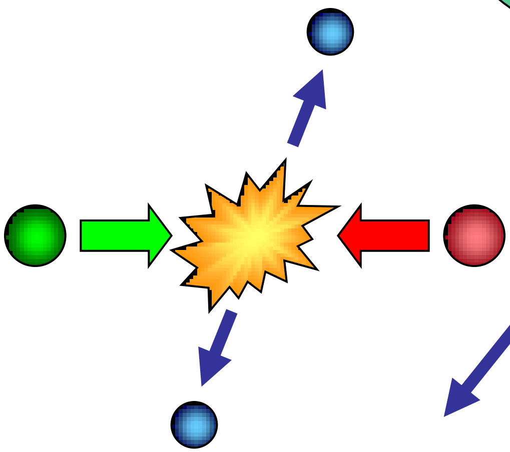
New Kaon projects

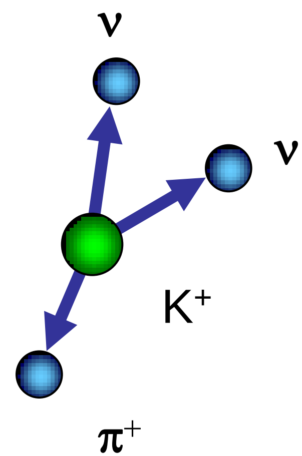
Augusto Ceccucci / CERN

Indirect Searches for New Physics at the time of LHC

Experimental Techniques

Search for New Physics Beyond the SM





Energy Frontier

- Produce heavy new particles directly
- Heavy particles need large colliders
- **LHC Media Event: March 30, 2010!**

Rarity Frontier

- Look for deviations from precise SM predictions, CKM, K, D, B Decays, Leptons
- Look for rare or forbidden processes
- Requires high precision & intensity

"New" Kaon Project "at the time of the LHC"

- There is some freedom in defining a "New Kaon" project when the framework is defined as the "time of the LHC"
- I take here a broad perspective considering projects that have been approved and in construction and also projects with a bit longer time-scale and an uncertainty.
- I will refrain from mentioning kaon projects for the 2030+, although one could argue that the exploitation of the LHC may well extend into those years…….

Motivation

- Physics motivation in Isidori's talk, in addition:
- Interplay between technology and science
  - Development of beyond state-of-the-art detectors for eventual use at future collided and other applications (e.g. time-stamping)
- Training ground for young experimentalists:
  - opportunities to educate the next generations of students giving them –if history is a guide– excellent opportunities

Outline

- CKM Unitarity (V_{us})
- Lepton Universality (R_K)
- Ultra-Rare K decays ($K\rightarrow\pi\nu\bar{\nu}$)
- Kaon Interferometry ($\varphi\rightarrow K\bar{K}$)

CKM Unitarity: V_{us}

- **Experiment:**

  Flavianet average of K^0_s / K^0_L / K semi-leptonic modes:

$f_+(0)\ |V_{us}| = 0.21664 \pm 0.00048$

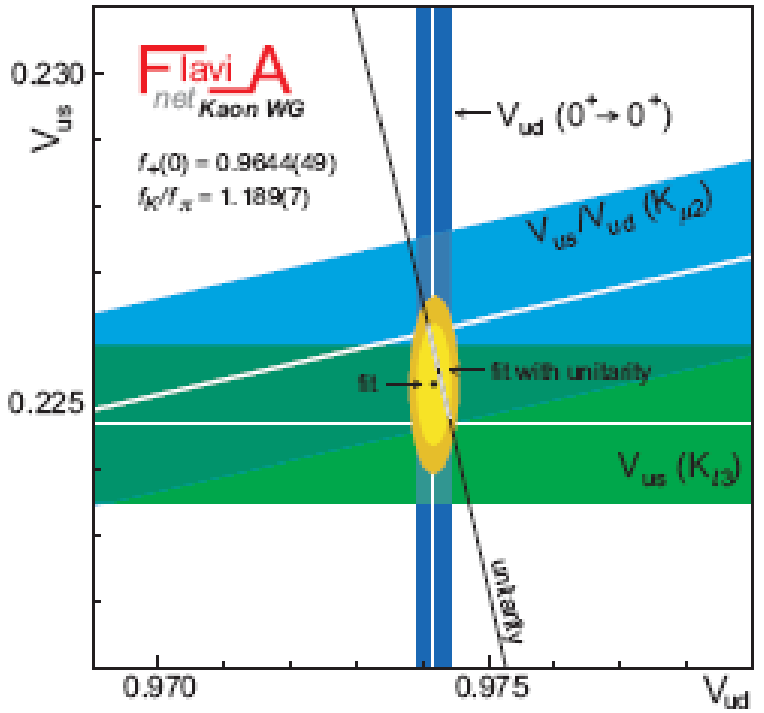
→ 0. 22 % relative error!

- **Lattice QCD (RBC UKQCD):**

  $f_+(0) = 0.9644 \pm 0.0049$

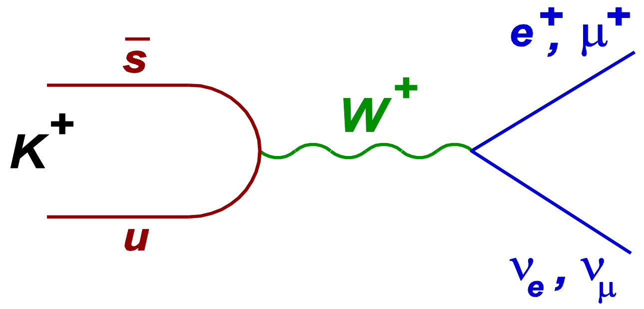
  $\rightarrow |V_{us}| = 0.2246 \pm 0.0012$

- **Wait for Chris Sachrajda's talk for lattice QCD $f_+(0)$ determination**

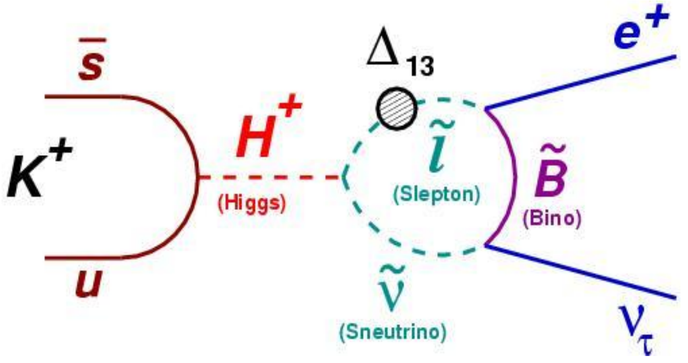


R_K: Lepton Universality Test with $K^+ \to l^+ \nu$

SM



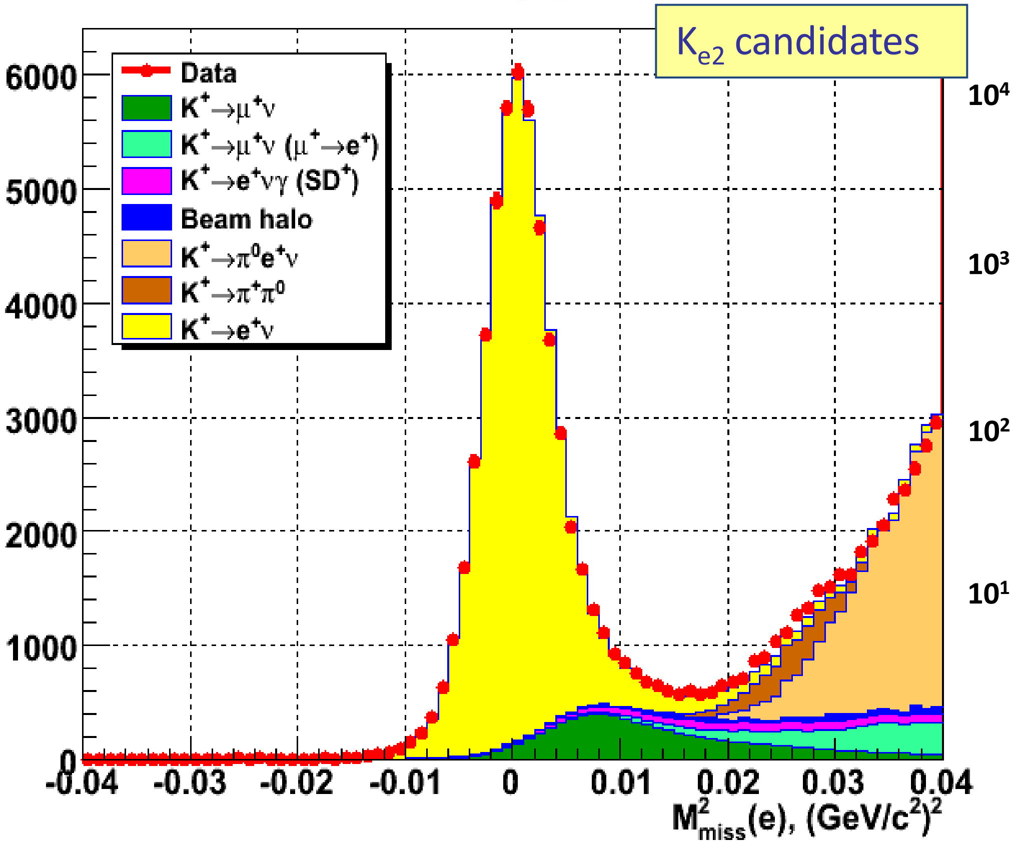
New Physics



$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right)^2 \cdot (1 + \delta R_K^{\mathrm{rad.corr.}})$$

<0.1 % precision of the SM prediction

K_{e2}: 40% of data set



51,089 $K^+ \to e^+\nu$ candidates,
99.2% electron ID efficiency,

Backgrounds:

Source	B/(S+B)
$K_{\mu 2}$	$(6.28\pm0.17)\%$
$K_{\mu 2}$ ($\mu \to e$)	$(0.23\pm0.01)\%$
$K_{e2\gamma}$ (SD^+)	$(1.02\pm0.15)\%$
Beam halo	$(0.45\pm0.04)\%$
K_{e3}	0.03%
$K_{2\pi}$	0.03%
Total	$(8.03\pm0.23)\%$

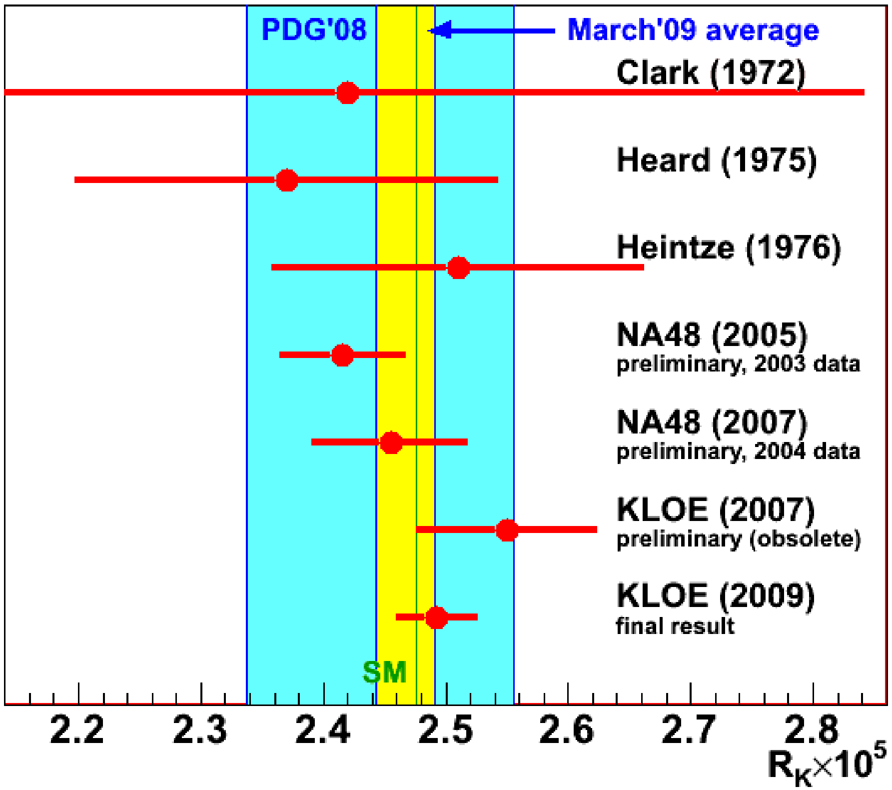
$$R_K = (2.500 \pm 0.012_{stat} \pm 0.011_{syst}) \times 10^{-5}$$

$$R_K = (2.500 \pm 0.016) \times 10^{-5}$$

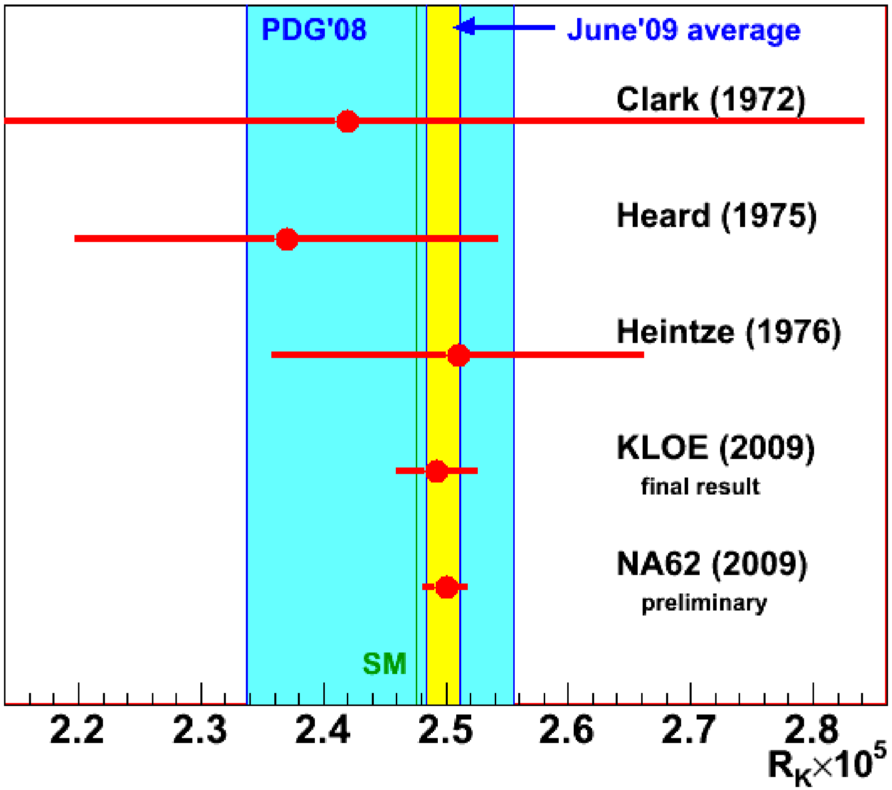
Presented by Evgueni Goudzovski at KAON2009

Comparison to world data

March 2009



June 2009



World average	$\delta R_K \times 10^5$	Precision
March 2009	2.467 ± 0.024	0.97%
June 2009	2.498 ± 0.014	0.56%

With the full NA62 data sample of 2007/08, the precision is expected to be improved to better than $\delta K_R/R_K = 0.5\%$.

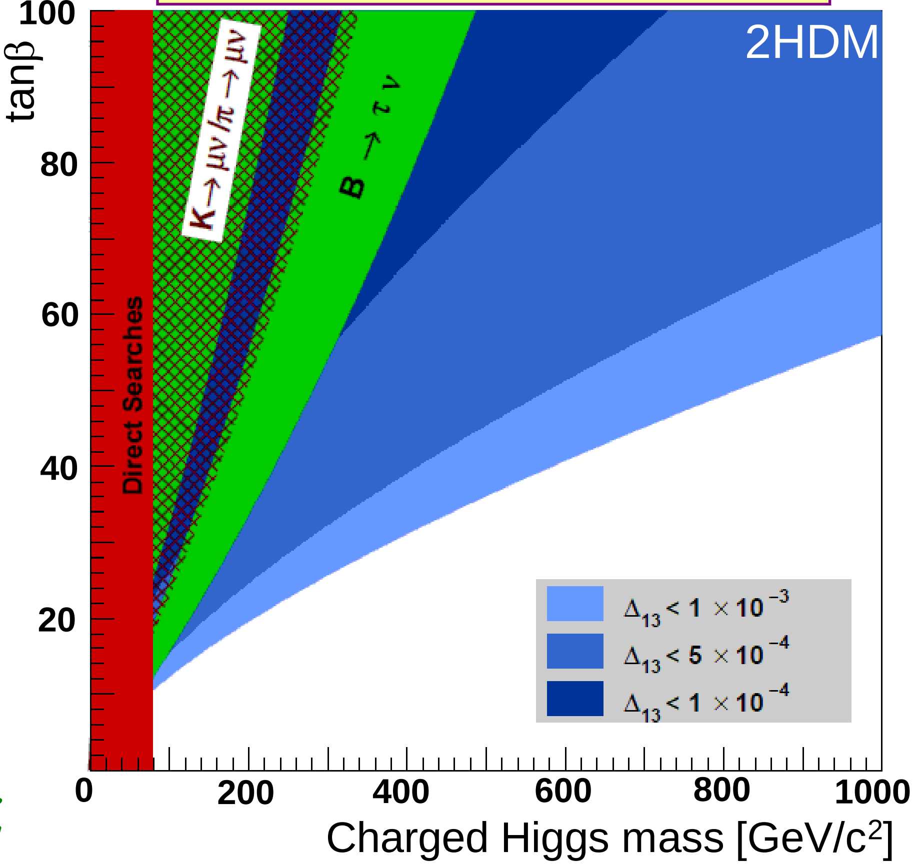
R_K: sensitivity to new physics

R_K measurements are currently in agreement with the SM expectation at ~1.5σ.
Any significant enhancement with respect to the SM value would be an evidence of new physics.

