WIN'09: Electroweak Theory Summary

Adam Falkowski

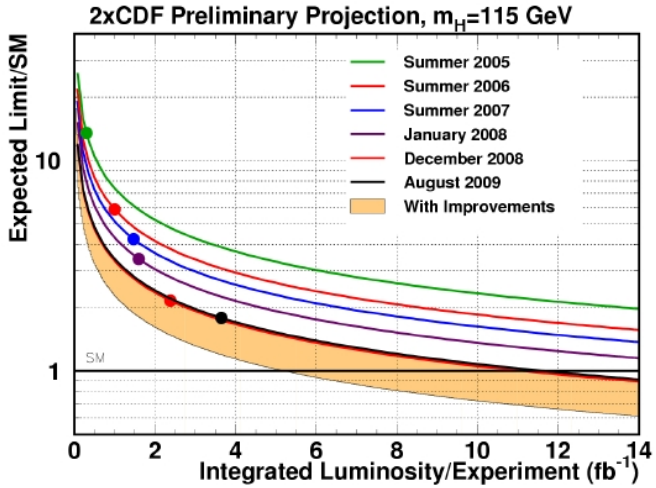
Rutgers University

WIN'09, Bosco in Italia; 18 September 2009

Outline

Collider physics now

Tevatron is zooming in on Higgs...



...but the center of the world is moving soon

What should we expect at the LHC?

`The honest answer:`

Standard Model plus a light Higgs boson and

...nothing else

This is the simplest interpretation of

- Electroweak precision data
- Flavor and CP data
- Tevatron direct searches

Any BSM scenario we know of requires a certain amount of conspiracy at the best, or large fine-tuning typically.

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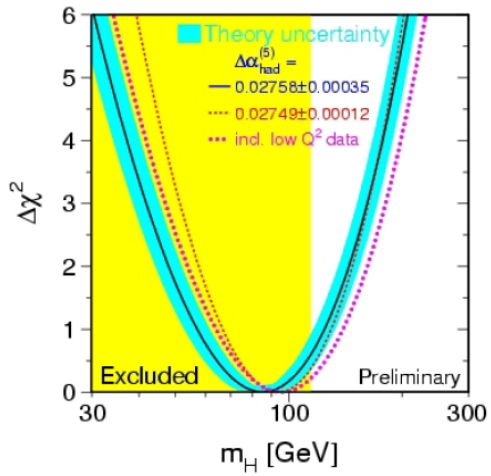
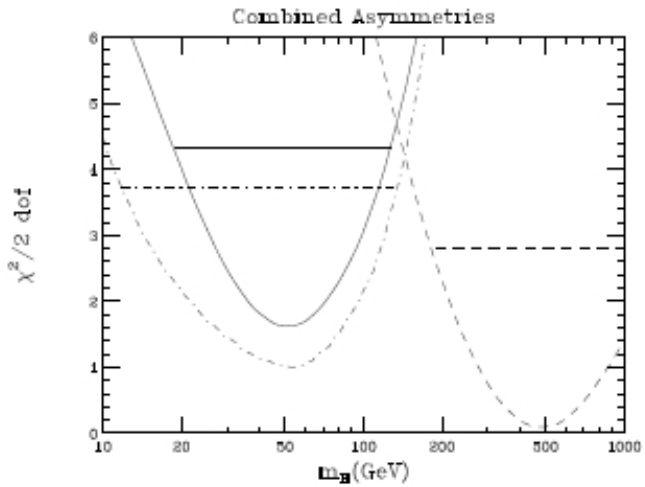
- Hierarchy problem: needs a new sector (susy? new strong interactions? little Higgs?) to stabilize the weak scale

  but: it's the first time we might be crossing a fundamental scale. We just don't know the rules
- A (small) set of collider anomalies
  - Muon g-2 (3.1 sigma deviation)
  - Forward-backward asymmetry for b quarks ($\sim 3\sigma$) (and maybe also top quarks $\sim 2\sigma$ anomaly Tevatron)
  - Higgs mass preferred by EWPT versus direct exclusion limits





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- Dark matter may be related to a TeV scale sector

  but: It may not
- There must be something or it'll be the end of us all

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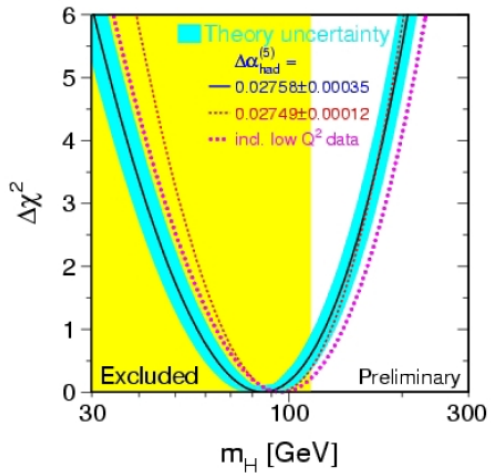

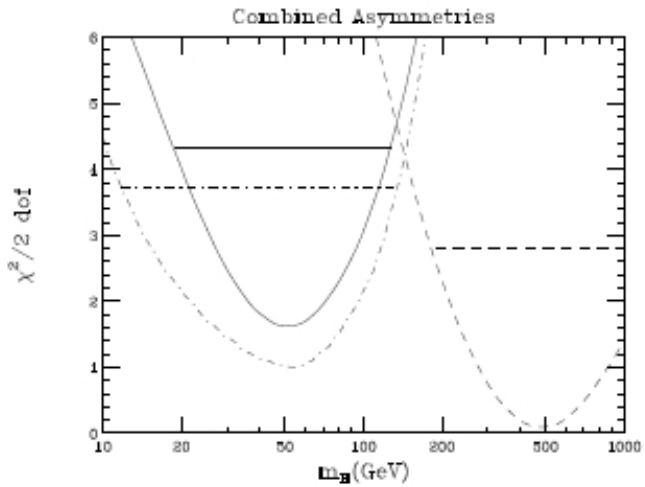

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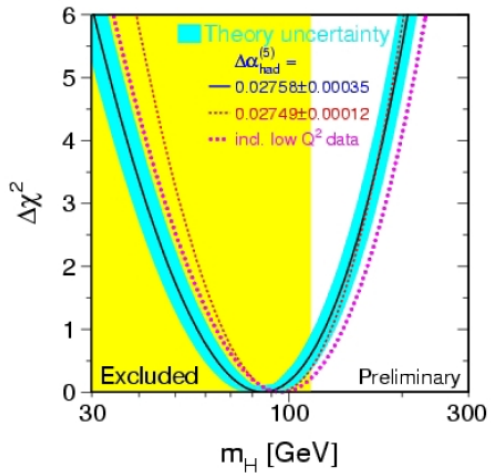

