Cosmological Signatures in Mirror Twin Higgs Models

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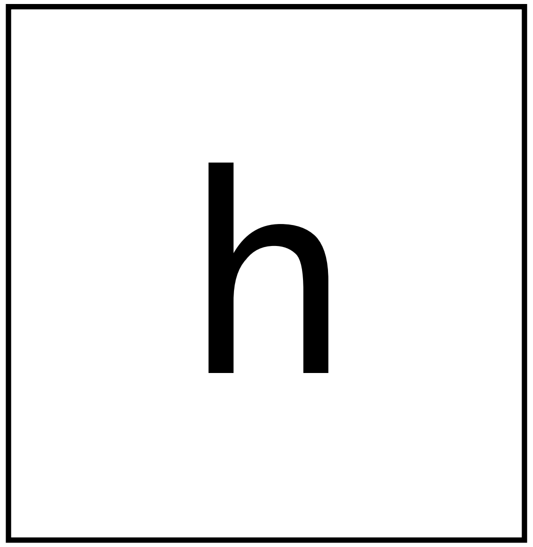
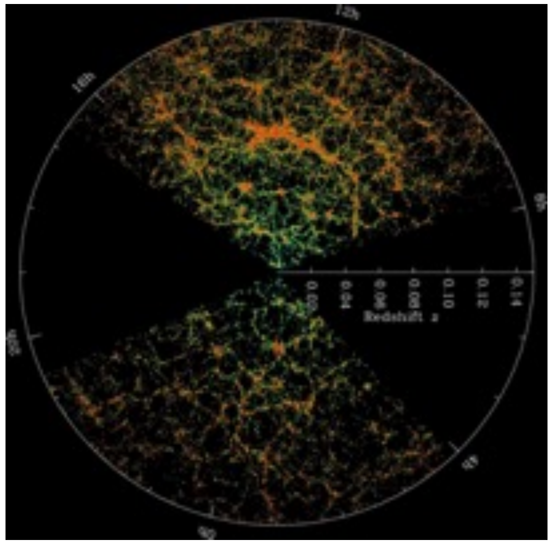
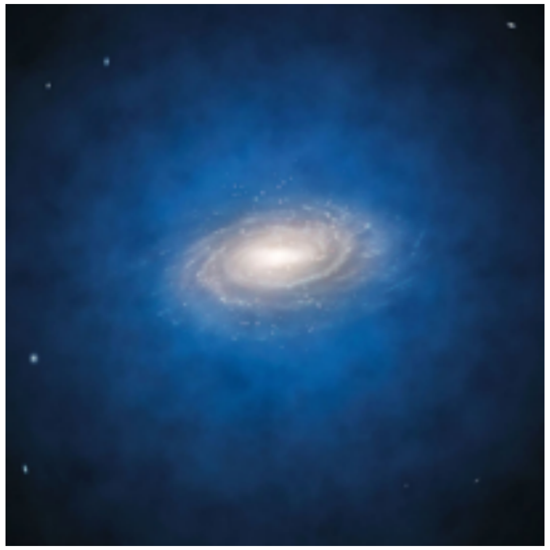
University of Maryland

arXiv:1803.03263, Z. Chacko, D. Curtin, M. Geller, YT

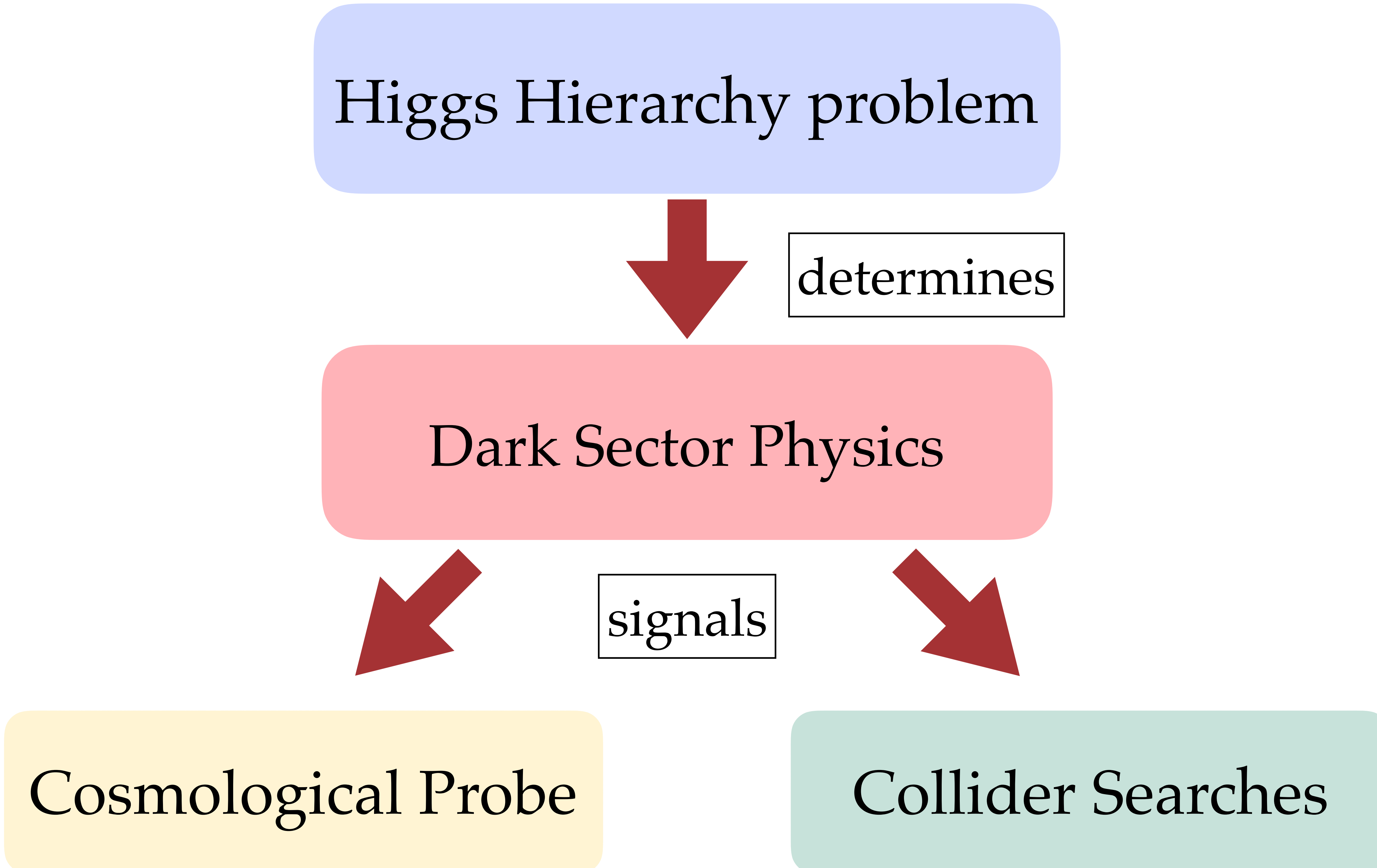
PASCOS, 2018





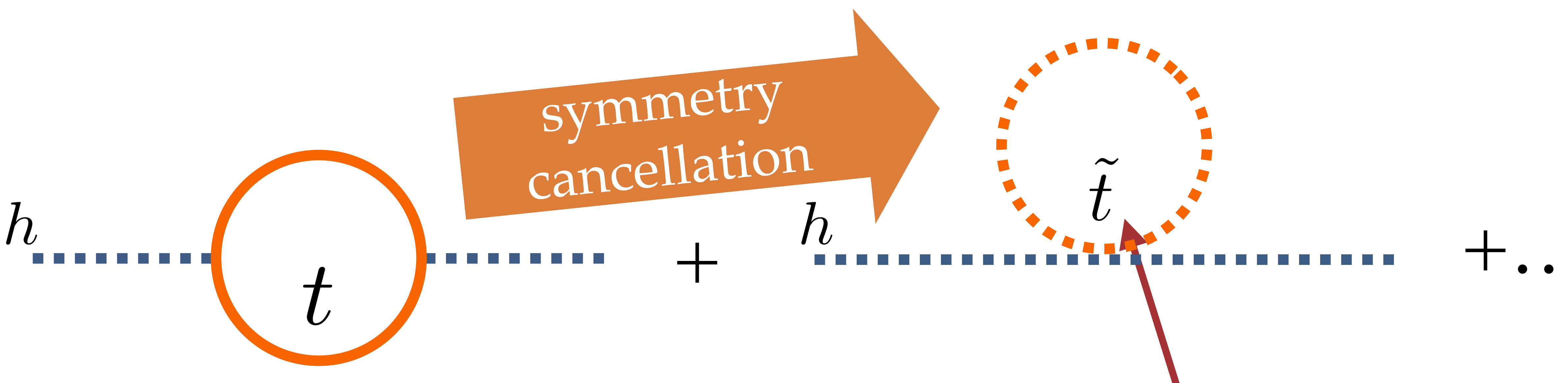


Hidden Naturalness scenario



One solution to the hierarchy problem:
Supersymmetry

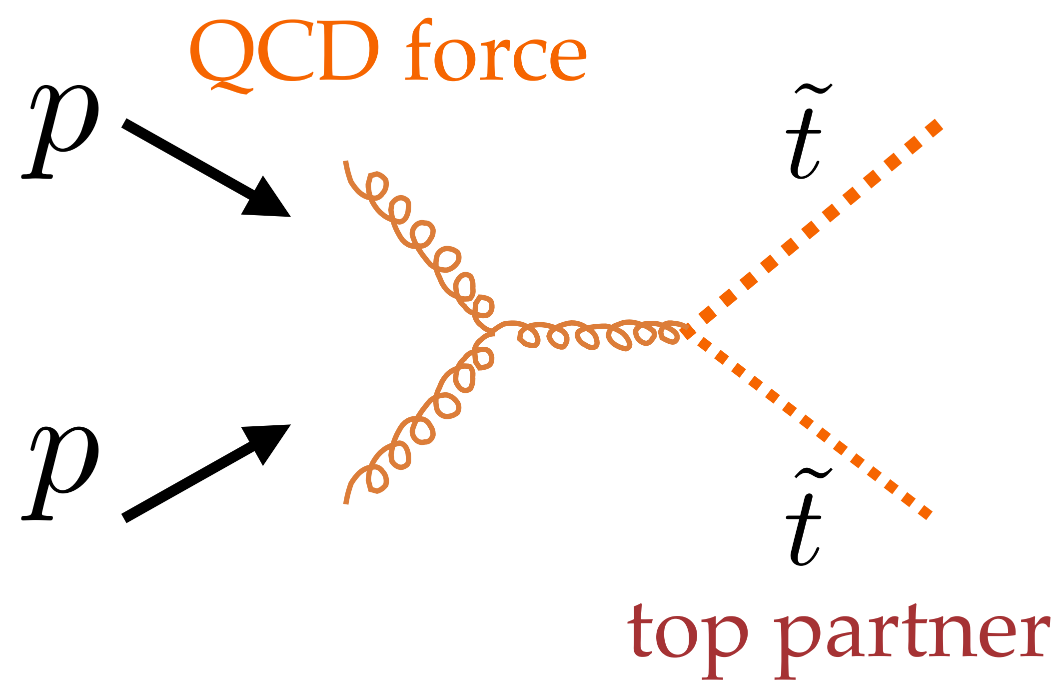
Super particle loops cancel the divergence



