International Workshop on Future Linear Colliders

LCWS13

11-15 November 2013, The University of Tokyo

Summary of the Top, QCD and Loopverein working group activities

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For the conveners and presenters of RD3 sessions

- 14 presentations, 10 theory talks, and 4 experimental ones

Andre Hoang:	“Subtleties in precise top quark mass determination at the LHC and ILC”
Pedro Ruiz Femenia:	“Non-resonant production of bbar W+W- at the top anti-top threshold”
Vicent Mateu:	“Event shapes at e+e- colliders in SCET”
Yuichiro Kiyo:	“ttbar threshold production”
P. H. Khiem:	“Full 1-loop electroweak corrections to the $t\bar{t}\gamma$ and $e^+e^-\gamma$ production at ILC with GRACE-Loop”
Sven Heinemeyer:	“Overview of QCD and parametric uncertainties on Higgs coupling extraction in a linear collider”
Marcel Vos:	“Top asymmetries”
Sven Heinemeyer:	“Linear collider precision in the MSSM”
Frank Simon:	“Top mass and future top studies at CLIC”
Minsuk Kim:	“LHC top mass-alternative methods and prospects for the future”
Tomohiro Horiguchi:	“Study of top pair production near the threshold at the ILC”
Paul Mackenzie:	“Charm, bottom quark mass and alpha_s determination from lattice”
Gionata Luisoni:	“Review of alpha_s determination from non-lattice”
Andre Hoang:	“Charm and bottom quark mass determination from non-lattice”

I apologize in advance for not covering all the presented talks in this 12 min summary !

Focus of Top, QCD and Loopverein in LCWS13

Fundamental parameters of QCD, and their impact on the precision Higgs program: eg. α_s, m_c, m_b

Andre Hoang
Sven Heinemeyer
Gionata Luisoni
Paul Mackenzie
Vicent Mateu

Top-quark properties: mass, width, and electroweak couplings

Pedro Ruiz Femenia
Tomohiro Horiguchi
Minsuk Kim
Yuichiro Kiyo
Frank Simon
Marcel Vos

Theoretical tools for higher-order radiative corrections at linear colliders

P. H. Khiem

Fundamental parameters

- Strong dependence of Higgs branching ratios on the input parameters alpha_s, mc, mb

- Their uncertainties are combined in quadrature to get the total parametric uncertainty

- The parametric uncertainties for Higgs branching ratios are comparable to or larger than the uncertainties from uncalculated higher-order corrections

- Their reduction, using both lattice and non-lattice determinations, is a focus of current research

Higgs Snowmass report 2013

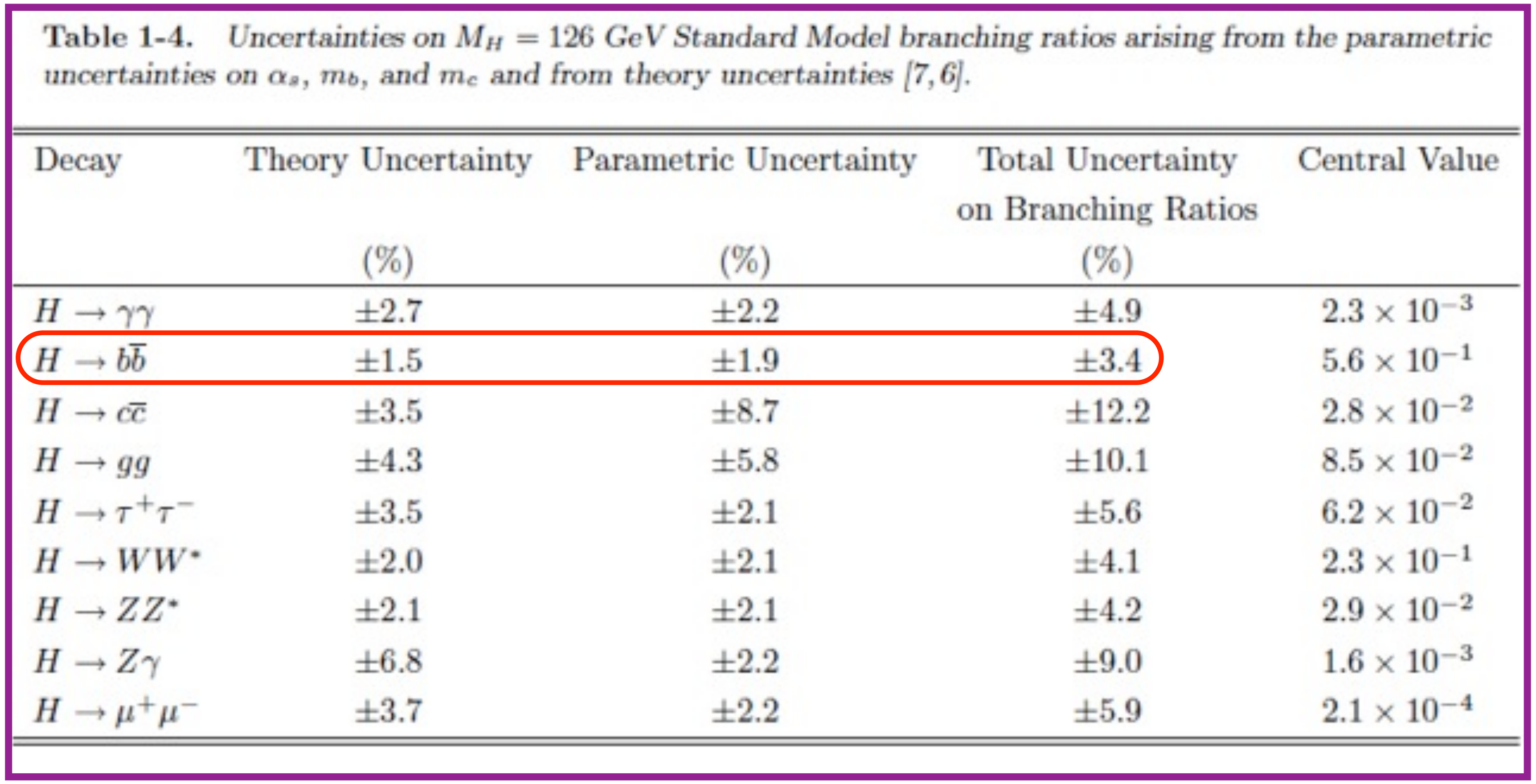
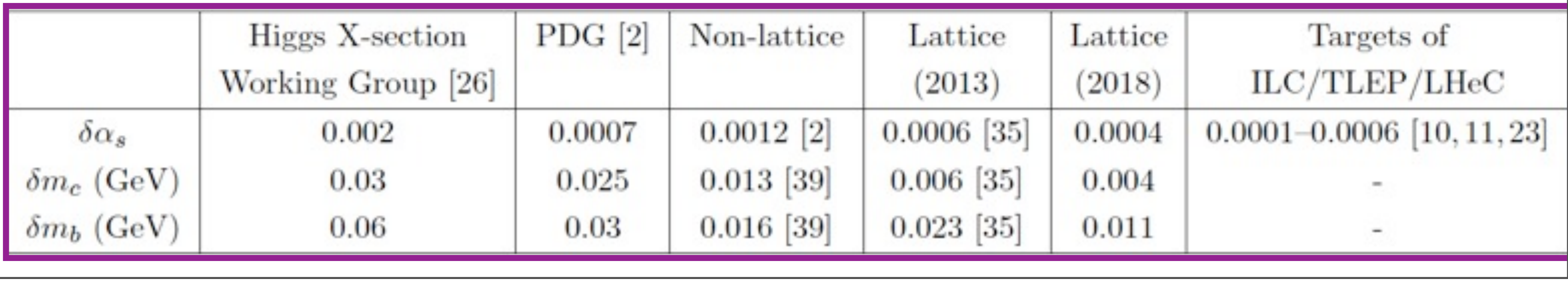


Table 1-4. *Uncertainties on $M_H = 126$ GeV Standard Model branching ratios arising from the parametric uncertainties on α_s, m_b, and m_c and from theory uncertainties [7,6].*

Decay	Theory Uncertainty (%)	Parametric Uncertainty (%)	Total Uncertainty on Branching Ratios (%)	Central Value
$H \to \gamma\gamma$	±2.7	±2.2	±4.9	2.3×10^{-3}
$H \to b\bar{b}$	±1.5	±1.9	±3.4	5.6×10^{-1}
$H \to c\bar{c}$	±3.5	±8.7	±12.2	2.8×10^{-2}
$H \to gg$	±4.3	±5.8	±10.1	8.5×10^{-2}
$H \to \tau^+\tau^-$	±3.5	±2.1	±5.6	6.2×10^{-2}
$H \to WW^*$	±2.0	±2.1	±4.1	2.3×10^{-1}
$H \to ZZ^*$	±2.1	±2.1	±4.2	2.9×10^{-2}
$H \to Z\gamma$	±6.8	±2.2	±9.0	1.6×10^{-3}
$H \to \mu^+\mu^-$	±3.7	±2.2	±5.9	2.1×10^{-4}

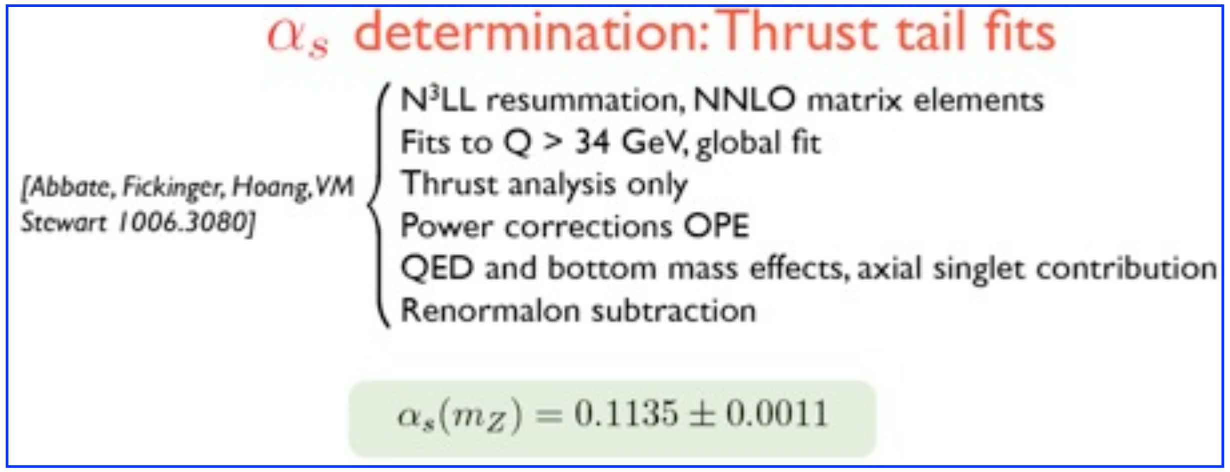
QCD Snowmass report 2013



	Higgs X-section Working Group [26]	PDG [2]	Non-lattice	Lattice (2013)	Lattice (2018)	Targets of ILC/TLEP/LHeC
$\delta\alpha_s$	0.002	0.0007	0.0012 [2]	0.0006 [35]	0.0004	0.0001–0.0006 [10, 11, 23]
δm_c (GeV)	0.03	0.025	0.013 [39]	0.006 [35]	0.004	-
δm_b (GeV)	0.06	0.03	0.016 [39]	0.023 [35]	0.011	-

