Expression of Interest

An LHC collider Beauty experiment for CP-violation measurements

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An LHC Collider Beauty Experiment for CP-Violation Measurements

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CP- VIOLATION HAS ONLY BEEN OBSERVED IN K-DECAY. IF IT IS DUE TO THE FAMILIAR WEAK INTERACTION, A PATTERN OF LARGE CP-VIOLATING EFFECTS IS EXPECTED IN B-DECAY

HOWEVER, IF CP-VIOLATION HAS ITS ORIGIN IN SOME NON-STANDARD MODEL PHYSICS AT A HIGH MASS SCALE, CP-VIOLATING EFFECTS IN B-DECAY COULD BE AS SMALL AS THEY ARE IN K-DECAY (10^{-3})

TO DISTINGUISH THESE TWO POSSIBILITIES, IT IS CRUCIAL TO STUDY CP-VIOLATION EFFECTS IN B-DECAY IN ALL POSSIBLE WAYS AND TO TEST ALL EXPECTED REDUNDANCIES

MEASURE:
Non-exponential decay time distributions FOR CP-EIGENSTATES and associated rate asymmetries

WE NEED: LARGE EVENT SAMPLES
CLEAN RECONSTRUCTED MASS PEAKS
Separate: B_d, B_s, B_c, etc
GOOD PROPER TIME RESOLUTION
INITIAL FLAVOR TAGGING

CP-VIOLATION

$N(B \to J/\psi K) = A(t)\, e^{-t}\, [1 - \sin(2\beta)\sin(x't)]$

$\overline{N}(\overline{B} \to J/\psi K) = A(t)\, e^{-t}\, [1 + \sin(2\beta)\sin(x't)]$

↑ ACCEPTANCE, TRIGGER, RECONSTRUCTION

Ideally → 2 Distinct Data Samples

In practice → Incorrectly flavor tagged events appear in wrong sample

→ ALL DATA SAMPLES ARE LINEAR SUPERPOSITIONS OF 2 EQUATIONS

2 sources of mistagging:

- Flavor oscillation of tag-providing B

  Probability (non-oscillation) $= \frac{1}{2}(2+x^2)/(1+x^2)$

  Probability (oscillation) $= \frac{1}{2}x^2/(1+x^2)$

→ $N(B) = A(t)\, e^{-t}\, [1 \pm \frac{1}{1+x^2} \sin(2\beta)\sin(x't)]$

- Bad tag from extraneous source

  g = good tag, b = bad tag

$$D = \left\langle \left(\frac{g-b}{g+b}\right) \cdot \left(\frac{1}{1+x^2}\right) \right\rangle$$

$$N(B) = A(t)\, e^{-t} [1 \pm \underbrace{D \sin(2\beta)}_{\text{MEASURE}} \sin(x't)]$$

Error in sin(2β)

$$\delta[\, D \sin(2\beta)\,]^2 = 1/(I_0\, N)$$

MC: $I_0 = 0.56$ is a statistical factor from fitting time dependence with our acceptance function

$N = N(B) + \overline{N}(\overline{B})$

MC: $D = 0.37$ (averaged over B_u, B_d, B_s etc.)

$$\boxed{\delta[\, \sin(2\beta)\,]^2 = 1/(I_0 \underbrace{D^2}_{D'^2} N)}$$

VALUES GIVEN LATER IN TALK

IT IS ESSENTIAL TO INCLUDE ALL DILUTION + STATISTICAL EFFECTS IN ANY ESTIMATES OF "CP-REACH" OF AN EXPERIMENT

COMPARE LHC COLLIDER B-FACTORY WITH e^+e^- B-FACTORY

e^+e^-: Small $\sigma_{b\bar{b}}$ (Larger Efficiences)

Need expensive new type facility; untested

Can't do B_s, B_c or B-baryons physics

Most likely a luminosity dead end at 10^{34}

LHC: Large $\sigma_{b\bar{b}}$ (Smaller Efficiences)

B_s, B_c, B-baryons are accessible

There is considerable experience at the ISR with the type of spectrometer we propose (see below). In addition, the associated silicon micro vertex detector configuration has recently been tested successfully at the SPS -Collider (P238 - see below).

WHY LHC-COLLIDER MODE?

COMPARE $\sigma_{b\bar{b}}$ TO σ_{TOTAL} (Approx.)

	$\sqrt{s}$	$\sigma_{b\bar{b}}$	$\sigma_{b\bar{b}}/\sigma_{tot}$
LHC F.T.	.12	1	1/50,000
SPS-Collider	.63	15	1/ 4000
Tevatron	1.8	50	1/ 1400
LHC-Collider	16	300	1/ 300

The $\sigma_{b\bar{b}}/\sigma_{tot}$ ratio is clearly much more favorable in the collider mode than in Fixed Target (even with the use of a nuclear target).

Larger $\sigma_{b\bar{b}}$ is in itself a considerable advantage and avoids having to run F.T. at high interaction rate.

NEED OPTIMIZED DEDICATED COLLIDER B- DETECTOR

ISSUES RELEVANT TO ITS DESIGN:

- ACCEPTANCE
- TRIGGERING   R+D: P238, RD21
- RECONSTRUCTION

  particle id - RICH   R+D { YPSILANTIS, SEGUINOT
  mass resolution($\sigma \approx$ 10 MeV)
  $\delta t / t$ resolution ($\leq$ 6 %)

- FLAVOR TAGGING

Extensive MC simulation has been done to reliably estimate the detector performance on each issue

Acceptance

Far above threshold, B production is forward-backward peaked due to interaction of unequal energy partons.

