C. A. HEUSCH
MONTAUK 1999

LIKE-SIGN H.E. MUON COLLIDER

- AN EXOTIC $|in\rangle$ STATE ?

  ADDITIVE QUANTUM NUMBERS

- MACHINE REQUIREMENTS:

  COMPATIBILITY WITH $\mu^+\mu^-$

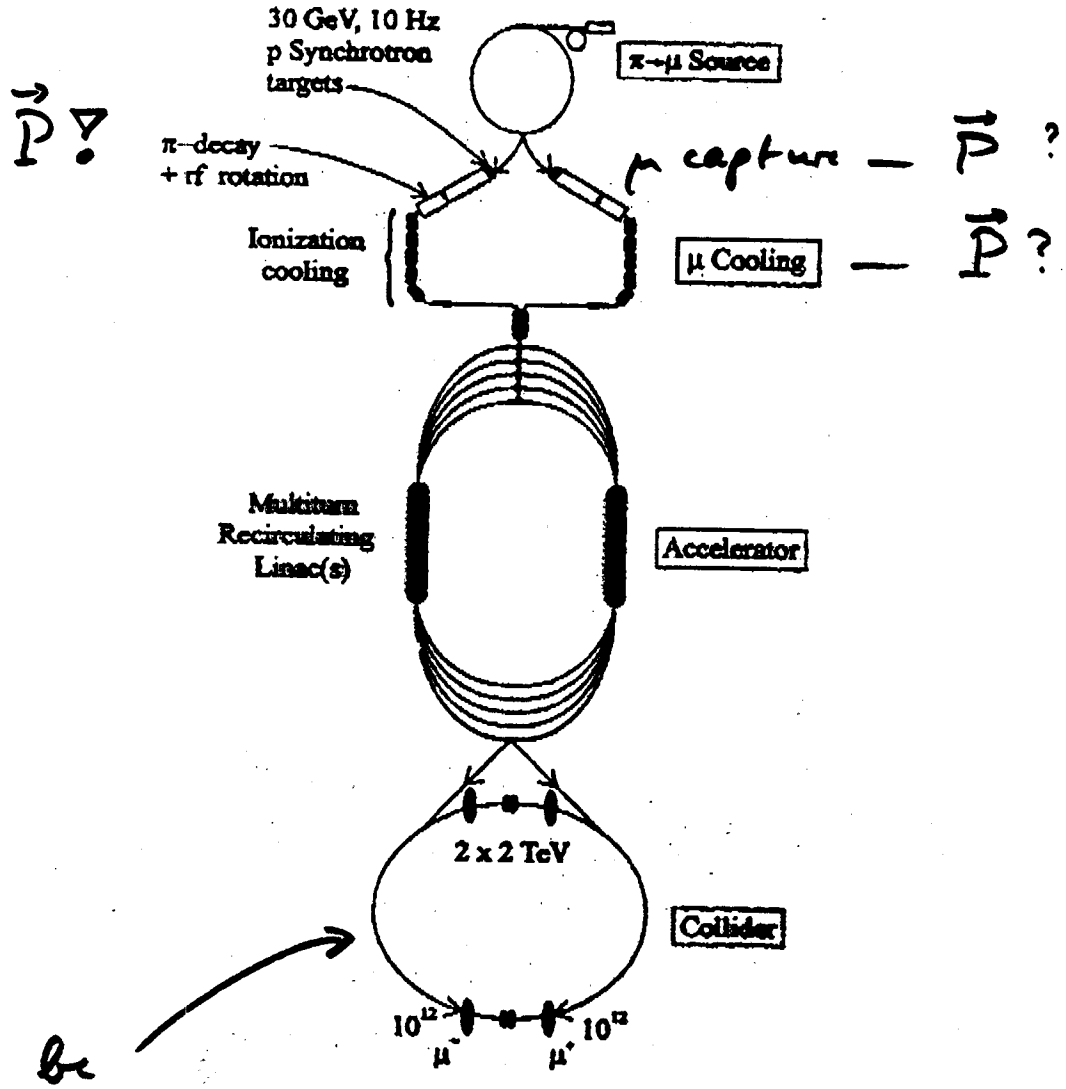
- PHYSICS PROCESSES: IMPORTANCE OF

  2nd GENERATION vs. 1st

  HIGH ENERGY REACH

  POLARIZATION

THE MUON COLLIDER:



Schematic of high energy $\mu\mu$ collider.

