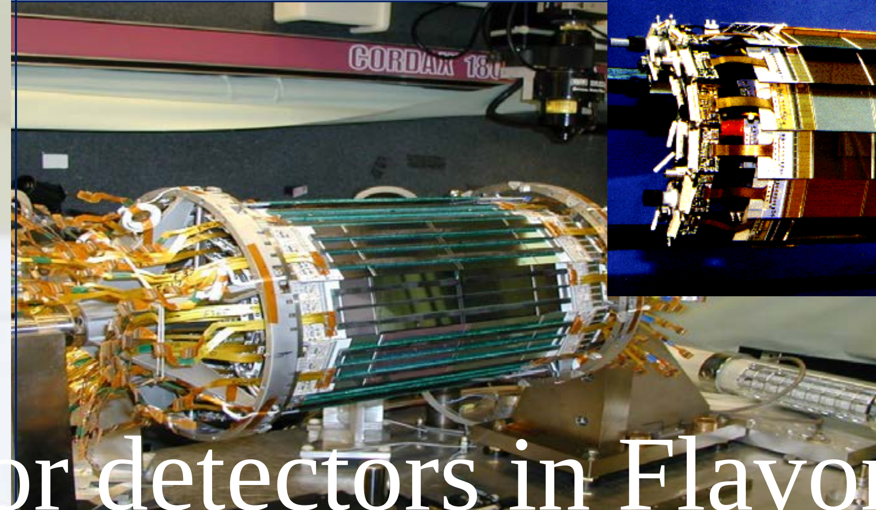
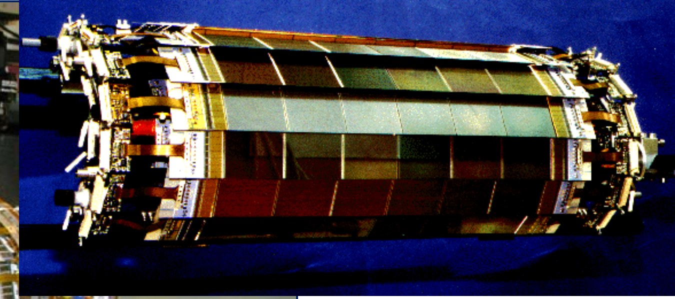




Semiconductor detectors in Flavor Physics

Marcello A Giorgi
Pavia 5 Dicembre 201

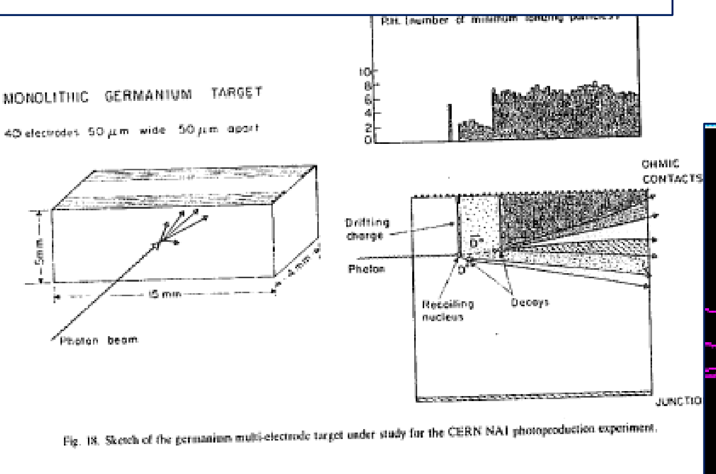
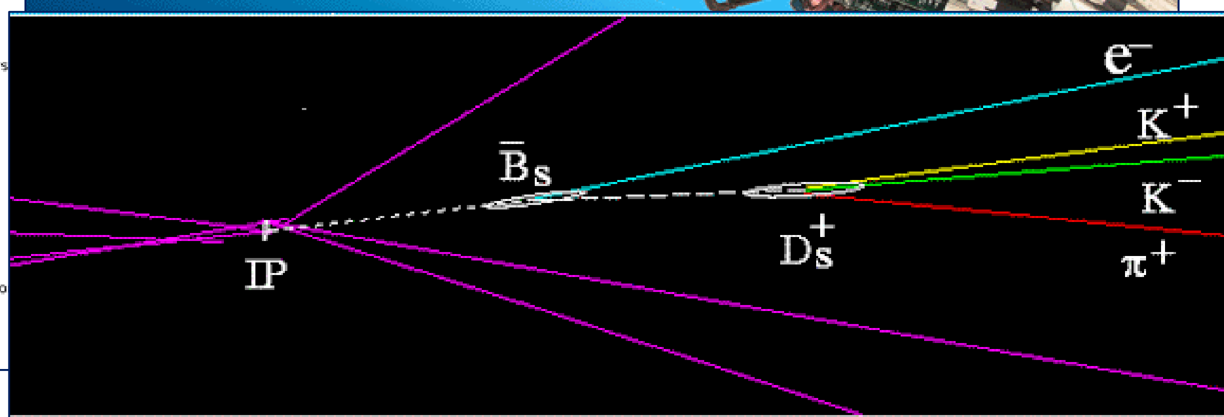


Fig. 18. Sketch of the germanium multi-electrode target under study for the CERN NA1 photoproduction experiment.



Outline

- Flavor Physics is relevant for the understanding of fundamental interactions
- The motivation for measuring decays and decay time of heavy flavor particles
- First steps .
- 36 years of experimental investigation.
- Evolution of the detectors.
- Role of low noise FE readouts

Pre-History

- Silicon and Germanium devices have been used since a very long time as energy detectors for nuclear spectroscopy and radiation monitoring.
- In High Energy experiments their use appears at the beginning of the eighties of last century, after the discovery of charm.

Beginning of Flavor Physics …….

- 1974 Discovery of charmonium (1^{--}) J/Ψ (3100).
- 1978 study of the ecited resonances Ψ' and Ψ''. Discovery of charm mesons D^0 e $D^\pm$
- Estimate of their mean lifetime $O(10^{-12} – 10^{-14}$ s) and very preliminary measurements with emulsions giving indication of $\tau \leq 10^{-14}$ s. (?)

Cont……..

A direct electronic measurement of τ_{charm} , two basic tools were needed :

1. A Lorentz boost=$\beta\gamma$ to extend the meson decay path.
2. The decay point measuremed with a good precision O(100-200μm).

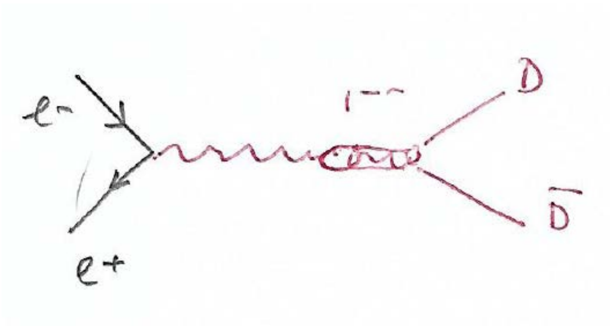
Diffractive photoproduction of charm

Basic idea to satisfy the two conditions:

- Diffractive photoproduction from nuclei (E_γ >100GeV) of a pure state (1^{--}) with a minimum momentum transferred to the recoiling nucleus. $\gamma A \rightarrow A D \bar{D}$ is among the processes allowed in the diffractive production.

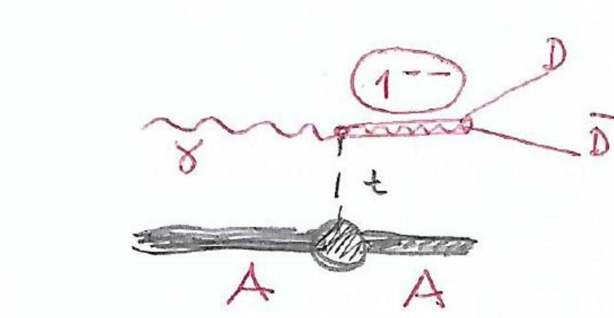
- The beam energy flows into the diffracted 1^{--} state $D^+ D^- or\ D^0 \bar{D}^0$
The resulting boost (βγ~20–30) of the cms allows decay paths of millimeters , making possible the measurement of lifetimes in the range 5 10^{-14} – 10^{-12} s.
- The detector space resolution at least O(100 μm).

Virtual photon production and Lorentz Boost



After discovery of J/Ψ Charm mesons were also discovered at Spear (SLAC) . It was the start of heavy flavor era. Charm spectroscopy and the measurement of the charm lifetimes were expected to allow the understanding of efundamental interactions eventually at the base of SM.

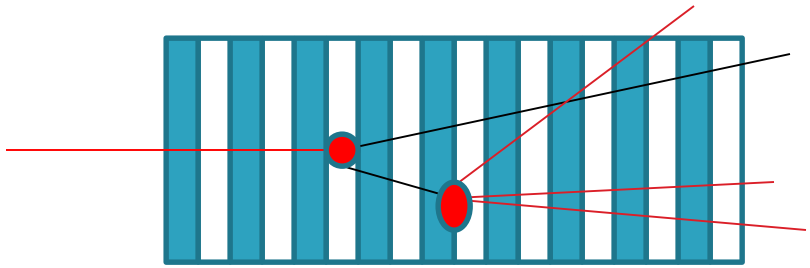
The gas chambers appeared to be inadequate for the measurement of lifetimes shorter then 10^{-11} s .Emulsion experiments failed to measure short decays of charm particles produced in hadronic processes.



The idea of NA1 was to use diffractive coherent photoproduction with photon of energy >100 GeV,of a clean state of Charm pair similar to the charm meson pair produced at SLAC. The final state was expected clean and in addition a boost of the state would have extended up to millimeters the decay path of a particle living between 10-13 and 10-12 s .

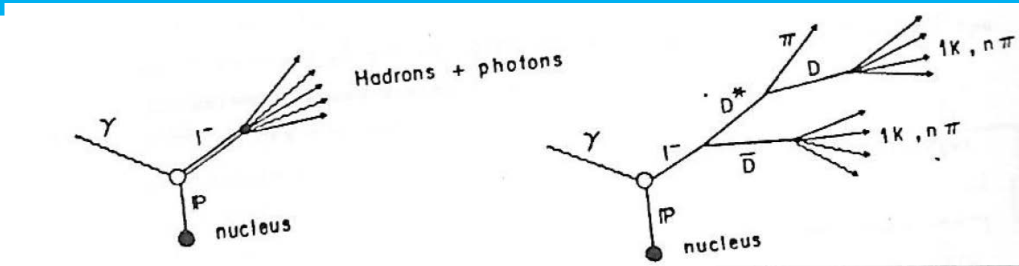
NA1 idea (measure Energy)

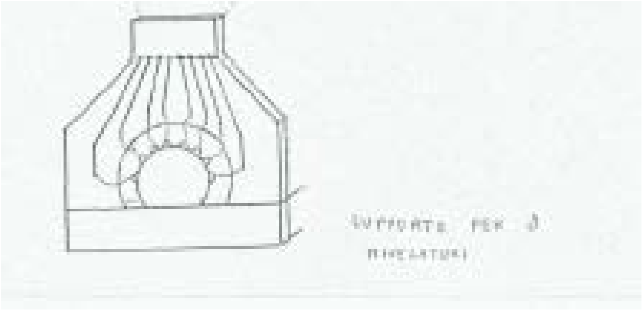
A detector telescope as a target. The signal of nuclear recoil gives the production point and the multiplicity variation in one layer gives a decay point.

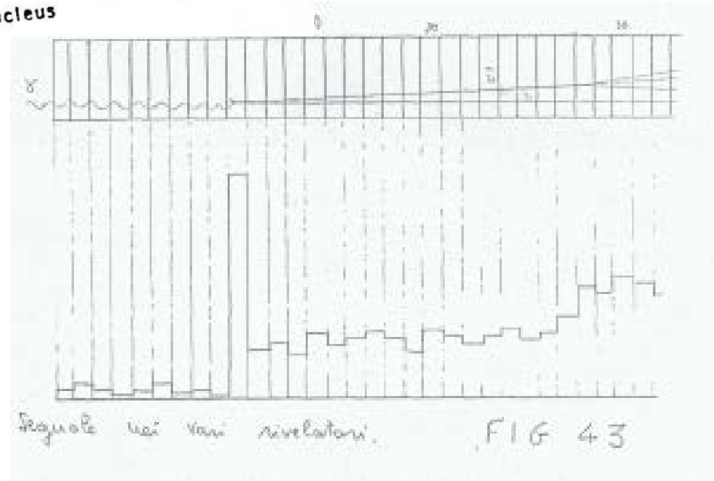


The multiplicity is measured by the pulse height proportional to the energy released in one layer of the telescope.

