Requirements of running at the Z-pole and WW-threshold

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(Uni Hamburg, DESY)

- Status physics and Collider options
- Impact of precision measurements at Z and WW
- Calibration Issues
- Technical remarks on the machine
- Conclusions

Why running at low energies (Z, WW) at ILC?

Clear distinction needed:

A. *For calibration purposes*

- Parameter group studies this question: dedicated questions to detector groups
- Status: preliminary answer from ILD (not yet official), not yet from SID
- A few remarks on this later, but not topic of this talk!

B. *For physics aspects*

- Status of physics case now
- For which cases may running at WW be important?
- For which cases may Z-pole runs be important?

Status physics

- Current physics case for e+e- (as well known):
  - Higgs precision physics
  - Top precision physics

  } guaranteed physics!

  - Light electroweak particles/DM searches
  - BSM detection in general, complementary to LHC

  } well motivated

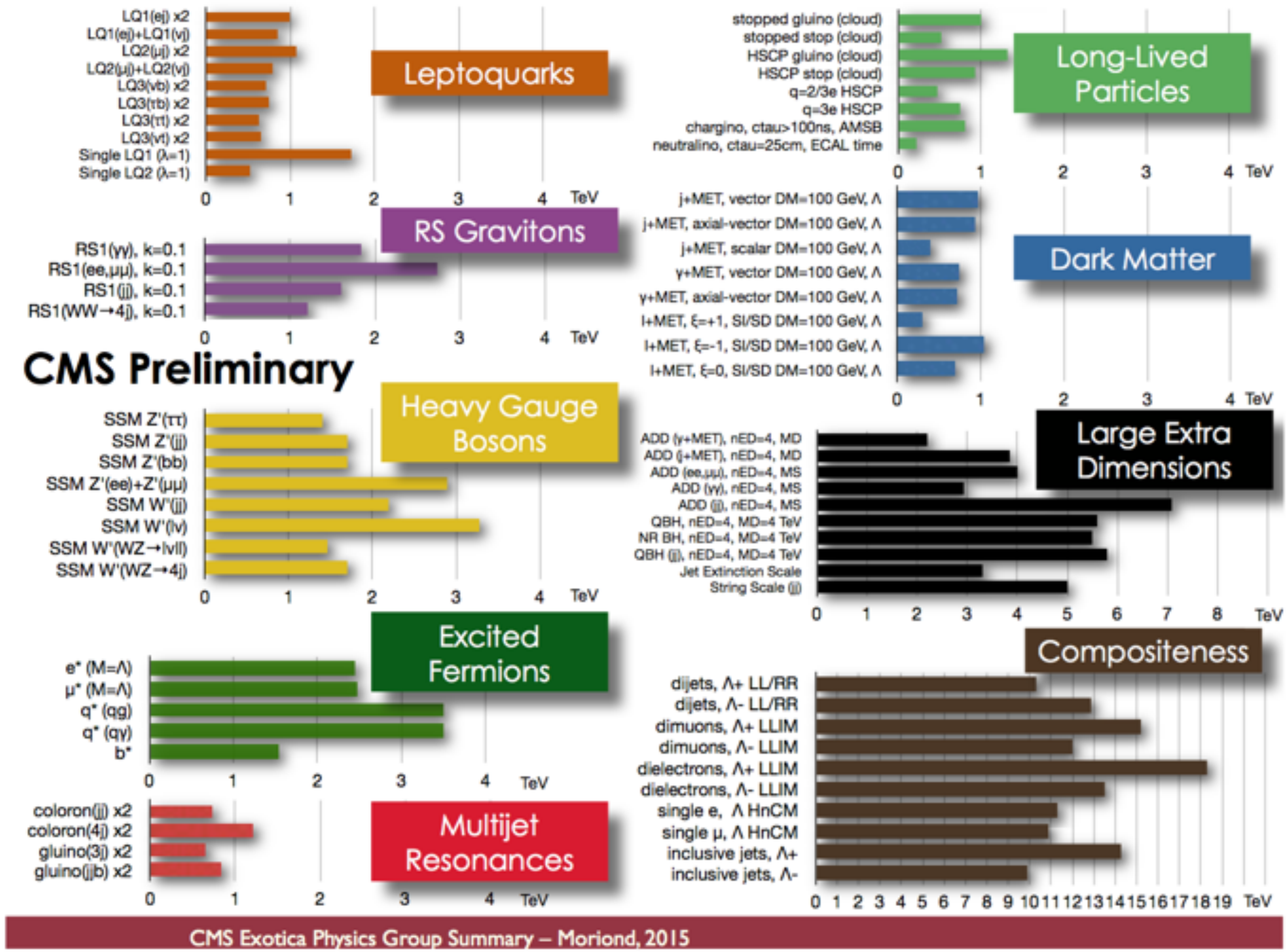
- HEP-e+e-: ILC, CLIC or CepC or Fcc-ee
  - ILC, $\sqrt{s}$=90-500 (1000) GeV, 163 MW, 31 km, polarized beams, t⩾2032
  - CLIC: $\sqrt{s}$=500 GeV,1.5, 3 TeV, 560 MW, 48 km, polarized beams,t≥2035(?)
  - CepC: $\sqrt{s}$=240 GeV, 500 MW, 54 km, polarization unclear, t⩾2028
  - FCC-ee: $\sqrt{s}$=350 GeV, 500 MW, 100km, no polarization at 350, t⩾2035?

P. Burrows
W. Chou, EPS15

- *Many ideas, but realistically only one mature project —the ILC—that could start operation before LHC switches off (~2035)*
  - ➢ *very substantial for future development of the field as a whole!*

Current experimental result from LHC (CMS)

- **Many model beyond the Standard Model on the market: no clear sign!**



- **High mass limits: any alternative to get sensitivity to new physics?**

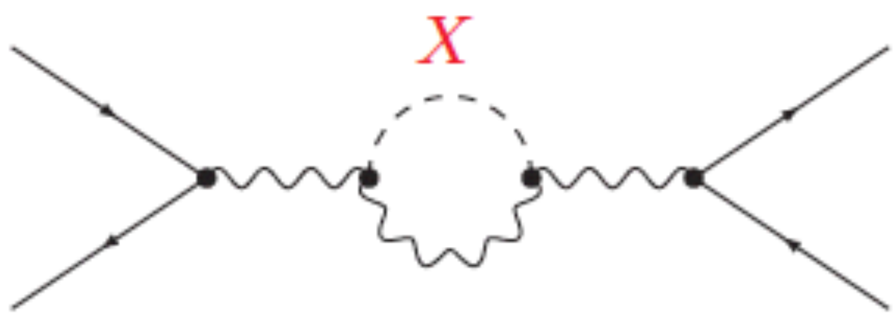
➢ ***exploit electroweak precision observables***

Electroweak precision observables: MW, sin2θeff, MH, (g-2)μ, b physics

- Comparison of observables with theory

Precision data: MW, sin2θeff, aμ, Mh	Theory: SM, SUSY, Z',…

Test of theory at quantum level: senstivity to heavy masses via loops!