has to be converted into 2 rings in 1 tunnel for like-sign operation

POTENTIALLY IMPORTANT FEATURES:

I

- AS WE ATTEMPT TO UNDERSTAND THE MECHANISM (S) OF E.W. SYMMETRY BREAKING, THE ADDED ENERGY REACH, BEYOND THE ~1.5 TeV PRESENTLY FOR THE NEXT ELECTRON COLLIDER, CAN MAKE A **DECISIVE** DIFFERENCE.

i.e., STRONG E.W.S.B

II

- GENERATION - SPECIFIC COUPLINGS

ADD A POTENTIALLY VITAL NEW FEATURE:

⇒ SUSY, EXTENDED GAUGE SECTOR : $L_e = 0$; $L_\mu = \pm L$

- MASS-DEPENDENT COUPLINGS FAVOR $m_\mu \gg m_e$

⇒ EXTENDED HIGGS SECTOR

- FINAL-STATE RECONSTRUCTION ADVANTAGES:

⇒ $\sqrt{s}$ RECONSTRUCTION EASIER THAN e^+e^- DUE TO GREATLY REDUCED RADIATIVE LOSSES

⇒ HIGH-$p_\perp$ MUONS WILL STICK OUT; ARE MOMENTUM-ANALYZABLE

IN CATEGORY I THE SAME-SIGN COLLIDER IS VITAL FOR A FULL EXPLORATION OF

STANDARD } HIGGS SECTORS
MSSM

SUPERSYMMETRY

STRONG WW SCATTERING

ANOMALOUS COUPLINGS

COMPOSITENESS STUDIES

IN CATEGORY II, IT OPENS THE DOOR TO THE STUDY OF

EXTENDED HIGGS SECTORS

MASSIVE MAJORANA NEUTRINOS

DILEPTON GAUGE BOSONS

⋮

IF CLEAN EXPERIMENTATION AT GOOD LUMINOSITY CAN BE ACHIEVED

PROBLEMS:

μ's are not easy to "catch"
"cool"
phase-compress

high polarization at good $\mathcal{L}$
excluded

helicity reversal essentially
impossible

decays → neutrino fluxes

CHANCES:

High luminosities } possible
high energies

either charge

same-sign feasible
at some cost

$L_\mu \neq L_e$ $\quad$ $L(\mu) = L(e)$

MANY OF THE PHYSICS FEATURES OF

LIKE-SIGN CHARGED-LEPTON COLLISIONS

[illegible]

