Propsects for B Physics at Hadron Colliders

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Why Aren't We Interested in B Physics?

- CP violation is expected to be more dramatic in the B-meson system than with K's.
  (Carter and Sanda, 1980)
- The B-meson lifetime is much long than expected, longer than that of D mesons.
  (Fernandez *et al.*; Lockyer *et al.*, 1983)
- B_d-$\bar{B}_d$ mixing is much larger than expected.
  (Albrecht *et al.*, 1987)
- The B-pair cross section at the SSC should be 3% of the total, much larger than previously expected.
  (Collins and Ellis, 1991)

Why Are We Interested in the Higgs Boson?

- The Higgs **field** can provide the large effective mass of the gauge bosons W and Z.

  (Weinberg, 1967)

Of all known phenomena, CP violation is the only indication of physics beyond the Standard Model.

Recent Speculation:

(N. Turok *et al.*, P.R.L. **65**, 2331 (1990))

The baryon asymmetry of the universe could be generated by CP violation in a two-Higgs-doublet model.

Phenomenology for the SSC is not yet known.

B Physics Initiatives at Hadron Colliders

- 1984, Snowmass: B physics hard to do with high-P_t trigger (Trilling *et al.*);
  needs new technology (Cronin).
- 1987: Two Letters of Intent to FNAL (Lockyer *et al.*, Reay *et al.*);
  Berkeley summer study, FNAL beauty workshop.
- 1989: R&D for B detectors: T-784 at FNAL; various Generic and Subsystem R&D at SSC.
- 1990: $B \to J/\psi K$ decays reconstructed at CDF; three EOI's at the SSC; two proposals at FNAL.
- 1992: Workshops at FNAL and SSC.

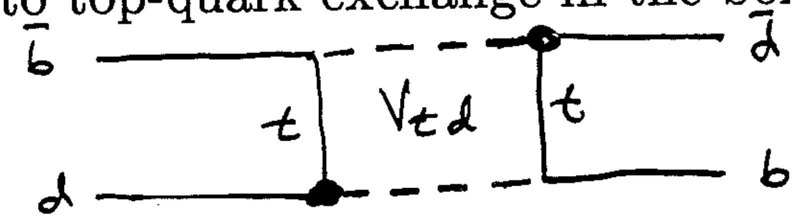
CP Violation in the B-Meson System

- CP violation occurs via first-order phases in the CKM matrix.

  In the Wolfenstein representation:

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} Re & Re & Im \\ Re & Re & Re \\ Im & Re & Re \end{pmatrix}.$$

- The phase of V_{td} enters in B_d (but not B_s) mixing due to top-quark exchange in the box diagram.



- The phase of V_{ub} enters in $b \to u$ (but not $b \to c$) decays.

- Hence there are 4 classes of CP violation in decays of neutral B's:

  1. B_d decay, $b \to c$ $(B_d \to J/\psi K_S)$ $\sim V_{td}$
  2. B_d decay, $b \to u$ $(B_d \to \pi^+\pi^-)$ $\sim V_{td}V_{ub}$
  3. B_s decay, $b \to u$ $(B_s \to \rho K_S)$ $\sim V_{ub}$
  4. B_s decay, $b \to c$ $(B_s \to J/\psi\phi)$ no effect

CP-Violating Asymmetries

For decays of neutral B's to CP eigenstates,

$$A(t) = \frac{\Gamma(B \to f) - \Gamma(\bar{B} \to \bar{f})}{\Gamma(B \to f) + \Gamma(\bar{B} \to \bar{f})} = \sin 2\varphi \sin xt,$$

where φ = phase of the CKM matrix element, and $x = \Delta M/\Gamma$ = mixing parameter.

Three classes of nonzero asymmetries,

$\Rightarrow$ Three measurements of the two CKM phases.

$\Rightarrow$ Can overconstrain the Standard Model.

But, must tag the particle/antiparticle character of the B by observation of the second B in the event.

The Einstein-Rosen-Podolsky Effect

If the B^0-$\bar{B}^0$ pair is produced in a C(odd) or C(even) combination, this quantum-mechanical correlation leads to the combined decay asymmetry

$$A(t_1, t_2) = \sin 2\varphi \sin x(t_1 \mp t_2).$$

If we don't observe the decay times, the integrated asymmetry is

$$A = \begin{cases} 0 & C(\text{odd}) \\ \frac{2x}{(1+x^2)^2} \sin 2\varphi & C(\text{even}) \end{cases}$$

For B^0-$\bar{B}^0$ produced at the $\Upsilon(4S)$ at an e^+e^- collider, we have only C(odd) states,

$\Rightarrow$ CP violation vanishes unless can observe the time evolution.

$\Rightarrow$ Need \$250M to build an asymmetric e^+e^- collider.

CP-Asymmetries at a Hadron Collider

Here, the B^0-$\bar{B}^0$ pair is produced as an incoherent sum of C(odd) and C(even) states,

$\Rightarrow$ The combined decay asymmetry averages to

$$A(t_1, t_2) = \sin 2\varphi \sin xt_1 \sin xt_2,$$

and the integrated asymmetry averages to

$$A = \frac{x}{(1+x^2)^2} \sin 2\varphi.$$

The asymmetry is 'diluted' by a factor $x/(1+x^2)$ from mixing of the first B, and by a factor $1/(1+x^2)$ from mixing of the second B.

With $x_d \approx 0.7$, we would have $A \approx (1/4) \sin 2\varphi$.

$\Rightarrow \quad A_{\min,3\sigma} = 12/\sqrt{N}$ for a sample of N events.

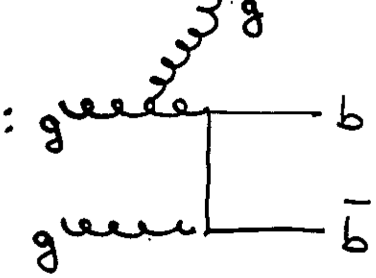
The Need for Kaon Identification

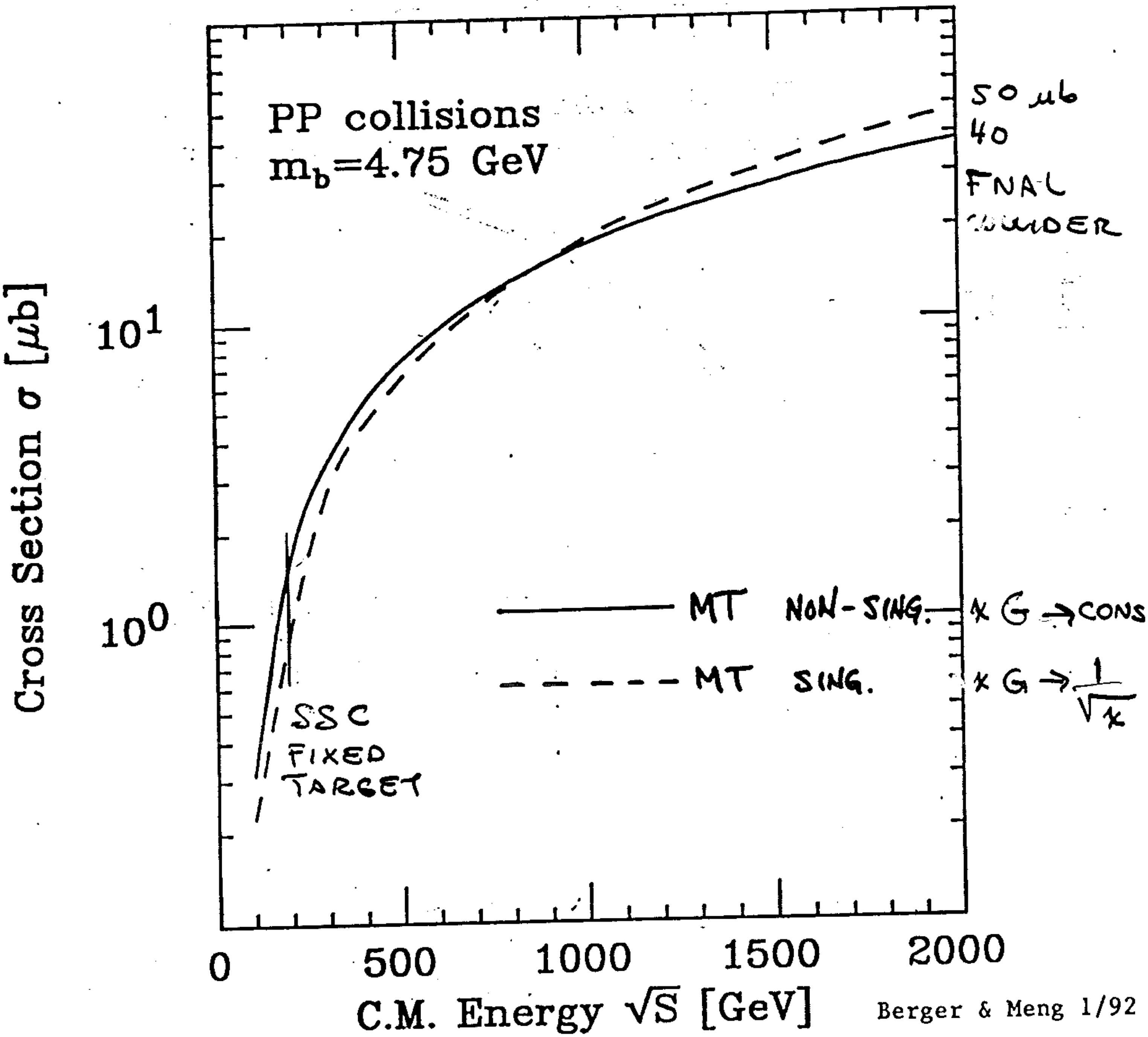
The decisive justification is for tagging the second B in the event via the sign of Kaon from the decay chain $b \to c \to s$.

A Kaon tag is 5 times as effective as combined electron and muon tags.

Kaon identification is needed for study of the majority of exclusive B-decays, particularly those relevant to B_s mixing. (See Addendum to P-827 for preliminary studies of the difficulty of using mass constraints to reconstruct B_d and B_s without Kaon ID.)

INCLUDES α_s^3 CORRECTIONS:



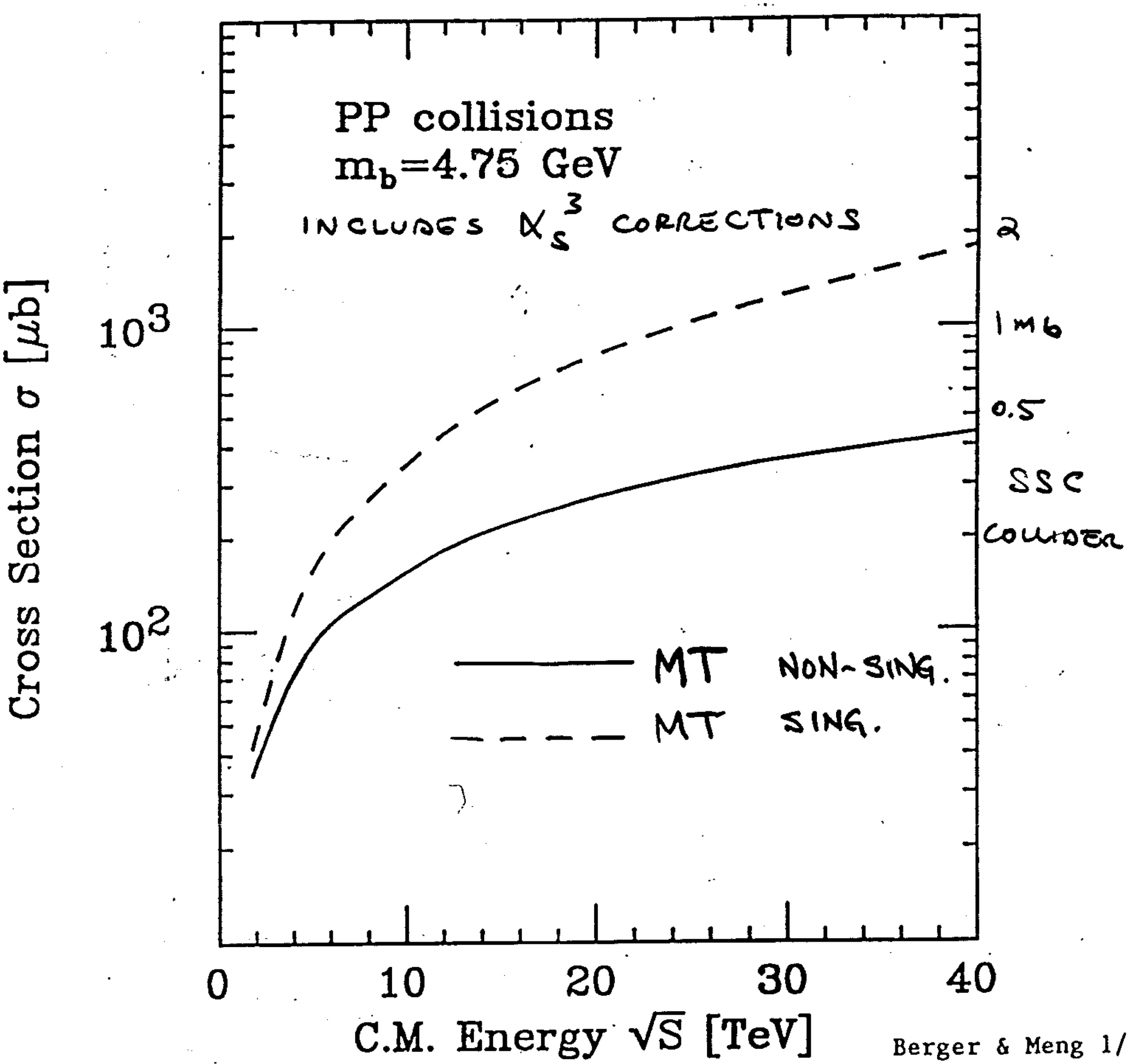


Berger & Meng 1/92

σ (200 GeV) = 1.38 μb ---
1.65 μb ——
(1.1 TO 2.0 μb)

