Rare K decays: results and prospects

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9th Intl. Symp. on Heavy Flavors 10 Sept 2001

Motivation for Rare K Decay Experiments

Forbidden

S.M. forbids (or greatly inhibits) many kinematically possible modes

A number of these are allowed (or enhanced) by alternative approaches

Accessible sensitivity to these processes corresponds to very high mass scales

Discouraged

Certain very inhibited processes cleanly sensitive to S.M. parameters

Tolerated

Suppressed processes are a good area for testing chiral perturbation theory and other approaches to understanding the low energy structure of the S.M.

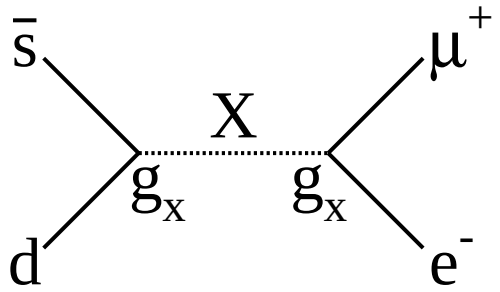
Rare K decay modes studied recently

$K^+ \to \pi^+ \nu\bar{\nu}$
$K_L \to \pi^0 \mu^+ \mu^-$
$K^+ \to \pi^+ \mu^+ \mu^-$
$K_L \to \mu^+ \mu^-$
$K^+ \to \pi^+ e^+ e^- \gamma$
$K_L \to e^\pm e^\mp \mu^\pm \mu^\mp$
$K_L \to \pi^+ \pi^- \gamma$
$K^+ \to \pi^+ \pi^0 e^+ e^-$
$K_L \to \pi^0 \gamma\gamma$
$K^+ \to \mu^+ \nu\gamma$
$K^+ \to \mu^+ \nu e^+ e^-$
$K_L \to e^+ e^- \gamma$
$K_L \to e^+ e^- \gamma\gamma$
$K_L \to e^+ e^- e^+ e^-$
$K^+ \to \pi^+ \mu^+ e^-$
$K_L \to \mu^\pm e^\mp$
$K^+ \to \pi^- e^+ e^+$
$K^+ \to \pi^+ X^0$
$K^+ \to \pi^+ \gamma$

$K_L \to \pi^0 \nu\bar{\nu}$
$K_L \to \pi^0 e^+ e^-$
$K^+ \to \pi^+ e^+ e^-$
$K_L \to e^+ e^-$
$K^+ \to \pi^+ \pi^0 \nu\bar{\nu}$
$K^+ \to \pi^+ \pi^0 \gamma$
$K_L \to \pi^+ \pi^- e^+ e^-$
$K^+ \to \pi^0 \mu^+ \nu\gamma$
$K^+ \to \pi^+ \gamma\gamma$
$K^+ \to e^+ \nu e^+ e^-$
$K^+ \to e^+ \nu \mu^+ \mu^-$
$K_L \to \mu^+ \mu^- \gamma$
$K_L \to \mu^+ \mu^- \gamma\gamma$
$K_L \to \pi^0 e^+ e^- \gamma$
$K_L \to \pi^0 \mu^\pm e^\mp$
$K^+ \to \pi^- \mu^+ e^+$
$K^+ \to \pi^- \mu^+ \mu^+$
$K_L \to e^\pm e^\pm \mu^\mp \mu^\mp$

Lepton Flavor Violation

Poster child for sensitivity to BSM processes such as $\rightarrow$ Attainable sensitivity corresponding to $M_X \gtrsim 100$TeV, clean signatures



A long list of BSM theories predict LFV in K decays at some level, e.g. extended technicolor, SUSY, heavy neutrinos, horizontal gauge bosons, etc. Also necessary to study both two and three body decays to check Lorentz structure of any new interaction, generation number sensitivity, etc.

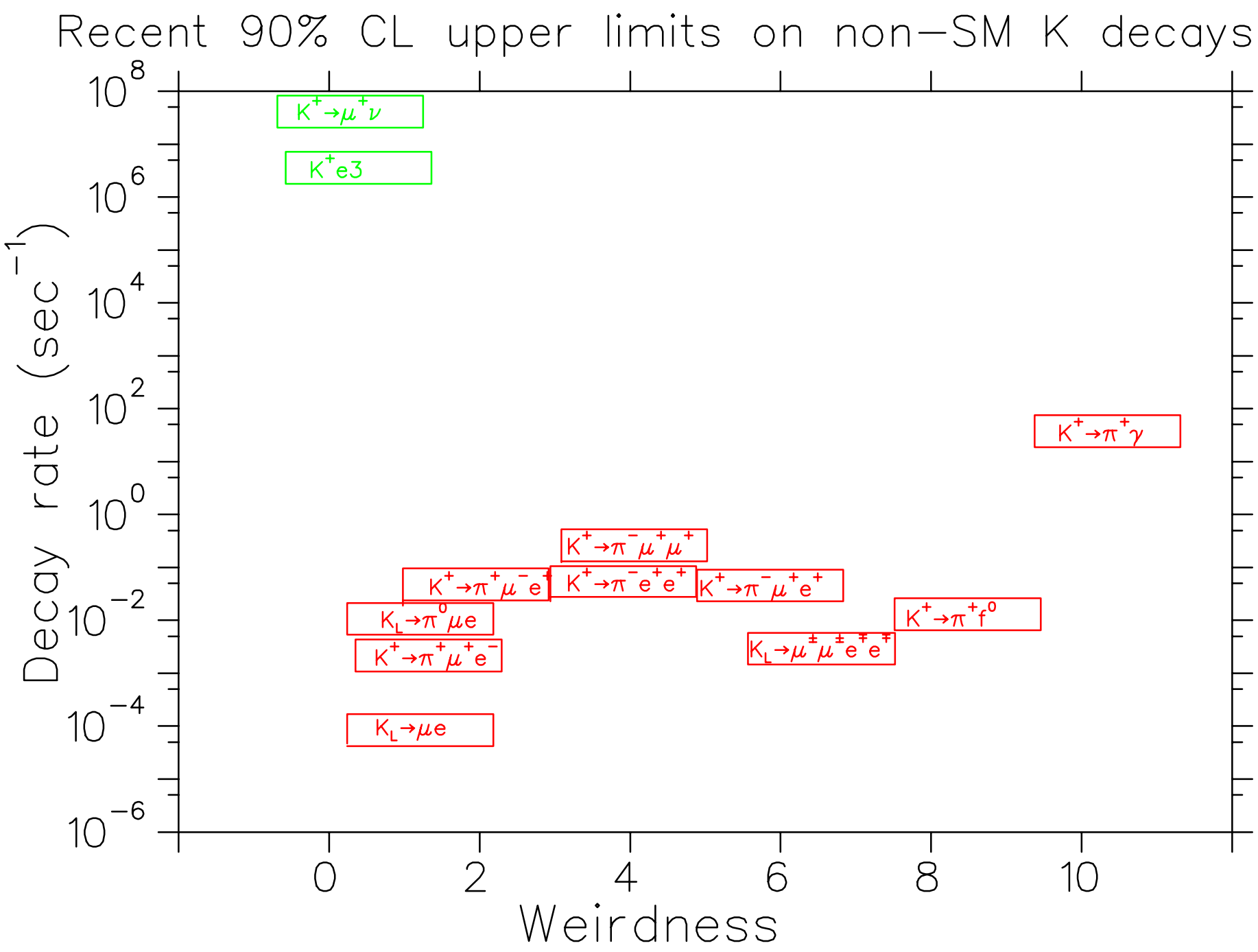
Current status:

Process	90% CL Limit	Experiment	Reference
$K_L \rightarrow \mu e$	4.7×10^{-12}	AGS-871	PRL 81:5734
$K^+ \rightarrow \pi^+ \mu^+ e^-$	2.8×10^{-11}	AGS-865	PRL 85:2450
$K^+ \rightarrow \pi^+ \mu^- e^+$	5.2×10^{-10}	AGS-865	PRL 85:2877
$K_L \rightarrow \pi^0 \mu e$	4.4×10^{-10}	KTeV	Bellantoni/Moriond

More $K^+ \rightarrow \pi^+ \mu^+ e^-$ and $K_L \rightarrow \pi^0 \mu e$ data under analysis.

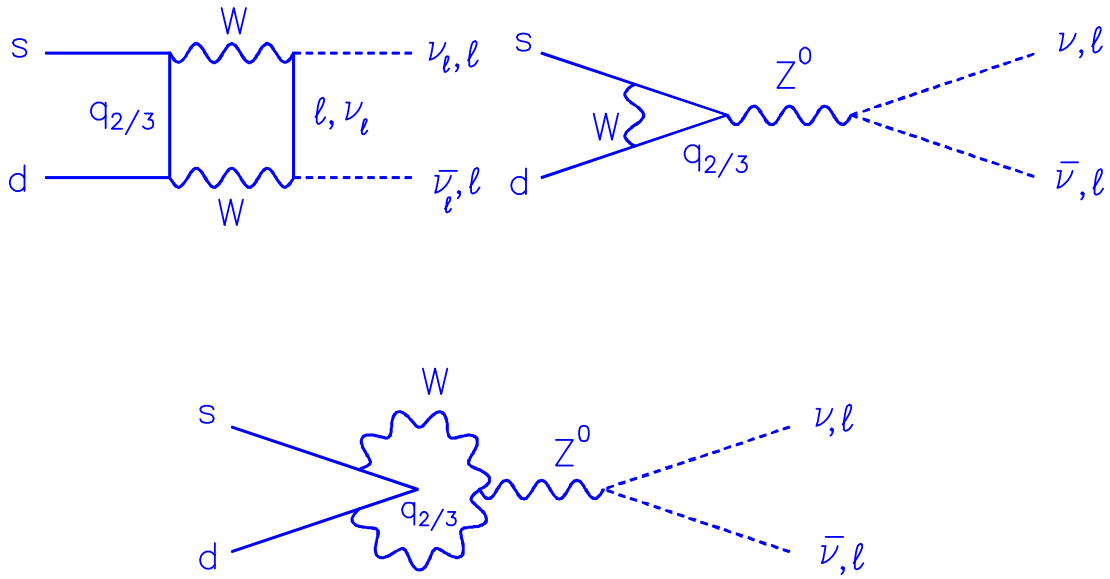
But these experiments have already helped kill the most promising approaches that predicted finite effects. Now theorists predicting more accessible levels of LFV in rare muon processes.

Future progress on LFV in kaon decays likely to be slow. No dedicated experiments on the horizon, and background getting harder to fight.

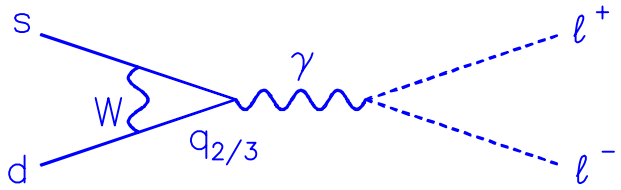

Recent 90% CL upper limits on non−SM K decays
Decay rate (sec^{-1})
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
0
2
4
6
8
10
Weirdness
$K^+\to\mu^+\nu$
K^+e3
$K^+\to\pi^+\gamma$
$K^+\to\pi^-\mu^+\mu^+$
$K^+\to\pi^+\mu^-e^+$
$K^+\to\pi^-e^+e^+$
$K^+\to\pi^-\mu^+e^+$
$K_L\to\pi^0\mu e$
$K^+\to\pi^+f^0$
$K^+\to\pi^+\mu^+e^-$
$K_L\to\mu^\pm\mu^\pm e^\mp e^\mp$
$K_L\to\mu e$

One-loop K Decays

Short-distance contributions to K decays. These decays include $K_L \to \pi^0 \nu\bar{\nu}$, $K^+ \to \pi^+ \nu\bar{\nu}$, $K_L \to \mu^+\mu^-$, $K_L \to \pi^0 e^+ e^-$, $K_L \to \pi^0 \mu^+ \mu^-$, etc. The hadronic matrix elements involved are known from common decays such as $K^0 \to \pi^+ e^- \bar{\nu}$. These contributions can be cleanly calculated in terms of m_t, m_c and the product of CKM elements $V_{ts}^* V_{td} \equiv \lambda_t$.



But there's a Murphy's Law for these processes:
The same interactions that allow charged final state leptons to be detected, mediate long-distance contributions. E.g.:



To avoid this one must exploit decays containing a $\nu\bar{\nu}$ pair.

$\underline{K^+ \to \pi^+ \nu\bar{\nu}}$

$V_{ts}^* V_{td}$

$$B\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = \frac{r_{K^+} \alpha^2 B(K^+ e3)}{V_{us}^2 2\pi^2 sin^4\theta_W} \sum_l \left|\lambda_c X_{NL}^{\ell} + \lambda_t X\left(x_t\right)\right|^2 \approx 10^{-10}$$

↑ contains QCD corr. has been calc'd to NLLA

$X \approx 1.57\left(m_t/170\right)^{1.15}$

$$= 4.1 \times 10^{-11} A^4 X^2\left(x_t\right)\left[\bar{\eta}^2 + \frac{2}{3}\left(\rho_o^e - \bar{\rho}\right)^2 + \frac{1}{3}\left(\rho_o^\tau - \bar{\rho}\right)^2\right]$$

where $\rho_o^{\ell} \equiv 1 + \frac{X_{NL}^{\ell}}{A^2\lambda^4 X(x_t)}$; $r_{K^+} = 0.9$

↑ calc. uncertainty only a few %

In leading order in Wolfenstein parameters,
$B\left(K^+ \to \pi^+ \nu\bar{\nu}\right)$ determines a circle in the ρ, η plane with center $(\rho_o, 0)$; $\rho_o \equiv \frac{2}{3}\rho_o^e + \frac{1}{3}\rho_o^\tau \approx 1.4$ and radius $\approx \frac{1}{A^2}\sqrt{\frac{B(K^+ \to \pi^+ \nu\bar{\nu})}{10^{-10}}}$

Don't need to deal with Wolfenstein parameters, instead:

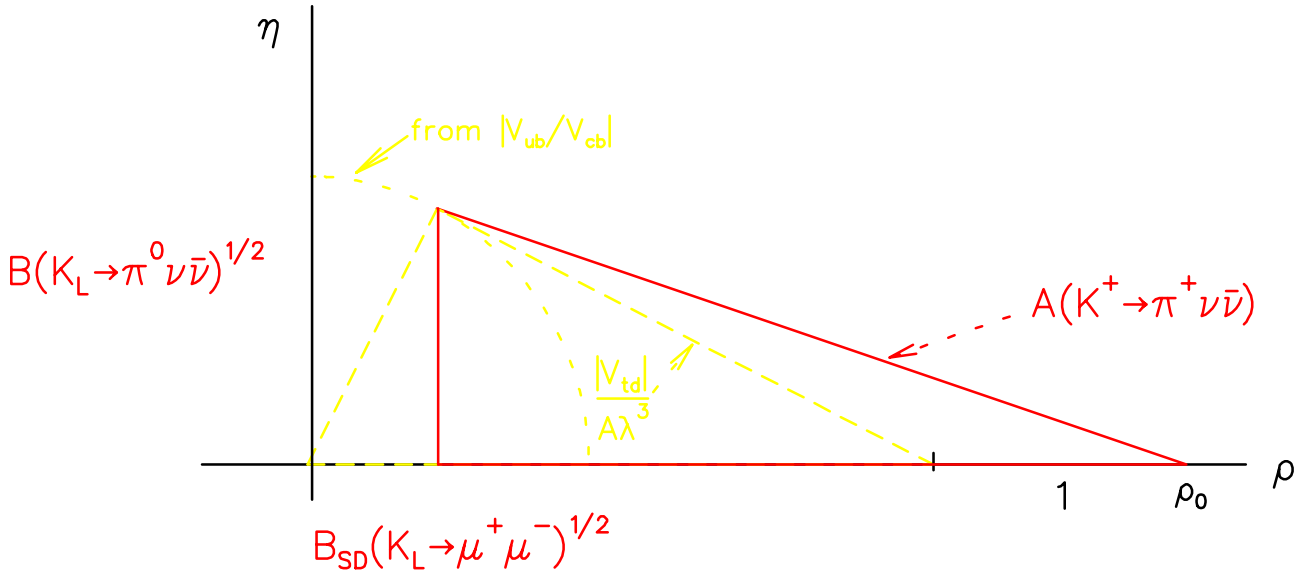
$$B\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = .00015\left[\left(\lambda_c \bar{X} + Re\left(\lambda_t\right) X\left(x_t\right)\right)^2 + \left(Im\left(\lambda_t\right) X\left(x_t\right)\right)^2\right]$$

