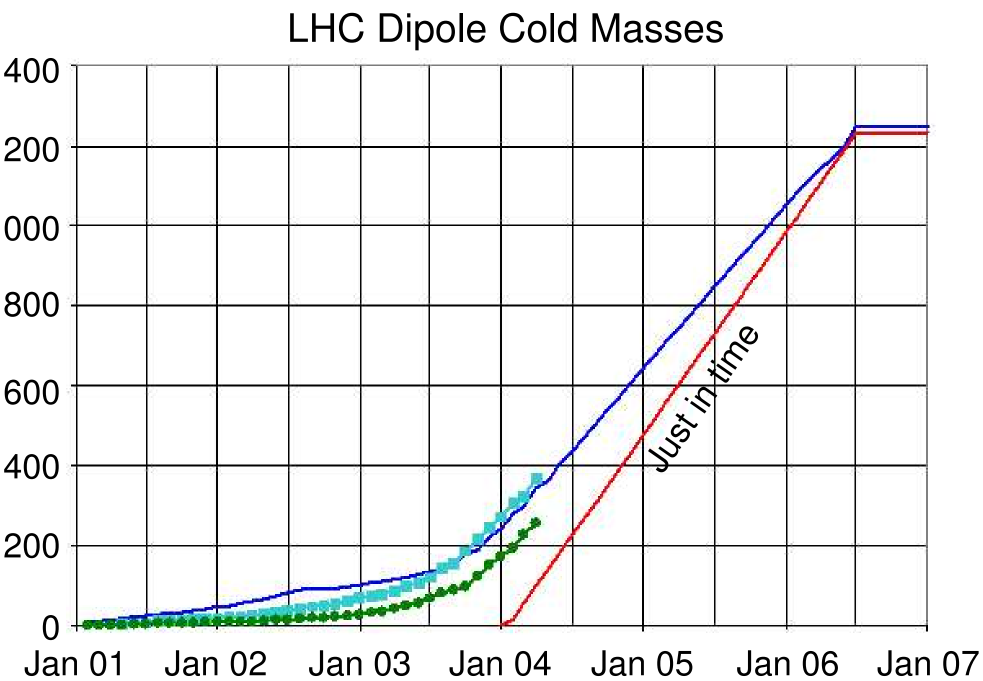
LHC Theory Activities

Frank E. Paige

LHC machine and detectors making good progress. Aymar is committed to 2007 schedule.

Now is right time to get involved in LHC physics.

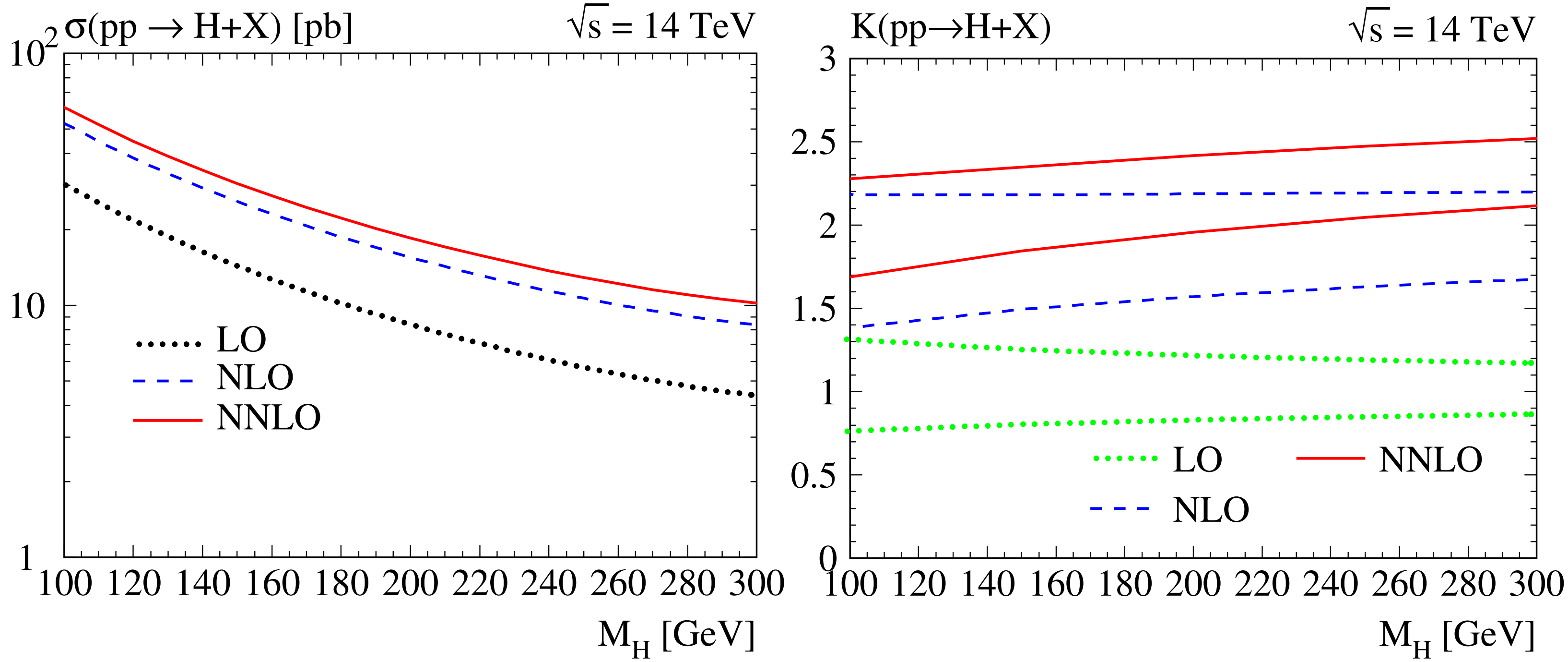


BNL Theory Group is active in NLO/NNLO Higgs physics and SUSY studies. Will briefly summarize recent highlights.

Higgs Physics at NLO and NNLO

Harlander and Kilgore [Kilgore1] computed $gg \to \phi X$ at NNLO for $m_t \to \infty$. First NNLO for hadronic process other than Drell-Yan.

