Experimental Wish-List

N(N)LO tools

Bruce Mellado

University of Wisconsin

CERN Workshop on MC Tools for the LHC
Geneva 2003

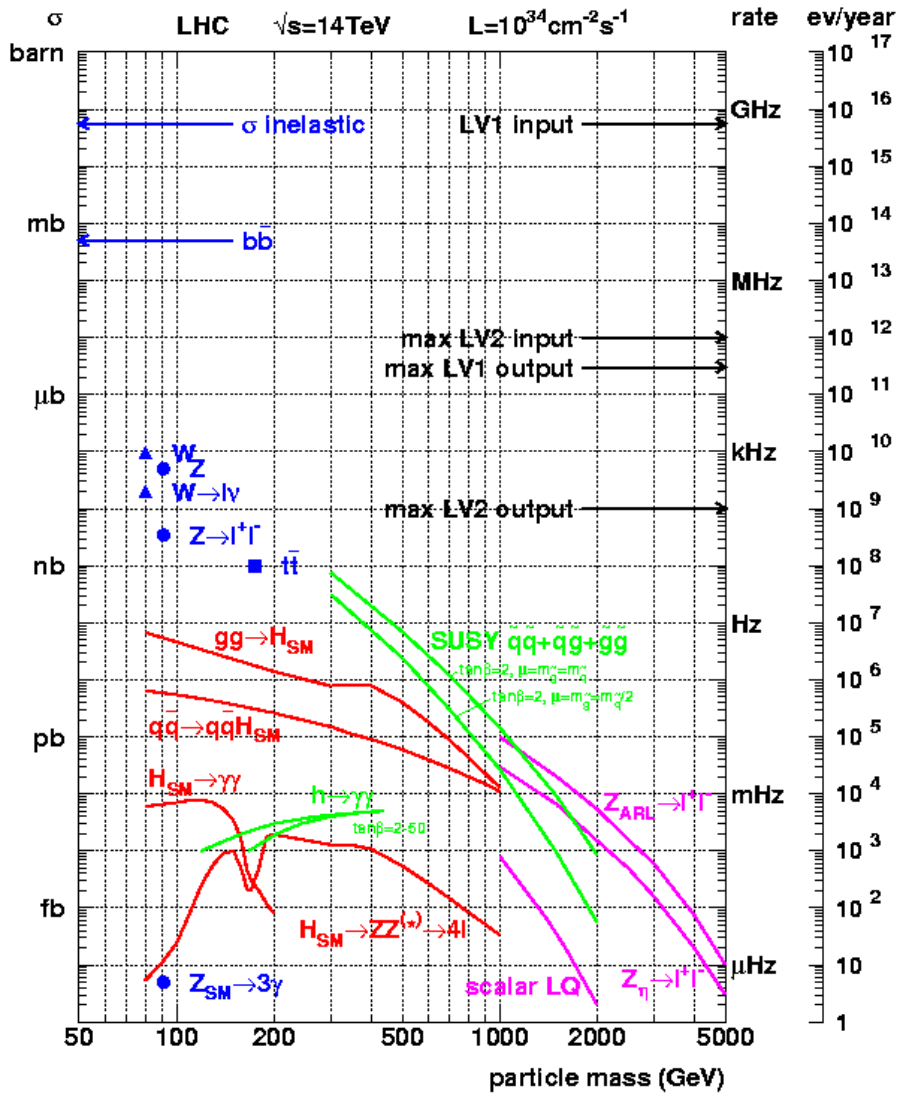
THE UNIVERSITY of WISCONSIN MADISON

Outline

- Introduction
  - LHC, a factory SM particles: Good simulation of production of SM particles processes crucial for discovery of new physics
- Selected topics
  - Higgs searches
  - SUSY
  - SM and BSM
  - Luminosity measurement
- Discussion and Conclusions

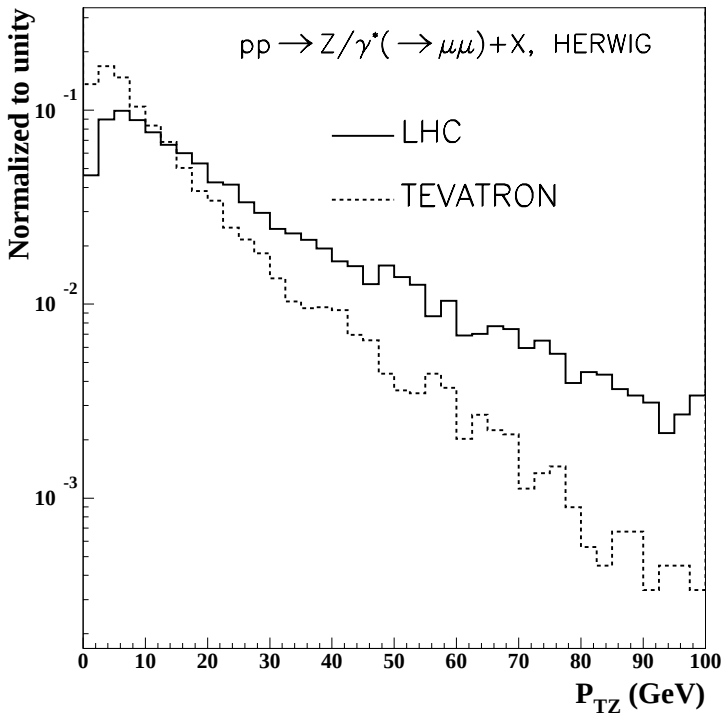
Introduction (1)

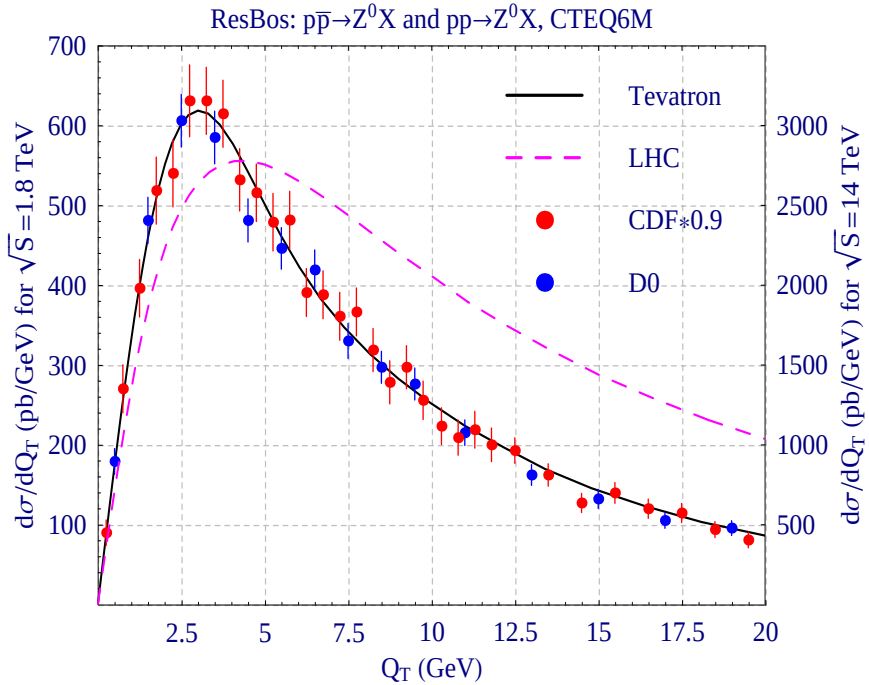
- Search for Higgs and new physics hindered by huge background rates
  - Known SM particles produced much more copiously
- This makes low mass Higgs specially challenging. Need to rely on
  - Narrow resonances
  - Complex signatures
    - Higgs in association with tops, W, Z and jets.



Introduction (2)

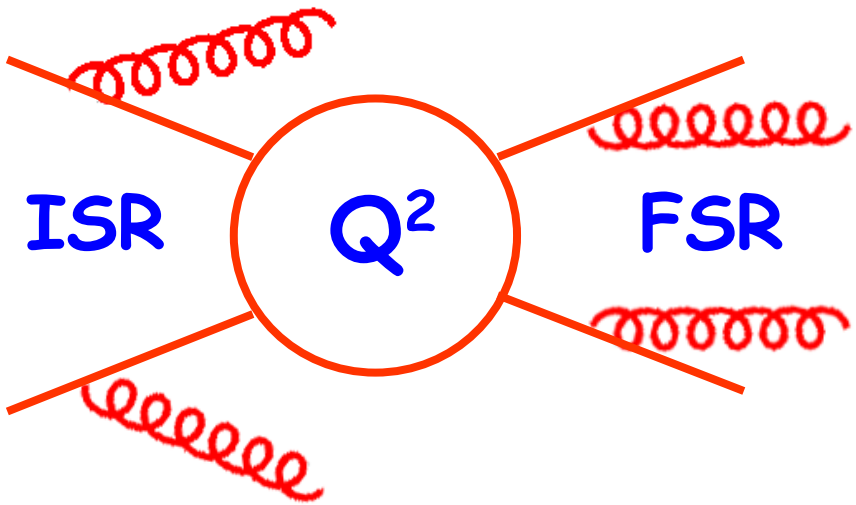
- **SM particles are produced in association with jets**
  - **At LHC additional jets will be harder**
    - *Application of N(N)LO corrections in MC's, crucial for proper understanding of backgrounds*
    - *Not just a question of normalization!*

