Stato e prospettive della fisica delle particelle

IFAE

Napoli, 11 Aprile 2007

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Status: progress since last IFAE

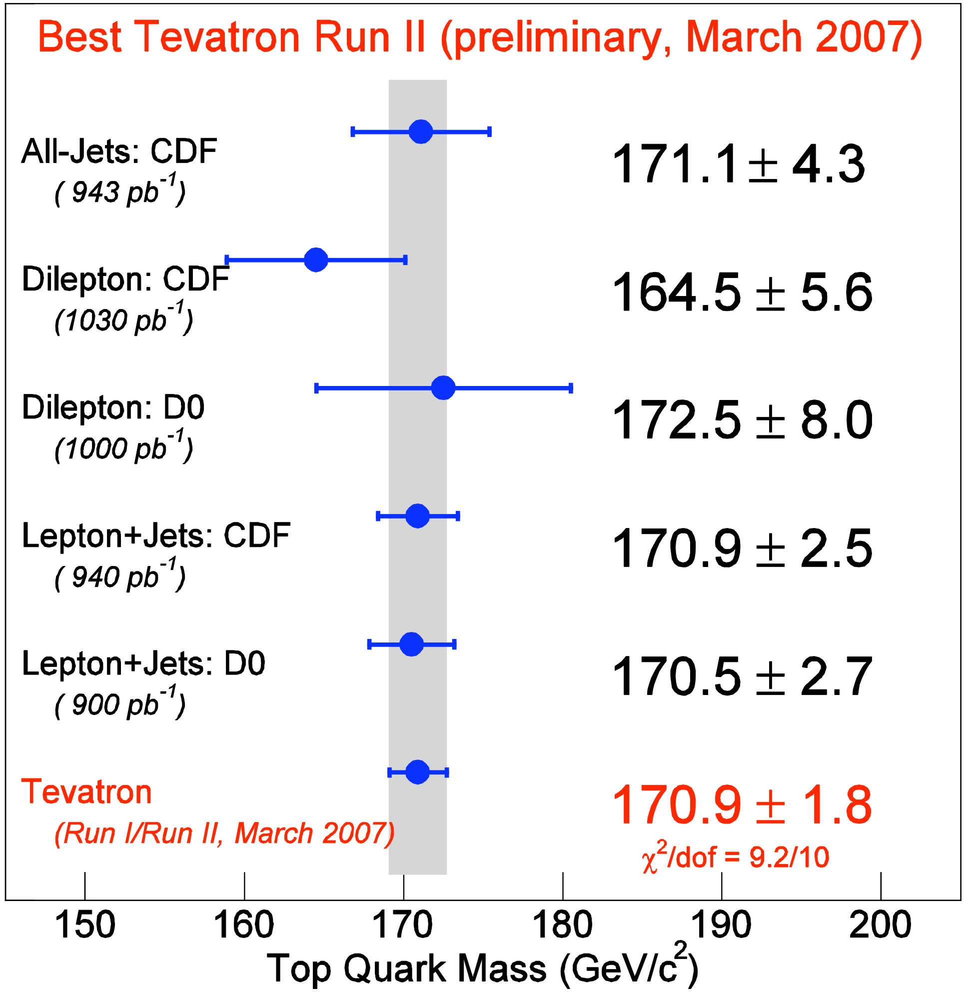
- Flavour physics (Martinelli)
  - B_s mixing
  - D^0 mixing
- Impressive performance of the Tevatron (Punzi)
  - m_{top} , m_W
  - approaching the Higgs sensitivity region
- Some facilities completed or are about to complete their runs
  - HERA (end '07)
  - KLOE (Meola/De Santis, Sapore WG, Wed aft)
- New facilities started commissioning:
  - BES 3 at Beijing
  - MEG at PSI (Dussoni, Sapore WG, Thu aft)
  - CNGS
- LHC startup ?? (Rolandi)
- Concrete steps toward new facilities:
  - Dafne2 (Bini, Nuove Tecnologie WG, Wed aft)
  - SuperB (Giorgi)
- We have a European strategy for particle physics (Petronzio)

Tevatron m_W and m_{top}

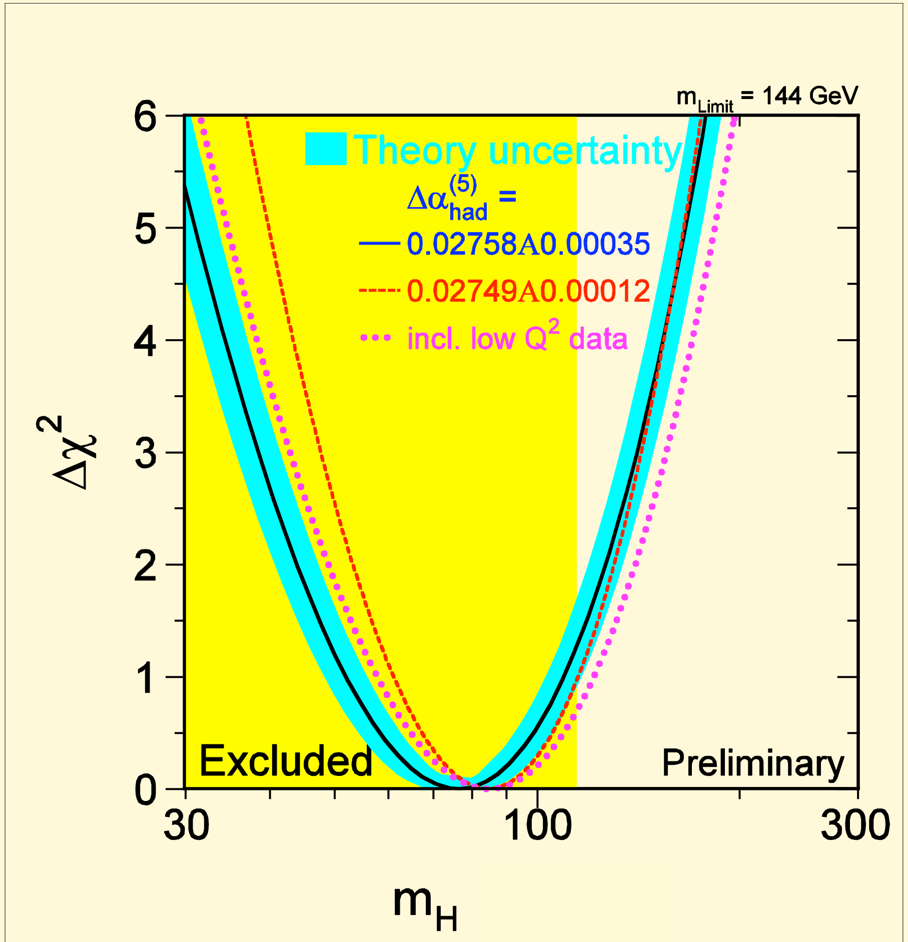
CDF II preliminary L = 200 pb^{-1}

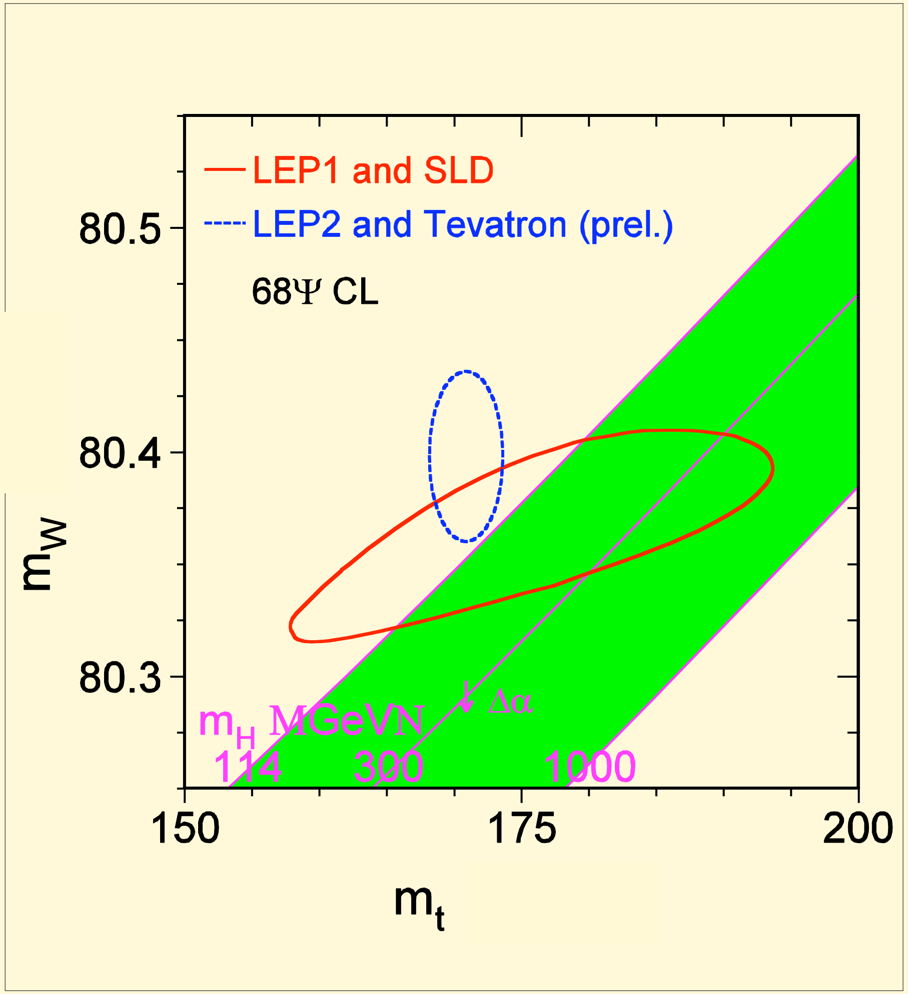
m_T Uncertainty [MeV]	Electrons	Muons	Common
Lepton Scale	30	17	17
Lepton Resolution	9	3	0
Recoil Scale	9	9	9
Recoil Resolution	7	7	7
$u_{\parallel}$ Efficiency	3	1	0
Lepton Removal	8	5	5
Backgrounds	8	9	0
$p_T(W)$	3	3	3
PDF	11	11	11
QED	11	12	11
Total Systematic	39	27	26
Statistical	48	54	0
Total	62	60	26