Much smaller correction and better scale dependence:



Higgs cross section at NNLO is under control.

Same authors calculated [Kilgore2] Higgs production via $b\bar{b} \to \phi X$ at NNLO. Goals:

- Calculate H and A production in SUSY for $\tan\beta \gg 1$;
- Understand relation between $b\bar{b} \to \phi X$ and $gg \to b\bar{b}\phi X$.

Inclusive $gg \to \phi X$ cross section has general form

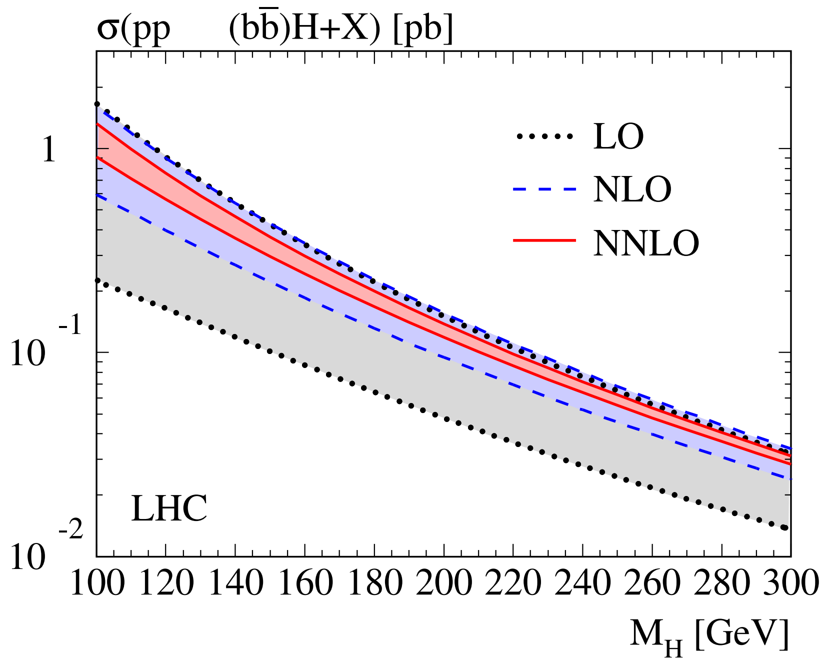
$$\sigma = \sum_n \alpha_s^n \ln^n \frac{m_\phi}{m_b} \left\{ \alpha_s^2 \left[c_{n0} \ln^2 \frac{m_\phi}{m_b} + c_{n1} \ln \frac{m_\phi}{m_b} + c_{n2} \right] + O(\alpha_s^3) \right\}$$

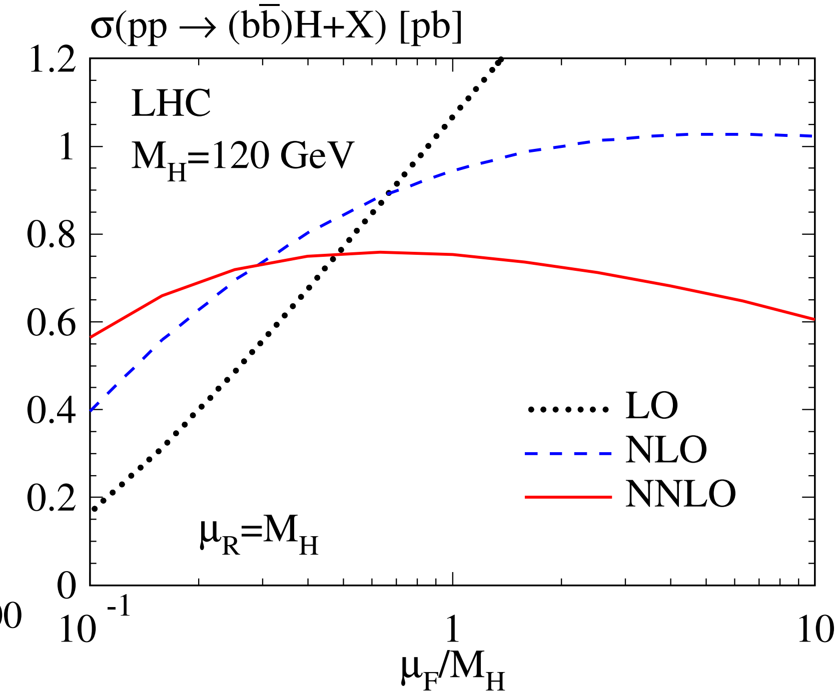
Need NNLO $b\bar{b} \to \phi X$ to include $gg \to b\bar{b}\phi$ in consistent way. Only then have full leading-log series.

(Very) general outline of calculation:

- Two-loop integrals reduced to single master integral.
- One-loop integrals plus phase space done analytically.
- Double emission phase space uses threshold expansion.

Again improved error band and scale dependence:



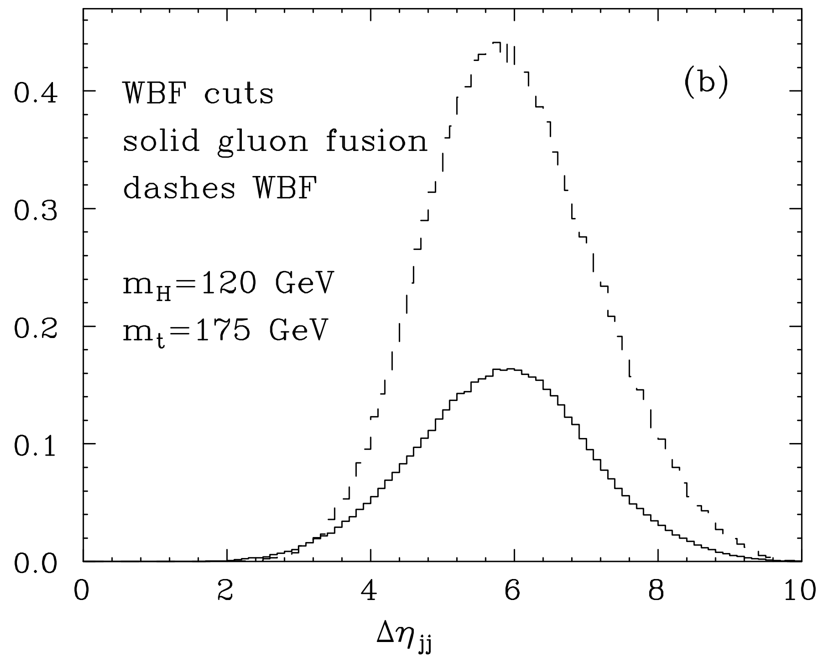


Confirm at NNLO that $\mu_F \approx M_H/4$, $\mu_R = M_H$ is good choice.