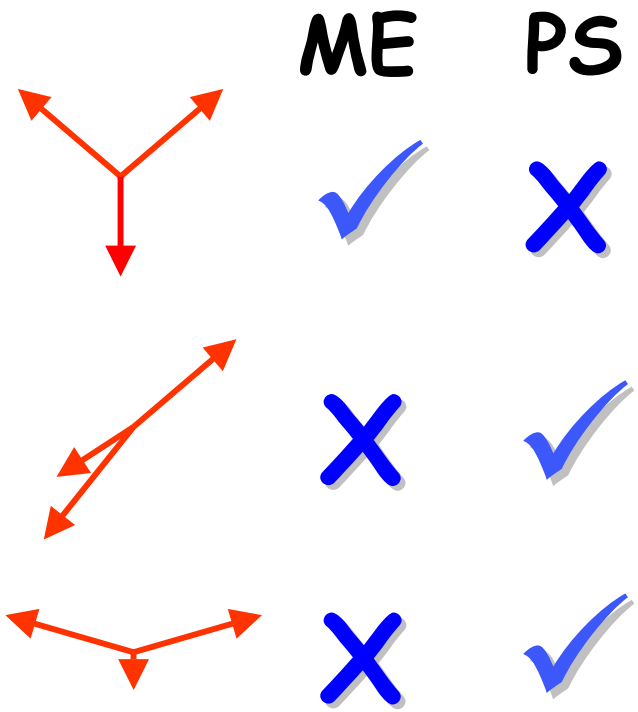




Attaching a Parton Showers to a LO ME will not work in many cases

- PS are good to cure infrared and collinear divergences
- But will fail to describe hard jets
  - Jets may be pretty hard at the LHC!





- **We'd like to have MC's good to all orders in perturbation + soft gluon re-summation**
  - Probably not a very reasonable thing to ask
- **However, the vast majority of physics studies are performed with LO ME + PS**
  - This may be ok for a discovery with narrow resonances or large excess of events
    - However, analysis restricted to simple cut on invariant mass distributions. Discriminating power is diminished
  - But this fails for more complex searches involving jets
    - Present level of analyses not acceptable
    - Higher order corrections are crucial and need to be somehow implemented in our MC's
- **Is re-weighting LO MC an acceptable solution?**

MC Integrators vs. MC Generators

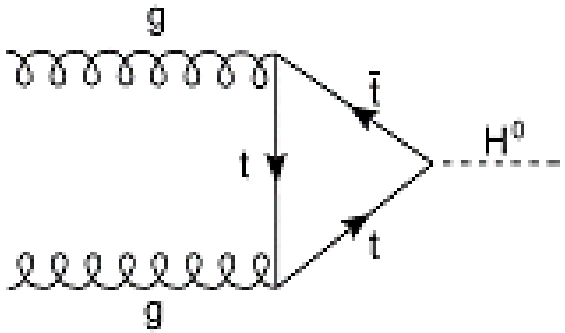
- A lot of progress in calculating K factors for relevant signal and background processes!
- However, re-scaling LO MC's is usually not acceptable experimentally
- In order to implement higher order corrections to experimental analyses MC's are required
  - Apply experimental cuts
    - MC integrators (like MCFM). Apply cuts at parton level
  - Hadronization + Experimental efficiencies
    - MC integrators not able to do this job
    - Need MC generators

Selected Topics

(certainly very biased, but not meant to be a full wish-list)

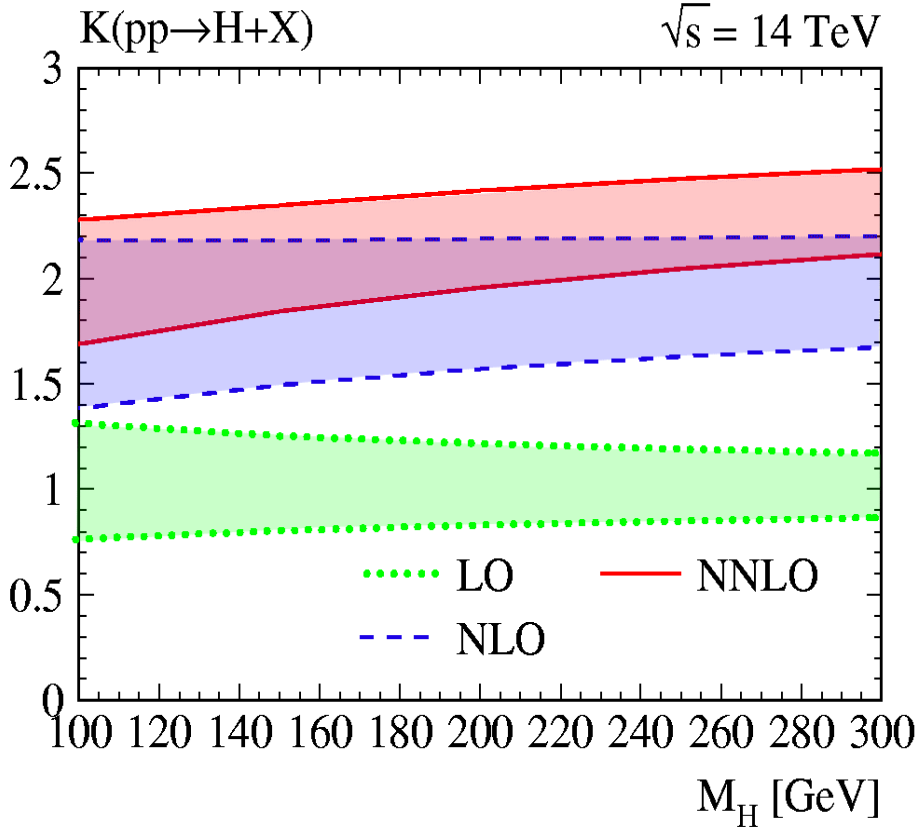
More in parallel session

QCD Corrections to gg->H (1)

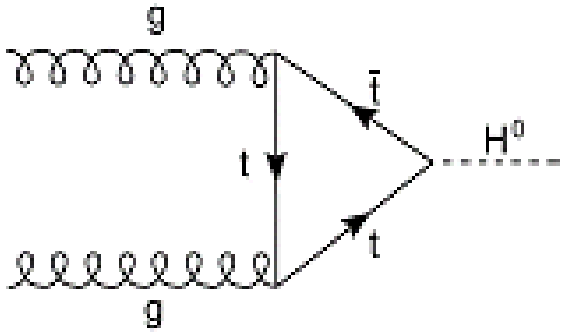


Harlander, Kilgore;
Anastasiou, Melnikov;
Ravindran, Smith, Van Neerver

- **Cross-section known to NNLO**
  - Infinite M_T approximation
  - Perturbative series seem to converge
    - NLO/NNLO overlap specially for low M_H
  - Scale uncertainty ~15%
    - More work on NNLO pdf

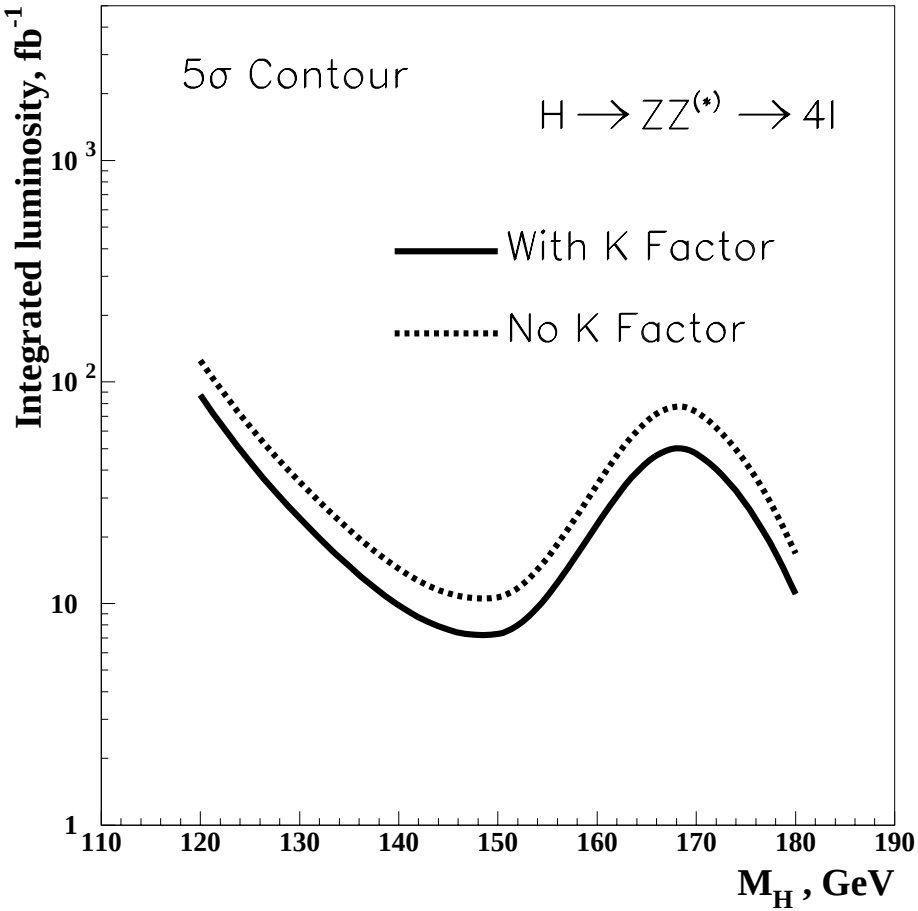


QCD Corrections to gg->H (2)



