

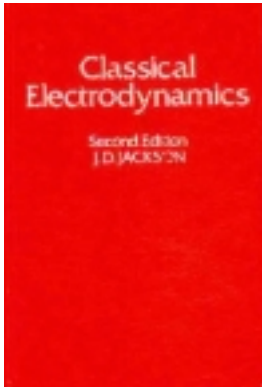
Physics Needs for Future Accelerators

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Physics needs for *building* future accelerators



- There is plenty of interesting physics involved in the technical challenges of building future accelerators.
- Are we attracting, training, supporting, and encouraging the next generation of accelerator physicists?

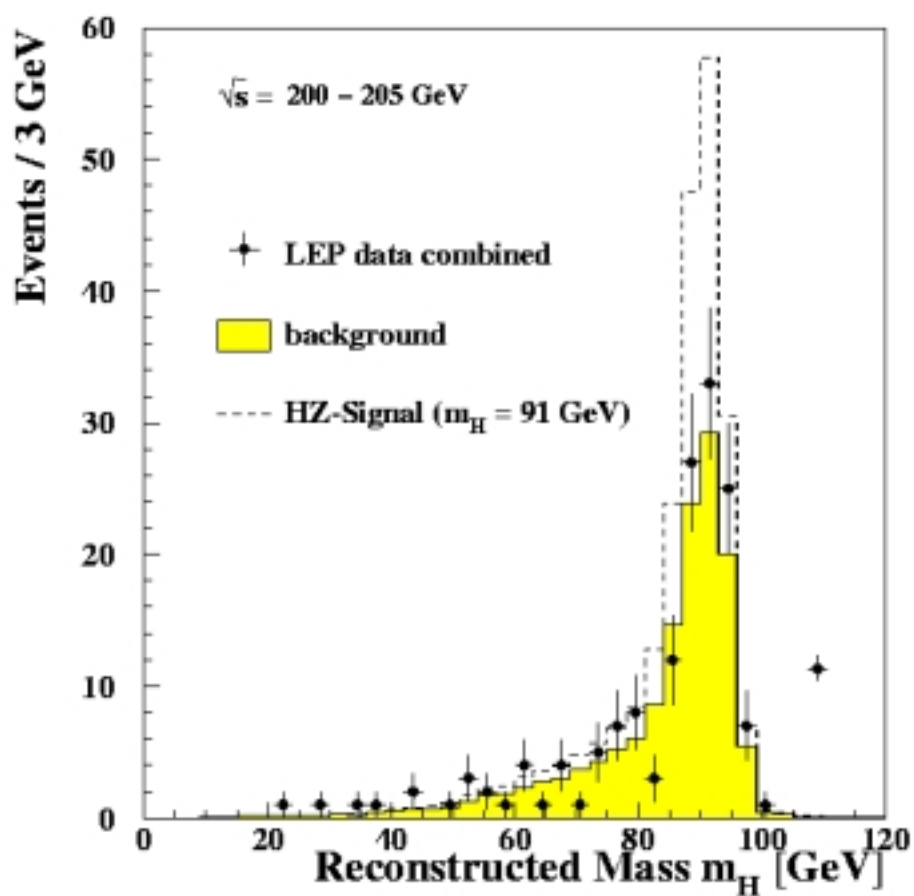


[J. D. Jackson at Fermilab examines the prototype for the VLHC dipoles.]



Physics needs for *funding* future accelerators

A transparency from LP 01:



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Crimes and misapprehensions

- Among the many crimes of the bourgeois overlords of HEP and their running dog lackeys...

... is to have allowed the misapprehension among students (and the public) that Particle Physics is almost “done”.

- This criminal behavior has two main forms:



Organized Religion

- The notion that **string theory** is the one true **Theory of Everything**, that people who are **a lot smarter than you** will have it figured out any day now, and by using mathematical consistency alone will compute the electron mass.
- **HEP is irrelevant.**



Feudalism

- The **Standard Model is king** and will reign forever. You missed out on most of the important discoveries and must content yourself with the few remaining scraps. We will find a SM Higgs but nothing else.
- **HEP is moribund.**



Trotsky was right

- In fact, high energy physics is exciting and will remain exciting precisely because it exists in a state of **Permanent Revolution**.
- As we have probed higher energies/smaller distances, our fundamental view of the physical world and how to describe it has changed dramatically.
- There is no reason to imagine that we are near the end of this process, barring the collapse of our civilization.



“Revolution whose every successive stage is rooted in the preceding one and which can end only in complete liquidation.”



