Status and prospects of Kaon experiments

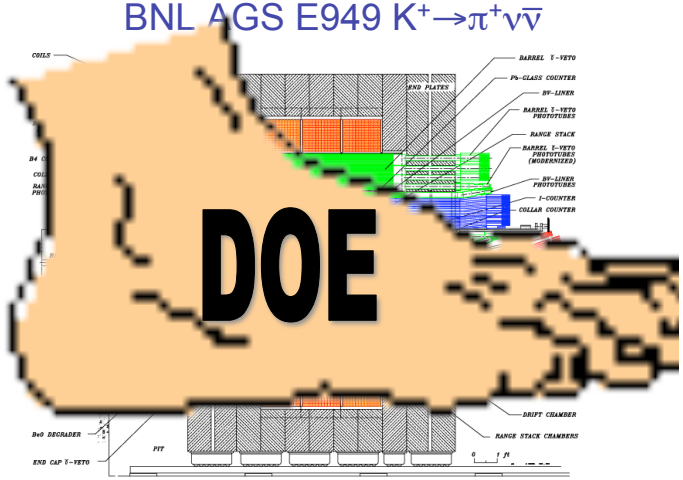
Final Plenary meeting:

CERN, March 26-28 2007

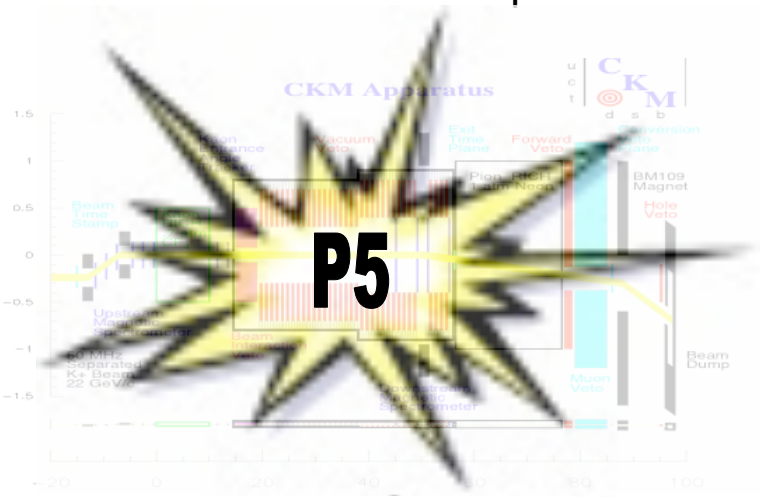
Takeshi K. Komatsubara（KEK, FlavLHC WG2）

L.Littenberg's Kaon talk at the 1st meeting (Nov 05)

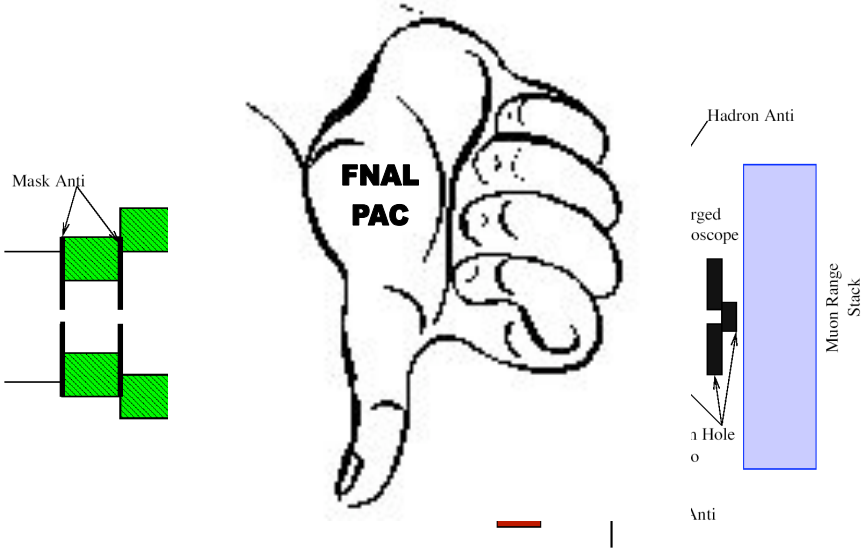
BNL AGS E949 $K^+ \to \pi^+ \nu\bar{\nu}$



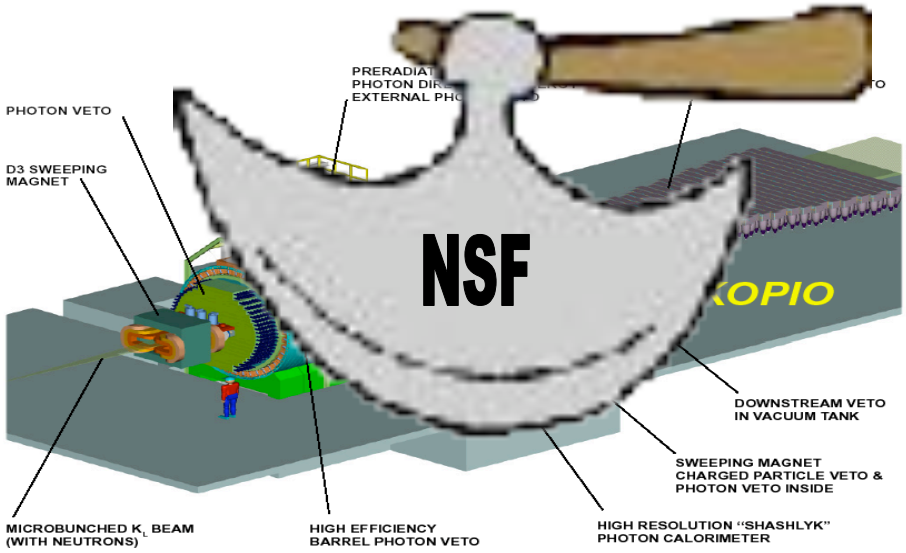
FNAL CKM $K^+ \to \pi^+ \nu\bar{\nu}$ Experiment

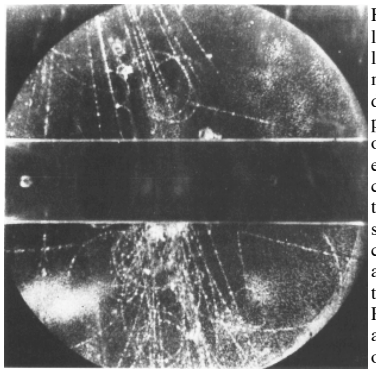


KAMI $K_L \to \pi^0 \nu\bar{\nu}$ at FNAL



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



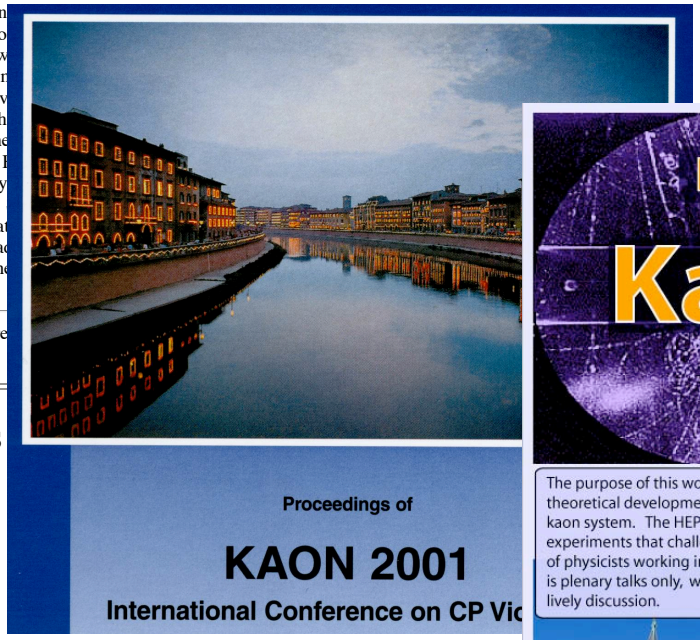


First **V** particle (1946). Just below the lead plate, in the lower right-hand quadrant, an inverted V extends to the lower right. Rochester and Butler measured the momentum of the upper particle as 300 MeV/*c* an determined its charge to be positive. The other (lo particle has a negative charge (if it is moving dow or a positive charge (if it is moving upward). Fron experience, they argued, the two tracks would hav closer together to be an electron-positron pair. Th tracks cannot be a two-track star; if they were, the should be a visible recoiling nucleus at the apex. I conservation of momentum excludes a pion decay an electron, or a muon decaying into an electron. this argument eliminates the only possible alternat Rochester and Butler concluded that this event ha a photographic record of a novel phenomenon: th of a previously unknown neutral meson.

From ***Image and Logic***, a study of the history and practice of experimental microphysics, authore **Peter Galison** and published by The University of Chicago Press.

The Chicago Conference on Kaon Physics

KAON '99



http://www.lnf.infn.it/conference/kaon07/

analyses of NA48, KLOE, KTeV, ISTR+, E949/E787, E391a, ...
continue for:

- lifetimes, branching fractions, ...
  for Vus and Vud

- semi-leptonic/non-leptonic/radiative decays, ...
  for low energy QCD

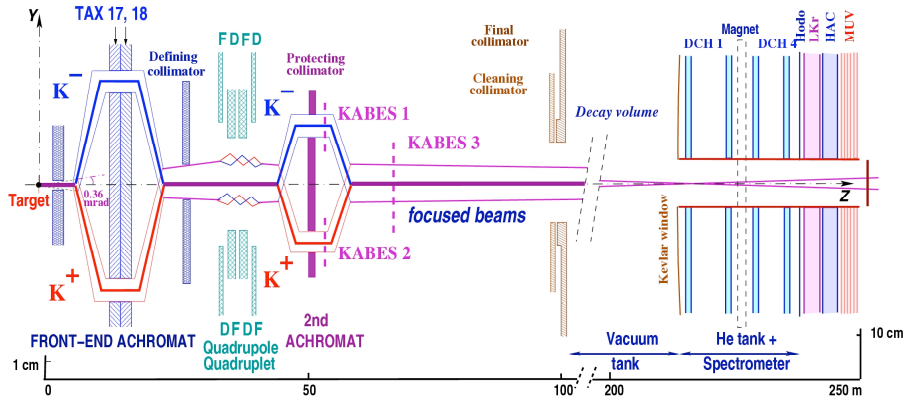
- CPT and QM tests

- Lepton Universality and LFV

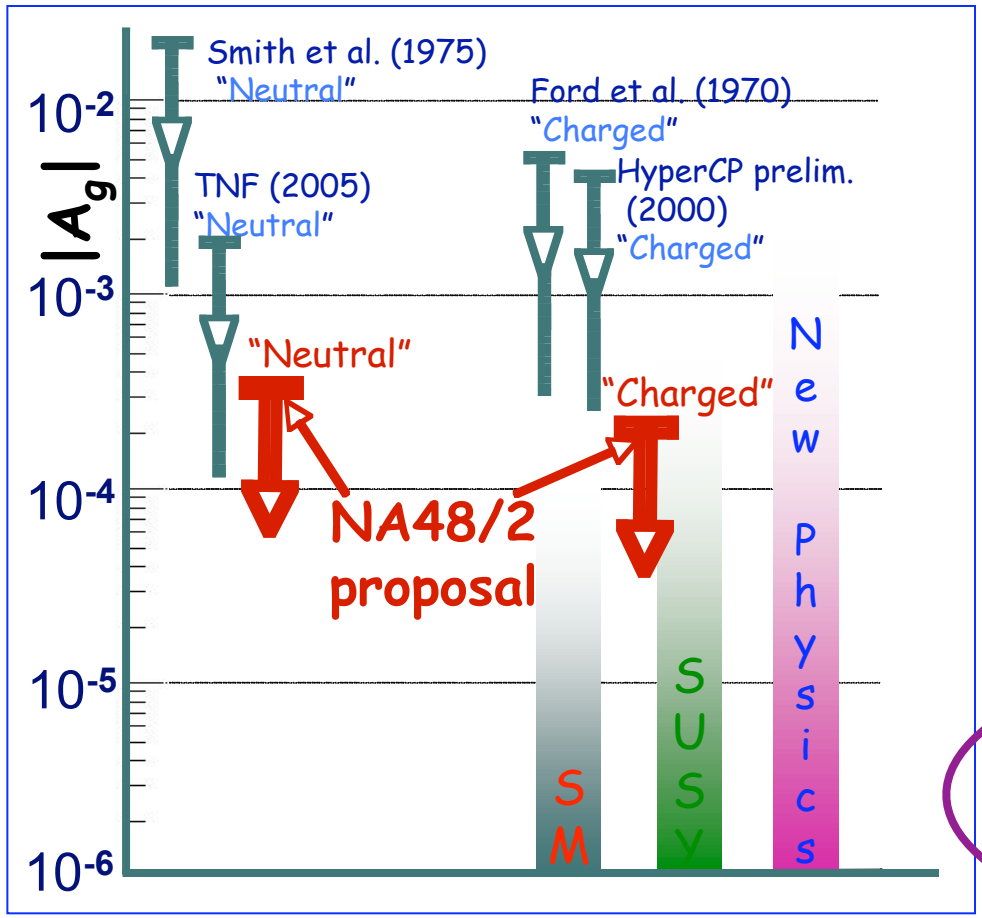
- Rare decays and CP violation
  for New Physics in the LHC era

See also the Kaon talks (NA48, KLOE, and KTeV) at Moriond 2007.