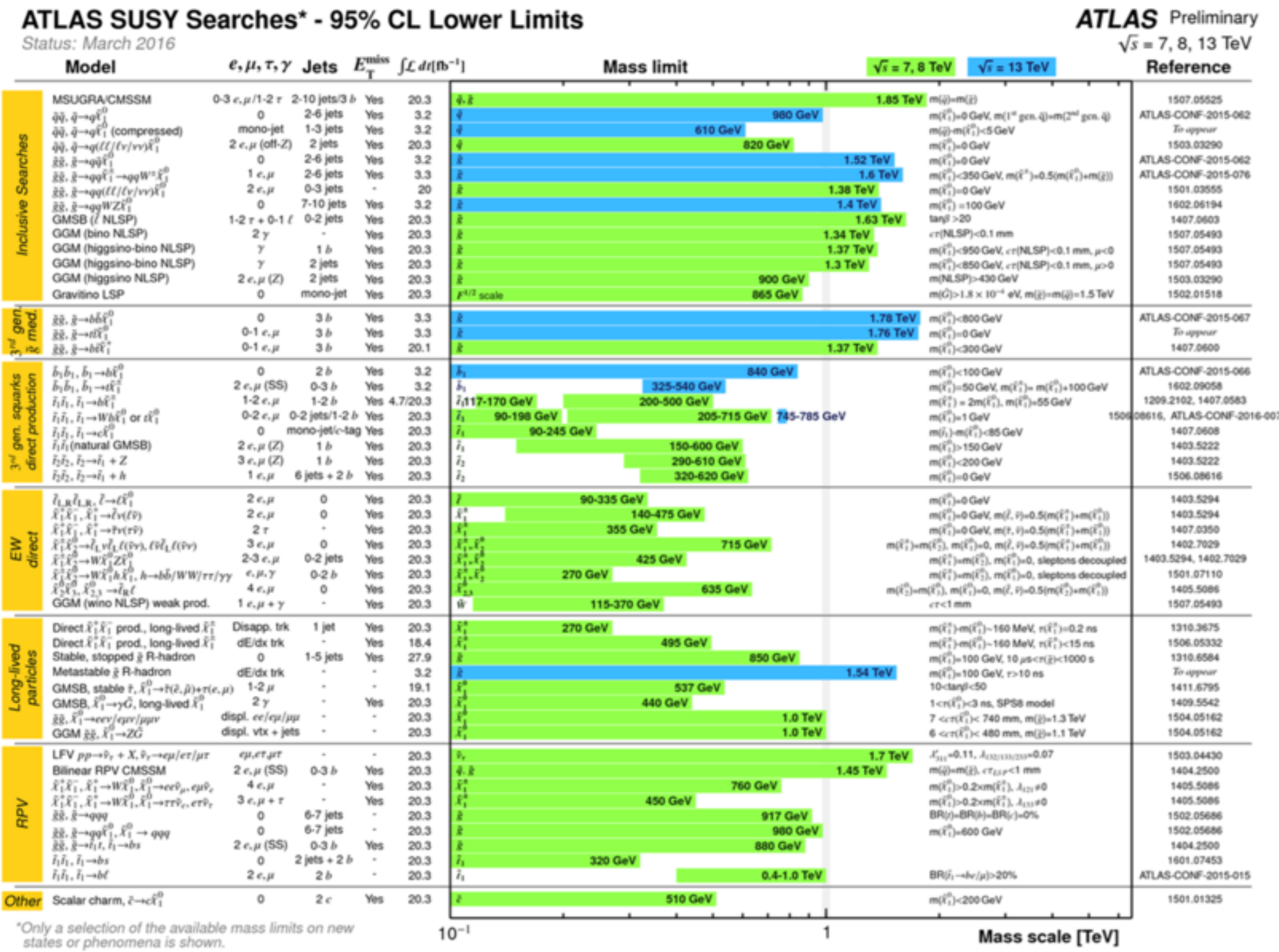
SM: limits on MH, BSM: limits on MX

Very high accuracy of measurements as well as theoretical predictions needed

➢ only models 'ready so far: SM, SM-like, SUSY
……still room for improvement from theory

➢ in the following —as case study only— SUSY

Current experimental result from LHC (ATLAS)



All simplified models!

➢ So far: rather heavy SUSY mass limits ….but not exclusively

Importance of M_W and mixing angle $\sin^2\theta_{eff}$

S. Heinemeyer
Talk at MPI
Munich, 5/16

A. Theoretical prediction for M_W in terms of M_Z, α, G_μ, Δr:

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\,\alpha}{\sqrt{2}\,G_\mu}(1+\Delta r)$$

loop corrections

Evaluate Δr from μ-decay ⇒ M_W

One-loop result for M_W in the SM:

$$\Delta r_{1-\mathrm{loop}} = \Delta\alpha - \frac{c_W^2}{s_W^2}\Delta\rho + \Delta r_{\mathrm{rem}}(M_H)$$

