MODELLO STANDARD

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VI
IFAE
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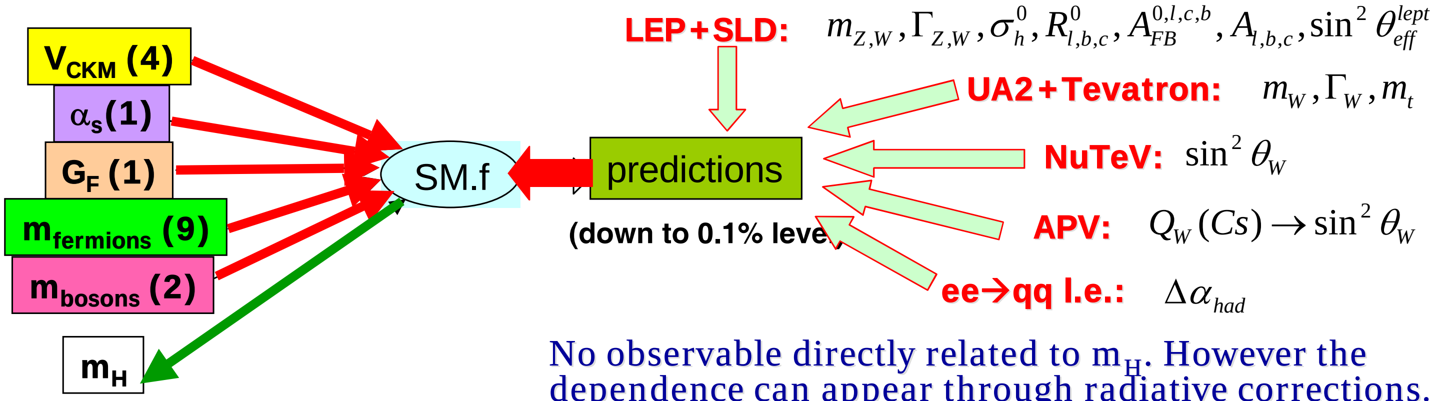
What we (think we) know

R. Chierici



V_{CKM} (4)

α_s(1)

G_F (1)

$m_{fermions}$ (9)

m_{bosons} (2)

m_H

SM.f

predictions

(down to 0.1% level)

LEP+SLD: $m_{Z,W}, \Gamma_{Z,W}, \sigma_h^0, R_{l,b,c}^0, A_{FB}^{0,l,c,b}, A_{l,b,c}, \sin^2\theta_{eff}^{lept}$

UA2+Tevatron: m_W, Γ_W, m_t

NuTeV: $\sin^2\theta_W$

APV: $Q_W(Cs) \rightarrow \sin^2\theta_W$

ee→qq l.e.: $\Delta\alpha_{had}$

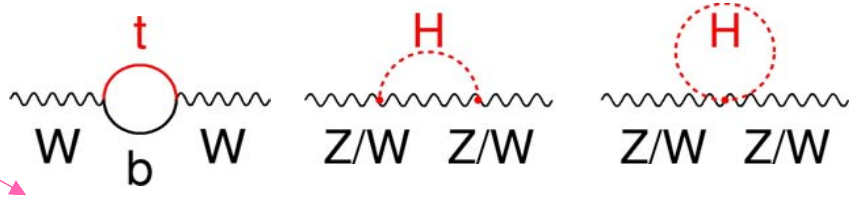
No observable directly related to m_H. However the dependence can appear through radiative corrections.

⇒ tree level quantities are changed

$$\frac{m_W^2}{m_Z^2\cos^2\theta_W} = 1 + \Delta\rho$$

$$m_W^2 = \frac{\pi\alpha}{\sqrt{2}\sin^2\theta_W G_F}(1+\Delta r)$$

$$\alpha(m_Z^2) = \frac{\alpha(0)}{1-\Delta\alpha}$$



$\Delta\rho$, Δr = f [log(m_H/m_W), m_t^2]

The uncertainties on m_t, m_W are the dominating ones in the electroweak fit

By making precision measurements (already interesting per se):

- one can get information on the missing parameter m_H
- one can test the validity of the Standard Model

The top quark

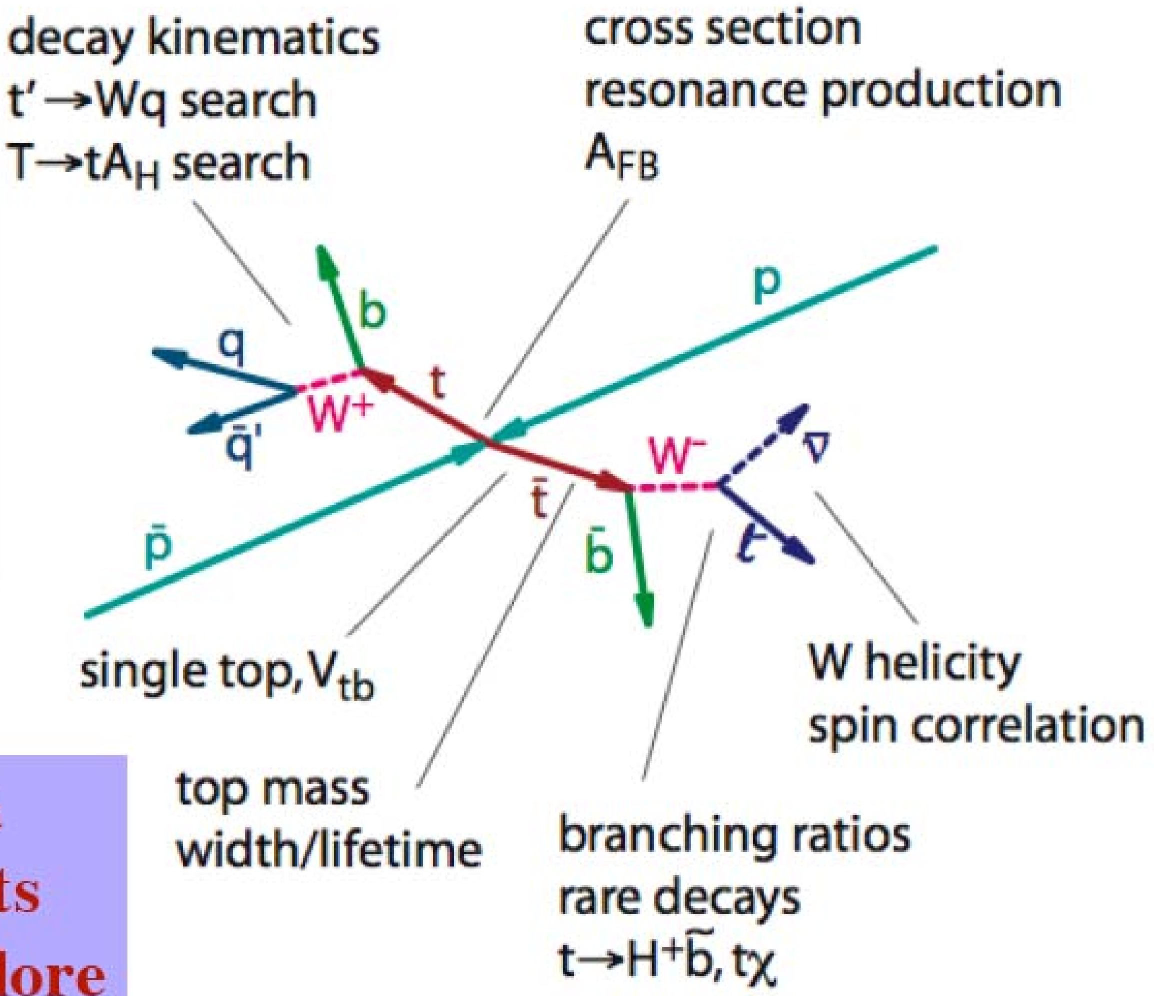
F. Margaroli

Huge mass,short lifetime: decays before hadronizing

Special role in EWSB?

Probes physics at highest allowable mass scale

Top physics is mature for a wide range of measurements which we just began to explore



Top @ Tevatron (I)

F. Margaroli

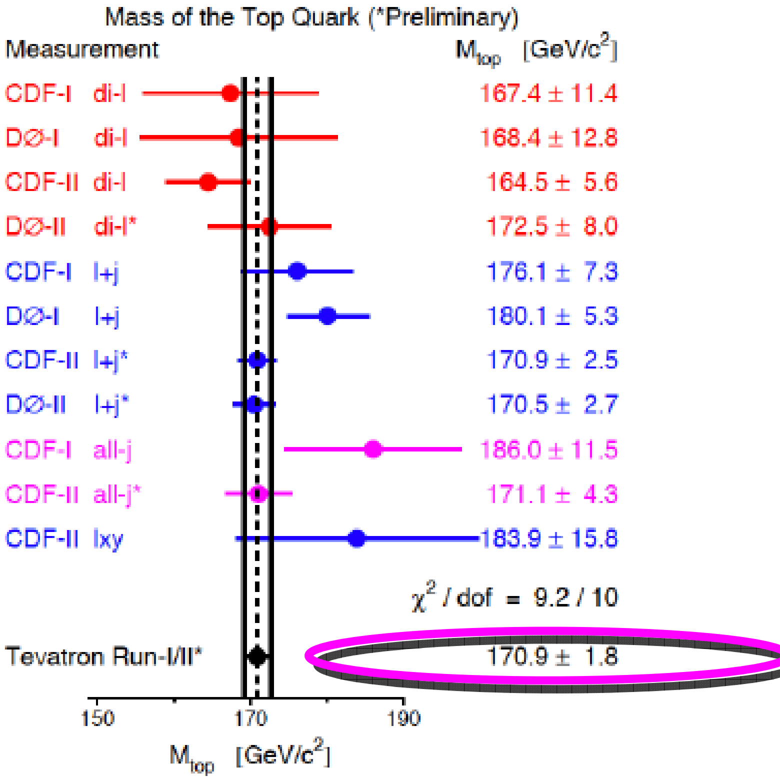
Observable	Measurements	SM expectation
M_{top}(GeV/c²)	170.9 ± 1.8	178^{+12}_{-9}
σ_{tt} (pb)	7.3 ± 0.9	6.7 ± 0.9
F_0	0.59 ± 0.14	0.70
F_+	<0.1@ 95% C.L.	0
gg/pp	0.01±0.16±0.07	0.15
σ_t (pb)	4.9 ± 1.4	2.9 ± 0.4

