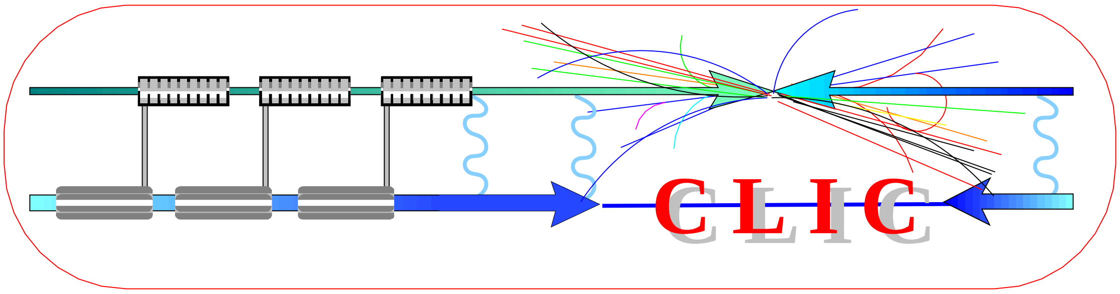
The legacy of LEP/SLC at the high energy frontier: CLIC



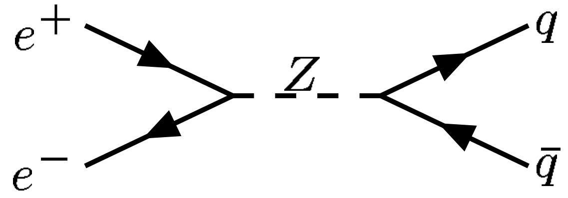
Siena 8-11 October 2001

Albert De Roeck, CERN

Contents

⇒ http://clicphysics.web.cern.ch/CLICphysics/

Linear e^+e^- Colliders



- Simple initial/final states ($\leftrightarrow$ pp)
- C.m.s. energy $\sqrt{s}$ well defined and tunable (scan, kinematic fits, missing mass techniques...)
- Measurements of masses, quantum numbers and couplings in model independent way:
- Polarised electron beams (80%)
- Options: polarized e^+ beams, $e\gamma$, $\gamma\gamma$, e^-e^-

$\Rightarrow$ Precision measurements (LEP par excellence)

$\Rightarrow$ Discovery potential (LEP $\leftrightarrow$ Tevatron)

HEP more favourable towards e^+e^- than in 1976...

Projects under discussion

Machine	$\sqrt{s}_{max}$ TeV	tech.	status	"Proposal"
TESLA (DESY)	0.5/0.8	cold	TDR	2001
NLC (USA)	0.5/1	warm	CDR	2002/2003 ?
JLC (Japan)	0.5/1	warm	CDR	2002/2003 ?
CLIC (CERN)	0.5/1	TBA$^{(*)}$	R&D	2008/2009 ?

Large & Expensive Projects...

(*) Two Beam Acceleration

CLIC

• An e^+e^- linear collider optimized for a c.m. energy of 3 TeV with $\mathcal{L} \cong 10^{35} cm^{-2} s^{-1}$

• Construction can be staged without major modifications, starting an experimental program at lower energies, if useful.

• Aim: 3 TeV collisions, complementing LHC/TeV class LC and breaking new ground, with a final stage up to 5 (10?)TeV

To achieve this within reasonable cost (length $\sim$ 35-40 km), and not too many active elements:

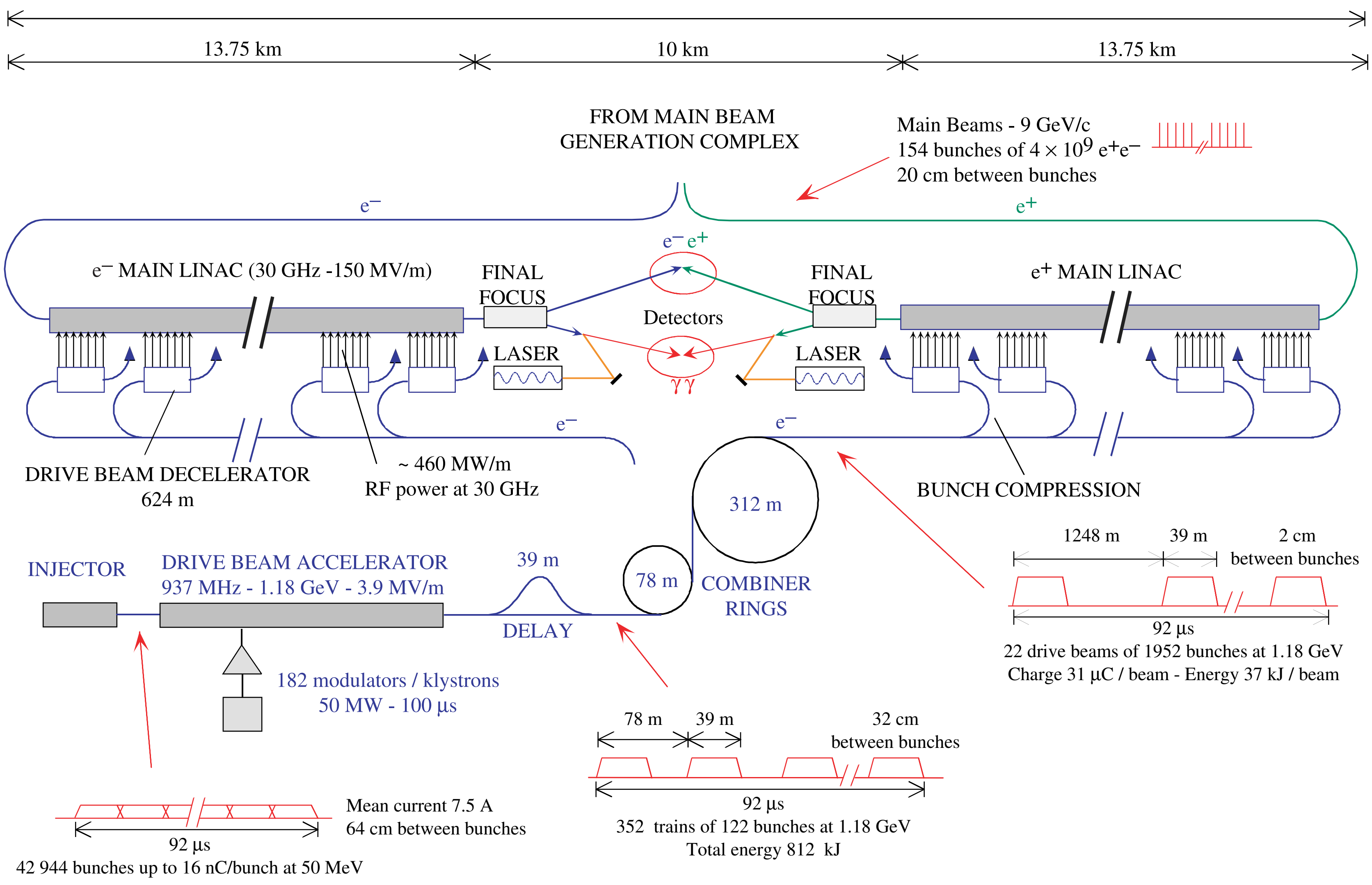
$\longrightarrow$ Accelerating gradient $\sim$ 150 MV/m: Two Beam Acceleration (TBA)

$\longrightarrow$ High beamstrahlungs regime to reach luminosity

$\longrightarrow$ Challenging beam parameters and machine requirements (nm stability, strong final focus, 30 GHz accelerating structures,...)

• Status CTF2: 70 MV/m (15 ns pulses), 150 MV/m (3 ns pulses)
CTF3: proposed for 2002-2006 (drive beam test)

CLIC Layout



13.75 km
10 km
13.75 km
FROM MAIN BEAM
GENERATION COMPLEX
Main Beams - 9 GeV/c
154 bunches of 4 × 10^9 e+e−
20 cm between bunches
e−
e+
e− e+
e− MAIN LINAC (30 GHz -150 MV/m)
FINAL
FOCUS
Detectors
FINAL
FOCUS
e+ MAIN LINAC
LASER
γγ
LASER
e−
e−
DRIVE BEAM DECELERATOR
624 m
~ 460 MW/m
RF power at 30 GHz
312 m
BUNCH COMPRESSION
1248 m
39 m
2 cm
between bunches
INJECTOR
DRIVE BEAM ACCELERATOR
937 MHz - 1.18 GeV - 3.9 MV/m
39 m
78 m
COMBINER
RINGS
DELAY
92 µs
22 drive beams of 1952 bunches at 1.18 GeV
Charge 31 µC / beam - Energy 37 kJ / beam
182 modulators / klystrons
50 MW - 100 µs
78 m
39 m
32 cm
between bunches
92 µs
352 trains of 122 bunches at 1.18 GeV
Total energy 812 kJ
Mean current 7.5 A
64 cm between bunches
92 µs
42 944 bunches up to 16 nC/bunch at 50 MeV

Experimenting at CLIC

Machine parameters lead to challenges for experimenting at CLIC

Beam-Beam effects lead to considerable backgrounds and distortion of the luminosity spectrum (beam strahlung)

FOR 3 TEV AND $\mathcal{L} = 10^{35} cm^{-2} s^{-1}$ (D. Schulte)

Luminosity/bunch	10^{-2} nb^{-1}
Beam energy spread	1%(FWHM)
buncher per train/ Rep. rate	$154/100$
Time between bunches	0.67 ns
Average energy loss	31%
photons/beam particle	2.3
Number/energy incoh. pairs	$4.6 \cdot 10^5 / 3.9 \cdot 10^4$ TeV
Number/energy coh. pairs	$1.4 \cdot 10^9 / 4.4 \cdot 10^8$ TeV
Hadronic ($\gamma\gamma$) events, $W_{\gamma\gamma} > 5$ GeV	4

- Coherent pairs disappear in beampipe (backscattering!)
- Incoherent pairs: suppressed by strong magnetic field of detector

Further backgrounds to consider: neutrons,muons,synchrotron radiation...

Luminosity Spectra

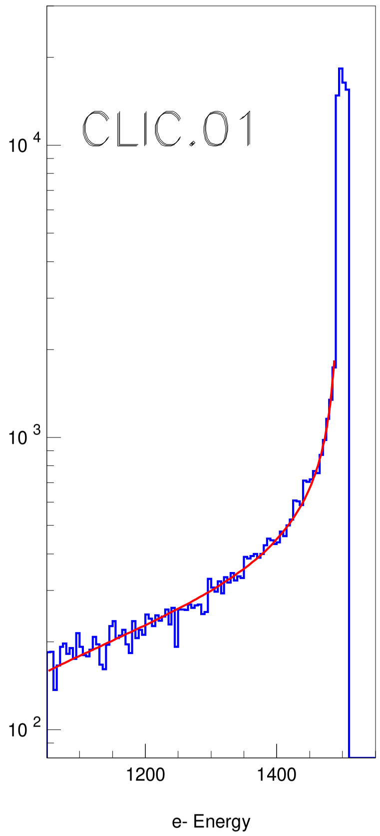
D. Schulte

Energy loss due to beam-beam interactions

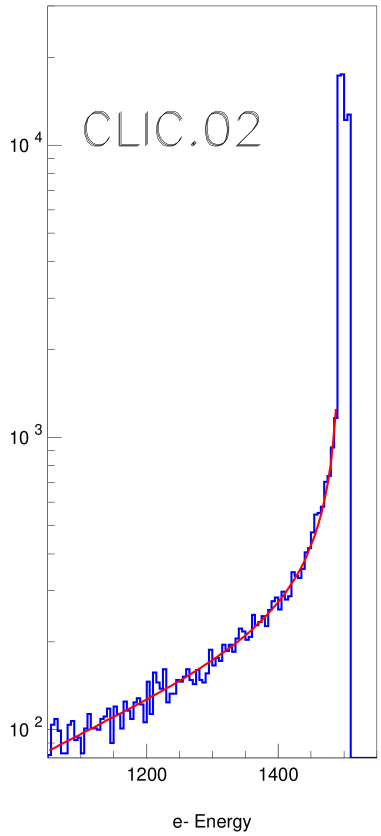
Luminosity within 1% & 5% of c.m. energy

Energy (TeV)	0.5	1	3	5
$\mathcal{L}$ in 1% $\sqrt{s}$	71%	56 %	30%	25%
$\mathcal{L}$ in 5% $\sqrt{s}$	87%	71 %	42%	34%

Spectra for CLIC studies (sharper $\leftrightarrow$ high lumi)



CLIC.01: $\mathcal{L} = 1.05 \times 10^{35}$



CLIC.02: $\mathcal{L} = 0.40 \times 10^{35}$

In total 7 spectra available for studies

Detector for a Multi-TeV Collider

The LEP/SLC Detector Legacy

Detector Concepts successfully exploited at LEP/SLC

❖ Hermeticity ❖ Tracking with TPC ❖ Vertex detectors ❖ Low Angle detectors ❖ High granularity and analyses techniques

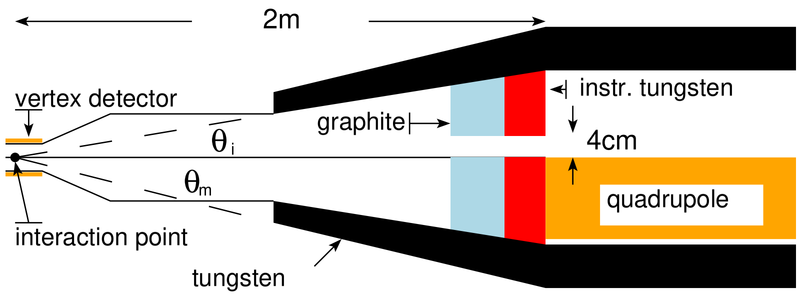
❖ Energy Flow ❖ B-tagging with i.p. and vertexing

$\Rightarrow$ Defined the direction of the next generation of experiments at a e^+e^- LC (TESLA...)