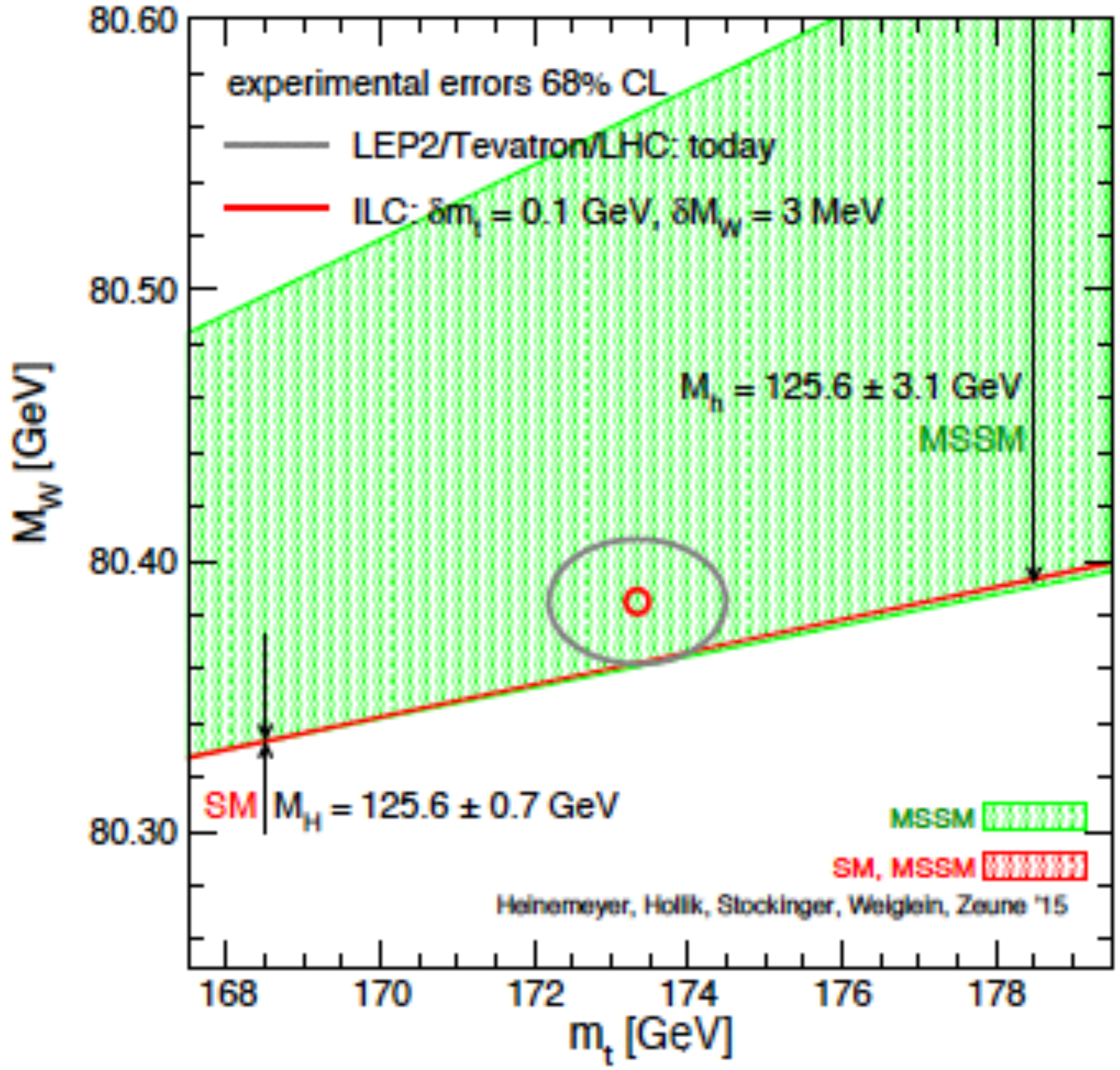
$$\sim \log\frac{M_Z}{m_f} \qquad \sim m_t^2 \qquad \log(M_H/M_W)$$

$$\sim 6\% \qquad \sim 3.3\% \qquad \sim 1\%$$

➢ **Large impact of m_{top}, M_H and M_Z and their uncertainties!**

Which precision in M_W do we need?

- Case study SUSY versus Standard Model
  - ➢ Strong correlation of M_W, M_t and M_H:



MSSM band: scan

SM and SM-like MSSM

Current experimental world average: M_W=80.385 ±0.015 GeV, M_t=173.34±0.76 GeV

S. Heinemeyer
Talk at MPI
Munich, 5/16

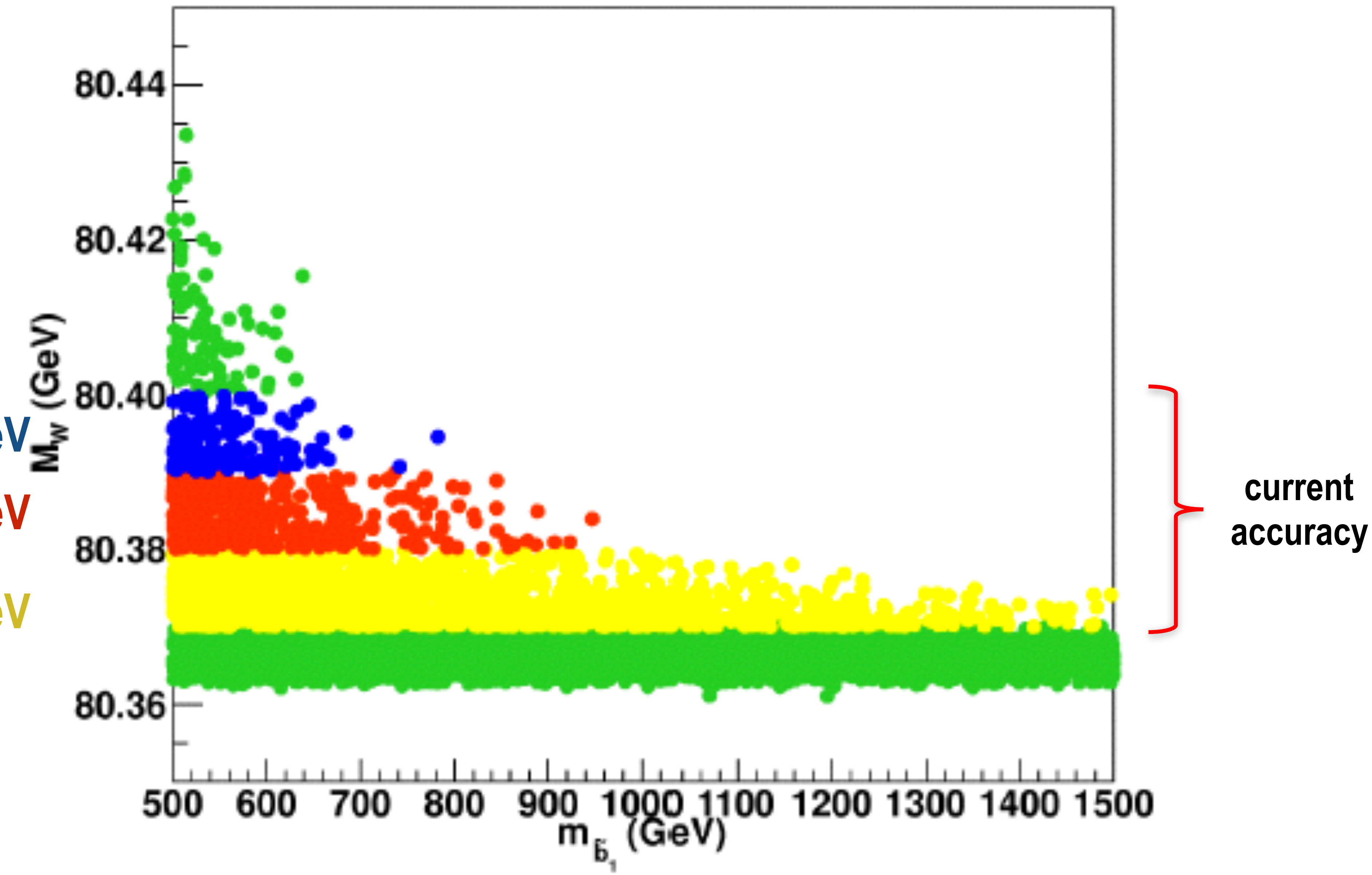
Which precision in M_W do we need?