where $\bar{X} \equiv \left(2X_{NL}^e + X_{NL}^\tau\right)/3$

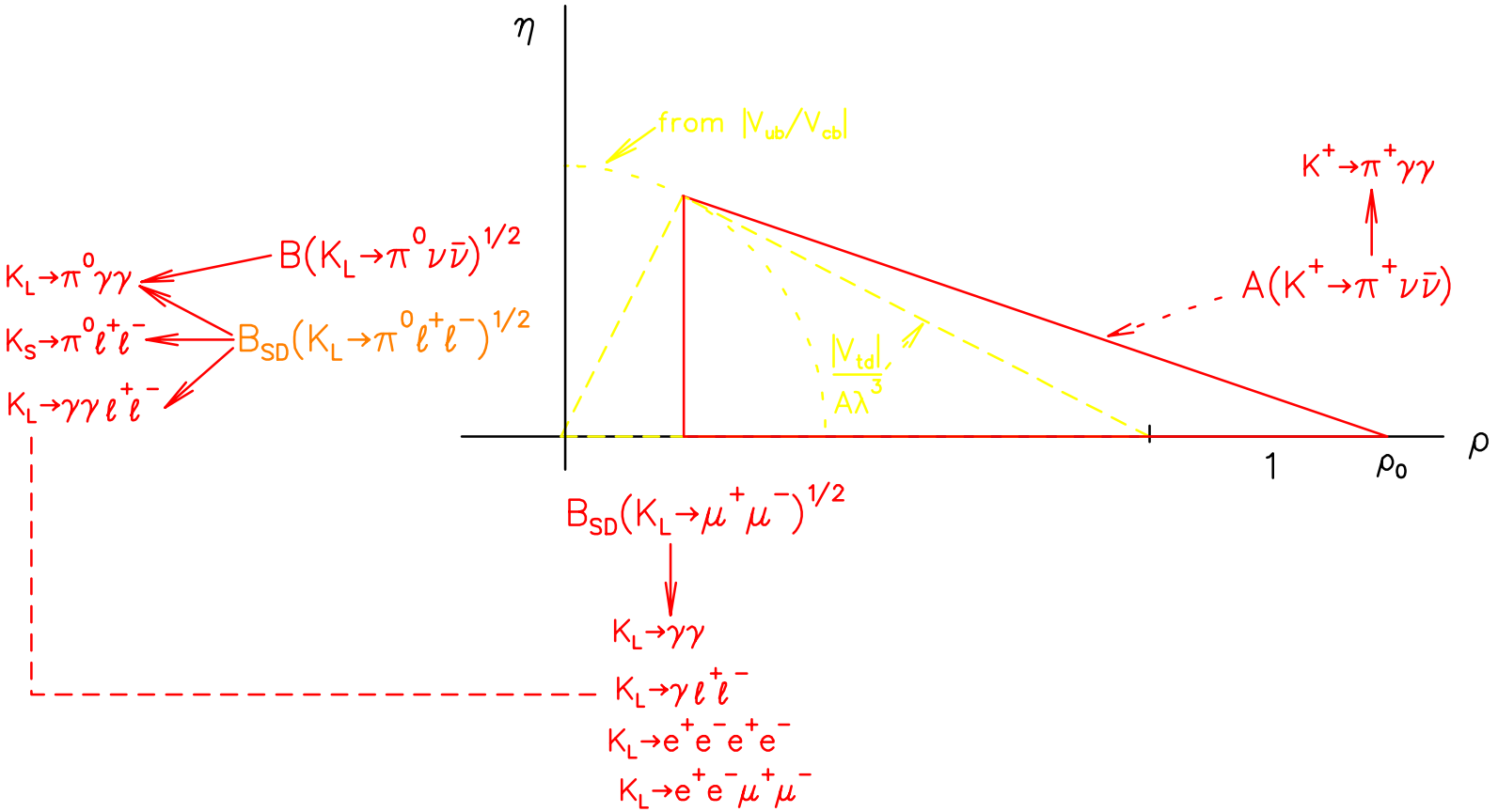
This gives a circle in the $Re\left(\lambda_t\right)$, $Im\left(\lambda_t\right)$ plane

From measurement of $B = \left(K^+ \to \pi^+ \nu\bar{\nu}\right)$, can get limits (tangents to circle)

Rare K Decay and the Unitarity Triangle



Rare K Decay and the Unitarity Triangle



$\underline{K_L \to \mu^+\mu^-}$

The **short distance** part of $B\left(K_L \to \mu^+\mu^-\right)$ given by:

$$B^{SD}_{\mu\mu} = \frac{\tau_{K_L}\alpha^2 B_{K^+\mu\nu}\xi}{\tau_{K^+}V^2_{us}\pi^2 sin^4\theta_W}\left[Re\left(\lambda_c\right)Y_{NL} + Re\left(\lambda_t\right)Y\left(x_t\right)\right]^2 \approx \mathcal{O}\left(10^{-9}\right)$$

where $Re\left(\lambda_c\right) = \lambda\left(\frac{\lambda^2}{2} - 1\right)$; $\lambda \equiv sin\theta_{Cabibbo}$; kinematic factor $\xi \approx 1$

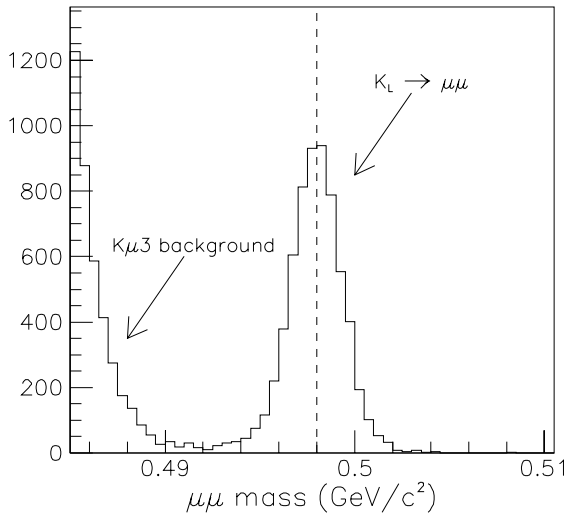
To a good approximation $Y\left(x_t\right) = 1.02\left(m_t/170\right)^{1.56}$, $Y_{NL} \approx 3 \times 10^{-4}$

$$= 1.75 \cdot 10^{-9} A^4 Y^2\left(x_t\right)\left(\bar{\rho}_0 - \bar{\rho}\right)^2 \quad = \quad (0.93 \pm 0.23) \cdot 10^{-9}$$

where $\bar{\rho}_0 \approx 1.2$

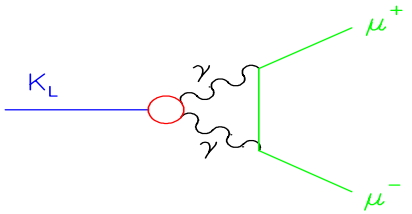
So could potentially measure $\bar{\rho}$ or be sensitive to BSM physics

Moreover there's a
Very good measurement
by AGS-871 (6000 evts!)



But there are a number of roadblocks to be overcome

First $B\left(K_L \to \mu^+\mu^-\right)$ is dominated by an absorptive contribution from intermediate $K_L \to \gamma\gamma$:



Much larger than the dispersive part which contains $B^{SD}_{\mu\mu}$!

If precise measurements are made, this can be subtracted.

$K_L \to \mu^+\mu^-$ - 2

Actual quantity measured is

$$\frac{B(K_L\to\mu\mu)}{B(K_L\to\pi^+\pi^-)} = (3.48 \pm 0.05)\cdot 10^{-6} \qquad \text{(PDG average)}$$

So best to compare to:

$$\frac{B^{abs}_{\gamma\gamma}(K_L\to\mu\mu)}{B(K_L\to\pi^+\pi^-)} = \frac{B^{abs}_{\gamma\gamma}(K_L\to\mu\mu)}{B(K_L\to\gamma\gamma)}\,\frac{B(K_L\to\gamma\gamma)}{B(K_L\to\pi^0\pi^0)}\,\frac{B(K_S\to\pi^0\pi^0)}{B(K_S\to\pi^+\pi^-)}\left(1 - 6Re\frac{\epsilon'}{\epsilon}\right)$$

- $\frac{B^{abs}_{\gamma\gamma}(K_L\to\mu\mu)}{B(K_L\to\gamma\gamma)}$: calculated — $1.2\cdot 10^{-5}$
- $\frac{B(K_L\to\gamma\gamma)}{B(K_L\to\pi^0\pi^0)}$: *last measured by NA31 in 1987* — 0.632 ± 0.009
- $\frac{B(K_S\to\pi^0\pi^0)}{B(K_S\to\pi^+\pi^-)}$: *from several exps. last in 1976!* — $(2.185 \pm 0.027)^{-1}$
- $\frac{B(K_L\to\pi^0\pi0)}{B(K_L\to\pi^+\pi^-)}$
- $1 - 6\,(17.2 \pm 1.8)\cdot 10^{-4}$

$$= (3.435 \pm 0.065)\cdot 10^{-6}$$

$$\frac{B^{disp}(K_L\to\mu\mu)}{B(K_L\to\pi^+\pi^-)} = (0.045 \pm 0.082)\cdot 10^{-6}$$

Then multiply by $B\left(K_L \to \pi^+\pi^-\right) = (2.056 \pm 0.033)\cdot 10^{-3}$ (PDG fit)

To get $B^{disp}\left(K_L \to \mu\mu\right) = (0.093 \pm 0.169)\cdot 10^{-9}$
i.e.

$B^{disp}\left(K_L \to \mu\mu\right) < 0.31\cdot 10^{-9}$ at 90% c.l.

Disagrees with $B^{SD}_{\mu\mu} = (0.93 \pm 0.23)\cdot 10^{-9}$ by $> 3\sigma$!

Why haven't we been hearing about this?

$K_L \to \mu^+\mu^-$ - 3

Problem is long distance contribution to $B^{disp}(K_L \to \mu\mu)$
This can interfere with the short distance amplitude
To untangle, must know $A(K_L \to \gamma\gamma)$ with γs off mass-shell
- size, calculability controversial:

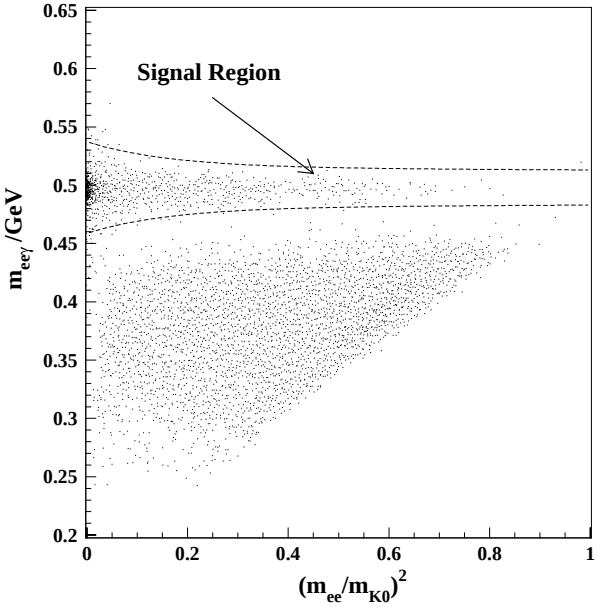
Pro	Con
Gomez-Dumm *et al.*, PRL **80** (1998) 4633	Valencia NP B **517** (1998) 339
D'Ambrosio *et al.*, PL B **423** (1998) 385	Knecht *et al.*, PRL **83** (1999) 5230

Can one **measure** this?

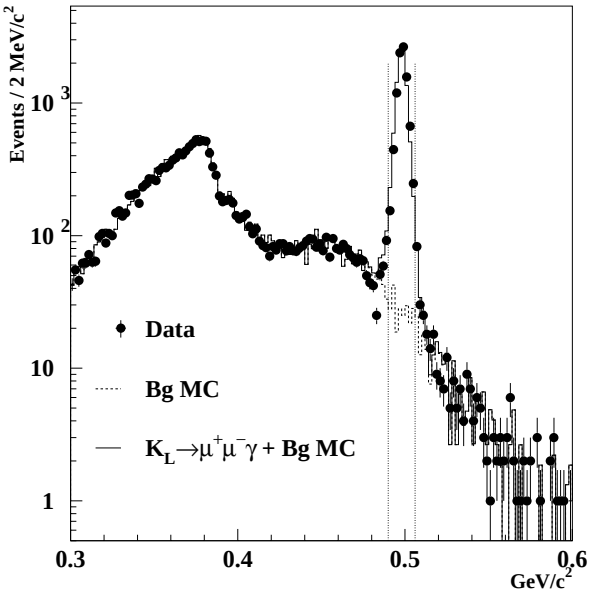
There are recent results on:

$K_L \to ee\gamma$	NA48
$K_L \to \mu\mu\gamma$	KTeV
$K_L \to eeee$	KTeV, NA48
$K_L \to ee\mu\mu$	KTeV, NA48

People have used fits to some of these to put a limit on ρ,
- how legitimate this is is still unclear



Scatter plot of $e^+e^-\gamma$ mass versus $m^2_{ee}/m^2_{K^0}$. The dashed lines define the signal region. From NA48.



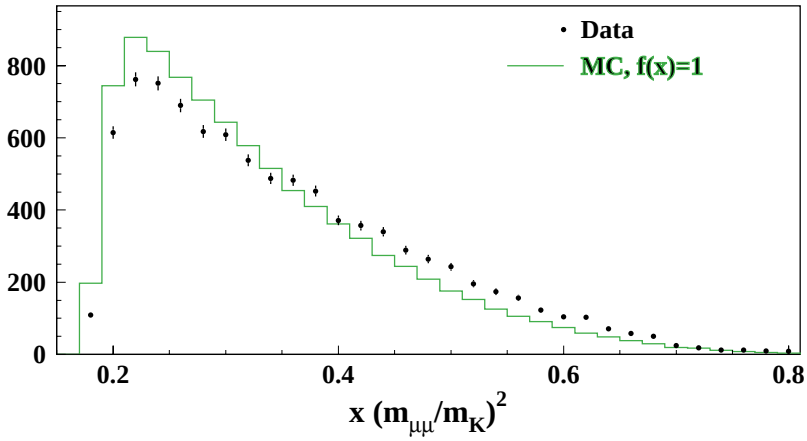
$\mu\mu\gamma$ mass from KTeV

Virtual photon form factors

Virtual photon form factors are needed to calculate the long-distance dispersive contribution to $K_L \to \mu^+\mu^-$.

That these processes not pointlike, now clear:

Data at right from KTeV $m_{\mu\mu}$ dist. in $K_L \to \mu^+\mu^-\gamma$

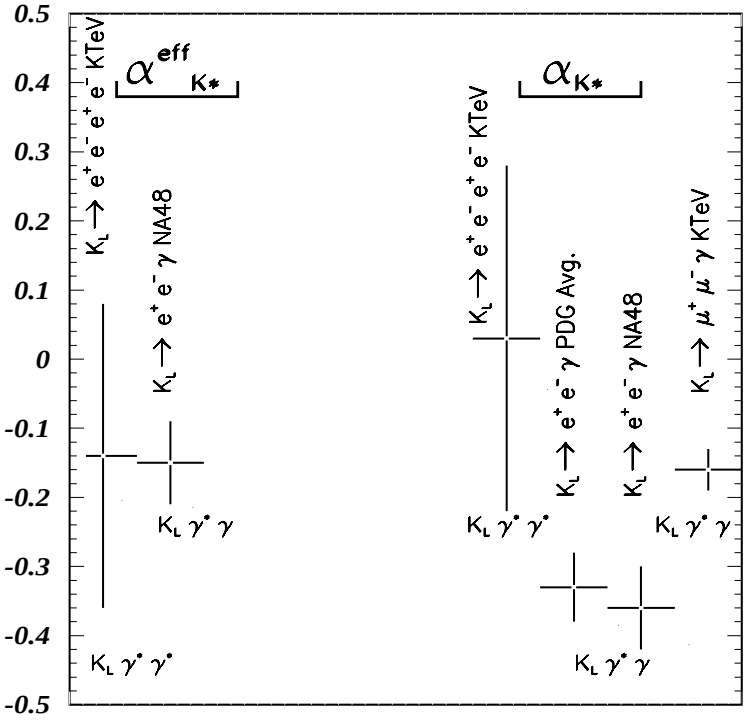


There are a couple of form factor parameterizations on the market; the traditional one is Bergström, Massó, & Singer (BSM), with parameter α_{K^*}

Figure at right shows α_{K^*} from recent experiments. (From E. Halkiadakis thesis)

