The Top Mass: Interpretation

and

Theoretical Uncertainties

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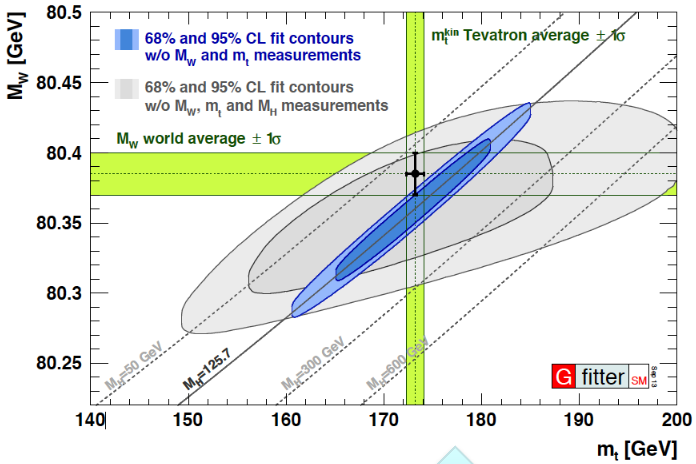
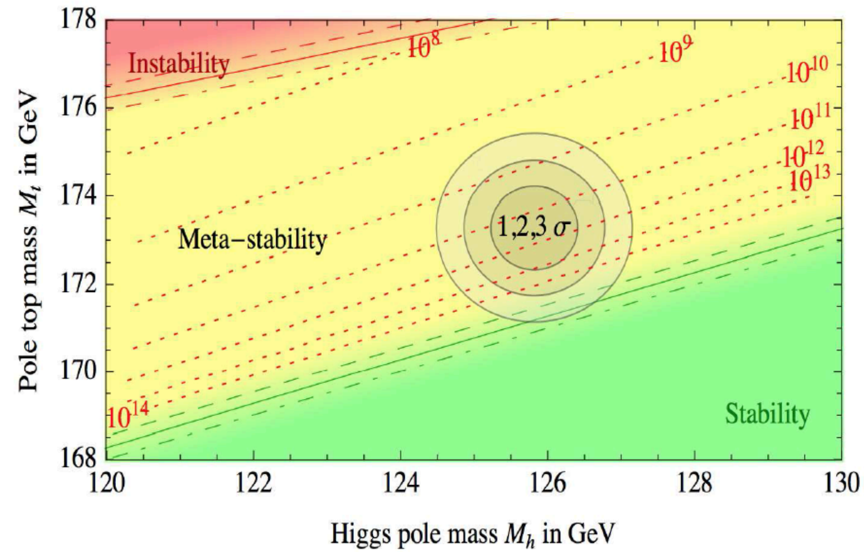
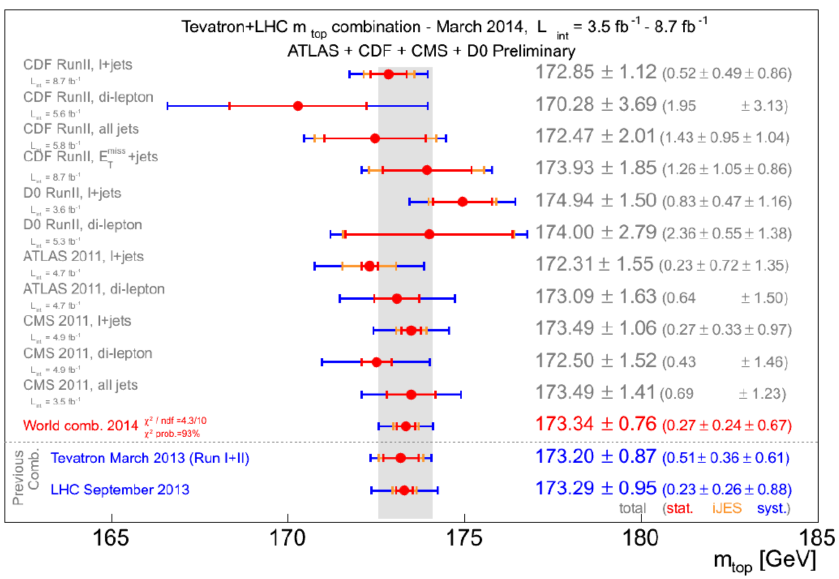
CERN Theory Seminar, May 21, 2014

Motivation



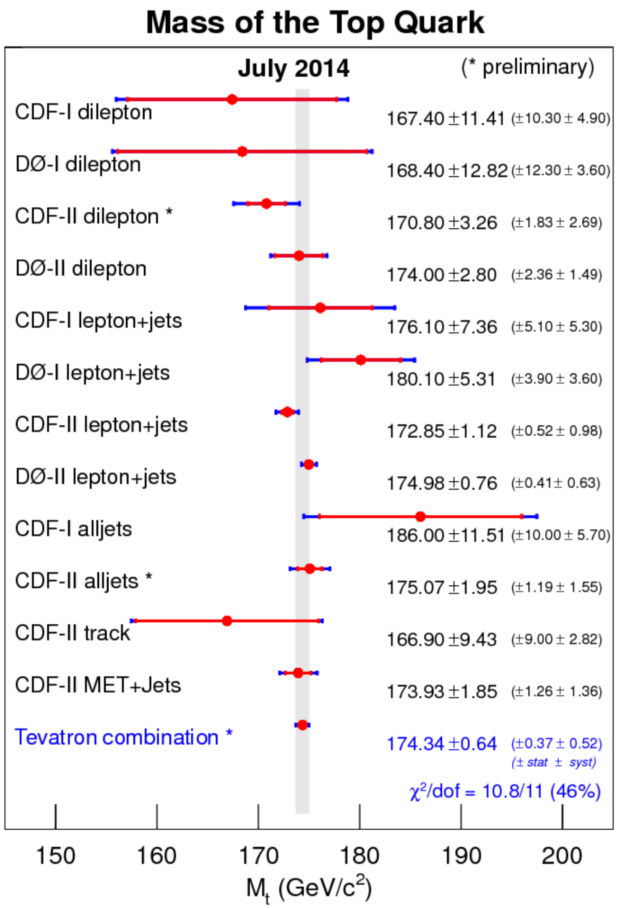


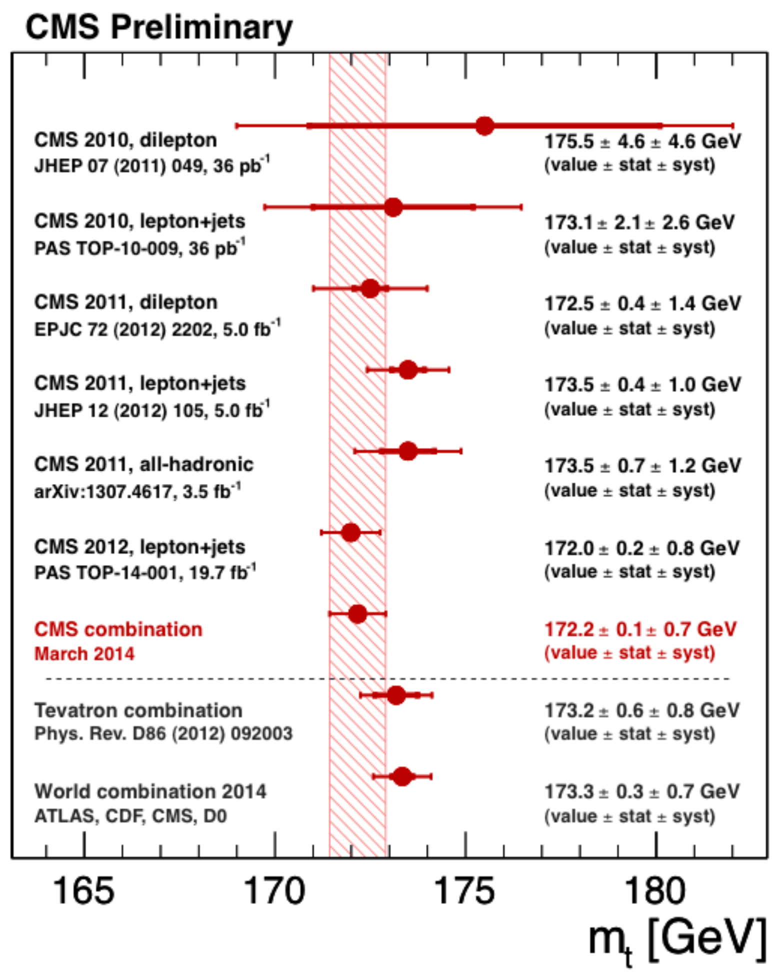


Aims: m_{top} wanted !