- Just as case study SUSY: m_{stop1}=400±40 GeV, other susy masses>500 GeV

M_W=80.395 ±0.005 GeV

M_W=80.385 ±0.005 GeV

M_W=80.375 ±0.005 GeV



➢ *precision for ΔM_W below/about 5 MeV required in order to be sensitive to heavy susy masses!*

The mass of the W boson

S. Heinemeyer
Talk at MPI
Munich, 5/16

- **Experimental accuracy:**

  Today: LEP2, Tevatron: MWexp=80.385±0.015 GeV

  ILC: - polarized threshold scan

  - kinematic reconstruction of WW

  - hadronic mass (single W)

  G. Wilson 2013

  $\Delta M_W^{exp,ILC(FCC\text{-}ee)}<3$ (1) MeV (from threshold scans) (but without Theo uncertainties!)

- **Theoretical accuracies:**

  intrinsic today: $\Delta M_W^{SM,theo}=4$ MeV $\Rightarrow$ future: $\Delta M_W^{SM,theo}=1$ MeV

parametric uncertainties today:		future:	
from Δmt =0.9GeV	$\Rightarrow \Delta M_W^{mt}$ =5.5MeV	Δmt =0.05 GeV	$\Rightarrow \Delta M_W^{mt}$ =0.5 MeV
from $\Delta\alpha had$=10-4	$\Rightarrow \Delta M_W^{\alpha had}$=2MeV	$\Delta\alpha had$=5x10-5	$\Rightarrow \Delta M_W^{\alpha had}$=1 MeV
from ΔmZ=2.1MeV	$\Rightarrow \Delta M_W^{mZ}$=2.5MeV	ΔmZ=1/0.1MeV	$\Rightarrow \Delta M_W^{mZ}$=0.2/0.02MeV

Impact of the precision of the mixing angle $\sin^2\theta_{eff}$

B. Effective mixing angle:

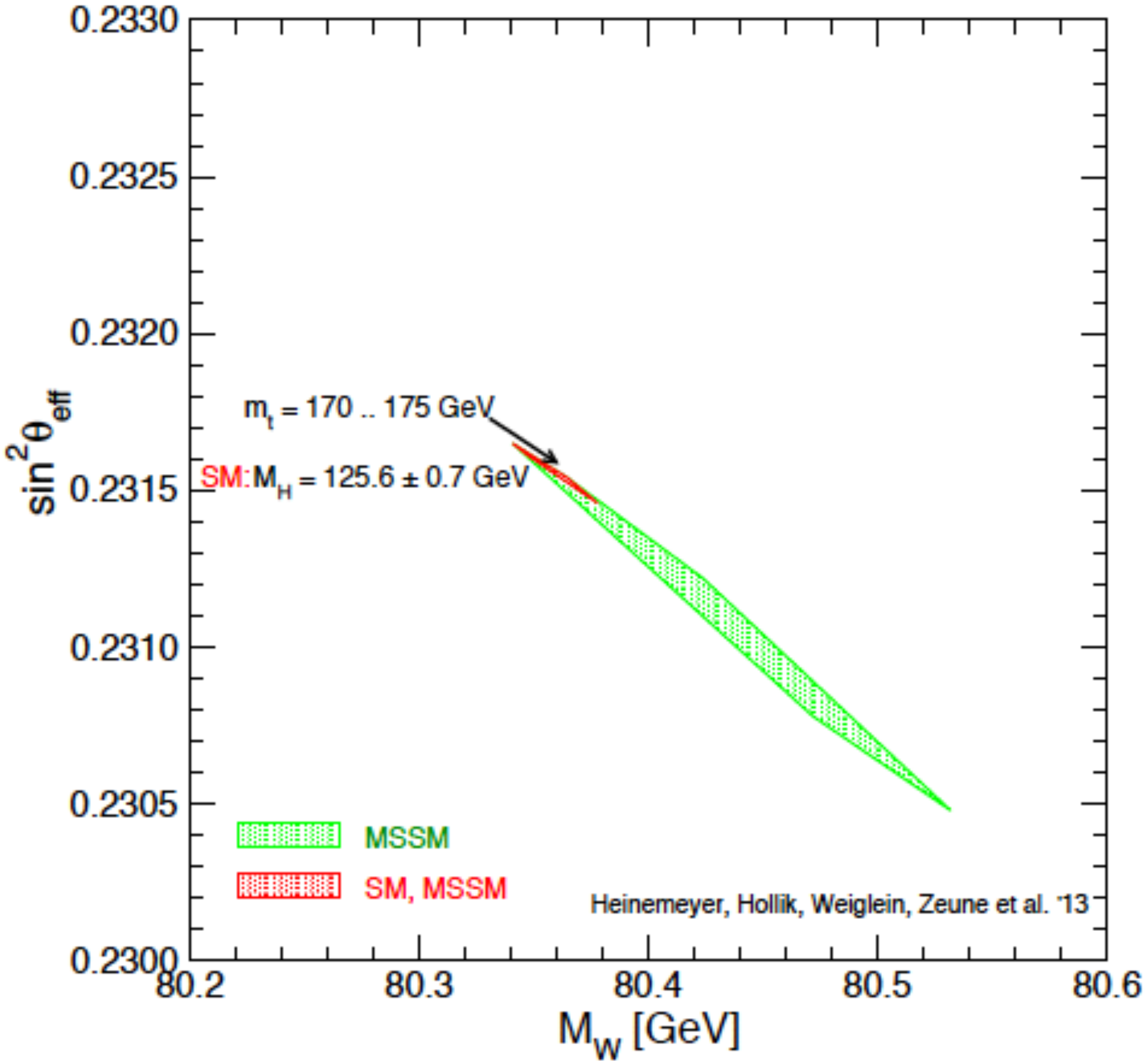
$$\sin^2\theta_{\text{eff}} = \frac{1}{4\,|Q_f|}\left(1 - \frac{\text{Re}\, g_V^f}{\text{Re}\, g_A^f}\right)$$