M_W = 80417 ± 48 (stat + syst) MeV



EW WG fits, Winter 07



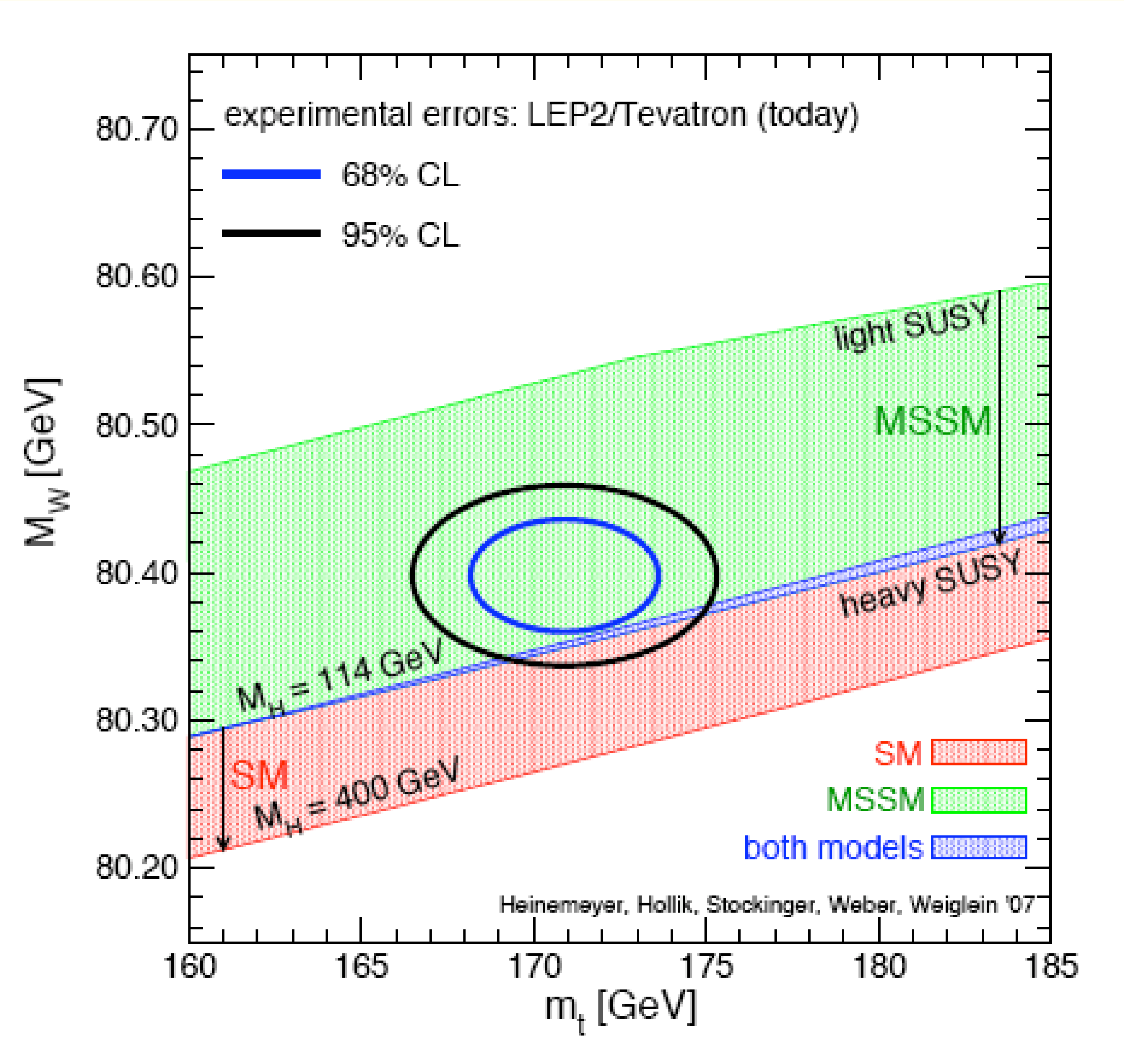


m_H = 76 at the minimum ,

m_H < 144 GeV at 95%CL

The tension with the SM is getting higher and higher ...

Higgs fits, SM vs MSSM

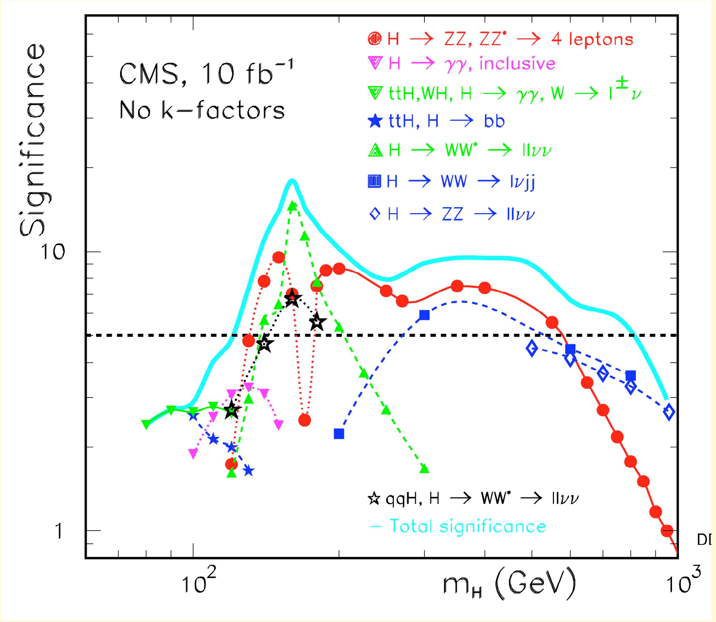


Heinemeyer, Hollik, Stockinger, Weber, Weiglein ‘07

What's the LHC going to tell us about EWSB?

The first conclusive YES/NO answer to the question of whether the SM Higgs mechanism is valid or not

IF SM, then the Higgs boson will be seen with $\int L \leq 15\ fb^{-1}$



- SM production and decay rates well known
- Detector performance for SM channels well understood
- $115 < m_H < 200$ from LEP and EW fits in the SM

IF seen with SM production/decay rates, but outside SM mass range:

- new physics to explain EW fits, or
- problems with LEP/SLD data

In either case,

- easy prey with low luminosity up to ~ 800 GeV, but more lum is needed to understand why it does not fit in the SM mass range!

IF NOT SEEN UP TO m_H ~ 0.8-1 TeV GEV:

$\sigma < \sigma_{SM}$: $\Rightarrow$ new physics

or

$BR(H \rightarrow visible) < BR_{SM}$: $\Rightarrow$ new physics

or

m_H>800 GeV: expect WW/ZZ resonances at $\sqrt{s}$ ~ TeV $\Rightarrow$ **new physics**

It may take longer to sort out these scenarios, but the conclusion about the existence of BSM phenomena will be unequivocal

N.B. Still room for weird scenarios

Has HyperCP Observed a Light Higgs Boson?
X-G He et al, hep-ph/0610362

CP-odd H in NMSSM
m_H=214.3 **MeV**

Abstract

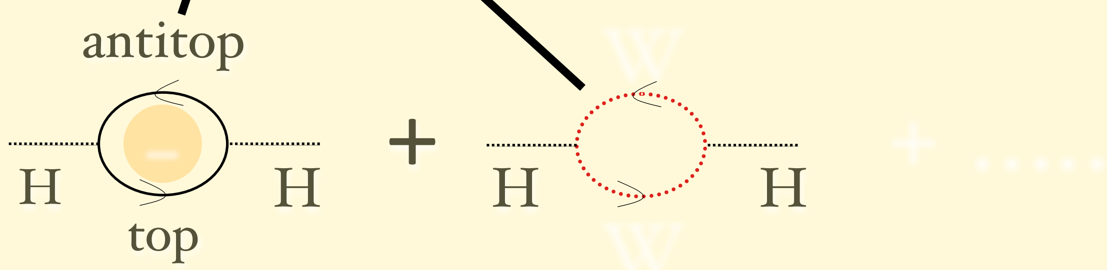
The HyperCP collaboration has observed three events for the decay $\Sigma^+ \to p\mu^+\mu^-$ which may be interpreted as a new particle of mass 214.3 MeV. However, existing data from kaon and B-meson decays severely constrain this interpretation, and it is nontrivial to construct a model consistent with all the data. In this letter we show that the "HyperCP particle" can be identified with the light pseudoscalar Higgs boson in the next-to-minimal supersymmetric standard model, the A_1^0. In this model there are regions of parameter space where the A_1^0 can satisfy all the existing constraints from kaon and B-meson decays and mediate $\Sigma^+ \to p\mu^+\mu^-$ at a level consistent with the HyperCP observation.

Typically tiny, finely tuned corners of parameter space for non-minimal BSM models, not favoured by any particular scenario

Seen the Higgs, what's next?

Calculating the radiative corrections to the Higgs mass in the SM poses an intriguing puzzle:

$$m_H^2 = m_0^2 - \frac{6G_F}{\sqrt{2}\pi^2}\left(m_t^2 - \frac{1}{2}m_W^2 - \frac{1}{4}m_Z^2 - \frac{1}{4}m_H^2\right)\Lambda^2 \sim m_0^2 - (115\mathrm{GeV})^2\left(\frac{\Lambda}{400\mathrm{GeV}}\right)^2$$



Λ= scale up to which the SM is valid

renormalizability =>

$$m_H^2(v) \sim m_H^2(\Lambda) - (\Lambda^2 - v^2) \quad , \quad v = \langle H \rangle \sim 250\mathrm{GeV}$$

Assuming Λ can extend up to the highest energy beyond which quantum gravity will enter the game, 10^{19} GeV, keeping m_H below 1 TeV requires a fine tuning among the different terms at a level of 10^{-34}:

$$\frac{m_H^2(\Lambda) - \Lambda^2}{\Lambda^2} \sim \frac{v^2}{\Lambda^2} = O(10^{-34}) \text{ if } \Lambda \sim M_{Planck}$$

extremely **unnatural** if it is to be an accident !!

hierarchy, or **fine tuning,** problem

The issue can be rephrased with the following example:

- Ask 10 of your friends to each give you an **irrational number**, **randomly** distributed between –1 and 1.
- **Sum the 10 numbers**
- **How would you feel** if the sum were smaller than 10^{-32} ?

Nothing wrong with it, it can happen, but **most likely** your friends agreed in advance on the numbers to give you, and forced the cancellation with a judicious choice.

Theorists feel the same about the Higgs mass .... the accurate cancellation between bare mass and rad corr's cannot be an accident!

Solution ....

Tie the Higgs mass to some symmetry which protects it against quadratic divergencies

Supersymmetry

H (scalar) ↔ fermion

$$\delta m_e = \frac{\alpha_{em}}{3\pi} m_e \log \frac{\Lambda}{m_e}$$

Gauge symmetry

H (scalar) ↔ 5th component of a gauge bosons in 5 dimensions or more

=> extra dimensional theories

Global symmetry

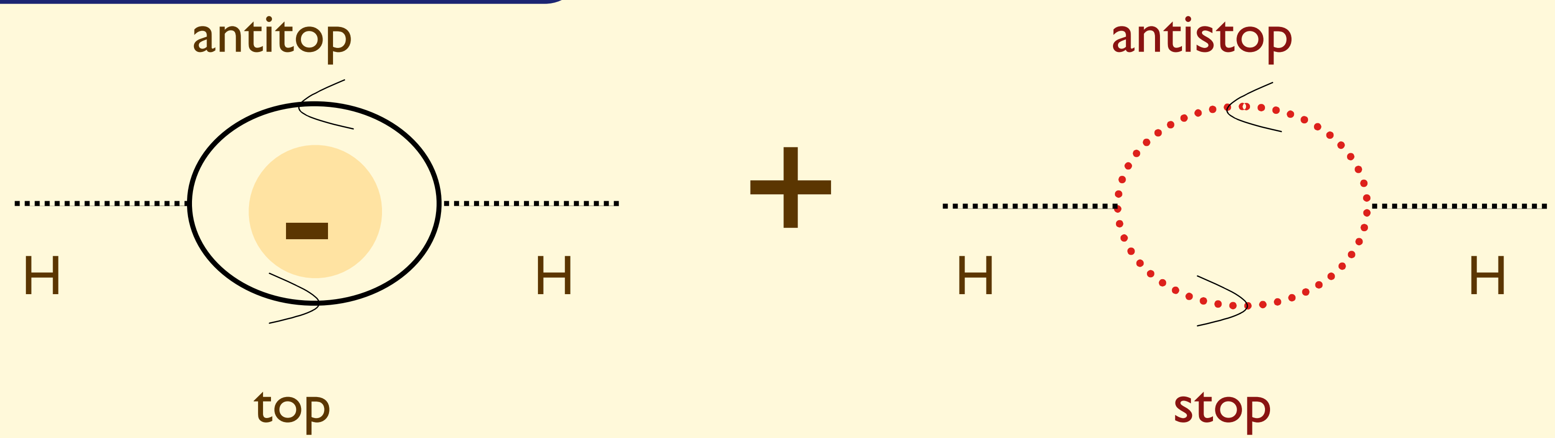
$H \to H + a \Rightarrow L(H)=L(\partial H)$