NA48/2 : simultaneous $K^{\pm}$ beam



Measuring $|A_g|$



$$K^{\pm} \to \pi^{\pm}\pi^0\pi^0,\ \pi^{\pm}\pi^+\pi^-$$

Kinematic variables:

$s_i = (P_K - P_{\pi i})^2$, i = 1-3 ($3 = \pi_{odd}$)

$s_0 = (s_1 + s_2 + s_3) / 3$

$u = (s_3 - s_0) / m_{\pi}^2$

$v = (s_2 - s_1) / m_{\pi}^2$

Dalitz plot analyses

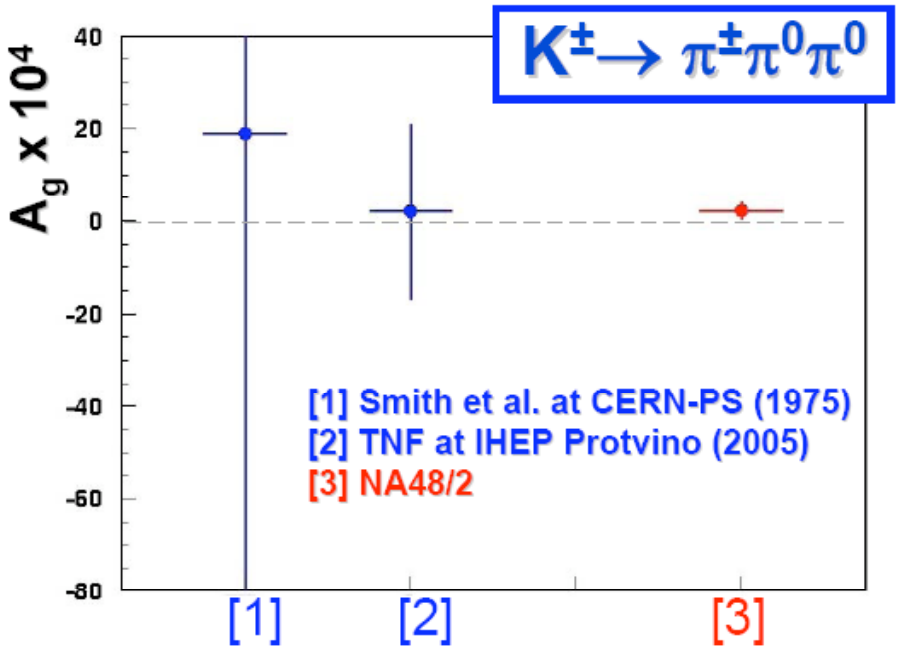
Matrix element expansion:

$|M(u,v)|^2 \sim 1 + gu + hu^2 + kv^2$

Direct CP violating quantity: slope asymmetry

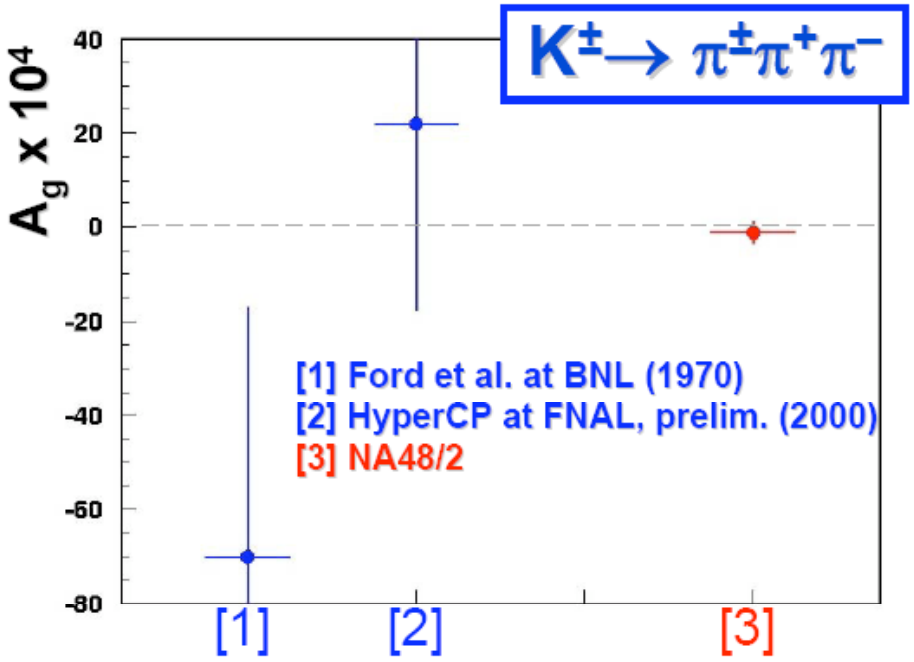
$A_g = (g^+ - g^-) / (g^+ + g^-) \neq 0$

SM theoretical prediction: $10^{-6} \div 5 \cdot 10^{-5}$



2003 + 2004 FINAL RESULT

$A_g = (1.8 \pm 1.7_{stat} \pm 0.5_{syst}) \cdot 10^{-4}$
$= (1.8 \pm 1.8) \cdot 10^{-4}$



2003 + 2004 FINAL RESULT

$A_g = (-1.5 \pm 1.5_{stat} \pm 0.9_{trig} \pm 1.1_{syst}) \cdot 10^{-4}$
$= (-1.5 \pm 2.1) \cdot 10^{-4}$

- No CP violation observed.

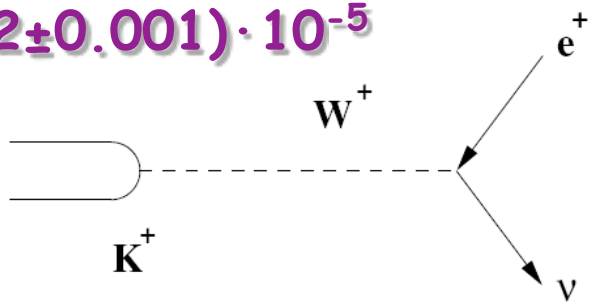
  - Statistical uncertainties dominate.

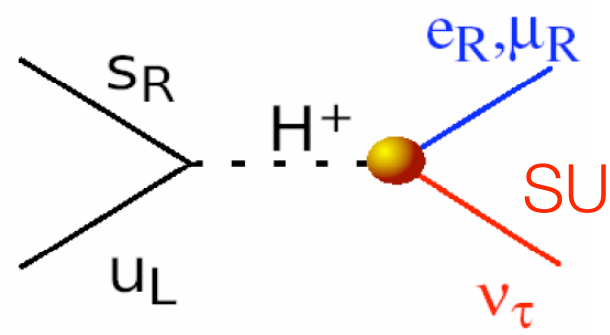
  - Results compatible with Standard Model predictions.

Lepton Universality: $\Gamma(K_{e2})/\Gamma(K_{\mu 2})$

V-A couplings - helicity suppressed

$(2.472 \pm 0.001) \cdot 10^{-5}$





$$R_{K_\bullet}^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}, \quad i = e, \mu, \tau$$

If tanβ=40 and M_{H^+}=500 GeV with $|\Delta_R^{31}|^2 = 5 \cdot 10^{-4}$

$$\Delta r_{K\,SUSY}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)|\Delta_R^{31}|^2 \tan^6\beta \approx 10^{-2}$$

A. Masiero: CERN TH seminar

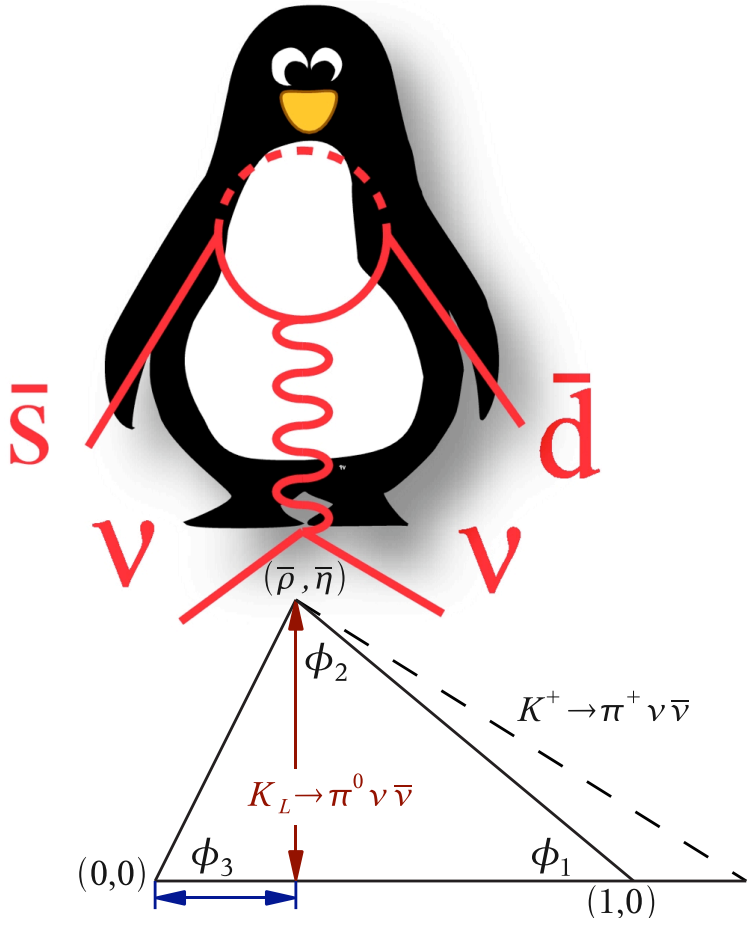
The effect can be as high as 2% and therefore measurable

PR D74 (2006) 011701 (A. Masiero et al.)

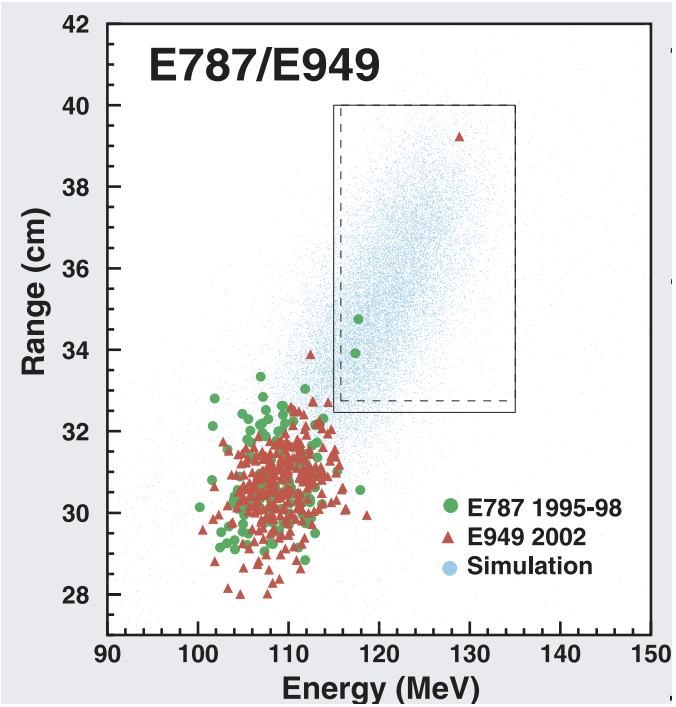
contents (in 35 slides) :

- status ✓
- prospects for the Golden Mode: $K \longrightarrow \pi\nu\bar{\nu}$
  - (theoretical motivation)
  - program at CERN
  - program at J-PARC

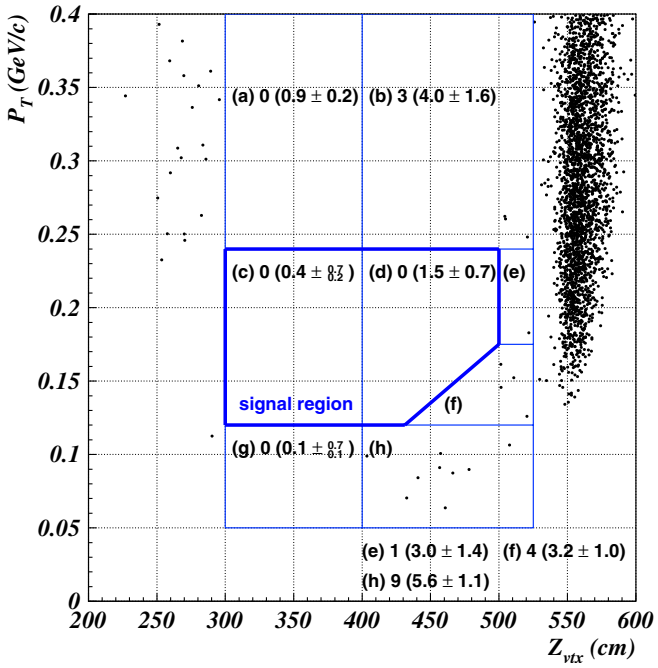
    updates on J-PARC accelerator



- T *odd* correlation in K → μνπ/μνγ decays at J-PARC
- DAΦNE upgrade - KLOE2

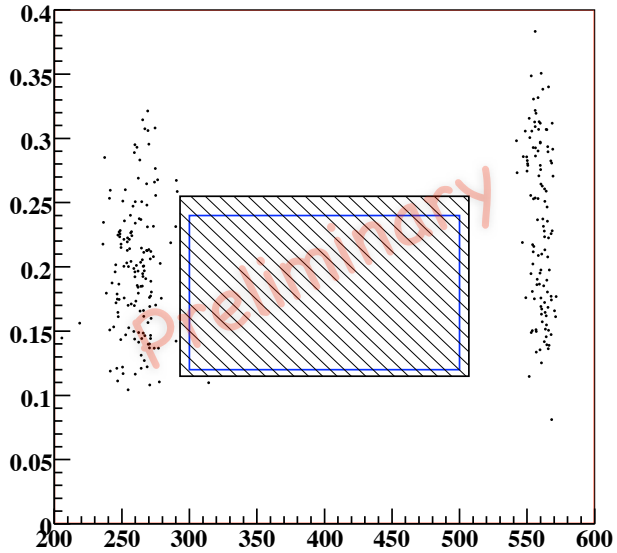


PRL 93 (2004)



