ChPT studies at NA62

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on behalf of the NA62 collaboration

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Kaon physics – the landscape

Kaon is the lightest strange particle, studied since 60's to test fundamental properties of nature

SM @ E ~ M_K appears remarkably simple:

$L_{SM} = L_{QCD}(m_u=m_d, m_s) + L_{QED} + L_{IB}(m_u-m_d) + L_{ew}$

only 2 parameters in L_{QCD}: m_s and $m_d \sim m_u \sim (m_d+m_u)/2$

L_{QED} and L_{IB} isospin-breaking: often neglected, but add 3rd parameter

L_{ew} is the link to physics at electroweak scale

breaks many symmetries: P, CP, flavor

Kaons reach the highest sensitivity to CPT violation, QM tests

Competitive with B decays to test NP in LFV or CPV transitions

K physics – past, present, future: study L_{QCD}

Precise study of low-energy realization of L_{QCD}, including L_{QED}, L_{IB}

- Benefit of soft momenta wrt scale of chiral symmetry breaking
- Only involve pseudoscalar mesons, photons, and leptons

Non-leptonic decays, comparison of strong ππ phase shifts from K decays with data from ππ scattering at few percent

- K → ππ(γ) ($\Delta I=1/2$ rule), Kl4 decays, K → πππ cusp

Radiative decays, non-trivial contribution from NLO ChPT, e.g.:

- K→ ππγ/ππee,ππμμ, SD $O(p^4)$: Strong and Weak, WZW
- K → eνγ (SD), NA62 → this talk
- $K^+ \to \pi^+ \gamma\gamma$, NA48/2 and NA62 → this talk
- $K_S \to \gamma\gamma$, starting from $O(p^6)$, long-standing KLOE vs NA48 discrepancy

K physics – past and present: deep study of L_{ew}

K^0-$\bar{K}^0$ system, 2nd order weak transitions allowing CPV, CPTV tests

30 years of high intensity/precision expts: NA31/48, E731/KTeV, KLOE, CPLEAR

- **$|\varepsilon_K| = (2.221 \pm 0.006)10^{-3}$, significant CKM constraint (w progress on B_K)**
- **$R(\varepsilon'/\varepsilon) = (16.8 \pm 1.4)10^{-4}$, reaching status of NP test, w lattice progress to beat uncertainty from cancellations btw e.m. and strong penguins**

Flavor physics (CKM unitarity) @ < 10^{-3} level from main K decays

- **$Vud^2 + Vus^2 - 1$ @ 6×10^{-4}, model independent exclusion $\Lambda_{NP} > 11$ TeV, 90% CL**
- **Synergy with lattice QCD, complemented with ChPT: $f^+(0)$, f_K/f_π**

LFV search (test H^+ exchange), $Ke2/K\mu2$ at NA62, this talk

K physics – future directions: deep study of L_{ew}

Future dominated by the high-intensity approach

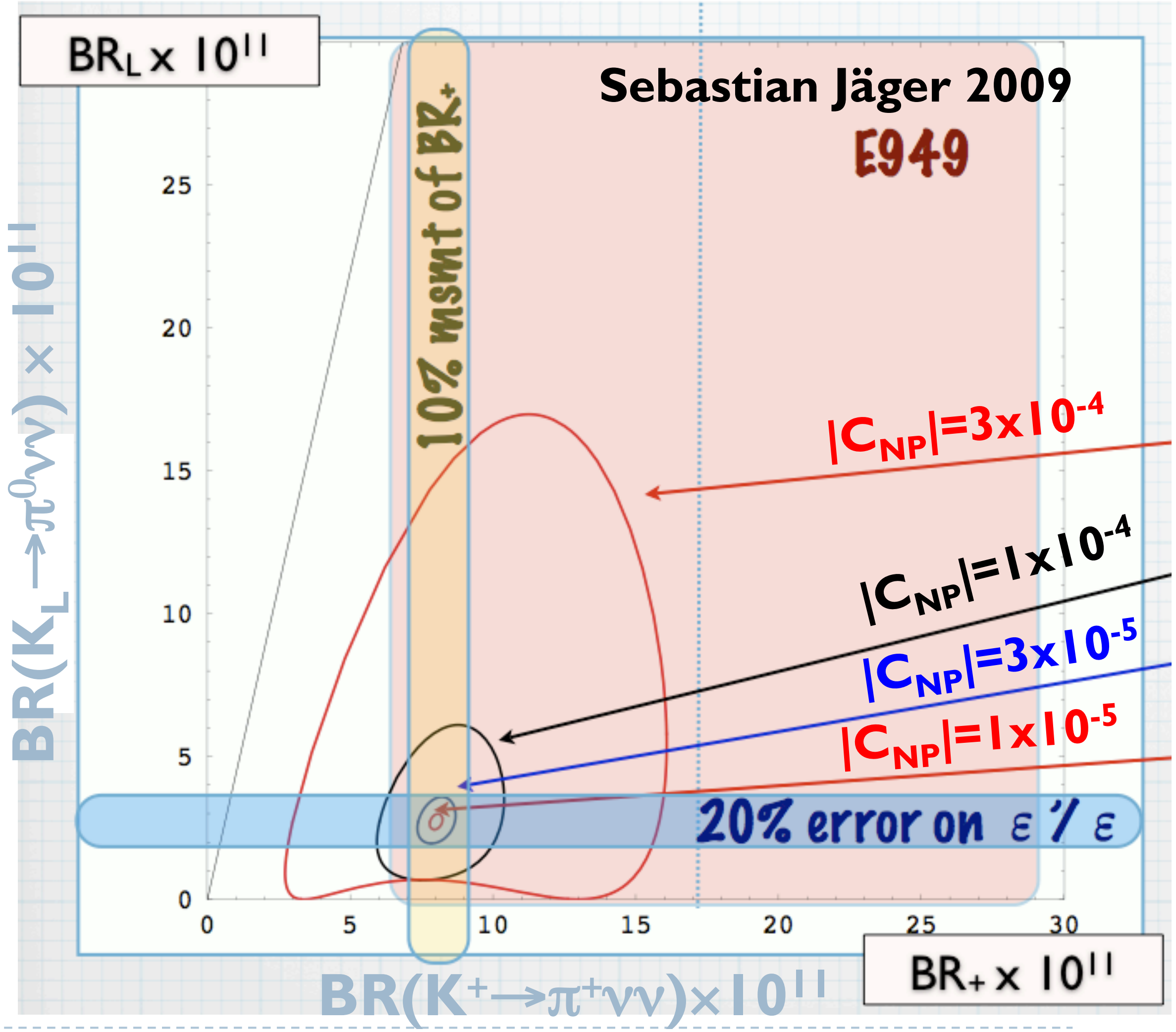
Ultra-rare K decays due to FCNC, precisely predicted in the SM, sensitive to NP contributions

$K^+ \to \pi\nu\nu$: NA62 experiment, this talk

$K^0 \to \pi^0\nu\nu$, KoTo experiment at J-Parc

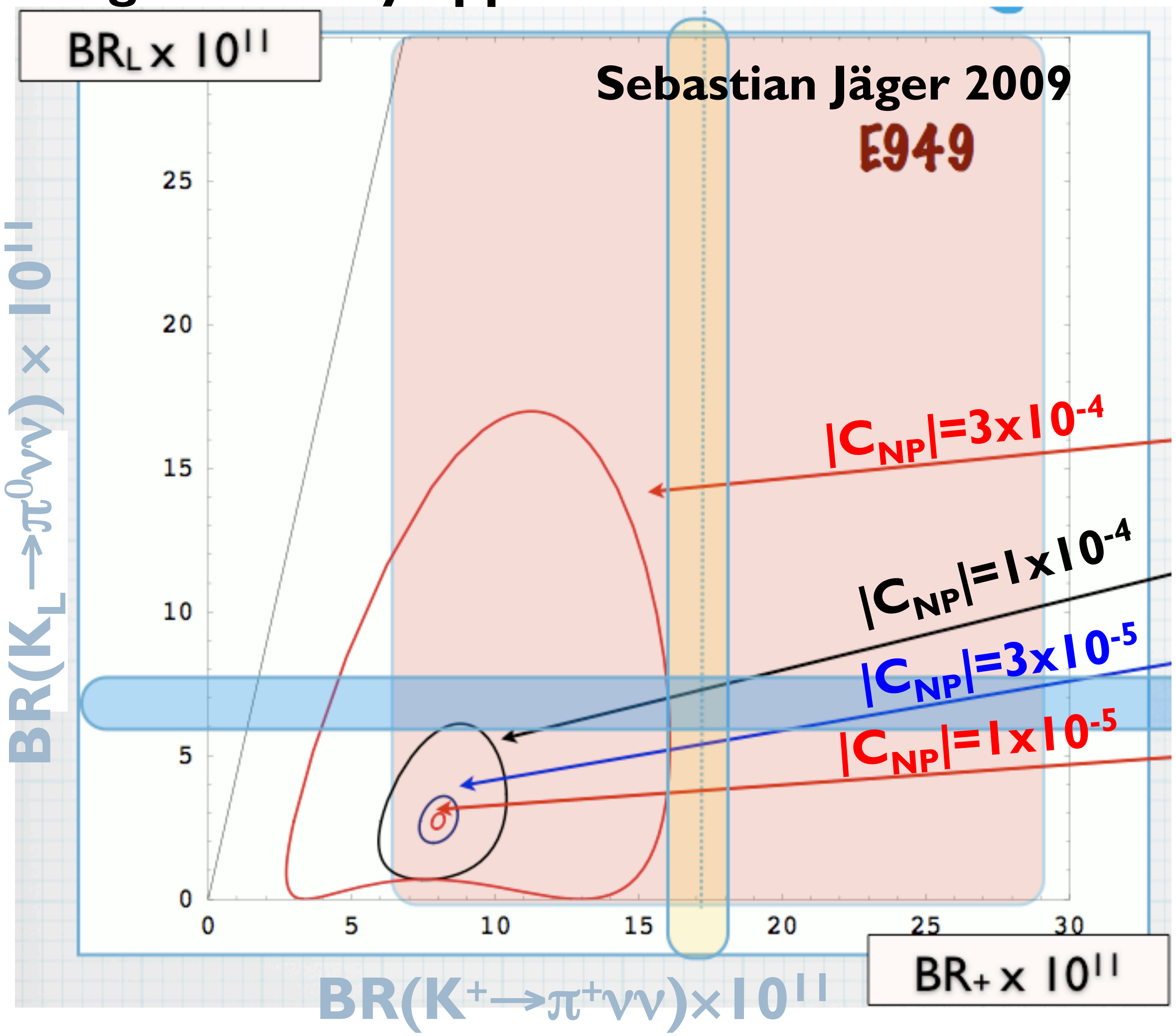
More players to come: Project X, Orka

Combine above mmts to perform a SM test from kaon inputs only



K physics – future directions: deep study of L_{ew}

The future is dominated by the high-intensity approach:



Ultra-rare K decays due to FCNC, precisely predicted in the SM, sensitive to NP contributions

K^+->$\pi\nu\nu$: NA62 experiment, this talk

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Combine above mmts to perform a SM test from kaon inputs only

Motivations for a precise measurement of RK

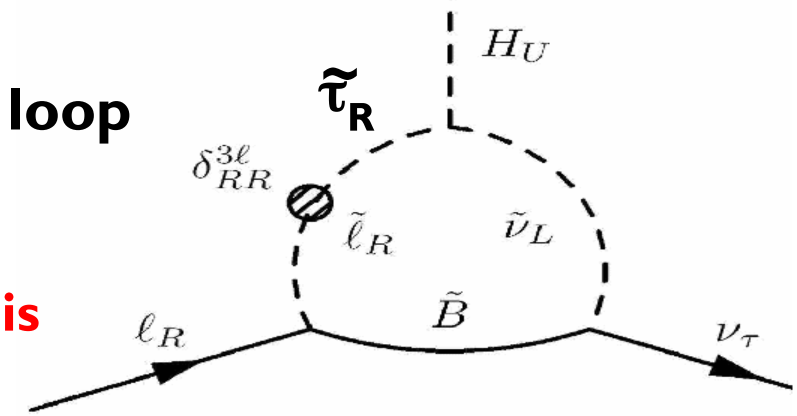
SM prediction w 0.04% precision, benefits of cancellation of hadronic uncertainties (no f_K): $R_K = 2.477(1) \times 10^{-5}$ [Cirigliano Rosell arXiv:0707:4464]

Helicity suppression can boost NP [Masiero-Paradisi-Petronzio PRD74 (2006) 011701, JHEP 0811 (2008) 042]

In R-parity MSSM, LFV can give 1% deviations from SM [Girrbach, Nierste, arXiv:1202.4906]**:**

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

NP dominated by contribution of $e\nu_\tau$ final state, with effective coupling $lH^\pm\nu_\tau \rightarrow \frac{g_2}{\sqrt{2}}\frac{m_\tau}{M_W}\Delta_{13}$ **, from loop**



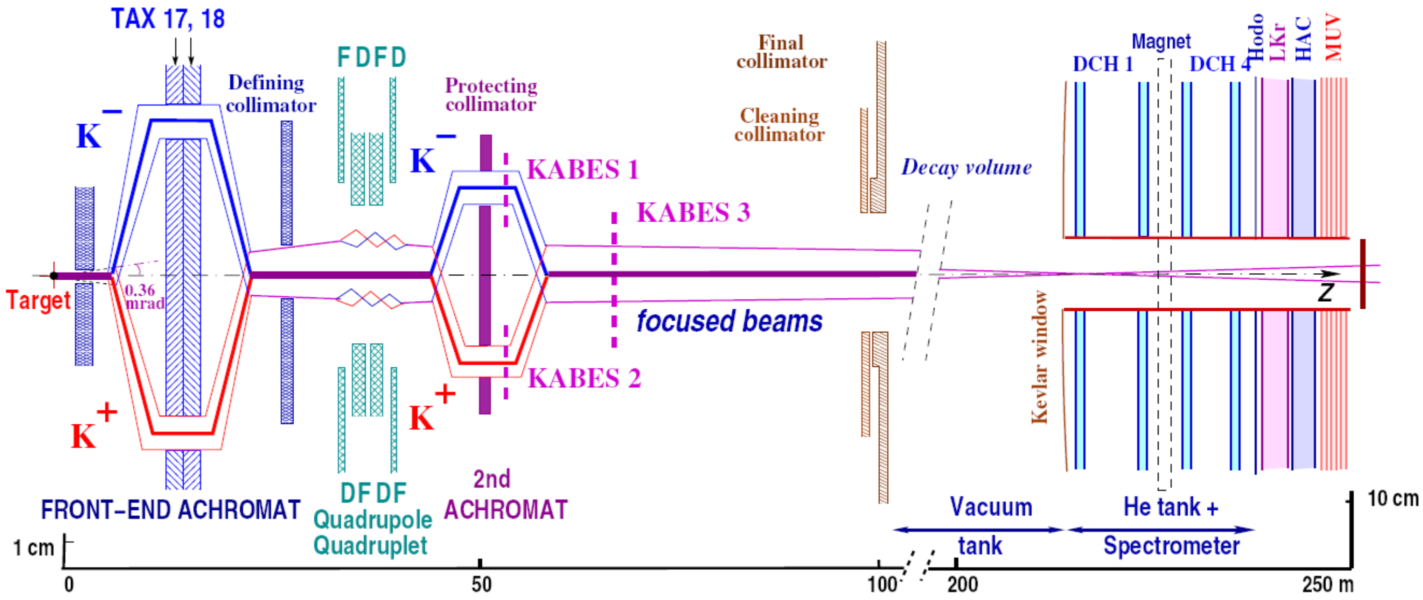
Exp. accuracy was $\delta R_K \sim 1.3\%$ (KLOE)

