SM HIGGS PHYSICS:
RECENT DEVELOPMENTS

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SM@LHC 2014

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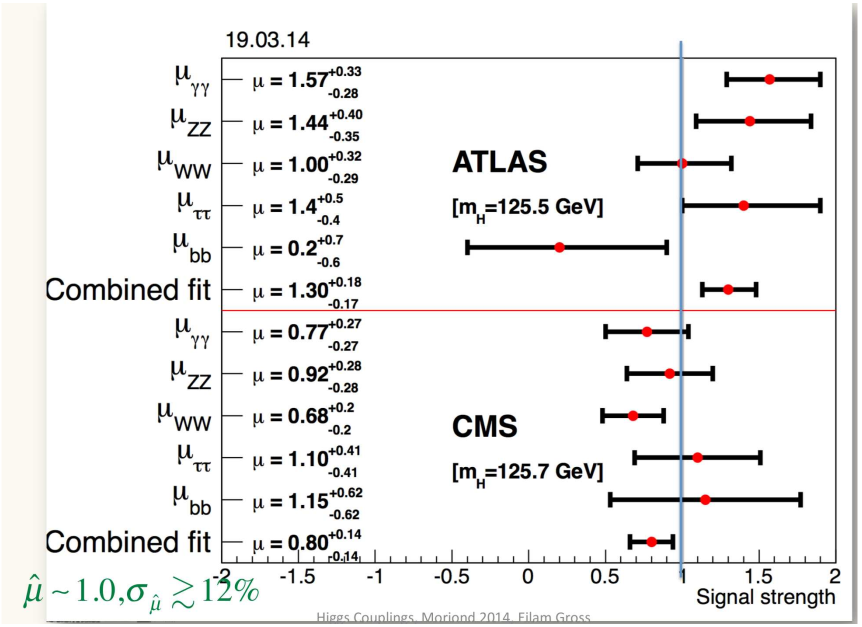
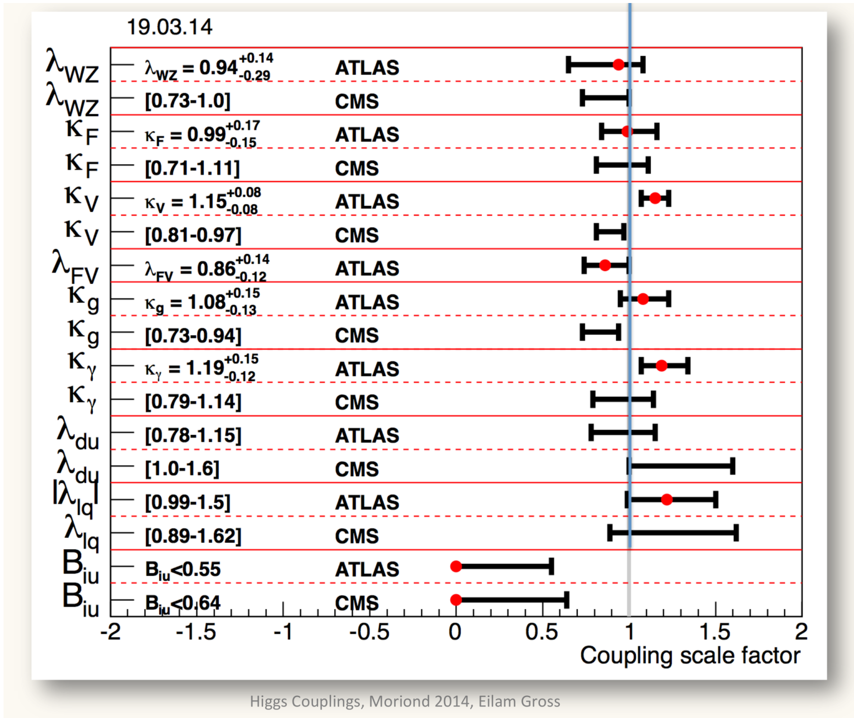
SM(?) HIGGS PHYSICS:
PRECISION PHYSICS(?)

FROM SIGNAL STRENGTHS



$\hat{\mu} \sim 1.0, \sigma_{\hat{\mu}} \gtrsim 12\%$

TO COUPLINGS



(E. Gross, Moriond 2014)

SM(?) HIGGS PHYSICS: PRECISION PHYSICS(?)

- PRECISION:
  - HIGHER ORDERS
  - PDFS (AND α_s)
  - THEORETICAL UNCERTAINTIES
- PRECISION?:
  - $t\bar{t}H$
  - SINGLE TOP
  - COUPLING TO CHARM (AND BOTTOM)
- PRECISION!:
  - RESUMMATION: JET VETOS
  - MULTISCALE: QUARK MASS DEPENDENCE
  - FINAL STATES: MATCHING TO MC

PRECISION

HIGHER-ORDER CALCULATIONS

"2013 WILL BE REMEMBERED AS THE YEAR OF $2 \to 2$ AT NNLO" (L. Dixon)

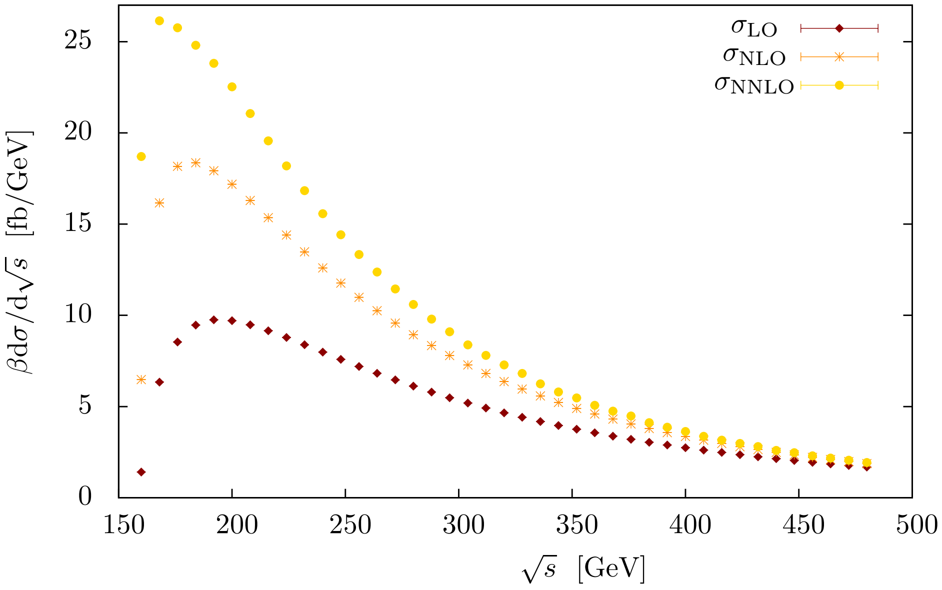
HIGHER-ORDER CALCULATIONS

"2013 WILL BE REMEMBERED AS THE YEAR OF $2 \to 2$ AT NNLO" (L. Dixon)

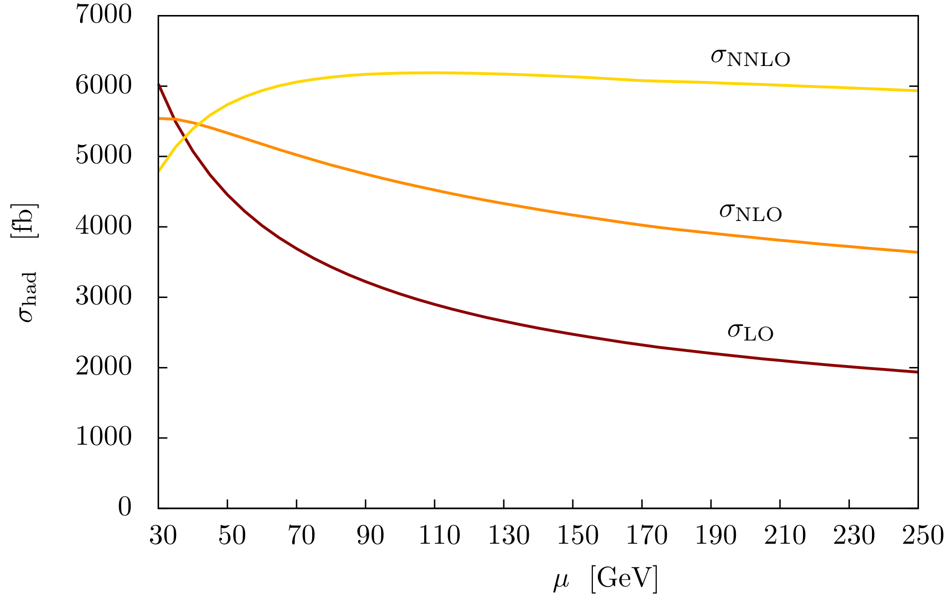
THE HIGGS+JET CROSS-SECTION IN THE GG CHANNEL

- k_t JET ALGORITHM, $R = 0.5$, $p_T > 30$ GEV
- GG CHANNEL DOMINANT, 70%
- SIGNIFICANTLY REDUCED SCALE DEPENDENCE $\sim 4\%$
- LARGE K FACTORS: $\sigma_{rmNLO}/\sigma_{\rm LO} \sim 1.6$, $\sigma_{\rm NNLO}/\sigma_{\rm NLO} \sim 1.3$

DIFF. WR TO PARTONIC CM ENERGY



SCALE DEP. OF TOTAL

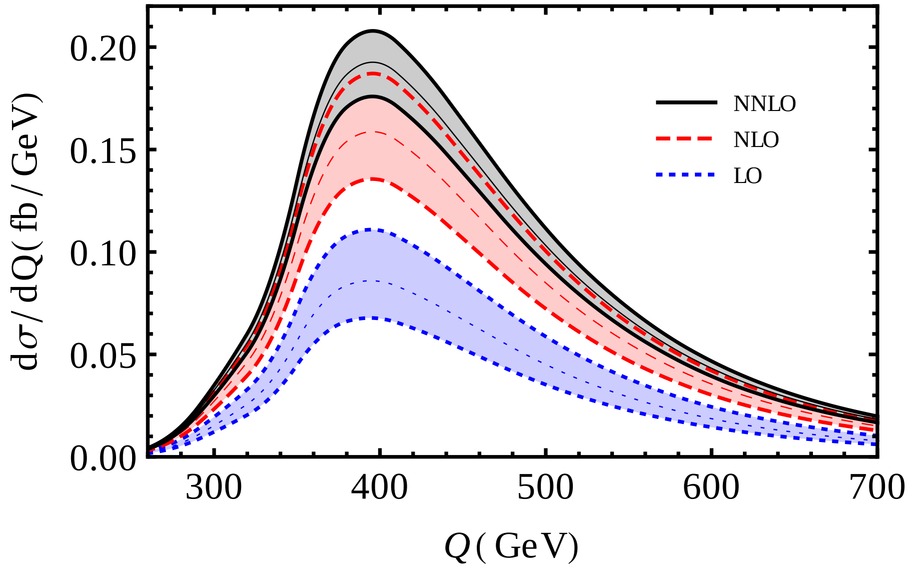


(Boughezal, Caola, Melnikov, Petriello, Schulze, 2013)

DOUBLE HIGGS PRODUCTION

- IMPORTANT FOR TRIPLE HIGGS COUPLING
- NNLO COMPUTED IN THE POINTLIKE LIMIT
- SIZABLE K FACTORS: $\sigma_{\rm NLO}/\sigma_{\rm LO} \sim 1.9$, $\sigma_{\rm NNLO}/\sigma_{\rm NLO} \sim 1.2$ FOR TOTAL XSECT

DIFF. WR TO MASS OF H PAIR



(de Florian, Mazzitelli, 2013)

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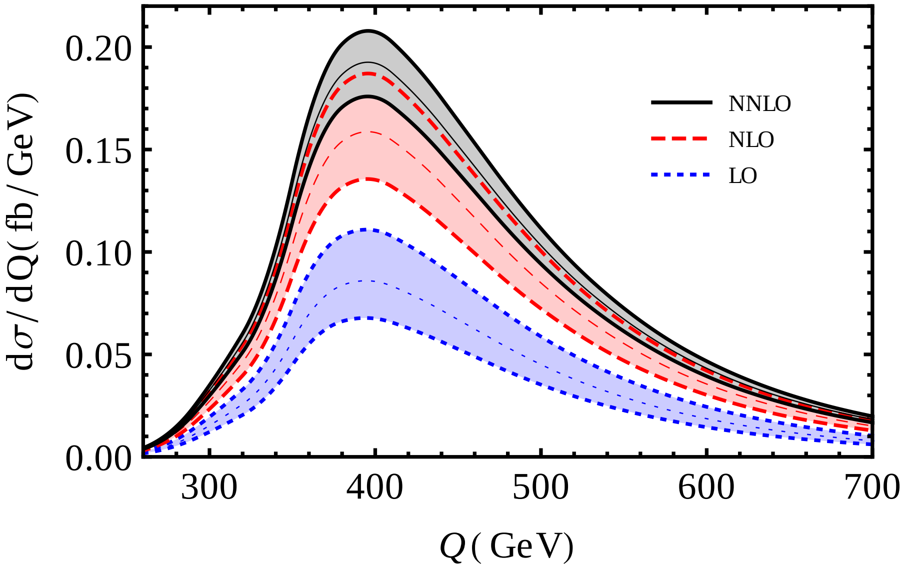
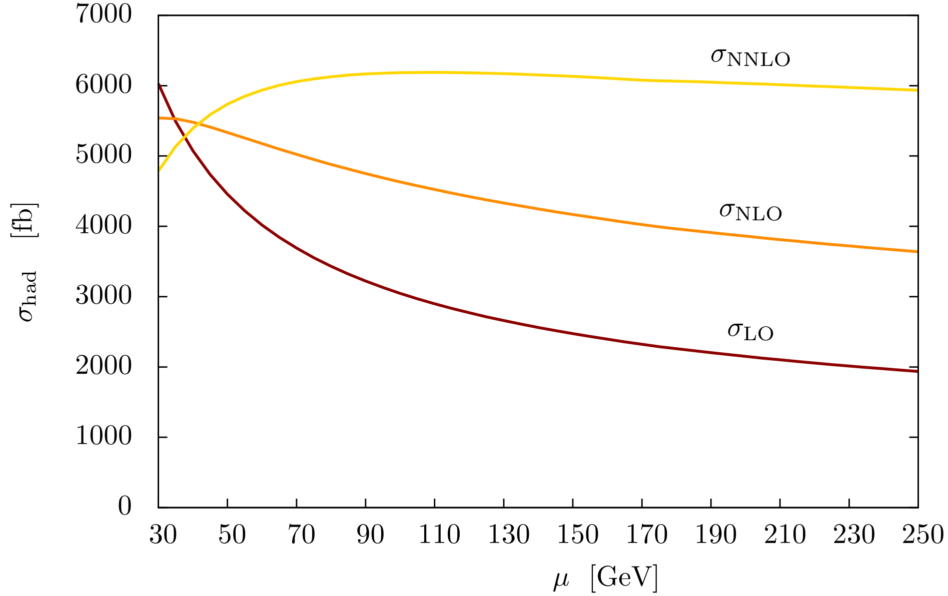
- SIZABLE K FACTORS: $\sigma_{\rm NLO}/\sigma_{\rm LO} \sim 1.9$, $\sigma_{\rm NNLO}/\sigma_{\rm NLO} \sim 1.2$ FOR TOTAL XSECT
- NLO DEPENDENCE ON m_t ALSO KNOWN AS EXPANSION IN $\frac{m_h^2}{m_t^2}$ SIZABLE FOR LARGE INVARIANT MASS