PR D74 (2006)
10% of the 1st dataset

E391a
Run-2 analysis
in progress



aim at sensitivity 10^{-8}

Golden Modes	Standard Model	Experiment	
$K^+ \to \pi^+ \nu\bar{\nu}$	$8.0^{+1.1}_{-1.1} \times 10^{-11}$	$14.7^{+13.0}_{-8.9} \times 10^{-11}$	E787 E949
$K_L \to \pi^0 \nu\bar{\nu}$	$2.9^{+0.4}_{-0.4} \times 10^{-11}$	$< 2.1 \times 10^{-7}$	E391a

15% due to present CKM accuracy

Grossman-Nir bound PLB **398**, 163 (1997)

$$r_{is} \times \frac{\Gamma(K_L \to \pi^0 \nu\bar{\nu})}{\Gamma(K^+ \to \pi^+ \nu\bar{\nu})} = sin^2\theta$$

relative CP-violating phase

isospin breaking correction 0.954

$$\frac{BR(K_L \to \pi^0 \nu\bar{\nu})}{BR(K^+ \to \pi^+ \nu\bar{\nu})} < \frac{\tau_{K_L}}{\tau_{K^+}} \times \frac{1}{r_{is}} = 4.371... \simeq 4.4$$

$$BR(K_L \to \pi^0 \nu\bar{\nu}) < 4.4 \times UL_{90\%}(K^+ \to \pi^+ \nu\bar{\nu})$$

$$\underline{1.4 \times 10^{-9}}$$

$$< 32.2 \times 10^{-11}$$

Golden Modes	Standard Model	Experiment
$K^+ \to \pi^+ \nu\bar{\nu}$	$8.0^{+1.1}_{-1.1} \times 10^{-11}$	$14.7^{+13.0}_{-8.9} \times 10^{-11}$ E787 E949
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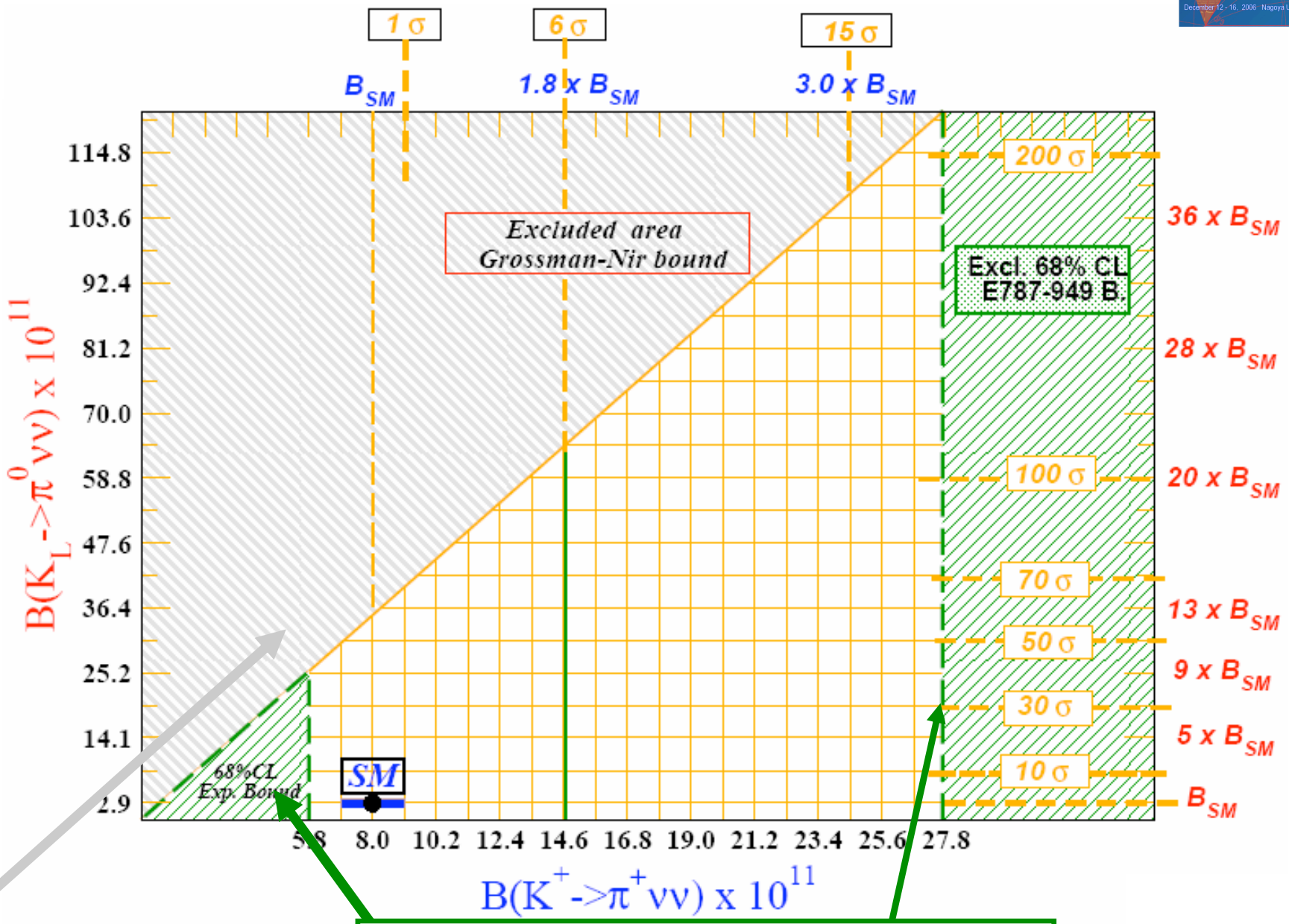
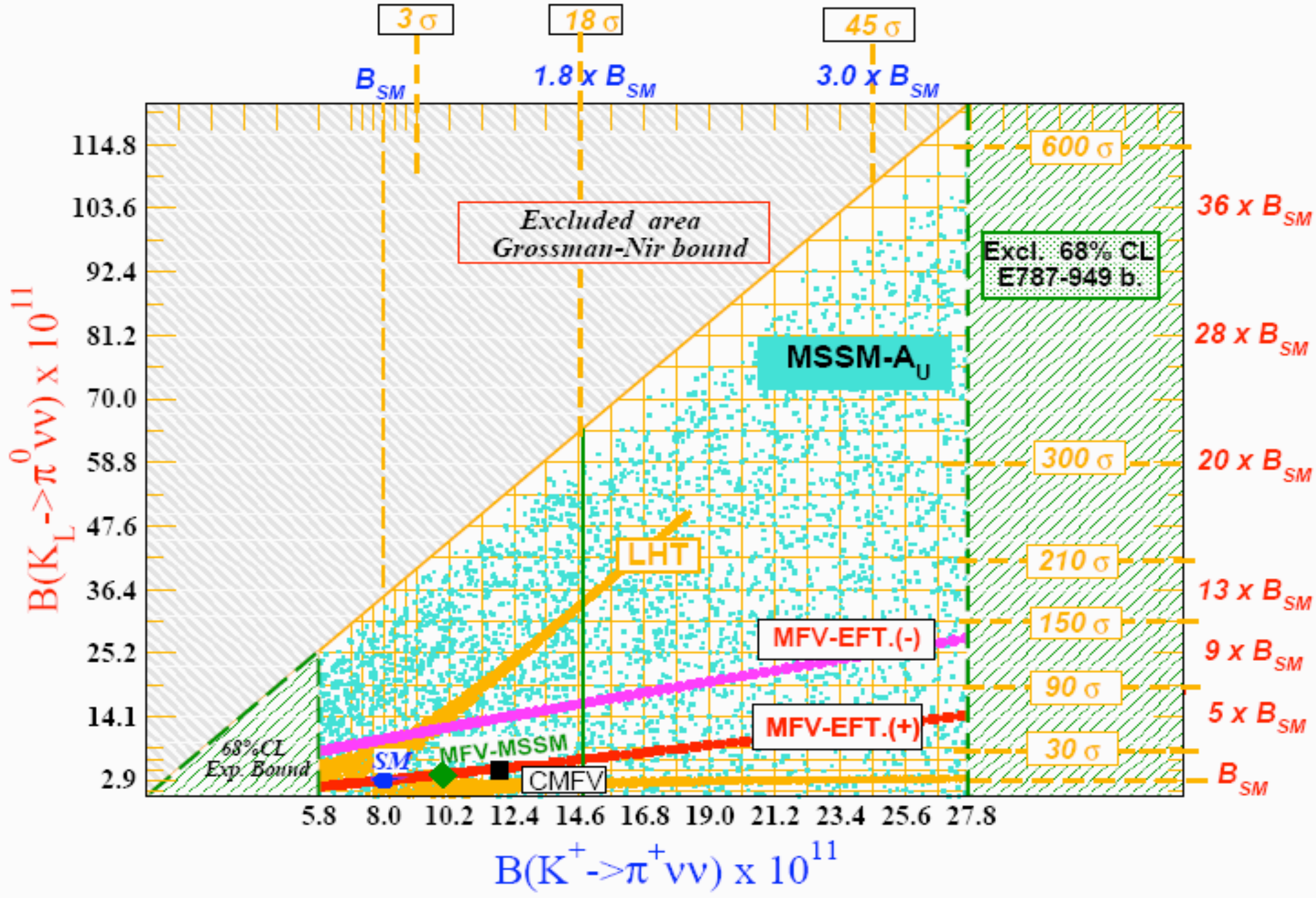
15% due to present CKM accuracy

Federico Mescia @



$B(K^+ \to \pi^+ \nu\bar{\nu}) = 14.7^{+13.0}_{-8.9} \times 10^{-11}$ [E787-E949]

$B(K_L \to \pi^0 \nu\bar{\nu}) \leq 4.4 B(K^+ \to \pi^+ \nu\bar{\nu})$ [Grosmann - Nir Bound]


3 σ
18 σ
45 σ
B_SM
1.8 x B_SM
3.0 x B_SM
600 σ
36 x B_SM
300 σ
20 x B_SM
210 σ
13 x B_SM
150 σ
9 x B_SM
90 σ
5 x B_SM
30 σ
B_SM
Excluded area
Grossman-Nir bound
Excl. 68% CL
E787-949 b.
MSSM-A_U
LHT
MFV-EFT.(-)
MFV-EFT.(+)
MFV-MSSM
SM
CMFV
68%CL
Exp. Bound
114.8
103.6
92.4
81.2
70.0
58.8
47.6
36.4
25.2
14.1
2.9
5.8
8.0
10.2
12.4
14.6
16.8
19.0
21.2
23.4
25.6
27.8
B(K_L->π^0νν) x 10^11
B(K^+->π^+νν) x 10^11

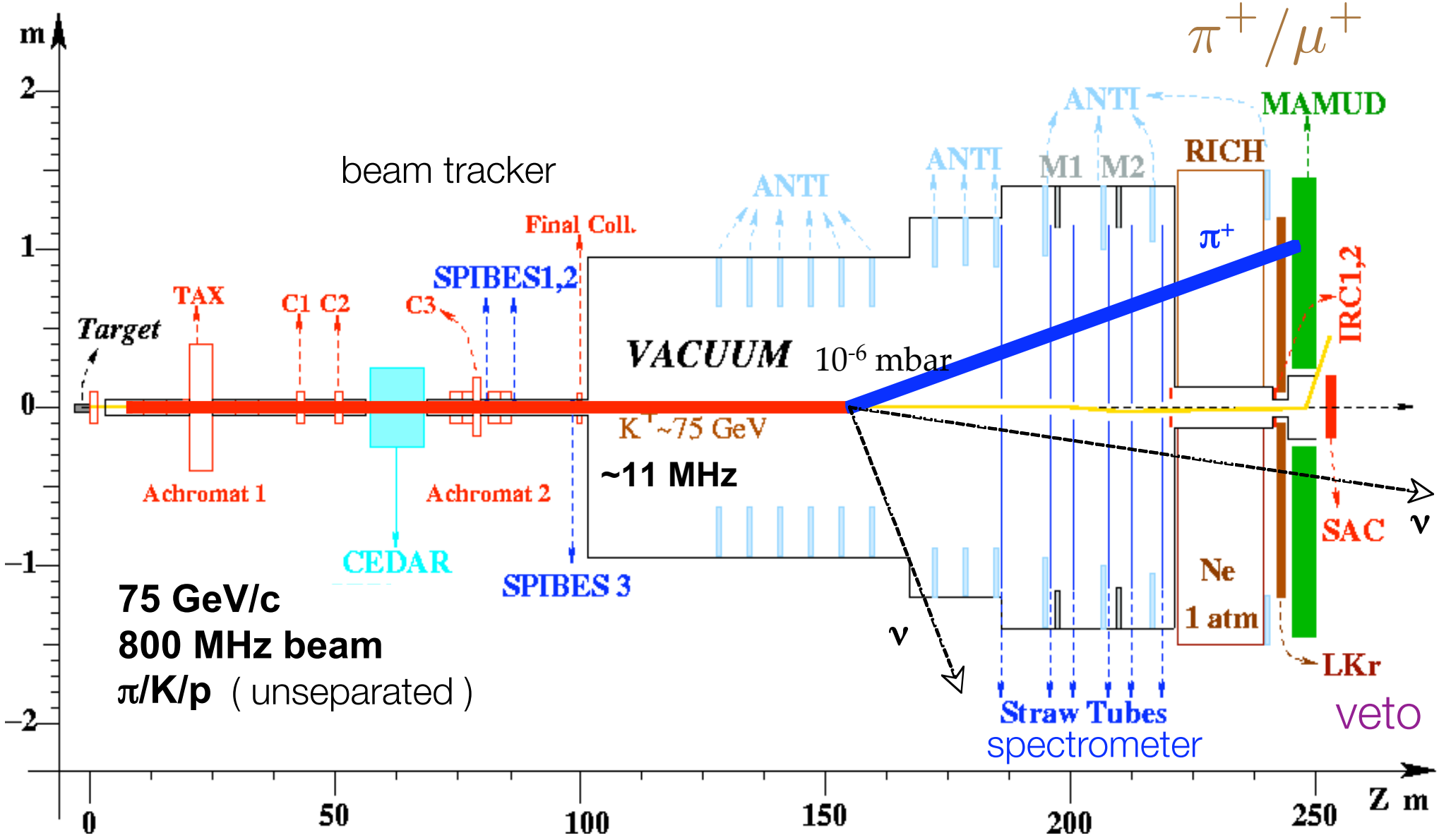
$$K^+ \rightarrow \pi^+ \nu\bar{\nu}$$

program at CERN: NA48/3 - P326

CERN, Dubna, Ferrara, Florence, Frascati, Mainz, Merced, Moscow, Naples, Perugia, Protvino, Pisa, Rome, Saclay, San Luis Potosi, Sofia, Turin, TRIUMF

