9 November 2007

ARGUS Symposium

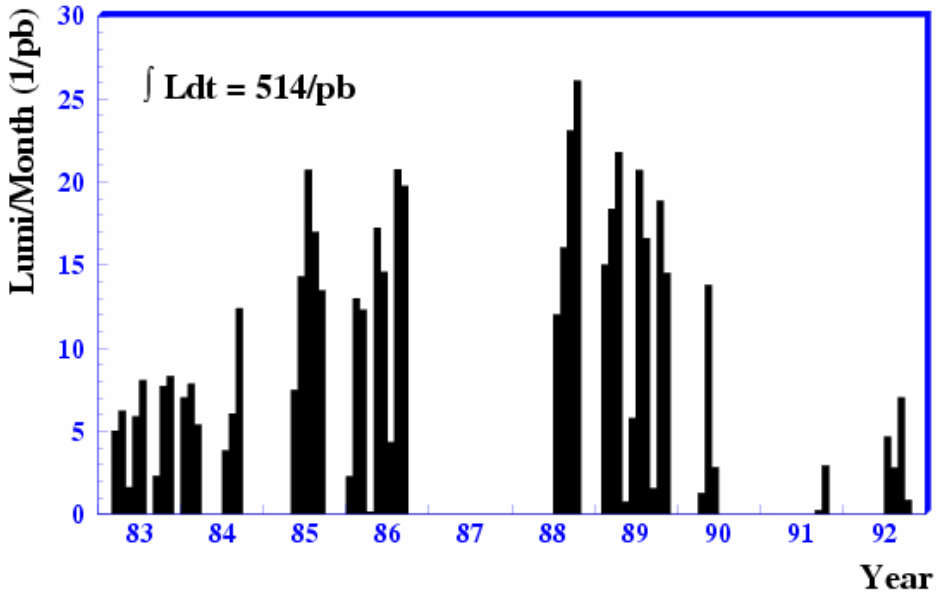
Twenty Years of B-Meson Mixing

„From ARGUS to B-Meson Factories“

Klaus R. Schubert, TU Dresden

Past	1987 $\rightarrow$ 1941 $\rightarrow$ 1993
Present	Discovery of the Year
Future	SuperB Plans

1987, ARGUS Monthly Luminosity



These 3 results, together with many others 1980-87 from CESR & DORIS made widely visible that e^+e^- annihilation is the cleanest and the most promising way to discover and to study CP violation in B-meson decays [M. K. Gaillard 1977]

19 ARGUS publications in 1987, the top 3:

$B^0 \bar{B}^0$ Mixing, PLB 192(1987)245, 1089 citations

$B^0 \rightarrow D^{*-}\ell^+\nu$, PLB 197(1987)452, 172 citations

Full B reconstruction, PLB 185(87)218, 151 citations

1987 was the breakthrough year of the B-Meson Factory idea.

e^+e^- Storage Rings, the Beginning

The storage-ring idea goes back to B. Touschek and R. Wideroe 1941.

First e^-e^- storage-ring collider built by G. O'Neill et al. at Stanford 1959.

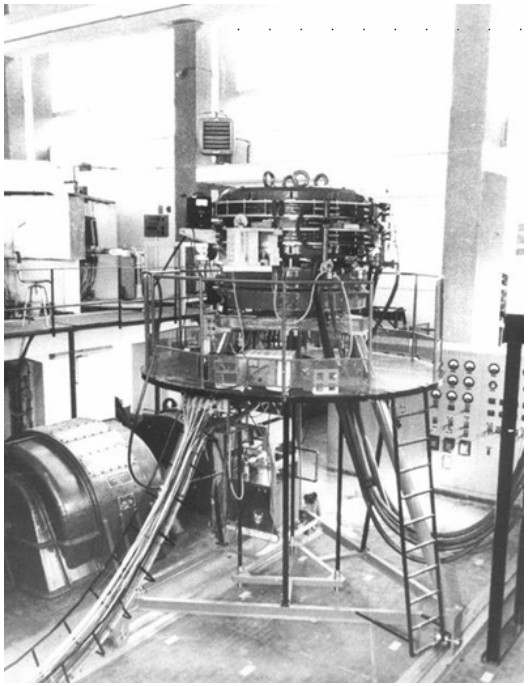
First experiment (Moeller scattering) with B. Richter et al. 1965.

First e^+e^- storage-ring collider built by B. Touschek et al. at Frascati 1961, single ring, AdA, $2 \cdot 0.25$ GeV, first collisions 1964 at Orsay.

Bruno Touschek

Austrian theorist

(1920 - 1978)



AdA today

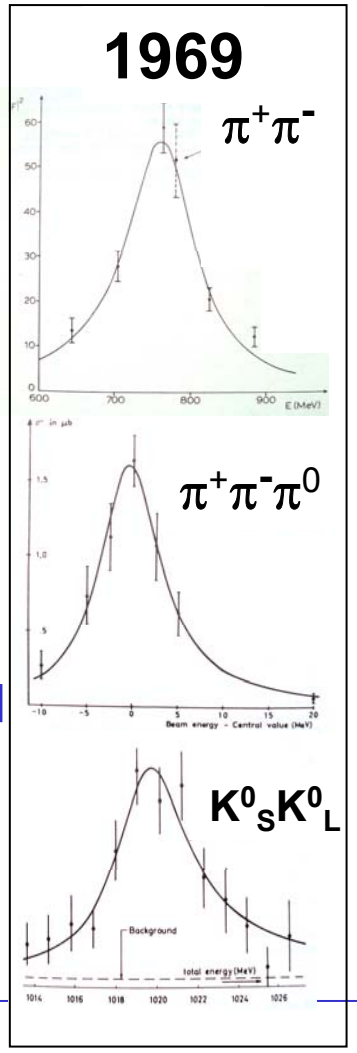
at Frascati

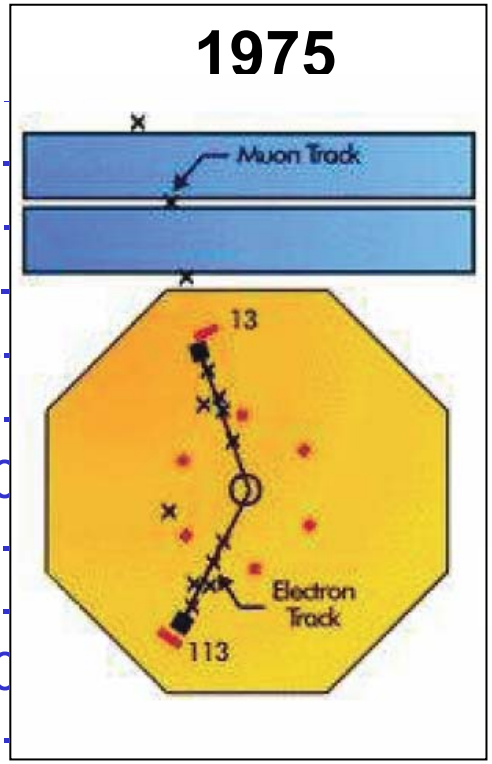
1987 List of e^+e^- Storage Rings, fragmentary

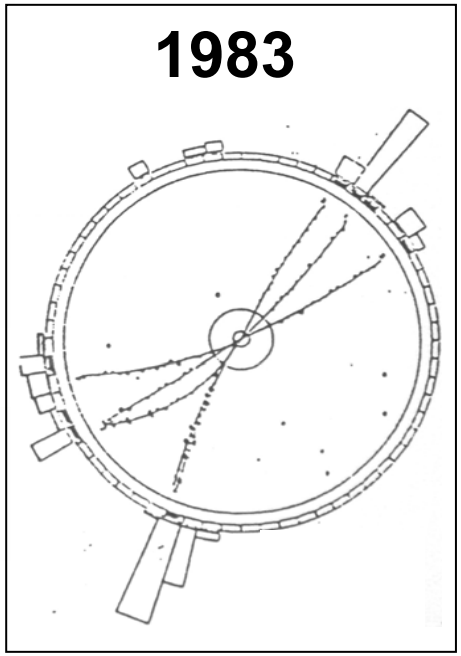
ACO,DCI	Orsay	1965-75	2·0.8 GeV	ρ, ω, ϕ
VEPP2	Novosibirsk	1965-75	2·0.5 GeV	multi-π production
ADONE	Frascati	1969-93	2·1.5 GeV	
SPEAR	SLAC	1972-90	2·4 GeV	jets, ψ, ψ', D, τ
DORIS	DESY	1973-77	2·3.5 GeV	
DORIS2	DESY	1978-92	2·5.5 GeV	$\chi(B^0)$
VEPP4	Novosibirsk	1975-	2·6 GeV	m($c\bar{c}$), m($b\bar{b}$)
PETRA	DESY	1978-90	2·17 GeV	gluon
CESR	Cornell	79-2007	2·6 GeV	Υ(4S), B, V_{ub}
PEP	SLAC	1980-90	2·14 GeV	τ(b)
TRISTAN	KEK	1987-90	2·32 GeV	
DAΦNE	Frascati	99-2007	2·0.6 GeV	
BEPC	Beijing	1989-	2·2.2 GeV	m(τ)
LEP	CERN	89-2002	2·90 GeV	m(Z), N(ν), m(W)

1987 List of e^+e^- Storage Rings, fragmentary

ACO,DCI	1965-75	2·0.8 GeV	ρ, ω, ϕ
VEPP2	1965		multi-π production
ADONE	1969		
SPEAR	1972		jets, ψ, ψ‘, D, τ
DORIS	1973		
DORIS2	1978		
VEPP4	1975		
PETRA	1978		
CESR	79-20		
PEP	1980		
TRISTAN	1987		
DAΦNE	99-20		
BEPC	1989		
LEP	89-2002	2·90 GeV	







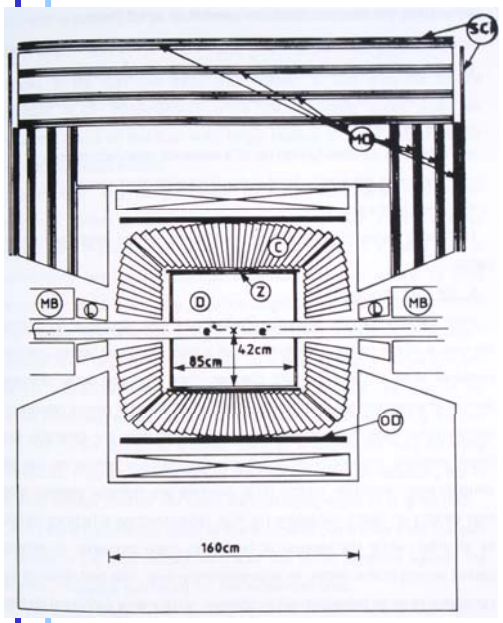
B-Meson-Factory Dreams

Dreams that Europe urgently needs a Cornell-like Lab where B mesons and the search for CP violation in their decays have highest priority started in spring 1985. My first public talk: U Zurich, 28 Nov.1985.

