CP Violation in Hyperon Decays:

Revisiting an experimental idea in light of new developments

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UIUC

- Basic Idea from LEAR days experience
- Since then ...
  - now know that ε' is not zero
    - $\Delta s = 1$ CPV
  - M.I. implies $\bar{p}$ "availability"
  - anticipated large $\bar{p}$ intensities
- Outline of original effort
  - thoughts on grander effort (best in working group)
- OTHER
  - SIN 2β ≠ 0
  - B factory efforts worldwide
- CPV REMAINS ONE OF THE HOTTEST PROBLEMS

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/SPSLC 92–19
SPSLC/M491
30 March 1992

Report to the SPS and LEAR Experiments Committee

CP VIOLATION IN HYPERON DECAYS: THE CASE $\overline{p}p \rightarrow \overline{\Lambda}\Lambda \rightarrow \overline{p}\pi^{+}p\pi^{-}$

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Abstract

An account is given of the experimental status of CP violation and of the phenomenology of hyperon non-leptonic decays. Updated information on the estimate of CP-violating observables in these decays is presented. An experimental programme is outlined, with which to pursue the search for direct CP violation in hyperon–antihyperon decays by means of the reaction $\overline{p}p \rightarrow \overline{\Lambda}\Lambda \rightarrow \overline{p}\pi^{+}p\pi^{-}$. The experiment as well as analysis methods are described. Alternative approaches employing hyperons are discussed as well.

* chair

Λ *Decays vs* $\bar{\Lambda}$ *Decays*

- decay parameters

  $B \to B\pi$ — like $\Lambda \to p\pi$

  $M = S + P\sigma \cdot \boldsymbol{q}$

  $\Gamma = |S|^2 + |P|^2$ — rate

  $$\alpha = \frac{2\,\mathrm{Re}(S^*P)}{|S|^2 + |P|^2}$$

  $$\beta = \frac{2\,\mathrm{Im}(S^*P)}{|S|^2 + |P|^2}$$

  } decay asymmetry parameters

- acknowledged tests of CP

  $$\Delta = \frac{(\Gamma - \bar{\Gamma})}{(\Gamma + \bar{\Gamma})}$$

  $$\boxed{A = \frac{(\alpha + \bar{\alpha})}{(\alpha - \bar{\alpha})}} \longleftarrow$$

  $$B' = \frac{(\beta + \bar{\beta})}{(\alpha - \bar{\alpha})}$$

- comparing relative tests...

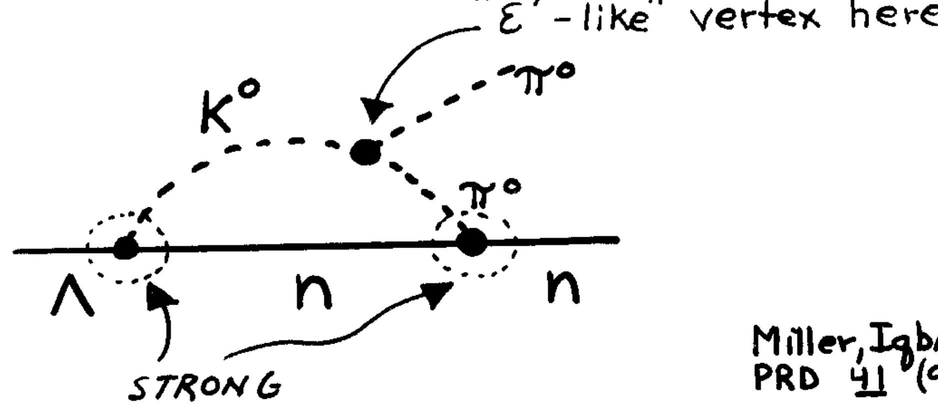
  $B' \approx 10A \approx 200\Delta \approx \chi$, the scale of the violation (to be calculated)

- an interesting level is a test of **A to** ~~10^{-4}~~

See FNAL PAC, etc $\rightarrow 10^{-5}$

CP VIOLATION IN HYPERON DECAYS
(compared to ANTIHYPERON Decays)

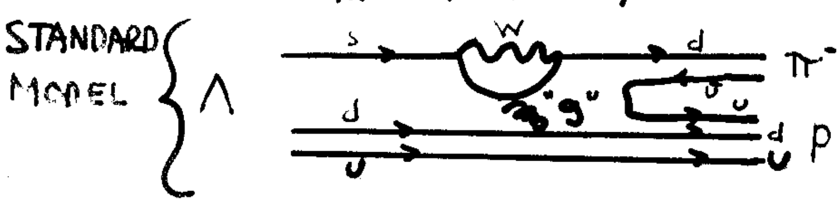
First, a cartoon ....



Miller, Iqbal
PRD 41 (90) 2817

More typically ....
Donoghue et al.....

"Model Independent Analysis" to gauge strength of CPV in Y-$\bar{Y}$ systems



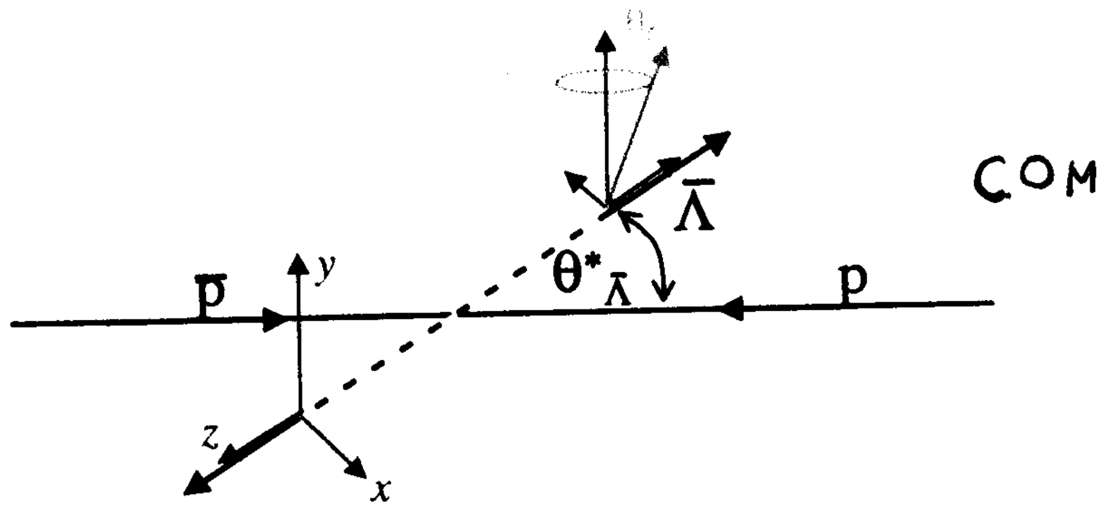
PRD 34 (86) 833
PL B178 (86) 319
+
⋮

X.G. He & H. Steger & G. Valencia

CPV in Λ decay with LARGE m_{top}

electroweak penguin effect

CP Tests with $\bar{\Lambda}\Lambda$



- The reaction $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ produces equal and clean samples of hyperon-antihyperon pairs

- The decay proton is partially aligned with the hyperon spin

$$\alpha_{\Lambda} \text{ and } \alpha_{\bar{\Lambda}}$$

- In SM, the α values differ by a small amount

- FOR A SAMPLE OF POLARIZED Λ's,

$$I(\theta) = I_0 \left[1 + \alpha P_\Lambda \cos\theta \right]$$

- $\alpha_\Lambda P_\Lambda$ is the MEASURABLE (and $\bar{\alpha} P_{\bar{\Lambda}}$) *

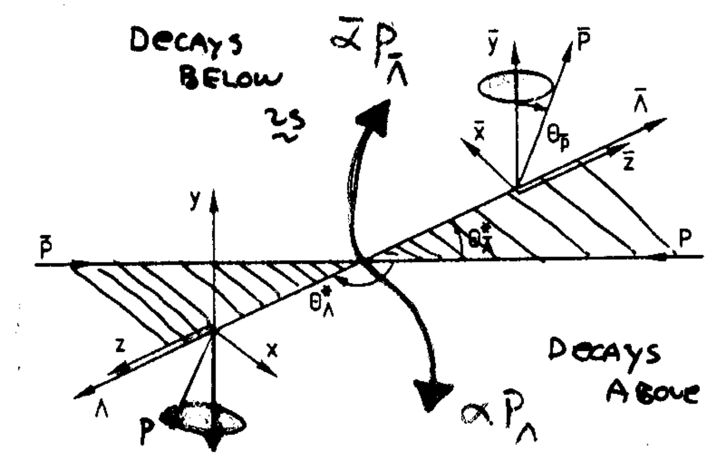
- ESSENTIALLY, DECAY ABOVE OR BELOW PRODUCTION PLAN[E]

  WITH NO Monte Carlo Correction....