P326

K^+ decay in flight to π^+ plus "nothing"



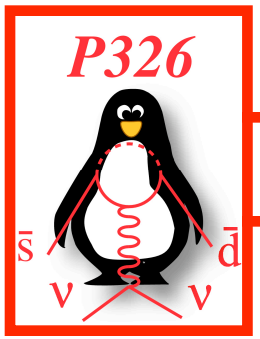
75 GeV/c
800 MHz beam
π/K/p (unseparated)

12-MARCH-2007 2007 SPS Fixed Target Programme

Version 2.1

Colour code: blue (dark shading) = not yet allocated ; yellow (light shading) = not allocatable or Machine Development

	P1A	P1B	P2	P3	P4	P5
	21 2 May 23 May	26 23 May 18 Jun	37 18 Jun 25 Jul	41 25 Jul 4 Sep	36 4 Sep 10 Oct	33 10 Oct 12 Nov
T2 -H2		EA Setup 2 · CMS ZDC 5 · SILC R&D 11	CMS SI R&D 9 · CMS Combined 28	CMS Combined 14 · CMS HCAL R&D 12 · CMS CASTOR 14 · 1	PHENIX 9 · CREAM 6 · CHERCAM 8 · NA49 FUTURE 13	NA49 FUTURE 19 · PAMELA 7 · NUCLEON 7
T2 -H4		EA Setup 2 · CMS EACL 16	DREAM 7 · 0 · DREAM 8 · ECC 7 · AMS RE1 7 · PICH 7	CMS ECAL 21 · GLAST 8 · 1 · LHCf 11	LHCf 7 · BRAN 8 · CMS ECAL 21	CRYSTAL 26 · EA MD 4 · 3
T4 -H6		EA Setup 2 · 6 · MEDIPIX 3 · CERF 7	ALICE ZDC 9 · RD42 7 · CALICE 14 · ALICE ECAL 7	ALICE ECAL 14 · CALICE 14 · MEDIPIX 5 · RD42 8	MONOPIX 7 · DEPFET 6 · 0 · 1 · CERF 8 · MIMOROMA 6 · DESY TELESCOPE 7	SILC R&D 14 · RD42 12 · MONOPIX 7
T4 -H8		EA Setup 2 · RD22 16	EA MD 2 · LHCb 14 · ATLAS LUCID 7 · ATLAS BCM 7 · ATLAS ZDC 7	LHCb 14 · TOTEM 14 · LHCb 13	ATLAS 3DSI 9 · EA MD 6 · RD22 14 · ATLAS RP 7	ATLAS RP 19 · RD22 14
T4 -P0		EA Setup 2	P326 37	P326 41	P326 36	P326 33
T6 -M2		EA Setup 2 · COMPASS 16	COMPASS 37	COMPASS 41	COMPASS 36	COMPASS 33
CNGS						



SPS/PS-Coordinator: Christoph Rembser

E-mail: SPS.Coordinator@cern.ch

phone: 73113 (ext. +41 22 767 3113)

mobile: 160497 (ext. +41 76 487 0497)

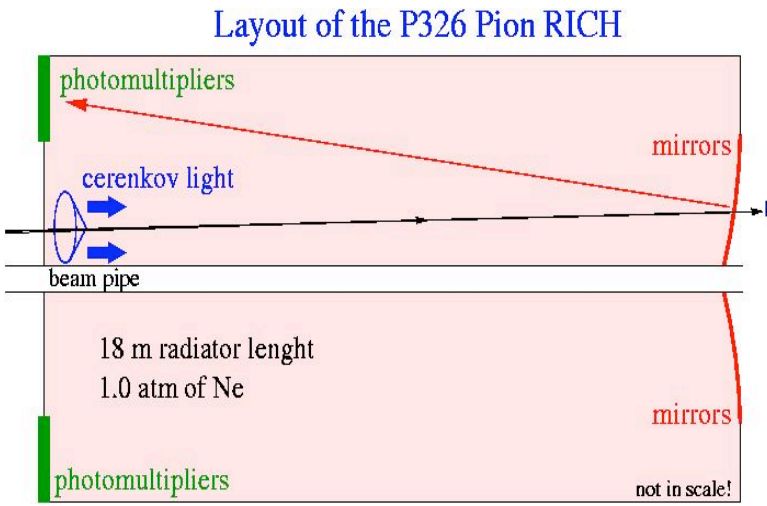
Comments:

- CNGS start subject to PS/SPS Committee (SPSC) decision
- COMPASS Muon run approved
- Summer Student Courses: H6 beam line, 4 mornings/afternoons in August (week 31/32)
- SILC R&D (H2, H6) to be approved by SPSC
- Week 44 and week 45: pion beam for P0 beam line

June-Nov 2007: P326 run at SPS

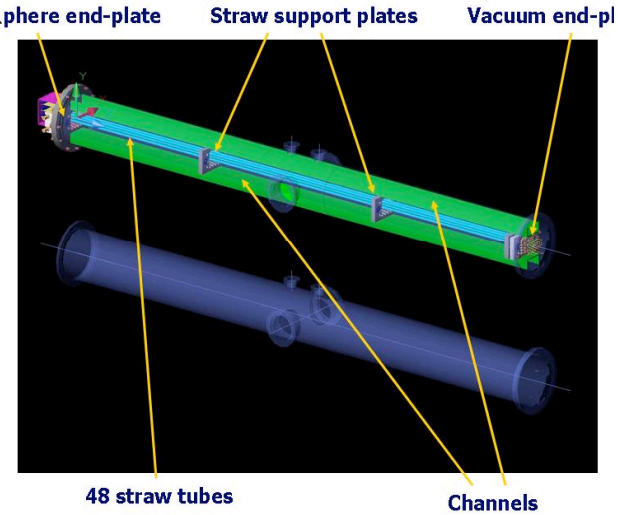
- run for $\Gamma(K_{e2})/\Gamma(K_{\mu 2})$ to accumulate 150K Ke2 events

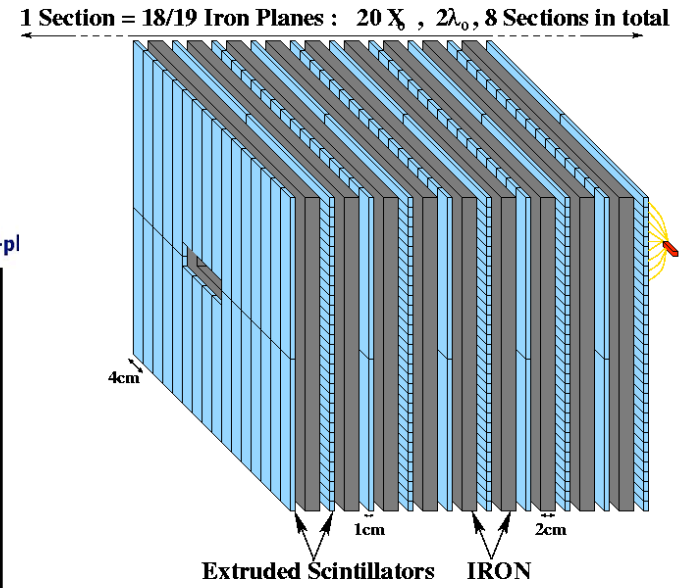
- test of new prototype detectors
  in the NA48 beam/detector environment:



RICH

straw



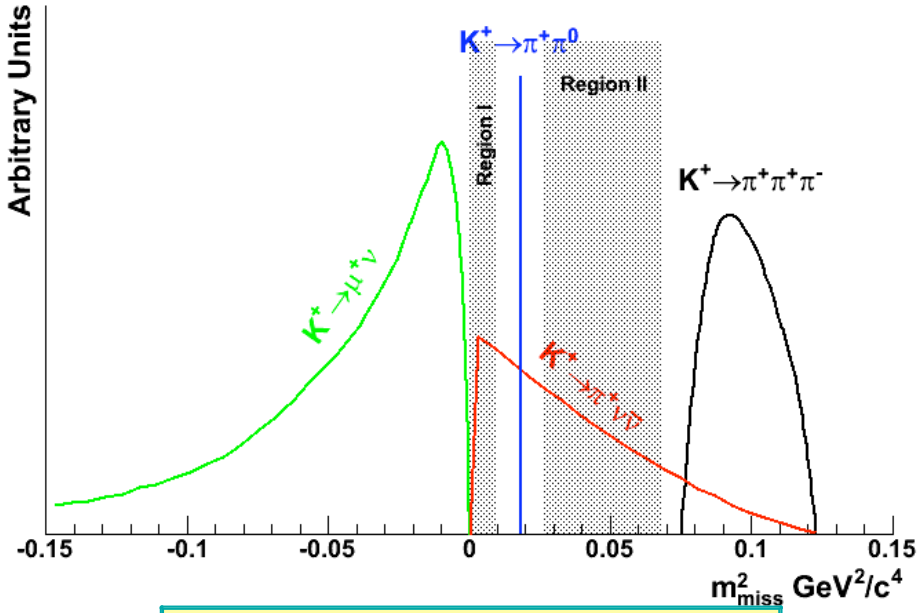


muon veto

Backgrounds

P326

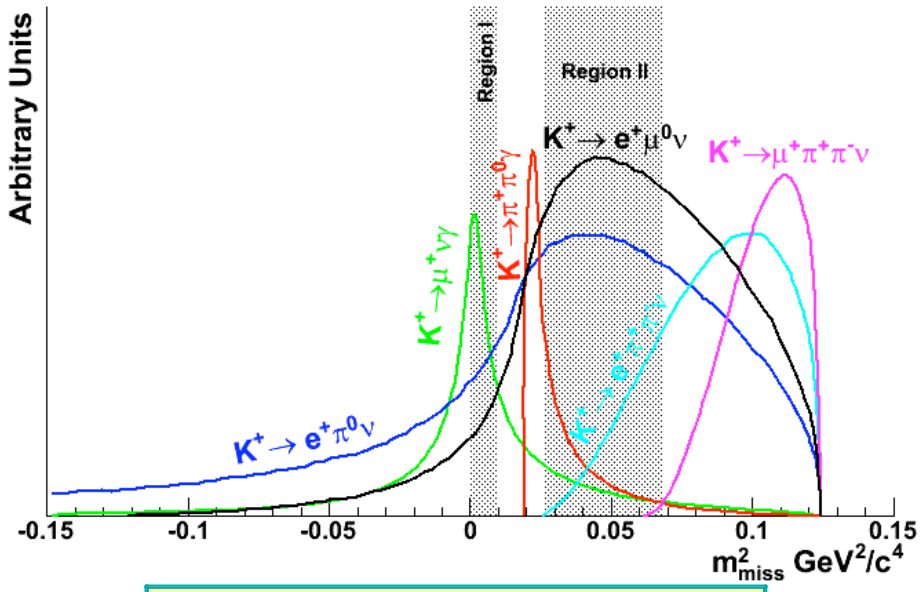
Kinematically constrained



92% of total background

- Allows us to define a signal region
- $K^+\to\pi^+\pi^0$ forces us to split it into two parts (Region I and Region II)

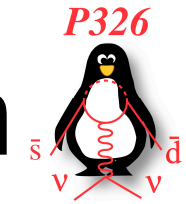
Not kinematically constrained



8% of total background

- Span across the signal region
- Rejection must rely on veotes

Analysis: background rejection



Events/year	Total	Region I	Region II
Signal *(acc=17%)*	65	16	49
$K^+ \to \pi^+\pi^0$	2.7	1.7	1.0
$K^+ \to \mu^+\nu$	1.2	1.1	<0.1
$K^+ \to e^+\pi^+\pi^-\nu$	~2	negligible	~2
Other 3 – track decays	~1	negligible	~1
$K^+ \to \pi^+\pi^0\gamma$	1.3	negligible	1.3
$K^+ \to \mu^+\nu\gamma$	0.5	0.2	0.2
$K^+ \to e^+(\mu^+)\,\pi^0\nu$, others	negligible	–	–
Total bckg.	9	3.0	6

➧ S/B ~ 8 (Region I ~5, Region II ~9)