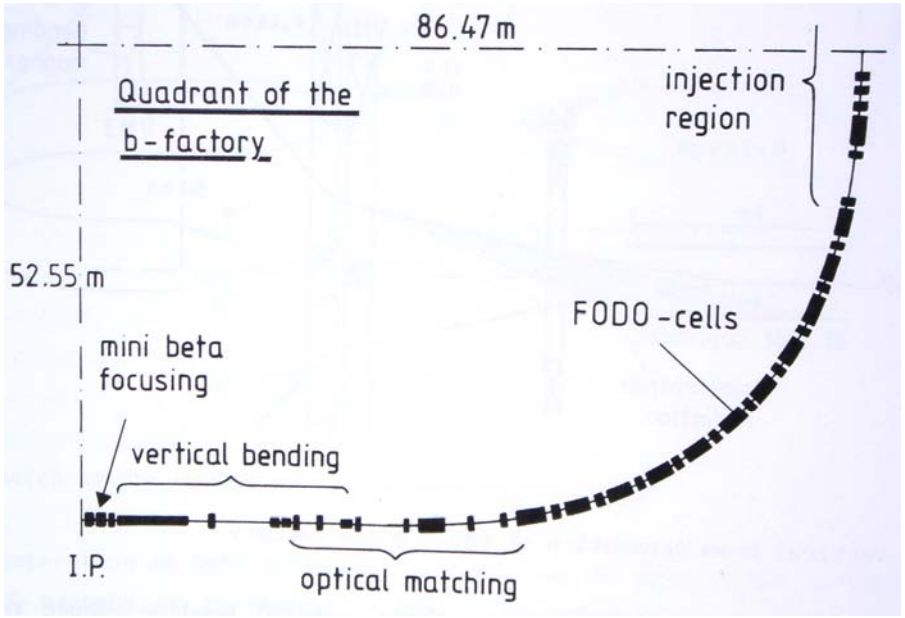
May 1986: „Heavy Hadron“ Symposium with 130 participants in Heidelberg.

Main goal: Collecting and spreading arguments for a B-Meson Factory

E.Lorenz:



K. Wille:



5 GeV for e^+ and e^-

$L > 5 \cdot 10^{32}/cm^2/s$

double ring,

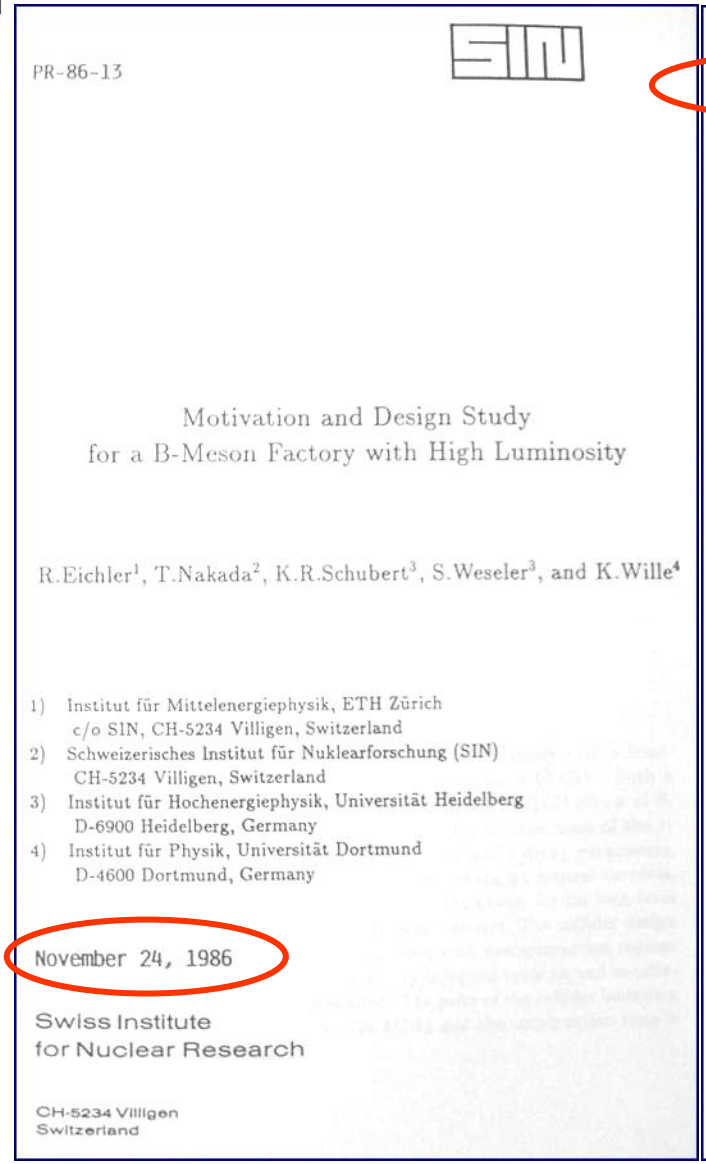
24 bunches each,

$u = 480\,m$, $d_b = 20\,m$

DORIS-II: $d_b = 300\,m$

$L \approx 2 \cdot 10^{31}/cm^2/s$

The SIN/PSI Project 1986-88



PR-86-13

Motivation and Design Study
for a B-Meson Factory with High Luminosity

R.Eichler[1], T.Nakada[2], K.R.Schubert[3], S.Weseler[3], and K.Wille[4]

1) Institut für Mittelenergiephysik, ETH Zürich
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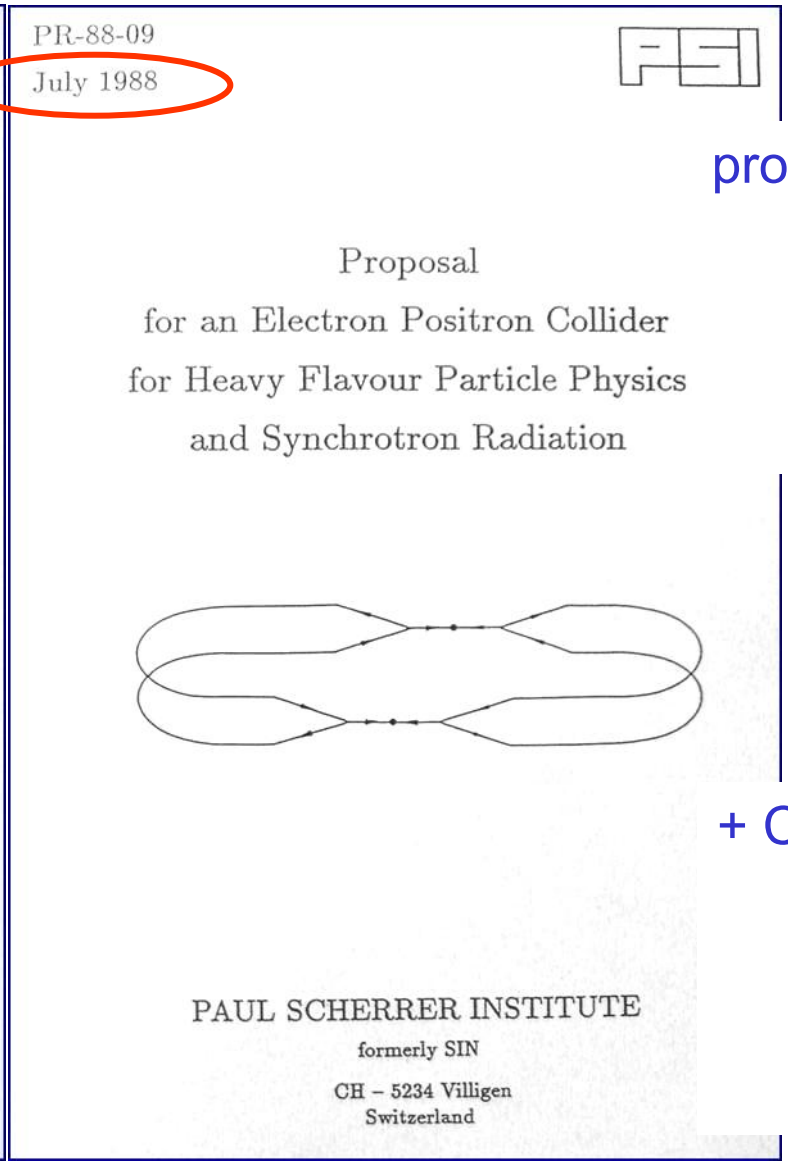
2) Schweizerisches Institut für Nuklearforschung (SIN)
CH-5234 Villigen, Switzerland
3) Institut für Hochenergiephysik, Universität Heidelberg
D-6900 Heidelberg, Germany
4) Institut für Physik, Universität Dortmund
D-4600 Dortmund, Germany

