First evidence of direct CP violation: Kaons, the NA31 experiment and DANIEL

Thanks to :Sabine Starita, Dominique Longieras, Dominique Bony
A.M Lutz, Olivier Perdereau, Daniel Fournier, Don Cundy, Manoel Dialinas

The kaon-history time arrow

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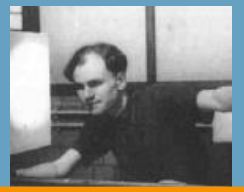

1950 — Discovery of the Λ hyperons produced always in association with Kaons

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V. D. Hopper and S. Biswas
Department of Physics, University of Melbourne, Melbourne, Australia
October 30, 1950

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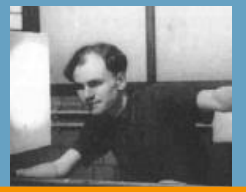

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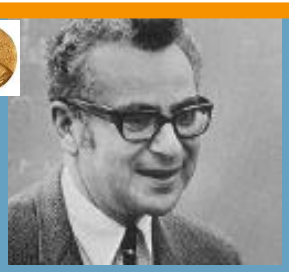

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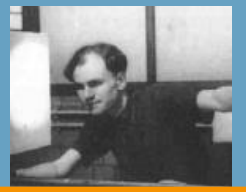

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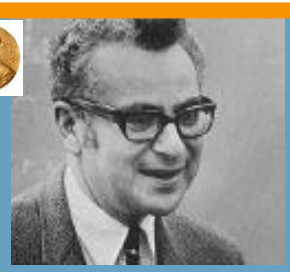

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1955 Proposal of how to find K2: **A.Pais and O.Piccioni**

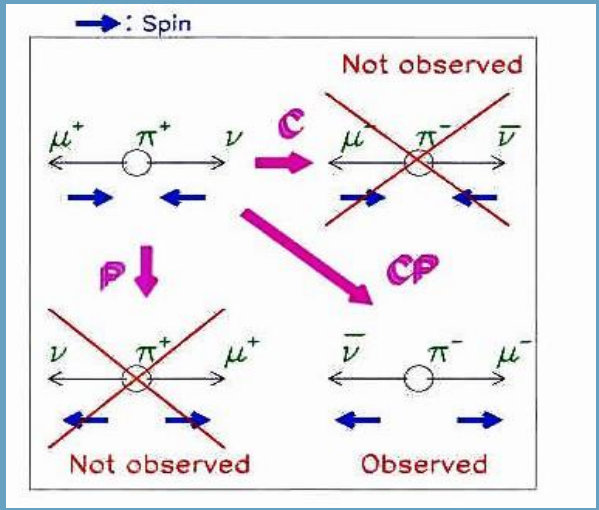
1956 Discovery of the K2

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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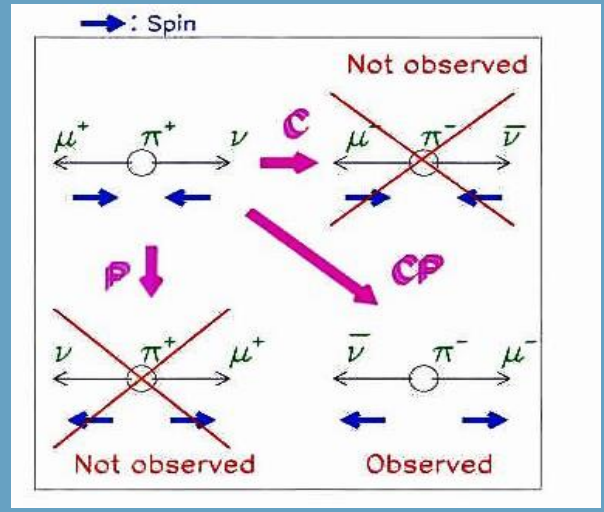

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CP = -1

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Short-live K1 can decay only into 2body
Long-live K2 can decay only into 3 body

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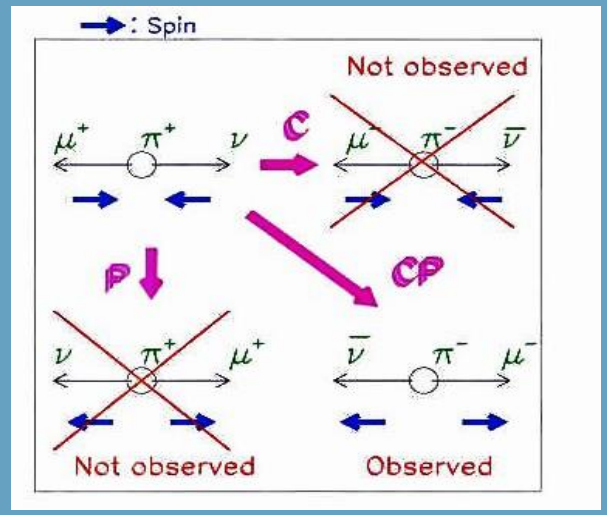

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Princeton University, Princeton, New Jersey
(Received 10 July 1964)

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

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

What happens to kaons?

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

Physics particles : **K_S** and **K_L**
They are mixtures of the two eigenstates K_1 and K_2

The observed $K_L \to 2\pi$ arises because of the K_1, K_2 mixing.

Call it **" Indirect CPV"**

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In charged and neutral 2-body final states

$$\eta^{00} = A(K_L \to \pi^0\pi^0)/A(K_S \to \pi^0\pi^0)$$

$$\eta^{+-} = A(K_L \to \pi^+\pi^-)/A(K_S \to \pi^+\pi^-)$$

CP violation in the standard model

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,
'77: b quark, '95: top quark

$$M_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3 re^{i\delta} \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-re^{i\delta}) & -A\lambda^2 & 1 \end{pmatrix}$$

$\lambda = \sin\vartheta$ δ=phase

With 2 families : M = M* ➔ CP is conserved

With 3 families : irreducible phase ➔CP is violated if $\delta \neq 0$

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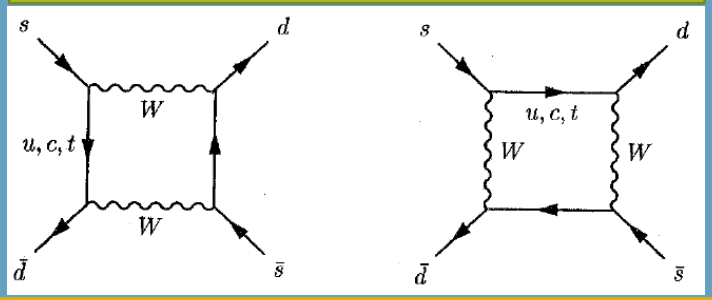

CPV in mixing ΔS=2 . Measured by ε~0.2%

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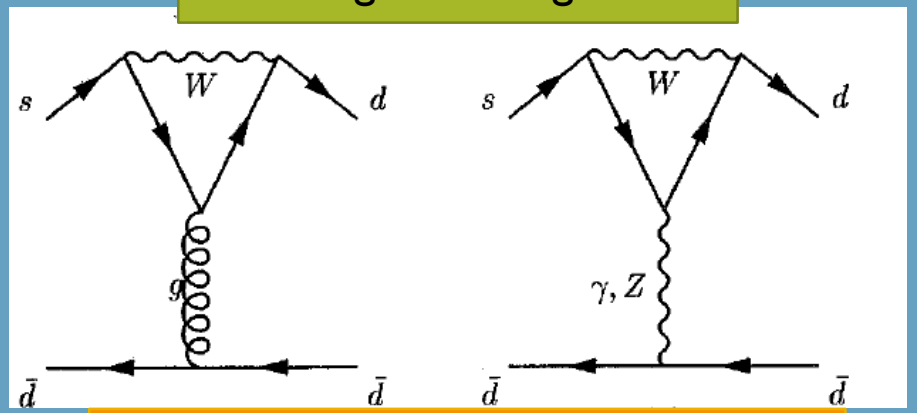

CPV in decay ΔS=1. Measured by ε'

Call it « Direct CPV »

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

1976

~2% Ellis, Gaillard, Nanopoulos

1979

~10% Gilman , Wise

~1985

>0.2% Gilman , Hagelin

~0.15%*f(m_t) Buras, Gerard

1989

γ-penguins Flynn, Randall

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

The NA31 proposal

B6: QCD penguins

B8: EW penguins

Need 10^{-4} precision!

Final NA31 resultl

Short summary of previous slides

1964 : Unexpected discovery of a major non-predicted phenomenon

Observation of 42 K_2->$\pi^+\pi^-$ decays, forbidden if CP conserved

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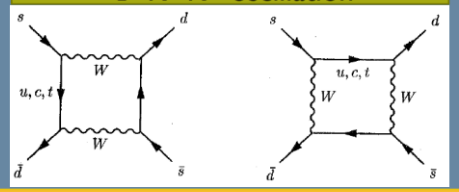

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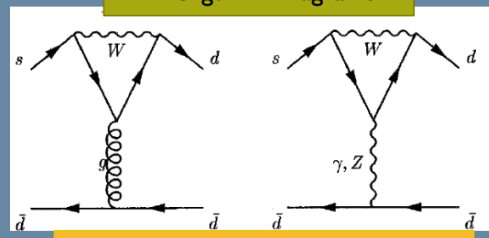

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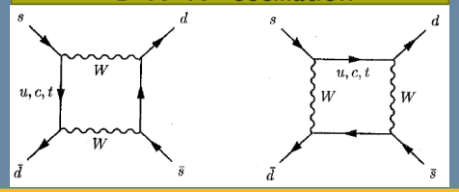

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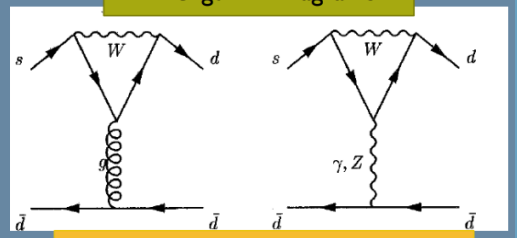

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How large ε'/ε is expected to be??

Theory predictions :
From few % (~1975) to few permill (1995)

Lagarrigue and CP Violation

A MEASUREMENT OF THE BRANCHING RATIO OF THE *CP* VIOLATING DECAY MODE $K_L^0 \rightarrow 2\pi^0$

I. A. BUDAGOV *, D. C. CUNDY, G. MYATT, F. A. NEZRICK, G. H. TRILLING **, W. VENUS and H. YOSHIKI
CERN, Geneva, Switzerland

B. AUBERT, P. HEUSSE, I. LE DONG, J. P. LOWYS, D. MORELLET, E. NAGY *** and C. PASCAUD
Faculté des Sciences, Orsay †, France

L. BEHR, P. BEILLIÈRE, G. BOUTANG, M. SCHIFF and J. VAN DER VELDE ‡
Ecole Polytechnique, Paris, France

Received 11 October 1968

The collaboration would like to thank, in particular, Professor A. Lagarrigue, who suggested this experiment, and Professors L. Leprince-Ringuet, Ç. A. Ramm and A. Rousset for their help and encouragement; and also the CERN Proton Synchrotron and Heavy-Liquid Bubble Chamber crews for their assistance in obtaining the pictures.

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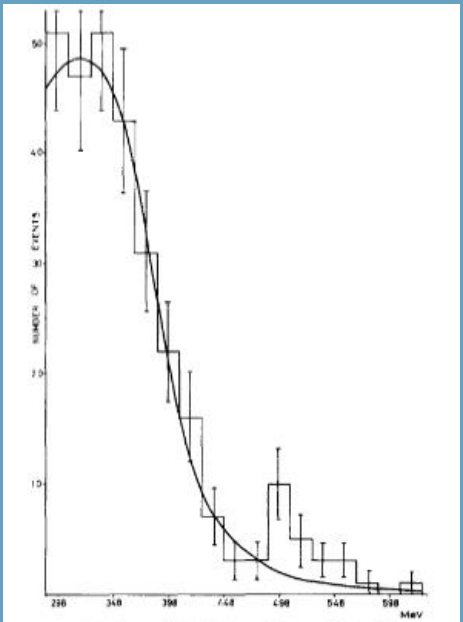

Fig. 4. Fitted mass distribution of 4γ candidates after cuts.

Bubble Chamber filled with Freon
Count 63+-24 K_L-> $2\pi^0$ events

$$|\eta_{00}| = \left|\frac{A(K_L^0 \to 2\pi^0)}{A(K_S^0 \to 2\pi^0)}\right| = (2.2 \pm 0.4) \times 10^{-3}$$

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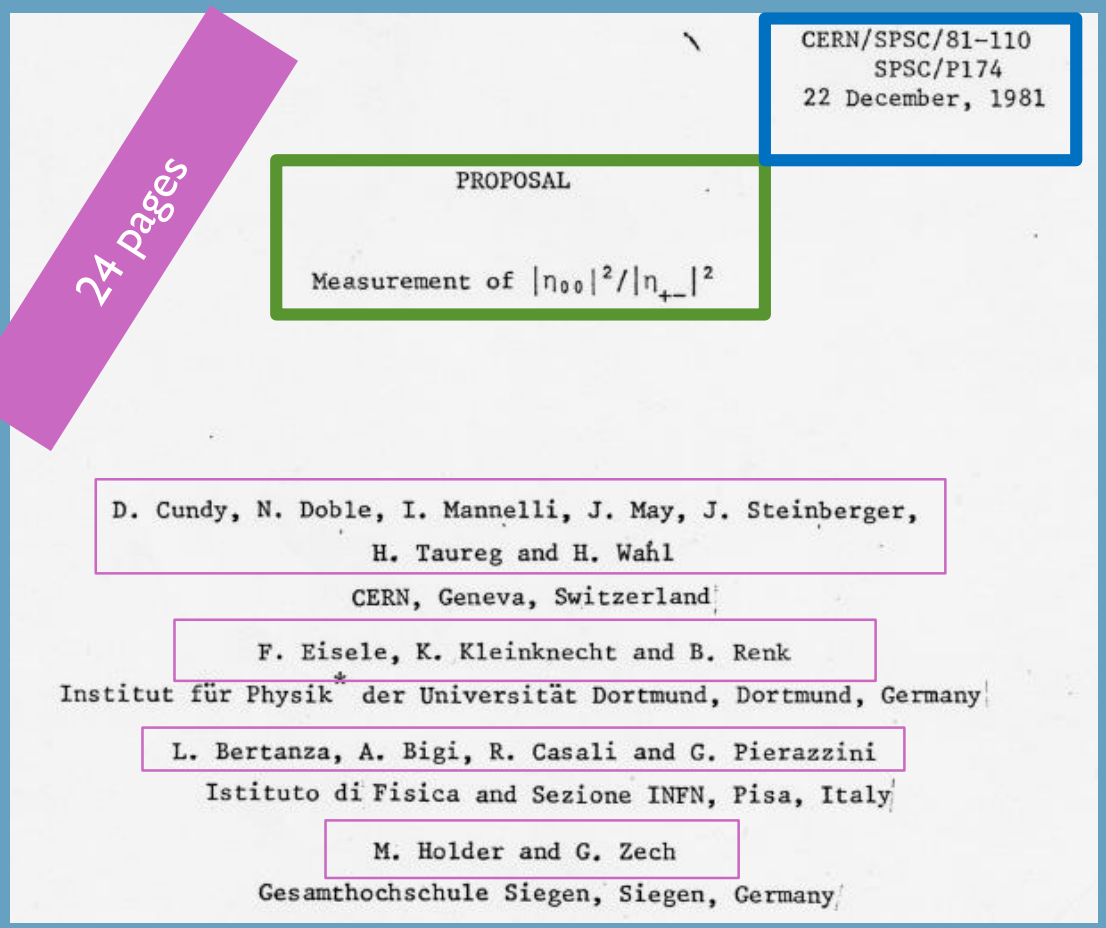

24 pages

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

PROPOSAL

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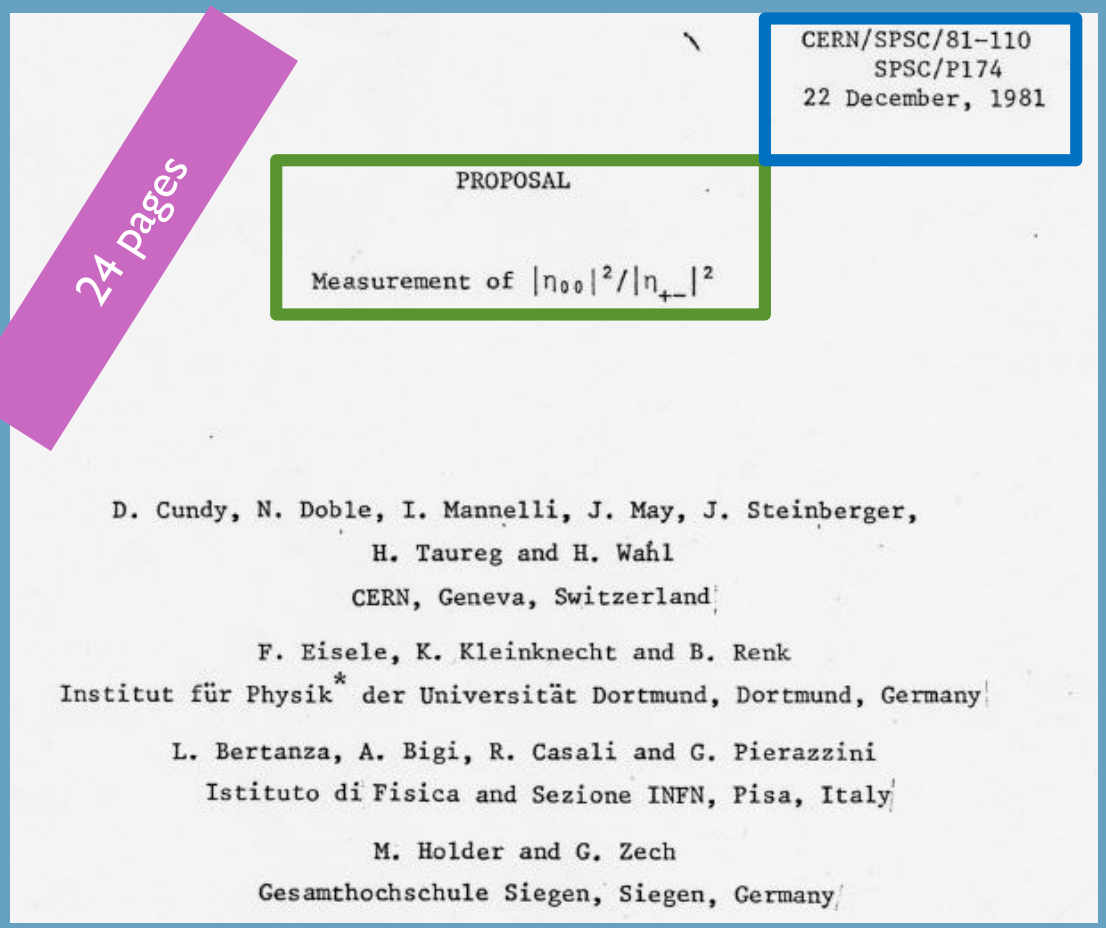

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AIM : Measure Re(ε'/ε) with 0.1% of precision

- **14 authors from 4 Institutes**
- **10 pages of text,** with
  - 9 lines on tracking
  - 1 page on calorimetry
  - 7 lines on veto anticounters
  - ¾ of a page on trigger
  - half a page on systematics
  - 1,5 on charged and neutral background,
  - 10 lines on time scale
  - Half a page on Cost
- **11 References**
- **11 (huge) figures**

The birth of NA31 experiment

Very light and simple description of analysis, background treatment and systematics

It is essential that the uncertainties in these differences, as they affect the ratio of accepted neutral and charged decays, be kept at the one per mille level. We omit here a detailed discussion of the strategies to be employed to try to achieve this level, but limit ourselves to the claim that although the problem is very challenging, such systematic precision is possible.