Cross section uncertainty reduced to about 15%.

Part of NNLO calculation, $\phi + 2$jets, is irreducible LO background to $qq \to \phi qq$ via WW fusion.

Want to separate these to measure Higgs couplings. Background is small after cuts but not negligible.

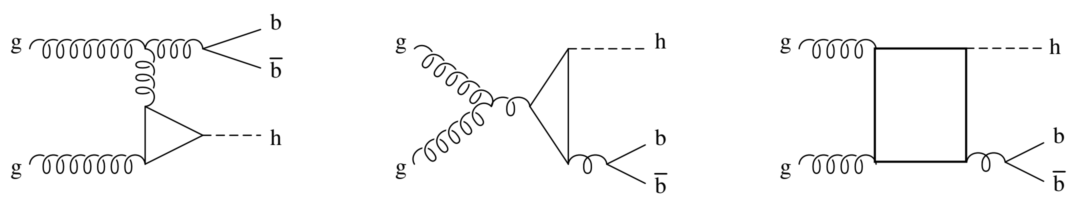


Would like NLO background calculation, but LO $gg \to \phi jj$ involves massive pentagons.

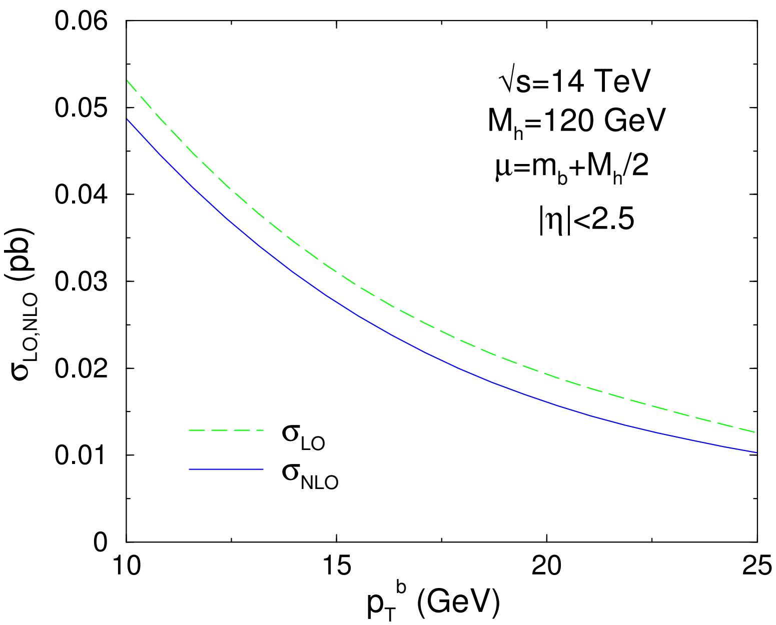
Result well described in relevant region by high energy limit with Reggeized gluon exchange [Kilgore3]. NLO with $m_t \to \infty$ might be possible. Needs study.

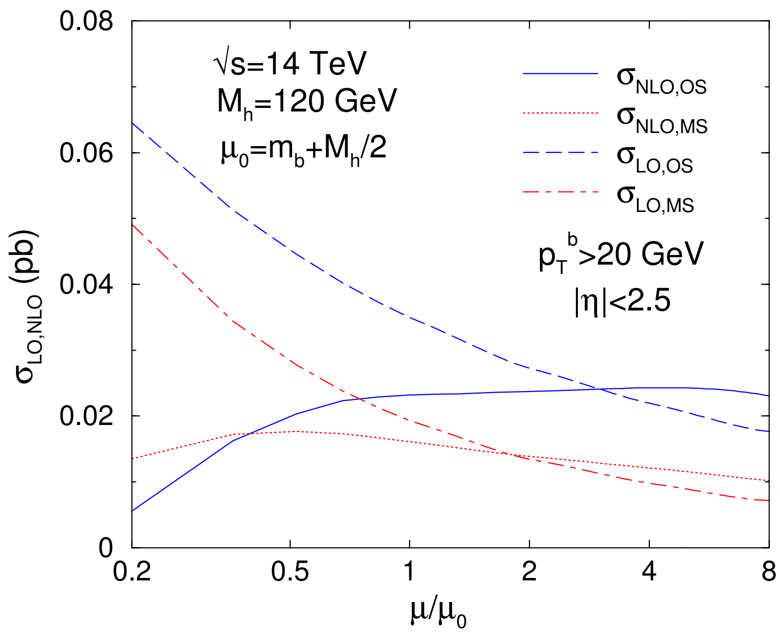
Less inclusive process $pp \to \phi \overset{(-)}{b} X$ is closely related to $b\bar{b} \to \phi X$ inclusive cross section. Must tag b jet $\Rightarrow$ need p_T cut.

