Detector Optimisation and Physics

ILD Meeting

Oshu City, Sept. 7,2014

J.List

Goals of further Simulation Studies

Open physics case questions

- High-level perspective
- Ultimate luminosity requirements
- Polarisation sharing
- Not yet (fully) demonstrated key measurements

=> interplay with running strategy & accelerator & detectors

Detector issues not yet studied (sufficiently)

- Calibration & alignment
  => need for Z pole running?
  => machine implications!
- Systematic uncertainties
- PID, low momentum particles…

Detector cost justification (reduction?)

- shrink overall size
- Ecal technology
- **Why a TPC?**
- …

Change requests from machine

- L* = 4.4 m -> 4.0 m ?
- Crossing angle
  14mrad -> 10mrad ?

=> cf Yokoya-San's presentation & MDI session

What we need to agree on

- New detector models
  - Cheaper
  - L* = 4m?
- Detector level performance benchmarks
  - incl. sofar uncovered aspects
- Physics level performance benchmarks
  - Incl. systematic uncertainties
- Important physics case questions
  - To be answered independently of detector optimisation
- Required "helper studies":
  - Calibration
  - Alignment
  - Systematic uncertainties

Physics Case - Overview

This is the key
for realising the ILC!
Need answers on the same topics,
but from a higher-level perspective

- Higgs
  - **Mass (250 GeV … ->)**
  - Couplings to W,Z,f (250 GeV ->)
  - Self-coupling (500 GeV ->)
  - **CP properties (250 GeV ->)**
- Top
  - Mass (350 GeV)
  - **EW couplings (400 GeV ->)**
  - ttH (500 GeV ->
- Direct BSM (250 GeV… ->)
  - **WIMPs in mono-photons**
  - **Natural SUSY: light Higgsinos**
  - Low ΔM new particles
  - …
- Z
  - ALR (91 GeV)
  - Mass ? (91 GeV)
- W
  - **Mass (500 GeV ->)**
  - TGCs, QGCs (250->

Detailed detector requirements of these topics cf also talks at ILD meeting 2013 in Krakow!

Distributing Luminosity & Polarisation

- Sofar, we "overbooked" run time since every analysis picked just their favourite energy & polarisation configuration
- Need to know for *every* analysis:

Luminosity sharing between helicities:

- What is the optimal sharing between (-+,+-,++,--)?
- What is the "price" for deviating from this?
  -> results for all 4 settings

At which integrated luminosity do we become systematics limited?

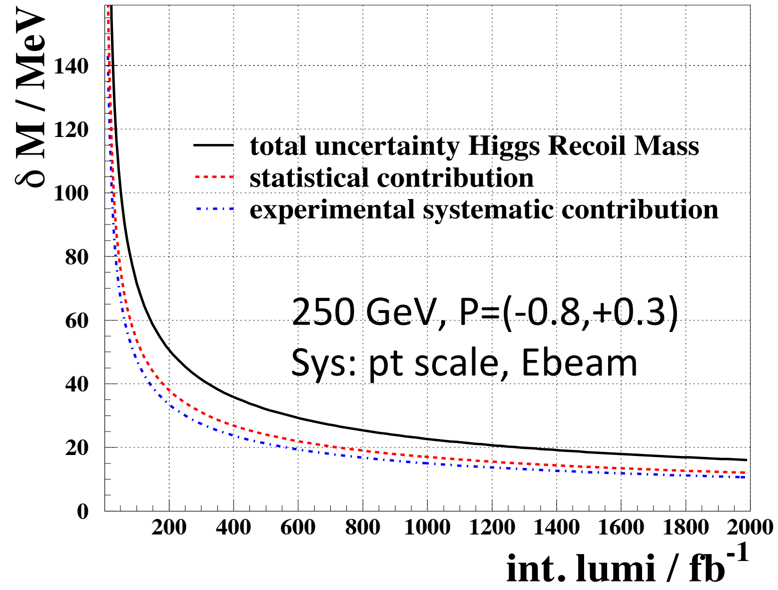
- Theory
- Parametric
- *Experimentally*
  -> will need dedicated studies!

Taking a "higher-level perspective" Example: Higgs Mass

How precisely do we need m_H?