- Reduce error in m_{top}(MC)
- Clarify mass scheme m_{top}(MC)
- Improve / understand better MC

Motivation


Mass of the Top Quark
July 2014
(* preliminary)
CDF-I dilepton 167.40 ±11.41 (±10.30 ± 4.90)
DØ-I dilepton 168.40 ±12.82 (±12.30 ± 3.60)
CDF-II dilepton * 170.80 ±3.26 (±1.83 ± 2.69)
DØ-II dilepton 174.00 ±2.80 (±2.36 ± 1.49)
CDF-I lepton+jets 176.10 ±7.36 (±5.10 ± 5.30)
DØ-I lepton+jets 180.10 ±5.31 (±3.90 ± 3.60)
CDF-II lepton+jets 172.85 ±1.12 (±0.52 ± 0.98)
DØ-II lepton+jets 174.98 ±0.76 (±0.41 ± 0.63)
CDF-I alljets 186.00 ±11.51 (±10.00 ± 5.70)
CDF-II alljets * 175.07 ±1.95 (±1.19 ± 1.55)
CDF-II track 166.90 ±9.43 (±9.00 ± 2.82)
CDF-II MET+Jets 173.93 ±1.85 (±1.26 ± 1.36)
Tevatron combination * 174.34 ±0.64 (±0.37 ± 0.52)
(± stat ± syst)
χ^2/dof = 10.8/11 (46%)
150 160 170 180 190 200
M_t (GeV/c^2)


CMS Preliminary
CMS 2010, dilepton
JHEP 07 (2011) 049, 36 pb^{-1}
175.5 ± 4.6 ± 4.6 GeV
(value ± stat ± syst)
CMS 2010, lepton+jets
PAS TOP-10-009, 36 pb^{-1}
173.1 ± 2.1 ± 2.6 GeV
(value ± stat ± syst)
CMS 2011, dilepton
EPJC 72 (2012) 2202, 5.0 fb^{-1}
172.5 ± 0.4 ± 1.4 GeV
(value ± stat ± syst)
CMS 2011, lepton+jets
JHEP 12 (2012) 105, 5.0 fb^{-1}
173.5 ± 0.4 ± 1.0 GeV
(value ± stat ± syst)
CMS 2011, all-hadronic
arXiv:1307.4617, 3.5 fb^{-1}
173.5 ± 0.7 ± 1.2 GeV
(value ± stat ± syst)
CMS 2012, lepton+jets
PAS TOP-14-001, 19.7 fb^{-1}
172.0 ± 0.2 ± 0.8 GeV
(value ± stat ± syst)
CMS combination
March 2014
172.2 ± 0.1 ± 0.7 GeV
(value ± stat ± syst)
Tevatron combination
Phys. Rev. D86 (2012) 092003
173.2 ± 0.6 ± 0.8 GeV
(value ± stat ± syst)
World combination 2014
ATLAS, CDF, CMS, D0
173.3 ± 0.3 ± 0.7 GeV
(value ± stat ± syst)
165 170 175 180
m_t [GeV]

Outline

Part 1: $\rightarrow$ Theoretical considerations on $m_t^{\rm MC}$

$\rightarrow$ "What is the physics MC mass ?" $\leftarrow$

- How $m_t^{\rm MC}$ is related to field theoretic masses.

Part 2: $\rightarrow$ Method to determine $m_t^{\rm MC}$

- Variable Flavor Number Scheme for final state jets.
  Full massive event shape distribution
- First encouraging preliminary results

QCD Parameters

QCD Lagrangian: $\mathcal{L}_{\rm QCD} = \mathcal{L}_{\rm classic} + \mathcal{L}_{\rm gauge-fix} + \mathcal{L}_{\rm ghost}$

$$\mathcal{L}_{\rm classic} = -\frac{1}{4} F^A_{\alpha\beta} F^{\alpha\beta}_A + \sum_{\text{flavors } q} \bar{q}_\alpha (i\not{D} - m_q)_{\alpha\beta}\, q_b$$

$$D^\mu = \partial^\mu + igT^C A^{\mu C}$$

Formally $m_{\rm top}$ and α_s are couplings of the Lagrangian.

$m^0_{\rm top}\,,\quad \alpha^0_s$

- $\rightarrow$ bare UV-divergent
- $\rightarrow$ field theoretically unique
- $\rightarrow$ pure UV-object – NO IR dependence

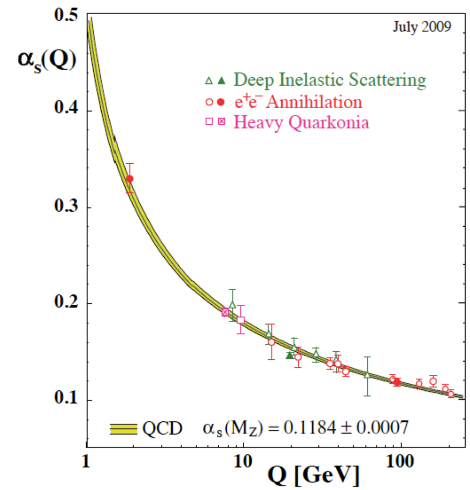
$m^R_{\rm top}\,,\quad \alpha^R_s$

- $\rightarrow$ renormalized UV-finite
- $\rightarrow$ renormalization scheme dependent
- $\rightarrow$ regularization scheme dependent

Strong Coupling

$\overline{\text{MS}}$ scheme:

$$\alpha_s^0 = \alpha_s(\mu)\,\mu^{2\epsilon}\left[1 - \underbrace{\frac{\alpha_s}{4\pi\epsilon}\beta_0 + \ldots}_{\text{pure UV-divergent}}\right] \qquad d = 4 - 2\epsilon \longrightarrow 4$$



→ $\alpha_s(\mu)$ is pure UV-object without IR-sensitivity

→ Choice of scale μ is not unique (scheme dependence)

→ Good choices for μ related to the energy scale in the quantity

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

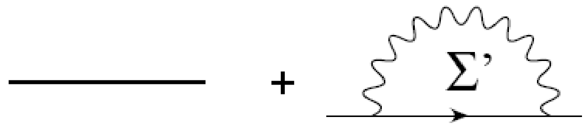
$$= N_c \sum_q e_q^2 \left\{1 + \frac{\alpha_s(\mu_0)}{\pi} + \frac{\alpha_s^2(\mu_0)}{\pi^2}\left[f_3 - \frac{\beta_0}{4}\ln\left(\frac{s}{\mu_0^2}\right)\right] + \ldots\right\}$$

$$= N_c \sum_q e_q^2 \left\{1 + \frac{\alpha_s(\sqrt{s})}{\pi} + \ldots\right\}$$

Summation of (large) logarithms

→ <u>"good choices of μ":</u> $\alpha_s(\mu)$ captures most of the quantum corrections in its definition

Heavy Quark Mass



$$= p - m^0 - \Sigma(p, m^0, \mu)$$

$$\Sigma(m^0, m^0, \mu) = m^0 \left[\frac{\alpha_s}{\pi\epsilon} + \ldots \right] + \Sigma^{\text{fin}}(m^0, m^0, \mu)$$

$\overline{\text{MS}}$ scheme: $$m^0 = \overline{m}(\mu) \left[1 - \frac{\alpha_s}{\pi\epsilon} + \ldots \right]$$

- $\rightarrow$ $\overline{m}(\mu)$ is pure UV-object without IR-sensitivity
- $\rightarrow$ Useful scheme for $\mu > m$
- $\rightarrow$ Used a lot in beyond TeV physics

- Very energetic processes (E>>m)
- Total cross sections
- Off-shell massive quarks
- Away from thresholds/endpoints

Pole scheme: $$m^0 = m^{\text{pole}} \left[1 - \frac{\alpha_s}{\pi\epsilon} + \ldots \right] - \Sigma^{\text{fin}}(m^{\text{pole}}, m^{\text{pole}}, \mu)$$

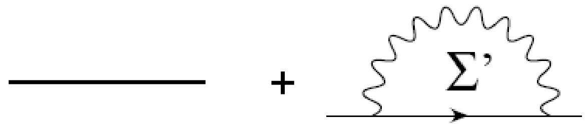
- $\rightarrow$ m^{pole} = perturbative single particle pole of perturbative S-matrix
- $\rightarrow$ Absorbes all self energy corrections into the mass parameter

Should not be used if uncertainties are below 1 GeV !

$\rightarrow$ Separation: self energy corrections $\leftrightarrow$ inter quark/gluon interactions for all momenta

$\rightarrow$ Has perturbative instabilities due to sensitivity to momenta < 1 GeV (Λ_{QCD})

Heavy Quark Mass



$$= p - m^0 - \Sigma(p, m^0, \mu)$$

$$\Sigma(m^0, m^0, \mu) = m^0 \left[\frac{\alpha_s}{\pi\epsilon} + \ldots \right] + \Sigma^{\rm fin}(m^0, m^0, \mu)$$

$\overline{\text{MS}}$ scheme: $$m^0 = \overline{m}(\mu) \left[1 - \frac{\alpha_s}{\pi\epsilon} + \ldots \right]$$

Pole scheme: $$m^0 = m^{\rm pole} \left[1 - \frac{\alpha_s}{\pi\epsilon} + \ldots \right] - \Sigma^{\rm fin}(m^{\rm pole}, m^{\rm pole}, \mu)$$

MSR scheme: $$m^{\rm MSR}(R) = m^{\rm pole} - \Sigma^{\rm fin}(R, R, \mu)$$

Jain, AH, Scimemi, Stewart (2008)

→ Interpolates between MS and pole mass scheme

$$m_t^{\rm MSR}(R = 0) = m^{\rm pole}$$

$$m_t^{\rm MSR}(R = \overline{m}(\overline{m})) = \overline{m}(\overline{m})$$

→ Separation: self energy corrections ↔ inter quark/gluon interactions only for scales above R

→ Stable in perturbation theory.

Masses Loop-Theorists Like to use

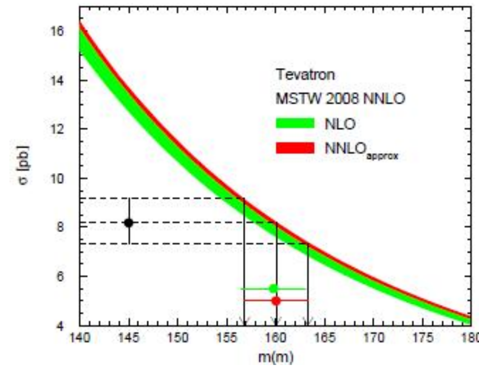
Total cross section (LHC/Tev):

$$m_t^{\mathrm{MSR}}(R = m_t) = \overline{m}_t(\overline{m}_t)$$

- more inclusive
- sensitive to top production mechanism (pdf, hard scale)
- indirect top mass sensitivity
- large scale radiative corrections

$$M_t \,=\, M_t^{(O)} \,+\, M_t(0)\alpha_s \,+\, \ldots$$

Langenfeld, Moch, Uwer



Threshold cross section (ILC):

$$m_t^{\mathrm{MSR}}(R \sim 20 \text{ GeV})\,,\ m_t^{1\mathrm{S}}\,,\ m_t^{\mathrm{PS}}(R)$$

