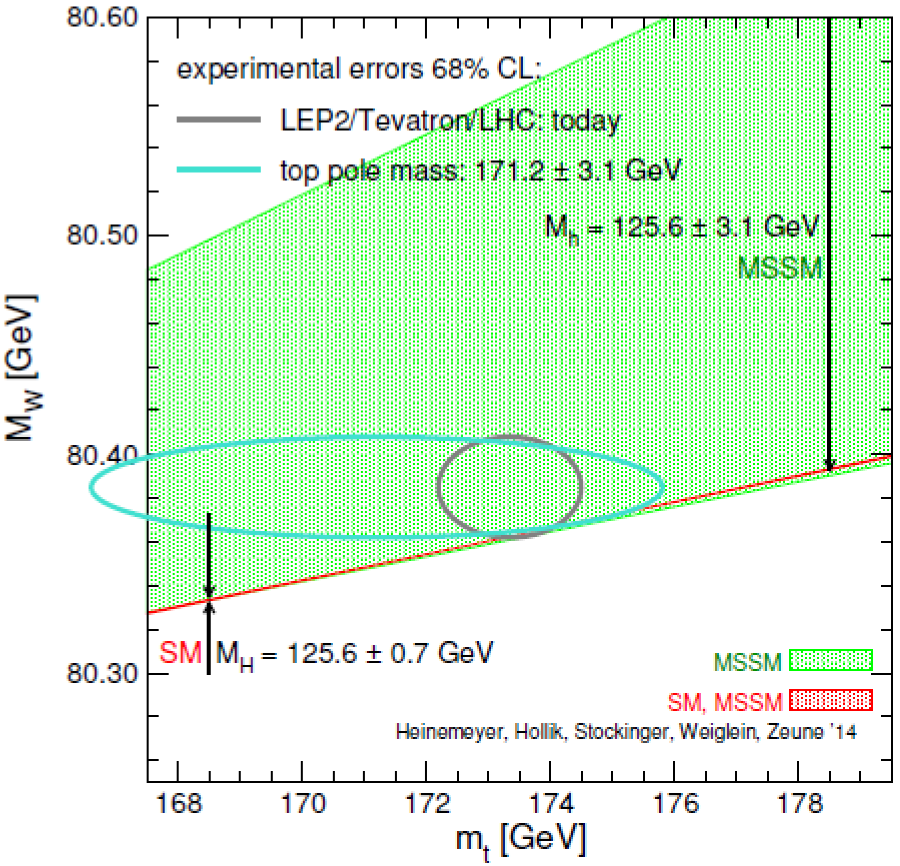
Discussion:

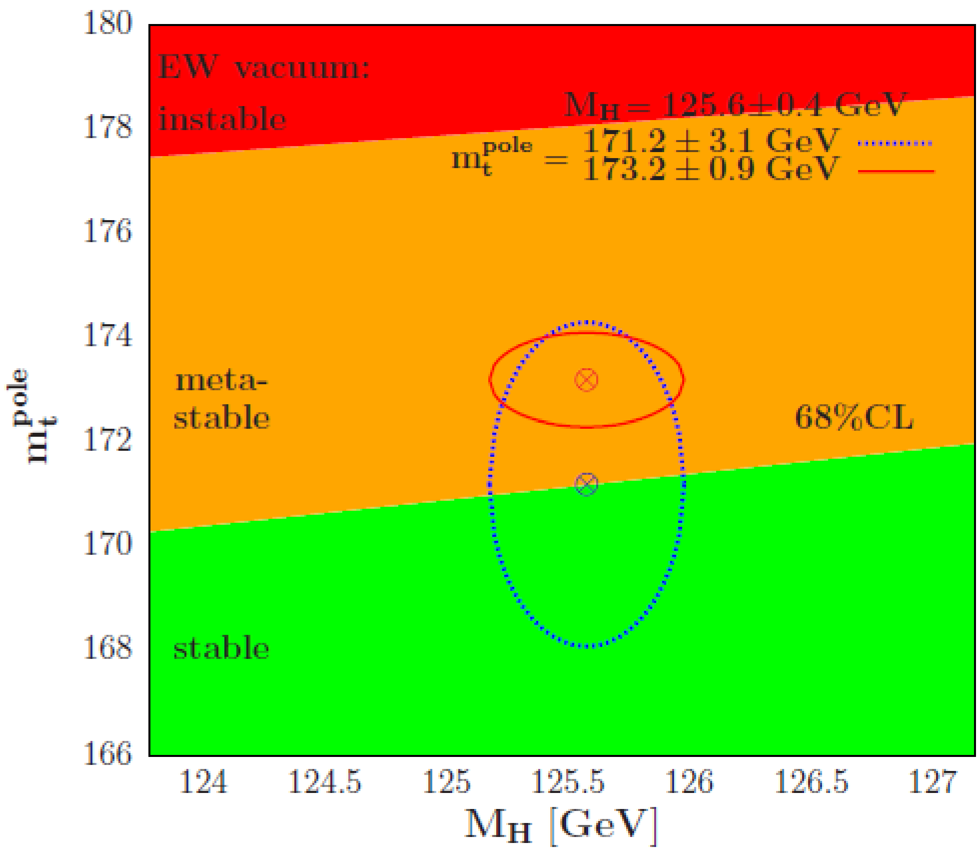
Top quark mass

Markus Schulze

CERN

Motivation





±0.9 GeV on m_t ↔ ±5.4 MeV on m_W

→ in order to not limit el.weak precision fits m_t needs to be measured to ±0.5 GeV

Changing m_t by ~2 GeV around 173.1 GeV the turnover where the Higgs potential becomes negative changes by 6 orders of magnitude:

$10^8 - 10^{14}$ GeV.

Mainz Institute for Theoretical Physics

High precision fundamental constants at the TeV scale

10-21 March 2014
Europe/Berlin timezone

- Overview
- General Information
- Scientific Programme
- Timetable
- Application
  - Application Form
- List of registrants

Current registrants (25)

name	institution	position	city	country/region
Dr. ALEKHIN, Sergey	DESY		Zeuthen	GERMANY
Prof. BLUEMLEIN, Johannes	DESY		Zeuthen	GERMANY
Prof. DITTMAIER, Stefan	University of Freiburg		Freiburg	GERMANY
Prof. ERLER, Jens	IF-UNAM (Mexico) & MITP		Mainz	GERMANY
Prof. ESPINOSA, José Ramón	ICREA/IFAE		Barcelona	SPAIN
Prof. FUSTER, Juan	IFIC Valencia	Rsearch Professor at CSIC	Ptaerna (Valencia)	SPAIN
Dr. GARCIA TORMO, Xavier	University of Bern	Postdoc	Bern	SWITZERLAND
Prof. HOANG, Andre	University of Vienna		Vienna	AUSTRIA
Dr. KALMYKOV , Mikhail	DESY-Zeuthen		Zeuthen	GERMANY
KLUTH, Stefan	MPI für Physik		München	GERMANY
Prof. KNIEHL, Bernd	II. Inst. f. Theor. Phys.	Professor	22761 Hamburg	GERMANY
Prof. LINDNER, Manfred	Max-Planck-Institut für Kernphysik		Heidelberg	GERMANY
MOCH, Sven-Olaf	Hamburg U.		Hamburg	GERMANY
Prof. MULDERS, Martijn	CERN		1211 Geneva 23	SWITZERLAND
Dr. PAPANASTASIOU, Andrew	DESY		Hamburg	GERMANY
Prof. PENIN, Alexander	University of Alberta	Professor	Edmonton	CANADA
PICLUM, Jan	RWTH Aachen / TU München		München	GERMANY
RABBERTZ, Klaus	Institut für Experimentelle Kernphysik, KIT		Karlsruhe	GERMANY
SCHULZE, Markus	CERN	Fellow	Geneva	SWITZERLAND
SCHWINN, Christian	Freiburg University		Freiburg	GERMANY
SPIESBERGER, Hubert	Universität Mainz		Mainz	GERMANY
UWER, Peter	Humboldt-Universität zu Berlin		Berlin	GERMANY
Dr. VERNAZZA, Leonardo	INFN and University of Turin	Postdoc	Turin	ITALY
WEINZIERL, Stefan	Universität Mainz		Mainz	GERMANY

