The physics of higher Intensity PS or SPS

Kaons, Muons, Neutrinos

Augusto Ceccucci/CERN

May 26, 2004

Workshop on Physics with a Multi-MW proton source

Framework

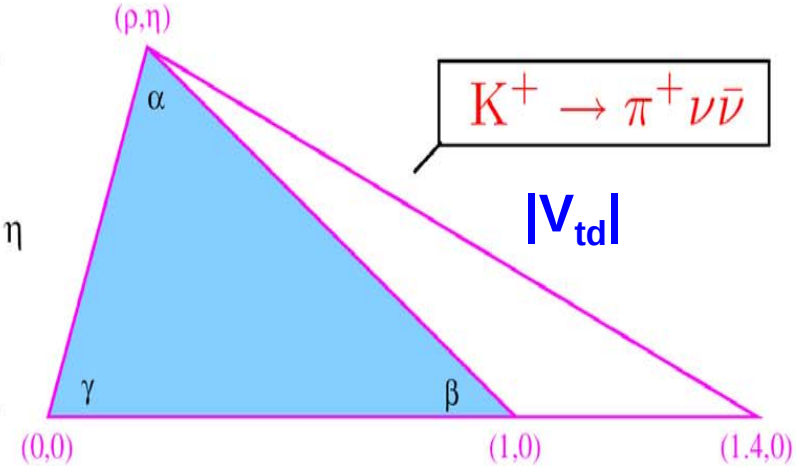
- **Short to medium term scenario:**
- **Current PS and SPS**
  - **Intensity increase always welcome (x 1.5 ?)**
  - **As outlined by Cappi et al. (CERN-SL-2001-032):**
    - **A gain of a factor 3.0 is unrealistic even with an SPL**
    - **PS and SPS collective effects are the essential limitations**
- **Evaluate the next logical experiments in KAON, MUON and/or NEUTRINO physics that could take place at the current machines**
- **Longer term scenario:**
- **Assume new PS and/or SPS capable of higher intensity/energy as ultimate injectors for LHC**
- **Assume refurbished extraction areas to handle larger intensities**

Kaon Rare Decays and the SM

CP-Violation

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

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



CP-Conservation

$K_L \to \mu^+ \mu^-$ { $K_L \to \gamma\gamma$, $K_L \to e^+e^-\gamma$; $K_L \to e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$ }

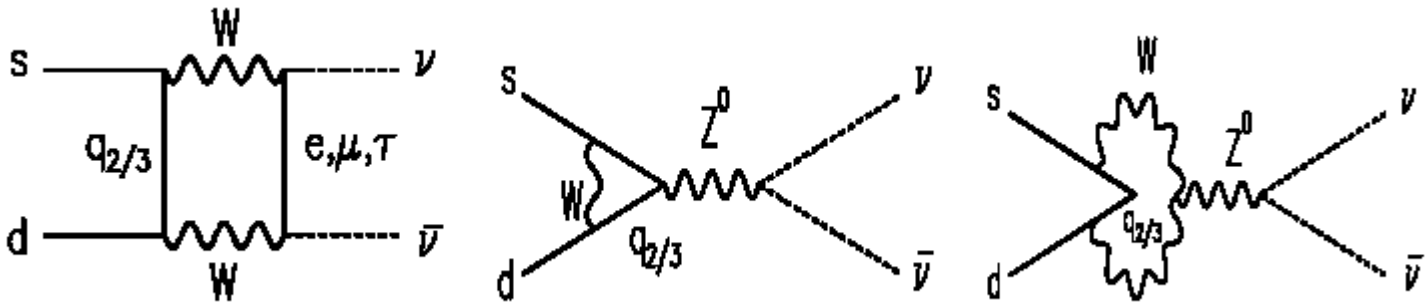
Kaons provide quantitative tests of SM independent from B mesons

Some of these tests are the most theoretically pristine

Kaons @ SPS
“Short to medium term”

$K^+ \to \pi^+ \nu\nu$: Theory

- **The hadronic matrix element can be extracted from the well measured $K^+ \to \pi^0 e \nu$**
- **No long distance contributions**



$$B_{SD}(K^+ \to \pi^+ \nu\bar{\nu}) = \frac{\kappa_+ \alpha^2 B(K_{e3})}{2\pi^2 \sin^4\theta_W |V_{us}|^2} \sum_l |X_t \lambda_t + X_c \lambda_c|^2 =$$

$$8.9 \times 10^{-11} A^4 \left[(\rho_0 - \bar{\rho})^2 + \bar{\eta}^2\right]$$

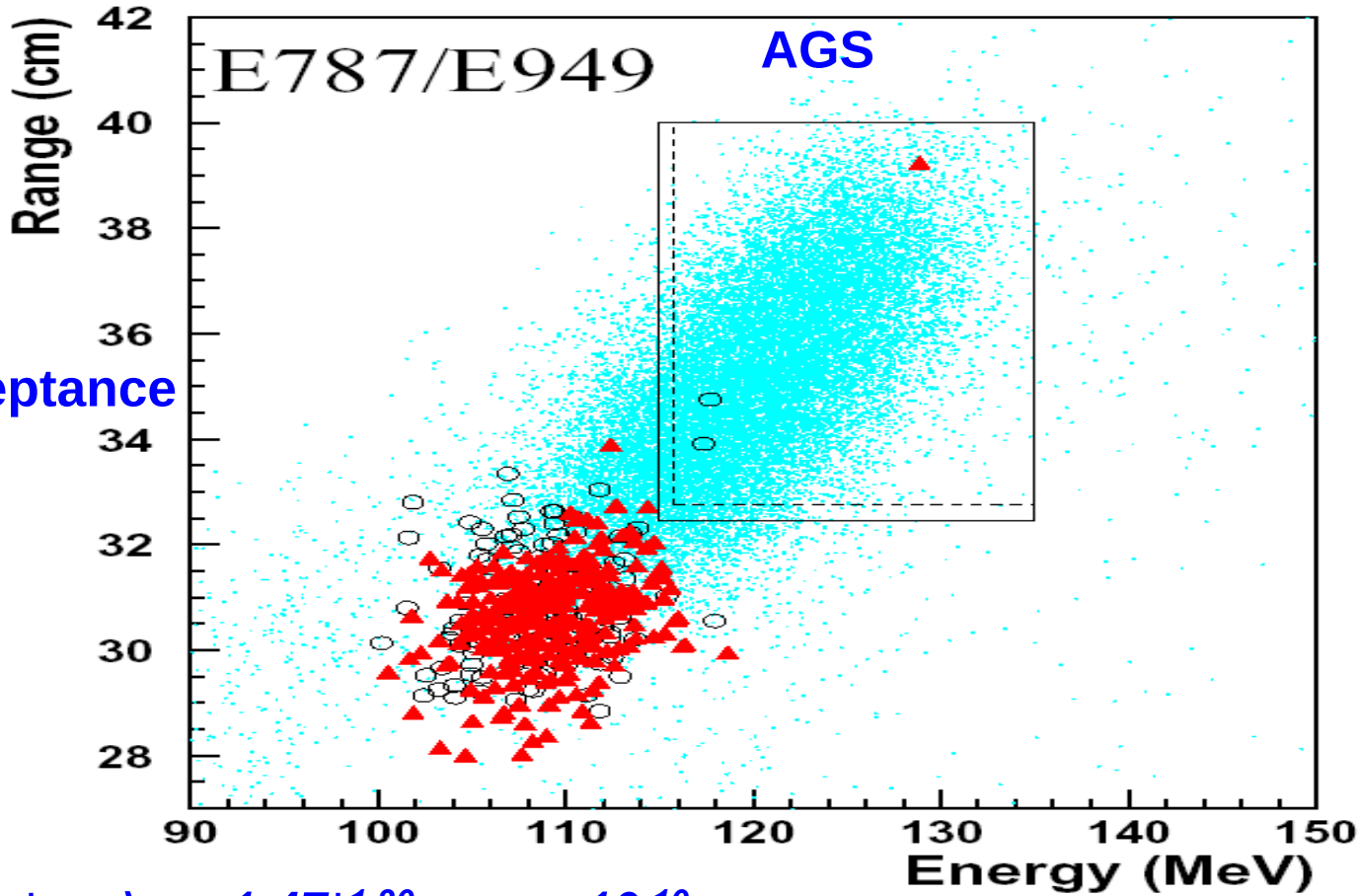
QCD NLO Buchalla, Buras 1999

Prediction (CKM Workshop): $BR(K^+ \to \pi^+ \nu\nu) = 8.0 \pm 1.1 \times 10^{-11}$

Expect improvements NNLO calculation + reduction parametric uncertainty

$K^+ \to \pi^+ \nu\nu$: State of the art

hep-ex/0403036



Stopped K
~0.1 % acceptance

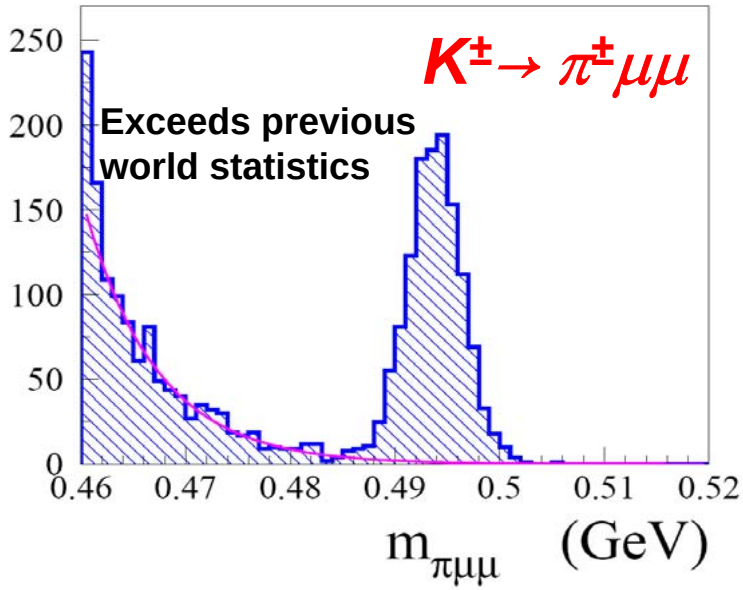
$BR(K^+ \to \pi^+ \nu\nu) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$

- Twice the SM, but only based on 3 events…
- May accumulate ~10 SM events before 2010

NA48 Data Taking

NA48: ε'/ε	1997
ε'/ε	1998
ε'/ε	1999
no spectrometer K_L / NA48/1 K_S	2000
ε'/ε lower inst. intensity	2001
NA48/1: K_S	2002
NA48/2: $K^{\pm}$	2003
NA48/2: $K^{\pm}$	2004

2003 Data, Preliminary



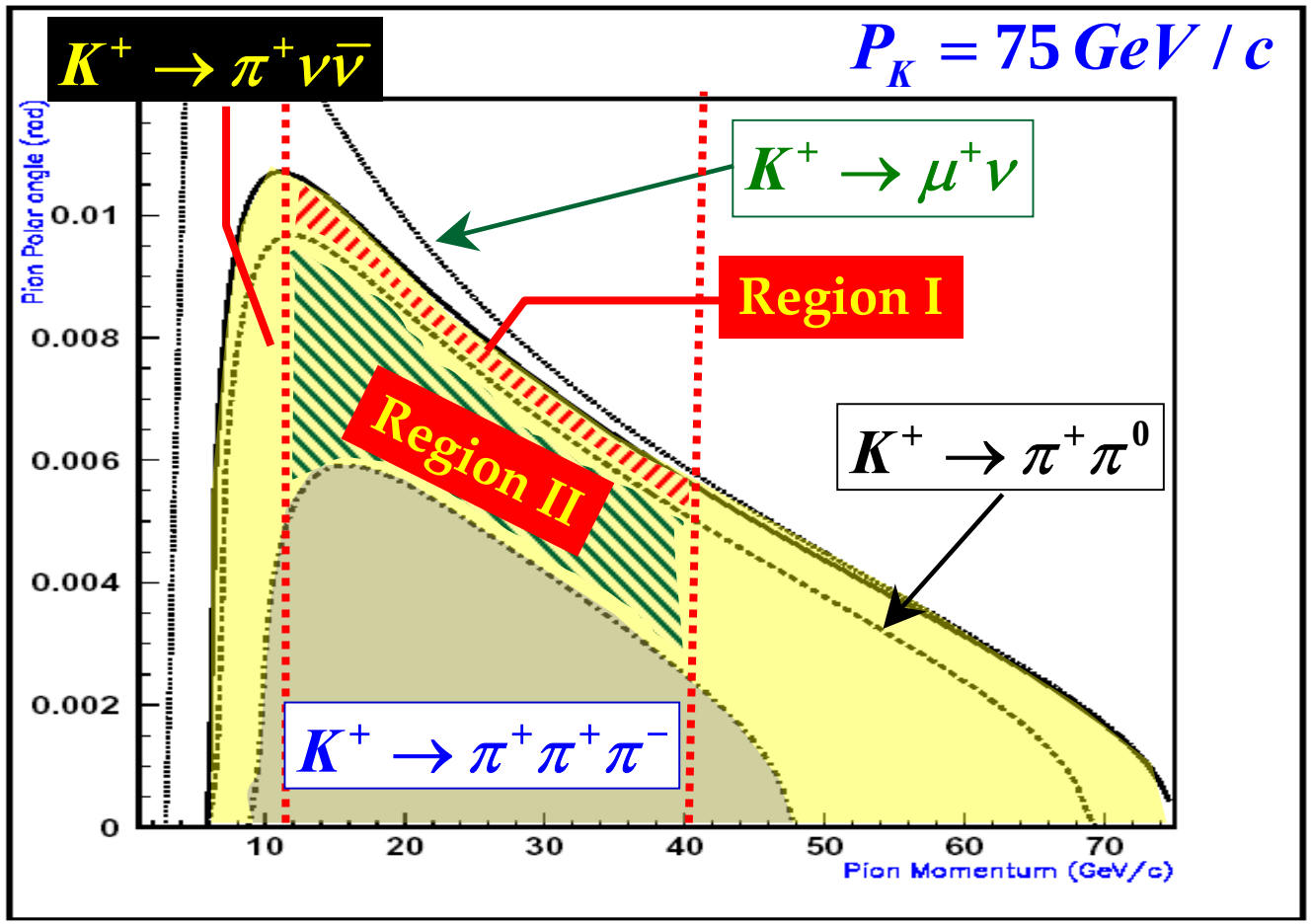
Magnetic spectrometer

Liquid krypton EM calorimeter

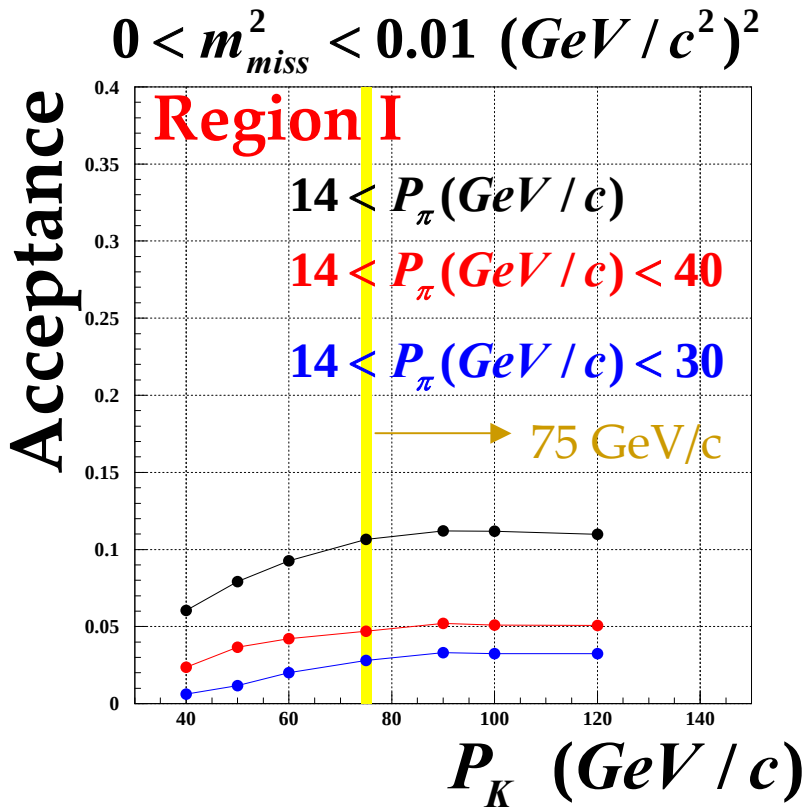
Possible new high-intensity K^+ beam for 'NA48/3' ($K^+ \to \pi^+ \nu\nu$)