top quark
carry SM QCD charge

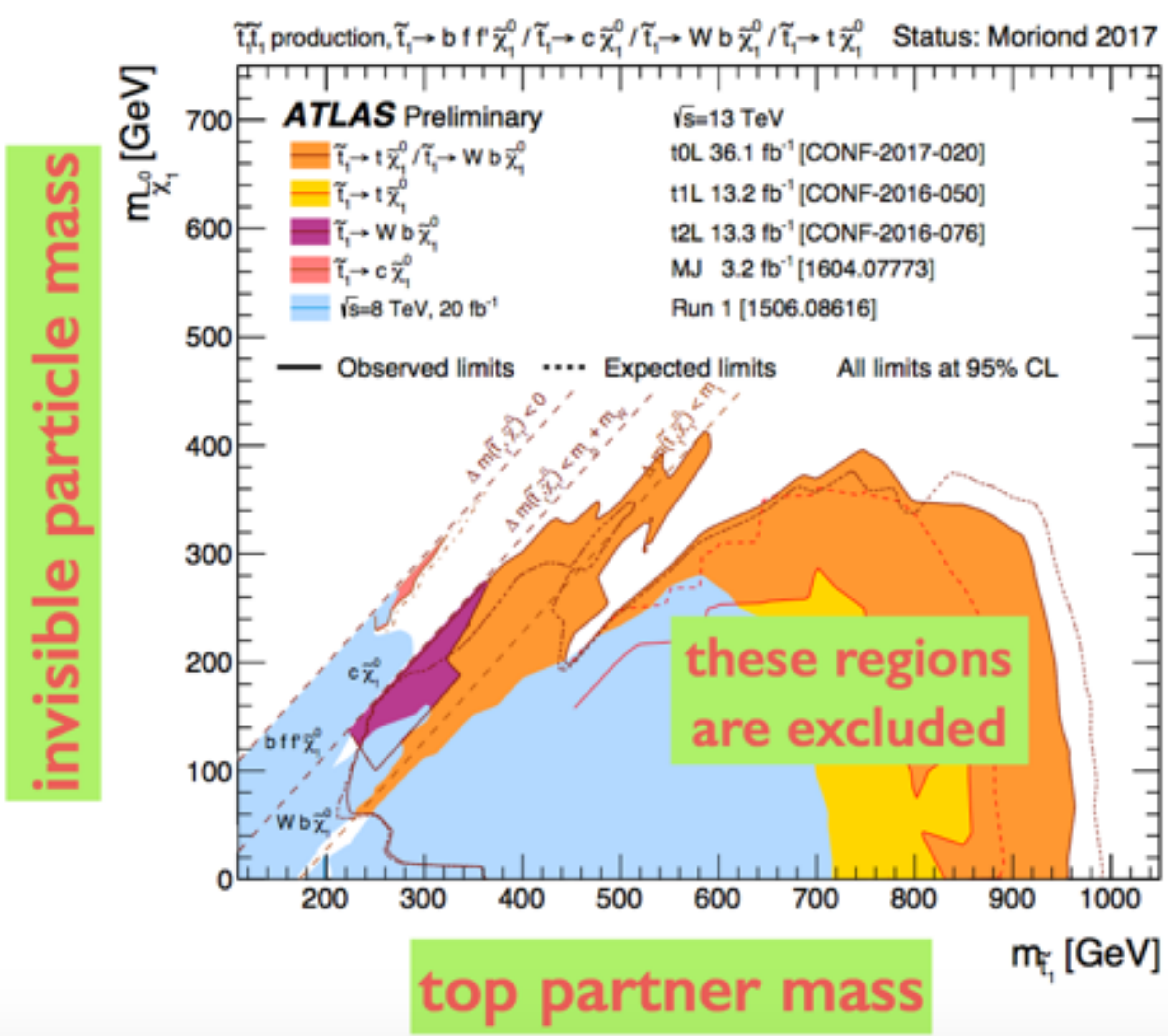
Top Partner
carry SM QCD charge

symmetry



collider signal

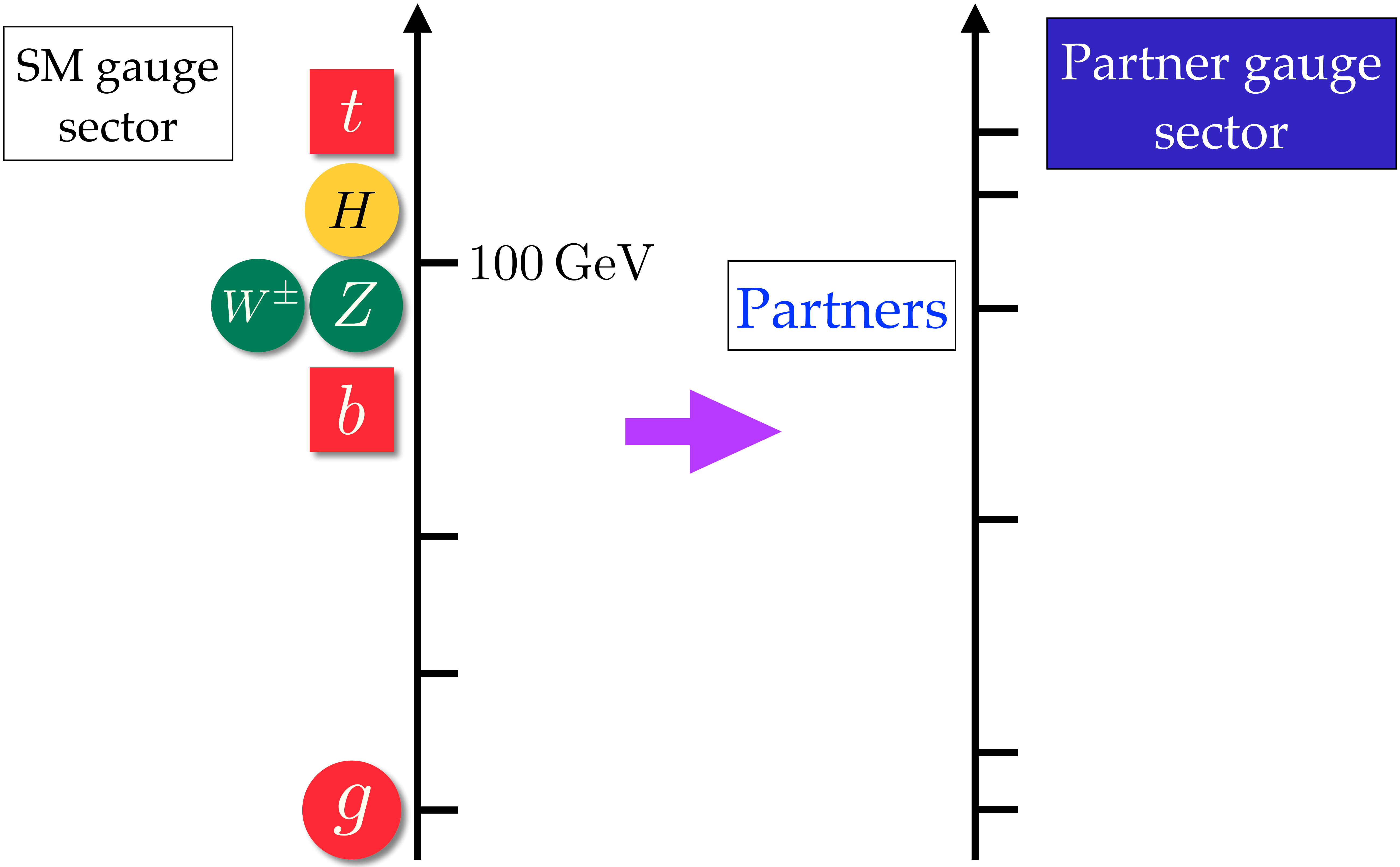
No SUSY so far…



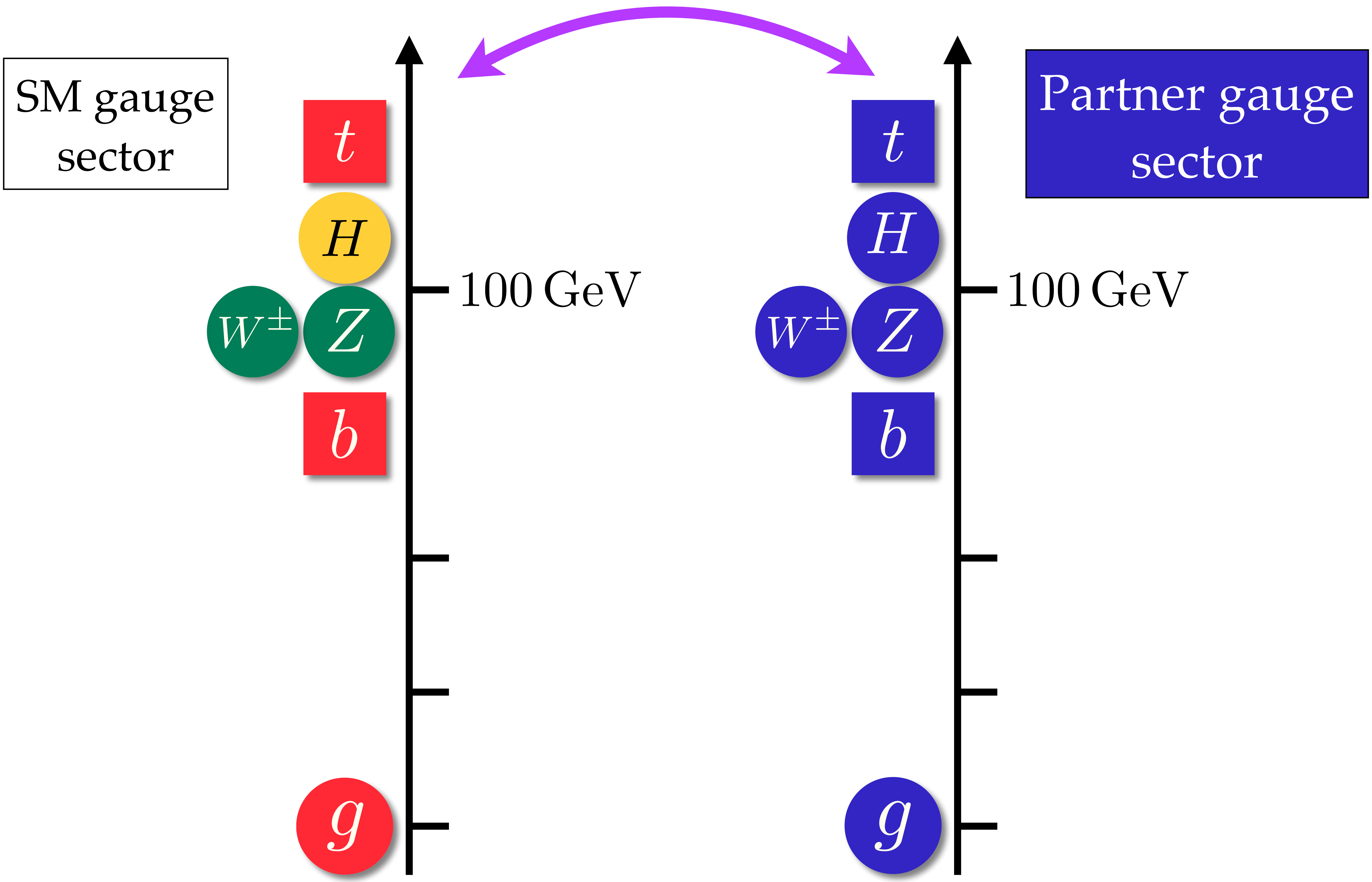
$$m_{\tilde{t}} \gg m_t$$

The hope for symmetry cancellation is fading…

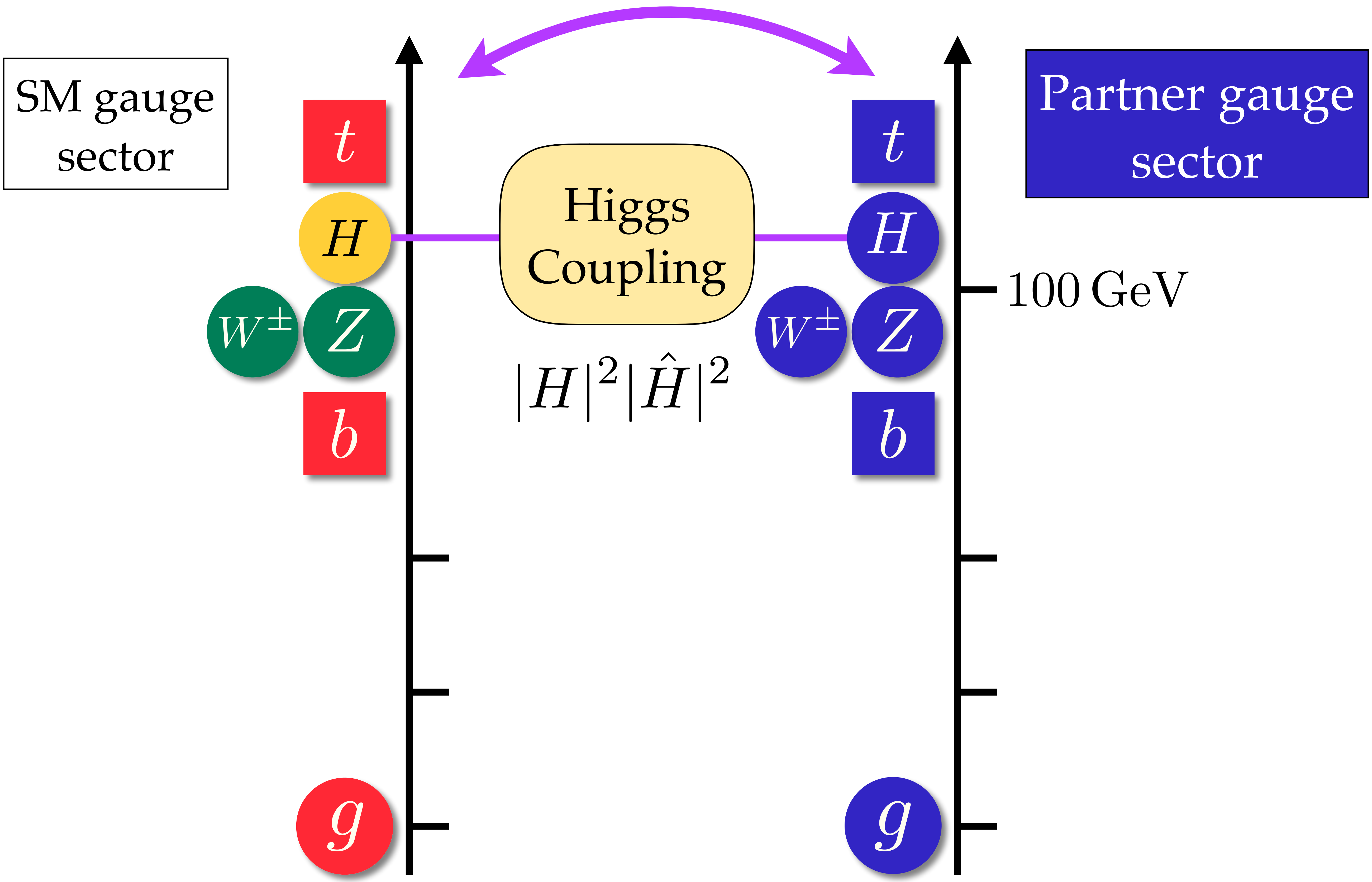
Partner fields in a different gauge sector



