The quest of the Direct CP Violation in the Kaon system at CERN: The NA31 and NA48 experiments

Lydia Iconomidou-Fayard

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

UNIVERSITÉ PARIS SUD
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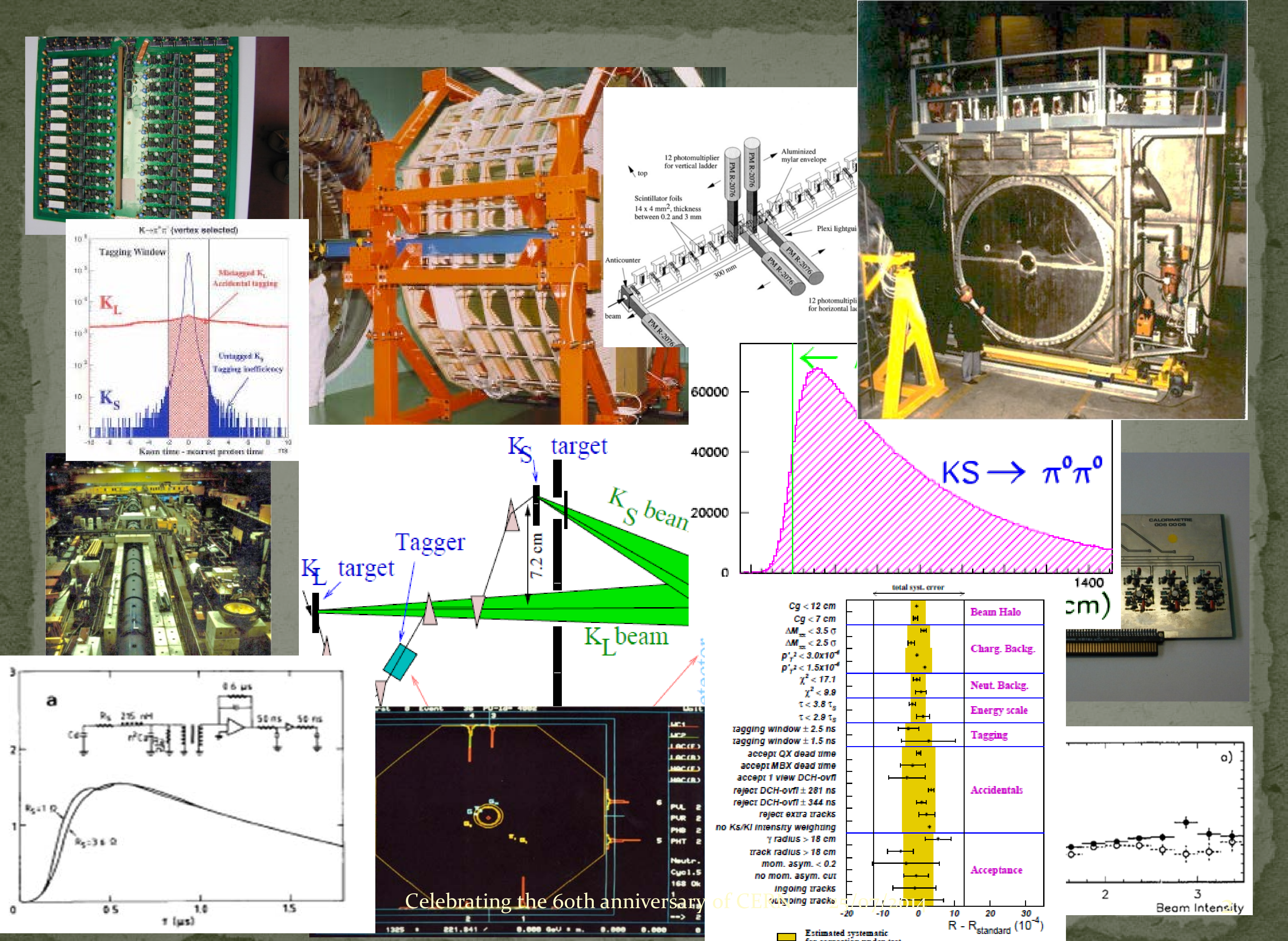
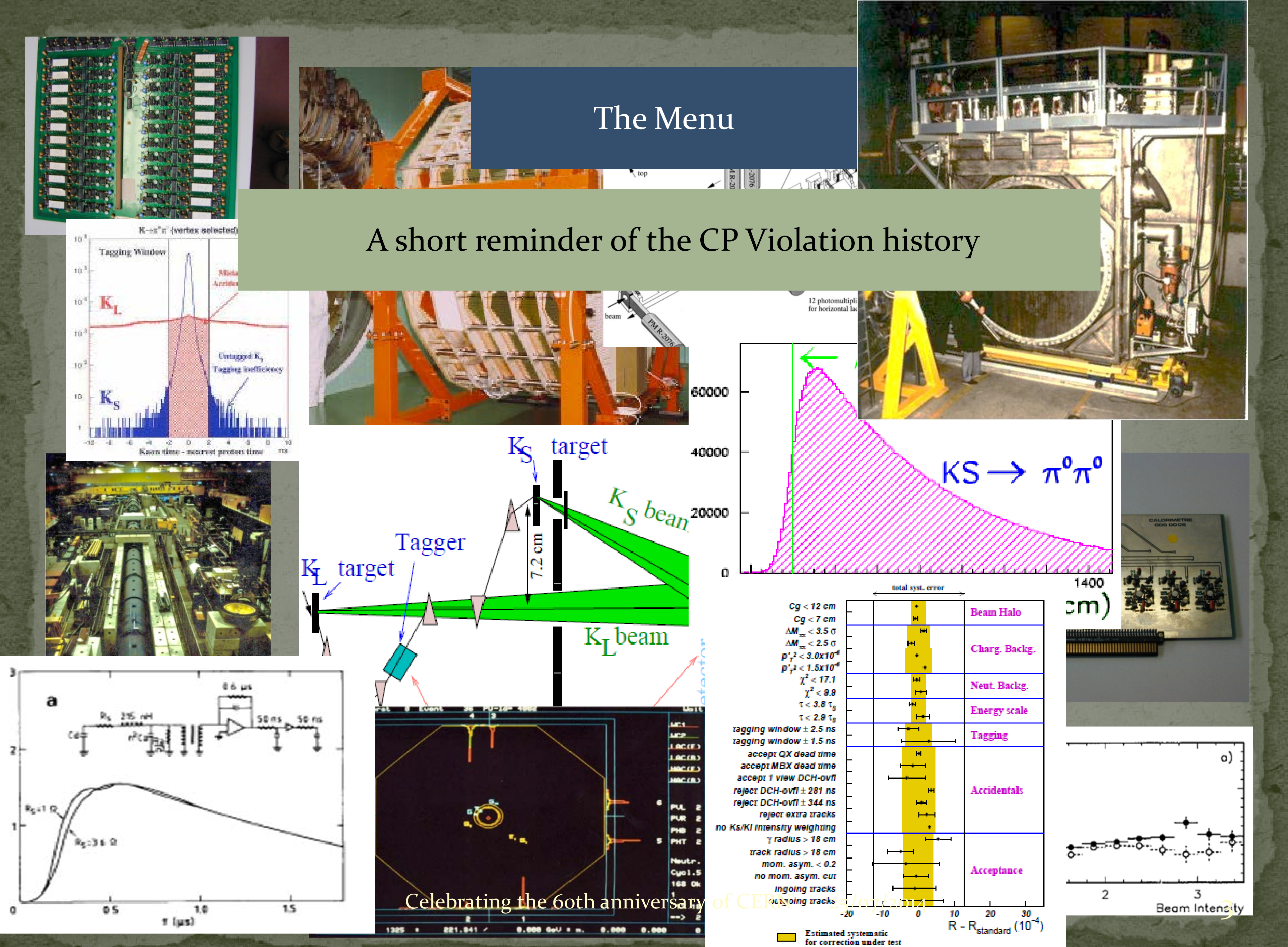
CNRS IN2P3 Les deux infinis

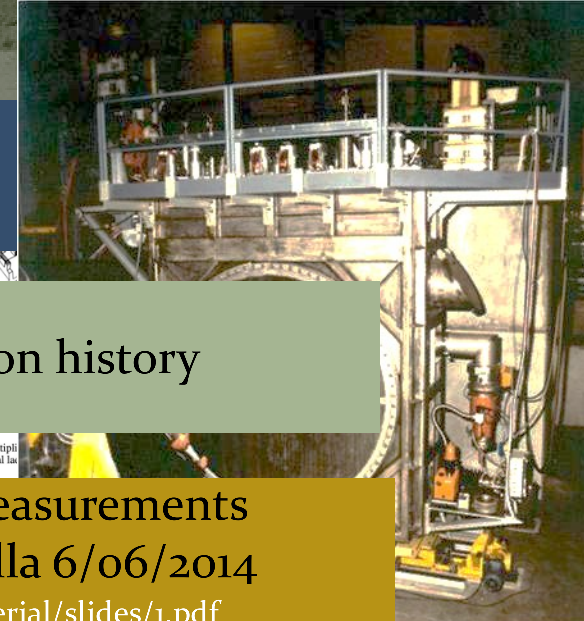


Tagging Window
K_L
K_S
Mistagged K_L Accidental tagging
Untagged K_S Tagging inefficiency
Kaon time - nearest proton time
12 photomultiplier for vertical ladder
Aluminized mylar envelope
Scintillator foils 14 x 4 mm², thickness between 0.2 and 3 mm
Anticounter
beam
300 mm
PM R-2076
K_S target
K_L target
Tagger
7.2 cm
K_S beam
K_L beam
$KS \rightarrow \pi^0\pi^0$
60000
40000
20000
0
1400
Beam Halo
Charg. Backg.
Neut. Backg.
Energy scale
Tagging
Accidentals
Acceptance
$R - R_{standard}$ (10^{-4})
Estimated systematic for correction under test
Beam Intensity

The Menu

A short reminder of the CP Violation history





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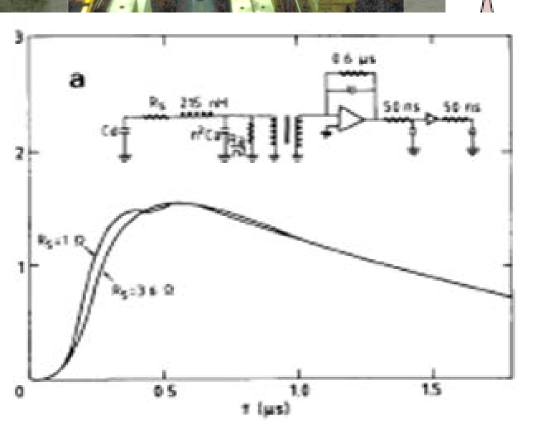
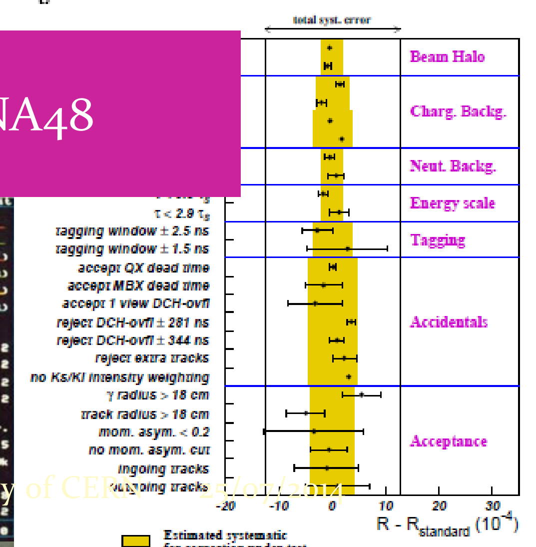
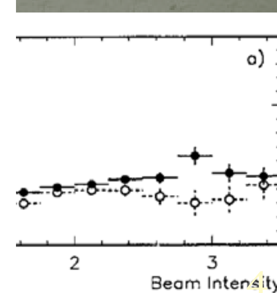
For CERN contributions to CPV measurements
see previous seminar by Luigi Di Lella 6/06/2014
http://indico.cern.ch/event/320481/contribution/1/material/slides/1.pdf

We concentrate here to the CERN efforts to elucidate the Direct component of CP-Violation

NA31 and NA48







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NA31 and NA48

Many thanks to my colleagues
Daniel Fournier, Ivan Mikulec, Guillaume Unal, Lau Gatignon, Eddy Mazzucato for sharing their memories

The Kaon-history time arrow

1947

Observation of Kaons in cosmic rays

G.D.Rochester

C.C. Butler

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V. D. Hopper and S. Biswas
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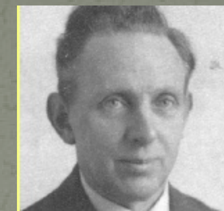
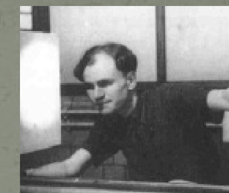

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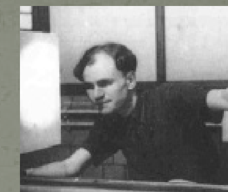

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Observation of Long-Lived Neutral *V* Particles*

K. Lande, E. T. Booth, J. Impeduglia, and L. M. Lederman,

Columbia University, New York, New York

and

W. Chinowsky, *Brookhaven National Laboratory, Upton, New York*

(Received July 30, 1956)

Kaons and symmetries in the 60's

Weak interaction violates both C& P symmetries, preserving in general CP

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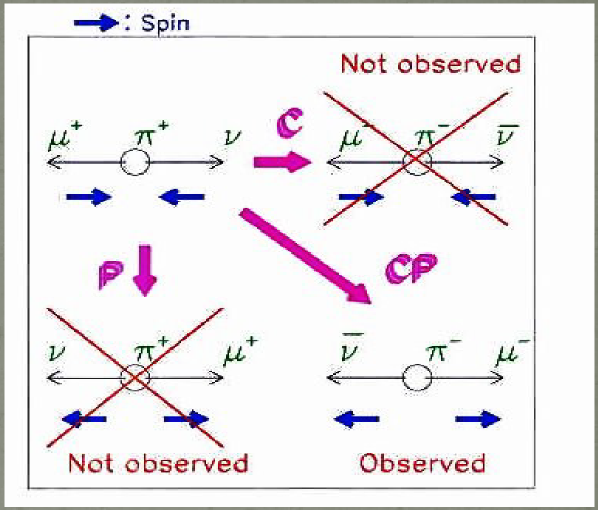

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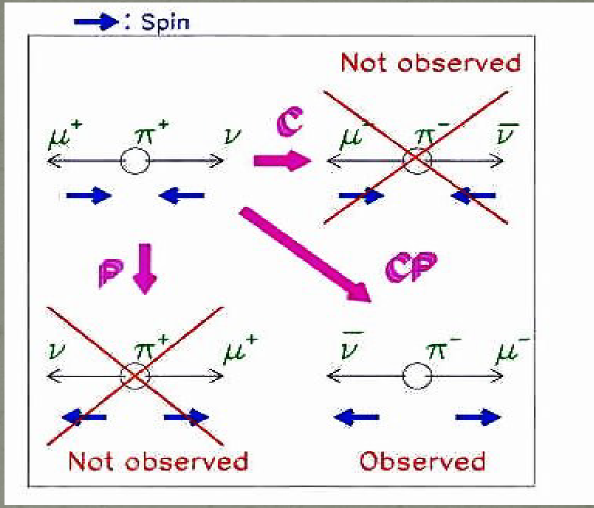

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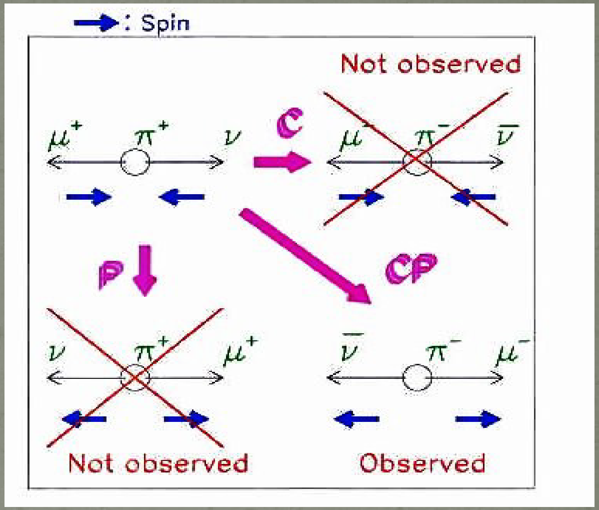

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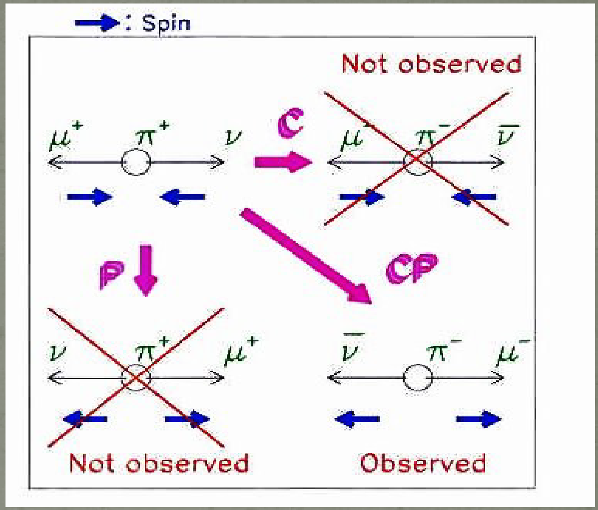

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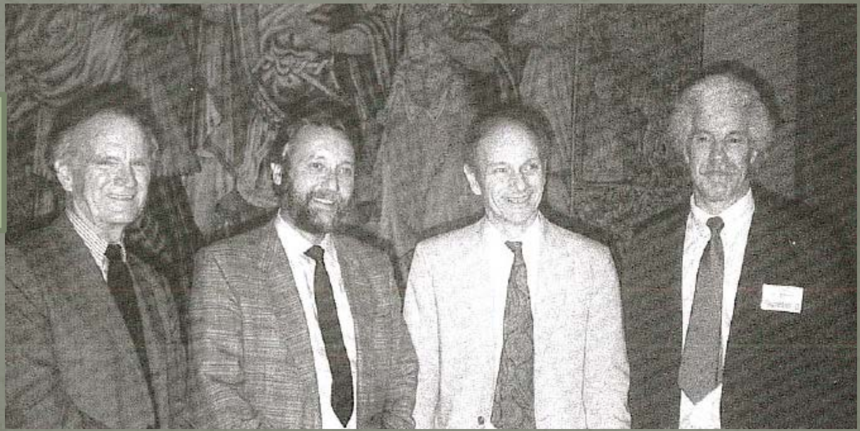
1964

PHYSICAL REVIEW LETTERS

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

J. H. Christenson, J. W. Cronin,‡ V. L. Fitch,‡ and R. Turlay§
Princeton University, Princeton, New Jersey
(Received 10 July 1964)

Observation of 42 $K_2 \to \pi^+\pi^-$ decays



Fitch, Turlay, Cronin, Christenson
Château de Blois, May 1989

What happens to Kaons?

$$K_S = \frac{K_1 + \tilde{\varepsilon}\ K_2}{\sqrt{1+|\tilde{\varepsilon}|^2}} \qquad K_L = \frac{K_2 + \tilde{\varepsilon}\ K_1}{\sqrt{1+|\tilde{\varepsilon}|^2}}$$

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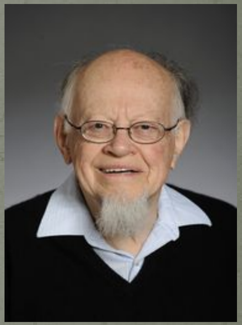
$$M = \begin{pmatrix} M_s & im' + \delta' \\ -im' + \delta' & M_L \end{pmatrix}$$



L.Wolfenstein

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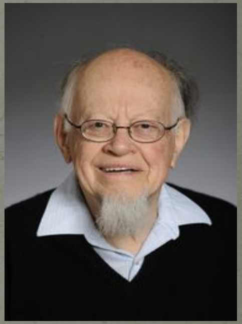

L.Wolfenstein

1972

CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

In a framework of the renormalizable theory of weak interaction, problems of CP-violation are studied. It is concluded that no realistic models of CP-violation exist in the quartet scheme without introducing any other new fields. Some possible models of CP-violation are also discussed.

CP Violation in the Standard Model

CP Violation naturally included in the Standard Model if 3 quark families.
(only 3 quarks known in 1973!)

’74 : c quark, ‘75: τ lepton,
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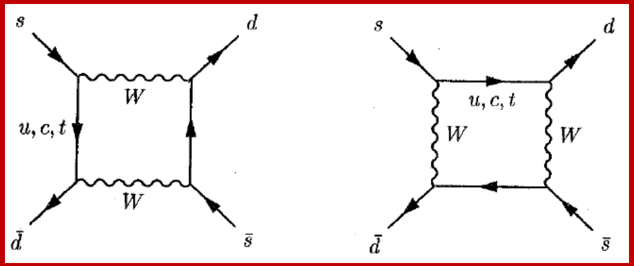

CPV in mixing ΔS=2 . Measured by ε~0.2%

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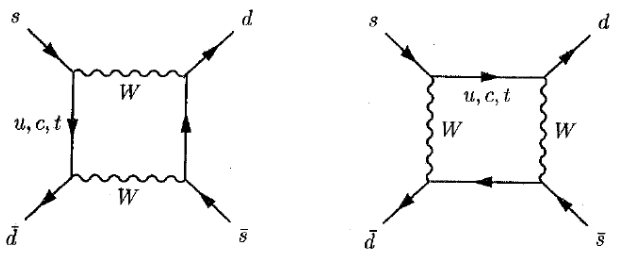

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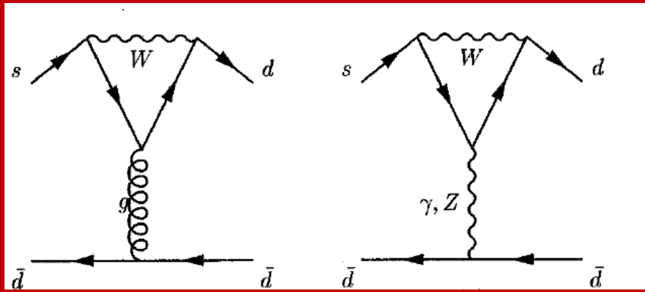

CPV in decay ΔS=1. Measured by ε'

Call it « Direct CPV »

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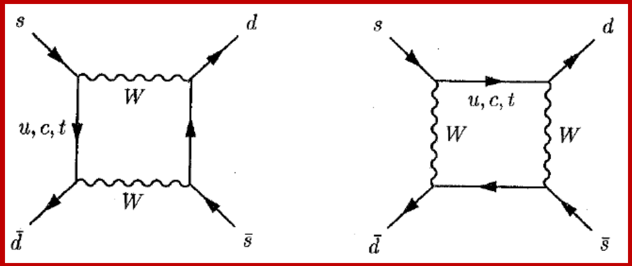

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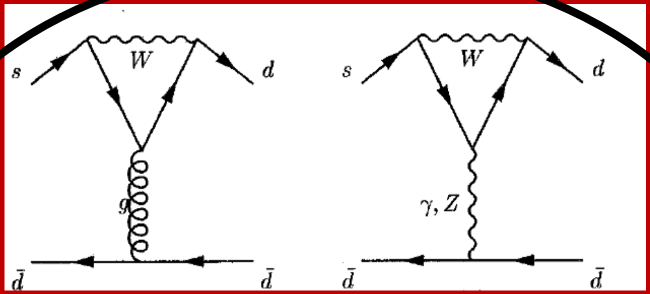

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Theory time-arrow of the Re(ε'/ε) size

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Few permil precision seems enough

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1990	$\frac{\varepsilon'}{\varepsilon} = 11.10^{-4}\left[\frac{\eta\lambda^5 A^2}{1,3.10^{-4}}\right]\left[\frac{140MeV}{m_s(2GeV)}\right]^2\left[\frac{\Lambda^{(4)}_{\overline{MS}}}{300MeV}\right]^{0,8}[B_6 - Z(x_t)B_8]$ Buras, Jamin,Lautenbacher
~1995	10^{-4}->16 10^{-4} Buras et al, Ciuchini et al

Few permil precision seems enough

B6: QCD penguins
B8: EW penguins

Need 10^{-4} precision!

What we need to measure

$$Re\left(\frac{\varepsilon'}{\varepsilon}\right) \approx \frac{1}{6}\left(1 - \left|\frac{\eta_{00}}{\eta_{+-}}\right|^2\right)$$

$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \bigg/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)}$$

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Challenges to face in an experiment

1) Isolate the very rare K_L to 2π decays
2) Suppress the abundant 3-body K_L decays
3) Handle the very different K_S and K_L lifetimes ($c\tau_S$ =2.675cm, $c\tau_L$=1554 cm
4) Measure precisely R^{meas} -> R

The NA31 experiment 1981-1993

14 authors, 4 labs

CERN/SPSC/81-110
SPSC/P174
22 December, 1981

PROPOSAL

Measurement of $|\eta_{00}|^2/|\eta_{+-}|^2$

D. Cundy, N. Doble, I. Mannelli, J. May, J. Steinberger,
H. Taureg and H. Wahl
CERN, Geneva, Switzerland

F. Eisele, K. Kleinknecht and B. Renk
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Votre référence
Your reference

Notre référence
Our reference SPSC - JL/em

Dr. H. Wahl
CERN - EP

Geneva, 8 July 1982

Dear Dr. Wahl,

The committee at is last meeting decided to recommend P 171 for approval. However there was a widespread feeling that the committee should suggest to enlarge the collaboration with some physicist dedicated to this experiment.