Physics *questions* for future accelerators

- The Standard Model is **an effective theory** for physics below some high energy cutoff Λ . What is the value of Λ ?
- What are the relevant degrees of freedom for **the new effective theory** at energies above Λ ?
- What are the **symmetries** of this new effective theory?
- What symmetries and organizing principles of the Standard Model turn out to be **artifacts of the “low energy” approximation?**
- Do the symmetries and organizing principles of the new effective theory **explain parameters/hierarchies of the SM**, e.g. the flavor problem?
- Does the new effective theory give any hints (e.g. spontaneously broken symmetries) of **physics at even higher scales?**



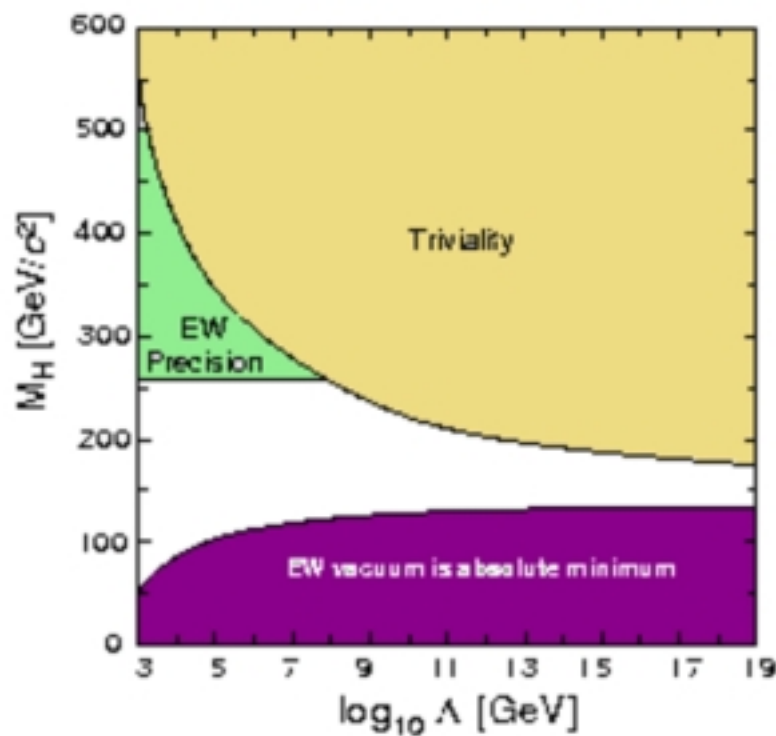
How do we determine Λ for the Standard Model?

- Look for new degrees of freedom:
 - new particles, resonances, solitons.
 - evidence of compositeness, symmetry restoration, symmetry breaking.
 - new spatial dimensions.
- Look for evidence of higher order terms in \mathcal{L}_{eff} , e.g. 4-fermion couplings. Note that symmetries and approximate symmetries of the SM **may not** be respected by the full effective action. Look for FCNC, CP violation, $\mu \rightarrow e \gamma$, proton decay, etc. etc..



- Look at the Higgs sector, which is **more sensitive** to Λ for several reasons:

- **The hierarchy problem:** because of radiative corrections, the Higgs mass is naturally of order Λ .
- If the Higgs mass is large, it becomes strongly coupled at some scale Λ .
- If the Higgs mass is small, it's effective potential becomes unstable at some scale Λ .



-C. Quigg, hep-ph/9905369



What is our best guess for Λ ?

500 GeV to 1 TeV

- Large enough to explain decoupling of the new physics in most processes. There are important exceptions (proton decay, FCNC, W' , Z' , etc.).
- The hierarchy problem wants Λ to be close to the electroweak scale.



What could be out there?

- Most theoretical speculation about the new effective theory at high energies involves **ADDING** things to the Standard Model:
 - **add particles** (e.g. 4th generation, superpartners, messenger sector)
 - **add symmetries** (e.g. supersymmetry)
 - **add gauge interactions** (e.g. technicolor, Z')



Sacred Cows

- However it is just as likely that at higher energy scales we have much more radical changes:
 - qualitatively new degrees of freedom (e.g. strings, membranes, extra dimensions)
 - symmetries are broken (e.g. B and L violation)
 - sacred principles are violated!

This would not be the first time that sacred cows got ground into hamburger.



History Lessons

- Newtonian mechanics \Leftrightarrow electromagnetism \rightarrow special relativity

Lesson: Galilean invariance is only an approximation, good at low speeds.

- Thermodynamics \Leftrightarrow electromagnetism \rightarrow quantum mechanics

Lesson: Rayleigh's formula for blackbody emittance is only an approximation, good at low frequencies.

- Newtonian gravity \Leftrightarrow special relativity \rightarrow general relativity

Lesson: Newtonian gravity is only an approximation, good for weak gravitational fields and low speeds.