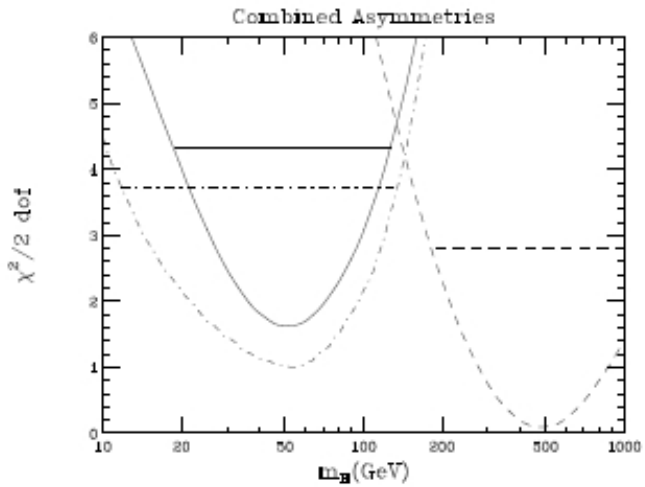

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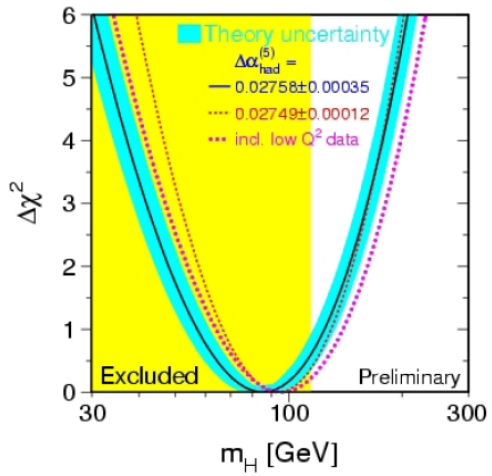

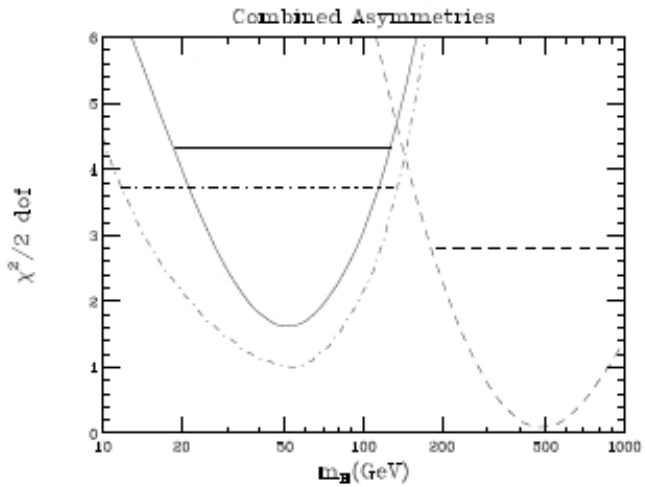

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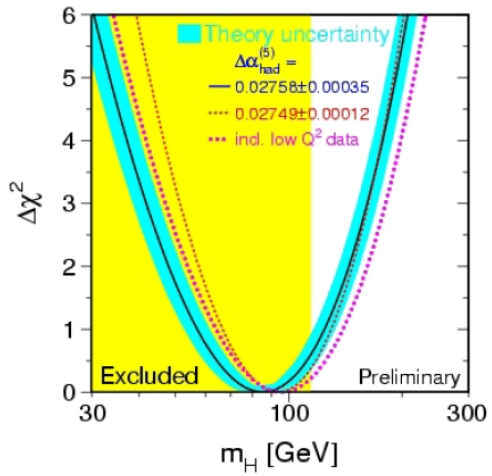

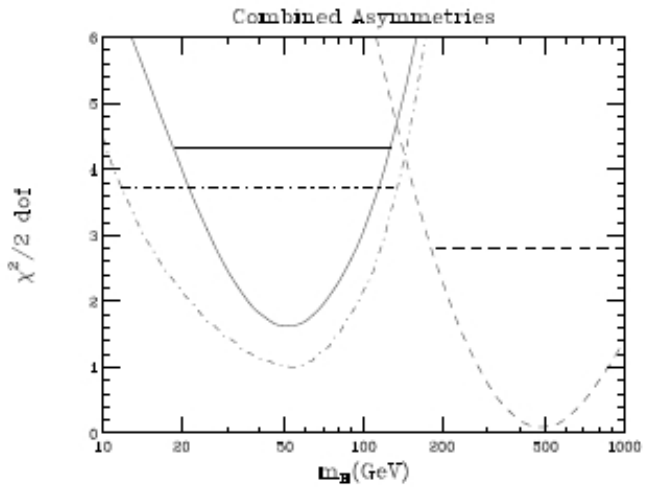

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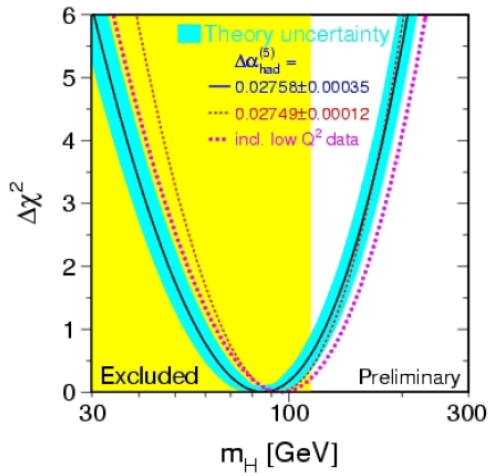