Furthermore it was felt that the contribution from CERN should not exceed 2 MSF. I hope some reassurance on these two points can be given in time for the September 16th research board.

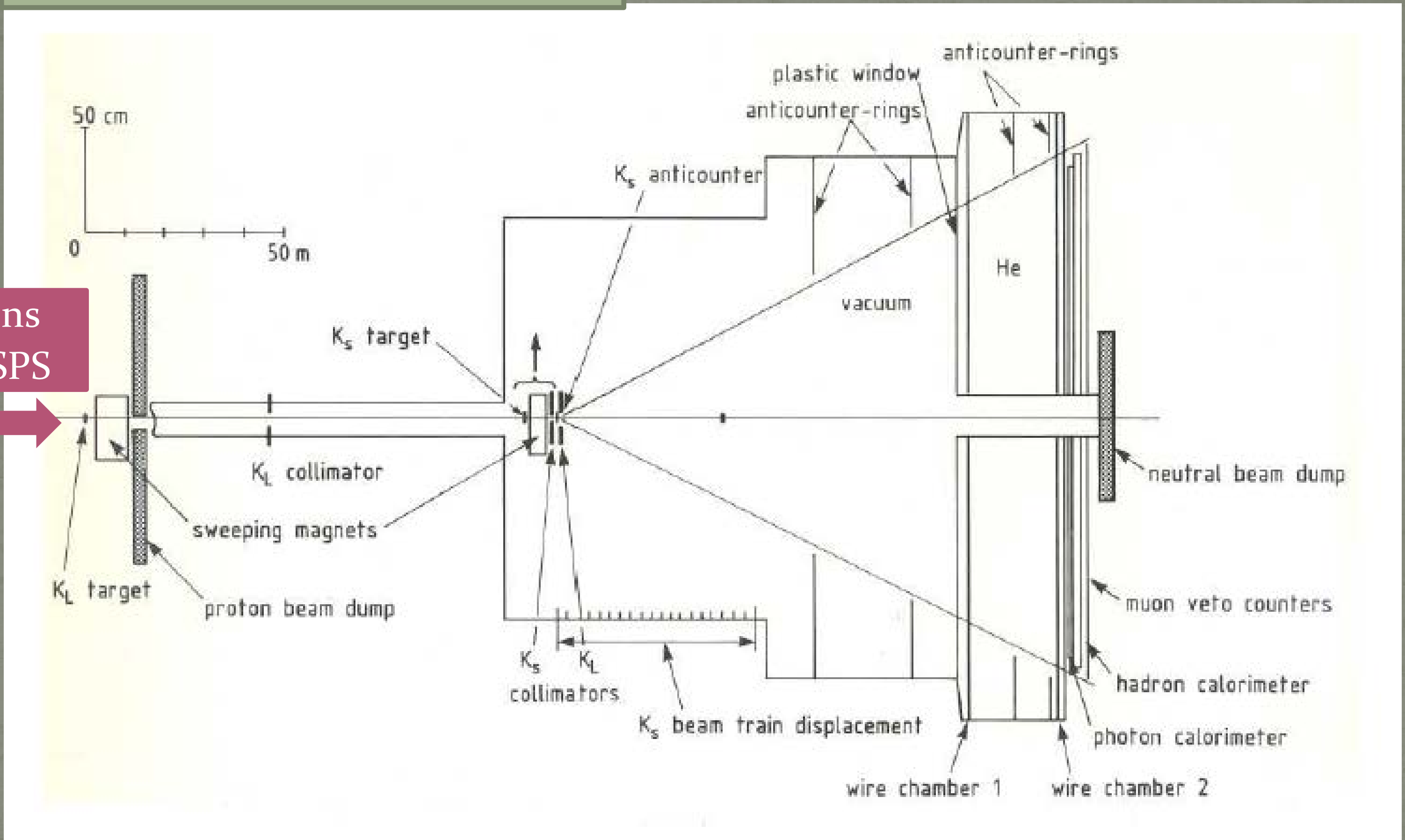
Yours truly,

J. Lefrançois

The NA31 experiment in a sketch

Alternate K_S and K_L beams

Protons from SPS



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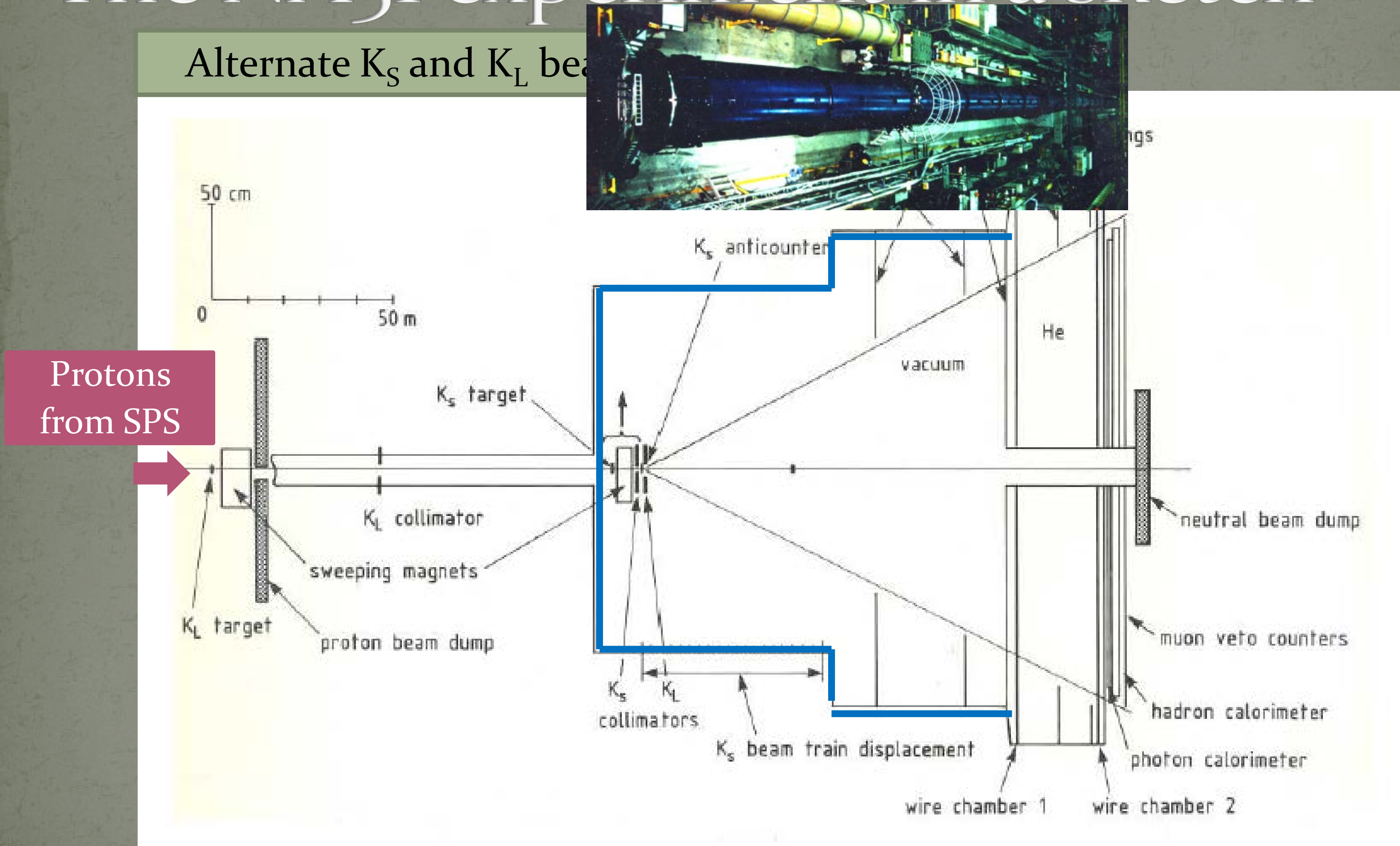
Alternate K_S and K_L bea



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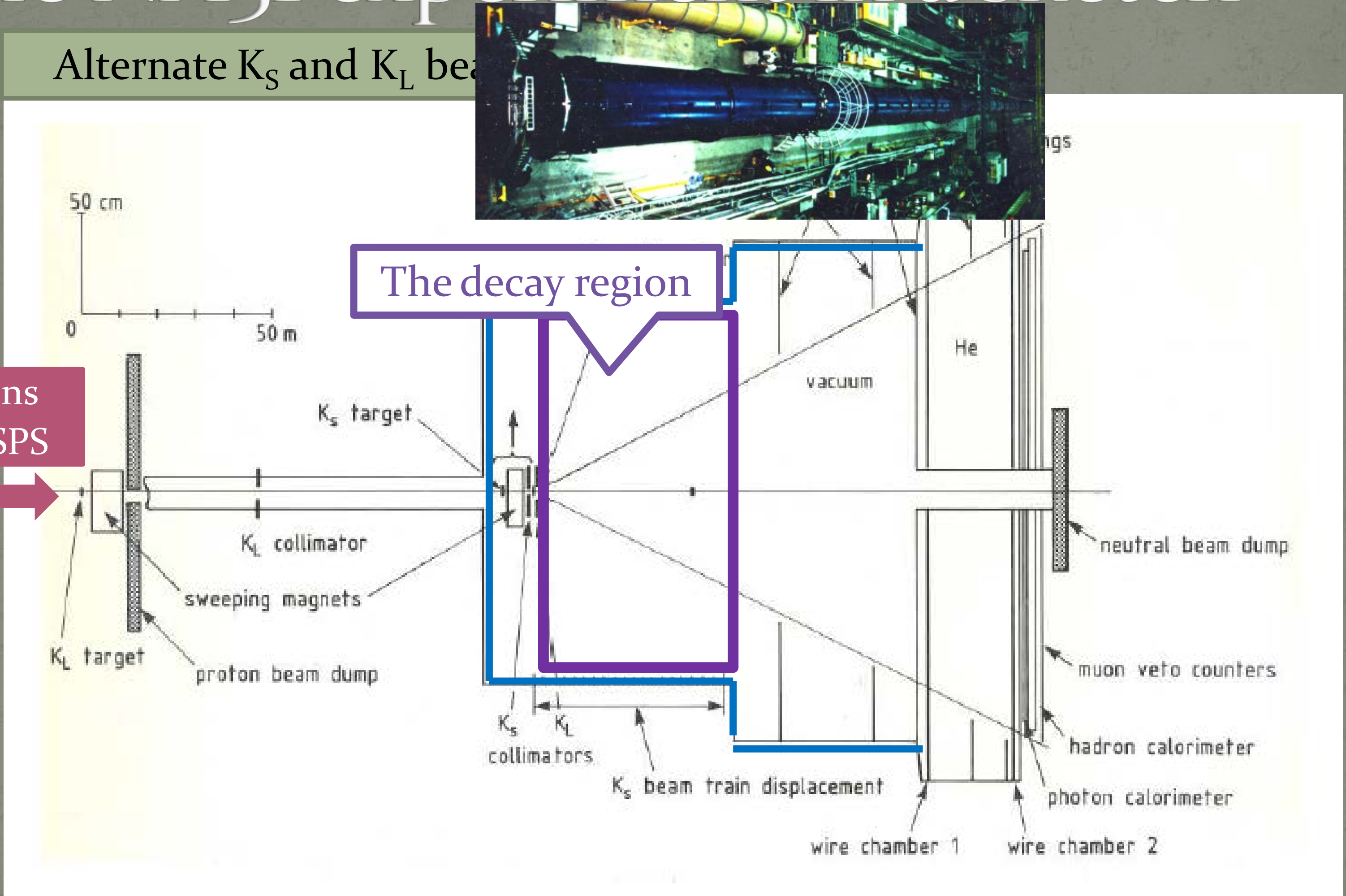

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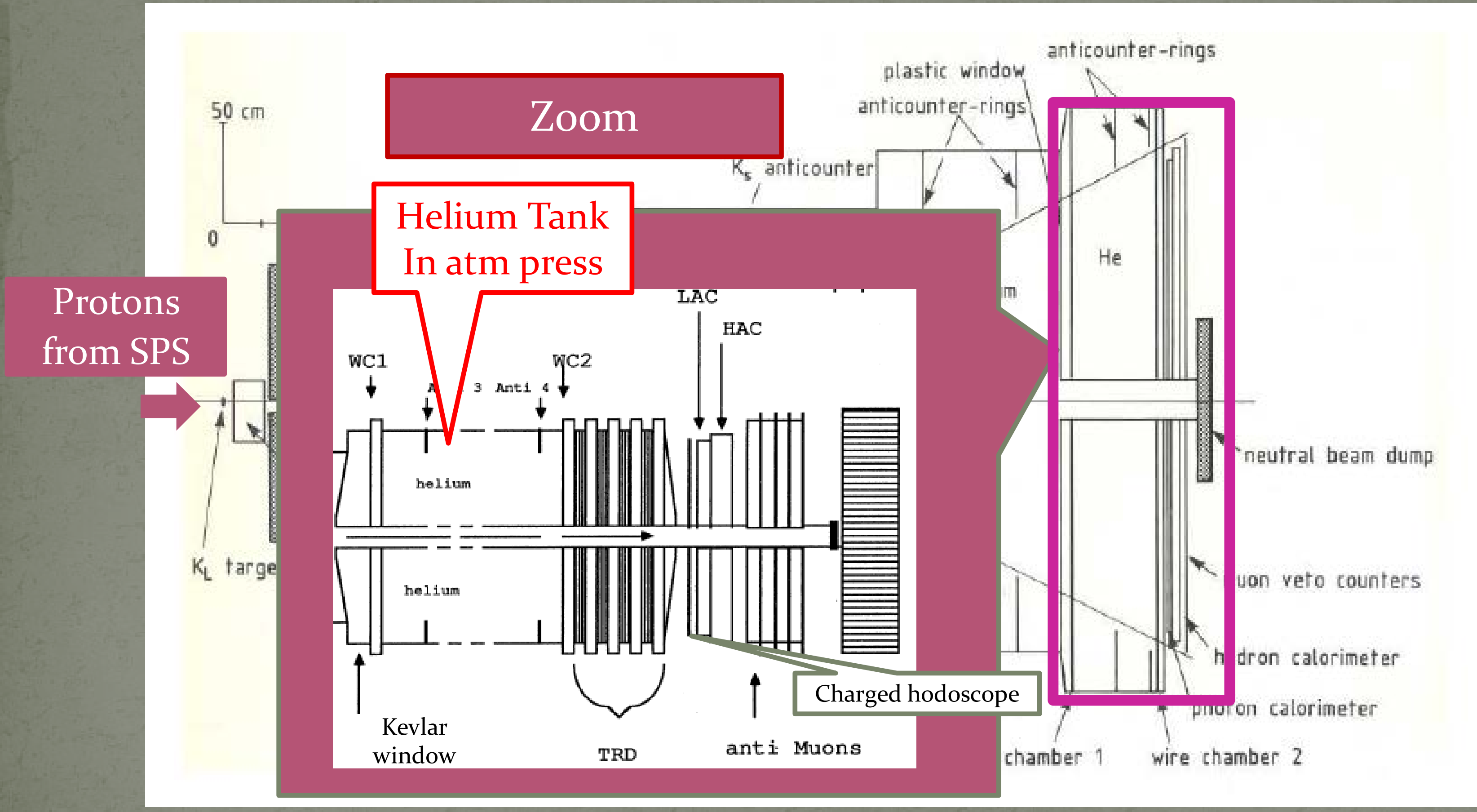

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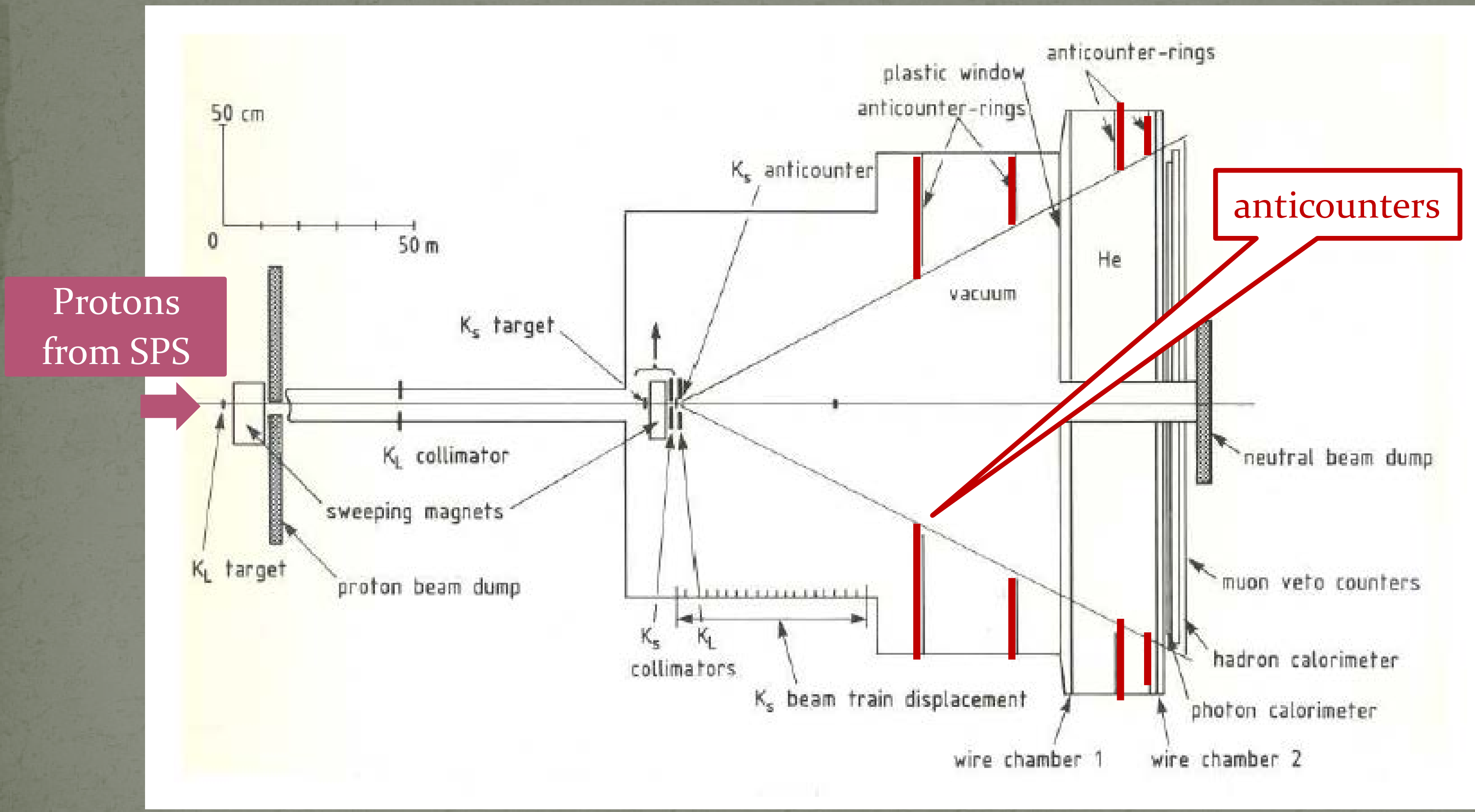
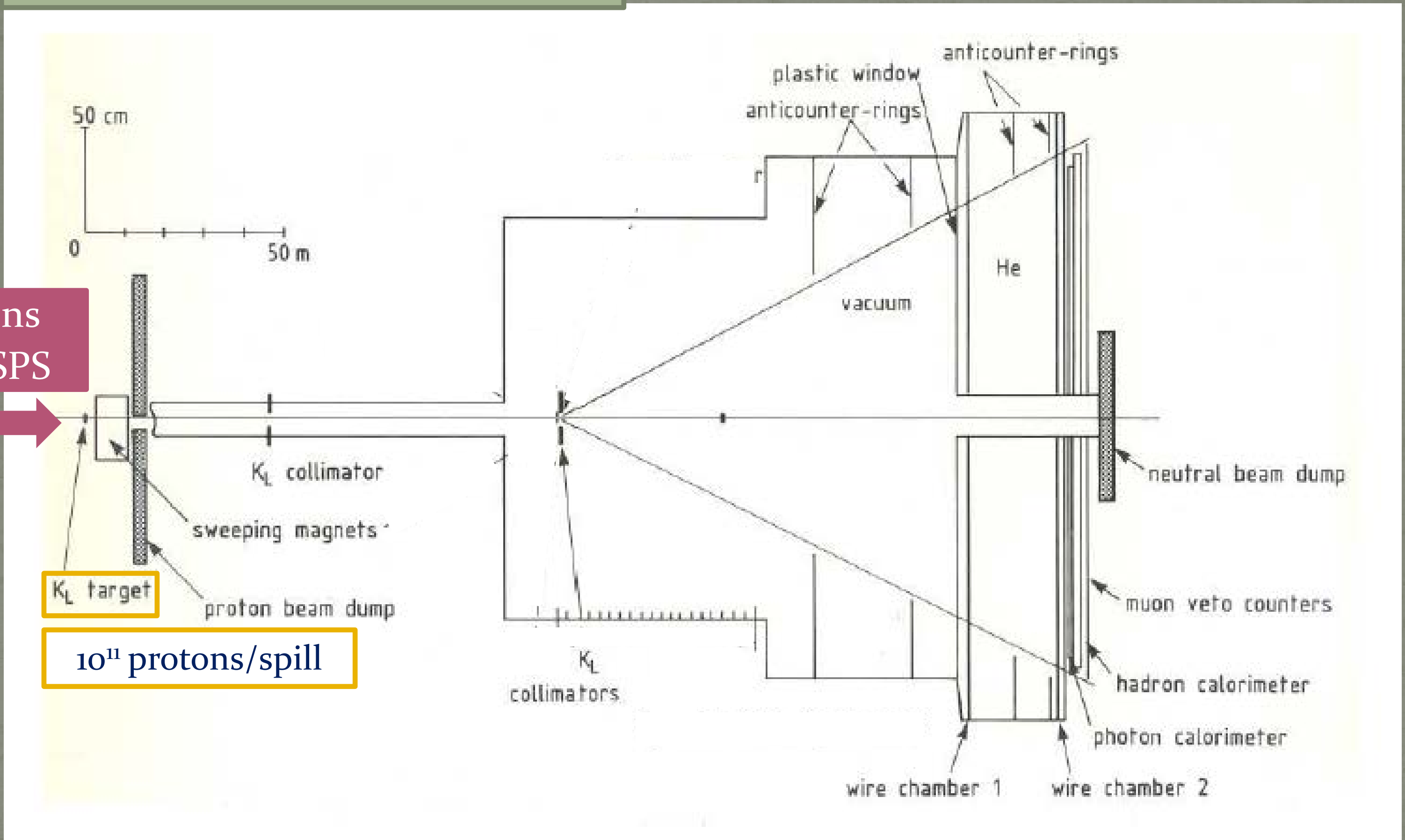


The NA31 experiment : K_L set-up

Alternate K_S and K_L beams

Protons from SPS



10^{11} protons/spill

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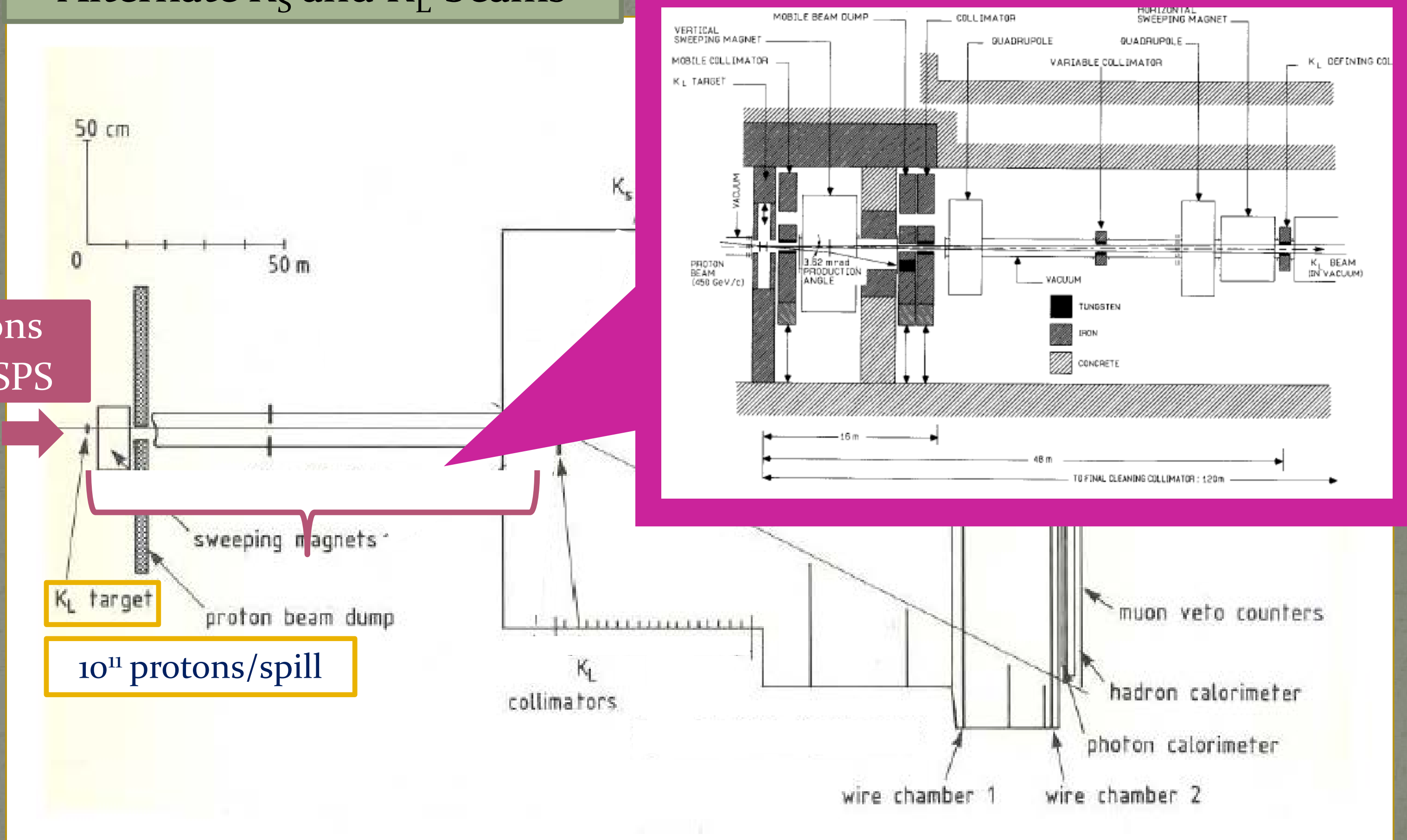