  (method of weighted sums)

- CP VIOLATION ...

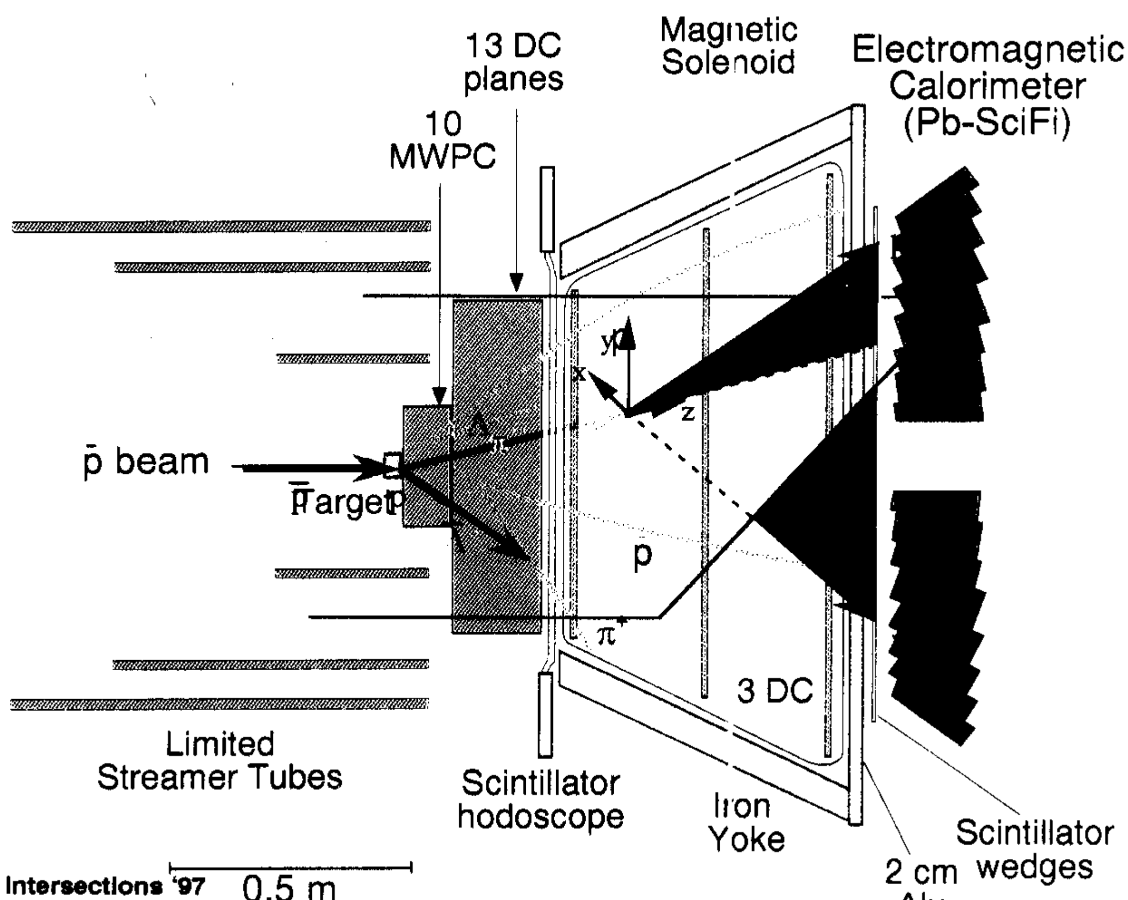
$$\text{DIFFERENCE, } A \propto \frac{[N_\Lambda(\text{up}) - N_\Lambda(\text{down})] + [N_{\bar{\Lambda}}(\text{up}) - N_{\bar{\Lambda}}(\text{dow[n]})]}{\#\ \text{EVENTS}}$$



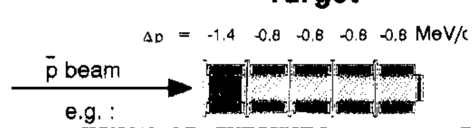
Hyperon-Antihyperon

$\bar{p}p \to \bar{\Lambda}\Lambda,\ \bar{\Lambda}\Sigma^0 + \bar{\Sigma}^0\Lambda,\ \bar{\Sigma}^-\Sigma^+,\ \bar{\Sigma}^+\Sigma^-$

