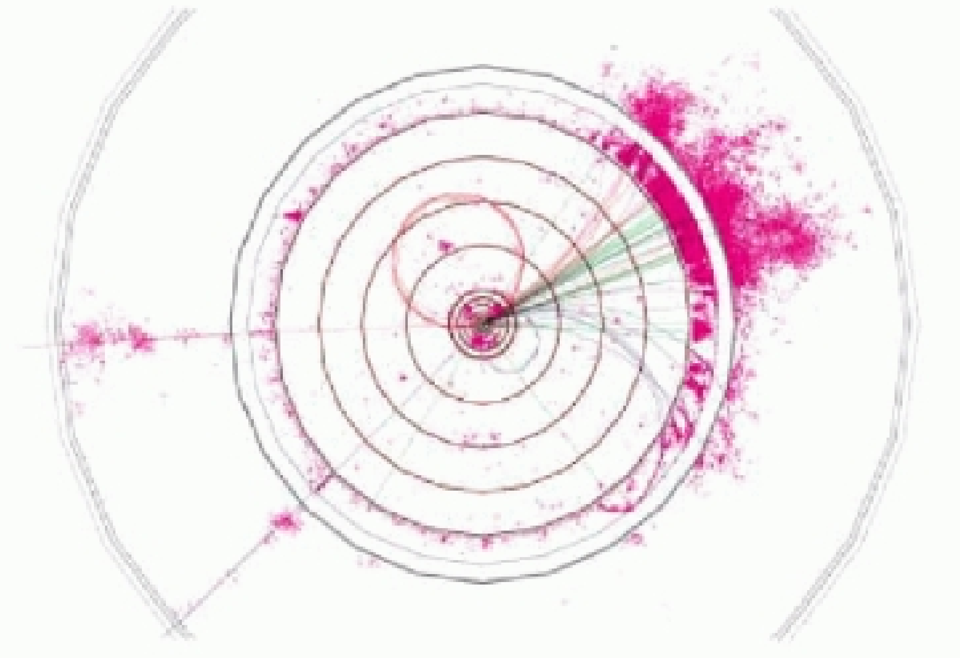
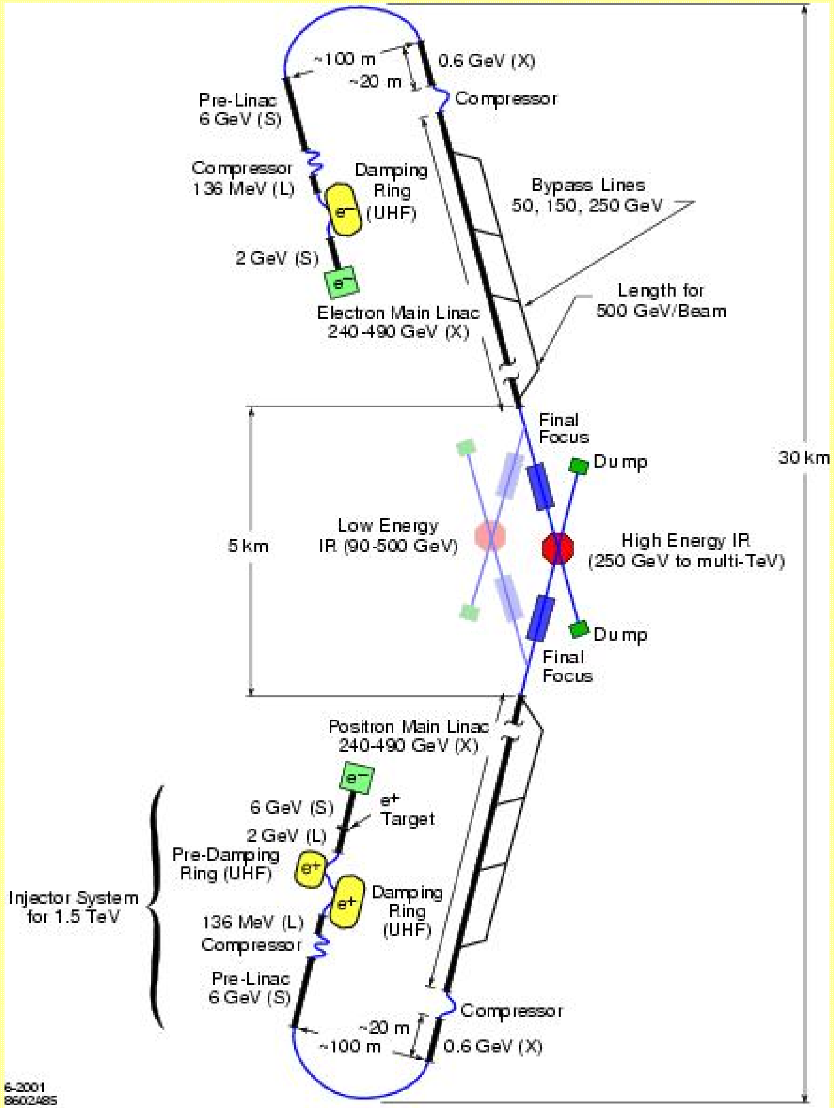
Detectors at the Linear Collider