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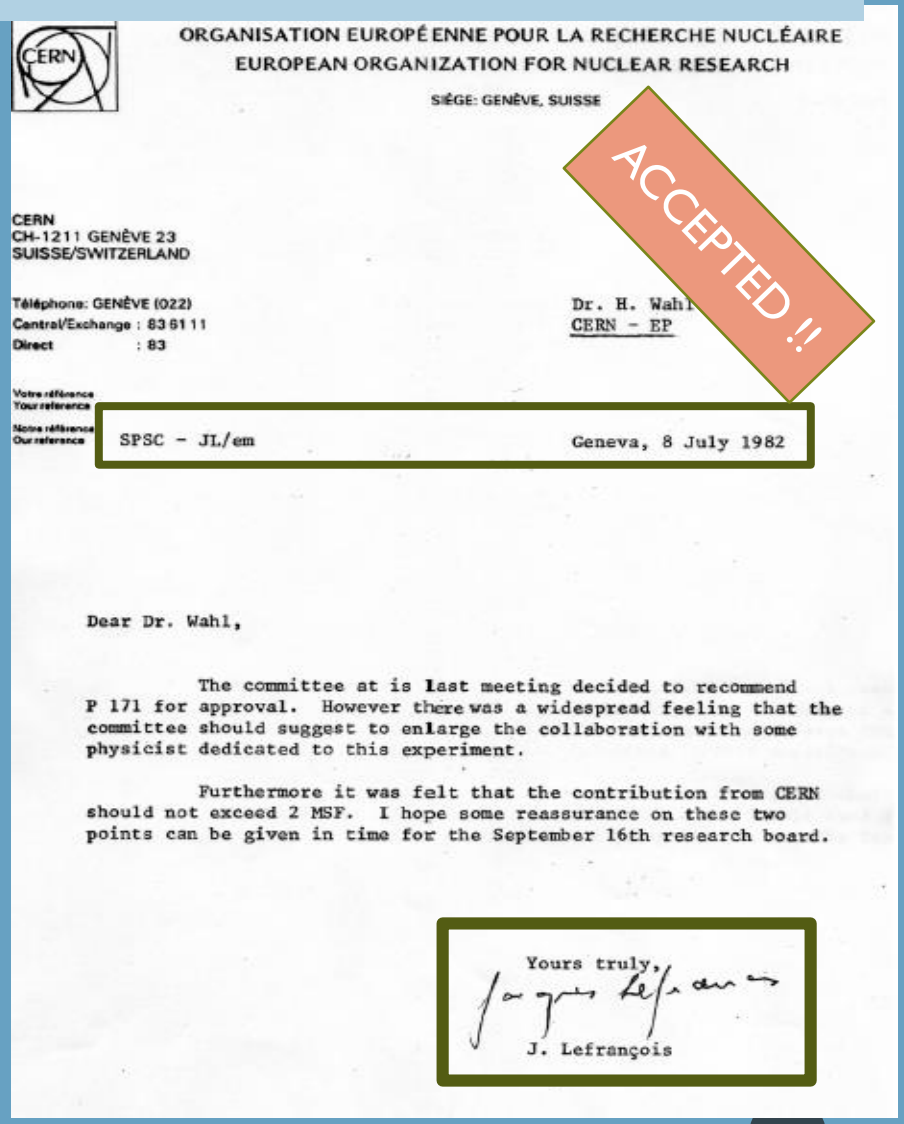

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
SIÈGE: GENÈVE, SUISSE

ACCEPTED !!

CERN
CH-1211 GENÈVE 23
SUISSE/SWITZERLAND

Téléphone: GENÈVE (022)
Central/Exchange : 83 61 11
Direct : 83

Dr. H. Wahl
CERN - EP

Votre référence / Your reference
Notre référence / Our reference
SPSC - JL/em

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

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Very light and simple description of analysis, background treatment and systematics

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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
SIÈGE: GENÈVE, SUISSE

ACCEPTED !!

CERN
CH-1211 GENÈVE 23
SUISSE/SWITZERLAND

Téléphone: GENÈVE (022)
Central/Exchange : 83 61 11
Direct : 83

Dr. H. Wahl
CERN - EP

SPSC - JL/em

Geneva, 8 July 1982

Dear Dr. Wahl,

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Supported by Perez Y Jorba at LAL

The NA31 method

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

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

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$\pi e \nu$		0.386
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→Alternate Ks and Kl beams

→Detect concurrently Charged and Neutral Decays to cancel out beam flux instabilities, in the same decay volume

The NA31 experiment in a sketch

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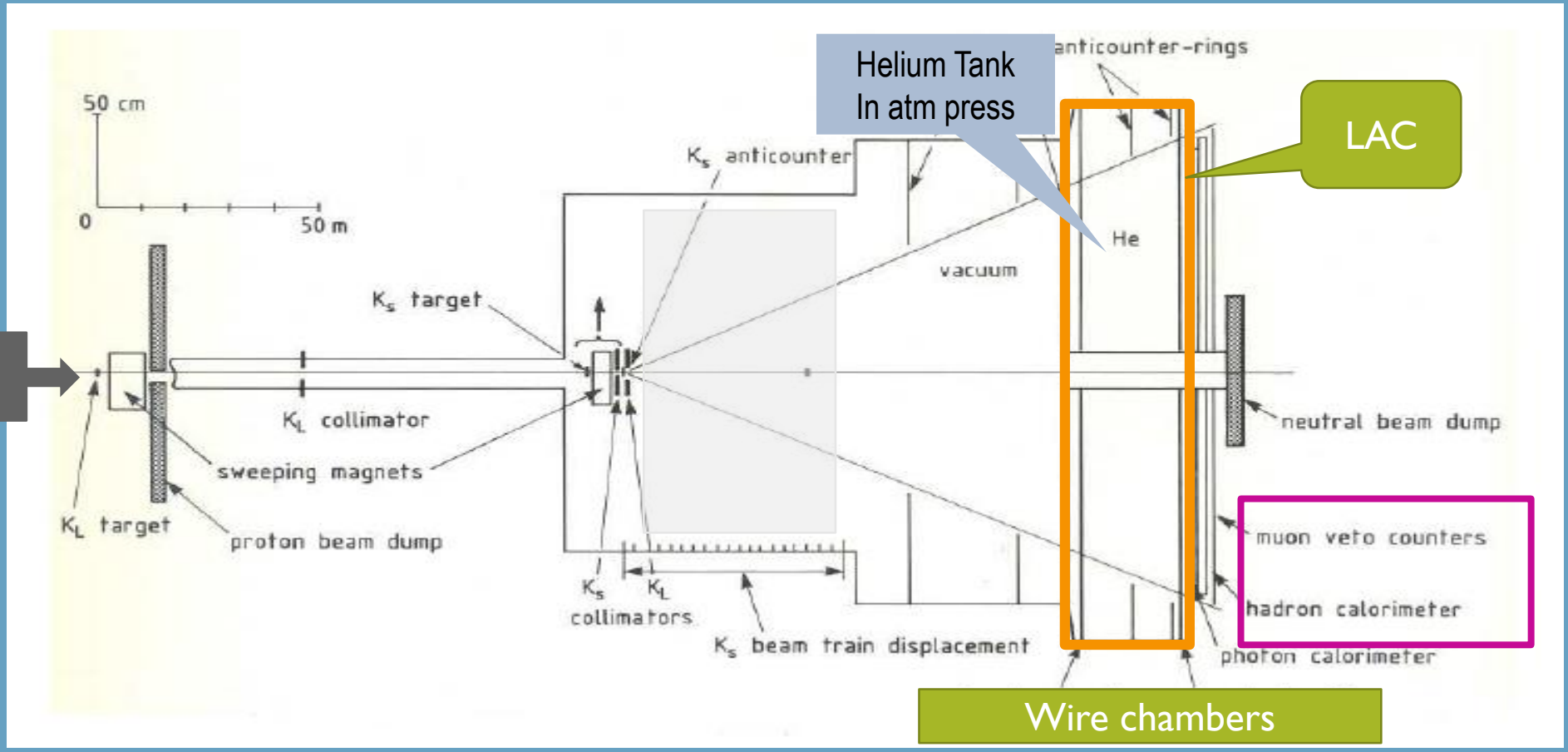
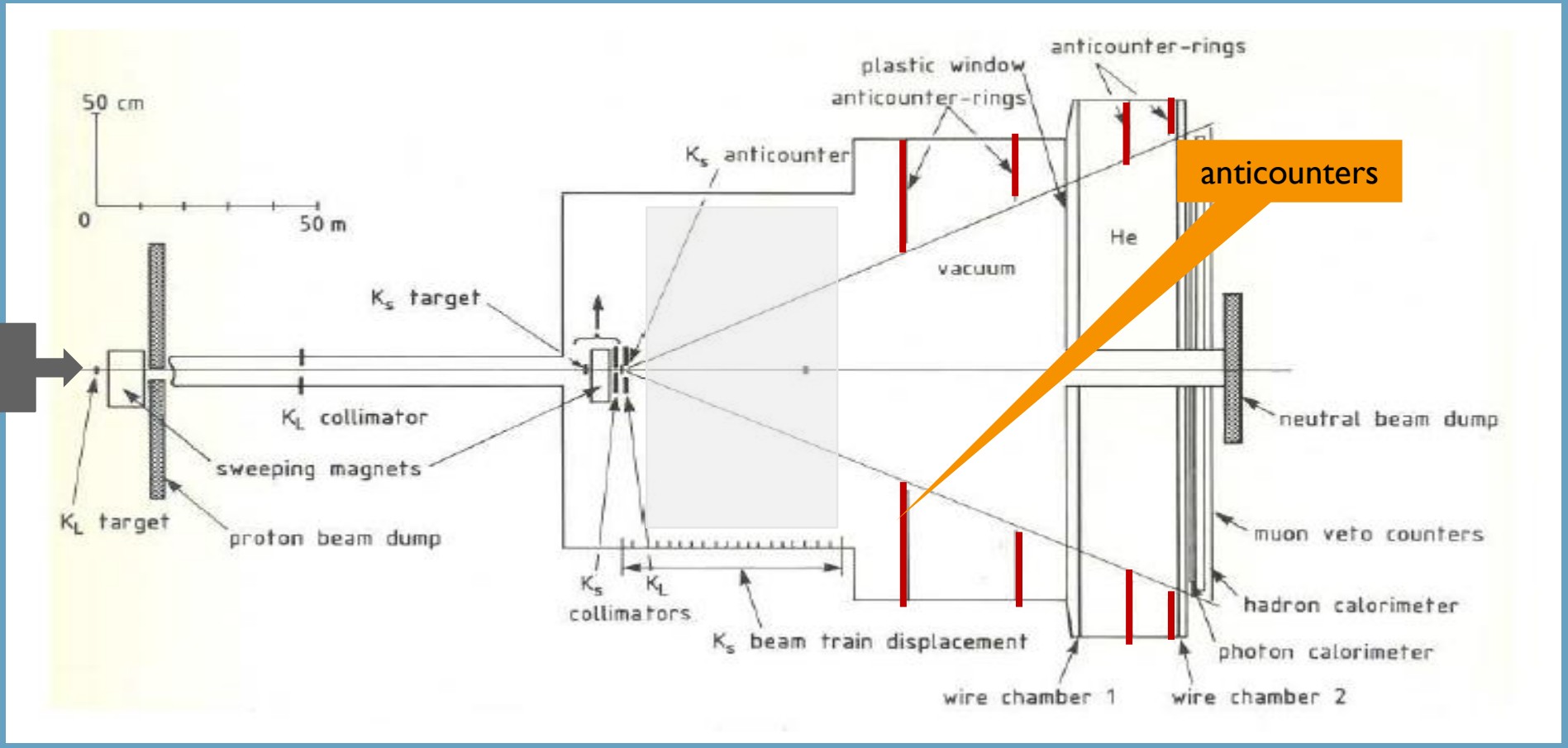
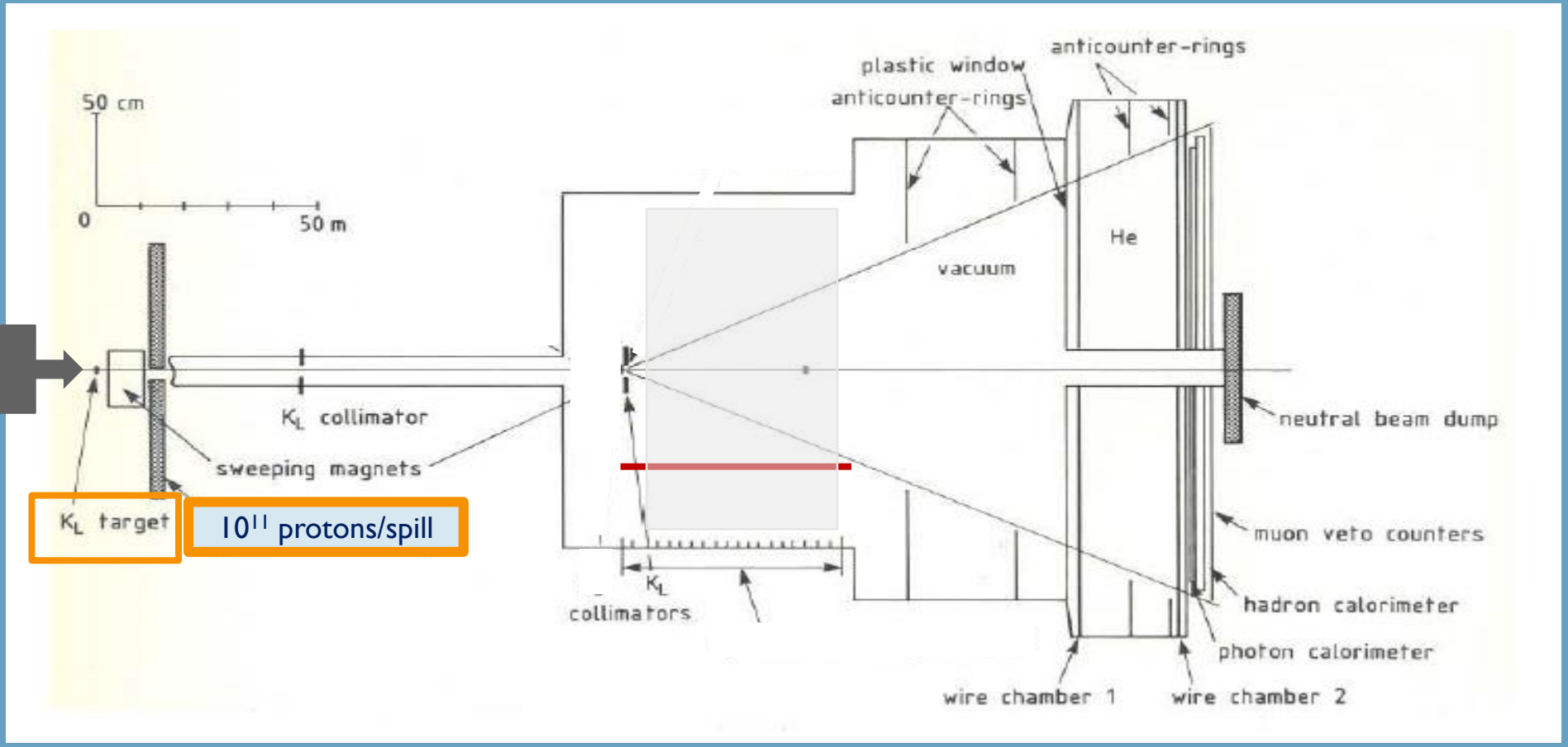


