SNOWMASS 2001
7/6/01
C. A. HEUSCH

THE IMPORTANCE OF BEING $e^- e^-$

THE IMPORTANCE OF

- BEING A "CLEAN" $|in\rangle$ STATE
- BEING POLARIZED
- THE POLARIZATION BEING EASILY REVERSIBLE
- HAVING "EXOTIC" QUANTUM NUMBERS
- BEING COMPATIBLE WITH e^+e^-
- BEING NEEDED FOR $e^-\gamma$, $\gamma\gamma$ OPERATION

CONCLUSION:

THE IMPORTANCE OF MAKING THE RIGHT CHOICES <u>NOW</u>!

THE ONLY REALLY PURE FIELD AT OUR DISPOSAL IS

$$\boxed{e_L, \quad e_R}$$

NOT AVAILABLE IN e^+

γ

hadron beams

(also, to a certain extent, $\boxed{\mu}$s; but we cannot switch their polarization).

$|\vec{P}_{e^-}| = 80\%$ is routinely reached in SLD running at SLAC

- There is no known calc' limit'n
- Theoretical estimates put attainable $|\vec{P}|_{e^-}$ values at $< 95\%$

$|\vec{P}|_{e^+}$ is a much harder task

NO PROJECT BEYOND 65% IS BEING ENVISIONED.

Polarization

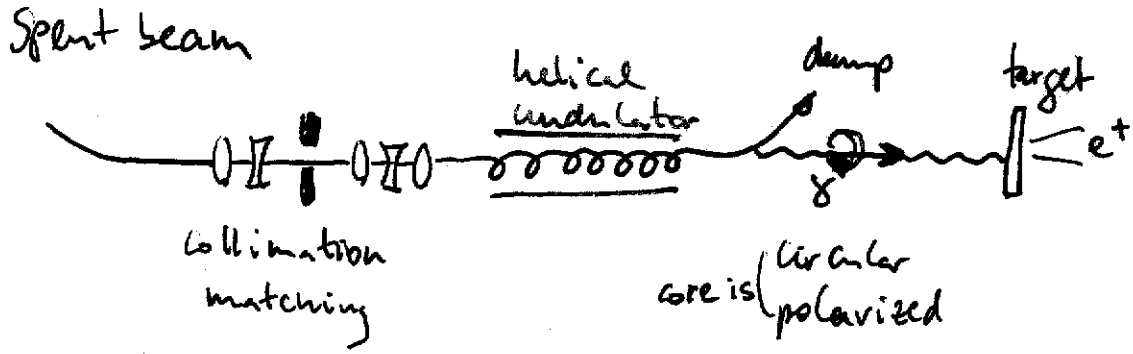
- e^- beam: polarization >80%

  → SLC! GaAs cathode

  prob. >90%

- e^+ beam: polarization 50... 60%

  using an helical undulator



Balakin
Mikhailichenko '79

no. hard to switch polarization

- WE CAN DO e^-e^- WELL

THERE IS A GREAT DEAL OF EXPERIENCE IN THE PREPARATION OF ELECTRON BEAMS

⇒ SOURCES

HIGH-POWERED
HIGH-DUTY-CYCLE
HIGH-POLARIZATION
} GUNS

ARE AVAILABLE, STEADILY IMPROVING

⇒ EMITTANCE

- COOLING RINGS HAVE BEEN PERFECTED, DO NOT LIMIT POLARIZATION
- STUDIES FOR OPTIMAL EMITTANCE RETENTION ARE SUCCESSFUL
- WAKEFIELD OPTIMIZATION IS STEADILY IMPROVING
- ACCELERATOR STRUCTURE (SURVEYING, ALIGNMENT, GEOMETRIES) NEEDS MAINLY BENIGN ENVIRONMENT TO PERMIT HIGH BEAM QUALITY

