Scattering Rates and Spectator Effects in Leptogenesis

Pedro Schwaller
CERN

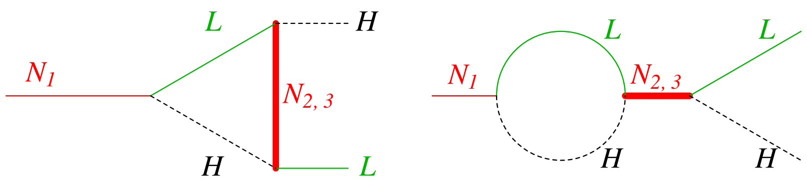
Rencontres de Moriond
March 18, 2014

Neutrino see-saw and Leptogenesis

- Small ν masses from see-saw

$$m_\nu \sim \frac{Y^2 v^2}{M} \qquad Y \sim 1 \Rightarrow M \sim 10^{13}\ \mathrm{GeV}$$

- Leptogenesis: CPV decay of RH neutrinos
  - CP violation



  - L violation: Majorana mass
  - Non-equilibrium: $\Gamma(N_1 \to \ell H) \sim H(T = M_1)$

$$\frac{\Gamma}{H} \approx M_{\mathrm{Planck}} \frac{Y^2}{M_1} \stackrel{!}{=} 1 \quad \Longleftrightarrow \quad m_\nu \sim \mathrm{meV}$$

Neutrino mass conspiracy

Recent Progress

- Leading candidate for baryogenesis
  - Thorough theoretical understanding desirable
- Systematic improvement
  - Quantum kinetic equations
  - Finite temperature effects
  - Flavour effects
  - Scattering rates at finite temperature
  - Spectator effects

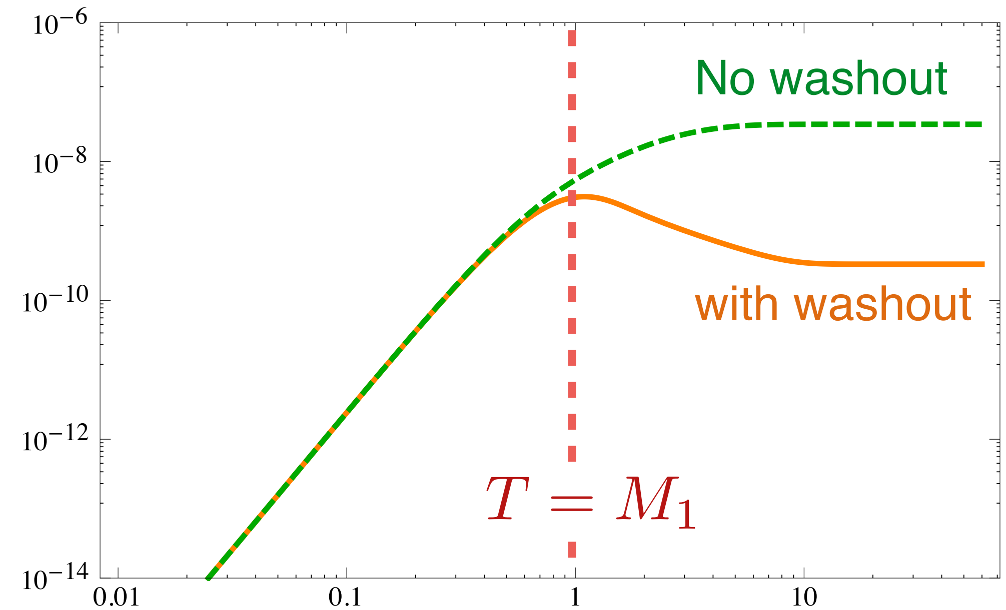
based on:
Garbrecht, Glowna, PS, NPB 2013
Garbrecht, PS, 2014