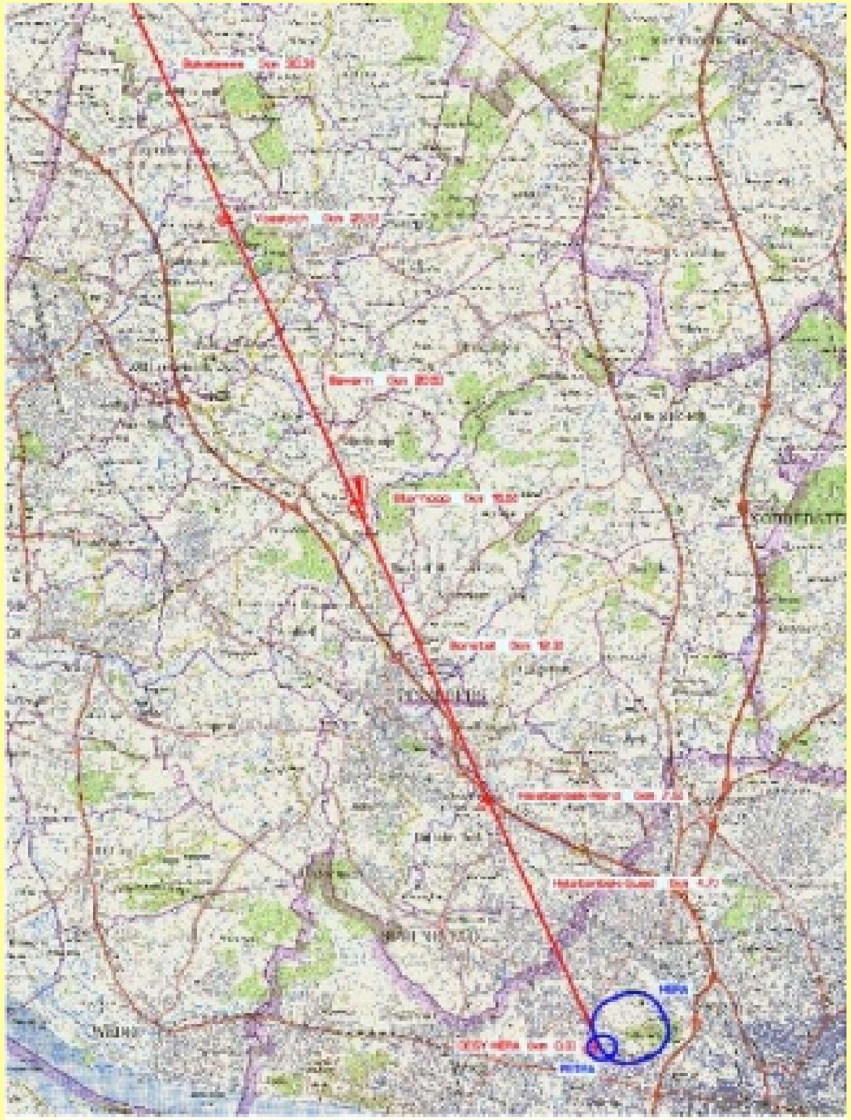


$e^+e^- \rightarrow ZH \rightarrow \mu\mu bb$ event

David Gerdes
University of Michigan
March 26, 2002

Linear Collider Overview



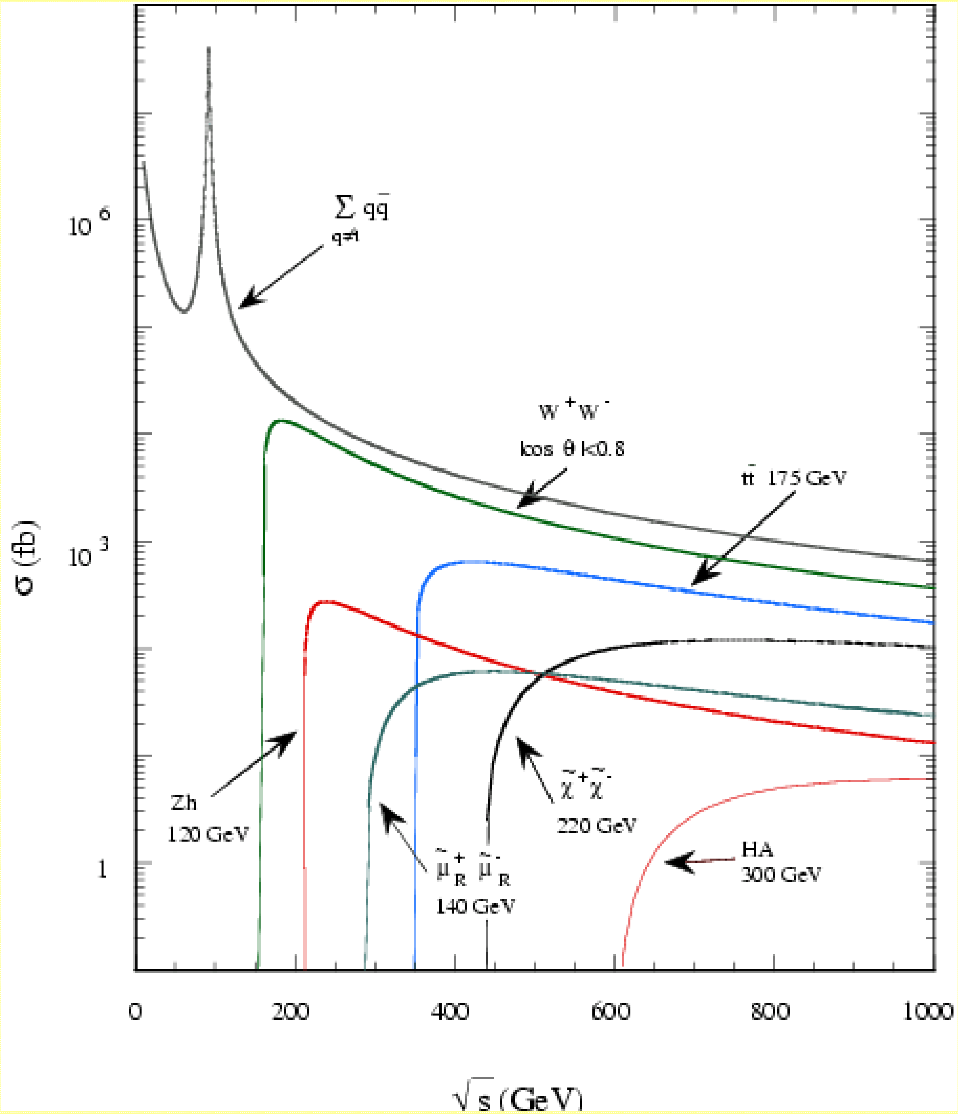


Machine Parameters

	TESLA(500)	TESLA(800)	NLC(500)	NLC(1000)	Tevatron
E (GeV)	500	800	500	1000	2000
Lum. x 1E33	31	5	20	34	0.1
Rep rate (Hz)	5	3	120	120	−−
Bunches/pulse	2820	4500	190	190	−−
Bunch sep (ns	337	189	1.4	1.4	396
σ(x) at i.p.	553 nm	391 nm	245 nm	190 nm	30 μm
σ(y) at i.p.	5 nm	2 nm	2.7 nm	2.1	30 μm
σ(z) at i.p.	0.4 mm	0.3 mm	110 nm	110 nm	30 cm
δB(%)	3.3	4.7	4.7	10.2	0
P(e−) (%)	80−90	80−90	80−90	80−90	−−
P(e+)(%)	60	60	−−	−−	−−