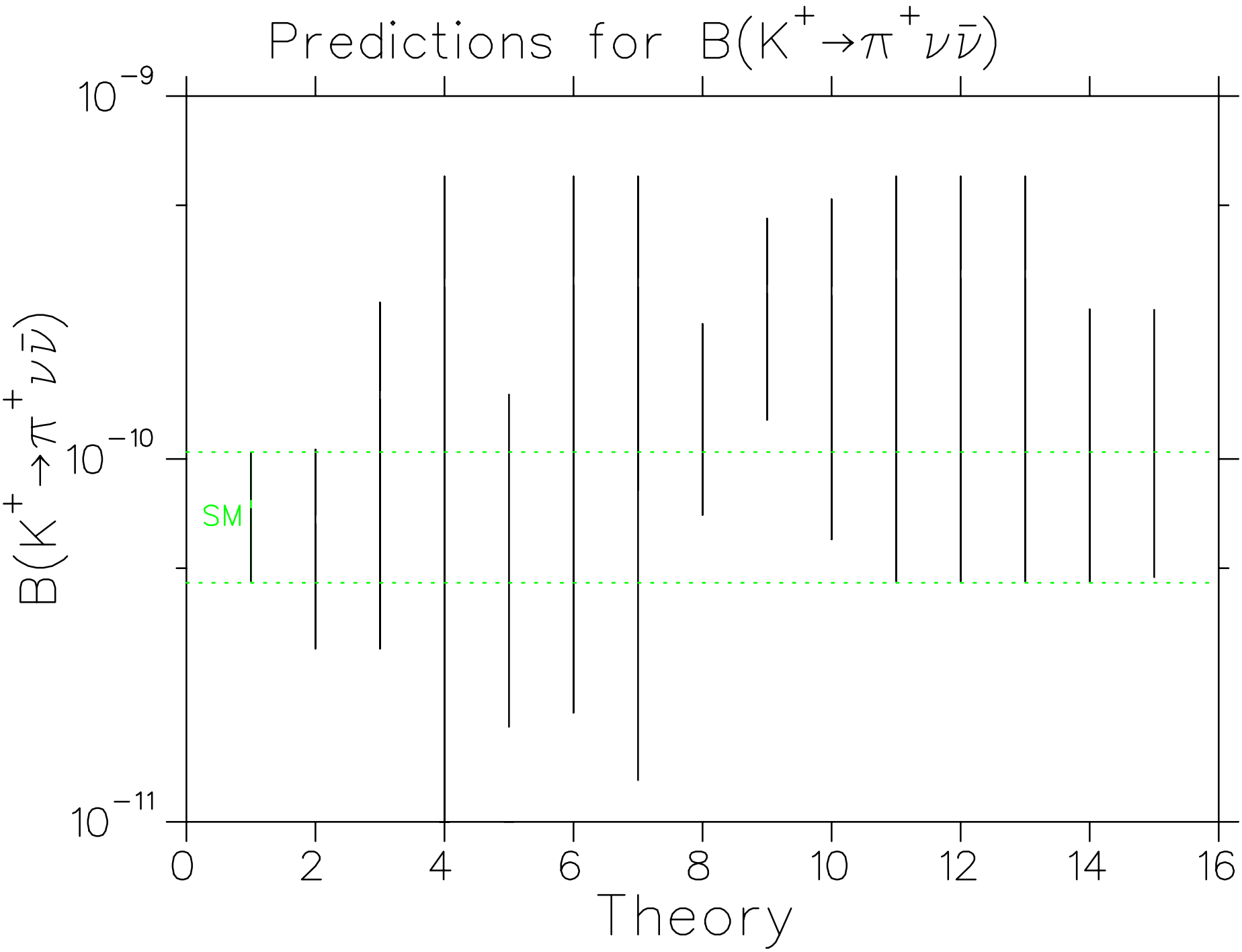
Agreement not inspiring but proper radiative corrections may help.

+ some issues not apparent in figure

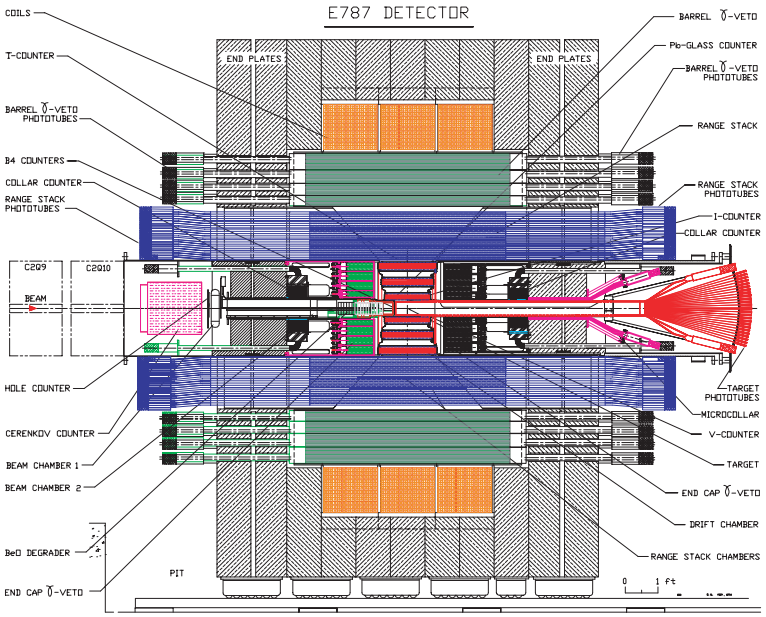


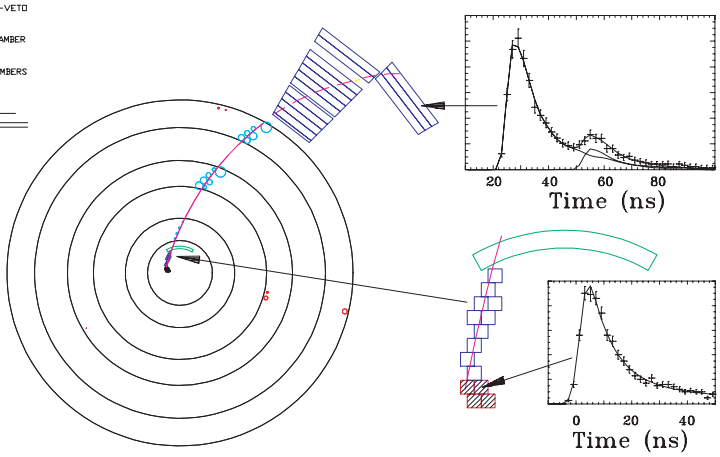
Finally, different parameterizations give different results, *e.g.* from KTeV $K_L \to \mu\mu\gamma$:

$|ReA_{LD}^{BMS}| < 3.6 \times 10^{-5}$ but $|ReA_{LD}^{DIP}| < 2.07 \times 10^{-5}$


Predictions for B(K+→π+νν̄)
10−9
10−10
10−11
B(K+→π+νν̄)
SM
0
2
4
6
8
10
12
14
16
Theory

AGS-E787





First event in 1995 data set:

1995-7 data set still had only 1 event, with bckgnd < 0.1 evts.

$$B(K^+ \to \pi^+ \nu\bar{\nu}) = (1.5^{+3.4}_{-1.2}) \times 10^{-10} \ (\sim \text{ twice SM}).$$

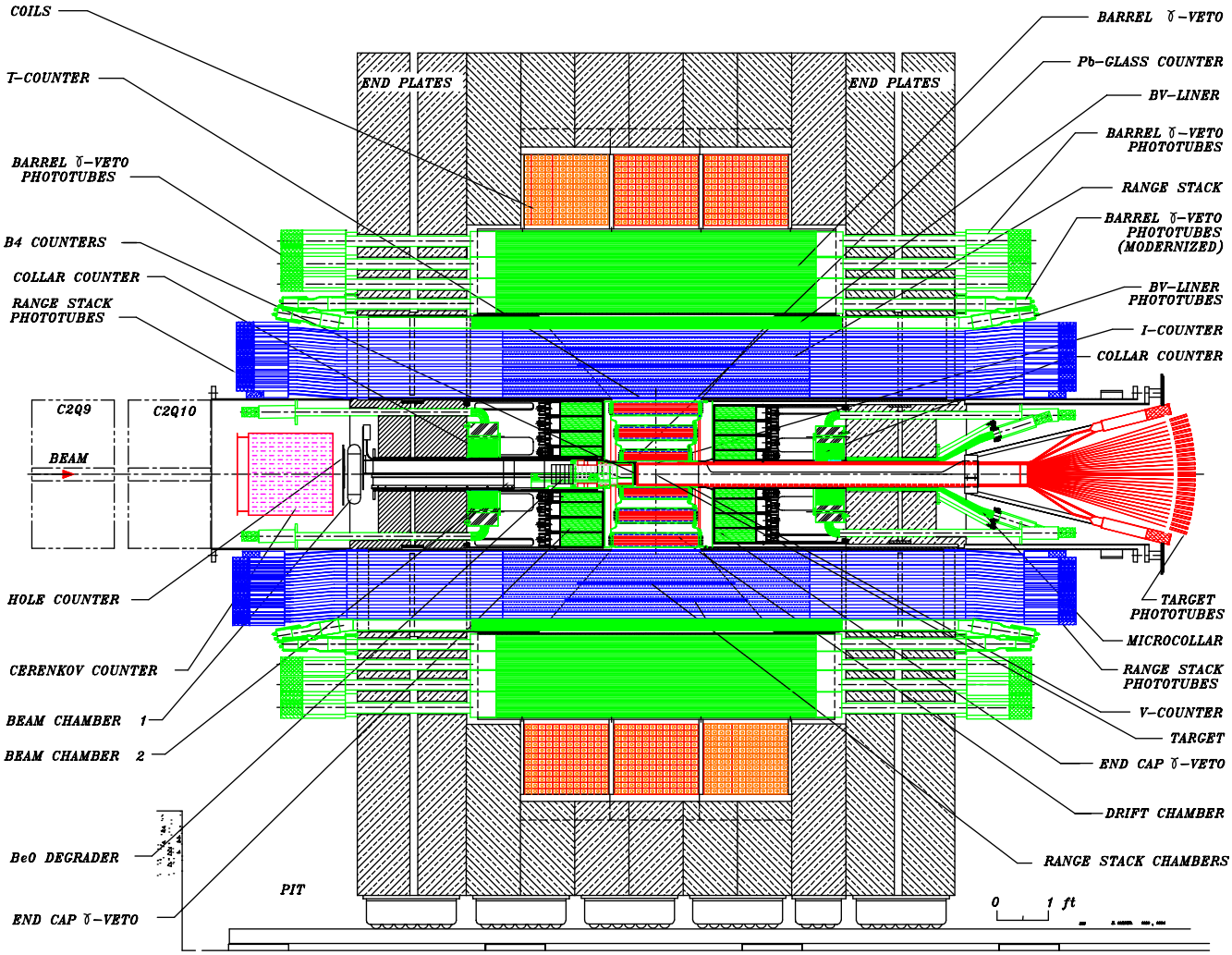
1998 data set $\approx$ to all previous E787 data
- background very similar to that of 1995-7:

Background type	1998 (prelim.)	1995-7
$K^+ \to \mu^+ \nu$	0.034 ± 0.044	0.0282 ± 0.0097
$K^+ \to \pi^+ \pi^0$	0.035 ± 0.035	0.0212 ± 0.0049
beam (1)	0.004 ± 0.001	0.0042 ± 0.0032
beam (2)	0.000 ± 0.000	0.0027 ± 0.0023
charge exchange	0.012 ± 0.002	0.0096 ± 0.0068
total	0.085 ± 0.056	0.0786 ± 0.0198

Stay tuned!

E949 Measurement of $B(K^+ \to \pi^+ \nu\bar{\nu})$

Albera, UBC, BNL, FNAL, Fukui, IHEP, INR, KEK, JAERI,
Kyoto, NDAJ, New Mexico, Osaka, RCNP, TRIUMF



Upgrade of BNL AGS 787

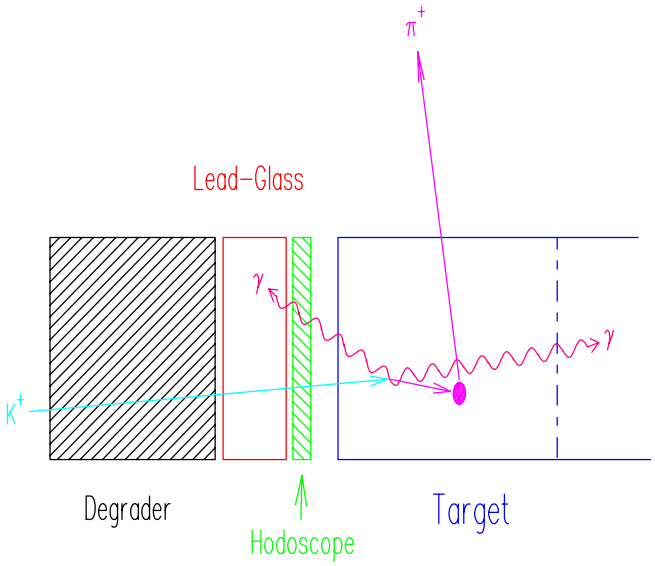
Sensitivity improvement with respect to E787 (1995):

- Increased spill length ($\times 1.56$)
- Lower momentum ($\times 1.38$)
- Increased efficiency (trigger, DAQ, analysis) ($\times 3.2$)
- Acc. below $K\pi 2$ + higher rate analysis reopt. ($\times 2$)
- Total gain - $\times 14$ per hour of data taking

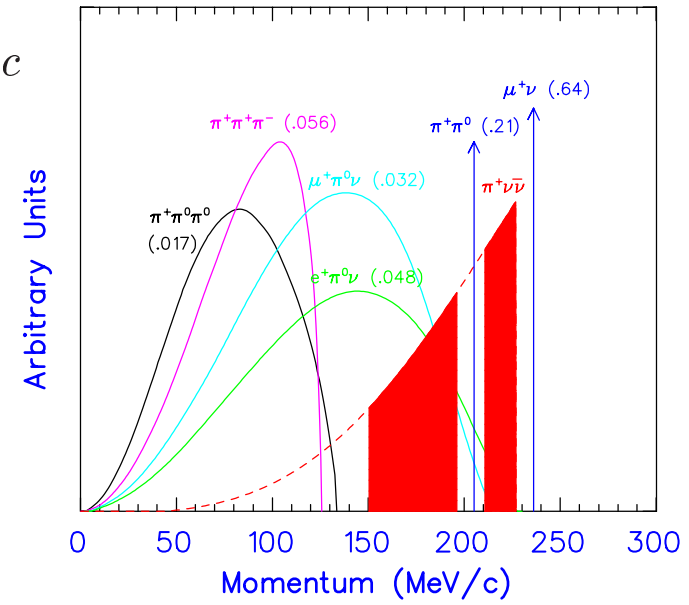
Expect to reach $\sim 10^{-11}$/evt by 2004

$K^+ \to \pi^+ \nu\bar{\nu}$ "below the $K\pi 2$"

$\approx$ all $K^+ \to \pi^+ \nu\bar{\nu}$ sensitivity so far
In kinematic region $P_{\pi^+} > 205\text{MeV}/c$
Softer p_{π^+} region suffers from
$K^+ \to \pi^+ \pi^0$ downshift +
correlated γ inefficiency:



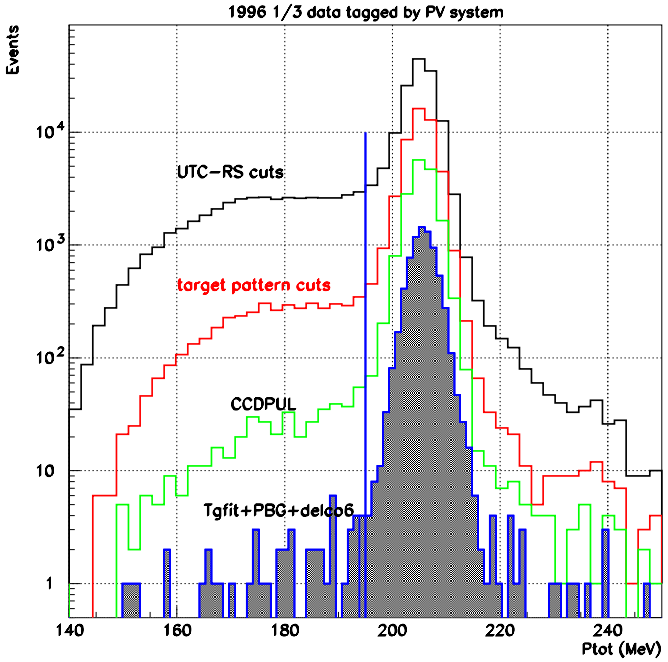
Correlation between photon veto
and nuclear interactions



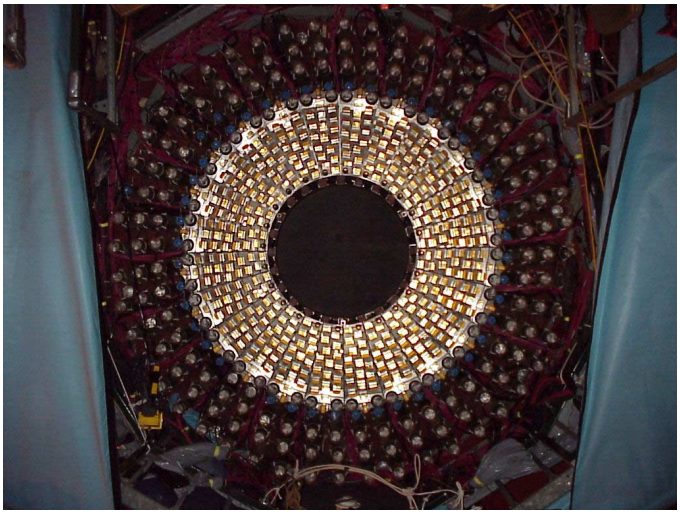
Major effort to clean up region
Now bearing fruit.