Why are scattering rates important

- Boltzmann equation

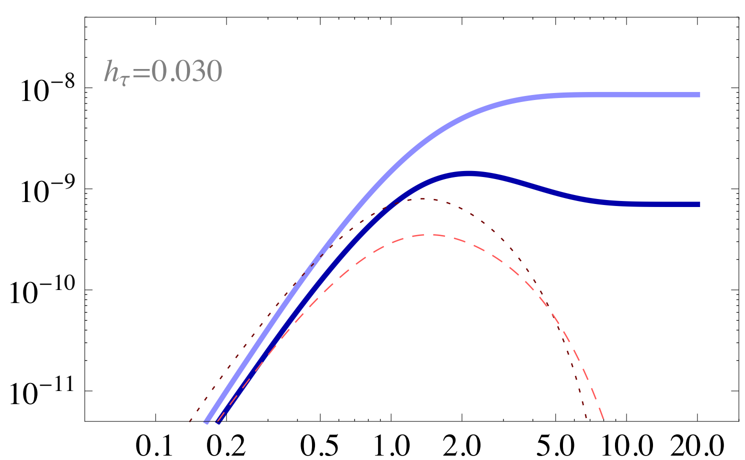
$$\frac{d}{dt}Y_\ell = S - W\left(Y_\ell + \tfrac{1}{2}Y_H\right)$$

$$Y_X = \frac{n_X - n_{\bar{X}}}{s}$$



→ Washout rate determines final asymmetry

- Flavour effects:

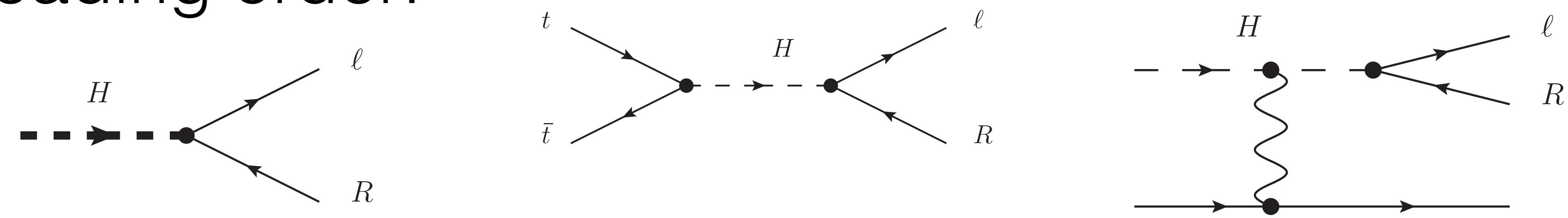


different washout for different flavours, relevant when

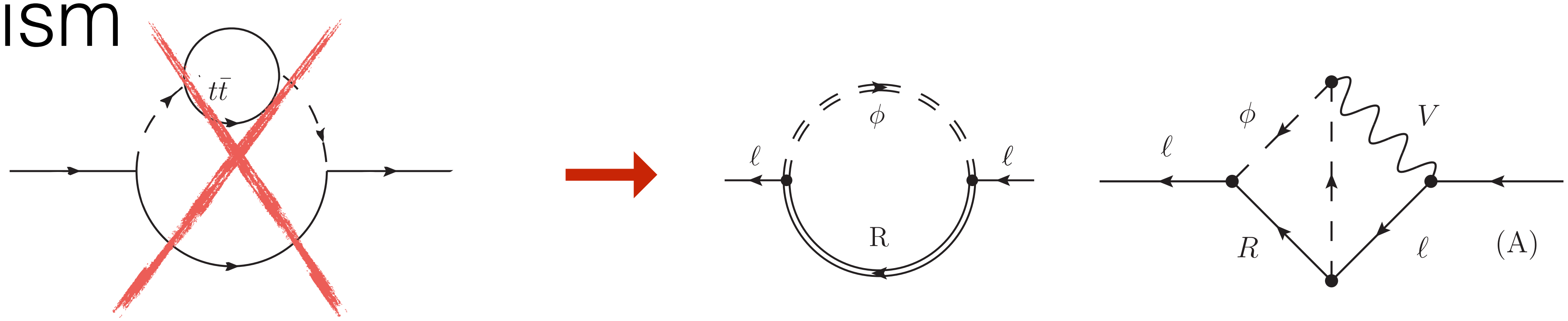
$$\Gamma^{\rm fl} \gtrsim H\,,\,\Gamma_{N1}$$