NB:Total cross section: ~5 pb (e^+e^-, 500 GeV)
~50 mb (p−pbar, 2 TeV)

e^+e^- Cross Sections

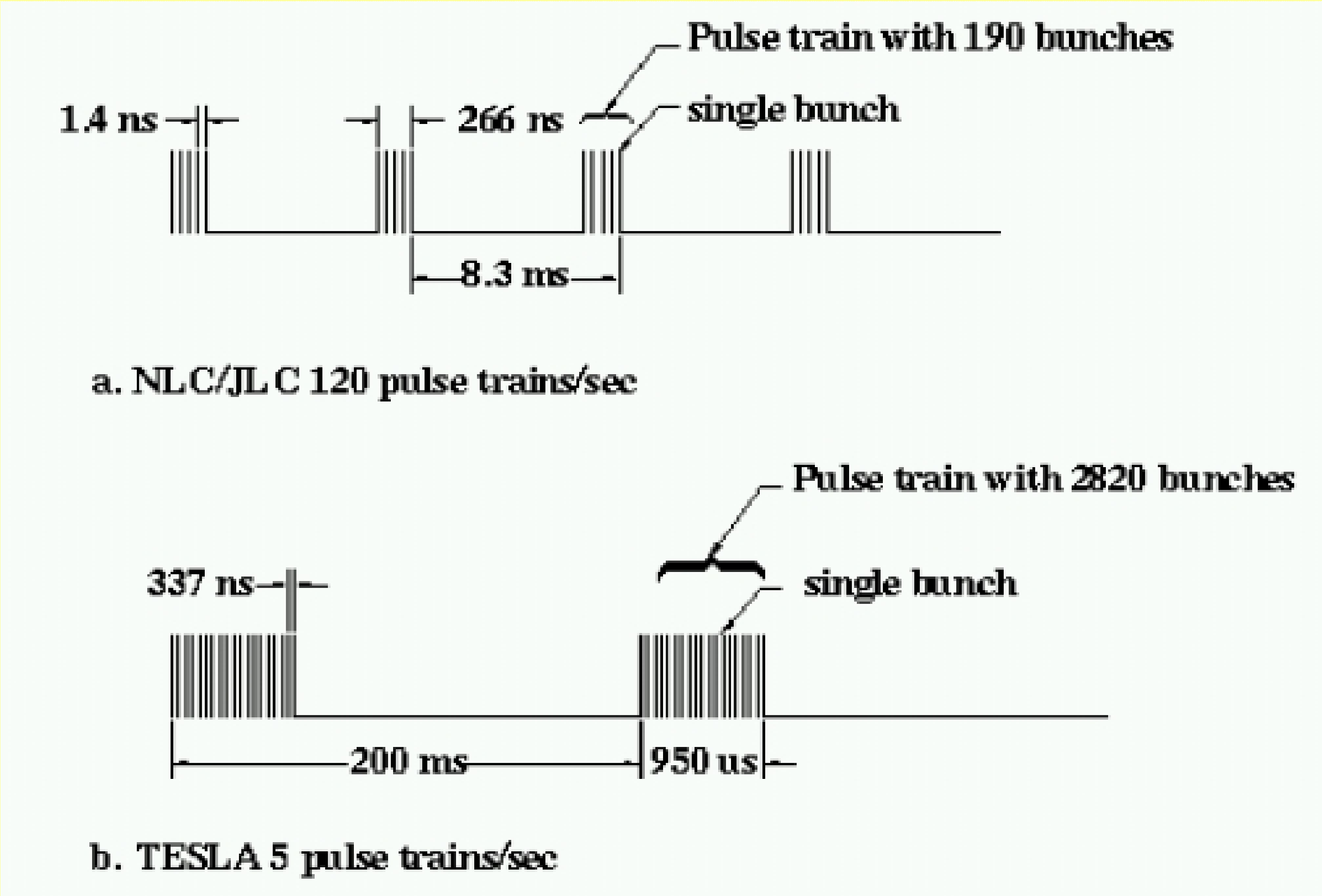


Objects with electroweak couplings are produced "democratically"

Bunch structure

NLC

TESLA



Low rates ⇒ Read out between crossings and "trigger" in software

The Challenge of LC detectors?

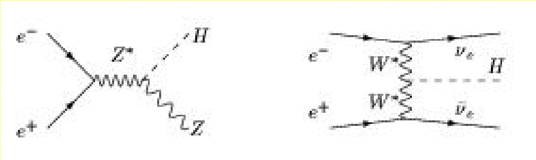
- Typical Tevatron experimentalist's view:
  - "It's trivial!"
  - "Just copy a LEP detector or SLD!"
- Sure, the issues of trigger/DAQ appear straightforward.
- But the challenge is to build a high−precision instrument capable of producing the "textbook data on the next energy scale" (M. Peskin)

Physics Unique to the LC

- Measurement of Higgs branching ratios, e.g. via $e^+e^- \to Zh$ followed by $Z \to ll$, $h \to X$
- Study of the top quark threshold, measurements of m_t, Γ_t, α_s, g_{tth}
- Precision SUSY spectroscopy
- ttH production; top−Higgs Yukawa coupling
- Trilinear Higgs coupling; reconstruction of the Higgs potential.