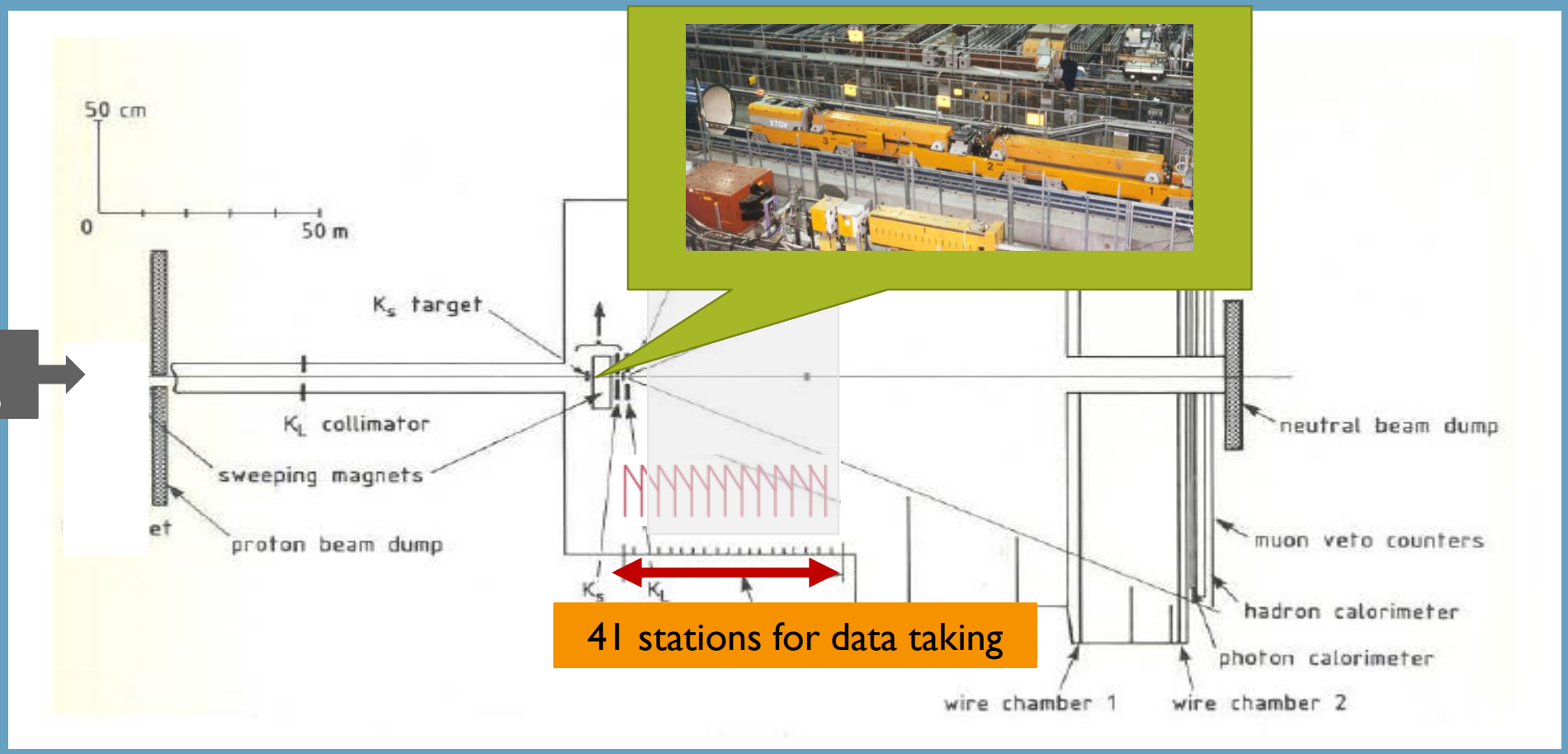
The NA31 experiment in a sketch



Alternate the beams : the K_L setup



Alternate the beams : the K_S setup



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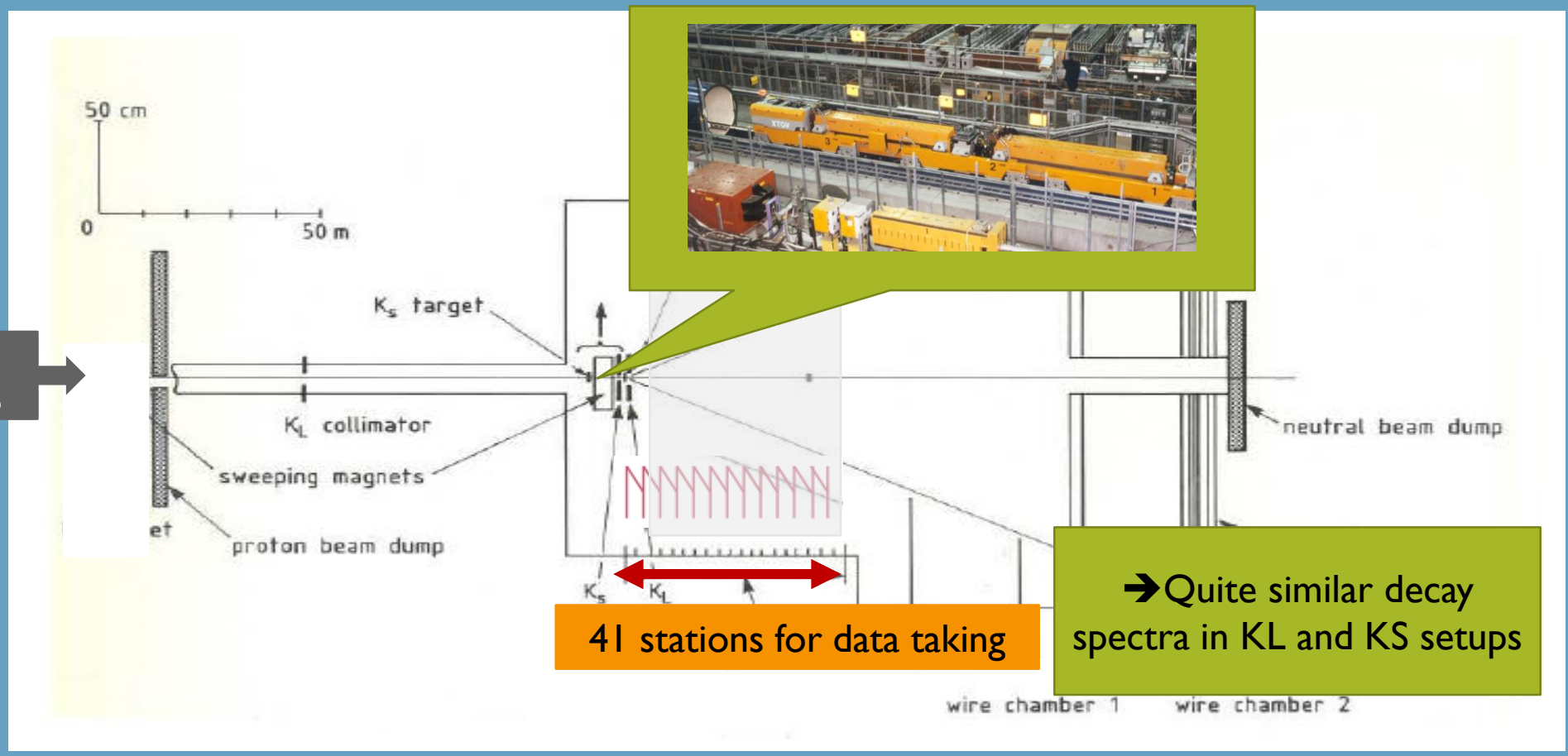
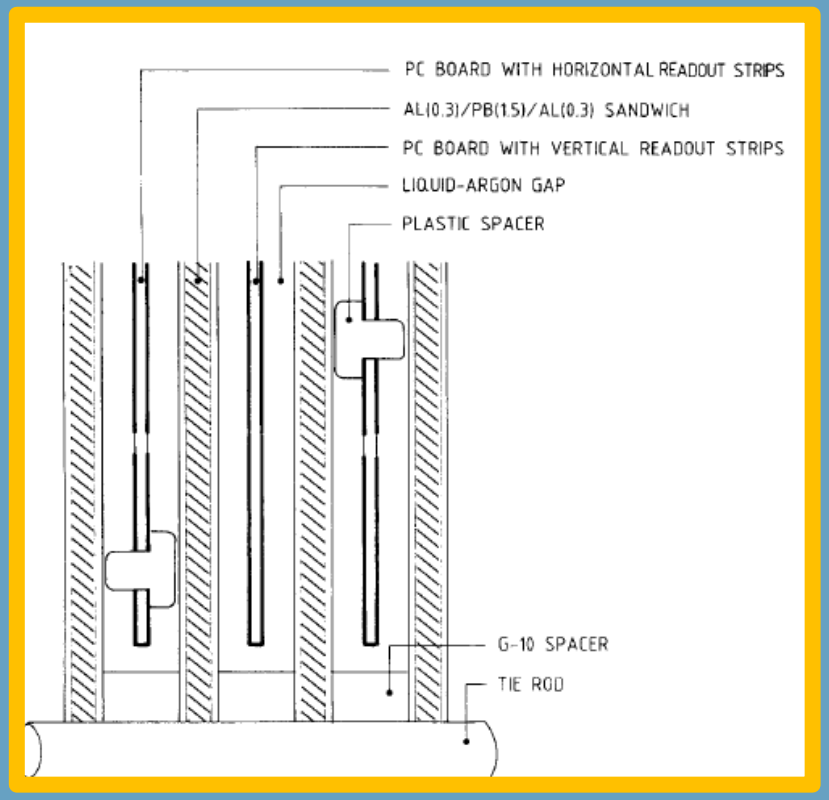
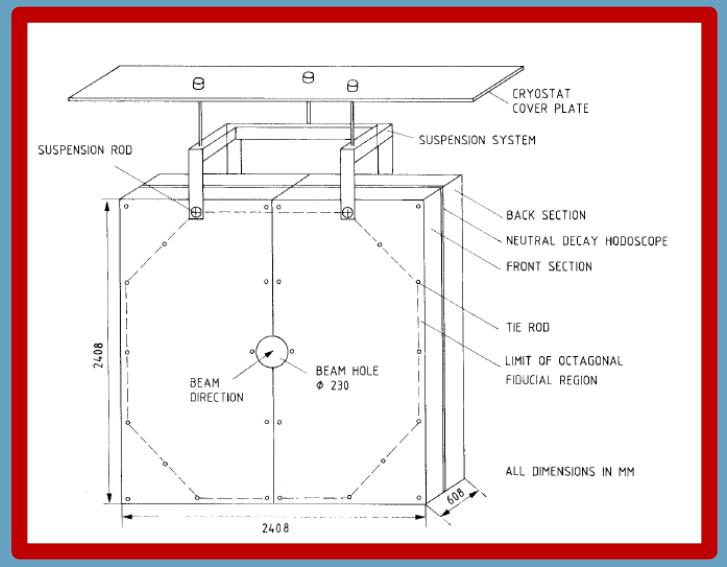
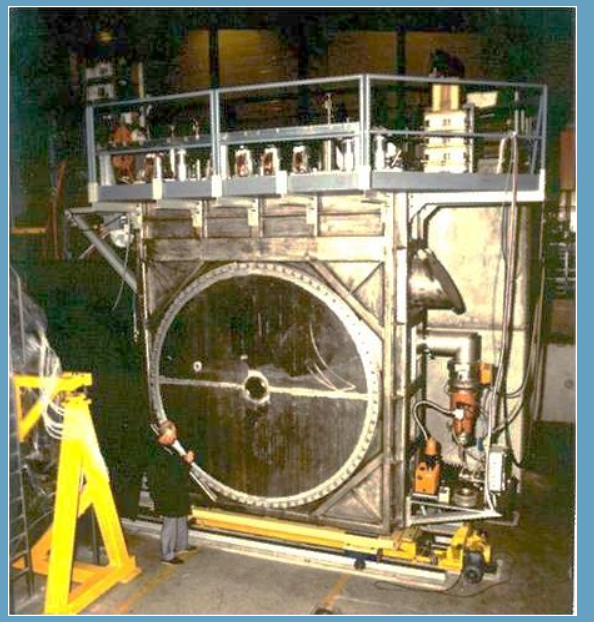


The NA31 experiment: the Liquid Argon Calorimeter (LAC)



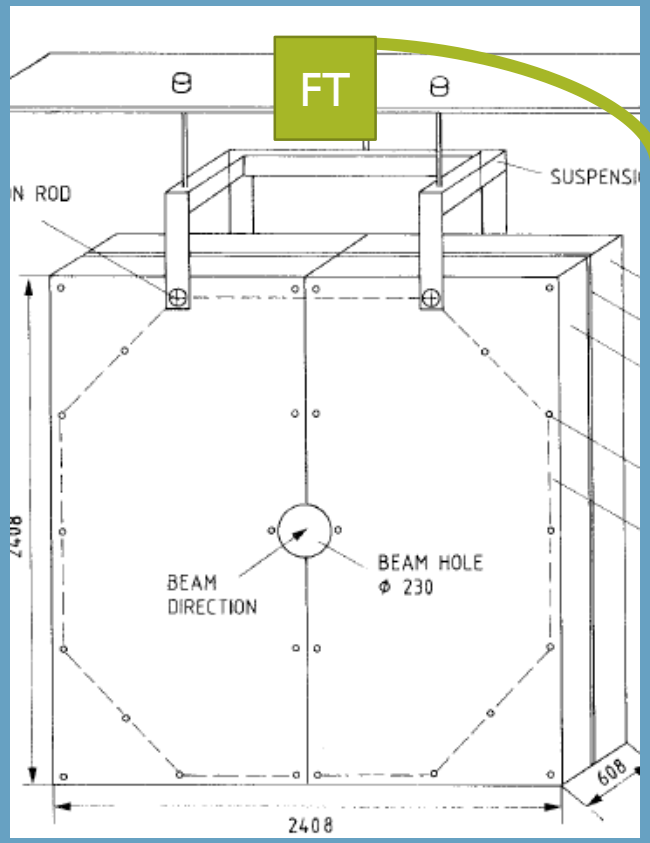




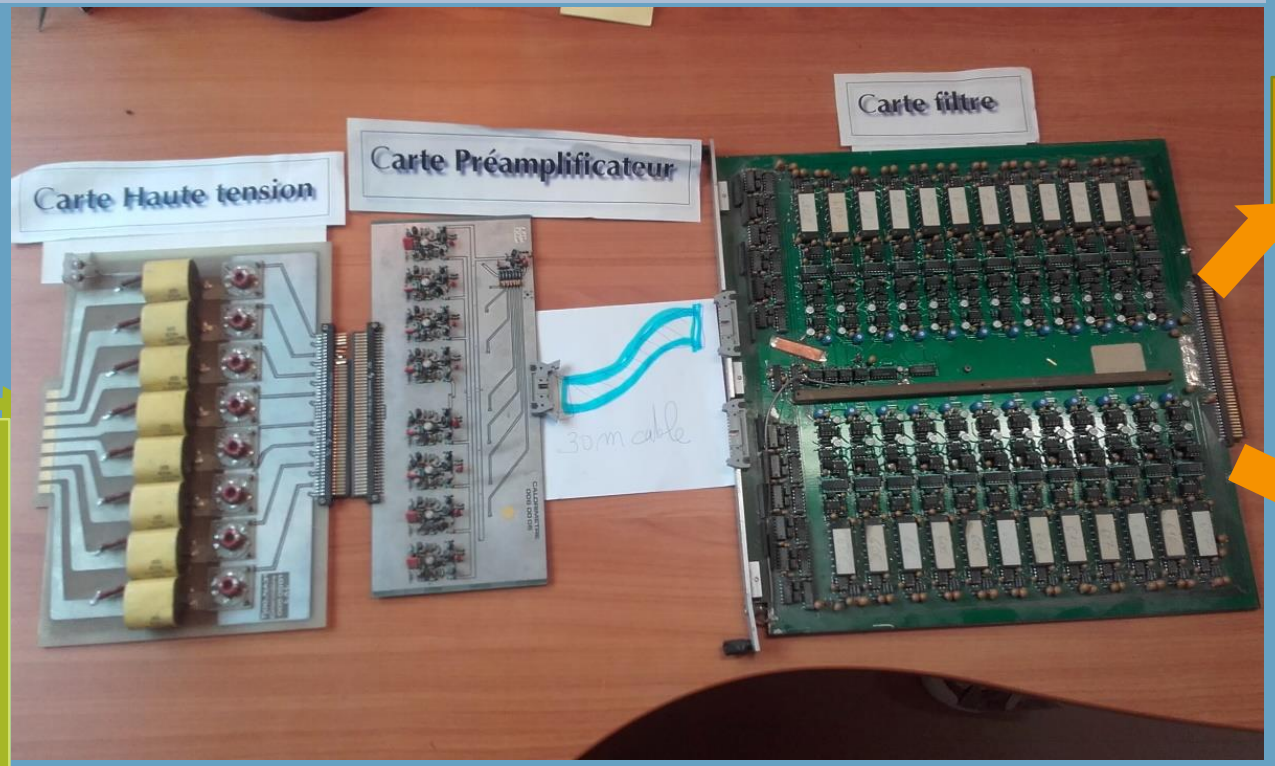
25X0 divided in Front and Back
Into a cryostat at T= 90 K