Computed to NLO with masses [Dawson1]. Typical NLO graphs:



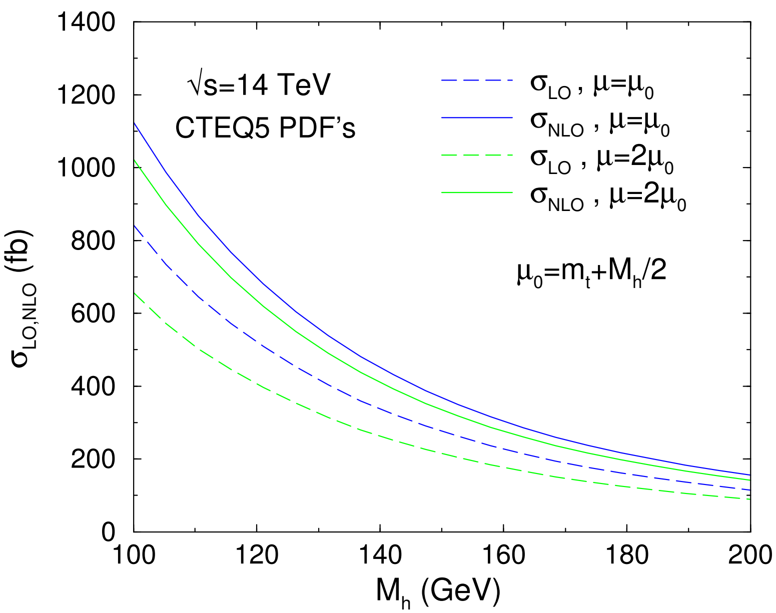
Resulting cross section and scale dependence:

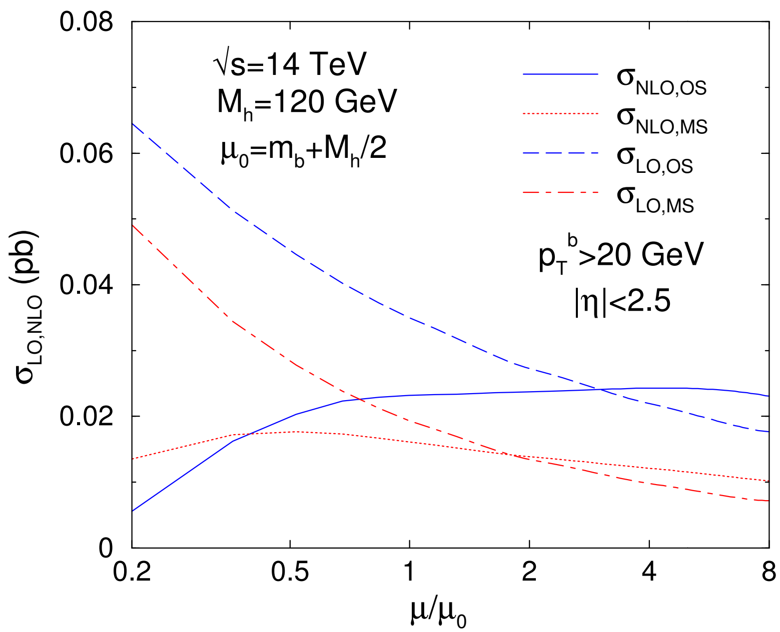




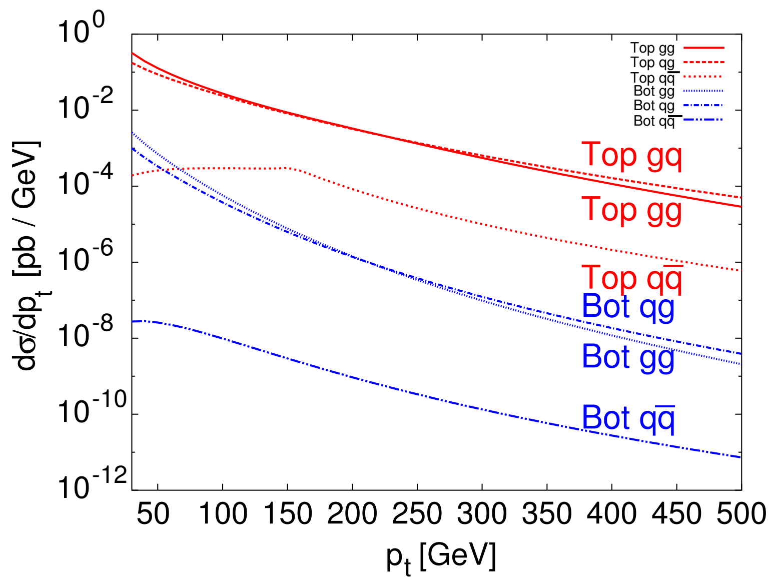
Rate for $\phi \overset{(-)}{b} X$ with b tag measures $\phi b\bar{b}$ coupling, while inclusive ϕ rate includes contribution from $\phi t\bar{t}$ coupling.

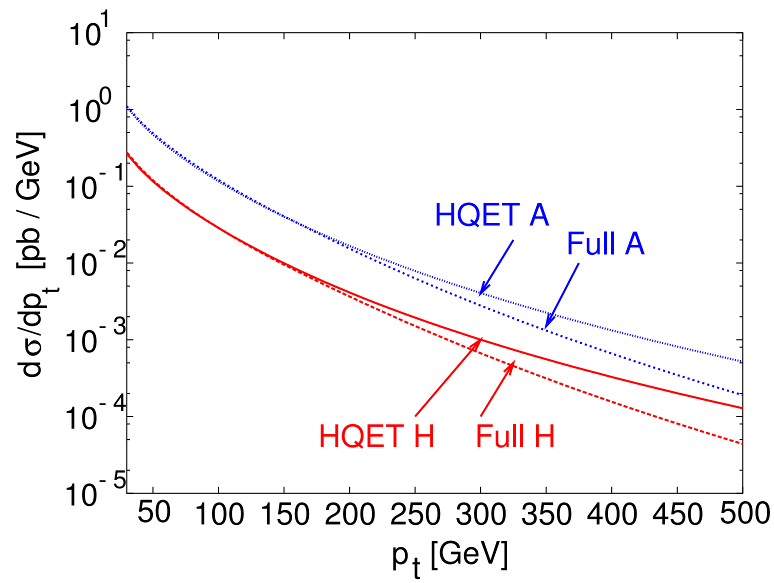
Associated $\phi t\bar{t}$ rate measures $\phi t\bar{t}$ coupling more directly. Calculated to NLO including masses [Dawson2]. Again smaller errors from reduced scale dependence:





Cross section for $\phi + $jet calculated by Bryan Field (Stony Brook student) including m_t and m_b dependence.