Non SM process	Limits
resonance	(BRxσ) < 1 pb @ 95 C.L. for M_X> 600GeV/c²

- Mass measurements with two techniques: Matrix element and Template method

Error below 2 GeV (Run II design goal)Further improvement expected

- Cross section measurements: combination gives 15 % improvement with respect to the best measurement alone

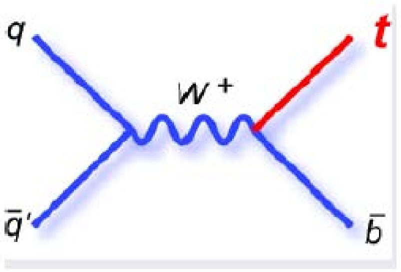


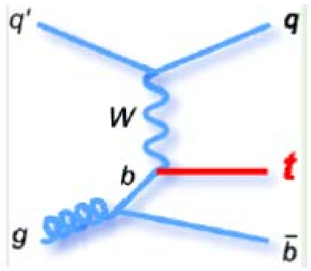
Top @ Tevatron (II)

F. Margaroli

SINGLE TOP:

- Allows measurement of V_{tb}
- Background for Higgs searches





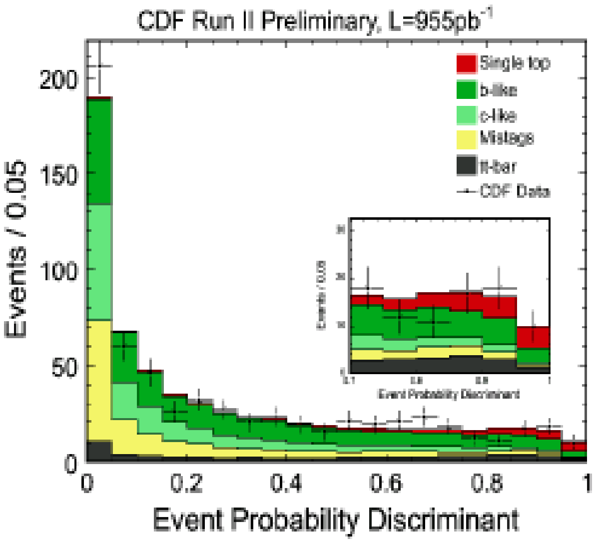
Matrix Element Discriminant

s+t channel

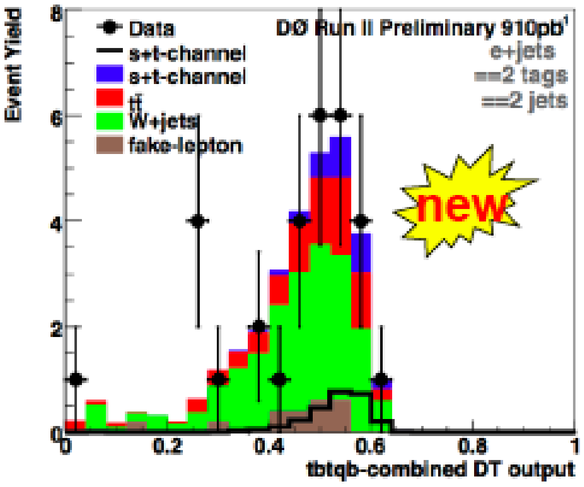
$\sigma=2.7^{+1.5}_{-1.3}$pb

obs p-value=

1.0% (2.3 σ)



Boosted Decision Tree



➔ *Evidence!*

s+t channel

σ= 4.9 ± 1.4 pb

3.4σ from background only hypothesis

➔ *Evidence!*

$0.68 < |V_{tb}| \leq 1$

Top @ LHC

A. Dotti

	1.96 TeV	14 TeV	
ttbar pairs	$5.06^{+0.13}_{-0.36}$ pb	833^{+52}_{-39} pb	(x170)
Single top (s-channel)	0.88±0.12 pb	10±1 pb	**(x10)**
Single top (t-channel)	1.98±0.22 pb	245±17 pb	(x120)
Single top (Wt channel)	0.15±0.04 pb	60±10 pb (sara' scoperto a LHC)	(x400)
Wjj (*)	~1200 pb	~7500 pb	(x6)
bb+other jets (*)	~2.4x10⁵ pb	~5x10⁵ pb	(x2)

(*) with kinematic cuts in order to better mimic signal
Belyaev, Boos, and Dudko [hep-ph/9806332]

LHC goal: reduce error on mass measurement down to 1 GeV

Statistics will not be a problem:

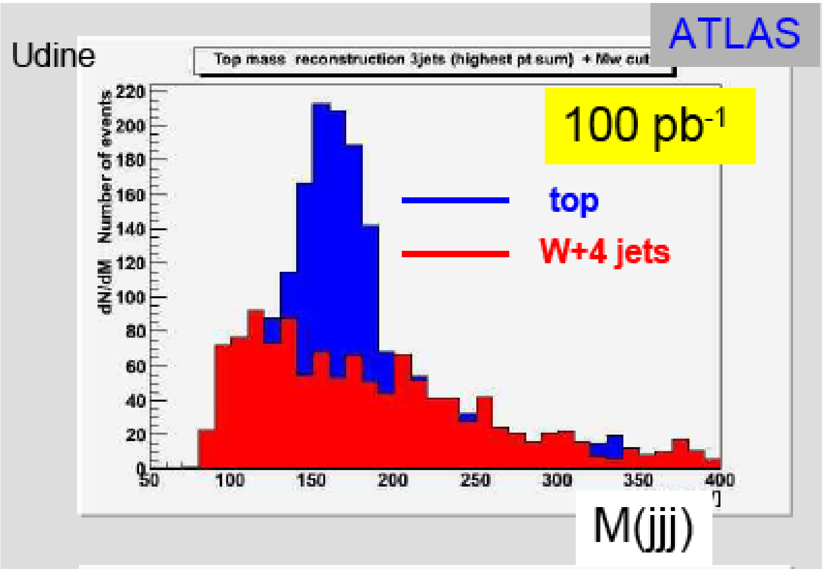
$$1\, t\bar{t}/sec \ @\ L = 10^{33} cm^{-2} s^{-1}$$

Precise measurements require good knowledge of MET, JES, b-tagging.....

But... top quark can be "rediscovered" already during first weeks of run

Based on detector construction quality, test beam results, cosmics and simulation

Simple analysis with few robust selection cuts and no b-tagging !



W mass

P. Mastrandrea, M. Malberti

$$M_W = \sqrt{\frac{\pi\alpha}{G_F\sqrt{2}}}\cdot\frac{1}{\sin\theta_W\sqrt{1-\boxed{\Delta r}}} \longrightarrow f(m_{top}^2, \log(M_H))$$

Test of SM combining precise measurement of M_W and m_{top} and a direct measurement of M_H

comparable impact on M_H if $\Delta M_W \sim 0.7\times 10^{-2}\Delta m_{top}$

→ $\Delta m_{top} < 2\,\mathrm{GeV} \Longrightarrow \Delta M_W < 15\,\mathrm{MeV}$

Traditional methods (Tevatron)

- p_T^l sensitive to p_T^W but less to detector effects
- $M_W^T = \sqrt{2p_T^l p_T^\nu(1-\cos\theta_{l\nu})}$ sensitive to detector effects

Binned likelikood fit including also MET

W/Z ratio (CMS):

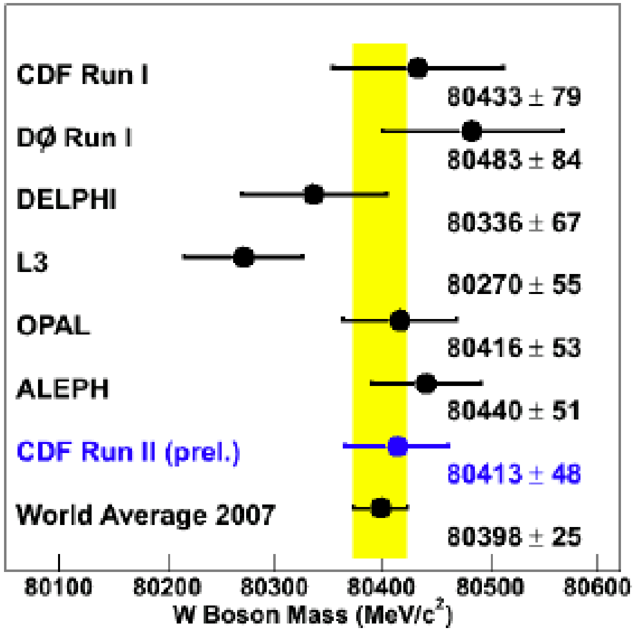
predict lepton spectra from W decay using Z data (systematics cancel in the ratio)

