Detectors and Physics Issues

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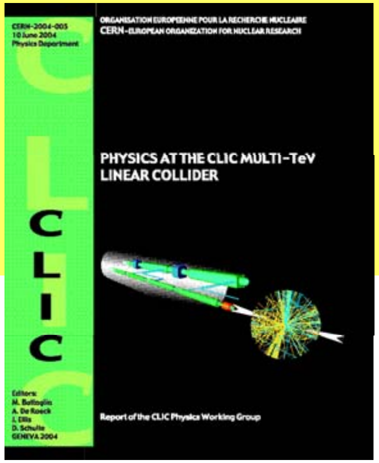
CLIC ACE meeting
CERN 20-22 June

Content

- Introduction
- Experimental issues at CLIC for precision physics: backgrounds, luminosity spectra
- Physics examples: The Higgs particle
  BSM searches & measurements

- *Also some comments concerning CLIC @ 500-1000 GeV*

- Details in the report hep-ph/0412251



CERN-2004-005
10 June 2004
Physics Department

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
CERN-EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PHYSICS AT THE CLIC MULTI-TeV
LINEAR COLLIDER

CLIC

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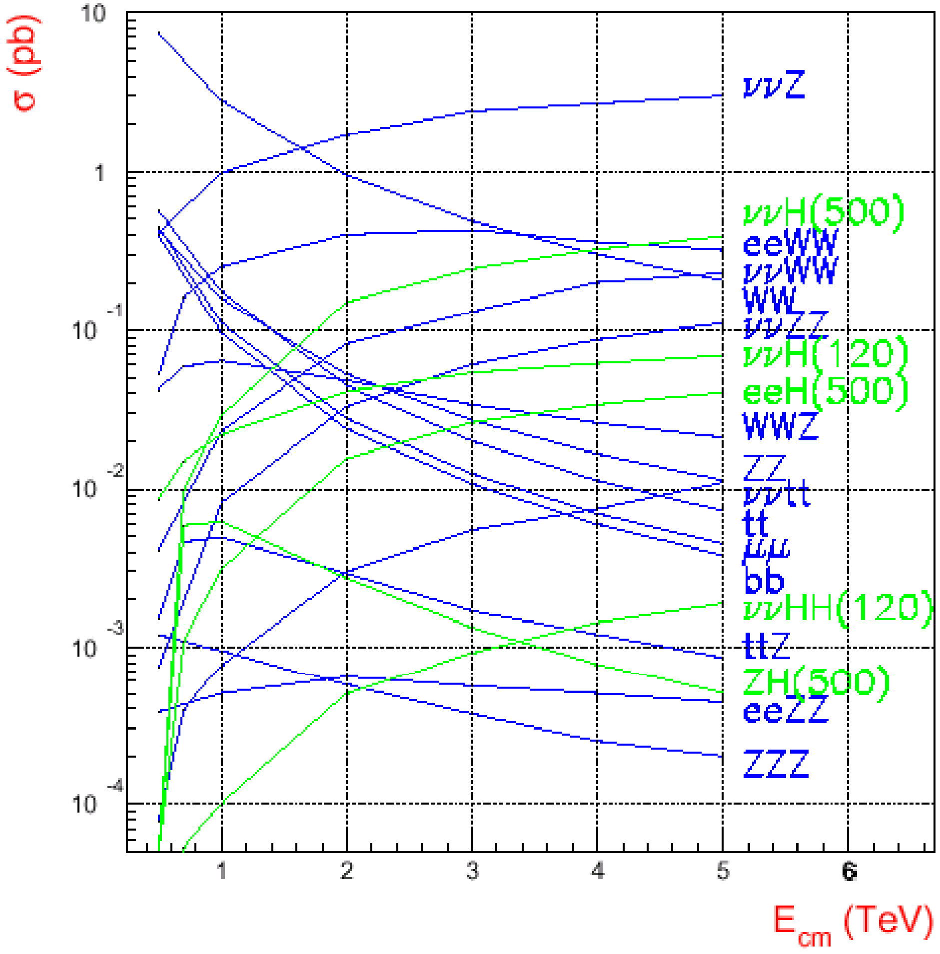
GENEVA 2004

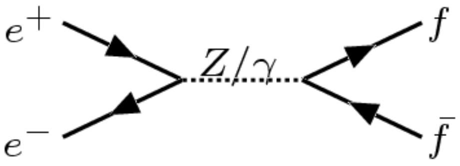
Report of the CLIC Physics Working Group

Cross Sections at CLIC



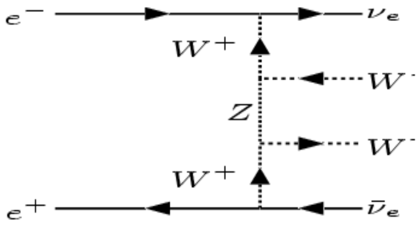
Event Rates/Year (1000 fb^{-1})	3 TeV 10^3 events	5 TeV 10^3 events
$e^+e^- \to t\bar{t}$	20	7.3
$e^+e^- \to b\bar{b}$	11	3.8
$e^+e^- \to ZZ$	27	11
$e^+e^- \to WW$	490	205
$e^+e^- \to hZ/h\nu\nu$ (120 GeV)	1.4/530	0.5/690
$e^+e^- \to H^+H^-$(1 TeV)	1.5	0.95
$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$ (1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

s-Channel Production



$$\sigma \propto 1/s$$

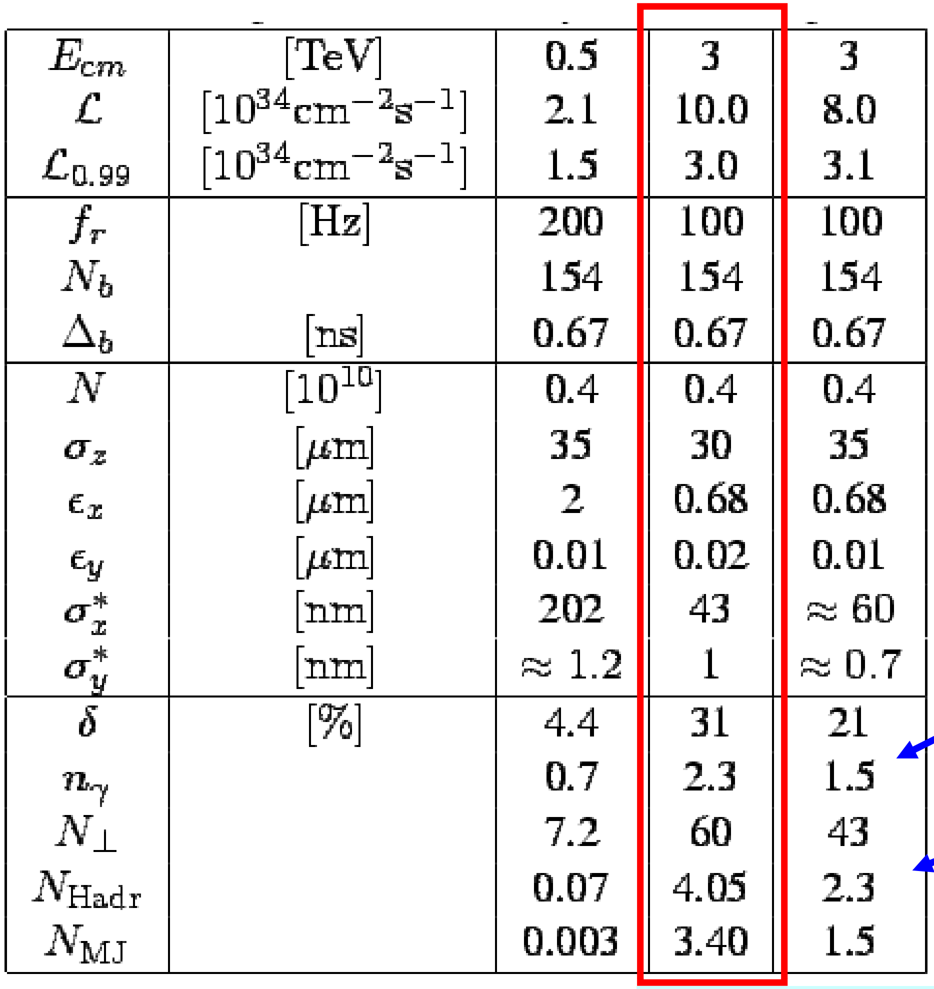
t-Channel Production



$$\sigma \propto log(s)$$

Experimental Issues: Backgrounds

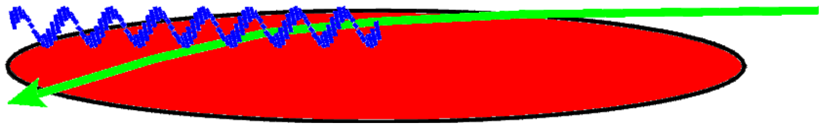
CLIC 3 TeV e+e- collider with a luminosity ~ $10^{35}\text{cm}^{-2}\text{s}^{-1}$ (1 ab^{-1}/year)



E_{cm}	[TeV]	0.5	3	3
$\mathcal{L}$	$[10^{34}\text{cm}^{-2}\text{s}^{-1}]$	2.1	10.0	8.0
$\mathcal{L}_{0.99}$	$[10^{34}\text{cm}^{-2}\text{s}^{-1}]$	1.5	3.0	3.1
f_r	[Hz]	200	100	100
N_b		154	154	154
Δ_b	[ns]	0.67	0.67	0.67
N	$[10^{10}]$	0.4	0.4	0.4
σ_z	$[\mu\text{m}]$	35	30	35
ϵ_x	$[\mu\text{m}]$	2	0.68	0.68
ϵ_y	$[\mu\text{m}]$	0.01	0.02	0.01
σ_x^*	[nm]	202	43	≈ 60
σ_y^*	[nm]	≈ 1.2	1	≈ 0.7
δ	[%]	4.4	31	21
n_γ		0.7	2.3	1.5
$N_\perp$		7.2	60	43
N_{Hadr}		0.07	4.05	2.3
N_{MJ}		0.003	3.40	1.5

Report → Old Values

To reach this high luminosity: CLIC has to operate in a regime of high beamstrahlung



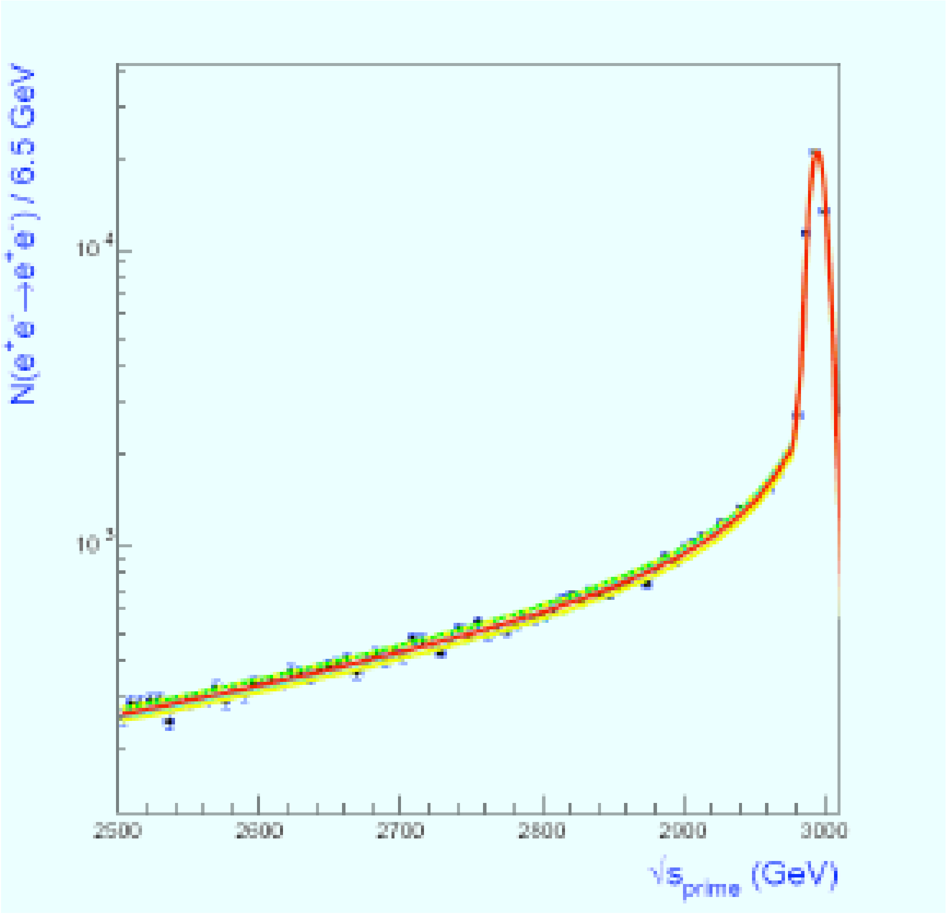
Expect large backgrounds

# of photons/beam particle

- e+e- pair production
- γ γ events
- Muon backgrounds
- Neutrons
- Synchrotron radiation