Detector

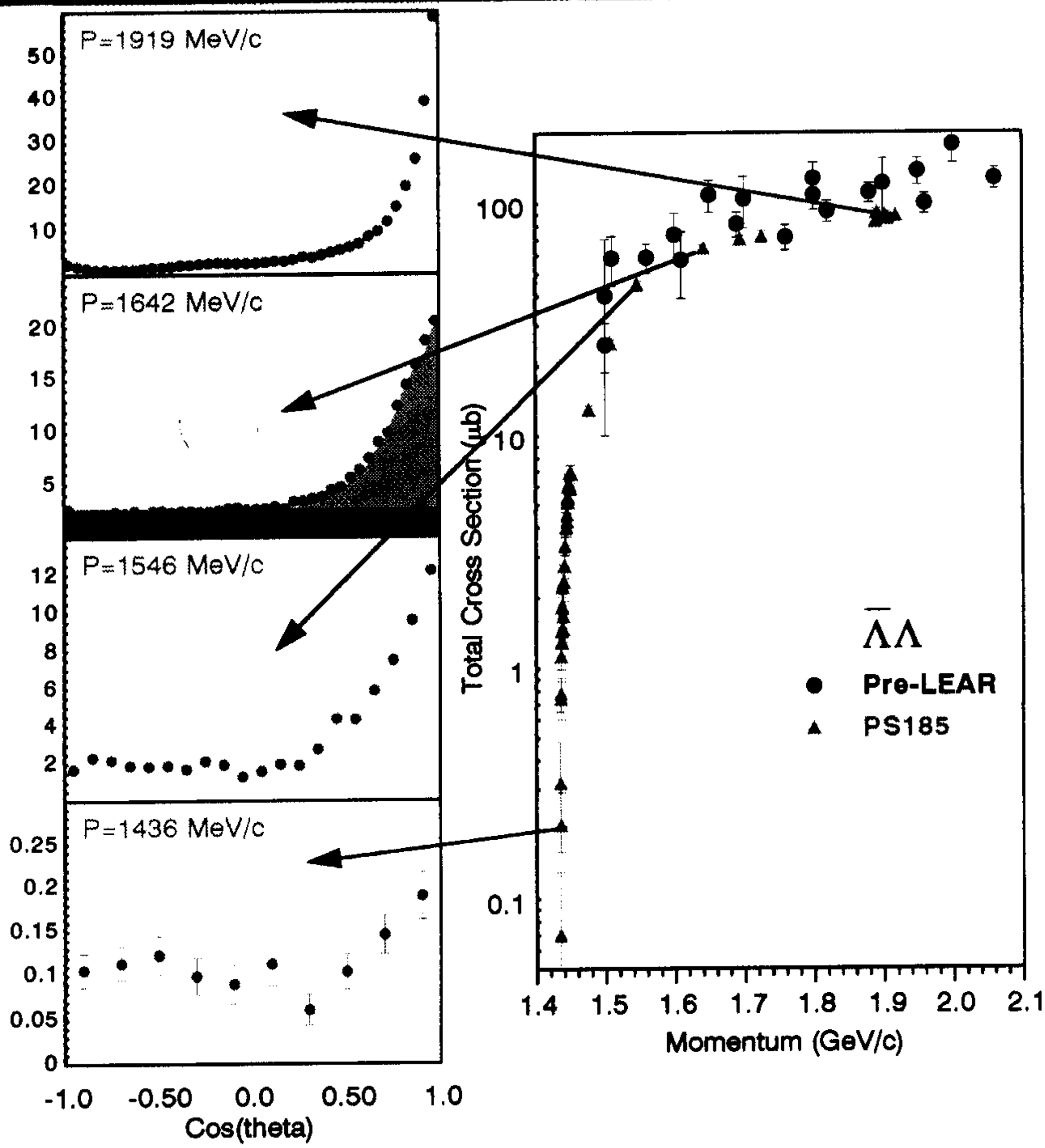


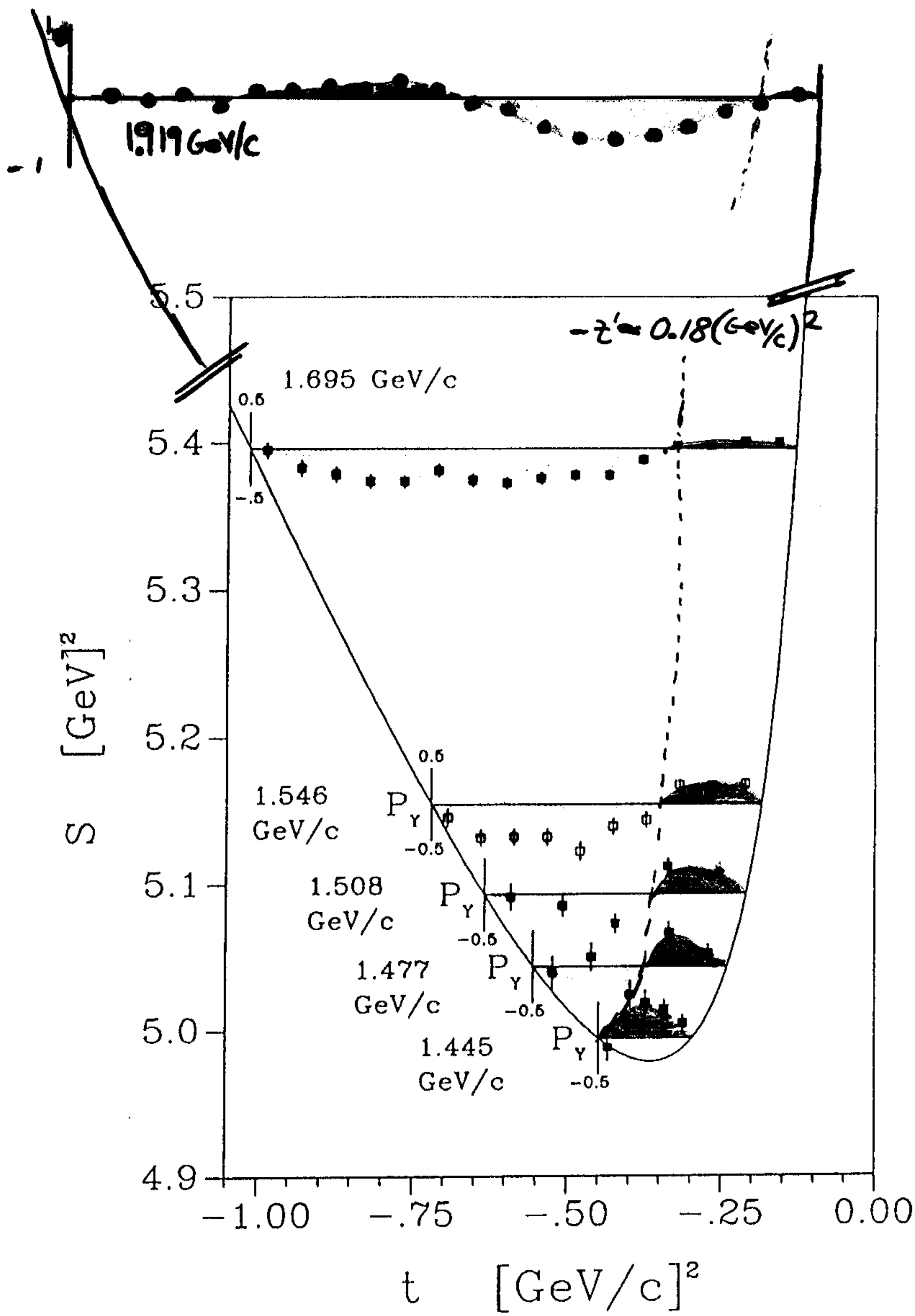
Segmented Target



See J. Franz

$\bar{\Lambda}\Lambda$ Results





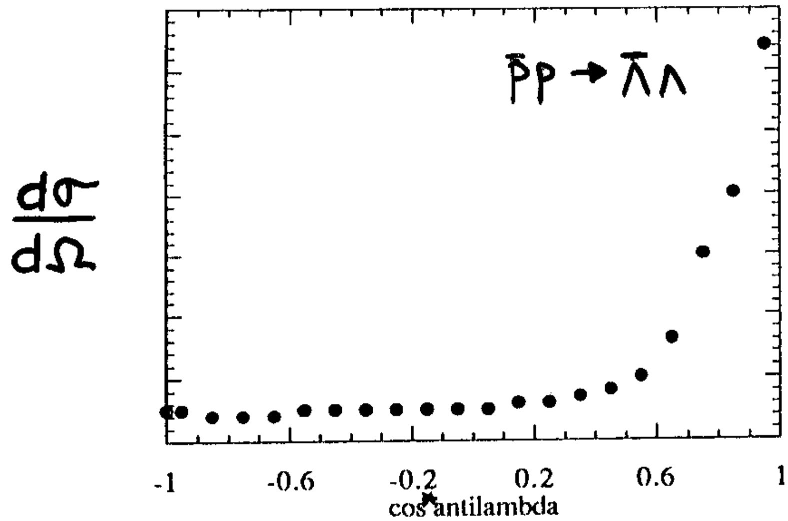
Basic Question: Why the pattern?