Related by a **Mirror Symmetry** Z_2

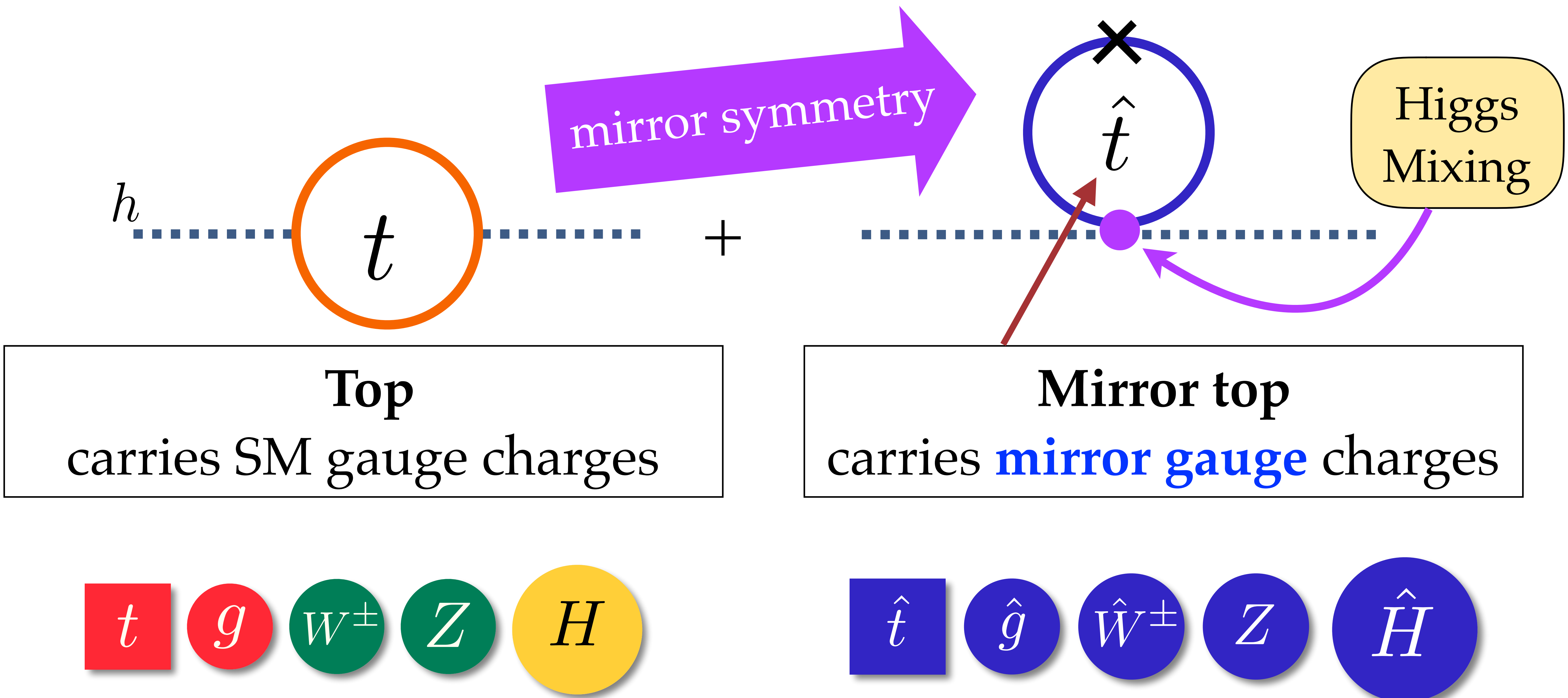


Related by a **Mirror Symmetry** Z_2

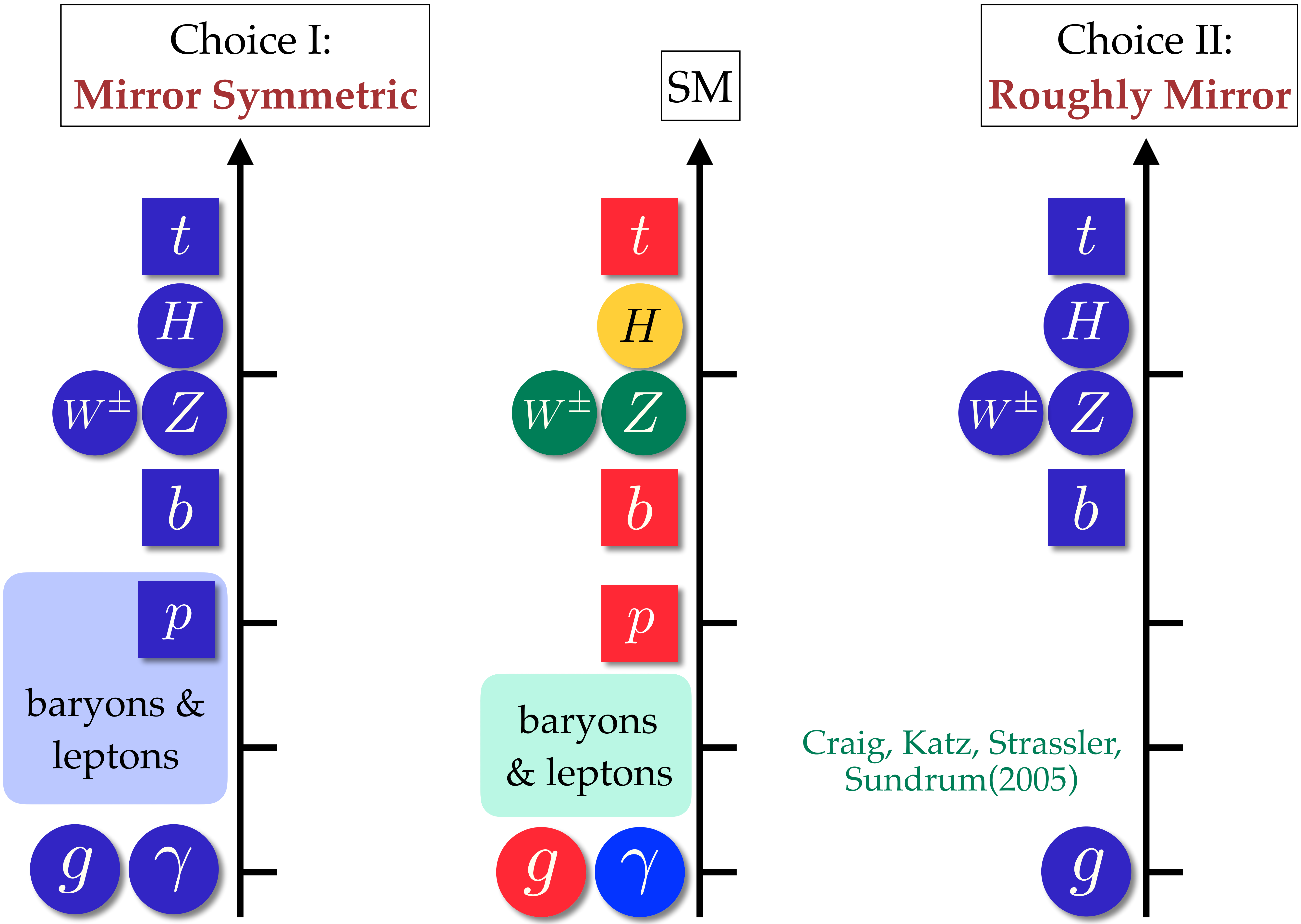


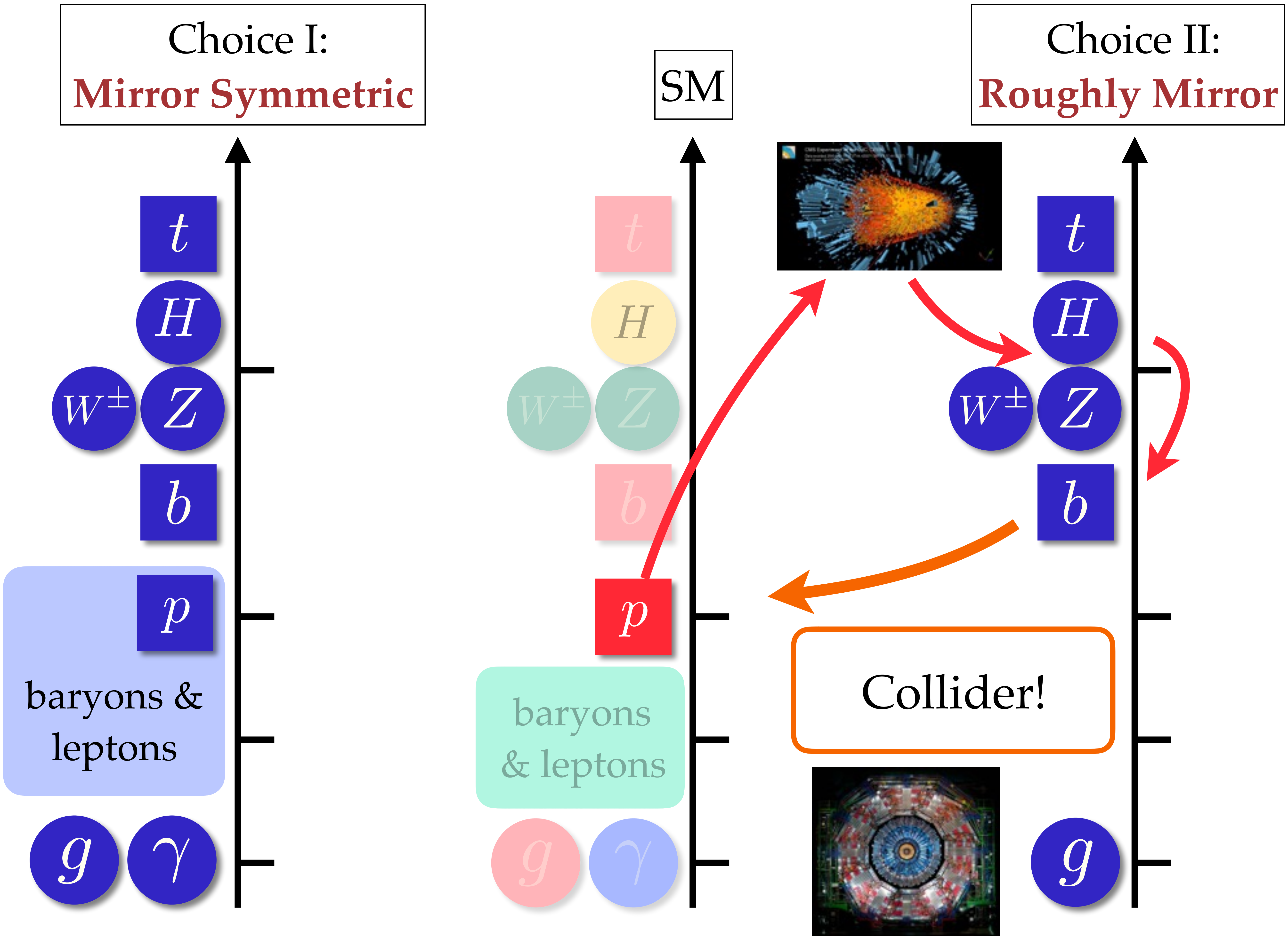
A concrete example: Twin Higgs

Chacko, Goh, Harnik (2005)



Mirror copy of the relevant particles


Choice I:
Mirror Symmetric
SM
Choice II:
Roughly Mirror
t
H
W±
Z
b
p
baryons & leptons
g
γ
t
H
W±
Z
b
p
baryons & leptons
g
γ
t
H
W±
Z
b
Craig, Katz, Strassler, Sundrum(2005)
g


Choice I:
Mirror Symmetric
SM
Choice II:
Roughly Mirror
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baryons & leptons
g
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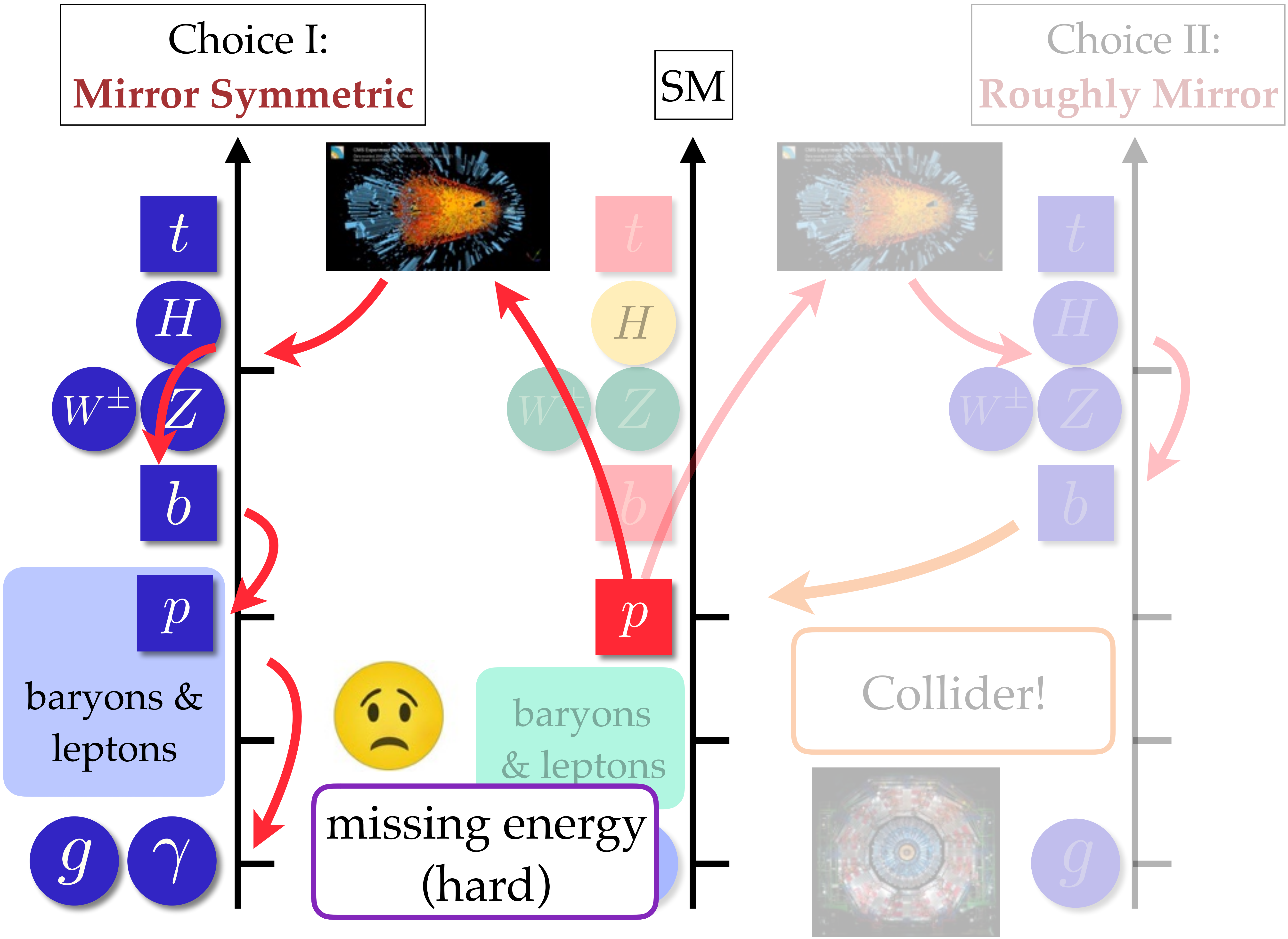
W±
Z
b
Collider!
g


Choice I:
Mirror Symmetric
SM
Choice II:
Roughly Mirror
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W±
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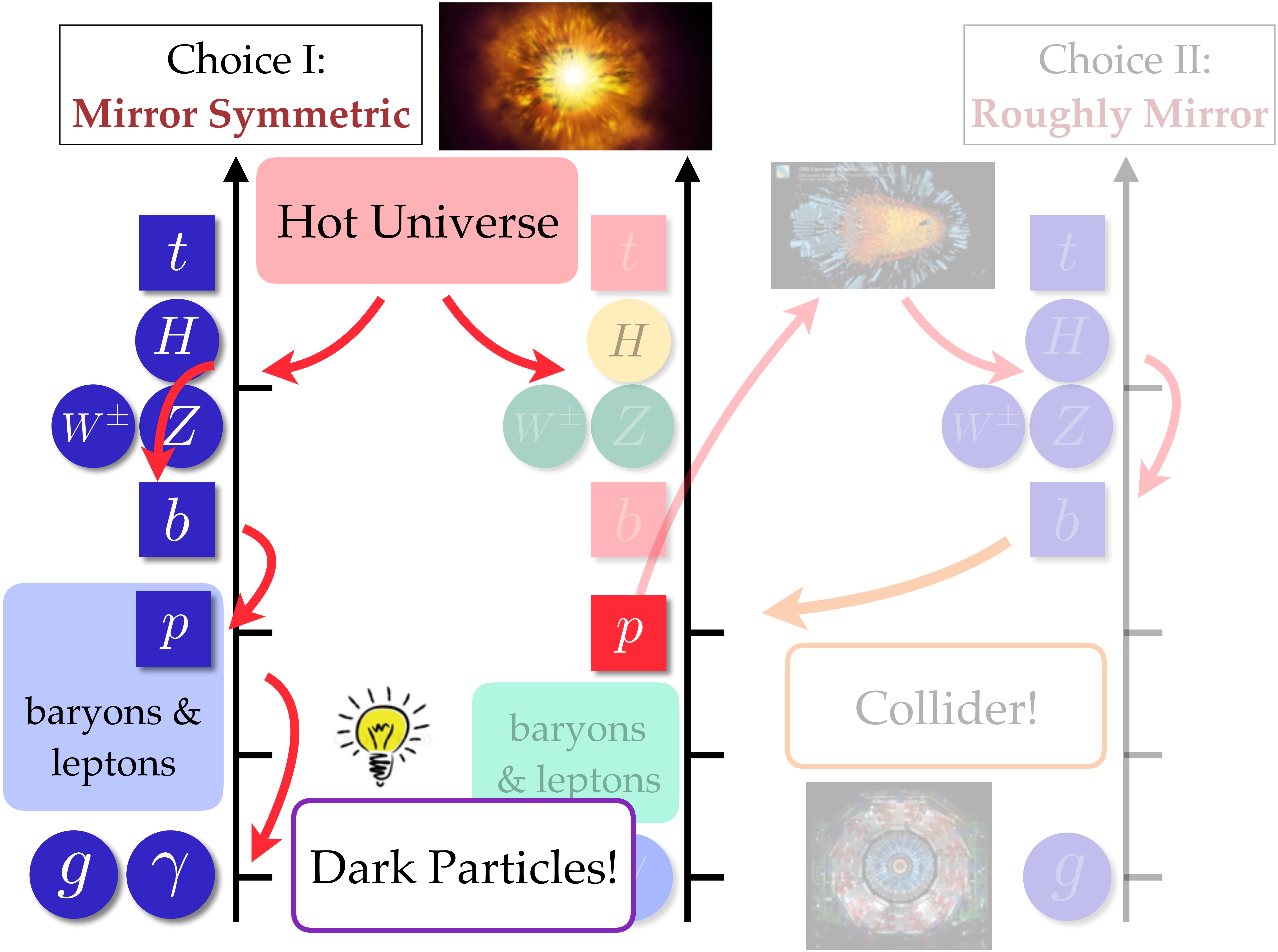
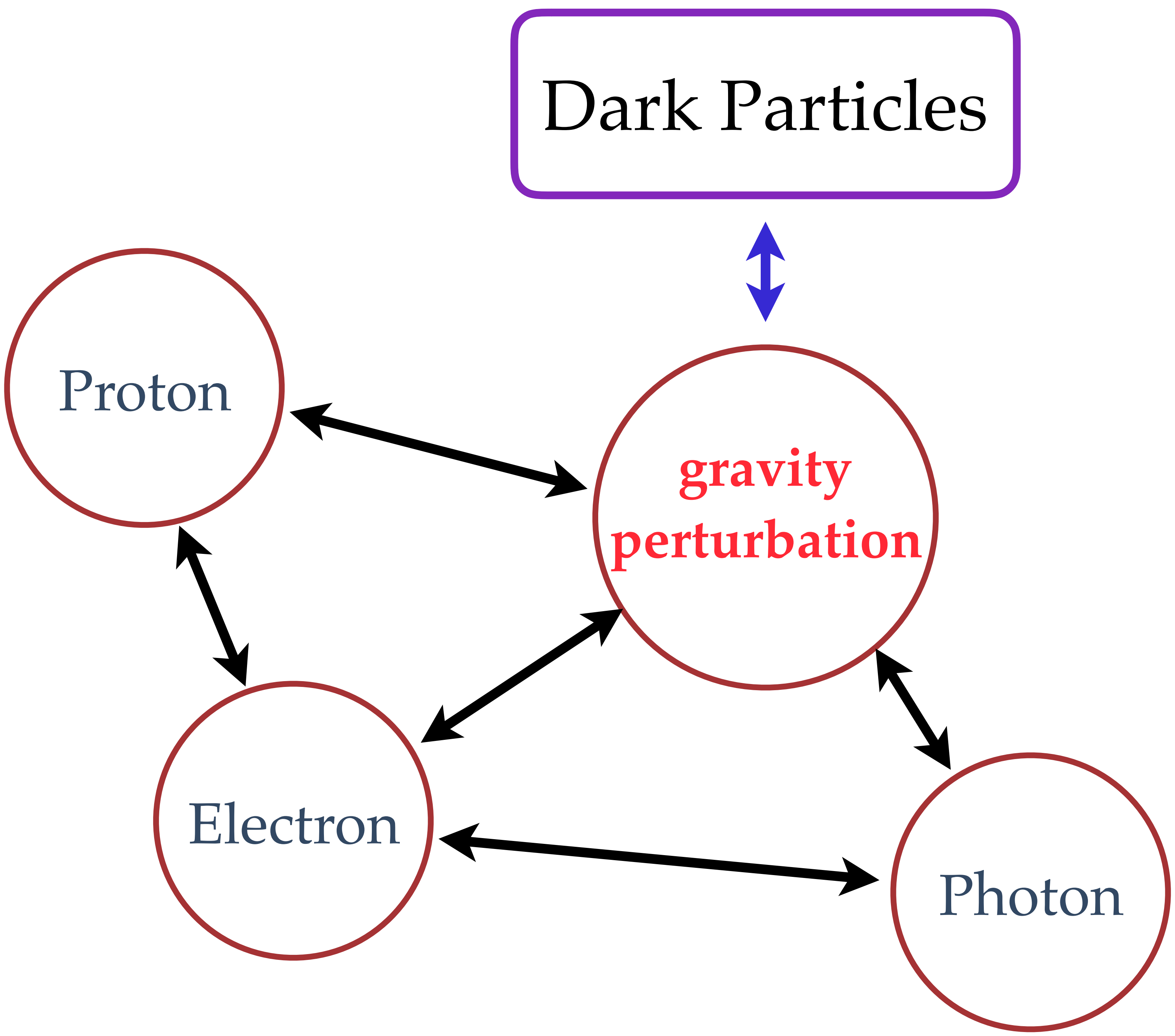
b
p
baryons & leptons
g
γ
t
H
W±
Z
b
p
baryons & leptons
missing energy (hard)
t
H
W±
Z
b
Collider!
g

