



CLIC CDR detector benchmarks

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Introduction

CDR Vol3 deals with **Physics&Detectors**. While the main emphasis of the CDR is clearly on Vol2, i.e. the feasibility of the CLIC accelerator, we have to show in Vol3 that some **basic detector performances will provide the interesting physics** we want to extract from CLIC.

The idea is to select **few benchmark processes** and do the analysis including **full simulation, backgrounds, beamstrahlung, etc...** The assumption is that both proposals, CLIC_ILD and CLIC_SiD, should **have similar sensitivity to these benchmark channels** so to some approximation it does not matter which detector is used for each benchmark → **No detailed comparison of detector performance is foreseen in the CDR.**

The **benchmark processes** have been selected to **test complementary requirements** on the detectors performance. They have not been selected as the most interesting physics case for CLIC (i.e. they have not been optimized to show the best possible CLIC results), but rather the scenarios chosen are **required to be compatible with existing measurements**, and having a **high probability to provide signatures at the LHC.**

Introduction

LHC “almost” guaranteed to find SUSY if it has any relevance to the Naturalness problem

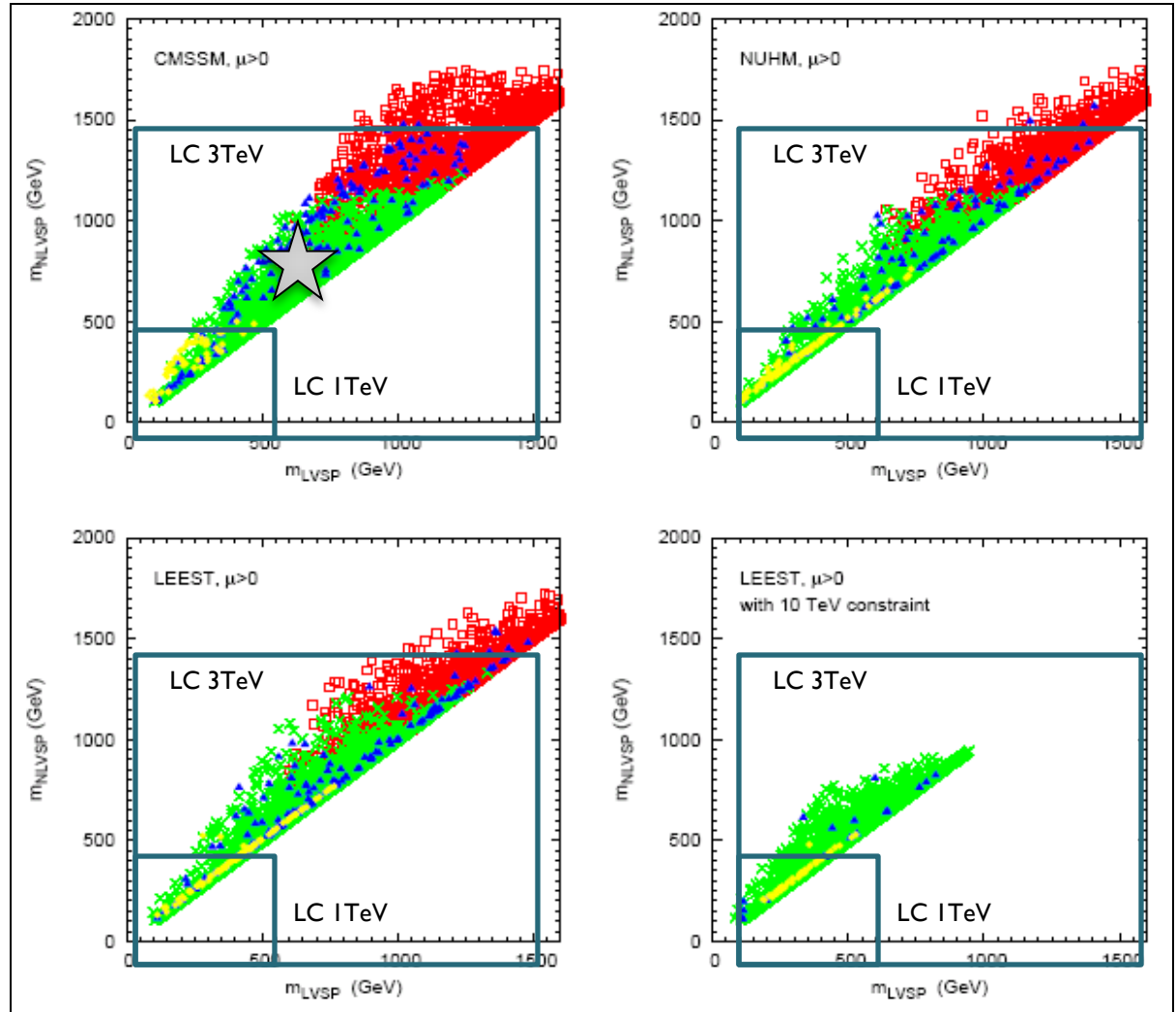
From J.Ellis

all samples

Detectable @ LHC

Provide Dark Matter

