# τ-c COLLIDER - PROPERTIES - PROSPECTS

## SLAC - MAR 6-9 '99

INTRO.

- τ-cF HISTORY > DECADE → many interesting ideas. WILL NOT REVIEW DEVT.

- MOST new IDEAS INCORP. IN "REFERENCE DESIGN" of 1996 = "BTCF FEASIBILITY STUDY"

- THIS REVIEW BASED ON '96 STUDY: IF START TODAY ?? "DREAM" OF FUTURE ??

BASICS

- $e^+e^-$ SR COLLIDER : VERY E SPECIFIC (RADIATION) → $E_{opt}$. $E(\hat{L})$ - Ref. Des. - ~2 GeV/bm. [atten' paid to 1.5 GeV oper as well] $\hat{E} \gtrsim 2.5$

- $\mathcal{L} \propto \frac{\xi \cdot E \cdot I}{\beta^*}$ ; E (specified), ξ ("constant" of Nat.)

  $\beta^*$ (technology, physics constr - some variability)

  $I = k N_b e f_0$ ; $N_b$ limited, $f_0$ heavy constraints,

  → go for big k (# bunches)

- BIG k → small $S_{13}$ → fast separation at IP to avoid sacrifice ξ uselessly → separate rings → constrained IR

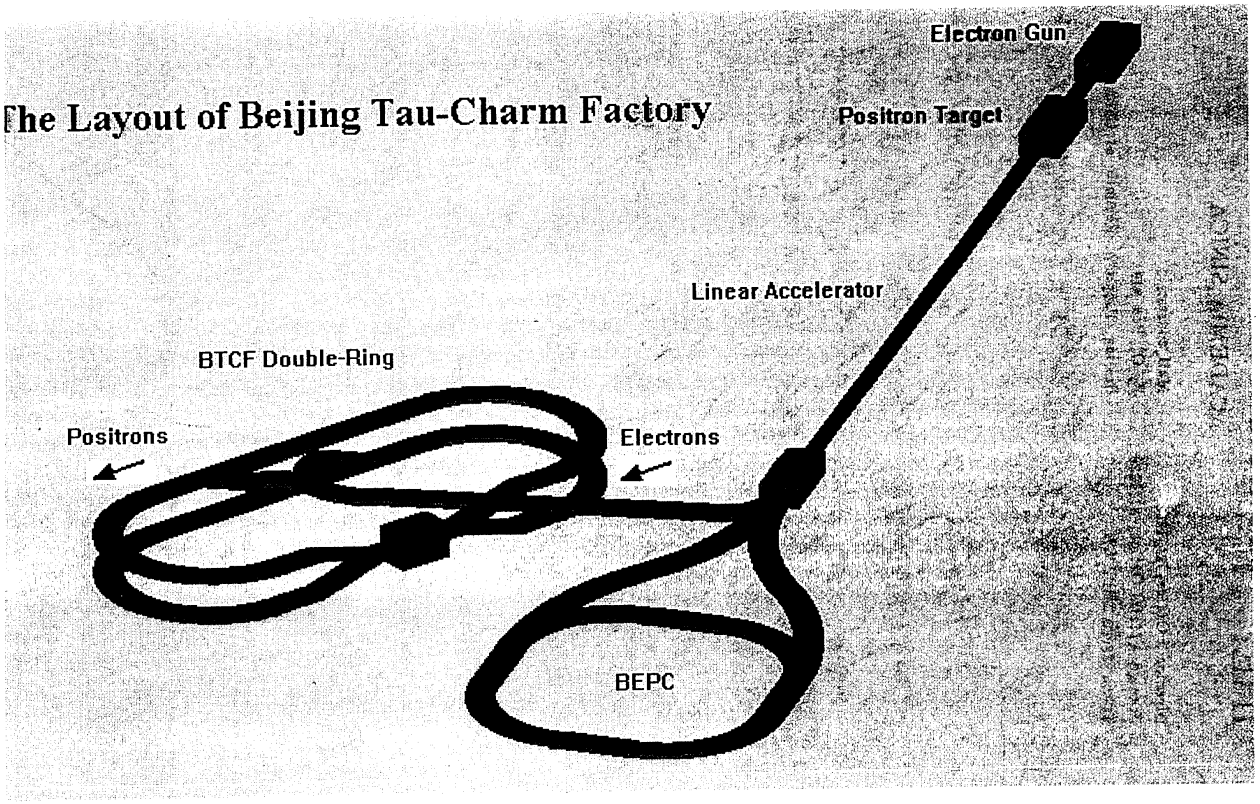
REF. DES.

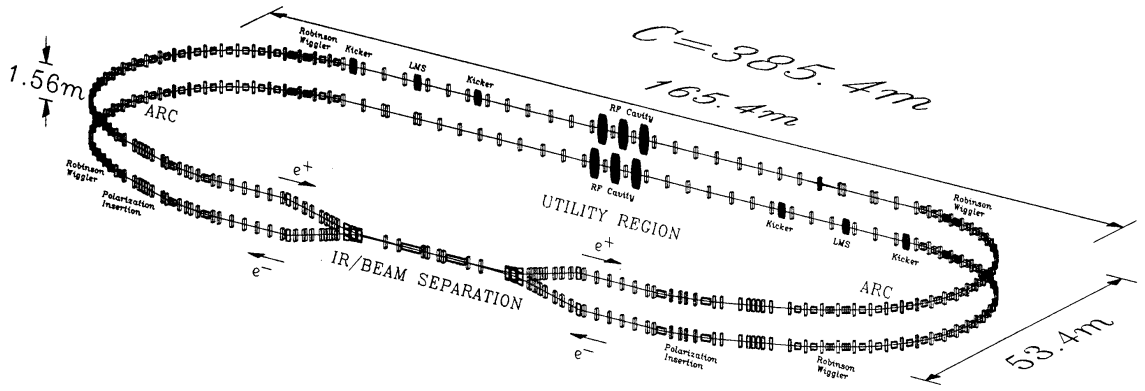
- $\geq 2$ MODES, e.g. Hi $\mathcal{L}$, $\vec{n}$, mono ...
  CONDENSE TO 2: (Hi $\mathcal{L}$, $\vec{n}$, 2GeV); (mono, 1.55GeV)