Expect distorted lumi spectrum

Experimental issues: Luminosity Spectrum



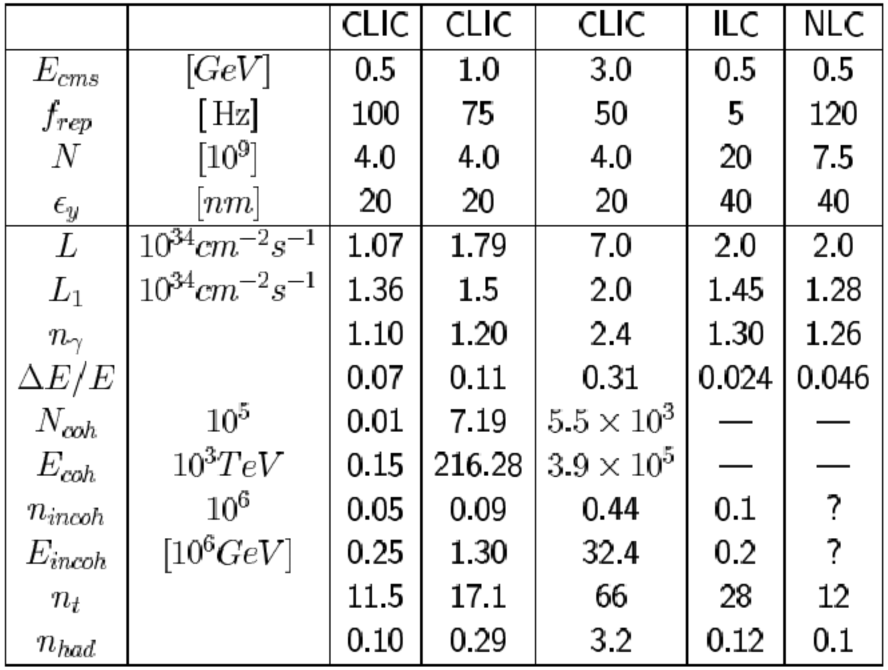
Reconstructed $\sqrt{s'}$ Spectrum from
Bhabha Angles

Preliminary Results: expect accuracy $\frac{\delta\sqrt{s'}}{\sqrt{s}} \simeq 10^{-4}$ for 100 fb^{-1}

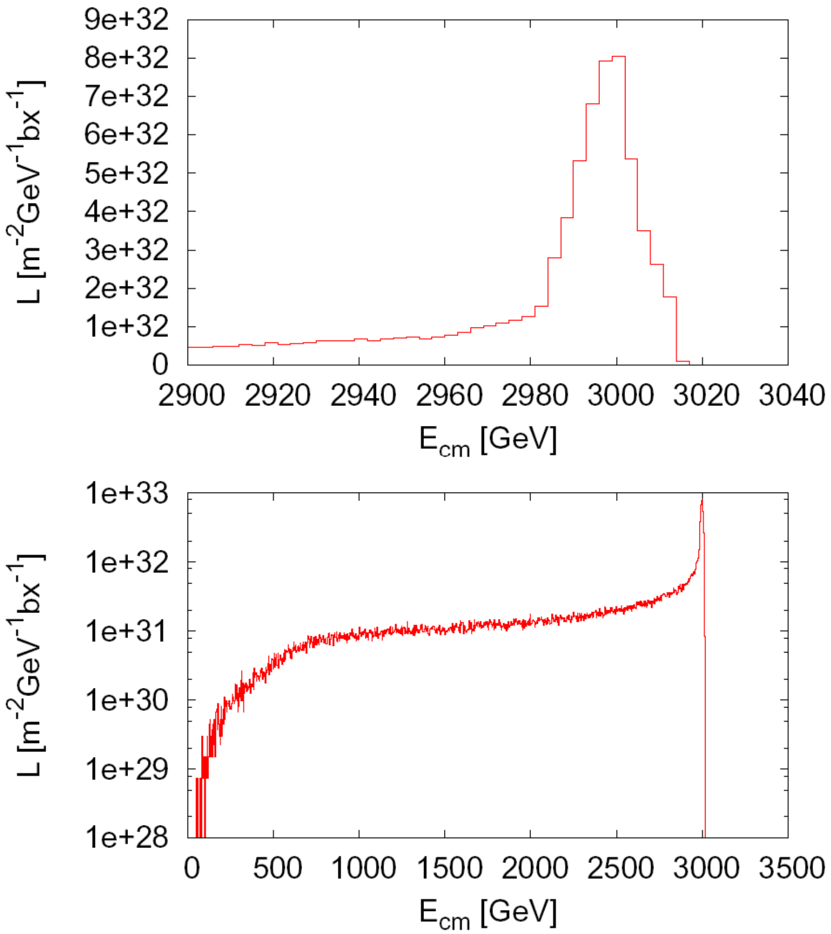
Luminosity spectrum not as sharply peaked as e.g. at LEP or TESLA/NLC

New Parameters..

See D. Schulte



		CLIC	CLIC	CLIC	ILC	NLC
E_{cms}	$[GeV]$	0.5	1.0	3.0	0.5	0.5
f_{rep}	[Hz]	100	75	50	5	120
N	$[10^9]$	4.0	4.0	4.0	20	7.5
ϵ_y	$[nm]$	20	20	20	40	40
L	$10^{34}cm^{-2}s^{-1}$	1.07	1.79	7.0	2.0	2.0
L_1	$10^{34}cm^{-2}s^{-1}$	1.36	1.5	2.0	1.45	1.28
n_γ		1.10	1.20	2.4	1.30	1.26
$\Delta E/E$		0.07	0.11	0.31	0.024	0.046
N_{coh}	10^5	0.01	7.19	5.5×10^3	—	—
E_{coh}	$10^3 TeV$	0.15	216.28	3.9×10^5	—	—
n_{incoh}	10^6	0.05	0.09	0.44	0.1	?
E_{incoh}	$[10^6 GeV]$	0.25	1.30	32.4	0.2	?
n_t		11.5	17.1	66	28	12
n_{had}		0.10	0.29	3.2	0.12	0.1



- Same bunch distance (0.6 nsec)
- 2 x more bunches per train
- Backgrounds similar or somewhat better

Do not except significant differences with studies in the report

e+e- Pair Production

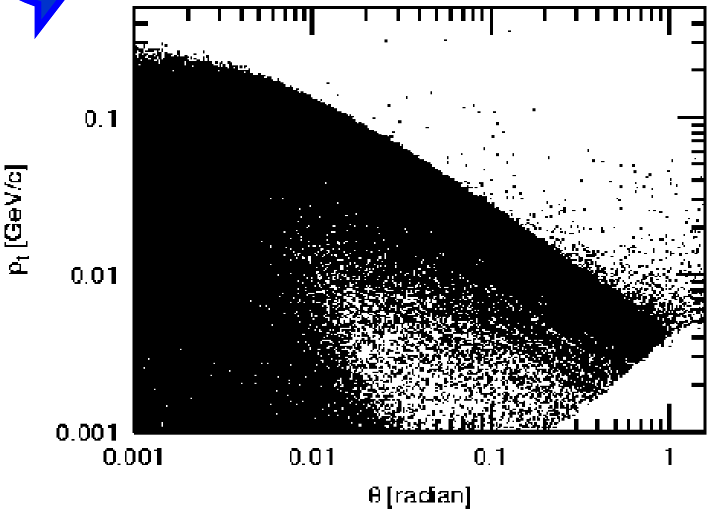
Coherent pair production
- number/BX   4.6 10^9
- energy/BX   3.9 10^8 TeV

Disappear in the beampipe

Can backscatter on machine elements
Need to protect detector with mask

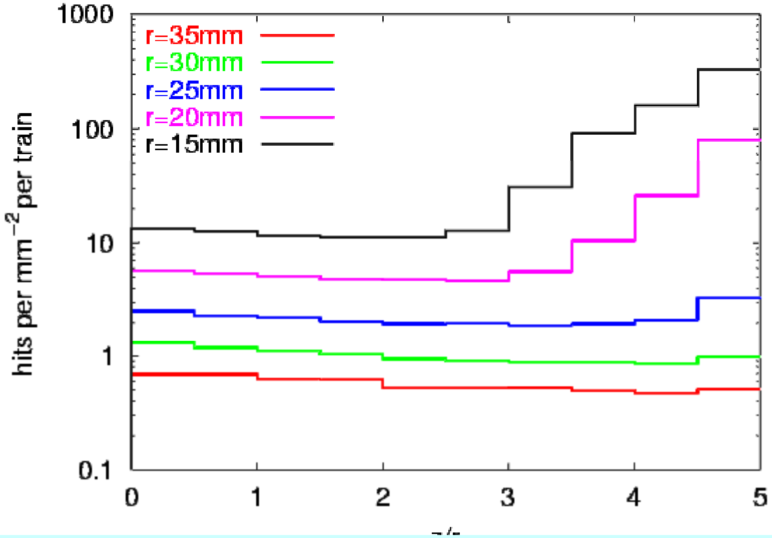
Incoherent pair production:
- number/BX   4.6 10^5
- energy/BX   3.9 10^4 TeV