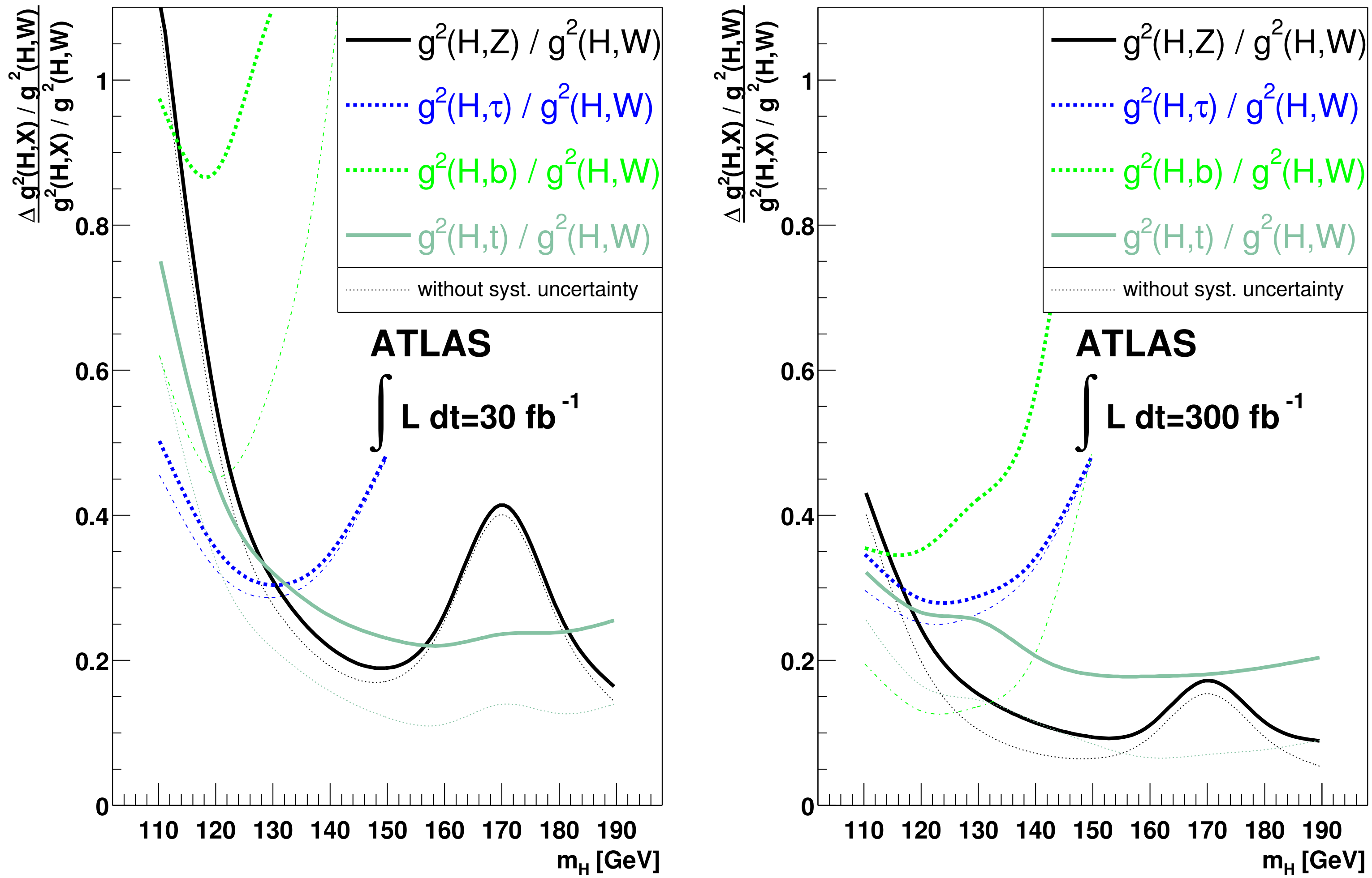




Need $p_{T,\phi} \gtrsim M_\phi$ for $\phi \to \tau^+\tau^-$ reconstruction. Also may be relevant for WW fusion.

Light Higgs is narrow, so discovery requires observing peak on smooth background. But extracting couplings needs accurate cross sections.

Estimated LHC errors based on LO Monte Carlo [Duhrssen] determine several couplings to 5–20%. Would show signal is Higgs-like provided cross sections are known with sufficient precision:



Supersymmetry

Long-standing involvements in calculation of masses and decays and simulation of events for SUSY [Isajet].

If R-parity conserved, lightest SUSY particle (LSP) $\tilde{\chi}_1^0$ is neutral and weakly interacting:

- Distinctive signatures, so discovery is "easy".
- But no mass peaks: must infer masses from kinematic distributions.

Mostly based on event generation + fast detector simulation.

In October 2002 began study using ATLAS GEANT-3 simulation and Athena reconstruction. Minimal SUGRA parameters:

$$m_0 = 100\,\mathrm{GeV},\ m_{1/2} = 300\,\mathrm{GeV},\ A_0 = -300\,\mathrm{GeV},\ \tan\beta = 10,\ \mathrm{sgn}\,\mu = +$$

Similar to "Point 5" of ATLAS TDR [TDR] but $M_h \approx 115\,\mathrm{GeV}$. Resulting ATLAS note recently completed [Fullsusy].