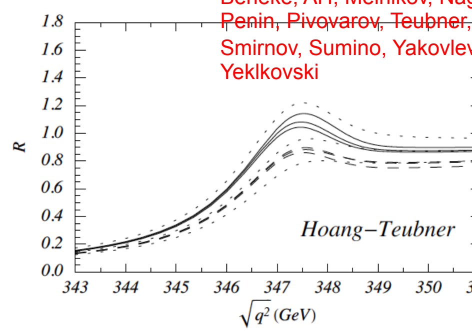
$$M_t \,=\, M_t^{(O)} \,+\, \langle p_{\mathrm{Bohr}}\rangle\alpha_s \,+\, \ldots$$

$$\langle p_{\mathrm{Bohr}}\rangle \,=\, 20\,\mathrm{GeV}$$

Mass schemes related to different computational methods

Relations computable in perturbation theory

Beneke, AH, Melnikov, Nagano, Penin, Pivovarov, Teubner, Signer, Smirnov, Sumino, Yakovlev, Yeklkovski



Inv. mass reconstruction (ILC/LHC):

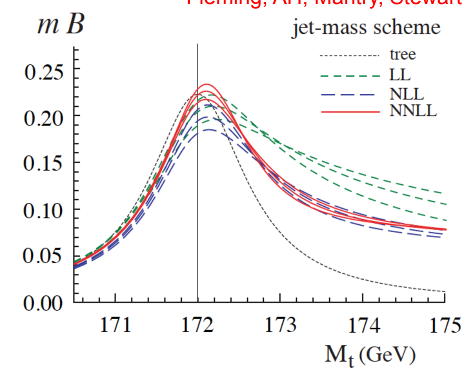
$$m_t^{\mathrm{MSR}}(R \sim \Gamma_t)\,,\ m_t^{\mathrm{jet}}(R)$$

$$M_t \,=\, M_t^{(O)} \,+\, \Gamma_t\alpha_s \,+\, \ldots$$

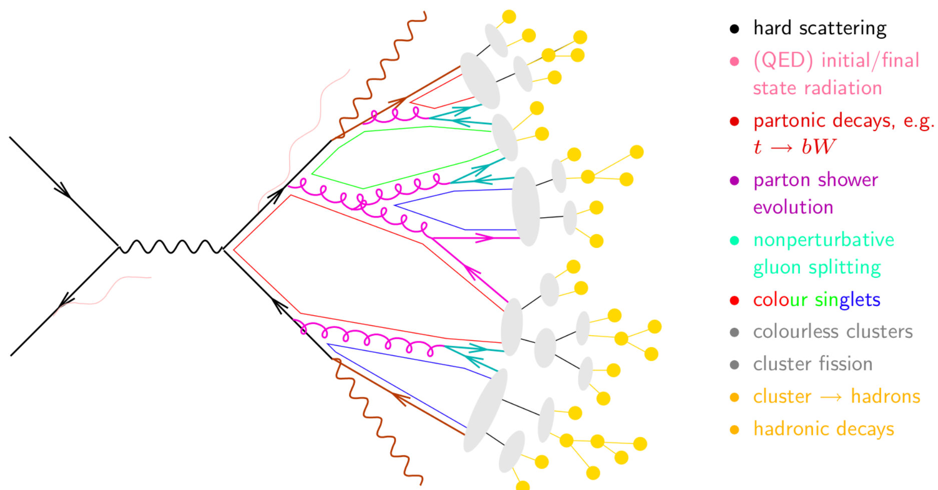
$$\Gamma_t \,=\, 1.3\,\mathrm{GeV}$$

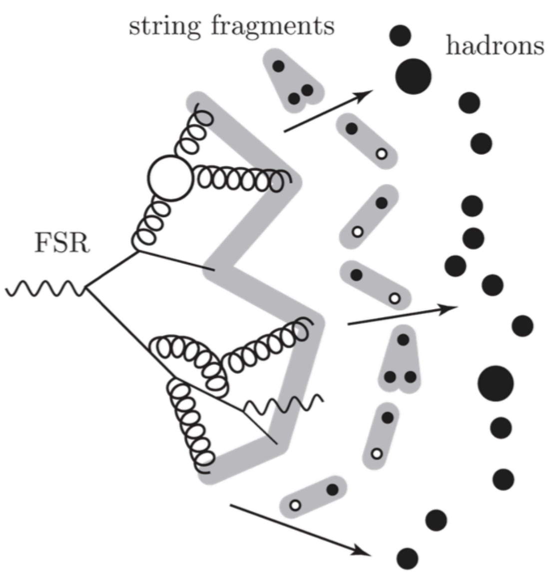
- more exclusive
- sensitive to top final state interactions (low scale)
- direct top mass sensitivity
- small scale radiative corrections

Fleming, AH, Mantry, Stewart



Heavy Quark Mass in the MC





Monte-Carlo QCD Computer:

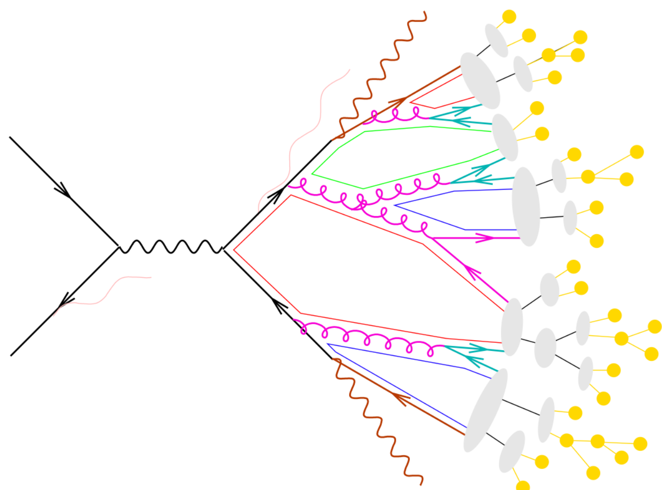
- Computes all inter-quark/gluon and radiation processes
- Computes hadronization of partons
- Electroweak radiation effects

- Does NOT calculate self-energy processes
- Value of MC mass parameter is intrinsically related to the interquark/gluon radiation contained in the MC

MC top mass does NOT depend on the observable since the MC calculates always the same way !

MC top mass is unique for each MC.

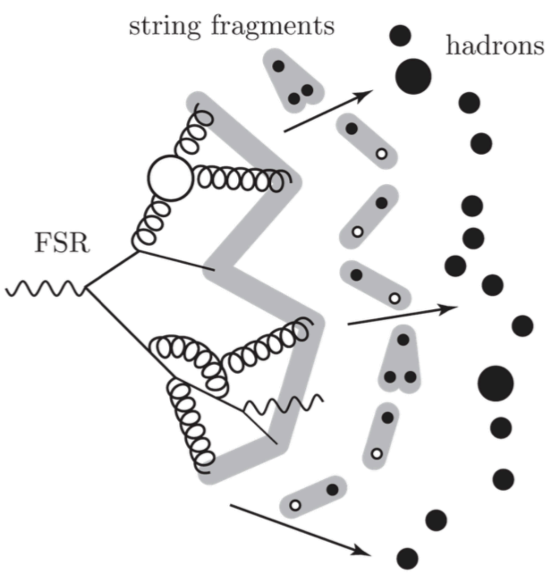
Heavy Quark Mass in the MC



Monte-Carlo QCD Calculator:

- Computes all inter-quark/gluon and radiation processes
- Computes hadronization of partons
- Electroweak radiation effects

- Does NOT calculate self-energy processes

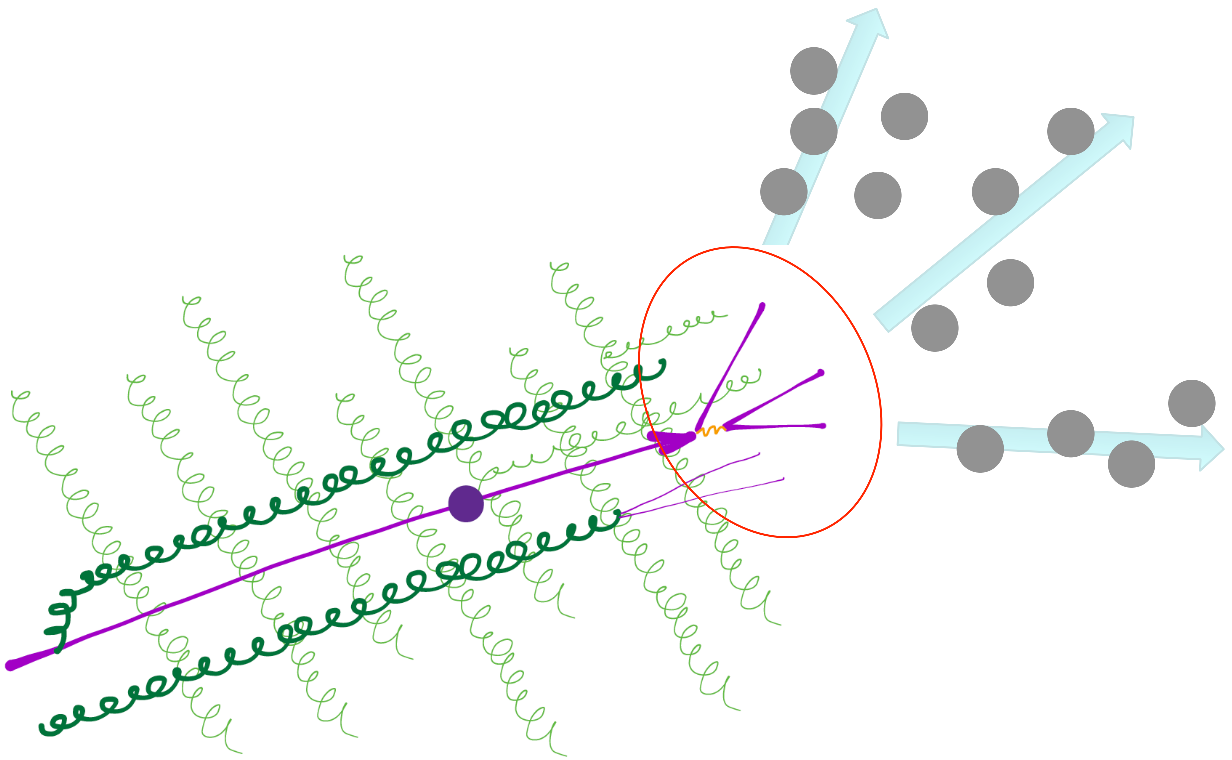


Inter-quark/gluon radiation/
Parton shower
cut-off at $\Lambda_s = 1\ \mathrm{GeV}$

Hadronization model below.