- See Layouts
  - ✓ 2 RINGS (2)
  - ✓ IR (3)

- Hi $\mathcal{L}$, $\vec{n}$ (See Param List)
  ($X \cdot \mathcal{L}$ ??)

- Monochromater - $D_y \rightarrow \Delta y_\epsilon \gg \Delta y_\beta$
  (See Param List) ($X \cdot \mathcal{L}$ ??)


The Layout of Beijing Tau-Charm Factory
Electron Gun
Positron Target
Linear Accelerator
BTCF Double-Ring
Positrons
Electrons
BEPC


C=385.4m
165.4m
1.56m
53.4m
ARC
Robinson Wiggler
Kicker
LMS
Kicker
RF Cavity
RF Cavity
Robinson Wiggler
Kicker
LMS
Kicker
Robinson Wiggler
Polarization Insertion
UTILITY REGION
IR/BEAM SEPARATION
ARC
Polarization Insertion
Robinson Wiggler
e+
e+
e−
e−

CHALLENGES IN IR - DETECTOR / ACC. INTERFACE
peculiar to τ-cf (w.r.t. B-fac)

- ✓ Hi B-sol / BP ; compensation steals fac. sp.
- ✓ Pol'n adds some constraints (maybe not bad-v)
- ✓ SR less than B-fac
- ✓ BEAM-GAS (Bremst + Coulomb) ≈ same [DETAILS]
- ✓ TOUSCHEK MUCH worse (study ESSENTIAL!!)

  e.g. BTCF: $\tau_{Tk} < \frac{1}{2}\tau_{BG}$ — gas can be pumped
  Touschek trickier?

(See Prelim Bkgnd Calcs - Zhang Dehong)

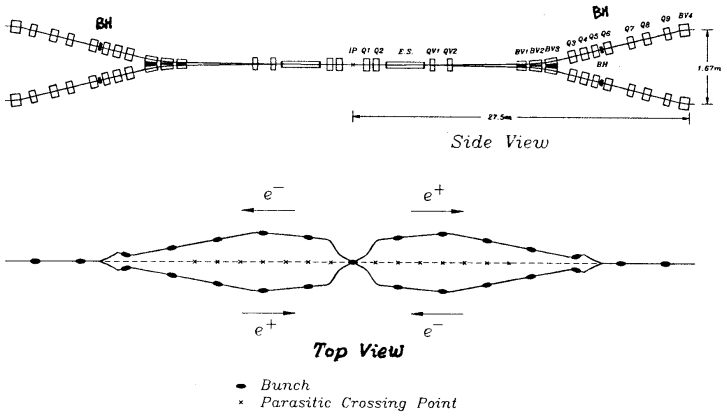
THEN

(See POLARIZATION - Wang Dong's wk)

# (3) Compatibility for Different Modes

## *a) The crossing angle collision optics*

- The crossing angle by a pair of horizontal dipoles BHs.




- Main parameter choice

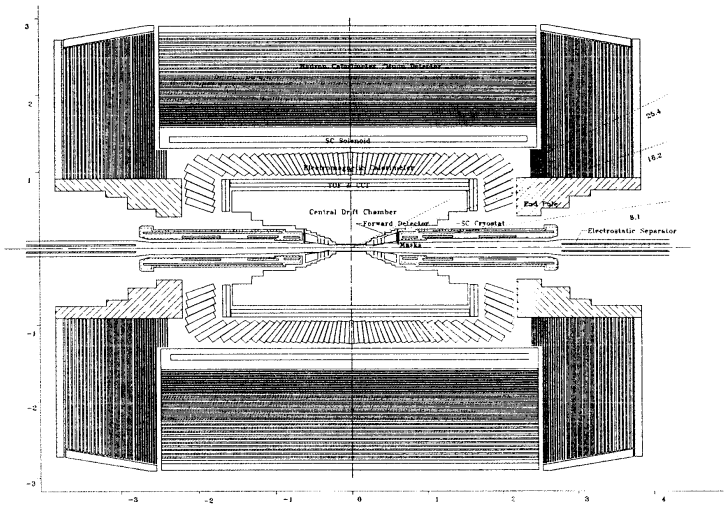
| | |
|---|---|
| **crossing angle** | $2\phi_c = 2.6 \times 2$ mrad |
| **bunch spacing** | 3.78 m |
| bunch number | 86 |
| natural emittance | $\varepsilon_{xo}$=140nmrad |
| beam current | 570 mA |
| $\beta_x^*$ / $\beta_y^*$ | 0.65 m / 0.01 m |

# (1) Interaction Region

## *a) Detector boundary conditions*

- The accelerator components must fit within a conical space with an opening angle of 18.2°, and must be located beyond 0.6m from the IP.