Higher order contributions:

$$g_V^f \to g_V^f + \Delta g_V^f, \quad g_A^f \to g_A^f + \Delta g_A^f$$

also impact of new physics contributions!

Impact of the precision of the mixing angle $\sin^2\theta_{eff}$

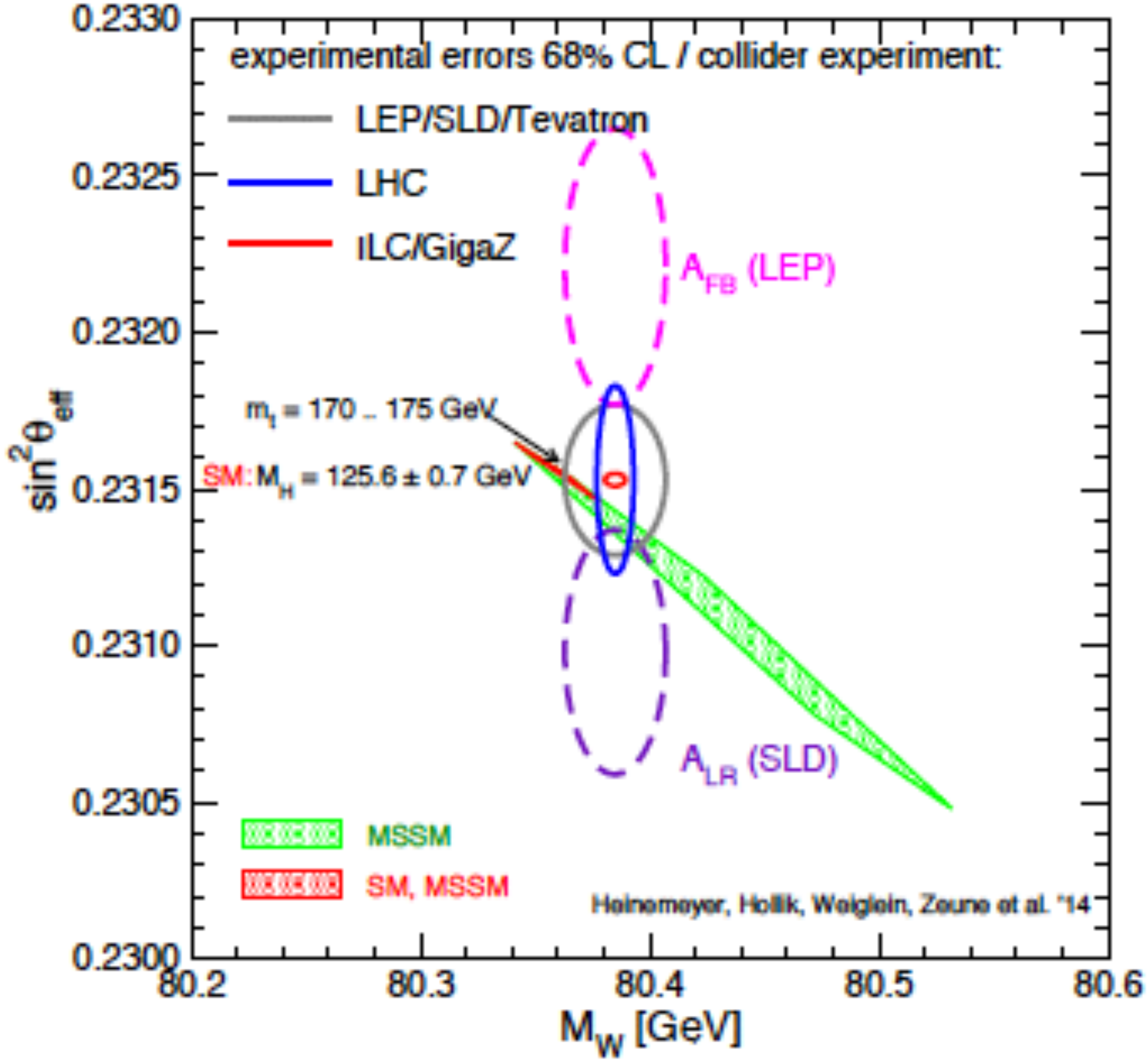


MSSM band: scan over SUSY masses

Overlap:
SM is SUSY-like
SUSY is SM-like

SM band: variation of M_H and M_t

Impact of the precision of the mixing angle $\sin^2\theta_{eff}$



MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

SM band:
variation of M_H^{SM}

Impact of the precision of the mixing angle $\sin^2\theta_{eff}$

*S. Heinemeyer
Talk at MPI
Munich, 5/16*

- **Experimental accuracy:**

  Today: LEP, SLD: sin2θeff=0.23153 ± 0.00016

  GigaZ/TeraZ: both beams polarized, Blondel scheme

  $\Delta\sin2\theta_{eff}^{exp,ILC(FCC\text{-}ee)}$=13/3 x 10-6 (but without Theo uncertainties!)