HAVE BEEN EXTENSIVELY INVESTIGATED

IN THE e^-e^- CASE

→ UP TO $\sqrt{s} \simeq 2$ TeV

→ FIRST GENERATION

→ EASILY POLARIZED FOR e^- ONLY

MUTATIS MUTANDIS,

WE CAN APPLY MOST OF THESE STUDIES

TO THE SECOND-GENERATION

$\mu^+\mu^+$ OR $\mu^-\mu^-$

CONFIGURATION

⇒ HIGHER $\mathcal{L}$

" $\sqrt{s}$

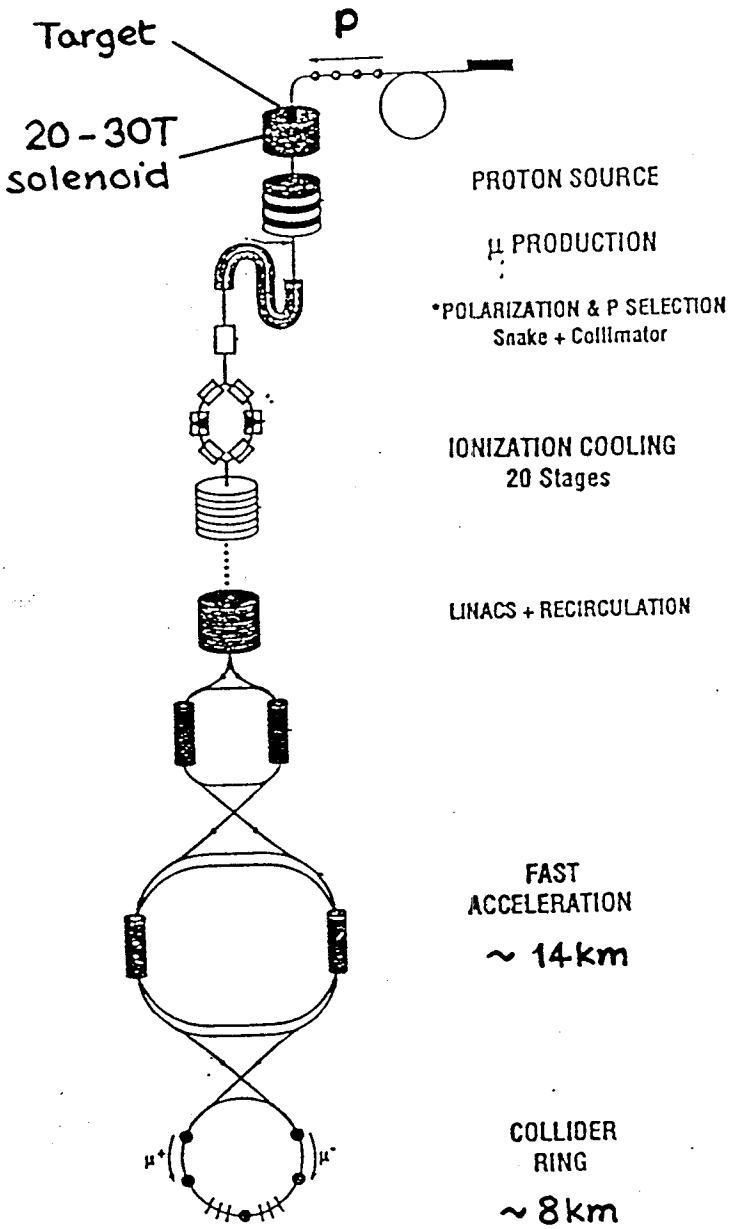
⇒ UNCERTAIN POLARIZATION --

BUT FOR $\mu^+\mu^-$ EQUALLY

Rf's: Proc' "e^-e^- 95", INT. J. MOD. PHYS. A 11 (1996)

Proc' "e^-e^- 97", " , to be published (1998)

$\mu^+\mu^-$ Colliders → $\mu^+\mu^+$ $\mu^-\mu^-$



Advantages:

- Clean initial state
- Higher energy possible due to reduced synchrotron radiation 2 – 4 TeV
- Luminosity goal at 4 TeV 1000 fb^{-1}/yr = 10^{35} !
- Better energy definition due to less beamstrahlung and initial state radiation
- Much larger cross section for s-channel Higgs production ($\sigma \propto m_\ell^2$)

Concerns

- Detector backgrounds due to μ decay
- Simultaneous high luminosity and high polarization difficult ✗
- Untried technology requires an aggressive R&D program ($5 - 10M /yr for 5 years)

- Fits on Fermilab, Brookhaven sites
- Potentially considerably cheaper than e^+e^-

ONLY LAST STAGE HAS TO BE ADAPTED FOR $\mu^+\mu^+$, $\mu^-\mu^-$

- A UNIQUE SET OF $|in\rangle$ QUANTUM NUMBERS

$\|in\rangle$	Q_{el}	S_z	L	L_e	L_μ	I_3^W	Y^W
$\mu_R^+ \mu_R^+$	+2	1	−2	0	−2	1	2
$\mu_R^+ \mu_L^+$	+2	0	−2	0	−2	½	3
$\mu_L^+ \mu_L^+$	+2	−1	−2	0	−2	0	4
$\mu^+ \mu^+$	+2	1, 0, −1	−2	0	−2	1, ½, 0	2, 3, 4
$\mu_L^- \mu_L^-$	−2	−1	2	0	2	−1	−2
$\mu_R^- \mu_L^-$	−2	0	2	0	2	−½	−3
$\mu_R^- \mu_R^-$	−2	1	2	0	2	0	−4
$\mu^- \mu^-$	−2	1, 0, −1	2	0	2	0, −½, −1	−2, −3, −4

THE FULL DEFINITION OF THESE INITIAL STATES PROVIDES A POWERFUL SET OF SELECTION RULES

EXPERIMENTAL CHALLENGE:

HOW WELL CAN WE DO TO PROVIDE HIGHLY POLARIZED μ^+, μ^- BEAMS ?

