Physics with Low Energy Hadrons

Working Group Report

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Muon Collider Workshop

Where the FMC fits in

Machine:	AGS	AGS'	FMI	JHF	FMCFE
p (GeV/c):	25	25	120	50	16
Duty factor:	0.33	0.27	0.33	0.16	0.90
TP/sec:	20	30	10	60	400
av fwd K_L:	$1.3\ 10^9$	$2\ 10^9$	10^9	$3.8\ 10^9$	$25\ 10^9$
acc(2bdy):	.02	.02	.10	.04	.013
"K_L sens":	26	40	100	150	325
K^+ stop:	12	18	8	47	210

Hyperons, et al

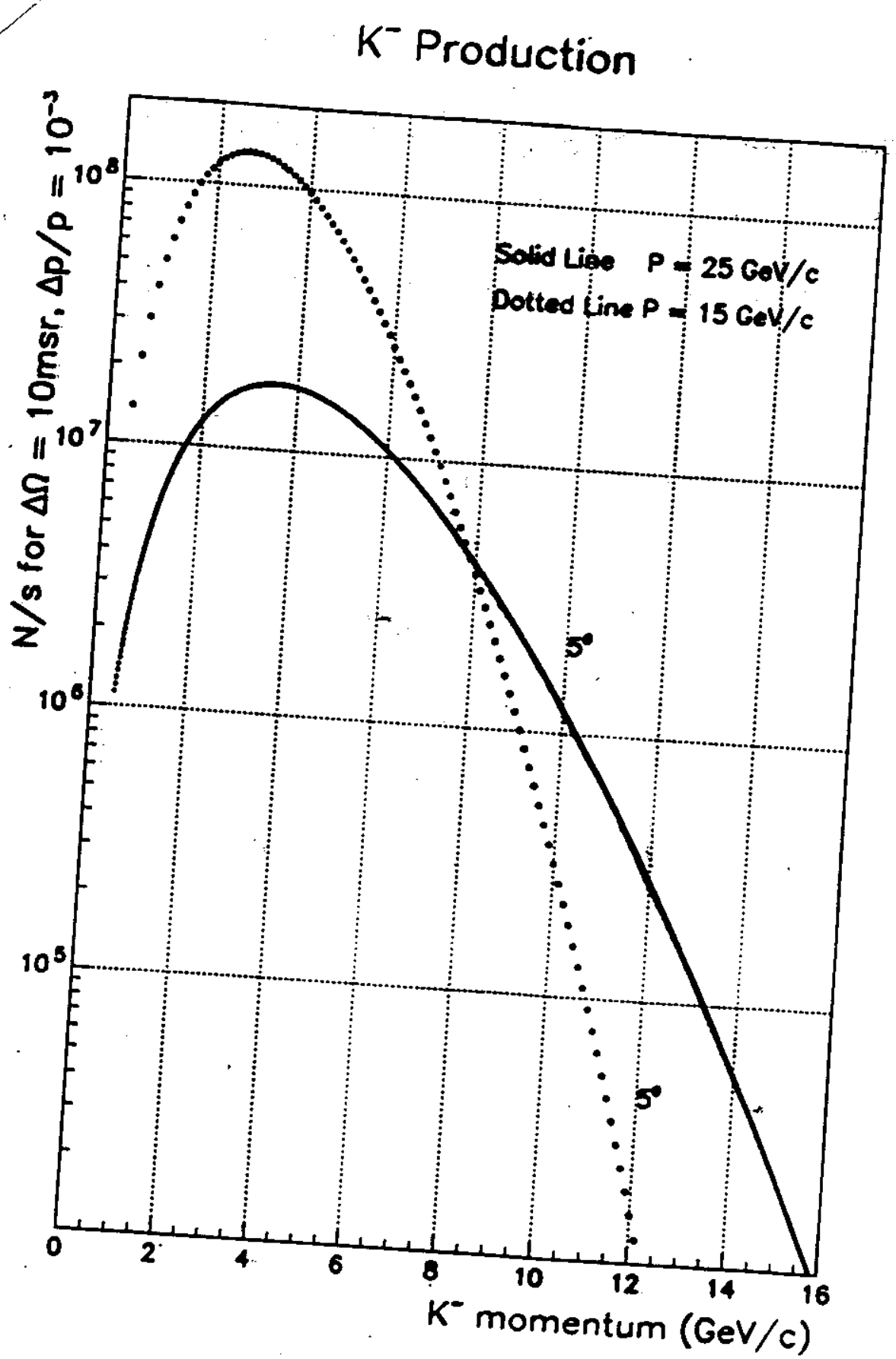
- Production Mechanisms
  - OBE vs Quark Mechanisms
- Spectroscopy
  - Baryons and Mesons
- NN $\rightarrow$ Strange sector
  - Hyper nuclei
  - FSI and scattering
  - Isospin violations
  - Many body & media modifications
- Weak Interactions
  - $\Delta I = \frac{1}{2}$ rule decays
  - CP violations

Franklin

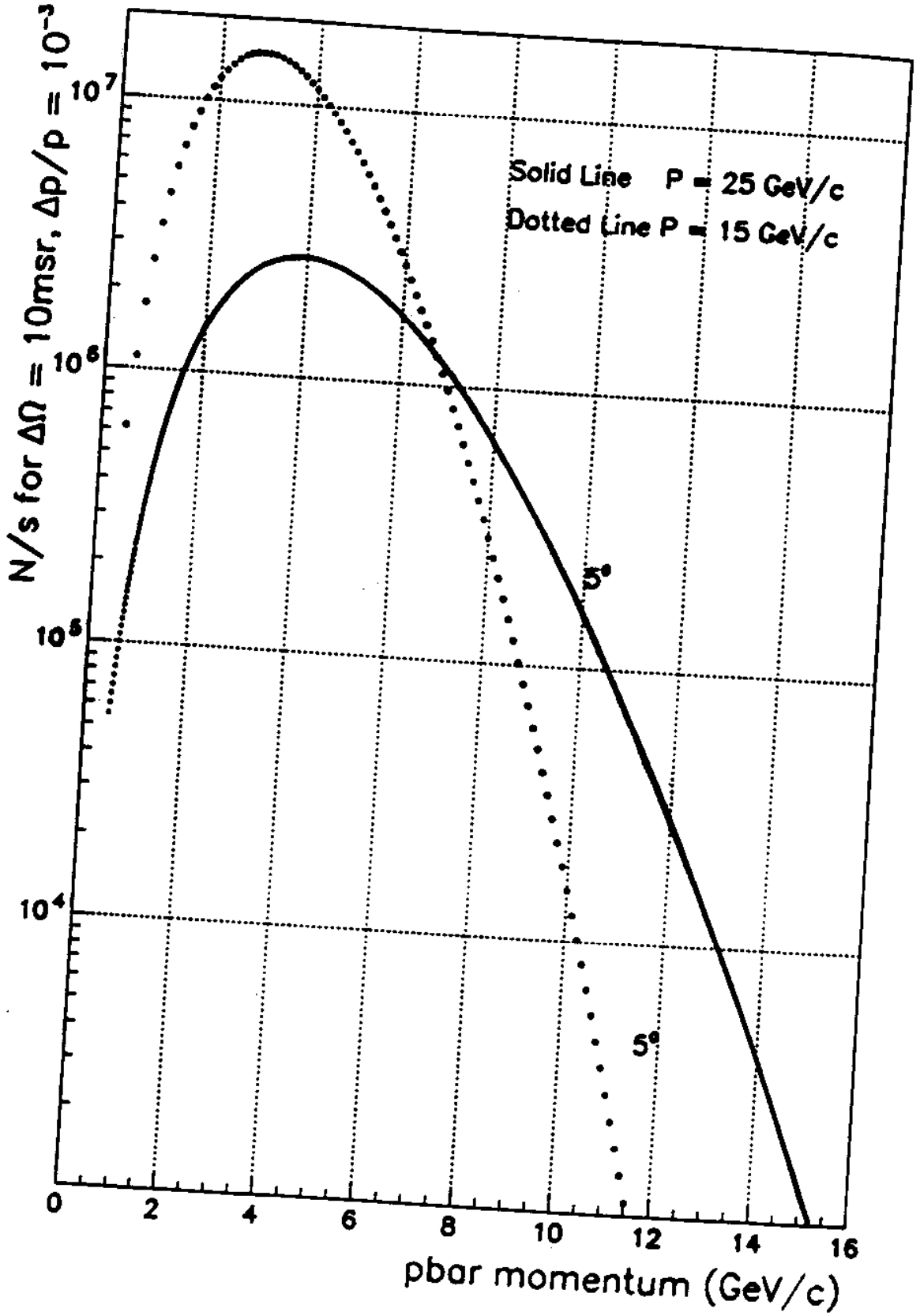
The Hadronic Physics topics discussed in these workshops extend over a wide range:

- Proton Exclusive Scattering and Polarization
- Proton & Antiproton Forward Scattering
- Proton Formfactors
- Hypernuclear Physics
- Baryon Spectroscopy
- Rare η decays and Symmetry Tests
- Light Quark Spectroscopy
- Charmonium Spectroscopy
- CP Violation
- Exotic Meson and Glueball Searches

The range is too wide. I will therefore only discuss a select few. The choice is strictly personal.


K⁻ Production
N/s for ΔΩ = 10msr, Δp/p = 10⁻³
10⁸
10⁷
10⁶
10⁵
Solid Line P = 25 GeV/c
Dotted Line P = 15 GeV/c
5°
5°
0
2
4
6
8
10
12
14
16
K⁻ momentum (GeV/c)