C.M. ENERGY AT SSC FIXED TARGET

σ_{TOTAL} (SSC) ≈ 100 mb

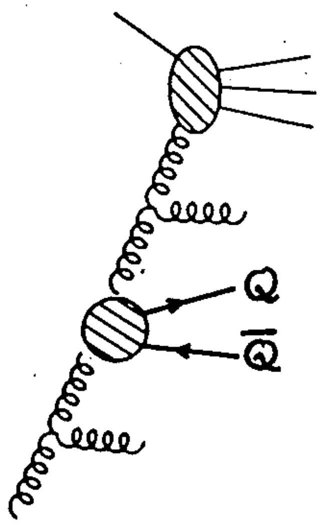


Berger & Meng 1/92

B Production at SSC is "Semi-Hard"

Scale $M_Q >> \Lambda$ but $M_Q << \sqrt{s}$. Potentially large next to leading order contributions from a series in $\left[\alpha_s \, ln \, (s/M_Q^2)\right]^n$

Example:

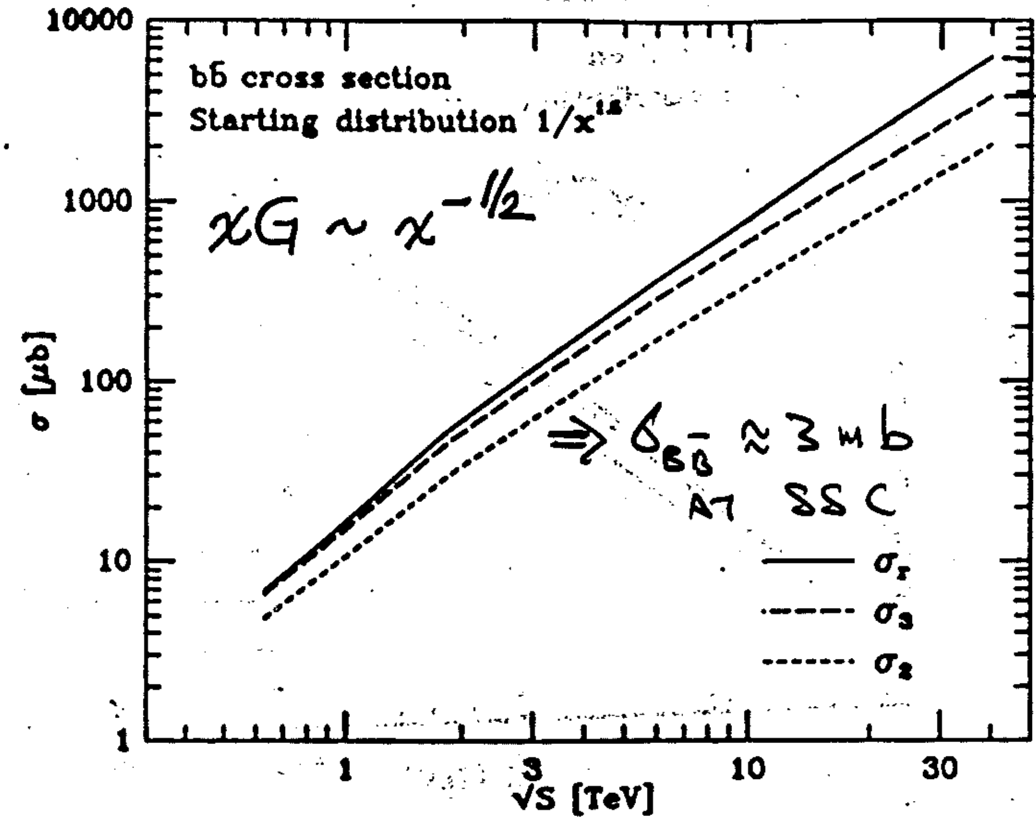


RESUMMATION IS REQUIRED

These contributions modify the short-distance cross section $\hat{\sigma}$ and the kernel of the evolution equation for parton densities, and they induce p_T of the $Q\overline{Q}$ pair (Collins and Ellis; Levin, Ryskin, Shabelski, Shuvaev).

At SSC the expected increase of σ above the $0(\alpha_s^3)$ result is substantial for a conventional gluon distribution ($xG \rightarrow$ constant) but modest if a singular gluon density is used ($xG \rightarrow x^{-\frac{1}{2}}$)