For non-tiny values of the LFV slepton mixing Δ_{13}, the sensitivity to $H^{\pm}$ in $R_K=K_{e2}/K_{\mu 2}$ is strong

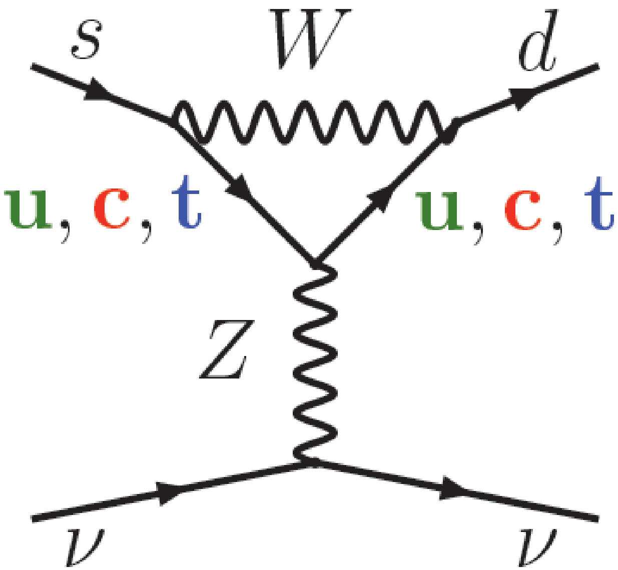
"Maybe NA62 will find the first evidence for a charged Higgs exchange?"
-- John Ellis (arXiv:0901.1120)

(M_H, tanβ) 95% exclusion limits



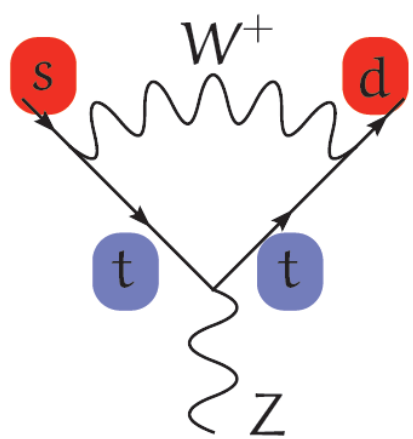
Ultra-rare K Decays

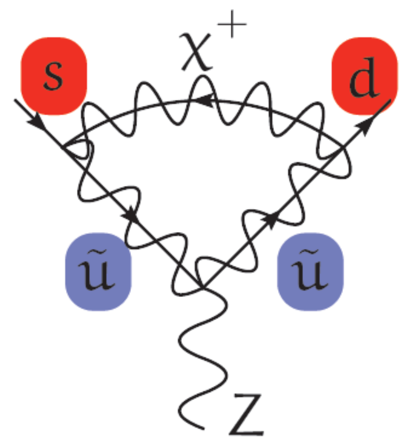
$$K \to \pi \nu \bar{\nu}$$



- **The contribution to these processes due to the Standard Theory is strongly suppressed ($<10^{-10}$) and calculable with excellent precision (~%)**

- **They are very sensitive to possible contributions from New Physics**





$K \rightarrow \pi \nu \bar{\nu}$: Current Status

Decay	Branching Ratio ($\times 10^{10}$)	
	Theory (SM)	Experiment
$K^+ \rightarrow \pi^+ \nu \bar{\nu} (\gamma)$	0.85 ± 0.07[1]	$1.73^{+1.15}_{-1.05}$[2]
$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$	0.26 ± 0.04[3]	< 260 (90% CL)[4]

[1] J.Brod, M.Gorbahn, PRD78, arXiv:0805.4119
[2] AGS-E787/E949 PRL101, arXiv:0808.2459
[3] M. Gorbahn
[4] KEK-E391a arXiv:0911.4789v1

Neutral Beams for $K^0_L \to \pi^0 \nu\bar{\nu}$

"Pencil"

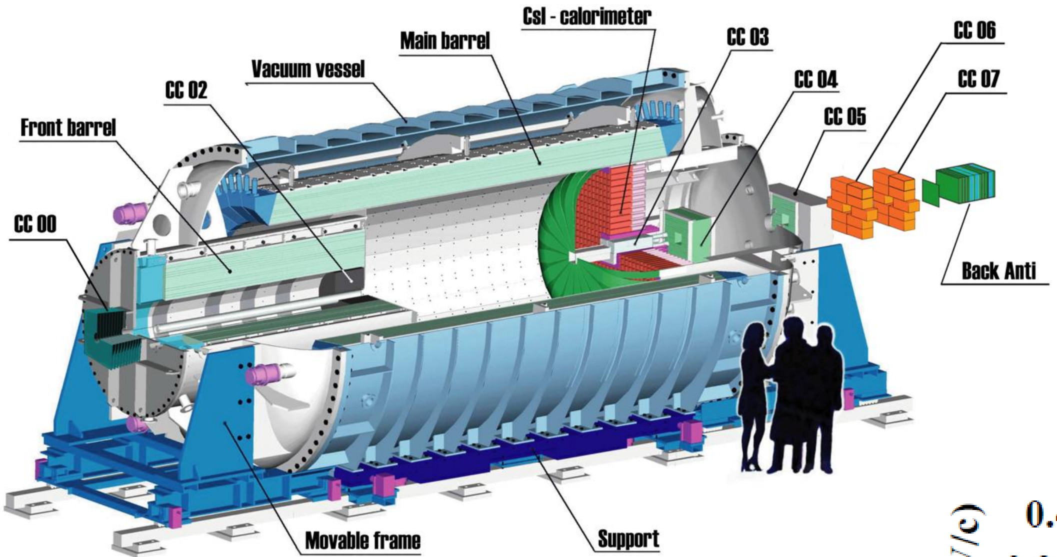
- π^0 + "nothing"
- P_T cut for $\Lambda \to n\pi^0$ & $K^0_L \to 2\pi^0$ suppression
- hermetic calorimetry

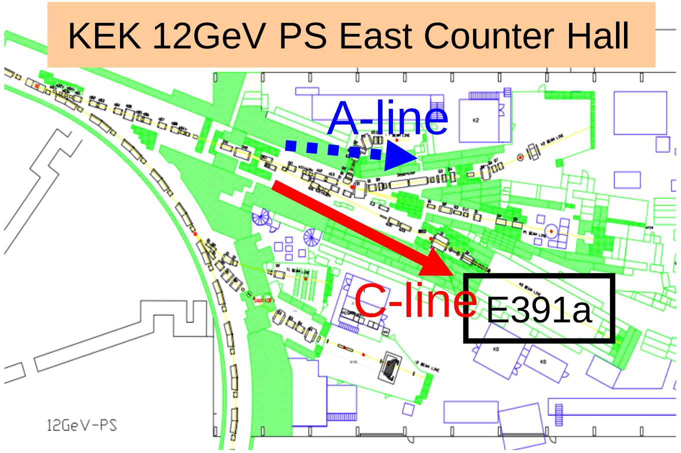
"Microbunched"

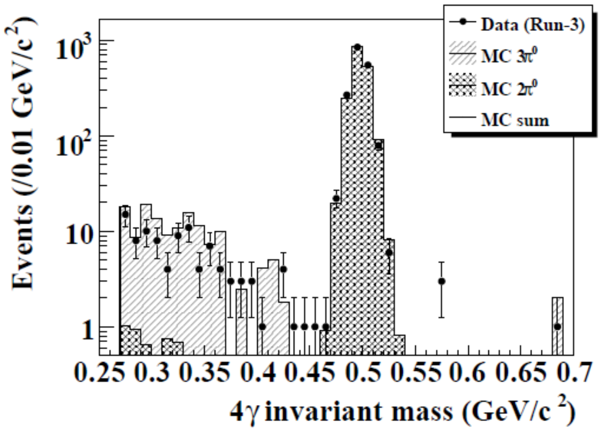
- E_K from Time Of Flight
- Low(er) Kaon Energy
- KOPIO BNL Concept further elaborated for FNAL (Bryman@KAON09)

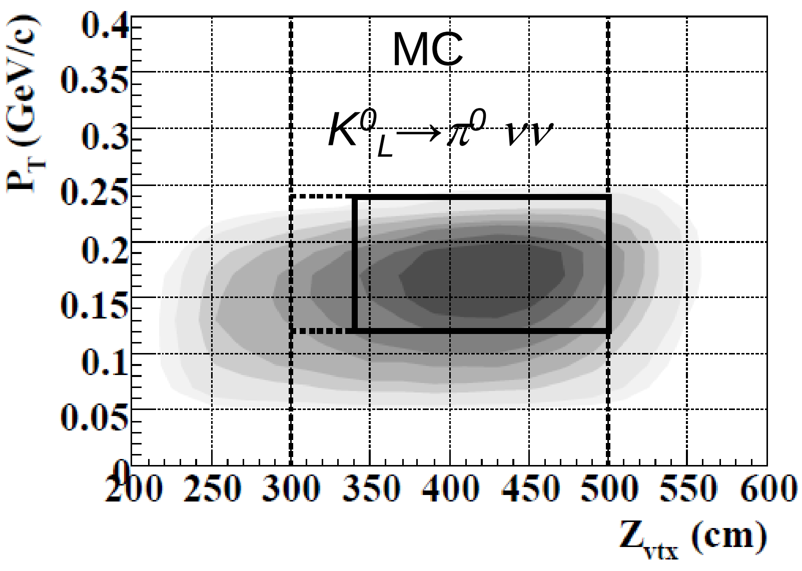
Exp	Machine	UL 90% CL	Notes
KTeV	Tevatron	$< 5.7 \times 10^{-7}$ ($\pi^0 \to ee\gamma$)	
E391a	KEK-PS	$<2.6 \times 10^{-8}$	
KOTO	J-PARC		Aim at 2.7 SM evts / 3 y
KLOD	U70		Excellent Design
KOPIO			Opportunity at Project X (IC2) ?

E391a @ KEK PS


CsI - calorimeter
Main barrel
Vacuum vessel
CC 02
Front barrel
CC 00
CC 03
CC 04
CC 05
CC 06
CC 07
Back Anti
Movable frame
Support


KEK 12GeV PS East Counter Hall
A-line
C-line
E391a
12GeV-PS

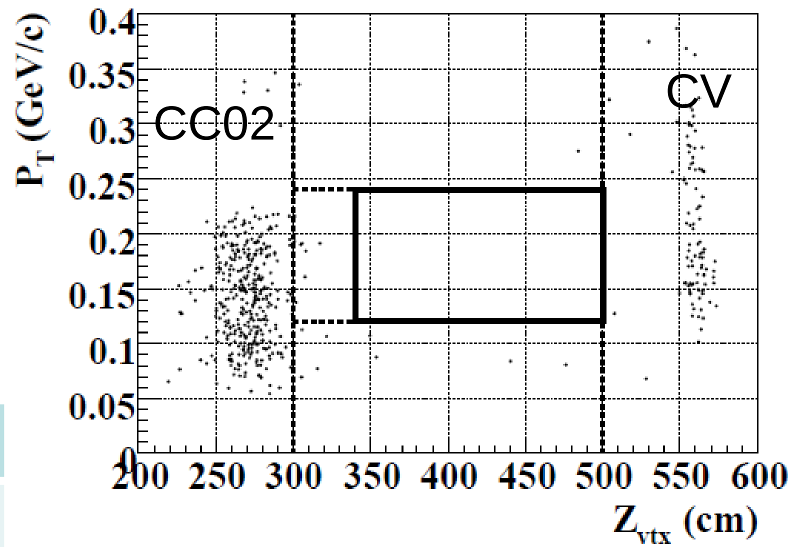

Data (Run-3)
MC 3π0
MC 2π0
MC sum
Events (/0.01 GeV/c2)
4γ invariant mass (GeV/c2)


MC
K0L→π0 νν
PT (GeV/c)
Zvtx (cm)

E391a Final Result

- **arXiv:0911.4789v1**
- **Based all full statistics (2004-2005) including reanalysis of already published data**
- **At these sensitivities backgrounds from kaon decays are negligible w.r.t. neutron induced ones**

Signal Acceptance ~1%
Flux 8.7 x 10^9 K^0_L



Background		**Estimated # evt**
Beam Halo neutron	CC02-π^0 CV-π^0 CV-η	0.66 0.39 <0.39 0.19 0.13
$K^0_L \rightarrow \pi^0\pi^0$		(2.4 1.8) x 10^{-2}
Other	Backward π^0	<0.05
Total		**0.87 0.41**

$B(K^0_L \rightarrow \pi^0 \nu\nu) < 2.6 \times 10^{-8}$ 90% CL

Factor of x3 improvement

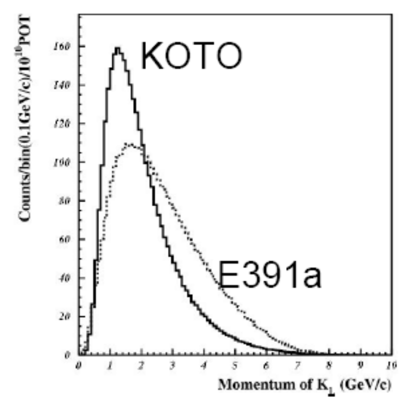
KOTO (E14) @ JPARC

Aim for **Flux x Run Time x Acceptance = 3000 x E391a**

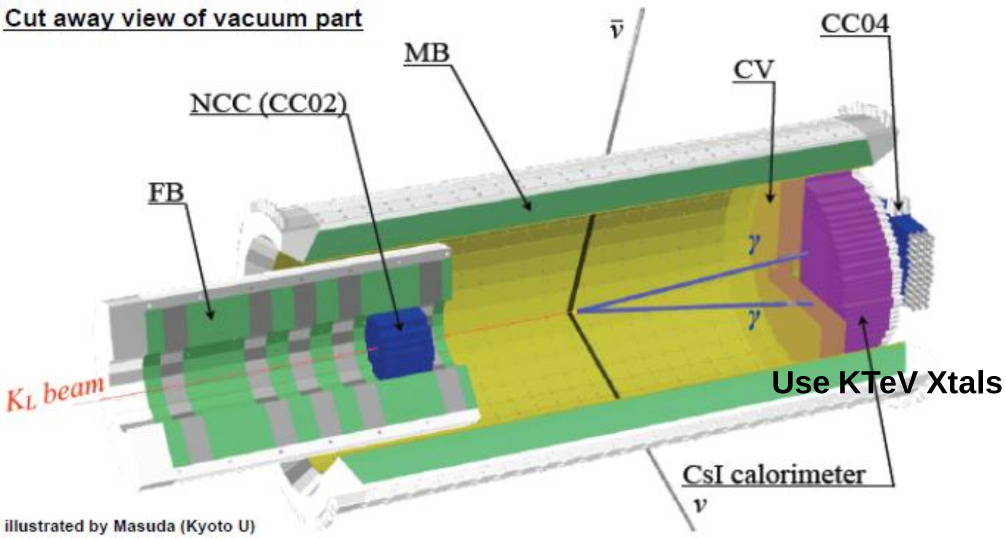
	KOTO	E391a (Run2)	
Proton energy	30 GeV	12 GeV	
Proton intensity	2e14	2.5e12	
Spill/cycle	0.7/3.3sec	2/4sec	
Extraction Angle	16 deg	4 deg	
Solid Angle	9μStr	12.6μStr	
KL yield/spill	7.8e6	3.3e5	x30 /sec
Run Time	3 Snowmass years =12 months.	1 month	x10
Decay Prob.	4%	2%	x 2
Acceptance	3.6%* *without Back splash loss	0.67%	x5

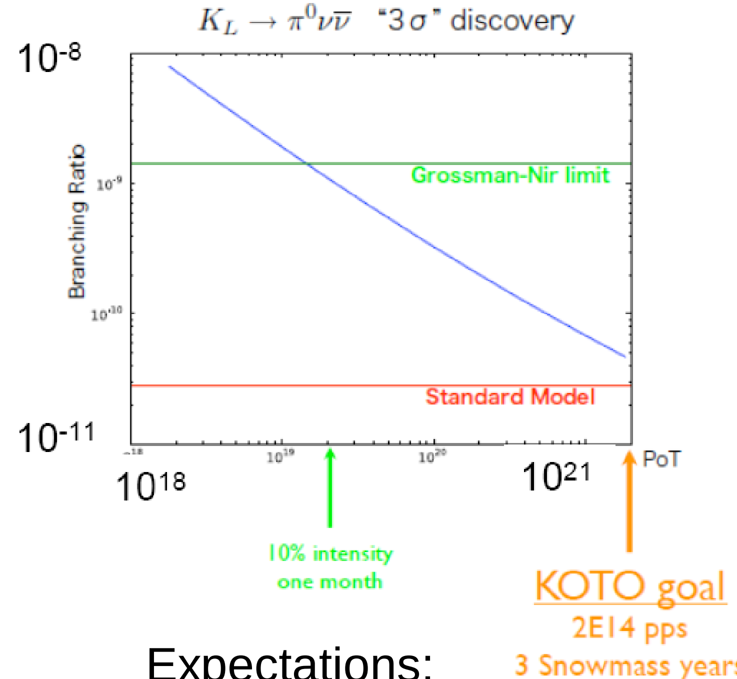
Main Ring Parameters:
L=1.6 Km
30 GeV
2 x 10^{14} ppp
0.3 MW
0.7 s spill / 3.3 s

Details in H. Nanjo KAON'09



KOTO @ JPARC





Schedule (H. Nanjo, KAON2009)

2009

- Beamline construction
- Beam Survey

2010

- CsI Calorimeter Construction
- Engineering run with CsI calorimeter

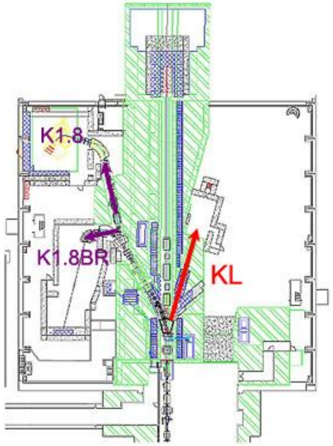
2011

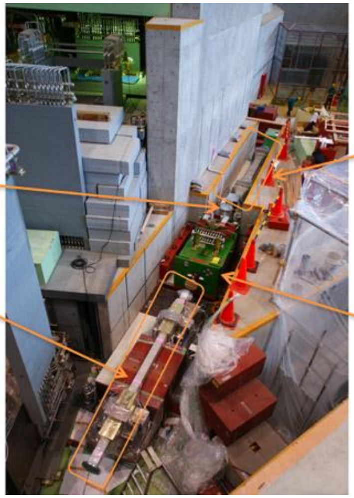
- Physics Run start

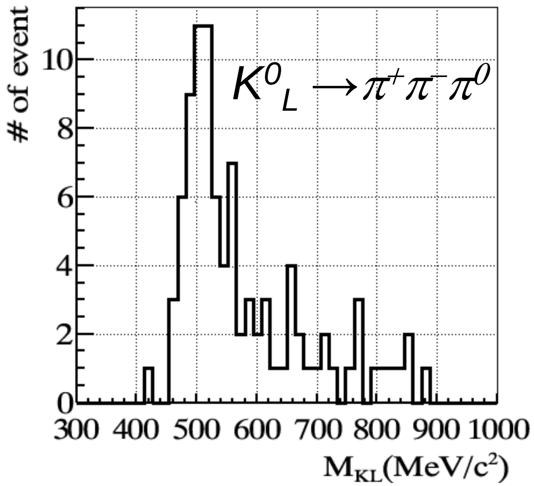
Expectations:

Signal	$K^0_L \to \pi^0 \nu\nu$	2.7
K^0_L Background	$\pi^0\pi^0$	1.7
	$\pi^+\pi^-\pi^0$	0.08
	$e^+\pi^- \nu$	0.02
Halo Neutrons		0.38

"Confirmation of neutral kaons in the KL beam line at Hadron Hall, J-PARC" Dec 7, 2009

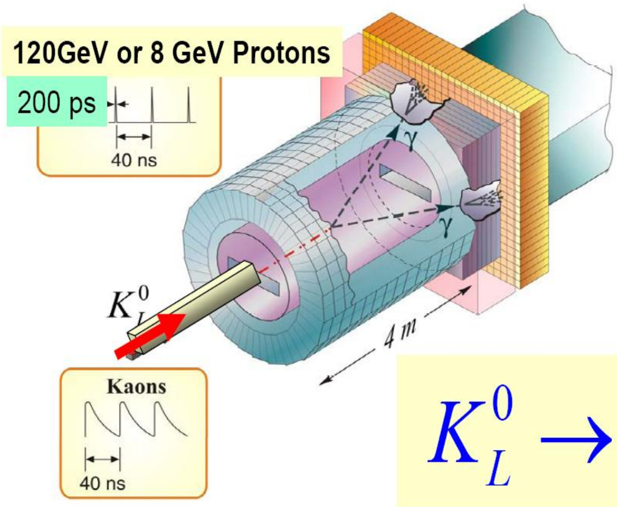




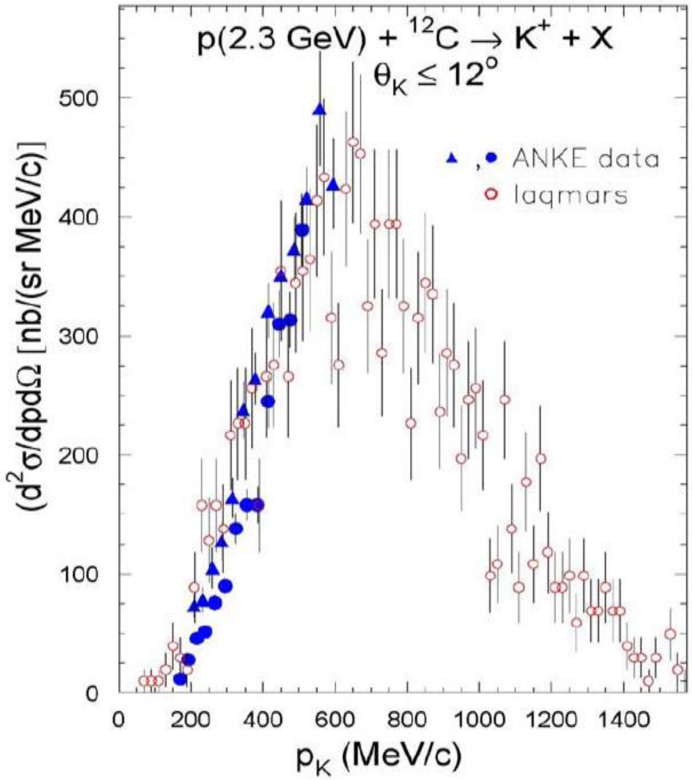


Beam Survey

Plans for K^0_L @ FNAL Project X



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



- KOPIO-like: TOF to determine Kaon Energy
- Knowledge of E_K allows rejection of two body decays
- Pointing Calorimeter
- 4 π veto for neutral and charged particles
- Small Beam instead of flat beam

- Project X (IC2): CW p LINAC ~3 GeV
- Excellent bunch timing
- High flux of low energy K^0_L

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

"Stopped"

- Work in Kaon frame
- High Kaon purity (Electro-Magneto-static Separators)
- Compact Detectors

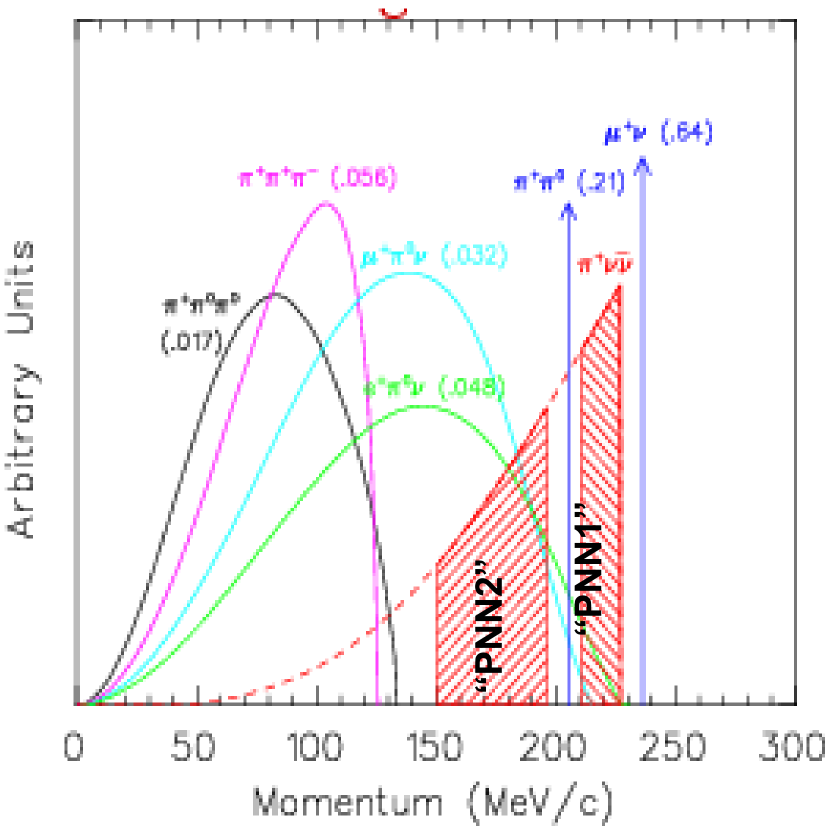
"In-Flight"

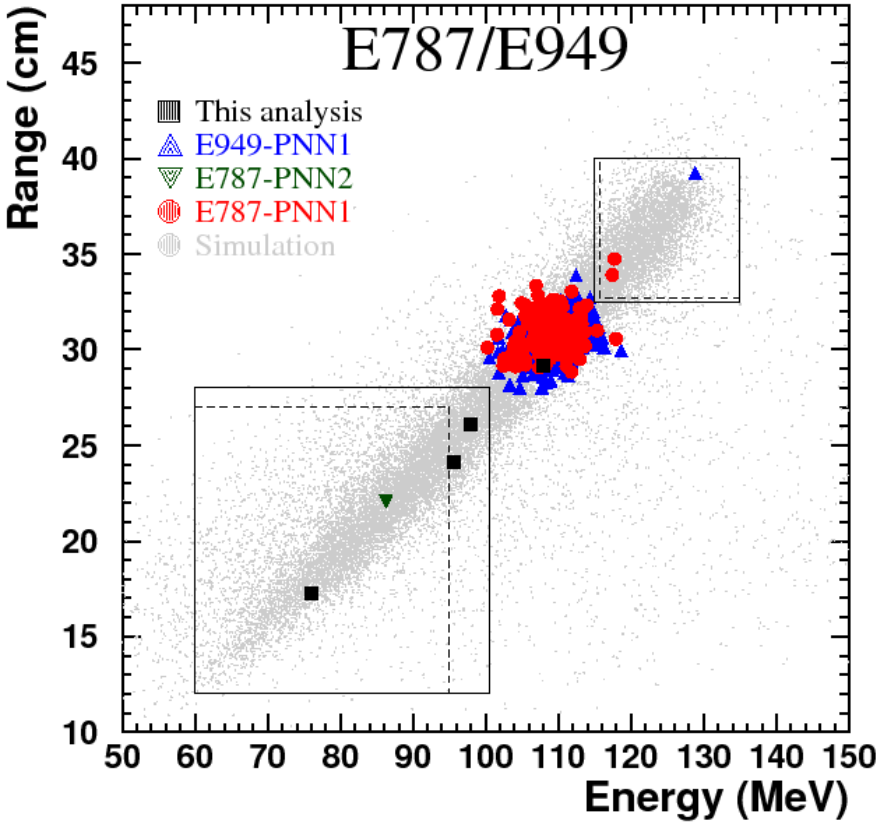
- Decays in vacuum (no scattering, no interactions)
- RF separated or Unseparated beams
- Extended decay regions

Exp	Machine	Meas. or UL 90% CL	Notes
	Argonne	$< 5.7 \times 10^{-5}$	Stopped; HL Bubble Chamber
	Bevatron	$< 5.6 \times 10^{-7}$	Stopped; Spark Chambers
	KEK	$<1.4 \times 10^{-7}$	Stopped; $\pi^+ \rightarrow \mu^+ \rightarrow e^+$
E787	AGS	$(1.57^{+1.75}_{-0.82}) \times 10^{-10}$	Stopped
E949	**AGS**	**$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$**	**Stopped; PPN1+PPN2**
NA62	**SPS**		**In-Flight; Unseparated**
P996	FNAL		Stopped; Tevatron as stretcher ring?

E787/E949: Final Result

arXiv:0903.0030v1   PRD79:092004,2009

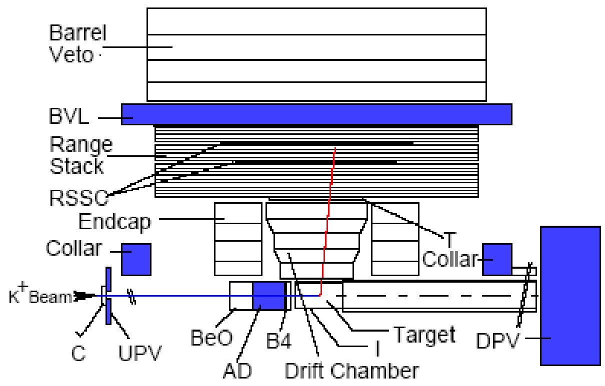


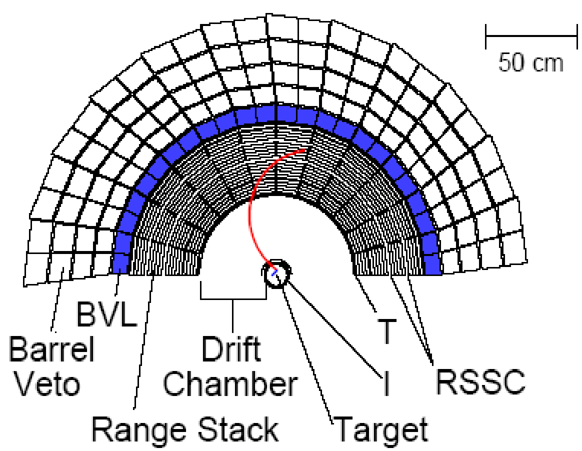


$$B(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$$

E787/E949 Technique

"The entire AGS beam of 65 x 10^12 (Tp/ spill) at a momentum of 21.5 GeV/c was delivered to the E949 K$^+$ production target"





- Duty Factor: 2.2 s / 5.4 s **~ 40%**
- 1 int. length Pt target
- Before separators: 500 π : 500 p : 1 K
- After separators: Purity **K:π ~ 3-4 : 1**
- Incoming **710 MeV/c** K$^+$ identified by Č and slowed down by BeO and Active Degrader
- **~27%** K$^+$ stopped in the target (1.6 MHz)
- 1 T solenoid

K$^+$: Č x B4 x Target

π^+: Delayed Coincidence
Range
Energy
Momentum
$\pi^+ \rightarrow \mu^+ \rightarrow e^+$

Stopped Kaon Redux?

Can one improve significantly over the E949 PNN1 efficiency figures?

Selection	α	Notes
$K\mu 2$	0.38	Beam,T, RS rec.
$K\pi 2$	0.88	E, range, selection
Pscat	**0.62**	Rej. of beam scat.
$\pi \rightarrow \mu \rightarrow e$	**0.35**	Decay chain
Trig	**0.18**	Trigger eff.
PS	**0.36**	Phase Space
nucl.	**0.50**	Pion interaction
T2	0.94	topology
fs	**0.77**	Stopping Fraction
"Standard"	1.7×10^{-3}	Total efficiency

- "Only" ~22% (.77 x .28) of kaons stopped in target
- The product of the red factors (1.5×10^{-2}) Is a high price to pay: $1/(1.5 \times 10^{-2}) \sim$ **66x**

Possible Improvements (Bryman@KAON09):

1. Lower Kaon Momentum to increase the stopped kaon fraction
2. Larger Beam acceptance

→ **4-5x**

3. Detector Improvement: finer RS segmentation; LXe γ veto

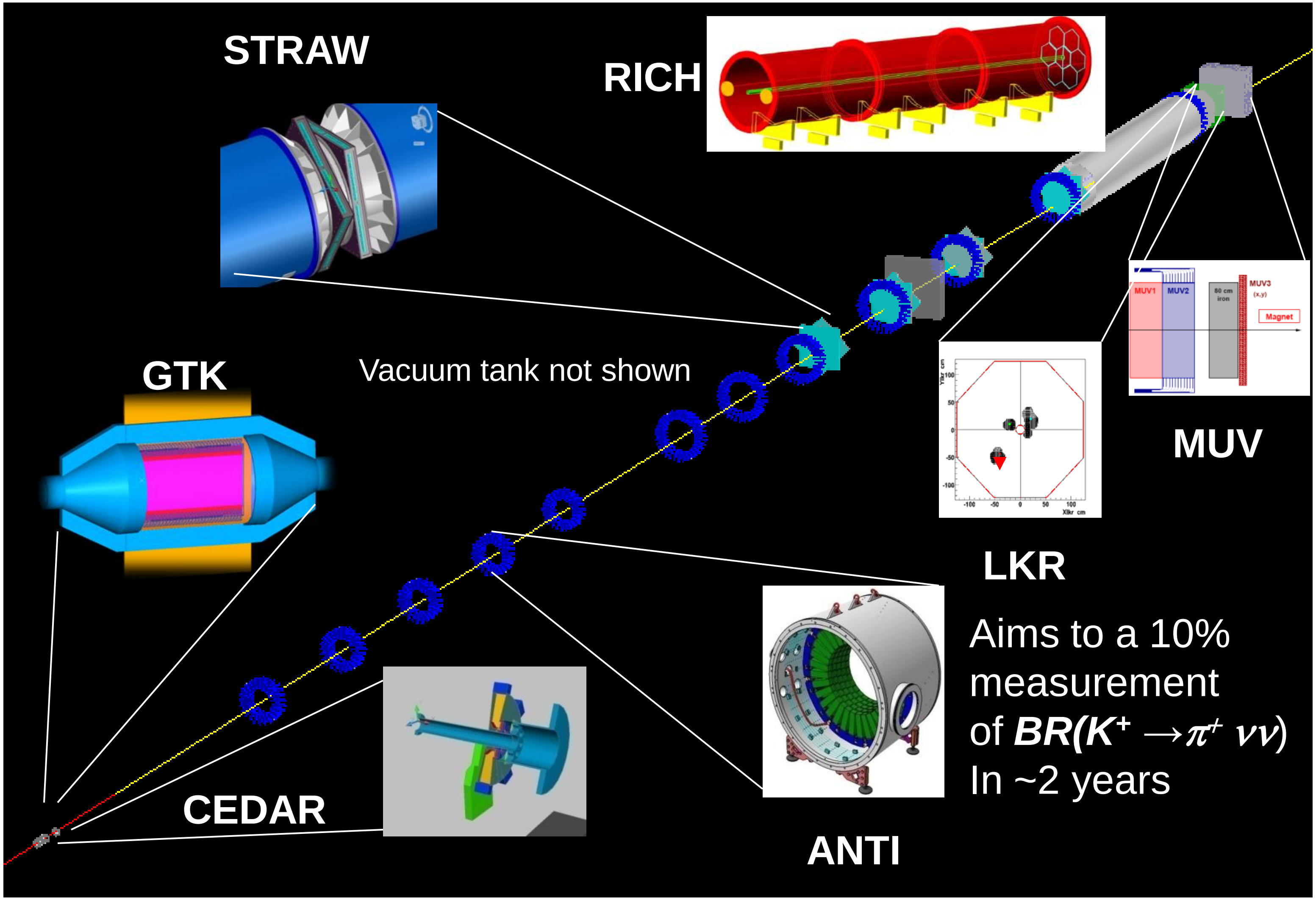
→ **> 5x**

Stopped Kaons at Fermilab: P996

- The status of P996 is that the Fermilab PAC has stated that "Proposal meets the criteria for Stage-I [scientific] approval" .
- P996 as proposed requires 3-5 years of running the Tevatron after RunII as a 150 GeV Stretcher to reach a 1000 event SM sensitivity.
- Fermilab and the P996 collaboration are now in discussions with the Department of Energy exploring the possibility of running the Stretcher after RunII

(Update kindly provided by Bob Tschirhart from Fermilab)

