ICHEP2010 **ILCW2010**

21-28 VII 2010, Paris 18-22 X 2010, CERN

Higgs: New results

Maria Krawczyk
IFT

Seminarium Fizyki Wielkich Energii 19.XI.2010

ICHEP2010 Palais de Congres, Paris

1088 participants

plenary

6 parallel sessions

169 talks

132 posters

Sessions

01 - Early Experience and Results from LHC
02 - The Standard Model and Electroweak Symmetry Breaking
03 - Perturbative QCD, Jets and Diffractive Physics
04 - Hadronic Structure, Parton Distributions, soft QCD, Spectroscopy
05 - Heavy Quarks Properties (experiment and theory)
06 - CP violation, CKM and Rare Decays
07 - Neutrinos
08 - Heavy Ion Collisions and Soft Physics at Hadron Colliders
09 - Progress in Lattice Techniques and New Results
10 - Beyond the Standard Model (theory and experimental searches)
11 - Particle Astrophysics and Cosmology
12 - Beyond Quantum Field Theory Approaches (including String Theories)
13 - Advances in Instrumentation and Computing for HEP
14 - Future Machines and Projects

Highlights

LHC- first results

Tevatron – constraining the Higgs

M. le Président de la République Nicolas SARKOZY

La Nuit des Particules

http://www.ichep2010.fr/nuitdesparticules.html

N. SARKOZY..

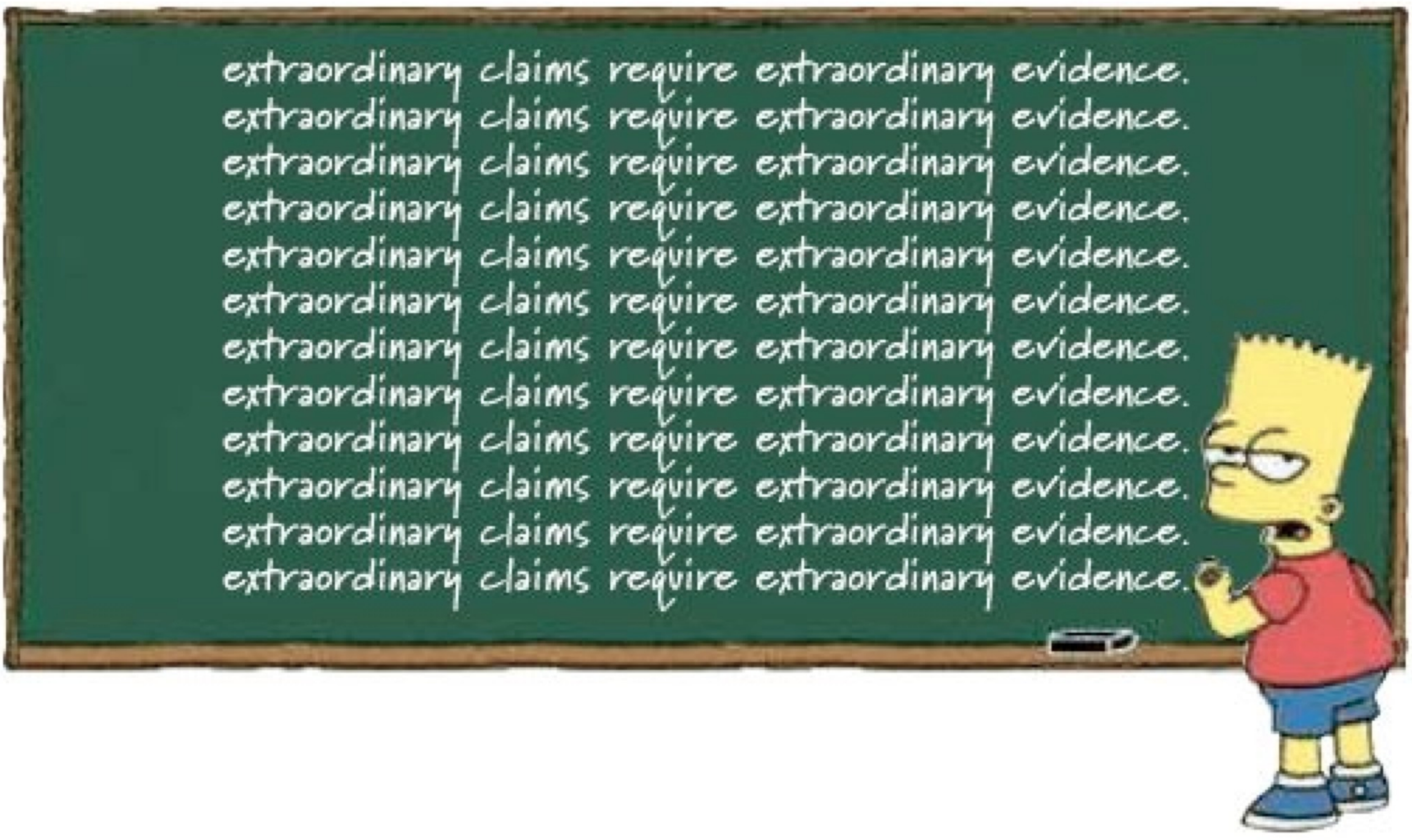
Allow me, here, to pay tribute to the French scientific community working in your field. Our country cultivates materials science; the Nobel Prize that went to Pierre Gilles De Gennes is a case in point. Our physicists build on a long tradition of research in France, extending from Pierre and Marie Curie to George Charpak, the inventor of the multiwire proportional chamber, and recent Nobel laureate Albert Fert, to mention only those working in atomi physics.

....

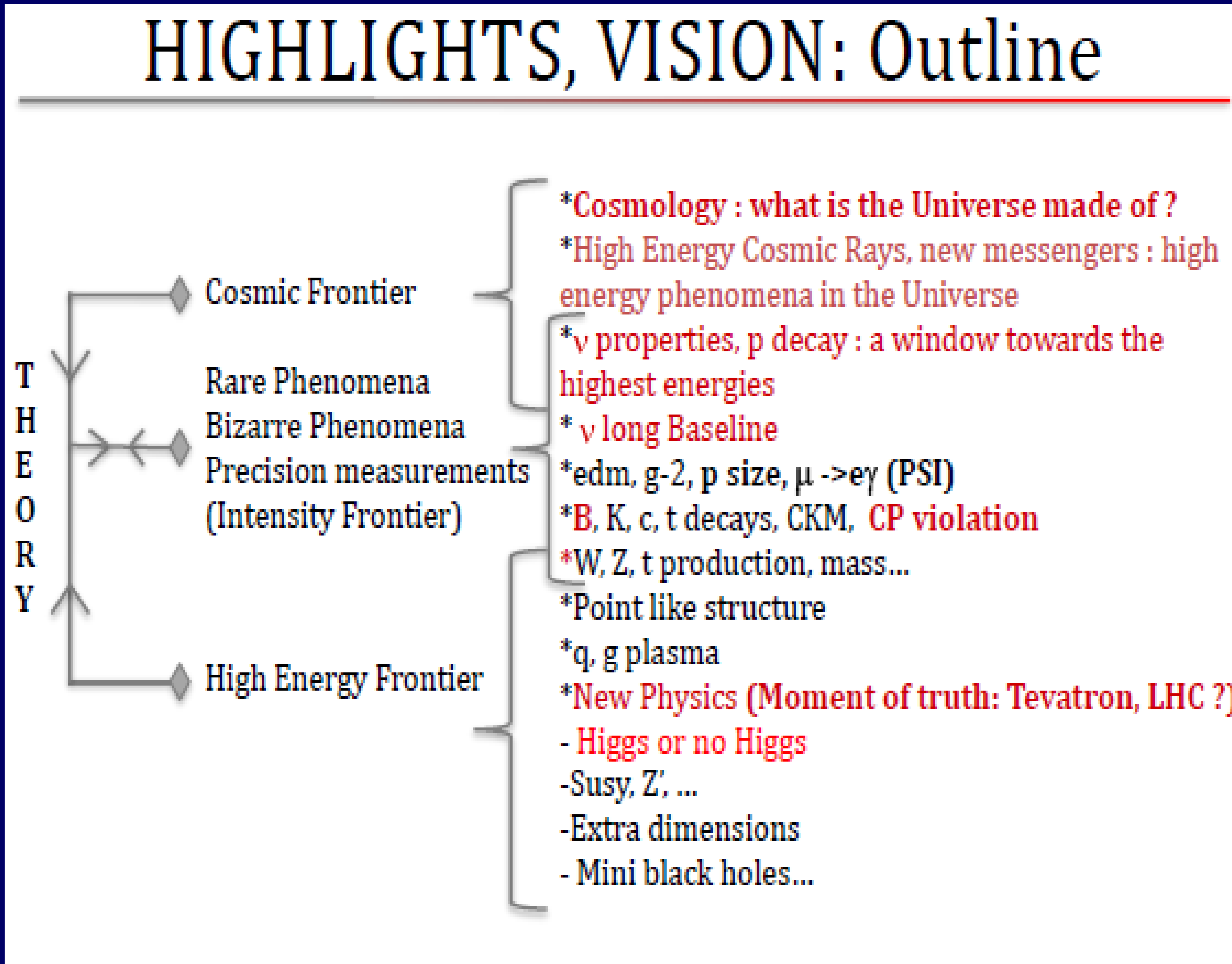
With western economies going through a difficult period - a recession unlike any the world has experienced since 1929 - governments are obviously tempted to postpone needed investments in science. If you were in our shoes, you would be tempted too.

But we in France took the opposite tack, considering that higher education and research are the solution to the recession. The economic downturn should not prompt us to postpone investment in science, but rather to bring it forward and consolidate it.

This talk – Higgs, mainly SM



Summary – M. Spiro



LHC – the first results

Decided Scenario 2010-2011

Following the technical discussions in Chamonix (Jan 2010) the CERN management and the LHC experiments decided

- Run at 3.5 TeV/beam up to a integrated luminosity of at least 1fb^{-1}.
- Then consolidate the whole machine for 7TeV/beam (during a shutdown in 2012)
- From 2013 onwards LHC will be capable of maximum energies and luminosities

LHC

Discovery Potential at LHC 1 fb^{-1}

3.5 TeV (end 2011 or beginning 2012)

- HIGGS competitive with the Tevatron
- Z': extend by a factor 2 the Tevatron potential
- SUSY from 400 GeV (Tevatron) to 800 GeV exclusions or discoveries
- Extra dimensions, mini black holes (extend by factor 2 the Tevatron limits (or discovery)

LHC

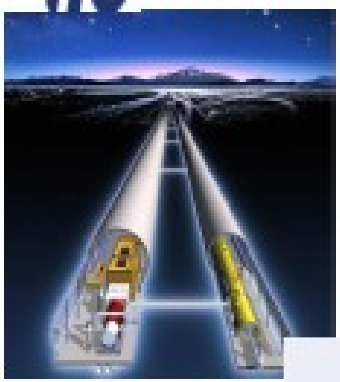
Some highlights

- High rapidity plateau: gluon gluon collider?
- Rediscovery of all Standard Model particles: K, π, p, Λ, 1000 Ω, 1000 W,100 Z, 10 top
- Use data from less than a week!!!
- 100 papers
- Measurements of jets, di jets, soon α_s already competitive with Tevatron
- However uncertainties on luminosity and jet energy scale to be improved

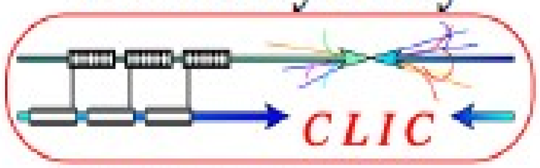
International Linear Collider ILC
Compact Linear Collider CLIC

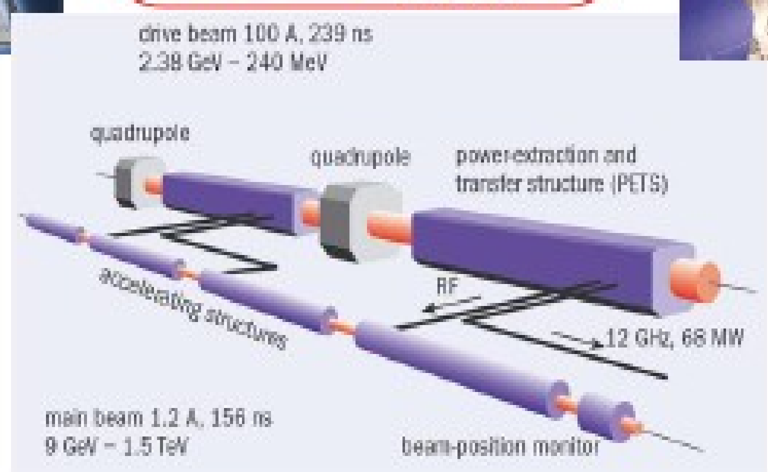
Vision for next machine (2030 ?)

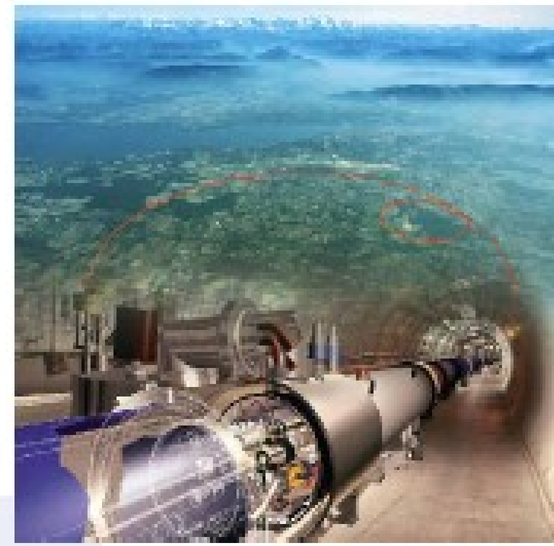
e+e- 500 GeV
Mature



e+e- 3 TeV
Feasibility Study

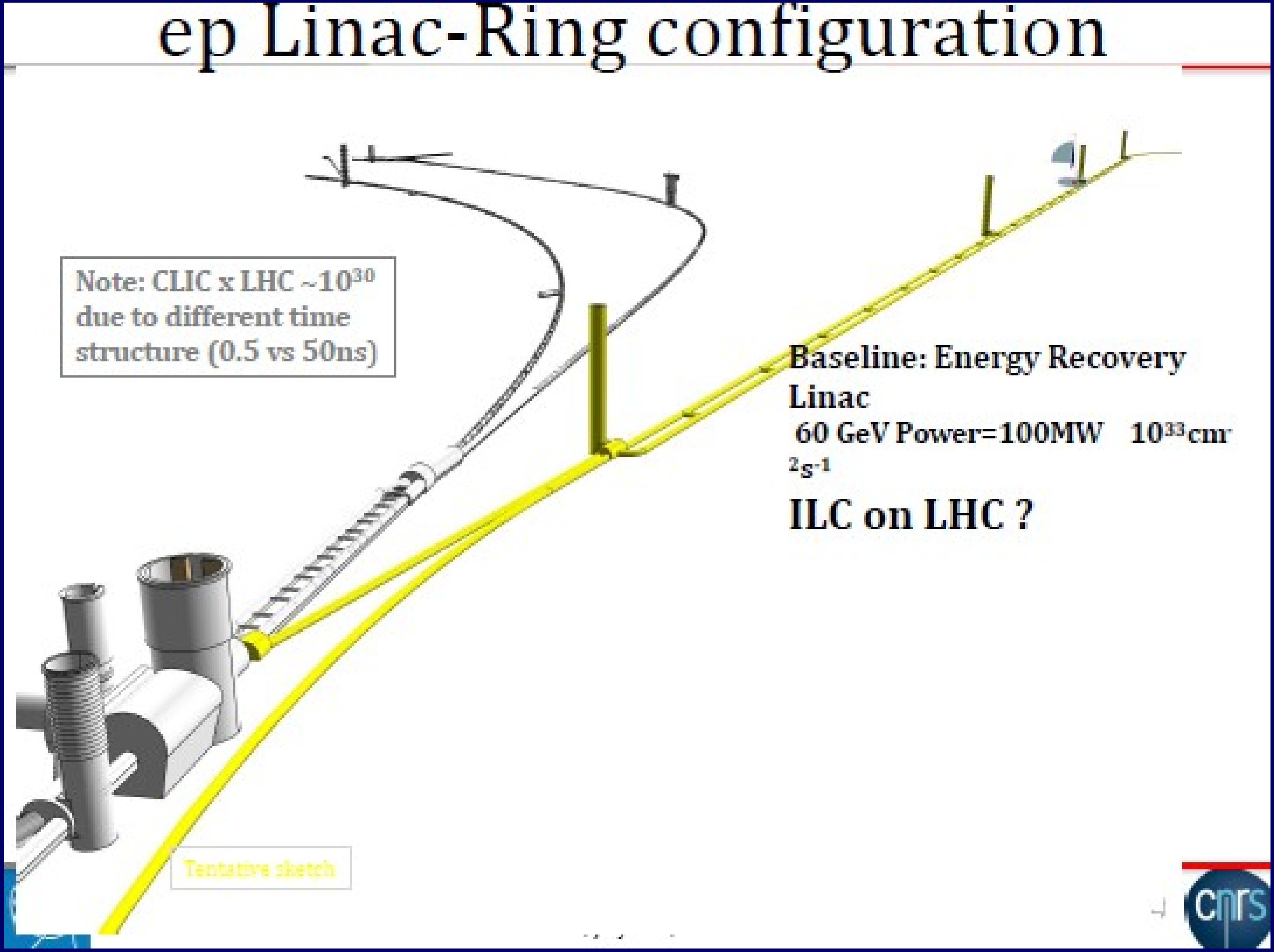




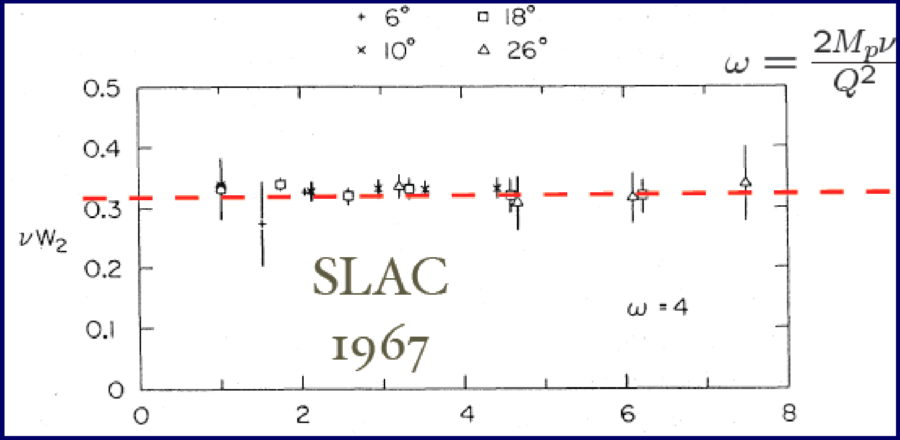


High Energy LHC
≥ 30 TeV
New Idea

LHeC Large Hadron electron Collider 40-140 GeV on 1-7 TeV $e^{\pm}p$, also eA



The LHeC is a PeV equivalent fixed target ep scattering experiment, at 50 000 times higher energy than the pioneering SLAC MIT experiment. It may need a LINAC not much longer than the 2mile LINAC to the right. Its physics potential is extremely rich.

