ECFA / DESY Linear Collider Workshop

20-23 March 1999

Top Quark WG

Plenary Review

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+ Gonzalo Merino (IFAE)

Plan:

0. Thanks to everybody who contributed!
1. What is top?
2. Threshold Studies
3. top in the continuum
4. Sitges and beyond
5. G. Merino: Simulation of $e^+e^- \to t\bar{t}H$

1. What is top ?

- the heaviest known particle plays a special role in EWSB

→ $\Delta m_t \overset{!}{\lesssim} 200\ MeV \implies \frac{\Delta M_H}{M_H} \lesssim 17\%$

→ test of EWSB

→ $\frac{\Delta m_t}{m_t} \sim 1‰$ (several % for b)

$\lambda_t^2 \overset{!}{\sim} 0.5$ $(\lambda_b^2 \sim 4 \cdot 10^{-4})$

top as the key to Physics beyond the SM that links masses + mixings, q + ℓ ?!

- the only free quark : $\Gamma_t \sim 1.5\ GeV$ decays before hadron. $\gg \Lambda_{QCD}$

→ "clean" QCD @ high scales ⋯> α_s

→ + spin physics!

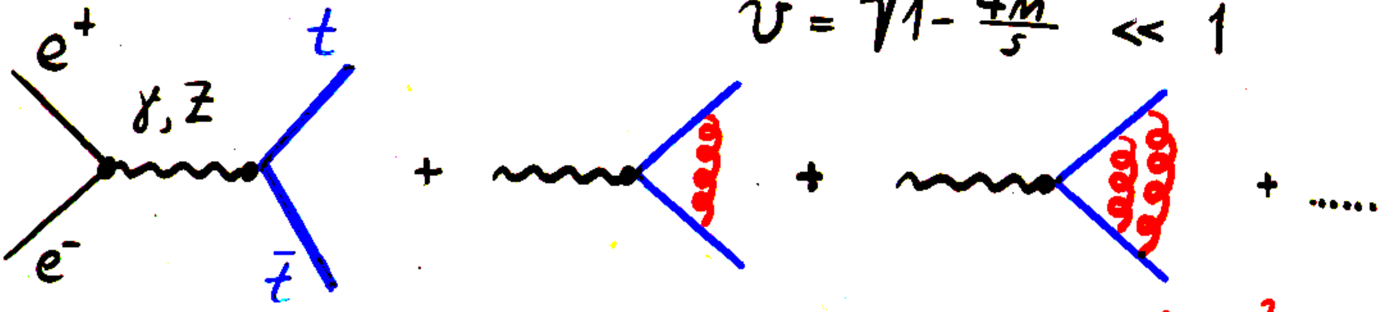
- anything else ? non SM coupling ?

→ better check it ...

2. Threshold Studies

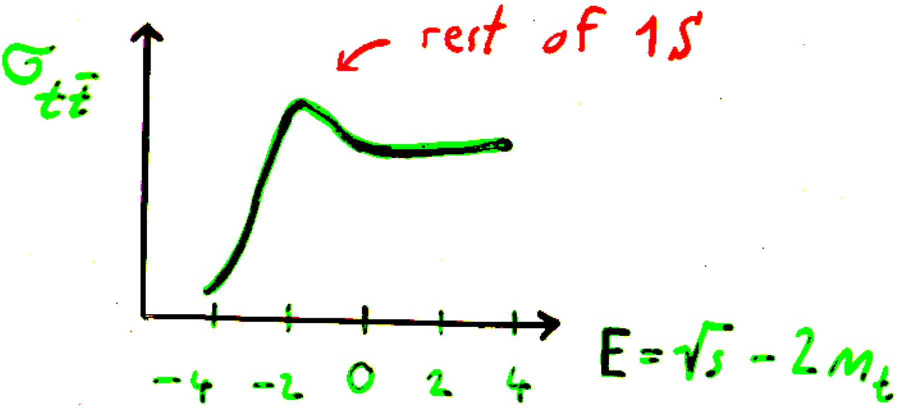
allow for the most precise m_t determination : $\sqrt{s} \approx 2m_t$ →

$v = \sqrt{1 - \frac{4m^2}{s}} \ll 1$



$\sim 1 \qquad \sim \frac{\alpha_s}{v} \qquad \sim \left(\frac{\alpha_s}{v}\right)^2 \;\cdots\; \left(\frac{\alpha_s}{v}\right)^n$

Strong coulombic interaction near threshold → ~~resonances~~ → Γ_t smeares them out

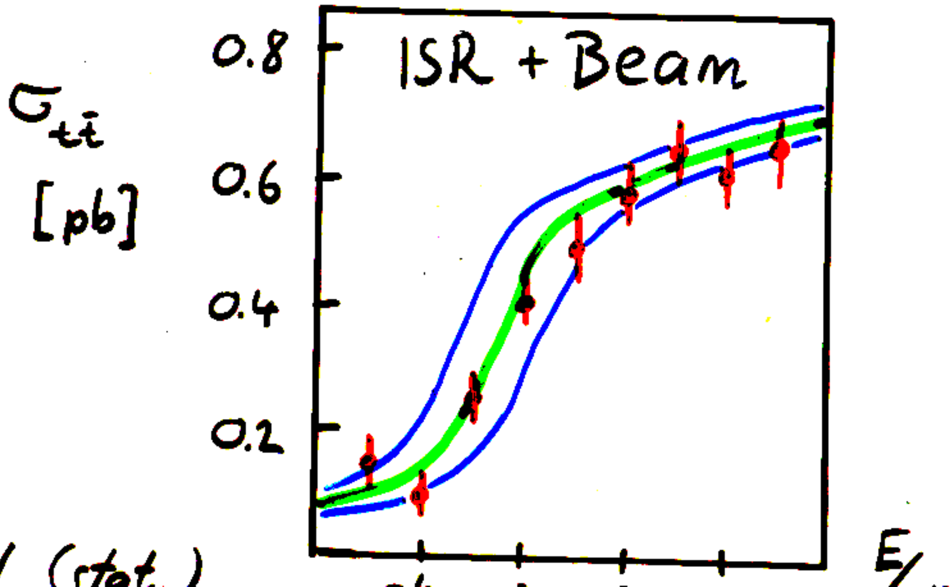


Still: fit steep rise of $\sigma_{t\bar{t}}$ to measure m_t :