Produced 100k events (about $5\,\mathrm{fb}^{-1}$). Significant effort:

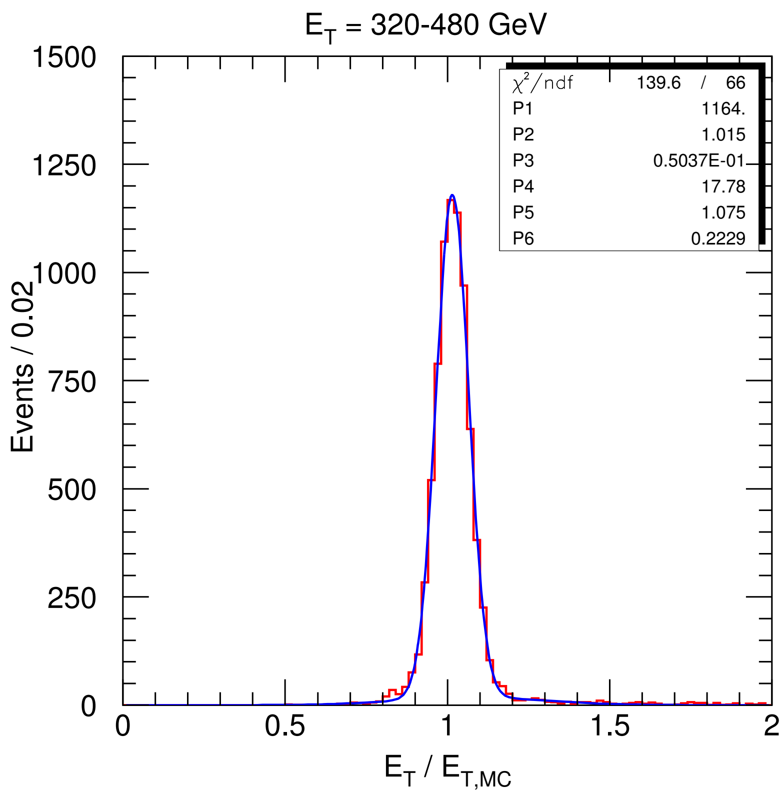
- Simulation takes $\sim 15\,\mathrm{min/event}$.
- Reconstruction takes $\sim 1\,\mathrm{min/event}$; done many times.

SUSY signals involve jets, e, μ, τ, $\not\!\!E_T$, b-tagging, so good test.

Calorimeter calibrated at EM scale. Wrong for jets since $e/h > 1$.

Developed H1-style jet calibration in Athena for SUSY study. Weights also used for $\not\!\!E_T$.

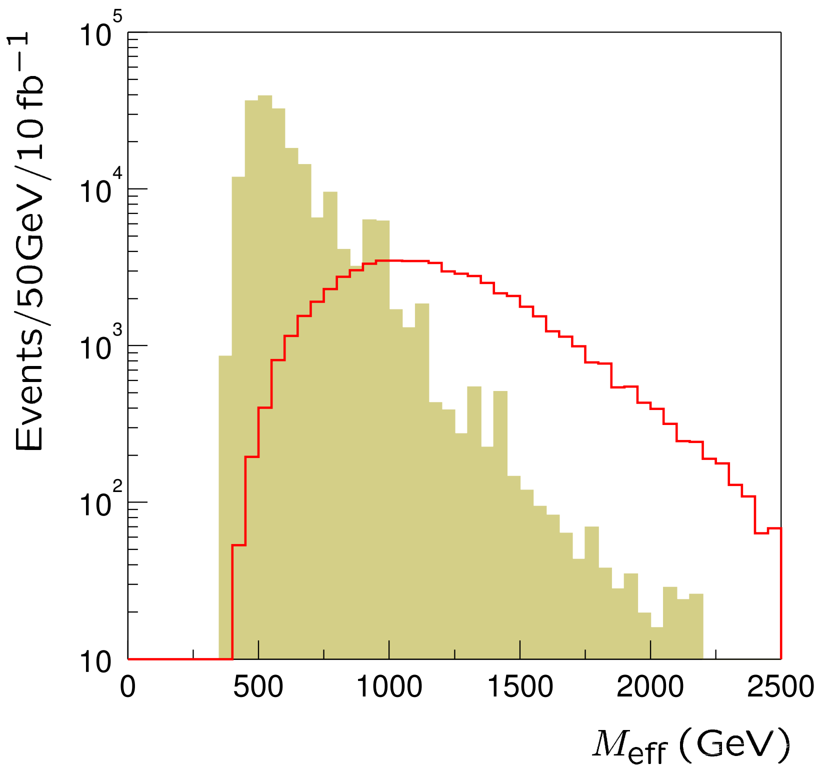
K_T algorithm sensitive to noise. Implemented simple local noise cancellation.



Require $\not\!\!E_T > 100\,\text{GeV}$ and ≥ 4 jets with $E_T > 100, 50, 50, 50\,\text{GeV}$. Then plot

$$M_{\text{eff}} = \not\!\!E_T + \sum_j E_{T,j}$$

Gives clean SUSY sample with $S/B \sim 10$ for large M_{eff}.