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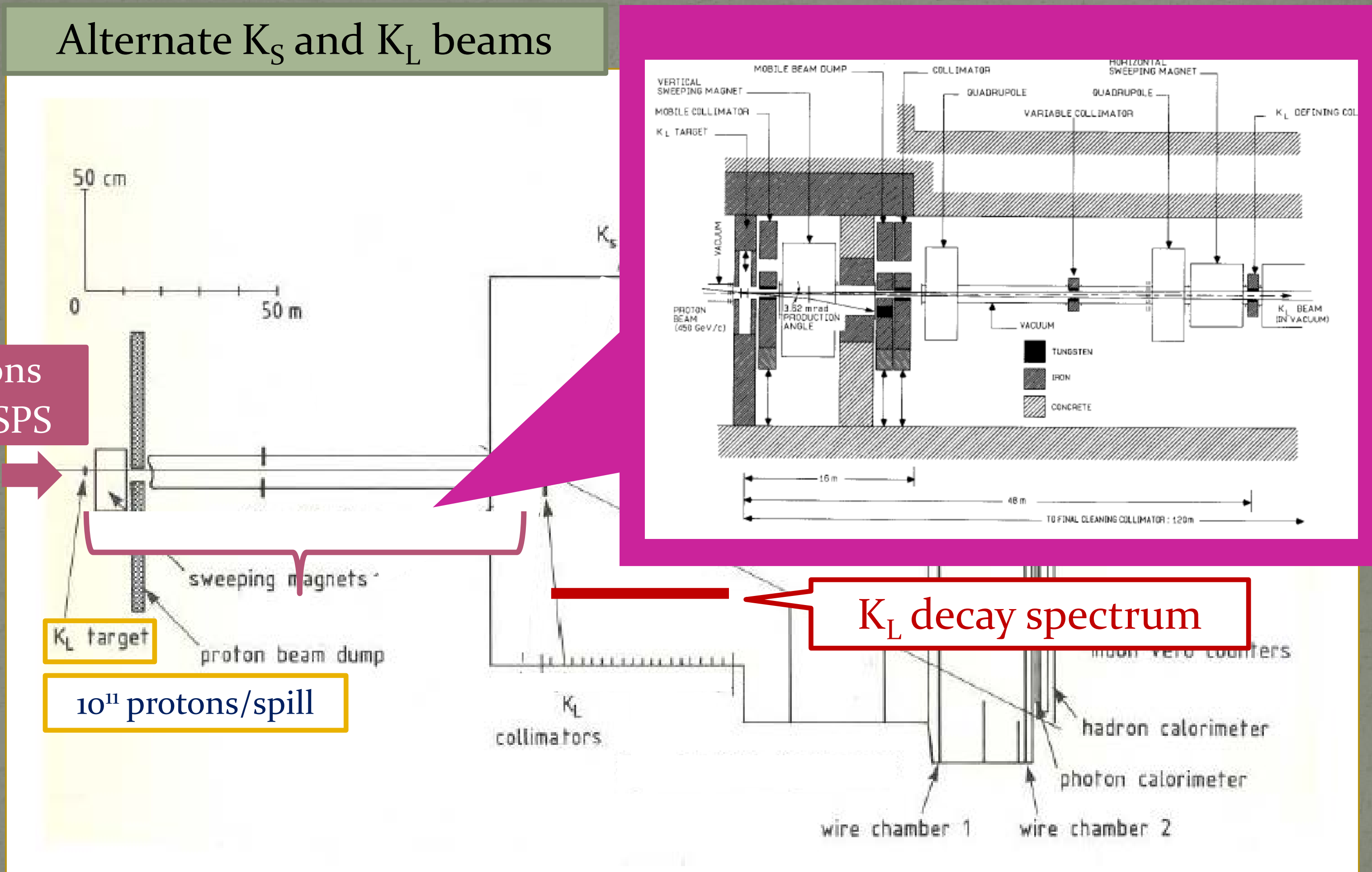

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K_L decay spectrum

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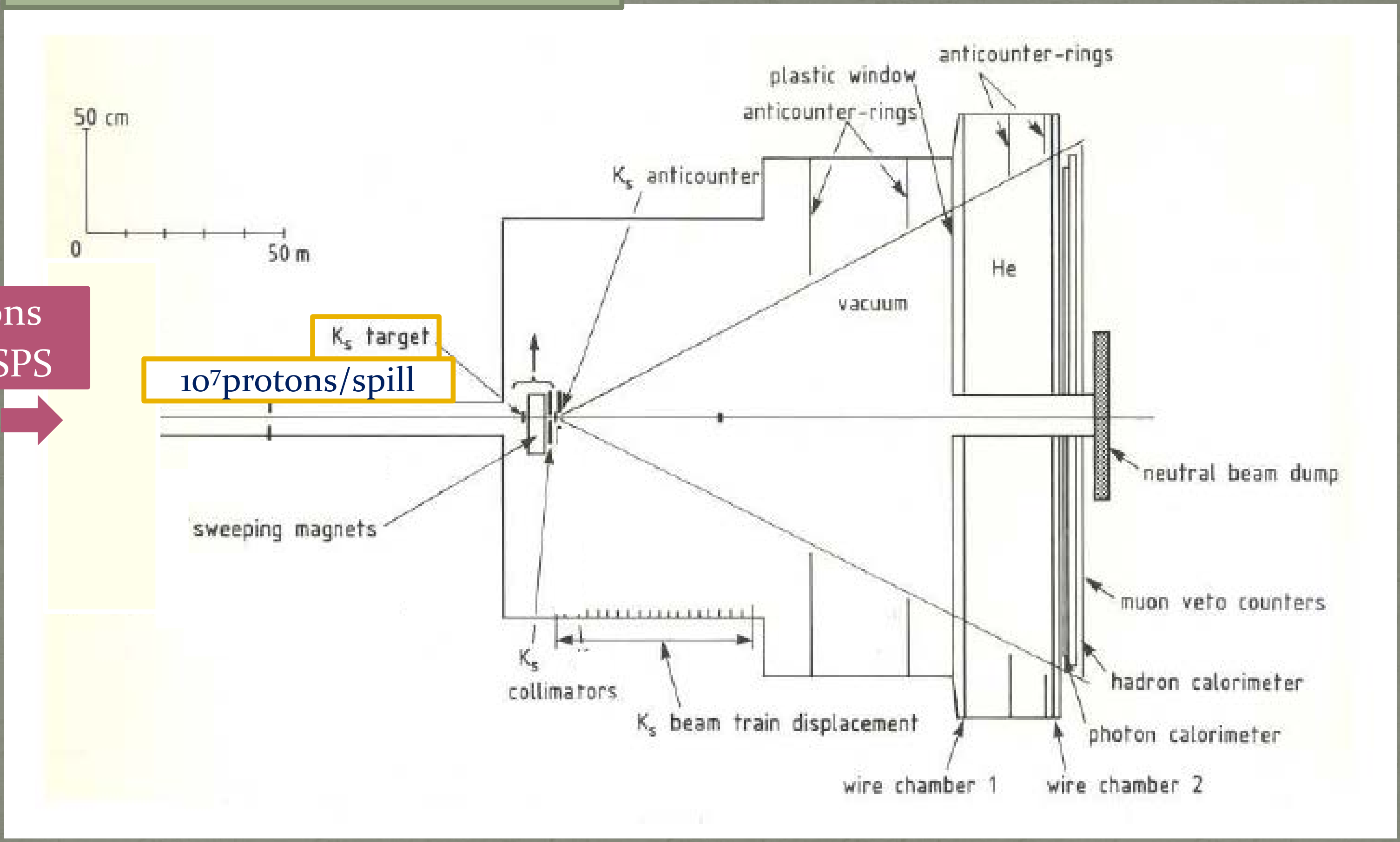

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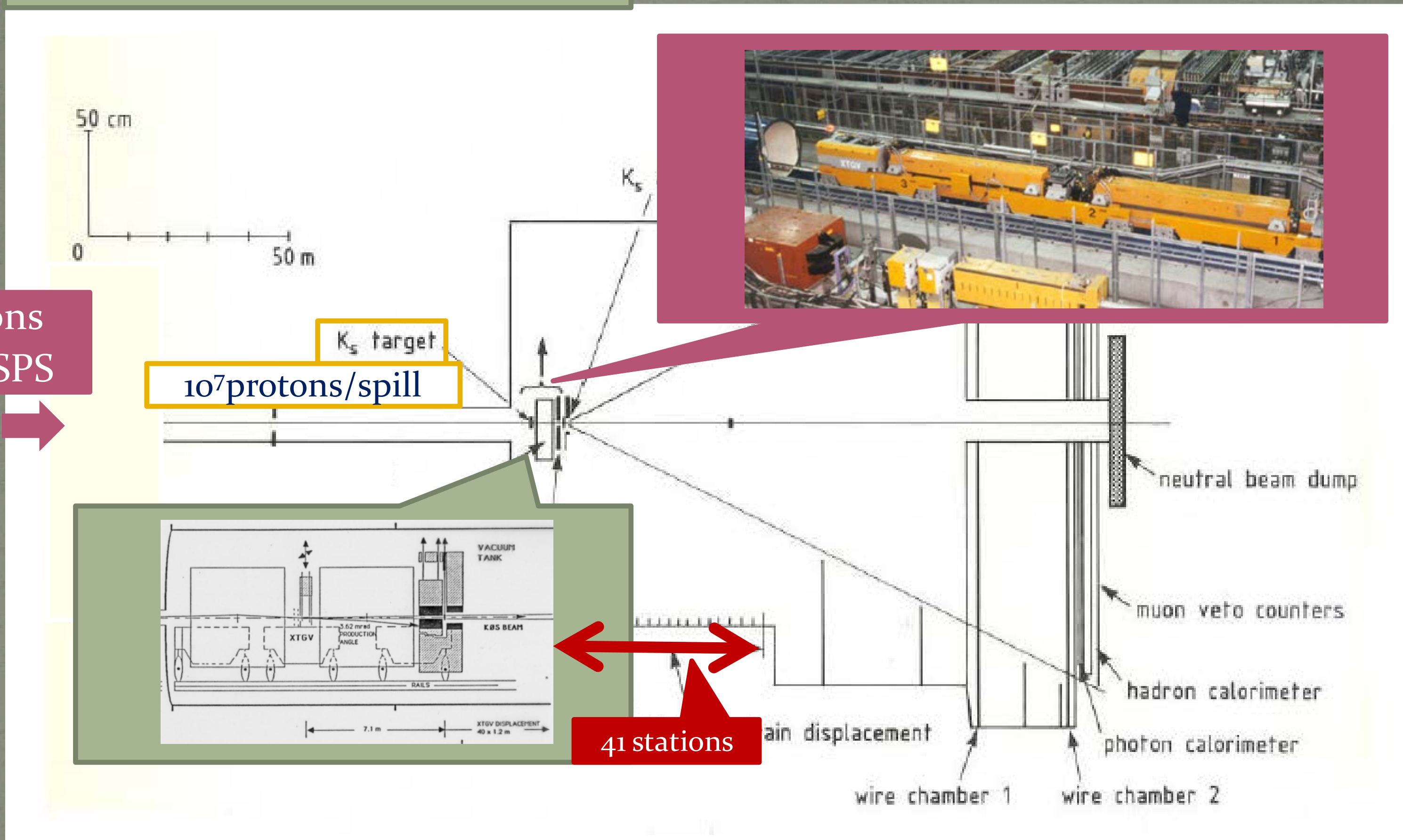

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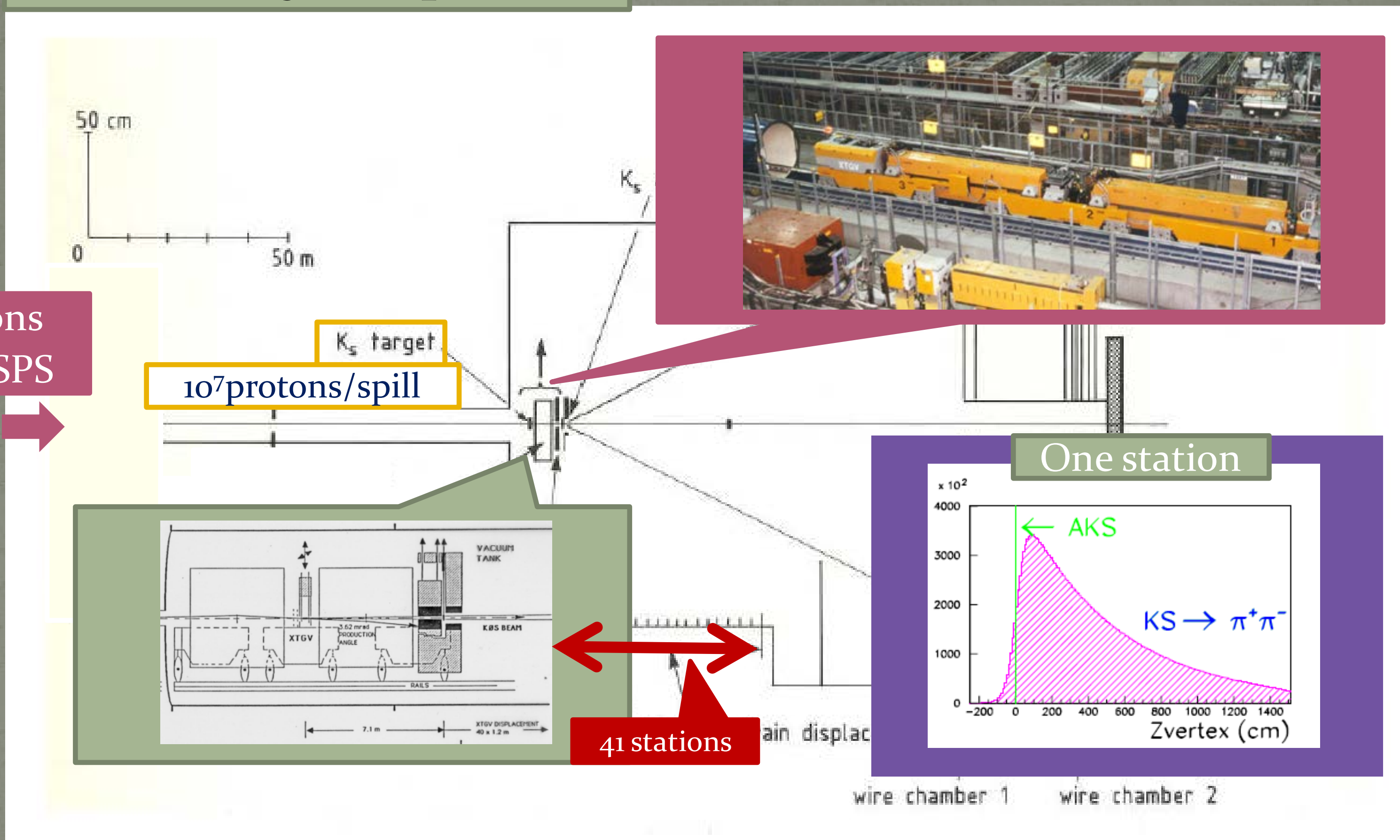

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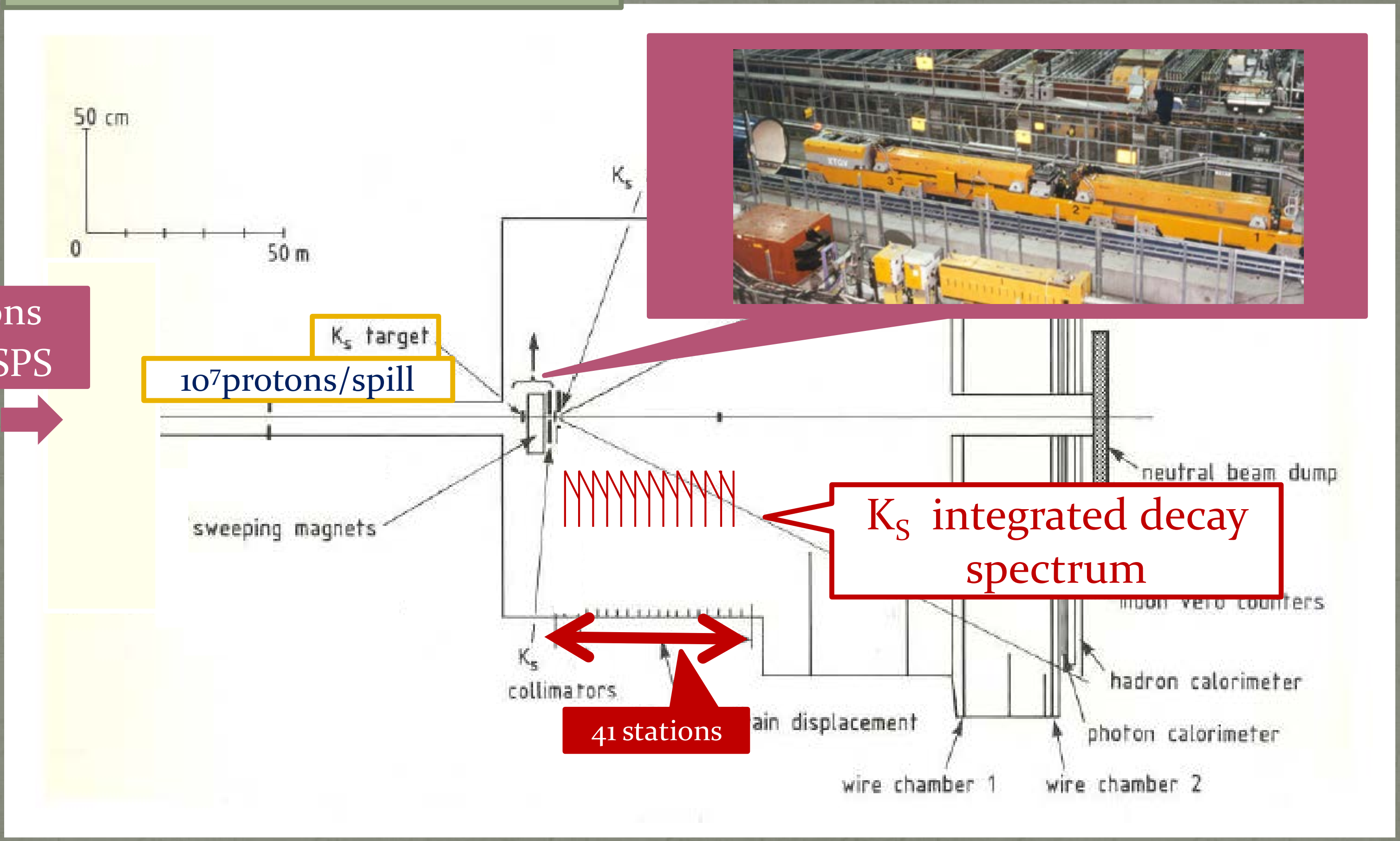

The NA31 way

Alternate K_S and K_L beams in the same detector

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Detect concurently charged and neutral

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3-level trigger system to select 2π and reject 3body events.
Synchronous part : Counters, Energy, Hits
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Single rates ~10^5 , pretrigger 10KHz, write on tape 1000events/burst

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Make K_S spectra similar to K_L

Reduce acceptance corrections

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→Charged tracks from the 2 WC

→ E1 and E2 energies from LAC +HAC

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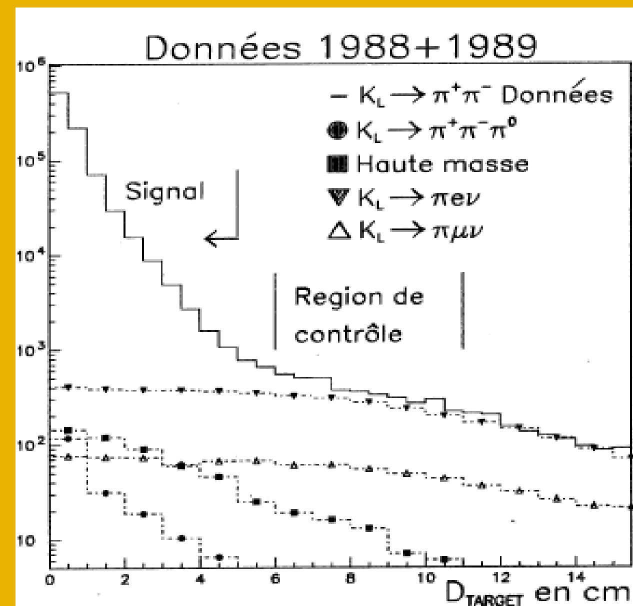

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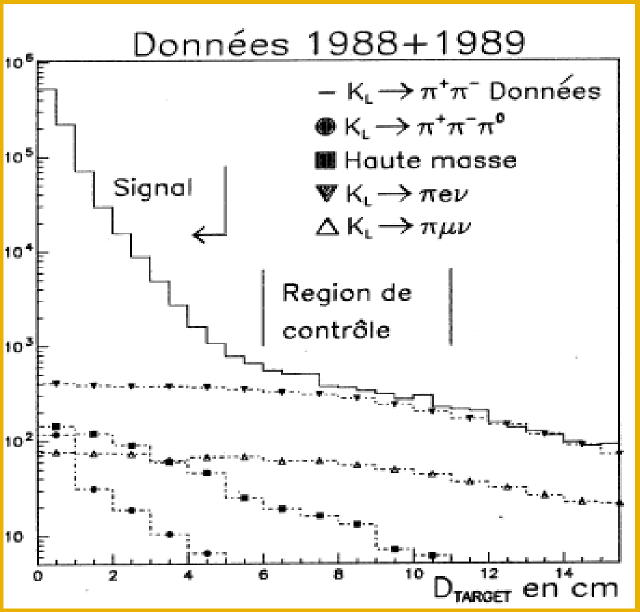
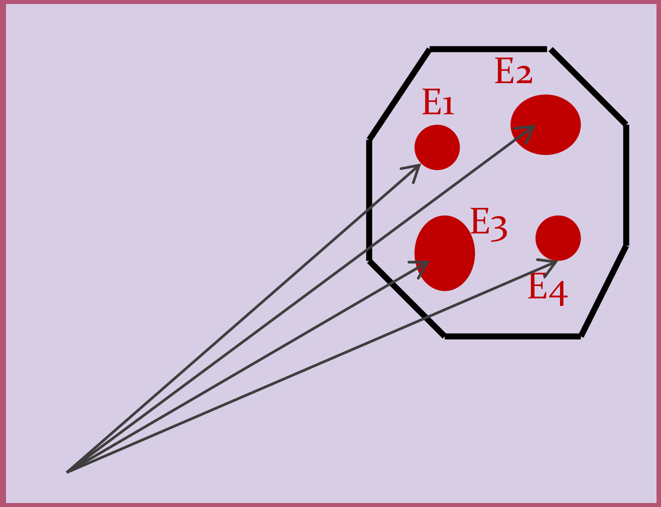


Checked from 1988 on with the Transition Radiation Detector

Reconstruction of $\pi^0\pi^0$ in a nutshell

Only four clusters in LAC



Reconstruction of π⁰π⁰ in a nutshell

Only four clusters in LAC

$$Z_{K^0} = Z_{LAC} - \frac{1}{M_{K^0}} \times \sqrt{\sum_{i=1,j>i}^{4} E_i \times E_j \times [(x_i - x_j)^2 + (y_i - y_j)^2]}$$