Antiproton Production

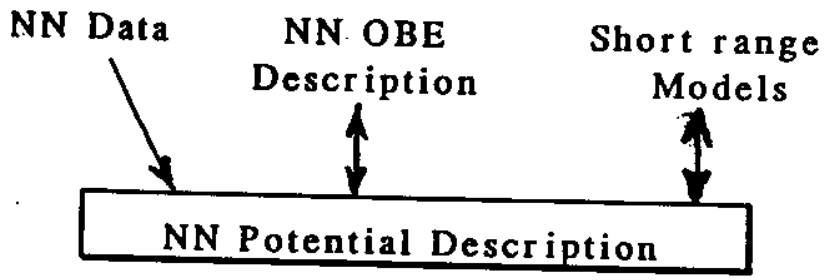


Seth

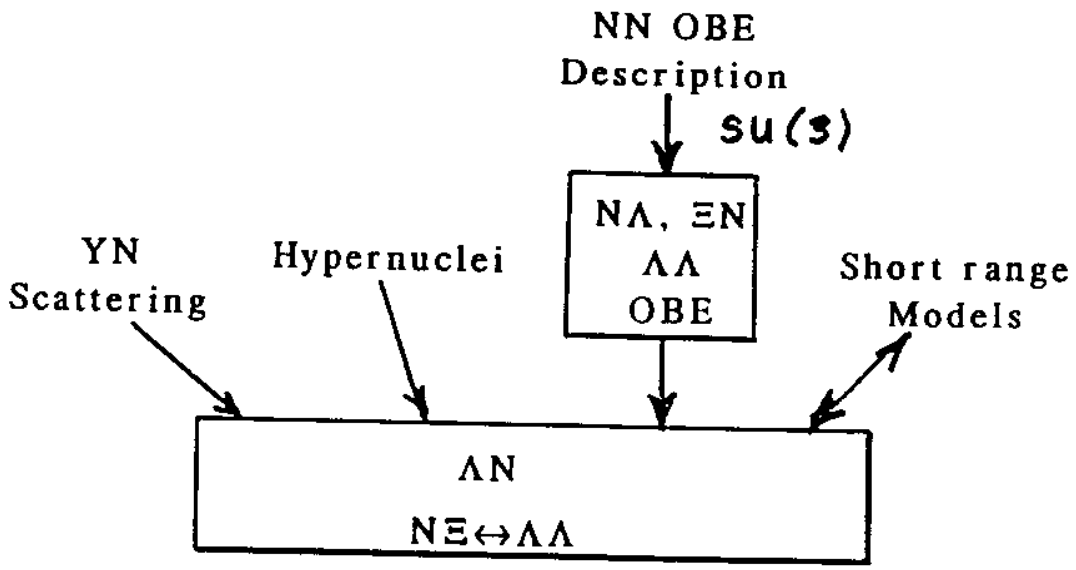
NN → Strange Sector

The Baryon-Baryon Interaction

S=0



S= -1, -2



- Equivalent NN descriptions → conflicting ΞN, ΛΛ

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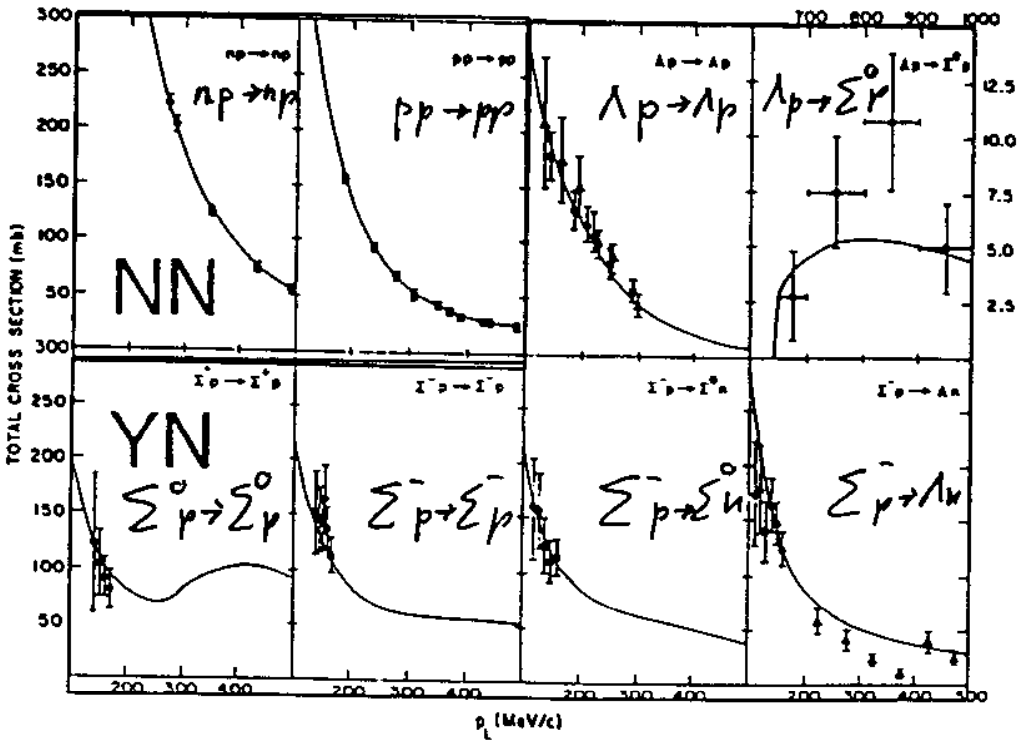
Poor existing YN data



from Dover & Feshbach Ann.Phys.198(90)321

Use 2 GeV K^- line + CDS

$\Xi^- p \to \Xi^- p$
$\Xi^- p \to \Lambda\Lambda$ } Imai + Ichi P928

$\pi^- p \to K^0 \Lambda$
$\Lambda p \to \Lambda p$ } Ransome LOI

$K^- d \to K^0 \Lambda\Lambda$ "Franklin"

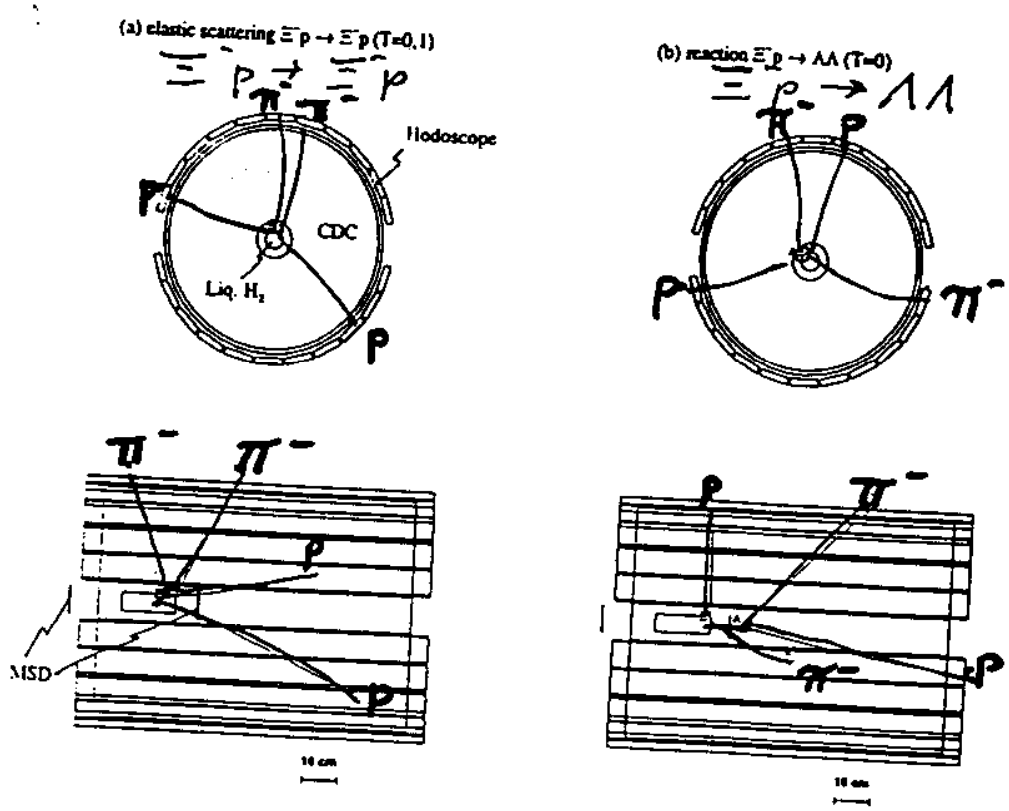


Fig. 1 A schematic drawing of a liquid hydrogen and the CDS. Typical events are also displayed in the figure: (a) elastic scattering $\Xi^- p \to \Xi^- p$, (b) reaction $\Xi^- p \to \Lambda\Lambda$.

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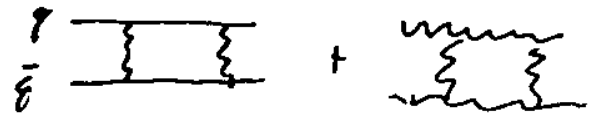
Spectroscopy

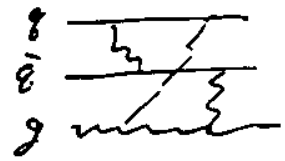
Light Mesons

Glueball sector very active

- Scalar Glueball Mixed States
  Crystal Barrel f(1500), etc
  Need theoretical guidance



- Hybrids with Exotic Quantum Numbers
  BNL E852
  18 GeV/c pion beam
  1370 MeV/c^2 JPC = 1^{-+}
  PRL 79 (Sep. 97)
  (+NPR, CNN, Pittsburgh Post Gazette...)



- Tensor Glueball
  $\xi(2230)$ now confirmed at BES

  not seen in $p\bar{p}$ (PS185, Crystal Barrel)

  AGS E924 D. Hertzog et al
  When will it be done?

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THE GLUEBALL STORY

- One of the most unique predictions of QCD is that gluons bind. Therefore, GLUEBALLS (gg, ggg) must exist if QCD is true. But,

WHERE ARE THE GLUEBALLS?

- Lattice gauge calculations predict that the two lightest glueballs are:
  Scalar (0^{++}): $M(0^{++}) = 1.6 \pm 0.1$ GeV, $\Gamma = 0.1$ GeV
  Tensor (2^{++}): $M(2^{++}) = 2.3 \pm 0.1$ GeV, $\Gamma = ?$

- Good experimental candidates now exist for the scalar glueball:

$$f_0(1500) \text{ by CB, } f_J(1710) \text{ by IBM.}$$

But there are problems, particularly mixing with the normal $q\bar{q}$ mesons.

We need to find the tensor glueball.

- Beijing has proposed that the newly rejuvenated

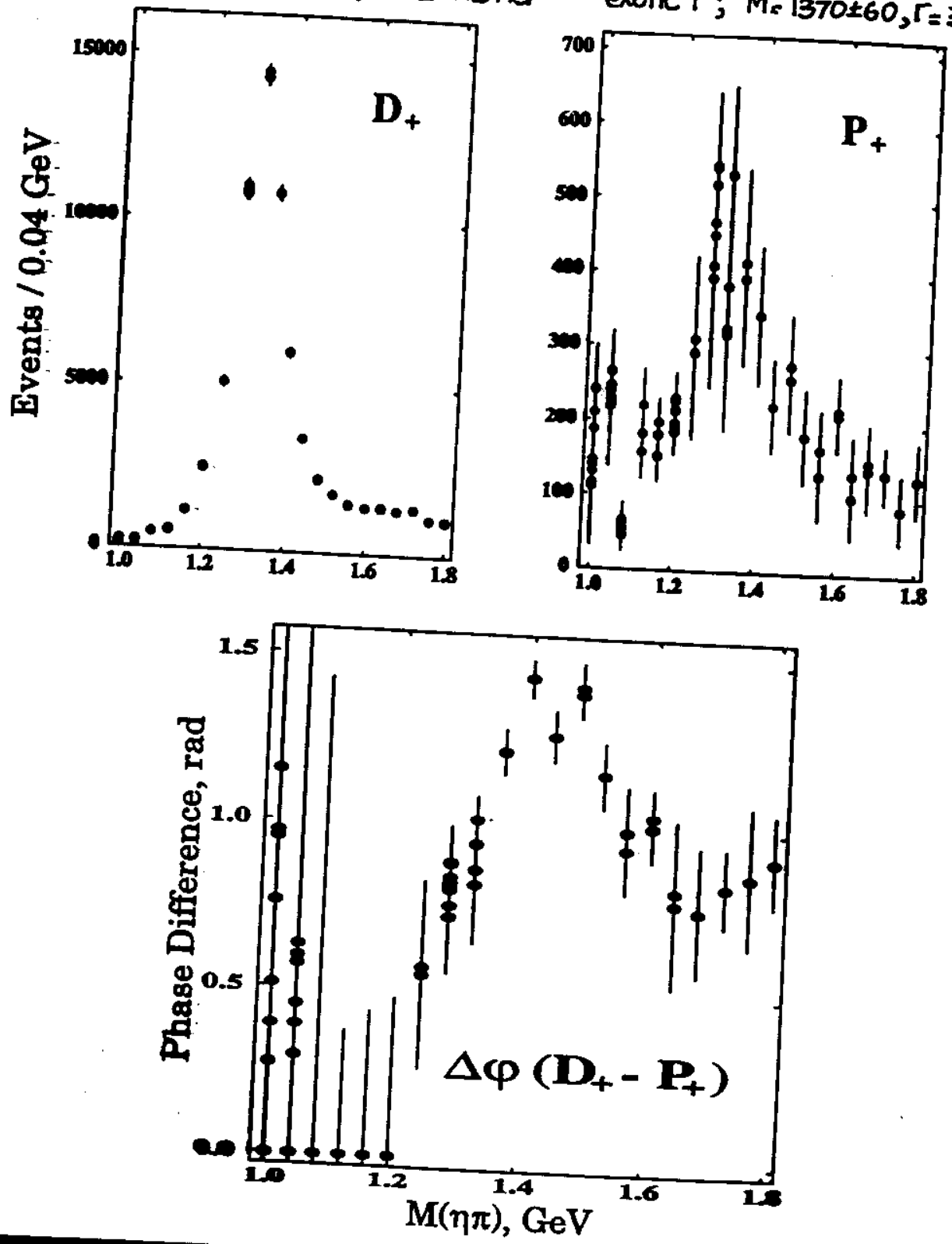
$$\xi(2230),\ \Gamma \approx 20\,\text{MeV}$$

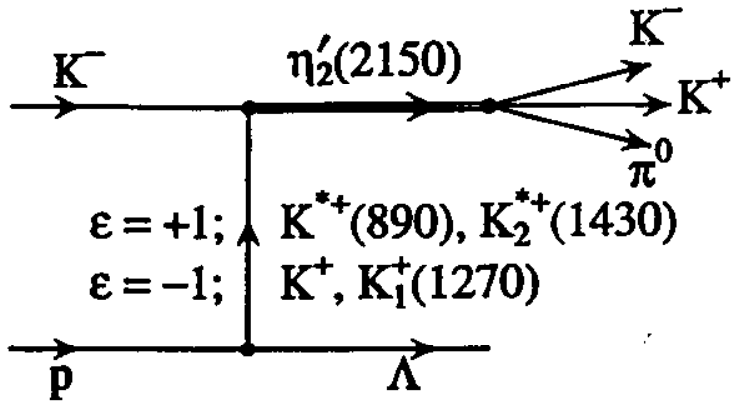
is an excellent candidate for the tensor glueball.