Exploring the multi-TeV high energy frontier opens up new questions:

- Timing (ns) - Many highly colimated jets - Energy flow applicable? - granularity

Background at the IP enforces use of a mask



CLIC: mask covers to 120 mrad (Θ_m).

Electron tagging possible down to 40 mrad.

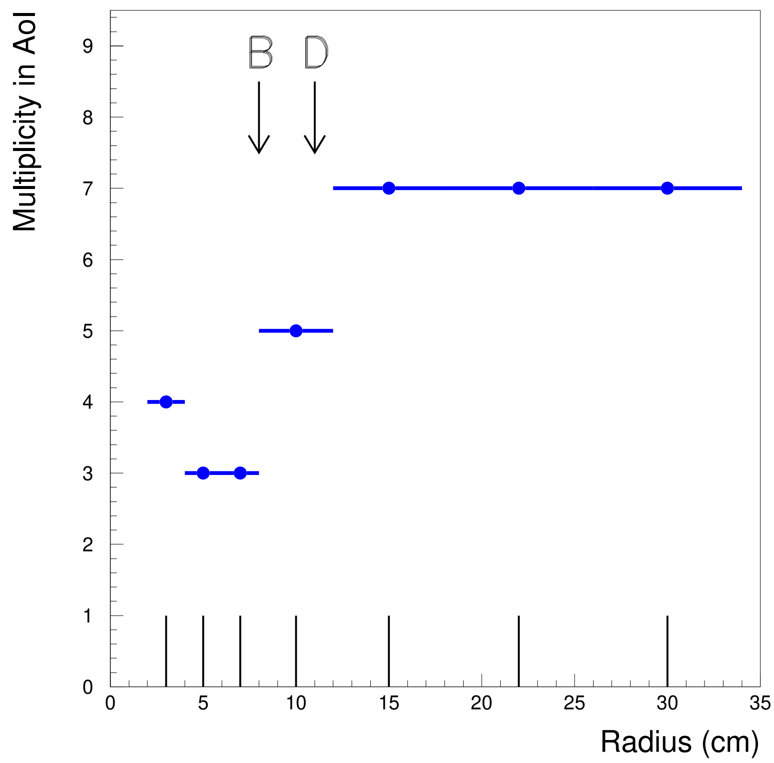
Example: B-Tagging

$B \to X$ Decay Length — M. Battaglia

$\sqrt{s}$ (TeV)	0.09	0.2	0.35	0.5	3.0	
	Z^0	HZ	HZ	HZ	H^+H^-	$b\bar{b}$
d_{space} (cm)	0.3	0.3	0.7	0.85	**2.5**	**9.0**

B-Decay length is long!

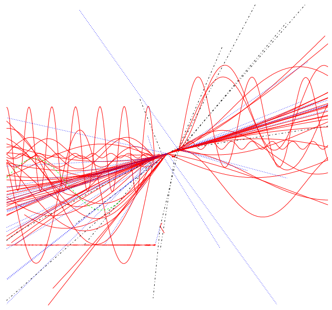
- Define Area of Interest by ± 0.04 rad cone around Jet axis
- Count hit multiplicity (or pulse heigh) in Vertex Tracker layers
- Tag heavy hadron decay by step in detected multiplicity

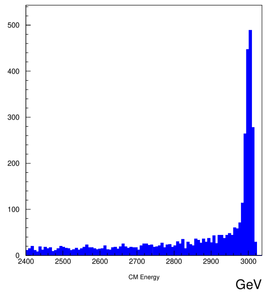


CLIC Analysis Tools

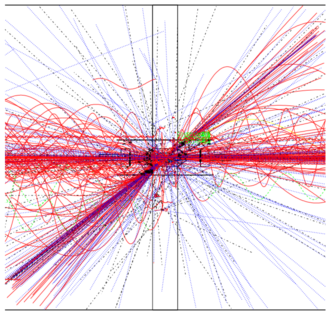
CLIC physics study group

Physics Generator ((CompHep +) Pythia 6)
+ CLIC Beamstralhung Spectrum (Calypso)





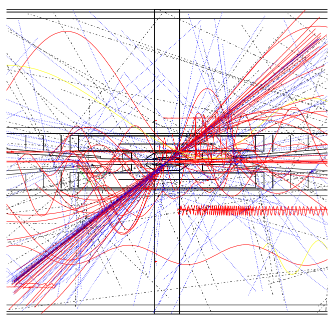
+ $\gamma\gamma \rightarrow$ hadron Background (Hades)

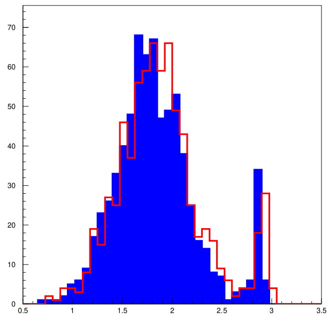


$\rightarrow$ Hepevt File

Geant **Full Sim** (Brahms **v.1**)

Simdet **Par. Smear** **B = 4-6 T**





Physics at a Multi-TeV LC

✦ Light Higgs: $\Rightarrow$ Higgs potential
triple (& quartic?) couplings; Rare decays
✦Heavy Higges: $\Rightarrow$ production and properties

✦ Supersymmetry: $\Rightarrow$ complete sparticle spectrum
$m_{\tilde{p}} < \sqrt{s}/2$, precision measurements of heavy
sparticles (flavour, mass, width, couplings)
Use of polarization to disentangle mixing, CP studies
Will need all sparticles to fully pin down the theory

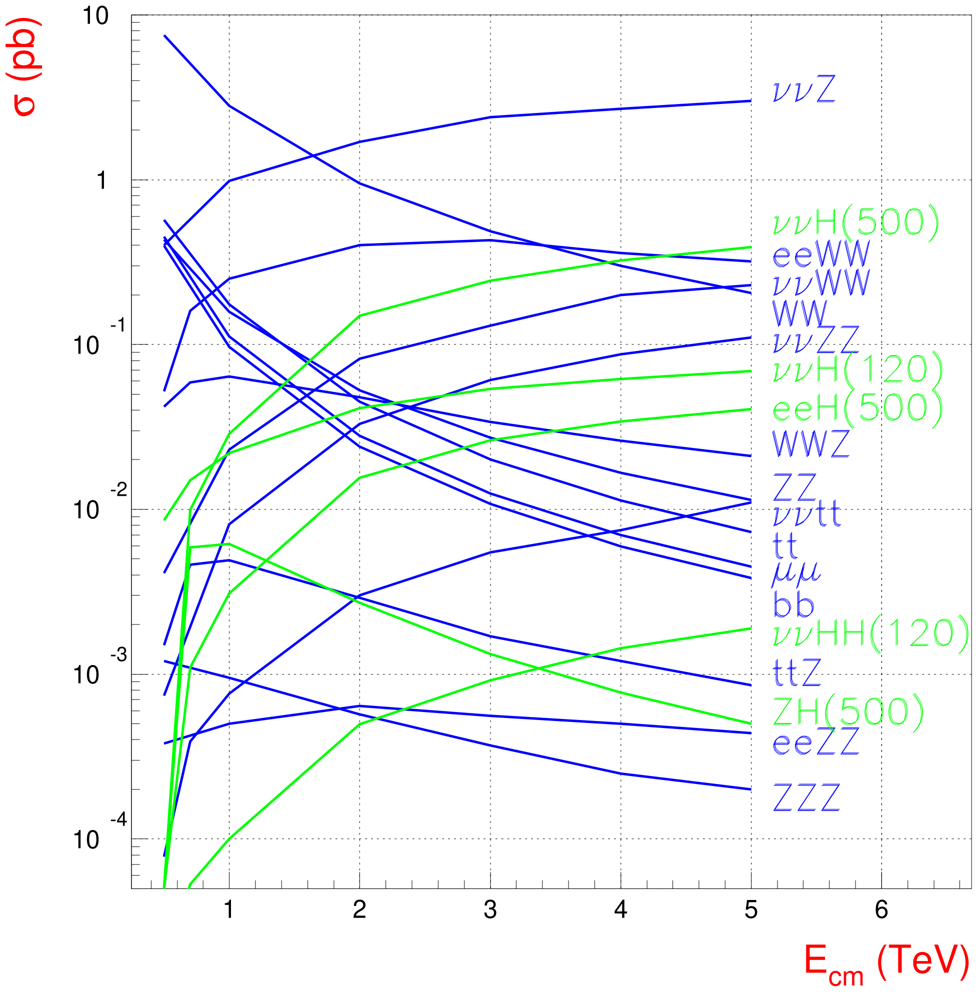
✦ If new resonances in the 1 TeV - 5 TeV range
(E.G. New Gauge bosons, Kaluza-Klein resonances,
$W_L W_L$ resonances...) $\rightarrow$ Particle Factory!
Produced directly & accurate determination of their
properties ($\leftrightarrow Z^0$ at LEP)

✦ If NO new particles are observed directly, probe
new physics (Extra Dimensions, Z', contact
interactions...) for scales in the range of 30-400 TeV
indirectly via precision measurements
($\leftrightarrow$ precision measurements at LEP)

✦ The unexpected...? E.g. String quantum gravity
effects, non-commutative effects, black hole
formation, nylons, split fermions,...

$\sqrt{s} \simeq$ 3-5 TeV Expect to Break New Grounds

Cross Sections



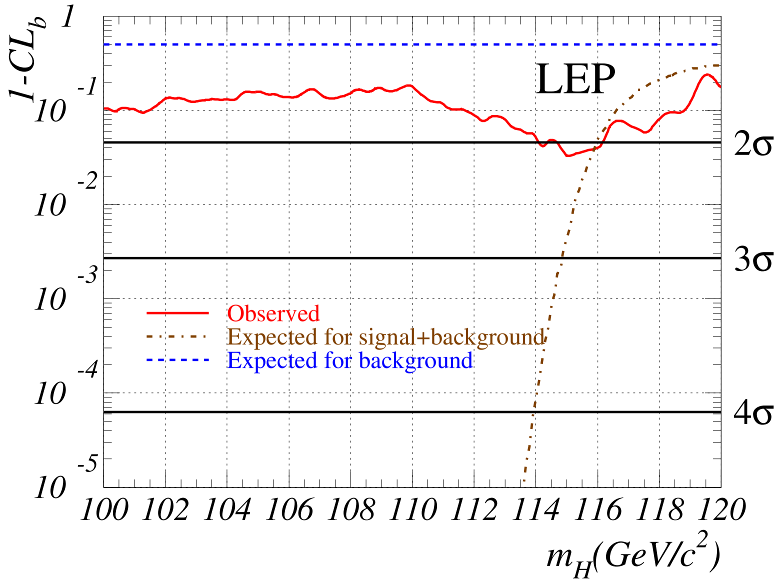
Event Rates/Year (1000 fb^{-1})	3 TeV 10^3 events	5 TeV 10^3 events
$e^+e^- \to t\bar{t}$	20	7.3
$e^+e^- \to b\bar{b}$	11	3.8
$e^+e^- \to ZZ$	27	11
$e^+e^- \to WW$	490	205
$e^+e^- \to hZ/h\nu\nu$ (120 GeV)	1.4/530	0.5/690
$e^+e^- \to H^+H^-$(1 TeV)	1.5	0.95
$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$ (1 TeV)	1.3	1.0

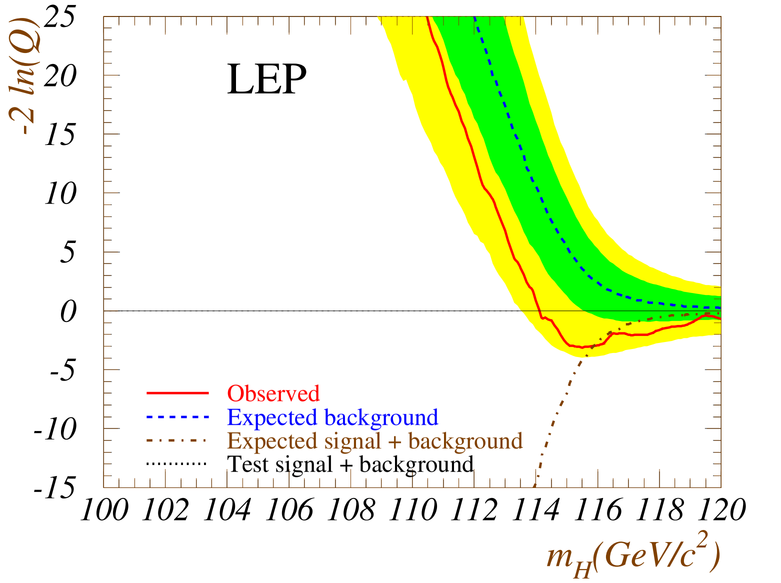
σ(t-channel) $\simeq$ σ(s-channel)!

Light Higgs

Presently the "Holy Grail" in HEP

The Legacy of LEP: A Light Higgs???