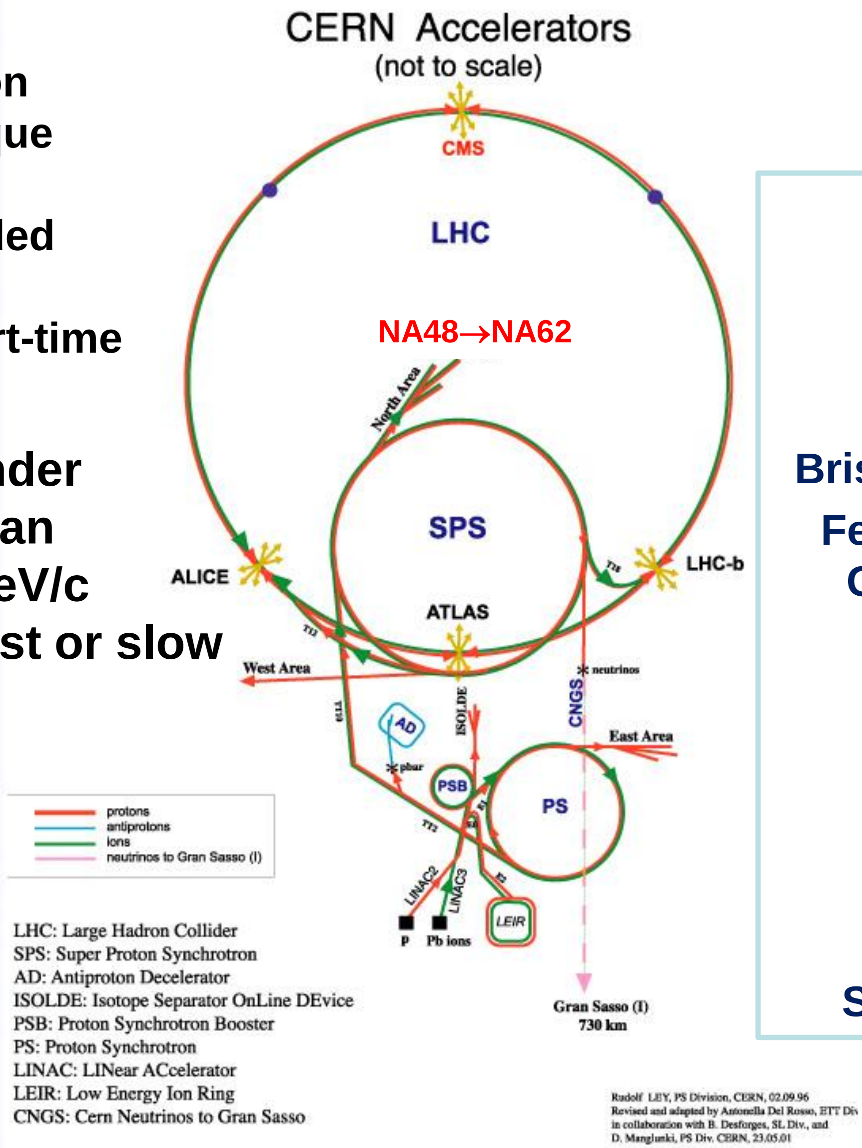
K^+ Decays in flight:NA62



The CERN proton Complex is unique

The SPS is needed as LHC proton injector only part-time

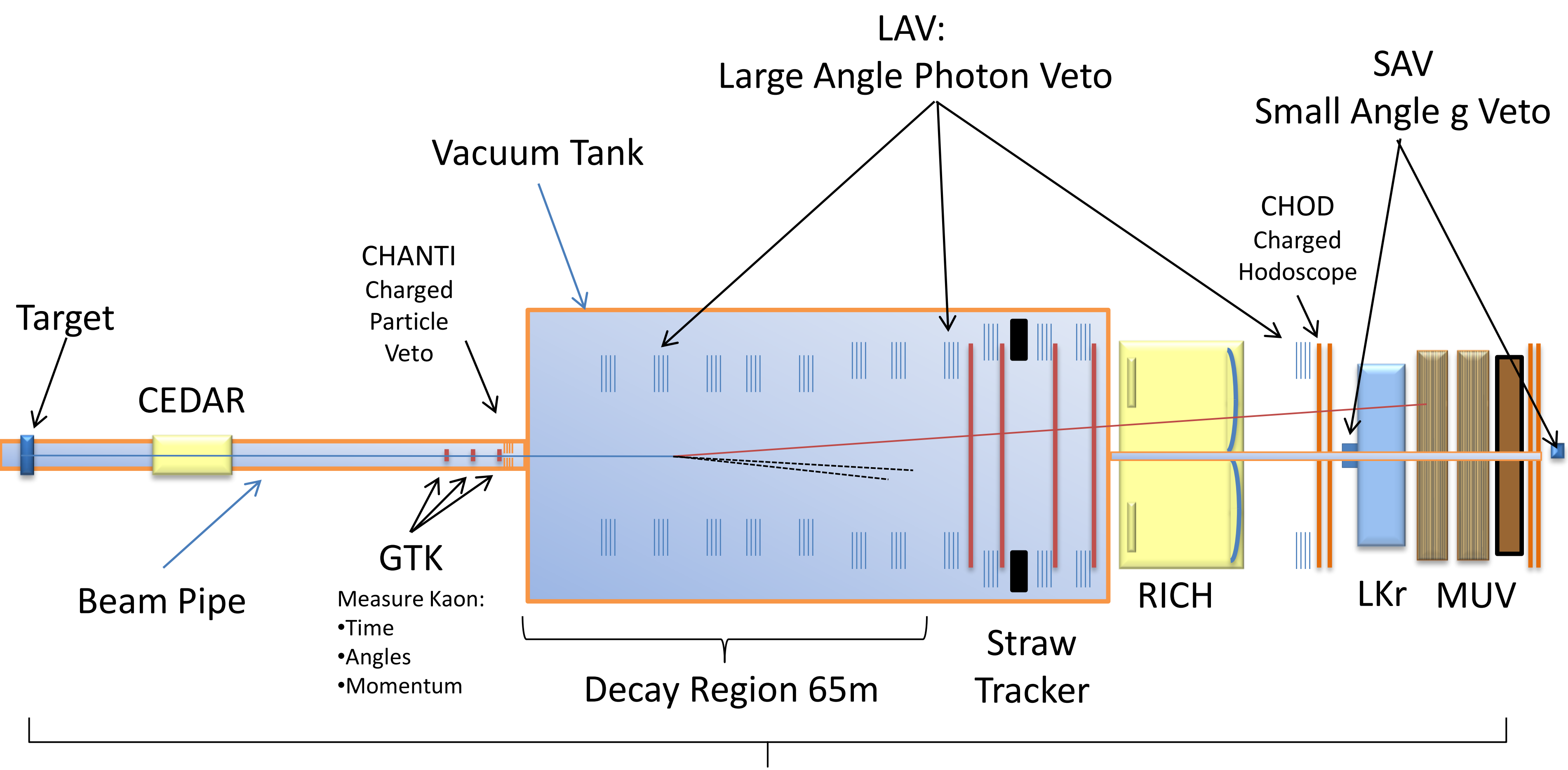
For the remainder of the time it can provide 400 GeV/c protons for fast or slow extraction



NA62:

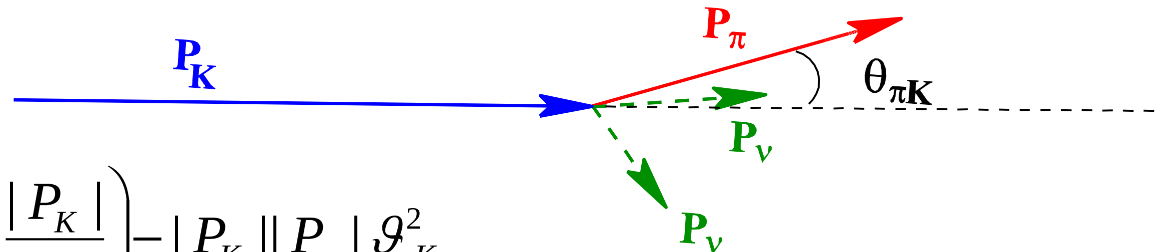
Birmingham, Bratislava
Bristol, CERN, Dubna,Fairfax,
Ferrara, Florence, Frascati,
Glasgow, IHEP Protvino,
INR Moscow,
Liverpool, Louvain,
Mainz, Merced, Naples,
Perugia, Pisa,
Rome I, Rome II,
San Luis Potosí,
SLAC,Sofia,TRIUMF,Turin

NA62 Detectors



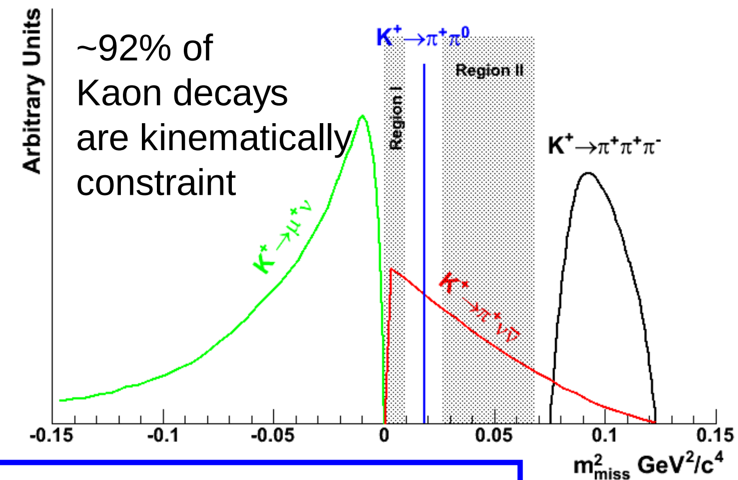
Drawing by Ferdinand Hahn

Background Rejection



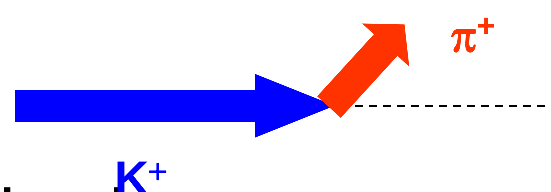
$$m^2_{miss} \approx m^2_K\left(1-\frac{|P_\pi|}{|P_K|}\right)+m^2_\pi\left(1-\frac{|P_K|}{|P_\pi|}\right)-|P_K||P_\pi|\vartheta^2_{\pi K}$$

Decay	BR
$K^+ \to \mu^+\nu$ ($K_{\mu 2}$)	0.64
$K^+ \to \pi^+\pi^0$ ($K_{\pi 2}$)	0.21
$K^+ \to \pi^+\pi^+\pi^-$ $K^+ \to \pi^+\pi^0\pi^0$	0.07



Signature:

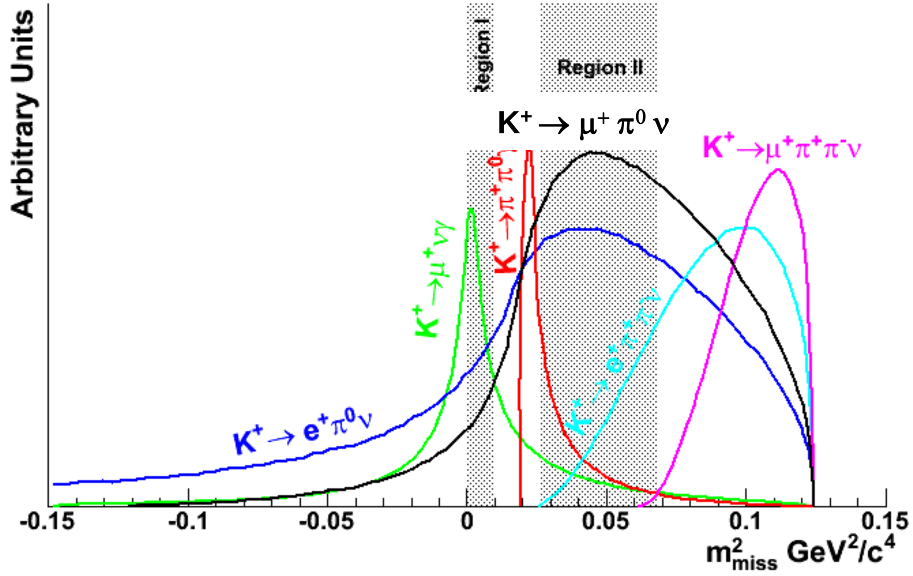
- **Incoming high momentum (75 GeV/c) K^+**
- **Outgoing low momentum (< 35 GeV/c) π^+**
- **For $K_{\pi 2}$ $P(\pi^0)$ > 40 GeV/c: it can hardly be missed**



4. Particle Identification

- K^+ Positive identification (CEDAR)
- π/μ separation (RICH)
- π/e separation (E/P)

Decay	BR
$K^+ \to \pi^0 e^+ \nu$ (K_{e3})	0.051
$K^+ \to \pi^0 \mu^+ \nu$ ($K_{\mu3}$)	0.034
$K^+ \to \mu^+ \nu \gamma$ ($K_{\mu2\gamma}$)	6.2×10^{-3}
$K^+ \to \pi^+ \pi^- e^+ \nu$ (K_{e4})	4.1×10^{-5}
$K^+ \to \pi^+ \pi^- \mu^+ \nu$ ($K_{\mu4}$)	1.4×10^{-5}



NA62 Sensitivity

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

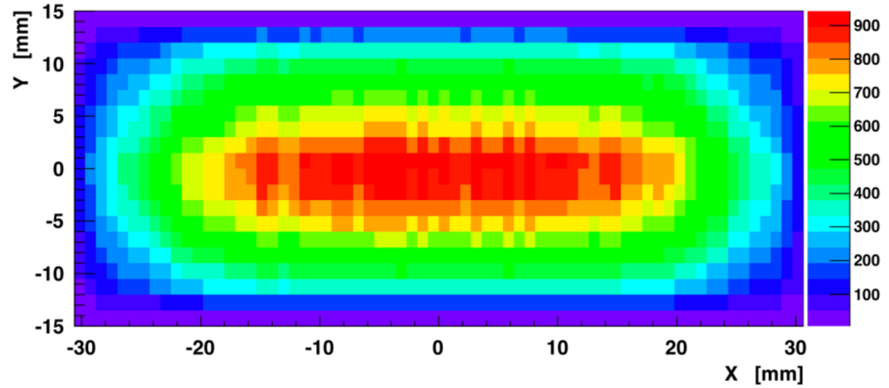
Definition of "year" and running efficiencies based on NA48 experience: ~100 days/year; 60% overall efficiency

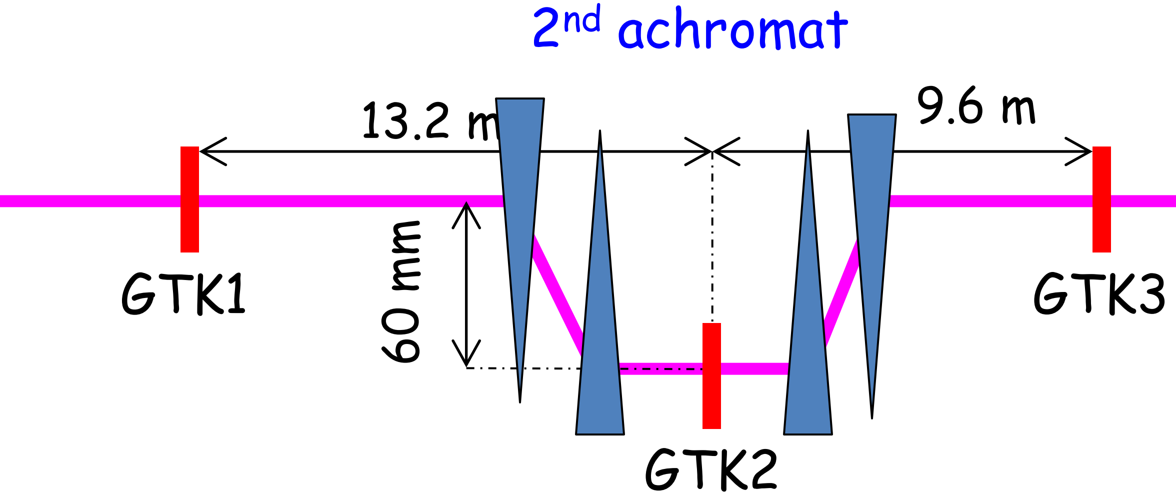
NA62 Focused R&D

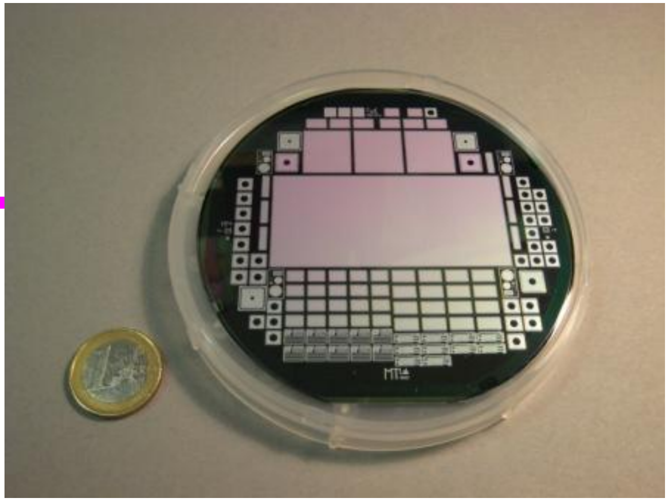
- **Gigatracker (GTK) :** Beam tracker (10^9 part/s) based on Si micro pixels with **~100 ps time** resolution; thickness of one station **~0.5% X_0**
- **Straw Tracker (STRAW) :** To be operated in the vacuum tank: **total thickness** for 16 views **~1 % X_0**
- **P.I.D. (π/μ)** up to **P = 35 GeV/c**
  Neon RICH with 17 m focal length spherical mirrors
- **Hermetic Coverage: π^0 suppression factor ~ 10^8**
  Employ high performance calorimeters as photon vetoes: **Liquid Krypton (NA48) + Lead Glass (OPAL)**

NA62 Beam & GTK

SPS primary p: 400 GeV/c
Unseparated beam:
- **75 GeV/c**
- **750 MHz**
- **π/K/p (~6% K^+)**







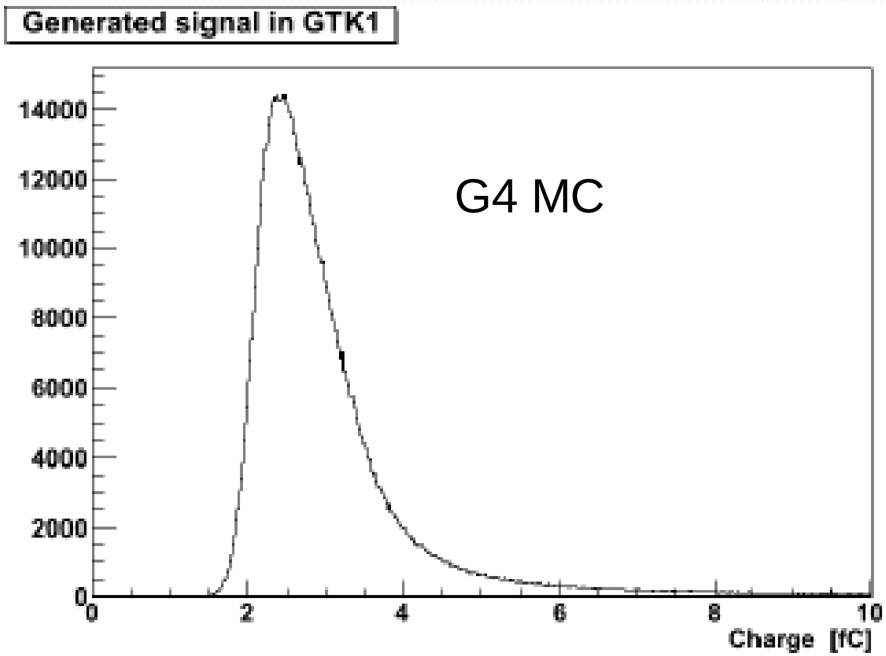
- **Sensitivity is NOT limited by protons flux but by beam (GigaTracKer (GTK))**
- **Similar amount of protons on target as NA48 (~5 10^{12} / pulse)**