Dark Matter Detectable Directly



↑ Second lightest visible particle

Lightest visible particle →

List of benchmark processes:

- 5+1 benchmark channels for the CDR
- At 3 TeV

- $e^+e^- \rightarrow H\nu_e\nu_e$ $H \rightarrow bb, \mu\mu$ ($m_H = 120$ GeV)

$$\begin{array}{l}
 M_1 = 780 \text{ GeV}, M_2 = 940 \text{ GeV}, M_3 = 540 \text{ GeV}, \\
 A_0 = -750 \text{ GeV}, m_0 = 303 \text{ GeV}, \tan\beta = 24, \mu > 0 \\
 m_{1/2} = 800 \text{ GeV}, A_0 = 0, m_0 = 966 \text{ GeV} \\
 \tan\beta = 51, \mu > 0
 \end{array}
 \left\{
 \begin{array}{l}
 e^+e^- \rightarrow H^+H^- \rightarrow tbtb \quad e^+e^- \rightarrow HA \rightarrow bbbb \quad (m_{H,H^+,A} = 900 \text{ GeV}) \\
 e^+e^- \rightarrow \tilde{q}_R \tilde{q}_R \quad m_{\tilde{q}_R} = 1.1 \text{ TeV} \\
 e^+e^- \rightarrow \tilde{l}^+ \tilde{l}^- \quad \begin{array}{l} m_{\tilde{e}_R} = m_{\tilde{\mu}_R} = 1.0 \text{ TeV} \\ m_{\tilde{e}_L} = m_{\tilde{\mu}_L} = 1.1 \text{ TeV} \end{array} \\
 e^+e^- \rightarrow \chi^+\chi^-, \chi^0\chi^0 \\
 m_{\chi^0} = 340 \text{ GeV}
 \end{array}
 \right.$$

- At 500 GeV

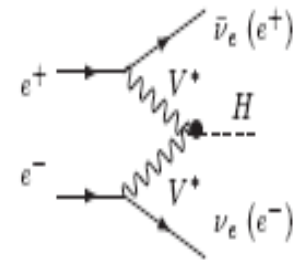
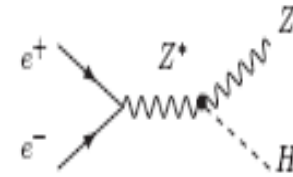
- $e^+e^- \rightarrow tt$ (same as ILC Benchmark)



Higgs Physics

Light SM-like Higgs

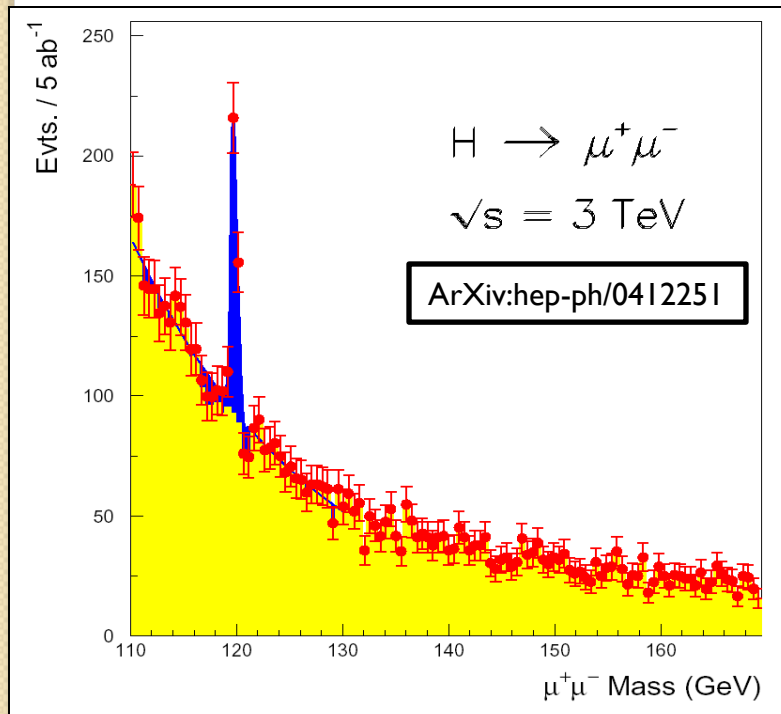
Assume the Higgs has been found at LHC/Tevatron with $M_h \sim 120$ GeV. The SM cross-section at ~ 3 TeV is enormous \rightarrow access to very rare decays ($BR \sim 10^{-4}$).