THE ACCESSIBILITY OF

I

- HIGH DEGREES OF POLARIZATION
- EASY HELICITY REVERSAL

FOR <u>BOTH</u> INCOMING BEAMS

IS ESSENTIAL FOR ENHANCEMENT OF SIGN/

AND SUPPRESSION OF BACKGROUND

→ <u>EASY</u> CHOICE OF CHIRAL COUPLINGS

II

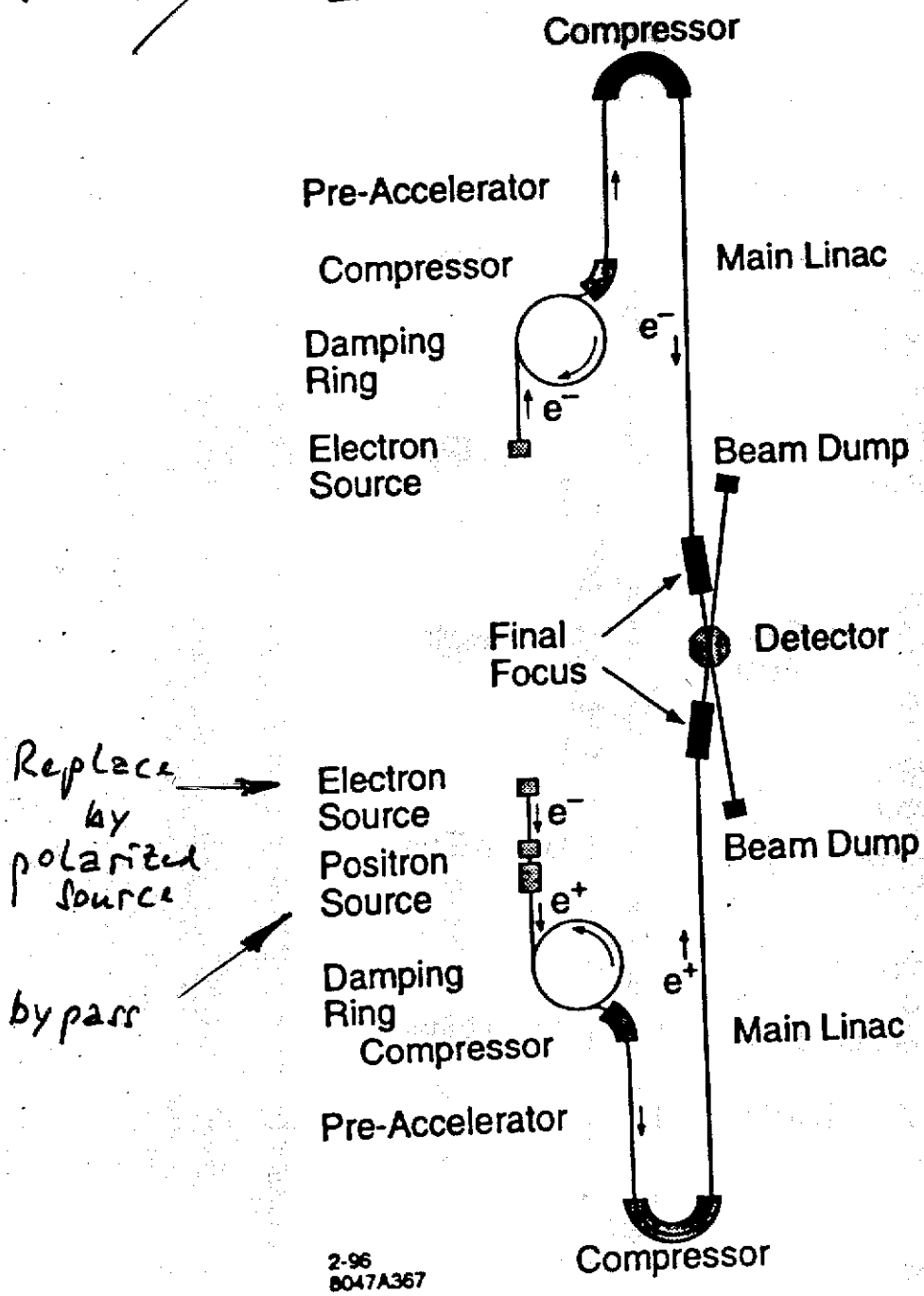
- DISTINCTIVE CHOICE OF INCOMING QUANTUM #'s FOR INITIAL STATE:

	Q_{ee}	S_z	L	L_e	I_3^W	Y^W
$e_L^- e_L^-$	-2	$+1$	2	2	-1	-2
$e_L^- e_R^-$	-2	0	2	2	$-1/2$	-3
$e_R^- e_R$	-2	-1	2	2	0	-4