→ Instrument 2 forward arms
600 mrad aperture open geometry

EXAMPLE: $B^0 \rightarrow J/\psi K^0_s \rightarrow l^+ l^- \pi^+ \pi^-$

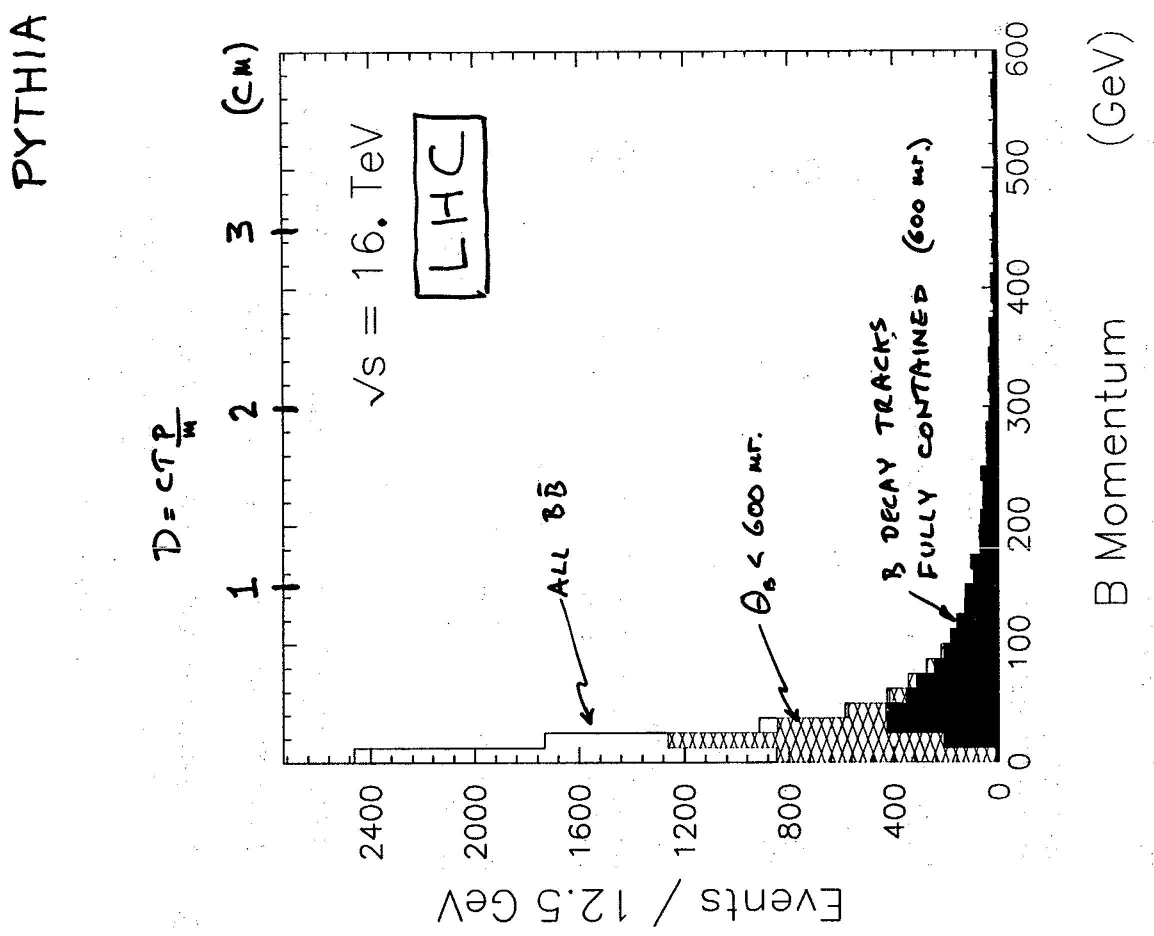
LHC: 55% fully contained (Same for $\bar{B}^0$)
SPS: 23% " "

Observation:

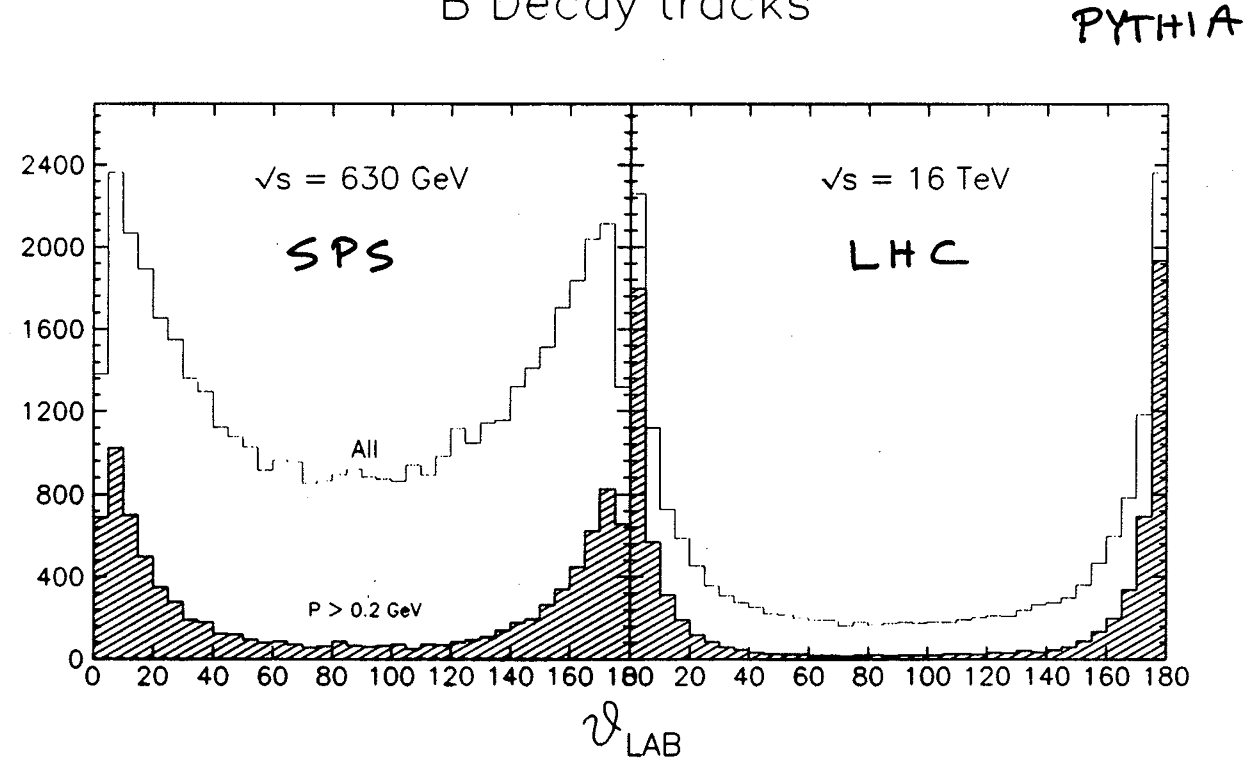
$P_B \geq 20$ GeV ⇒ B decay tracks contained