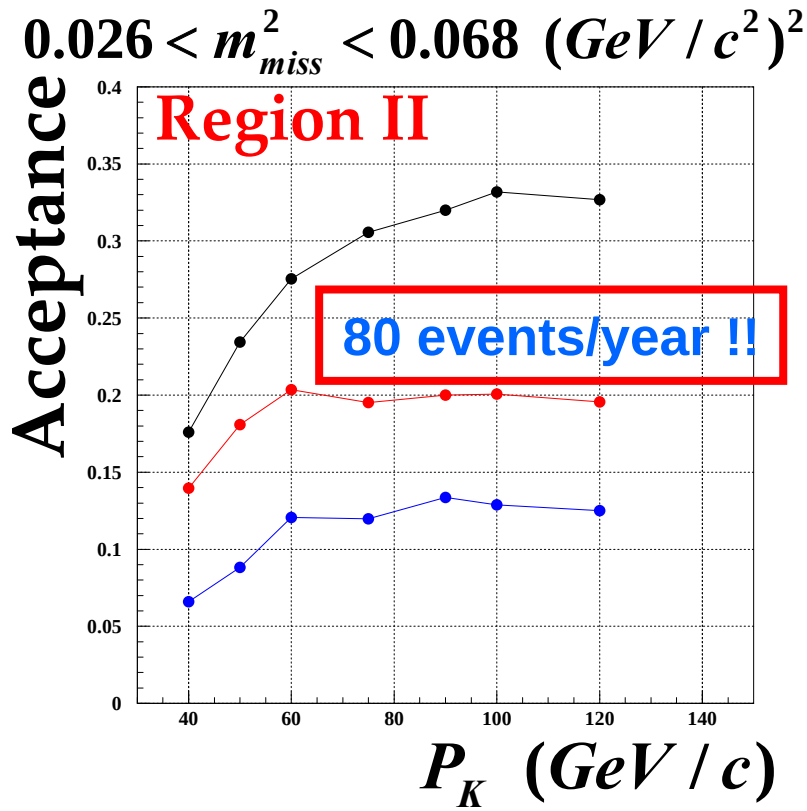
Beam:	Present K12 (NA48/2)	New HI K^+ > 2006	Factor wrt 2004
SPS protons per pulse	1×10^{12}	3×10^{12}	3.0
Duty cycle (s./s.)	4.8 / 16.8	→	1.0
Solid angle (μsterad)	≈ 0.40	≈ 16	40
Av. K^+ momentum $\langle p_K \rangle$ (GeV/c)	60	75	Total : 1.35
Mom. band RMS: ($\Delta p/p$ in %)	≈ 4	≈ 1	~0.25
Area at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

Acceptance


$K^+ \to \pi^+ \nu\bar{\nu}$
$P_K = 75\,GeV/c$
$K^+ \to \mu^+ \nu$
Region I
Region II
$K^+ \to \pi^+ \pi^0$
$K^+ \to \pi^+ \pi^+ \pi^-$
Pion Polar angle (rad)
0
0.002
0.004
0.006
0.008
0.01
10
20
30
40
50
60
70
Pion Momentum (GeV/c)

Acceptance (II)





$P_K = 75\ GeV/c \quad P_\pi < 40\ GeV/c$

Acceptance (Region I) ~ 5%

20 events per year
@ BR = 10^{-10} (Region I)

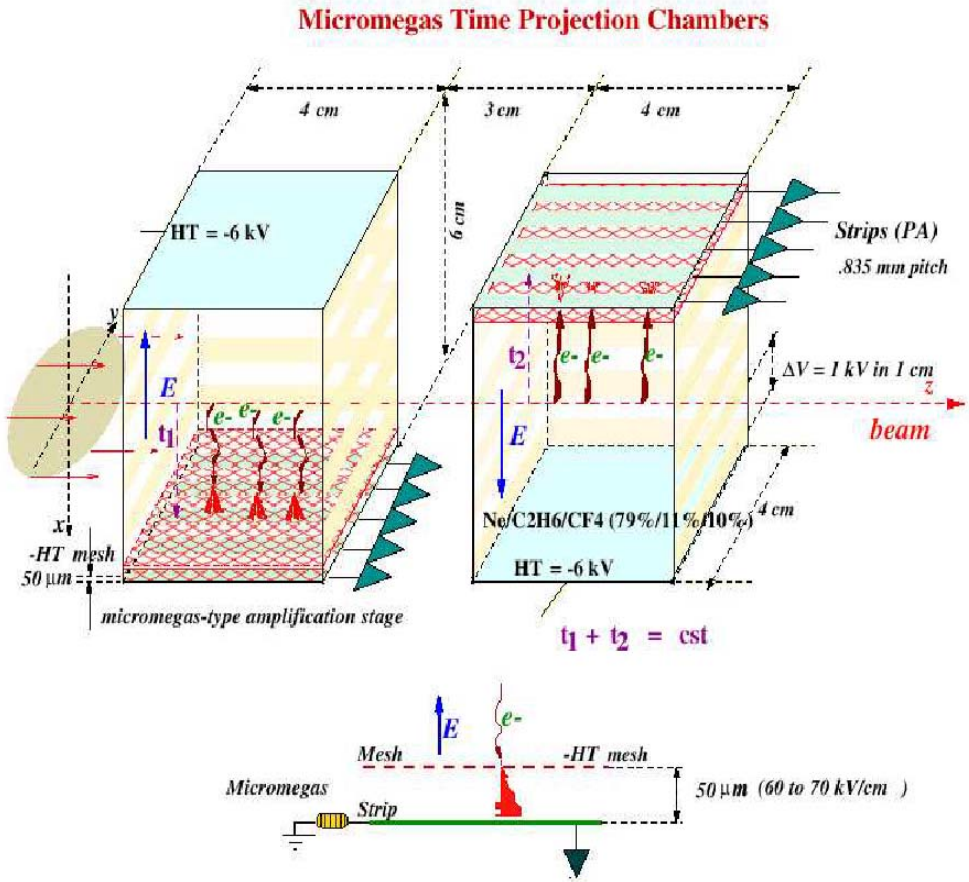
The Challange: Beam Spectrometer

Currently used in NA48/2
@ 2 MHz/strip

- Resolution strips 80 μm
- Resolution drift 50 μm
- Time resolution 0.7 ns
- Dead time/strip 40 ns
- ΔP/P 0.5 %

Improvement for NA48/3
(expected 20 MHz/strip)

- New micro-mesh 25 μm
- New gas
- FADC → Old NA48 Tagger readout (1 GHz FADC)
- Smaller strip size
- Si micro-pixels (sub-ns time resol.)



Test foreseen during 2004 run

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

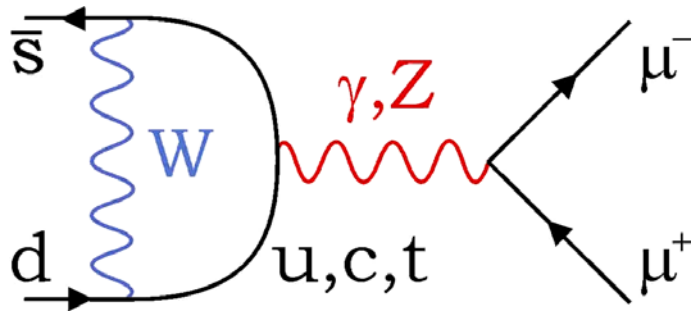
- Similar plans @FNAL
- Upstream tracker @ 40 MHz/cm^2 , ~100 ps time resolution
  - Very interesting for super LHC
- The experiment would profit from high energy separated kaon beam
  - requires ~100 times more protons to employ same beam momentum
- Difficulty of experiment, not to be underestimated:
  - 800 MHz charged beam crossing the kaon spectrometer
  - Minimal material budget allowed
  - 2/3 invisible signal, three body decay
  - Hermetic photon detection required
  - Redundant measurement of kinematics
  - Good vacuum over a large volume
- But the reward could be very important: possibly the most precise determination of $|V_{td}|$

Kaons: Longer term (i.e. More Protons Needed!)

- $K^0_L \to \pi^0 e^+ e^-$ and $K^0_L \to \pi^0 \mu^+ \mu^-$
- $K^0_L \to \pi^0 \nu \nu$

$K^0_L \to \pi^0 e^+ e^-$ and $K^0_L \to \pi^0 \mu^+ \mu^-$

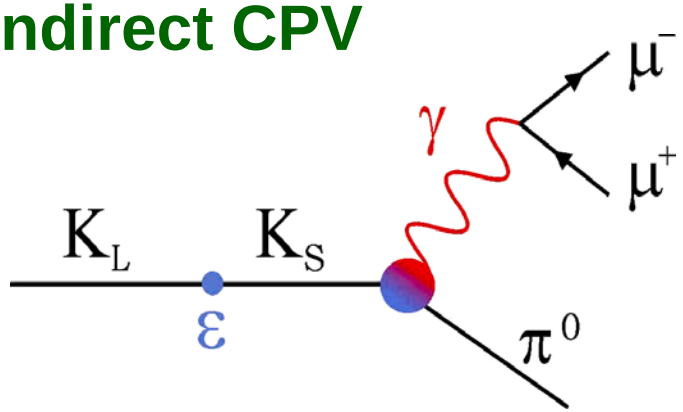
Study Direct CP-Violation

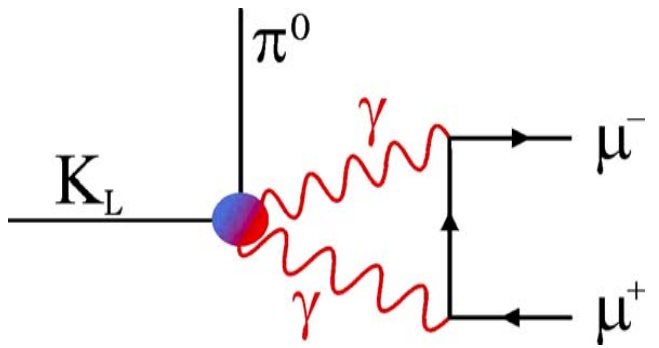


Direct CPV

- Indirect CP-Violating Contribution has been measured (NA48/1)
- Constructive Interference (theory)
- CP-Conserving Contributions are negligible

Indirect CPV

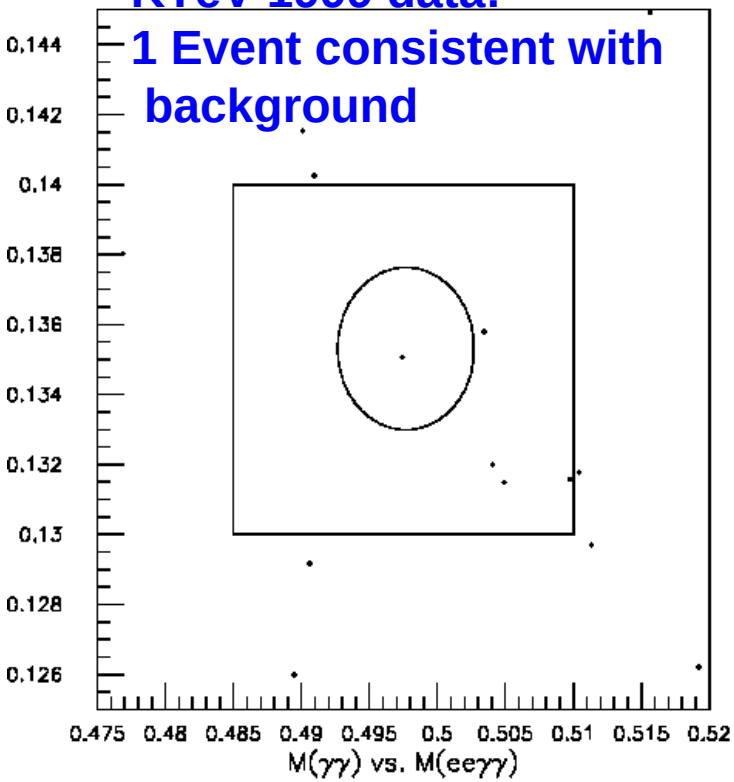




CPC

$K^0_L \to \pi^0 e^+ e^-$ and $K^0_L \to \pi^0 \mu^+ \mu^-$

KTeV 1999 data:
1 Event consistent with background



KTeV 1997+1999:
BR($K_L \to \pi^0$ ee) < 2.8 × 10^{-10} @90%CL

KTeV 1997:
BR($K_L \to \pi^0 \mu^+\mu^-$) < 3.8 × 10^{-10} @90%CL

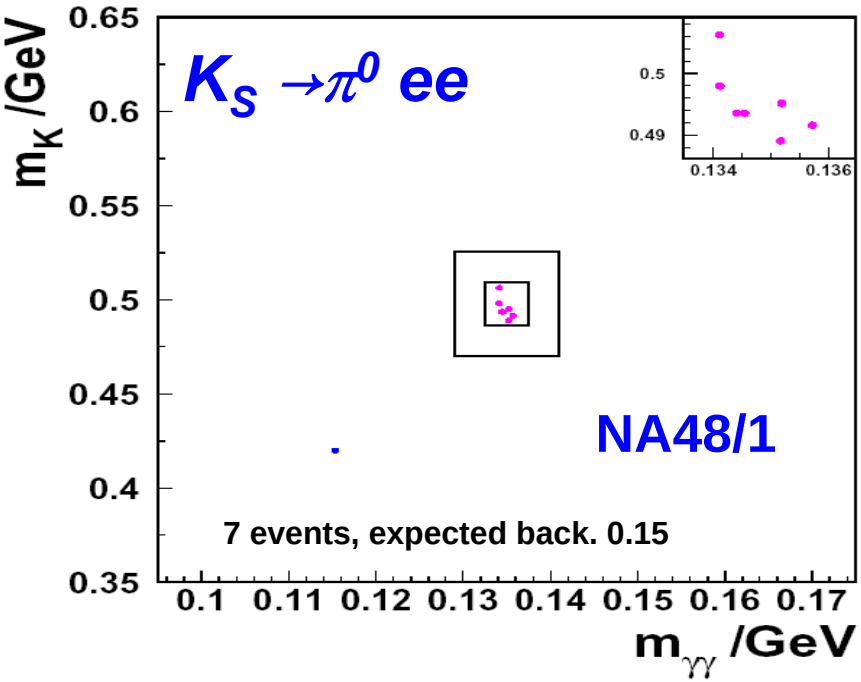
$K^0_L \to \pi^0 e^+ e^-$ is affected by radiative background

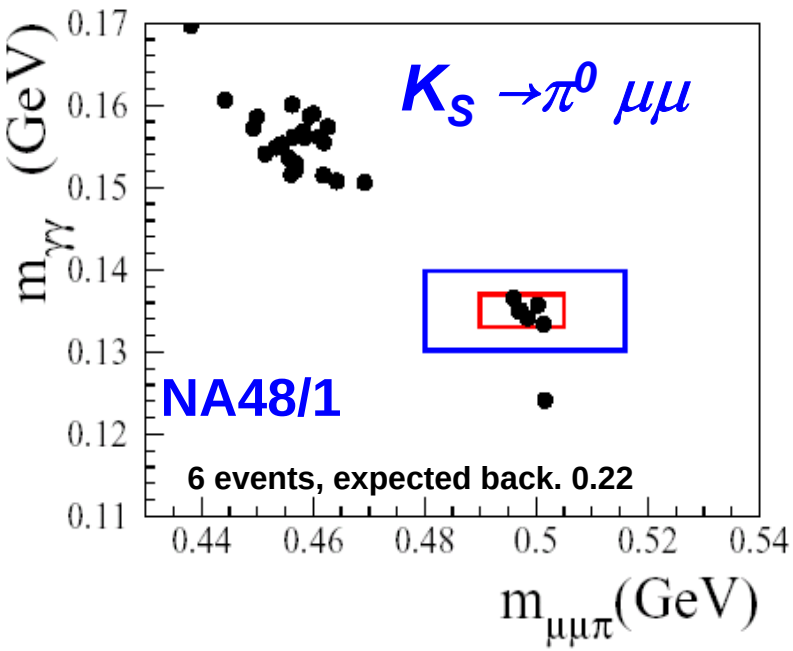
→ Further progress will not linear with beam time!!