Measure Higgs couplings to leptons, for instance with 0.5 ab^{-1} , we expect ~ 20 $H \rightarrow \mu^+ \mu^-$ candidates in $\pm 2\sigma$ ($B/S \sim 1$) for $M_h = 120$ GeV/ c^2 , hence measure the couplings with $\sim 10\%$ precision, and compare with other (bb, cc, tt, \dots) couplings \rightarrow test Higgs coupling

$$\sigma \propto 1/s$$

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



- Detector requirements:**
1. Muon ID and flavour tagging
 2. Momentum resolution
 3. Forward track acceptance
 4. Forward jet reconstruction

If there is NP the Higgs may not be light or alone...

The presence of **New Physics** may partially cancel the virtual effects of a **heavy Higgs** and still be in agreement with precision measurements.

Indeed **LHC** should have discovered a heavy Higgs, and **roughly measure its properties**.

However a **precise determination** of its mass, width and couplings will **require a LC**.

$$\begin{aligned}
 e^+ e^- \rightarrow H^+ H^- \rightarrow tb \, tb & \quad m_{A^0} = 902.6 \text{ GeV} \\
 e^+ e^- \rightarrow H^0 A^0 \rightarrow bb \, bb & \quad m_{H^0} = 902.4 \text{ GeV} \\
 & \quad m_{H^\pm} = 906.3 \text{ GeV}
 \end{aligned}$$

At $\sqrt{s} = 3 \text{ TeV}$:

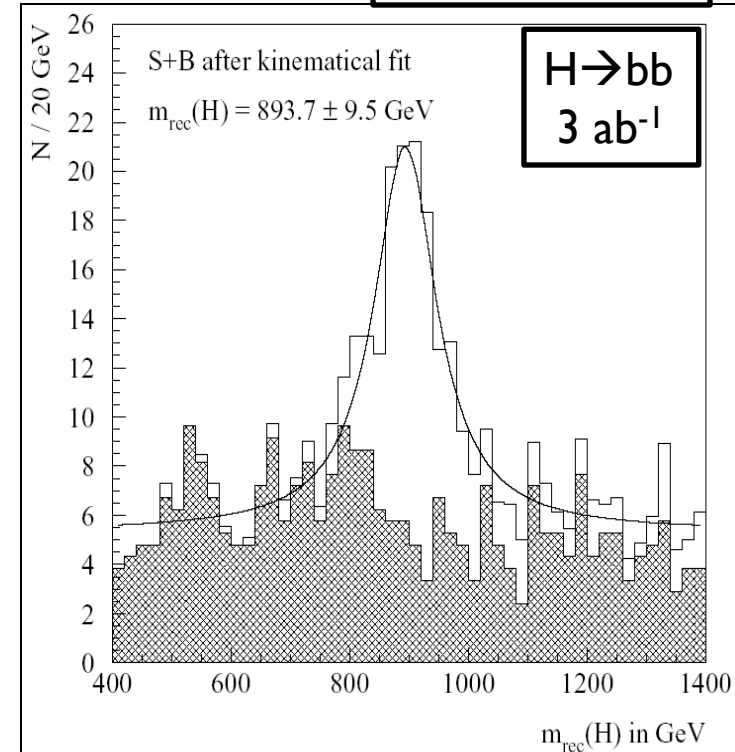
$$\begin{aligned}
 e^+ e^- & \rightarrow H^+ H^- & 1.67 \text{ fb} \\
 e^+ e^- & \rightarrow H^0 A^0 & 0.692 \text{ fb}
 \end{aligned}$$

Many jets topology in busy events.