→ $<P_B>$ ~ 45 GeV SPS
~100 GeV LHC (BECAUSE OF TAIL !)
D ~ 1 mm / 15 GeV

20 GeV corresponds to smaller X_F at larger $\sqrt{s}$.
∴ Larger fraction of σ is accepted.

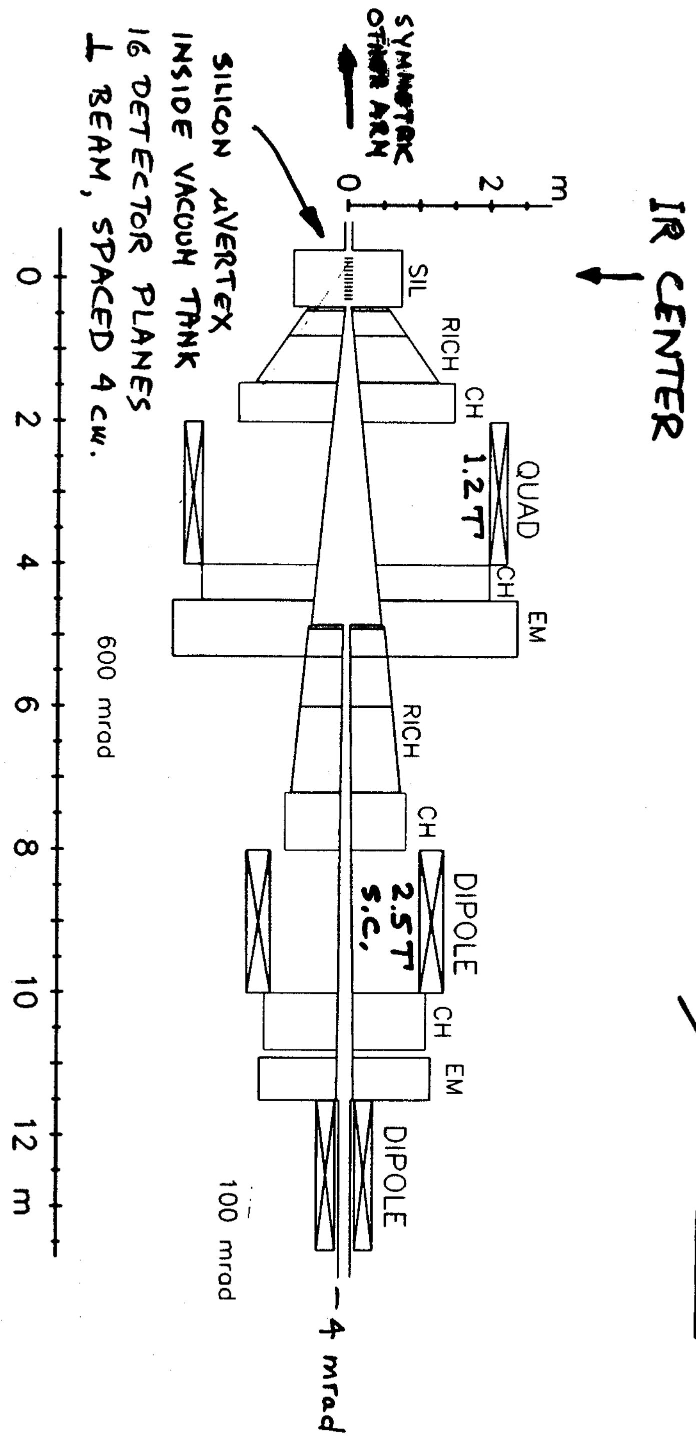


B Decay tracks



FORWARD SPECTROMETER SYSTEM

~~P238~~ LHC



Spectrometers

	No. 1	No. 2
Maximum aperture (mrad)	600	100
Minimum aperture (mrad)	100	4
Magnet type	quad.	dipole (s.c.)
Integrated field (Tm)	2.4(max)	5.0
RICH momentum for 3σ π/K separation:		
C_5F_{12} liquid (GeV)	7	7
C_5F_{12} gas "	46	72
CF_4 gas "	–	90
3×3 mm PADS (YPSILANTIS)		
Chambers		
spatial resolution / plane (µm)	100	100
time resolution (nsec)	≈50	≈50
Electromagnetic calorimetry required energy resolution	< 4%/√E	

Installation of 2nd arm is optional (doubles statistics)

Muon filter may be useful (under study)

⊛ Cost/arm ≈ 15 MSF + e.m. calorimetry
COST IS LOW BECAUSE DEVICE IS ESSENTIALLY A LOW-ENERGY FIXED-~~TARGET~~ SPECTROMETER.

SPS-COLLIDER
1990

TOPOLOGY TRIGGER

Real-time calculations on silicon-strip detector planes perpendicular to beams

⇒Fixed target geometry

Planes distributed throughout source region with only a few cm longitudinal spacing:

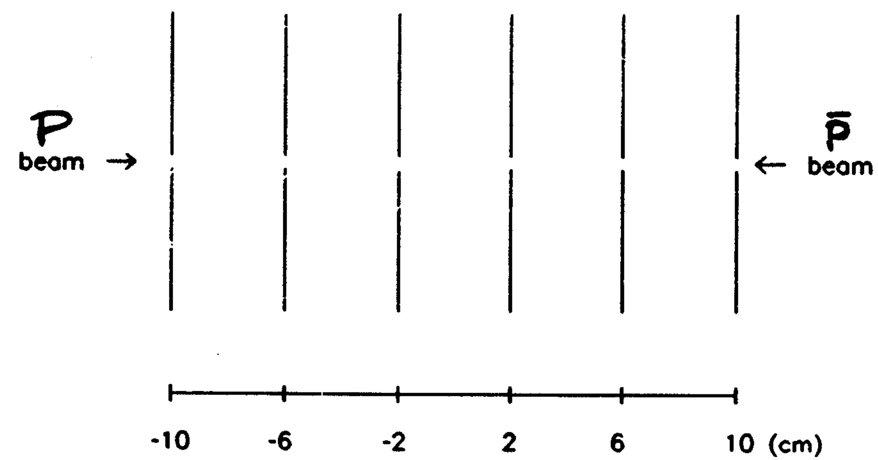
Minimize extrapolation distance

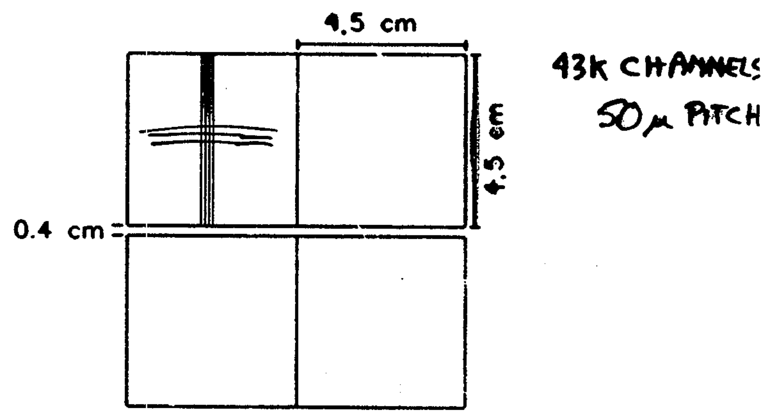
→ **STRATEGY:** Veto events which are consistent with a single vertex

R+D: P238 Si RUN, SPS-COLLIDER (1990)
RD21 INTERFACE Si TO DATA-DRIVEN PROCESSOR (1992)