$\eta\pi^-$ PWA: *Natural parity exchange*

a_2: M = 1317±2, Γ = 127±3 MeV

exotic 1^{-+}; M = 1370±60, Γ = 385±4





'Narrow' Strangeonium Hybrids*

$$s\bar{s} + g \Rightarrow I = 0$$

$M \simeq 2150$ MeV and $\Gamma \simeq 200$ MeV

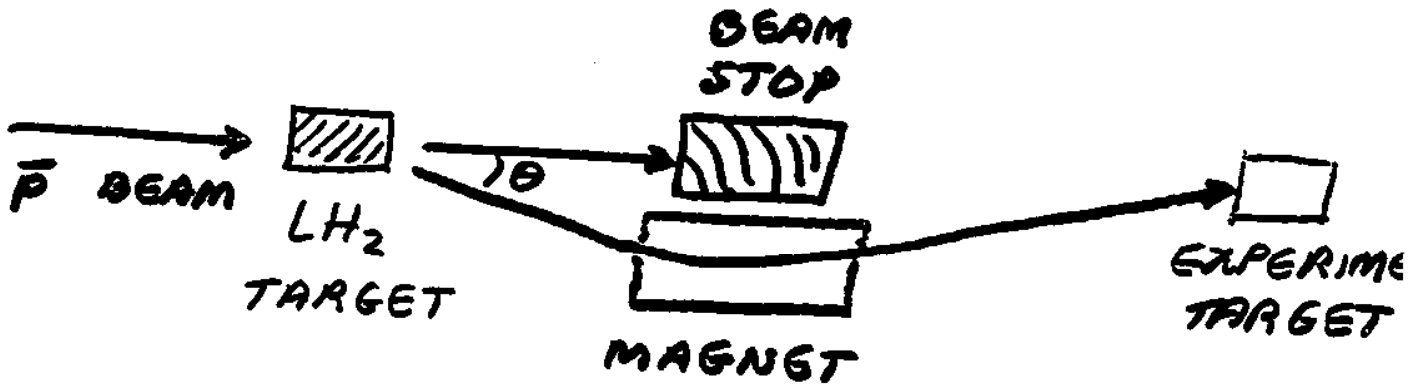
I^G	J^{PC}	State	Decay	L	Γ(MeV)
0^-	1^{--}	$\phi(2150)$	$\bar{K}K_2^*$	D	20
			$\bar{K}K_1$	S	185
0^-	2^{+-}	$h_2'(2150)$	$\bar{K}K_2^*$	P	90
			$\bar{K}K_1$	P	100
0^+	2^{-+}	$\eta_2'(2150)$	$\bar{K}K_2^*$	S	100
			$\bar{K}K_1$	D	20

*F. E. Close and P. R. Page, NP B**443**, 233 (1995)

Seth

PRELIMINARY DESIGN, RATES, ETC.

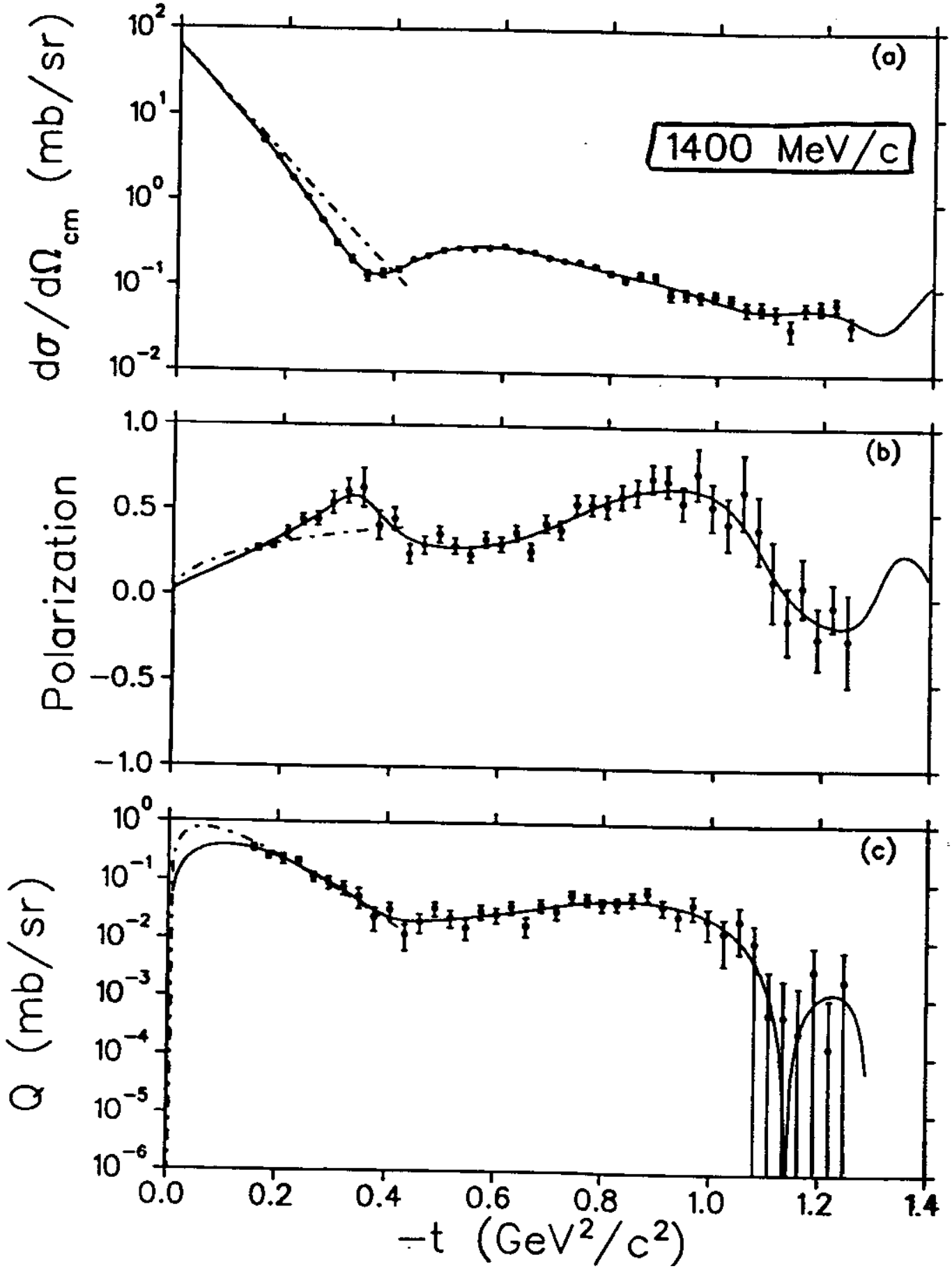
- THE $\bar{p}p$ POLARIZATION PARAMETER IS <u>NONZERO</u>. SO, USE A $\bar{p}$ BEAM INCIDENT ON A LH_2 TARGET, AND SCATTER AT $\theta \neq 0$. THE $\bar{p}$ SPIN WILL BE $\perp$ TO THE SCATTERING PLANE.



NOTE, THE MAGNET DOES NOT PRECESS THE $\bar{p}$ SPIN IN THIS CASE. HOPEFULLY THE ELASTIC SCATTERIN EVENTS WILL NOT NEED TO BE "TAGGED"

- IT IS DESIRED TO MAXIMIZE THE POLARIZED $\bar{p}$ INTENSITY, WITH HIGH $\bar{p}$ POLARIZATION,

FROM R. KUNNE et al. NP B 323, 1 (1989)



THE DETAILED DESIGN

- THE TOROID GEOMETRY WAS CHOSEN AND FIXED. IT INCLUDED AN IDEAL TOROID, BUT ONLY HALF THE ϕ ACCEPTANCE.
  NO CORRECTION COILS WERE INCLUDED.

- Δz_T WAS CHOSEN TO GIVE $-t \sim 0.12$ GeV^2/c^2

- FITS WERE INCLUDED FOR $d\sigma/d\Omega_{cm}$ AND ρ

A MONTE CARLO PROGRAM GENERATED

INCOMING $\bar{p}$ — $\pm 5\%$ $\Delta P/P$
± 1 cm SPOT SIZE
± 5 mrad DIVERGENCE

SCATTERING — 10 cm LH_2 TARGET
θ_{LAB}, ϕ

TRAJECTORIES WERE NUMERICALLY INTEGRATED THROUGH THE TOROID FIELD.

GOOD EVENTS $\Rightarrow$ TRAJECTORY WAS WITHIN
± 2 cm RADIUS OF BEAM
± 5 cm LENGTH
AT THE EXPERIMENTAL TARGET

- ADJUST Δz_G TO MAXIMIZE GOOD EVENTS

RESULTS: $\langle P \rangle \sim 0.2$

$\langle$INTENSITY$\rangle \sim 2 \times 10^{-4}$ PER INCOMING $\bar{p}$.

PROGRAM OF $\bar{p}p$ MEASUREMENTS

- THERE ARE 5 $\bar{N}N$ ELASTIC AMPLITUDES AND TWO ISOSPIN STATES. $\gtrsim 20$ SPIN PARAMETERS MUST BE MEASURED AT EACH ANGLE + ENERGY FOR A FULL AMPLITUDE DETERMINATION.

- WITH THIS BEAM AND A POLARIZED PROTON TARGET, CAN MEASURE

  $P,\ C_{NN},\ C_{SS},\ C_{LL},\ C_{SL}$ $\qquad \bar{p}p \to \bar{p}p,\ \bar{n}n$

  USING QUASIELASTIC SCATTERING FROM A POLARIZED DEUTERIUM TARGET, THEN COULD MEASURE

  $P,\ C_{NN},\ C_{SS},\ C_{LL},\ C_{LS}$ $\qquad \bar{p}\ \text{"}n\text{"} \to \bar{p}n$

- NOTE MEASUREMENTS WITH NEUTRONS WILL BE HARDER BECAUSE OF LOW DETECTION EFFICIENCIES AND LARGE DETECTOR VOLUMES REQUIRED.

- OTHER REACTIONS COULD BE MEASURED SIMULTANEOUSLY

  $\bar{p}p \to \pi^+\pi^-,\ K^+K^-,\ \ldots$

  $\Delta\sigma_L(\bar{p}p),\ \Delta\sigma_T(\bar{p}p)$

"Hadronic" Physics

Vast multiplicity of topics
- You probably worked on some of this once...
  - you were young
  - it was the sixties
  - everybody did it

Most could be profitably pursued at FMC front end

Most don't require the high flux
- they are mainly just looking for a home
- they need good beams and detectors
  - some could be just brought from other labs

Some exceptions, where flux is necessary
- *e.g.* polarized $\bar{p}$'s

SEARCH FOR CPT VIOLATION and STUDY OF CP VIOLATION IN THE K_S SYSTEM

Steve Schnetzer
Rutgers

<u>Tests of CPT</u>

- measure phase difference of η_{+-}
- evaluate Bell-Steinberger

<u>Measure CP violation</u>

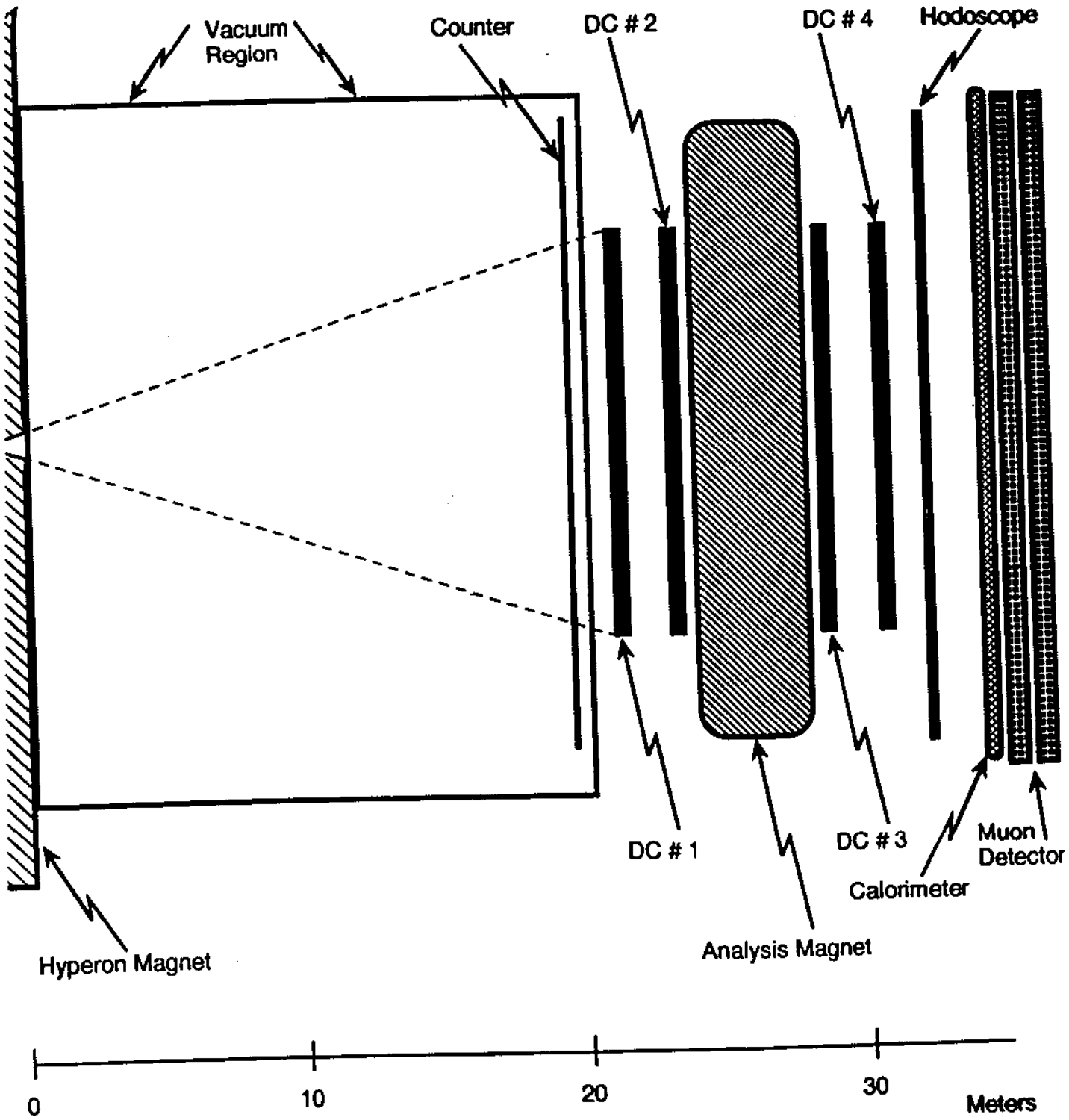
- first measure of $\not{CP}$ outside of K