Strong coupling constant and mb from non-lattice determinations

[Vicent Mateu: using event shapes]



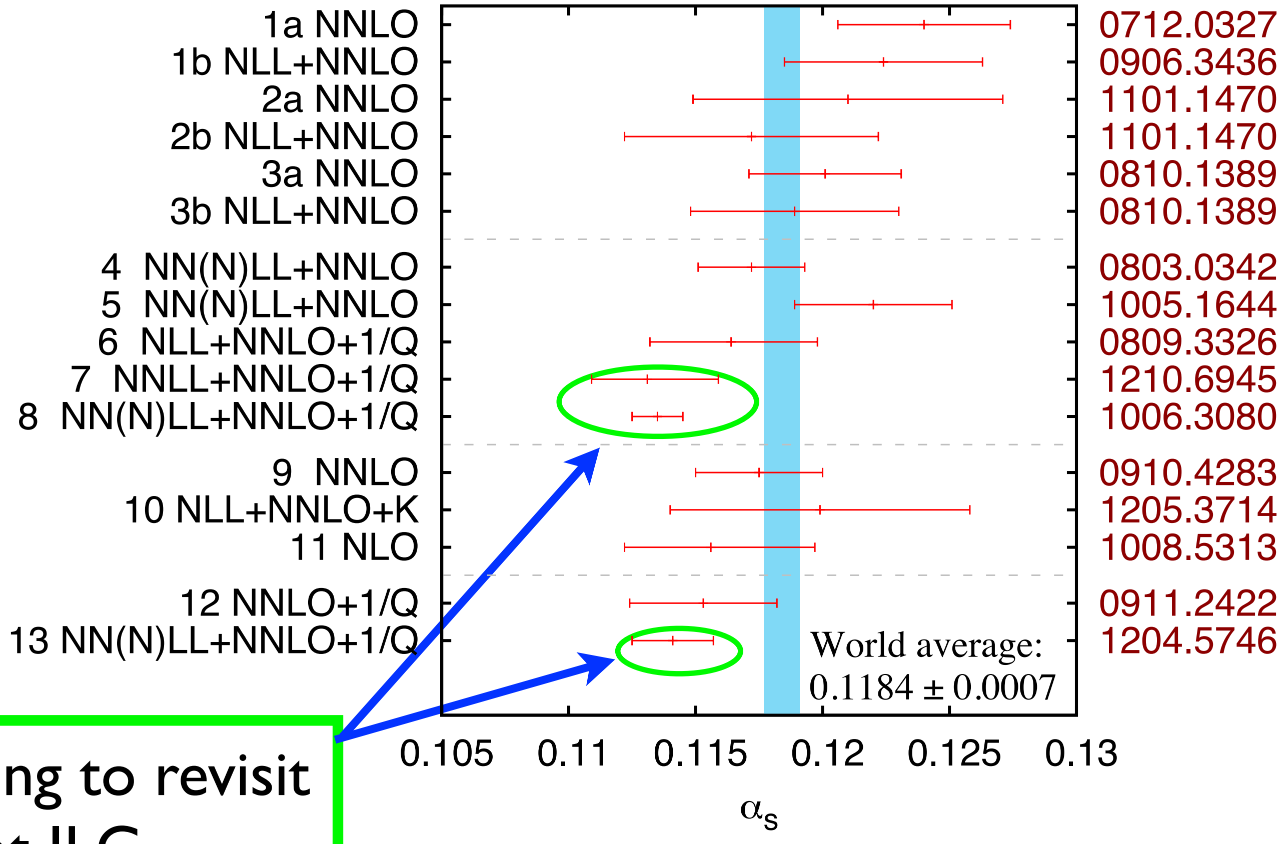
α_s determination: Thrust tail fits

[Abbate, Fickinger, Hoang, VM Stewart 1006.3080]

- N³LL resummation, NNLO matrix elements
- Fits to Q > 34 GeV, global fit
- Thrust analysis only
- Power corrections OPE
- QED and bottom mass effects, axial singlet contribution
- Renormalon subtraction

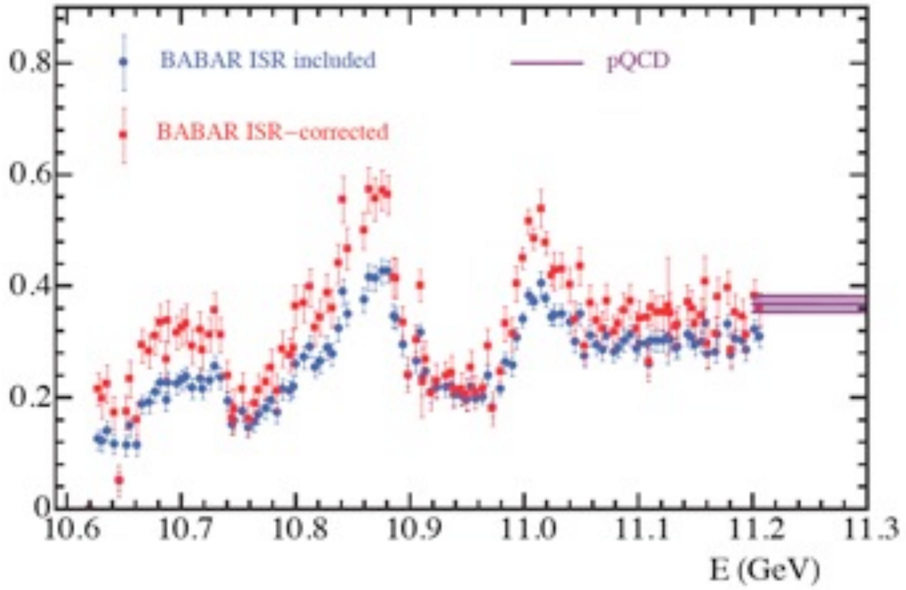
$$\alpha_s(m_Z) = 0.1135 \pm 0.0011$$

[See Luisoni's talk for details, fits based on e+e- data]



It would be interesting to revisit the outliers at ILC

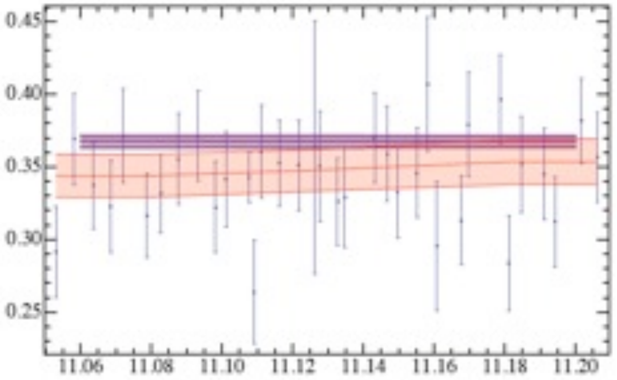
Continuum (11.06 – 11.21 GeV):



[Hoang]

Dehnadi, AH, Mateu, w.i.p.

Very preliminary



Agreement (averaged) data vs. theory : 4%

→ conservative continuum model:

R_b(theory) ± 4%

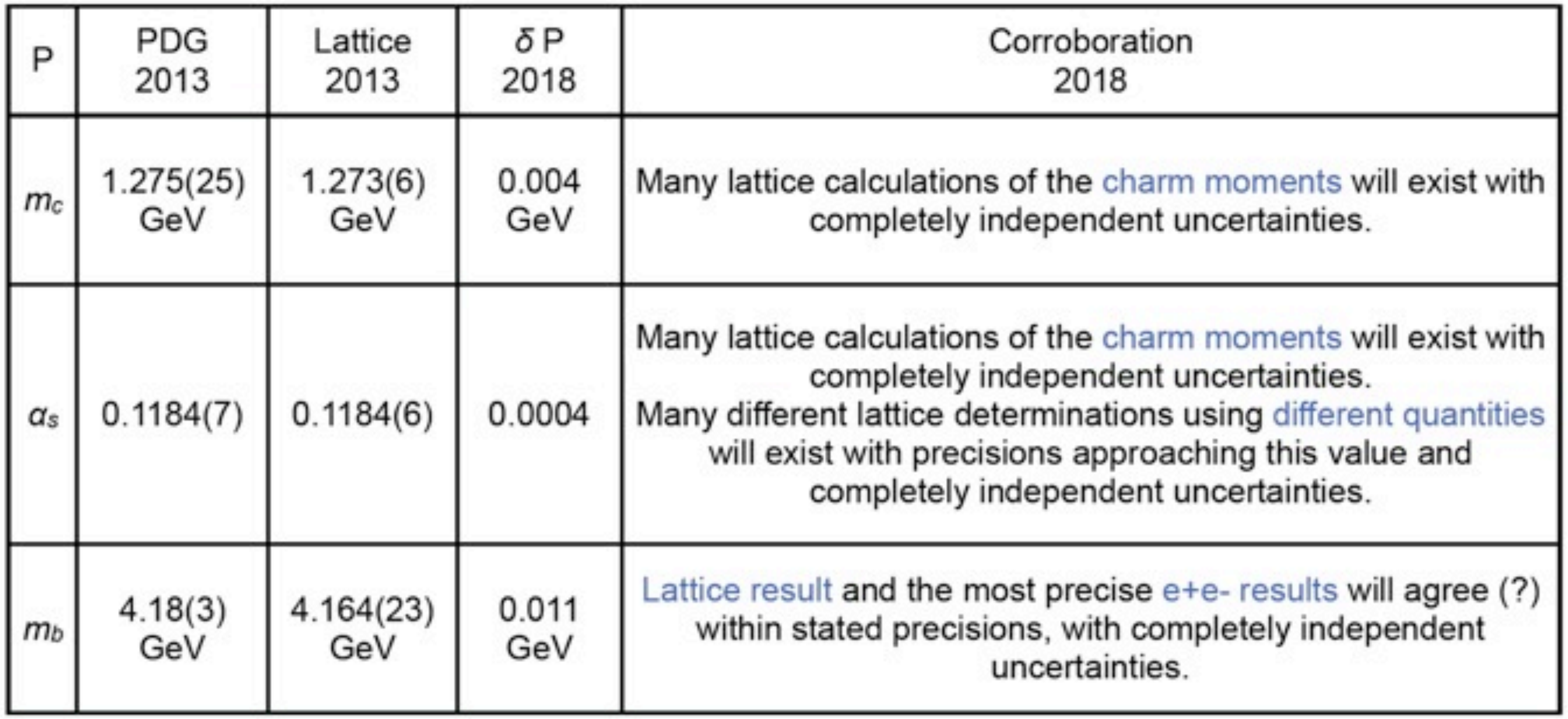
mb from upsilon sum-rules. Central value consistent with lattice determinations