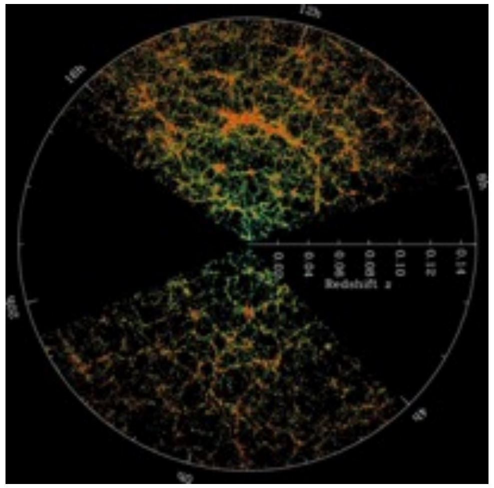


Choice I:
Mirror Symmetric
Choice II:
Roughly Mirror
Hot Universe
t
H
W±
Z
b
p
baryons & leptons
g
γ
Dark Particles!
baryons & leptons
Collider!

Study Dark Particles through gravity perturbation

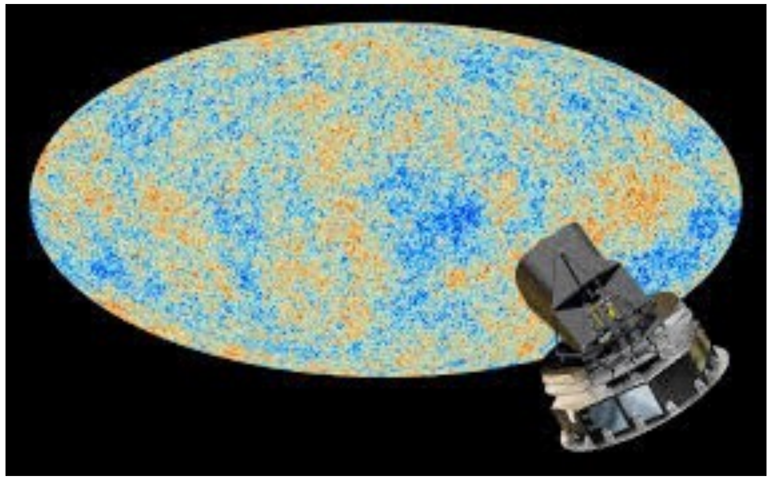


galaxy structure

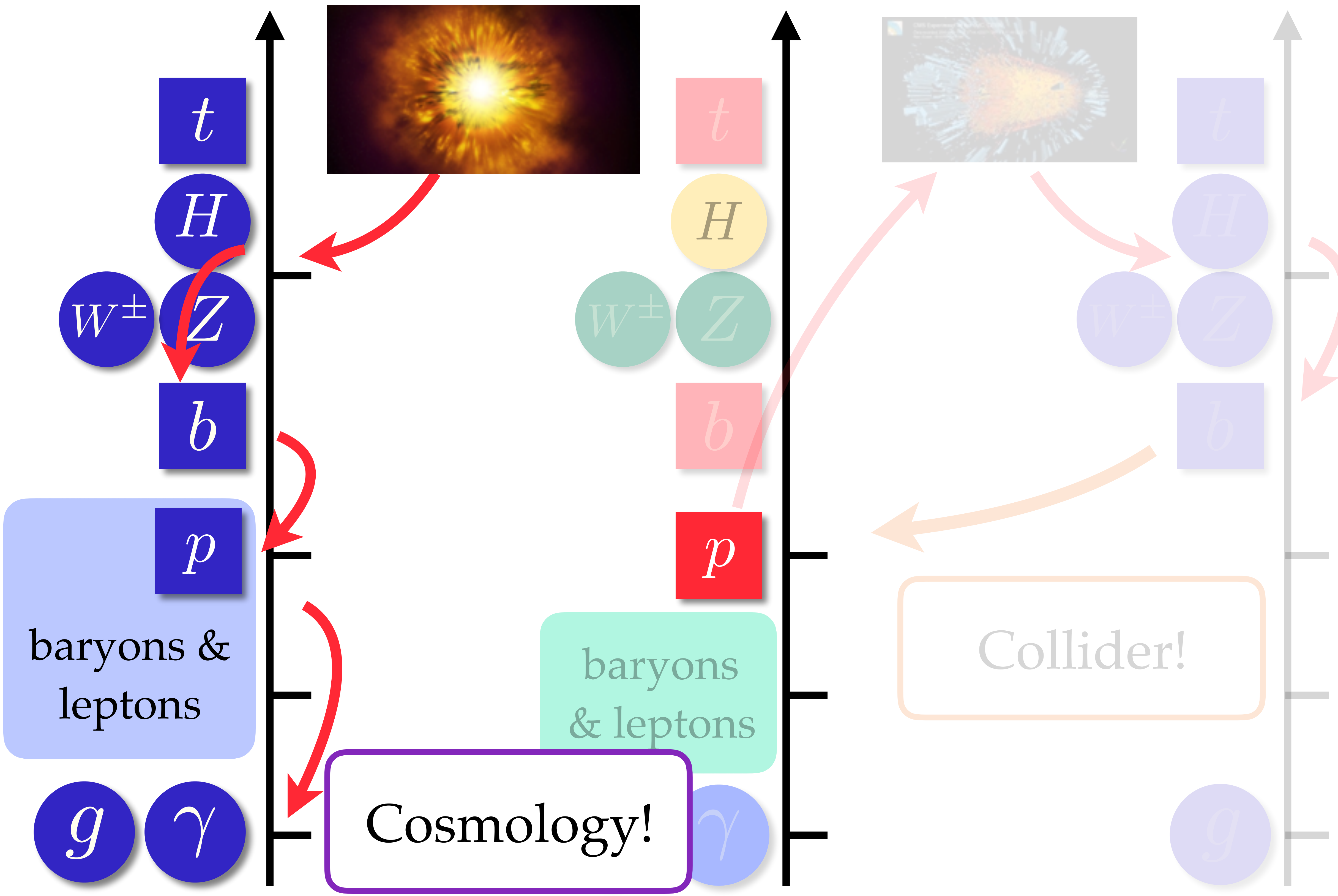


Large scale structure

CMB



Cosmological Signature from Hidden Naturalness



Mirror universe cannot be identical to the SM universe

From existing experimental constraints,

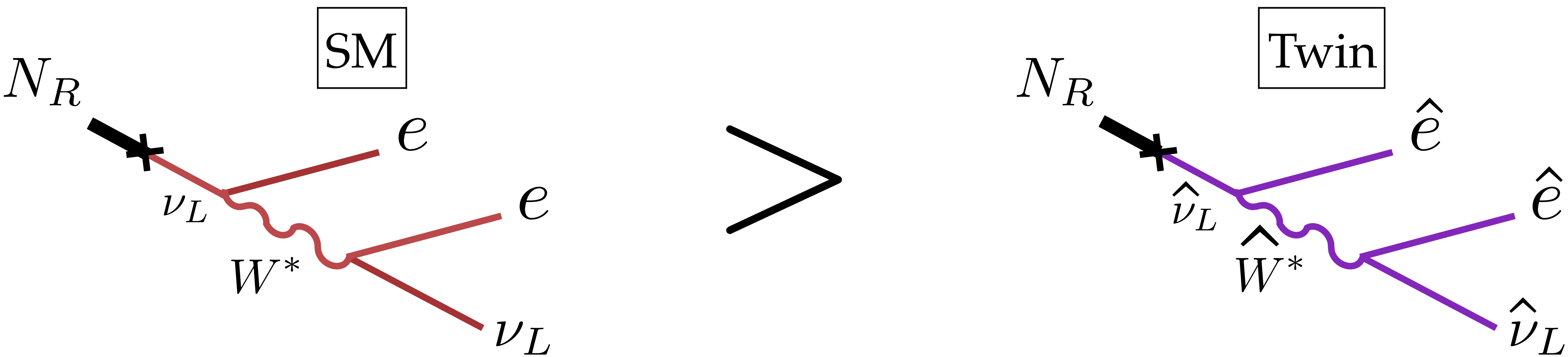
Higgs coupling measurement	$\frac{v_{\rm Mir}}{v_{\rm SM}} \geq 3$	mirror particles are heavier
CMB constraint	$\frac{T_{\rm Mir}}{T_{\rm SM}} < 0.5$	mirror temperature is lower

Mirror cosmology is different from SM cosmology

Dark radiation, asymmetric reheating

$\hat{\gamma}$ $\hat{\nu}$ give too much radiation density $\Delta N_{eff} = 5.7$

e.g., heavy neutrino decay can suppress ΔN_{eff}

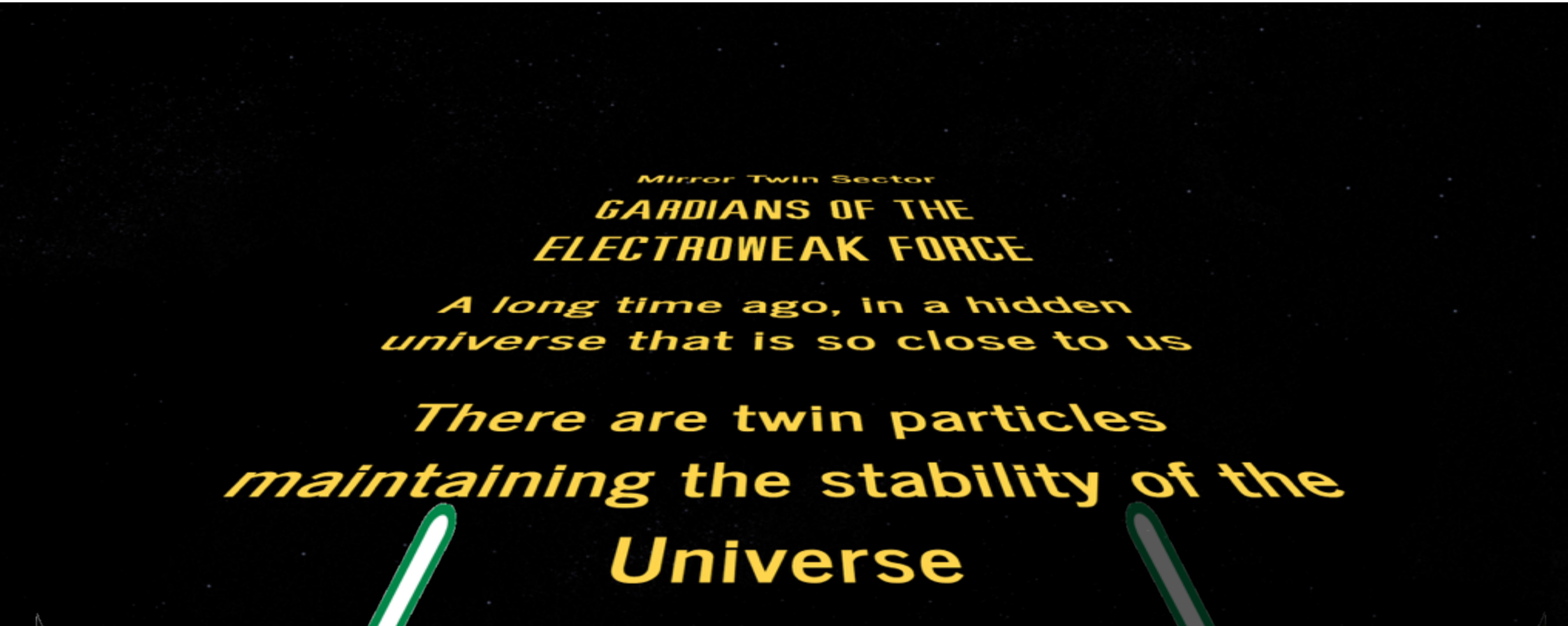


(since twin-W is heavier)

Chacko, Craig, Harnik (17')

Other process: Craig, Koren, Trott (17')