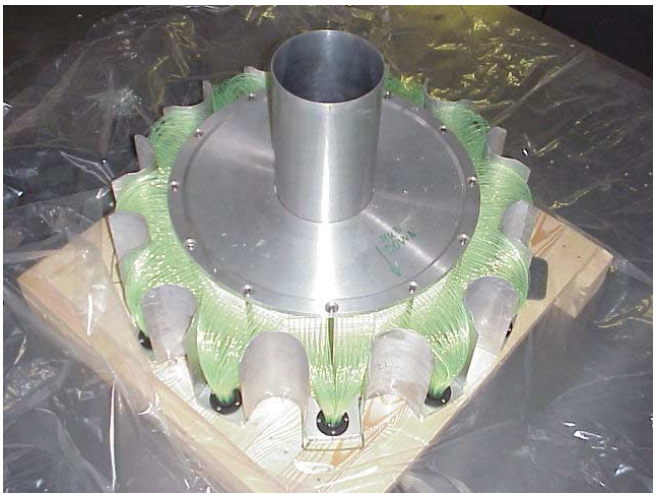
One year of E787 data
Gives s.e.s. $\sim 10^{-9}$
w/background of 0.7 events

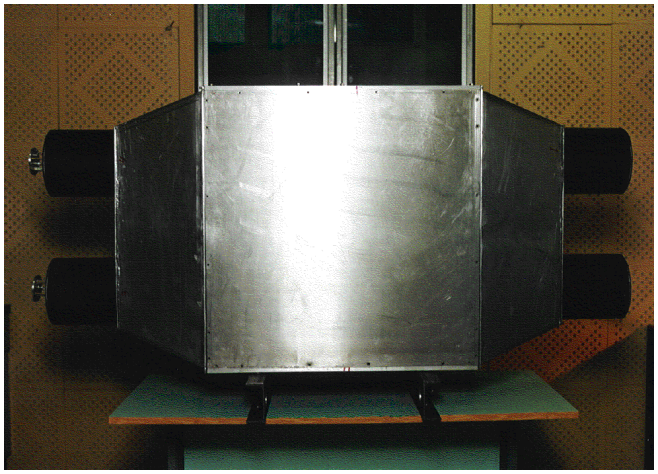
Expect E949 upgrade to
improve by factor 10



Status of E949







Almost all hardware upgrades completed & installed

Commissioning run in progress

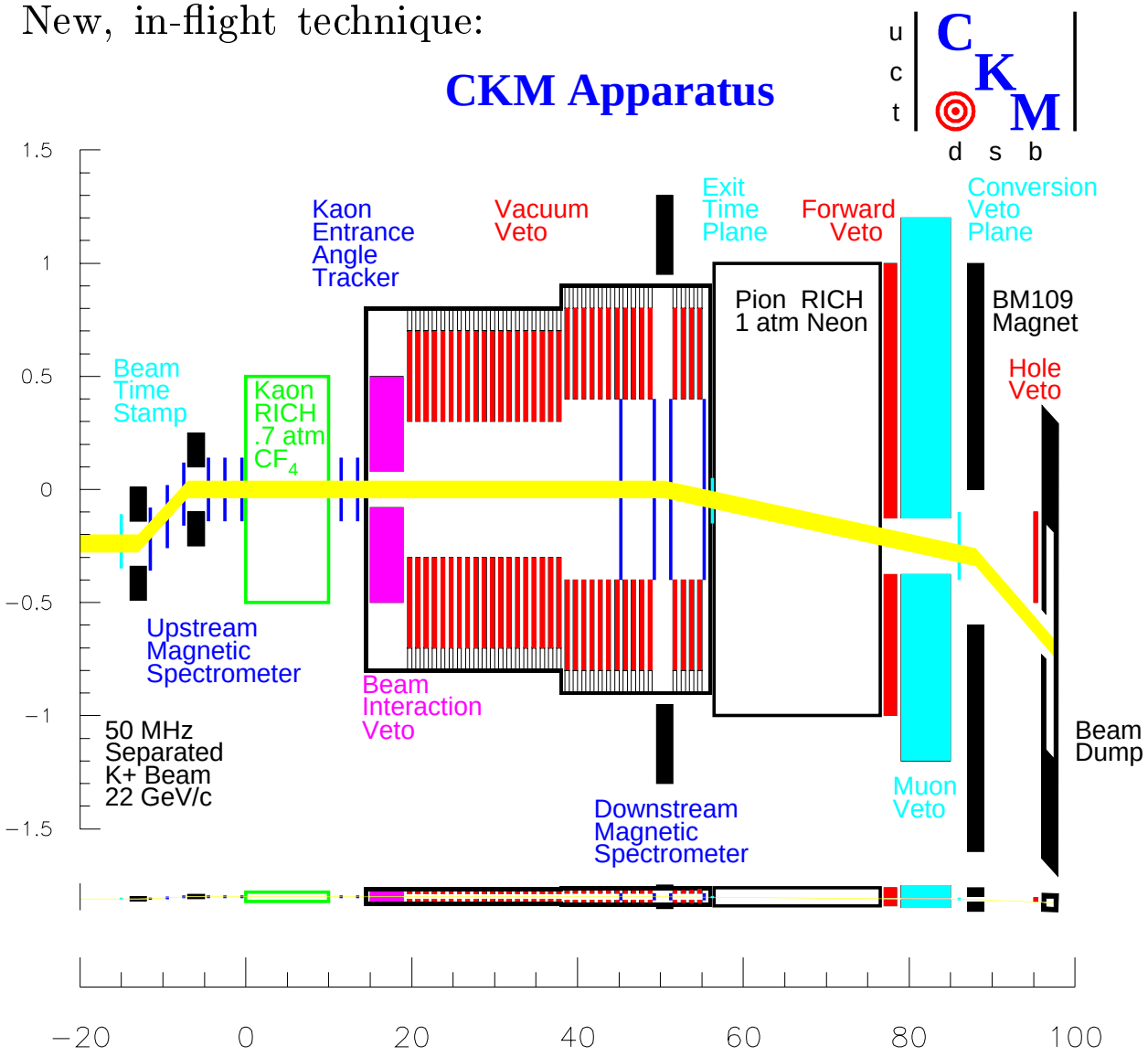
New systems work well - being calibrated

Technique for heavy ions/protons switch tested

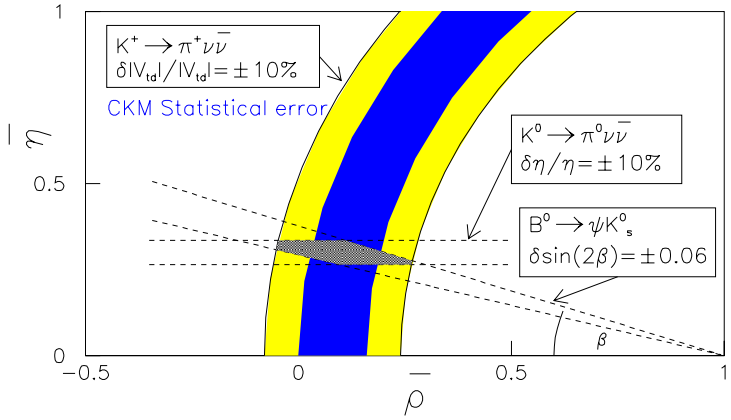
RHIC running getting smoother

CKM Experiment to Measure $K^+ \to \pi^+ \nu\bar{\nu}$

New, in-flight technique:

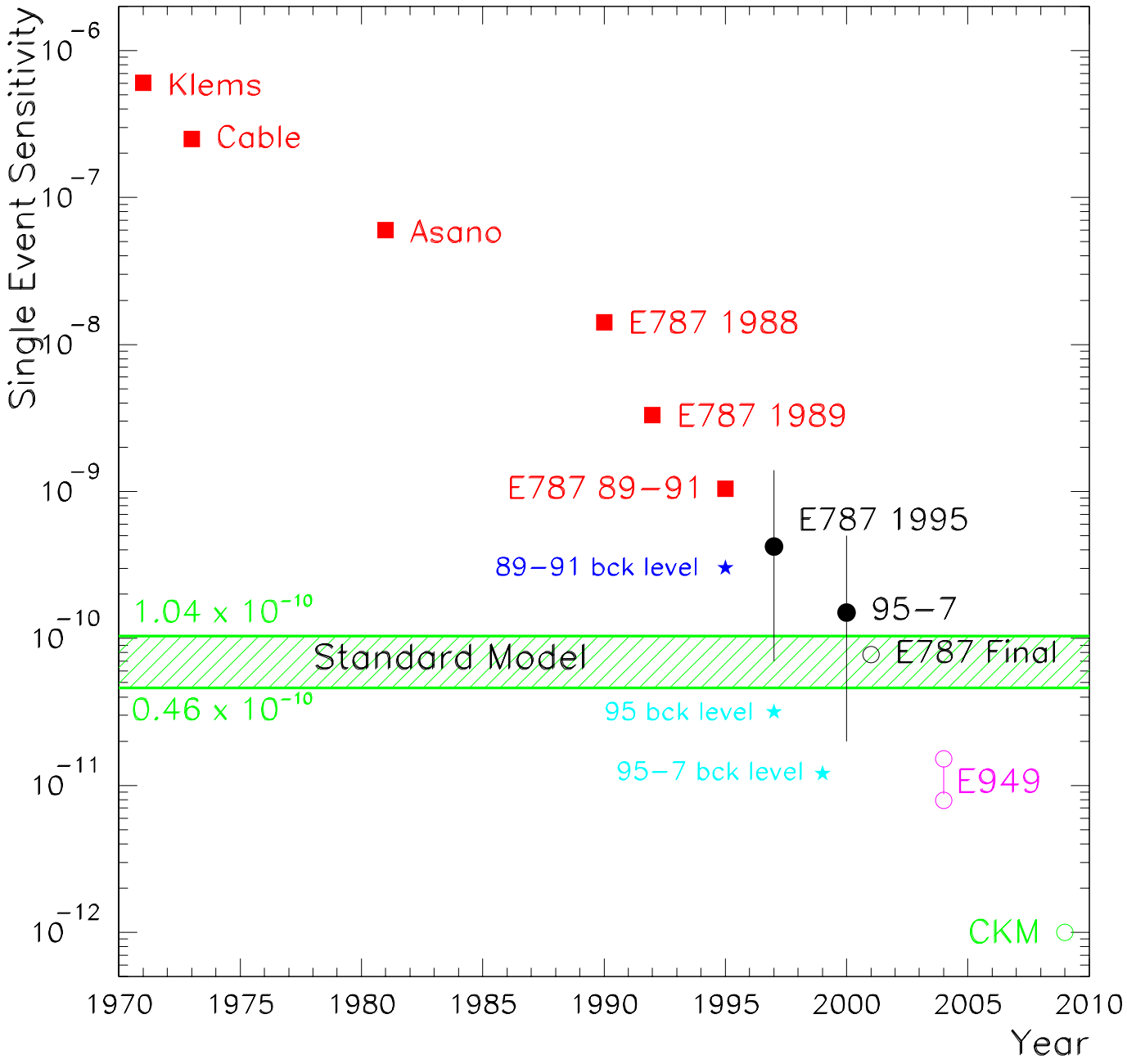


Reach for ~ 100 events:



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

- E787 observed 1 event in 1995 run
- Analysis of 1995-7 data shows background rejection adequate for measurement at the S.M. level.
- Data collected in 1998 equal in sensitivity to previous total.
- Full E787 data sample (1995–98) will reach S.M. level.
- E949 should reach $\mathcal{O}(10^{-11}/\text{evt})$ with ~ 10 S.M. events
- CKM proposes to reach $\mathcal{O}(10^{-12}/\text{evt})$ by ~ 2010



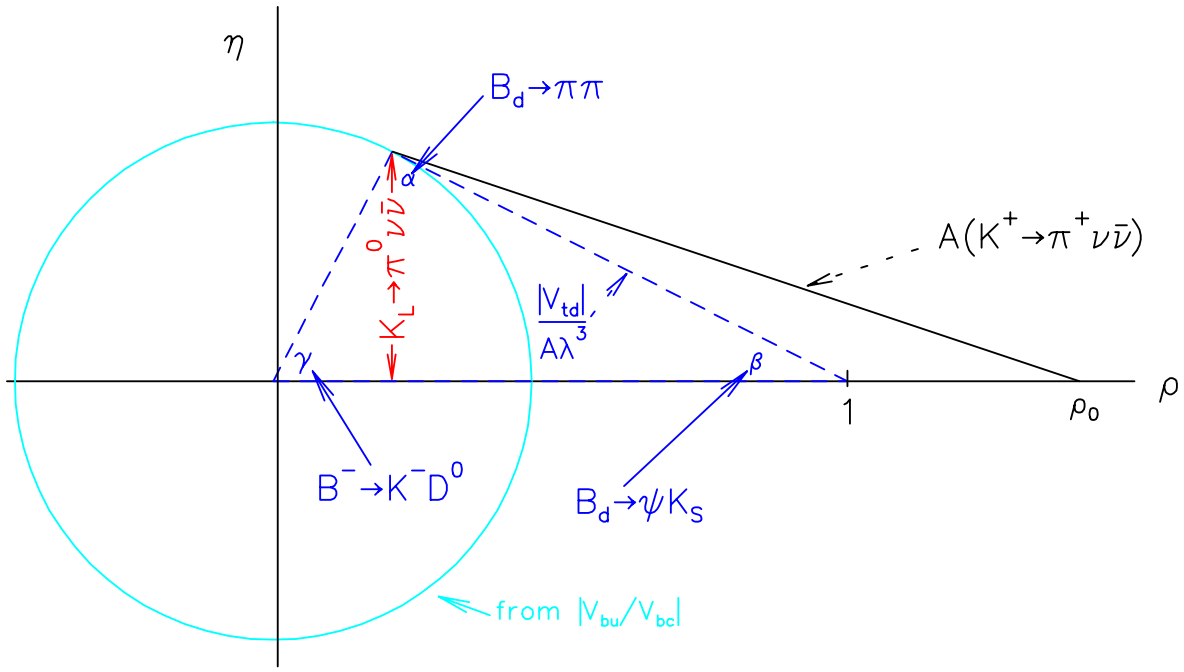
$K_L \to \pi^0 \nu\bar{\nu}$ in the Standard Model

Pure direct CP-violating (state-mixing very small)

Calculation in terms of fundamental parameters good to $\lesssim 2\%$

In terms of usual unitarity triangle parameterization:

$B(K_L \to \pi^0 \nu\bar{\nu}) = 4 \cdot 10^{-10} A^4 \eta^2$



Gives height of UT without triangulation

- with $K^+ \to \pi^+ \nu\bar{\nu}$ can determine ρ as well

Also note that

$B(K_L \to \pi^0 \nu\bar{\nu}) = 1.56 \cdot 10^{-4} [Im(V_{ts}^* V_{td})]^2 \equiv 1.56 \cdot 10^{-4} [Im\lambda_t]^2$

$Im\lambda_t$ presently triangulated to $\sim 20\%$,

- A dedicated experiment could directly measure it to 10%

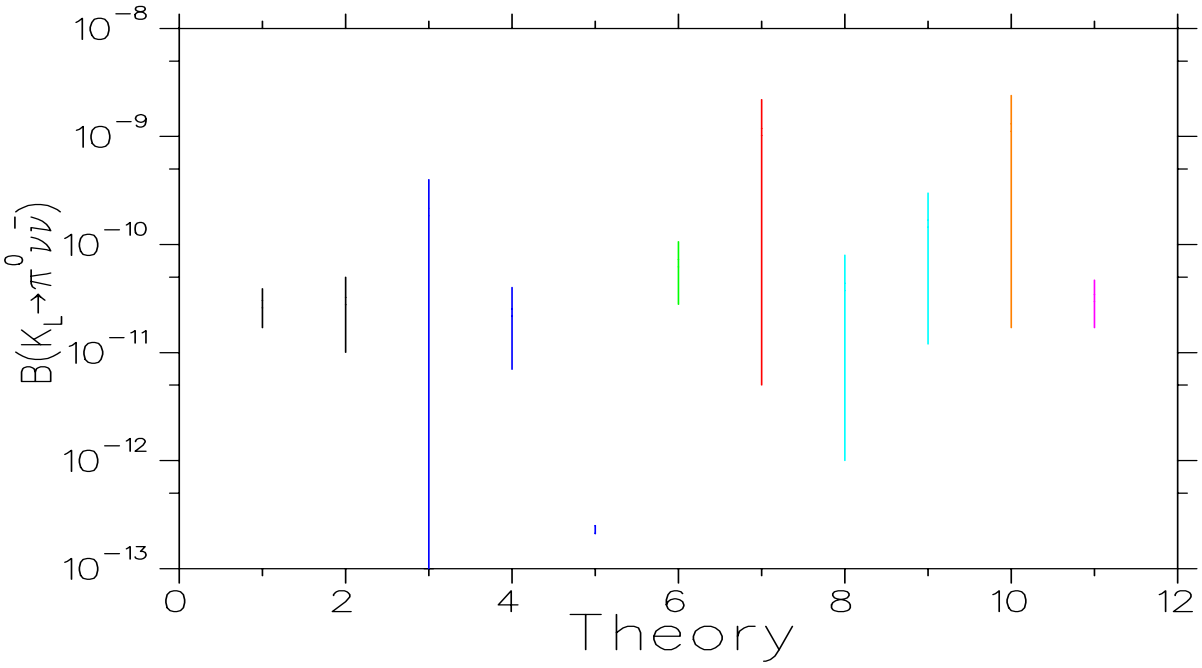
There are only a few solid measurements on the UP

- none is better!