MANY ARGUMENTS IN FAVOR OF PROVIDING A SAME-SIGN LEPTON COLLIDER FOR THE NEXT GENERATION OF EXPERIMENTATION

OR, AT THE LEAST, THE EQUIVALENT LOOK INTO

$\ell^+\ell^+$ OR $\ell^-\ell^-$ WITH $\ell^+\ell^-$

APPLY EQUALLY FOR → $\ell = \mu, e$

BUT:

μ COLLIDERS PROVIDE

- SHARP DEFINITION OF $\sqrt{s}$
- HIGH ENERGY REACH
- DIFFERENT L_i
- MUCH LOWER RADIATIVE BACKGROUNDS/CORRECTIONS

E.W.S.B. - HIGGS

By the time the HEMC may come on, the question of an elementary Higgs boson will have been answered.

BUT: • heavier neutral scalars

• extended Higgs sectors

$H^{\pm}$, $H^{\pm\pm}$

may well occupy our curiosity.

THESE QUESTIONS ARE WELL ADDRESSED BY LIKE-SIGN COLLIDERS:

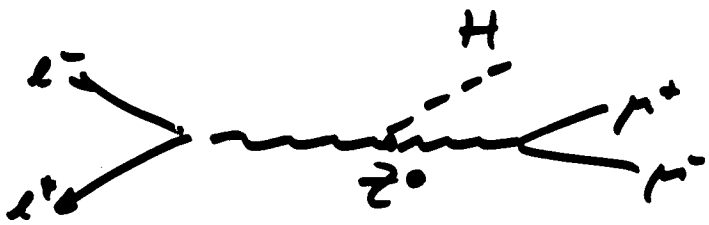
WEAK SYMMETRY BREAKING -

THE HIGGS SECTOR

(plus extensions)

THE CLASSICAL DISCOVERY GRAPH

CLOSE TO THRESHOLD

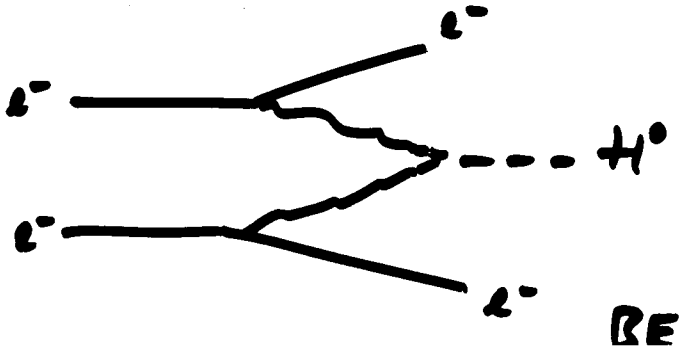


BUT: need $\mu^+\mu^-$ decay of Z^0 for definition

cross-section falls $\sim s^{-1}$

AT HIGHER ENERGIES,

ZZ FUSION GRAPH

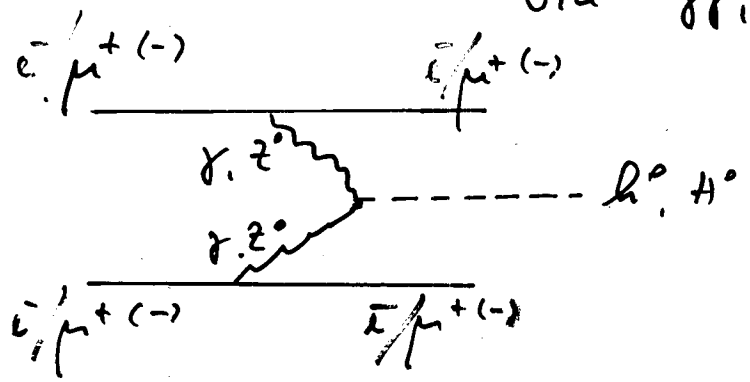


BECOMES COMPETITIVE

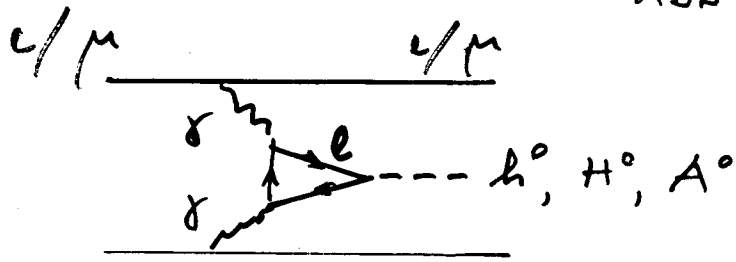
• HIGGS SCALARS:

SINGLE $\begin{matrix} H^0 \\ h^0 \end{matrix}$ PRODUCTION

via $\gamma\gamma$, Z^0Z^0 FUSION



ADD CP-odd A^0



AT ENERGIES $\sqrt{s} > 2.5\, m_H$,

"CENTRAL PRODUCTION"