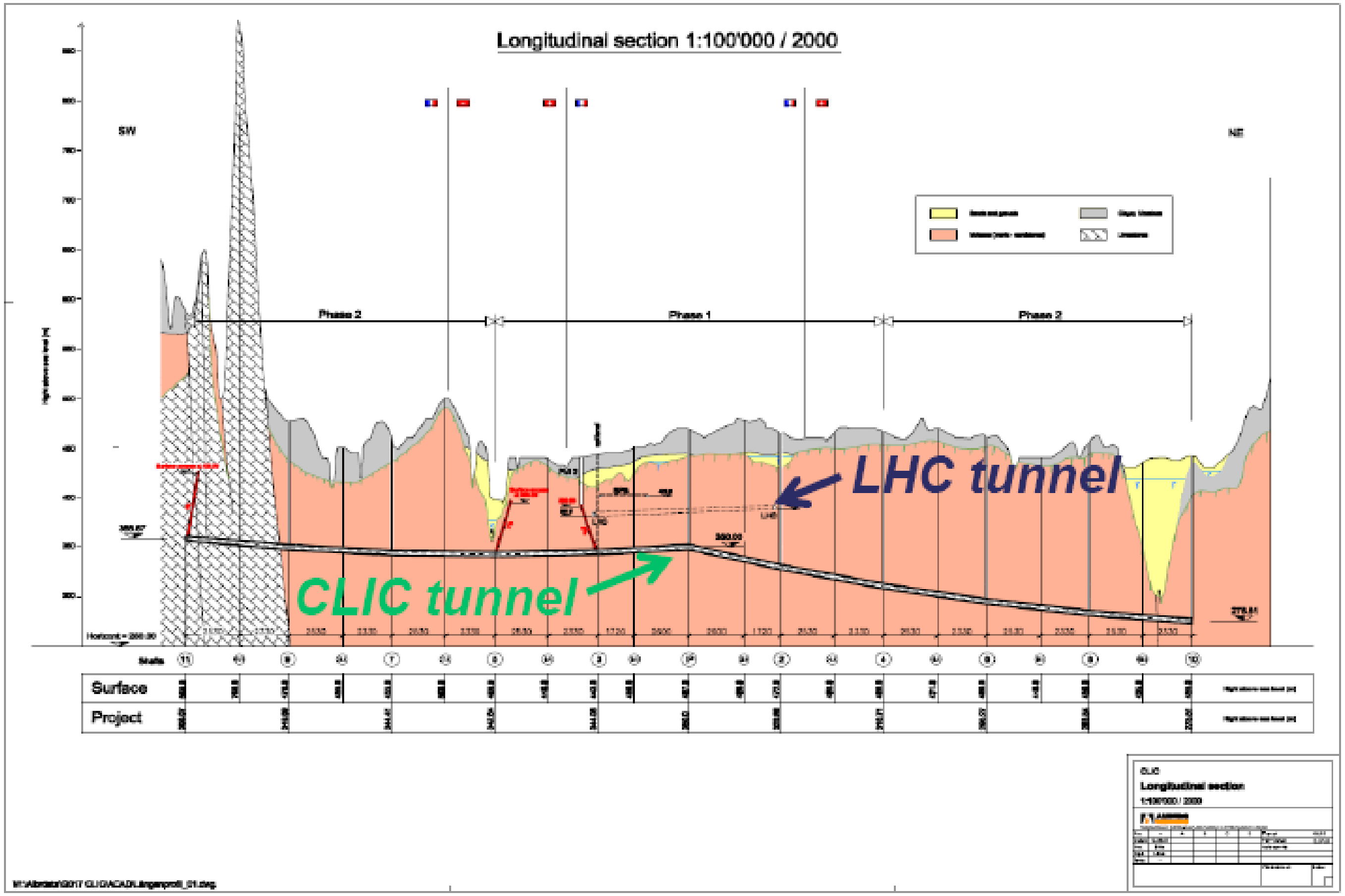


Q²

Pief

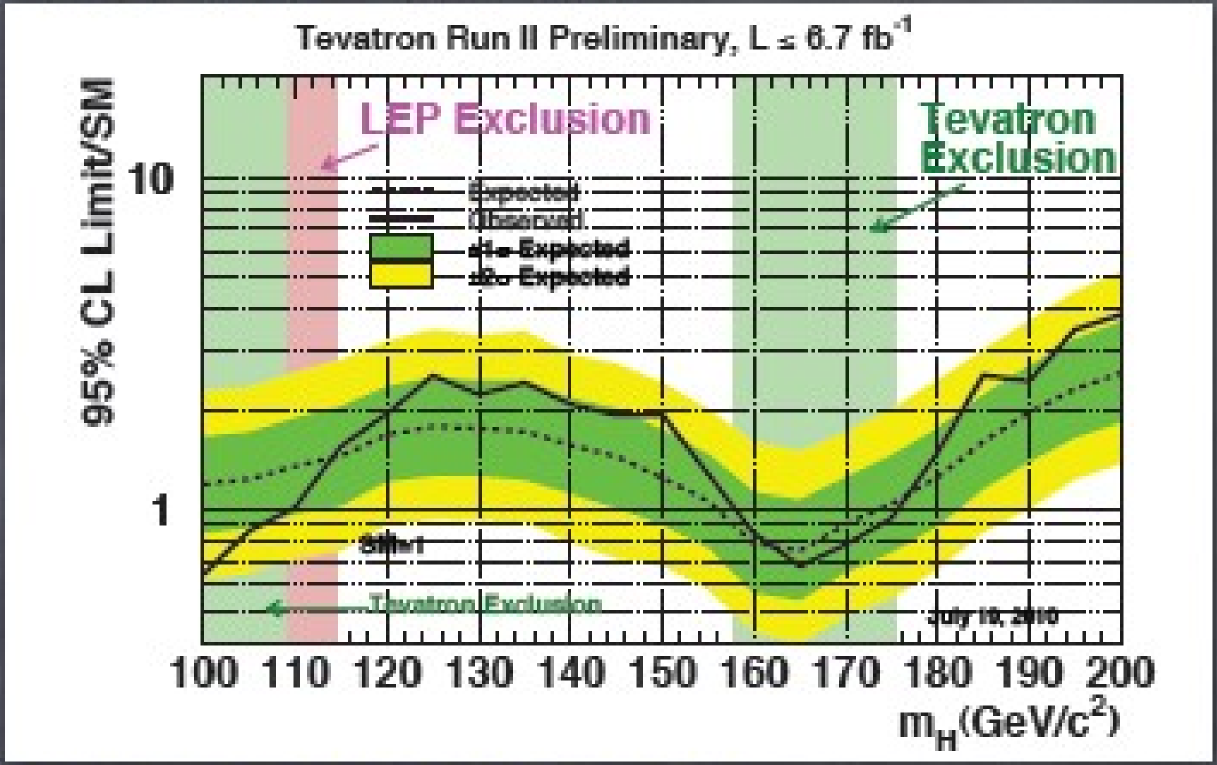
Can tunnel for LHeC Linac be build as first part of a LC tunnel at CERN ?

Tunnel studies for CLIC and ILC at CERN both have tunnels which are deeper underground than LHC and seen from top they both pass close to LHC ring center. Therefore they are not suited to send e^- beam tangential to LHC ring.

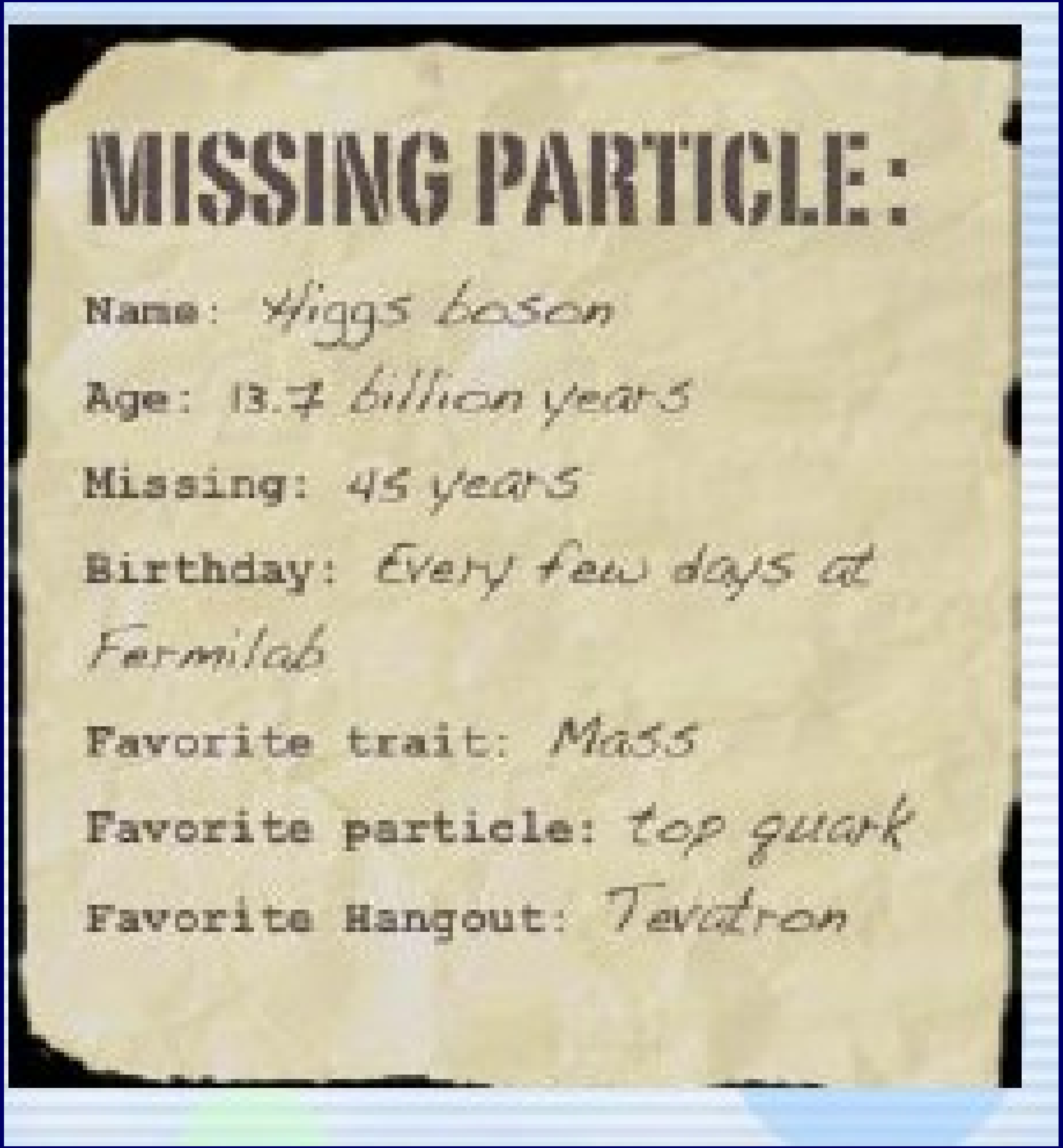


Un physicien est un spécialiste de physique et observe les phénomènes naturels.

Approaching the moment of truth

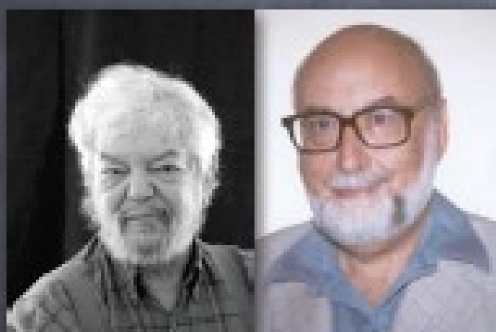


- Higgs has no place to hide !
  - Squeezing allowed mass from both sides
    - 95% CL Exclusion 158 < m_H < 175 GeV (about expected)
    - Limit 1.5*SM @ 115 GeV
- BSM searches : consistent with SM
  - 2 sigma is largest discrepancy in CDF MSSM H→bb (so far)


MISSING PARTICLE:
Name: Higgs boson
Age: 13.7 billion years
Missing: 45 years
Birthday: Every few days at Fermilab
Favorite trait: Mass
Favorite particle: top quark
Favorite Hangout: Tevatron

2010 Sakurai Prize

... for "elucidation of the properties of spontaneous symmetry breaking in four-dimensional relativistic gauge theory and of the mechanism for the consistent generation of vector boson masses."

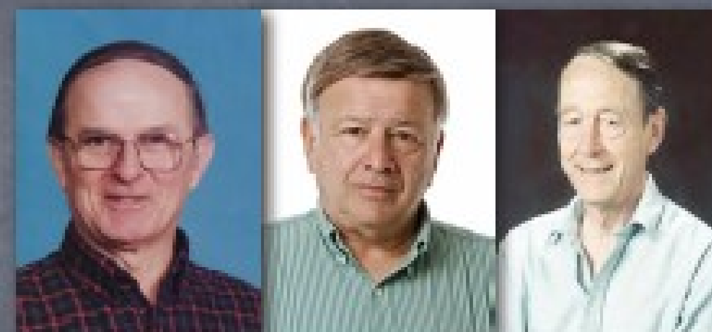


Brout Englert

PRL 13, 321-323 (1964)

Higgs

PRL 13, 508-509 (1964)

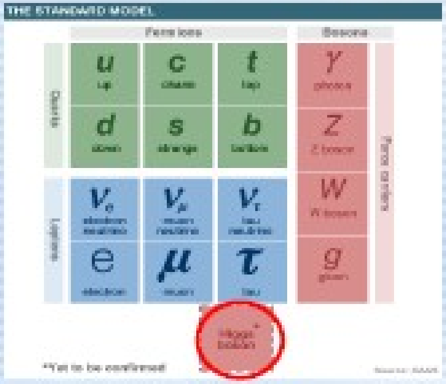


Hagen Guralnik Kibble

PRL 13, 585-587 (1964)

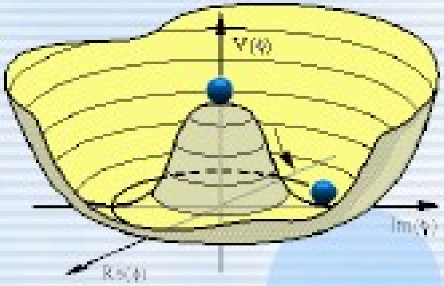
Motivation

- The Higgs boson is the only undiscovered **"elementary"** particle in the Standard Model
- Its discovery will help answer the questions:
  - How do fermions/weak bosons acquire mass?
  - How EW symmetry is broken?
- The SM can not predict the Higgs boson mass
  - Needs to be determined by experiment !!



Status of SM Higgs Search

- Current constraint on the SM Higgs boson



– **Precision electroweak measurements (top mass, W mass, etc)**

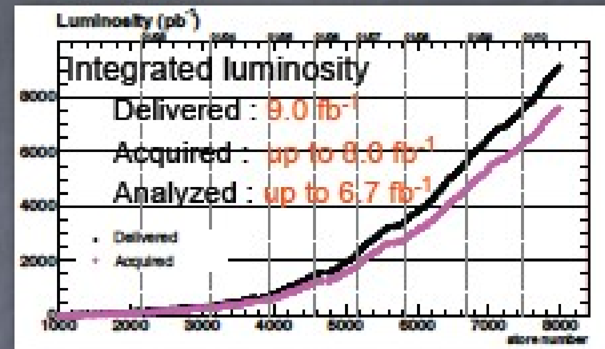
$M_H = 89^{+35}_{-26}\, GeV/c^2 \quad M_H < 158\, GeV/c^2$

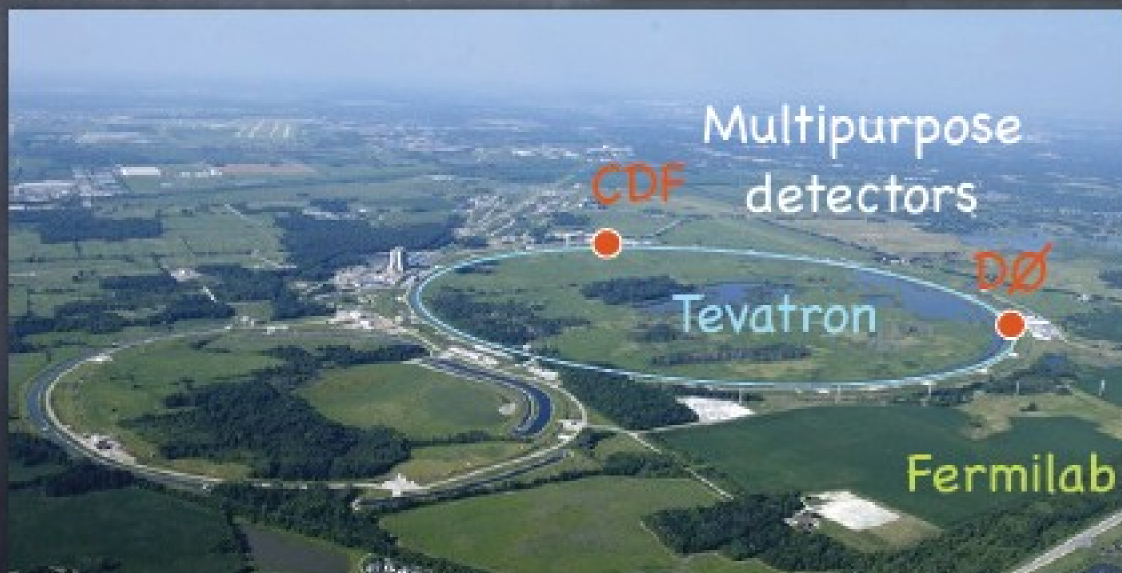
(LEP EWG 2010, http://lepewwg.web.cern.ch/LEPEWWG/

→ **Tevatron covers whole mass region**

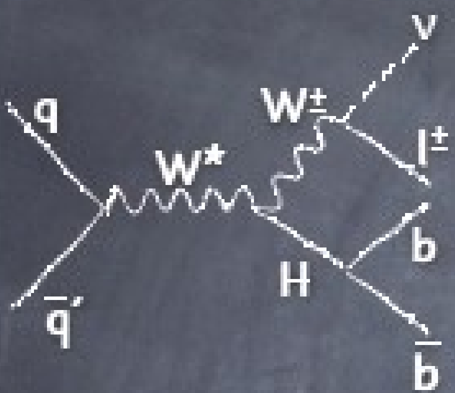
Tevatron

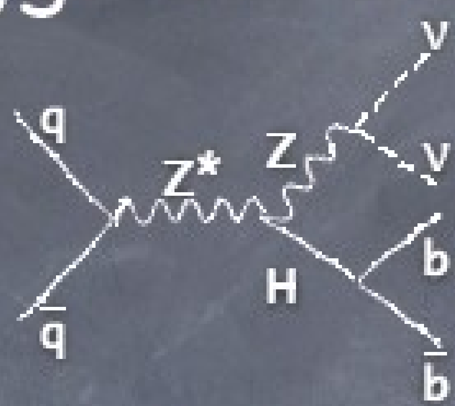
- $p\bar{p}$ collisions with $\sqrt{s}$ = 1.96 TeV
- Two collider experiments, CDF & D0

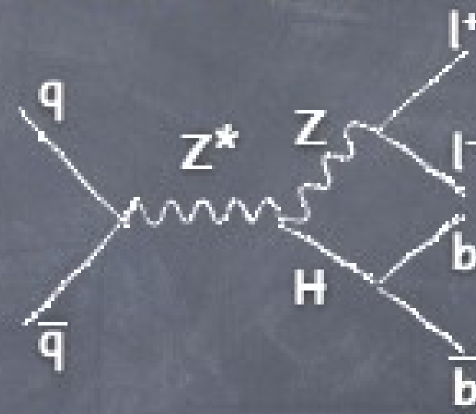




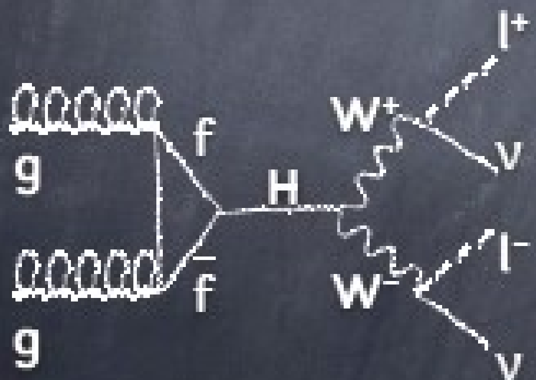
SM Higgs at the Tevatron

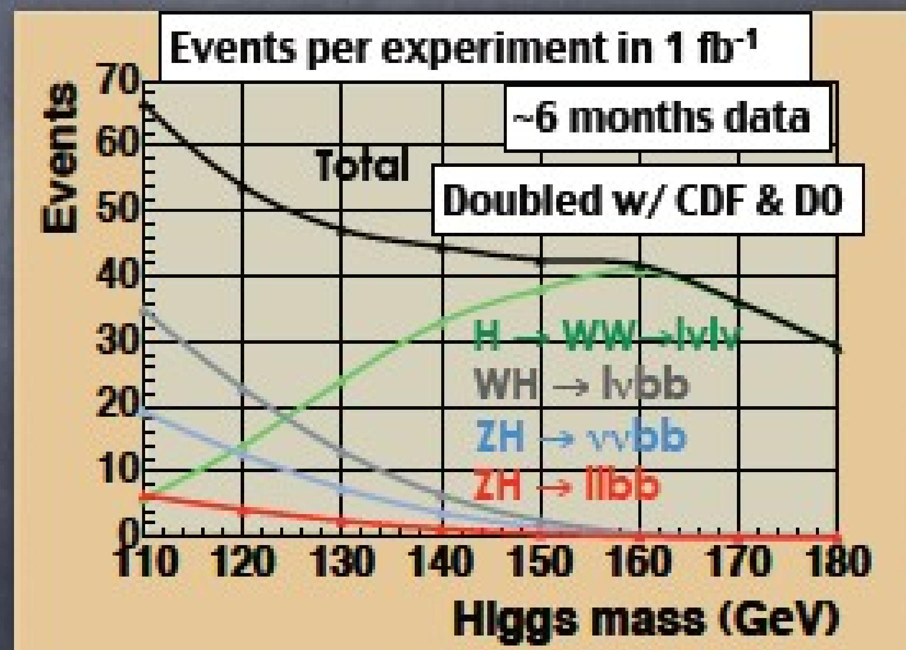






Main decay modes





Higgs acceptance

Higgs rate small, we reconstruct additional topologies

Production:

$gg \rightarrow H$

$qq \rightarrow H + W$

$qq \rightarrow H + Z$

$qq \rightarrow H + qq$

Decay:

$H \rightarrow WW$

$H \rightarrow bb$

$H \rightarrow \tau\tau$

$H \rightarrow \gamma\gamma$

W , Z decays :

$W \rightarrow l\nu$

$Z \rightarrow ll$

$Z \rightarrow \nu\nu$

$W \rightarrow \tau\nu$

$W \rightarrow qq$

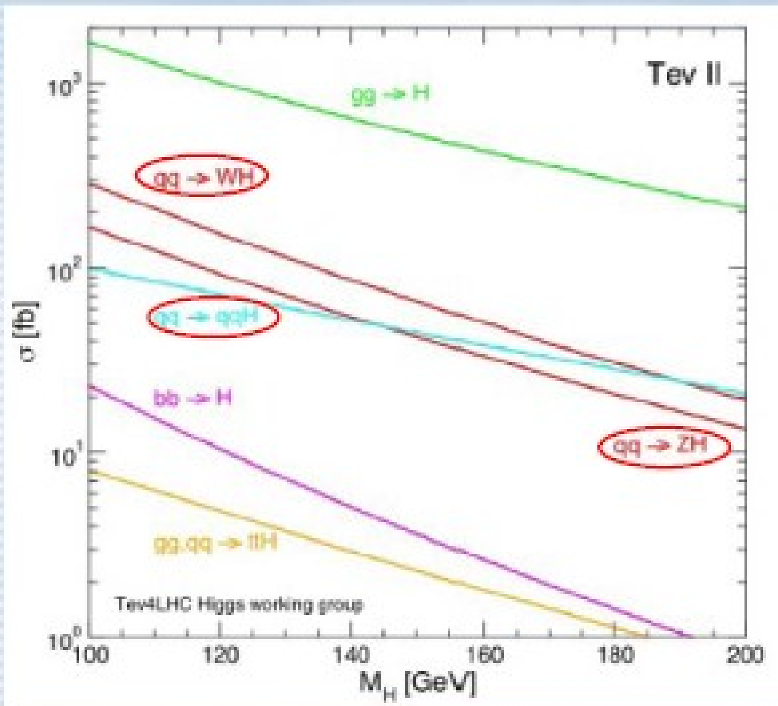
For example :

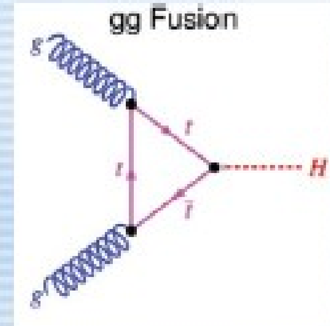
$qq \rightarrow HZ \rightarrow WWZ \rightarrow l\nu llqq$