G.Batignani (Laurea Thesis) (nov 1978)

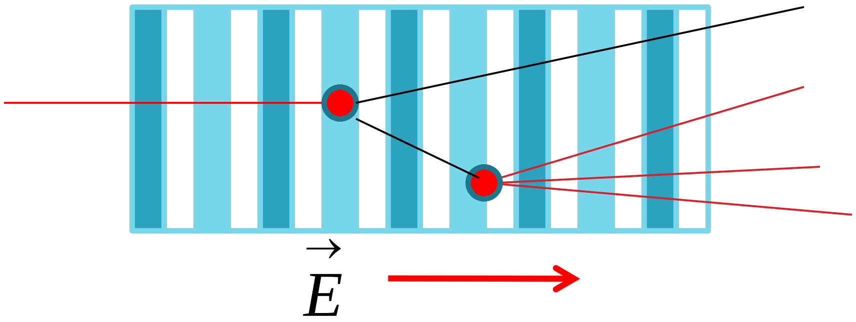






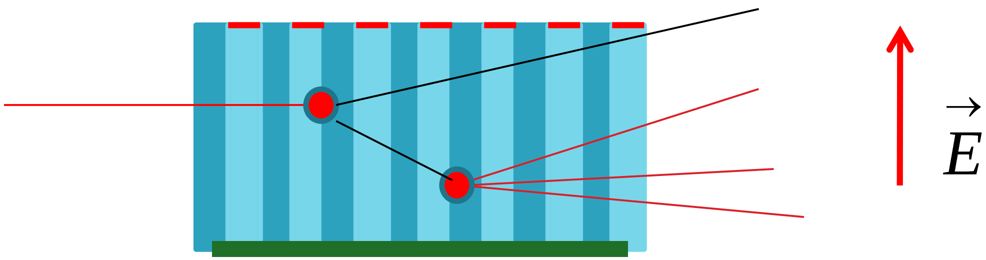
In 1980 data were taken with a telescope of 300 mm thick silicon detectors. This first telescope was built in the INFN lab of Pisa with home made single pixel surface barrier diodes .

2^{nd} step: From Si telescope to Ge strip target



Silicon telescope 300mm pitch

eliminate the useless gaps



Monolithic Ge Detector strip 25 μm (50 μm pitch)

Ge Strip Detector (NA1 Target)

(1982) NA1 improved precisionin the charm lifetime

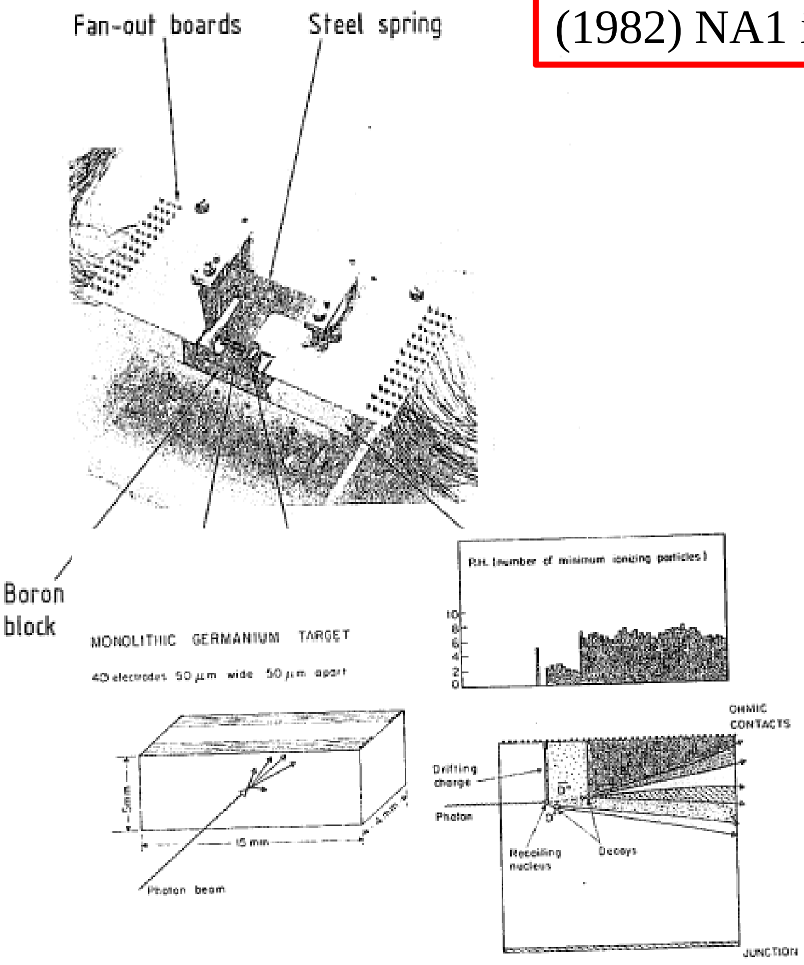


Fig. 18. Sketch of the germanium multi-electrode target under study for the CERN NA1 photoproduction experiment.

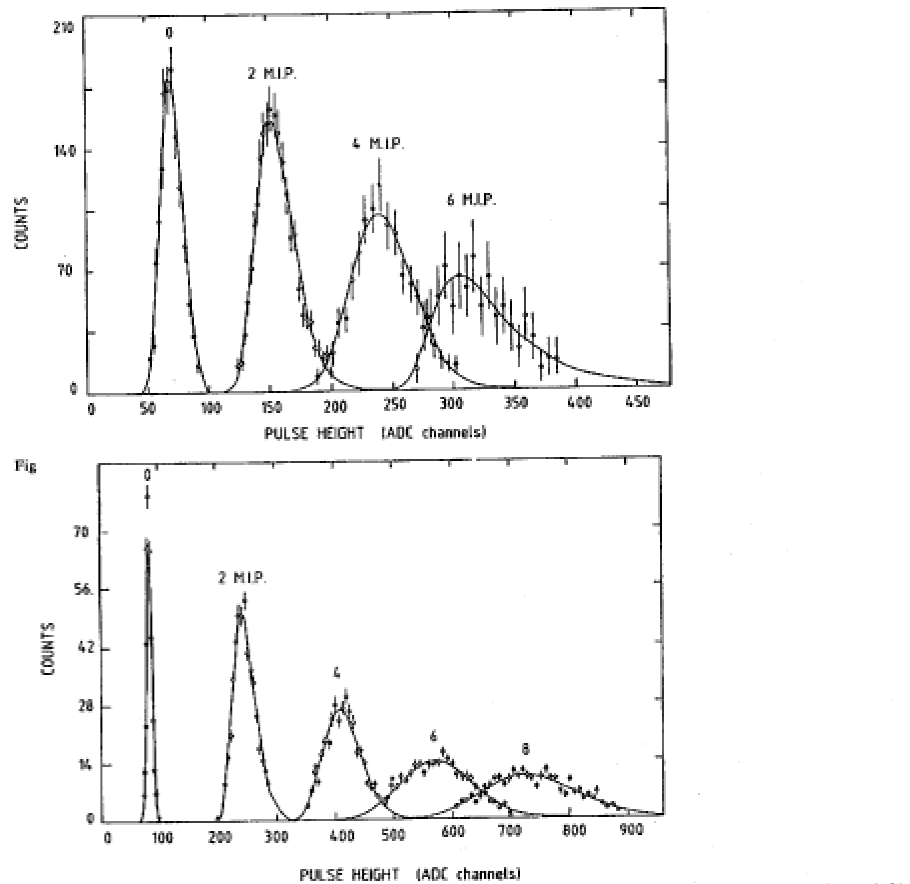
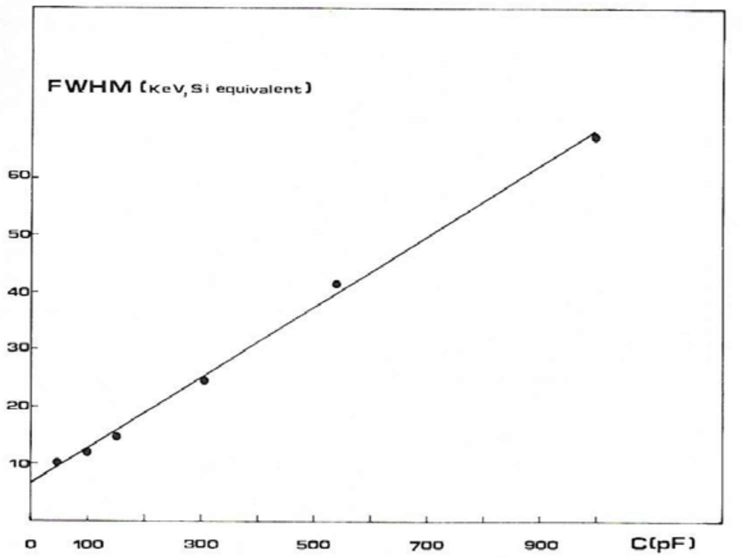
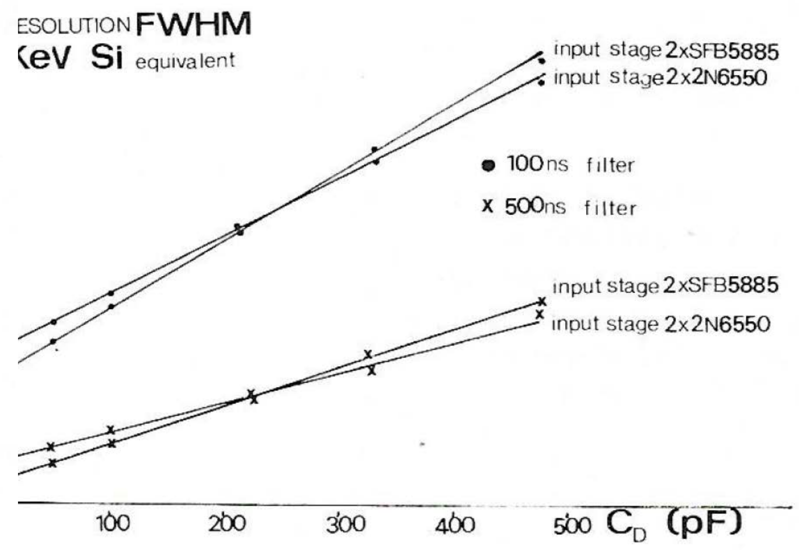


Fig. 7. Pulse-height spectra for even multiplicities of minimum ionizing particles in one strip of detector 501-8.6b (100 μm pitch).

Filtering the signals





Each detector of NA1 telecope had a capacitance of 60pF.

Nucl. Instrum. and Meth. 193, 539 (1982)

38 – S. Benso, P.F. Manfredi et al: Silicon Telescopes as Charm Decay Detectors.

Nucl. Instrum. and Meth. 201, 329 (1982)

39 – P. D’Angelo, A. Hrisoho, P. Jarron, P.F. Manfredi, J. Poinsignon:

Analysis of Low Noise Bipolar Transistor Head Amplifiers for High Energy Applications of Silicon Detectors.

Nucl. Instrum. and Meth. 193,533 (1982)

40 – R. L. Chase, P. D’Angelo, A. Hrisoho, P.F. Manfredi, J. Poinsignon:

A Periodically Stabilized Amplifier System for Silicon Telescopes on Pulsed Accelerators.

Start of the strip detectors era

First surface barrier strip detector using charge division (Laurea thesis M. Dell'Orso, Pisa).

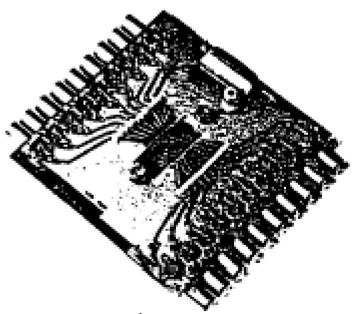


Fig. 3: The assembly of MESD.

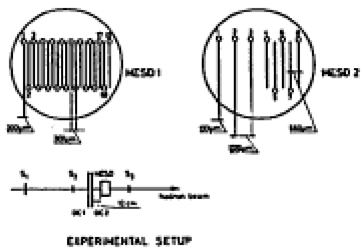


Fig. 7: Experimental set-up.

Miniaturization of High-Energy Physics Detectors

Edited by
A. Stefanini
INFN Sezione di Pisa
Pisa, Italy

Plenum Press • New York and London

First Pisa meeeting on advanced Detectors (Elba series)

• • In this experiment a multilayer silicon detector telescope was set on a 150 GeV bremsstrahlung beam at CERN SPS and used as a target to measure the lifetime of coherently produced charmed mesons [4].

During the project and construction of part of the target employed in the FRAMM-NaI experiment a fair competence on solid state detectors has been developed in the INFN laboratory at Pisa which has helped the development of a new high spatial resolution detector: MESD (Multi Electrode Silicon Detector) [5].

The MESD is a step forward in the solid state detectors technique because by structuring one or both the electrodes one can achieve a very good spatial resolution although space sensitive detectors for use different from high energy physics have been studied in the past [6]. This development is still at its early stages. I report here the results obtained in our laboratory. • • • • •

6) High spatial resolution

MESD is therefore a very powerful tool to investigate production vertices and decay path of long living heavy mesons in fixed target experiments.

Point 3 can allow them to be put inside the pipes of colliding beams accelerators around interaction regions to work in situation free of multiple scattering from the pipe walls.