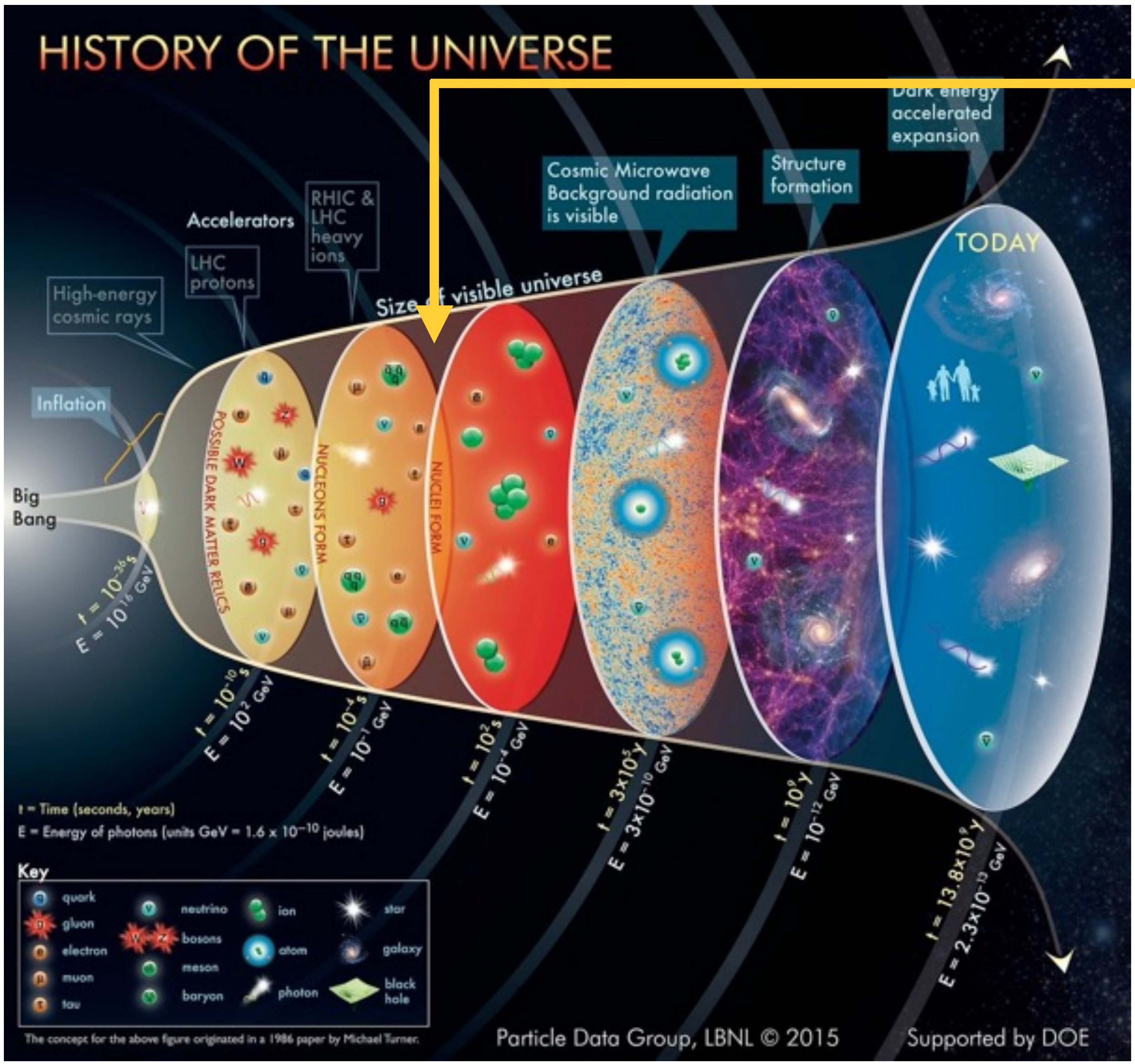
A long time ago, when T ~ MeV (~1 sec)



SM $(p,\, n,\, e,\, \gamma,\, \nu)$

Mirror $(\hat{p},\, \hat{n},\, \hat{e},\, \hat{\gamma},\, \hat{\nu})$

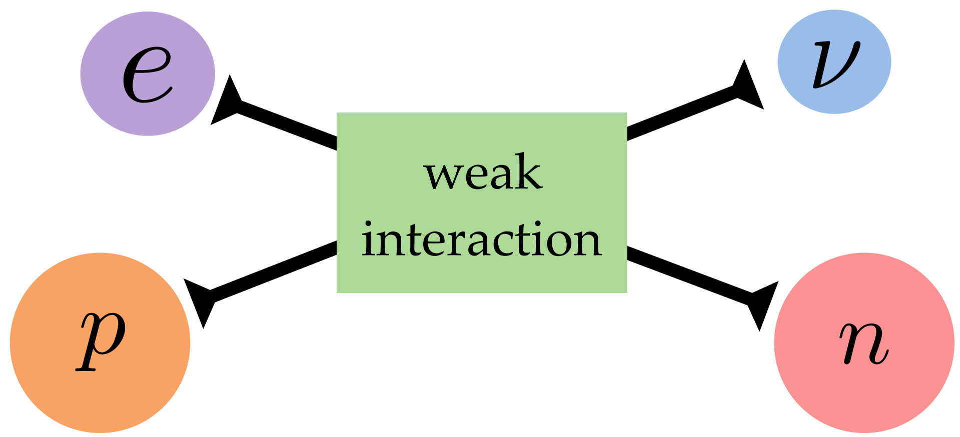
Big-bang Nucleosynthesis (~1 sec, T ~ MeV)



Nucleosynthesis

Two important BBN processes

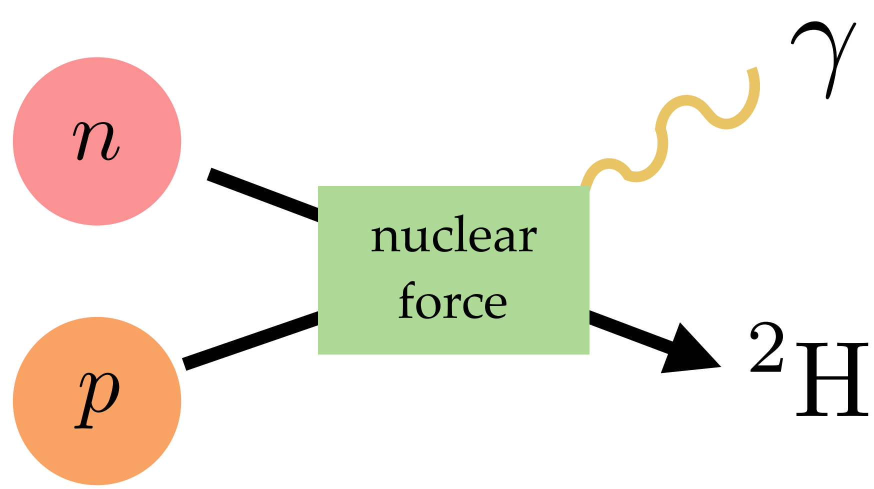
neutron / proton freeze out



twin neutron / proton mass splitting?

$$\left(\frac{n}{p}\right) \sim e^{-\frac{\Delta M_{np}}{T_F}}$$

Deuterium Bottleneck



twin deuterium binding energy?

Cosmology is very sensitive to twin baryon masses!

A rough estimation of twin baryon masses

twin neutron/proton mass splitting

$$\frac{m_{\hat{p}}}{m_p} \approx \frac{m_{\hat{n}}}{m_n} \approx \frac{\Lambda_{QCD_B}}{\Lambda_{QCD_A}} \approx 0.68 + 0.41 \log(1.32 + v_B/v_A)$$

from RGE

twin deuterium binding energy

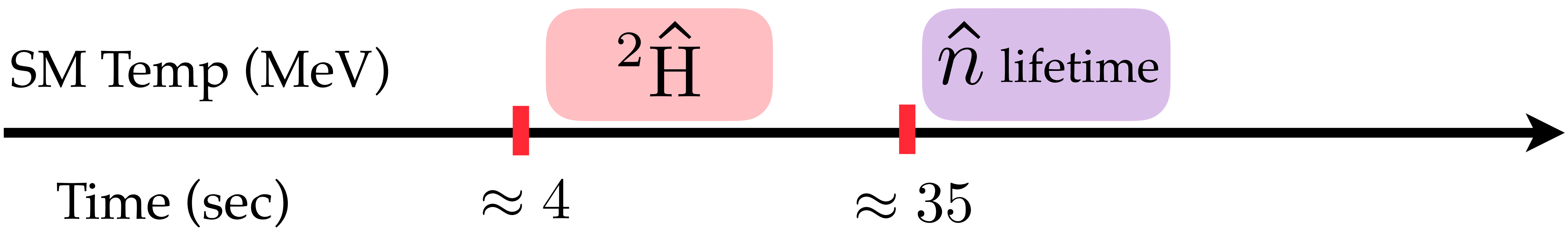
$$\frac{\Delta M_{\hat{n}\hat{p}}}{\Delta M_{np}} \approx 1.68 v_B/v_A - 0.68, \qquad \Delta M_{np} = 1.29\,\mathrm{MeV}.$$

from lattice result, Borsanyi et al. (2014)

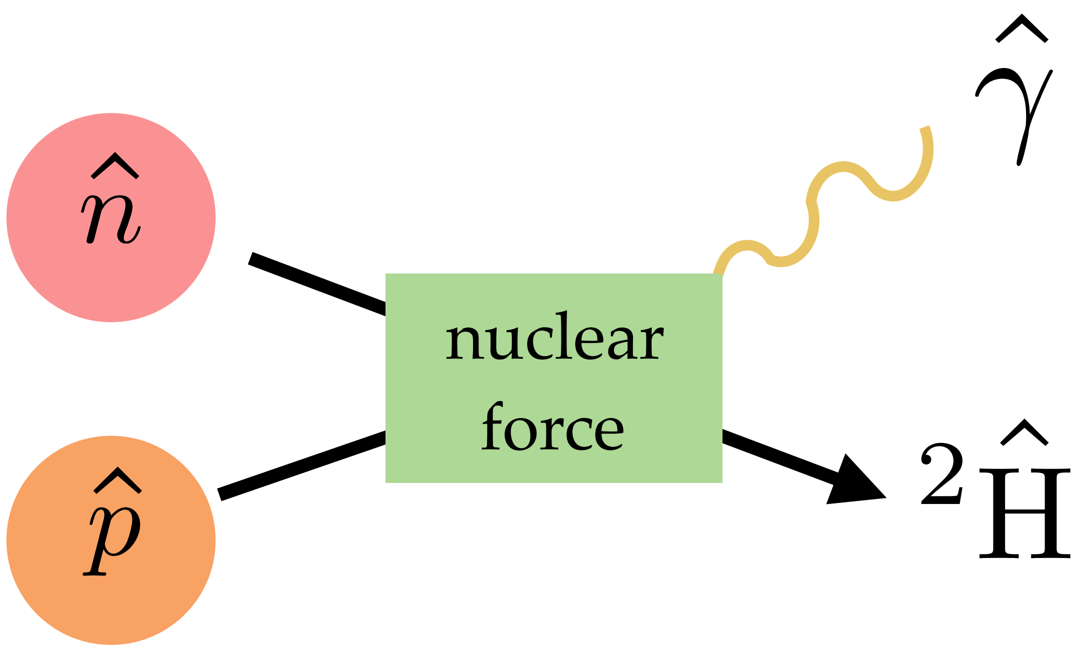
For $v_B/v_A = 3$, twin proton ~ 30% heavier than SM proton

twin neutron/proton splitting ~ 5.6 MeV

Mirror Deuterium Bottleneck



$$\frac{t_{^2\hat{\mathrm{H}}}}{t_{\hat{n}\ \mathrm{decay}}} \approx \frac{t_{^2\mathrm{H}}}{t_{n\ \mathrm{decay}}}$$

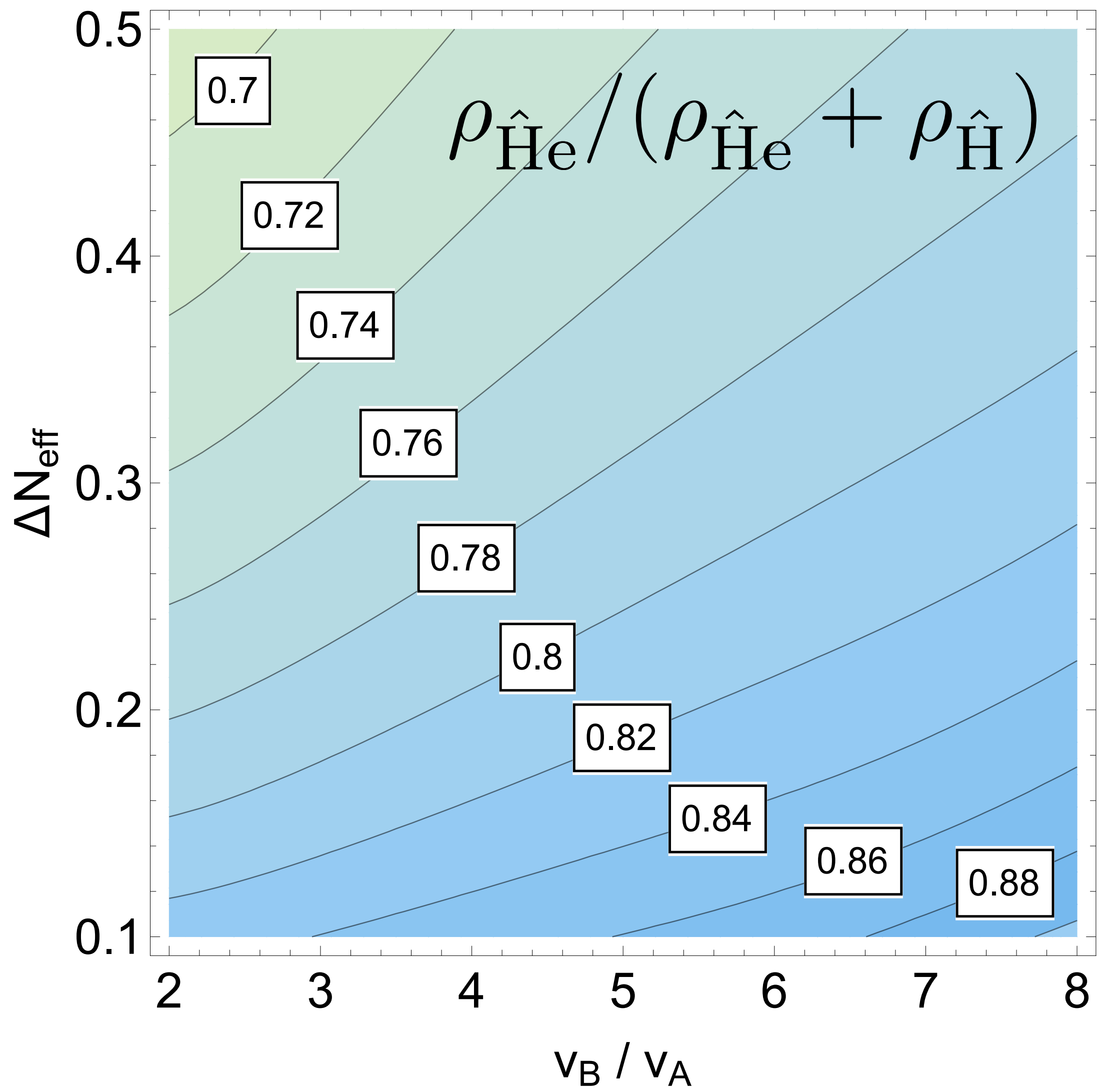


Mirror deuterium/helium can form

Estimate twin ^{2}H binding energy from lattice calculation

Orginos et al. (2015)