25

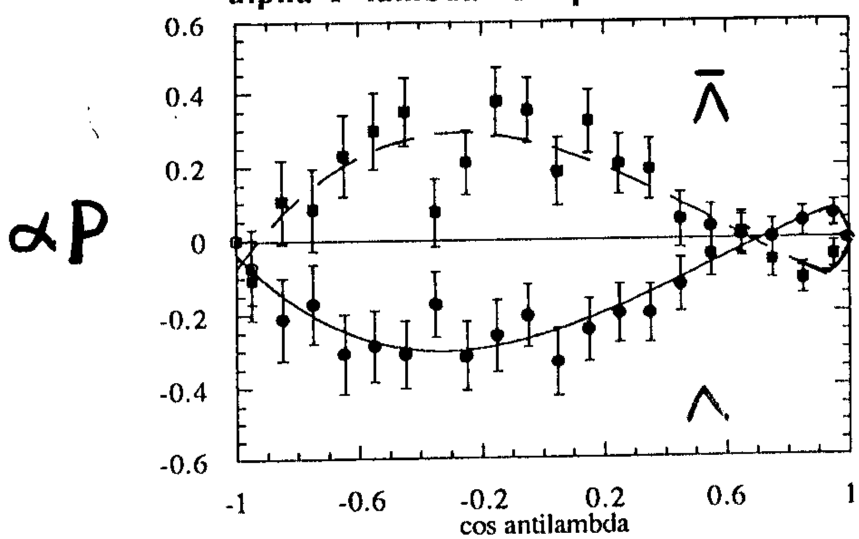
1.695 GeV/c

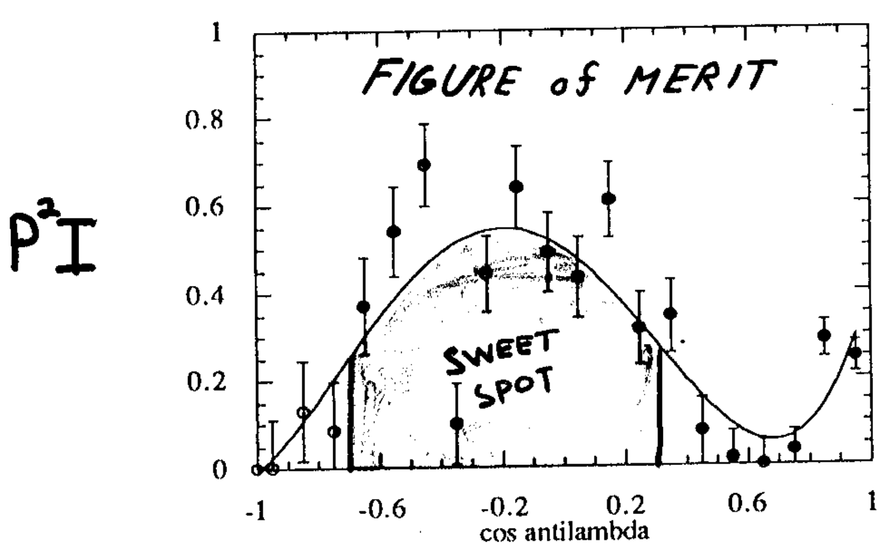
PS185

Differential Cross Section



alpha P lambda vs alpha P antilambda





FINAL PS185 RESULT
$\pm 1.4 \times 10^{-2}$

The average is 0.006±0.014, a factor of four lower limit than given by the PDG [21].

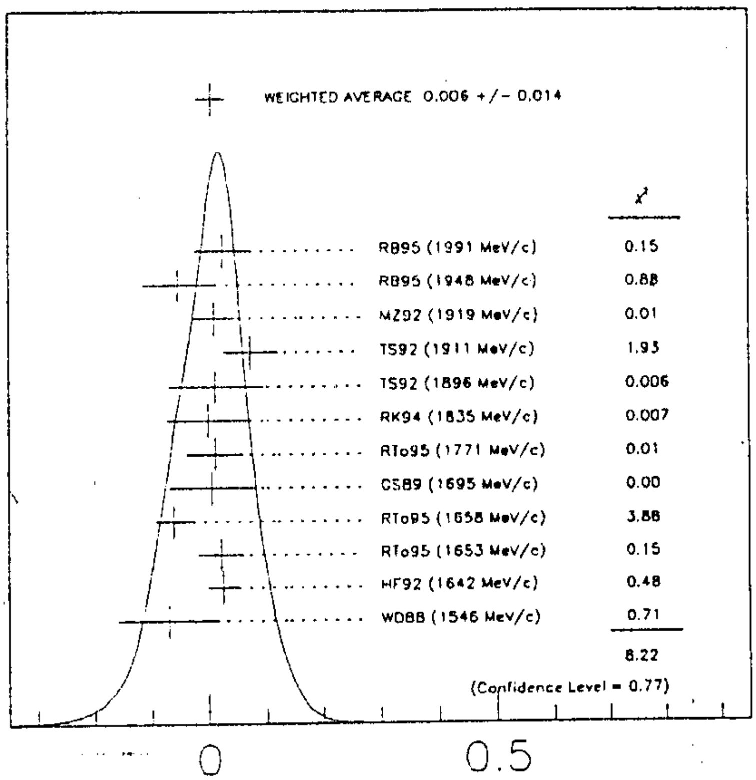


Figure 10. PS185 data points for the parameter A, relevant for CP violation in the $\bar{\Lambda}\Lambda$ system.

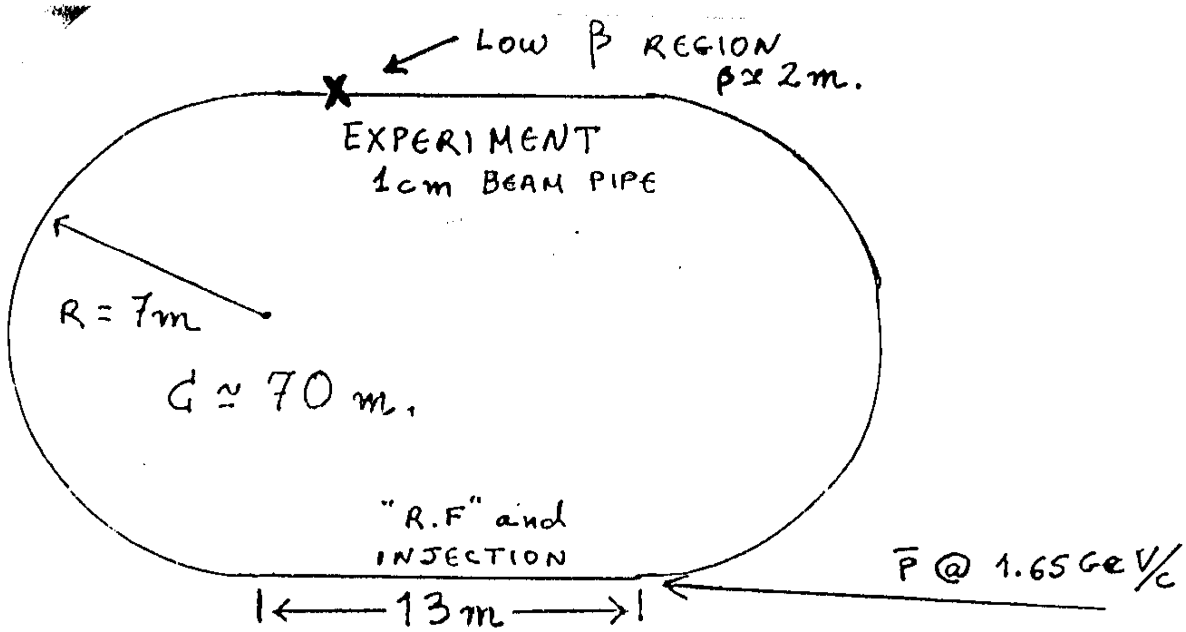
Recall Goal ~ 1000x better!

"Pushing the envelope. How about you?"

Low Energy Antiproton Rings at Fermilab

F. Mills, D. Moehl, J. MacLachlan, J. Marriner

Dreckenridge '89



- A RACETRACK MACHINE OPERATING AT A <u>FIXED ENERGY</u> (<u>1.65</u> GeV/c).
- $N_{\bar{p}} = 10^{11}$
  $\Rightarrow \mathcal{L} = 4 \times 10^{31}$ (5×10^{31} in text)
- THIS MACHINE GETS ~~FILLED~~ BY A COOLED AND DECELERATED BEAM FROM THE ACCUMULAT THUS A SIMPLE STORAGE RING.
- SMALL ACCEPTANCE MACHINE ($\epsilon \simeq 10\pi$ mm
  $\Rightarrow$ A <u>SMALL</u> BEAM PIPE
- MODEST VACUUM REQUIREMENT ($\sim 10^{-8}$ TOR.
- EMMITANCE BLOWUP TIME $\frac{\epsilon}{\dot{\epsilon}} \simeq 1.45$ hours WITH GAS JET ON
  $\Rightarrow$ MODEST STOCHASTIC COOLING SYSTEM.
- **10-20 M$** COST OF TYPICAL FIXED-TARGET EXPT @ FNAL

25'

How Long to Run?