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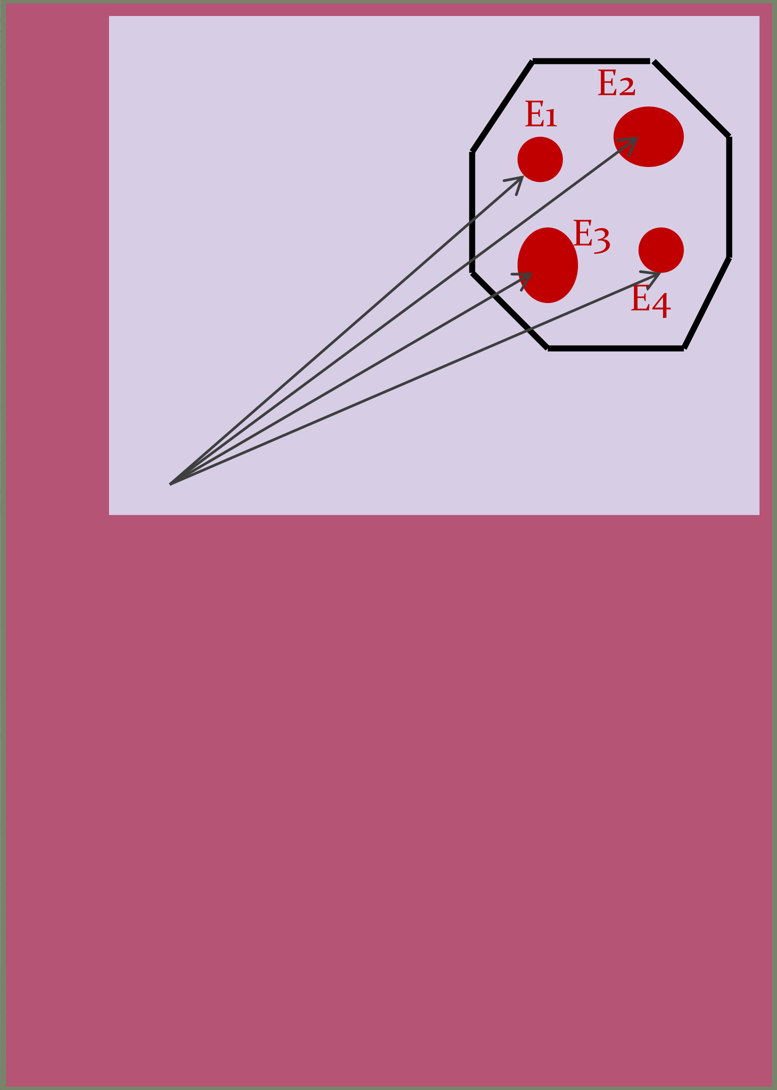

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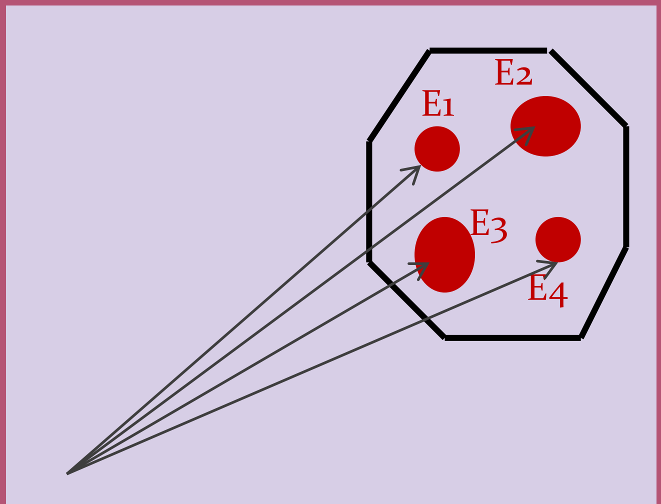
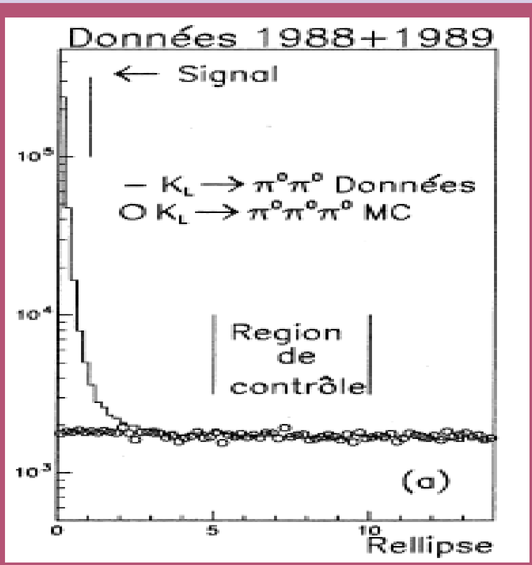
$$R_{ellipse} = \left(\frac{m_{\pi_1^0} - m_{\pi_2^0}}{S\sigma_1(E_{\gamma_{min}})}\right)^2 + \left(\frac{m_{\pi_1^0} + m_{\pi_2^0} - 2 \times M_{\pi^0}}{S\sigma_2(E_{\gamma_{min}})}\right)^2$$





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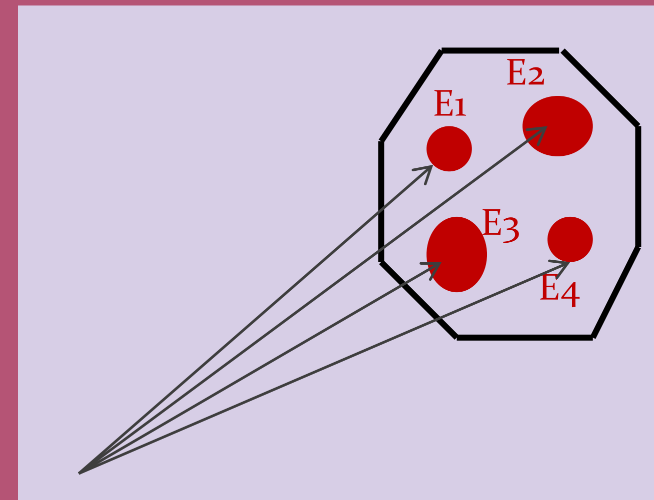
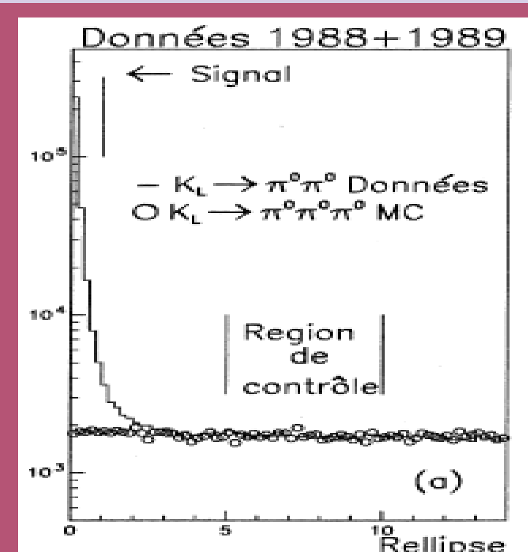
$3\pi^0$ background with fused or lost photons appear at the tail of the Rell distribution





The Energy Scale determination

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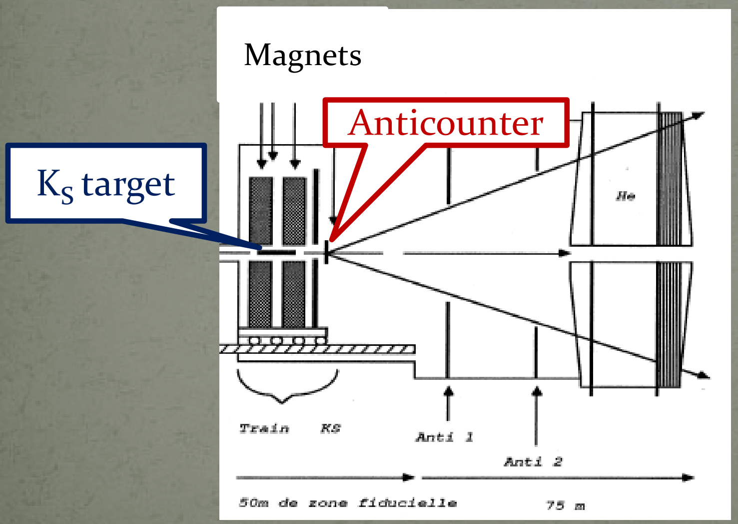

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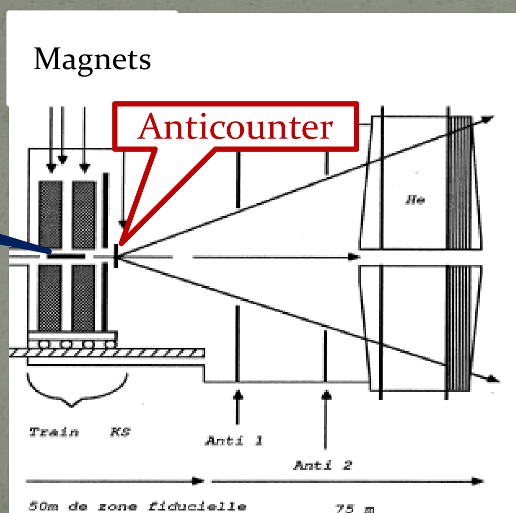
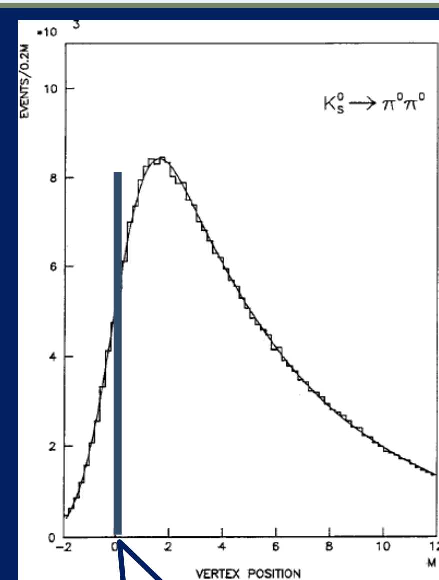
Energy Scale = Distance Scale

Anticounter's main goal:
Veto early K_S decays
Used also as a distance scale



K_S target



Scale known to <0.05%

Accidental activity

Particles accompanying the beam, recorded during an event acquisition.

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Can cause gain or loss of a good event

Different in K_S and K_L

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Build the overlay method

1) Record random triggers
2) Overlay them to the data
3) Each event on tape as : original, random, overlayed.

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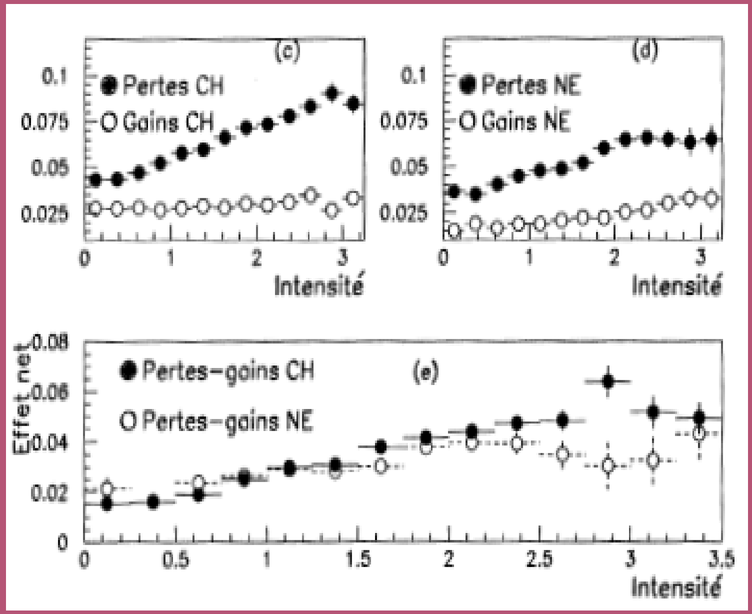
Effect on K_L events



Working in NA31 in the 80's-90's

No laptops! Connection to the computers via Modem

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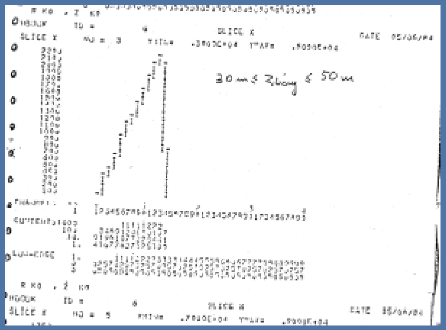

« Plot » shown in a meeting

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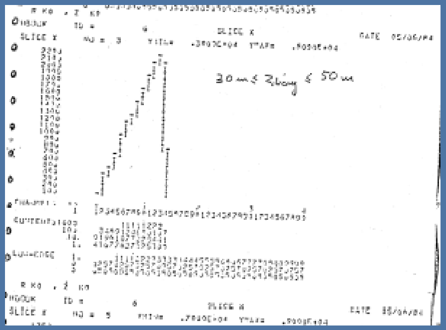

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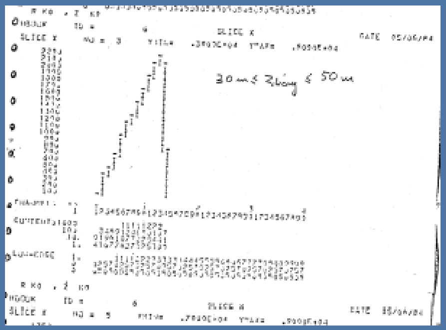
Weekly and collaboration meetings



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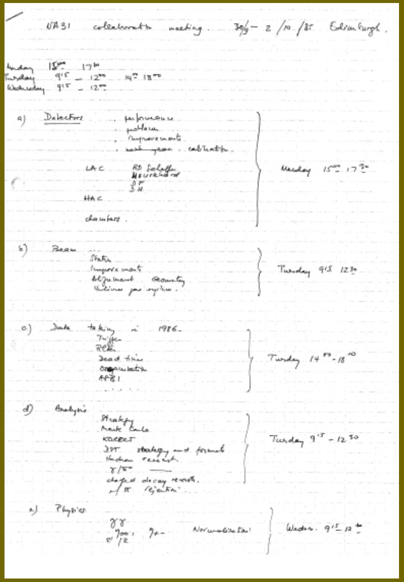
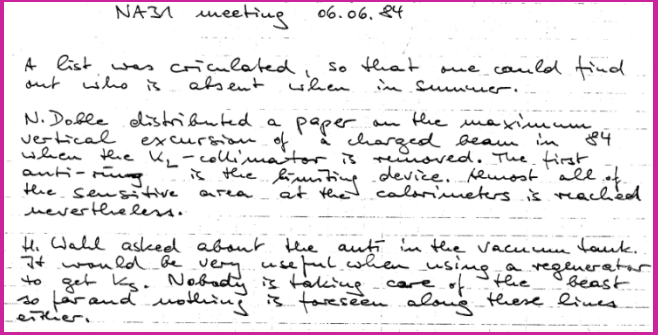
A.M. Lutz



H.Taureg



NA31 meeting 06.06.84

A list was circulated, so that one could find out who is absent when in summer.

N. Doble distributed a paper on the maximum vertical excursion of a charged beam in 84 when the K_L-collimator is removed. The first anti-ring is the limiting device. Almost all of the sensitive area at the calorimeters is reached nevertheless.

H. Wahl asked about the anti in the vacuum tank. It would be very useful when using a regenerator to get K_S. Nobody is taking care of the beast so far and nothing is foreseen along these lines either.

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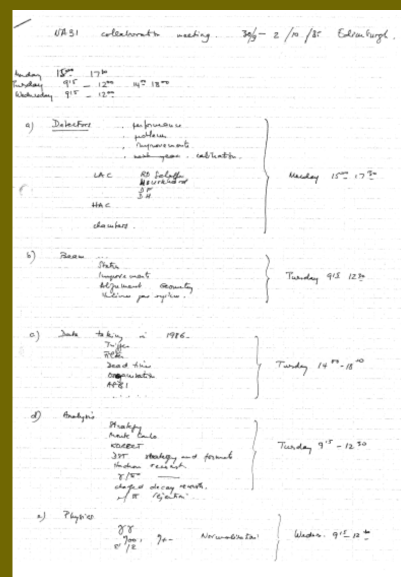
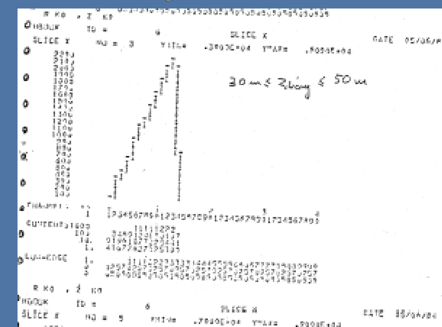
Simple hierarchy: A single spokeperson Heiner Wahl

« Relaxed » organisation

A.M. Lutz





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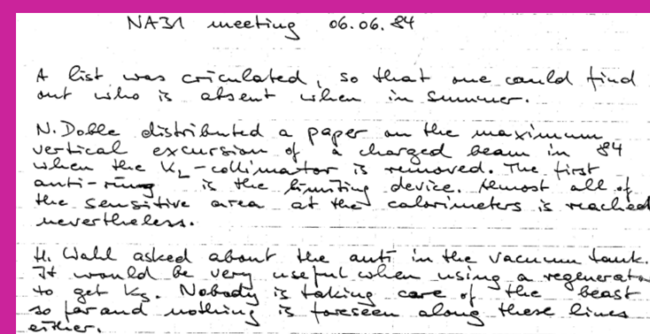

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NA31 Direct CPV results

55 authors, 7 labs

FIRST EVIDENCE FOR DIRECT *CP* VIOLATION

CERN–Dortmund–Edinburgh–Mainz–Orsay–Pisa–Siegen Collaboration

H. BURKHARDT [1], P. CLARKE, D. COWARD [2,3], D. CUNDY, N. DOBLE, L. GATIGNON, V. GIBSON, R. HAGELBERG, G. KESSELER, J. VAN DER LANS, I. MANNELLI [4], T. MICZAIKA [5], A.C. SCHAFFER [6], J. STEINBERGER, H. TAUREG, H. WAHL, C. YOUNGMAN [7]
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Laboratoire de l'Accélérateur Linéaire, Université de Paris-Sud, F-91405 Orsay, France [12]

A. BIGI, M. CALVETTI [13], R. CAROSI, R. CASALI, C. CERRI, G. GARGANI, E. MASSA, A. NAPPI, G.M. PIERAZZINI
Dipartimento di Fisica e Sezione INFN, I-56100 Pisa, Italy

C. BECKER [5], D. HEYLAND [5], M. HOLDER, G. QUAST, M. ROST, W. WEIHS and G. ZECH
Fachbereich Physik, Universität Siegen, D-5900 Siegen 21, Fed. Rep. Germany [14]

1988

Received 31 March 1988

$Re(\varepsilon'/\varepsilon)=(3.30+-1.09)10^{-3}$

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FIRST EVIDENCE FOR DIRECT *CP* VIOLATION

CERN–Dortmund–Edinburgh–Mainz–Orsay–Pisa–Siegen Collaboration

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1988

Received 31 March 1988

$Re(\varepsilon'/\varepsilon)=(3.30+-1.09)10^{-3}$

49 authors, 6 labs

A new measurement of direct *CP* violation in the neutral kaon system

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NA31 Direct CPV results

55 authors, 7 labs

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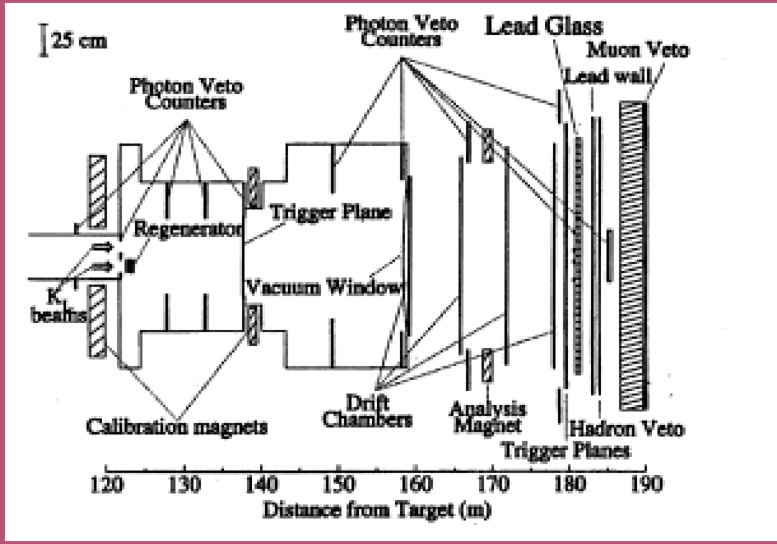
Combined NA31 : (23.0+6.5) 10^{-4} 3.5σ

NA31-E731 and next

E731 Collaboration - FermiLab
L.K.Gibbons et al., Phys.Rev.Lett. 70 (1993) 1203.



Concurrent $K_L - K_S$
Alternate $\pi^+\pi^-$ and $\pi^0\pi^0$

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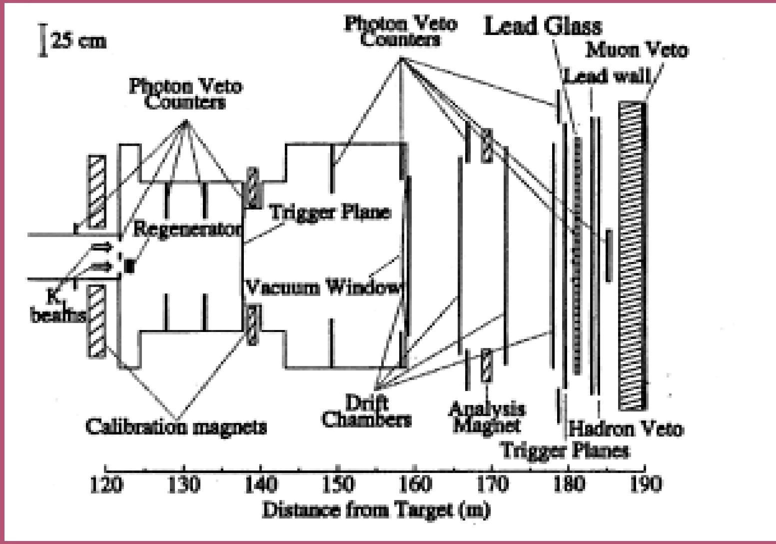

Concurrent $K_L - K_S$
Alternate $\pi^+\pi^-$ and $\pi^0\pi^0$

Our final result is

$$\mathrm{Re}(\varepsilon'/\varepsilon) = [7.4 \pm 5.2(\mathrm{stat}) \pm 2.9(\mathrm{syst})] \times 10^{-4}.$$

The combined uncertainty is 5.9×10^{-4}. Compared to our previous publication [5], the statistical (systematic) error is a factor of 2.7 (2.1) smaller. Our value is not significantly different from zero. It implies $\mathrm{Re}(\varepsilon'/\varepsilon) < 17 \times 10^{-4}$ (95% confidence), which does not support earlier evidence [4] for a large $\mathrm{Re}(\varepsilon'/\varepsilon)$.

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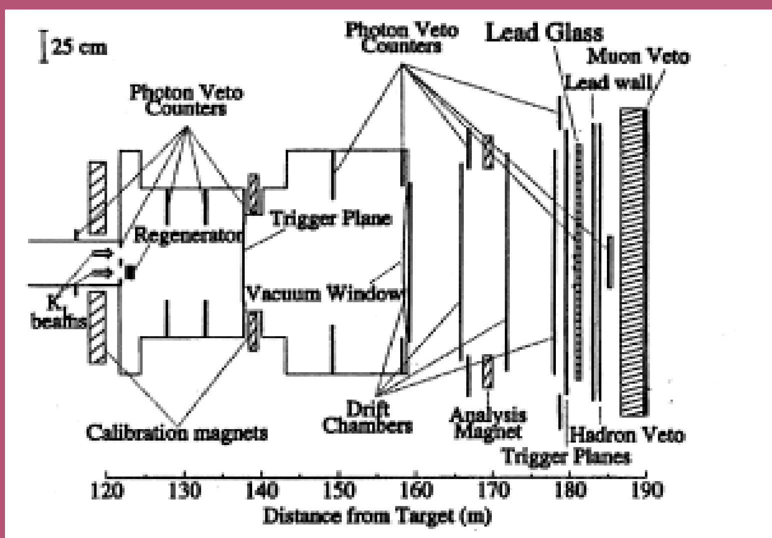

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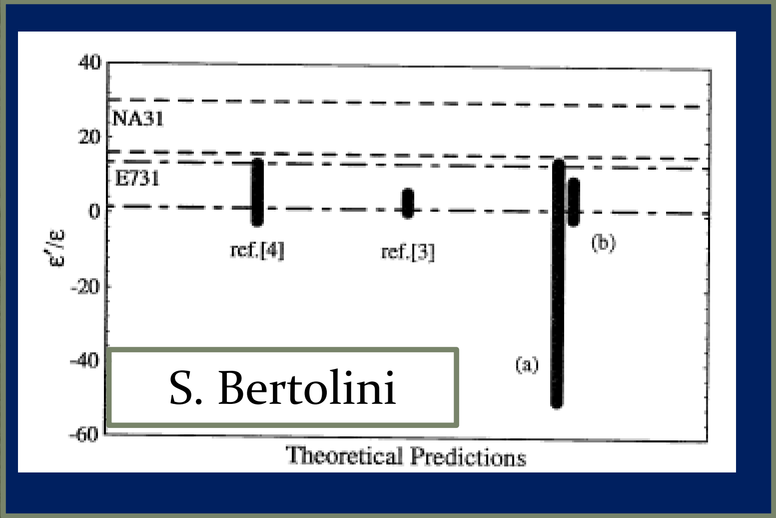
Tension

Most theory schools favoured
➔The « very small ε'/ε» region

PROCEEDINGS OF THE WORKSHOP ON K PHYSICS

ORSAY, France,
30 mai - 4 juin 1996



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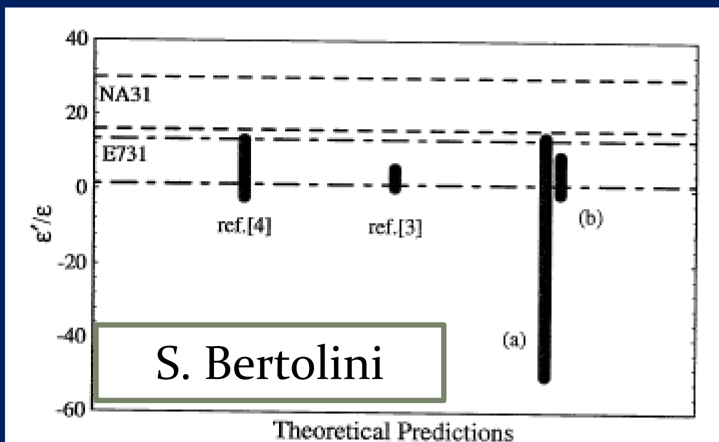

S. Bertolini

Bruce Winstein
Exper. Summary

- If Re(ε'/ε) is indeed of order 0.002, then we could already have a signal of physics beyond the Standard Model.