Small angle processes with high angular resolution and decay of new heavy flavours produced in e+e-/$p\bar{p}$ extremely high energy collisions could be then studied. • • • • •

(M.A.G/. Proc. Miniaturization of High Energy Physics Detectors 1980-. Plenum Press)

Scheme of a charge partition strip detector

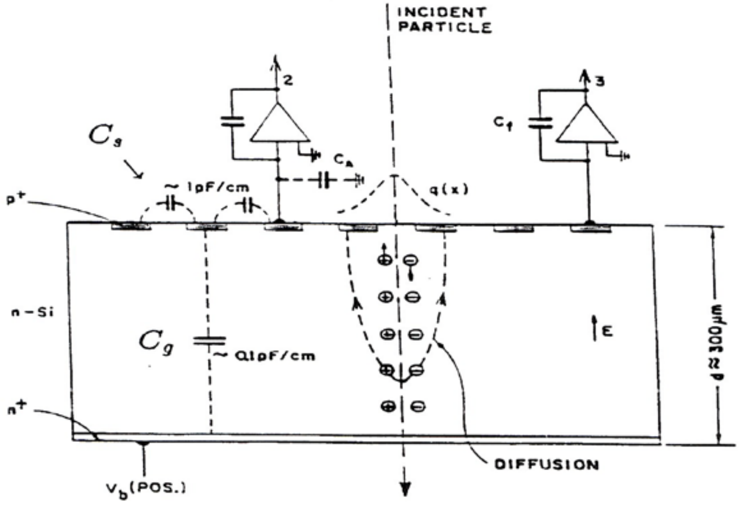
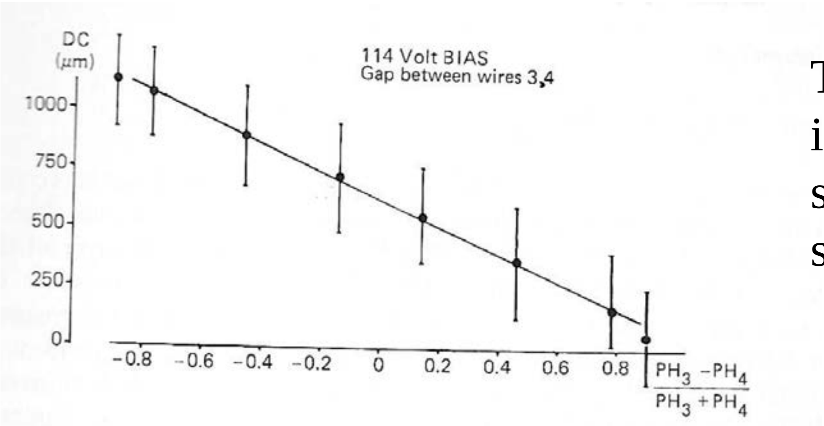


Figure 3.7: A schematic representation of a generic silicon strip detector together with the read-out electronics (from Ref. [58]). Capacitors between non-neighboring strips have been neglected.



The particle hit position is reconstructed with a simple interpolation of signals of adjacent strips.

First use of strip detectors in charm physics as tracking device (NA11)

NUCLEAR INSTRUMENTS AND METHODS 169 (1980) 499-502, © NORTH HOLLAND PUBLISHING CO

FABRICATION OF LOW NOISE SILICON RADIATION DETECTORS BY THE PLANAR PROCESS

J KEMMER

Fachbereich Physik der Technischen Universitat Munchen, 8046 Garching, Germany

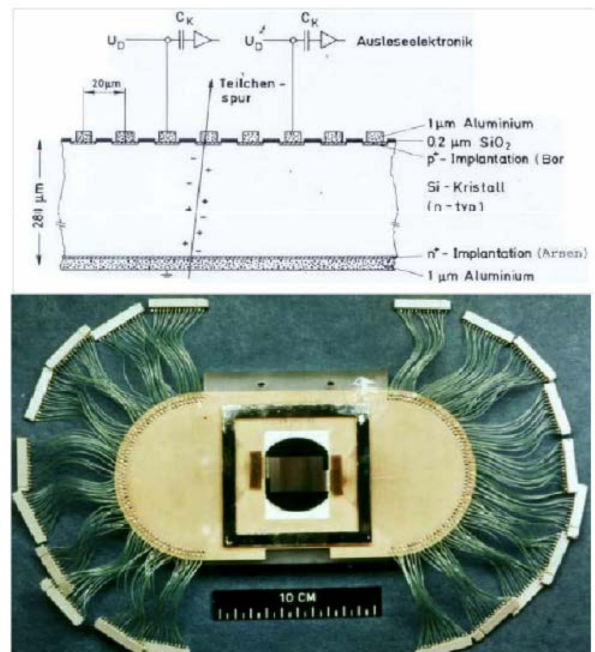
Received 30 July 1979 and in revised form 22 October 1979

Dedicated to Prof Dr H -J Born on the occasion of his 70th birthday

By applying the well known techniques of the planar process oxide passivation, photo engraving and ion implantation, Si pn-junction detectors were fabricated with leakage currents of less than 1 nA cm^{-2}/100 μm at room temperature Best values for the energy resolution were 10 0 keV for the 5 486 MeV alphas of ^{241}Am at 22 °C using 5×5 mm^2 detector chips

Detectors with planar technique.
Idea of J.Kemmer.
Built by ENERTEC (Strasbourg)

A different approach to lifetime
using tracking detectors for decay vertex measurements in hadronic envuronment



Planar process

Polishing and cleaning

Oxidation at 1300 K

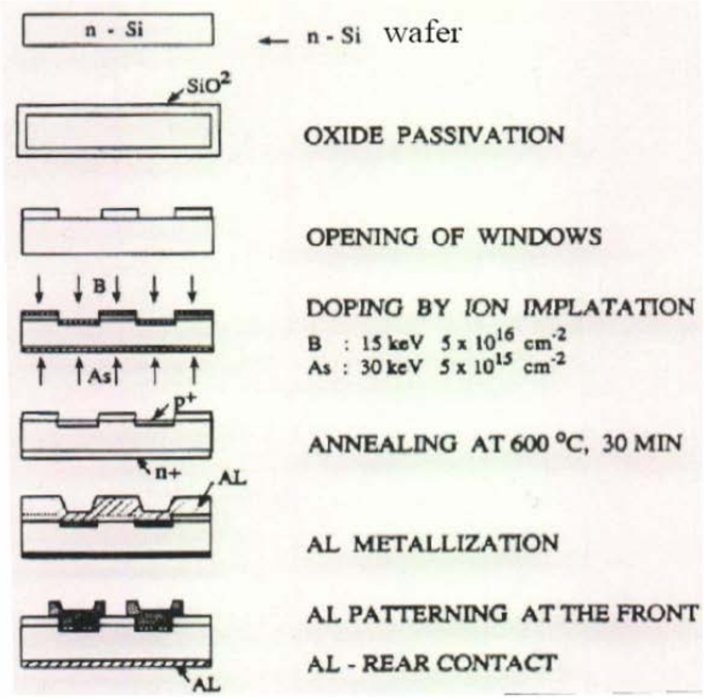
Deposition of photosensitive polymer, UV illumination

Creation of p-n junction via implantation/diffusion

Annealing: implanted ions occupy lattice sites

Deposition of Al and

patterning for electric contacts

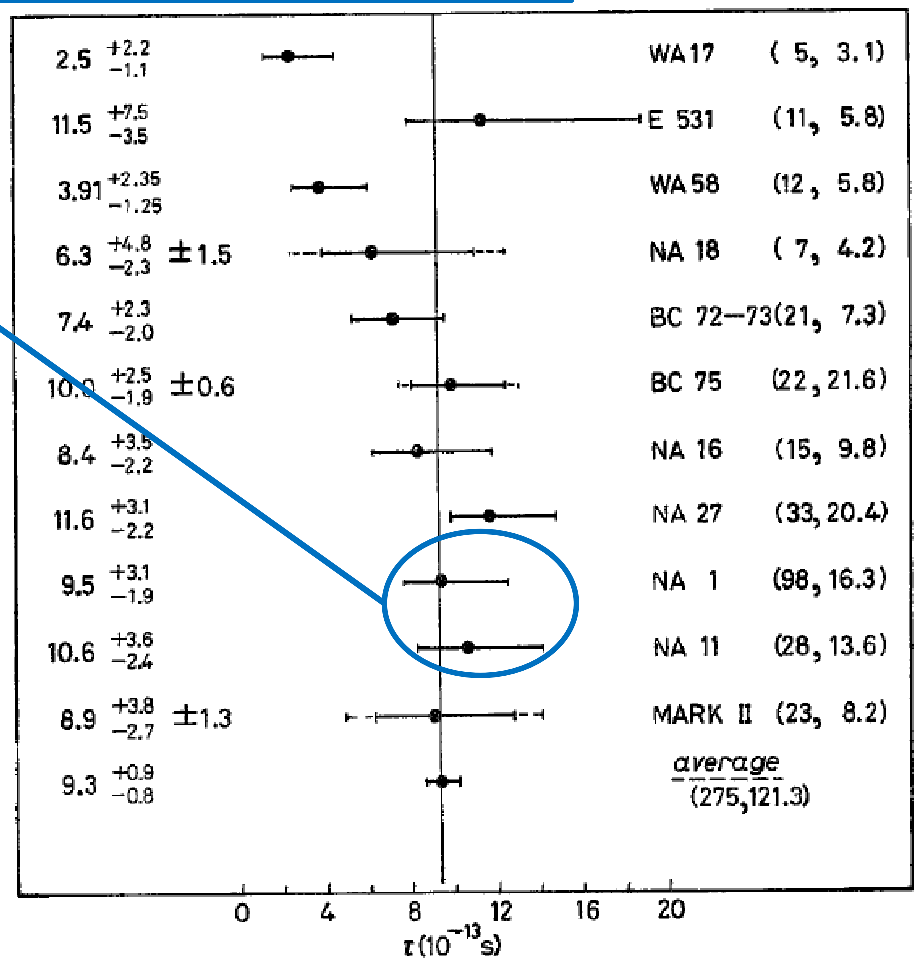


RESULTS on Charm Lifetime (1986)

NA1 Collaboration (E. Albini *et al.*): *Phys. Lett. B*, **110**, 339 (1982).
NA11 Collaboration (R. Bailey *et al.*): *a*) *Phys. Lett. B*, **132**, 230 (1983);

PDG 2016
$T(D^{+}) = 10.4 \pm 0.07 \; 10^{-13}$ s

Na1 and Na11 published the first electronic measurements of the charm lifetimes



LEP was built to validate the Standard Model and measure the SM parameters (es. sin θ_w). The silicon detectors played an imprtant role in heavy flavor physics.

Es: B particle lifetimes measured by precise vertex detectors coupled with low noise front end electronics.

