Determining Higgs CP via $t(\bar{t})H$ partial reconstruction at the LHC

Justin Albert

Work with:

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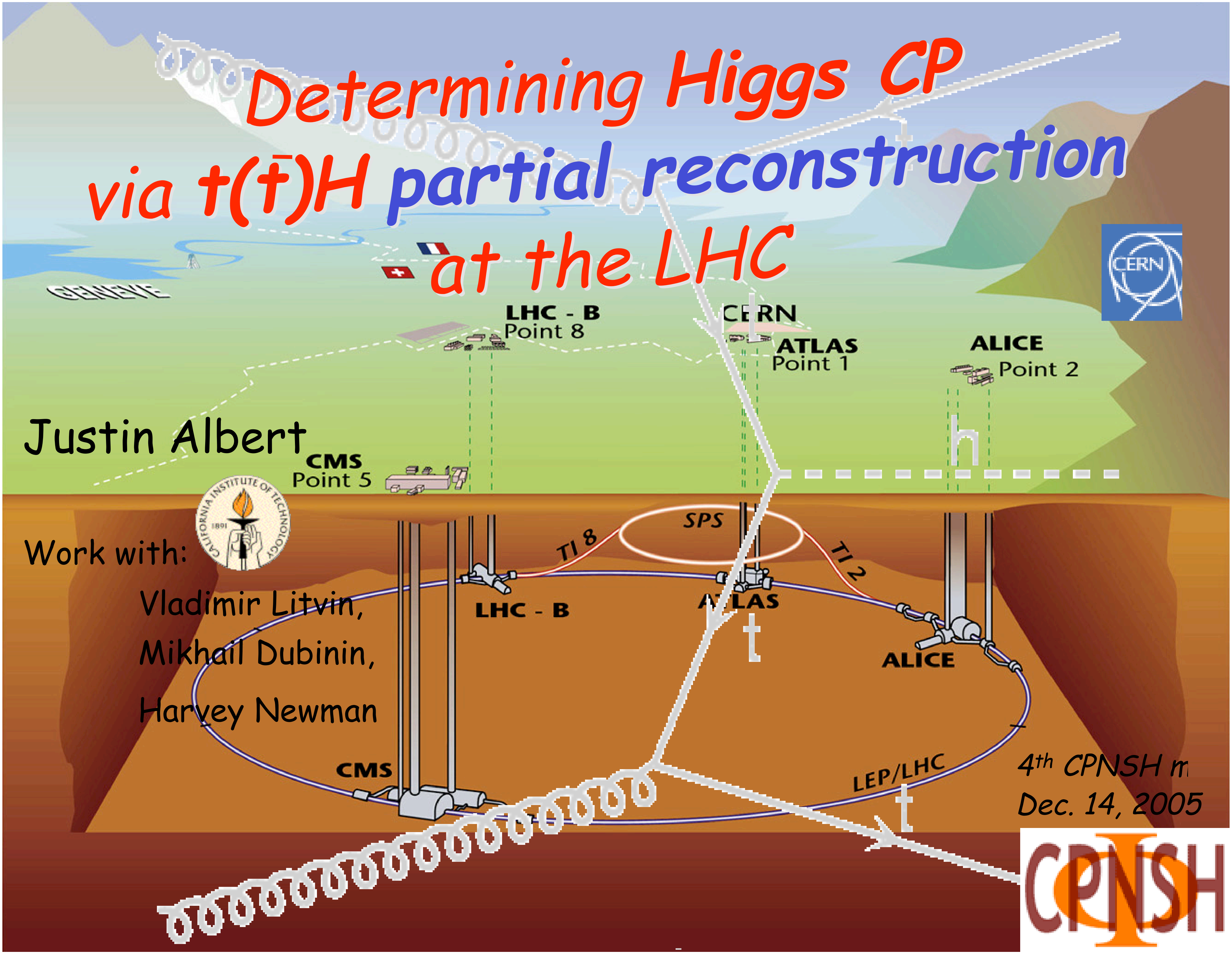
Harvey Newman



4th CPNSH m

Dec. 14, 2005

Higgs properties

- **Standard model Higgs: spin-0 and *CP*-even.**
- **Extensions** can beg to differ:
  - **2HDM**
  - **MSSM** contains h, H (*CP*-even), and A (*CP*-odd).
    - Given a general set of complex mixing parameters, neutral Higgs sector will mix, and mass eigenstates (h_1,h_2,h_3) will have **mixed *CP***. (Carena, Ellis, Mrenna, Pilaftsis, Wagner. Nucl.Phys. B659 (2003) 145-178, hep-ph/0211467)