WITH MASS DETERMINATION FROM THE DETECTION OF HIGH-$p_\perp$ $e/\mu^{\pm\pm}$ IS

THE PREFERRED DETECTION MECHANISM:

→ LARGE (SATURATED) X-SECTION

→ GOOD $m(H)$ RESOLUTION

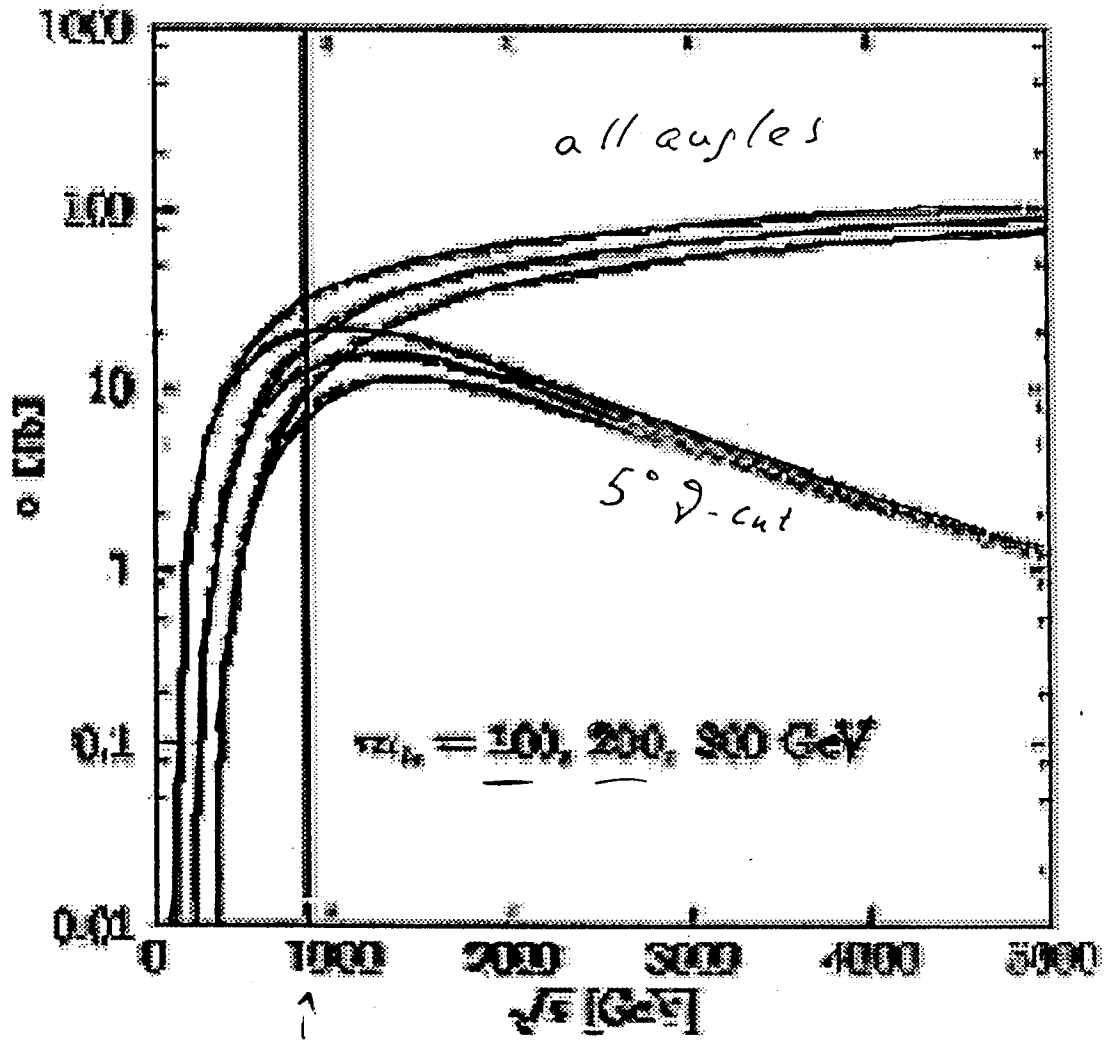
→ APPLIES TO "INVISIBLE DECAYS"

CROSS SECTION (σ_{LL}) SATURATES

all angles $\sigma_{LL} \to$ const? $\frac{1}{m_Z^2}$ $\sqrt{s} \to \infty$

OR,
WITH CUT $\vartheta_{ij} \geq 5^\circ$ $\sigma_{LL} \to$ const $\frac{1}{s}$ $\sqrt{s} \to \infty$

...



