# Higgs report

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TeV4LHC@BNL

February 5, 2005

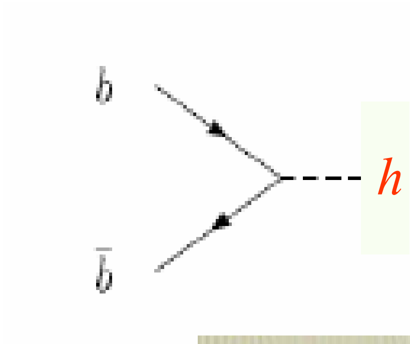
# Talks

- Fabio Maltoni — $b\bar{b} \to h, Z$
- Alessandro Vicini — NLO EW corrections to $gg \to h$
- Kirill Melnikov — NNLO differential $gg \to h$
- Marcela Carena — $\not{CP}$ violating Higgs in MSSM
- Kamal Benslama — $H^{++}$ in the LR symmetric model
- Ariel Schwartzman — SVX from D0 to CMS
- Ariel Schwartzman — Jet energy resolution for Higgs
- Bruce Mellado — Higgs plus 1-jet signatures

# Update on $b\bar{b} \to Z$

Fabio Maltoni
CERN

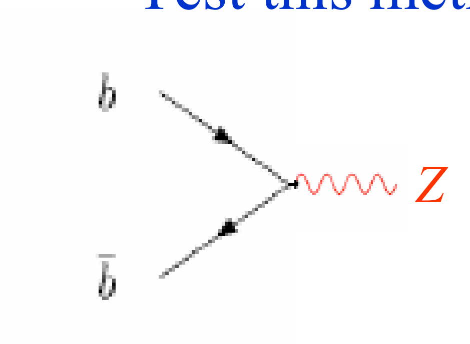
# Motivation



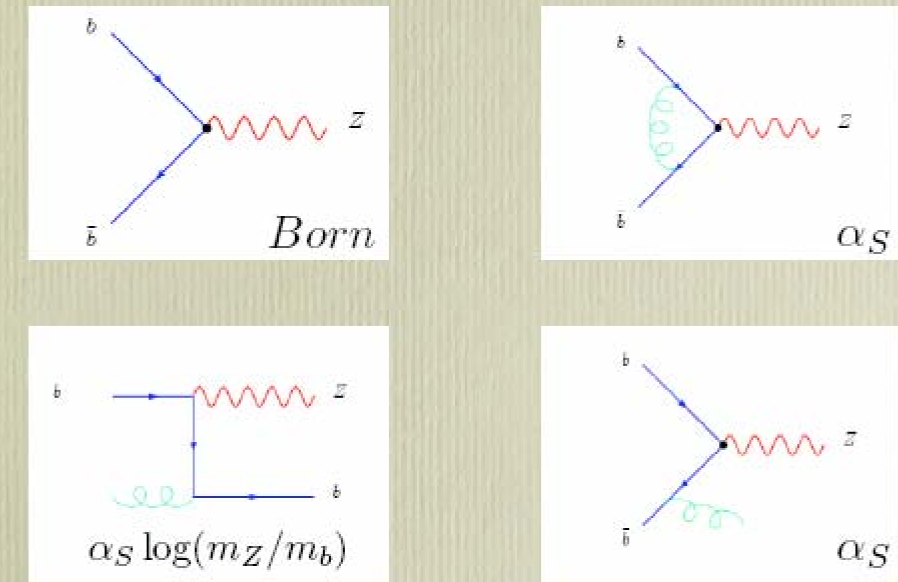

"Inclusive" b tagging

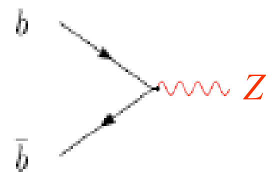
Inclusive approach: look only at the track displacements in the vertex detector and give to the event a probability of containing a b quark.

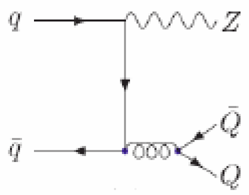
Test this method on



# $b\bar{b} \rightarrow Z$ at NLO






## Cross sections (pb) for Z + "inclusive b" Summary

| Process | TeV | LHC |
|---|---|---|
| bb>Z | (30.6) 30.0 | (1860) 1800 |
| qq > Zbb | 14.0 | 122 |

$$\mu_F = \mu_R = m_Z$$

# Proposal for the TEV4LHC

Study "inclusive" bottom measurements in W/Z production

- theory: we can predict cross sections extremely well
- experiment: new approach, maybe better sensitivity

- theory : perform the new NLO (and NNLO) calculations for Z and W that are needed
- experiment: look at what CMS has done, use CDF and DO data for Wbb and Zbb to test feasibility, find efficiencies, etc...

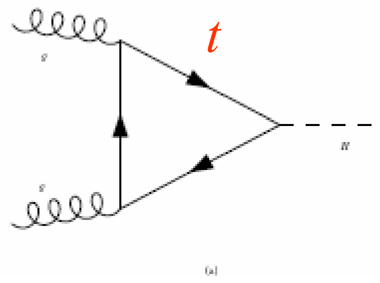
# Two-loop light fermion corrections to Higgs production and decays

Alessandro Vicini

Università degli Studi di Milano and

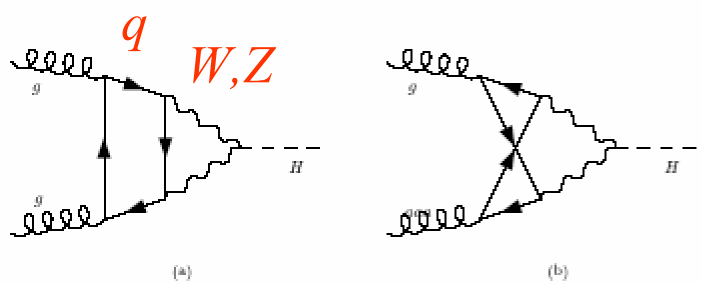
INFN - Sezione di Milano

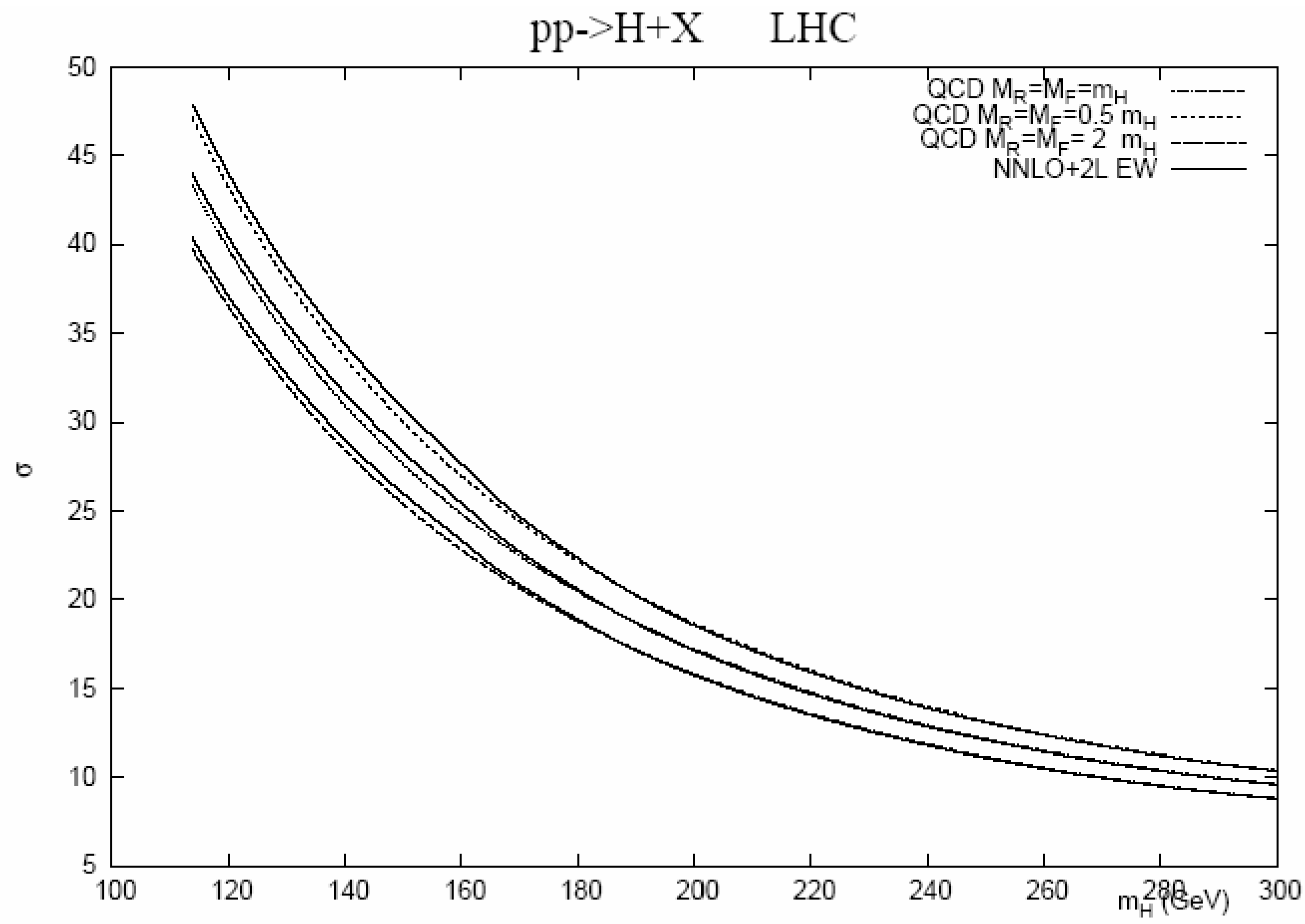
The gluon fusion process:




NNLO QCD (large $m_t$)

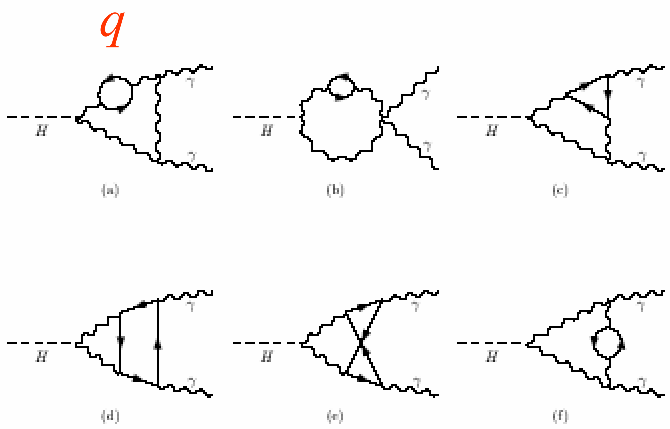
NLO EW correction:



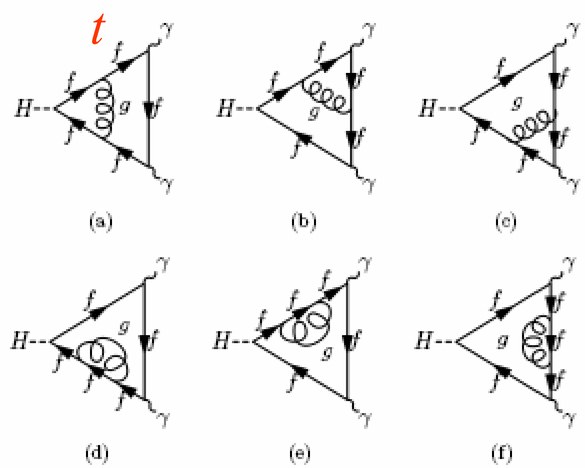


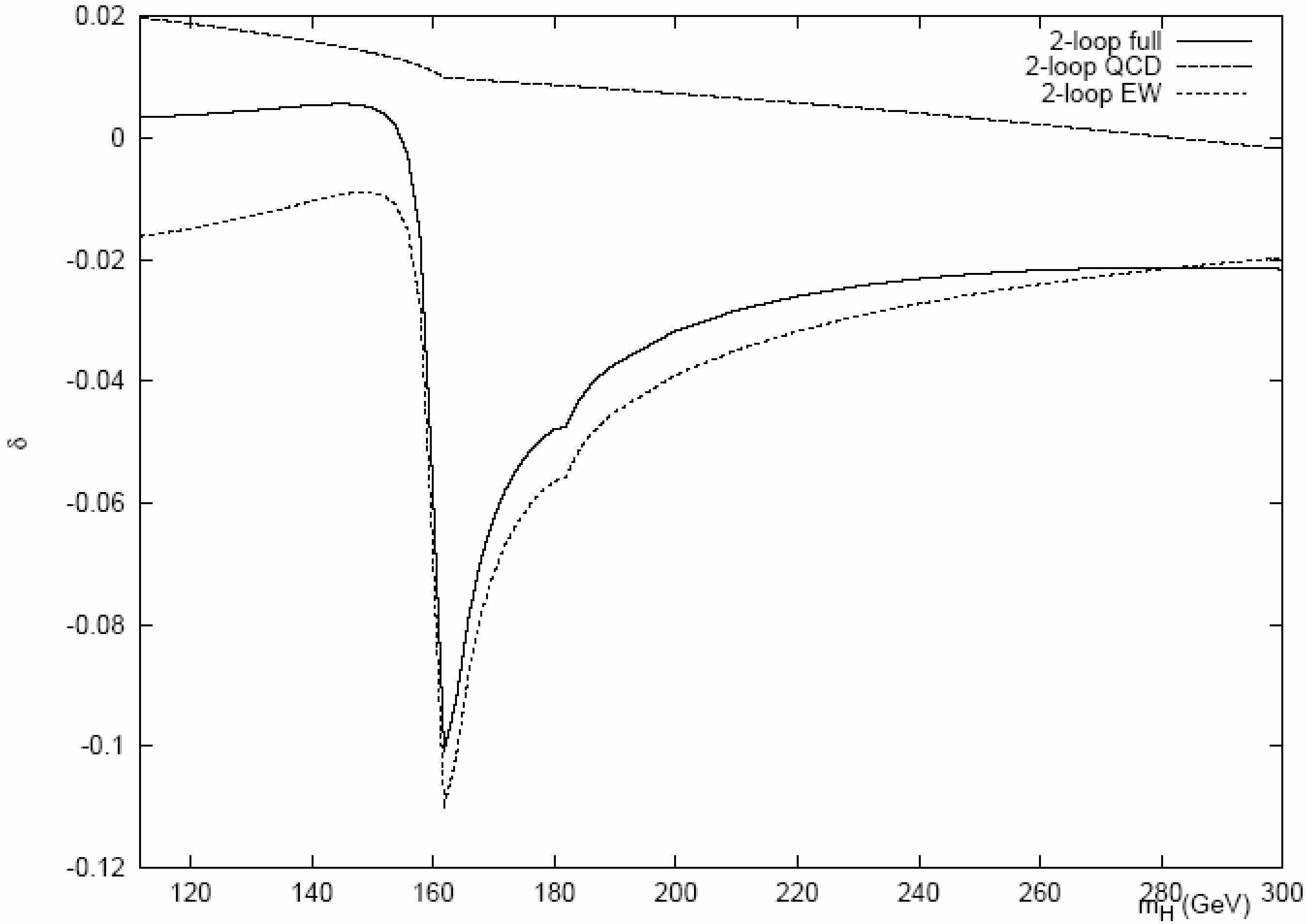

NLO EW correction at most 4%

# $H \to \gamma\gamma$: 2-loop EW light fermion corrections




# $H \to \gamma\gamma$: 2-loop QCD corrections






Relative corrections to the decay width $\Gamma(H \to \gamma\gamma)$.

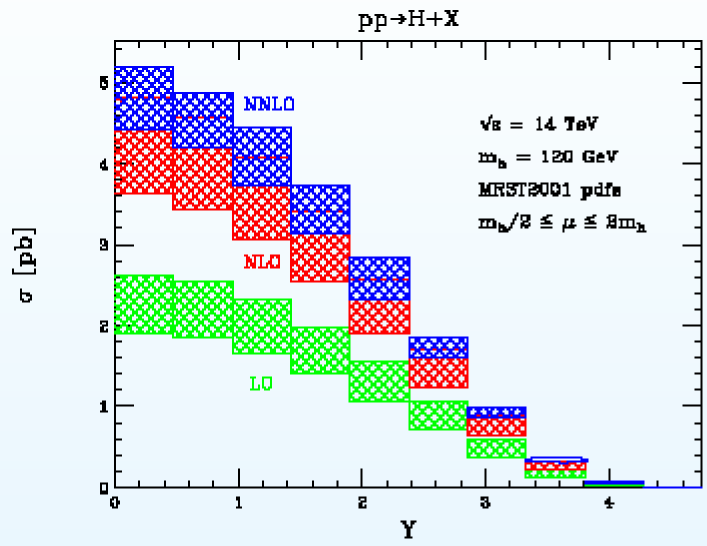
*Higgs boson di-photon signal at the LHC: realistic $K$-factors through NNLO in pQCD*

Kirill Melnikov

University of Hawaii at Manoa

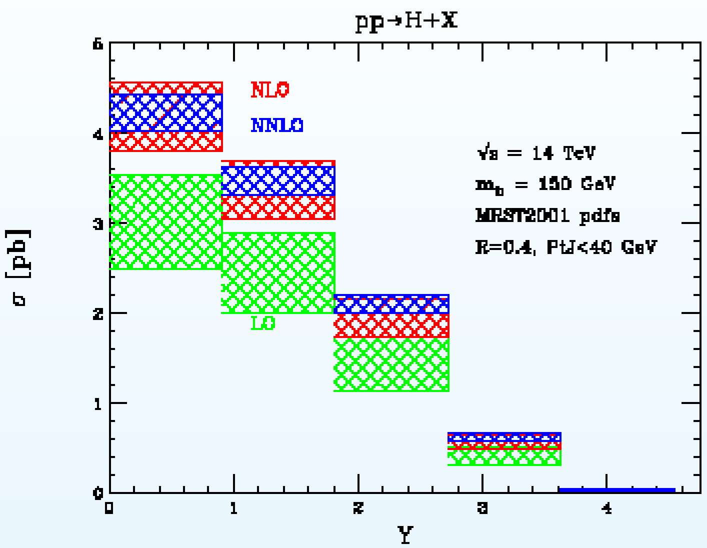
Existence proof: first NNLO calculation of the fully differential cross-section for any process at hadron colliders;

# Results: Higgs rapidity distribution



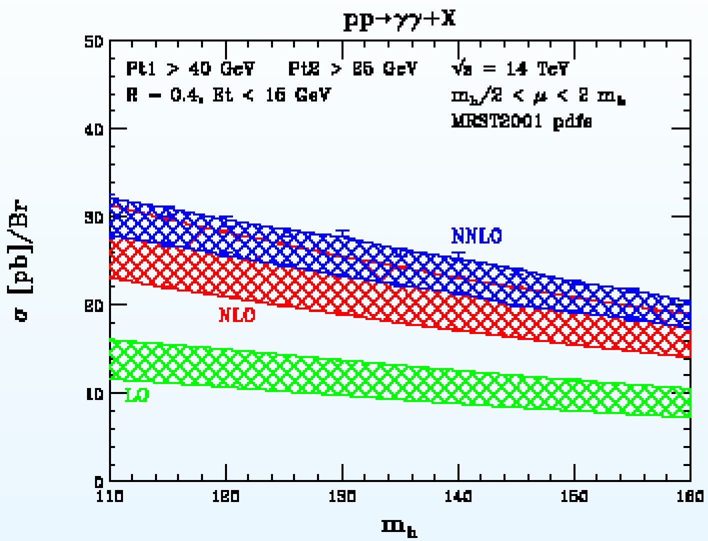

- NNLO corrections important, but things do look convergent;
- Improved stability w.r.t. scale variations;
- Insignificant rapidity dependence of the $K$-factor.

## Results: Higgs rapidity distribution and the jet veto




- Relevant for heavier Higgs discovery ( $H \to WW \to l\nu l\nu$);
- Only events with $p_\perp^J < 40\ \mathrm{GeV}$ are accepted ⇔ cuts away $pp \to t\bar{t}$ background;
- Smaller $K$-factors, compared to inclusive case;
- $p_\perp^H$ increases from NLO to NNLO ($p_\perp^{H,\mathrm{NLO}} = 37.6\ \mathrm{GeV}$, $p_\perp^{H,\mathrm{NNLO}} = 44.6\ \mathrm{GeV}$ ; hence, larger fraction of the NNLO cross-section is removed.

