NLO QCD corrections to WWbb production with leptonic decays in the light of top quark asymmetries

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Work in collaboration with Gudrun Heinrich and Jan Winter

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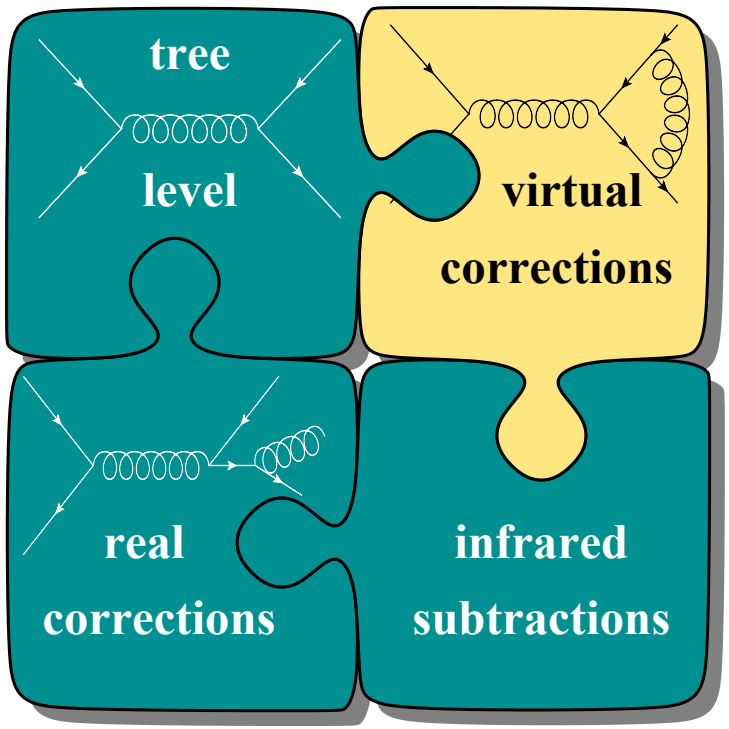
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Overview

1. The one-loop amplitude generator GoSam
2. The Binoth Les Houches Accord
3. The process $pp \to W^+W^-b\bar{b}$ at NLO
4. Top mass measurements with the observable m_{lb}
5. Top quark asymmetries

Parts of a NLO calculation



- tree level amplitude
- real corrections
- infrared subtraction terms

→ Monte-Carlo event generator (MC)

- virtual corrections

→ One-loop amplitude provider (OLP)

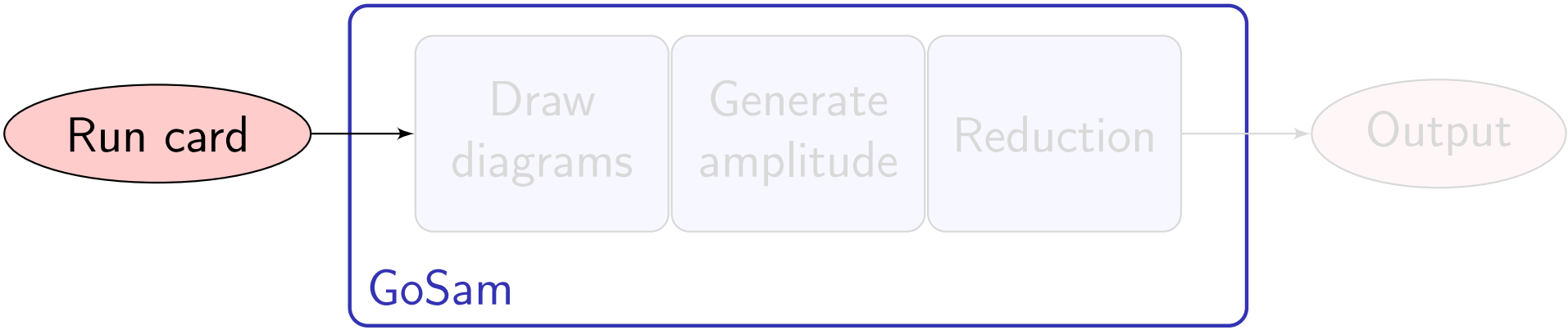
In this calculation:

MC: Sherpa Gleisberg, Höche, Krauss, Schönherr, Schumann, Siegert, Winter, Zapp

OLP: GoSam Cullen, Greiner, Heinrich, Luisoni, Mastrolia, Ossola, Reiter, Tramontano (2011)

GoSam

Cullen, Greiner, Heinrich, Luisoni, Mastrolia, Ossola, Reiter, Tramontano (2011)



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- Feynman diagram topologies are generated with QGRAF Nogueira (1993)
- Integrand is generated with FORM Vermaseren (1984 -) and Fortran code is produced
- Integrand reduction can be chosen at runtime: Samurai (D-dimensional OPP) Mastrolia, Ossola, Reiter, Tramontano (2010), Golem95c (Tensor-reduction) Binoth, Cullen, Guillet, Heinrich, Kleinschmidt, Pilon, Reiter, Rodgers, von Soden-Fraunhofen (2005 -)
- Evaluation of scalar master integrals with OneLOop van Hameren (2010), QCDLoop Ellis, Zanderighi (2007), LoopTools Hahn, Perez-Victoria (1998) or Golem95c

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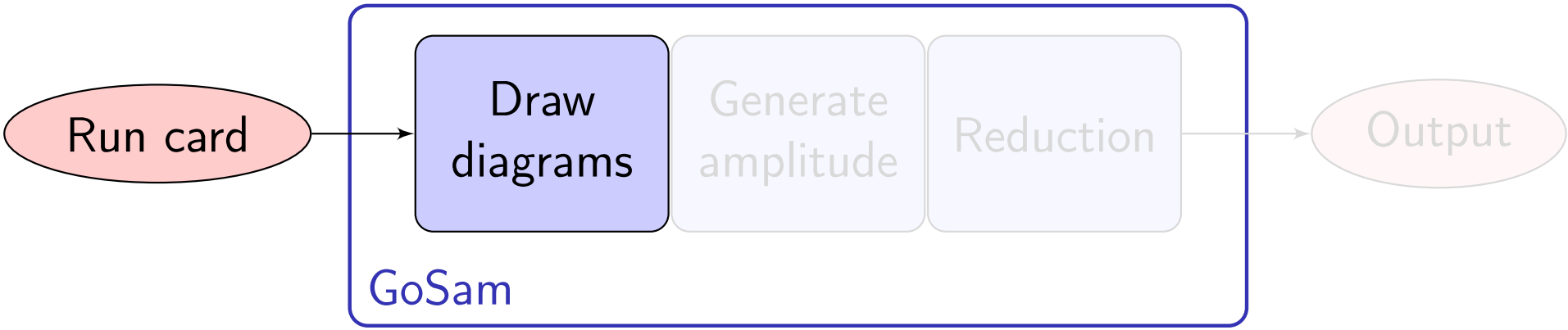