Nontrivial calculation

- Finite temperature: Several processes contribute at leading order:



- Automatic regularisation of soft divergencies in 2PI formalism



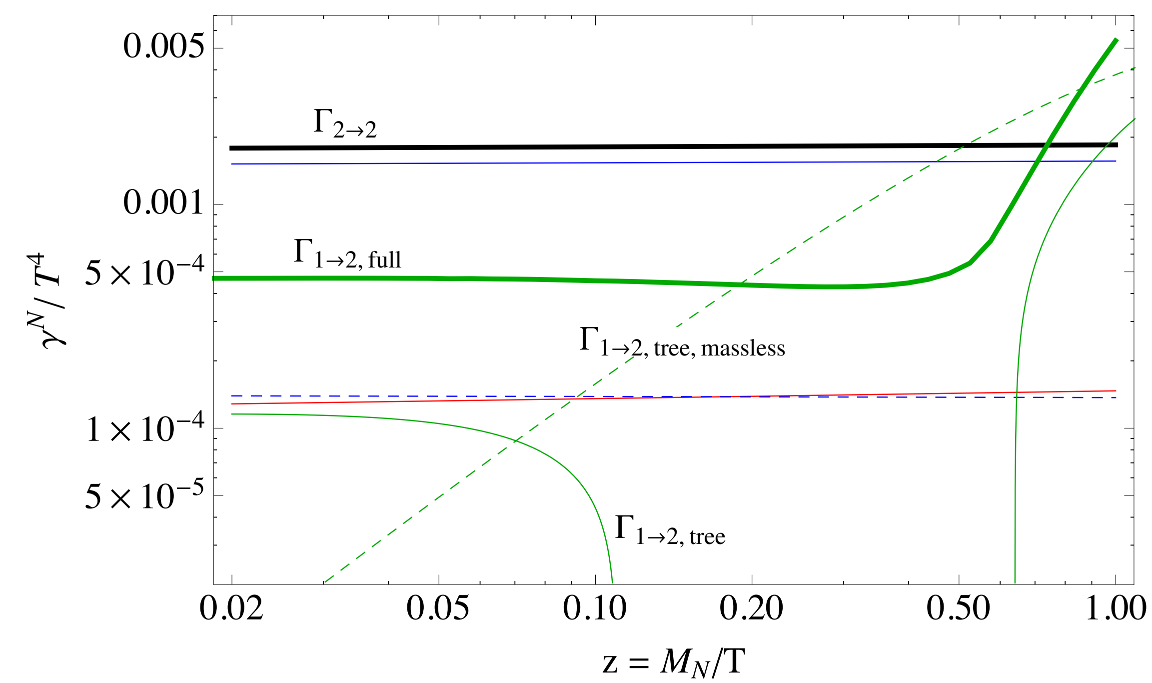
- Prescription is unique, result does not depend on phase space slicing