W mass (II)

P. Mastrandrea

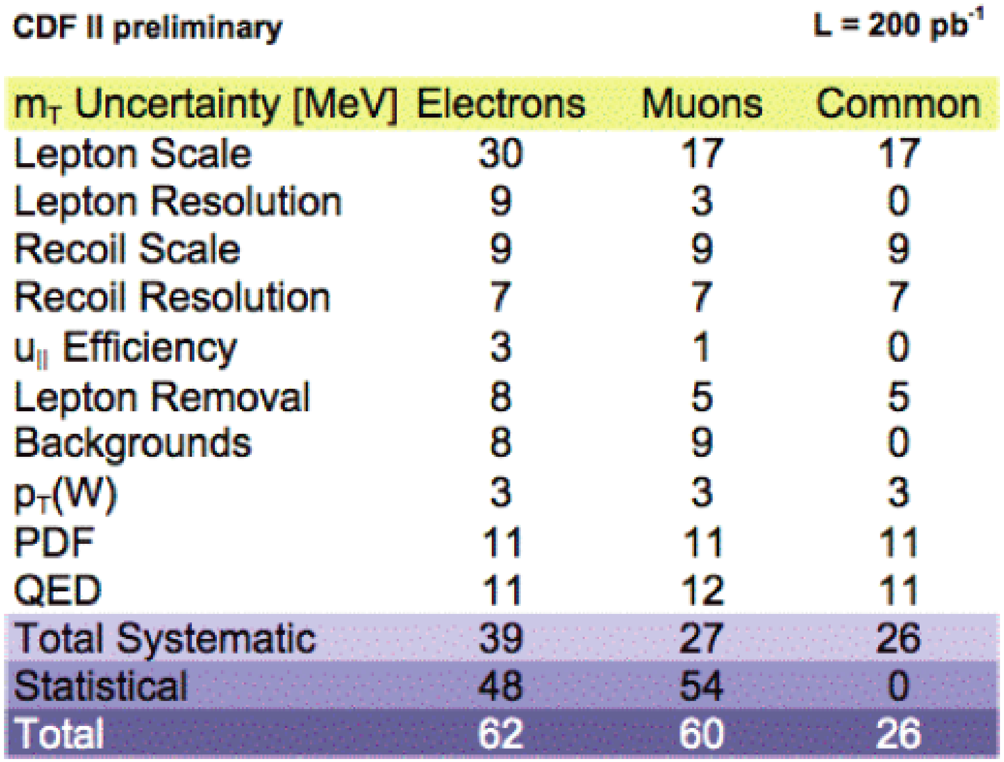
New result from CDF:
Single most precise measurement up to date

M_W = 80413 ± 48 MeV



M. Malberti

ATLAS Source of uncertainty	ΔM_W [MeV/c^2] for 10 fb^{-1}, e channel, M_T
Statistics	< 2
Background	5
lepton E-p scale	15
lepton E-p resolution	5
Total Instrumental	**< 10**
Recoil Model	5
PDF	< 10
Γ_W	7
Radiative decays	< 10
p_T^W	5
Total	**< 25**



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
$u_{\|\|}$ 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

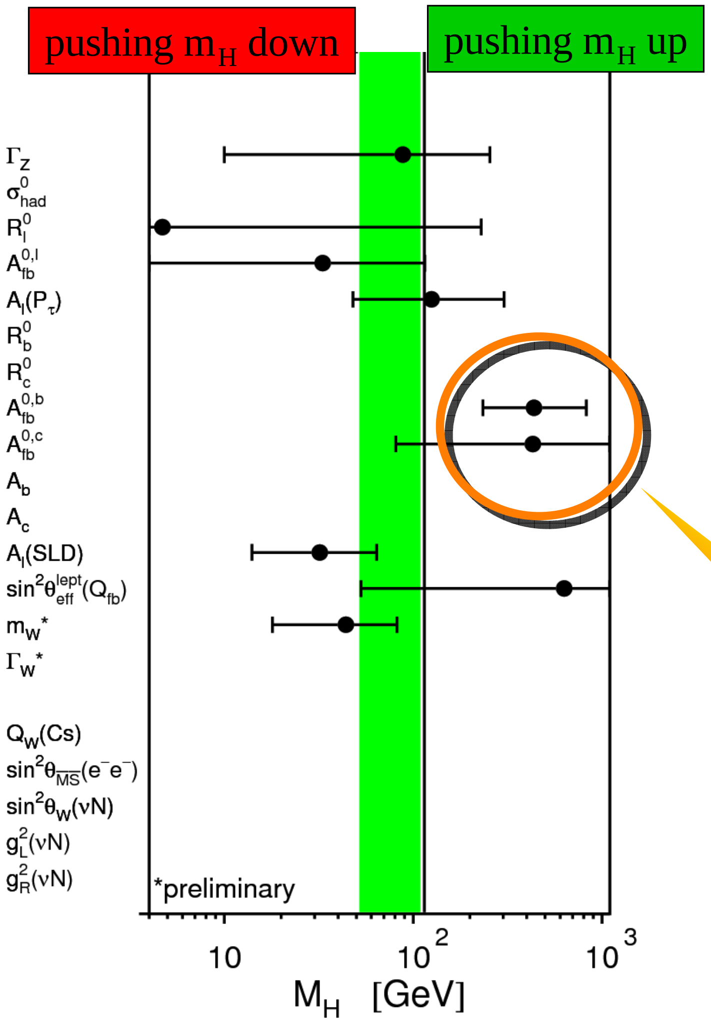
The ElectroWeak fit

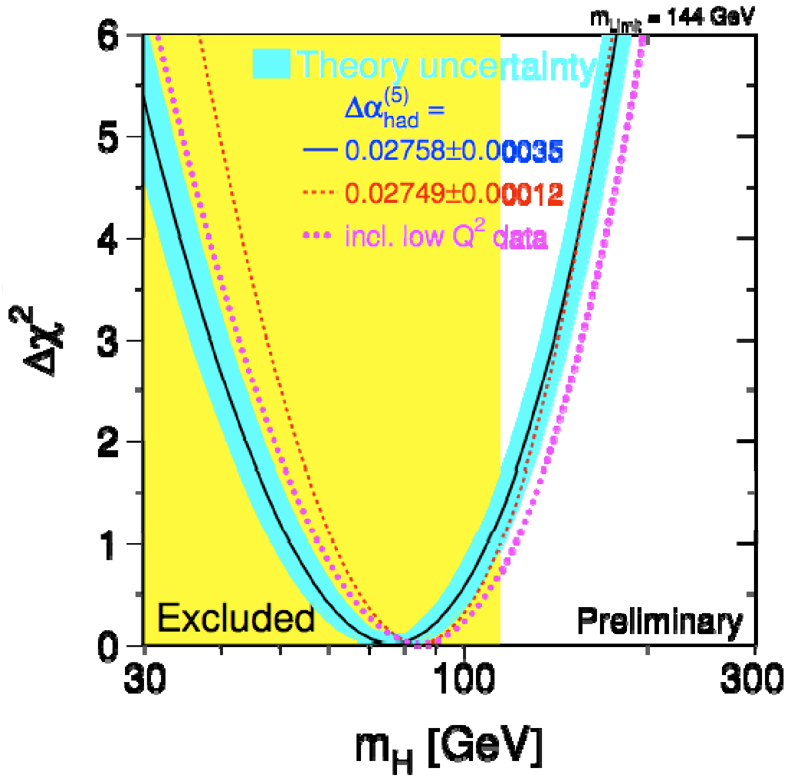
R. Chierici

$$M_H = 76^{+33}_{-24}\ \mathrm{GeV}$$

$$M_H < 144\ \mathrm{GeV}\ (95\%\ \mathrm{CL})$$

LEP EWWG, march 2007





Taking into account LEP limit:

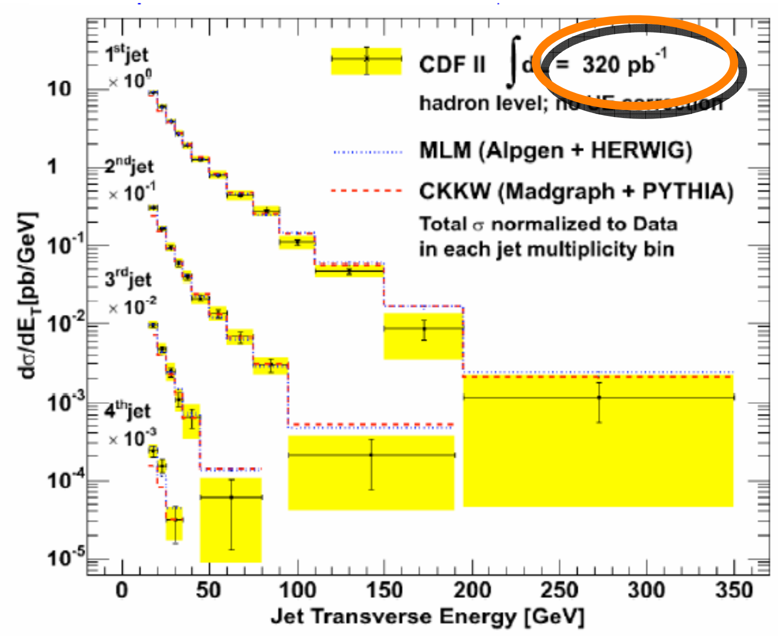
$$M_H < 182\ \mathrm{GeV}\ (95\%\ \mathrm{CL})$$

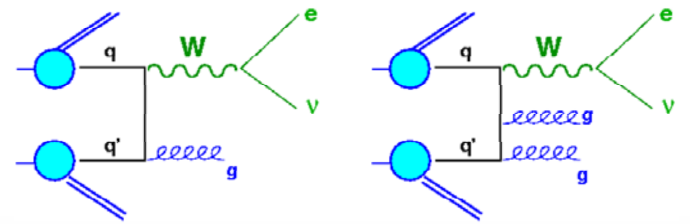
Only hadronic asymmetries (and NuTeV) push for a high Higgs mass !