- The superconducting solenoid of the detector has a field strength of 1.0 T over a distance of ±2.65 m around the IP.

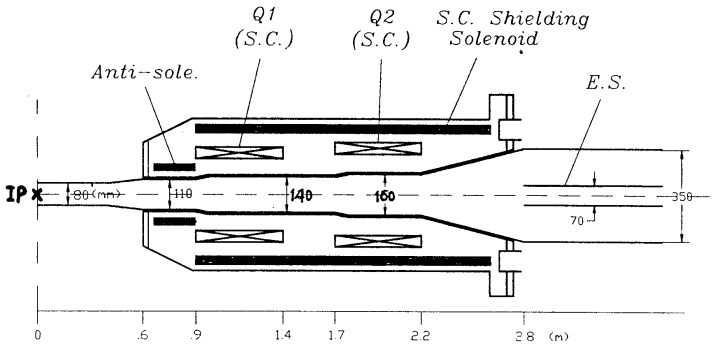



Schematic layout of the detector facilities
and IR accelerator components

## *c) Compensation Solenoids and IR Aperture*

- Anti-solenoid with -3.0 T, 0.3 m long to cancel the detector solenoid field between IP and Q1.

  Shielding solenoid to eliminate the detector solenoid field in the Q1, Q2 region.




Vacuum chamber and cryostat in the IR

- All the aperture in the IR are designed for a beam with at least $14\sigma$ in detector .

- The inside diameter of the vacuum chamber in IR is 80 mm at the IP, 140 mm at Q1 and 160 mm at Q2; the vacuum chamber with 0.8 m long at the IP will be made of pure beryllium.

**Table 3.1** Machine parameters for high luminosity mode with a horizontal crossing angl

| | |
|---|---|
| Beam energy $E$ (GeV) | 2.0 |
| Circumference $C$ (m) | 385.447 |
| Revolution frequency $f_0$ (MHz) | 0.778 |
| Crossing angle at IP $2\phi_c$ (mrad) | 5.2 |
| $\beta$-function at IP $\beta_x^*/\beta_y^*(m)$ | 0.65/0.01 |
| Dispersion at IP $D_x^*/D_y^*$ (m) | 0.0 /0.0 |
| Betatron tunes $Q_x/Q_y$ | 11.8/12.6 |
| Momentum compaction $\alpha_p$ | 0.014 |
| Synch. rad. loss/turn $U_0$ (keV) | 172 |
| Damping time $\tau_x/\tau_y/\tau_\epsilon$ (ms) | 30/30/15 |
| Natural emittance $\epsilon_{x0}$ (nm) | 153 |
| Vertical emittance $\epsilon_y$ (nm) | 2.3 |
| Momentum spread $\sigma_\epsilon$ | $5.84 \times 10^{-4}$ |
| Synchrotron tune $Q_s$ | 0.068 |
| Natural chromaticity $Q'_x/Q'_y$ | -20/-36 |
| Total current per beam $I$ (A) | 0.57 |
| Number of bunches $k_b$ | 86 |
| Particles per bunch $N_b(10^{11})$ | 0.54 |
| RF frequency $f_{rf}$ (MHz) | 476 |
| RF voltage $V_{rf}$ (MV) | 6.8 |
| Natural bunch length $\sigma_l$ (cm) | 0.76 |
| Beam-beam effect $\xi_x/\xi_y$ | 0.04/0.04 |
| Luminosity $L$ ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$) | $1 \times 10^{33}$ |
| CM energy spread $\sigma_\omega$ (MeV) | 1.7 |

## *c) Monochromator scheme*

- Polarity change: Q1, Q2, Q6, QV2;

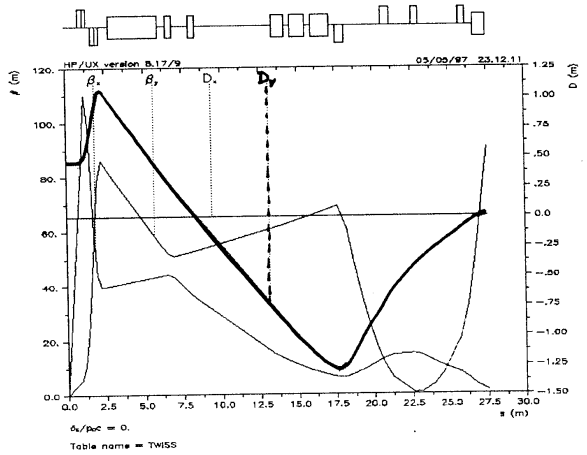
  switching off: Q4, Q8, BH.

- Using Robinson wigglers to adjust the emittance and the energy spread.

- The main parameters:

  $\beta_x^*$ 1cm $\beta_y^*$ 15cm $D_y^*$ ±0.45 m

  $\varepsilon_{x0}$ 35nmrad L $2\times10^{32}cm^{-2}s^{-1}$




IR for monochromator scheme

- The machine studies about beam-beam interaction when $\eta^*$ is lager will be arranged at BEPC.