=> Little Higgs theories, Technicolor
H=pseudo-goldstone boson

More by Rattazzi and Contino (Nuova Fisica WG, Wed aft)

In all cases, new particles must appear at a scale O(TeV) to cancel the quadratic divergence and remove the fine tuning

Ex: Supersymmetry



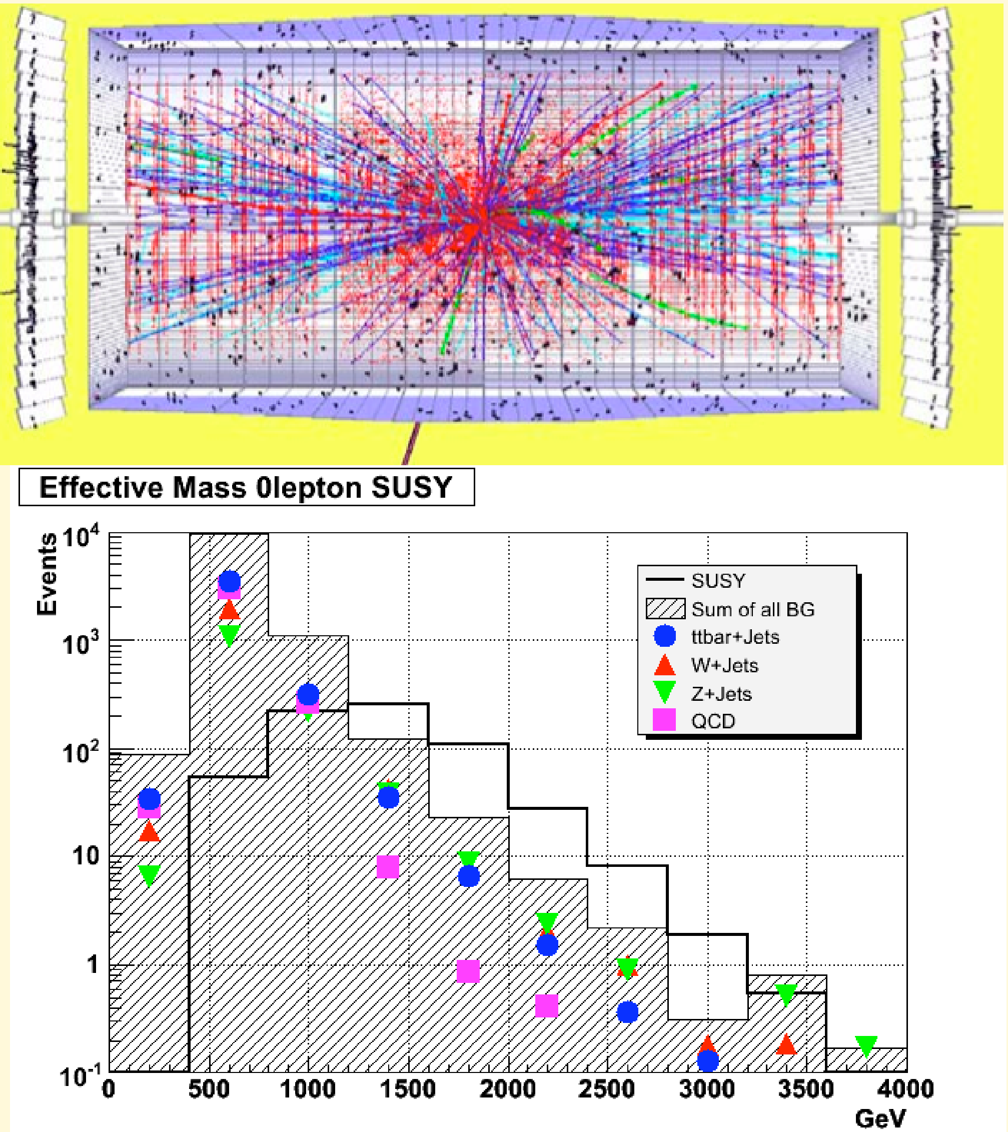
$$\delta m_H^2 \sim G_F \, m_t^2 \, \log \frac{m_{\tilde{t}}}{m_t}$$

Important constraint

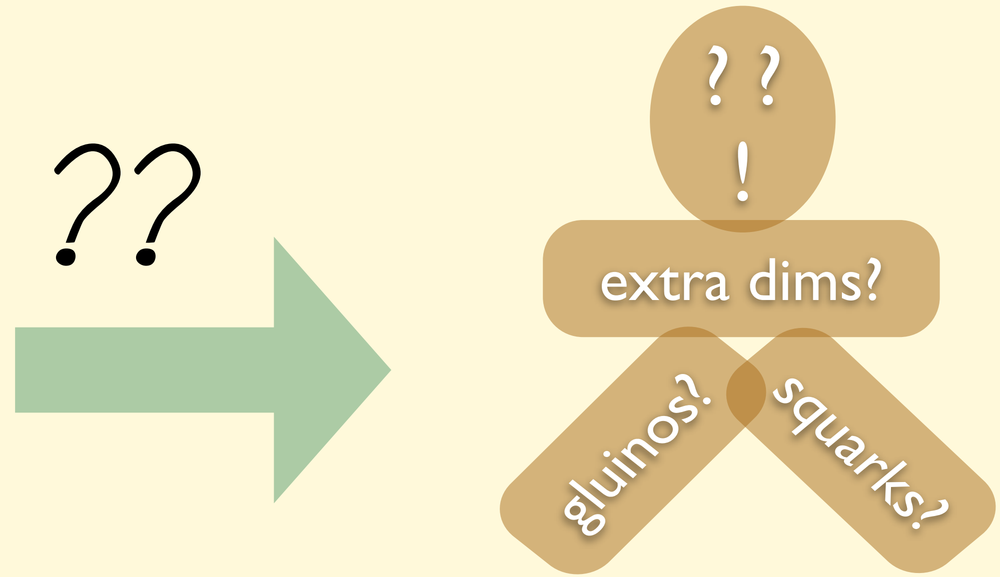
These new particles and interactions shoud not spoil the accuracy of the EW precision data form LEP/SLC/LEP2

The LHC inverse problem

Reconstruct the Lagrangian of new physics from the LHC data



$$M_{eff}\ (\text{GeV}) = \sum_{i=1,4} E_T\ (i) + E_T^{\ miss}$$



$\mathcal{L}$

Easy case:

Higgs search: driven by the signal expectations, which propose several test signatures. Similar to the times of LEP, or to the top search.

Difficult case:

BSM: search for deviations from SM backgrounds less biased:

Step 1:

- search in rather inclusively defined quantities, whose choice is typically be driven by theoretical prejudice (e.g. M_{eff} in 4 jet + MET final states)
- **observation** and **validation** of "discrepancy" based on use of data

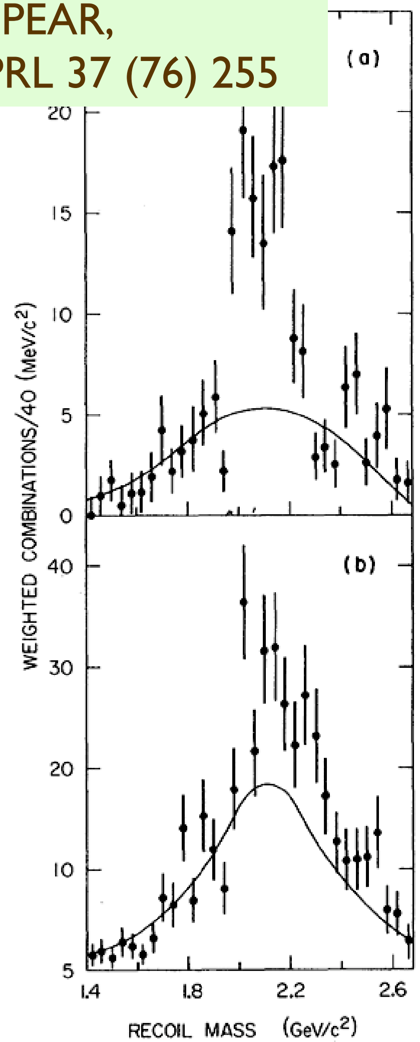
Step 2:

interpretation in terms of new physics. Aside from trivial cases (e.g. Z' resonance), there is ***no obvious or general strategy***

Non-trivial example from the past: open charm discovery

Data:

SPEAR,
PRL 37 (76) 255



Recoil mass of a $K^+ \pi^-$ system

Recoil mass of a $K^+ \pi^- \pi^+ \pi^-$ system

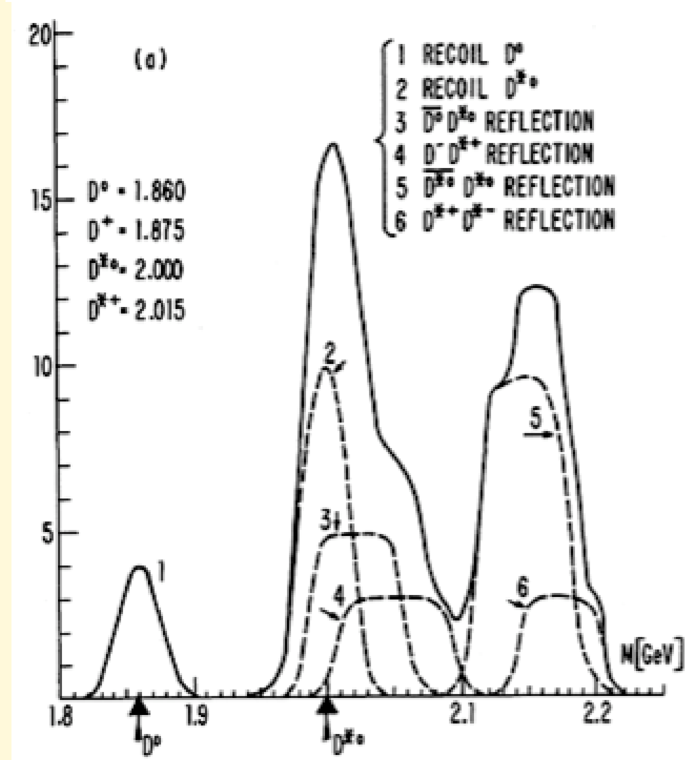
- o Obscure structure of recoil system
- o No evidence of $D^\pm$

Interpretation:

De Rujula, Georgi, Glashow, PRL 37 (76) 398

$$D^{*+} \to \begin{cases} D^0\pi^+, & Q = 15 \text{ MeV}, \quad B \sim 90\%, \\ D^+\pi^0, & Q = 5 \text{ MeV}, \quad B \sim 10\%, \\ D^+\gamma, & Q = 140 \text{ MeV}, \quad B \sim 1\%, \end{cases}$$

$$D^{*0} \to \begin{cases} D^0\pi^0, & Q = 5 \text{ MeV}, \quad B \sim 90\%, \\ D^+\pi^-, & Q = -5 \text{ MeV}, \quad B \sim 0, \\ D^0\gamma, & Q = 140 \text{ MeV}, \quad B \sim 10\%. \end{cases}$$



DD : D* D : D* D* = 1 : 3 : 7 ⇒

$D^0 : D^+ = 7 : 1$

Several groups are building SUSY fitting packages (things called like, e.g. *SFITTINO*), to go directly from data (e.g. MET distributions) to the Lagrangian parameters.