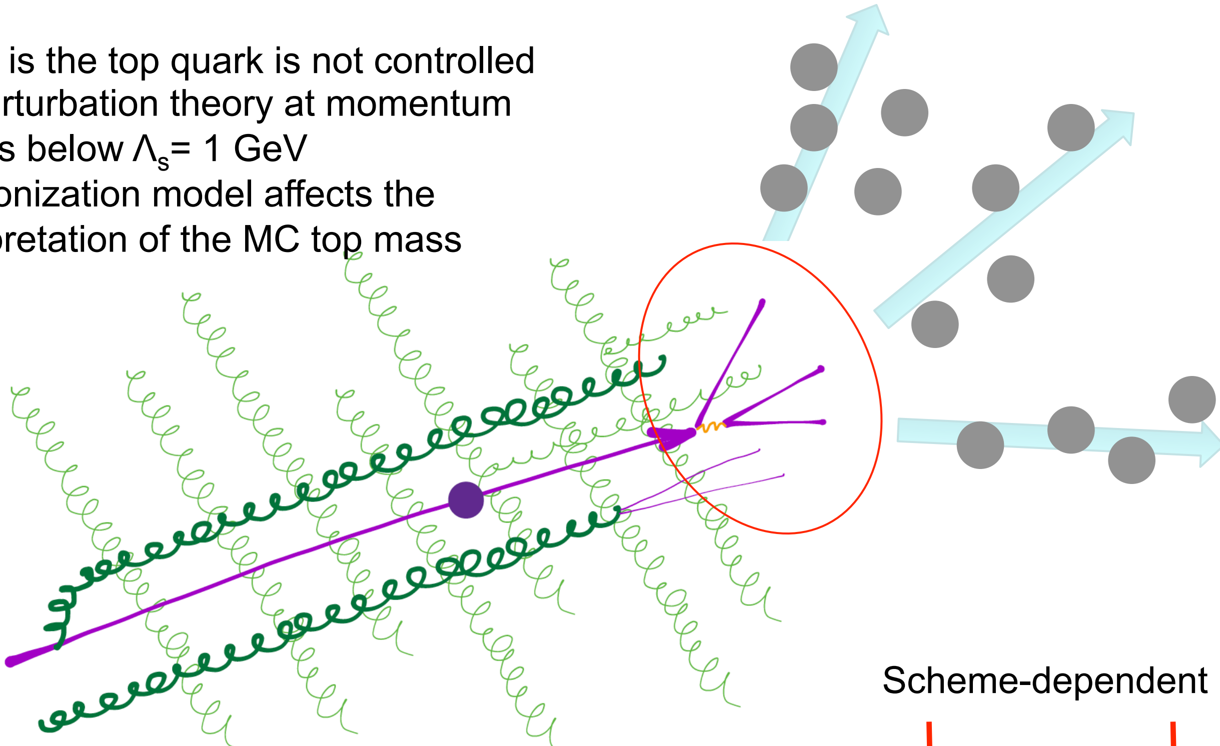
Shower, shower cut, model details affect the value of top mass.

Heavy Quark Mass in the MC



Heavy Quark Mass in the MC

- What is the top quark is not controlled by perturbation theory at momentum scales below Λ_s= 1 GeV
- Hadronization model affects the interpretation of the MC top mass



Scheme-dependent

~ O(1 GeV)

$$
\begin{aligned}
m_t^{\mathrm{MC}} &= m_t^{\mathrm{quark}} + \Delta \\
&= m_t^{\mathrm{MSR}}(R) + \Delta^{\mathrm{MSR}}(R)
\end{aligned}
$$

MC mass has features similar to the mass of a Top-meson.

We use knowledge from B-meson physics.

Suitable scales: $R = 1 - 3\,\mathrm{GeV}$

Lessons on the MC top mass (for a perfect MC)

The interpretation (and value) of the top mass parameter in each MC generator is unique and should be observable-independent.

The value measured for the top mass depends on details of the MC, so in principle different MC have different top mass values.

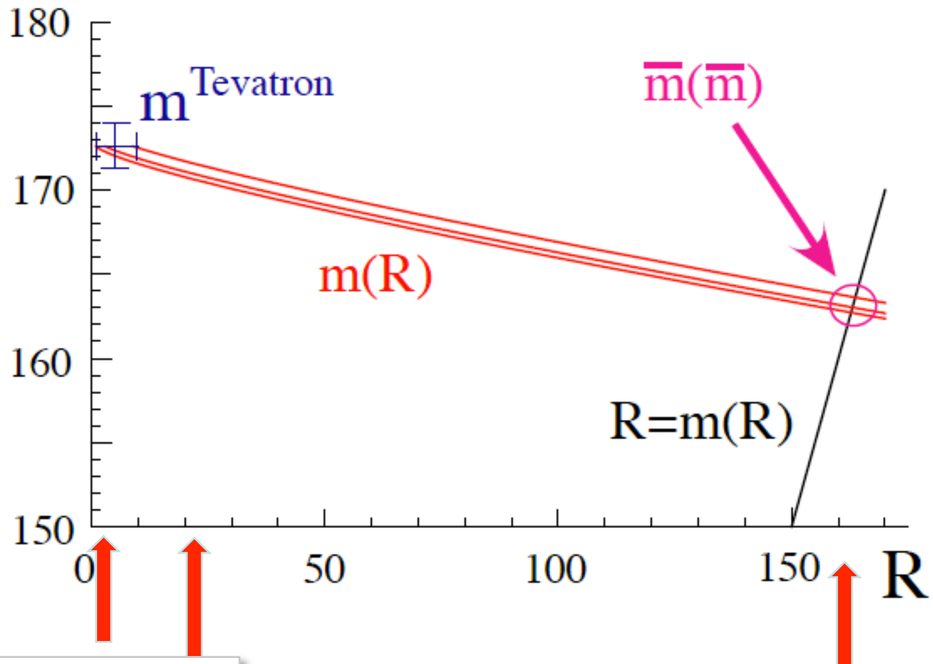
The MC top mass parameter has features similar to a Top meson mass, and the way how to extract a field theoretical mass (in a suitable scheme) is analogous to methods in B physics

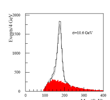
Without further knowledge there is an uncertainty of order $\lesssim$ 1GeV one has to add when translating the MC top mass to a suitable suitable field theoretical top mass ($m_t^{MSR}(R=1 - 3\ \mathrm{GeV})$)

MSR Mass Definition

AH, Stewart: arXive:0808.0222

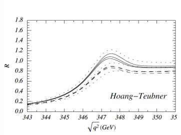
$$m_t^{\mathrm{MC}} = m_t^{\mathrm{MSR}}(3^{+6}_{-2}\ \mathrm{GeV}) = m_t^{\mathrm{MSR}}(3\ \mathrm{GeV})^{+0.6}_{-0.3}$$





Peak of invariant mass distribution, endpoints

Top-antitop threshold at the ILC



Total cross section, e.w.precsion obs., Unification, MSbar mass

Theory Tools to Measure the MC mass

Part 2

The relation between MC mass and field theoretical mass can be made more precise by measuring the MC mass using a hadron level QCD prediction of a mass-dependent observable.

Need:

- Accurate analytic QCD predictions beyond LL/LO with full control over the quark mass dependence
- Theoretical description at the hadron level for comparison with MC at the hadron level

- Implementation of massive quarks into the SCET framework
- **VFNS for final state jets (with massive quarks)***

* In collaboration with: P. Pietrulewicz, V. Mateu, I. Jemos, S. Gritschacher

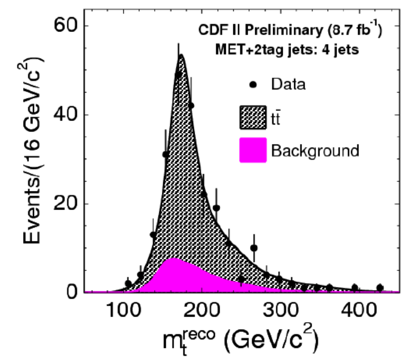
arXiv:1302.4743 (PRD 88, 034021 (2013))
arXiv:1309.6251 (PRD 89, 014035 (2013))
arXiv:1405.4860 (PRD ..)
More to come …

Theory Tools to Measure the MC mass

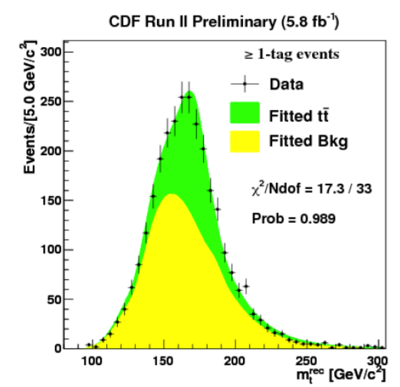
Observable: Thust in e+e-

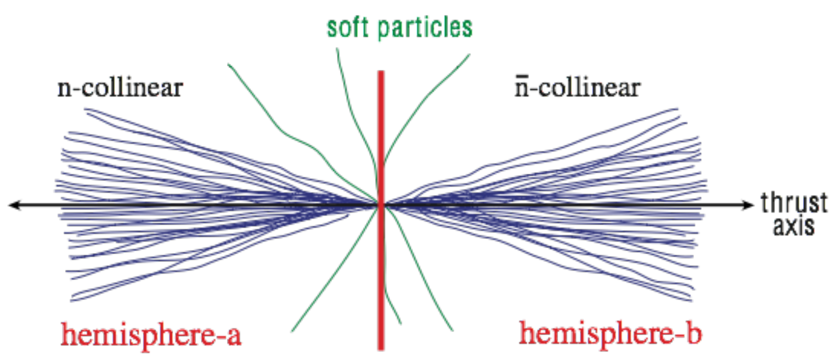
$$\tau \;=\; 1 - \max_{\vec{n}} \frac{\sum_i |\vec{n}\cdot\vec{p}_i|}{Q}$$

$$\overset{\tau\to 0}{\approx}\; \frac{M_1^2 + M_2^2}{Q^2}$$



Invariant mass distribution in the resonance region !