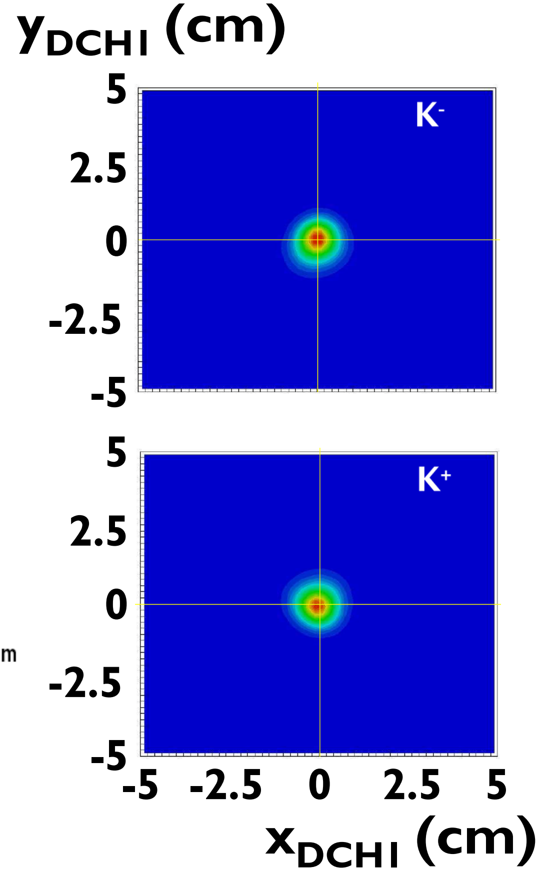
New measurement of R_K interesting, if error is pushed @ few per mil

RK in the NA48/2 experiment

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

- **$p_K \sim 60$ GeV, $\sigma_p \sim 3$ GeV (3.8% p-bite)**
- **spot of ~ 5 mm width @ DCH1 entrance**





Track decay products with 4 DCH's:

- **$P_{\perp}$ kick of 121 MeV after DCH2**
- **$\sigma_p/p \sim 1.02\% \oplus 0.044\%$ p [GeV]**

Analysis of Ke2/Kμ2 at NAxx

Scintillator hodoscope:

- **establish event time (σ~150 ps), initiate trigger**

LKr calorimeter: efficient vetoing, e.m. energy resolution

- **$\sigma_E/E = 3.2\%/\sqrt{E[\mathrm{GeV}]} \oplus 9\%/E[\mathrm{GeV}] \oplus 0.42\%$**
- **$\sigma_{x,y} = 4.2\mathrm{mm}/\sqrt{E[\mathrm{GeV}]} \oplus 0.6$ mm, granularity of ~13,000 2×2 cm^2 cells**

Hadron calorimeter, Muon veto system

Analysis starting samples:

K_{e2} trigger: 1 trk (hodoscope) & 1-trk activity in DCH's & E_{LKr}>10 GeV

$K_{\mu2}$ trigger: 1 trk (hodoscope), downscaled

First useful data in 2003-4 NA48/2 runs, two preliminary results …

Analysis of Ke2/Kμ2 at NA62 – 2007 data

…then design of NA62 run optimized for R_K, main parameters tuned:

P_K: ~60 GeV → ~75 GeV

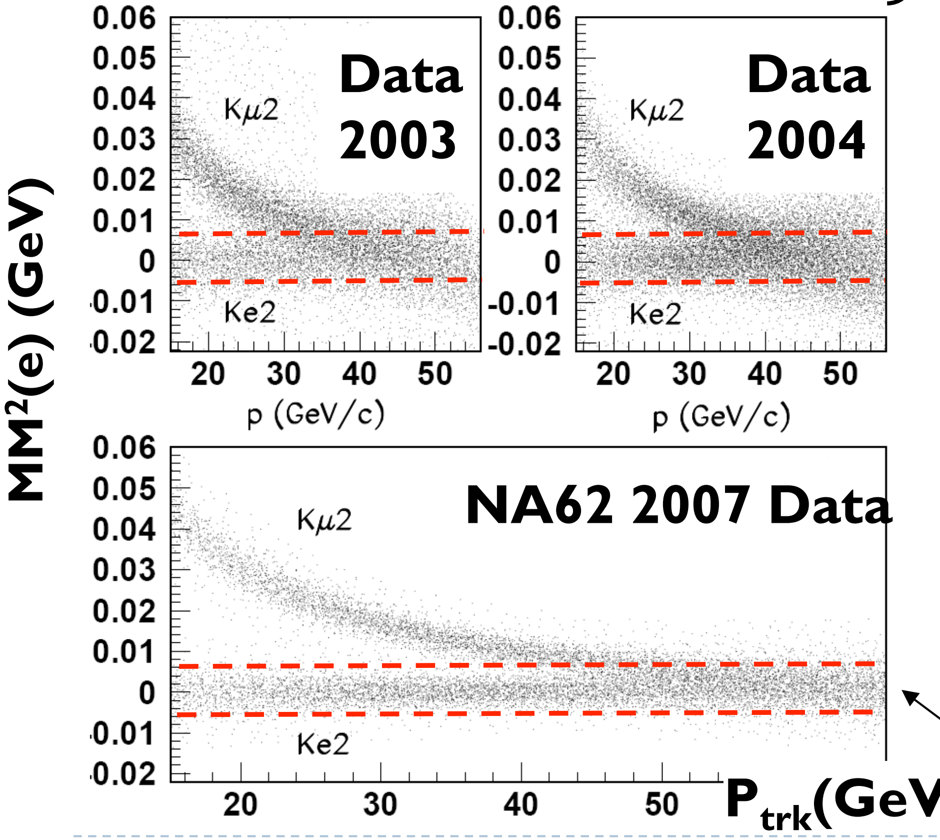
Momentum bite: 3.8% → 2.5%

$P_\perp$ kick: 121 MeV → 263 MeV

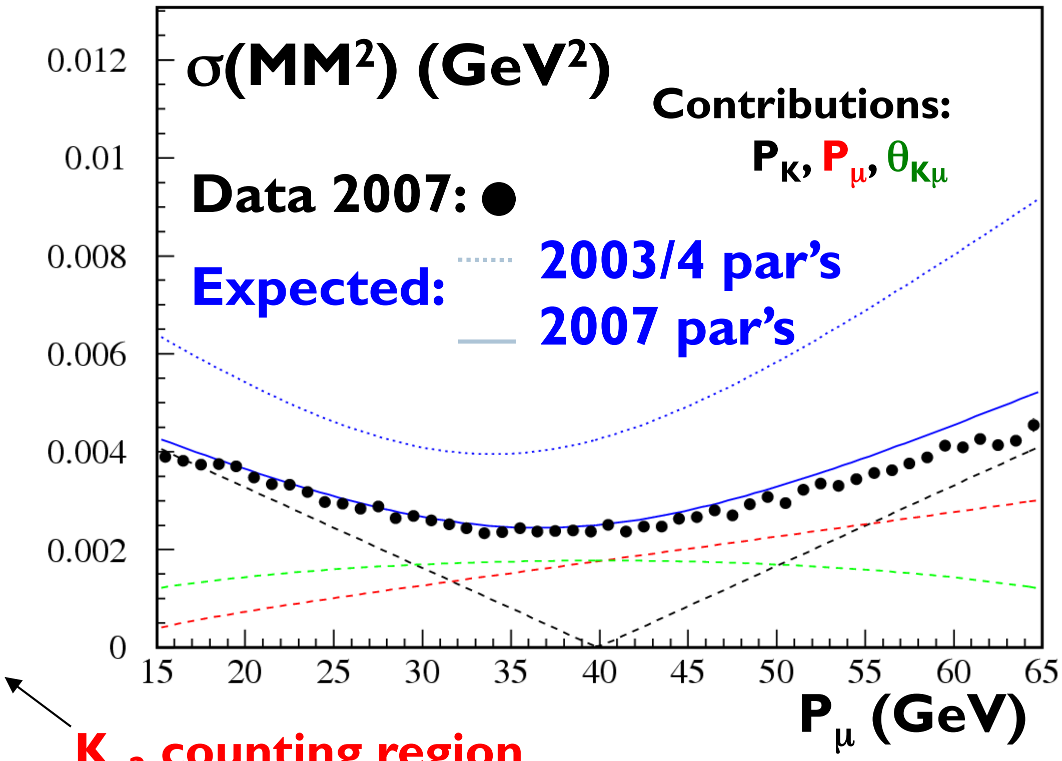
$\sigma_p/p = 0.48\% + 0.009\%\ p(\mathrm{GeV})$

MM² resolution improved

Better separation for Ke2 and Kμ2



K_{e2} counting region



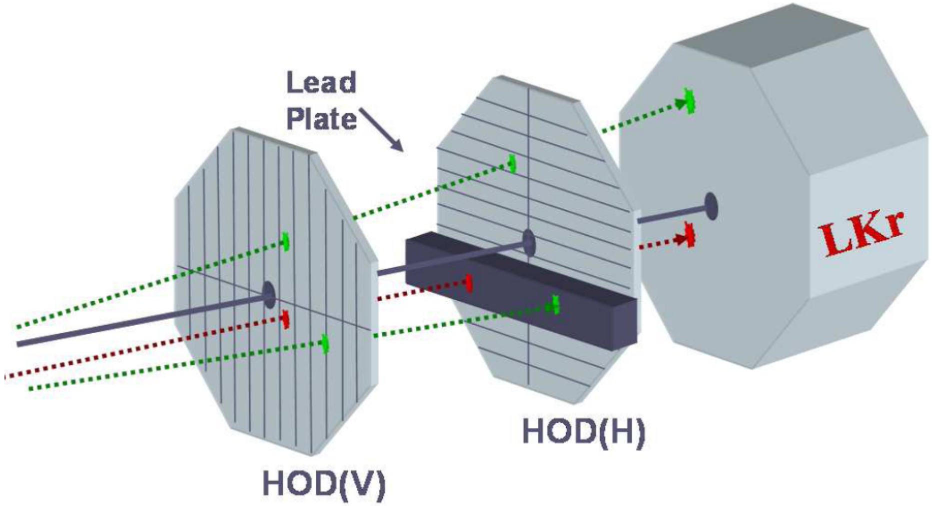
Analysis of Ke2/Kμ2 at NA62: μ background

e PID by LKr: (0.90 to 0.95)$<E_{cl}/P_{trk}<$1.10 gives μ rejection by ~10^6!

electron ID efficiency: 99.28(5)%

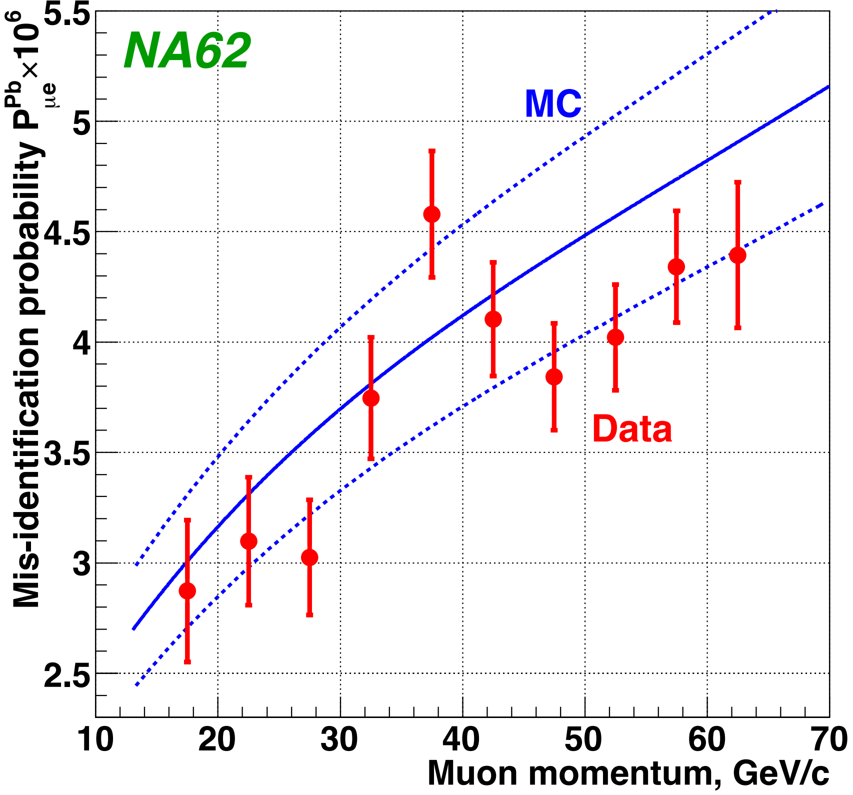
But check probability for μ's to fake e's [~3×10^{-6}, due to the so-called muon "catastrophic" energy loss] by direct mmt:

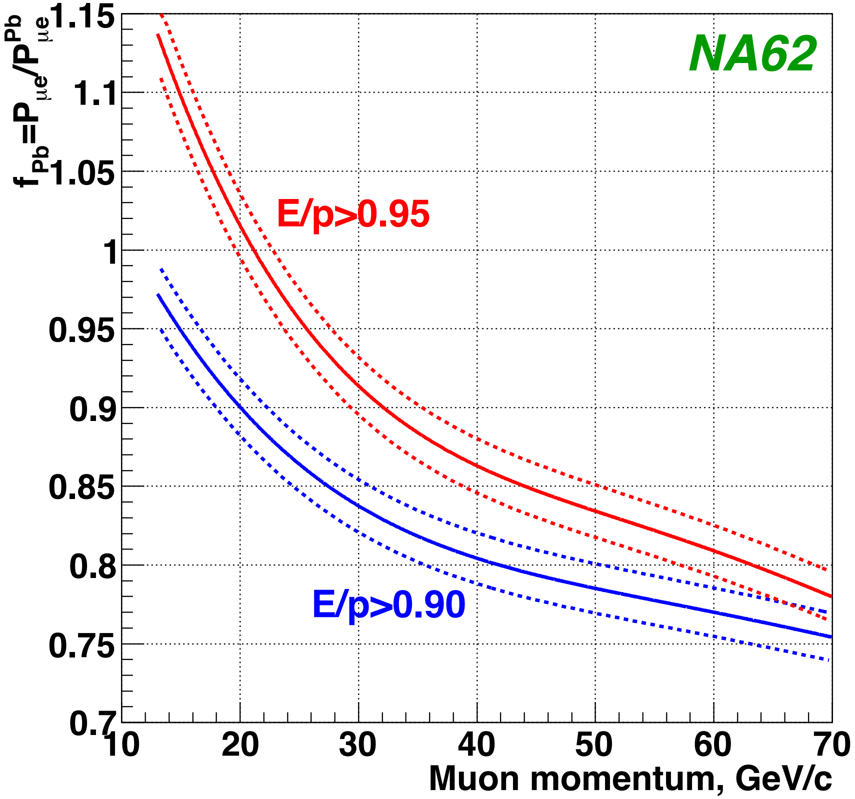
- **Subsample of data taken with a 9.2-X_0 Pb bar between HOD's**
- **Select μ's (pure @$<10^{-8}$) with MIP energy loss in Pb**
- **Correct method bias (ionization loss @ low P, brems. @ high P) w GEANT4**