LEP: Aleph started the game first, immediately followed by the others

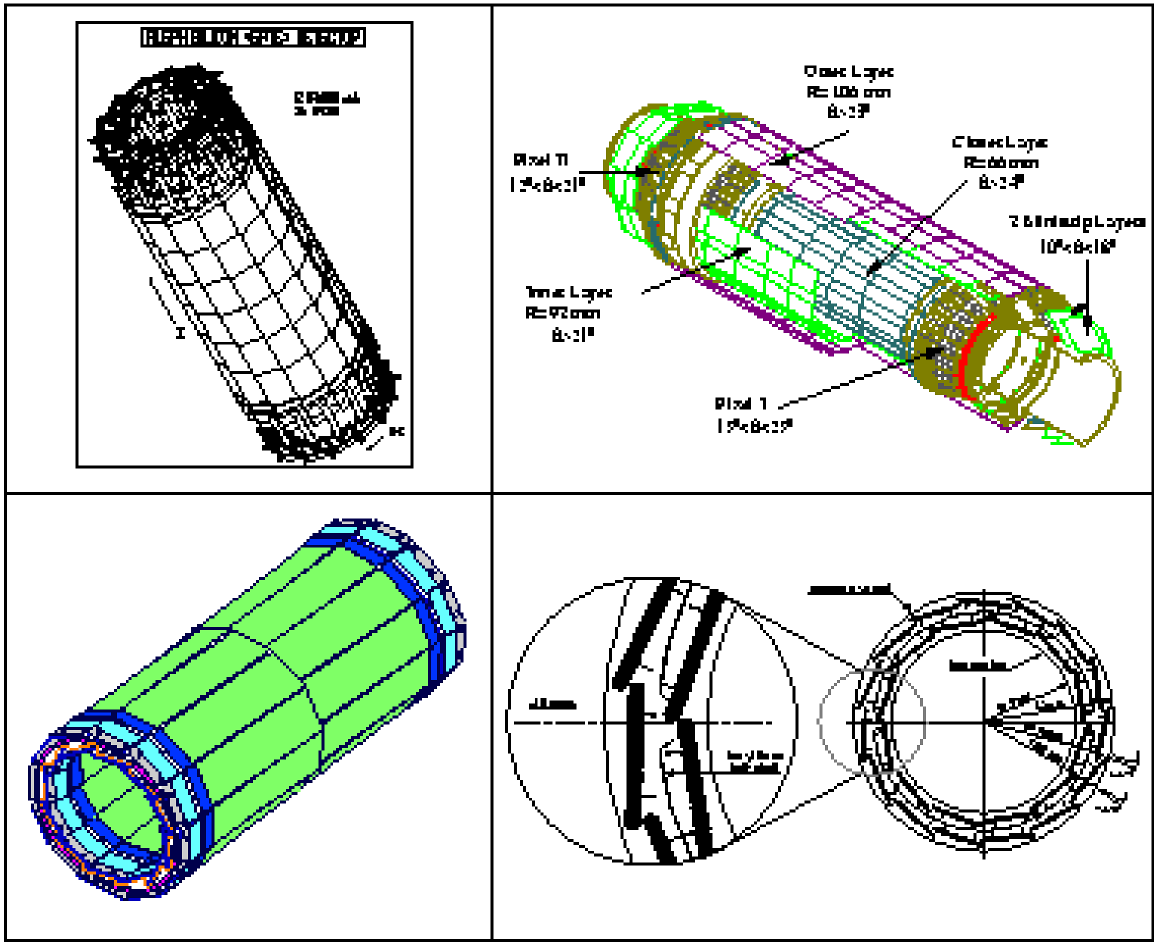
1986-2000

ALEPH
VDETII

DELPHI
Si Tracker

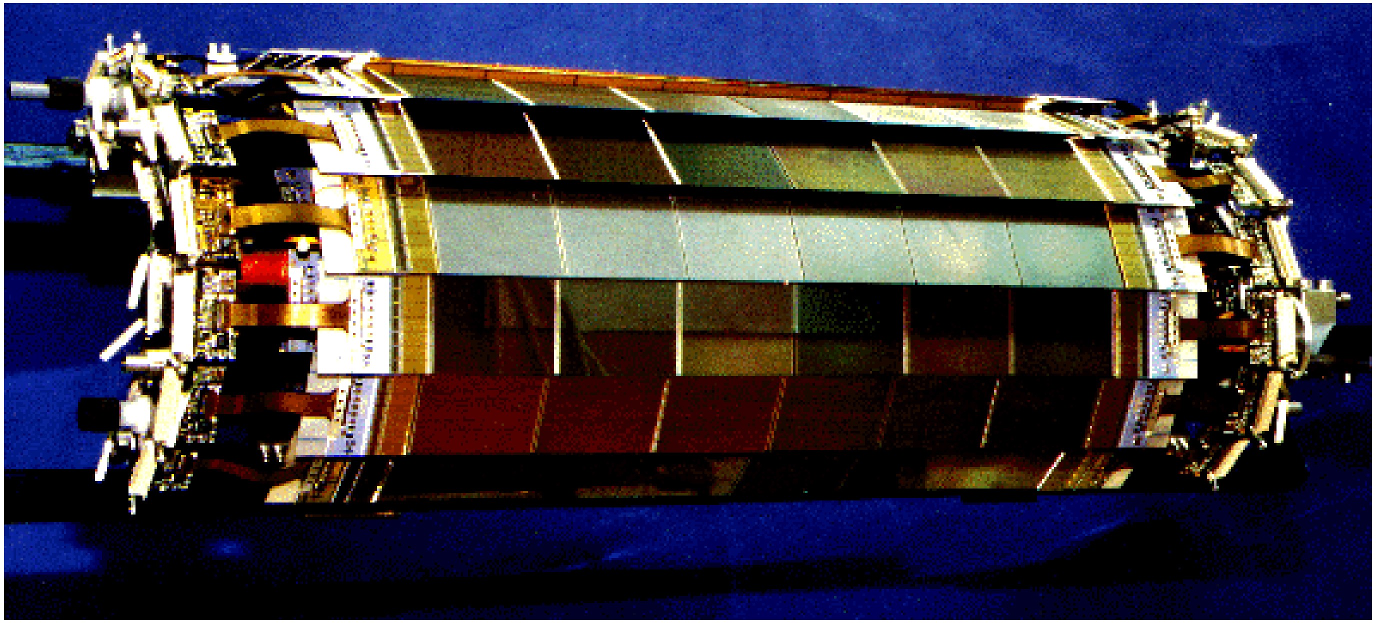
OPAL
μVTX3

L3
SMD



K.Österberg, Performance of the vertex detectors at LEP2, NIM A435 (1999)

ALPEH – VDET (the upgrade)



- 2 silicon layers, 40cm long, inner radius 6.3cm, outer radius 11cm
- 300μm Silicon wafers giving thickness of only $0.015X_0$
- S/N rΦ = 28:1; z = 17:1
- $\sigma_{r\phi} = 12\mu m$; $\sigma_z = 14\mu m$

Risoluzione sul parametro d'impatto per tracce ricostruite con 2 hits nel rivelatore di vertice (ALEPH)

$$\sigma_b = 25\mu m + \frac{95\mu m}{p(GeV/c)^{-1}}$$

Senza hit in VDET tracce a 45 GeV/c

$$\sigma_b = 110\mu m$$

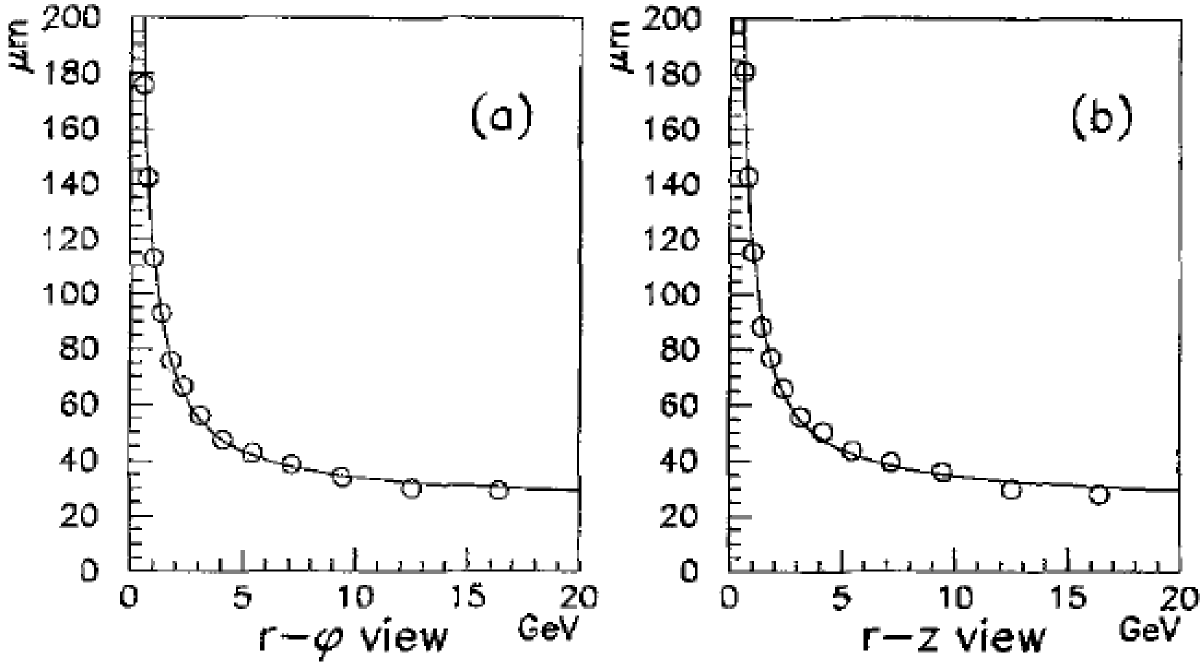
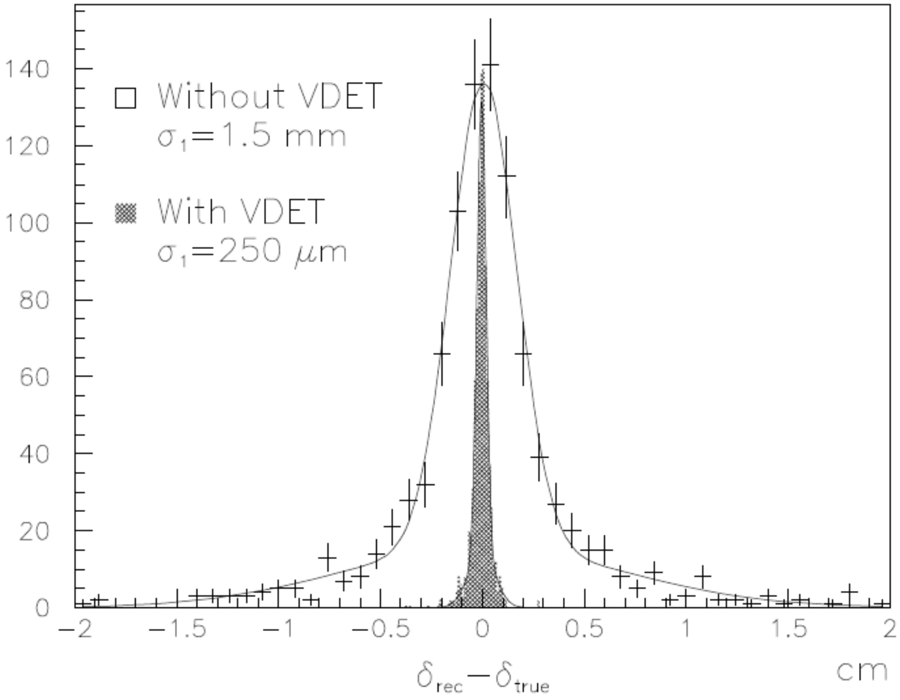
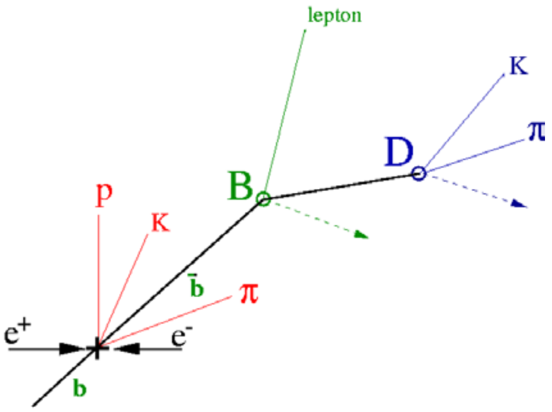


Fig. 15. The impact parameter resolution for tracks with VDET hits in two layers as a function of their momentum.

Decay length precision with and withoutsilicon vertex detector (ALEPH)



Results on B lifetimes (LEP)



$\tau_{B^+}=1.631\ \pm0.012(stat.)\ \pm0.021(syst.)\ ps$

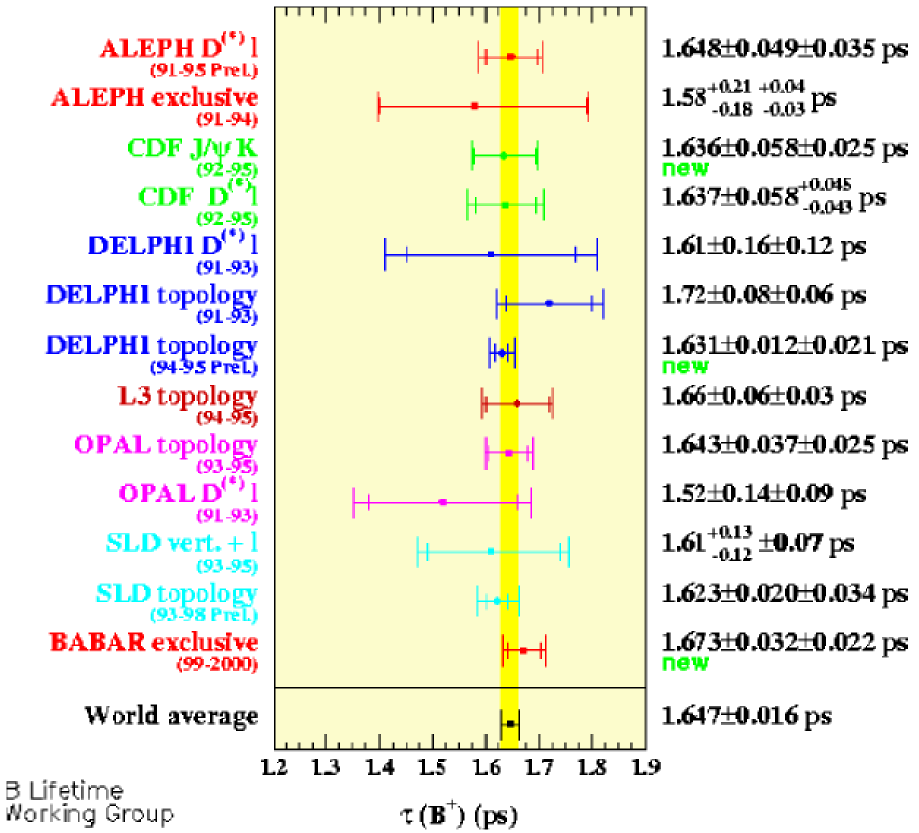
$\tau_{B^0}=1.546\ \pm0.018(stat.)\ \pm0.035(syst.)\ ps$

