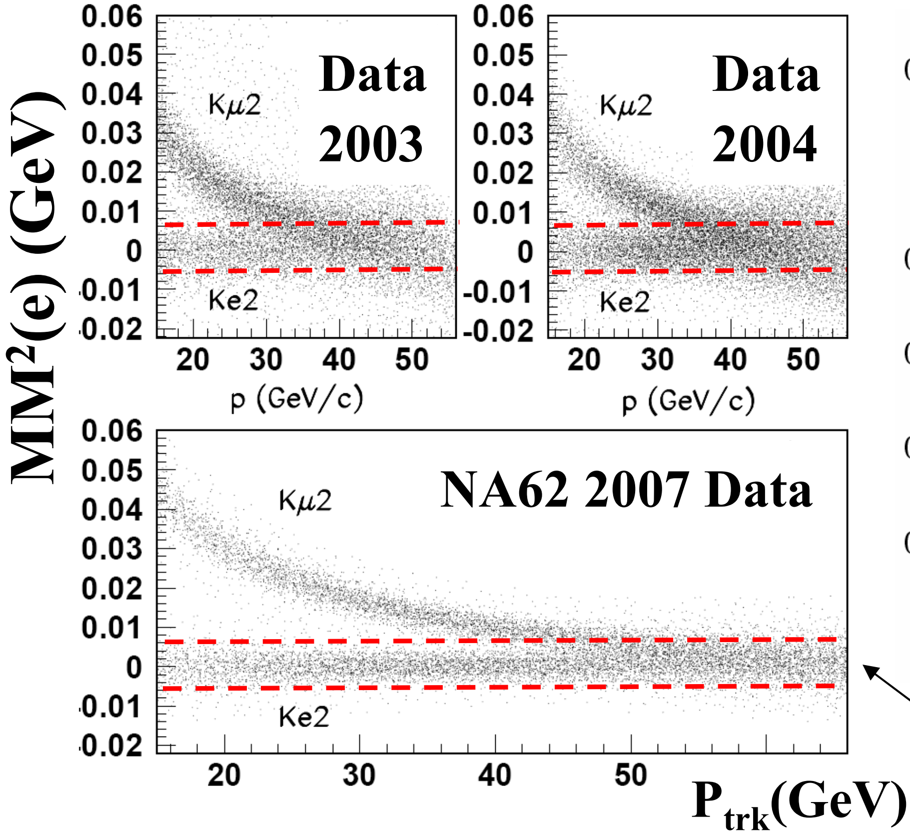
Analysis of R_K: 2007 data

…then design of NA62 run optimized for Ke2/Kμ2; major parameters tuned:

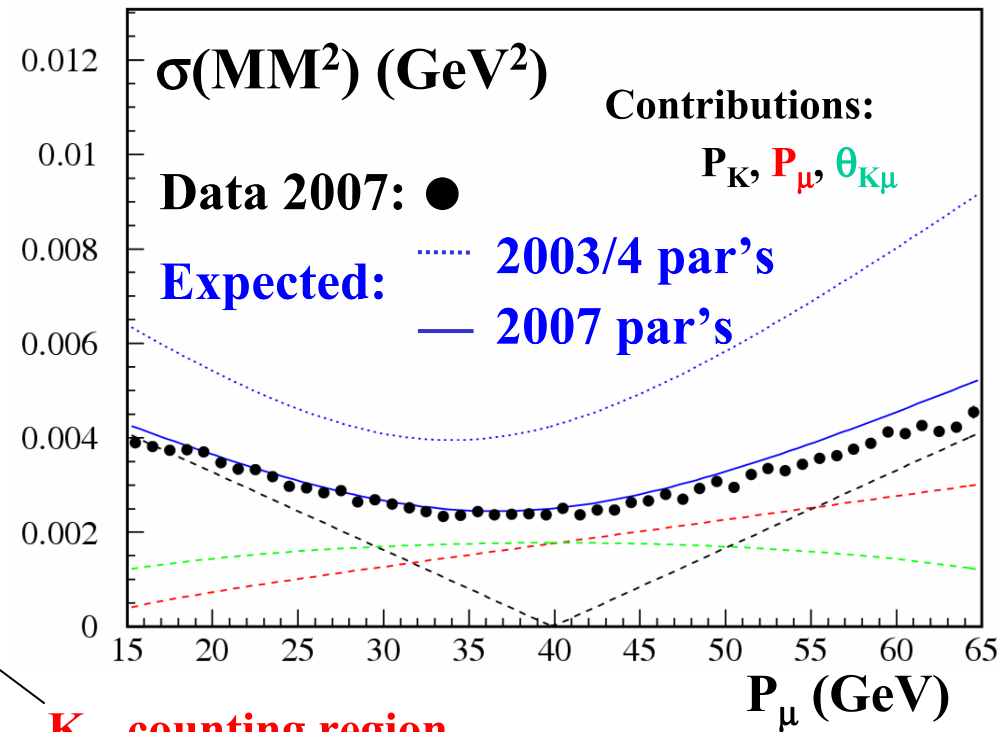
- P_K: ~60 GeV → ~75 GeV
- Momentum bite: 3.8% → 2.5%

MM² resolution improved

Better separation for Ke2 and Kμ2



K_{e2} counting region



Analysis of R_K: μ background

Electron PID by LKr: $0.95 < E_{cl}/P_{trk} < 1.10$ guaranteeing rejection by ~10^6!

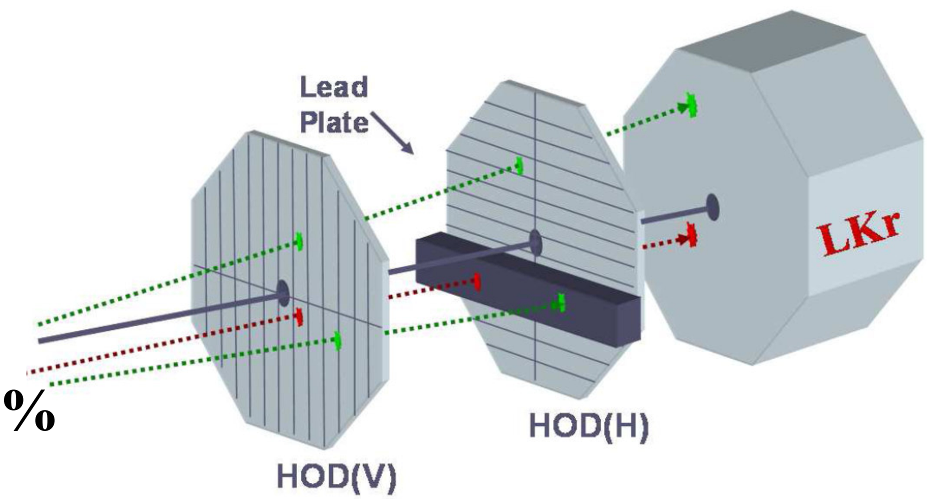
But: check probability for μ's to fake e's [$O(10^{-6})$] by directly measuring it:

- **Subsample of data taken with Pb wall between HOD's**
- **Use HOD pulse heights to select μ's (pure @ $<10^{-7}$) with MIP energy loss in Pb**