Lattice: mb = 4.164(23) GeV

[Hoang]: mb = 4.18(3) GeV

Strong coupling constant, m_b and m_c from lattice determinations

What to expect from lattice



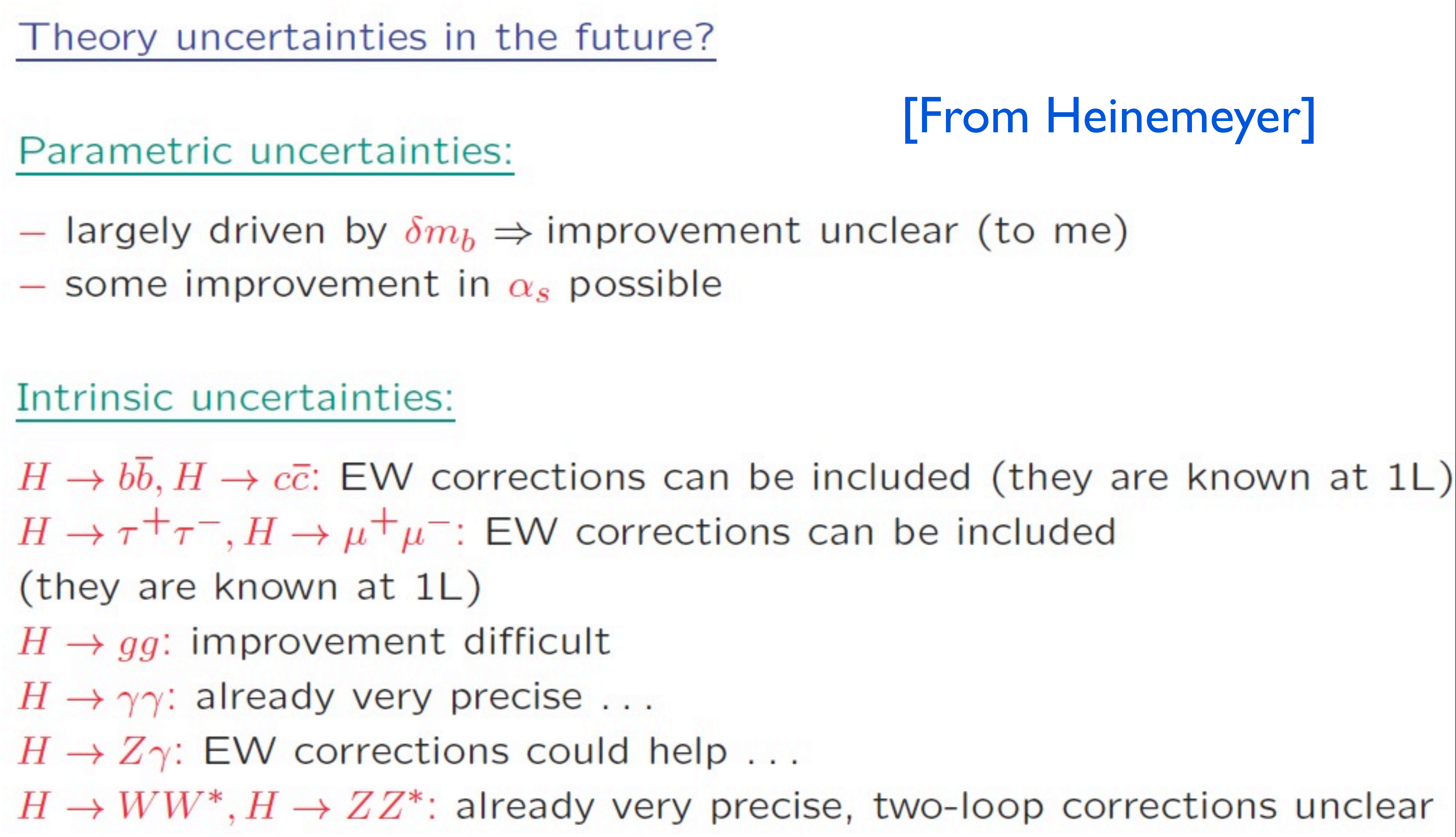
P	PDG 2013	Lattice 2013	δ P 2018	Corroboration 2018
m_c	1.275(25) GeV	1.273(6) GeV	0.004 GeV	Many lattice calculations of the charm moments will exist with completely independent uncertainties.
α_s	0.1184(7)	0.1184(6)	0.0004	Many lattice calculations of the charm moments will exist with completely independent uncertainties. Many different lattice determinations using different quantities will exist with precisions approaching this value and completely independent uncertainties.
m_b	4.18(3) GeV	4.164(23) GeV	0.011 GeV	Lattice result and the most precise e+e- results will agree (?) within stated precisions, with completely independent uncertainties.

[From Mackenzie]

- Lattice calculations now provide the most precise determinations of α_s and m_c. They soon will also provide the most precise determination of m_b. [Mackenzie]

Errors on lattice and other mass determinations subject of healthy debate in the community [many conversations]. Needs more discussion!

[From Heinemeyer]



Theory uncertainties in the future?

Parametric uncertainties:

- largely driven by $\delta m_b \Rightarrow$ improvement unclear (to me)
- some improvement in α_s possible

Intrinsic uncertainties:

$H \to b\bar{b}, H \to c\bar{c}$: EW corrections can be included (they are known at 1L)

$H \to \tau^+\tau^-, H \to \mu^+\mu^-$: EW corrections can be included (they are known at 1L)

$H \to gg$: improvement difficult

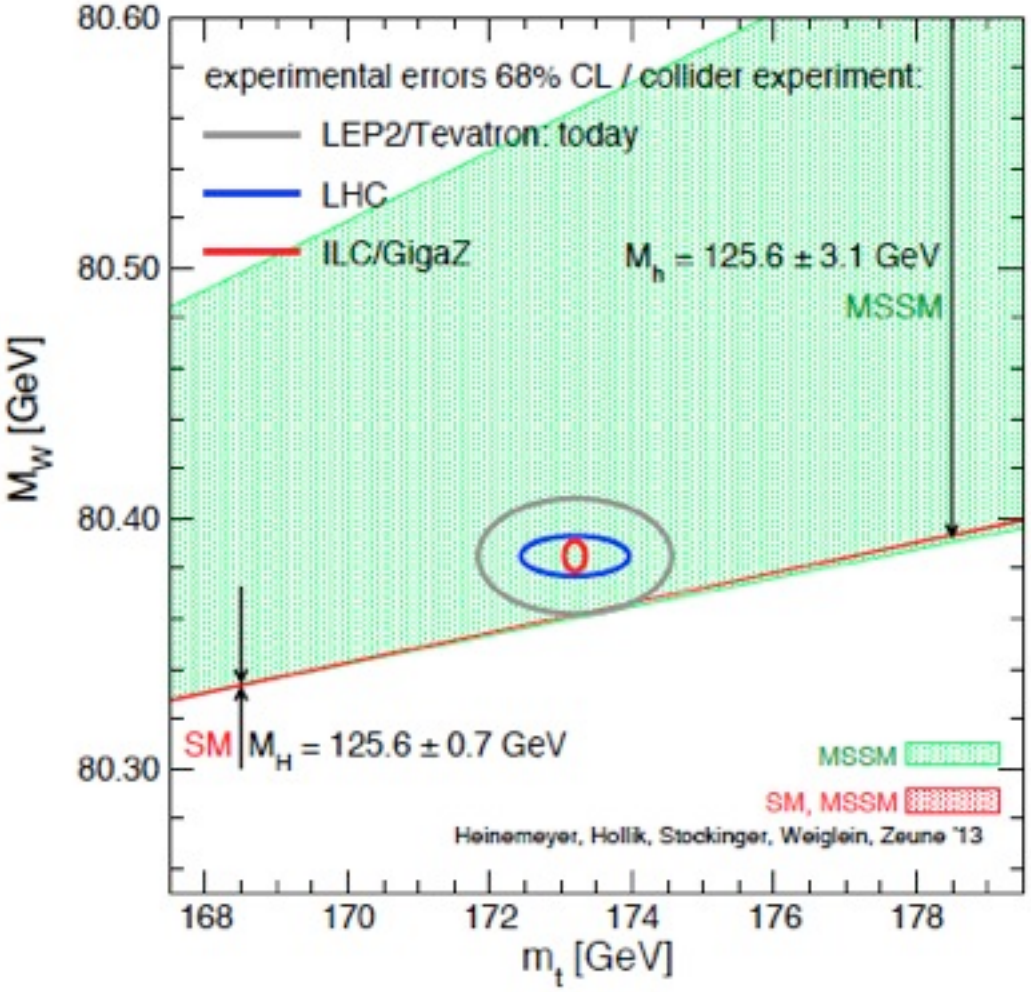
$H \to \gamma\gamma$: already very precise . . .

$H \to Z\gamma$: EW corrections could help . . .