VERY DANGEROUS, and potentially useless !!

How do we know it's **XXX** (e.g. SUSY)?
How do we know ***which class*** of XXX models?
How to test whether bgs/systematics drive the fit to ***false minima***?
etc.etc.

Alternatives?

On-shell effective theories (OSETs)

Arkani-Hamed, Schuster, Toro, Thaler, Wang,
Knuteson & Mrenna, hep-ph/0703088

Abstract the key final state features from the detailed Lagrangian structure

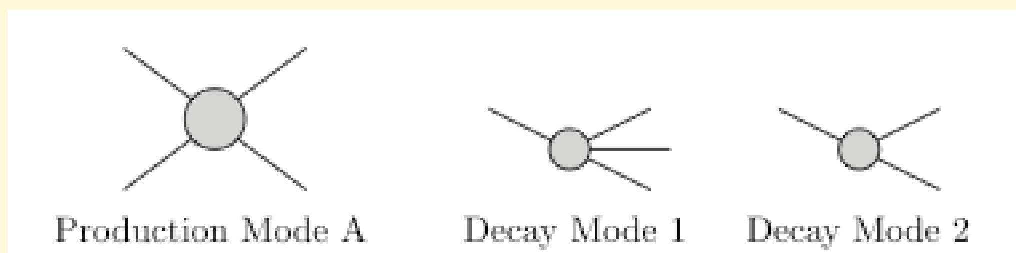
Couplings ⇒ Production channels and decay modes and BR's

Spectrum ⇒ Kinematics

Approximate production and decay by stitching together simple building blocks

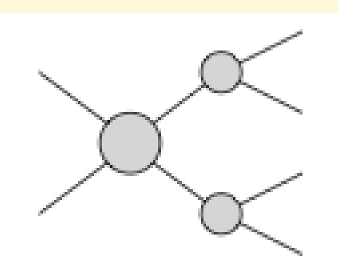
E.g.

Building blocks:

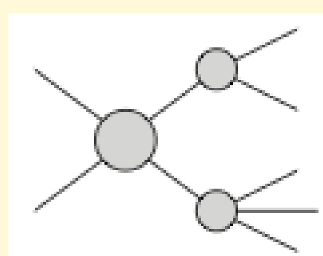


σ_A **BR$_1$** **BR$_2$**

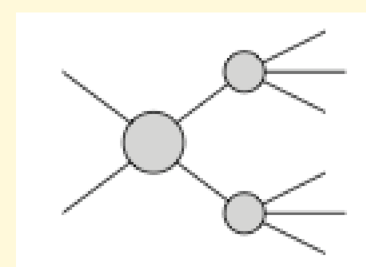
Possible final states:



$\sigma_A \times BR_1{}^2$

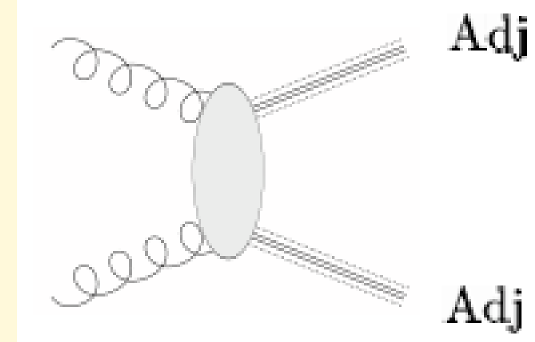


$2\,\sigma_A \times BR_1 \times BR_2$



$\sigma_A \times BR_2{}^2$

$$|\mathcal{M}(gg\to\tilde{g}\tilde{g})|^2 \propto \left(1-\frac{t_g u_g}{s^2}\right)\left[\frac{s^2}{t_g\,u_g}-2+4\,\frac{m_{\tilde{g}}^2 s}{t_g u_g}\left(1-\frac{m_{\tilde{g}}^2 s}{t_g u_g}\right)\right]$$



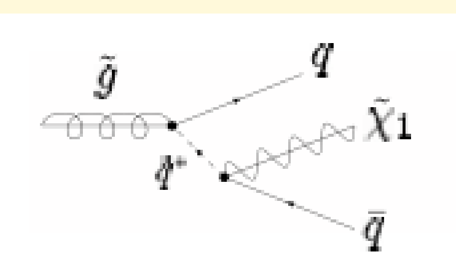
$$|\mathcal{M}|^2 = A_{gg} + B_{gg}\begin{cases}(1-1/X)\\(X-1)\end{cases}$$

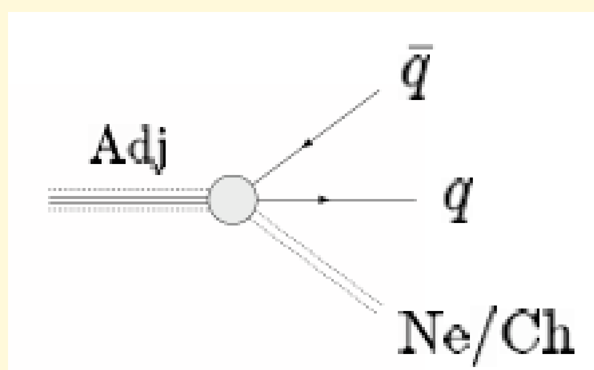
$X = s\,/\,s_{min}$

$$|\mathcal{M}(q\bar{q}\to\tilde{g}\tilde{g})|^2 \propto \left[\frac{t_g^2+m_{\tilde{g}}^2\,s}{s^2}+\frac{4}{9}\frac{t_g^2}{t_q^2}+\frac{t_g^2+m_{\tilde{g}}^2\,s}{s\,t_q}+\frac{1}{18}\frac{m_{\tilde{g}}^2 s}{t_g\,u_g}+(t\leftrightarrow u)\right],$$