- $\Gamma(H\text{->}X) \sim g_X^2$ * phase space
- Phase space depends on m_H especially for H->WW* / ZZ*
- Current estimate: δm_H = 200 MeV
  => parametric uncertainty of
  2.2% on Γ(H->WW*)
  2.5% on Γ(H->ZZ*)
- Acceptable parametric uncertainty?

$\delta\Gamma^{para}$	δm_H	Lumi [fb^{-1}]
1%	80 MeV	75
0.5%	40 MeV	300
0.25%	20 MeV	1200 (!!!)



If <0.5% required, investigate

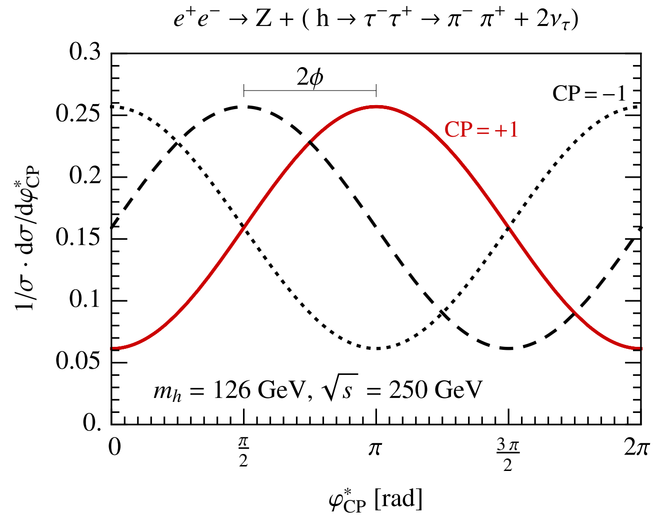
- Contribution from leptonic recoil at higher ECM
  -> tracking performance!!!
- Kinematic reconstruction H->bb, H->WW ? ....?

Uncovered Physics Case Studies
Ex: Higgs CP properties

CP properties of Higgs-fermion coupling from $H \to \tau^+\tau^-$

- Exploit ττ spin correlation,
  eg $\tau \to \rho\nu$, $\pi\nu$, $a_1\nu$.. other $\tau \to l\nu\nu$
- Very hard at LHC,
  theory study $\delta\varphi_\tau$ = 14° for 300fb^{-1}
- ILC: Last experimental study (SimDet): Desch, Was, Worek '03
- Recent theory study: S.Berge etal, **Phys.Lett. B727 (2013) 488-495:**

  $\delta\varphi_\tau$ = 2.8° for 1ab^{-1} @ 250 GeV



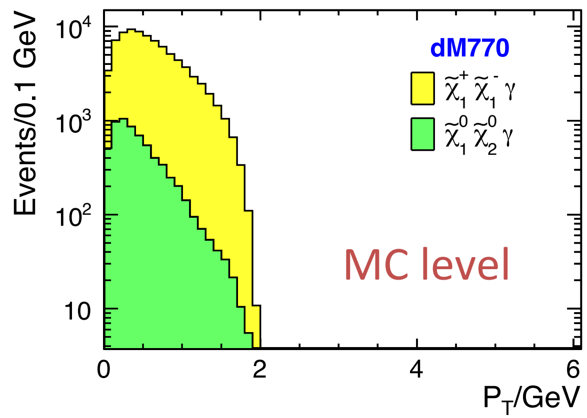
To study:

- Other ECM?
- Pair & γγ backgrounds
- π^0 reconstruction
- Exclusive τ decay reconstruction
- Impact parameter resolution
- Momentum resolution

Not fully demonstrated Physics Case
Ex: low ΔM New Physics

- unique discovery potential for the ILC, complementary to LHC
- Famous example:
  natural SUSY -> light, near-degenerate Higgsinos
- Feasibility study in SGV showed ability to constrain **multi-TeV** SUSY-parameters