P238 SILICON DETECTOR

✱ CENTERED ON INTERACTION REGION LSS5



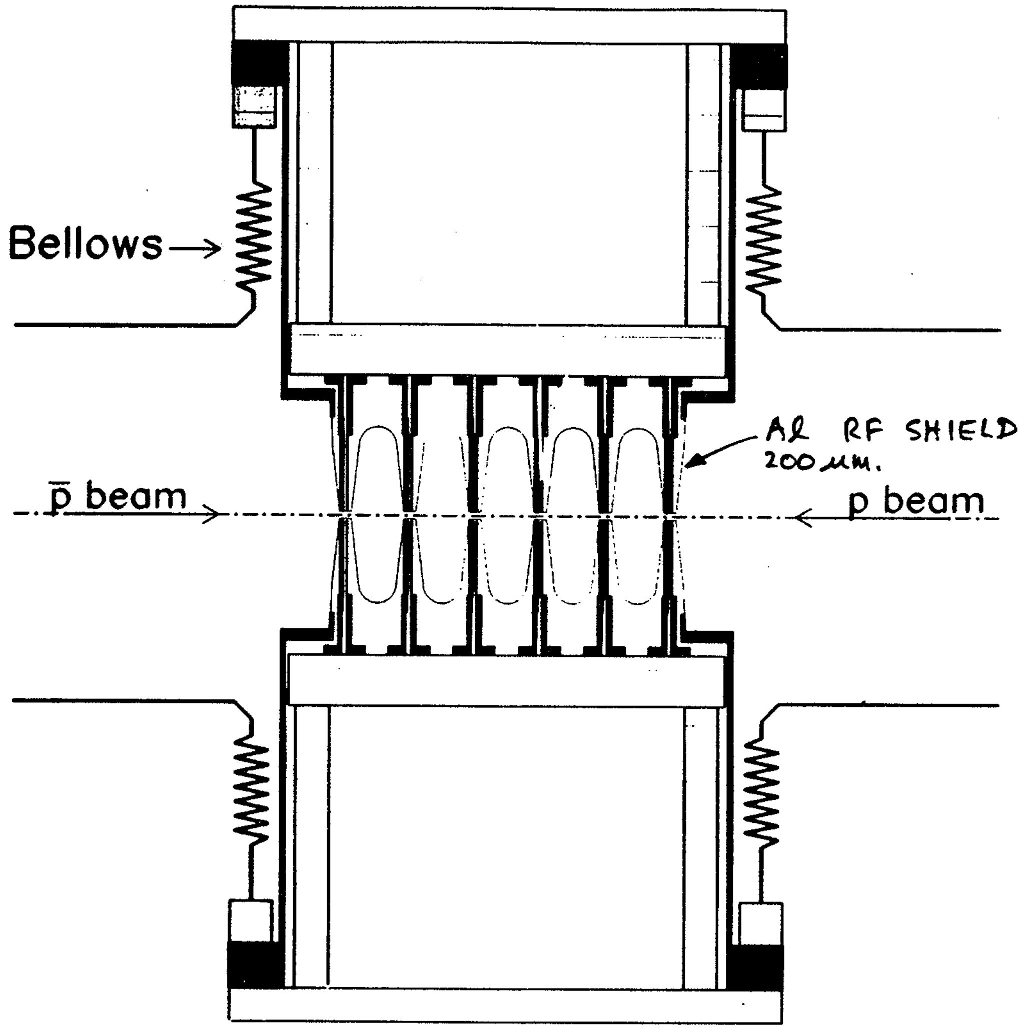


LHC EXPERIMENT REQUIRES 16 PLANES

P238

POSITIONED AT CENTER 400 OF LSS5 (SEPT-DEC 1990)

SEPT-DEC 1990
LSS5



P238 Silicon Micro-vertex Detector

Operational Summary

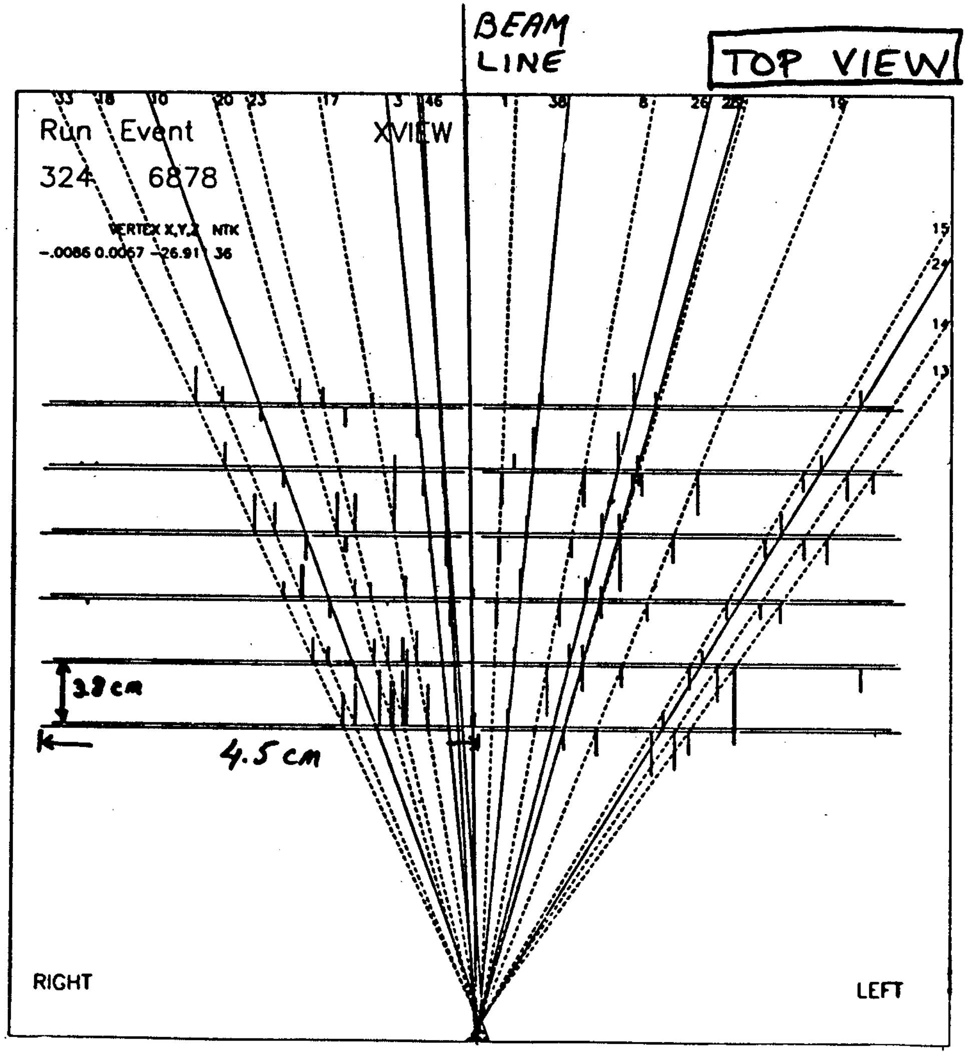
- **The detector was routinely run at a distance of ± 1.5 mm from the collider beam**
  - RF pick-up from passing beams was not a problem
  - no increase in interaction rates was observed as detectors were brought into position
  - beam positions were stable
- **Detectors worked well in vacuum**
  - signal/noise ~ 25
  - point resolution 4-8 microns
- **Events were clean:**
  - few halo tracks
  - hit and track distribution as expected from the Monte Carlo (VALIDATES OUR SIMULATION WORK)