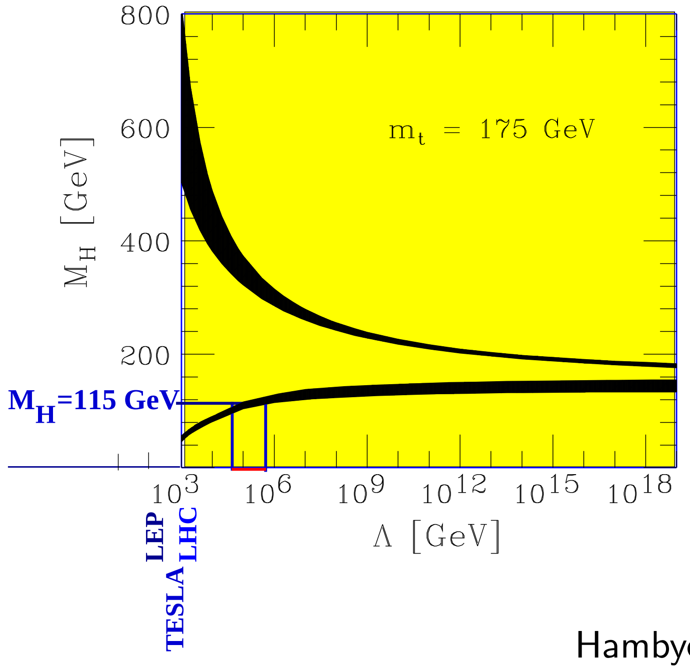


$M_h = 115.6$ GeV $\quad 1{-}CL_b = 3.5\%$

Significance of the signal 2.9σ (Nov 2000) $\rightarrow \simeq 2\sigma$

Light Higgs

- A light Higgs has important consequences

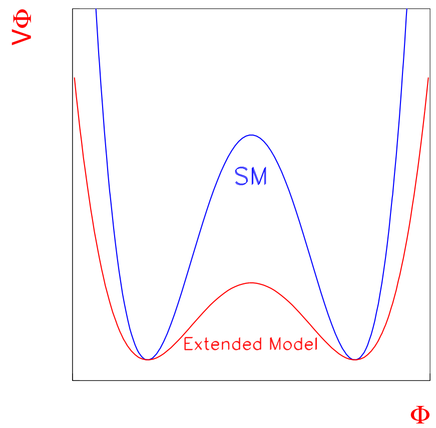


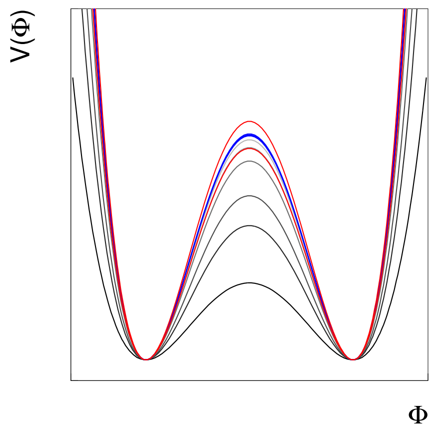
Hambye and Riesselmann

If $M_H = 115$ GeV $\Rightarrow$ New physics at a scale of $10^2 - 10^3$ TeV or below

- Study of the properties of the Higgs is very important

The Higgs potential



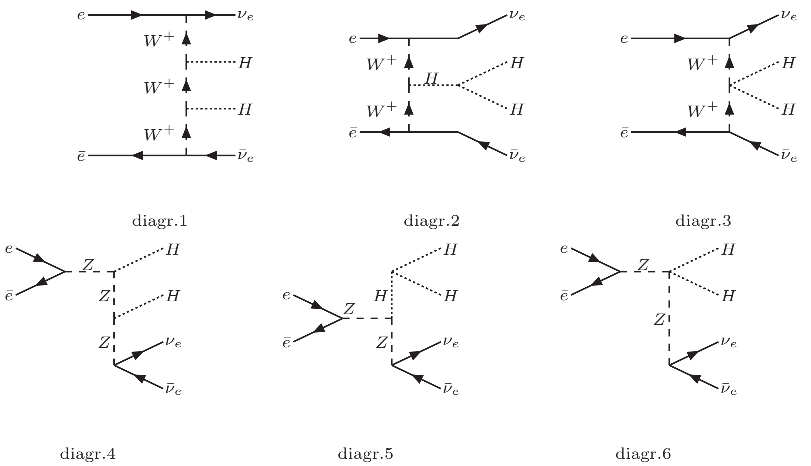


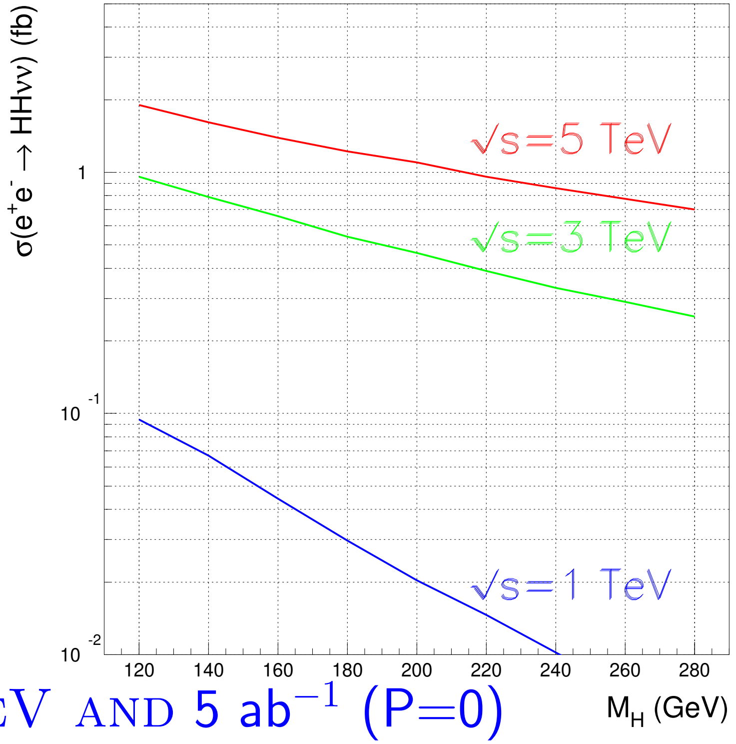
Light Higgs

M. Battaglia

Probe shape of the Higgs potential through triple couplings λ_{HHH}:

$e^+e^- \to HH\nu\nu$ Strong energy dependence of cross section.





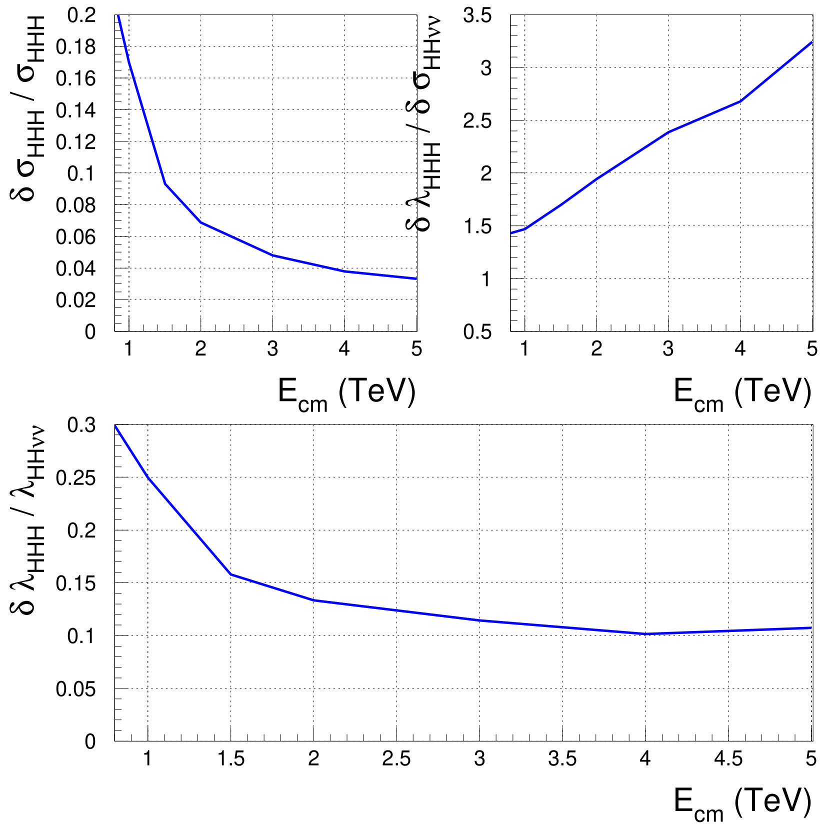
RESULTS FOR $\sqrt{s} = 3$ TeV AND 5 ab^{-1} (P=0)

M_H (GeV)	λ_{HHH}
120	$\pm$ 0.075 (stat)
180	$\pm$ 0.082 (stat)

Light Higgs

- Extract λ_{HHH} from $\sigma(e^+e^- \to \nu\nu HH)$ for $M_H = 120$ GeV/c^2
- Full detector and background simulation

Precision on λ_{HHH} (5000 fb^{-1})



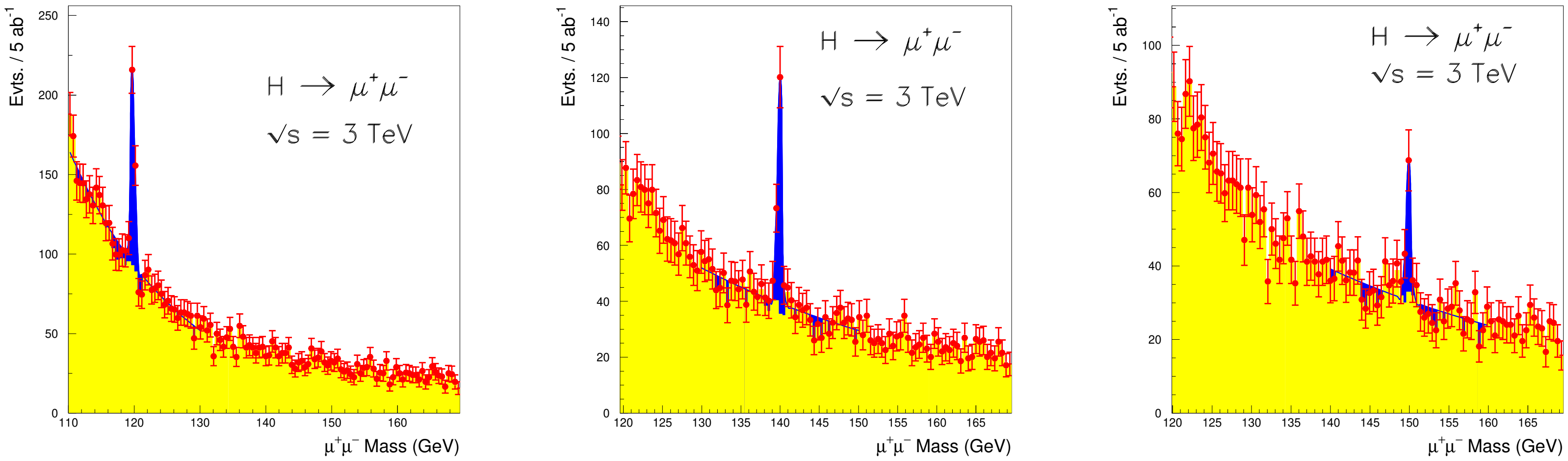
Initial study: precision of O(10)%

Still ways to improve improve (e.g. using spin information)...

Rare Higgs Decays: $H \to \mu^+\mu^-$

M. Battaglia

$H \to \mu^+\mu^-$: Branching Ratio $\sim 10^{-4}$



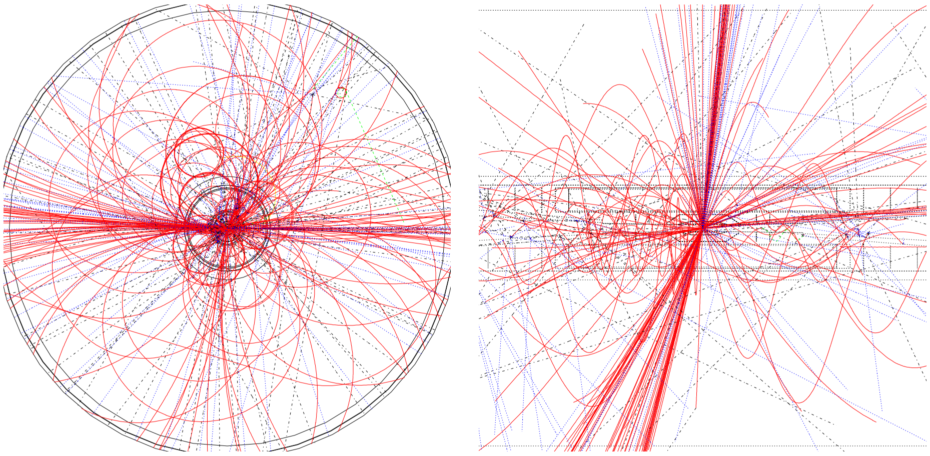
Result for $\sqrt{s} = 3.0$ TeV with $\int \mathcal{L} = 5$ ab^{-1}