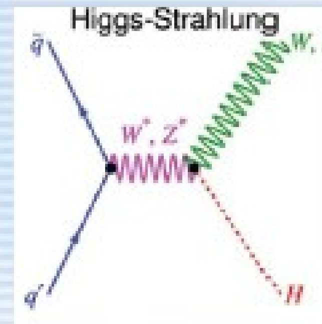
Select : electrons,
muons, MET, jets

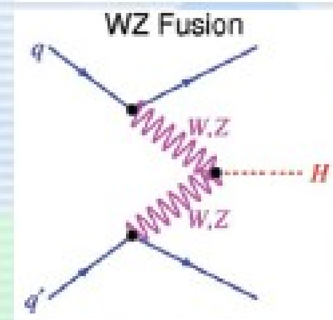
Higgs Production @ Tevatron

- Dominant SM Higgs production channels at the Tevatron

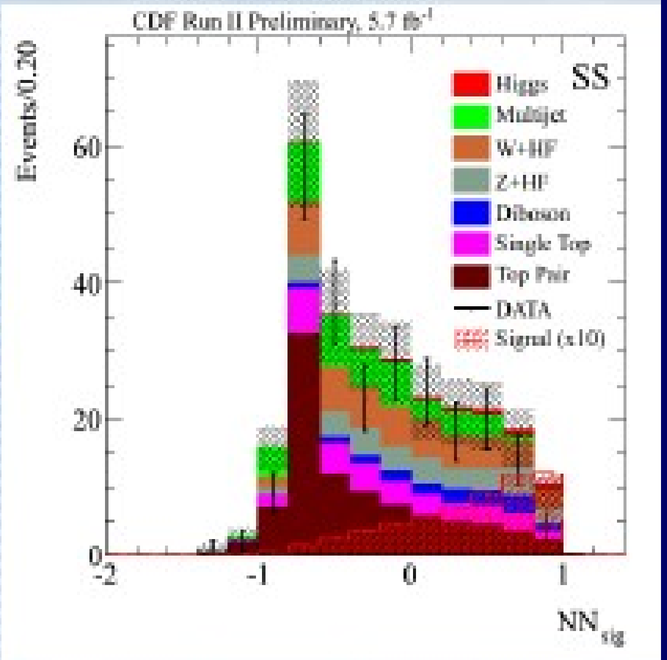








ZH->ννbb & WH->lνbb



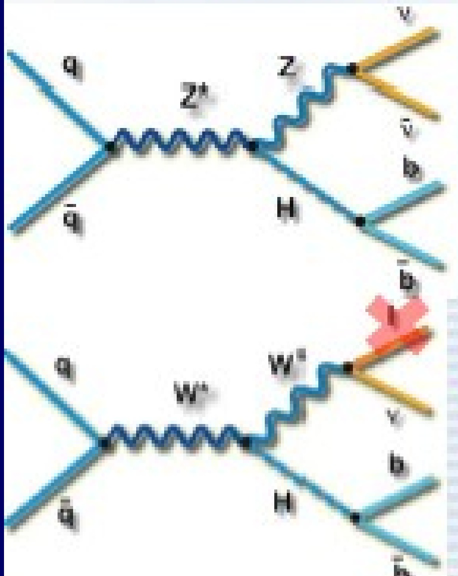
Event Selection

large MET + 2 high-E_T jets

Include WH->(l)vbb and ZH->(ll)bb

Analysis techniques

- First NN to remove huge QCD multijet background
- Three b-tagging categories (SECVTX and JETPROB)
- Jet energy resolution improvement by combining tracking and calorimeter information
- Second Neural Network for final discriminant

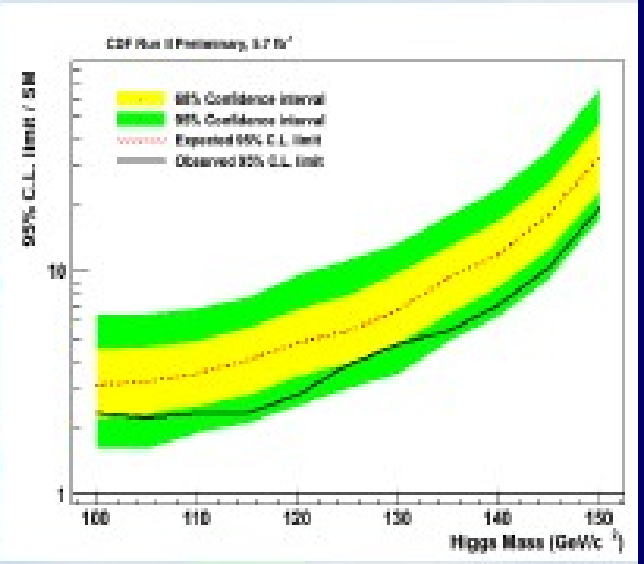


Expected upper limit

4.0 x σ(SM) (@115 GeV)

Observed upper limit

2.3 x σ(SM) (@115 GeV)



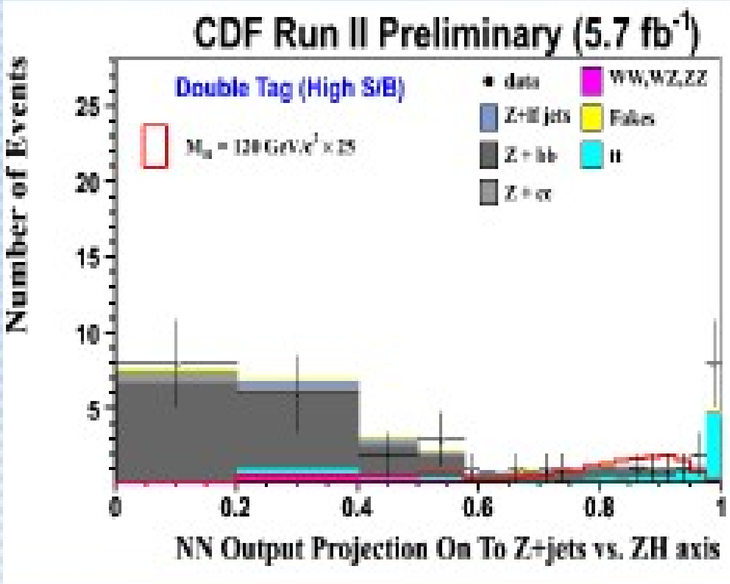
ZH->llbb

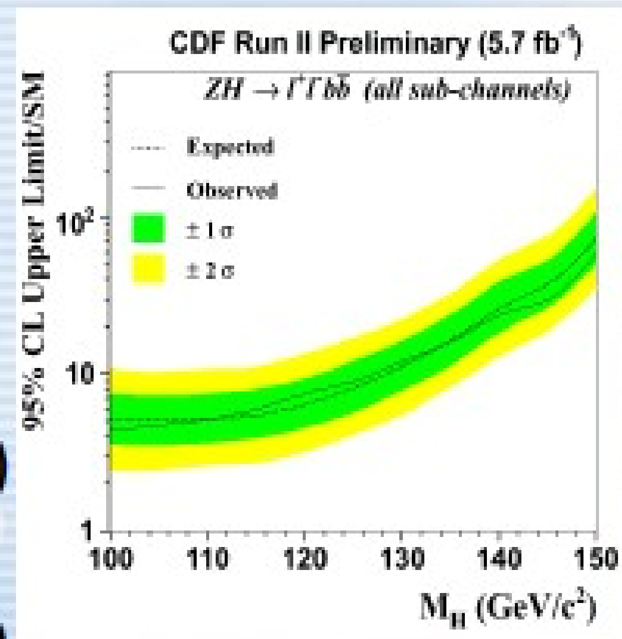
Event Selection

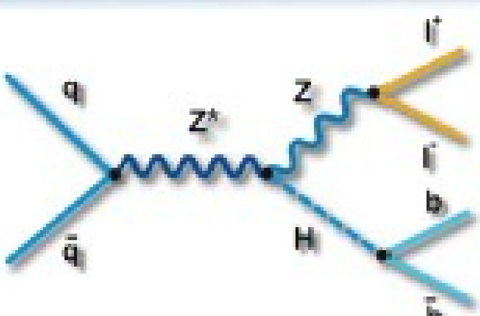
Two high-p_T leptons (ee,μμ), m(ll) within Z boson mass window + 2 high-E_T jets

Analysis techniques

- NN to correct jet energies based on observed missing E_T
- Three b-tagging categories (SECVTX and JETPROB)
- Recover loose muon pairs using NN selection (first use of multivariate lepton ID in a low-mass analysis)
- 2-D Neural Network as discriminant
  (ZH vs top-pair, ZH vs Z+jets)







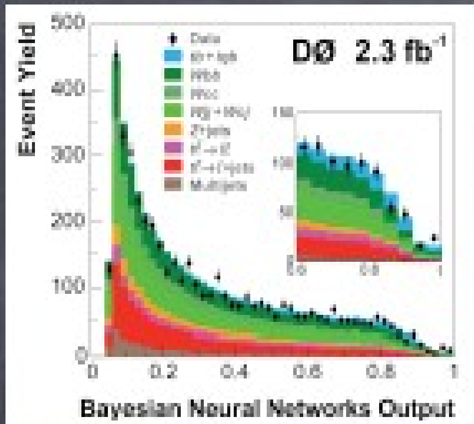
Expected upper limit

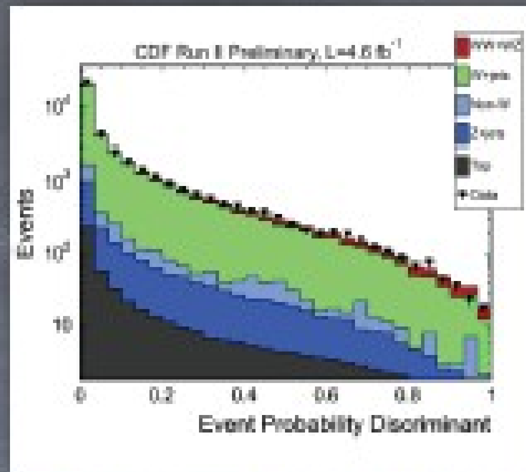
5.5 x σ(SM) (@115 GeV)

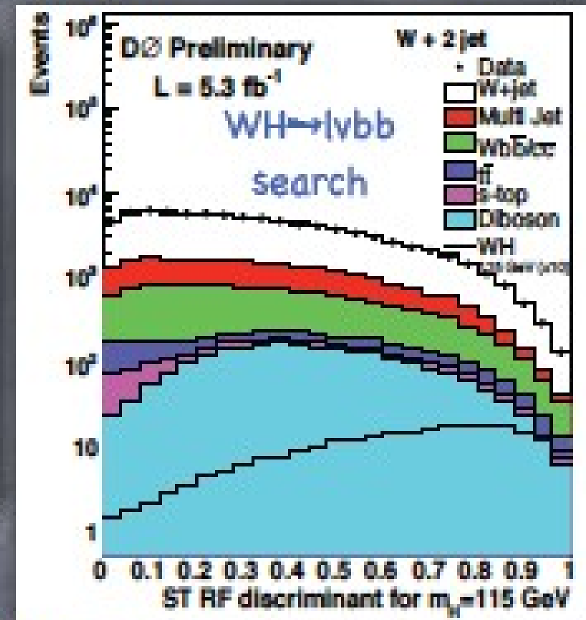
Observed upper limit

6.0 x σ(SM) (@115 GeV)

Gaining faith in multivariate methods







Single top observation
t+q → lνjj (with b-tag)

Similar to WH → lνbb

Neural Network :

Us : $\sigma(t) = 4.70\ ^{+1.18}_{-0.93}$ pb

SM : $\sigma = 3.46 \pm 1.8$ pb

Diboson observation :
WW + WZ → lνjj

Similar to WH → lνbb

Matrix Element :

Us: $\sigma(WW+WZ) = 16.6^{+3.5}_{-3.0}$ pb

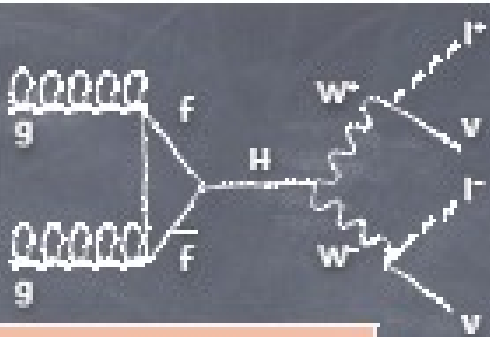
SM : $\sigma = 15.1 \pm 0.8$ pb

WH sample before b-tag

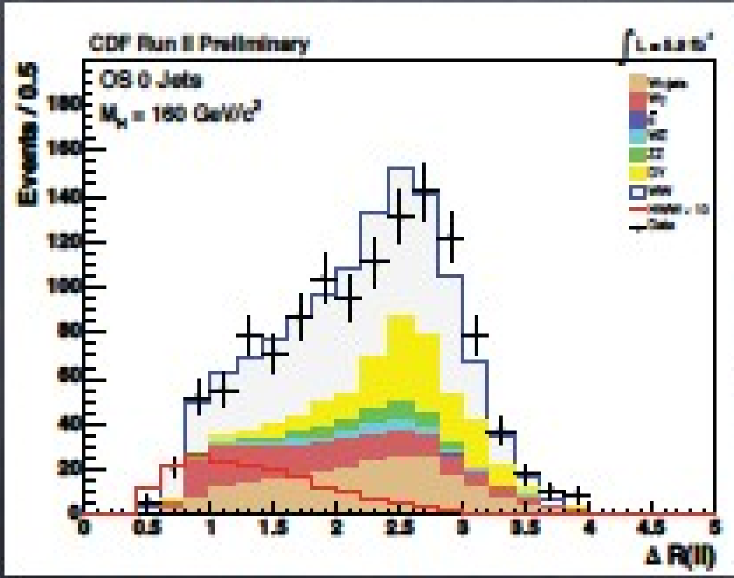
- Similar to WH → lνbb
- Actual control region for WH
- Same object kinematics
- Statistics = 30 * tagged sample
- Random Forest trained on :
  - Masses of jets
  - P_T of combinations
  - Angular separations

Basic H → WW analysis

Signature: Opposite charge leptons, high MET, no jets

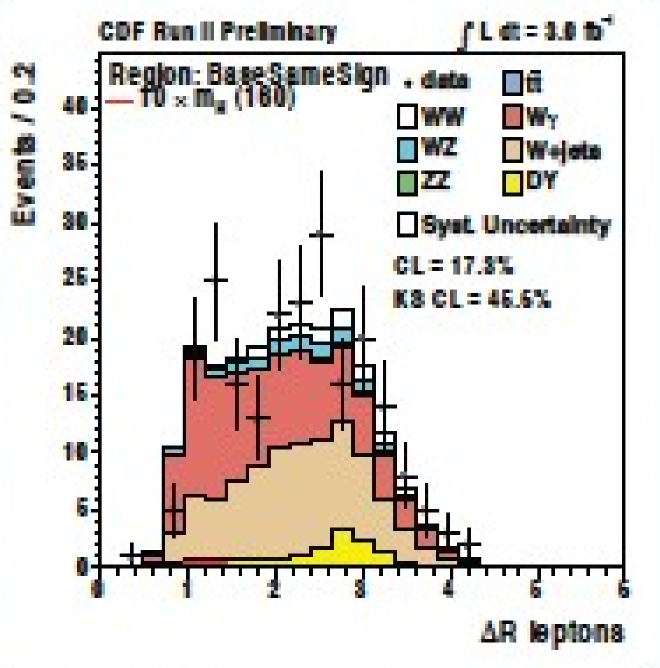


Main Signal	Main BKGs	Key discriminant
gg → H	WW, Wγ	ΔR leptons = "Angle" between leptons



Spin 0 H → WW
Spin 1 Z → WW

Fakes & conversions: Can check Same Sign modeling

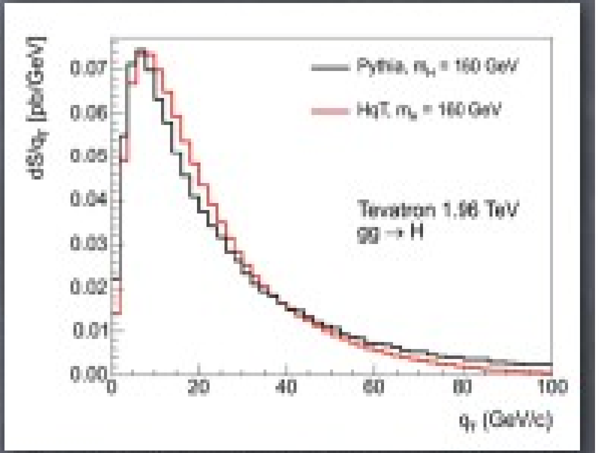


Theory & uncertainties

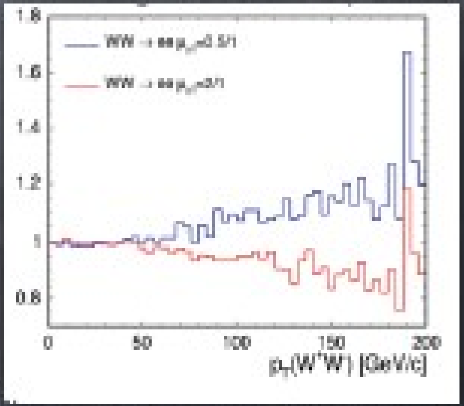
- We make use of well-motivated and state of the art gluon fusion cross-section calculations and uncertainties
  - gg → H uses NNLL + NNLO calculations
    - "Next to Next to Leading Log/Order"
  - de Florian & Grazzini (Phys.Lett.B674:291-294, 2009)
    - Soft-gluon resummation treatment
    - MSTW2008 Parton Density Function
  - Anastasiou, Boughezal, Petriello (JHEP:0904:003, 2009)
    - Proper treatment of b-quarks at NLO
    - Inclusion of two-loop electroweak effects

- For those interested in a detailed explanation of our choices and comparison with more extreme approaches :

http://tevnphwg.fnal.gov/results/SMHPubWinter2010/gghtheoryreplies_may2010.html



Reweight PYTHIA Higgs kinematics to full NNLL calculation



Consider same variations for dominant WW bkg

Summary of low & high mass results

Channel	Expt	Dataset now	Increase since Nov. 2009 combination
H → WW	D0	6.7	24%
H → WW	CDF	5.9	23%
WH → lνbb	CDF	5.7	30%
WH → lνbb	D0	5.3	6%
ZH/WH→METbb	CDF	5.7	60%
ZH/WH→METbb	D0	6.4	23%
ZH → llbb	CDF	5.7	40%
ZH → llbb	D0	6.2	45%
H → γγ	CDF	5.4	New!
H → γγ	D0	4.2	0%
H → ττ	CDF	2.3	15%
H → ττ	D0	4.9	0%
ZH/WH→qqbb	CDF	4	100%
ttH	D0	2.1	0%

Each channel represents several "sub-channels"

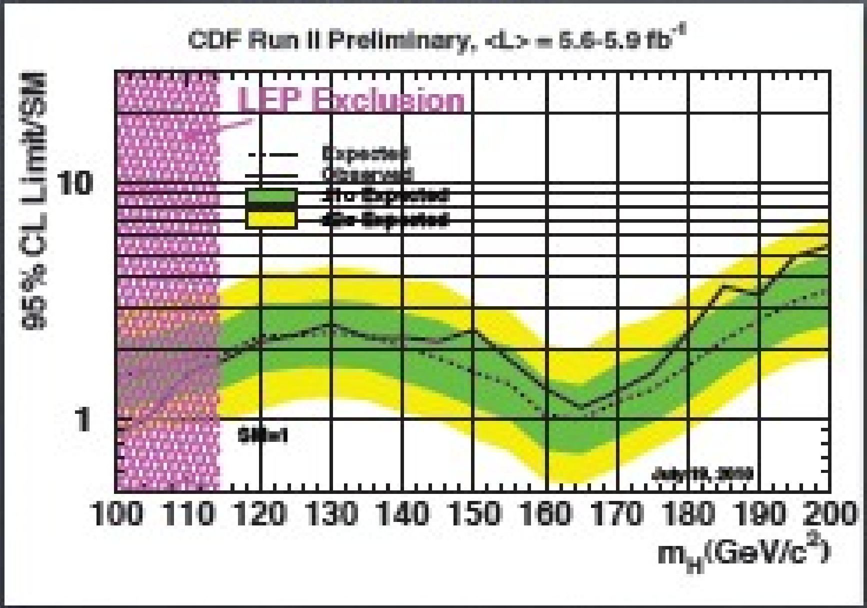
H→WW Sub-channels
opposite sign leptons + 0-jets
opposite sign leptons + 1-jets
opposite sign leptons + 2-jets
opposite sign leptons , low M_{ll}
same sign leptons
trileptons, no Z candidate
trileptons, Z candidate, 1-jet
trileptons, Z candidate, 2-jet
electron + hadronic tau
muon + hadronic tau
leptons + jets