$\tau_{B^0}=1.541\ \pm\ 0.028(stat.)\ \pm\ 0.023(syst.)\ ps$

$\tau_{B^+}=1.631\ \pm0.012(stat.)\ \pm0.021(syst.)\ ps$

$\tau_{B^0}=1.546\ \pm0.018(stat.)\ \pm0.035(syst.)\ ps$

τ_{B^+}



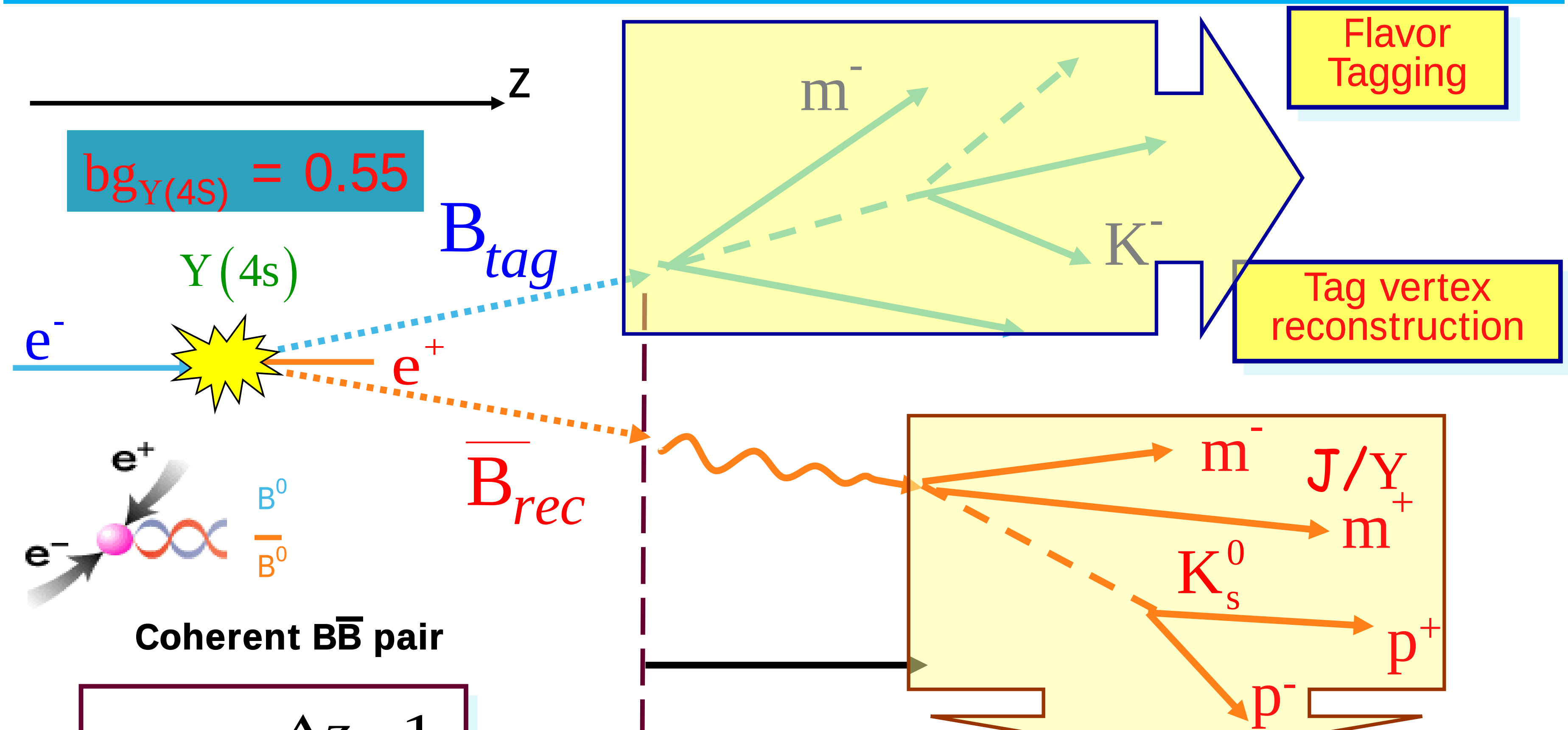
Looking for CP violation in B decays

- Discovery of CP violation in b decays and mesuring the parameters of the Unitarity condition of the flavor mixing matrix is one of the crucial tests of the CKM mechanism explaining the simmetry violation inside the Standard Model.
- How to reach the goal?

How to get it?

- By measuring the asymmetry between decay time of B meson and anti-B meson , once they are produced at the same space-time point.
- Therefore a precise measurement of decay time is required, (easier if the experiment is in a clean environment as in a e+ e- collider).
- It is clean if one pair of b –anti b meson is exclusevely produced in the decay of a resonance 1^{--} (the same quantum numbers of the virtual photon).
- A Lorentz boost of center of mass of B-anti B pair (again a boost) allows the measurement of their decay points. It has been obtained with an asymmetyric e+ e- collider.
- The a very good vertex tracker meaures the decay points of the two mesons that are less than 300 μm apart.

