Charm Physics at a Super Flavour Factory

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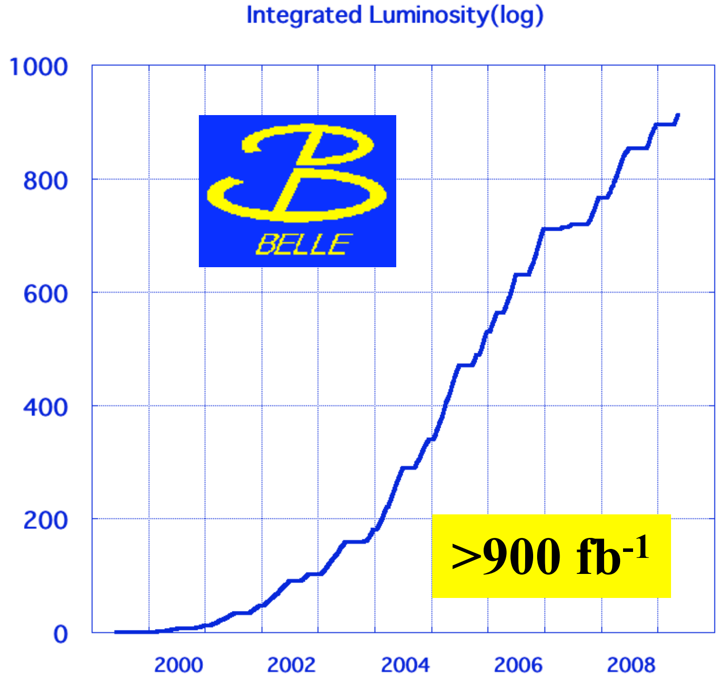
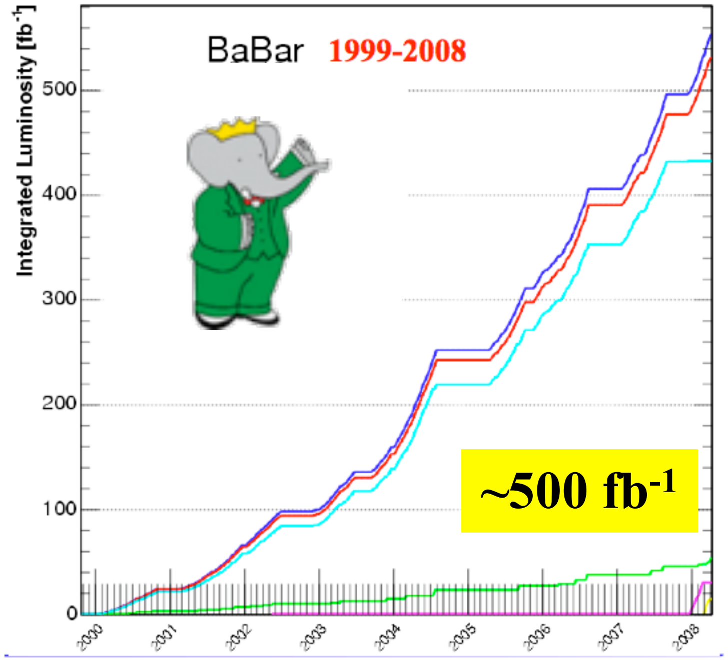
Super KEKB Quest for BSM

SuperB

Charm Physics on the Υ(4S)





Among the B-factories′ most successful achievements are two unexpected discoveries in the charm sector:

1. New charmonium states X, Y, Z
2. Charm mixing

What are the perspectives for factor ~100 higher statistics?

Super Flavour Factories

Two projects for high-luminosity asymmetric Super-B-factories

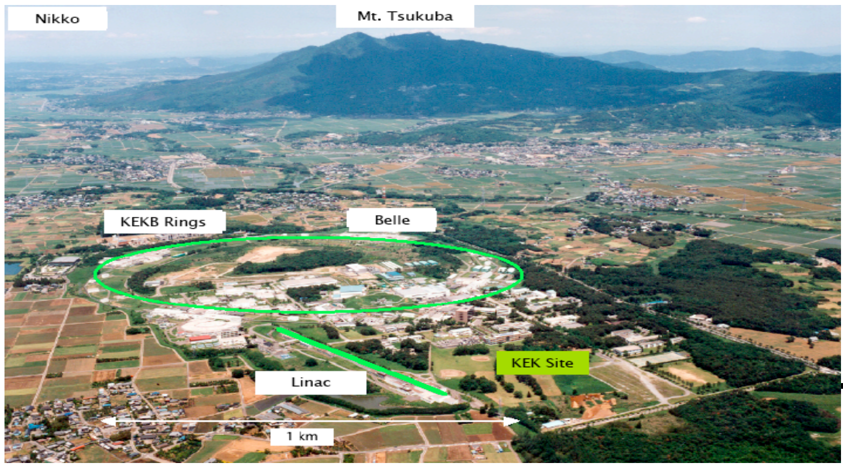
$\int \mathscr{L}\, dt \approx O(50\ ab^{-1})$