EFFECT OF RESUMMATION

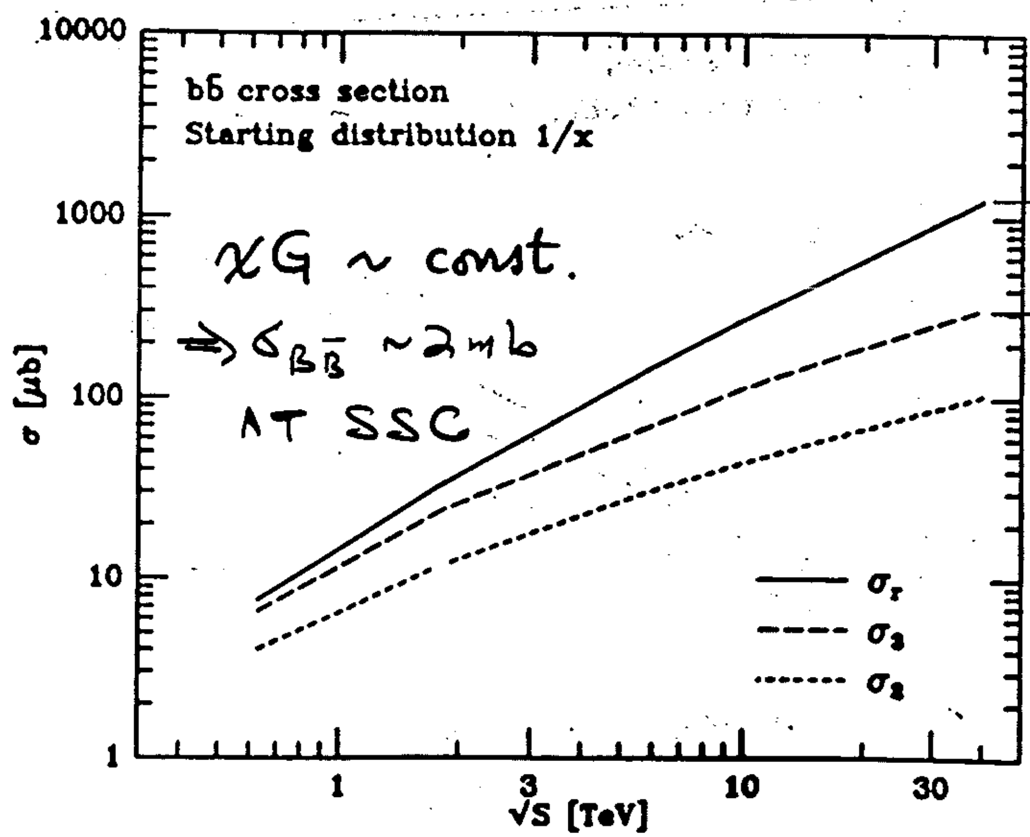


$\sim \times 1.5$

LHC $\times 1.4$

J. Collins + R.K. Ellis

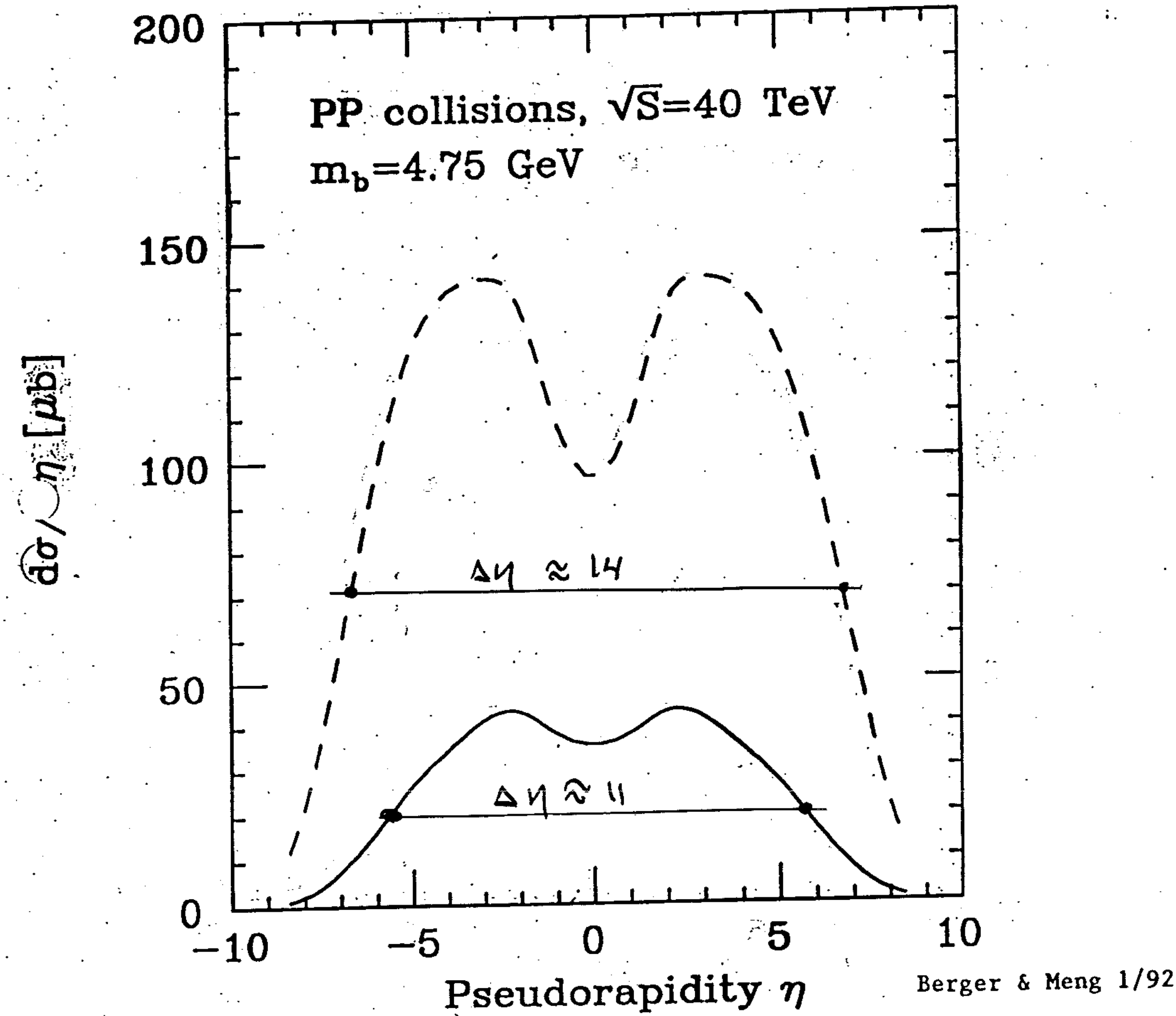
FNAL-PUB-91/22T



$\sim \times 4$

LHC $\times 3$

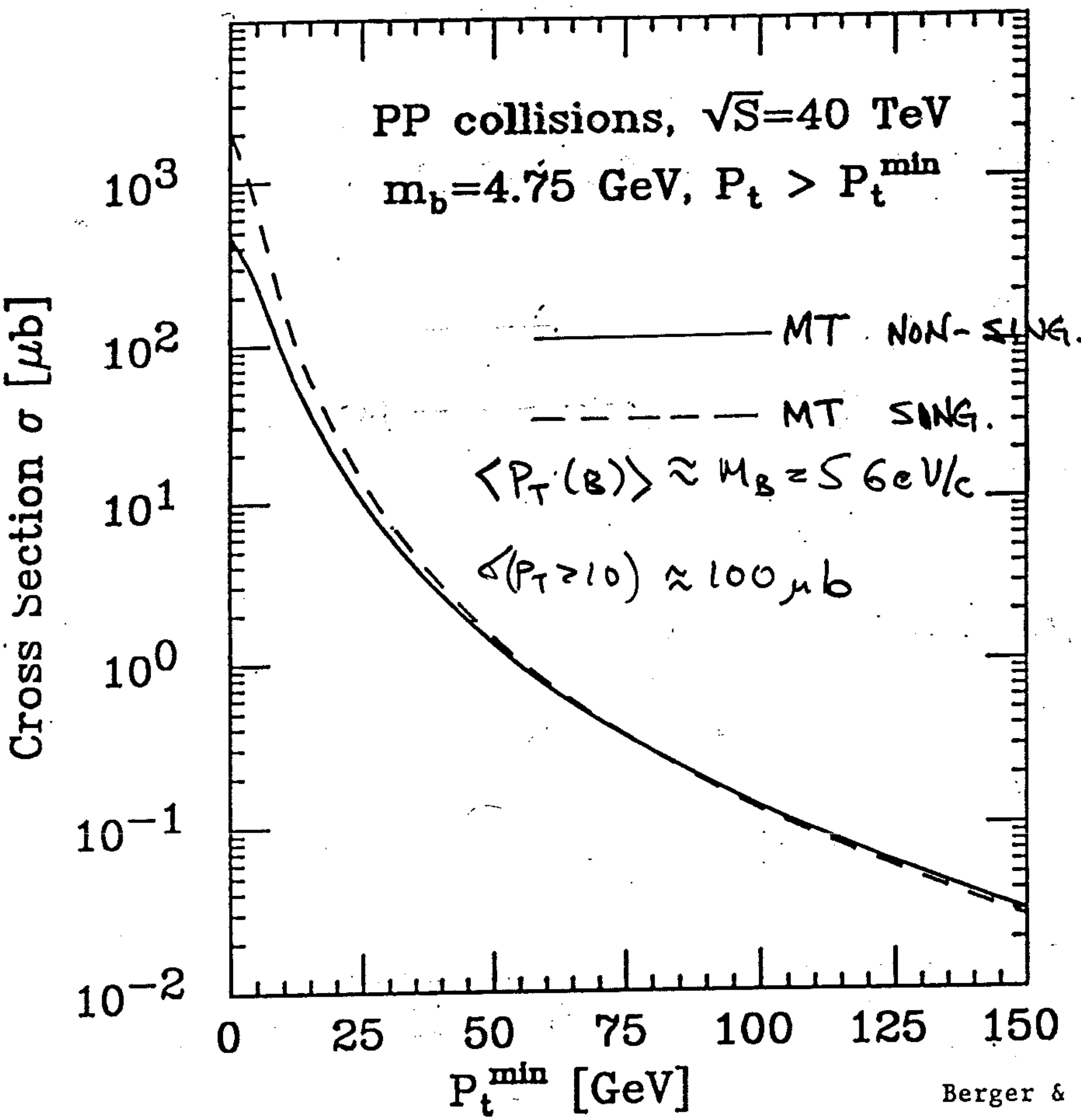
$\eta \equiv -\ln \tan \theta/2$



– – – – – MT SINGULAR

——— MT NON-SINGULAR

$\sigma(p_T \geq p_T^{MIN})$



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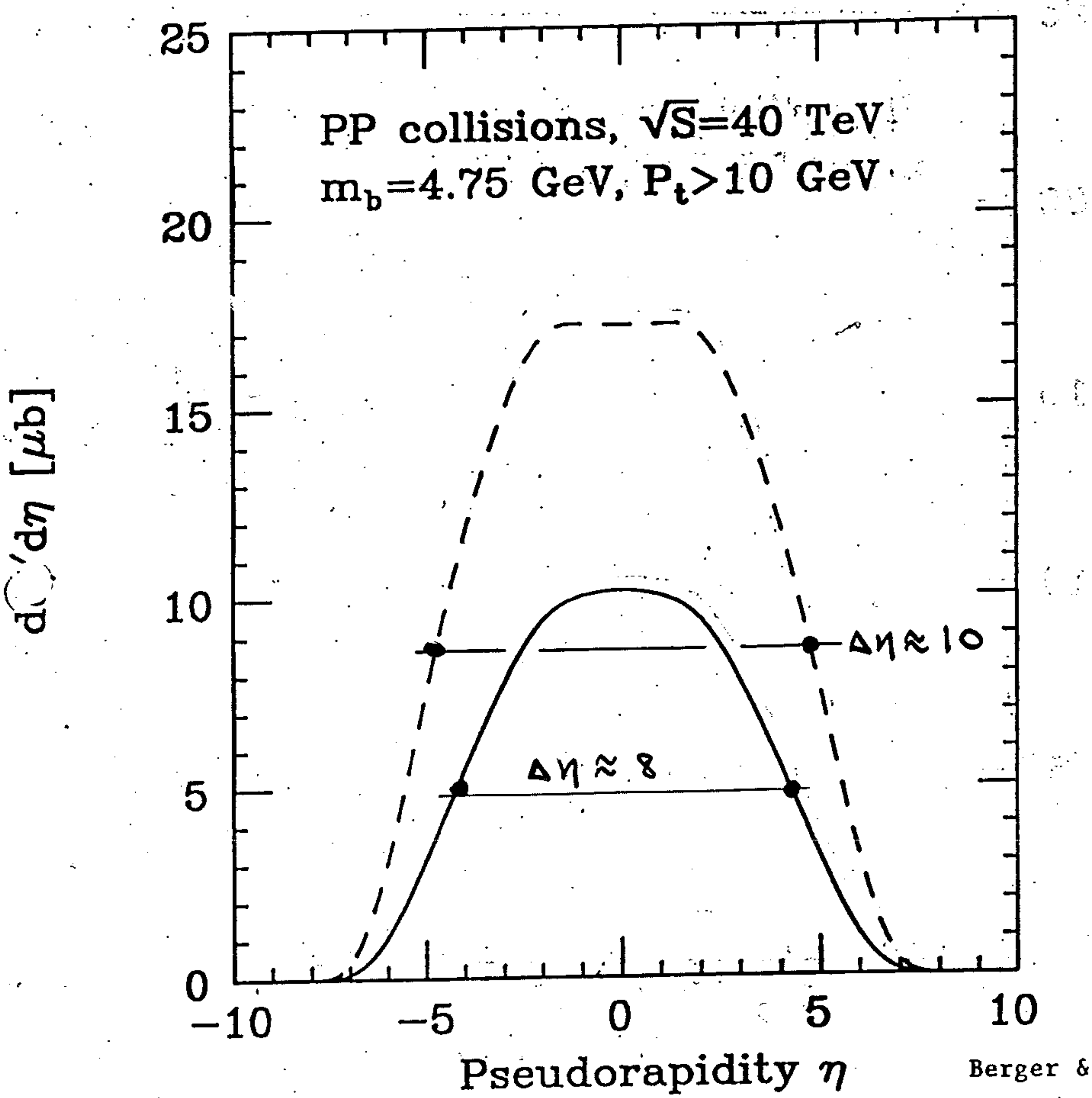

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B-Production/Decay Kinematics

$\langle P_t(B) \rangle \approx M_B$, so $\langle P_t(\text{daughter}) \rangle \approx M_B/4 \approx 1$ GeV/c.

Roughly flat in pseudorapidity $\eta = -\ln \tan \theta/2$,
$|\eta| \lesssim 4$ at FNAL, $\lesssim 6$ at SSC.

B-pair correlation very weak,
so acceptance for pairs $\approx (\Delta\eta)^2$.

A B-physics Experiment Must Emphasize:

- $P_t < M_B = 5$ GeV/c.
- Wide angular range: $|\eta| < 4$ at TEV I.
- A 3-D silicon vertex detector.
- Momentum measurement and particle ID of π, K, e and μ.
- High-rate trigger and data acquisition for any mode but $B \to J/\psi X$.
- Hadron calorimetry not needed.

$\Rightarrow$ Optimized experiment not like one for W/Z/top/Higgs.

See the BCD Expression of Interest to the SSC.

A detailed B-physics program requires the full reconstruction of one B decay of the B-$\bar{B}$ pair.

- Identification of rare (and not-so-rare) decay modes.
- Measurement of proper time for mixing studies.
- Unravelling the CKM matrix elements via study of several decays to CP eiogenstates.

A B-Physics Program

1. Study nonleptonic decay modes of B mesons and baryons by measuring the relative branching ratios, differential cross sections, and (hence) gluon structure functions.

2. Study B_s-$\bar{B}_s$ mixing. This is needed for CP studies of B_s mesons.

3. Study CP effects in self-tagged decays. This may give first evidence for CP in B system.

4. Study CP violation using CP eigenstates. This is the most powerful method of studying CP violation.

Part of Item 1 can be accomplished by CDF.

Items 2 and 3 require Kaon ID and high data rates.

Can Item 4 be done by CDF?

All-Charged Decays of B's

Following J.D. Bjorken, *Estimates of Decay Branching Ratios for Hadrons Containing Charm and Bottom Quarks* (1986):

B.R.$(B_u \to$ all charged$) \sim 0.7\%$.

B.R.$(B_d \to$ all charged$) \sim 1.6\%$.

B.R.$(B_s \to$ all charged$) \sim 0.7\%$.

Average B.R. $\sim 1\%$.

The higher branching ratio for B_d arises because preferentially $B_u \to \bar{D}^{\star 0}X$, $B_d \to D^{\star -}X$; and $B_s \to D_s^{\star -}X$, but of the $D^\star$'s only $D^{\star -}$ has all-charged decays.

Study Decays $B \to J/\psi X$

Several all-charged modes are accessible:

$B_u \to J/\psi K^+$.

$B_d \to J/\psi K^{*0}$ or $J/\psi K^0_S$.

$B_s \to J/\psi \phi$.

$B_c \to J/\psi \pi^+$.

CDF has a good prospect to discover the B_s and B_c in the next run.

B Physics at the TEV I – A BCD View

1. Study of $B \to J/\psi X$ modes ($X = K_S^0$, ϕ, *etc.*)

   - Increase rapidity coverage.
   - Add Kaon tagging.
   - Need Main Ring Injector upgrade to reach CP signal.
   - Vertex detector and high-rate DAQ not critical.

2. Study $B \to$ all-charged modes (*i.e.*, $B \to \pi^+\pi^-$)

   - Vertex detector critical.
   - Triggering difficult, but requires high-rate DAQ.
   - Kaon ID needed both for tagging and for exclusive modes.
   - B_s mixing likely accessible.
   - CP violation in these modes will take major effort.

Can a credible study of CP violation be made as part of the existing Fermilab Collider program?

No! unless major priority is given to B-physics, entailing several detector upgrades not needed for the top-quark search.

R&D for vertex detector, particle ID, and high-rate data acquisition, compatible with later installation in CDF of D0, could be begun in association with a modest B-physics program in the C0 intersect.

See P-827, the μBCD proposal to Fermilab, Oct. 8, 1990, plus Addendum Jan. 7, 1991.

Estimate of Rates for CP Violation at CDF

CDF has already reconstructed 10 or so decays $B_d^0 \to J/\psi K_S^0$ (against a large background) from a data sample of 3 pb^{-1}.

If 1000 events were reconstructed **and tagged** in this mode, a CP-violating asymmetry of $0.38 = 12/\sqrt{N}$ could be resolved to 3 standard deviations.

Optimistically the efficiency of a Kaon tag could reach 10%, while a tag on either electrons or muons could reach 2% efficiency.

Thus 10,000-50,000 reconstructed $B \to J/\psi K_S^0$ decays are needed for an entry-level study of CP violation.

Will the needed factor of 1,000-5,000 in data sample emerge readily from the existing collider program?

Luminosity improvements should provide a factor of 50, acceptance improvements in CDF might provide another factor of 10.

But no Kaon identification is available at CDF, so we will likely fall short by one order of magnitude of the needed 50,000 reconstructed decays at CDF.