⇒ **Knowing Higgs properties *very important for constraining models*.**

- ***We will show*** that we can determine properties using t($\bar{t}$)H *partial* reconstruction. ***But first*** we'll need to know how to deal with:
  - **1) *Small cross-sections!***
  - **2) *Backgrounds!***

Full Reconstruction Analysis

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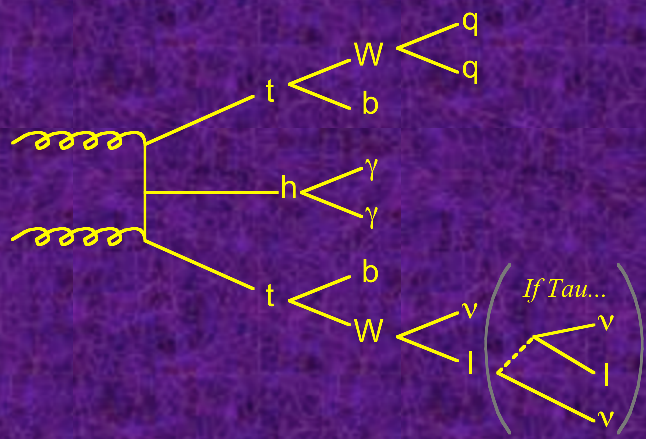
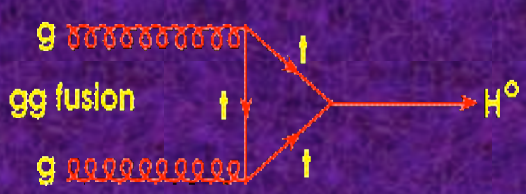
- An SM or two-doublet neutral Higgs boson produced in association with a tt pair with H(h^0) → __ shares the following minimal signature with the WH and ZH channels (O.Ravat, M. Lethuillier [IPNL]):

  2 isolated high-pt photons with $m_{\gamma\gamma}=m_H$: fully reconstructible mass peak

  1 isolated high-pt tagging lepton from a t decay product (usually a W): Handle to beat down QCD background, and reconstruct primary vertex. Less dependence on photon energy resolution than gluon fusion channel



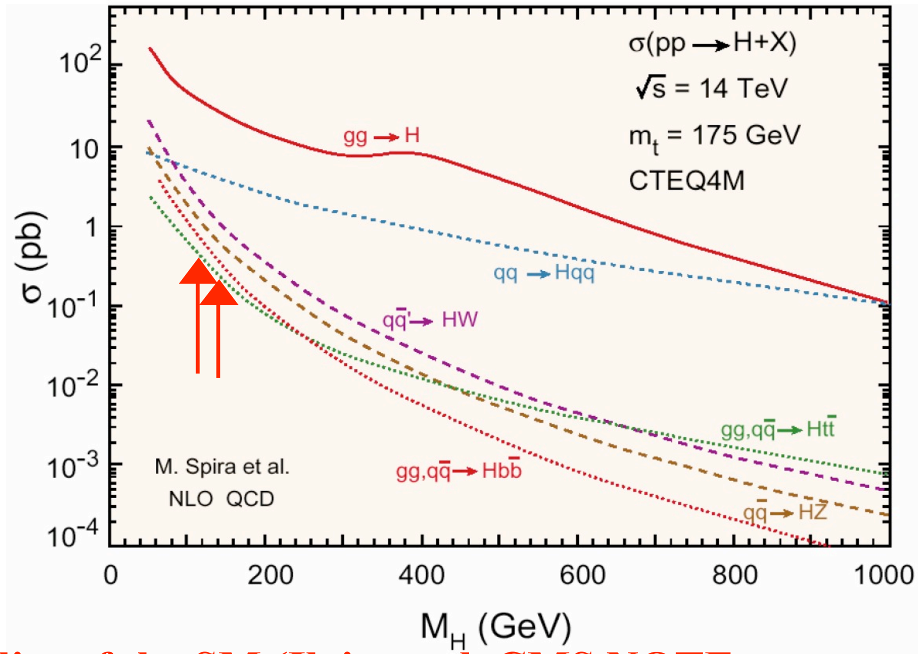


- Particular 2-doublet case of MSSM: gluon fusion production channel subject to suppression given top-stop degeneracy (maximal mixing) , not true for associated production channels.