Can be suppressed by strong magnetic field in of the detector



4T field

hits/mm²/bunch train

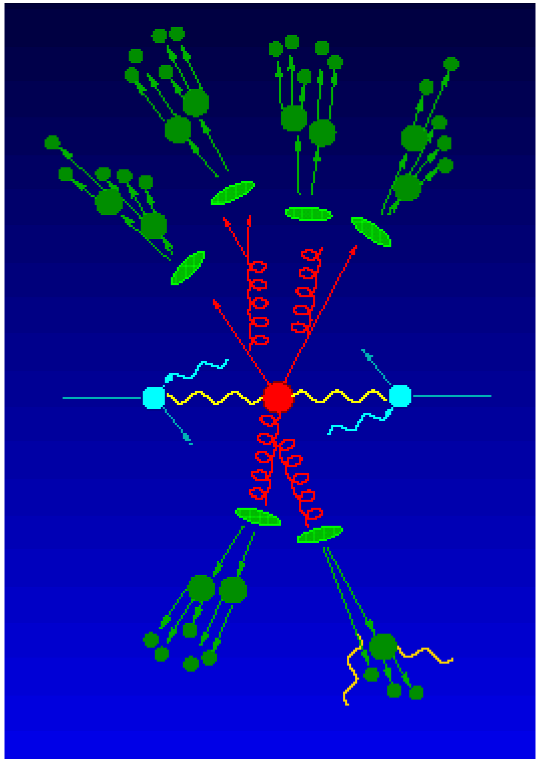


30mm ⇒O(1) hit/mm²/bunch train 👍

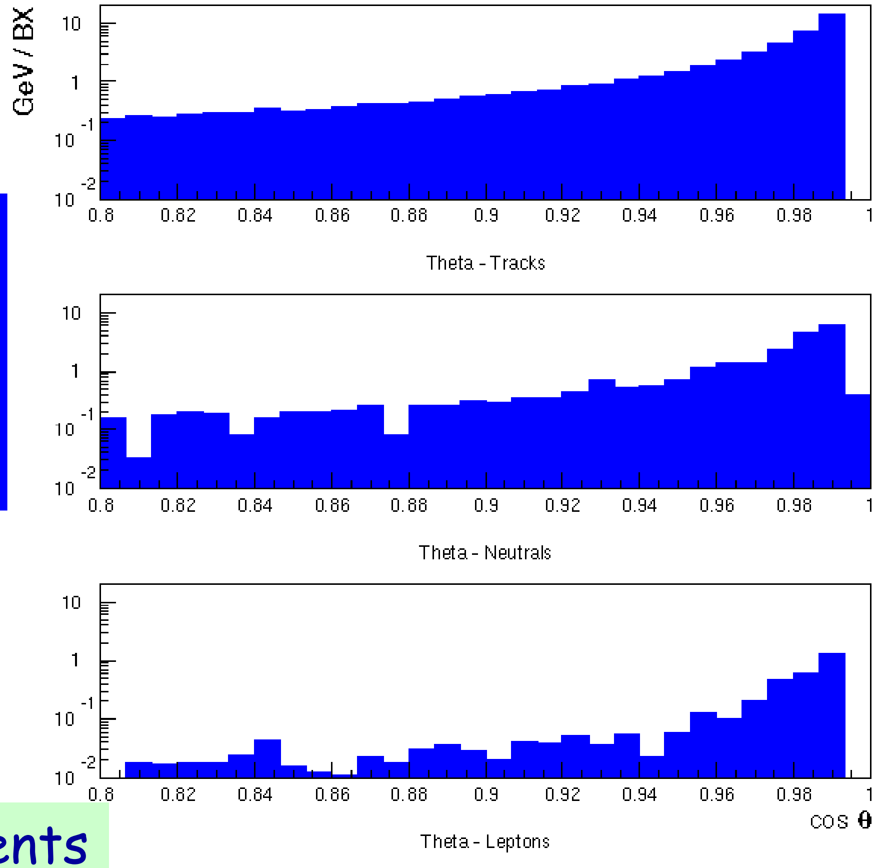
$\gamma\gamma$ Background

$\gamma\gamma \rightarrow$ hadrons: 4 interactions/bx with W_{HAD}>5 GeV

Neutral and charged energy as function of cosθ per bx



Particles accepted within θ > 120mrad

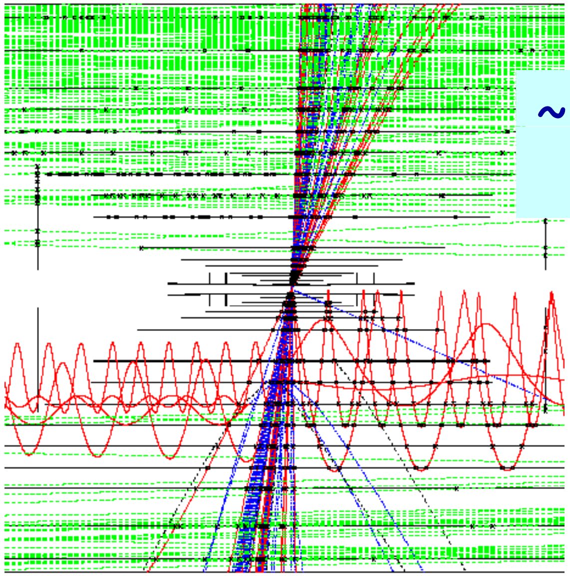


For studies: take 20 bx and overlay events

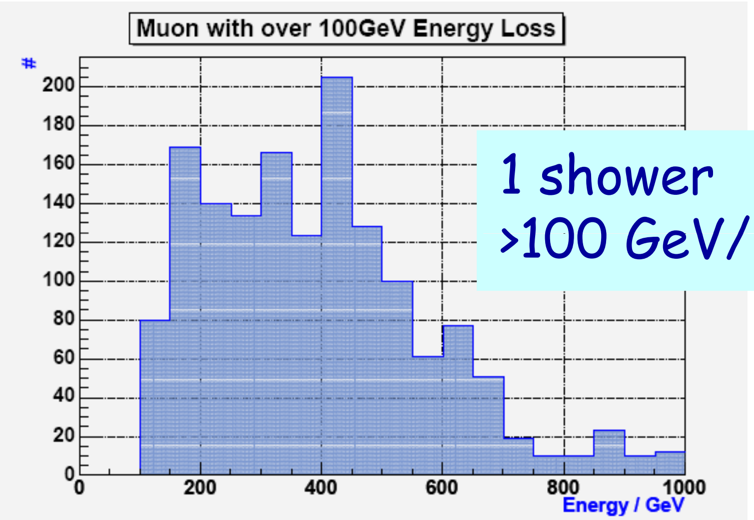
Most activity at small angles

Muon Background

$e^+e^- \rightarrow t\bar{t}$ AT $\sqrt{s} = 3$ TEV
+ MUON BACKGROUND (10 BX)



~20 muons per bx



1 shower
>100 GeV/5 bx

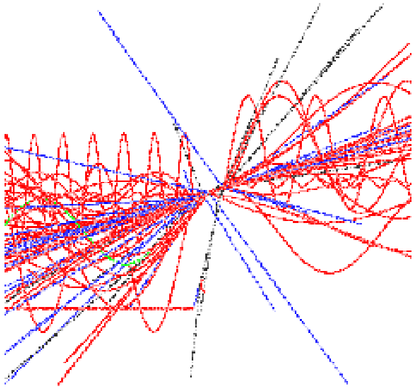
Muon pairs produced in electromagnetic interactions upstream of the IP e.g beam halo scraping on the collimators

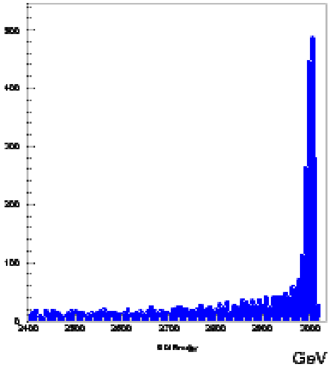
GEANT3 simulation, taking into account the full CLIC beam delivery system

# of muons expected in the detector ~ few thousand/bunch train (150 bunches/100ns)

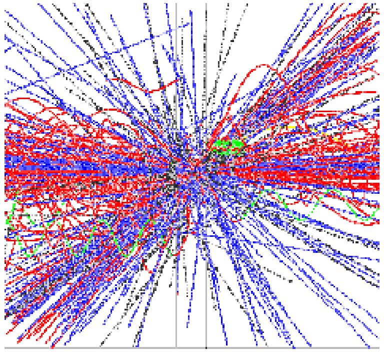
$\Rightarrow$ OK for (silicon like) tracker
$\Rightarrow$ Calorimeter?

Studies include background, spectra,…

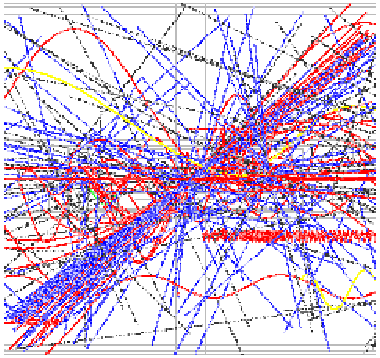




Physics generators (COMPHEP PYTHIA6,…)
+ CLIC lumi spectrum (CALYPSO)



+ γ γ→ hadrons background
e.g. overlay 20 bunch crossings
(+ e+e- pair background files…)

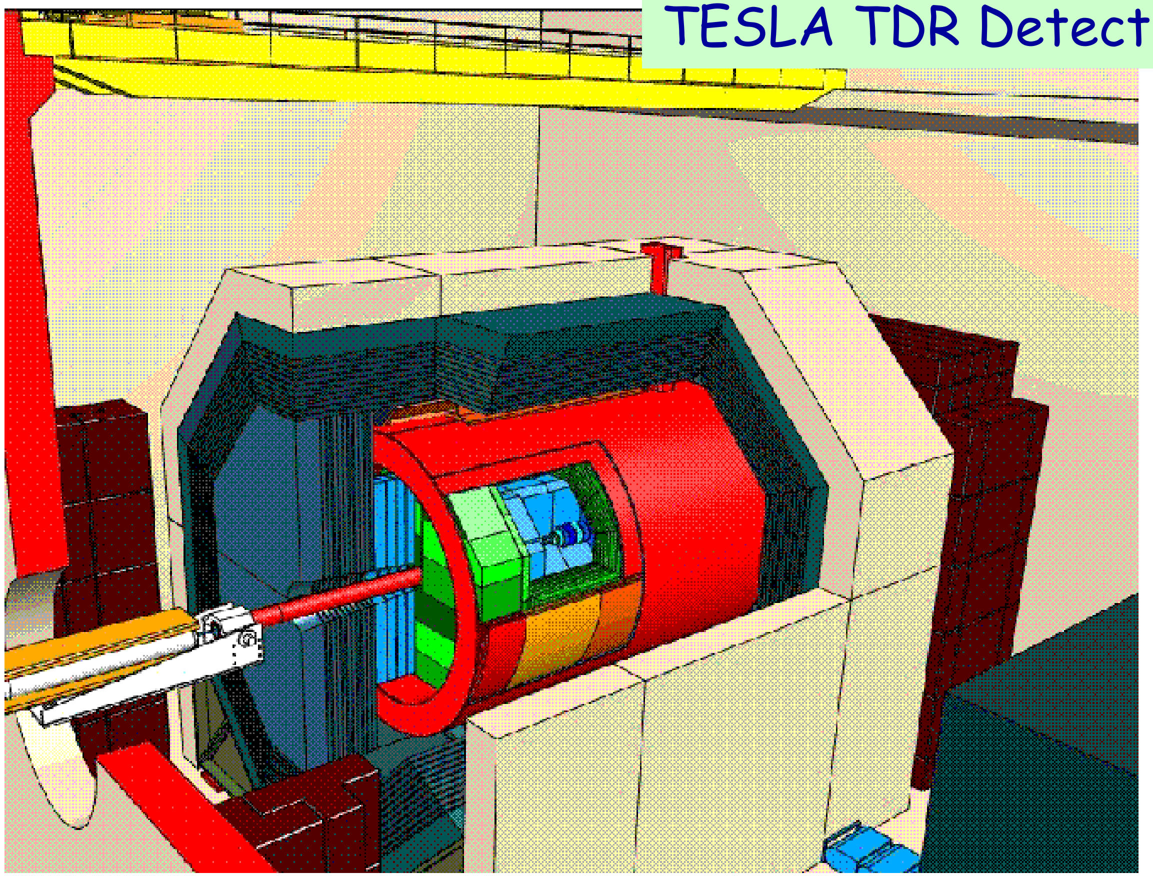


Detector simulation

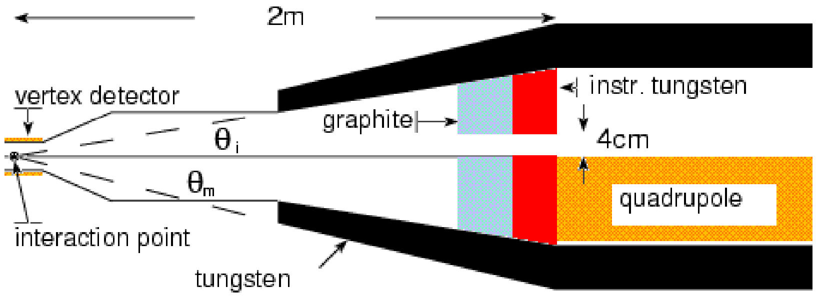
- SIMDET (fast simulation)
- GEANT3 based program

⇒Studies of the benchmark processes include backgrounds, effects of lumi spectrum etc.

A Detector for a LC


TESLA TDR Detector

Background at the IP enforces use of a mask



CLIC: Mask covers region up to 120 mrad
Energy flow measurement possible down to 40 mrad

~TESLA/NLC detector qualities: good tracking resolution, jet flavour tagging, energy flow, hermeticity,…

Detector Specifications

Detector	CLIC
Vertexing	$15\mu m \oplus \frac{35\mu m GeV/c}{p\sin^{3/2}\theta}$ $15\mu m \oplus \frac{35\mu m GeV/c}{p\sin^{5/2}\theta}$
Solenoidal Field	$B = 4\ T$
Tracking	$\frac{\delta p_t}{{p_t}^2} = 5. \times 10^{-5}$
E.m. Calorimeter	$\frac{\delta E}{E(GeV)} = 0.10\frac{1}{\sqrt{E}} \oplus 0.01$
Had. Calorimeter	$\frac{\delta E}{E\ (GeV)} = 0.40\frac{1}{\sqrt{E}} \oplus 0.04$
μ Detector	Instrumented Fe yoke $\frac{\delta p}{p} \simeq 30\%$ at 100 GeV/c
Energy Flow	$\frac{\delta E}{E\ (GeV)} \simeq 0.3\frac{1}{\sqrt{E}}$
Acceptance mask beampipe small angle tagger	$\lvert\cos\theta\rvert < 0.98$ 120 mrad 3 cm $\theta_{min} = 40$ mrad

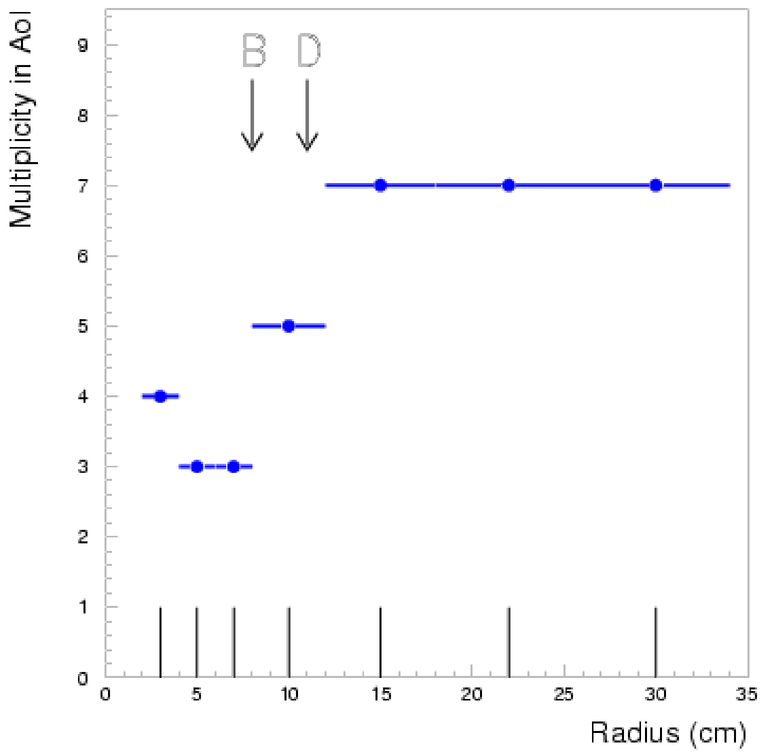
Starting point: the TESLA TDR detector adapted to CLIC environment

- Detailed studies performed for previous CLIC parameters
- Update with new CLIC parameters needs to be done
- Greater need for time-stamping of events
- No significant physics difference found previously between NLC and TESLA at sub-TeV energies
- None expected between old and new multi-TeV parameters

Example B-tagging

$B \rightarrow X$ DECAY LENGTH

$\sqrt{s}$ (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**



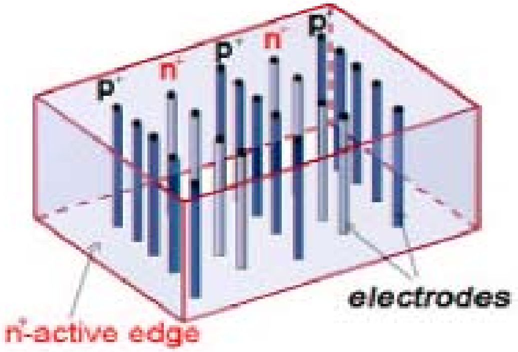
B-Decay length is long!