Table 1: The numbers of tagged, reconstructed $B \to J/\psi K_S$ decays in a run of 1000 pb^{-1} at CDF, at an upgraded D0, at a Bottom Solenoid Detector (BSD), and a Bottom Collider (dipole) Detector (BCD) for J/ψ decays to $\mu\mu$ and ee and for tagging of the second B via $\mu^{\pm}$, $e^{\pm}$, and $K^{\pm}$. Also listed is the minimum value of the CP-violating asymmetry A that could be resolved to three standard deviations. The numbers in parentheses might be obtained in CDF with the addition of Kaon identification, which is not part of the present CDF-upgrade plan.

Technique	CDF		D0		BSD		BCD	
	Events	A_{min}	Events	A_{min}	Events	A_{min}	Events	A_{min}
μ only	50	1.00	140	1.00	140	1.00	200	0.85
e only	50	1.00	50	1.00	500	0.52	500	0.52
$\mu + e$	200	0.85	400	0.60	1200	0.35	1250	0.34
$\mu + K$	(250)	(0.76)	—	—	1400	0.32	2250	0.25
$e + K$	(250)	(0.76)	—	—	3750	0.20	4650	0.18
$\mu + e + K$	(1000)	(0.38)	—	—	5600	0.16	8400	0.13

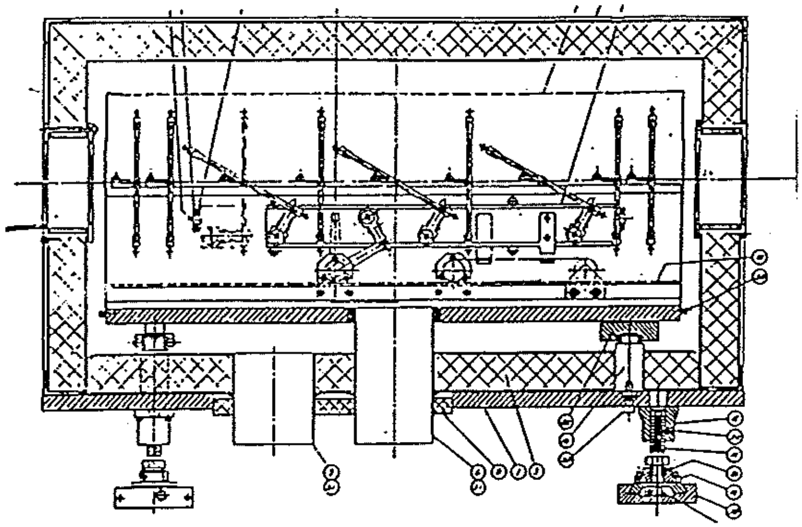
BCD (T-784) Ongoing R&D

- Silicon Vertex Detector
  - BVX readout chip: 1 ADC per channel.
  - Beam tests of double-sided DC-coupled detectors (Micron).
  - Mechanical studies of air-cooled detector with interleaved disks and barrels.
- Straw Tracker prototype: U. Penn bipolar preamp
  - 200-channel system test Fall 91.
- RICH Counter: solid CsI photocathode
  - 400-channel system test Fall 91.
- Barrel-Switch Event Builder
  - 600 event/sec demo in 1/4 crate, Summer 91.
- Processor Farm: high-bandwidth network
  - 1991: 512 *i860* cpu's on mesh network.

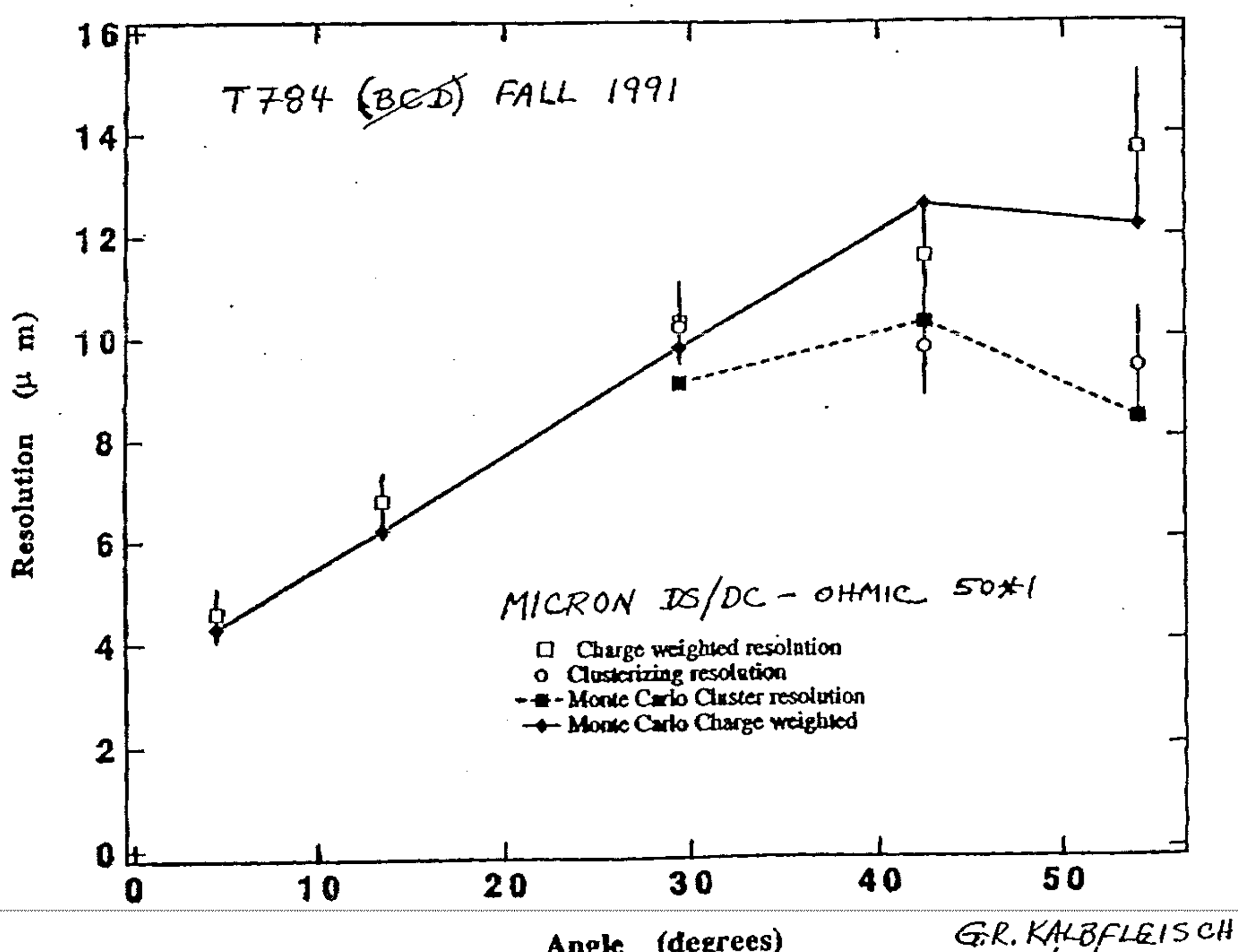
Silicon Detector Beam Tests

Iowa State U. – U. Oklahoma – Yale U.

- Study position resolution *vs.* angle of incidence.



- Results on resolution ⊥ to track:

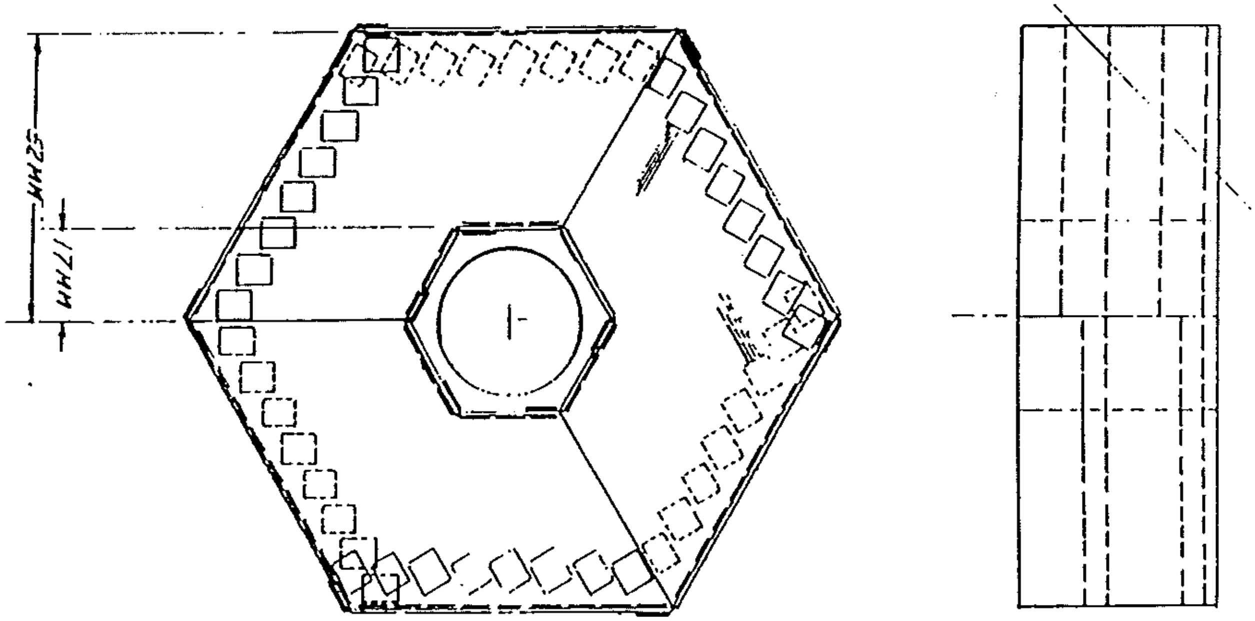


G.R. KALBFLEISCH
1/15/1992

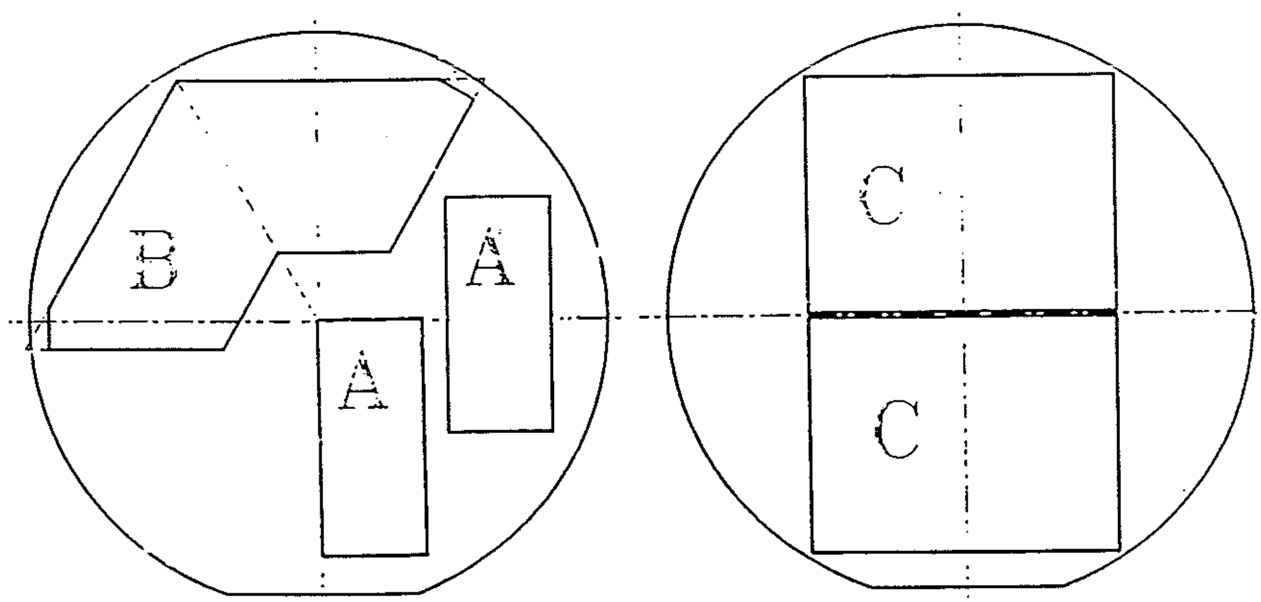
A Silicon Vertex Detector with Interleaved Disks and Barrels

Fermilab–Langston U.–U. Oklahoma–Princeton U.

- Hexagonal modules with spiral cooling path.