**Table 3.14** Machine parameters of the monochromator mode

| | |
|---|---|
| Beam energy $E$ (GeV) | 1.55 |
| Circumference $C$ (m) | 385.447 |
| Revolution frequency $f_0$ (MHz) | 0.778 |
| Crossing angle at IP $2\phi_c$ (mrad) | 0.0 |
| $\beta$-function at IP $\beta_x^*/\beta_y^*$ (m) | 0.01/0.15 |
| Dispersion at IP $D_x^*/D_y^*$(m) | 0.0/0.35 |
| Betatron tunes $Q_x/Q_y$ | 13.08/11.11 |
| Momentum compaction $\alpha_p$ | 0.0115 |
| Synch. rad. loss/turn $U_0$ (keV) | 71 |
| Damping time $\tau_x/\tau_y/\tau_\epsilon$ (ms) | 25/59/95 (with wig.) |
| Natural emittance $\epsilon_{x0}$ (nm) | 48 (with wigglers, Jx=2.37) |
| Vertical emittance $\epsilon_y$ (nm) | 4.0 |
| Momentum spread $\sigma_p$ | $8.0 \times 10^{-4}$(with wigglers) |
| Synchrotron tune $Q_s$ | 0.057 |
| Natural chromaticity $Q'_x/Q'_y$ | -37/-29 |
| Total current per beam $I$(A) | 0.2 |
| Number of bunches $k_b$ | 29 |
| particle per bunch $N_b(10^{11})$ | 0.57 |
| Bunch space $S_b$ (m) | 11.97 |
| RF frequency $f_{rf}$ (MHz) | 476 |
| RF voltage $V_{rf}$ (MV) | 4.4 |
| Bunch length $\sigma_l$ (cm) | 1.0 |
| Beam-Beam effect $\xi_x/\xi_y$ | 0.014/0.015 |
| Beam life time $\tau$ (hrs) | $\geq$1 |
| Luminosity $L$ ($cm^{-2}s^{-1}$) | $1 \times 10^{32}$ |
| CM energy spread $\sigma_\omega$ (MeV) | 0.12 |

**Table 3.15** Touschek lifetime of the monochromator mode

| Energy acceptance $10^{-3}$ | Emittance x/y (nm) | Touschek lifetime hours |
|---|---|---|
| 8 | 13/2 | 0.5 |
| 8 | 48/4 | 1.7 |
| 9 | 13/2 | 0.7 |
| 9 | 48/4 | 2.2 |

## Charmonium Summary Walter Toki

The charmonium section of the tau charm workshop included talks by Yifan Gu ($\psi'$ physics), Kam Seth (charmonium results from $p\bar{p}$ gas jet experiments) and Walter Toki (topics in $J/\psi$ and $\psi'$ decays). This summary will discuss (1) the existing data, (2) the expected rates at a tau charm factory,(3) a survey of the physics topics, and (4) calibration procedures.

### CHARMONIUM EXPERIMENTS

The previous $e^+e^-$ experiments on $J/\psi$ and $\psi'$ physics include the Mark II, Crystal Ball, Mark III, and DM2 and the only running experimeint is BES. The existing data sets are listed below.

| Table 1. $J/\psi$ and $\psi'$ Data Sets | | |
|---|---|---|
| Experiment | $J/\psi$ data | $\psi'$ data |
| Mark II | 1.3M | 1M |
| Crystal Ball | 2M | 1.3M |
| MarkIII | 5.8M | .3M |
| DM2 | 8M | - |
| BES | 9M | 1.5M |

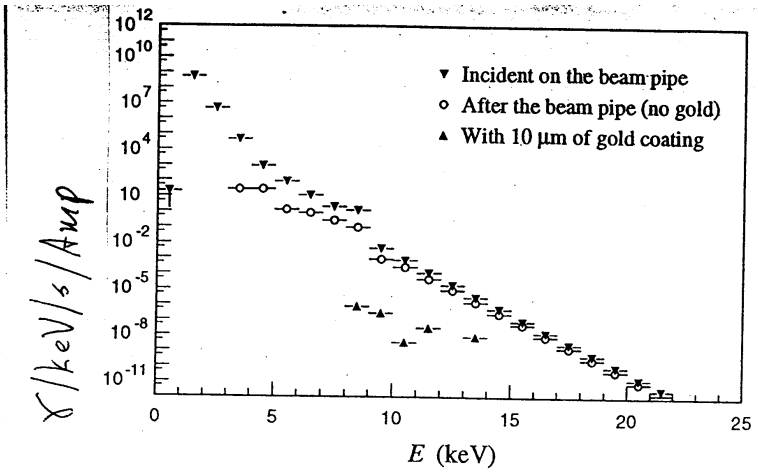
Another important charmonium experiment is the antiproton experiment[1], E760, with a proton gas jet target in the FNAL antiproton accumulator. This experiment has produced in $p\bar{p}$ collisions the $J/\psi$, $\psi'$, $\chi_c$, $\eta_c$ and recently the $^1P_1$. The experiment can measure very precisely the masses and widths by using a cooled antiproton beam whose momentum spread is very small. Typically the center of mass energy spread is 0.5 KeV (full width). The widths have been measured for several resonances. The experiment has been approved for another fixed target run in 1995 (E835).