M_H	120 GeV	140 GeV	150 GeV
δBR/BR	0.072	0.121	0.210

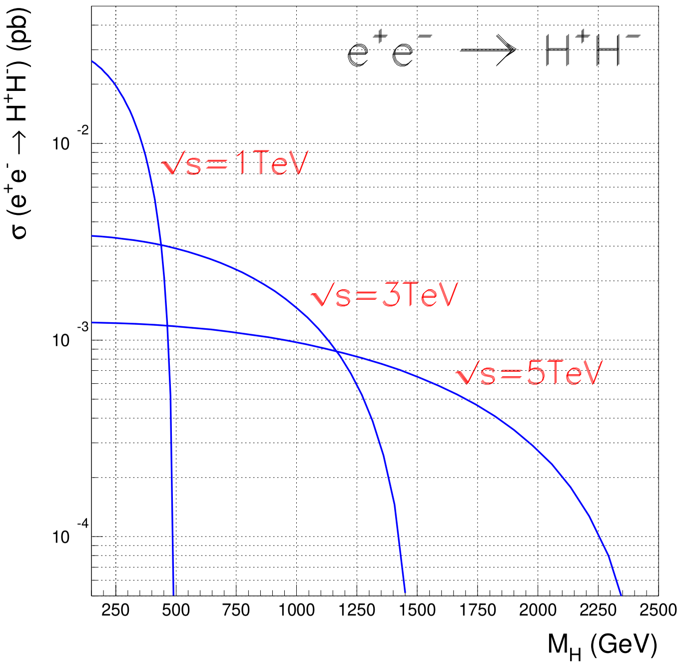
$\Rightarrow$ Precision on $g_{H\mu\mu} : 3.5\% \to 10\%$

Heavy Higgs

$e^+e^- \to H^+H^- \; M_H = 900$ GeV



Cross section as function of Higgs mass



- Note: to make full use of available kinematic range for searches, high luminosity will be needed

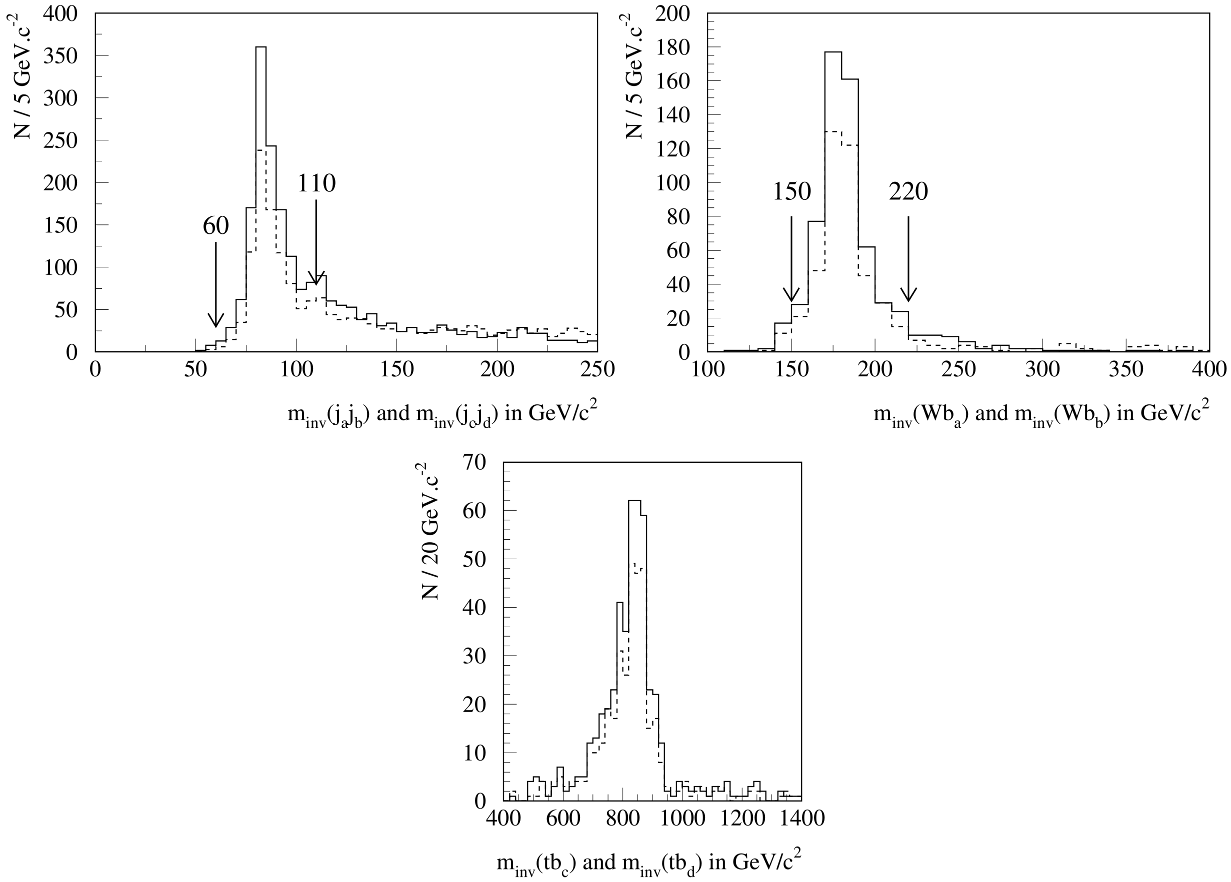
Heavy Higgs

A. Ferrari

Study the channel $H^{\pm} \to tb \to Wbb \to qqbb$

Example for $M_H = 860$ GeV

Tag 4 b jets / reconstruct W's from 4 'light' jets / reconstruct t jet $\to$ events with 8 jets



$O(20)$ events/ ab^{-1}, with negligable background

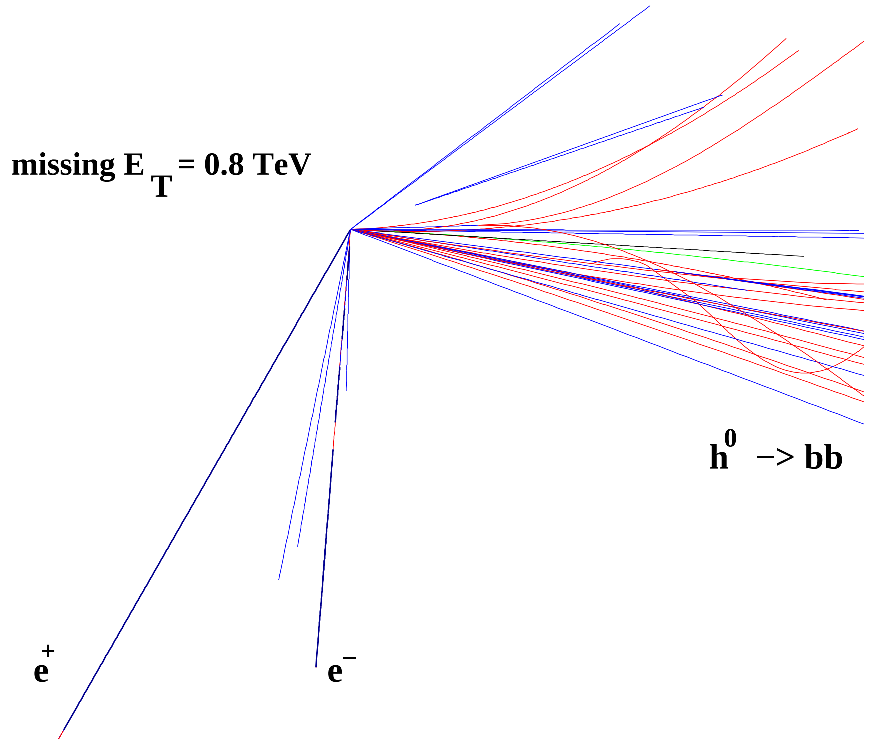
Increase statistics by factor 10 for 'single' H tags

SUSY

Completing the Sparticle Spectrum at a multi-TeV Collider

CLIC 3 TeV

$e^+ e^- \to e_L e_R$



$m_{\tilde{e}} = 1050$ GeV $\quad m_{h^0} = 115$ GeV

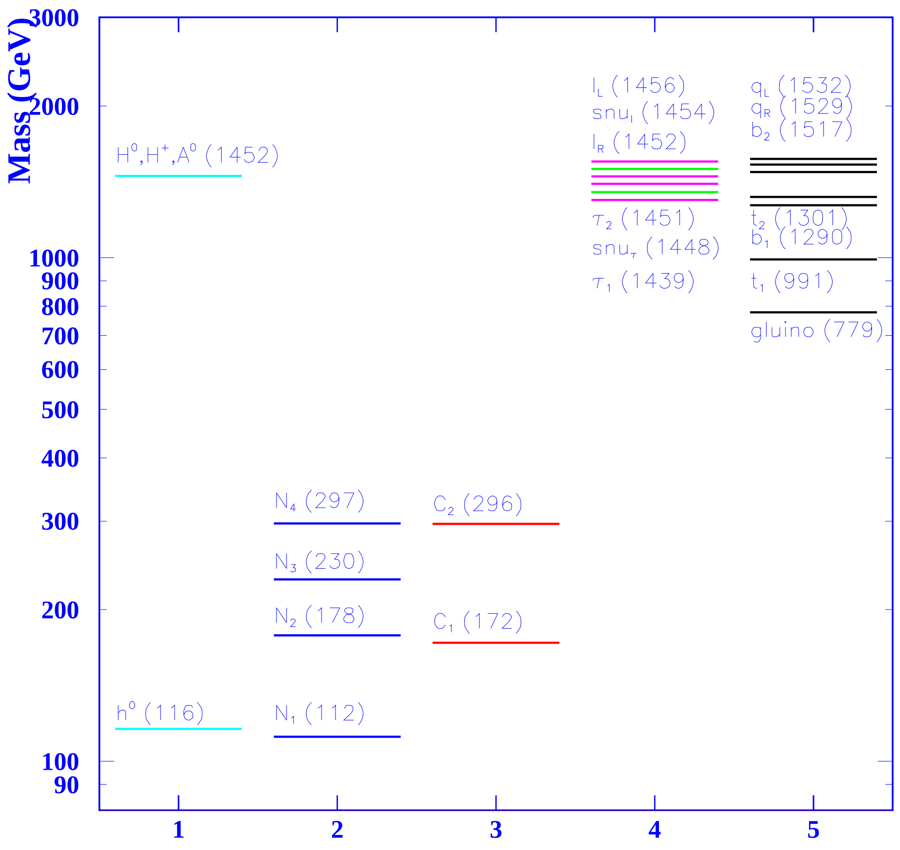
$\tilde{e}_L \to e\tilde{\chi}_2^0 \quad \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h \quad h \to b\bar{b}$

$\tilde{e}_R \to e\tilde{\chi}_1^0$

SUSY

Completing the Sparticle Spectrum at a multi-TeV Collider

Example: CMSSM, point E (M.Battaglia et al., hep-ph/0106204)



$m_{1/2} = 300$ GeV, $m_0 = 1450$ GeV. $\tan\beta = 10$, A=0 GeV, $sign(\mu) > 0$

$\Rightarrow$ Define benchmark points

Take into account LEP/Tevatron Limits, dark mater constraints, $g-2$, $b \to s\gamma$...

SUSY

J. Ellis et al.

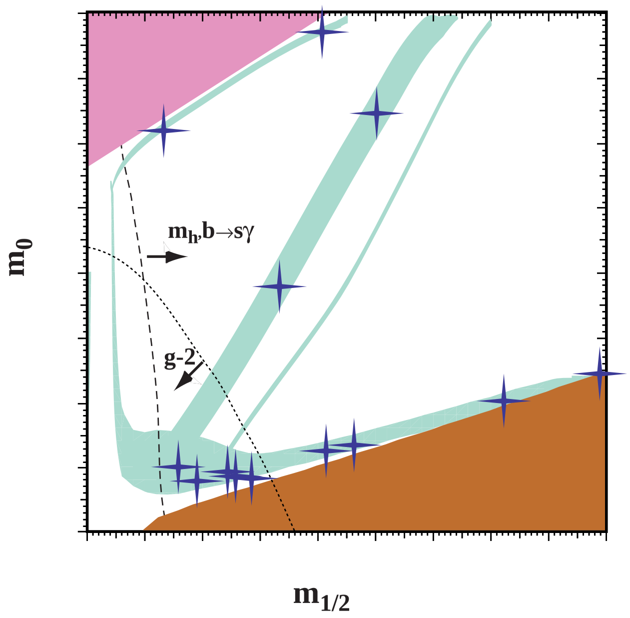
Benchmarks: (M.Battaglia et al., hep-ph/0106204)

Based on constrained MSSM model

Take into account:

- Experimental limits on sparticles, Higgs and $\tan\beta$
- $b \to s\gamma$ results
- Compatibility with Dark Matter $(0.1 < \omega h^2 < 0.3)$
- Compatibility with $g-2$ (not for all points)

Selected points in $m_0, m_{1/2}$ plane



Note: NOT a sampling of the region according to the 'likelyness' or compatibility with constraints, rather a collection of possible different scenarios