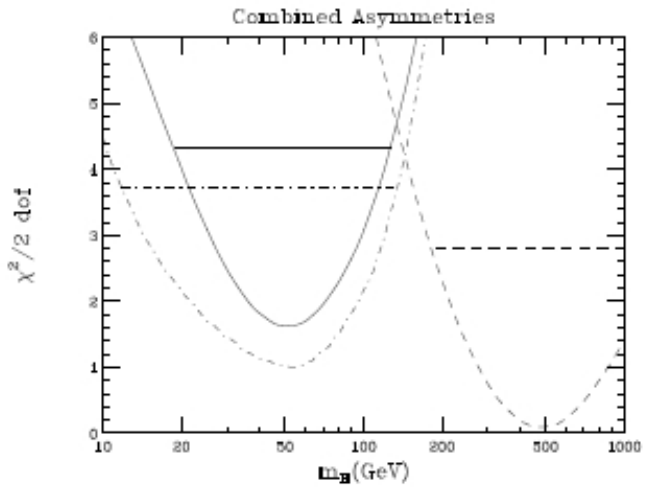

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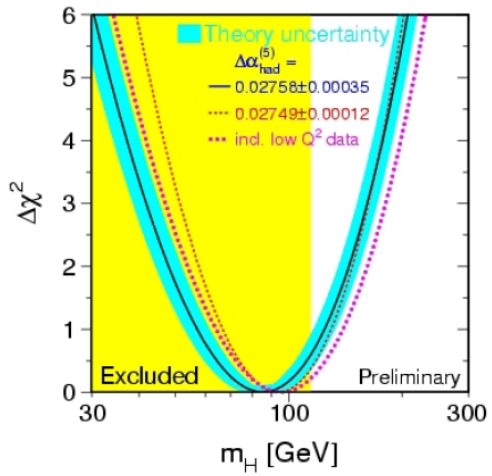

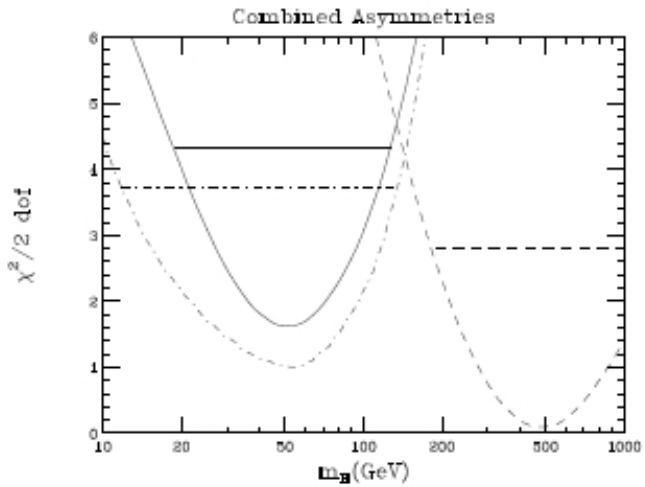

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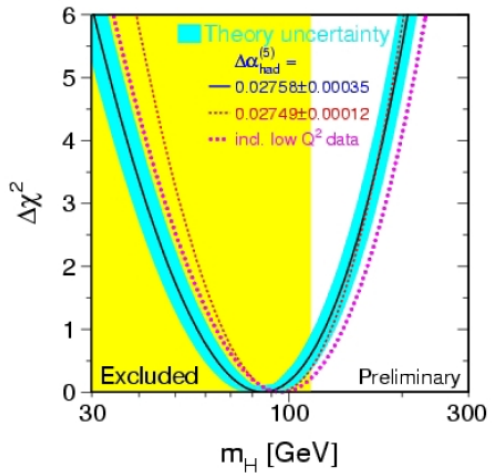

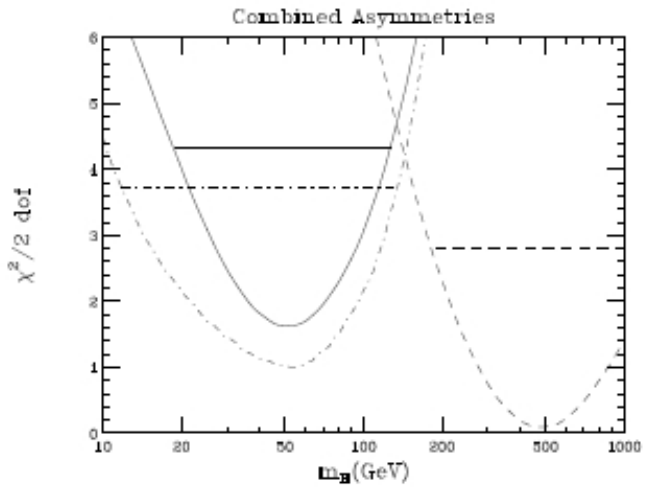

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Evolution of model building

- Everything is allowed as long as it is a point in mSUGRA
  `"String motivated" supergravity models`
- Everything is allowed as long as it is supersymmetric
  `Gauge mediation, Anomaly mediation, NMSSM...`
- Everything is allowed as long as it solves the hierarchy problem
  `Large extra dimensions, Randall-Sundrum, Little Higgs, Holographic composite Higgs models`
- Everything is allowed as long as it leads to interesting phenomenology
  `Split susy, UED, Hidden valley, Quirks`

It is highly unlikely than ANY of the popular models is true
Hopefully, the net will be tight enough that we will not miss the right one at the LHC

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Early physics

Not clear what the first year implies (7 TeV? 10 TeV? what luminosity?)