9-point fit with data :

theory

$m_t \pm 400$ MeV



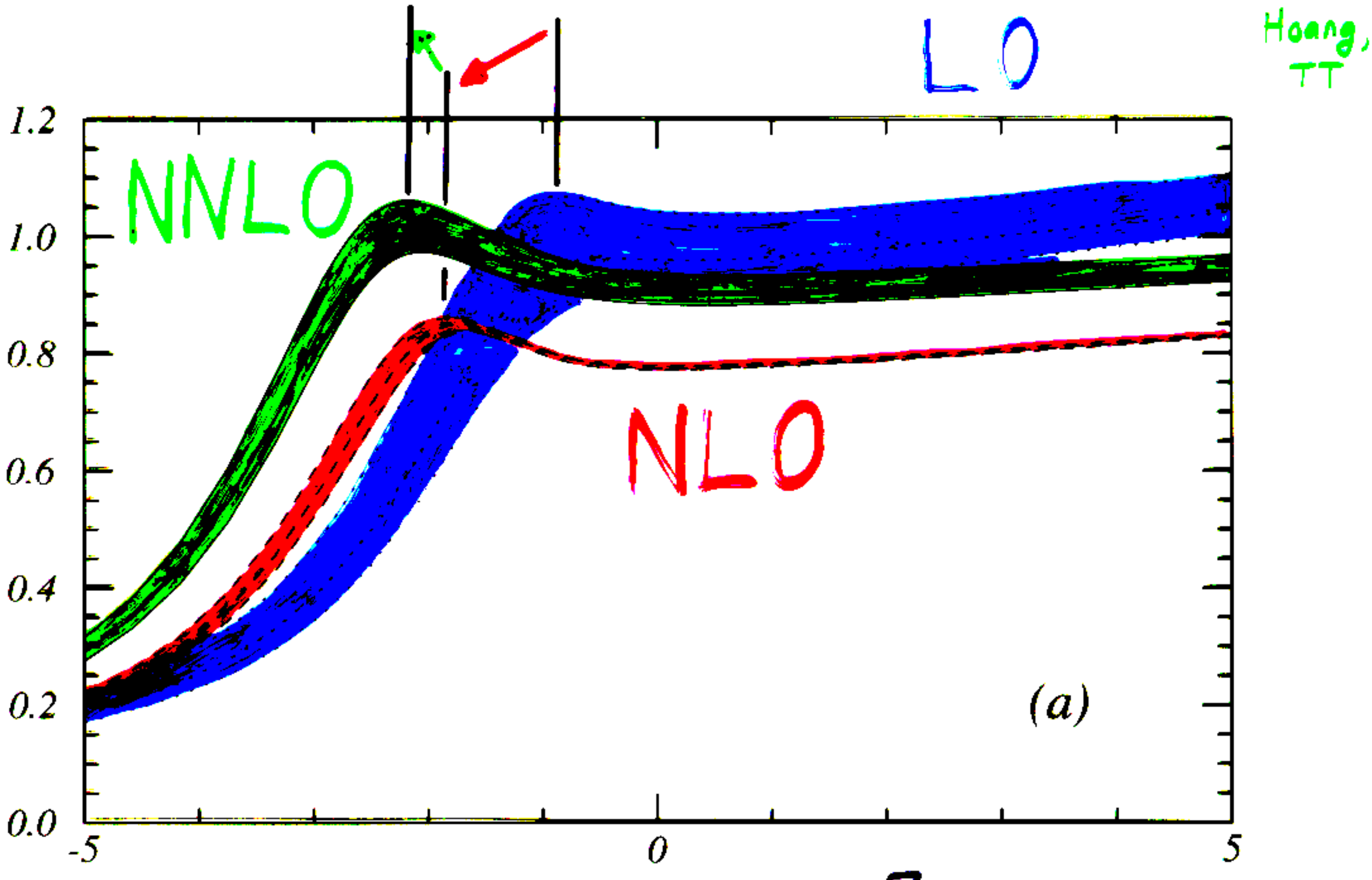
→ $\Delta m_t \sim 120$ MeV (stat.)

3'
19'

$\frac{\sigma(e^+e^- \to t\bar{t})}{\sigma(e^+e^- \to \mu^+\mu^-)}$ in fixed

L, NL, NNL order +

scale dependence



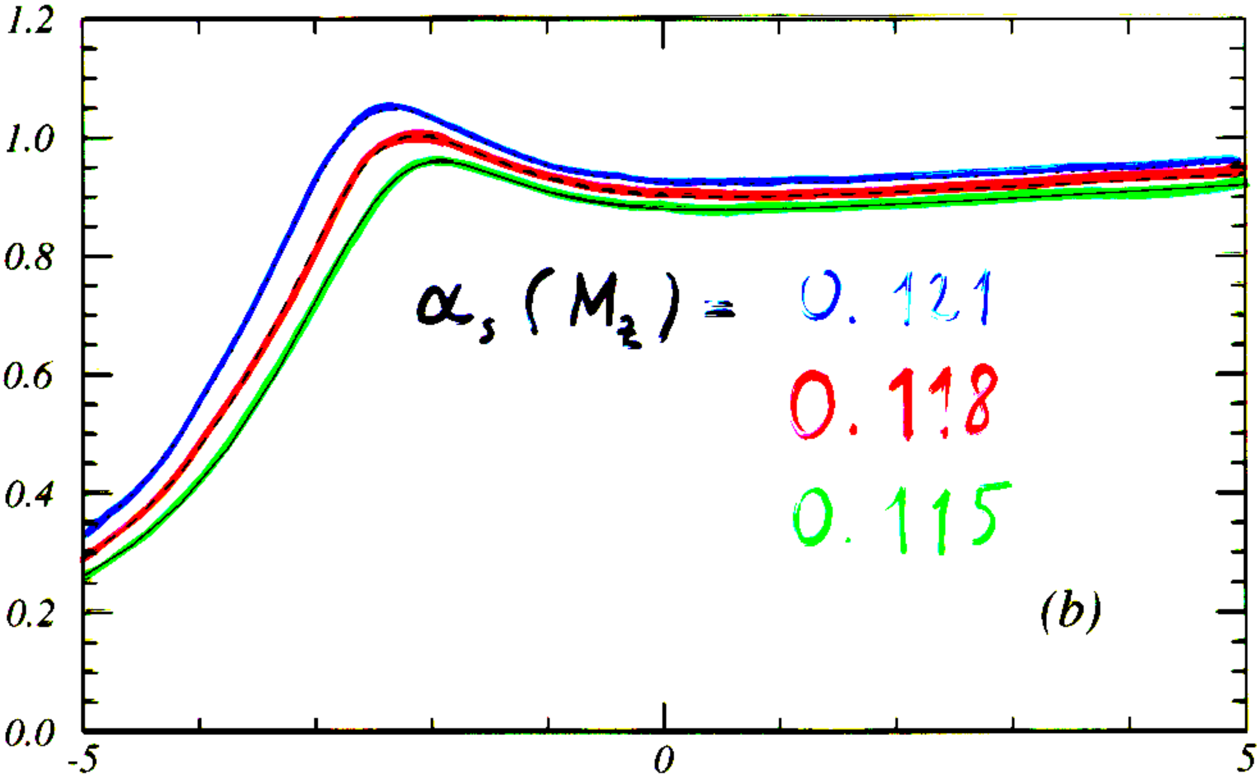
$= \sqrt{s} - 2m_t$

scale μ_{soft} = 50 / 75 / 100 GeV

13 3'' 19'

$$\frac{\sigma(e^+e^- \to t\bar{t})}{\sigma(e^+e^- \to \mu^+\mu^-)} \quad \text{in NNLO}$$

Hoang, TT



$E(\text{GeV}) = \sqrt{s} - 2m_t$

In the past:

- Fit σ_{tot}, $\frac{d\sigma}{dp_t}$ $(, A_{FB})$ to get

  m_t, α_s $(, \Gamma_t)$ with very high

  120 MeV 0.003 5% ← accuracy.

Recently ('98 → '99, situation at Orsay, Lund):

- NNLO ($O(\alpha_s^2, \alpha_s v, v^2)$) corrections are large!