MITP Workshop March 2014

2nd week on top quark mass

Extraction from the total *ttbar* cross section

C. Schwinn:
"Status of mtop determination from the total cross section"

S. Moch:
"Determination of the running top quark mass"

Extraction from kinematic distributions

M. Schulze:
"Top quark mass determination from kinematic distributions"

P. Uwer:
"Determination of mtop using jet rates at the LHC"

A. Papanastasiou:
"Unstable top quark and effective field theories"

Implications for BSM physics

J. Espinosa:
"Implications of mtop for EW Vacuum Stability"

M. Lindner:
"Relevance of the exact mtop value for BSM ideas"

N. Zerf:
"SUSY corrections to top production at threshold"

Measurements in e^+e^- collisions

J. Piclum:
"Determination of mtop from threshold at the ILC"

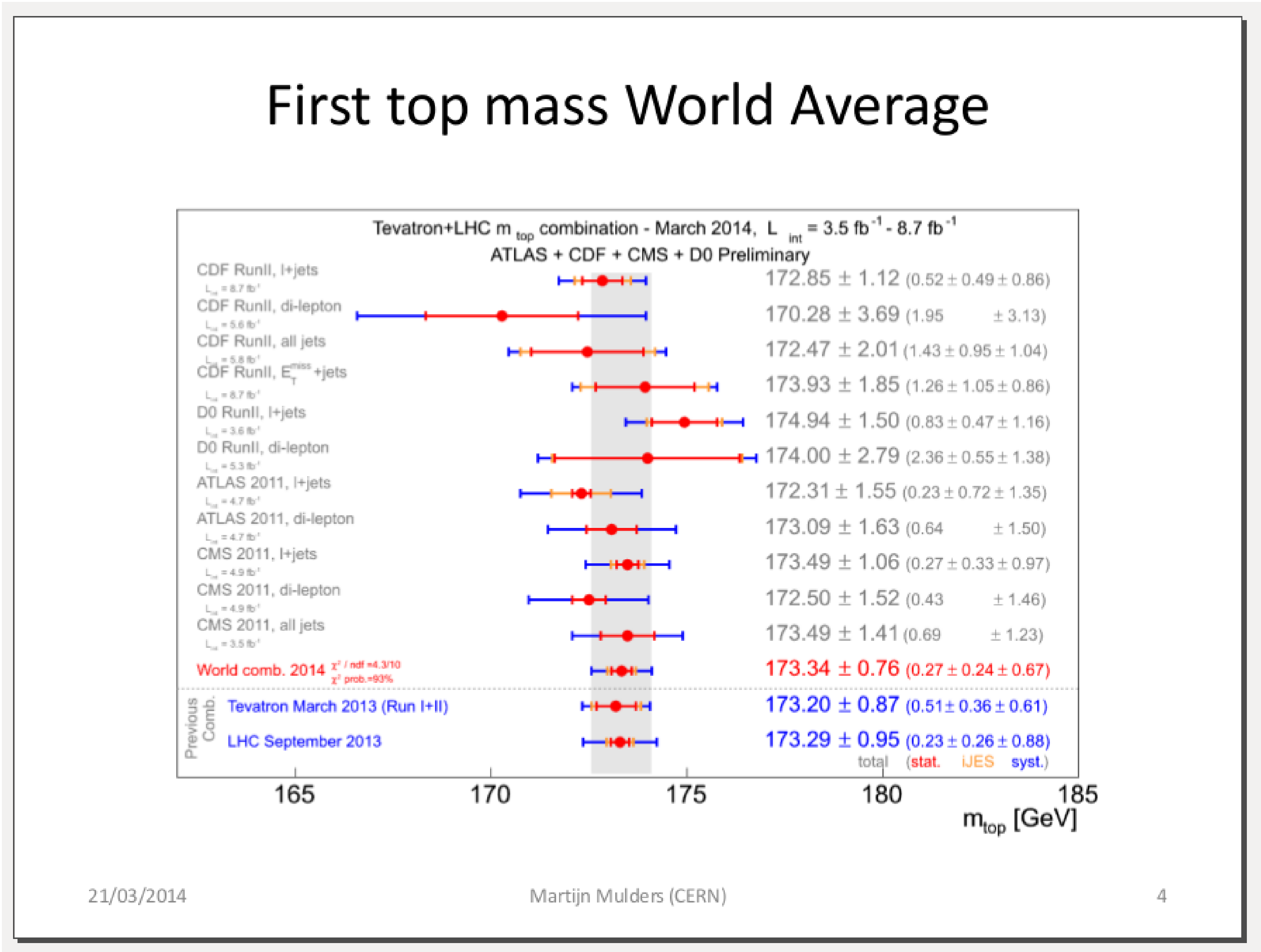
J. Fuster:
"mtop perspectives at the future linear collider"

A. Hoang:
"Event shapes with massive final state jets"

Experimental summary (ATLAS & CMS)

M. Mulders:
"mtop and LHC activities"

Experimental summary



Experimental summary

Mass definition

$\mathcal{L}_{\mathrm{int}} = 4.9\ \mathrm{fb}^{-1}$ of data, refer to the $t\bar{t} \to$ lepton+jets, $t\bar{t} \to$ dilepton and $t\bar{t} \to$ all jets channels [16–18]. In all measurements considered in the present combination, the analyses are calibrated to the Monte Carlo (MC) top-quark mass definition. It is expected that the difference between the MC mass definition and the formal pole mass of the top quark is up to the order of 1 GeV (see Refs. [19, 20] and references therein).

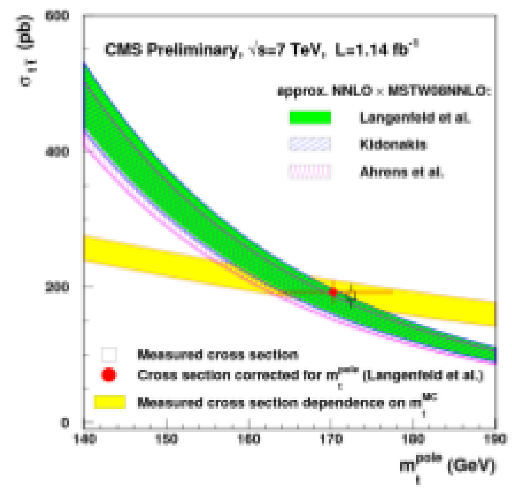
Proposal 1a (to be refined by A. Hoang) -- replace this disclaimer by: "The uncertainty on the translation from the MC mass definition to a theoretically well defined short-distance mass definition is currently estimated to be of the order of 1 GeV []"

Proposal 1b : provide a Table (or code) to translate the MC mass (?) to the Msbar mass definition?

Proposal 2 : quantify the systematic uncertainty of experimental observables related to the mass interpretation, by comparing the prediction of the MC Tool "of choice" to a well-defined NLO calculation *as a function of kinematic variables*, similar to what was done in CMS-TOP-12-029 (see next slide)

Extraction from the total cross section

Theory prediction for $\sigma_{t\bar{t}}$ in QCD:
function of α_s, m_t, PDFs
Proposal: determine m_t in
well-defined scheme (pole, $\overline{\text{MS}}$,...)
from $\sigma_{t\bar{t}}$ measurement
(Langenfeld/Moch/Uwer 09)
Experimental measurement
depends on m_t^{MC}
used to determine acceptances



Earlier experimental results: (for MSTW and NNLO$_{\text{approx}}$ from Langenfeld et al.)

- DO: $m_t = 167.5^{+5.2}_{-4.7}\,\text{GeV}$ using $\sigma_{t\bar{t}} = 8.13^{+1.02}_{-0.90}\,\text{pb}$
- CMS: $m_t = 170.3^{+7.3}_{-6.7}\,\text{GeV}$ using $\sigma_{t\bar{t}} = 169.9 \pm 18.4\,\text{pb}$

This talk: focus on pole scheme, take α_s, PDFs as input

($\overline{\text{MS}}$-scheme, simultaneous fits $\Rightarrow$ Sven's talk)

Extraction from the total cross section

Total top-pair production cross-section

Full NNLO calculation (Bärnreuther/Czakon/Fiedler/Mitov 12–13)

NNLL resummation

Soft threshold logarithms $\alpha_s \log \beta$ (Czakon/Mitov/Sterman 09)

Threshold logs and Coulomb corrections α_s/β (Beneke/Falgari/CS 09)

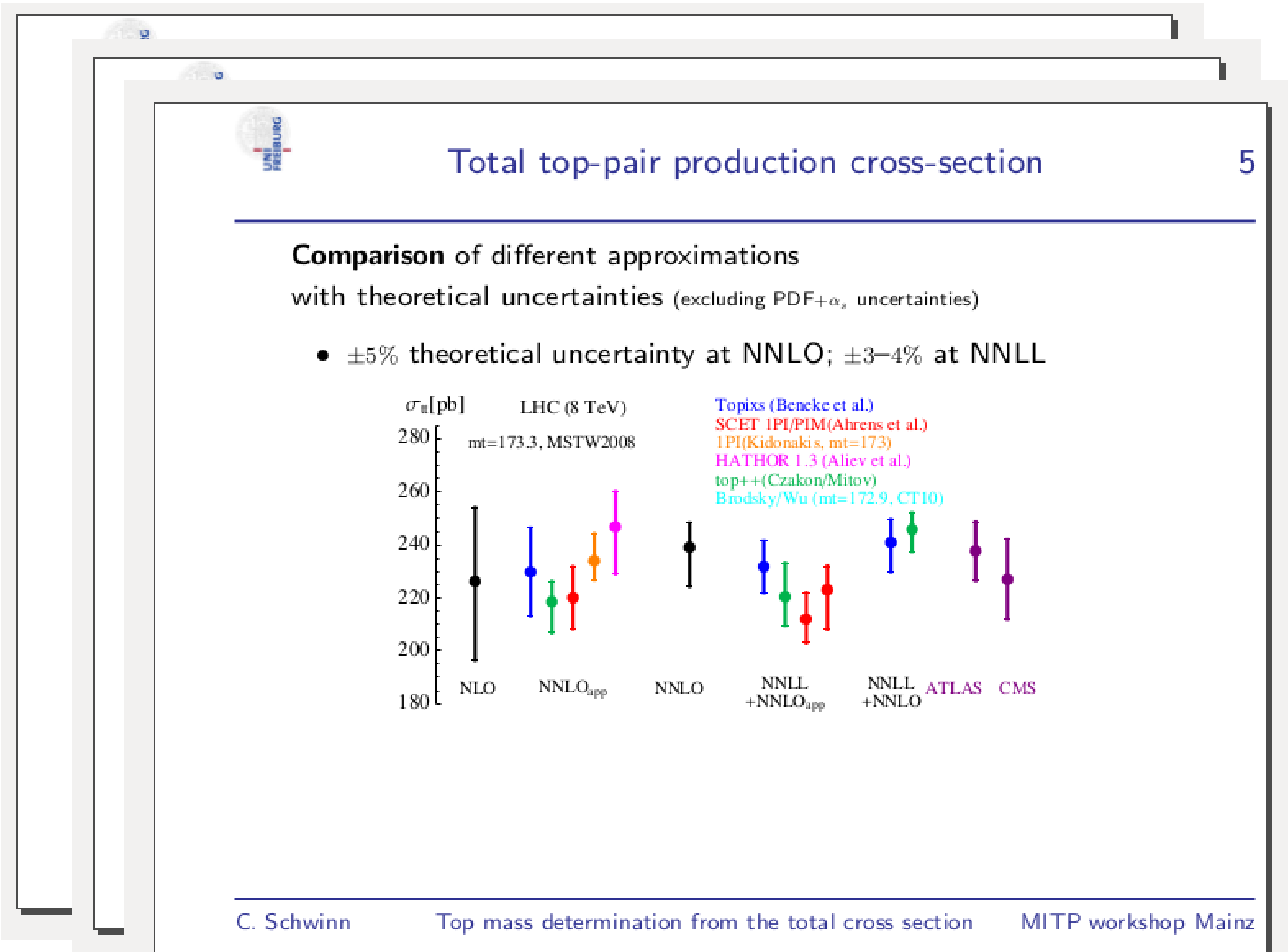
Programs including exact NNLO result

- TOP++ v2.0: NNLO+NNLL (soft) (Czakon/Mitov)
- HATHOR v1.5: NNLO (Aliev et al.)
- TOPIXS v2.0 NNLO+NNLL (soft+Coulomb) (Beneke et al.)