Results

- N1 production rate

from Garbrecht, Glowna, PS, NPB 2013

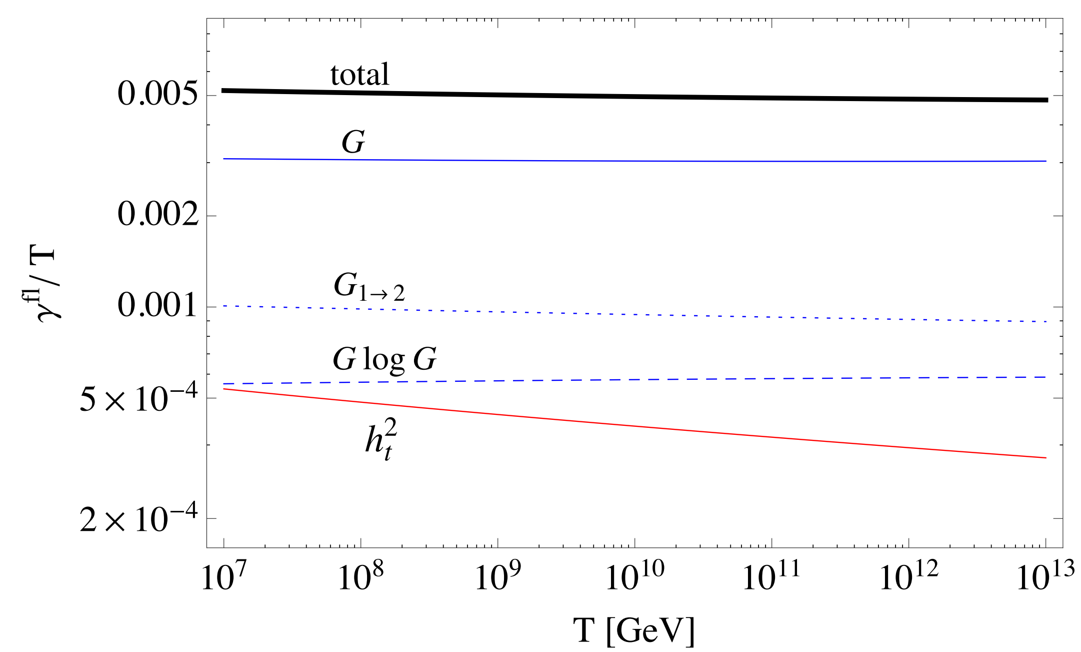
see also:
Salvio, Lodone, Strumia, 2011;
Anisimov, Besak, Bodeker, 2010, 2012;
M. Laine, 2013;



- Flavour equilibration rate

$$\Gamma_\alpha^{\rm fl} \approx 5\times10^{-3}|h_\alpha|^2 T$$

compare with $(3-17)\times10^{-3}$ in literature



Spectator effects

- Return to Boltzmann Equation

$$\frac{d}{dt}Y_\ell = S - W\left(Y_\ell + \tfrac{1}{2}Y_H\right)$$

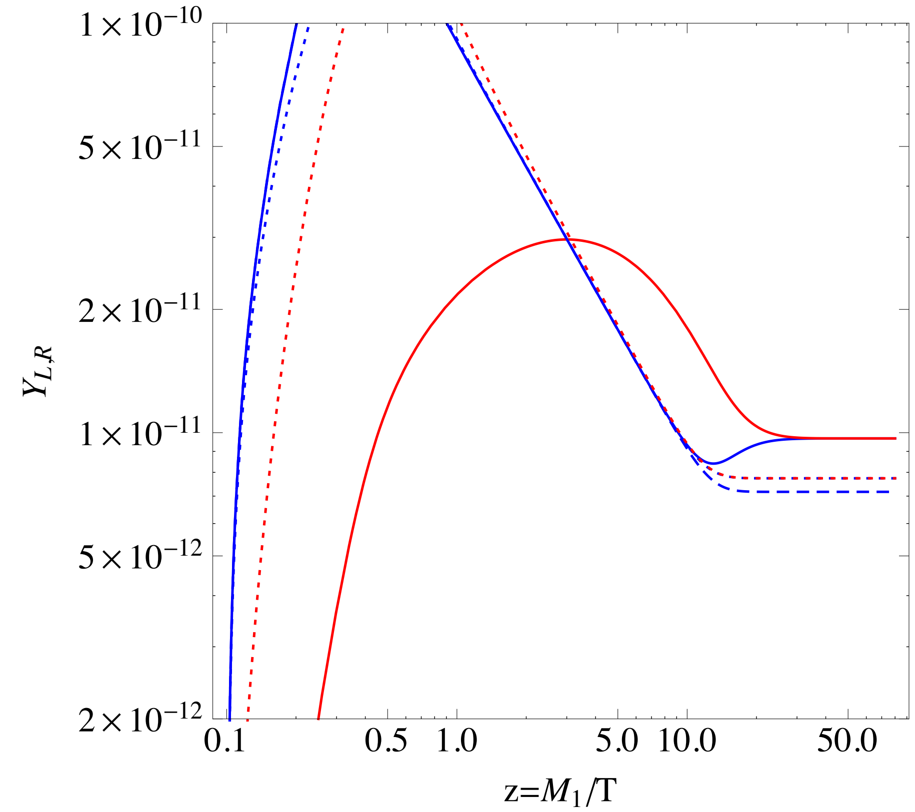
- In principle $Y_H = Y_\ell$ from hyper-charge neutrality
  - Y_H also modified by (top) Yukawa interactions, Y_ℓ by electroweak spalerons: spectator effects
- Solution so far: $$\frac{d}{dt}Y_{B-L} = -S + W(c_\ell + c_H)Y_{B-L}$$
- Find c_ℓ , c_H using chem. equilibrium relations, assuming that spectators are either fully equilibrated or inactive