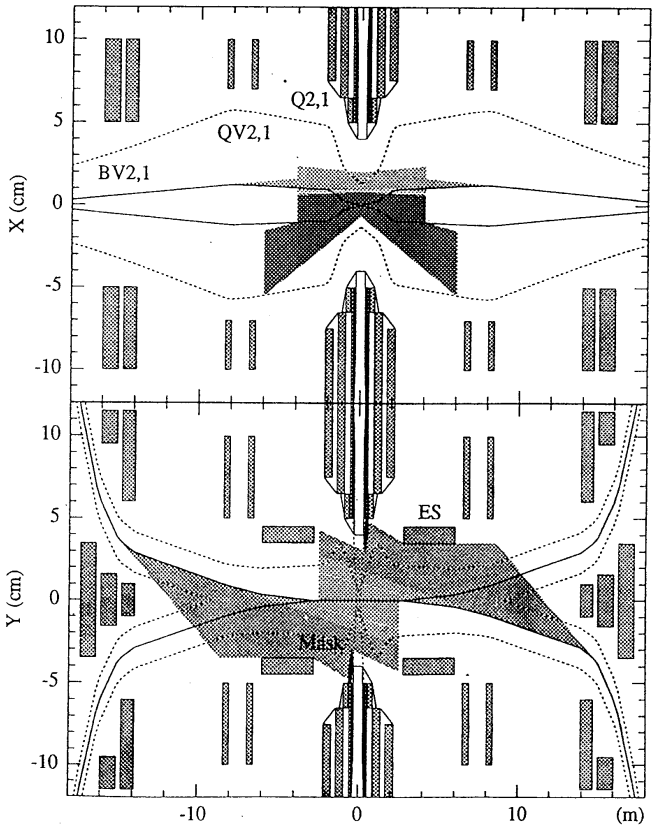
### TAU CHARM FACTORY RATES

In a tau charm factory, the projected luminosity is $10^{33}$ cm$^{-2}$sec$^{-1}$ with a energy spread of ~1 MeV. With a monochrometer, the energy spread can be reduced to 0.14 MeV to increase the peak luminosity for narrow resonances. Using the particle data book values for the $\Gamma$(hadron) and $\Gamma_{ee}$ for the $J/\psi$ and $\psi'$, we can estimate the peak luminosity.[2]

| Table 2. | | | |
|---|---|---|---|
| Resonance | peak cross section | instantaneous rate at $10^{33}$ cm$^{-2}$sec$^{-1}$ | number of events per day(50% efficiency) |
| $J/\psi$ | ~2600 nb | 2.6 Khz | $112\times10^6$ |
| $\psi'$ | ~800 nb | 0.8 Khz | $34\times10^6$ |
| $J/\psi$ with mono-chrometer | ~16000 nb | 16 Khz | $688\times10^6$ |
| $\psi'$ with mono-chrometer | ~5000 nb | 5 Khz | $215\times10^6$ |

[1] Kam Seth talk, this worksbop.
[2] D Yennie, Phys. Rev. Lett., 34,239(1975)


γ/keV/s/Amp
Incident on the beam pipe
After the beam pipe (no gold)
With 10 μm of gold coating
E (keV)


Q2,1
QV2,1
BV2,1
ES
Mask
X (cm)
Y (cm)
(m)

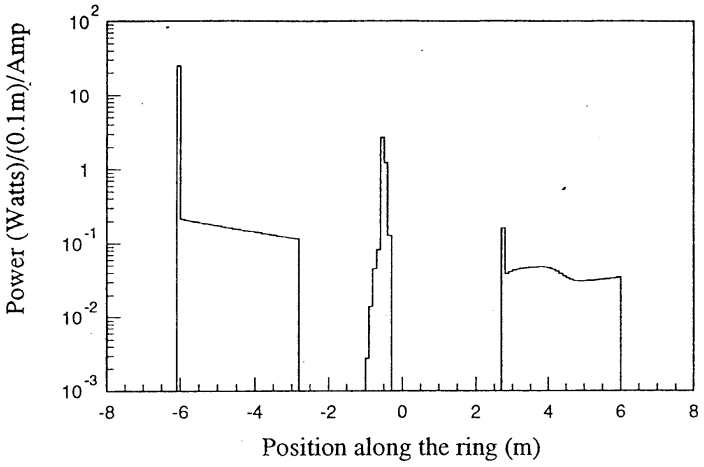



**Figure 3.17** SR power deposited by the electron beam into the vacuum chamber wall within $\pm 8$ m of the IP.

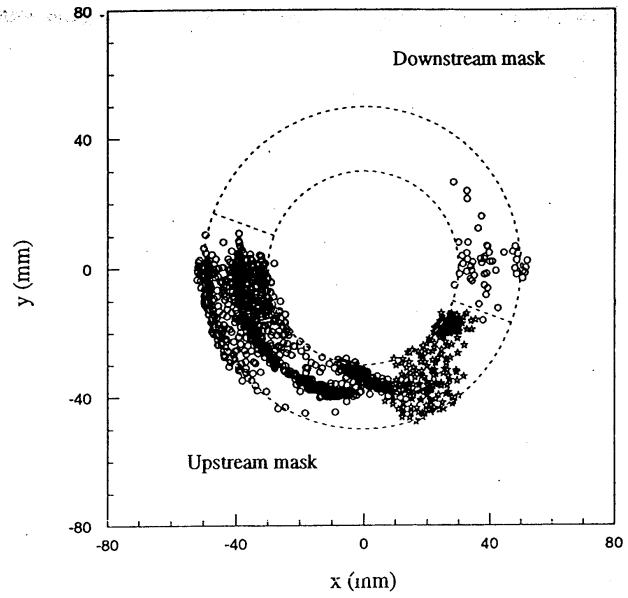
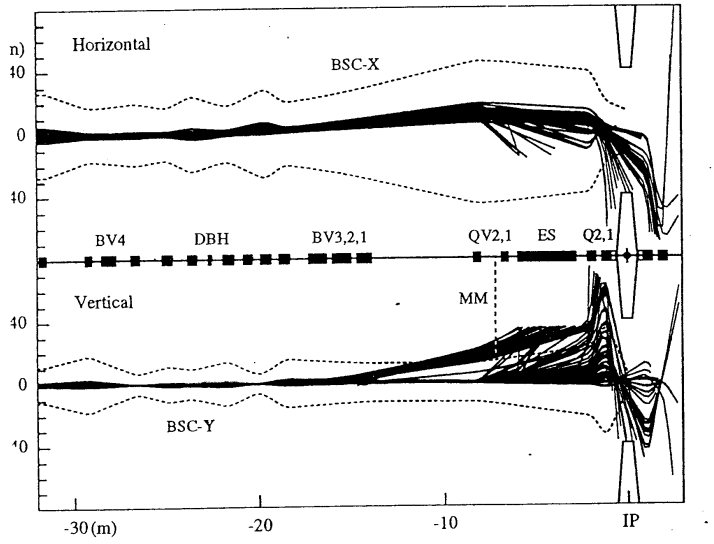