DIFF. WR TO MASS OF H PAIR



(de Florian, Mazzitelli, 2013)

m_t DEP OF NLO/LO TOTAL UP TO $\sqrt{s_{cut}}$

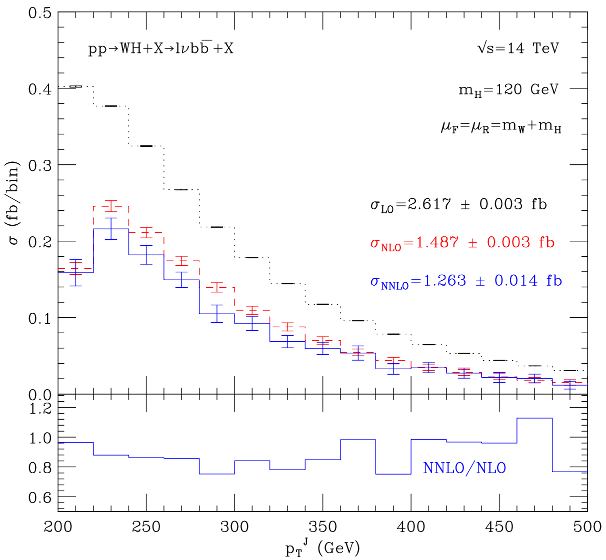


(Grigo, Hoff, Melnikov, Steinhauser, 2013)

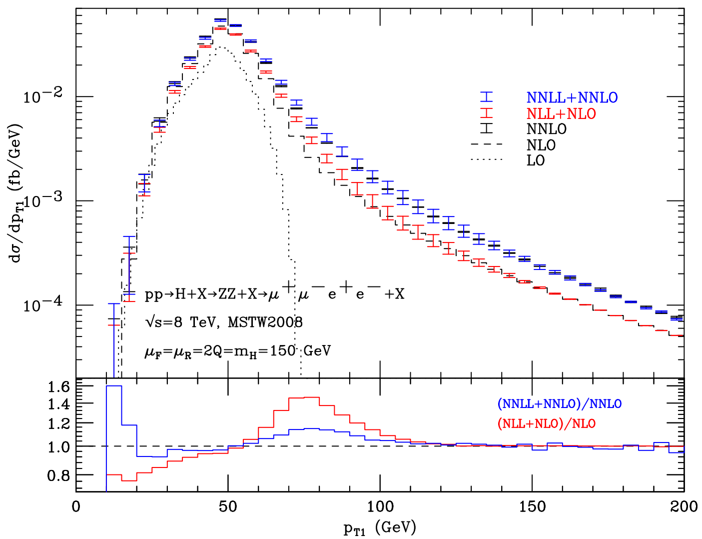
RESUMMATION

- FULLY EXCLUSIVE NNLO COMPUTATIONS GRADUALLY EXTENDED TO MANY SM AND MSSM PROCESSES (DRELL-YAN, DIPHOTON,. . .)
- AVAILABLE FOR $pp \to WH + X \to \ell \to \bar{b}b + X$
  (Ferrera, Grazzini, Tramontano, 2011)
- NNLO+NLL RESUMMED (THRESHOLD+p_T) RESULTS AVAILABLE FOR $H \to \gamma\gamma$, $H \to WW \to \ell\nu\ell\nu$, $H \to ZZ \to 4\ell$
  $\Rightarrow$ CAN STUDY FULL p_T SPECTRUM
  (de Florian, Ferrera, Grazzini, Tommasini, 2012)

$H \to WH$ @ NNNLO:
SPECTRUM OF FAT JET



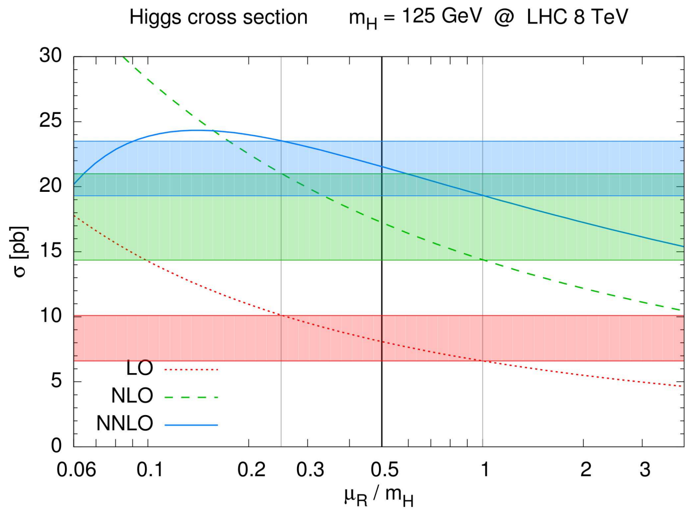
$H \to ZZ + X$:
SPECTRUM OF HARDEST LEPTON



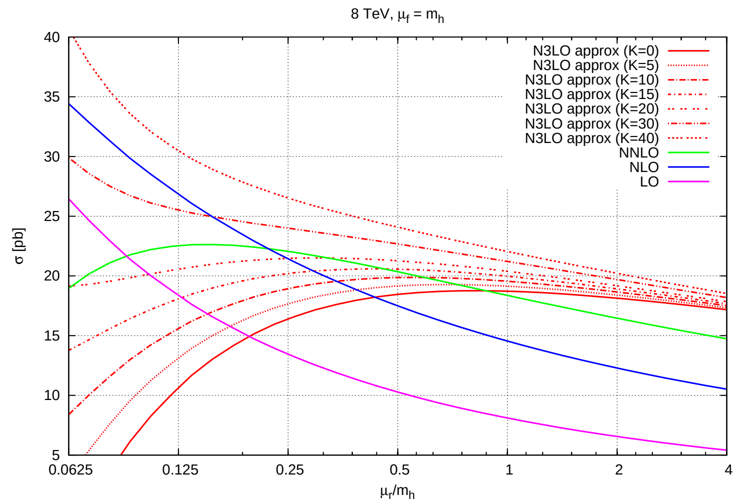
BEYOND NNLO

GLUON FUSION

RENORMALIZATION SCALE DEP.



APPROXIMATE $\mathrm{N^3LO}$ SCALE DEP.



- THE PERTURBATIVE SERIES FOR $gg \to H$ CONVERGES SLOWLY
- SCALE VARIATION UNDERESTIMATES NEXT ORDER (FACTORIZATION SCALE DEPENDENCE NEGLIGIBLE; ONLY RENORMALIZATION SCALE DEPENDENCE SIGNIFICANT)
- $\mathrm{N^3LO}$ SCALE DEPENDENCE DETERMINED EXPLICITLY:
  $\Rightarrow$ APPROXIMATE $\mathrm{N^3LO}$ DETERMINED; ASSUMING NON-LOGARITHMIC TERMS AT $\mathrm{N^3LO}$ PROPORTIONAL TO NNLO (Buehler, Lazopoulos), AS A FUNCTION OF PROPORTIONALITY K
- $\mathrm{N^3LO}$ COMPUTATION IN GLUON CHANNEL UNDERWAY, SEVERAL INGEDIENTS COMPUTED IN 2013 (Anastasiou, Duhr, Dulat, Gehrmann, Herzog, Mistlberger 2013; Li and Zhu, 2013; Kilgore, 2013) $\Rightarrow$ SEE BUEHLER'S TALK
- FULL RESULT IN THE SOFT LIMIT (ALL TERMS WHICH SURVIVE LIMIT $\tau \to 1$) RECENTLY PUBLISHED (Anastasiou, Duhr, Dulat, Furlan, Gehrmann, Herzog, Mistlberger 2014) $\to$ LOG TERMS KNOWN, NOW ALSO CONSTANT!

APPROXIMATE N^{3}LO RESULTS

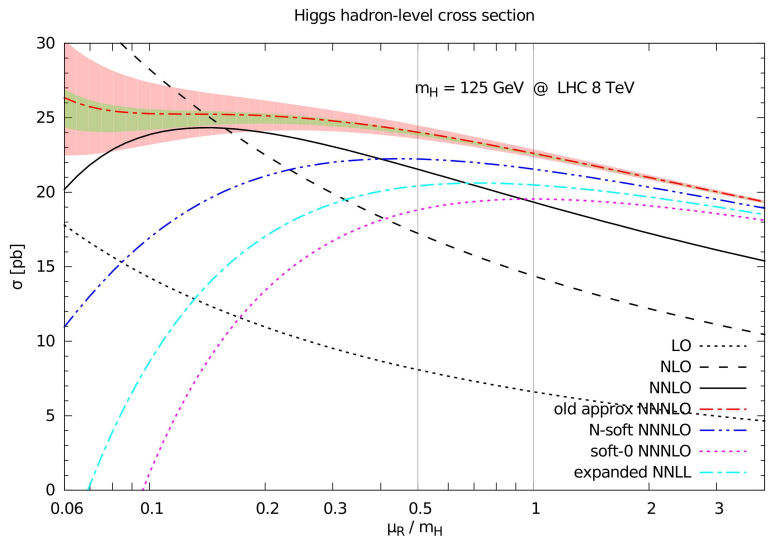
- RESUMMATION (de Florian, Grazzini 2012) EFFECTIVELY AMOUNTS TO APPROXIMATE N^{3}LO (8% INCREASE WR TO NNLO, 6% FROM $O(\alpha_s^3)$)
WITH SPECIFIC "N-SOFT" CHOICE OF LOG APPROX, & UNDETERMINED (ARBITRARY) $O(\alpha_2^3)$ CONST. $g_{0,\,3} = 0$

- APPROXIMATE N^{3}LO FROM MELLIN-SPACE ANALYTICITY
$\Rightarrow$ SINGULARITY AT $N \to \infty$ FROM SUDAKOV RESUMMATION; RIGHTMOST POLES FROM BFKL RESUMMATION (Ball, Bonvini, SF, Marzani, Ridolfi, 2013), CONSTANT ESTIMATED AS $g_{0,\,3} = 114.5$ (FINITE m_t, POINTIKE: $g_{0,\,3} = 112.6$)

- CHANGING CONST. IN RESUMMED (N-SOFT) AMOUNTS TO HALF THE DIFFERENCE BETWEEN RESUM. & APPROXIMATE

- VERY DIFFERENT RESULT OBTAINED IF ONE RESUMS IN x SPACE ("SOFT-0") AS IN (Anastasiou et al, 2014)

RENORMALIZATION SCALE DEP.



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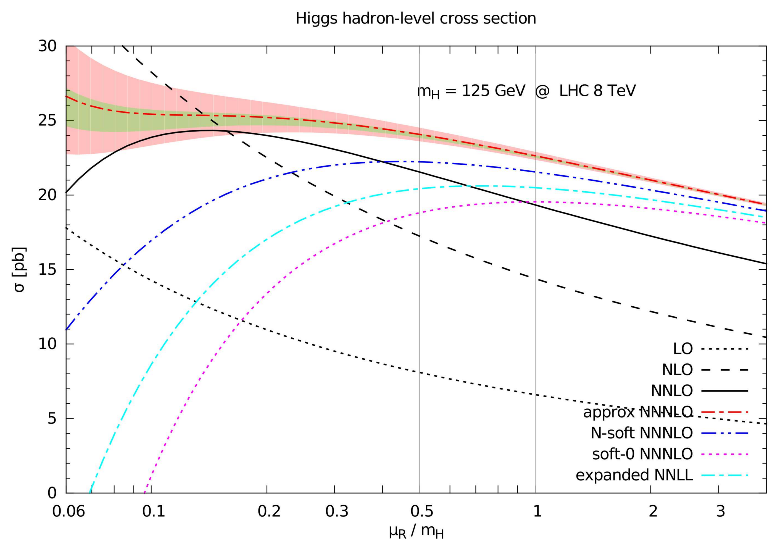
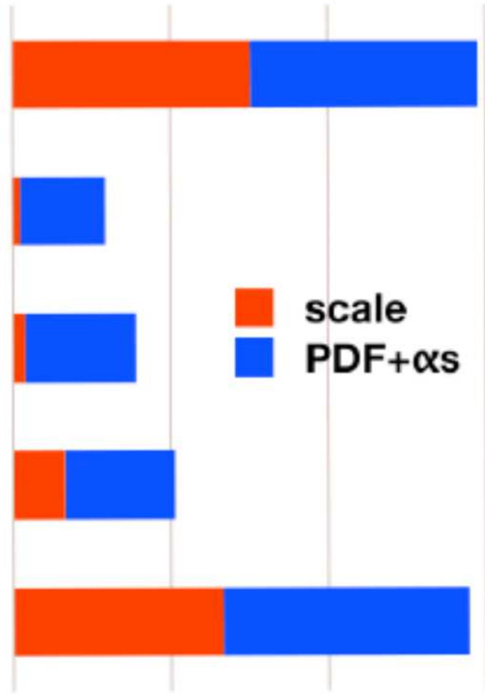
- RESUMMATION (de Florian, Grazzini 2012) EFFECTIVELY AMOUNTS TO APPROXIMATE N^{3}LO (8% INCREASE WR TO NNLO, 6% FROM $O(\alpha_s^3)$) WITH SPECIFIC "N-SOFT" CHOICE OF LOG APPROX, & UNDETERMINED (ARBITRARY) $O(\alpha_2^3)$ CONST. $g_{0,3} = 78.13$
- APPROXIMATE N^{3}LO FROM MELLIN-SPACE ANALYTICITY
  $\Rightarrow$ SINGULARITY AT $N \to \infty$ FROM SUDAKOV RESUMMATION; RIGHTMOST POLES FROM BFKL RESUMMATION (Ball, Bonvini, SF, Marzani, Ridolfi, 2013), CONSTANT ESTIMATED AS ~~$g_{0,3} = 114.5$~~ (FINITE m_t, POINTIKE: $g_{0,3} = 112.6$)
  NOW KNOWN EXACTLY $g_{0,3} = 114.8$
- CHANGING CONST. IN RESUMMED (N-SOFT) AMOUNTS TO HALF THE DIFFERENCE BETWEEN RESUM. & APPROXIMATE
- VERY DIFFERENT RESULT OBTAINED IF ONE RESUMS IN x SPACE ("SOFT-0") AS IN (Anastasiou et al, 2014)

RENORMALIZATION SCALE DEP.