November 24, 1986

Swiss Institute
for Nuclear Research

CH-5234 Villigen
Switzerland



PR-88-09
July 1988

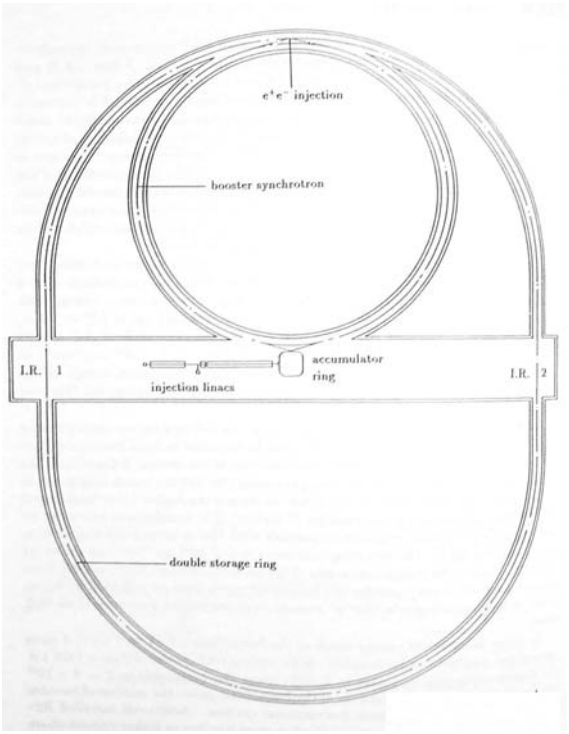
Proposal
for an Electron Positron Collider
for Heavy Flavour Particle Physics
and Synchrotron Radiation

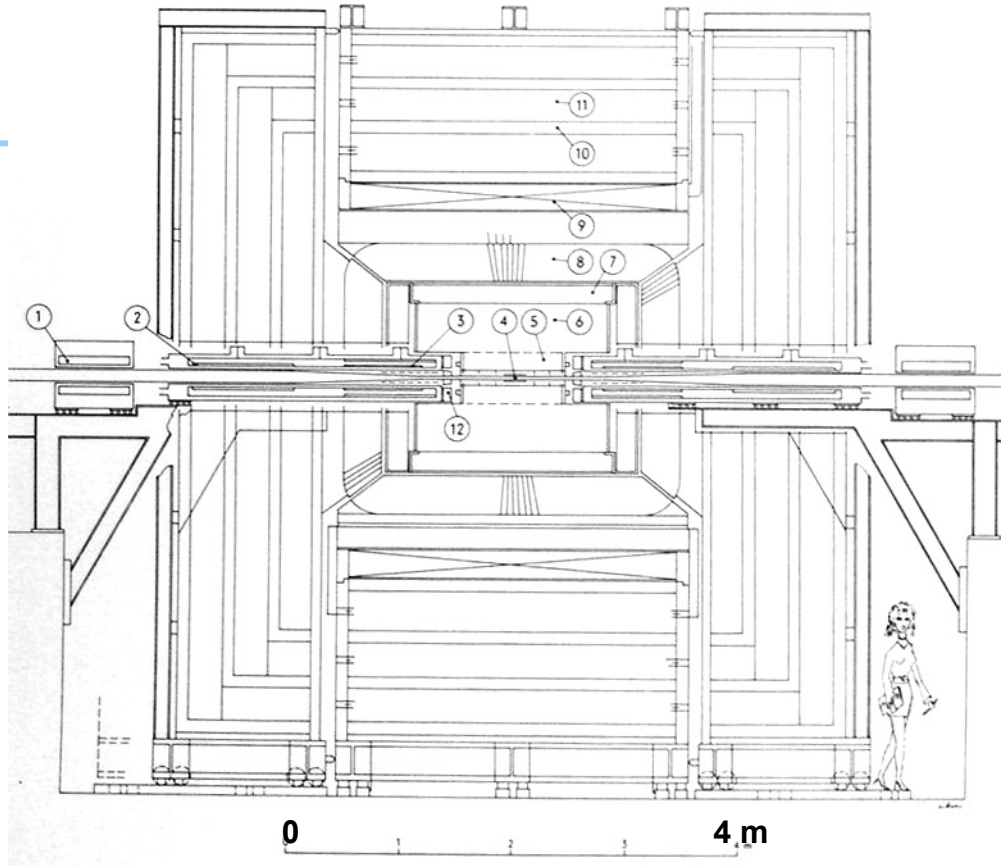
PAUL SCHERRER INSTITUTE
formerly SIN
CH – 5234 Villigen
Switzerland

proposal funded by PSI-CH, BMBF-D, IN2P3-F.

~ 50 authors from CH, D, F, PL + Crystal Barrel for the 2nd interaction region

PSI Proposal 1988





double ring, u = 648 m, 20 bunches,

d_b = 32 m, electrostatic beam separation at IPs

synchrotron injection, $I_1 = I_2$ = 500 mA,

$L = (1\text{-}3)\cdot 10^{33}/cm^2/s$.

4 = SiVxD
5 = Precision Tracking Ch.
6 = Main Tracking Ch.
7 = RICH
8 = CsI
9 = Coil for 1.5 T
10 = Muon Chambers
11 = Iron

More Studies 1986 / 87

LETTER OF INTENT

FOR July 86

UPGRADING THE TRISTAN ACCUMULATION RING FOR B PHYSICS

H.Aihara

University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113 JAPAN

T.Adachi, K.Egawa, K.Hirata, E.Kikutani, M.Kobayashi, H.Koiso, Y.Masuda, T.Shinkawa, M.Wake, K.Yokoya

National Laboratory For High Energy Physics (KEK), Oho-machi, Tsukuba-gun, Ibaraki-ken, 305 JAPAN

$4 \cdot 10^{32}$ A.I.Sanda

Rockefeller University, 1230 York Avenue, New York, New York, 10021-6399 USA

In addition to the PSI and KEK intentions, the following e^+e^- studies were presented at the Linear-Collider $B\bar{B}$-Factory Design Workshop, UCLA Jan.87. D. Cline's postulate:

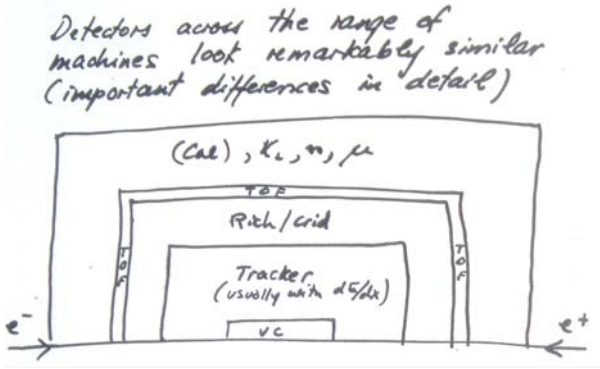
„We need a $\bar{B}B$ Factory in the 1990s with $L \geq 10^{34}$; this can only be done with a new type of machine; we will establish a working group."

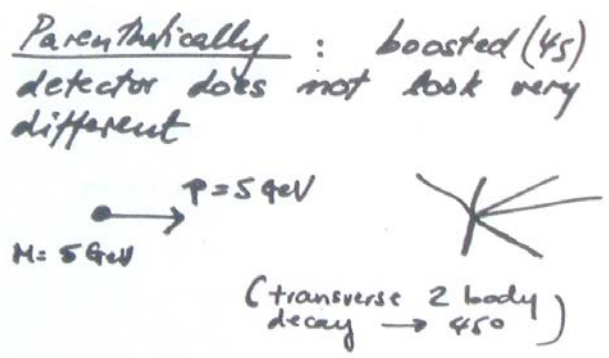
J. Wurtele & A. Sessler, Linac with 10^{33} on Y4S.

U. Amaldi and G. Coignet, Supercond. Linac with 10^{33} (Y4S) and 10^{34} ($b\bar{b}$).

E. Bloom, „NPEP" with two E-symmetric rings in the PEP tunnel, $2 \cdot 10^{33}$.

P. Oddone, Detector Physics Group Summary:





Another 1987 Publication

Nucl.Phys.B 281(1987)41

CP VIOLATION IN HEAVY FLAVOR DECAYS:
PREDICTIONS AND SEARCH STRATEGIES*

I. I. BIGI†

Stanford Linear Accelerator Center
Stanford University, Stanford, California, 94305

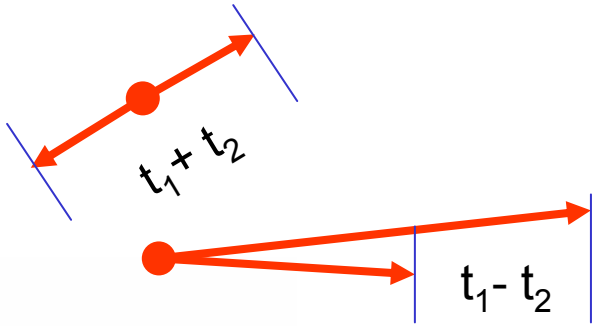
and

A. I. SANDA*

Rockefeller University, New York, N. Y. 10021

333 citations.