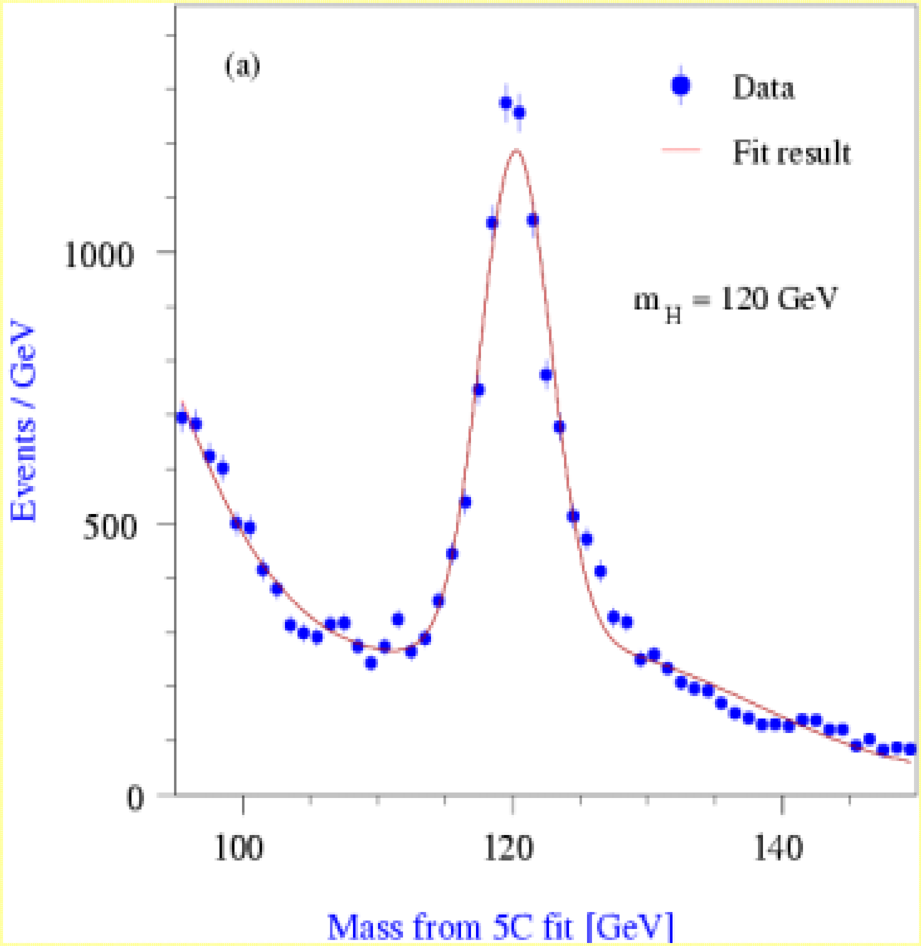
Higgs Reconstruction

- Current EWK fits favor a light Higgs, $m_h < 200$ GeV
- Produced at the LC in recoil off the Z



Detector requirement:

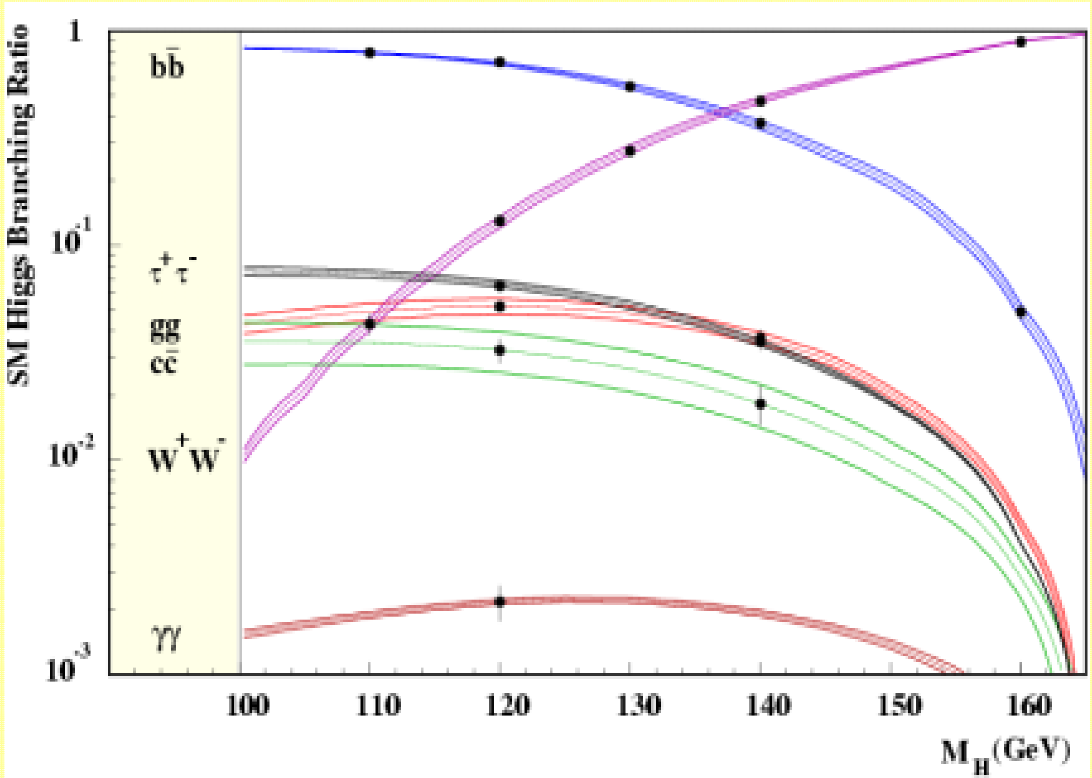
Excellent tracking resolution, $\sigma(1/p_T) \sim 5\times10^{-5}\ \mathrm{GeV}^{-1}$



Measurement of Higgs BR's

- Event selection is based on the Z, not the H, so the Higgs decays constitute an unbiased, inclusive sample.
- Key to determining that "the Higgs is the Higgs"−−or something else!