  η_{+-0} η_{000}

- direct $\not{CP}$ $\eta_{+-\gamma}$

<u>Rare K_S decays</u>

- $K_S \to \pi^0 e^+ e^-$



The CPT Experiment

Summary of Principle Measurements

	existing	this expt.
ϕ_{+-}	$\pm 1^\circ$	$\pm 0.02^\circ$
$Im(x)$	$\pm 2.6 \times 10^{-2}$	$\pm 5 \times 10^{-4}$
$Im(\eta_{+-0})$	$\pm 1.7 \times 10^{-2}$	$\pm 6 \times 10^{-4}$
$Im(\eta_{000})$	$\pm 3 \times 10^{-1}$	$\pm 2 \times 10^{-3}$
$\lvert\eta_{+-}\rvert$	$\pm 1\%$	$\pm 0.1\%$
$\lvert\eta_{+-\gamma}\rvert$	$\pm 3\%$	$\pm 0.2\%$
$K_S \to \pi^0 e^+ e^-$	$< 10^{-6}$	$\sim 10^{-10}$

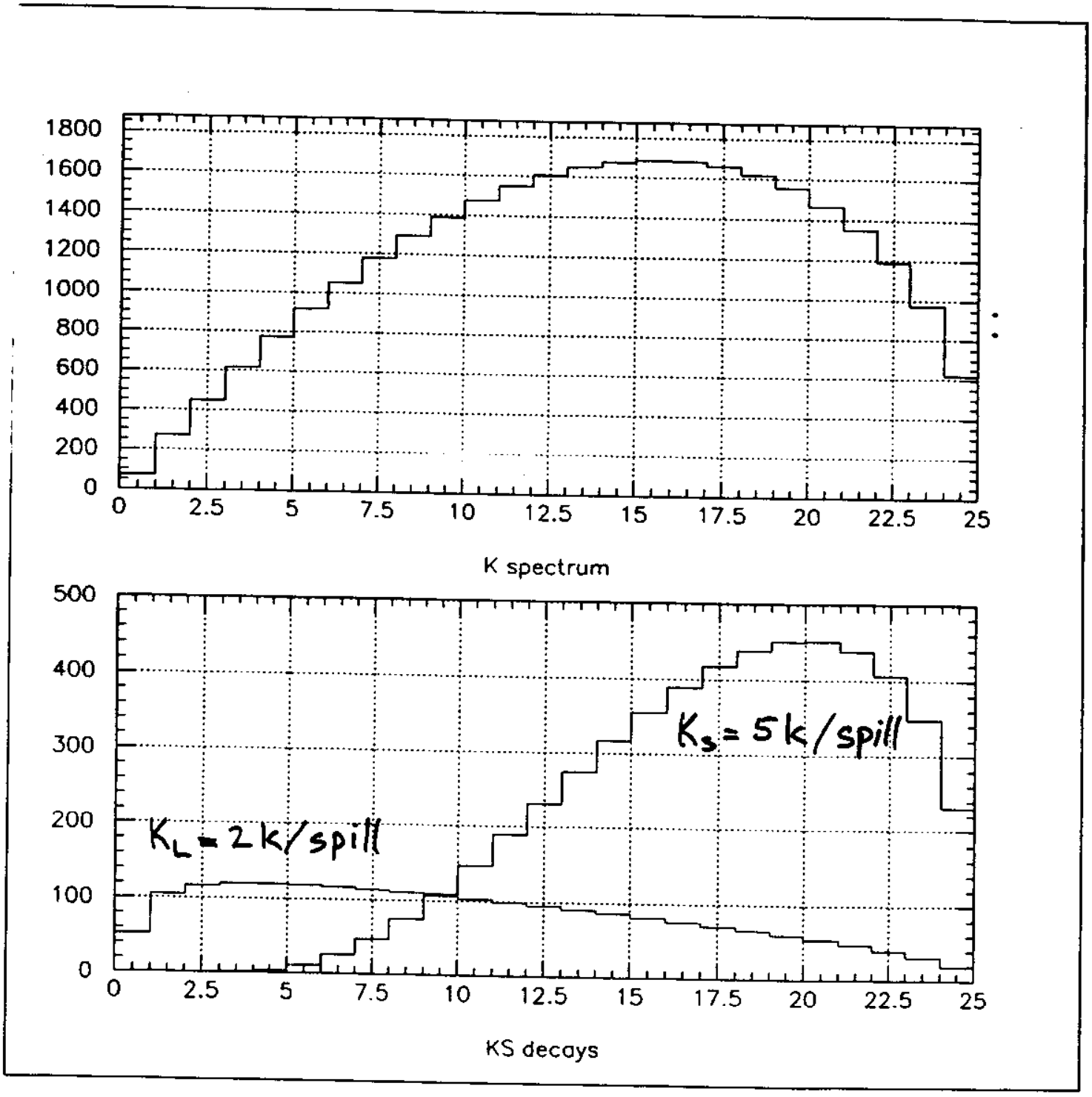

1800
1600
1400
1200
1000
800
600
400
200
0
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
K spectrum
500
400
300
200
100
0
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
$K_S = 5k/spill$
$K_L = 2k/spill$
KS decays

Fig. 3

With Muon Collider Front-End

Use 10 GeV K^+ beam

$$\frac{\sigma(pN \to K^+X)\,[p = 120\,\text{GeV};\ K^+ = 25\,\text{GeV}]}{\sigma(pN \to K^+X)\,[p = 16\,\text{GeV};\ K^+ = 10\,\text{GeV}]}$$

$$= 12$$

$\Rightarrow$ 5×10^{12} p/spill

$\longrightarrow$ 2×10^{13} p/s

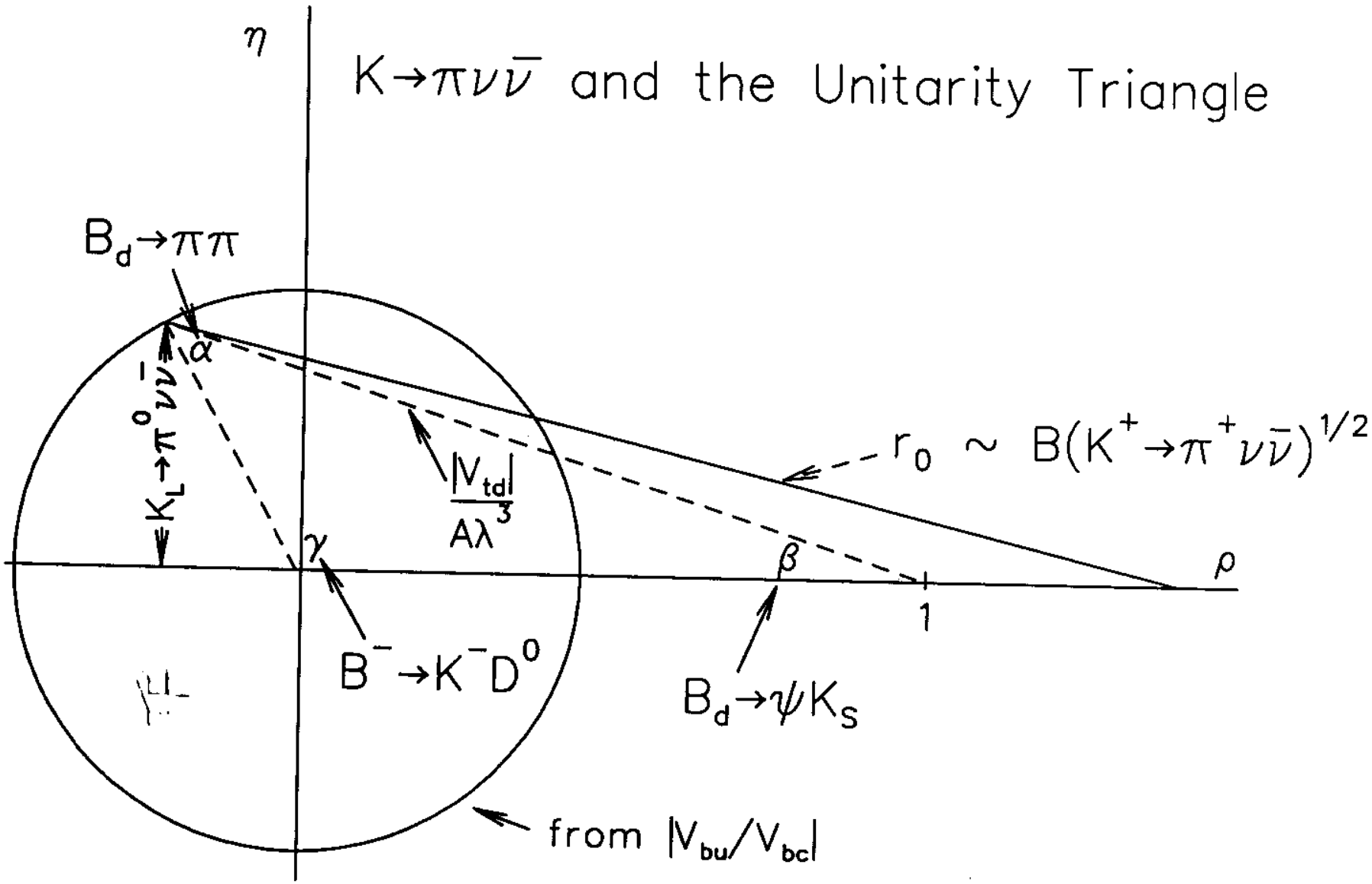
Acceptance somewhat reduced

η_{000} becomes hard

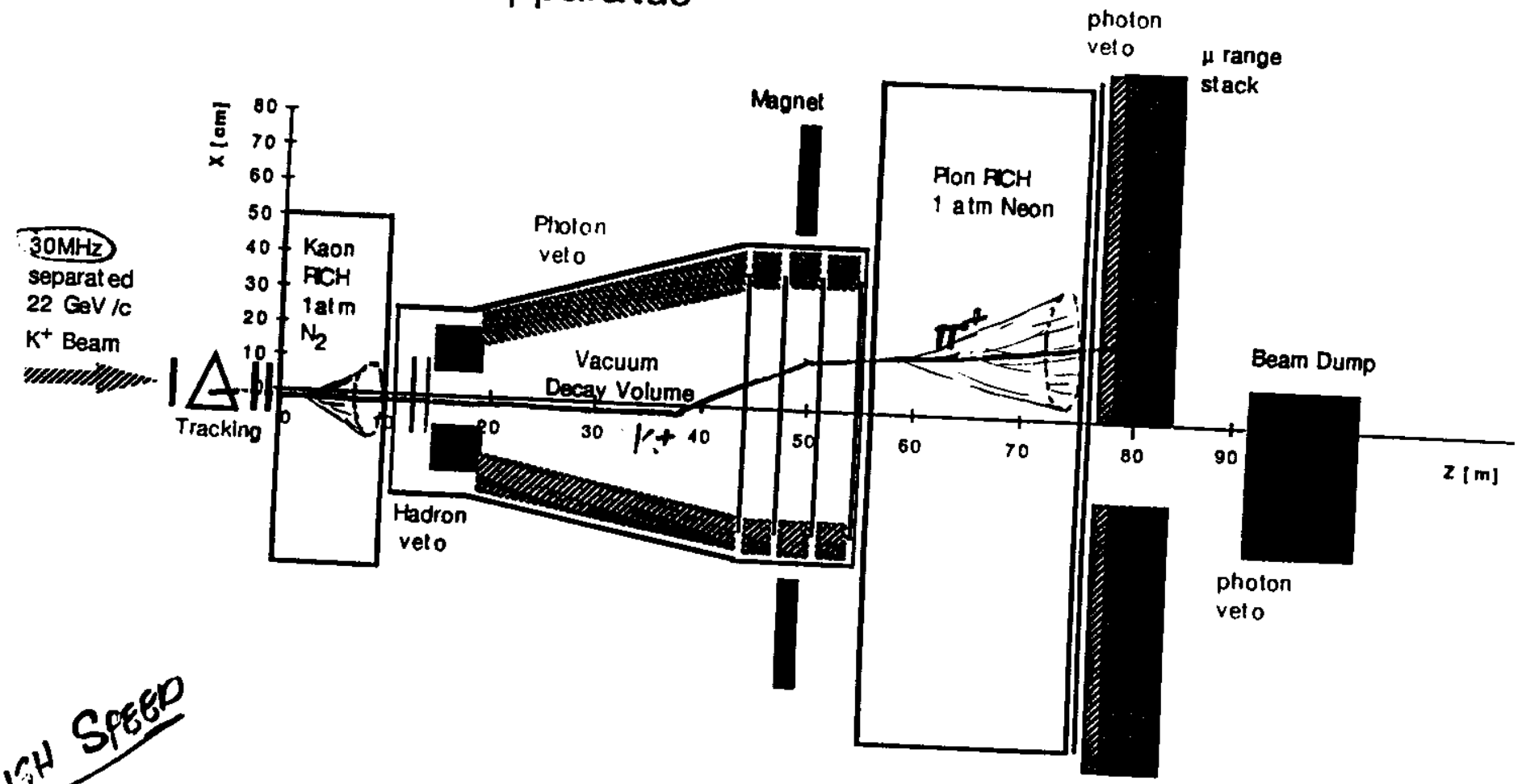
Comparison of "CPT"