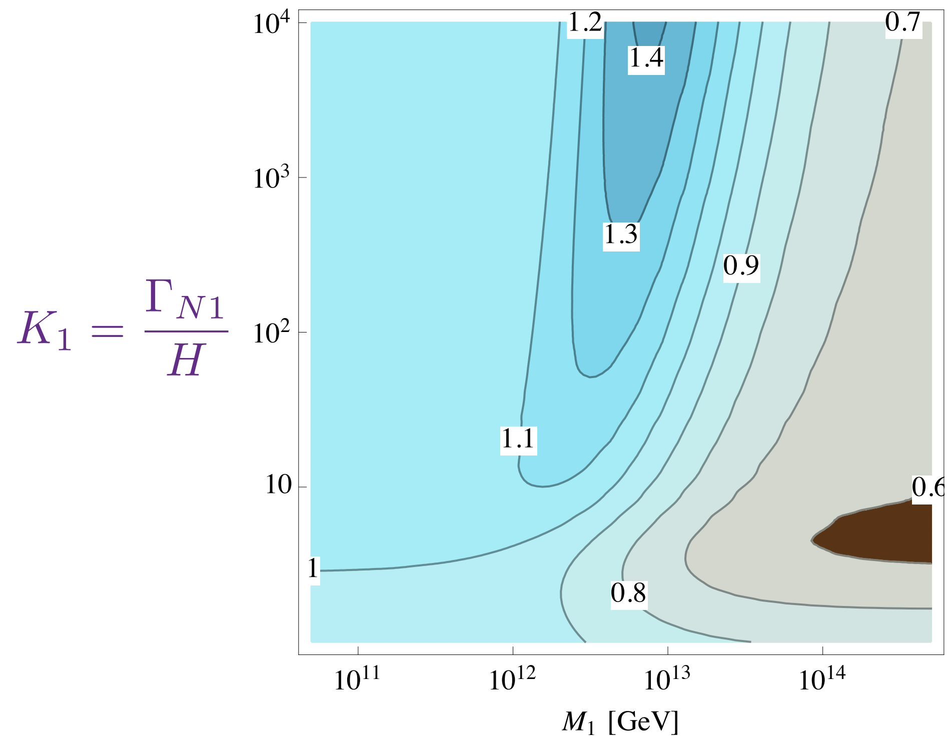
Partial tau Yukawa equilibration

- Evolution equations

$$\frac{d}{dt}Y_\ell = S - WY_\ell - \gamma^{\text{fl}} h_\tau^2 (Y_\ell - Y_R)$$
$$\frac{d}{dt}Y_R = -\gamma^{\text{fl}} h_\tau^2 (Y_R - Y_\ell)$$