Advantages/Disadvantages

Robert Frazier **Alexander Nikitenko**
Suzanne Gascon-Shotkin, Damien Mercier, Jean-Laurent Agram

- tt pair: high multiplicity events
- Less vulnerable to QCD background than WH/ZH channels
- But… Low cross-section even when compared to WH/ZH channel



- **Prior work in CMS: Generator-level studies of the SM (Ilyin et al, CMS NOTE 1997/101), and MSSM (R. Kinnunen & D, Denegri, CMS NOTE 1997/057) cases demonstrated S/B~1.**
- **In ATLAS: Full simulation study in Physics TDR (based on thesis of G. Eymard (LAPP), S/sqrt(B)={4.3-2.8} for mH={100-140} , signal efficiency ~30%**
- **CERN-ATL-COM-PHYS-2004-056 par Beauchemin, P and Azuelos, Georges "Search for the SM Higgs Boson in the gamma gamma + ETmiss channel" For 100fb-1, for ttbarh channel, for mH=120 GeV, S/B of ~2 (10.2 signal events for 5.4 background events).**

Some recent work done at ATLAS

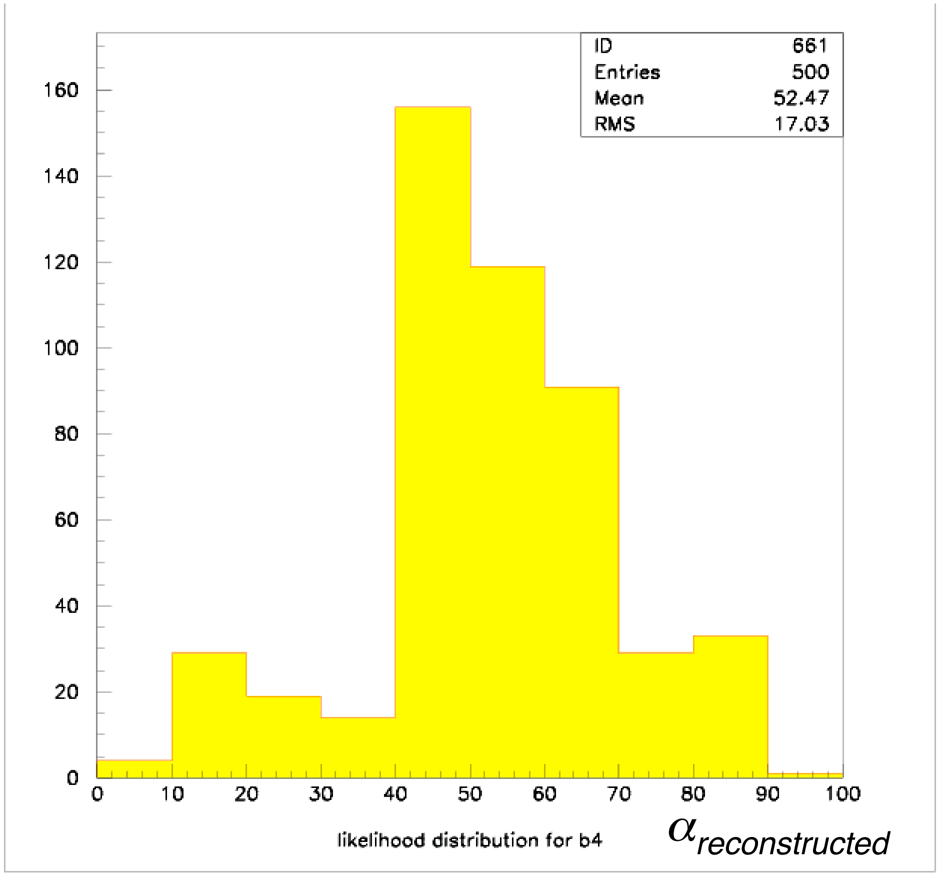
Scott McGarvie *et al*

Royal Holloway University of London

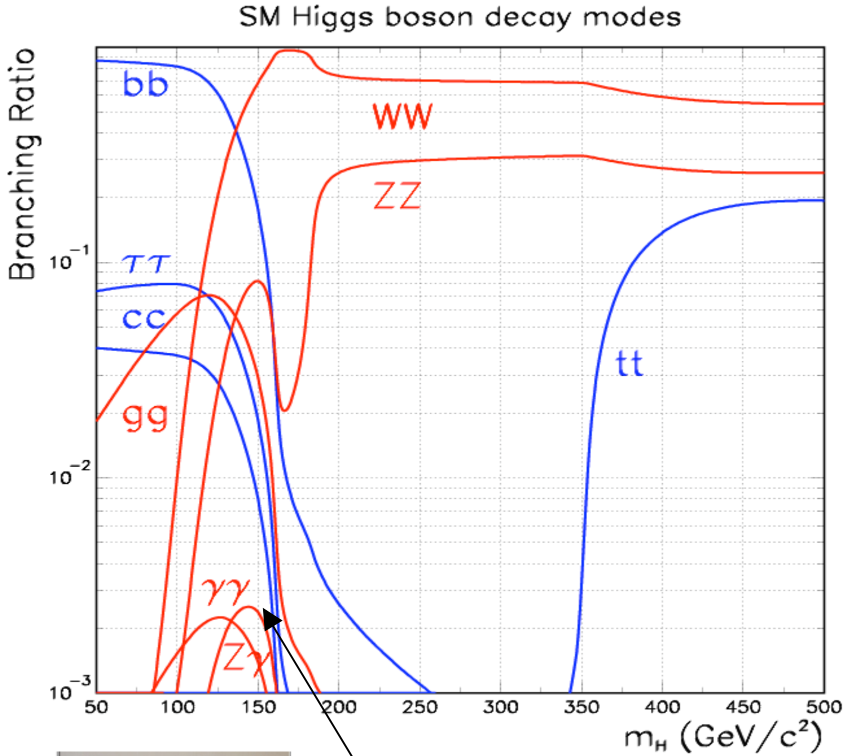
Uncertainty on Higgs *CP*

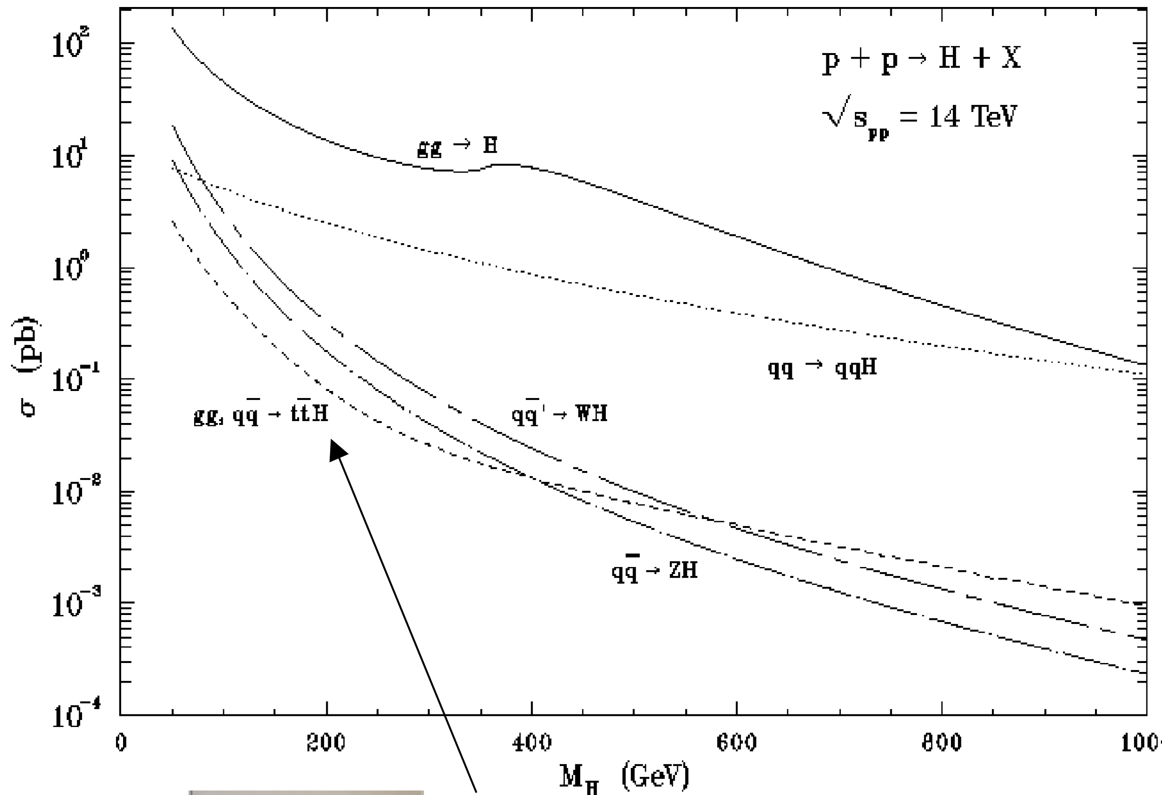
The uncertainty in using this method is given by the distribution of $\alpha_{reconstructed}$ (generator level) for independent data samples (≈200 fb^{-1})

Distribution of maximum likelihood for α_{true} = 50%



A Tough Neighborhood





Take that!