THE IMPACT OF PDF+α_s UNCERTAINTIES

		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
	VBF	1.56 pb	2.9%
NNLO QCD +NLO EW	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%

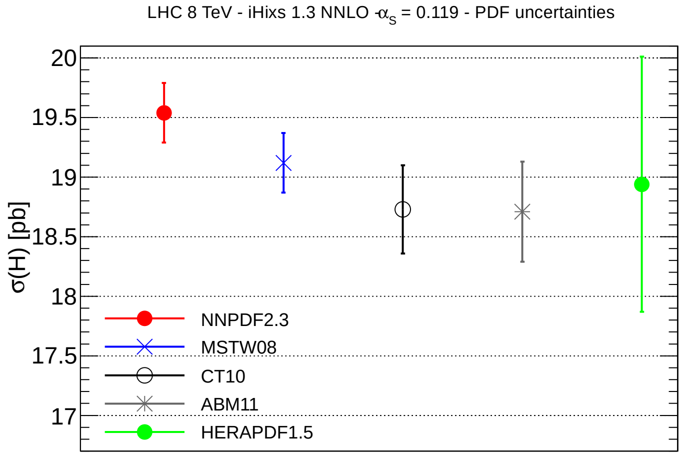


(J. Campbell, HCP2012)

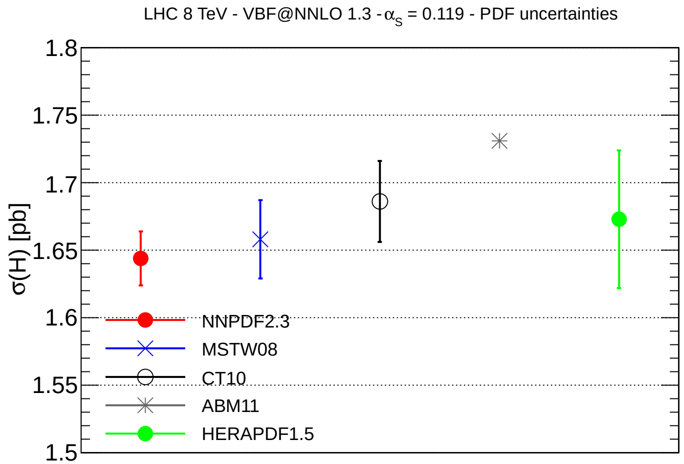
- PDF UNCERTAINTY ALWAYS DOMINANT
- IN GLUON FUSION, COMPARABLE TO SCALE BUT VERY LARGE

PRODUCTION MODES
PDF UNCERTAINTY

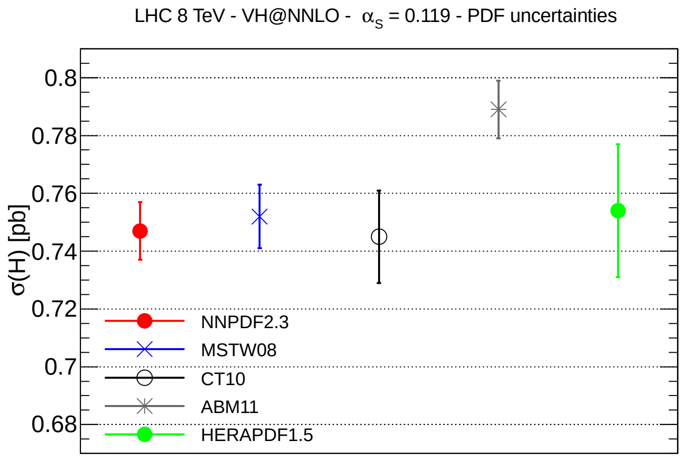
GLUON FUSION



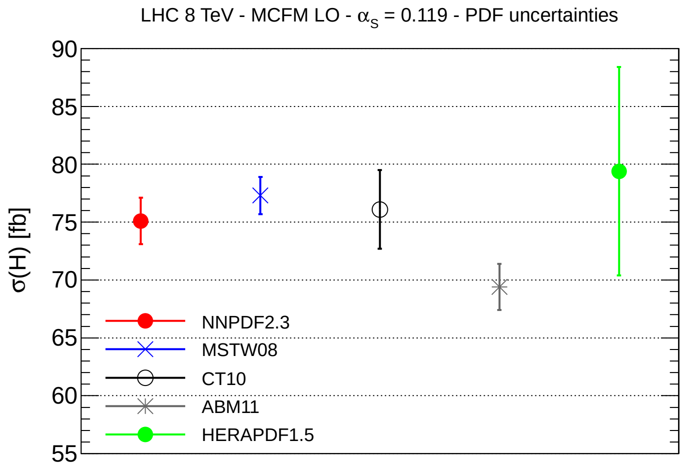
VB FUSION



WH



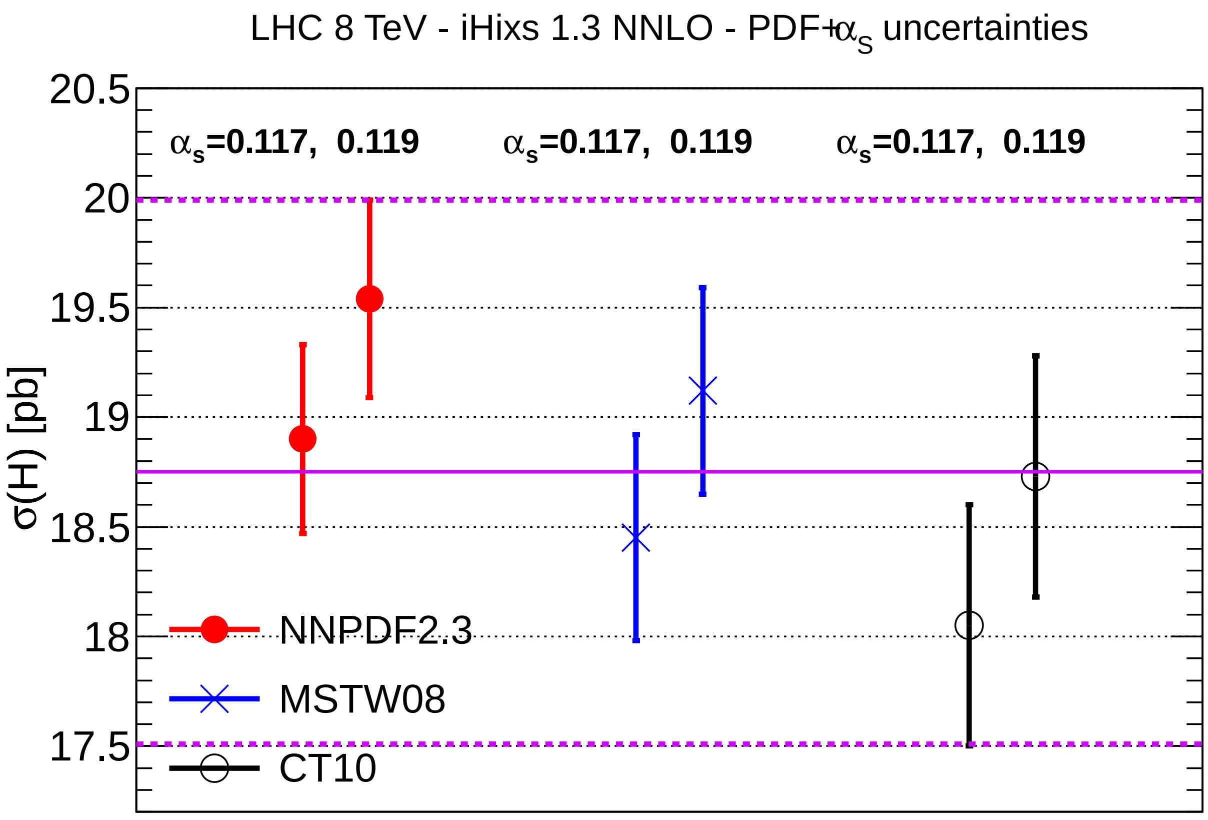
$t\bar{t}H$



- LHC8, highest available QCD order; only PDF uncertainty shown; $\alpha_s = 0.119$
- GOOD AGREEMENT BETWEEN GLOBAL PDF SETS;
  SOME SPREAD FOR GLUON FUSION

(CT-MSTW-NNPDF, 2013)

HIGGS IN GLUON FUSION
THE PDF4LHC PRESCRIPTION

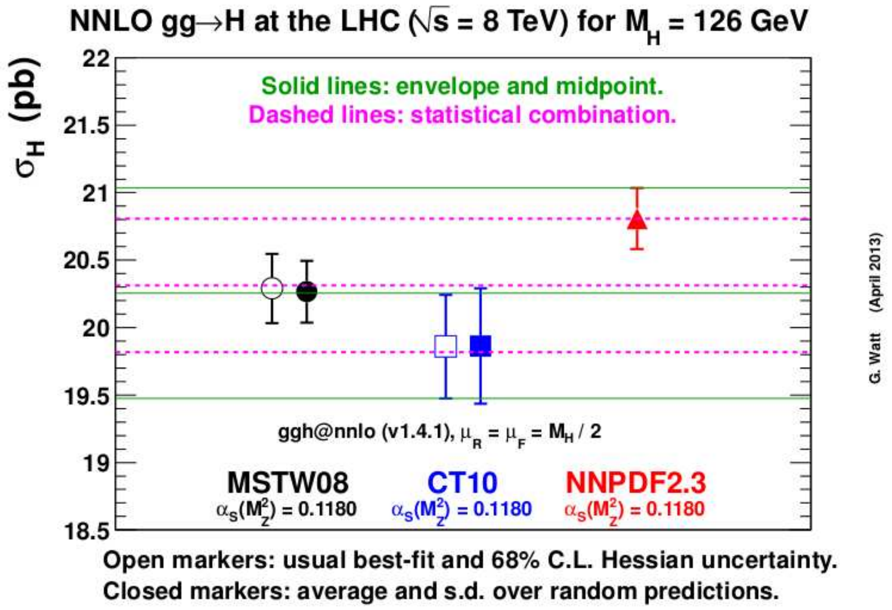


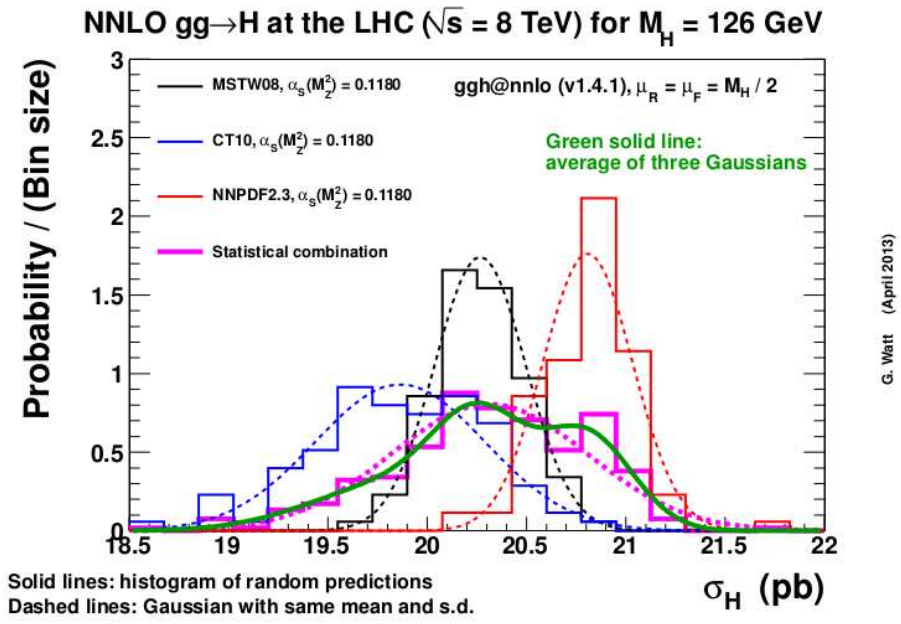
- HOW CAN ONE HANDLE DISCREPANCIES WHICH ARE NOT UNDERSTOOD?
- CONSERVATIVE ANSWER: TAKE THE ENVELOPE OF RESULTS

CRITICISM

- IT IS VERY CONSERVATIVE: α_s UNCERTAINTY IS COUNTED TWICE
- TAKING AN ENVELOPE HAS NO CLEAR STATISTICAL MEANING

THE PDF4LHC PRESCRIPTION
IMPROVEMENT





A LESS CONSERVATIVE PRESCRIPTION:

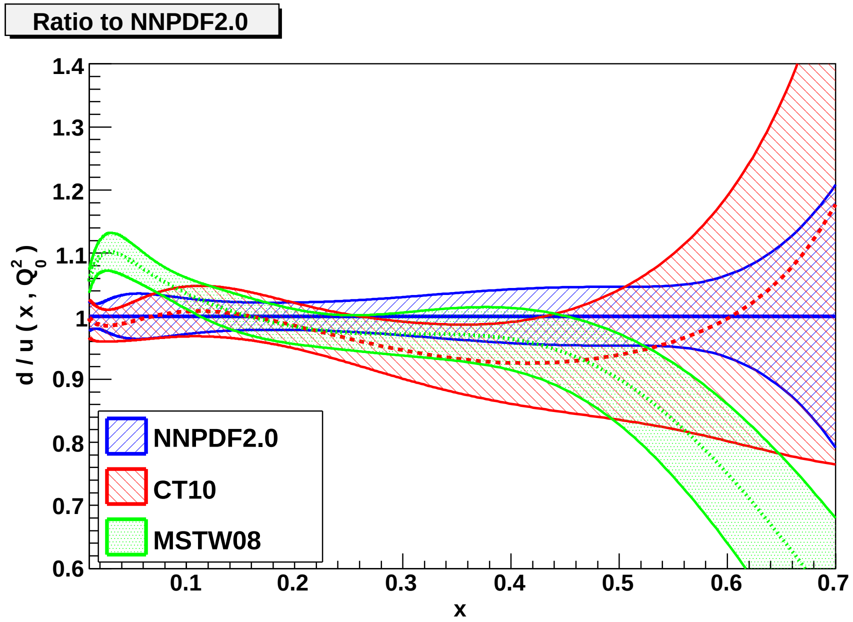
- COMBINE PDF UNCERTAINTIES WITH SINGLE CENTRAL α_s VALUE
- PERFORM STATISTICAL COMBINATION OF THREE SETS (COMBINE HISTOGRAMS)
- ADD α_s UNCERTAINTY IN THE END

