Experimental Prospects for CP Violation In Charm

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Workshop on CP Violation
Institute of Theoretical Physics
Adelaide

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07/17/98 FRI 10:01 FAX 630 840 6311 FERMILAB 13 NORTH 001

Outline of my talk:

- Charm ~~CP~~ limits from current experiments
- Projections for future experiments
- BTeV (charm and beauty)
- Conclusions

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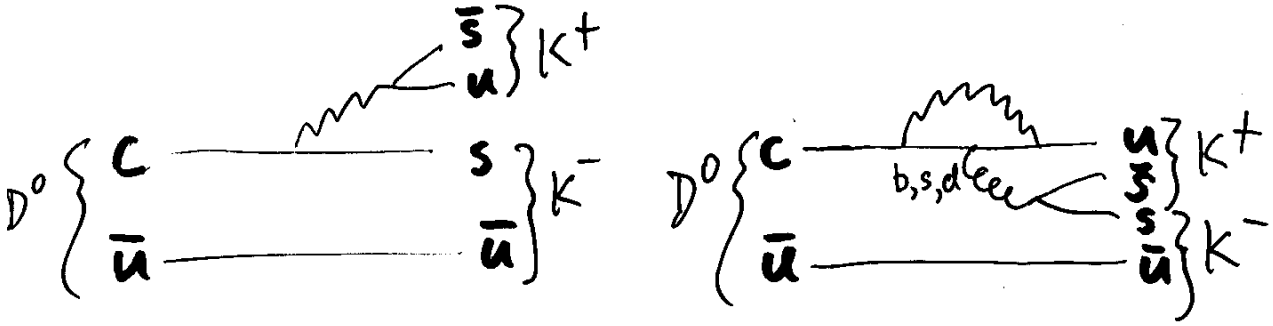
Charm CP Violation

- Predicted in SM for CS decays due to interference of trees with penguins:

E.g., $D^0 \to K^+K^-$:



$\longrightarrow A_{CP} \sim 10^{-3}$

- If ∃ New Physics, can occur at $\mathcal{O}(10^{-2})$, also in CA + DCS decays!

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CHARMED MESONS
($C = \pm 1$)

$D^+ = c\bar{d}$, $D^0 = c\bar{u}$, $\overline{D}^0 = \bar{c}u$, $D^- = \bar{c}d$, similarly for D^*'s

PDG '98

$D^\pm$

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1869.3 \pm 0.5$ MeV (S = 1.1)

Mean life $\tau = (1.057 \pm 0.015) \times 10^{-12}$ s

$c\tau = 317\ \mu$m

CP-violation decay-rate asymmetries

$A_{CP}(K^+K^-\pi^\pm) = -0.017 \pm 0.027$

$A_{CP}(K^\pm K^{*0}) = -0.02 \pm 0.05$

$A_{CP}(\phi\pi^\pm) = -0.014 \pm 0.033$

$A_{CP}(\pi^+\pi^-\pi^\pm) = -0.02 \pm 0.04$

Cabibbo-suppressed modes

Direct ~~CP~~

$D^+ \to \overline{K}^*(892)^0 \ell^+ \nu_\ell$ form factors

$r_2 = 0.72 \pm 0.09$

$r_v = 1.85 \pm 0.12$

$\Gamma_L/\Gamma_T = 1.23 \pm 0.13$

$\Gamma_+/\Gamma_- = 0.16 \pm 0.04$

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D^0

$I(J^P) = \frac{1}{2}(0^-)$

PDG '98

Mass $m = 1864.6 \pm 0.5$ MeV (S = 1.1)

$m_{D^\pm} - m_{D^0} = 4.76 \pm 0.10$ MeV (S = 1.1)

Mean life $\tau = (0.415 \pm 0.004) \times 10^{-12}$ s

$c\tau = 124.4\ \mu$m

$|m_{D_1^0} - m_{D_2^0}| < 24 \times 10^{10}\ \hbar\ \text{s}^{-1}$, CL = 90% [tt]

$|\Gamma_{D_1^0} - \Gamma_{D_2^0}|/\Gamma_{D^0} < 0.20$, CL = 90% [tt]

$\Gamma(K^+ \ell^- \overline{\nu}_\ell \text{ (via } \overline{D}^0))/\Gamma(K^- \ell^+ \nu_\ell) < 0.005$, CL = 90%

$\frac{\Gamma(K^+\pi^- \text{ or } K^+\pi^-\pi^+\pi^- \text{(via} \overline{D}^0))}{\Gamma(K^-\pi^+ \text{ or } K^-\pi^+\pi^+\pi^-)} < 0.0085$ (or < 0.0037), CL = 90% [uu]

CP-violation decay-rate asymmetries

$A_{CP}(K^+K^-) = 0.026 \pm 0.035$

$A_{CP}(\pi^+\pi^-) = -0.05 \pm 0.08$

$A_{CP}(K_S^0\phi) = -0.03 \pm 0.09$

$A_{CP}(K_S^0\pi^0) = -0.018 \pm 0.030$

Direct + indirect CP

$\overline{D}^0$ modes are charge conjugates of the modes below.

D^0 DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Inclusive modes			

Phys. Lett. B403 (1997) 377

Search for CP Violation in Charged D Meson Decays

Fermilab E791 Collaboration

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Phys. Lett. B421 (1998) 405

Branching Fractions for $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$, and a Search for CP Violation in D^0 Decays *

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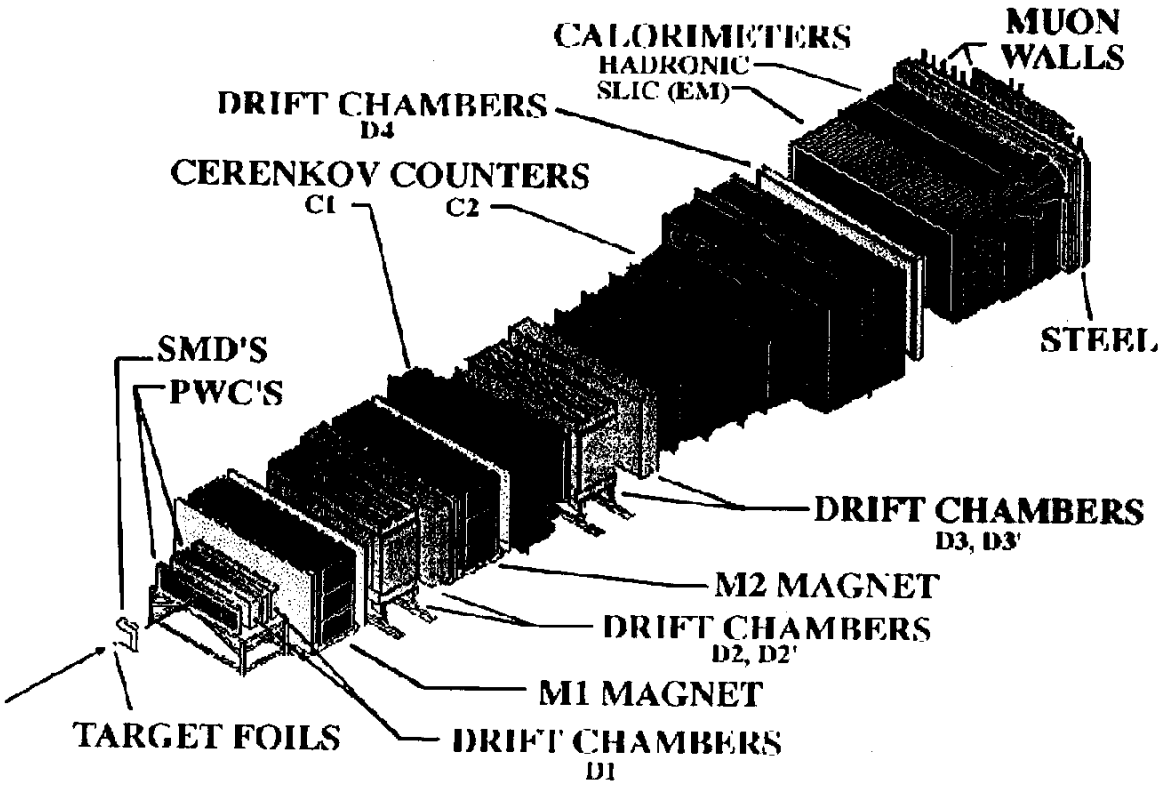
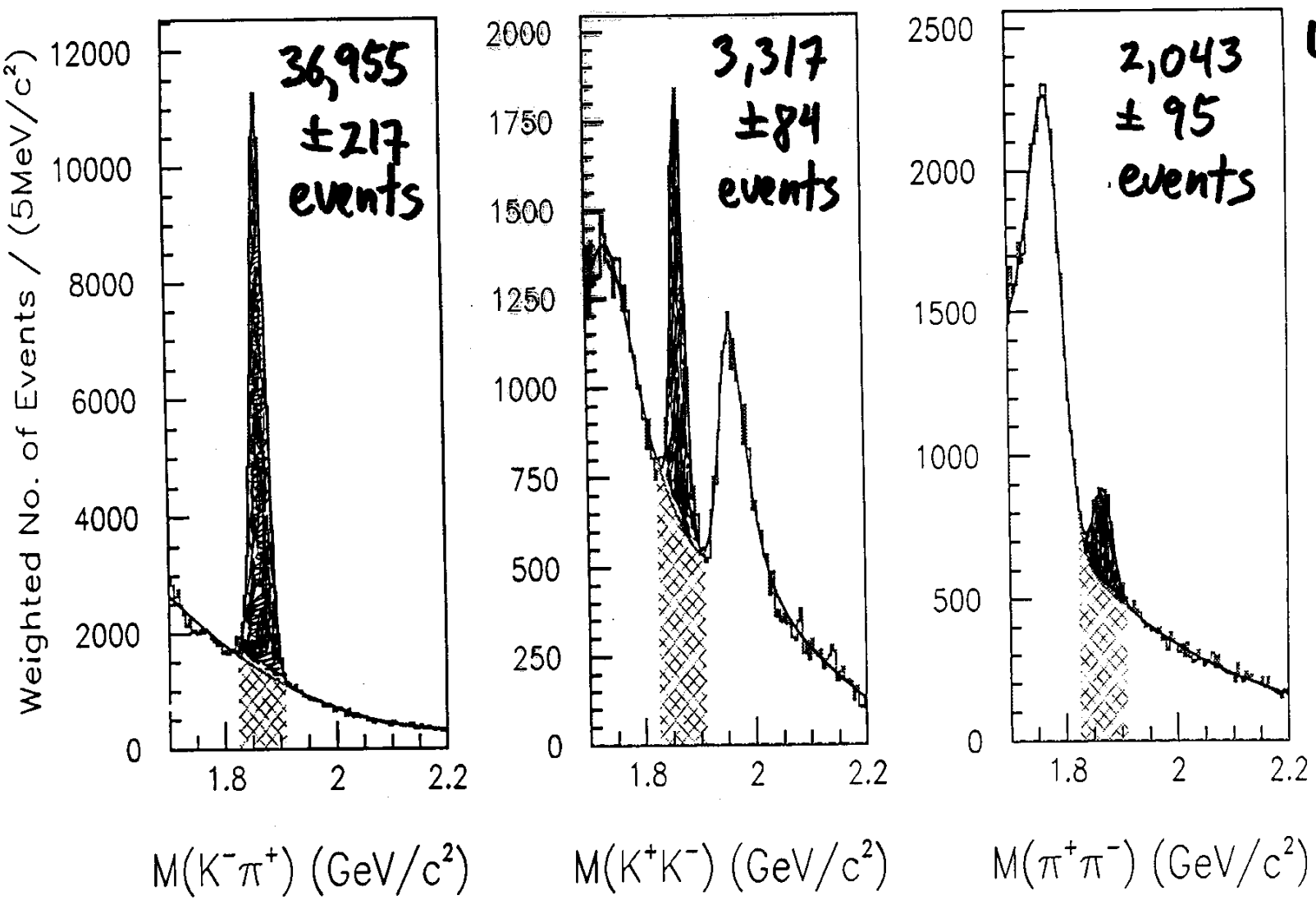
E-791 Spectrometer