EW corrections $\sim 2\%$ (Bernreuther/Fücker/Si; Kühn/Scharf/Uwer, 05/06)

EW corrections to pole–$\overline{\mathrm{MS}}$ mass relation? (Jegerlehner/Kalmykov/Kniehl 12)

Extraction from the total cross section



Extraction from the total cross section

Mass measurement from cross section

Further potential example measurement (ATLAS - CONF - 2013 - 097)

$$\sigma_{t\bar{t}}(8\text{TeV}) = 237.7^{+11.3}_{-11.3}\text{pb} \qquad \frac{d\sigma_{t\bar{t}}}{dm_t} = -0.26\%\,\text{GeV}^{-1}$$

Results for NNLO, default PDF value for α_s

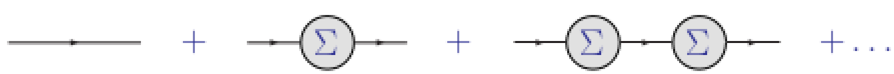
	MSTW08	CT10	NNPDF2.3	ABM11
m_t	$174.0^{+4.1}_{-4.5}$	$174.3^{+4.9}_{-5.4}$	$174.8^{+4.1}_{-4.4}$	$166.4^{+3.7}_{-4.4}$

- Effect of NNLL prediction: $174.0^{+4.1}_{-4.5} \to 174.2^{+3.6}_{-3.9}$
- Effect of $m_t = m_t^{\text{MC}} \pm 1\,\text{GeV}$: $\Delta m_t = \pm 0.1\,\text{GeV}$
- 50% reduction of exp. uncertainty: $174.2^{+3.6}_{-3.9} \to 174.2^{+3.2}_{-3.7}$
- 50% reduction of th. uncertainty: $174.2^{+3.6}_{-3.9} \to 174.0^{+2.5}_{-2.4}$
- 50% reduction of both uncertainties: $174.2^{+3.6}_{-3.9} \to 174.0^{+1.8}_{-1.9}$

Extraction from the total cross section

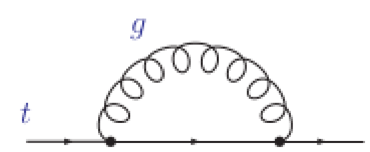
Quark mass renormalization

- Heavy-quark self-energy $\Sigma(p, m_q)$



$$= \frac{\mathrm{i}}{\not{p} - m_q - \Sigma(p, m_q)}$$

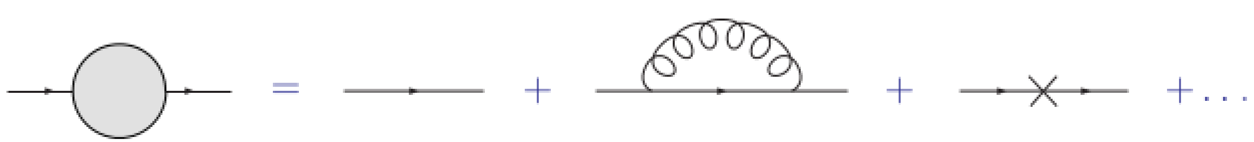
QCD



- QCD corrections to self-energy $\Sigma(p, m_q)$
  - dimensional regularization $D = 4 - 2\epsilon$
  - one-loop: UV divergence $1/\epsilon$ (Laurent expansion)

$$\Sigma^{(1),\mathrm{bare}}(p, m_q) = \frac{\alpha_s}{4\pi}\left(\frac{\mu^2}{m_q^2}\right)^{\epsilon}\left\{(\not{p} - m_q)\left(-C_F\,\frac{1}{\epsilon} + \text{fin.}\right) + m_q\left(3C_F\,\frac{1}{\epsilon} + \text{fin.}\right)\right\}$$

- Relate bare and renormalized mass parameter $m_q^{\mathrm{bare}} = m_q^{\mathrm{ren}} + \delta m_q$



$\Sigma^{\mathrm{ren}}(p, m_q)$ $\qquad$ $(Z_\psi - 1)\not{p} - (Z_m - 1)m_q$

Extraction from the total cross section

Mass renormalization scheme

Pole mass

- Based on (unphysical) concept of top quark being a free parton
  - $m_q^{\rm ren}$ coincides with pole of propagator at each order

$$\not{p} - m_q - \Sigma(p, m_q)\Big|_{\not{p}=m_q} \rightarrow \not{p} - m_q^{\rm pole}$$

- Definition of pole mass ambiguous up to corrections $\mathcal{O}(\Lambda_{QCD})$
  - heavy-quark self-energy $\Sigma(p, m_q)$ receives contributions from regions of all loop momenta – also from momenta of $\mathcal{O}(\Lambda_{QCD})$

$\overline{MS}$ scheme

- $\overline{MS}$ mass definition
  - one-loop minimal subtraction

$$\delta m_q^{(1)} = m_q \frac{\alpha_s}{4\pi} 3C_F \left(\frac{1}{\epsilon} - \gamma_E + \ln 4\pi\right)$$

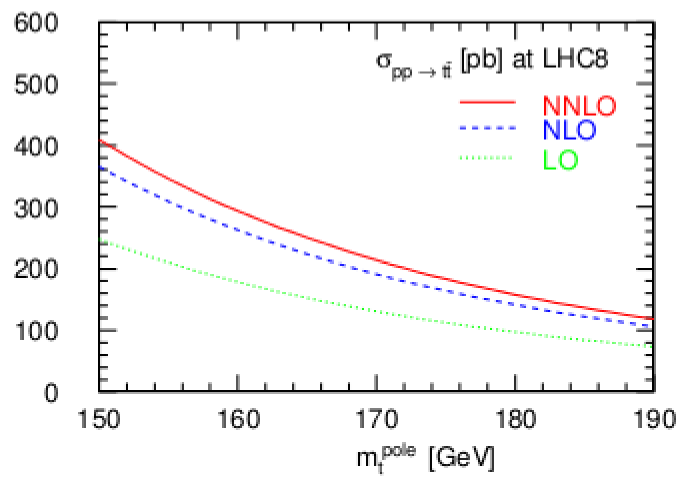
- $\overline{MS}$ scheme induces scale dependence: $m(\mu)$

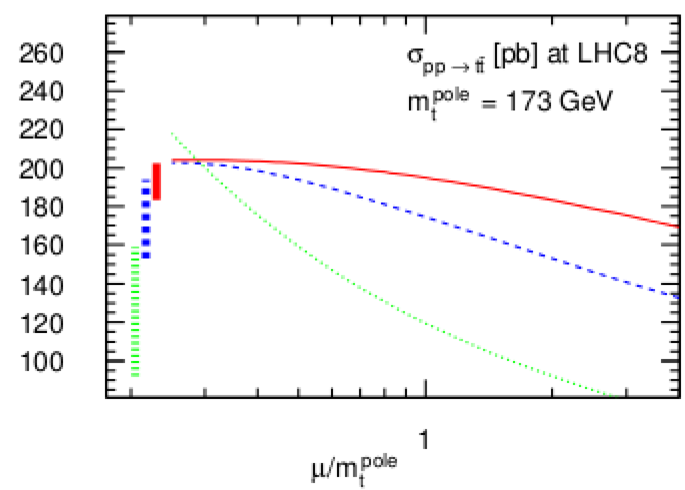
Extraction from the total cross section

Total cross section

Exact result at NNLO in QCD

Czakon, Fiedler, Mitov '13



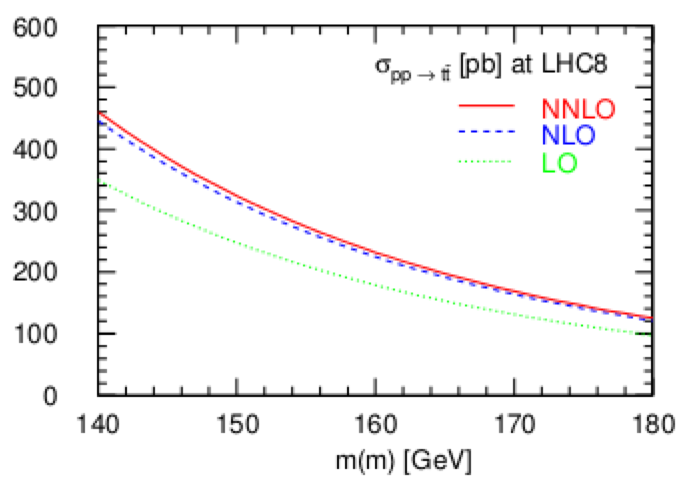


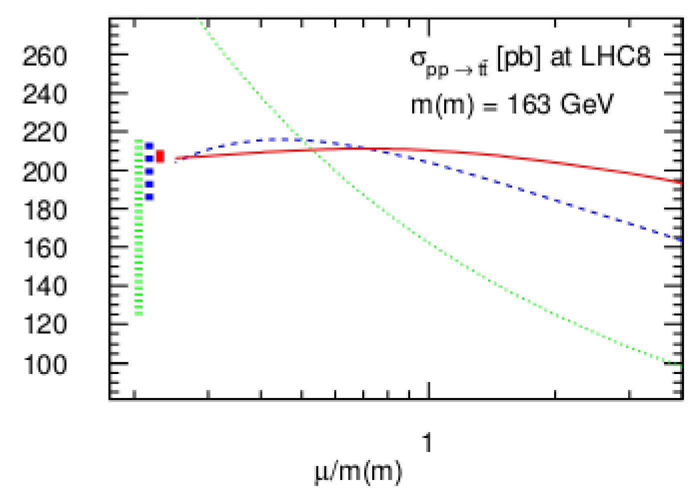
- NNLO perturbative corrections (e.g. at LHC8)
  - K-factor (NLO $\to$ NNLO) of $\mathcal{O}(10\%)$
  - scale stability at NNLO of $\mathcal{O}(\pm 5\%)$

Extraction from the total cross section

Total cross section with $\overline{MS}$ mass

- $\overline{MS}$ mass definition $m(\mu_R)$ realizes running mass (scale dependence)
  - short distance mass probes at scale of hard scattering
  - conversion between pole mass and $\overline{MS}$ mass definition in perturbation theory: $m_t = m(\mu_R)\left(1 + a_s(\mu_R)d^{(1)} + a_s(\mu_R)^2 d^{(2)}\right)$
- Good apparent convergence of perturbative expansion
- Small theoretical uncertainity form scale variation