Removing hadronic asymmetries makes fit very good but clash with direct search

W/Z+jets

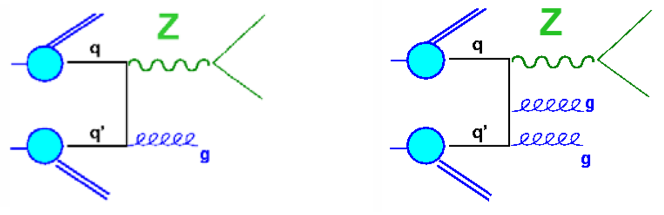
P. Mastrandrea





Jets reconstructed with JetClu algorithm (R=0.4)

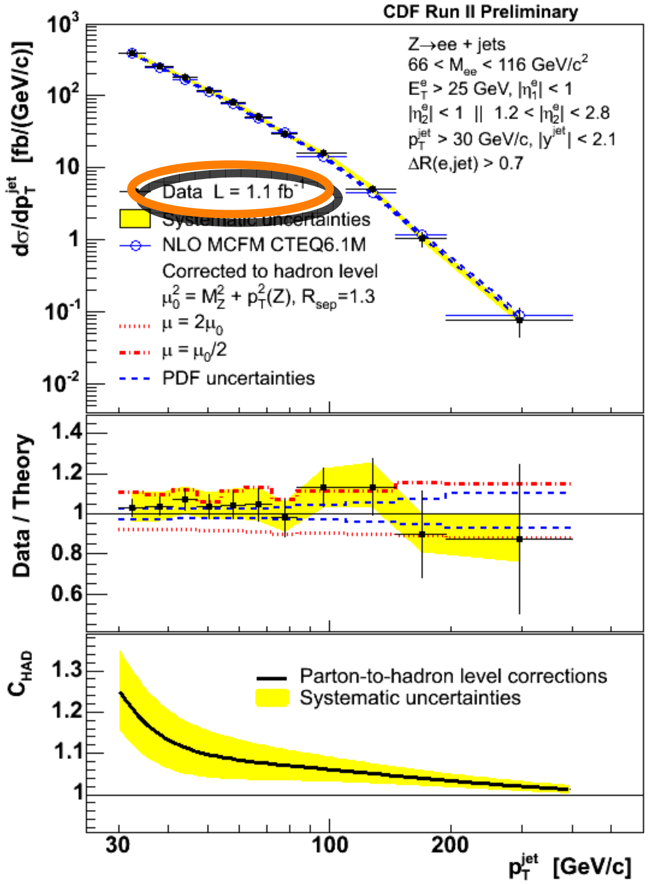
$$E_T^{jet} < 15\,\mathrm{GeV} \qquad |\eta^{jet}| < 2$$



$$p_T^{jet} > 30\,\mathrm{GeV} \qquad |\eta^{jet}| < 2.1$$

Jets reconstructed with Midpoint algorithm (R=0.7)

Good agreement with NLO with NP corrections



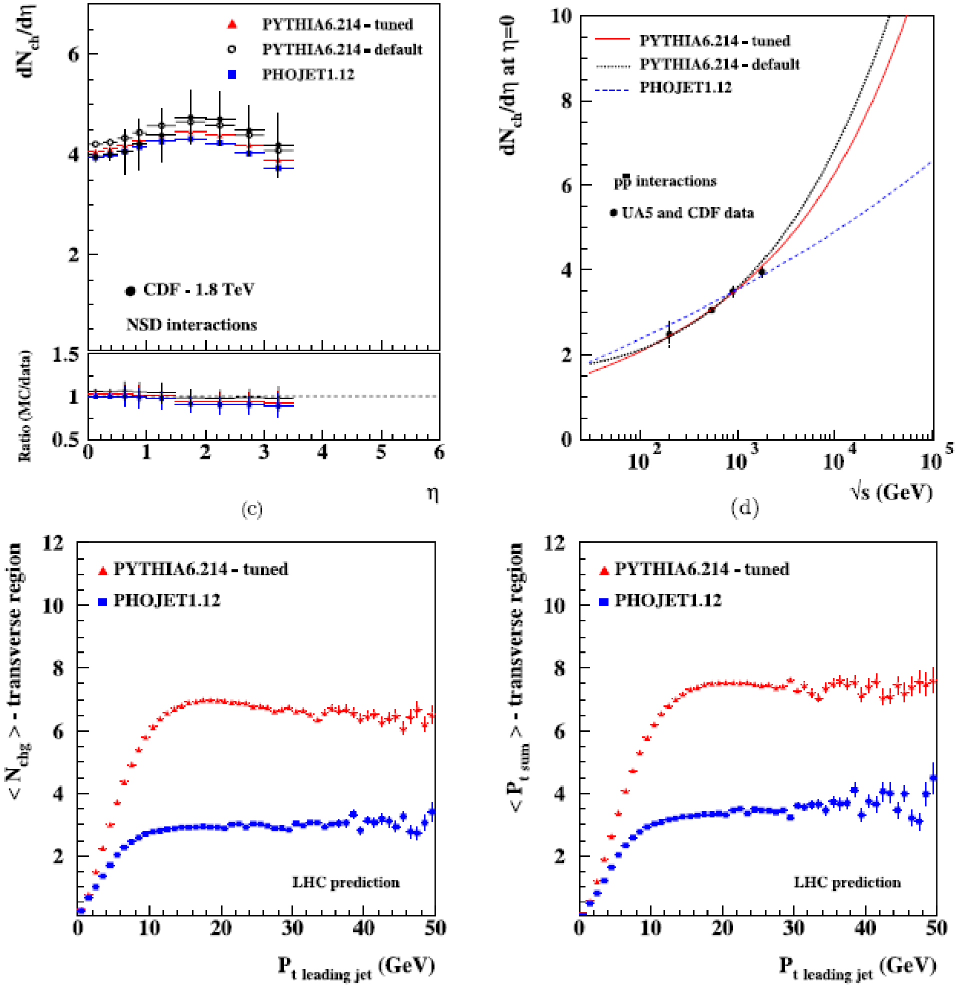
Minimum bias and Underlying event

I. Vivarelli

Minimum bias: generic pp interaction with minimal trigger

Underlying event: all that does not belong to the hard interaction (multiple parton interaction, ISR, FSR....)

Example of MB+UE tuning:



(c)

(d)

Use Pythia 6.2 and data from 200 GeV to 1.8 TeV

Extrapolation at the LHC is extremely model dependent:

MB: 35 % uncertainty on number of tracks at $\eta = 0$

UE: 80 % uncertainty on number of tracks and <pt>

→ measure MB and UE from data

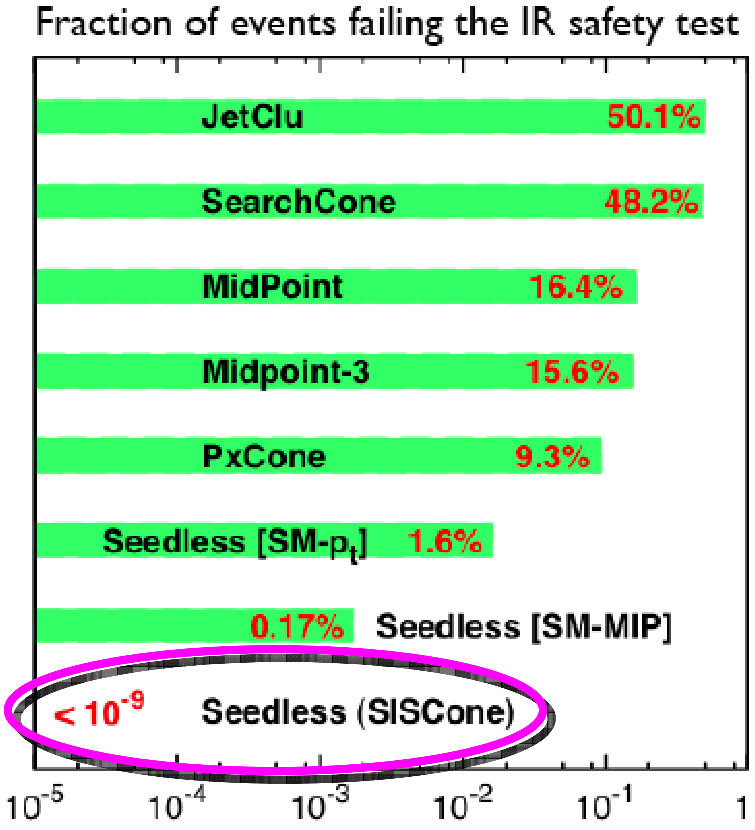
Developments in jet algorithms

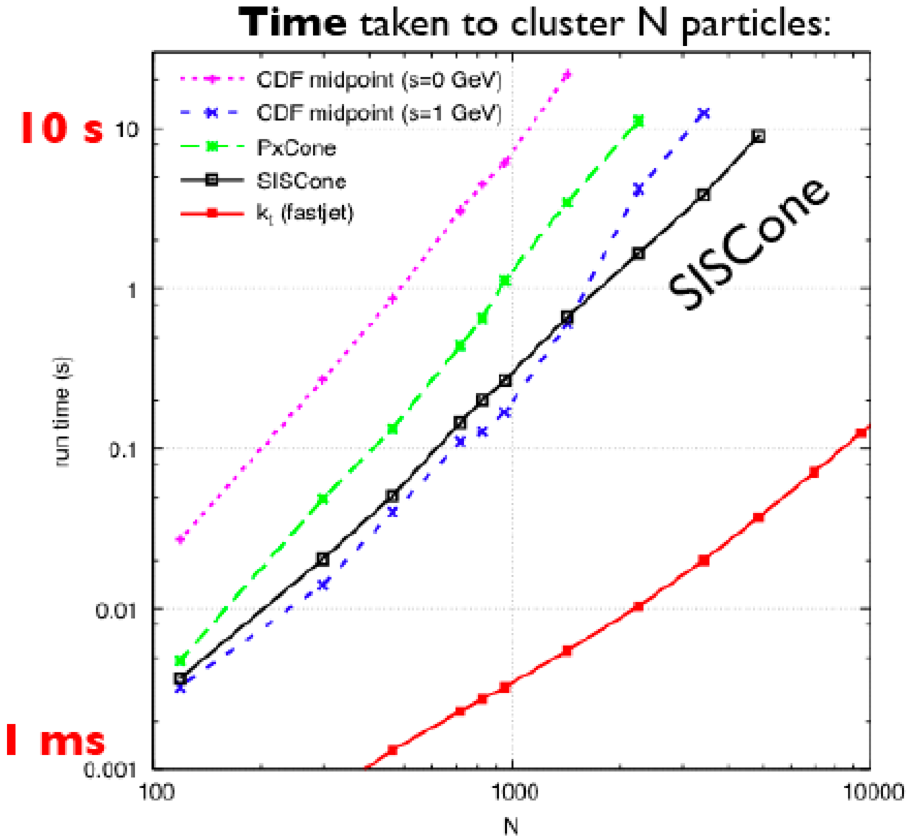
M. Cacciari

Fast implementation of kt algorithm (fastjet) → **from N^3 to N lnN**

New practical seedless IR safe cone algorithm: **SISCone**

G. Salam, G. Soyez (2007)



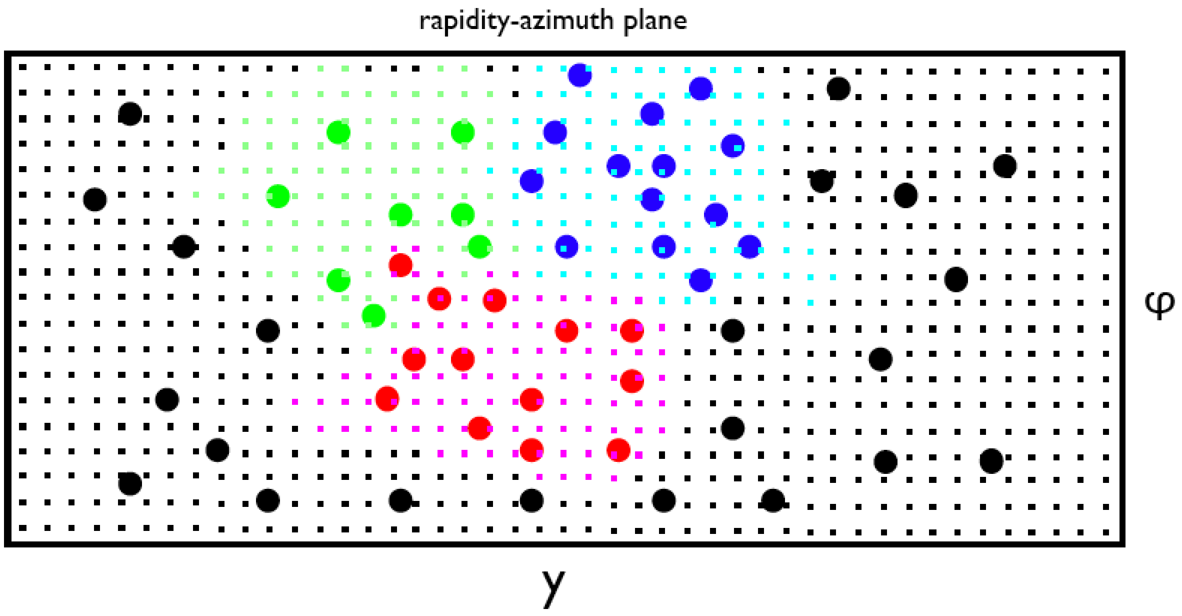


This is a **new** cone algorithm (results can differ)

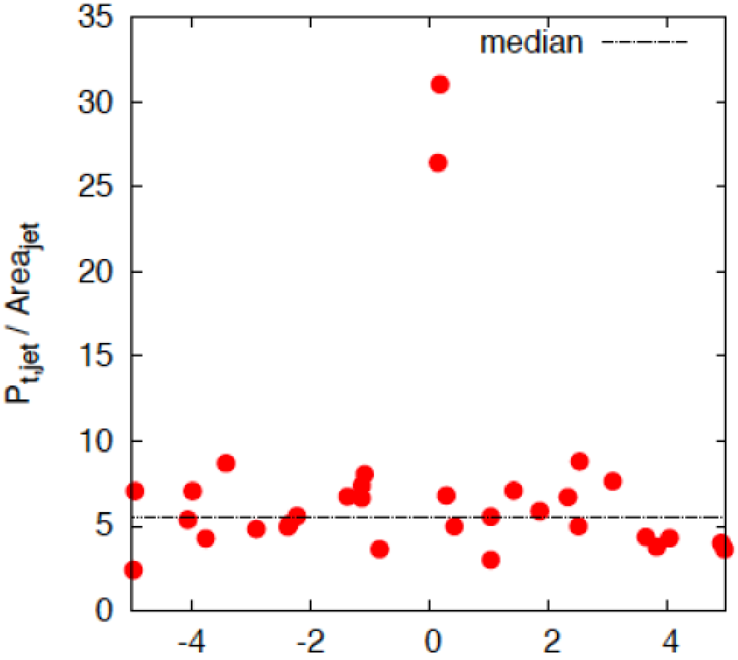
M. Cacciari

Once an IR safe jet finder is defined and implemented in a reasonably fast way → **JET AREAS** can be defined

The 'active area' of a jet is (proportional to) the number of uniformly distributed infinitely soft particles that get clustered in it



A concrete example:
a 50 GeV di-jet event at the LHC with pile-up
(10 min-bias events added)



It can be used to subtract the background contribution from hard jets

SM Higgs @ Tevatron

S. Amerio

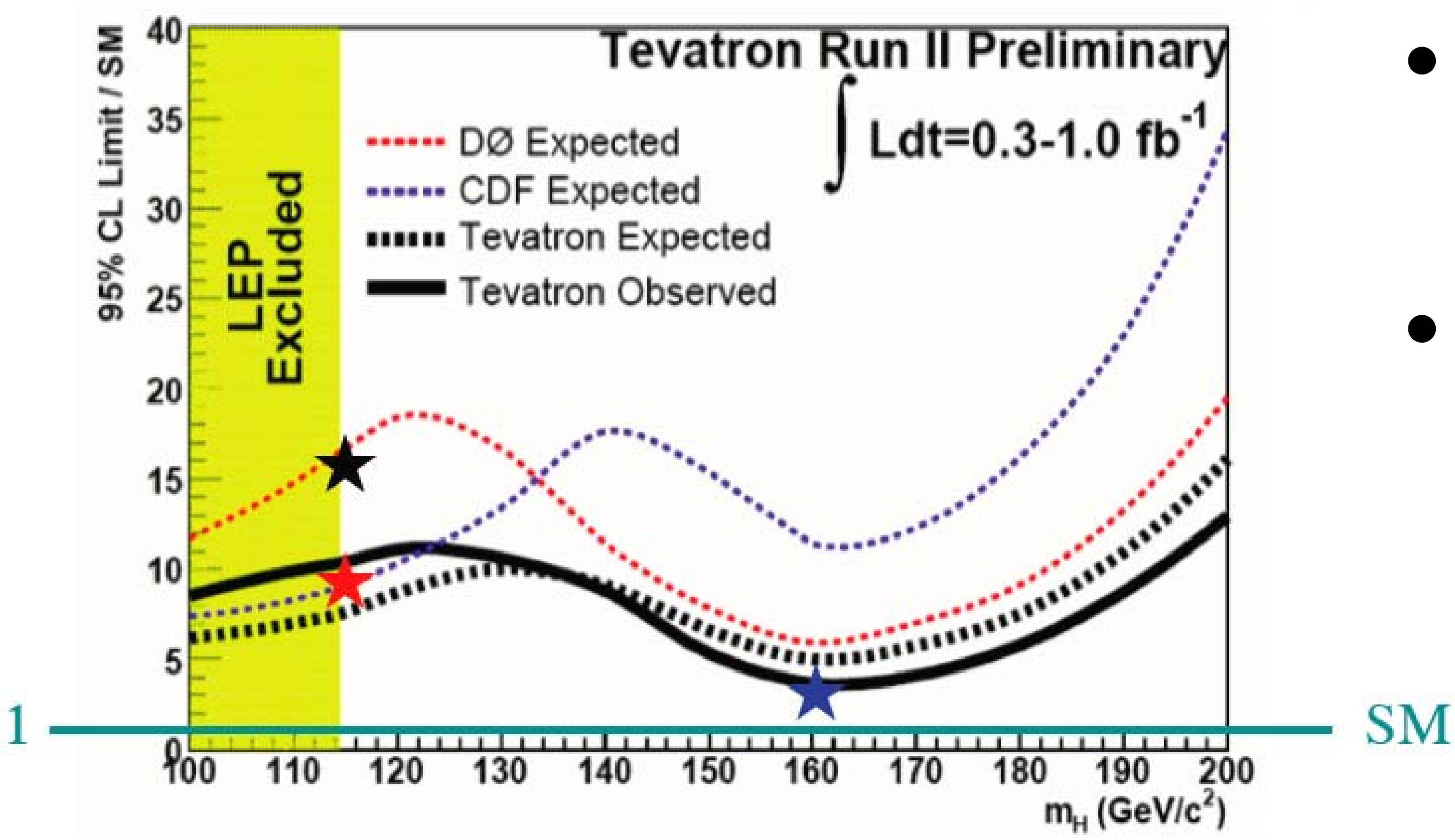
New results presented up to $1\ fb^{-1}$