($\Delta A = 10^{-4}$) ← OLD GOAL "LEAR-2

$$\mathcal{L}_{(\text{realistic})} = \left(2 \times 10^{11} \frac{\bar{p}}{\text{ring}}\right)\left(3.32 \times 10^{6} \frac{\text{rev}}{\text{sec}}\right)\left(10^{14} \frac{\text{Atoms}}{\text{cm}^2}\right)$$

$$= \underline{\underline{6.64 \times 10^{31}\ \text{cm}^{-2}\text{s}^{-1}}}$$

$\sigma_{TOT}(\bar{\Lambda}\Lambda)$ @ 1.65 GeV/c = 65 μb — CAN IMPROVE

$(BR)^2\ (p\pi^- \bar{p}\pi^+)$ = 0.41

"sweet spot" fraction = 0.36

Efficiency of Collection / Analysis ≈ 0.35

---

223 events/sec

Need ~ **1.8×10^9** events into "sweet spot"

⇒ 10^7 sec

≡ 1 physics year (on beam)

OKAY, LET'S "DREAM"

	factor
$\mathcal{L} = 10^{33}\ cm^{-2}s^{-1}$	× 15
DAQ Deadtimeless, eff	× 1.5
	~ × 20

⇒ STILL REQUIRE
$\sim 5 \times 10^{7}$ s **beam on**
$\approx$ 2 years or more

AND that's "just" $A \sim 10^{-5}$, not beyond!

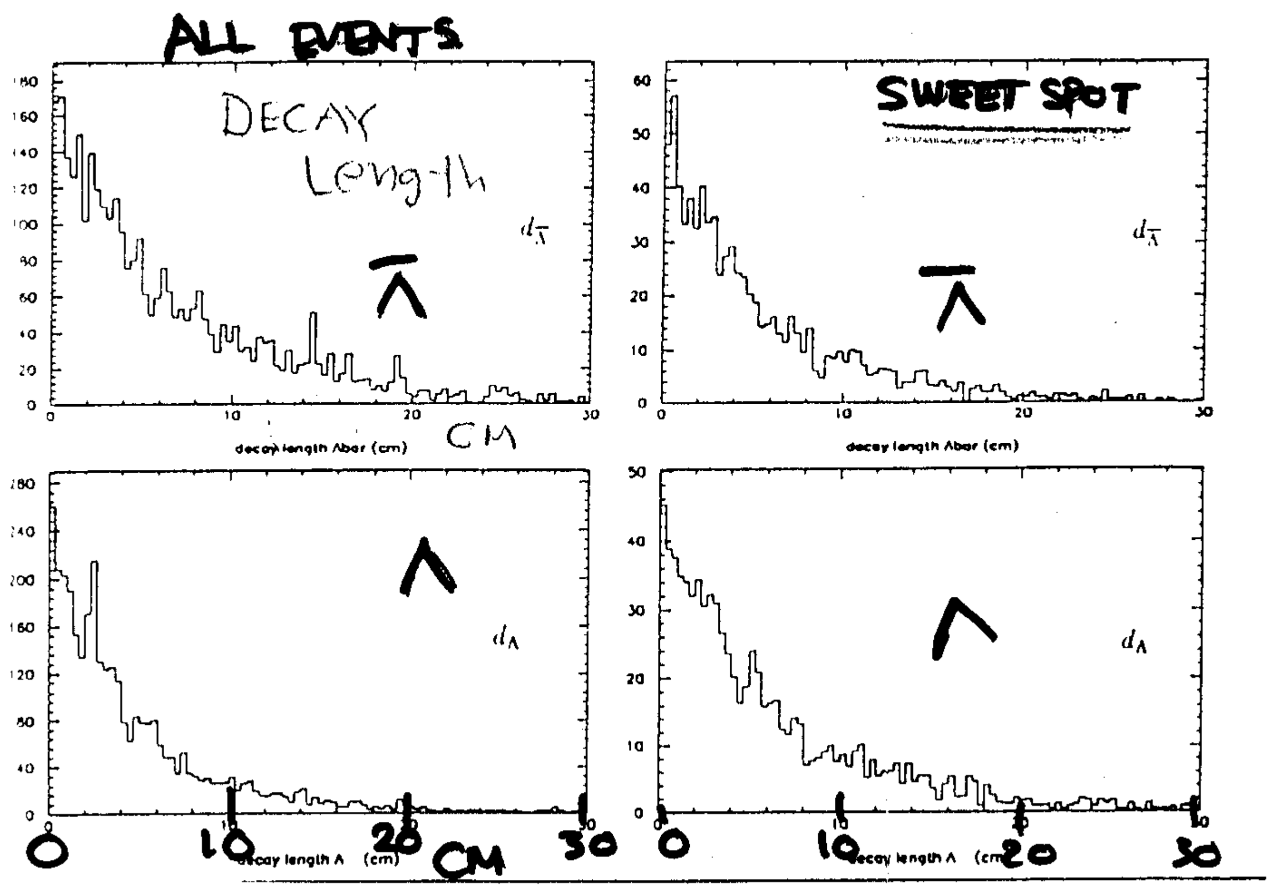
Now consider background ...
@ 10^{33}

$\sigma_{TOT}(\bar{p}p) \sim 100$ mb

⇒ 10^{8} interactions / sec!