**Figure 3.21** Spatial distribution for bremsstrahlung particles (circles) and photons (stars) when they hit the upstream mask and the beam pipe. The half-circle shaped masks are shown with dash lines.




**3.19** Typical trajectories for bremsstrahlung particles which hit the vacuum chamber the IP. Also shown is the position to place a movable mask (MM).

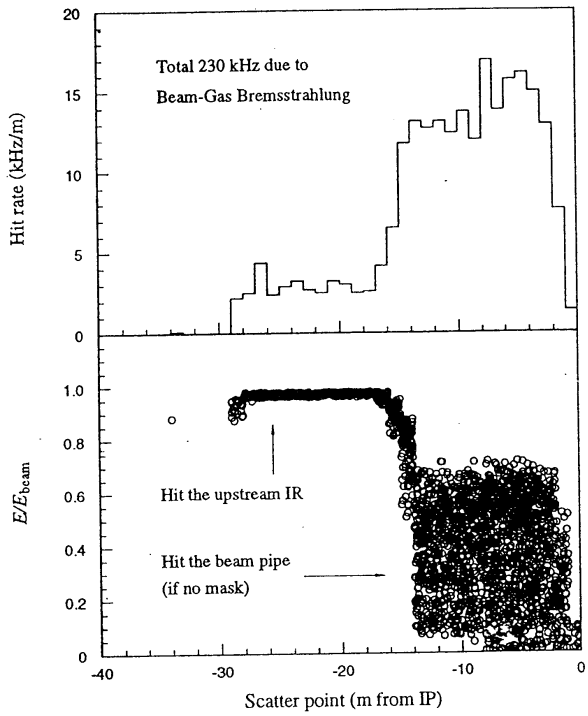



**Figure 3.20** Hit rate as a function of the bremsstrahlung point for one beam (top) and the correlation between energy and the scatter point (bottom).

# Longitudinal Polarization in a Tau-charm Factory

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Institute of High Energy Physics

December 10, 1998

# Longitudinal Polarization in BTCF
## — Definitions:

1, Energies preferred:

So far, 1.8436 GeV is most wanted

If possible: around 2.0 GeV, 1.55 GeV

2, Must both beams be polarized?

Single beam polarized: OK

Both beams polarized: perfect

3, How frequently must helicity be reversed?

Once a week or so

4, Must polarization be available at the start?

If possible

5, Polarization level

Nobody sets a quantity for BTCF, up to now

Mostly depends on the possiblity

1990: Soergel limit for HERA: 50%

# Electron polarization in strorage rings

Table 1: The history of spin polarization in storage rings.

| Name | Year | Polarization | Energy |
|---|---|---|---|
| VEPP | 1970 | 80% vert | 0.65 GeV |
| ACO | 1970 | 90% vert | 0.53 GeV |
| VEPP–2M | 1974 | 90% vert | 0.65 GeV |
| VEPP–3 | 1976 | 80% vert | 2 GeV |
| SPEAR | 1975 | 90% vert | 3.7 GeV |
| VEPP–4 | 1982 | 80% vert | 5 GeV |
| CESR | 1983 | 30% vert | 5 GeV |
| DORIS | 1983 | 80% vert | 5 GeV |
| PETRA | 1982 | 70% vert | 16.5 GeV |
| LEP | 1993 | 57% vert | 47 GeV |
| HERA | 1993 | 60% vert | 26.7 GeV |
| HERA | 1994 | 70% long | 27.5 GeV |
| Amps+BINP | 1996 | ~ long | 0.6 – 0.9 GeV (Shatunov) |

## Longitudinal polarization:

1, Get beam polarized — similior to transverse case

2, Spin rotator: layout

3, Depolarization effects

## Sokolov-Ternov polarization time(hour) vs. bending radius in BTCF

| E(GeV) | 1.55 | 1.77 | 1.84 | 2.0 | 2.5 | 3.0 |
|---|---|---|---|---|---|---|
| ρ = 6m | 6.8 | 3.5 | 2.9 | 1.9 | 0.6 | 0.2 |
| ρ = 7m | 9.2 | 4.6 | 3.9 | 3.7 | 0.8 | 0.3 |
| ρ = 8m | 12.0 | 6.2 | 5.1 | 3.4 | 1.1 | 0.4 |
| ρ = 9m | 15.2 | 7.8 | 6.5 | 4.3 | 1.4 | 0.6 |
| ρ = 10m | 18.8 | 9.7 | 8.0 | 5.2 | 1.7 | 0.7 |
| ρ = 12m | 27.1 | 14.0 | 11.5 | 7.6 | 2.5 | 1.0 |
| ρ = 15m | 42.3 | 21.8 | 18.0 | 11.8 | 3.9 | 1.6 |

$$\rho(\mathrm{m}) = \frac{\mathrm{E(GeV)}}{0.3\mathrm{B(Tesla)}}$$

BTCF:

$E_{max}$ = 3.0 GeV

$B_{max}$ = 1.2 Tesla

⇓

ρ = 8.3 m

Sokolov-Ternov effect on BTCF

| E(GeV) | 1.3 | 1.55 | 1.77 | 1.84 | 2.0 | 2.8 |
|---|---|---|---|---|---|---|
| $\tau_p$ (hour | 30.2 | 12.5 | 6.5 | 5.3 | 3.5 | 0.65 |

Too long!

# SLC polarized electron gun

| Main parameters | Achieved level |
|---|---|
| Electron polarization | ~ 80 % |
| Electrons/bunch peak | $9 \times 10^{10}$ |
| operation | $7 \times 10^{10}$ |
| Availability | ~ 99 % |
| Repetition rate | 120 Hz |
| Kinetic energy of e- | 120 KeV |
| Pause width (FWHM) | 2 ns |

Fufill the requirement of BTCF e- injection

## BTCF e- source: Similar scheme as SLC

- Thermal gun for positron production;
- Polarized gun for polarized e- injection

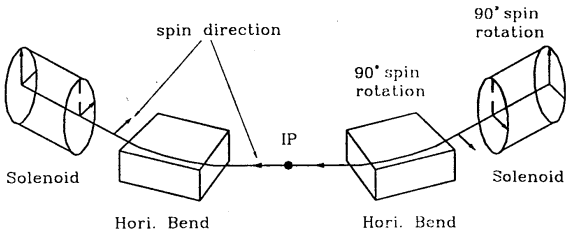
## Compact pre-polarization ring(C=96m) with s.c. dipoles

Polarization time: a few minutes

Refresh(top-up) 1/4 of e+(or e-) bunches each time

Efficient enough?

# Symmetric dipole solenoid spin rotator




## Dipole-solenoid spin rotators in τ-charm factory

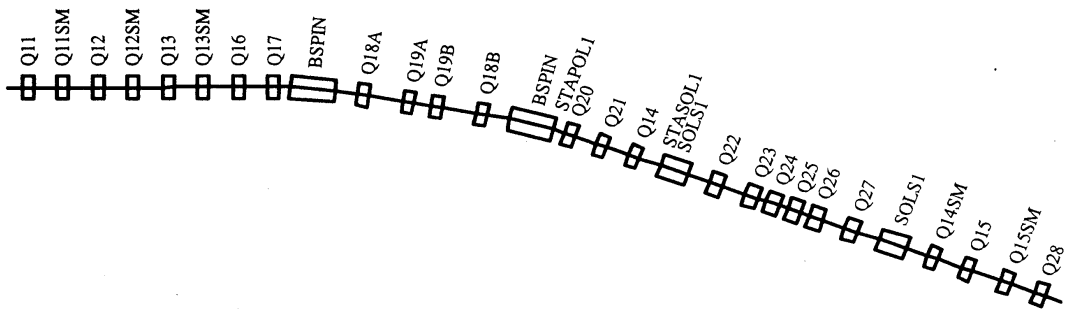
| Energy | 1.55 GeV | 1.84 GeV | 2.0 GeV |
|---|---|---|---|
| Solenid field | 8.1 T·m | 9.7 T·m | 10.5 T·m |
| Bend angle | 25.6° | 21.5° | 19.8° |

## Longitudinal field(L=1.5m)

| Energy | 1.55 GeV | 1.84 GeV | 2.0 GeV |
|---|---|---|---|
| Field strength | 5.4 T | 6.5 T | 7.0 T |

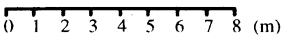
## Quadrupole for coupling compensation

| quadrpoles | length | strength |
|---|---|---|
| SQ1A skew quad. | 0.1 m | -0.2610876 $1/m^2$ |
| SQ1B skew quad. | 0.1 m | 0.2610876 $1/m^2$ |
| SQ2A skew quad. | 0.2 m | -1.112822 $1/m^2$ |
| SQ2B skew quad. | 0.2 m | 1.112822 $1/m^2$ |
| QSOL normal quad. | 0.4 m | 1.167048 $1/m^2$ |




The Layout of Symmetric Solenoid

Spin-rotator Section of BTCF




\NGDONG@SOLAR03, OCT18/20:34

# Depolarization effects and spin matching studies

The presence of spin rotators can cause strong diffusive depolarization, even for perfect machine.

BTCF, 1995, calculated with SLIM by Chao, Minty, Nosochkov. (Rotators on, no spin matching)

Less than 10% !