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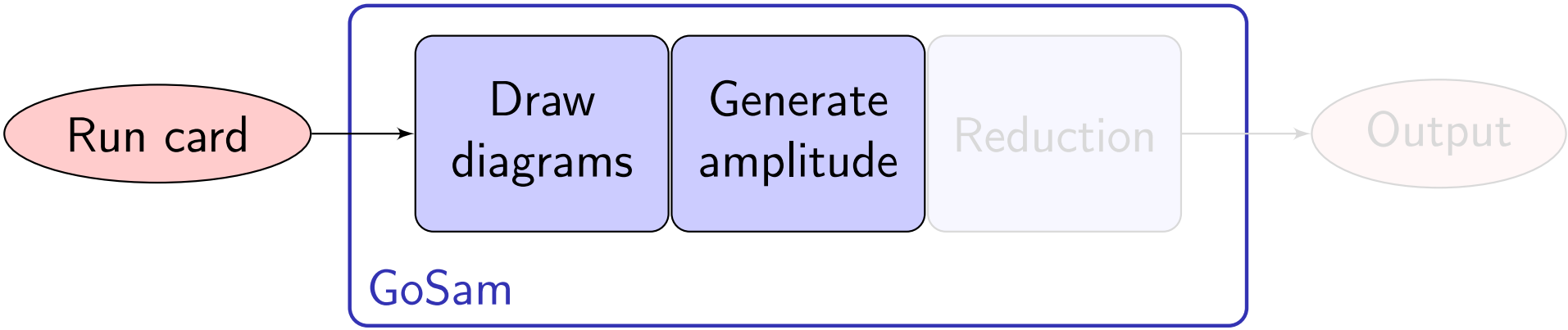

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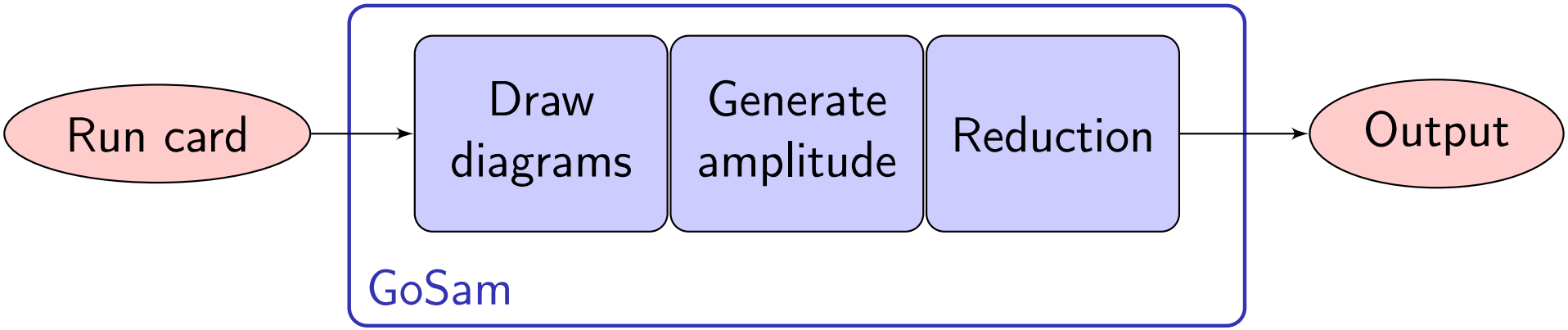

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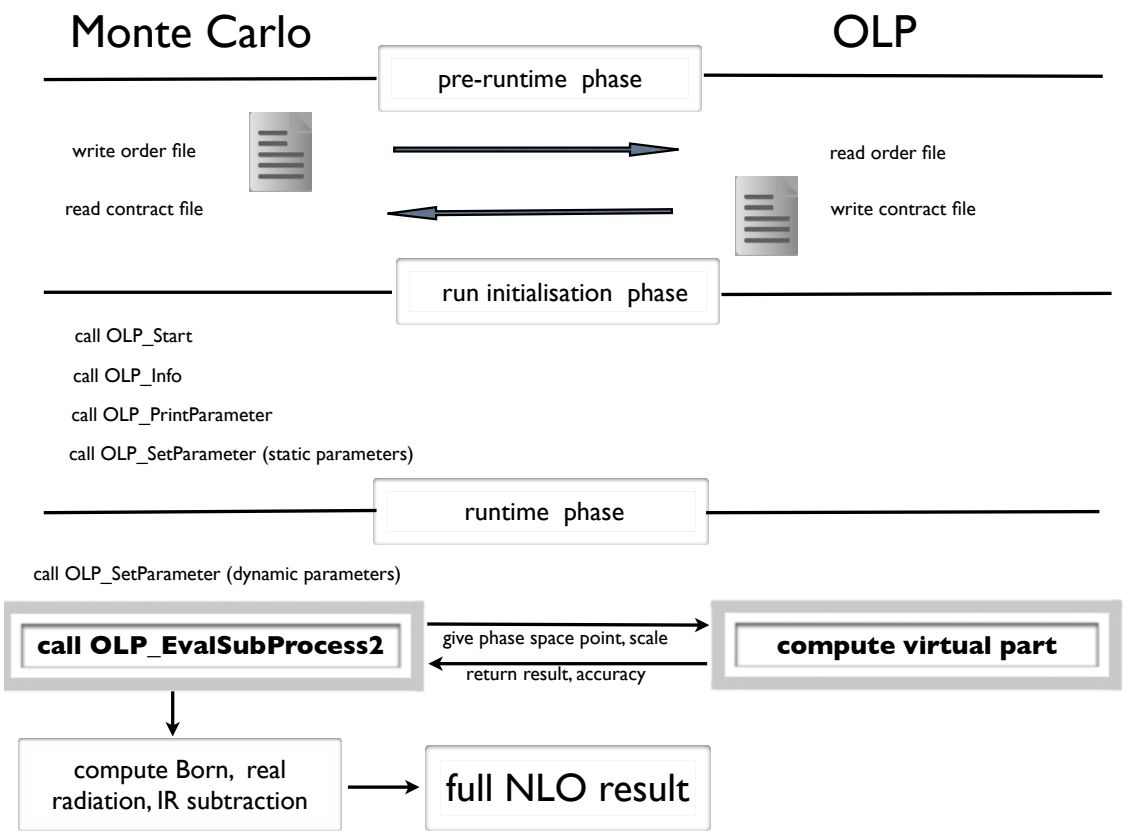
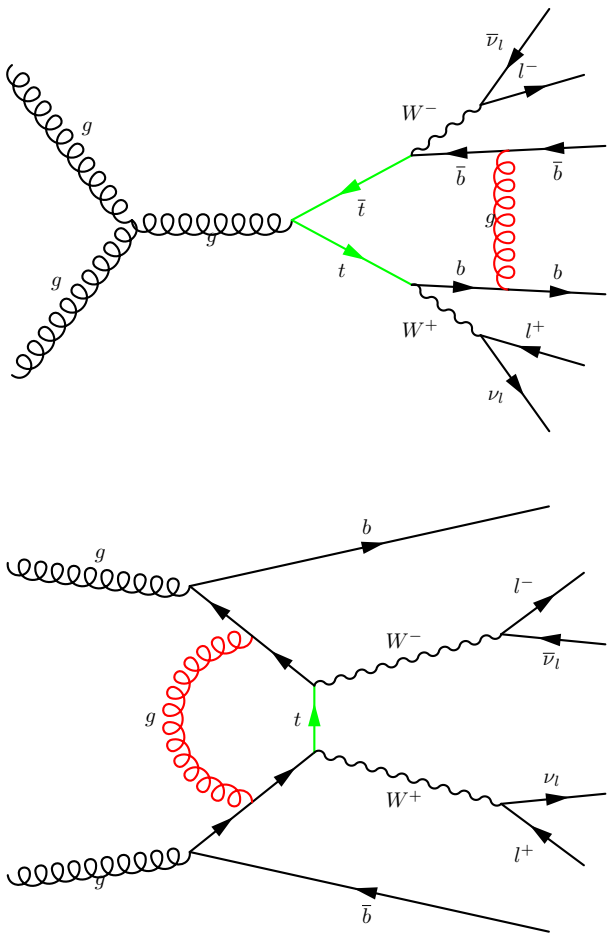
The Binoth Les Houches Accord