→ ~10^{13} p/s, high kaon energy (for best possible $m_{\gamma\gamma}$ resolution)

→ Slow extraction

$K^0_S \to \pi^0 e^+e^-$ and $K^0_S \to \pi^0 \mu^+\mu^-$





$BR(K_S \to \pi^0 ee) \times 10^{-9} =$
$5.8\ ^{+2.8}_{-2.3}(stat) \pm 0.8(syst)$

$|a_s| = 1.06^{+0.26}_{-0.21}\ (stat) \pm 0.07\ (syst)$
PLB 576 (2003)

$BR(K_S \to \pi^0 \mu\mu) \times 10^{-9} =$
$2.9\ ^{+1.4}_{-1.2}(stat) \pm 0.2(syst)$

$|a_s| = 1.55^{+0.38}_{-0.32}\ (stat) \pm 0.05\ (syst)$
La Thuile, Moriond 2004

$K^0_L \to \pi^0 ee$ ($\mu\mu$): Sensitivity to New Physics

Isidori, Unterdorfer,Smith:

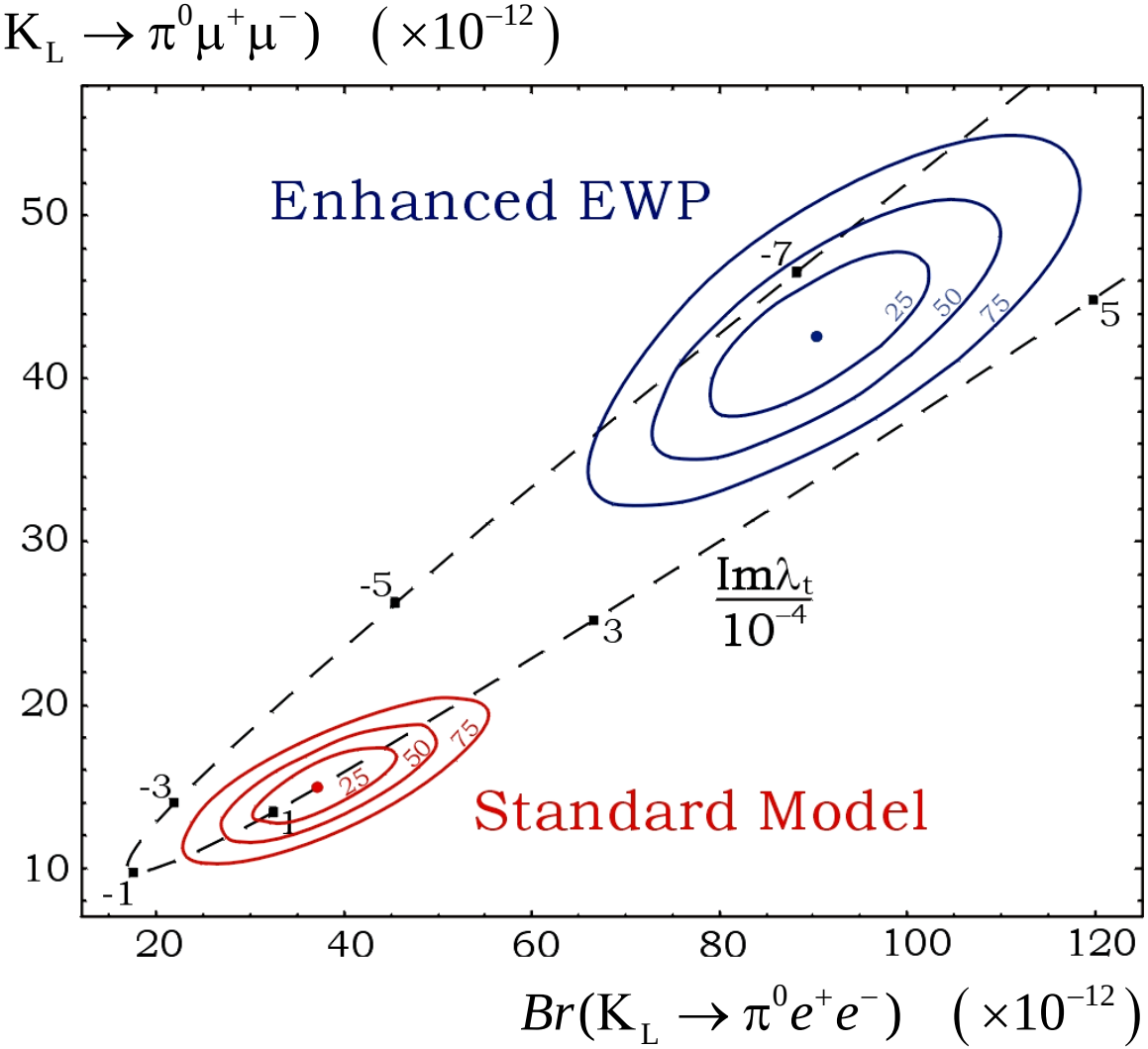
Fleisher et al:

Ratios of B → Kπ modes could be explained by enhanced electroweak penguins

and enhance the BR's:

$$B^{NP}_{e^+e^-} = 9.0^{+1.6}_{-1.6} \times 10^{-11}$$

$$B^{NP}_{\mu^+\mu^-} = 4.3^{+0.7}_{-0.7} \times 10^{-11}$$



$K^0_L \to \pi^0 \nu \nu$

- **Purely theoretical error ~2%: SM $3\ 10^{-11}$**
  - **Purely CP-Violating (Littenberg, 1989)**
  - **Totally dominated from t-quark**
  - **Computed to NLO in QCD (Buchalla, Buras, 1999)**
  - **No long distance contribution SM~3×10^{-11}**

- **Experimentally: 2/3 invisible final state !!**
- **Best limit from KTeV using $\pi^0 \to ee\gamma$ decay**

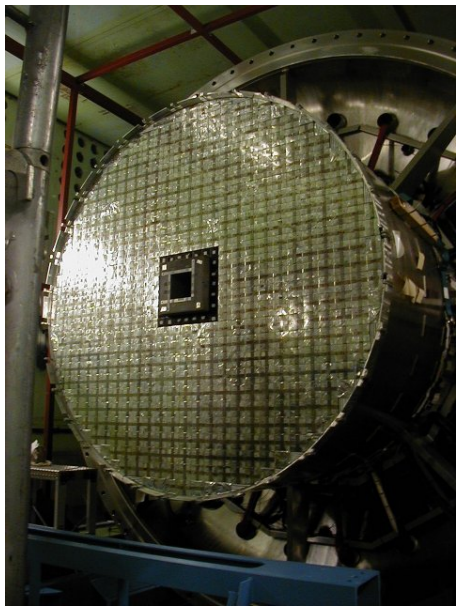
$$BR(K^0 \to \pi^0 \nu\nu) < 5.9 \times 10^{-7} \quad 90\%\ CL$$

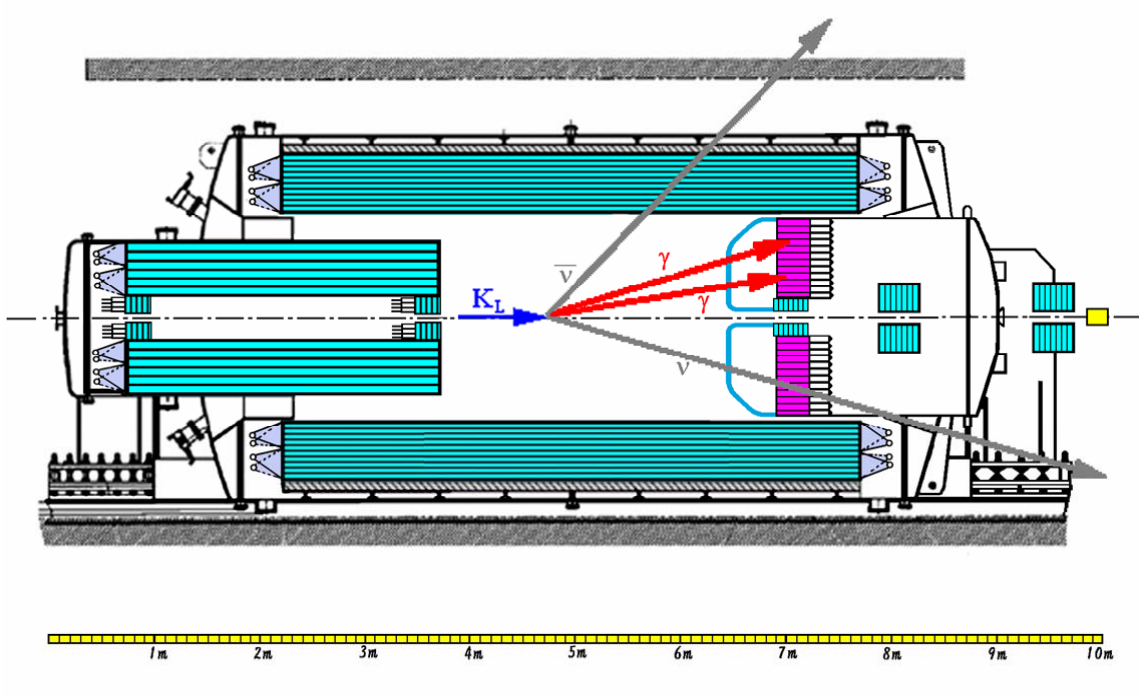
Still far from the model independent limit:

$$BR(K^0 \to \pi^0 \nu\nu) < 4.4 \times BR(K^+ \to \pi^+ \nu\nu) \sim 1.4 \times 10^{-9}$$

Grossman & Nir, PL B407 (1997)

E391a@PS-KEK





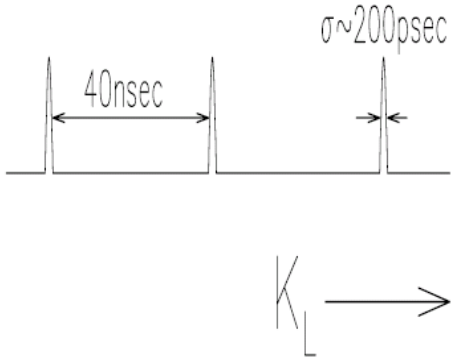
- First dedicated experiment to search for $K_L \rightarrow \pi^0 \nu\nu$
- SES~ 3 10^{-10}
- Based on pencil kaon beam and photon vetoes

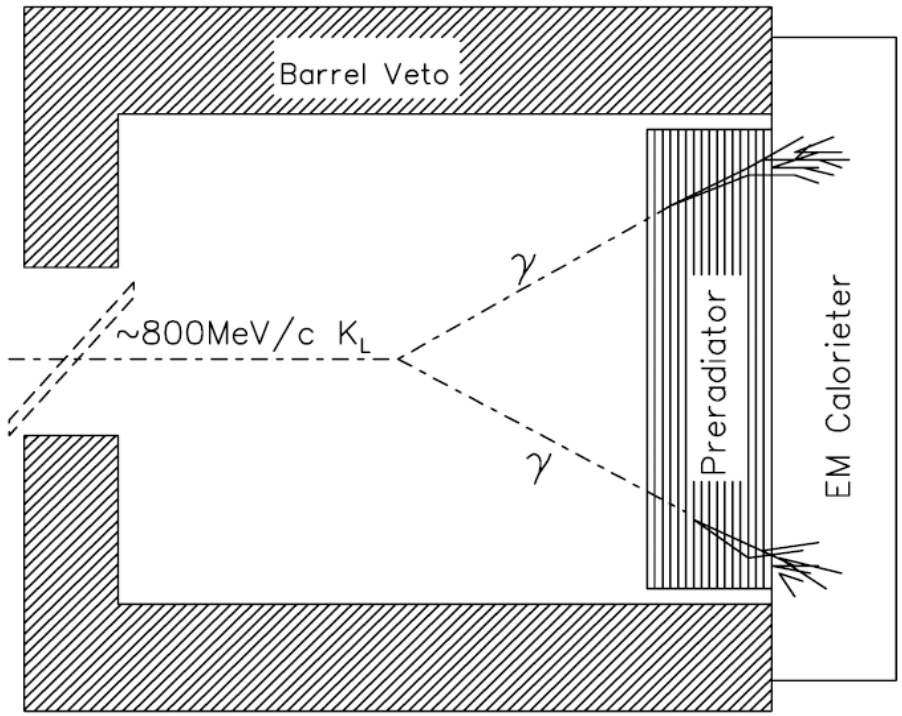
Collecting data right now!

This is a Stage I project for further study at J-PARC

BNL-KOPIO

Employ Time of Flight to determine the energy of the K_L
~3 10^{14} protons /s

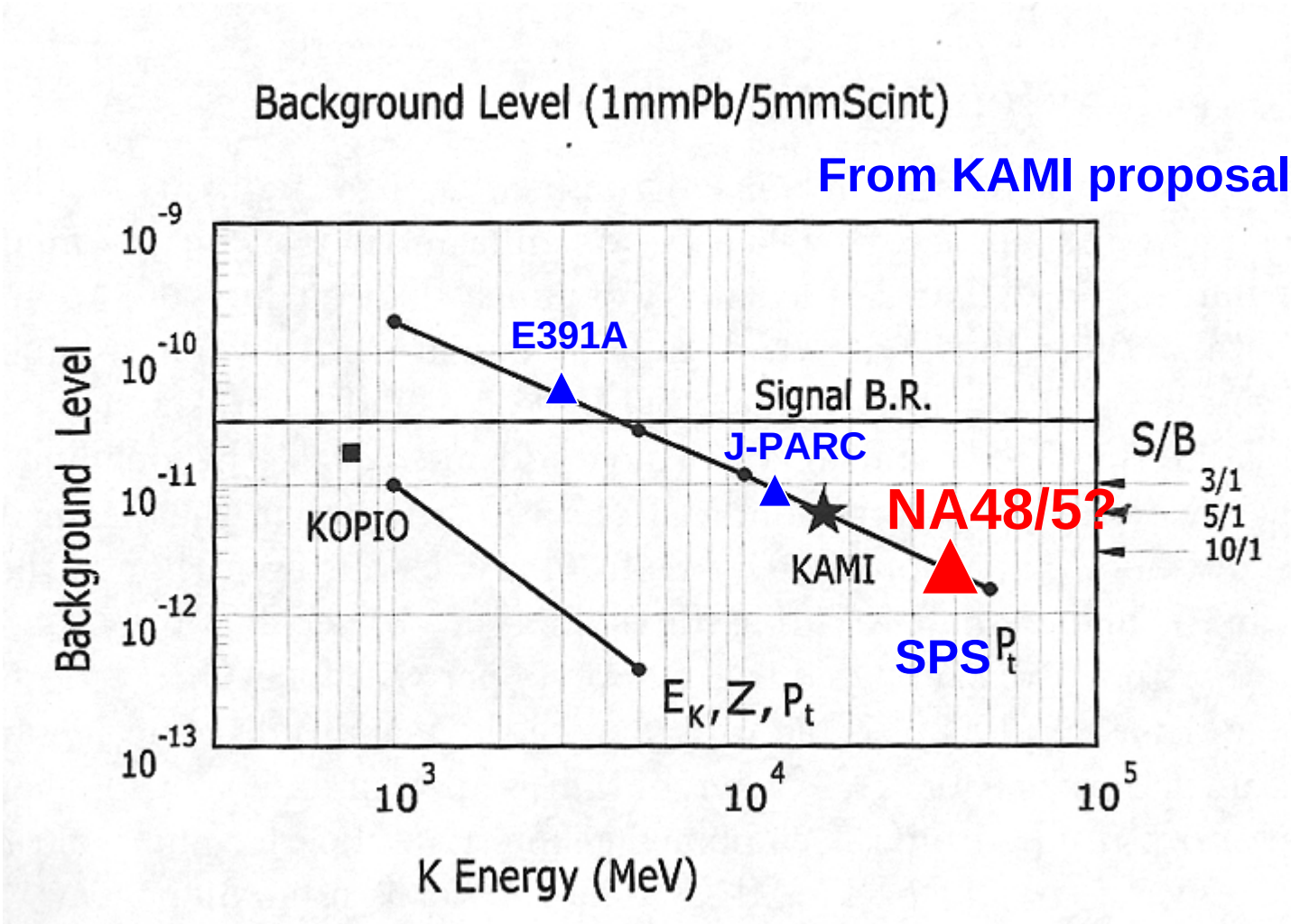




Aims to collect 50 events
With S/B~2
Theory could use 1000 events !!