Chances for a quick discovery...

..if something spectacular and just outside reach of Tevatron

- Very light susy
- Diquark resonance
- Z prime gauge boson decaying to leptons
- . . .

Very narrow window between Tevatron exclusion limits and the early LHC reach

Early physics: Z prime

Quite model independent approach to Z', talk of Ennio Salvioni this conference

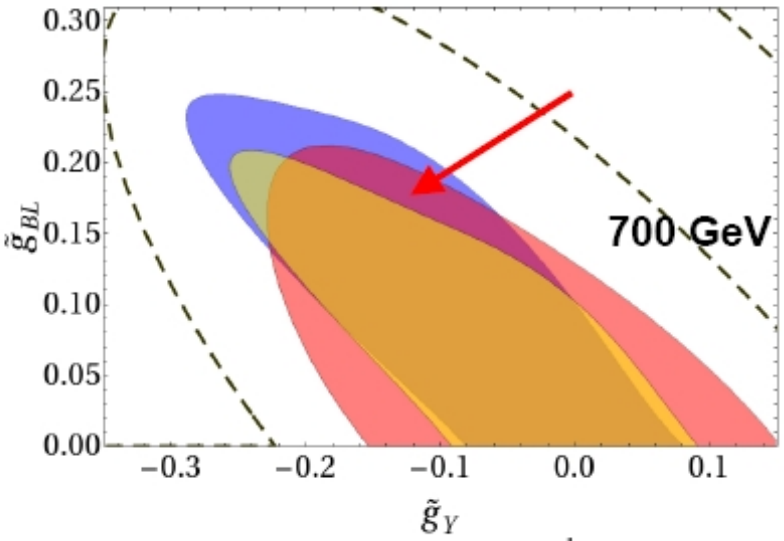
- $G = G_{SM} \times U(1)'$
- SM fermions + 3 RH neutrinos
- anomaly-free $\Longleftrightarrow$ $U(1)'$ lin. comb. of *Y* and *B-L*
- flavor-blind couplings

Not restrictive to write, in **mass eigenstate basis** (kinetic & mass mixing included): $\mathcal{L}_{NC} = eJ_{em}A + g_Z(Z\,J_Z + Z'\,J_{Z'})$

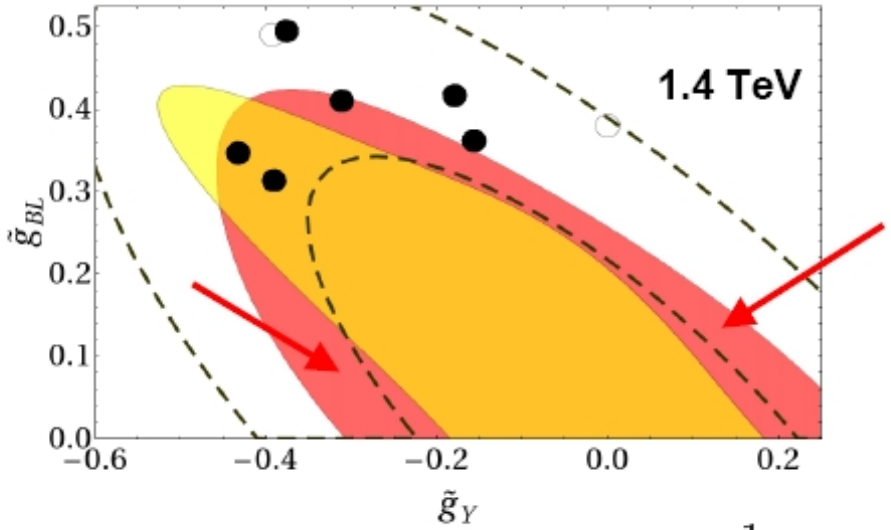
$J_Z, J_{Z'}$ obtained rotating by θ' the currents

$$J_{Z'0} = \frac{g_Y}{g_Z} J_Y + \frac{g_{BL}}{g_Z} J_{B-L},$$

Early LHC reach



7 TeV, $100\,\mathrm{pb}^{-1}$



10 TeV, $200\,\mathrm{pb}^{-1}$

= region allowed (95%) by EWPTs

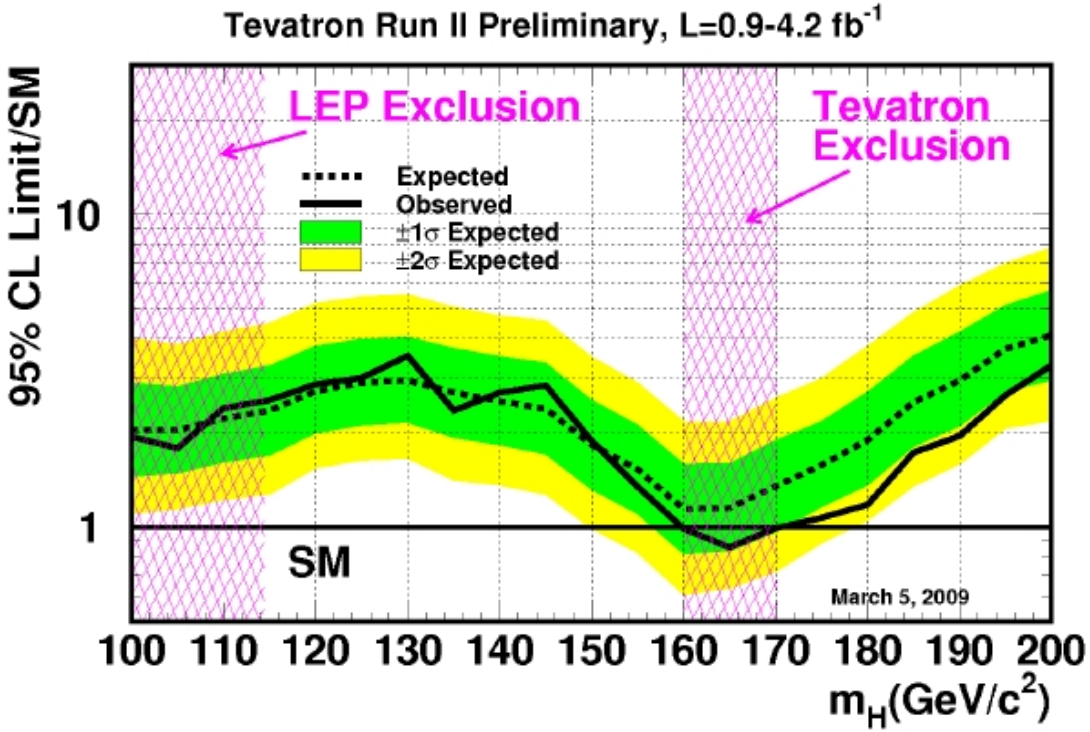
= region allowed (95%) by Tevatron searches

