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Charged Higgs Bosons at the Compact Linear Collider (CLIC)

cHarged 2008
Uppsala, September 17th

CLIC

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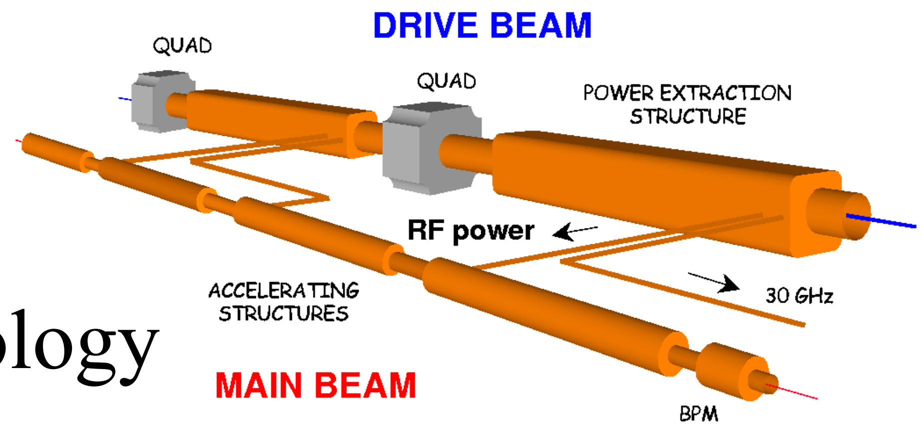

- Proposed future linear collider
- e^+/e^- at $\sqrt{s} = 3$TeV
- Two-beam acceleration technology
- Low-energy, high-intensity drive beam parallel to the main linac → RF power for accelerating structures.
- CLIC Test Facility (CTF3) & extensive beam dynamics studies: demonstrate key tech issues by 2010

Charged Higgs

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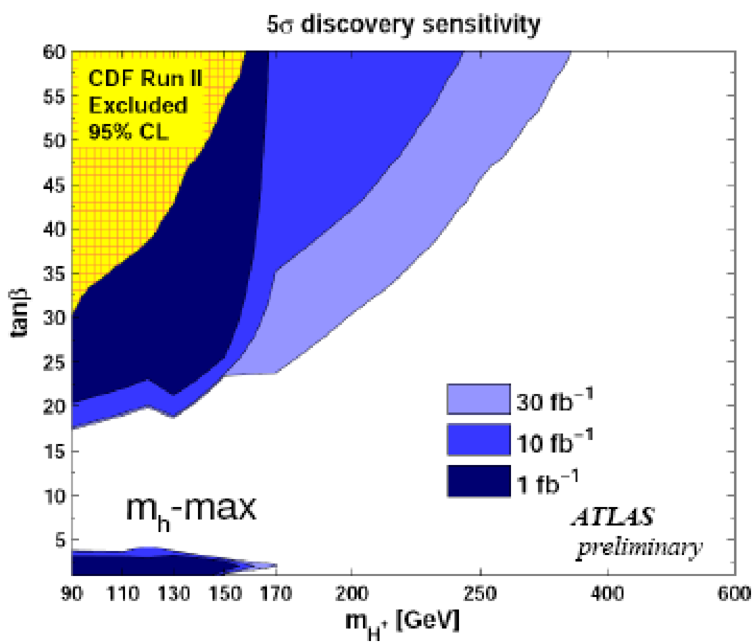
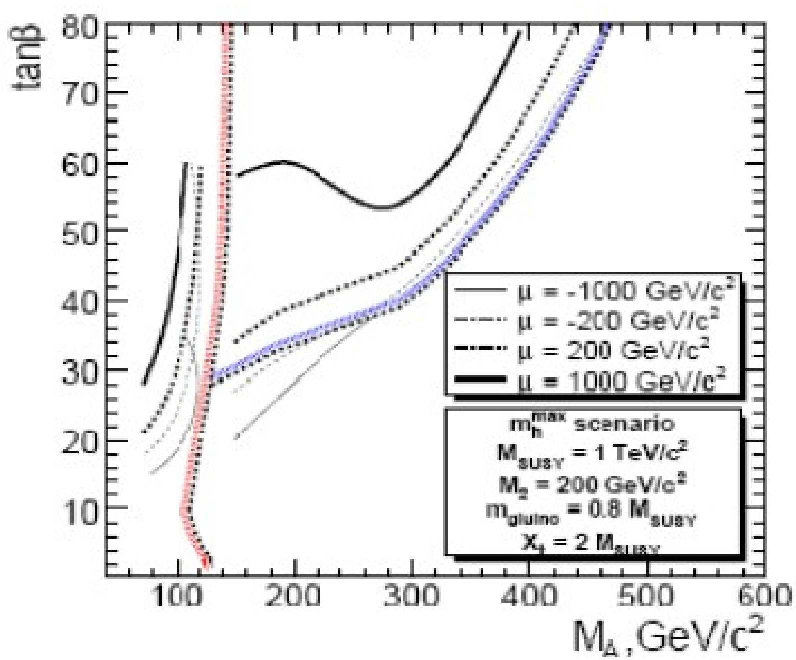
- LHC: Significant discovery reach, but:
  - Discovery very challenging for heavy H^+, or $\tan\beta$ in region around 7
  - Precise parameter determination very difficult