## Results: realistic di-photon cross-sections




- $p_\perp^{\gamma,1} > 40$ GeV and $p_\perp^{\gamma,2} > 25$ GeV; $|\eta^{\gamma,1(2)}| < 2.5$.
- Isolation cut: $E_\perp^{\mathrm{hadr}} < 15$ GeV for $R < 0.4$.

## Results: realistic di-photon signal

- Is it sufficient to know only inclusive $K$-factors?

| $m_h$, GeV | $\sigma^{\text{cut}}_{\text{NNLO}}/\sigma^{\text{inc}}_{\text{NNLO}}$ | $K^{(2)}_{\text{cut}}/K^{(2)}_{\text{inc}}$ |
|---|---|---|
| 110 | 0.559 | 0.93 |
| 115 | 0.589 | 0.95 |
| 120 | 0.601 | 0.95 |
| 125 | 0.632 | 0.98 |
| 130 | 0.669 | 1.00 |
| 135 | 0.668 | 1.00 |

$K^{(2)} = \frac{\sigma_{\text{NNLO}}}{\sigma_{\text{NLO}}}$.

$\mu = \frac{m_h}{2}$.

- The ratio of inclusive to "cut" $K$-factors is the best guess for the NNLO differential cross-section if only inclusive NNLO $K$-factor and the differential NLO cross-section were available.
- The heavier the Higgs, the smaller the impact of the cuts on the $K$-factor is.

## Conclusions

- New method for NNLO calculations (real radiation) in QCD; applicable to many phenomenologicaly relevant processes;
- Existence proof: first NNLO calculation of the fully differential cross-section for any process at hadron colliders;
- Complete control over the kinematics of the final states allows arbitrary cuts to be imposed;
- State-of-the-art calculation of the Higgs signal in the di-photon channel for the LHC;
- We plan to extend FEHiP to include $H \to W^+W^-$ and $H \to ZZ$ decays in the future. http://www.phys.hawaii.edu/ kirill/FEHiP.htm
- We hope FEHiP will be useful in devising strategies to enhance the signal to background ratio and facilitate the Higgs boson discovery.

# MSSM Higgs Sector with CP Violation

Marcela Carena
Fermilab

# Motivation for CP-Violation in SUSY Models

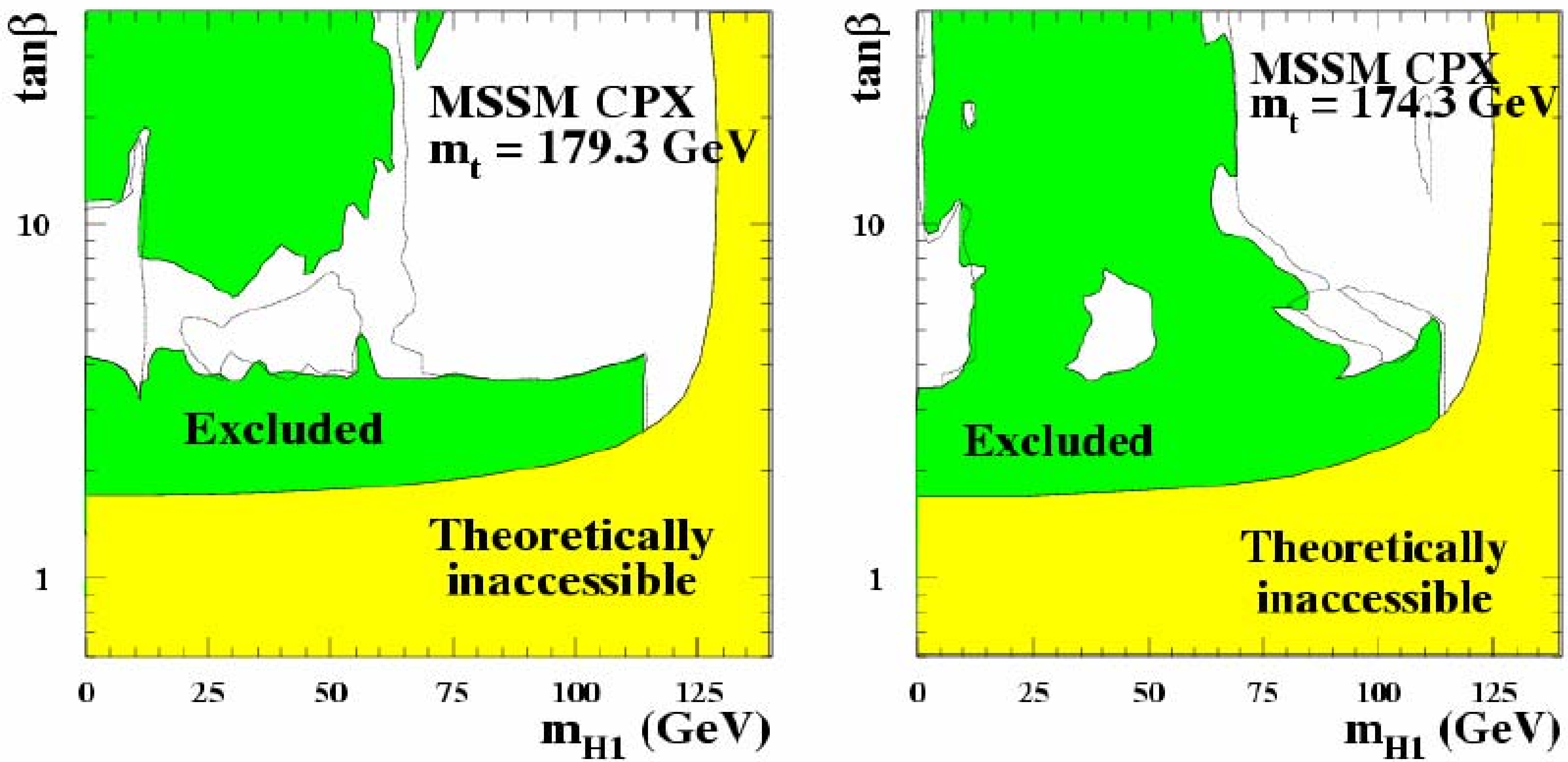
- In low energy SUSY, there are extra CP-violating phases beyond the CKM ones, associated with complex SUSY breaking parameters.

- One of the most important consequences of CP-violation is its possible impact on the explanation of the matter-antimatter asymmetry.

  Electroweak baryogenesis may be realized even in the simplest SUSY extension of the SM, but demands new sources of CP-violation associated with the third generation sector and/or the gaugino-Higgsino sector.

- CP-violation in the Higgs sector appears at the loop-level, but can still have important consequences for Higgs physics

# LEP

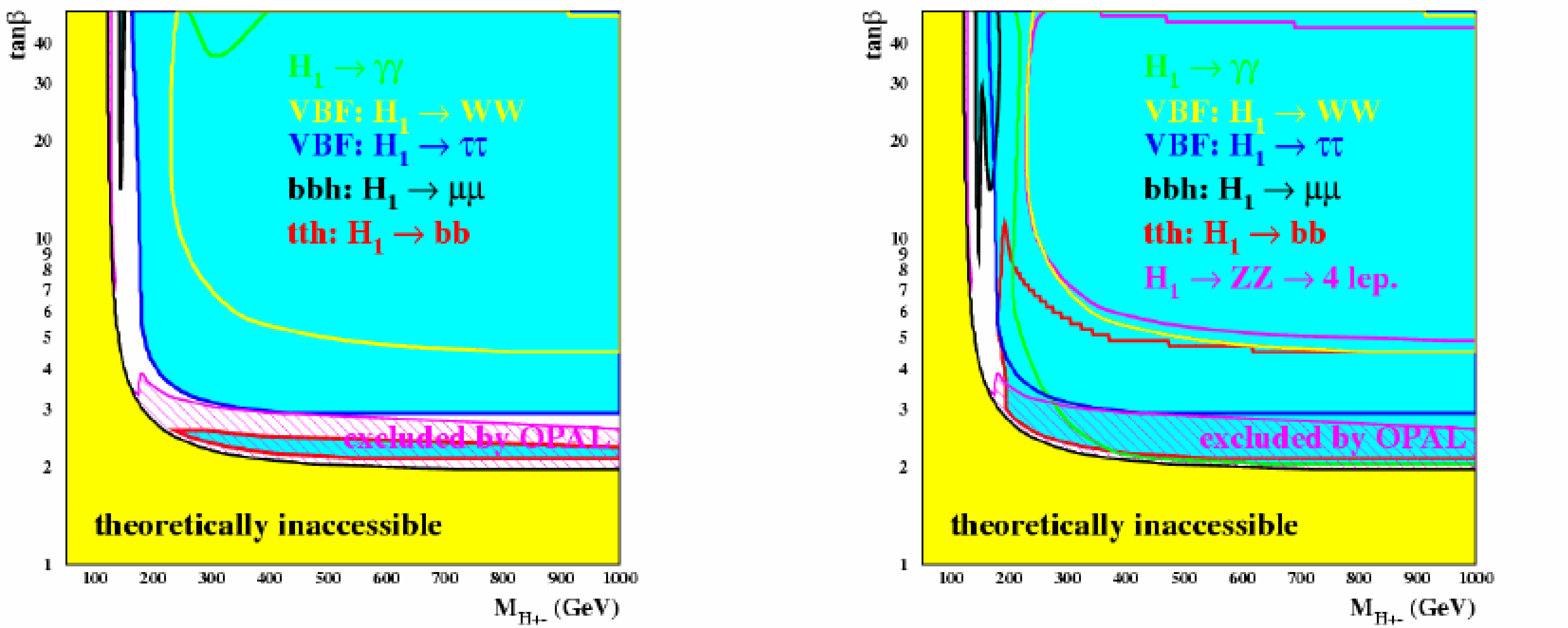



$ZH_1$ suppressed and/or $H_2 \rightarrow H_1H_1$ allowed

# Light Higgs Boson $H_1$

**ATLAS preliminary**

30 $fb^{-1}$ — 300 $fb^{-1}$




- border of discovery region at low tanb mostly determined by availability of inputs (VBF >110 GeV, ttH and γγ > 70 GeV)
- border at low $M_{H+-}$ due to decoupling of $H_1$ from W,Z and t
- for VBF channels: assume same efficiencies for contribution of CP even and CP odd states (needs to be checked)
- for ttH: efficiencies for CP even and odd bosons are the same

M. Schumacher, SUSY 04

# Tevatron/LHC

## Looking for $H_2 \rightarrow H_1 H_1$

- Standard signatures not sufficient to probe the presence of Higgs bosons decaying into lighter Higgs states.
- Lighter states have weak couplings to the weak gauge bosons, but large couplings to third generation down quarks and leptons.
- Possibility of looking for two taus and two bottoms (jets) signatures at LHC in the weak boson fusion production channel of two CP-odd like Higgs bosons. (J. Gunion et al. with 300 inverse fb at the LHC)

- Encourage the study of $gg \rightarrow H_2$, $t\bar{t}H_2$, W/Z $H_2$ and WW/ZZ $H_2$ with subsequent decay $H_2 \rightarrow H_1 H_1$, using the extra leptons from W/Z's.