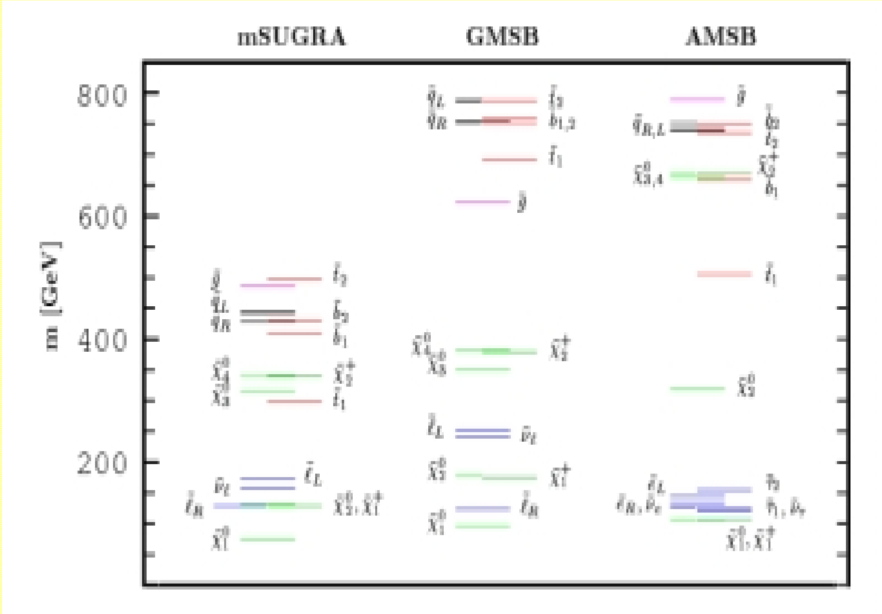
- Detector requirements: precision vertexing, flavor tagging.

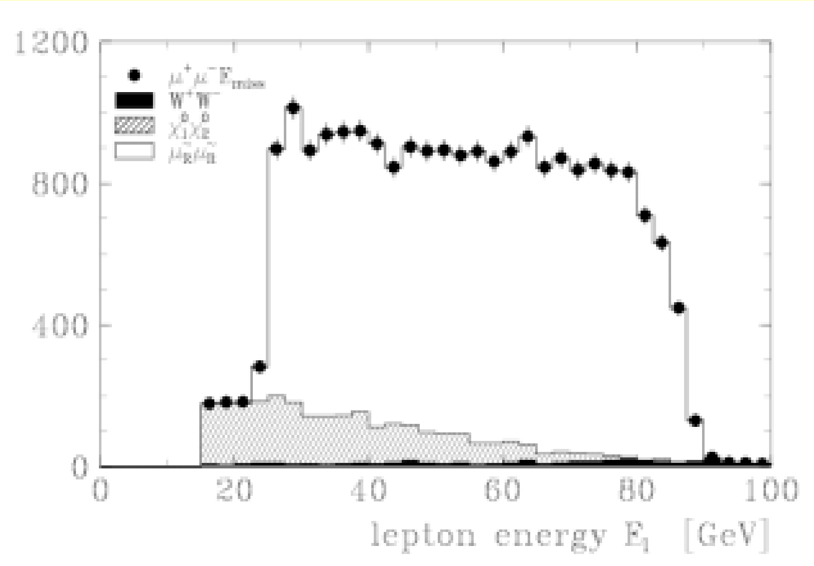


M. Battaglia

SUSY Spectroscopy

- Pattern of sparticle masses encodes info about SUSY−breaking.
- Example: endpoints of muon energy spectrum in $e^+e^- \to \mu_L\mu_L \to \mu^+\mu^-\chi_L^0\chi_L^0$



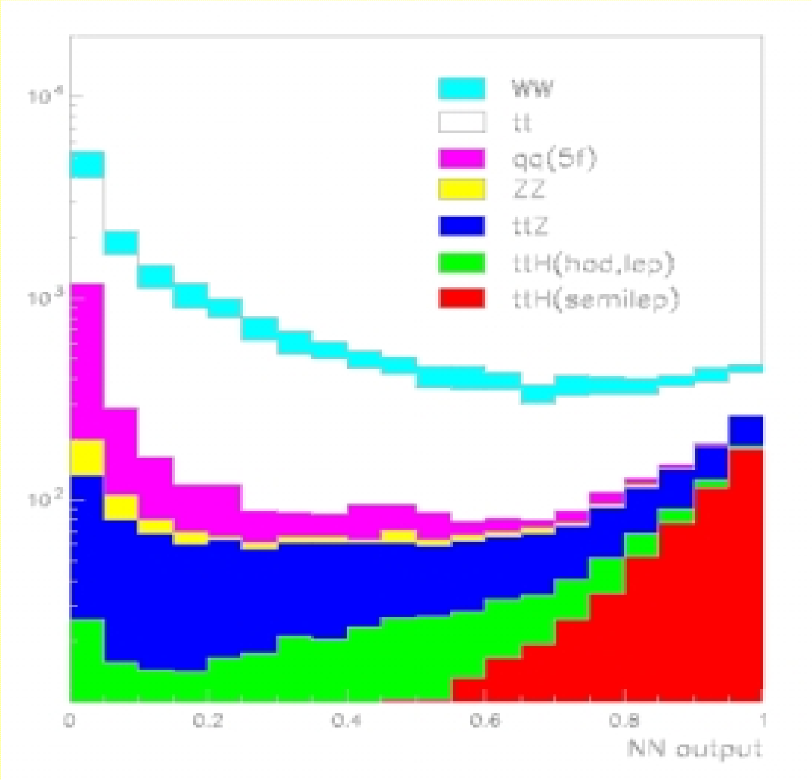


Detector requirements:
- Excellent resolution
- Hermeticity

Accelerator requirements:
- Ability to vary energy over wide dynamic range
- Adjustable beam polarization

ttH production and the Top Yukawa Coupling

- $e^+e^- \to ttH \to WbWb\ bb$
- Very complicted final state:
  - Up to 8 jets
  - 4 b's
  - Many kinematic constraints
- Tiny cross section (~2 fb), with backgrounds ~3 orders of magnitude higher.
- Detector requirements:
  - Excellent jet resolution
  - Flavor tagging