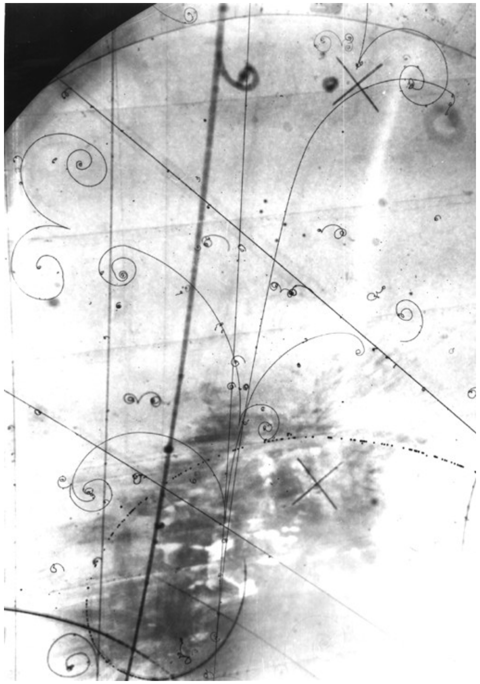


(ATLAS, from Martin's talk yesterday)



(CMS, from Ritva's talk yesterday)

Charged Higgs



- High-energy e^+e^- collider could tackle these challenges
  - More precise knowledge of collision energy
  - Cleaner environment
  - Fewer backgrounds
- In present study:
  - Focus on very high H+ masses
  - Examine potential for parameter determination

Charged Higgs

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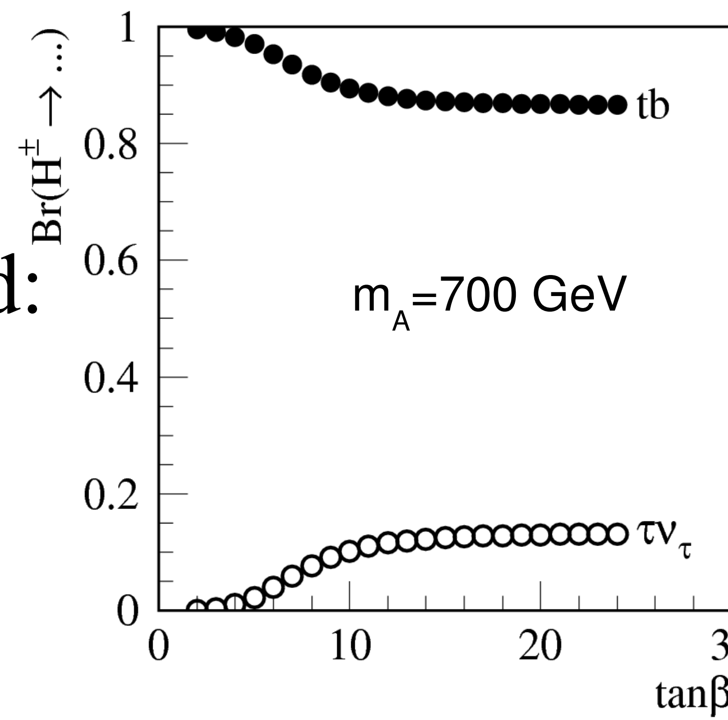
- MSSM
  - H^+ only decays to SM particles
  - No SUSY backgrounds considered
- Both dominant decay modes studied:
  - $H^+ \rightarrow tb$ & $H^+ \rightarrow \tau\nu$
- Two channels:
  - $e^+e^- \rightarrow H^+H^- \rightarrow tbtb$
  - $e^+e^- \rightarrow H^+H^- \rightarrow tb\tau\nu$
- All results for integrated luminosity of 3000 fb^{-1} (~4 years)