Detector requirements:

1. Flavour tagging in busy events
2. Dijet mass resolution in high multiplicity events

ArXiv:hep-ph/0412251



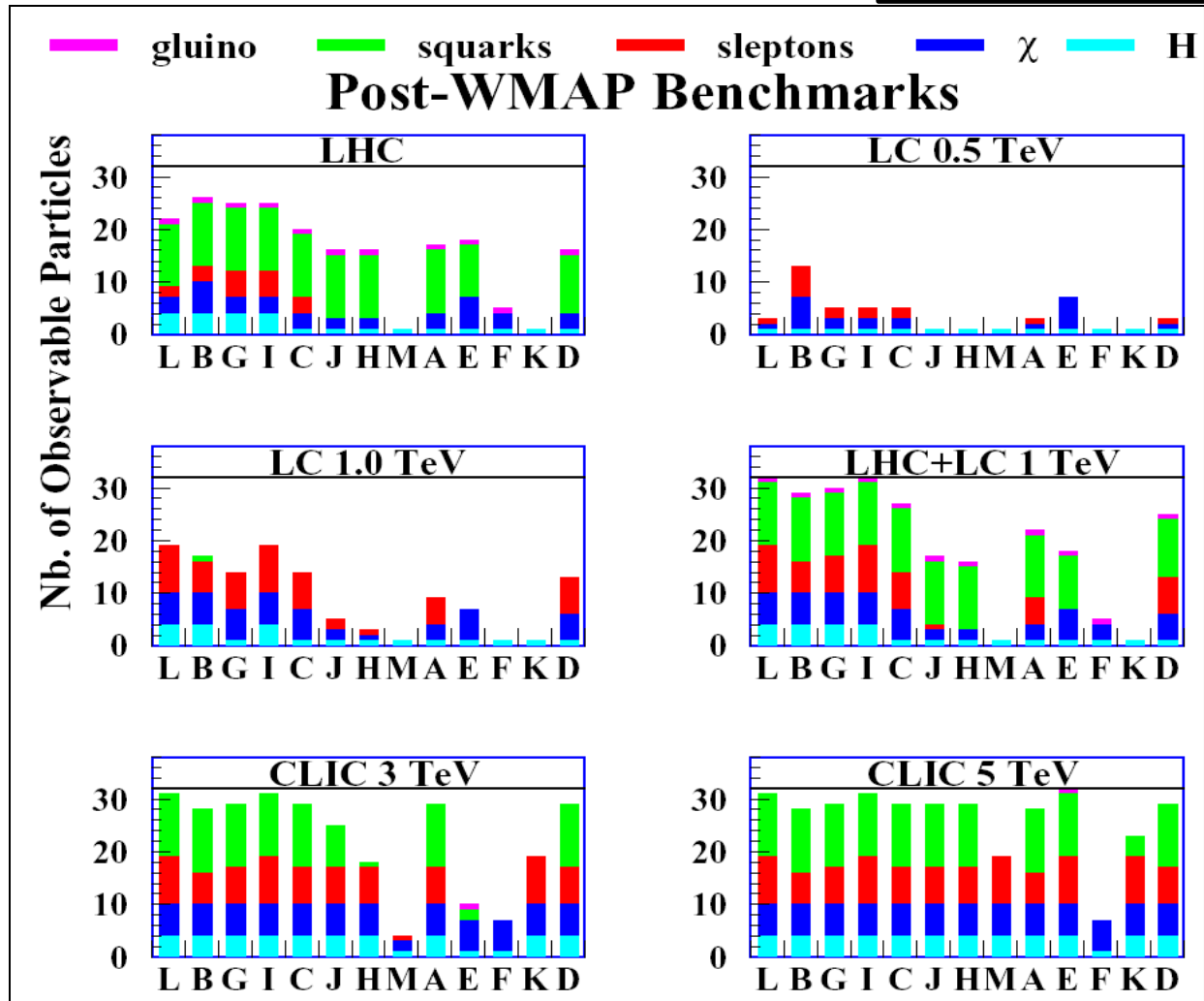


Supersymmetry

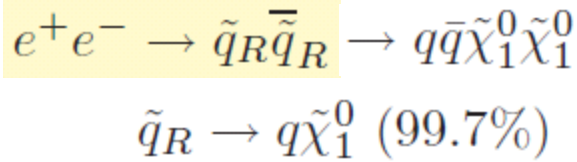
LHC vs LC

LHC is good with sparticles that mainly **interact strongly**, (gluino, squarks, ...), while a **LC could complement the spectra** with sparticles that mainly **interact weakly** (sleptons, neutralinos,...)