$$|\mathcal{M}|^2 = A_{qq} + B_{qq}\begin{cases}(1-1/X)\\(X-1)\end{cases}$$

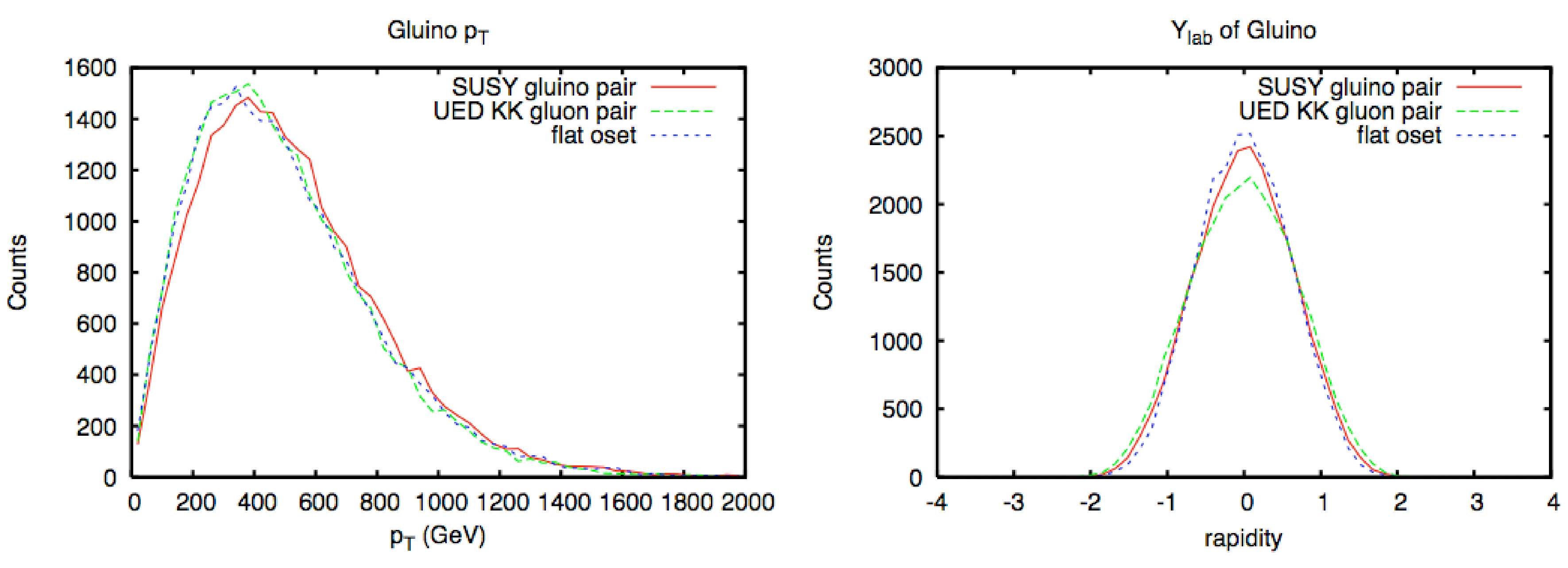
$X = s\,/\,s_{min}$



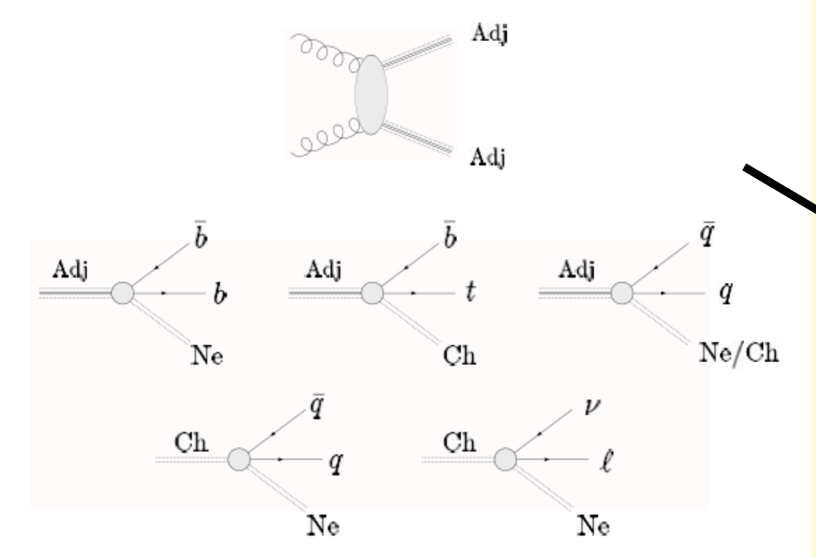


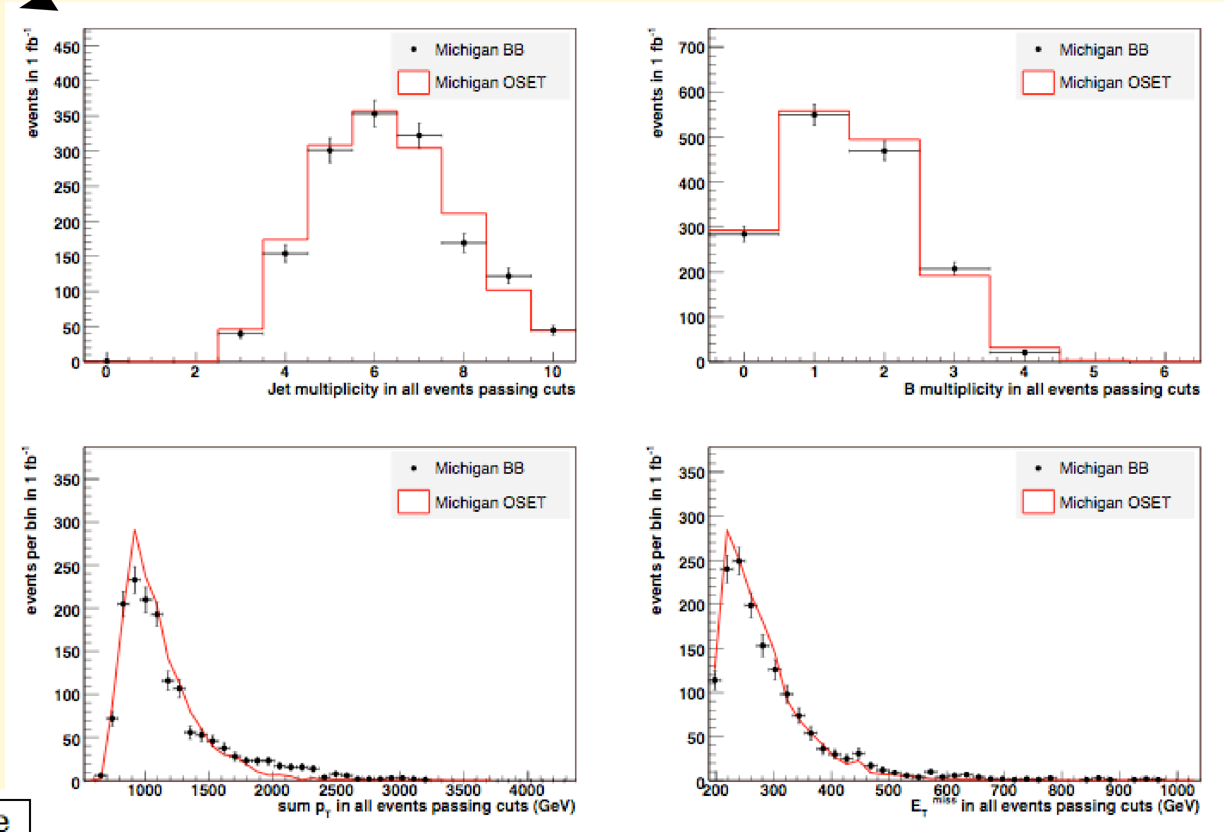
$d\Gamma$ = *ph-space*

- The ~constant approximation for production works because the rapidly decreasing PDFs smear away the details of the MEs
- What determines the distributions is the mass of the produced particles and of the decay products:



Black-box exercises

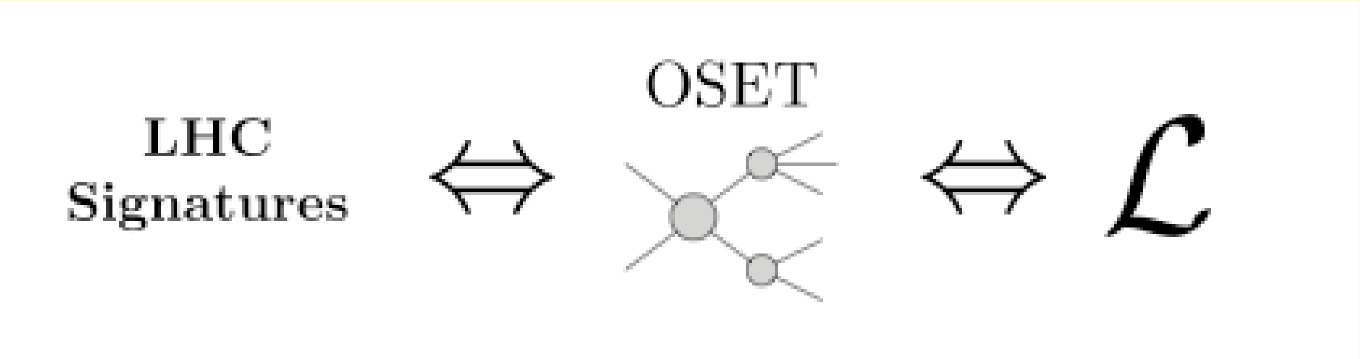




5 fb^{-1}

Process	Fit Rate	Actual Rate
$\sigma(gg \to Adj\ Adj)$	30.1 ± 0.9 fb	28.0 fb
$\sigma(gu \to Adj\ Q')$	0.31 ± 0.04 fb	0.41 fb
$\mathrm{Br}(Q' \to u Adj)$	1.0	1.0
$\mathrm{Br}(Adj \to \bar{t}bCh^{+}$ or c.c.$)$	0.82 ± 0.03	0.77
$\mathrm{Br}(Adj \to b\bar{b}Ne)$	0.17 ± 0.02	0.22
$\mathrm{Br}(Adj \to q\bar{q}Ne)$	0.01 ± 0.01	0.01
$\mathrm{Br}(Ch \to q\bar{q}'Ne)$	0.56 ± 0.10	0.60
$\mathrm{Br}(Ch \to e/\mu\bar{\nu}Ne)$	0.43 ± 0.10	0.40

- These ideas have been incorporated in a practical tool, MARMOSET, which works like a "thinking pad" for testing hypothesis
- Removes the redundancy of BSM parameter sets (the same kinematics may correspond to many parameter points)
- Facilitates testing of many different hypothesis
- Ultimately allows to identify the key ingredients of a BSM framework, and to fit Lagrangian parameters:



  - Several examples, and details on the use of the package, discussed in hep-ph/0703088

The far future ...

From R. Orbach (DoE Undersecretary)
remarks to HEPAP, Febr 22 2007:

"Even assuming a positive decision to build an ILC, the schedules will almost certainly be lengthier than the optimistic projections. Completing the R&D and engineering design, negotiating an international structure, selecting a site, obtaining firm financial commitments, and building the machine could take us well into the **mid-2020s, if not later**."

⇒ the burden of exploring and measuring the properties of phenomena at the high-energy frontier will rest with the LHC for a long long time! ⇒ **SLHC**

⇒ the case for going "directly" to **CLIC** is strenghtened

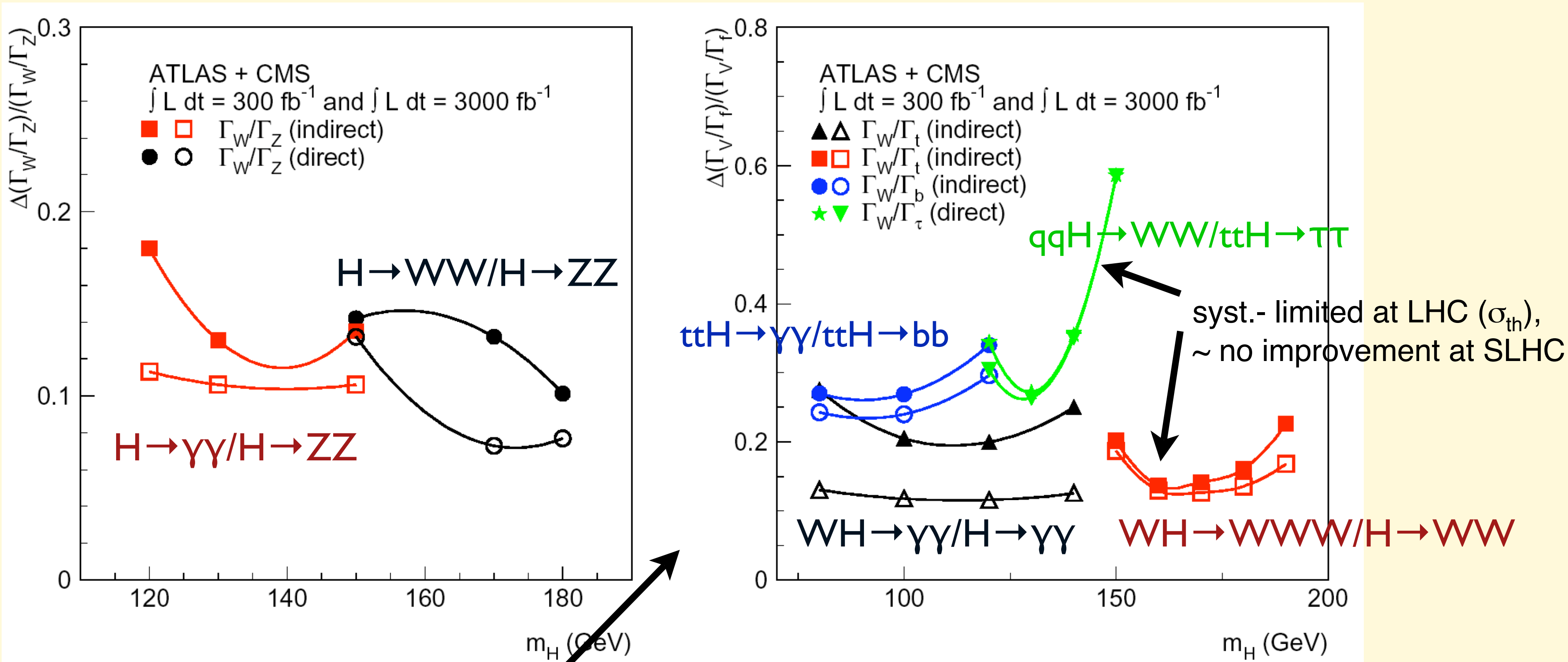
What can the LHC achieve with extended, higher luminosity operations (SLHC)?

1. Improve measurements of new phenomena seen at the LHC. E.g.
   - Higgs couplings and self-couplings
   - Properties of SUSY particles (mass, decay BR's, etc)
   - Couplings of new Z' or W' gauge bosons (e.g. L-R symmetry restoration?)
2. Detect/search low-rate phenomena inaccessible at the LHC. E.g.:
   - $H \to \mu^+\mu^-$, $H \to Z\gamma$
   - top quark FCNCs
3. Push sensitivity to new high-mass scales. E.g.
   - New forces (Z', W_R)
   - Quark substructure
   - ....

Energies/masses in the few-100 GeV range. Detector performance at SLHC should equal (or improve) in absolute terms the one at LHC

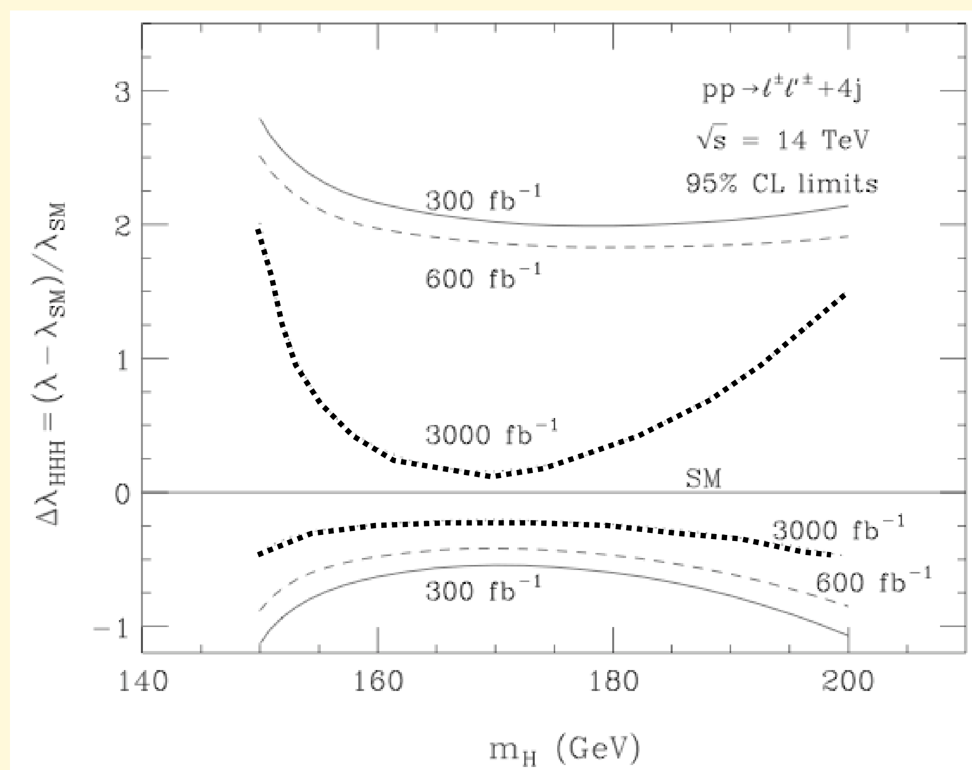
Very high masses, energies, rather insensititive to high-lum environment.
Not very demanding on detector performance
Slightly degraded detector performance tolerable