Analysis of Ke2/Kμ2 at NA62: μ background

Evaluate 5.64(20)% Kμ2 bkg to Ke2, error dominated by statistics





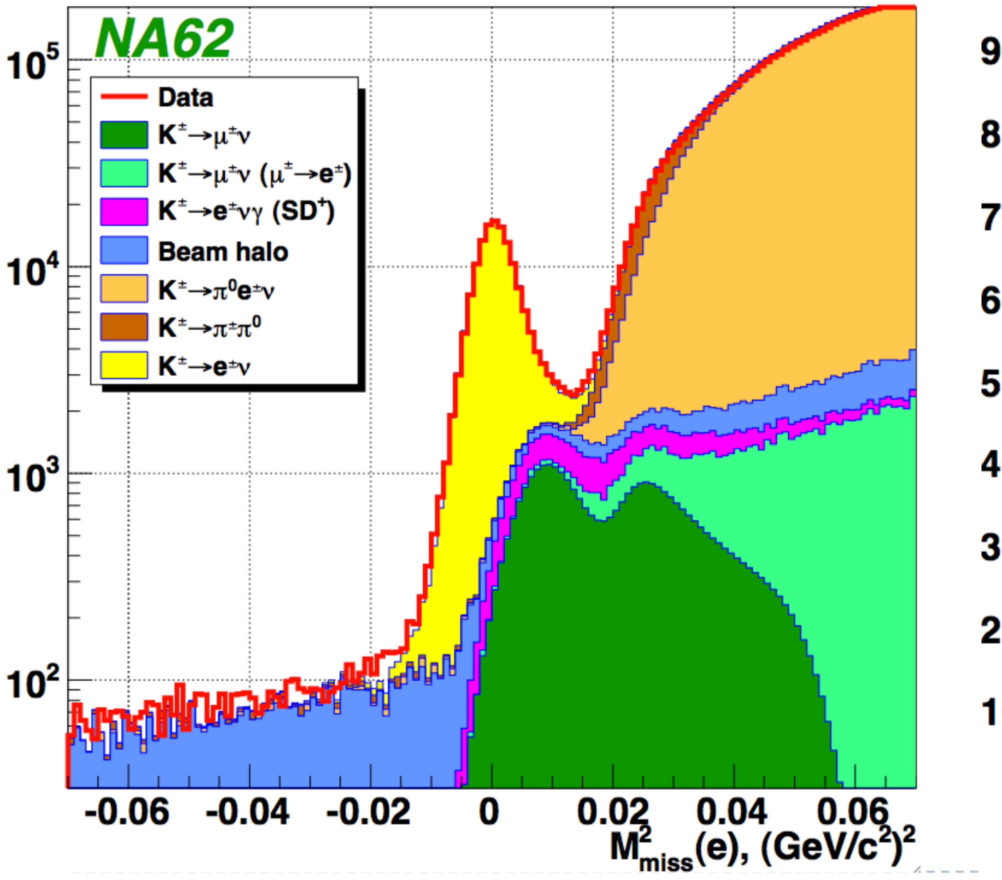
Analysis of R_K for the 4 configurations: K^+/K^- Lead bar/No lead bar

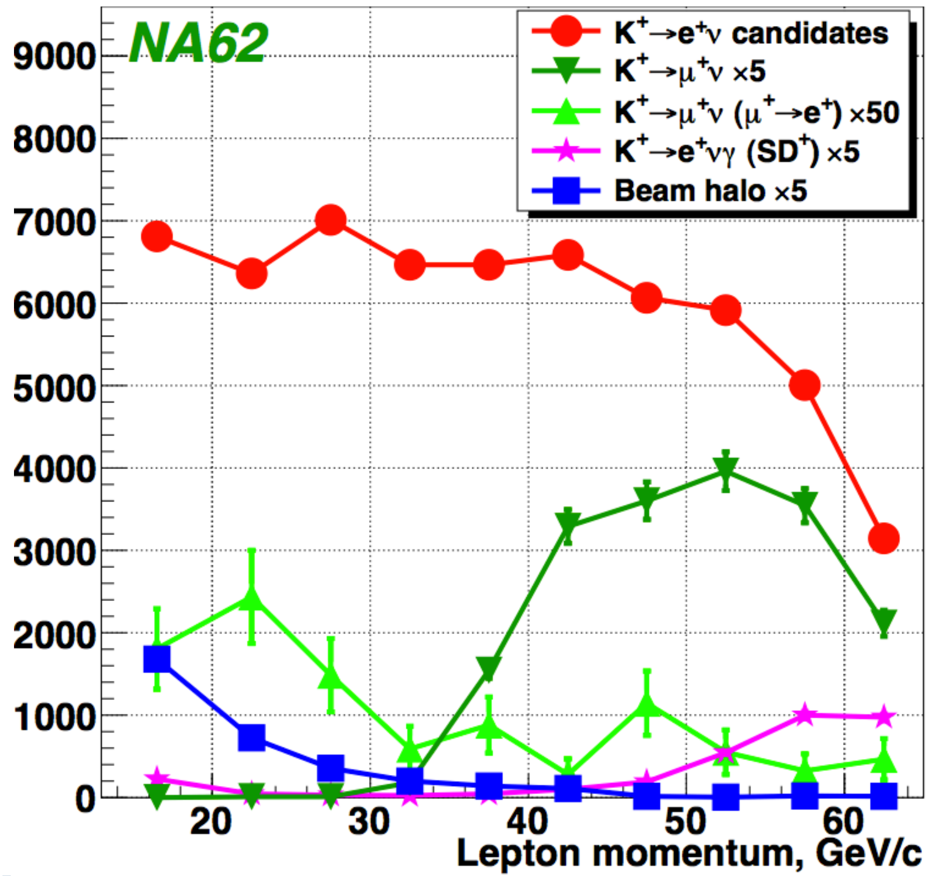
Analysis performed in lepton momentum bins, to check reliability of μ mis-ID evaluation and of bkg subtraction, acceptance correction

Analysis of Ke2/Kμ2 at NA62: other backgrounds

World largest Ke2 data set, 145958 K^+e2 candidates, 10.95(27)% bkg

Source	Kμ2	Kμ2(μ→e)	Ke2γ(SD⁺)	Ke3	K2π	K ∓	μ halo
Fraction, %	5.64(20)	0.26(3)	2.60(11)	0.18(9)	0.12(6)	0.04(2)	2.11(9)

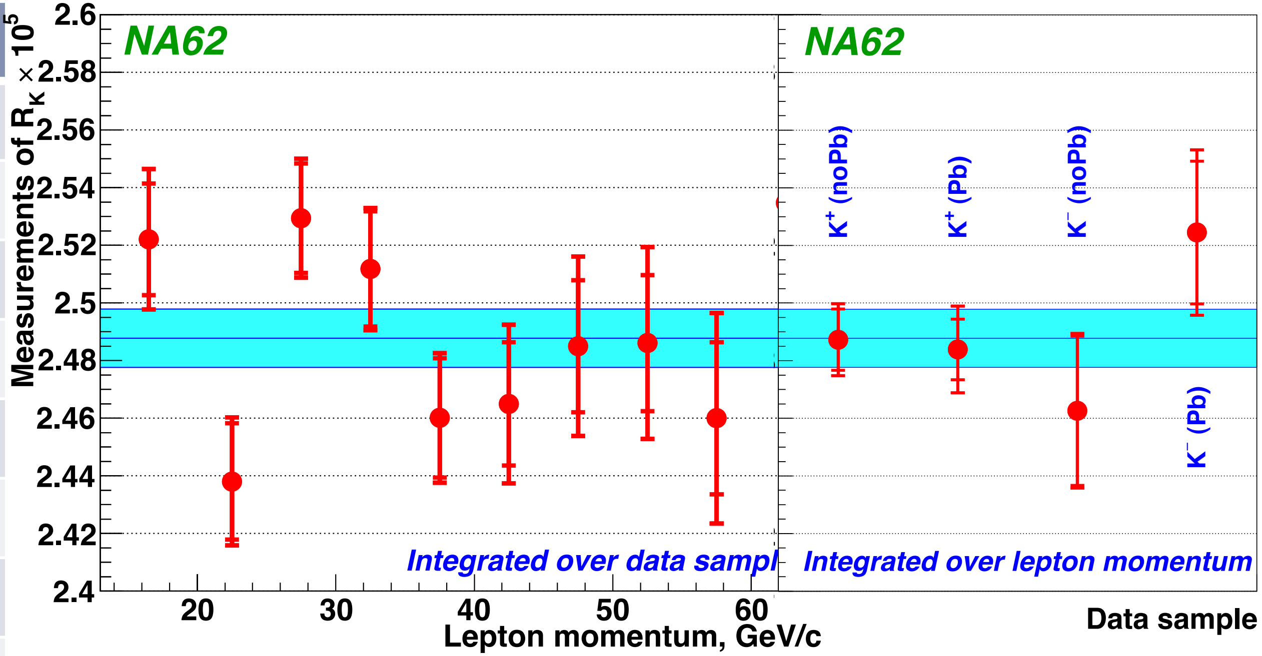




2012 RK preliminary result, impact for NP search

Entire data set: $R_K = 2.488(7)_{stat}(7)_{syst} 10^{-5}$, close to submission

Source	δR_K (10^{-5})
Statistics	0.007
Kμ2 bkg	0.004
Ke2γ SD+ bkg	0.002
Ke3, pp0 bkg	0.003
Beam halo bkg	0.002
Material budget	0.003
Acceptance corr	0.002
DCH alignment	0.001
Electron ID	0.001
1 TRK trigger eff	0.001
LKr readout eff	0.001
Total	0.010



Fit over 40 independent mmts, 10 lepton momentum bin × 4 configurations:

χ^2 / Nd.o.f. = 47/39

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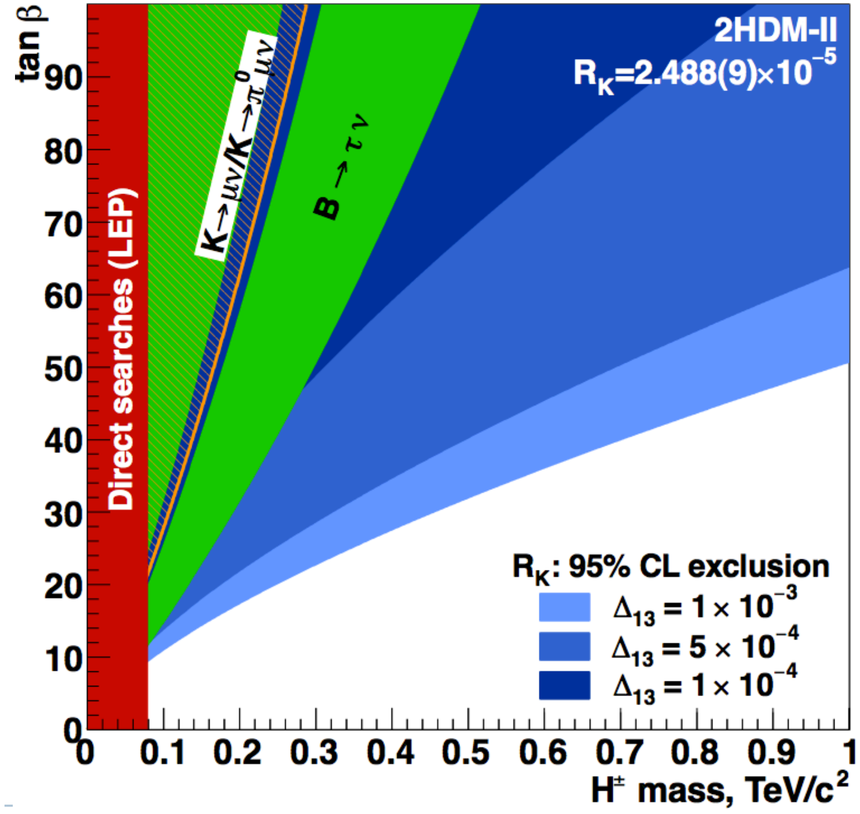
Acceptance corr	0.002
DCH alignment	0.001
Electron ID	0.001
1 TRK trigger eff	0.001
LKr readout eff	0.001
Total	0.010

Compare with $R_K(SM) = 2.477(1)\ 10^{-5}$:

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



$K^+ \rightarrow e^+ \nu \gamma$ SD contribution

To match theory for R_K have to count IB only, but SD ~ IB:

$$\frac{d^2\Gamma}{dxdy}(SD) = \frac{m_K^5 \alpha G_F^2 |V_{us}|^2}{64\pi^2} \times [(F_V + F_A)^2 f_{SD+}(x,y) + (F_V - F_A)^2 f_{SD-}(x,y)]$$

$x = 2E^*(\gamma)/M_K, y = 2E^*(e)/M_K$

f_{SD+}, f_{SD-} known functions of kinematics

Vector FF due to axial anomaly

Axial FF due to L_{strong} @ $O(p^4)$

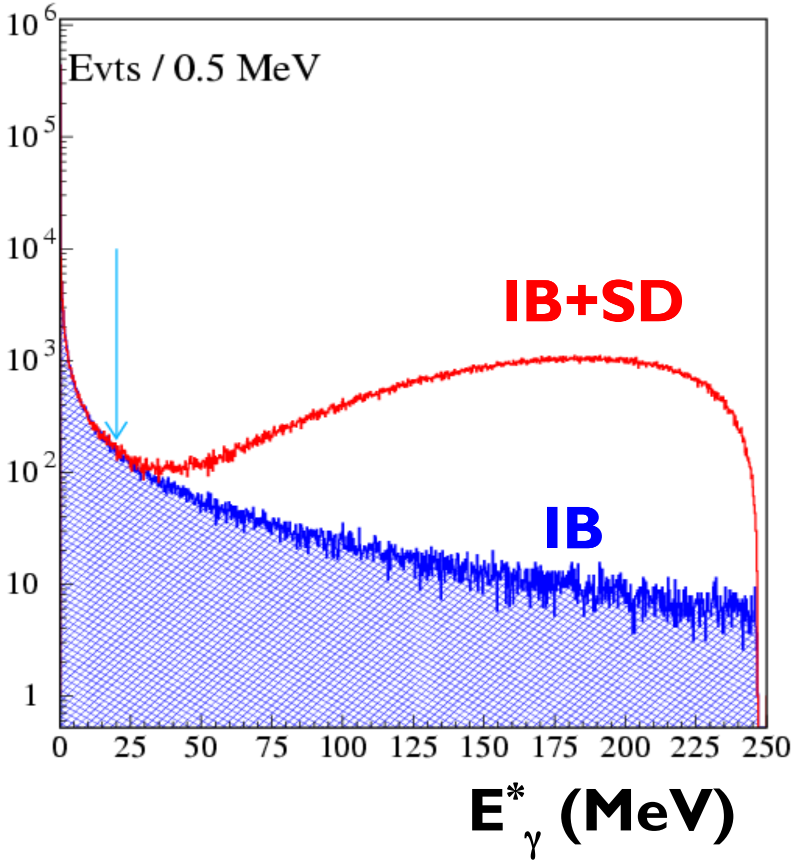
At $O(e^2p^4)$, FF's F_V and F_A are constant:

$$F_V(p^2) = \frac{m_K}{4\sqrt{(2)}\pi^2 F_K} + \mathcal{O}(p^6),$$

$$F_A(p^2) = \frac{4\sqrt{2}m_K}{F_K}(l_9^r + l_1^r0) + \mathcal{O}(p^6),$$

At $O(e^2p^6)$, slope in the vector FF:

$F_V(p^2) = F_V(0)\ (1 + \lambda\, p^2/M_K^2), \lambda \sim 0.4$



$K^+ \rightarrow e^+ \nu \gamma$ SD contribution: present status

$$\frac{d^2\Gamma}{dxdy}(SD) = \frac{m_K^5 \alpha G_F^2 |V_{us}|^2}{64\pi^2} \times [(F_V + F_A)^2 f_{SD+}(x,y) + (F_V - F_A)^2 f_{SD-}(x,y)]$$

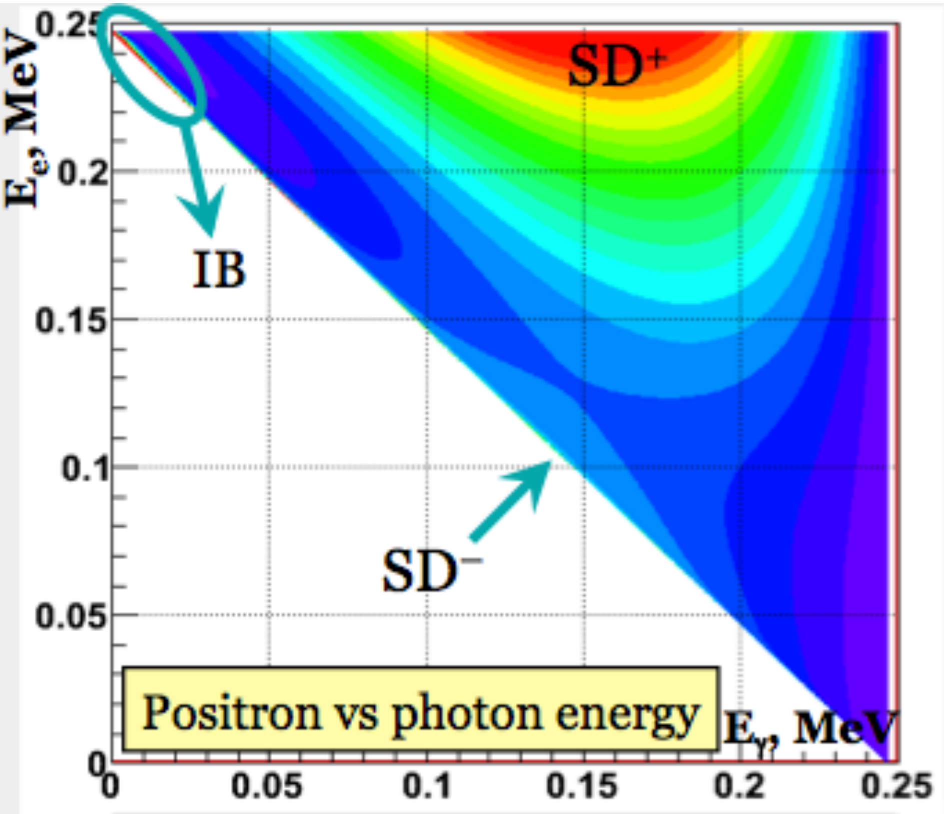
KLOE 2009 measurement for $E^*\gamma$ >10 MeV and p^*e >200 MeV:

- **$\delta\Gamma(SD^+)/\Gamma(SD^+) \sim 4\%$**
- **~1500 cts, bkg contributes to erro**
- **No sensitivity to SD^-**
- **Fair agreement with χPt $O(p^4)$**
- **Data tends to favour slope for F_V,**

  $\lambda = 0.38\,(20)_{stat}\,(2)_{syst}$,

but can't state $\lambda \neq 0$ @ >2σ

Imply 0.15% error for RK(NA62)



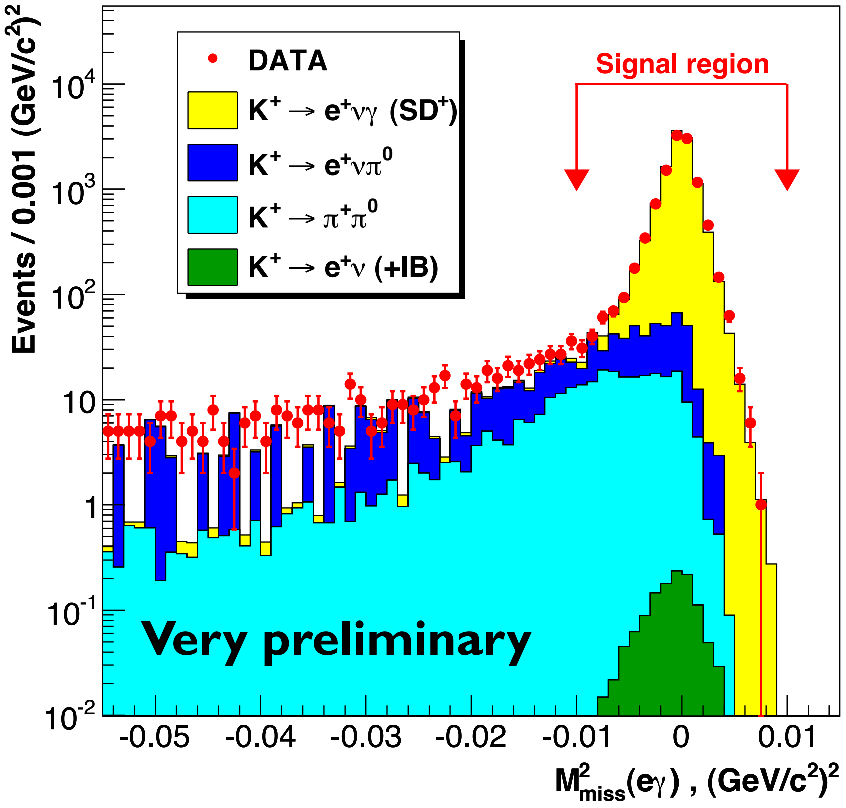
$K^+ \rightarrow e^+ \nu \gamma$ SD analysis at NA62

Selection of SD component, many steps common to the R_K analysis

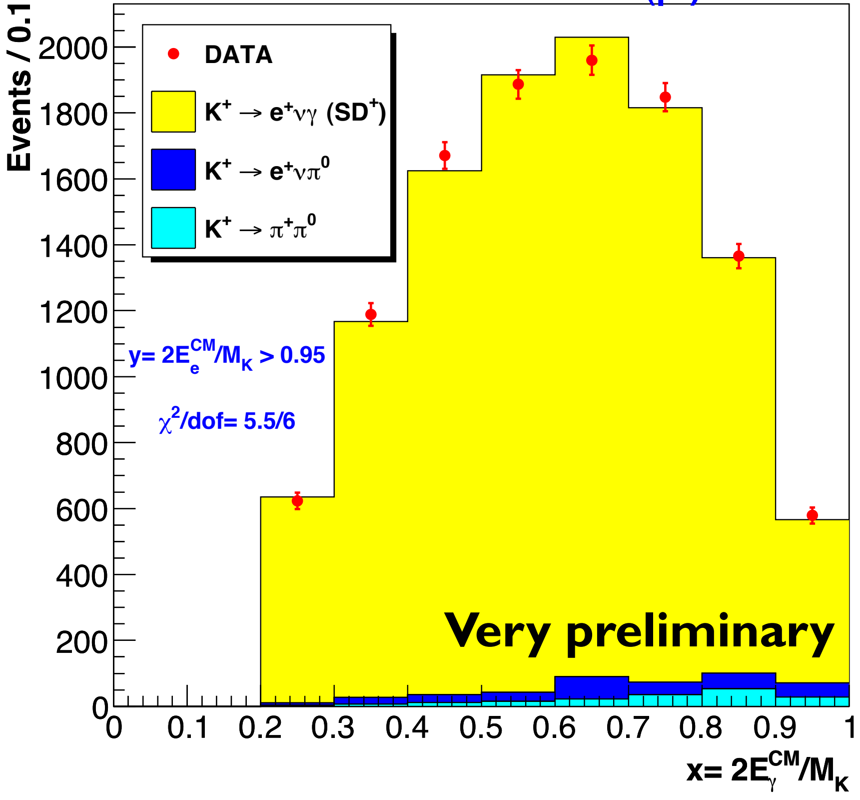
$\pi\pi^0$, Ke3 backgrounds → photon explicitly detected + tighter e PID

Will count ~10 k events w $P^*_e > 234$ MeV, 10% acceptance, few % bkg

Analysis in progress, plan is to perform a model-independent FF mmt



Fit data with ChPT at O(p^6)



$K^+ \rightarrow \pi^+ \gamma\, \gamma$ decay at ChPt $O(p^4)$

Contributions to amplitude $M(K^+(p) \to \pi^+(p')\gamma(q_1,\epsilon_1)\gamma(q_2,\epsilon_2))$ **from $O(p^4)$**

$$\epsilon_\mu(q_1)\epsilon_\nu(q_2)\left[A(y,z)\frac{(q_2^\mu q_1^\nu - q_1\cdot q_2 g^{\mu\nu})}{M_K^2} + C(y,z)\varepsilon^{\mu\nu\alpha\beta}\frac{q_{1\alpha}q_{2\beta}}{M_K^2}\right]$$

where $y = p\cdot(q_1-q_2)/M_K^2$ **and** $z = (q_1+q_2)^2/M_K^2$

***A* from $L_{ew}L_{QDC}$ loops + L_{QDC} $O(p^4)$ counter terms + L_{weak} $O(p^4)$:**

$$A(z) = \frac{G_8 M_K^2 \alpha}{2\pi z}\left[(r_\pi^2 - 1 - z)F\left(\frac{z}{r_\pi^2}\right) + (1 - r_\pi^2 - z)F(z) + \hat{c}z\right]$$

$$\hat{c} = \frac{128\pi^2}{3}[3(L_9 + L_{10}) + N_{14} - N_{15} - 2N_{18}]$$

C from anomaly (WZW), accounts for ~10% of width

Both *A* and C independent of y @ $O(p^4)$

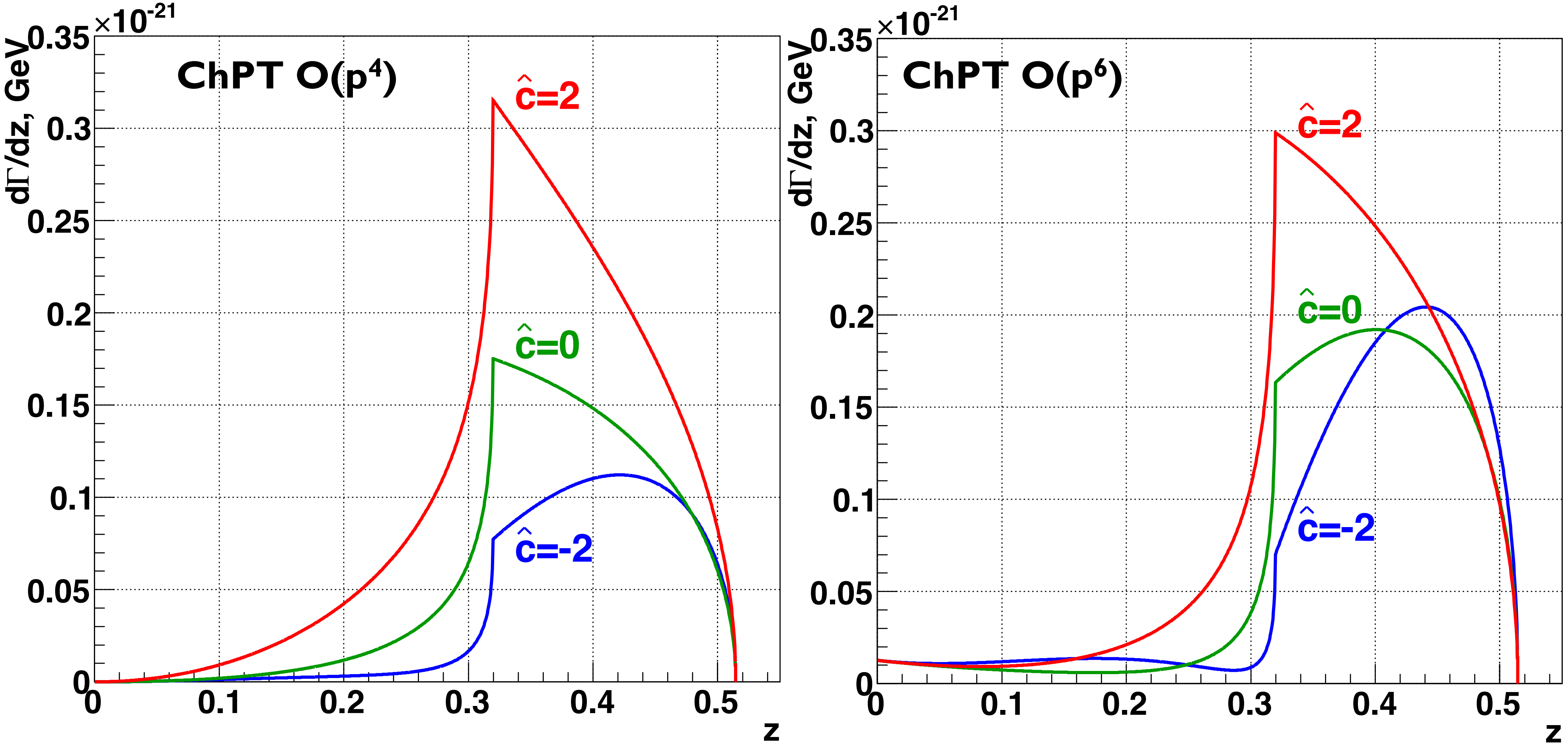
$\Gamma = \Gamma_{loops} + \Gamma_{WZW} = (\,2.80 + 0.87\,\hat{c} + 0.17\,\hat{c}^2 + 0.26\,)\ 10^{-23}$ GeV

Expect $\hat{c}$~1, rate dominated by π loop with cusp @ $z = z_+ = (2M_{\pi+}/M_K)^2$

$K^+ \rightarrow \pi^+ \gamma \gamma$ decay, ChPt $O(p^4)$ vs $O(p^6)$

@ $O(p^6)$ loop amplitude correction, evaluated from $K \rightarrow 3\pi$ @ $O(p^4)$

@ $O(p^6)$ *A* gets a y dependence, sizable correction to $d\Gamma/dz$ for $z < z_+$