  Hoang, TT
  Melnikov, Yelkovsky
  Yakovlev
  Beneke, Signer, Smirnov

large theoretical uncertainties ?
(normalization, "1S peak")

the problem plot →

Δm_t (theory) = ?

$\Delta \alpha_s$ (theory) = ?

what to do?

Think again:

What is m_t ?

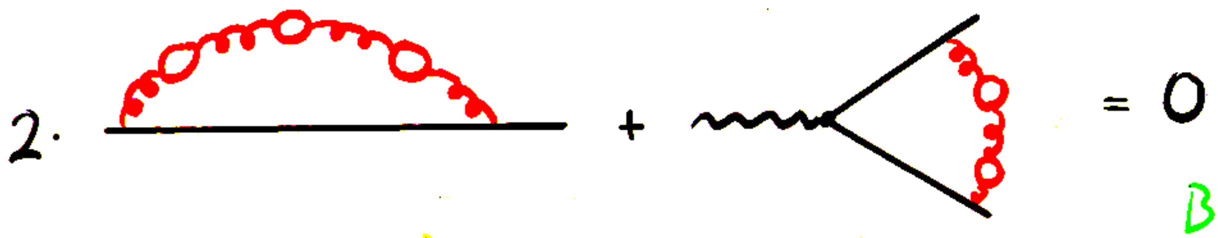
Here: m_t^{pole} .... but

Now we know :

- m^{pole} is NOT an observable.
  Only defined up to $\mathcal{O}(\Lambda_{QCD})$
  (despite large Γ_t)

- <u>But</u>: $E_{static} = 2m + E_{binding}$ is as a physical observable unambiguous.
  (but m_{xyz} and $V_{xyz}(r)$ are xyz scheme dependent)

<u>And</u>: The leading IR Renormalons cancel in



Beneke
Hoang et al.

- Therefore: use a suitable
  Short Distance Mass which is free from IR ambiguities and cures the large NNLO (NLO) corrections!

- Two recent proposals:

► 1S mass : ~ position of the 1S peak (for stable quarks) — Hoang et. al.

► PS mass : $m^{PS}(\mu_f) = m^{pole} - \delta m(\mu_f)$ — Beneke

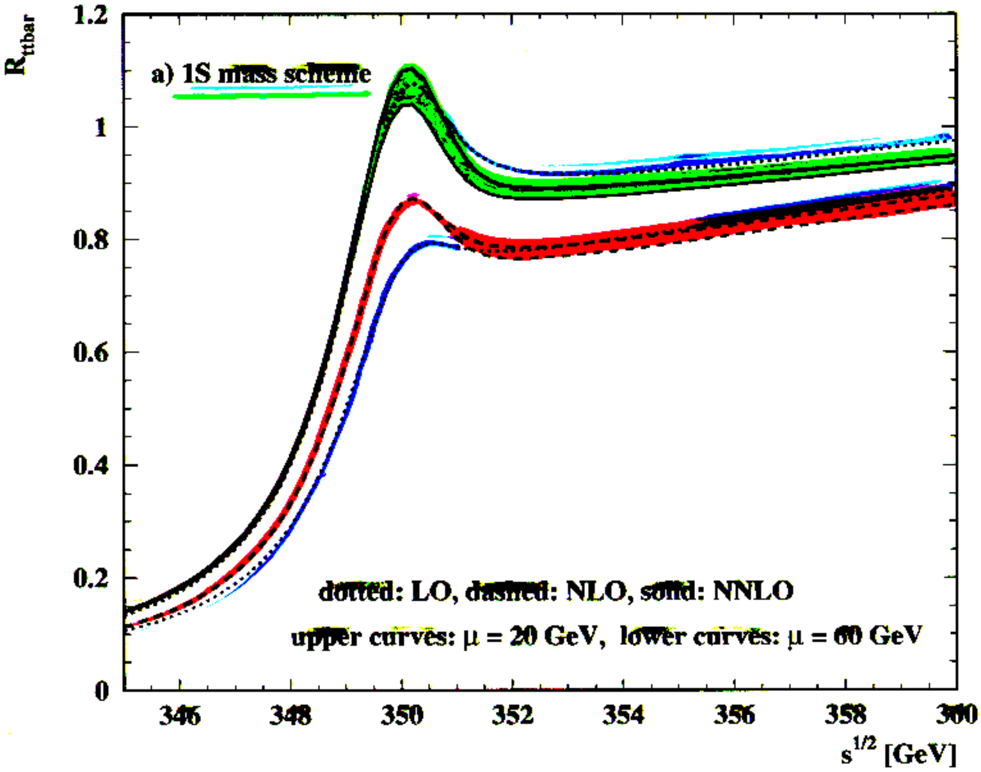
$$\delta m(\mu_f) = -\frac{1}{2} \int_{|\vec{q}|<\mu_f} \frac{d^3 q}{(2\pi)^3} \tilde{V}(q)$$

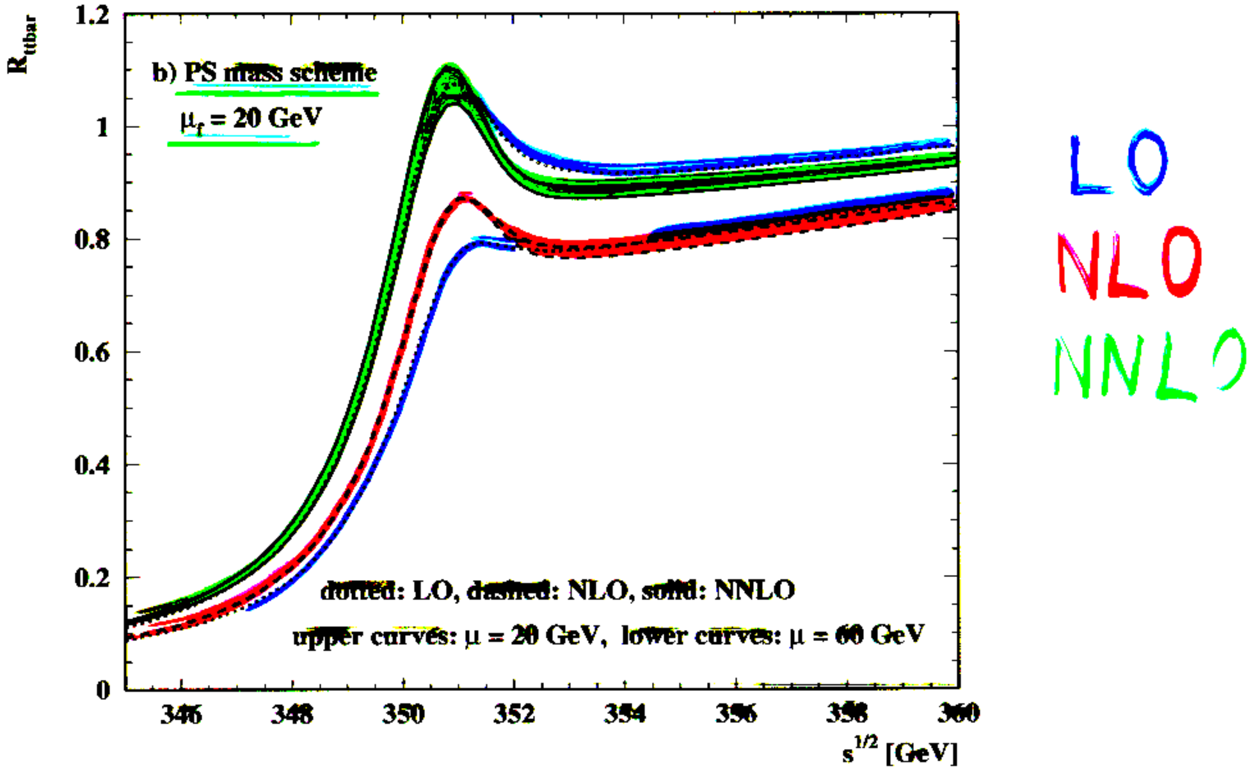
subtract the IR-part due to the potential.