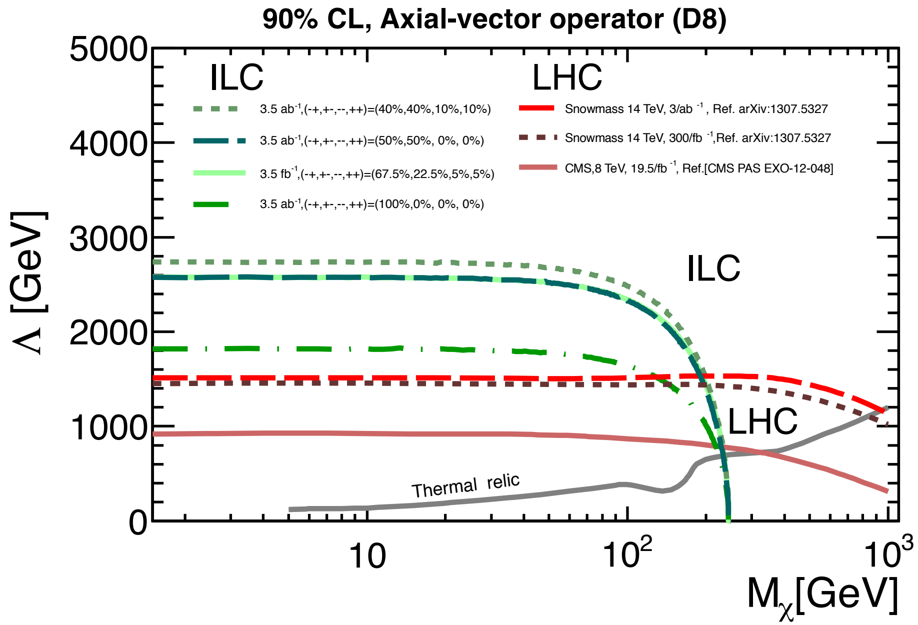
- But short cutting:
  - Particle IP
  - γγ->hadrons overlay
  - Fake tracks from pairs



Requires:
- stand-alone Si tracking with low number of fakes
- PID for < 2 GeV , vertexing / impact parameter, π^0 reconstruction
- Excellent hermeticity and γ energy resolution

Second Example– Dark Matter

- unique discovery potential for the ILC, complementary to LHC
- Reinterpretation of (pre-)LoI study
- Detector & machine issues:
  - Bhabha suppression
    => hermeticity
    => L* / crossing angle
  - Photon energy resolution
  - Fwd tracking
  - Fake tracks, γγ->hadrons



Systematic uncertainties:

- very important
- dP, dE_{CM}, dL/dE_{CM}
- Fake tracks
- Photon efficiciency, energy scale

From Physics to Detector Optimisation

- 1-1 relation between physics measurement and one specific detector performance aspect is *rare*
- For precision measurements, control of *systematics* might pose the most critical detector requirements
  [eg top threshold mass: control of dL/dE_{CM}-> Bhabha's -> LumiCal, fwd tracking, …]

=> optimise not just for statistical uncertainties, but also for calibration & control of systematics!

- Eg: Jet energy scale uncertainty vs jet energy resolution

-> scale calibration for individual particles, neutral hadron fraction, gluon splitting, fragmentation, …

Physics & Systematic Uncertainties

- We know the *statistical* uncertainties for many important physics studies
  -> fine for > O (few percent) precision ✔
- In many cases, we aim far beyond: eg δ^{stat}BR (H->bb) < 1%
- Here, our purely statistical uncertainties are *not convincing!*

⇒ need to include **systematics** in **physics case** *and* **detector optimisation**, both theoretical/parametric *and* experimental, eg:

- Momentum / energy scales
- Flavour tag, gluon splitting -> bb / cc, …
- Parton Shower: currently LO ME + PS – this is not state of the art! & Fragmentation, hadronisation, neutral hadron fraction, …
- Luminosity, E_{CM}, Polarisation, but also dL/dE_{CM}

⇒ **Need appropriate simulation & reconstruction tools, and "control benchmarks", eg determination of dL/dE_{CM}**

Calibration & Alignment

- Which precisions can be achieved?
  - Tracker momentum scale?
  - Calorimeter scales for different (neutral) particles
  - Jet energy scale
  - L, E, P incl. dL/dE
  - …
- And on which time scales?
  - Ultimate long-term?
  - For one push-pull period?
  - …

⇒ input for estimation of systematic uncertainties!

- How much Z pole data do we need for that?
- And how often?
  - Once a year?
  - After every push-pull?
  - …

⇓

requirement for accelerator design!