- **ATLAS is also thinking about applying K factors**
  - K(NLO) factors evaluated for signal and major backgrounds factors in H->ZZ*->4l analysis
    - Used MCFM (Campbell, Ellis)
    - Simple cut analysis
    - Luminosity required to reach 5σ effect decreases by 30-35%
    - P_T distributions not used

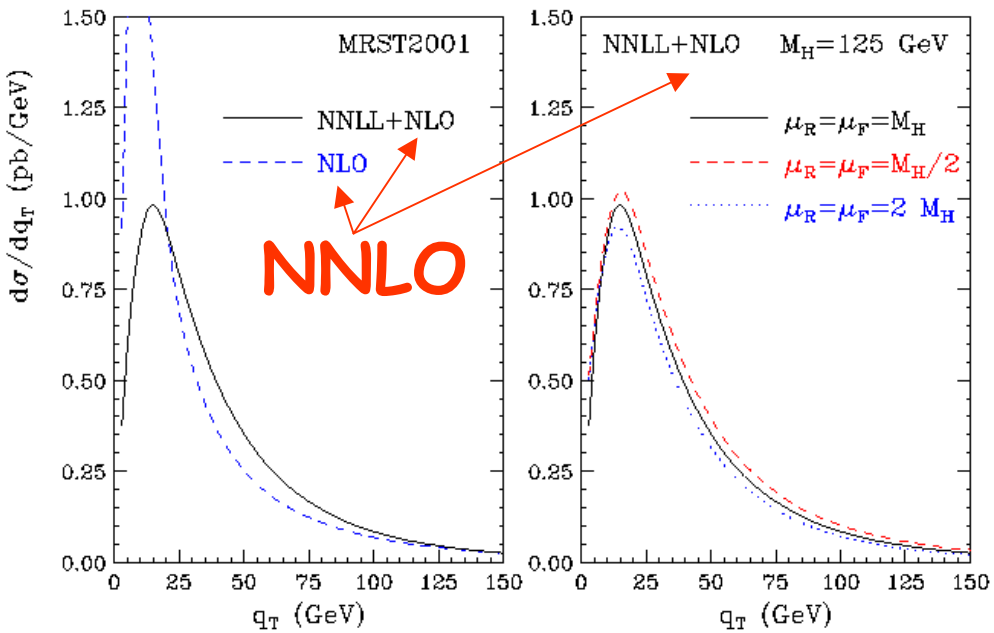
Preliminary



P_T of Higgs in gg->H (1)

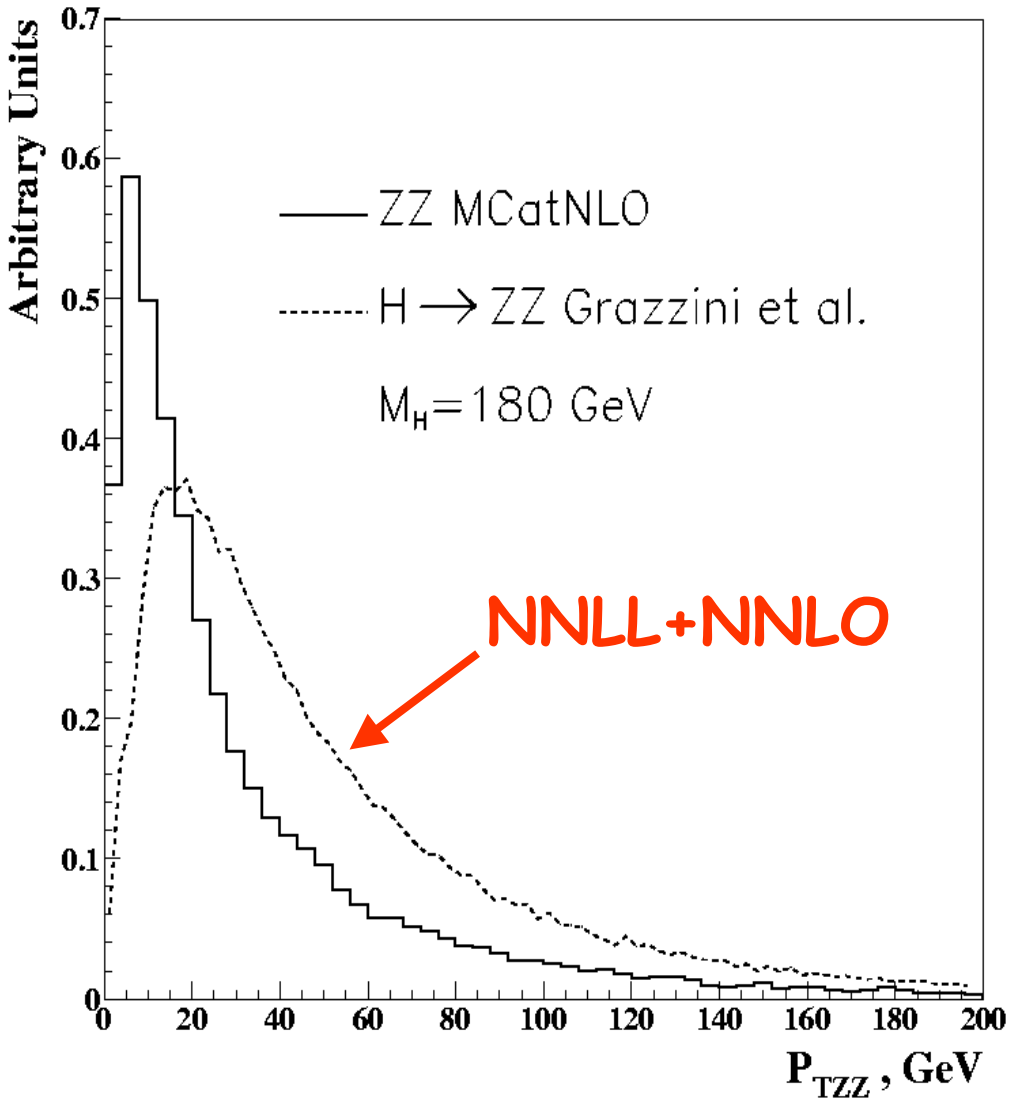
- Soft gluon emission enhances cross-section by ~6%
- Higgs transverse momentum distribution
  - Very important variable for discrimination
- Perturbation breaks down at low transverse momentum
  - Log re-summation to all orders
    - Small scale uncertainty

Bozzi, Catani, de Florian, Grazzini



P_T of Higgs in gg->H (2)

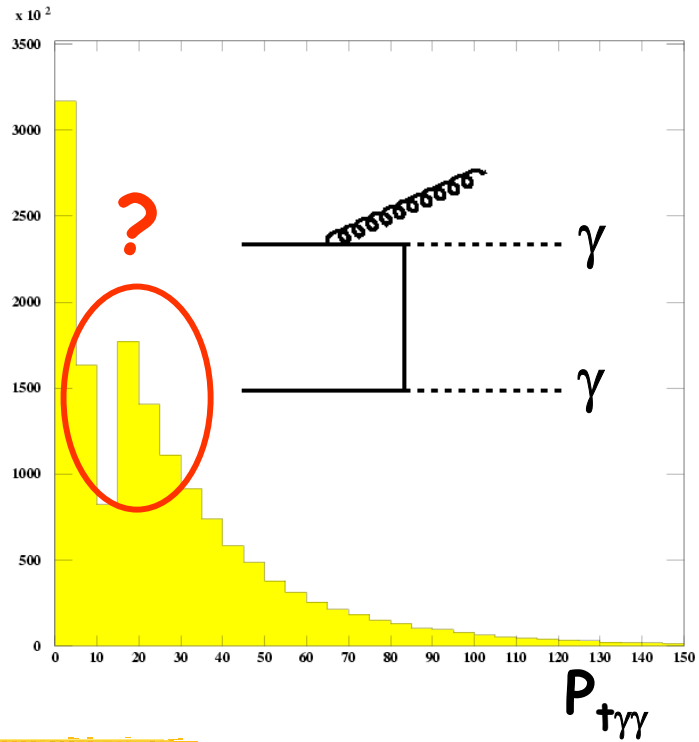
- Higgs transverse momentum distribution
  - Higgs is harder than background
  - Very important variable for discrimination
- May we re-weight LO MC to reproduce NNLL+NNLO P_T?
  - May be ok for a simple cut based analysis
  - Not acceptable for a multivariate analysis
- N(N)LO event generator would be a BIG step forward



QCD corrections in H->γγ analysis

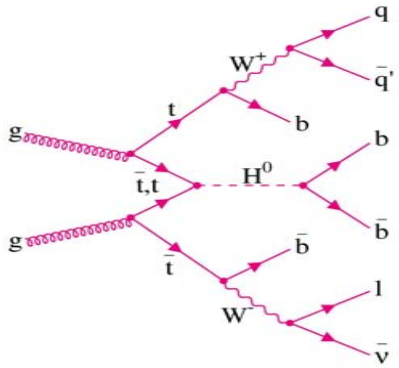
- A lot progress recently in QCD corrections to irreducible γγ
  - Diphox: NLO MC
    - Displays kink at $P_{t\gamma\gamma}$~20 GeV
  - Resummation available (ResBos)
    - Try to correct kink in Diphox
- H->γγ + jet search
  - NLO for QCD γγ+jet calculated recently
    - Maltoni, Nagy, Trocsangyi, del Duca
    - With standard γ isolation, large K factor and scale uncertainty
- See Unal's talk