PERMITS PROBING BEYOND THE CAPABILITIES OF LHC **AND** e^+e^- COLLIDERS

EASY SWITCH FROM e^+e^- to e^-e^-:

e.g., NLC / JLC



Straightforward changes for changeover $e^+e^- \rightarrow e^-e^-$

e– e– SWITCHOVER IN THE NLC LINAC

(Ray Larsen)

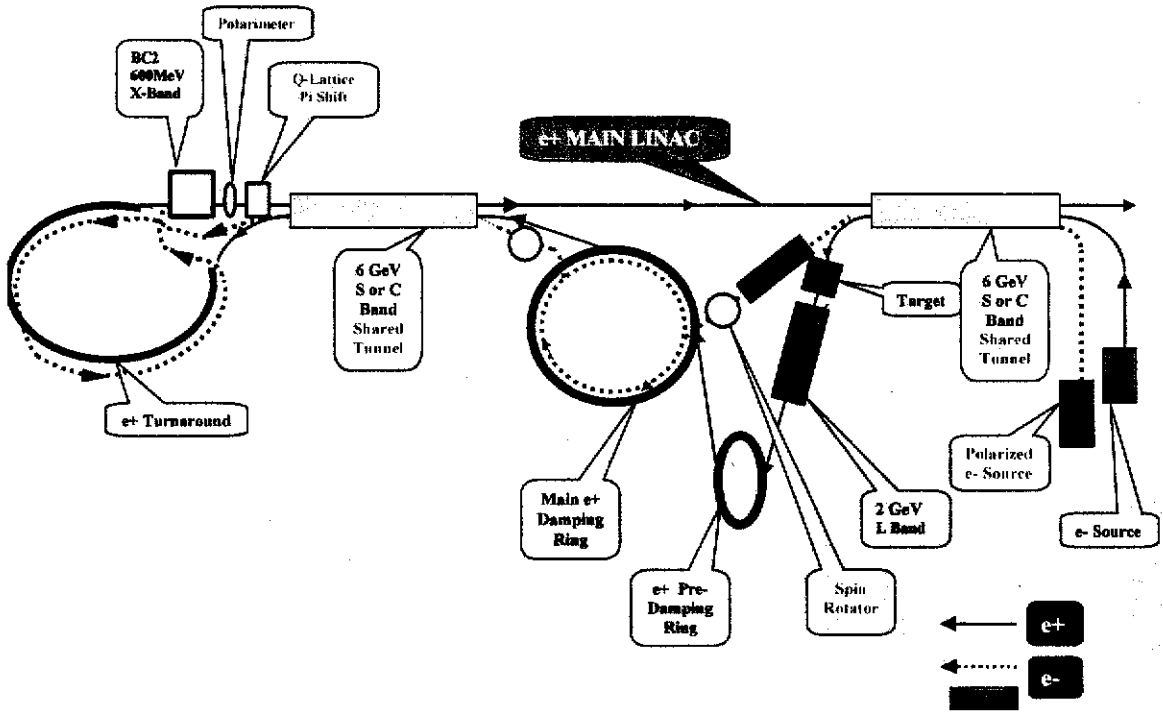


Fig. 2 Direction Reversal Model

Description:
A new Polarized e– Source is located near the e⇐ Source.
Beam is extracted from the first linac at 2 GeV.
A new tunnel and transport line injects beam into the Main DR in reverse direction.
A new Spin Rotator and Polarimeter are added.
A new extraction line is added for the reversed beam out of the MDR.
Beam is injected into the Turnaround in the reverse direction.
Reverse Polarity fast Kickers are added (not shown).
Launch into Q Lattice π Shift after Turnaround.

Advantages:
Avoids polarity reversals of all magnets in MDR and Turnaround.
Avoids PDR bypass entirely.
Avoids problems associated with juxtaposition of electromagnets and permanent magnets.
Switchover essentially automated and quick.

Disadvantages:
Requires additional tunneling.
Requires additional components for injection, extraction, kickers.

•• UNIQUE QUANTUM NUMBERS FOR e^-e^- INITIAL STATE.