Optimisation benchmarks – Detector Level

- Hermeticity:
  - for high E (>90%E_{beam}?) e^{+-}/ γ
  - for "normal" e, μ, γ, π, n
- Calorimeters:
  - Jet energy resolution, including $5 < E_{jet} < 50$ GeV
  - Photon energy & angle resolution
  - Bhabha reconstruction
- Tracking system:
  - Efficiency, fake rate
  - $\sigma(1/p_t)$, σ_{IP}
  - Vertex efficiency, resolution
  - Jet charge
  - Flavour tag
- Low momentum particles (p_t = 0.1….2 GeV):
  - Tracking efficiency, $\sigma(1/p_t)$, σ_{IP}
  - Calorimeter detection efficiency
- Particle ID (dE/dx & calo)
  - e / μ / π^{+-} / p / K / n / π^0/ γ
  - Low p_t and "normal"
  - Particle ID in jets
- Exclusive decay mode reconstruction:
  - τ leptons
  - B, D hadrons

+ "control benchmarks":
  - LEP, dL/dE
  - gluon splitting g->bb ?
  - …..

Detector Optimisation and E_{CM} - what will be replaced when?

- Vertex detector:
  - exchange “frequently”?
  - Can optimise now for initial energy (250...350 GeV)
  - Late technology decision: Extrapolate more agressively for physics case studies, in particular for 500 GeV, 1 TeV
- SIT, FTD:
  - replace for 1 TeV upgrade?
  - Optimise for 500 GeV
- ECal / HCal granularity:
  - Long time scales -> less extrapolation
  - Optimise for at least 500 GeV
- Coil radius:
  - Never ever?
  - Optimise for 1 TeV

  => TPC radius, ECal, HCal depth
- Same for TPC length
- LumiCal, LHCal, BeamCal?
- SET?

For Physics Case:
one detector simulation model sufficient in view of limited person power

Optimisation benchmarks Physics Level – a suggestion

m_H from ee->ννH->ννbb

- JER
- π^0 reconstruction
- b-tag, l in jet, excl. B decays
- JES, b-tag, had., frag, neutral hadrons fraction uncertainties

Similar, but for "light jets":
m_W from ee->eνW->eνqq

A_{FB} (top)

- JER, lepton ID, b-tag
- *Jet charge*, excl. B-decays,

Higgs CP properties H->ττ

- τ reconstruction
- PID, Exclusive decay modes
- momentum & impact parameter

Near-degenerate Higgsinos

- Reco of low momentum particles
- Fake tracks
- PID, Exclusive decay modes
- Hermeticity
- Low and high-energy photon energy & angle resolution

Mono-photon WIMPs

- Photon energy resolution & scale, hermeticity, *suppression of Bhabhas, dL/dE_{CM}*

Balance manpower

Address remaining Physics Case question

Justify most important detector design choices

?

ILD needs to agree on a
balanced choice of priorities !

Conclusions

lots of studies to be done

- Cost / technology justification
- Change requests from machine
- Quantifying our calibration needs
- **Missing physics case arguments**

many more performance aspects than we focussed on so far – some of them make TPC case?

- Low momentum particles
- Particle ID
- Jet charge, ….
- Systematic uncertainties

Suggestion:

- Get together a small group of people to prepare a more precise proposal for a prioritised list of studies, both for physics case and detector optimisation on a short timescale
- Maybe start with an informal gathering after end of sessions today?

Backup

Strategy Proposal

Detector-level performance

- Efficiencies, resolutions etc
- Study for O(3-4) detector models in full simulation

Example: Particle ID

- Determine actual capabilities in FullSim
- Study impact on analyses by varying PID efficiencies & fake rates in SGV