$H \to WW^*, H \to ZZ^*$: already very precise, two-loop corrections unclear

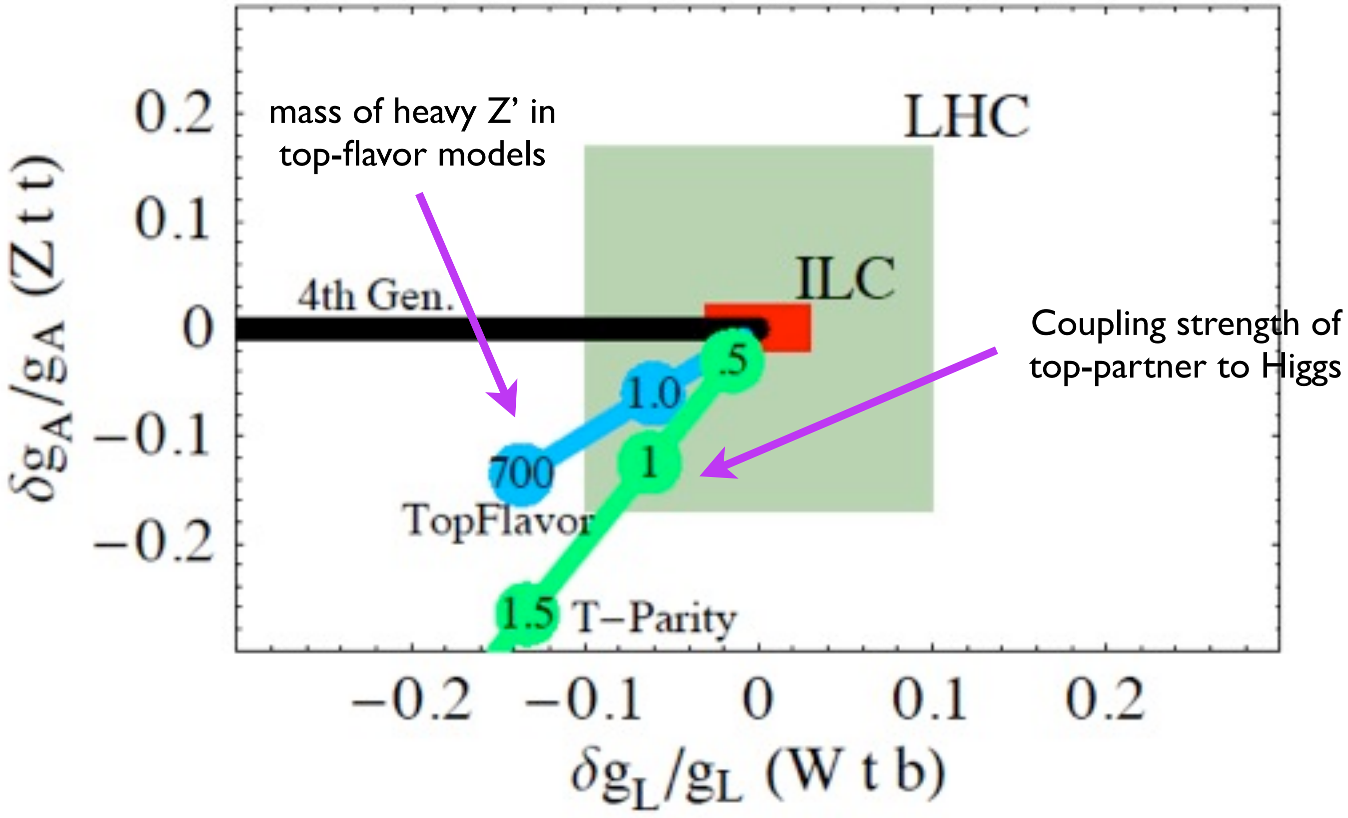
The top quark

- The top quark is the heaviest known elementary particle, with an O(1) Yukawa coupling
- Plays a special role in many theories beyond the Standard Model.



- A precision top-mass measurement is crucial to determine the quantum consistency of the Standard Model

Batra, Tait hep-ph/0606068



mass of heavy Z' in top-flavor models

Coupling strength of top-partner to Higgs

- Those attempting to explain the hierarchy problem generically have a 'top-partner' which couples to the top quark, modifying its couplings

Total ttbar cross section near threshold (ILC)

Status of NNLL (QCD) predictions:

[Hoang]

[From Riuz-Femenia]

NNLO QCD corrections

Hoang, Teubner '98-99; Melnikov, Yelkhovsky '98;
Yakovlev ´98; Beneke, Signer, Smirnov '99;
Nagano, Ota, Sumino '99; Penin, Pivovarov '98-99

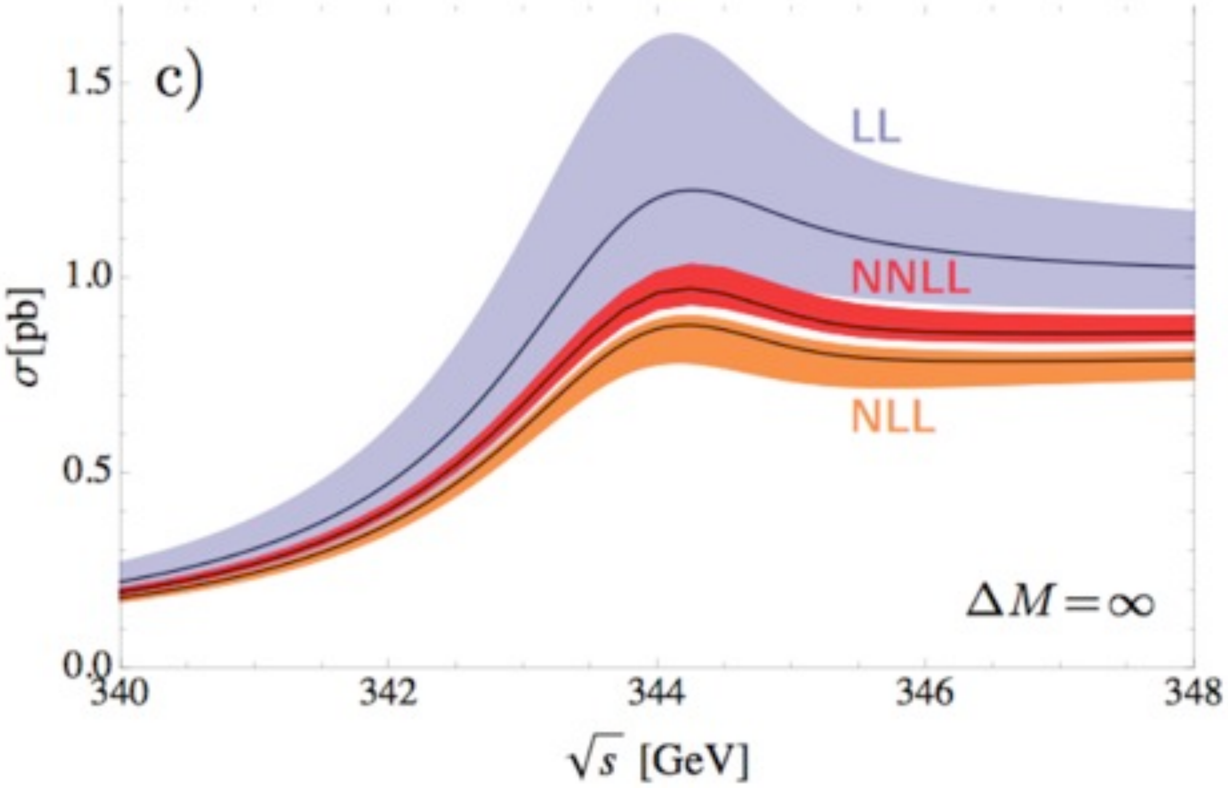
NNLL

Hoang, Manohar, Stewart, Teubner '00-01;
Hoang ´03; Pineda, Signer '06;
Hoang, Stahlhofen '06-11

NNNLO (full analysis soon...)

Beneke, Kiyo, Schuller '05-08 → see Y. Kiyo's talk

Hoang, Stahlhofen (2013)



QCD error at NNLL: $\frac{d\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} = \pm 5\%$

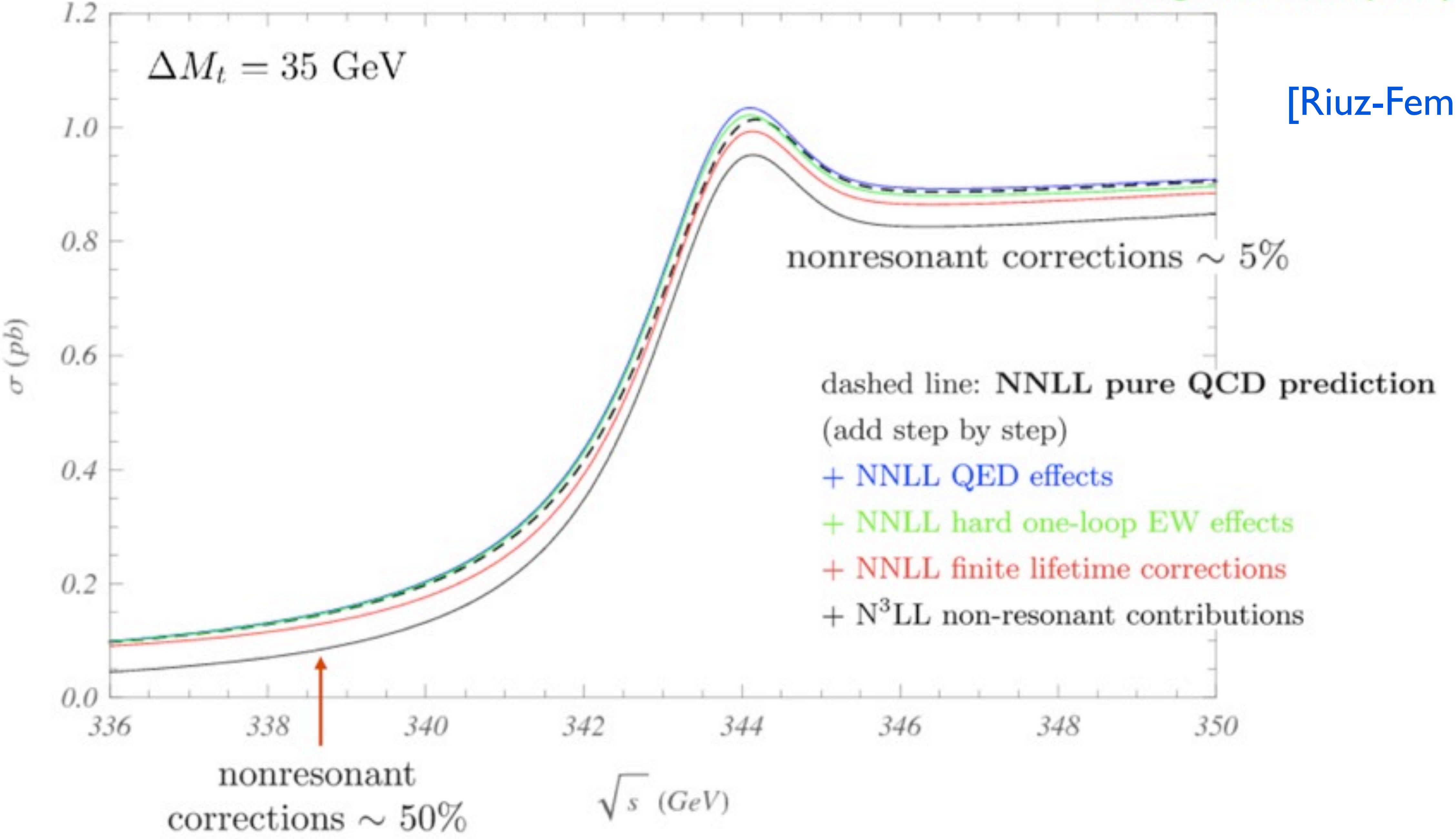
Significant recent progress on calculations of QCD corrections near the ttbar threshold