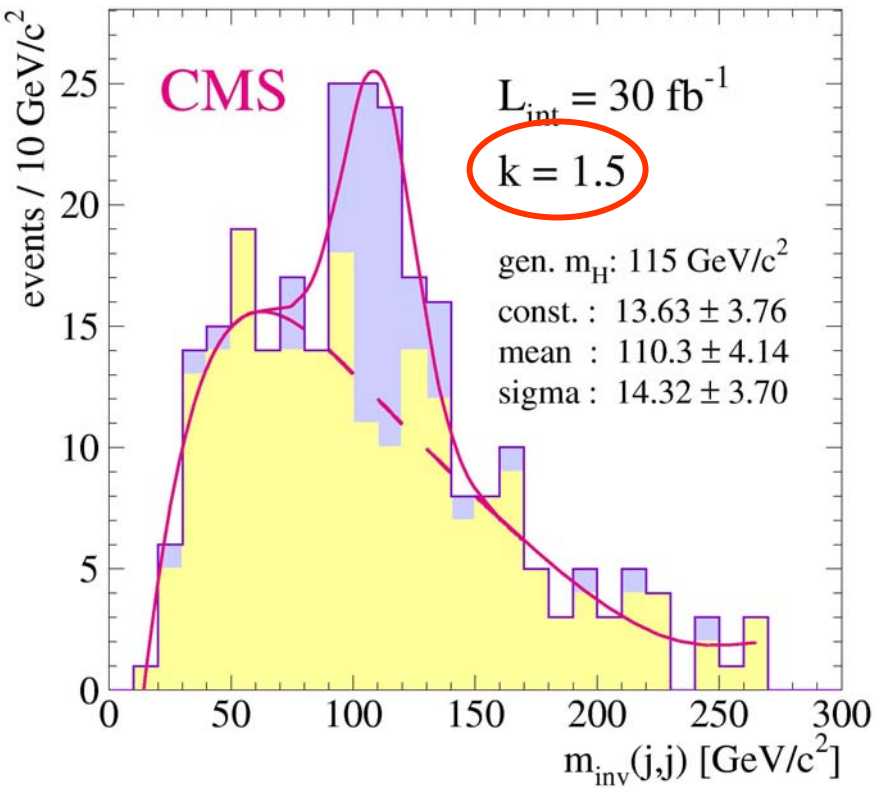
Binoth, Guillet, Pilon, Werlen (Diphox); Balazs (ResBos); Escalier, Unal (ATLAS)



Low Mass Higgs via ttH

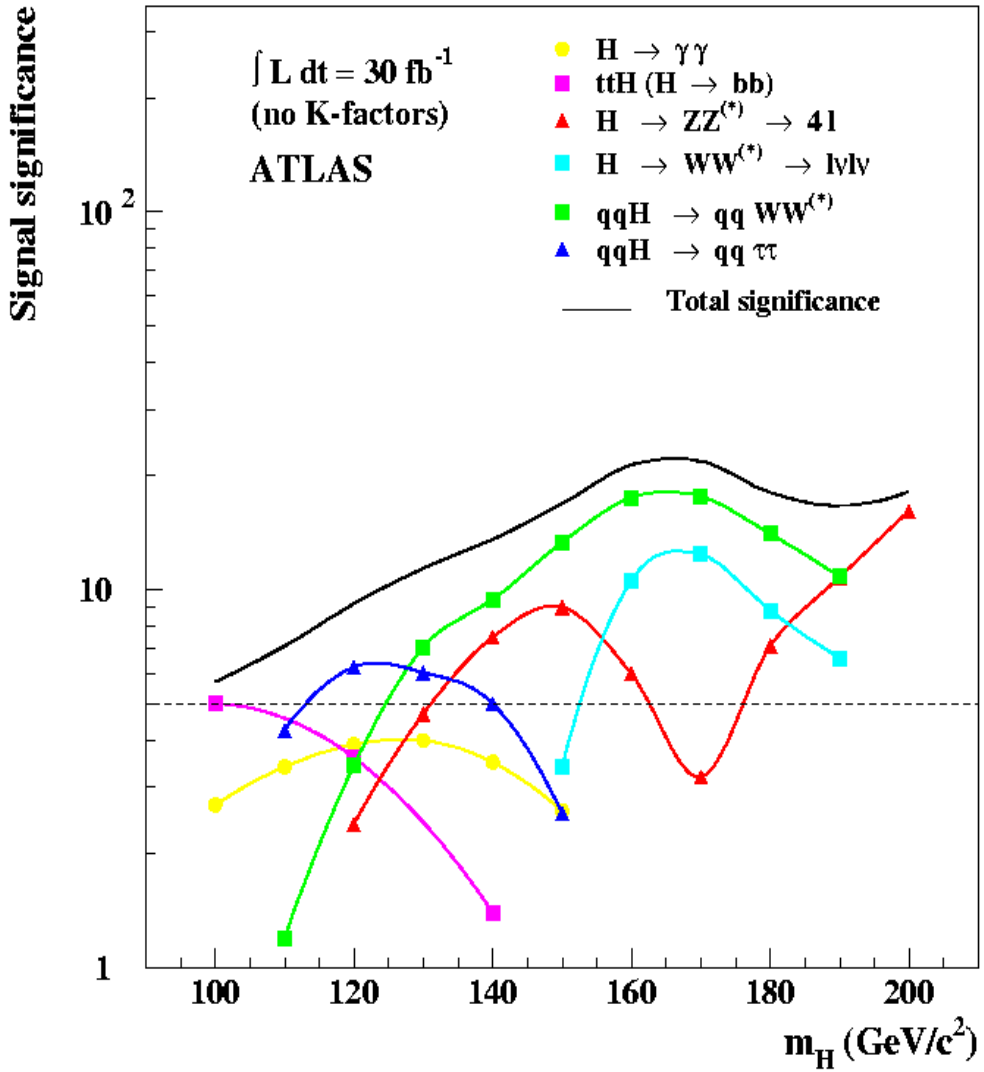
- Good for discovery of low mass Higgs ($100 < M_H < 150$ GeV) and Higgs Yukawa coupling determination
  - K factors known for signal
    - However, experimental analysis extremely complex
    - Really need a NLO event generator to evaluate impact of cuts and detector efficiency
  - Are K factors known for main background (ttbb)?



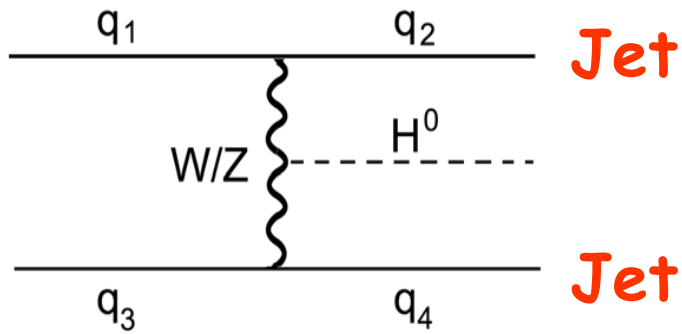


VBF's Discovery Potential

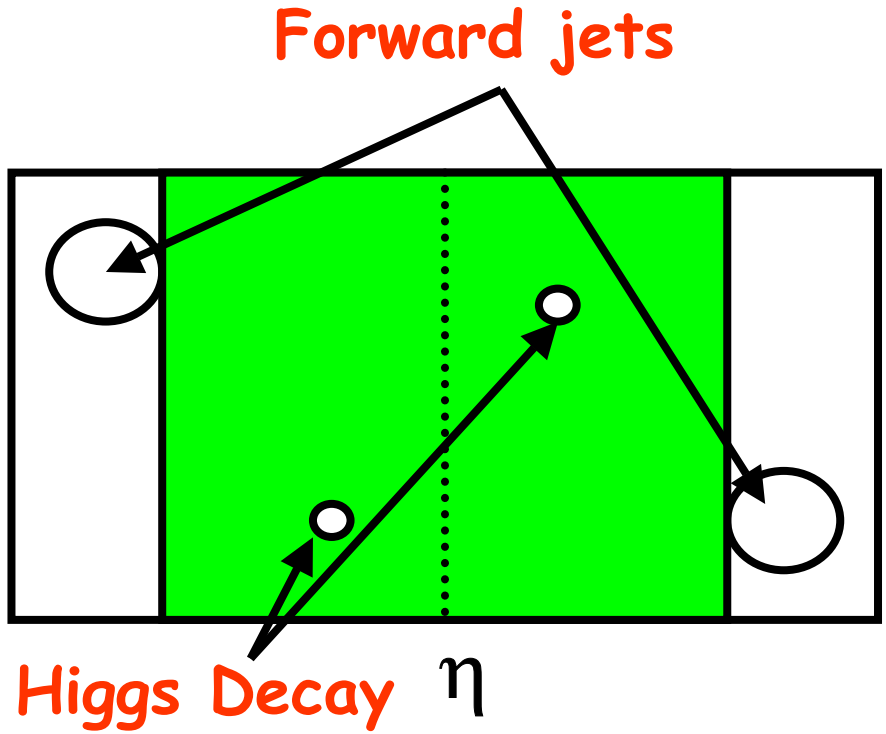
- VBF has changed the picture of low mass Higgs searches
  - Exclusive search
- Competitive with inclusive searches
- However, exclusive searches more challenging!
  - A lot of work on MC development needed