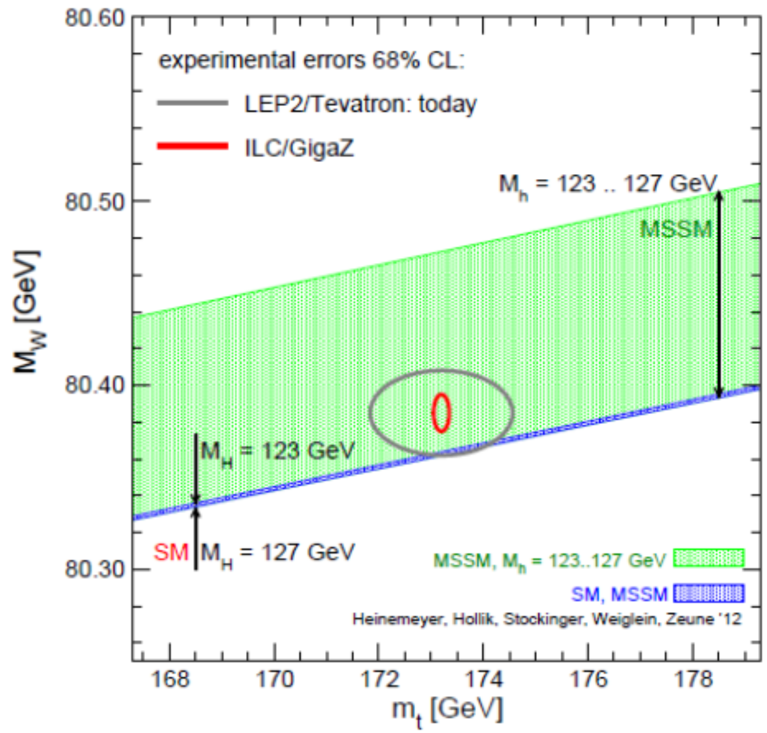
Physics performance

- ILD_o1 full simulation: reference analysis
- Where ever possible: determine *relative impact* of
  - efficiencies
  - resolutions
  - systematic uncertainties

  in SGV or cheated full sim

Physics Case - M_W

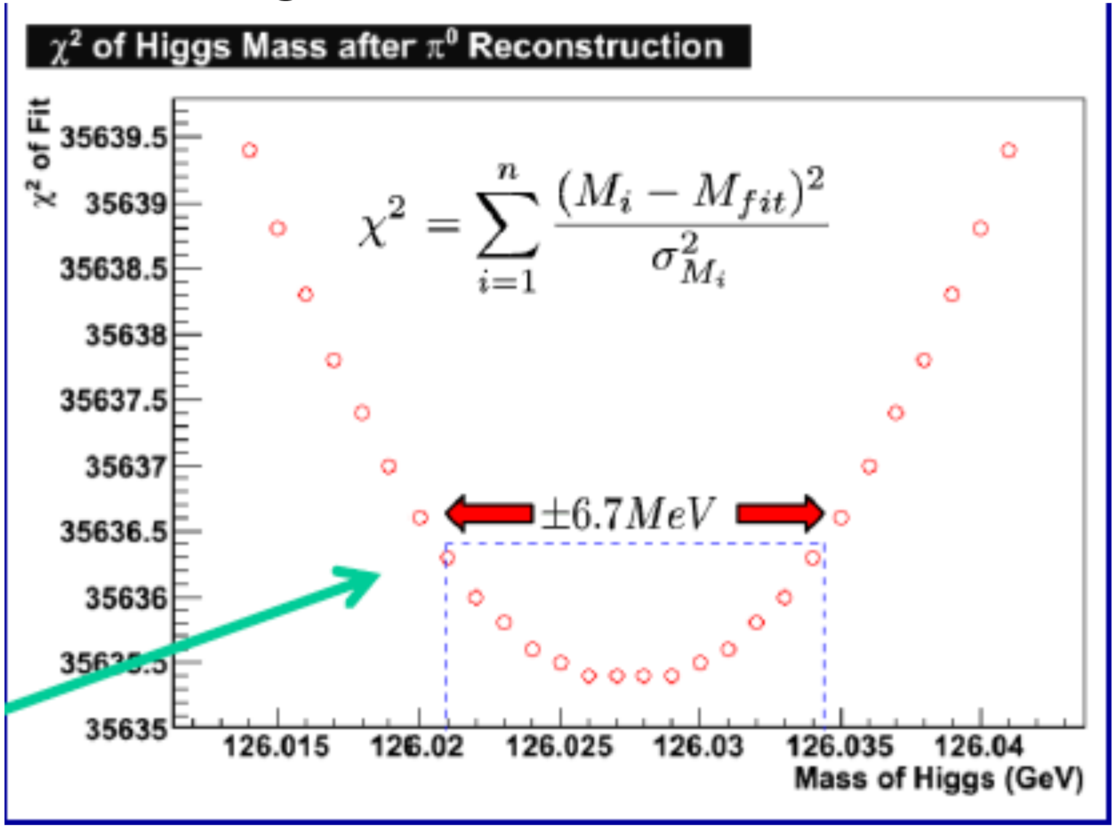
- m_H, m_W and m_t provide crucial SM closure test
- Classic for ultra-precise (few MeV) m_W: threshold scan
- Needs lot's of data at 161 GeV
- Interesting alternative: hadronic mass in ee->evW->evqq
- Decisive systematics: momentum scale and calorimeter energy scale for single particles