Evaluate 6.28(17)% Kμ2 bkg to Ke2, error dominated by sample statistics

Ke2γ Direct-Emission background suppressed by photon-veto w LKr

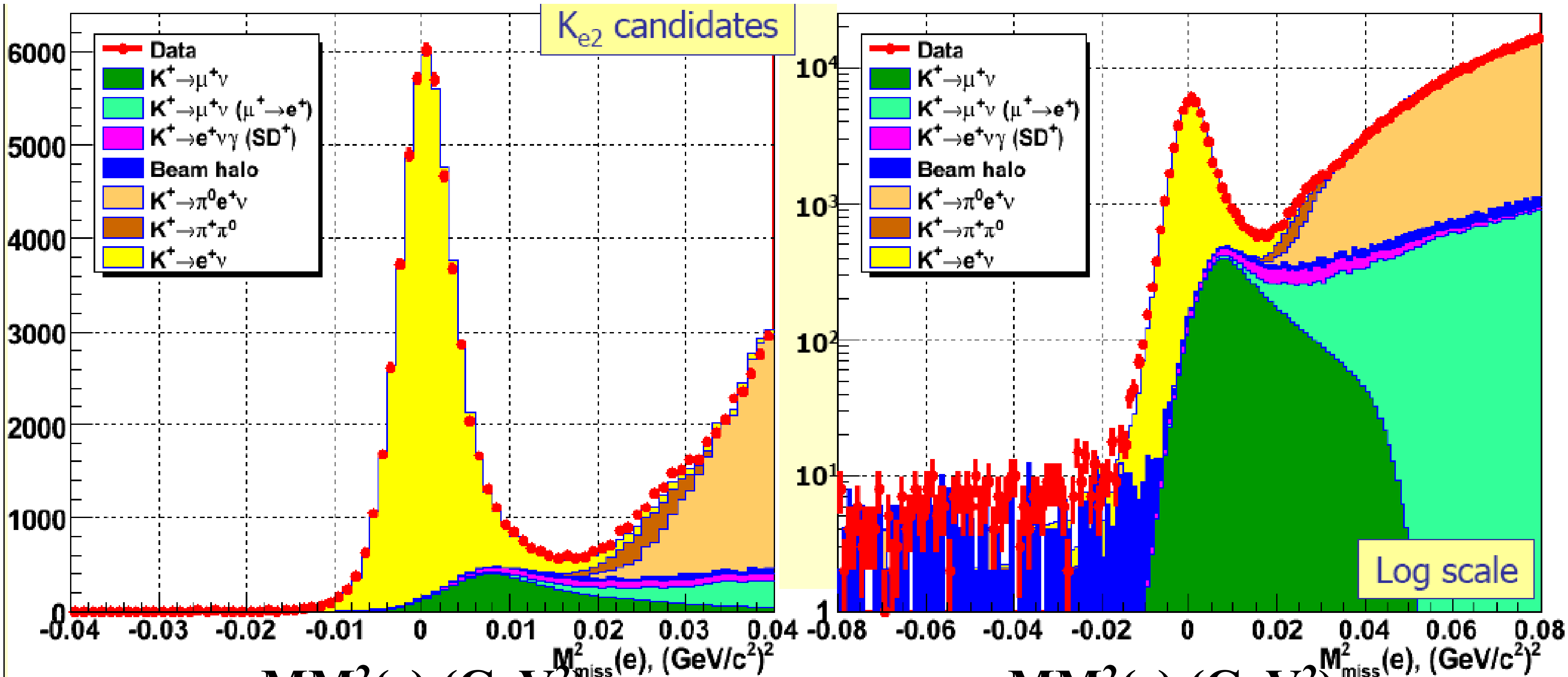
Total background to Ke2: 8.03(23)%



Analysis of R_K

Data taking lasted 4 months: the world largest data set of Ke2, > 100 Kevts

Preliminary result presented in 2009 from 51089 candidates



$MM^2(e)$ (GeV^2) **$MM^2(e)$ (GeV^2)**

Charged kaon at KLOE

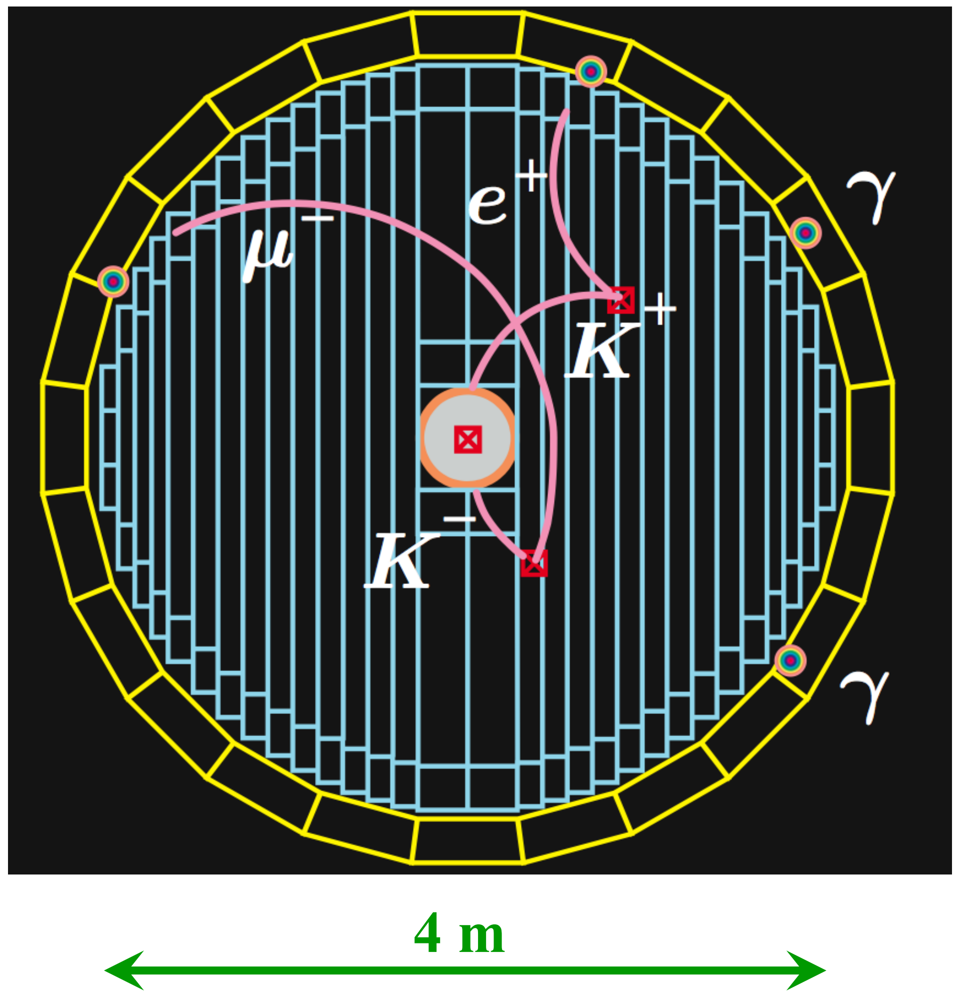
ϕ decay at rest provides pure kaon beams of know momentum
$p_K \sim 100$ MeV
$\lambda \sim 90$ cm (56% of $K^{\pm}$ decay in DC).

Kaon momentum measured (event by event) with 1 MeV resolution in DC.

Constraints from ϕ 2-body decay.

Particle ID with kinematics and ToF.

Tagging provides unbiased control samples for efficiency measurement.



Analysis basic principles

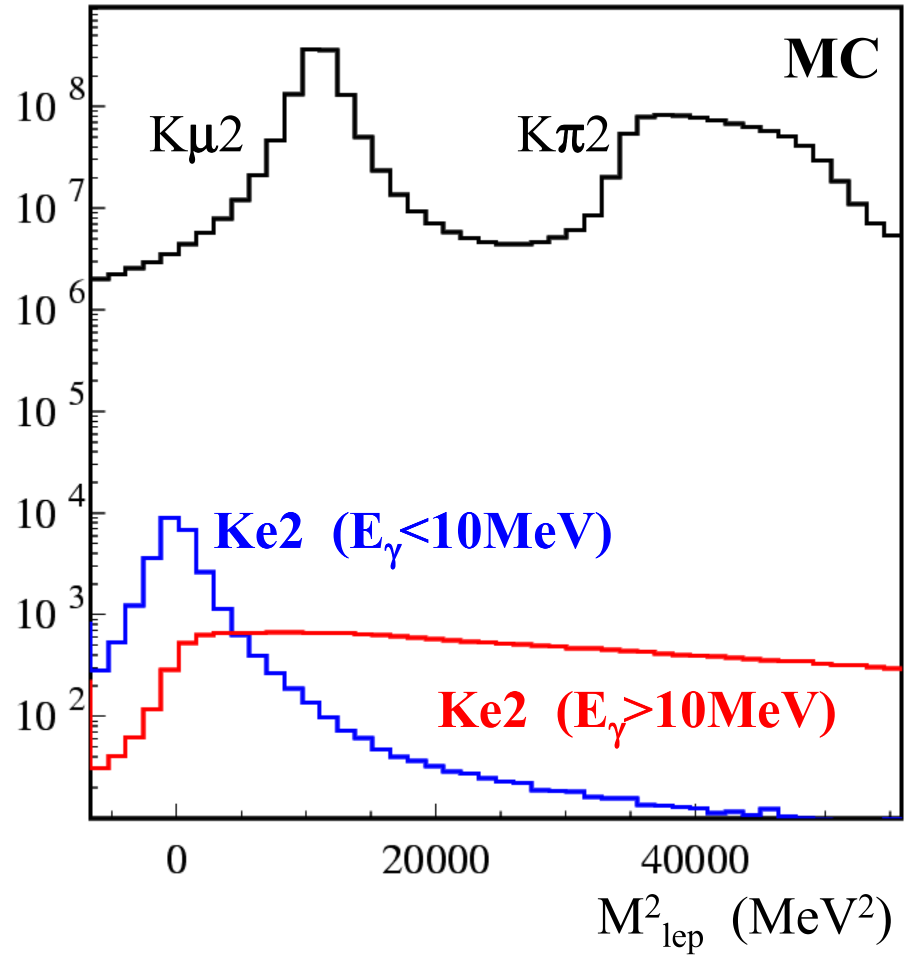
From K and secondary tacks and assuming $m_\nu=0$, get M^2_{lep}:

$$M^2_{lep} = (E_K - p_{miss})^2 - p^2_{lep}.$$

Around $M^2_{lep}=0$ we get **S/B ~ 10^{-3}**, mainly due to tails on the momentum resolution of Kμ2 events.

- after track quality cuts, accept ~35% of decays in the FV

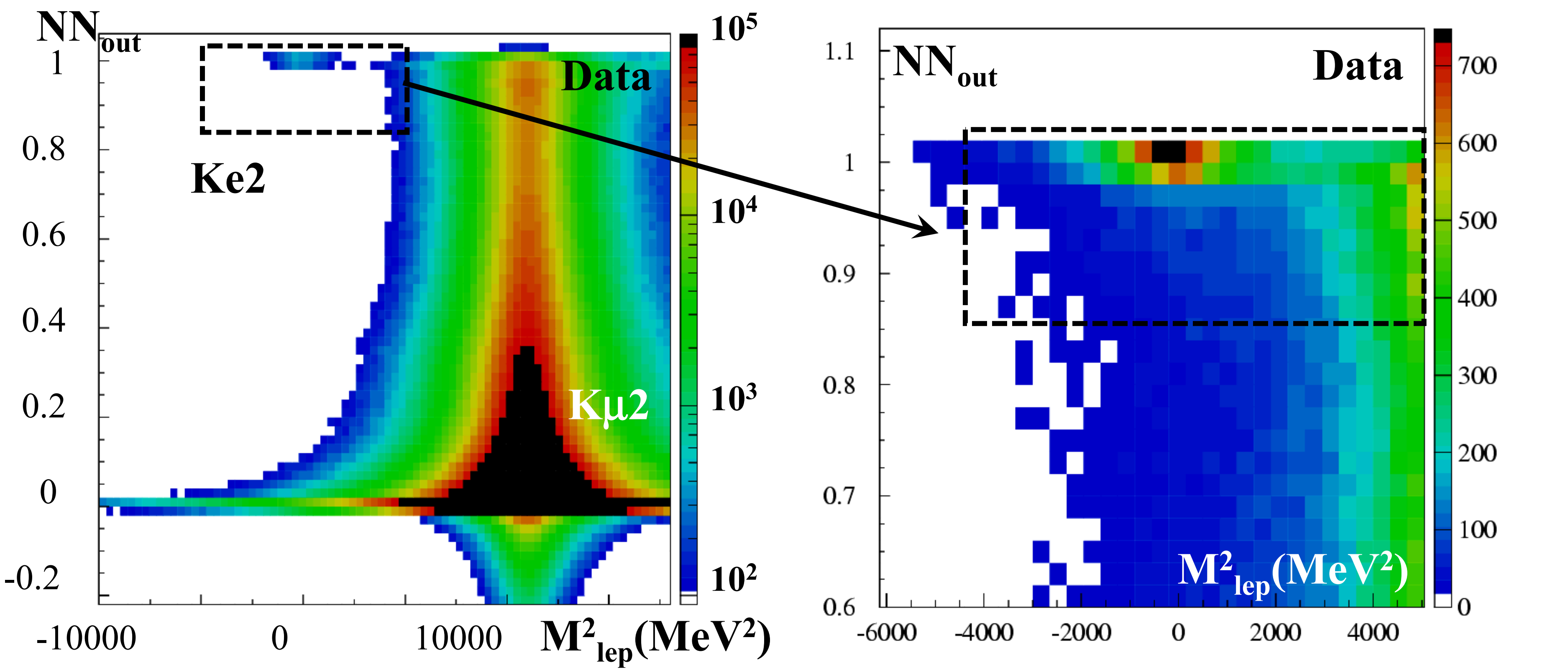
- **S/B ~ 1/20**, not enough!
- require the lepton track to be extrapolable to the calorimeter surface and to be associated to an energy release (cluster).