Examples

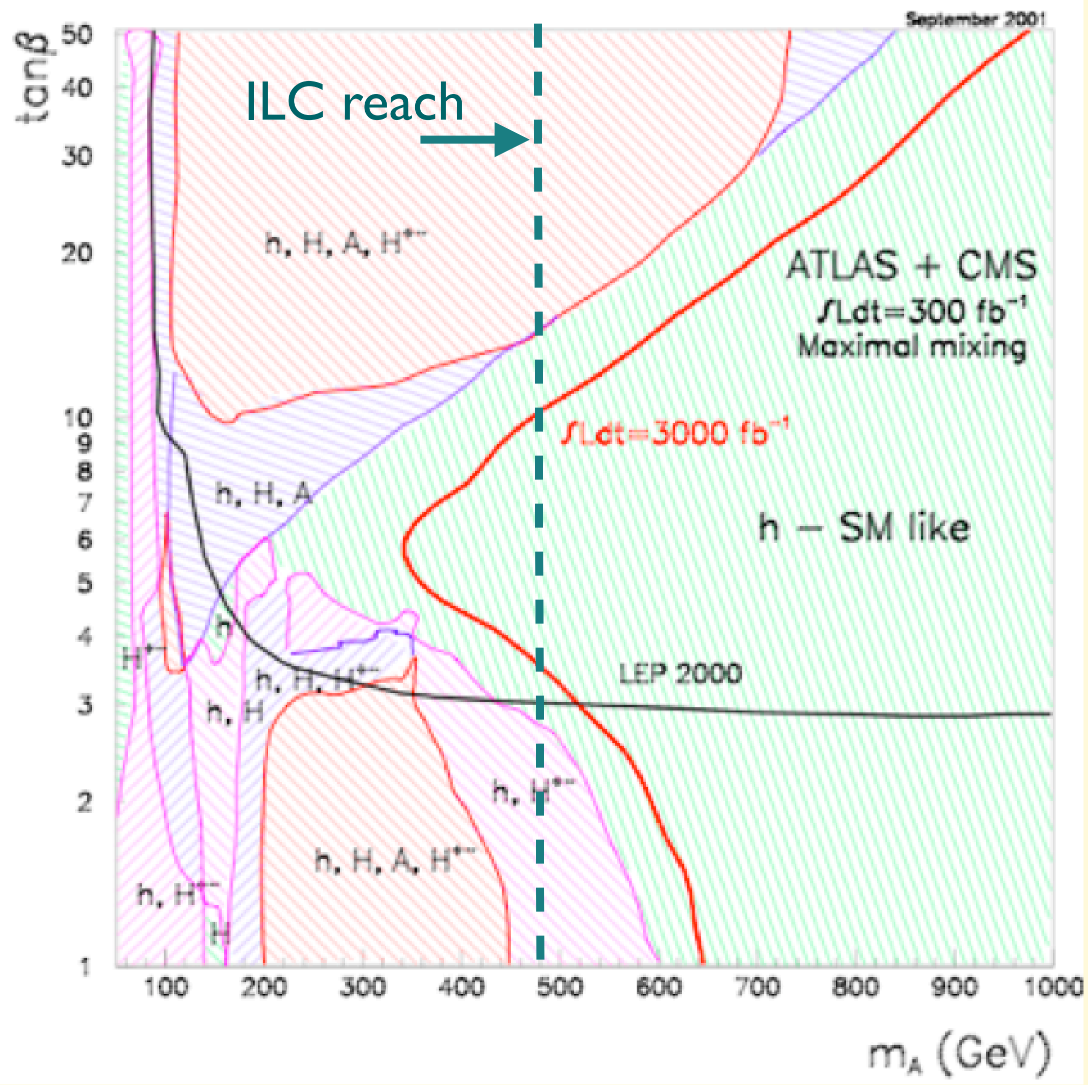


Higgs boson couplings to fermions and gauge bosons

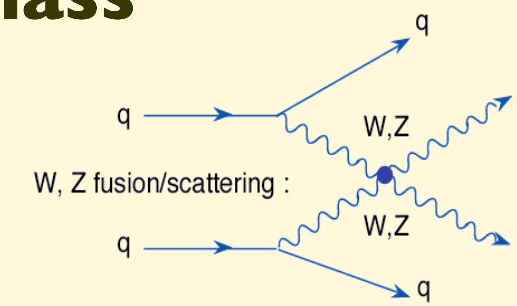
Higgs boson selfcouplings

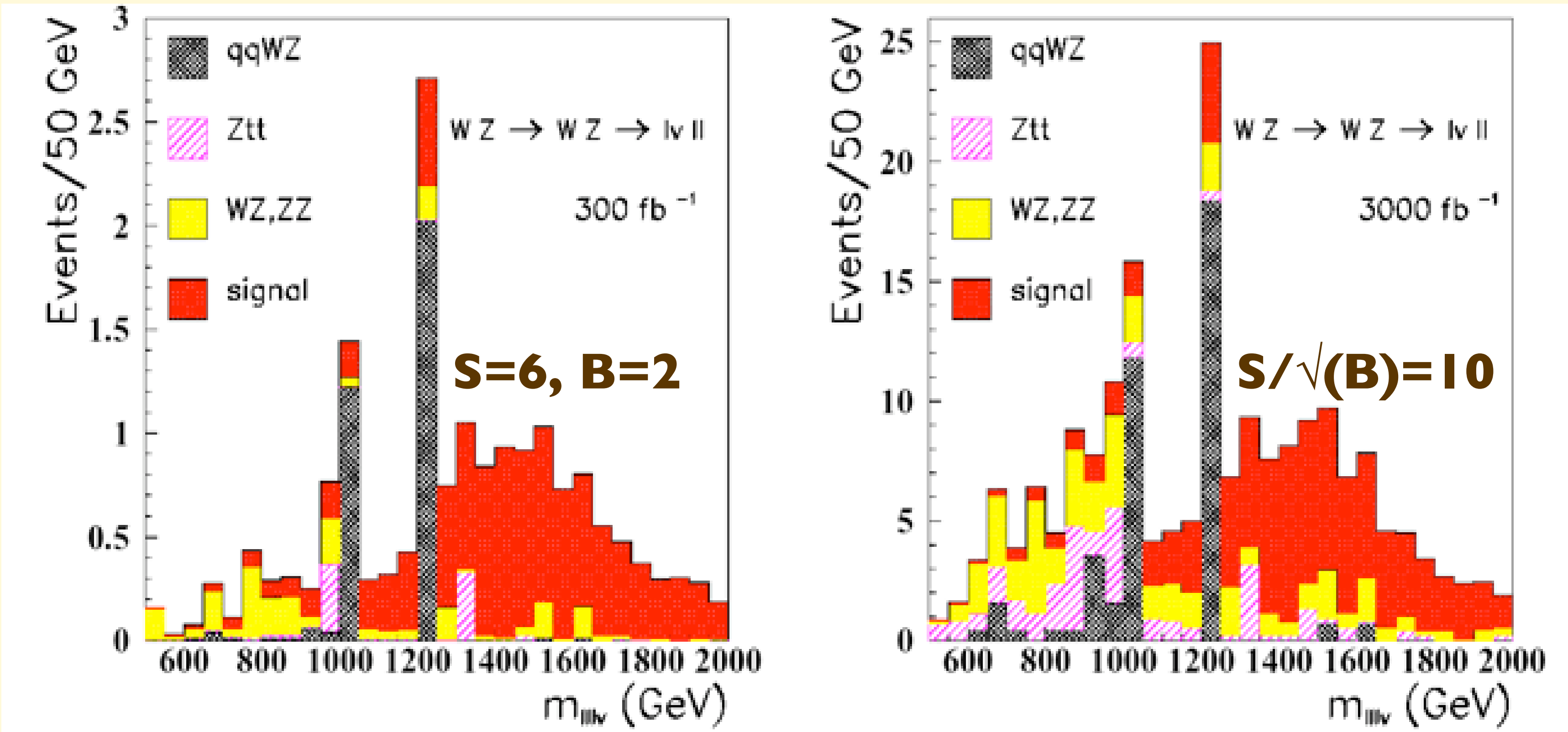


Detecting the presence of extra H particles (as expected in SUSY)



Strong resonances in high-mass WW or WZ scattering

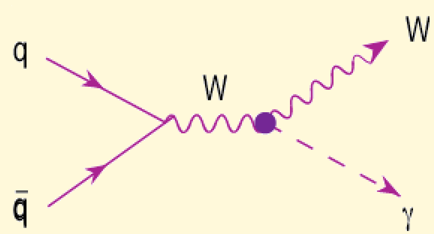


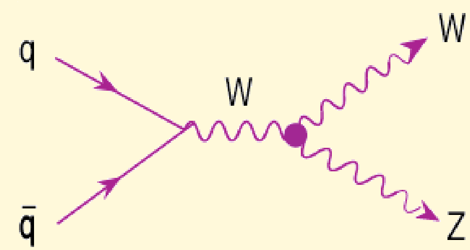


Vector resonance (ρ-like) in $W_L Z_L$ scattering from Chiral Lagrangian model
M = 1.5 TeV, leptonic final states, 300 fb^{-1} (LHC) vs 3000 fb^{-1} (SLHC)

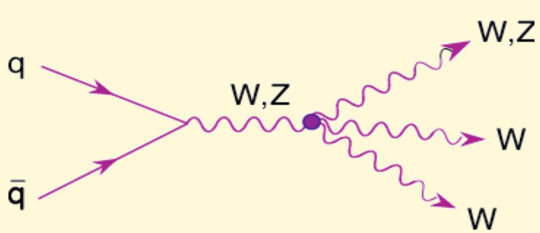
Ex: Precise determinations of the self-couplings of EW gauge bosons

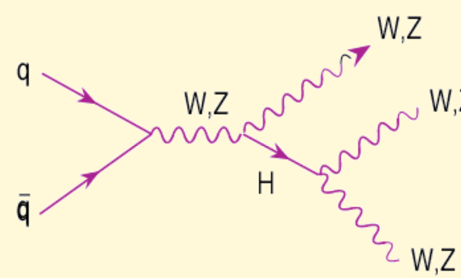
5 parameters describing weak and EM dipole and quadrupole moments of gauge bosons. The SM predicts their value with accuracies at the level of 10^{-3}, which is therefore the goal of the required experimental precision