E791

E. M. Aitala et al., Phys. Lett. B421 (1998) 405



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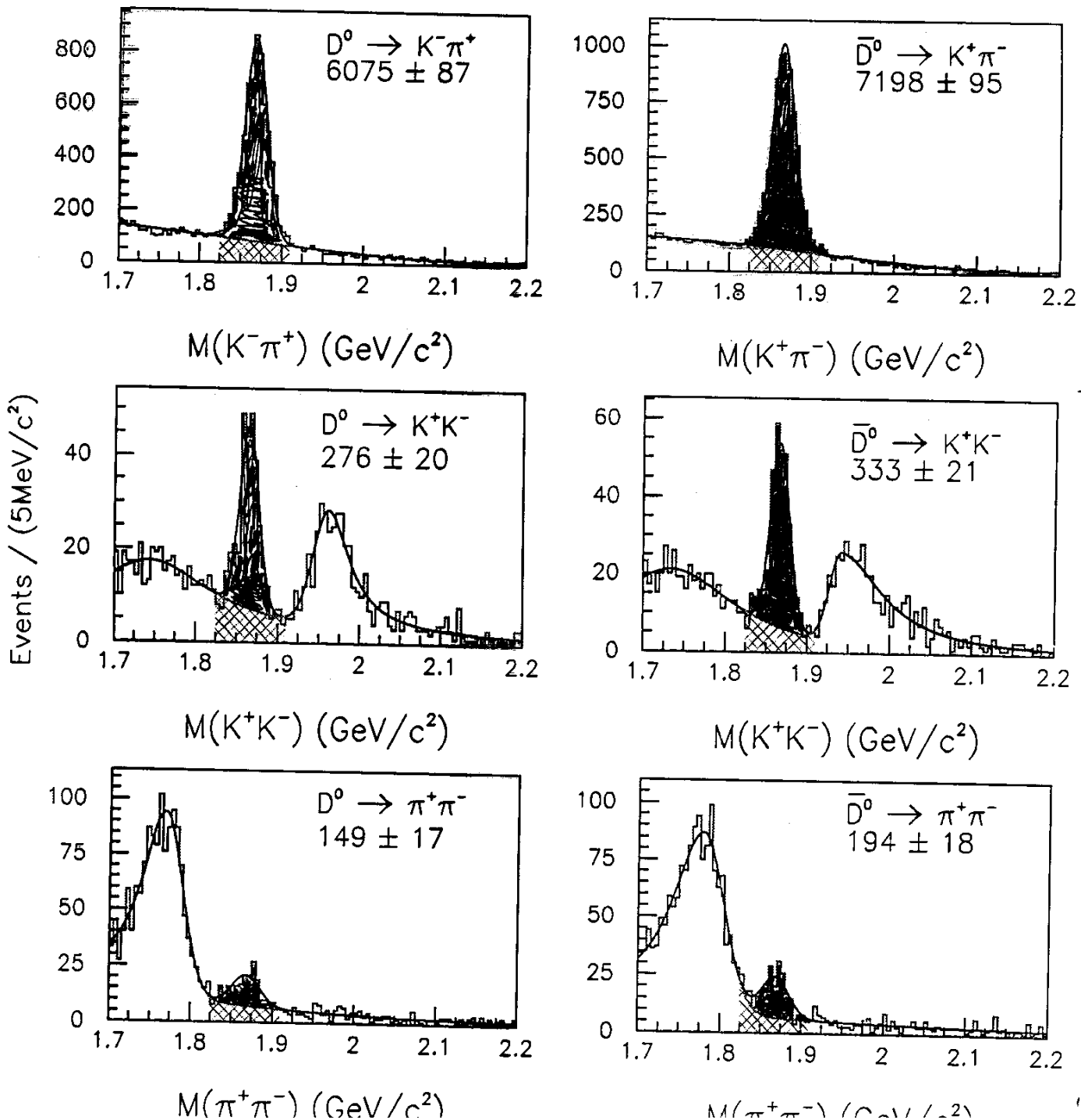

E791

D*-tagged samples

Cabibbo suppressed

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The signal for CP violation is an absolute rate difference between decays of particle and antiparticle to charge-conjugate final states f and $\overline{f}$, where $f = K^+K^-$ or $\pi^+\pi^-$:

$$A_{CP} = \frac{\Gamma(D \to f) - \Gamma(\overline{D} \to \overline{f})}{\Gamma(D \to f) + \Gamma(\overline{D} \to \overline{f})}. \quad (1)$$

(Sensitive to indirect CP due to τ cut) from E.M. Aitala et al., Phys. Lett. B421 (1998) 405.

In hadroproduction, D and $\overline{D}$ mesons are not produced equally. Therefore we normalized our signals to the Cabibbo-favored $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^+\pi^-$ signals and measured

$$\frac{\frac{N(D^0 \to f)}{N(D^0 \to K^-\pi^+)} - \frac{N(\overline{D}^0 \to \overline{f})}{N(\overline{D}^0 \to K^+\pi^-)}}{\frac{N(D^0 \to f)}{N(D^0 \to K^-\pi^+)} + \frac{N(\overline{D}^0 \to \overline{f})}{N(\overline{D}^0 \to K^+\pi^-)}} \quad (2)$$

where, for each channel, $N = \epsilon n$ is the observed number of events, n is the produced number of events, and ϵ is the efficiency of our detector and analysis procedure. To the extent that

$$\frac{\epsilon(D^0 \to f)}{\epsilon(D^0 \to K^-\pi^+)} = \frac{\epsilon(\overline{D}^0 \to \overline{f})}{\epsilon(\overline{D}^0 \to K^+\pi^-)}, \quad (3)$$

Acceptances, efficiencies cancel in the ratio

the measured quantity (Eq. 2) is A_{CP}. We verified the validity of Eq. 3 for this analysis in two stages. First, we used real data to determine that the Čerenkov identification efficiencies for kaons and pions are independent of charge in any given momentum range from 6 to 80 GeV/c. Then, we used our Monte Carlo simulation of the experiment to determine that the geometric acceptances are independent of charge.

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Charm CP sensitivities

Note:

CP sensitivity is complicated -

depends on

- reconstruction and **PID efficiency** for each mode
- D^*-tagging efficiency for neutral modes
- vertex cuts that optimize signal/background
- analysis technique for indirect CP

⇒ To compare experiments I will use simple benchmarks:

charm and $D^0 \to K\pi$ produced, reconstructed

I. Existing charm samples:

- FNAL E687[1] and E791[2], CLEO II[3] all have similar CP reach, and are averaged in PDG '98

1. P. L. Frabetti et al., Phys. Rev. D 50, 2953 (1994).
2. E. M. Aitala et al., Phys. Lett. B403 (1997) 377; Phys. Lett. B421 (1998) 405.
3. J. Bartelt et al., Phys. Rev. D 52, 4860 (1995).

	# charm		# $D^0 \to K\pi$		δA_{CP}
exp't	prod.	reconst.	prod.	reconst.	typ.
FNAL E687		0.8×10^5			$\approx$ **0.1**
FNAL E791	$\approx 10^8$	2.5×10^5	1.2×10^6	3.7×10^4	$\approx$ 0.05
CLEO II	2.7×10^6		1.0×10^6	1.8×10^4	$\approx$ 0.05

- FOCUS (E831) should improve on E687 by $\approx\sqrt{10}$

  10^6 charm reconst. $\Rightarrow \delta A_{CP} \approx 0.03$?

  (analysis in progress)

II. Future charm experiments:

1. COMPASS:

- FT experiment under construction at CERN SPS, start of data-taking expected ≈2000

  Project 7×10^4 $D^0 \to K\pi$ reconst. $\Rightarrow \delta A_{CP} \approx 0.03$?

2. HERA-B:

- Charm sensitivity has not been assessed?

- High-p_t triggers probably exclude charm

3. B-Factories:

$$\sigma_{c\bar{c}} = n_c \frac{4\pi\alpha^2}{3s} q^2 = 1.0 \text{ nb}$$

$\mathcal{L} = 3 \times 10^{33} \Rightarrow 3 \times 10^7$ charm produced /10^7 s

$\Rightarrow \delta A_{CP} \approx 0.01$?