Total ttbar cross section near threshold (ILC)

Cut on bW invariant masses of the form $|\sqrt{p^2_{t,\bar{t}}} - m_t| \leq \Delta M_t$

Hoang, Reisser, RF (2010)

[Riuz-Femenia]



nonresonant corrections ~ 5%

dashed line: **NNLL pure QCD prediction**

(add step by step)

+ NNLL QED effects

+ NNLL hard one-loop EW effects

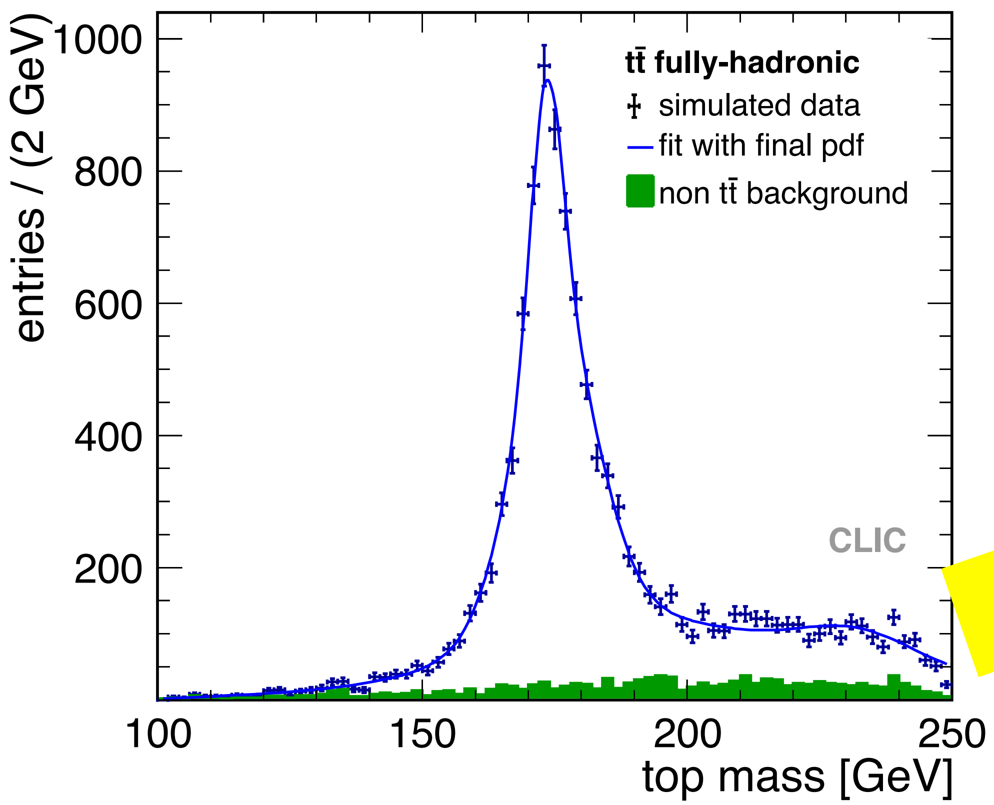
+ NNLL finite lifetime corrections

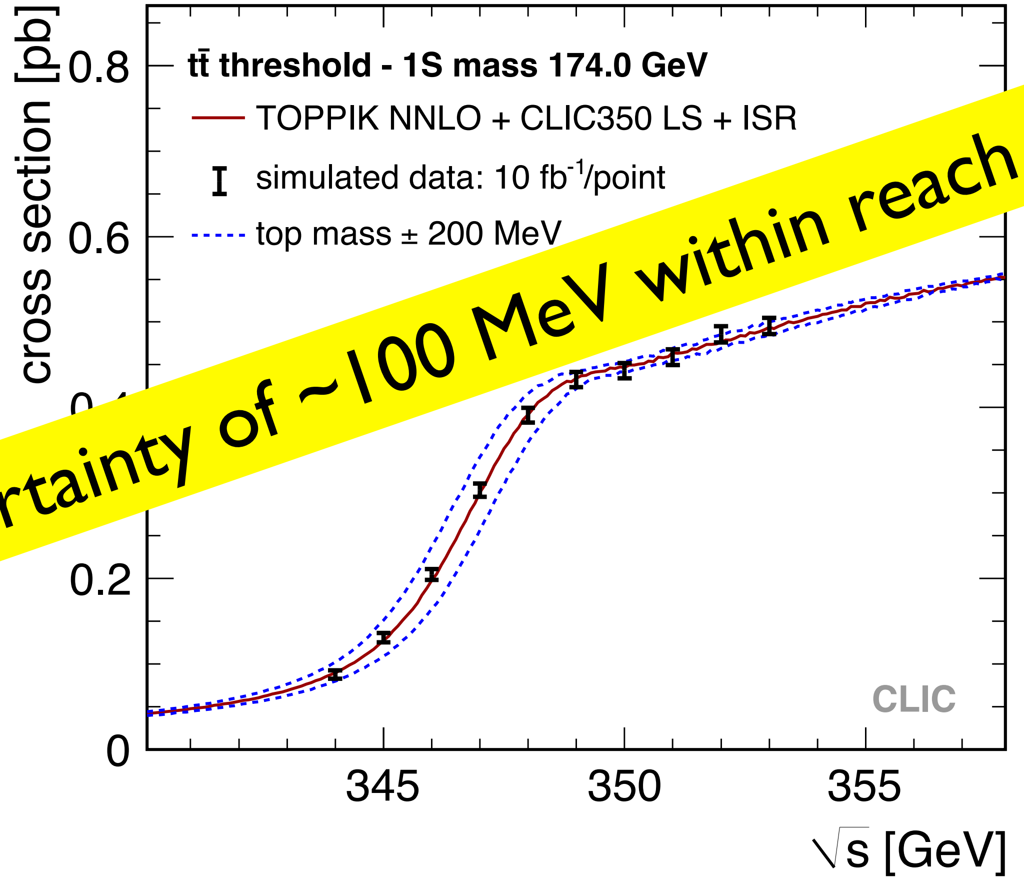
+ N^3LL non-resonant contributions

nonresonant corrections ~ 50%

Effects of electroweak and non-resonant corrections now carefully considered

Top Mass at CLIC (and ILC) [Simon]

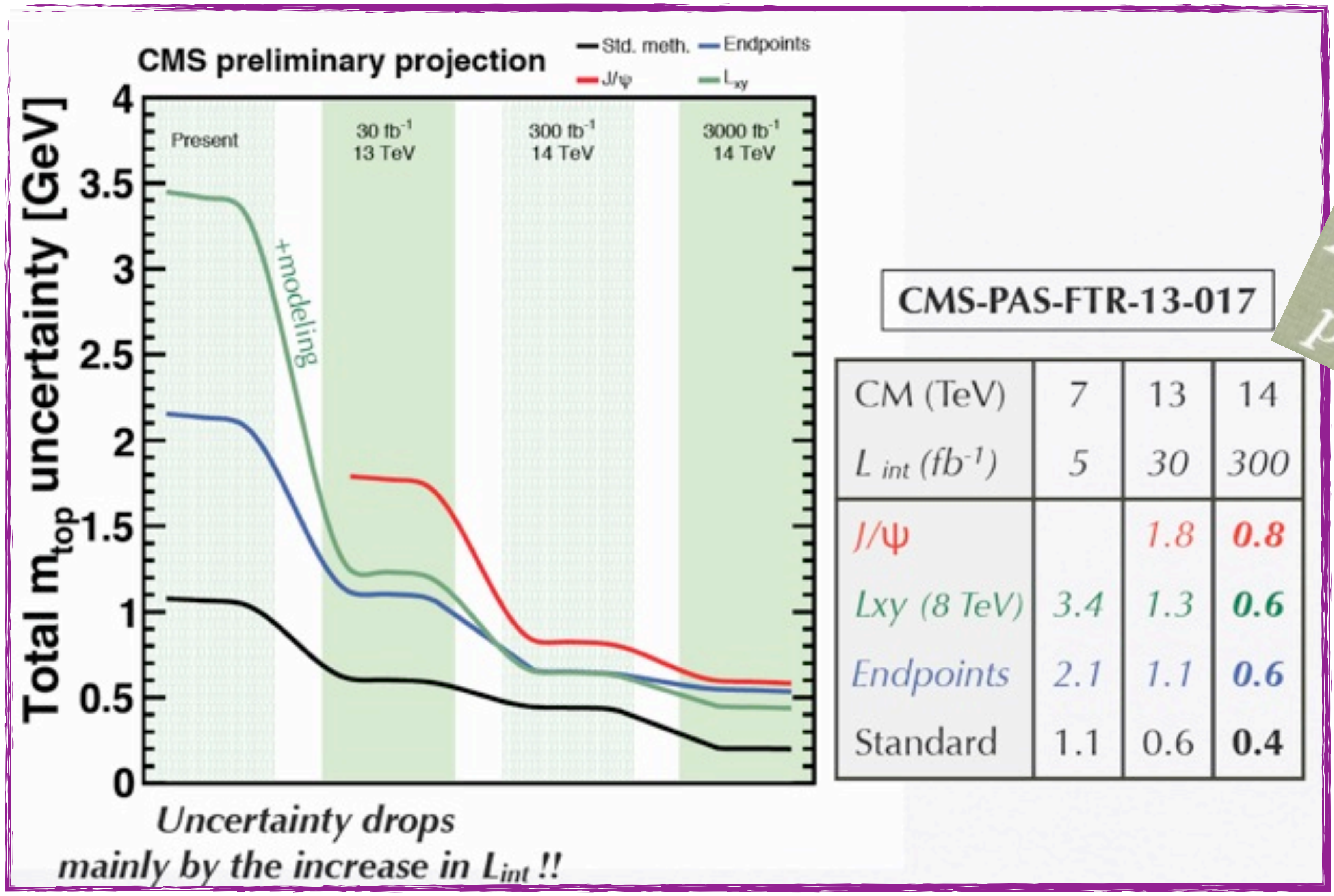




Total uncertainty of ~100 MeV within reach !