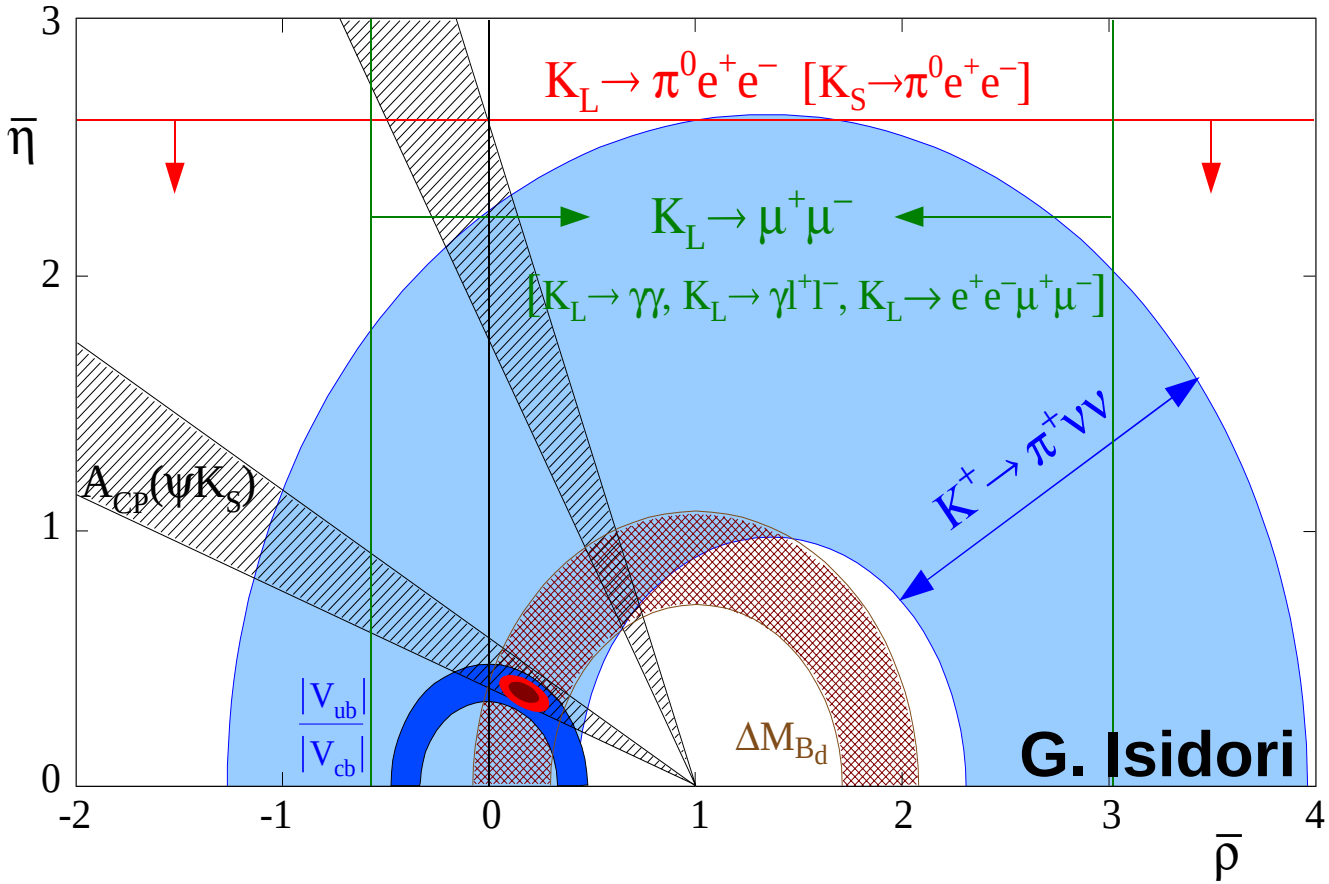
Start construction in 2005

$K_L \to \pi^0 \nu\nu$ @CERN?



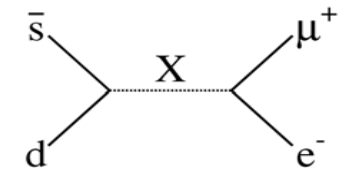
CERN may become competitive if the E391A technique works

Current Status

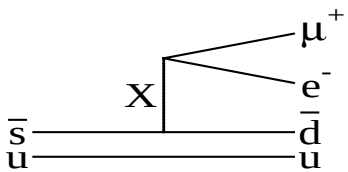


STILL A LARGE WINDOW OF OPPORTUNITY EXISTS

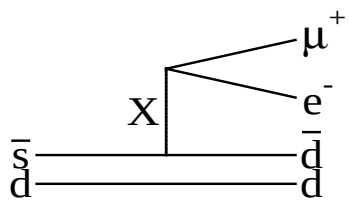
Lower limits on "horizontal" bosons (g_X/g_W)~1



$B(K_L^0 \to \mu^{\pm} e^{\mp}) < 4.7 \times 10^{-12}$ >150 TeV/c²



$B(K^+ \to \pi^+ \mu^+ e^-) < 2.8 \times 10^{-11}$ >60 TeV/c²



$B(K_L^0 \to \pi^0 \mu^+ e^-) < 3.2 \times 10^{-10}$ >37 TeV/c²

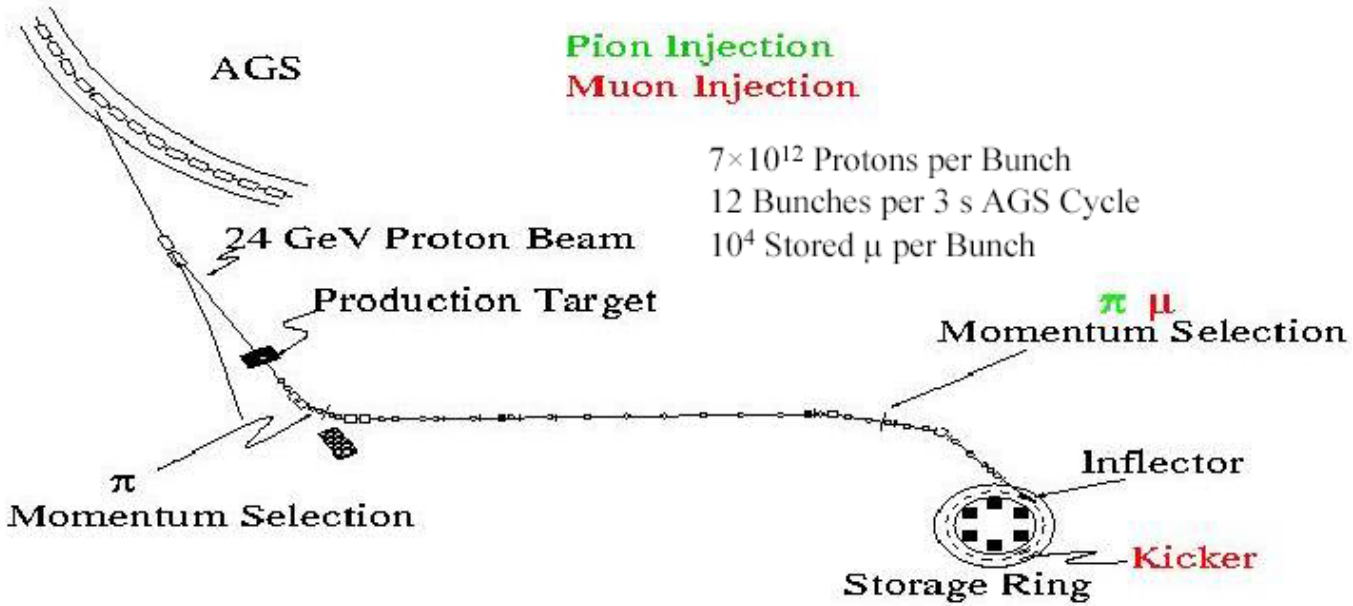
Further progress on LFV expected in the muon sector:

- $\mu \to e\gamma$ PSI
- $\mu^- N \to e^- N$ MECO@AGS, J-PARC?

Muon properties and rare decays

- **High Energy proton source**
  - **g-2**
  - **μ + N → e + N (Internal Conversion)**
  - **μ + N → τ + N (Recent idea)**
- **Low energy proton source (~1-2 GeV)**
  - **μ → e γ , μ → eee (Rare Decays)**
  - **μ EDM**
  - **μ + N → e + N**

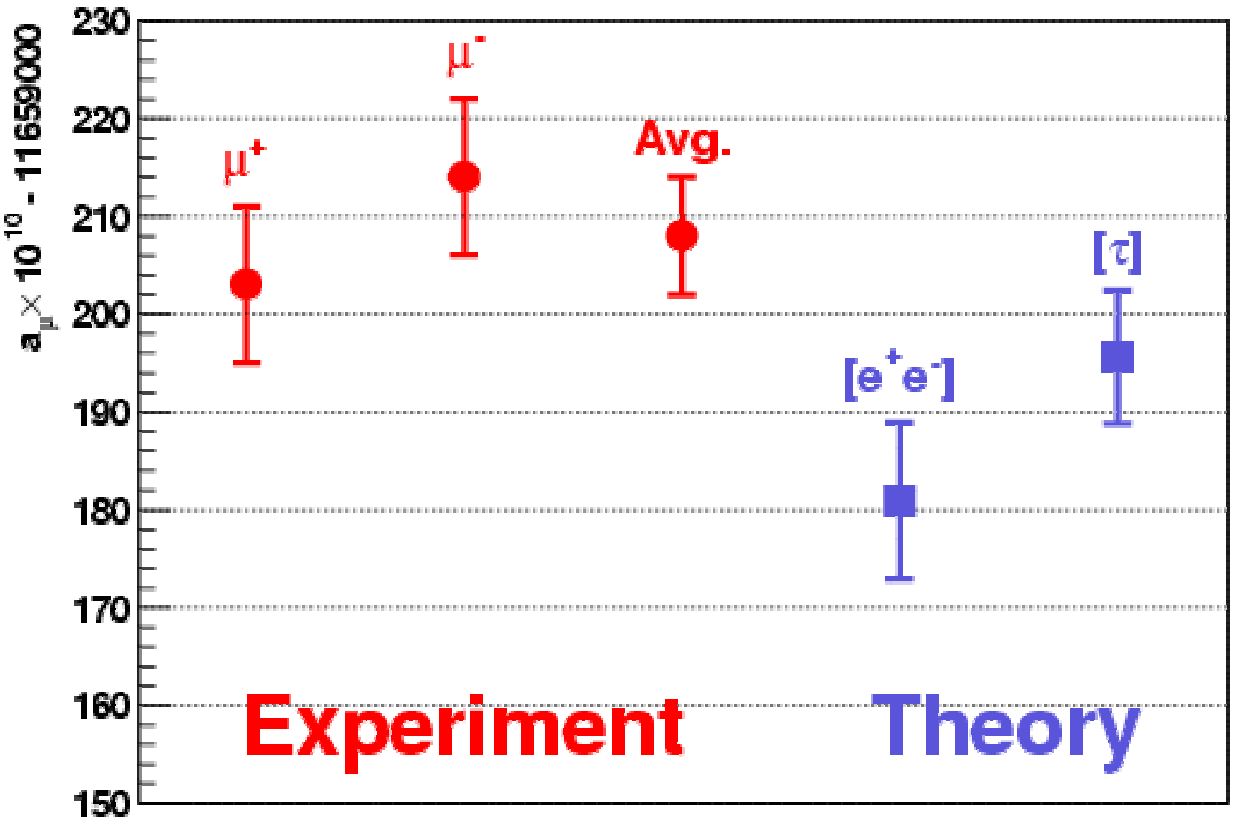
BNL-E821: g-2



- **"the three miracles":**
  1. **γ_{magic} corresponds to E_μ~3 GeV , not 300MeV or 30 GeV**
  2. **It's very easy to have strongly polarized muons**
  3. **It's very easy to measure the polarization of the μ by looking at decay electrons**

$a_\mu = (g-2)/2$

BNL: Muon (g-2) Colaboration

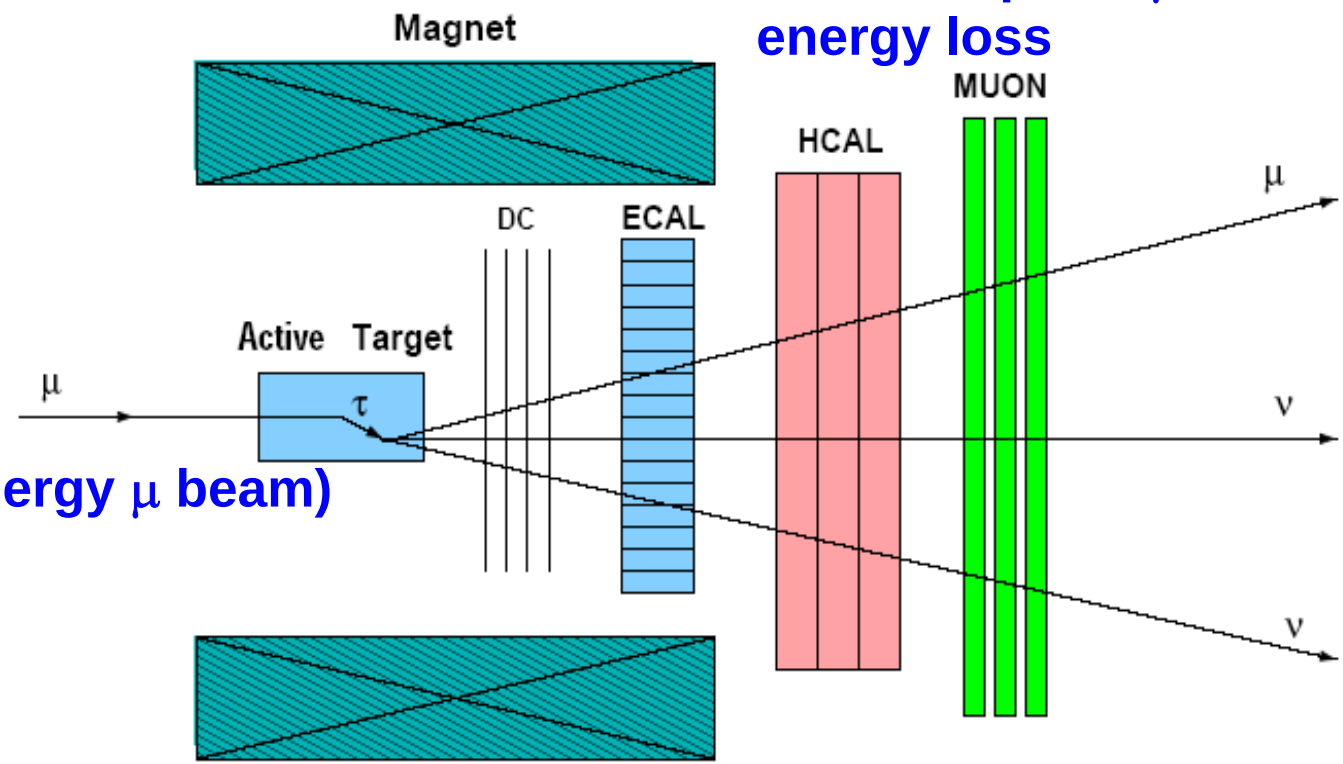


Experiment is statistically limited

μ+ N → τ + N (Internal Conversion)

Gninenko et. al (2002) **(μτ)(cu)**
Sher and Turan (2004) **(μτ)(qq)**

"Catastrophic" μ energy loss



(High Energy μ beam)

Neutrino Oscillations

$$U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$S_{12} = \sin\theta_{12}$ etc.