CLIC parameters and beam-beam effects considered for this study

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Center-of-mass energy	3	TeV
Main linac RF frequency	30	GHz
Accelerating gradient	150	MV/m
Linac and site lengths	28/33.2	km
Linac repetition rate	150	Hz
No. of bunches per pulse	220	
No. of particles per bunch	2.56	10^9
Bunch spacing	0.267	ns
Horizontal emittance $(\beta\gamma)\epsilon_x$	0.660	mm.mrad
Vertical emittance $(\beta\gamma)\epsilon_y$	0.001	mm.mrad
Horizontal beam size σ_x	60	nm
Vertical beam size σ_y	0.7	nm
Bunch length σ_z	30.8	μm
Peak luminosity	6.5	10^{34} cm^{-2} s^{-1}
Luminosity within 1% of E_{cm}	3.3	10^{34} cm^{-2} s^{-1}
Beamstrahlung loss	16.0	%
Coherent pairs per bunch crossing	5	10^7
$\gamma\gamma \rightarrow$ hadrons per bunch crossing	0.73	

(Parameters have changed since study was performed. For up-to-date parameters, please see http://clic-meeting.web.cern.ch/clic-meeting/clictable2007.html)

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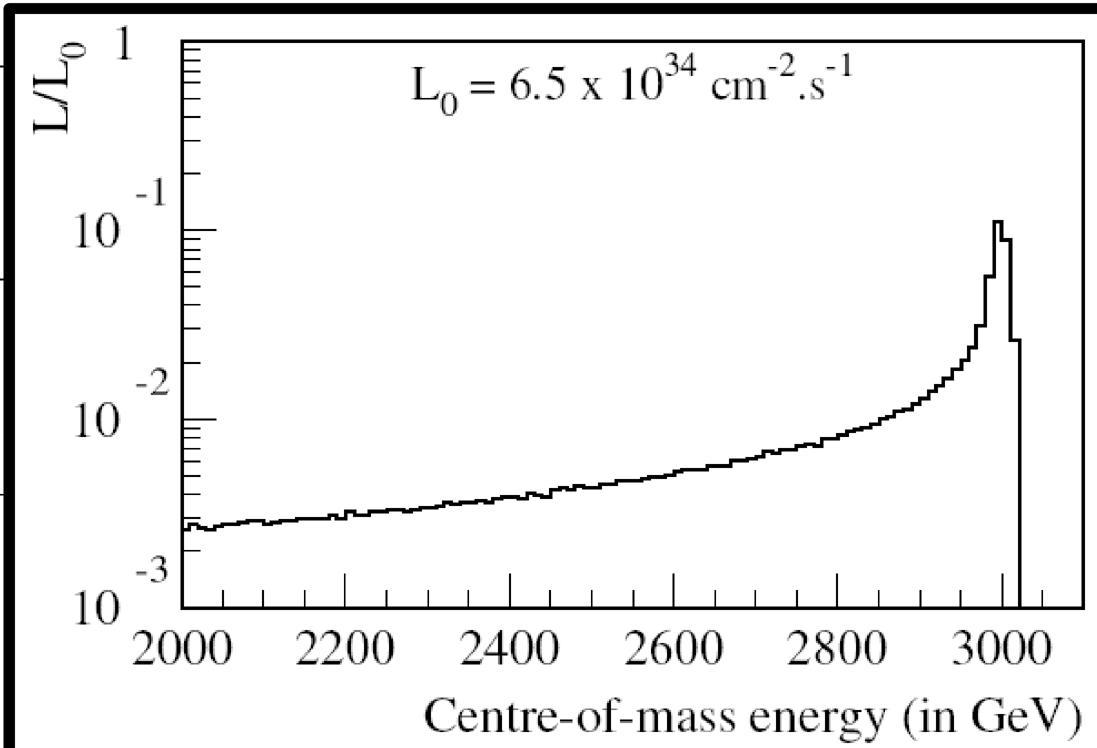