PROCEEDINGS OF THE WORKSHOP ON K PHYSICS

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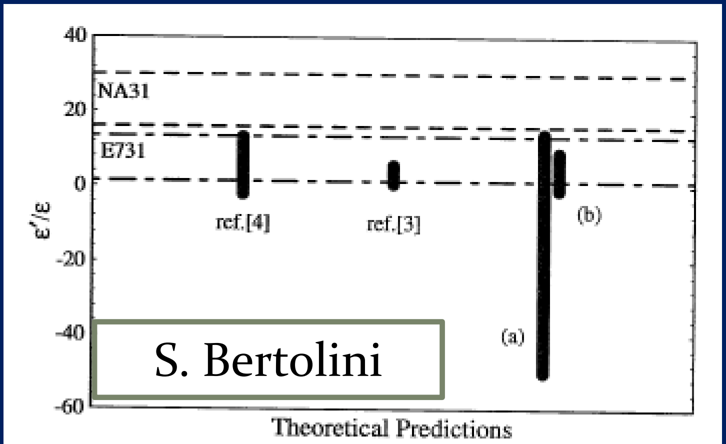

S. Bertolini

Andrzej Buras
Theory Summary

$$0 \leq \varepsilon'/\varepsilon \leq 43.0 \cdot 10^{-4} \quad (31)$$

and

$$\varepsilon'/\varepsilon = (10.4 \pm 8.3) \cdot 10^{-4} \quad (32)$$

for the "scanning" method and the "gaussian" method respectively. We observe that the "gaussian" result agrees well with the E731 value and as stressed in [55] the decrease of m_s with $m_s(2\,\mathrm{GeV}) \geq 85\ MeV$ alone is insufficient to bring the standard model to agree with the NA31 result. However for $B_6 > B_8$, sufficiently large values of $|V_{ub}/V_{cb}|$ and $\Lambda_{\overline{MS}}$ and small values of m_s, the values of ε'/ε in the standard model can be as large as $(2-4)\cdot 10^{-3}$ and consistent with the NA31 result.

Let us hope that the future experimental and theoretical results will be sufficiently accurate to be able to see whether $\varepsilon'/\varepsilon \neq 0$ and whether the standard model agrees with the data. In any case the coming years should be very exciting.

Bruce Winstein
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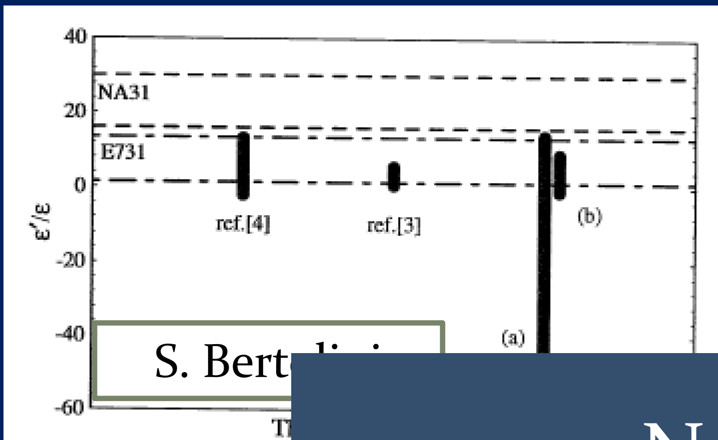

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...ecrease of m_s
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New experiments: NA48 (CERN) and KTeV (FNAL)

Bruce Winstein
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The NA48 experiment at CERN

10-4

NA48 Experiment:

A precision measurement of ε'/ε in CP violating $K^0 \rightarrow 2\pi$ decays

Cagliari-Cambridge-CERN-Dubna-Edinburgh-Ferrara-Florence-Mainz-Orsay-Perugia-Pisa-Saclay-Siegen-Torino-Warsaw-Vienna Collaboration

Proposal 22 July 1990

Approved 28 Nov 1991

Heinrich Wahl HEP2005

3 ε'/ε Run periods 97, 98-99 and 2001 .

The NA48 experiment: how to do better

1. At least 10× the statistics of present experiments
2. Reduction of systematic uncertainties by a factor 3

Principal elements:

1. Concurrent detection of all 4 decay modes in the same detector
2. Tagging of K_S and K_L : coll. beams
3. Fast LKr calorimeter 2.4 m ϕ for photon detection
4. Magnet spectrometer for $\pi^+\pi^-$ to reduce background to 10^{-3} level
5. New method of analysis to reduce systematic error (K_L : K_S weighting)

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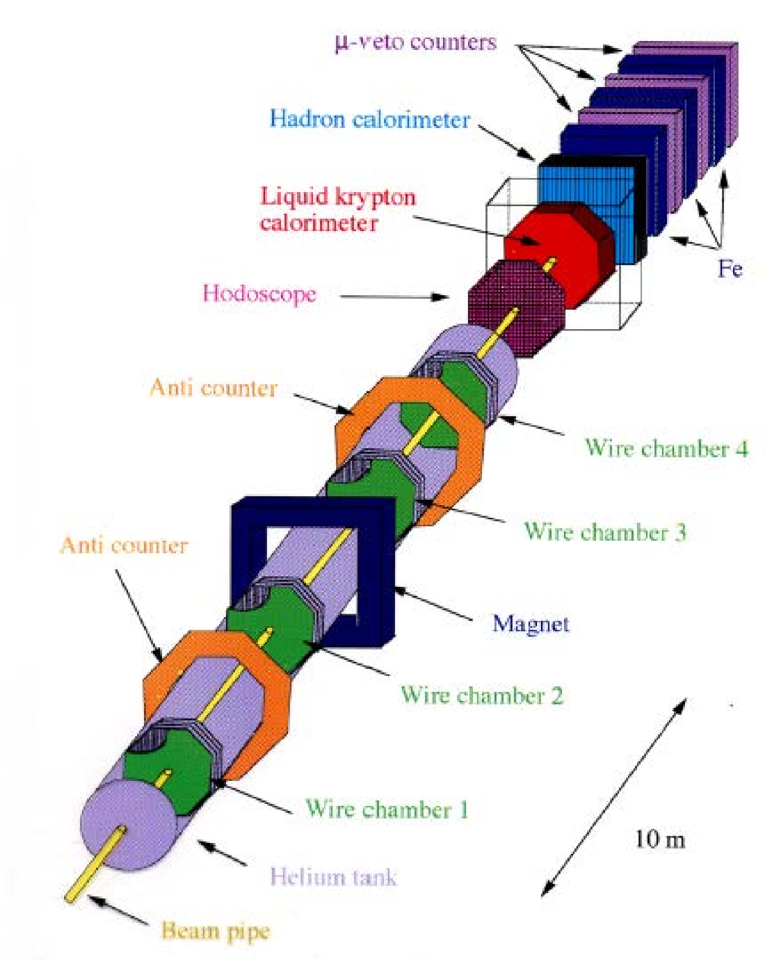
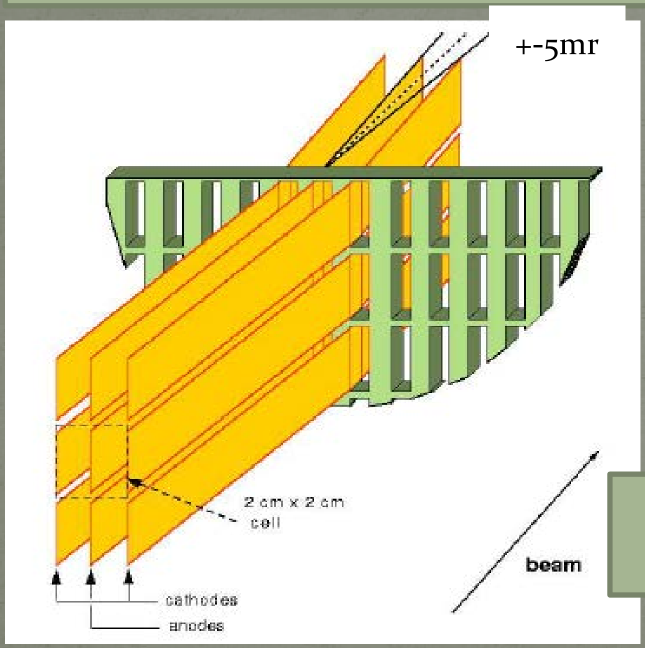


One master piece: The LKr calorimeter

$9m^3$ of liquid krypton at 121K.
A total of $27X^0$
Made of ~13000 identical projective cells converging to 110m in front.



Electrode positionning accuracy +-45µm

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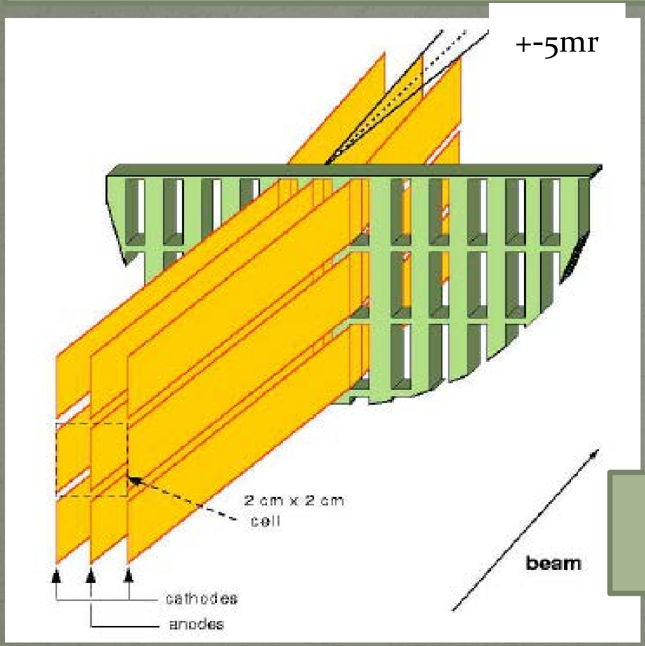

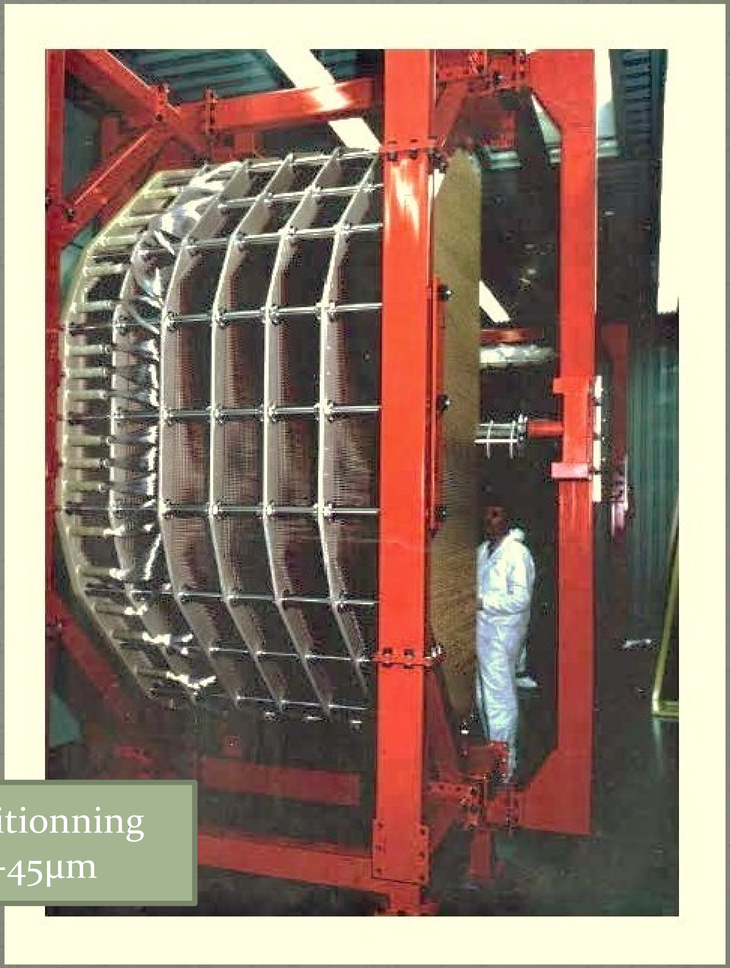

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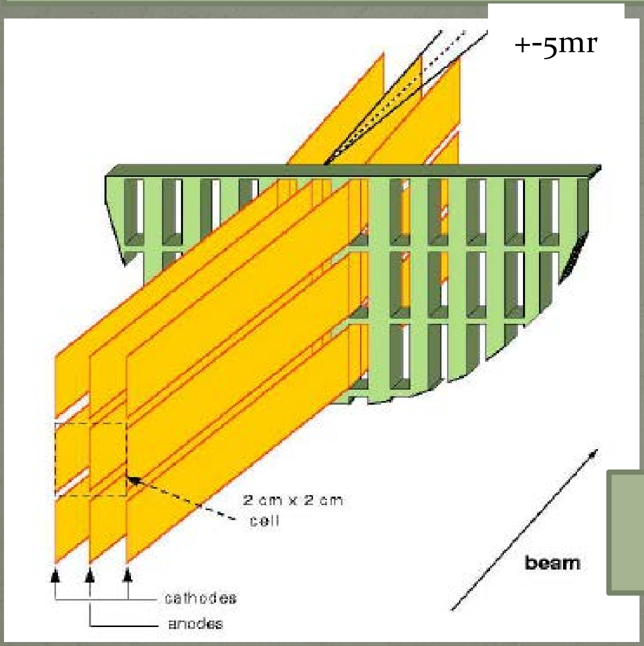

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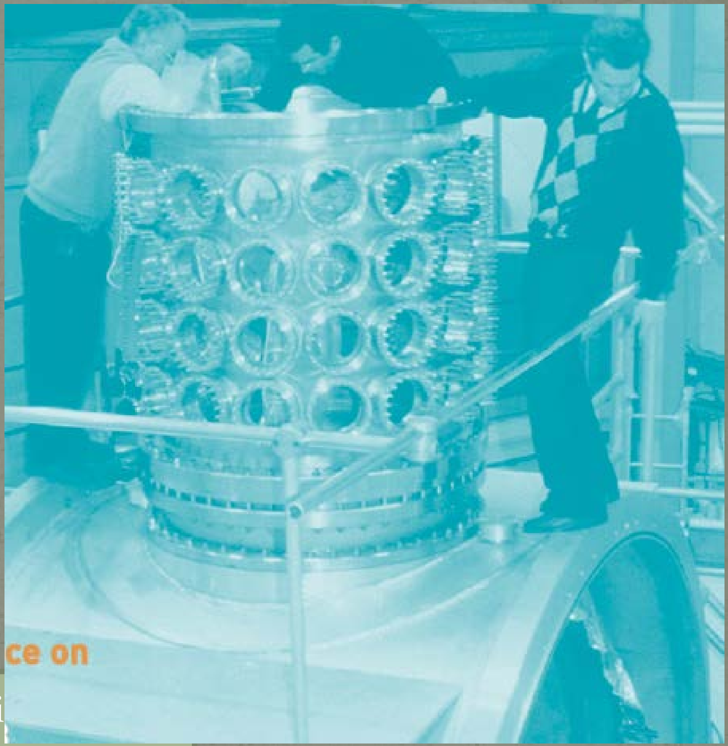
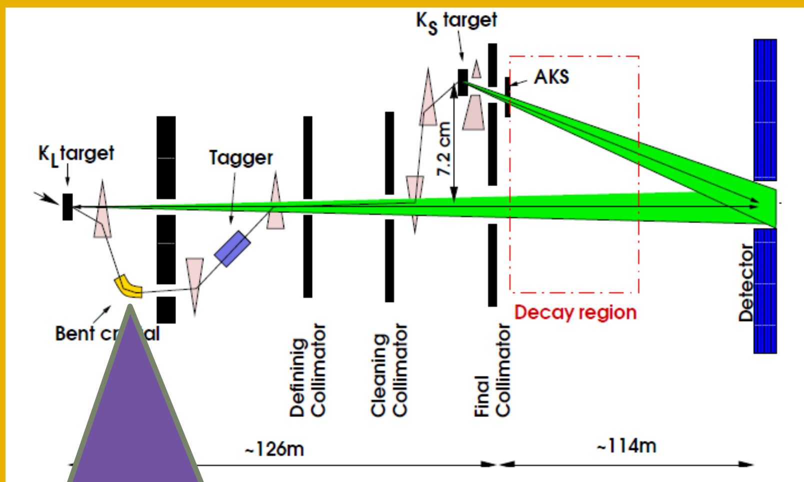
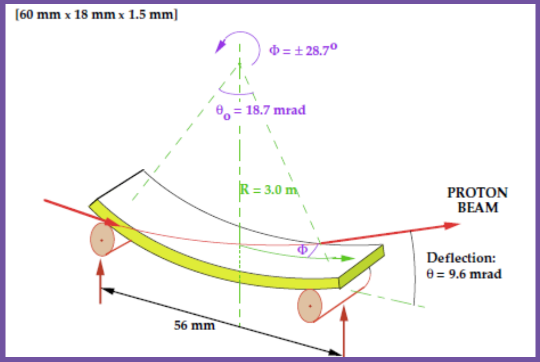


A second master piece : The bending crystal

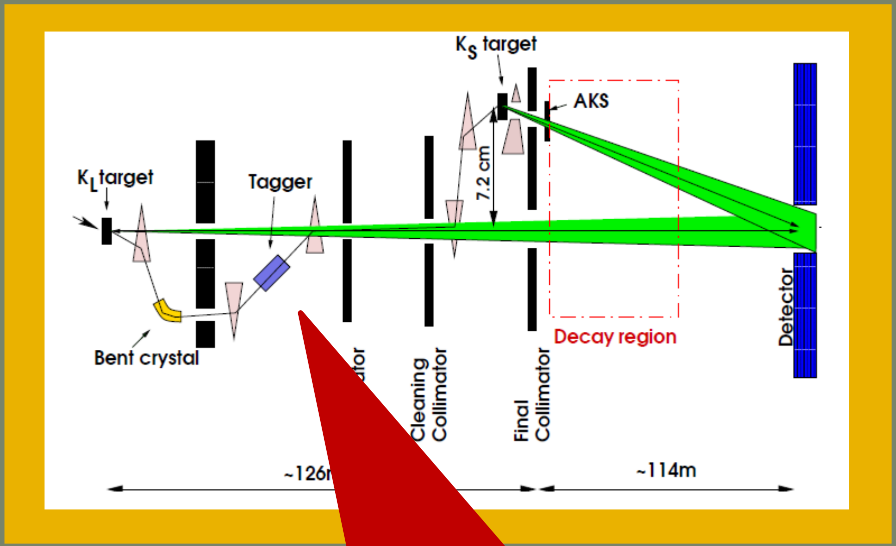


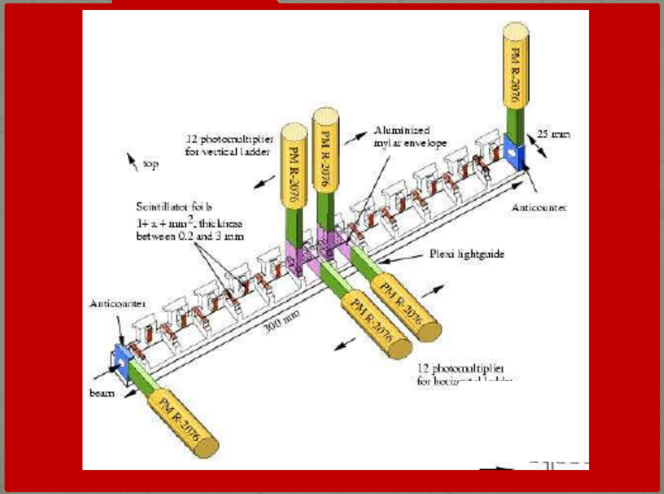


➔Silicon mono-crystal mounted on a motorized goniometer.

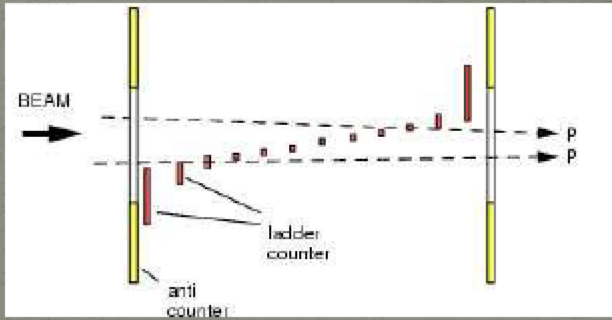
➔Selects 10^{-5} of the incident proton beam and deflects them towards the K_S target

A third master piece : The tagger



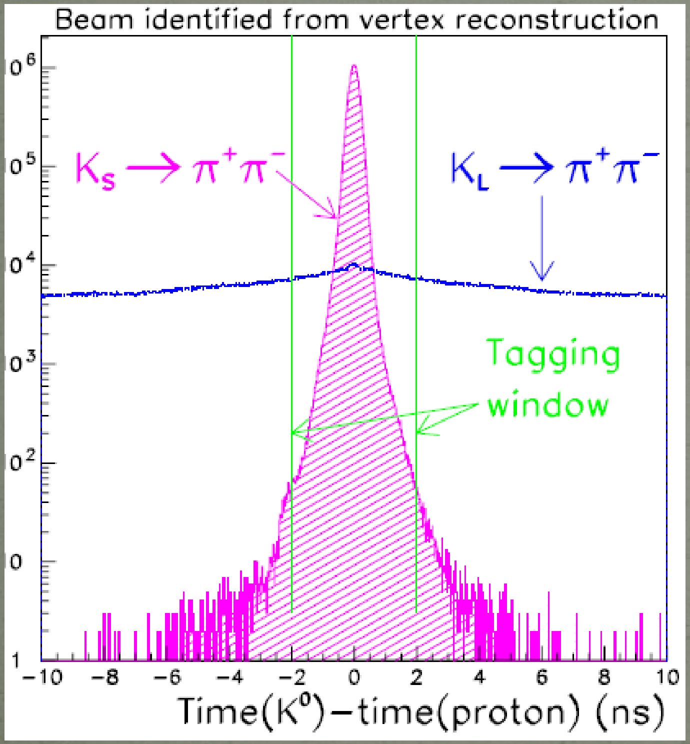


- →12 scintillators with alternating vertical and horizontal orientations
- →Traversed ONLY by K_S protons Readout by a 1Ghz 8-bit FADC
- → Gives the proton time ~180ps



Distinguishing K_S from K_L decays

Looking at time-coincidences:
Charged hodoscope-Tagger ($\pi^+\pi^-$)
LKr - Tagger ($2\pi^0$)



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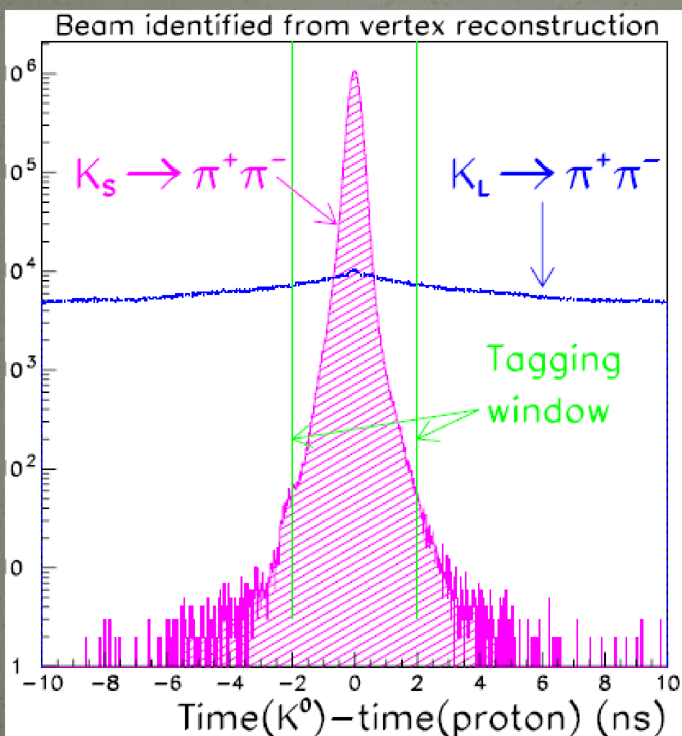


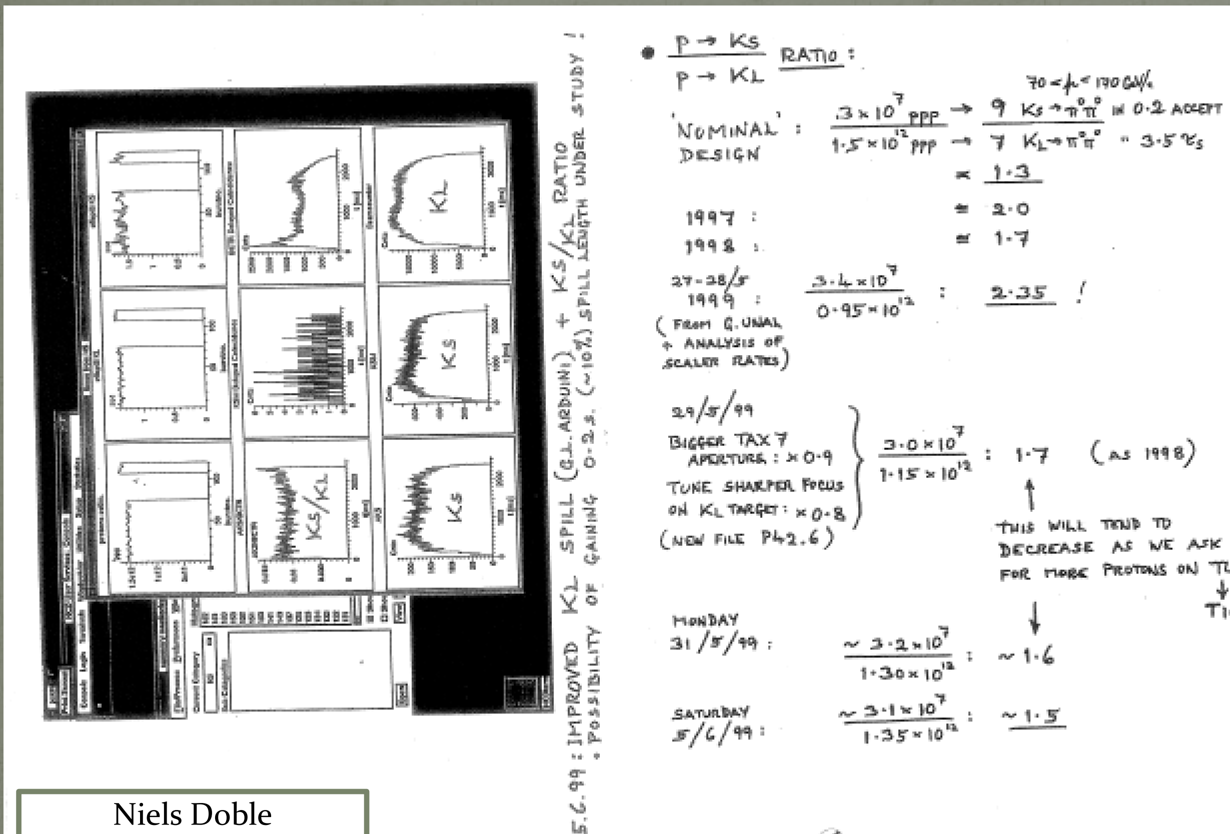
Neads to know :
How many K_S are tagged as K_L
(in both $\pi^+\pi^-$ and $\pi^0\pi^0$)

$$\alpha_{SL}^{+-} = (1.64 \pm 0.03) \times 10^{-4}$$

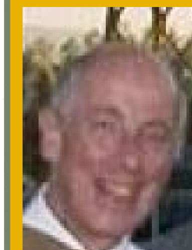
Nead to know:
How many K_L are tagged as K_S
(in both $\pi^+\pi^-$ and $\pi^0\pi^0$)

$$\alpha_{LS}^{+-} = (10.649 \pm 0.008)\%$$

On beams ….