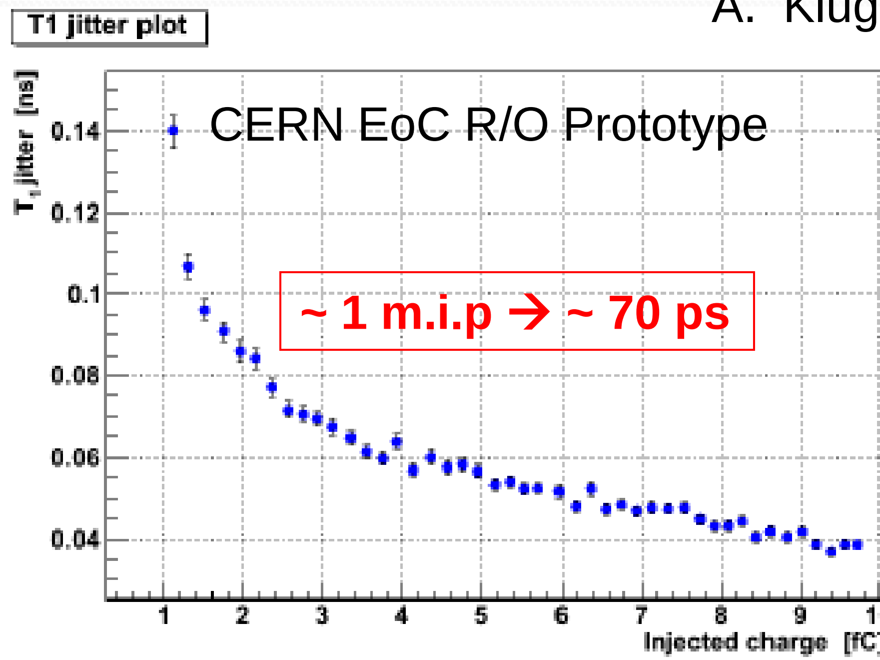
First Results from GTK Tests

Preliminary

Charged weighted time jitter measured with test pulses

M. Fiorini
M. Noy
A. Kluge



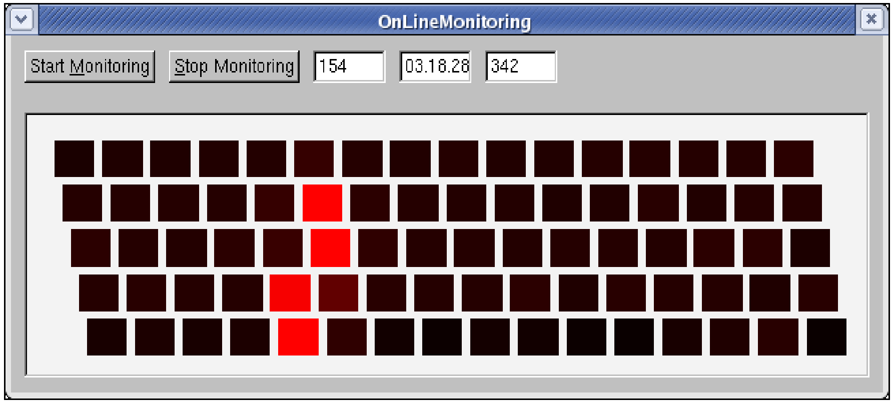


- taking into account the energy distribution of particle hits in the Gigatracker, one can extract a weighted average value for the jitter on T_1

"We come from Research to working Prototype"
Flavio Marchetto

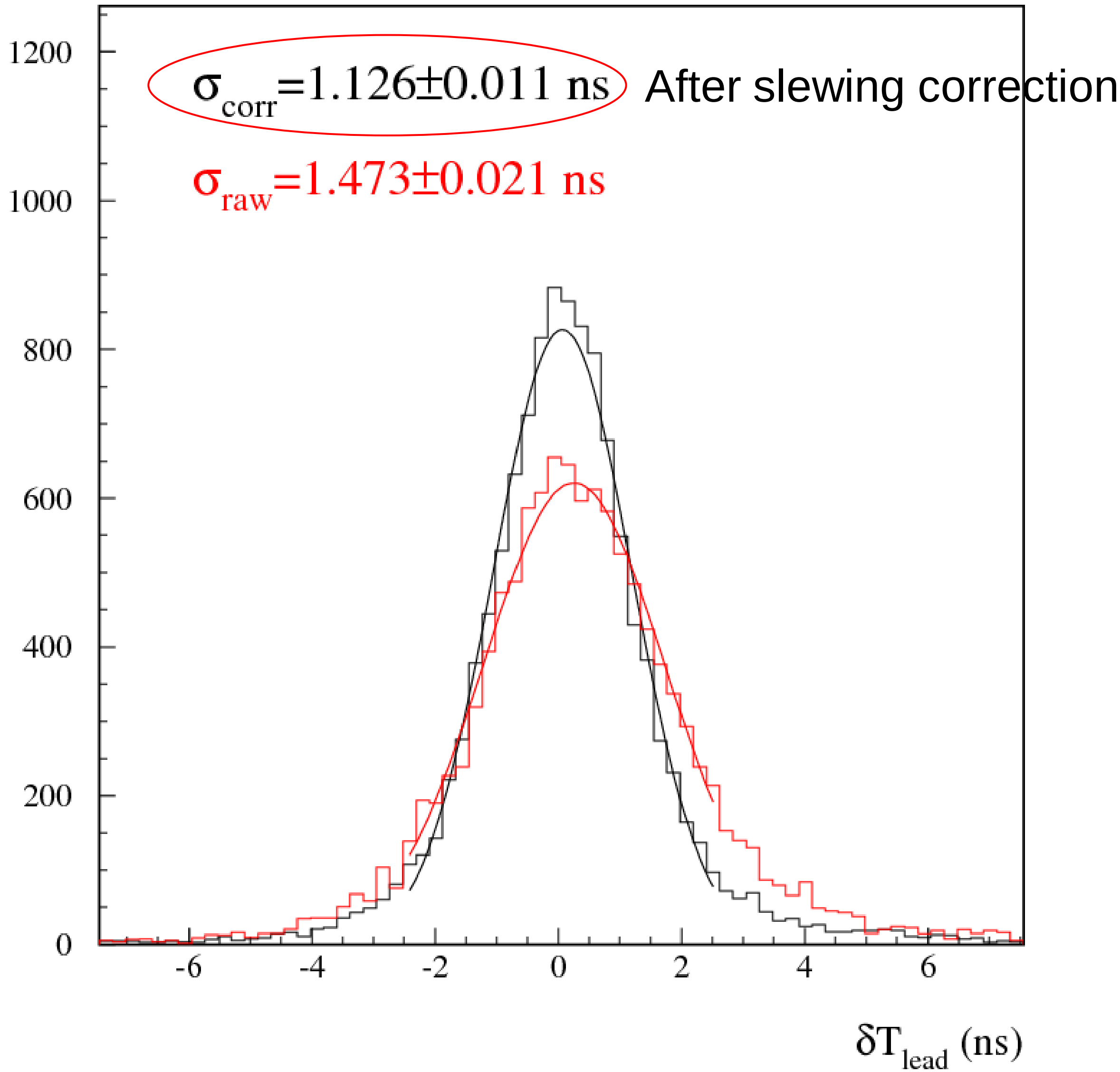
LAV ANTI-A1

- In summer 2009 the first station A1 was built at LNF and shipped to CERN. It is now mounted on the blue tube
- A test beam run with the complete system including prototype front-end electronics (FEE) was performed at the end of October 2009

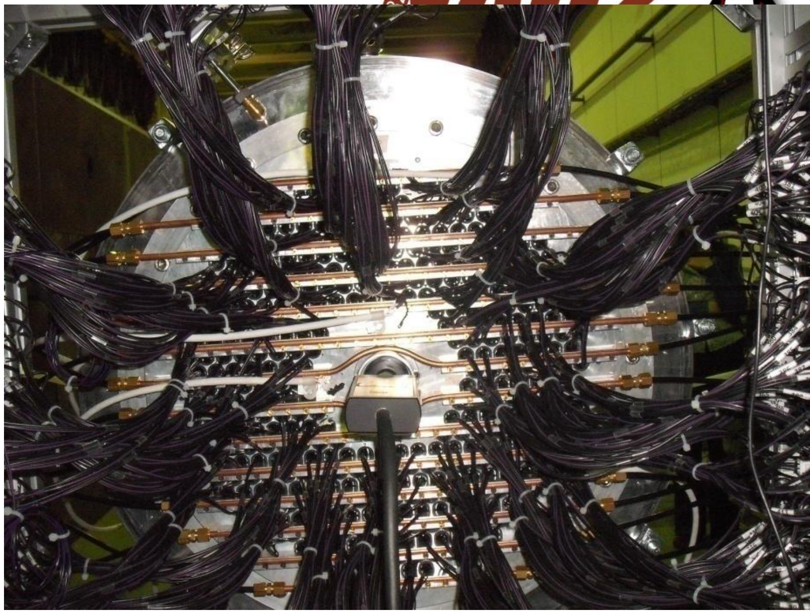


LAV Time resolution

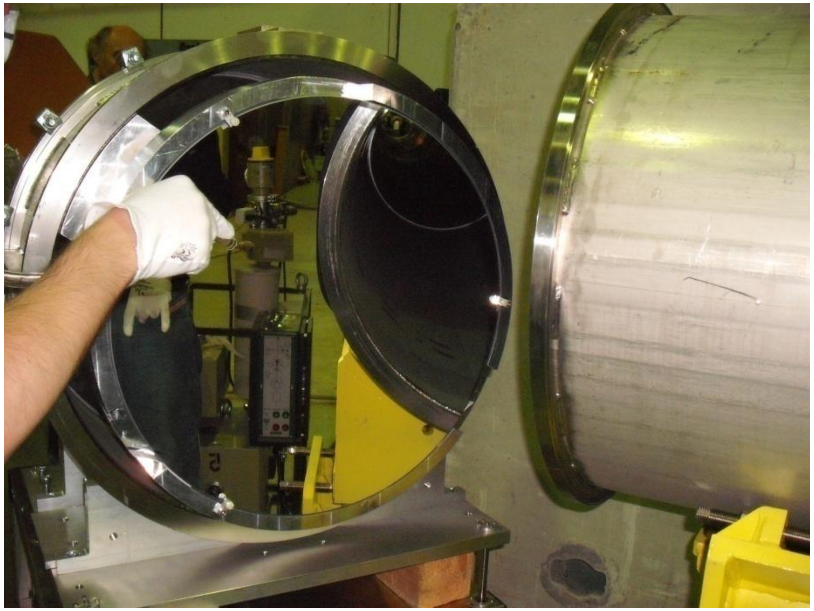
- 4 GeV electrons
- Time differences between two subsequent blocks
- Slewing correction
- Q obtained from time over threshold



RICH 2009 prototype test beam



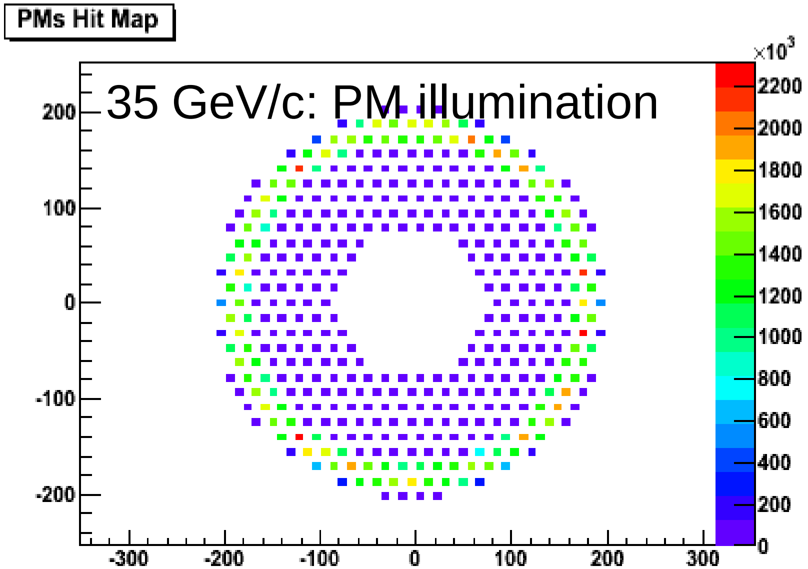
- 12.5.-27.6.2009: test beam
- 1 mirror with f=17m, 50 cm wide
- 414 PMT + full electronics chain