$\Rightarrow$ NOT meant for statistical study

SUSY

Supersymmetric spectra

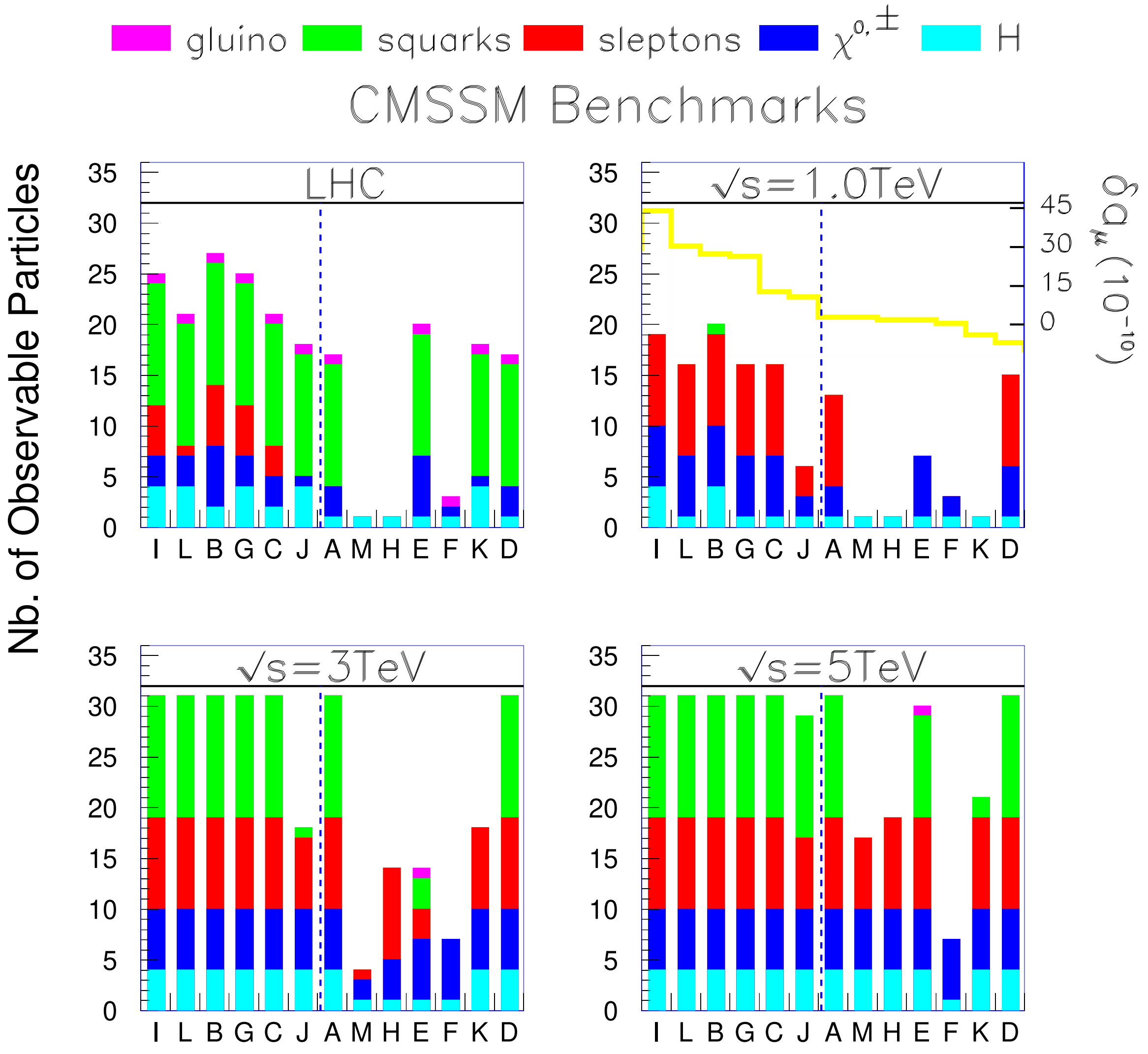
Model	A	B	C	D	E	F	G	H	I	J	K	L	M
$m_{1/2}$	600	250	400	525	300	1000	375	1500	350	750	1150	450	1900
m_0	140	100	90	125	1500	3450	120	419	180	300	1000	350	1500
$\tan\beta$	5	10	10	10	10	10	20	20	35	35	35	50	50
$\mathrm{sign}(\mu)$	+	+	+	−	+	+	+	+	+	+	−	+	+
$\alpha_s(m_Z)$	120	123	121	121	123	120	122	117	122	119	117	121	116
m_t	175	175	175	175	171	171	175	175	175	175	175	175	175
Masses													
$\|\mu\|$	739	332	501	633	239	522	468	1517	437	837	1185	537	1793
h^0	114	112	115	115	112	115	116	121	116	120	118	118	123
H^0	884	382	577	737	1509	3495	520	1794	449	876	1071	491	1732
A^0	883	381	576	736	1509	3495	520	1794	449	876	1071	491	1732
$\mathrm{H}^\pm$	887	389	582	741	1511	3496	526	1796	457	880	1075	499	1734
χ_1^0	252	98	164	221	119	434	153	664	143	321	506	188	855
χ_2^0	482	182	310	425	199	546	291	1274	271	617	976	360	1648
χ_3^0	759	345	517	654	255	548	486	1585	462	890	1270	585	2032
χ_4^0	774	364	533	661	318	887	501	1595	476	900	1278	597	2036
$\chi_1^\pm$	482	181	310	425	194	537	291	1274	271	617	976	360	1648
$\chi_2^\pm$	774	365	533	663	318	888	502	1596	478	901	1279	598	2036
$\tilde{g}$	1299	582	893	1148	697	2108	843	3026	792	1593	2363	994	3768
e_L, μ_L	431	204	290	379	1514	3512	286	1077	302	587	1257	466	1949
e_R, μ_R	271	145	182	239	1505	3471	192	705	228	415	1091	392	1661
ν_e, ν_μ	424	188	279	371	1512	3511	275	1074	292	582	1255	459	1947
τ_1	269	137	175	233	1492	3443	166	664	159	334	951	242	1198
τ_2	431	208	292	380	1508	3498	292	1067	313	579	1206	447	1778
ν_τ	424	187	279	370	1506	3497	271	1062	280	561	1199	417	1772
u_L, c_L	1199	547	828	1061	1615	3906	787	2771	752	1486	2360	978	3703
u_R, c_R	1148	528	797	1019	1606	3864	757	2637	724	1422	2267	943	3544
d_L, s_L	1202	553	832	1064	1617	3906	791	2772	756	1488	2361	981	3704
d_R, s_R	1141	527	793	1014	1606	3858	754	2617	721	1413	2254	939	3521
t_1	893	392	612	804	1029	2574	582	2117	550	1122	1739	714	2742
t_2	1141	571	813	1010	1363	3326	771	2545	728	1363	2017	894	3196
b_1	1098	501	759	973	1354	3319	711	2522	656	1316	1960	821	3156
b_2	1141	528	792	1009	1594	3832	750	2580	708	1368	2026	887	3216

Table 1: BENCHMARK POINTS, Version 1.6 (13/06/01). Mass spectra in GeV for minimal SUGRA models calculated with ISASUGRA v 7.51 and not including radiative corrections on chargino/neutralino masses. It is assumed in all cases that $m_t = 175$ GeV and $A(M_X) = 0$, except point F where $m_t = 176$ GeV is used.

1

SUSY

The number of particles which can be detected at a LC for the choosen SUSY benchmark points.



code: squarks, sleptons, $\chi^{\pm,0}$ Higgses

Points are ordered according to decreasing value of (compatibility with) $g-2$

Note: Does not reflect measurement precision

Not all points equally 'likely'

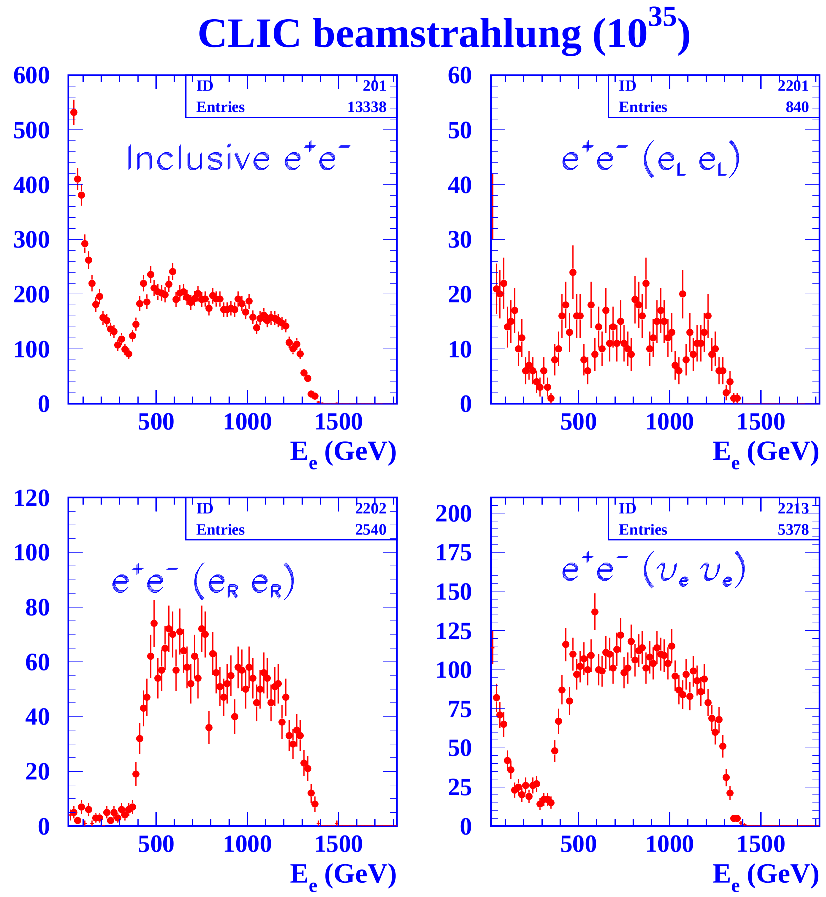
SUSY

G. Wilson

Case Study: sneutrino pair production

sneutrino mass determination

E.G. $m_{1/2} = 300$ GeV, $m_0 = 1450$ GeV, $\tan\beta = 10$, $A = 0$ GeV, $sign(\mu) > 0$ (mSUGRA) (point E)



Signal $\tilde{\nu}_e\tilde{\nu}_e \rightarrow e^+\tilde{\chi}_1^- e^-\chi_1^+(180)$

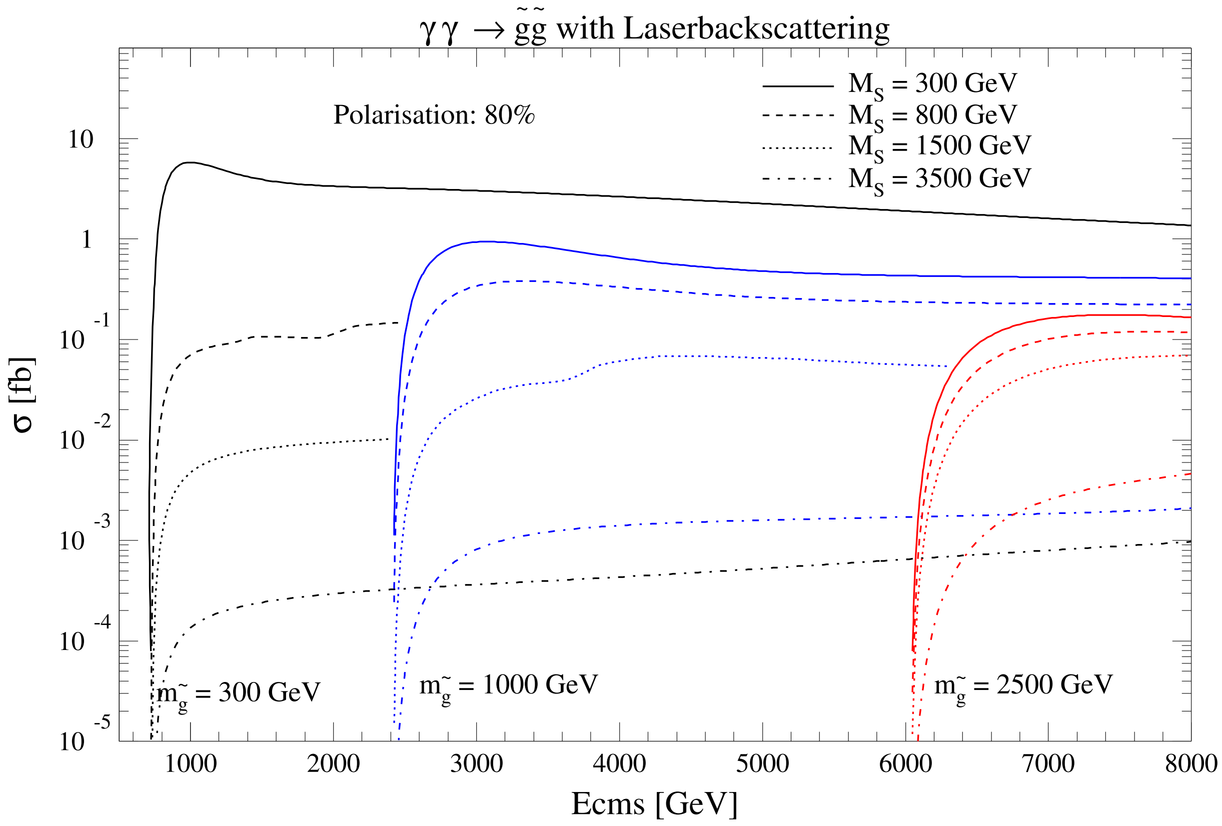
Typical 'box' shape of the signal preserved in CLIC environement

Mass measurements to $O(1\%)$ possible

SUSY

S.Berge, M.Klasen

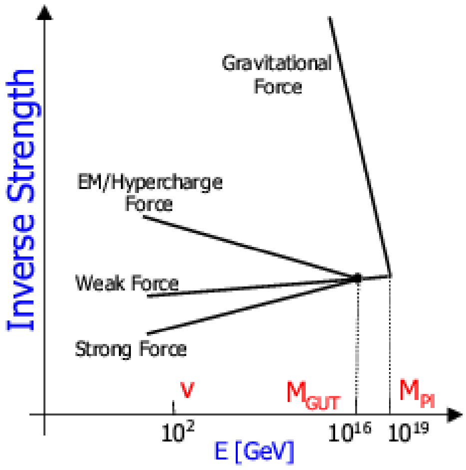
Gluino production: larger cross section in $\gamma\gamma$ than in the e^+e^- mode (few orders of magnitude)

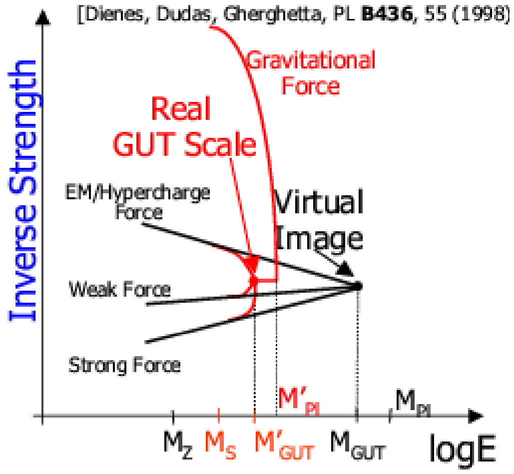


Extra Dimensions

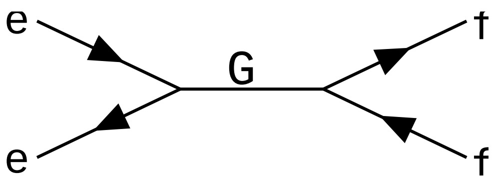
Originally: If you can't get to the Planck scale, try to bring the Planck scale to you

!Large Extra Dimensions!