New

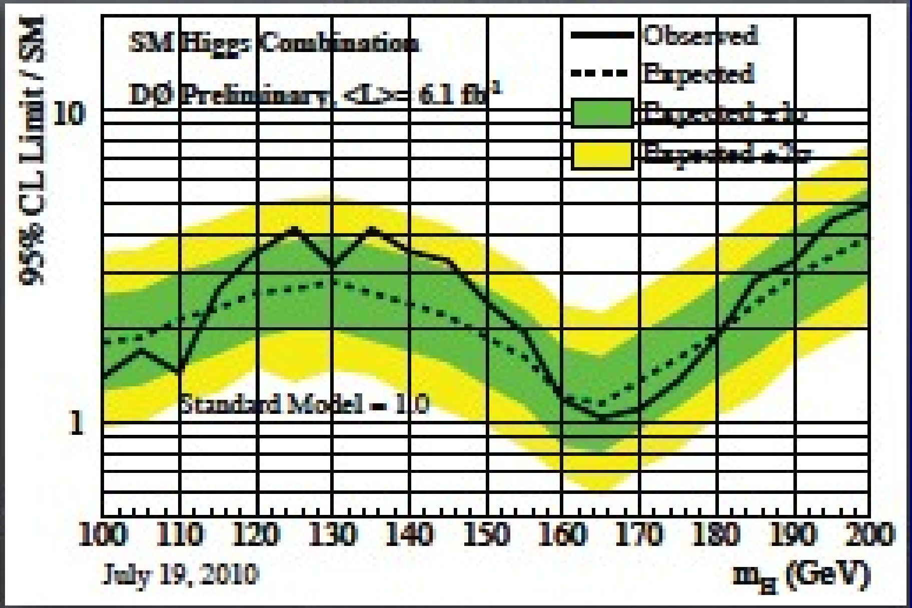
CDF & D0 combinations

Shown first on July 23, 2010

CDF's limits



D0's limits



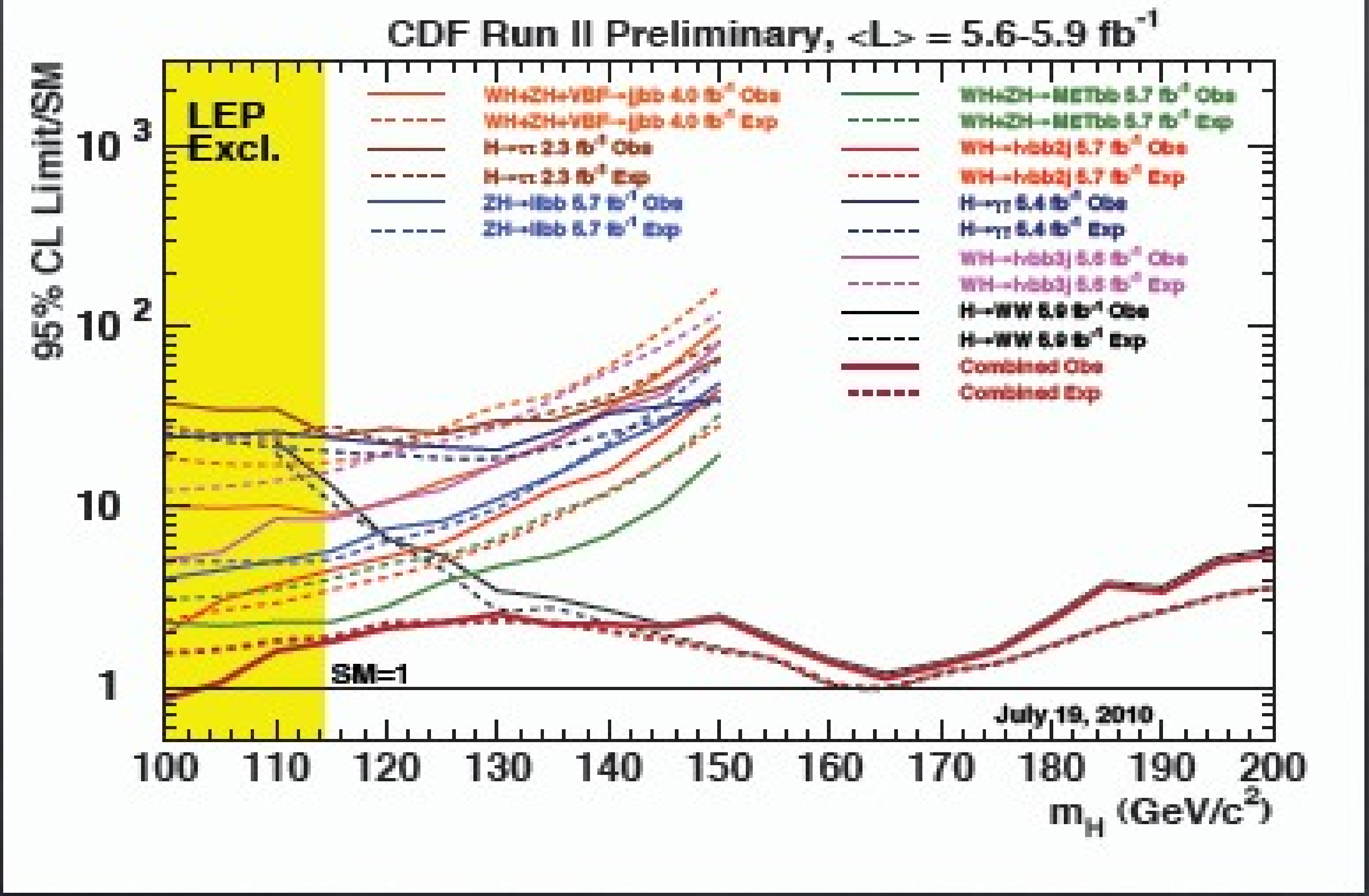
CDF achieves expected exclusion at 165 GeV

D0 almost achieves observed exclusion at 165 GeV

@ m_H = 100 GeV, both set observed limits below expected

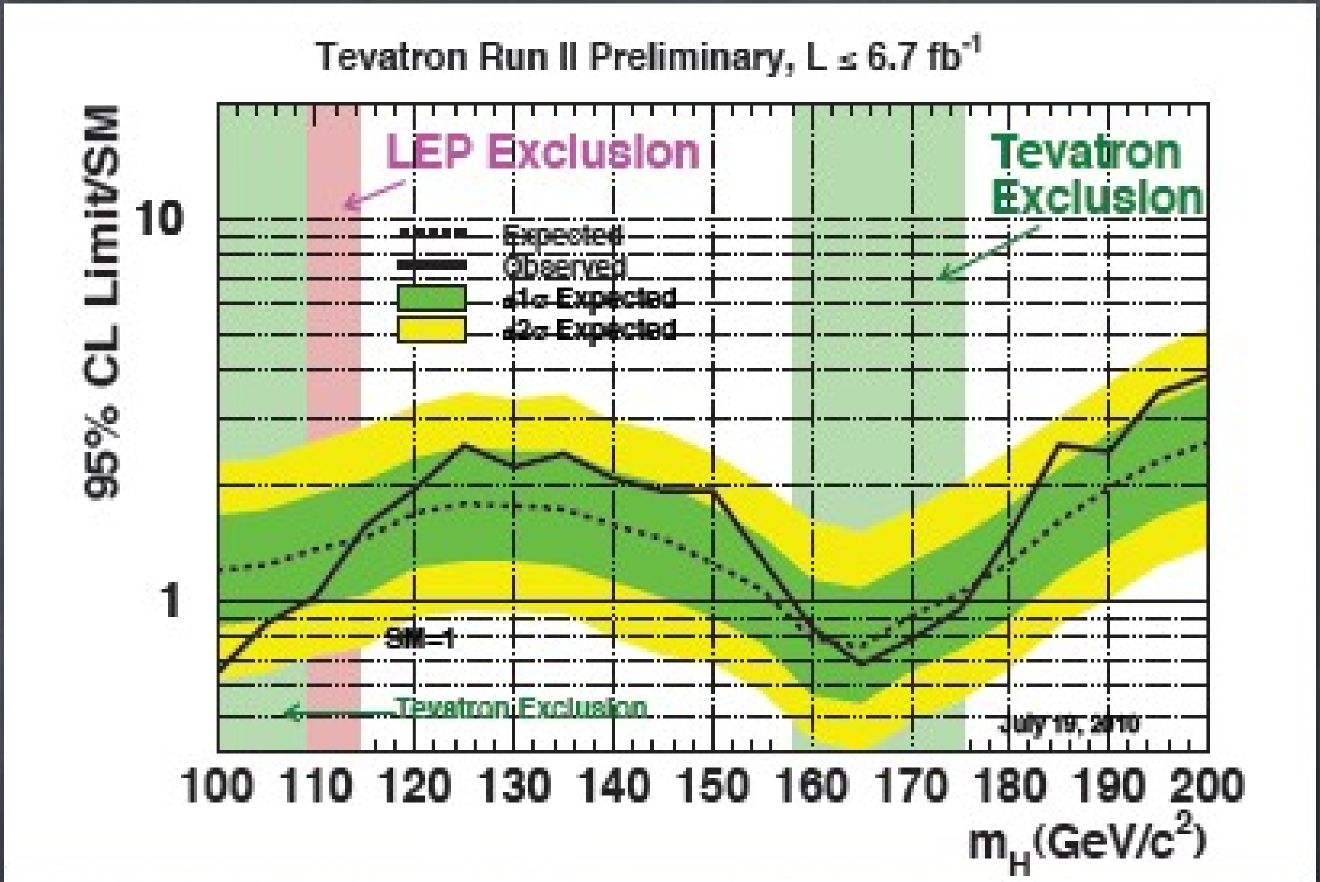
Closing in on low mass LEP exclusion

What goes into the combination?



Tevatron combination

"Expected sensitivity"



- Low mass sensitivity approaching LEP exclusion :
  - Expected 1.45*SM @ 115 GeV
  - Expected 1.24*SM @ 105 GeV
- High mass 95% CL exclusion :
  - 158 < m_H < 175 GeV
    - 4 times previous (162 - 166 GeV)
    - Expected (156 < m_H < 175 GeV)

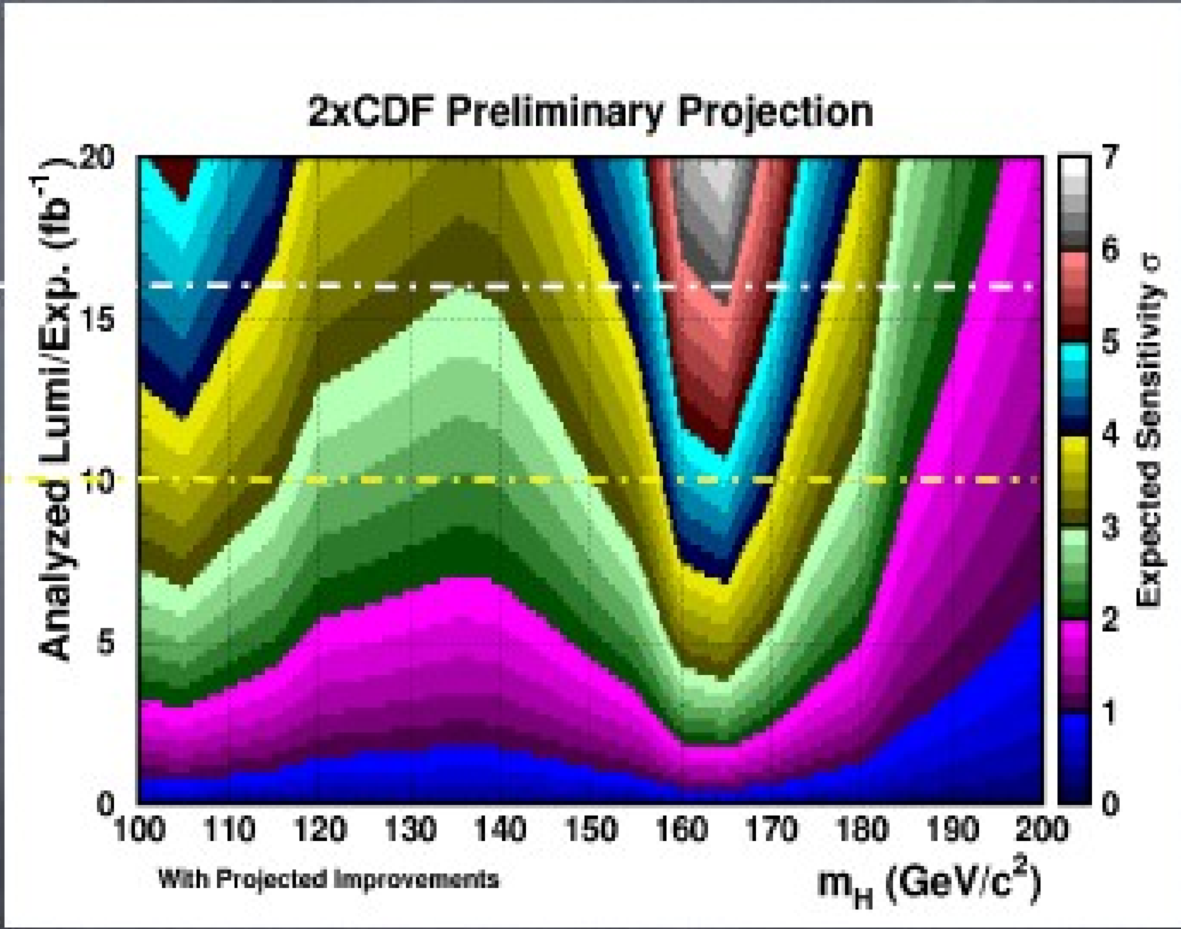
Prospects for Higgs evidence

~16 fb^{-1} :*

> 3 σ expected sensitivity from 100 – 185 GeV
4 σ @ 115 GeV

End of 2011:

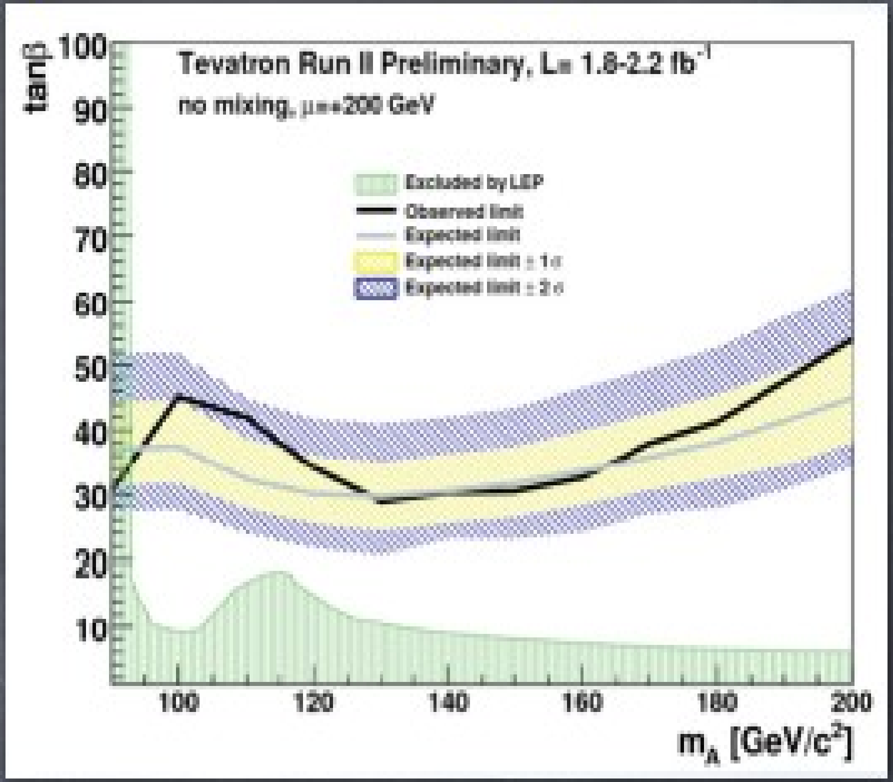
> 2.4 σ expected sensitivity across mass range
3 σ at 115 GeV



* 16 fb^{-1} : based on "Run III" proposal to run 3 more years

Search for Supersymmetric Higgs boson

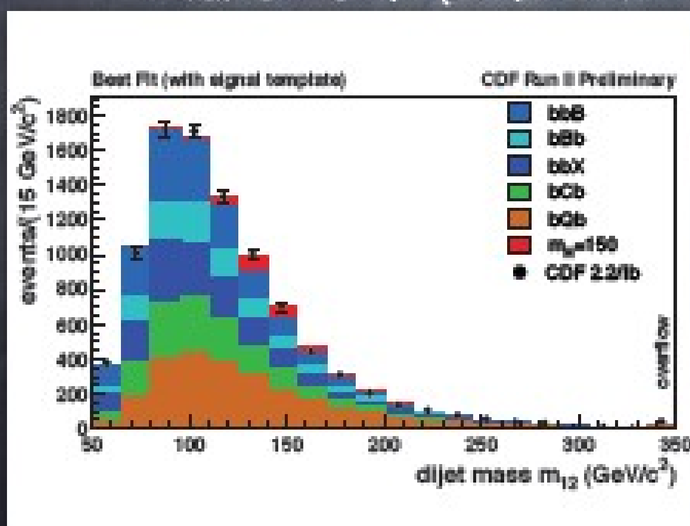
- Supersymmetric models extend Higgs sector
  - $\Phi = (H^0, A^0, h^0)$, and $H^\pm$
  - Introduces $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$ parameter
    - $\sigma(\Phi)$ enhanced by $(\tan\beta)^2$ ~ 1000 over SM
- Branching ratio
  - ~ 90% bb, 10% ττ
- Tevatron has comprehensive MSSM Higgs program
  - $\Phi \to \tau\tau$
  - $\Phi+b \to bb+b$
  - $\Phi+b \to \tau\tau+b$

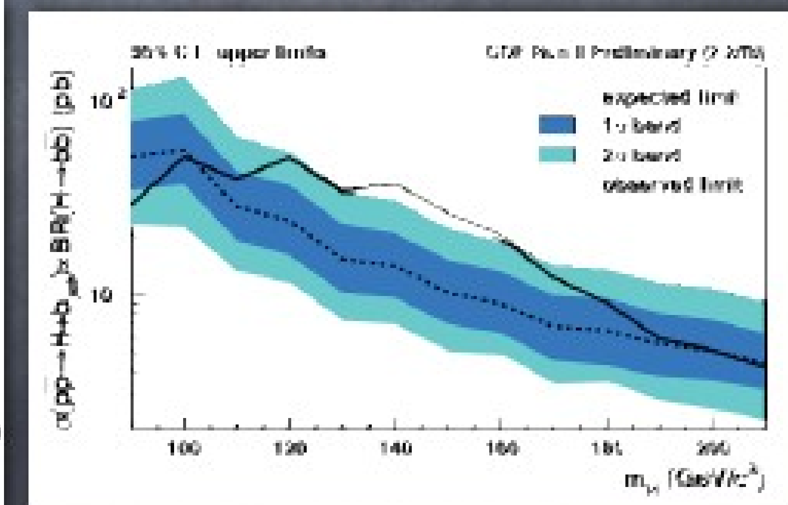


- CDF & D0 combined search for $\Phi \to \tau\tau$ with 2 fb^{-1}
  - Probes interesting value of $\tan\beta \sim m_t/m_b$ ~ 30

Search for Supersymmetric Higgs boson

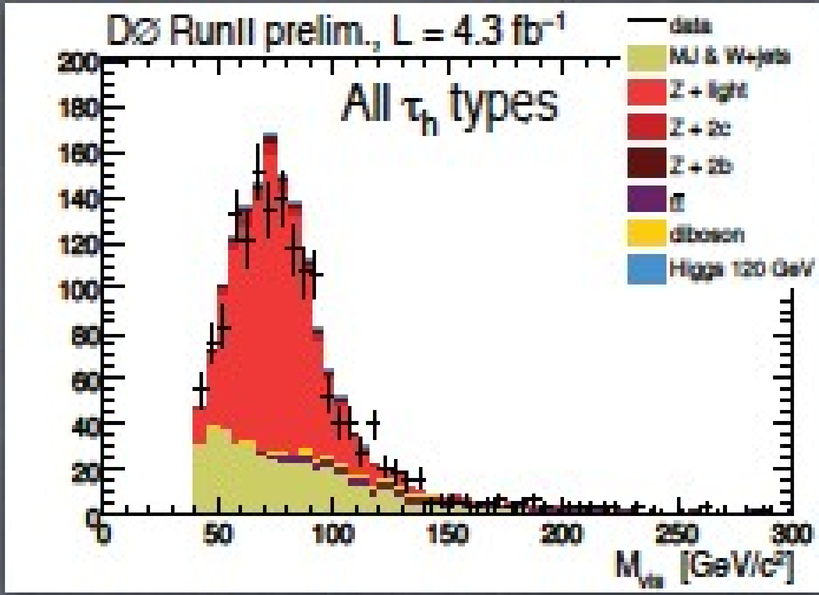
- MSSM Higgs 3b search (Φ+b→ bb+b)
  - Complements MSSM H → ττ search
  - Relies on CDF's trigger-level b-tagging used in b physics
  - New version of analysis 2x more acceptance
    - m_H = 140 GeV most significant excess
      - P-value = 0.9% (5.7% with trials factor)