at Main Injector vs. FMC

P_K	Relative Yield	Relative charge EX. σ	Relative decay loss	Relat K_s dec per pro
25	1*	1	1	1
10	0.1	10	0.2	0.2
8	0.3	12	0.1	0.3
6	1.4	20	0.03	0.8
4	4.2	50	0.003	0.6
2	8.3	200	3×10^{-6}	0.005


$K \to \pi\nu\bar{\nu}$ and the Unitarity Triangle
η
ρ
1
$B_d \to \pi\pi$
α
$K_L \to \pi^0 \nu\bar{\nu}$
$\frac{|V_{td}|}{A\lambda^3}$
$r_0 \sim B(K^+ \to \pi^+ \nu\bar{\nu})^{1/2}$
γ
β
$B^- \to K^- D^0$
$B_d \to \psi K_S$
from $|V_{bu}/V_{bc}|$

CKM Apparatus

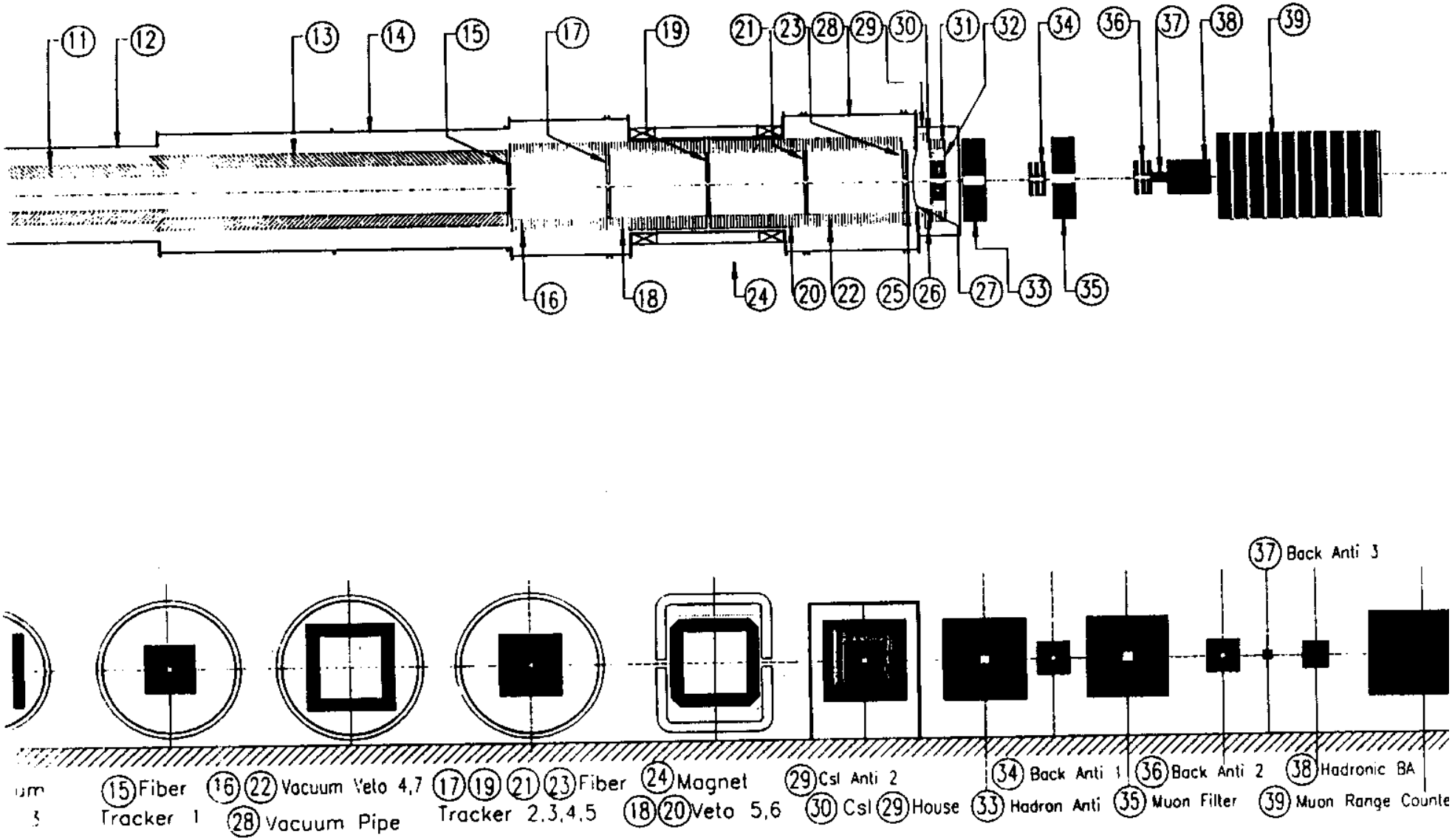


HIGH SPEED

MOMENTUM SPECTROMETER → $K^+, \pi^+ (\vec{p})$ ← $(\vec{p})$

VELOCITY SPECTROMETER → $K^+ \pi^+$ (a [illegible])