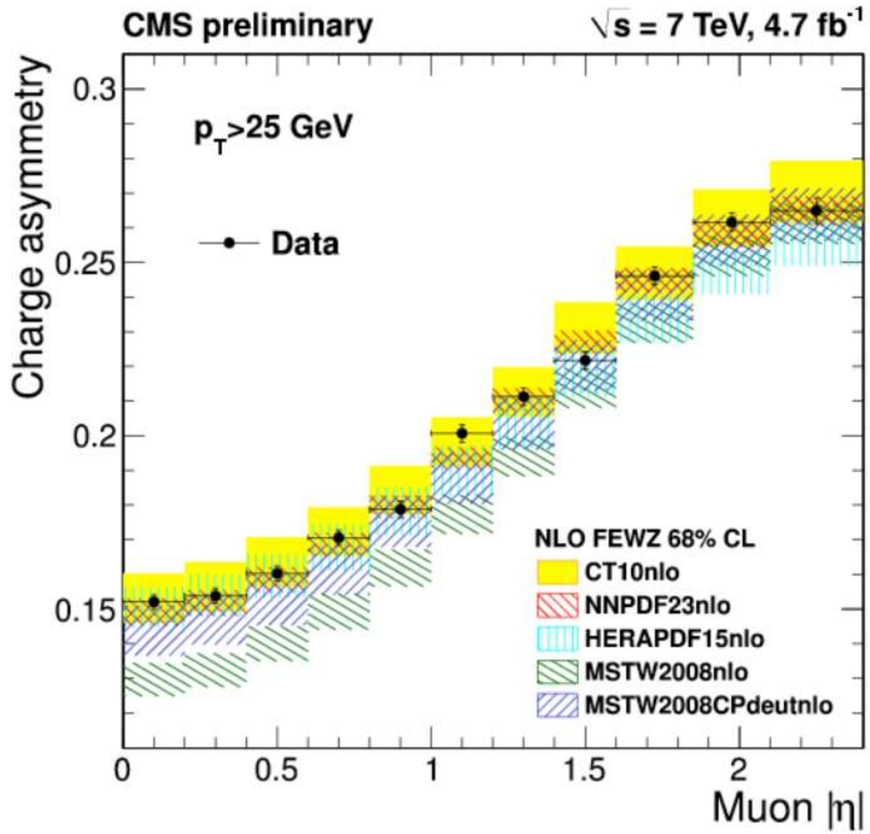
(G.Watt, Higgs WG Theoretical Uncertainty Task Force, in progress)

RATIONALE FOR THE PRESCRIPTION
AN EXAMPLE: THE d/u RATIO

THE CMS W ASYMMETRY

THE d/u RATIO



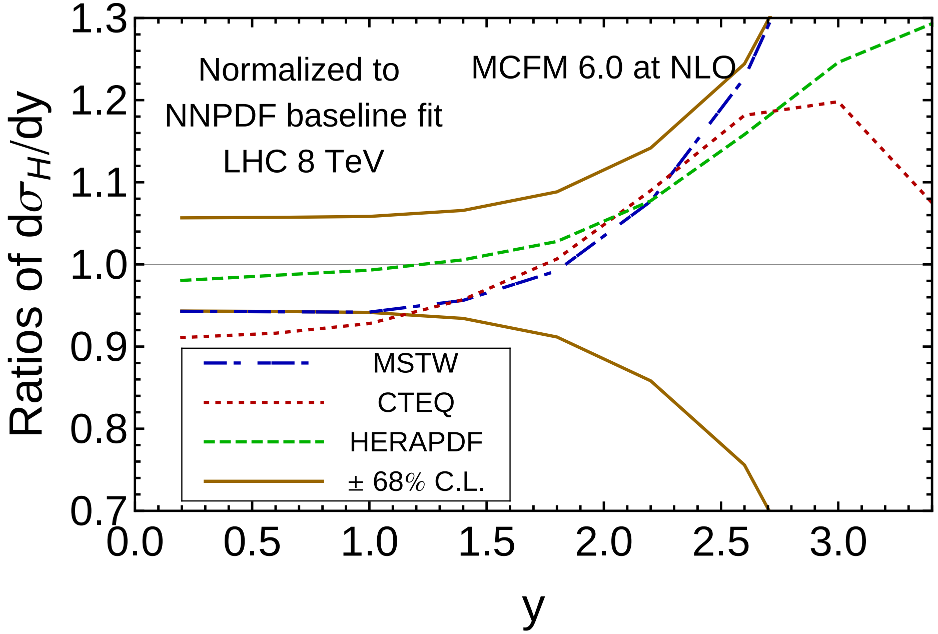


- LONG-STANDING DISCREPANCY IN THE d/u RATIO BETWEEN MSTW AND OTHER GLOBAL FITS
- RESLOVED BY CMS W ASYMMETRY DATA
- EXPLAINED BY INSUFFICIENTLY FLEXIBLE PDF PARAMETRIZATION $\rightarrow$ NEW MSTW08DEUT SET

RESOLVING THE DISCREPANCIES?

- ONGOING BENCHMARKING CT-MSTW-NNPDF-HERAPDF
- HERA-ONLY FITS AGREE, BUT LARGE UNCERTAINTIES

HIGGS RAPIDITY DISTN.,
HERAONLY PDFS

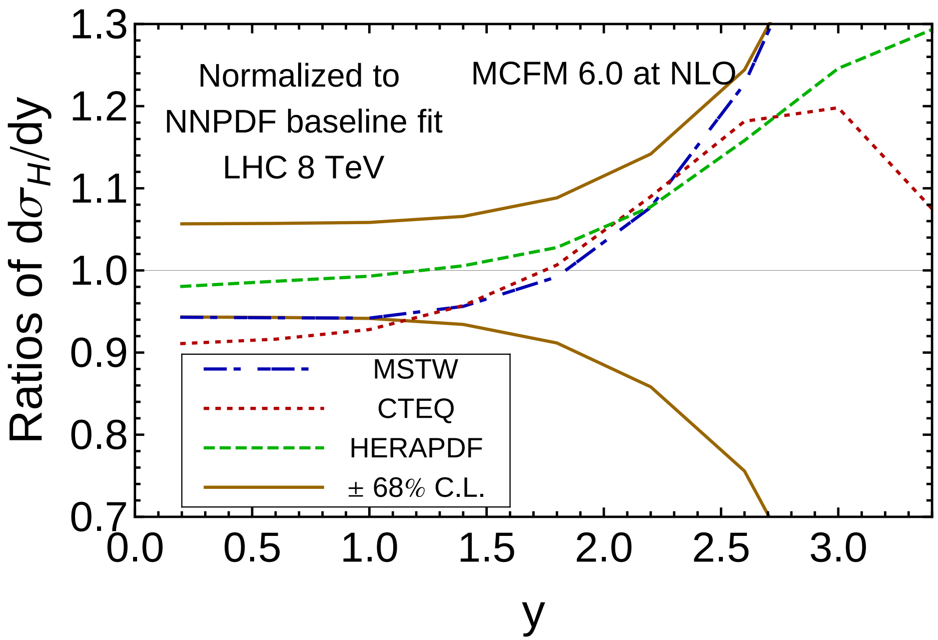


(Cooper-Sarkar et al, Les Houches 2014)

RESOLVING THE DISCREPANCIES?

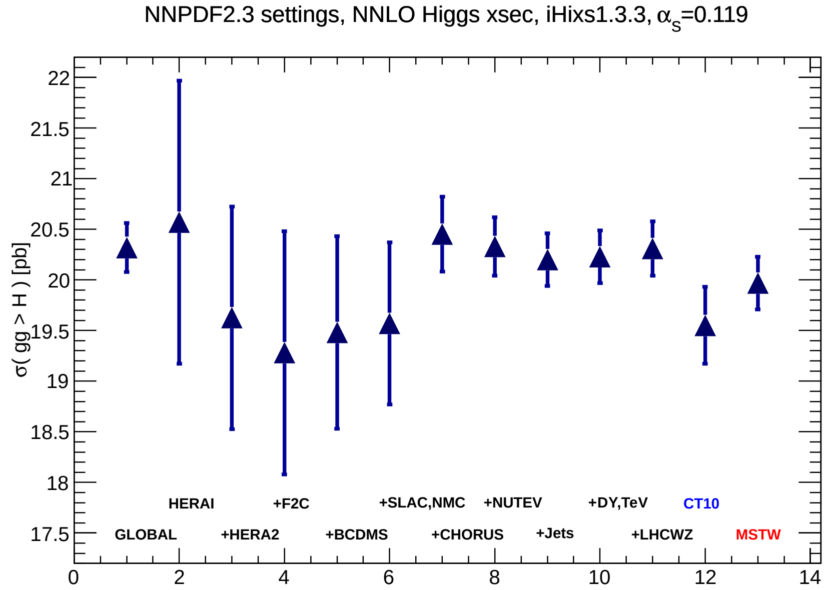
- ONGOING BENCHMARKING CT-MSTW-NNPDF-HERAPDF
- HERA-ONLY FITS AGREE, BUT LARGE UNCERTAINTIES
- FITS TO DATA SUBSETS CONSISTENT, BUT ONLY MARGINALLY: TENSION BETWEEN COLLIDER AND NEUTRINO DATA

HIGGS RAPIDITY DISTN., HERAONLY PDFS



(Cooper-Sarkar et al, Les Houches 2014)

NNPDF PDFS: ONE EXPT AT A TIME



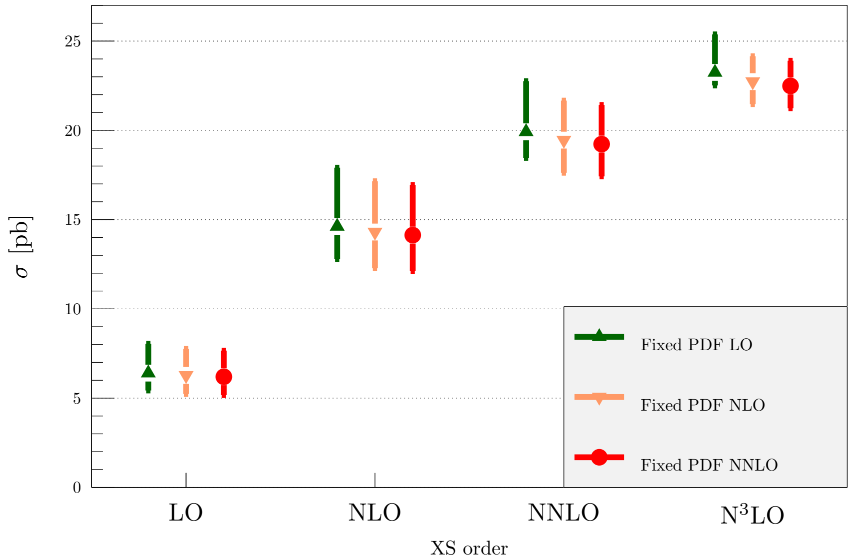
(S.F. and J.Rojo, Les Houches 2014))

DO WE NEED N^{3}LO PDFs?

- IN PRINCIPLE, YES
- LOOK AT THE CROSS SECTION AS A FUNCTION OF THE PERTURBATIVE ORDER OF THE PDF AND THE MATRIX ELEMENT
- – HIGGS GLUON FUSION: PERTURBATIVE DEP. OF PDF NEGLIGIBLE IN COMPARISON TO MATRIX ELEMENT ⇒ TH. UNCERTAINTY ALMOST ENTIREY DUE TO MATRIX ELEMENT ⇒ NO!

SCALE UNCERTAINTY & DEP. ON PERTURBATIVE ORDER

HIGGS



(s.f., Isgrò, Vita, 2014)

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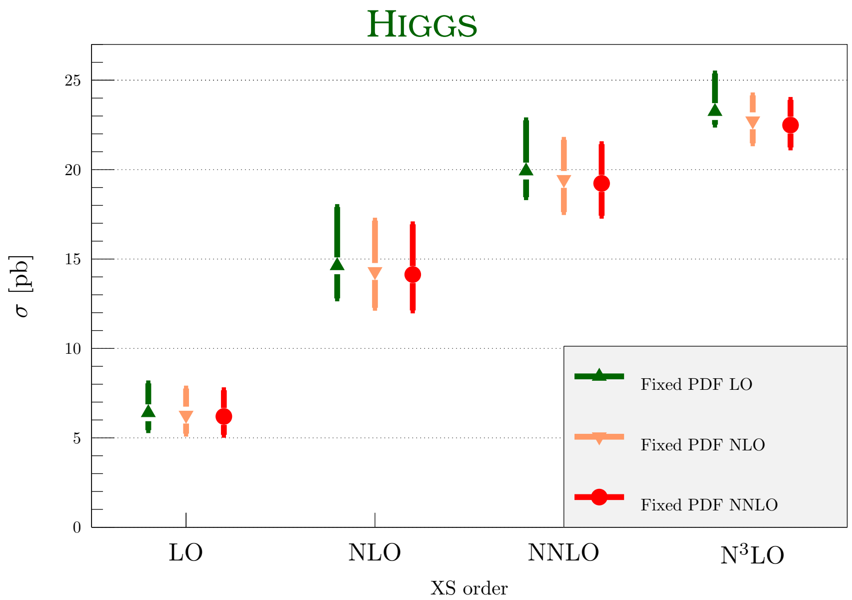
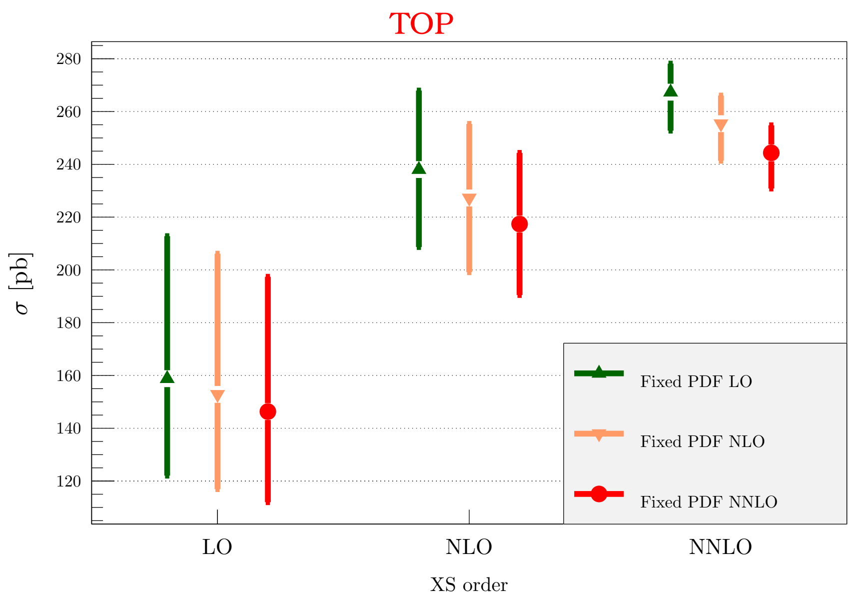
  – TOP: PERTURBATIVE DEP. OF PDF SMALLER, BUT NOT NEGLIGIBLE IN COMPARISON TO MATRIX ELEMENT, ANTICORRELATED TO IT ⇒ COMBINED UNCERTAINTY SMALLER⇒ YES!