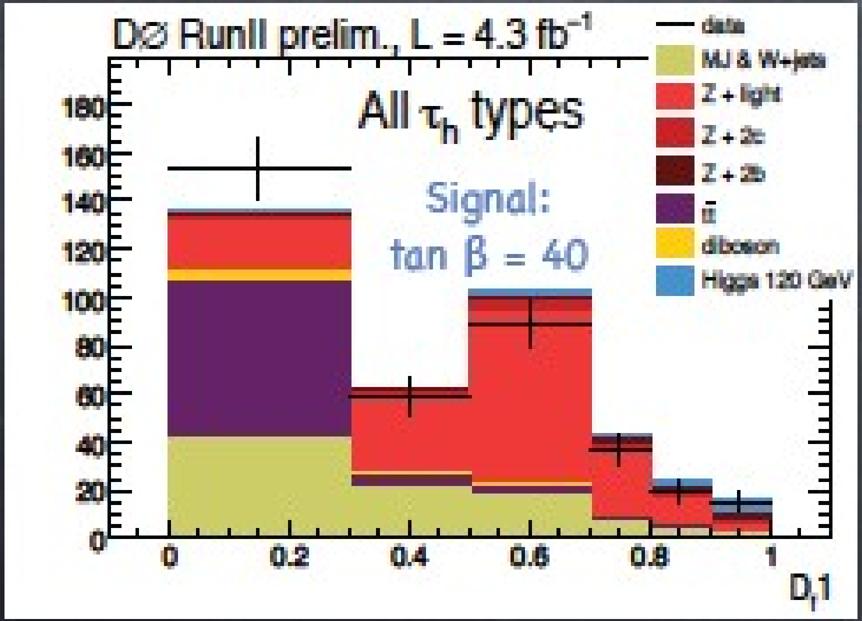


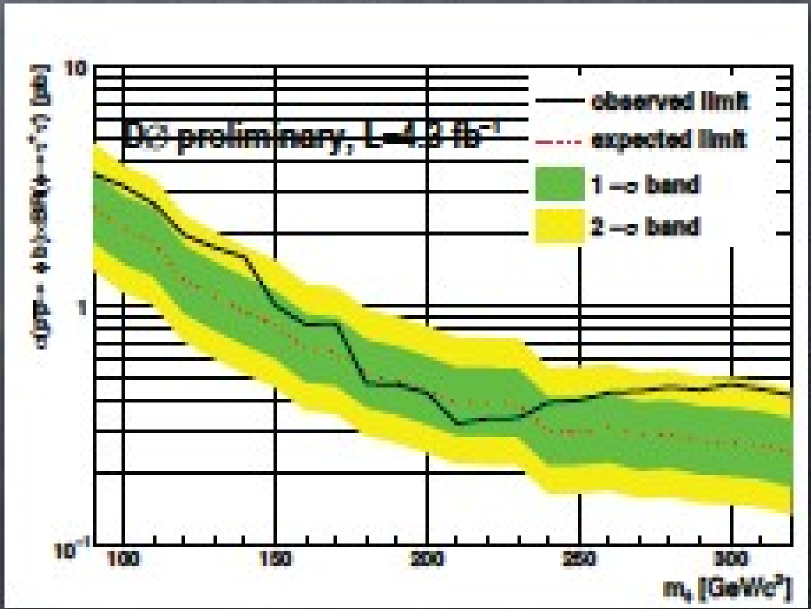


New MSSM Higgs search

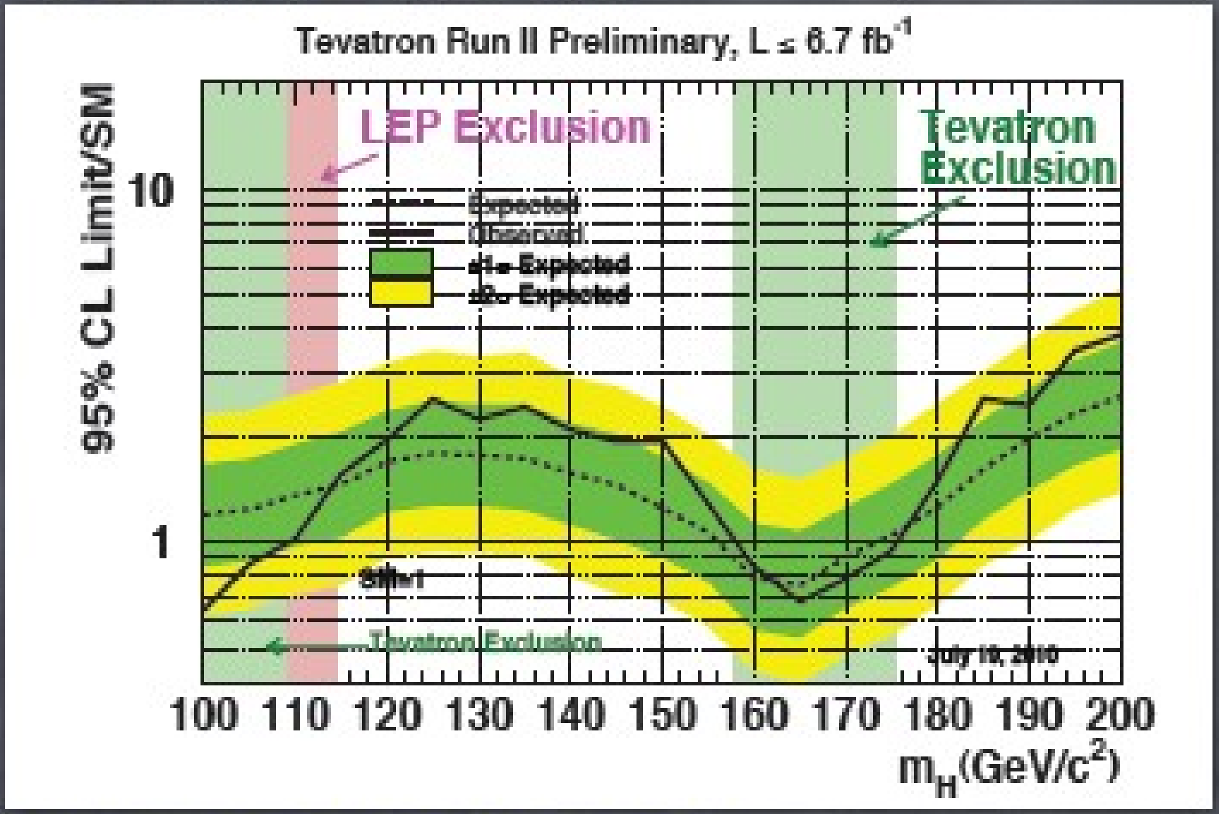
- D0's $\Phi \to \tau\tau + b$
  - Does not suffer radiative corrections which increase Higgs width as in $\Phi \to bb+b$
  - Exclusive from $\Phi \to \tau\tau$
    - Provides similar sensitivity







Conclusions



- Higgs has no place to hide !
  - Squeezing allowed mass from both sides
    - 95% CL Exclusion 158 < m_H < 175 GeV (about expected)
    - Limit 1.5*SM @ 115 GeV
- BSM searches : consistent with SM
  - 2 sigma is largest discrepancy in CDF MSSM H→bb (so far)

Higgs production at Tevatron

Baglio

$M_H \gtrsim 150$ GeV, $gg \to H$ channel

Exact at NLO QCD[a], $K_{\rm NLO} \sim 2$

Infinite top mass at NNLO QCD[b], $K_{\rm NNLO} \sim 3$

Exact NLO EW corrections[c],

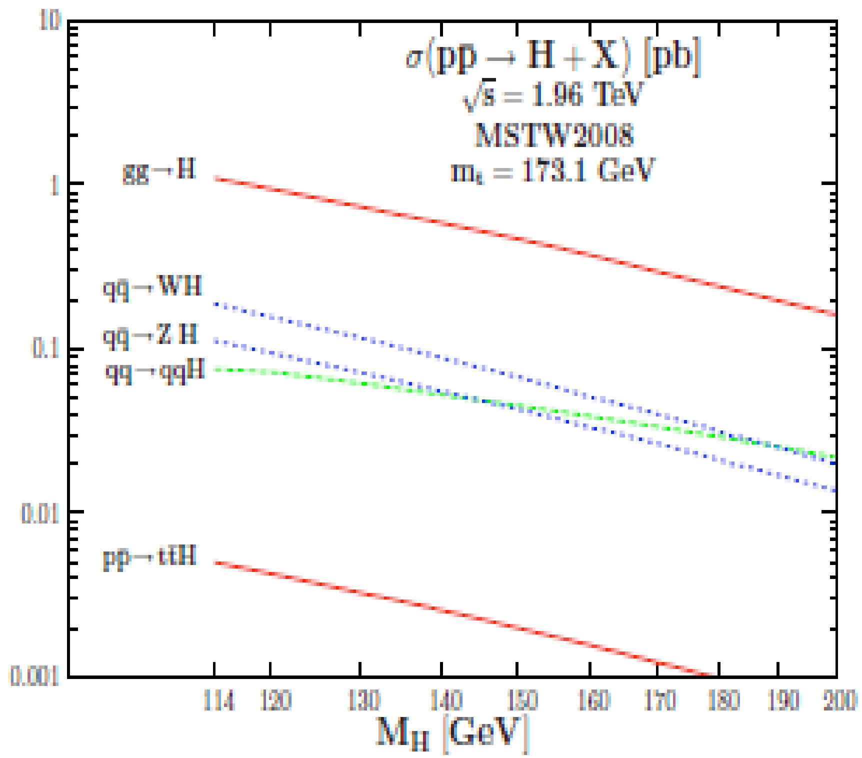
Effective NNLO mixed QCD-EW[d]: $\simeq \pm$ a few %

$M_H \lesssim 150$ GeV, $p\bar{p} \to HV$ channel

Exact at NNLO QCD[e], $K_{\rm NNLO} \sim 1.5$

Exact NLO EW corrections[f] $\simeq -5\%$

CKM effects included ($\sim -5\%$)



[a] Dawson (EFT, 1991), Djouadi, Spira & Zerwas (EFT, 1991); Spira, Djouadi, Graudenz, Zerwas (1995)

[b] Harlander & Kilgore (2002), Anastasiou & Melnikov(2002), Ravindran, Smith & V. d. Neerven (2003)

[c] Djouadi & Gambino (1994), Aglietti *et al.* (2004), Degrassi & Maltoni (2004), Actis *et al.* (2008)

[d] Anastasiou, Boughezal, Pietriello (2009)

[e] Hamberg, V. d. Neerven & Matsuura (1991), Brein, Djouadi & Harlander (2004)

[f] Ciccolini, Dittmaier, Krämer (2003)

Resummation in the gluon–gluon fusion channel?

Gluon–gluon fusion channel known up to Next-to-Next-to-Leading-Logarithm (NNLL)
(Catani, de Florian, Grazzini & Nason (2003)). But here not included because:

- Experimental analysis still at the NNLO
  $\Rightarrow$ theoretical input should be (for now) at NNLO
- Cross section with cuts (and no resummation) have reduced K–factors
  $\Rightarrow$ should be seen in the NNLO scale uncertainty
- No PDF at the NNLL level until now
  $\Rightarrow$ calculation slightly inconsistant (Corcella & Magnea (2005))

Scale uncertainty

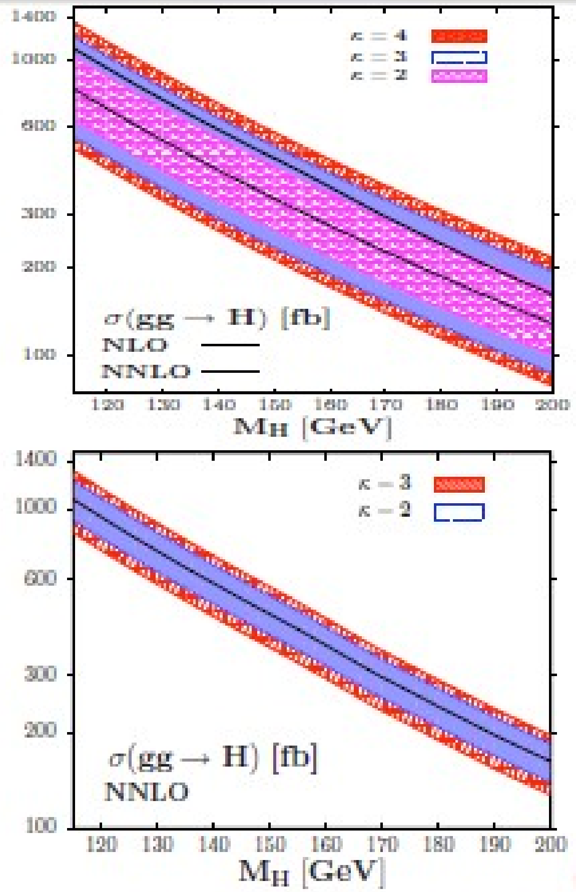
Higher orders (HO) guessed with μ_R, μ_F variation around central $\mu_0 = m_H$

$$\frac{m_H}{\kappa} \leq \mu_R, \mu_F \leq \kappa m_H$$

Small HO $\Rightarrow \kappa = 2$ enough (ex. $q\bar{q} \to HV$)

Large HO in $gg \to H$ ($K_{HO} \simeq 3$)
guess scale domain from $\sigma_{\rm NLO}$:
NLO band catches $\sigma_{\rm NNLO}$
$\Rightarrow \kappa = 3$ needed (at least) according to our criterium
NNLO $gg \to H$: $\simeq 20\%$ scale variation

($\neq 10\%$ assumed by CDF/D0)



Different sets of PDFs on the market
$\Rightarrow$ differents errors on individual PDF
+ different central values
All have $\sim 5-7\%$ error, but central ABKM is 25% smaller than MSTW/CTEQ !

~20%

Putting together all the errors

Combining the errors: quadature or linear?

CDF: 10% scale $\oplus$ 5% PDF = 11% total error

D0: 10% total error

Reasonable way: add in quadature

PDF+$\Delta^{\rm exp+th}\alpha_s$ on $^{\rm min}_{\rm max}\sigma(\mu)$

and eventually linearly the small EW and b–loop errors

$gg \to H$: $\sim \pm 40\% \gg\sim 10\%$ CDF/D0

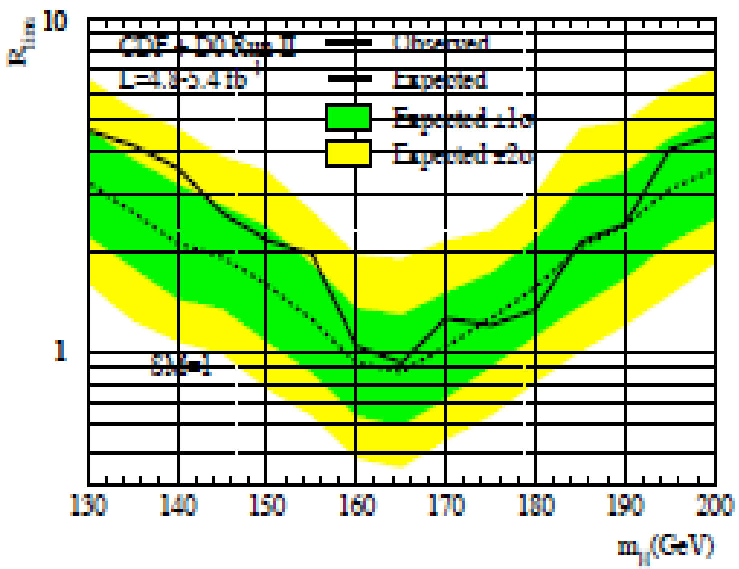
$p\bar{p} \to HV$: $\sim \pm 10\% >\sim 5\%$ CDF/D0

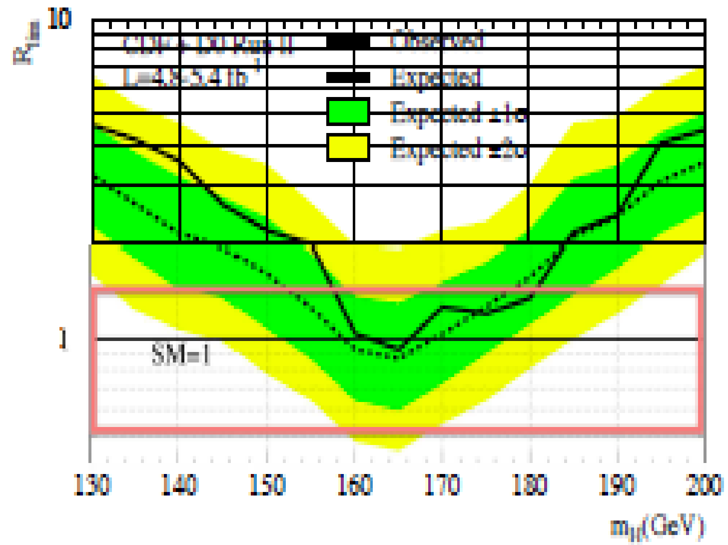
$p\bar{p} \to HV$ much more under control

CDF+D0 exclusion bands?

CDF& D0: excluded $M_H \in [162 - 166]$ GeV (Phys. Rev. Lett. 104, 061803 (2010))

But with our errors:





This 95% CL exclusion should therefore be reconsidered

Summary and conclusion

Higgs production at Tevatron

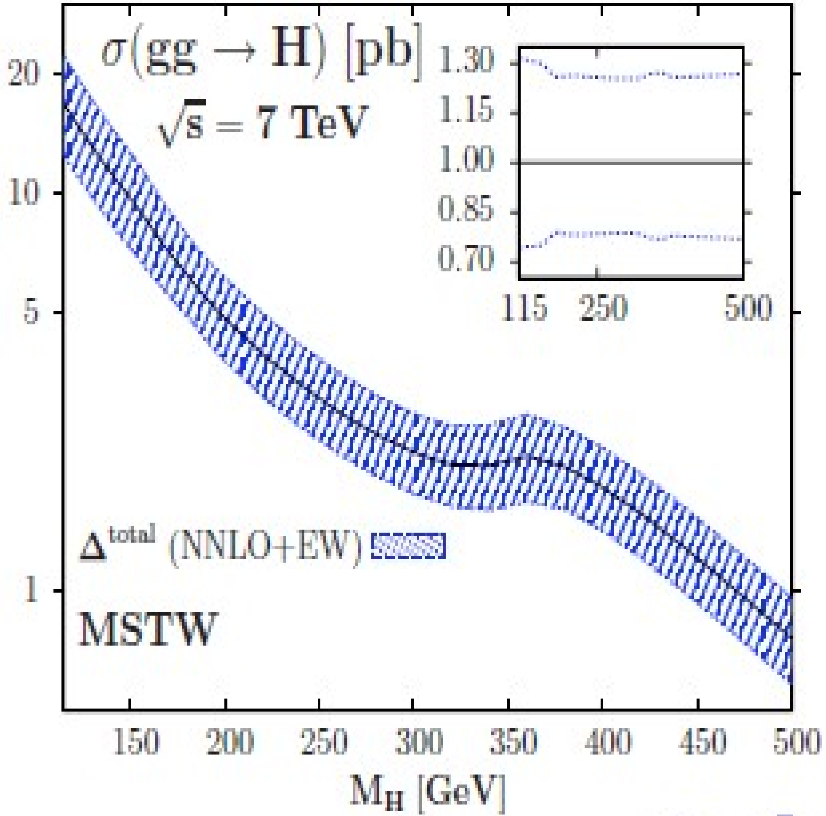
- The two most important channels have been revisited at Tevatron (minor update for the two others)
- gluon–gluon fusion has been thoroughtly studied with all uncertainties: scale, PDF, $\alpha_s^{\rm exp+th}$, EFT
- Higgs–strahlung has been revisited with all major uncertainties: scale, PDF, $\alpha_s^{\rm exp+th}$
- **The overall $\simeq 40\%$ error on $gg \to H$ cross section implies that the Tevatron exclusion bands on Higgs mass should be revisited**
- **Same has also been done at ℓHC = LHC@7 TeV and 1 fb^{-1} for gluon–gluon fusion**, MSSM study under way

Backup: $gg \to H$ at the LHC@7 TeV

Combination: same exercice as at Tevatron

Final error in gg → H: $\sim -25\%$, $\sim +30\%$

much more under control than at Tevatron ($\sim -40\%$, $+50\%$ error).



International Workshop on Linear Colliders
Geneva, October 18-22, 2010

(ECFA-CLIC-ILC Joint Meeting)

https://espace.cern.ch/LC2010/default.aspx

479 participants

Origin of the Linear Collider Idea

M. Tigner,
Nuovo Cimento **37** (1965) 1228

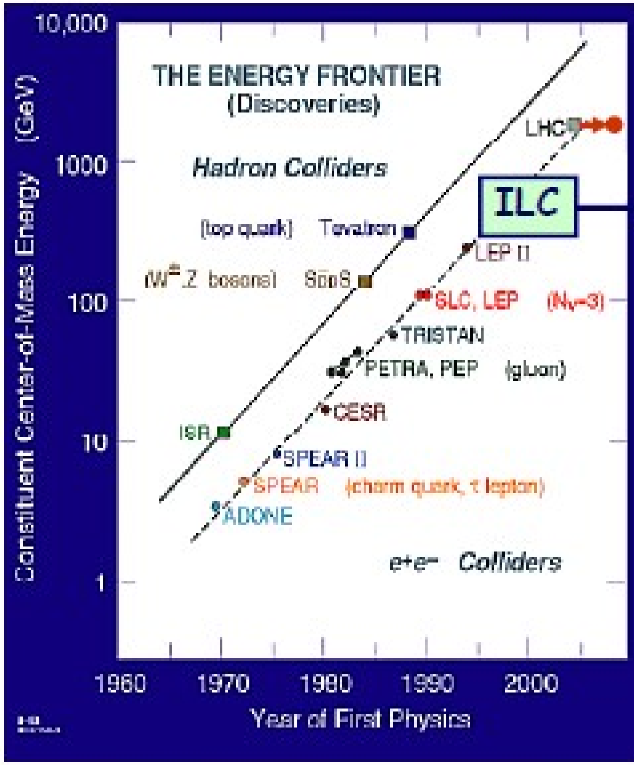
A Possible Apparatus for Electron-Clashing Experiments (*).

M. Tigner

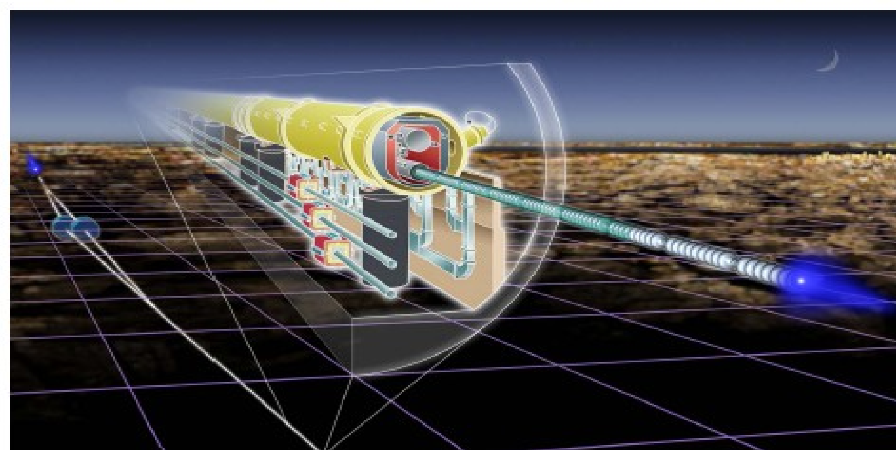
Laboratory of Nuclear Studies. Cornell University - Ithaca, N.Y.

"While the storage ring concept for providing clashing-beam experiments ([1]) is very elegant in concept it seems worth-while at the present juncture to investigate other methods which, while less elegant and superficially more complex may prove more tractable."