They are expressed in terms of R=95% CL limits/SM

Number of events expected at CDF (**1fb-1**)
- H→ WW : **20** (Mh = 160)
- ZH → llbb : **5**
- ZH → ννbb : **15**
- WH → lνbb : **30**

} Mh = 115 GeV

D.Cho, Aspen 2007



- R=1 with $3\ fb^{-1}$ for $M_H = 115\,\mathrm{GeV}$
  → **seems difficult**
- R=1 with $5.5\ fb^{-1}$ for $M_H = 160\,\mathrm{GeV}$
  → **seems feasible**

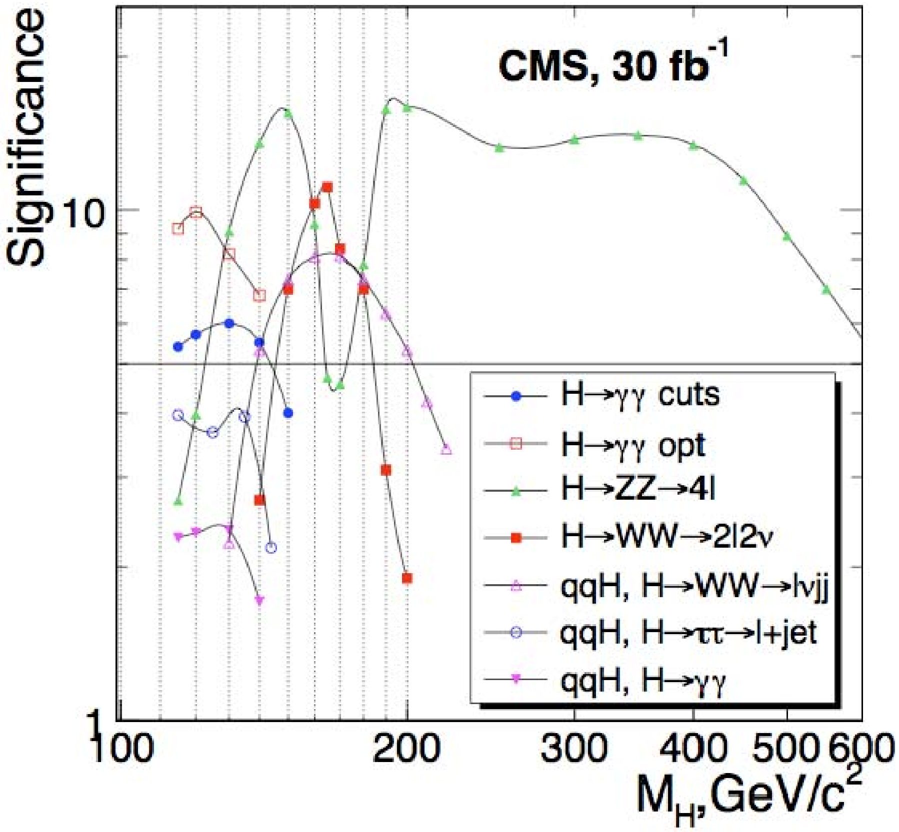
The above limits do not include
- new CDF ZH->llbb ★
- new CDF H->WW results ★
- **new D0 WH results** ★

SM Higgs @ LHC

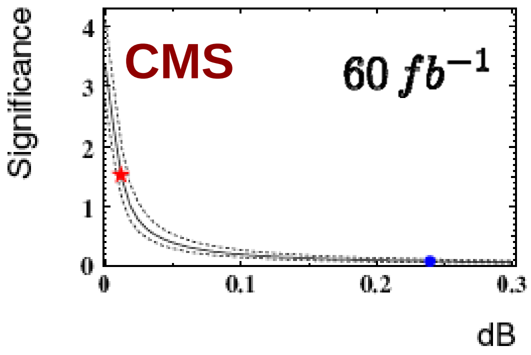
M. Sani

Expected discovery capability at the LHC with full detector simulation

- $0.2\, fb^{-1}$ exclusion limits start
- $1\, fb^{-1}$ discovery possible for $M_H \sim 165\, \mathrm{GeV}$ (2008 ?)
- $10\, fb^{-1}$ SM Higgs discovered or excluded in the full mass range (2009-2010)



NOTE THAT: $t\bar{t}H$: full detector simulation and better background evaluation lead to more pessimistic view

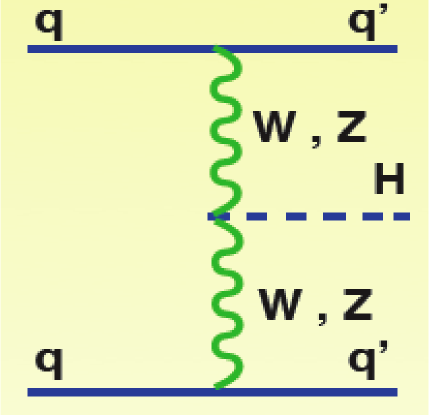


Note even considered in CMS TDR

..... and now theory ....

New channel: $pp \to H(\to b\bar{b}) + 2j + \gamma$

B. Mele



Constraining Hbb coupling at the LHC: use VBF

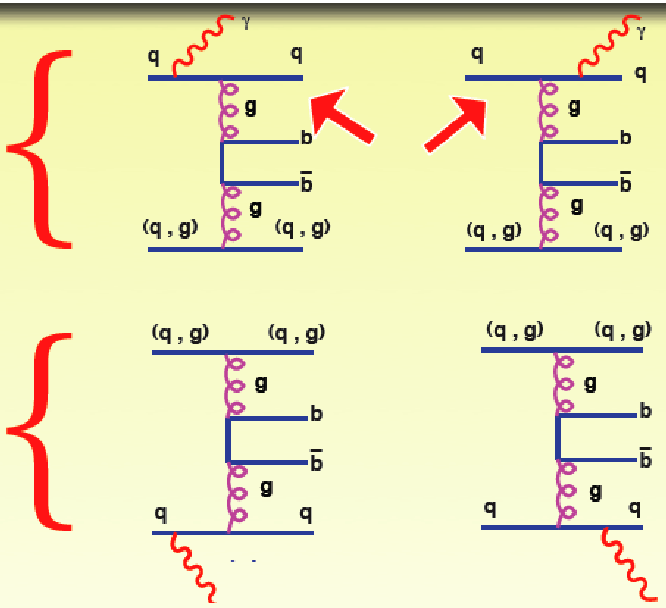
Potential difficult to assess → **require a further central photon**

From QED naive scaling:

$$(S/\sqrt{B})|_{H\gamma\, jj} \sim \sqrt{\alpha}\,(S/\sqrt{B})|_{H\, jj} \lesssim 1/10\,(S/\sqrt{B})|_{H\, jj}$$ but....

destructive interf.s in central γ emissions off q_{in} and q_{fin} in a t-channel gluon diagram

→ bckg suppressed by requiring a central photon by O(1/10) compared to naive QED scaling!