Low Mass Higgs via VBF (1)

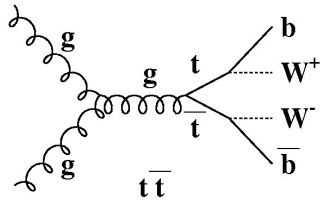


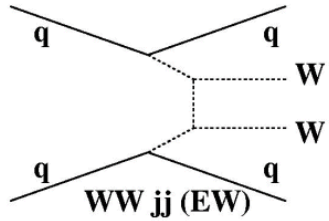
- Wisconsin Phenomenology Institute (D.Rainwater, D.Zeppenfeld et al.):
  - Two high P_T jets with large $\Delta\eta$ separation
  - Strong discovery potential for low Higgs mass
  - Can measure Higgs couplings
  - Good for invisible decays
- CMS & ATLAS looking in detail



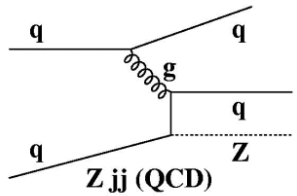
Low Mass Higgs via VBF (2)

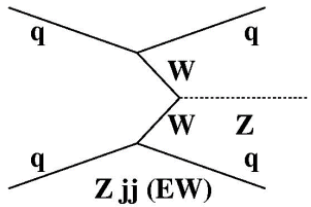
- H->WW*->llνν, lνqq. Strong for M_H>120 GeV
  - Main background:
    - tt and EW WWjj
    - W + 4 jets



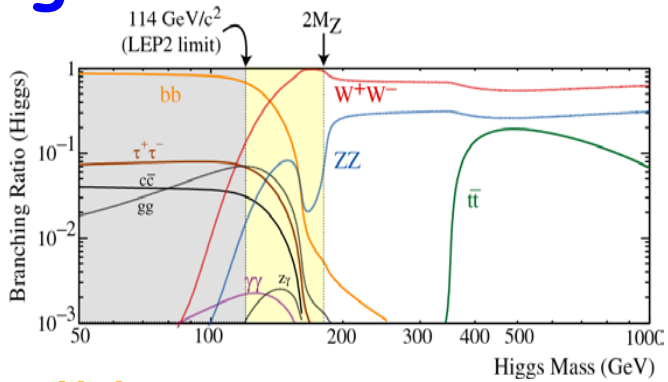


- H->ττ->ll, lh (+ptmiss). Good around LEP limit
  - Main background
    - QCD and EW Zjj

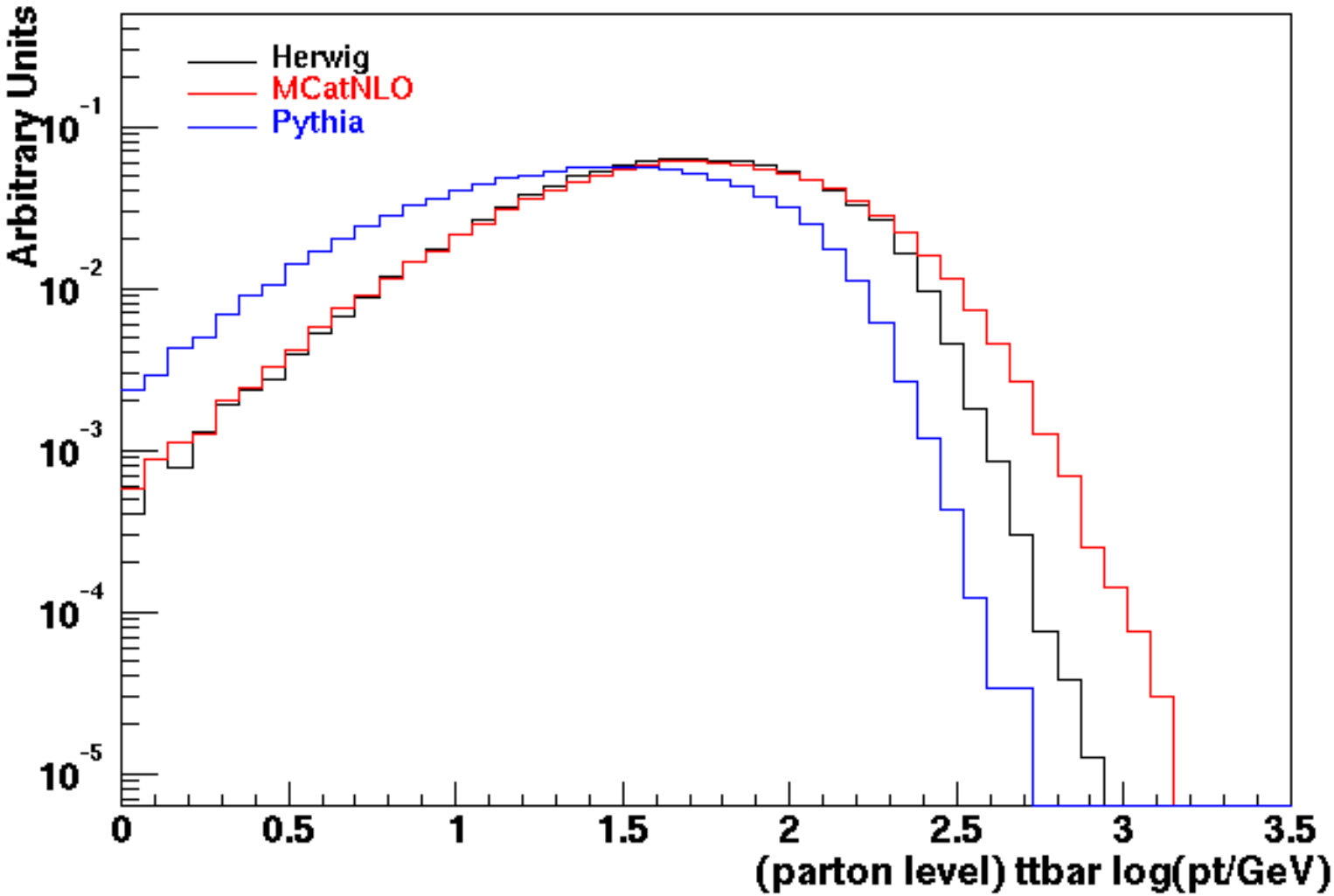




- H->bb. Useful for Yukawa coupling measurement
- H->γγ
  - Main background
    - real and fake non-resonant γγ

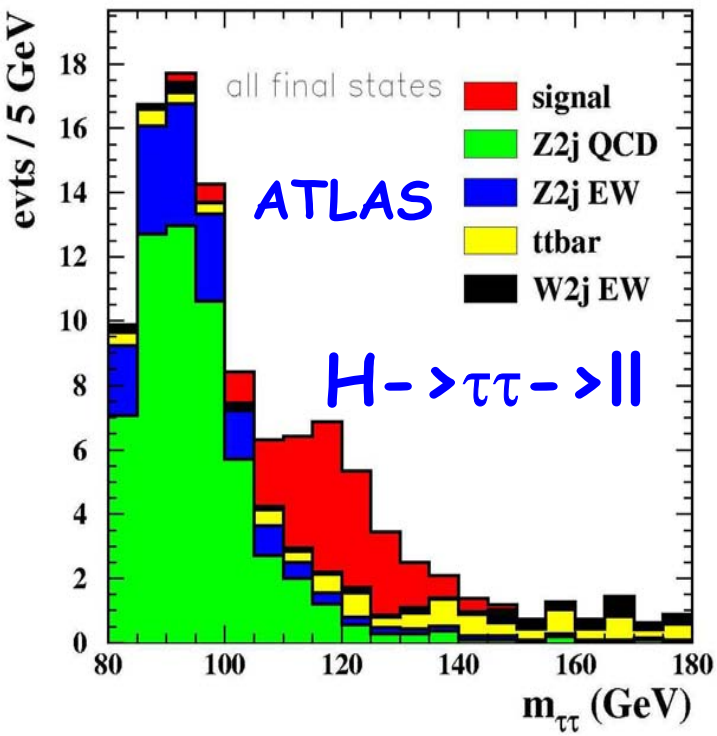


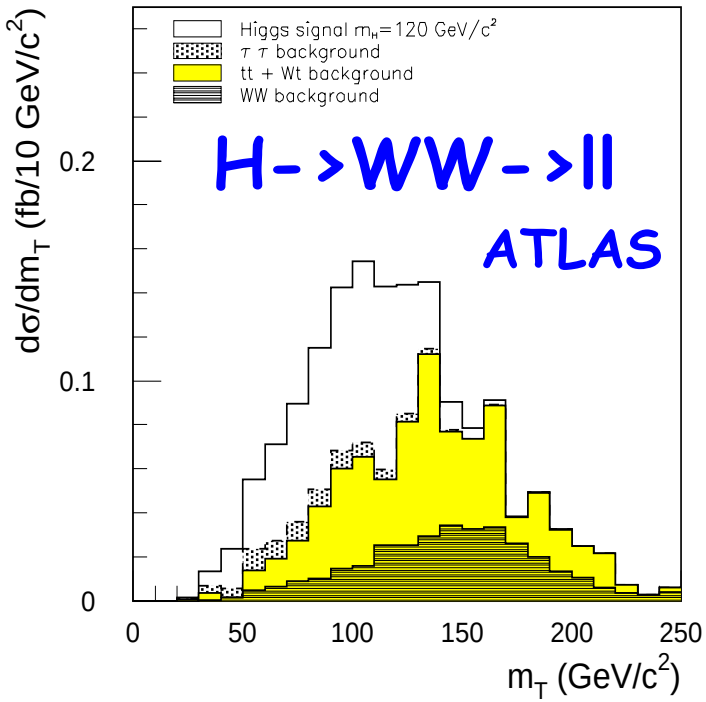
Strong differences between Pythia and Herwig with regards to tt production (see Talk of Paganis)