Mirror helium dominates twin matter density

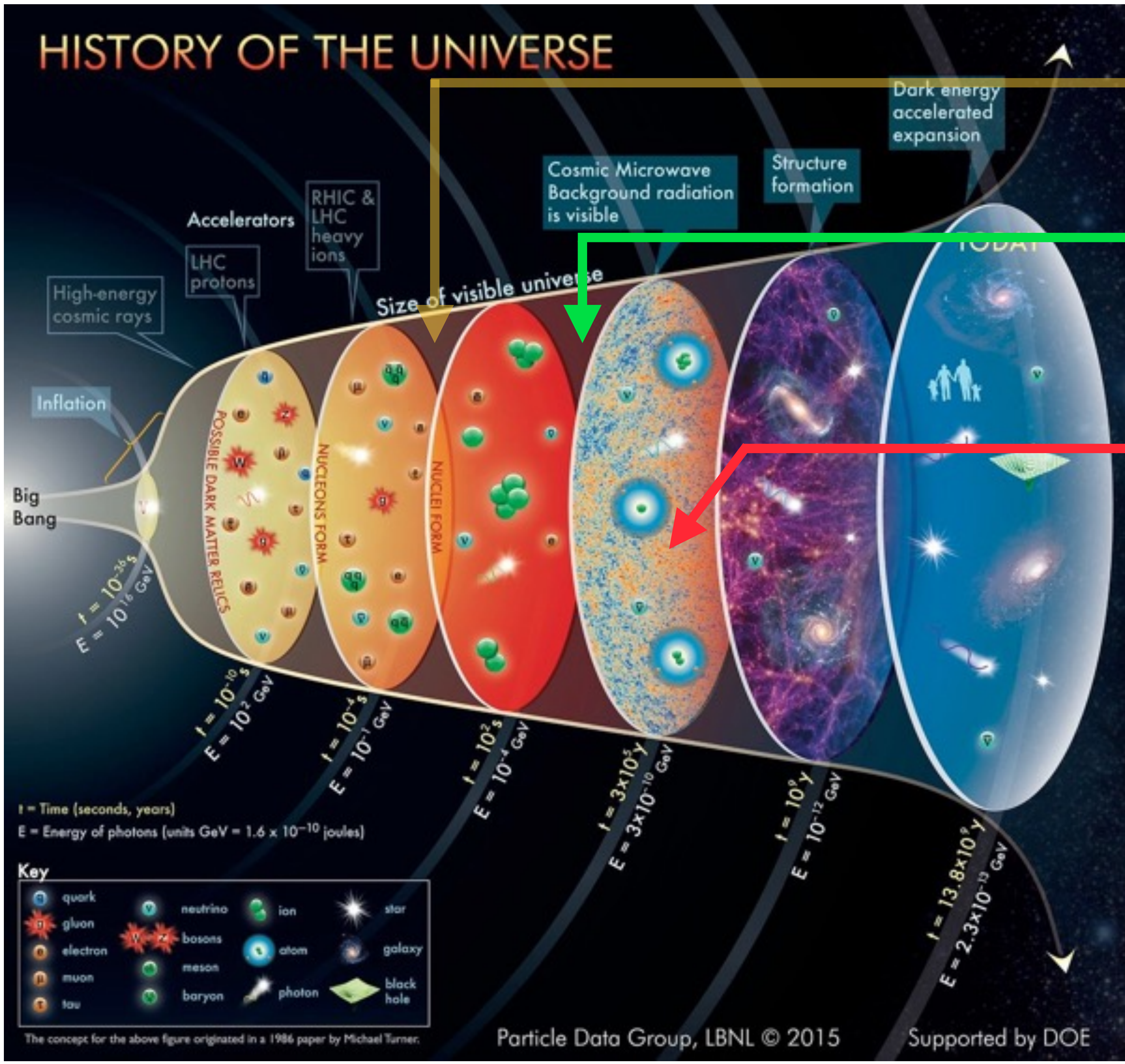


Mirror: ~ 75% mass is in **mirror He**

SM: ~ 75% mass is in **Hydrogen**

The result will determine the
Large Scale Structure of Universe

Era for the Large Scale Structure & CMB

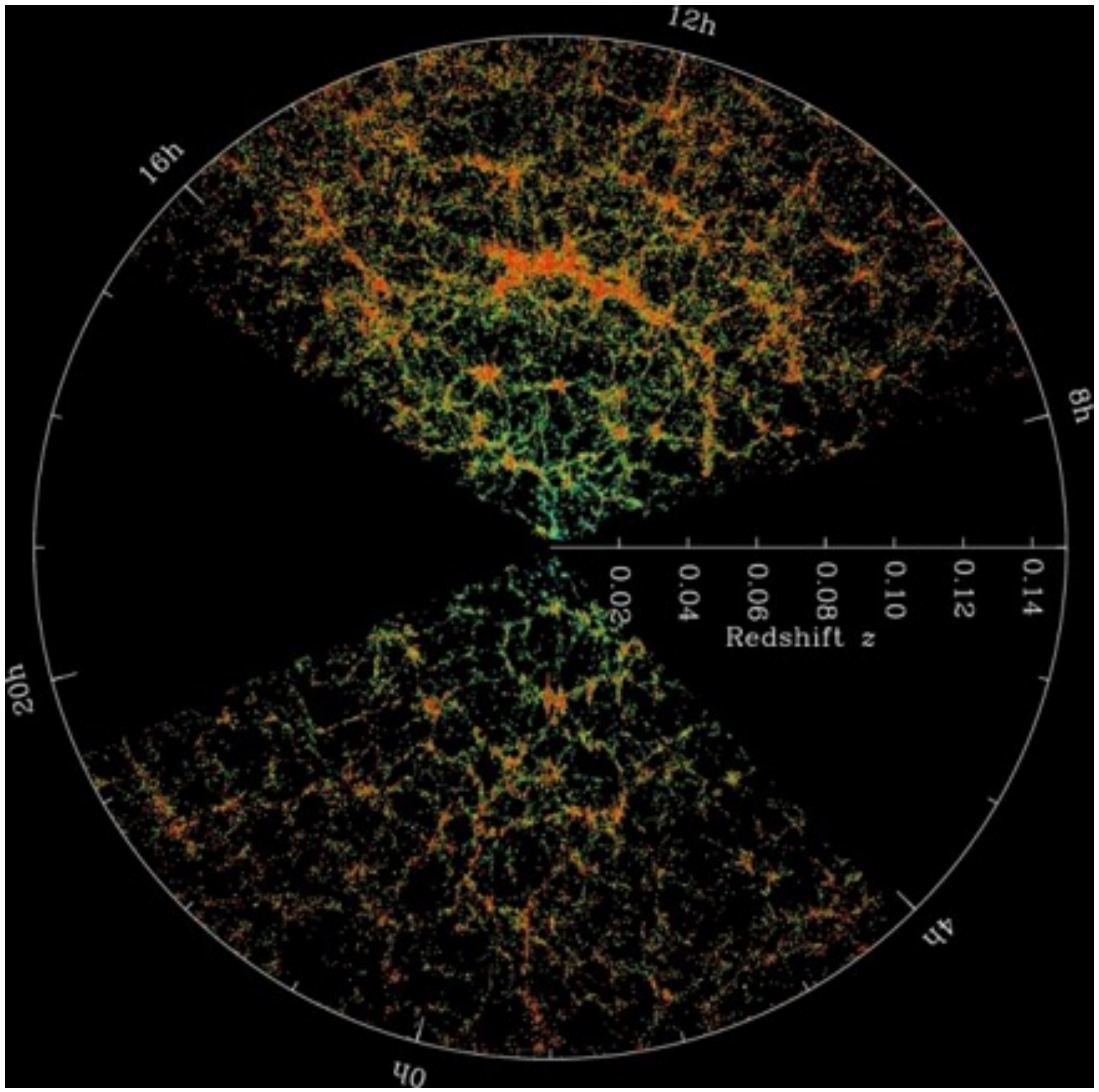


Nucleosynthesis

Matter-radiation equilibrium

Large Scale Structure

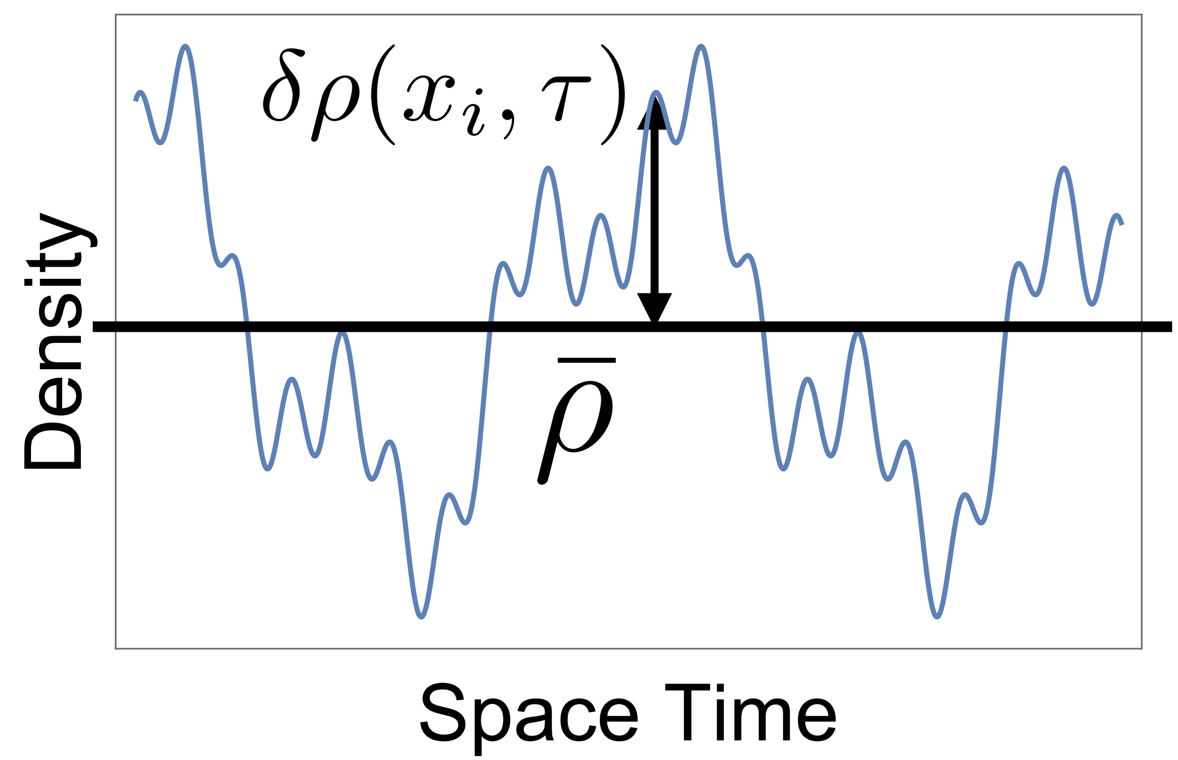
Large Scale Structure of the Universe



SDSS

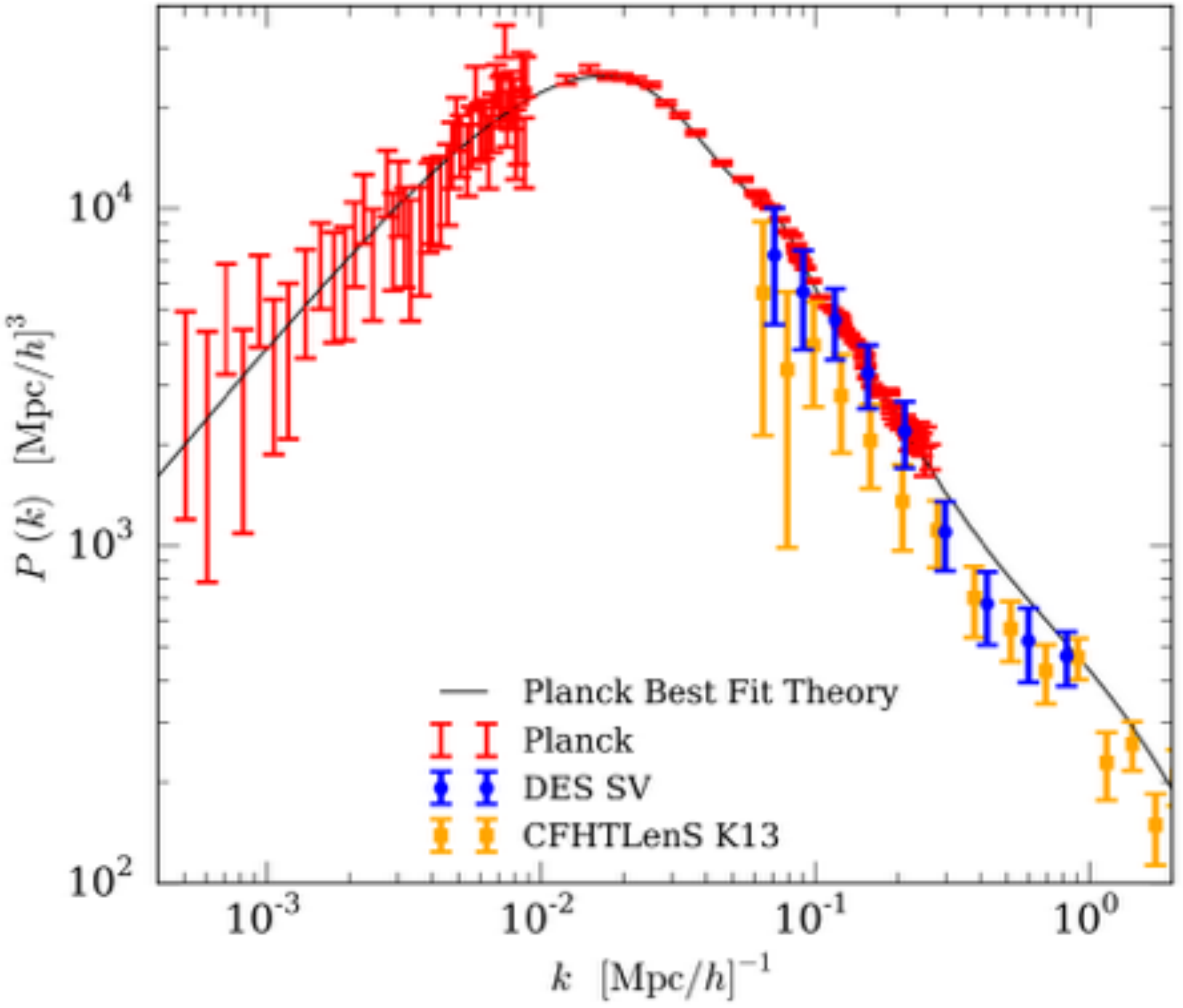
Density Perturbation

$$\delta_i \equiv \frac{\delta\rho_i}{\bar{\rho}_i} \quad i = \mathrm{DM},\ \gamma,\ b,\ \nu$$