Parts of the arguments already in Bigi and Sanda Nucl. Phys. B 193(1981)85



Eq.2.6 and $\Upsilon(4S) \to (J/\psi K_S) B_{tag}$:

$$\text{rate}\left(B_q(t)\,\overline{B}_q(t)\big|_{C=\mp} \longrightarrow f_a\, f_b\right) \propto \exp\{-\Gamma_q(t+\bar{t})\}$$

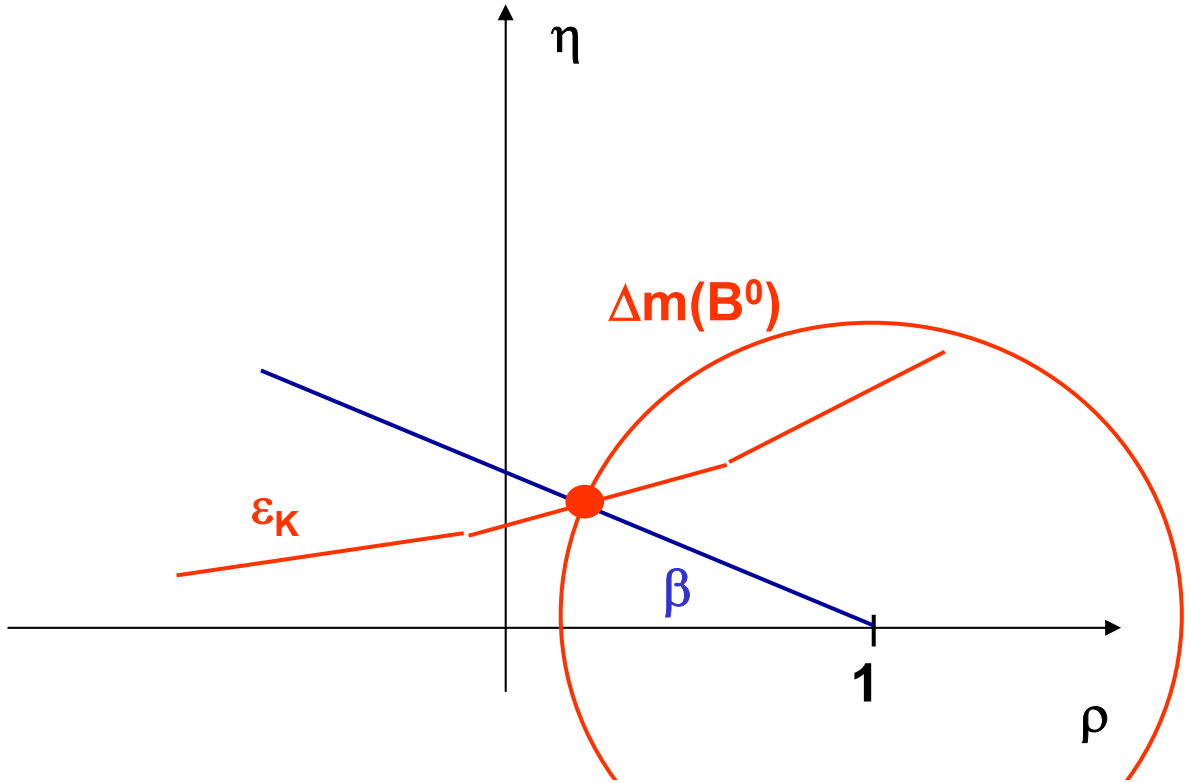
$$\times \left\{[1+\cos\Delta m_q(t\mp\bar{t})]\left|A_a\,\bar{A}_b \mp A_b\,\bar{A}_a\right|^2\right.$$

$$+ \quad [1-\cos\Delta m_q(t\mp\bar{t})]\left|\frac{p}{q}\,A_a\,A_b \mp \frac{q}{p}\,\bar{A}_a\,\bar{A}_b\right|^2$$

$$+ \quad 2\sin\Delta m_q(t\mp\bar{t})\ \mathrm{Im}\left(\frac{p}{q}\,A_a\,A_b \mp \frac{q}{p}\,\bar{A}_a\,\bar{A}_b\right)(A_a\,\bar{A}_b \mp A_b\,\bar{A}_a)^*\Big\}$$

A symmetric e^+e^- storage ring measures only $t + \bar{t}$. $t - \bar{t}$ requires boost.

1987: Measured $\Delta m(B^0)$ and $B^0 \rightarrow J/\psi\ K^0 \Rightarrow$



If $A_{CP}(J/\psi\ K^0) = \sin 2\beta$, you need a few years with $10^{33}/cm^2/s$ for excluding that $A_{CP} = 0$ with ~ 5 σ

More Workshops & Boost Optimization

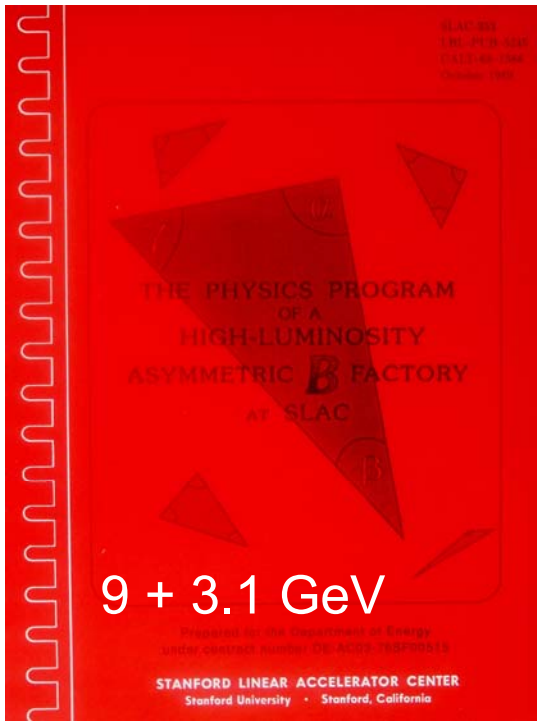
Sept.87 SLAC (E.Bloom, A.Fridman), B-Meson Factory Workshop

Wille: PSI, Bloom: NPEP→SBF (sym.Y4S, boosted Y4S, sym.continuum)

Cline: Linac, Amaldi: Linac, Berkelman: CESR upgrade.

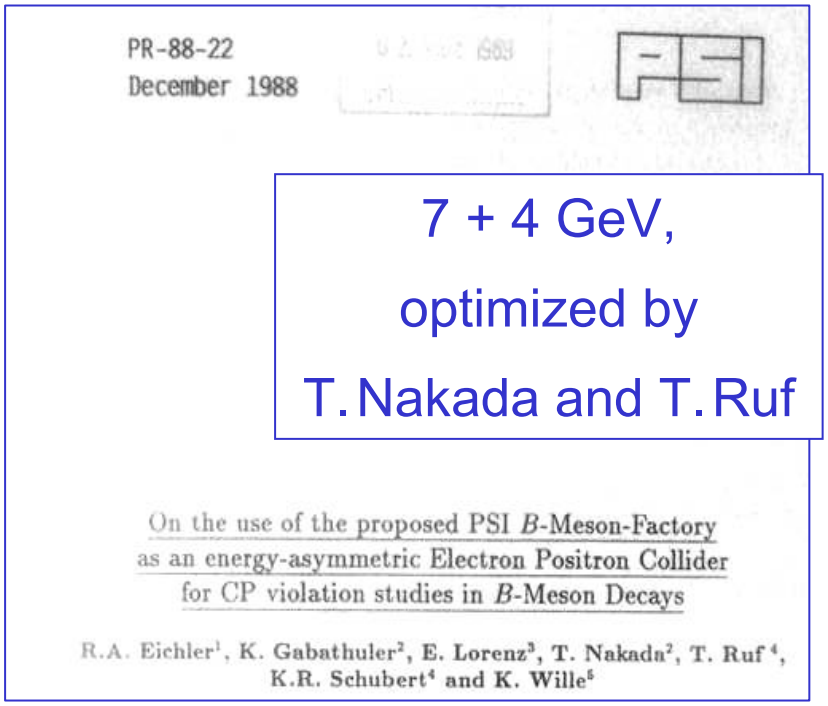
Starting Summer 88, workshops at Snowmass, SLAC, and Caltech.

Writeup SLAC-353 (Oct.89) has 40 authors (Dorfan, Hitlin, Nir, Oddone ...)



Machine paper SLAC-352, also appeared Oct.89.

With asymmetry, SLAC (early 1988) was faster than PSI (late 1988).


PR-88-22
December 1988

7 + 4 GeV, optimized by T. Nakada and T. Ruf

On the use of the proposed PSI *B*-Meson-Factory as an energy-asymmetric Electron Positron Collider for CP violation studies in *B*-Meson Decays

R.A. Eichler[1], K. Gabathuler[2], E. Lorenz[3], T. Nakada[2], T. Ruf[4], K.R. Schubert[4] and K. Wille[5]

7 Complete Proposals in 1991

Technical advantage of energy asymmetry: Beam separation in the IPs works with static B, no static E fields needed $\Rightarrow$ smaller $d_b \Rightarrow$ larger L.

KEK Documents: Task Force Report on Physics and Detectors KEK-90-23, on Accelerator Design: KEK-90-24, 3.5 + 8 GeV, $L \geq 1 \cdot 10^{34}/cm^2/s$.