- **80 MeV** statistical uncertainty in ***direct reconstruction*** systematics (excl. interpretation) on a similar level
- **25 - 35 MeV** statistical uncertainty at ***threshold*** (depending on collider and fit scheme) extensive study of experimental systematics - most important: **~30 MeV** beam energy, **~6 MeV** luminosity spectrum (+ potential bias up to **20 MeV**)
- interpretation: in MSbar scheme *O* **100 MeV**

- Almost background-free reconstruction of top quarks at and above threshold
  - Full simulations including machine background
- Two ways to measure the mass:
  - Direct reconstruction - Theoretical meaning unclear
  - Threshold scan - Theoretically well under control



CMS-PAS-FTR-13-017

CM (TeV)	7	13	14
L int (fb^{-1})	*5*	*30*	*300*
J/ψ		*1.8*	***0.8***
Lxy (8 TeV)	*3.4*	*1.3*	***0.6***
Endpoints	*2.1*	*1.1*	***0.6***
Standard	1.1	0.6	**0.4**

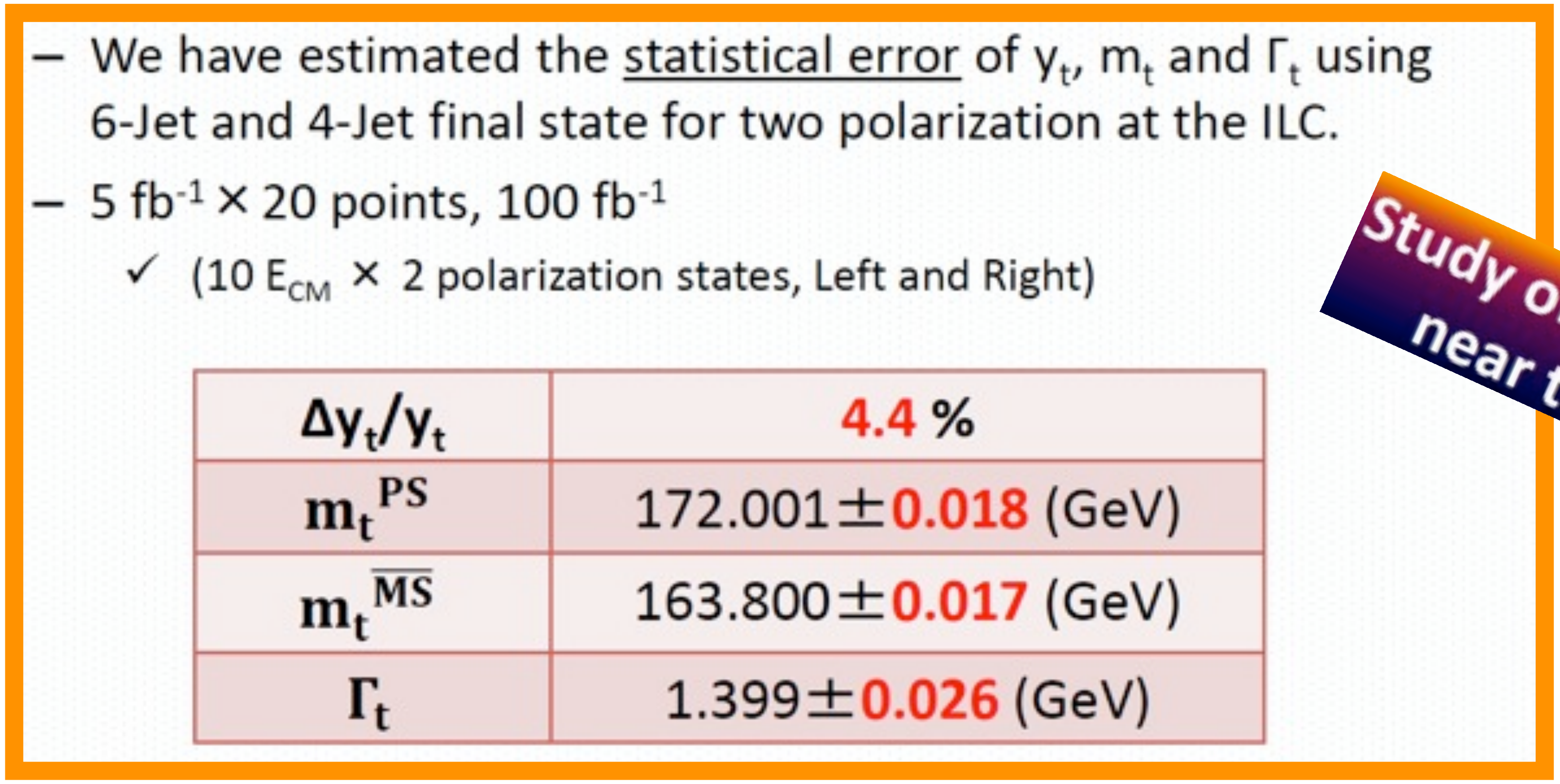
Uncertainty drops mainly by the increase in L_{int} !!

LHC top mass

Alternative methods and prospects for the future

[Minsuk Kim]

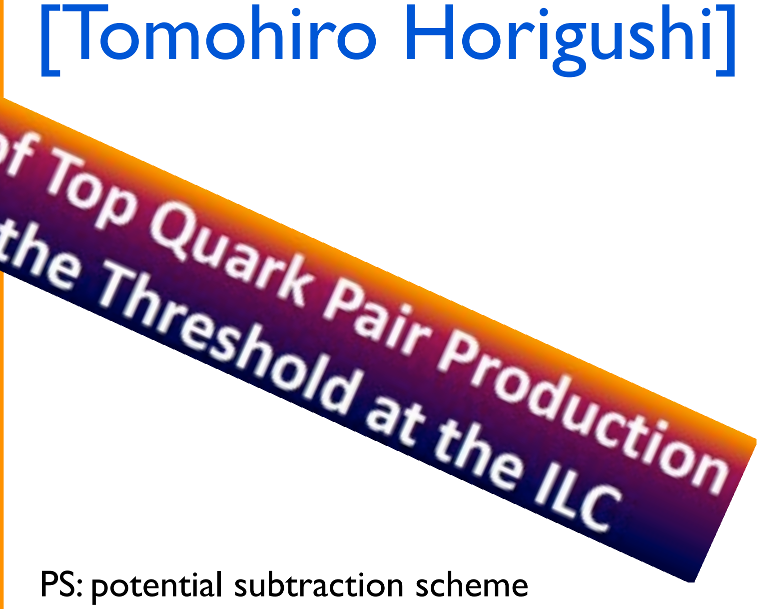
Standard methods seem to perform very well when increasing Lint to 3000/fb at 14 TeV



- We have estimated the statistical error of y_t, m_t and Γ_t using 6-Jet and 4-Jet final state for two polarization at the ILC.
- 5 fb^{-1} × 20 points, 100 fb^{-1}
  - ✓ (10 E_{CM} × 2 polarization states, Left and Right)

$\Delta y_t/y_t$	4.4 %
m_t^{PS}	172.001±0.018 (GeV)
$m_t^{\overline{MS}}$	163.800±0.017 (GeV)
Γ_t	1.399±0.026 (GeV)

[Tomohiro Horigushi]

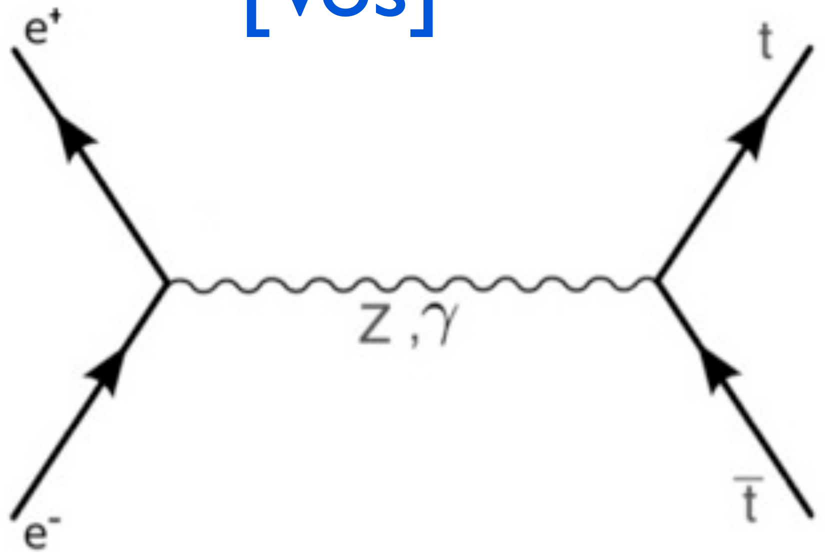


Study of Top Quark Pair Production near the Threshold at the ILC

PS: potential subtraction scheme

Measurement of EW couplings of the top quark

[Vos]



Top production at the (I)LC:

- Top quark production is one of the dominant processes
  → Clean and efficienct selection

- Top quark production through **electroweak** processes
  → no competing QCD production

-ILC is promising for high precision top quark 'tomography'

ILC500 measures top quark electroweak couplings to

$\delta F_{1V}^{\gamma,Z}, \delta F_{1A}^{\gamma,Z}$ ~1%   An order of magnitude better than LHC prospects!