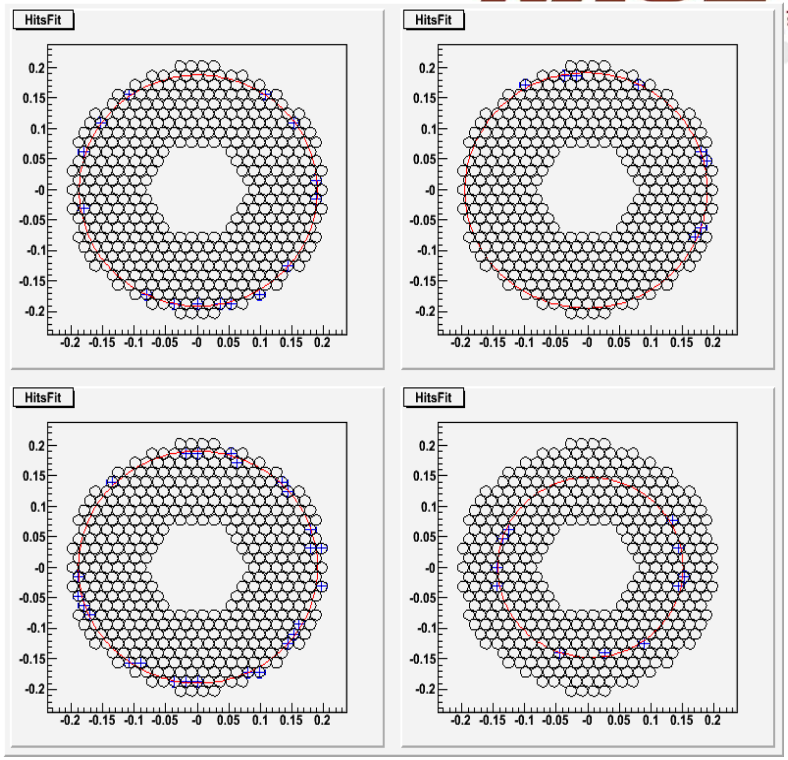


2009 test beam

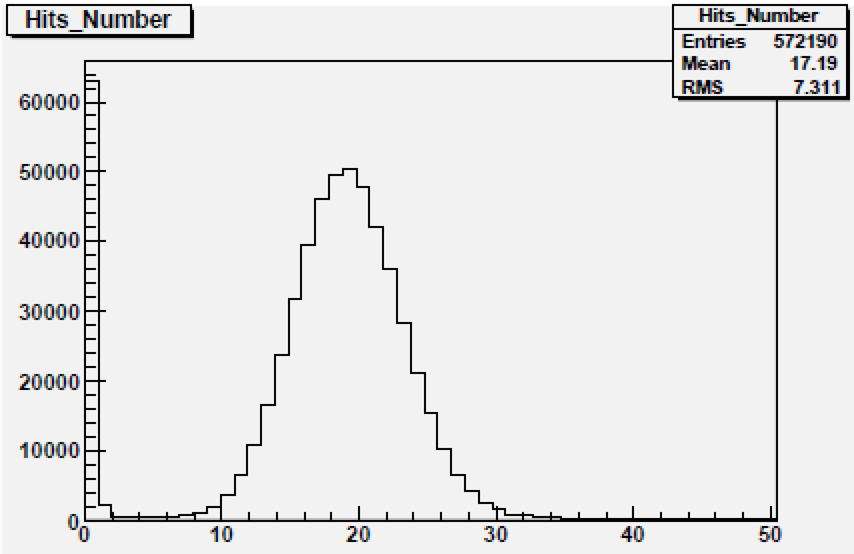
20 GeV/c: 3 positrons and 1 pion events

35 GeV/c: PM illumination

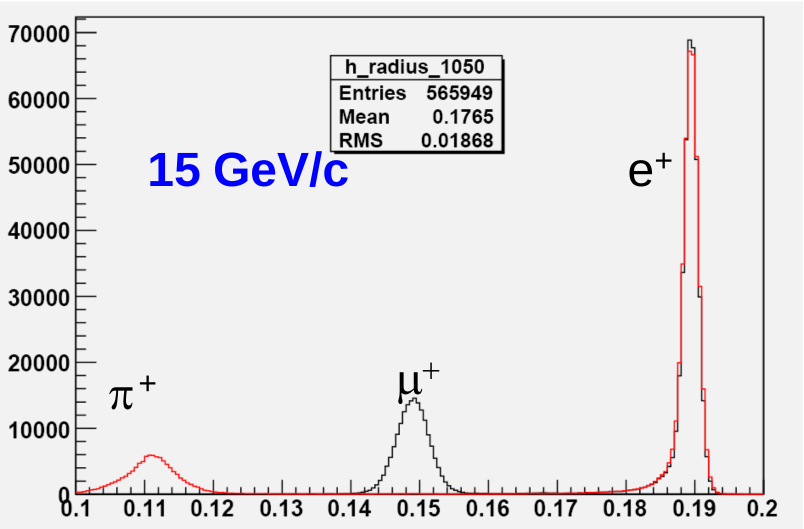


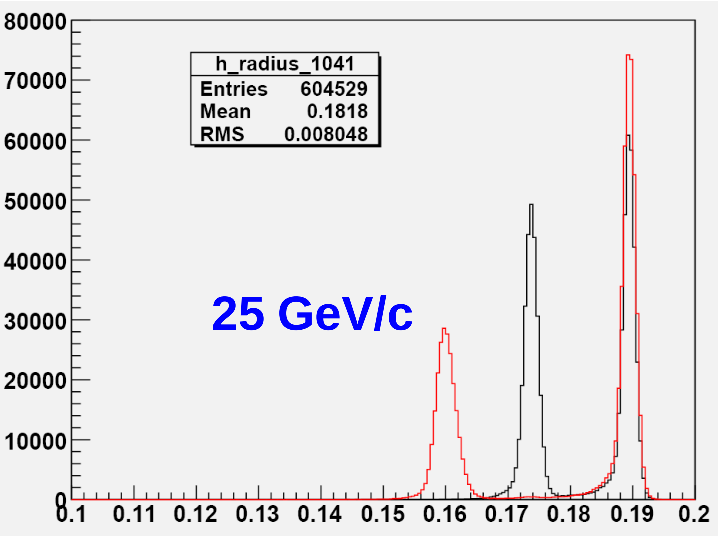


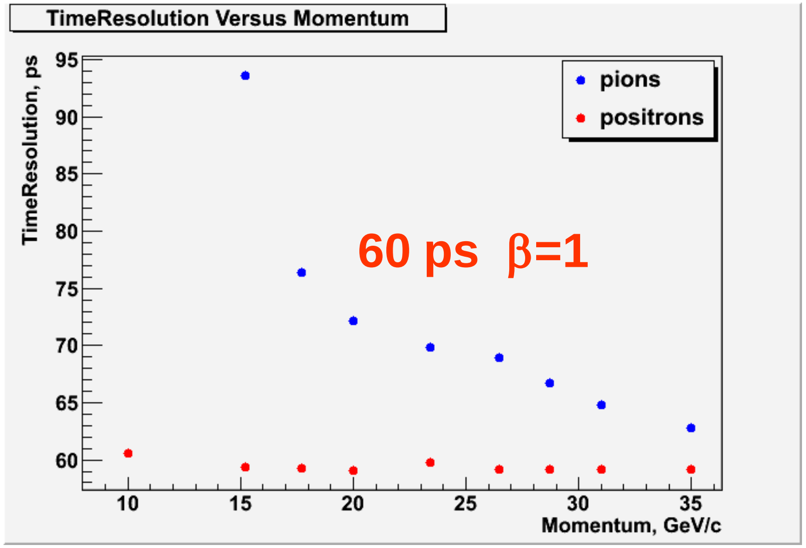
N. of hits
per event
at 35 GeV/c

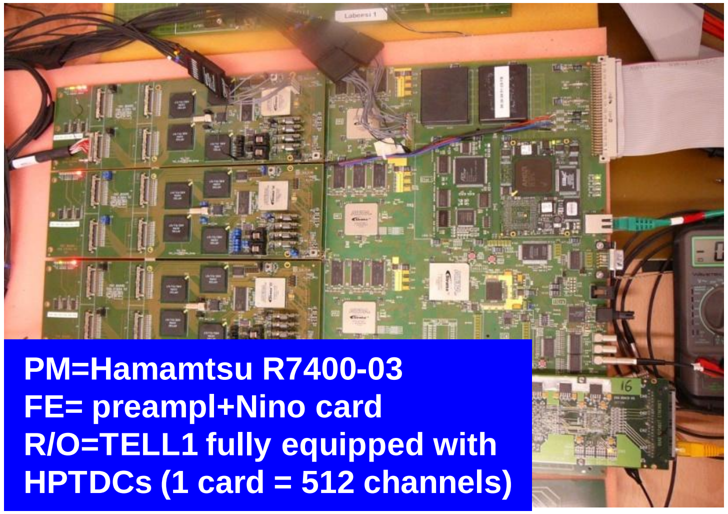


RICH Test, June 2009, Preliminary





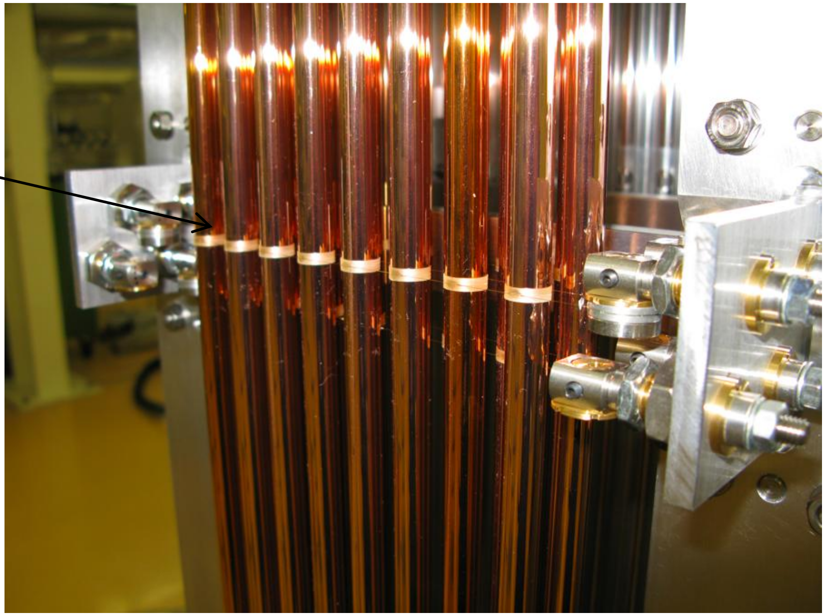




PM=Hamamtsu R7400-03
FE= preampl+Nino card
R/O=TELL1 fully equipped with HPTDCs (1 card = 512 channels)

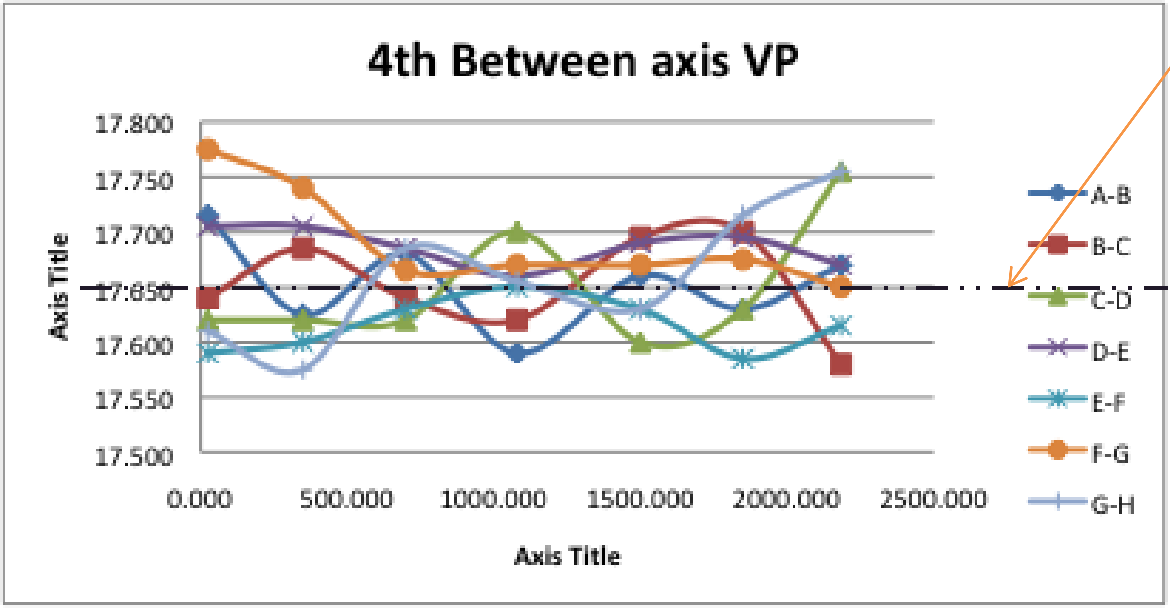
64 Straw technology Prototype

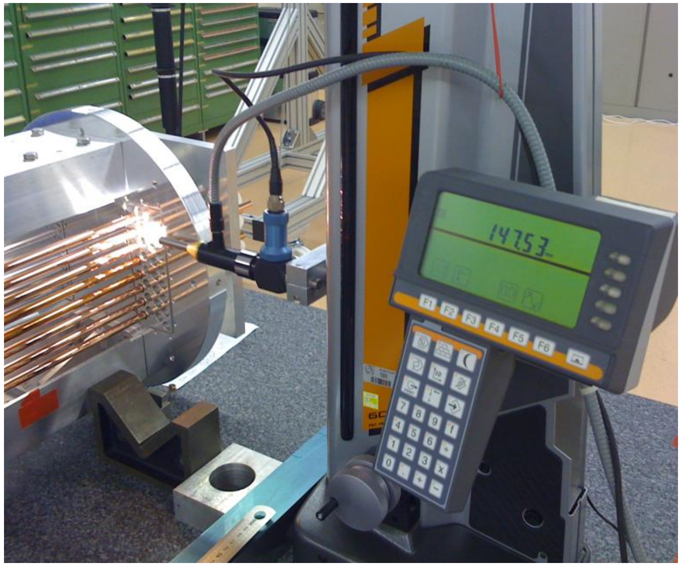
- The straws are installed in vertical position
- Pretension is 1.5 kg
- Spacer validated over 2.1 m.

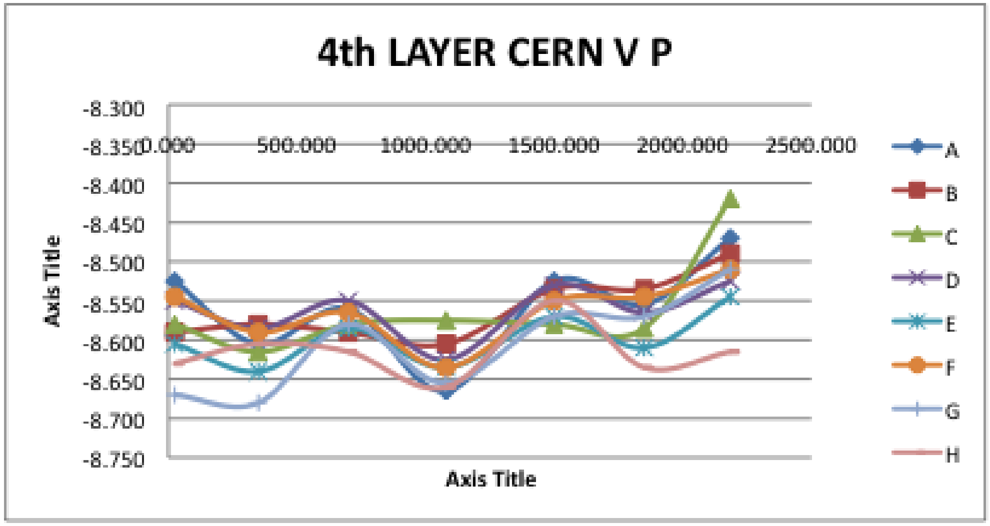


Straw straightness

Nominal

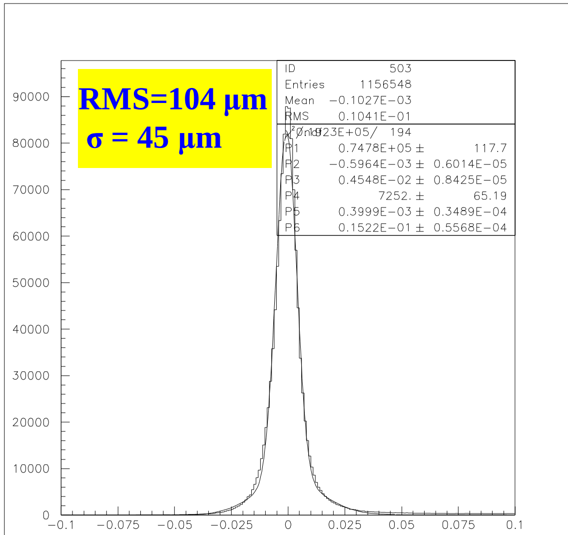




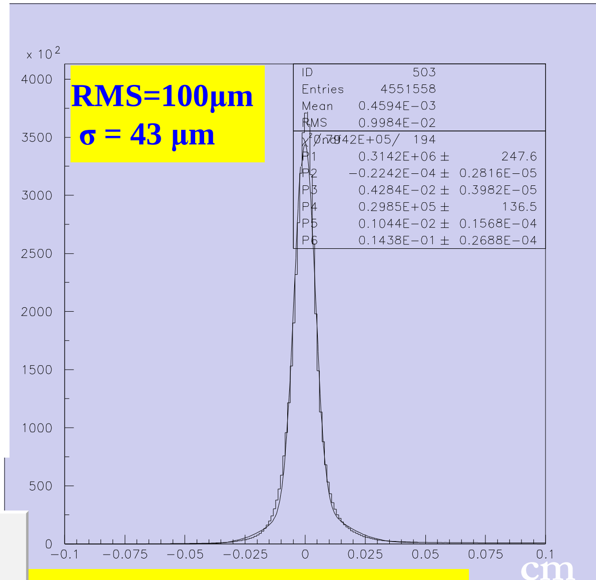


STRAW Prototype: Beam Test

Residuals

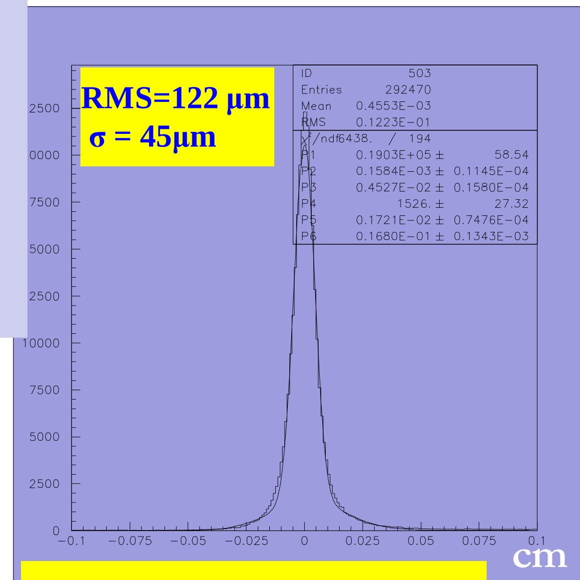


RUN 20629, muons

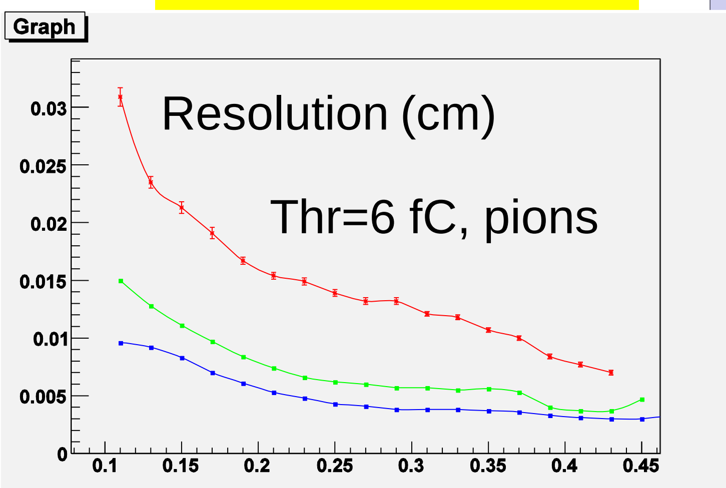


RUN 20650, pions

full length Straw Prototype: 2.1 m long Operated in Vacuum



RUN 20694, kaons



2200V
2300V
2400V

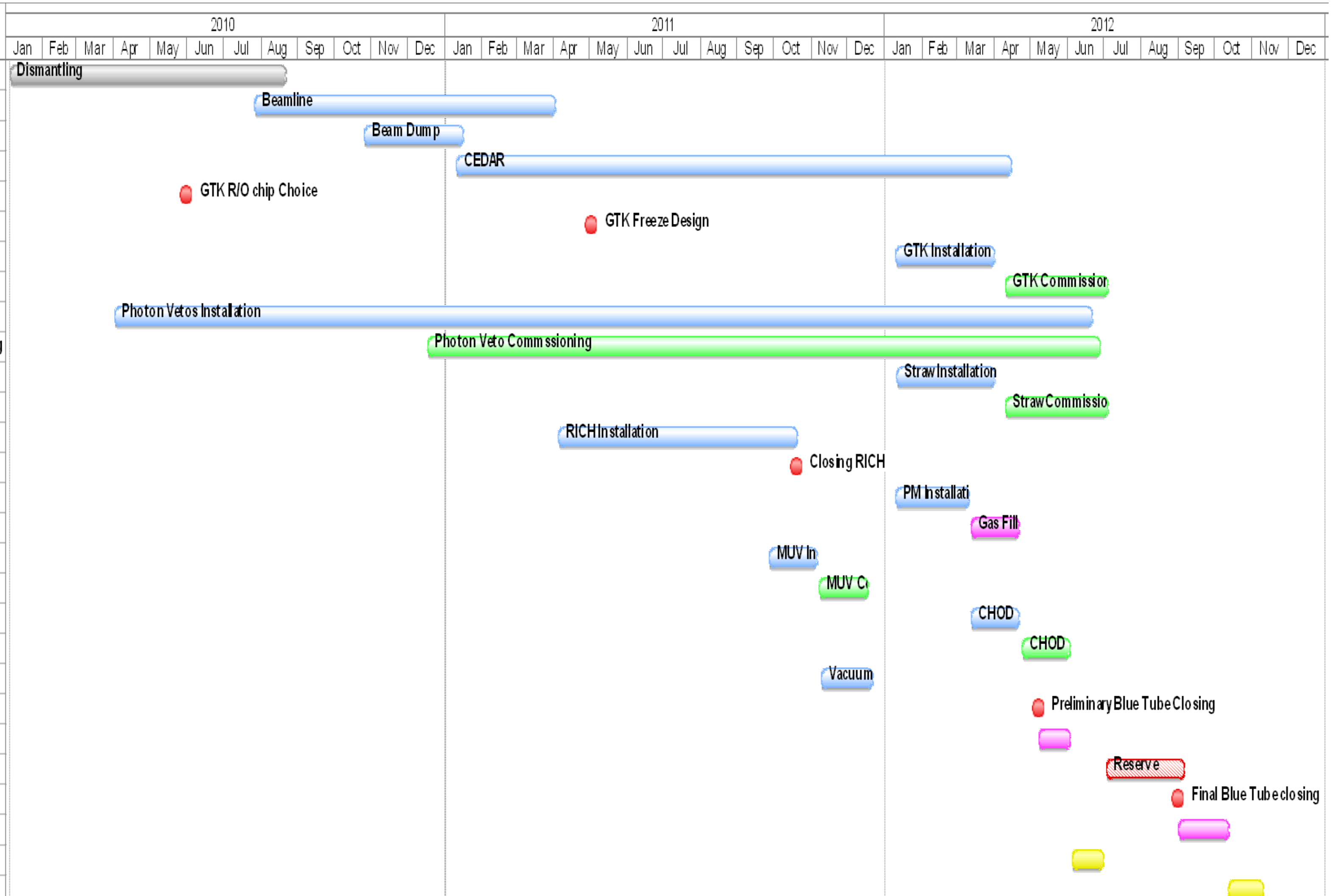
Drift Distance (cm)