Example: Deviations from SM due to virtual Kaluza Klein Graviton effects



Many different models...

ADD model: Large extra dimensions

T. Han, T. Rizzo, J.Hewett...

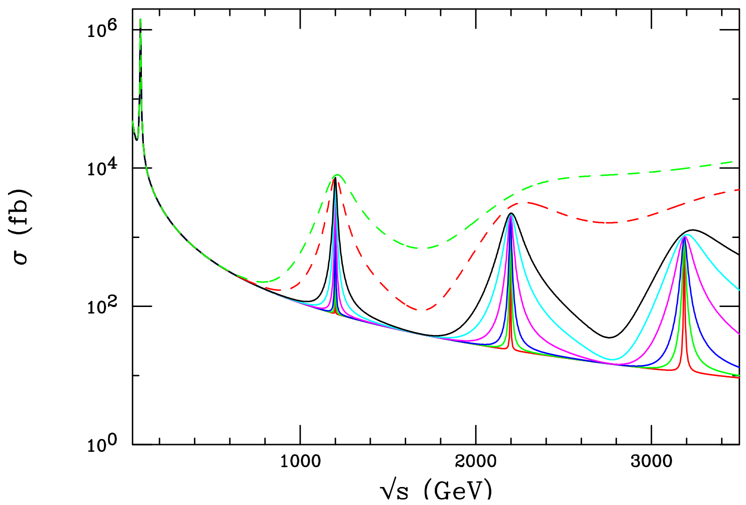
Collider	$\mathcal{L}$ (fb^{-1})	Reaction	Limit
LC	100	$e^+e^- \to f\bar{f}$	$6.5\sqrt{s}$
$\gamma\gamma$ Collider	100	$\gamma\gamma \to WW$	$11\sqrt{s}$
LHC	100	$p\bar{p} \to t\bar{t}$	6.0

Extra Dimensions

T. Rizzo

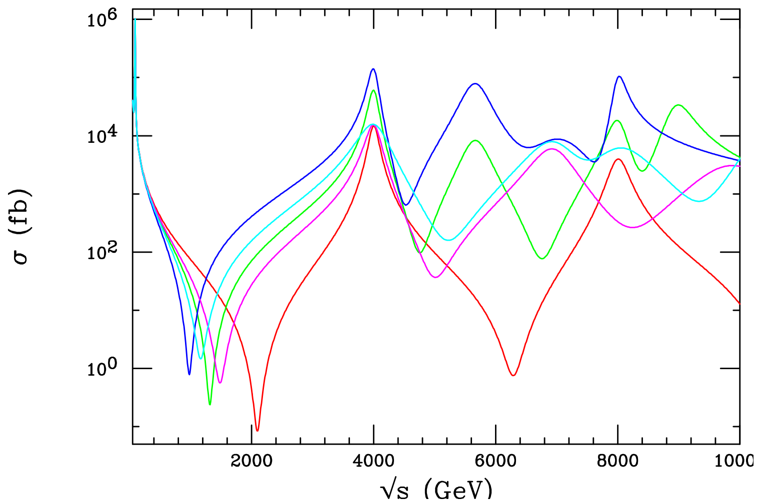
Warped dimensions (Randall-Sundrum)

- SM fields on brane and graviton in bulk
- Observe Kaluza-Klein (KK) resonances in e.g. the $e^+e^- \longrightarrow \mu^+\mu^-$ cross section



TeV scale extra dimensions

- SM gauge fields in the bulk



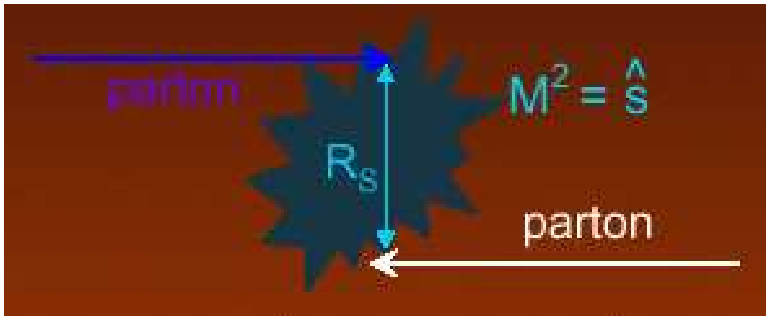
$\Rightarrow$ KK resonance factory

Black Holes

G. Lansberg, ADR.

If $M_{\text{Planck}} \sim O(1\text{TeV})$

$\Rightarrow$ Black Hole production at Multi TeV scale



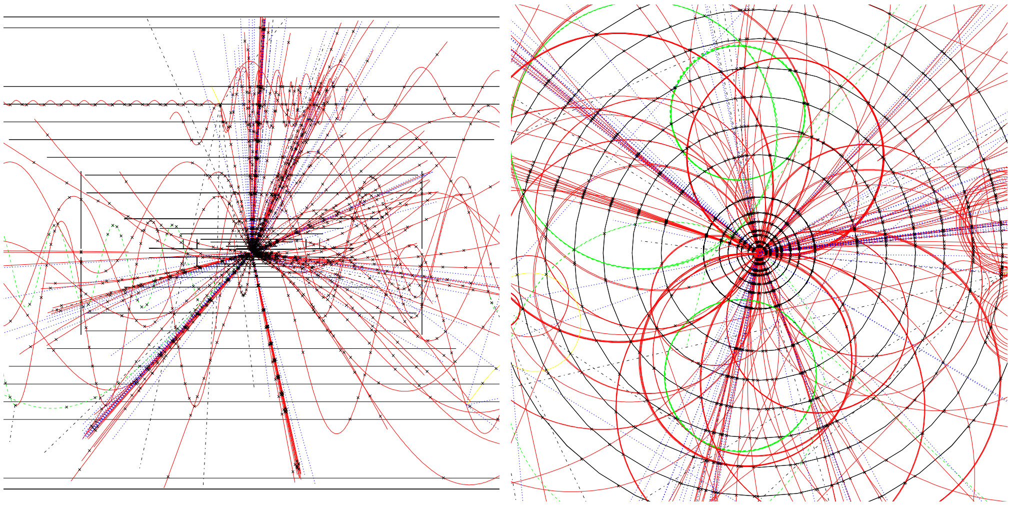
$\sigma = \pi R_s^2 \sim 1$ TeV$^{-2} \sim O(100)$ pb

R_S = Schwarzschild Radius

If $\sqrt{s_{e^+e^-}} > M_{BH} > M_{\text{Planck}} \to$ BH Factory

BH Lifetime $\sim 10^{-25} - 10^{-27}$ sec.

Decay via 'Democratic' Hawking radiation

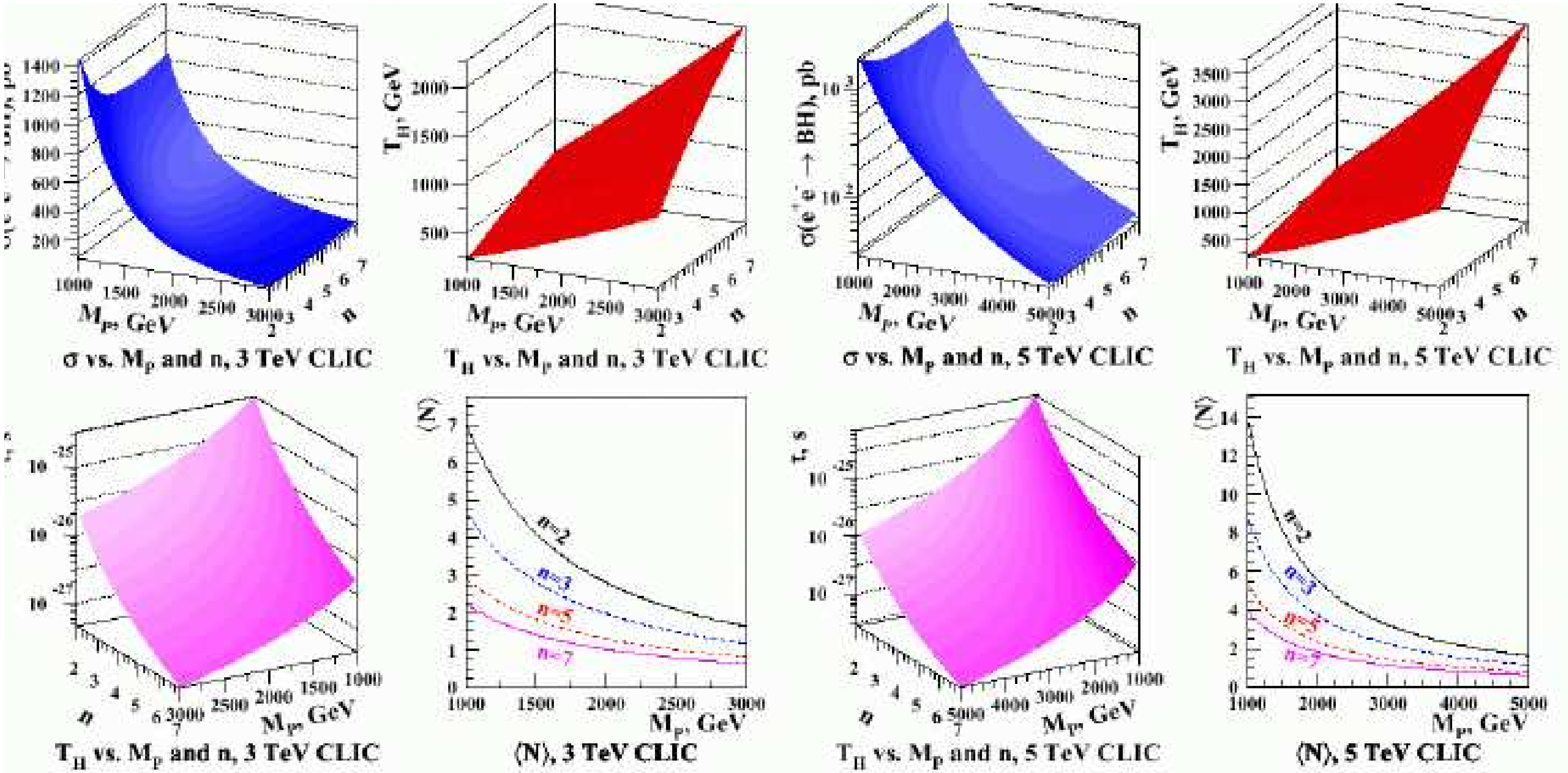


Many jets, 2% hard photons, 10% $\ell^{\pm}$...

Maybe the first signs of Quantum Gravity at TeV

Don't worry: Not dangerous for Mankind...