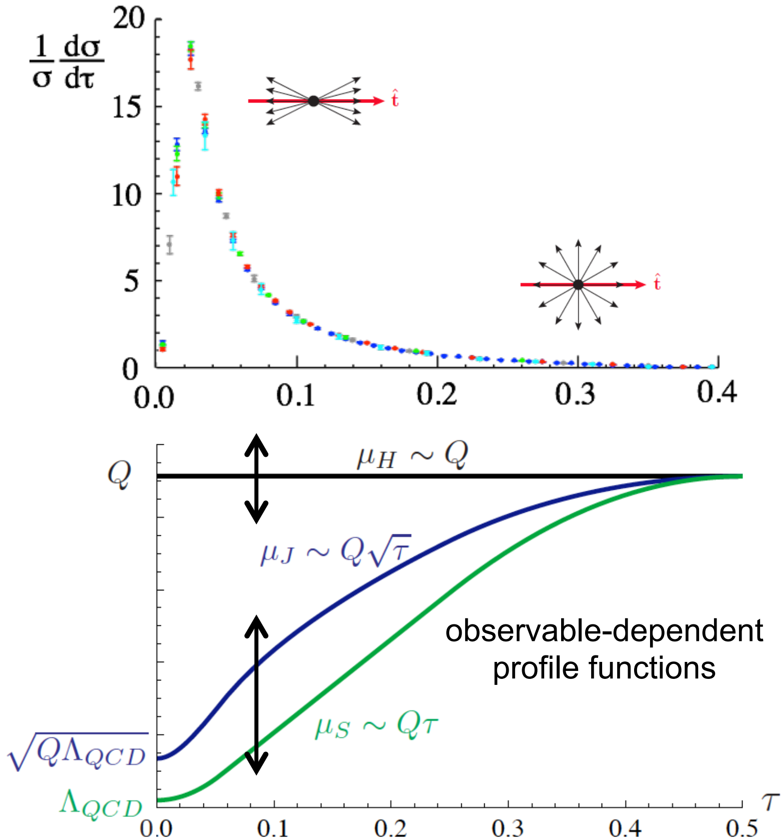




Factorization for Massless Quarks

$$\frac{d\sigma}{d\tau} = Q^2 \sigma_0 H_0(Q,\mu) \int d\ell \; J_0(Q\ell,\mu)\, S_0\,(Q\tau - \ell, \mu)$$

Korshemski, Sterman
Schwartz
Fleming, AH, Mantry, Stewart
Bauer, Fleming, Lee, Sterman



Abbate, AH, Fickinger, Mateu,
Stewart

$$\left(\frac{d\sigma}{d\tau}\right)^{\rm sing}_{\rm part} \sim \sigma_0\, H(Q,\mu_Q) U_H(Q,\mu_Q,\mu_s) \int d\ell d\ell' \, U_J(Q\tau - \ell - \ell', \mu_Q, \mu_s)\, J_T(Q\ell', \mu_j)\, S_T(\ell - \Delta, \mu_s)$$

VFN Scheme for Final State Jets

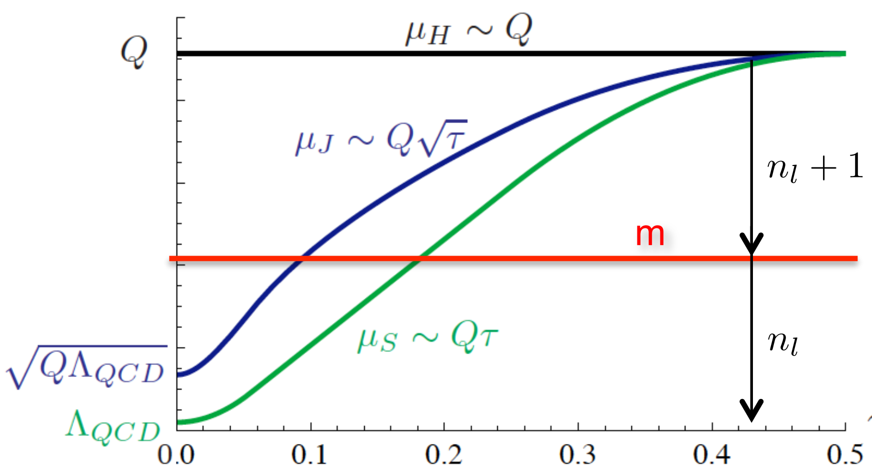
Gritschacher, AH, Jemos, Pietrulewicz

→ consider: dijet in e^+e^- annihilation, n_l light quarks ⊕ one massive quark

→ obvious: (n_l+1)-evolution for $\mu \gtrsim m$ and (n_l)-evolution for $\mu \lesssim m$

→ obvious: different EFT scenarios w.r. to mass vs. Q – J – S scales

"profile functions"



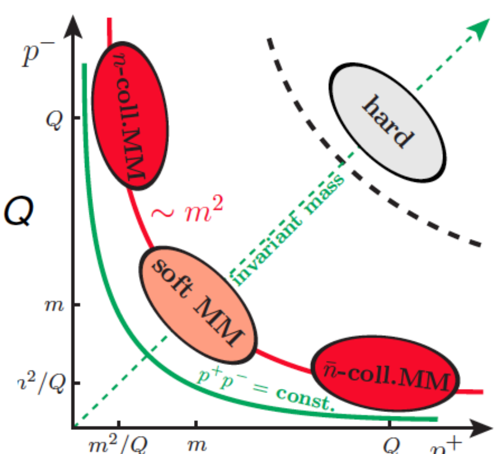
Aims:

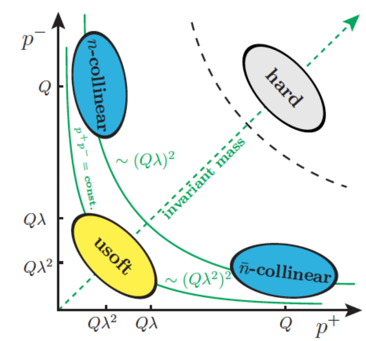
- Full mass dependence (little room for any strong hierarchies): decoupling, massless limit
- Smooth connections between different EFTs
- Determination of flavor matching for current-, jet- and soft-evolution
- Reconcile problem of $SCET_2$-type rapidity divergences

→ Deal with collinear and soft "mass modes"

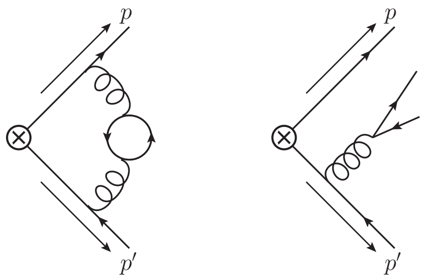
→ Additional power counting parameter $\lambda_m = m/Q$

mode	$p^\mu = (+,-,\perp)$	p^2
n-coll MM	$Q(\lambda_m^2, 1, \lambda_m)$	m^2
soft MM	$Q(\lambda_m, \lambda_m, \lambda_m)$	m^2





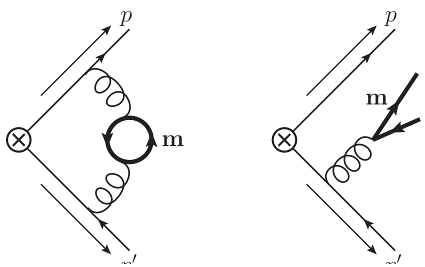
Fully Massive Thrust



→ fully massless

- Full N^{3}LL' (u.t. 4-loop cusp)+ 3-loop non-singular
- Gap scheme for soft function

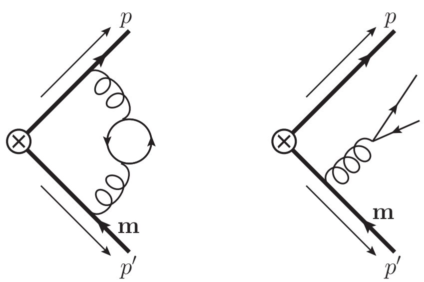
SCET authors: Becher, Schwartz,
Fleming, AH, Mantry, Stewart
Bauer, Fleming, Lee, Sterman
Fixed-order authors: Ge]hrmann etal, Weinzierl



→ secondary massive

- Full N^{2}LL'/N^{3}LL
- Four different physical situations

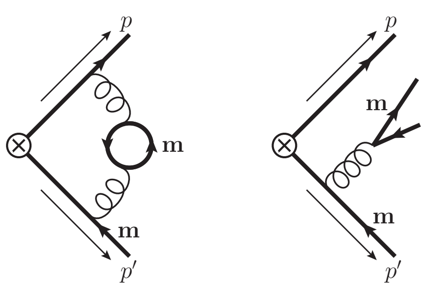
Pietrulewicz, AH, Gritschacher, Jemos 2013+2014



→ primary massive

- Full N^{2}LL'/N^{3}LL finished
- Three different physical situations
- Massive quark loops in log resummation

To be published



→ primary massive
secondary massive

Counting Rules

LL NLL NNLL NNNLL

$$\ln \frac{d\sigma}{dy} = (\alpha_s \ln)^k \ln + (\alpha_s \ln)^k + \alpha_s (\alpha_s \ln)^k + \alpha_s^2 (\alpha_s \ln)^k + \dots$$