Tschirhart



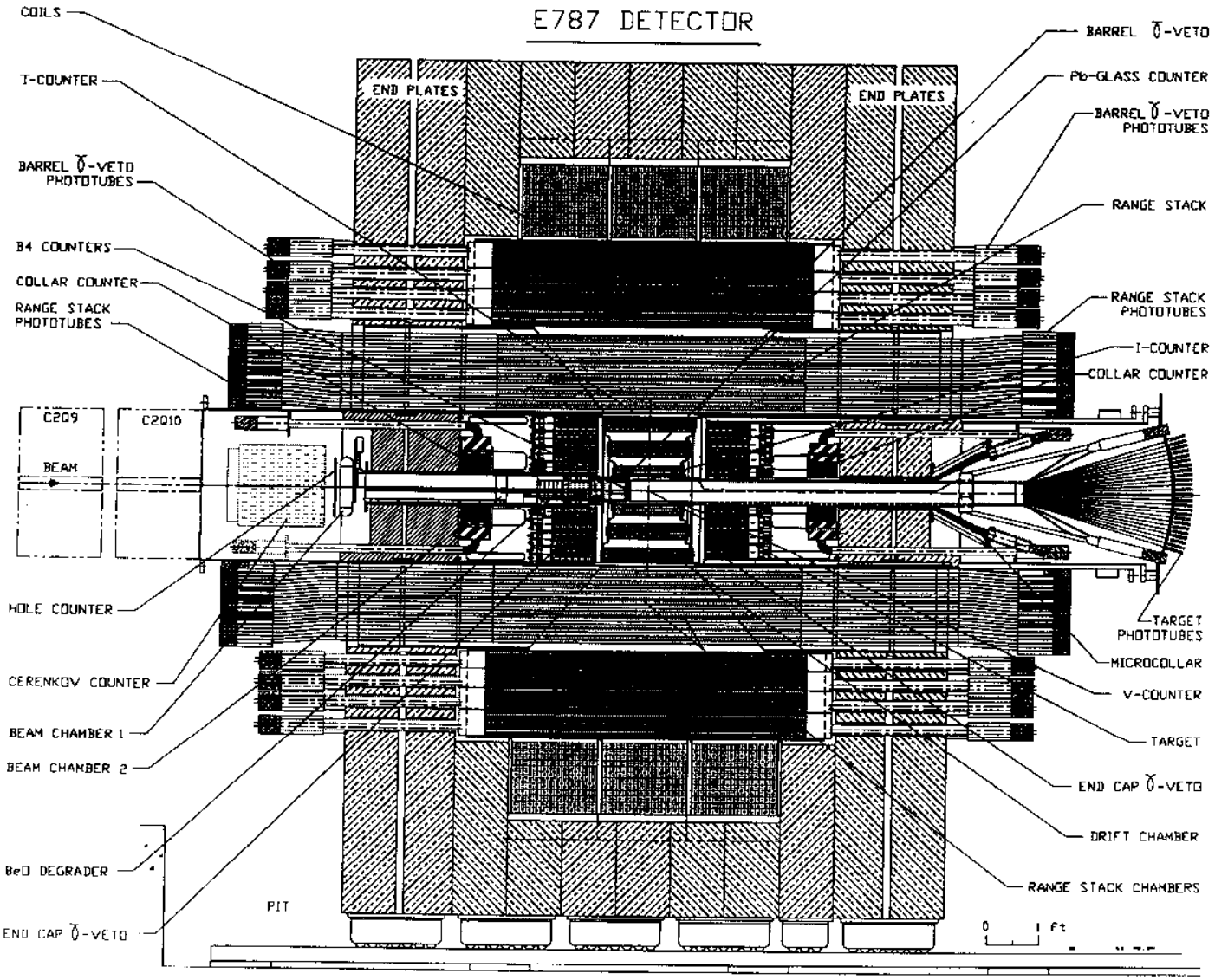
KAMI Detector

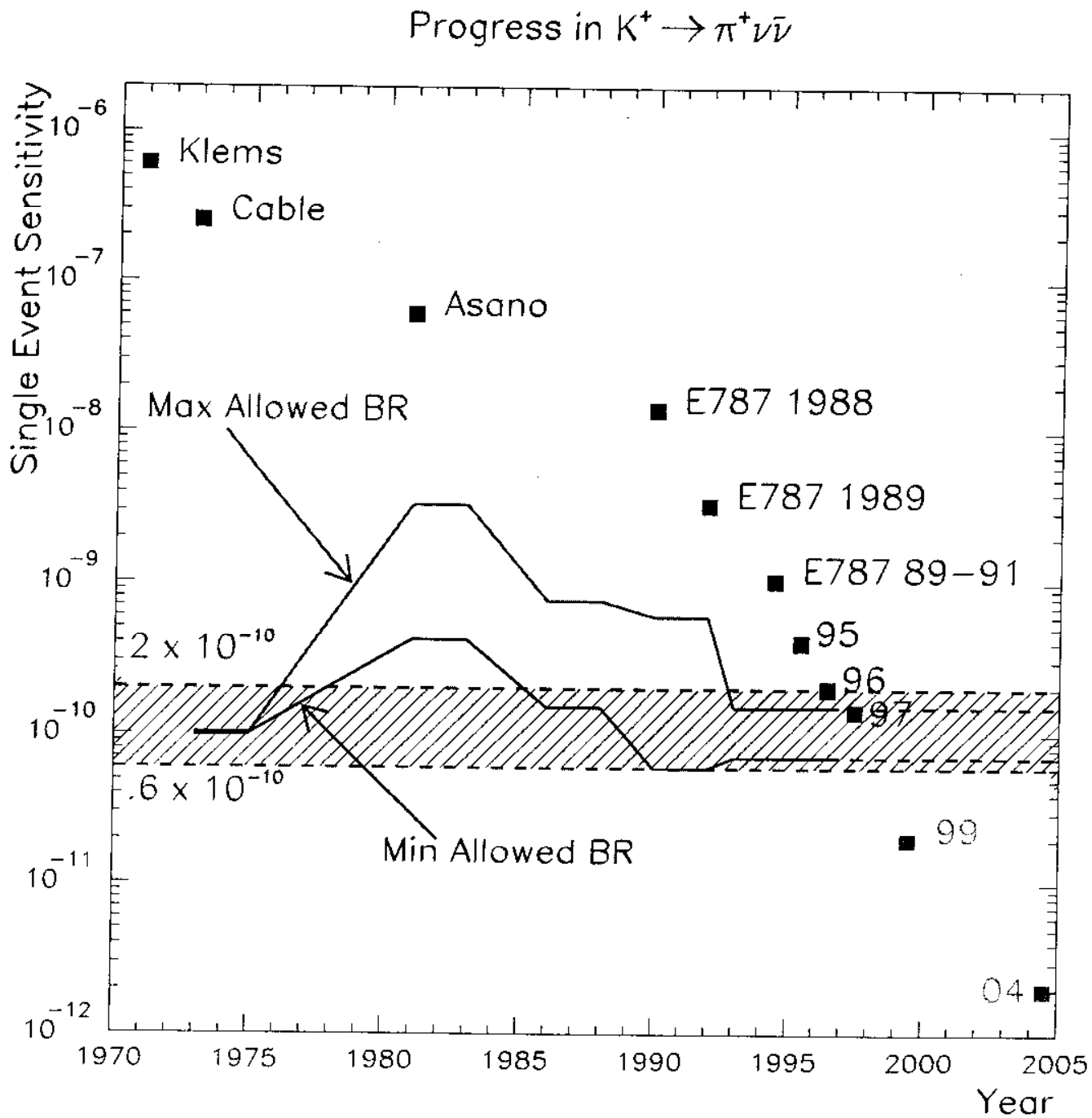
Arisaka

E787

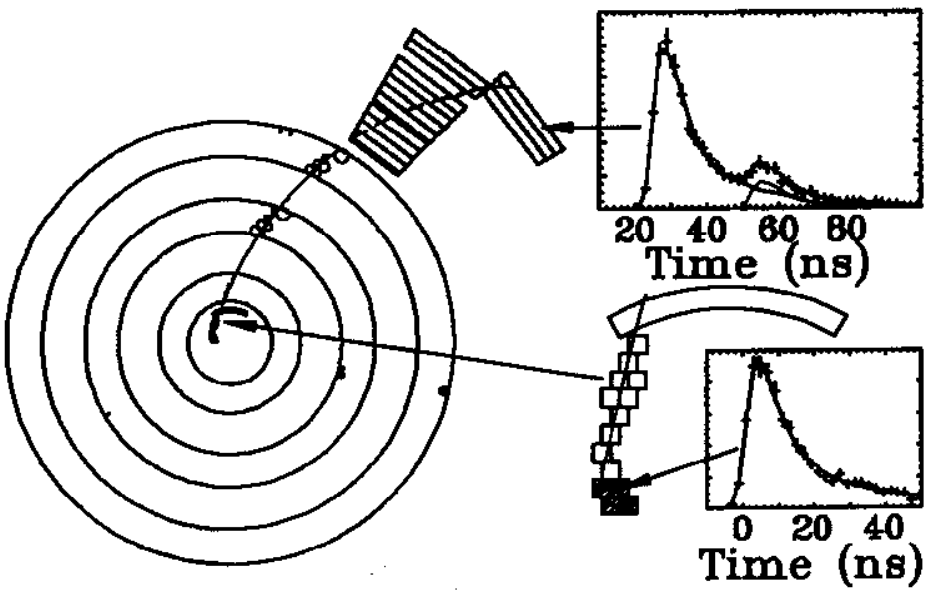
Search for $K^+ \to \pi^+ \nu\bar{\nu}$ and related processes

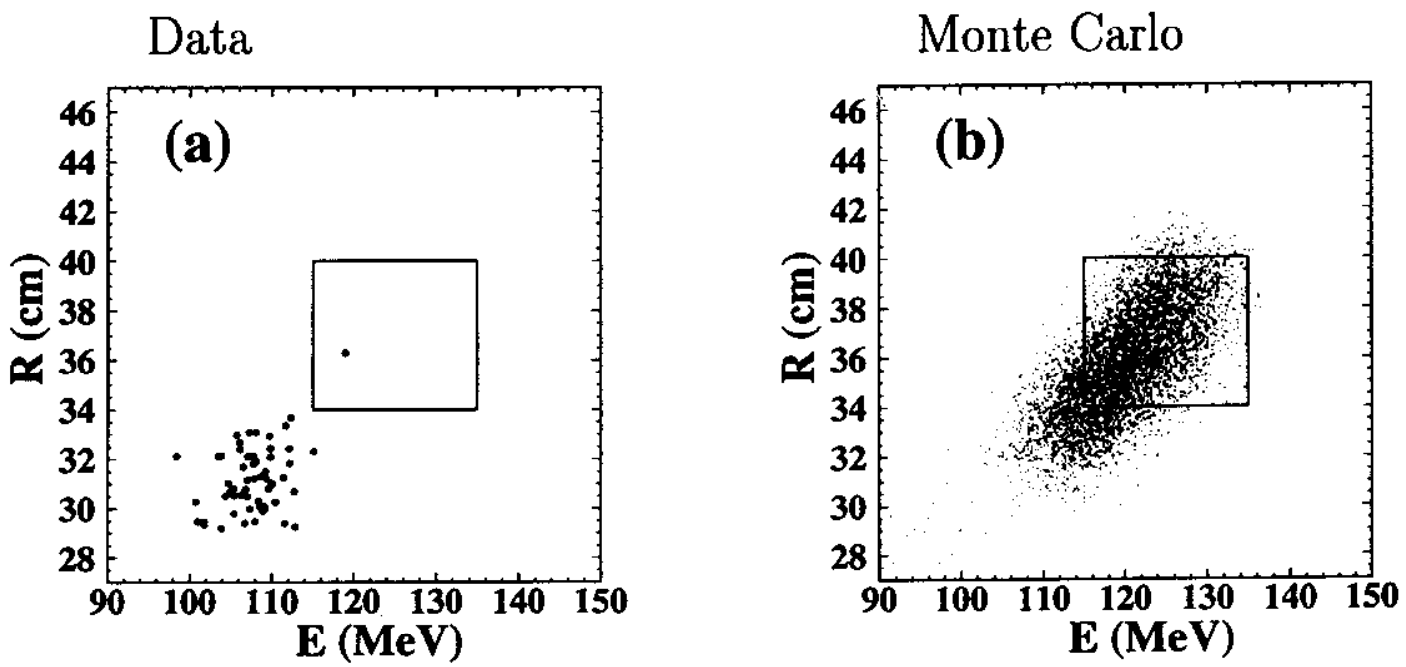
BNL/KEK/Osaka/Princeton/TRIUMF




Progress in $K^+ \to \pi^+ \nu\bar{\nu}$
Single Event Sensitivity
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
Klems
Cable
Asano
E787 1988
E787 1989
E787 89−91
95
96
97
99
04
Max Allowed BR
Min Allowed BR
2×10^{-10}
$.6 \times 10^{-10}$
1970
1975
1980
1985
1990
1995
2000
2005
Year

$K^+ \to \pi^+ \nu\bar{\nu}$ event





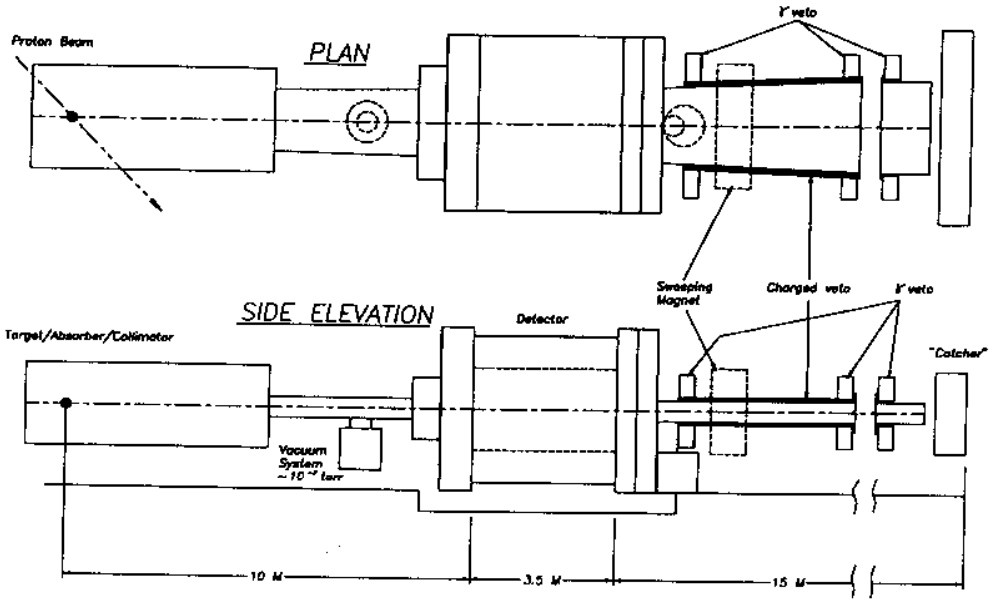
- Probability for the event to be one of the known backgrounds is very low.

$K^+ \to \pi^+ \nu\bar{\nu}$: from E787 to FMC Front End

How we think we're doing lately:	2×10^{-10}/yr	15TP
Max spill, double year (to 30wks):	6×10^{-11}/yr	50 TP
Reduce beam p, use $\pi\nu\bar{\nu}2$:	2×10^{-11}/yr	100TP
Go to MCFE (d.f. $0.73 \Rightarrow 0.9$):	1.7×10^{-11}/yr	25TP/sec
Further reduce beam p:	1.3×10^{-11}/yr	50TP/sec
Drop e from $\pi \Rightarrow \mu \Rightarrow e$:	9.5×10^{-12}/yr	50TP/sec
30 weeks $\Rightarrow$ 45 weeks/year:	6.4×10^{-12}/yr	50TP/sec
Speed up vetoes:	3.2×10^{-12}/yr	100TP/sec
Reduce Δp, increase geom. acc.:	2.5×10^{-12}/yr	300TP/sec
Better beam/tgt instrumentation:	1.6×10^{-12}/yr	300TP/sec
Improved stopping cntr technology:	1.0×10^{-12}/yr	300TP/sec

Notes -
Background $\sim 10\%$ of signal
Maximum proton flux = 375 TP/sec

Detector for $K_L \to \pi^0 \nu\bar{\nu}$



Goal is ~ 100 events with S/B ≥ 10

Strategy is to get as much information as possible:

- measure P_{K_L} by microbunching 1GeV/c beam
- measure γ angles as well as energies and times

Large (asymmetric) aperture beam at 45°

Large geometric acceptance

γ angles measured in $\sim 1.5 r.l.$ preconverter/calorimeter

Scifi calorimeter

Hermetic veto, including *in* the beam

Expected background levels

1. $K_L \to \pi^0\pi^0$ (the main background)

   - Contributes at 10% of SM prediction (detailed MC).
     $10^{-3}(BR) \times (10^{-4})^2(\bar{\pi^0}) \times 0.05(kinematics) \times 6({}_4C_2)$
     $= 3 \times 10^{-12}$
   - Reliable estimate of the background using
     2 independent cuts ($\bar{\gamma}$ and kinematics) like E787.

2. Other backgrounds are negligible at the AGS.

   - $K_L \to \pi^0\pi^0\pi^0$ (Vertex,$\bar{\gamma}$)
   - $K_L \to \pi^-e^+\nu$ (Kinematics, Charged veto)
   - Accidentals (Vertex, TOF)
   - $(\Xi \to)\Lambda \to n\pi^0$ (Low energy K_L)
   - n interaction (Vacuum, TOF, Low energy)

Process	Modes studied	Main	events
$K_L \to \pi^0\nu\bar{\nu}$			70
K_L decays ($\bar{\gamma}$)	$\pi^0\pi^0$,$\pi^0\pi^0\pi^0$,$\pi^0\gamma\gamma$	$\pi^0\pi^0$	7
$K_L \to \gamma\gamma$	$\gamma\gamma$	$\gamma\gamma$	0.04
K_L decays ($\overline{chrg}$)	$\pi^\pm e^\mp\nu$,$\pi^\pm\mu^\mp\nu$,$\pi^+\pi^-$	$\pi^-e^+\nu$	0.01
K_L decays ($\bar{\gamma}, \overline{chrg}$)	$\pi^+\pi^-\pi^0$,$\pi^\pm l^\mp\nu\gamma$, $\pi^\pm l^\mp\nu\pi^0$,$\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^0$	0.003
Other decays	$\Lambda \to \pi^0 n, K^- \to \pi^-\pi^0, \Sigma^+ \to \pi^0 p$	$\Lambda \to \pi^0 n$	0.03
Interactions	n, K_L, γ	$n \to \pi^0$	0.5
Accidentals	n, K_L, γ	n, K_L, γ	0.3

$K_L \to \pi^0 \nu\bar{\nu}$: from E926 to FMC Front End

Nominal estimate of E926:	1.2×10^{-12}/yr	50TP
MCFE: Comfort factors/d.f.=0.9: Longer beam Filter Tune angle/aperture	1×10^{-12}/yr	50 TP/sec
Shorten decay volume, smaller beam:	5×10^{-13}/yr	200 TP/sec
Better time response, double rate:	3×10^{-13}/yr	375 TP/sec

T-violating μ polarization in $K\mu 3$

T-violating μ^+ polarization in $K^+ \to \pi^0 \mu^+ \nu_\mu \approx 0$ in SM

Predicted to be finite by many non-SM explanations of CP-violatio

15-year old BNL experiment gives $|P_\mu^T| < .009$ at 95% c.l.