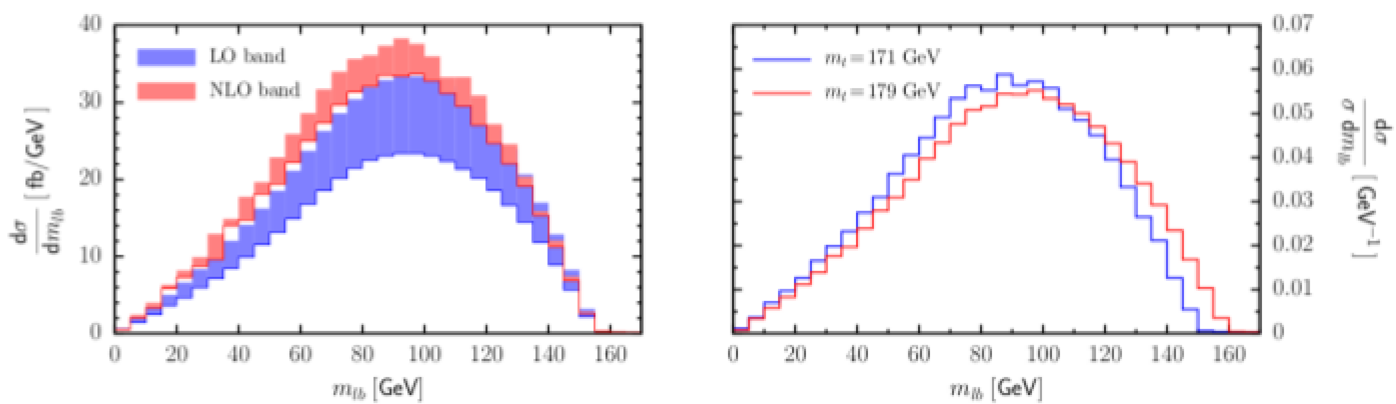


Extraction from kinematic distributions

Top quark mass determination from kinematic distributions

$m_{\rm lb}$ distribution

- Shape of $m_{\rm lb}$ distribution



→ Good sensitivity within the range $m_{\rm top} \in [171..179]$ GeV

M.Schulze

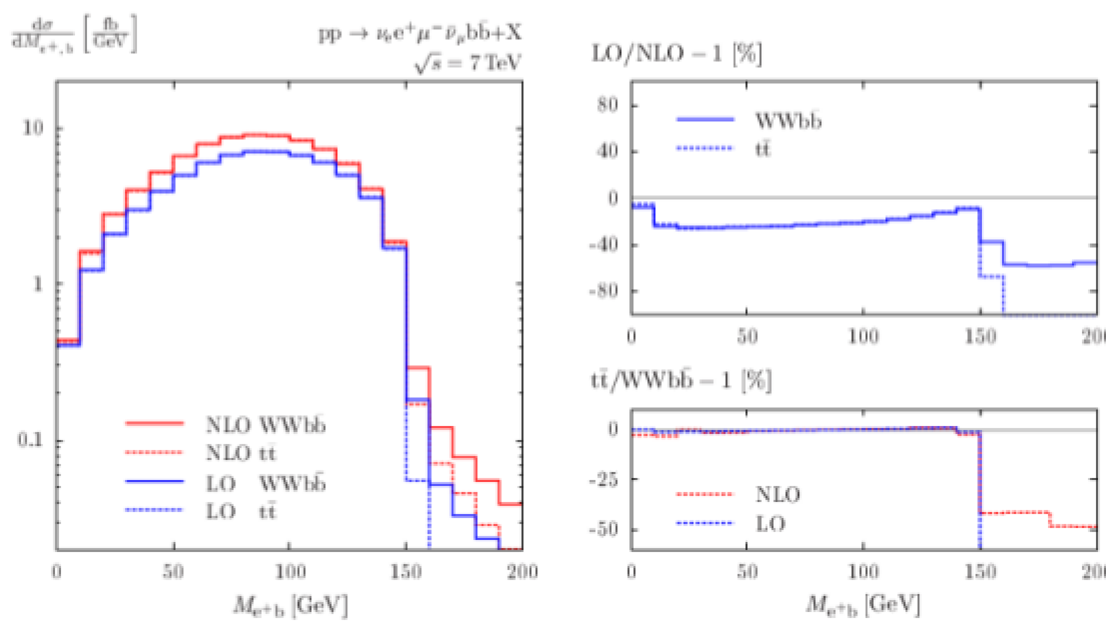
Extraction from kinematic distributions

Top quark mass determination from kinematic distributions

m_{lb} distribution

Study of finite width effects and non-factorizable corrections

[Denner,Dittmaier,Kallweit,Pozzorini,M.S.]



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Extraction from kinematic distributions

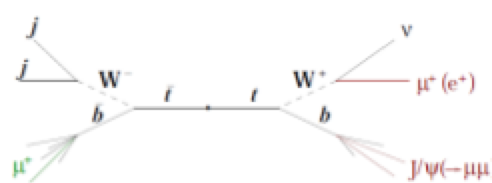
Top quark mass determination from kinematic distributions

The J/ψ method

- Basic idea:

  Study $m_{lJ/\psi}$ from top quark decay in a "*very*" leptonic decay channel

  → Clean final state **vs.** low event rate



- One in 10^5 top quark pairs decays in this channel.

  Hence, an integr. luminosity of ~100 fb^{-1} is required to obtain $\mathcal{O}(1\,\mathrm{GeV})$

- With relaxed assumptions, uncert. of $\mathcal{O}(1.5\,\mathrm{GeV})$ seems possible with 20 fb^{-1}

Extraction from kinematic distributions

Top-quark mass from jet rates

[S. Alioli, P.Fernandez, J.Fuster, A. Irles, S. Moch, PU, M. Vos '13]

To enhance mass sensitivity study:

$$\mathcal{R}(m_{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{Jet}}} \frac{d\sigma_{t\bar{t}+1\text{Jet}}}{d\rho_s}(m_{\text{pole}})$$

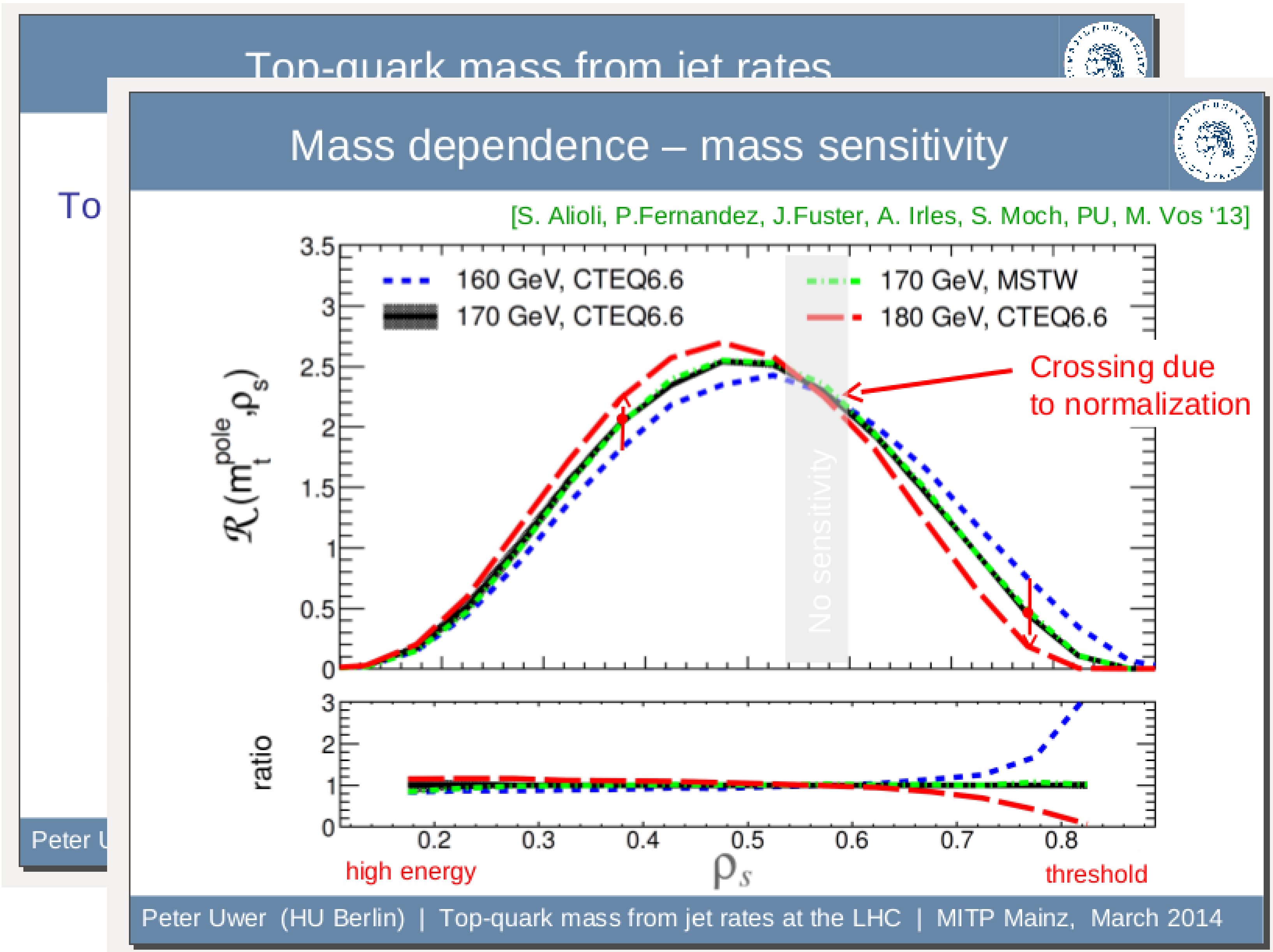
with $\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}+1\text{Jet}}}}, \quad m_0 = O(m)$