Binoth et al. (2010) Alioli et al. (2013)

- Interface between Monte-Carlo program (MC) and one-loop amplitude provider (OLP)
- Divided in initialization and runtime phase
- The interface is implemented in GoSam and Sherpa
- Recent update introduces new functionalities including passing of parameters and accuracy estimates at runtime

The process $pp \to W^+W^-b\bar{b}$



- Top quark pair production and decay including nonresonant contributions
- Both W bosons decay into leptons
- The approximation $m_b = 0$ is made
- First calculated at NLO by Denner, Dittmaier, Kallweit, Pozzorini (2011) and Bevilacqua, Czakon, van Hameren, Papadopoulos, Worek (2011)
- Previous top quark calculations were done under the assumption that production and decay factorise (neglects contributions suppressed by powers of $\frac{\Gamma_t}{m_t} \sim 0.02$) Biswas, Melnikov, Schulze (2010)
- NNLO corrections to production of stable top quarks were calculated recently Czakon, Fiedler, Mitov (2013)

The process $pp \to W^+W^-b\bar{b}$

- Four subprocesses:

	Diagrams	Hel.	$t/PS[ms]$
$u\bar{u}$	$14 + 334$	4	53
$d\bar{d}$	$14 + 334$	4	52
$b\bar{b}$	$28 + 668$	4	141
gg	$31 + 1068$	8	859

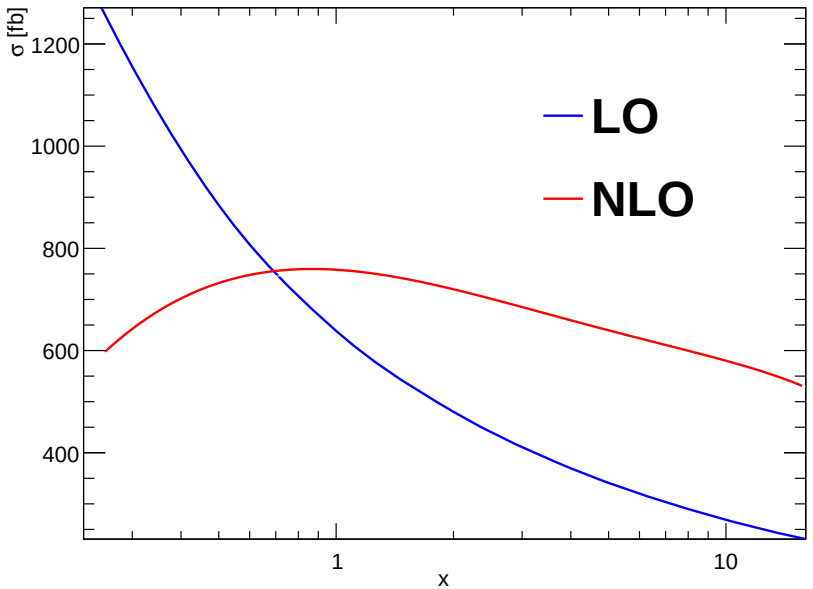
- Complex mass for top quarks: $m_t^2 \to m_t^2 - im_t\Gamma_t$
  Necessary integrals included in Golem95c
- Checks on the result:
  - Virtual amplitude agrees with Denner, Dittmaier, Kallweit, Pozzorini (2012) for given phase-space point
  - Comparison of total cross-section with Denner, Dittmaier, Kallweit, Pozzorini (2012) gives good agreement
  - Cross-section is stable under variation of α_{dipole}

Cross section

Renormalization scale:

$$\mu = \frac{H_T}{2} = \frac{1}{2}\sum_i p_{T,i}$$

Scalar sum over transverse momenta of all final state particles



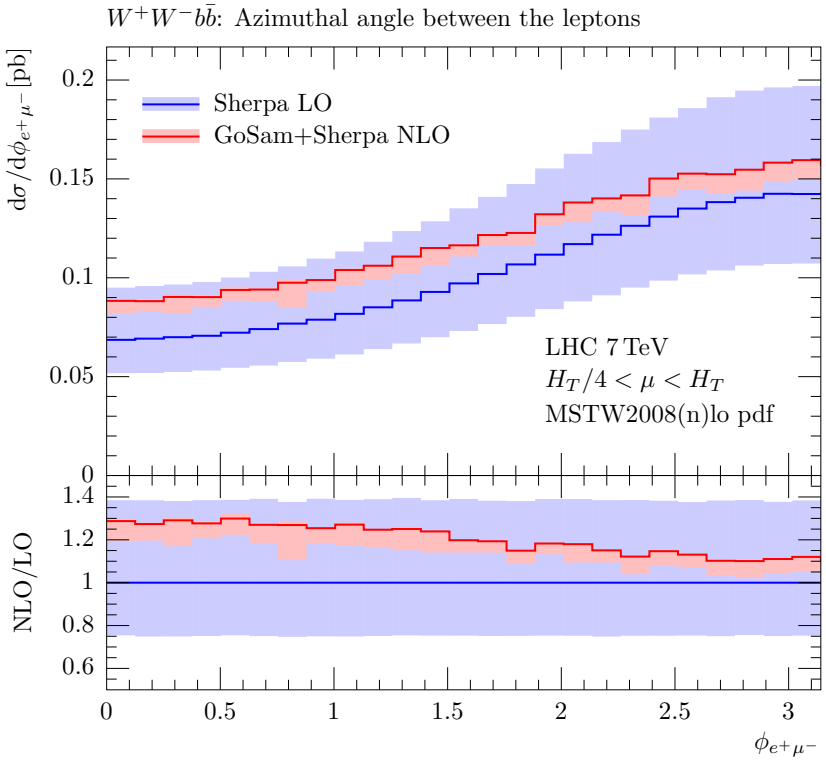
$$x = \frac{\mu}{H_T/2}$$

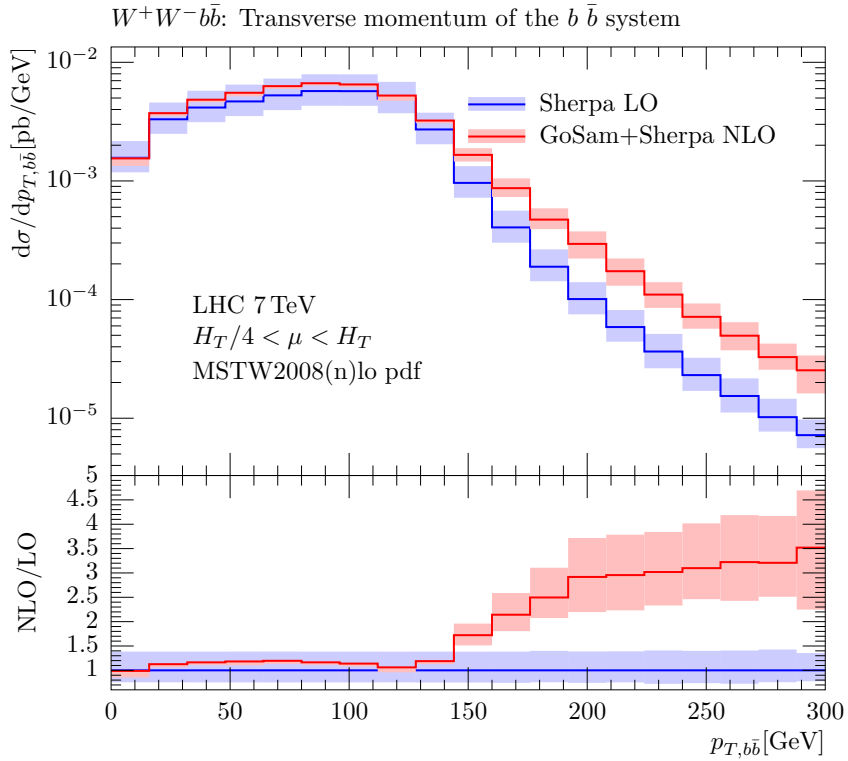
Total cross section (LHC 7 *TeV*):

$$\sigma_{\mathrm{LO}}[\mathrm{fb}] = 638.5^{+38.5\%}_{-24.8\%}(\mathrm{scale}) \pm 0.014\%(\mathrm{stat.})$$

$$\sigma_{\mathrm{NLO}}[\mathrm{fb}] = 757.3^{-3.0\%}_{-5.4\%}(\mathrm{scale}) \pm 0.3\%(\mathrm{stat.})$$

NLO distributions



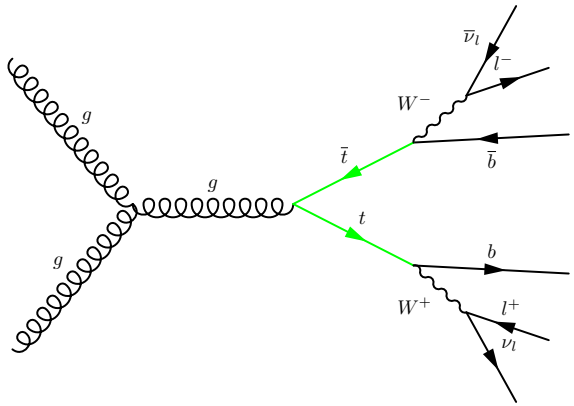


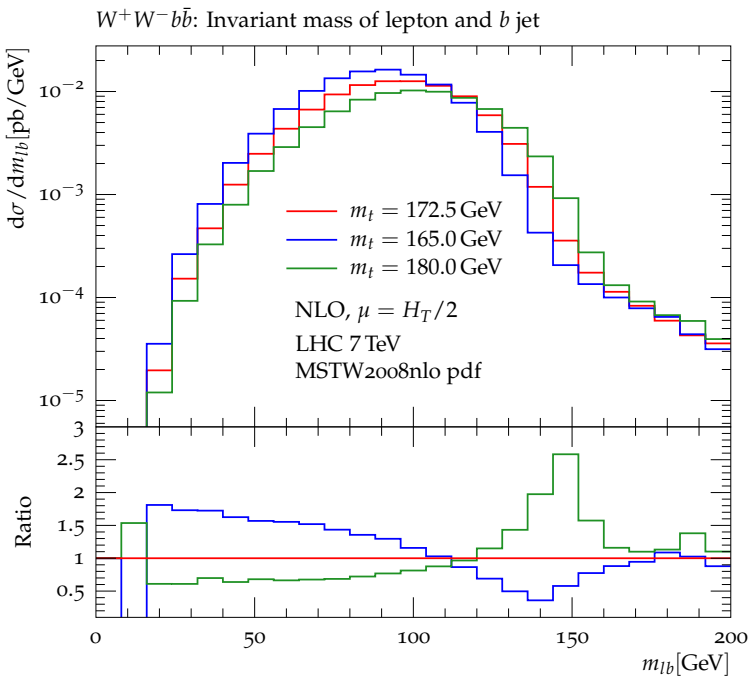
Cuts:

B-Jets: anti-kT algorithm with $\Delta R > 0.5$, $p_{T,b} > 30$ *GeV and* $|\eta_b| < 2.5$
Leptons: $p_{T,l} > 20$ *GeV,* $|\eta_l| < 2.5$ *and* $p_{T,miss} > 20$ *GeV*