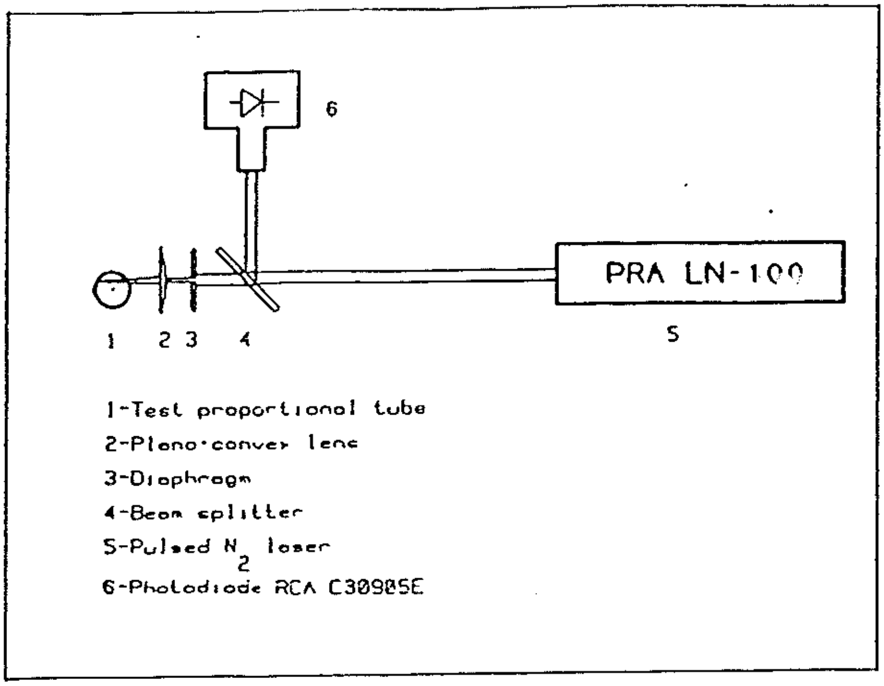
- Custom silicon-strip detectors from two 4″ wafers.

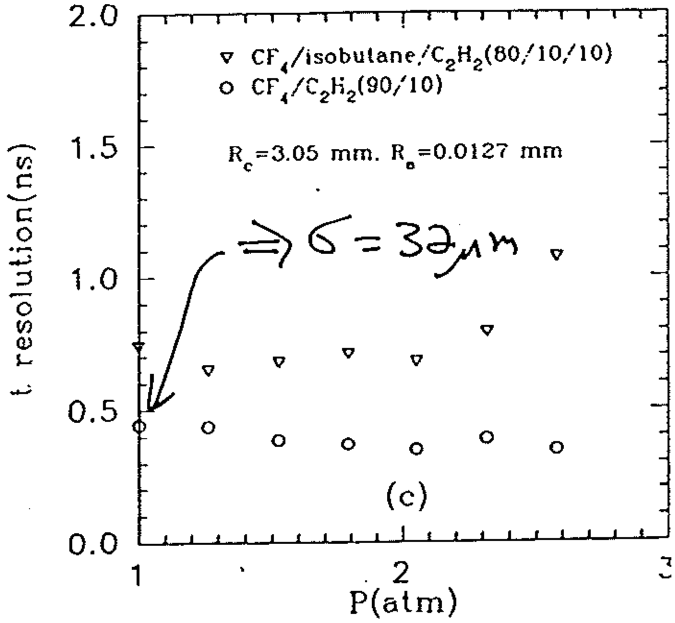


Precision Straw Tube Tracking

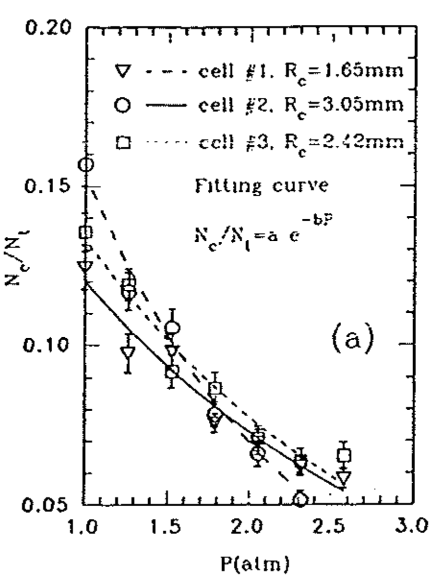
Princeton U.

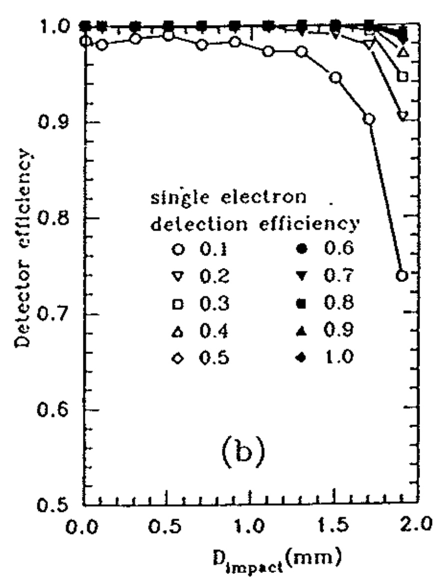
- Characterization of single-electron avalanches.

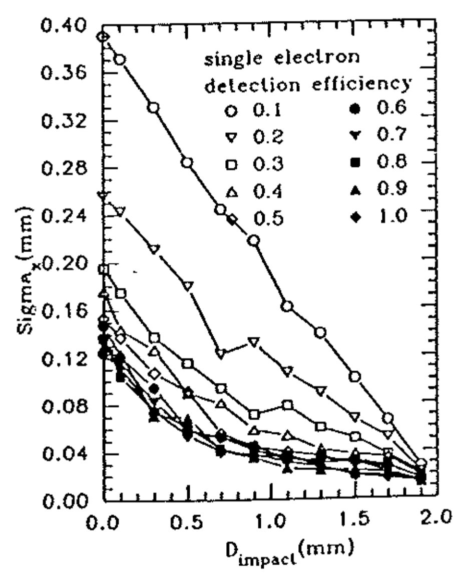




- Electron attachment in CF_4 gas mixtures.







Precision Straw Tube Tracking

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- Work in progress: gain and attachment coefficients.

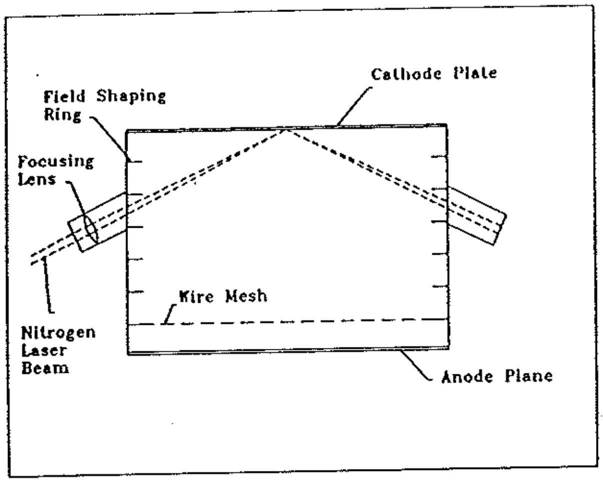

Figure 22: Set-up to measure $\alpha - \eta$.

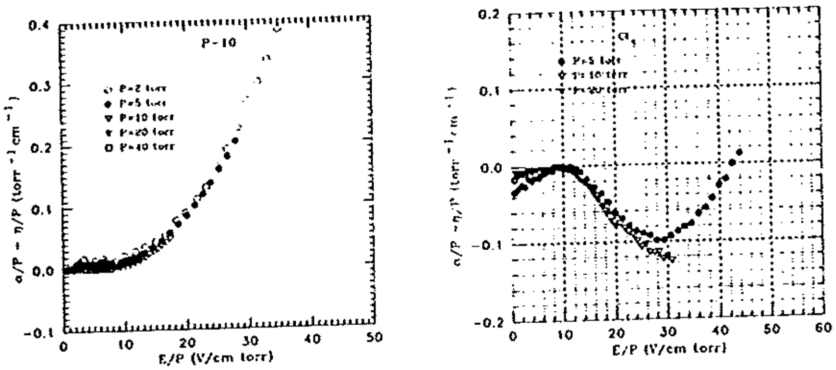

Figure 23: Preliminary measurement of the gas coefficients $(\alpha - \eta)/P$ as a function of E/P for (a) P-10, and (b) CF_4.

- New studies of attachment, and of drift velocity.

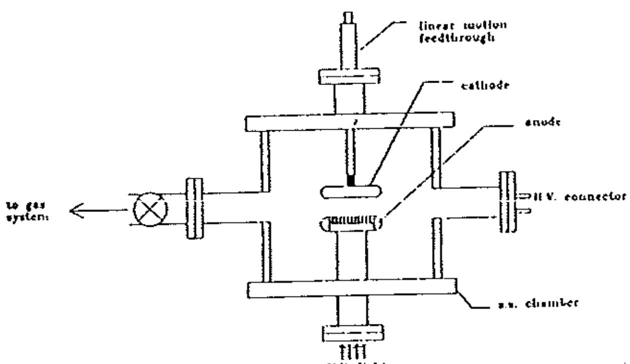

Figure 24: Set-up to measure a second function of the gas coefficients α and η.

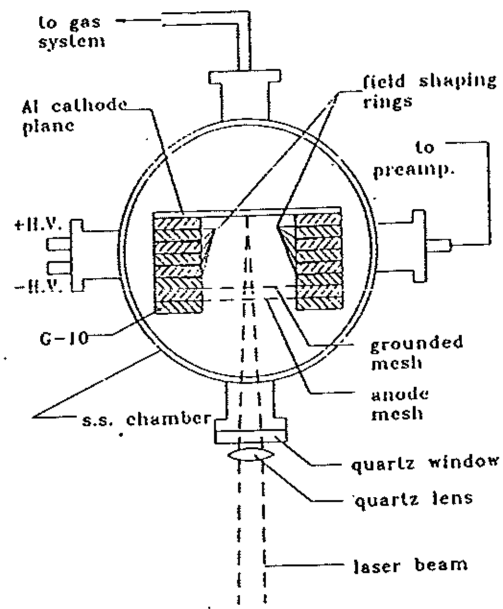

Figure 25: Set-up for measurement of drift velocity.

- $\Rightarrow$ complete characterization of drift, gain, attachment, and diffusion.

Precision Straw Tube Tracking

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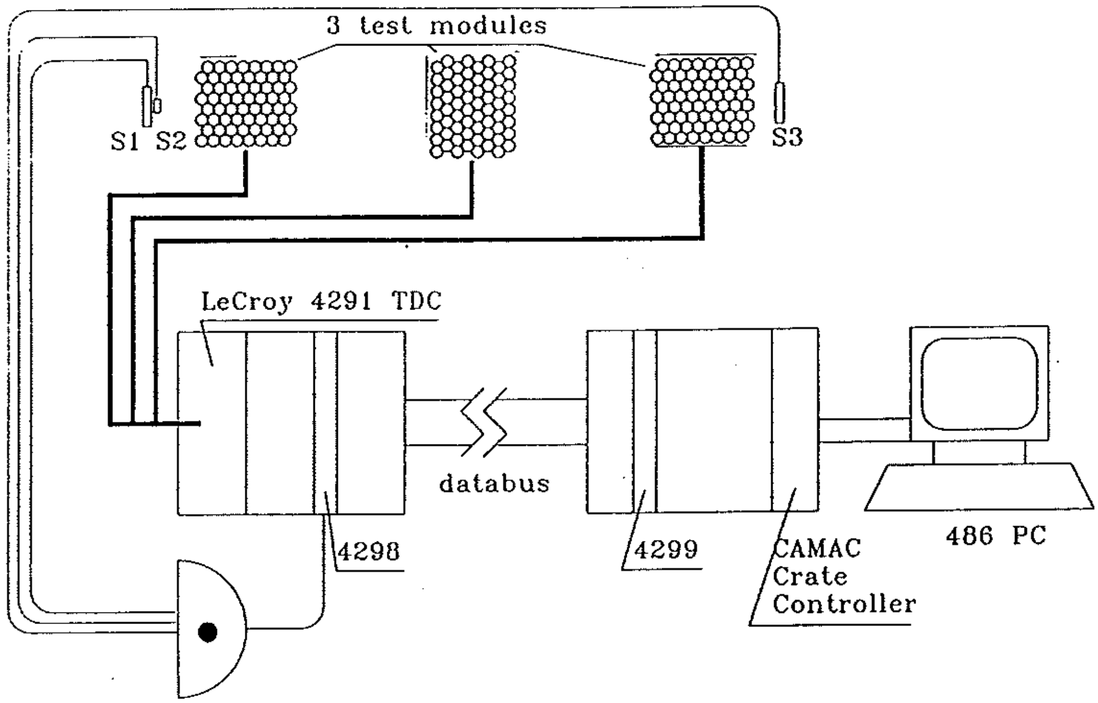
- Prototype straw-tube system test (Fall 1991, FNAL).