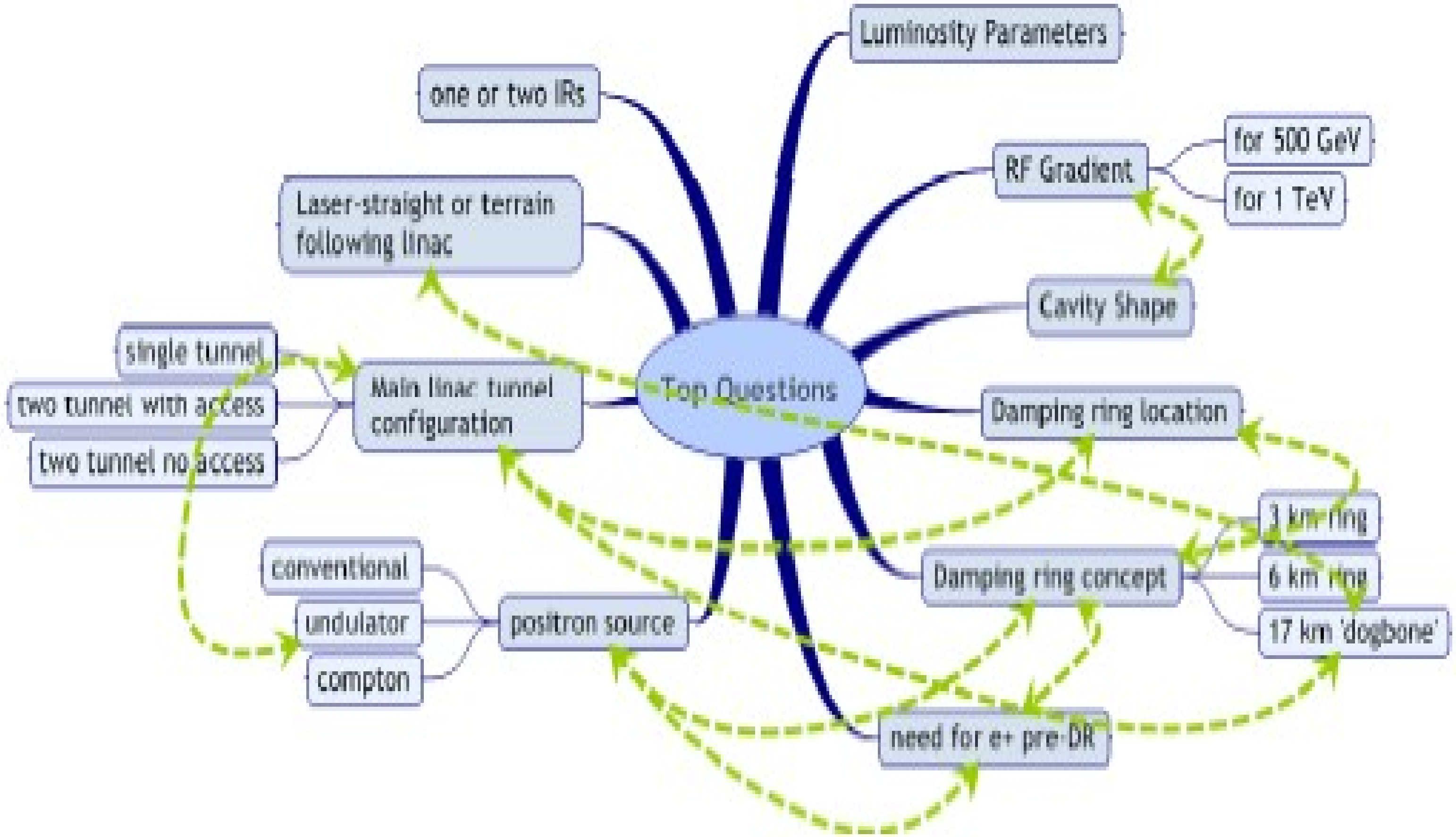
Energy Frontier and e^+e^- Colliders



ILC Pictorial View



Making Choices – The Tradeoffs



Energy&Lumi

Towards a future Linear Collider and The Linear Collider studies at CERN

Steinar Stapnes (CERN)

		CLIC	CLIC	ILC
E_{cms}	[TeV]	0.5	3.0	0.5
f_{rep}	[Hz]	50	50	5
f_{RF}	[GHz]	12	12	1.3
G_{RF}	[MV/m]	80	100	31.5
n_b		354	312	2625
Δt	[ns]	0.5	0.5	369
N	$[10^9]$	6.8	3.7	20
σ_x	[nm]	202	40	655
σ_y	[nm]	2.26	1	5.7
ϵ_x	[μm]	2.4	0.66	10
ϵ_y	[nm]	25	20	40
$\mathcal{L}_{total}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	2.3	5.9	2.0
$\mathcal{L}_{0.01}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.4	2.0	1.45

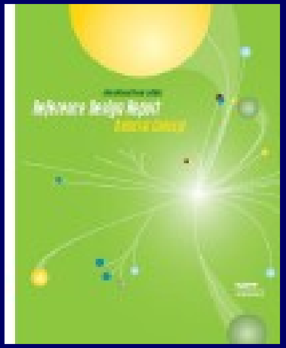
Train repetition rate 5 Hz (ILC) or 50 Hz (CLIC)

CLIC:	1 train = 312 bunches	0.5 ns apart	50 Hz
ILC:	1 train = 2625 bunches	369 ns apart	5 Hz

RDR Design Parameters

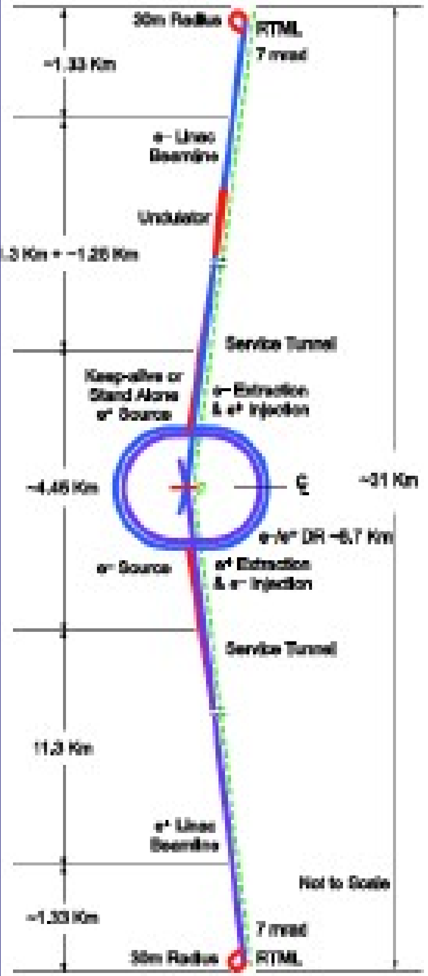
Max. Center-of-mass energy	500	GeV
Peak Luminosity	~2×10^{34}	$1/cm^2s$
Beam Current	9.0	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.95	ms
Total Site Length	31	km
Total AC Power Consumption	~230	MW

2007

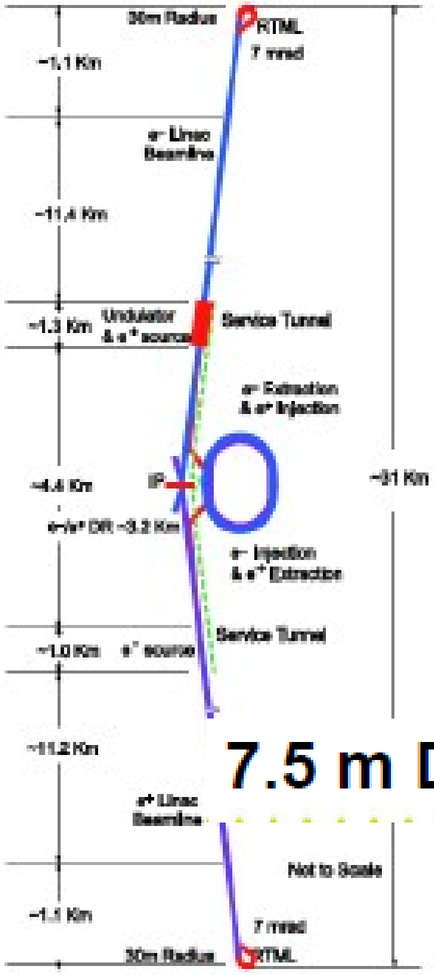


Proposed Design changes for TDR

RDR



SB2009



- Single Tunnel for main linac
- Move positron source to end of linac ***
- Reduce number of bunches factor of two (lower power) **
- Reduce size of damping rings (3.2km)
- Integrate central region
- Single stage bunch compressor

7.5 m Diameter Single Tunnel

Compact Linear Collider CLIC   Poland?

Delsahaye

CLIC Feasibility status

System	Item	Feasibility Issue	Unit	Nominal	Achieved	How	Feasibility
Two Beam Acceleration	Drive beam generation	Fully loaded accel effic	%	97	95	CTF3	✓
		Freq&Current multipl	-	2*3*4	2*4	CTF3	✓
		12 GHz beam current	A	4.5*24=100	3.5*8=28	CTF3	✓
		12 GHz pulse length	nsec	240	240	CTF3	✓
		Intensity stability	1.E-03	0.75	0.6	CTF3	✓
		Drive beam linac RF phase stability	Deg (1GHZ)	0.05	0.035	CTF3, XFEL	✓
	Beam Driven RF power generation	PETS RF Power	MW	130	130	TBTS/SLAC	✓
		PETS Pulse length	ns	170	>170	TBTS/SLAC	✓
		PETS Breakdown rate	/m	< 1·10-7	>1.2 10-6	TBTS/SLAC	✓
		PETS ON/OFF	-	@ 50Hz	-	CTF3/TBTS	2011
		Drive beam to RF efficiency	%	90%	-	CTF3/TBL	2010-11
		RF pulse shape control	%	< 0.1%	-	CTF3/TBTS	
	Accelerating Structures (CAS)	Structure Acc field	MV/m	100	100	CTF3 Test Stand, SLAC, KEK	✓
		Structure Flat Top Pulse length	ns	170	170		✓
		Structure Breakdown rate	/m MV/m.ns	< 3·10-7	5·10-5(D)		2010-11
		Rf to beam transfer efficiency	%	27	15		2010-11
	Two Beam Acceleration	Power producton and probe beam acceleration in Two beam module	MV/m - ns	100 - 170	55 - 170	TBTS	2011-12
		Drive to main beam timing stability	psec	0.05	-	CTF3	2012
		Main to main beam timing stability	psec	0.07	-	CTF3	2012
Ultra low beam emittance & sizes	Ultra low Emittances	Emittance generation H/V	nm	500/5	3000/12	ATF, NSLS/SLS + simulation	✓
		Emittance preservation: Blow-up	nm	160/15	160/15		2010-12
	Alignment	Main Linac components	microns	15	10 (princ.)	Alignment & Mod.Test Bench	2010
		Final-Doublet	microns	2 to 8			2010
	Vertical stabilisation	Quad Main Linac	nm>1 Hz	1.5	0.13 (principle)	Stabilisation Test Bench	2010-12
		Final Doublet (assuming feedbacks)	nm>4 Hz	0.2			

"Circumstances Beyond Our Control"

- **The fire (March 4th)**

  → 6 months delay

- **The "Lehman" effect**
  - **Reduced CERN budget 2011-2015**

    (Lehman: 16/9/08
    CERN impact 16/6/10)

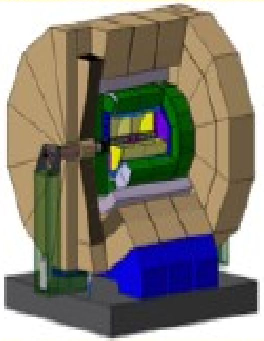
Combined ILC/CLIC working groups

	CLIC	ILC
Physics & Detectors	L Linssen	F Richard, S Yamada
Beam Delivery System (BDS) & Machine Detector Interface (MDI)		
Civil Engineering & Conventional Facilities		
Positron Generation		
Damping Rings		
Beam Dynamics		
Cost & Schedule		

Validated ILC concepts

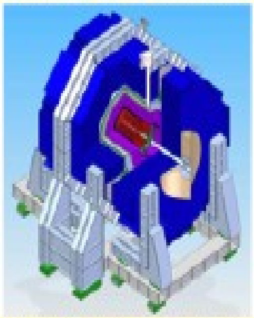
ILD: International Large Detector

"Large" : tracker radius 1.8m
B-field : 3.5 T
Tracker : TPC + Silicon
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid



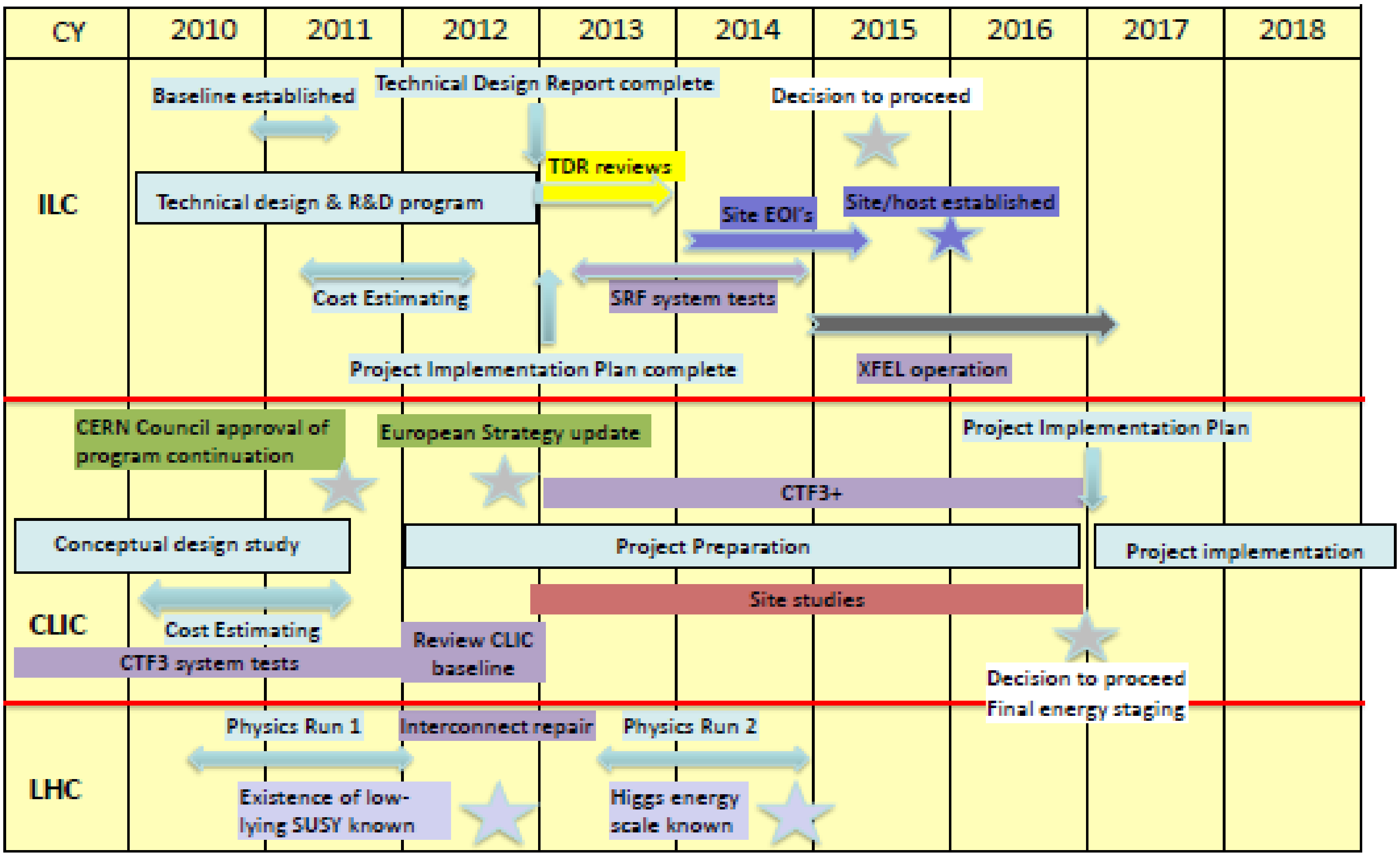
SiD: Silicon Detector

"Small" : tracker radius 1.2m
B-field : 5 T
Tracker : Silicon
Calorimetry : high granularity particle flow
ECAL + HCAL inside large solenoid



CLIC detector concepts will be based on SiD and ILD.
Modified to meet CLIC requirements

CLIC & ILC roadmaps



Ph.Lebrun

ILC (250 GeV)-

From the LOIs to the DBDs- Coverage of Higgs Studies - Roman Pöschl

Benchmarks for the LOIs 2009

$e^+e^- \rightarrow h^0Z^0$: 120 GeV Higgs @ 250 GeV

- Based on compelling arguments for a light Higgs

- Production at threshold

- Precision measurements to pin down nature of Higgs boson

- Higgs-strahlung cross section and recoil mass
  => Coupling Modifications wrt. SM?
  Precision in Higgs Mass (????),
  Currently no direct "application" for σ_{Mh} ~ 30 MeV

- Branching ratios into heavy quarks (and gluons)
  Scaling with quark mass, crucial test of nature of Higgs boson

Precision in ILD and SiD LOI
h → bb: 1-3%
h → cc: 10% (SID), 12% (ILD, shown at LCWS10)

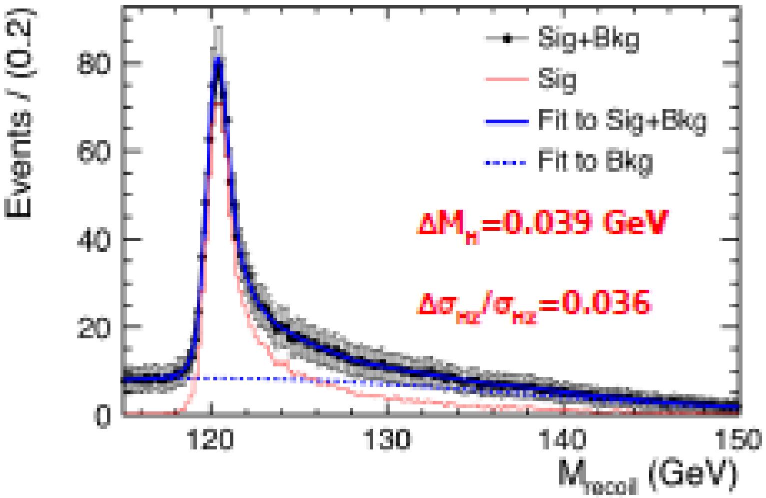
detailed baseline design (DBD)

Letters of Intents (LOIs)

Reminder - Results LOI 2009

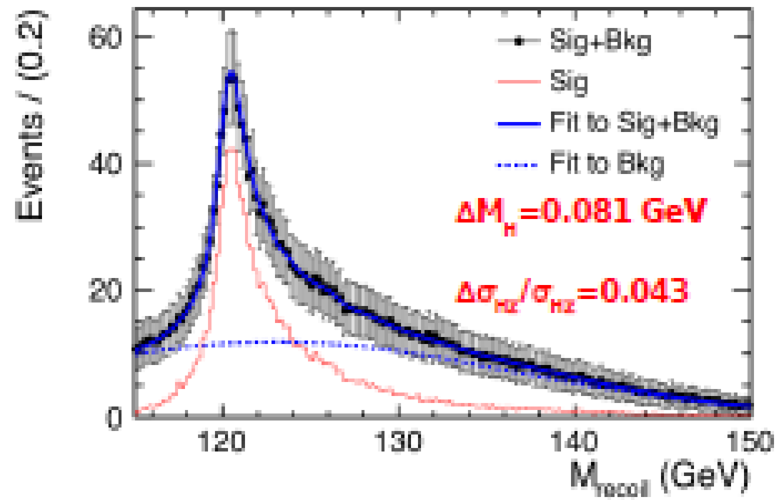
Total energy 250 GeV

Muon Channel



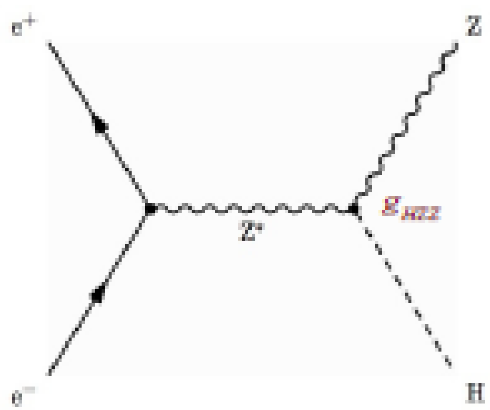
Very Precise Measurement
S/B = 8 in Peak Region

Electron Channel



Less Precise
Bremsstrahlung in detector material

Combined: ΔM_H=0.035 GeV, $\Delta\sigma_{HZ}/\sigma_{HZ}$=0.027



$$\sigma_{HZ} \sim g^2_{HZZ}$$

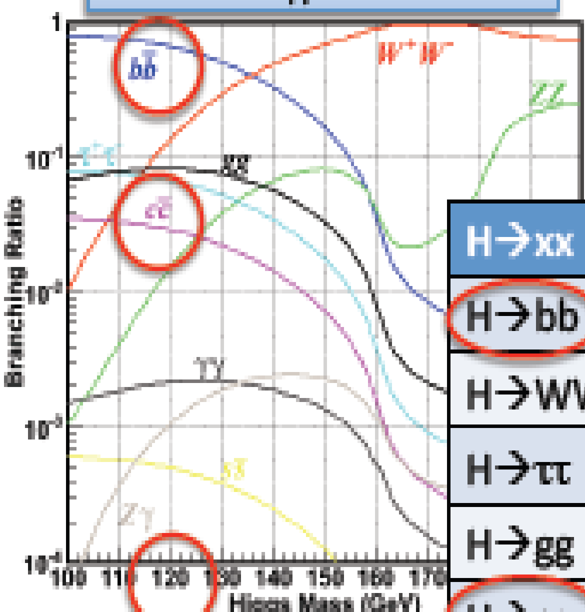
⇒ Precision in g_{HZZ} coupling 1-2%

Sensitivity to 15% deviations
SM prediction of cross section

ZH Branching Ratio measurement

Higgs BR study at Ecm=250 GeV is one of the benchmark process in LOI
Higgs BR at Ecm=350 GeV is also the new benchmark process for DBD