SCALE UNCERTAINTY & DEP. ON PERTURBATIVE ORDER





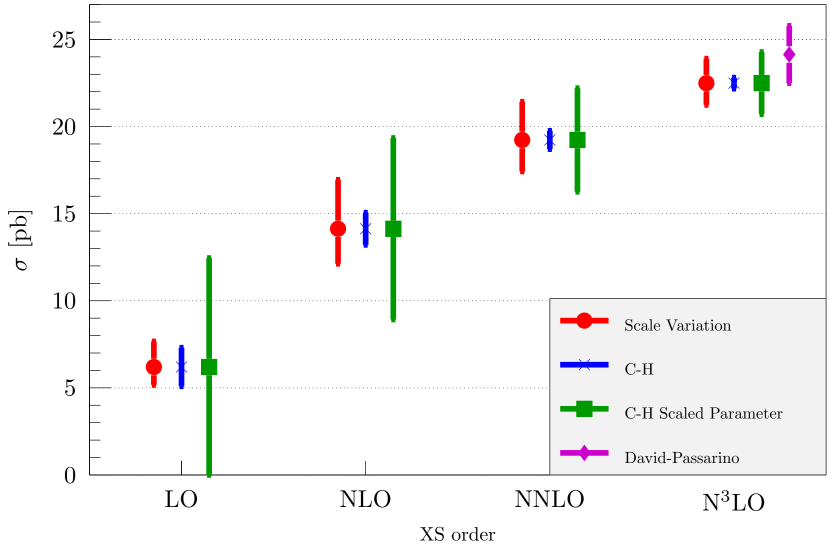
(s.f., Isgrò, Vita, 2014)

THEORETICAL UNCERTAINTIES

GLUON FUSION AS A CASE STUDY

- ALL ORDER RESULT MUST BE SCALE INDEPENDENT
  $\Rightarrow$ SCALE DEPENDENCE GIVES LOWER BOUND TO UNCERTAINTY DUE TO MISSING HIGHER ORDERS
  UNCERTAINTIES UNDERESTIMATED
- IF SEVERAL ORDERS KNOWN, LOOK AT THE BEHAVIOUR OF KNOWN ORDERS, ASSUMING COEFFICIENTS ARE OF SIMILAR ORDER
  $\rightarrow$ BAYESIAN ESTIMATE OF UNCERTAINTY (Cacciari, Houdeau, 2011);
  RESULT DEPEND ON THE CHOICE OF EXPANSION PARAMETER $\alpha_s \rightarrow \lambda\alpha_s$
  UNCERTAINTIES UNDERESTIMATED IF EXPANSION IN α_s,
  OK IF EXPANSION PARM. RESCALED
- ALTERNATIVELY, USE FIRST SEVERAL ORDERS TO CONSTRUCT AN ALL-ORDER APPROXIMANT (POSSIBLY BASED ON BOREL SUMMATION)
  $\Rightarrow$ ALL-ORDER - FIXED ORDER DIFFERENCE ESTIMATES UNCERTAINTY (David, Passarino, 2013)
  ALMOST IDENTICAL TO RESCALED CH!

THEORETICAL UNCERTAINTY ON $gg \rightarrow H$



(s.f., Isgrò, Vita, 2014)

THE VALUE OF α_s

- SENSITIVITY IN GLUON FUSION CHANNEL LARGE!:
  $\Delta\sigma \sim 3\Delta\alpha$ (IN PERCENTAGE AT NNLO, BY POWER COUNTING)
- WHAT IS THE VALUE OF $\Delta\alpha$??
  - PDG VALUE (S. BETHKE) $\alpha_s = 0.1184 \pm 0.0007$
  - IT IS AN AVERAGE OF AVERAGES
  - SOME SUB-AVERAGES (E.G. DIS) INCLUDE DATA/EXTRACTIONS WHICH HAVE BEEN SHOWN TO BE INCORRECT
  - OTHER SUB-AVERAGES (E.G. τ OR JETS) INCLUDE DETERMINATIONS WHICH DIFFER FROM EACH OTHER BY EVEN FOUR-FIVE σ
- AVERAGING THE TWO MOST RELIABLE VALUES (GLOBAL EW FIT & τ, BOTH N^3LO, NO DEP. ON HADRON STRUCTURE) GIVES
  $\alpha_s = 0.1197 \pm 0.0014$

THE VALUE OF α_s AND ITS UNCERTAINTY REMAIN AN OPEN QUESTION!

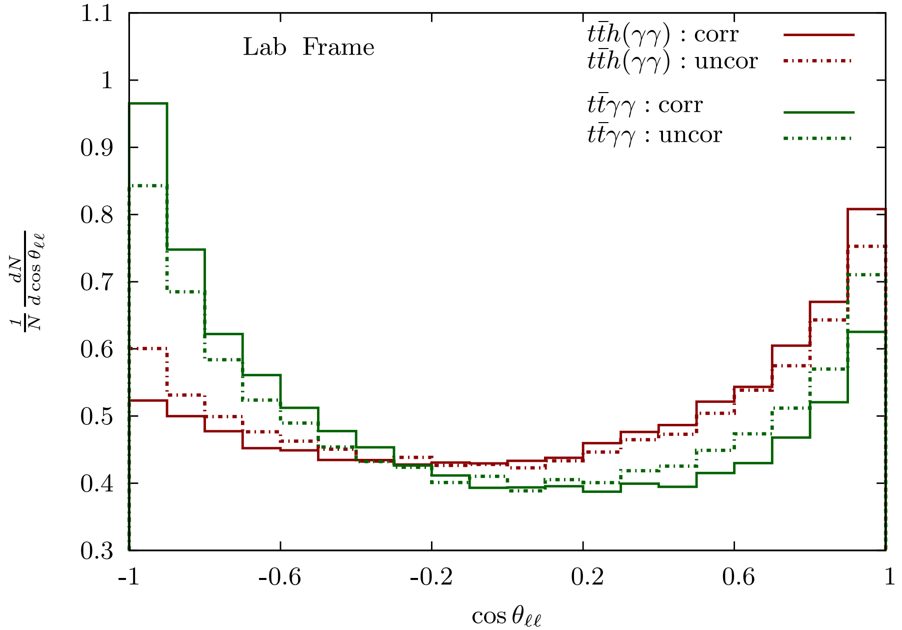
PRECISION?

COUPLING TO TOP

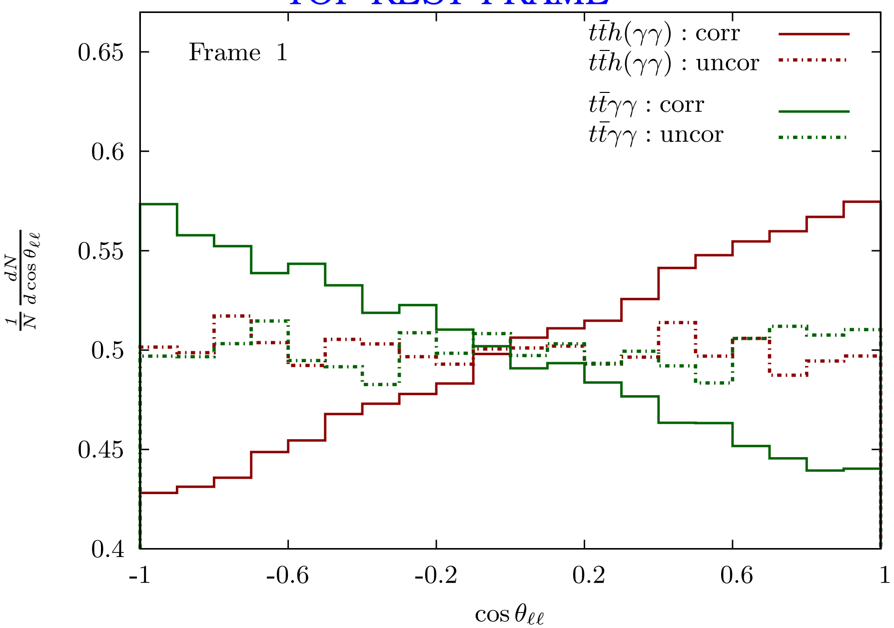
- TOP YUKAWA $\Rightarrow H t\bar{t}$
- ENHANCE SIGNAL-TO-BACKGROUND RATIO:
  - BOOSTED (Plehn, Salam, Spannowsky, 2013) & MATRIX ELEMENT METHOD (Artoisenet, de Aquino, Maltoni, Mattelaer, 2013)
  - KEEPING SPIN CORRELATIONS,
    ANGULAR $\cos\theta_{\ell\ell}$ DISTRIBUTION DISCRIMINATES SIGNAL VS. BACKGROUND (WOULD BE COMPLETE IN CHIRAL LIMIT)
  - DISCRIMINATION MAXIMAL IN TOP REST FRAME

SIGNAL VS BACKGROUND
DASHED: WITHOUT SPIN CORRELATION

LAB FRAME

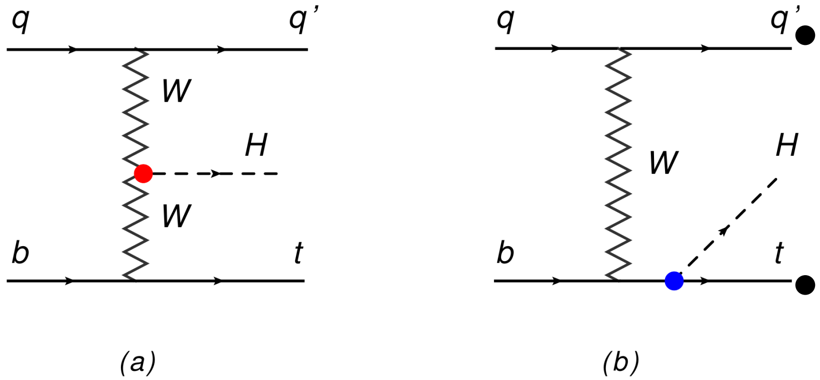


TOP REST FRAME



(Biswas, Frederix, Gabrielli, Mele, 2014)

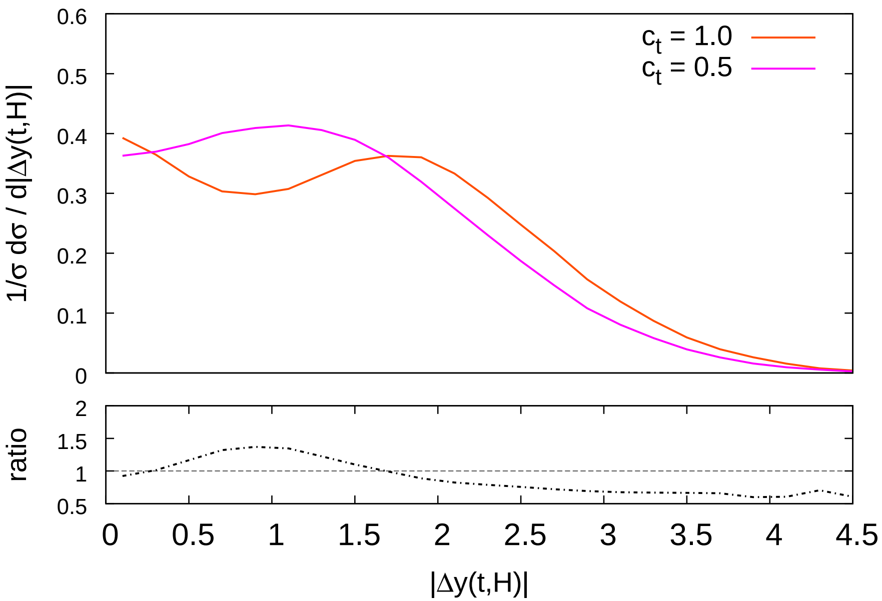
INTERFEROMETRY
SINGLE-TOP PRODUCTION



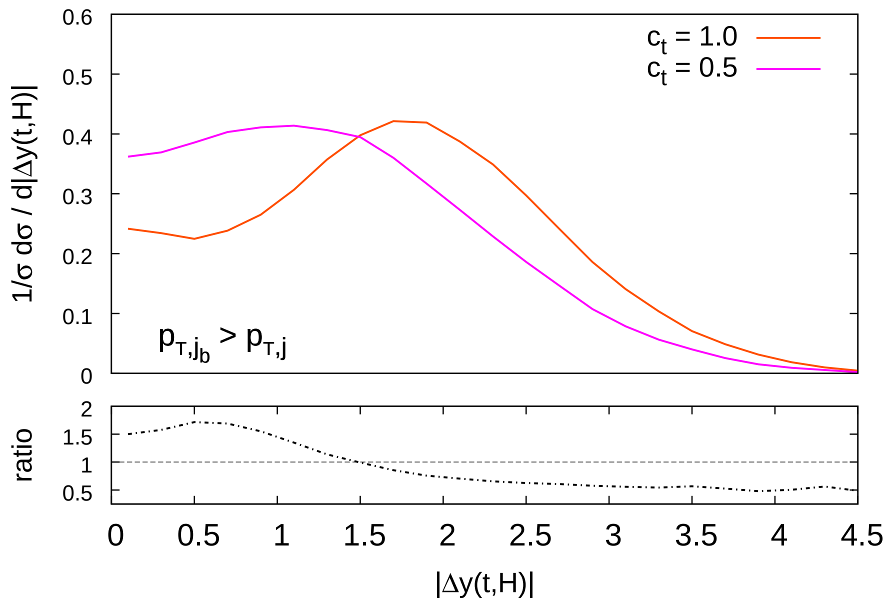
- IN SM, STRONG DESTRUCTIVE INTERFERENCE BETWEEN CONTRIBUTIONS
  $\Rightarrow$ VERY SENSITIVE TO BSM (Farina, Grojean, Maltoni, Salvioni, Thamm 2102; Biswas, Gabrielli, Mele, 2012)
- HADRON-LEVEL ANALYSIS AVAILABLE (Englert, Re, 2014)

- SHAPE STRONGLY DEPENDENT ON CANCELLATION OR LACK THEREOF (BSM)
- CAN ENHANCE DISCRIMINATION BY SUITABLE CUTS & VETOS

TOP-HIGGS RAPIDITY DISTANCE:
SM VS. BSM



b jet harder than light jet

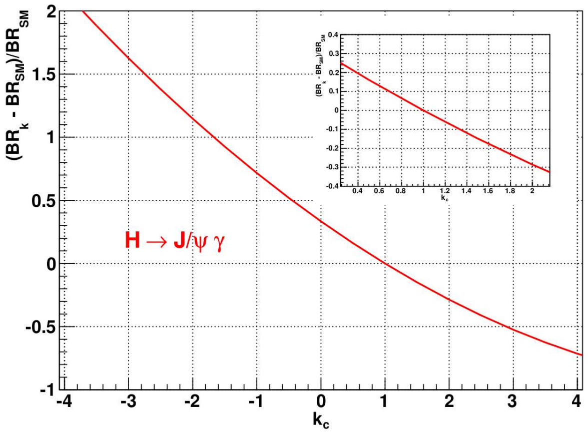


INTERFEROMETRY
COUPLING TO CHARM (AND B)