- U. Penn bipolar front-end preamps.

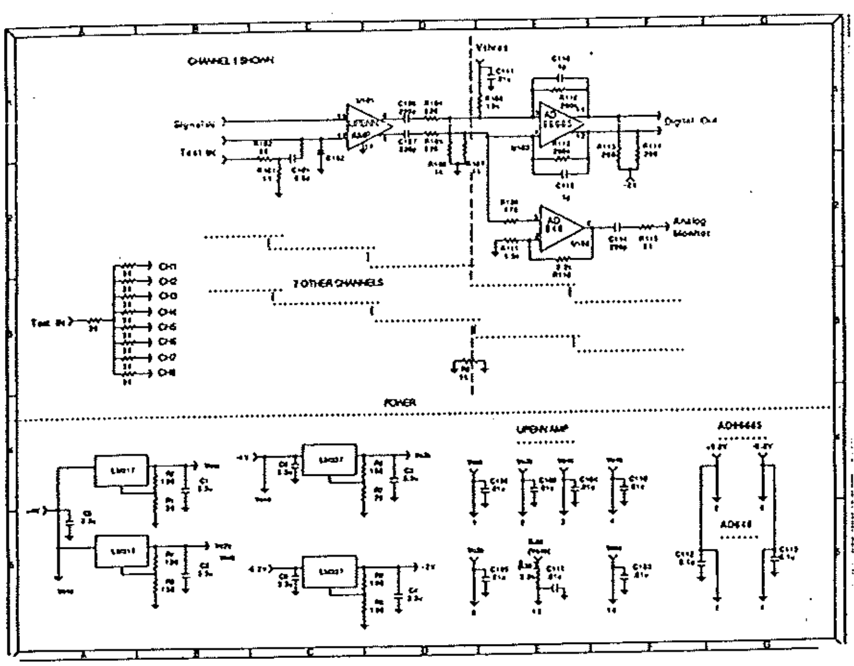


Figure 33: Circuit diagram of the preamplifier card.

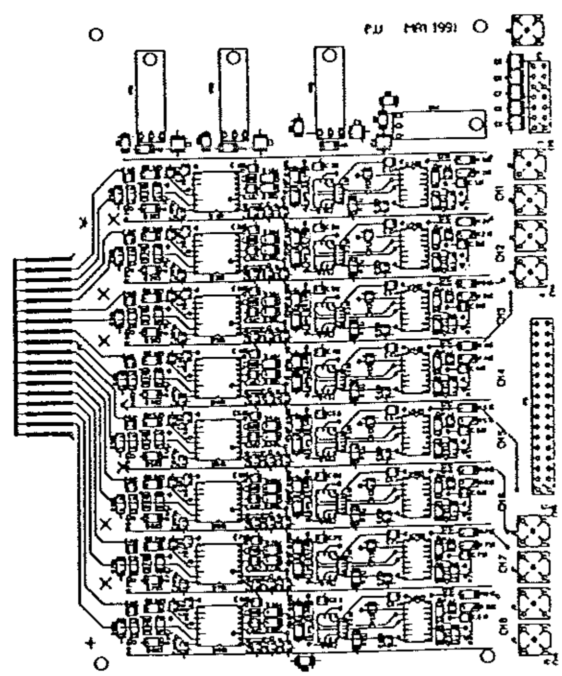


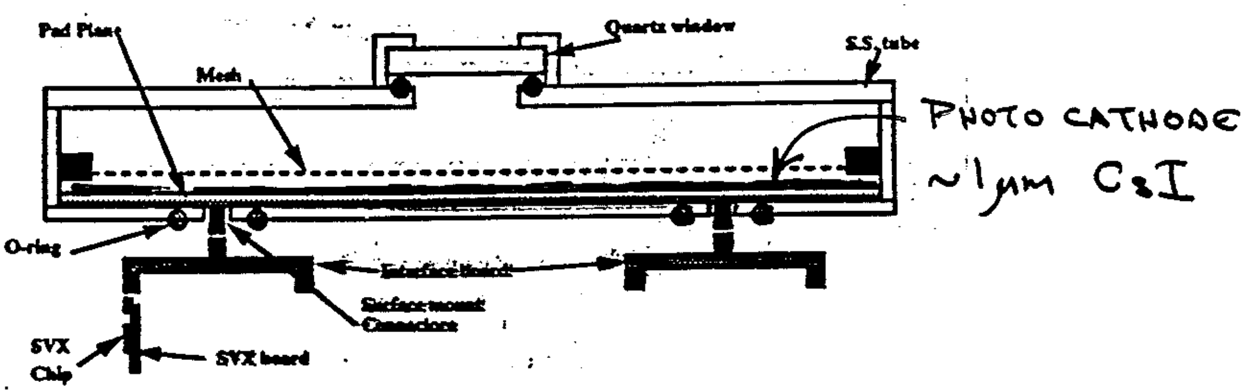
Figure 34: Component layout of the preamplifier card.

RICH Detector with Solid Photocathode

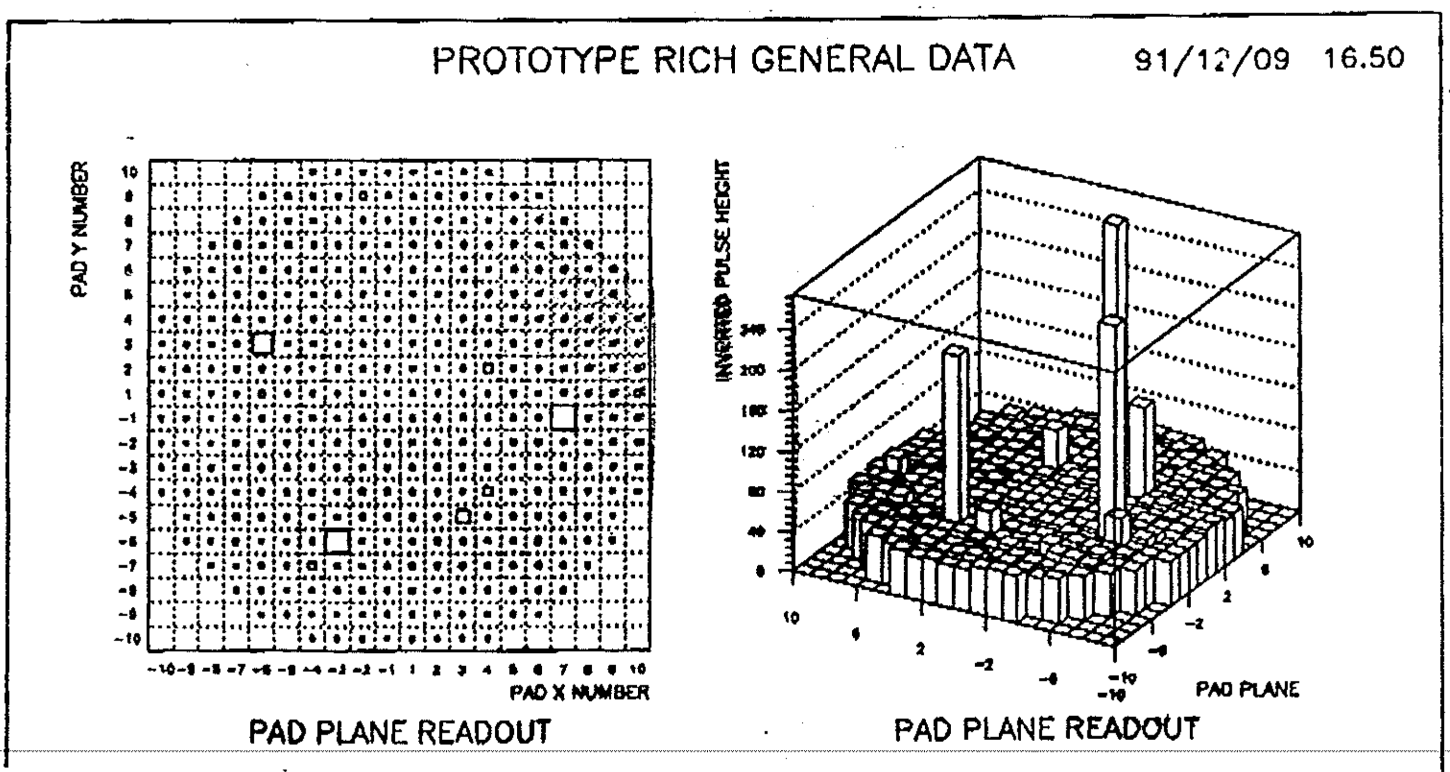
Fermilab – U. San Francisco de Quito – ORNL

U. Pennsylvania – Princeton U. – U. Puerto Rico

- **High quantum efficiency** in UV with CsI-TMAE photocathode
- Prototype RICH **detector.**



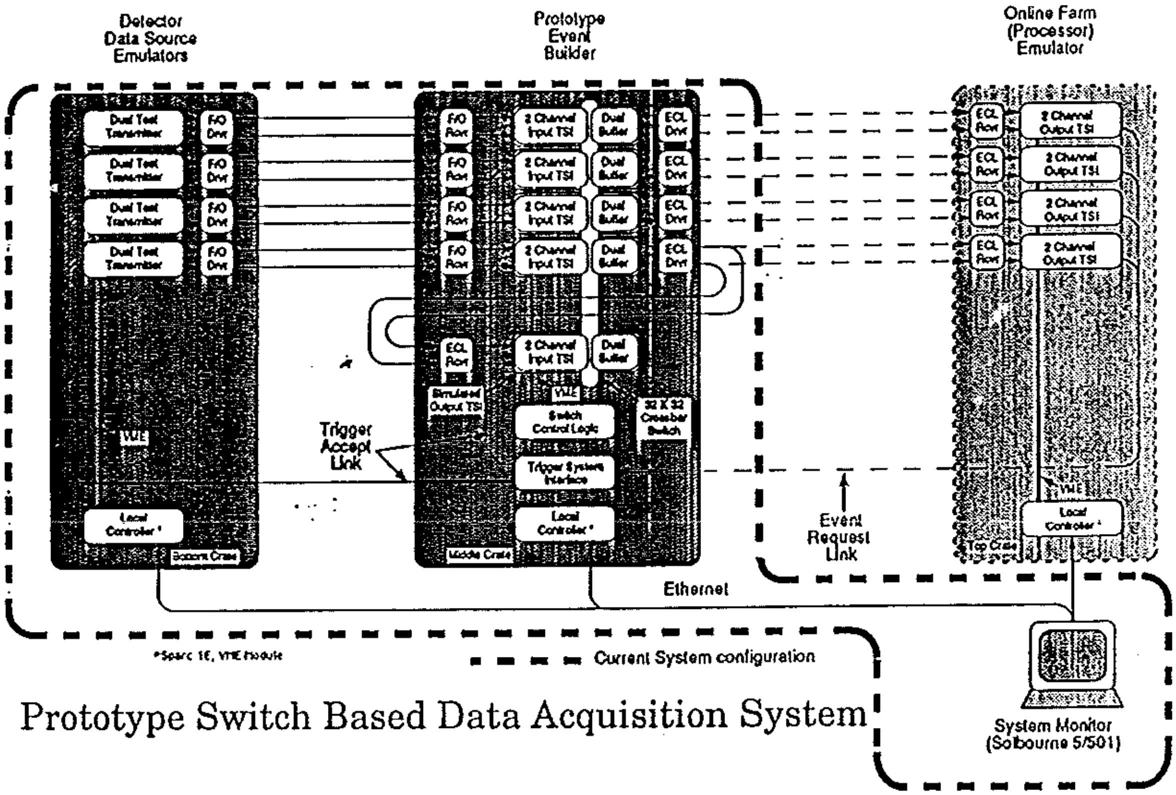
- Event display from beam test:



Barrel-Switch Event Builder

Fermilab

- Prototype demonstration (Summer 1991)
  - 8 channels = 1/4 crate.
  - 20 MByte/sec per channel.
  - Event size = 160 kByte (= present CDF size).
  - Throughput = 600 events/sec via 8 channels.