$O(5\mathrm{x}10^{10})\ B\bar{B}$ pairs

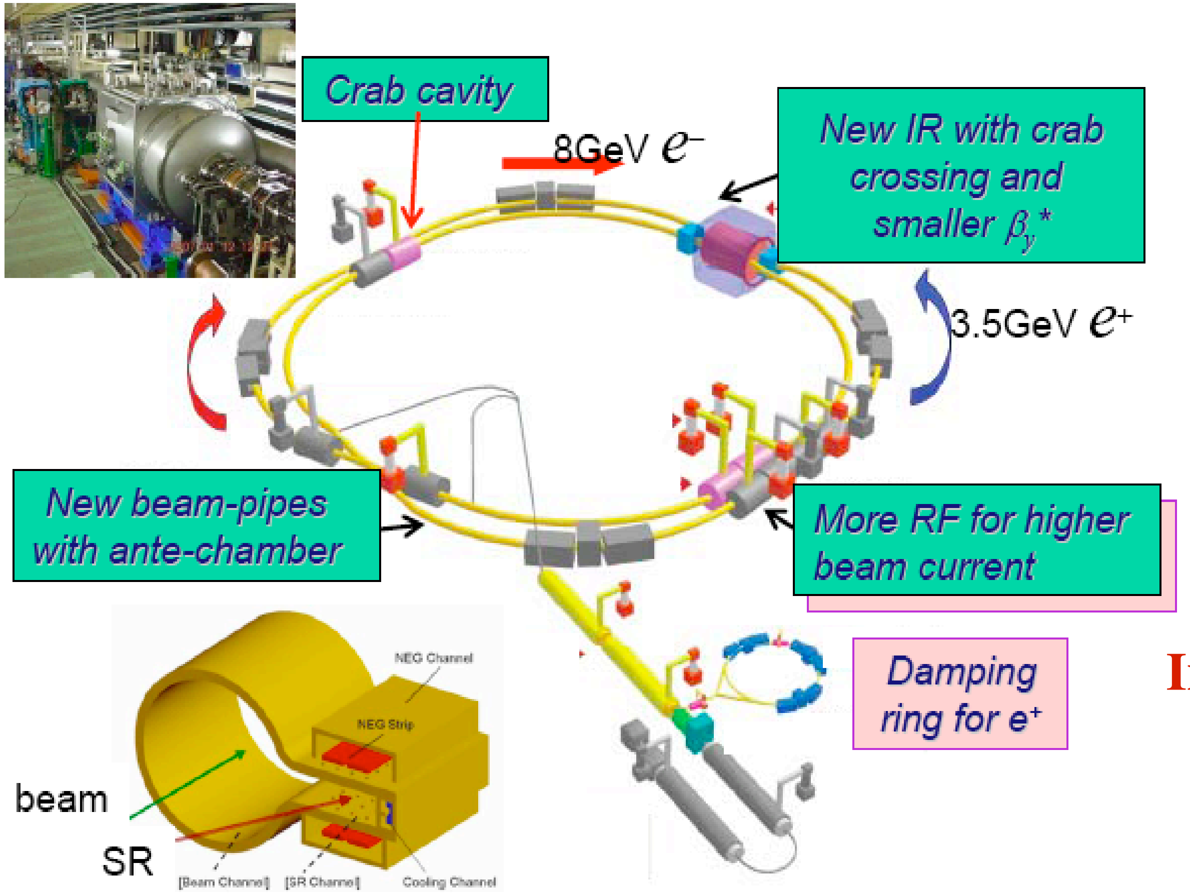
- **KEK/Japan**
- **more convential design**
  - **high beam current**
  - **high RF**
- **Crab crossing concept**
- $\mathscr{L} = 8\mathrm{x}10^{35}\ cm^{-2}s^{-1}$

- **Rome/Italy**
- **Challenging design (ILC-like)**
  - **Crab waist**
  - **vertical beam size nanometer range**
- **Use of PEP-II magnets**
- $\mathscr{L} > 1\mathrm{x}10^{36}\ cm^{-2}s^{-1}$

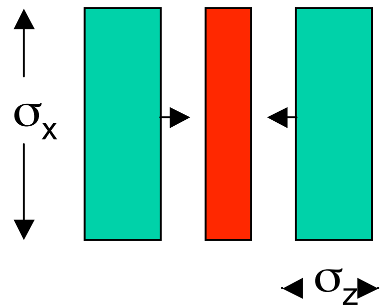
For this talk no distinction btw. the two concepts



Super KEK-B (Japan)