- $\Phi_{e^+\mu^-}$ is relevant for the measurement of spin correlations
- Large K-factor in $p_{T,b\bar{b}}$ because the top pair can recoil from the real radiation at NLO

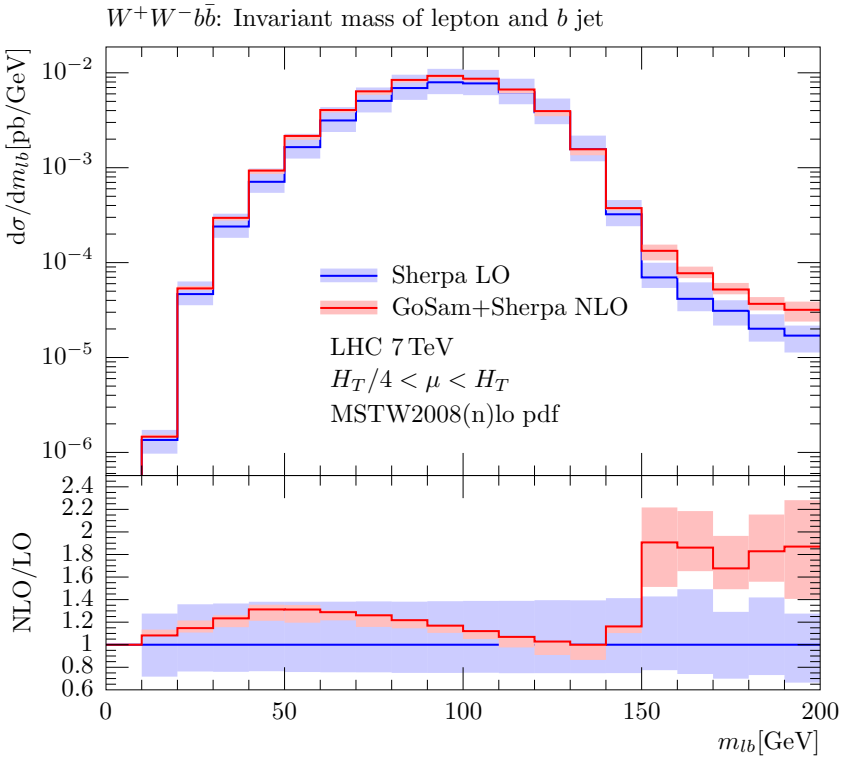
Invariant mass of b-jet and lepton m_{lb}





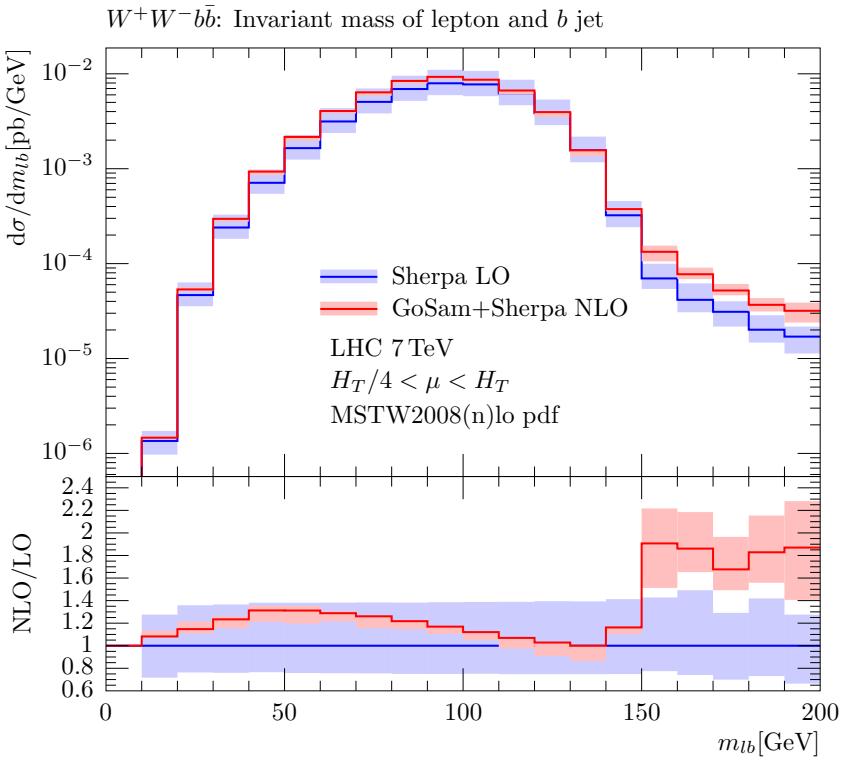
- Definition: $m_{lb} = (p_{\text{b-jet}} + p_l)^2$
- NLO calculations for different top masses
- Distribution is sensitive to the value of the top quark mass
- Template fit for precision measurement of the top quark mass
- Analysis and cuts according to ATLAS measurement described in ATLAS-CONF-2013-077