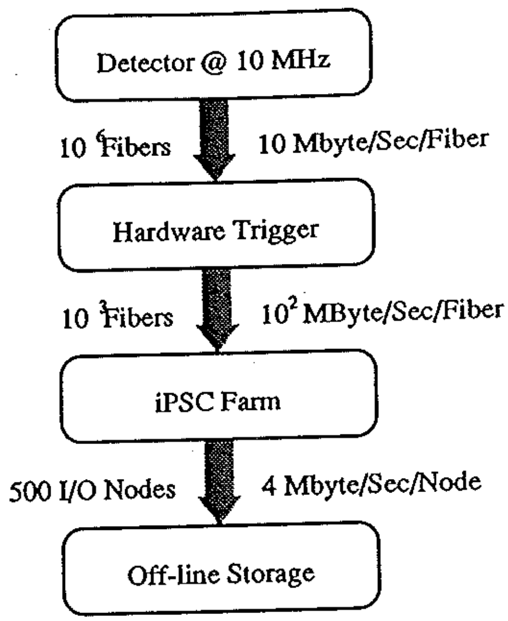
Prototype Switch Based Data Acquisition System

- Switch expandable to 10^5 events/sec in 6 racks.

Online Parallel Computing Farm

U. Pennsylvania – Princeton U. – SSCL – Intel

- Trigger/data-acquisition architecture.



- Mutliprocessor networking.

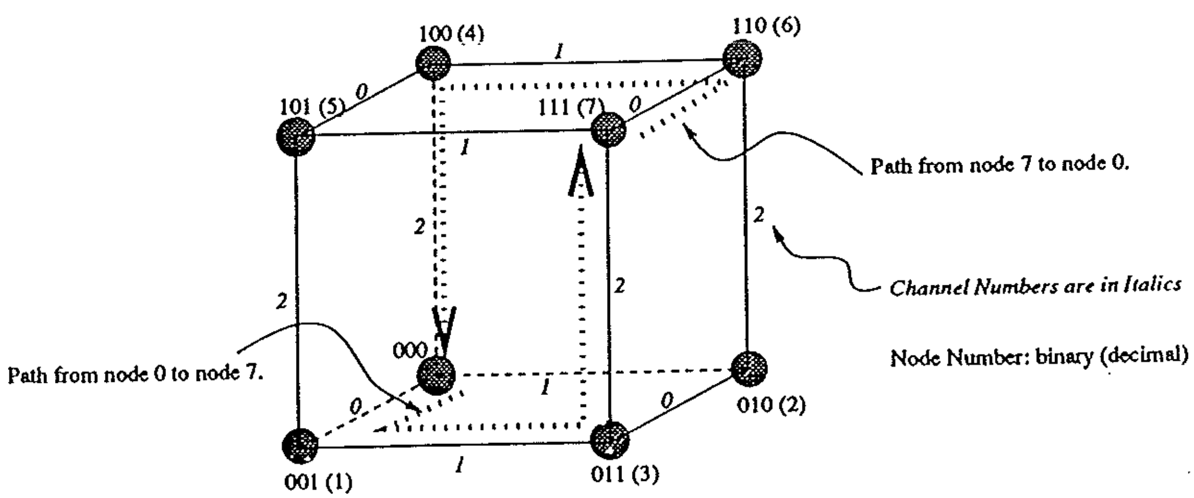


Table 5: B-$\bar{B}$ production at hadron accelerators. In this comparison we suppose that the experiments all operate at 10^7 interactions/sec, and that corresponding luminosity $\mathcal{L}$ can be achieved. We then consider $\sigma_{b\bar{b}}/\sigma_{\rm tot}$, as the figure of merit of the various accelerator options.

Accelerator	$\sqrt{s}$ (TeV)	$\sigma_{b\bar{b}}$ (μb)	$\sigma_{\rm tot}$ (mb)	$\sigma_{b\bar{b}}/\sigma_{\rm tot}$	$\mathcal{L}_{\rm ave}$ (cm^{-2}sec^{-1})	$N_{b\bar{b}}/10^7$ sec	Figure of Merit
TEV II (p-W)	0.04	0.003	6	5×10^{-5}	1.7×10^{33}	1.7×10^{7}	1/10,000
SSC (p-Si)	0.2	3	15	1/5000	6.7×10^{32}	2×10^{10}	1/100
RHIC (p-p)	0.5	10	40	1/4000	2.5×10^{32}	2.5×10^{10}	1/80
TEV I (p-$\bar{p}$)	1.8	40	40	1/1000	2.5×10^{32}	10^{11}	1/20
LHC (p-p)	16	600	75	1/125	1.3×10^{32}	7.9×10^{11}	2/5
SSC (p-p)	40	2,000	100	1/50	10^{32}	2×10^{12}	1

B-Physics Proposals to the SSC

I. EOI-14 'SFT' (B. Cox *et al.*).

- Fixed-target experiment in an extracted beam-line.
- Detector similar to the successful E-691 experiment at Fermilab.

II. EOI-13 (J. Rosen).

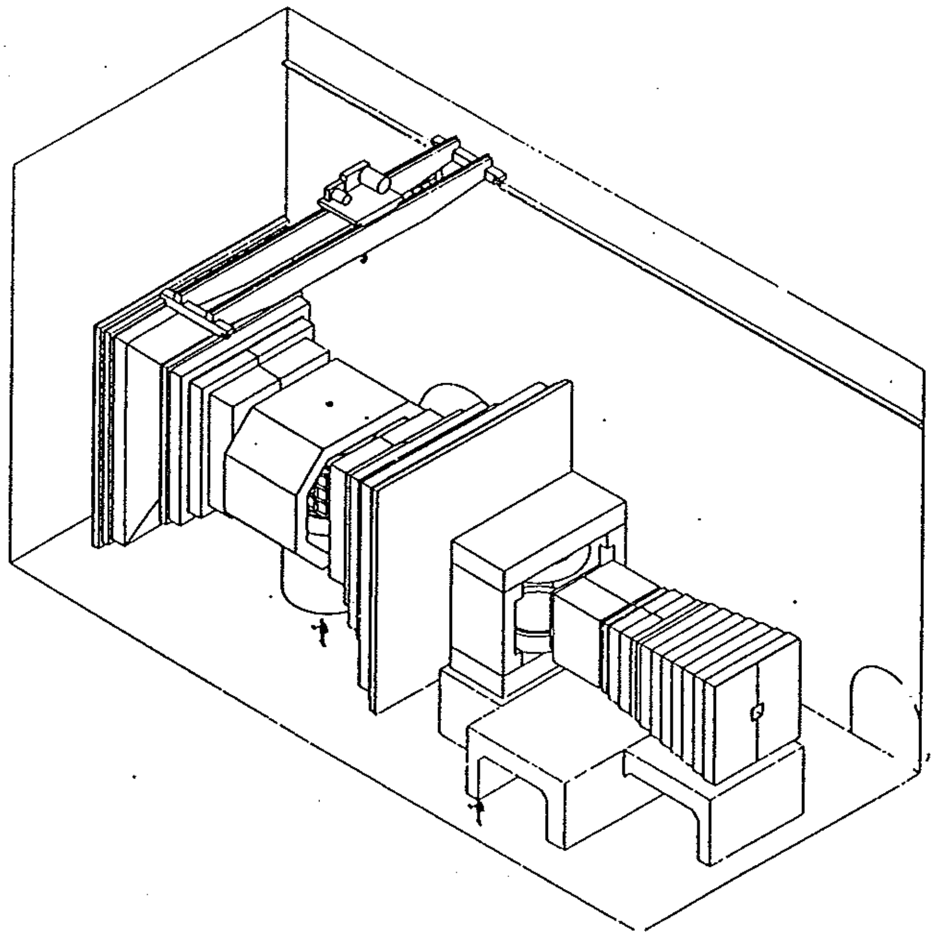
- Fixed target experiment with a gas-jet target at a collider ring.
- Detector and rates essentially the same as for EOI-14.
- Avoid the expense of an extracted beam.

B-Physics Proposals to the SSC, cont.

III. EOI-8 'BCD' (N. Lockyer *et al.*).

- Collider experiment with 4π detector based on a dipole magnet.
- $\sigma_{B\bar{B}}/\sigma_{\rm tot} \sim 100$ times that in the fixed-target experiments.
- Cost (for coverage $\Delta\eta = 11$) ~ 3 times that of the fixed-target experiments.
- $\Rightarrow$ collider experiment thirty times as cost effective as fixed target.

BCD (EOI0008)



- Designed for maximal coverage of CP-violation physics at the SSC.
- Dipole geometry with Central, Intermediate, and Forward detectors.
- $|\eta| < 5.5$, $P_t \gtrsim 0.3$ for π, K, $P_t \gtrsim 1$ for e, μ.
- Cost $\sim$ \$200M for the full detector.

Proceedings of the 1984 Summer Study on the Design and Utilization of the Superconducting Super Collider

June 23-July 13, 1984, Snowmass, Colorado

Editors
Rene Donaldson and Jorge G. Morfín

REPORT OF THE WORKING GROUP ON CP VIOLATION AND RARE DECAYS

J.W. Cronin, University of Chicago; N.G. Deshpande, University of Oregon; G.L. Kane, University of Michigan; V.C. Luth, Stanford Linear Accelerator Center; M.E. Machacek, Northeastern University; A.C. Odian, Stanford Linear Accelerator Center; F. Paige, Brookhaven National Laboratory; M.P. Schmidt, Yale University; J. Slaughter, Yale University; G.H. Trilling, Lawrence Berkeley Laboratory; M. Witherell, University of California at Santa Barbara; S.G. Wojcicki, Stanford University.

With respect to the SSC, these calculations suggest an a-priori two-order-of-magnitude advantage for operation in the collider mode as opposed to the fixed target mode. It is conceivable that the acceptance in a fixed-target experiment can be better for less cost, but it seems doubtful that the two orders of magnitude can be regained. For this reason, we have chosen to emphasize experiments in the SSC collider mode.

BCD Program in 1991-1993

- Design lower-cost collider detector ($\sim$ \$50M).

  1. Naive scaling:

     Acceptance for both B's $\sim (\Delta\eta)^2 \sim (\text{cost})^2$.

     $\Rightarrow$ learn how to do better.

  2. $\Delta\eta = 3$ at SSC $\sim \mathcal{L} = 10^{34}$ at e^+e^- collider.

  3. Initial configuration: Central, Intermediate, or Forward?

  4. Preserve option to expand after successful Phase I.

- R&D

  1. Silicon vertex detector.

  2. Straw-tube tracking.

  3. Hadron ID.

  4. Online parallel computer farm (trigger, DAQ)

A Generic Experimental Hall at IR-1

DRAFT-2

Ron Hoffmann and Ray Stefanski
Physics Research Division
Superconducting Super Collider Laboratory
2550 Becklemeade Avenue
Dallas, TX 75237

January 20, 1992

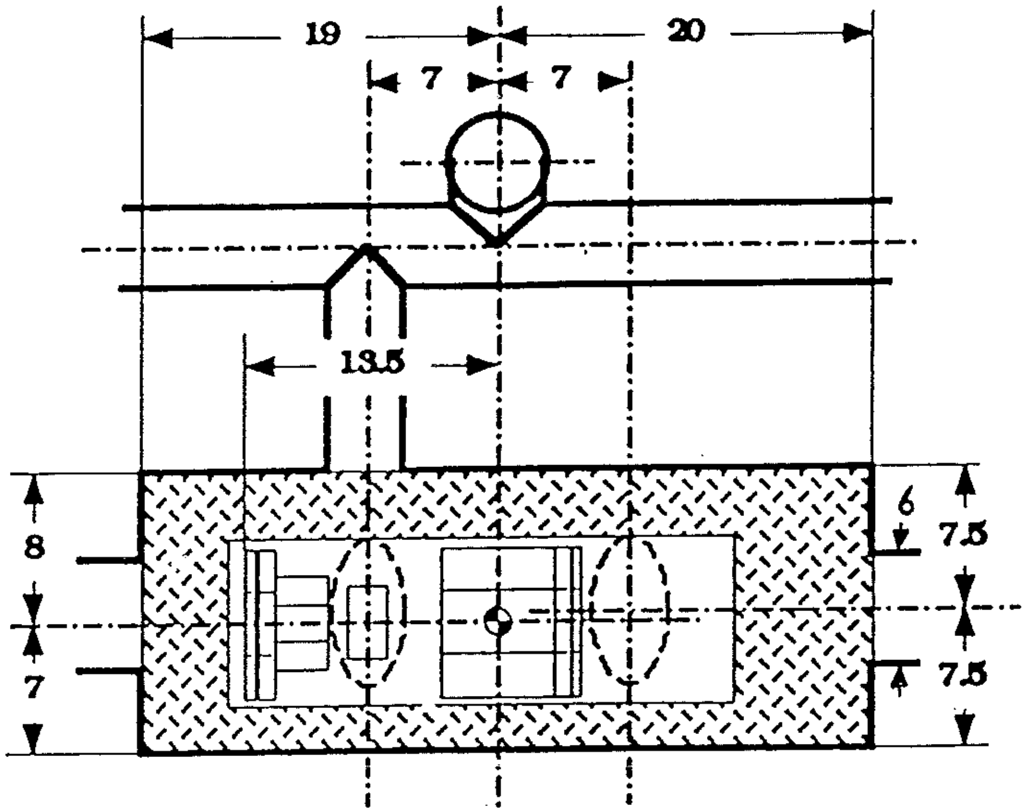


Figure 5.A.1. Interaction Hall Plan Without Assembly Hall

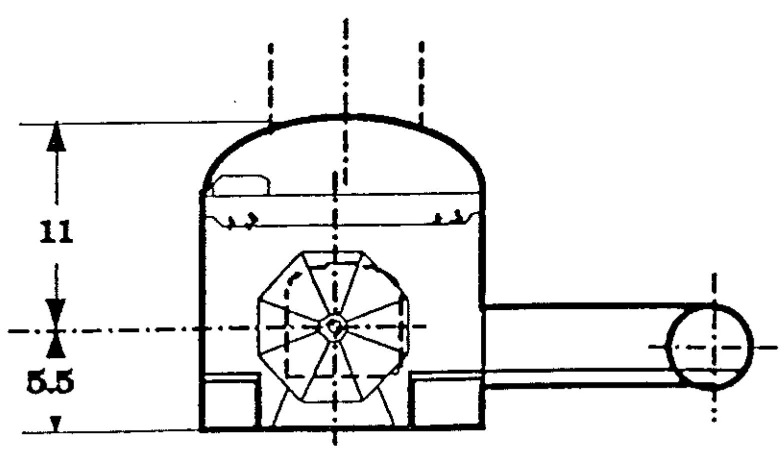


Figure 5.A.2. Interaction Hall Section Without Assembly Hall

Central or Forward?