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

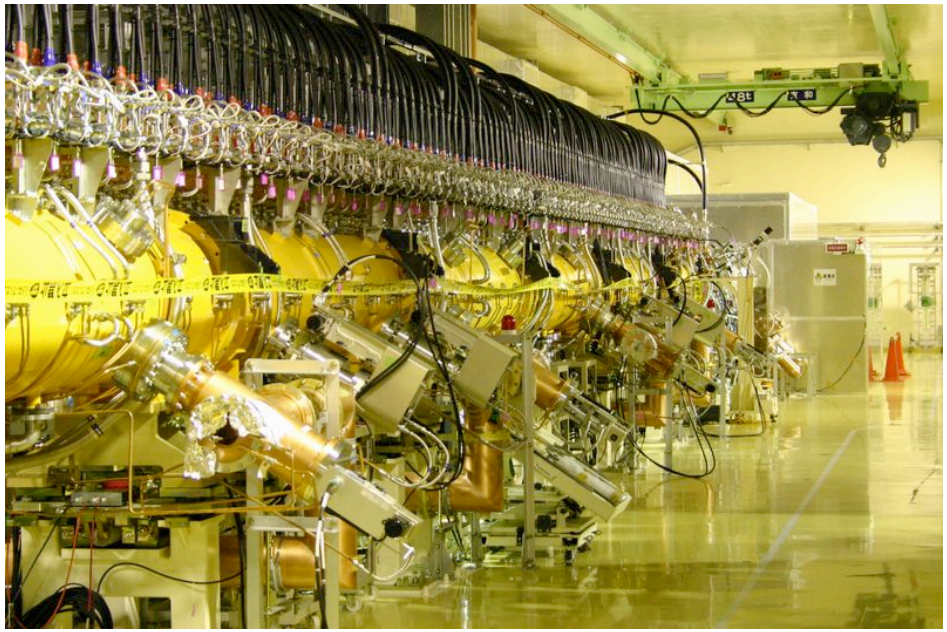
program at J-PARC: E14

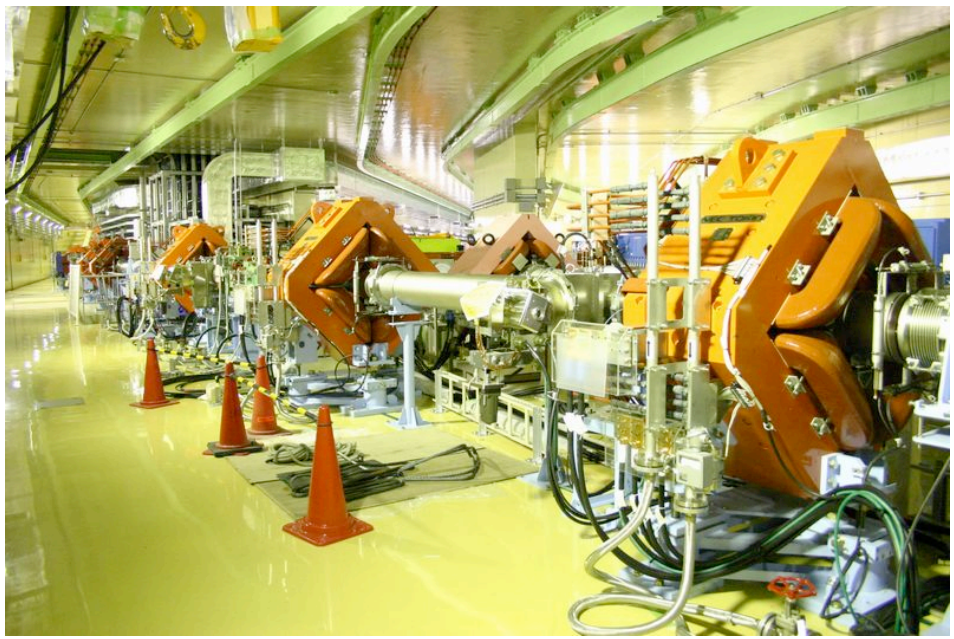
KEK, Kyoto, NDA, Osaka, Saga, Yamagata,
Arizona State, Chicago, Michigan-Ann Arbor,
JINR,
National Taiwan,
Pusan National, Seoul, CheonBuk

J-PARC

2006.Dec

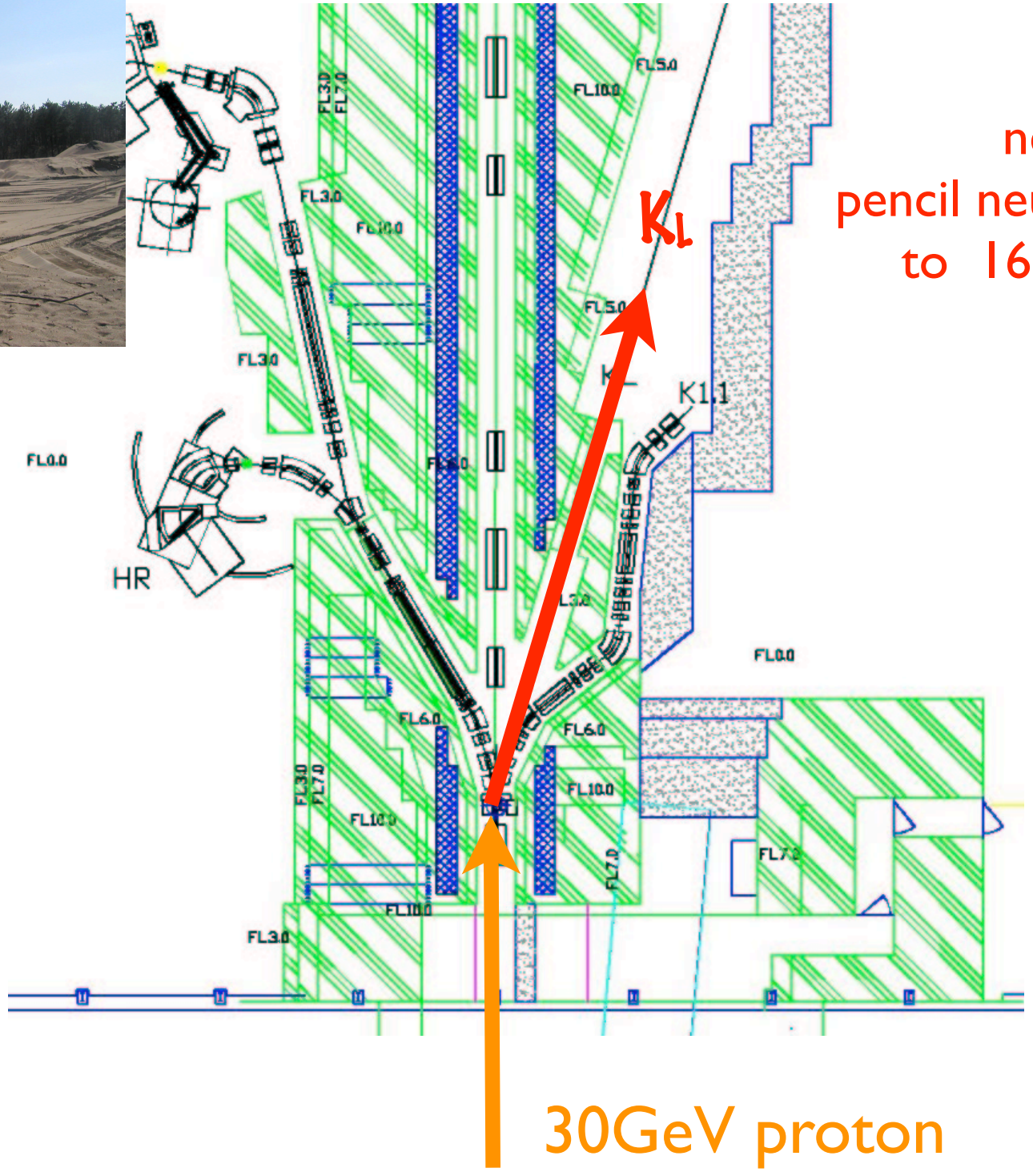
CERN COURIER
March 2007





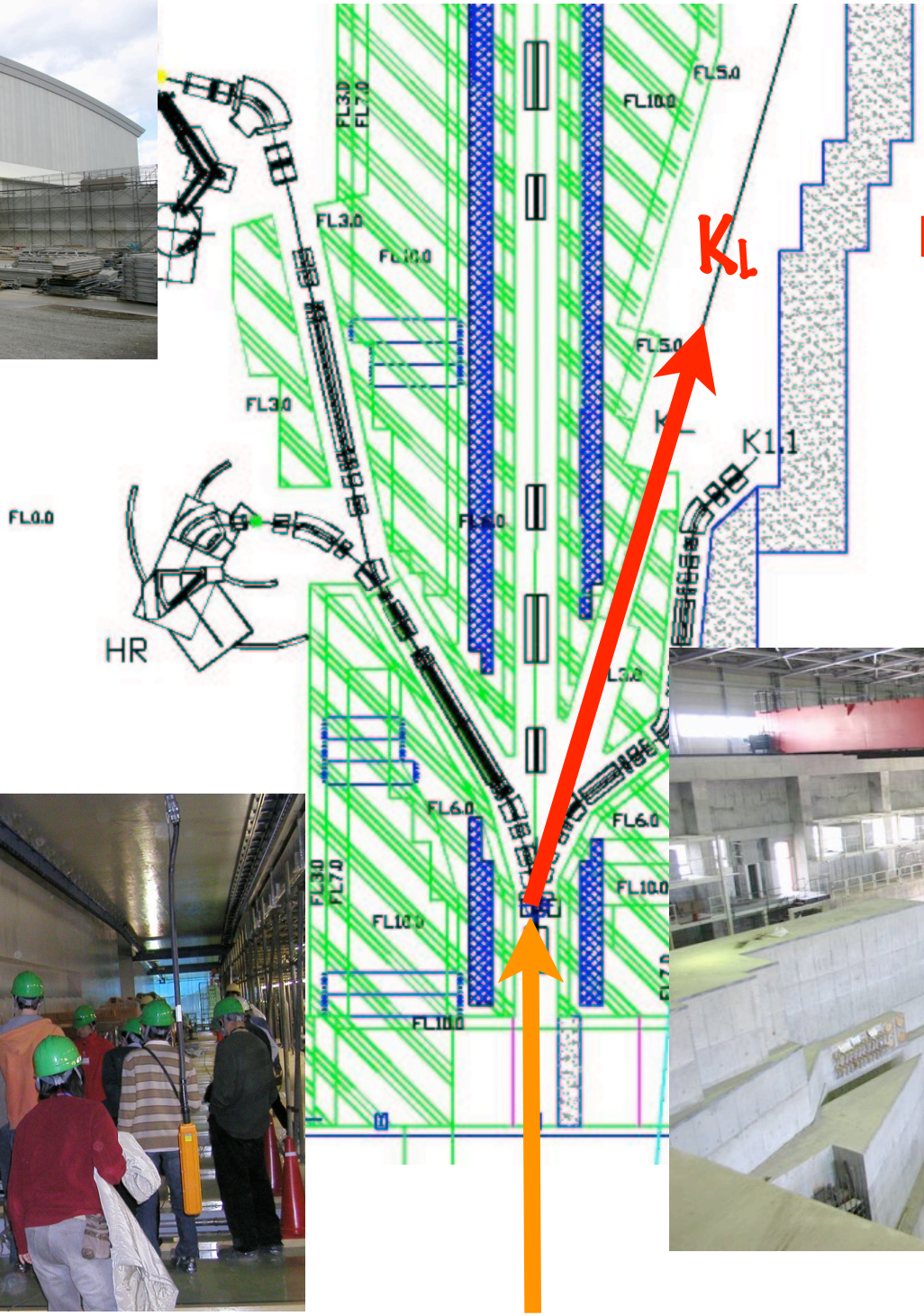
Schedule of construction and commissioning