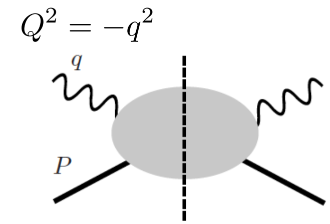
		cusp	non-cusp	matching	alphas	Classic Counting
standard counting	LL	1	–	tree	1	LLA
	NLL	2	1	tree	2	NLLA
	NNLL	3	2	1	3	NNLLA + LLO
	N^3LL	4^{pade}	3	2	4	NNNLLA + NLO
primed counting emphasizes fixed order	LL'	1	–	tree	1	LLA
	NLL'	2	1	1	2	NLLA + LLO
	$NNLL'$	3	2	2	3	NNLLA + NLO
	N^3LL'	4^{pade}	3	3	4	NNNLLA + NNLO

Theory error from Padé estimate of $\Gamma_3^{\rm cusp}$

Ok for ILC
Still massing for LHC

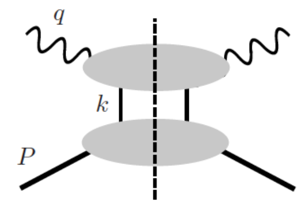
VFNS for Inclusive Hadron Collisions

e.g. Deep Inelastic Scattering: $\dfrac{d\sigma(e^- p \to e^- + X)}{dQ\,dx}$



→ consider all quarks as as light ($m_q < \Lambda$)

→ quark number operators with an anomalous dimension between proton states → DGLAP equations

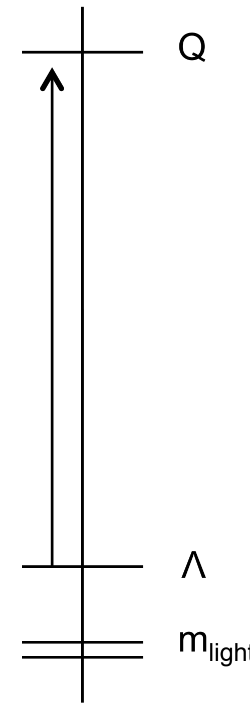


→ Hadronic tensor:

$$W_{\mu\nu}(Q,x) \sim \sum_{\text{partons a}} f_a(\mu) \otimes w_{\mu\nu}(Q,x,\mu)$$

→ μ-dependence with DGLAP equations for (light) parton distribution functions

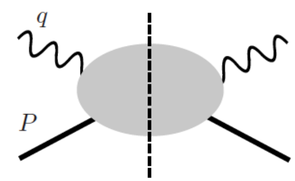
$$\frac{\partial}{\partial \ln Q^2}\begin{pmatrix} q_i(x,Q^2) \\ g(x,Q^2)\end{pmatrix} = \frac{\alpha_s(Q^2)}{2\pi}\sum_j \int_x^1 \frac{d\xi}{\xi} \times \begin{pmatrix} P_{q_iq_j}\left(\frac{x}{\xi},\alpha_s(Q^2)\right) & P_{q_ig}\left(\frac{x}{\xi},\alpha_s(Q^2)\right) \\ P_{gq_j}\left(\frac{x}{\xi},\alpha_s(Q^2)\right) & P_{gg}\left(\frac{x}{\xi},\alpha_s(Q^2)\right)\end{pmatrix}\begin{pmatrix} q_j(\xi,Q^2) \\ g(\xi,Q^2)\end{pmatrix}, \qquad (11)$$



$$\frac{d\alpha_s(Q)}{d\ln Q^2} = -\beta_0\,\frac{\alpha_s^2(Q)}{(4\pi)} + \ldots \qquad \beta_0 = 11 - \frac{2}{3}n_{\text{light}}$$

VFNS for Inclusive Hadron Collisions

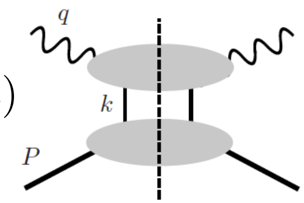
e.g. Deep Inelastic Scattering: $\dfrac{d\sigma(e^- p \to e^- + X)}{dQ\, dx}$



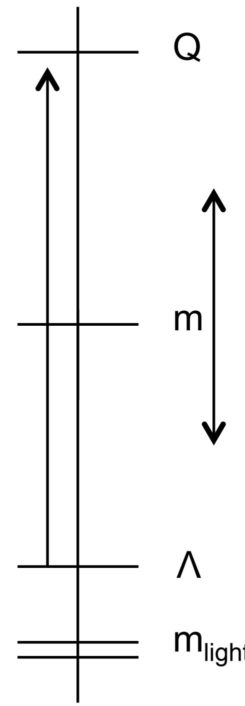
→ realistic case: massive quarks with Q > m > Λ
(charm, bottom [top])

→ Hadronic tensor:

$$W_{\mu\nu}(m,Q,x) \sim \sum_{a=q,g,Q} f_a^{(n_l+1)}(\mu) \otimes w_{\mu\nu}(m,Q,x,\mu)$$



VFNS for pdf evolution:

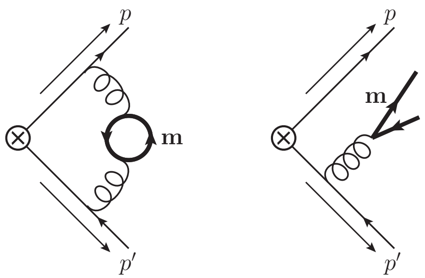


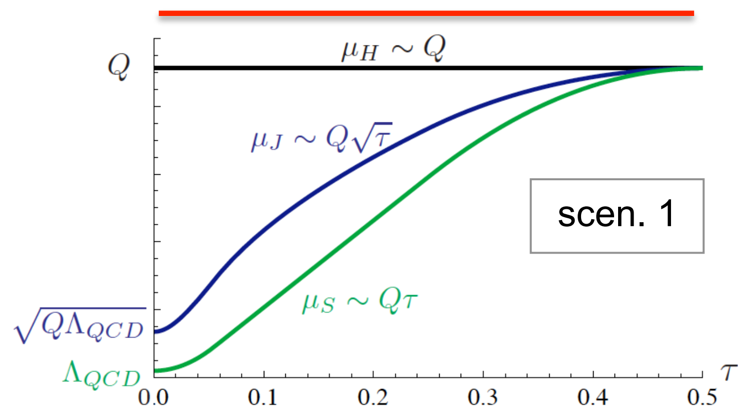
- DGLAP evolution for n_l flavors for $\mu \lesssim m$ (only light quarks)
- DGLAP evolution for n_l+1 flavors for $\mu \gtrsim m$ (light quarks + massive quark)
- Flavor matching for α_s and the pdfs at $\mu_m \sim m$

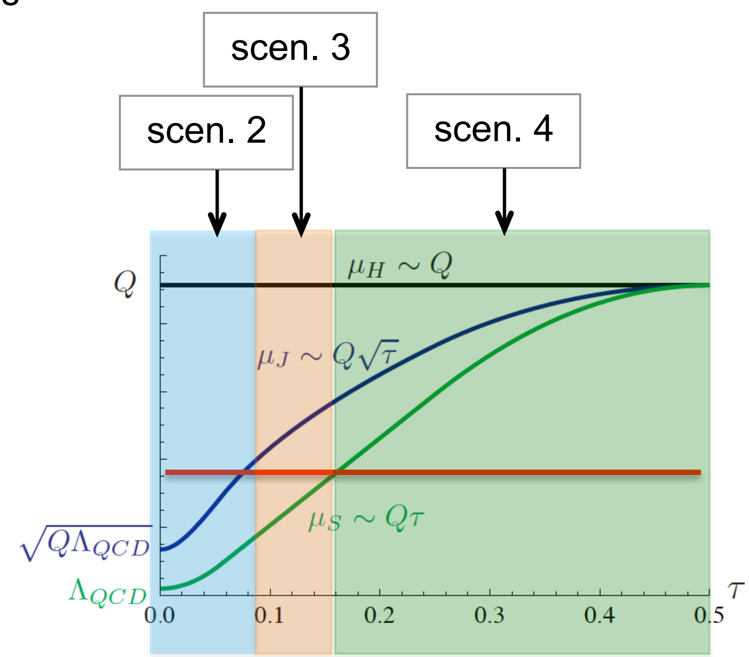
$$f_{q,g,Q}^{(n_l+1)}(\mu_m) = \sum_{a=q,g} F_{q,g,Q|a}(m,\mu_m) \otimes f_a^{(n_l)}(\mu_m)$$

→ hard coefficient $w_{\mu\nu}$(m,Q,x) approaches massless $w_{\mu\nu}$(Q,x) for m→0
→ calculations of $w_{\mu\nu}$(m,Q,x) involves subtraction of pdf IR mass singularities
→ full dependence on m/Q without any large logarithms

VFN Scheme: Secondary Massive Quarks

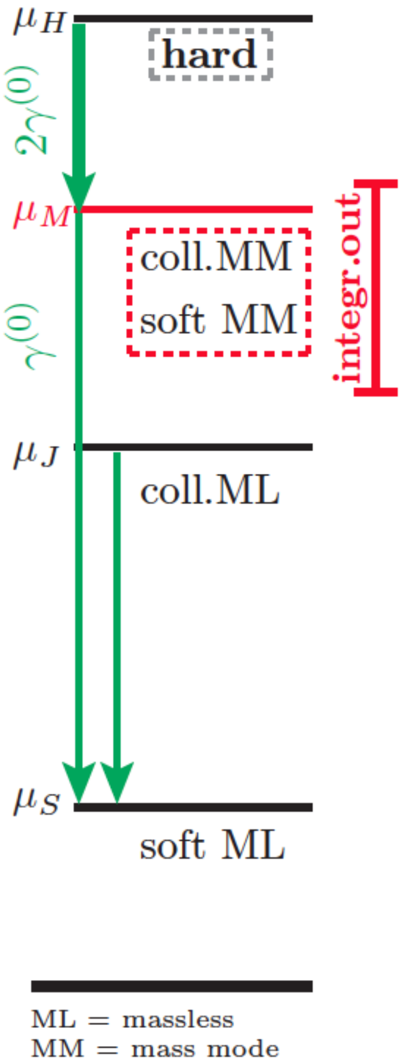






- Provided results for factors with complete mass dependence at O(as^2) [NNNLL/NNLL']
- Flavor threshold correction factors at O(as^2)
- Reconcile problem of $SCET_2$-type rapidity divergences
- Establish consistency conditions of flavor threshold matching factors (e.g. universality between thrust and DIS@ large x
- Simple implementation rules related to modified renormalization conditions
- Removal of $O(\Lambda_{QCD})$ renormalon effects concerning mass and soft effects