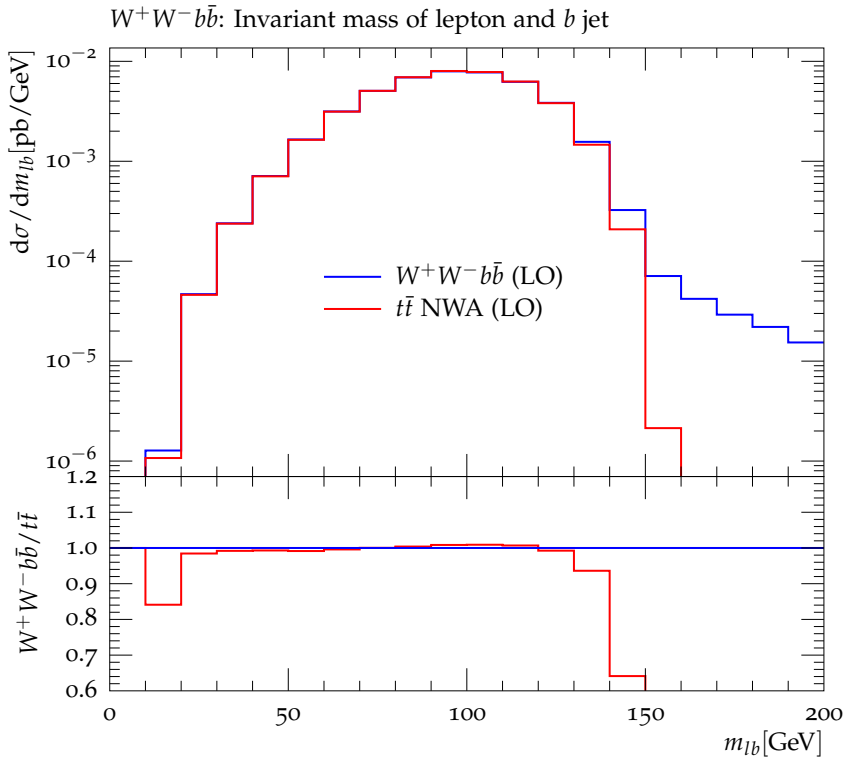
m_{lb} at NLO



- Important NLO corrections to the shape of m_{lb}

m_{lb} at NLO





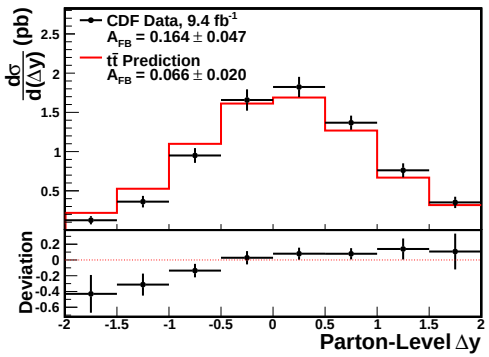
- Important NLO corrections to the shape of m_{lb}
- Values of m_{lb} larger than $\sqrt{m_t^2 - m_W^2}$ are kinematically forbidden in narrow width approximation at LO

Top quark asymmetries

Top quark forward-backward asymmetry at Tevatron

$$A_{t\bar{t}}^{FB} = \frac{\sigma\left(\Delta y > 0\right) - \sigma\left(\Delta y < 0\right)}{\sigma\left(\Delta y > 0\right) + \sigma\left(\Delta y < 0\right)}$$

$$\Delta y = y_t - y_{\bar{t}}$$

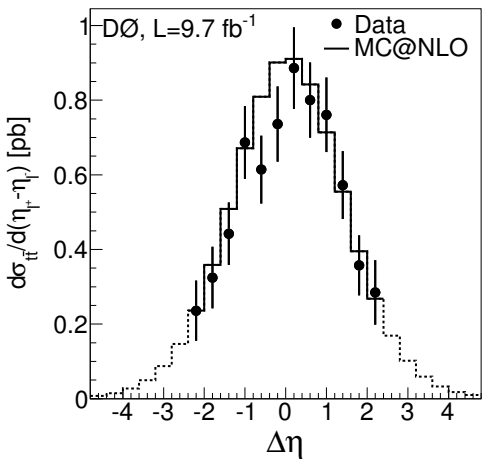


CDF [1211.1003]

Leptonic asymmetry

$$\Delta y \to \Delta\eta = \eta_{l^+} - \eta_{l^-}$$

Partly inherits Δy effect, no dependence on reconstruction



DØ [1308.6690]

- Discrepancy between Tevatron data and SM predictions
- Asymmetries are zero for LO top quark production

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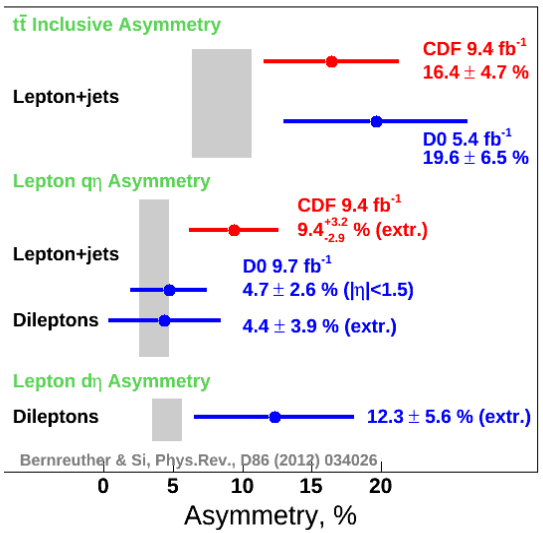
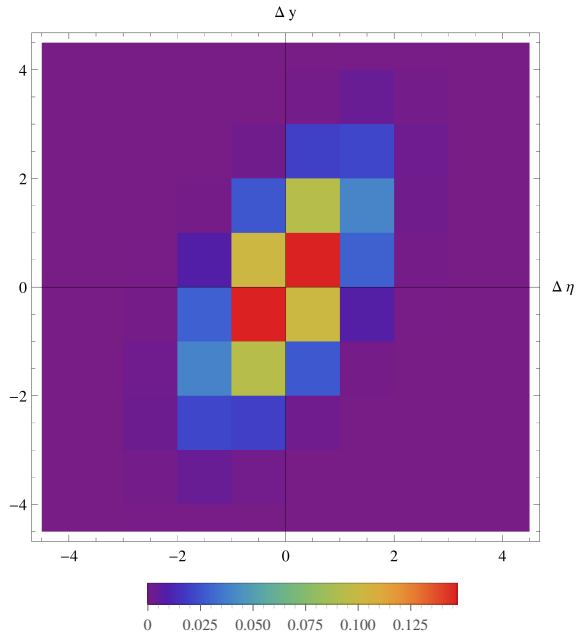


Talk of V. Sharyy at TOP2013

Correlation between Δy and $\Delta\eta$



$$\frac{1}{\sigma_{\mathbf{LO}}}\frac{\mathrm{d}\sigma_{\mathbf{LO}}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta y}$$

Cuts:

B-Jets: anti-kT algorithm with $\Delta R > 0.4$, $p_{T,b} > 20$ *GeV and* $|\eta_b| < 2.5$
Leptons: $p_{T,l} > 20$ *GeV,* $|\eta_l| < 2.5$ *and* $p_{T,miss} > 25$ *GeV*

- LO distribution is symmetric
- NLO corrections shift Δy in positive direction and induce shift in $\Delta\eta$

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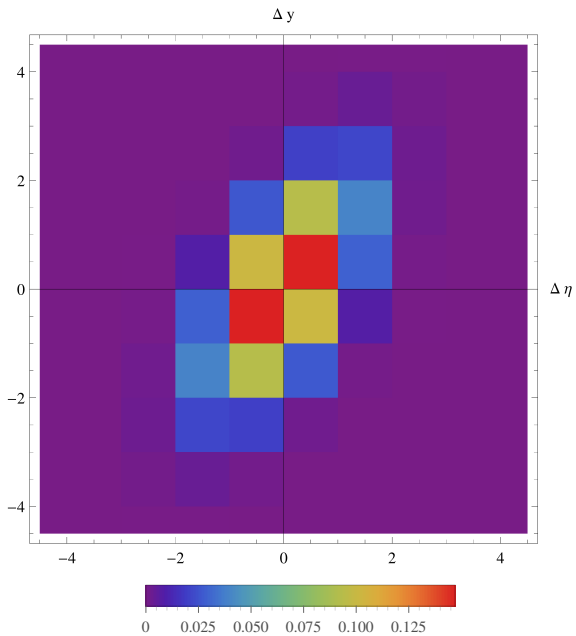