Niels Doble



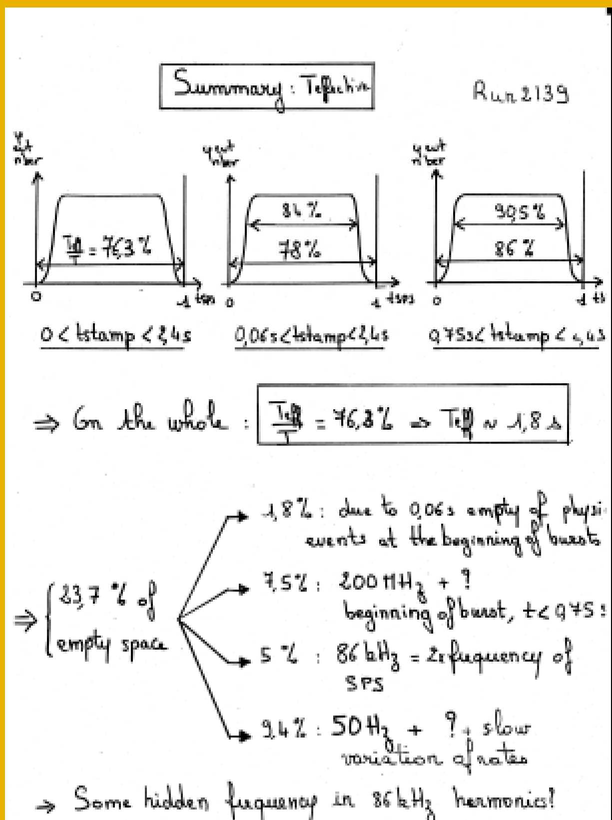
Niels Doble

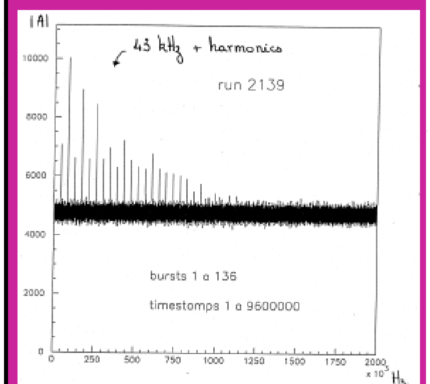
Per Grafstrom

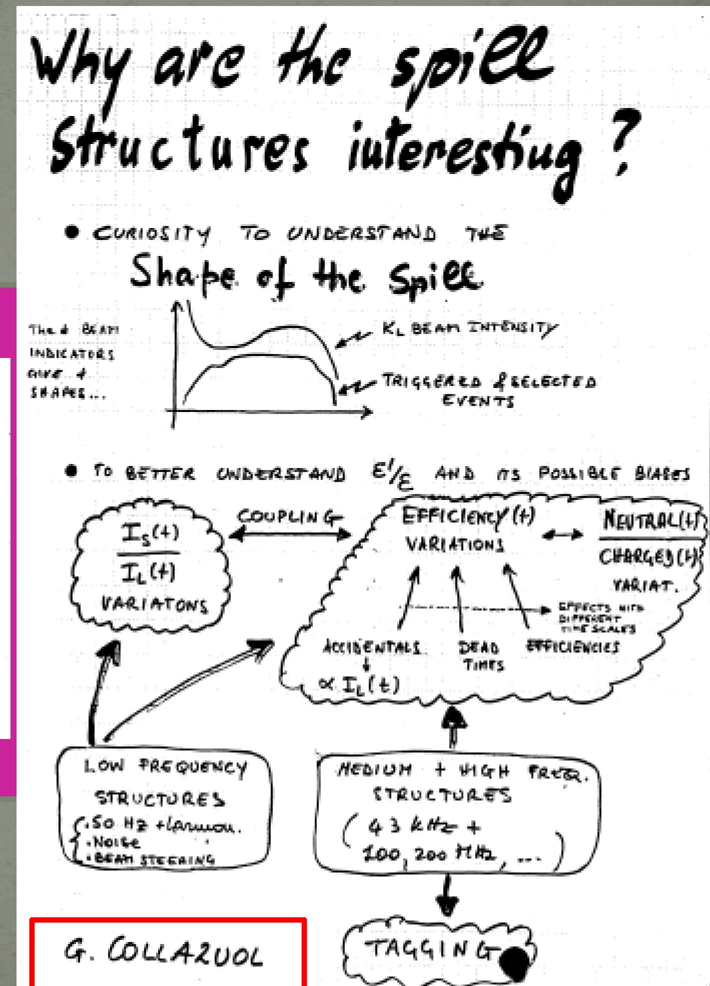
Lau Gatignon

As usually: the miracles of the beam masters

…and their structures



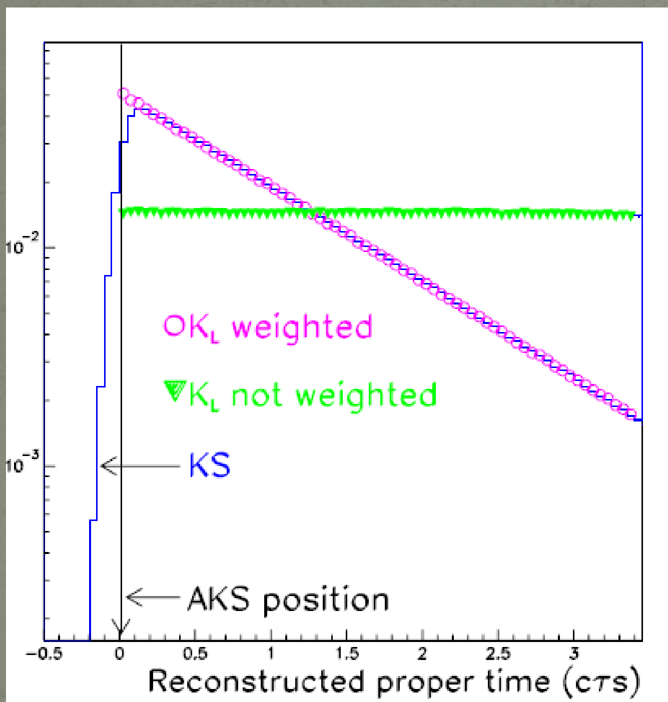




S. Crépé-Renaudin

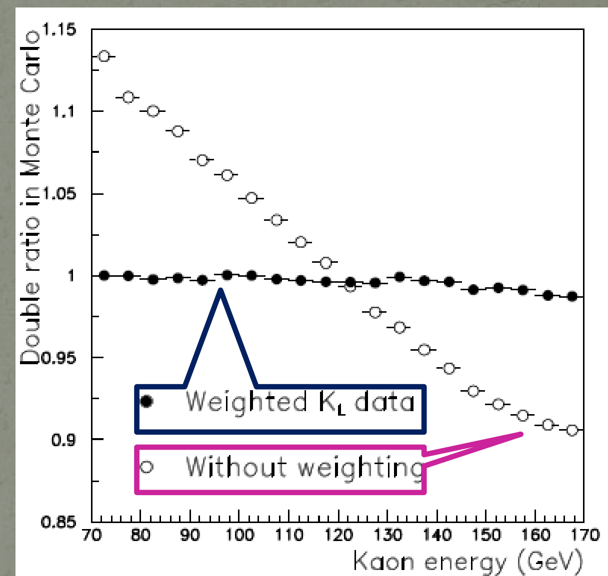
Minimize acceptance correction

Blue : K_S Green : K_L



Weight K_L spectra to K_S one

MC acceptance correction

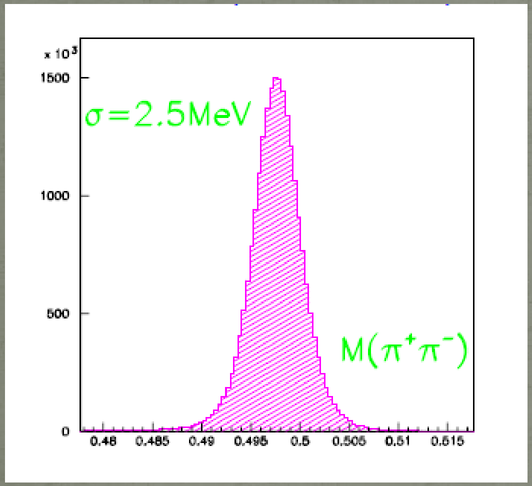


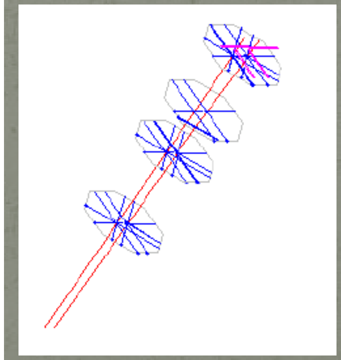
After weighting: remaining correction for small residual differences.

Typical plots

Kaon mass in π+π-

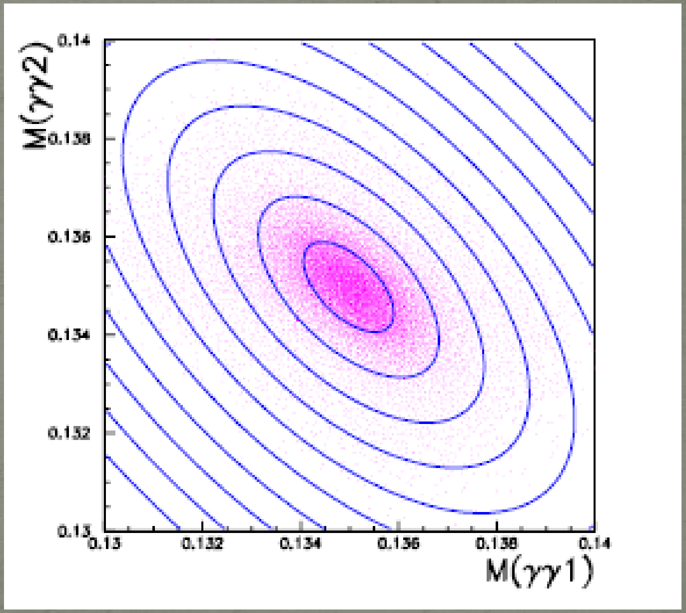
Field integral ->P_T kick=275 MeV/c
σ(p) = 1% for 100GeV pion





Neutral mode

σ(E) ~1% for photons>25GeV



On the NA48 atmosphere

« Large » collaboration (~160 authors)!

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Structured in groups with conveners!

Per detector → Charged reconstruction / Neutral reconstruction → ε'/ε analysis

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Per detector → Charged reconstruction / Neutral reconstruction → ε'/ε analysis

Rare Decays

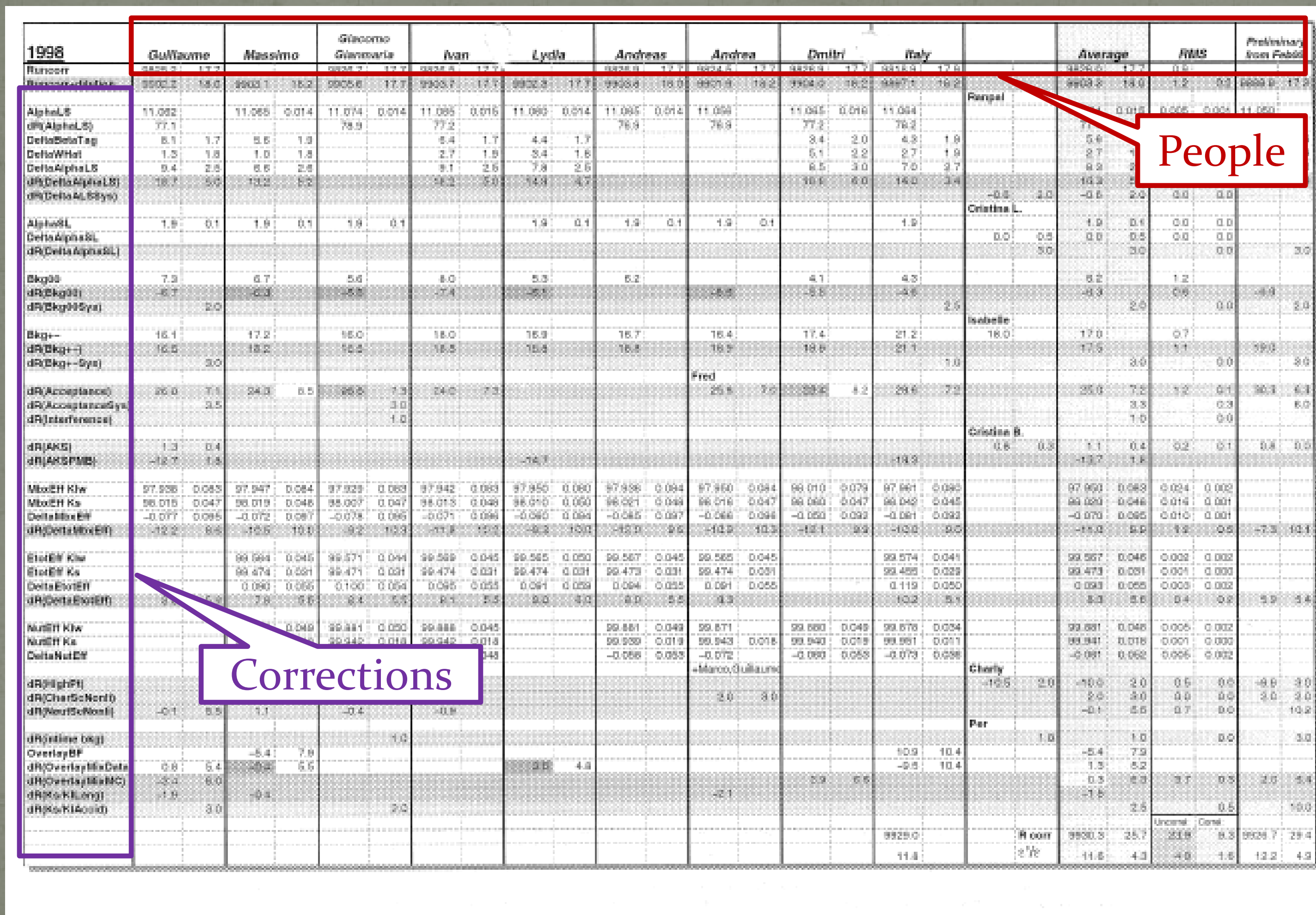
Regular rotation of spoke-persons: Peyaud, Calvetti, Bluemer, Debu,Wahl

Still possible to master the code and the methods in few months

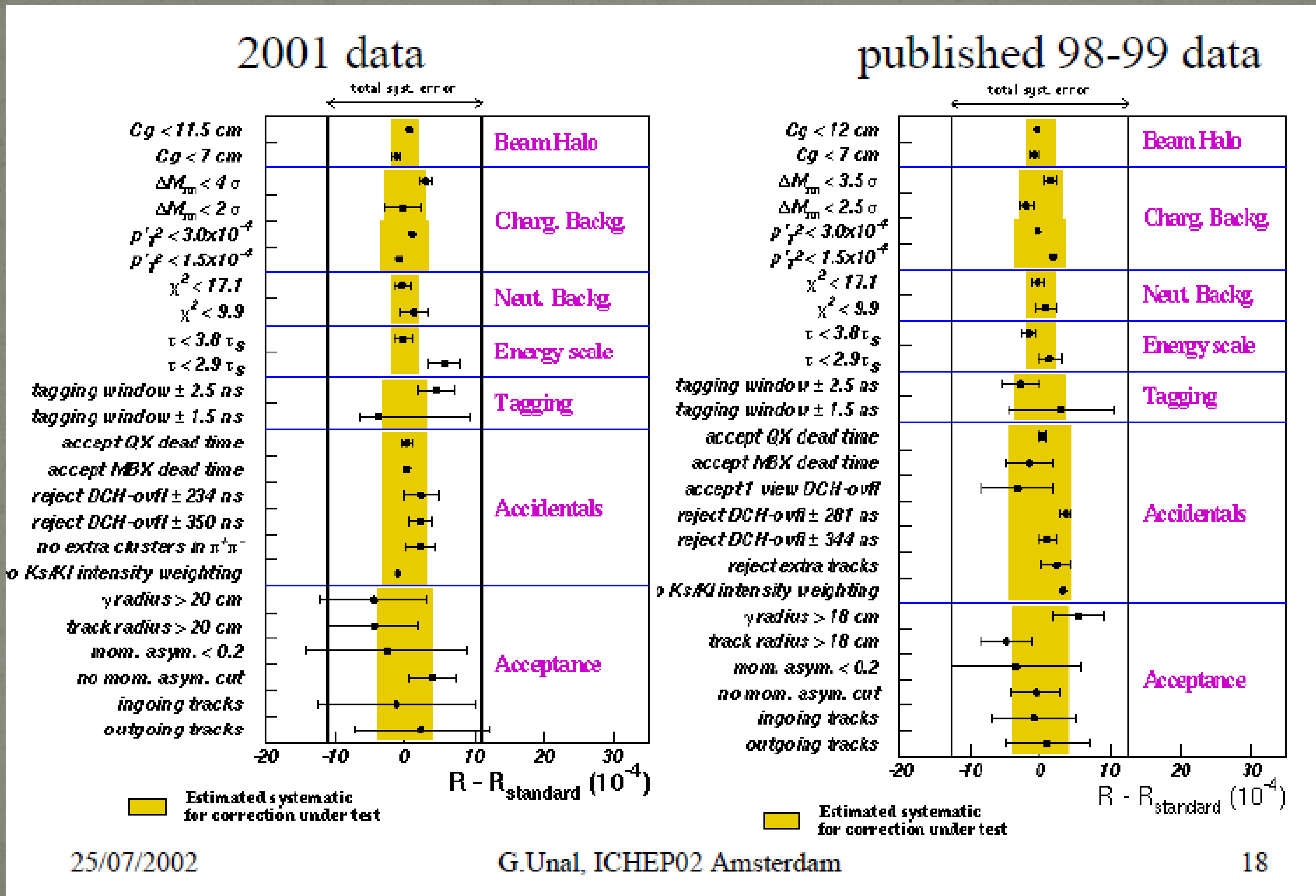
Friendly athmosphere, lively , motivating and inspiring discussions

Several groups of analysis running in parallel
Data not realy blinded, concentrate on checks

Exemple of check list in 98 analysis



Numerous checks



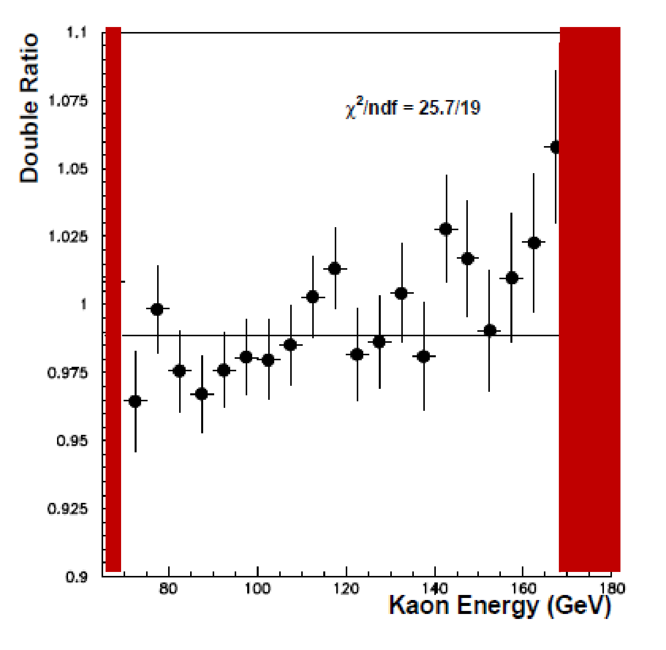
The obsession of checks

The 1997 statistics

Table 1: Statistical samples (in thousands of events).

$K_L \to \pi^0\pi^0$	$K_S \to \pi^0\pi^0$	$K_L \to \pi^+\pi^-$	$K_S \to \pi^+\pi^-$
489	975	1,071	2,087

Is there any slope?



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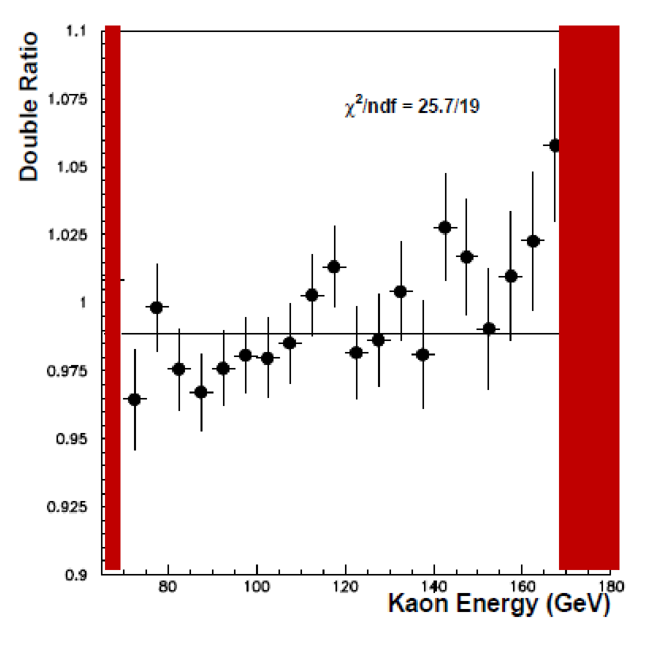

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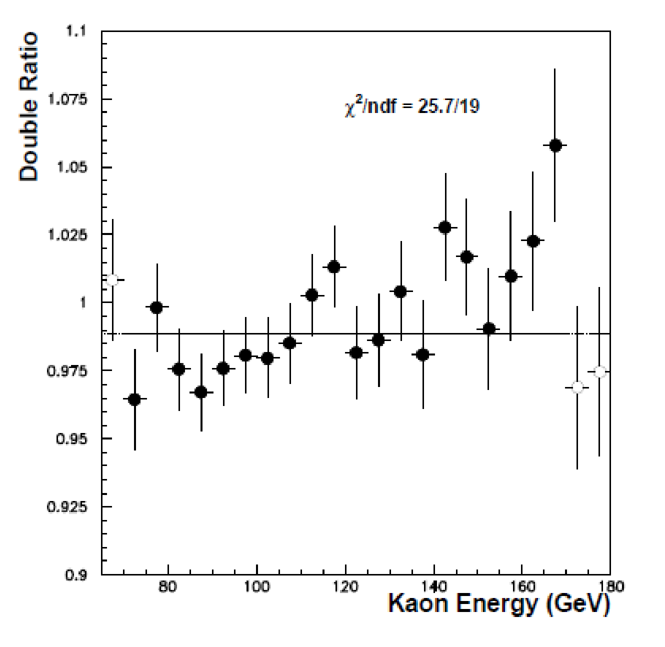
Result released in June 1999

The NA48 experiment at CERN has performed a new measurement of direct CP violation, based on data taken in 1997 by simultaneously collecting K_L and K_S decays into $\pi^0\pi^0$ and $\pi^+\pi^-$. The result for the CP violating parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ is $(18.5 \pm 4.5(\mathrm{stat}) \pm 5.8(\mathrm{syst})) \times 10^{-4}$.