MANY produce $\langle \pi \rangle \sim 5$

Detector: VERY FAST
VERY SELECTIVE TRIGGER
HIGHLY SEGMENTED
LONG-TERM RELIABILITY



DECAY LENGTH

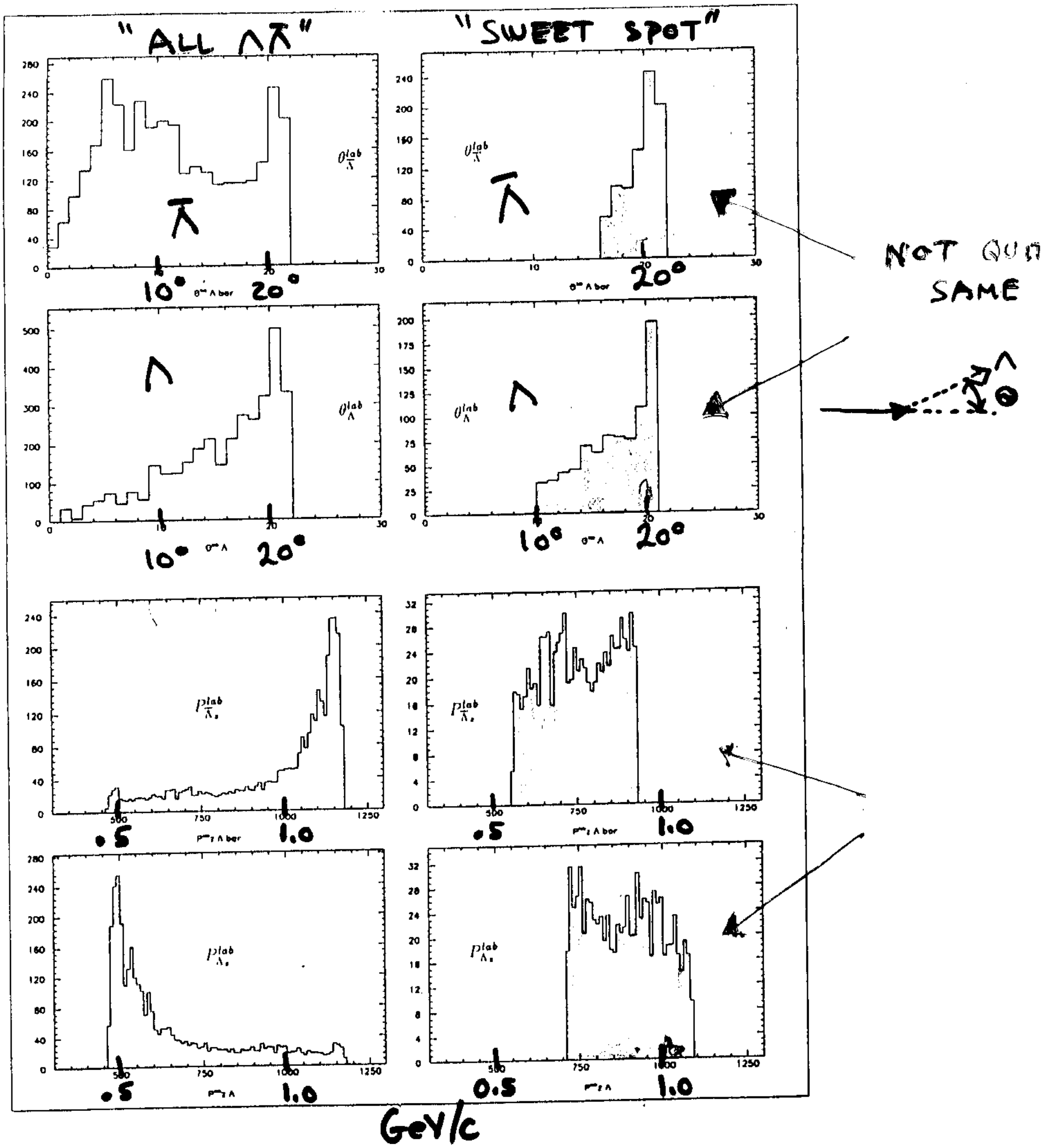


Figure 4: Laboratory angles and momenta for $\bar{p}p \to \bar{\Lambda}\Lambda$. For data simulated at 1.65 GeV/c incident antiproton momentum shown are, from top to bottom, distributions of the laboratory production angles $\theta^{lab}_{\bar{\Lambda}}$, θ^{lab}_{Λ} (in degrees) and of the laboratory longitudinal momenta $P^{lab}_{\bar{\Lambda}_z}$, $P^{lab}_{\Lambda_z}$ (in MeV/c). The plots on the left side include all events, those on the right side only events falling into the region-of-interest.

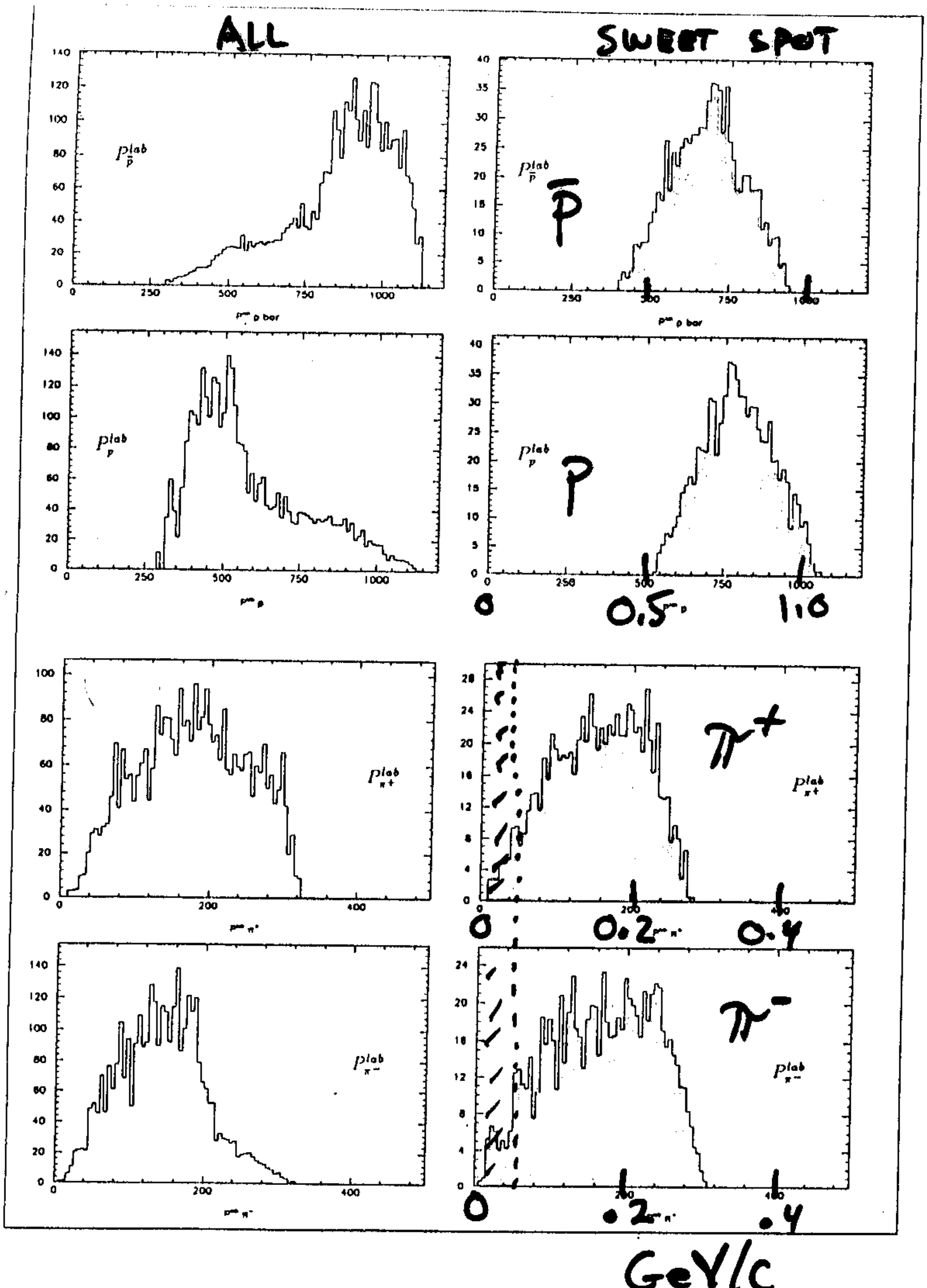


Figure 5: Laboratory momenta for $\overline{\Lambda}\Lambda \rightarrow \bar{p}\pi^+ p\pi^-$ decay products. For $\bar{p}p \rightarrow \overline{\Lambda}\Lambda$ data simulated at 1.65 GeV/c incident antiproton momentum shown are, from top to bottom, distributions of the final-state particle laboratory momenta $P_{\bar{p}}^{lab}$, P_{p}^{lab}, $P_{\pi^+}^{lab}$, $P_{\pi^-}^{lab}$ (in MeV/c). The plots on the left side include all events, those on the right side only events falling into the region-of-interest.