A POTENT TOOL FOR

CONSERVATION STUDIES IN

SEARCH OF

⇒ FUNDAMENTAL SYMMETRIES

⇒ EXTENDED GROUP STRUCTURE / BEYOND-THE STANDARD MODE

TO WIT: e^-e^- INITIAL STATE HAS

$Q_\ell = -2$	
$L = +2$	$L_e = +2$
$I_W = -1$	
$Y_W = -2$	
$S_z = 1, 0, -1$ (easily tunable)	

THESE PROPERTIES PERMIT STUDIES OF

- THE MEANING OF LEPTON #

$$\left(\sum (B-L) = \text{const} \, ? \right)$$

LOOKING FOR

- "EXOTIC" PARTICLES THAT ARE HARBINGERS OF HIGHER SYMMETRY GROUPS,

  PROVIDES HINTS AT UNIFYING CRITERIA FOR G.U.T.S.

  → EXAMPLES: H^{++}, H^{--}

  DILEPTONS

  LEPTOQUARKS

- THE POTENTIAL LIMITS OF OUR MOST HALLOWED THEORY – <u>Q.E.D.</u>

  BY TAKING IT TO

  DENSITIES,

  CLEAN IMPACT PARAMETER STUDIES

  NEVER BEFORE REALIZED

JUST RECALL THE

ADDITIVE QUANTUM NUMBERS OF e^-e^- INITIAL STATES

	Q_{el}	s_z	L	L_e	I_3^W	Y^W
$e_L^- e_L^-$	-2	-1	2	2	-1	-2
$e_L^- e_R^-$	-2	0	2	2	$-1/2$	-3
$e_R^- e_R^-$	-2	$+1$	2	2	0	-4

- "EXOTIC" QUANTUM NUMBERS ARE FAVORABLE FOR ENHANCEMENT OF BEYOND-THE-S.M.-EFFECTS
- EASY FLIPPING OF HELICITIES SUPPRESSES "BACKGROUND EFFECTS"
  - permits only certain chiral couplings
  - changes I_3^W, Y^W

MAKING THE BEST USE OF "EXOTIC" QUANTUM NUMBERS

Imagine we find unexpected structure in

$\sigma_{tot}(\sqrt{E})$ $(e^-e^- \to e^-e^-)$

$\frac{d\sigma}{d\Theta}(e^-e^- \to e^-e^-)$

We cannot always do a meticulous energy scan,

but it is TRIVIAL TO CHANGE e^- HELICITY

e.g. → a structure could easily be

due to

strong WW scattering H^{--}

extended (strong) Higgs sector

dilepton gauge boson X^{--}

prod' and decay

changing $e_L^- \leftrightarrows e_R^-$ can decide very quickly!

DOES THE SIGNAL SURVIVE?

- - - VANISH?

J. GUNION WORKED OUT THE DETAILS OF SUCH NON-MINIMAL MODELS.

PHYSICAL MANIFESTATIONS. SEVERAL MORE HIGG BOSONS REQUIRED, OF WHICH

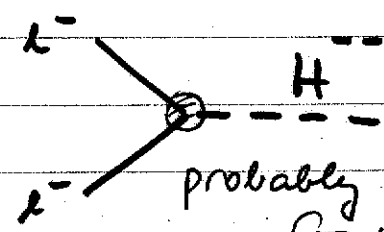
SIGNATURE H_5^{--} $(I_w = 1)$

CAN BE PRODUCED IN

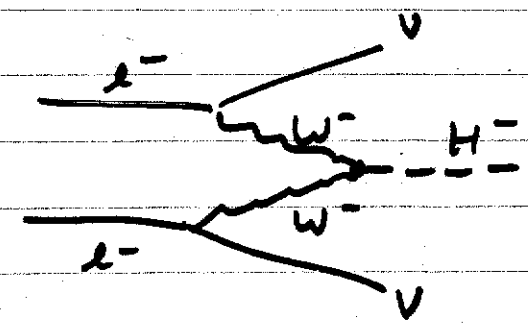
$$e^+e^- \xrightarrow[\gamma, Z^0]{} H_5^{++} H_5^{--}$$