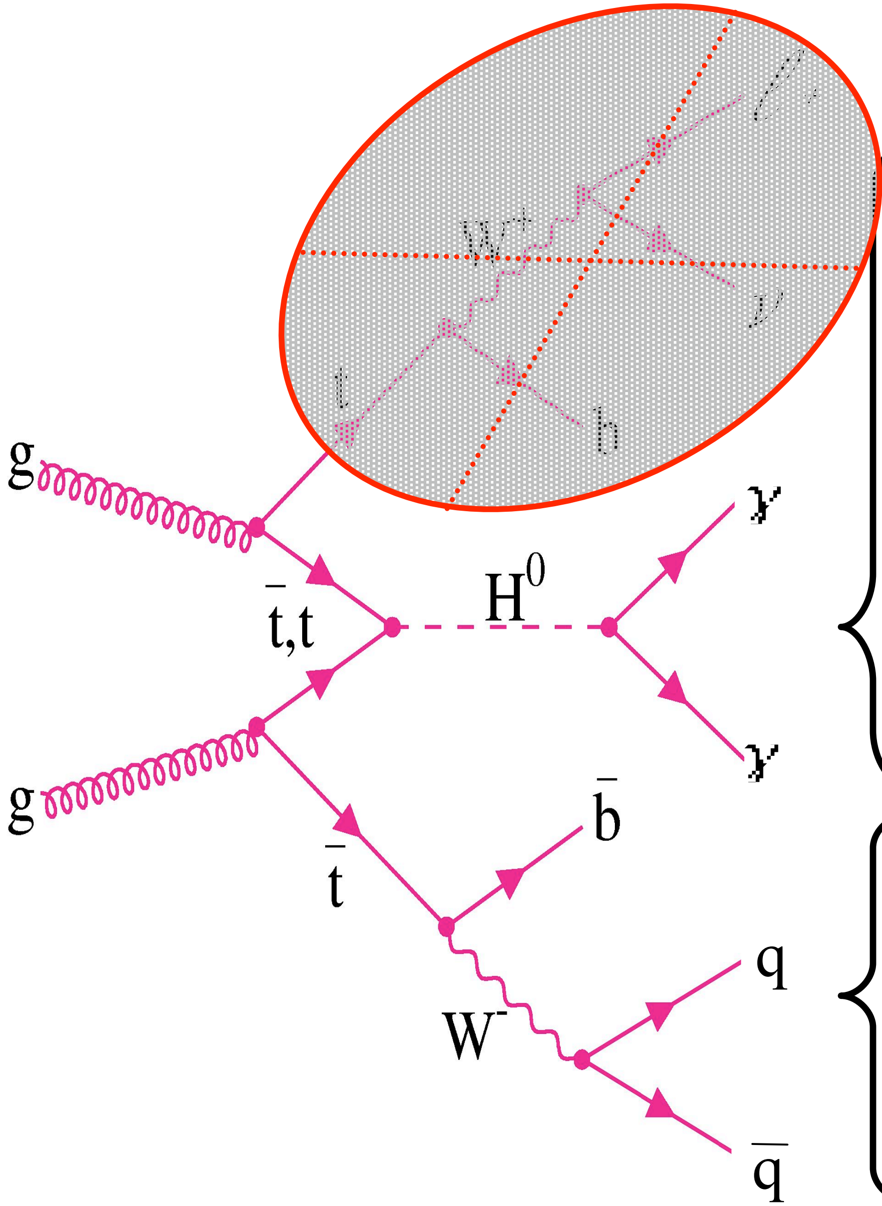
And that!

- **How can the analysis take the one-two punch of small branching fraction and small cross-section???**

Keys to Survival

- In order to manage, one must keep the efficiency as high as possible *without introducing additional backgrounds*.
- Efficiency for top reconstruction is ~20%, so by reconstructing both tops, one would be reduced to ~4% *from top reco alone*.
- But what about ***reconstructing just one of the tops***. As we'll show, using just one of the tops provides enough information to extract Higgs *CP*. *And either top will do*. So instead of 4%, one is up to ~36%, nearly an order of magnitude!!
- But does this introduce large additional backgrounds?
- Events containing reconstructed Higgs + top are dominated by $t\bar{t}$+X, so **no**!