- not official -



new
pencil neutral beam
to 16 degree

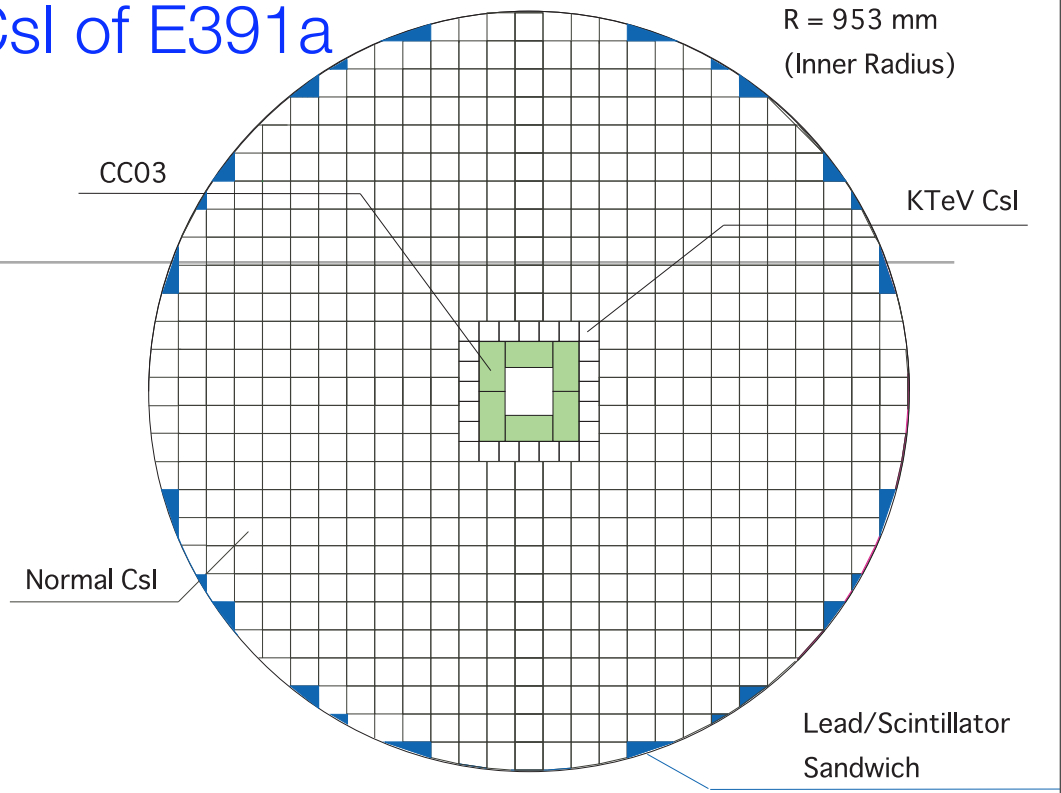
30GeV proton

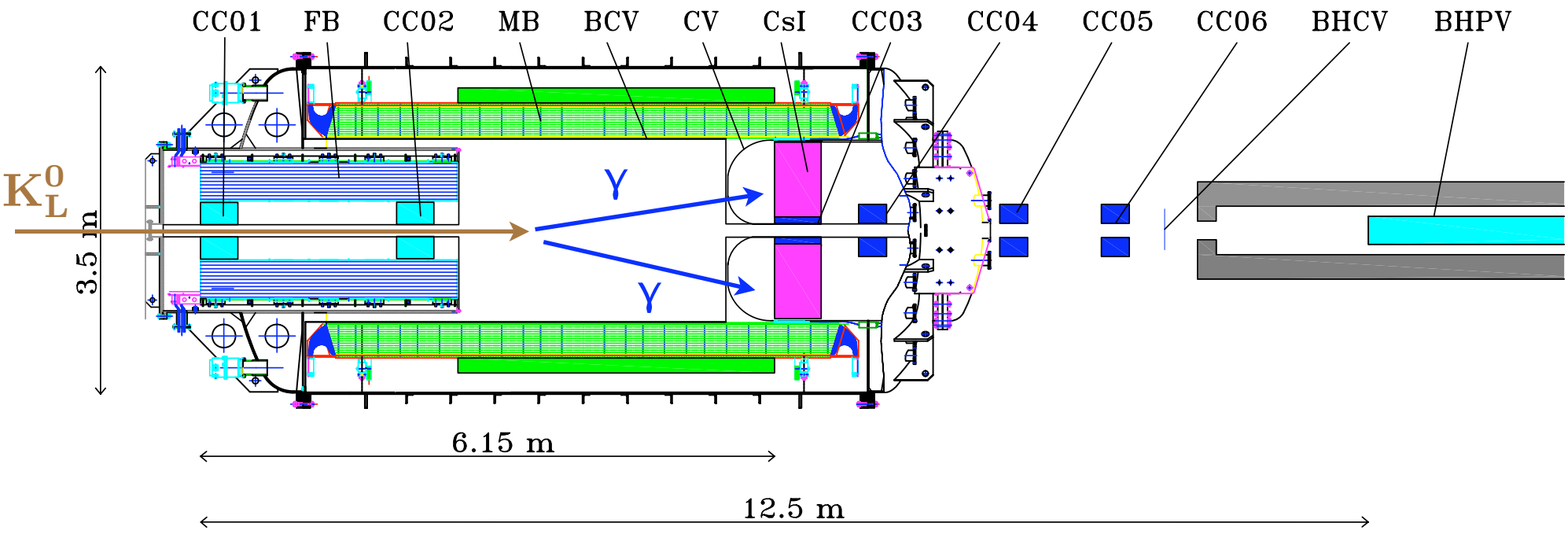


new
pencil neutral beam
to 16 degree

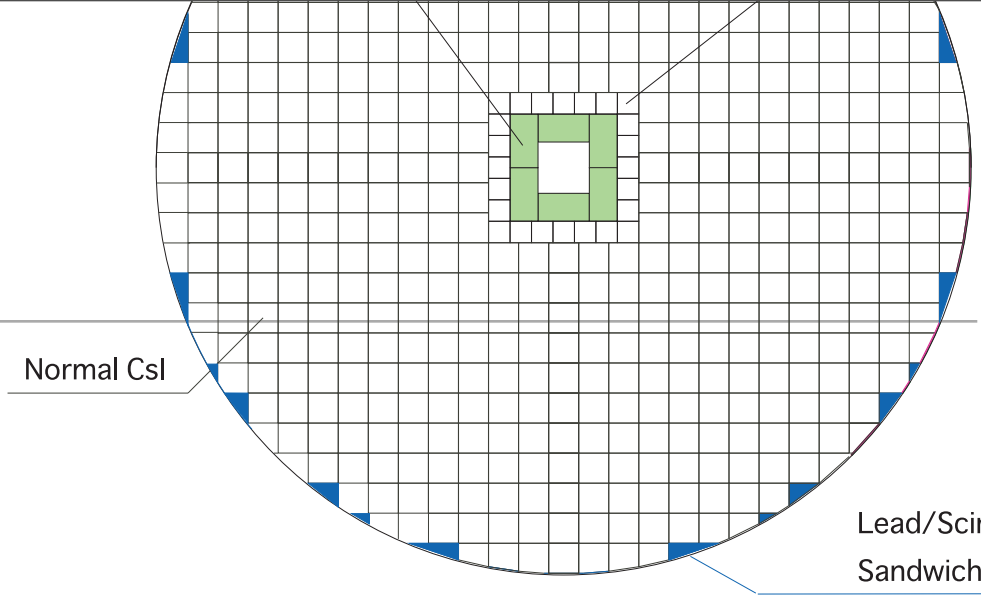
detector for $K_L^0 \to \pi^0 \nu\bar{\nu}$

- transfer and upgrade E391a detector
  - CsI calorimeter
  - readout: waveform digitization
  - photon veto in the beam



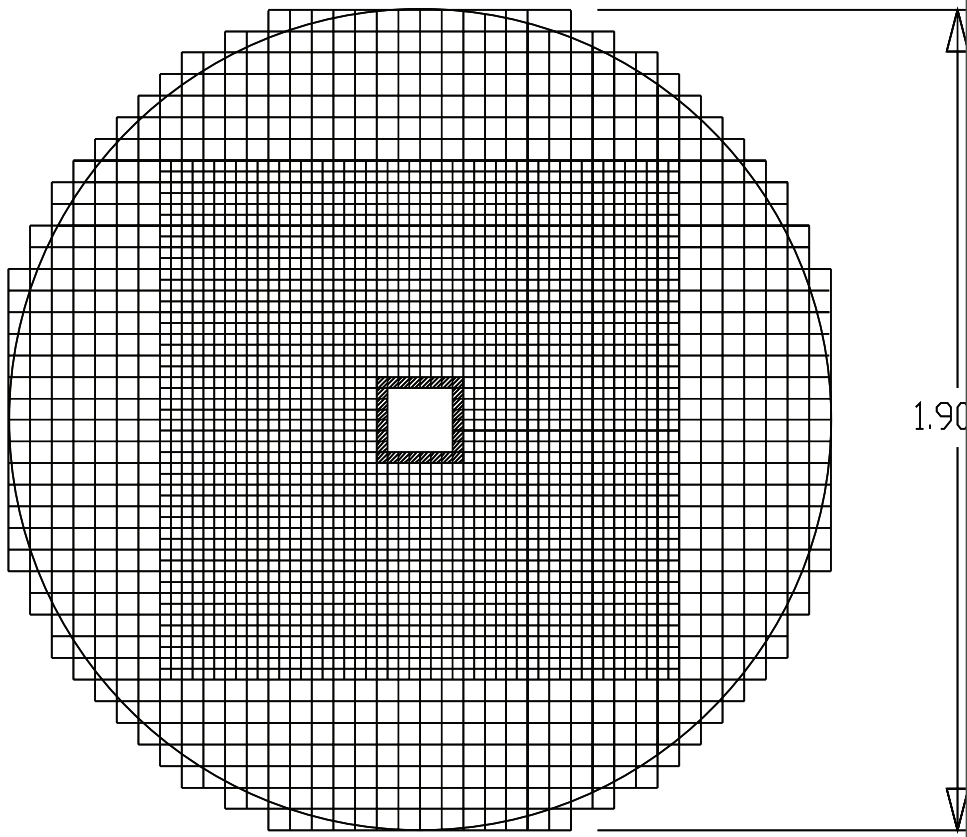


Calorimeter



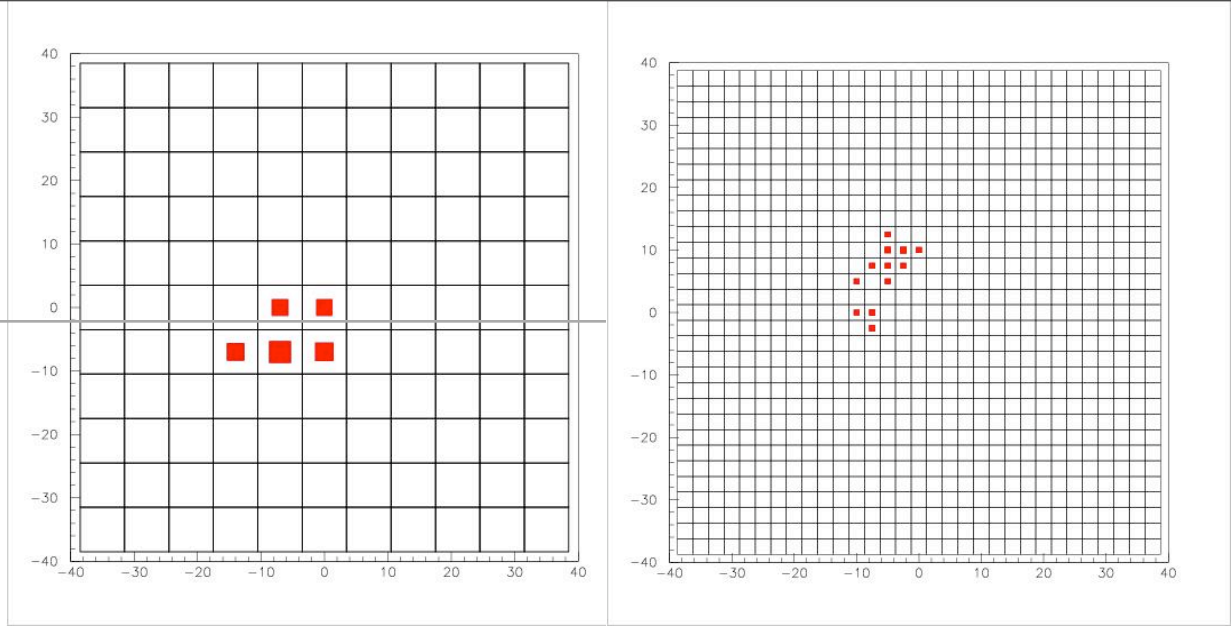
- 7cm x 7cm x 30cm (16 r.l.)
  CsI blocks for E391a (576 ch)

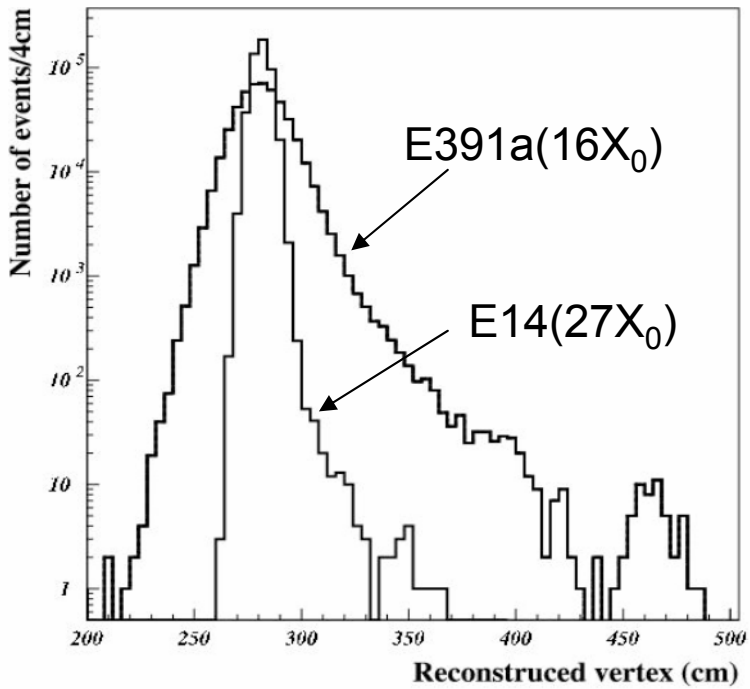
- 2.5cm x 2.5cm x 50cm (27 r.l.)
  or 5cm x 5cm x 50cm
  CsI blocks from KTeV (2816 ch)