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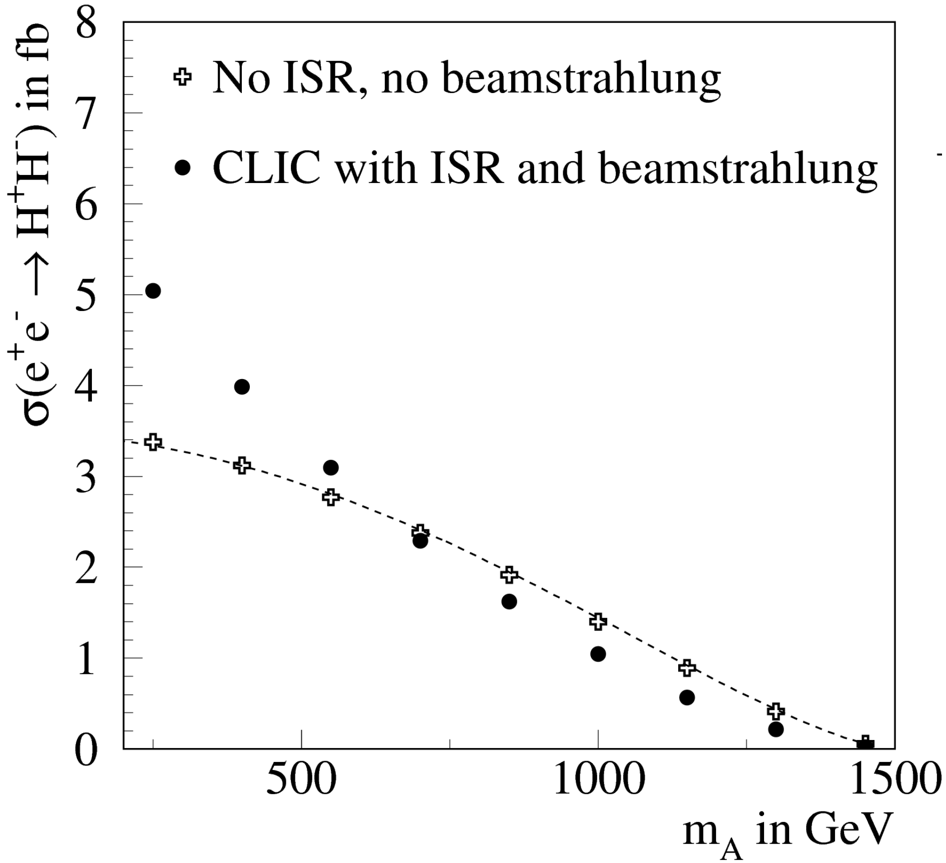
Production Cross-section

- Production cross-section affected by beam-beam effects



Codes & Tools

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- **HDECAY:** Charged Higgs boson decay widths and branching ratios calculation
- **PYTHIA 6.342:** Signal generation & fragmentations. Beamstrahlung, $\gamma\gamma \rightarrow$ hadrons included
- **MadGraph/MadEvent:** SM background generation. Beamstrahlung, $\gamma\gamma \rightarrow$ hadrons included with a custom routine
- **SIMDET:** Fast detector simulation and event reconstruction

$e^+e^- \rightarrow H^+H^- \rightarrow tbtb$

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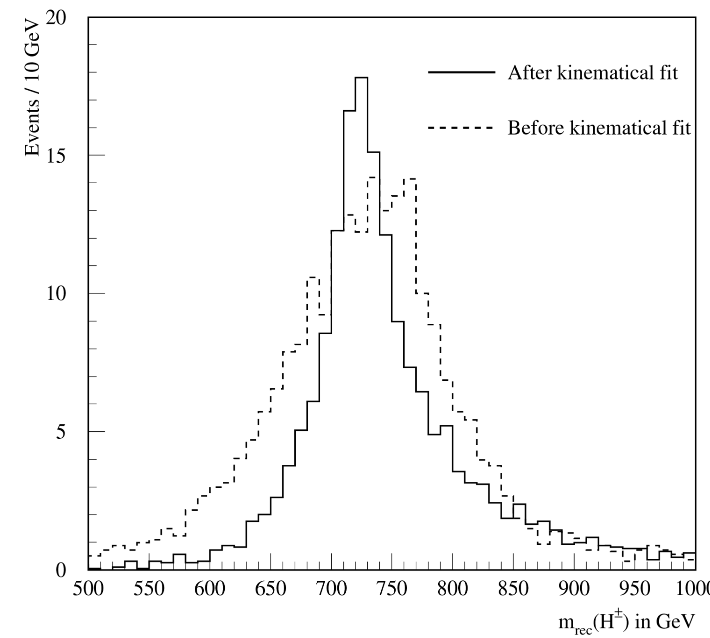
- Events with no isolated lepton, at least 8 jets, of which 4 b-jets
- Assignment of the non-b jets to 2 W bosons, reconstruction of top quarks and of the charged Higgs bosons
- Reduce SM $e^+e^- \rightarrow$ tbtb, bbbb, tttt background: Cuts on bb, tt and tb inv. mass
- Mass constrained kinematical fit: better reconstruction.