- Define Area of Interest by ± 0.04 rad cone around the jet axis
- Count hit multiplicity (or pulse height) in Vertex Track layers
- Tag heavy hadron decay by step in detected multiplicity
- Can reach 50% eff./~80% purity

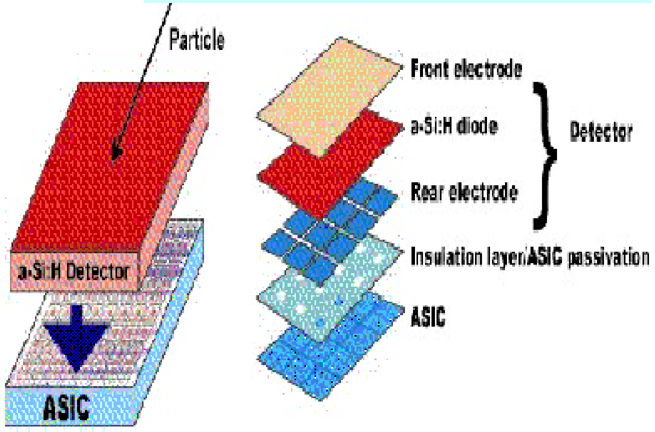
Tracking Technologies

Properties	Standard planar crystal silicon	3D- silicon	Monolithic CMOS pixel detector	a-Si:H pixel detector
Collection speed Electron transient t Holes transient t	10ns 20ns	Short drift < 1ns 1ns	Thermal drift 100ns 200ns	Short drift, high field 2ns 150ns
Thickness	300μm	100μm -200μm	2μm - 8μm	30μm - 50μm
MIP charge signal	24 000 e-	10 000e-20 000e-	100 e- 500 e-	1000 e- 2000 e-
Radiation hardness Fluence n/cm^2	3 10^{14} at -20^0C	At least 10^{15} at +20^0C	$<$ 10^{13}, strong surface effects	$>$ 510^{15}, limit not known, self-annealing by mobile H
Operating temperature	-20^0C, cryogenic T	Room T	Room T	Room T to 60^0C
Manufacturing Cost	High	High	Low	Low
Field of applications	Microvertex detector tracker	Small detector area, fast timing, high radiation level	Microvertex detector, low radiation level, slow readout	Large area detector, macropad and microvertex, high radiation environment

3D Silicon



Amorphous Silicon



- Time stamping will be important O(ns)
- Macro-pixels?
- Radiation however not a big issue
  ~ 5 10^{10} neutrons/cm^{-2}/year

⇒R&D will be required!!

⇒Discussion in the Physics working group has started with in-house experts

Ultra-Fast tracking Layer for time stamping

P. Jarron/CLIC-PH meeting
Fall '06

- Technologies?
  - Sensors
    - Planar silicon pixel detector P326 Gigatracker:
    - More exotic:
      - 3-D silicon detector faster than planar silicon, but no power reduction
      - SPAD, very high gain, lower power consumption
      - MCP, very high gain , lower power consumption
  - Questions
    - probability to have 2, 3.. successive BX's with interaction determines the sensor speed
    - Segmentation of the fast time stamp layer?
    - Longitudinal spread of BX's influence complexity of track reconstruction
- Time stamps are local
  - Signal processing and event reconstruction
    - Each pad provide time stamps for each BX's of beam train (150/s),
    - Vertex operates as an imager 150 frame (train)/s
    - Each vertex hit in front of the time stamp layer will be associated to a bunch number

To be continued in CLIC-PH discussions… But detector R&D needed

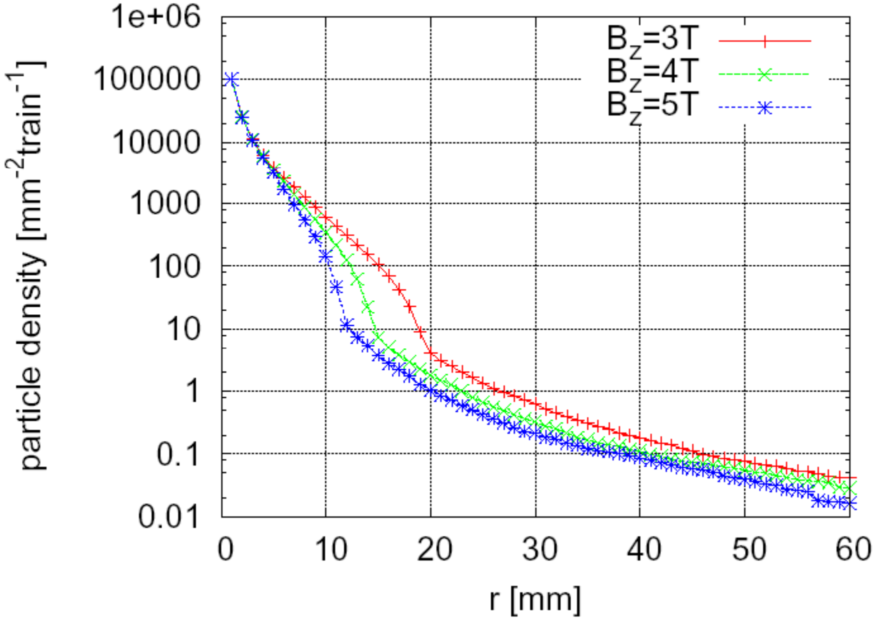
Consequences for the Detector

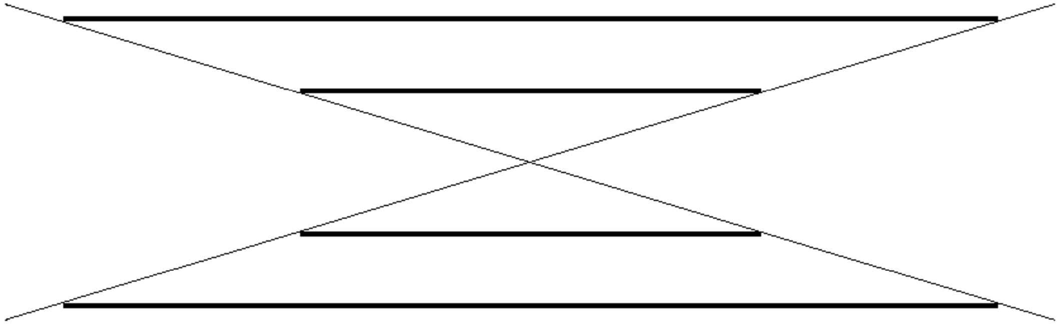
Impact of the Pairs on the Vertex Detector

Hits of the pairs in the vertex detector can confuse the reconstruction of tracks

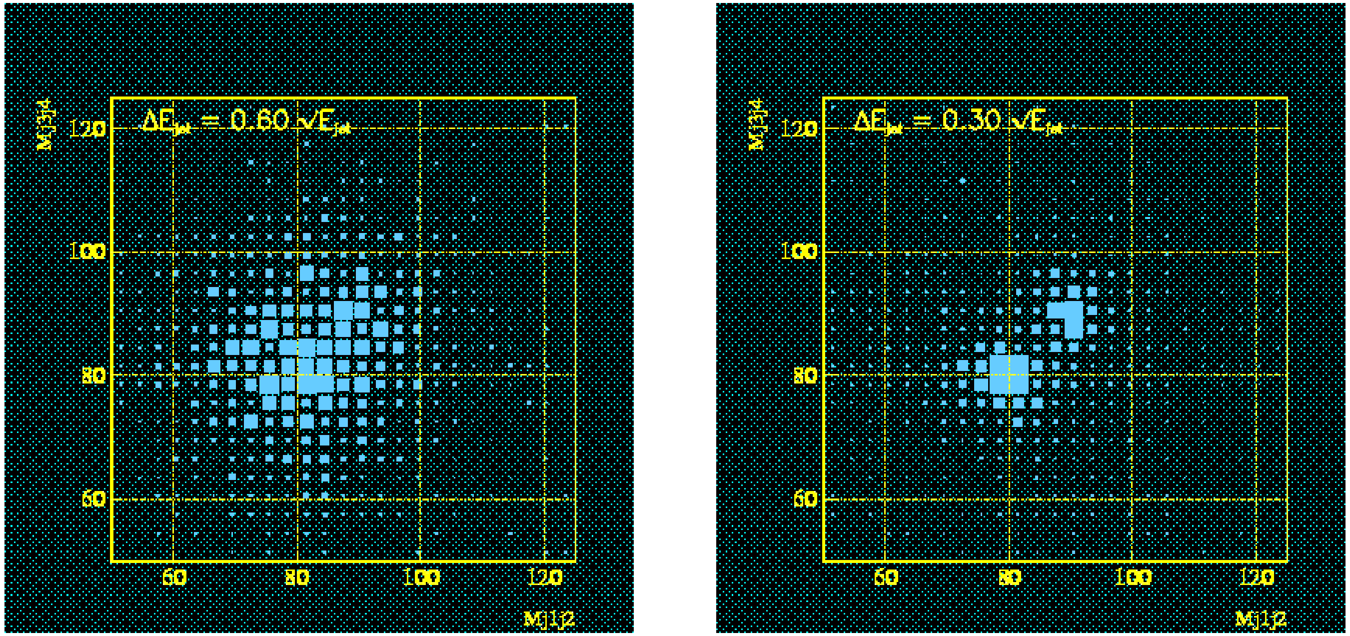
Can avoid this problem by combination of two means

- use sufficient opening angle of the vertex detector
- confine pairs to small radii by use of longitudinal magnetic field
  this exists in the detector anyway





Calorimetry



$$e^+e^- \to \nu\bar{\nu}W^+W^-, \nu\bar{\nu}ZZ\,, \qquad W, Z \to 2\mathrm{jets}$$

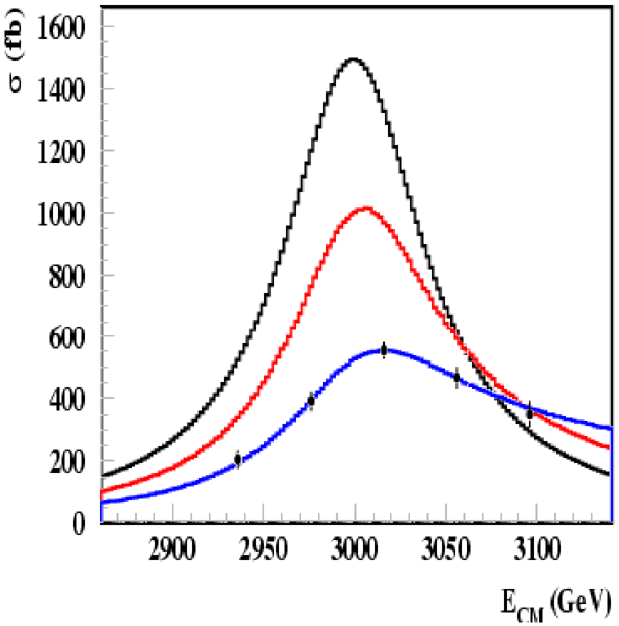
Importance of good energy resolution (e.g via energy flow)
Interesting developments in TeV-class LC working groups
e.g. compact 3D EM calorimeters, or "digital" hadronic calorimeters
⇒Detailed simulation studies of key processes required
⇒R&D accordingly afterwards/Join ILC detector efforts?