Juste, Merino: hep−ph/9910301

Note: tth cross section maximized at $\sqrt{s}$~800 GeV

Reconstructing the Higgs Potential

Physical basis of EWSB: nonzero minimum of the Higgs potential,

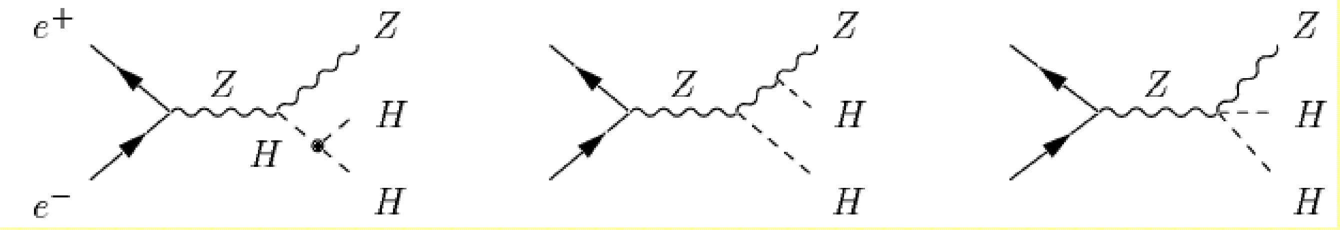
$$V = \lambda(|\phi|^2 - \frac{1}{2}v^2)^2$$
$$\rightarrow \lambda v^2 H^2 + \lambda v H^3 + \frac{1}{4}\lambda H^4,$$

where v=246 GeV.

- Measure coefficient of the quadratic term by measuring the mass,

$$M_h^2 = 2\lambda v^2$$

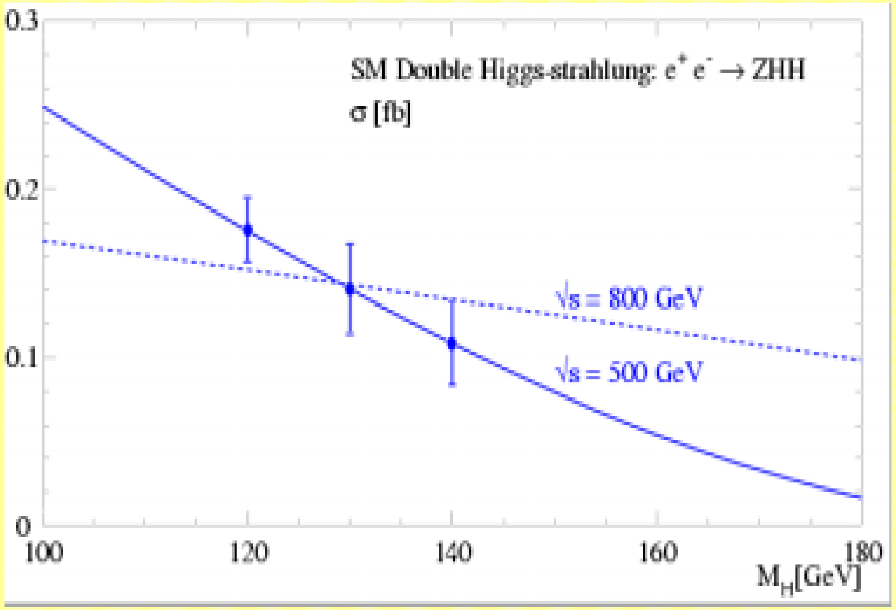
- Measure the trilinear self−coupling via Higgs pair production, $e^+e^- \rightarrow ZHH$



Reconstructing the Higgs Potential

Striking final state: 4 b jets, plus dileptons, jets, or missing energy from the Z decay.
But: Tiny cross section (~0.2 fb), huge 4−, 6−fermion backgrounds make this among the most challenging processes to study at the LC.

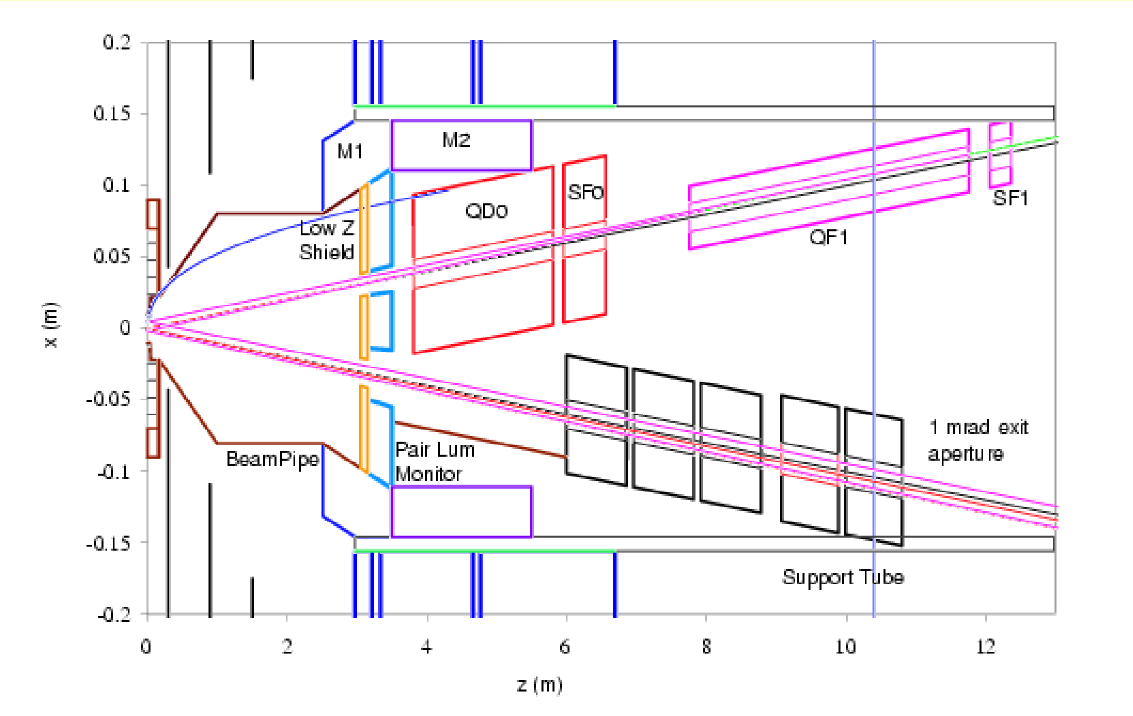
Sensitivity with 1 ab^{-1}:



Detector requirements:
- Excellent jet resolution
- Flavor tagging

Accelerator requirements:
- Lots and lots of luminosity

The Interaction Region: Where the Rubber Meets the Road

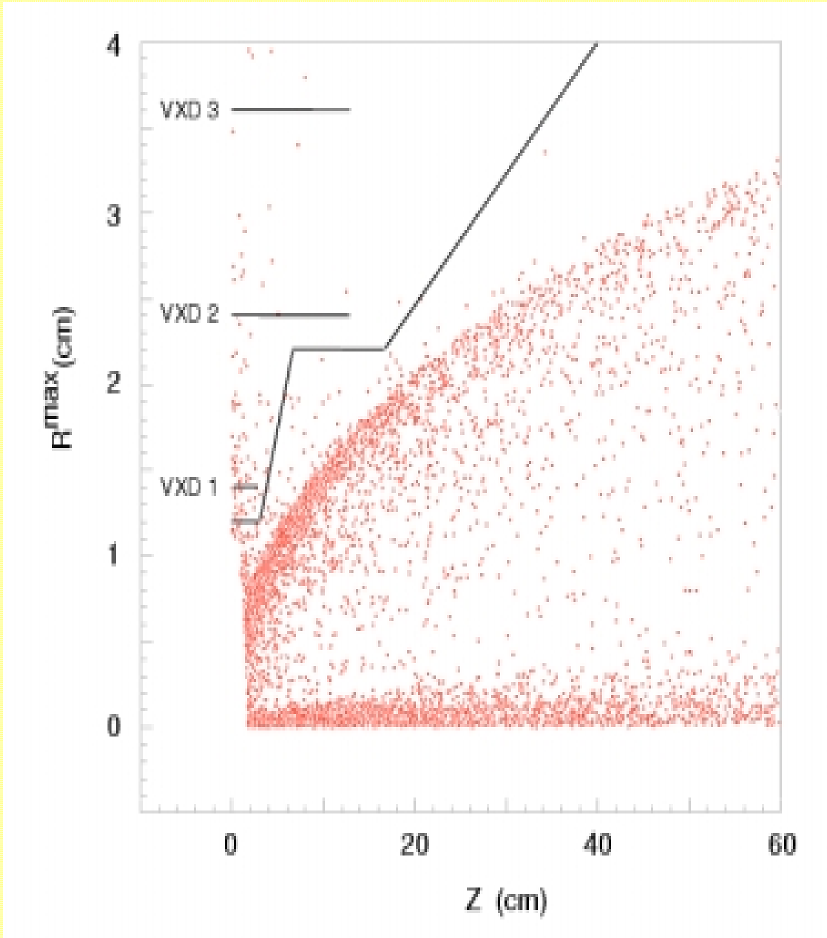


Beams collide at a 20 mrad crossing angle to avoid parasitic collisions.

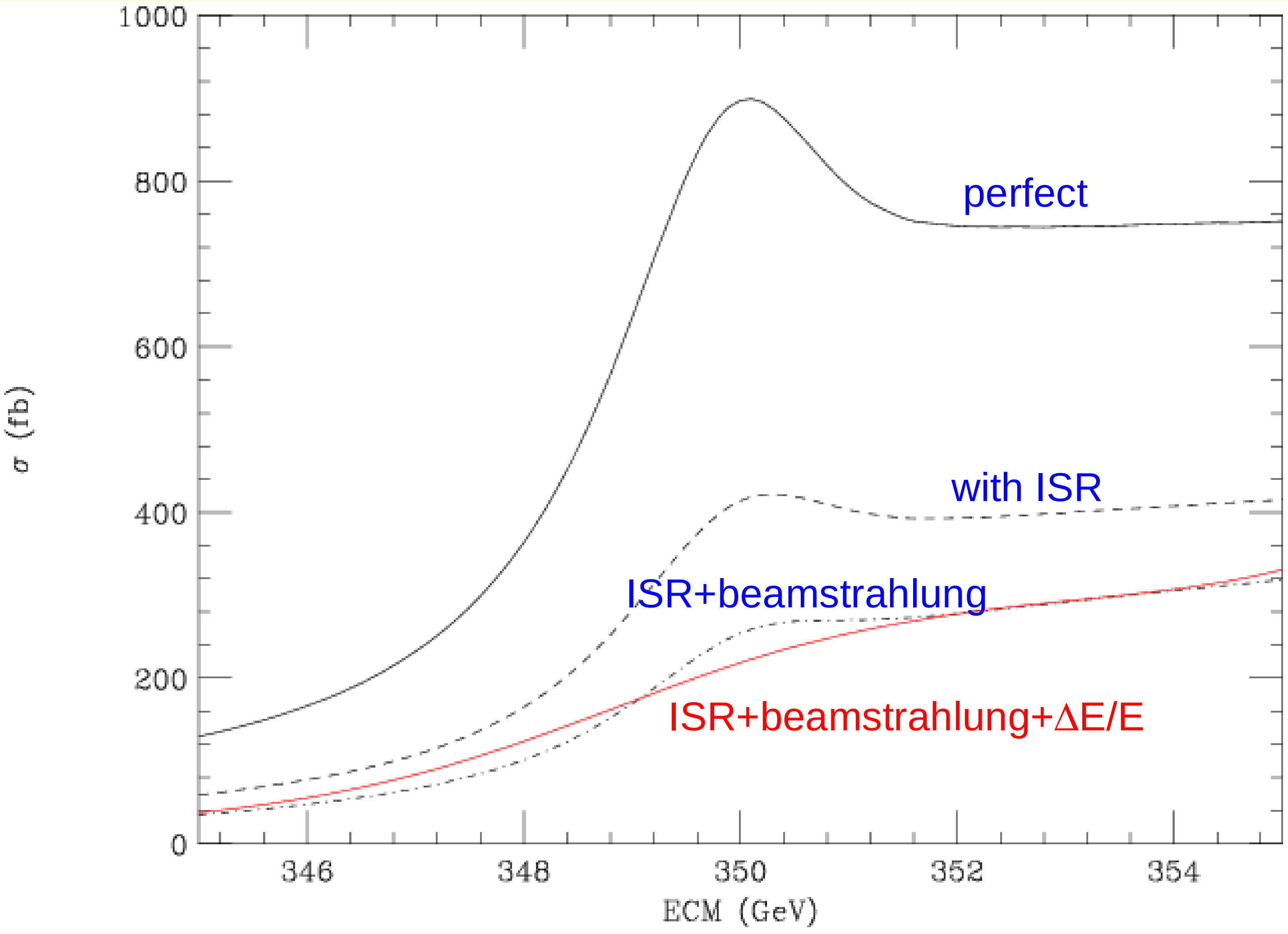
Leads to effects from the solenoidal field of the detector → compensate by offsetting the final quadrupole (QD0)