4. BTeV charm sensitivity:

	FT	Coll.	
Running time	10^7 s	10^7 s	
Interaction rate	2×10^6 s^{-1}	1.5×10^7 s^{-1}	($\mathcal{L} = 2 \times 10^{32}$)
D^0 ($\bar{D}^0$) / int.	6.5×10^{-4} $A^{0.29}$	1% ?	
$A^{0.29}$	2 - 4.5 (C - W)	1	
$B(D^0 \to K\pi)$	3.85%	3.85%	
$D^0 \to K\pi$ produced	**(1 - 2.3) $\times 10^9$**	**6 $\times 10^{10}$?**	
Acceptance	35%	30%	
Trigger eff.	10%	1% ?	
Reconst. eff.	25%	25%	
$D^0 \to K\pi$ reconst.	**(0.9 - 2.0) $\times 10^7$**	**4 $\times 10^7$?**	

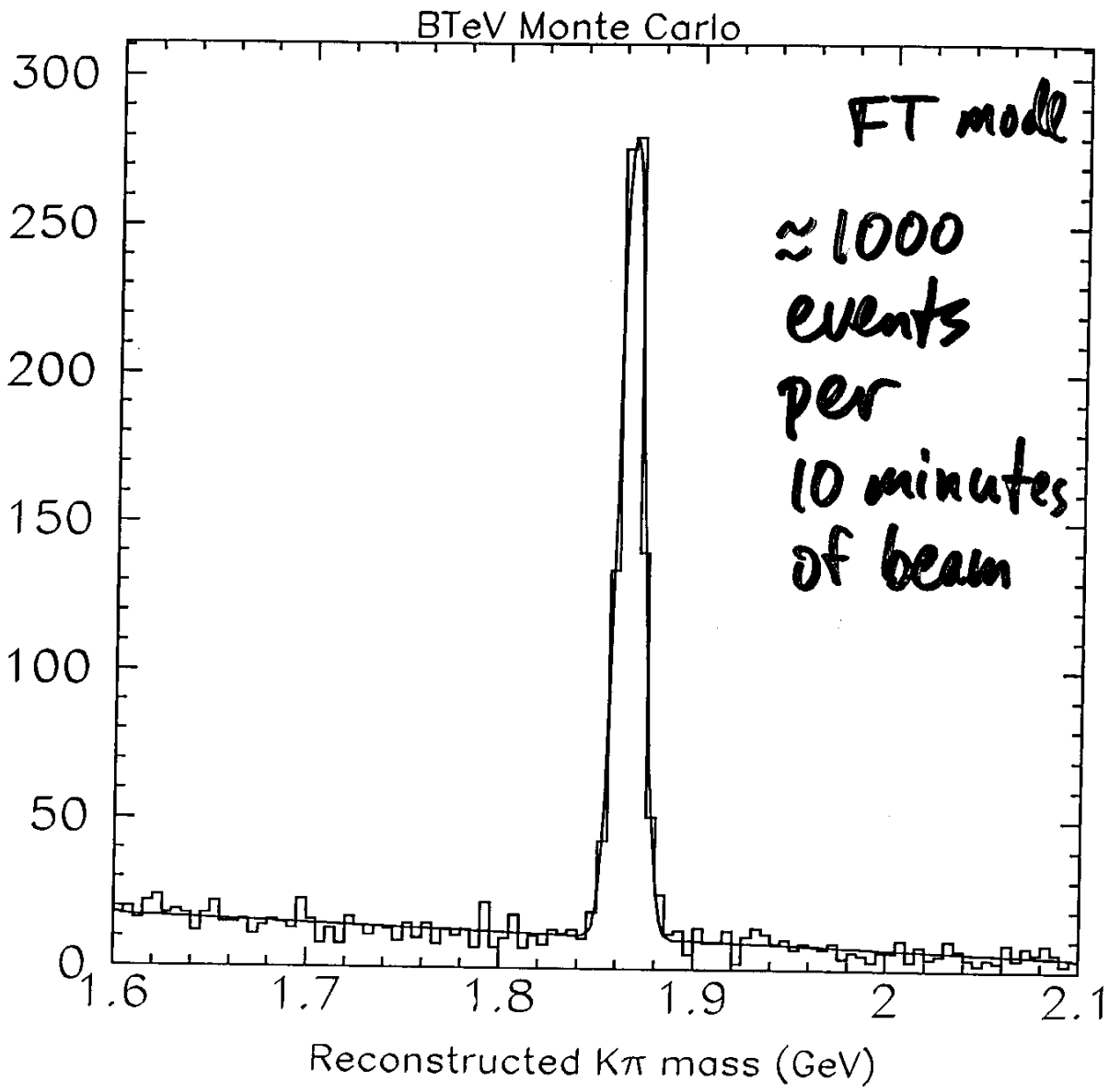
$\Rightarrow \delta A_{CP} \approx 0.001$?

→ Approaching SM sensitivity!

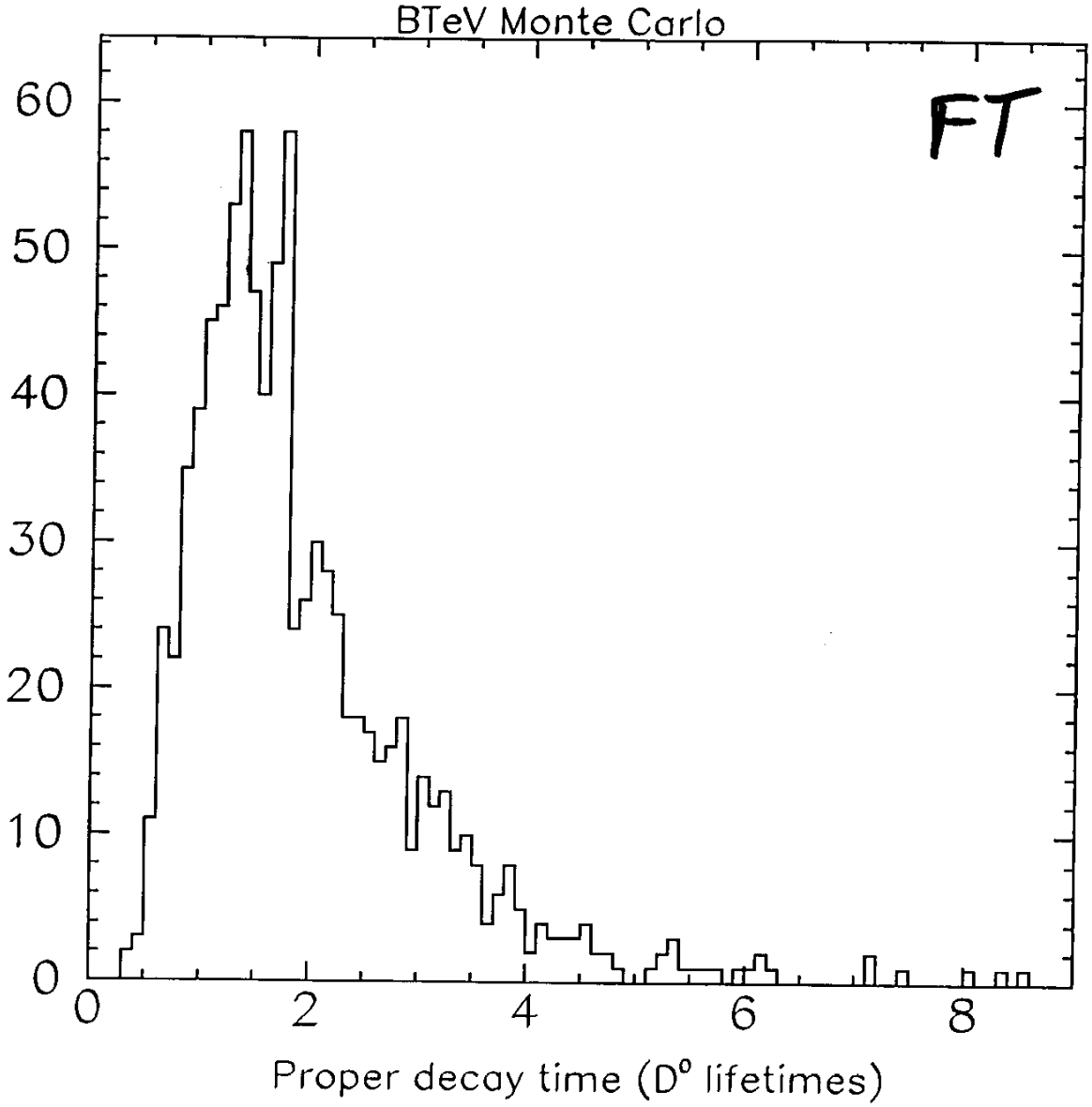
(SM: $A_{CP} \lesssim$ few $\times 10^{-3}$ in SCS Λ modes with largest FSI $\Delta\phi$)

$\exists$ N.P. models with $A_{CP} > 10^{-3}$ in CA, DCS modes as well!