γ emission from $b\bar{b}$ pair suppressed by b electric charge

B. Mele

EVENT SELECTION

basic cuts :

$p_T^j \geq 30\,\mathrm{GeV}, \quad p_T^b \geq 30\,\mathrm{GeV}, \quad \Delta R_{ik} \geq 0.7,$

$|\eta_\gamma| \leq 2.5, \quad |\eta_b| \leq 2.5, \quad |\eta_j| \leq 5,$

$m_{jj} > 400\,\mathrm{GeV}, \quad m_H(1-10\%) \leq m_{b\bar{b}} \leq m_H(1+10\%),$

$$\begin{cases} 1)\ p_T^\gamma \geq 20\,\mathrm{GeV}, \\ 2)\ p_T^\gamma \geq 30\,\mathrm{GeV}, \end{cases}$$

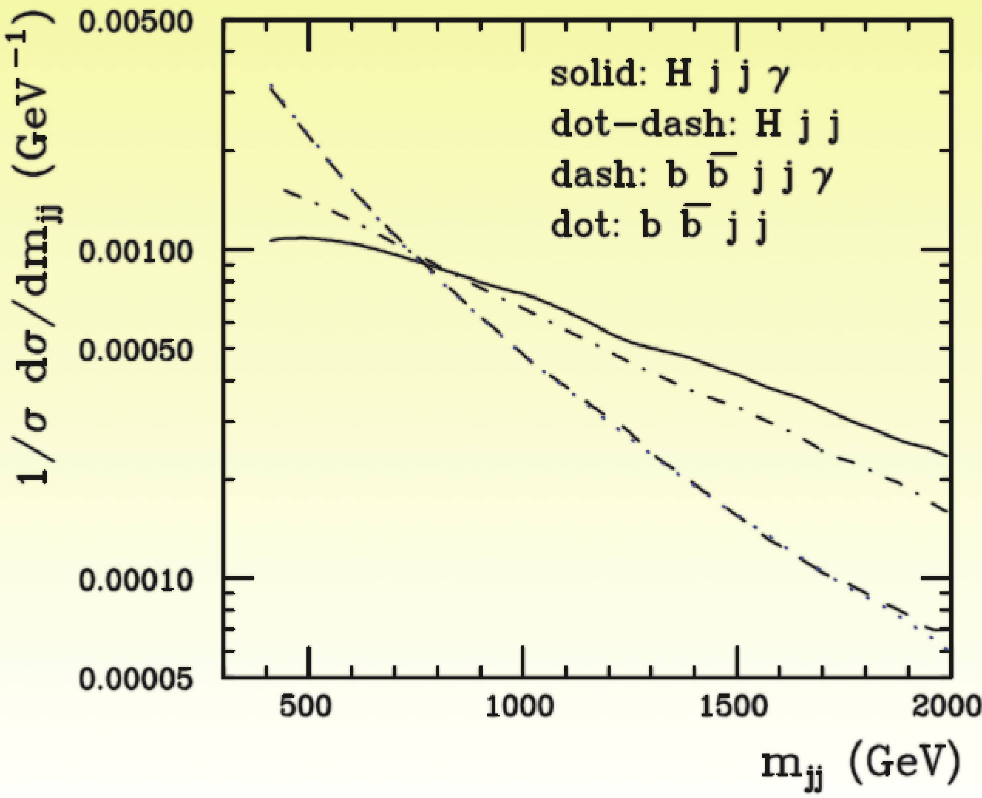
then, look at distrib's :

$$\frac{d\sigma}{dm_{jj}}, \quad \frac{d\sigma}{dp_T^{j1}}, \quad \frac{d\sigma}{dp_T^{b1}}, \quad \frac{d\sigma}{dm_{\gamma H}}, \quad \frac{d\sigma}{|\Delta\eta_{jj}|},$$

→ add optimized cuts :

$m_{jj} \geq 800\,\mathrm{GeV}, \quad p_T^{j1} \geq 60\,\mathrm{GeV}, \quad p_T^{b1} \geq 60\,\mathrm{GeV},$

$|\Delta\eta_{jj}| > 4, \quad m_{\gamma H} \geq 160\,\mathrm{GeV}, \quad \Delta R_{\gamma b/\gamma j} \geq 1.2\,.$



bckg(γ)/bckg ~ *33 fb / 103 pb* ~ 1/3000

→ cf. signal(γ)/signal ~ 1/100

$S/\sqrt{B} \sim 2$ for $100\ fb^{-1}$

Factor of 2 improvement expected when parton shower effects are included

NLO calculations

- LO predictions often affected by large uncertainties
- NLO corrections required to reliably predict cross sections for signal and background processes and to quantify theoretical uncertainties

NLO corrections obtained by combining:

- V: virtual n-point amplitudes
- R: real n+1-point amplitudes
- R+V: combine to cancel infrared singularities

- NLO calculations performed over a period of 25 years but...

Progress is slow (from 3 to 4 jets in e^+e^- took almost 20 years !)

More legs implies more scales → lengthy expressions

Efficient techniques exist to compute tree amplitudes

The way to handle and cancel IR singularities is known

BOTTLENECK: One loop amplitudes for many legs

Techniques to compute virtual corrections imply reduction of tensor to scalar integrals that involve large intermediate expressions and spurious singularities

Recent new NLO calculations:

$pp \longrightarrow t\bar{t} + \text{jet}$	S. Dittmaier, P. Uwer , S. Weinzierl (2007)	→	traditional method
$pp \longrightarrow ZZZ$	A. Lozopoulos, K. Melnikov, F. Petriello (2007)	→	sector decomposition

OPP: REDUCTION AT THE INTEGRAND LEVEL

G. Ossola

Write loop amplitude as

$$A(\bar{q}) = \frac{N(q)}{\bar{D}_0 \bar{D}_1 \cdots \bar{D}_{m-1}}$$

where $\bar{D}_i = (\bar{q} + p_i)^2 - m_i^2$

bar denotes $4 + \epsilon$ objects

numerator can be organized as:

G. Ossola

$$
\begin{aligned}
N(q) = & \sum_{i_0<i_1<i_2<i_3}^{m-1} \left[d(i_0 i_1 i_2 i_3) + \tilde{d}(q; i_0 i_1 i_2 i_3)\right] \prod_{i \neq i_0, i_1, i_2, i_3}^{m-1} D_i \\
& + \sum_{i_0<i_1<i_2}^{m-1} \left[c(i_0 i_1 i_2) + \tilde{c}(q; i_0 i_1 i_2)\right] \prod_{i \neq i_0, i_1, i_2}^{m-1} D_i \\
& + \sum_{i_0<i_1}^{m-1} \left[b(i_0 i_1) + \tilde{b}(q; i_0 i_1)\right] \prod_{i \neq i_0, i_1}^{m-1} D_i \\
& + \sum_{i_0}^{m-1} \left[a(i_0) + \tilde{a}(q; i_0)\right] \prod_{i \neq i_0}^{m-1} D_i \\
& + \tilde{P}(q) \prod_{i}^{m-1} D_i
\end{aligned}
$$

a,b,c,d correspond to 4-3-2 and 1 point scalar integrals

the remaining terms are “spurious”

computation of $N(q)$ reduced to an algebraic problem

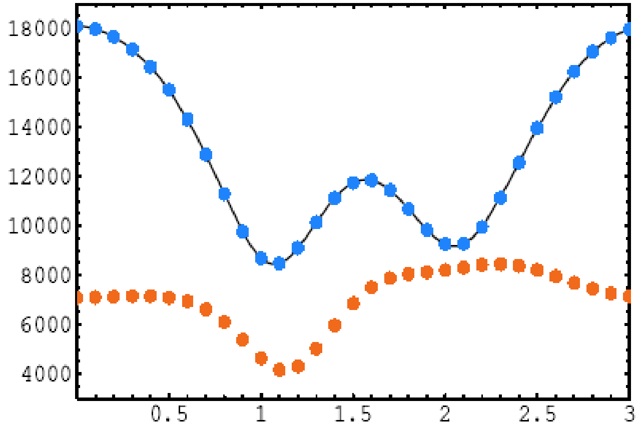
extract all the coefficients by evaluating $N(q)$ at special values of the integration momentum