WITH $R=1$, BUT ONLY AT $\sqrt{s} > 2m$

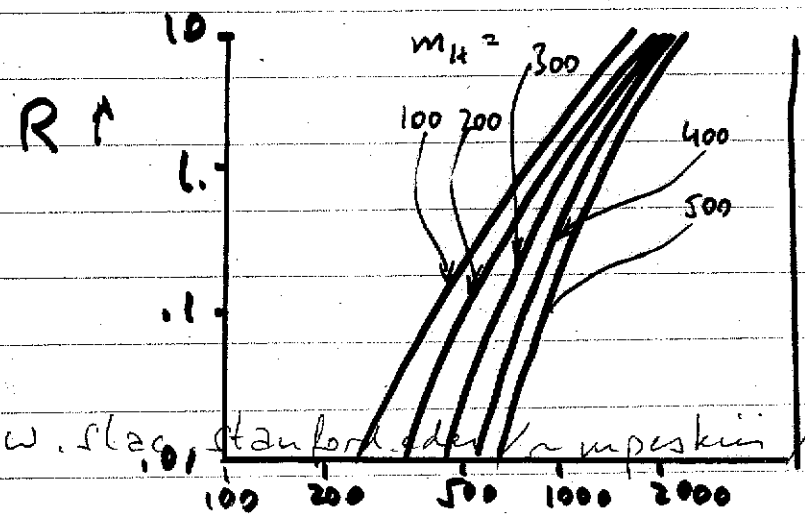
MOST SPECTACULARLY



probably SMALL, but



$R = 1$



www.slac.stanford.edu/~mpeskin/LC/pandora.html

SPECTACULAR SIGNATURES IN S-CHANNEL STRUCTURE

WITH TYPICAL H WIDTHS !

→ DECAYS

2-body $H^{--} \to W^- W^-$; $e^- e^-$

$H^- H^-$

↳ $e^- e^- + \nu$'s

3-body → $W^- W^{-*}$

↳ ...

4-body → $W^{-*} W^{-*}$

↳ $e^- + \nu$

→ $e^- + \nu$

IF $m(H^{--}) < 2m_W$,

2-body $H^{--} \to e^- e^-$!

$e^- e^-$ COLLIDER CERTAINLY APPEARS NEEDED

FOR FULL EXPLORATION OF

EXTENDED HIGGS SECTOR !

NOTE OF CAUTION: Beware of $e^- e^- \to$ $\boxed{\text{di leptons}}$ →

narrow peaks $\boxed{e^- e^- \quad \mu^- \mu^-}$

see below !

Width Y
≈ 3% mass
(like Z, W)
if M(Q) > M(Y)
as expected
otherwise
Width Y ≈
10%-12% mass.

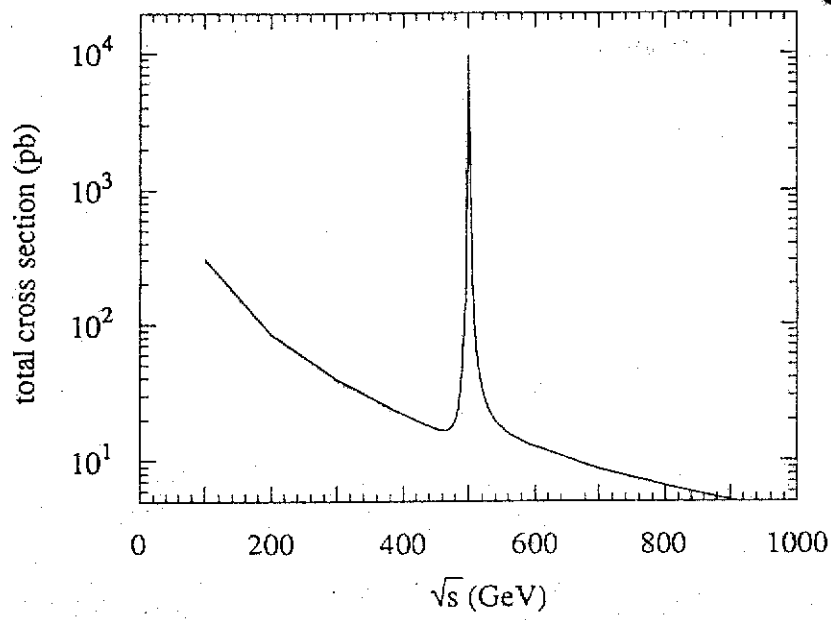


FIG. 6. Total cross section for $e^-e^- \to e^-e^-$ in the presence of X^{--} as a function of $\sqrt{s}$, where $|\cos\theta| < 0.8$ is used and $M_X = 500$ GeV is assumed.