Results are quite similar: the solution → plot

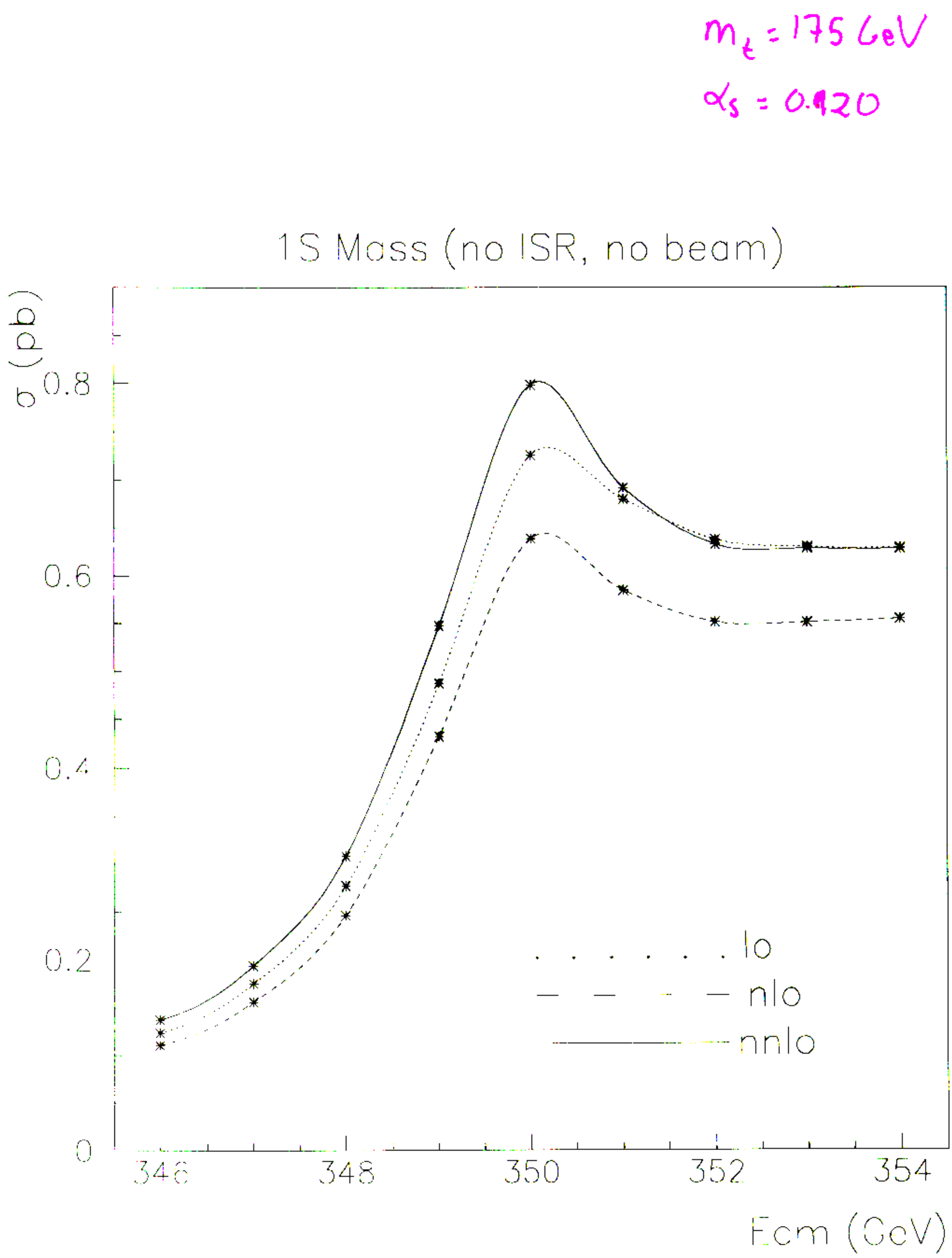
Both can, as short distance masses, be reliably transformed to $m_{\overline{MS}}$.
(or maybe used directly in other cases ?)