$\sqrt{s} = 850$ GeV

→ $\sqrt{s} = 500$ GeV is sufficient to cover a narrower m_H band: $m_H \leq 150$ GeV

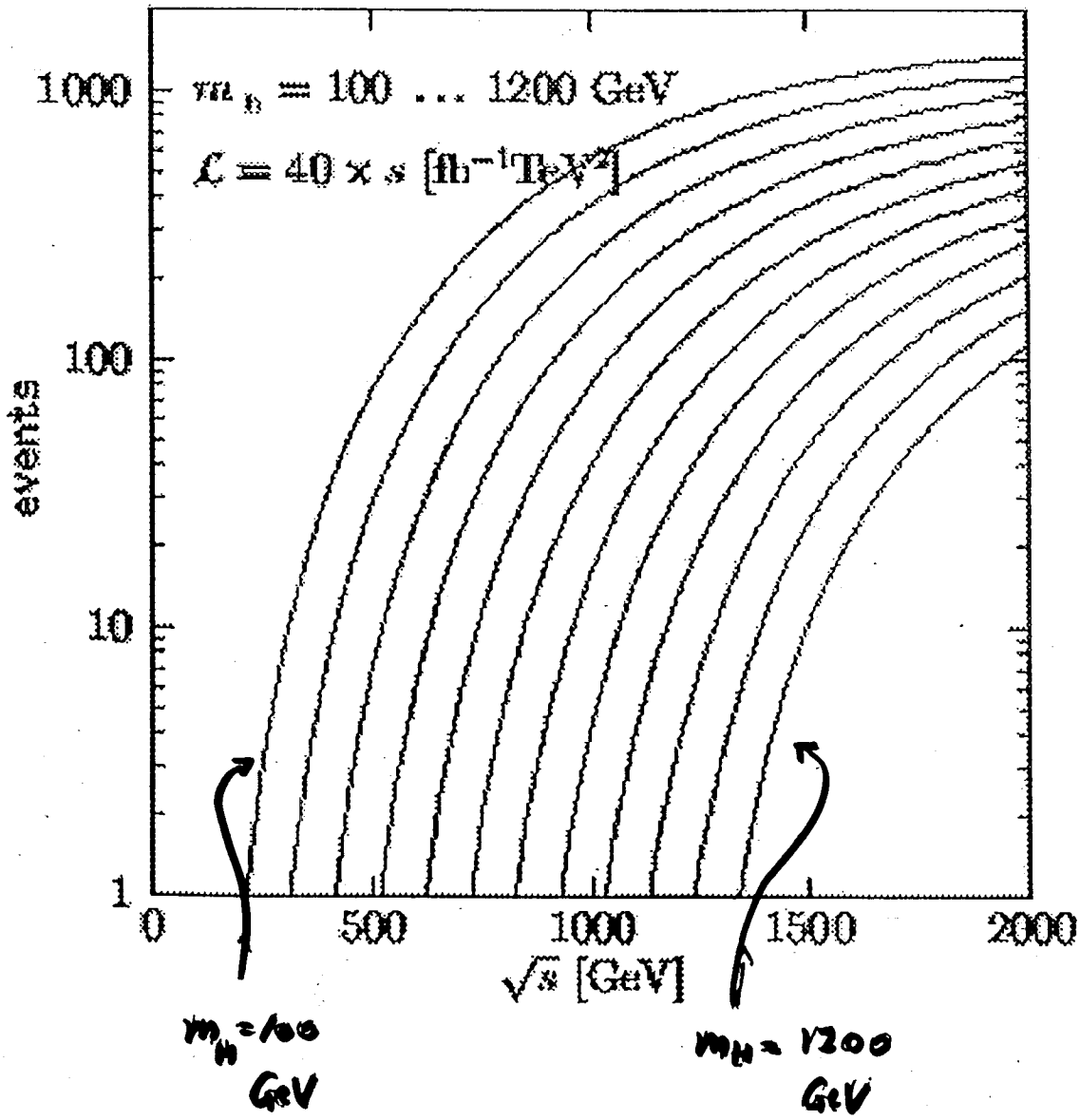
P. Minkowski

$\sigma_{LL} \cdot \mathcal{L} = N_{LL}$ event rates for $m_H = [100, (100), 1200]$ GeV.