Black Holes

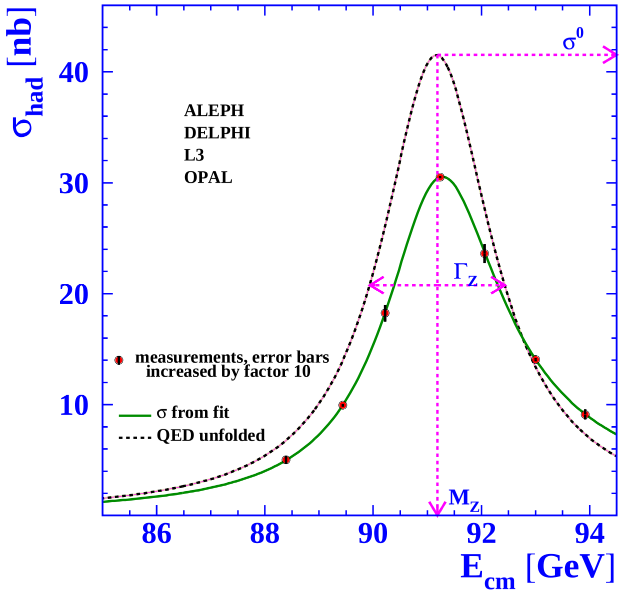


σ vs. M_P and n, 3 TeV CLIC
T_H vs. M_P and n, 3 TeV CLIC
σ vs. M_P and n, 5 TeV CLIC
T_H vs. M_P and n, 5 TeV CLIC
T_H vs. M_P and n, 3 TeV CLIC
⟨N⟩, 3 TeV CLIC
T_H vs. M_P and n, 5 TeV CLIC
⟨N⟩, 5 TeV CLIC
M_P, GeV
n
T_H, GeV
σ(e⁺e⁻ → BH), pb
τ, s
⟨N⟩
n=2
n=3
n=5
n=7

Z' Study at CLIC

Z^0 at LEP

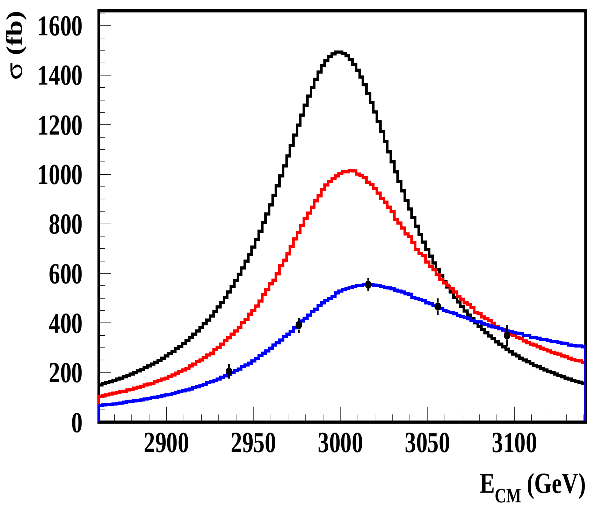
M. Battaglia



$$\delta M_Z/M_Z \sim 2.5 \cdot 10^{-5};\ \delta\Gamma_Z/\Gamma_Z \sim 1 \cdot 10^{-3}$$

Assume $M_{Z'}$ = 3.0 TeV and

$$\Gamma(Z')/M_{Z'} \simeq \Gamma(Z^0)/M_{Z^0}$$



$\Rightarrow$ Fit Accuracy $(1\mathrm{AB}^{-1})$

$$\delta M'_Z/M'_Z \sim 10^{-4};\ \delta\Gamma'_Z/\Gamma'_Z \sim 3 \cdot 10^{-3}$$

Degenerate Resonances

E.G. Degenerate BESS Model (Strong EWSB)

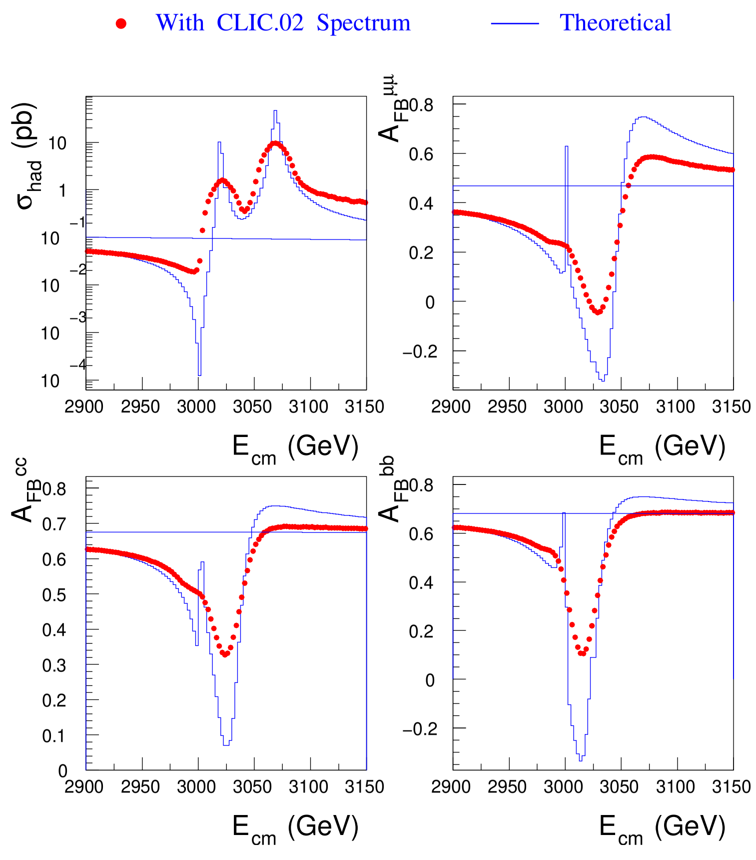
D. Dominici, De Curtis, M. Battaglia

Two (almost) degenerate Triples $L_3, L_3^\pm, R_3, R_3^\pm$

Sensitivity to L_3 and R_3 with M =3 TeV for L =500 fb^{-1} at LHC and L =1000 fb^{-1} at CLIC

g/g''	M (GeV)	Γ_{L_3} / Γ_{R_3} (GeV)	$S/\sqrt{S+B}$ LHC $(e+\mu)$	$S/\sqrt{S+B}$ CLIC (had.)	ΔM CLIC
0.1	3000	2.0 / 0.3	(3.4)	62	23.20 $\pm$ .06
0.2	3000	8.2 / 1.2	(6.6)	152	83.50 $\pm$ .02

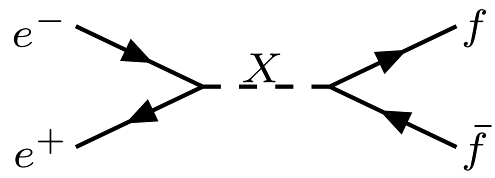
Energy Scan of Narrow Resonances $(g/g'' = 0.15)$



CLIC: can measure ΔM down to 13 GeV $(g/g'' > 0.08)$

Precision Measurements

M. Battaglia

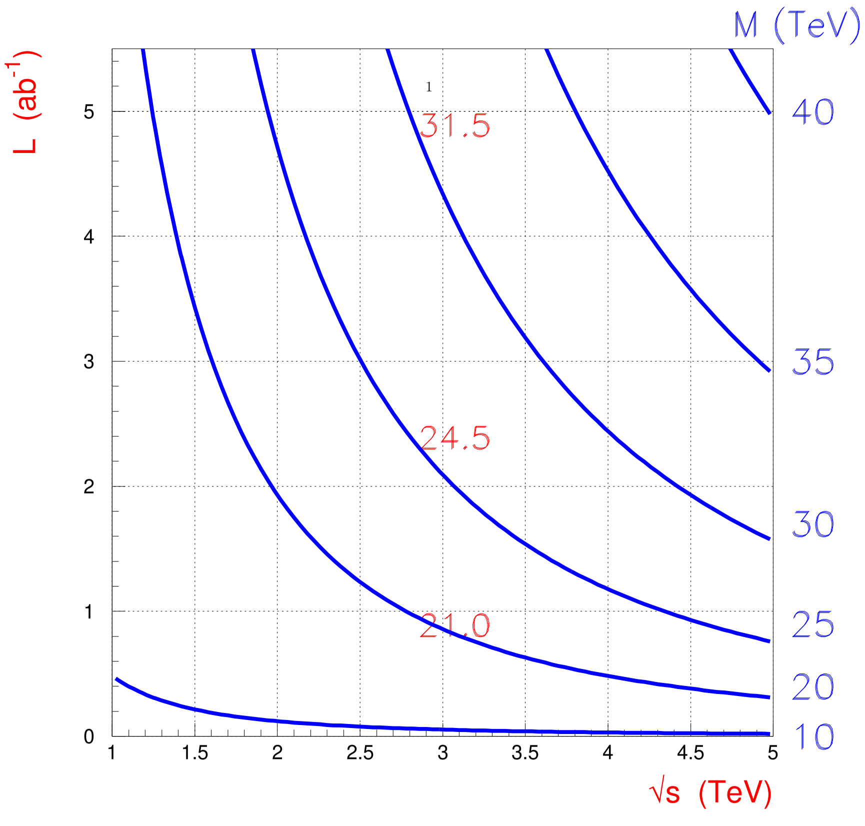


Measure $\sigma_{b\bar{b}}$, $A_{FB}^{\mu^+\mu^-}$ and $A_{FB}^{b\bar{b}}$

Examples: $\frac{\delta\sigma_{b\bar{b}}}{\sigma_{b\bar{b}}} = 0.012/\ 1\ \text{ab}^{-1}$

$$\frac{\delta A_{FB}^{\mu^+\mu^-}}{A_{FB}^{\mu^+\mu^-}} = 0.018/\ 1\ \text{ab}^{-1}$$