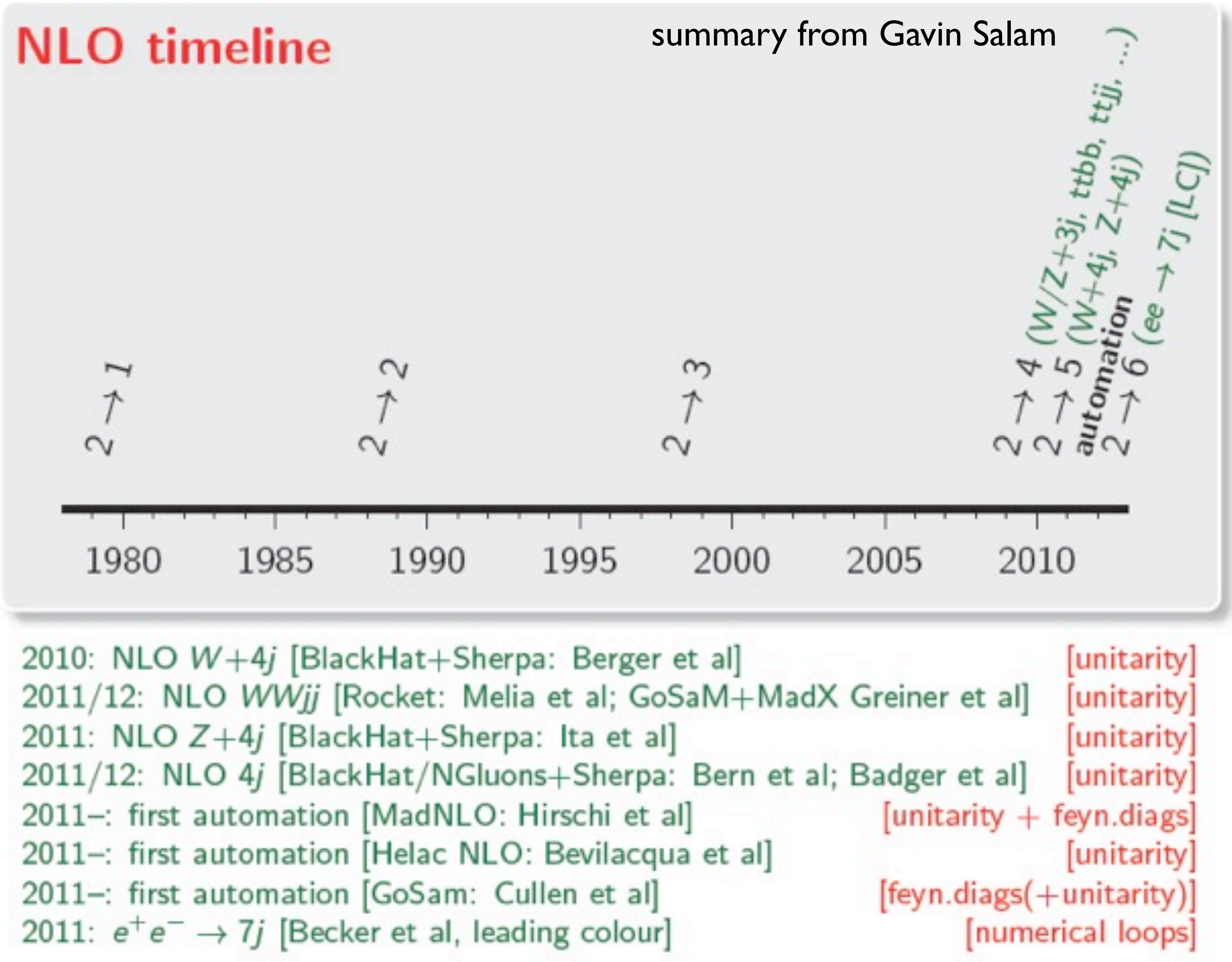
Results for the CP violating form factor expected in one of the next LCWS workshops

$$\Gamma_\mu^{ttX}(k^2,q,\bar{q}) = -ie\left\{\gamma_\mu\left(F_{1V}^X(k^2)+\gamma_5 F_{1A}^X(k^2)\right)+\frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\mu\left(iF_{2V}^X(k^2)+\boxed{\gamma_5 F_{2A}^X(k^2)\right)}\right\}$$

Tools for radiative corrections

- Incredible progress coming from unitarity-based techniques for multi-leg one-loop calculations

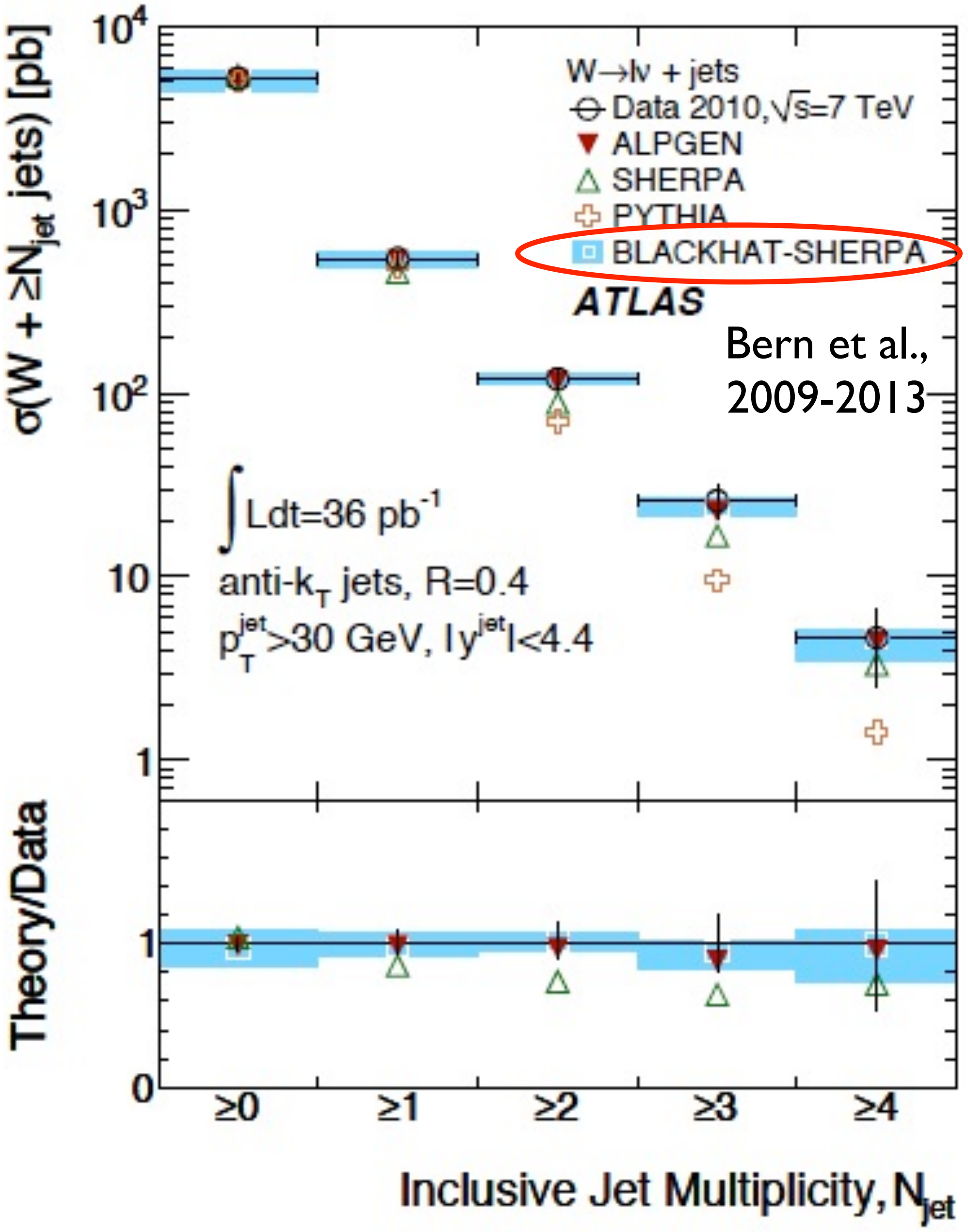
summary from Gavin Salam



2010: NLO $W+4j$ [BlackHat+Sherpa: Berger et al]	[unitarity]
2011/12: NLO $WWjj$ [Rocket: Melia et al; GoSaM+MadX Greiner et al]	[unitarity]
2011: NLO $Z+4j$ [BlackHat+Sherpa: Ita et al]	[unitarity]
2011/12: NLO $4j$ [BlackHat/NGluons+Sherpa: Bern et al; Badger et al]	[unitarity]
2011–: first automation [MadNLO: Hirschi et al]	[unitarity + feyn.diags]
2011–: first automation [Helac NLO: Bevilacqua et al]	[unitarity]
2011–: first automation [GoSam: Cullen et al]	[feyn.diags(+unitarity)]
2011: $e^+e^- \to 7j$ [Becker et al, leading colour]	[numerical loops]

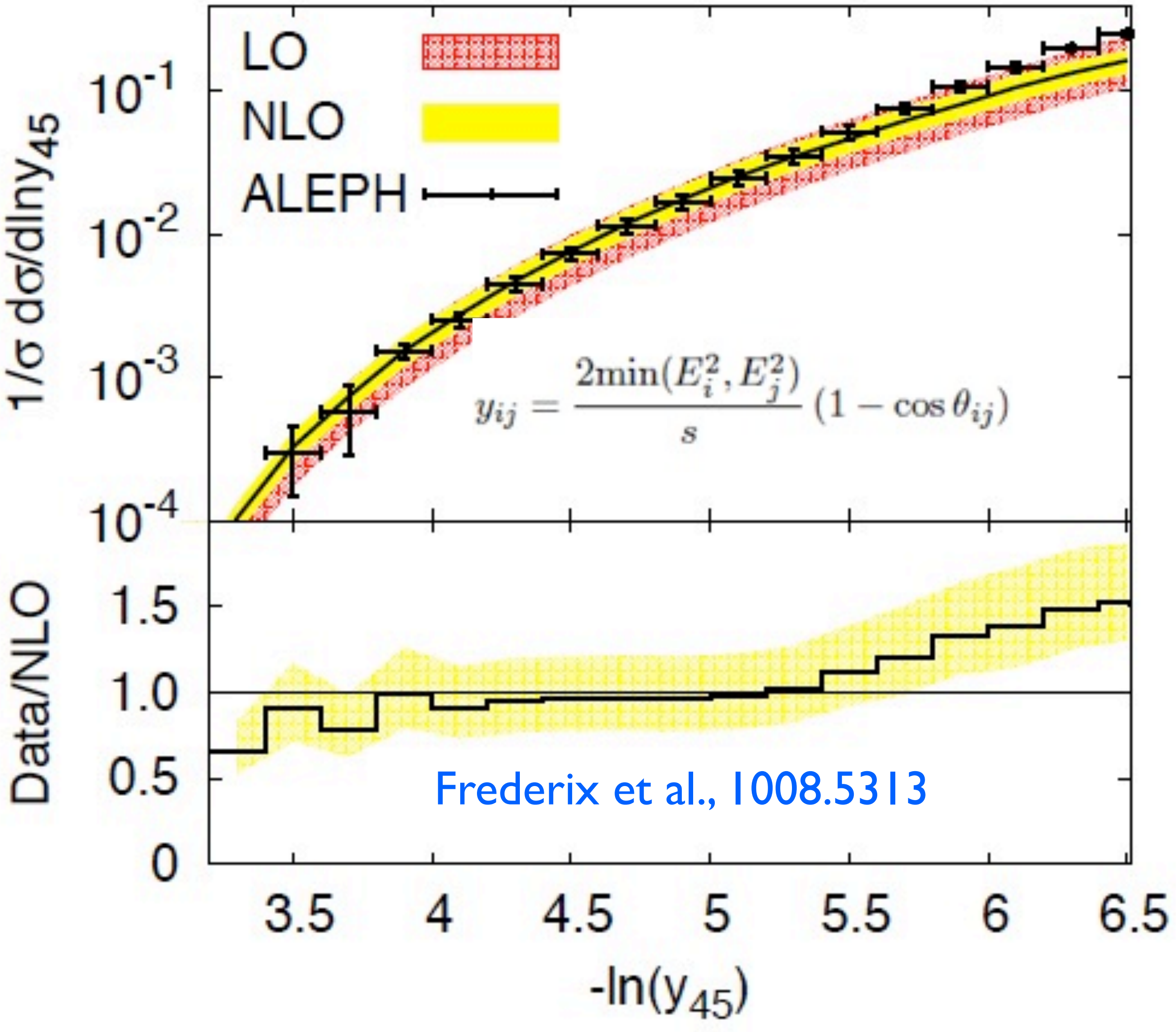
“Yesterday’s impossible is today’s commonplace” -2013 Snowmass QCD report