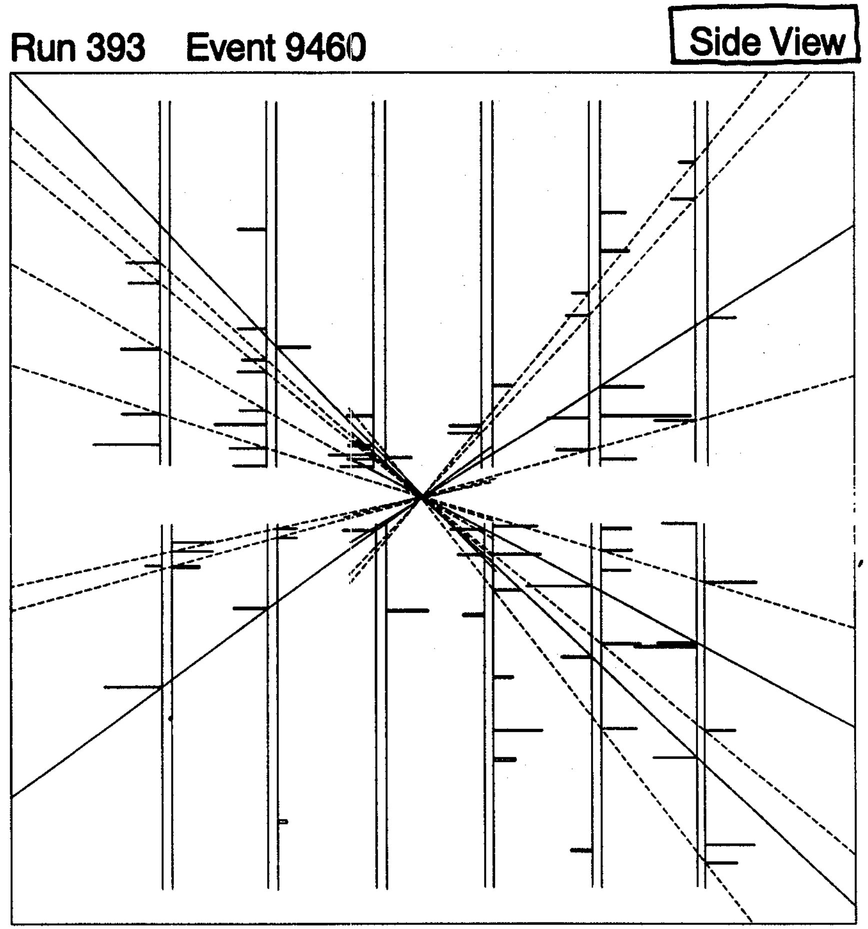
IN PRESS - NIM

P238
1990

REAL DATA

P238 TYPICAL EVENT





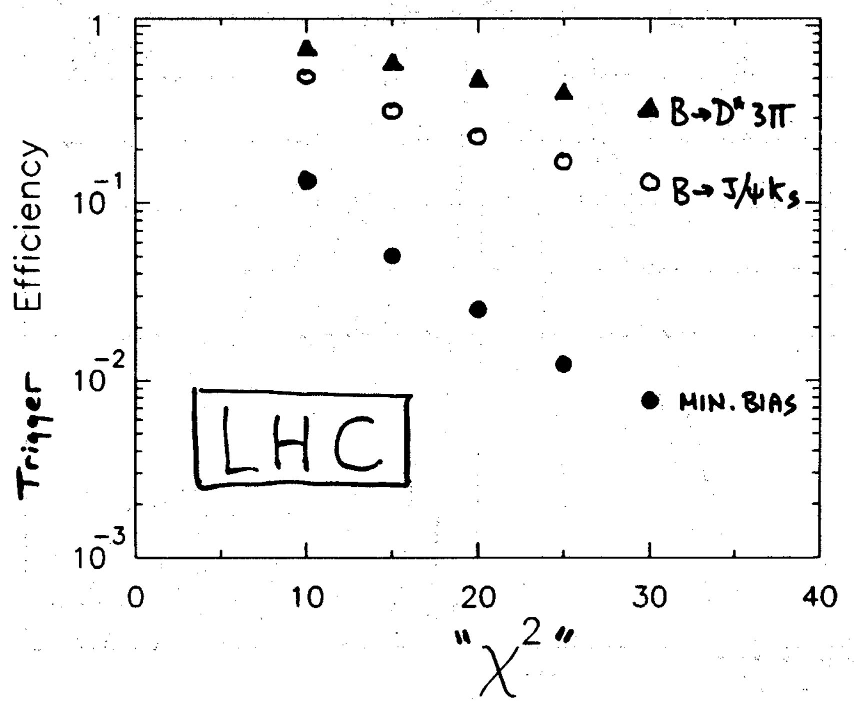
BOTH HEMISPHERES CONTRIBUTE PRIMARY VERTEX INFORMATION

P238 { σ_z = 350 μm, $\sigma_{x,y}$ = 38 μm } → FULL Si DETECTOR MATCHED TRACKS MOMENTUM MEASUREMENT YIELD $\sigma(\Delta z_B) \sim 180$ μm.

$\sigma(T)/T \sim 6\%$

TRIGGER EFFICIENCY

PYTHIA- GEANT SIMULATION



SUPPRESS MIN BIAS $\frac{1}{100}$

" $B\bar{B}$ $\sim\frac{1}{7}-\frac{1}{2}$ MULTIPLICITY DEPENDENT

RELATIVE SUPPRESSION
(ENHANCEMENT FACTOR) 15-50

Machine Interface

- Maximum luminosity ≈ 4 x 10^{31}
  - pileup
  - radiation damage
  - data rate (particularly front end)

⇒ (Keith Potter) β^* ≈ 200 m

σ_{beam} ≈ 300 μm

closest distance of approach of vertex detector to beam ≈ <u>3 mm</u>

→ ALL OUR LHC M.C. ASSUME THIS VALUE

from study by F. Ruggiero:

- Power loss of beam due to RF shield is negligible (≈ 1 watt), but requires a smooth transition from shield to beam pipe

- Under study:
  - coherent tune shifts
  - (possible) multi-bunch instabilities
  - transverse impedence

RD-21:

SILICON + DATA-DRIVEN PROCESSOR

GOAL: Develop and verify the techniques necessary for a topology-triggered B experiment at the LHC.

Builds on P238 run which demonstrated that a planar geometry silicon strip detector runs background-free in the SPS collider environment.

NEXT STEP: interface silicon system to data-driven trigger processor for real-time calculations.

Processor and high-speed silicon readout system interface is under construction.

Fixed-target test run anticipated: Dec. 1992

EVENT RECONSTRUCTION SIMULATION

Full Multi-Vertex Reconstruction requires:

$z_B - z_{primary} > 0.5$ mm

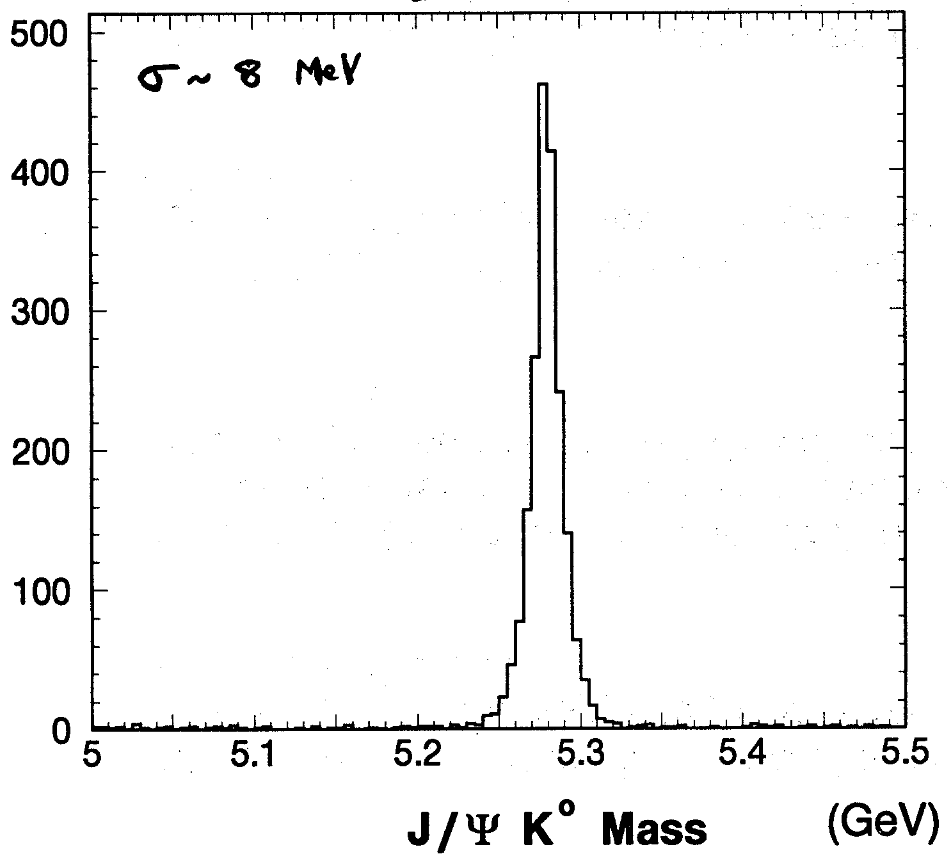
Transverse momentum balance at B, and sometimes D, vertices