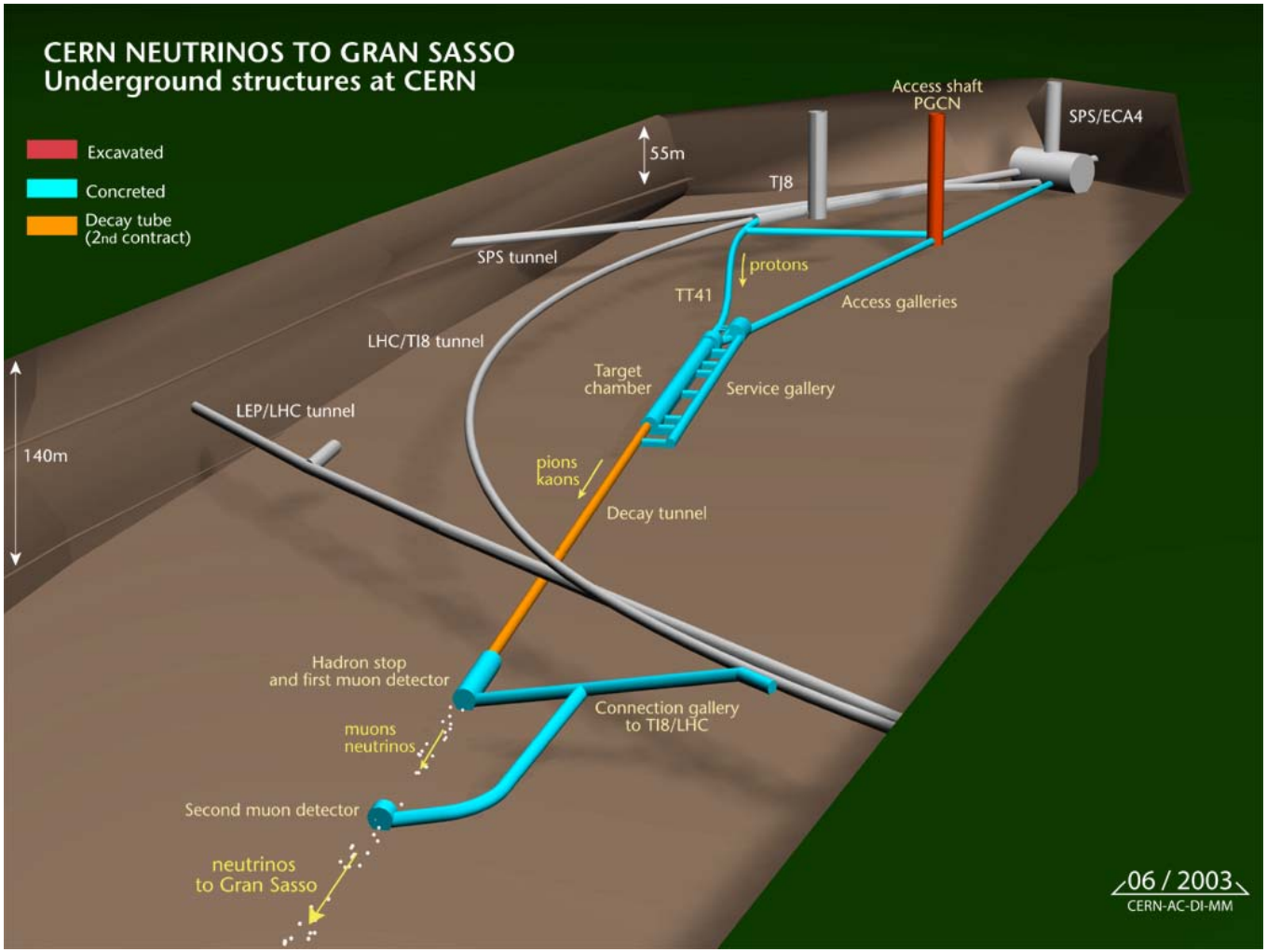
Atm.+K2K
$(\Delta m_{23})^2 = (2.6 \pm 0.4)\ 10^{-3}\ eV^2$
$0.9 < \sin^2\theta_{23} < 1.0$

$\Theta_{13} < 14^o$
$\delta = ?$
Sign $(\Delta m)^2 = ?$

Solar+KAMLAND
$(\Delta m_{12})^2 \sim 7\ \ 10^{-5}\ eV^2$
$0.2 < \sin^2\theta_{12} < 0.5$

- **Current SPS-CNGS Programme**
  - From 2006 onward
  - $E_\nu \sim 18$ GeV; 4.5×10^{19} POT/YEAR
  - Optimised for τ appearance
  - OPERA & ICARUS at Gran Sasso

CNGS


CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
Excavated
Concreted
Decay tube
(2nd contract)
55m
TJ8
Access shaft
PGCN
SPS/ECA4
SPS tunnel
protons
TT41
Access galleries
LHC/TI8 tunnel
Target
chamber
Service gallery
LEP/LHC tunnel
140m
pions
kaons
Decay tunnel
Hadron stop
and first muon detector
Connection gallery
to TI8/LHC
muons
neutrinos
Second muon detector
neutrinos
to Gran Sasso
06 / 2003
CERN-AC-DI-MM

Future SPS Options?

- **Optimise for $\nu_\mu \rightarrow \nu_e$ appearance (θ_{13})**
- **Example: Off-Axis (Dydak)**
  - **90% CL on $\sin^2\theta_{13} \sim 0.002$**
  - **$E_\nu \sim 3$ GeV**
  - **2 Mton see water Cherenkov detector in the Gulf of Taranto**
  - **Possible detector?**
  - **Background from π^0?**
  - **Competition from Reactor Experiments, NOνA?**
  - **Timescale ?**

Conclusions

- **Kaons**
  - **A competitive programme could take place in the near future for charged kaons at the current SPS**
  - **For a very competitive neutral kaon decay experiment, ~ 1 MW of slowly extracted, high energy protons would be ideal**
- **Muons**
  - **The g-2 measurement is statistically limited, more protons could be used**
  - **Constraints on SUSY if experiment agrees with SM, but:**
  - **Theoretical SM prediction has hadronic uncertainties to be fixed by other data (wait and see?)**
- **Neutrinos**
  - **Neutrino Physics is evolving so rapidly**
  - **It is addressing the most fundamental questions**
  - **CERN investment should be fully exploited**

Backup Material

CP-Violation in SM

A phase in the quark-quark current leads to CP-Violation (Kobayashi, Maskawa, 1973)

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$N_g=2 \quad N_{phase}=0 \Rightarrow$ **No CP-Violation**

$N_g=3 \quad N_{phase}=1 \Rightarrow$ **CP-Violation Possible**

6 unitarity relations (triangles in the complex plane)

$$\sum_{i=u,c,t} V_{ij} V_{ik}^* = \sum_{i=u,c,t} V_{ji}^* V_{ki} = \delta_{jk}$$

$\lambda_t = V^*_{ts} V_{td}$

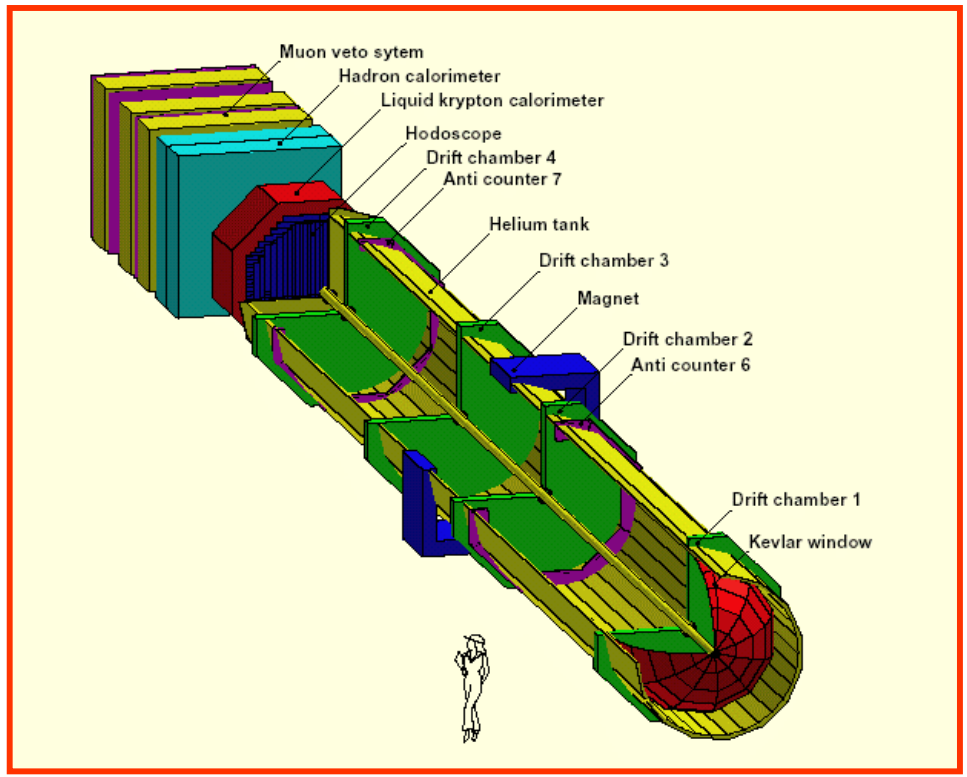
$\mathrm{Im}\ \lambda_t \neq 0$ ⇒ **CP-Violation**

Paradigm shift:

After the demonstration of the existence of direct CP-Violation, $\varepsilon'/\varepsilon \neq 0$, (NA48, KTeV) and of CP-Violation in B mixing (BaBar, Belle) one is searching for inconsistency in the CKM model

NA48 Detector & Data Taking

NA48: ε'/ε	1997
ε'/ε	1998
ε'/ε	1999
no spectrometer K_L / NA48/1 K_S	2000
ε'/ε lower inst. intensity	2001
NA48/1: K_S	2002
NA48/2: $K^{\pm}$	2003
NA48/2: $K^{\pm}$	2004

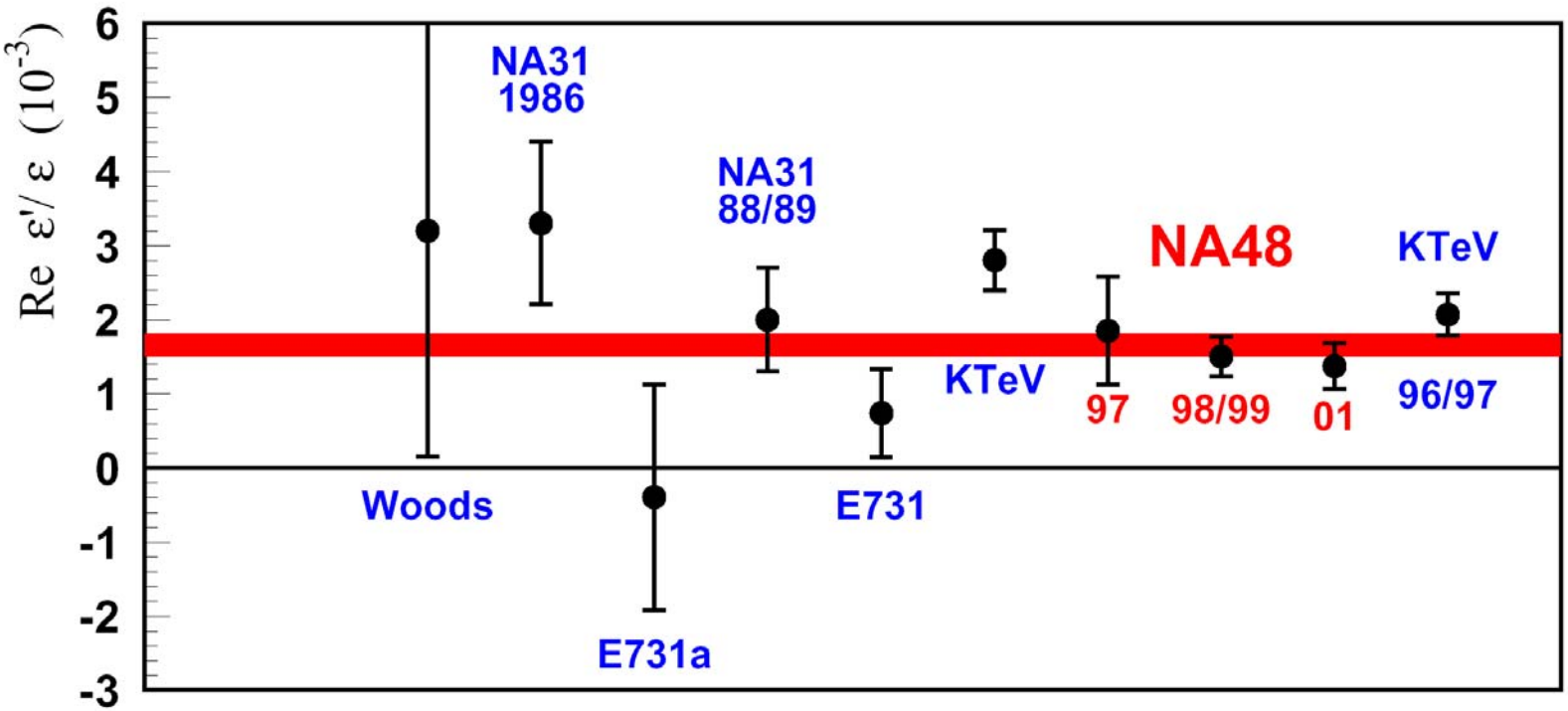


Magnetic spectrometer

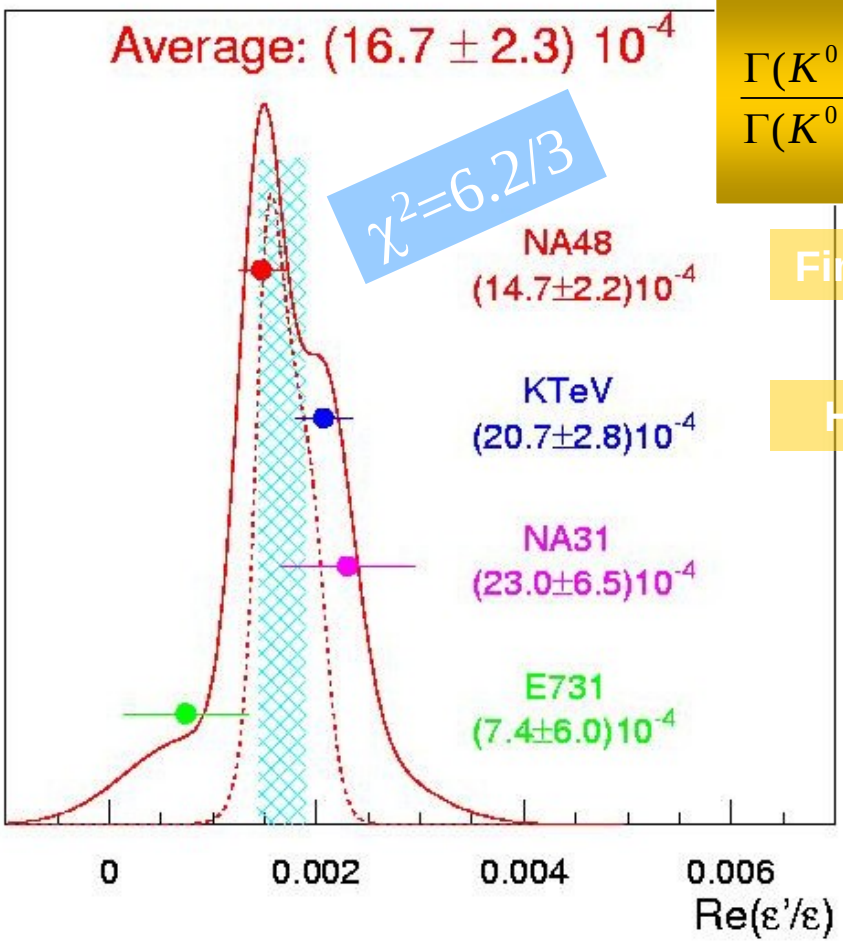
Liquid krypton EM calorimeter

Re ε'/ε measurements versus time

$$R \equiv \frac{\Gamma\left(K_L \to \pi^0\pi^0\right)}{\Gamma\left(K_S \to \pi^0\pi^0\right)} \Big/ \frac{\Gamma\left(K_L \to \pi^+\pi^-\right)}{\Gamma\left(K_S \to \pi^+\pi^-\right)} = 1 - \ 6 \ \mathrm{Re}\left(\varepsilon'/\varepsilon\right)$$