Maitres d'oeuvre :
Italie-CERN

The Orsay contribution to LAC



Cables to extract the signals from the FT



Peak Finder

ADC

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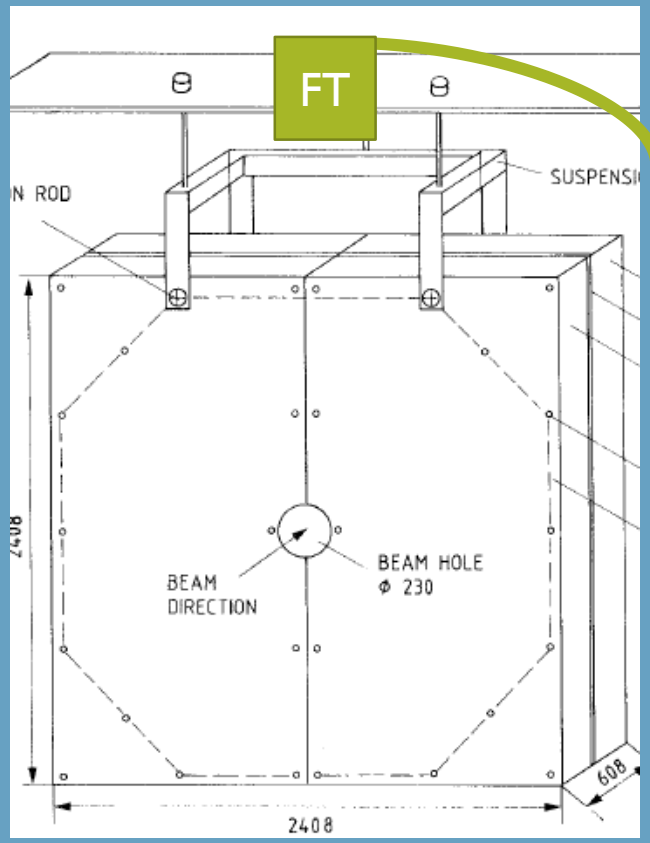

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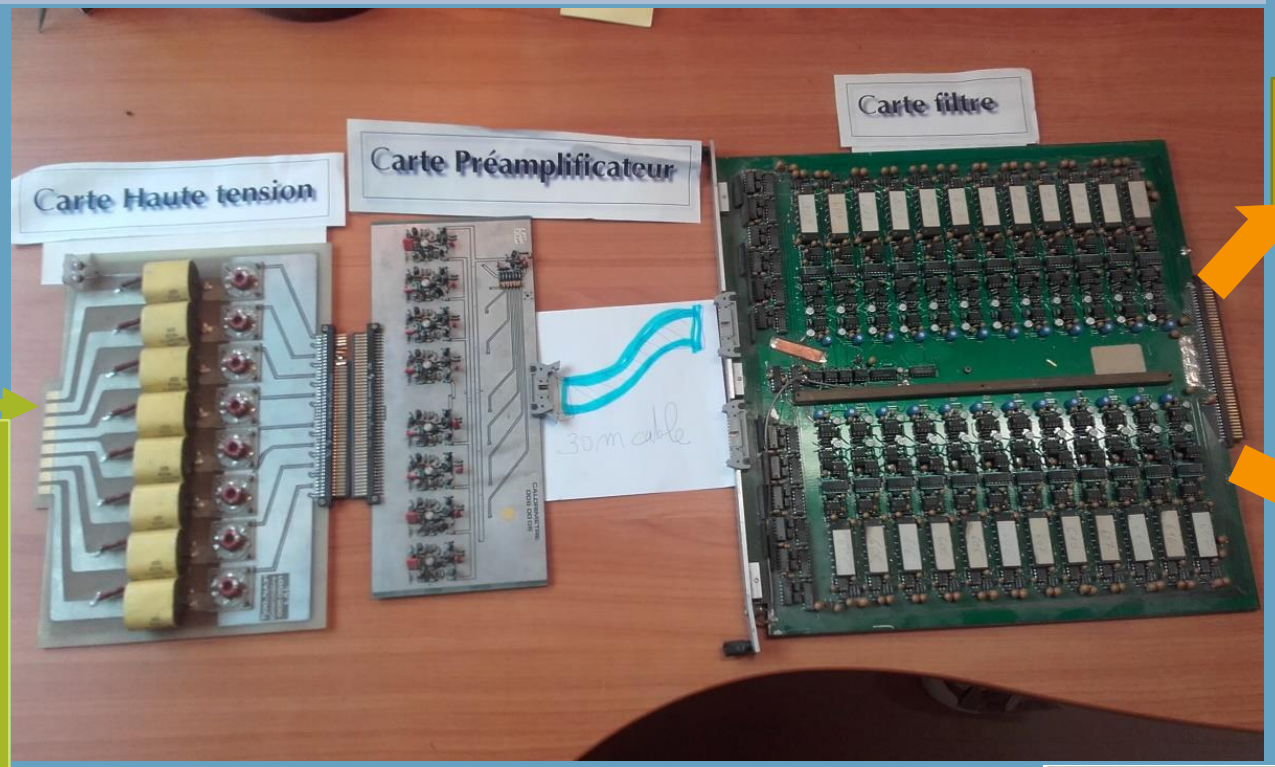

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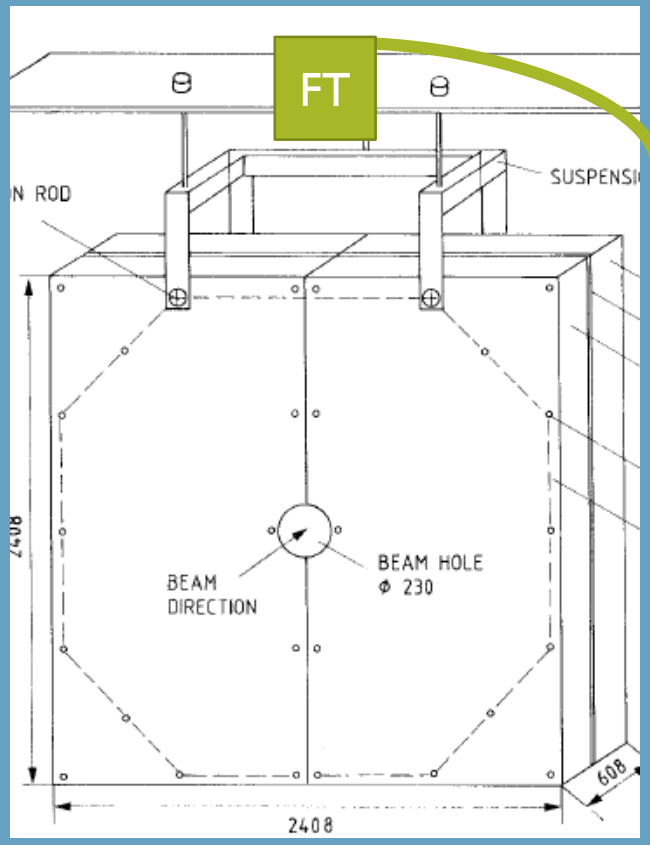
Orsay (Bob Chase et al)

The Orsay contribution to LAC



Cables to extract the signals from the FT

LALORS 690369F
118 1019
23698X CERN CH

27.04.84/10:16
GENEVA OUR REF 7615 MH

27 avril 84

M D. FOURNIER

WE HAVE NOT YET RECEIVED FLAT CABLE ASSEMBLY.
IS ESSENTIAL FOR TEST, PLEASE PUSH

BEST REGARDS

JAN VAN DER LANS CERNLAB / EF

LALORS 690369F
23698X CERN CH

Already delivery delays at that time….

Orsay contributions to Data Taking

AFBI (Atithmetic FASTBUS Interface)
Second level hard wired trigger

What for: Compute energy sums and first and second moments

➔**Neutral events** : cuts on vertex, CoG and Energy in LAC to reject $3\pi^0$

➔**Charged events** : cuts on LAC/EHAD, energy in HAD to reject ke3 and $K\mu 3$

Rejection rate : 50% (30%) in K_L (K_S) beam
Loss of good events <0.1%

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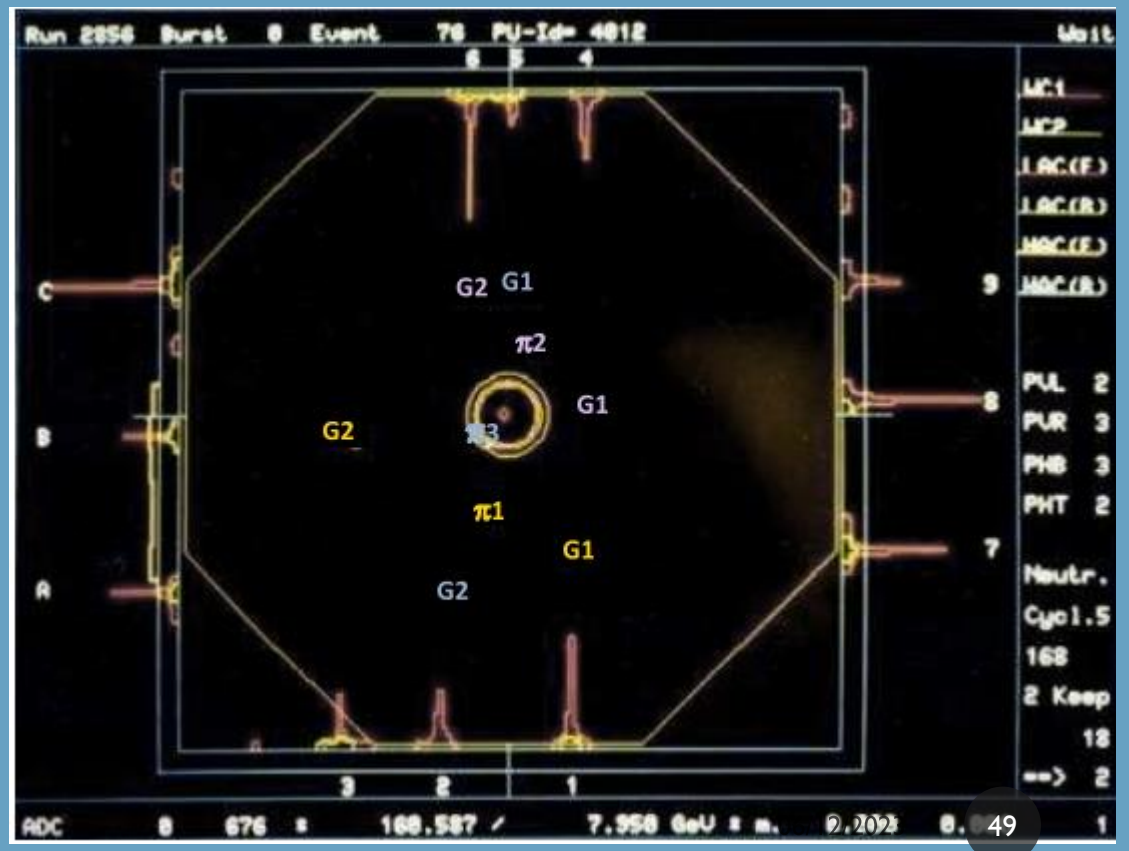

The first Direct CPV evidence : 1986 NA31 data

55 authors, 7 labs

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

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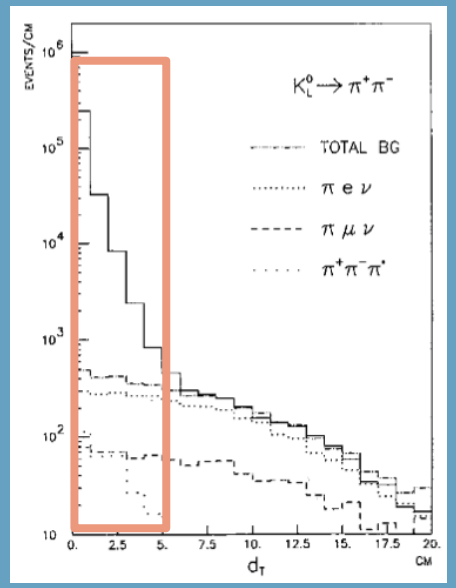
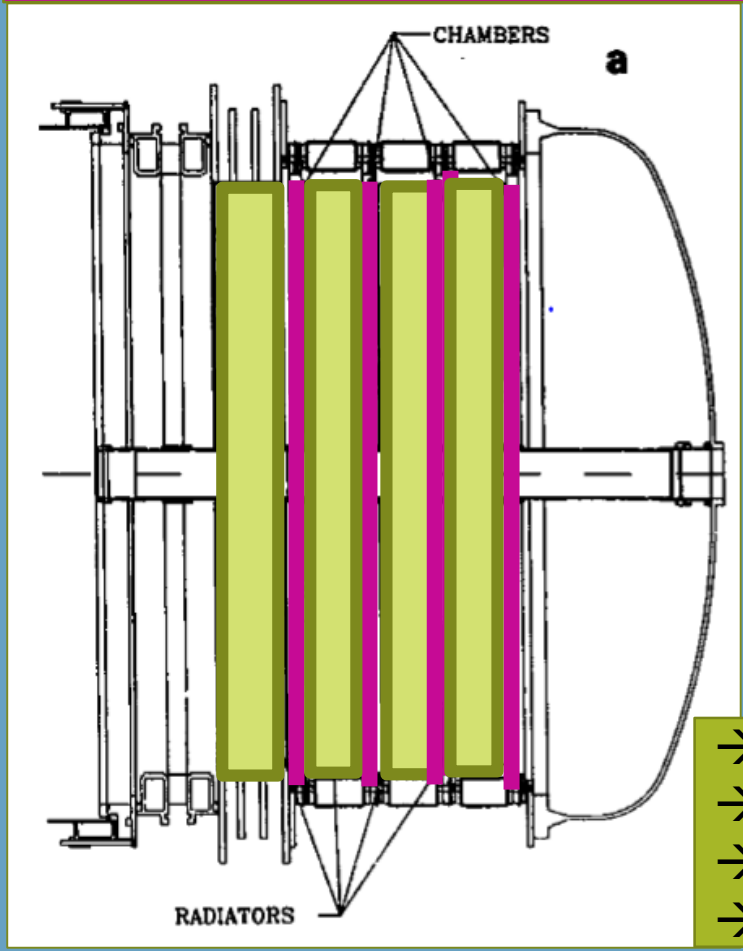


➔ 70% of backg in signal region : Ke3

DANIEL : Construction of a TRD to validate the Ke3 yield and shape for the 1988 run

Test the charged background : The Transition Radiation Detector for 1988 data taking

Wire chambers 2X and 2Y
Gaz : 30%Xe+55%He+15%CH4



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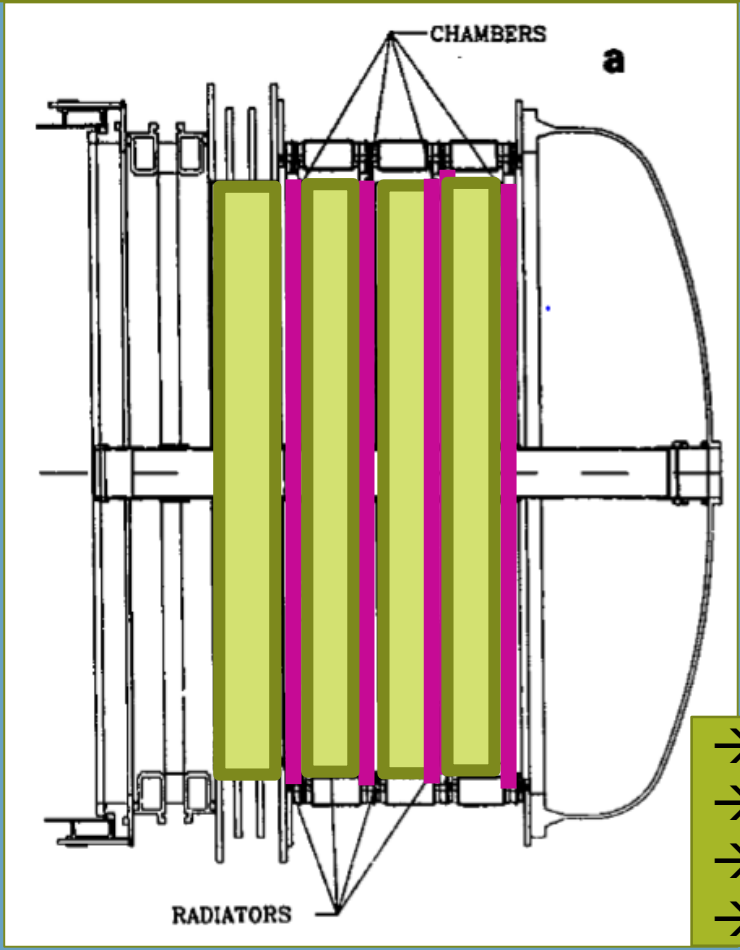