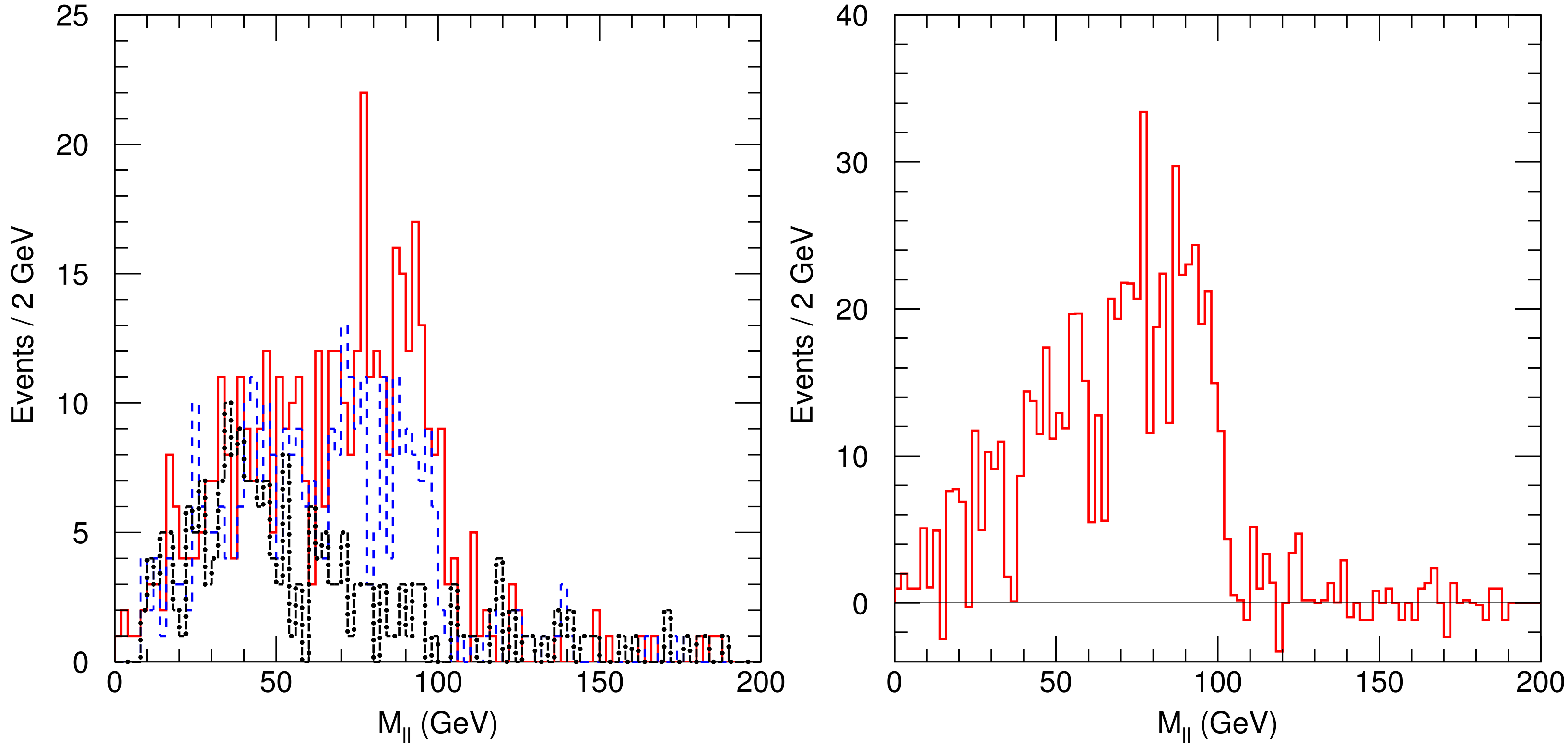


Cannot generate Standard Model background with full simulation.

Reasonable approximation to ignore Standard Model background after these cuts for $M_{\text{eff}} > 800\,\text{GeV}$.

Background in leptonic samples is even smaller.

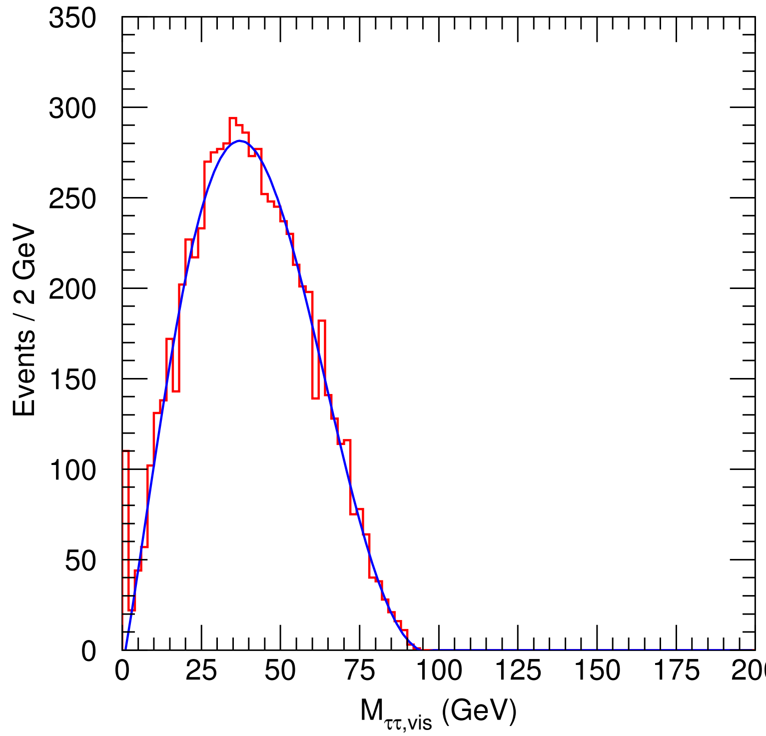
For this point $B(\tilde{\chi}_2^0 \to \tilde{\ell}^\pm \ell^\mp) = 2 \times 8.8\%$. Reconstructed $\mu^+\mu^-$, e^+e^-, $e^\pm\mu^\mp$ after cuts and weighted $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$ mass distribution:

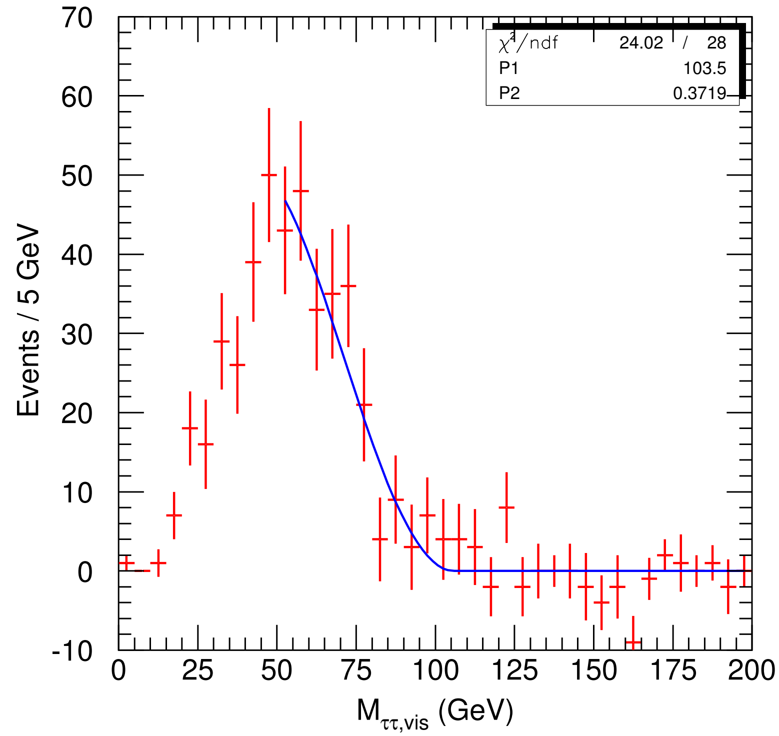


Calculated endpoint from $\tilde{\chi}_2^0 \to \tilde{\ell}_R^\pm \ell^\mp \to \tilde{\chi}_1^0 \ell^+\ell^-$ is

$$\sqrt{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\ell}_R}^2)(M_{\tilde{\ell}_R}^2 - M_{\tilde{\chi}_1^0}^2)/M_{\tilde{\ell}_R}^2} = 100.31\,\mathrm{GeV}$$