= region NOT accessible to the LHC (5σ discovery)

POSSIBLE DISCOVERY

Higgs physics

- It is absolutely essential to understand the mechanism of electroweak symmetry breaking
- LEP and Tevatron have excluded a large mass range for the Standard Model Higgs

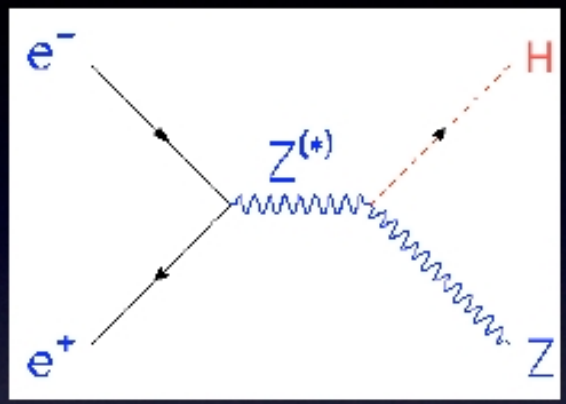


- LHC will scan the entire mass range consistent with unitarity
- Several alternative scenarios will be probed: hidden Higgs, composite Higgs, Higgsless (Gino Isidori's talk this conference)
- New physics likely to show up via Higgs couplings, production cross section and branching ratio (Bob McElrath's talk this conference)

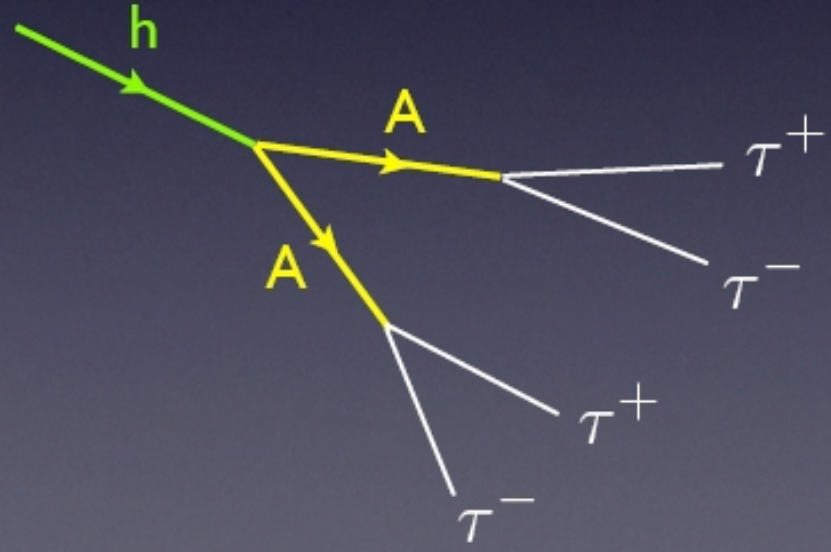
Non-standard Higgs

$h \to aa \to 4\tau$ at LEP:

C. Tully, L3



$e^+e^- \to Zh$

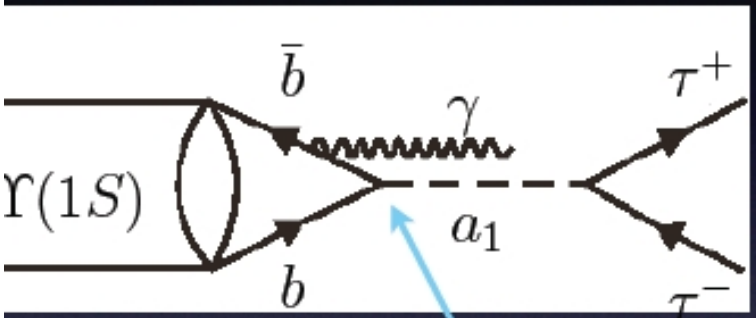


Light CP-odd Higgs at B factories

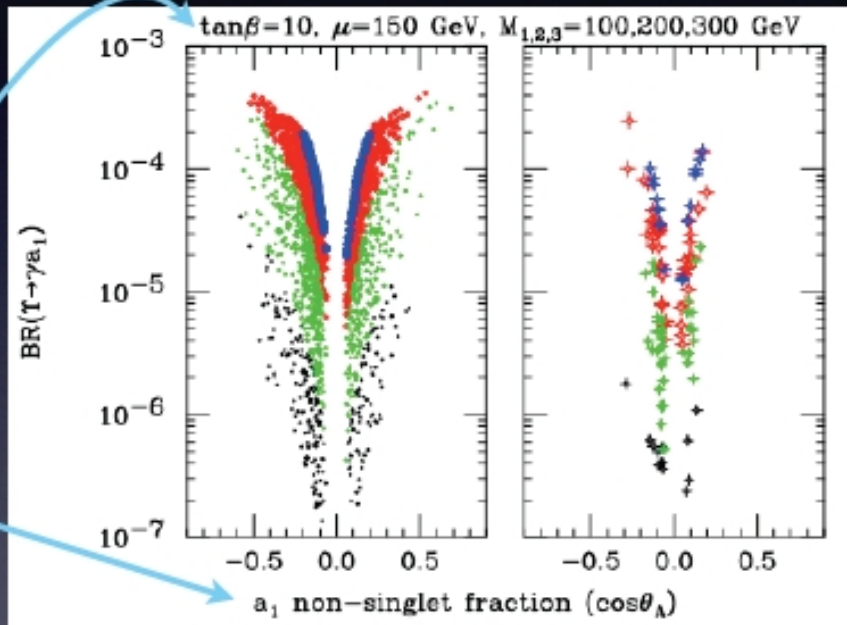
R.D., J. Gunion and B. McElrath, hep-ph/0612031

A could have been produced at B factories: $\Upsilon \to A\gamma$

(it is advantageous to search in $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ data)



$$C_{a_1 b\bar{b}} = \cos\theta_A \tan\beta$$



A_κ, A_λ, κ, λ scan $\quad F < 15$ scan

$m_{a_1} < 2m_\tau$

$2m_\tau < m_{a_1} < 7.5\,GeV$

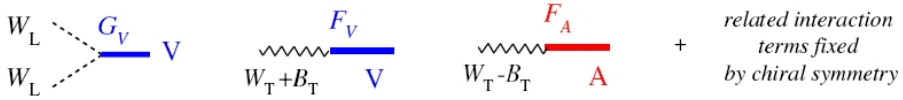
$7.5\,GeV < m_{a_1} < 8.8\,GeV$

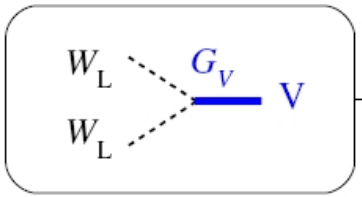
$8.8\,GeV < m_{a_1} < 9.2\,GeV$

Within the reach at existing facilities!

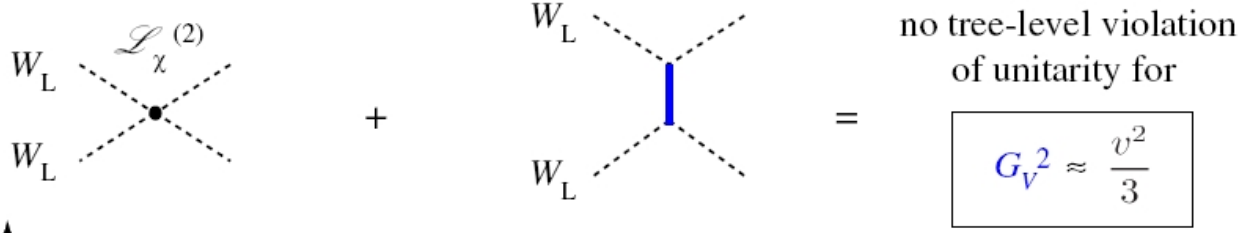
Higgsless

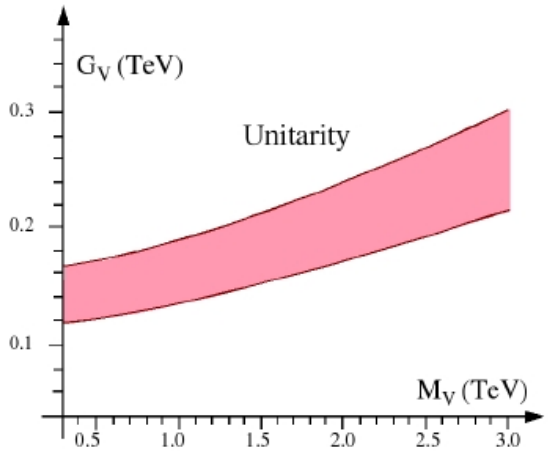
The dynamics of the system below the cut-off is described by 3 + 2 parameters:
$(M_V, G_V, F_V) + (M_A, F_A)$ [naive dimensional analysis implies $F_{V(A)}, G_V = O(v)$]





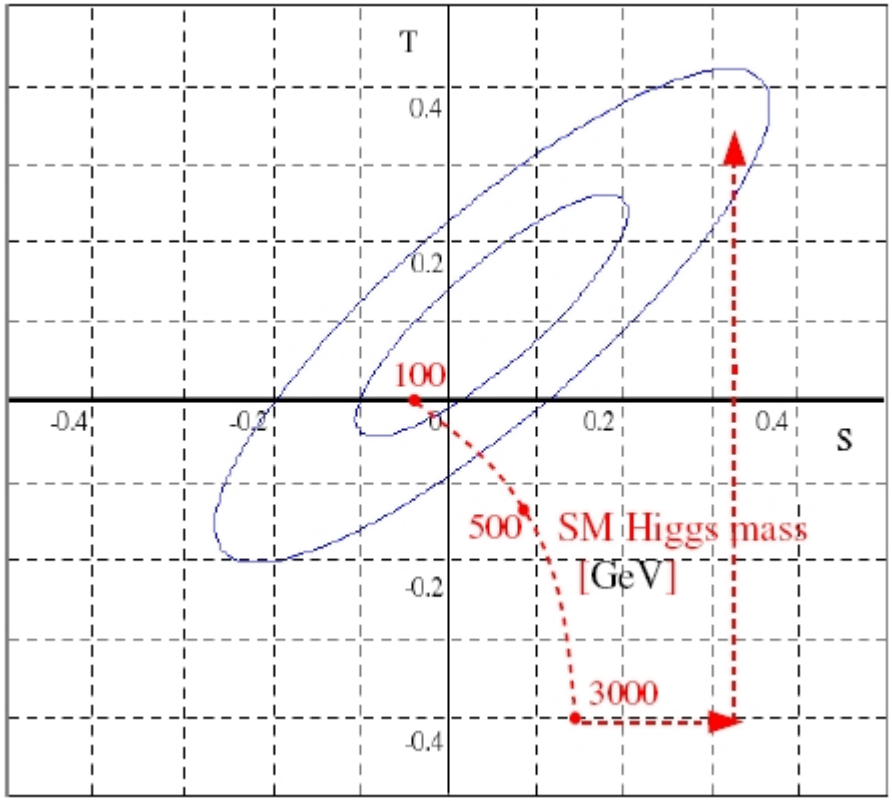
→ Control unitarity of $W_L W_L$ scattering