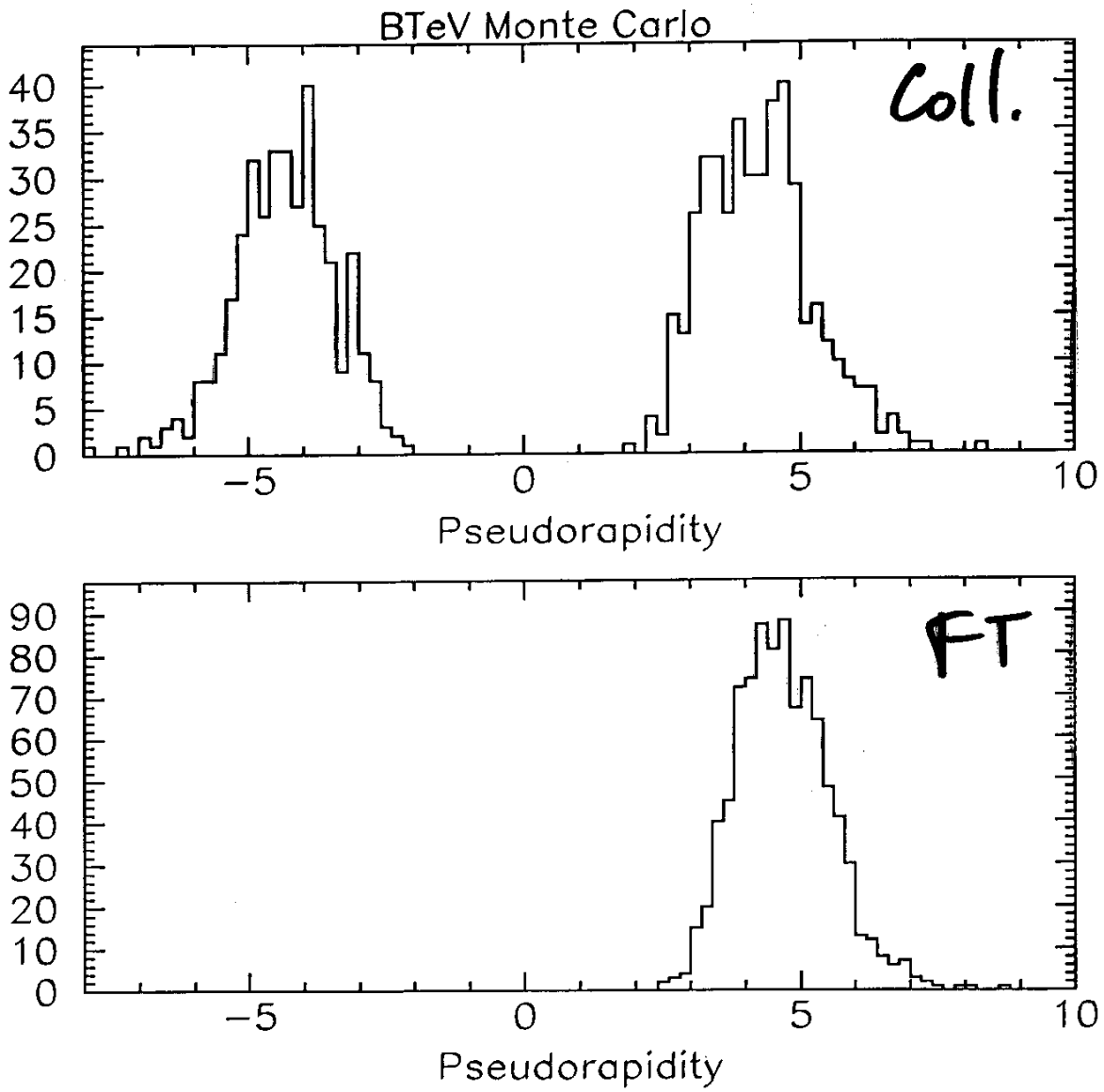
98/07/04 17.39


BTeV Monte Carlo
300
250
200
150
100
50
0
1.6
1.7
1.8
1.9
2
2.1
Reconstructed Kπ mass (GeV)
FT mode
≈1000 events per 10 minutes of beam

98/07/04 17.39


BTeV Monte Carlo
FT
60
50
40
30
20
10
0
0
2
4
6
8
Proper decay time (D° lifetimes)

98/07/05 17.49


BTeV Monte Carlo
Coll.
40
35
30
25
20
15
10
5
0
−5
0
5
10
Pseudorapidity
FT
90
80
70
60
50
40
30
20
10
0
−5
0
5
10
Pseudorapidity

→ Similar in collider and fixed-target modes:

- Collider per-nucleon cross section ↑ × ≈10 - 20, can make up × ≈2-4 from A-dependence:

$$\sigma_{charm} \propto A^{1}$$

$$\sigma_{total} \propto A^{0.71}$$

- FT int. rate assumed limited by pile-up in p_t trigger - can do better?

  (HERA-B has achieved 30 MHz)

- Collider trigger efficiency ↓ × ≈10 ?

→ still need to study trigger optimizations!

Purpose of BTeV

(in a nutshell)

A dedicated experiment to study CP violation, mixing, and rare decays of b and c hadrons

Beauty:

- CP violation is one of the deep mysteries of particle physics.
- The Standard Model predicts striking CP-violation in B decay.
- If SM correct, current experiments will discover B CP violation, but will only scratch its surface.

→BTeV can go beyond discovery and perform decisive tests

Charm:

- The SM predicts negligible mixing and flavor-changing decay and small CP violation in charm.

→Any large effect will be direct evidence of new physics

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BTeV: An Expression of Interest for a Heavy Quark Program at C0 [†]

May 18, 1997

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≈ lin. comb. of CLEO & FNAL F.T. collaborations

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Now an approved R+D pgm
Aim: Technical Proposal in 1999

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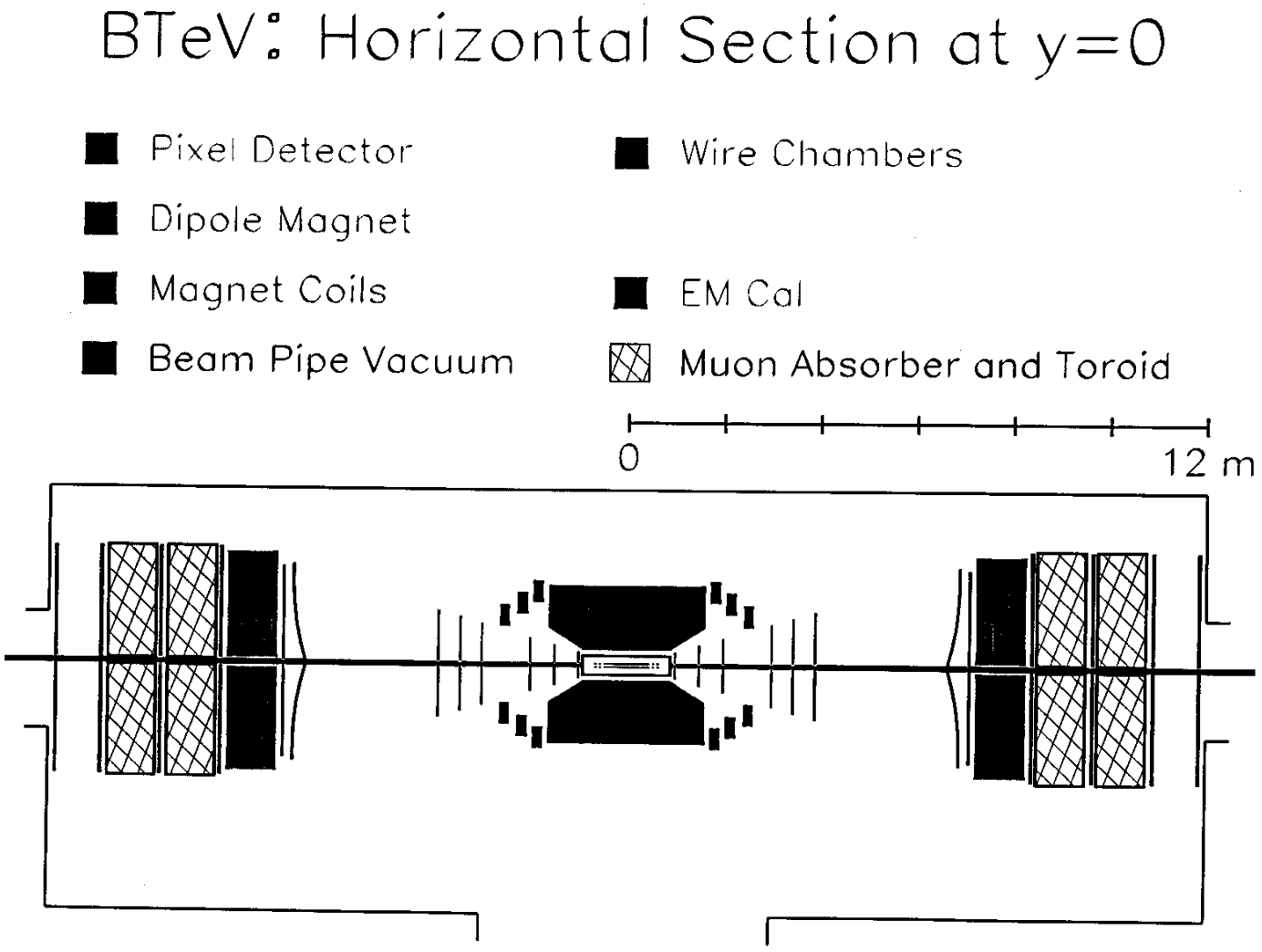
Key features of BTeV:

- Fast, rad-hard pixel detectors near beam
- Level-1 displaced-vertex trigger
- Fast RICH particle ID
- Forward geometry:
  - → excellent vertex resolution:

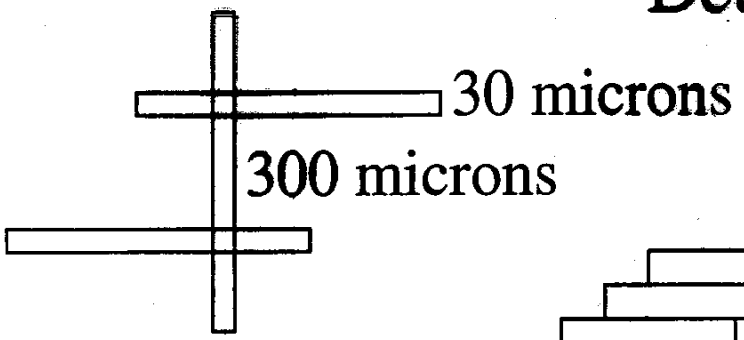
    $\delta\tau \approx$ 30 fs typ.