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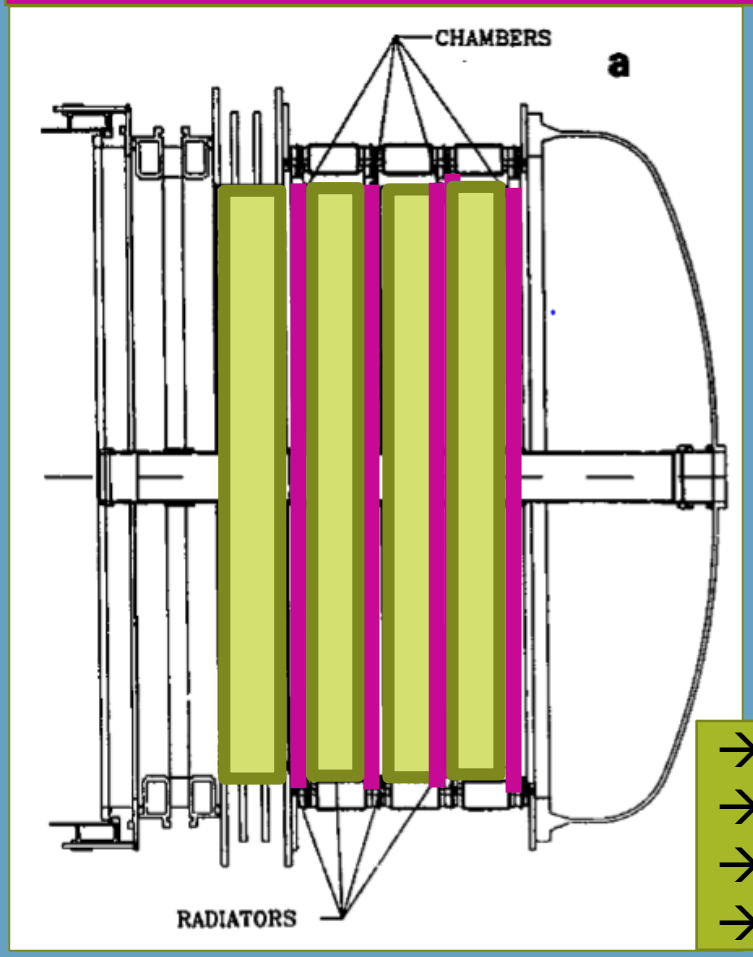
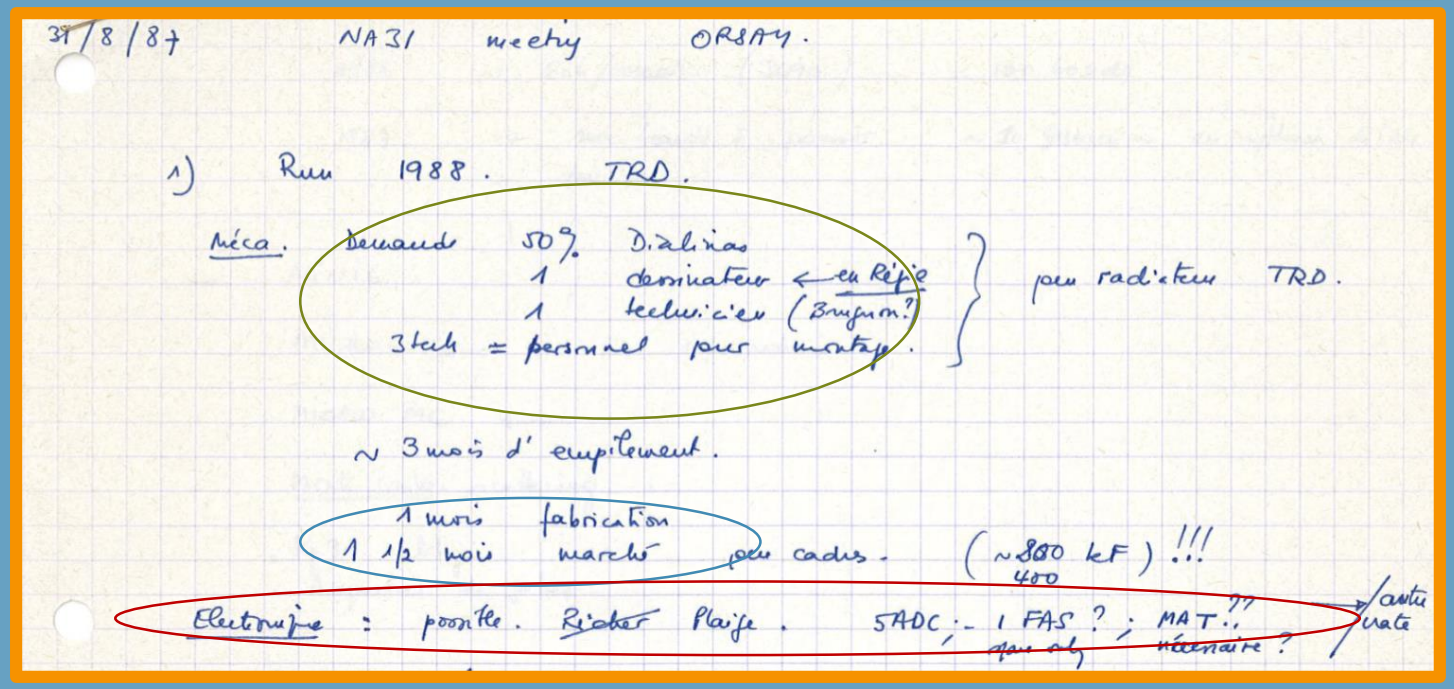


Minutes from A.M.Lutz



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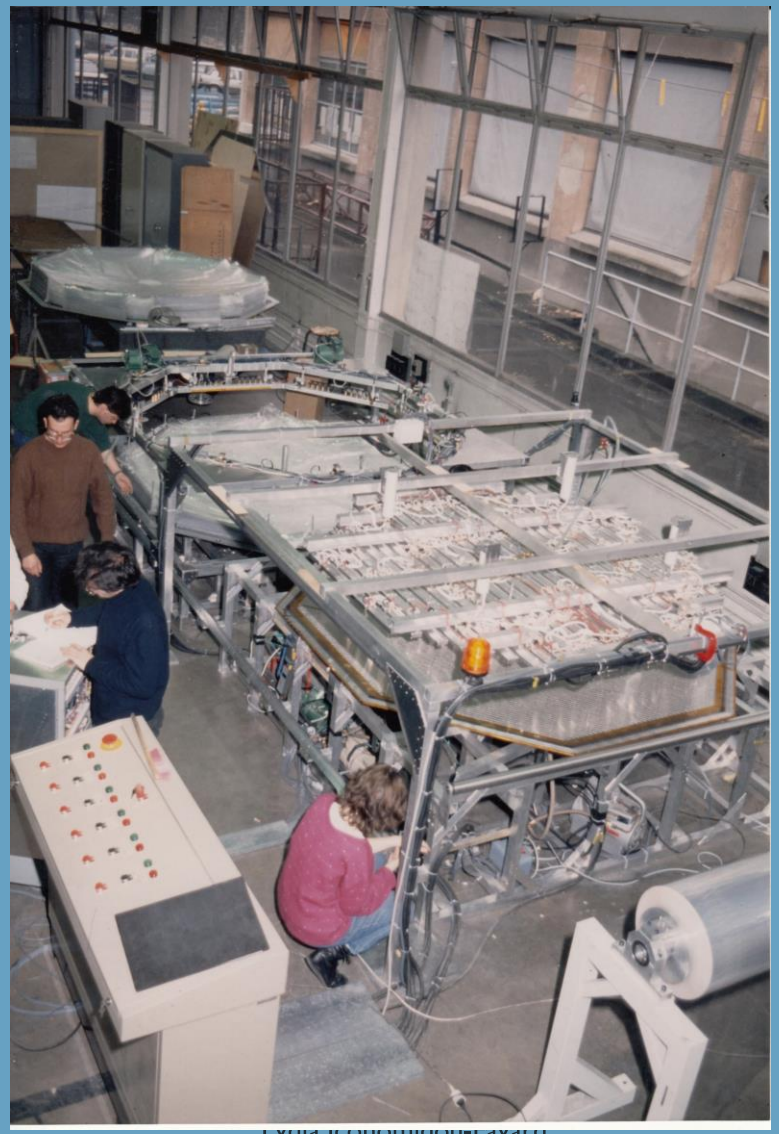
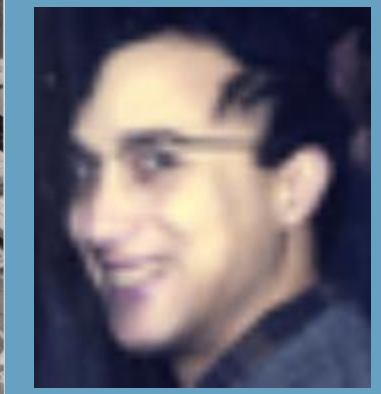
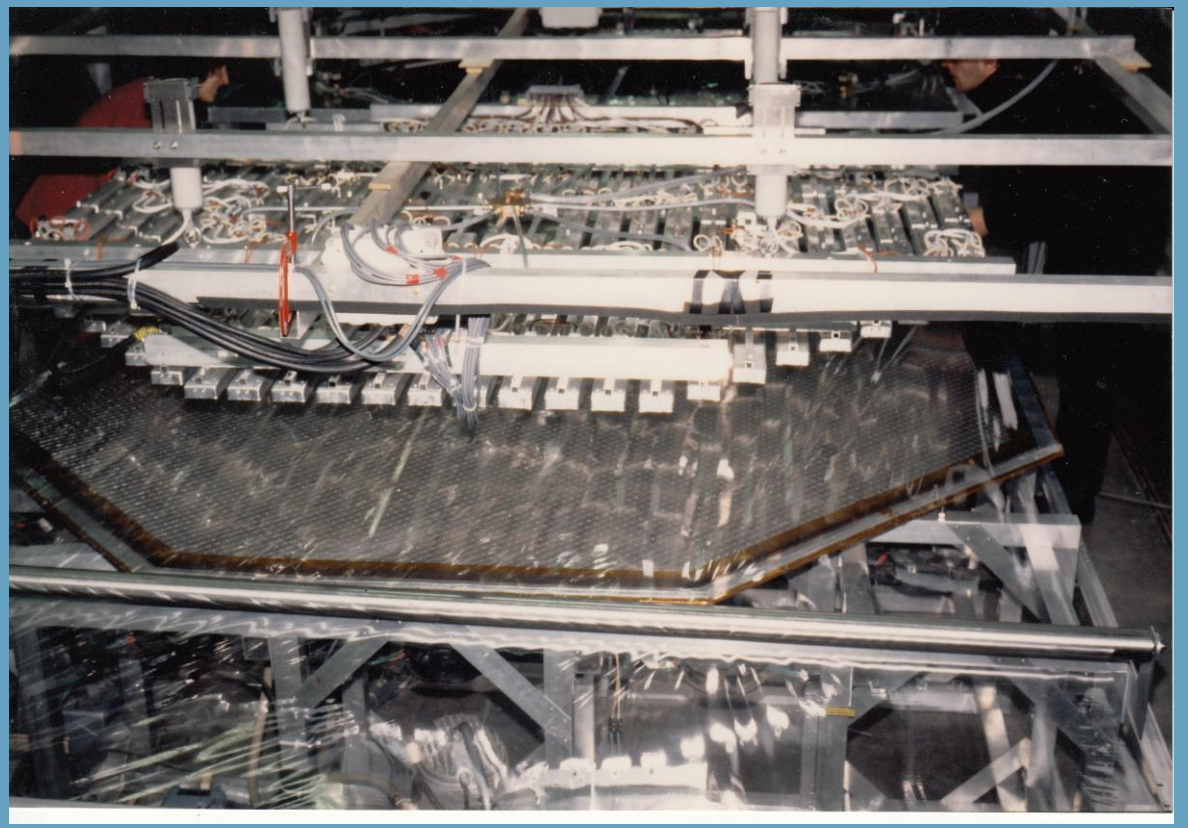
TRD: from construction to the analysis

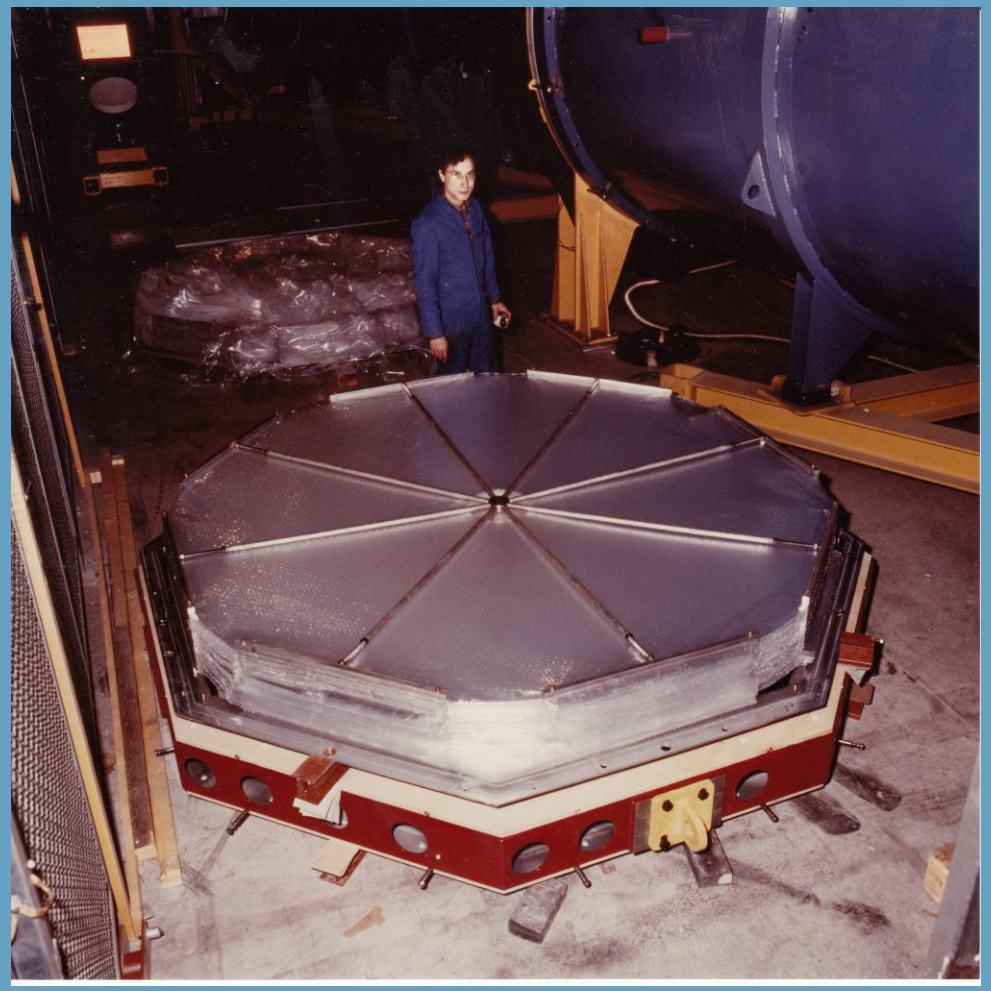


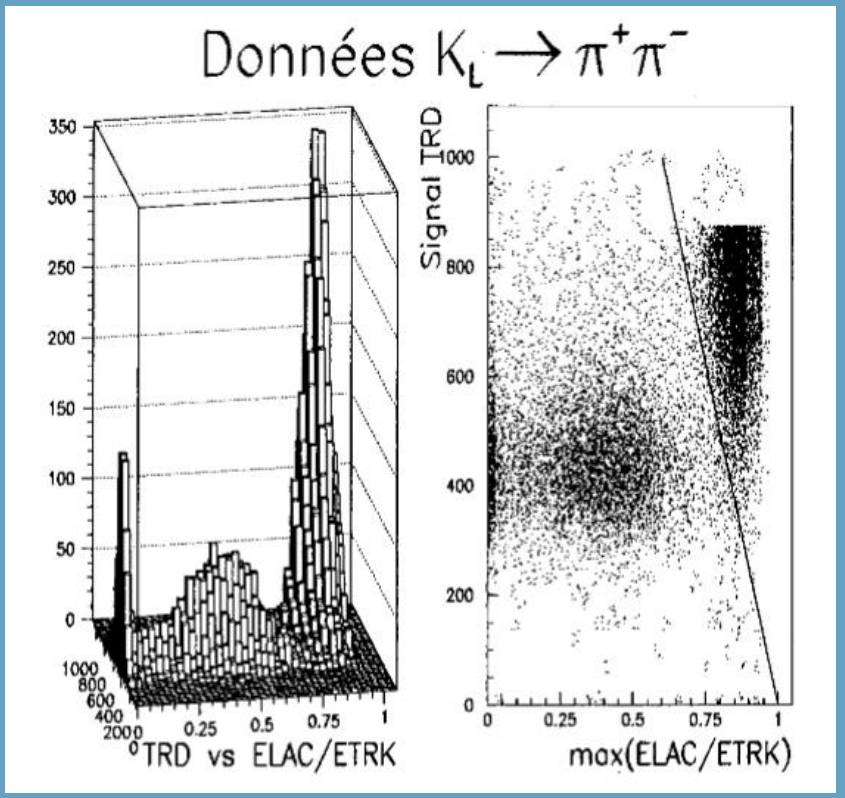




Construction of the Radiators
Hall "taup" at LAL
Maitre d'oeuvre M.Dialinas

TRD: from construction to the analysis





- Vaiidation of the background yield in the signal region.
- Confidence → Uncertainty ~0.1% (Gain of factor 2)

Test the accidental activity: the ZTDC for the 1989 half-data taking

The NA31 baseline method :

→Overlay by software the events with random triggers

→Compute gains and losses

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The NA31 baseline method :
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To test the baeline result:
Idea born at the end of a shift,
Daniel discussing with Ken Peach

Seeking for a “easy to build” and fast solution

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The NA31 baseline method :
→Overlay by software the events with random triggers
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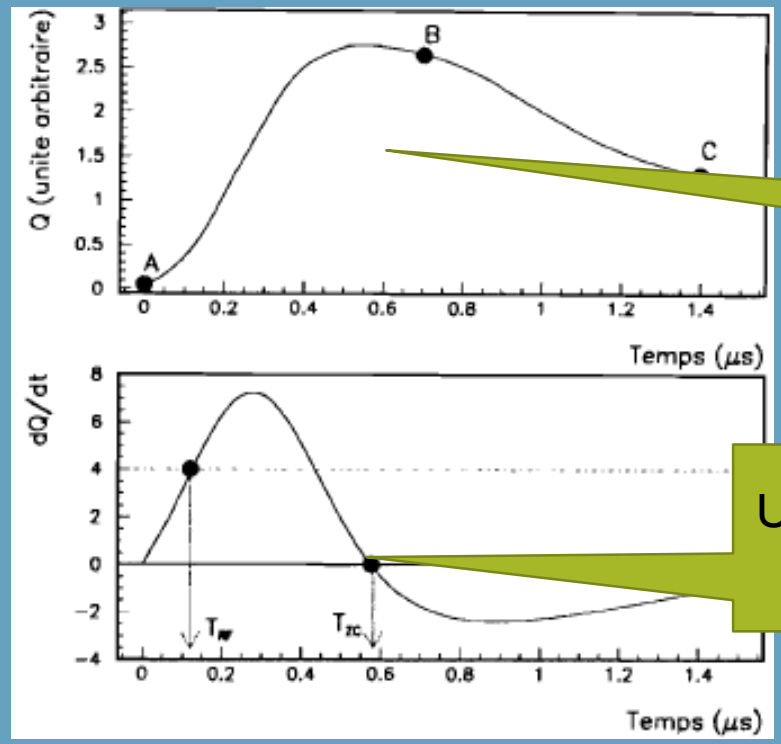
To test the baeline result:
Idea born at the end of a shift,
Daniel discussing with Ken Peach