Note that the unitarity constraint is almost insensitive to the value M_V

Higgsless



The leading contributions to S & T generated by the sole exchange of heavy vector/axial fields are:

$$\Delta\hat{S}^{\text{vectors}}_{\text{(tree)}} = g^2\left(\frac{F_V^2}{4M_V^2} - \frac{F_A^2}{4M_A^2}\right)$$

$$\Delta\hat{T}^{\text{vectors}}_{\text{(1-loop)}} = \frac{3\pi\alpha}{c_W^2}\left[\frac{F_A^2}{4M_A^2} + \left(\frac{F_V - 2G_V}{2M_V}\right)^2\right]\frac{\Lambda^2}{16\pi^2 v^2} + \dots$$

O(1) factor

Top physics

- Around thousand top events collected at Tevatron
- Comparable number expected at the LHC in the first year
- The LHC running at full steam will produce 10^7 tops per year

Top is the least studied elementary fermion in the SM, but that will change soon

- Top mass is the only quark with mass of order electroweak symmetry breaking scale
- It might be the one who triggers electroweak symmetry
- Due to its large coupling to EW breaking sector it might easily be affected by new physics
  - Via its couplings to the SM, e.g. corrections to V_{tb}, couplings of W to right handed tops
  - Via a resonance in the t-tbar invariant mass distribution

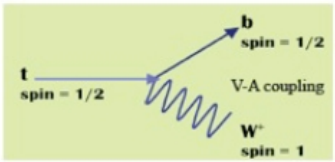
Need precision top physics (Gilad Perez' talk this conference)
Need to improve top identification (Seung Lee talk this conference)

W polarization

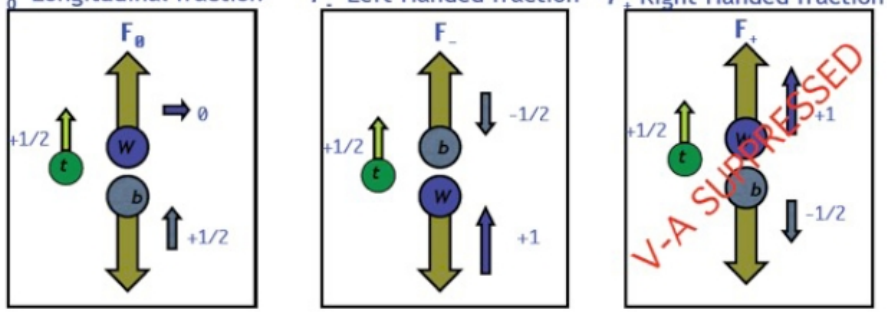
Are there new interactions in top quark decay ?

- Positive helicity F_+ suppressed by chiral factors $\sim M_b^2 / M_W^2$
- Relative fraction of F_0 is:

$$F_0 = \frac{M_t^2 / 2M_W^2}{1 + M_t^2 / 2M_W^2} \cong 0.7$$



F_0 Longitudinal fraction F_- Left-Handed fraction F_+ Right-Handed fraction

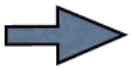


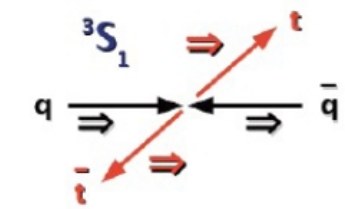
$\mathbf{F_0}$ - CDF: 0.62 ± 0.11 D0: 0.490 ±0.106 (stat) ±0.085 (syst); SM: 0.7

$\mathbf{F_+}$ - CDF: -0.04 ± 0.05 D0: 0.110 ±0.059 (stat) ±0.052 (syst); SM: 0

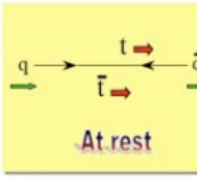
Spin-Spin Correlation

Near theshold!

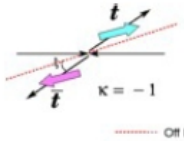
Tevatron 

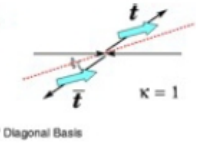


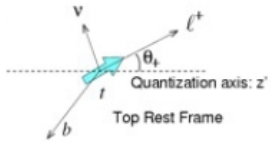
LHC is via gluons.



- Production, Spin-Spin correlation:







Off Diagonal Basis

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1+\kappa\cos\theta_+\cos\theta_-}{4}$$

$$\kappa = \frac{N(\uparrow\uparrow)+N(\downarrow\downarrow)-N(\uparrow\downarrow)-N(\uparrow\downarrow)}{N(\uparrow\uparrow)+N(\downarrow\downarrow)+N(\uparrow\downarrow)+N(\uparrow\downarrow)}$$

Tevatron: SM predicts κ=0.78

LHC improve by O(10)

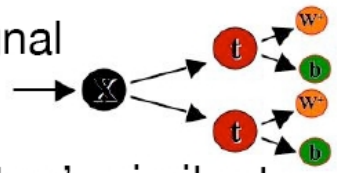
D0 (4 fb^{-1}):
$\kappa = -0.17\ ^{+0.64}_{-0.53}$