$I_w(X^{--}) = 1/2$

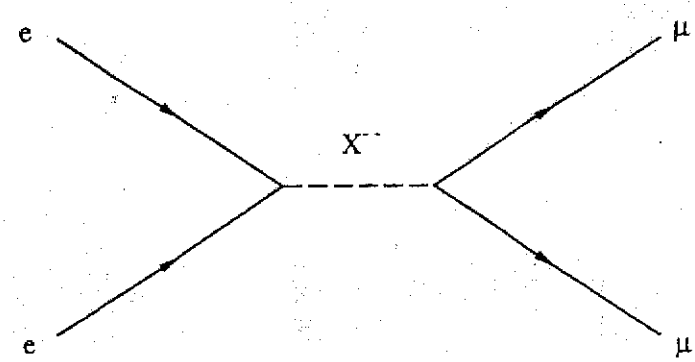


FIG. 7. Feynman diagram for the process $e^-e^- \to \mu^-\mu^-$ induced by X^{--}.

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of Energy C

From PHF + D. Ng PR D45, 4240 ('92)
See also: PHF MPL A7, 2017 (1992)

Doubly Charged Lepton Y^{--} (P. FRAMPTON)

H^{--} belongs to $I_W = 1$ triplet

Y^{--} "dilepton" $\in I_W = \frac{1}{2}$ doublet

We can easily disentangle these two effects by reversing helicities:

If the signal shows up in

we see a

$$e^-_L e^-_L \longrightarrow H^{--}$$

$$e^-_L e^-_R \longrightarrow Y^{--}$$

$$e^-_R e^-_R \longrightarrow \text{neither}$$

B.G.?

e^-e^- AND e^+e^- ARE FULLY COMPATIBLE INITIAL STATES

FEW ADJUSTMENTS PERMIT RUNNING THE SAME LINEAR COLLIDER IN ONE OR THE OTHER CHARGE MODE.

DIFFERENCES:

- e^-e^- OBVIOUSLY DOES NOT NEED A POSITRON "SOURCE"
- e^-e^- LUMINOSITY IS NOT ENHANCED BY BEAM-BEAM "PINCH"
  → ELECTROSTATIC DISRUPTION AROUND INTERACTION POINT HAS TO BE MADE UP FOR BY LARGER INCIDENT CURRENT
- BEAM DISPOSAL HAS TO BE HANDLED SUCH THAT "SPENT" BEAM DOES NOT HAVE TO FOLLOW BENDS IN OPPOSITE BEAMLINE

SEE
D ERICKSON J. SPENCER IN e^+e^- 91 PROCEEDINGS

$e^- e^-$ { COMPLEMENTS / COMPETES WITH } $e^+ e^-$ COLLIDERS

ON ESSENTIALLY ALL PRINCIPAL PHYSICS ISSUES (SAVE m_t, QCD).

TODAY, I WILL ADDRESS MOSTLY

- WEAKLY
- STRONGLY

} COUPLED E.W.S.B

→ HIGGS
→ SUSY
→ $W_L W_L \to \ldots$
→ ANOMALOUS COUPLINGS

AND BRIEFLY MENTION A FEW UNIQUE CAPABILITIES:

→ COMPOSITENESS
→ HEAVY MAJORAN NEUTRINOS

① e^-e^- SHOULD BE PART OF THE BASE-LINE DESIGN

- TO MINIMIZE THE OVERHEAD
- BECAUSE IT WILL BE NEEDED LATER ANYWAY FOR THE $e^-\gamma$, $\gamma\gamma$ OPTION.