KEK E246 plans to improve this by $\gtrsim$ 1 $O.M.$
and now propose to move experiment to the AGS in 2000
goal is to reach $\Delta P_T = 3.5 \times 10^{-4}$

Proposal for new BNL experiment to take this to 1.5×10^{-4}

In multi-Higgs model can to be compared to:

Measurement	Value	$P_\mu^T <$	
		$m_h \sim m_W$	$m_h \sim 2m_W$
d_n	$< 1.2 \times 10^{-25} e - cm$ (95% c.l.)	0.064	0.064
d_e	$< 1.7 \times 10^{-26} e - cm$ (95% c.l.)	-	-
$\frac{\epsilon'}{\epsilon}$	$(1.5 \pm 0.8) \times 10^{-3}$	-	-
Δm_K	$(3.510 \pm 0.018) \times 10^{-6}$eV	-	-
$B(b \to s\gamma)$	$(2.32 \pm 0.67) \times 10^{-4}$	0.08	0.02
$B(b \to X\tau\nu)$	$(4.08 \pm 0.98) \times 10^{-2}$	0.009	0.009
P_τ^T in $b \to X\tau\nu$	23%	0.0013	0.0013

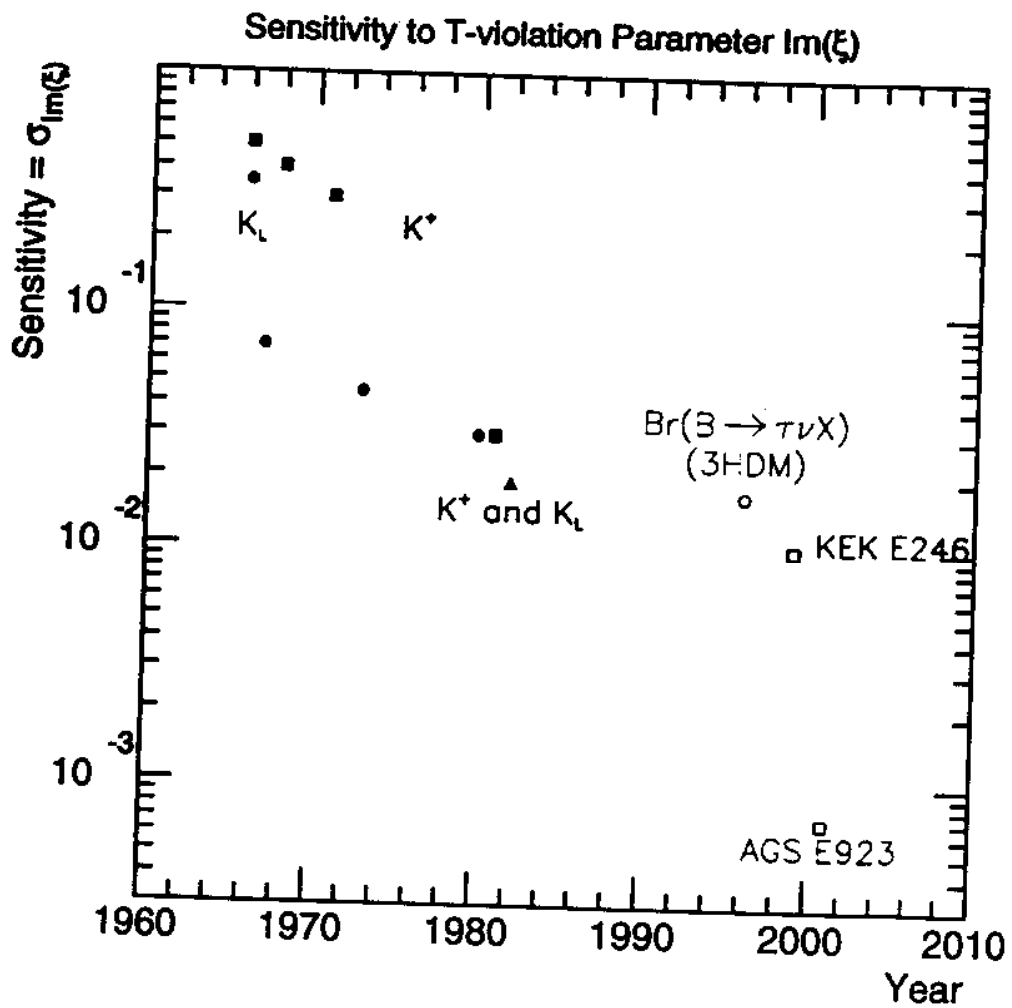
MHM effect that induces $|P_\mu^T| = .00015$, will give $|P_\tau^T| \sim 2.5\%$
- still far too small to be seen until well into 21st century

Bottom line:

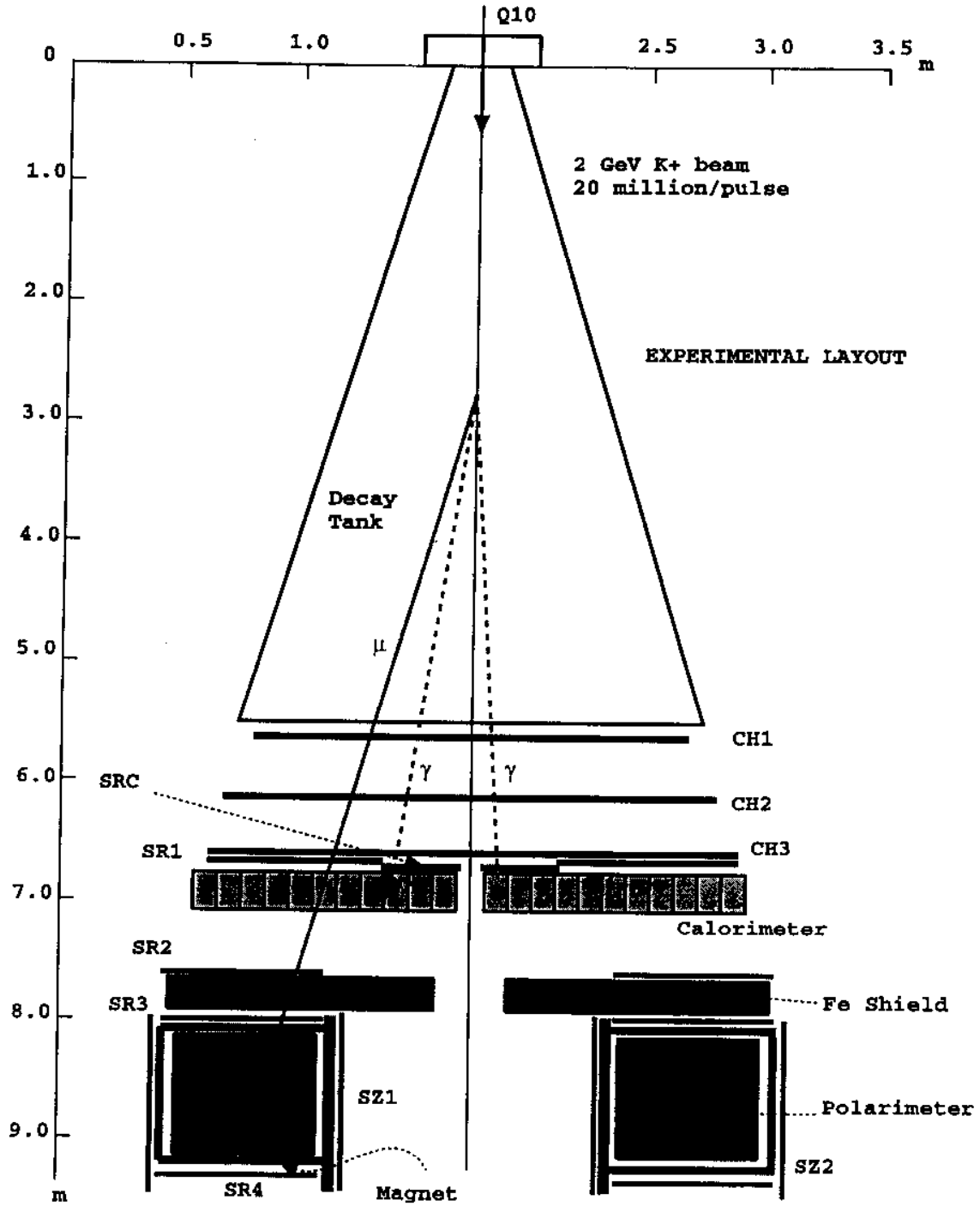
K experiment will still be uniquely sensitive

- J. J. Sakurai in 1958 proposed the tests of Time reversal in $K_{\mu 3}$ decay.

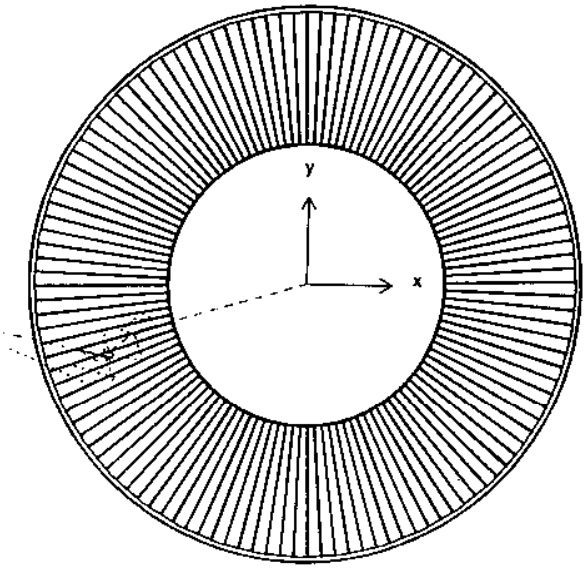
- Experimental measurements:

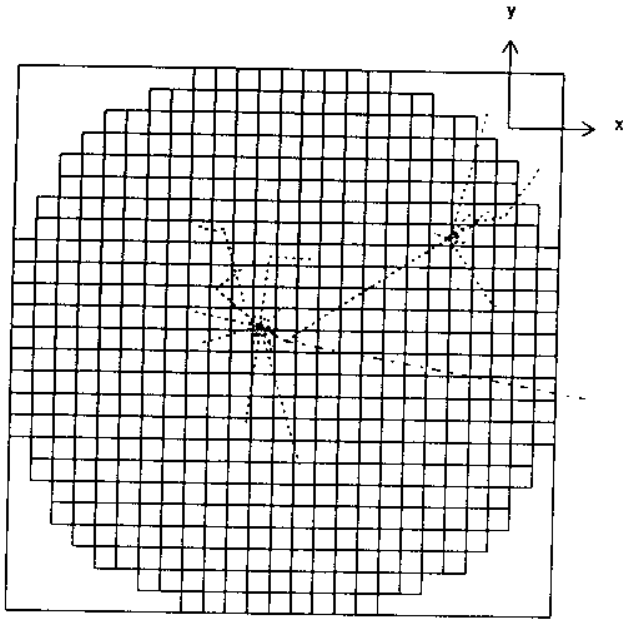


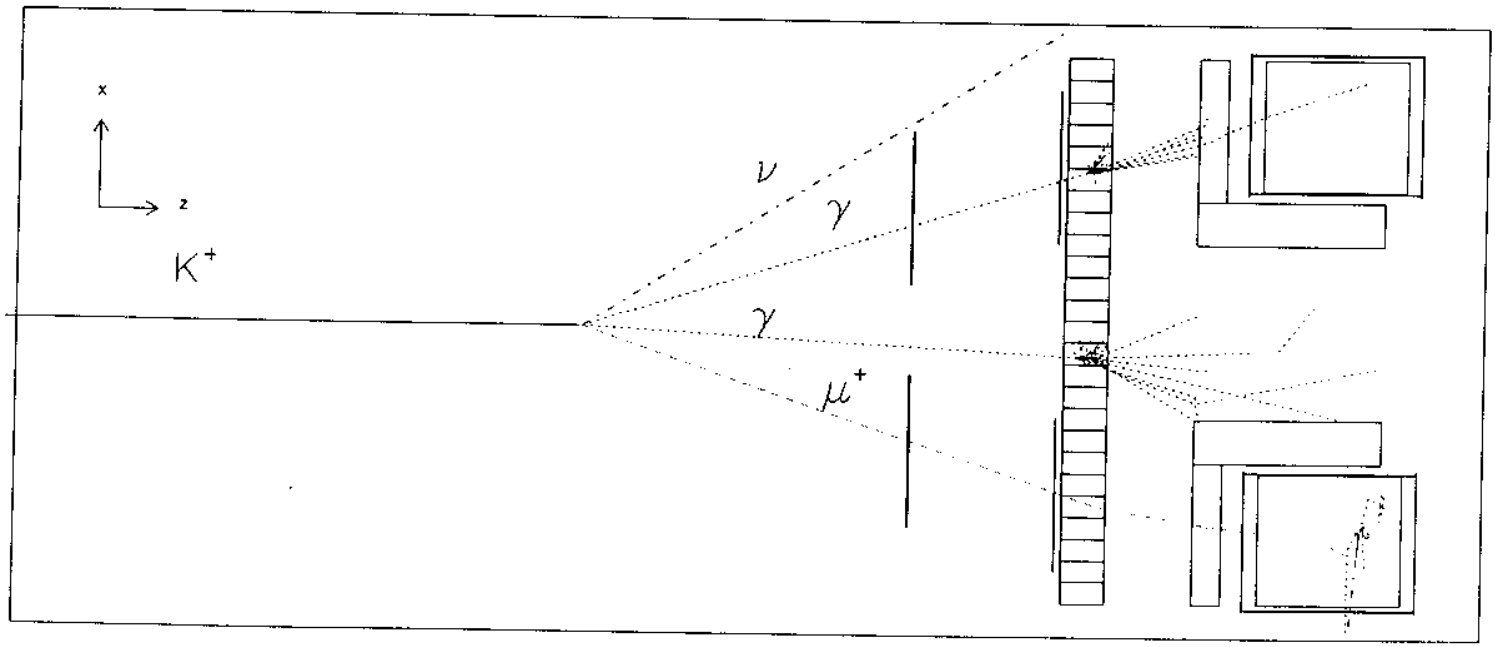
- Recent theoretical interests:
  M. Leurer, PRL 62(1989) 1967
  G. Belanger and C. Geng, PRD 44(1991)2789
  R. Garisto and G. Kane, PRD 44(1991)2038
  Y. Grossman and Z. Ligeti, Phys. Lett. B347(1995)399
  G. Wu and J. Ng, Phys. Lett. B392(1997)93


Q10
0
0.5
1.0
2.5
3.0
3.5
m
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
m
2 GeV K+ beam
20 million/pulse
EXPERIMENTAL LAYOUT
Decay
Tank
μ
γ
γ
CH1
CH2
CH3
SRC
SR1
Calorimeter
SR2
SR3
Fe Shield
SZ1
Polarimeter
SZ2
SR4
Magnet

$K_{\mu 3}$ Polarization Experiment, Baseline Design







Intensity Increase in E923

Max beam at AGS D6 line

5 MHz particle flux in Calorimeter

1.5 MHz " " Polarimeter

125 KHz Positron Signal

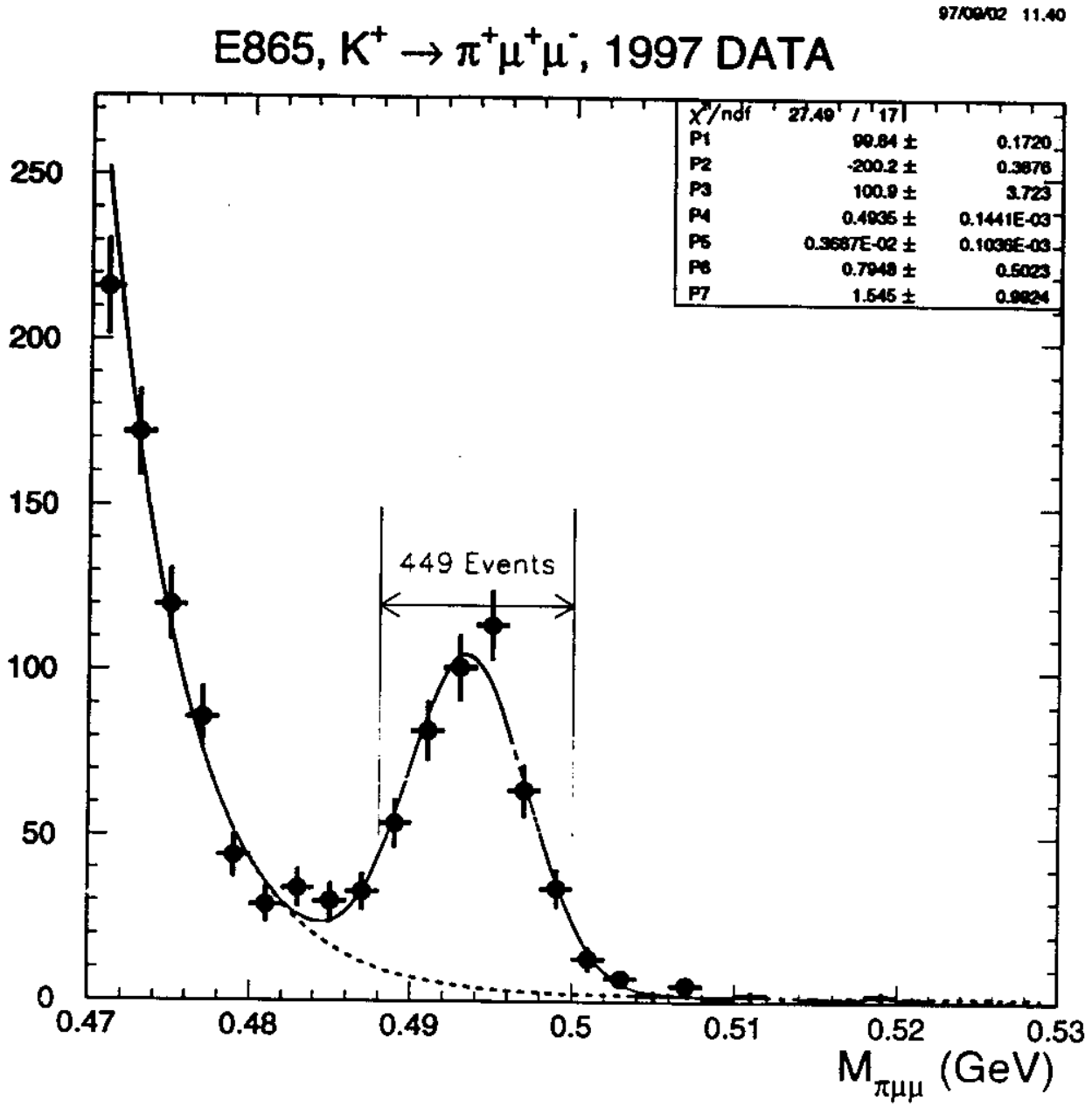
Limitation by muon life time

Need to segment the polarimeter more

Systematic error.

System	Rate (MHz)
CH1	4.8
CH2	4.8
CH3	4.8
SR1	3.8
SRC	1.0
SR2	2.0
SR3	1.3
SZ1	0.5
SZ2	0.3
SR4	1.1
Calor. > 0 CL	5.6
Calor. $\geq$ 3 CL	0.61
Polarimeter	2.5

Table 3: *Singles rates in the detector elements for an incoming flux of* 2×10^7 K^+ *particles per second. The calorimeter rates are for at least 1 cluster (a group of adjacent hits) above 75 MeV and at least 3 clusters above 75 MeV. The polarimeter hit rate includes both stopping and through-going particles.*


97/09/02 11.40
E865, K+ → π+μ+μ-, 1997 DATA
χ²/ndf 27.49 / 17
P1 99.84 ± 0.1720
P2 -200.2 ± 0.3876
P3 100.9 ± 3.723
P4 0.4935 ± 0.1441E-03
P5 0.3687E-02 ± 0.1036E-03
P6 0.7948 ± 0.5023
P7 1.545 ± 0.9924
449 Events
250
200
150
100
50
0
0.47
0.48
0.49
0.5
0.51
0.52
0.53
Mπμμ (GeV)

Kaons

FMI $K \to \pi\nu\bar{\nu}$ exps. optimized for high energy
- very hard to adapt to FMC front end

BNL $K \to \pi\nu\bar{\nu}$ exps. easy to adapt
- some progress "free"
- but these techniques may not surpass FMI exps.

Some goals of CPT experiment could be pushed at FMC
- beam may lend itself to other uses

$K\mu 3$ T-violation experiment fairly well matched to FMC
- possibly do P-viol. μ pol. in $K^+ \to \pi^+\mu\mu$

Conclusions

If you build it, they will come
- but, do you really want *them* around?
- well, maybe if they are willing to pay.

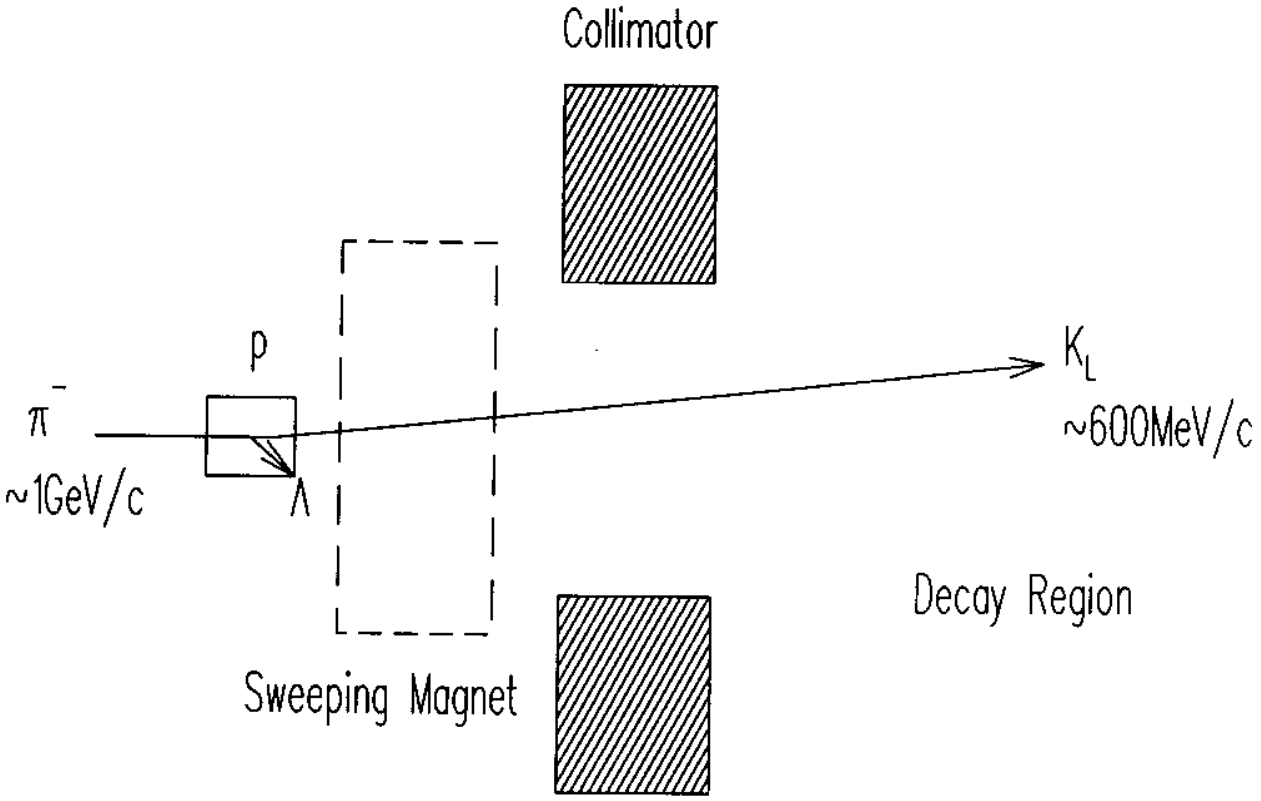
Can the muon collider afford a beam switchyard, etc.?
- could tap the stretcher fund.
- more likely only a few experiments.

Clear niche for certain very interesting experiments
- *e.g.* T-violating μ polarization in $K\mu 3$

Could be a lot more than this, if other projects falter
- prospects very scenario dependent

Best experiments in mature areas
- could make some progress with recycled detectors
- but considerable investments needed for big gains
- case or two where a new threshold may be crossed
  e.g. strangeness exchange beam of K_L

Commitment of machine availability a must!


Collimator
p
π^-
~1GeV/c
Λ
K_L
~600MeV/c
Decay Region
Sweeping Magnet