# CPsuperH

- Code to compute Higgs spectrum, couplings and decay modes in the presence of CP-violation

Lee, Pilaftsis, M.C., Choi, Drees,Ellis, Lee,Wagner.'03

- CP-conserving case: Set phases to zero. Similar to HDECAY, but with the advantage that charged and neutral sector treated with same rate of accuracy.

- Combines calculation of masses and mixings by M.C., Ellis, Pilaftsis, Wagner. with analysis of decays by Choi, Drees, Hagiwara, Lee and Song.

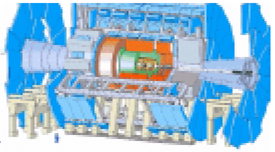
- Available at

http://theory.ph.man.ac.uk/~jslee/CPsuperH.html

# Prospects for the Search for a Doubly Charged Higgs with ATLAS

Kamal Benslama
Columbia University

# Physics Motivation



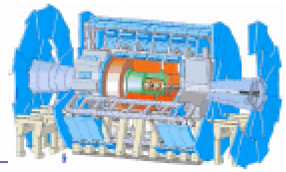
**L-R symmetric model would be a natural extension of the SM**

- $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
- predicts new fermions:
  heavy Majorana neutrino
- predicts new gauge bosons:
  $W_R$
- predicts new Higgs sector

$\Delta_R = (\Delta_R^0, \quad \Delta_R^+, \quad \Delta_R^{++})$

$\Delta_L = (\Delta_L^0, \quad \Delta_L^+, \quad \Delta_L^{++})$ (if Lagrangian is invariant under $\boldsymbol{L} \leftrightarrow \boldsymbol{R}$ symmetry)

# $\Delta_L^{++} \rightarrow l^+ l^+$



Signal : consider $\Delta_L^{++} \rightarrow \ell^+ \ell^+$ , only e or μ
( cannot decay to quark pair because of charge conservation)

Backgrounds : $W t \bar{t}$, $W^+W^+(QCD)$, $W^+W^+(EW)$, $WZqq$, $t\bar{t}$

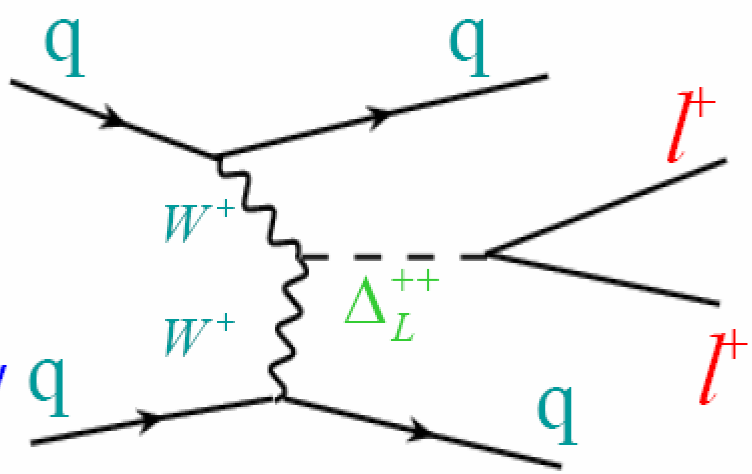
Main background

$$nlep = 2$$

$$\Delta\phi_{ll} > 2.5$$

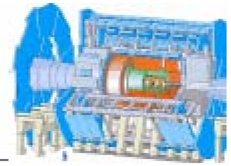
$$\Delta P_T^{ll} = f(M_{ll})$$

**Forward jets tagging:**
E_j1>200 GeV, E_j1>200 GeV
well separated in eta

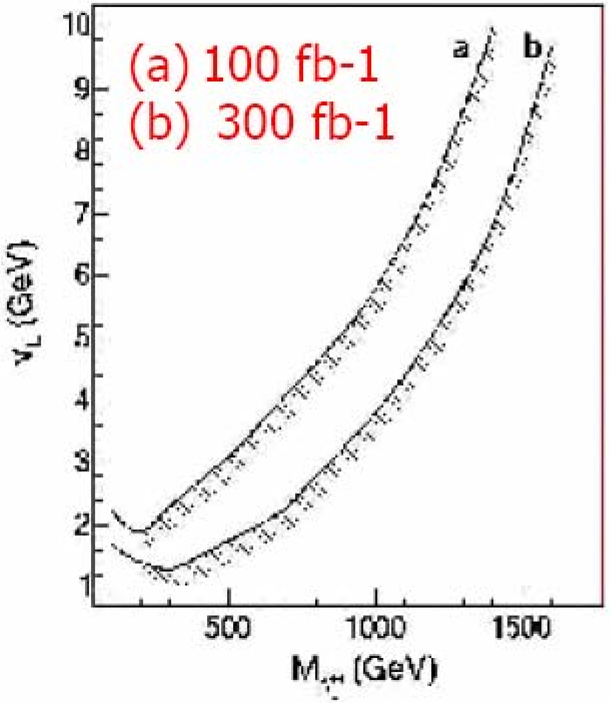



**Missing transverse momentum cut**

# Results



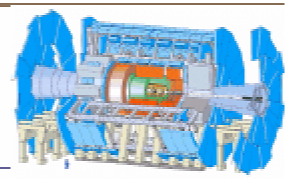
| 100 fb-1 | $\Delta^{++}$ 300 GeV | $\Delta^{++}$ 800 GeV | total backg |
|---|---|---|---|
| Isolated leptons | 330 (384) | 59 (69) | 133/13 |
| $\lvert\Delta\phi_{ll} > 2.5\rvert$ | 253 (289) | 56 (65) | 75/8.3 |
| $\Delta_{P_T^{ll}} > (\frac{M_{ll}}{2}+50)$ | 220 (260) | 50 (59) | 37/2.5 |
| Fwd Jet tagging | 156(185) | 40 (47) | 17/1.4 |
| ptmiss | 152(180) | 34 (40) | 3.0/0.1 |




**Nb of Events after each cut**

**Discovery reach**

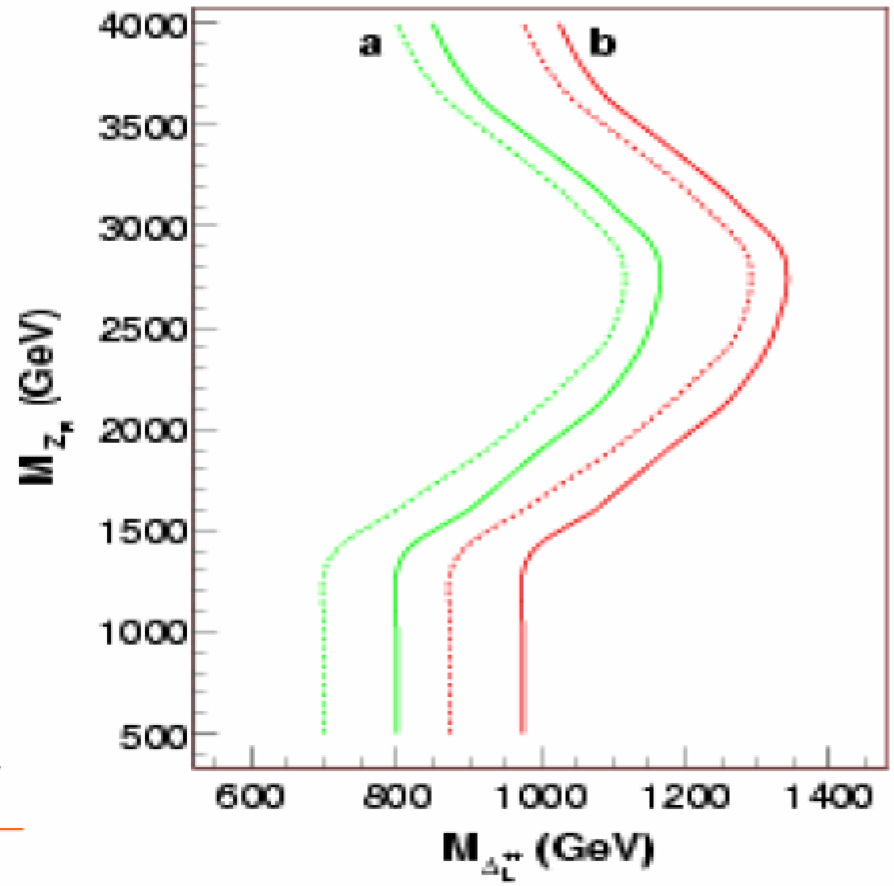
# $\Delta_L^{++}\Delta_L^{--} \to l^+l^+l^-l^-$