- **Theoretical accuracies: [10-6]**

  intrinsic today: $\Delta\sin2\theta_W^{SM,theo}$ =47 ⇒ future: $\Delta M_W^{SM,theo}$ =15

  parametric uncertainties today: future:

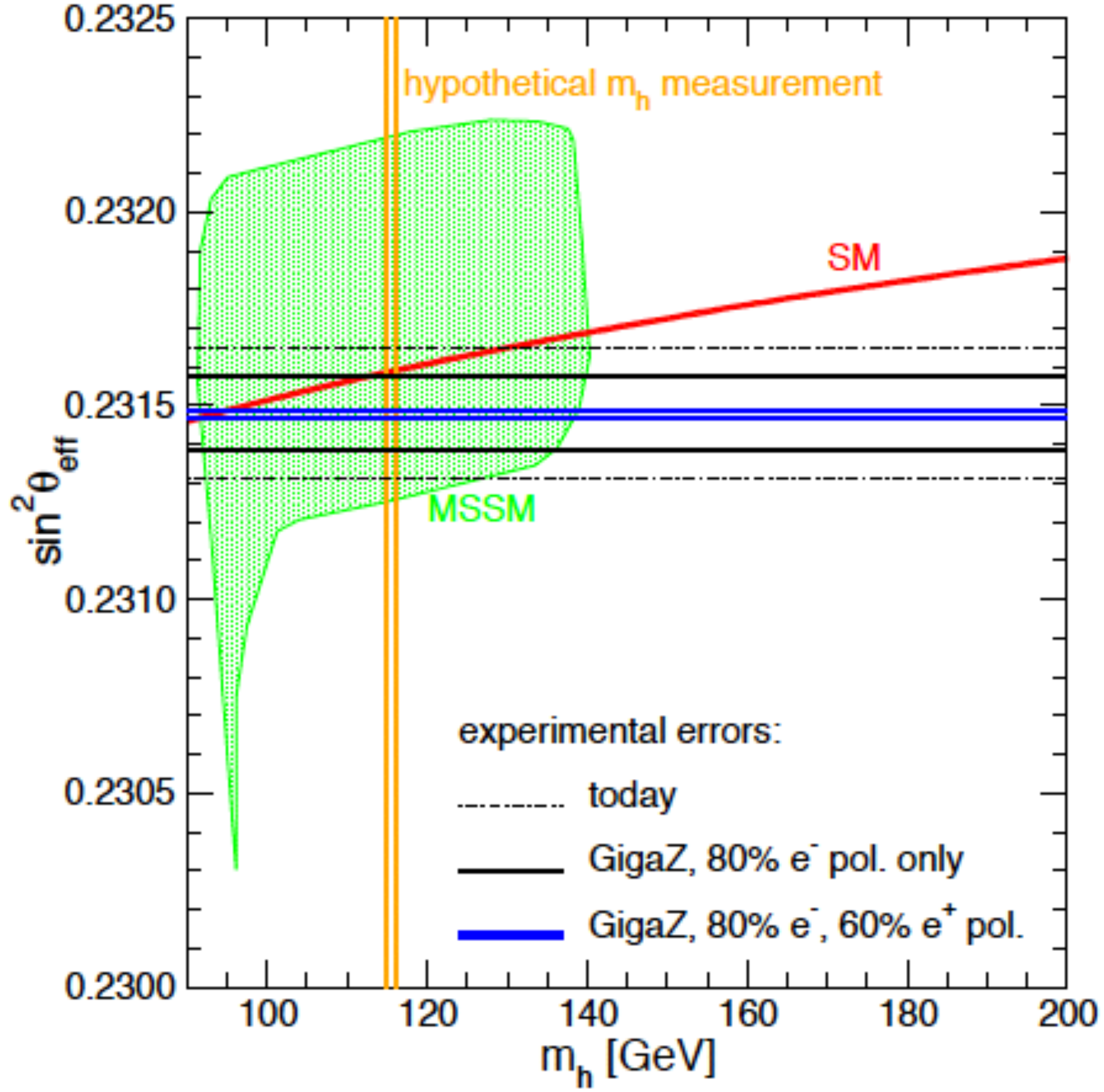
  from Δmt =0.9GeV ⇒ $\Delta\sin2\theta_{eff}^{mt}$ =30 Δmt =0.05 GeV ⇒ $\Delta\sin2\theta_{eff}^{mt}$ =2

  from Δαhad=10-4 ⇒ $\Delta\sin2\theta^{\alpha had}$=36 Δαhad=5x10-5 ⇒ $\Delta\sin2\theta_{eff}^{\alpha had}$=18

  from ΔmZ=2.1MeV ⇒ $\Delta\sin2\theta_{eff}^{mZ}$=14 ΔmZ=1/0.1MeV ⇒ $\Delta\sin2\theta_{eff}^{mZ}$=6.5/0.7

Impact of the precision of the mixing angle $\sin^2\theta_{eff}$

- **Last but not least: relevance of both beams polarized:**



Heinemeyer, Weiglein 2005

➢ **precision on $\sin^2\theta_{eff}$ relies strongly on both beams polarized**

➢ **crucial to reach sensitivity!**

Remark on running at Z/WW for calibration

- **Calibration needs with Z pole data**
  - ➢ referred to in the TDR, but without specific design
  - ➢ promised precision can only be guaranteed if matched by alignment and calibration
  - ➢ not clear whether switching between low and high energy running is critical
  - ➢ clear question to the detector groups: how often and which lumi is needed and which detector component does really need Z pole running?

G. Wilson Talk at DESY Hamburg, 5/16

$\sqrt{s}$	$\sigma(\mu\mu)$ (pb)	$\sigma(q\bar{q})$ (pb)	$\rho_Z(\mu\mu)$	$\rho_Z(q\bar{q})$
91.2	1580	30500	1.0	1.0
250	4.99	50.1	316	609
350	2.57	24.8	614	1230
500	1.30	12.6	1210	2420
1000	0.386	3.64	4080	8370

  - ➢ Assuming γ scaling of lumi: hadronic events are 440 times higher at Z-pole compared to 500 GeV.
  - ➢ Calibration that may need about a year at 500 can be done in 1 day at Z-pole,…if well mature designed

Remark on running at Z/WW for calibration

J. List
Talk at DESY
Hamburg, 5/16

Preliminary intermediate results (thanks to Jenny!)