- **Central:** $|\eta| < 1.2 - 1.5$

  Low $P \Rightarrow$ poorer secondary vertex resolution.

  Solenoid or dipole?

  Solenoid is poor match to $\eta > 1.5$.

  Tracking, P_t trigger easier in solenoid.

  20% loss of azimuth in central dipole.

- **Forward:** $1.2 < \eta < 5.5$

  Detectors more accessible, $\Rightarrow$ cheaper.

  Vertex detector can use disks only.

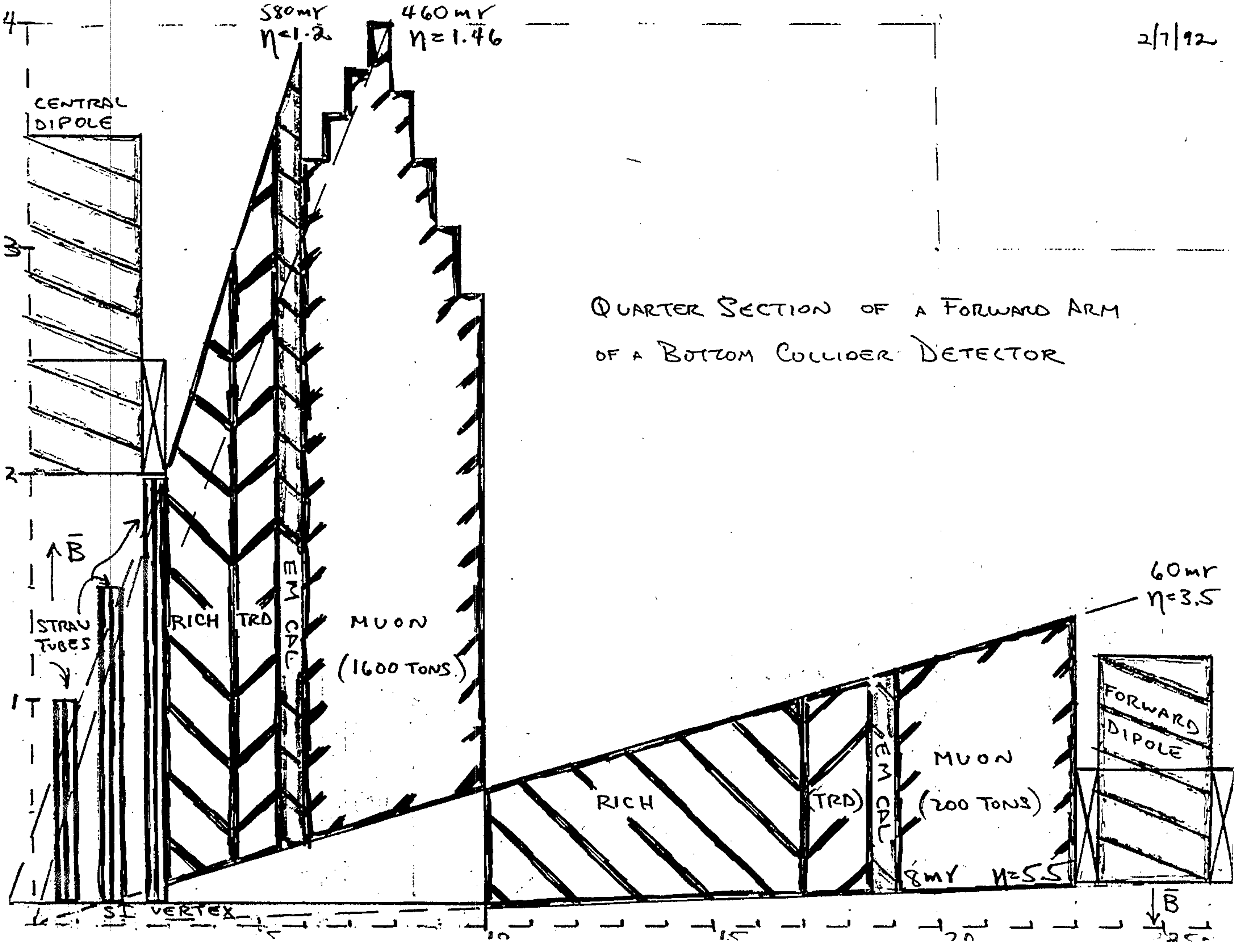
  Interactions in beam pipe are troublesome.

  Good momentum analysis via central dipole.

  Compensating dipoles $\Rightarrow$ no net kick for $|\eta| > 5.5$.

2/7/92

Quarter Section of a Forward Arm of a Bottom Collider Detector



Triggering

- Lepton-pair trigger viable for $B \to J/\psi X$ modes at luminosities $> 10^{32}$ cm^{-2}sec^{-1}.

- Triggering is difficult for non-J/ψ decay modes:

  $\mathcal{L} = 10^{32} \Rightarrow 10^7$ events/sec;

  High-rate DAQ $\Rightarrow$ can write 10^3 events/sec to tape;

  Need hardware/software trigger rejection of 10^4;

  Options:

  – Secondary-vertex trigger.

  – High-P_t trigger.

  – Reduce luminosity.

- Need running experience to optimize trigger.

BCD Phase I: Single Forward Arm

$1.2 < \eta < 5.5$

1. Central dipole magnet,

   1 T, gap height 4 m, pole tip radius 2 m,

   two small forward dipoles \$5M

2. Silicon vertex detector,

   49 disks, 550k channels, \$10/channel \$5M

3. Straw-tube tracking,

   72 planes, 75k straws, \$65/straw \$5M

4. RICH counter,

   60k channels, \$40/channel \$2.5M

5. Transition radiation detector ($\eta < 3.5$ only),

   50k channels, \$50/channel \$2.5M

6. EM calorimeter,

   4k cells, 5 samples/cell, \$250/channel \$5M

7. Muon detector ($\eta > 1.5$ only),

   1800 tons, 12k channels. $5M

8. Data-acquisition, barrel-switch event builder,

   1000-processor online computer farm. $10M

9. Contingency. $10M

10. **Total**. **$50M**

Table 2: The minimum values of $\sin 2\varphi_i$ resolvable to three standard deviations in 10^7 sec of running at luminosity of 10^{32} $\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ in an SSC experiment covering $1.2 < \eta < 5.5$.

Angle	Mode	Tag	Tagged Events	$1-2p$	b	x_q	D	$\sin 2\varphi_{\mathrm{min},3\sigma}$
φ_1	$B_d^0 \to J/\psi K_S^0$	$e^{\pm}$	9,600	0.60	0.1	0.7	0.47	0.11
φ_1	$B_d^0 \to J/\psi K_S^0$	$K^{\pm}$	73,000	0.40	0.1	0.7	0.47	0.066
φ_2	$B_d^0 \to \pi^+\pi^-$	$e^{\pm}$	40,000	0.60	1.0	0.7	0.47	0.076
φ_2	$B_d^0 \to \pi^+\pi^-$	$K^{\pm}$	307,000	0.40	1.0	0.7	0.47	0.041
φ_3	$B_s^0 \to \rho^0 K_S^0$	$e^{\pm}$	267	0.60	1.0	~ 10	0.64	0.68
φ_3	$B_s^0 \to \rho^0 K_S^0$	$K^{\pm}$	2,300	0.40	1.0	~ 10	0.64	0.34
φ_3	$B_s^0 \to K^+K^-$	$e^{\pm}$	1,000	0.60	~ 0.1	~ 10	0.64	0.27
φ_3	$B_s^0 \to K^+K^-$	$K^{\pm}$	9,200	0.40	~ 0.1	~ 10	0.64	0.12
φ_4	$B_s^0 \to J/\psi\phi$	$K^{\pm}$	107,000	0.40	~ 0.1	~ 10	0.64	0.039

Table 1: Update of Table 11 of the BCD EOI to include a Kaon tag. The minimum values of $\sin 2\varphi_i$ resolvable to three standard deviations in 10^7 sec of running at luminosity of 10^{32} $cm^{-2}sec^{-1}$. The factor $1-2p$ is the analyzing power of the tag which has a probability p for a wrong tag. b is the background to signal for the final-state reconstruction. The dilution factor D due to mixing is given by $x_q \coth(\pi/2x_q)/(1+x_q^2)$.

Angle	Mode	Tag	Tagged Events	$1-2p$	b	x_q	D	$\sin 2\varphi_{\min,3\sigma}$
φ_1	$B_d^0 \to J/\psi K_S^0$	$e^\pm$	57,600	0.60	0.1	0.7	0.47	0.047
φ_1	$B_d^0 \to J/\psi K_S^0$	$K^\pm$	440,000	0.40	0.1	0.7	0.47	0.027
φ_2	$B_d^0 \to \pi^+\pi^-$	$e^\pm$	240,000	0.60	1.0	0.7	0.47	0.031
φ_2	$B_d^0 \to \pi^+\pi^-$	$K^\pm$	1,840,000	0.40	1.0	0.7	0.47	0.017
φ_3	$B_s^0 \to \rho^0 K_S^0$	$e^\pm$	1,600	0.60	1.0	~ 10	0.64	0.28
φ_3	$B_s^0 \to \rho^0 K_S^0$	$K^\pm$	14,000	0.40	1.0	~ 10	0.64	0.14
φ_3	$B_s^0 \to K^+K^-$	$e^\pm$	6,240	0.60	~ 0.1	~ 10	0.64	0.11
φ_3	$B_s^0 \to K^+K^-$	$K^\pm$	55,200	0.40	~ 0.1	~ 10	0.64	0.05
φ_4	$B_s^0 \to J/\psi\phi$	$K^\pm$	640,000	0.40	~ 0.1	~ 10	0.64	0.016

Table 3: The sensitivity of an asymmetric e^+e^- collider to $\sin 2\varphi_1$ at 3-σ statistical significance via the decay $B_d^0 \to J/\psi K_S^0$. A 'year' consists of 10^7 sec. The BCD sensitivity is 0.03 (0.07 for Phase I) in one year of running.

$\mathcal{L}$	Running Time (Years)		
$cm^{-2}sec^{-1}$	1	3	10
10^{33}	0.48	0.28	0.15
3×10^{33}	0.28	0.16	0.09
10^{34}	0.15	0.09	0.05

Table 4: The sensitivity of an asymmetric e^+e^- collider to $\sin 2\varphi_2$ at 3-σ statistical significance via the decay $B_d^0 \to \pi^+\pi^-$. The BCD sensitivity is 0.02 (0.04 for Phase I) in one year of running.

$\mathcal{L}$	Running Time (Years)		
$cm^{-2}sec^{-1}$	1	3	10
10^{33}	0.61	0.35	0.19
3×10^{33}	0.35	0.20	0.11
10^{34}	0.19	0.11	0.06

Summary

- Hadron colliders are the best B-factory investment in terms of ultimate potential.
- A dedicated B-physics experiment at FNAL could be comparable to one at an e^+e^- collider.
- The SSC promises statistical power $\gtrsim$ 10 times that of FNAL or e^+e^- .
- A Phase I, $50M-experiment at the SSC still has a factor of 3 statistical advantage over FNAL or e^+e^- .