General Physics Context

- New physics expected in TeV energy range
  - Higgs, supersymmetry, extra dimensions, …?
- LHC will indicate what physics, and at which energy scale
- Two possible scenarios:
  - New physics at a low energy scale
    - But perhaps more at higher energies (e.g., supersymmetry)
  - New physics threshold at higher energy scale
- In many scenarios, e.g., SUSY, LHC will soon tell us the threshold

Example: Resonance Production

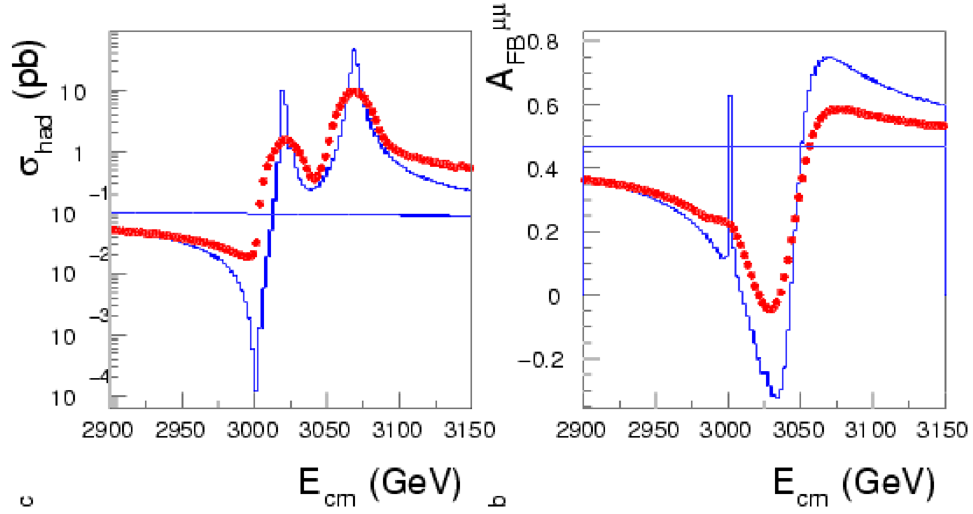
Resonance scans, e.g. a Z'



FIT ACCURACY

Observable	Breit Wigner	CLIC.01	CLIC.02
$M_{Z'}$ (GeV)	$3000 \pm .12$	$\pm .15$	$\pm .21$
$\Gamma(Z')/\Gamma_{SM}$	$1. \pm .001$	$\pm .003$	$\pm .004$
σ^{eff}_{peak} (fb)	1493 ± 2.0	564 ± 1.7	669 ± 2.9

1 ab^{-1} $\Rightarrow \delta M/M \sim 10^{-4}$ & $\delta\Gamma/\Gamma = 3.10^{-3}$

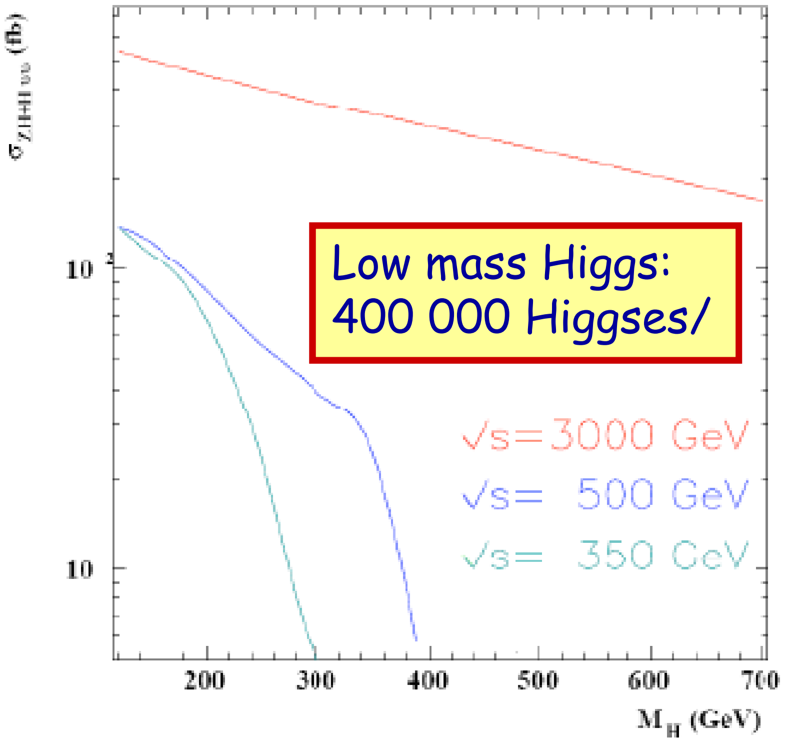


Degenerate resonances e.g. D-BESS model

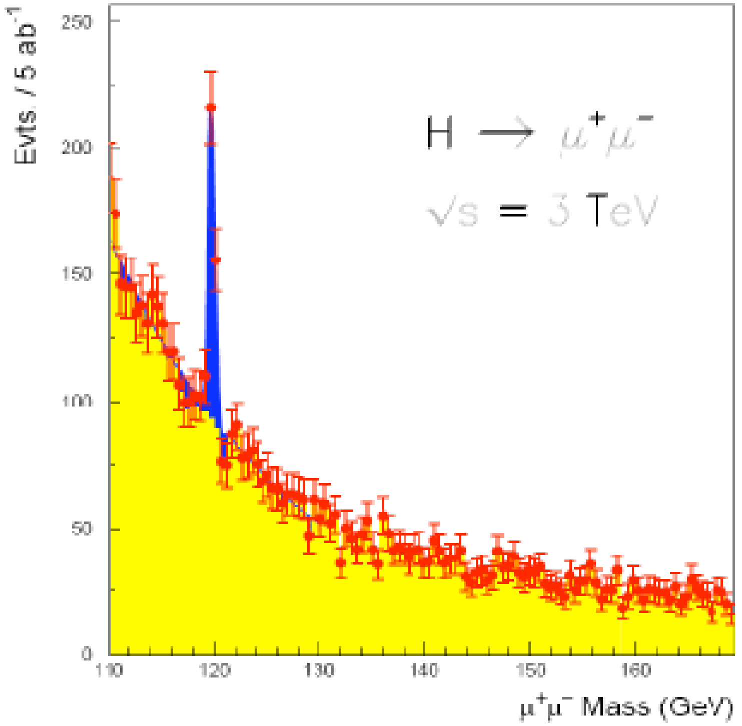
Can measure ΔM down to 13 GeV

Smeared lumi spectrum allows still for precision measurements

Physics Case: the light Higgs



Low mass Higgs:
400 000 Higgses/



- Large cross sections
- Large CLIC luminosity

→Large events statistics

- Keep large statistics also for highest Higgs masses

⇒ O(500 K) Higgses/year

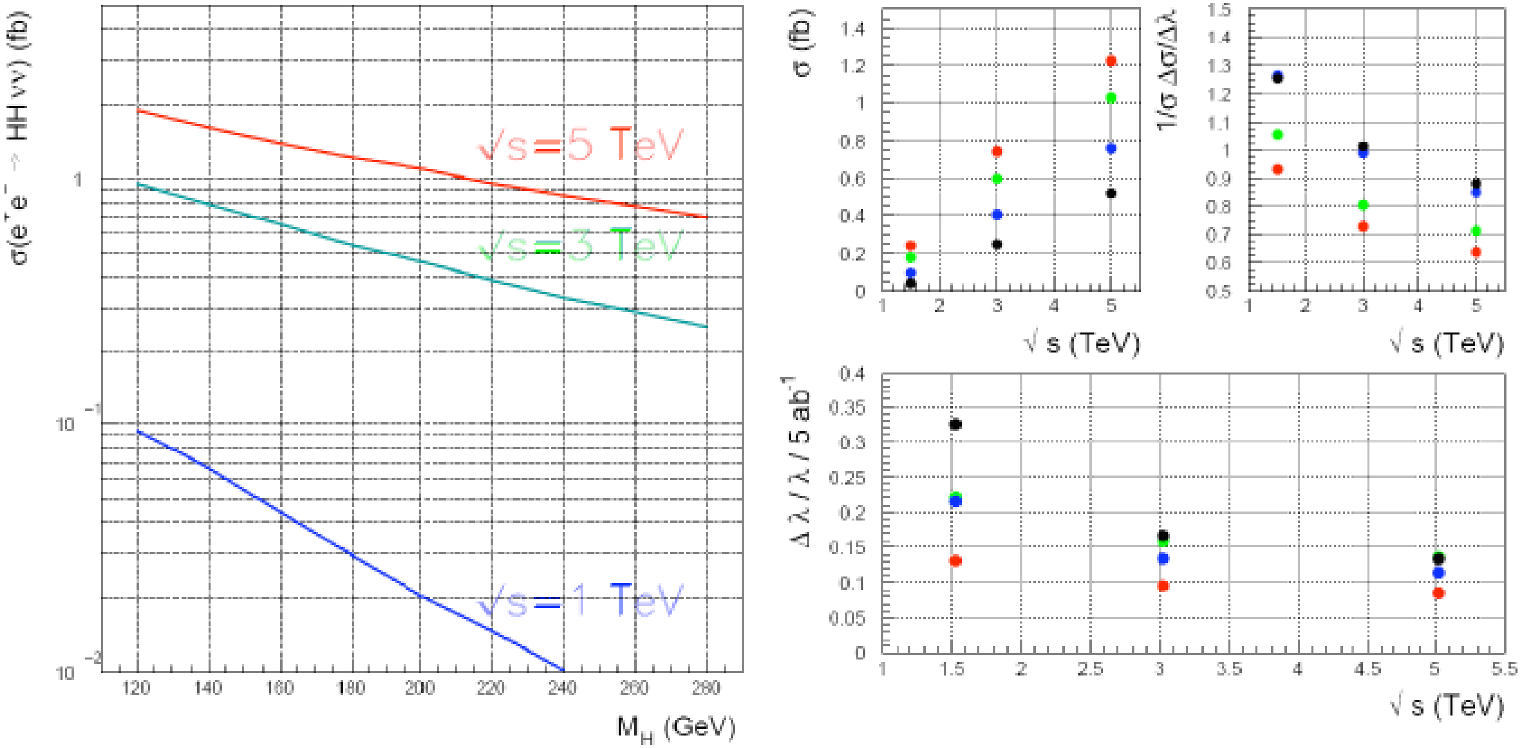
Allows to study the decay modes with BRs ~ 10^{-4} such as H→μμ and H→bb (>180 GeV)

Eg: determine $g_{H\mu\mu}$ to ~4%

Physics case: the Higgs Potential

Reconstruct shape of the Higgs potential to complete the study of the Higgs profile and to obtain a direct proof of the EW symmetry breaking mechanism

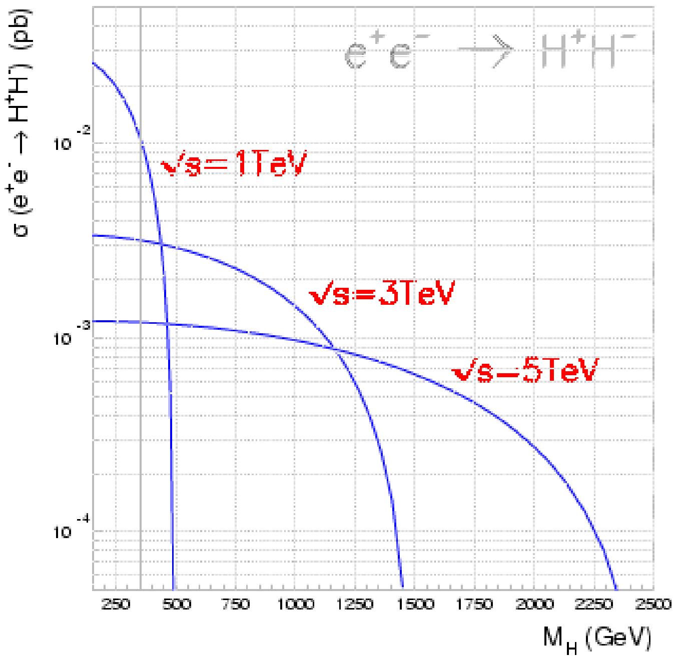
$$e^+e^- \to (WW)\nu\bar{\nu} \to hh\nu\bar{\nu}$$



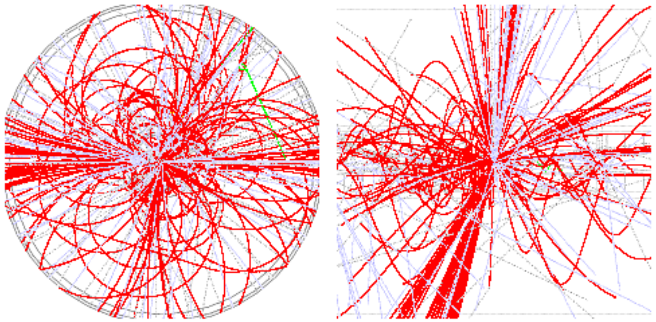
Can measure the Higgs potential for Higgs even for masses up to 300 GeV with precision up to 5-10% (using polarization/weighting)

Physics case: Heavy Higgs (MSSM)