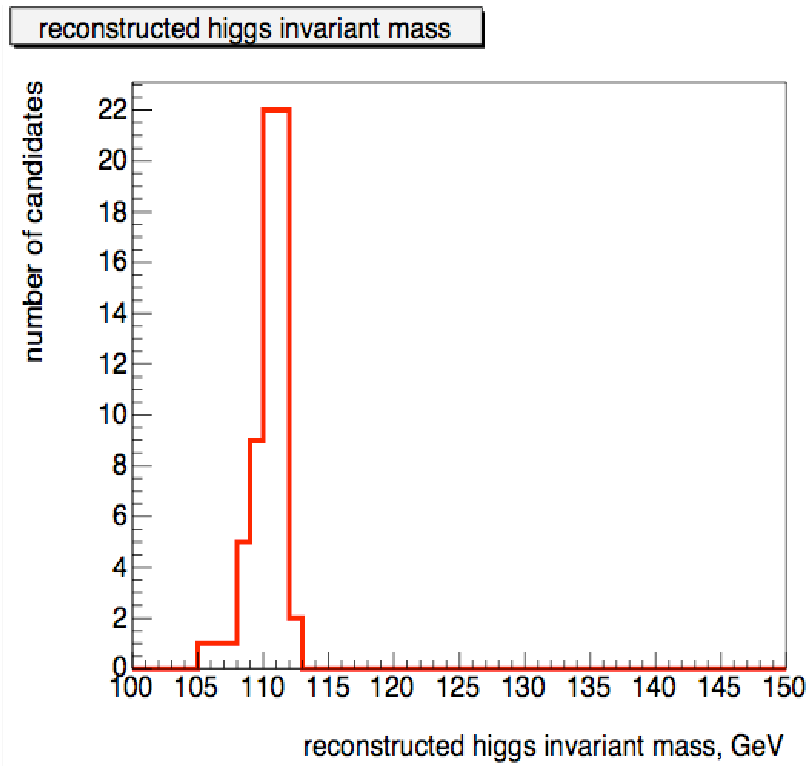
Strategy



- Select H in a similar manner to CMS (Caltech+UCSD) ***inclusive*** Higgs → γγ analysis.
  - ✓ Photon selection
  - ✓ Track isolation
  - ✓ ECAL isolation
- Backgrounds thus a **subset** of inclusive Higgs → γγ analysis.
- Add two light quark jets and a b-jet and to reconstruct W, then top (or reconstruct W semileptonically with a high-p_T lepton!)

Reconstruction

- **Higgs reconstruction:**
  - Two highest-pT photon clusters, highest w/ pT > 40 GeV, 2nd highest w/ pT > 25 GeV, in acceptance range of $|\eta| < 1.442$ or $1.566 < \eta < 2.5$.
  - Track isolation:
    - ✓ No charged tracks of pT > 1.5 GeV within ΔR of 0.3.
  - ECAL isolation:
    - ✓ Total ECAL energy within cone of $\Delta R <$ 0.35 less than 1.2 GeV (photon in barrel) and 1.6 GeV (photon in endcap).

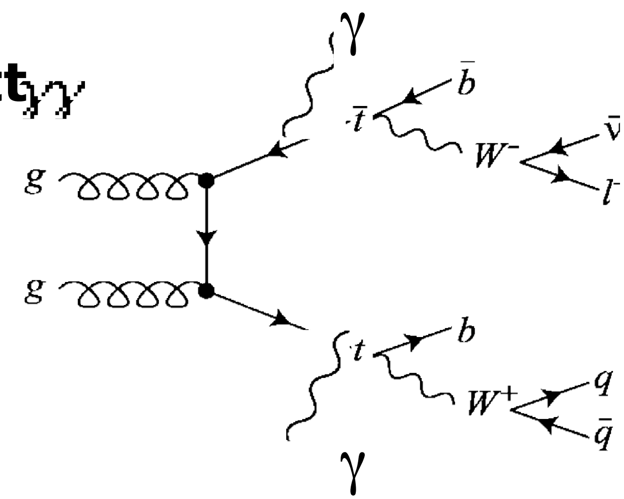


- **Top reconstruction:**
  - Two non-*b*-tagged jets with ET > 45 GeV and invariant mass btw. 60 & 150 GeV.
  - Add *b*-tagged jet with ET > 45 GeV.
- Final efficiency **btw. 10-20%**

Backgrounds

- Most backgrounds have both t and t-bar, so reconstructing both would not gain one anything in terms of background rejection (only loss in efficiency):

$tt\gamma\gamma$



Cross-section 12.6 fb

Process	σx BR σ (1 W->l ν)
ttγγ 1	1.6 fb (<1/mil)
ttγγ 2	6.1 fb (<1%)
ttγγ 3	4.9 fb (<1%)
bbγγ	283.7 fb
Wγγ 4j	11.5 fb (1.2%)
Wγγ	23.6 fb
Zγγ	27.0 fb

(List from full reco analysis, Shotkin et al. NOTE: ALPGEN is presently the only generator that includes all 3 *ttγγ* processes.)