MAKE IT CLEAR FROM THE START THAT e^+e^-, e^-e^- ARE FULLY

COMPATIBLE (I.R. detector)

COMPLEMENTARY (physics)

② THERE IS NO VIABLE WAY TO MAKE

monochromatic
highly polarized } high-energy photons from e^+e^-

FOR $e\gamma$, $\gamma\gamma$ COLLIDER CONFIGURATIONS:

THE PHOTON SPECTRUM IS PEAKED DEEPLY

AT $x \equiv \frac{k}{E_e} \approx 0.8$ FOR $\left\{ \begin{array}{l} \lambda_e = 1 \\ \lambda_\gamma = -1 \end{array} \right\}$

IT IS BROAD, FEATURELESS FOR $\left\{ \begin{array}{l} \lambda_e = 1 \\ \lambda_\gamma = 1 \end{array} \right\}$

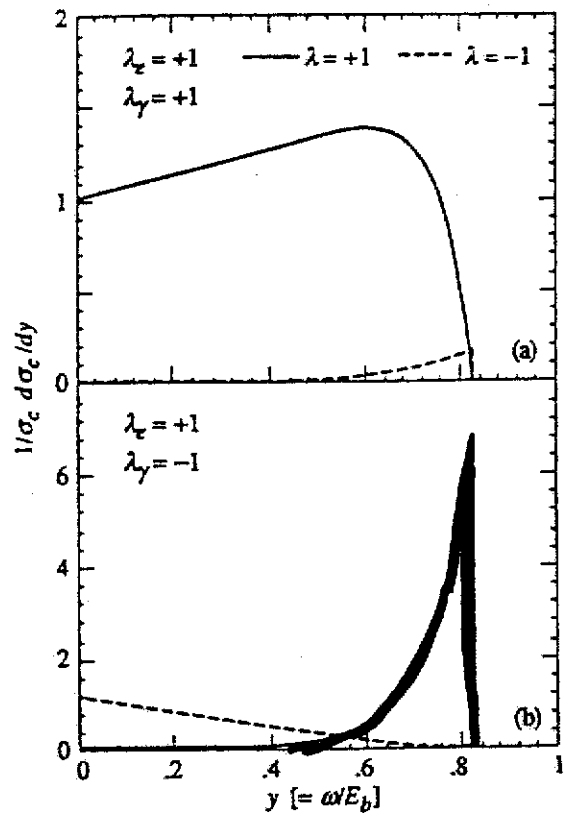
FOR MANY $\gamma\gamma$ (γe) EXPERIMENTS, PHOTON POLARIZATION IS AN IMPORTANT FEATURE:

AGAIN, THE PHOTON CIRCULAR POLARIZATION IS MOST ADVANTAGEOUS FOR $\left\{ \begin{array}{l} \lambda_e = 1 \\ \lambda_\gamma = -1 \end{array} \right\}$

TO SWITCH "SIGNALS" ON AND OFF IN γe, $\gamma\gamma$ COLLISIONS,

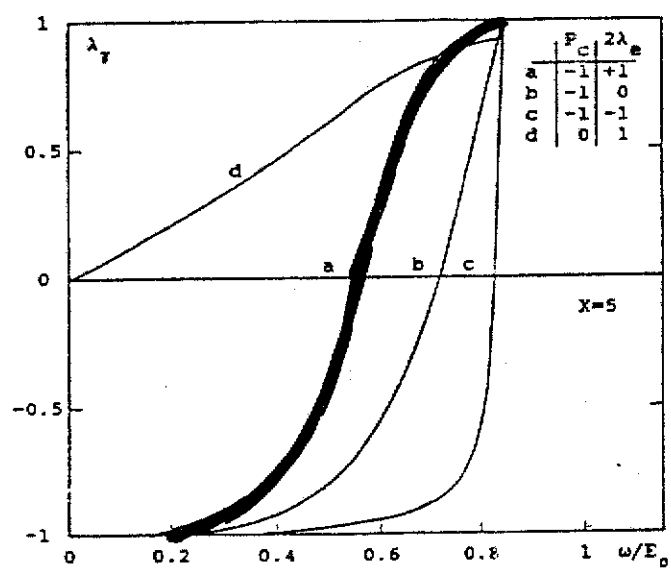
$\Rightarrow$ ELECTRON POLARIZATION REVERSAL ARE VITAL!

BACKSCATTERED LASER PHOTONS



SPECTRUM

Figure 1: Energy spectrum of Compton-backscattered laser photons for (a) aligned and (b) anti-aligned helicities of photons and electrons (from ref. 5).