$\mathcal{L} = 40 \cdot \frac{s}{1(\mathrm{TeV})^2} \frac{1}{fb}$ assumed.

 # events

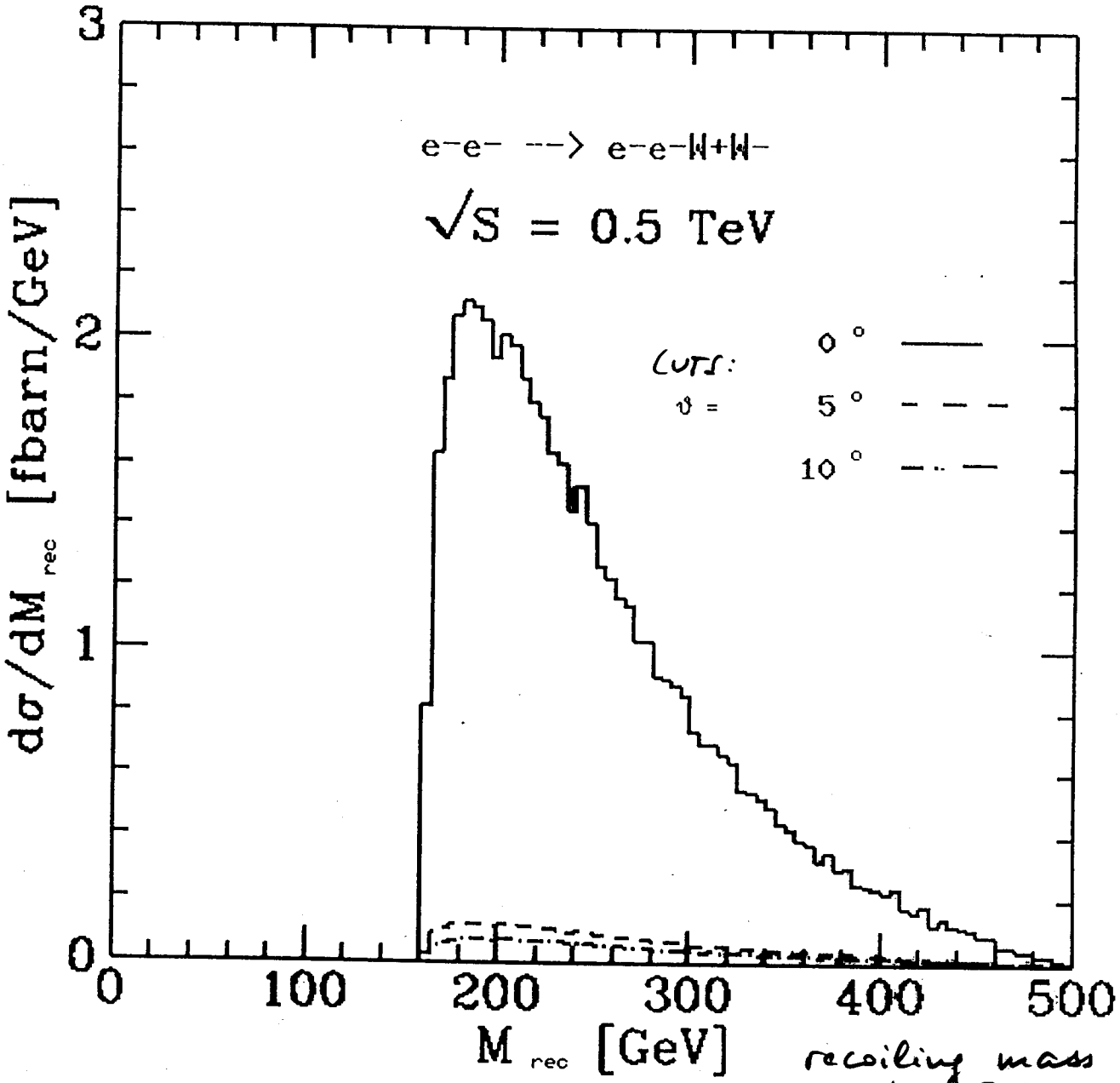
no angular cuts.