Multi-leg NLO



Bern et al., 2009-2013

- NLO tools have been validated with remarkable success at the LHC



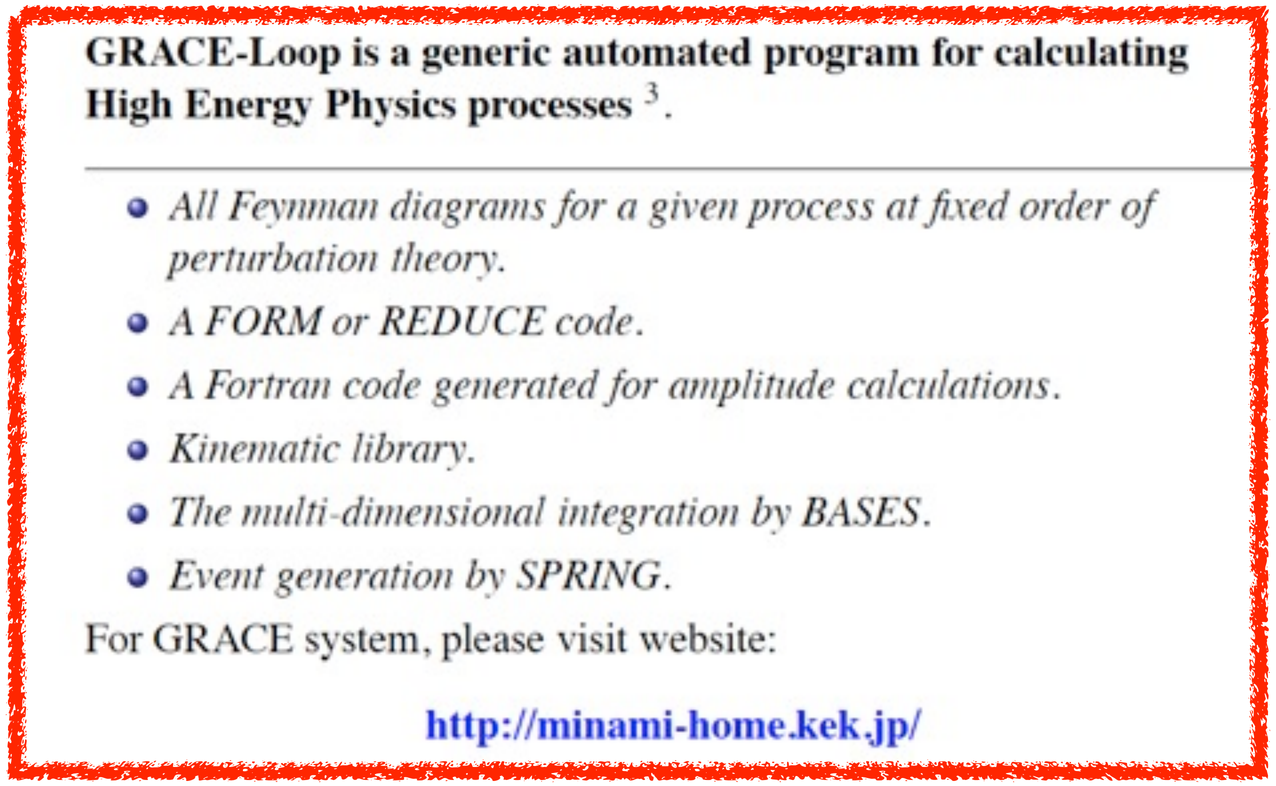
Frederix et al., 1008.5313

- Ready for, and already applied to, e^+e^- collisions

$$\boxed{\alpha_s(M_Z) \quad 0.1159\ {}^{+0.0070}_{-0.0055}}$$

(from e+e- to 5 jets @ NLO)

GRACE-Loop



GRACE-Loop is a generic automated program for calculating High Energy Physics processes [3].

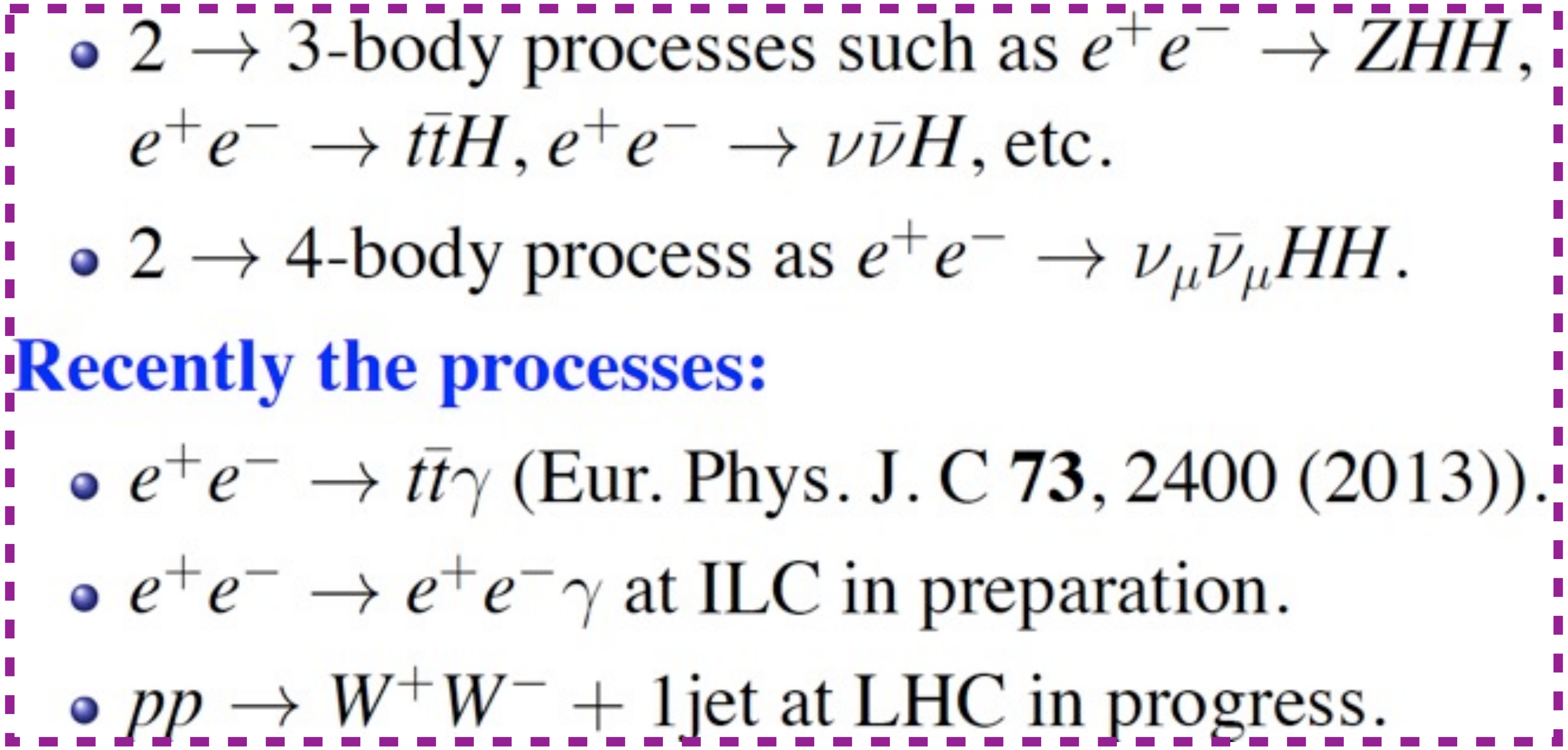
- *All Feynman diagrams for a given process at fixed order of perturbation theory.*
- *A FORM or REDUCE code.*
- *A Fortran code generated for amplitude calculations.*
- *Kinematic library.*
- *The multi-dimensional integration by BASES.*
- *Event generation by SPRING.*

For GRACE system, please visit website:

http://minami-home.kek.jp/

[P. H. Khiem]

GRACE-Loop was successfully used to calculate various e+e- processes, and there is more to come:



- $2 \to 3$-body processes such as $e^+e^- \to ZHH$, $e^+e^- \to t\bar{t}H$, $e^+e^- \to \nu\bar{\nu}H$, etc.
- $2 \to 4$-body process as $e^+e^- \to \nu_\mu\bar{\nu}_\mu HH$.

Recently the processes:

- $e^+e^- \to t\bar{t}\gamma$ (Eur. Phys. J. C **73**, 2400 (2013)).
- $e^+e^- \to e^+e^-\gamma$ at ILC in preparation.
- $pp \to W^+W^- + 1$jet at LHC in progress.

Summary

It's been very stimulating 4 days - lots of great talks representing advances in research across many fronts

Excellent progress on all topics discussed in this working group. Looking forward to more at the next LCWS !