Re(ε'/ε) Results



$$\frac{\Gamma(K^0 \to \pi^+\pi^-) - \Gamma(\overline{K}^0 \to \pi^+\pi^-)}{\Gamma(K^0 \to \pi^+\pi^-) + \Gamma(\overline{K}^0 \to \pi^+\pi^-)} = (5.04 \pm 0.82) \times 10^{-6}$$

Final result (1997-2001)

Half statistics (1997)

Direct CP violation proved at >7σ level… after 36 years!

NA48: Re $\varepsilon'/\varepsilon = 14.7 \pm 2.2 \times 10^{-4}$

Top 10 articles from Physics Letters B:

- 1. The hierarchy problem and new dimensions at a millimeter http://dx.doi.org/10.1016/S0370-2693(98)00466-3 Physics Letters B, Volume 429, Issues 3-4 , 18 June 1998, Pages 263-272 Nima Arkani-Hamed, Savas Dimopoulos and Gia Dvali
- **2. A precision measurement of direct CP violation in the decay of neutral kaons into two pions http://dx.doi.org/10.1016/S0370-2693(02)02476-0 Physics Letters B, Volume 544, Issues 1-2 , 19 September 2002, Pages 97-112 J. R. Batley et al. (NA48 Collaboration)**
- 3. Has the GZK suppression been discovered? http://dx.doi.org/10.1016/S0370-2693(03)00105-9 Physics Letters B, Volume 556, Issues 1-2 , 13 March 2003, Pages 1-6, John N. Bahcall and Eli Waxman
- 4. Testable scenario for relativity with minimum length http://dx.doi.org/10.1016/S0370-2693(01)00506-8 Physics Letters B, Volume 510, Issues 1-4 , 21 June 2001, Pages 255-263 Giovanni Amelino-Camelia
- 5. Role of effective interaction in nuclear disintegration processes http://dx.doi.org/10.1016/S0370-2693(03)00801-3 Physics Letters B, Volume 566, Issues 1-2 , 24 July 2003, Pages 90-97 D. N. Basu
- 6. Determination of solar neutrino oscillation parameters using 1496 days of Super-Kamiokande-I data http://dx.doi.org/10.1016/S0370-2693(02)02090-7 Physics Letters B, Volume 539, Issues 3-4 , 18 July 2002, Pages 179-187 S. Fukuda et al.
- ....

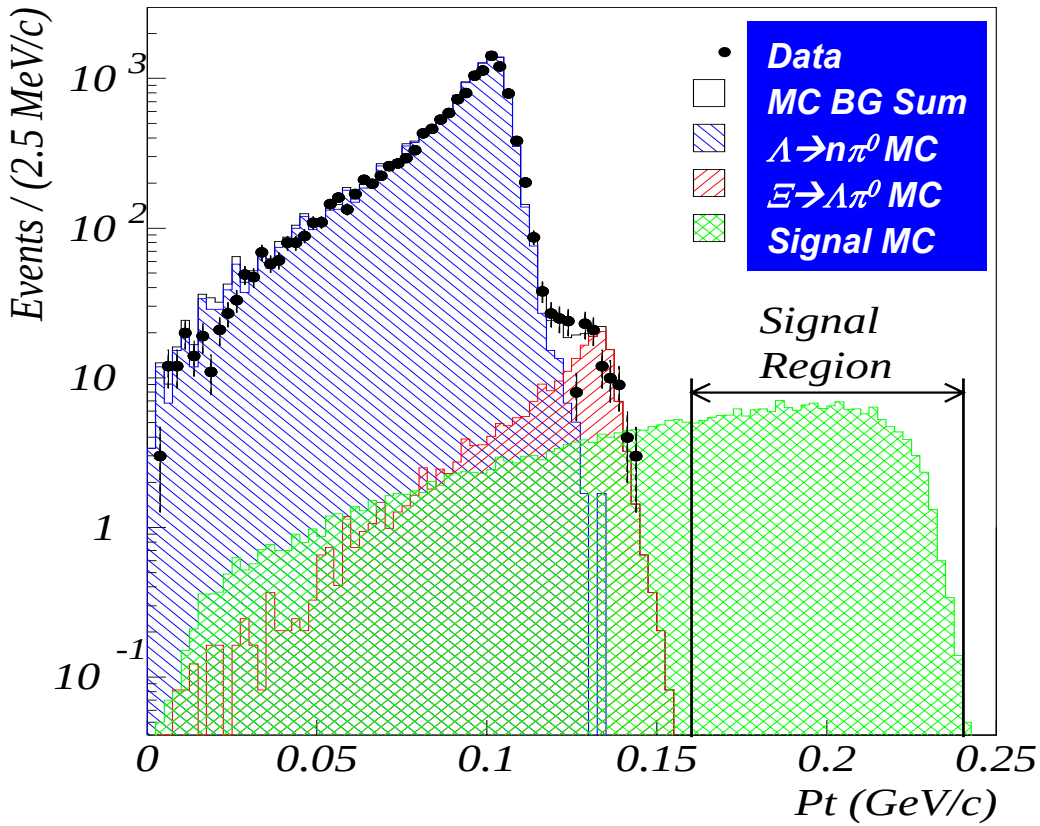
Kaon Experiments @ Proton Accelerators

Machine	Energy (GeV)	Current (μA)	Rate (Hz)	ppp (10^{13})	Kaon Experiments
CERN-PS	26	1.6	0.5	2	----
CERN-SPS	400	0.8	0.07	7	NA48
BNL-AGS	24	5	0.3	10	E871,E865,E787, E949,KOPIO*
FNAL-MI	120	1.6	0.33	3	KTeV**,CKM*
J-PARC	50	10	0.16	40	E391*
KEK-PS	12	0.16	0.25	0.4	E391a
IHEP-U70	70	0.32	0.11	2	OKA*

* Planned

** Employed the 800 GeV beam from Tevatron

KTeV: $K^0_L \to \pi^0 \nu\nu$



1997 Data Dalitz Analysis

$BR(K_L \to \pi^0\nu\nu) < 5.9 \times 10^{-7}$ ($\pi^0 \to ee\gamma$, 1997 Data) [PRD 61,072006 (2000)]

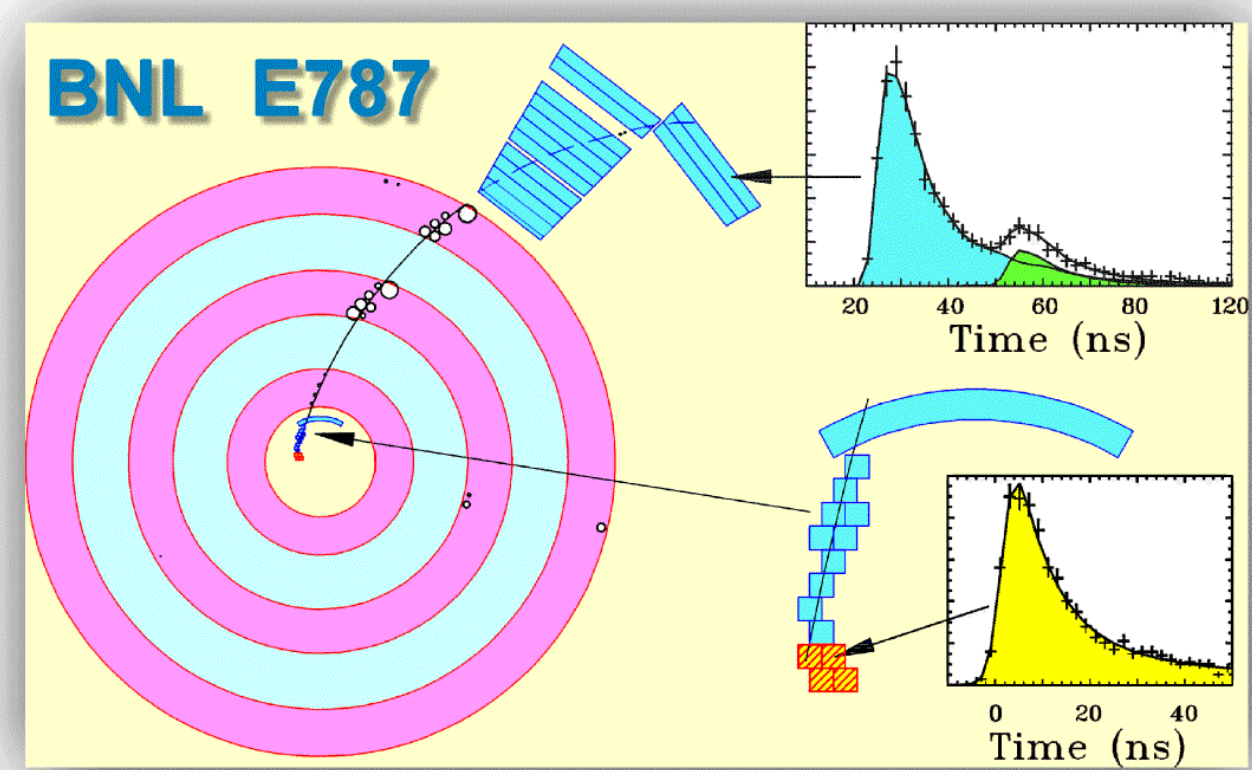
$BR(K_L \to \pi^0\nu\nu) < 1.6 \times 10^{-6}$ ($\pi^0 \to \gamma\gamma$, 1997 1 Day) [PLB 447, 240 (1999)]

$K^0_L \to \pi^0 ee(\mu\mu)$: Perspectives

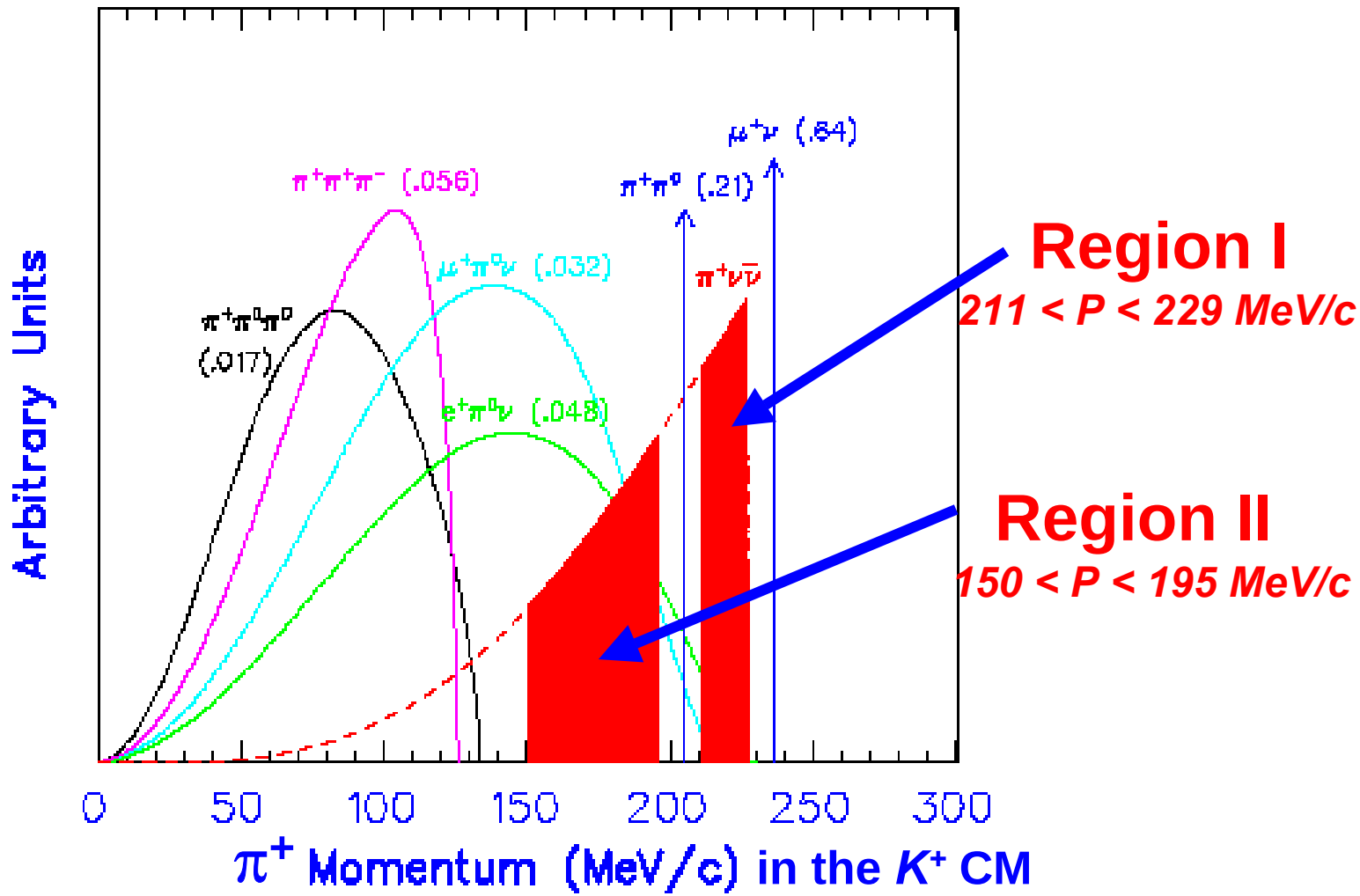
- **Detector $\sigma(\gamma\gamma)$ ×2**
  - Very ambitious, KTeV/NA48 already state of the art
- **K_S-K_L time dependent interference ×2**
  - Position experiment between 9 and 16 K_S lifetimes (hep-ph/0107046)
- **K_S-K_L time independent interference ×3**
  - Assume constructive interference (theoretically preferred)
- **Data Taking ×5**
  - Run in "factory mode". After all E799-II run only for a few months to collect ~7 × 10^{11} K_L decays
- **Beam intensity ×4**
  - Need ~10^{12} protons/sec, slowly extracted, high energy, DC
- **Tot ~ ×240 → sens on BR ~ ×15 (on Im λ_t ~×4-15)**
  - close the window of opportunity between current upper limit and SM

NA48/KTeV resolutions with E871 beam intensities !!