Is there any slope?



The NA48 family

Regular meetings with draft agenda !

DRAFT AGENDA FOR THE LKr ANALYSIS MEETING

on Thursday 10 october 1996 at 9 o'clock

in the conference room 530-R-030

M. MARTINI :	Calibration of sums
V. MARZULLI :	Propagation delays (calibration)
A. FORMICA :	Propagation delays (single cell data)
S. CRÉPÉ :	Timing single cells
L. FAYARD :	Time resolution of the sums
J. OCARIZ :	Switching problems
G. UNAL :	Cure of switching problems, measurements on Trx outputs
H. WAHL :	Studies of hardware problems (calibration, switching)
S. GIUDICI :	Drift time measurements, calibration problems with sums
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W. FUNK :	Neutral reconstruction of sum read-out

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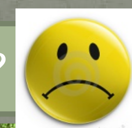
How many trees?

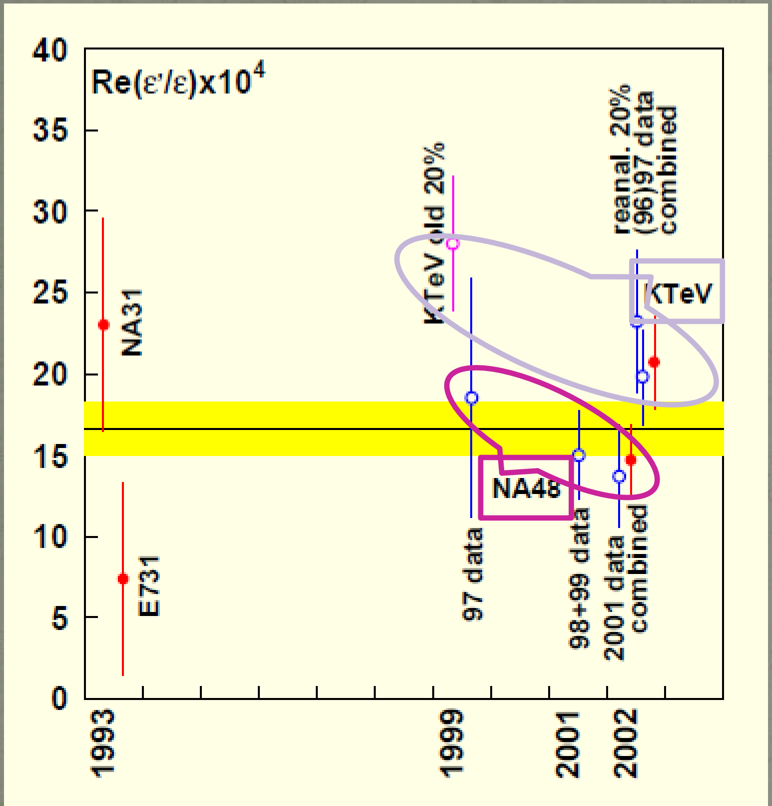


3 times more!

NA48 Collaboration meeting in Paris

Collège de France 1996

2003 : The overall picture



Plot from I.Mikulec 2003

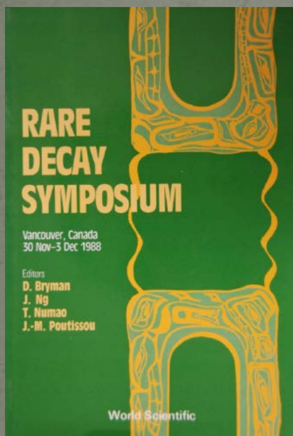
World average

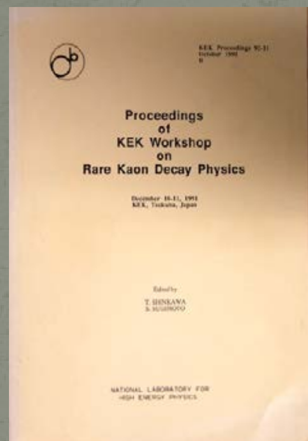
$Re(\varepsilon'/\varepsilon) = (16.4 \pm 1.9)\ 10^{-4}$

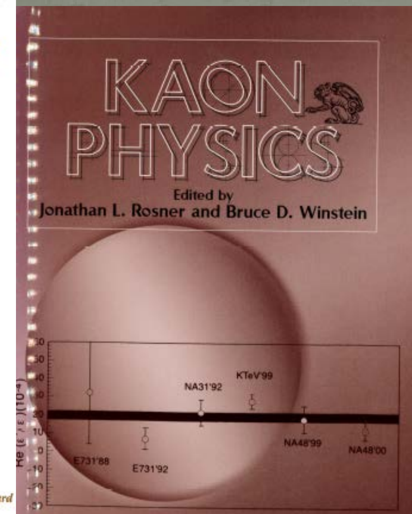
Confirmation of a « large » Direct CPV component

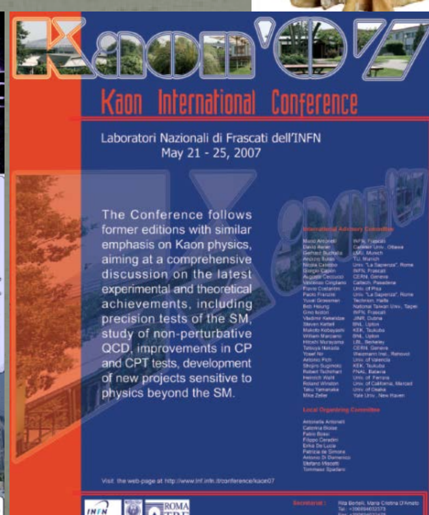
In next years, computations on lattice might improve the theoretical expectation.

Kaon conferences: a place to meet

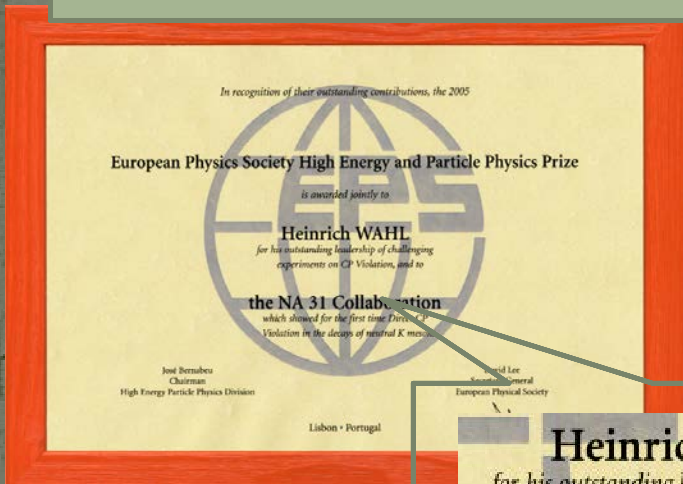


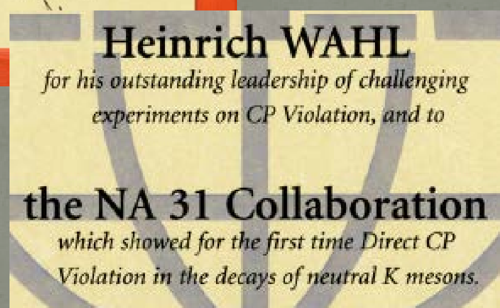






2005 : the EPS prize





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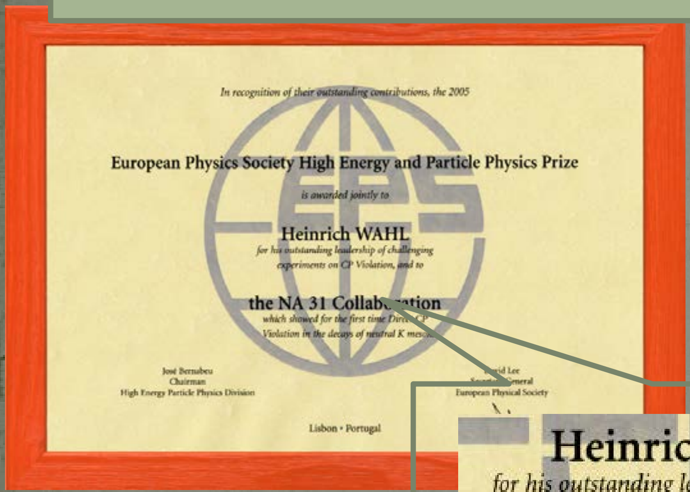

In recognition of their outstanding contributions, the 2005

European Physics Society High Energy and Particle Physics Prize

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for his outstanding leadership of challenging experiments on CP Violation, and to

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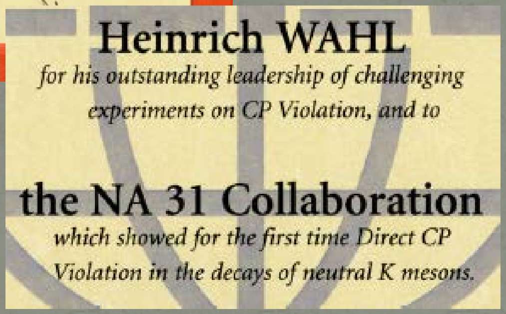
José Bernabeu
Chairman
High Energy Particle Physics Division

European Physical Society

Lisbon • Portugal



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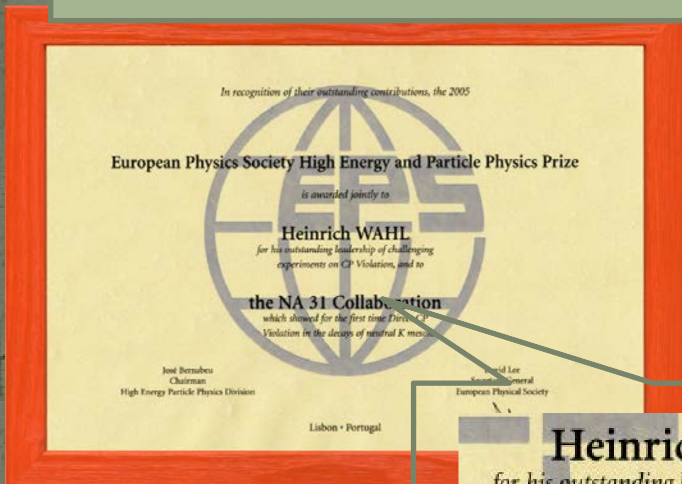
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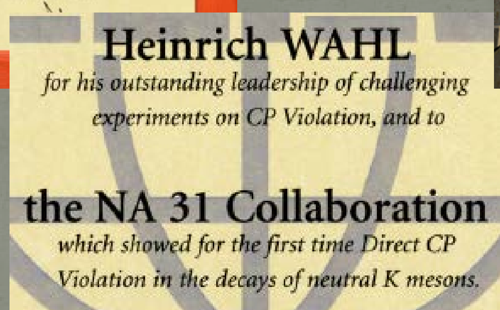
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2007 : the Panofsky prize

APS physics

Italo Mannelli, Univ.of Pisa/INFN
Heinrich Wahl, CERN
Bruce Winstein, Univ. of Chicago

"For leadership in the series of experiments that resulted in a multitude of precision measurements of properties of neutral K mesons, most notably the discovery of direct CP violation."

Conclusions (1)

CP Violation is one among the very few poping-up, non-predicted discoveries

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Several of the employed methods and analyses were pioneering and paved the way for the LHC experiments

40MHz trigger

Handle 100Tb/year of data

First pc farms
Remote data recording

Optimal filter for sampled calo signal reconstruction

Beam channeling

Accidental studies through overlay

Conclusions(2)

Small experiments-> flexibility

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NA31

Construct and install TRD in 1988, to Xcheck the K->πeν background

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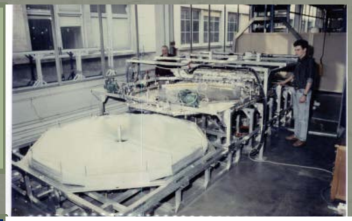
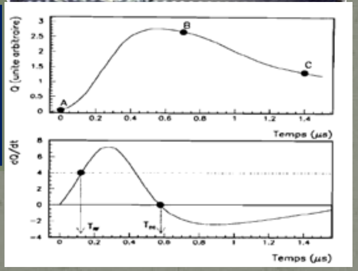


Construct and ZTDC in 1989 to Xcheck the accidentals in LAr



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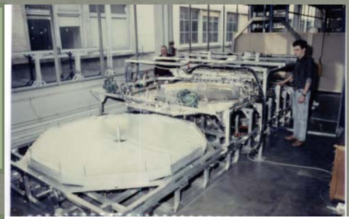

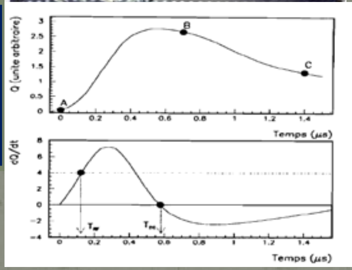

NA48

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Take K_L beam to Xcheck accidental tagging studies

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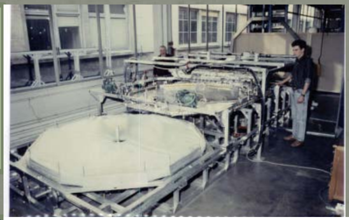

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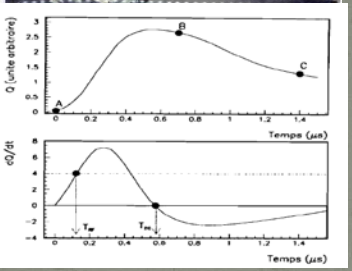

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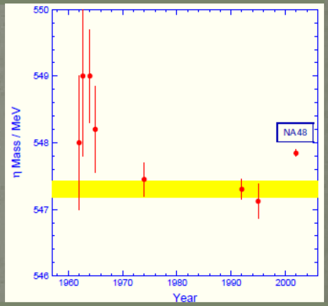
Also registered η decays for Xchecks on energy scale

New PDG M(η) value!!!



Plot from I.Mikulec 2002

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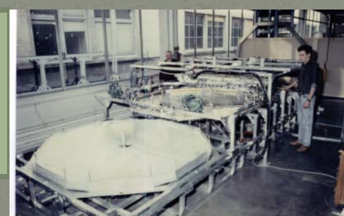

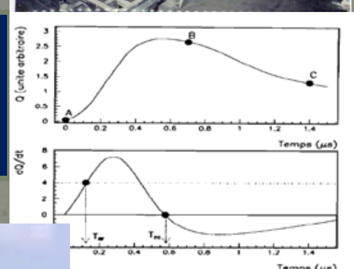

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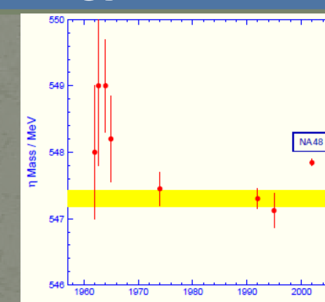

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Plot from I.Mikulec 2002

Reconstructed WC in 18 months!

Conclusions(2)

Small experiments-> flexibility

NA

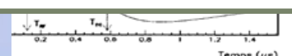
Construct
TRD in 198
the K->πe

Construct a
1989 to X
accident

Moreover : Both NA31 and NA48 experiments pursued in parallel a rich and diversified program on rare kaon decays.
NA48-> NA48/1, NA48/2

er in repair
Xcheck
g studies

decays for
rgy scale



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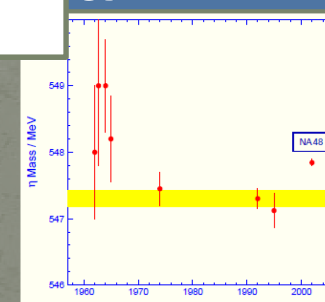

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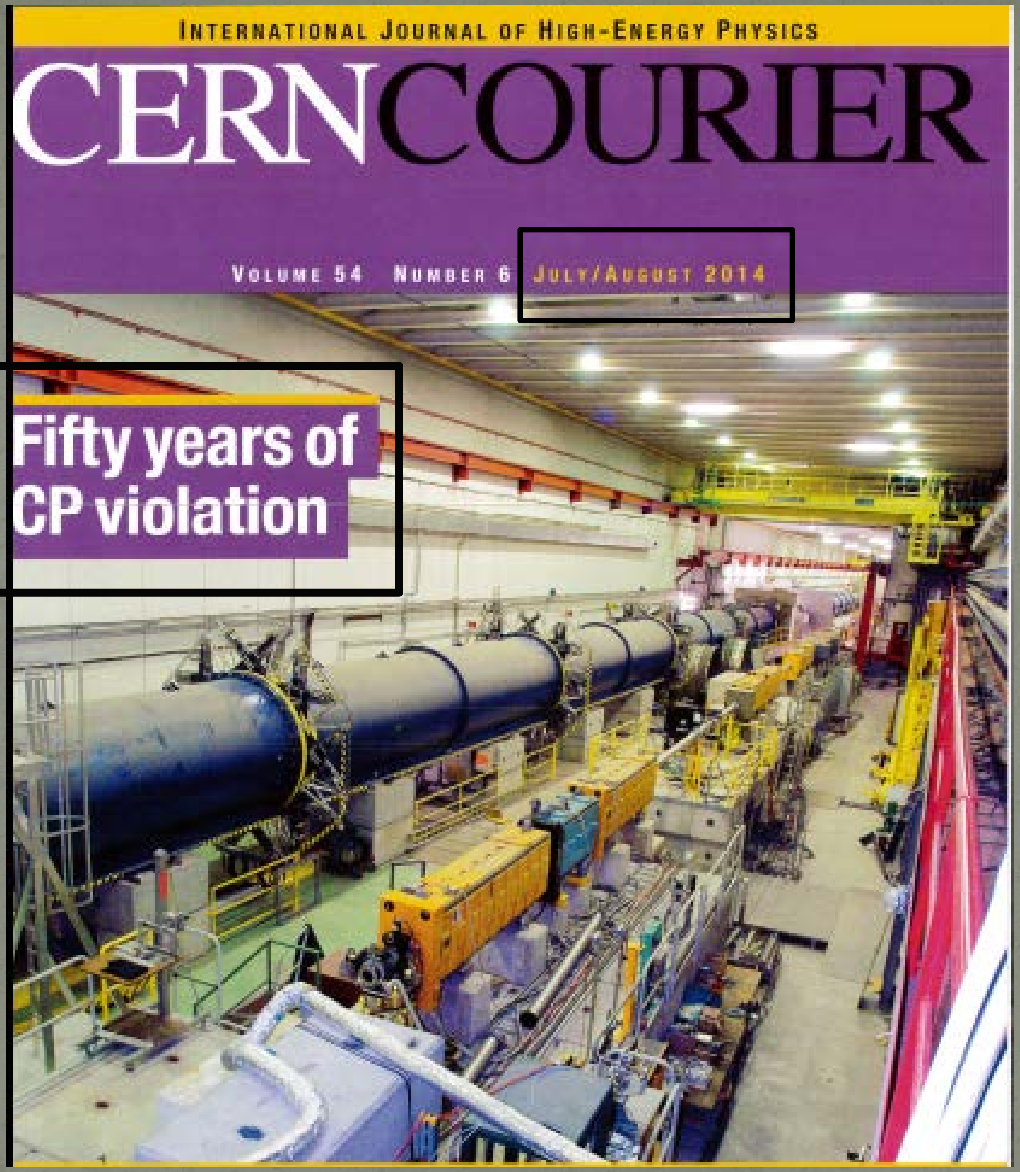
A lot of questions remain on CPV. Answers expected from NA62 (starting in 2014!) , LHCb, neutrinos, SuperKEK, ...

Expect more answers for the 70th anniversary of CERN?


INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS
CERNCOURIER
VOLUME 54 NUMBER 6 JULY/AUGUST 2014
Fifty years of CP violation

60 years of CERN -50 years of CPViolation

生日快樂

La mulţi ani

Честит рожден ден

¡feliz cumpleaños!

お誕生日おめでとうございます

Alles Gute zum Geburtstag

Všetko najlepšie k narodeninám

Boldog születésnapot

С днём рождения!

Buon compleanno

Joyeux anniversaire

Χρόνια Πολλά!

Grattis på födelsedagen

Feliz aniversário!

יום הולדת שמח

كل عام و أنت بخير

생일 축하합니다

Срећан рођендан

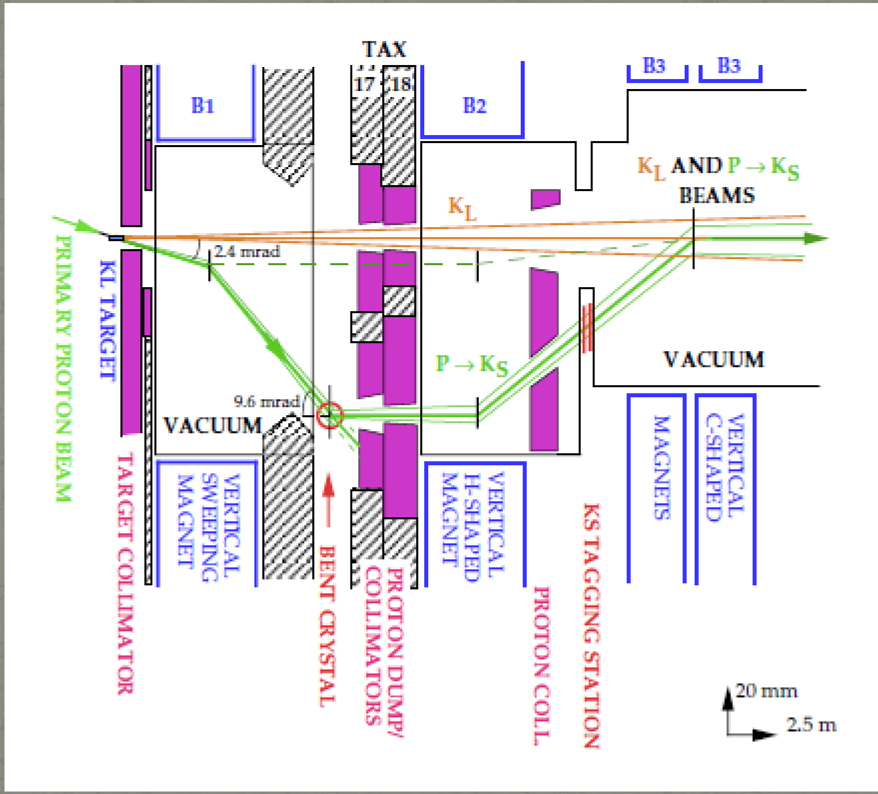
Vse najboljše

Wszystkiego najlepszego z okazji urodzin

Všechno nejlepší k narozeninám!