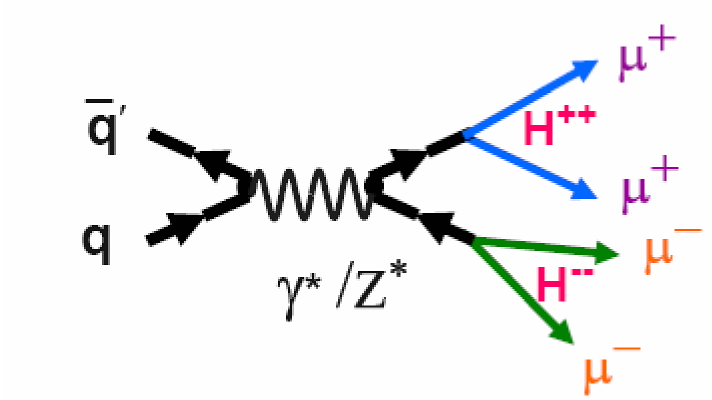


(a) 100 fb-1
(b) 300 fb-1

**Full = 3 leptons are observed**

**Dashed =4 leptons are observed**




Similar results for $\Delta_R^{++}$

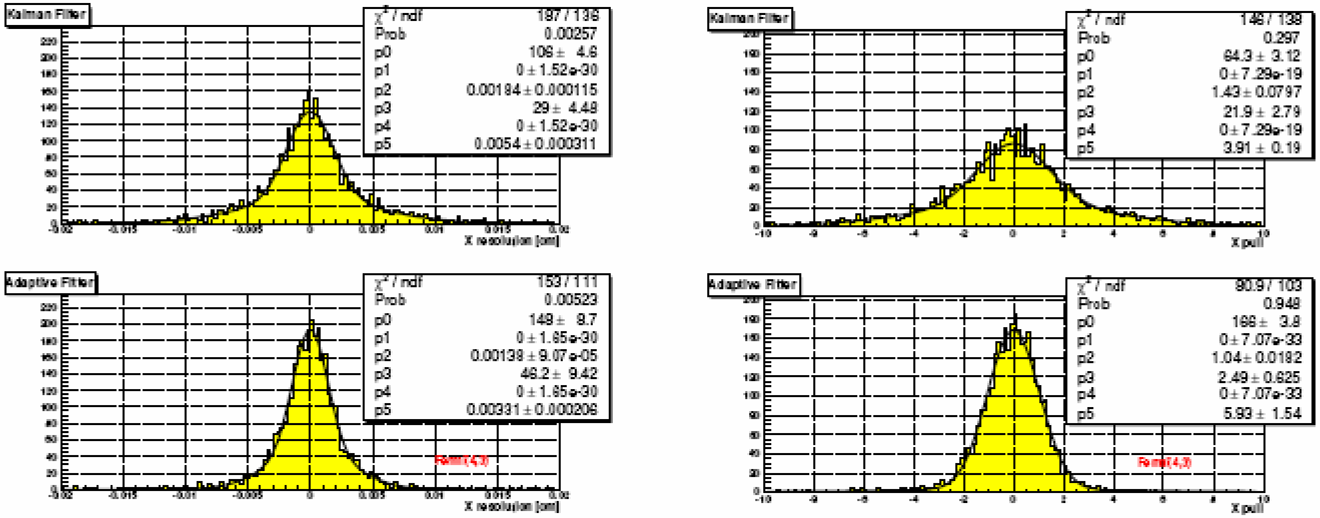
# Robust Vertex Reconstruction in Heavy Flavor Events

Ariel Schwartzman
Princeton University

- Standard methods for primary vertex reconstruction:
  - Biased by the presence of secondary vertex tracks. Square cuts designed to reject outliers have the effect of reducing the vertex resolution by removing true primary vertex tracks.
- The Adaptive Fitter:
  - Robust, iterative Kalman Filter. Secondary vertex tracks are down-weighted, depending on the $x^2$ contribution to the vertex and the presence of all other neighbor tracks. All tracks are considered in the fit.

Adaptive algorithm down-weights SV tracks from small decay length vertices.

# Adaptive Primary Vertex Performance (I)




Zbb simulated events

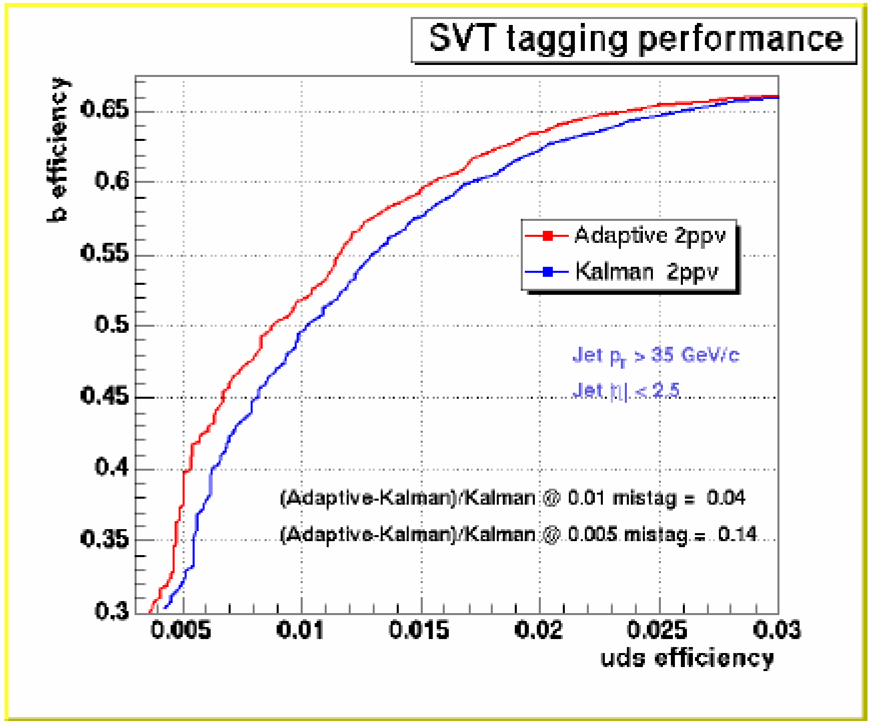
- Multiplicity = 18.7
- Resolution = 13.8 um.
- Pull = 1.04.
- Tails = 7.9%

| | | |
|---|---|---|
| Resolution improvement: | 18.3um | 13.8um |
| Pull improvement: | 1.43 | 1.04 |
| Tails improvement: | 48.2% | 7.9% |

Resolution = X(reco) - X(true)

Pull = ( X(reco) – X(true) ] / SigmaX(reco)

# Secondary Vertex Performance using Adaptive Primary Vertexing




New Adaptive PV allows a better separation between primary and secondary vertices.

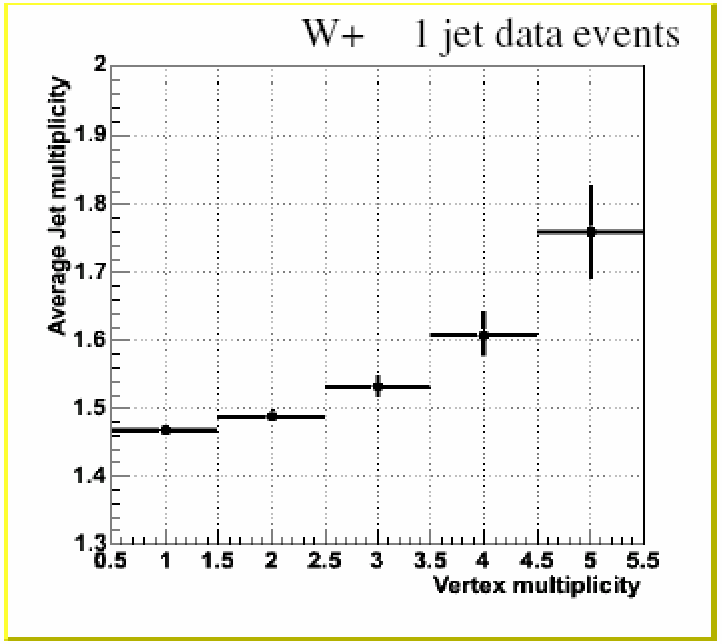
At a same mistag rate, secondary vertex b-tagging efficiency in the simulation is improved.

Further improvement expected by using SV adaptive fitting.

# Improving Calorimeter Jet Reconstruction Using Tracks and Vertices

Ariel Schwartzman
Princeton University

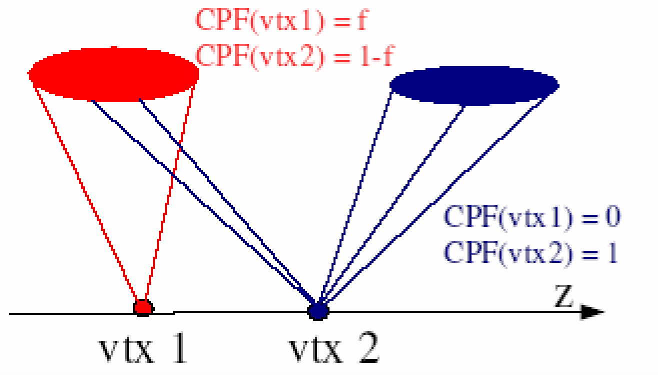
# Jet Multiplicity at High Luminosity




- Average jet multiplicity increases with number of primary vertices.
- Jet kinematics is distorted at low pT (extra low-pT jets)

  → Additional minimum bias interactions can give rise to extra jets.

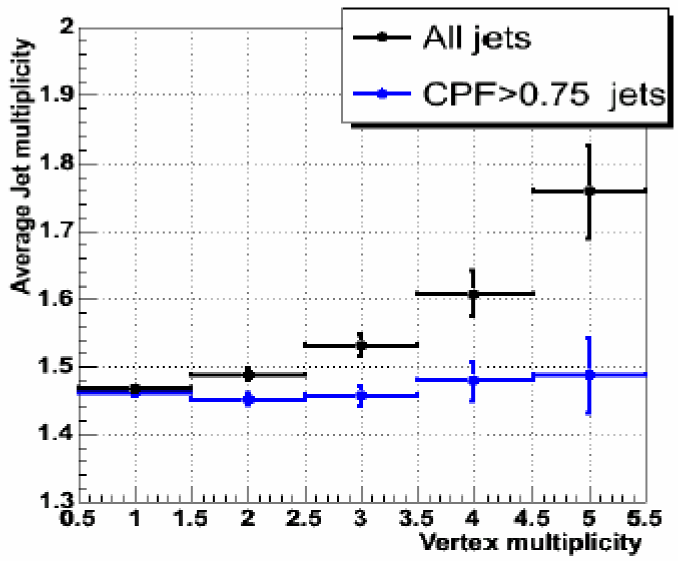
# Jet-Vertex Identification




associate *jet j* to the vertex *i* for which $CPF(jet_j, vtx_i)$ is maximum.

CPF is the charged particle energy fraction of jet *j* from vertex *i*.

# Jet Multiplicity at High Luminosity




The dependence of jet multiplicity on the number of interactions is significantly reduced for jets with more than 75% of its energy coming from the hard scatter vertex.

Jet-Vertex algorithm allows to identify (remove) soft jets arising from min-bias interactions.