Head-on, short bunch

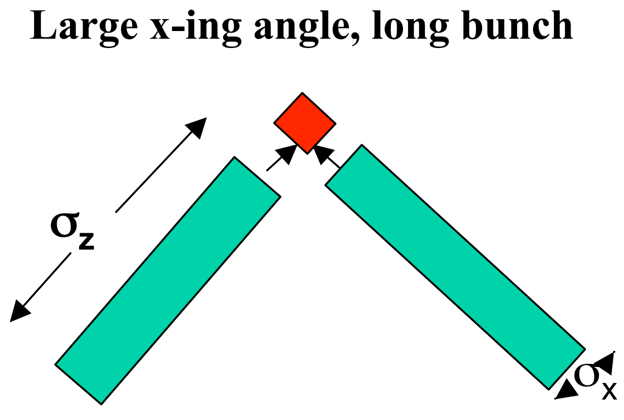


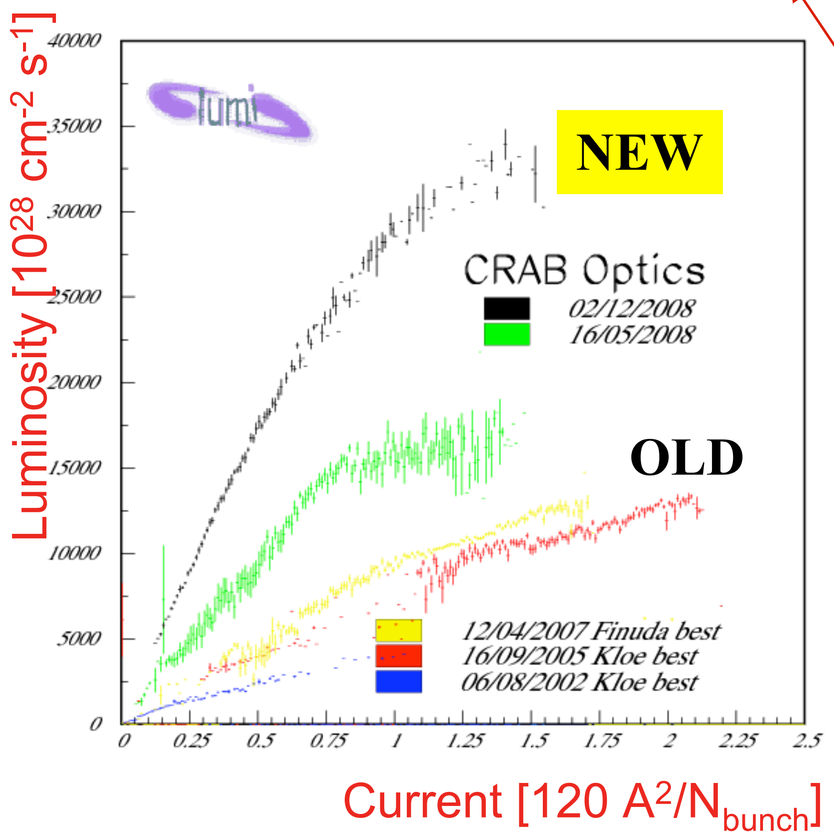
Increase of beam current
- electron cloud,
- RF shielding
- costs

Crab crossing
= head-on collision
tested at KEK-B since 2006

Super - B (Italy)

$$\mathcal{L} = f_{\text{coll.}} \times \frac{N_{e^+}\, N_{e^-}}{4\pi\, \sigma_x\, \sigma_y} \times R_l$$





Bunch sizes: from $\sigma_y = 3\mu m$ down to σ_y = 40 nm

- **Crab Waist and large Piwinsky angle to optimize beam dynamics**
- **Technically: Installation of sextupoles**
- **Successful test of principle at phi-factory DAΦNE**

Super Flavour and the rest of the World

- **BABAR+BELLE**:
  2 ab^{-1} total after ~2009 at or close to ϒ(4S)
- **BESIII**:
  ~ order of magnitude higher luminosity than **CLEO-c**;
  20 fb^{-1} at ψ(3770) and 12 fb^{-1} at ψ(4170) (8 years)
- **LHCb**:
  statistics no issue; very good perspectives for charged channels;
  channels with γ, ν, K_S challenging
- **PANDA**:
  Open charm large statistics; final systematics t.b.determined
- **Super Flavour**
  ϒ(4S) energy: 75 ab^{-1} (5 years)
  in 4 GeV region (2 mon.): 0.3 ab^{-1} / year

***O*(~5 x 10^9 D's) / year on ϒ(4S)**
***O*(~1 x 10^9 D's) at ~4 GeV**

Open Charm Physics at Super Flavour Factory

Charm Physics ↔ New Physics Search

Approach 1 (*INDIRECT*): Precision Charm CKM Physics

Use precision CKM to resolve 'New Physics' by overconstraining the system
Charm measurements are needed for an improvement in the B-sector