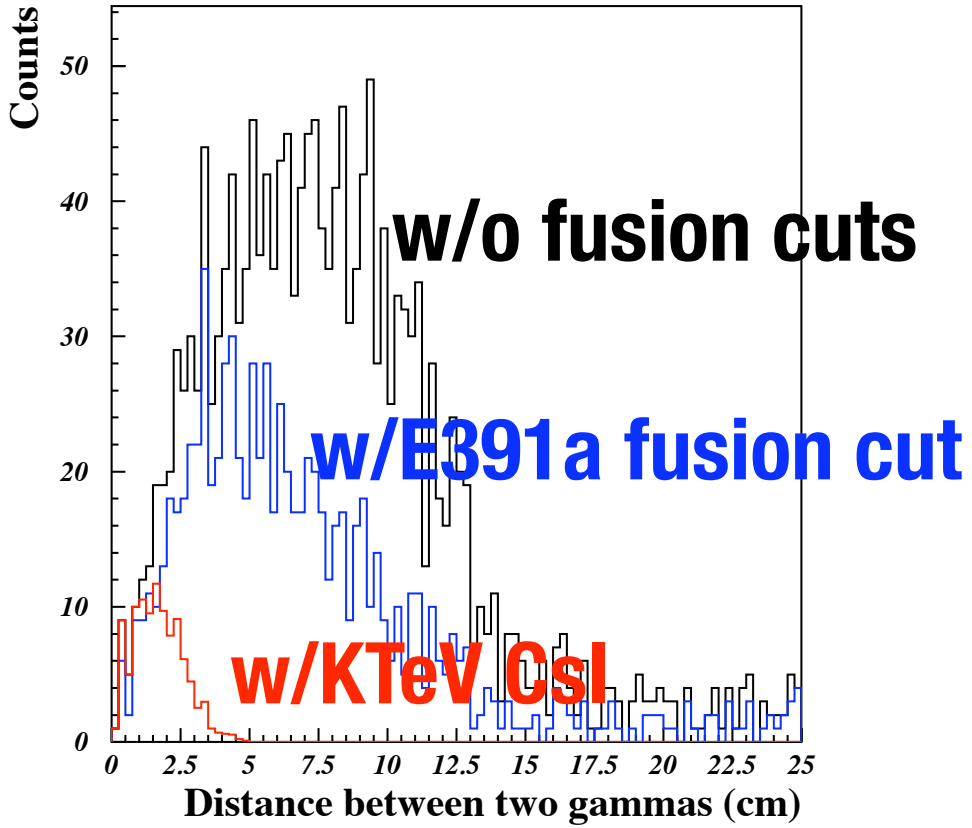


improvements

- photon isolation
  - x8 bkg reduction
- energy resolution (punch-through)
  - suppress neutron bkg



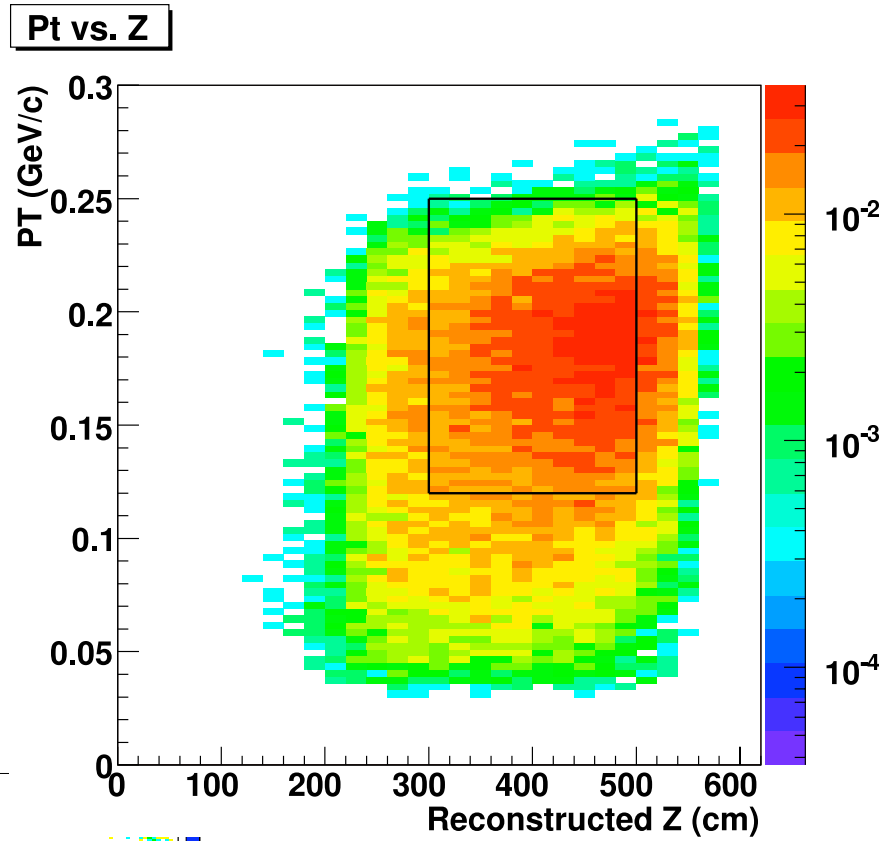


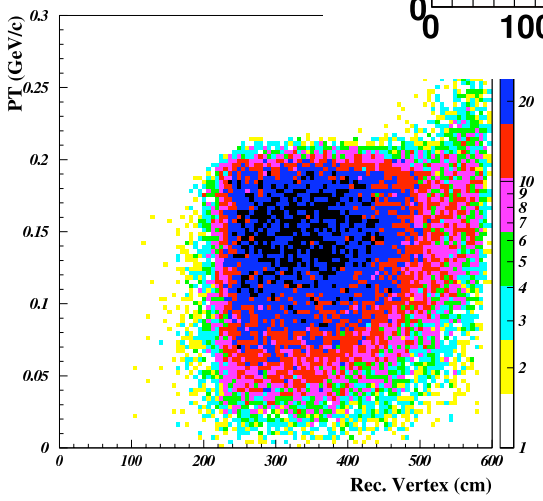


Signal Sensitivity for “Step1” = first observation

- acceptance : 4.7%
- 2.6x10^{12} K_L decays
  w/ 2E14 protons x 3E7 sec
- Sensitivity =8x10^{-12}

  3.5 SM events
- Backgound = 2 events





$K_L \to \pi^0\pi^0$

even pairing

schedule

- NA48/3 : R&D endorsed by CERN Research Board
  - Aims to complete R&D by the end of 2007
  - Start of data taking in 2011
- E14 : Stage-1(scientific) approved by PAC
  - preparation of the beam line and detector upgrade
  - make 100 channel system for CsI readout and do beam test
  - Beam survey at the end of JFY2008
  - assemble detector in JFY2009
  - start Step1 expeirment in JFY2010

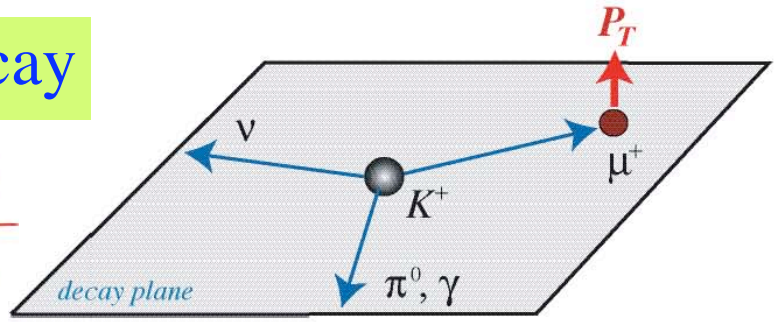
to be performed
by the date of
"5 years of LHC" (~ 2012/2013)

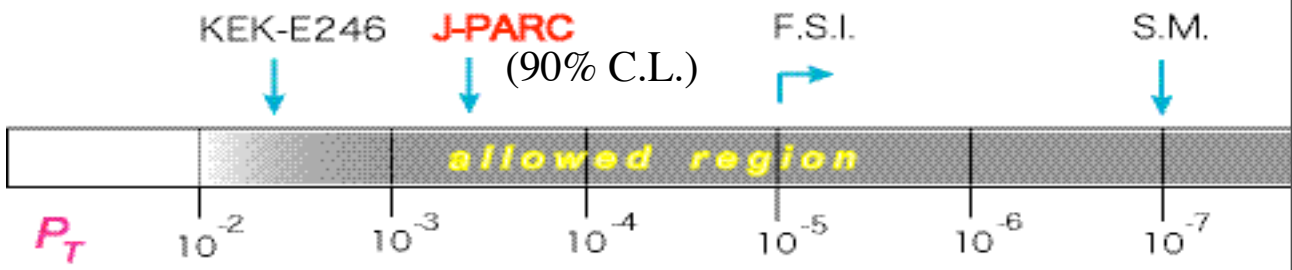
see also I.Bigi's report on Tuesday

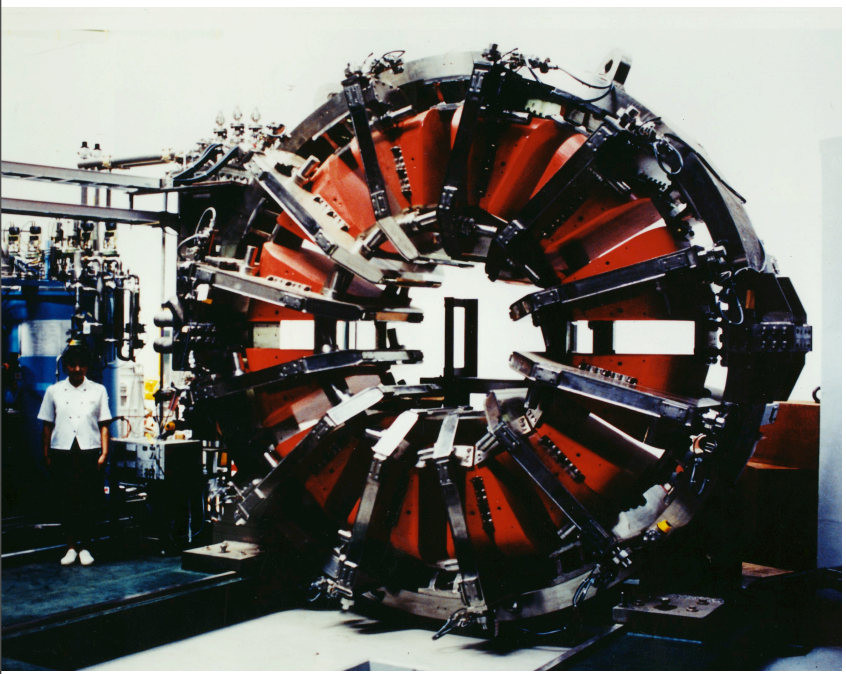
Transverse muon polarization

$K^+ \to \pi^0 \mu^+ \nu$ decay

$$P_T = \frac{\sigma_\mu \cdot (p_{\pi^0,\gamma} \times p_{\mu^+})}{|\,(p_{\pi^0,\gamma} \times p_{\mu^+})\,|}$$







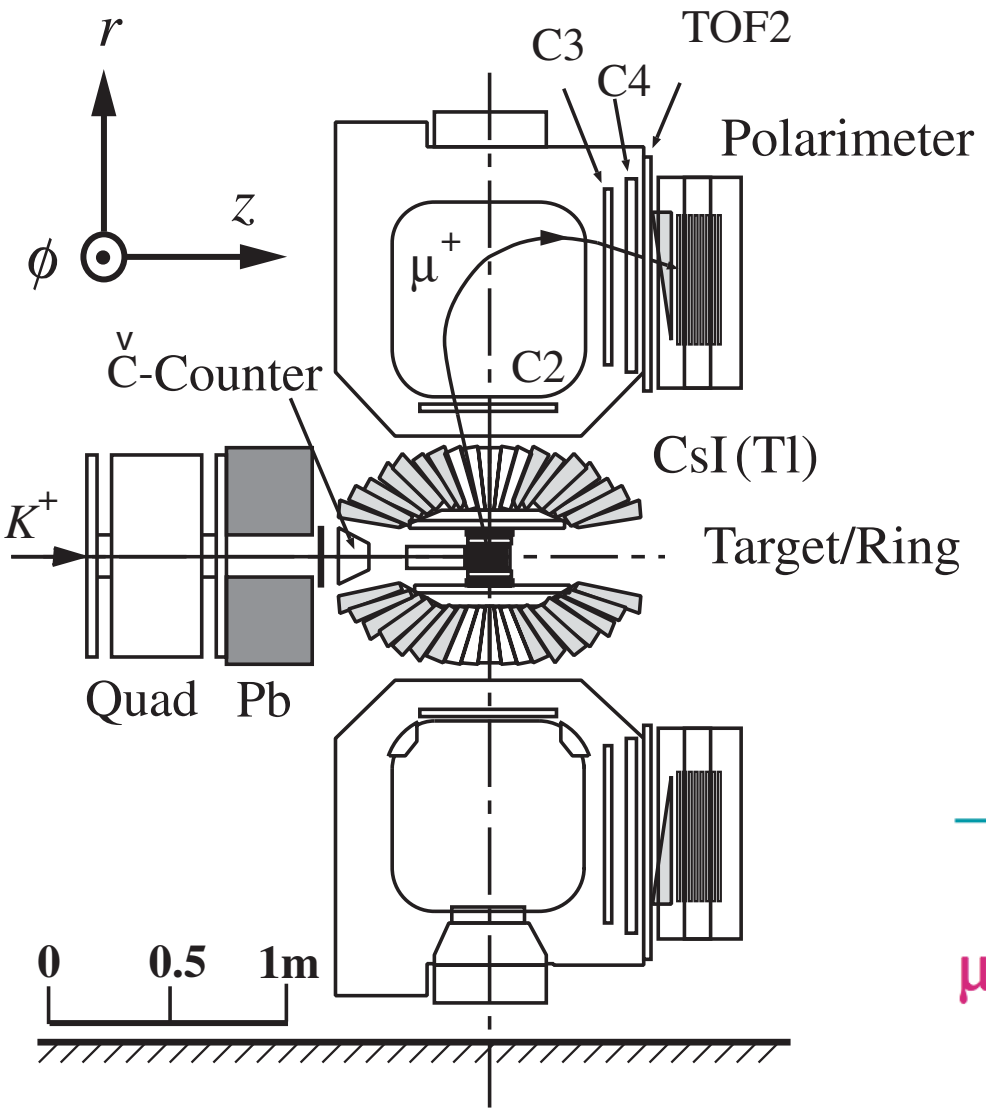
KEK-PS experiment E246 (1996-2000)