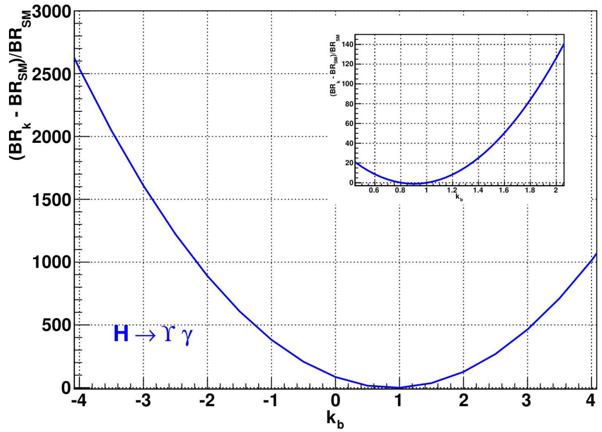
- $H \to V + \gamma$ WITH $V = J/\psi, \Upsilon \Rightarrow$ COUPLING TO HEAVY QUARKS
- $Hc\bar{c}$ (AND $Hb\bar{b}$): ACCESS COUPLING OF HIGGS TO 2ND GENERATION QUARKS!
- HIGGS DECAYS IN $Q\bar{Q}$ PAIR WHICH FRAGMENTS INTO $V + \gamma \Rightarrow$ SMALL
- INTERFERES WITH $H \to \gamma\gamma^*$ WITH SUBSEQUENT FRAGMENTATION OF γ^* INTO $V \Rightarrow$ LARGE
- COMPUTED AT NLO: (Bodwin, Petriello, Stoynev, Velasco, 2013))
- HIGH SENSITIVITY TO BSM DEVIATIONS

$$k = g_{H\bar{c}c}/g^{SM}_{H\bar{c}c}$$

$h \to J/\psi\gamma$



$h \to J/\Upsilon\gamma$



MORE INTERFEROMETRY

THE HIGGS WIDTH

- INTERFERENCE BETWEEN $gg \to H \to ZZ$ & CONTINUUM CAN BE USED TO DETERMINE WIDTH (Dixon, Li, 2013)

- STRONG SENSITIVITY OF INTERFERENCE TO WIDTH FOR INVARIANT MASSES ABOVE THE PEAK (Passarino, Kauer, 2012; Caola, Melnikov, 2013)

- CAN USE ANALITICITY METHODS TO GET APPROXIMATE NLO INTERFERENCE (Bonvini, Caola, SF, Melnikov, Ridolfi, 2013)

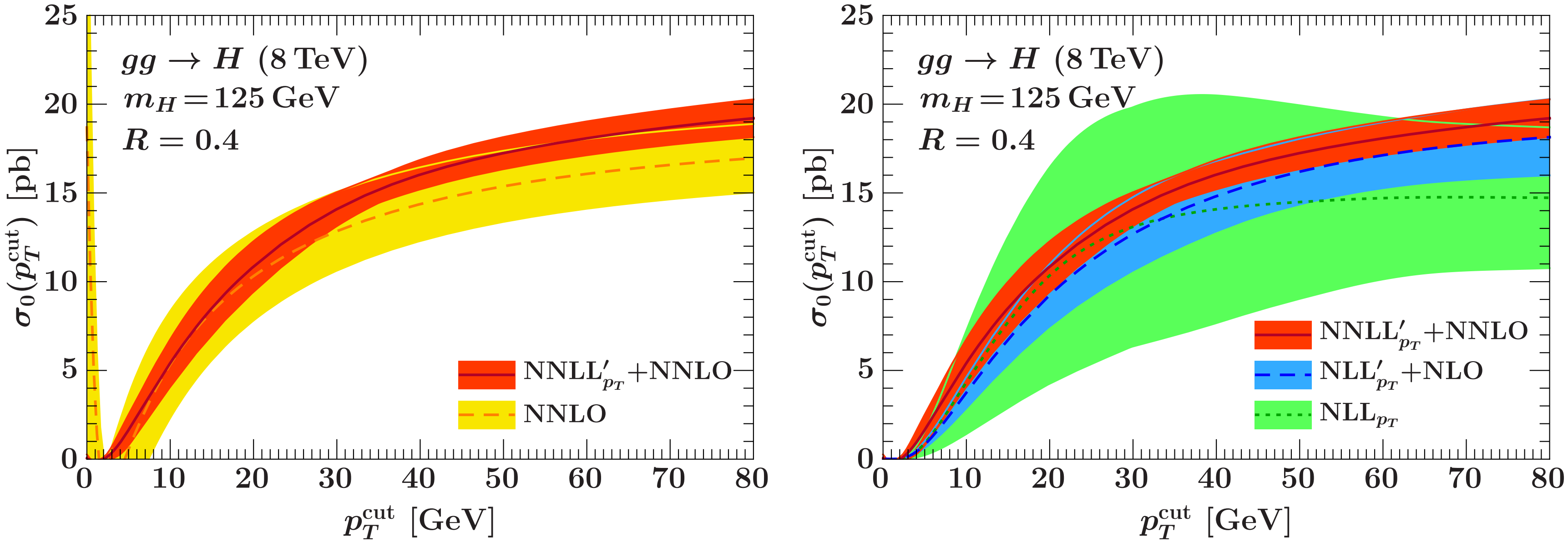
$\Rightarrow$ SEE PASSARINO'S TALK

PRECISION!

JET VETOS ⇒ SEE TACKMANN'S TALK

- CROSS-SECTION FOR HIGGS+ AT LEAST ONE JET CONTAINS DOUBLE LOGS OF MINIMAL p_T OF JET
- ⇒ CROSS SECTION WITH JET VETO CONTAINS DOUBLE LOGS OF p_t^{veto}:
  $\sigma_{\geq 1} \sim (\alpha L^2)^n$; $\sigma_{tot} \sim \alpha^n \to \sigma_o \equiv \sigma_{tot} - \sigma \geq 1 \sim (\alpha L^2)^n$;
- RESUMMATION OF ZERO-JET CROSS-SECTION PERFORMED UP TO NNLL+NNLO WITH PERTURBATIVE APPROACH (Banfi, Monni, Salam, Zanderighi, 2012) & SCET (Stewart, Tackmann, Walsh, Zuberi, 2012-2013; Becher, Neubert, Rothen, 2013)
- GOOD PERTURBATIVE STABILITY; SIGNIFICANTLY IMPROVED UNCERTAINTY

0-JET CROSS-SECTION FOR HIGGS IN GLUON FUSION



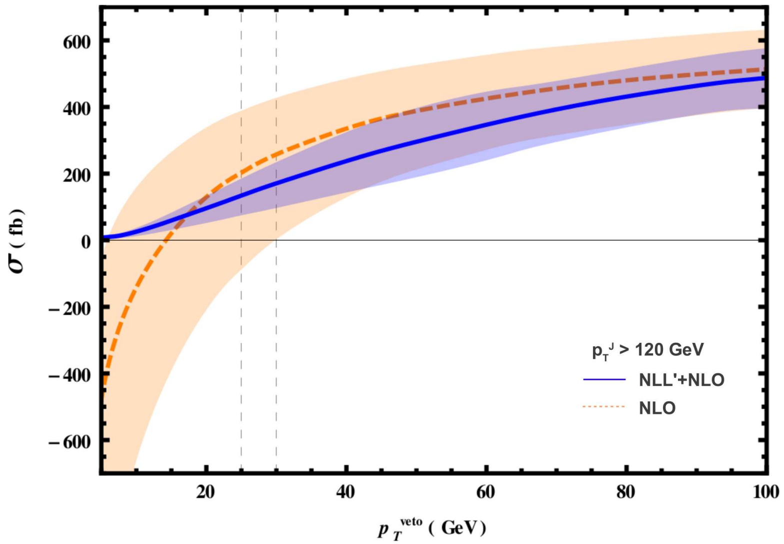
(Stewart, Tackmann, Walsh, Zuberi, 2013)

THE ONE-JET CROSS SECTION

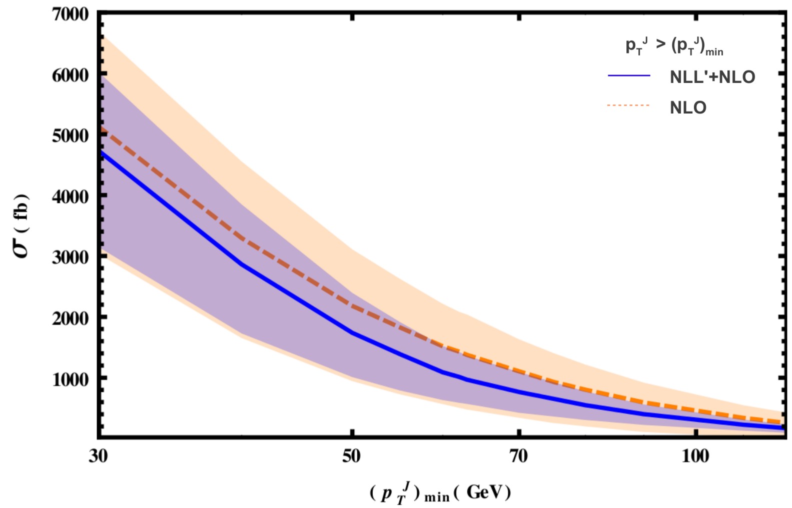
- TWO DIFFERENT REGIONS: $p_t^{\mathrm{veto}} \ll p_T \sim M_h$; $p_t^{\mathrm{veto}} \sim p_T \ll M_h$
- FIRST REGION RESUMMED AT NLL+NLO (MATCHED) USING SCET (Liu, Petriello, 2012-2013),
- HUGE REDUCTION IN UNCERTAINTY $\Rightarrow$
  25% IF CONSERVATIVELY SWITCH OFF RESUMMATION AT $p_t^{\mathrm{jet}} = m_h/2$

ONE-JET INTEGRATED XSECT

VS.p_t^{veto} FOR $p_t^{\mathrm{jet}} > 120$ GEV



VS. CUT ON p_t^{jet} FOR $p_t^{\mathrm{veto}} = 30$ GEV



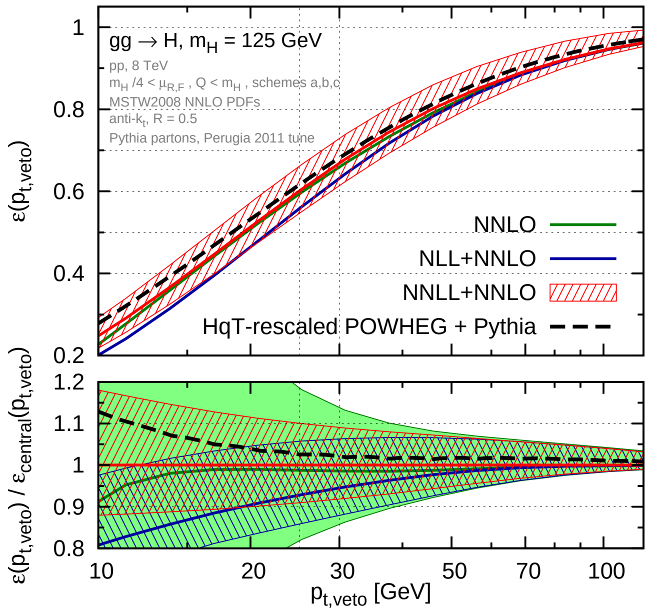
(Liu, Petriello, 2013)

EFFICIENCIES AND UNCERTAINTIES

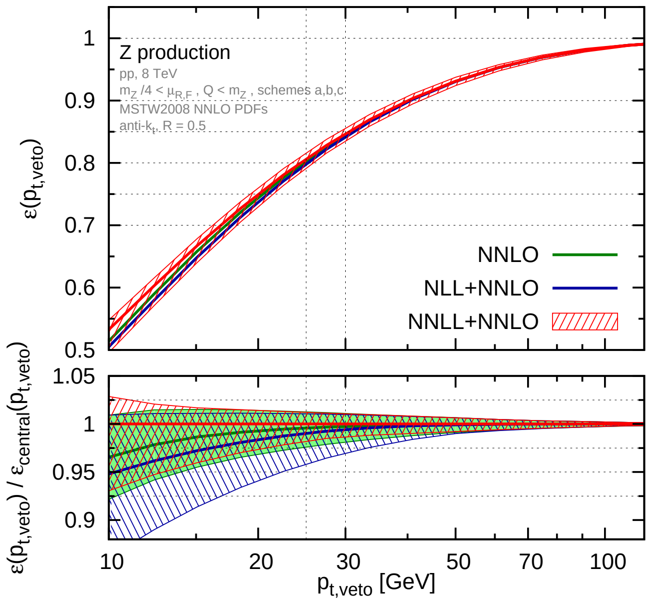
- EXPERIMENTALLY, ONE IS INTERESTED IN THE EFFICIENCY, DEFINED AS
  $\epsilon_0(p_T^{\rm veto}) \equiv \frac{\sigma_0(p_T^{\rm veto})}{\sigma_{tot}}$
- SUBTLE ISSUES IN UNCERTAINTY ESTIMATION:
  - WHAT IF ONE INSTEAD DEFINES $\epsilon_0(p_T^{\rm veto}) \equiv 1 - \frac{\sigma_{\geq 1}(p_T^{\rm veto})}{\sigma_{tot}}$? EQUIVALENT UP TO HIGHER ORDERS
  - CORRELATIONS BETWEEN UNCERTAINTIES: σ_{tot} & $\epsilon_0(p_T^{\rm veto})$ UNCORRELATED
    $\Rightarrow$ CORRELATIONS INDUCED BETWEEN σ_0 AND $\sigma_{>1}$
    $\Rightarrow$ MUST COMPUTE COVARIANCE MATRIX!