Low Mass Higgs via VBF (3)

- Main VBF discovery modes do not display narrow resonances
  - Knowledge of SM background <u>shapes</u> crucial

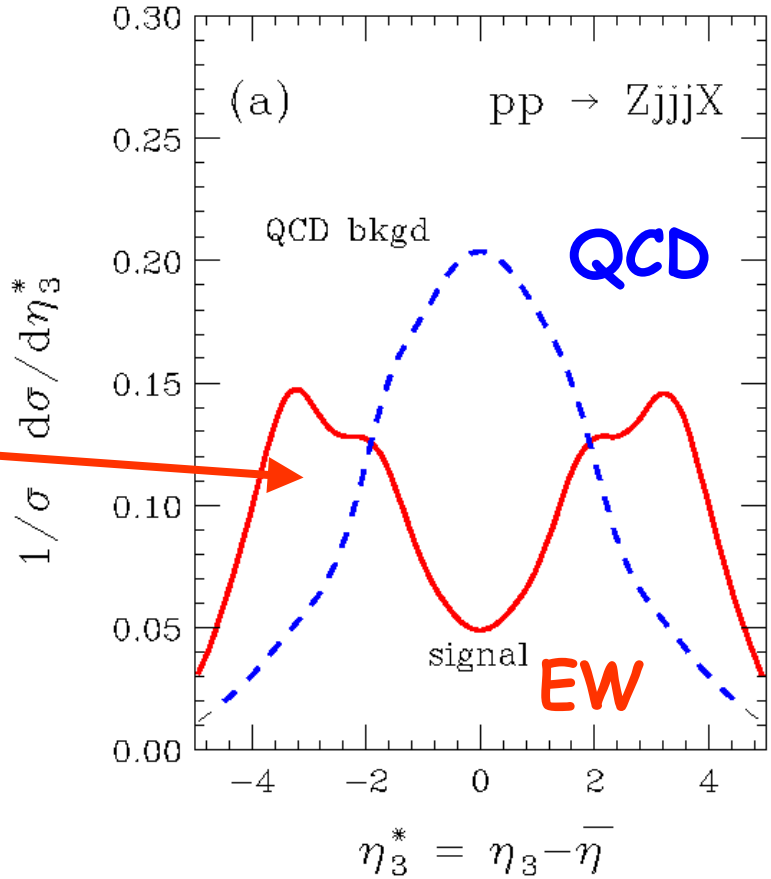




Central Jet Veto (1)

- VBF analysis is an exclusive search:
  - Two hard and well separated jets (tagging jets)
  - Veto on third jet in central region of the detector.
    - Need to distinguish between QCD and EW processes
- Need to implement higher order corrections
- A lot of MC development needed before turn on!

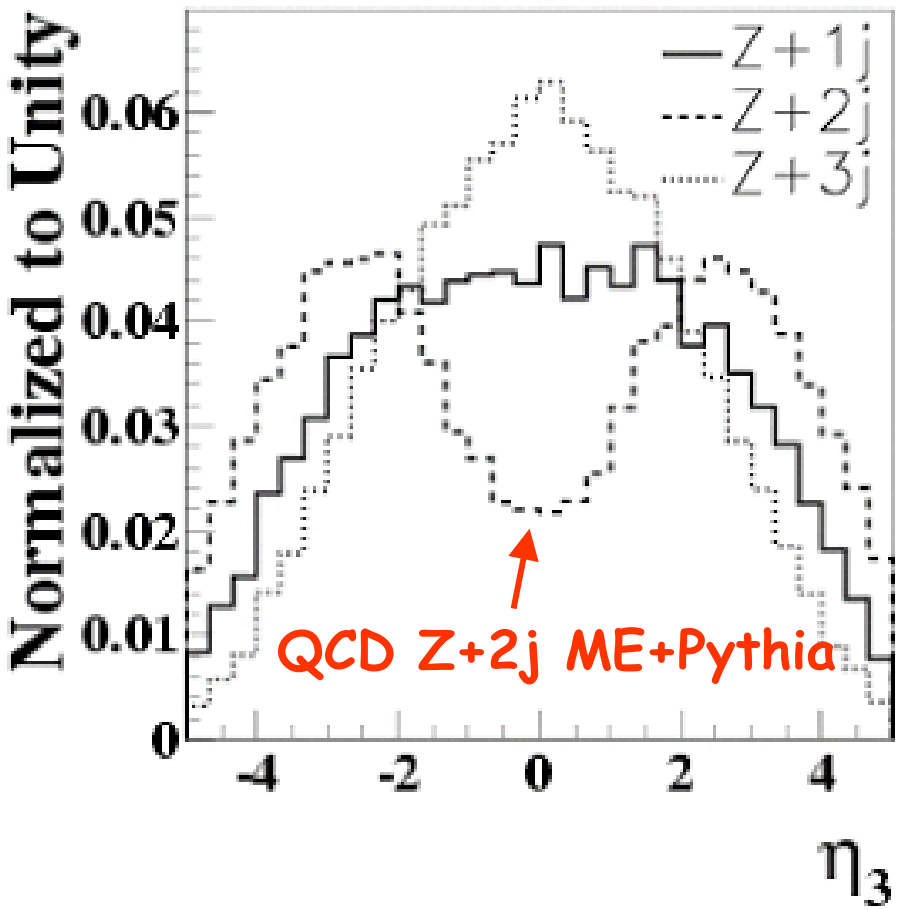
Zeppenfeld et al. PRD54 6680



Central Jet Veto (2)

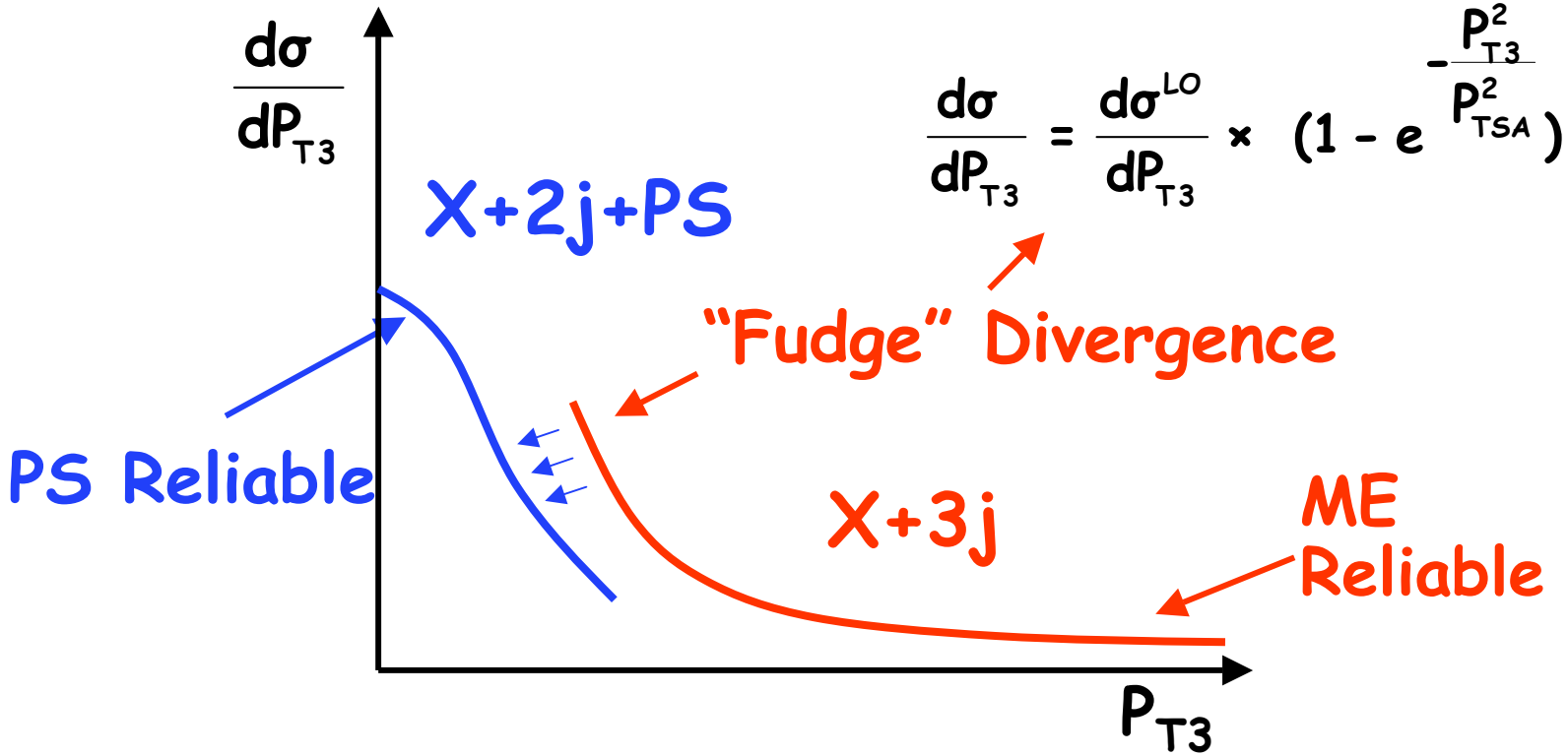
- Example: VBF H->ττ
  - Major background: Z+2j
  - Two hard and well-separated jets (tagging jets) modeled with Z+2j ME
  - Central jet veto (third jet)
    - Z+3j ME is divergent
    - With Z+2j ME + PYTHIA (PS) η_3 distribution displays unphysical depletion in central region
    - Need to find a solution!