P. Minkowski

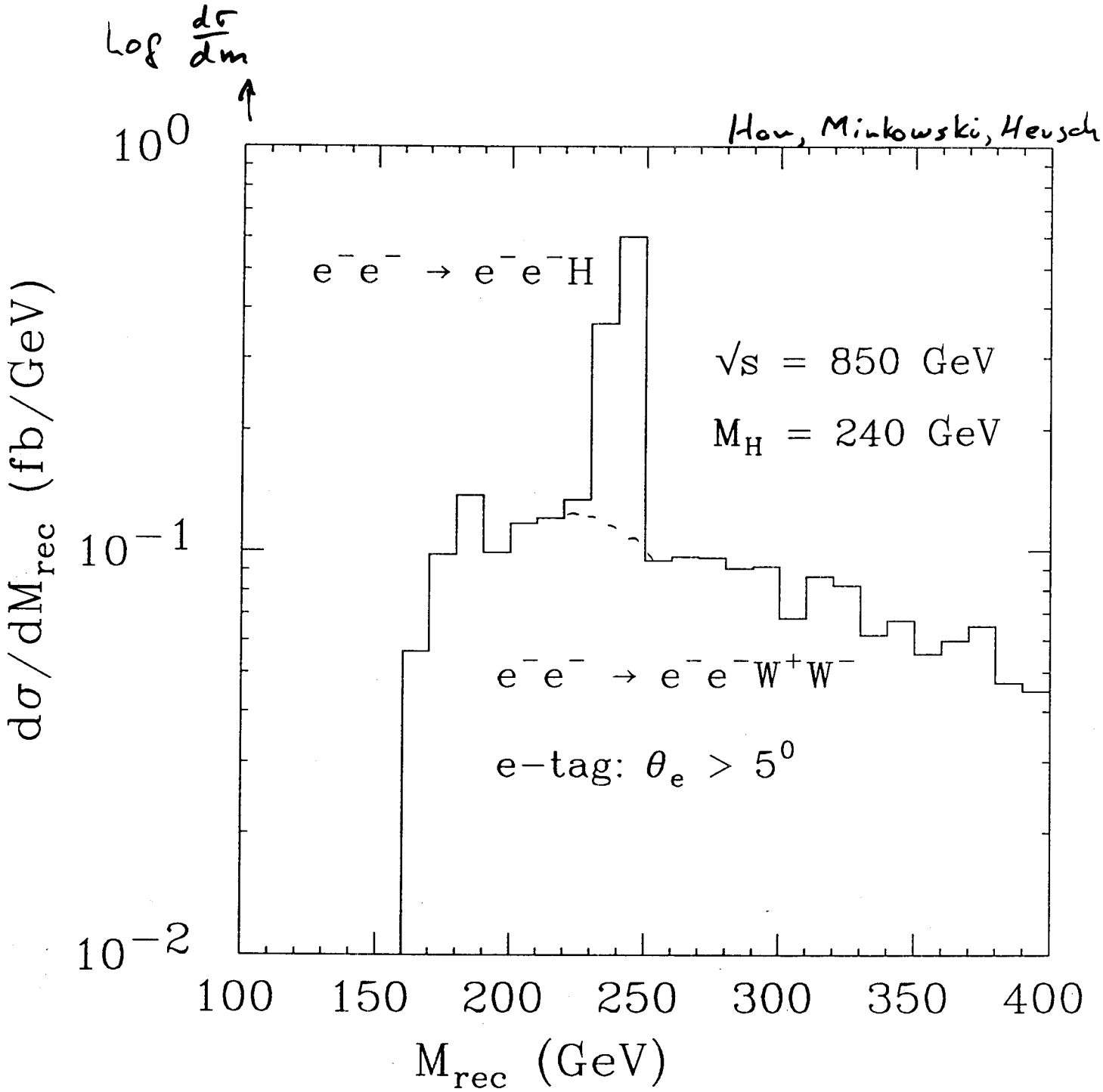
PRINCIPAL BACKGROUND:

$\mu^\pm\mu^\pm$ or e^-e^- : unpolarized



recoiling mass for B.G.

⇒ EASILY SUPPRESSED BY ANGULAR (DETECTOR) CUTS


Log dσ/dm
Hou, Minkowski, Heusch
10^0
10^{-1}
10^{-2}
$e^-e^- \to e^-e^-H$
$\sqrt{s}$ = 850 GeV
M_H = 240 GeV
$e^-e^- \to e^-e^-W^+W^-$
e−tag: $\theta_e > 5^0$
$d\sigma/dM_{rec}$ (fb/GeV)
100
150
200
250
300
350
400
M_{rec} (GeV)