$e^+e^-\rightarrow H^+H^-\rightarrow tb\tau\nu$

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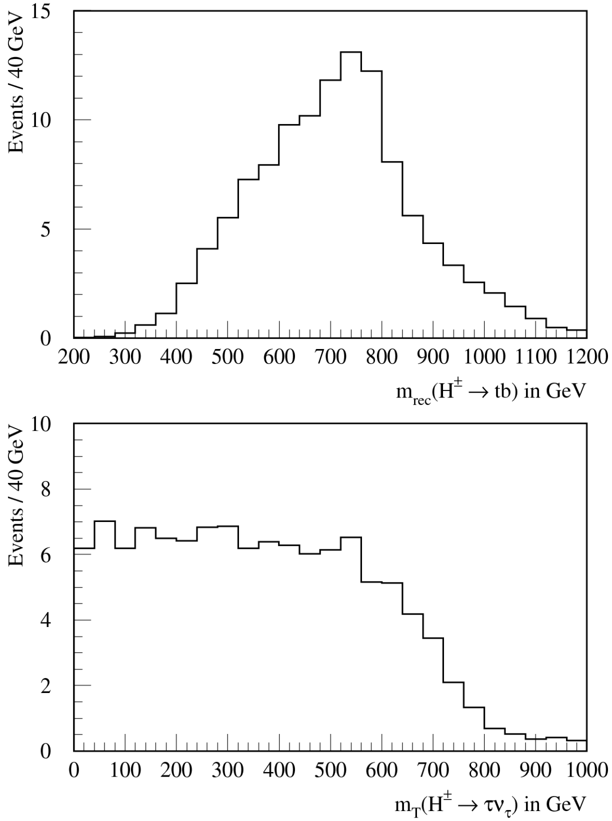
- Events with no isolated lepton, at least 5 jets, of which 2 b-jets and 1 τ-jet,
- Assignment of 2 non-b jets to a W boson, reconstruction of the top quark and of $H^+\rightarrow tb$,
- Transverse mass reconstruction for $H^-\rightarrow\tau\nu$
- Reduce SM background: Cuts on missing p_T, $H^\pm$ transverse mass and transverse angle between $H^\pm$ candidates