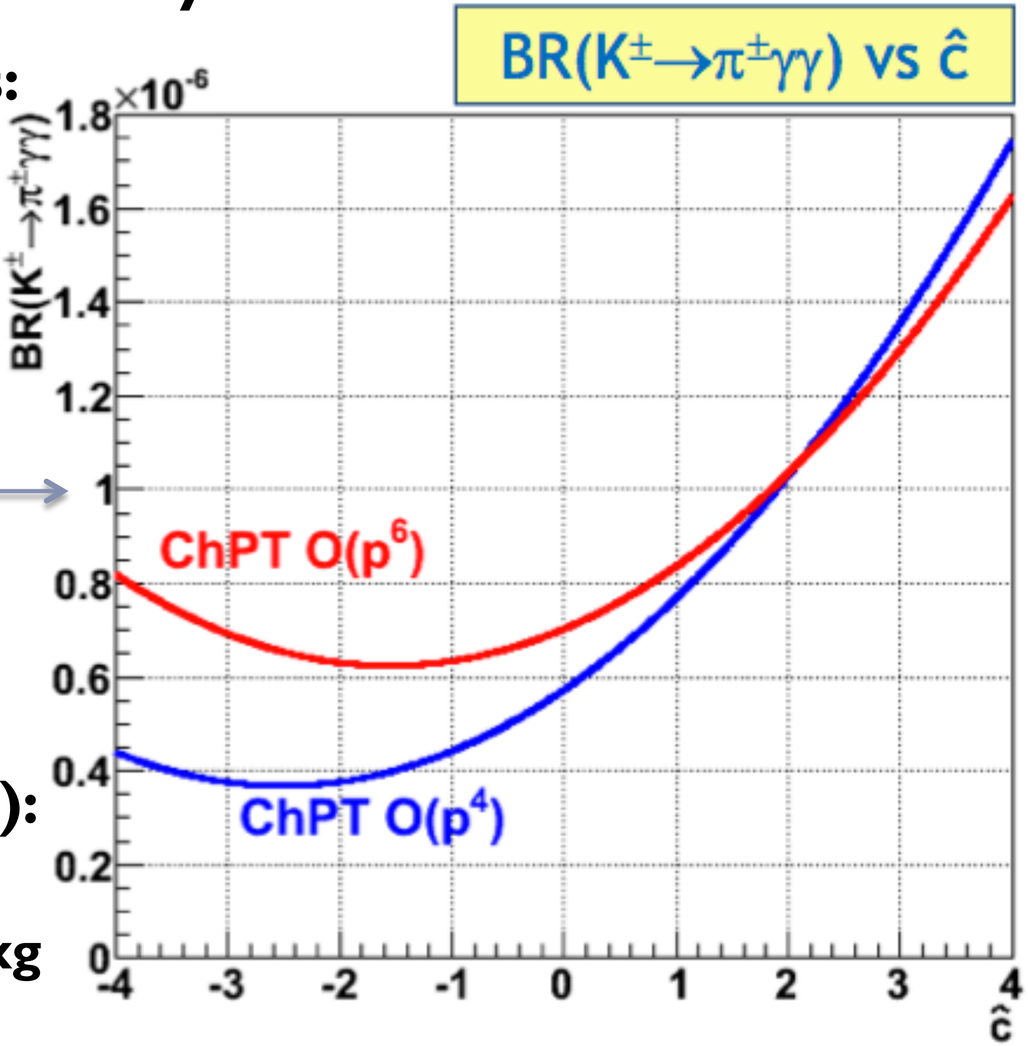
$K^+ \rightarrow \pi^+ \gamma \gamma$ decay at ChPt $O(p^4)$ vs $O(p^6)$

$O(p^6)$ correction might increase rate by 30-40%

Additional unknown parameters:

finite part of counterterms (polynomial contribution)

Example for polynomial contributions $\eta_i = 0$ and $K_{3\pi}$ amplitude parameters from Bijnens, Dhonte, Borg [NPB 648 (2003) 317]



Experimental status, E787 (1987):

BR = $(1.10 \pm 0.32) \times 10^{-6}$

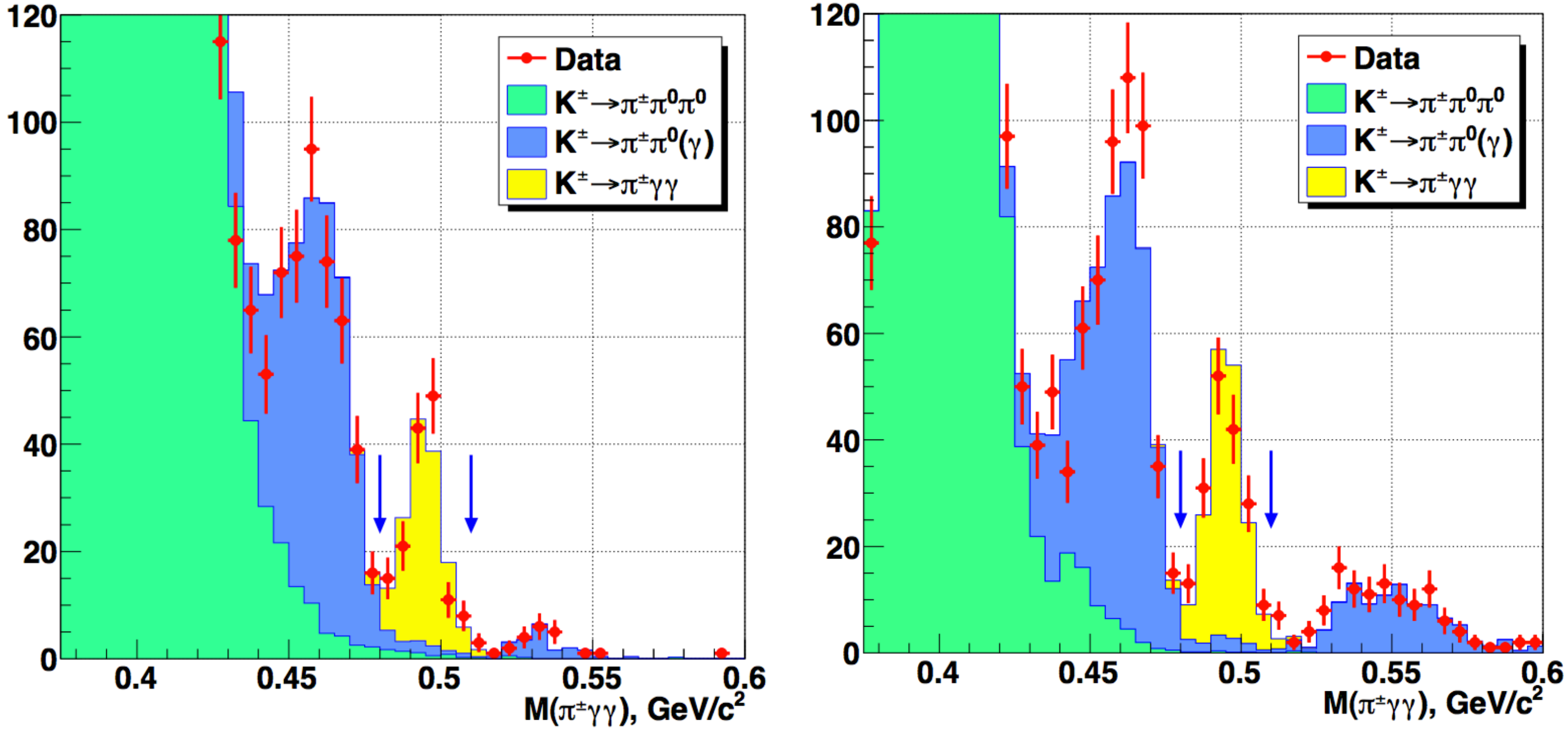
31 candidates counted, 5 exp. bkg

$K^+ \rightarrow \pi^+ \gamma \gamma$ analysis at NA62

Mmt starts from data acquired w no $K \rightarrow \pi\gamma\gamma$-specific trigger

For NA48/2 (NA62) data dominated by $K \rightarrow 3\pi$ ($K \rightarrow e\nu$) trigger data set

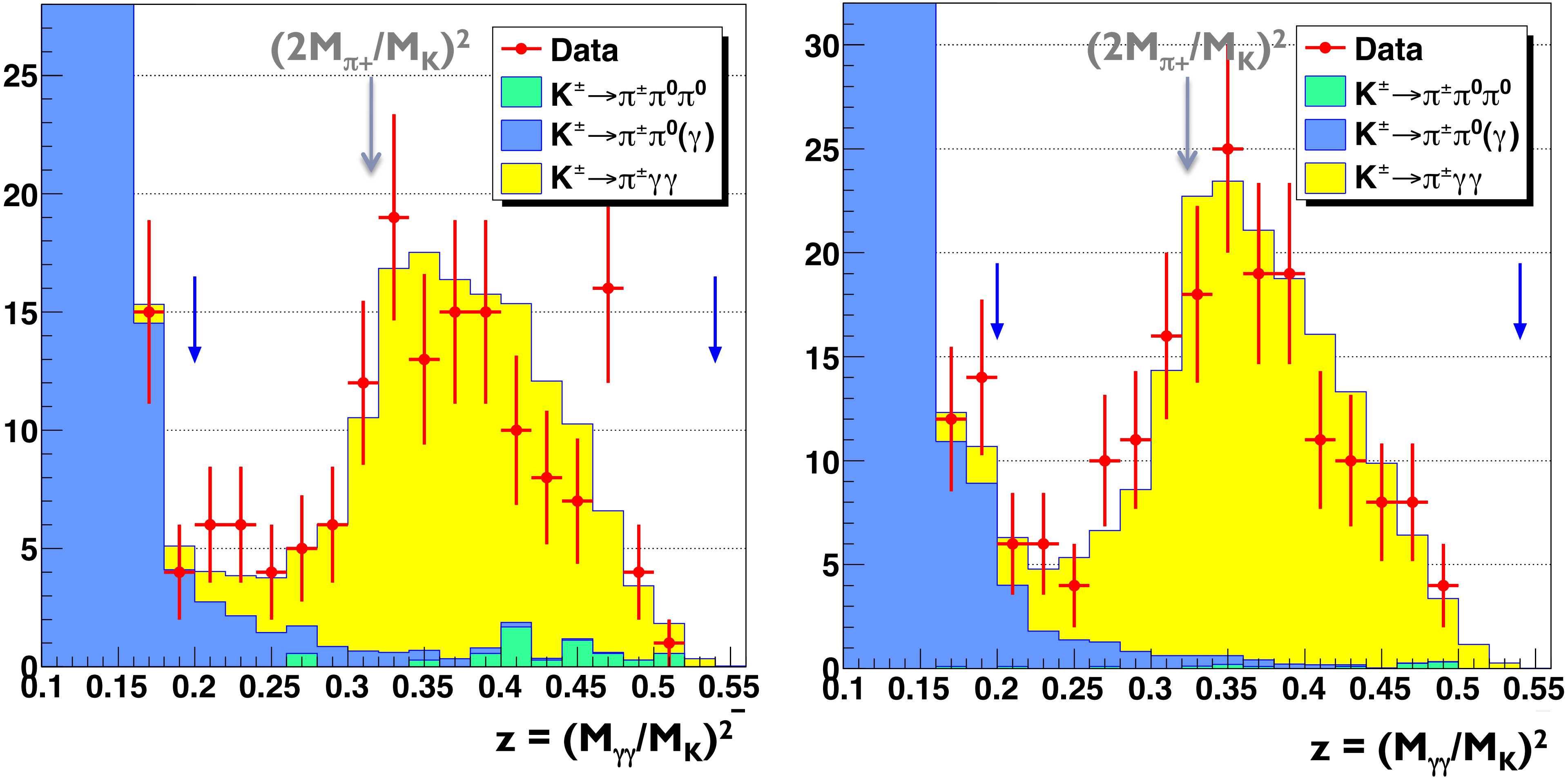
From minimum-bias samples, ~300 candidates with O(10%) bkg



Background dominated by $K^+ \rightarrow \pi^+\pi^0(\pi^0)(\gamma)$ with γ--γ cluster merging

$K^+ \rightarrow \pi^+ \gamma \gamma$ analysis at NA62: ChPT fits

Background limits sensitivity to z > ~ 0.2


2004 data from NA48/2

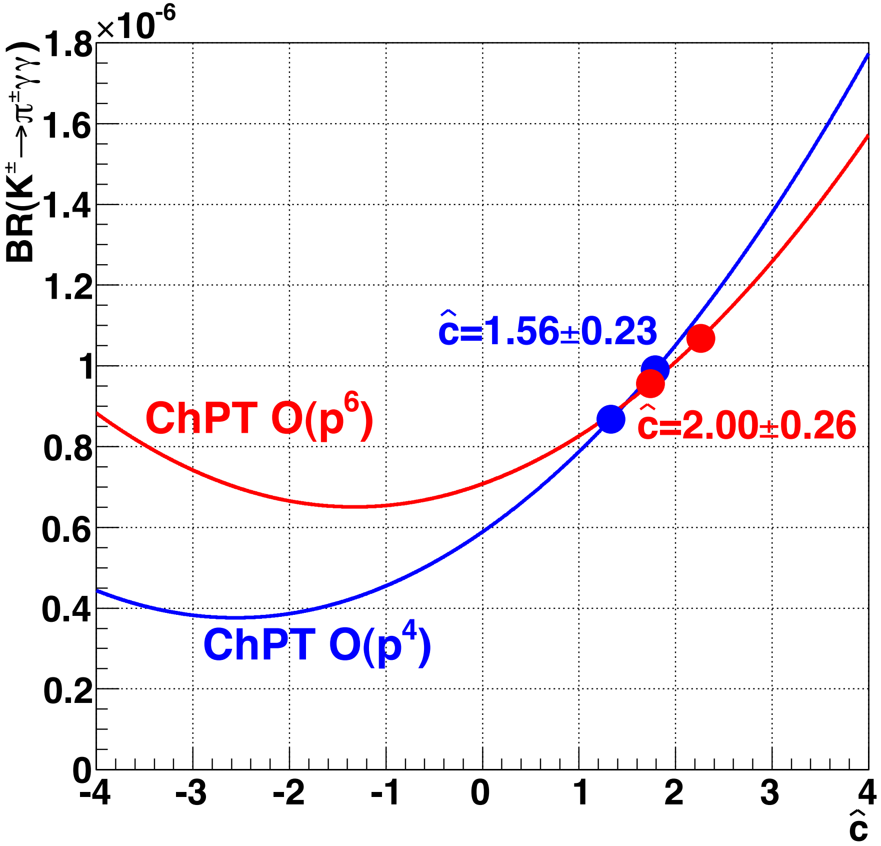
2007 data from NA62

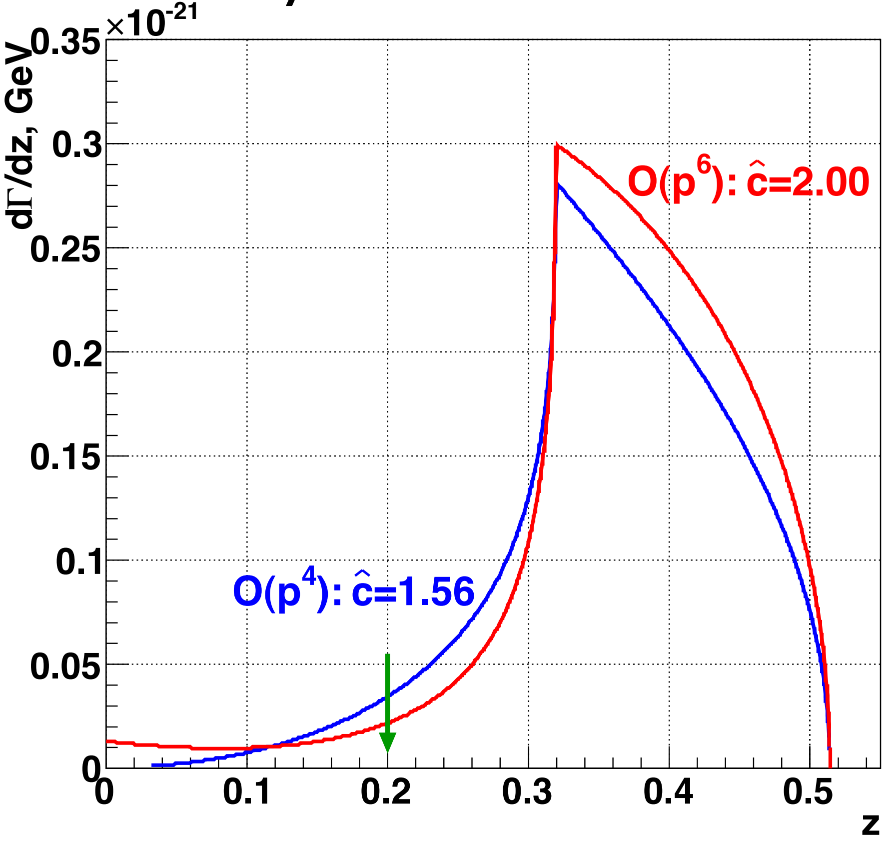
$K^+ \to \pi^+\gamma\gamma$ analysis @NA62: preliminary results