No strong 1S peak shifts from LO → NLO → NNLO



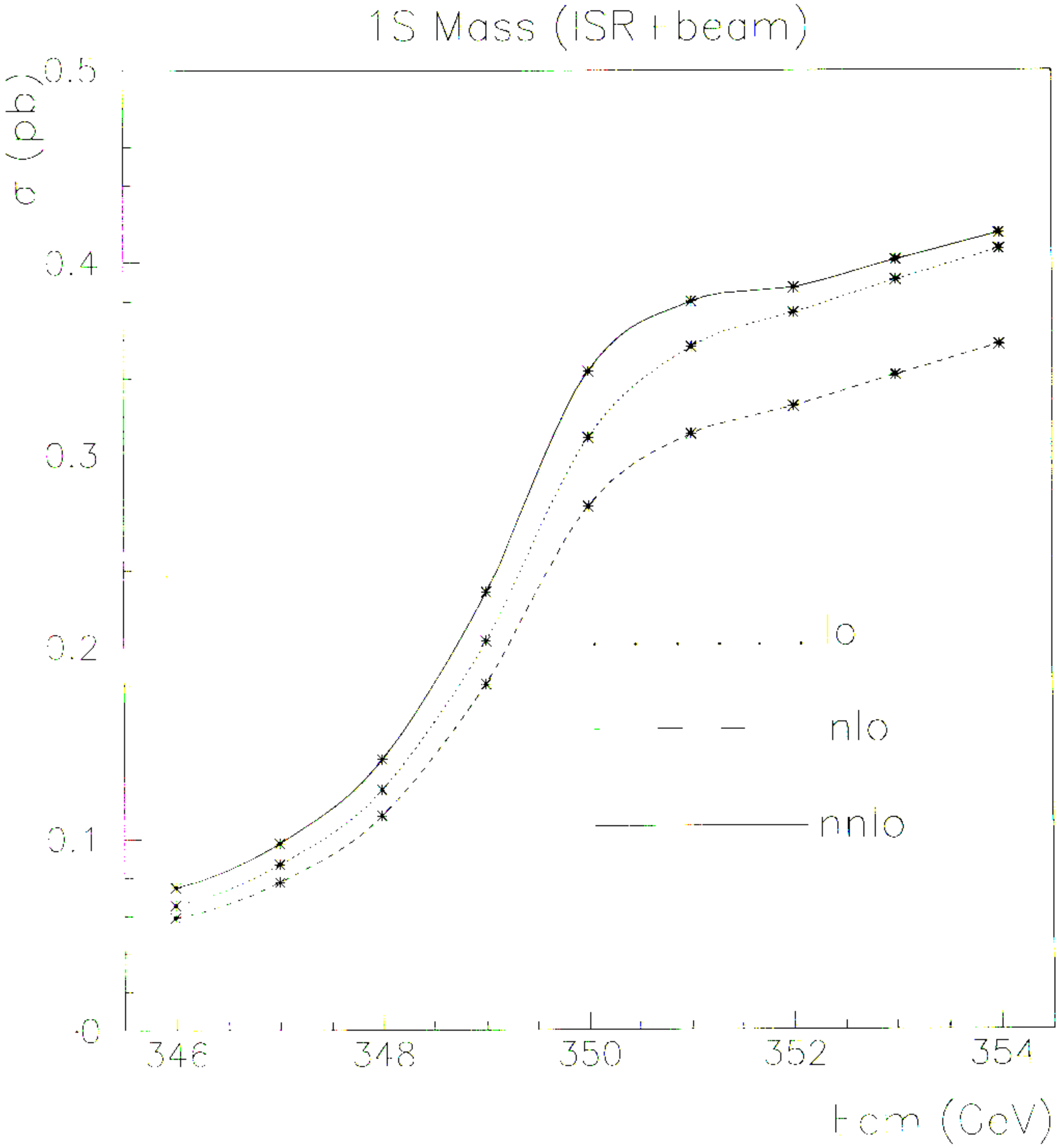


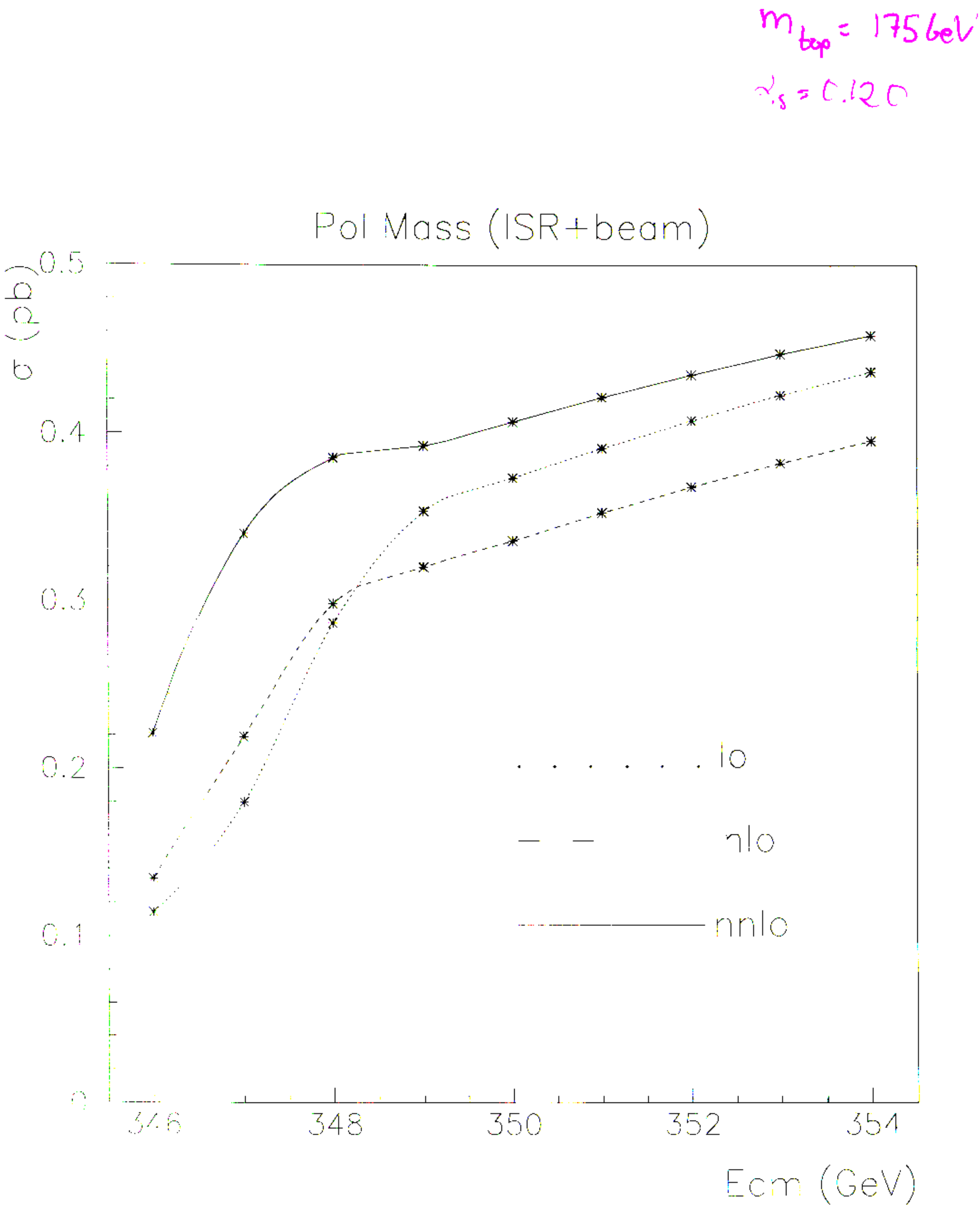
NNLO à la Hoang, TT



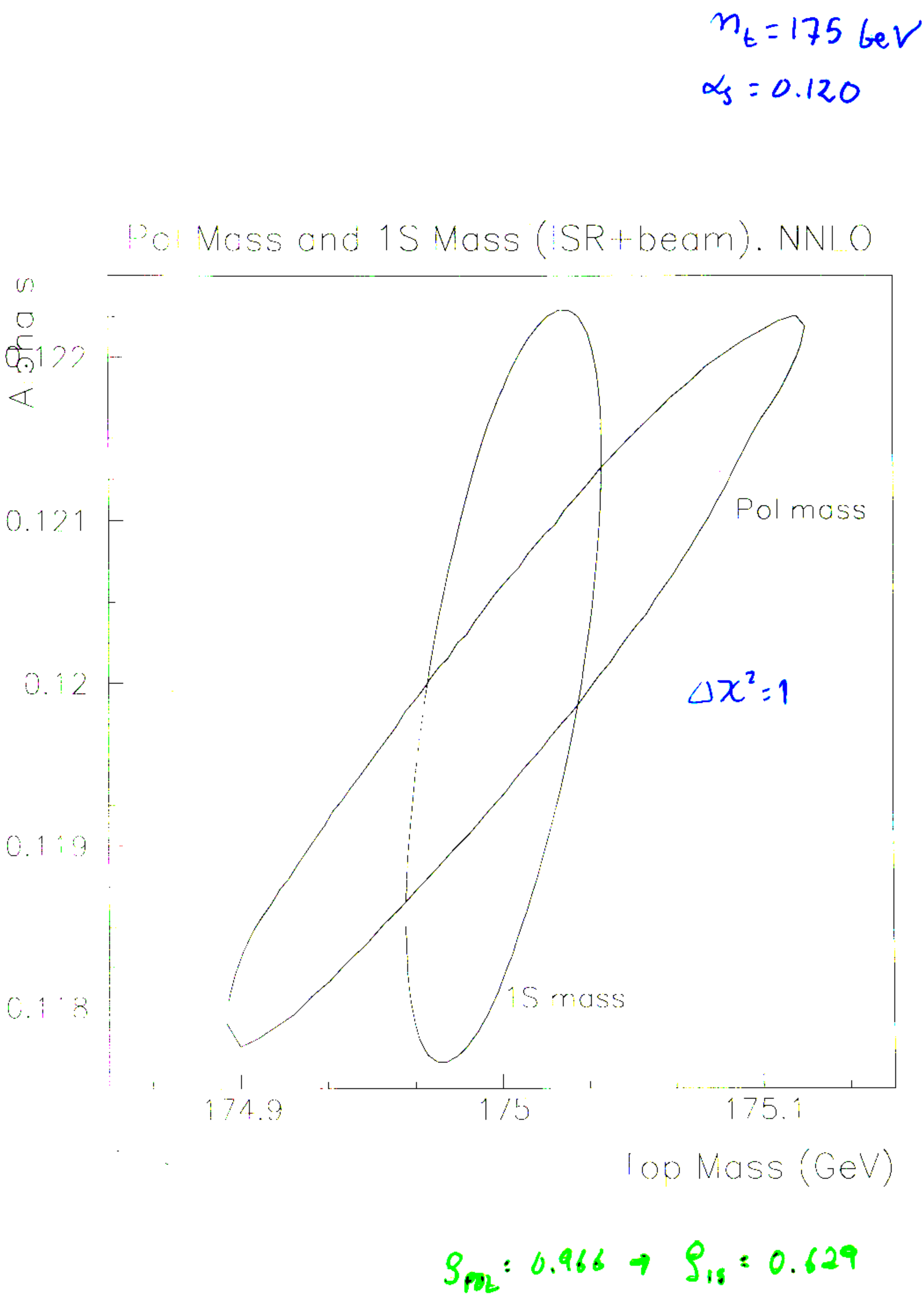
m_t = 175 GeV
α_s = 0.120
1S Mass (no ISR, no beam)
σ (pb)
0.8
0.6
0.4
0.2
0
346
348
350
352
354
Ecm (GeV)
lo
nlo
nnlo

$m_t = 175$ GeV
$\alpha_s = 0.120$





m_{top} = 175 GeV
α_s = 0.120
Pol Mass (ISR+beam)
σ (pb)
0.5
0.4
0.3
0.2
0.1
0
346
348
350
352
354
Ecm (GeV)
lo
nlo
nnlo



mt = 175 GeV
αs = 0.120
Pol Mass and 1S Mass (ISR+beam). NNLO
Alpha s
0.122
0.121
0.12
0.119
0.118
Pol mass
Δχ² = 1
1S mass
174.9
175
175.1
Top Mass (GeV)
ρPOL = 0.966 → ρ1S = 0.629