η_3 after requiring two tagging jets



Central Jet Veto (3)

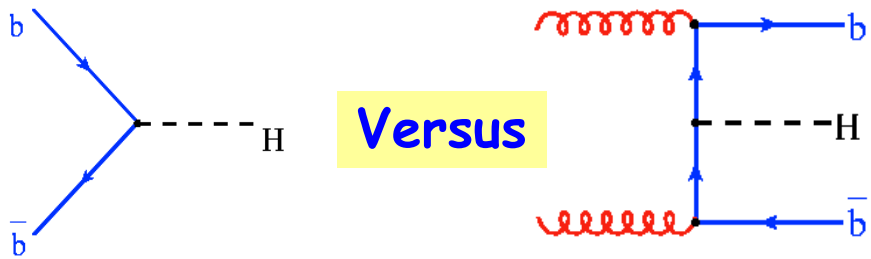
- **Procedure attempted in ATLAS**
  - Match X+2j and X+3j ME with respect to P_{T3}
    - Tedious: needs to be done by hand process by process
    - Need an automated procedure



Wish-List for VBF

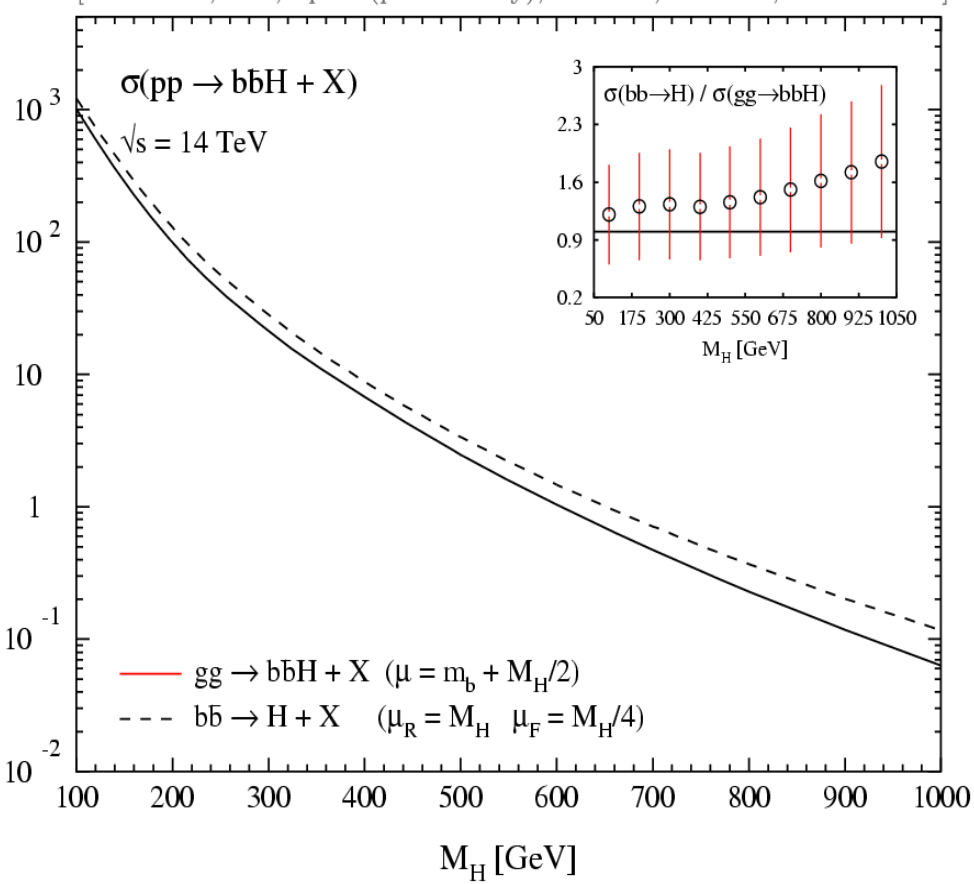
- VBF searches involve tagging and vetoing on jets
  - Parton level NLO MC's will not do the job
    - Forward tagging and central jet veto efficiencies are non trivial functions of a number of kinematic variables
  - Central jet veto is a CENTRAL and unresolved issue
    - Applies equally to signal and background processes
  - EW production of Z/W's deserve special attention
- VBF for heavier Higgs ($2M_Z < M_H < 1$ TeV) searches involves controlling W/Z+4jet production
  - Understanding the central jet veto here involves generating W/Z+5jet events!
  - Obviously, a job that can be done by LO ME + PS matching

MSSM h + b's (Two b or not Two b)



- **Experimentalists would like to see:**
  - Differences resolved
  - Higher order corrections applied in an <u>event generator</u>
    - *A parton level generator will not do the job!*
      - B-tagging efficiency, a complex function of kinematics

[Dittmaier, MK, Spira (preliminary); Maltoni, Sullivan, Willenbrock]

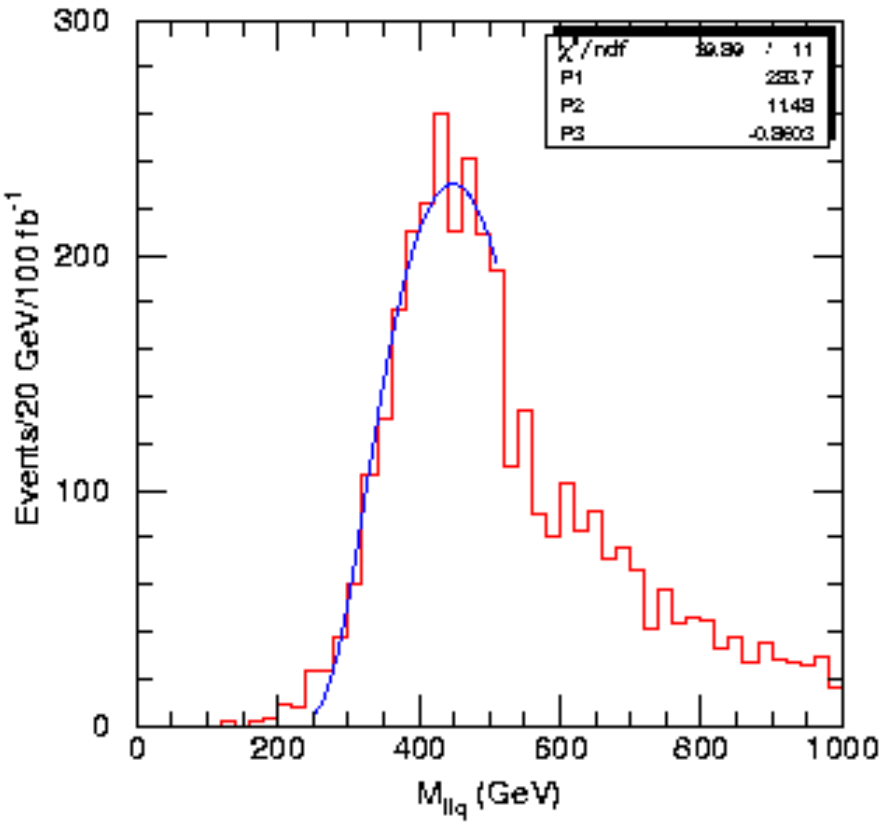


SUSY

- **Backgrounds:**
  - W/Z-tt-b's + jets, multiple jets
  - Parton shower approach predicts small contribution
  - Very important to see ME/PS matching for high multiplicity
    - Eager to see CKKW prescription working for pp
- **MC's with higher order corrections could be of great help indeed**
  - Mass determination uses threshold and end-point shapes. Hard gluon radiation distorts these distribution

Thanks to F.Paige and G.Polleselo

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q \rightarrow \tilde{\ell}^{\pm}\ell^{\mp} \rightarrow \tilde{\chi}_1^0 \ell^+ \ell^- q$$