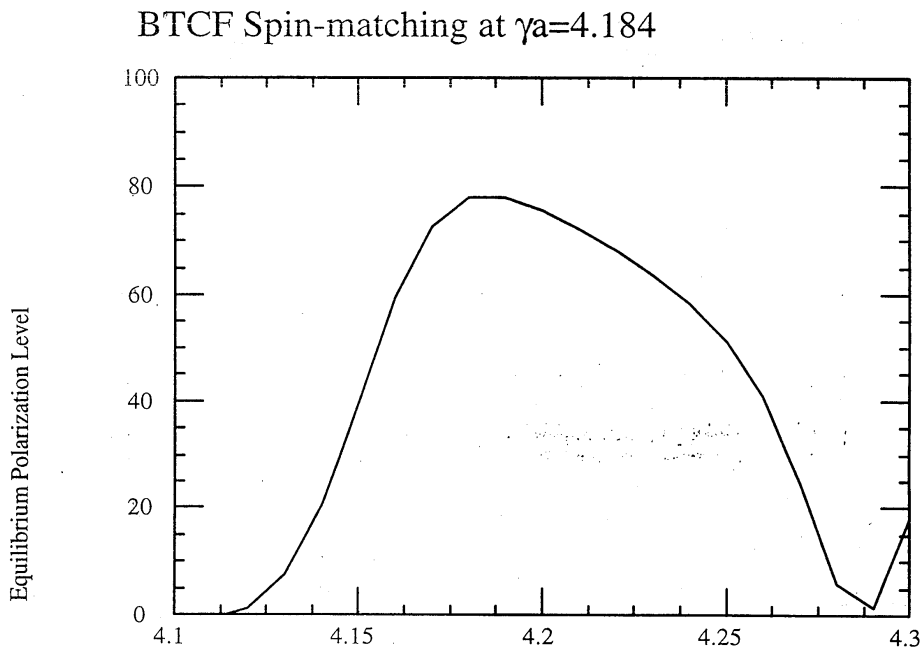
Derbenev-Kondratenko formula (1973)

$$P_{eff} = P_{ST}\frac{\left\langle \oint \frac{ds}{|\rho(s)|^3}\vec{b}\cdot\left[\vec{n}-\gamma\frac{\partial\vec{n}}{\partial\gamma}\right]\right\rangle}{\left\langle \oint \frac{ds}{|\rho(s)|^3}\left[1-\frac{2}{9}(\vec{n}\cdot\vec{v})^2+\frac{11}{18}\left|\gamma\frac{\partial\vec{n}}{\partial\gamma}\right|^2\right]\right\rangle}$$

minimize spin-orbit coupling term by

**Spin-matching**

Chao, Yokoya(1981)


BTCF Spin-matching at γa=4.184
Equilibrium Polarization Level
100
80
60
40
20
0
4.1
4.15
4.2
4.25
4.3

- CONVERSION OF REF. DES. to WORKING DES.

✓ RETHINK ENTIRE DESIGN i.l.of. Progress:
  ✓✓ BEGIN W. IR & WORK OUTWARD i.l.of:
    - BACKGROUND - INCL. TOUSCHEK - from start
    - DYNAMIC APERTURE*
    - POLARIZATION CONSTRAINTS
    - POSSIBILITY OF "MONO" W. PLANAR RINGS
    - DIFFICULTIES OF VERTICAL SEPARATION
    - UPGRADE POTENTIAL
    - - -

  ✓✓ REVIEW ARC DESIGN
    - DYNAMIC APERTURE / TOUSCHEK AMELIORATION
    - PEL
    - POLARIZATION CONTROL
    - - - - -

  ✓✓ INJECTION SCHEMES & INJECTORS
    - REEXAMINE ALTERNATIVES FOR SIMPLICITY
    - - - - -

* INTERPLAY OF SOLENOID COMPENSATION AND L*

TECHNICAL PROSPECTS ($10^{33}$, 2GeV, $\vec{n}$ e⁻)

✓ PRETTY GOOD: WILL LEARN A GREAT DEAL FROM CURRENT GENERATION + THEIR BUILDERS WILL BE AVAILABLE TO HELP:

| FACILITY | Knowledge useful for ~CF |
|---|---|
| BEPC | Background Studies - TOUSCHEK + PEI & ION |
| CESR | Möbius; ∴ L-Xing |
| DAΦNE | Large XL, $\sigma_s$(nat) ~ 5mm Hi Bad/Bφ, NOVEL Sol. Comp., Heavy Touschek, PEI, Ions |
| KEK-B | Large XL, $\sigma_s$ ~ 4mm, Crab Xing, HEAVY TOUSCHEK, local ξ, PEI, ions, Super feedback |
| PEP-II | VERTICAL DISPOSITION, ion, PEI, Super feedback, LER Vac., Local ξ comp. |

- TECHNICAL PROSPECTS ("Mono")
  - ✓ IDEA WILL WORK TO SOME EXTENT. Q: Optimum balance among Touschek life/bkgnd, $\mathcal{L}$ and $\sigma_w$ (DE cm)
    - ✓✓ small $\epsilon$ → small D → $\tau$ short owing to small beam size
    - ✓✓ small D → strong G-pole → reduced dynamic aperture
    - ✓✓ Large $D_y$ at IP compromises DE Ap in IR → shorter life → higher background.

⇓

ROUGH SLEDDING → MUCH TIME TO BRING UP.

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- TECHNICAL PROSPECTS (5–10 x $\mathcal{L}_{33}$ "Dream")
  2 GeV
  - ✓ IF B-FACS → $10^{34}$, $\tau$CF @ $5\times10^{33}$ not crazy.
    " " higher, so $\tau$CF : $\mathcal{L} \propto EI$
    - ✓✓ More q / bunch (optics, Z)
    - ✓✓ more K w. bigger XL & mm bunches
    - ✓✓ higher $\mathcal{L}/I$ ξ bk. Mr., Möbius, Phase conjugation ...

- TECHNICAL PROSPECTS (Mono "Dream")
  - ✓ as never been done, no basis for upgrade discussion.