  - → excellent particle ID
- Can run with wire target in halo
  - → early apparatus shakedown
  - → trigger and calibration studies
  - → charm physics

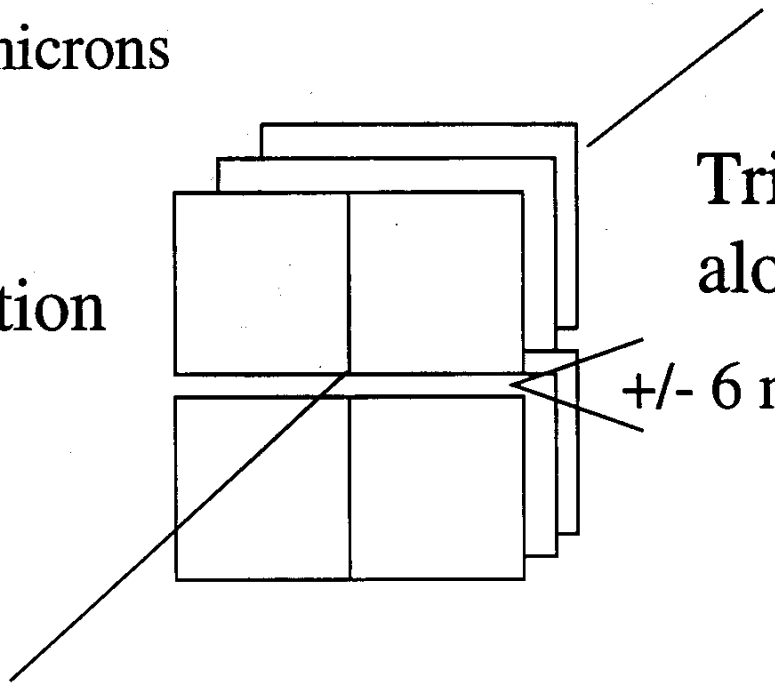
2-arm "forward-geometry" heavy-quark spectrometer:



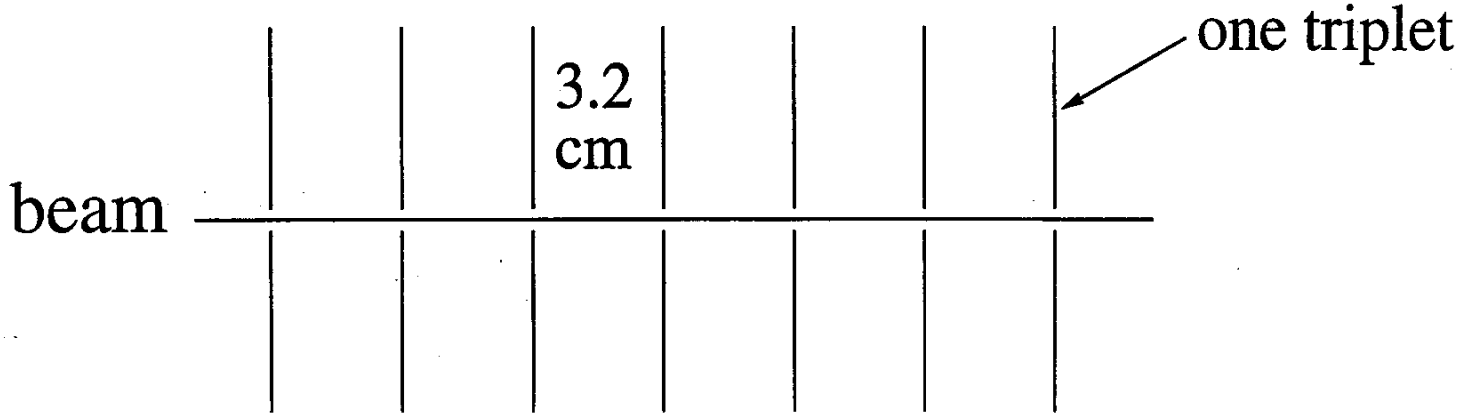
Details of Reference Pixel Detector



Pixel Orientation
in Triplet



Elevation View



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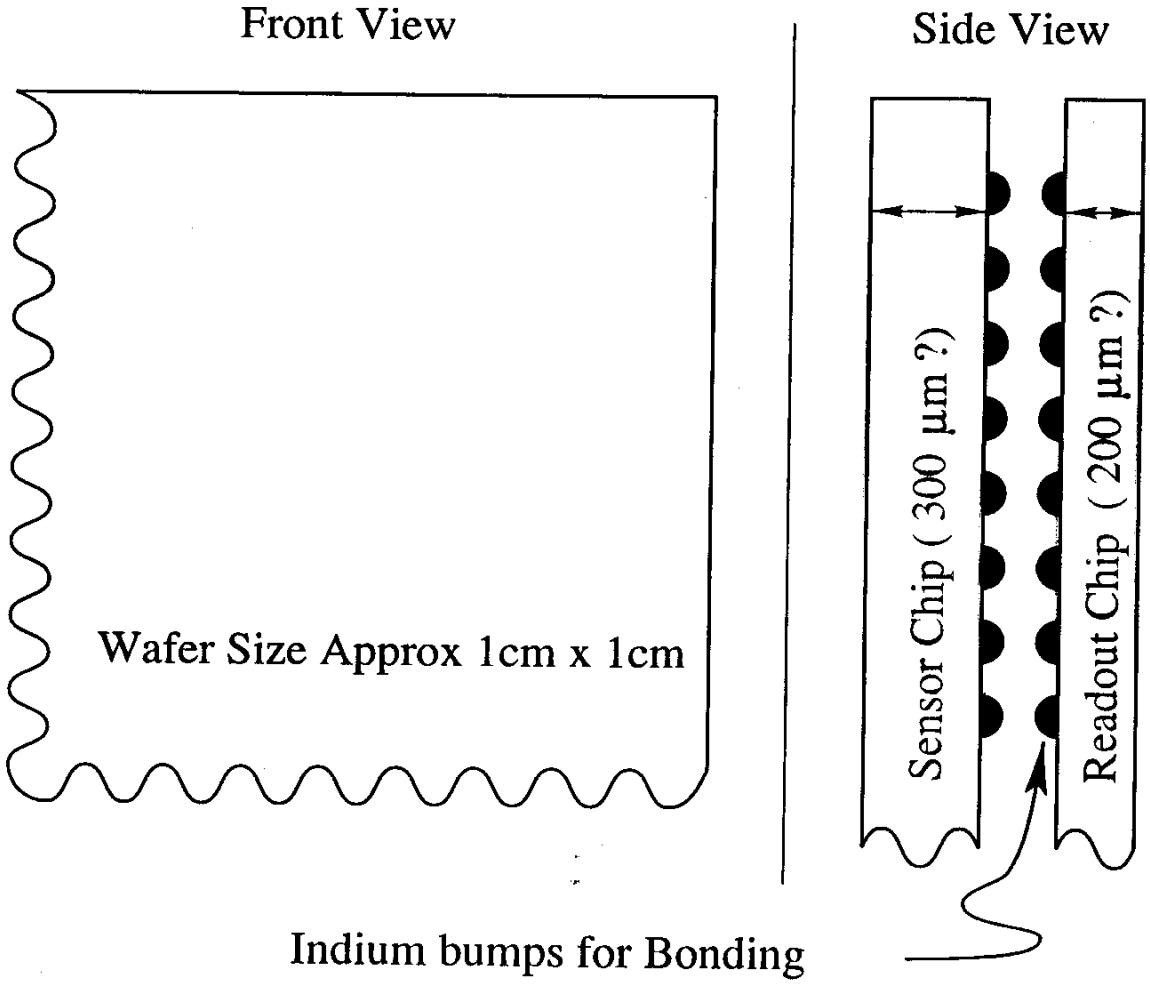
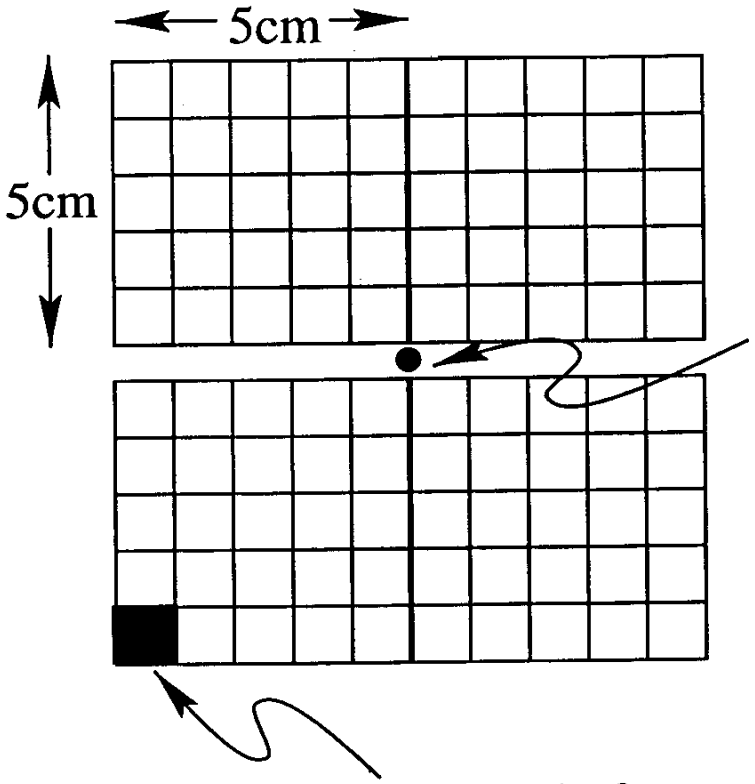
Cartoon of a Pixel Wafer + Readout



- Bumps deposited on both sensor and readout chips.
- Pressed together to make electrical/mechanical contact.

Cartoon of a Pixel Detector Plane



1 Plane =
4 quadrants

Beam spot.
Larger than scale.

Upper half
moves up
for injection.

Lower half
moves down
for injection.

- Quadrant composed of many small chips.
- Tiled to achieve ~ 100% coverage.
- Each chip is about 1cm on a side.
- Up/down motion via Roman pots.