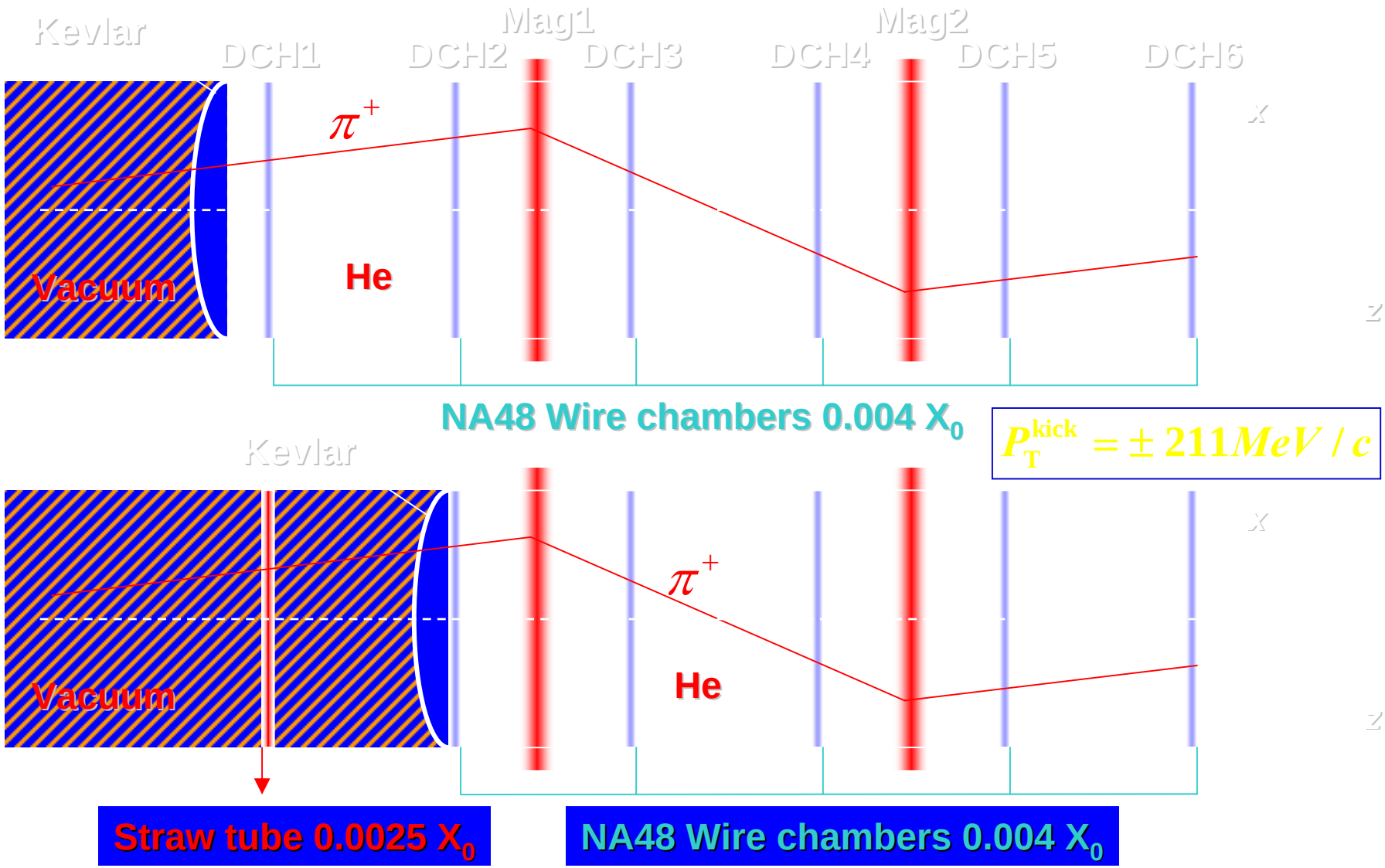
AGS-E787



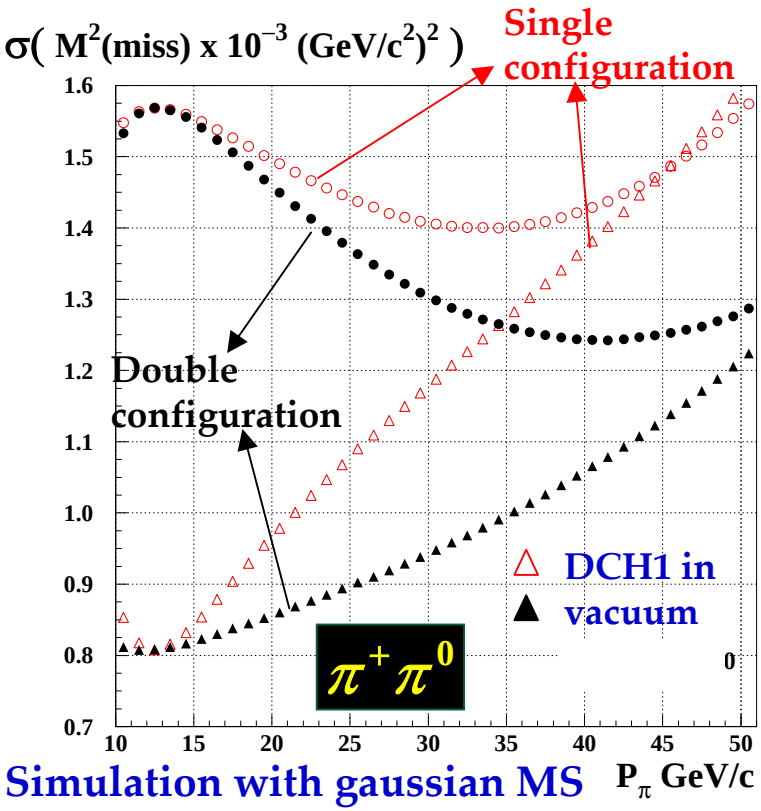
$K^+ \to \pi^+ \nu\nu$: Experiment



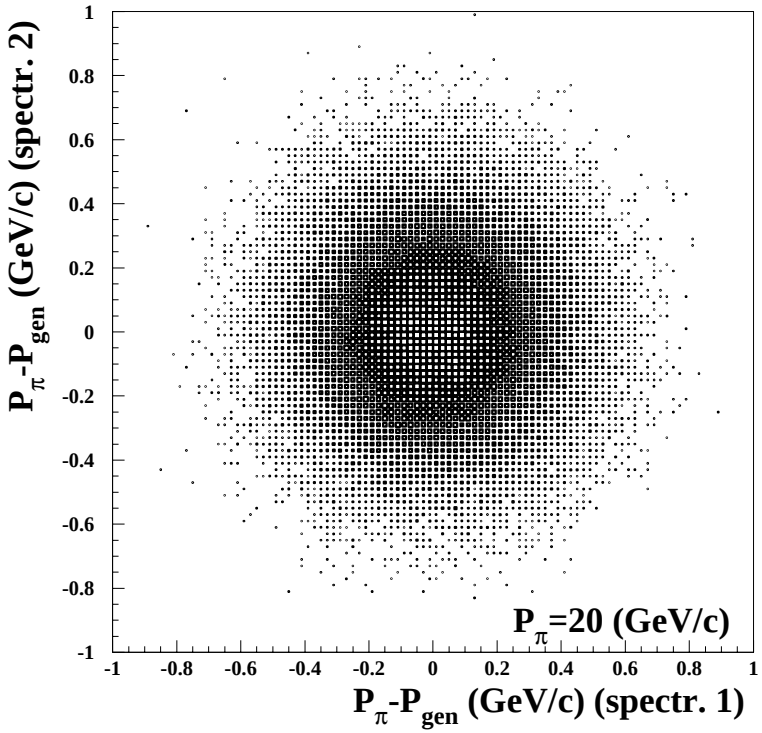
Double spectrometer layout



Double spectrometer performance



Two independent measurement of P_π

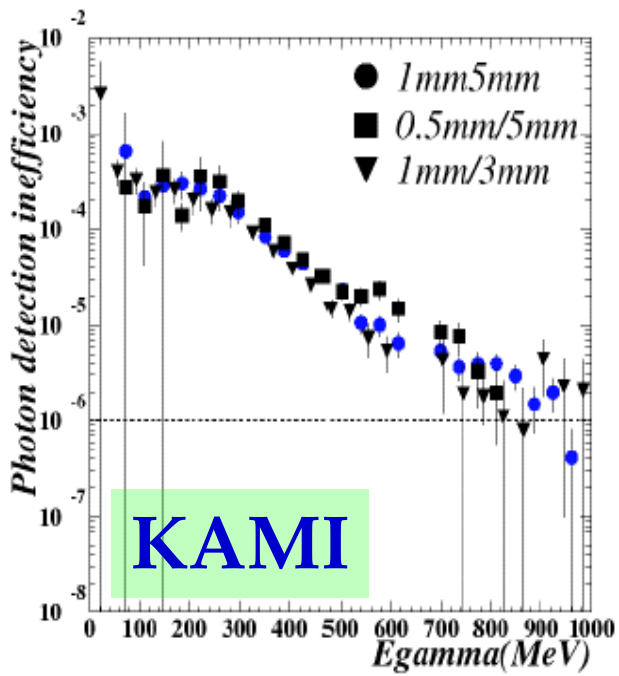


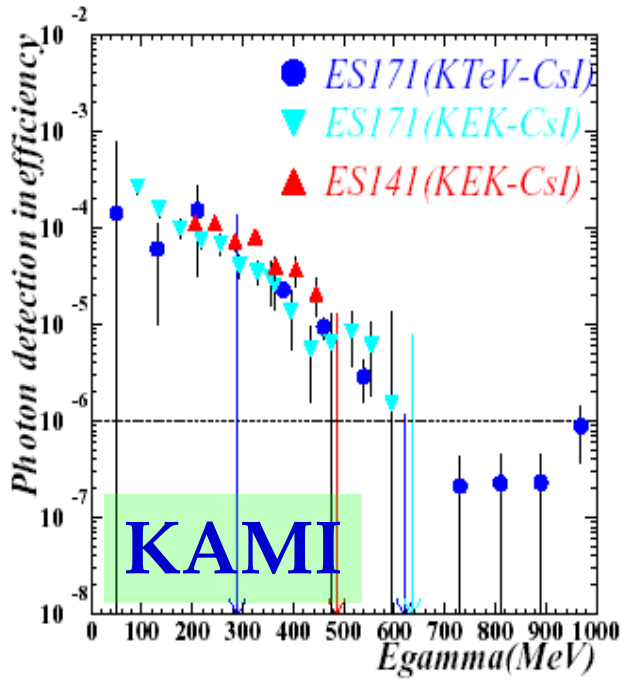
- Much higher intensity on DCH in NA48/3

Intensity and performance vs HV tests foreseen in 2004 run

Photon rejection

- Aim to reach 10^{-6} inefficiency
- For $P_\pi < 40$ GeV/c there are at least 35 GeV/c in the e.m. calorimeters





- Plans to study <u>inefficiency</u> (LKr calorimeter + small angle veto) by collecting a large sample of $\pi^+\pi^0$ events in 2004 run

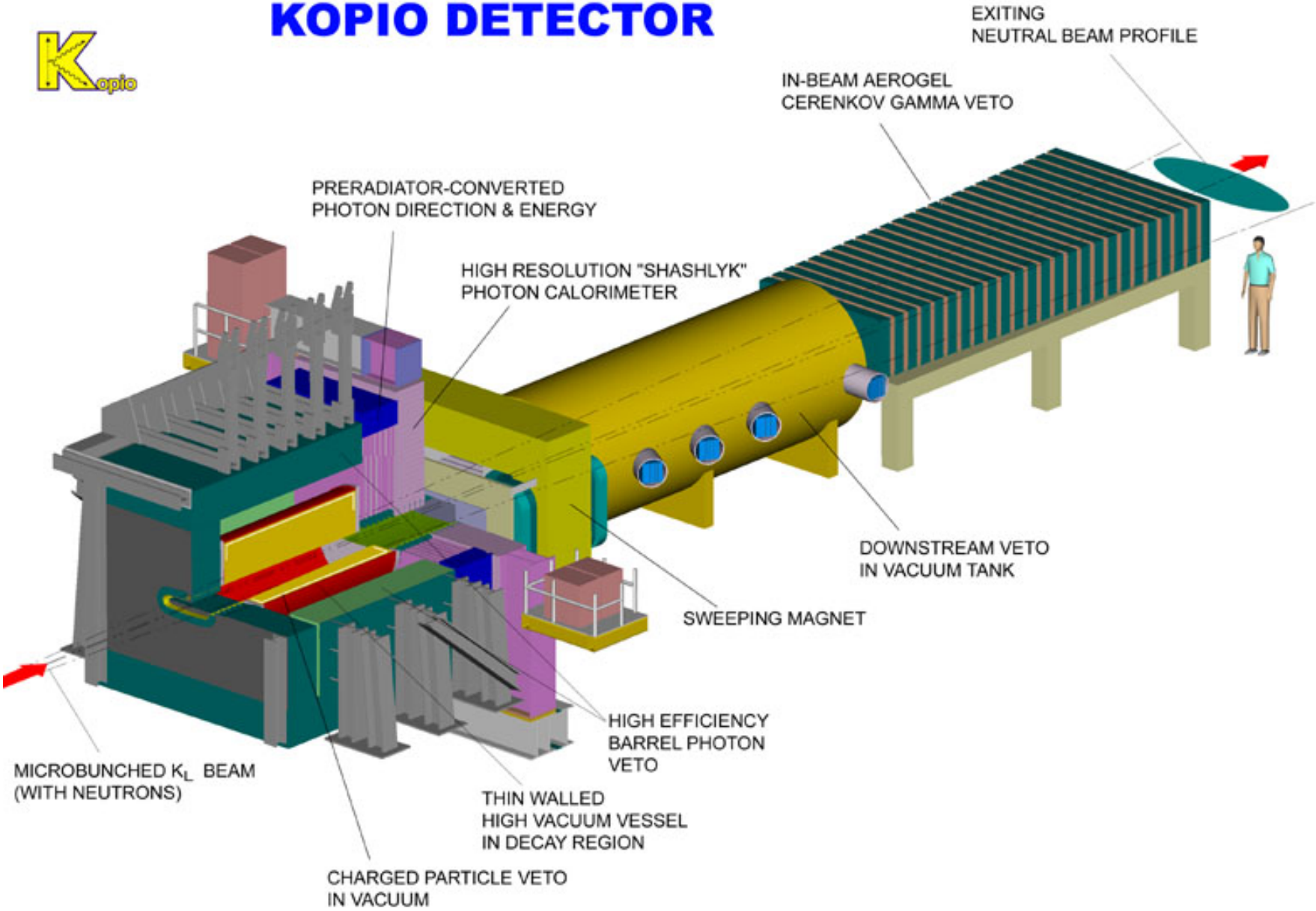
KAONS

- **Rare Kaon Decays**
  - Decisive tests of Flavour sector in Standard Model (SM)
    - Flavour Changing Neutral Currents
  - Search for explicit SM violations
    - Lepton-Flavour Violation
- **Must collect >> 10^{12} useful decays**
  - Typical Proton Intensities: from 10^{11} to 10^{13} p/s
  - As long as possible Duty Cycle
  - Long extraction to reduce pile-up
  - Minimum proton energy: 30 GeV
  - Maximum proton energy: 1 TeV ?