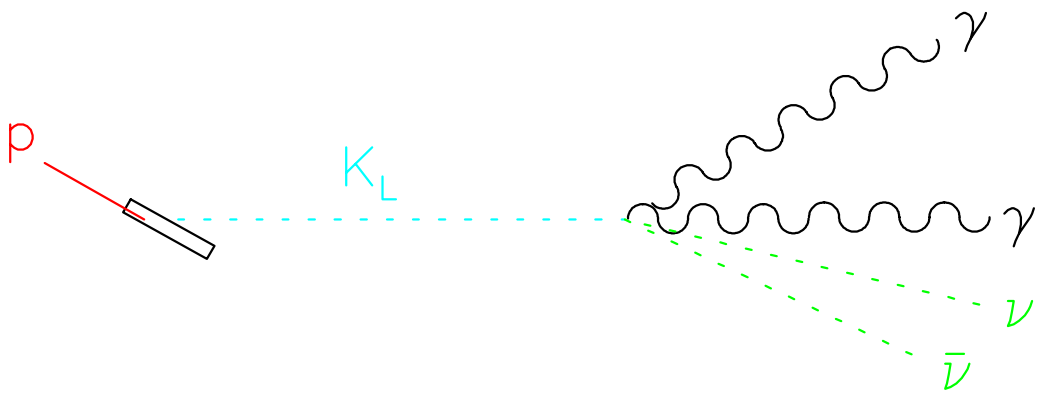
$K_L \to \pi^0 \nu\bar{\nu}$ Beyond the Standard Model

	Who	What	$10^{11} B(K_L \to \pi^0 \nu\bar{\nu})$
1	Buchalla	Standard Model CKM fit	2.8 ± 1.1
2	Plaszczynski/Schune	Conservative SM fit	$1 - 5$
3	Buras, *et al.*	Generic SUSY w/min. part. content	$0 - 40$
4	Buras, *et al.*	MSSM w/o new flavor or CP viol.	$(0.41 - 1.03)\times$ SM
5	Brhlik, *et al.*	all CP-viol. due to SUSY	$\sim .023$
6	Chanowitz	$SU(2)_L \times SU(2)_R$ Higgs	$2.8 - 10.6$
7	Hattori, *et al.*	4th generation	$0.5 - 260$
8	Xiao, *et al.*	top-color assisted technicolor	$0.1 - 8$
9	Xiao, *et al.*	multiscale walking technicolor	$1.2 - 30$
10	Grossman/Nir	Extra "vector-like" quarks	$1.7 - 260$
11	Kiyo, *et al.*	seesaw L-R model†	$(1 - 1.2)\times$ SM

† predicts spectrum will be altered.



$K_L \to \pi^0 \nu\bar{\nu}$ experimental issues



All neutral initial & final state, γ's make π^0

Expected branching ratio 3×10^{-11}
- need high flux of K_L

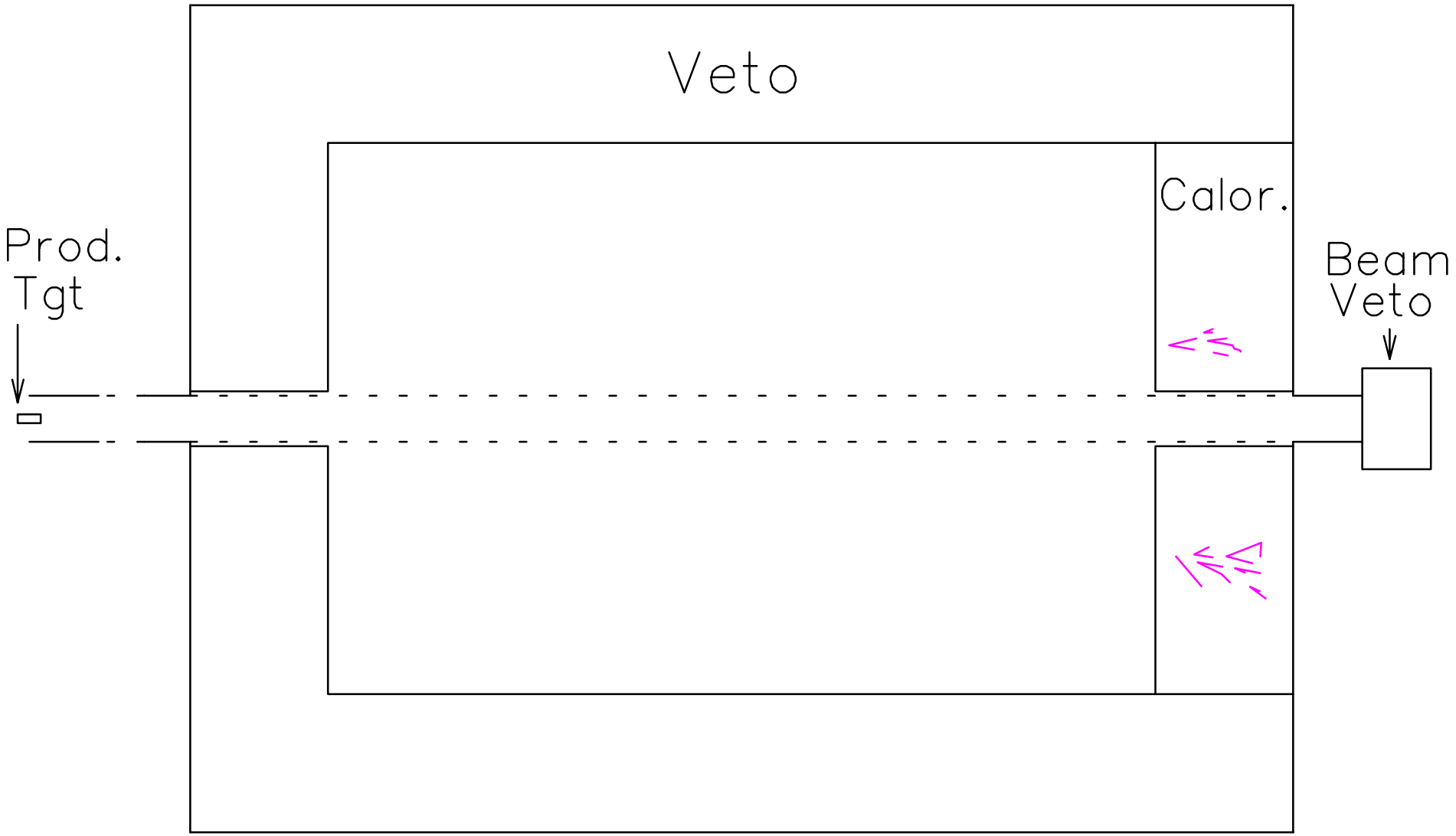
Largest background $K_L \to \pi^0\pi^0$, BR $\sim 10^{-3}$
- need excellent vetoing, other handles if possible

Background from neutron-produced π^0's, η's
- requires vacuum of 10^{-7}
- need to make sure decay vertex was in beam

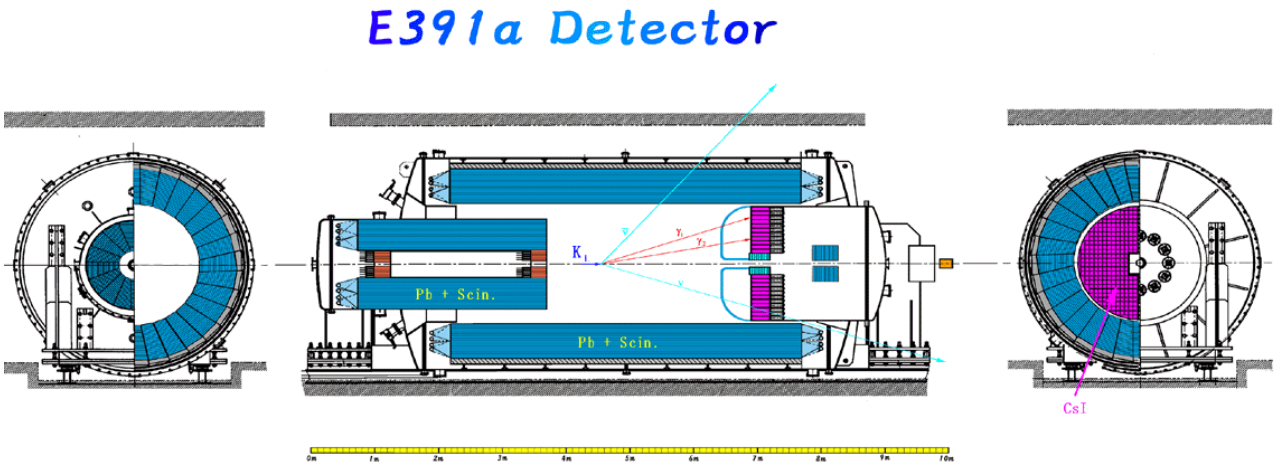
Potential backgrounds from hyperon decay π^0's
- could use a clever way of getting rid of them

Present status: $B(K_L \to \pi^0\nu\bar{\nu}) < 5.9 \times 10^{-7}$
- from KTeV, using Dalitz-converted π^0's

$K_L \rightarrow \pi^0 \nu\bar{\nu}$ Experiment



KEK E391a search for $K_L \to \pi^0 \nu\bar{\nu}$



Carefully designed "pencil" beam, compact detector

Entire apparatus in vacuum

Very high performance photon veto

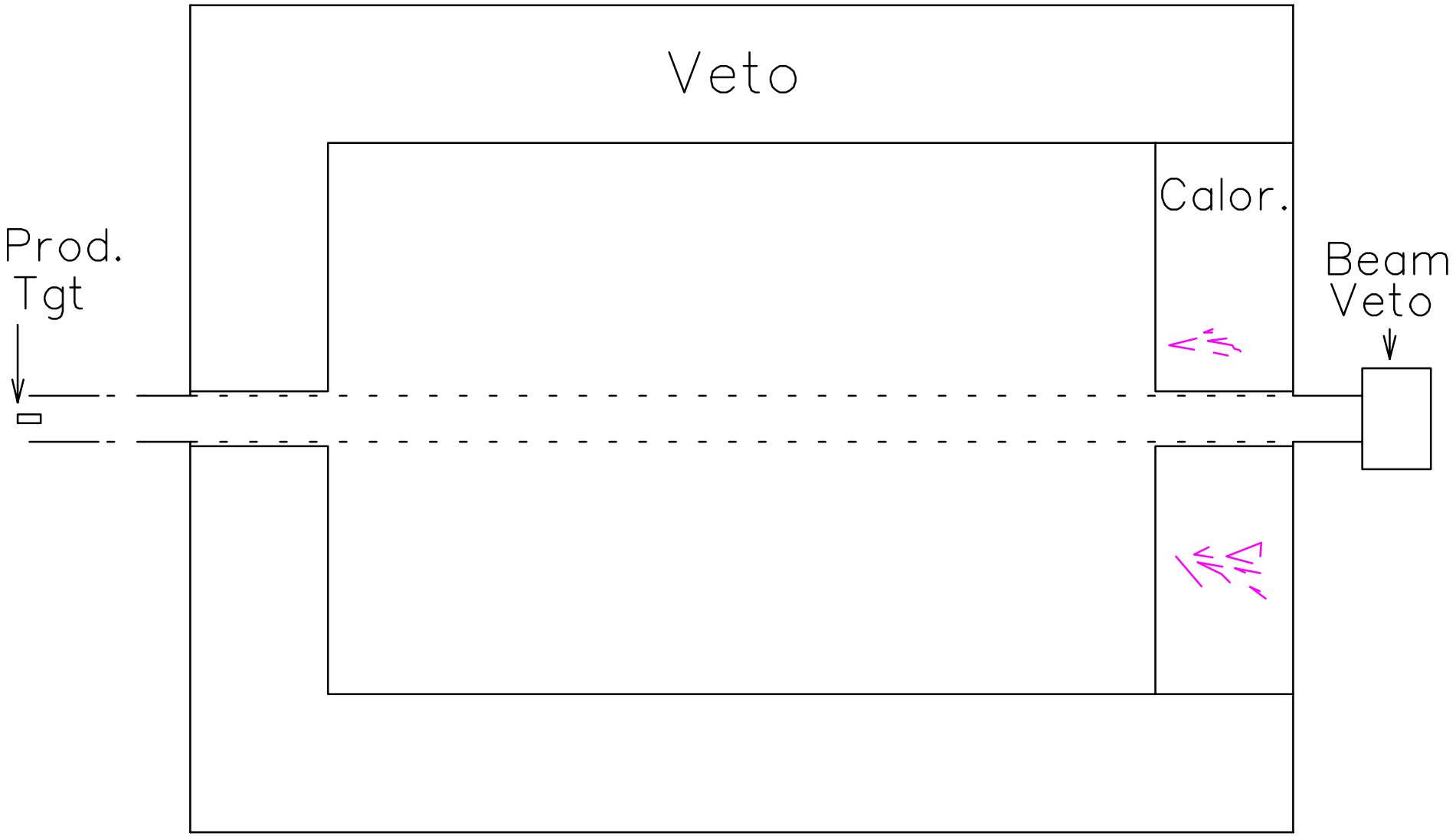
Expected to reach $\sim 3 \times 10^{-10}$ single event sensitivity
- *i.e.* w/i an order of magnitude of S.M. prediction