Preliminary results for combined samples (NA48/2 and NA62):

Fit to ChPT $O(p^4)$: $\hat{c} = 1.56(22)_{stat}(7)_{syst} = 1.56(23)$

Fit to ChPT $O(p^6)$: $\hat{c} = 2.00(24)_{stat}(9)_{syst} = 2.00(26)$

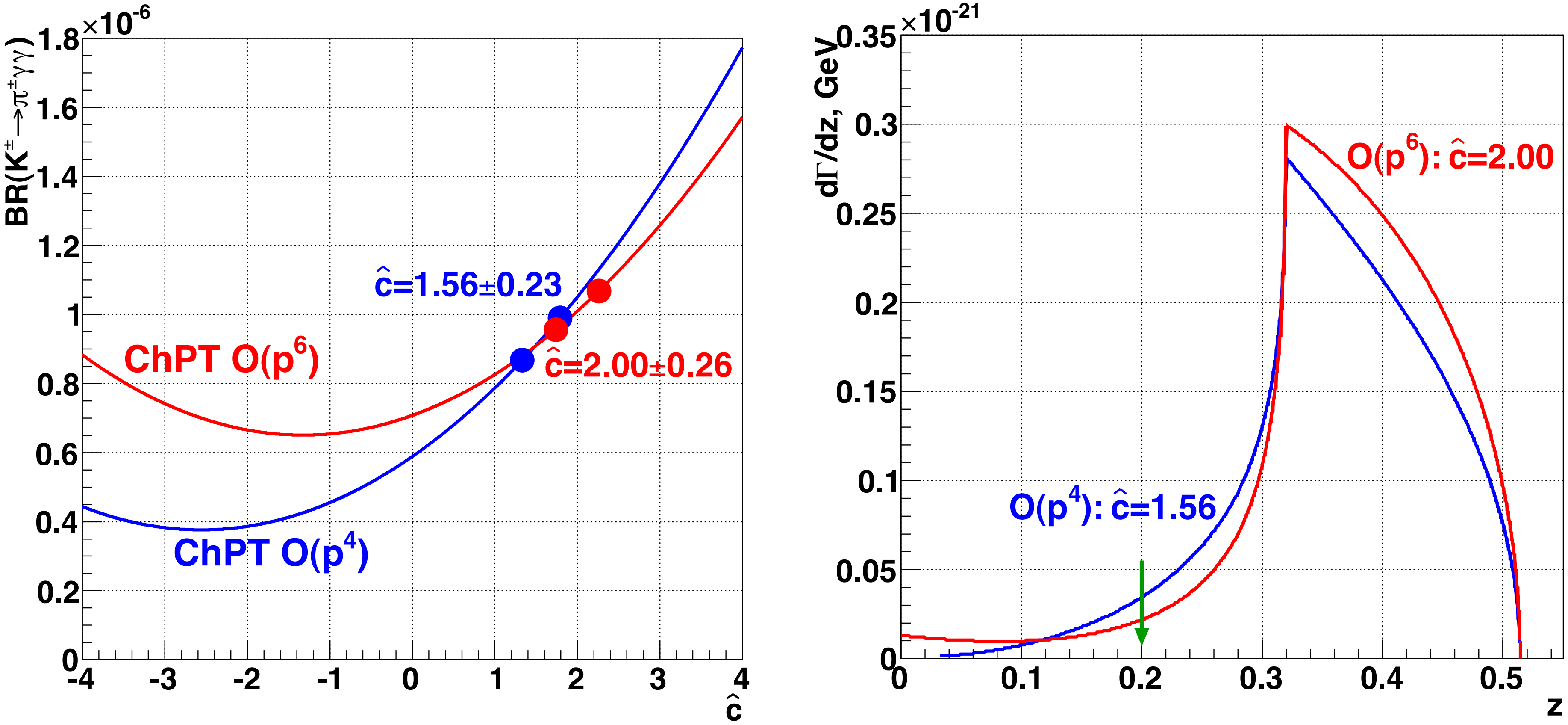




$K^+ \rightarrow \pi^+ \gamma\gamma$ analysis @NA62: preliminary results

Fits yield $\hat{c}$~2, can't distinguish btw $O(p^4)$ and $O(p^6)$

BR = $1.01(6) \times 10^{-6}$, improves by ~×5 on present knowledge

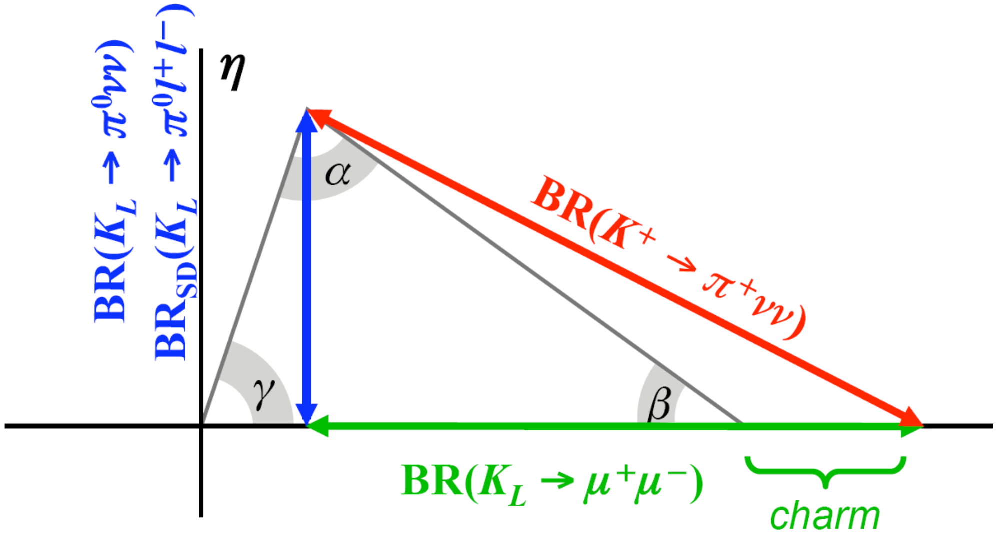


Golden K modes for new-physics search

FCNC processes dominated by Z-penguin and box diagrams

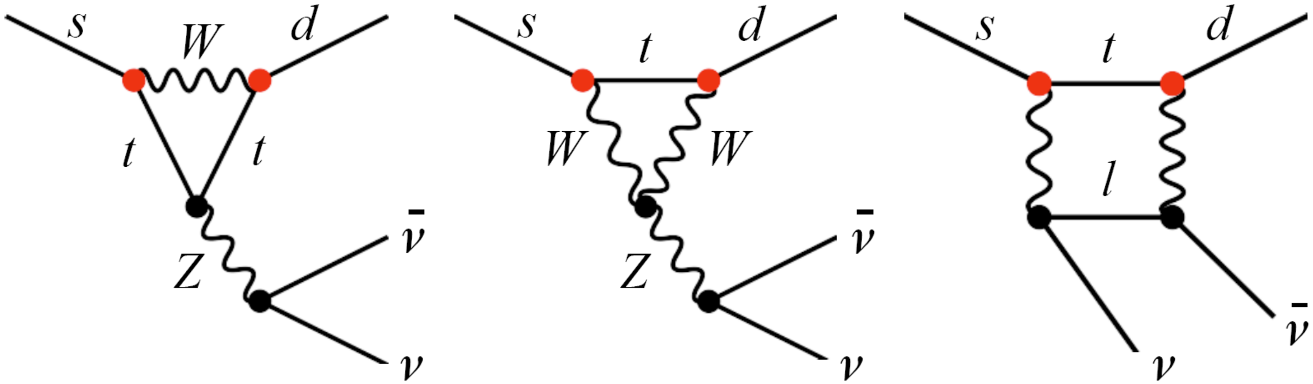
Can give direct information on CKM matrix elements:

- **No long distance contributions from processes with intermediate γ's**
- **Hadronic matrix elements can be obtained from BR's of leading K decays**
- **$K_L \to \pi^0\nu\nu$ is nearly pure due to direct CPV (1% contribution from mixing CPV)**



	Γ_{SD}/Γ	Irreducible theory err. (amp)	SM BR
$K_L \to \pi^0\nu\nu$	>99%	**2%**	3×10^{-11}
$K^+ \to \pi^+\nu\nu$	88%	**4%**	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}

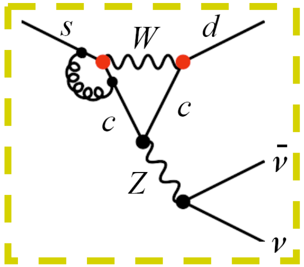
Standard model prediction for K → πνν



SM prediction (10^{-11} units) [Brod, Gorbahn and Stamou 2011 and refs therein]

$$\mathrm{BR}(K^+\to\pi^+\nu\bar{\nu})=\underline{\kappa_+}(1+\Delta_{\mathrm{EM}})\left[\underline{\left(\frac{\mathrm{Im}\lambda_t}{\lambda^5}X_t\right)}^2+\left(\underline{\frac{\mathrm{Re}\lambda_c}{\lambda}(P_c+\delta P_{c,u})}+\underline{\frac{\mathrm{Re}\lambda_t}{\lambda^5}X_t}\right)^2\right]=(7.81\underline{{}^{+0.80}_{-0.71}}\pm\underline{0.29})$$

$$\mathrm{BR}(K_L\to\pi^0\nu\bar{\nu})\ =\underline{\kappa_L}\ \underline{\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5}X(x_t)\right)}^2=(2.43\underline{{}^{+0.40}_{-0.37}}\pm\underline{0.06})$$ **where** $x_q\equiv m_q^2/m_W^2$, $\begin{array}{rcl}\lambda&=&V_{us}\\ \lambda_c&=&V_{cs}^*V_{cd}\\ \lambda_t&=&V_{ts}^*V_{td}\end{array}$



Loops favor top contribution

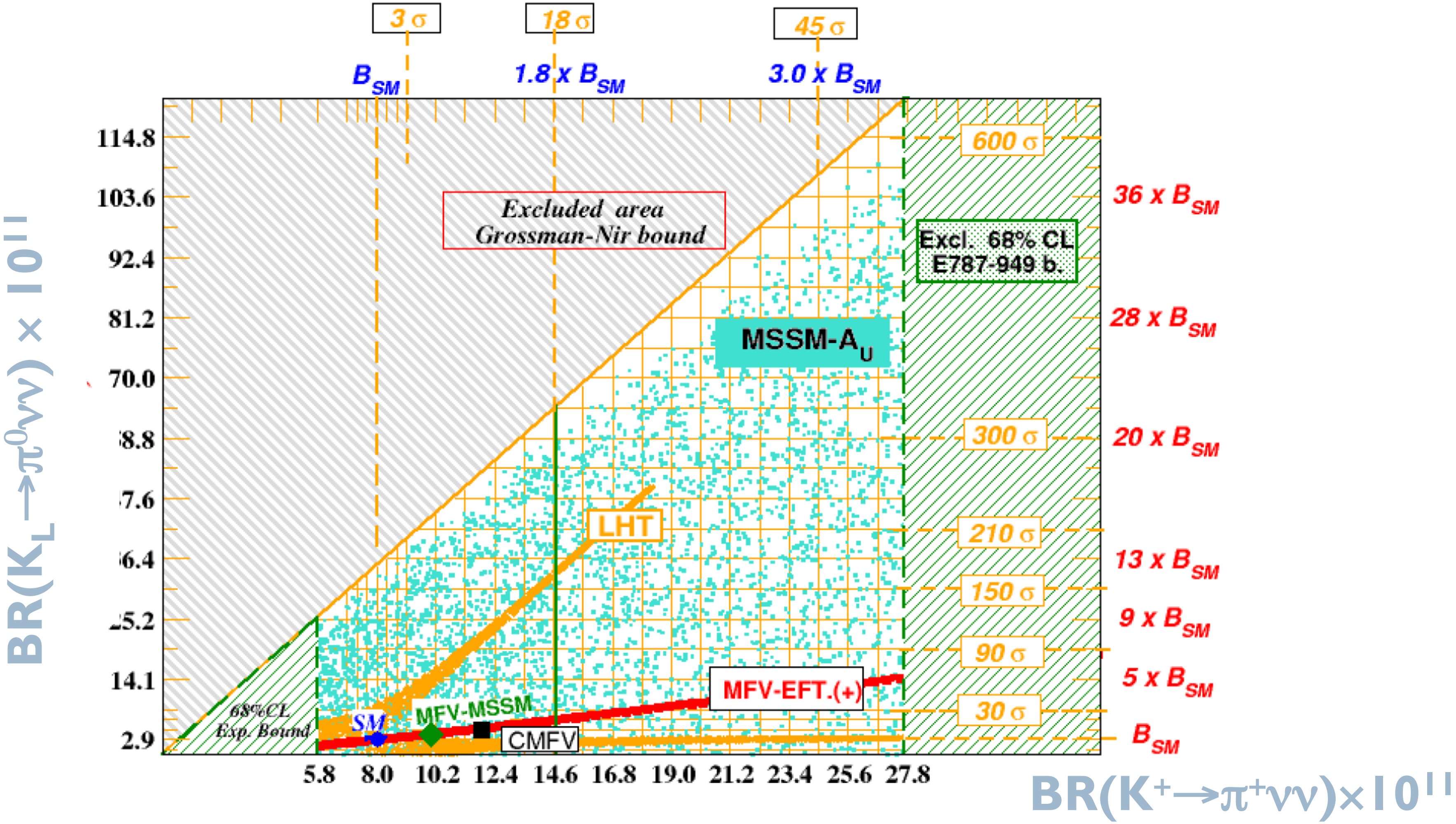
Hadronic matrix elements from BR(Ke3) via isospin rotation