VFN Scheme: Secondary Massive Quarks



Scenario 2: Q > m > J > S > m

mass modes enter SCET, but integrated out before the jet scale

$$\frac{d\sigma}{d\tau} \sim \left|C^{ll}(\mu_H)\right|^2 U_H^{(1)}(\mu_H,\mu_M)\left|\mathcal{M}_H(\mu_M)\right|^2 U_H^{(0)}(\mu_M,\mu_S) \times \int d\ell \int ds\, J_0(s,\mu_J)\, U_J^{(0)}(Q\ell - s,\mu_J,\mu_S)\, S_0\left(Q\tau - \ell,\mu_S\right)$$

$U_H^{(1)}$: evolution factor ($\gamma_H^{(1)} = 2\gamma_H^{(0)}$)

$C^{ll}(\mu_H) = C^{l}(\mu_H) - \delta F_m^{\rm eff}(\mu_H)$ ← Contains all mass-singularities

$\delta F_m^{\rm eff}$: massive SCET contribution

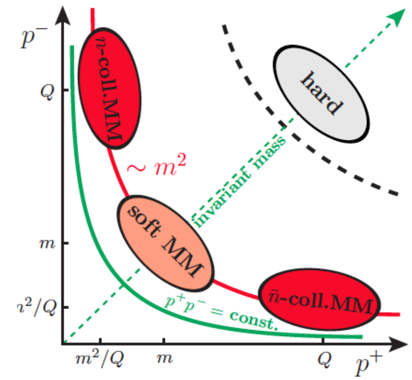
$U_i^{(0)}$ stands for: (a) massive gluon integrated out
(b) (n_l)-evolution

$U_i^{(1)}$ stands for: (a) massive gluon dynamical
(b) (n_l+1)-evolution

Rapidity Logarithms

- Secondary mass effects start at O(α_s^2)
- Counting for rapidity logs: α_s Log ~ 1
- At O(α_s^2):
  - No resummation not needed
  - Need terms at O(α_s^3 Log) and O(α_s^4 Log^2)
- Extract O(α_s^3 Log) $M_H^{(3)}$ term from DIS

Use results from Alblinger, Blümlein, etal. 2014



O(α_s)

O(α_s^2)

$$\mathcal{M}_H(Q,m,\mu_m) = 1 + \boxed{\frac{\left(\alpha_s^{(n_l+1)}\right)^2 C_F T_F}{(4\pi)^2} \ln\left(-\frac{\mu_m^2}{Q^2}\right)\left\{\frac{4}{3}L_m^2 + \frac{40}{9}L_m + \frac{112}{27}\right\}}$$

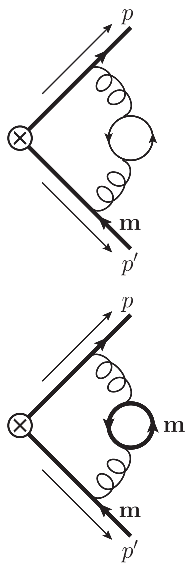
$$+ \Bigg[\frac{\left(\alpha_s^{(n_l+1)}\right)^2 C_F T_F}{(4\pi)^2}\left\{\frac{4}{9}L_m^3 + \frac{38}{9}L_m^2 + \left(\frac{242}{27}+\frac{2\pi^2}{3}\right)L_m - \frac{52}{9}\zeta(3) + \frac{875}{54} + \frac{5\pi^2}{9}\right\}$$

$$+ \frac{\left(\alpha_s^{(n_l+1)}\right)^3 C_F T_F}{(4\pi)^3}\ln\left(-\frac{\mu_m^2}{Q^2}\right)\left\{\mathcal{M}_H^{(3)} + \sum_{n=0}^{3} a_n L_m^n\right\}$$

$$+ \frac{\left(\alpha_s^{(n_l+1)}\right)^4 C_F^2 T_F^2}{(4\pi)^4}\ln^2\left(-\frac{m^2}{Q^2}\right)\left\{\frac{8}{9}L_m^4 + \frac{160}{27}L_m^3 + \frac{416}{27}L_m^2 + \frac{4480}{243}L_m + \frac{6272}{729}\right\}\Bigg]$$

$$L_M = \ln\left(\frac{m^2}{\mu_m^2}\right)$$

VFN Scheme: Primary Massive Quarks

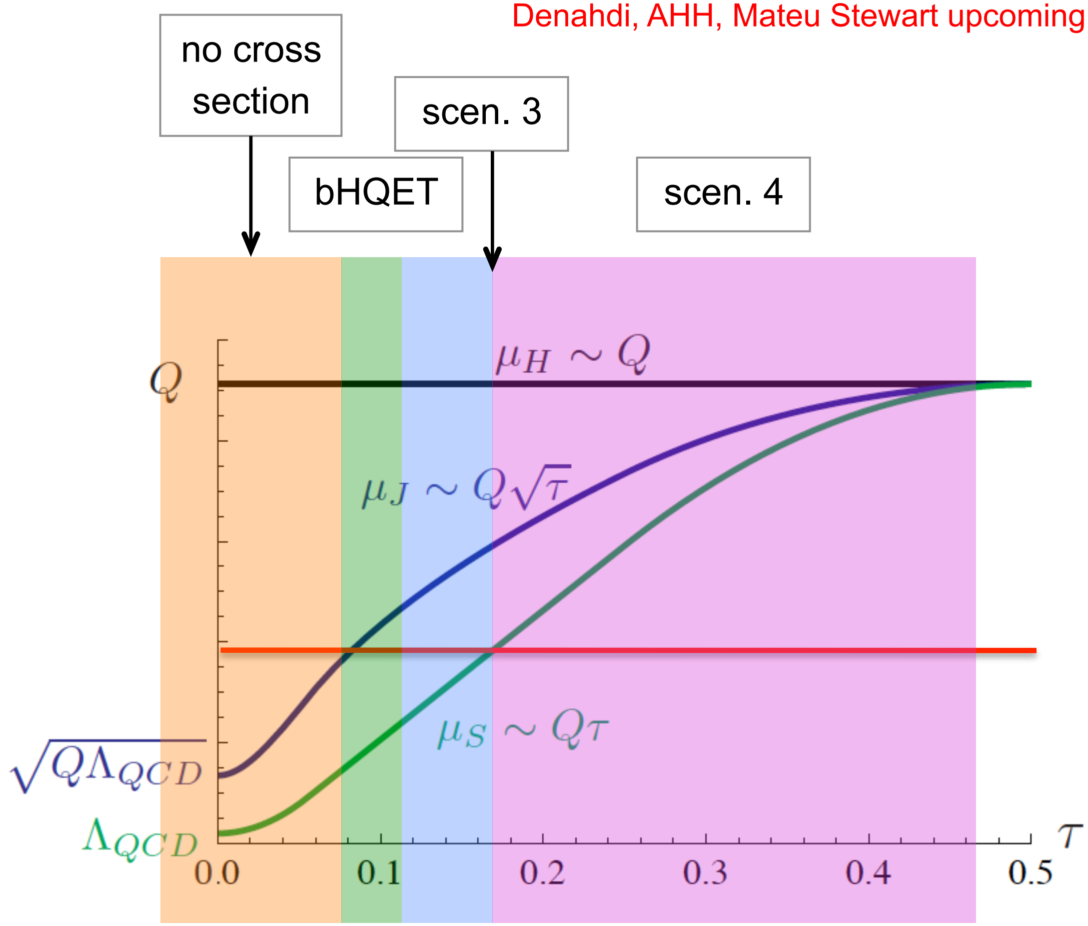


→ bHQET-type theory when the jet scale approaches the quark mass

Fleming, AHH, Mantry, Stewart 2007

→ two SCET-type theories

Denahdi, AHH, Mateu Stewart upcoming



MC vs. SCET: Primary Bottom Production

Preliminary !!

Denahdi, AHH, Mateu

Compare MC with SCET (pQCD, summation, hadronization effects) @ NNLL for Thrust

- Take central values for α_s and Ω_1 from our earlier NNLL thrust analysis for data on all-flavor production (=massless quarks)

$$\alpha_s(M_Z) = 0.1192 \pm 0.006$$
$$\Omega_1 = 0.276 \pm 0.155$$

- Compare with Pythia (m_b^{Pythia}=4.8 GeV) for consistency and mass sensitivity

- Which mass does m_b^{Pythia}=4.8 GeV correspond to for a field theoretic bottom mass?