Approach 2 (*DIRECT*): Rare Decays, Mixing , CP-Violation

- **Charm decays are from 'up'-type quarks!**

  Leading charm decays are not CKM suppressed – unlike B and K sector
  FCNC dynamcis could be much stronger in 'up'-type quarks

- **Charm Oscillation is Cabibbo and GIM suppressed in SM!**

  Evidence might be a signal of 'New Physics'

- **Standard model prediction for CP violation in D sector small!**

  Any evidence for CP violation indicates New Physics
  Sensitivity in the charm sector might be large

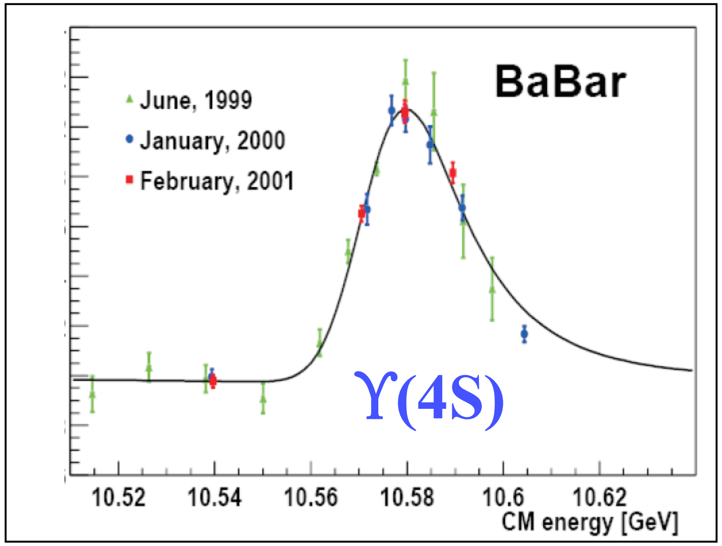
Petrov
Bigi

Charm Hadron Production on the Υ(4S)

High Cross Section →
High statistics: ~1.3 x 10^6 D's / fb^{-1}

e^+e^- →	σ
$b\bar{b}$	1.05 nb
$c\bar{c}$	1.30 nb
$s\bar{s}$	0.35 nb
$u\bar{u}$	1.39 nb
$d\bar{d}$	0.35 nb