Charm contributes to theory error: 4% (2%) for K$^+$ (K$_L$)

Error on input parameters (V$_{cb}$, ρ, η, …) dominant wrt other theory errors

Beyond standard model prediction for K → πνν

Deviations from SM by more than 10% quite possible in many NP models

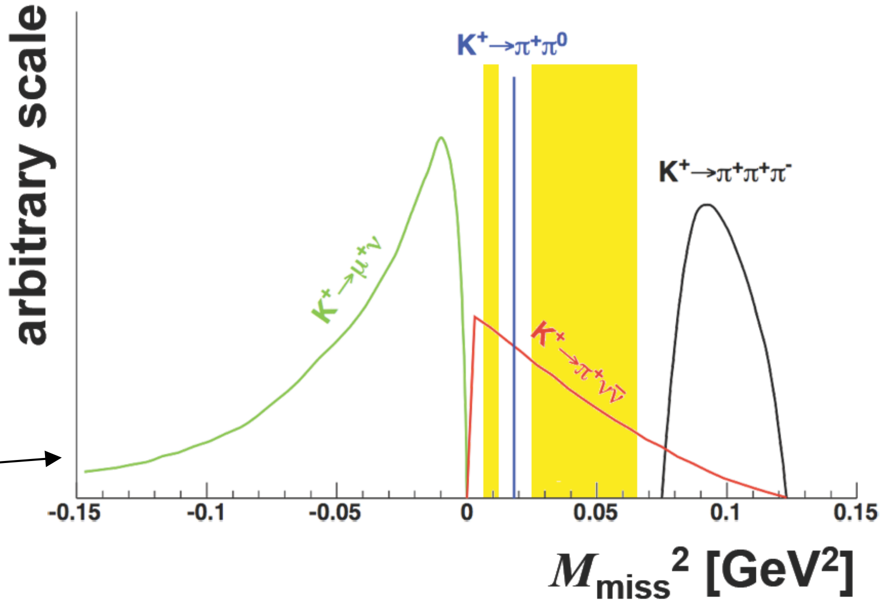


Experimental methods for $K^+ \rightarrow \pi^+\nu\nu$

Main backgrounds to $K^+ \rightarrow \pi^+\nu\nu$:

- **$K^+ \rightarrow \mu\nu$ with π ID for μ**
  - **need excellent PID, especially μ/π**
- **$K^+ \rightarrow \pi\pi^0(\gamma)$ with γ's lost**
  - **need excellent γ vetoes**

Kinematic rejection for 2 body →



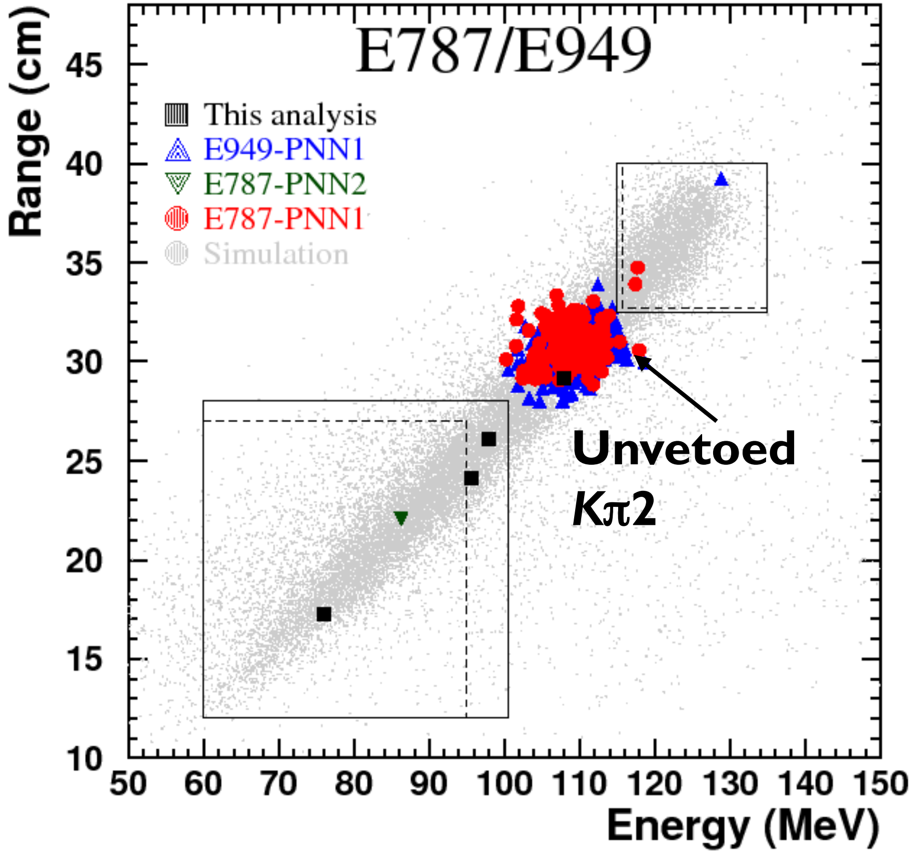
To reach 10^{-12}, PID & vetoes also reject unclosed bkg (K_{l3}, K_{l4}, …)

	Stopped K^+	**Decay in flight**
Kinematics	K^+ at rest	Must track K^+
Photon vetoes	Low-energy photons	High-energy photons
PID	Range π-μ-e decay chain	Advanced Cerenkov counters Muon detectors

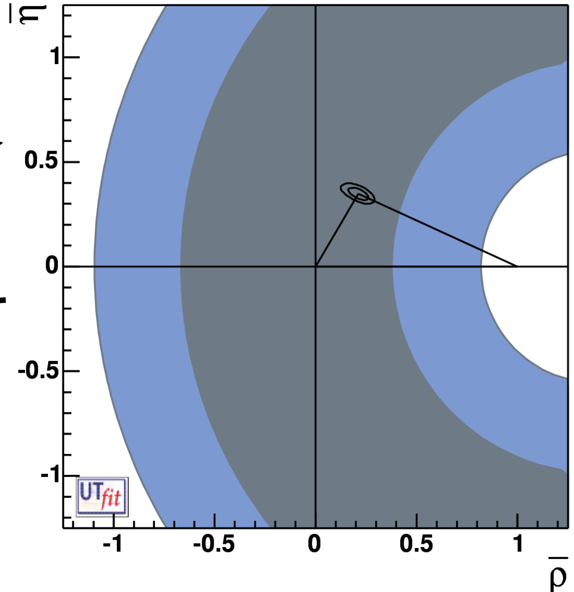
Experimental status for $K^+ \rightarrow \pi^+\nu\nu$

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

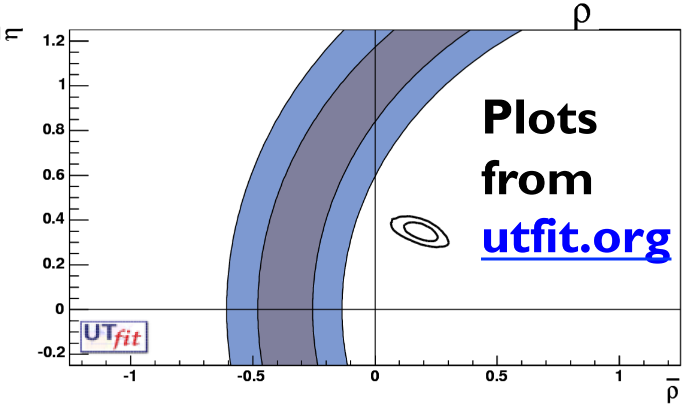
$BR(K^+ \rightarrow \pi^+\nu\nu) = (1.73\,^{+1.15}_{-1.05}) \times 10^{-10}$



Unvetoed Kπ2



Same central value, 100 evts

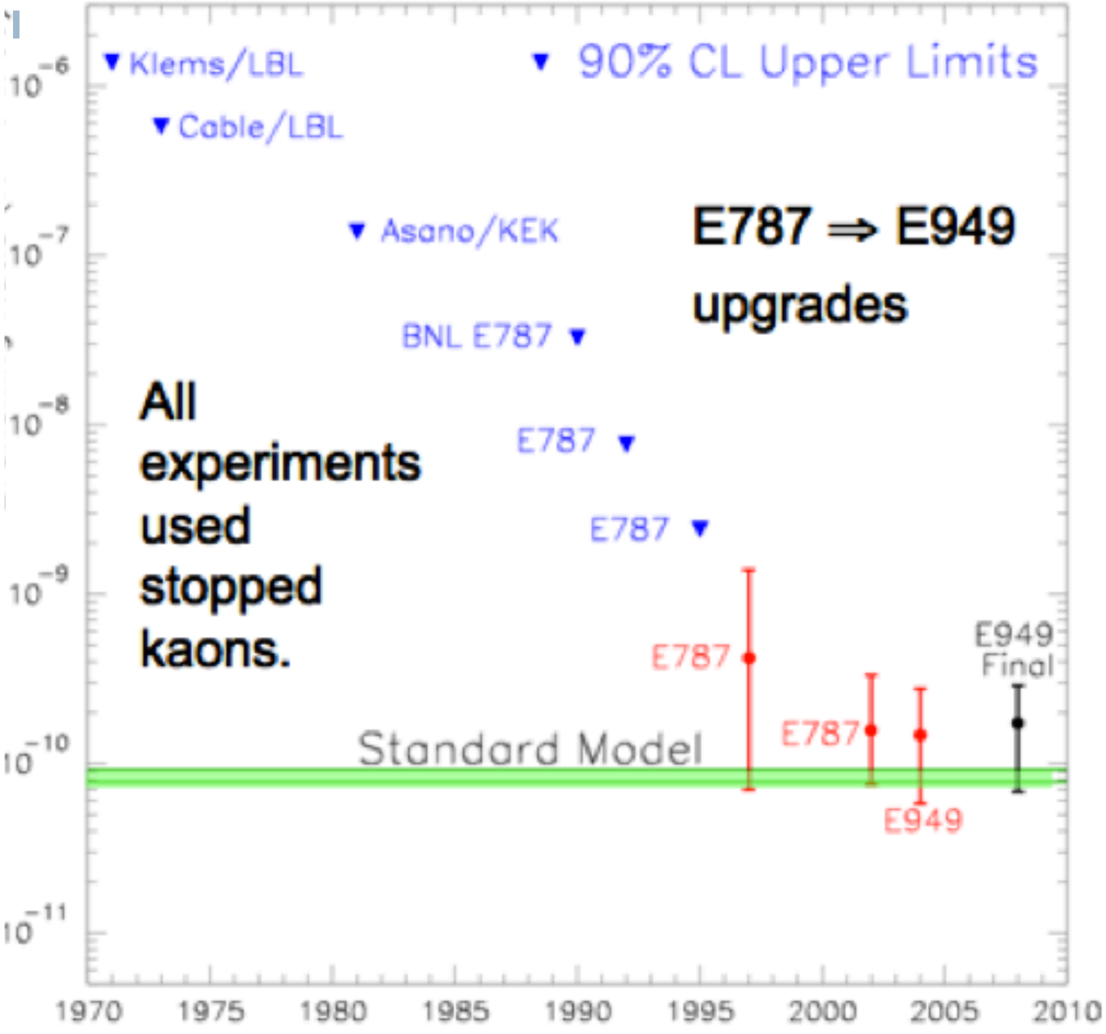


Plots from utfit.org

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

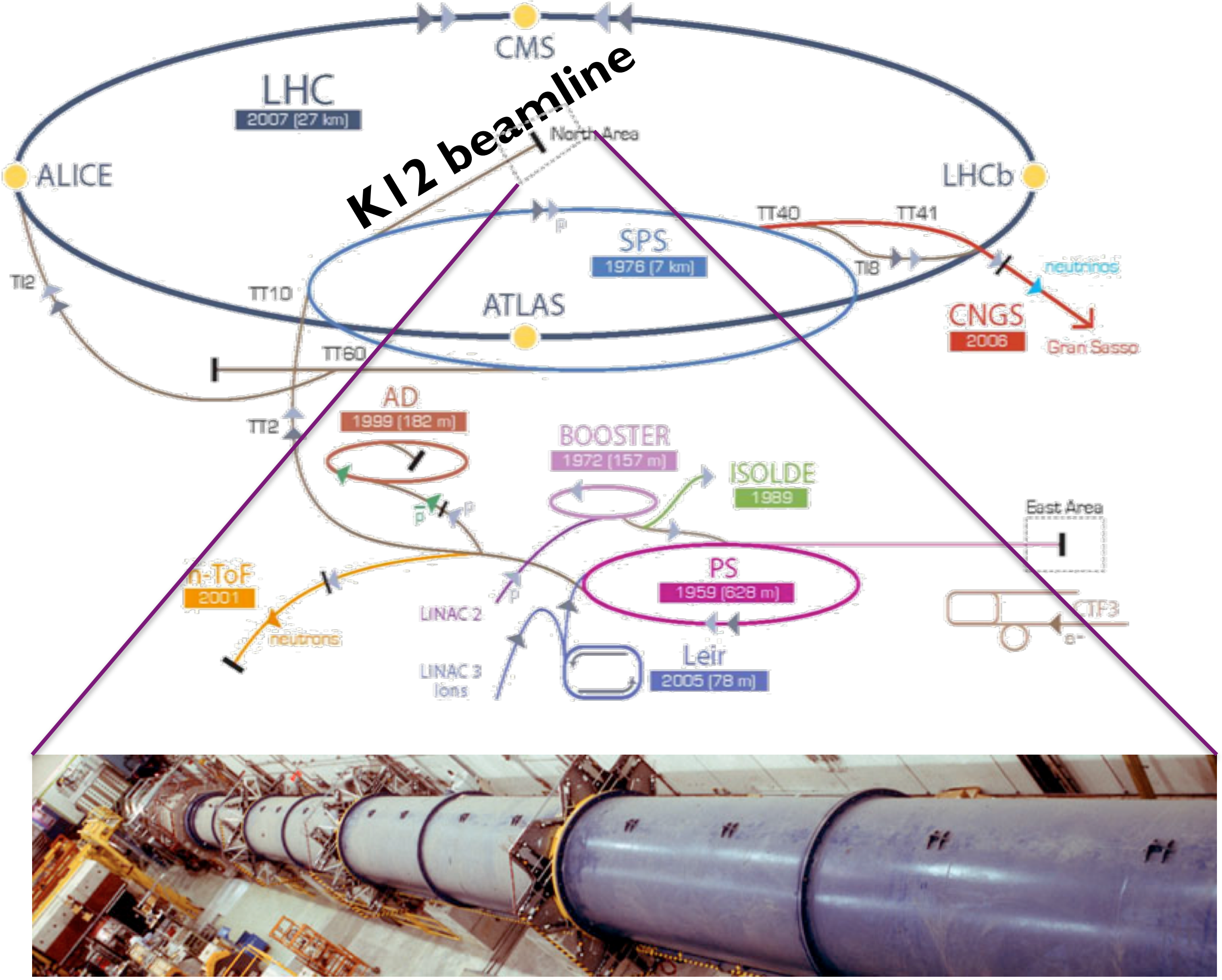
Hopefully not the end of a long story...