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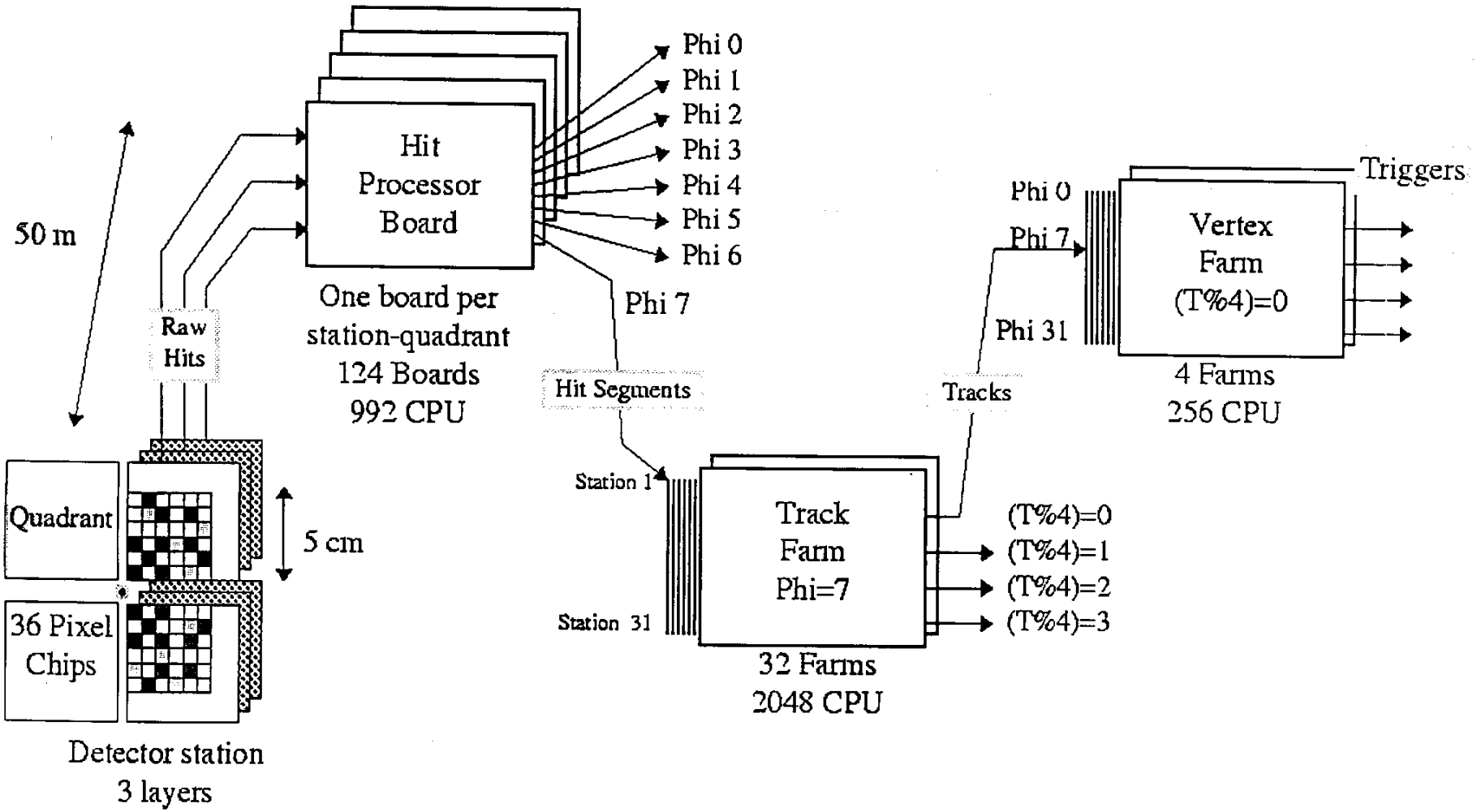
Proposed Level-1 Vertex Trigger



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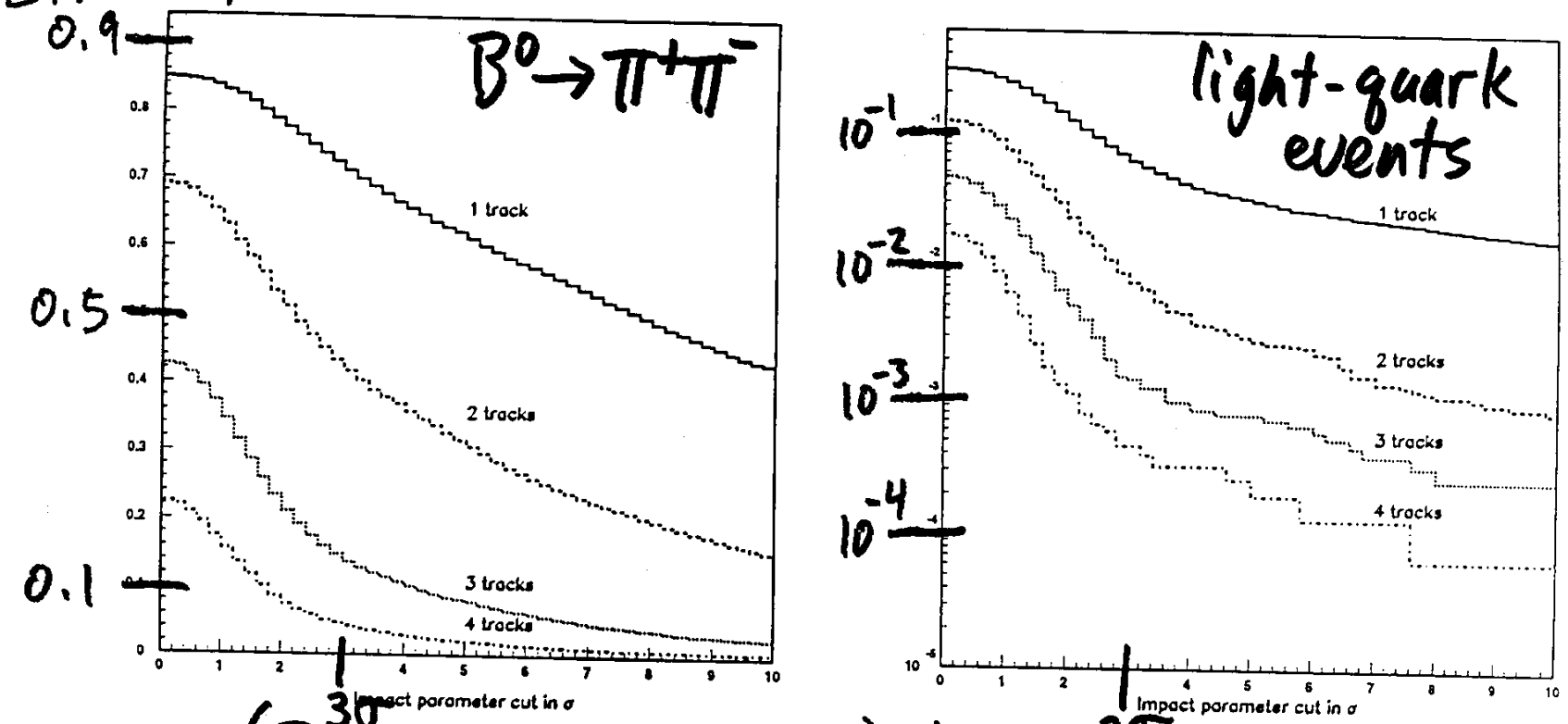
BTeV Vertex trigger performance (Monte Carlo)

Collider $\sqrt{s} = 2$ TeV



(Impact parameter)/$\sigma_{\text{Impact-parameter}}$

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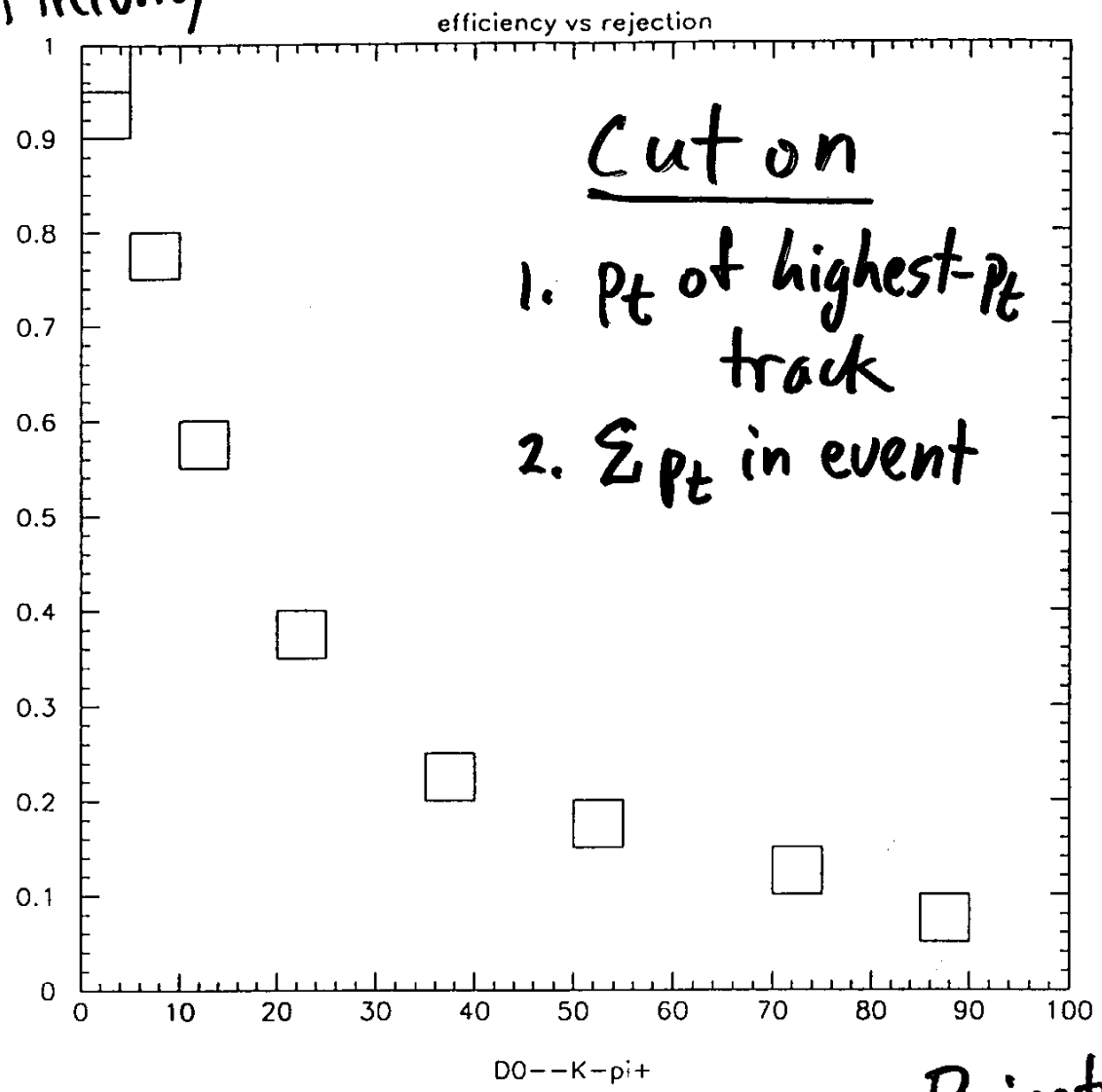
Pt trigger for FI charm