PSI project did not find approval and moved 1990 into the ISR Tunnel at CERN, T. Nakada et al, CERN 90-02

Proposal List 1991:

PSI	E = 7+4 GeV	(1-3) · $10^{33}/cm^2/s$	u = 648 m	d_{bunch} = 32 m
SLAC	9 + 3.1	$3 \cdot 10^{33}$	2200 m	1.3 m
KEK	8 + 3.5	**10^{34}**	3020 m	**0.6 m**
CERN	8 + 3.5	10^{34}	963 m	3 m
Novosibirsk	6.5 + 4.3	$5 \cdot 10^{33}$	714 m	4.2 m
DESY	9.3 + 3	$3 \cdot 10^{33}$	2300 m	3.6 m
Cornell	8 + 3.5	$3 \cdot 10^{33}$	765 m	3.3 m

PEP-II (SLAC) and KEK-B approved 1993. More on these two in J. Olsen's presentation

B-Meson Factories produce also D^0 Mesons (The 2007 Discovery: $D^0\bar{D}^0$ Mixing)

All meson systems which are allowed to mix are observed to mix

$K^0\bar{K}^0$ 1956, $\chi = 0.498$, $\Delta\Gamma$, Δm

$B^0\bar{B}^0$ 1987, $\chi = 0.19$, Δm

$B_s\bar{B}_s$ 2006, $\chi = 0.499$, Δm, $\Delta\Gamma$ ($\neq 0$ with 1.5σ),

$D^0\bar{D}^0$ 1987 ARGUS: PL 199B,447 $\chi < 0.014$ (90% CL) from $D^{*+} \to \pi^+(K^\mp\pi^\pm)$

2007, $\chi \approx 1\cdot 10^{-4}$ ($\neq 0$ with 5σ), $\Delta m, \Delta\Gamma$ ($\neq 0$ with 2σ)

Common mixing phenomenology: $\psi(t) = a(t)\mathrm{M} + b(t)\overline{\mathrm{M}}$

$$i\,\partial_t \begin{pmatrix} a \\ b \end{pmatrix} = \left(m_{ij} - \frac{\Gamma_{ij}}{2} \right) \begin{pmatrix} a \\ b \end{pmatrix}$$

$$\mathrm{M}_h(t) = \left(p\,\mathrm{M} + q\,\overline{\mathrm{M}}\right)\cdot e^{-i(m+\Delta m/2)t-(\Gamma/2+\Delta\Gamma/4)t}$$

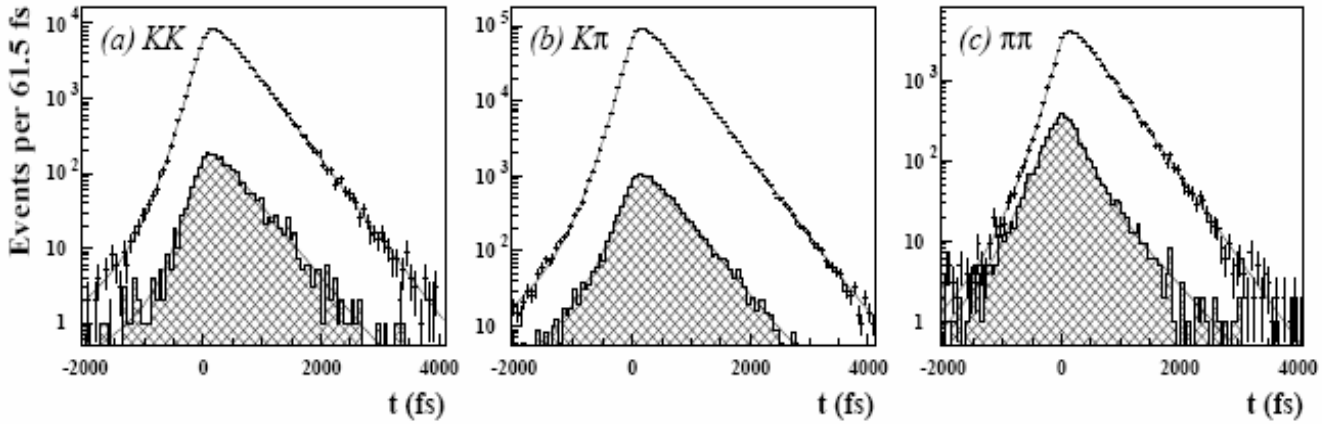
$$\mathrm{M}_l(t) = \left(p\,\mathrm{M} - q\,\overline{\mathrm{M}}\right)\cdot e^{-i(m-\Delta m/2)t-(\Gamma/2-\Delta\Gamma/4)t}$$

$\lvert q/p\rvert \approx 1$ in all four systems	$\Rightarrow$ All four M_h and M_ℓ are CP eigenstates	3 independent pairs of properties

K Long = CP-odd = heavy
B_s Long = CP-odd (1.5σ) = ?
D L = CP-odd (4σ) = light (2σ)
B^0 Long = ? = ?

$x = \Delta m/\Gamma$, $y = \Delta\Gamma/2\Gamma$, sign(q) $\Rightarrow$ unnecessary ϕ

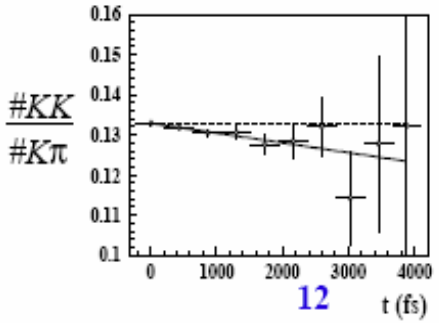
$y_{CP} = y \cos \phi$ (BELLE)



$\tau = 403.2 \pm 1.4$ fs (110k events)

$\tau = 408.6 \pm 0.7$ fs (1200k events)

$\tau = 402.5 \pm 2.2$ fs (50k events)



⇒ there is a difference between *KK* and *Kπ*

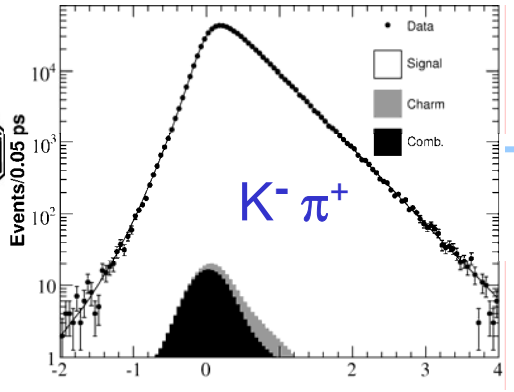
(here, t0 is free for Kπ)

A. J. Schwartz *FPCP'07 - Bled, Slovenia* 12

$$y_{CP} = \frac{\hat{\tau}\left(D^0 \to K^-\pi^+\right)}{\hat{\tau}\left(D^0 \to K^-K^+\right)} - 1 = (1.31 \pm 0.32 \pm 0.25) \cdot 10^{-2} \quad \textbf{3.2 } \sigma$$

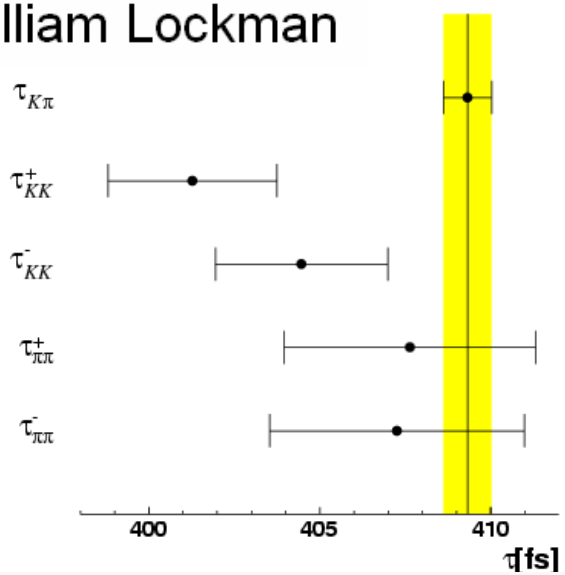
PRL 98, 211803 (2007), 540 fb^{-1}

y (BABAR, preliminary)

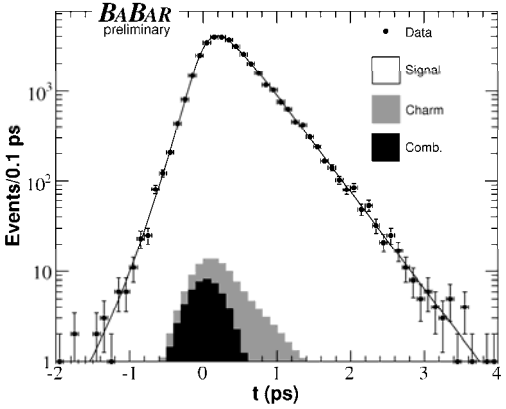


384/fb

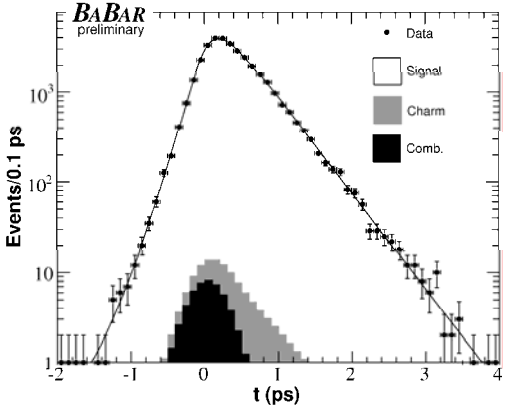
LP07 - William Lockman



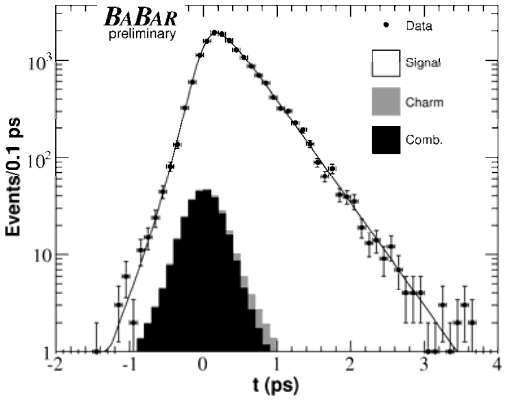
$D^0 \to K^+ K^-$



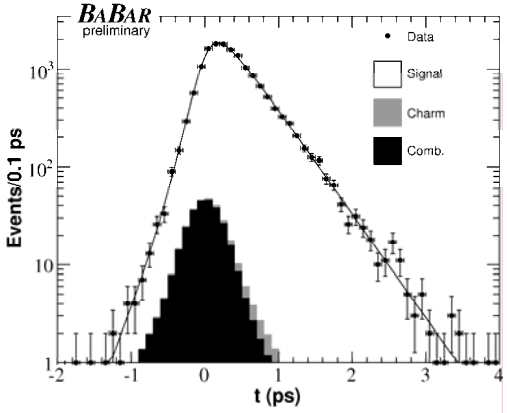
$\bar{D}^0 \to K^+ K^-$



$D^0 \to \pi^+ \pi^-$



$\bar{D}^0 \to \pi^+ \pi^-$



	y_{CP}
K^+K^-	$(1.60 \pm 0.46(\text{stat}) \pm 0.17(\text{syst}))\%$
$\pi^+\pi^-$	$(0.46 \pm 0.65(\text{stat}) \pm 0.25(\text{syst}))\%$
Combined	$(1.24 \pm 0.39(\text{stat}) \pm 0.13(\text{syst}))\%$