# Improving Jet Energy Resolution Using Tracks

Classify tracks:

R(vtx)<0.5, R(cal)<0.5 : IN jet

R(vtx)<0.5, R(cal)>0.5 : Out-of-cone

**Technique**: for every charged hadron (track) matched to a jet:

- *subtract* the expected energy deposited in the calorimeter.
- *add* the track momentum.

$$E_{jet} = E_{jet} + (1 - R^{cal}(E_{track}))E_{track}$$

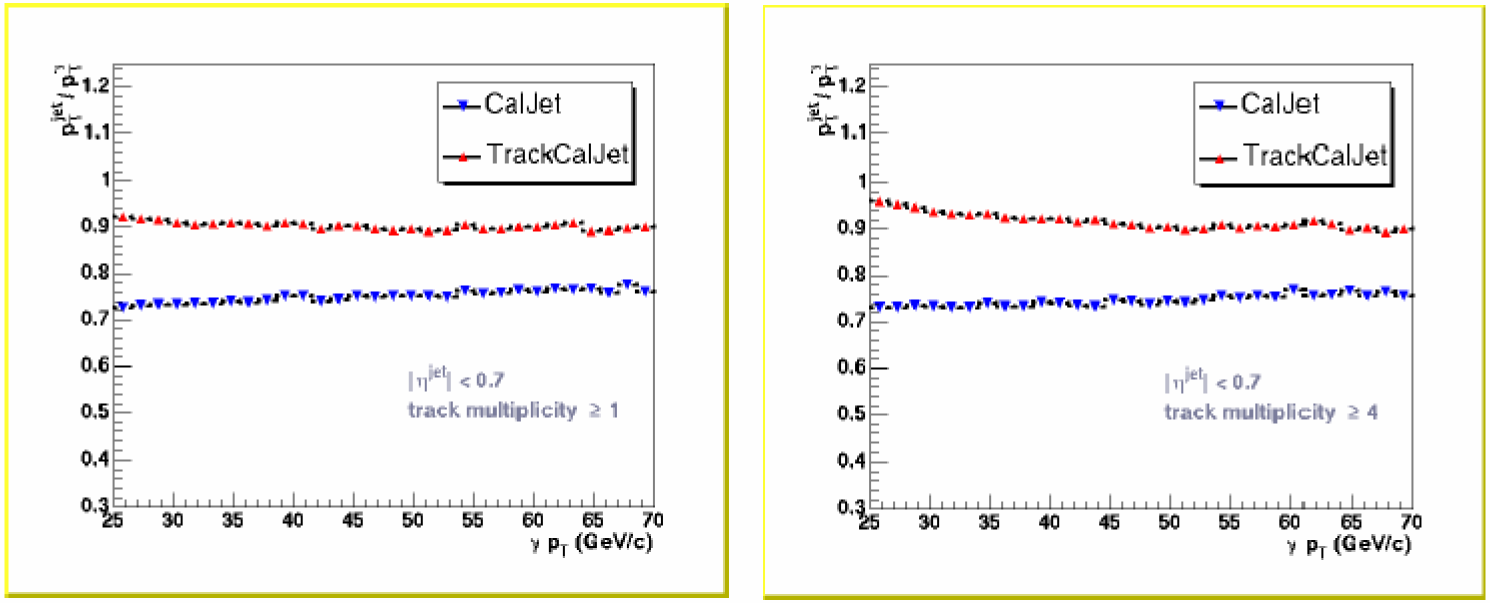
$$R^{cal}(E_{track}) = E^{cal}/E^{track}$$

is the single pion calorimeter response.

- *Add* the energy of out-of-cone tracks.

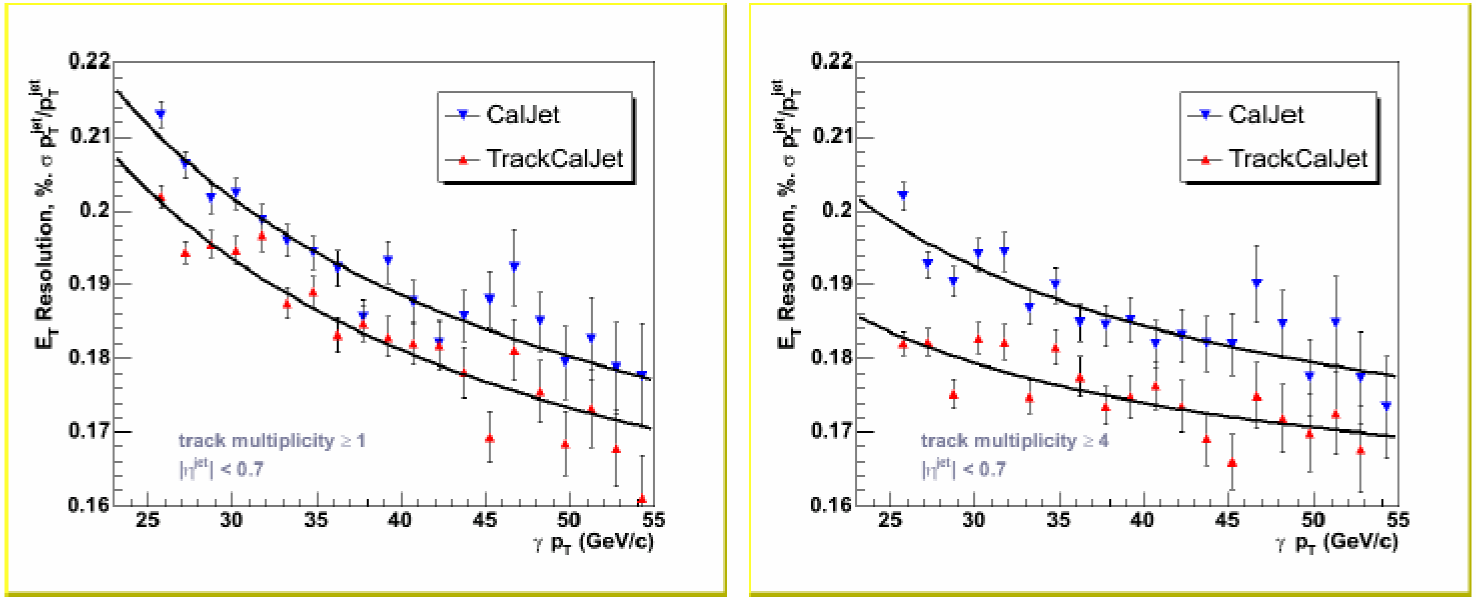
$$E_{jet} = E_{jet} + E_{track}$$

# Jet Energy Scale in photon+jet Data



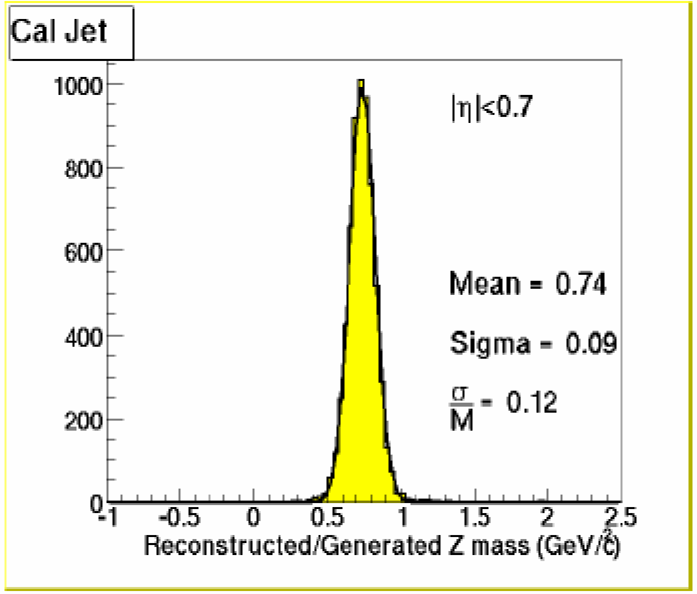

Jet energy offset is significantly improved with the use of tracks.

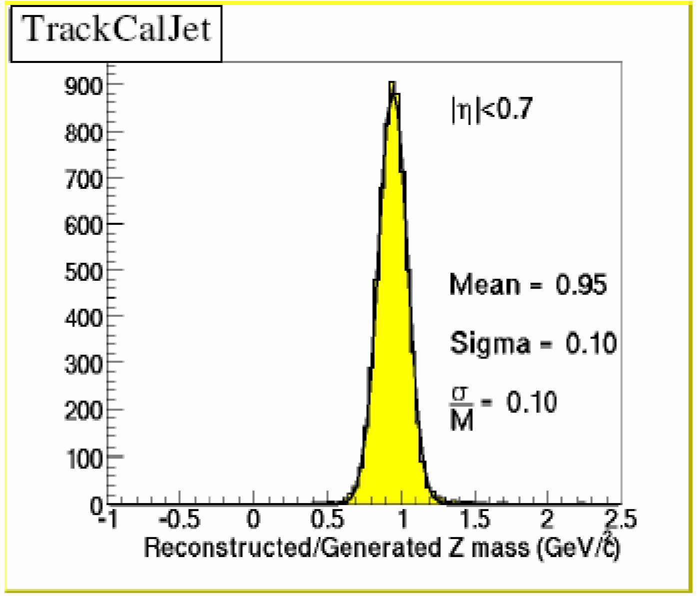
# Jet Energy Resolution in photon+jet Data




Jet energy resolution dependence on Jet $p_T$ for low and high track-multiplicity jets. ~10% Improvement.