Seeking for a “easy to build” and fast solution

Using LAC and HAD signals from existing electronics, to define the time of the maximum

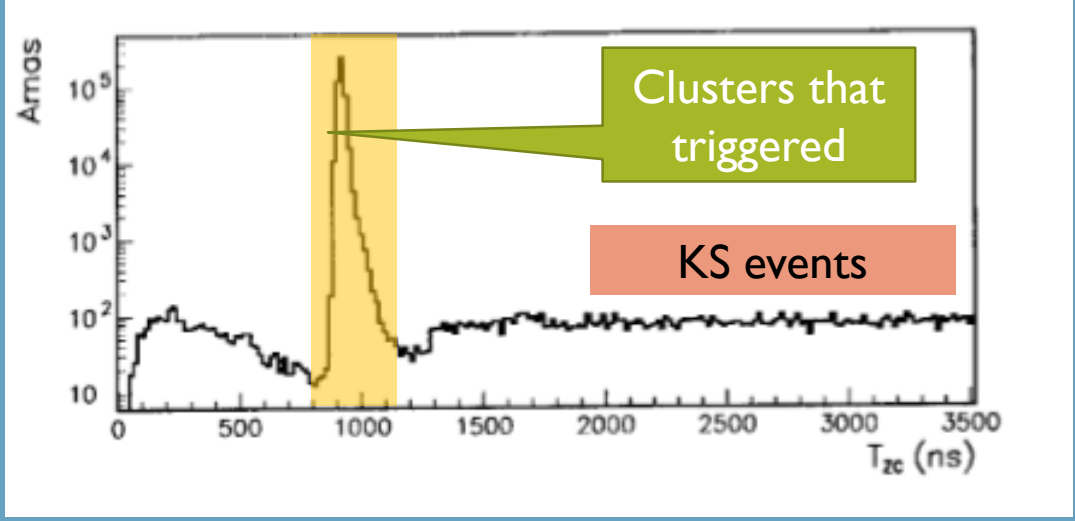


Calorimetric Signal

Use the time of the signal maximum

Maitre d’oeuvre : Orsay

Test the accidental activity: the ZTDC for the 1989 half-data taking



Mode	Losses-Gains % Charged	Loosses-Gains % Neutral
KS overlay KS ZTDC	(0.90+-0.04)% (0.89+-0.06)%	(1.20+-0.05)% (1.30+-0.07)%
KL Overlay KL ZTDC	(1.45+-0.05)% (1.52+-0.08)%	(1.55+-0.06)% (1.78+-0.10)%

➔**ZTDC** confirmed the accidental analysis from the baseline method

The final NA31 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]
CERN, CH-1211 Geneva 23, Switzerland

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Received 31 March 1988

1988

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

Combined NA31 : **$Re(\varepsilon'/\varepsilon)=(23.0+6.5)\ 10^{-4}$ 3.5σ**

49 authors, 6 labs

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

G.D. Barr, P. Buchholz, R. Carosi, D. Coward [1,2], D. Cundy, N. Doble, L. Gatignon, V. Gibson [3], P. Grafström, R. Hagelberg, J. van der Lans, H.N. Nelson [4], H. Wahl
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Fachbereich Physik, Universität Siegen, Siegen, Germany [12]

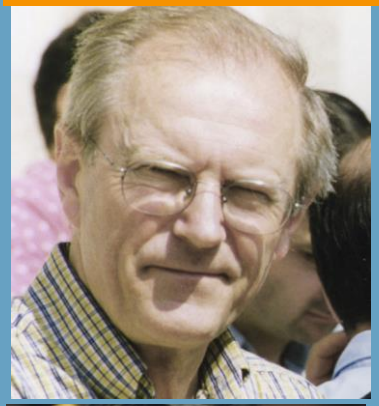
Received 13 September 1993

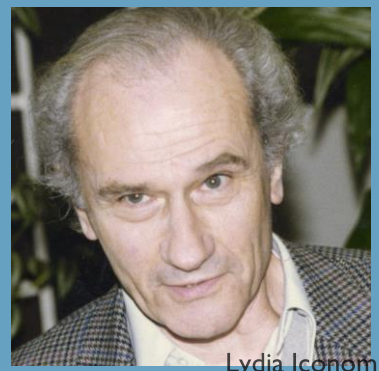
1993

$Re(\varepsilon'/\varepsilon)=(2.03+-0.67)10^{-3}$

The LAL-Orsay NA31 group

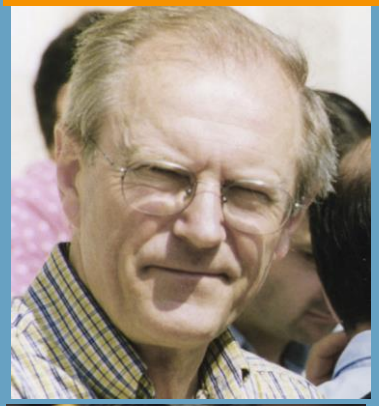
The "seniors"

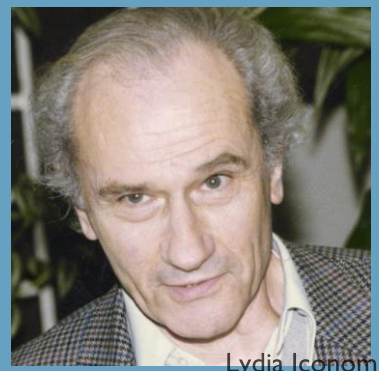




The LAL-Orsay NA31 group

The "seniors"





The Post-Docs

M. Corti

The LAL-Orsay NA31 group

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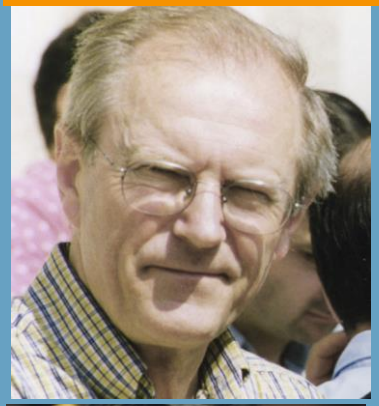

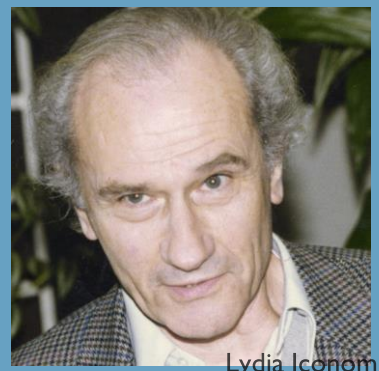

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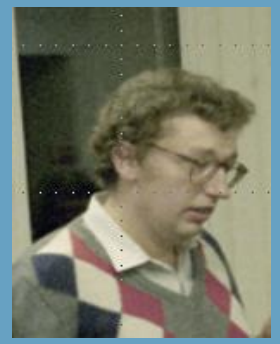
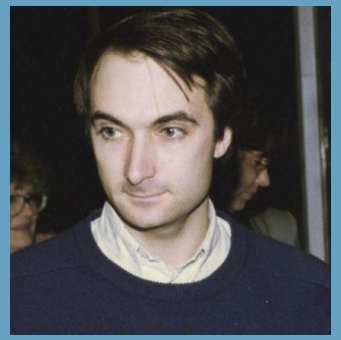


The HDRs



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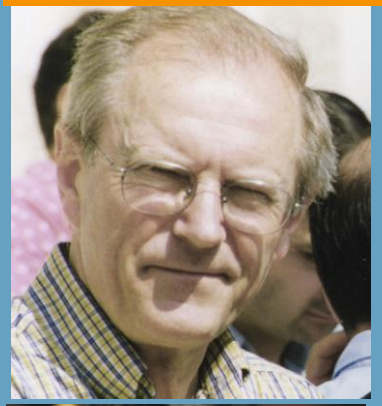

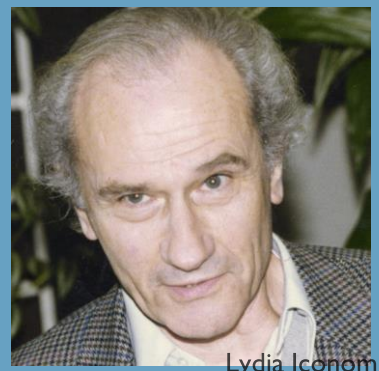

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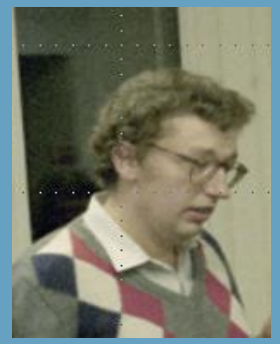

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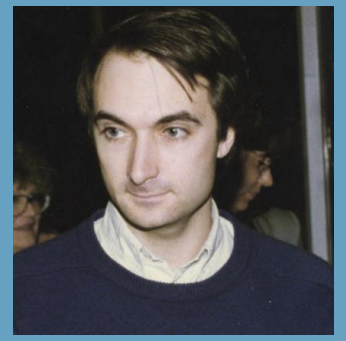
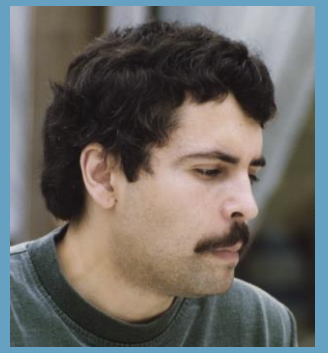


The PHD's

M.Hassan



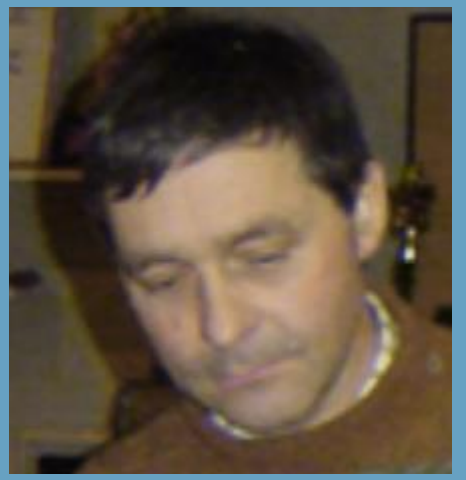
$K_S \rightarrow \gamma\gamma$

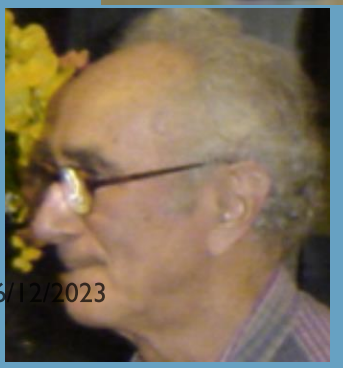
$K_L \rightarrow \pi^0\gamma\gamma$

The LAL-Orsay NA31 engineer-technician team

TRD : F.Berny J. Brugnon, J.P. Coulon, M. Dialinas, J.P. Marolleau, E.Plaige, D.Richard, J.P Richer

Calorimeter readout et AFBI “C.Arnault, A.Bellemain, R.Bernier, A.Bozzon[illegible] B.Chase, J.P.Coulon,J,C, Drulot, J.P. Marolleau, E,Plaige, J.P. Richer, A.Roudier





Daniel in NA31 and after

At that time Daniel was professor at Orsay University.

Despite the load of lectures, he was driving the Orsay activities efficiently and in all areas

Construction, data taking, Full epsilonPrime analysis

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Start involvement on LHC
Studies on LArg calorimetry

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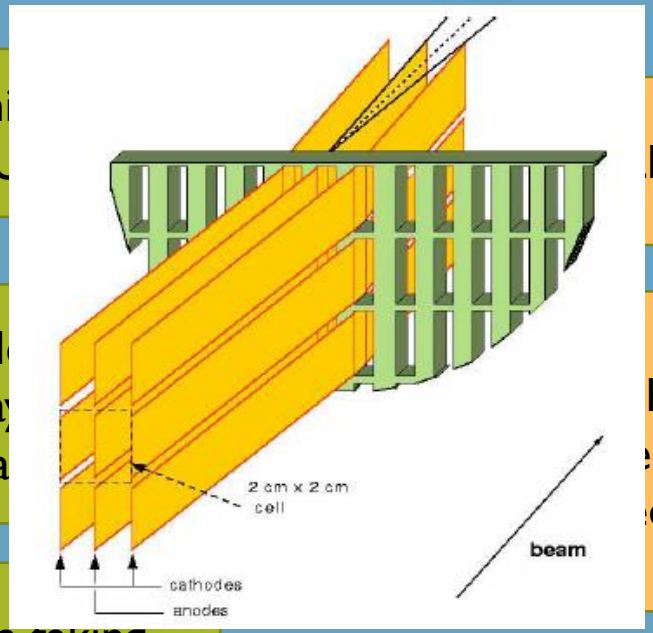
A small team from LAL joined NA48, the "new CERN DCPV in kaons experiment"
Aim : higher precision, more cancellations

Daniel in NA31 and after

At that time Dani
professor at Orsay U



HC delays…….

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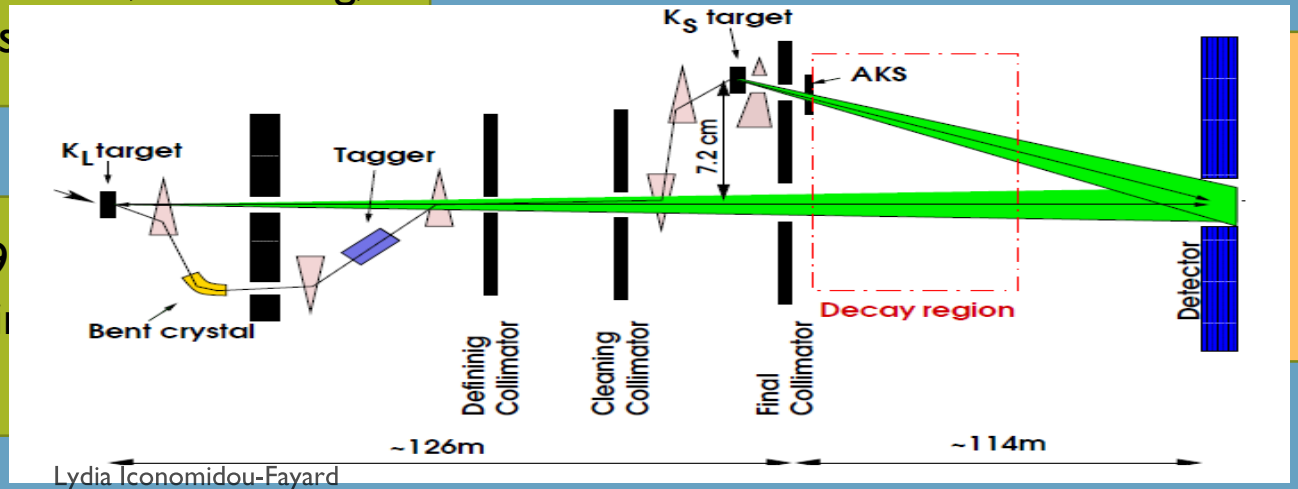
Construction, data taking,
Full eps

1989-19
Start i
Studies



NA48 :
→Challenging homogeneous Liquid Krypton calorimetry
→Record all 4 modes concurrently thanks to very clever beam setup

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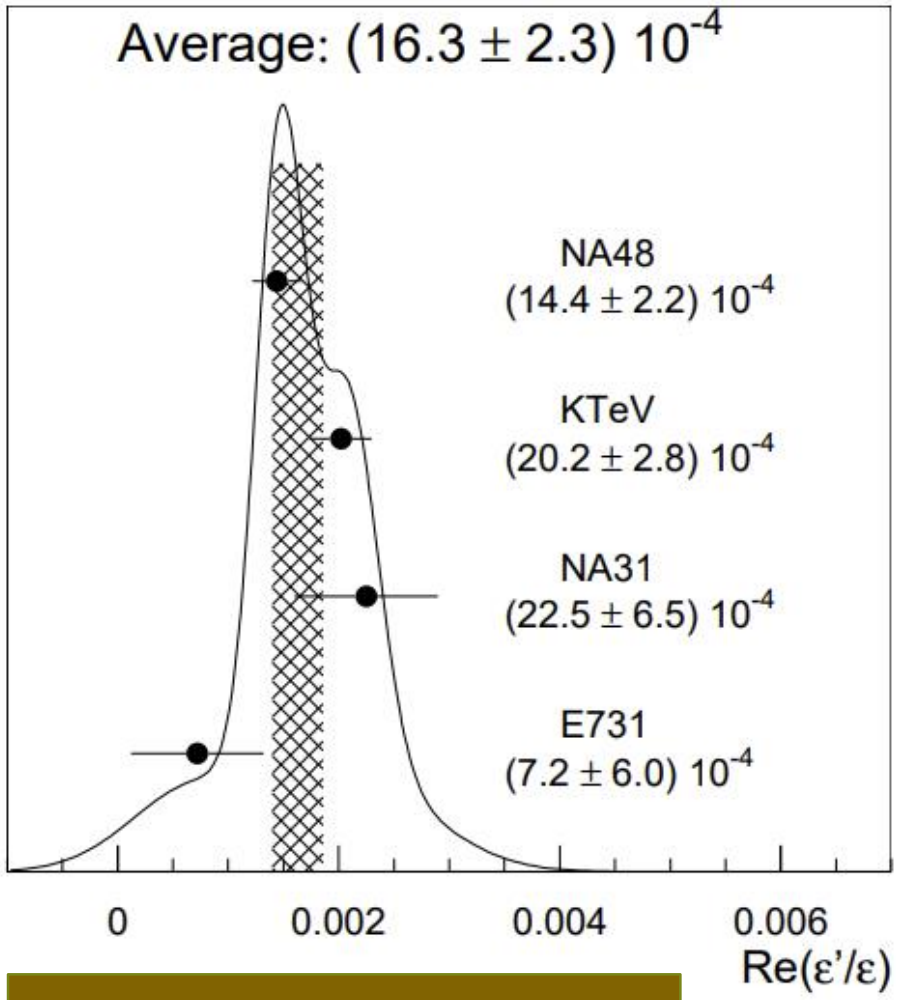
→Challenging homogeneous Liquid Krypton calorimetry
→Record all 4 modes concurrently thanks to very clever beam setup