- Asymmetry hidden in Y_R

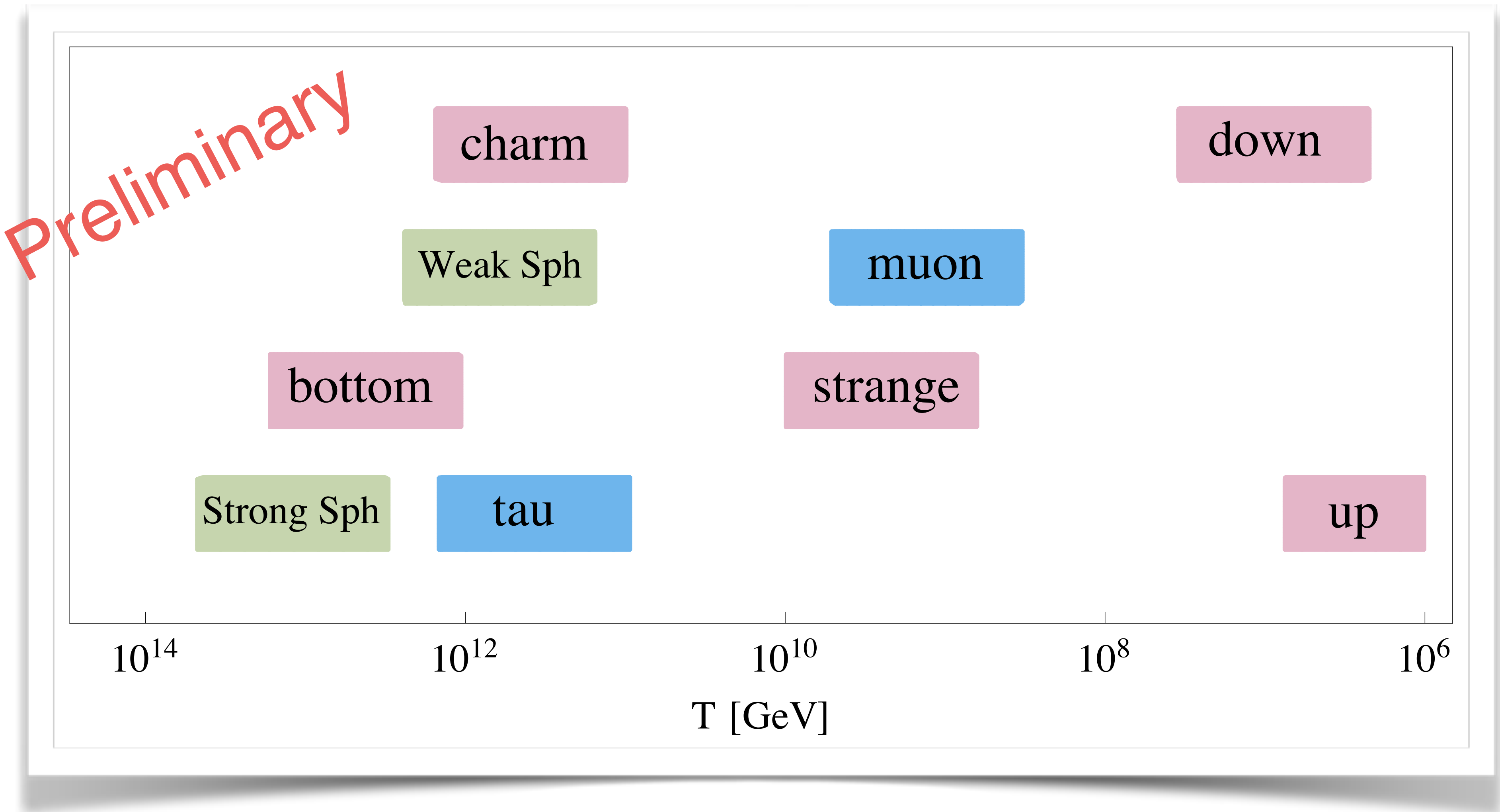




- Up to 40% enhancement compared to old approach
- $\Gamma_\tau^{\text{fl}}/H = 1$ at $T_\tau \approx 3.7\times10^{11}$ GeV

(Just for illustration! Other spectators, and flavour effects neglected)