# Dijet Mass Resolution in Zqq events



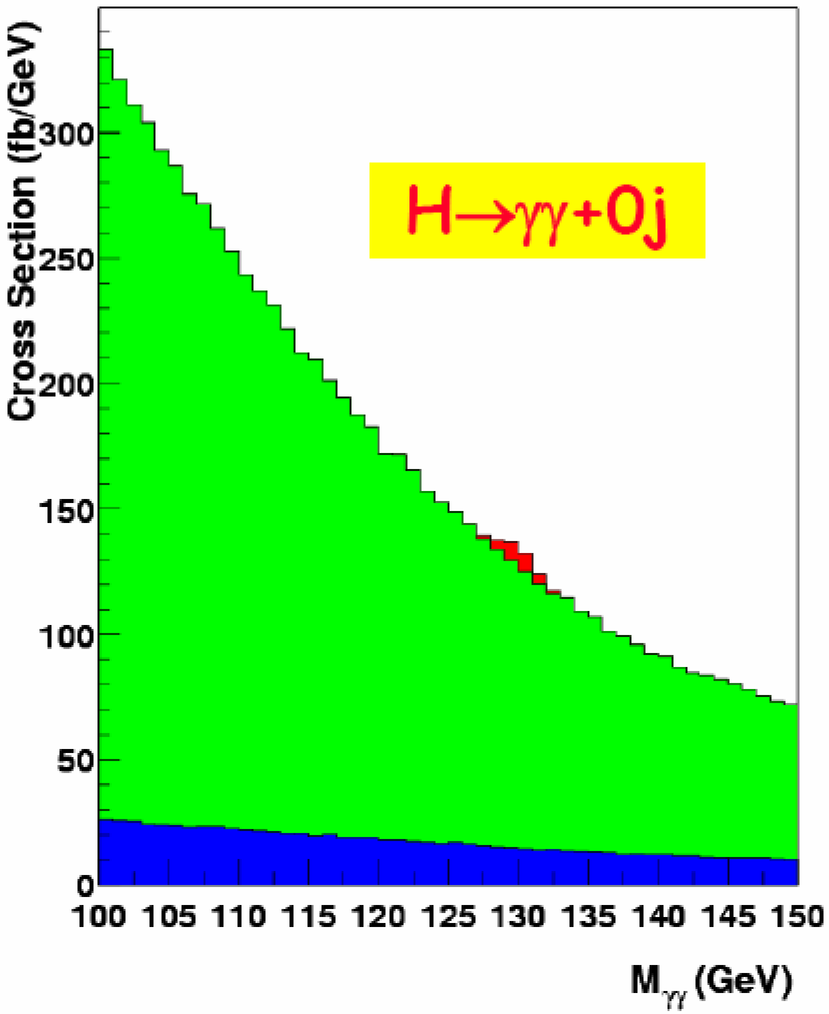



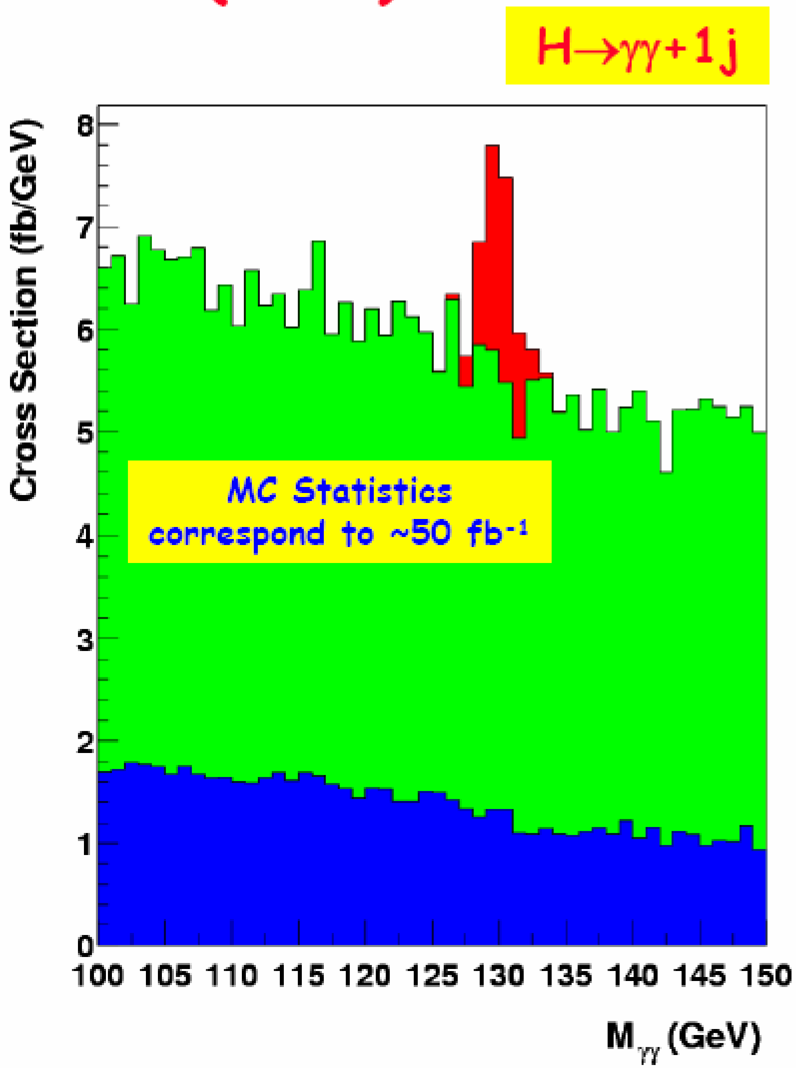

15% mass resolution improvement.

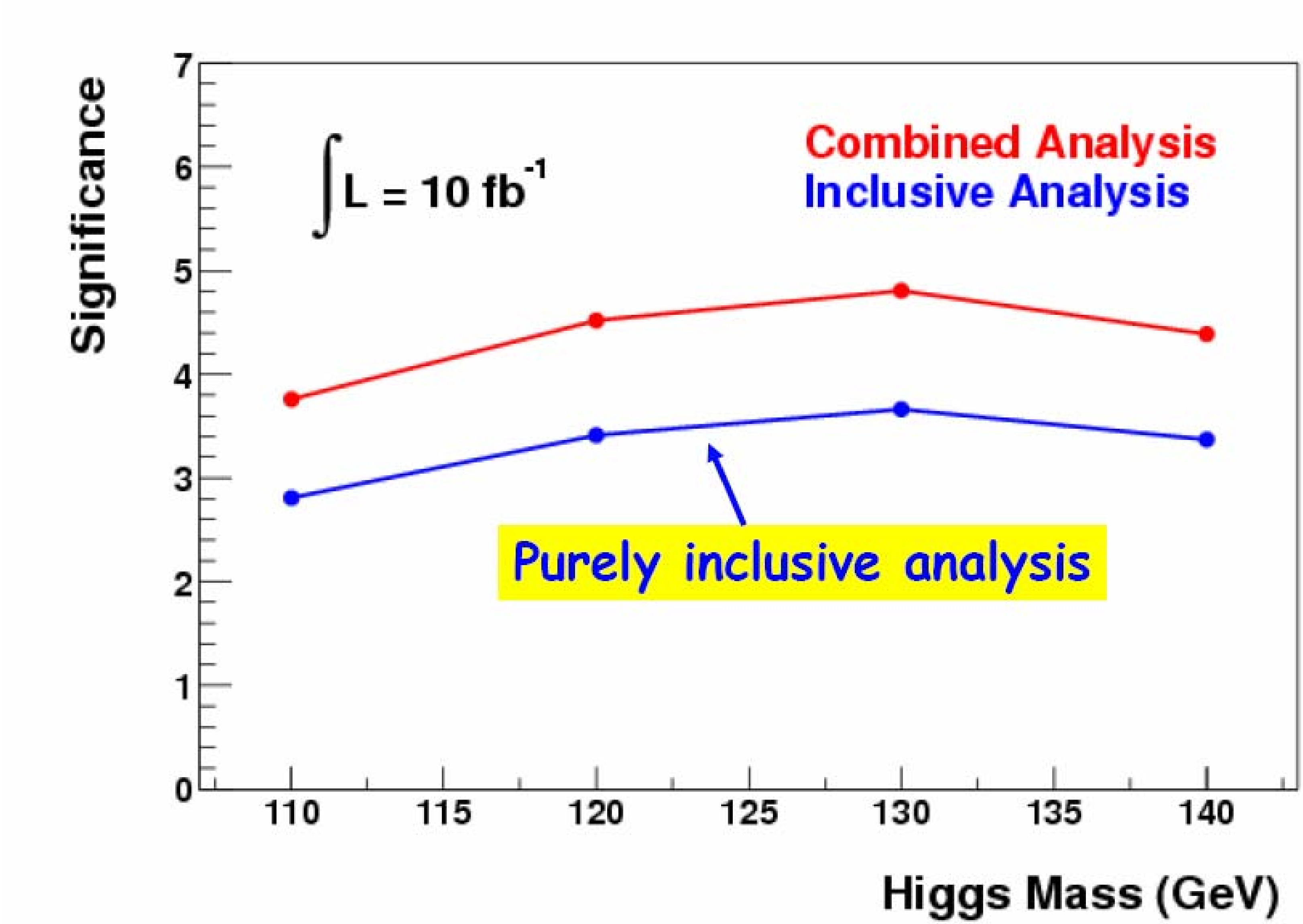
# Higgs + 1jet Signatures

Yaquan Fang, Bruce Mellado, William Quayle
and Sau Lan Wu
University of Wisconsin-Madison