Preliminary results of experimental analysis:

Martinez Peralta

- $m_t \leftrightarrow \alpha_s$ correlation strongly reduced
- for $\int \mathcal{L} = 100\ fb^{-1}$ very small stat. errors for the m_t (α_s) fit ($\Delta m_t \sim 40$ MeV) to NNLO

Warning: This is NOT the total error!

- Compare different orders to estimate theoretical uncertainty:

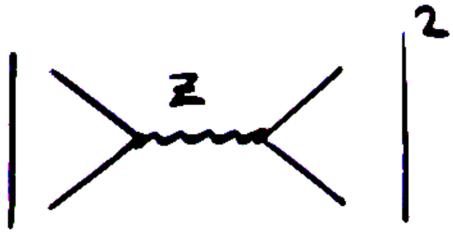
$\Rightarrow \Delta^{\text{"theor."}} m_t \sim 100$ MeV (prelim.!)

and no good α_s-error due to large corrections to the normalization (independent of mass scheme).

....> take α_s from elsewhere!

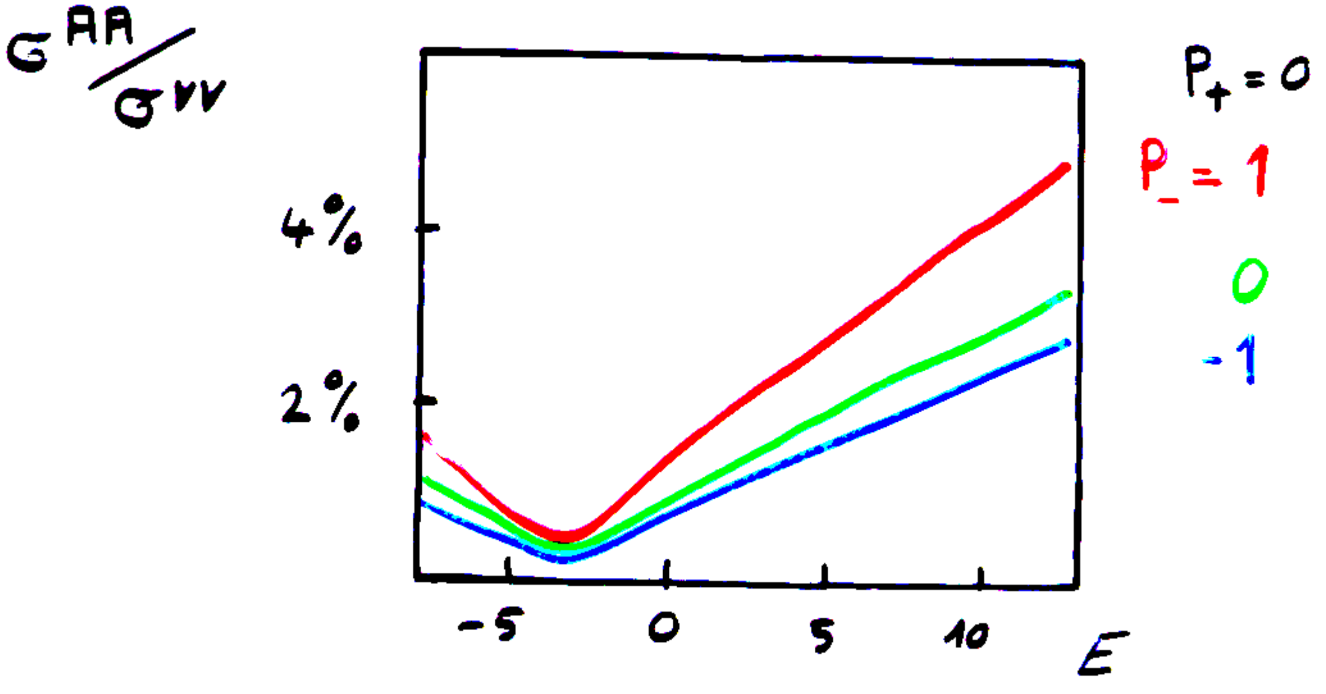
Different threshold topics:

- "Axial contributions at the top threshold" Kühn, TT



$\sim v^2$ relative to vector contributions.

Small correction, but completes the picture at NNLO and allows for an independent measurement due to e^- Polarization dependence:



Can be included in future NNLO analyses.

• Polarization of t ($\bar{t}$)

Harlander, Ježabek, Kühn, TT, Peter Sumino

can be measured throug energy-angular distributions of decay ℓ.

Peter, Sumino: construction of observable sensitive only to the decay !

and note:

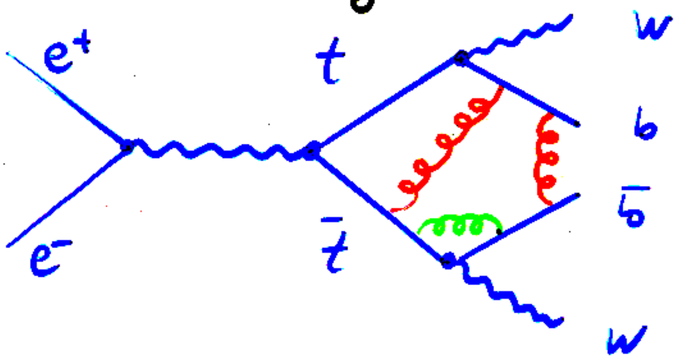
P_-	+80%	0	-80%
P_t	+60%	-40%	-90%

($P_+ = 0$)

But: need for experimental analysis ....

• $\mathcal{O}(\alpha_s)$ Final state interactions

(~ rescattering ~ interconnection ~ non-factorizable)



Peter, Sumino
Yakovlev, Melnikov
Khoze, Sjostrand
Chapovski, Beenakker, Berends

Cancel in σ_{tot}, but distort (invariant mass) distributions ! $\Delta M_{max} = -85$ MeV

Corrections known at threshold for $\frac{d\sigma}{dp}$, A_{FB}, Polarization to $O(\alpha_s)$.

Peter, Sumino

3. top in the continuum

- these FSI might be important for the kinematic mass reconstruction (event by event), but $\Delta M_{max} = -10$ MeV only at $\sqrt{s} \sim 500$ GeV.

Chapovski et al.

- $O(\alpha_s)$ corrections to t spin-polar. and spin-correlations

Brandenburg, Flesch, Uwer
Groote, Körner, Leyva

corrections up to ~5% : →

Need for exp. analysis including hadronization and detector effects !

QCD corrections to top spin-polarization and spin-correlations*

$$e^-(\mathbf{p},\lambda_+)\, e^+(-\mathbf{p},\lambda_-) \to t(\mathbf{k}_t,\hat{\mathbf{s}}_t)\, \bar{t}(\mathbf{k}_{\bar{t}},\hat{\mathbf{s}}_{\bar{t}})\, X$$

$\hat{\mathbf{s}}_t(\hat{\mathbf{s}}_{\bar{t}})$ polarization vector of $t(\bar{t})$ quark, $\lambda_\pm$ longitudinal polarization of $e^\pm$.

- In general, QCD corrections to expectation values of spin observables are small.

Examples: $m_t = 175\,\mathrm{GeV}$, $\alpha_s = 0.1$, $\lambda_+ = 0$, $\lambda_- = +1$,
$\mathbf{S}_t = \frac{\boldsymbol{\sigma}}{2} \otimes \mathbb{1}$ ($\mathbf{S}_{\bar{t}} = \mathbb{1} \otimes \frac{\boldsymbol{\sigma}}{2}$) spin operator of $t(\bar{t})$.

$$2\langle \hat{\mathbf{p}} \cdot \mathbf{S}_t \rangle|_{\sqrt{s}=500\,\mathrm{GeV}} = 0.8998 - 0.278\,\frac{\alpha_s}{\pi} = 0.8910 \qquad (\sim 1\%),$$

$$2\langle \hat{\mathbf{k}}_t \cdot \mathbf{S}_t \rangle|_{\sqrt{s}=400\,\mathrm{GeV}} = 0.4198 + 0.450\,\frac{\alpha_s}{\pi} = 0.4341 \qquad (\sim 3\%),$$

$$\langle \mathbf{S}_t \cdot \mathbf{S}_{\bar{t}} \rangle|_{\sqrt{s}=1\,\mathrm{TeV}} = 1/4 - 0.405\,\frac{\alpha_s}{\pi} = 0.2371 \qquad (\sim 5\%).$$

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*A. Brandenburg, M. Flesch, P. Uwer, Phys. Rev. D **59** (1999) 014001

- Formfactors

Bernreuther →

Also no recent exp. analysis.

Important: P_{e^-}

- $e^+e^- \to t\bar{t} + \begin{Bmatrix} g \\ Z \\ H \end{Bmatrix} \to b\bar{b}$

Moretti →

Corcella, Seymour

$t\bar{t}g$, $t\bar{t}Z$ background for $t\bar{t}H$.

↑ radiation from b ($\bar{b}$) important!

M.E. correction soon in Herwig 6.1.

→ $\Delta M_{max} = ?$ in progress.

- Complete $O(\alpha_s^2)$ + EW corrections for $t\bar{t}$ above threshold available.

Kühn

⇝ large EW contributions from box-diagrams.

⋯→ α_s determination from σ_{tot} ?