Background rejection (PID)

NN_{out}: Particle ID exploiting EMC granularity + E/p + ToF

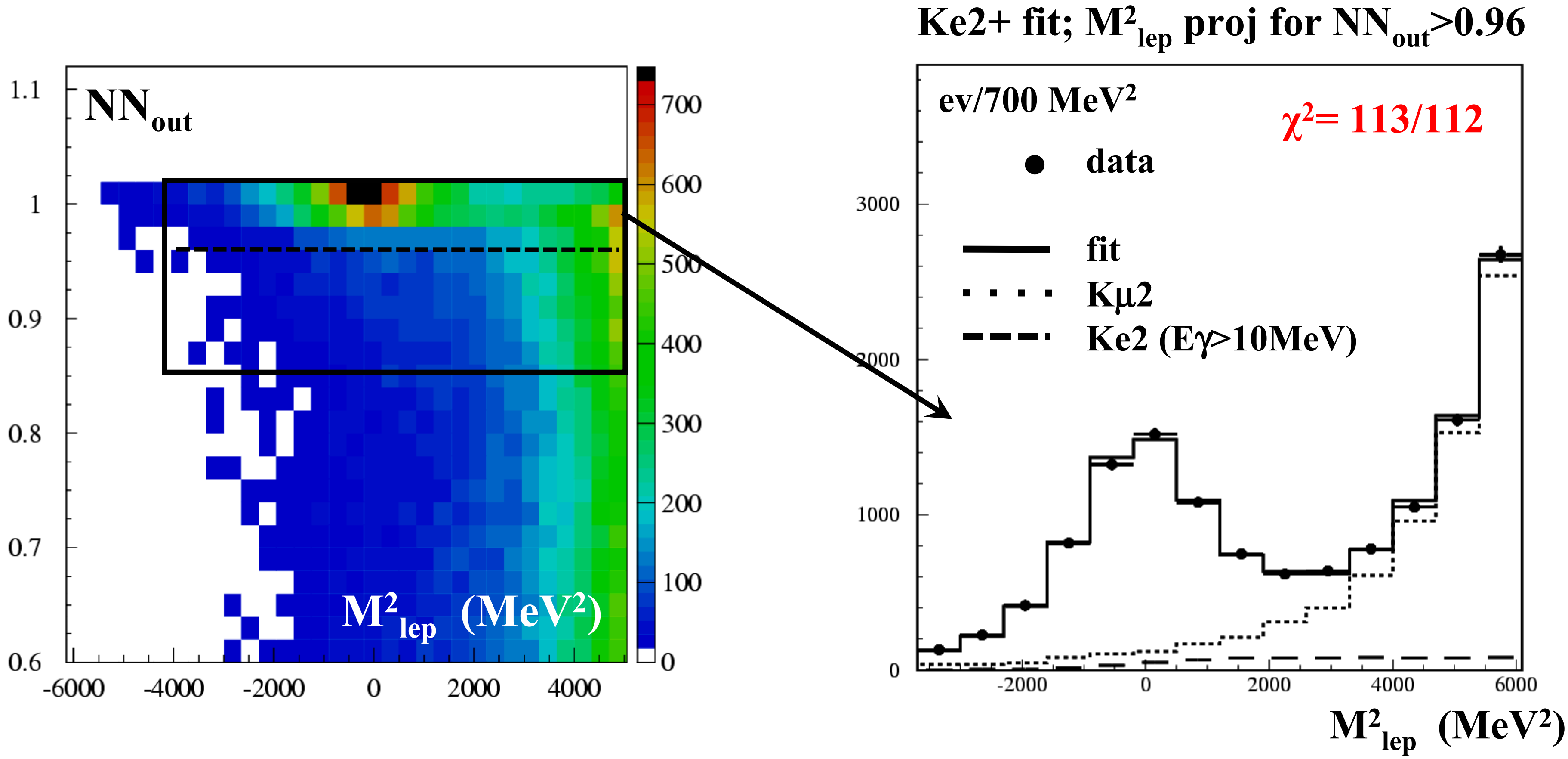
Select a region with good S/B ratio in the M^2_{lep} – NN_{out} plane



after selection: ε~50% (~15,000 K_{e2}) **S/B ~ 5**

K_{e2} event counting

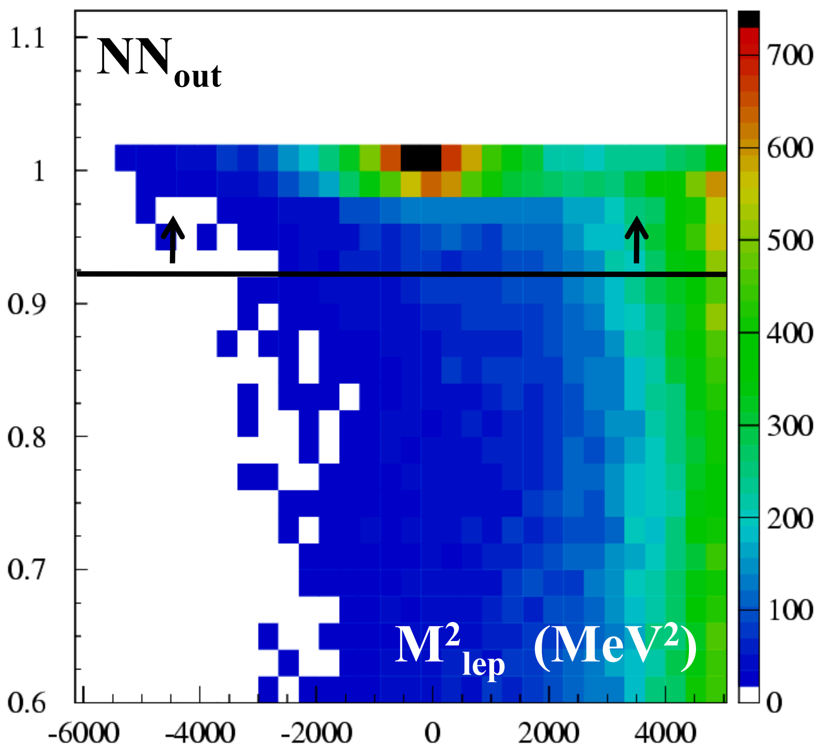
Two-dimensional binned likelihood fit in the M^2_{lep}–NN_{out} plane
in the region **$-4000 < M^2_{lep} < 6100$** and **$0.86 < NN_{out} < 1.02$**

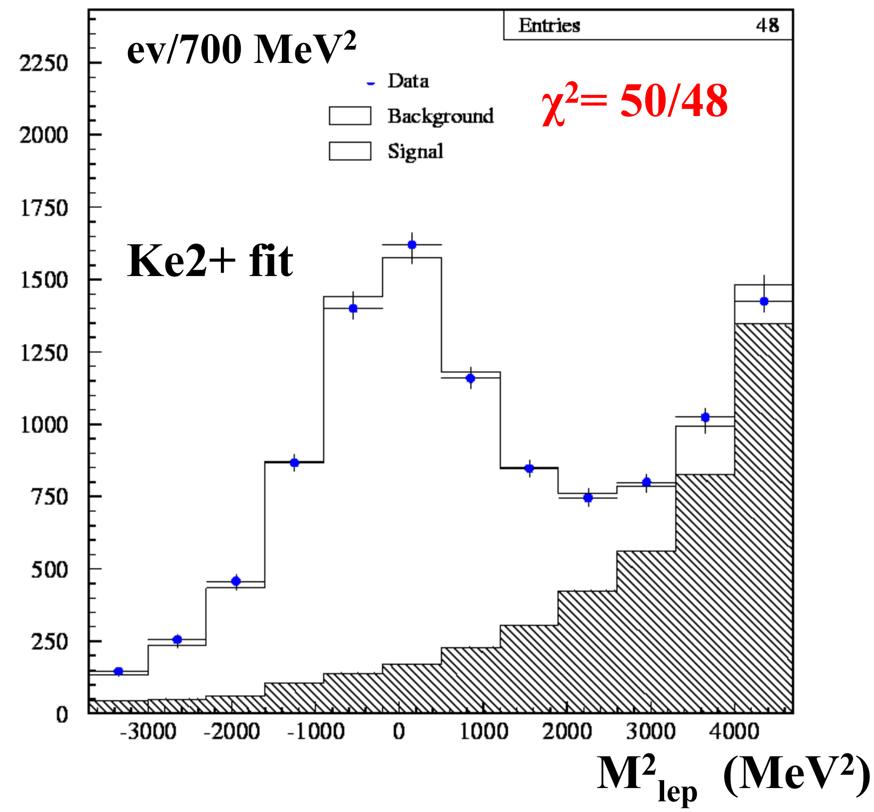


We count **7060 (102) Ke2+** **6750 (101) Ke2–** **(σ_{STAT}=1%, 0.85% from Ke2)**