$\mathrm{BR}(K^+\to\pi^+\nu\nu)\times 10^{11}$



Year of publication

...the in-flight approach, NA62 @ CERN



Improve intensity of existing NA48 beamline by ×50

400 GeV SPS primary proton beam, producing unseparated 75-GeV K^+ beam:

- **~800 MHz beam**
- **6% are K^+, i.e., ~ 50 MHz**
- **~ 5 MHz decay in a 60-m fiducial volume**

NA62 guiding principles

Support a high-rate environment

high-resolution timing, charged hodoscope (scintillator), $\sigma_t < 200$ ps

Kinematic rejection of ~10^4 by cutting on missing mass at decay

- **fast tracking of incoming particles: 3 Si-pixel stations, $\delta x \sim 200$ μ, hit ε > 99%, provide $\delta P/P \sim 0.2\%$, sustain 800 MHz beam flux, $\sigma_t < 200$ ps/station**
- **tracking of daughter particles: 4 stations of straw tubes in vacuum, hit ε > 99%, provide $\delta P/P < 1\%$, sustain 500 kHz in hottest area**

Rejection of ~10^3 for $K_{\mu 2,3,4, e2,3,4}$, … bkg, PID for all charged particles

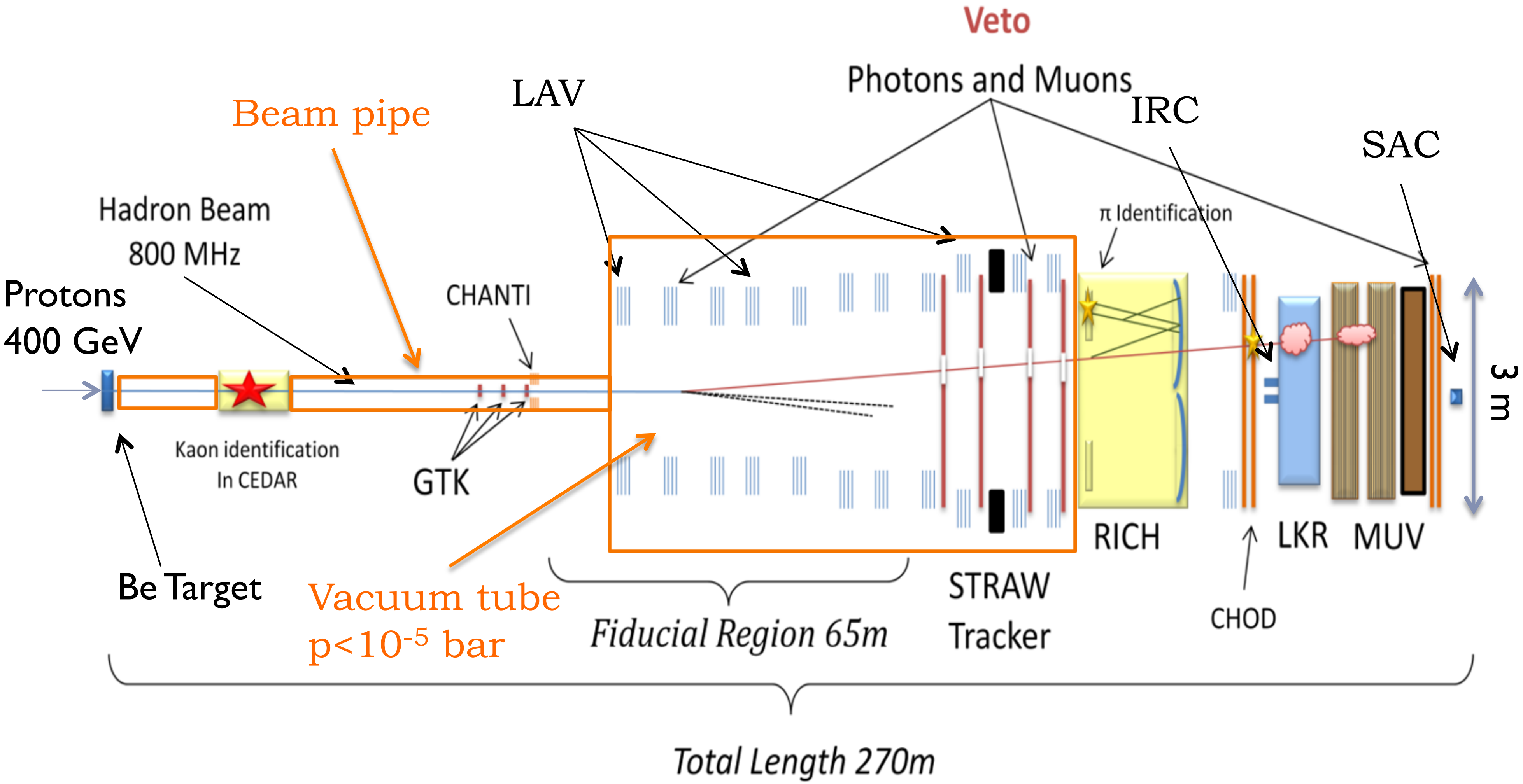
- **positive, non-destructive ID for incoming K: Thr. Č, $\sigma_t \sim 100$ ps, >99% K purity, 50 MHz operation**
- **ID for daughter pions, muons, electrons: RICH, reduces μ bkg < 1% up to 35 GeV, $\sigma_t < 100$ ps**
- **ID for outgoing μ's: iron/scintillator calorimeters, $1-\varepsilon < 10^{-5}$ for μ's**

Rejection of ~10^8 for modes with π^0's and ~10^4 for single photon

- **Hermetic, high-efficiency γ veto, 0--50 mrad: 5×10^{-8} rejection for $K \rightarrow \pi\pi^0$**

Redundancy of information

The in-flight approach, NA62 @ CERN



NA62 expected sensitivity

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

Aim to obtain O(~10%) signal acceptance with <10% background

year & running efficiency from NA48 story: ~100 days/year, 60% data taking eff.

Conclusions: NA62 past, present, and future

In 2007-2008, NA62 "RK phase":

- **Runs with original NA48/2 detector, beam carefully tuned for the measurement of $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$, now (2012) at few per mil**
- **Data acquired useful for ChPt studies here presented: Ke2γ, $K^+ \rightarrow \pi^+\gamma\gamma$**
- **In parallel, R&D studies for new sub-detectors**
- **December 2008, approval by CERN research board**

In 2009-2010, the new NA62 experiment:

- **Collaboration consolidated, presently ~250 participants from 26 institutes**
- **Main beam tests for advanced prototypes (RICH, GTK) or parts of single sub-detectors (LAV)**

In 2011-2013, construction & commissioning: dry & technical runs

In 2014, first physics run after long shutdown

K → πνν sensitivity summary

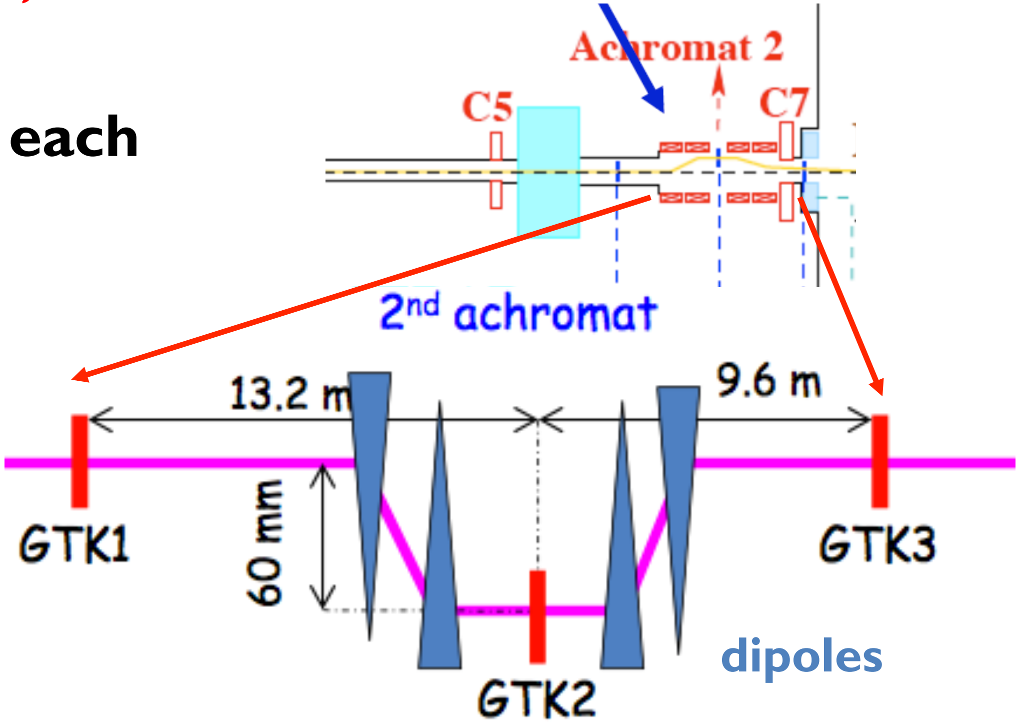
Expt	Primary beam	Intensity (ppp)	SM evts/yr	Start date + run yrs	Total SM evts
NA62	**SPS 450 GeV**	3×10^{12}	**55**	**2014+2**	**110**
FNAL $K^{\pm}$	Project X 8 GeV	2×10^{14}	250	2018+5	1250
ORKA	Tevatron up <150 GeV	5×10^{13}	120	2018+5	600
E14	**JPARC-I 30 GeV**	2×10^{14}	**1-2**	**2013+3?**	**3-7**
E14	JPARC-II 30 GeV	3×10^{14}	30	2020+3?	100
FNAL K_L	Booster 8 GeV	2×10^{13}	30	2016+2	60
FNAL K_L	Project X 8 GeV	2×10^{14}	300	2018+5	1500

All dates/estimates are speculative, some are more speculative than others

Spare slides

Fast tracking before decay volume – GTK

Aim to measure time, coordinates, and momentum of individual particles in a 800 MHz beam



3 silicon μ-pixel stations, <0.5% X_0 each

Other demanding constraints:

- **100 μm space resolution**
- **δp/p ~ 0.2%, i.e., δp ~ 150 MeV**
- **δα/α ~ 12 μrad**

Structure:

- **18000 300×300 μm^2 pixels, sensitive area of 60×27 mm^2**

Technological challenge:

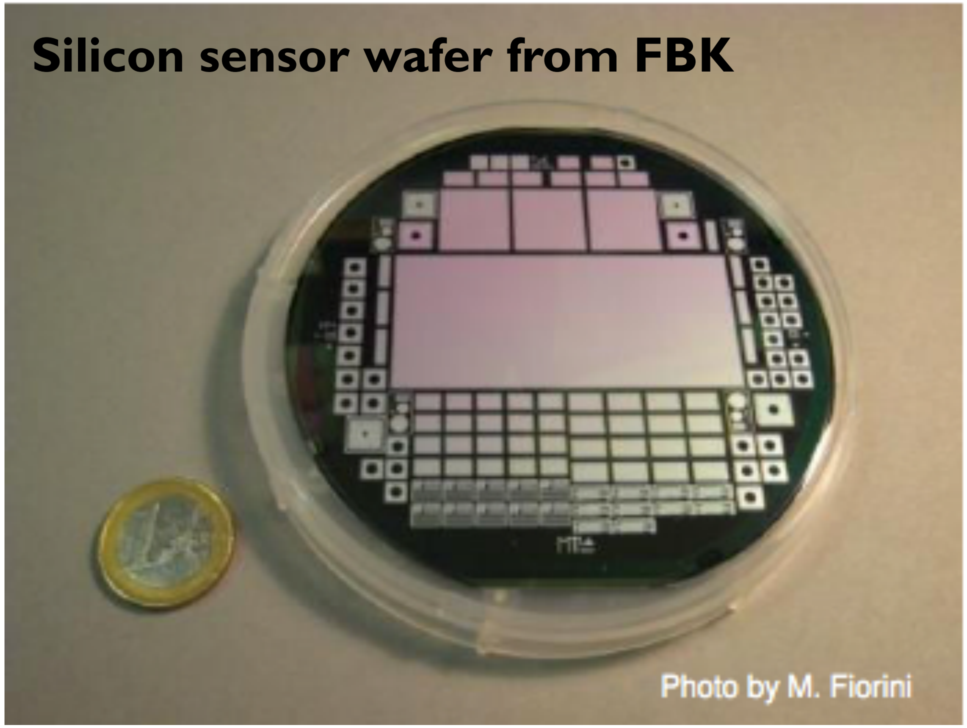
- **<1% hit mismatch @ 800 MHz → 200 ps time resolution**
- **read out able to sustain rates up to 150 KHz/pixel**

GTK technology and read out

Have to read out with dead time <100 ns, with a charge/pixel varying between 0.8 fC (5000 e-) to 10 fC (60000 e-)

- **have to correct for slewing**
- **maintain noise < 200 e-**
- **operate with reasonable power consumption, < 2 W/cm^2**

R&D completed



- **2 read out prototypes developed & compared, both with FE circuits in 130-nm IBM CMOS technology**

For details, see Report by J. Kaplon et al., IEEE NSS conference, Orlando, FA, USA

Photon vetoing in NA62

Have to reject $K^+ \to \pi^+\pi^0$ @ the level of 10^{-12}

Need π^0 rejection of $O(10^{-8})$ for γ's from K decay in FV (~60 m)

A composite system:

- **Very small angle, below 2 mrad**
  - **A new compact calorimeter**
  - **Inefficiency required $<10^{-6}$ for γ's above 6 GeV**
- **Small angle, 1 to ~8 mrad:**
  - **Re-use NA48 LKr calor. , $\sigma_E/E = 0.032/\sqrt{E[GeV]} + 0.09/E[GeV] + 0.0042$**
  - **Inefficiency measured $<10^{-5}$, for γ's above 6 GeV**
- **Large angle, ~8 to 50 mrad:**
  - **A new veto system (LAV system)**
  - **Inefficiency required $< \sim 10^{-4}$ for $100\ \mathrm{MeV} < E_\gamma < 25\ \mathrm{GeV}$**
  - **Able to operate in a vacuum of 10^{-6} mbar**

Large angle veto layout and geometry

Rearrange SF4 lead crystals from OPAL in staggered layers (rings)
Install rings inside existing vacuum vessel (so called "blue tube")

12 stations of increasing diameter cover hermetically the range $\theta = 7\text{–}50$ mrad

3 different sizes of vacuum vessels (last downstream station operated in air)

4 to 5 layers/station for a total depth of 29 to 37 X_0, particles traverse > 20 X_0

32 to 48 crystals/layer

A total of ~ 2500 blocks