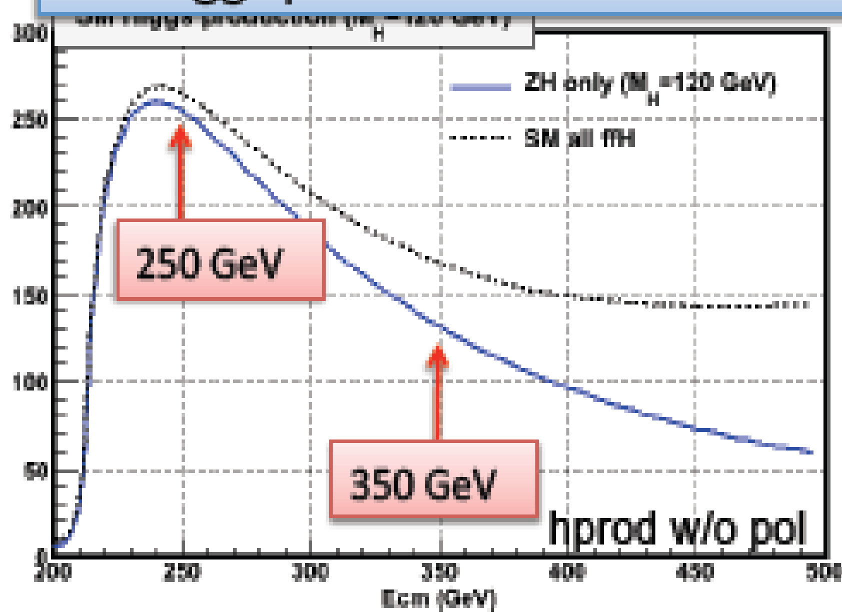
BR at M_H=120 GeV



H→xx	BR
H→bb	66.7%
H→WW	14.0%
H→ττ	6.8%
H→gg	5.5%
H→cc	3.6%

(in pythia)

SM Higgs production cross section



Cross section	Ecm=250GeV	Ecm=350GeV
ffH (w/ beam pol)	319.4 fb^{-1}	274.9 fb^{-1}

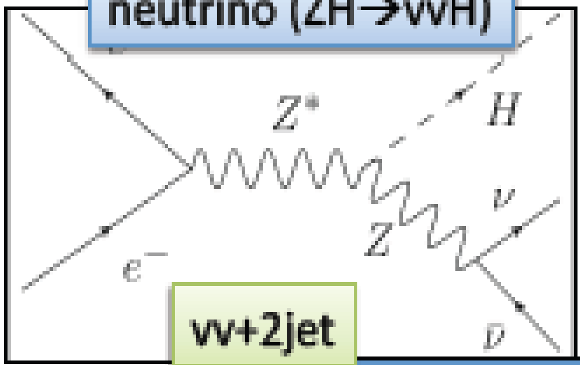
ZH (hprod)	254 fb^{-1}	131 fb^{-1}

Simulation setup and signal samples

H.Ono

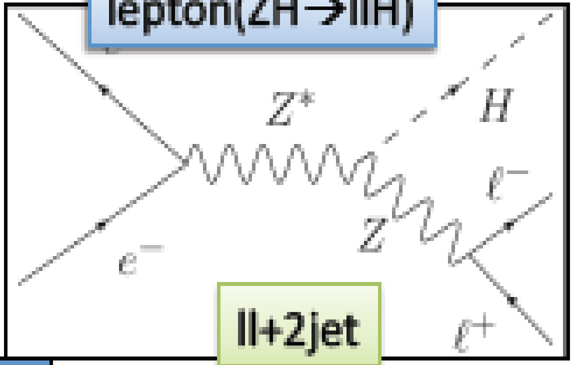
Event generation : whizard
Simulation and analysis : ilcsoft v01-06
Detector model : ILD_00 full simulation
Beam parameter : RDR(LOI 250GeV), SB2009 w/ TF (350 GeV)
Data samples : DST sample produced in KEK (A. Miyamoto)
lfn:/grid/ilc/users/miyamoto/CDS/reconstructed/ILD_00/CMS_350

neutrino (ZH→vvH)



hadron(ZH→qqH)

lepton(ZH→llH)



DST sample include t-channel

Cross section	vvH	qqH	llH
250 GeV	77.4 fb	210.0 fb	31.7 fb
350 GeV	105.2 fb	144.4 fb	25.3 fb

Beam polarization (e+,e-)=(+30%, -80%)

(Complicated) Final States of the Higgs Boson I

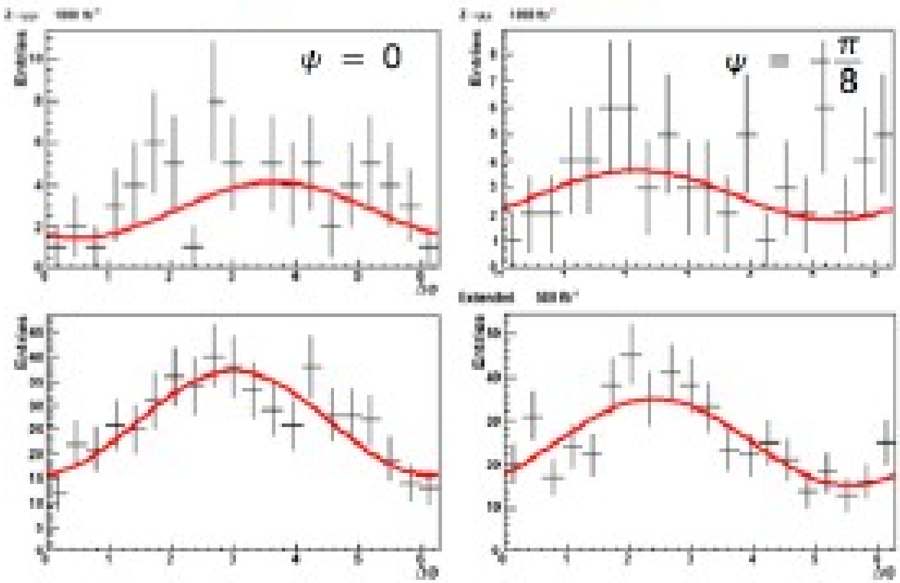
Higgs properties via ee → ZH → ff ττ   e.g. CP violating Higgs: $g\bar{\tau}(\cos\psi + i\sin\psi\,\gamma_5)\tau$

Look at hadronic decays of the τ lepton: $\tau^{\pm}\to\nu_{\tau}\pi^{\pm}$ $\tau^{\pm}\to\nu_{\tau}\rho^{\pm}\to\nu_{\tau}\pi^{\pm}\pi^{0}$

Information on CP violating phase can be extracted via (azimuthal) angles between decay mesons in tau restframe and flight direction of τ
(nice exercise on kinematics and frame transformation)

PID based on photon counting in SiW electromagnetic calorimeter (of ILD)

m_H = 120 GeV
√s = 250 GeV
L=300/fb



$Z \to \mu^+\mu^-$

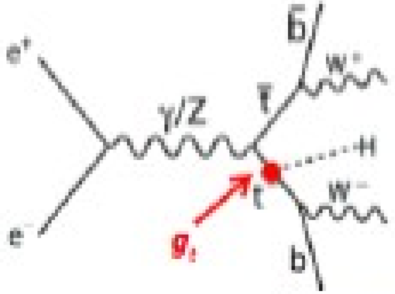
$Z \to \mu^+\mu^-$, e^+e^-, $q\bar{q}$ q=u,d,s

χ² fit with the function

$$W_{fit}(\Delta\phi) = a(1 - b\cos(\Delta\phi - 2c))$$

Net result: CP violating phase larger than pi/8 can be excluded at 4.5 sigma level

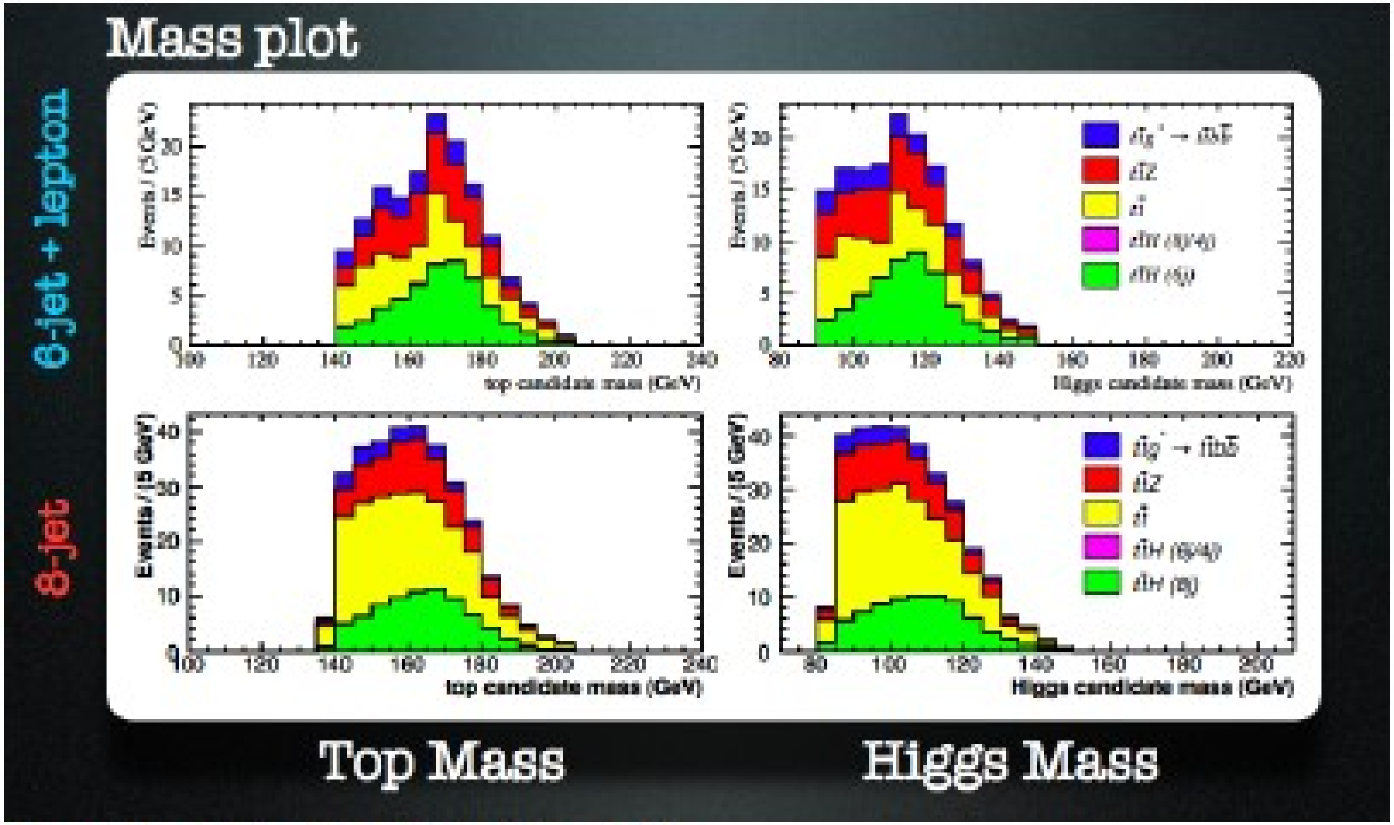
(Complicated) Final States of the Higgs Boson II



Top Yukawa Coupling

Benchmark scenario √s @ = 1 TeV

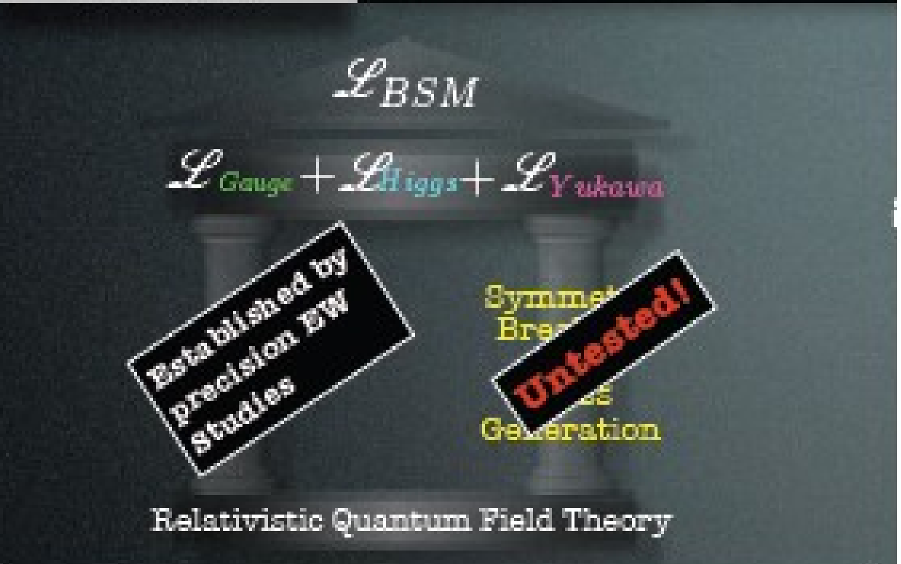
Here preliminary study at √s=500 GeV with fast simulation

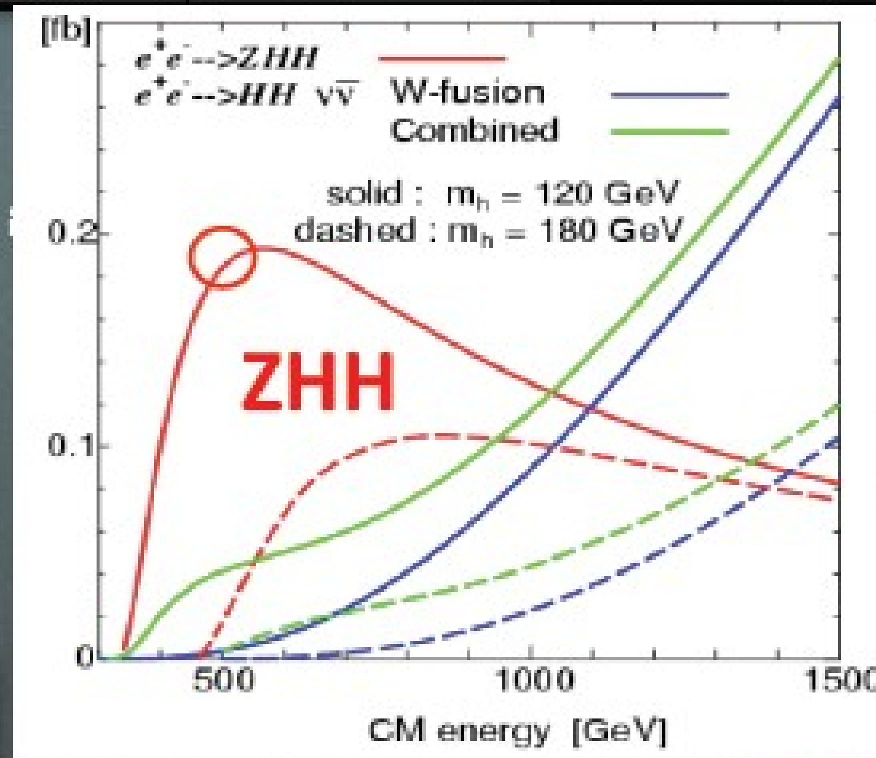


Beam Polarisation: (Pe-, Pe+) = (-0.8, +0.3)

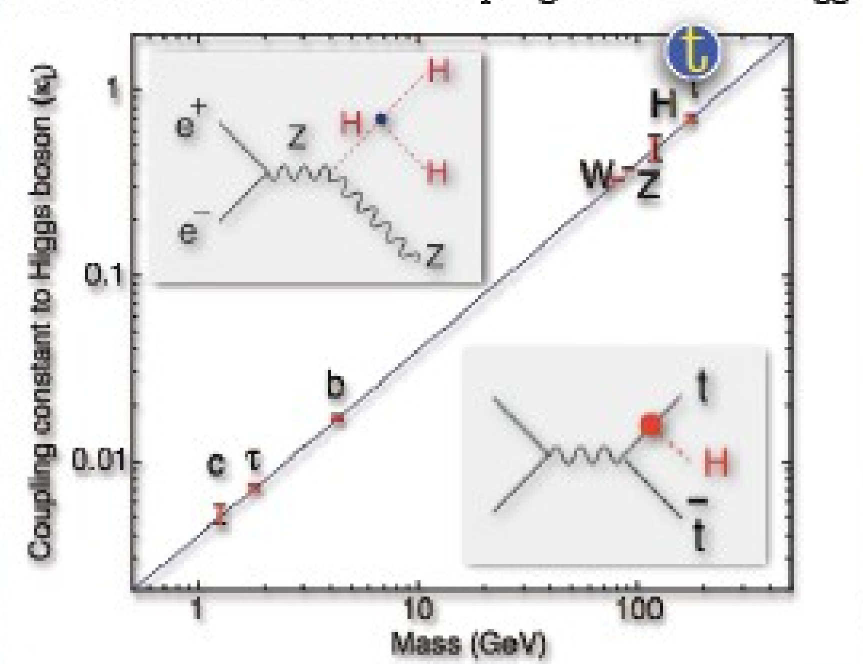
Main Conclusion: Top Yukawa Coupling can be measured to 10% accuracy

Needs, however confirmation in full simulation!!!





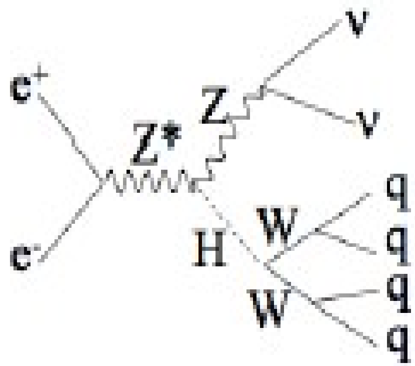
Relation between mass and coupling constant with Higgs



Higgs self coupling will be tested at ~500 GeV where e+e- -> ZHH cross section attains its maximum.

Our motivation is to confirm the untested pillar by measuring Top-Yukawa coupling at 500 GeV (1st stage of ILC) concurrently to measuring Higgs self coupling.

Complicated Final States of the Higgs boson III



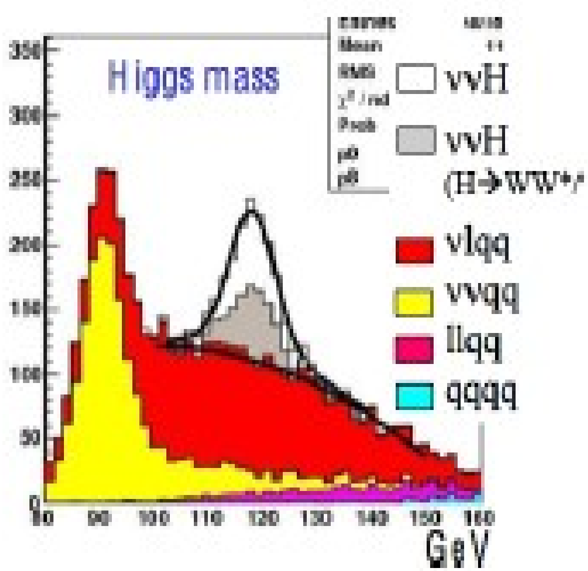
(Anomalous) couplings: H → W*W

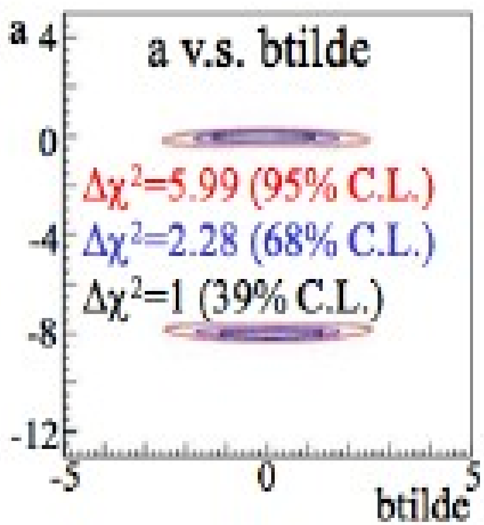
CP even   CP odd

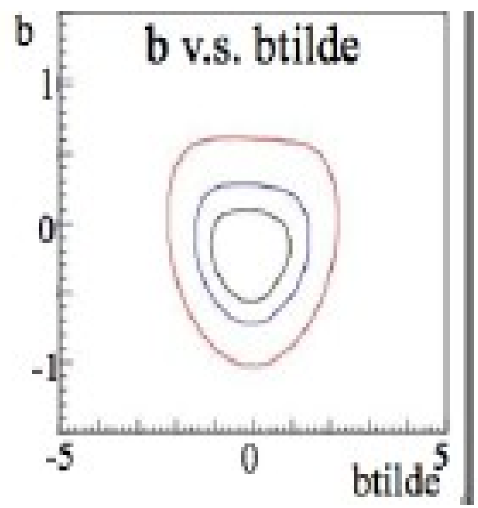
$$\mathcal{L} = 2m_W^2 \left(\frac{1}{v} + \frac{a}{\Lambda}\right) H W^+_\mu W^{-\mu} + \frac{b}{\Lambda} H W^+_{\mu\nu} W^{-\mu\nu} + \frac{\tilde{b}}{\Lambda} H \epsilon^{\alpha\beta\mu\nu} W^+_{\mu\nu} W^-_{\alpha\beta}$$

Study @ $\sqrt{s}$ = 250 GeV for m_H=120 GeV

Likelihood analysis to cope with considerable background







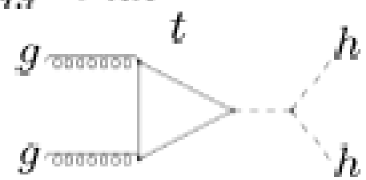
Study of Higgs Self-couplings at ILC

J. Tian (Tsinghua U.)
Y. Takubo (Tohuko U.)
K. Fujii (KEK)
Y. Gao (Tsinghua U.)

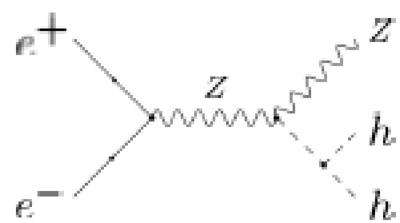
Measurement of hhh coupling

Measurement of hhh coupling at collider experiment

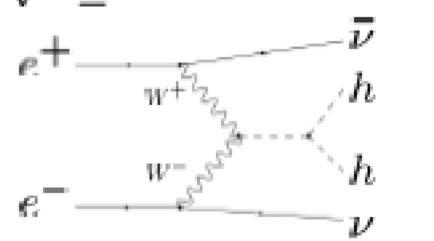
- LHC (SLHC) $gg \to hh$



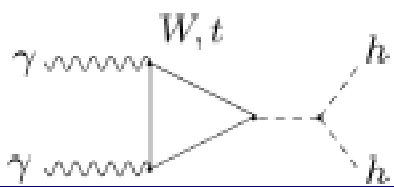
- ILC $e^+e^- \to Zhh$
  $\sqrt{s} = 500\text{GeV}$