MOMENTA DECAY p, π

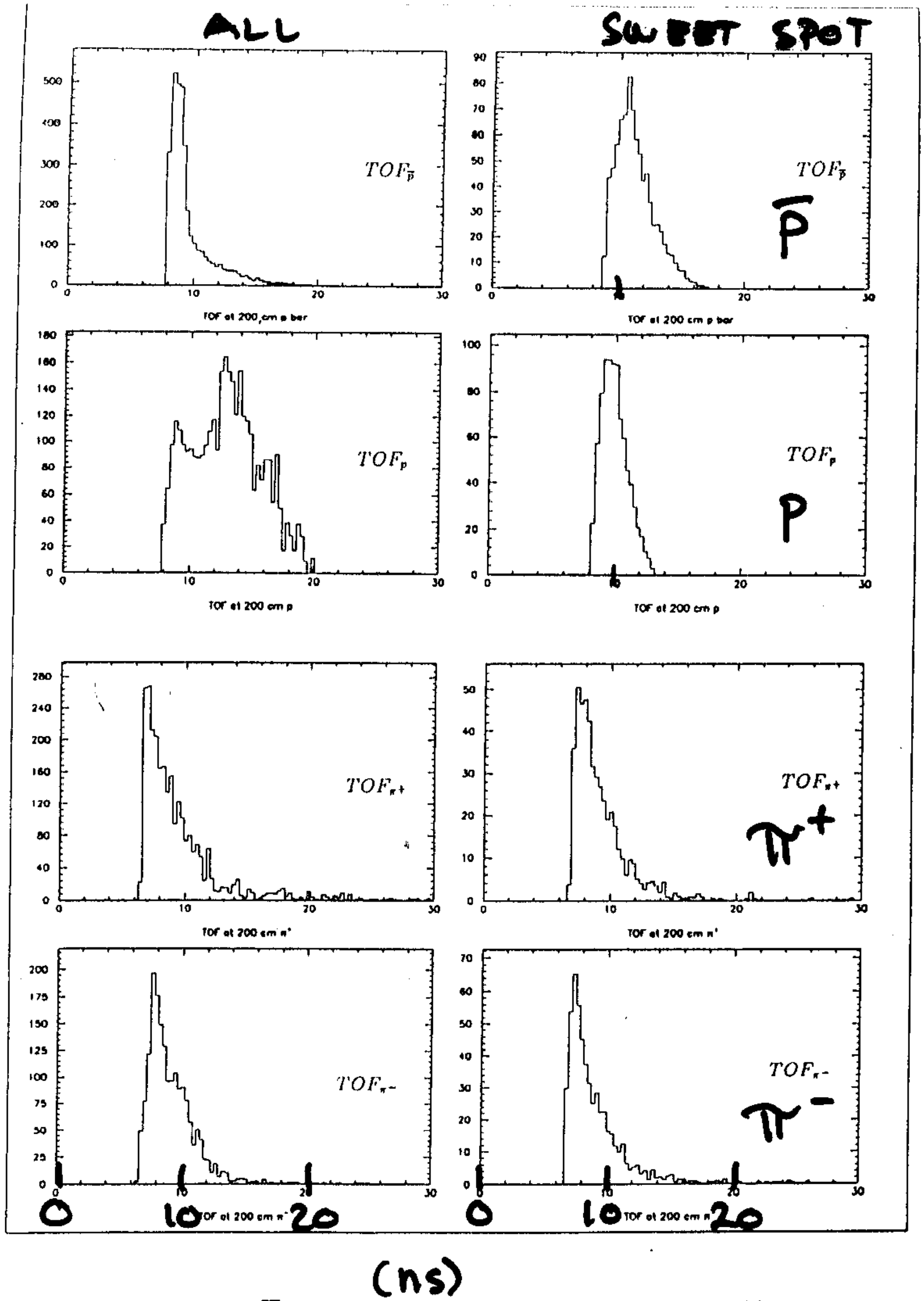
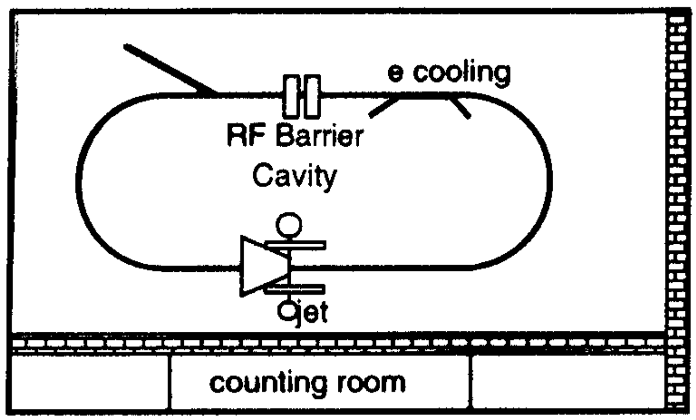


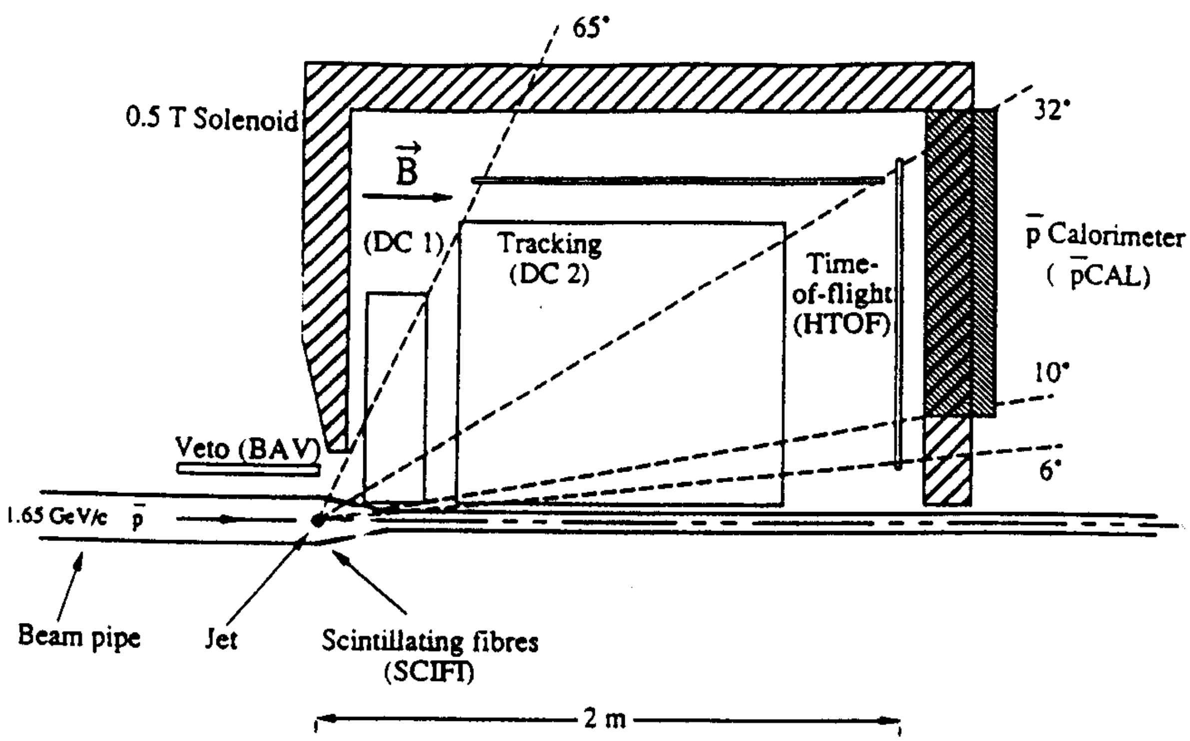
Figure 8: Time-of-flight for $\overline{\Lambda}\Lambda \rightarrow \overline{p}\pi^+p\pi^-$ decay products. For $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ data simulated at 1.65 GeV/c incident antiproton momentum shown are, from top to bottom, distributions of the final-state particle times-of-flight, over a 2 m distance, $TOF_{\overline{p}}$, TOF_p, TOF_{π^+}, TOF_{π^-} (in ns). The plots on the left side include all events, those on the right side only events falling into the region-of-interest.