Discovery Potential

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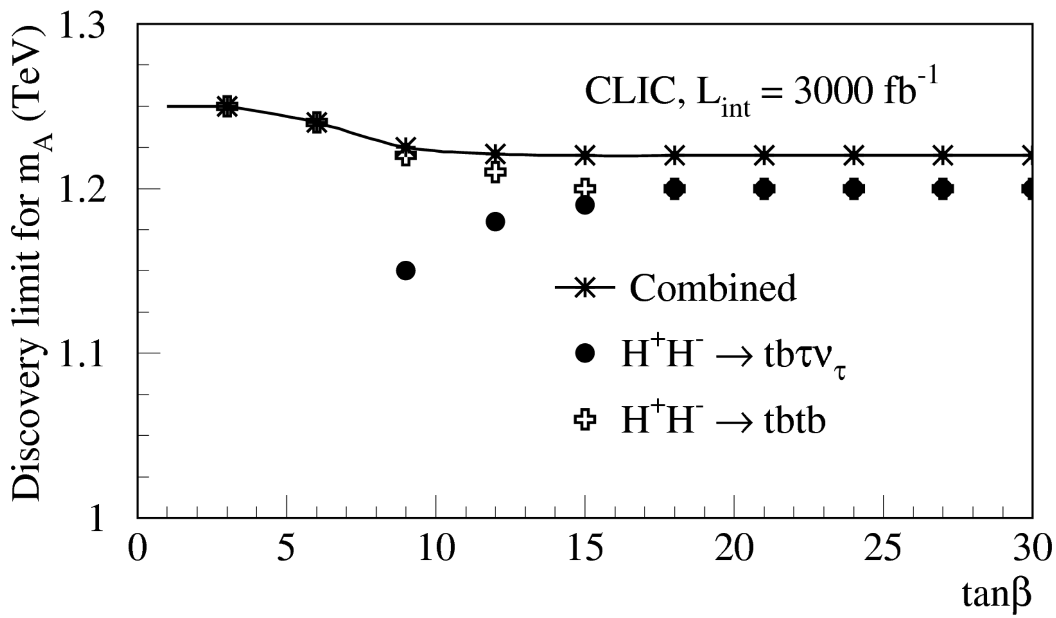
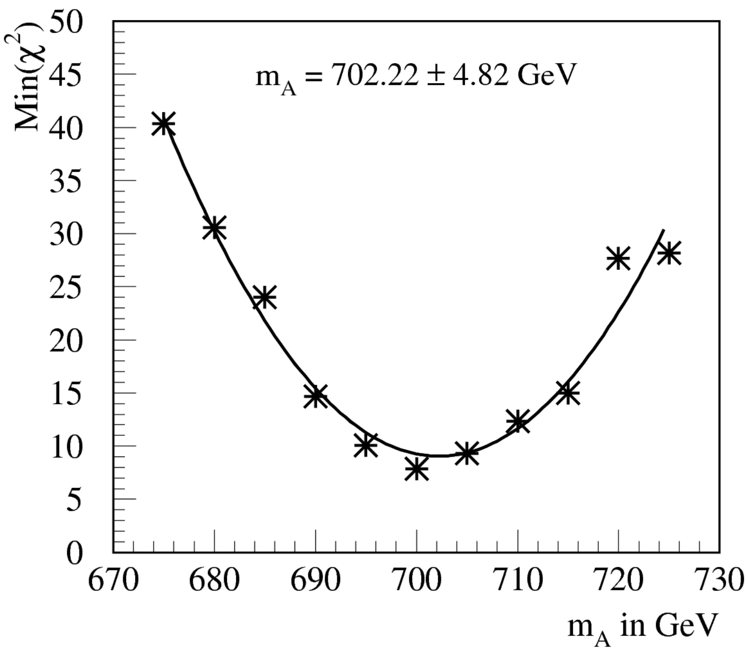
- For discovery, require $S/\sqrt{B}>5$ and $S\geq10$
  - No systematics included



- Discovery contour only slightly tanβ-dependent.
- Reaching masses above 1 TeV

Mass Measurement

- χ^2 fit on $H^+H^- \rightarrow$ tbtb (+ background) sample to determine $H^\pm$ mass (and thereby m_A)
- Obtained relative uncertainties for m_{H+} typically <1%