i.e. $m_0 = 170$ GeV

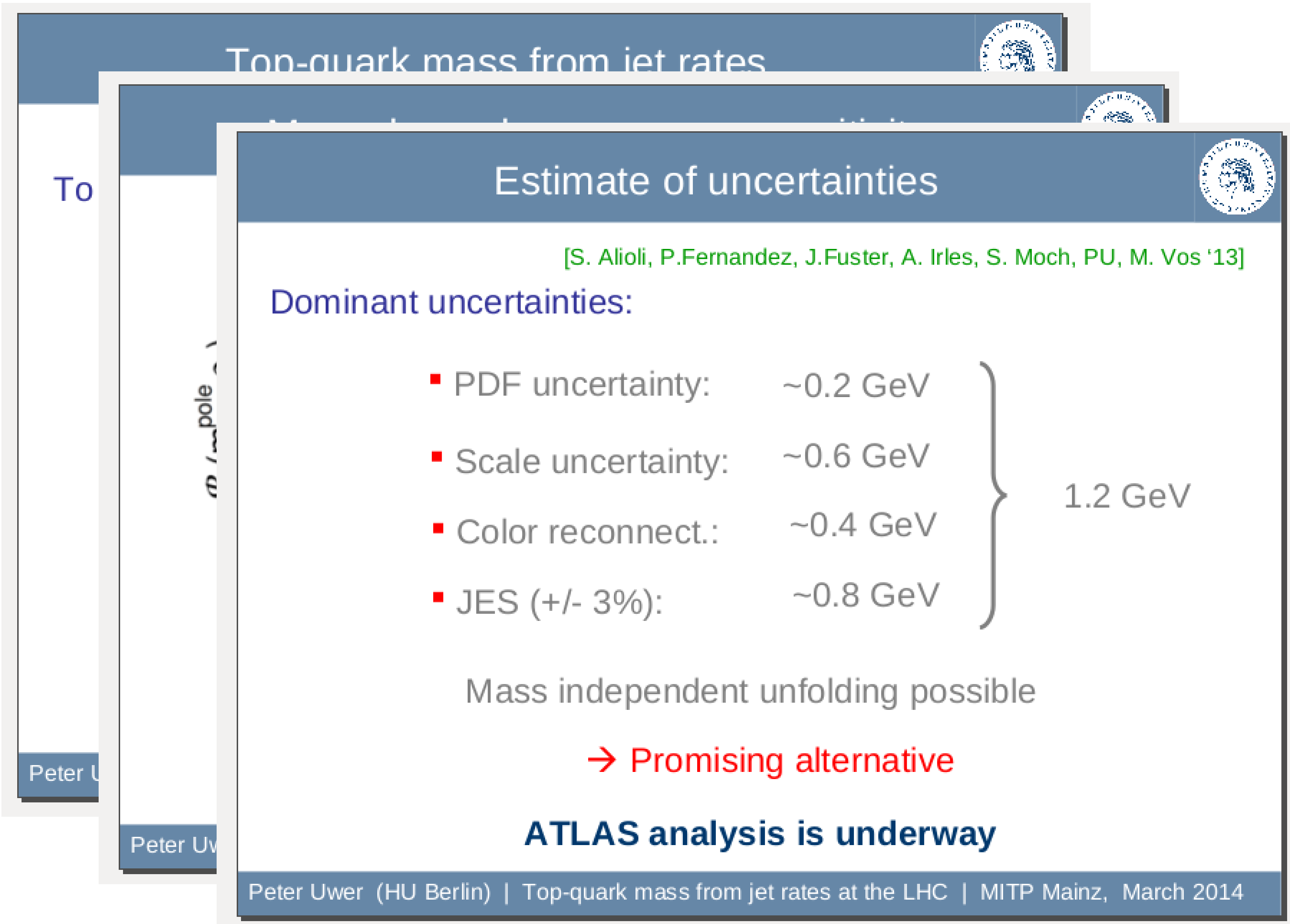
ρ_s similar to $\rho = \frac{4m_t^2}{s}$ used in incl. $t\bar{t}$ production

many uncertainties cancel in ratio

Extraction from kinematic distributions



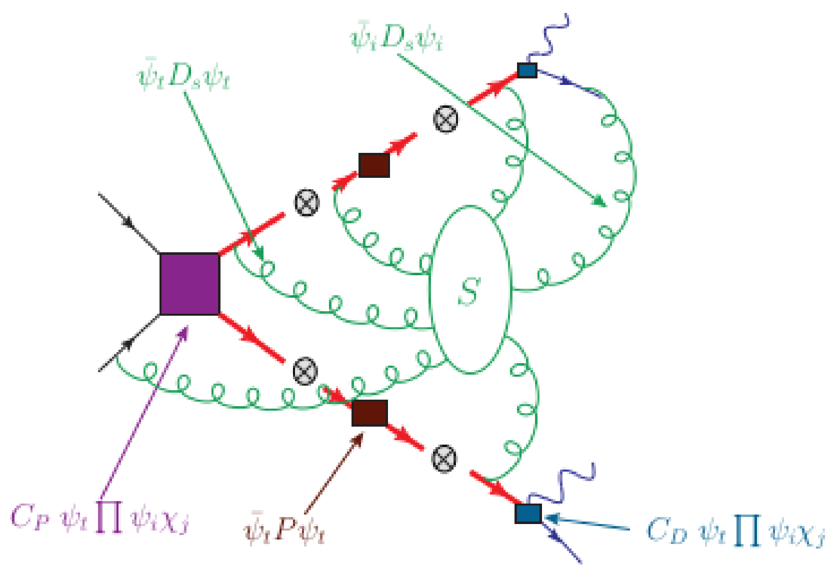
Extraction from kinematic distributions



Extraction from kinematic distributions

Expansion → EFT structure

Matrix element organization ≃ Wilson coefficients × operators
& dynamical degrees of freedom