ArXiv:hep-ph/0412251



Looking for heavy squarks



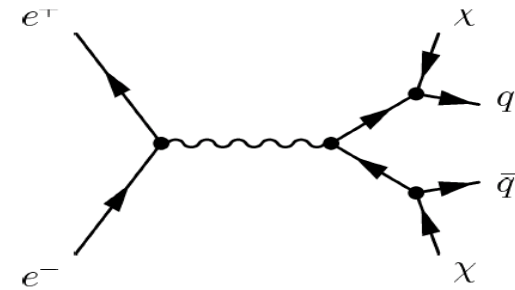
At $\sqrt{s} = 3$ TeV:

$$m_{\tilde{u}_R} = m_{\tilde{c}_R} = 1126 \text{ GeV}$$

$$m_{\tilde{d}_R} = m_{\tilde{s}_R} = 1116 \text{ GeV}$$

$$e^+e^- \rightarrow \tilde{u}_R \bar{\tilde{u}}_R \quad 1.14 \text{ fb} \quad (\times 2 \text{ for } \tilde{c}_R)$$

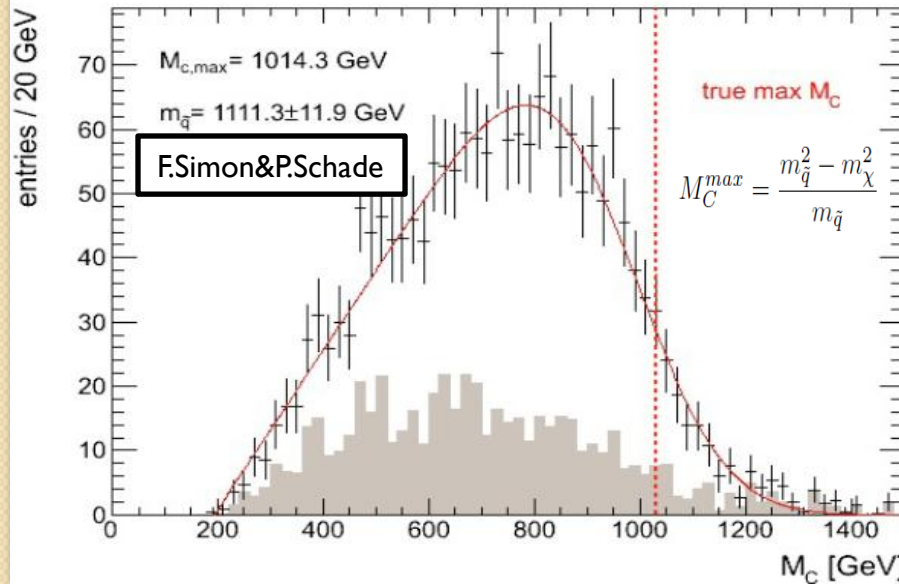
$$e^+e^- \rightarrow \tilde{d}_R \bar{\tilde{d}}_R \quad 0.291 \text{ fb} \quad (\times 2 \text{ for } \tilde{s}_R)$$



Relatively simple to extract the **mass of the squarks** (one can assume the neutralino mass is known from other processes), from the **2-jets and missing energy** distribution in a **clean event**.

The classic approach is to look at **$E_{min,max}$** which suffers from **beamstrahlung** and **backgrounds**. Alternative approaches using **modified definition of invariant mass**, reduces these dependences, see:

D.R. Tovey, JHEP 04, 34 (2008)



Detector requirements:

1. High energy jet reconstruction
2. Missing energy

Looking for heavy sleptons

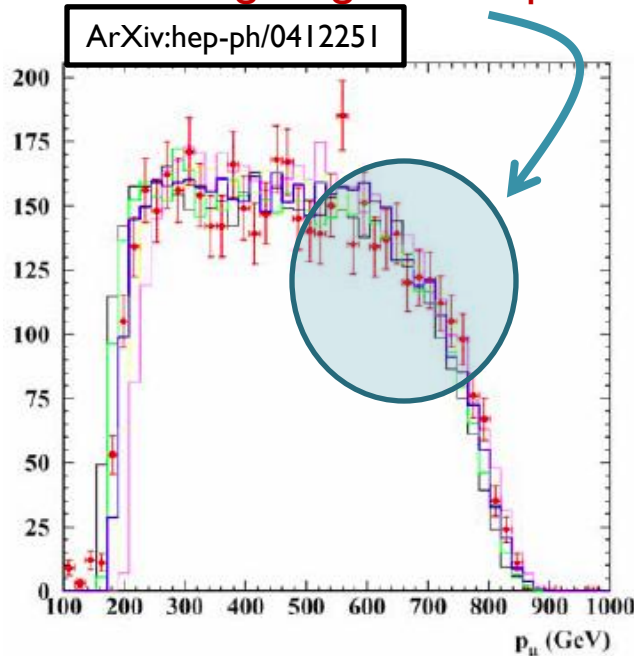
Mass determinations: $e^+e^- \rightarrow \tilde{\mu}_L^+ \tilde{\mu}_L^- \rightarrow \mu^+ \chi_1^0 \mu^- \chi_1^0$

- If $\sqrt{s} \gg 2\tilde{m}_\mu$, μ spectrum end points

$$E_{\min,\max} = \frac{\sqrt{s}}{4} \left(1 - \tilde{m}_\chi^2 / \tilde{m}_\mu^2\right) \left(1 \pm \sqrt{1 - 4\tilde{m}_\mu^2 / s}\right)$$

$\sigma(e^+e^- \rightarrow s\mu^+s\mu^-) = 3.2 \text{ fb.}$
 $\sigma(e^+e^- \rightarrow sel^+ sel^-) = 25.2 \text{ fb.}$

Here **beamstrahlung** is again an important issue! Maybe alternative techniques are also useful here... in any case the beamstrahlung probability will be determined with other techniques.



Detector requirements:

1. High energy electron and muon reconstruction
2. Missing energy
3. Beam polarization

1 ab^{-1} $\tilde{m}_\mu = (1145 \pm 25) \text{ GeV}$ 2%

$\tilde{m}_\chi = (652 \pm 22) \text{ GeV}$ 3%

Looking for charginos/neutralinos

$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow W^+W^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

$$m_{\tilde{\chi}_{1,2,3,4}^0} = 340.3, 643.1, 905.5, 916.7 \text{ GeV}$$

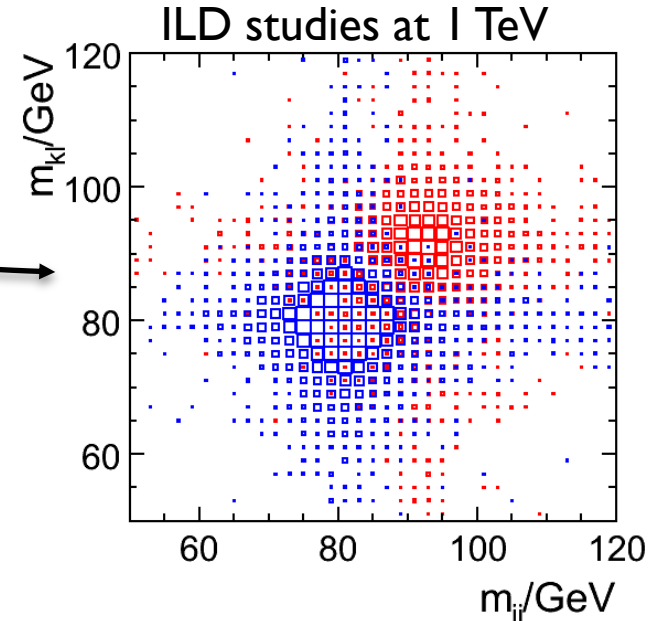
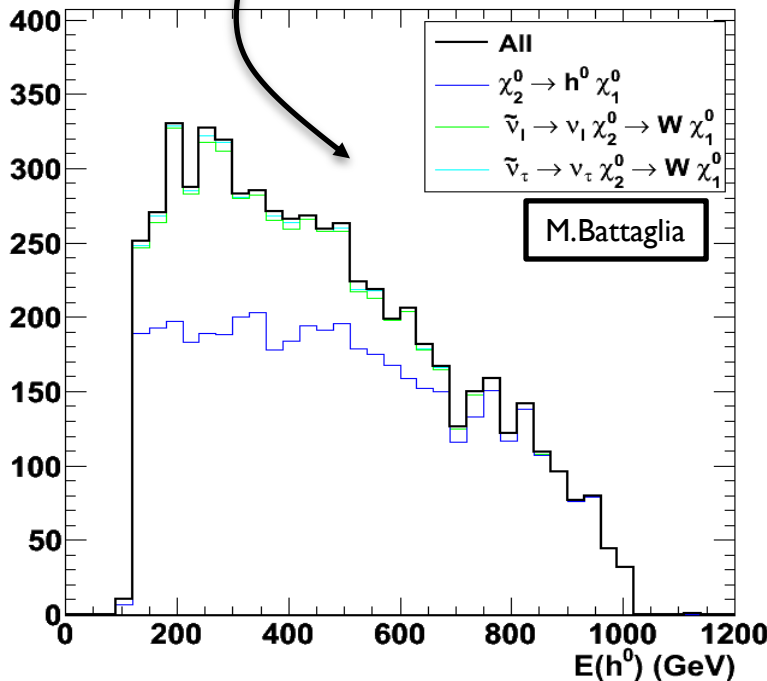
$$m_{\tilde{\chi}_{1,2}^\pm} = 643.2, 916.7 \text{ GeV}$$