K_{e2} event counting: systematics

Repeat fit with different values of **max(M^2_{lep})** and **min(NN_{out})**:
vary significantly (×20) bkg contamination + lever arm.





minimal bkg with: $-4000 < M^2_{lep} < 4650$ and $0.94 < NN_{out} < 1.02$

maximum bkg with: $-4000 < M^2_{lep} < 7500$ and $0.78 < NN_{out} < 1.02$

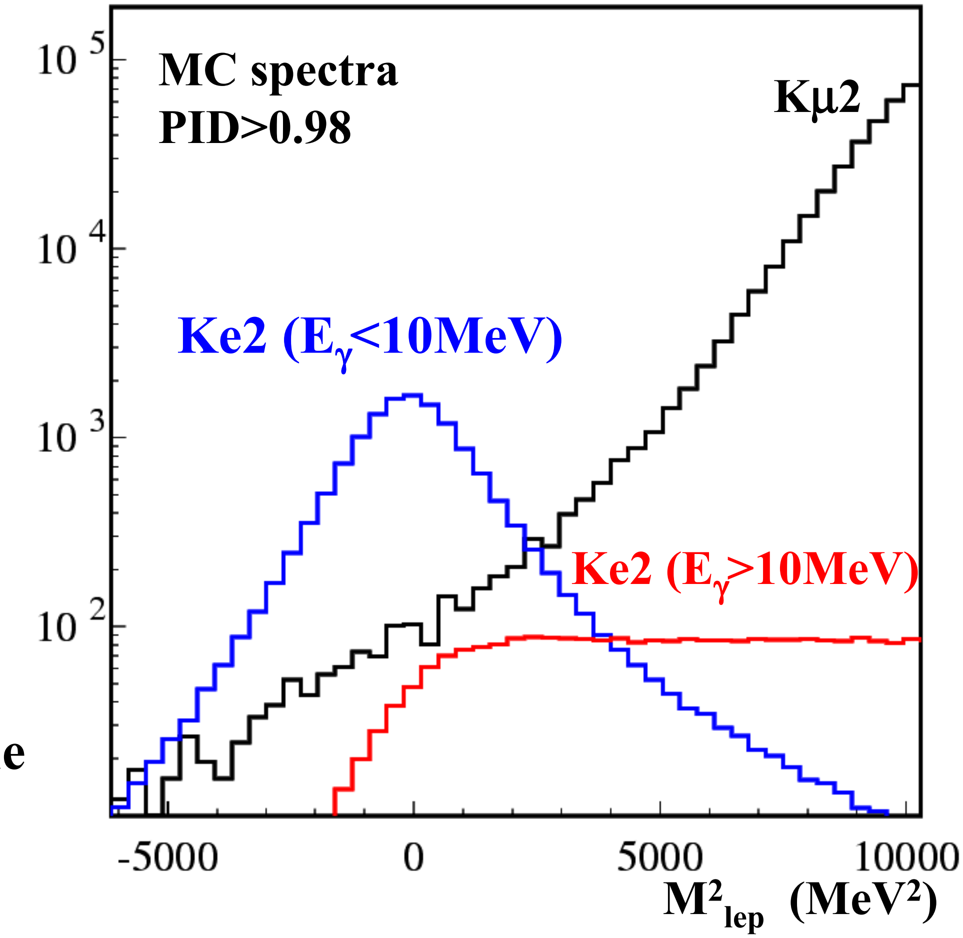
Ke2 fit: radiative corrections

• Analysis **inclusive of photons in the final state**. In our fi region we expect:

$$\frac{\text{Ke2 } (E_\gamma > 10\text{MeV})}{\text{Ke2}(E_\gamma < 10\text{MeV})} \sim 10\%$$

• Repeat fit by varying Ke2 (E_γ>10 MeV) by 15% (DE uncertainty) **get 0.5% error**.

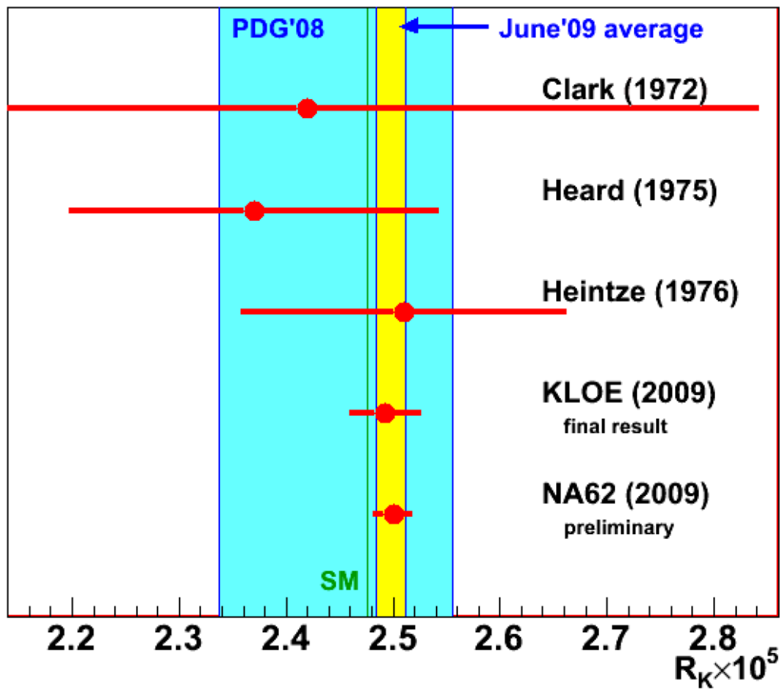
KLOE performed a **dedicated study of the Ke2γ differential decay rate**



This confirm the SD content of MC, evaluated with ChPT O(p^4), within an accuracy of 4.6% and allows a 0.2% systematic error on $Ke2_{IB}$ to be assessed

New results for R_K (2009)

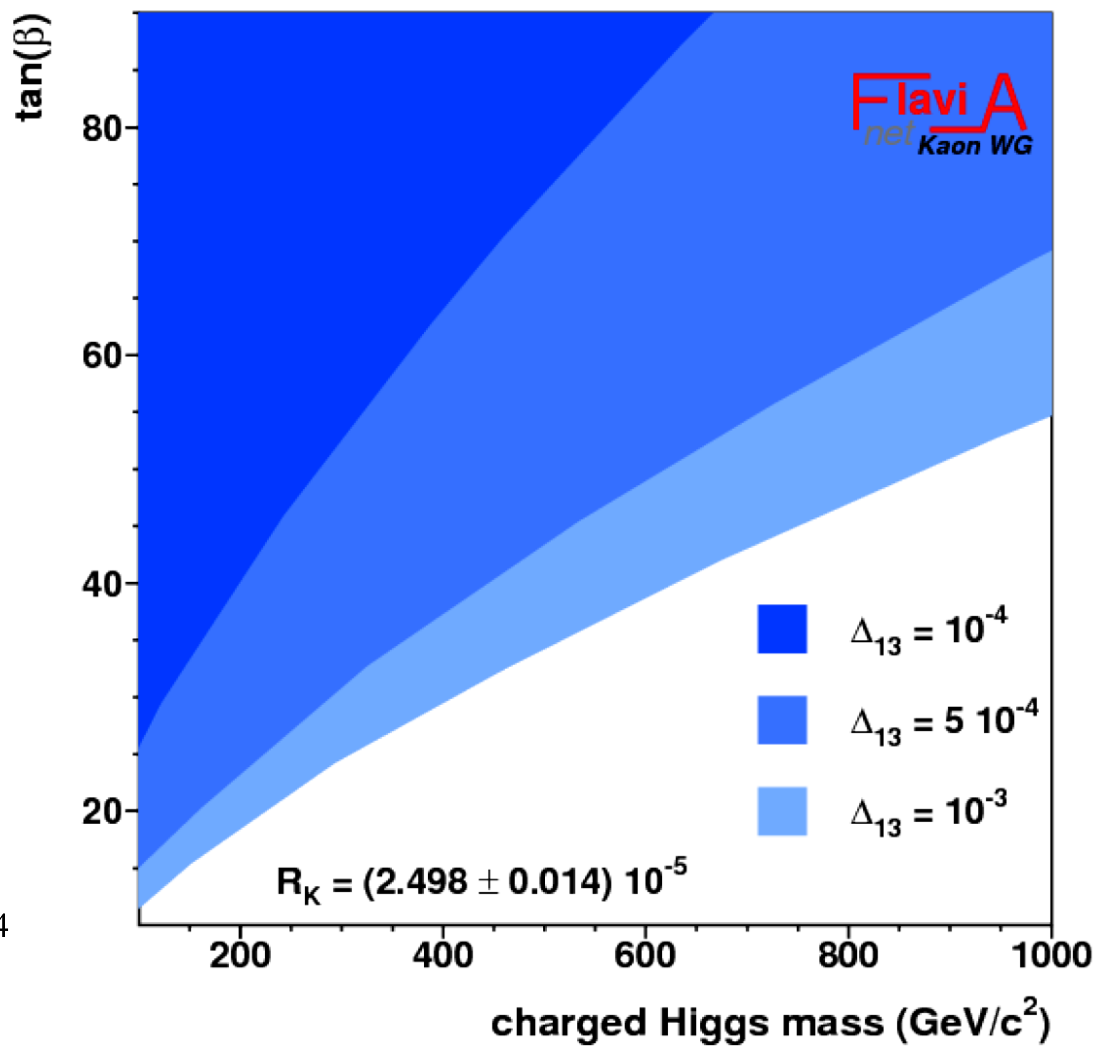
Experiment	KLOE	NA62
Ke2's on tape	30 k	100 k
Kin. Rejection	10^3 @ $\varepsilon \sim 60\%$	10^3—1, p_{lep} in 20—60 GeV
e/μ rejection	10^3	3—1.5 10^5, p_{lep} in 20—60 GeV
Bkg to Ke2	16%	8%
Ke2g (SD)	Include as bkg Dedicated mmt.	Suppress in analysis
Ke2 counts	14 k	50 k
$R_K \times 10^5$	2.493(25)(19)	2.500(12)(11)
Total error	1.3%	0.64%
Status	Final result	Preliminary