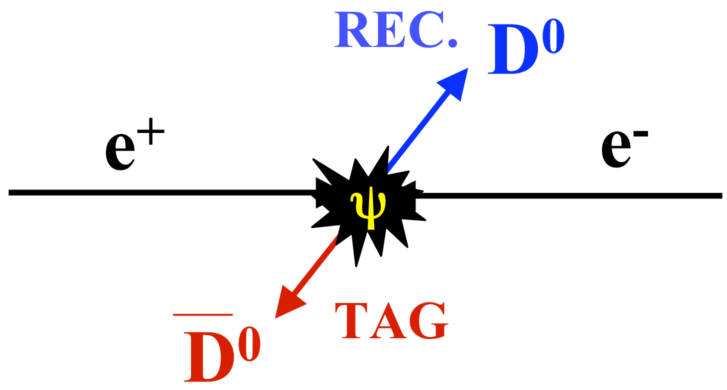
Charm Factory

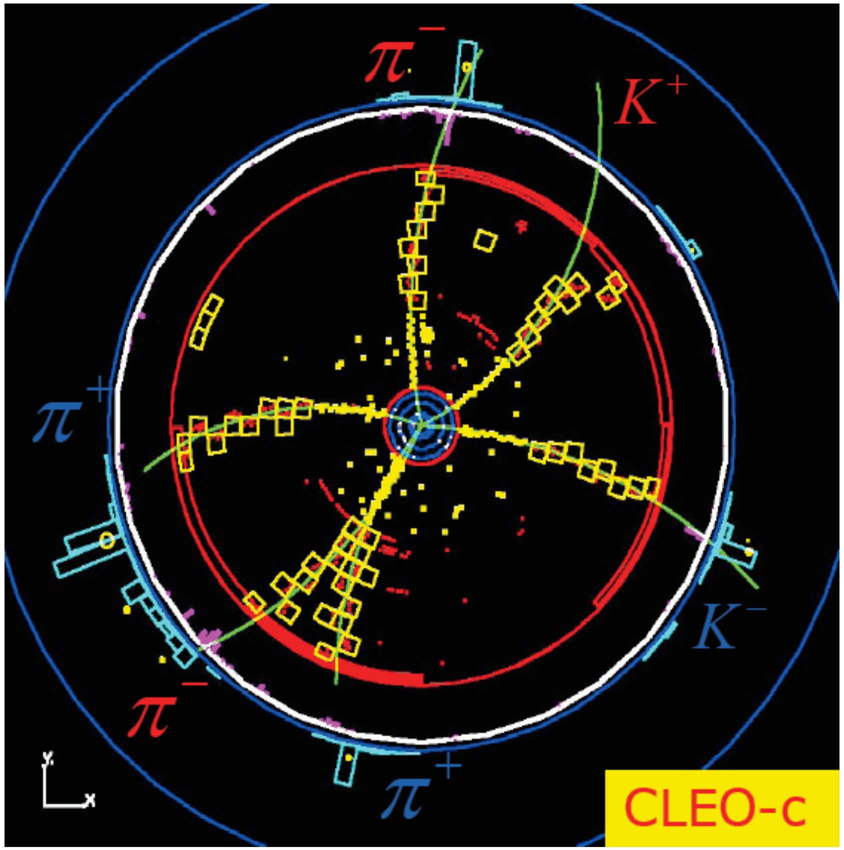


Features:

- Continuum production at the energy of the Υ(4S) large
- Also a large charmonium data sample in ISR events
- B decays: allows measurement of absolute BR's
- Charm tagging through $D^{*+} \to \pi^+ D^0$, $D^{*-} \to \pi^- \bar{D}^0$

Running on the ψ_{3770} Resonance



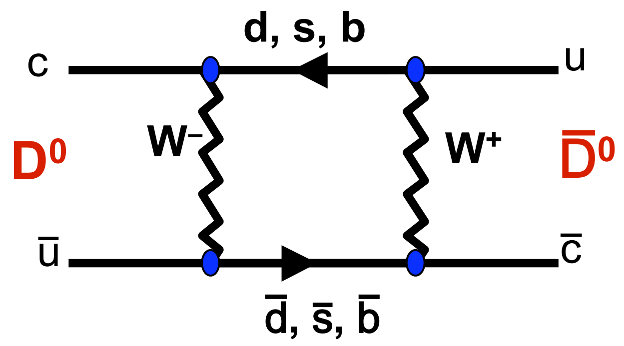


Absolutely normalized hadronic, leptonic and semileptonic decays (tag!)

- Very High cross section $\sigma(D\bar{D})$ = 6.4 nb but luminosity ~factor 10 smaller
- Low multiplicities (~5-6 particles/event) → low background; clean signature
- Very high tagging efficiency ~22%
- Well defined quantum mechanical state $|D\bar{D}\rangle = 1/\sqrt{2}\ (|D_1D_2\rangle - |D_2D_1\rangle)$ excellent for mixing, CP-violation, ... Coherent quantum state → **later**

D^0 - $\overline{D^0}$ - Mixing (Theory)

- Described in the standard model via box diagram 2nd order weak interaction



- **Flavour eigenstates D^0, $\overline{D^0}$ ≠ Mass eigenstates D_1, D_2**
  with masses m_1, m_2 and life times Γ_1, Γ_2
  $| D_{1,2} > \sim p\, |D^0> \pm q\, |\overline{D^0}>$ (CP conservation: $|p| = |q|$)

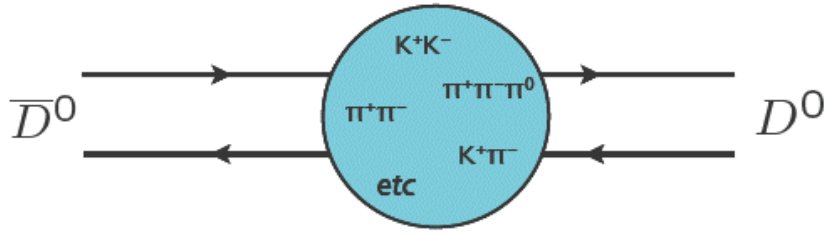
- Introduce standard parametrization

$$x = \frac{m_1 - m_2}{\Gamma} \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma} \qquad \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

- **Mixing rate $\sim (x^2 + y^2)$** expected to be small in the SM (reason: CKM elements and d,s,b quark masses)

D^0 - $\overline{D^0}$ - *Mixing (Theory)*

- In D^0-$\overline{D}^0$-mixing actually the long-distance physics dominates the dynamics:
  $D^0 \rightarrow \pi^+\pi^- / K^+K^- \rightarrow \overline{D}^0$