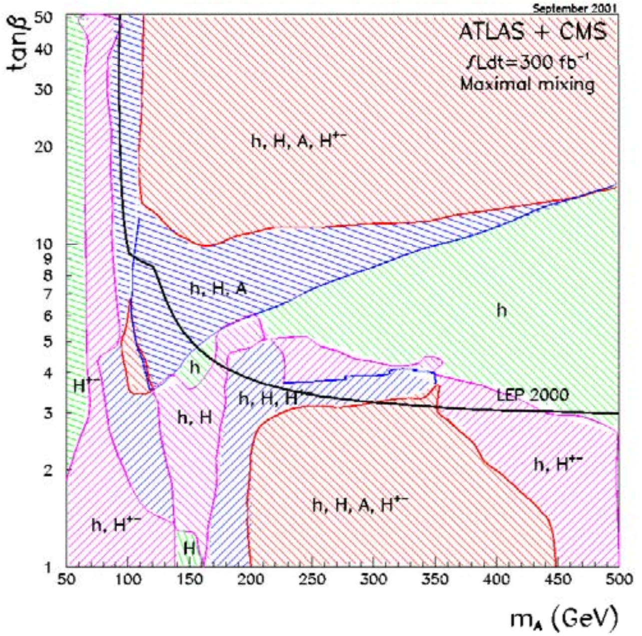
Cross section as function of Higgs mass



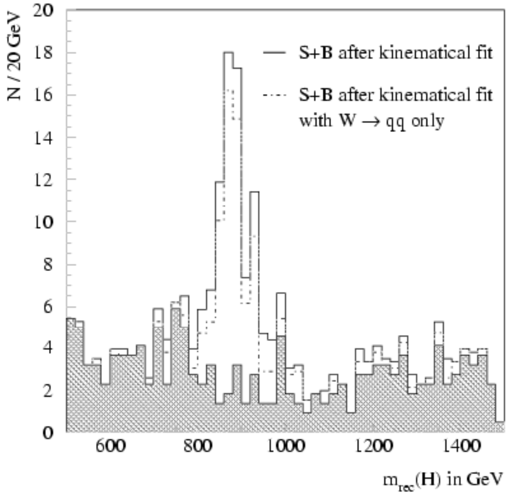
$e^+e^- \to H^+H^-$ $M_H = 900$ GeV



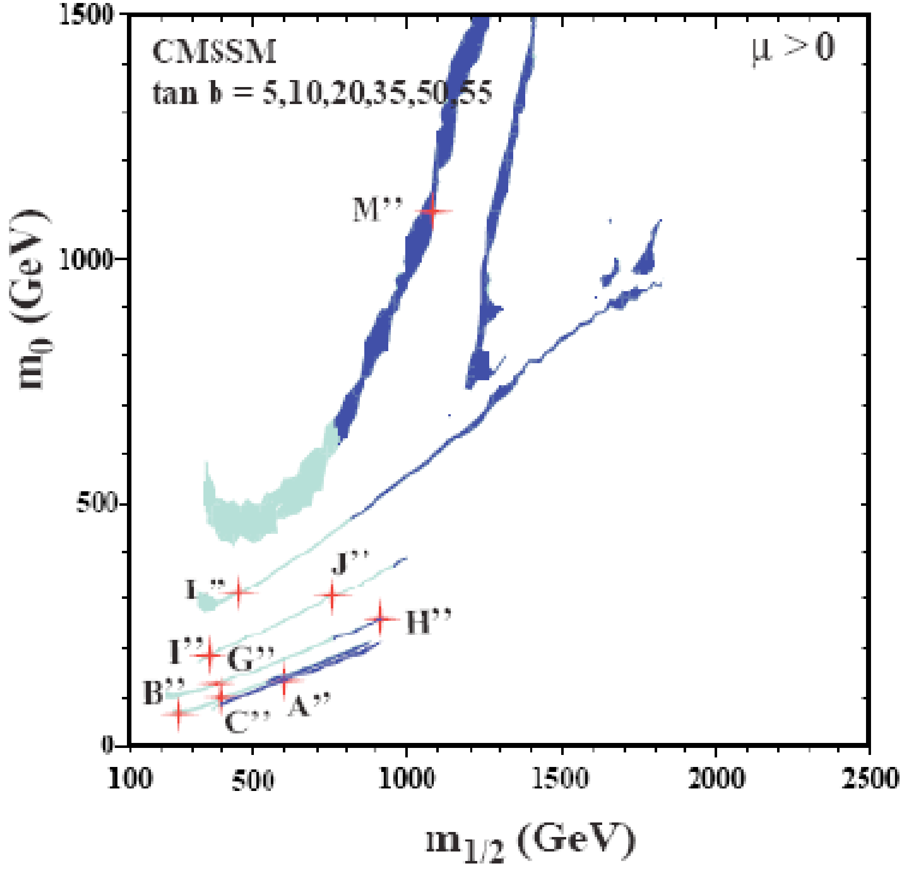
LHC: Plot for 5 σ discovery

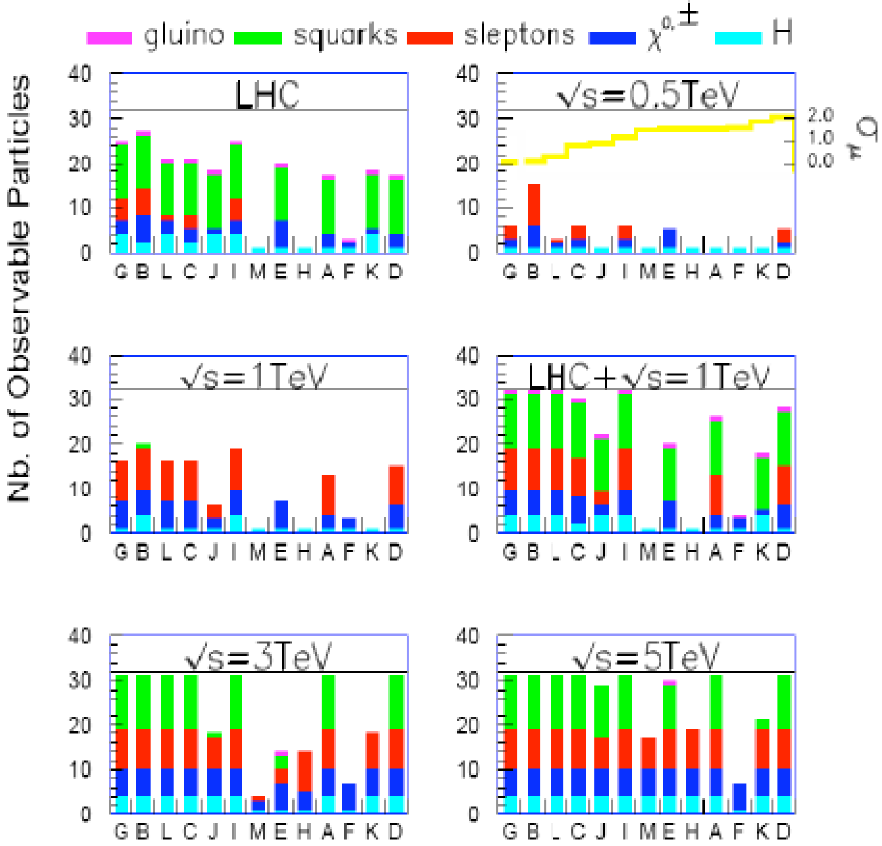


3 TeV CLIC
⇒ H, A
detectable
up to ~ 1.2 TeV



Physics case: SUSY measurements





Benchmark Scenarios: CMSSM
Allowed by present data constraints
ADR,F., Gianotti,JE,F. Moortgat, K. Olive, L. Pape
hep-ph/0508198

⇒ LC/LHC complementarity
Precision measurements at ILC/CLIC
Eg. 1150 GeV smuon mass to O(1%)
Will a 0.5-1 TeV collider be enough?

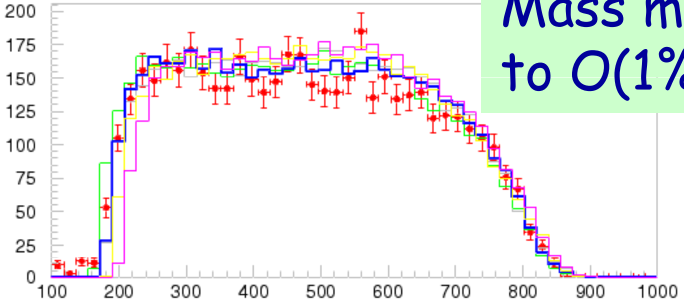
Susy Mass Measurements

E.G. $m_{1/2} = 1500$ GeV, $m_0 = 420$ GeV, $\tan\beta = 20,\ A = 0$ GeV, $sign(\mu) > 0$ (mSUGRA) (point H)

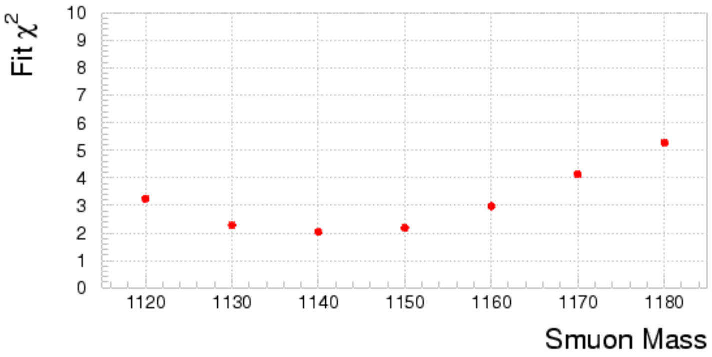
$\Rightarrow M_{\tilde{\mu}} = 1150$ GeV

Measure inclusive muon spectrum in $\tilde{\mu} \rightarrow \mu\chi^0$

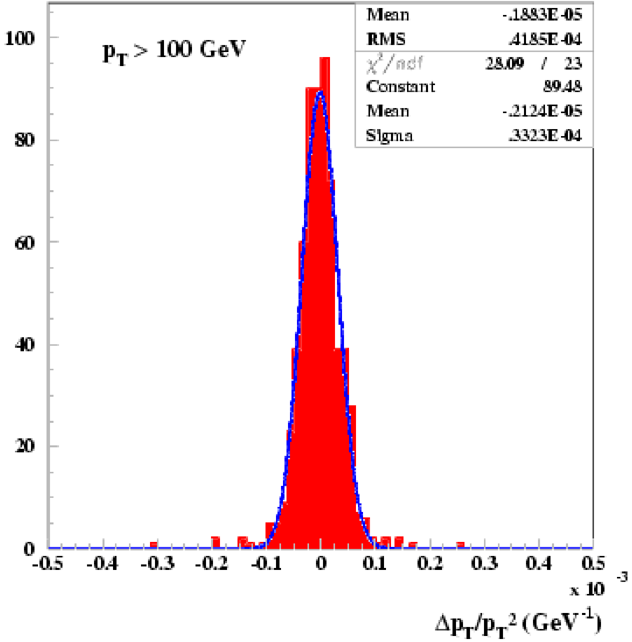
$$\Rightarrow E_{max/min} = \frac{E_{beam}}{2}\left(1 - \frac{M^2_{\chi^0}}{M^2_{tilde\mu}}\right) \times \left(1 \pm \sqrt{1 - \frac{M^2_{\tilde{\mu}}}{E^2_{beam}}}\right)$$



Mass measurements to O(1%)



Momentum resolution (G3)



Momentum resolution $\delta p_t/p_t^2 \sim 10^{-4}$ GeV^{-1} adequate for this measurement

Sparticle Detection

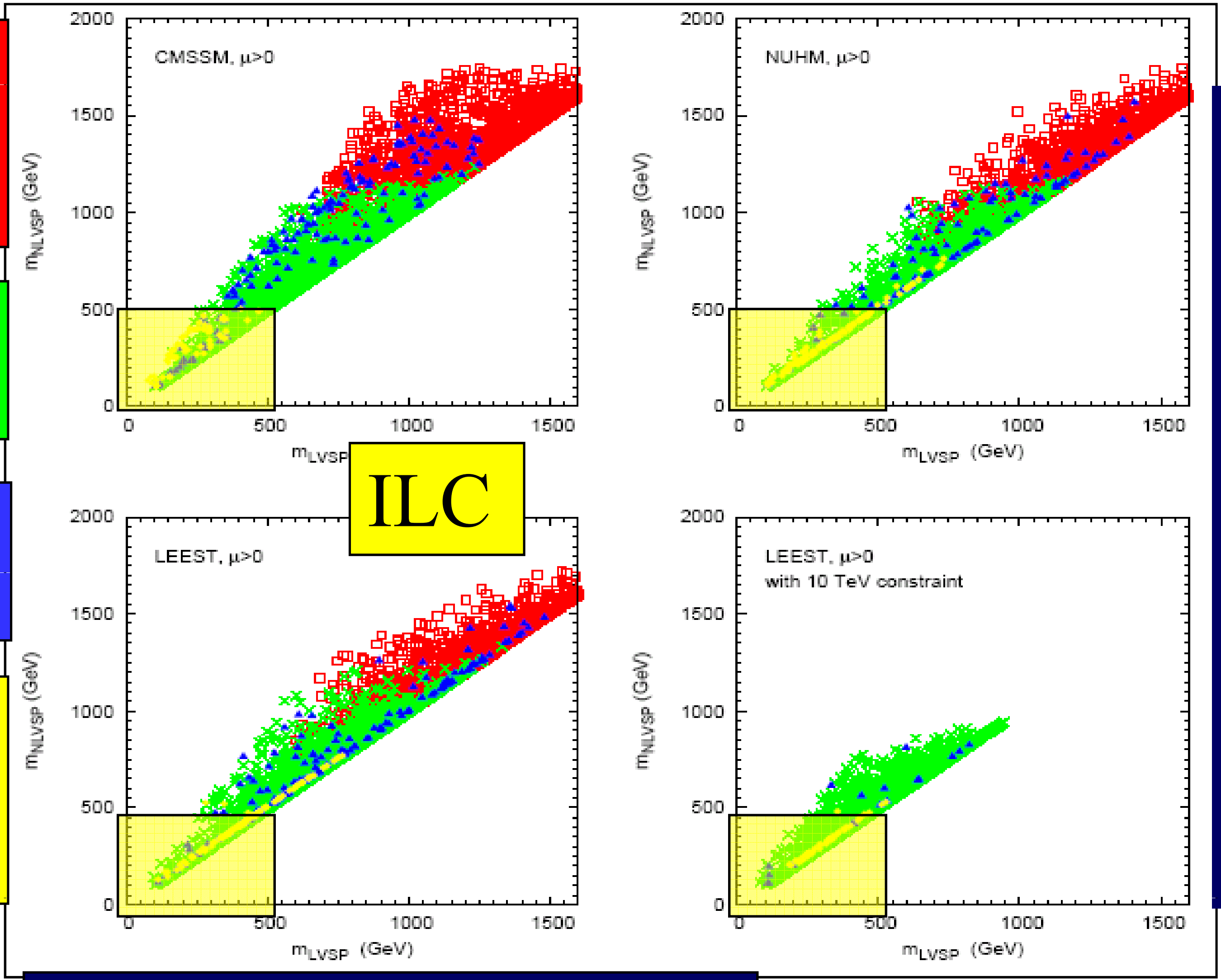
J. Ellis et al.