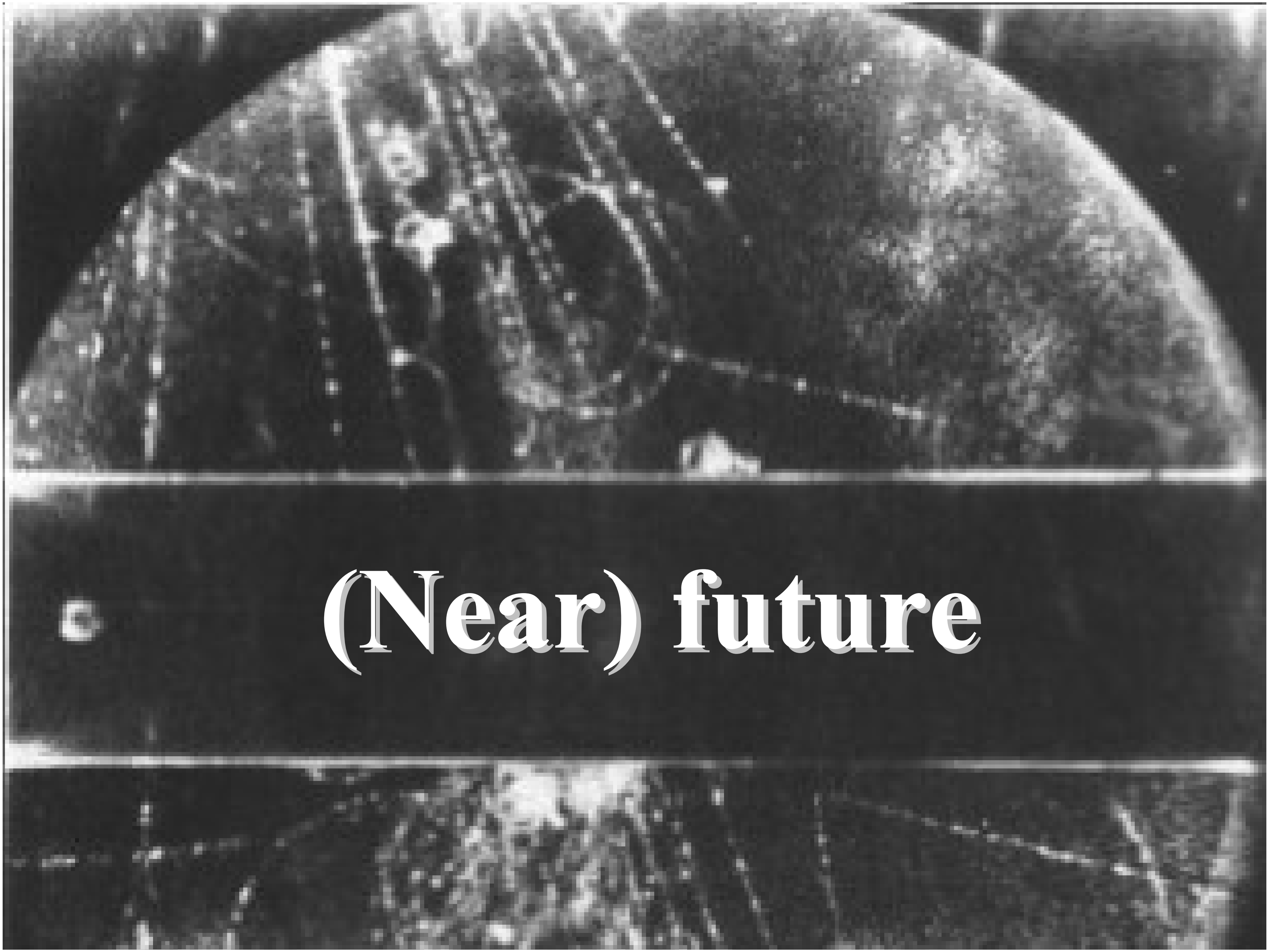
NP search from 2009 R_K results

- **PDG 2008: $R_K = (2.45\pm0.11)\times10^{-5}$ (4.5% accuracy)**
- **2009 WA: $R_K=2.498(4)\times10^{-5}$ (1% accuracy)**
- Compare with SM prediction: $R_K^{SM} = 2.477(1)\times10^{-5}$.

Test NP from LFV transitions in R-parity SUSY: sensitivity shown as 95% CL excluded regions in the $\tan\beta$–M_H plane, for different values of the LFV effective coupling, $\Delta_{13} = 10^{-3}, 5\times10^{-4}, 10^{-4}$



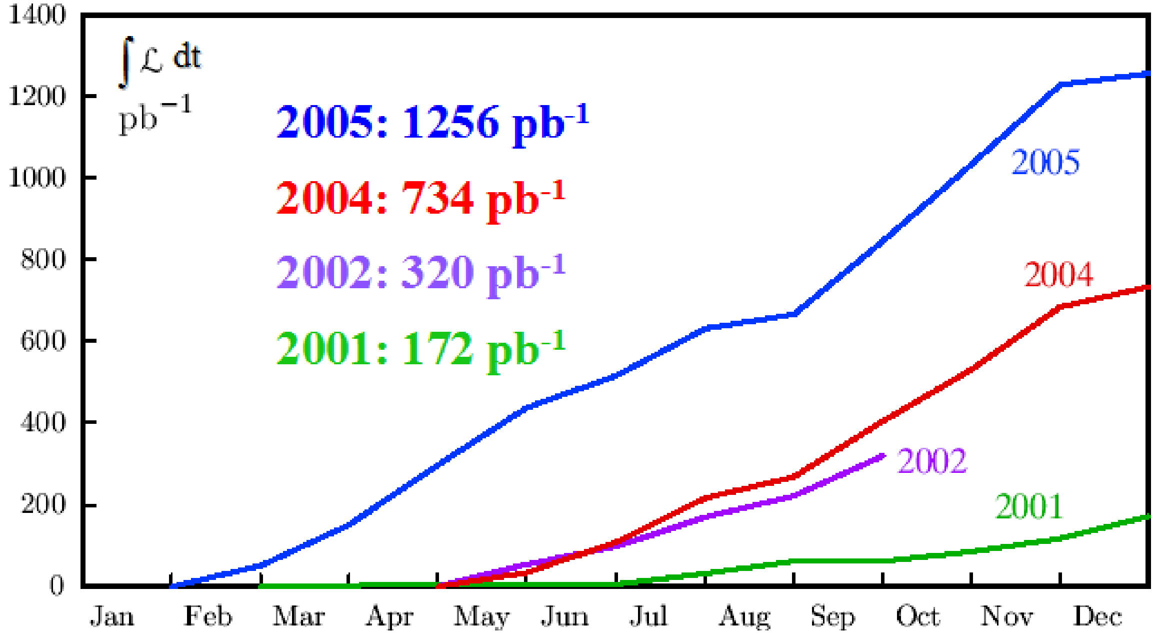
(Near) future



KLOE and DaΦne

e^+e^- **collider**, cm energy: $\sqrt{s} \sim m_\phi$**=1019.4 MeV**
Angle between the beams at IP: $\alpha \sim$ **12.5 mrad**
Residual laboratory momentum of ϕ: $p_\phi \sim$ **13 MeV**
Cross section for ϕ production at peak: $\sigma_\phi \sim$ **3.1 μb**
KLOE data taking completed (2001/5):

- **2.5 fb^{-1}** integrated at $\sqrt{s}=M(\phi)$;
- 0.25fb^{-1} at $\sqrt{s}\sim$1GeV