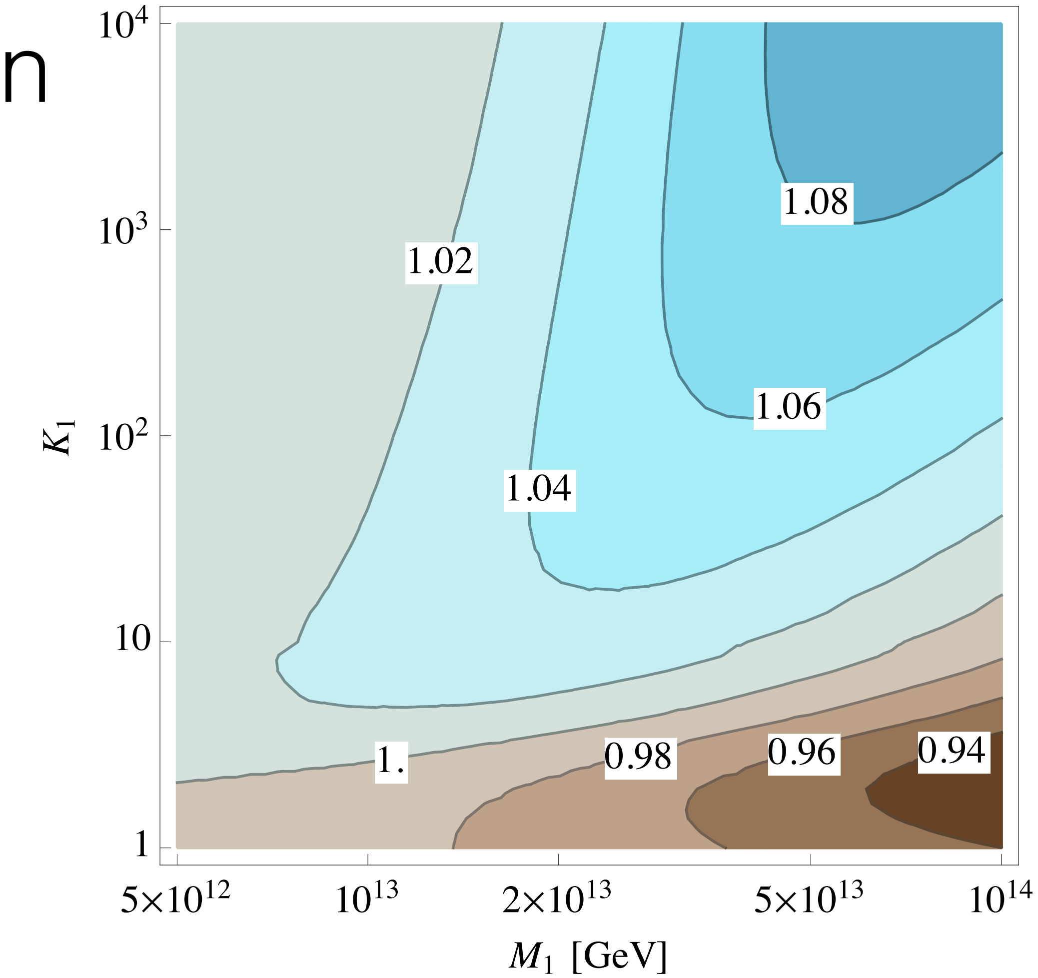
Temperature ranges



- Some shifts with respect to literature
- Can treat bottom + strong sphaleron together

Bottom Equilibration

- Consider partial equilibration of strong sphalerons and bottom Yukawa



- Equilibration around

$$(0.5 - 1) \times 10^{13}\ \mathrm{GeV}$$

- Up to 10% increase
- Mostly bottom Yukawa, strong sphaleron negligible

Implications

- Order 10% - 40% corrections. Should be included in quantitative treatments

- When does it actually matter?
    - Strong washout ~ degenerate ν masses
    - Neutrino model building, SUSY(?)
    - Bound on reheating temperature (or naturalness) *

* Treatment of muon Yukawa equilibration, including full flavour effects, to be done

Conclusions

- Complete leading order Yukawa interaction rates for leptogenesis now available

$$\Gamma_\alpha^{\text{fl}} \approx 5 \times 10^{-3} |h_\alpha|^2 T$$

- Partially equilibrated spectator effects can hide asymmetry
    - few % to 40% modifications (mostly enhancement)
    - combination with flavour effects could be interesting