T.O.F.

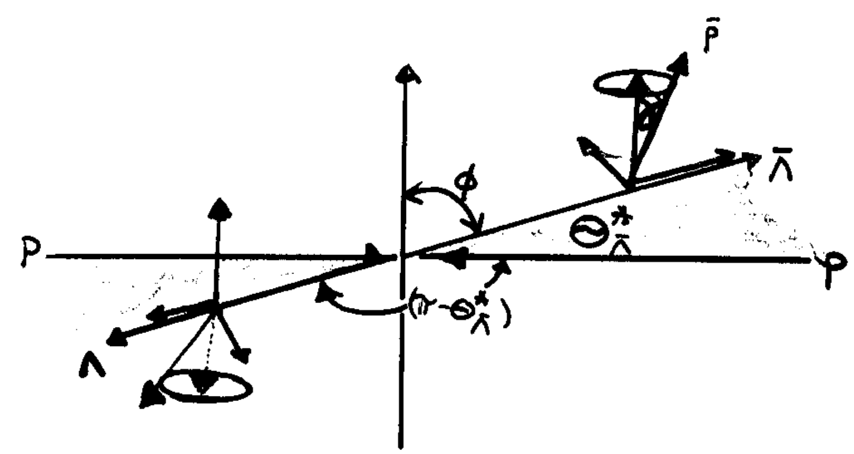
Σ TOF is fairly good discriminator

The Experiment is a RING and a Detector

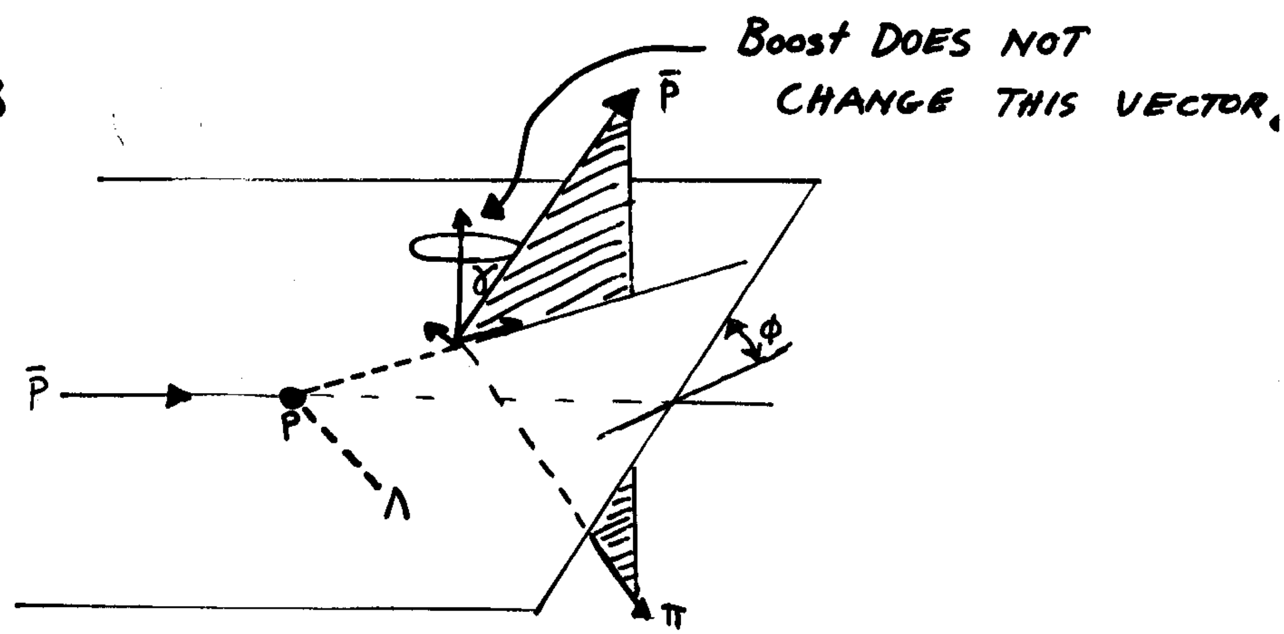




COM



LAB



REQUIRE: "N" ≡ ACCEPTANCE

STRONG $$N_{uu}(\Theta^*_{\bar\Lambda}, \phi) = N_{dd}(\Theta^*_{\bar\Lambda}, \phi)$$

OR

INTERMEDIATE $$N_{uu}(\Theta^*_{\bar\Lambda}, \phi) + N_{uu}(\Theta^*_{\bar\Lambda}, \phi+\pi) = N_{dd}(\ ) + N_{dd}(\ )$$

OR

WEAK $$\int N_{uu}(\Theta^*_{\bar\Lambda}, \phi)\, d\phi = \int N_{dd}(\Theta^*_{\bar\Lambda}\ \phi)\, d\phi$$

INTERESTING CONSIDERATIONS ....

VALIDITY of ASSUMPTIONS

- ASSUME C, P, & CP INVARIANCE IN PRODUCTION

  < C NOT TESTED AS WELL AS WE REQUIRE >

  $\vec{\mathbb{P}}$ of $\Lambda(\theta) \cdot \bar{\Lambda}(\pi - \theta)$

- $\vec{\mathbb{P}}(\bar{p} \text{ beam}) = \vec{\mathbb{P}}(\text{JET}) = 0$

  ⇒ *SIBERIAN MONGOOSE NEEDED?*

- No *selective* DEPOLARIZATION of Λ vs $\bar{\Lambda}$ before decay

BUILT-IN PROBLEMS

- $\Lambda, \bar{\Lambda}$ finite decay path ⇒ π ROTATION * of detector does *NOT* really work to cancel asymmetries $\varepsilon(\gamma_{p_{decay}}) \neq \varepsilon(\gamma{+}\pi_{p_{decay}})$

- *$\pi^+ - \pi^-$ INTERACT DIFFERENTLY*

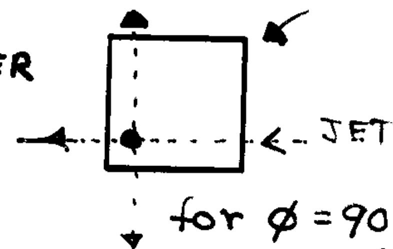
- *$\bar{p} - p$ DRAMATIC DIFFERENCE*

CONDITIONS WHICH BIAS the MEASUREMENT

➜ PAIRS of effects contribute - 2nd Order

SINGLE PROBLEMS <IN PAIRS ... WATCH OUT>

- MisAlignment of TRACKER
  ⇒ ε differences

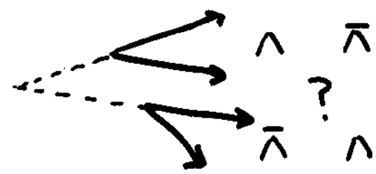


for $\phi = 90°$, A CLEAR effect

- NON UNIFORM TRACKER

- MISIDENTIFY $p - \pi^-$
  (OR) $\bar{p} - \pi^+$
  ok if = & RANDOM

- MISIDENTIFY $\Lambda - \bar{\Lambda}$
  dilution



- Some more particular detector-specific effects

BUILT-IN CHECKS

*

- ξ_Λ vs $\xi_{\bar{\Lambda}}$ CPT
  uses "All" events

- Wrong production plane Analysis
  choose $\phi \neq \phi_{ACTUAL}$
  ⇒ $P = 0$, $A = 0$, ...

- $\bar{p}p \to \bar{p}p\pi^+\pi^-$ TEST DETECTOR UNIFORMITY

At this point ...

I am increasingly discouraged about reaching 10^{-5}...

... but I hope to eat these words someday.

Needed!
- A smart idea (outside the box)
- Some very good detector thoughts
- A TON of work