JET VETO EFFICIENCIES

HIGGS



Z



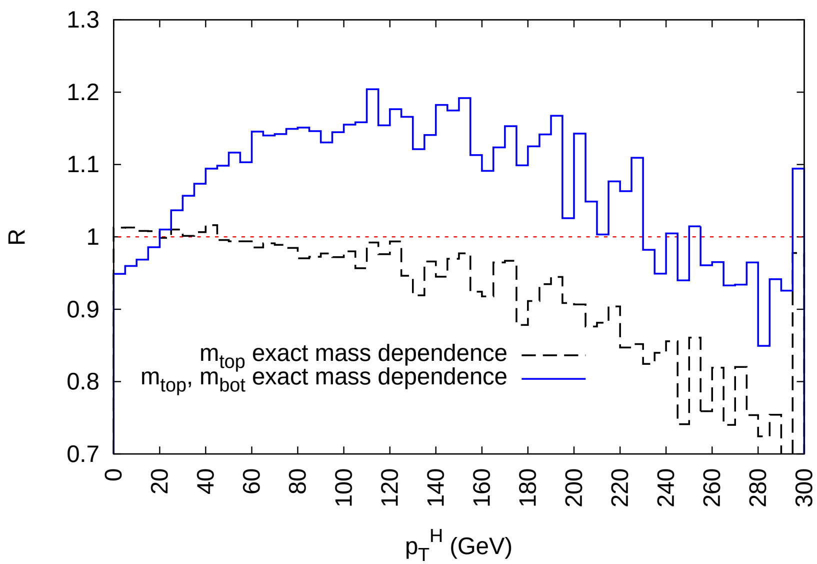
(Banfi, Monni, Salam, Zanderighi, 2012)

HQ MASSES IN HIGGS PRODUCTION

- AN EXTREME MULTISCALE PROBLEM: p_T SPECTRUM IN HIGGS PRODUCTION IN GLUON FUSION
- SCALES: m_t, m_b, m_H, p_T, s
- EFFECT OF FINITE m_B IS VISIBLE AT SMALL p_T
- DISCREPANCY BETWEEN POWHEG AND NLO+NLL COMPUTATION
- GLUONS WITH $m_b \lesssim p_T \lesssim m_H$ ARE TREATED AS SOFT IN NLO+NLL (NO EFFECT ON b LOOP), WHILE THEY DO AFFECT THE b LOOP IN POWHEG APPROACH $\rightarrow$ NEITHER APPROACH FULLY CAPTURES ALL THE RELEVANT PHYSICS

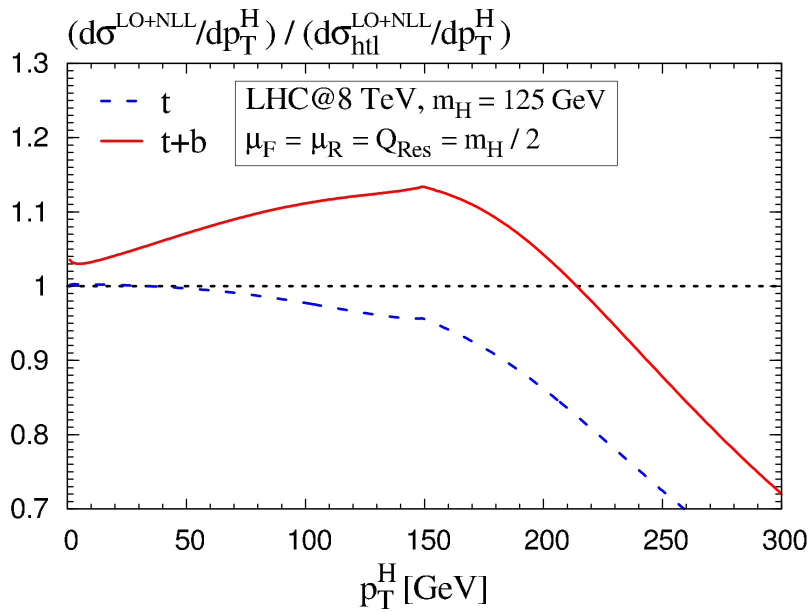
FINITE m_t, m_t, RATIO TO POINTLIKE

POWHEG



(Bagnaschi, Degrassi, Slavich, Vicini, 2012)

NLO+NLL



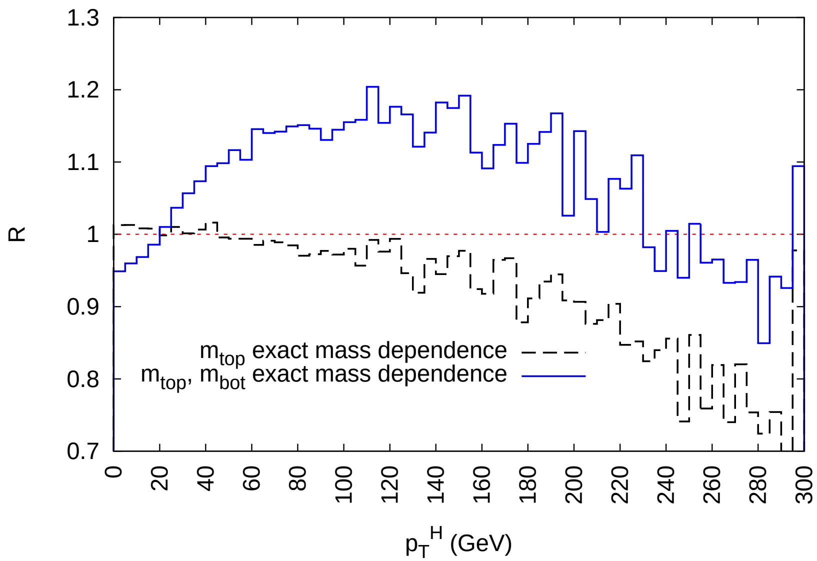
(Mantler, Wiesemann, 2012)

HQ MASSES IN HIGGS PRODUCTION

- EFFECT OF FINITE m_B IS VISIBLE AT SMALL p_T
- DISCREPANCY BETWEEN POWHEG AND NLO+NLL COMPUTATION
- GLUONS WITH $m_b \lesssim p_T \lesssim m_H$ ARE TREATED AS SOFT IN NLO+NLL (NO EFFECT ON b LOOP), WHILE HEY DO AFFECT THE b LOOP IN POWHEG APPROACH $\rightarrow$ NEITHER APPROACH FULLY CAPTURES ALL THE RELEVANT PHYSICS
- FIXED BY TREATING RESUMMATION SEPARATELY FOR b LOOP: ONLY GLUONS WITH $p_T \lesssim M_b$ RESUMMED BY CHOICE OF RESUMMATION SCALE

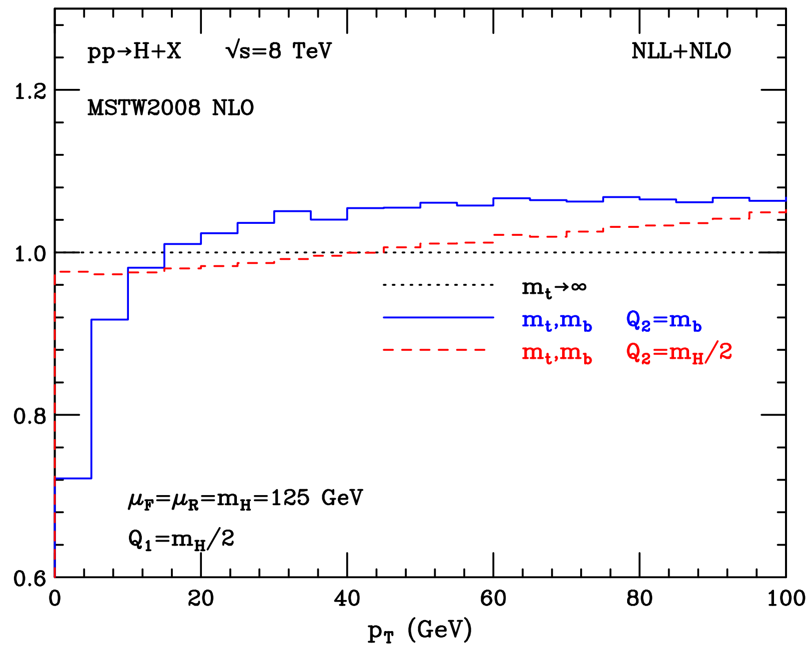
FINITE m_t, m_t, RATIO TO POINTLIKE

POWHEG



(Bagnaschi, Degrassi, Slavich, Vicini, 2012)

NLO+NLL



(Grazzini, Sargsyan, 2013)

JET VETOS+ HQ MASSES!

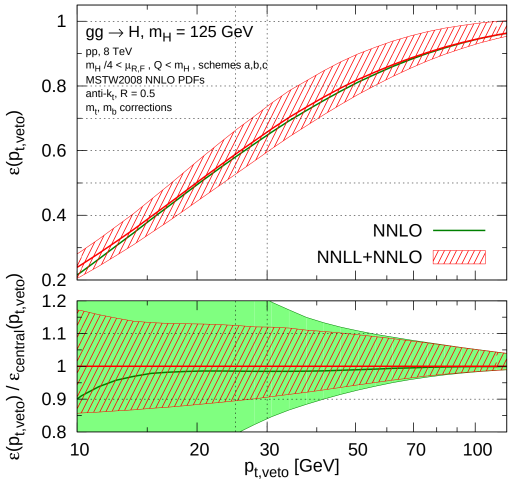
(Banfi, Monni, Zanderighi, 2013)

- ZERO-JET VETO XSECT & EFFICIENCY COMPUTED WITH FULL INCLUSION OF BOTTOM % TOP MASSES UP TO NNLO+NNLL
- MULTISCALE, NON FACTORIZED $\ln \frac{m_b}{p_T^{\rm veto}}$ IN $p_T^{\rm veto} > m_b$ REGION
- m_T DOMINANT; m_B, m_t CANCELLATION, GENERALLY SMALL CORRECTIONS UNLIKE p_T DISTRIBUTION: WHY?

EFFICIENCY VS $p_T^{\rm veto}$

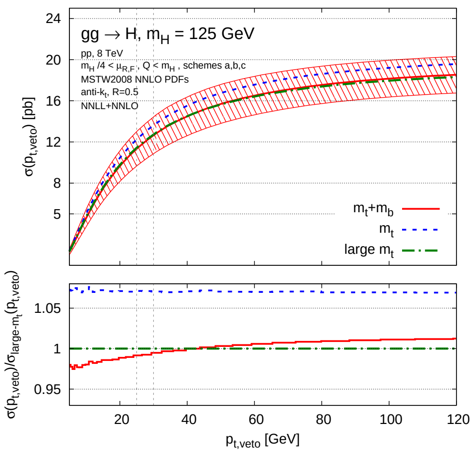
RESUMMED VS.

FIXED ORD.



POINTLIKE VS FINITE m_b

VS FINITE m_b, m_t



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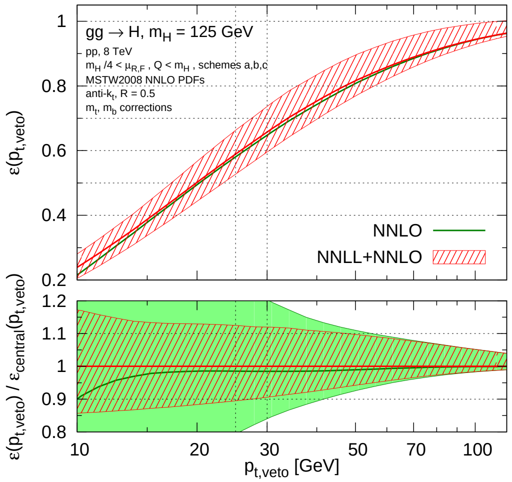
- MULTISCALE, NON FACTORIZED $\ln \frac{m_b}{p_T^{\text{veto}}}$ IN $p_T^{\text{veto}} > m_b$ REGION
- m_T DOMINANT; m_B, m_t CANCELLATION, GENERALLY SMALL CORRECTIONS UNLIKE p_T DISTRIBUTION: WHY?
- LARGE EFFECTS AT NLO+NLO, SMALL AT NNLO+NNLO: RESUMMATION PERTURBATIVE!

EFFICIENCY VS p_T^{veto}

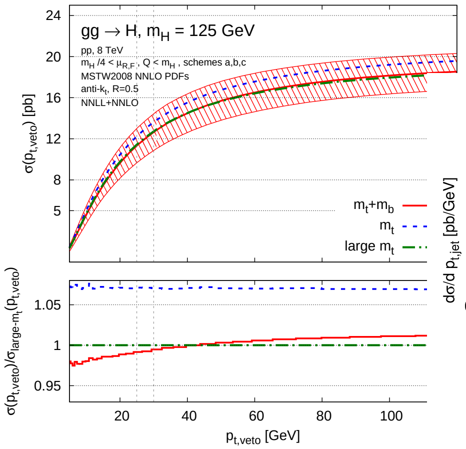
RESUMMED VS.

FIXED ORD.



POINTLIKE VS FINITE m_b

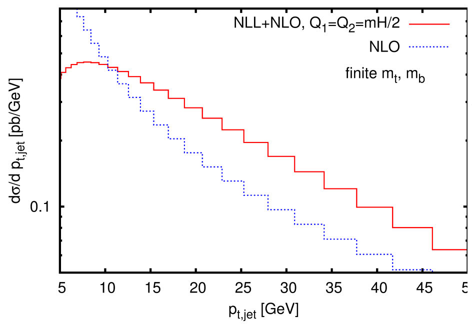
VS FINITE m_b, m_t



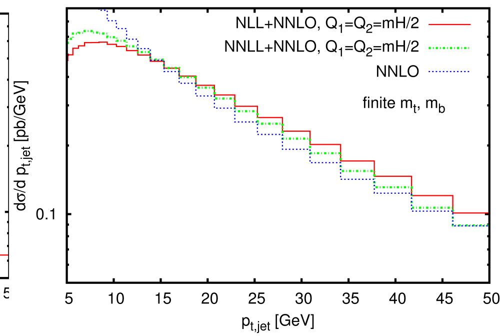
p_T DISTRIBUTION

RESUMMED VS FIXED ORD.

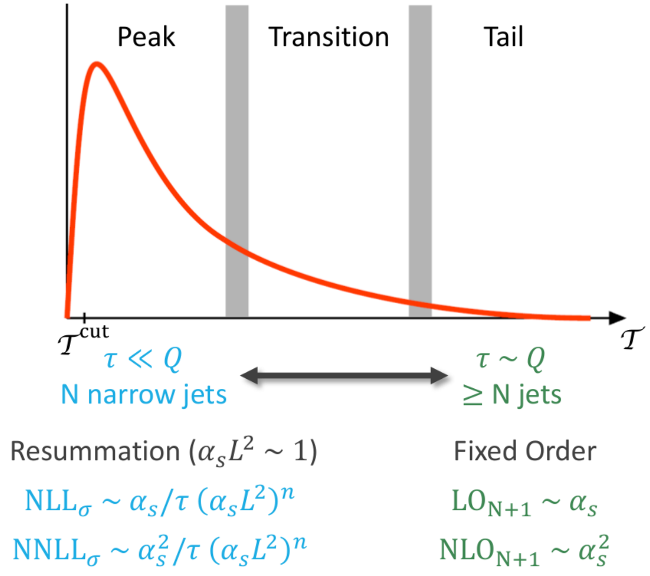
NLO



NNLO



MATCHING: FIXED ORDER, RESUMMATION, SHOWER



(Alioli et al., 2012)

- HIGGS PRODUCTION AT LHC (ESPECIALLY IN GLUON FUSION) SITS IN THE TRANSITION REGION
  $\Rightarrow$ MUST CONSIDER BOTH & MATCH RESUMMATION AND FIXED ORDER
- ACCURATE FINAL STATE: BOTH MERGED WITH PARTON SHOWER!
- SEVERAL RECENT MERGING ATTEMPS (Alioli, Hamilton, Re, 2011; Hoeche, Krauss, Schönherr, Sieger 2012; Frederix, Frixione, 2012; Platzer, 2012; Prestel and Lönnblad, 2012) SEE PRESTEL'S TALK
- FULL NLO+NLL ACCURACY ACHIEVED:
  - GENEVA (SCET-BASED): APPLIED TO THRUST IN e^+e^-, (Alioli, Bauer, Berggren, Hornig, Tackmann, Vermilion, Walsh, Zuberi, 2012) ; GENERAL THEORY AVAILABLE (Alioli, Bauer, Berggren, Tackmann, Walsh, Zuberi, 2013)
  - NNLOPS: FULL NLO+NLL ACCURACY ACHIEVED FOR H/W/Z+0/1 JET (Hamilton, Nason, Oleari, Zanderighi, 2012); NNLO+NLL ACHIEVED FOR HIGGS IN GLUON FUSION (Hamilton, Nason, Re, Zanderighi, 2013)