Beamline construction & tuning begun in March 2000

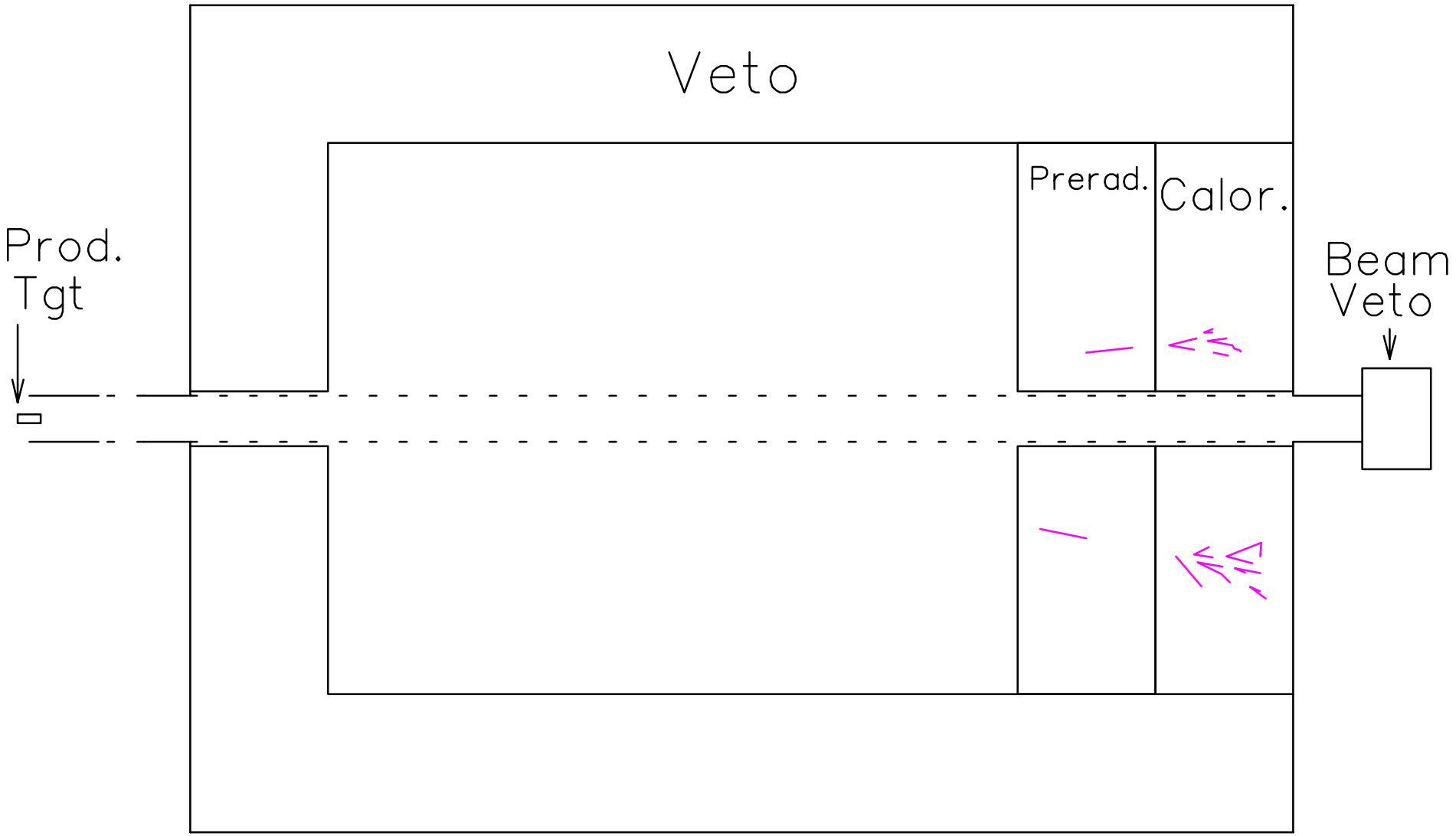
Run start scheduled for Fall, 2003

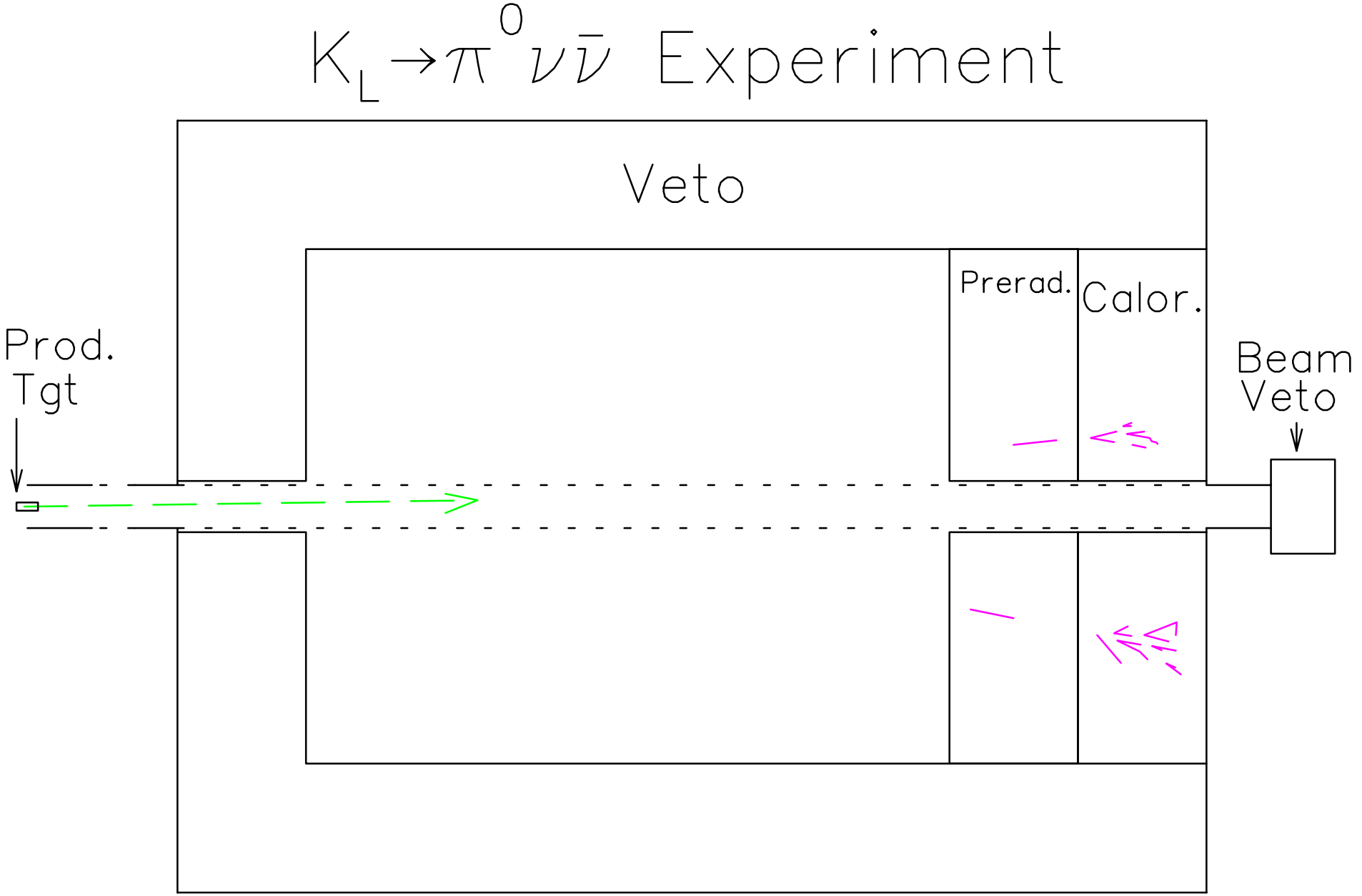
Test bed for JHF experiment

$K_L \rightarrow \pi^0 \nu\bar{\nu}$ Experiment

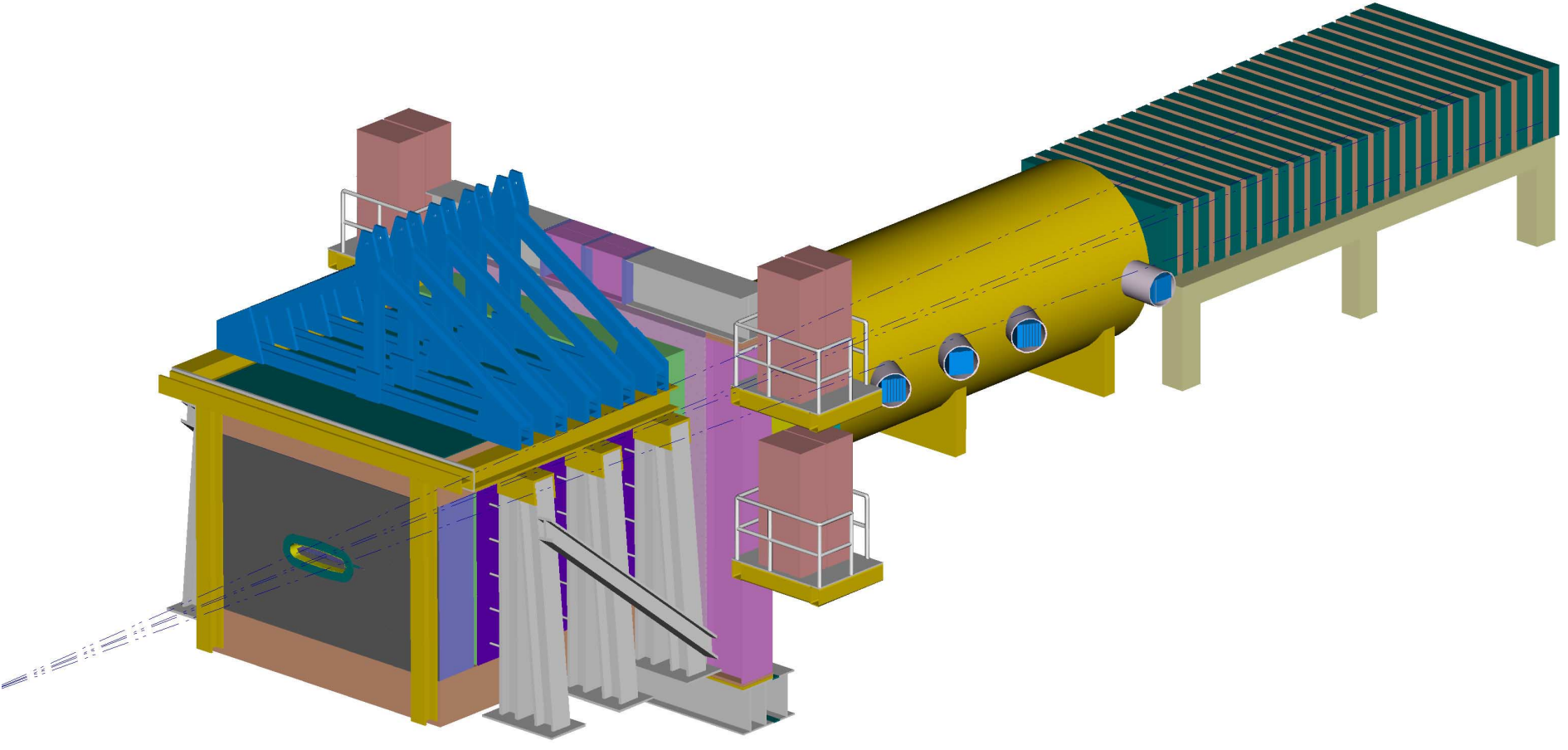


$K_L \rightarrow \pi^0 \nu\bar{\nu}$ Experiment




$K_L \to \pi^0 \nu\bar{\nu}$ Experiment
Veto
Prerad.
Calor.
Prod.
Tgt
Beam
Veto

BNL, Cinncinnati, INR-Moscow, KEK, Kyoto, INFN-Perugia, Stony Brook, TJNAF, TRIUMF, British Columbia, New Mexico, Virginia, Virginia Tech, Yale, Zurich



KOPIO $K_L \to \pi^0 \nu\bar{\nu}$

Proposal recommended by National Science Board
- NSF-funded R&D has begun

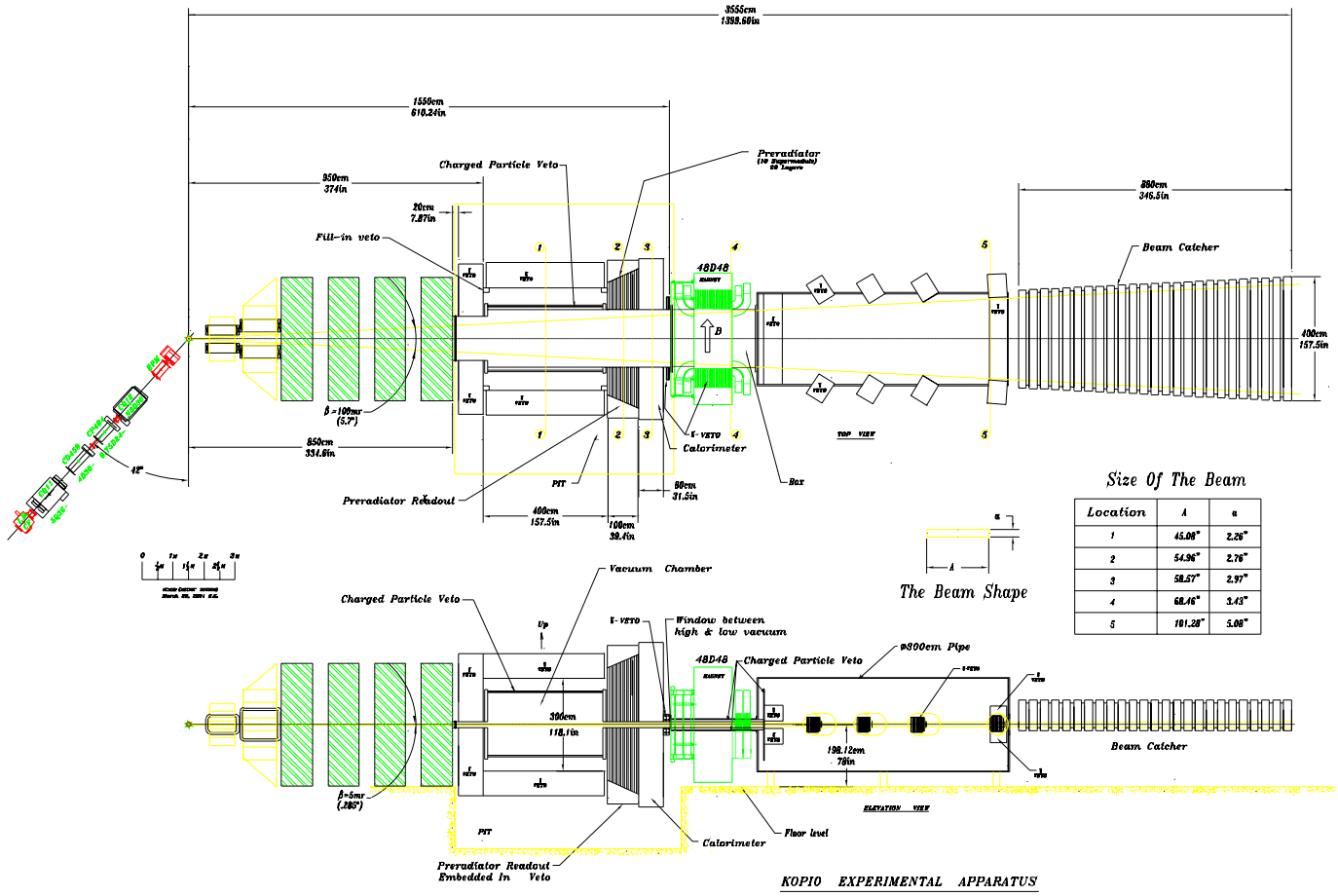
Uses the BNL AGS ~ 20 hrs/day it's not serving RHIC

Microbunched, low energy beam allows TOF determination of p_K

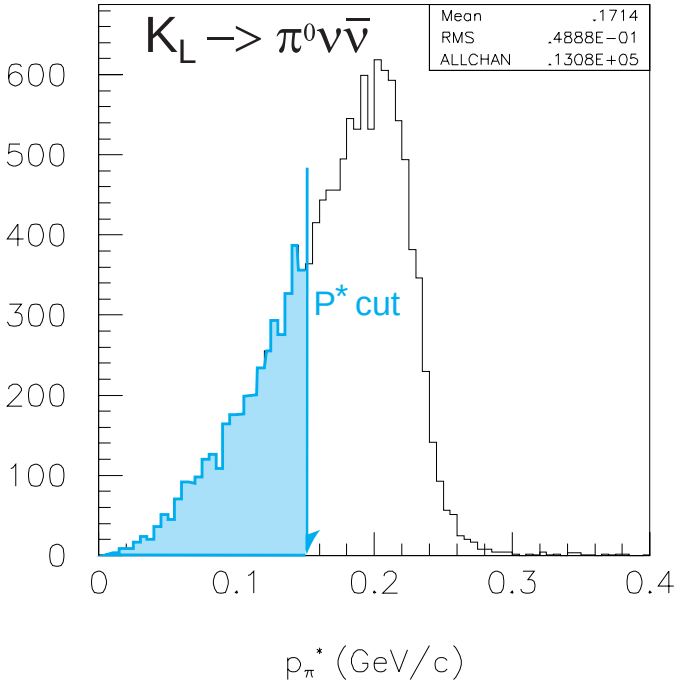
Measures photon direction as well as energy, time, position

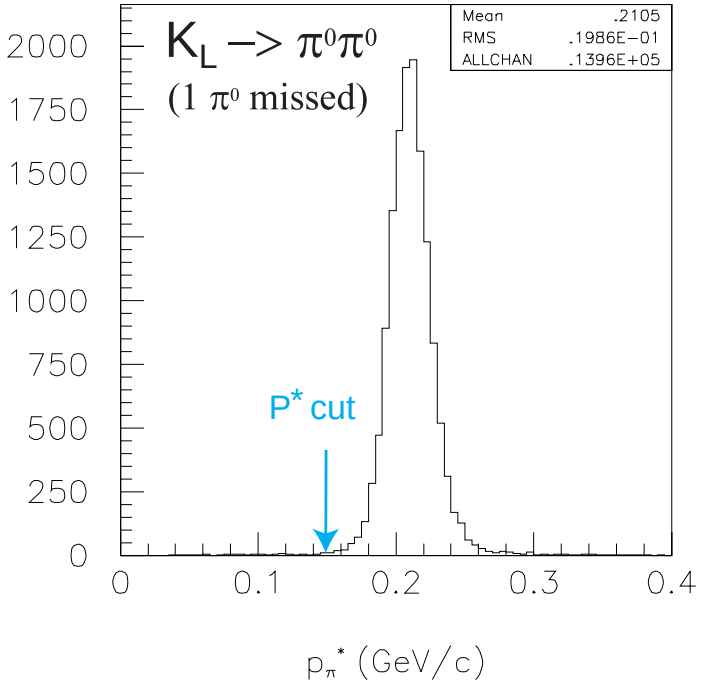
Hermetic veto with proven level of inefficiency