Abbate,Fickinger, AHH, Mateu, Stewart 2010

order	$\bar{\Omega}_1$ ($\overline{\mathrm{MS}}$)	Ω_1 (R-gap)
NLL′	0.264 ± 0.213	0.293 ± 0.203
NNLL	0.256 ± 0.197	$\boxed{0.276 \pm 0.155}$
NNLL′	0.283 ± 0.097	0.316 ± 0.072
N^{3}LL	0.274 ± 0.098	0.313 ± 0.071
N^{3}LL′ (full)	0.252 ± 0.069	$\mathbf{0.323 \pm 0.045}$
N^{3}LL′$_{(\mathrm{QCD}+m_b)}$	0.238 ± 0.070	0.310 ± 0.049
N^{3}LL′$_{(\mathrm{pure\ QCD})}$	0.254 ± 0.070	0.332 ± 0.045

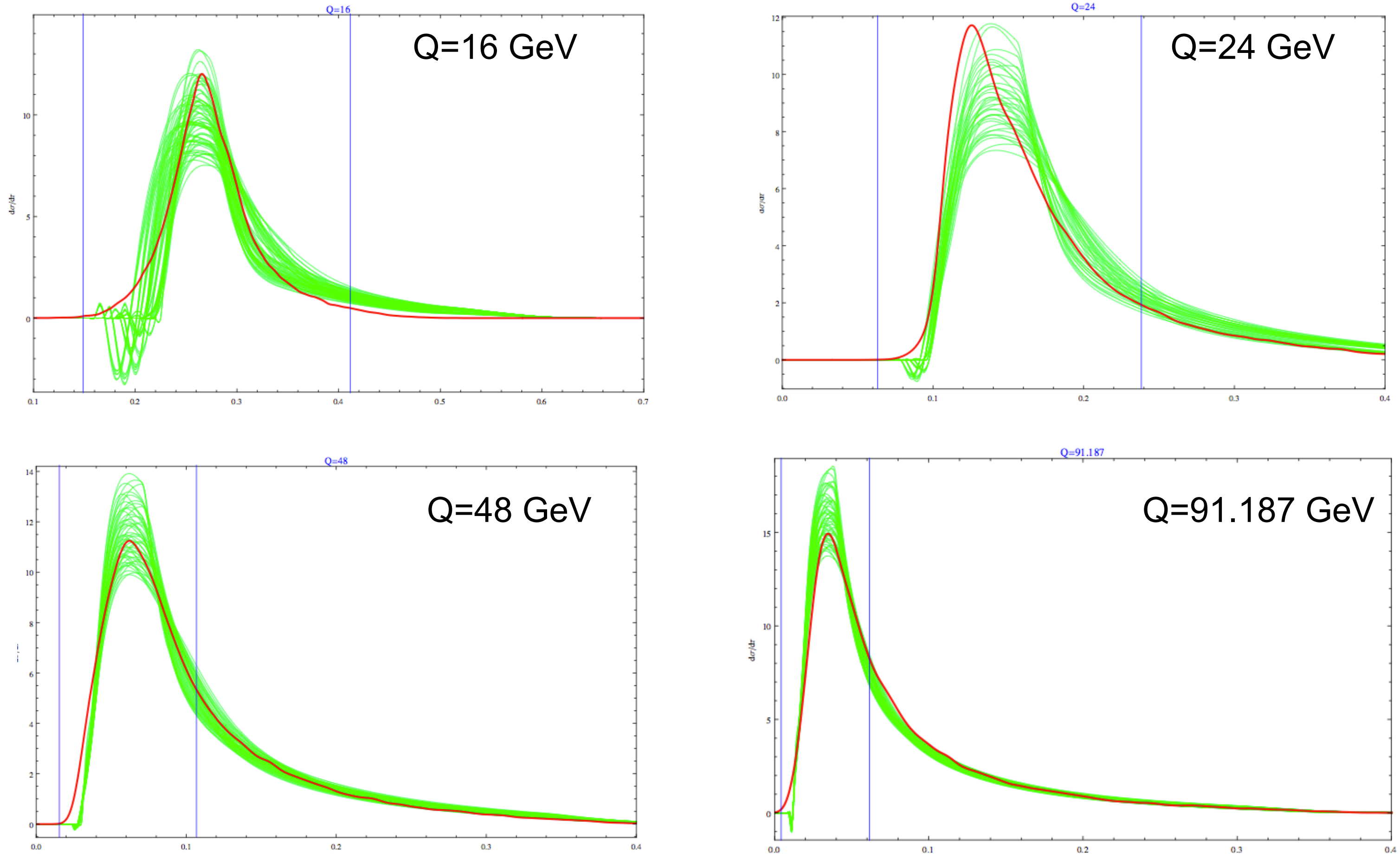
order	$\alpha_s(m_Z)$ (with $\bar{\Omega}_1^{\overline{\mathrm{MS}}}$)	$\alpha_s(m_Z)$ (with Ω_1^{Rgap})
NLL′	0.1203 ± 0.0079	0.1191 ± 0.0089
NNLL	0.1222 ± 0.0097	$\boxed{0.1192 \pm 0.0060}$
NNLL′	0.1161 ± 0.0038	0.1143 ± 0.0022
N^{3}LL	0.1165 ± 0.0046	0.1143 ± 0.0022
N^{3}LL′ (full)	0.1146 ± 0.0021	$\mathbf{0.1135 \pm 0.0009}$
N^{3}LL′$_{(\mathrm{QCD}+m_b)}$	0.1153 ± 0.0022	0.1141 ± 0.0009
N^{3}LL′$_{(\mathrm{pure\ QCD})}$	0.1152 ± 0.0021	0.1140 ± 0.0008

MC vs. SCET: Primary Bottom Production

Preliminary !! (no fit yet) all NNLL+NLO

Pythia: $m_b^{\rm Pythia} = 4.8\ \mathrm{GeV}$

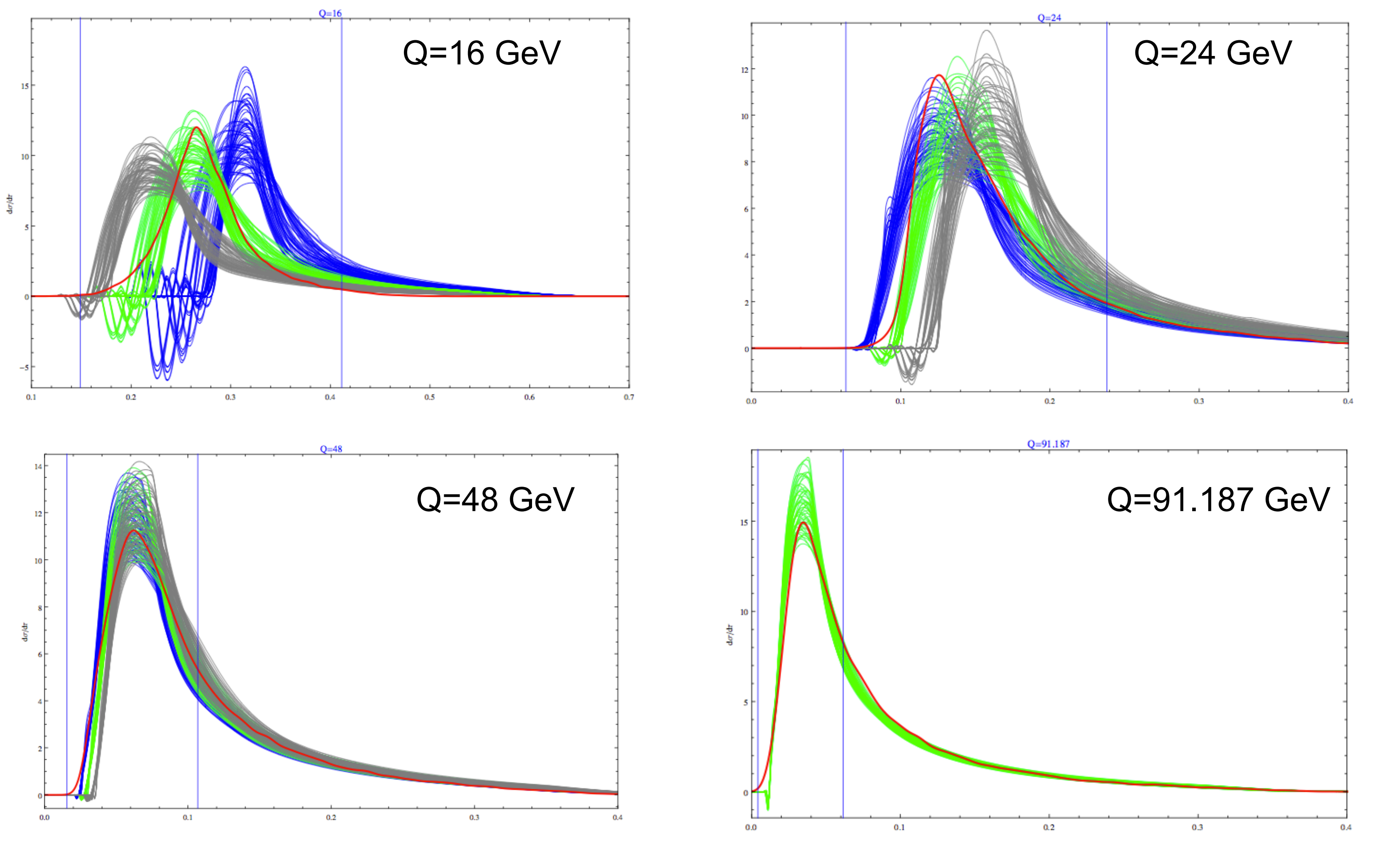
QCD calc.: $\overline{m}_b(\overline{m}_b) = 4.2\ \mathrm{GeV}$ $\alpha_s(M_Z) = 0.1192$ $\Omega_1 = 0.276\,\mathrm{GeV}$



MC vs. SCET: Primary Bottom Production

Preliminary !! (No fit yet)

$$\overline{m}_b(\overline{m}_b) = 3.7, 4.2, 4.7 \text{ GeV} \qquad \alpha_s(M_Z) = 0.1192 \qquad \Omega_1 = 0.276\,\text{GeV}$$



Conclusions

→ The MC top mass parameter has the status of a hadronic parameter and is therefore not a field theoretic mass definition

→ The issue is becomes relevant when uncertainties in the MC top mass are becoming smaller than 1 GeV.

→ Ignoring the issue means that there is a conceptual uncertainty of about 1 GeV one needs to account for when relating the MC mass to a field theory mass.

→ Suitable field theory mass definition in this context: e.g. MSR mass (R=1-3 GeV)

→ It is possible to relate the MS top mass to a field theoretic mass by fits of QCD calculations at the hadron level to MC output for very mass sensitive quantities.

→ When one does that there are still theoretical uncertainties (in the QCD predictions used for the fit) one has to account for.

→ Fully massive thrust using a VFNS for final state inclusive jets.

→ Upcoming:
- C parameter, heavy jet mass, inv. mass distr. @ NNLL
- NNNLL for e+e- → Need: 2-loop massiv quark jet function
- DIS for massive quarks @ large x
- pp → tt+X (2-jettiness) @ NLL → NNLL possible, NNNLL need NNLO full. Diff.