Beam axis

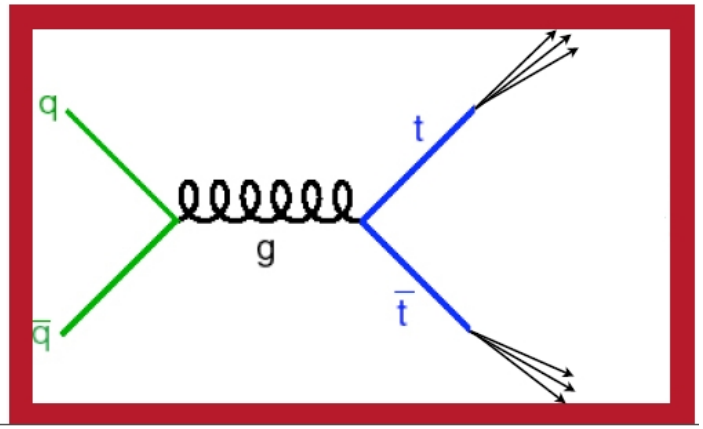
CDF (2.8 fb^{-1}):
$\kappa = 0.32\ ^{+0.55}_{-0.78}$

Boosted tops

- High PT tops, might be crucial signal for various NP models

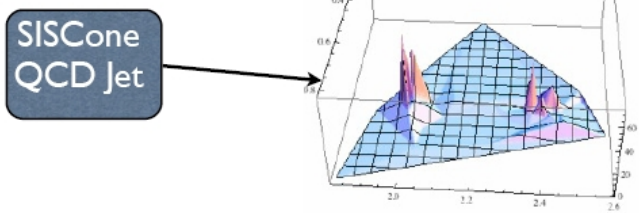


- Above a TeV, due to collimation, top's similar to light jet (efficiency decrease & fake rate increase)



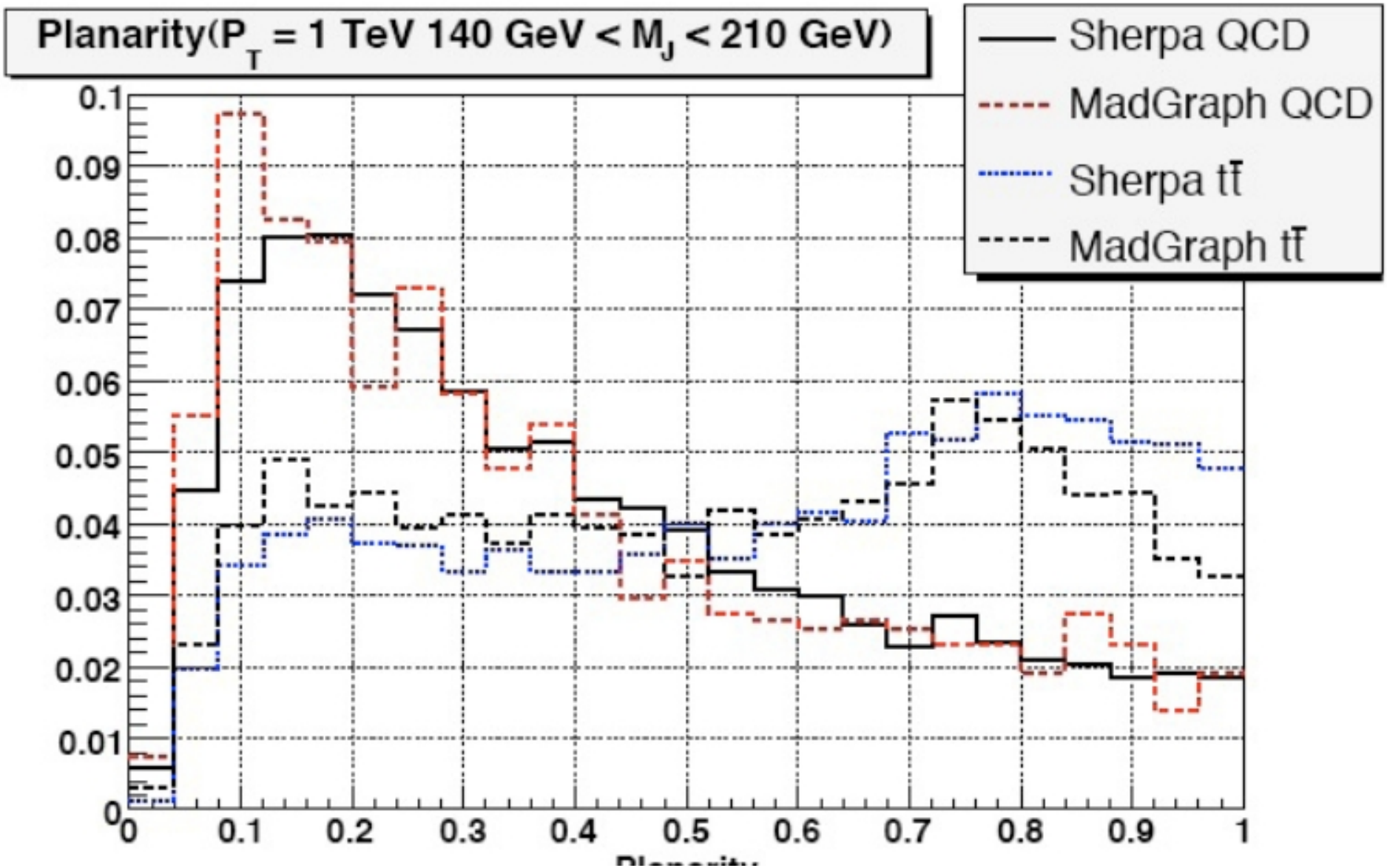
- The concept of top jet emerges

- QCD jets are democratic & broad, shown both for cone & anti-kt jets.



- QCD-linear, top-planar E-deposition in the cone

Boosted tops



Last Word

- It is essential to search for as wide class of signals as possible and in as model independent way as possible