Reconstruction software written for many different final states and run on Monte-Carlo data samples to find efficiency

Same software packages also run on MIN. BIAS AND inclusive $b\bar{b}$ Monte-Carlo sample to determine the combinatoric background

LHC

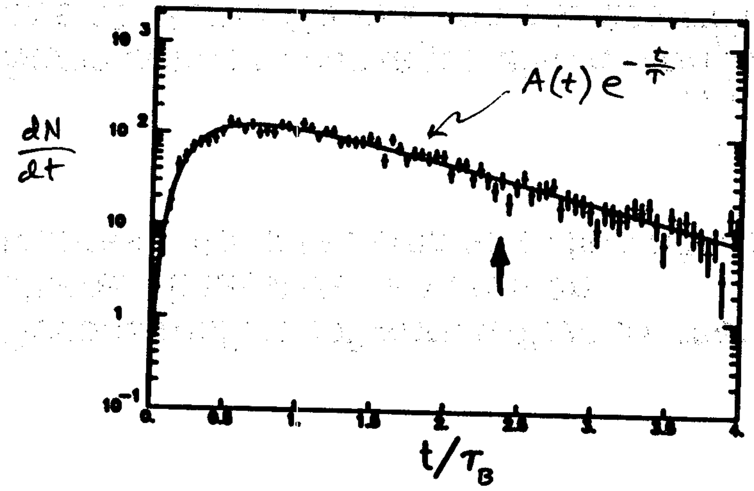
$B_d \rightarrow J/\psi \; K_s \rightarrow \ell^+\ell^-\pi^+\pi^-$



NO EVIDENCE FOR SIGNIFICANT BACKGROUND IN THIS CHANNEL.

$B \rightarrow \pi^+\pi^-$ UNDER STUDY ($\sigma \sim 20$ MeV WITHOUT SUPERCONDUCTING QUAD)

PROPER TIME DISTRIBUTION ACCEPTED, TRIGGERED, RECONSTRUCTED B-MESONS — SIMULATION



→ DISTORTION OCCURS FOR $t < 1$ MEAN LIFE.

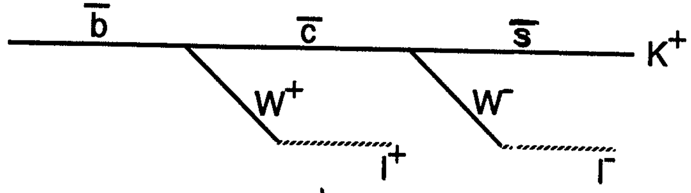
MAXIMUM CP-VIOLATION DIFFERENCES IN $B_d, \bar{B}_d$ DECAYS OCCURS WHEN $\sin(xt) = \sin\left(\frac{\Delta M}{\Gamma}\frac{t}{\tau}\right) = 1$

$\frac{\Delta M}{\Gamma}\frac{t}{\tau} = \frac{\pi}{2} \quad \rightarrow \quad \frac{t}{\tau} = 2.4$

($\frac{\Delta M}{\Gamma} \approx 0.7$)

21a

FLAVOR TAGGING



Use PYTHIA (depend on its hadronization scheme) to study effectiveness. Oscillation included in generation.

Consider as tags, all reconstructed spectrometer tracks :

High transverse momentum leptons (> 1.2 GeV) - no vertex requirement

$K^{\pm}$ not coming from primary vertex (> 3σ) - using SVX information (~2/3 OF TAGS)

Form event tag as "majority vote" of all tagging particles (usually only 1 voter)

⇒ tagging efficiency = 35.5%
D = 0.37

COMPARATIVE CP - REACH FOR $B^0_d \rightarrow J/\psi\, K^0_s$

	LHC Collider	e^+e^- (e.g. SLAC)
Peak Luminosity	$4 \cdot 10^{31}$	$3 \cdot 10^{33}$
$\sigma_{b\bar{b}}$	$3 \cdot 10^{-28}$	$1.2 \cdot 10^{-33}$
2-Arm Geom. Accept.	.55	1.0
Trigger Efficiency	.20	1.0
Reconstruction Eff.	.20	.58
Tagging Efficiency	.36	.45
$D'^2 = I_0 D^2$	.077	.25
Rate = $D'^2 N$ (Hz)	$35 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$
δ[sin(2β)], $t = 2 \cdot 10^7$	0.012 (800 pb⁻¹)	0.060 (60 fb⁻¹)

$D'^2 N$ also contains BR=$6 \cdot 10^{-5}$ ($B_d \rightarrow \ell^+\ell^-\pi^+\pi^-$), 2x for B and $\bar{B}$ and 0.4 for hadronization probability (0.5 for e^+e^-)

THE "BOTTOM LINE" → {2,4x10" $b\bar{b}$ PRODUCED} {THE REQUIRED NUMBER FOR ANY HADRON EXP