Experimental ingredients for CP Violation experiments

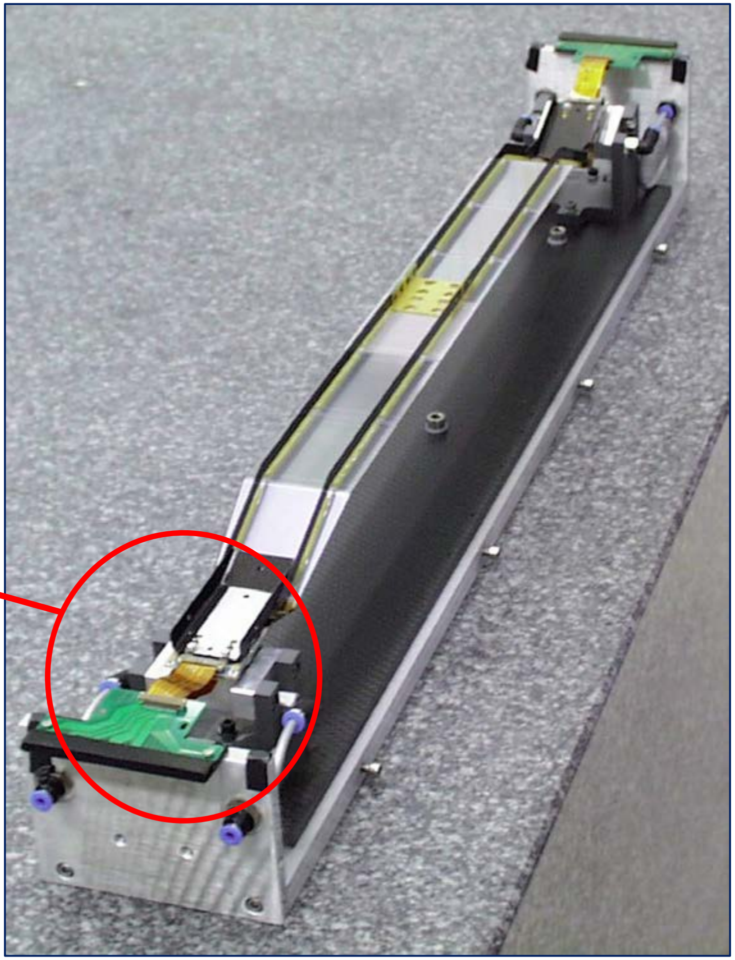


$$\Delta t \approx \frac{\Delta z}{\langle \beta\gamma \rangle}\frac{1}{c}$$

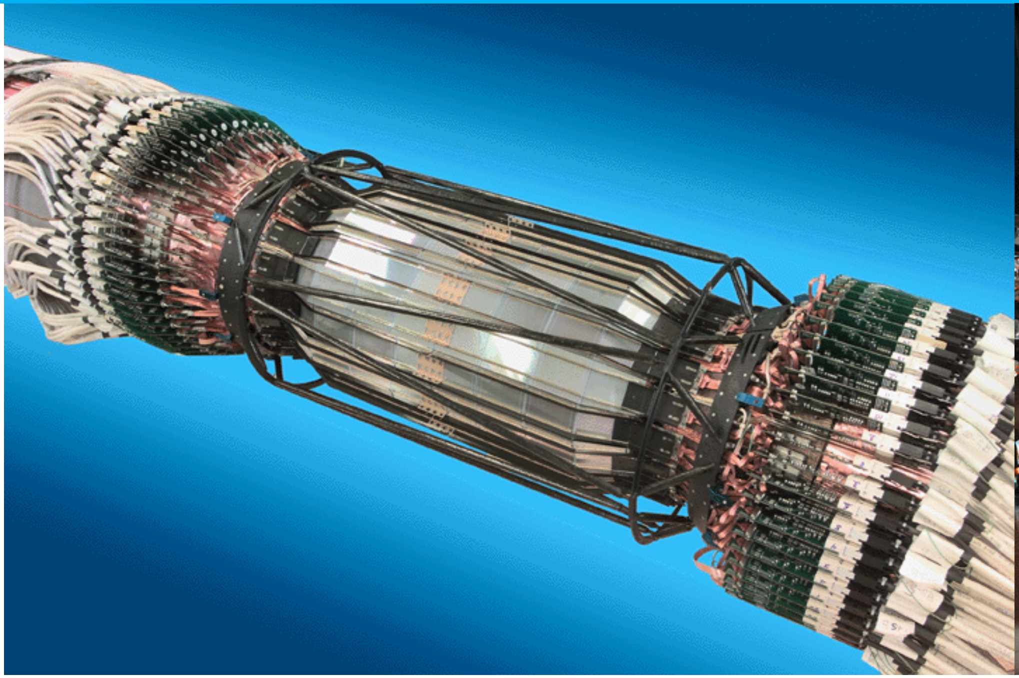
Δt is a signed quantity

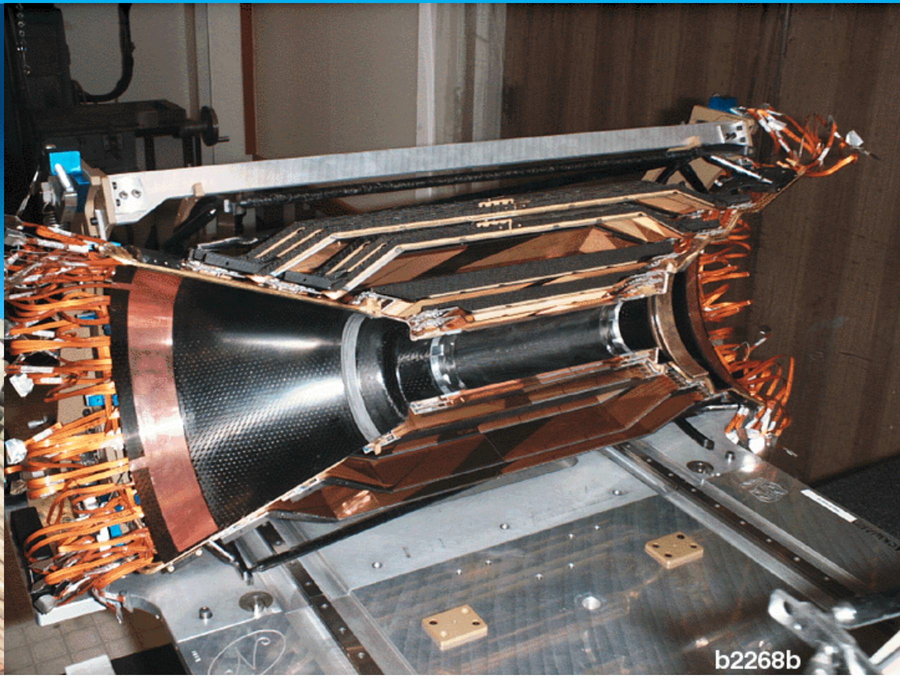
Lamp shade shaped module of VDET

Module of BaBar VDET assembled with ATOM Chips and the interface



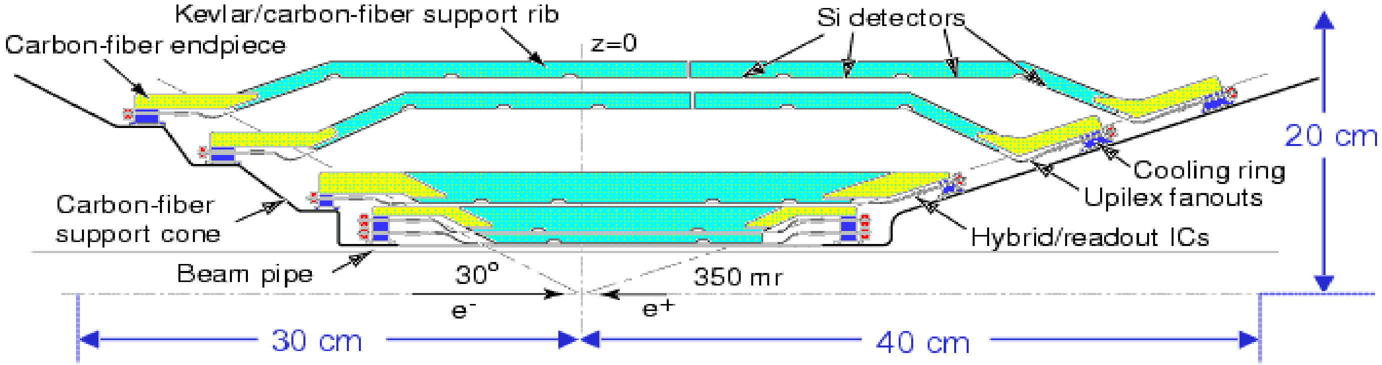
BaBar VDET





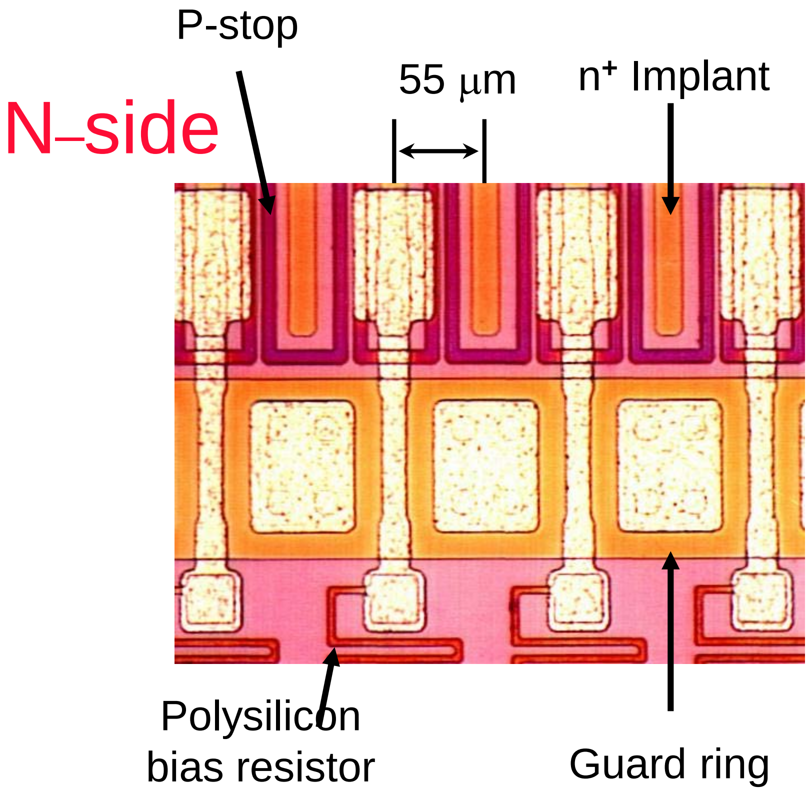
- SVT standalone tracking for p_t < 120 MeV/c
-Single vertex resolution along z-axis better than 80 μm (<Δz> of B mesons about 250 μm)
- Radiation hard up to 2 Mrad

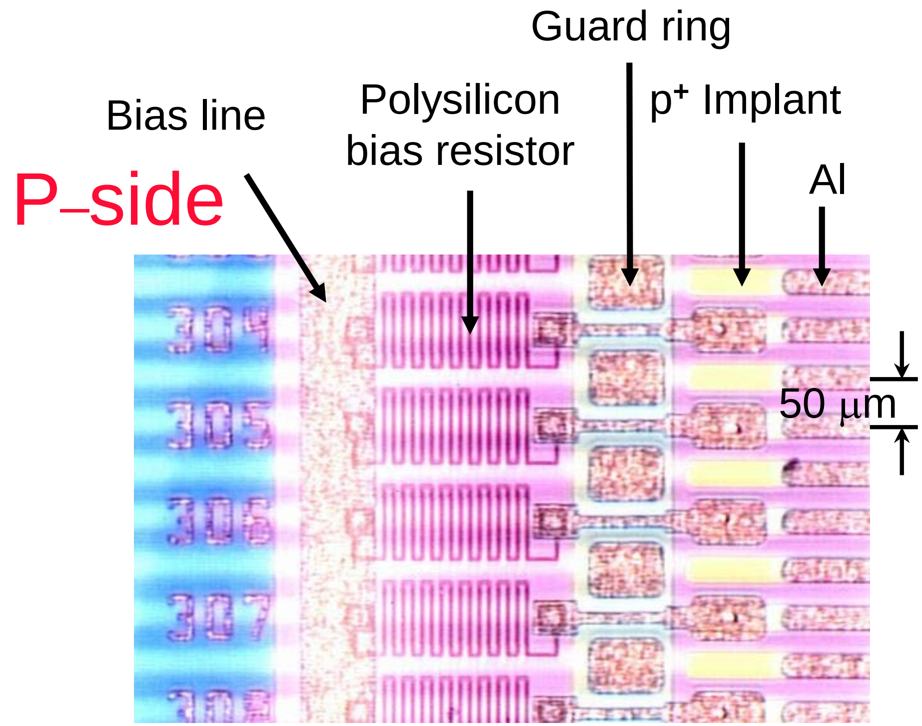
SVT Layout



- Bunch crossing period: 4.2 ns (almost continuous interactions !)
- Radiation hardness

- Microstrip silicon detector; 5 double-sided layers
- Layer 1-3 (barrel-shaped) for a precise measurement of track impact parameter
- Layer 4-5 (arch shaped) for pattern recognition and low pt tracking
- X_0(Si) = 9cm: multiple scattering is the limiting factor to the resolution
- 150 k channels, 340 wafers (6 different models)





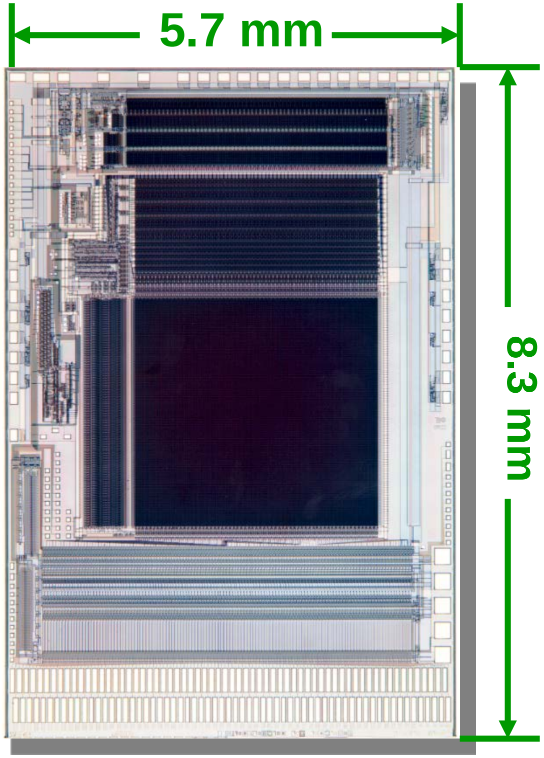
- Double-sided, AC-coupled Si
- Integrated polysilicon bias resistors
- 300 μm n-type (4-8 kΩcm)
- P+ and n+ strips perpendicular to each other

Front End Chip ATOM
A Time over Threshold Machine

See:

R. Becker, A. Grillo, R. Jacobsen, R. Johnson, I. Kipnis, M. Levi, L. Luo, P.F. Manfredi, M. Nyman, V. Re, N. Roe, S. Shapiro: "Signal processing in the front-end electronics of BaBar vertex detector", **Nucl. Instrum. Methods,** A377 (1996) pp. 459-464.

128 Ch's/chip
- Rad-Hard bulk 0.8 mm CMOS process (HONEYWELL 4")
- Capable of simultaneous:
  - Acquisition
  - Digitization
  - Sparsified Readout
- No common mode noise:
  - separation analog/digital parts in the chip layout
  - proper system shielding
- Info from AToM: Timestamp T_0 and TOT
- Internal charge injection
- Digital-based diagnostics



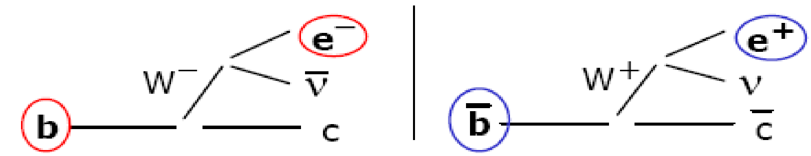
VDET performance

VDET MACHINE:

mechanics, sensors (fabricated by MICRON SEMICONDUCTOR under design , recipes and supervision of the VDET group) and FE electronics behaved as a perfect organism for a decade, the entire lifetime of the SLAC PEPII BFactory.

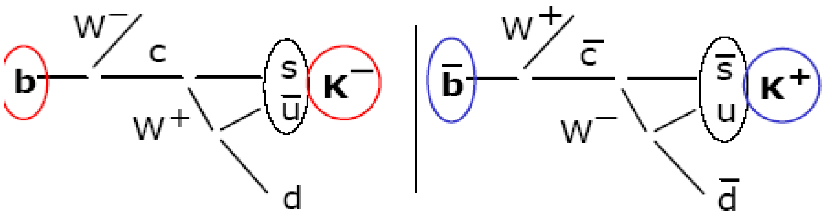
B Flavour Tagging

Leptons : Cleanest tag. Correct >95%



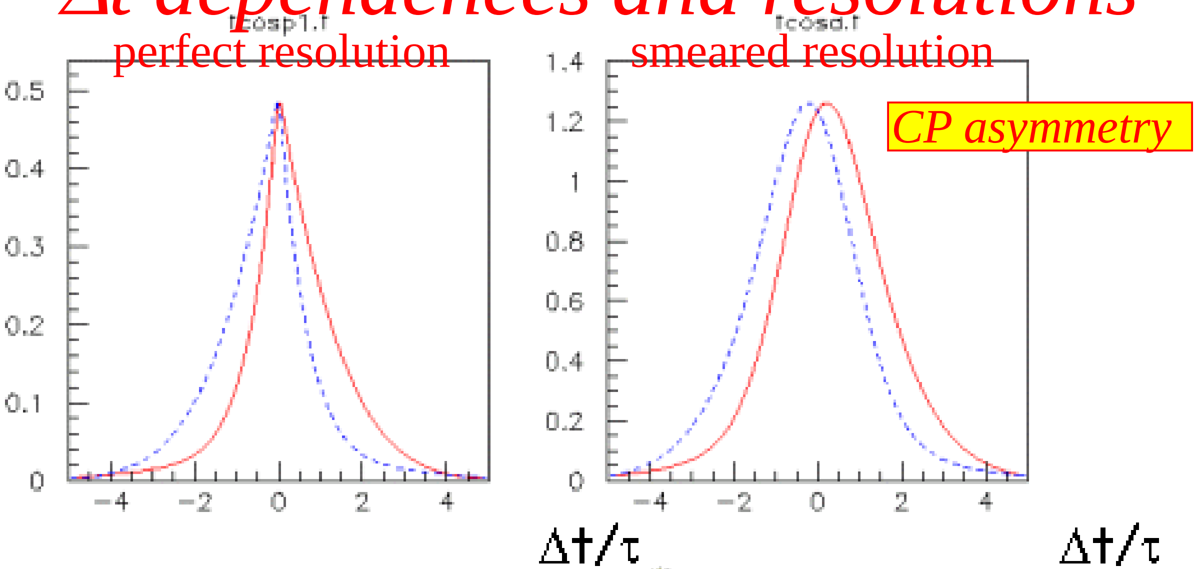
$$Q_T = \sum_i \varepsilon_i (1-2\omega_i)^2 \qquad \sigma(S_{f_{CP}}) \propto \frac{1}{\sqrt{N \times Q_T}}$$

Kaons : Second best. Correct 80-90%



Tagging performance
Q_T=30.5% *(6 categories) from full Neural Network including these & other physics processes to identify b quark state*