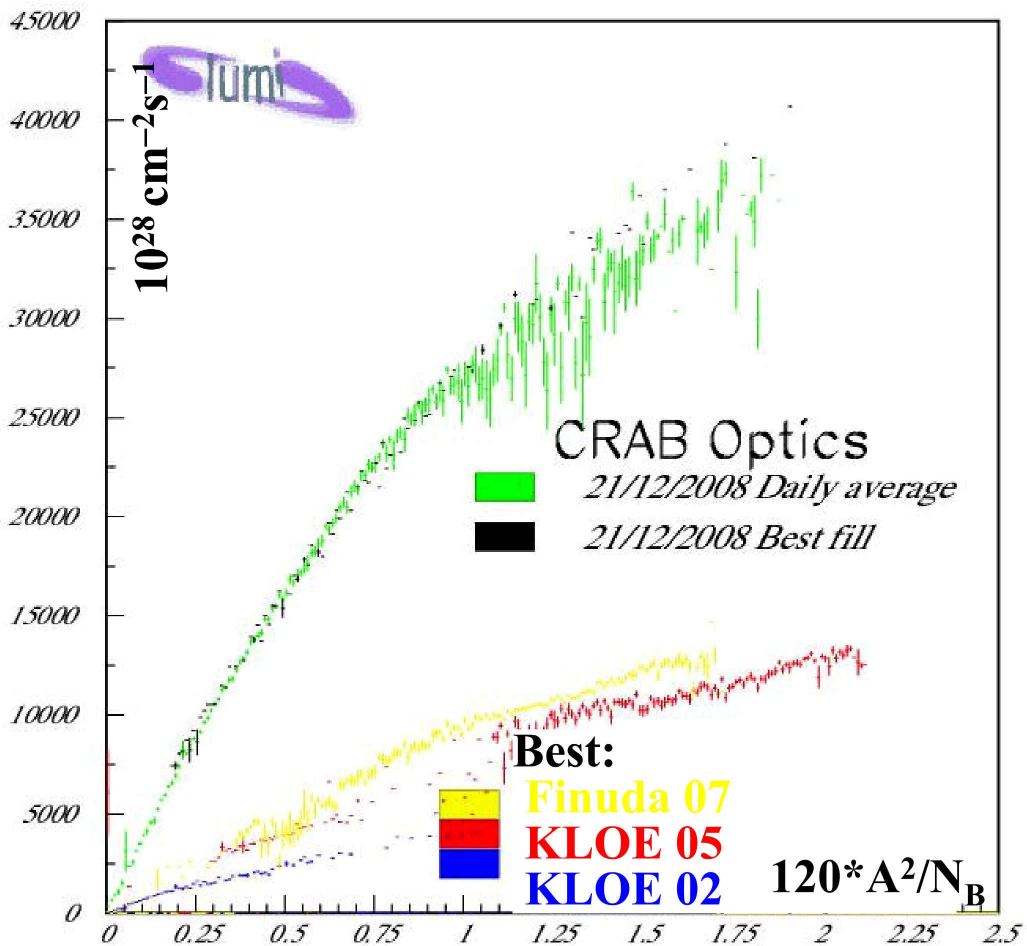


Best of KLOE run:

L_{PEAK}=1.4×10^{32} cm^{-2}s^{-1}
L_{INT}=8.5 pb^{-1}/day

KLOE and DaΦne

e^+e^- collider, cm energy: **$\sqrt{s} \sim m_\phi$=1019.4 MeV**
KLOE data taking completed (2001/5)



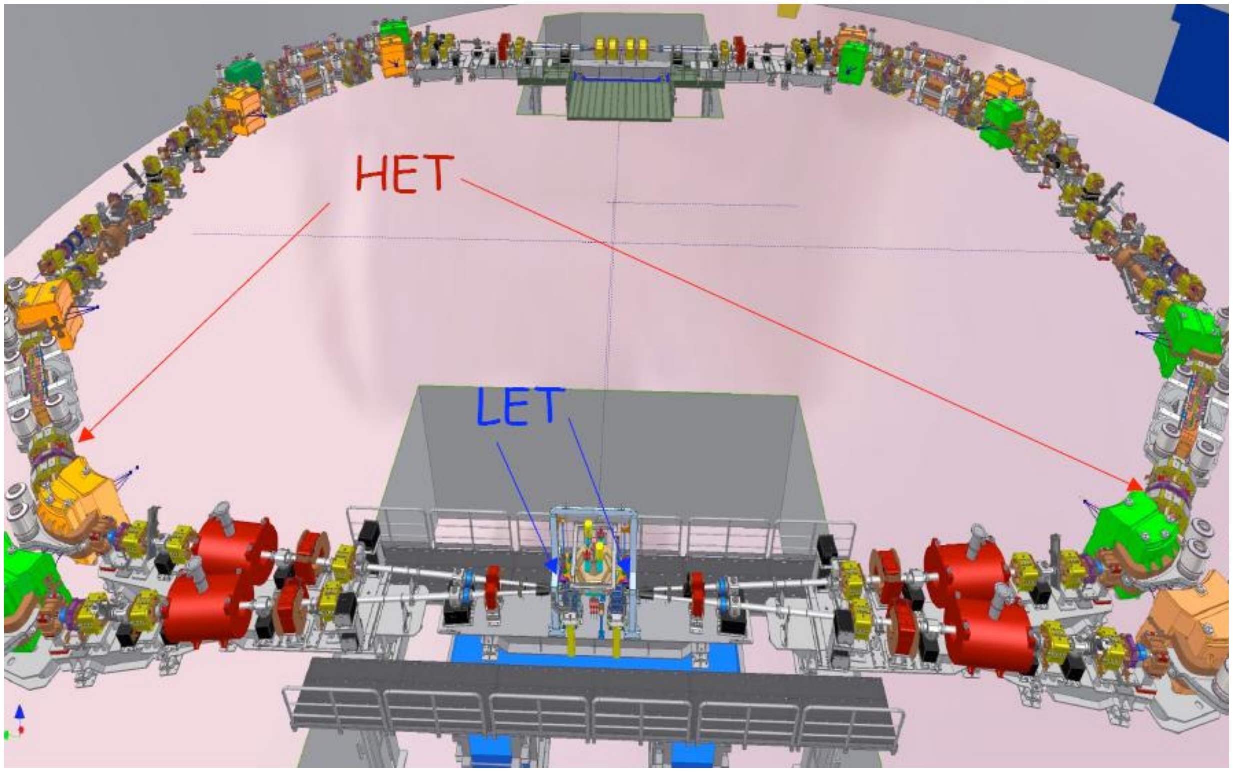
A novel collision scheme "**large Piwinsky angle and crabbed waist**" implemented:
(**at least**) L ~3×
⇒ **Ldt~1pb^{-1}/hour**.

KLOE(2 step0) luminosity goal: 5 fb^{-1} at $\sqrt{s}$=M(ϕ)

KLOE-2 Step 0

Roll-in (Dec 2009) and alignment (Jan 2010): done

Ready for resume data taking, foreseen for the 4th of May

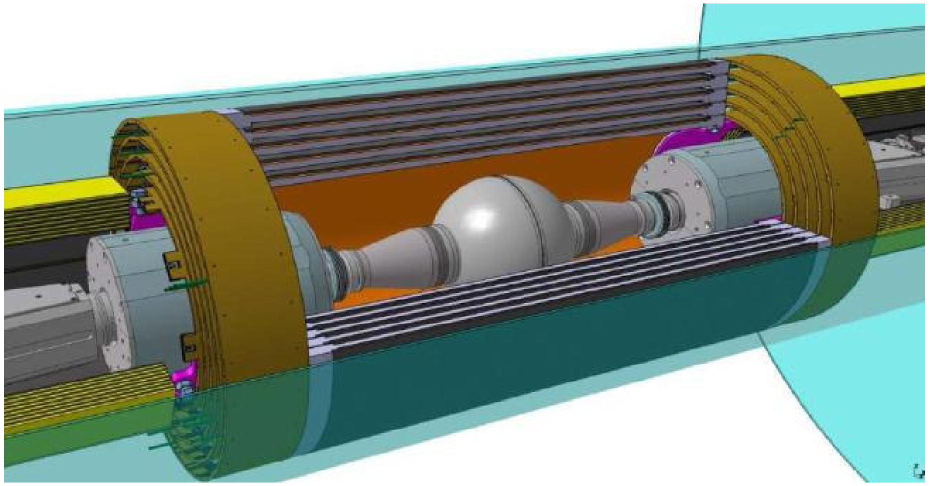


Minimal **detector** upgrade: tagger for $\gamma\gamma$ physics: detect off-momentum $e^{\pm}$ from $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$ (where $X=\pi\pi$, π^0, or η)

Low Energy Tagger (E_e=130-230 MeV) High Energy Tagger (E_e>400 MeV).

KLOE-2 Step 1

Luminosity goal > $20fb^{-1}$.

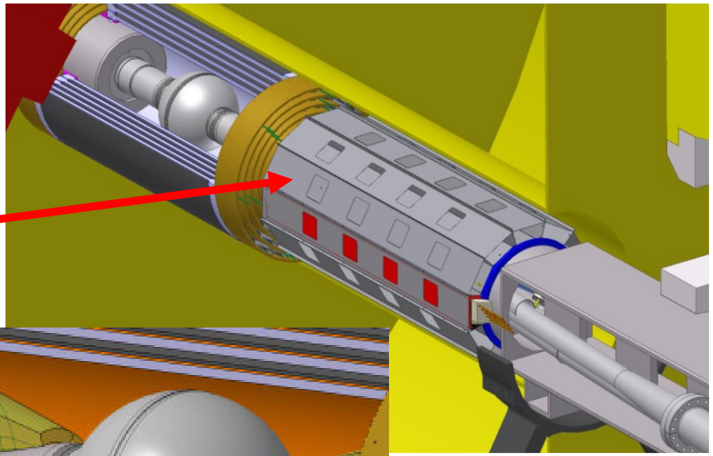


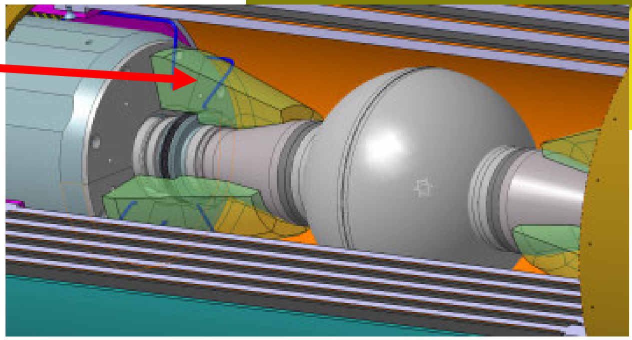
Major detector upgrade;

Inner tracker (IT) between the beam pipe and the DC (see the talk of G. Morello).