BNL-KOPIO


PHOBOS
10:00 o'clock
12:00 o'clock
BRAHMS & PP2PP (p)
2:00 o'clock
RHIC
4:00 o'clock
PHENIX(p)
8:00 o'clock
STAR (p)
6:00 o'clock
NASA - BAF
μg-2
HEP/NP(p)
RSVP
LINAC
BOOSTER
AGS
TANDEMS

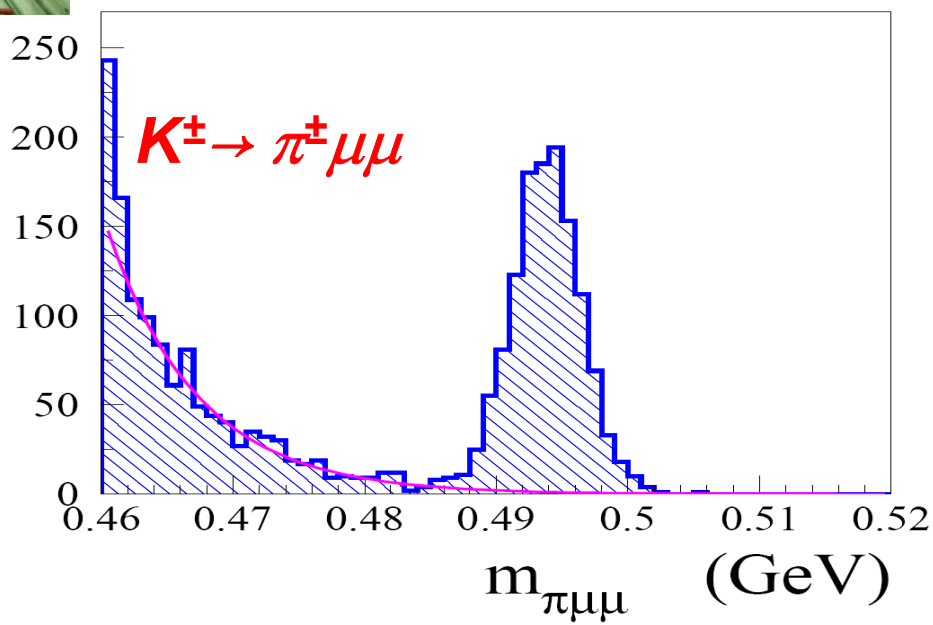
KOPIO DETECTOR



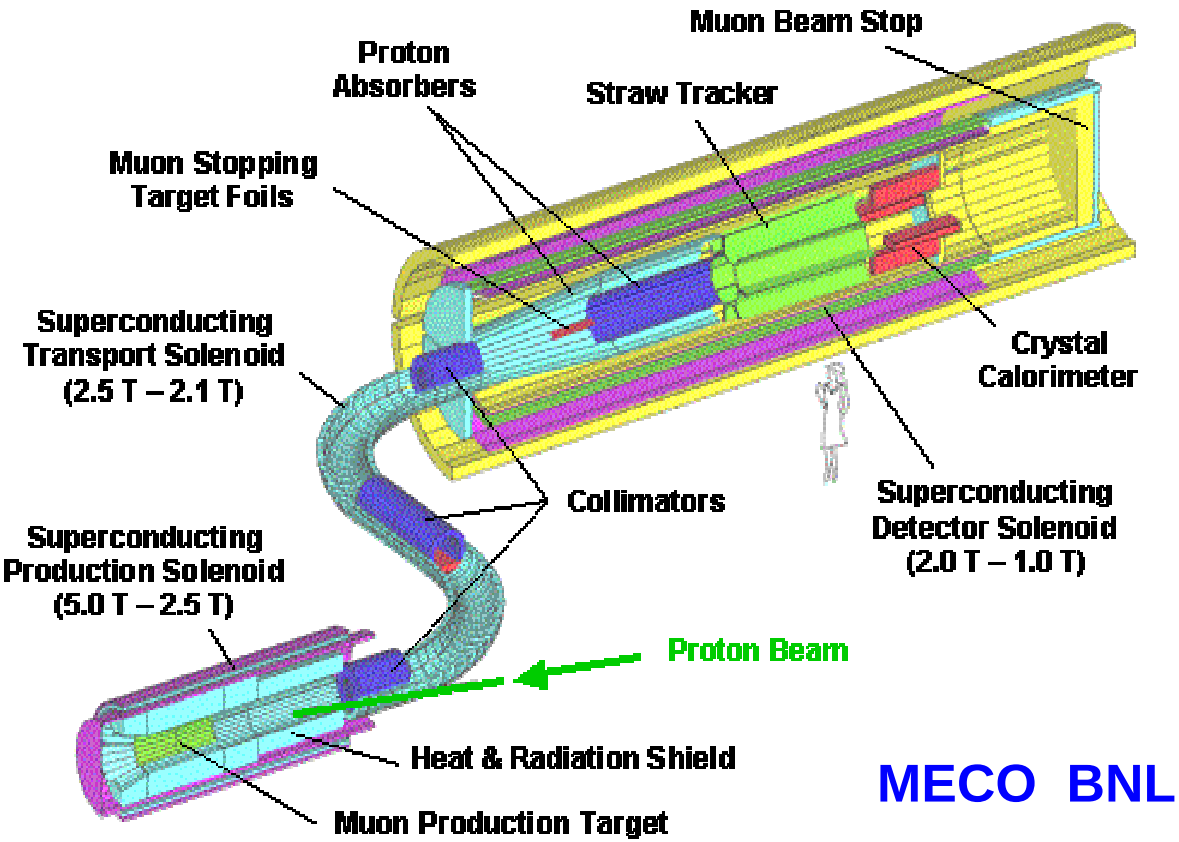
NA48/2 : K^+/K^-

- Search for direct CP violation in Dalitz plot slope asymmetry in $K^{\pm} \to 3\pi$ decay
- *Ke4* decays
- Rare $K^{\pm}$ decays

Simultaneous K^+ and K^- beams

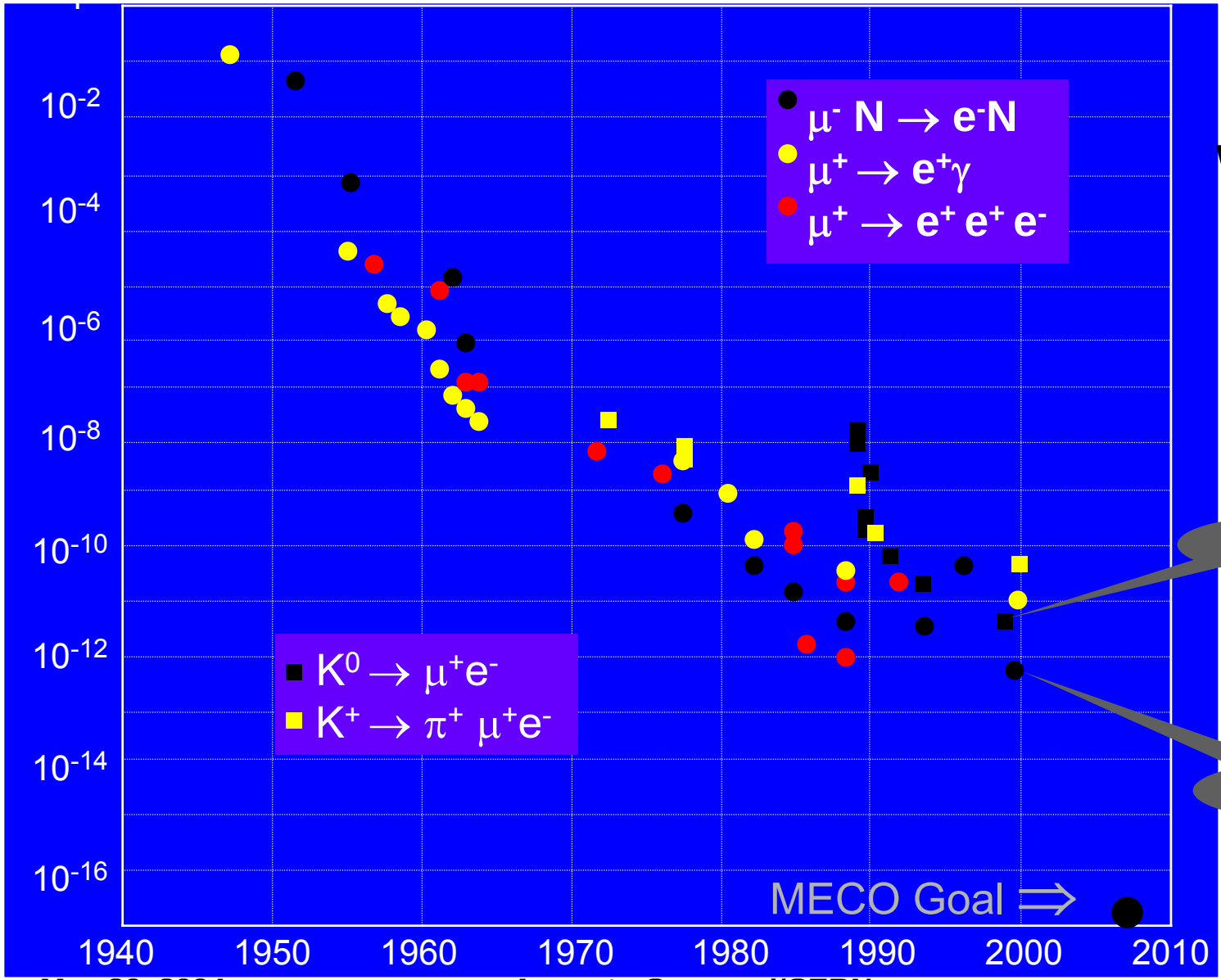


$\mu + N \rightarrow e + N$
(Internal Conversion)



MECO BNL

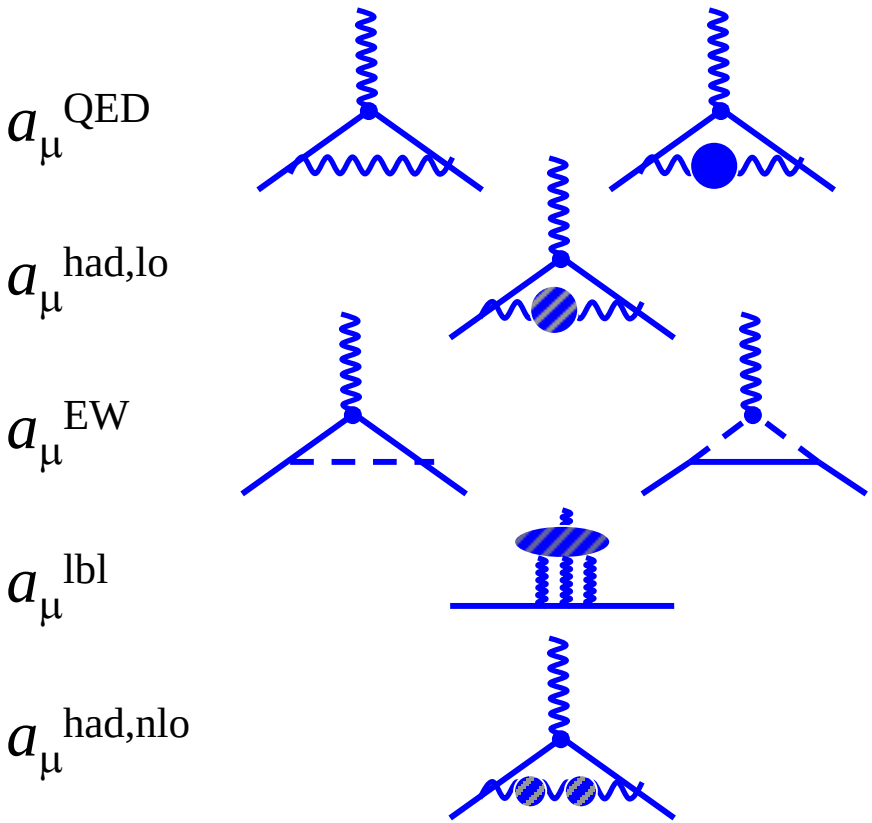
Charged LFV limits versus time



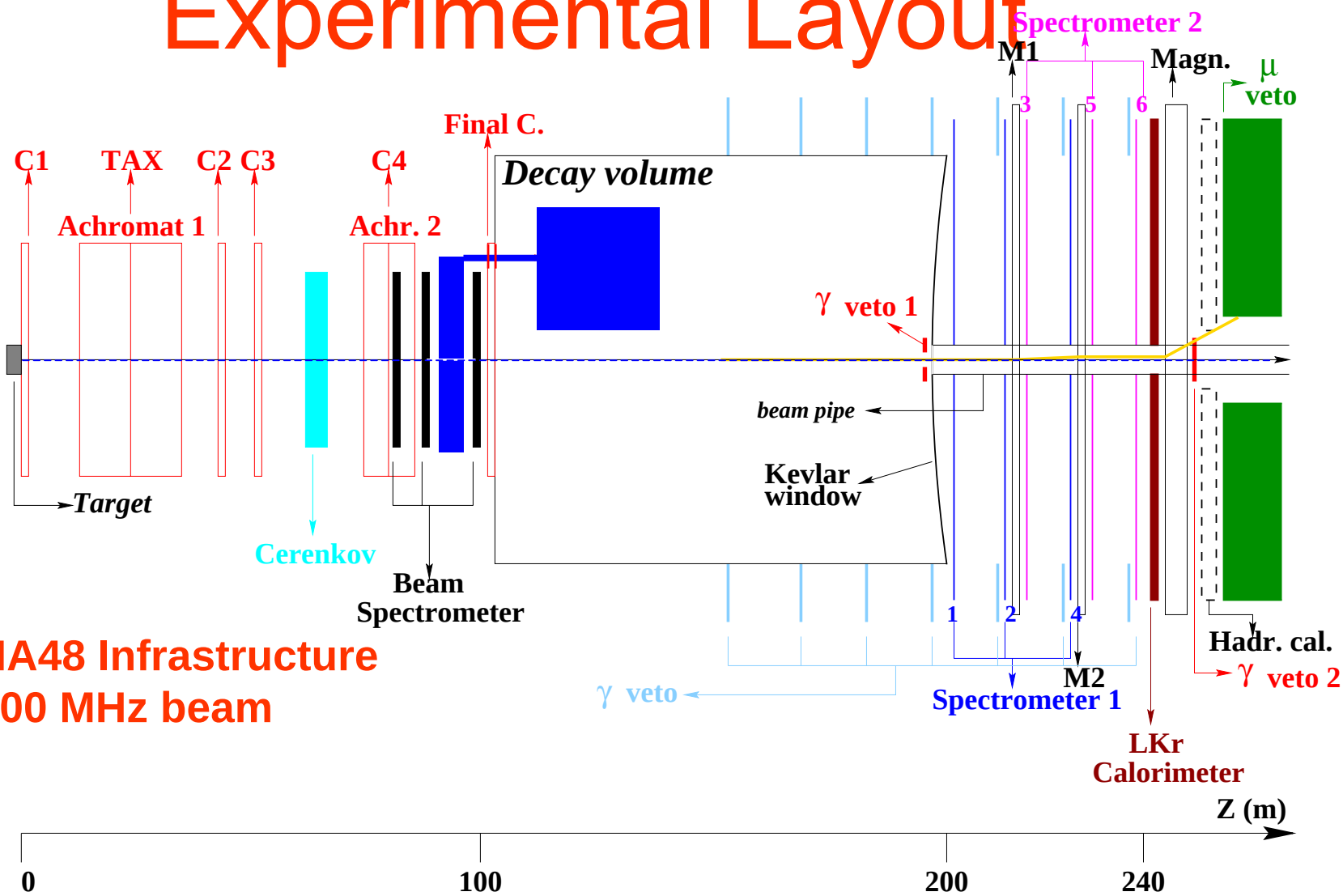
W. Molzon

Magnetic Dipole Moment - *g*

$$\vec{\mu} = g\frac{e\hbar}{2mc}\vec{s} = g\mu_0\vec{s}$$



Experimental Layout



NA48 Infrastructure
800 MHz beam