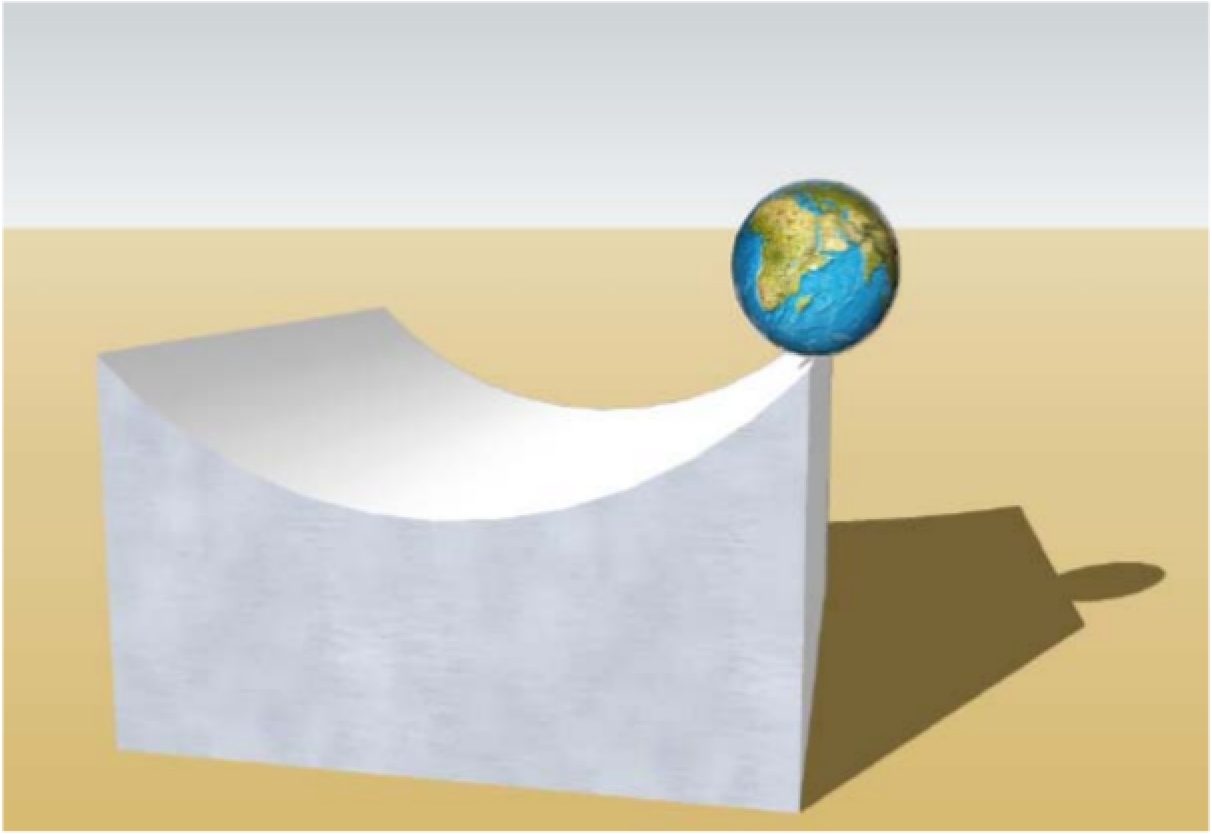


Operators: production, propagation & decay of heavy tops

Dynamical dof: soft gluons

Implications for BSM physics

LIVING AT THE EDGE



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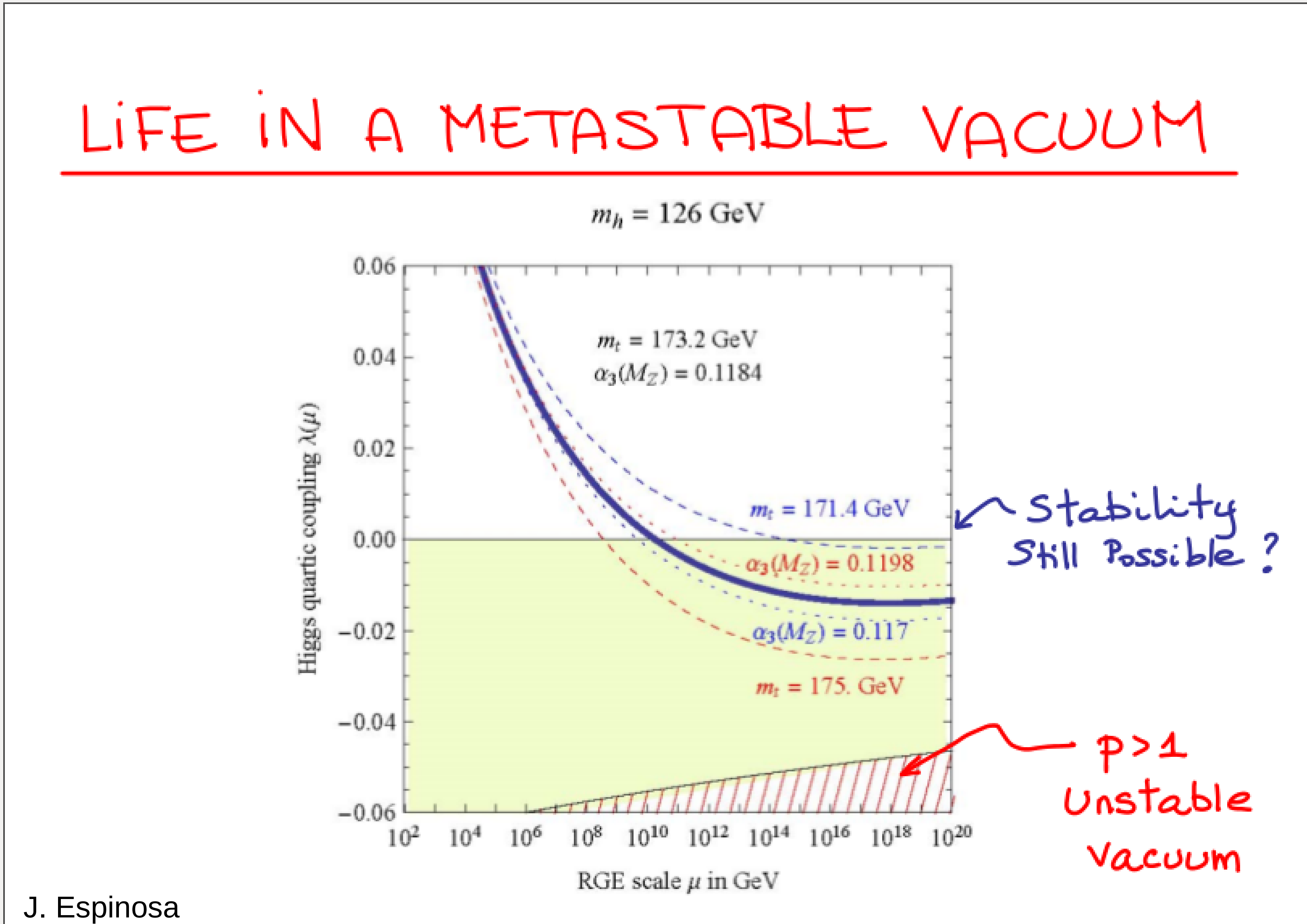
Implications for BSM physics



Implications for BSM physics

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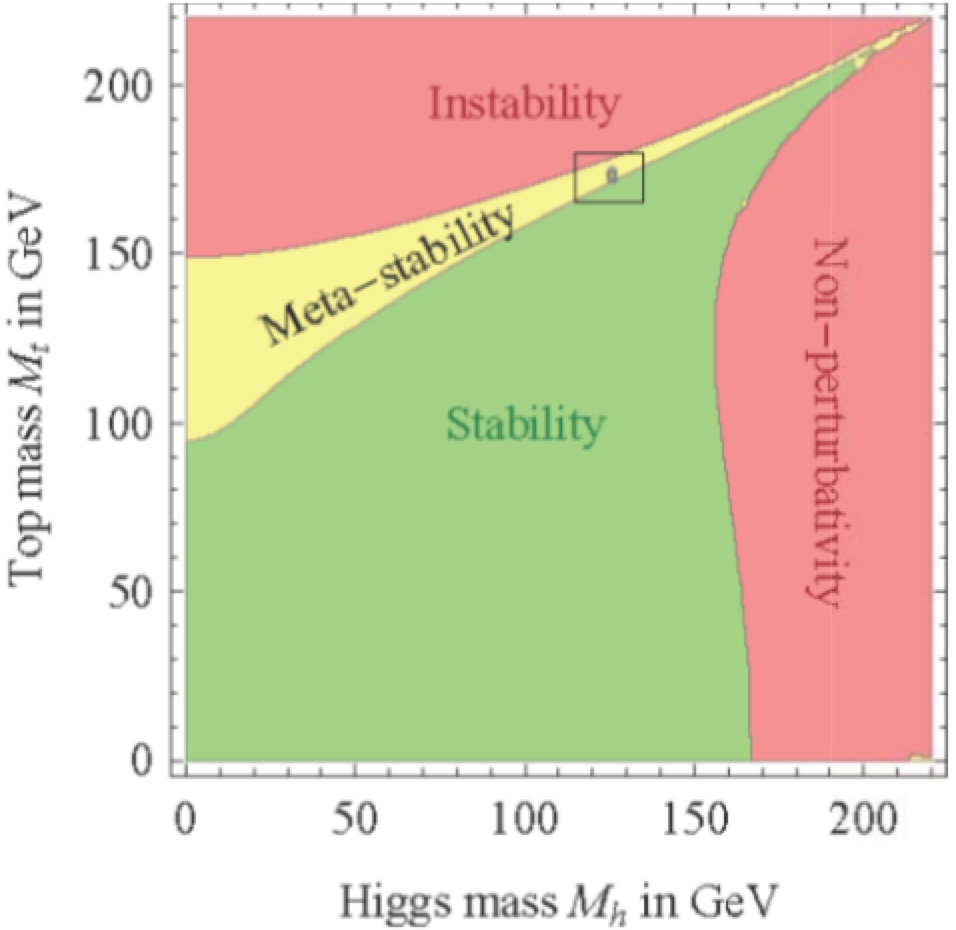

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Implications for BSM physics

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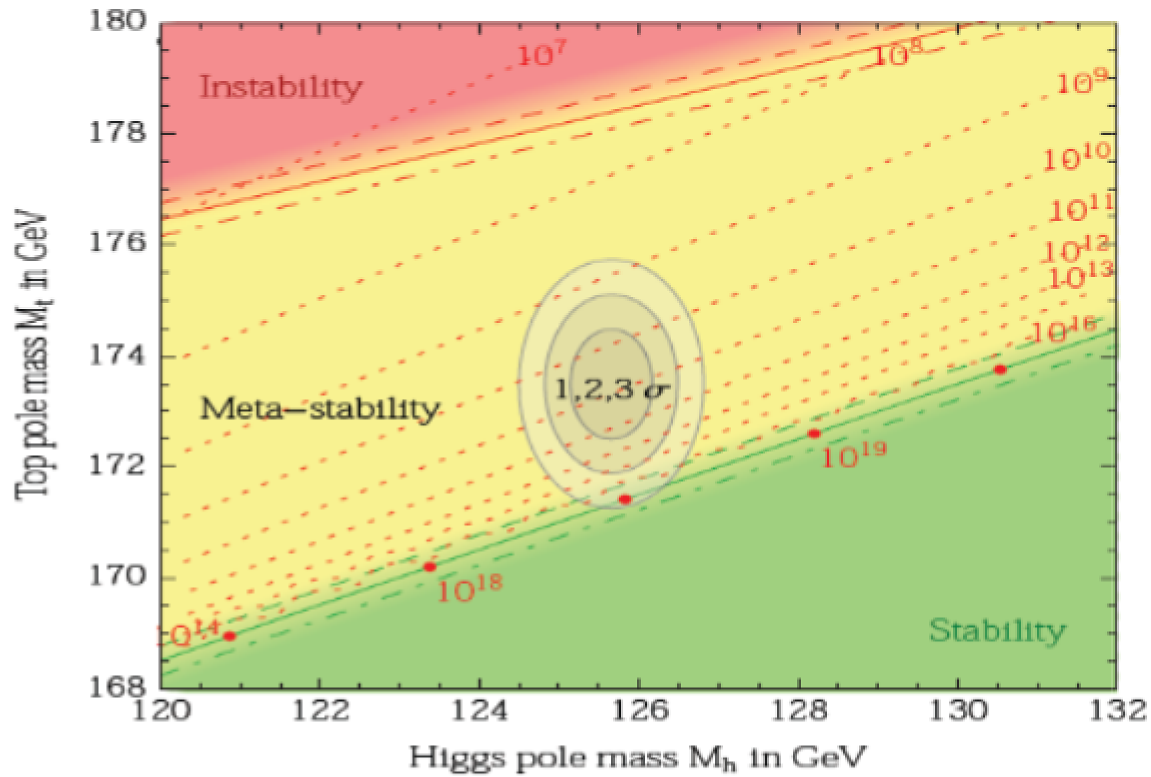

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Implications for BSM physics

NNLO STABILITY BOUND

Lower bound on M_h for stability up to M_{Pl}:

State-of-the-art NNLO calculation:

- 2-loop V_{eff} (Ford, Jack, Jones [ph/0111190])
- 3-loop RGEs (..., Chetyrkin, Zoller [ph/1205.2892], Bednyakov, Pikelner, Velizhanin [ph/1212.6829])
- 2-loop matching in $\lambda \leftrightarrow M_h^2$; $h_t \leftrightarrow M_t$ (..., Shaposhnikov et al [ph/1205.2893], Degrassi et al [ph/1205.6497], Buttazzo et al [ph/1307.3536])

Implications for BSM physics

BSM & STABILITY

Even without naturalness, BSM must exist...