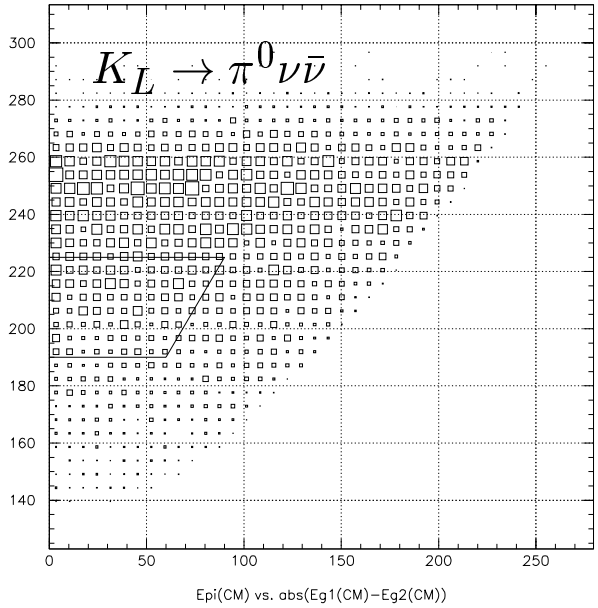
~ 50 events, S:B $\sim 2:1$

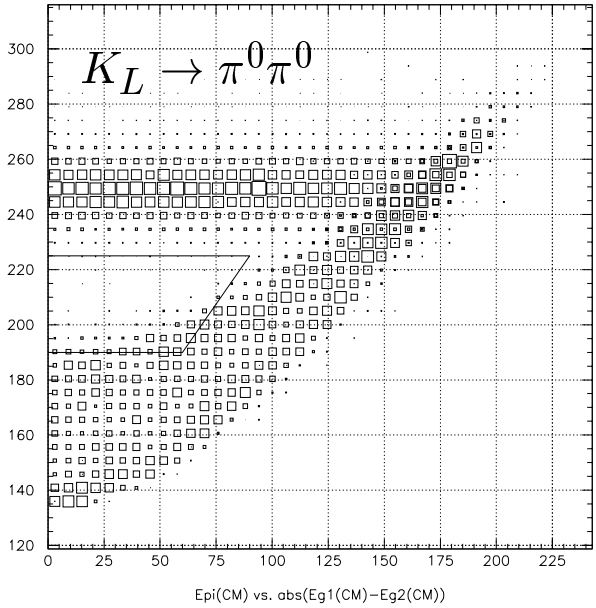


$K_L \to \pi^0\nu\bar{\nu}$ and $K_L \to \pi^0\pi^0$ identification



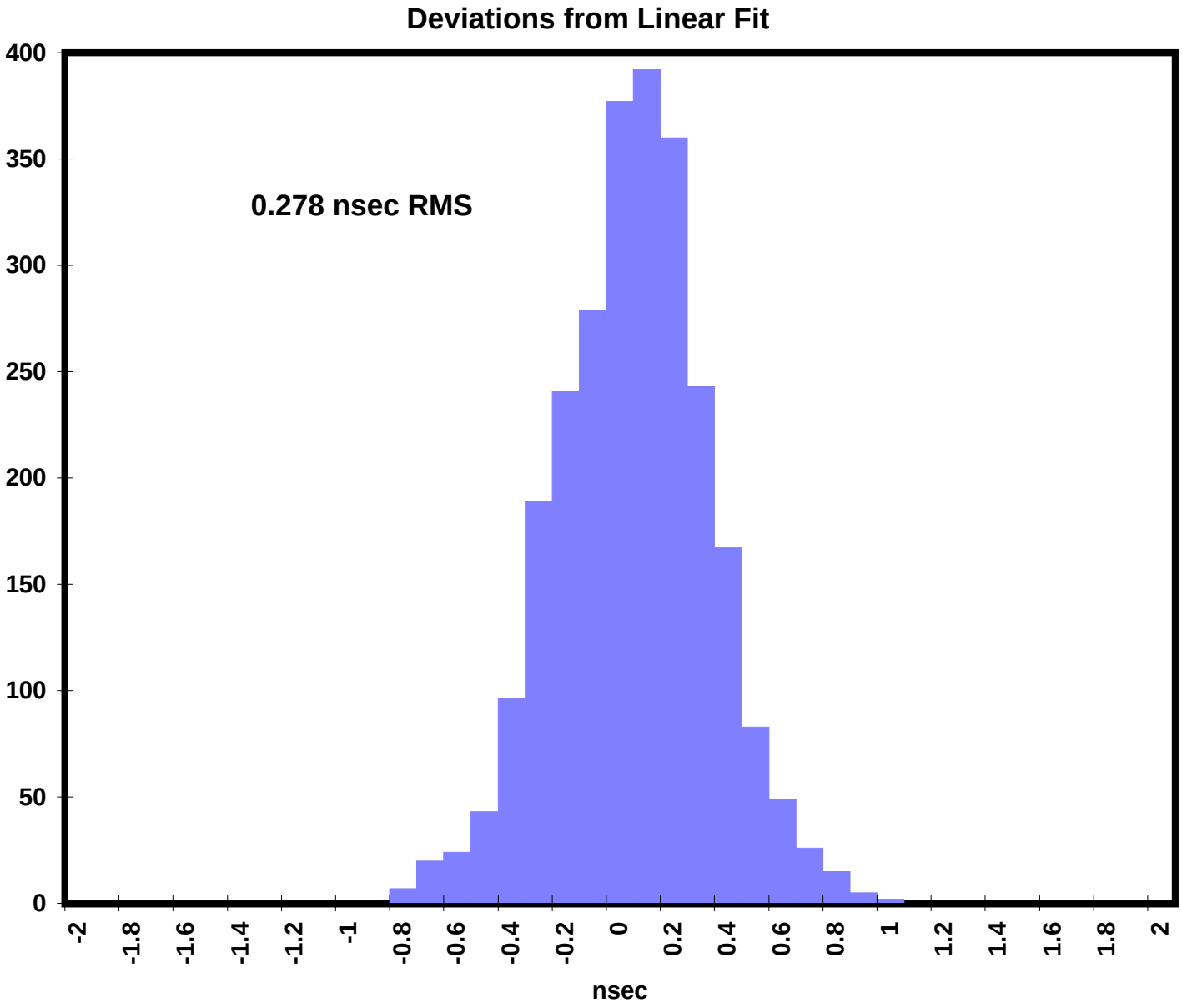






Energy of the purported π^0 (vertical) vs absolute value of the difference of the energies of the two detected γ's (horizontal) both in the K_L cm system.

Test of microbunching on extraction at AGS



Technique now well established
Very successfully used to smooth AGS spill

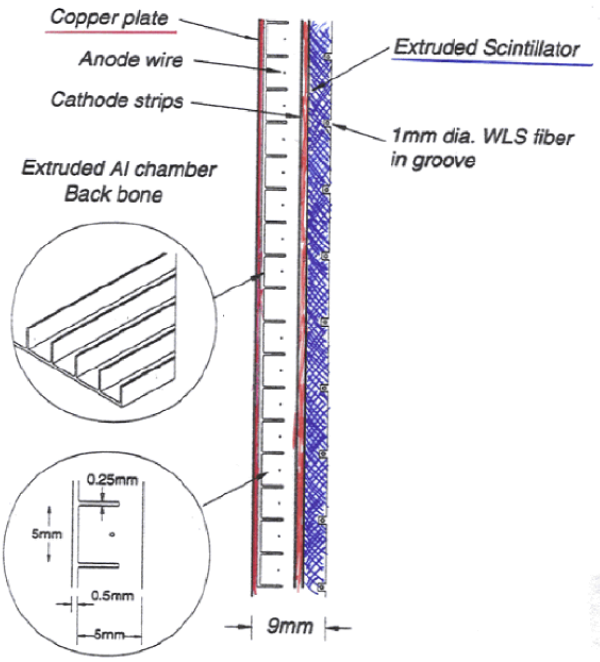
Photon angle measurement

Principle: track 1st converted pair in low-density preradiator

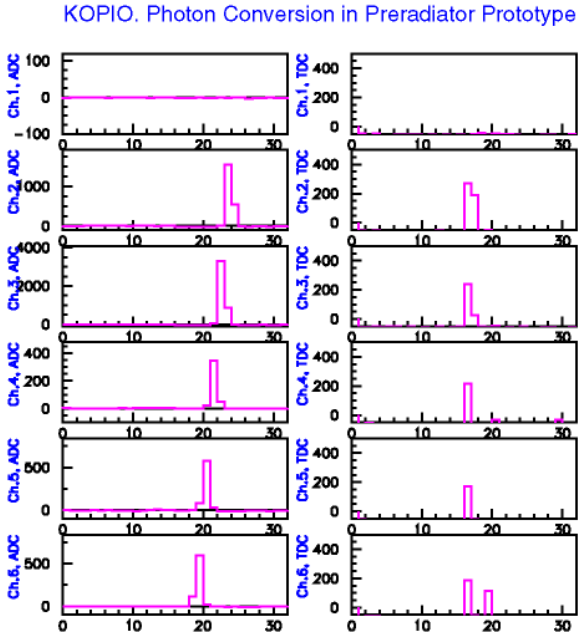
64 layers of chamber + scintillator
- each station $0.03X_0$

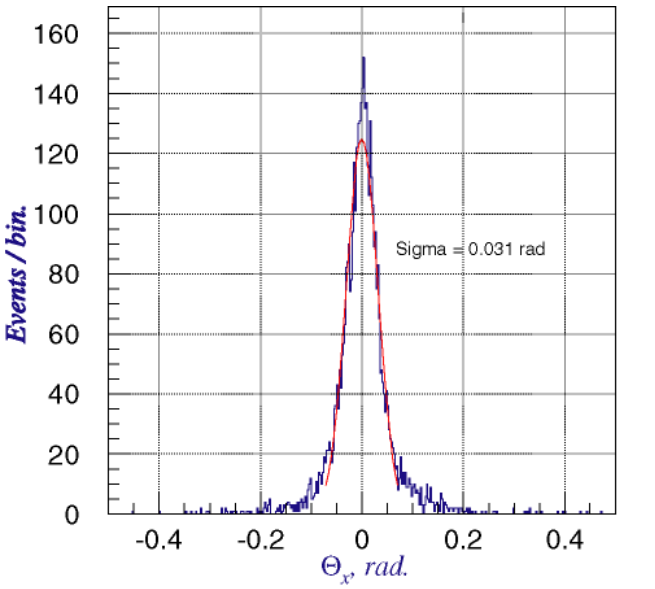
We will need $\sigma_\theta \sim 30$mr

MC indicates this can be done



Prototype tests in the LEGS tagged γ beam at the BNL NSLS confirmed this:





Θ_x distribution of detected photons. E_γ = 150 MeV.

$K_L \to \pi^0 \ell^+ \ell^-$

These decays also sensitive to $ImV_{ts}^* V_{td}$

At first sight much more tractible than $K_L \to \pi^0 \nu\bar{\nu}$

But they suffer from a number of problems, both experimental and theoretical

In addition to $B\left(K_L \to \pi^0 \ell^+ \ell^-\right)_{dir}$ there are 3 problematical contributions:

1. Background from $K_L \to \gamma\gamma \ell^+ \ell^-$
   $\sim 10^{-5}\times$ larger than $K_L \to \pi^0 \ell^+ \ell^-$
   Even with very good resolution very hard to fight,
   already seems to be appearing in signal boxes

2. CP-conserving 2γ-mediated state
   Roughly comparable in size to CP-violating piece
   Information on $K_L \to \pi^0 \gamma\gamma$ relevant
   New data from NA48
   But not so easy to make the connection
   F. Gabbiani & G. Valencia hep-ph/01005006
   absorptive contribution model dependent
   + large uncertainty in dispersive contribution

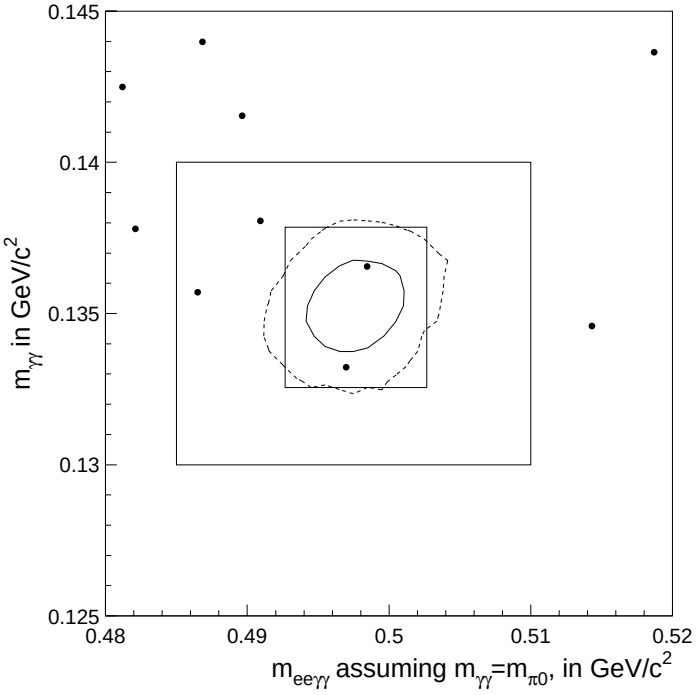
3. State-mixing CP-violating contribution $\propto |\epsilon|^2 B\left(K_S \to \pi^0 \ell^+ \ell^-\right)$
   Best knowledge is of $B\left(K_S \to \pi^0 e^+ e^-\right)$, $< 1.6 \times 10^{-7}$ (NA48)
   This yields $B\left(K_L \to \pi^0 e^+ e^-\right)_{indir} < 4.8 \times 10^{-10}$
   Still probably $100\times$ larger than actual effect
   To make life even more interesting, there's interference

Is there a way out of this morass?

KTeV $K_L \to \pi^0 \ell^+ \ell^-$

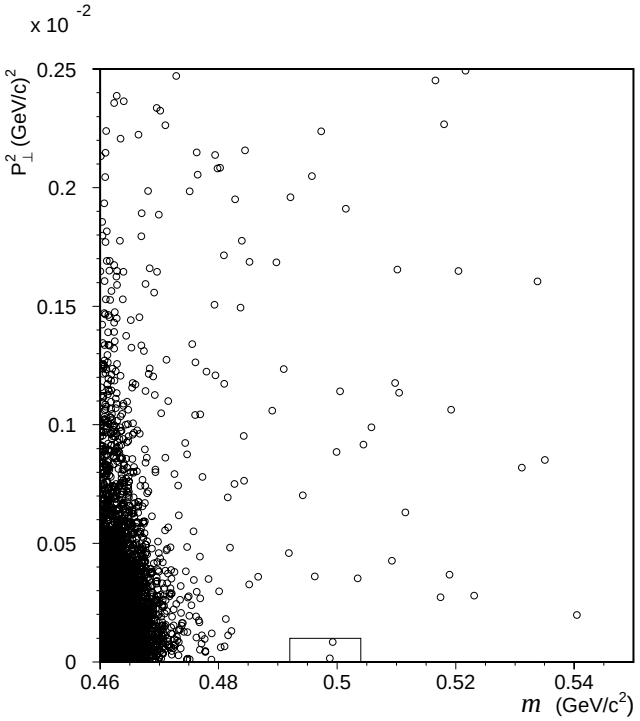
$B(K_L \to \pi^0 e^+ e^-) < 5.1 \times 10^{-10}$

Main background:
$K_L \to \gamma\gamma e^+ e^-$



$B(K_L \to \pi^0 \mu^+ \mu^-) < 3.8 \times 10^{-10}$

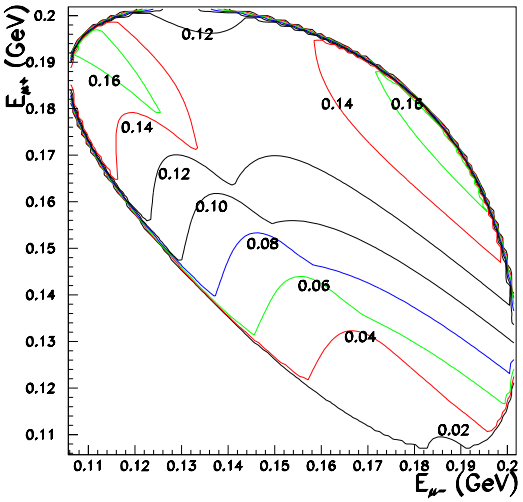
Main backgrounds:
$K_L \to \gamma\gamma\mu^+\mu^-$
$K_L \to \pi^0\pi^+\pi^-$
$K_L \to \pi^\pm\mu^\mp\nu$ + 2 accid γ



Near term prospect: $\sim 2.5\times$ more data
- but background already closing in.