3.0 σ

BELLE:

$1.31 \pm 0.32 \pm 0.25$

My average:

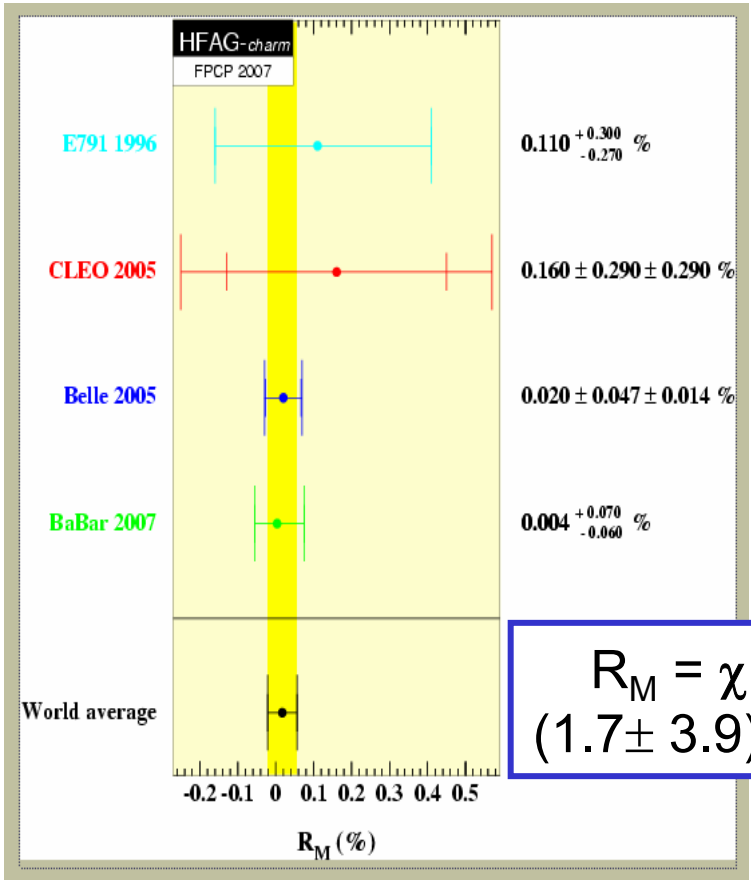
$(1.28 \pm 0.29)\ 10^{-2}$ **4.4 σ**

$x^2 + y^2$

$R_M = \chi = (x^2+y^2)/(2+2x^2)$

$D^{*+} \rightarrow D^0 \pi^+$,

$D^0 \rightarrow K^- \ell^+ \nu$, $D^0 \rightarrow \bar{D}^0 \rightarrow K^+ \ell^- \bar{\nu}$



$R_M = \chi = (1.7 \pm 3.9)\ 10^{-4}$

$D^0 \rightarrow \bar{D}^0 \rightarrow K^+ \pi^- \pi^0$

$R_M = (2.3 \pm {}^{1.8}_{1.4})\ 10^{-4}$

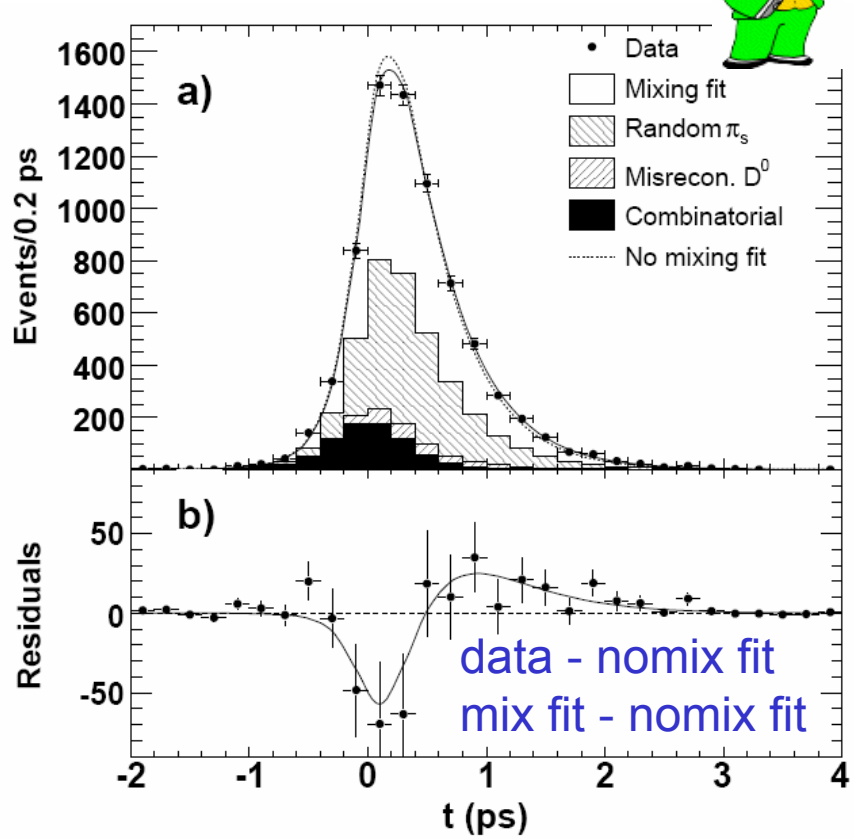
$D^0 \rightarrow \bar{D}^0 \rightarrow K^+ \pi^- \pi^+ \pi^-$

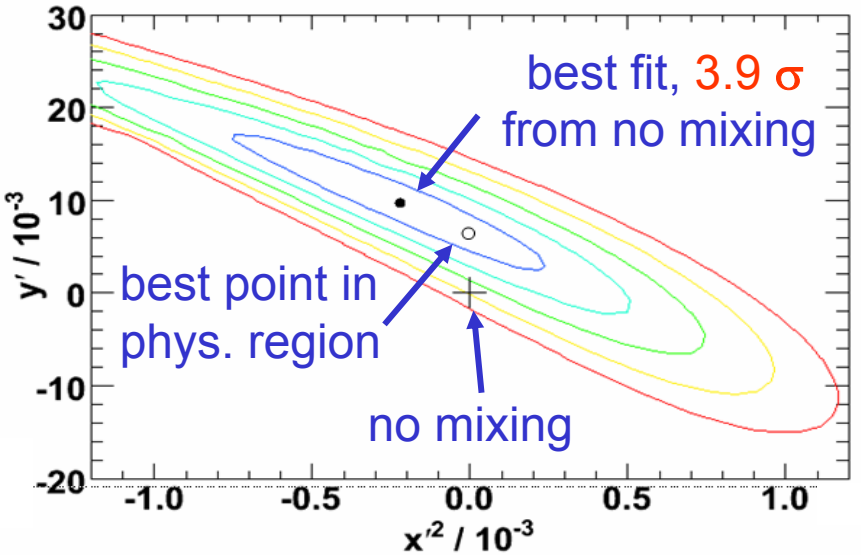
$R_M = (1.9 \pm 1.6)\ 10^{-4}$

y‘ and $x^2 + y^2$ in $D^0 \to \bar{D}^0 \to K^+\pi^-$

$$N_{K^+\pi^-}(t) = N_{K^-\pi^+}(0)\, e^{-\Gamma t}\left[R_D + \sqrt{R_D}\, y'\, \Gamma t + \frac{x'^2 + y'^2}{4}(\Gamma t)^2 \right] \quad \begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

PRL 98 (2007) 211802





R_D: (3.03 ± 0.16 ± 0.10) x 10^{-3}
x'^2: (-0.22 ± 0.30 ± 0.21) x 10^{-3}
y': (9.7 ± 4.4 ± 3.1) x 10^{-3}