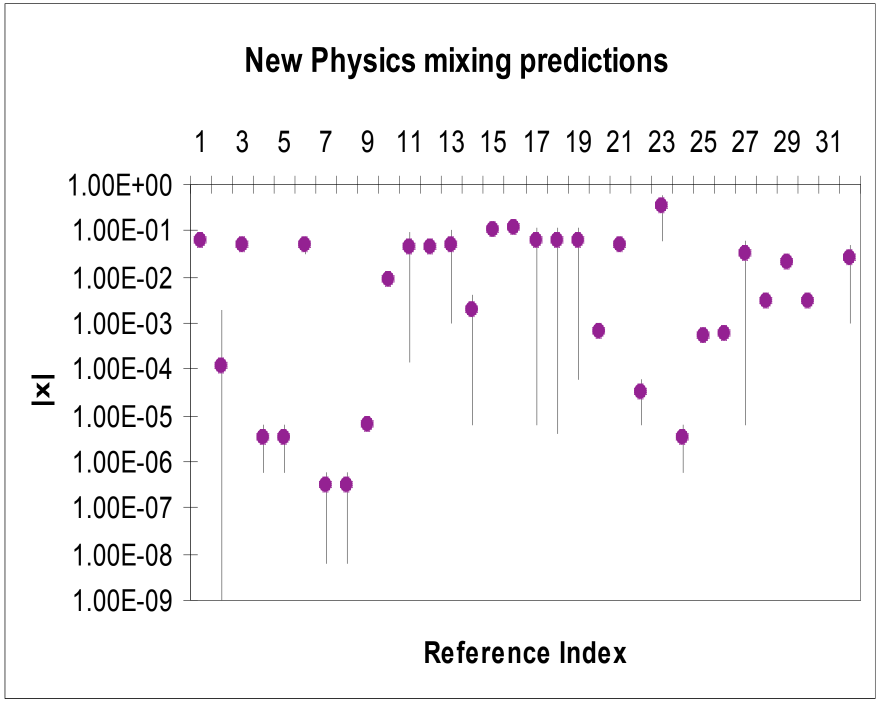


Alexey Petrov

- Predictions for long-distance effect: **$x, y < 10^{-3} \ldots 10^{-2}$!**

- Box diagram sensitive to New Physics
  |x|>>|y| not any more clear signature for New Physics!

Petrov



State of the Art .... Charm 2009

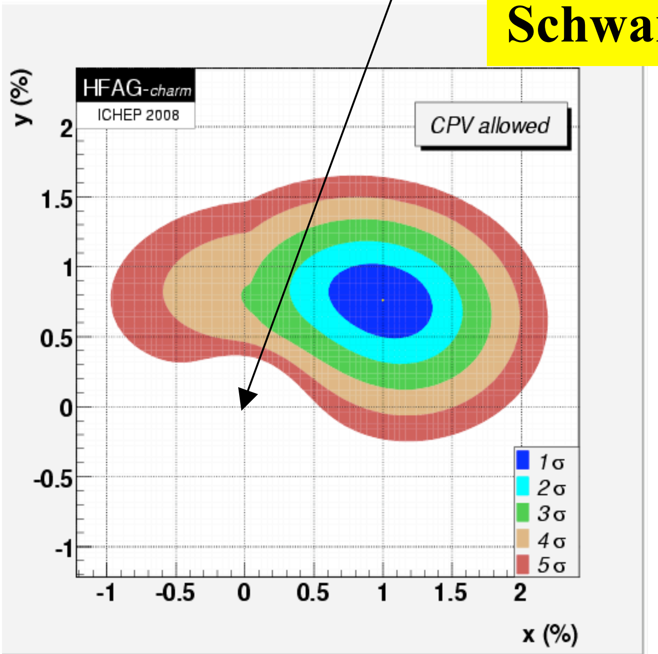
Cartaro
Staric
Naik
di Canto

Mixing measurements

- $D^0 \to K^+K^-, \pi^+\pi^-$
- $D^0 \to K^+\pi^-$
- $D^0 \to K^{(*)-}l^+\nu$
- $D^0 \to K^+\pi^- \pi^0$
- $D^0 \to K_s\pi^+\pi^-$
- $D^0 \to K_sK^+K^-$
- Quantum Correlations

No-mixing point excluded at ~10σ
$x \approx y \approx 1\%$; precision $x, y \approx 0.3\%$

Schwartz



Methods

- Lifetime difference measurements ($D^0 \to h^+h^-$)
- Wrong sign measurement ($D^0 \to K\pi$)
- Dalitz plot analyses (>2 body modes)

Mixing: Expectations for Super B

Estimated from BABAR / BELLE experiences

Numbers from Super-B CDR

Exp. sensitivities	$y_{CP}(10^{-3})$	y' (10^{-3})	x'^2 (10^{-4})	$\cos\delta$
B-factories ($2ab^{-1}$)	2-3	2-3	1-2	-
SuperB (75 ab^{-1})	0.4-0.5	0.7	0.3	-
CLEO-c (750 pb^{-1})	10	-	2-3	0.1-0.2
BESIII ($20fb^{-1}$)	4	-	0.5-1	0.05
LHCb $10fb^{-1}$	0.5 (stat only)	0.9 (stat only)	0.64 (stat only)	-

Factor 2-5 improvement wrt. B-factories, LHCb?