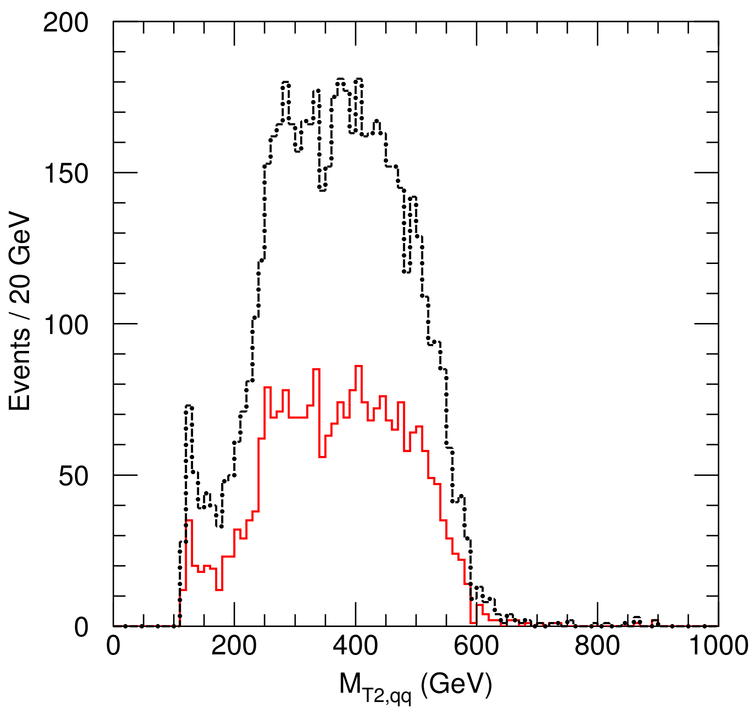
$B(\tilde{\chi}_2^0 \to \tilde{\tau}_1^{\pm}\tau^{\mp}) = 75.4\%$, but τ's are hard. Use $\tau^{\pm}\tau^{\mp} - \tau^{\pm}\tau^{\pm}$ to reduce background from misidentified jets. Fit visible $\tau\tau$ mass to shape derived from Monte Carlo $\tilde{\chi}_2^0$ decays:

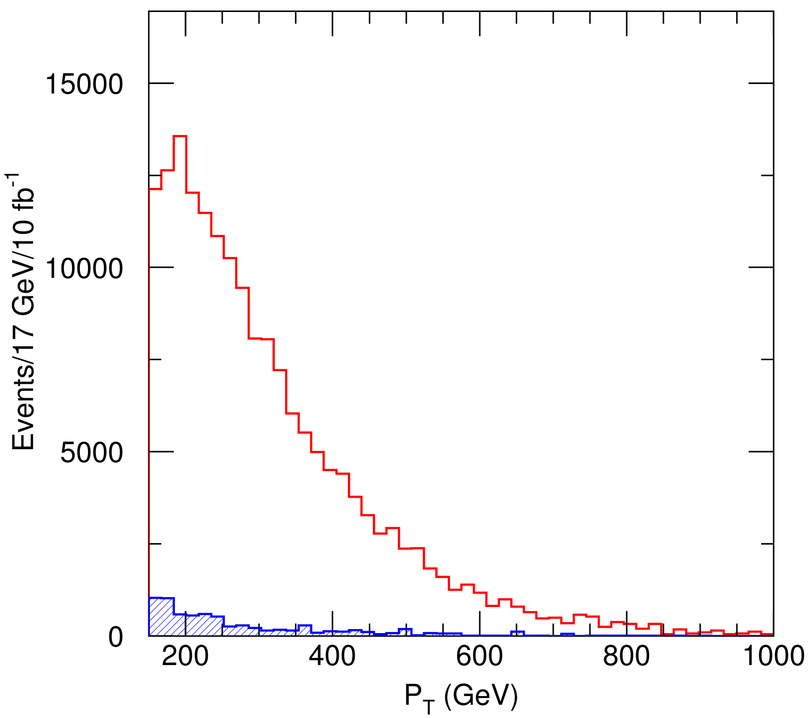




Fit gives $103.5 \pm 4.9\,\mathrm{GeV}$, consistent with expected $98.3\,\mathrm{GeV}$.

$\tilde{q}_R\tilde{q}_R \to \tilde{\chi}_1^0 q \tilde{\chi}_1^0 q$ gives 2 jets + $\not{E}_T$. Veto jets with $E_T > 25(50)$ GeV and plot M_{T2} using correct $M_{\tilde{\chi}_1^0}$. True endpoint is 611 GeV. Compare with single jet distribution for Point 6 [TDR]:





Much better result from full simulation using M_{T2} than from fast simulation using p_T(!).

Summary

BNL theory group active both in higher order QCD calculations and in SUSY phenomenology for LHC.

Former BNL postdocs (Robert Harlander, Laura Reina) and students (Bryan Field) have played essential role in QCD work.

BNL will be Tier I center for ATLAS computing, so a natural center for LHC analysis. Important to expand effort — especially postdocs — to complement this.

And we all look forward to real LHC data.

References

[Kilgore1] R. Harlander, W.B. Kilgore, Phys. Rev. Lett. 88, 201801 (2002).

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[Kilgore3] V. Del Duca, et al., hep-ph/0301013 (2003).

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[Duhrssen] M. Duhrssen, ATL-PHYS-2003-030 (2003).

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[Fullsusy] M. Biglietti, et al., ATL-PHYS-2004-100 (2004).