Daniel , from ATLAS side, was closely following the NA48 progress

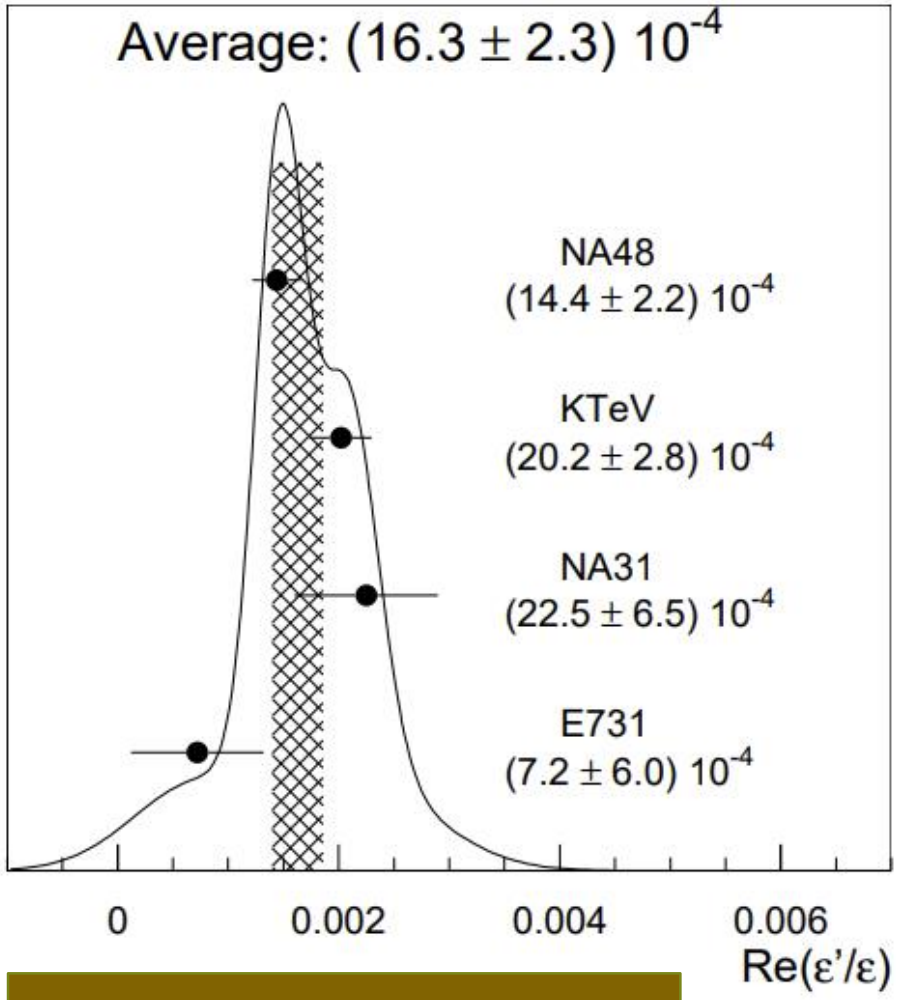
Very satisfied to see the final confirmation of the NA31 result

The “final” overall picture



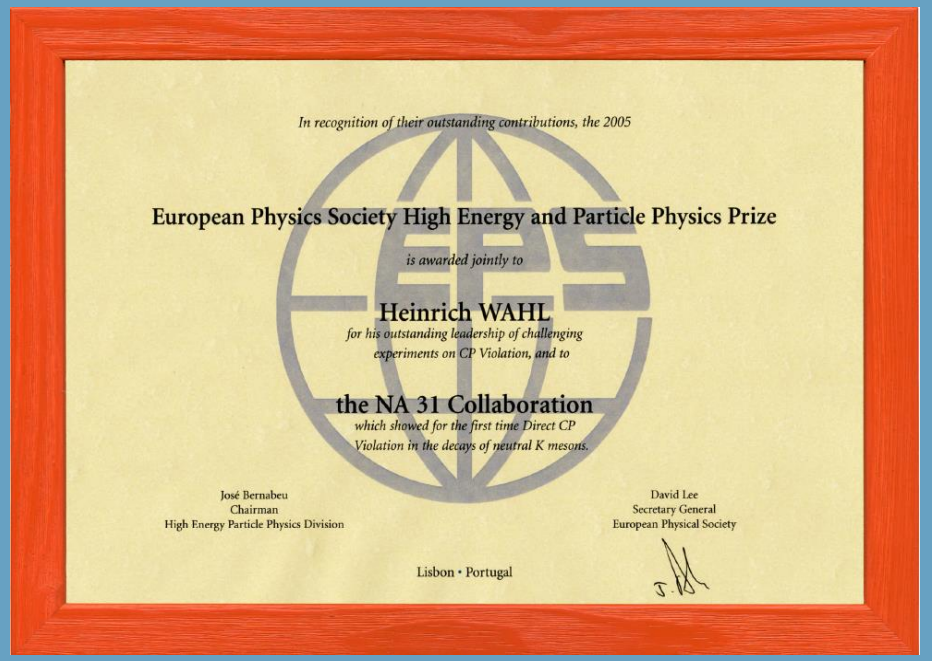
Confirmation of a « large »
Direct CPV component

The “final” overall picture



Confirmation of a « large » Direct CPV component

2005 : the EPS prize



Few words from Mario Calvetti

What I remember about Daniel in NA31 is that he was one of the nicest collaborators to work with. Clearly, he was understanding everything of the experiment, the details of the electronics, of the detectors and of the data analysis, besides having a deep understanding of the physics that we were looking for. The impression I had is that he was a very good scientist.

I would like to say few more things about him.

I have appreciated very much his positive active contribution to the work of the CERN LHC scientific committee, during the time of the construction of the LHC accelerator and detectors.

What I have admired the most of him, has been his engagement in the ATLAS project, taking the responsibility with his collaborators to build the liquid argon calorimeter. At that time, it was an incredible project, many years of work ahead, with many problems to solve, with no guaranties of been successful on a critical component of the experiment, sealed in a cryostat, as we know a very big responsibility.

When I have seen the reconstructed two photons invariant mass distribution of ATLAS, showing the Higgs mass, I realized the that was a dream coming to reality, beautiful.

Few words from a CP-Violating Physicist, Don Cundy

Looking back over 15 years to NA31, the first thing that comes to mind is that Daniel was a very agreeable and friendly collabotator and an excellent physicist. In addition, he always carried out his many responsibilities in his characteristic calm and efficient manner. His passion for calorimeters took precedence over NA48, but it turned out to be an excellent choice.

Le mot de la fin: Ilana, the PhD on NA31 TRD

Je peux aussi dire que j'ai vraiment apprécié la façon dont Mr Fournier m'a considéré en tant qu'étudiante. J'ai toujours eu l'impression qu'il me traitait de façon juste et equitable. Je suis aussi sure que je ne serais pas la seule à commenter sur son tempérament: Je ne crois pas l'avoir vu perdre son sang froid une seule fois (avec moi ou avec quiconque), ce qui, considérant la pression et ses responsabilités dans la collaboration NA31 (il fallait livrer les TRD à temps, les calibrer, s'assurer que l'on pouvait séparer les electrons des muons, …) est remarquable. J'ai travaillé sur plusieurs missions (Astro-E, XMM-Newton, Suzaku, Fermi, RXTE, Swift, Hitomi) quand j'étais à la NASA et je peux témoigner que cette capacité à rester calme sous pression est très rare.

Transmets toutes mes felicitations à Mr. Fournier et un bonjour à ceux que je connais.

Daniel's qualities (on top of calm..) to mimic:

Reaction

Innovation

Perseverance

Hard work

Organisation

Efficiency

BACKUP

Reconstruction of charged mode in NA31

→Charged tracks from the 2 WC

→ E1 and E2 energies from LAC +HAC

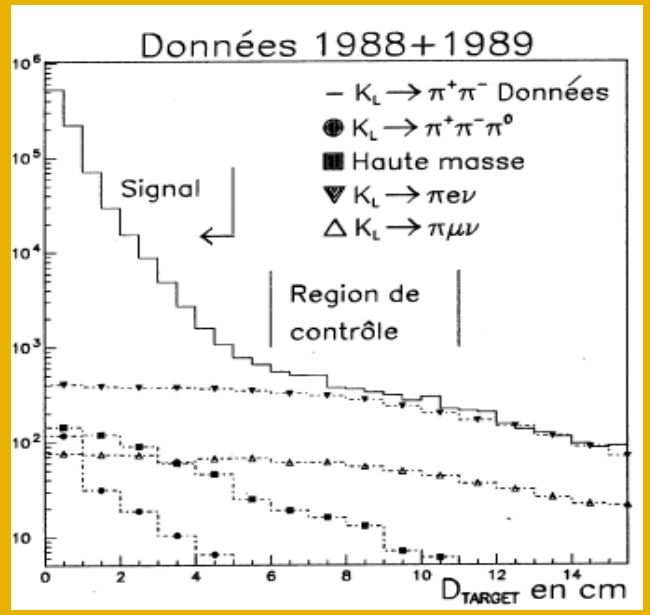
$$E_{K^0} = \frac{1}{\vartheta} \times \sqrt{(M_{K^0}^2 - m_\pi^2 \times T) \times T)}$$

$$T = 2 + \frac{E_1}{E_2} + \frac{E_2}{E_1}$$

$M^2_K = \vartheta^2 (E1+E2)^2/T + M^2_\pi T$

➔ Reject πμν : muon vetoes
➔Reject πεν: looking at LAC1/HAC
➔Reject $\pi^+\pi^-\pi^0$: no close photon

Require NO accoplanarity



Reconstruction of pi0pi0 mode in NA31

Only four clusters in LAC

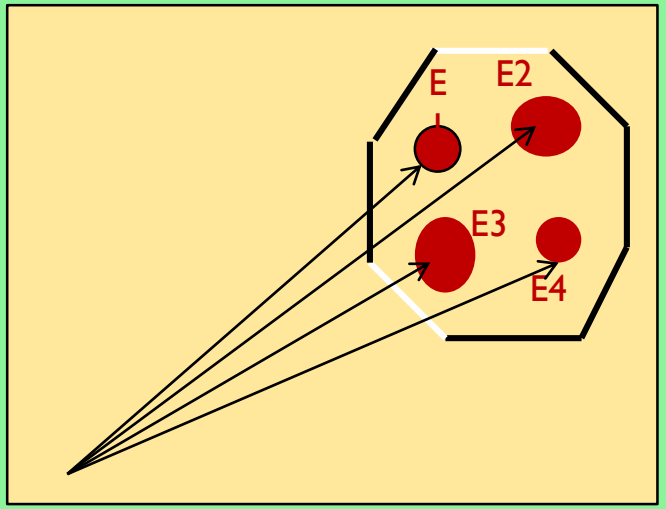
$$Z_{K^0} = Z_{LAC} - \frac{1}{M_{K^0}} \times \sqrt{\sum_{i=1,j>i}^{4} E_i \times E_j \times [(x_i - x_j)^2 + (y_i - y_j)^2]}$$

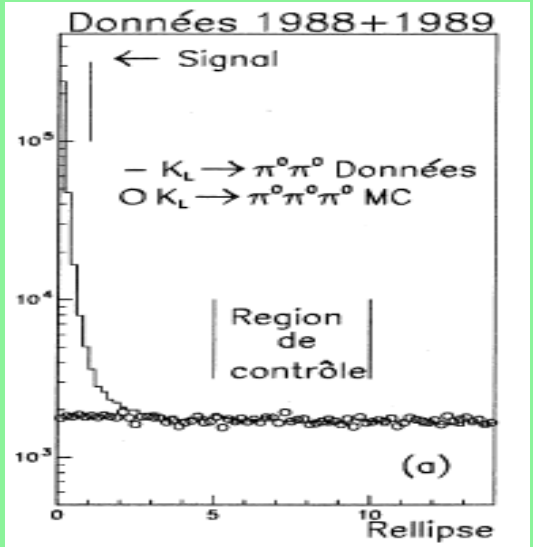
$$M_{\gamma_i\gamma_j} = \frac{1}{Z_{K^0}} \times \sqrt{E_i \times E_j \times [(x_i - x_j)^2 + (y_i - y_j)^2]}$$

Use a χ^2 to test event compatibility with a $2\pi^0$-decay

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

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

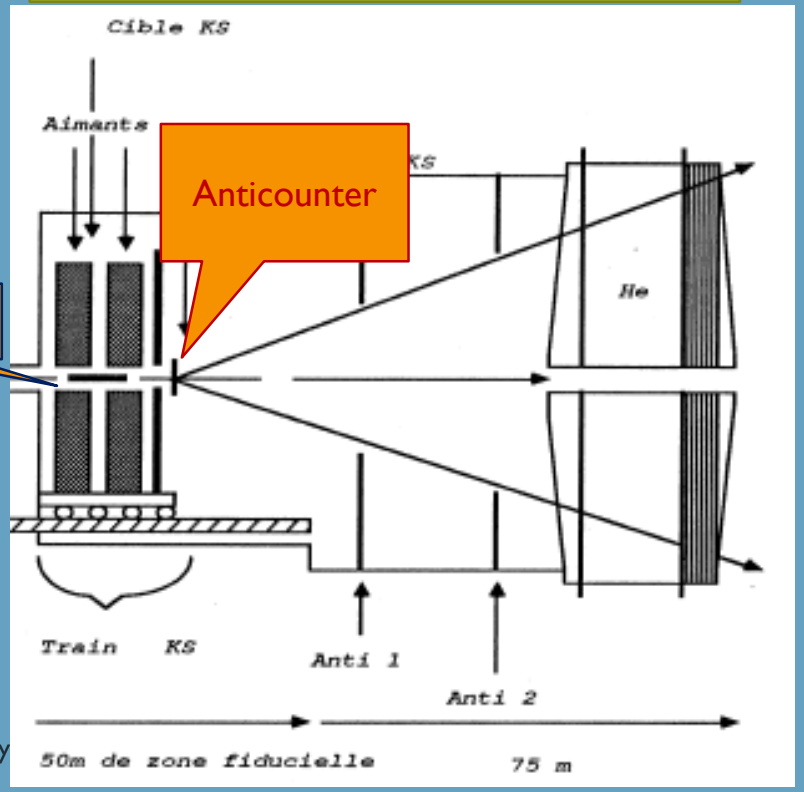




La determination de l'echelle d'énergie.

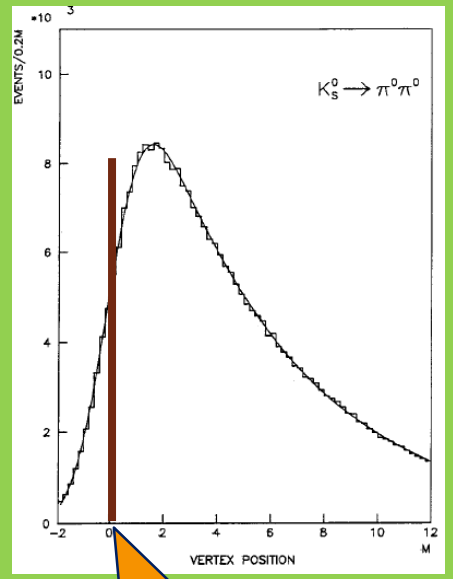
$$Z_{K^0} = Z_{LAC} - \frac{1}{M_{K^0}} \times \sqrt{\sum_{i=1,j>i}^{4} E_i \times E_j \times [(x_i - x_j)^2 + (y_i - y_j)^2]}$$

Energy Scale = Distance Scale



K_S target

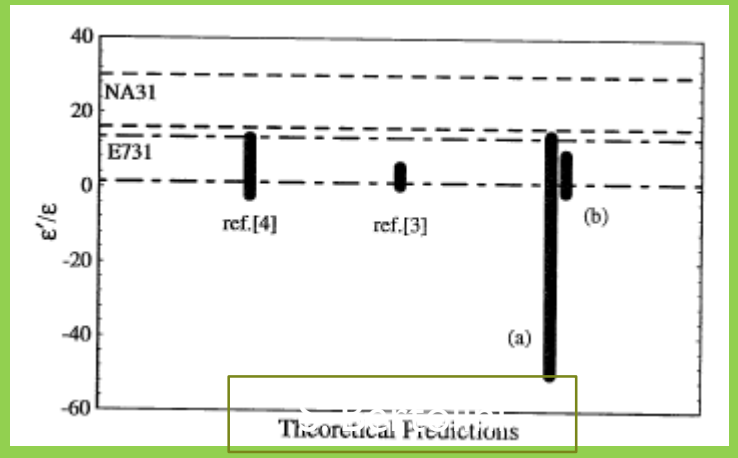
Anticounter's main goal:
Veto early K_S decays
Used also as a distance scale



Scale known to <0.05%

PROCEEDINGS OF THE WORKSHOP ON K PHYSICS

ORSAY, France,
30 mai - 4 juin 1996



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.