BELLE, PRL 96 (2006) 151801

similar result with 2.0 σ from nomix

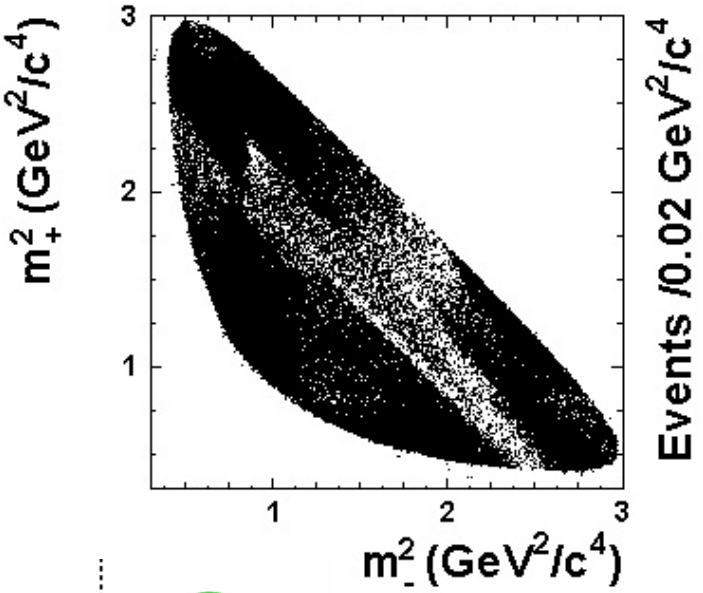
x and y from $D^0 \to K^0_S \pi^+ \pi^-$ Dalitz Analysis

$$\mathcal{M}(m_-^2, m_+^2, t) \equiv \left\langle K_S \pi^+ \pi^- \middle| D^0(t) \right\rangle = \frac{1}{2}\left\{ \mathcal{A}(m_-^2, m_+^2)\left[e^{-i\lambda_1 t} + e^{-i\lambda_2 t}\right] + \mathcal{A}(m_+^2, m_-^2)\left[e^{-i\lambda_1 t} - e^{-i\lambda_2 t}\right] \right\}$$

BELLE

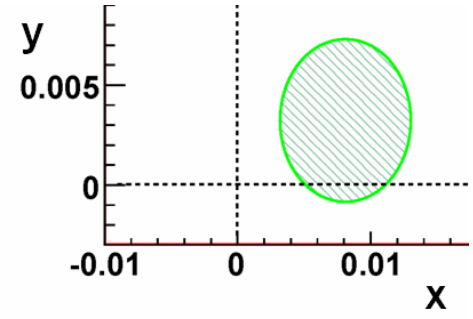
540/fb

PRL 99 (2007) 131803



$$x = (0.80 \pm 0.29 \pm ^{0.13}_{0.16})\%$$

$$y = (0.33 \pm 0.24 \pm ^{0.10}_{0.14})\%$$



2σ from no mixing

$\chi(D^0)$ Summary

$\tau(K^+K^-, \pi^+\pi^-)/\tau(K^-\pi^+)$

$\Rightarrow y \neq 0$ with 3.2 and 3.0 σ

$D^0(t) \rightarrow K^+ \pi^-$

$\Rightarrow (y', x'^2) \neq (0,0)$ with 3.9 σ

$D^0(t) \rightarrow K^0_S \pi^+\pi^-$ Dalitz

$\Rightarrow (x,y) \neq (0,0)$ with 2 σ

HFAG average August 2007

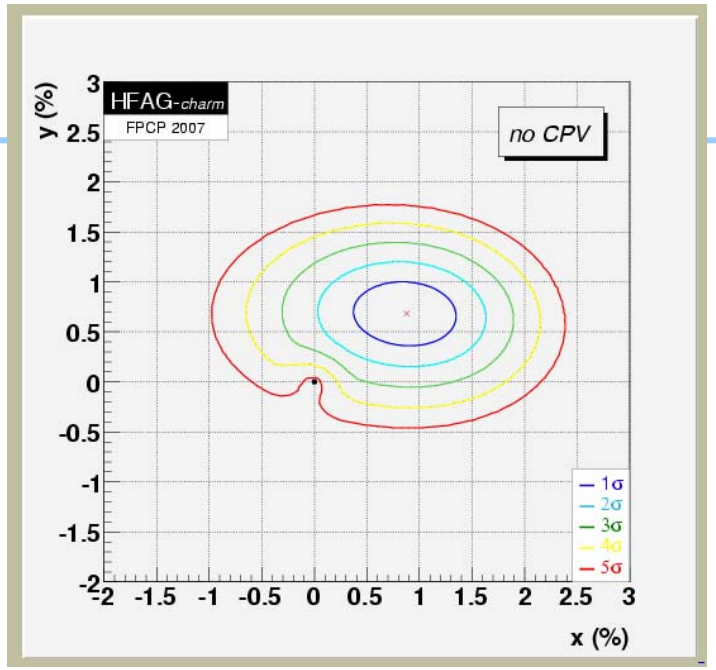
$x = (8.8 \pm 3.3)\ 10^{-3}$

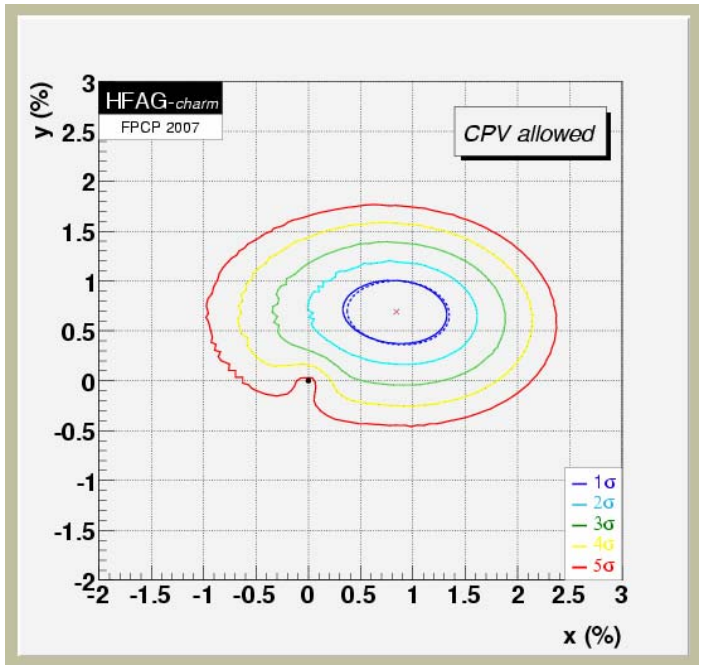
$y = (6.8 \pm 2.1)\ 10^{-3}$

$\chi = (x^2+y^2)/2 = (0.7 \pm 0.3)\ 10^{-4}$

of all produced D^0 decay as $\bar{D}^0$,

$\chi \neq 0$ with 5 σ.





A few Words on B-Meson-Factory Future

Two main activities:

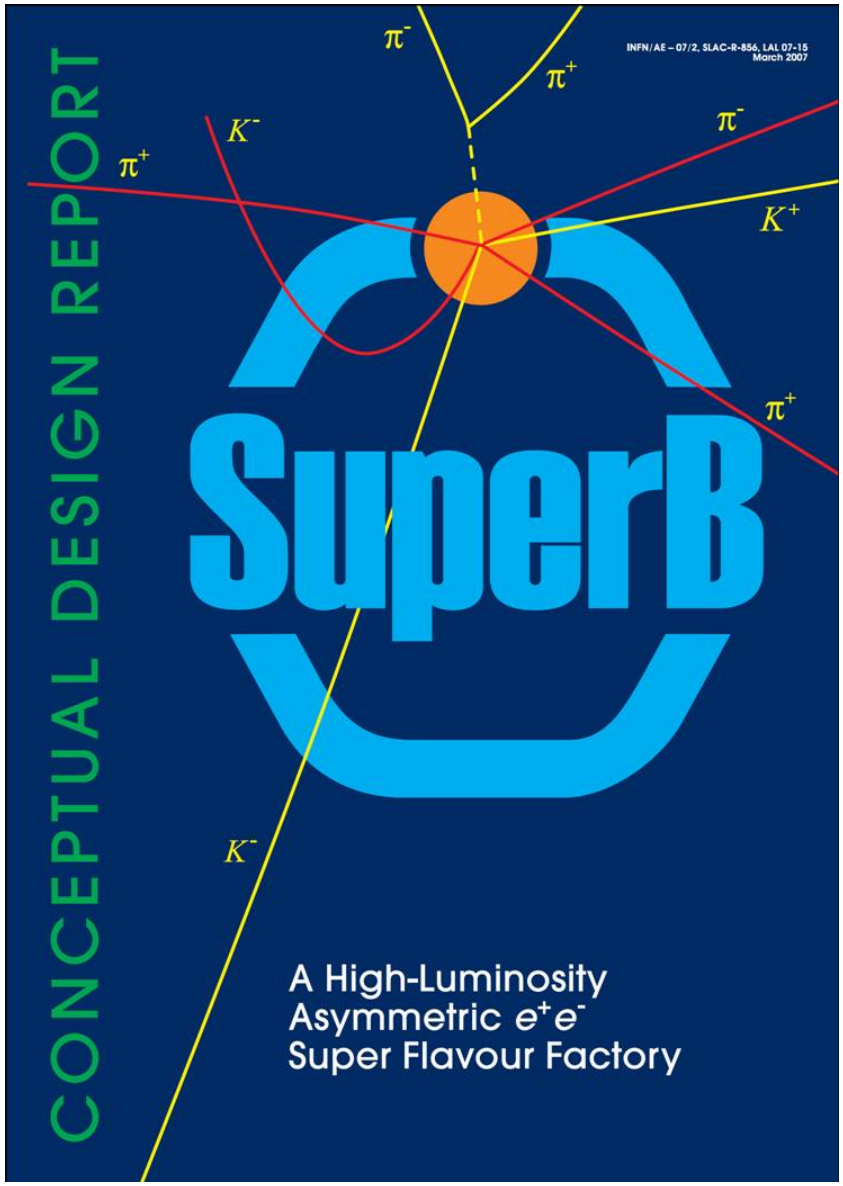
- KEK roadmap will be announced in a few weeks, likely to include KEK-B upgrade as a major programme,
- SuperB project from BABAR physicists, US, INFN, IN2P3...

material here from M. Giorgi (23/8/07) and F. Forti (19/9/07).