Big Unknowns

- Determine the energy scale and conditions for which the following theoretical assumptions break down:
 - The fundamental dynamical entities are point-like particles.
 - Relativistic quantum field theory (locality, microcausality, CPT).
 - General relativity.
 - Quantum mechanics.

Werner Heisenberg, 1939: quantum mechanics probably breaks down at an energy scale around 1 GeV.



String theory

- Although string theory has not (yet) done a good job of matching to the SM at low energies, it has proven to be a great exercise for liberating our thinking.
- If string theory is correct, both general relativity and quantum field theory break down at some energy scale M_s . We don't know what this string scale is!
- If string theory is correct, the fundamental physical entities are not quarks and leptons, but perhaps a whole collection of particle-like, string-like, and membrane-like objects.
- Furthermore these objects propagate in a 10+1 dimensional spacetime.



“Model-independent” Conclusions

- There is a whole new effective theory waiting to be explored at the TeV scale.
- The new physics will be rich, surprising, confusing, and take a long time to untangle.
- For exploration you will want high energies, reasonable luminosities, and reasonable detectors.
- For detailed studies, you need excellent luminosities and excellent detectors.
- You will need detailed studies not only to unravel the new effective theory, but also to give you hints about physics at even higher scales.



Future Accelerators

My opinion of what we might have and when:

- **2006 – 2012:**
 - **LHC:** $\sqrt{s}=14$ TeV, $\mathcal{L}=10^{33}\text{-}10^{34}$.
 - **LC:** $\sqrt{s}=350$ GeV to 1 TeV, $\mathcal{L}=10^{34}$ ish.
 - **ν factory:** 1 millimole of 40 GeV muons/year.
- **2013 – 2025:** Within Energy Frontier:
 - **stretch LC:** $\sqrt{s}=1.5$ TeV.
 - **$\gamma\gamma, e^-e^-$:** piggyback on LC.
 - **First Muon Collider:** Higgs factory? Heavy Higgs factory?
- **2013 – 2025:** Extending Energy Frontier:
 - **upgraded LHC?:** $\sqrt{s}=?$.
 - **CLIC:** $\sqrt{s}=3 - 5$ TeV, $\mathcal{L}=10^{35}$.
 - **High Energy Muon Collider:** $\sqrt{s}=3 - 4$ TeV, potential for 10 TeV if you can overcome Death by Neutrinos.
 - **VLHC:** $\sqrt{s}=100 - 200$ TeV, $\mathcal{L}=10^{35}$.



What is the Physics driving the LHC?

(You are supposed to know this already!)



What is the Physics driving the LC?

My opinion:

- Higgs physics is golden.
- The LHC won't be sufficient to unravel the new physics at the TeV scale.
- The LC has unique capabilities to divine new physics at even higher scales.



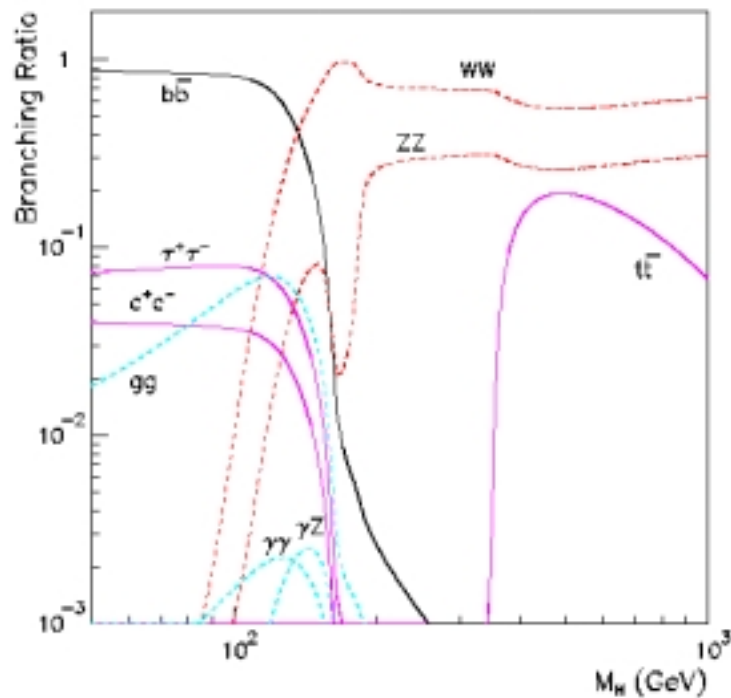
Higgs physics is golden

- Precision measurements \rightarrow either the Higgs is light, or new physics is misleading us!
- A discovery of a $b\bar{b}$ invariant mass bump will be only the beginning of understanding the Higgs.
- Is this the Higgs of electroweak symmetry breaking?
- Is this the Higgs associated with the generation of fermion masses?
- Is this the only Higgs?