$$m_h = 118.52 \text{ GeV}$$

Gives **two energetic bosons**, hence the final state is **4 jets (or 2l+2nu)** and missing energy. Good test bench for **PFA**.

$$\tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow hh \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

$$\tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow hZ \tilde{\chi}_1^0 \tilde{\chi}_1^0$$



2 bosons + missing energy. Irreducible bkg from **sneutrino decays** and effect of **beamstrahlung** are relevant.

Detector requirements:

1. Dijet mass resolution in high multiplicity events
2. Missing energy



Conclusions

Conclusions

We have proposed a **few benchmark** channels to **test the detector performance in Volume 3** of the CLIC CDR.

The plan is to generate MC samples including the **most up-to-date detector description, beamstrahlung and backgrounds**. Evaluate the performance of the **reconstruction** (tracking, PID, flavour tagging,...) and quote the **sensitivity to the relevant physics parameters** for the benchmark channels → CDR, Volume 3, Chapter 14.

We also would like to have an estimation on how the sensitivity to the relevant physics parameters, **depends on a worse/better detector performance** → feedback to the detector design.

A green scroll graphic with a white border and rounded corners. The scroll is partially unrolled at the top and bottom. The word "Backup" is written in a bold, black, sans-serif font in the center of the scroll.

Backup

Introduction

LHC will show the way, but as we wait for some indication, the safest option is to **plan for the highest possible energy → CLIC (3 TeV) CDR**

However, this is **not the easiest option** in terms of machine&detector(s) design and physics analysis.

Not all events are produced at the relevant energy: **significant beamstrahlung** → needs to be measured.

Particle **multiplicity at low angles** is significantly increased → large background, requires special design at low Radius.

CLIC **bunch structure** (0.5 ns separation) → significant event overlap in detectors, need time stamping.

Taking into account all the above, two detector designs are going to be described in the CDR:

CLIC_ILD

CLIC_SiD

	CLIC_SiD	CLIC_ILD
Vertex detector	inner radius 2.7 cm 5 single barrel layers 6 single layer forward disks	inner radius 3.1 cm 3 double layers 3 double layer pixel forward disks
Tracker	Si, unchanged	TPC, unchanged
ECAL	unchanged	unchanged
HCAL Barrel	W+Scintillator, 3x3 cm tiles 7.5 \wedge 1 cm plates W+RPC, 1x1 cm tiles 7.5 \wedge 1 cm plates	W+Scintillator, 3x3 cm tiles 7.5 \wedge 1 cm plates
HCAL Endcap	Fe+Scintillator, 3x3 cm tiles 7.5 \wedge 2 cm plates Fe+RPC, 1x1 cm tiles, 7.5 \wedge 2 cm plates	Fe+Scintillator, 3x3 cm 7.5 \wedge 2 cm plates
Coil	5T, Radius=2.68 m	4T, Radius=3.35 m