GLUON FUSION: MATCHED RESULTS

THE NNLOPS APPROACH

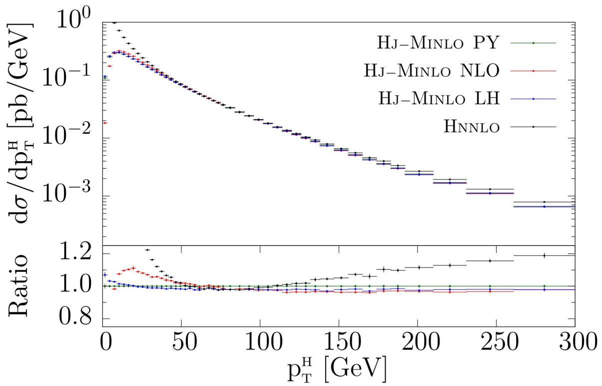
(Hamilton, Nason, Re, Zanderighi, 2013)

- NLO+NLL PRESERVED IN MATCHING TO SHOWER THANKS TO MINLO METHOD

GLUON FUSION: MATCHED RESULTS

THE NNLOPS APPROACH

NLOPS VS NLO & SHOWERING



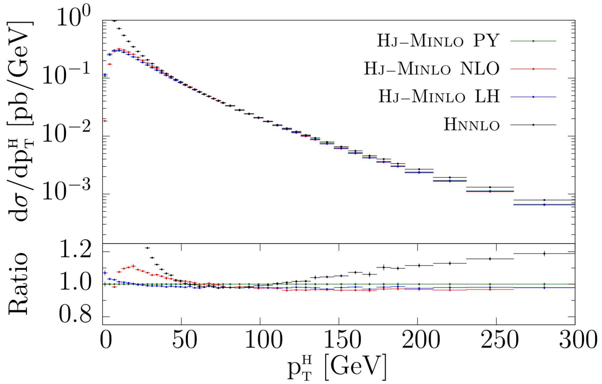
(Hamilton, Nason, Re, Zanderighi, 2013)

- NLO+NLL PRESERVED IN MATCHING TO SHOWER THANKS TO MINLO METHOD
- FIXED ORDER (HNNLO) FAILS AT LOW p_T (NO RESUMMATION) AND HIGH p_T DUE TO FIXED (LOW) FACT. SCALE
  ENHANCED FIXED ORDER OK AT LARGE P_t;
  PARTON LEVE RESUMMED VERY CLOSE TO FINAL PYTHIA SHOWERED RESULT

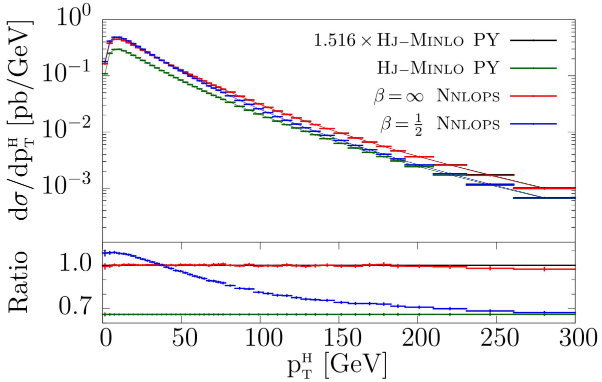
GLUON FUSION: MATCHED RESULTS

THE NNLOPS APPROACH

NLOPS VS NLO & SHOWERING



NNLOPS VS NLOPS



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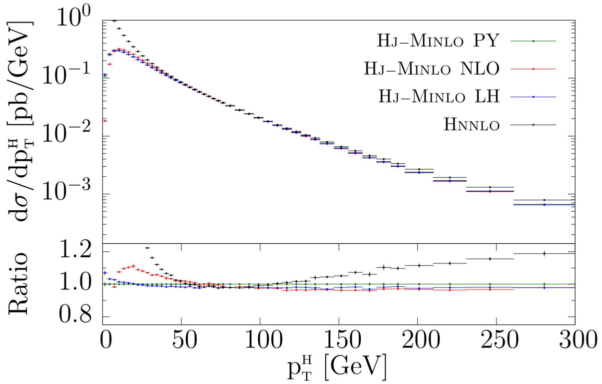
- NNLO ACCURACY OBTAINED BY REWEIGHTING; FURTHER MADE p_T DEPENDENT

GLUON FUSION: MATCHED RESULTS

THE NNLOPS APPROACH

NLOPS VS NLO & SHOWERING



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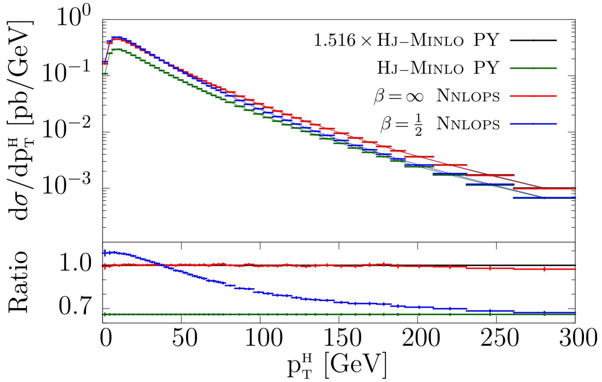
NNLOPS VS NLOPS



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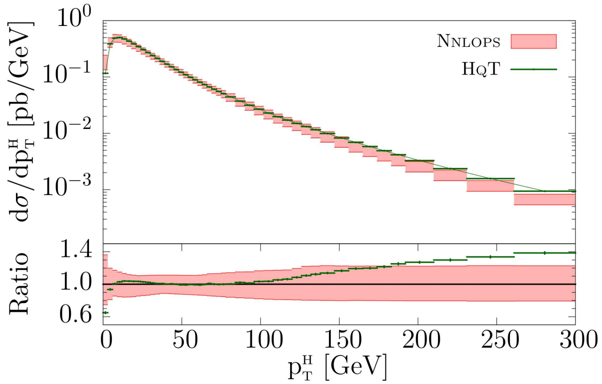
NNLOPS VS NNLL



- NNLO ACCURACY OBTAINED BY REWEIGHTING; FURTHER MADE p_T DEPENDENT

- GOOD AGREEMENT WITH ANALYTIC p_T RESUMMATION (HQ_T)

SUMMARY

- STEADFAST PROGRESS
  - RESUMMATION
  - $2 \to 2$ AT NNO
  - TOWARDS N^3LO RESUMMATION WITH FINAL STATES
- PHENOMENOLOGICAL CHALLENGES
  - PDFS
  - & $\alpha_s \Rightarrow$ A SHOW-STOPPER?
- NEW THEORETICAL IDEAS
  - SPIN CORRELATIONS
  - INTERFEROMETRY
- STRETCHING THE THEORY
  - MULTISCALE RESUMMATION
  - MATCHING TO MONTE CARLO

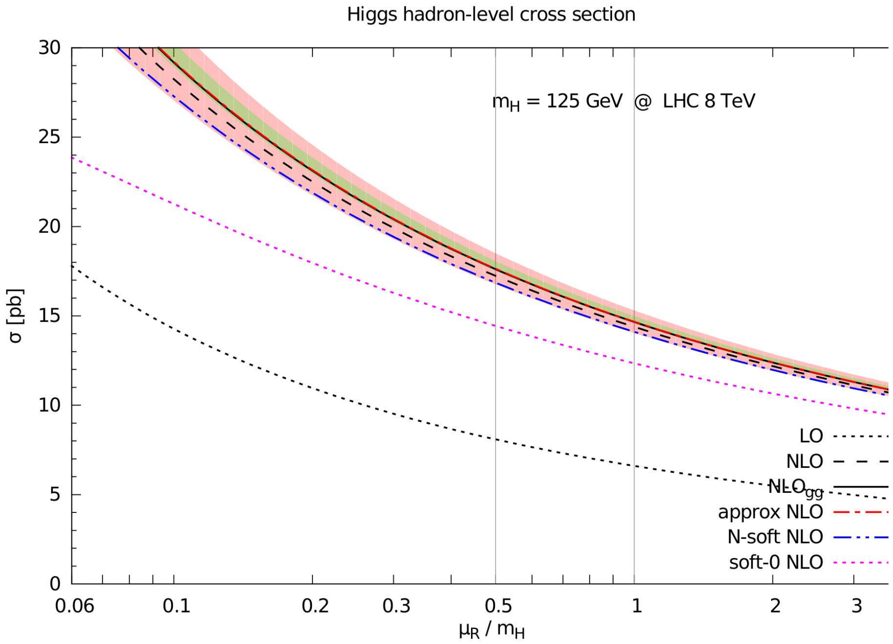
"...the period of the famous triumph of quantum field theory. And what a triumph it was, in the old sense of the word: a glorious victory parade, full of wonderful things brought back from far places to make the spectator gasp with awe and laugh with joy" (Sydney Coleman, 1988)

EXTRAS

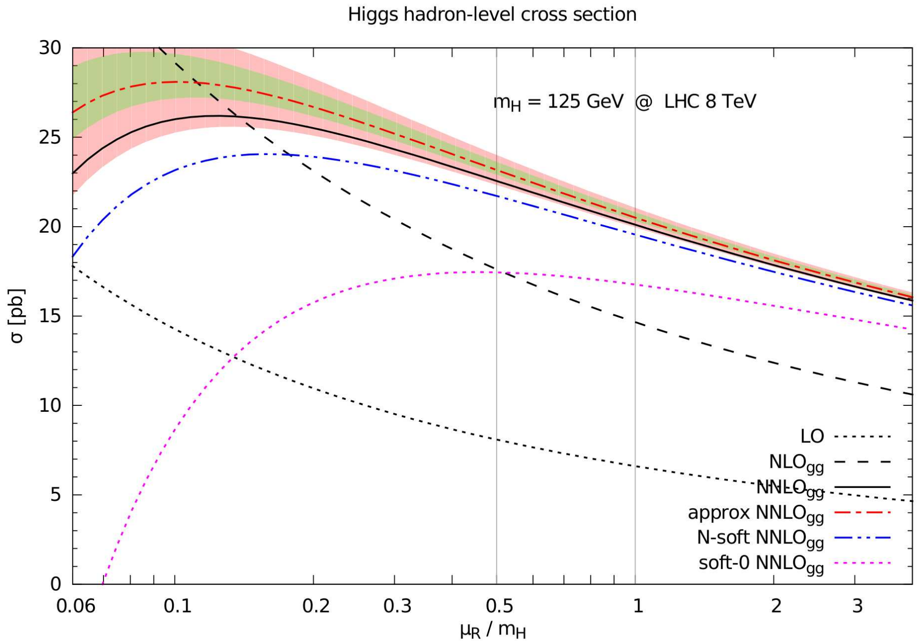
APPROXIMATE N^3LO RESULTS
LOWER ORDERS

- APPROX MATCHED LARGE-SMALL N RESUMMATION + ANALITICITY $\Rightarrow$ OPTIMAL
- N-SOFT EXPANDED RESUMMATION $\Rightarrow$ FAIR
- SOFT-0 x-SPACE RESUMMATION $\Rightarrow$ BAD
  x-SPACE RESUMMATION VIOLATES MOMENTUM CONSERVATION BY SUBLEADING TERMS
  (Catani, Mangano, Nason, Trentadue, 1996)

NLO

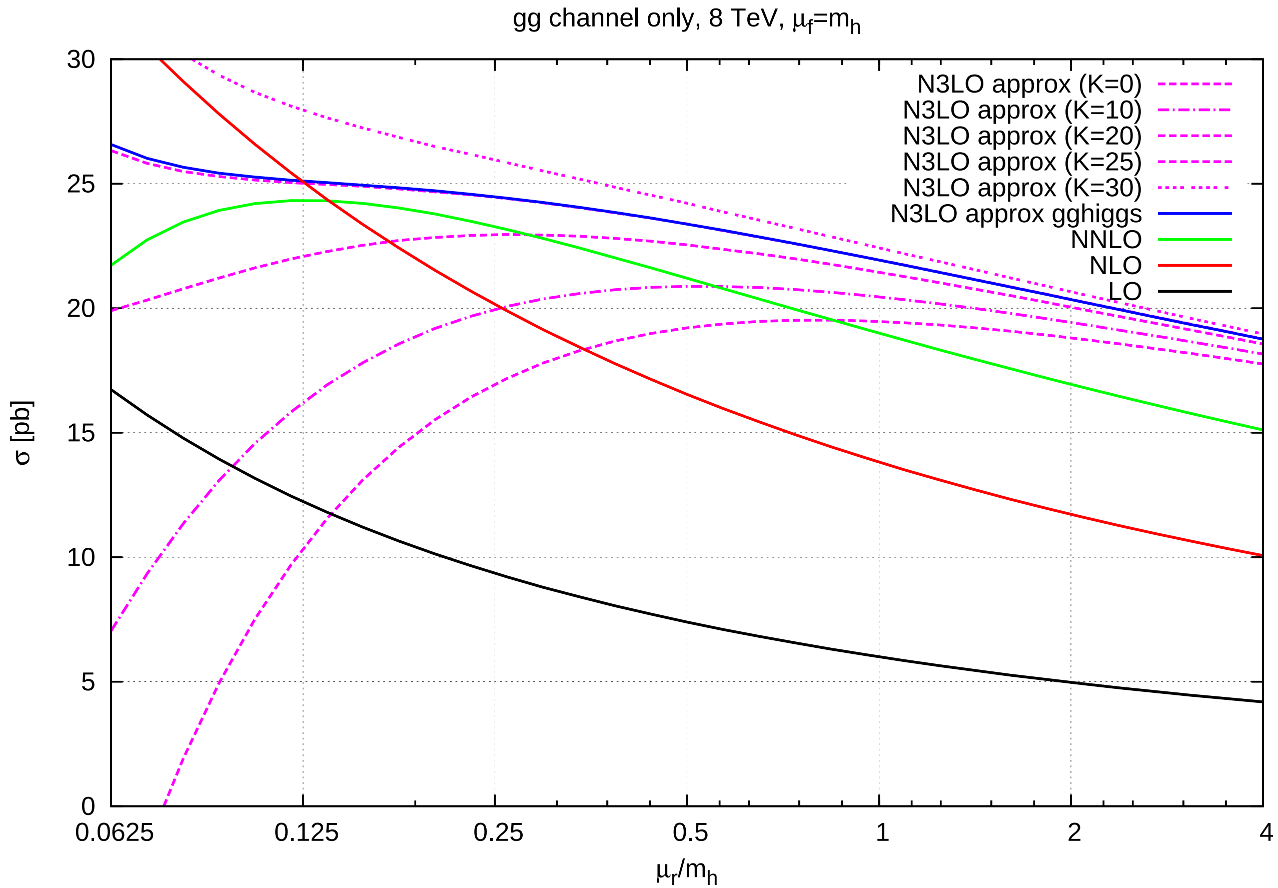


NNLO



APPROXIMATE N^{3}LO RESULTS

RENORMALIZATION SCALE DEP.



- APPROXIMATE RESULT CLOSE TO THAT FOUND ASSUMING THAT SCALE DEP AT N^{3}LO IS WEAKER THAN AT NNLO
- ESSENTIALLY COINCIDES WITH THAT DERIVED FROM SIMPLE PROPORTIONALITY WITH $K = 25$ DEP. DETERMINED ASSUMING $K = 25$;