Sensitivity to (non SM) form factors in $t\bar{t}$ prod. & decay:

only $t\bar{t} \to \ell^{\pm} \overset{(-)}{\nu}_{\ell}$ + jets channels considered
$\ell = e, \mu$

cuts: $E_\ell > 30$ GeV, $|\cos\Theta| < 0.95$

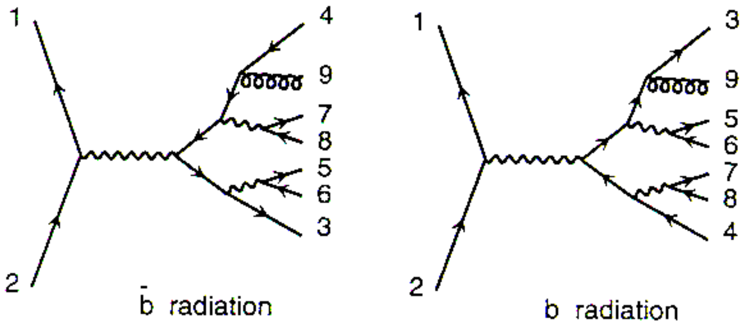
$B_{reco} = 16\,\%$, int. lumi $310\,fb^{-1}$ (500 GeV), $500\,fb^{-1}$ (800 GeV)

1σ stat. errors (68 % CL)

$\sqrt{s} = 500$ GeV — e^- polarization

	$p = 0$	$p = -0.8$	
F_{1R}^{W}	0.030	0.012	← V+A in $t \to W + b$
$F_{2V}^{\gamma,Z}$	0.015	0.011	← anom. mag. "moment"
Re F_{2A}^{γ}	0.035	0.007	CP in $t\bar{t}$ production dipole "moments" $d_t^{\gamma,Z} = \frac{e}{2m_t} F_{2A}^{\gamma,Z}$
Re F_{2A}^{Z}	0.012	0.008	
Im F_{2A}^{γ}	0.010	0.008	
Im F_{2A}^{Z}	0.055	0.010	
Im F_{2R}^{W}	0.025	0.010	← CP in $t \to W\,b$

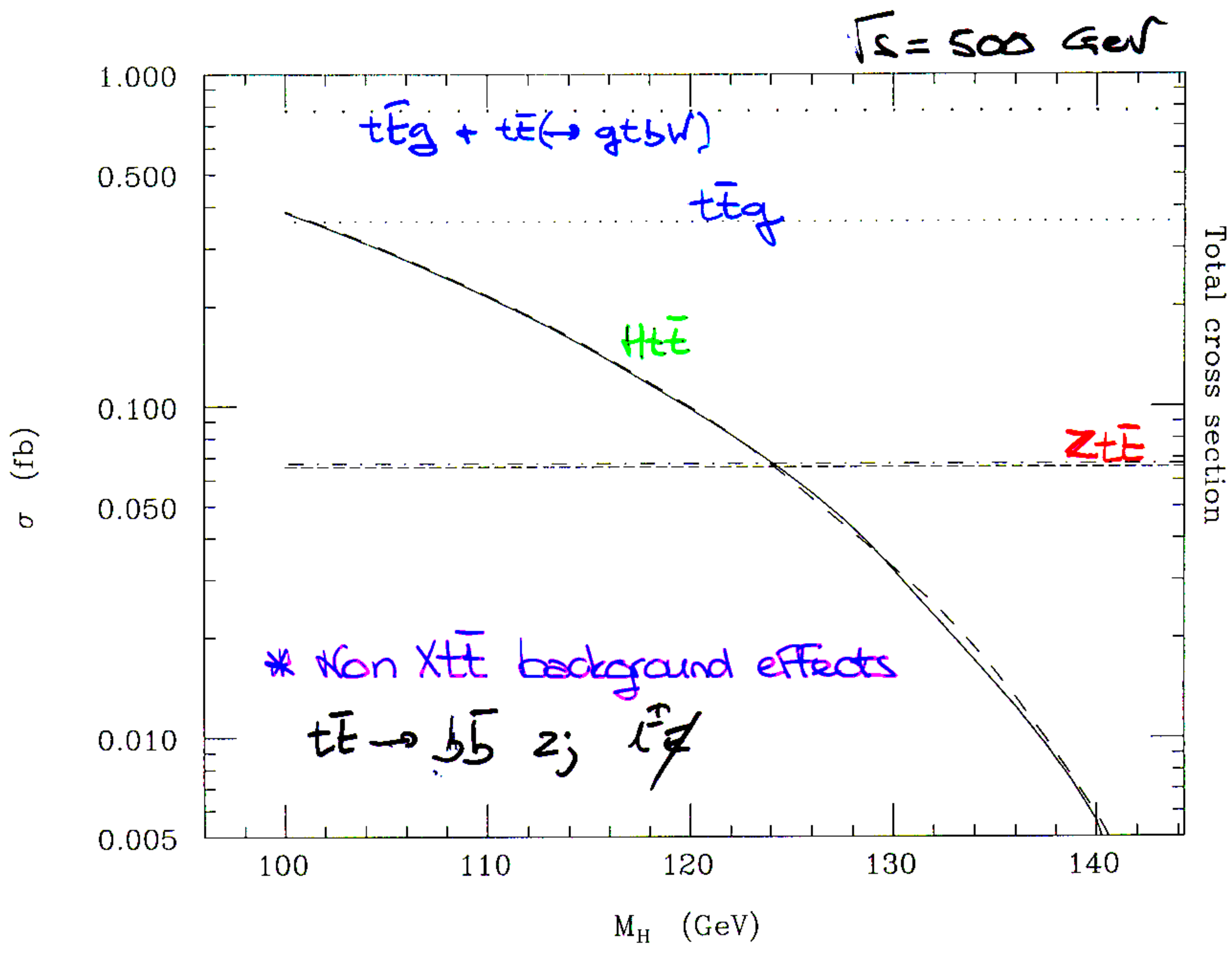
$\sqrt{s} = 800$ GeV	$p = 0$	$p = -0.8$
$F_{2V}^{\gamma,Z}$	0.011	0.008
Re F_{2A}^{γ}	0.015	0.004
Re F_{2A}^{Z}	0.008	0.007
Im F_{2A}^{γ}	0.006	0.005
Im F_{2A}^{Z}	0.037	0.007



- b-radiation + $\bar{b}$-radiation ≈ $t\bar{t}$ radiation...

  (Stirling/Stelzer 1996)

- Soon in HERWIG 6.1 (ME corrections)



√s = 500 GeV
Total cross section
σ (fb)
1.000
0.500
0.100
0.050
0.010
0.005
100
110
120
130
140
M_H (GeV)
tt̄g + tt̄(→ gtbW)
tt̄g
Htt̄
Ztt̄
* Non Xtt̄ background effects
tt̄ → bb̄ 2j ℓ±

• Rare t decays :

Mele et al.
Guasch, Solà

Are FCNC top decays a door to SUSY physics ?

SM: $Br(t \to cH) \approx 10^{-13}$, few $\cdot 10^{-4}$
$Br(t \to cg) \approx 10^{-11}$, few $\cdot 10^{-4}$

in MSSM!

⇢ Redo exp. analysis to check for accessibility with $500\,fb^{-1}$.

4. Sitges and beyond

Threshold:

* More detailed studies of theoretical uncertainties needed: sensitivity of the fitted m_t to order, scale in α_s, different mass definitions, different NNLO input...

* Optimization of the scan-strategy.

* Comparison of different calculations of nonfactorizable corrections.

Unified description for all energies?

Long term:

* Exp. analysis of Polarization, axial contributions, formfactors, spin-correl.
* Redo the studies for mass reconstruction above threshold.

5. $t\bar{t}H$ ...