Since 2002, the evident success of B Factories and the extremely clean e^+e^- environment has stimulated in the flavor communities the idea about new factories with a luminosity between 1 and 2 order-of-magnitudes higher than in the present facilities. INFN promoted at the end of 2005 the formation of an international study group for a CDR on SuperB containing:

- Physics case in the era of LHC for a Super Flavor Factory
- Design of machine and detector able to integrate 15-65/ab/y @Y4S
- Possibility of running at $\sqrt{s}$ = 4 GeV with a peak luminosity of $10^{35}/cm^2/s$
- At least one polarized beam for τ physics

CDR ready April 2007



INFN/AE-07/02,
SLAC-R-856,
LAL 07-15

arXiv.org/abs/0709.0451

476 pages, available at

www.pi.infn.it/SuperB

Copies can be requested from

Lucia.Lilli@pi.infn.it

320 authors (exp + th + acc)

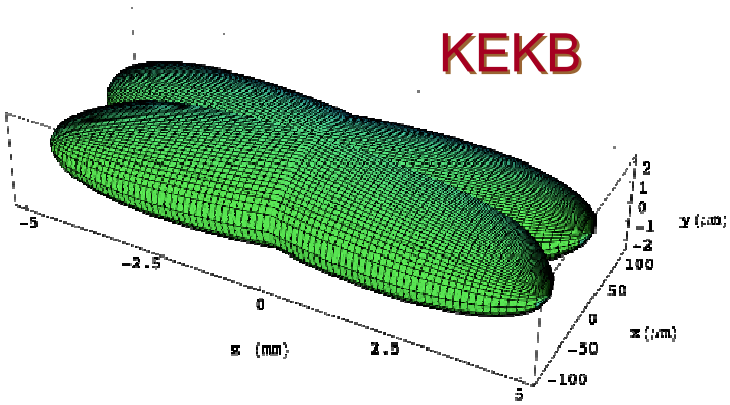
65 non-BABAR experimentalists

85 Institutions, 15 countries

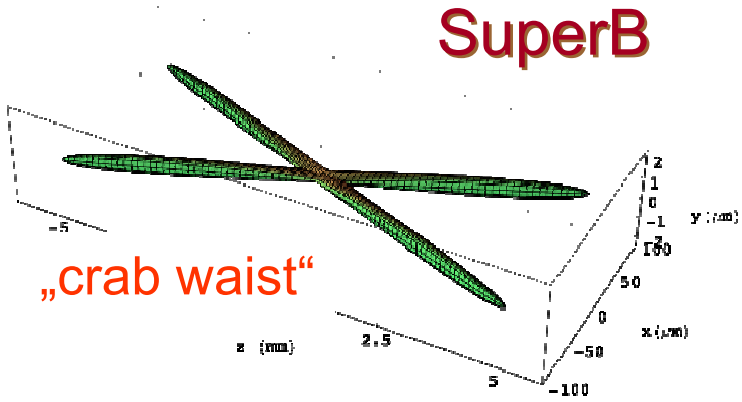
(I, USA, UK, F, RUS, E, D ...)

SuperB Storage Ring Parameters

KEKB



SuperB



„crab waist“

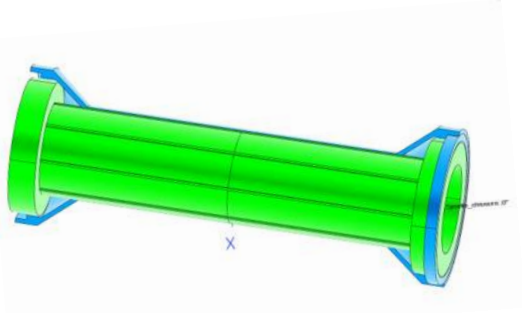
Main gain in lumi from bunch size: σ_y = 35 nm, σ_x = 5 μm, σ_z = 6mm,

Crossing angle = 30 mrad, u ~ 2000 m, n_b = 1733 (3466), d_b = 1.3 (0.65) m,

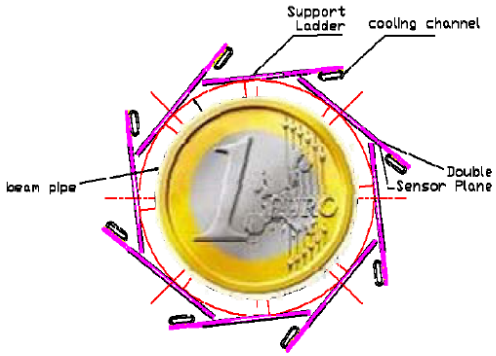
E^- = 7 GeV, E^+ = 4 GeV, I^- = 1.3 (2.2) A, I^+ = 2.3 (4.0) A, P = 17 (35) MW,

L = $1 \cdot 10^{36}$ ($2 \cdot 10^{36}$) /cm^2/s.

Smaller Boost than in BABAR requires better vertex resolution

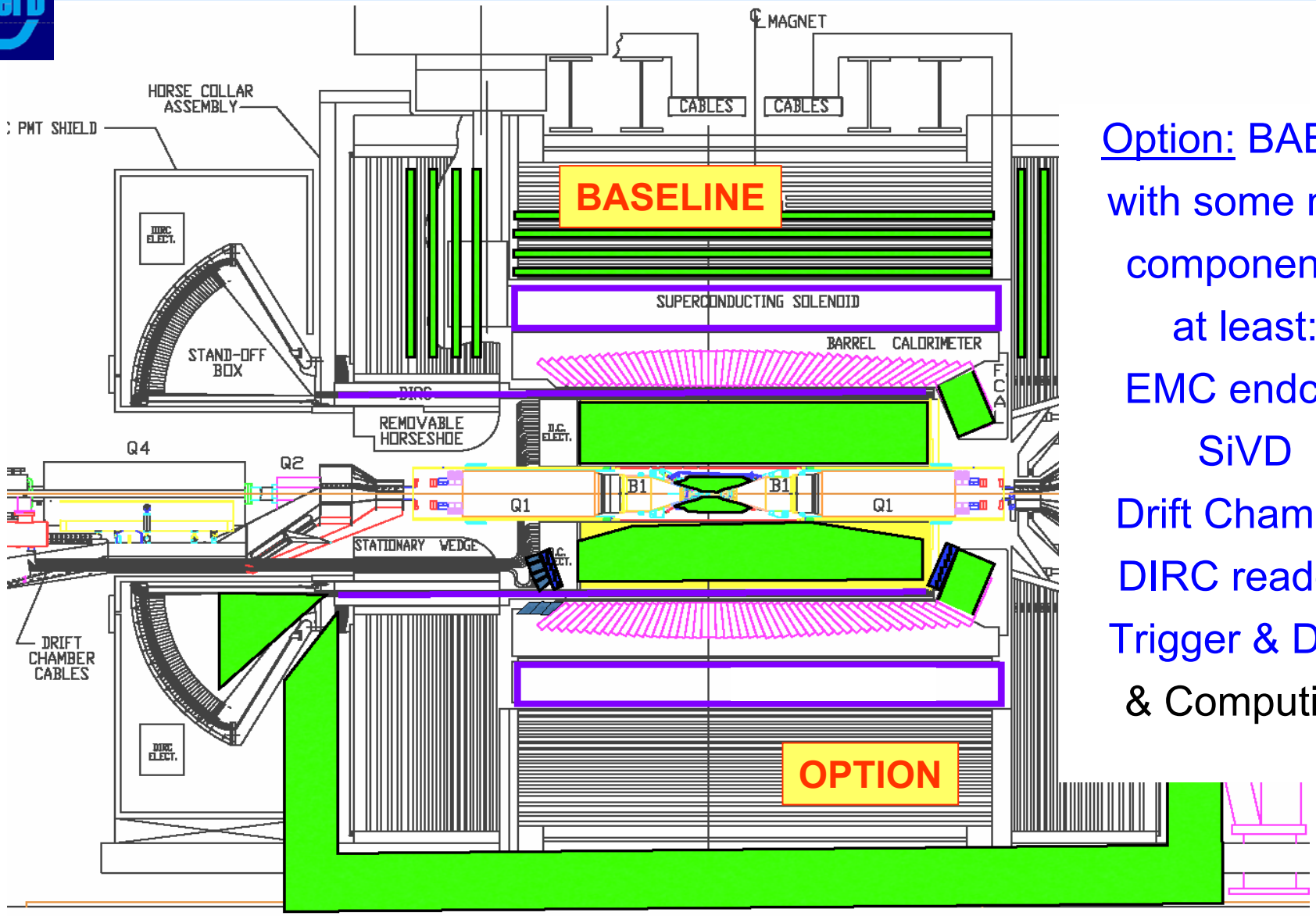


r (beamtube) = 1 cm



1st SiVD layer with pixels

SuperB Detector Concept



Option: BABAR with some new components, at least:

EMC endcap

SiVD

Drift Chamber

DIRC readout

Trigger & DAQ

& Computing

The Next Steps

- An International Review Committee has been appointed by INFN.
  - John Dainton – UK/Daresbury, chair
  - Jacques Lefrancois – F/Orsay
  - Antonio Masiero – I/Padova
  - Rolf Heuer – D/ Desy
  - Daniel Schulte – CERN
  - Abe Seiden – USA/UCSC
  - Young-Kee Kim – USA/FNAL
  - Hiroaki Aihara – Japan/Tokyo

- The review is scheduled for 12 and 13 November 2007 in Frascati
- The report is foreseen in spring 2008
-
  - After results of the DAΦNE test of crab waist foreseen in fall 2007

- Presentation to the CERN strategy group foreseen in spring 2008

A Possible Site for this International Project