Full Model samples

Detectable @ LHC

Provide Dark Matter

Dark Matter Detectable Directly



← Second lightest visible particle

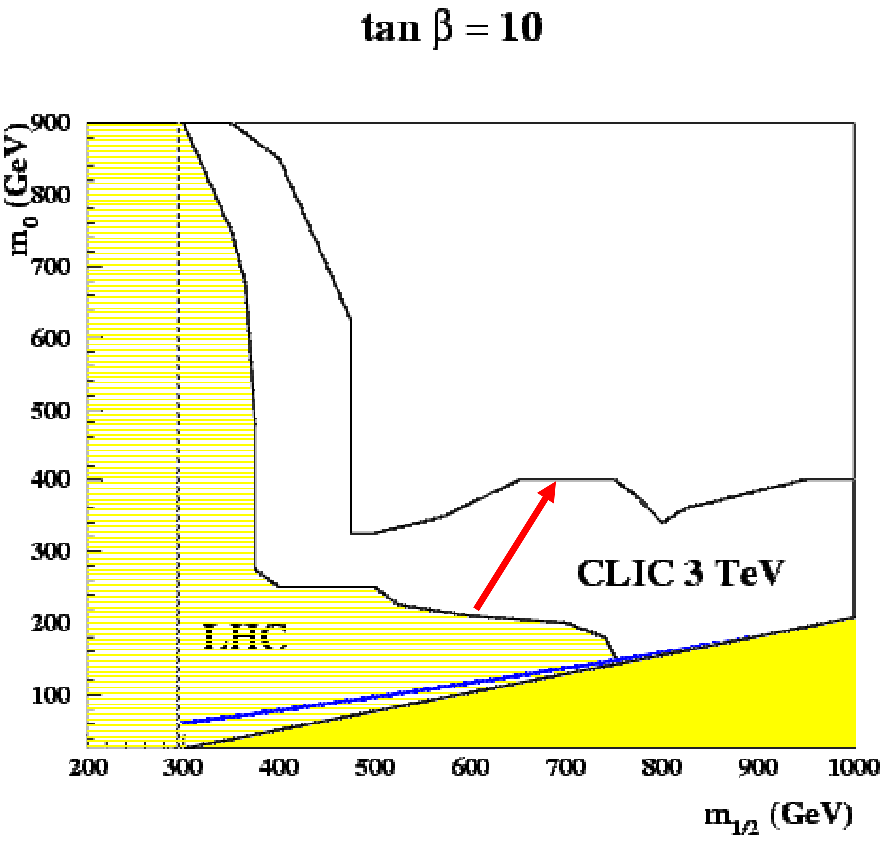
Lightest visible sparticle →

JE + Olive + Santoso + Spanos

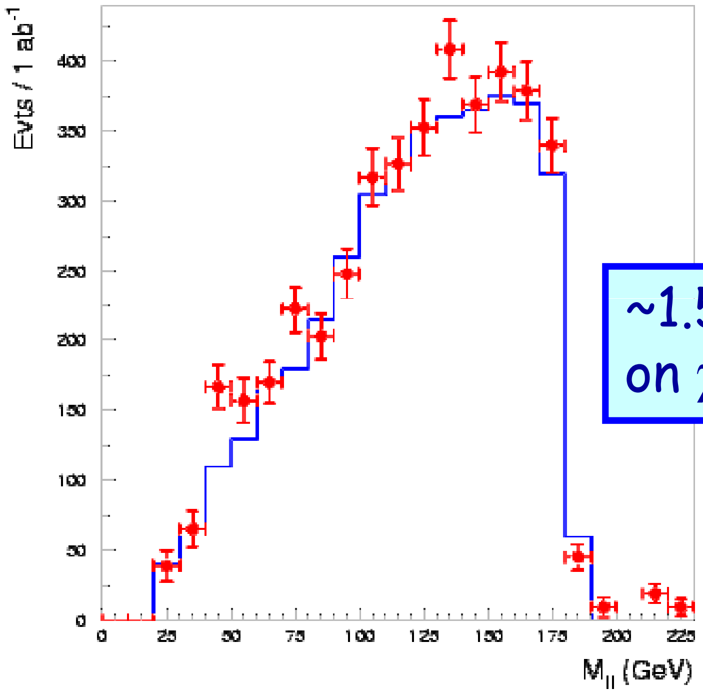
Sensitivity to $\chi_2 \rightarrow \chi_1$+2 leptons

Case study: χ_2

Sensitivity (5σ) for LHC and LC

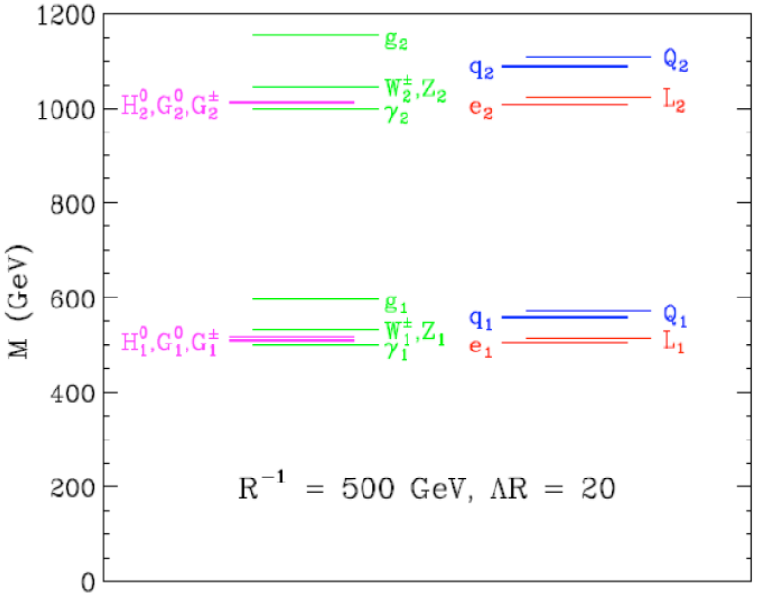


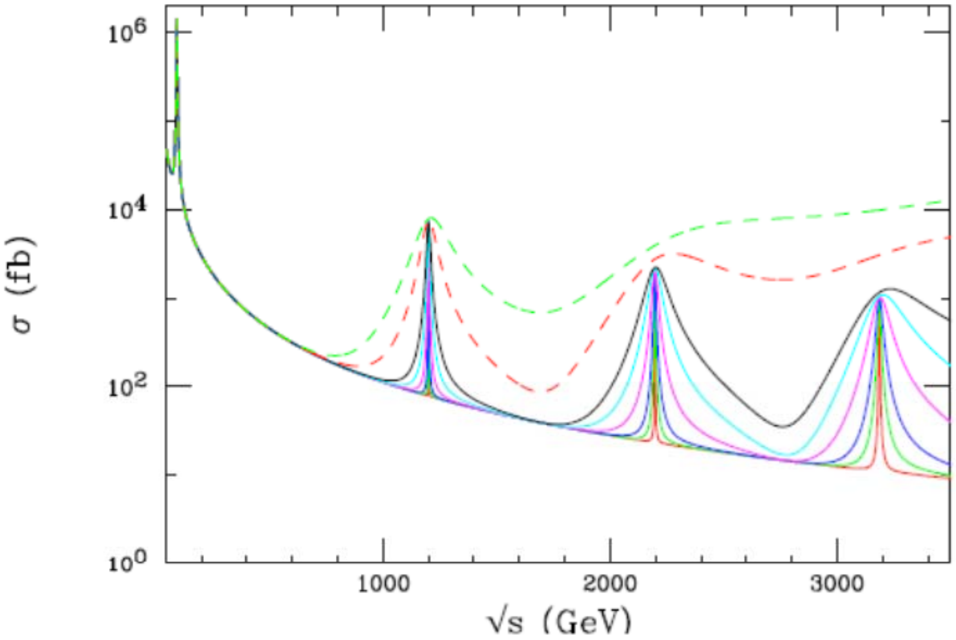
Mass measurement precision
$m\chi_2$= 540 GeV, $m\chi_1$=290 GeV



~1.5% precision on χ_2 mass

Physics Case: Extra Dimensions

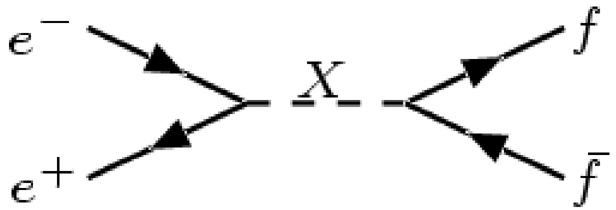




Universal extra dimensions:
⇒ Measure all (pair produced) new particles and see the higher level excitations

RS KK resonances…
Scan the different states

Precision Measurements

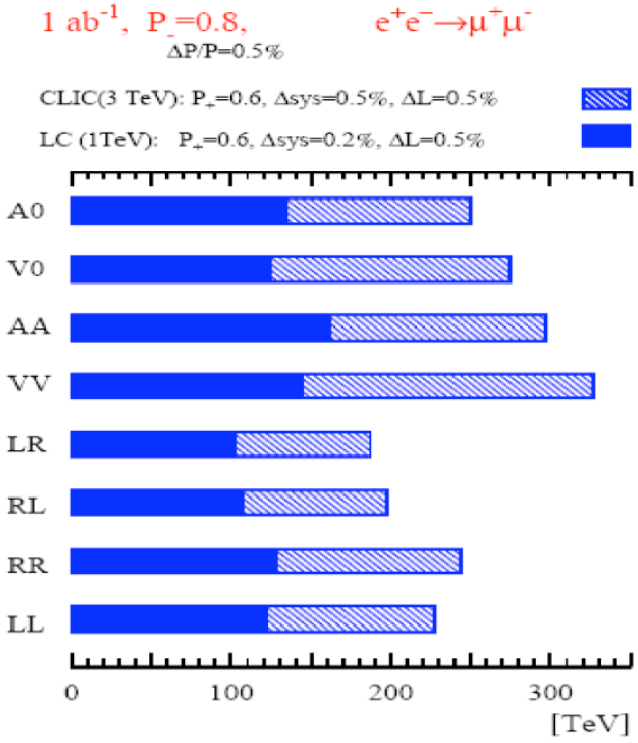


Measure $\sigma_{b\bar{b}}$, $A_{FB}^{\mu^+\mu^-}$ and $A_{FB}^{b\bar{b}}$

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

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

Observable	Relative Stat. Accuracy $\delta\mathcal{O}/\mathcal{O}$ for 1 ab^{-1}
$\sigma_{\mu^+\mu^-}$	±0.010
$\sigma_{b\bar{b}}$	±0.012
$\sigma_{t\bar{t}}$	±0.014
$A_{FB}^{\mu\mu}$	±0.018
A_{FB}^{bb}	±0.055
A_{FB}^{tt}	±0.040



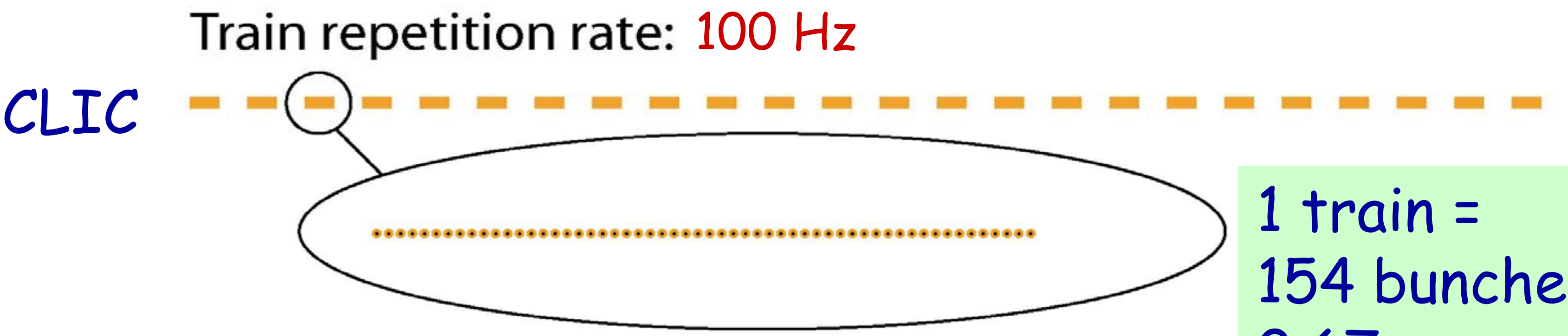
E.g.: Contact interactions:
Sensitivity to scales up to 100-400 TeV

Summary: scenarios with early LHC data…

- New physics shows up at the LHC ⇒ CLIC will
  - Complete the particle spectra, with a very high reach
  - Measure accurately parameters of the model (LC quality)
- Only a light Higgs at the LHC ⇒ CLIC will
  - Measure its properties very accurately, like ILC and more..
  - Extend the LHC direct search reach for non-colored particles
  - Extend the indirect search reach to a scale of 500 (1000?) TeV via precision measurements
- No signs of new physics or a Higgs at the LHC ⇒ CLIC will
  - Study WW scattering in the 1-2 TeV range in detail
  - Extend the LHC direct search reach for non-colored particles
  - Extend the indirect search reach to a scale of 500 (1000?) TeV via precision measurements