CP Violation

- **3 types of CP violation**:

(i) CP violation in mixing $|D_{1,2}> \sim p\,|D^0> \pm q\,|\overline{D}^0>$ $(|p|\,/\,|q| \neq 1)$

(ii) direct CP violation

→ possible in Standard Model only in SCS decays:

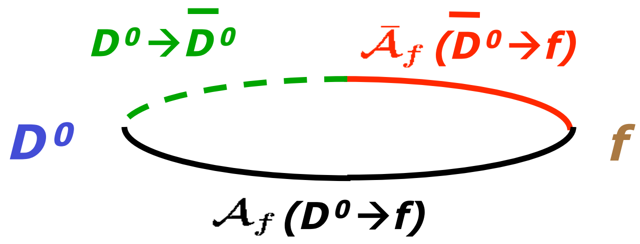
$$A(D \to f) \neq A(\overline{D} \to \overline{f})$$

needs a second weak amplitude (penguins)

<10^{-3} asymmetries in SM

(iii) mixing induced CP violation

$$\phi = \arg\left(\frac{q}{p}\frac{\overline{A}_f}{A_f}\right)$$



- **New Physics scenarios predict CP violation up to ~1%, measurement of CP violation would indicate New Physics**

CP Violation: Main Goal for SFF

Time integrated measurements

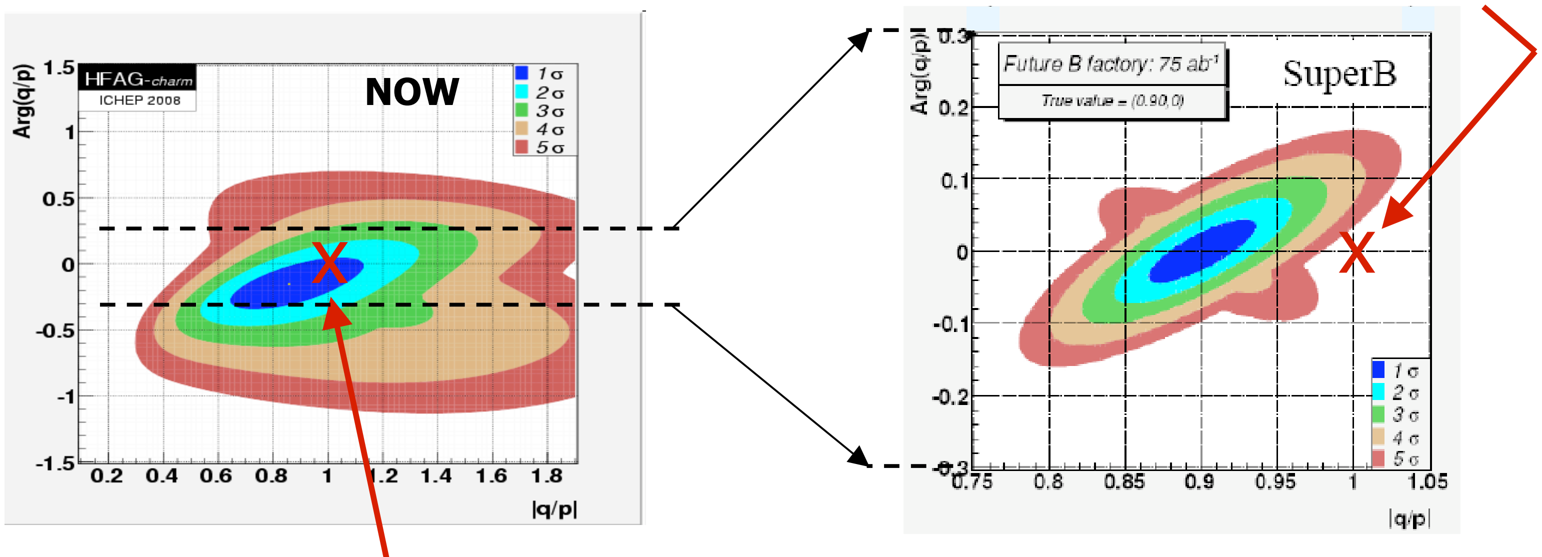
- $D^0 \to K^+K^-, \pi^+\pi^-$
- $D^0 \to \pi^+\pi^-\pi^0, K^+K^-\pi^0$

T odd correlations $D^0 \to K^+K^-\pi^+\pi^-$

Dalitz plot analyses

- $D^0 \to K^+\pi^-\pi^0$
- $D^0 \to K_S\pi^+\pi^-, K_SK^+K^-$

If central values persist:
Will observe >> 5σ effect !!