- So far, ILD tracking systems expects frequent Z calibration runs with 10^{32} or 1 pb-1 in few hours
- Calorimetry: absolute scale of ECAL — no Z pole running needed
  - ➢ MIP scale calibration requires couple of days Z pole calibration
  - ➢ HCAL: MIP scale most efficiently via Z pole
- Jet Energy scale: no dedicated running at Z or WW

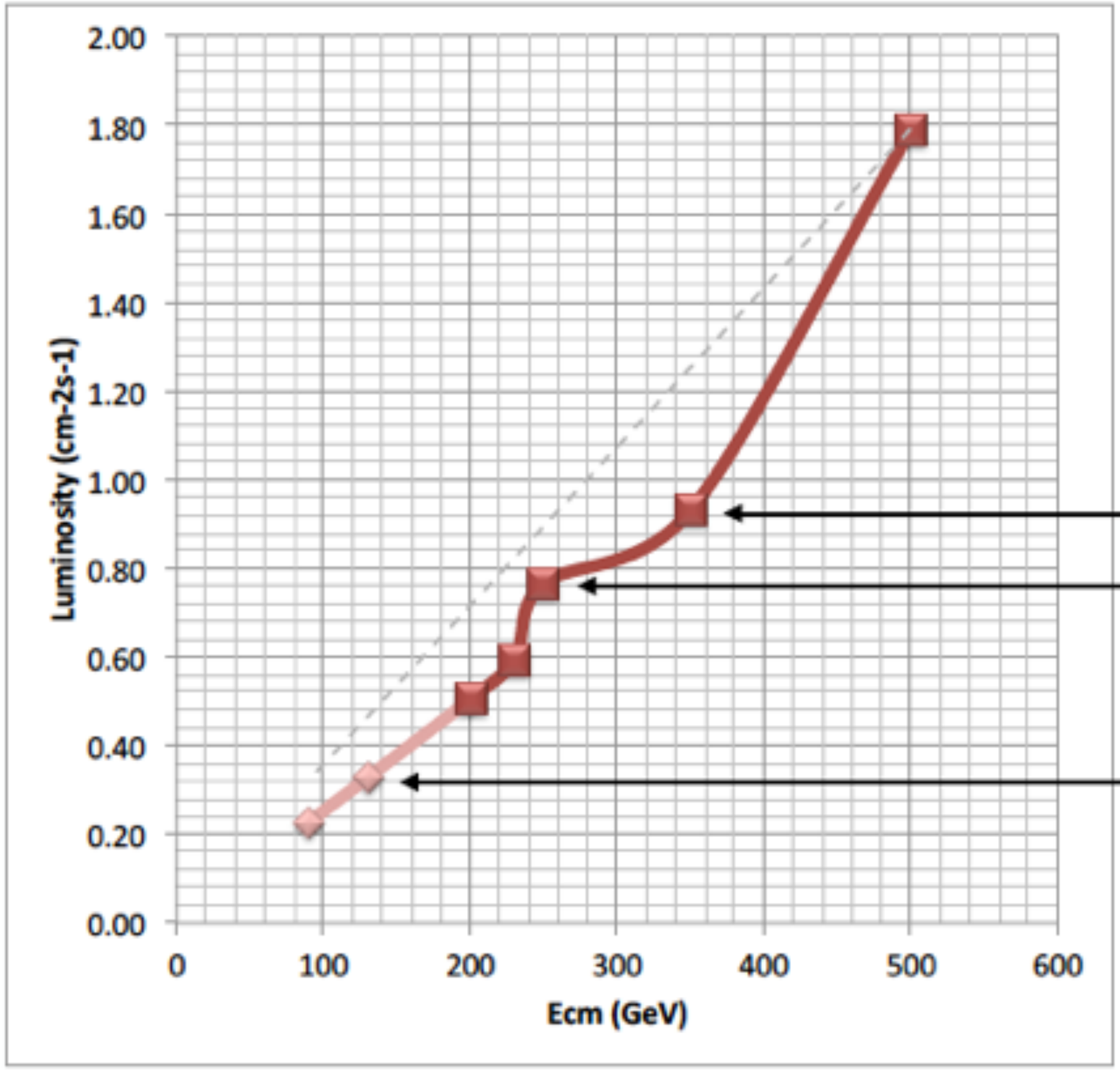
However: still many details under work

- no lumi-issues for positron source
- can be delivered with low intesity source

Machine issues: options to run at low energies

N. Walker
Talk at DESY
Hamburg, 12/15

- **Luminosity issues: γ scaling may not be appropriate**



constant hor. IP divergence (~ 44 mr)

short final double solution (~ 58 mr)

gamma scaling from 200 GeV ?

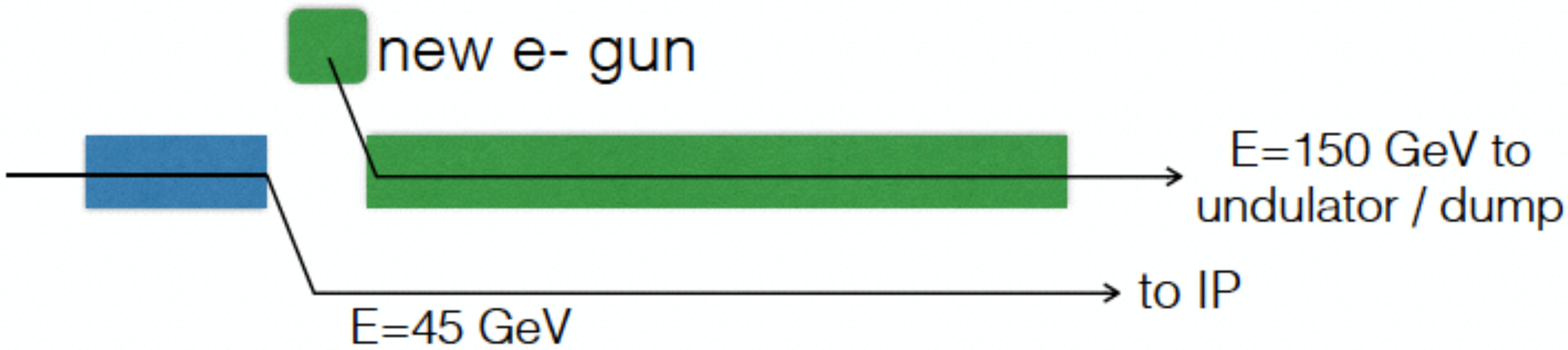
likely lower than this

- **also 10 Hz scheme not always applicable if ΔE between pulse too big, e.g. 45 GeV and 150 GeV…….problems with linac dynamics**

N. Walker
Talk at DESY
Hamburg, 12/15

Machine issues: options to run at low energies

- Further option: split linac !