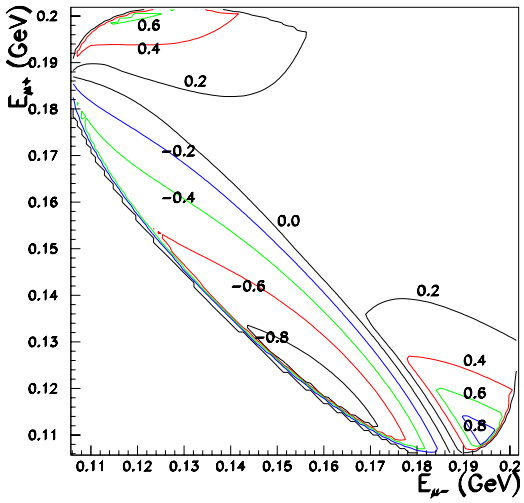
$\pi^0\mu^+\mu^-$ Summary

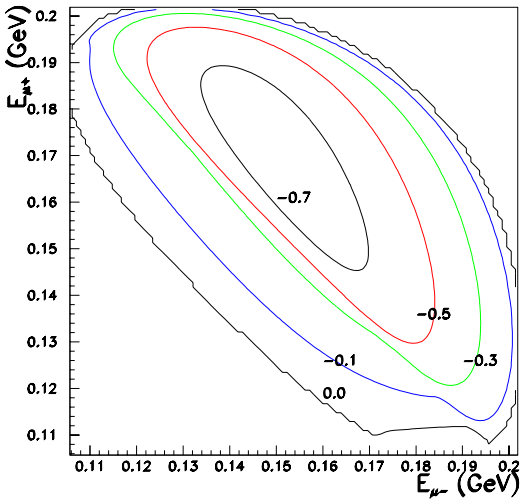
- The parity-odd observable P_L has the interesting property of being sensitive to Direct-CPV.
- Both out-of-plane polarization and the lepton energy asymmetry are sensitive to indirect CP.
- Could all three measurements and the branching ratio be used to obtain the direct component ?
- Still need to examine how well the decay is described in terms of a_s, α_V, and $Im(\lambda_t)$.



Decay distribution

Longitudinal and out-of-plane polarizations





Future for Rare Kaons

Near term:

- AGS-E949 $K^+ \to \pi^+ \nu\bar{\nu}$ to $\sim 10^{-11}$/evt
  is high BR as high as E787 level?
- KEK-E391a 1st dedicated $K_L \to \pi^0 \nu\bar{\nu}$ experiment
  pilot for JHF experiment
- NA48/1 and /2
  Rare K_S decays
  $K^+ \to 3\pi^\pm$ CP-asymmetry

Medium term:

- CKM - $K^+ \to \pi^+ \nu\bar{\nu}$ to $\sim 10^{-12}$/evt
- KOPIO - $K_L \to \pi^0 \nu\bar{\nu}$ measure $Im\,(\lambda_t)$ to 10%
- Very interesting comparisons with B sector

Long term:

Facility	E_p (GeV)	p/sec	$0.7\,GeV/c$ K^+	45° K_L	K_L (fw d.)
BNL AGS	24	3×10^{13}	1.	1.	1.
FNAL MI	120	10^{13}	0.51	0.47	1.68
JHF	50	6×10^{13}	2.12	2.23	3.74
CERN μSR	24	10^{15}	30.	30.	30.

Conclusions

LFV experiments have been pushed to remarkable sensitivities
- correspond to mass scale of well over 100 TeV

But success has killed most models predicting LFV in K decay
- future mainly as by-products of other studies

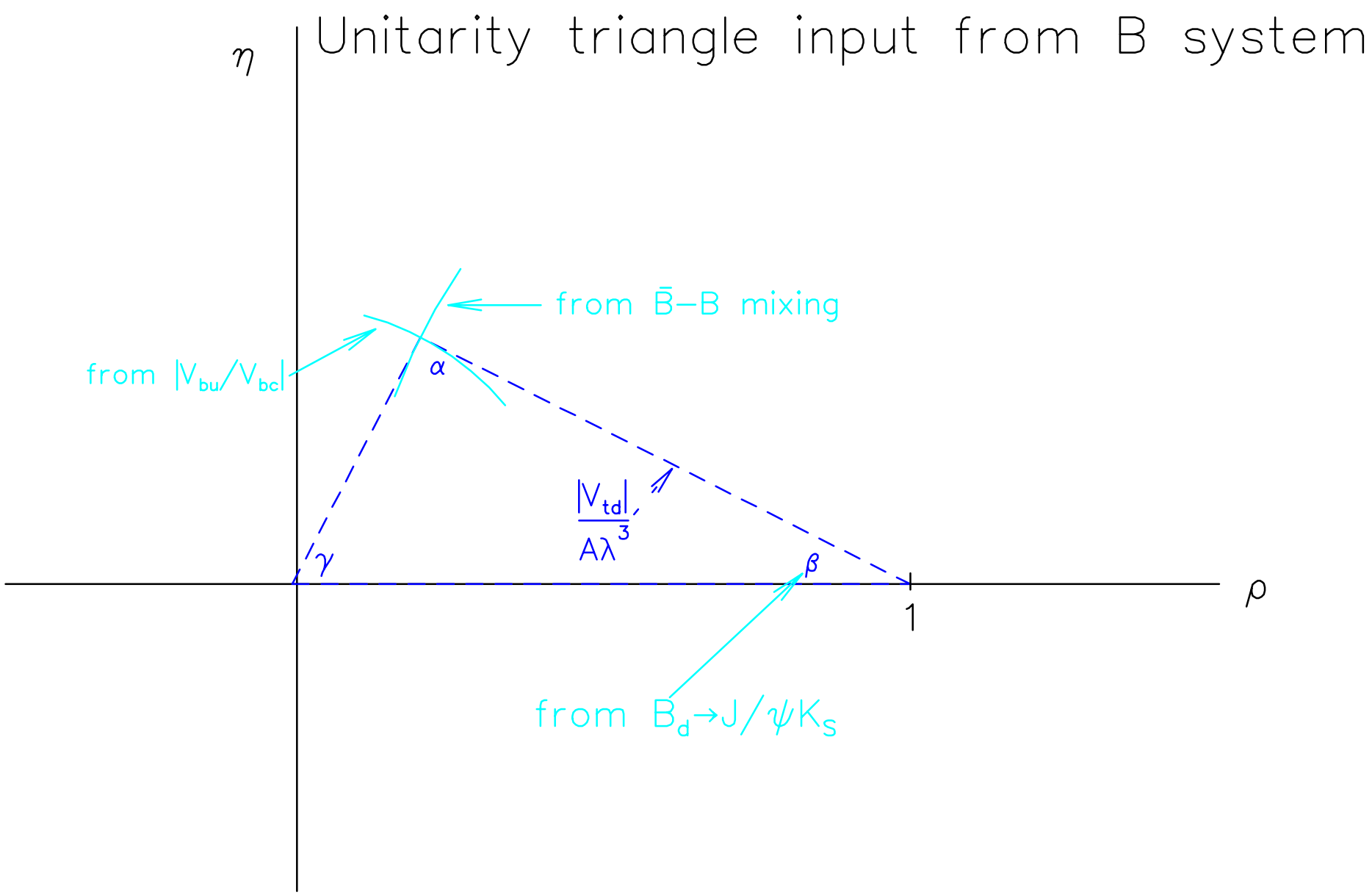
High precision measurement of $K_L \to \mu^+\mu^-$ available
- very useful if theoretical issues resolved
- auxilliary measurements to help this resolution in process
- but situation still unsettled

$K_L \to \pi^0\ell^+\ell^-$ experiments have been pushed by an O.M.
- Experiments on auxillary processes have made similar progress
- But background is starting to be seen
- and progress in untangling the components slow
- Maybe new idea will help

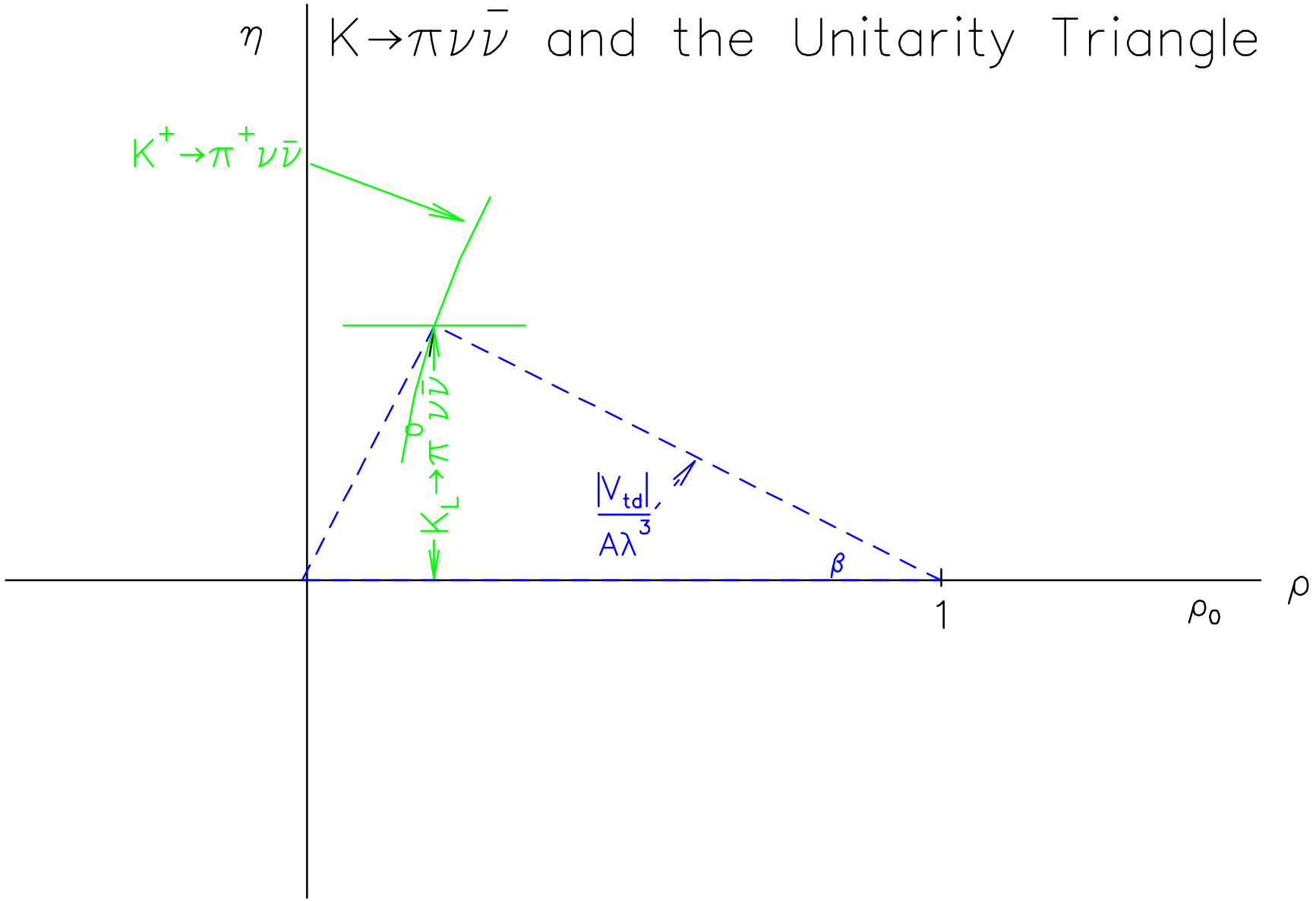
$K^+ \to \pi^+\nu\bar{\nu}$ has been seen,
- clear that it can be exploited
- two initiatives to pursue it further
  - 10^{-11}/evt level experiment in testing stage
  - 10^{-12}/evt level experiment in R&D phase

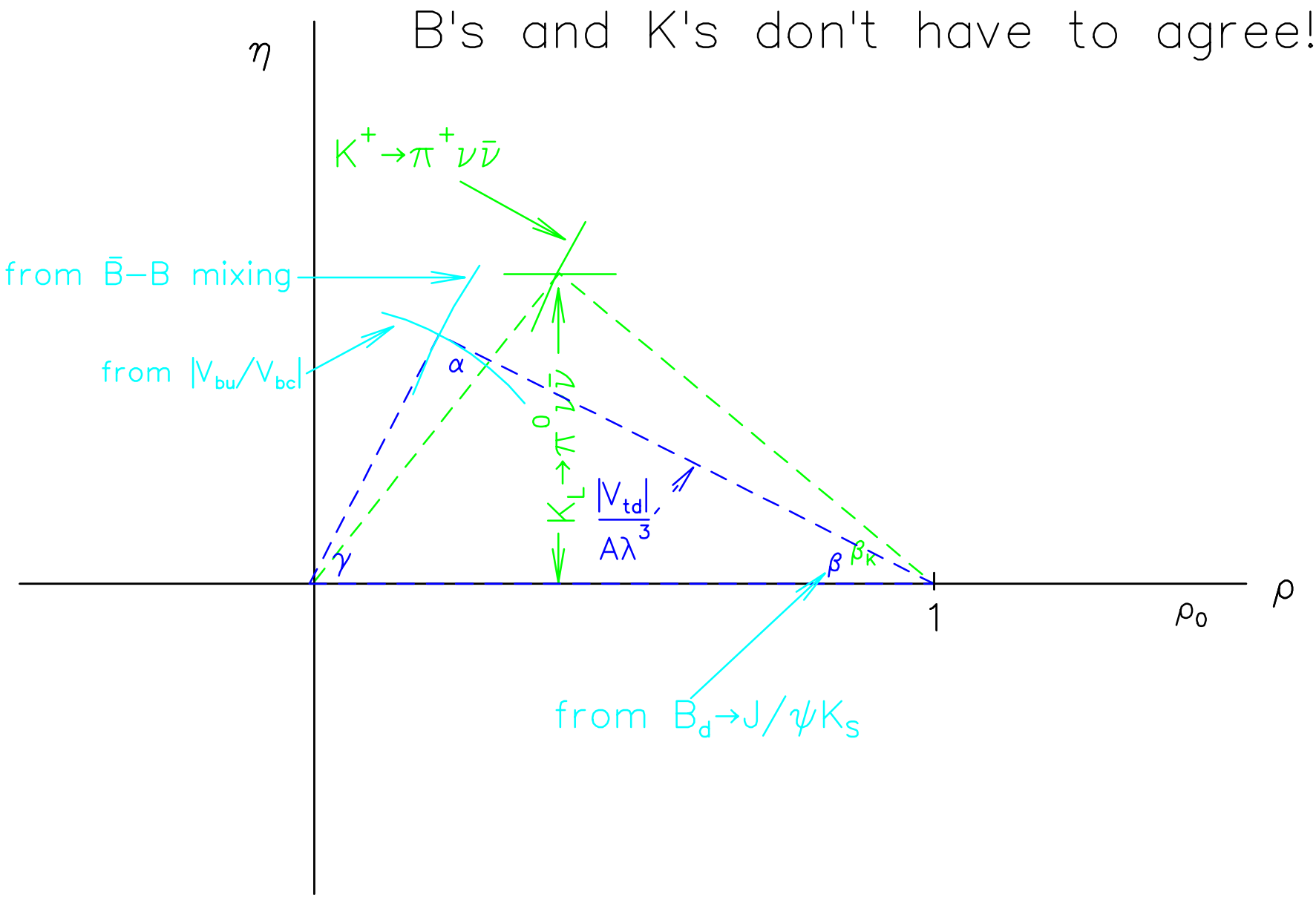
First dedicated experiment to seek $K_L \to \pi^0\nu\bar{\nu}$ proceeding
Initiative to go all the way in progress
- trying for $\sim 10\%$ measurement of η

Goal is future high precision determinations of λ_t from K's
to be compared to B information to critically test SM


Unitarity triangle input from B system
η
ρ
1
from B̄–B mixing
from |V_bu/V_bc|
α
β
γ
|V_td|
Aλ^3
from B_d→J/ψK_S

$K \to \pi \nu \bar{\nu}$ and the Unitarity Triangle




B's and K's don't have to agree!
η
ρ
ρ0
1
K+→π+νν̄
from B̄–B mixing
from |Vbu/Vbc|
α
β
γ
βK
KL→π0νν̄
|Vtd|/Aλ3
from Bd→J/ψKS