Its impact on the Higgs instability can be

	Example
IRRELEVANT	See-saw neutrinos $M_R \lesssim 10^{13}$ GeV
MAKE IT WORSE	See-saw neutrinos $M_R \gtrsim 10^{13}$ GeV
CURE IT	See-saw neutrinos $M_R \sim \langle S \rangle$ & $\lambda_{HS} \lvert H \rvert^2 \lvert S \rvert^2$ Lebedev '12, Elias-Miro et al. '12

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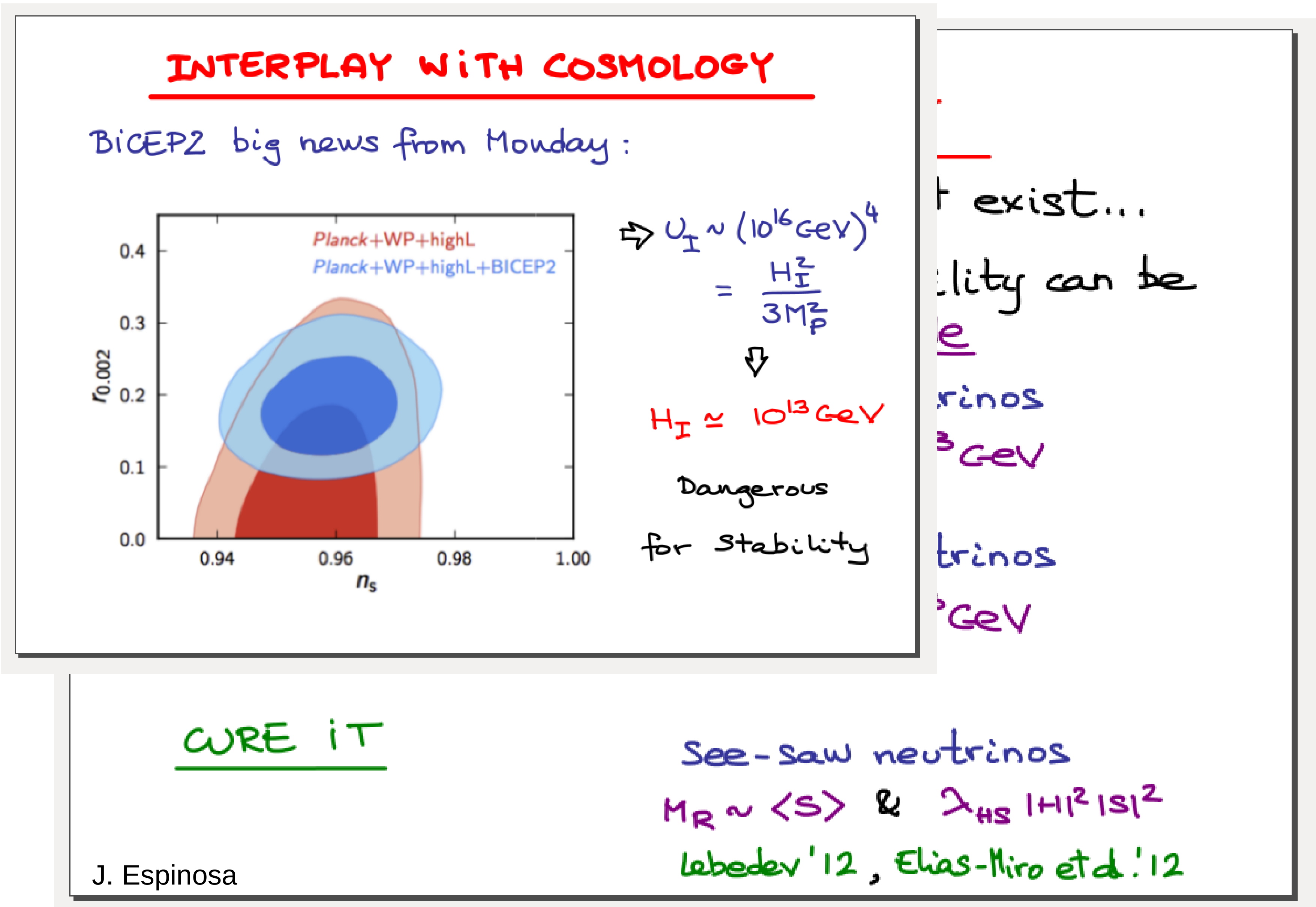
Implications for BSM physics



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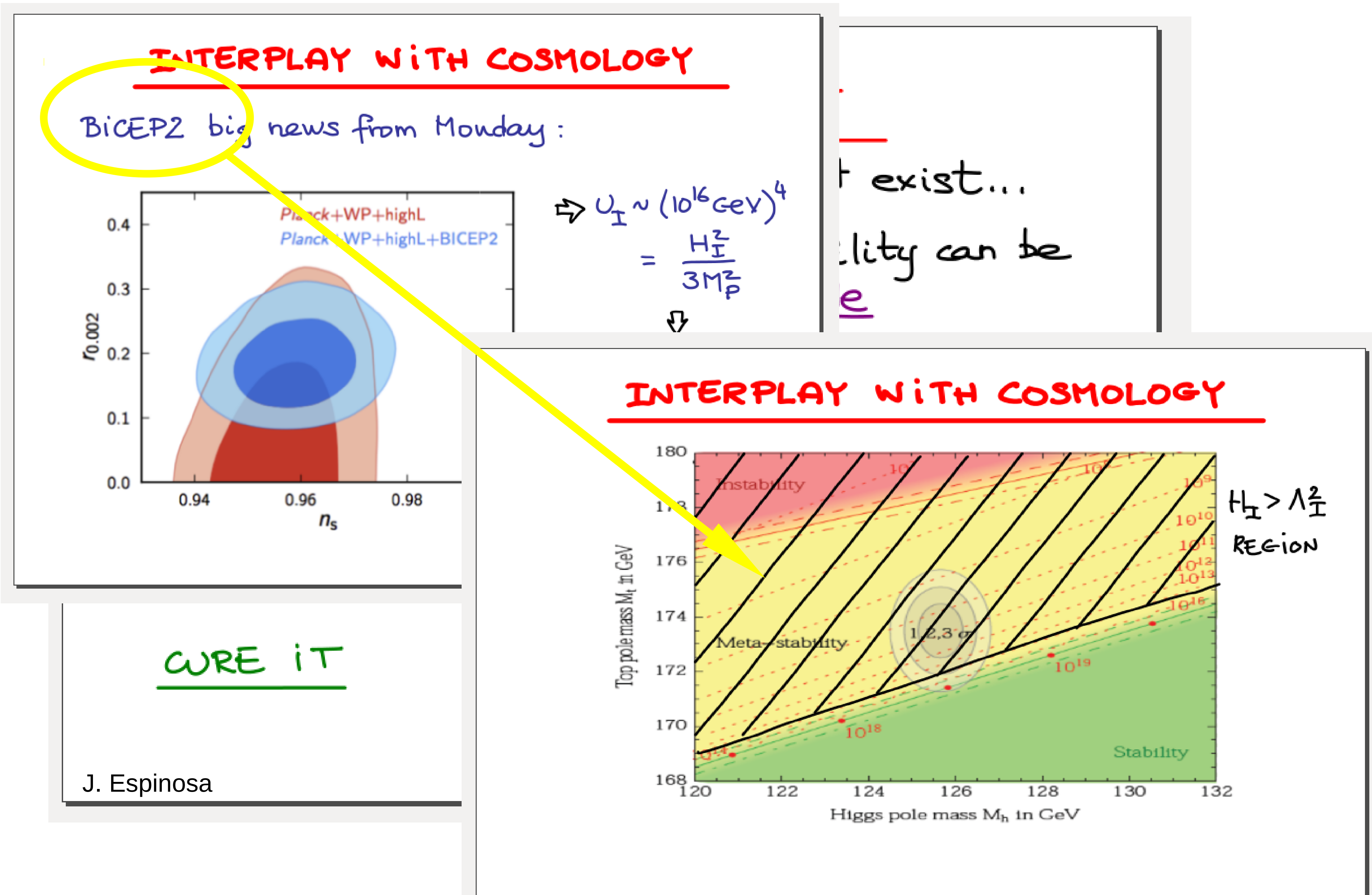
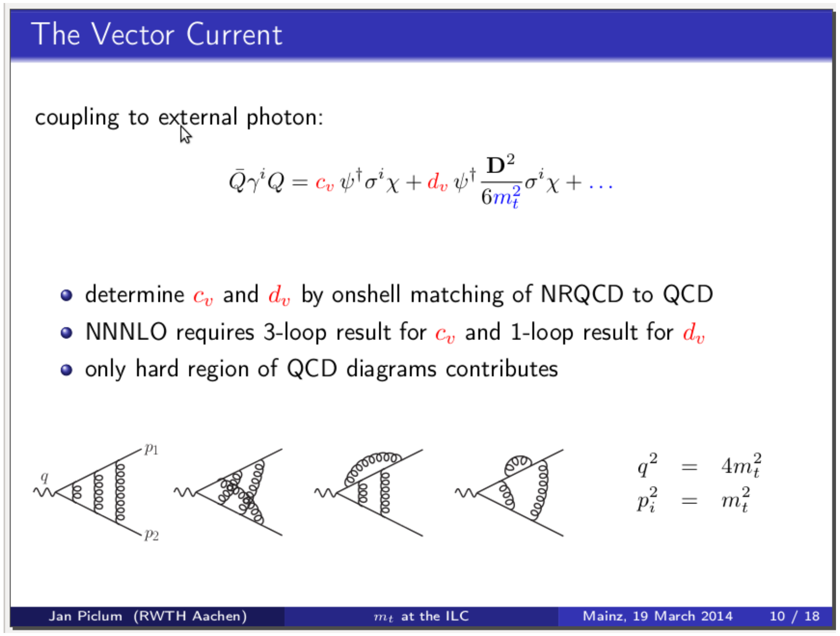
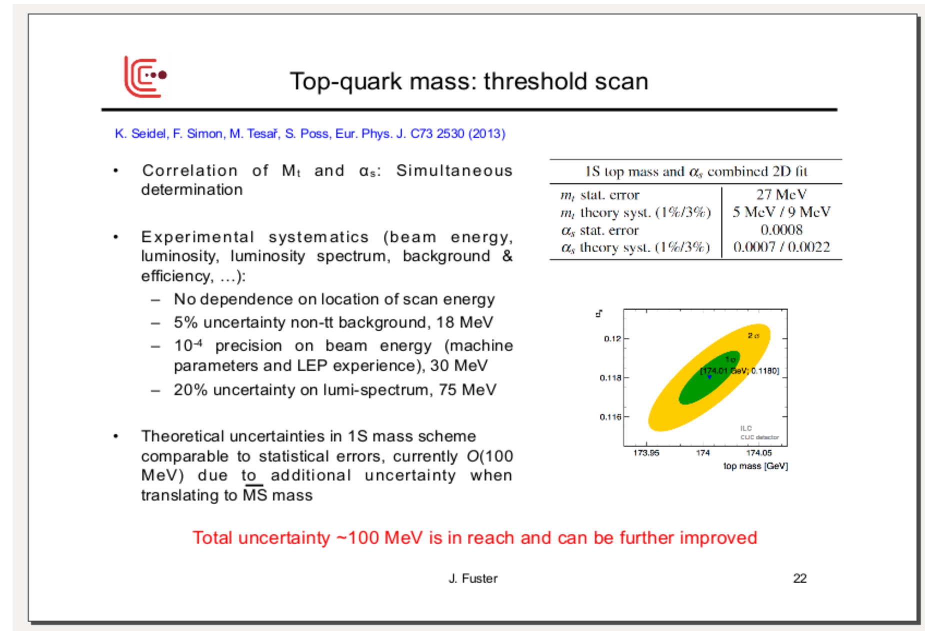
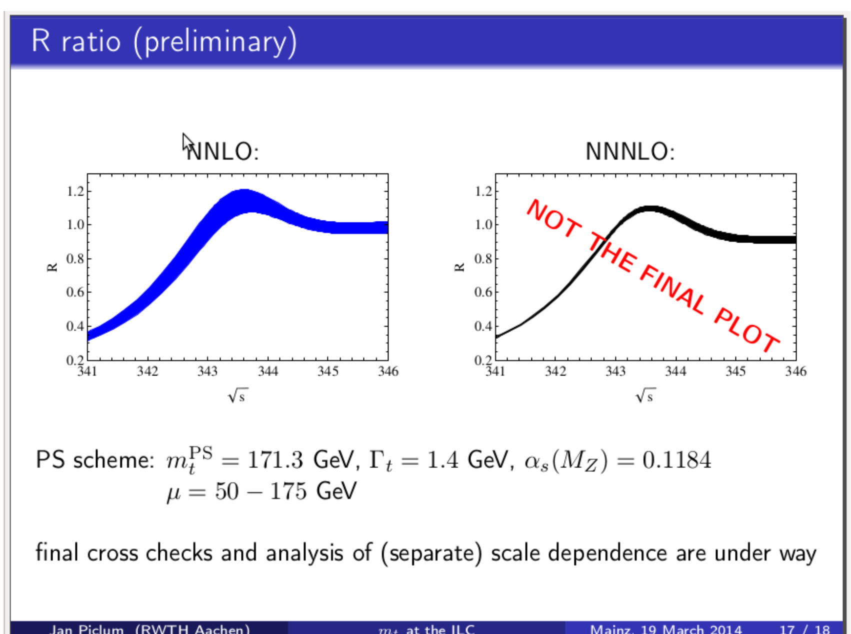
Implications for BSM physics