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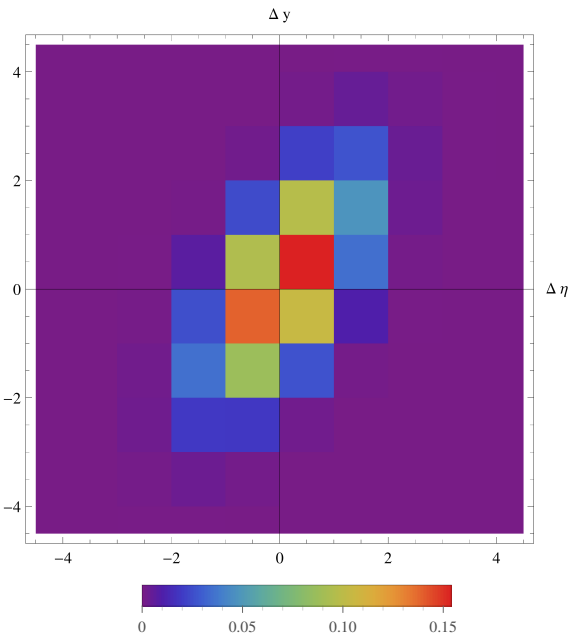

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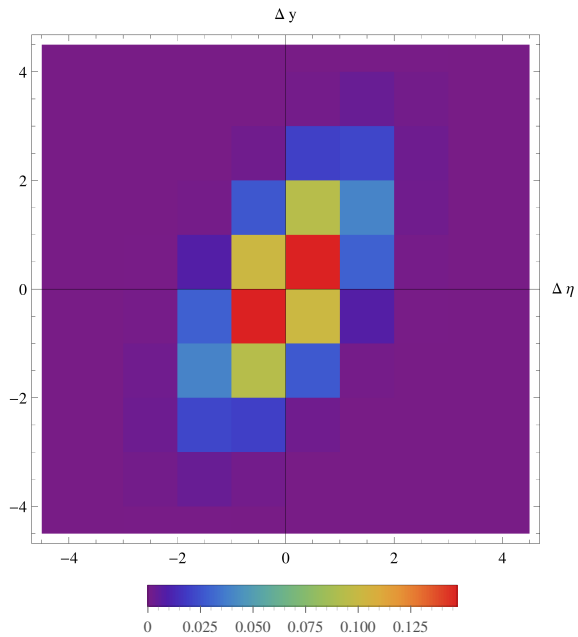

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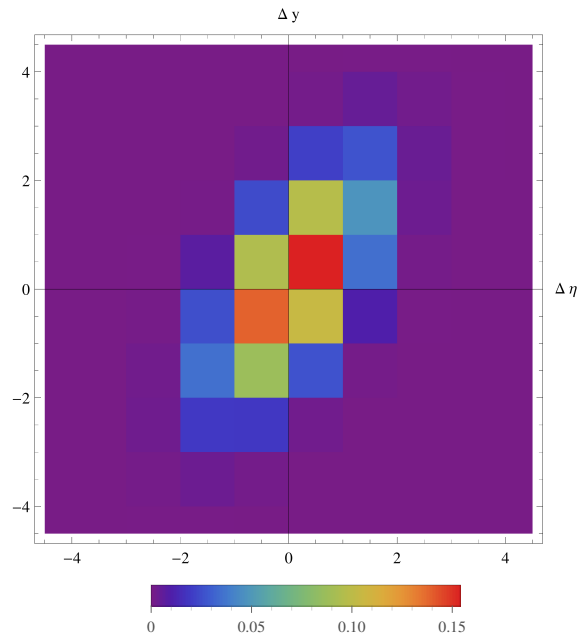

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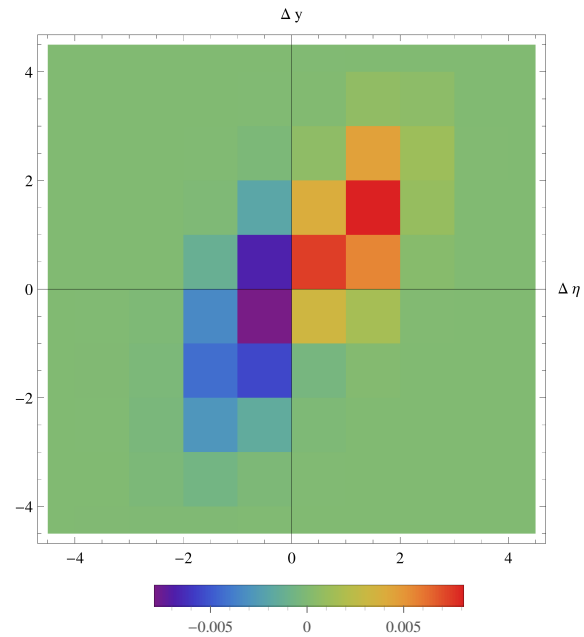

$$\frac{1}{\sigma_{\mathbf{NLO}}}\frac{\mathrm{d}\sigma_{\mathbf{NLO}}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta y} - \frac{1}{\sigma_{\mathbf{LO}}}\frac{\mathrm{d}\sigma_{\mathbf{LO}}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta y}$$