- Cf Graham's talk eg at ILD meeting 2013 in Krakow

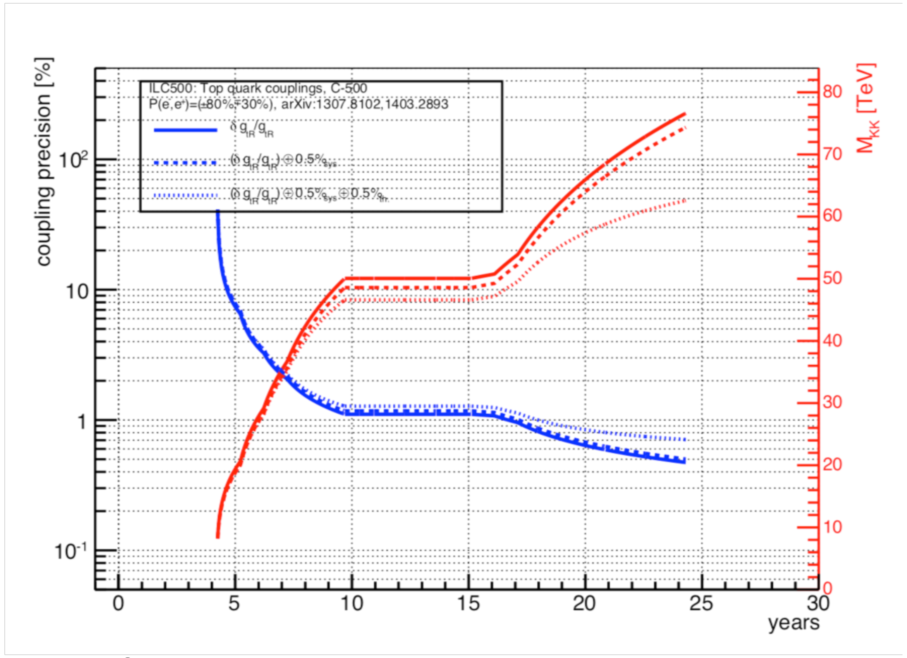
Physics Case – M_H fromH -> bb

- Cf Graham's talk at ILD meeting 2013 in Krakow
- Very competetive!
- Systematics?



Physics Case – Top Couplings

- Precision measurement of ew top couplings can constrain multi-TeV new physics
- Requires: σ(tt) and A_{FB} (top)
- The major open detector issue:
  - B-jet charge reconstruction!
- Systematics:
  - Beam polarisation precision (A_{FB})
  - Luminosity (σ(tt))
  - b-tagging, $R_{b,}$ g->bb?
  - ….
- Cf eg Roman's talk at ILD 2013 in Krakow



Polarisation split

- "Simulataneous" collection of data with all 4 helicity configurations is essential to minimize systematic uncertainties, eg from
  - Time-dependent detector efficiencies, calibration, aligment etc
  - Luminosity, beam energy and polarisation measurements
- Thus: fast helicity reversal with frequency chosen to obtain a preset "mix" of helicity configurations (sign(P(e-)), sign (P(e+))):

ECM	-+ [%]	+- [%]	++ [%]	-- [%]	Phys. driver
250 GeV	67.5	22.5	5	5	ZH
350 GeV	67.5	22.5	5	5	M_t
500 GeV	40	40	10	10	t coup / DM / TGC
1 TeV	40	40	10	10	H / DM / TGC
90 GeV	40	40	10	10	A_LR
160 GeV	78	17	2.5	2.5	M_W