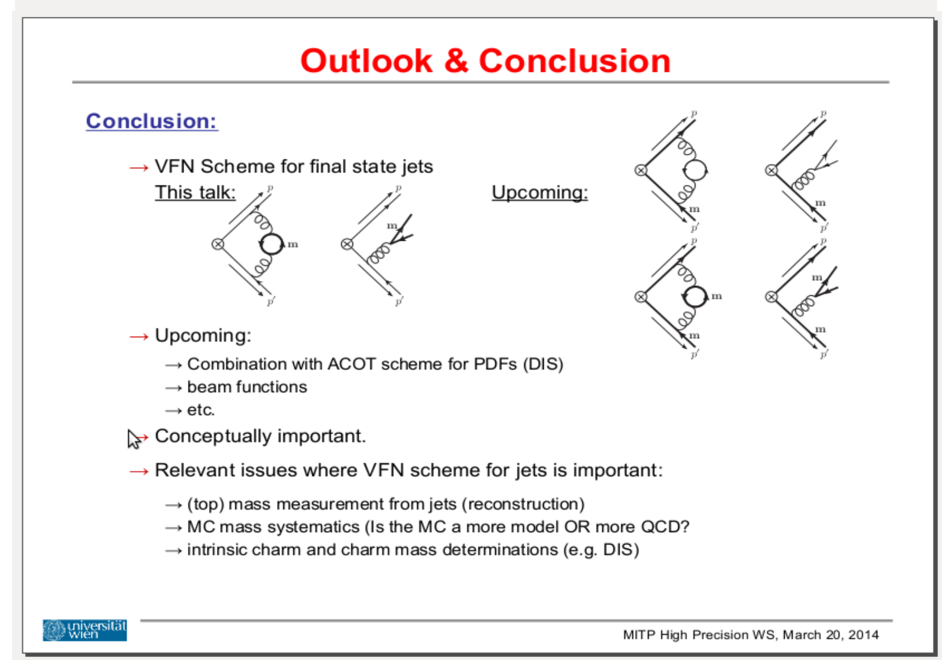


Measurements in e^+e^- collisions









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High Energy Physics - Phenomenology

High precision fundamental constants at the TeV scale

S. Moch, S. Weinzierl, S. Alekhin, J. Blumlein, L. de la Cruz, S. Dittmaier, M. Dowling, J. Erler, J.R. Espinosa, J. Fuster, X. Garcia i Tormo, A.H. Hoang, A. Huss, S. Kluth, M. Mulders, A.S. Papanastasiou, J. Piclum, K. Rabbertz, C. Schwinn, M. Schulze, E. Shintani, P. Uwer, N. Zerf

(Submitted on 19 May 2014)

This report summarizes the proceedings of the 2014 Mainz Institute for Theoretical Physics (MITP) scientific program on "High precision fundamental constants at the TeV scale". The two outstanding parameters in the Standard Model dealt with during the MITP scientific program are the strong coupling constant α_s and the top-quark mass m_t. Lacking knowledge on the value of those fundamental constants is often the limiting factor in the accuracy of theoretical predictions. The current status on α_s and m_t has been reviewed and directions for future research have been identified.

Comments:	57 pages, 24 figures, pdflatex
Subjects:	**High Energy Physics - Phenomenology (hep-ph)**
Report number:	MITP/14-036
Cite as:	**arXiv:1405.4781 [hep-ph]**
	(or **arXiv:1405.4781v1 [hep-ph]** for this version)

Submission history

From: Sven-Olaf Moch [view email]

[v1] Mon, 19 May 2014 16:02:45 GMT (2001kb,D)

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References & Citations

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CERN mini top quark workshop, May `14

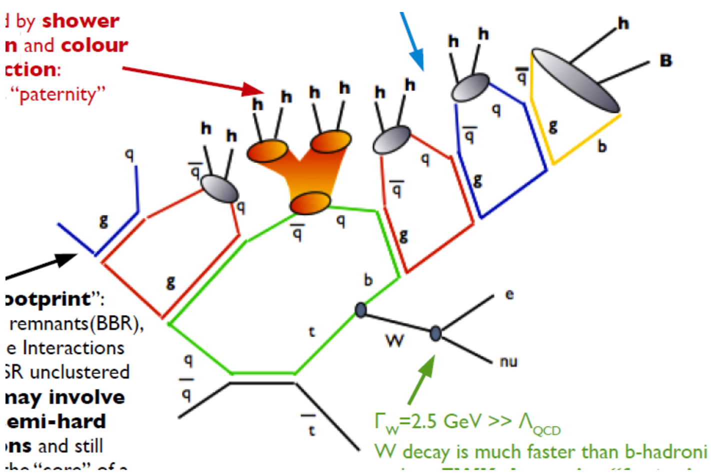
First studies of hadronization effects and color reconnection on mtop determination

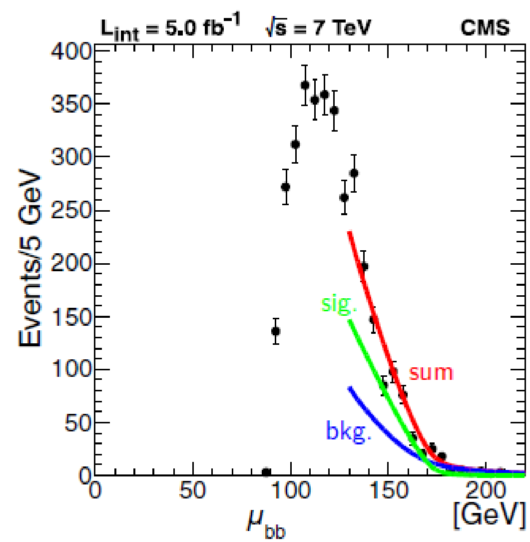
New observables: Best balance between large sensitivity and small systematics

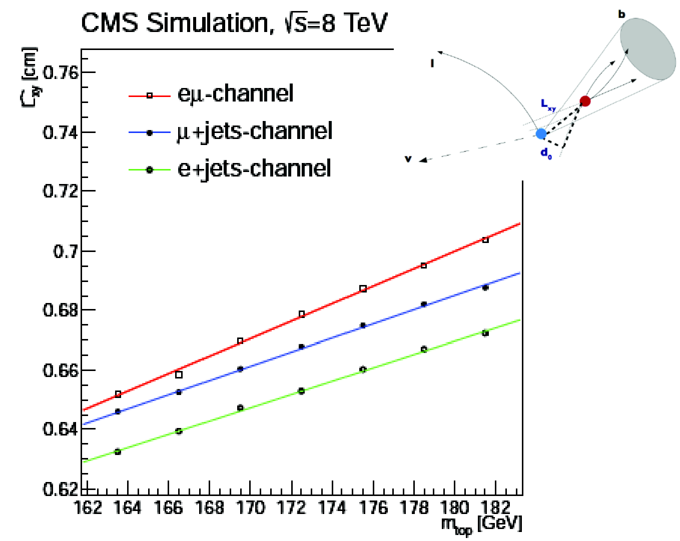
New ideas:

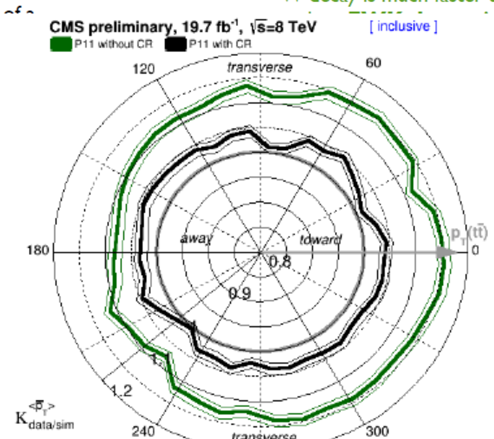
B-hadron lifetime

Kinematic end-points









In the range m_{top} = 171 – 175 GeV, α_S is ~constant, and, using the 3-loop expression above,

$$m_{pole} = \overline{m} \times [1 + 0.047 + 0.010 + 0.003] = 1.060 \times \overline{m}$$

showing an excellent convergence. In comparison, the expansion for the bottom quark mass behaves very poorly:

$$m^b_{pole} = \overline{m}^b \times [1 + 0.09 + 0.05 + 0.04]$$

Assuming that after the 3rd order the perturbative expansion of m_{pole} vs m_{MS} start diverging, the smallest term of the series, which gives the size of the uncertainty in the resummation of the asymptotic series, is of O(0.003 * m), namely O(500 MeV), consistent with Λ_{QCD}

Questions, Comments, Discussion…