# Optimization (cont)



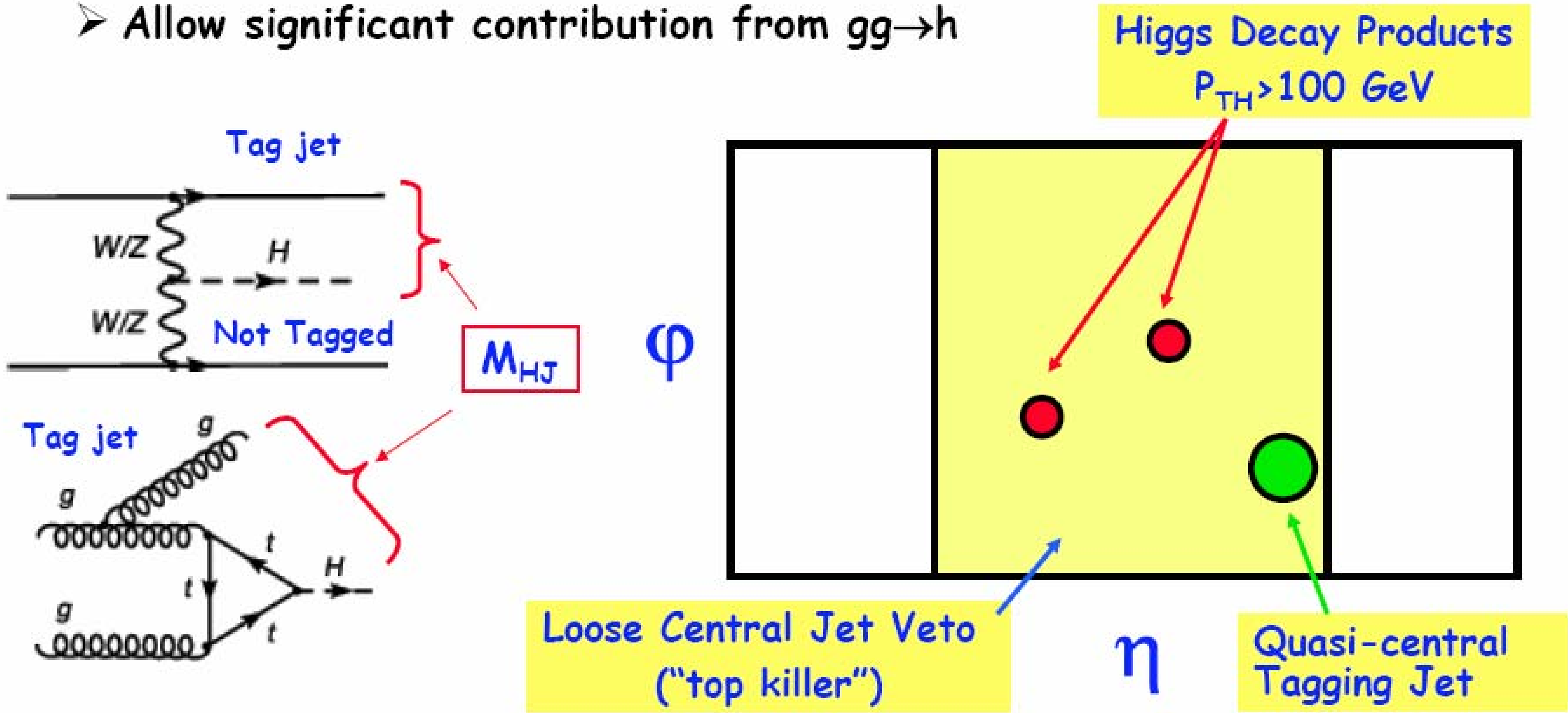



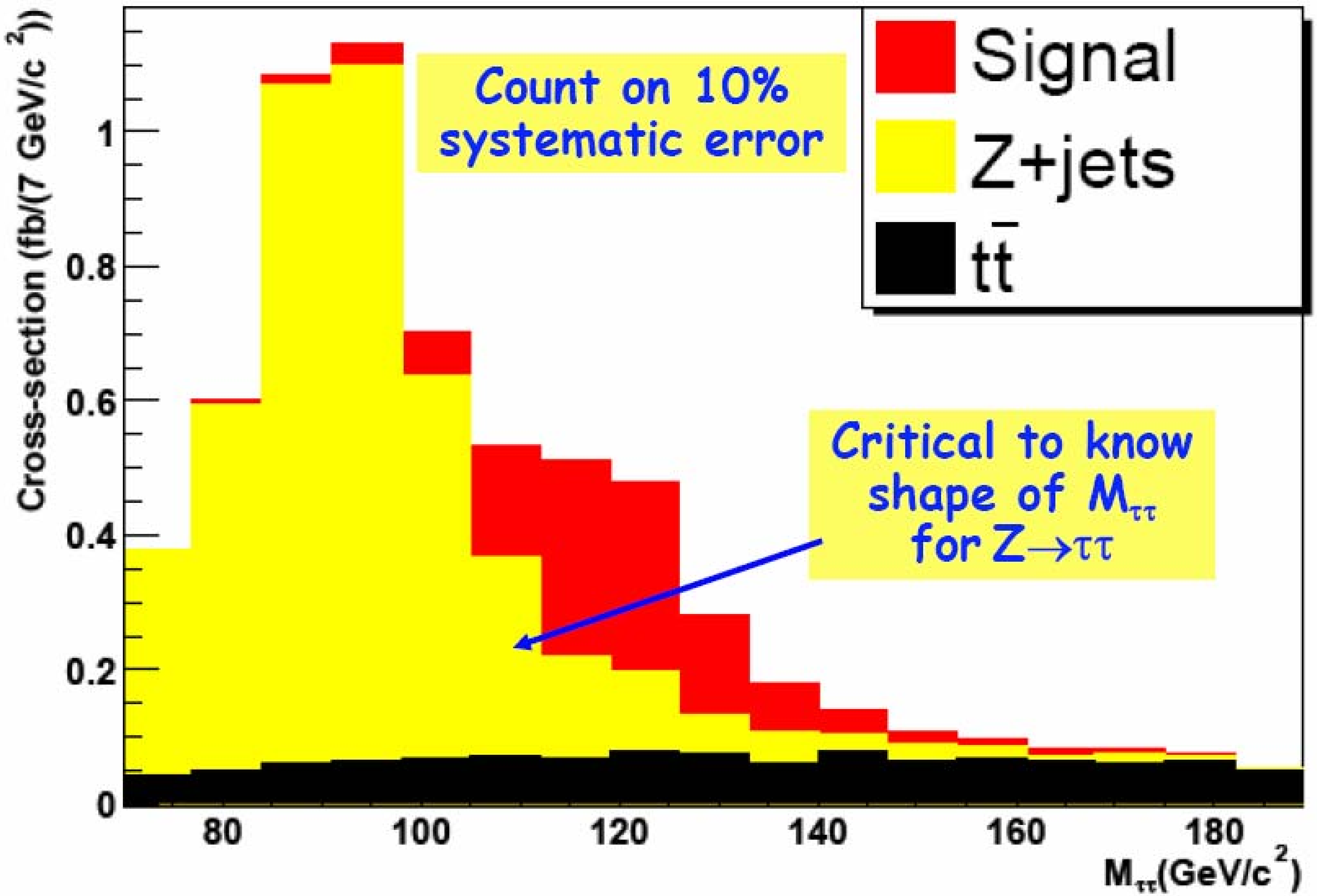


Significance
$\int L = 10\ fb^{-1}$
Combined Analysis
Inclusive Analysis
Purely inclusive analysis
7
6
5
4
3
2
1
0
110
115
120
125
130
135
140
Higgs Mass (GeV)

# $H(\rightarrow\tau\tau)$+1jet at the LHC

- Tag one semi-central jet, require $P_{TH}>100$ and $M_{HJ}>700$ GeV and a loose central jet veto ("top killer")
  - Allow significant contribution from $gg\rightarrow h$





Cross-section (fb/(7 GeV/c²))
0
0.2
0.4
0.6
0.8
1
80
100
120
140
160
180
Mττ(GeV/c²)
Signal
Z+jets
tt̄
Count on 10% systematic error
Critical to know shape of Mττ for Z→ττ

# Signal Significance for 30 $fb^{-1}$

($M_H$=120 GeV 10% systematic error on background)

| Higgs Mass ($GeV/c^2$) | 110 | 120 | 130 | 140 | 150 |
|---|---|---|---|---|---|
| Signal Significance for cut analysis ($\sigma$) | 4.3 | 5.0 | 4.8 | 3.6 | 2.1 |
| Signal Significance for NN analysis ($\sigma$) | 5.5 | 6.6 | 6.3 | 4.8 | 2.8 |

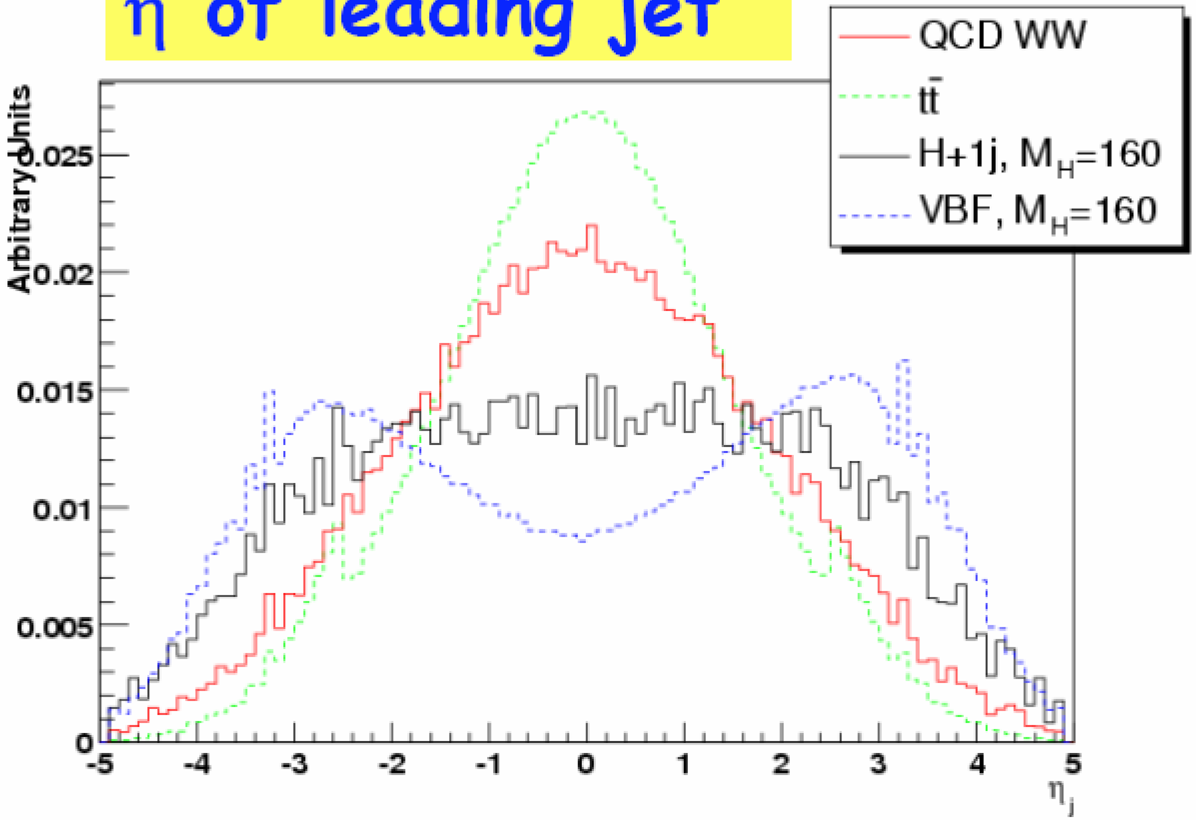
# Overlap With H+2jets (VBF)

the overlap is 24%

# $H \to WW^{(*)}$ +≥1 jet

- Use basic property that leading jet associated with Higgs is tends to be more forward than in QCD backgrounds

η of leading jet



# Conclusion

We still have a lot to learn
before the LHC turns on.

If you think we're busy now,
wait until we have data from the LHC