- ILC/CLIC $e^+e^- \to hh\bar{\nu}\nu$
  $\sqrt{s} \geq 1\text{TeV}$



- Photon Collider (PLC) $\gamma\gamma \to hh$



motivation

SM: $\tilde{\lambda} = \lambda = \lambda_{SM} = \frac{m_H^2}{2v^2}$

Higgs Potential: $V(\eta_H) = \frac{1}{2} m_H^2 \eta_H^2 + \lambda v \eta_H^3 + \frac{1}{4} \tilde{\lambda} \eta_H^4$

physical Higgs field

mass term

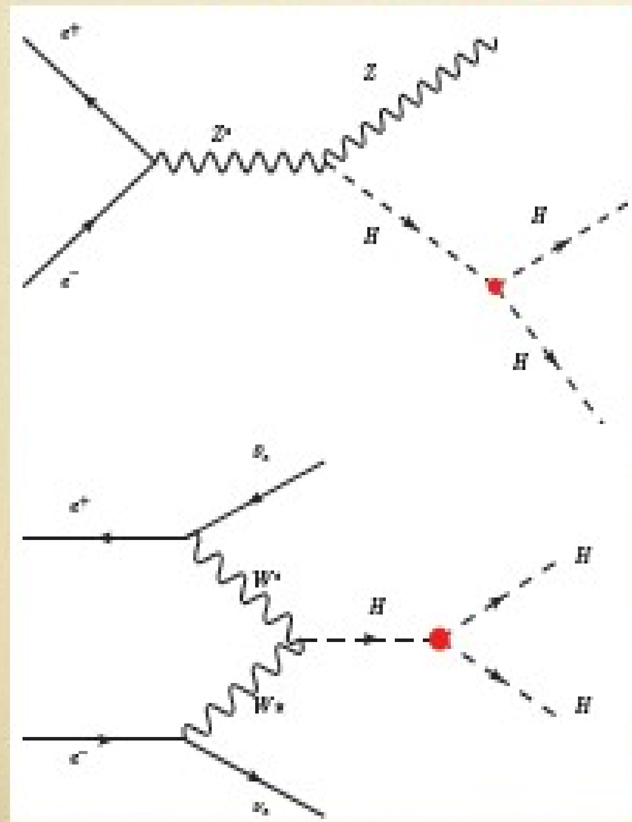
trilinear coupling

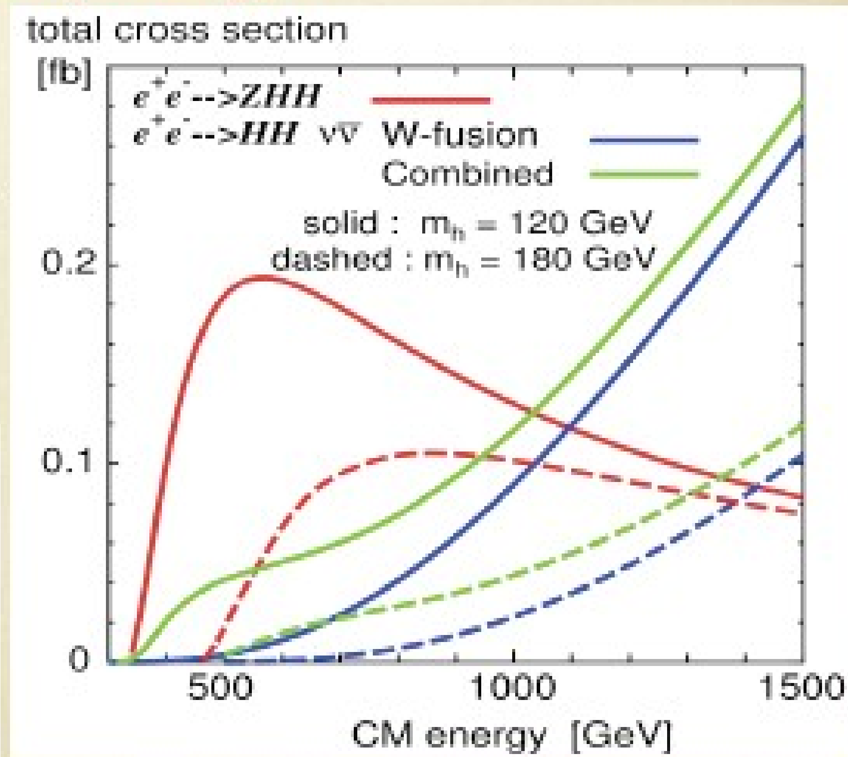
quartic Higgs coupling, which is difficult to measure at both LHC and ILC, even SLHC!

- a new interaction (non-gauge interaction).
- the non-trivial probe of the Higgs potential, offer a direct independent determination.
- accurate test of this coupling may reveal the extended nature of Higgs sector, like 2HDM and SUSY.
- difficult to measure at LHC for a light Higgs.

Measurement of the trilinear Higgs self-coupling @ ILC

- double Higgs-strahlung (dominate at lower energy)
- WW fusion (dominate at higher energy)





status of the simulation (preliminary)

$e^+ + e^- \rightarrow ZHH$ $e^+ + e^- \rightarrow \nu\nu HH$ $M(H) = 120\text{GeV}$ $\int Ldt = 2\text{ab}^{-1}$

Energy (GeV)	Modes	Fast Simulation	Full Simulation
500	$ZHH \rightarrow (l\bar{l})(b\bar{b})(b\bar{b})$	2.5σ	3.6σ
500	$ZHH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	0.8σ	1.3σ
500	$ZHH \rightarrow (q\bar{q})(b\bar{b})(b\bar{b})$	2.0σ	2.0σ
500	$ZHH \rightarrow (q\bar{q})(b\bar{b})(WW^*)$	0.05σ	-
1,000	$\nu\bar{\nu}HH \rightarrow (\nu\bar{\nu})(b\bar{b})(b\bar{b})$	2.5σ	-

- from LCWS2010, full simulations of llHH and vvHH were investigated (today's topic).
- qqHH analysis was presented at ALCPG09 by Takubo-san.
- improvement in full simulation comes from b tagging and background specification.

$e^+ + e^- \rightarrow ZHH \rightarrow (l\bar{l})(b\bar{b})(b\bar{b}) \rightarrow 2\ \text{leptons} + 4\ \text{bjets}$

full simulation @ 500GeV

pre-selection:

- two isolated charged leptons (the pair nearest to Z mass is selected)
- force the other particles(PFOs) to four jets
- combine the four jets by minimizing

$$\chi^2 = \frac{(M(b,\bar{b}) - M_H)^2}{\sigma_{H_1}^2} + \frac{(M(b,\bar{b}) - M_H)^2}{\sigma_{H_2}^2} + \frac{(M(l,\bar{l}) - M_Z)^2}{\sigma_Z^2}$$

do not effect minimization

requirement implied in the pre-selection:

- $|M(ll)-M(Z)| < 40$ GeV
- $|M(jj)-M(H)| < 80$ GeV

$$e^+ + e^- \to ZHH \to (l\bar{l})(b\bar{b})(b\bar{b}) \to 2 \text{ leptons} + 4 \text{ bjets}$$

(preliminary)

- 4.93 signal events with 0.50 background events:
  - ZHH excess significance: 3.6σ
  - 68% confidence level: $5.4^{+3.5}_{-2.3}$ 54% for cross section
  - precision for Higgs self-coupling: 97%
- llbbH not considered: as rough estimation, 1.0 event could be involved.
- statistics of llbb backgrounds is not enough (we are generating more samples)

CLIC Study at 3 TeV of Heavy Higgs Bosons

Battaglia

e+e- → H0A0 → bbbb in Dark Matter motivated SUSY

Scenario 1) (S Martin, CLIC Study Group)

MSSM model
with non-unified gaugino masses

M_1=780 GeV, M_2=940 GeV, M_3=540 GeV
m_0 = 303 GeV, A_0 = -750 GeV, tan β = 24,
μ>0

M_A = 902.6 GeV M_H = 902.4 GeV

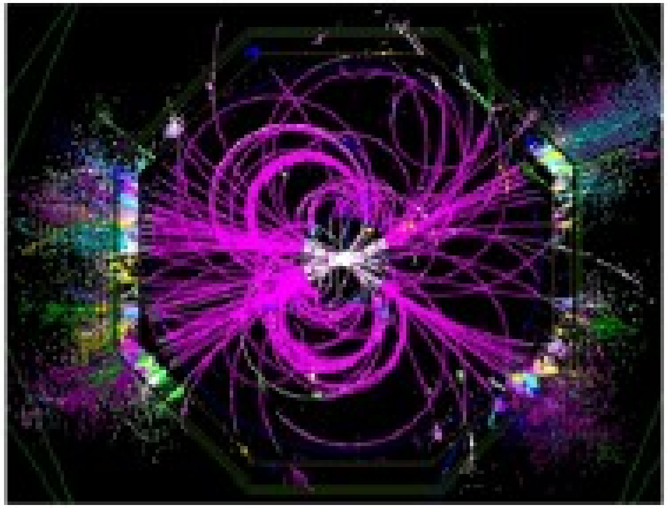
Scenario 2) (Point K' of
MB et al, Eur. Phys. J. C33 (2004))

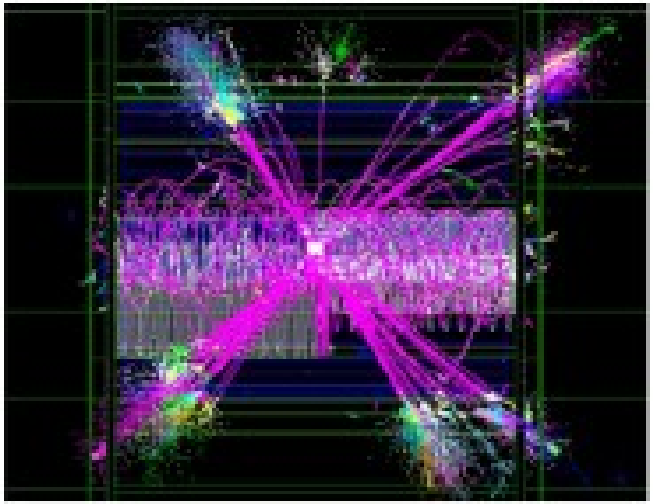
cMSSM model

m1/2=1300 GeV, m_0 = 1001 GeV,
A_0 = 0, tan β = 46, μ<0

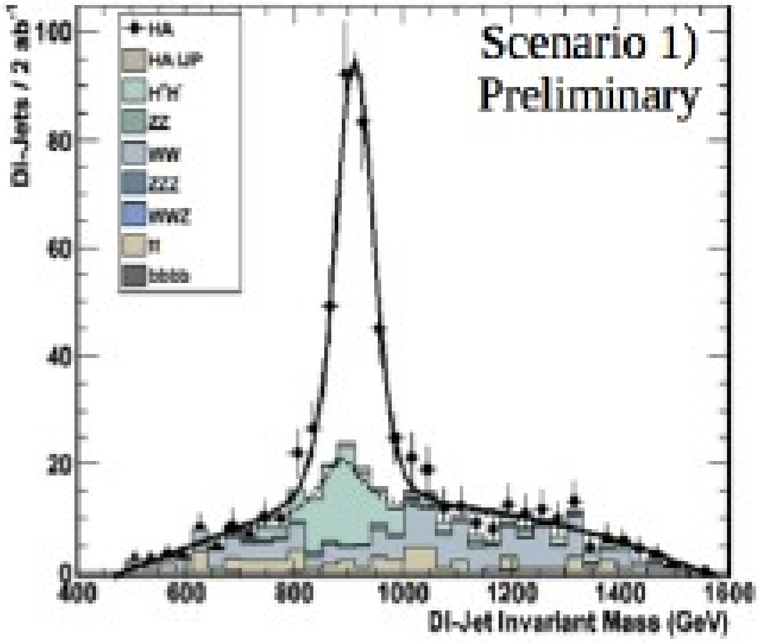
M_A = 1139.2 GeV M_H = 1143.8 GeV

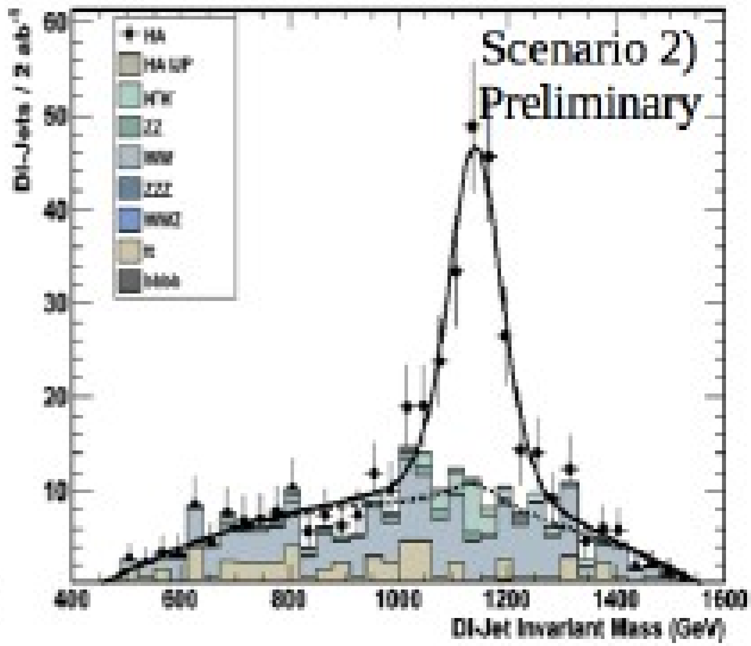
Study employing full detector simulation and reconstruction





Higgs Mass Reconstruction
(3 TeV, 2 ab^{-1})





7-par Fit (M_A, Γ, N_{sig}, Bkg shape)
M_A = (906.2+/-3.3 (stat)) GeV

7-par Fit
M_A = (1141.0+/-6.0 (stat)) GeV

Precision measurement
Robust against γγ background

Conclusion

- Linear Collider is (still) the ideal machine to study the properties of the Higgs boson

- Most analyses start from a light Higgs with m_H~120 GeV

- Most of the properties of the Higgs can be measured or determined in current energy range of the ILC
  - e.g. here CP violatiing Higgs or not
  - (anomalous) couplings to Fermions and gauge bosons

  (I think) turn towards 1 TeV starts after IWLC10

- A machine operated at higher energies need to prove that these Higgs properties can be determined with the same precision

  - CLIC would have a "final" word on Higgs compositeness
  - CLIC would see directly heavy Higgs states as suggested/required by/in SUSY scenarios

- Most of the analyses look directly into the Higgs decay
  Little use of the advantages of Model Independent determination of Higgs properties

- Question to community: What to do with ee → HZZ?

Physics scenarios at the LHC and their possible impact on the LC

Planned activities to investigate the impact of LHC results on the futur strategy of particle physics and possible input for the update of the European Strategy - Michelangelo Mangano (CERN)

Suppose the LHC does not find evidence for new physics with 1 fb-1 at 7 TeV: what is the remaining parameter space of new physics models and what does this imply for future prospects and for the LHC run at 14 TeV in 2013? - Michael Peskin (SLAC)

Suppose there is evidence for a (or several) new particle(s) at the LHC with 1 fb-1 at 7 TeV: how well would one know the properties of such a new state from the early data? - Oliver Buchmueller (Imperial College London)

Once a Higgs candidate has been detected, how precisely does one need to measure the properties (mass, couplings, ...) of such a state? Gian Giudice (CERN) , Georg Weiglein (DESY)

Preparing the LHC input to the 2012 CERN Council Strategy Group

Michelangelo L. Mangano, CERN PH-TH

Strategy Group:

- Council expected to complete the definition of the process and the SG composition by June 2011
- Current planning foresees an open Symposium around Febr 2012, a SG workshop in Summer 2012, and the final discussion by Council in the Fall 2012

Task assigned by CERN's DG: Assessment and documentation of the LHC findings, during the 2010-11 run, in the search for the Higgs boson and for new physics

This document will be submitted to the Strategy Group by Winter 2012, for its evaluation of the implications for the update of the European Strategy

- Common statistical tools, to combine input from all experiments
- Agreed benchmarks for input theory ingredients (cross-sections, BR's, etc)
- Representation of experimental results
  - model specific (e.g. cross-section limits/values for given model-parameter points)
  - model independent (e.g. cross-section limits/values for given production/decay topologies and selection cuts)

- RooStat: statistical tools
  (see e.g. https://indico.desy.de/getFile.py/access?contribId=12&sessionId=1&resId=0&materialId=slides&confId=3079)
- ATLAS/CMS combined statistics forum
  http://indico.cern.ch/categoryDisplay.py?categId=1579
- "Characterization of new physics" Working Group
  http://indico.cern.ch/conferenceDisplay.py?confId=107769
  http://www-conf.slac.stanford.edu/topologies10/
- SUSY/BSM Fit Working Group (includes tools like Gfitter, Fittino, HiggsBounds, Mastercode, SPheno, etc.)
  https://it-indico4.desy.de/conferenceOtherViews.py?view=standard&confId=3079
- Higgs cross-section Working Group
  https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

If no new physics appears at the LHC in 2011, is there a case for the ILC ?

expensive as LHC

The scientific case for the ILC based on precision measurements of the Higgs boson is very strong,

but for presidents and legislators, more might be needed.

The LHC has discovered new particles that cannot be a part of the Standard Model of particle physics. These particles indicate new laws of physics which we must know to understand the form and structure of the universe. We need a tool to advance our knowledge of these new particles beyond what can be learned at the LHC.

The appearance of new particles at the LHC will provide a magical moment of discovery when we will have the world's attention, from ministers to the man and lady on the street.

In conventional wisdom, what follows from this is the following:

1.) If new particles are found at 7 TeV and 1 fb-1, their energy scale is likely to be about 500 GeV. Then the ILC is the tool that we need.

2.) If the new particles are not found at 7 TeV, their energy scale is higher, and ILC is not the right machine.

If we are lucky, new particles will be found in 2011,

but the real expectation is simply that these particle have masses at the TeV energy scale and will be found in the longer LHC program.

There are two important caveats, recognized by everyone:

A light Higgs boson -- of the type found in the Standard Model and most viable BSM models -- will not be found in the 2011 LHC run.

But, there is a deeper problem with point 2. The statment is completely wrong !

It asks the wrong question. The right question is:

When we discover new particles at LHC and are mystified by their properties, when energy must we have in e+e- to obtain information that will solve the mystery ?

Particle physicists will always ask for higher energies. But, what we really want is better knowledge.

Example of a Z′:

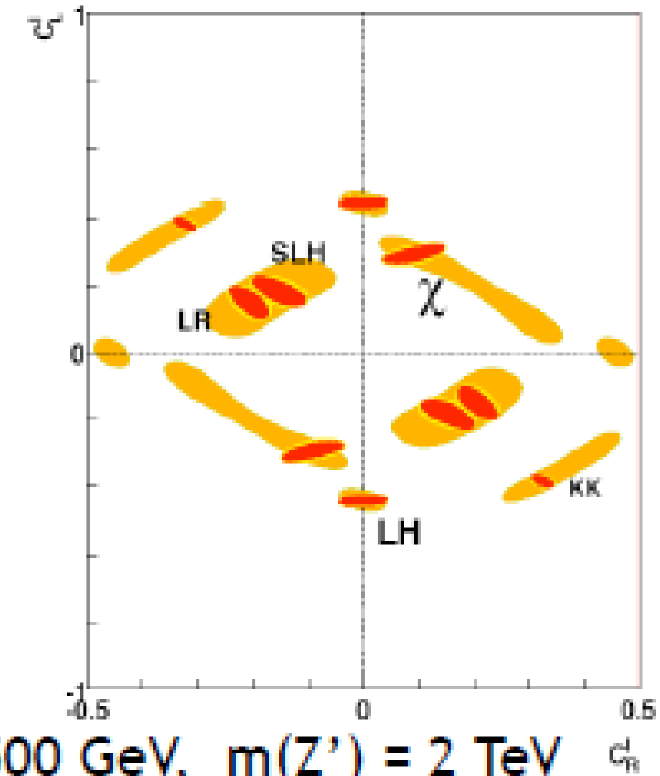
LHC can find Z′ boson up to about 5 TeV. The reach in 2011 is about 1.5 TeV.

If a resonance is discovered, don't we want to go there ?

The immediate question will be to learn the full set of helicity-dependent couplings of the Z′ to fermions. These can be measured by observing the interference with γ, Z in polarized

$$e^+e^- \rightarrow e^+e^-, \mu^+\mu^-, \tau^+\tau^-$$
$$e^+e^- \rightarrow q\bar{q}, c\bar{c}, b\bar{b}$$

500 GeV and high luminosity is already sufficient.



500 GeV, m(Z') = 2 TeV
1 ab-1, $e^+e^- \rightarrow \mu^+\mu^-$

Peskin

We will not want an ultimate-energy machine. We will want the machine that gives the answers to these urgent questions.

In this talk, I have given several examples in which the LHC discovery involves particles of high mass, but new information from a Linear Collider requires only 500 GeV.

This is the logic that motivated the ILC proposal in the first place. That logic is still correct.

one final point:

There is a significant opportunity for the discovery of new particles in the 2011 LHC run at 7 TeV. In this case, the magic moment of discovery will come in 2011 or 2012.

Presidents, legislators, and journalists have an attention span of years, not decades. We should be ready with a case for a new collider that addresses the physics questions raised by this discovery and can be implemented immediately.

In 2012, the only LC technology on the table will be ILC. To take advantage of the opportunity, we have be ready, as a community, to go forward with the ILC.

The Linear Collider Roadmap

R. Heuer

The next years

Important steps in the coming years

- CDR for CLIC 2011
- TDR for ILC 2012
- ICFA Seminar at CERN 3-6 October 2011

  use this occasion to

  - layout exciting future prospects in particle physics
  - synchronize regional strategies/roadmaps
- Update of European strategy for particle physics
start: EPS 2011, finalize Sept. 2012
- IEEE 2012 special event to promote LC