CO_2 (80%) CF_4 (10%) Isob. (10%)

NA62 Planning

Preliminary (by Ferdinand Hahn)

ID	Task Name
1	**Dismantling**
6	**Beamline**
8	Beam Dump
9	**CEDAR**
14	GTK R/O chip Choice
15	GTK Freeze Design
16	GTK Installation
17	GTK Commissioning
18	**Photon Vetos Installation**
35	**Photon Veto Commssioning**
39	**Straw Installation**
43	Straw Commissioning
44	**RICH Installation**
52	Closing RICH
53	PM Installation
54	Gas Filling
55	MUV Installation
56	MUV Commissioning
57	CHOD Installation
58	CHOD Commissioning
59	Vacuum Test
60	Preliminary Blue Tube Closing
61	Vacuum Pumping
62	Reserve
63	Final Blue Tube closing
64	Vacuum Pumping
65	Technical Run
66	Run 1

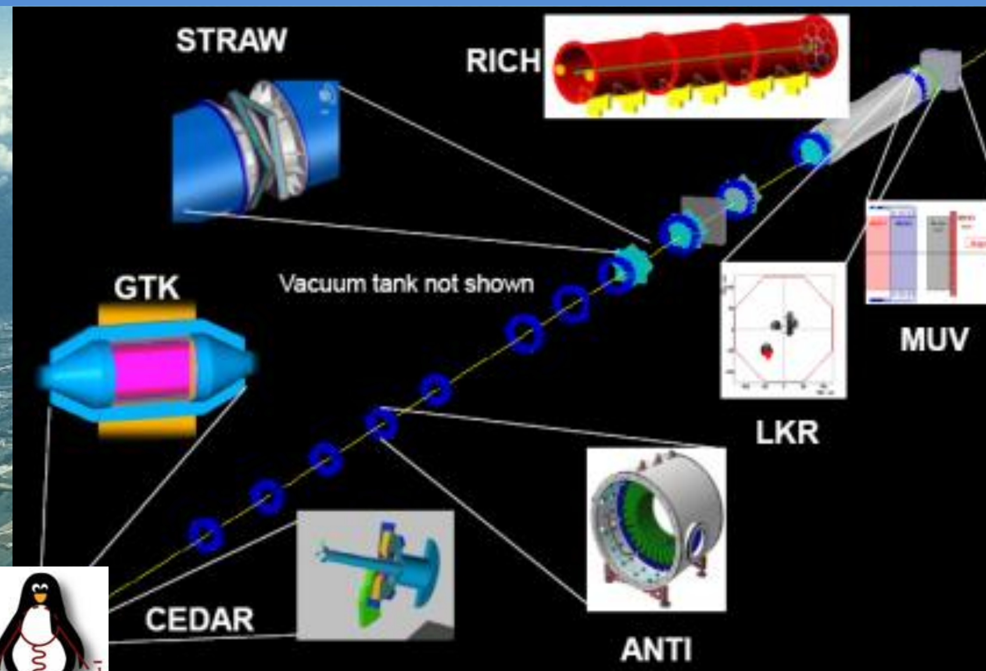


NA62 Physics Handbook

CERN, December 10-11, 2009

Advisory Committee:

Gerhard Buchalla
Andrzej Buras
Nicola Cabibbo
Vincenzo Cirigliano
Gerhard Ecker
Jonathan R. Ellis
Jean-Marc Gérard
Gino Isidori
Marc Knecht
Heinrich Leutwyler
Bill Marciano
Helmut Neufeld
Antonio Pich
Jorge Portoles
Eduardo de Rafael
Chris Sachrajda
Lalit Sehgal



Kaons @ CERN SPS, Topics:
- Rare Decays
- Radiative Decays
- Forbidden Decays & LFV tests
- (Semi)-Leptonic Decays
- Hadronic decays, $\pi\pi$ phases

Program Committee:

Johan Bijnens
Augusto Ceccucci
Patrizia Cenci
Gilberto Colangelo
Giancarlo D'Ambrosio
Martin Gorbahn
Ulrich Haisch
Federico Mescia
Matthew Moulson
Paride Paradisi
Christopher Smith

Secretariat: veronique.wedlake@cern.ch

http://na62pb.ph.tum.de/

Kaon Interferometry

The KLOE-2 strategy (Slides by F. Bossi)

We have proposed, and the Laboratory has accepted, an installation plan based on a two-step strategy

- *Step 0*: Preparation ongoing now. Start of data taking, spring 2010. Use of the present detector with the minimal upgrades required to run it safely and efficiently. Use also of newly built taggers for $\gamma\gamma$ physics.
- *Step 1*: Start of installation work, summer 2011. Insertion of the more demanding upgrades with the goal of a longer data taking campaign (2012-13)

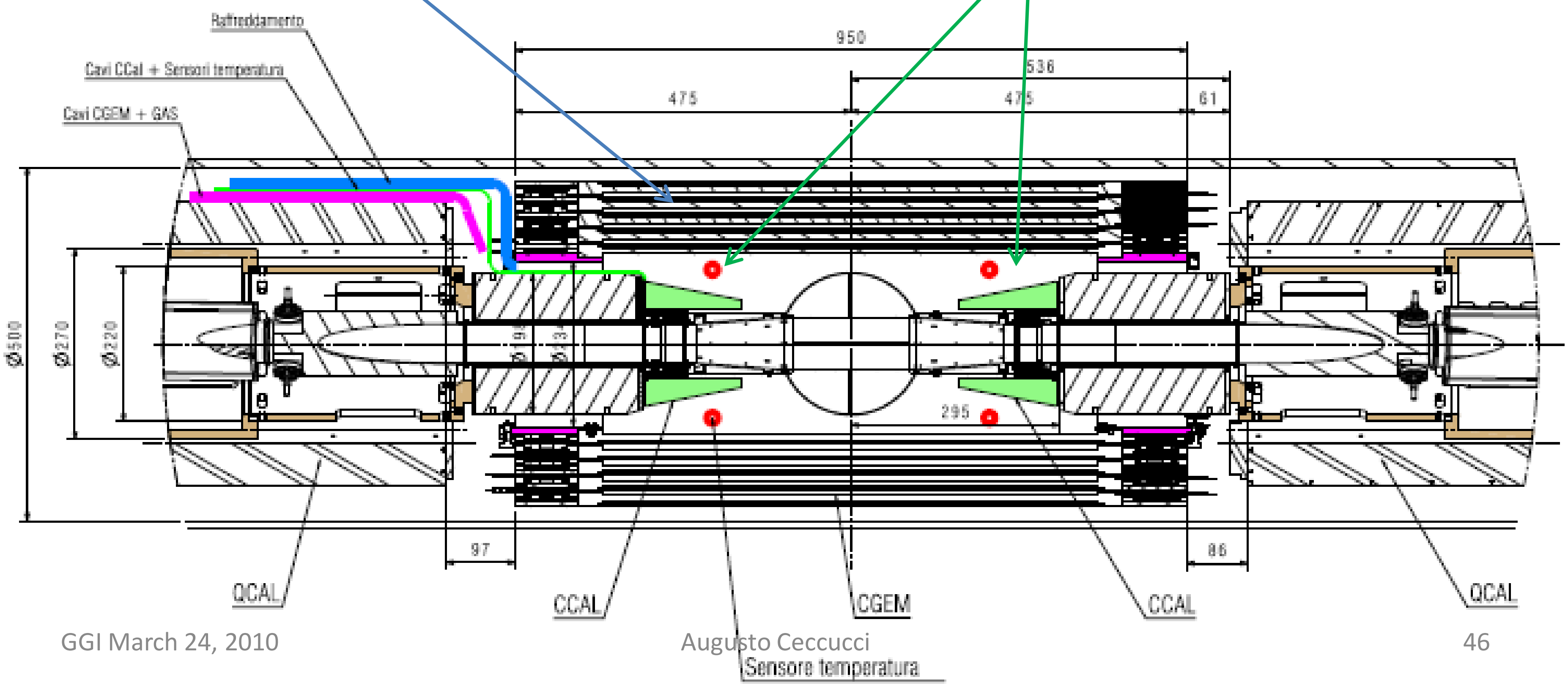
Thanks to crab waist upgrade, expect DAΦNE to deliver $\geq$ 300 pb^{-1}/month

The upgraded interaction region

New sub-detectors will be installed around the interaction region

An inner tracker to improve on tracking resolution and acceptance

Forward calorimeters to increase acceptance for photons



KLOE-2: physics motivations

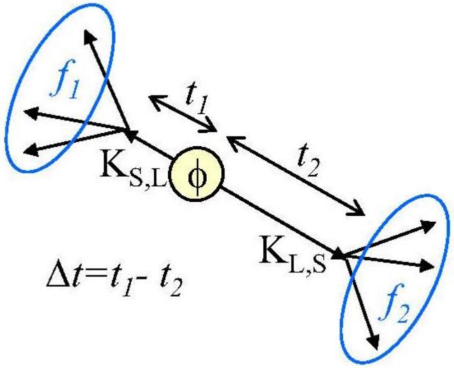
There are several physics topics that can benefit of an acquired luminosity of order $10\ fb^{-1}$ with an upgraded detector

- Studies on CPT and QM violation with neutral kaons interferometry
- Tests of Lepton Flavor Violation with K_{e2} decays
- Studies on C, P, CP violation using rare η and K_S decays
- Tests of Chiral Perturbation Theory with η, η', and K_S decays
- Searches for signals of a Secluded Gauge Symmetry

Quantum Interferometry

The most specific (and intriguing) feature of the neutral kaon system produced in Φ decays is that it is subject to quantum entanglement

This means that the decay probability of each one of the kaons depends also on what the other particles does



$$I(f_1,t_1;f_2,t_2) = C_{12}\{|\eta_1|^2 e^{-\Gamma_L t_1 - \Gamma_S t_2} + |\eta_2|^2 e^{-\Gamma_S t_1 - \Gamma_L t_2} - 2|\eta_1||\eta_2| e^{-(\Gamma_S+\Gamma_L)(t_1+t_2)/2} \cos[\Delta m(t_2 - t_1) + \phi_1 - \phi_2]\}$$

Quantum Gravity and CPT violation

Hawking suggested that at the microscopic level, in a QG picture, non trivial space-time fluctuation could give rise to decoherence effects, which would necessarily entail CPT violation

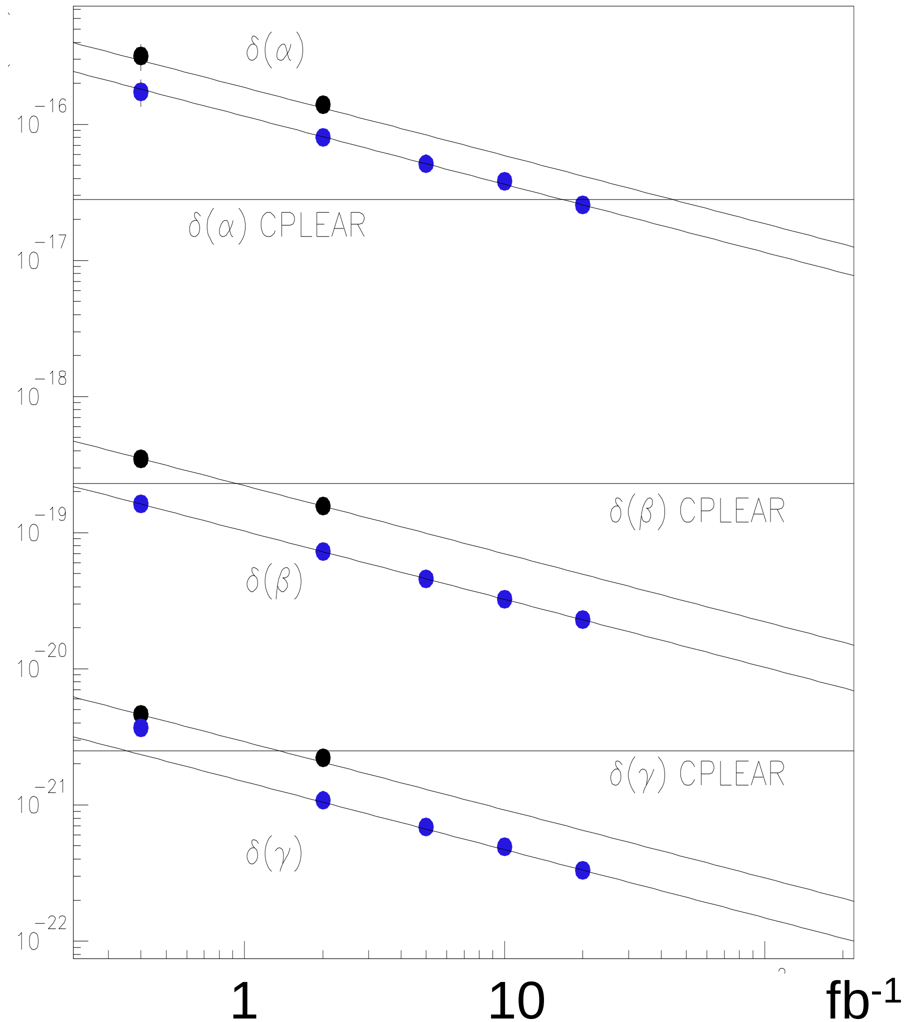
This idea has been applied, for instance, in a model by Ellis and collaborators, specifically for the neutral kaon system, introducing 3 CPTV parameters, α, β and γ, distorting the above mentioned decay intensity. Naively, one expects:

$$\alpha, \beta, \gamma = O\left(\frac{M_K^2}{M_{Plank}}\right) \approx 2 \times 10^{-20} GeV$$

KLOE-2 and QG

KLOE-2 becomes competive on γ and β with a few fb^{-1} collected, and also on α with $\geq 20\ fb^{-1}$

The use of a inner tracker (blue points in figure) improves on the reachable limits by a factor ~ 3 (note the logarithmic scale!)



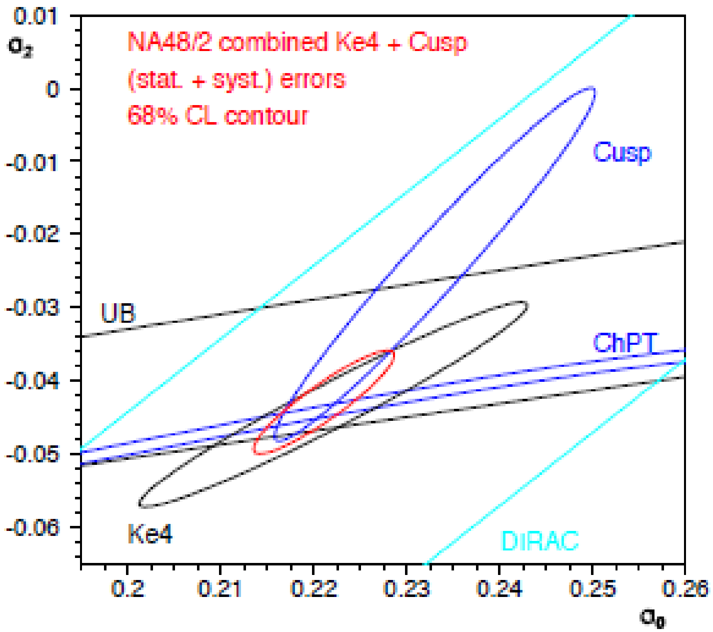
Summary

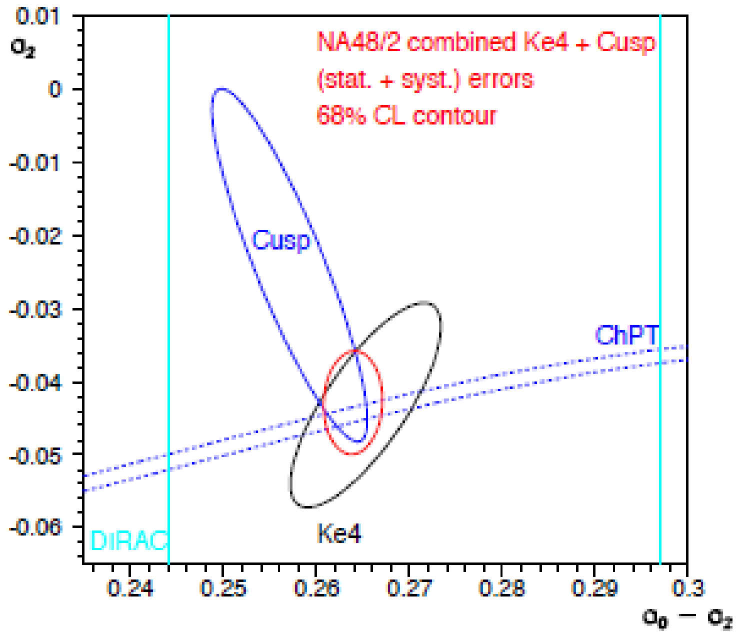
- **A World-Wide endeavor to corner the Standard Model in ultra-rare decays (CERN, J-PARC, possibly FNAL) is in place**
- **The Theory-Experiment interplay is pushing precision tests (e.g. V_{us}, Ke2) below 0.5% precision**
- **There is a stream of results coming from last round of experiments….**
- **….and new data are expected from OKA (Protvino) and KLOE-2 (Frascati) very soon**
- **The experimental programme in Kaon Physics "in the time of the LHC" is alive and kicking**

Spare Material

ππ Scattering Lengths from Ke4 Decays

Combination of Ke4 and cusp measurements:





$a_0 = 0.2210\ (47)\ (15)$
$a_2 = -0.0429\ (44)\ (16)$
stat. syst.

$a_0 - a_2 = 0.2639\ (20)\ (4)$
$a_2 = -0.0429\ (44)\ (16)$
stat. syst.