K+ decay at rest
SC toroidal spectrometer with 12 gaps

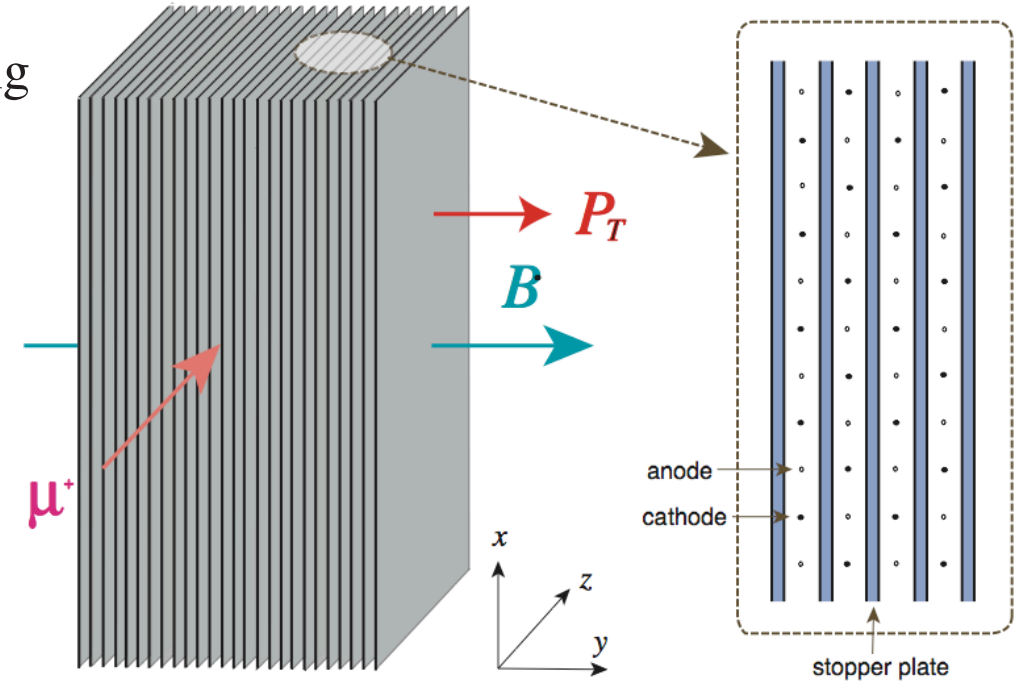
Final result **Phys. Rev. D73, 072005 (2006)**

"Stage-1 Approval"

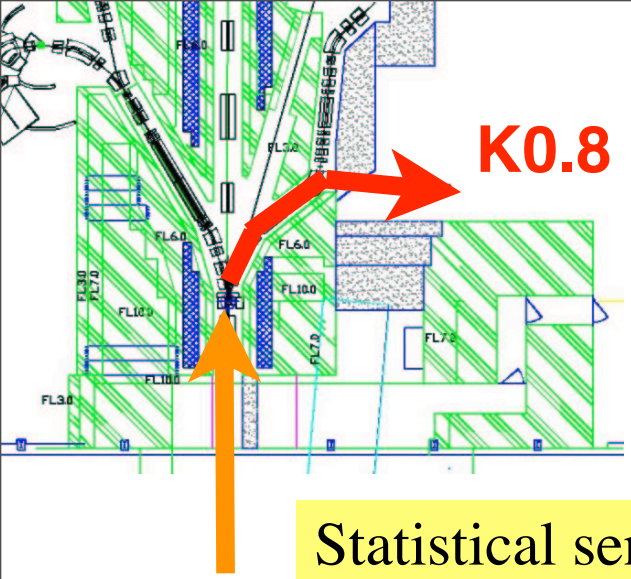
J-PARC experiment E06



detector upgrades with
active muon polarimeter



Parallel plate stopper with
Gap drift chambers



Sensitivity estimate

Statistical sensitivity

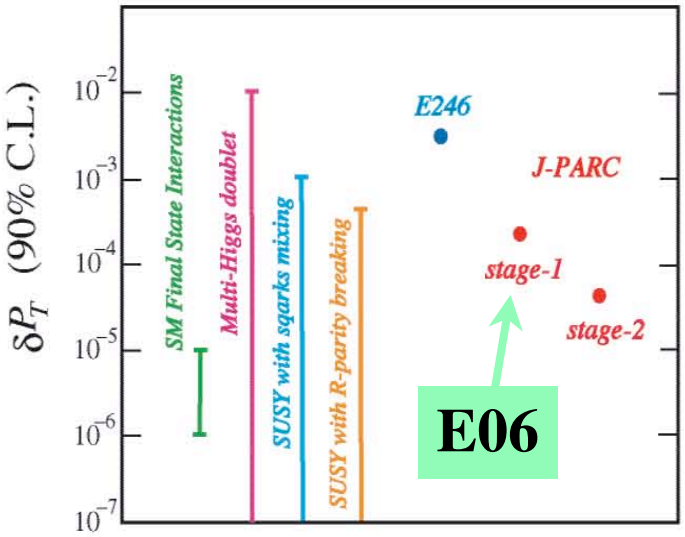
Standard analysis

- Net run time 1.0×10^7 s
- Proton beam intensity 9μA on T1
- K^+ beam intensity 3×10^6 /s
- Total number of good $K_{\mu 3}$ 2.4×10^9
- Total number of *fwd*/*bwd* (N) 7.2×10^8
- Sensitivity coefficient $3.73/\sqrt{N}$
- δP_T 1.35×10^{-4}

including left/right regions

- δP_T 0.8×10^{-4}

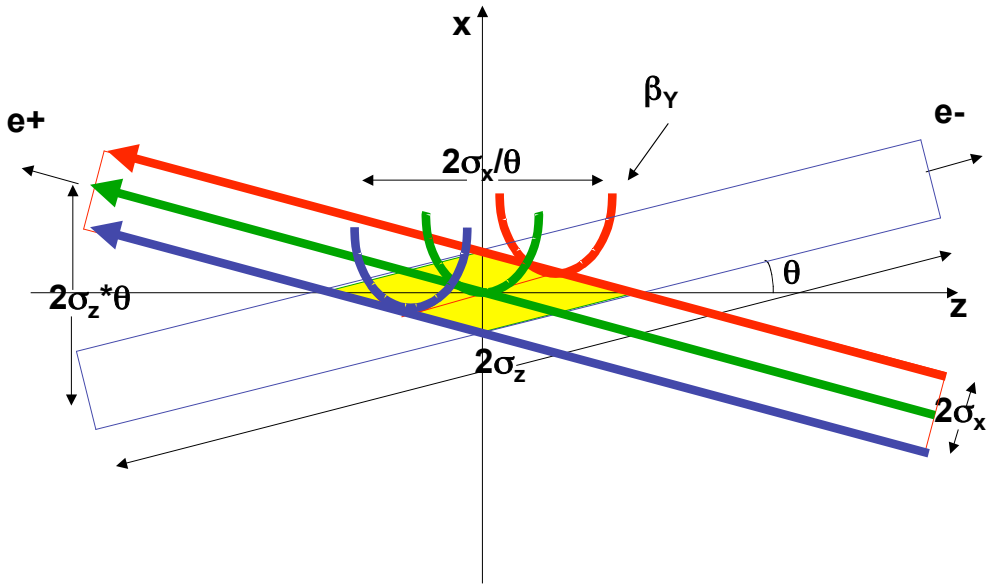
(A careful systematic error study is necessary)



Systematic errors

Source	δP_T
δ_z	$< 10^{-4}$
θ_z	$< 10^{-4}$
θ_{e+}, E_{e+}	$< 10^{-4}$
Total	$\sim 10^{-4}$

DAΦNE upgrade



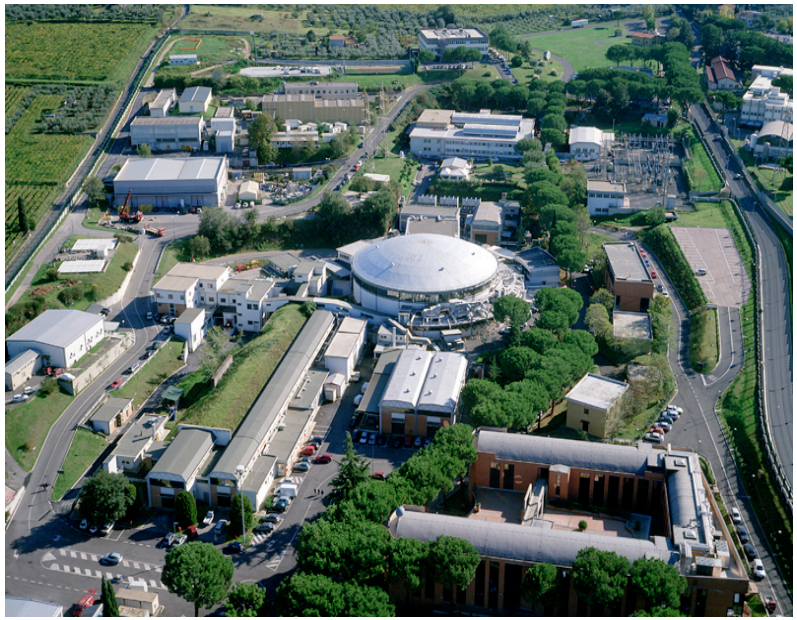
- Crabbed Waist collisions
  to increase the luminosity - $O(10^{33})$

  (and to test the idea
  for the SuperB project)

- new SIDDHARTA experiment : 2007 --
  (Kaonic atoms)

- KLOE detector upgrade (KLOE2)

  - neutral kaon interferometry
    (CPT and QM tests)
  - rare Ks decays
  - eta and eta' decays
  - hadron cross-section measurements
  - ...

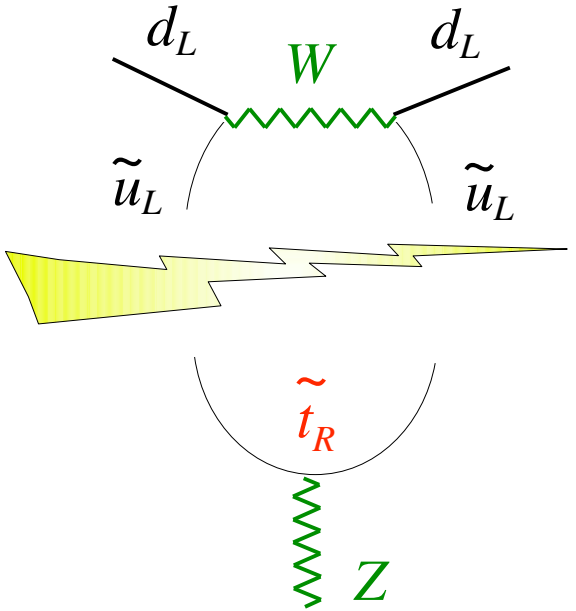


conclusions:

- The study of kaon physics continues to make great strides.

- Future kaon programs at the date of
  "5 years of LHC" (~ 2012/2013)
  will be:

  - $K \to \pi\nu\bar{\nu}$
  - T odd correlation in $K^+ \to \mu^+\nu\pi / \mu^+\nu\gamma$
  - Lepton Universality
  - CPT and QM tests, rare Ks decays [KLOE2]



- new super-flavor factory ***J-PARC*** is rising.

New physics is there !!

We know it for sure, at least from neutrino physics & dark matter [→ Masiero]

What we don't know yet are

energy scale & flavour strucutre of NP

LHC

we should not be pessimistic...

LHC will find NP @ TeV !

...and the collective effort toward flavour physics will be rewarded !

Rare K decays

Rare B decays

CPV in the Bs system

Super CKM fits

Precision tests in B & K semilept. decays

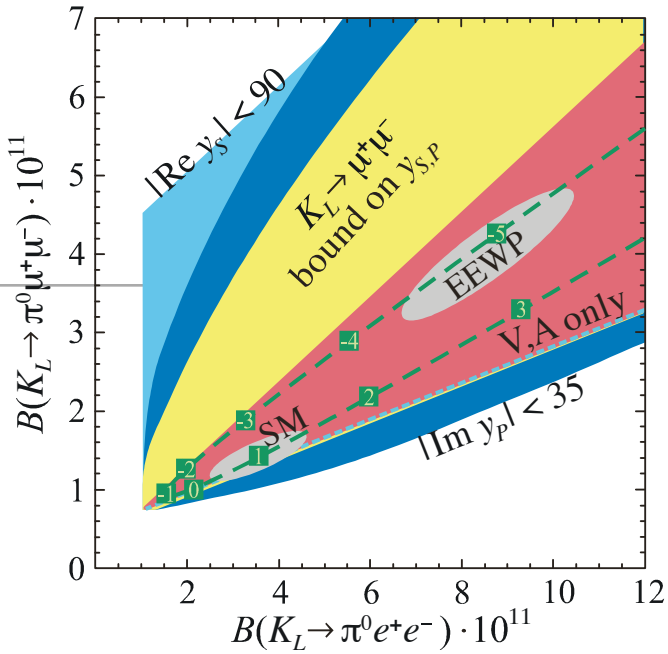
LFV in μ & τ decays

EDMs

g-2

Backup slides

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



- theoretical uncertainties (direct-CP/indirect-CP/CPC) are under control :
  allowing significant test of flavor physics

- need spectrometer for tracking $(\mu^+\mu^-)\,(e^+e^-)$
  do not need a pencil beam

- trackers in front of the calorimeter may do harm
  for $K_L \to \pi^0\pi^0$ background rejection (photon inefficiency);
  --> trackers will not be located
  at the Step1 experiment for $K_L^0 \to \pi^0 \nu\bar{\nu}$

- We are doing R&D of trackers for future.