Δt dependences and resolutions

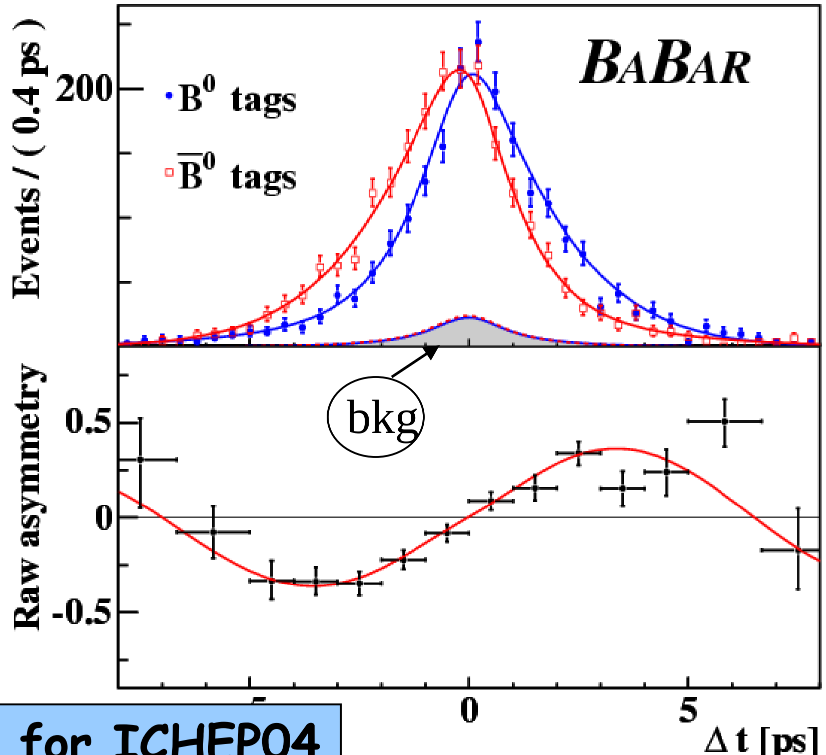


Δt resolution dominated by tag side:
s(Dt) ~1 ps ⇔ 170 μm

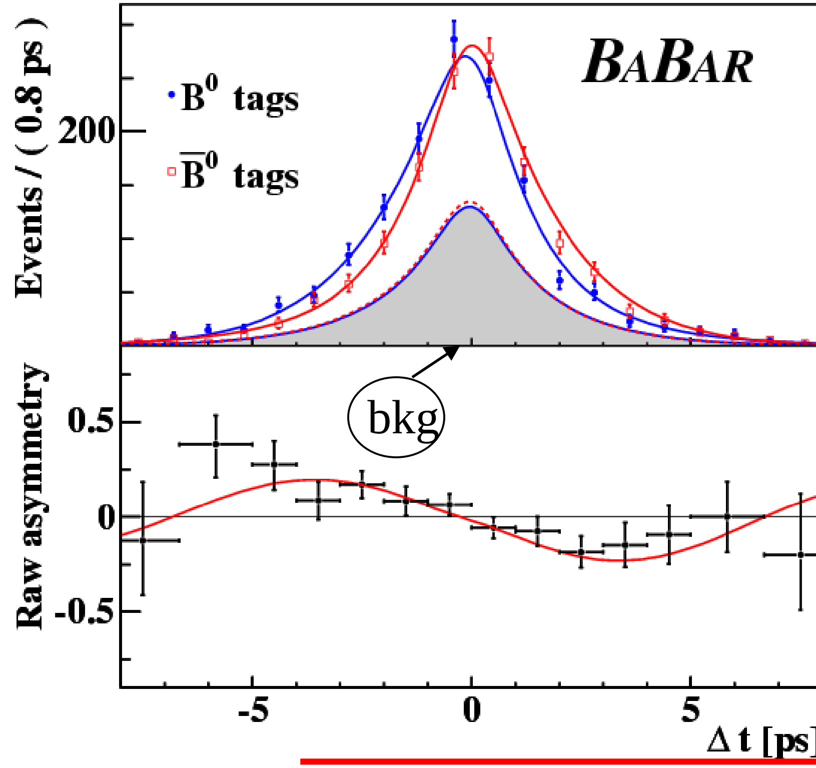
τ_B ~ 1.6 ps ⇔ 250 μm

Sin 2β results from charmonium modes

($c\bar{c}$) K_S (CP odd) modes



J/ψ K_L (CP even) mode



New for ICHEP04

sin2β = 0.722 ± 0.040 (stat) ± 0.023 (sys)

(2002 measurement: sin2β = 0.741±0.067±0.034)

Direct ~~CP~~ $|\lambda| = \left|\frac{A}{\bar{A}}\right| = 0.950 \pm 0.031$ (stat.) ± 0.013

205 fb^{-1} on peak (run 1-4)

227 M $B\bar{B}$ decays **2004**

7730 CP events (tagged, sig.)

81 fb^{-1} on peak (run 1-2)

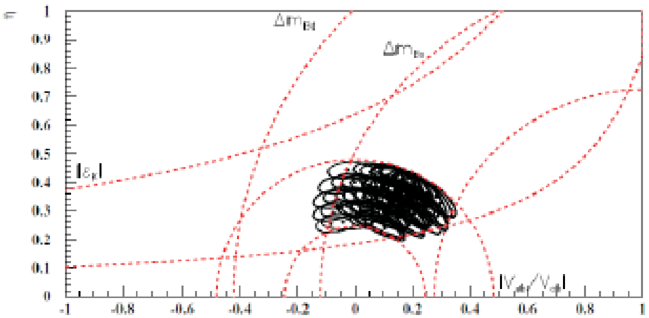
88 M BB decays **2002**

2641 CP events (tagged, sig.)

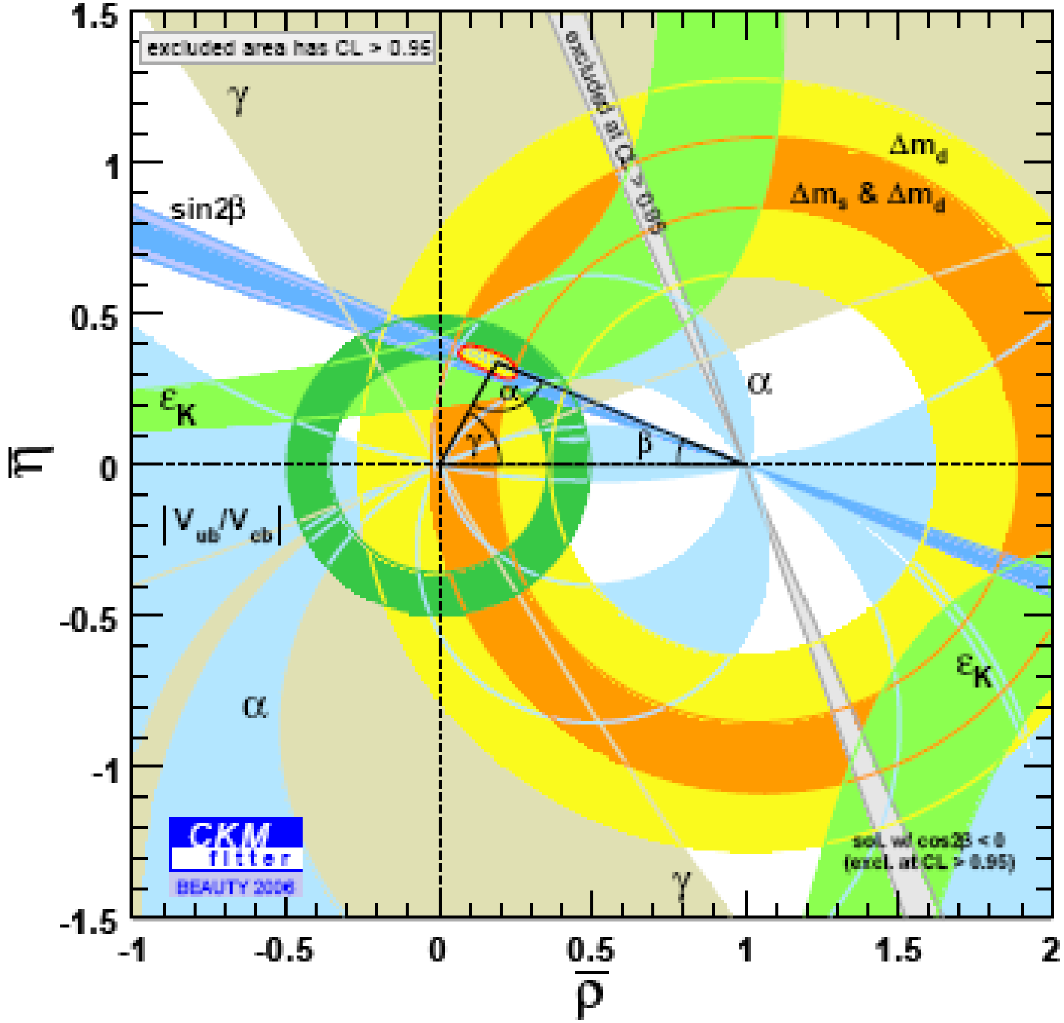
BaBar PUB-04/032

CKM Unitarity Triangle

Before Bfactories



The contribution of Franco to the success was fundamental!



Silicon strip also in Hadron colliders

University of Pisa - G. Bellettini, R. Bertani, L. Bosisio,
C. Bradaschia, R. DelFabbro, E. Focardi, M.A. Giorgi,
A. Menzione, L. Ristori, A. Scribano, G. Tonelli

DESIGN REPORT

FOR THE

FERMILAB COLLIDER DETECTOR FACILITY

(CDF)

AUGUST, 1981

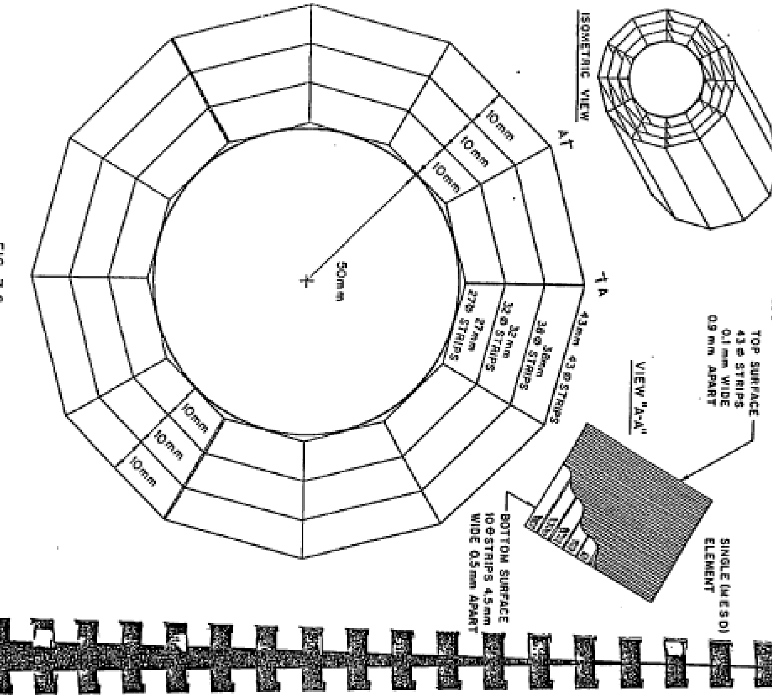


FIG. 7.6

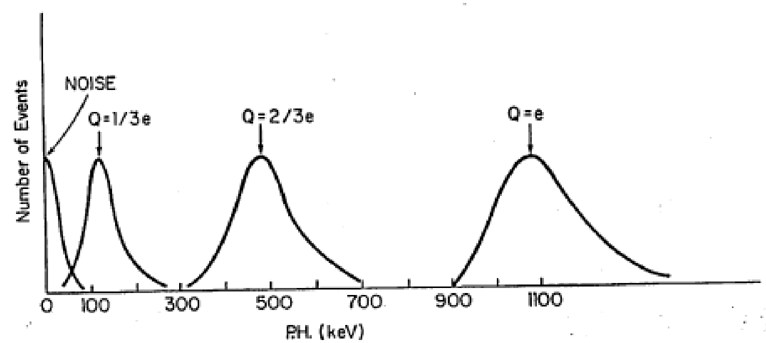
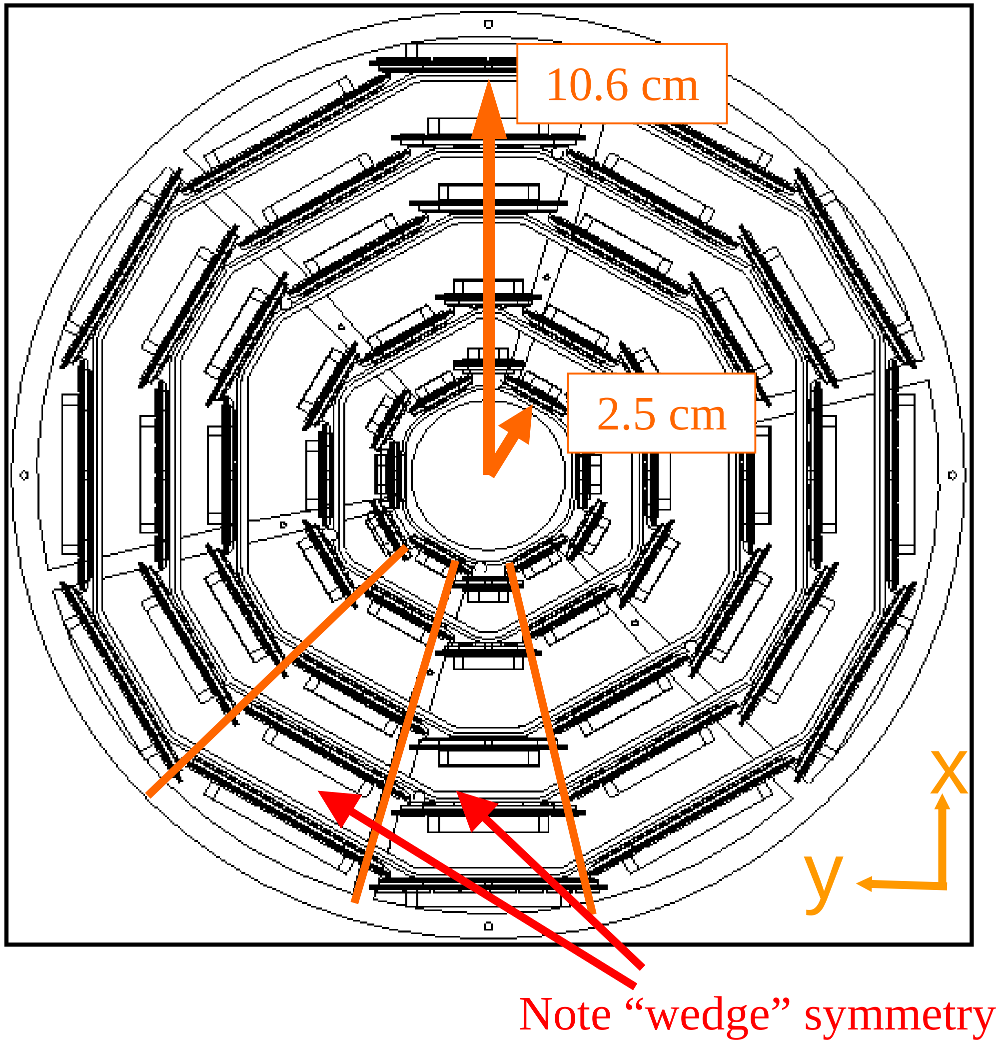
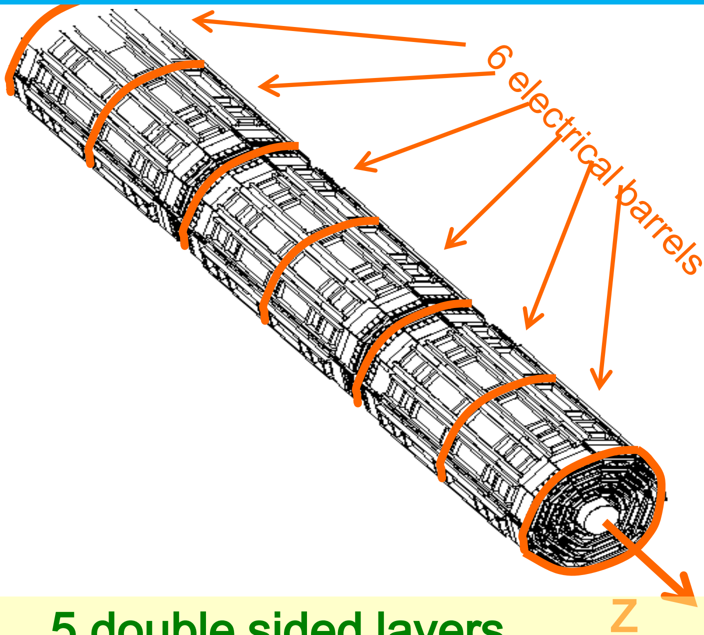