Q: what about using CLIC technology for a 500-1000 GeV collider

Time Structure of the Beams



1 train =
154 bunches
0.67 nsec apart
~ 20 cm

Sub-TeV colliders

Warm technology
⇒ 120 Hz 1 train = 192 bunches 1.4 nsec apart

Cold technology
⇒ 5 Hz 1 train = 2820 bunches 336 ns apart

➡ Experimenting at CLIC similar to the NLC

NLC/TESLA comparison: Summary

Benchmark: mass determination of 120 GeV Higgs in HZ→bbqq

# of BX	US/optimized for <10BX	US/optimized for>=10BX	EU/optimized for 1BX
0	71	74	68
1	74	78	
TESLA	77	79	75
4	79	82	78
5	79	82	
10	91	82	
20	92	81	92
64			110

From K. Desch at LCWS04 (Paris)

2-5 ns track/calorimeter time stamping needed, possible in principle with TPC and Si (SiW)

At NLC, a bunch tagging of few ns is needed to become comparable to the TESLA situation. R&D on detector timing is vital for warm technology

-and for CLIC-

But a similar precision can be reached

Conclusions

- Experimental conditions at CLIC are more challenging than e.g at LEP, or even a TeV class collider.
- Physics studies for the CLIC report have included the effects of the detector, and backgrounds such as e+e- pairs and $\gamma\gamma$ events. The muon background is only partially studied. We do not expect significant changes with the new parameters but can check a few channels
- Benchmark studies show that CLIC will allow for precision measurements in the TeV range (…theory…).
- Detector R&D will be needed (tracking with good time stamping, better calorimetry, forward detectors for lumi, etc.).
  A detailed, more complete, study is one of the most important issues to address for a continuing CLIC physics study group.
  Timing requirements are similar as for "warm techn." LC detector
- Synergy on R&D with other projects!
- Physics group (D. Schlatter, ADR, John Ellis) activity low right now. Expect some revival after parameters stabelize (but LHC…)

Backup

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_LW_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 (or Tevatron) will show where Nature takes us

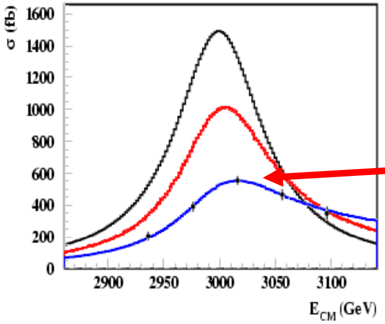
CLIC Accelerator R&D will continue till at least 2007
Good progress being made by the CLIC accelerator group

Physics study results will be available in a CERN yellow report by the end of the year

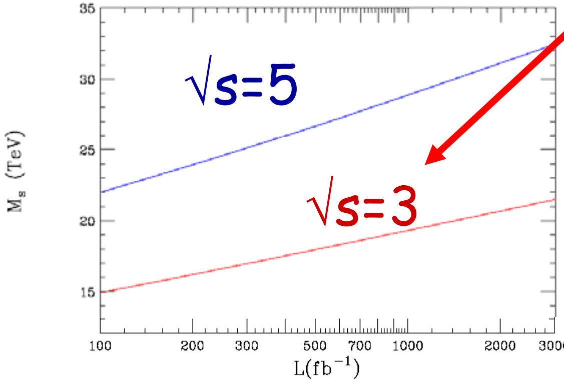
e+e- physics back at CERN around/ before 2020 or CLIC part of an e+e- facility somewhere (US?)

Examples of New High-Scale Physics

Assume $M_{Z'} = 3.0$ TeV and
$\Gamma(Z')/M_{Z'} \simeq \Gamma(Z^0)/M_{Z^0}$



$\Rightarrow$ FIT ACCURACY ($1\,\text{AB}^{-1}$)
$\delta M'_Z/M'_Z \sim 10^{-4}$; $\delta\Gamma'_Z/\Gamma'_Z \sim 3\cdot 10^{-3}$



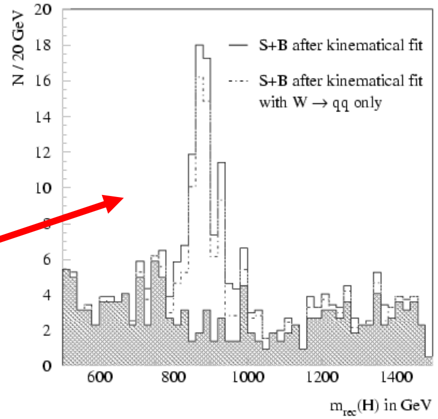
New Z' resonance

Heavy Higgs

Extra Dimensions

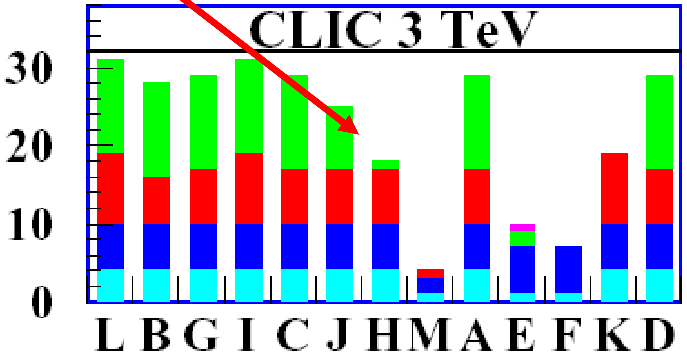
Supersymmetric particles:
# of higgses, sleptons
gauginos, squarks
detected for benchmark
scenarios
(hep-ph/0306219)

M_H=900 GeV



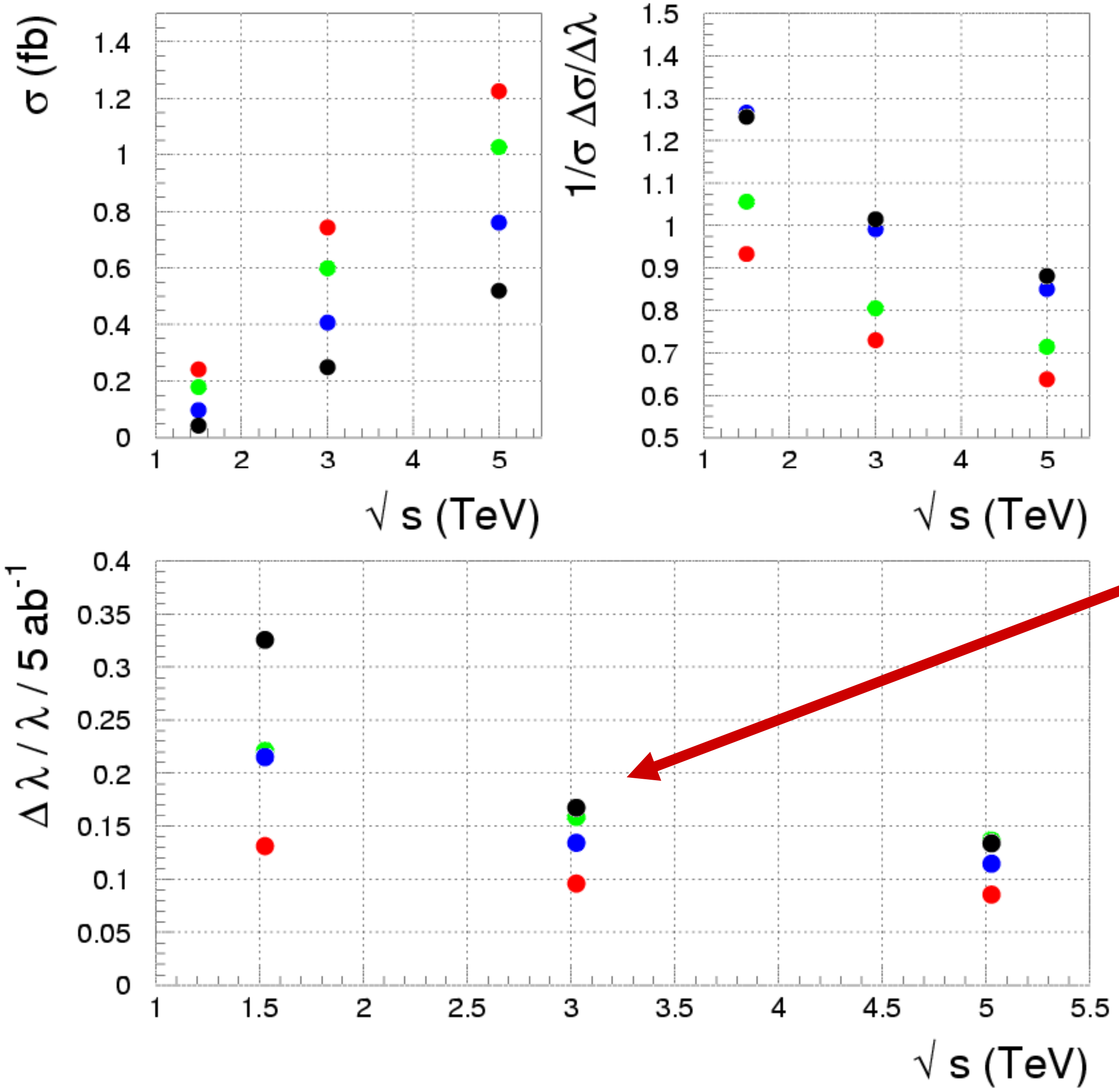
$O(20)$ events/ ab^{-1}, with negligable background
Increase statistics by factor 10 for 'single' H tags

Mass measurement $\Delta m/m \sim 1\%$ (3 ab^{-1})
Discovery potential $M_H < 1.2$ TeV (3TeV/3 ab^{-1})



CLIC physics study:
CERN Yellow Report, hep-ph/0412251

Example of Low-Scale Physics: e+e- →HHνν



Precision on triple-Higgs coupling for light Higgs masses:

- ● m_H = 120 GeV
- ● m_H = 140 GeV
- ● m_H = 180 GeV
- ● m_H = 240 GeV

3 TeV

M_H (GeV)	$\sigma_{HH\nu\bar{\nu}}$ Only	$\lvert\cos\theta^*\rvert$ Fit
120	± 0.094 (stat)	± 0.070 (stat)
180	± 0.140 (stat)	± 0.080 (stat)

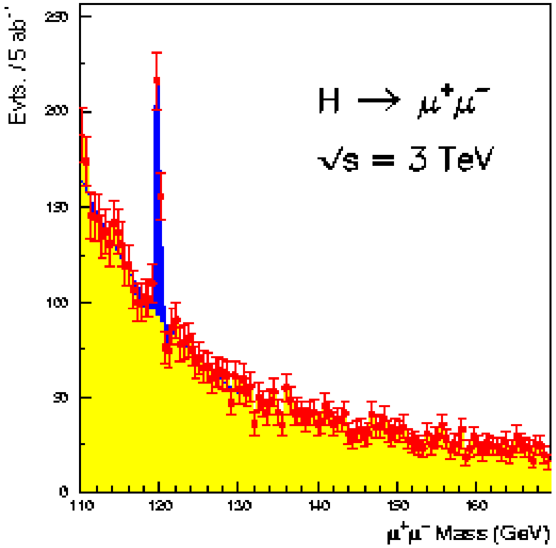
Can improve by factor 1.7 if both beams are polarized

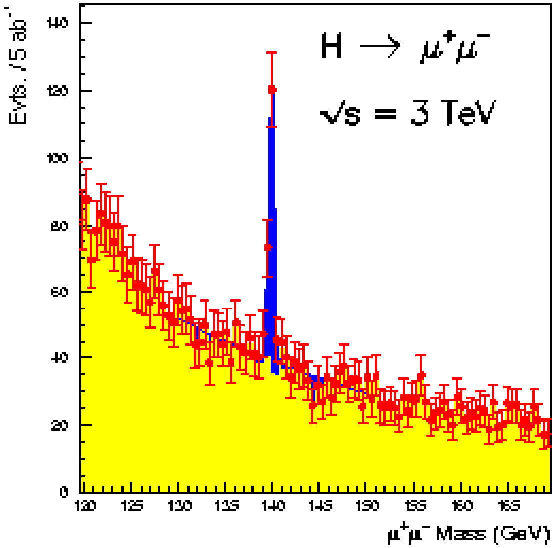
Also: measurements of rare Higgs decays

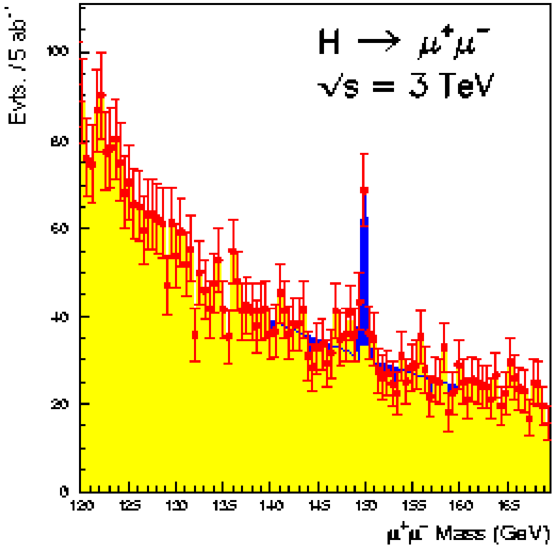
Rare Higgs Decays: H→μμ

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

Not easy to access at a 500 GeV collider







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

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