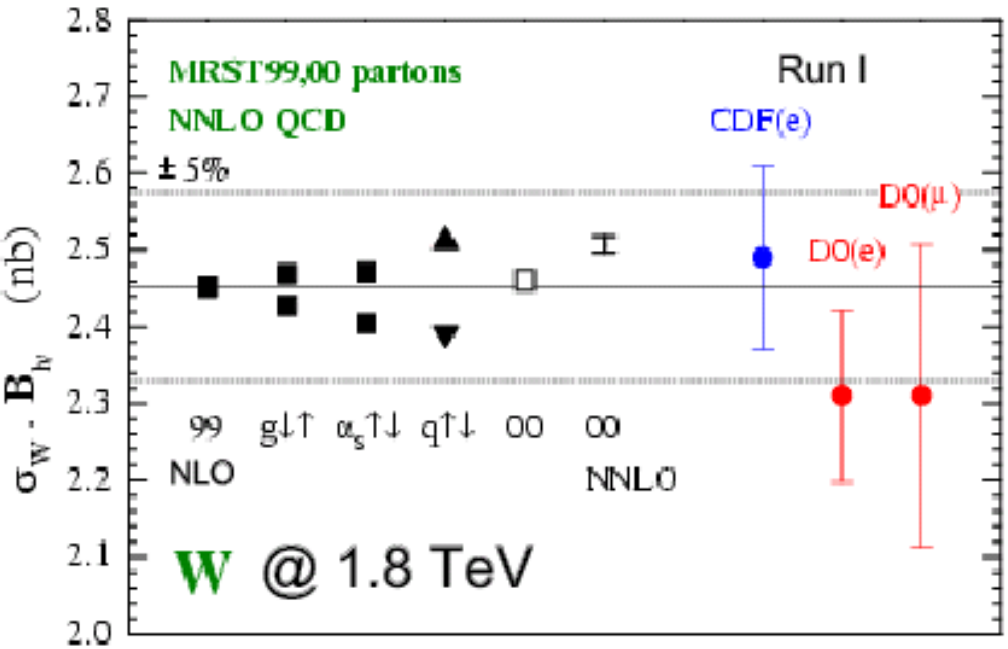
SM and BSM

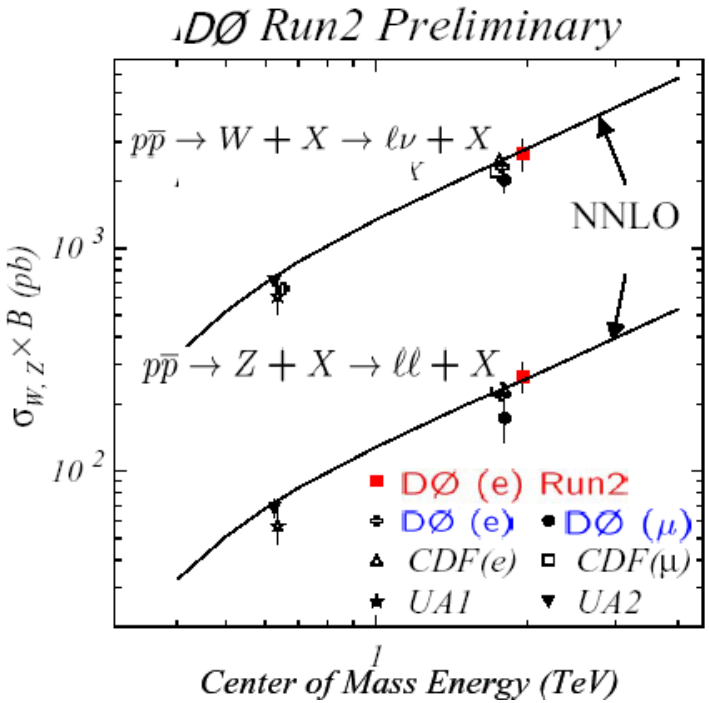
Thanks to G.Azuelos, M.Dobbs, L.Pogglioli, S.Tapproge

- Drell-Yan W,Z production plays a very important role at the LHC
  - Channels for precision measurements
  - Crucial for detector calibration: EM, jets, E_{Tmiss}
  - Luminosity monitoring (see next slide)
- A tool that incorporates EW and QCD corrections to (at least) NLO is mandatory
  - EW NLO corrections may shift W mass
    - Affects A_{FB} as well
  - $Z/\gamma^* \rightarrow l^+l^-$ major background to Z', narrow graviton resonances, extra dimensions…

Luminosity Monitor

- **Make use of large W/Z cross-section at LHC**
  - **Cross-sections measured at the Tevatron consistent with NNLO prediction. Expect few % of theoretical uncertainty**
  - **Certainly need N(N)LO event generator**





Discussion (1)

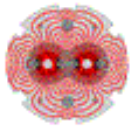
- Need to be aware of the limitations of re-weighting kinematic distributions produced by LO MC to match predictions by NLO ME
  - What is the theoretical uncertainty implied by this procedure?
  - Will correlations between relevant discriminating variables be properly taken into account?
- We are very happy to see NLO MC integrators like MCFM and NLO event generators like GRACE and MC@NLO adding new processes
  - How many processes will be described to NLO by turn on?
  - What will be the impact of NNLO corrections at the LHC?

Discussion (2)

- Looking at the problem from a different point of view: Matching of LO ME and PS
  - Probably little hope to get NLO corrections X+Njet when N>2 (or, in some cases, even N=1)
    - Need to understand central jet veto (VBF Higgs)
    - Need to simulate "jetty" events
  - Basic phase space slicing attempted in CMS (CompHep) and ATLAS:
    - Tedious: Need an automated procedure
  - Eager to see final results of Catani-Krauss-Kuhn-Webber (CKKW) prescription for p-p collisions

Conclusions

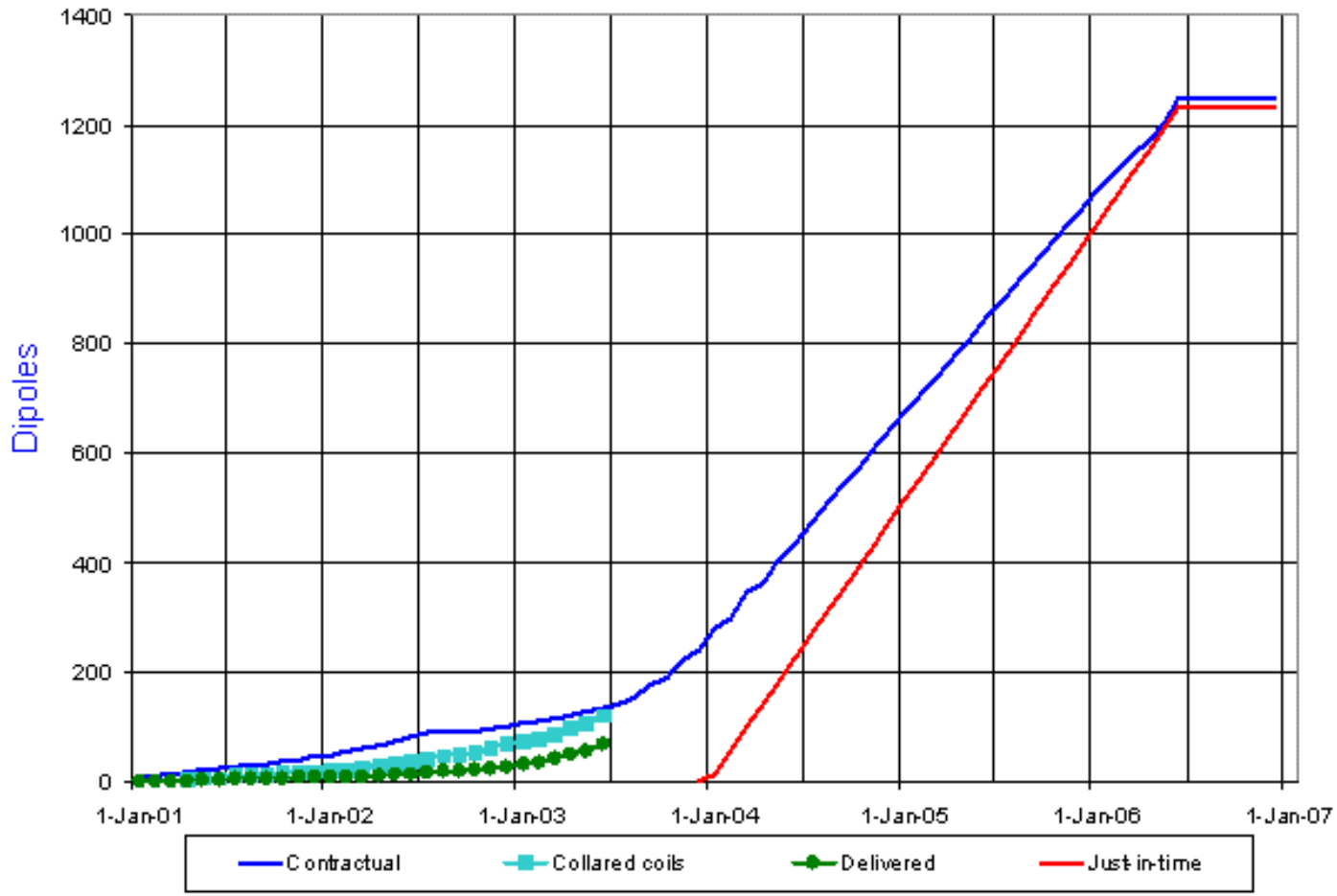
- Without NLO event generators power of inclusive Higgs searches is diminished
  - Need to implement P_T of Higgs in inclusive analyses
- Narrow resonances, not the only way to find Higgs
  - VBF very powerful discovery tool
    - But challenging: NLO description is MANDATORY
      - Need to understand central jet veto
- N(N)LO W/Z event generators is Mandatory
- Searches for new physics will profit from implementation of higher order corrections in MC's
- WE ARE RUNNING OUT OF TIME! ---->



LHC Progress Dashboard

Accelerator Technology Division

Dipole cold masses



Updated 30 Jun 2003

Data provided by P. Lienard AT-MAS