POLARIZATION

Figure 2: Degree of circular polarization of high-energy laser photons backscattered from beams with different helicities λ_e, as a function of the photons' fractional energy of the electron. It is seen that the anti-aligned configuration (curve a) yields by far the most useful results (from ref. 4).

FOR ALL THE MAJOR MOTIVATIONS TO BUILD A TeV LINEAR LEPTON COLLIDER

e^-e^- HAS COMPLEMENTARY / OFTEN UNIQUE } CAPABILITIES.

I'LL MENTION HERE:

- WEAK SYMMETRY BREAKING
  — HIGGS SECTOR
- STRONG SYMMETRY BREAKING
  WW SCATT'G, ANOMALOUS COUPLINGS
- NEW GAUGE BOSONS Z'
- SUSY
- EXOTICA: DILEPTONS, LEPTOQUARKS
- MASSIVE MAJORANA NEUTRINOS

FINALLY: e^-e^- AS THE ONLY LOGICAL STARTING POINT FOR γe / $\gamma\gamma$ } COLLIDERS

A CLOSER LOOK AT THE DESIGN FEATURES SHOWS THAT

THE JLC, TESLA, NLC, CLIC

ARE ALL NATURAL e^-e^- COLLIDERS

IF

WE PROVIDE THE NEEDED COMPLEMENTARY FEATURES FROM THE START!

THE SAME HOLDS FOR I.R., DETECTOR.

CONCLUSION

THE NEXT ELECTRON COLLIDER,

IN WHATEVER INCARNATION, CAN YIELD

$e^+ e^-$ COLLISIONS

$e^- e^-$ COLLISIONS

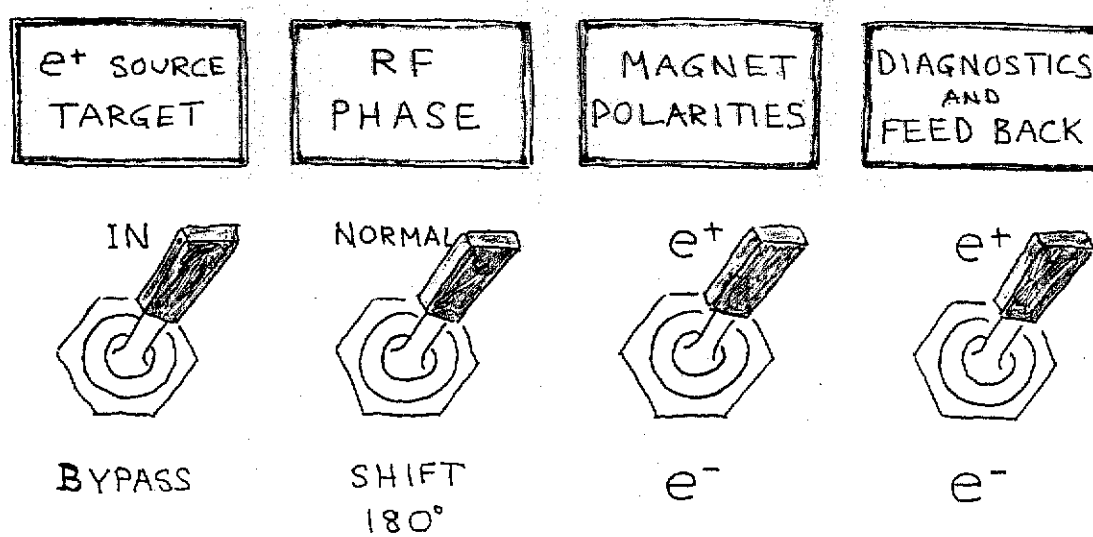
AT COMPARABLE LUMINOSITY
IDENTICAL ENERGY } FROM DAY ON

THE PHYSICS POTENTIAL OF BOTH VERSION

IS RICH AND COMPLEMENTARY

SETTING A FEW DECISIVE PARAMETERS EARLY ON, SWITCHOVER FROM ONE INITIAL STATE TO THE OTHER CARRIES MINIMAL OVERHEAD.

PHYSICS URGENCY WILL BE CALLED UPON TO DECIDE.

"Since the e^-e^- collider requires only minor changes to the hardware of the e^+e^- machine and detector, its programme could be pursued during the first phase of the facility...."

- International Linear Collider Technical Review Committee Report - 1995