No-CPV point allowed at 1σ

Extrapolation done using measured $D^0 \to K\pi$ and $D^0 \to K_S\pi\pi$ channels assuming that systematic error scales with statistics

Indirect CP Violation

Compare (x,y) for D^0 and $\bar{D}^0$

Flavour-tagged semileptonic asymmetry:

$$a_{SL} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = \frac{|q|^4 - |p|^4}{|q|^4 + |p|^4} \quad \left[\begin{array}{lcl} D^0 & = & "-", \; \bar{D}^0 = "+", \; \ell^{\pm} = "\pm" \\ N^{++} & = & \bar{D}^0 \to \ell^+ \nu K^-, \; N^{--} = D^0 \to \ell^- \bar{\nu} K^+ \end{array} \right]$$

- Can measure a_{SL} at Y(4S) with D^* tagging:
  - Large backgrounds
  - We estimate 13 500 events / yr. → **δa = 1% per year**
- Measure it at ψ(3770)
  - Much cleaner reconstruction
  - Can include WS hadrons since no DCS thanks to quantum correlation
  - Estimate 1 600 events per month → **δa = 1% in 4 months**

Bigi

Precise measurement restricts parameter space in LHT models

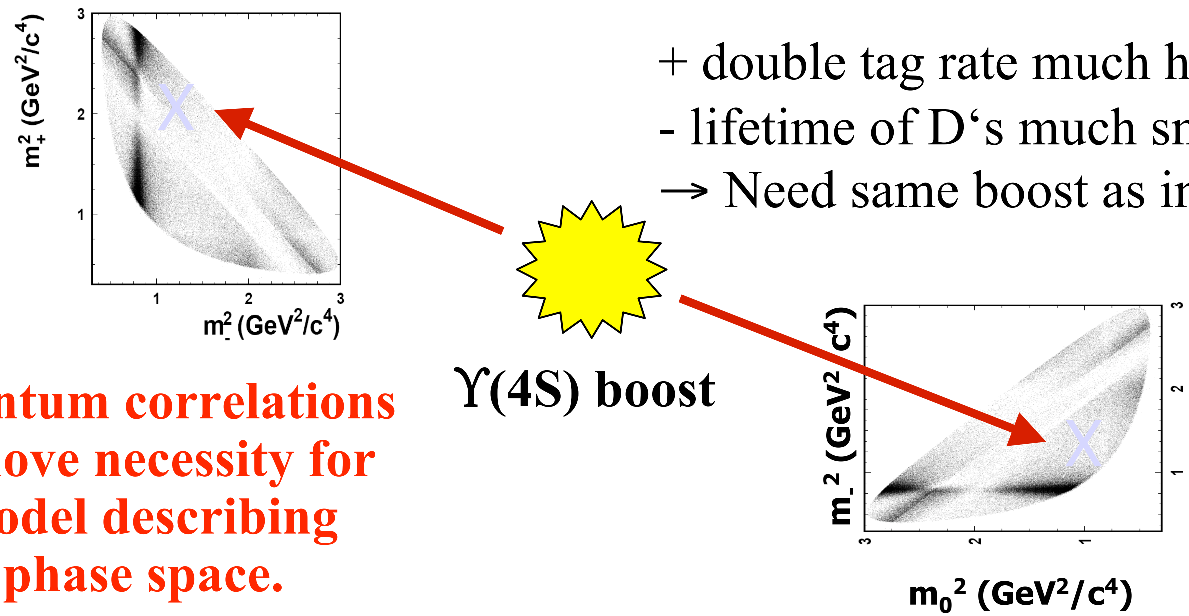
Exploit Quantum Correlations at ψ_{3770} ?

- **Strong phase δ_{Kp} needed for combining mixing events:**

$$\sigma(\cos\delta_{K\pi}) \sim \pm(0.01 \rightarrow 0.02)$$
$$\sigma(\delta_{K\pi}) \sim \pm(1 \rightarrow 2)^\circ$$

CLEO c: $\cos\delta_{K\pi} = 1.03^{+0.31}_{-0.17} \pm 0.06$

- **Measure relative phases bin-by-bin in DP:**



+ double tag rate much higher than at Υ(4S)
- lifetime of D's much smaller
→ Need same boost as in Υ(4S) runs

Quantum correlations remove necessity for model describing phase space.

Impact of low-energy run needs to be understood better

Conclusions

Conclusions

- **Super Flavour Factory is a challenge in accelerator technology**
  - factor 100 luminosity increase
  - exciting new concepts for e^+e^- collission
- **Discovery potential for New Physics whether or whether not Super Flavour can run in the charm threshold region**
- **Final systematics need to be determined in feasibility studies**
  - CP asymmetries ~1% need excellent understanding of detector
- **Many other charm related issues to be studied**
  - semileptonic decays
  - GIM suppressed rare decays $D^0 \rightarrow \mu^+\mu^-$, $D^0 \rightarrow X\, l^+l^-$
- **Charm(onium) spectroscopy aspects will remain interesting, competition from PANDA@FAIR**