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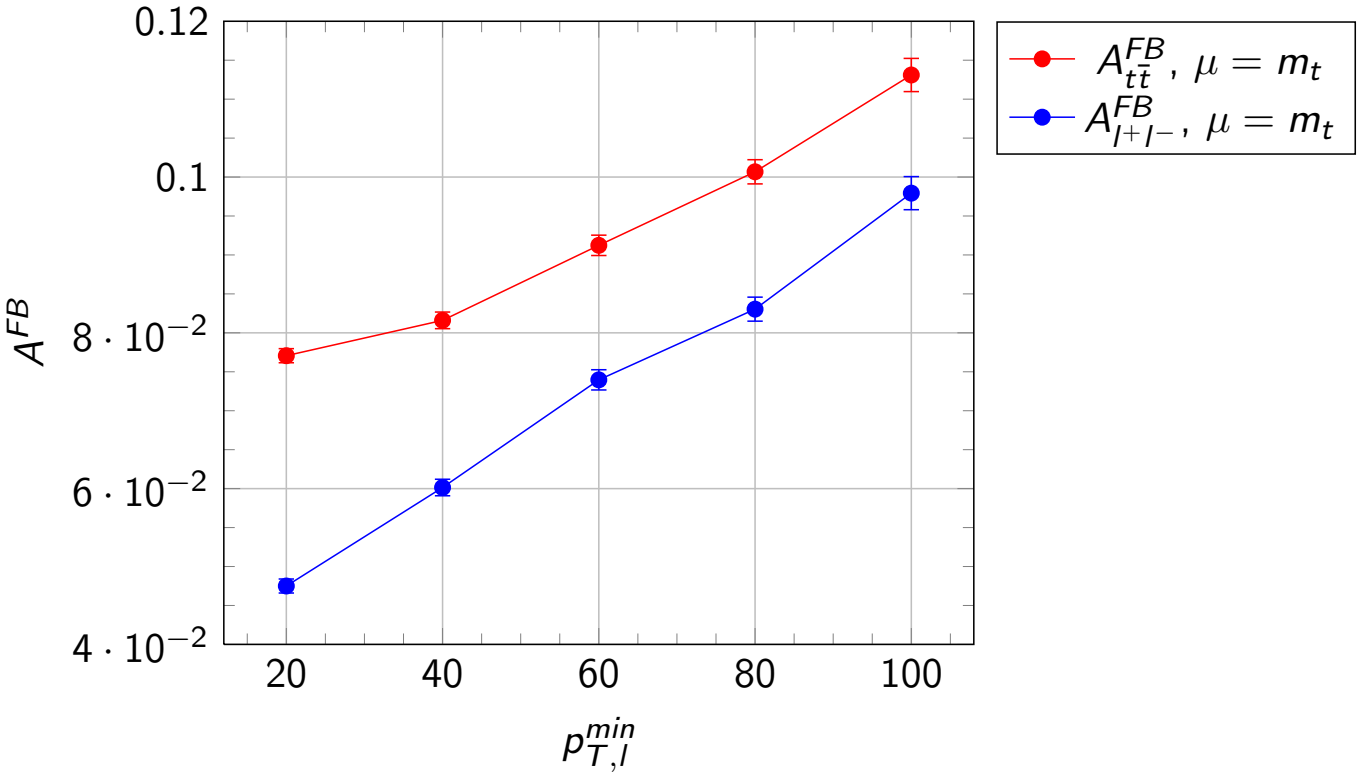

$\mu = m_t$

- Stronger correlation between $A_{t\bar{t}}^{FB}$ and $A_{l^+l^-}^{FB}$ at high $p_{T,l}^{min}$
- Change of $A_{t\bar{t}}^{FB}$ depends on scale choice

Falkowski, Mangano, Martin, Perez, Winter (2012)

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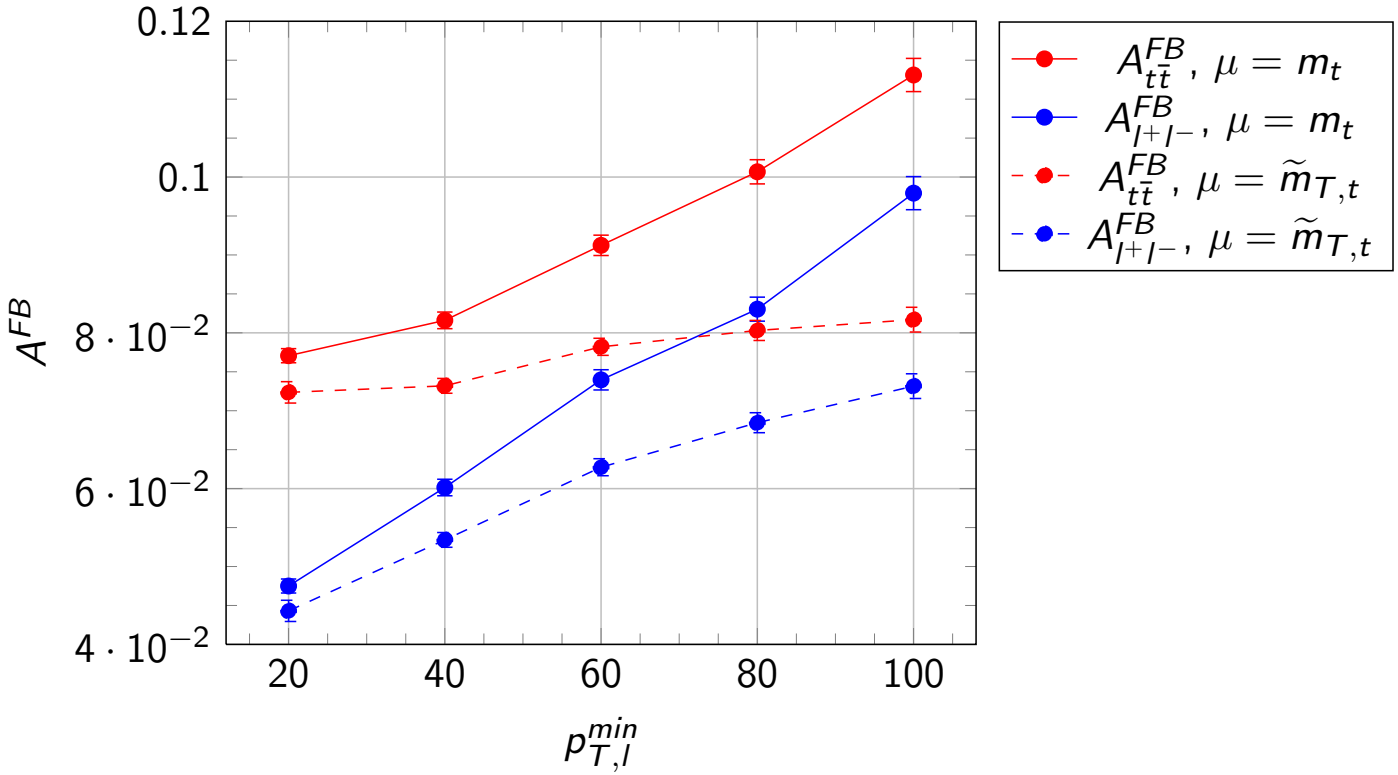

$$\mu = m_t$$

$$\mu = \widetilde{m}_{T,t} = \sqrt{m_t^2 + p_{T,\text{leading jet}}^2}$$

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Conclusions

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- The Binoth Les Houches Accord: A standard interface for the communication between Monte-Carlo and one-loop provider
- Application of GoSam and Sherpa to the calculation of $pp \to W^+W^-b\bar{b}$ including full off-shell effects of the top quarks
  - The observable m_{lb}: Precision top quark mass determination
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