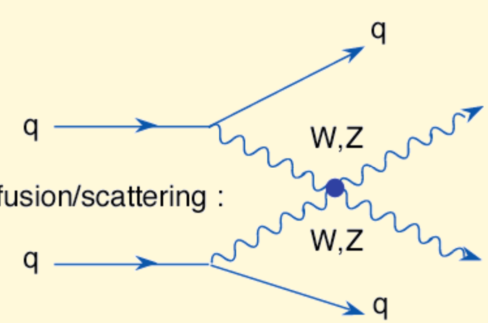


Coupling	14 TeV 100 fb^{-1}	14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	28 TeV 1000 fb^{-1}	LC 500 fb^{-1}, 500 GeV
λ_γ	0.0014	0.0006	0.0008	0.0002	0.0014
λ_Z	0.0028	0.0018	0.0023	0.009	0.0013
$\Delta\kappa_\gamma$	0.034	0.020	0.027	0.013	0.0010
$\Delta\kappa_Z$	0.040	0.034	0.036	0.013	0.0016
g^Z_1	0.0038	0.0024	0.0023	0.0007	0.0050



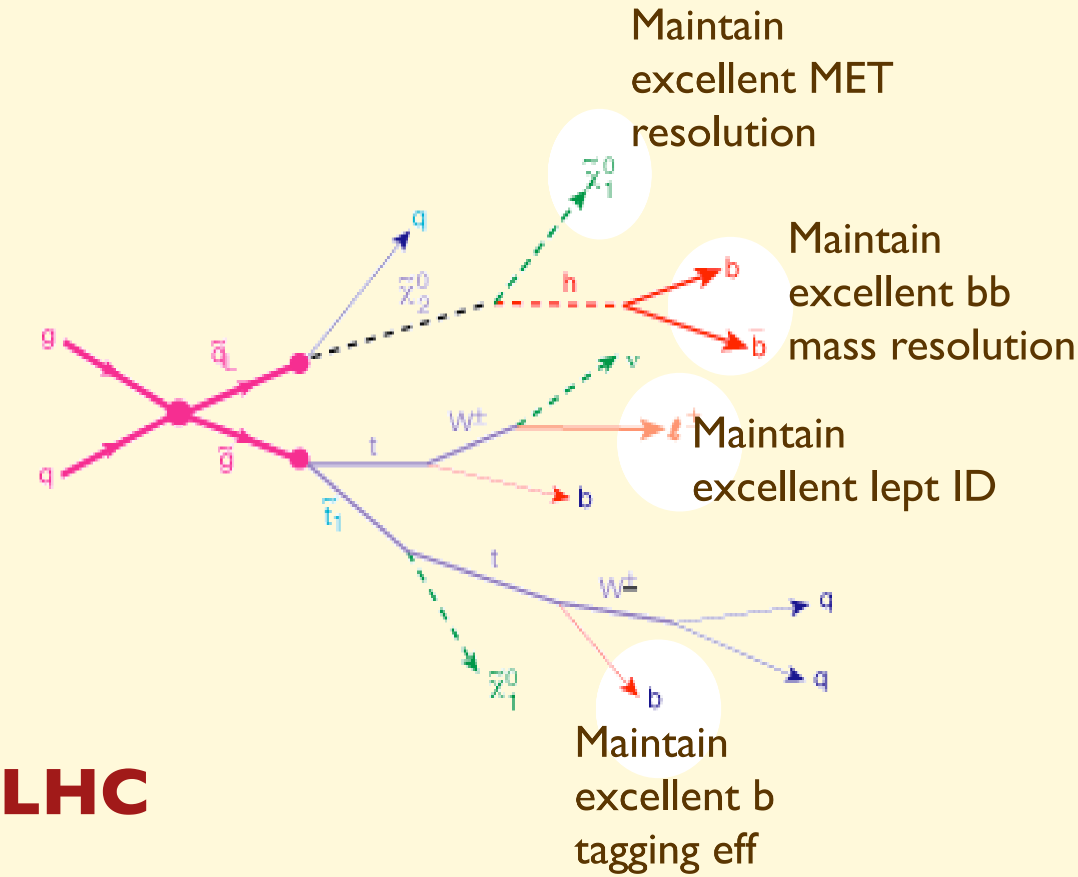


W, Z fusion/scattering :



(LO rates, CTEQ5M, k ~ 1.5 expected for these final states)						
Process	*WWW*	*WWZ*	*ZZW*	*ZZZ*	*WWWW*	*WWWZ*
$N(m_H = 120$ GeV)	2600	1100	36	7	5	0.8
$N(m_H = 200$GeV)	7100	2000	130	33	20	1.6

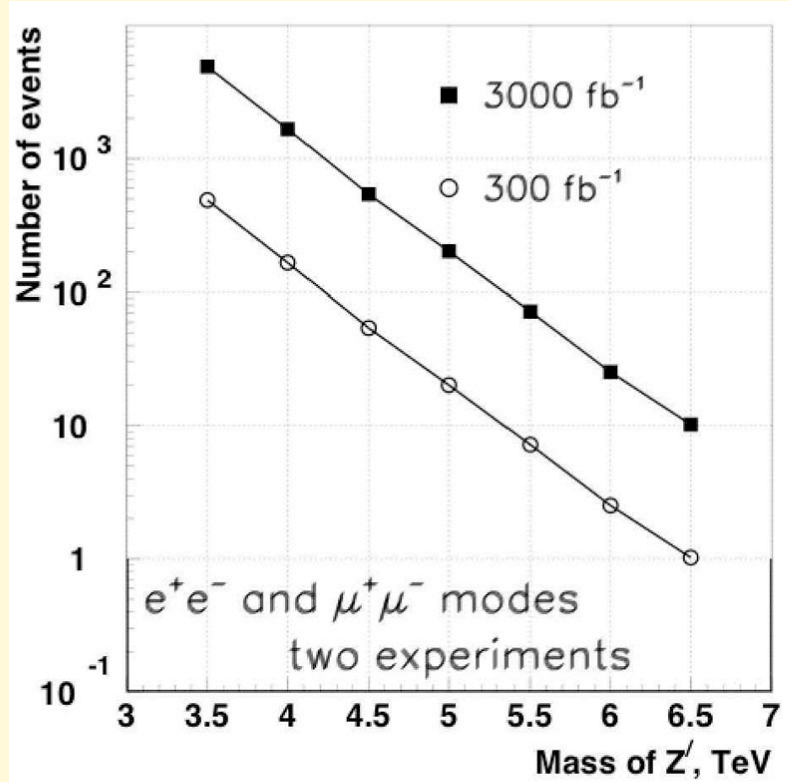
SUSY reach and studies



High momentum leptons, but lot of stat needed to reconstruct sparticle mass peaks from edge regions!
SLHC luminosity should be crucial, but also need for jets, b-tagging, missing E_t i.e. adequate detector performances (calorimetry, tracker) to really exploit the potential of increased statistics at SLHC…..

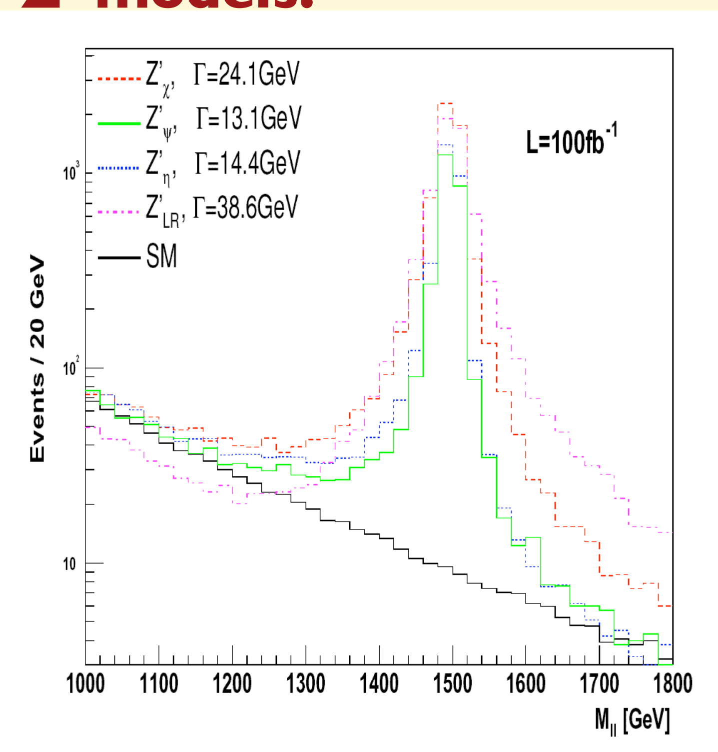
Searching new forces: W', Z'

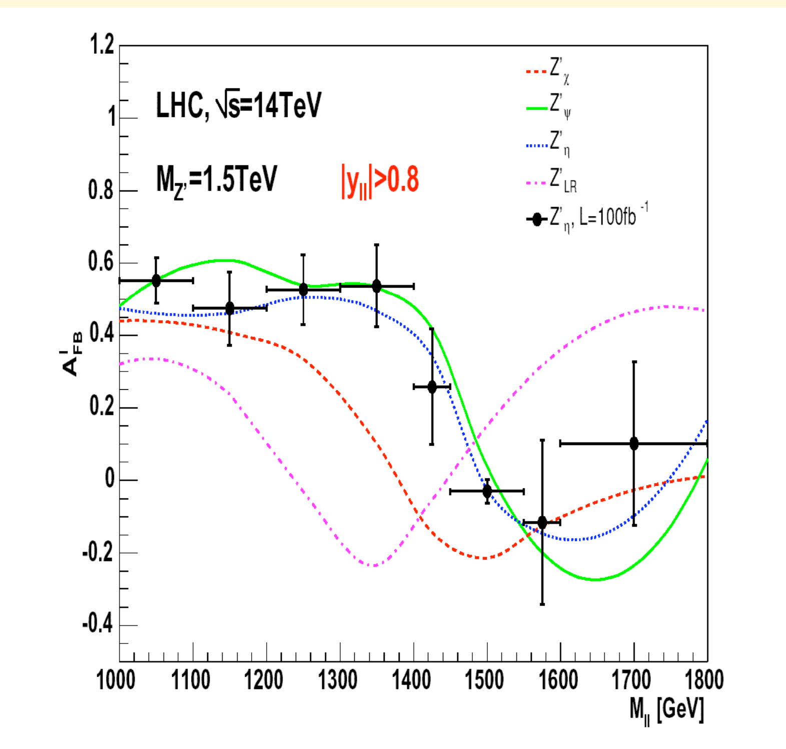
E.g. a W' coupling to R-handed fermions, to reestablish at high energy the R/L symmetry



100 fb^{-1} discovery reach up to ~ 5.5 TeV

Differentiating among different Z' models:





100 fb^{-1} model discrimination up to 2.5 TeV

Options for the SLHC beams

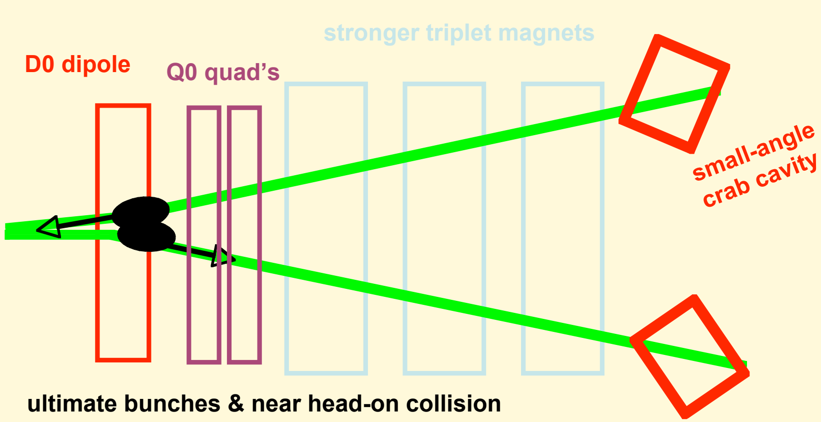
NB: Bunch spacing at 12.5 nsec deprecated, due to excessive heat load (>2.4 W/m)