efficiency

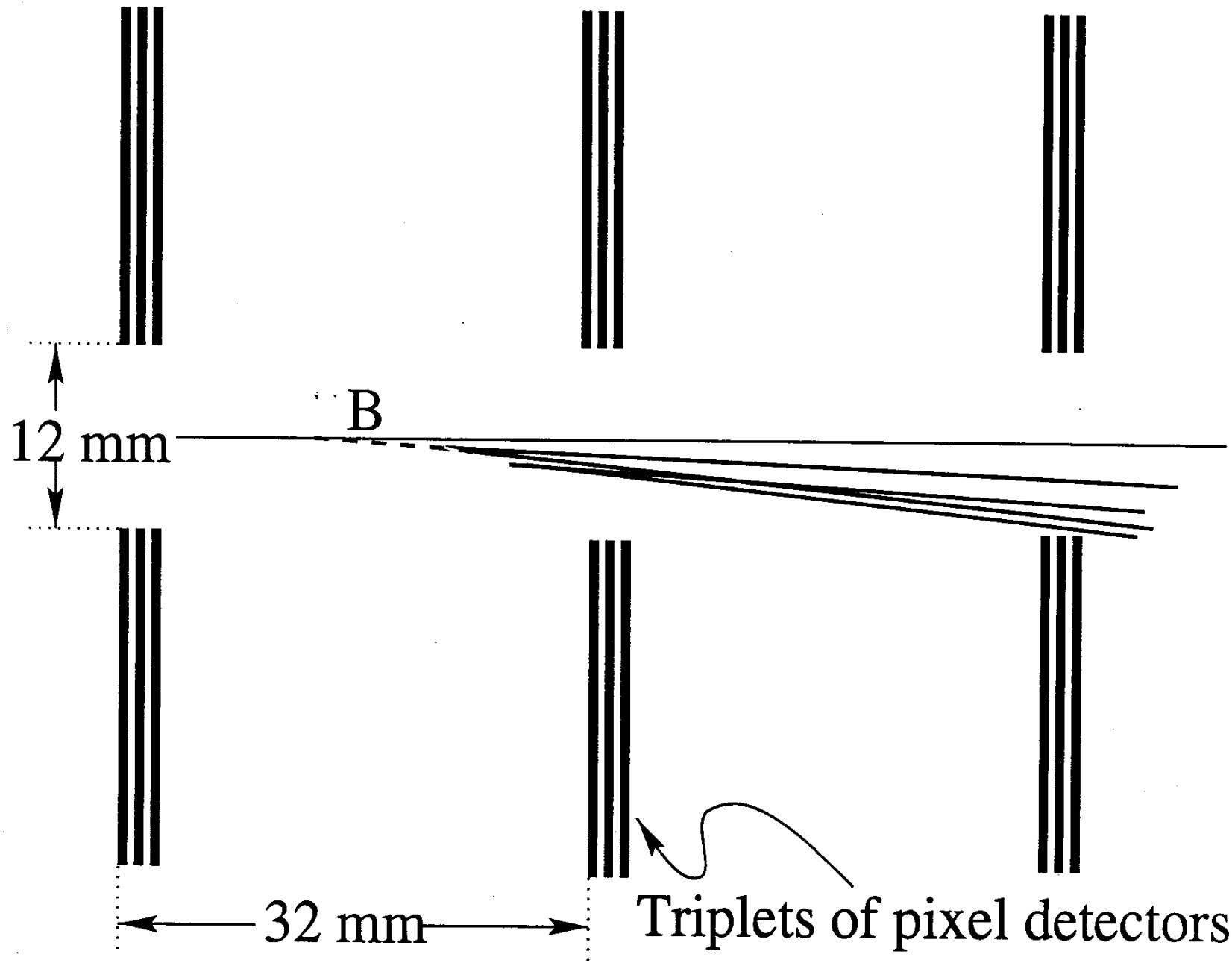


Cut on

1. p_t of highest-p_t track
2. Σp_t in event

Rejection

Cartoon of a B Decay in BTeV - To Scale



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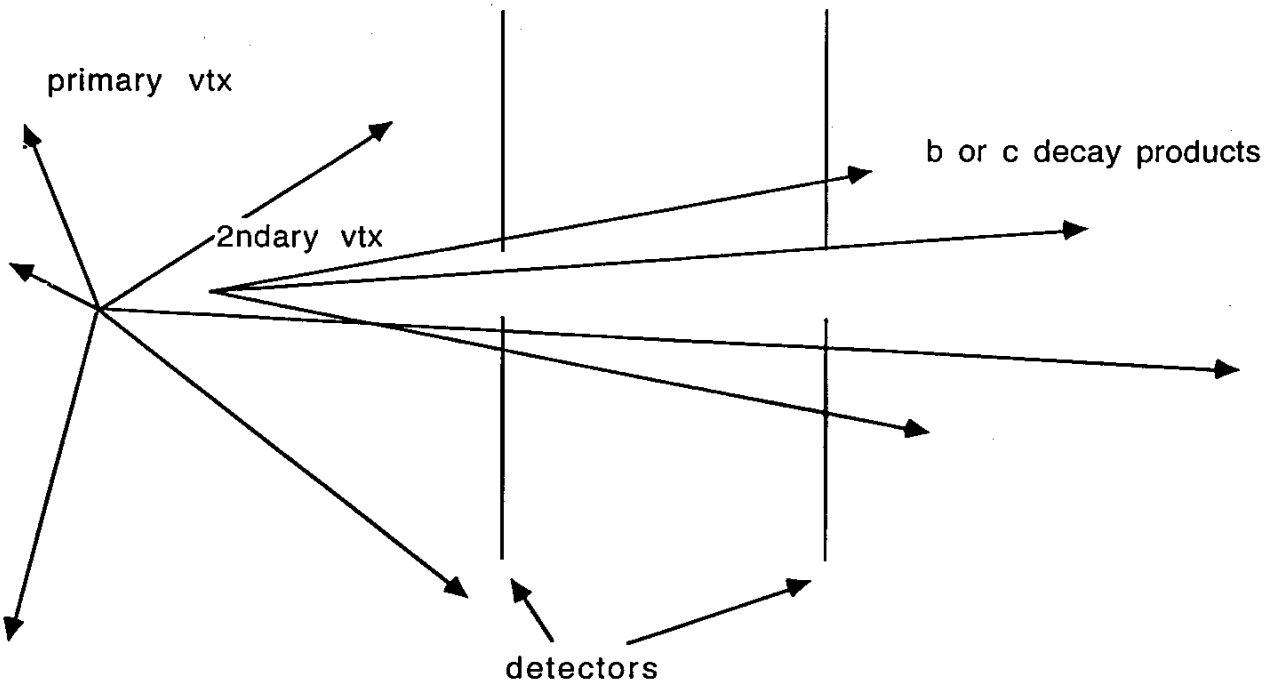
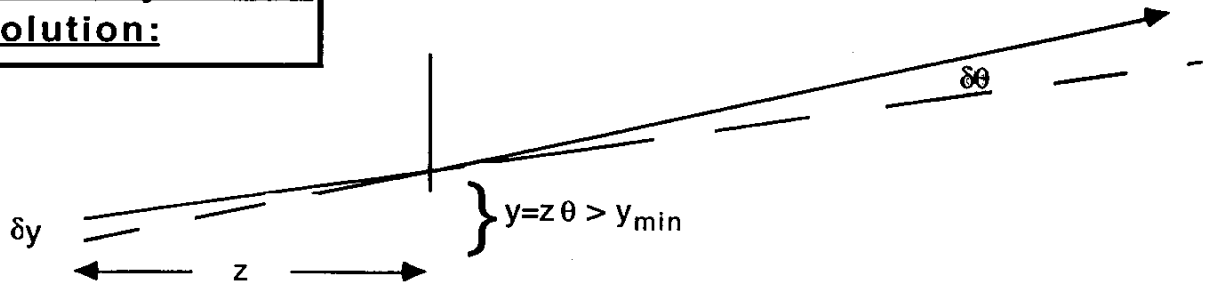
Importance of distance from beam:



Secondary-vertex resolution:

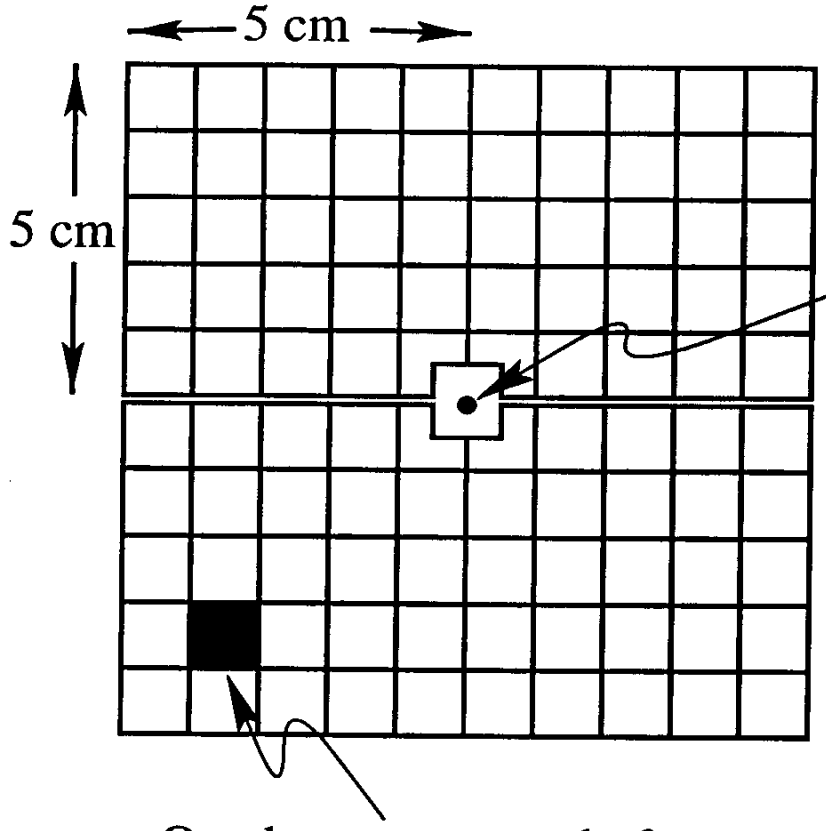


$$\delta\theta \approx \frac{0.015GeV}{p}\sqrt{\frac{X}{X_0}}$$

$$\delta y \approx z\delta\theta$$

$$\approx y_{\min}\left(\frac{0.015GeV}{p_\perp}\sqrt{\frac{X}{X_0}}\right)$$

Cartoon of a Pixel Detector Plane



1 plane
= 4 quadrants

Beam Spot
(larger than scale)

For injection
upper half
moves up and
lower half
moves down.