FIG. 7.7

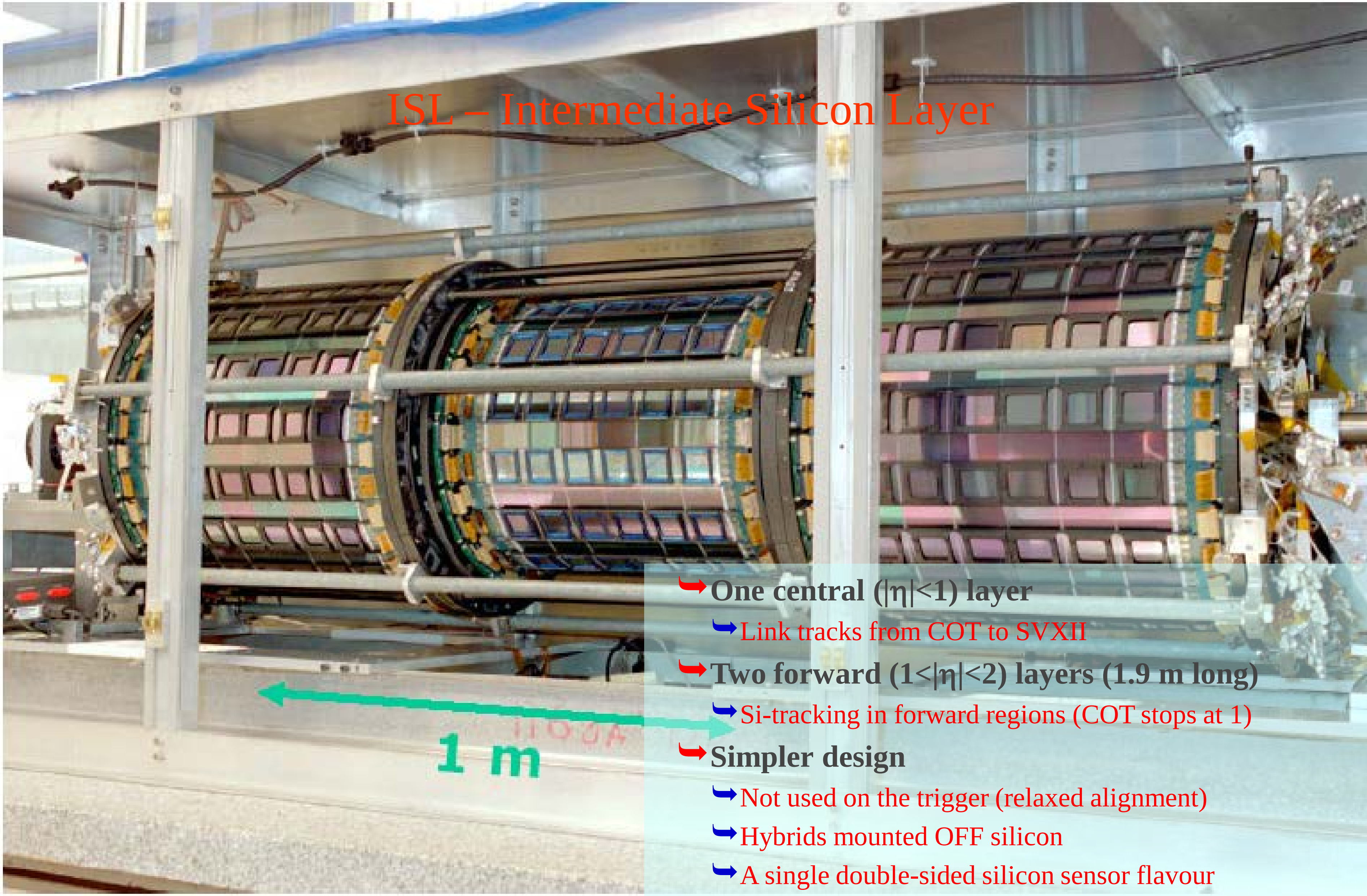
Now CDF :SVXII (double side as in the old report 1981)





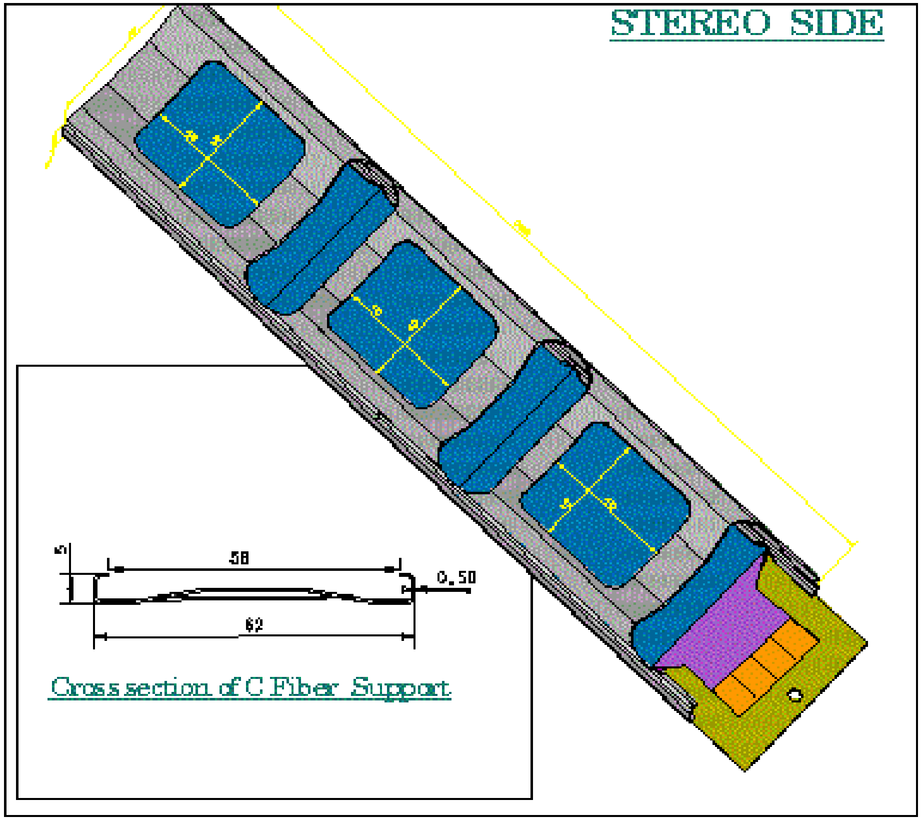
- 5 double sided layers
  - 5 axial + 3 x 90°, 2 x 1.2°
- Very compact
- Tight alignment tolerances
  - For the trigger
- Very symmetric
  - 12 fold in Φ
  - 6 barrels in Z

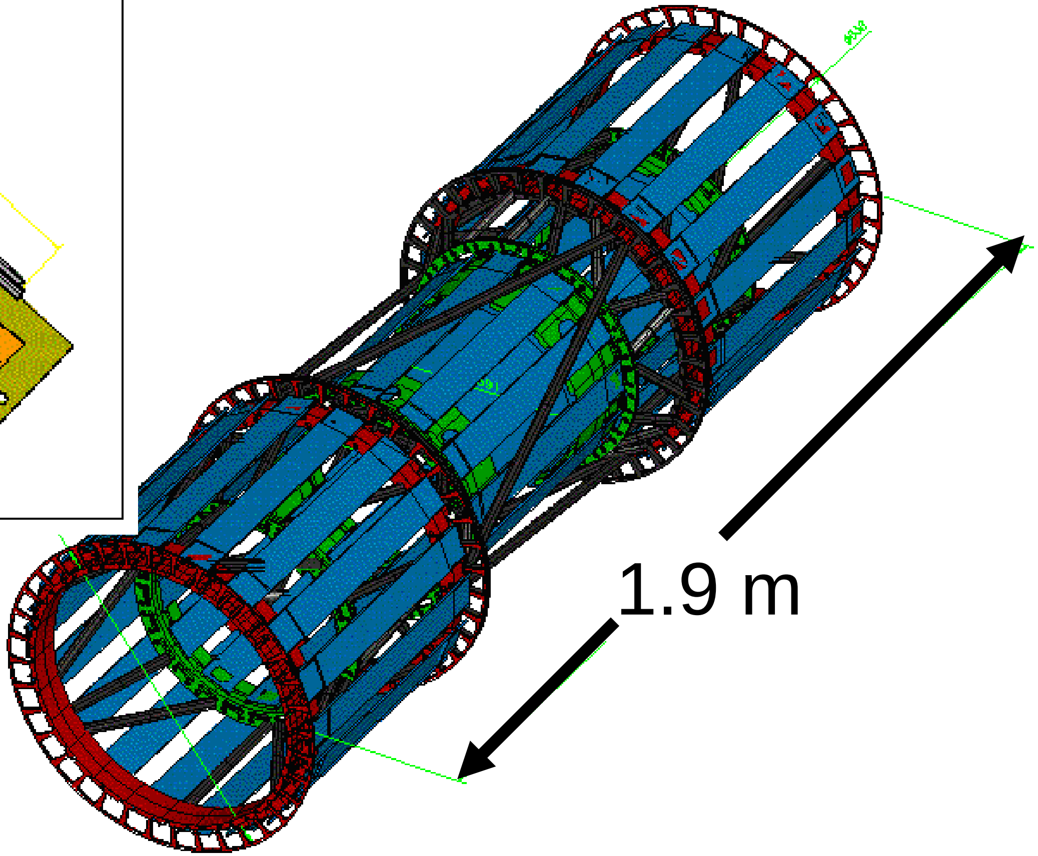
ISL – Intermediate Silicon Layer



- **One central (|η|<1) layer**
  - Link tracks from COT to SVXII
- **Two forward (1<|η|<2) layers (1.9 m long)**
  - Si-tracking in forward regions (COT stops at 1)
- **Simpler design**
  - Not used on the trigger (relaxed alignment)
  - Hybrids mounted OFF silicon
  - A single double-sided silicon sensor flavour

ISL Construction





Fundamental contribution to top quark discovery

- The use of silicon strip detectors has been crucial for the discovery of top quark.
- The detection of secondary vertices due to b decays allowed the tagging of channels with top quark going into beauty particles.

What now and in Future ?

What now and in Future ?

CP violation was measured with high statistics in hadron experiments. CDF has published nice results also thanks to a very performing trigger.

LHCb has already an incredible high statistics and has also seen the CP violation in Bs decays, even better can be achieved with the expected upgrades.

BelleII is expected to give very clean measurements with an expected statistics between 20 and 50 times hgher than what collected by BaBar and Belle.

Conclusions

The last 36 years of experiments in flavor physics have strongly confirmed the Standard Model .

Such achievement was largely made possible by the efforts of Emilio Gatti, Franco Manfredi and by the generations of their collaborators.