With ChPT constraint:

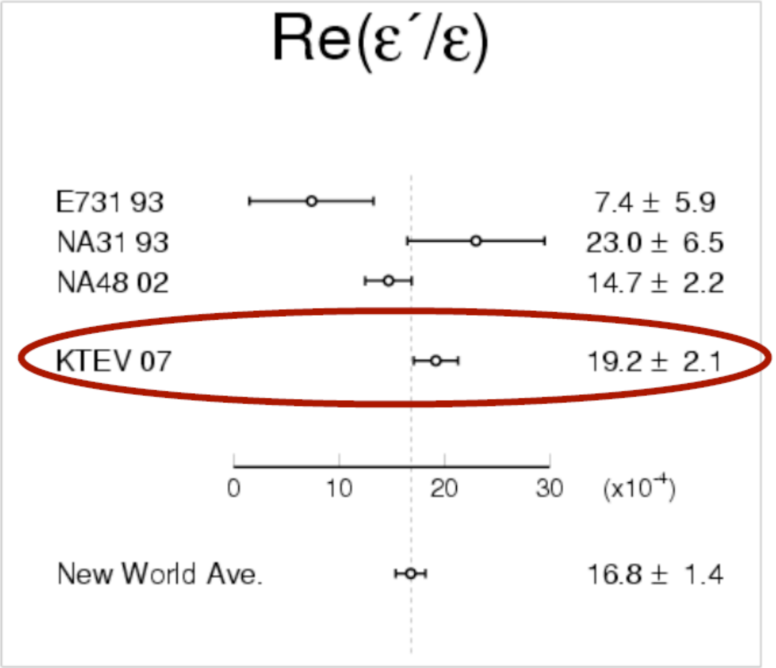
$a_0 = 0.2196\ (27)\ (21)$
$a_2 = -0.0444\ (7)\ (5)$

ChPT prediction:

$a_0 = 0.220 \pm 0.005$
$a_2 = -0.0444 \pm 0.0010$

Ed Blucher @KAON09

KTeV Result: $\mathrm{Re}(\varepsilon'/\varepsilon) = [19.2 \pm 1.1(\mathrm{stat}) \pm 1.8(\mathrm{syst})] \times 10^{-4}$
$= (19.2 \pm 2.1) \times 10^{-4}$



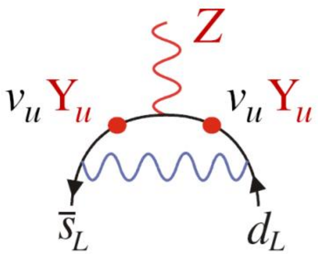
World average:
$\mathrm{Re}(\varepsilon'/\varepsilon) = (16.8 \pm 1.4) \times 10^{-4}$
(confidence level = 13%)

(KTeV 2003: $\mathrm{Re}(\varepsilon'/\varepsilon) = [20.7 \pm 1.5(\mathrm{stat}) \pm 2.4\ (\mathrm{syst})] \times 10^{-4}$)

Kaon Rare Decays and NP

(courtesy of Christopher Smith)

C. The Z penguin (and its associated W box)

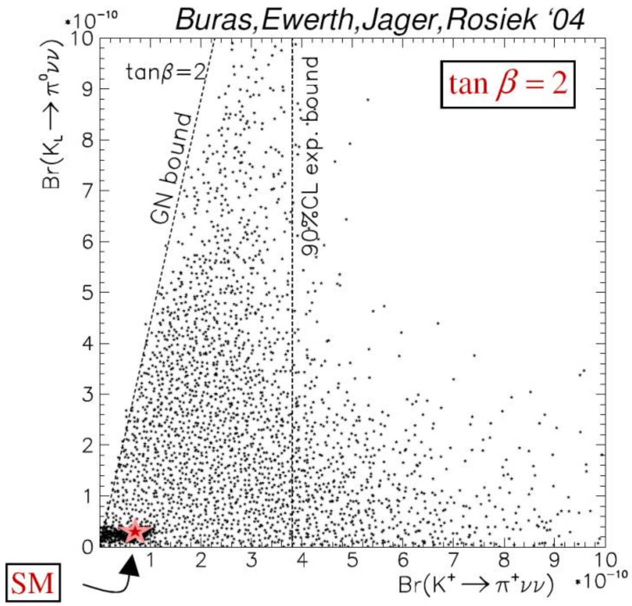


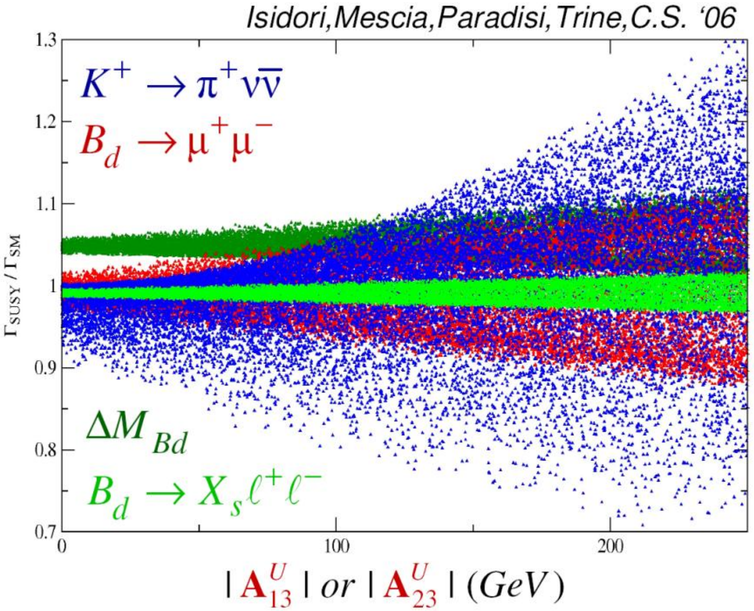
- $SU(2)_L$ breaking: $SM: v_u^2 \mathrm{Y}_u^{*32} \mathrm{Y}_u^{31} \sim m_t^2 V_{ts}^* V_{td}$

$$MSSM: v_u^2 \mathrm{A}_{\tilde{u}}^{*32} \mathrm{A}_{\tilde{u}}^{31} \sim m_t^2 \times O(1)\,?$$

$$MFV: v_u^2 \mathrm{A}_{\tilde{u}}^{*32} \mathrm{A}_{\tilde{u}}^{31} \sim m_t^2 V_{ts}^* V_{td} \left|A_0 a_2^* - \cot\beta\mu\right|^2 .$$

- Relatively slow decoupling (w.r.t. boxes or tree).





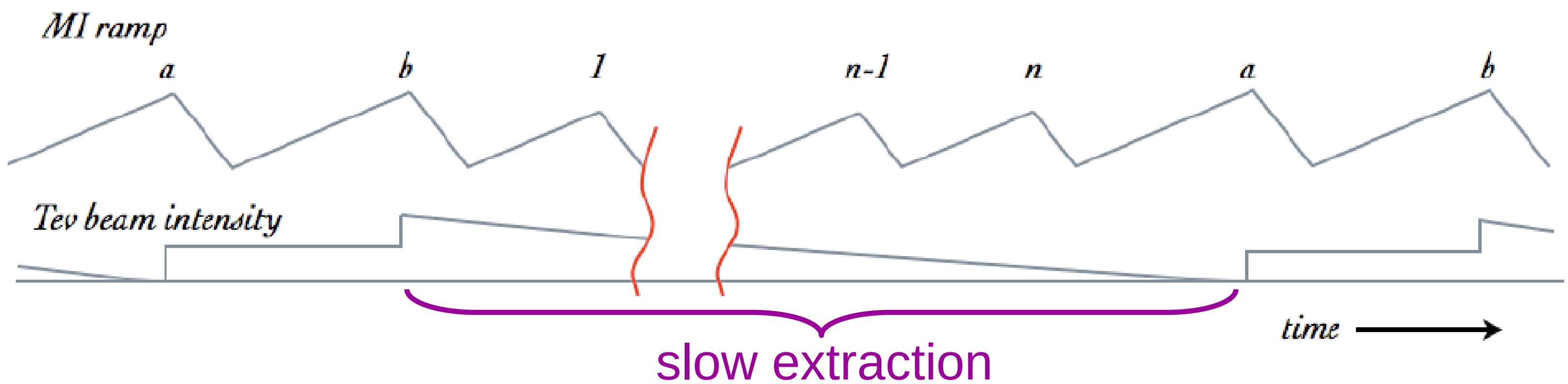
Tevatron in Stretcher Mode

Jack Ritchie @ Fermilab PAC

Stretcher operating scenario

- With NOvA, n pulses to NuMI beam (1.33 s ramp to 120 GeV) + 2 pulses to Tevatron (1.67 s ramp to 150 GeV); n ≈ 18

  10% hit in protons to NOvA; no effect on μBooNE, mu2e, g-2, …



- 96 Tp (1 TP = 10^{12} p) with 27.3 s cycle; duty factor = 94% (high duty factor is key to P996)
- Extraction hardware exists; 150 GeV is the normal Tevatron injection energy; 150 GeV extraction has been done before.
- If NOvA is off, higher intensity to P996 is possible.

Why here, why now?

- Existing Fermilab facilities (MI and Tevatron) provide an opportunity to make a decisive measurement.
  - Either New Physics will manifest, or severe constraints result.
- To be timely, this should compete head-to-head with CERN’s NA-62 experiment.
- Tevatron stretcher operation is only viable if done soon after collider running ends.
- This measurement can provide important input for planning the Project-X Intensity Frontier program.
- This experiment will be a nucleation site for rebuilding the U.S. kaon-physics community, which is needed for Project-X.

D. Jaffe @ Fermilab PAC

Projected Timescale

Milestone/Activity	Time Period
Stage One Approval	Fall 2009
DOE Approval of Mission Need (CD-0)	Spring 2010
Approve Alt. Selection/Cost Range (CD-1)	Fall 2010
Baseline Review (CD-2)	End of 2011
Start Construction (CD-3)	Spring 2012
Begin Installation	Mid-2013
First Beam/Beam Tests	End of 2013
Complete Installation	Mid-2014
First Data (CD-4)	End of 2014

Stage-1 approval is necessary to build a strong collaboration, make progress on the design, compete with NA62 (run start mid-2012) and use the Tevatron in stretcher mode.

Stopped Kaon @ FNAL?

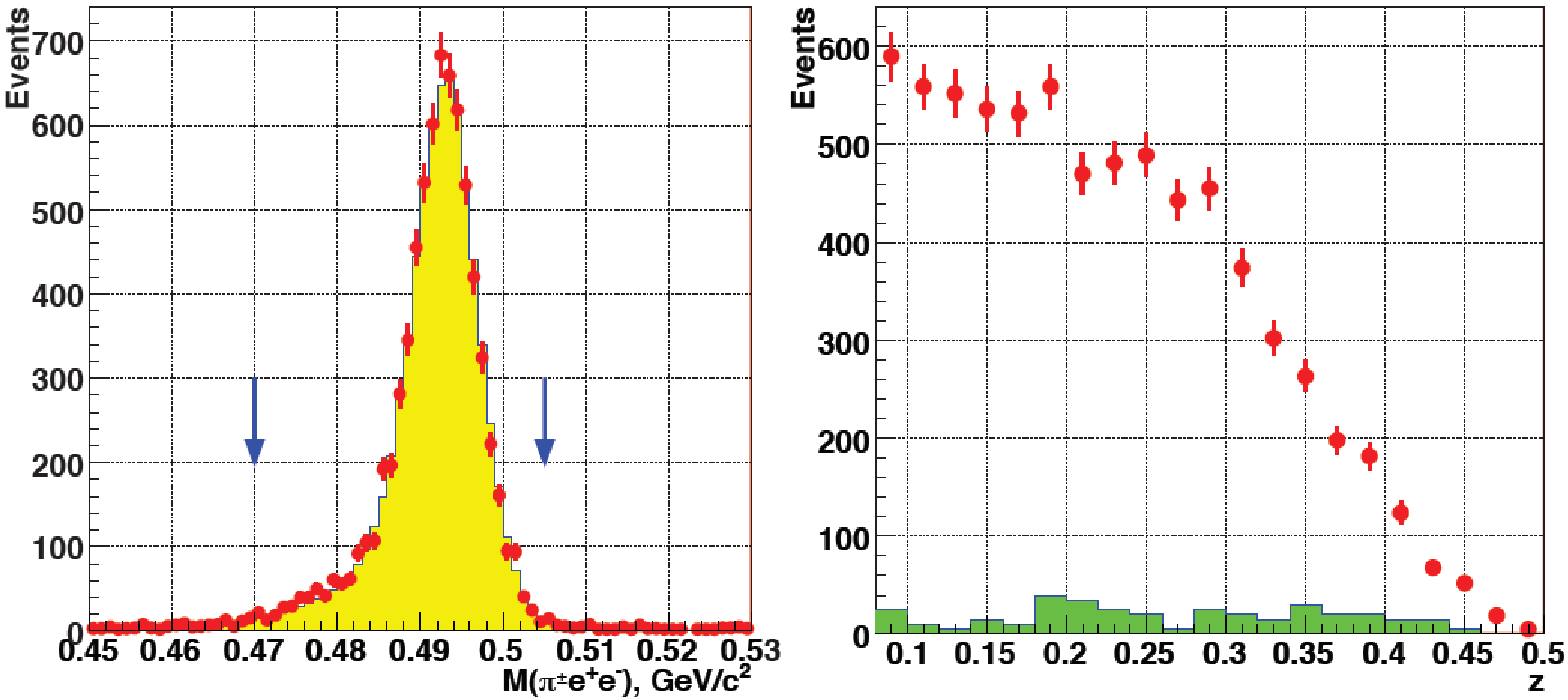
D. Bryman @ KAON09

$K^+ \to \pi^+ \nu\bar{\nu}$	FNAL "Booster" (20 kW)	FNAL Tevatron Stretcher 12%MI	FNAL Project-X
Events/yr*	40	200	325
Events/5yr	200	1000	1600
Precision**	**8**	**3.6**	**3**

**Estimates based on extrapolation of BNL E949.*

*** Includes separate estimates of backgrounds in Regions I (10%) and 2 (75%).*

Precise Measurement of $K^{\pm} \to \pi^{\pm} e^{+} e^{-}$

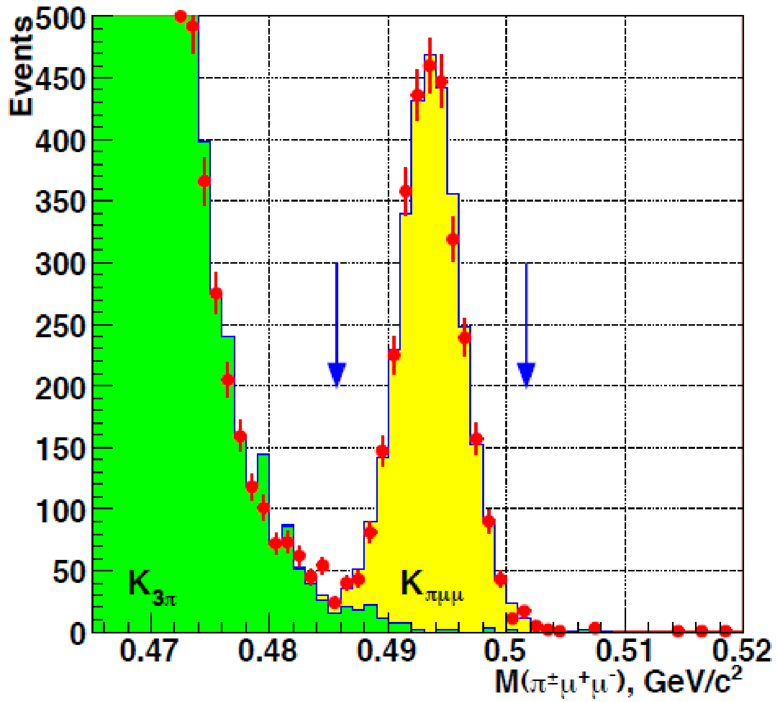


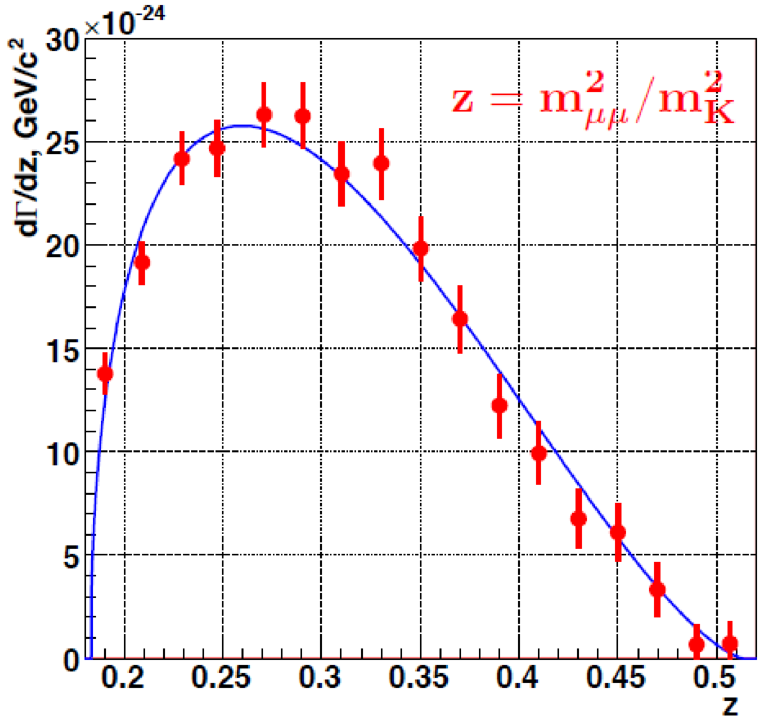
(PLB 677 (2009) 246)

$$\mathbf{Br}(K^{\pm} \to \pi^{\pm} e^{+} e^{-}) = 3.11\,(4)_{\mathbf{stat}}\,(5)_{\mathbf{syst}}\,(8)_{\mathbf{ext}}\,(7)_{\mathbf{model}} \times 10^{-7}$$

Also limit on direct CP violation: $\frac{\mathrm{Br}^{+} - \mathrm{Br}^{-}}{\mathrm{Br}^{+} + \mathrm{Br}^{-}} = (-2.1 \pm 1.5 \pm 0.6)\%$

Measurement of $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$





Whole NA48/2 data set:

3120 $K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ candidates

(World largest data sample)

$Br(K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}) = (9.6 \pm 0.2 \pm 0.1) \times 10^{-8}$