- As Higgs discovery and mass measurement will occur prior to this analysis to detemine properties, <u>selection on Higgs mass</u> can drastically reduce this main “irreducible” background.

Higgs CP Determination

- From Gunion, He (PRL 76, 24, 4468 (1996)):

Interaction Lagrangian:
(c is CP-even coupling and d is CP-odd)
SM: c=1, d=0

$$\mathcal{L} \equiv \bar{t}(c + id\gamma_5)th$$

CP-sensitive variables:
p_T of Higgs, or missing p_T from partial reconstruction can be ***substituted*** for p_T of second top.

$$a_1 = \frac{(\vec{p}_t \times \widehat{n}) \cdot (\vec{p}_{\bar{t}} \times \widehat{n})}{|(\vec{p}_t \times \widehat{n}) \cdot (\vec{p}_{\bar{t}} \times \widehat{n})|}$$

$$a_2 = \frac{p_t^x p_{\bar{t}}^x}{|p_t^x p_{\bar{t}}^x|}$$

$$b_1 = \frac{(\vec{p}_t \times \widehat{n}) \cdot (\vec{p}_{\bar{t}} \times \widehat{n})}{p_t^T p_{\bar{t}}^T} \qquad b_2 = \frac{(\vec{p}_t \times \widehat{n}) \cdot (\vec{p}_{\bar{t}} \times \widehat{n})}{|\vec{p}_t||\vec{p}_{\bar{t}}|}$$

$$b_3 = \frac{p_t^x p_{\bar{t}}^x}{p_t^T p_{\bar{t}}^T} \qquad b_4 = \frac{p_t^z p_{\bar{t}}^z}{|\vec{p}_t||\vec{p}_{\bar{t}}|}$$

- With the increased efficiency from single top reconstruction, sensitivity can likely be obtained with a few years (100-200 fb^{-1}) of data, as an estimate.

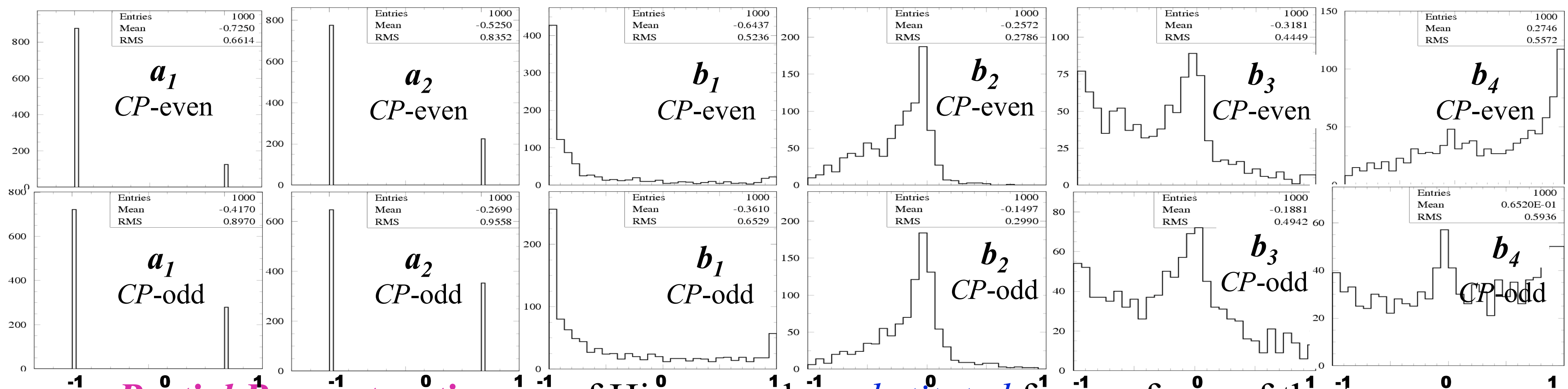
Partial Reco Higgs CP Determination

CP-sensitive variables:

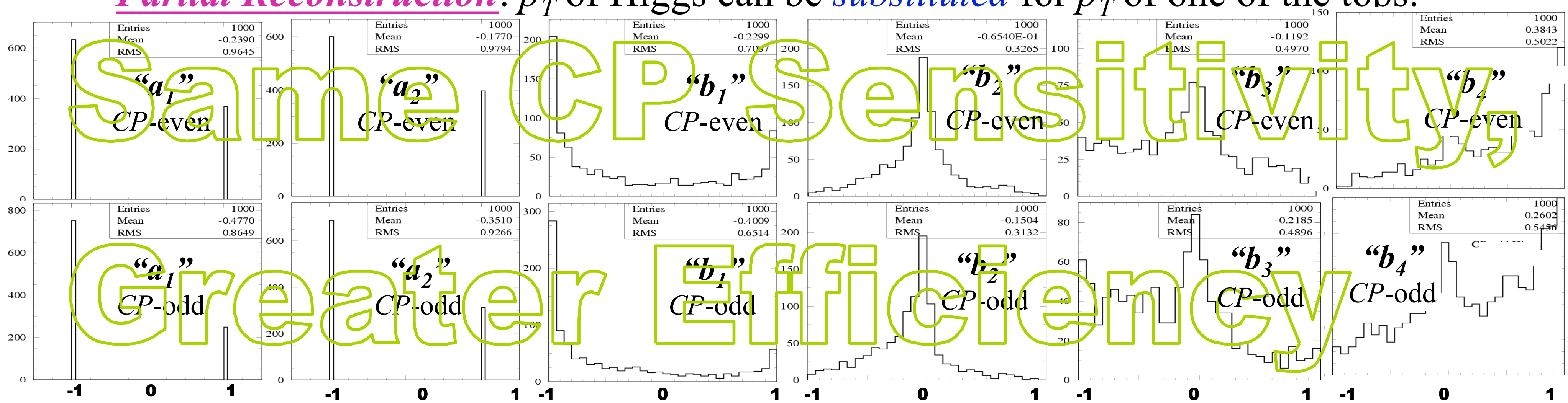
(Gunion & He, PRL 76, 4468 (1996))

$$a_1 = \frac{(\vec{p}_t \times \widehat{n})\cdot(\vec{p}_{\bar{t}} \times \widehat{n})}{|(\vec{p}_t \times \widehat{n})\cdot(\vec{p}_{\bar{t}} \times \widehat{n})|} \quad b_1 = \frac{(\vec{p}_t \times \widehat{n})\cdot(\vec{p}_{\bar{t}} \times \widehat{n})}{p_t^T p_{\bar{t}}^T} \quad b_2 = \frac{(\vec{p}_t \times \widehat{n})\cdot(\vec{p}_{\bar{t}} \times \widehat{n})}{|\vec{p}_t||\vec{p}_{\bar{t}}|}$$

$$a_2 = \frac{p_t^x p_{\bar{t}}^x}{|p_t^x p_{\bar{t}}^x|} \quad b_3 = \frac{p_t^x p_{\bar{t}}^x}{p_t^T p_{\bar{t}}^T} \quad b_4 = \frac{p_t^z p_{\bar{t}}^z}{|\vec{p}_t||\vec{p}_{\bar{t}}|}$$



Partial Reconstruction: p_T of Higgs can be *substituted* for p_T of one of the tops:



Next Steps

1) Further studies of *backgrounds* (irreducible, “irreducible,” & reducible!).

2) Combination of *CP*-sensitive variables into an ML fit for Higgs *CP*.

3) Study of beyond-MSSM mixed-*CP* models (generated using CompHep) (***see M. Dubinin’s talk!***).

4) Include semileptonic decays for the reconstructed top.

5) Include Higgs $\to b\bar{b}$ decays.

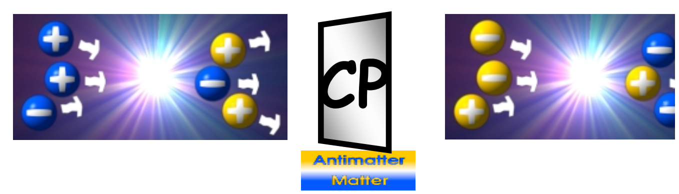
6) Write CMS note for partial reco (in addition to contribution to yellow book, [with latter a combined contribution, along with full reco!])

Conclusions

- The $t\bar{t}H$ process allows the determination of Higgs properties (*CP* and top coupling) to separate a Standard Model Higgs from the myriad other possibilities.
- The small $t\bar{t}H$ cross-section (and low $H \rightarrow \gamma\gamma$ branching fraction) are a challenge for the analysis, but efficient reconstruction (via requiring only a single top) allows for increase of signal significance.
- Efficiency and selection for the well-studied inclusive $H \rightarrow \gamma\gamma$ analysis selection will be very useful in this analysis. Backgrounds for the **inclusive** process, as a **superset** of those found in this analysis, also well studied and generated events / background generation machinery already in place.
- Higgs *CP* determination possible via momenta of reconstructed top and Higgs / missing p_T.
- Precision comparison of data and theoretical prediction such as this can be done at CMS and ATLAS --- LHC is not purely a search-and-discovery machine!

Overarching question:

Higgs ~~*CP*~~ significant for BAU??



Un petit peu?