- Quadrant composed of many small chips.
- Tiled to achieve ~100% coverage.
- Each chip is about 1 cm on a side.
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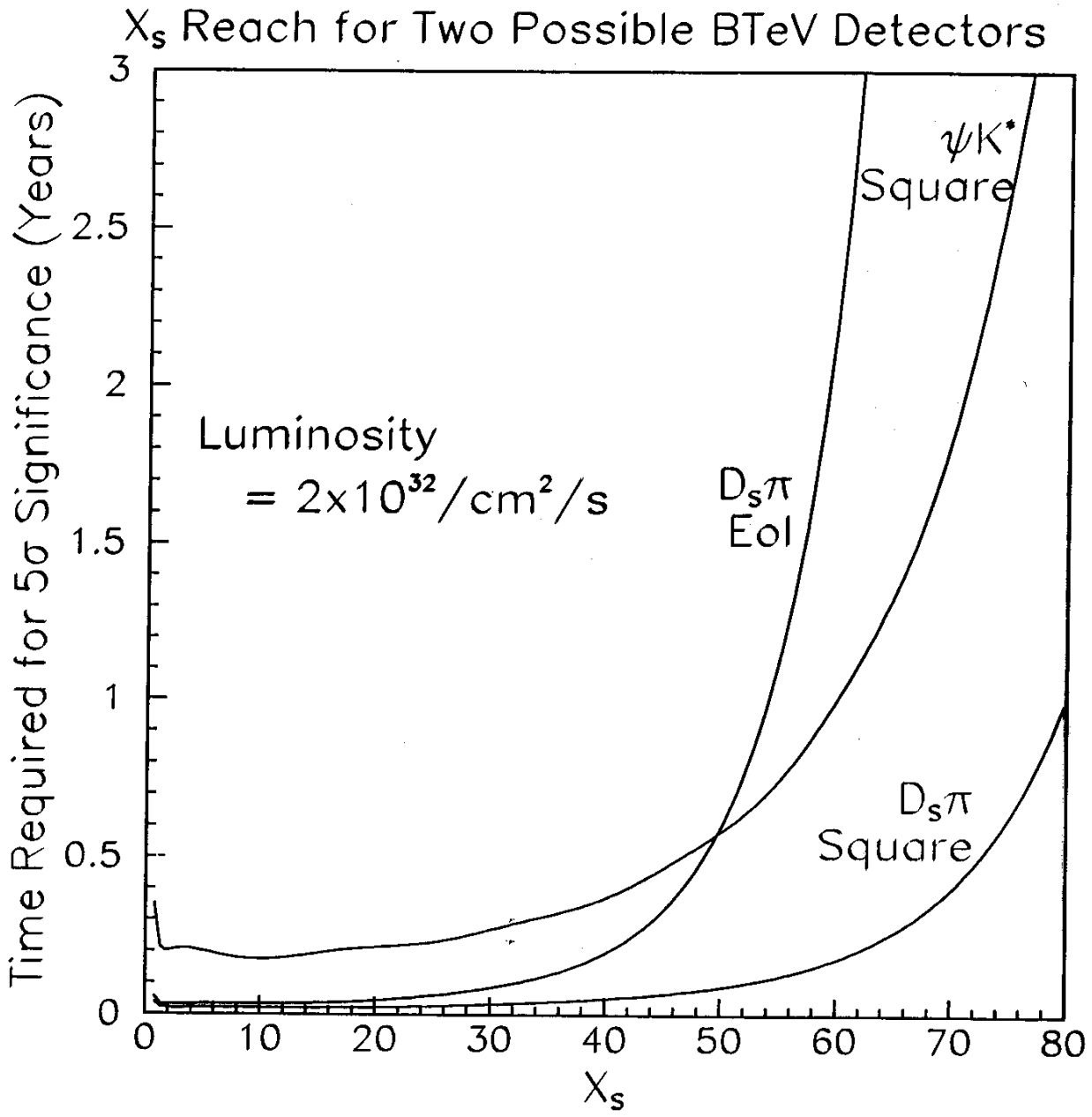

X_s Reach for Two Possible BTeV Detectors
Time Required for 5σ Significance (Years)
X_s
Luminosity
= 2x10^{32}/cm^2/s
$D_s\pi$ EoI
ψK^* Square
$D_s\pi$ Square
0
0.5
1
1.5
2
2.5
3
0
10
20
30
40
50
60
70
80

TABLE 5. BTeV Physics Reach: **Beauty:**

Measurement	Accuracy in 10^7 s $\mathcal{L} = 2 \times 10^{32}$, $\mathcal{L}$ leveled
x_s (square hole)	up to 80 & beyond
$A_{CP}(B^0 \to \pi^+\pi^-)$ (gap)	± 0.013
γ using $D_s K^-$ (square hole)	$\pm 8°$†
γ using $D^0 K^-$ (square hole)	$\pm 8°$‡
$\mathcal{B}(B^- \to K^-\mu^+\mu^-)$ (gap)	4σ at $\mathcal{B}$ of 5.4×10^{-8}
$\sin(2\beta)$ using $B^o \to \psi K_s$ (square hole)	± 0.013

†Assumes ρ=0.7, $\cos\delta$=0.7, $\sin\gamma$=0.5, x_s=20

‡For most values of strong phases and γ

charm:

A_{CP} $< 10^{-3}$ $(10^{-4}$ CA) ?

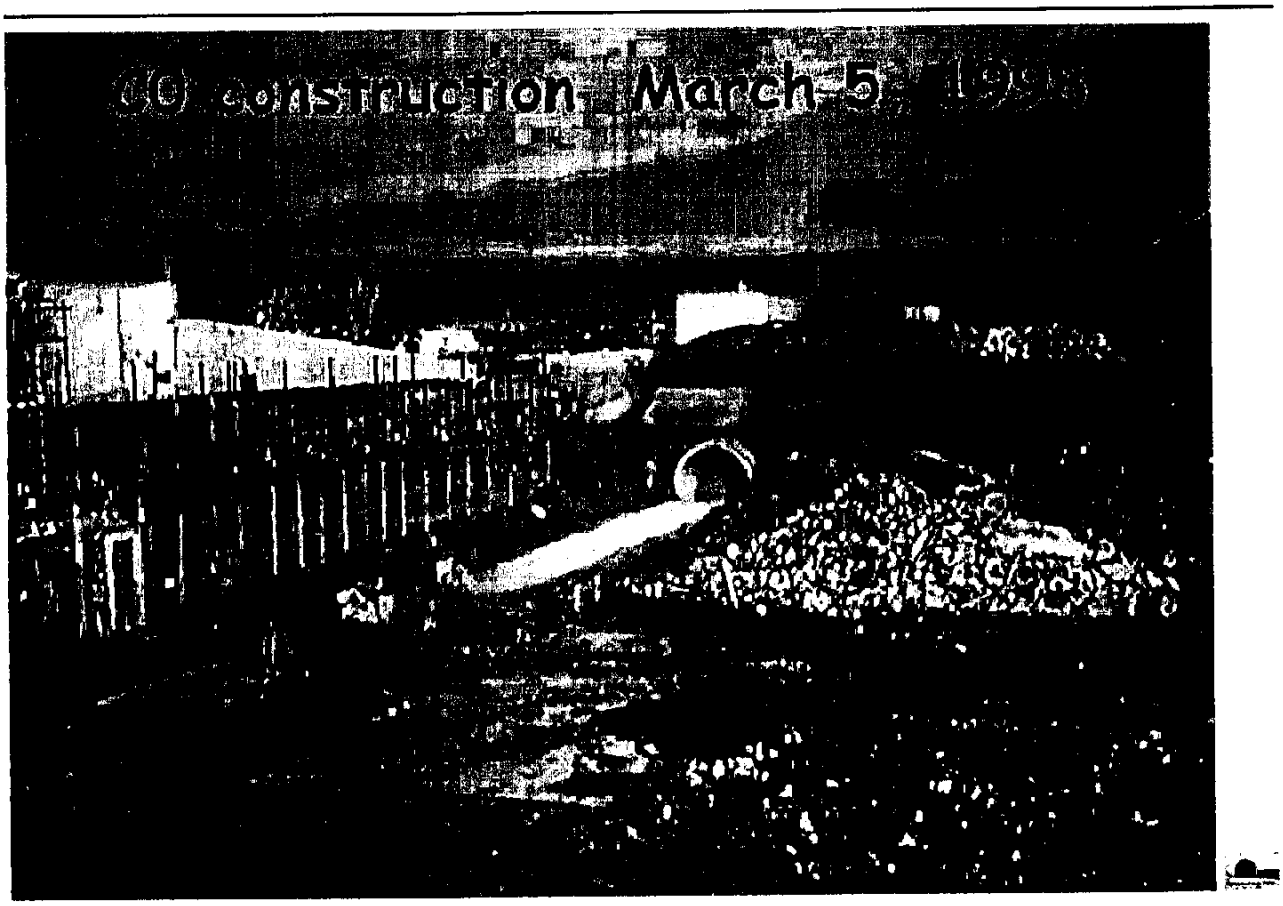
r_{mix} $\sim 10^{-5}$ 0

B_{FCNC} $< 10^{-6 \to -7}$

→ more charm simulation needed!

BTEV / C0

C0 Site Construction



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Conclusions:

- Definitive B CP-violation studies will require large samples available only in hadroproduction

- If approved, BTeV/C0 will be the state-of-the-art heavy-quark experiment in the mid-2000's

  → Design optimization in progress

  → Charm CP sensitivity $O(10^{-3})$ likely

  → May be able to see SM charm CP violation in multi-year run

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