Major reconfiguration of accelerator
Requires a mini design study
- 3rd beamline in linac tunnel
- additional doglegs, bypasses and possible dumps
- ...

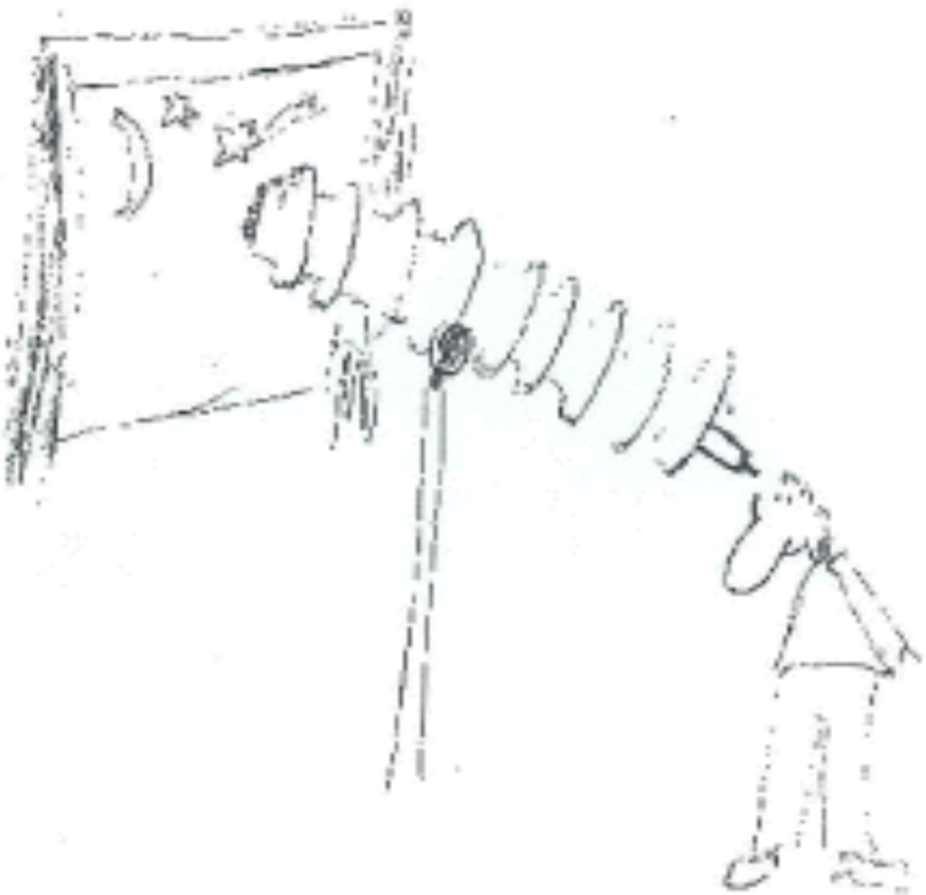
- Z and W running conceptually possible at 2—4Å~10^{33} and 3—6Å~10^{33} respectively but much more detailed studies required !

Conclusions

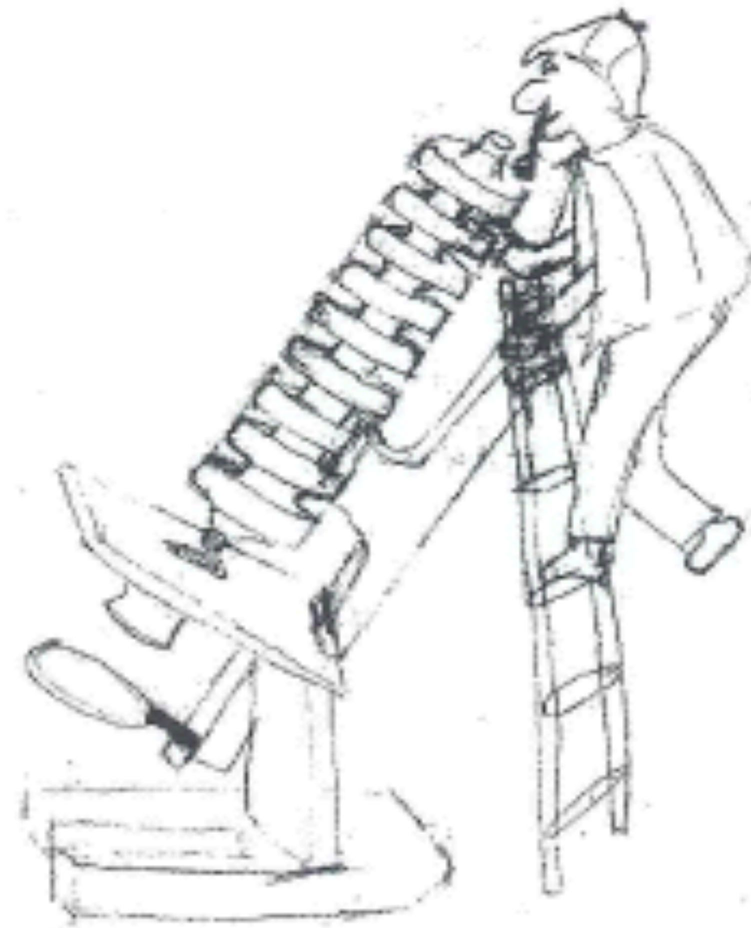
- **Calibration Issues:**
  - ➢ still under work, some detector parts require Z-pole (10^32)   (time issues!)
  - ➢ crucial information how quickly and how often energy changes are required: stay tuned, under work
- **Physics:**
  - ➢ Threshold runs at WW needed: mass precision
  - ➢ GigaZ run needed (including polarized beams!): electroweak precision angle
  - ➢ FCC-ee option: can not replace ILC@Z,WW
- **Accelerator issues:**
  - ➢ in principle no lumi issues but design changes required
  - ➢ Technical solution via split linac
  - ➢ For lumi upgrade still some more work to do (but also for e-driven source unclear)

ILC only compatible and complentary to LHC if physics runs with 10^{33} at low energy not excluded !

I Love Cavities



Unraveling the past



Revealing present mysteries

Feeding future brains

THE I L C