Gratulerer med dagen

BACKUP


TAX
17
18
B1
B2
B3
B3
K_L AND $P \to K_S$
BEAMS
K_L
2.4 mrad
9.6 mrad
VACUUM
VACUUM
$P \to K_S$
PRIMARY PROTON BEAM
KL TARGET
TARGET COLLIMATOR
VERTICAL
SWEEPING
MAGNET
BENT CRYSTAL
PROTON DUMP/
COLLIMATORS
VERTICAL
H-SHAPED
MAGNET
PROTON COLL.
KS TAGGING STATION
MAGNETS
VERTICAL
C-SHAPED
20 mm
2.5 m

Reconstruction of $\pi^0\pi^0$ in a nutshell

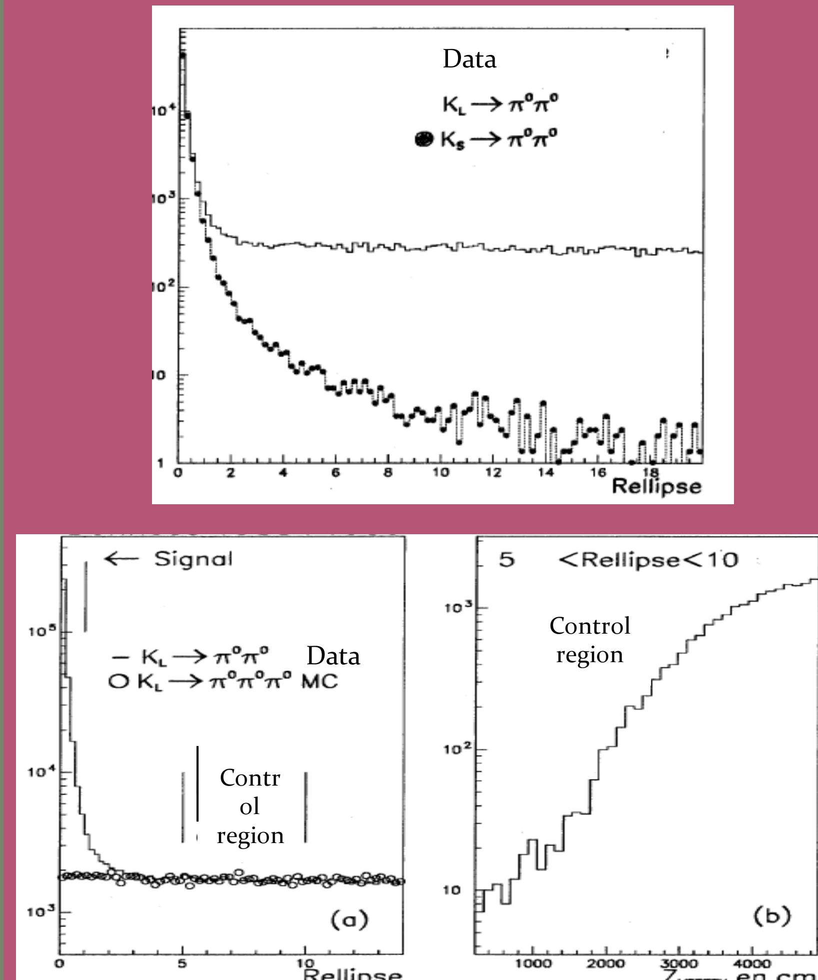
Only four clusters in LAC

$$Z_{K^0} = Z_{LAC} - \frac{1}{M_{K^0}} \times \sqrt{\sum_{i=1,j>i}^{4} E_i \times E_j \times [(x_i - x_j)^2 + (y_i - y_j)^2]}$$

$$M_{\gamma_i\gamma_j} = \frac{1}{Z_{K^0}} \times \sqrt{E_i \times E_j \times [(x_i - x_j)^2 + (y_i - y_j)^2]}$$

Use a χ^2 to chose the two most π^0-like photon combinations

$$R_{ellipse} = \left(\frac{m_{\pi_1^0} - m_{\pi_2^0}}{S\sigma_1(E_{\gamma_{min}})}\right)^2 + \left(\frac{m_{\pi_1^0} + m_{\pi_2^0} - 2 \times M_{\pi^0}}{S\sigma_2(E_{\gamma_{min}})}\right)^2$$



Tagging inefficiency

$$\alpha_{SL}^{+-} = (1.64 \pm 0.03) \times 10^{-4}$$

80% due to tagging ineff
20% due to charged hodos ineff

Table 2: Different evaluations of K_S tagging inefficiency for $\pi^0\pi^0$ events.

Method	α_{SL}^{00} in 10^{-4}
Conversions	1.64±0.5(stat+syst)
Single K_S beam	1.90±0.42(stat)
$\pi^0\pi^0$ with Dalitz	$1.9^{+1.0}_{-0.8}$(stat)

Accidental tagging

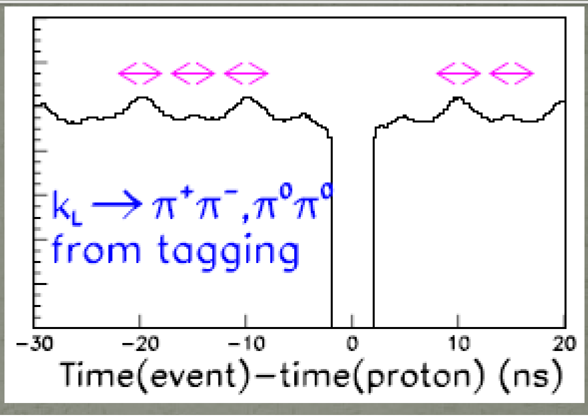


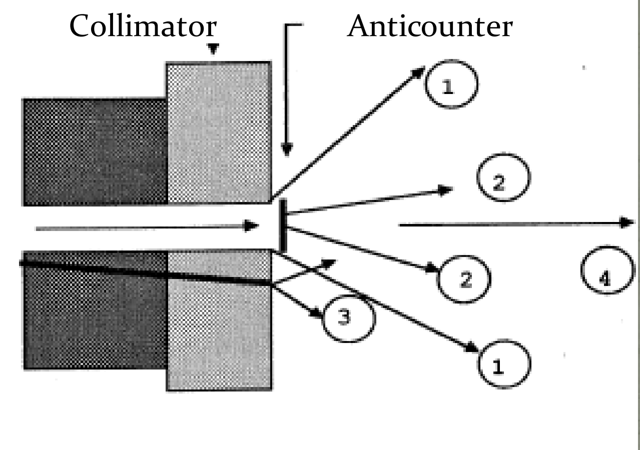
Table 3: Measured values of parameters $\Delta\beta_{tag}$, ΔW and $\Delta\alpha_{LS}$.

	Units of 10^{-4}
$\Delta\beta_{tag} = \beta_{tag}^{00} - \beta_{tag}^{+-}$	3.0 ± 1.0(stat)
$\Delta W = W^{00} - W^{+-}$	1.3 ± 1.1(stat)
$\Delta\alpha_{LS} = \alpha_{LS}^{00} - \alpha_{LS}^{+-}$	4.3 ± 1.4(stat) ± 1.0(syst)

Sources of $\Delta\alpha_{LS}$
--Different trigger losses
--Different reco losses

Some funny (and dangerous..) effects

Kaon interactions at the KS beam collimation



1) Large angle scattering in the collimator borders (unexpected)

2) Scattering in the anticounter material (expected)

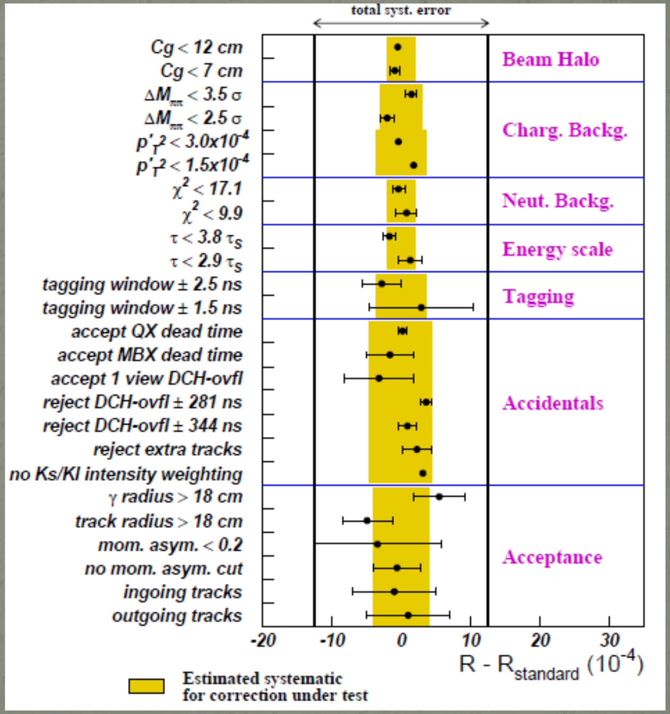
3) Hot-Spot: Kaons surviving the beam dump! (unexpected)

4) Normal beam (~97.4%)

Charge-neutral asymmetric Correction on R = -0.39+-0.08%

Exemple of Acorr in 98-99 NA48 result

		in 10^{-4}	
$\pi^+\pi^-$ trigger inefficiency		-3.6	$\pm$ 5.2
AKS inefficiency		$+1.1$	$\pm$ 0.4
Reconstruction	of $\pi^0\pi^0$	—	$\pm$ 5.8
	of $\pi^+\pi^-$	$+2.0$	$\pm$ 2.8
Background	to $\pi^0\pi^0$	-5.9	$\pm$ 2.0
	to $\pi^+\pi^-$	$+16.9$	$\pm$ 3.0
Scattering		-9.6	$\pm$ 2.0
Tagging : $\Delta\alpha_{LS}$		$+8.3$	$\pm$ 3.4
Tagging : $\Delta\alpha_{SL}$		—	$\pm$ 3.0
Acceptance	statistical	$+26.7$	$\pm$ 4.1
	systematic		$\pm$ 4.0
Accidental activity		—	$\pm$ 4.4
Long term variations of K_S/K_L		—	$\pm$ 0.6
Total correction on R		$+35.9$	$\pm$ 12.6



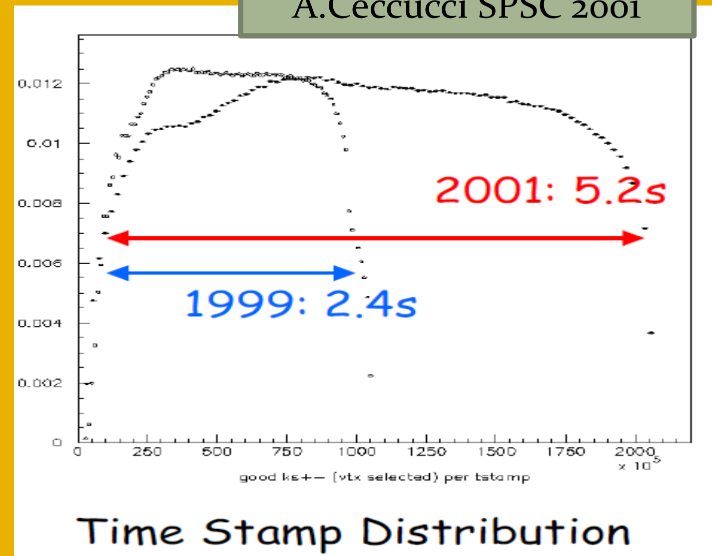
…and their structures

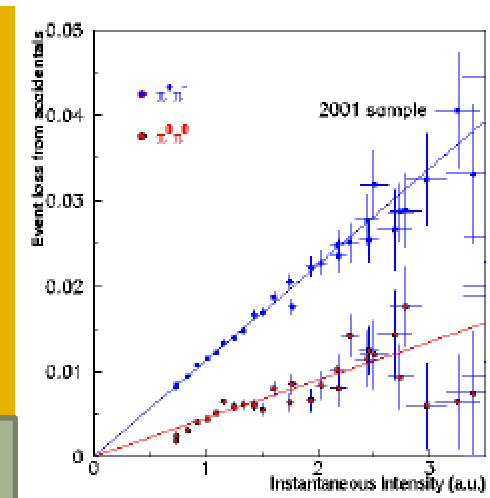
1998 and 1999 runs
Protons in target for 2.4s every 14.4 s

2001 run
Protons in target for 5.2s every 16.8 s

Lower instantaneous intensity I
Xcheck of accidental losses vs I

A.Ceccucci SPSC 2001





Plots from G.Unal
ICHEP 2002

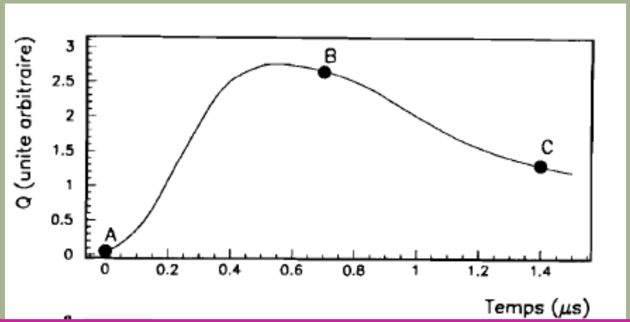
	NA31 (93)	NA48 98+99	NA48 2001
Kl	0.3 106	3.3 106	1.5 106
KLc	0.8 106	5.2 106	7.2 106
KS n	1.3 106	14.4 106	2.2 106
KSc	3.2 106	22.2 106	9.6 106

1998-1999/2001 Comparison

	1998-1999	2001
Accidental Tagging Probability	10.6 %	8.4%
MBX Efficiency	98.3%	99.2%
Drift Chamber Overflows (π^0 π^0)	21.5%	11.8%
STAT Error (10^{-4} on R)	10	15

Augusto Ceccucci

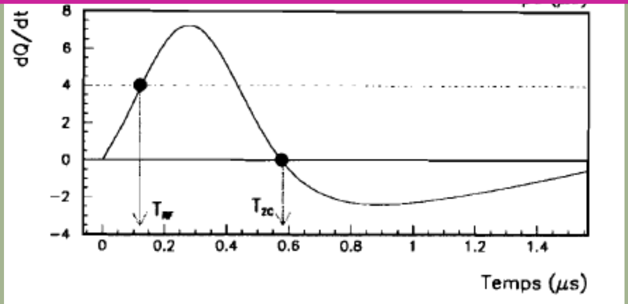
The NA31 calorimeter : the readout



➔1.6μs shaping
➔ 3 CMOS switches sample the signal
➔Total charge:

$$Q= (Q_B-Q_A)-(Q_C-Q_B)$$

From 1989 on:
Compute the signal derivative.
➔ Use the zero-crossing time of the calo signal to identify accidental activity (« ZTDC »)

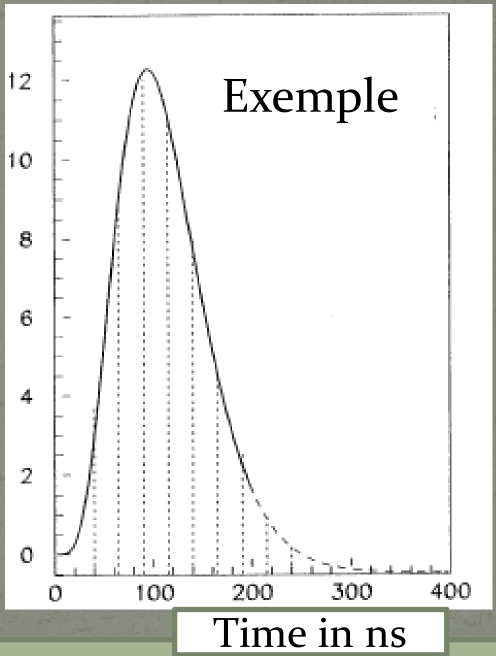


The LKr calorimeter signal & reco

Signal preamplified at cold

Shaped and digitized in the
« Calorimeter Pipelined Digitizer »
Bipolar signal ~70ns FWHM
4 gains (0-50GeV)

Asynchronous s 40Mhz
sampling of the signal by a
10bit FADC



Signal (E, T) reconstruction:
Using optimal filtering

The NA48 family

…..together with detailed minutes

<u>AIM</u> : be ready for a possible presentation of preliminary 98 results at La Thuile (28 Feb, R.Gr…ier) or at Moriond (13 march, G.Graziani)

<u>IF</u> decision is taken at meetings 17 Feb,

Cuts/samples have been fixed recently (see news on eprime)
- run > 6600
- QX dead time symmetrized
- reject bad bursts [Compact database]
- $\pi^+\pi^-$ mass Victoria's correction applied

⇒ need update soon of R, number of events and of Monte-Carlo corrections

Generate plots on
/afs/cern.ch/user/n/na48plot/pl98
with news on eprime
[news on eprime to be put today by Giles and me]

THE 98 ANALYSIS IS NOT BLIND AT ALL ANYMORE
Each change of cuts is associated to a ΔR
⇒ in order to minimize human bias one should try to avoid to change 97 cuts now

However we … (if we can) a better … of the corrections

Discussions on

▶ <u>Dilution difference</u> ~ 5.5 10^{-4} + corrections
- explain 5.5 10^{-4} (?)
- apply or not the corrections

▶ <u>scattering on collimator (high pt) correction</u>
- obtained from charged events [with cut on additional clus…
- obtained from neutral events

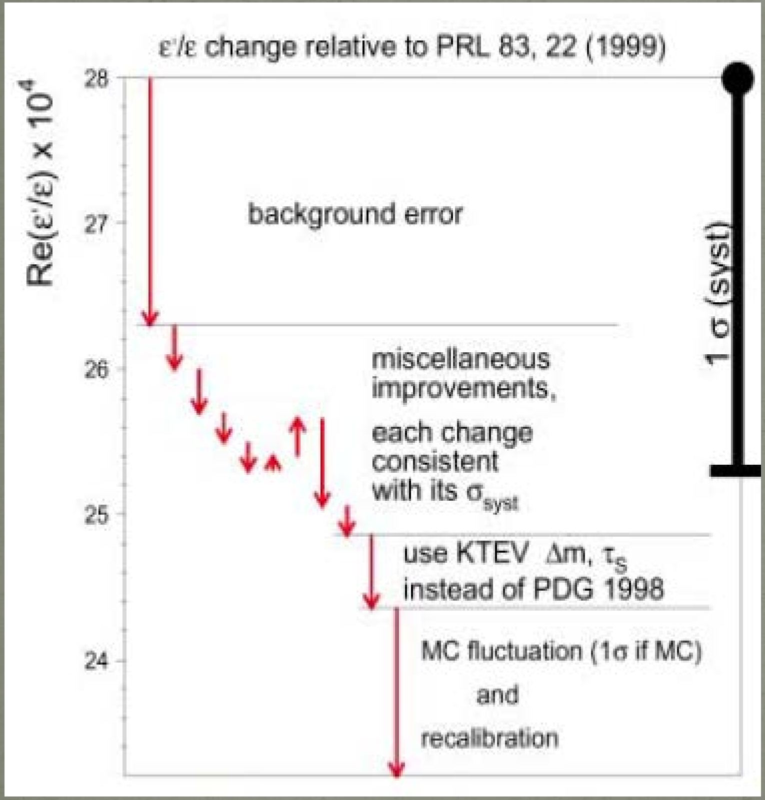
a proposal exists for a value/error

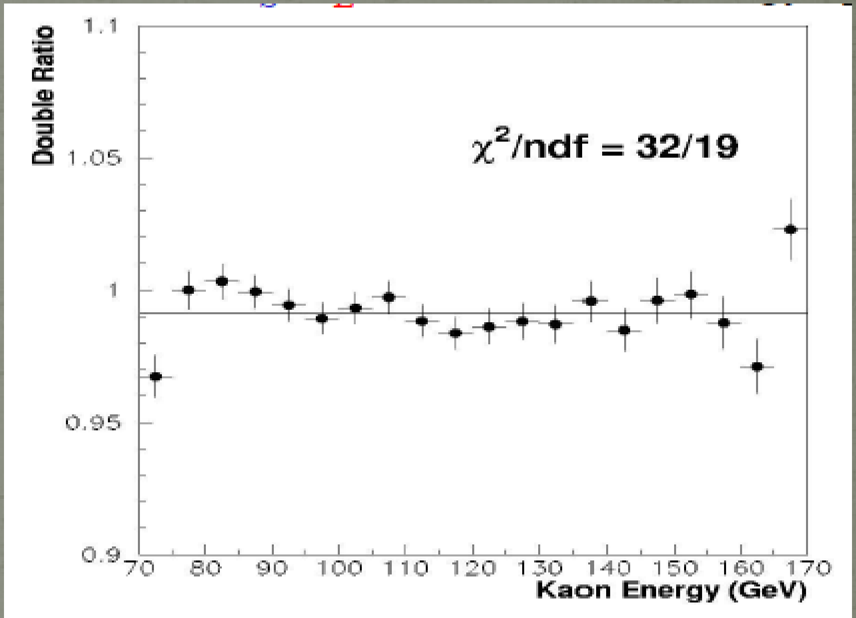
▶ <u>Trigger inefficiencies</u>

MBX :	$(1-\varepsilon)$ =	.023	±	3‰ $(1-\varepsilon)$
QX :	$(1-\varepsilon)$ =	.0006	±	30‰ $(1-\varepsilon)$
ETOT :	$(1-\varepsilon)$ =	.005	±	10‰ $(1-\varepsilon)$
NUT :	$(1-\varepsilon)$ =	.001	±	40‰ $(1-\varepsilon)$

Proposal : if error ≥ 5‰ $(1-\varepsilon)$ put error to 5‰ (1-…
[small correction proposal]

⇒ react <u>soon</u> to Giles and me
[discussion at meeting in front of ΔR values will not be he…


ε'/ε change relative to PRL 83, 22 (1999)
Re(ε'/ε) x 10^4
28
27
26
25
24
background error
miscellaneous improvements,
each change consistent with its σsyst
use KTEV Δm, τS instead of PDG 1998
MC fluctuation (1σ if MC)
and
recalibration
1 σ (syst)


Double Ratio
χ²/ndf = 32/19
1.1
1.05
1
0.95
0.9
70 80 90 100 110 120 130 140 150 160 170
Kaon Energy (GeV)

The double ratio

$$R^{meas} = \frac{Nb(K_L \to \pi^0\pi^0)}{Nb(K_S \to \pi^0\pi^0)} \Big/ \frac{Nb(K_L \to \pi^+\pi^-)}{Nb(K_S \to \pi^+\pi^-)}$$

At first order, corrections on R^{meas} cancel out IF :

Common to two decay channels recorded concurrently

Common to two beams recorded concurrently

The best:
record all 4 numbers concurrently
in the same detector

Moreover, for a given mode:
Different backgrounds for K_S and K_L
and much different decay spectra.

Not trivial at all because of the very different K_S and K_L lifetimes

The whole challenge:
compute remaining corrections Acorr

The observables

Direct CPV affects differently the two Kaon 2π decay channels

$\eta^{+-} = \langle\pi^+\pi^-|K_L\rangle / \langle\pi^+\pi^-|K_S\rangle = \varepsilon + \varepsilon'$

$\eta^{oo} = \langle\pi^o\pi^o|K_L\rangle / \langle\pi^o\pi^o|K_S\rangle = \varepsilon - 2\varepsilon'$

DirectCPV/IndirectCPV = ε'/ε

$$Re\left(\frac{\varepsilon'}{\varepsilon}\right) \approx \frac{1}{6}\left(1 - \left|\frac{\eta_{00}}{\eta_{+-}}\right|^2\right)$$

$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)}$$

Experimentaly, one needs to measure 4 decays :

$$R^{meas} = \frac{Nb(K_L \to \pi^0\pi^0)}{Nb(K_S \to \pi^0\pi^0)} \Big/ \frac{Nb(K_L \to \pi^+\pi^-)}{Nb(K_S \to \pi^+\pi^-)}$$

Such that $R = R^{meas} \times A_{corr}$

R^{meas} sensitive to flux, trigger, detector ,acceptance and background differences between 4 modes

The NA31 Calorimeter-the structure

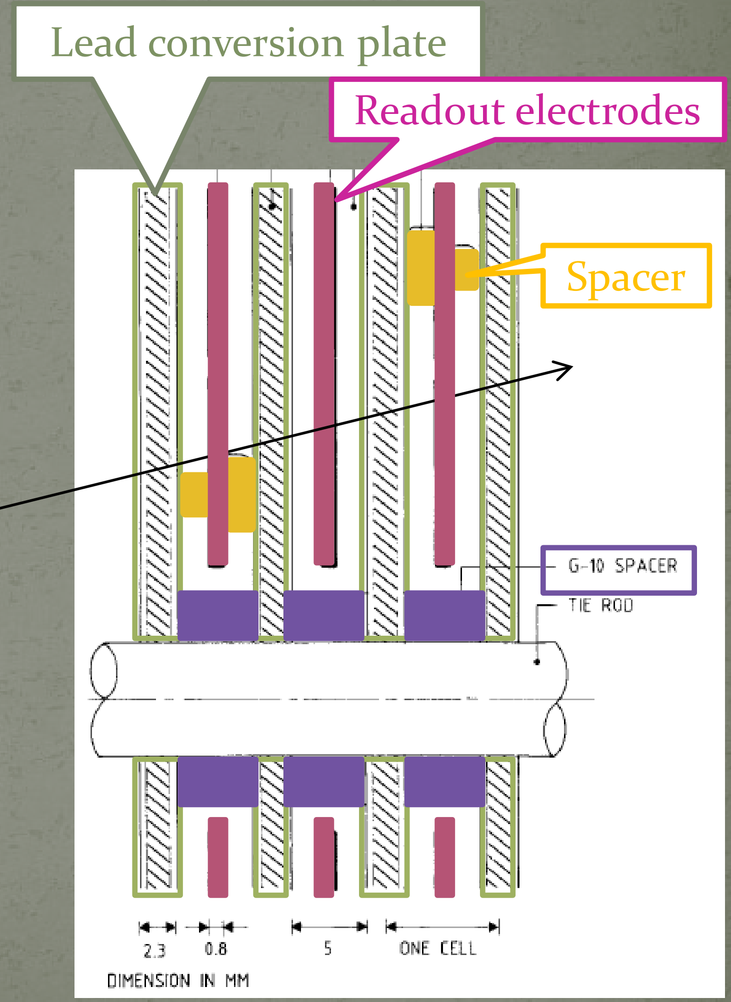
Stack of lead conversion plates alternating with readout planes suspended in a liquid argon bath

Alternate vertical and horizontal readout strips 12.5mm wide.

The neutral hodoscope used for triggering divides the detector into front and back parts

A total of 1536 channels, each made of 20 longitudinaly connected vertical or horizontal strips.

➔ $\sigma(\pi^0)$= 2Mev
➔ $\sigma(x,y)$< 1mm



The NA31 experiment in a sketch