Matter power spectrum of the Universe

$$P(k)_s \propto k^{-3} \langle \delta_s(k,a)^2 \rangle$$



DES: 1507.05552

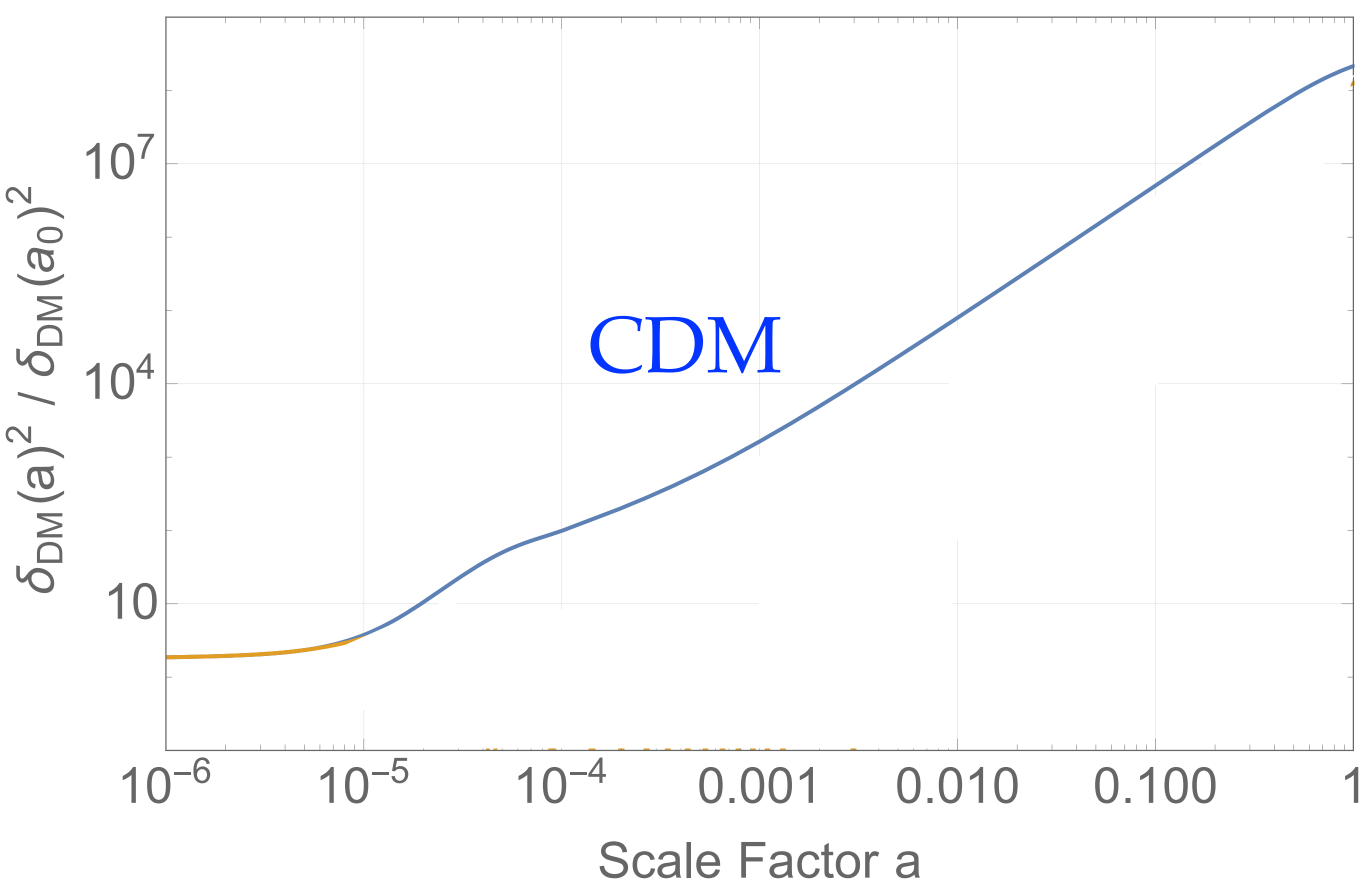
Density Perturbation

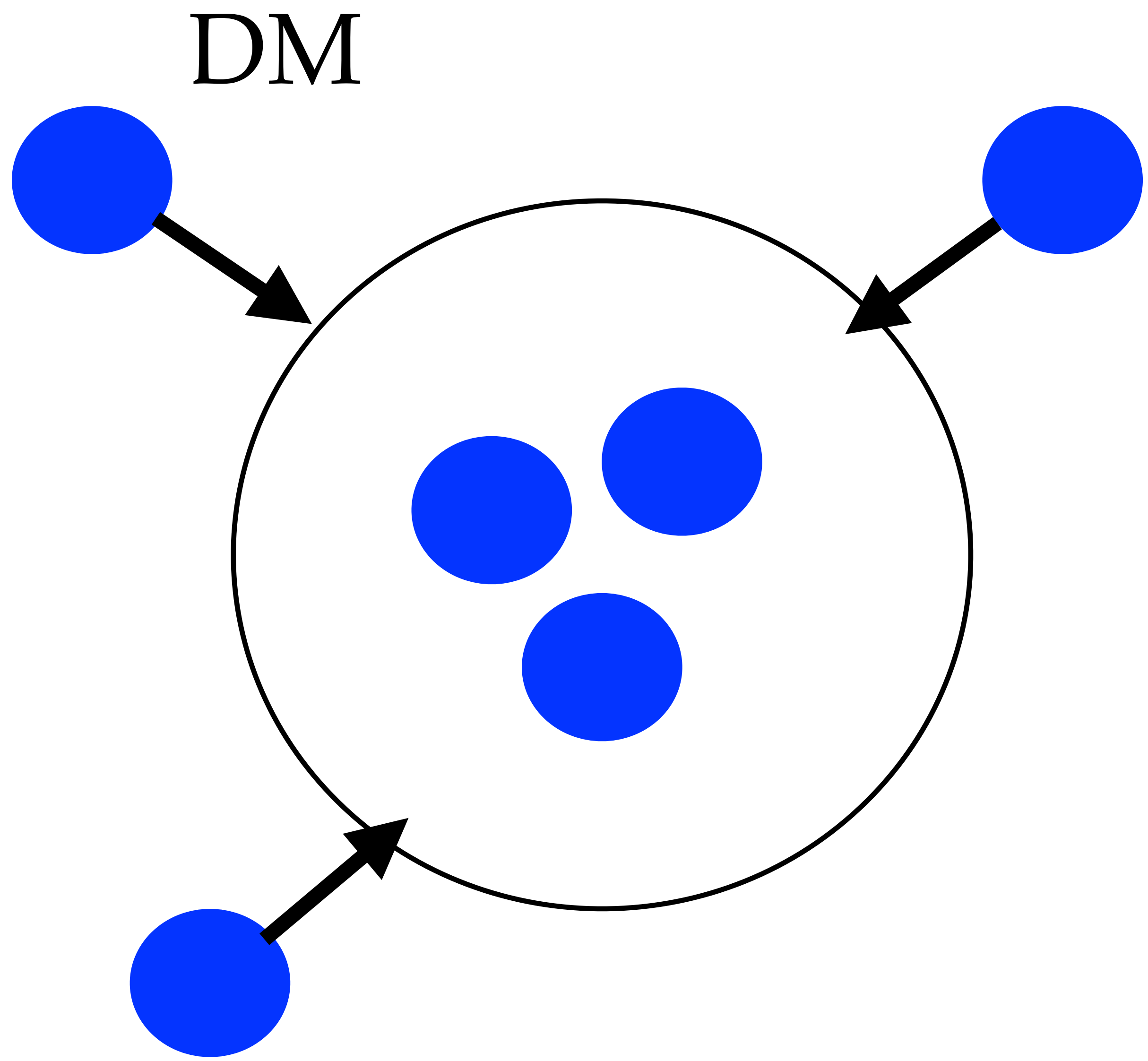
$$\delta_i \equiv \frac{\delta\rho_i}{\bar{\rho}_i} \qquad i = \mathrm{DM},\ \gamma,\ b,\ \nu$$

Fourier transform into frequency modes

$$\delta_i(x,a) \to \delta_i(k,a)$$

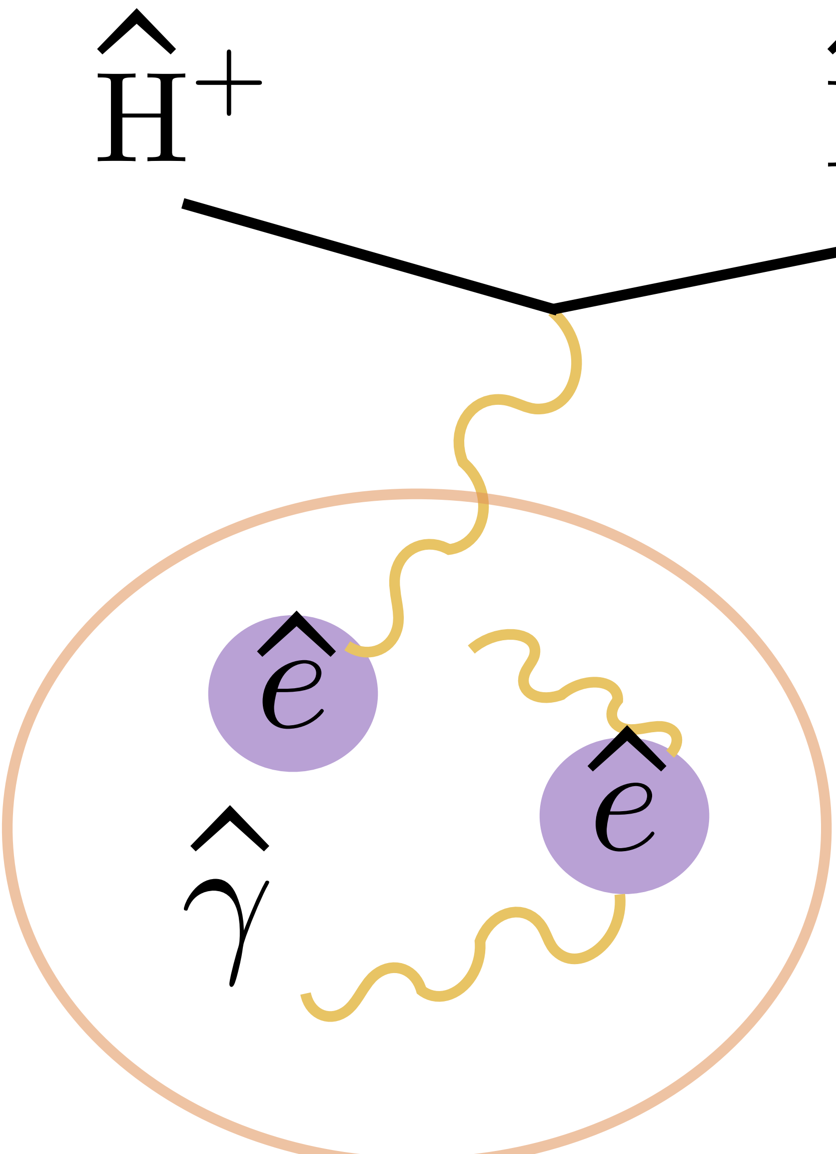
Structure formation of collision-less DM



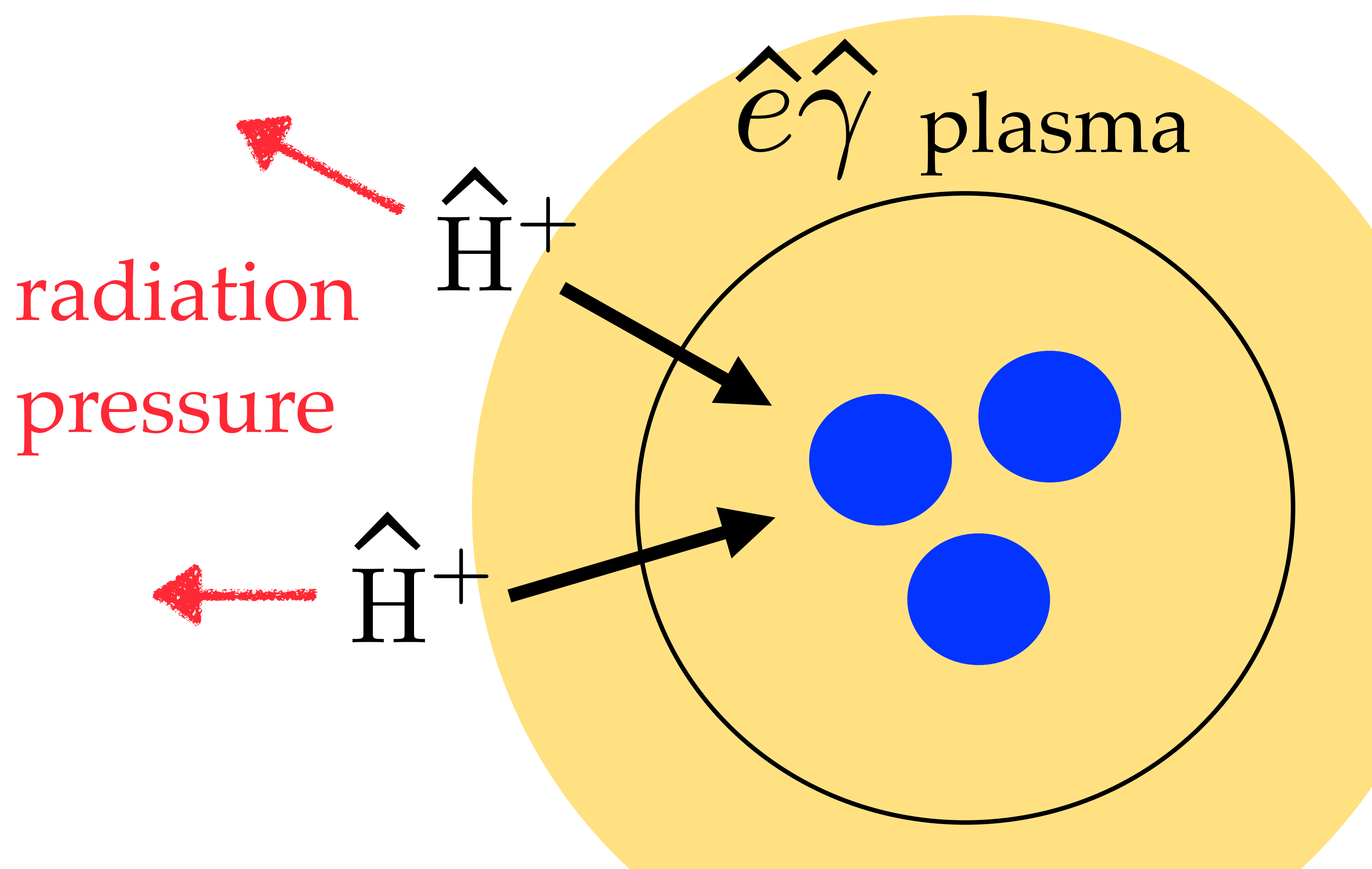


~ linear growth in matter-domination era

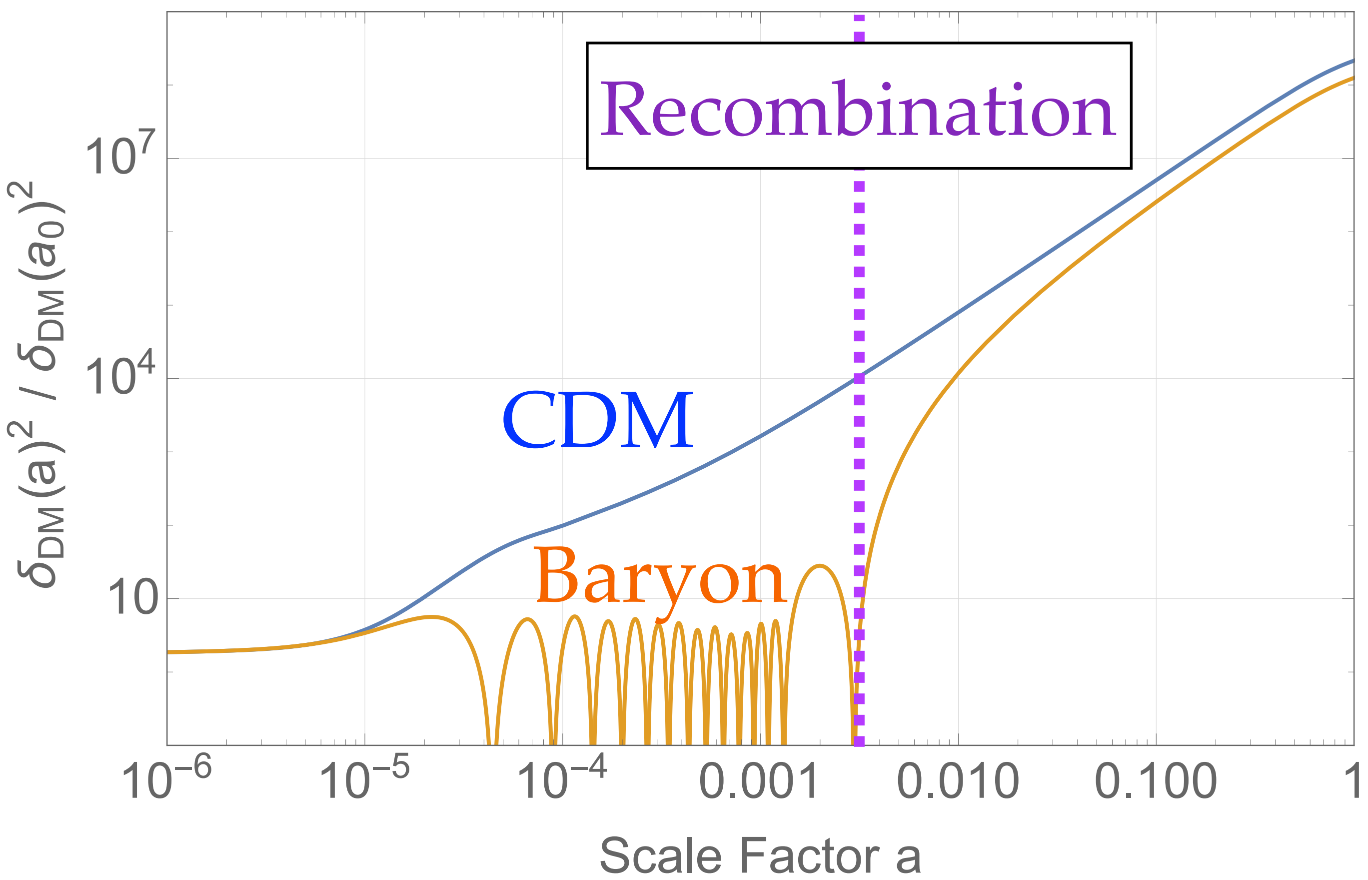
Structure formation of mirror baryons



Scattering forbids mirror baryons to form structure



Twin baryon acoustic oscillations suppress DM density perturbation



Mirror baryon cannot be all of the DM!