Mass sensitivity contours for SSM Z' bosons

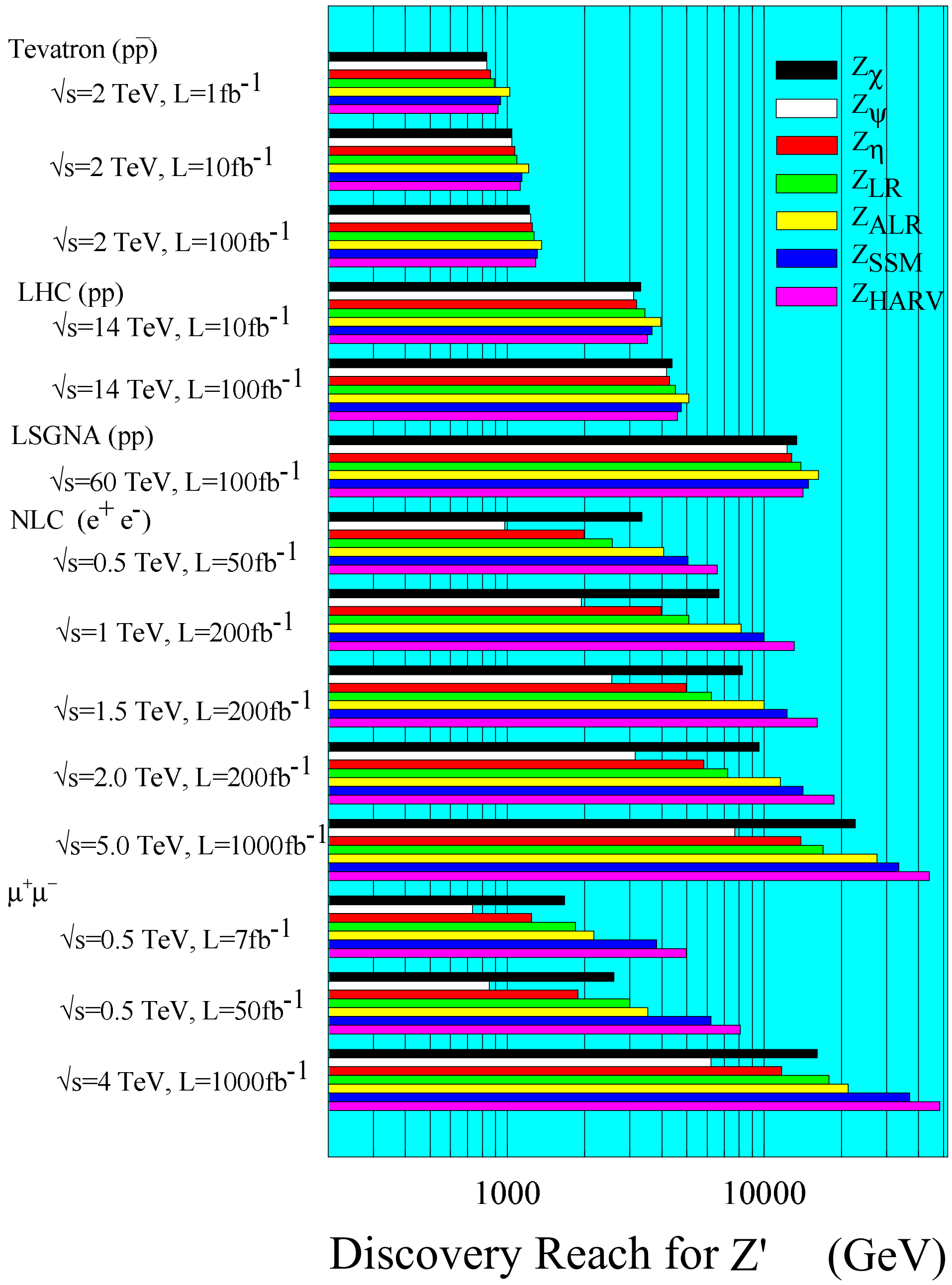


⇒ Sensitivity to $M_{Z'}$ to 30-40 TeV

Z' Reaches

S. Godfrey

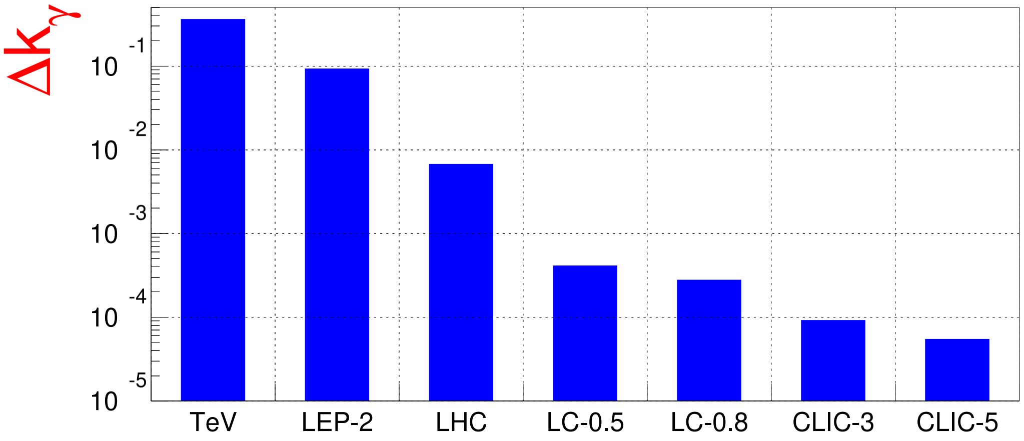
Different Extended Gauge Sector Models

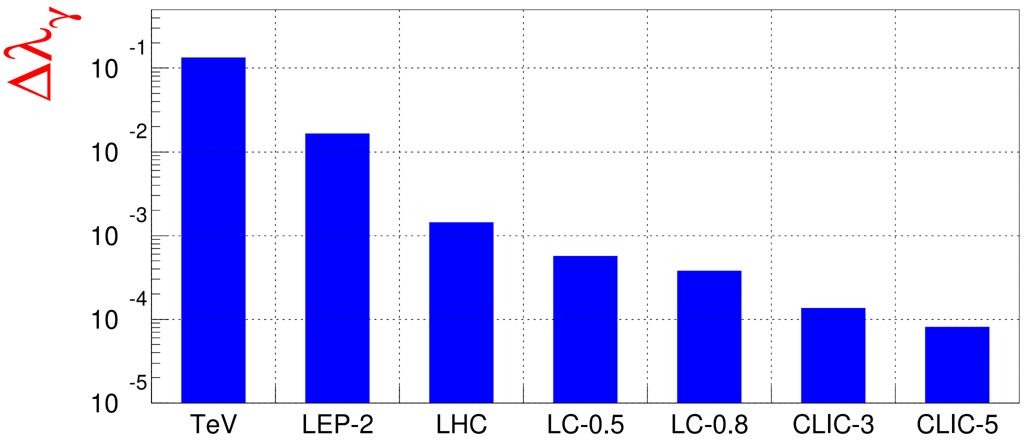


Triple Gauge Couplings

High precision analysis of the self coupling of the EW gauge bosons

T. Barklow

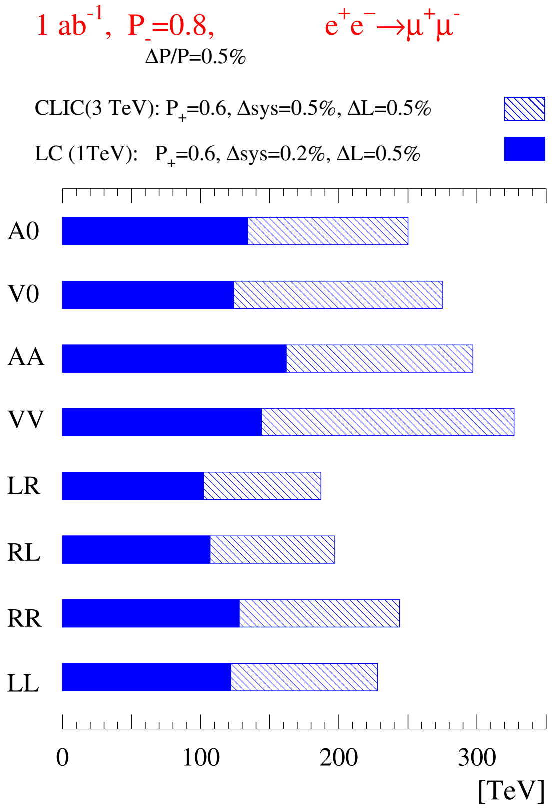


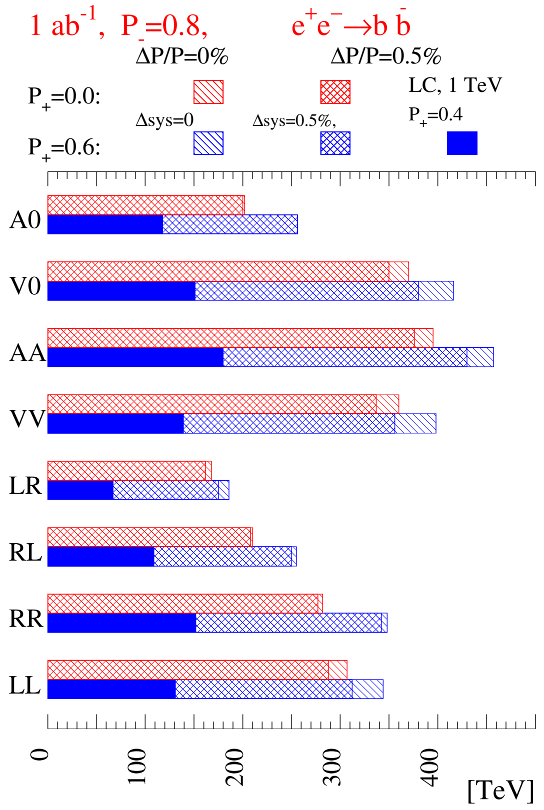


Expectation of the precison for $\Delta\lambda_\gamma$ and $\Delta\kappa_\gamma$. Measurements for 1 year of (high) luminosity for future colliders

Contact Interactions

S. Riemann





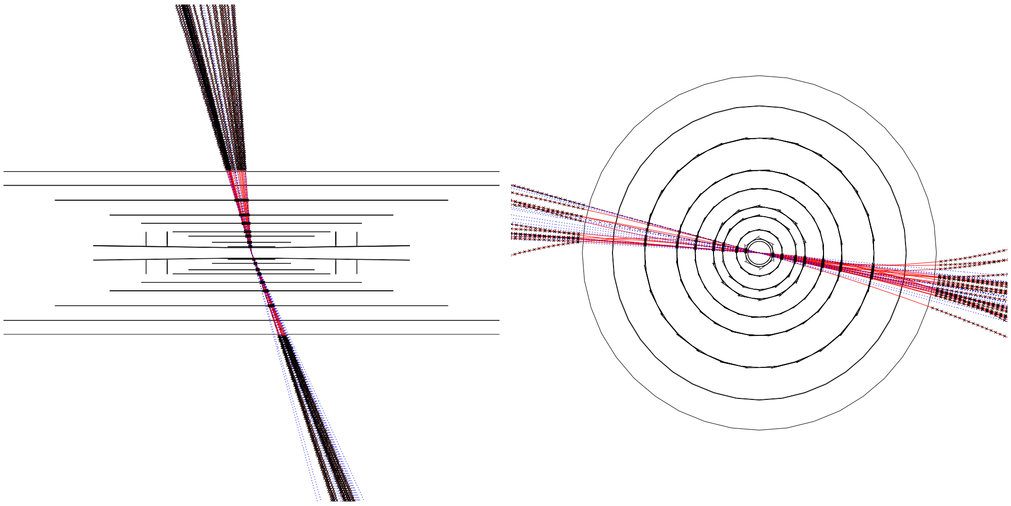
$\Rightarrow$ Contact Interactions: sensitivity to scales up to 100-400 TeV

Remember: If Higgs light $\longrightarrow$ something new must happen before 1000 TeV

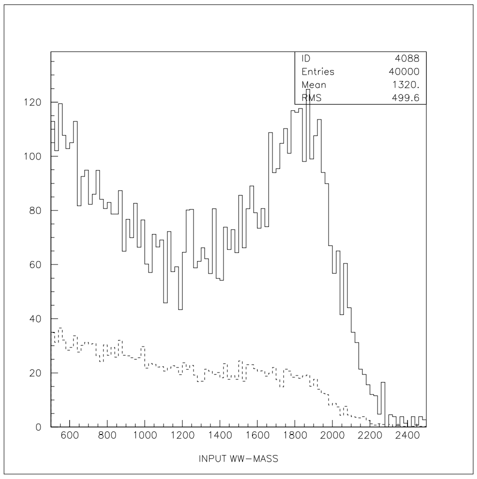
WW Scattering at CLIC

T.Barklow, ADR

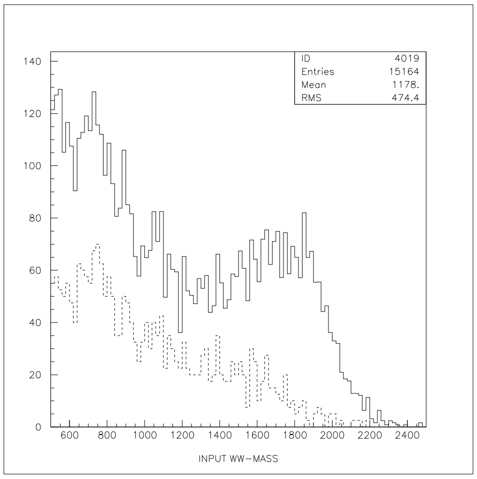
- Longitudinal W scattering $W_L W_L \to W_L W_L, (t\bar{t})$
- Analysis of WW spectrum: excess of events w.r.t. SM and possible resonance structure
- Study of vector model $M_{WW} \sim 2$ TeV



EWChL Langrangian form. $(a_5 = -0.002, a_4 = 0)$
1500 fb^{-1}



Before detector



After detector

The Weird and the Unexpected

M. Peskin

- String quantum gravity effects in $e^+e^- \to e^+e$ and $\gamma\gamma$

J. Hewett

- Effects of non-commutative interactions on physical observables

N. Arkani Hamed, J. Lykken

- Black hole formation in particle collisions ($\sqrt{s}/M_*$) and Hawking radiation detected as thermal spectrum of produced particles.

J. Lykken

- Brane fluctuation modes, (Nylons?)

N. Arkani Hamed et al.

- Split Fermions in Extra Dimensions

L. Hall et al.

- Extra Dimensions & Two supersymmetries

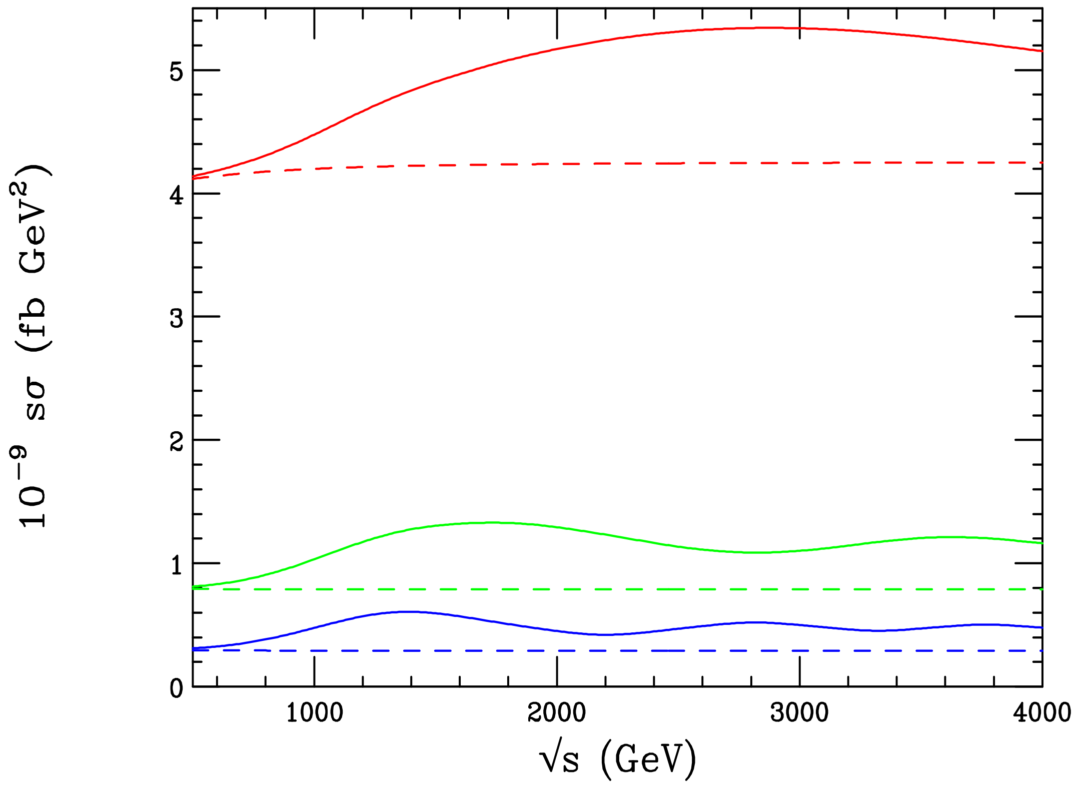
…

Non-Commutative Interactions

J. Hewett (hep-ph/0010354)

- String inspired non-commutative QFT
- Non abelian nature of QED can be tested in Moller and Bhabha scattering by looking for characteristics pattern from interference of Z and γ t-channel or s- and t- channel with different periods.
- Non commutative scales Λ_{NC} of the order of $(3.5 - 1.5) \times \sqrt{s}$ can be probed:

Bhabha Scattering



SUMMARY

Measurements at CLIC (5 TeV / 1 ab^{-1})

Higgs (Light)	λ_{HHH} to $\sim 5 - 10\%$ (5 ab^{-1})
Higgs (Light)	$g_{H\mu\mu}$ to $\sim 3.5 - 10\%$ (5 ab^{-1})
Higgs (Heavy)	2.0 TeV (e^+e^-) 3.5 TeV $(\gamma\gamma)$
squarks	2.5 TeV
sleptons	2.5 TeV
Z' (direct)	5 TeV
Z' (indirect)	30 TeV
l^*, q^*	5 TeV
TGC (95%)	0.00008
Λ compos.	400 TeV
$W_L W_L$	> 5 TeV
ED (ADD)	30 TeV (e^+e^-)
	55 TeV $(\gamma\gamma)$
ED (RS)	18 TeV (c=0.2)
ED (TeV^{-1})	80 TeV
Resonances	$\delta M/M, \delta\Gamma/\Gamma \sim 10^{-3}$
Black Holes	5 TeV

- LHC (Tevatron) will show where Nature takes us
- CLIC Accelerator R&D will continue till 2007
- e^+e^- physics back at CERN > 2015?
(or CLIC part of an e^+e^- LC facility?)