Scandale and Zimmermann

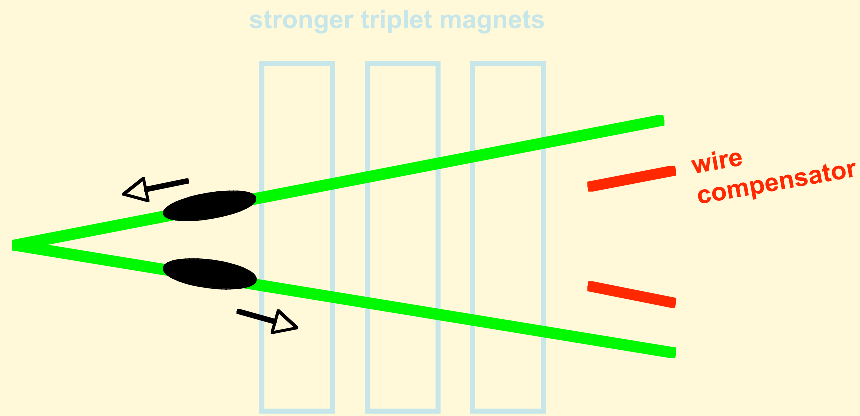
parameter	symbol	25 ns, small β^*	50 ns, long
transverse emittance	ε [μm]	3.75	3.75
protons per bunch	N_b [10^{11}]	1.7	4.9
bunch spacing	Δt [ns]	25	50
beam current	I [A]	0.86	1.22
longitudinal profile		Gauss	Flat
rms bunch length	σ_z [cm]	7.55	11.8
beta* at IP1&5	β^* [m]	0.08	0.25
full crossing angle	θ_c [μrad]	0	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2^*\sigma_x^*)$	0	2.0
hourglass reduction		0.86	0.99
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	15.5	10.7
peak events per crossing		294	403
initial lumi lifetime	τ_L [h]	2.2	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	2.4	2.5
	$T_{run,opt}$ [h]	6.6	9.5
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	3.6	3.5
	$T_{run,opt}$ [h]	4.6	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.04 (0.59)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.25	0.36
image current heat	P_{IC} [W/m]	0.33	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.06 (0.56)	0.09 (0.9)
extent luminous region	σ_l [cm]	3.7	5.3
comment		D0 + crab (+ Q0)	wire comp.

PAF & POFPA working groups

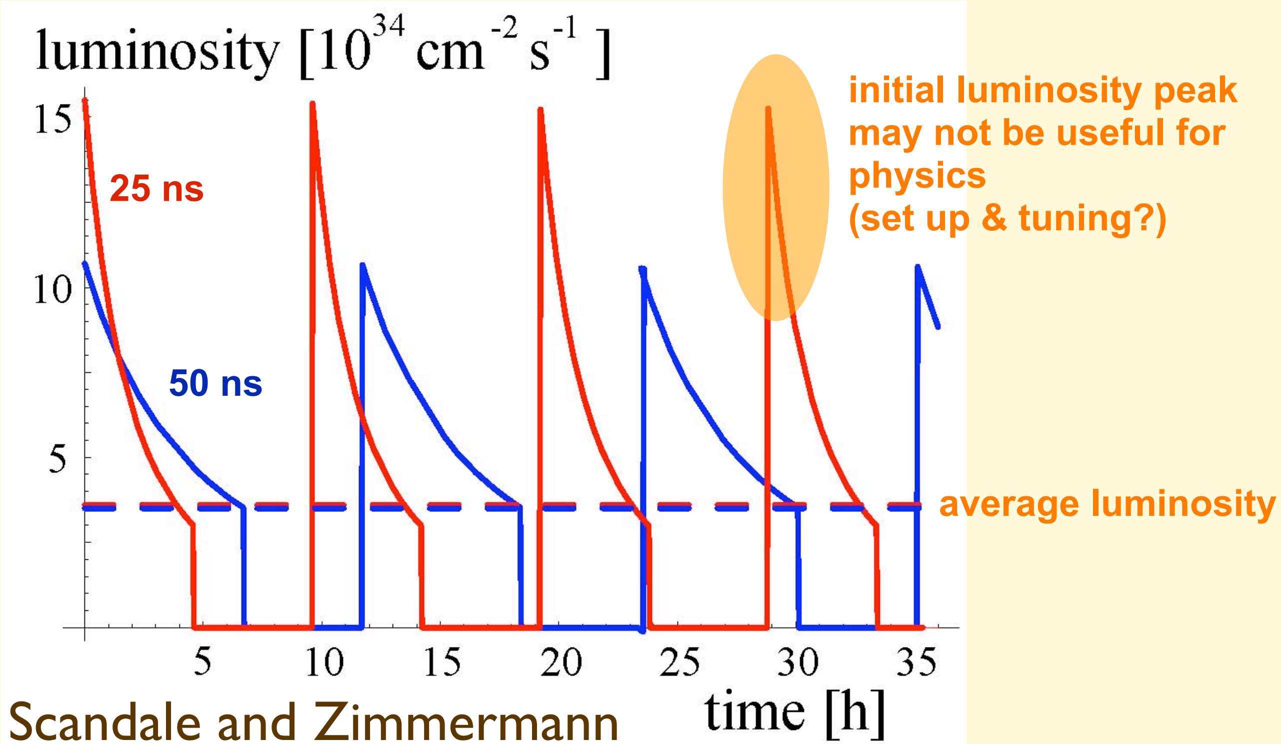
http://cern.ch/pofpa



- β^* = 10 cm
- D0 dipole at 3m from IP
- Q0 quads at 13 m from IP, Nb_3Sn
- 340 evts/Xing



- β^* = 25 cm , longer bunches, high charge
- standard Nb Ti quads, no crabs
- 400 evts/Xing



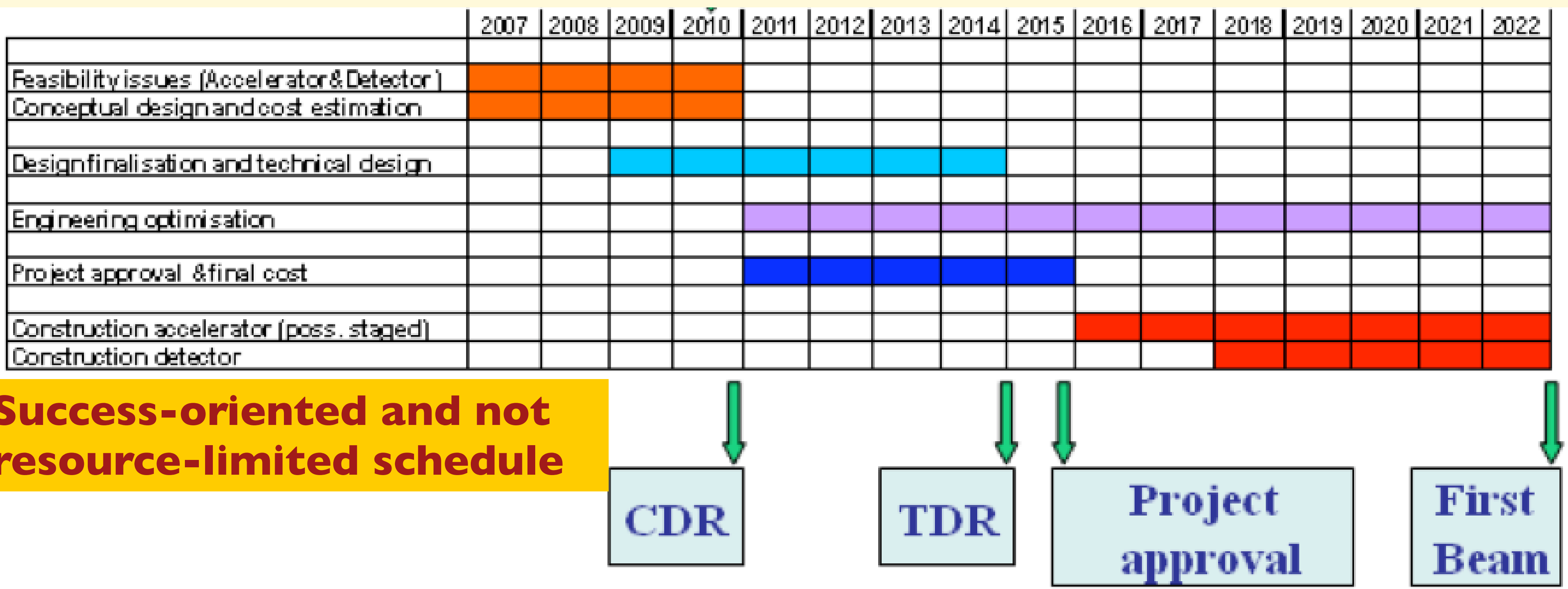
Scandale and Zimmermann

CLIC status

Performance and cost optimization at 3 TeV ⇒ gradient = 100 MeV/m, RF = 12 GHz (were 150 MeV/m and 30 GHz)

Remanining tasks for CTF3, to be completed by 2010:

- Test of damped accelerating structure at design gradient and pulse length
- Validation of drive beam generation with fully loaded Linac
- Design and test of power-extraction structure, with damping and ON/OFF capability
- Validation of beam stability and losses in the drive beam accelerator
- Test of Linac subunit with beam



Success-oriented and not resource-limited schedule

Outlook

- **< 1973: theoretical foundations of the SM**
  - renormalizability of SU(2)xU(1) with Higgs mechanism for EWSB
  - asymptotic freedom, QCD as gauge theory of strong interactions
  - GIM mechanism and family structure
  - KM description of CP violation
- **Followed by 30 years of consolidation:**
  - **technical theoretical advances** (higher-order calculations, lattice QCD)
  - **experimental** verification, via **discovery** of
    - **Fermions**: charm, 3rd family (USA)
    - **Bosons**: gluon, W and Z (Europe; .... waiting to add the Higgs ....)
  - **experimental** consolidation, via **measurement** of
    - EW radiative corrections
    - running of α_s
    - CP violation in the 3rd generation

Since 1973:

- Theory mostly driven by theory, not by data. Need of
  - deeper understanding of the **origin of EWSB**
  - deeper understanding of the **gauge structure of the SM**
  - deeper understanding of the **family structure of the SM**
  - **some** understanding of **quantum gravity** (includes understanding of the cosmological constant ~ 0)
- Milestones:
  - 1974: Grand Unified Theories ☹
  - 1974: Supersymmetry ☹
  - 1977: See-saw mechanism for ν masses ☺
  - 1979: Technicolor ☹
  - 1984: Superstring theories ☹
  - 1998: Large scale extra dimensions ☹
  - in parallel to the above: development and consolidation of the **SM of cosmology**

Time is long due for a first direct manifestation of at least one of the new phenomena predicted by the scenarios beyond the Standard Model

What will be the main driving theme of the exploration of the new physics revealed by the LHC?

the gauge sector
(Higgs, EWSB)

The High Energy Frontier

LHC
SLHC
VLHC
ILC
CLIC
....

the flavour sector
(ν mixings, CPV, FCNC, EDM, LFV)

The High Intensity Frontier

Neutrinos:	**Quarks:**	**Charged leptons:**
super beams	B factories	stopped μ
beta-beams	K factories	$\ell \to \ell'$ conversion
ν factory	n EDM	e/μ EDM

The answer is still open, but a new and very exciting era in HEP is awaiting us!