	m_A (GeV)	δm_A (GeV)
Small tan β	697.4	3.7
Large tan β	702.2	4.8

The real mass m_A is 700 GeV and $\mathcal{L} = 3000$ fb^{-1}

tanβ Determination

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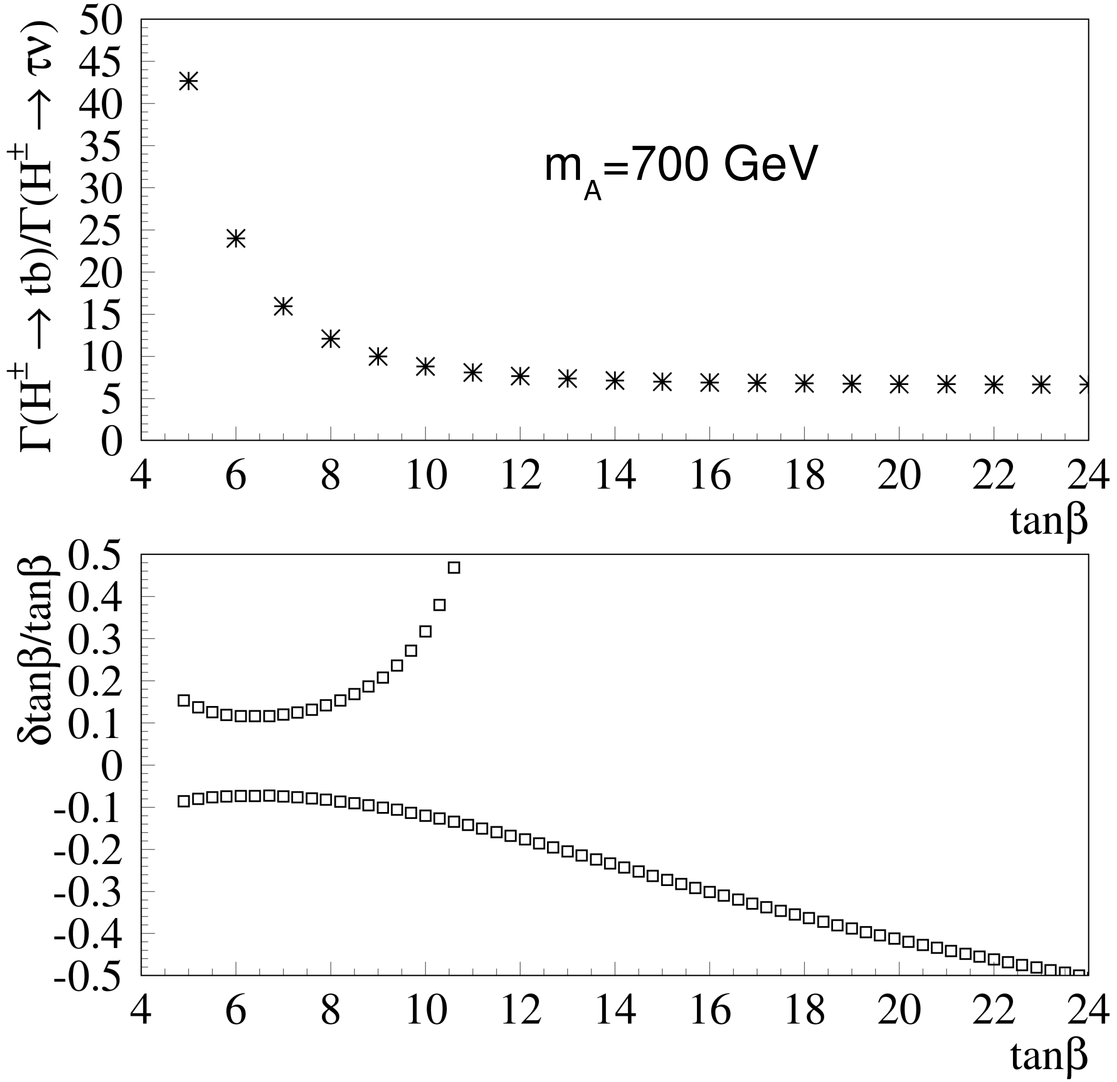
- Determine tanβ from ratio of signal rates for $H^+H^- \rightarrow tbtb$ and $H^+H^- \rightarrow tb\tau\nu$

$$\frac{\Gamma(H^\pm \to tb)}{\Gamma(H^\pm \to \tau\nu)} \simeq \frac{3\Delta_{QCD}}{m_\tau^2} \times \left[\bar{m}_t^2(m_{H^\pm})\cot^4\beta + \bar{m}_b^2(m_{H^\pm})\right]$$

$$R = \frac{N_{tbtb}}{N_{tb\tau\nu}} = \frac{\epsilon_{tbtb}}{2\epsilon_{tb\tau\nu}} \times \frac{\Gamma(H^\pm \to tb)}{\Gamma(H^\pm \to \tau\nu)}$$

- Calculate expected relative uncertainty in R

tanβ Determination



- Uncertainty is *smallest* in the tanβ = 5-10 region
  - Low tanβ: signal rate for $H^+H^- \to tb\tau\nu$ too small
  - High tanβ: ratio R constant

Summary

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- Simulation study of charged Higgs bosons for CLIC
- Sensitivity over the entire tanβ region and for masses up to 1 TeV
- Very accurate mass determination possible
- Possibility of determining tanβ in the "intermediate" region around 7

- For more details please see:

  E. Coniavitis & A. Ferrari, Phys. Rev. D75 (2007) 015004.

Backup Slides

CLIC

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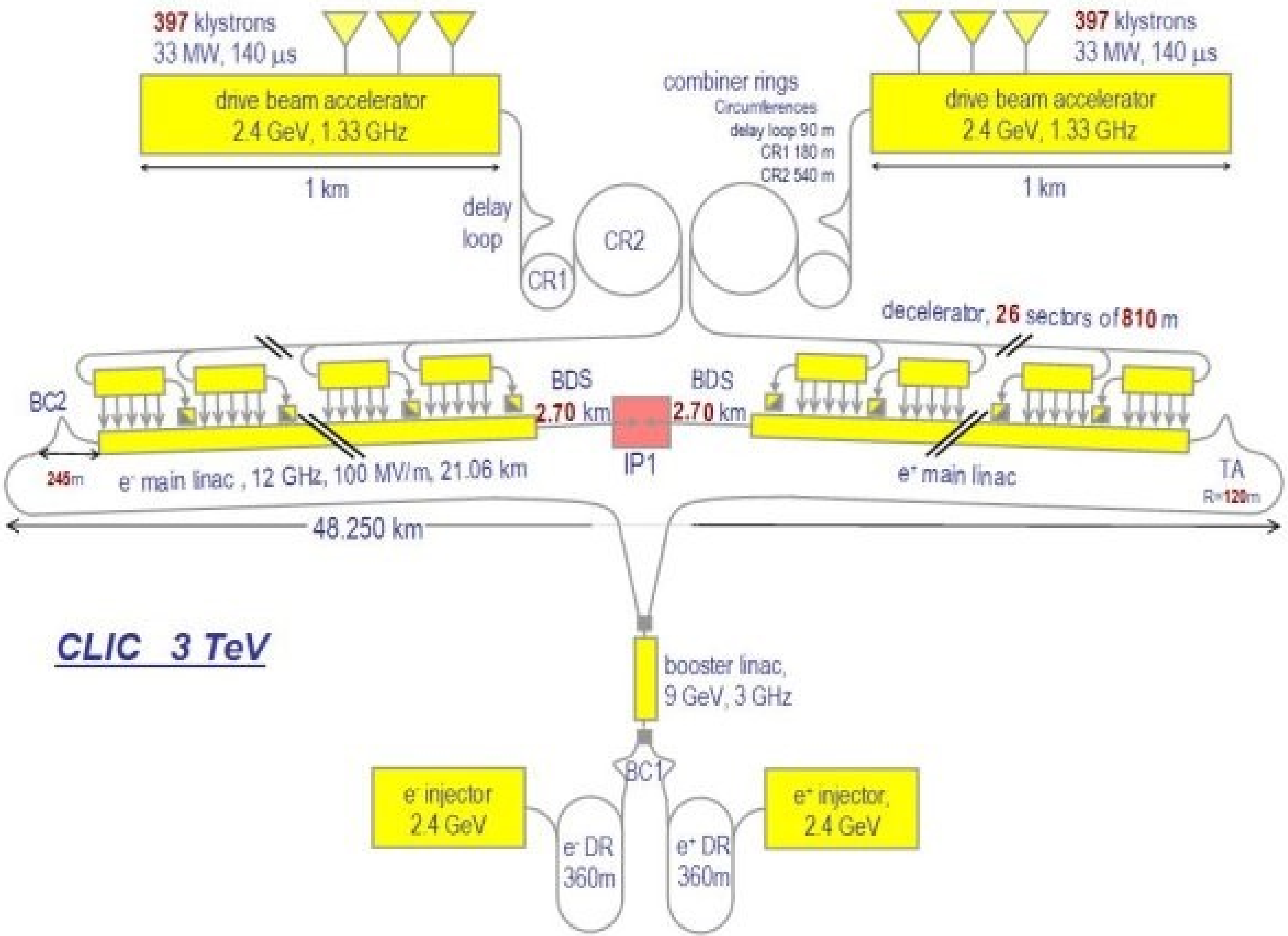

χ^2 Analysis

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- χ^2 fit on tbtb to determine H+ mass
- Compare a sample of *data* events to various large samples of *simulated* events, normalized to 3000fb^{-1}, using:

$$\chi^2 = \sum_i \frac{(N_r(i) - N_s(i))^2}{N_r(i)}$$

- For each mass, the number of *simulated* events is first adjusted to minimize χ^2. Then, Min(χ^2) is plotted as a function of the simulated mass parameter m_A, in order to find the value that maximizes the likelihood function.

Detailed cuts: tbtb

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- both *W* candidates must have a reconstructed mass between 50 and 150 GeV, and both *t* candidates must have a reconstructed mass between 100 and 300 GeV,
- the mass difference between the two (*tb*) systems must be smaller than 250 GeV,
- $m_{rec}(tt)$ and $m_{rec}(bb)$ must be smaller than 1 TeV,
- $\frac{1}{2}[m_{rec}(tt) + m_{rec}(bb)]$ must be larger than 1 TeV.

Detailed cuts: $tb\tau\nu$

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- the *W* candidate must have a reconstructed mass between 50 and 150 GeV, and the *t* candidate must have a reconstructed mass between 100 and 300 GeV,
- the missing transverse momentum must be larger than 400 GeV,
- the transverse mass m_T of the charged Higgs boson decaying into must be larger than 150 GeV,
- in the transverse plane, the angle between the two reconstructed charged Higgs bosons must be larger than 2.4 rad.