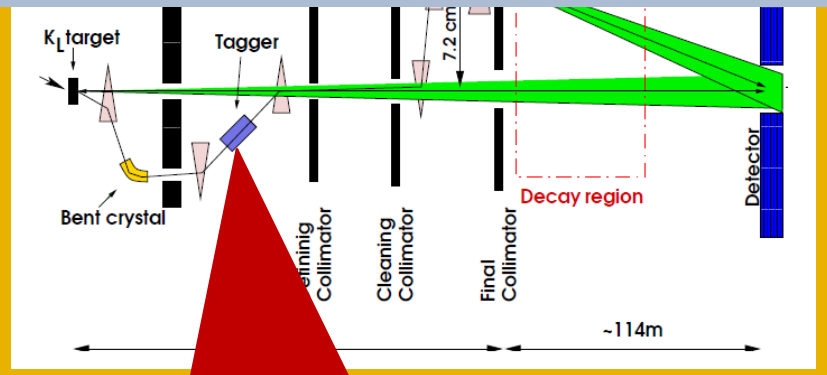
Let us hope that the future experimental and theoretical results will be sufficiently accurate to be able to see whether $\varepsilon'/\varepsilon \neq 0$ and whether the standard model agrees with the data. In any case the coming years should be very exciting.

Bruce Winstein 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.

➔New experiments:
NA48 (CERN) and KTeV (FNAL)

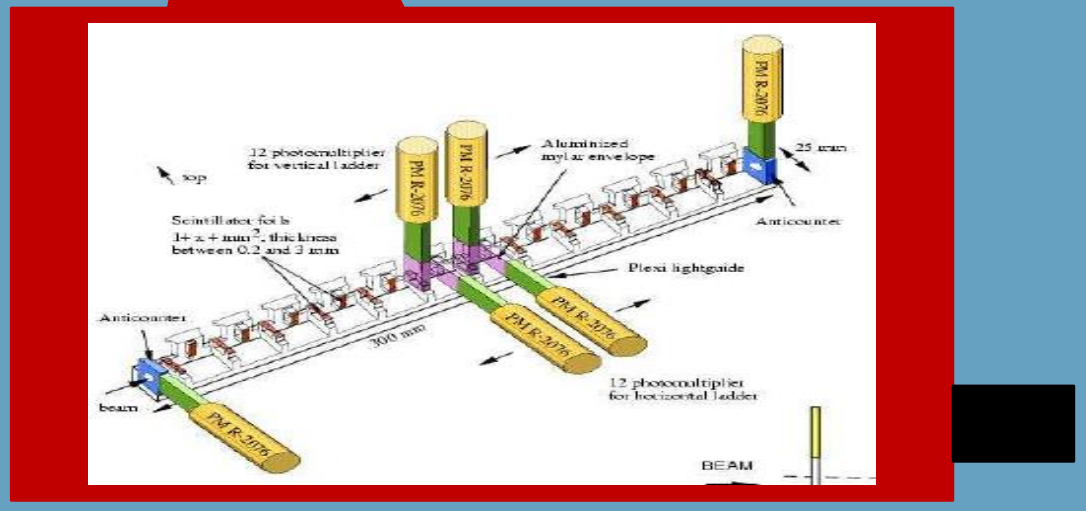
The NA48 beam Lines

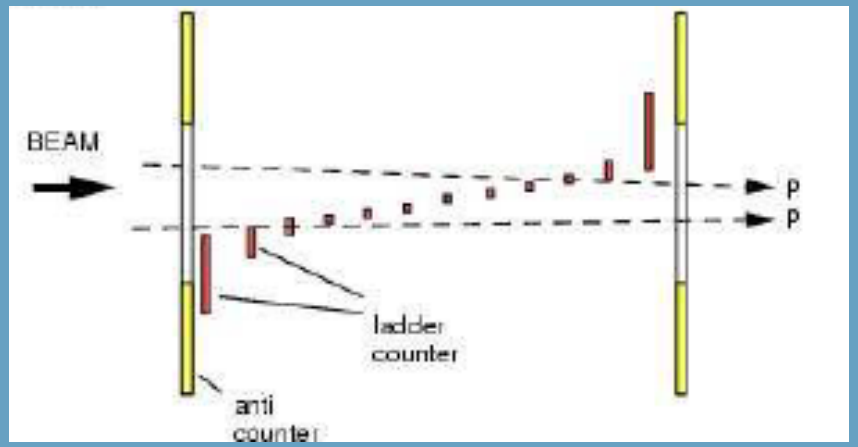


and horizontal orientations

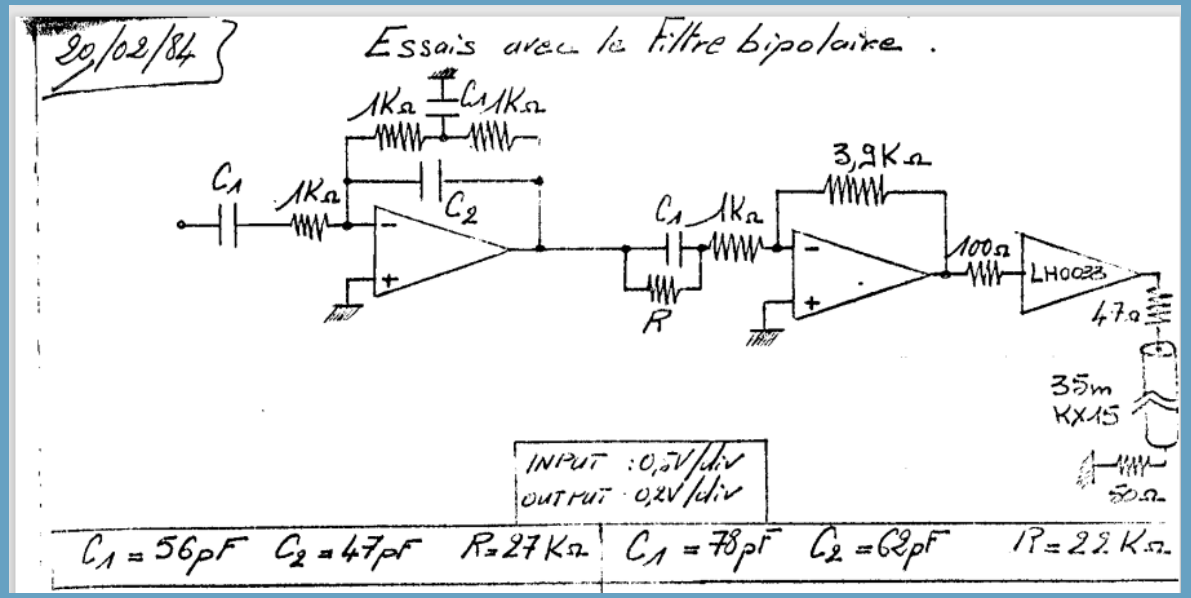
→Traversed ONLY by K_S protons
Readout by a 1Ghz 8-bit FADC

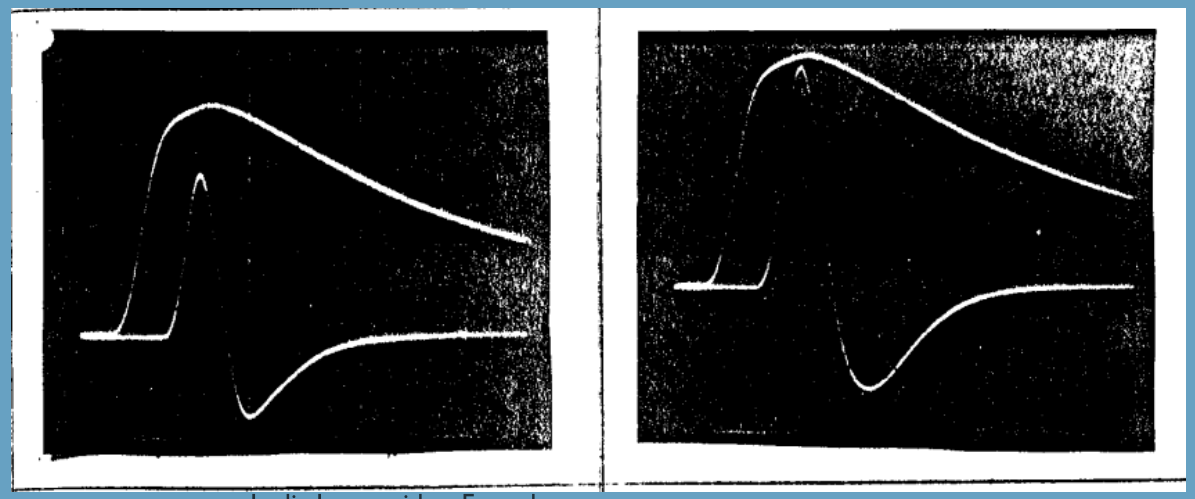
→ Gives the proton time ~180ps

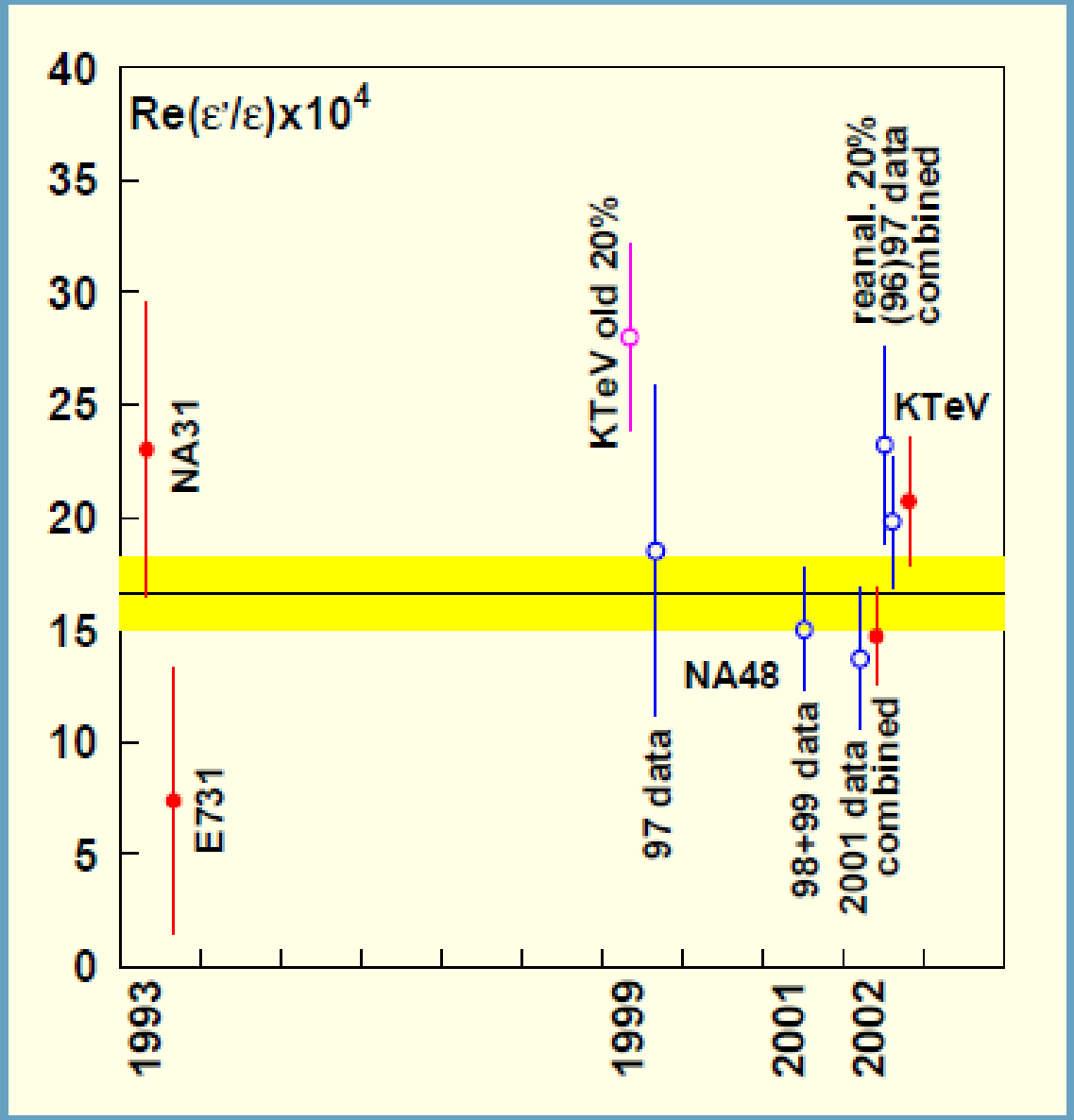




The Orsay contribution to LAC






Re(ε'/ε)x10^4
40
35
30
25
20
15
10
5
0
1993
1999
2001
2002
NA31
E731
KTeV old 20%
97 data
NA48
98+99 data
2001 data
combined
reanal. 20%
(96)97 data
combined
KTeV

Accumulated NA31 statistics

1986 Data

	Events	% Background
$K_L \to 2\pi^0$	109 000	4.0
$K_L \to \pi^+\pi^-$	295 000	0.6
$K_S \to 2\pi^0$	932 000	< 0.1
$K_S \to \pi^+\pi^-$	2 300 000	< 0.1

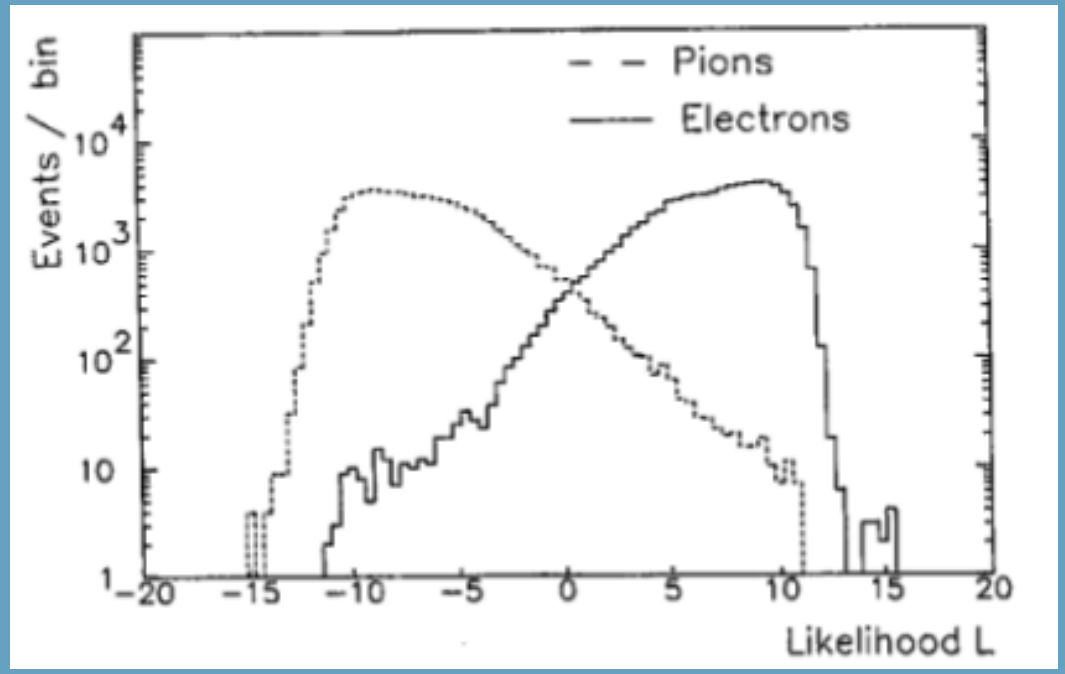
$$R_\eta = 0.977 \pm 0.004$$

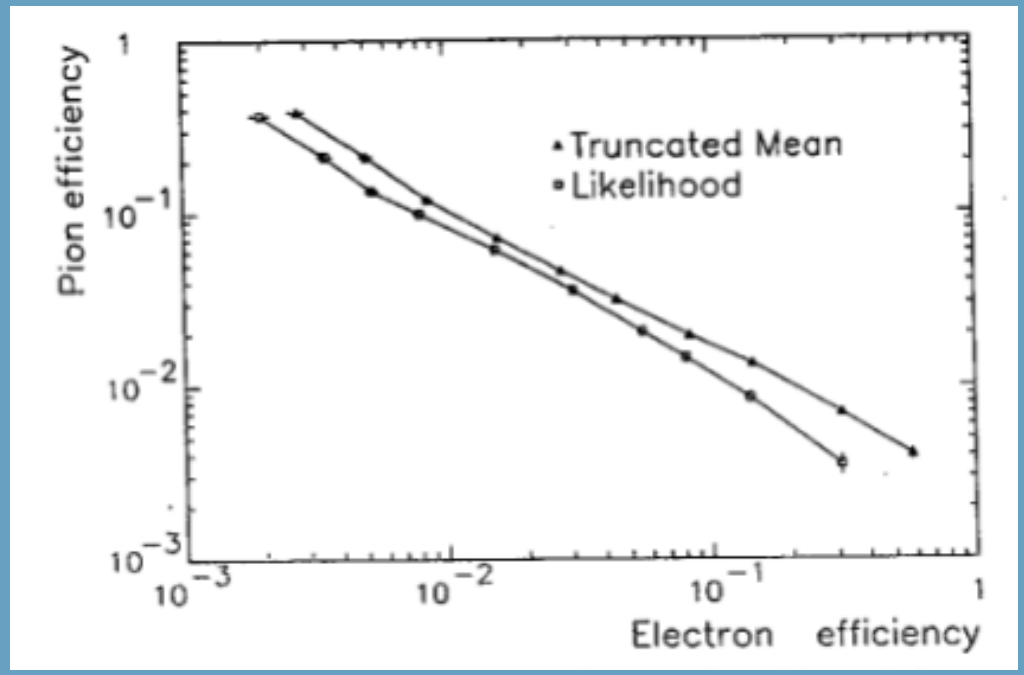
statistical error only

1988+1989 data

Mode de désintégration	Nombre d'événements	Bruit de fond en %
$K_L \to 2\pi^0$	319000	2.67
$K_L \to \pi^+\pi^-$	847000	0.76
$K_S \to 2\pi^0$	1322000	0.07
$K_S \to \pi^+\pi^-$	3241000	0.03

The NA31 TRD performances





For 90% rejected electons→~1.5% pions loss