- We need precise measurements of all the Higgs branching fractions.

SM Higgs



- The LHC can do part of this job, but we will need an LC (with good detectors) to do the rest. **350 - 500 GeV should be good enough.** Look for $t\bar{t}H$ at higher energies.
- Higgs physics will be interesting for a long time! ($\gamma\gamma$ option, s-channel Higgs factory).



The LHC won't be sufficient to unravel
the new physics at the TeV scale.

- The LHC can do a lot, including precision measurements.
- But the new physics at the TeV scale will be both rich and confusing.
- LC offers different sensitivities, polarization, reduced backgrounds, better contained events, more precise measurements.

Examples:

- Untangling the neutralino and slepton sectors in SUSY. What kind of SUSY is it?
- Deciphering virtual effects of extra dimensions. Is your Drell-Yan anomaly due to spin 2 Kaluza-Klein graviton exchange?



LC precision measurements can pin down new physics scales

- Detailed study for Gauge Mediation at 500 GeV LC.

–Ambrosanio and Blair, hep-ph/9905403

- Case of neutralino NLSP, $\tilde{\chi}_1^0 \rightarrow \gamma G$.
- Measure $c\tau$ of $\tilde{\chi}_1^0$ in the range 10 microns to 30 meters, using various techniques:
 - Projective tracking
 - 3D tracking
 - Photon pointing
 - Calorimeter timing
 - Statistical (counting single γ versus 2 γ)
- $c\tau$ has only log sensitivity to the messenger scale, but is proportional to the SUSY breaking scale \sqrt{F} :

$$c\tau_{\tilde{\chi}_1^0} \sim \frac{F^2}{M_{\tilde{\chi}_1^0}^5}$$

- **Conclusion:** with an appropriate detector and 200 fb^{-1} , measure \sqrt{F} to $\pm 5\%$.

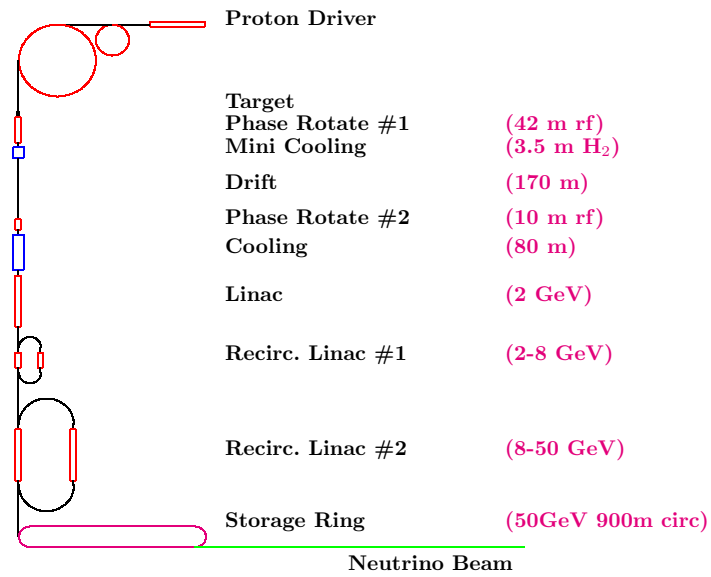


Why a Neutrino Factory?

- Neutrino oscillations are a strong hint at **new physics** associated with scales in the 10^{10} - 10^{16} GeV, or of brane-bulk physics in the case of extra dimensions.
- **How do we link this new physics to anything else?**
- We need precise and overconstrained measurements of the lepton mass matrix, just as we are now achieving for CKM!
- **Flavor problems are hard!**



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- μ charge, momentum, polarization determine ν composition, spectrum.
- Many long baseline possibilities \rightarrow truly international collaborations!
- Detector challenges: indentify e , μ , τ and measure charges.
- 1 neutrino factory \sim 3 B factories?
- A practical path to a muon collider?



Pushing the energy frontier

- If you want a new energy frontier collider in 2020, you had better be doing serious R& D now.
- BUT, we don't yet know how to estimate the next interesting energy scale.
- Will a 3-4 TeV lepton collider or an LHC upgrade be good enough, or do we need to push to a 10 TeV muon collider or 100-200 TeV VLHC?
- LHC/LC data is probably essential for making good decisions. E.g. if LHC/LC data indicate an effective Planck scale of 3 TeV, then hard scatterings may produce mostly black holes! This affects your choices for \sqrt{s} , luminosity, and detector design!



Outlook

It is much more likely that we will fail to
build new accelerators than that these
accelerators will fail to find interesting
physics!