QCALT: W plus scintillating tiles, readout by SiPM via WLS fibers

CCAL: LYSO crystals + APD, close to IP to increase the acceptance for photons coming from the IP (θ_{MIN} from 21° to 9°)



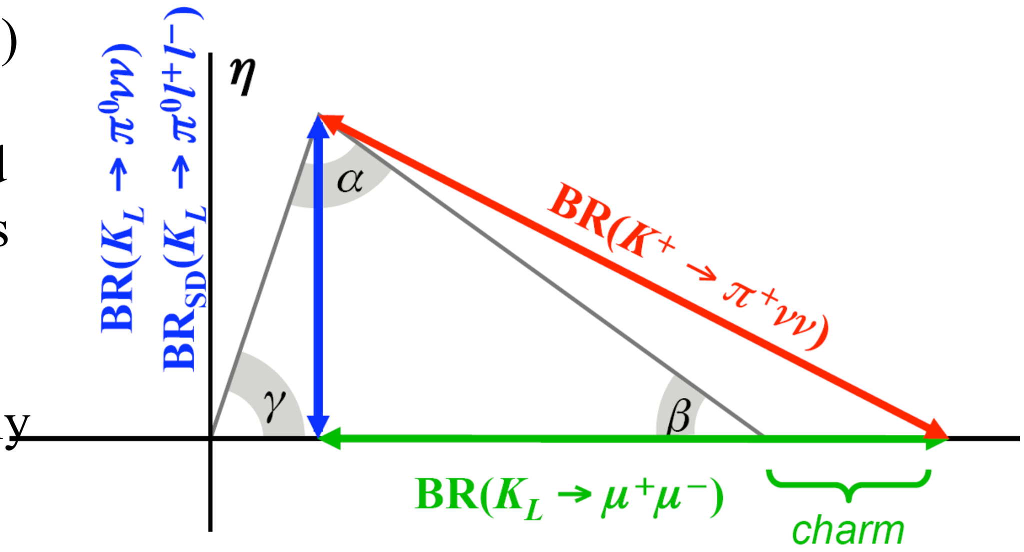


Installation: late in 2011

Golden K modes: K→πνν decays

• "Golden-plated decays": BR(K→πνν) can be predicted in the SM framework with very high theoretical accuracy and may provide grounds for precision tests of the flavor structure of the SM

• $\mathbf{K^0_L} \rightarrow \pi^0\nu\nu$ and $\mathbf{K^+}\rightarrow\pi^+\nu\nu$ completely determine the Unitarity Triangle.

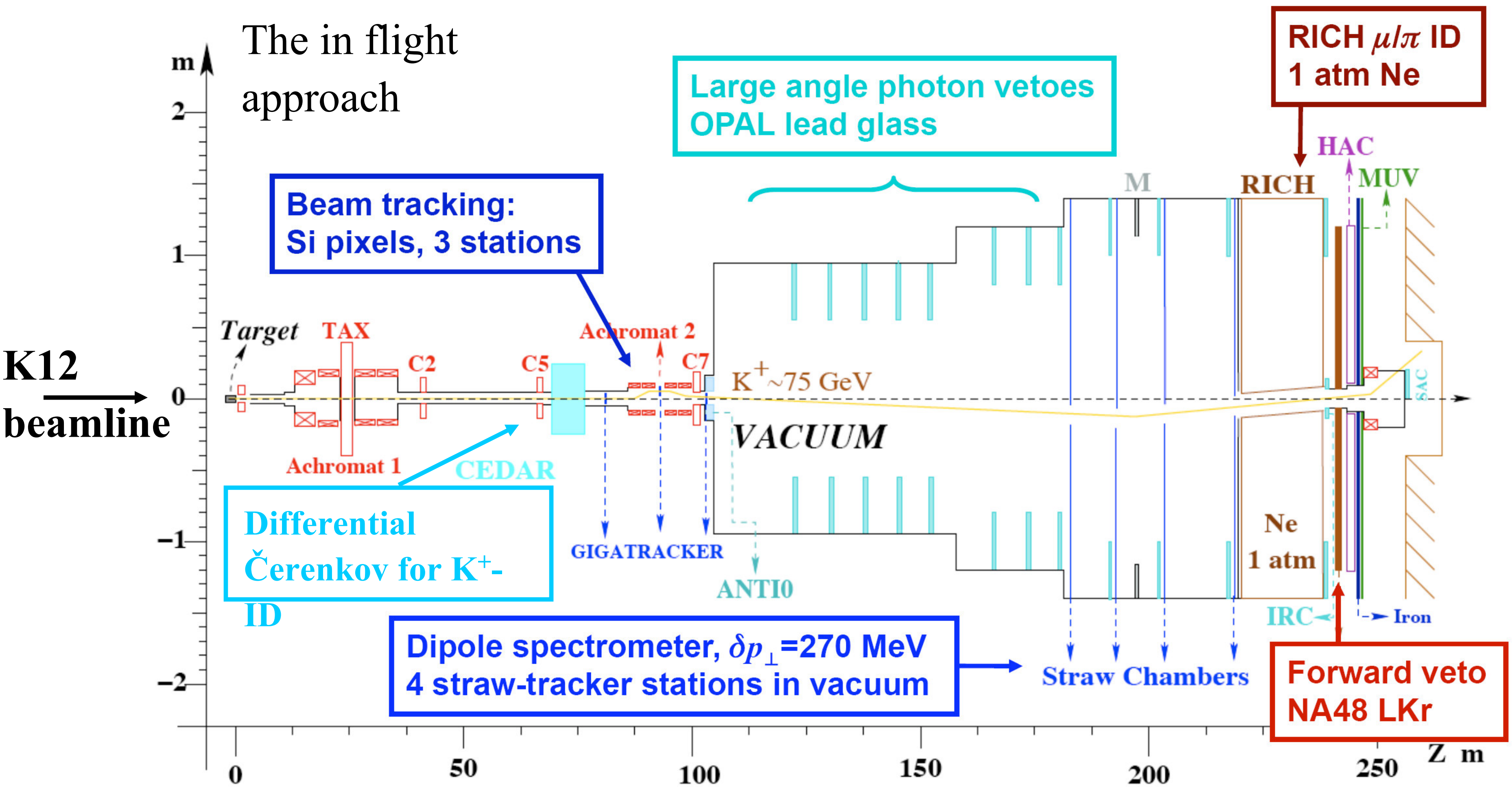


• Comparison with Unitarity Triangle from B sector could provides decisive tests in the flavor physics: new physics may differentiate between K and B measurement

• The *a priori* unknown hadronic matrix element obtained from K→πeν decays.

	Γ_{SD}/Γ	Irreducible theory err. (amp)	SM BR
$K_L \to \pi^0\nu\nu$	>99%	1%	3×10^{-11}
$K^+ \to \pi^+\nu\nu$	88%	3%	8×10^{-11}
$K_L \to \pi^0 e^+ e^-$	38%	15%	3.5×10^{-11}
$K_L \to \pi^0 \mu^+ \mu^-$	28%	30%	1.5×10^{-11}

NA62 @ CERN



400 GeV SPS primary proton beam → unseparated 75 GeV K^+ beam

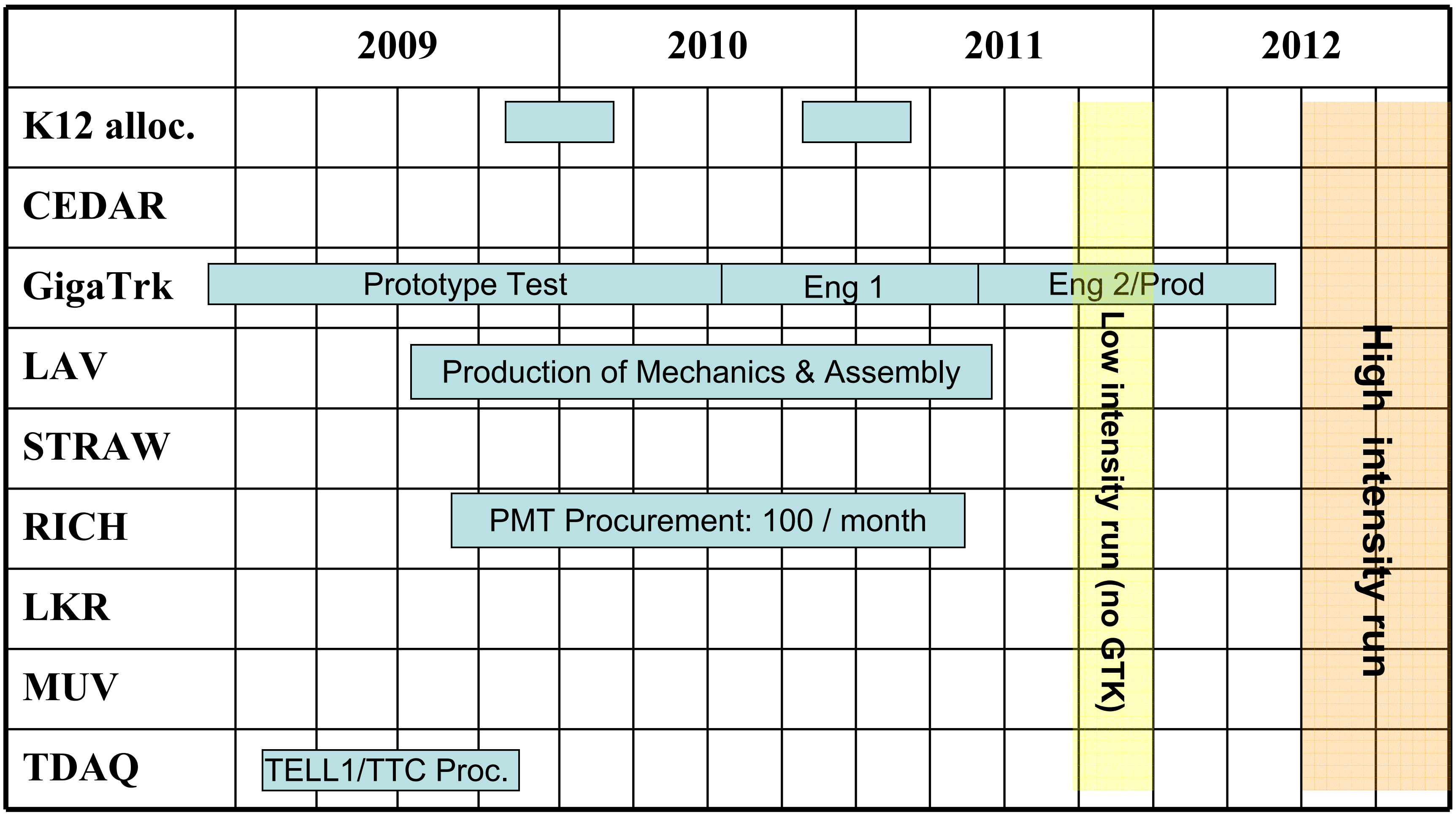
750 MHz beam → 50 MHz K+ → 6 MHz decay in 60-m fiducial volume