Suitable for numerical implementation

six photon amplitude

Comparison with known results by Mahlon

Massless case: $[++----]$ and $[++--+-]$



Similar results for $m_f \neq 0$

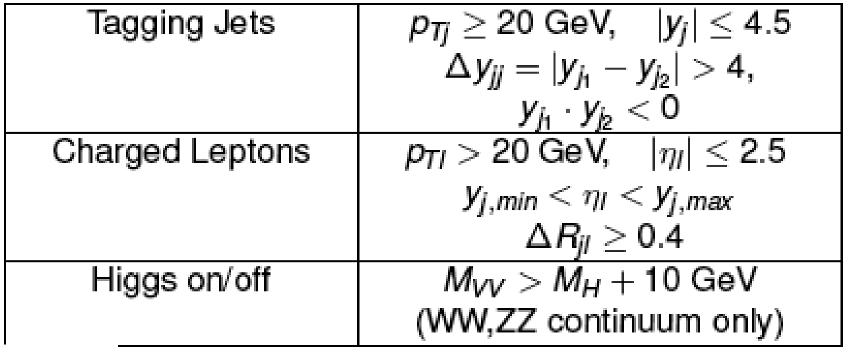
VV via VBF @NLO

G. Bozzi

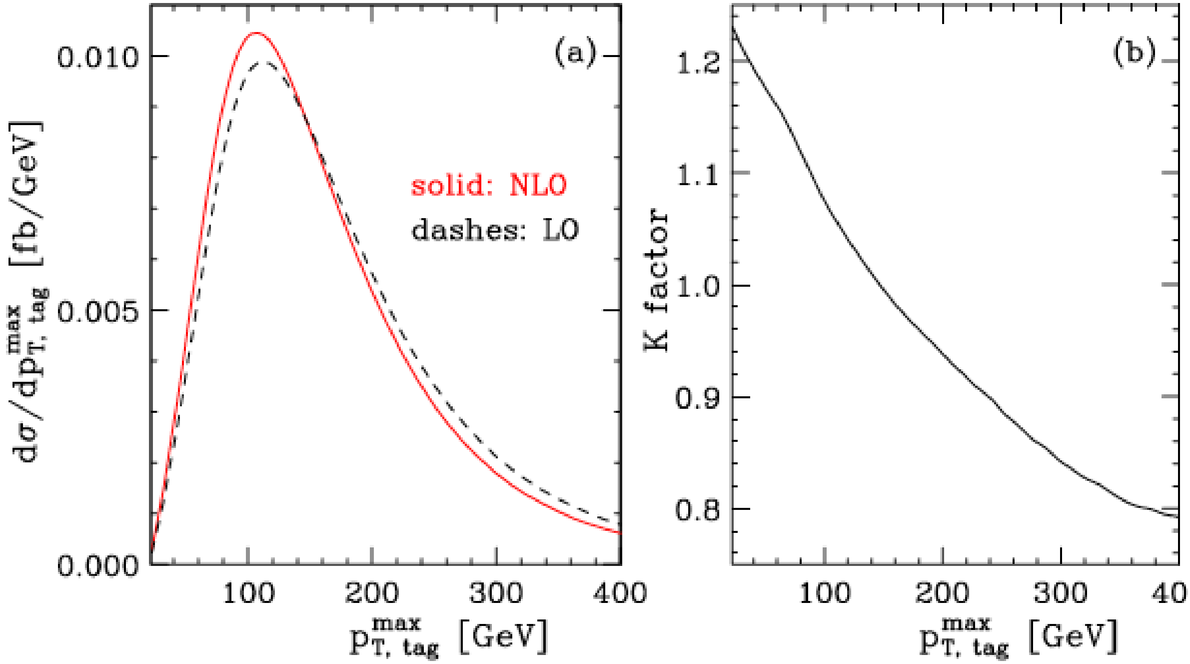
Background for Higgs search in VBF

NLO corrections computed and implemented in a parton level MC with inclusion of leptonic decay

VBFNLO due to release



Tagging Jets	$p_{Tj} \geq 20$ GeV, $\lvert y_j \rvert \leq 4.5$ $\Delta y_{jj} = \lvert y_{j_1} - y_{j_2} \rvert > 4$, $y_{j_1} \cdot y_{j_2} < 0$
Charged Leptons	$p_{Tl} > 20$ GeV, $\lvert \eta_l \rvert \leq 2.5$ $y_{j,min} < \eta_l < y_{j,max}$ $\Delta R_{jl} \geq 0.4$
Higgs on/off	$M_{VV} > M_H + 10$ GeV (WW,ZZ continuum only)



Example: WW

NLO effect is not large but strongly dependent on $p_{\mathrm{T,tag}}^{\mathrm{max}}$

- Strong change in shape → shift to smaller p_T at NLO
- Mainly due to extra parton from real emission
- K-factor varying between 1.2 and 0.8 (20 GeV < p_T < 400 GeV)

J/ψ and Υ production at NLO

F. Tramontano

Write production cross section as

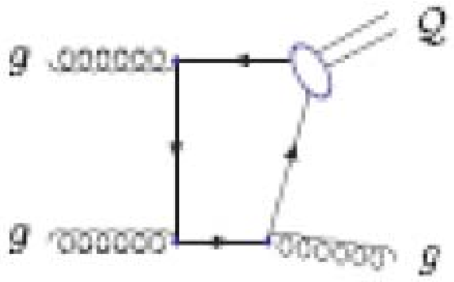
$$\sigma(pp \to Q + X) = \sum_{i,j,n} \int dx_1 dx_2 f_{i/p} f_{j/p} \times \hat{\sigma}[ij \to (Q\bar{Q})_n + x]\langle 0|\mathcal{O}_n^Q|0\rangle$$

partonic cross section

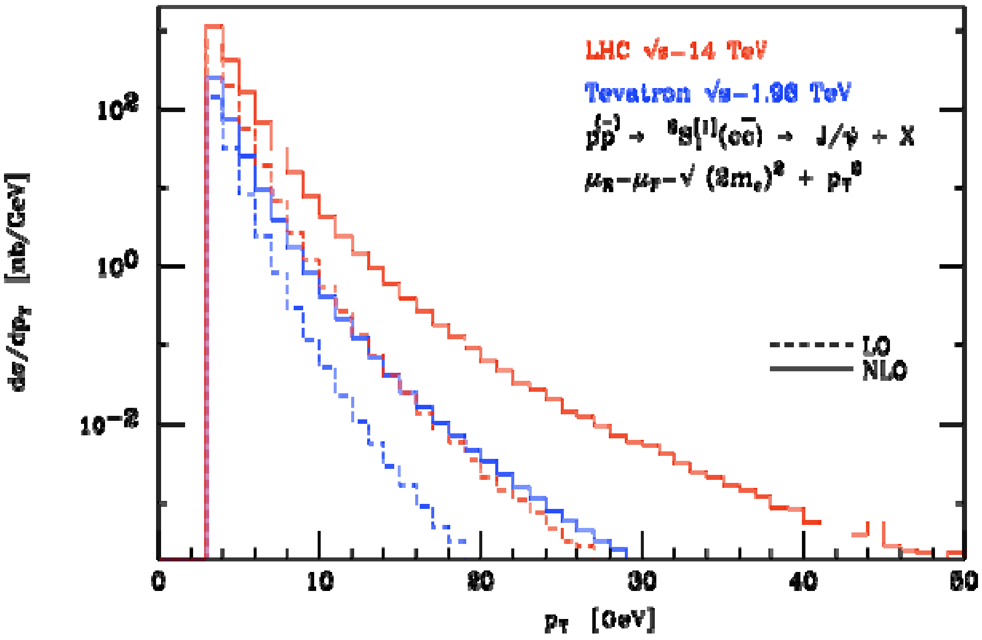
NP matrix element

The leading contribution in NRQCD is given by the $^3S_1$ color singlet state

LO



NLO



NLO effects are large

Electroweak logarithmic corrections

E. Accomando

In QCD initial state always averaged (summed) over colour

→ cancellation theorems at work for inclusive processes

On the contrary initial state has always definite EW quantum numbers

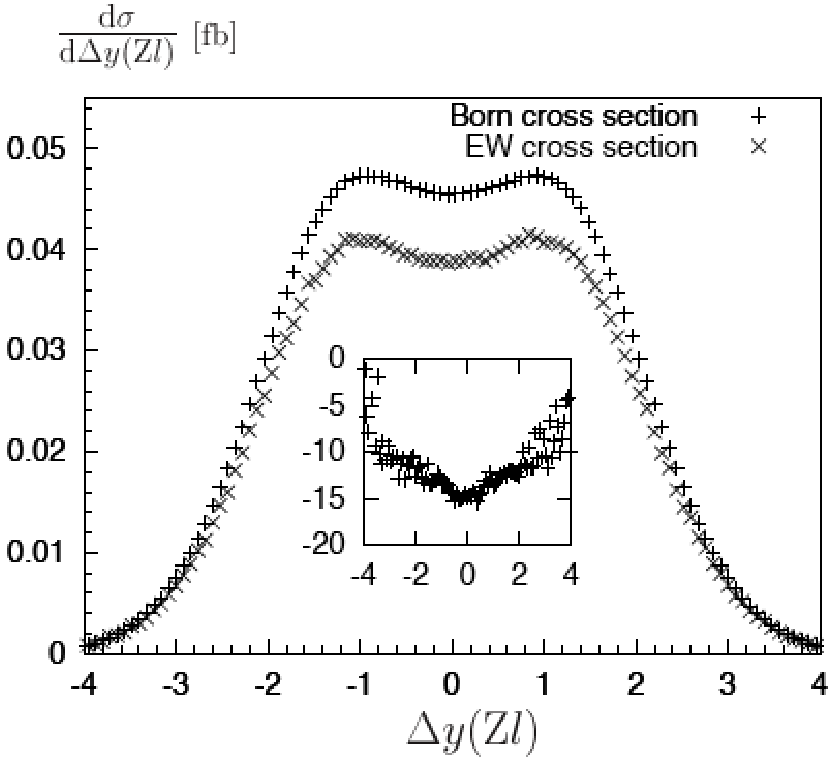
→ large logarithmic corrections of the form $\alpha^n \ln^{2n} E/M_W$ appear even for inclusive processes: they increase with energy

Relevant in the same (high-pt) region where new physics should show up

Example: WZ production

Strong interplay with QCD effects with a jet veto

→ EW effects can be in some cases as important as higher order QCD



Hadron spectroscopy

S. Nicotri

Many new hadrons recently observed in e^+e^- and $p\bar{p}$ collisions

open charm:

- $D_{sJ}(2860)$

Observed in $e^+e^- \rightarrow DK$

$Q\bar{q}$ → $s_l = s_{\bar{q}} + l$ for $m_Q \rightarrow \infty$

data and theoretical predictions in the heavy quark limit suggest $s_l^P = \frac{5}{2}^-$ and $J^P = 3^-$

hidden charm:

- $X(3872)$

Found in $J/\psi\pi^+\pi^-$ in B decays and $p\bar{p}$ collisio

not seen in e^+e^- annihilation

mass coincides with $D^{*0}\bar{D}^0$ system

What is it ?

- molecular bound state $D^{*0}\bar{D}^0$?
- charmonium ?
- $qq\bar{q}\bar{q}$?

$X \rightarrow D\bar{D}\gamma$ can shed light on its nature

Summary

- We are eagerly waiting for the LHC but in the meanwhile....
- ...new nice data from the Tevatron M_W, m_{top} and much more to come

→ m_{top} : such a high precision challenges us to reconsider our top mass definition

- From theory: ongoing effort in improving theoretical predictions

- new NLO calculations

- new techniques

- More realistic physics studies can lead to surprises

→ e.g. $t\bar{t}H$ channel in Higgs search at the LHC

Grazie a tutti gli speaker !

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