Beam−Beam Interactions

- Beamstrahlung: radiation of photons from one beam due to the field of the other beam
  - Leads to energy spread
- Production of e^+e^- pairs
  - About 10^5 per bunch, mean energy 13 GeV (~few W of power)
  - Most go into "dead cone" shown at right.
  - Drives B−field magnitude
- Other backgrounds: hadrons from $\gamma\gamma$ interactions; neutrons, muons.
- R&D question: time−stamp calorimeter and track info?



Machine Effects on Top Threshold Lineshape



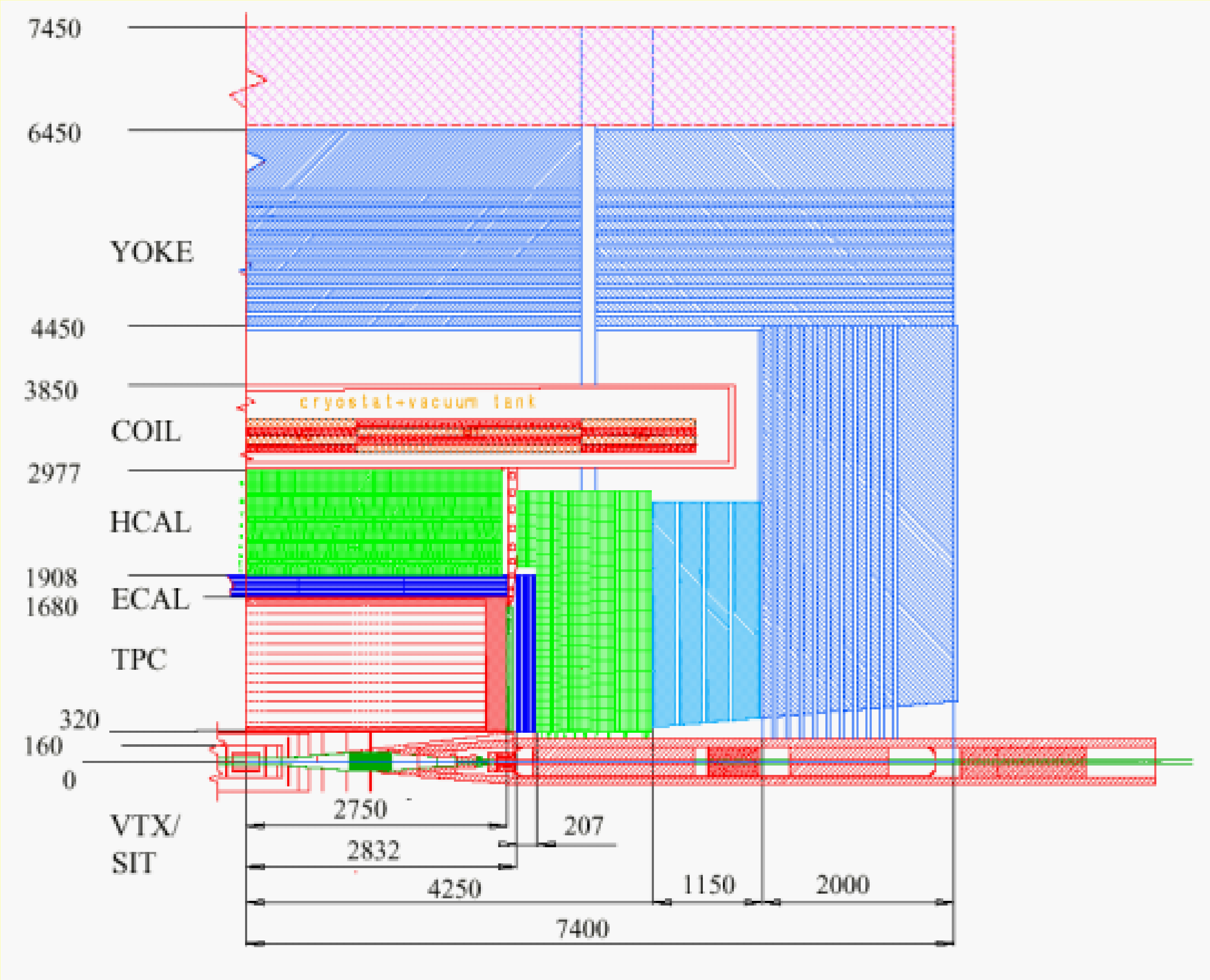
So to sum up the detector challenges, we need:

• Excellent hermeticity	multijet final states, forward−peaked cross sections
• Excellent calorimetry	W/Z separation
• Excellent tracking resolution	Precision mass measurements
• Excellent flavor−tagging	b/c/τ identification

•As opposed to a Tevatron or LHC detector where major design drivers include:

- Ability to handle very high rates
- Radiation tolerance

TESLA Detector



LC−LHC Detector Comparisons

	CMS	ATLAS	TESLA design
Tracker thickness (X0)	30%	28%	5%
Vertex layer thickness	1.7%	1.7%	0.06%
Vertex channel count (Mpixels)	39	100	800
ECAL granularity (det. elements)	76,000	120,000	32,000,000

- 6x less material for photon conversions
- Vertex detector 3−6x closer to interaction point
- 35x smaller vertex detector pixel size
- 30x thinner vertex detector layers
- >200x higher ECAL granularity *(expensive)*

"A Ferarri, as opposed to a state−of−the art Abrams battle tank." (C. Damerell)

North American "Large" Detector