NA62 expected sensitivity

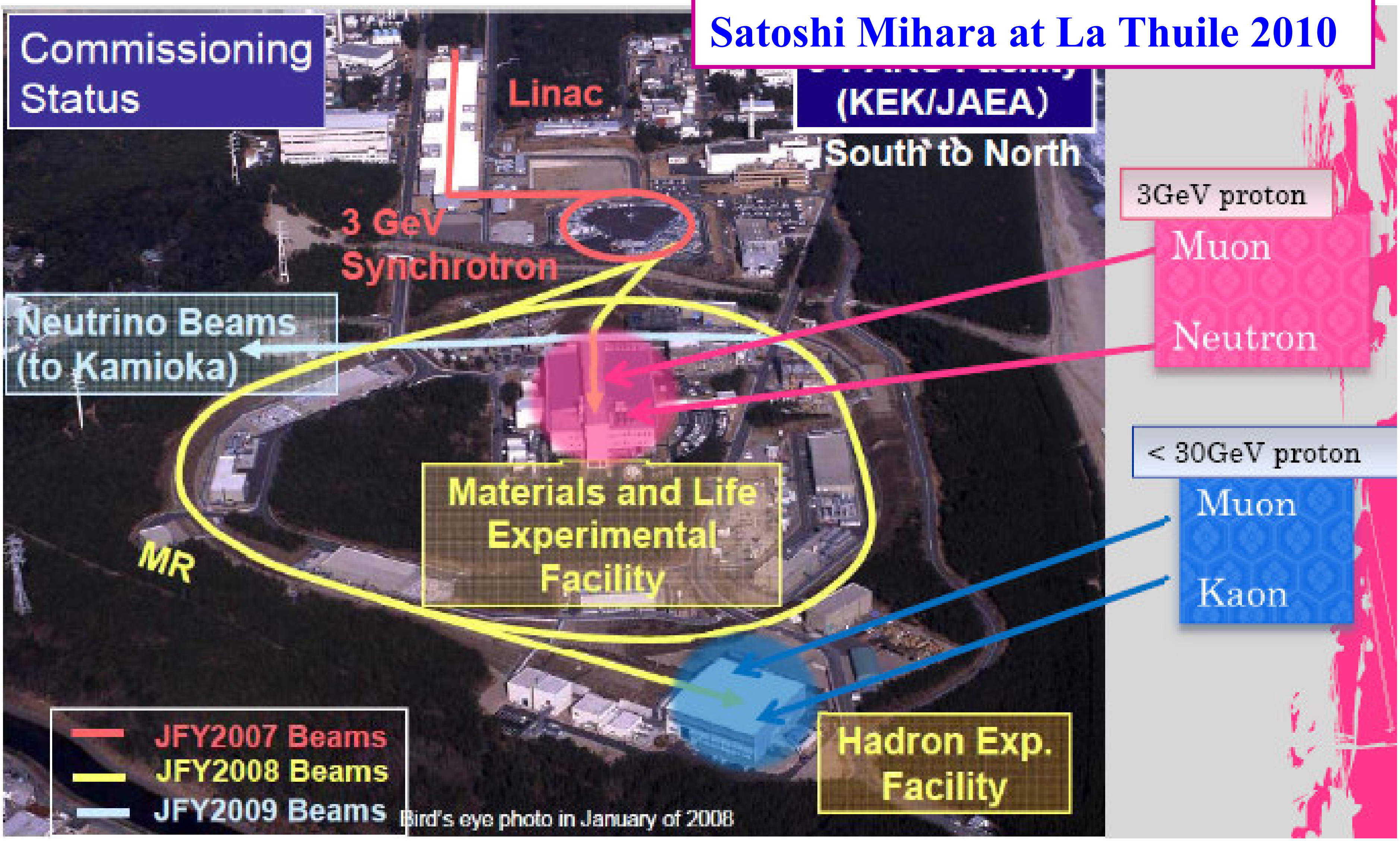
Decay Mode	Events
Signal: $K^+ \to \pi^+\nu\nu$ *[flux = 4.8×10^{12} decay/year]*	*55 evt/year*
$K^+ \to \pi^+\pi^0$ *[$\eta_{\pi0} = 2\times10^{-8}$ (3.5×10^{-8})]*	4.3% (7.5%)
$K^+ \to \mu^+\nu$	2.2%
$K^+ \to e^+\pi^+\pi^-\nu$	≤3%
Other 3 – track decays	≤1.5%
$K^+ \to \pi^+\pi^0\gamma$	~2%
$K^+ \to \mu^+\nu\gamma$	~0.7%
$K^+ \to e^+(\mu^+)\ \pi^0\nu$, others	negligible
Expected background	≤13.5% (≤17%)

year & running efficiency defined from NA48 story:
~100 days/year, 60% overall efficiency

NA62 timescale



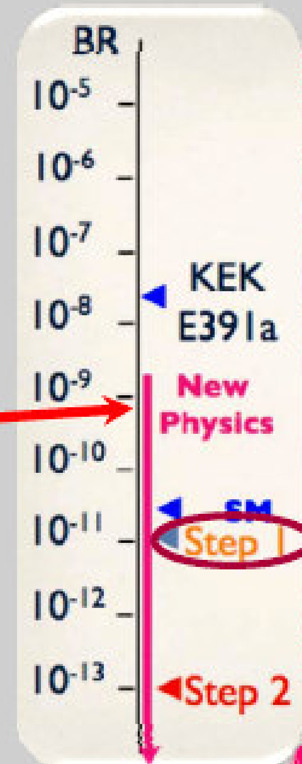
Satoshi Mihara at La Thuile 2010



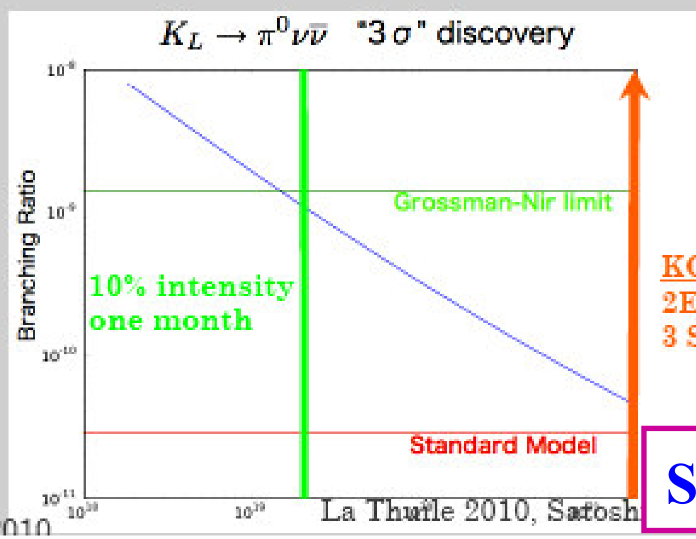
K0TO (K^0 at TOkai) @ J-PARC

Milestones of KOTO

- 2009: beamline construction
  - Beam survey (KL flux)
- 2010: CsI calorimeter construction
  - engineering run
  - beam properties with calorimeter
- 2011: detector installation
  - full engineering run, start physics run
  - 10% intensity(30kW) one month



Study of $K_L \to \pi\nu\nu$ decay



KOTO goal
2E14 pps
3 Snowmass years

2/March/2010 La Thuile 2010, Satoshi

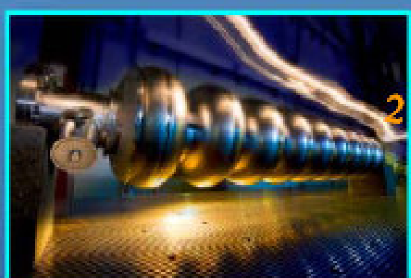
Satoshi Mihara at La Thuile 2010

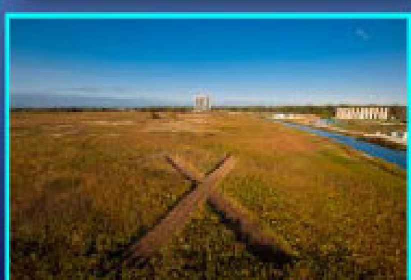
Project X at Fermilab

Young-Kee Kim at La Thuile 2010

<u>Project X</u>

Neutrino physics
Muon physics
Kaon physics
Nuclear physics
"simultaneouly"





Conclusions

Recent kaon decay measurements greatly improve knowledge of gauge couplings

- CKM matrix unitarity tested at 0.06%
- effective coupling measured at 0.03% constrains many NP scenarios
- progress from lattice will constrain more severely CKM fits soon

New and interesting tests of NP from kaon 2-body decays

- R_K golden LFV observable (w.a. at 1%)

Kaons can push findamental principles at severe test

Even in the “something else” era, Kaon physics continue to shed light on physics on and beyond SM