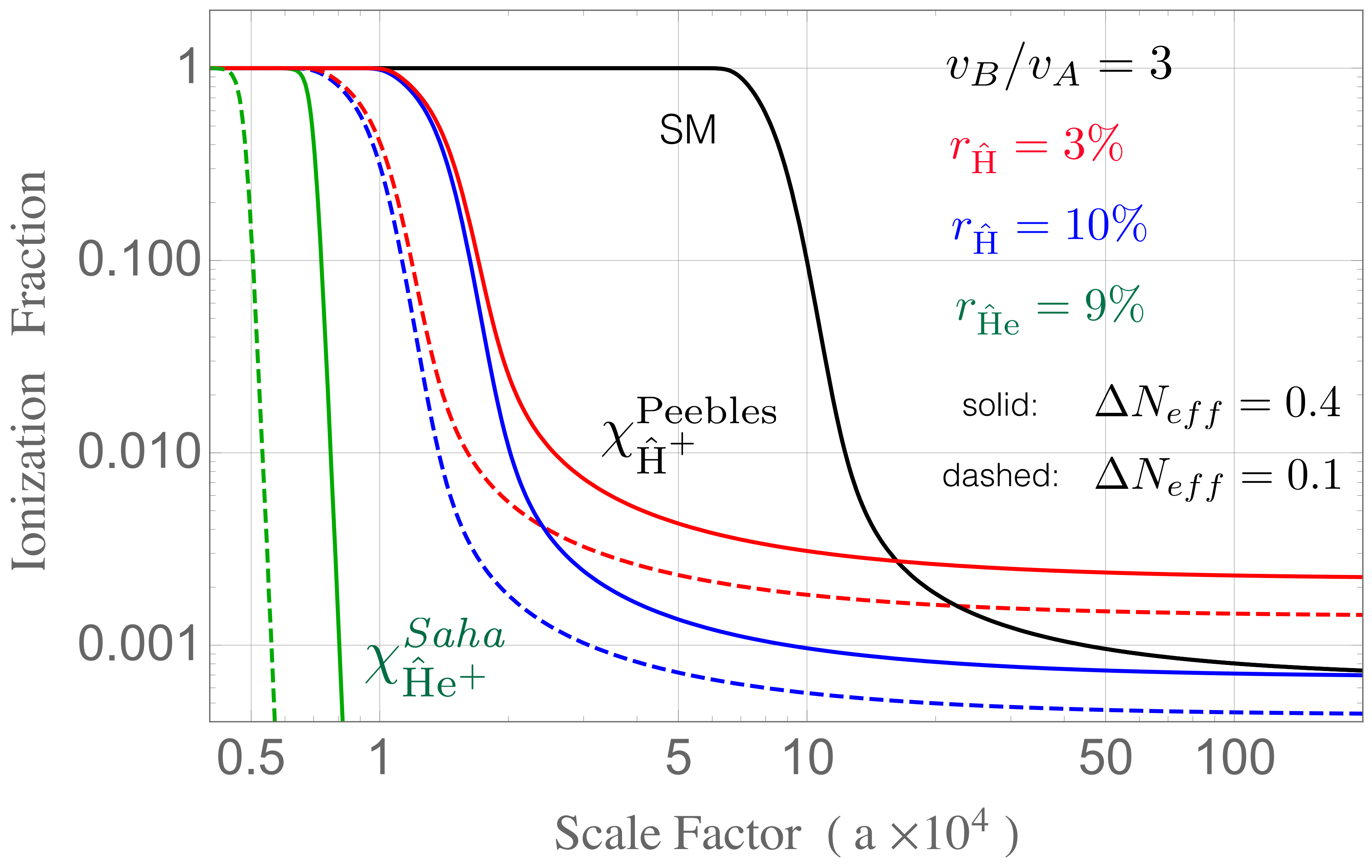
DM

CDM + $\hat{H}$ $\hat{H}e$

How much mirror baryon can we have?

The twin recombination

Similar to SM $\mathrm{H}^+ + e^- \to \mathrm{H}^0 + \gamma + (\gamma)$



Quantify the suppression of matter structure

$$\delta_{tot}(k) = \sum_{i=\chi,\hat{b},p} (\Omega_i/\Omega_m)\, \delta_i(k),$$

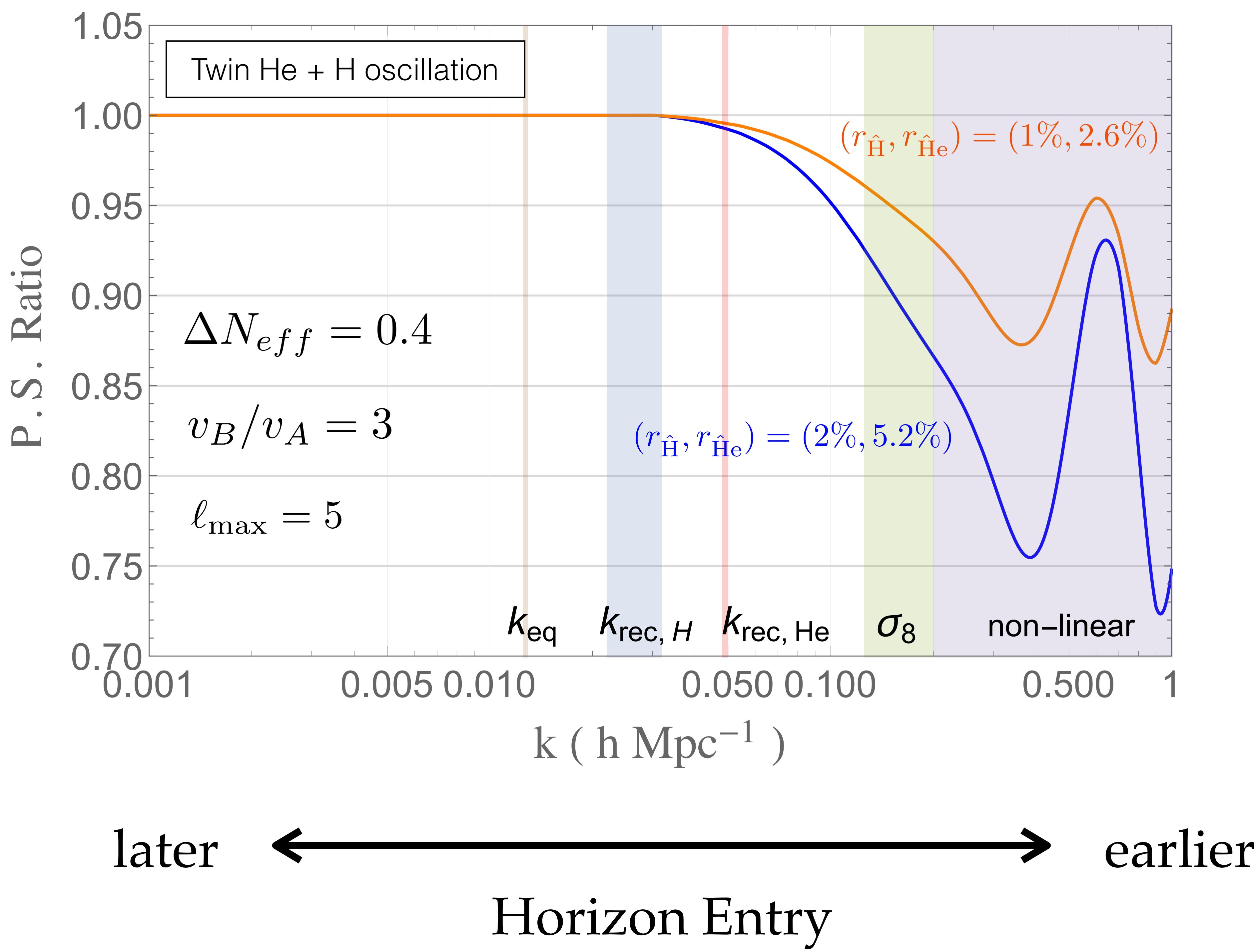
With mirror oscillations

$$\text{P.S. Ratio}(k) \equiv \frac{\delta^2_{tot}(k)\Big|_{\Lambda\text{CDM+MTH}}}{\delta^2_{tot}(k)\Big|_{\Lambda\text{CDM+DR}}}$$

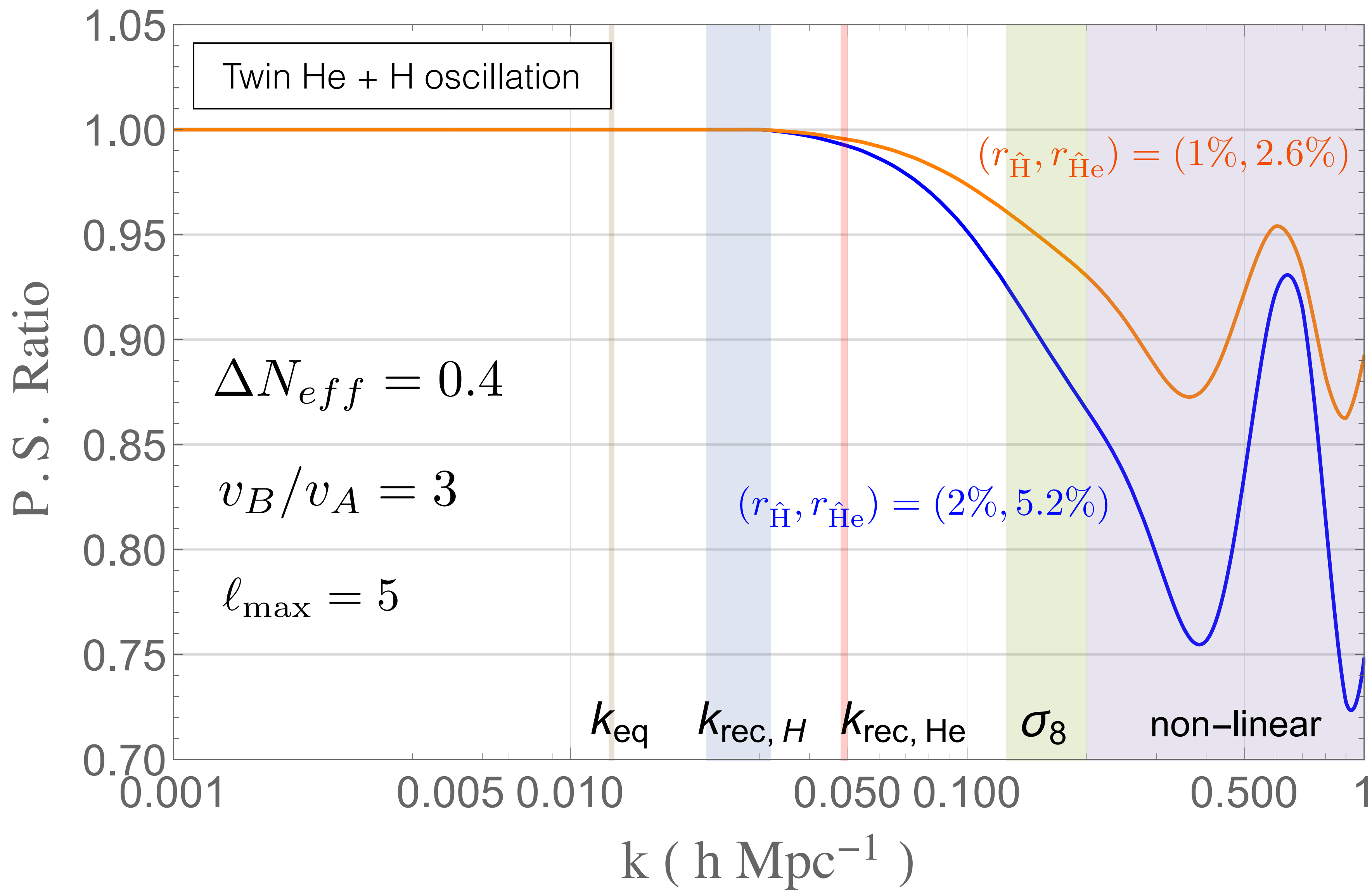
Without mirror oscillations

Twin acoustic oscillations → P.S. Ratio < 1

Suppression of the Large Scale Structure



Suppression of the Large Scale Structure

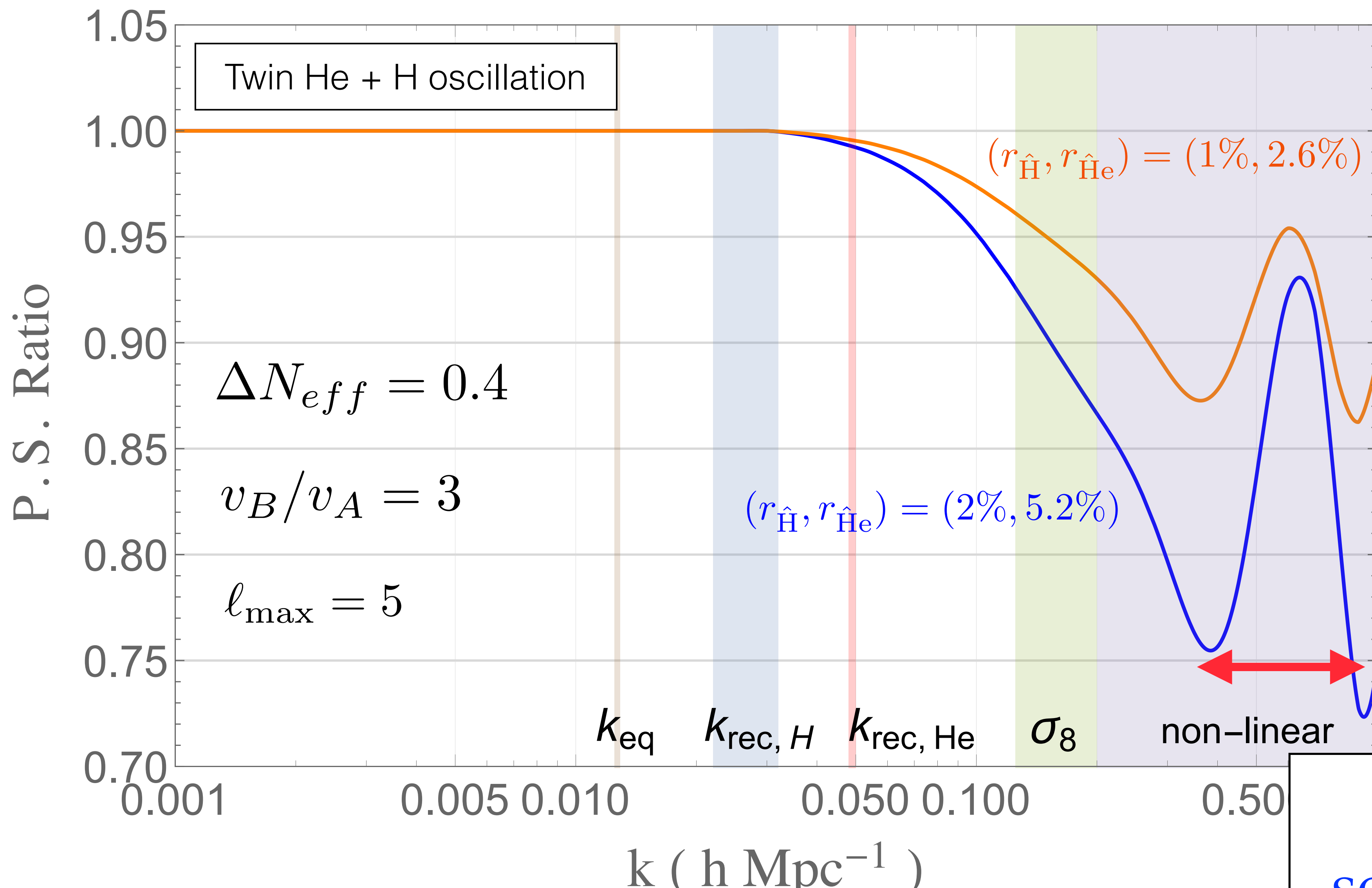


Suppression due to mirror oscillations

later ⟷ earlier

Horizon Entry

Oscillation pattern

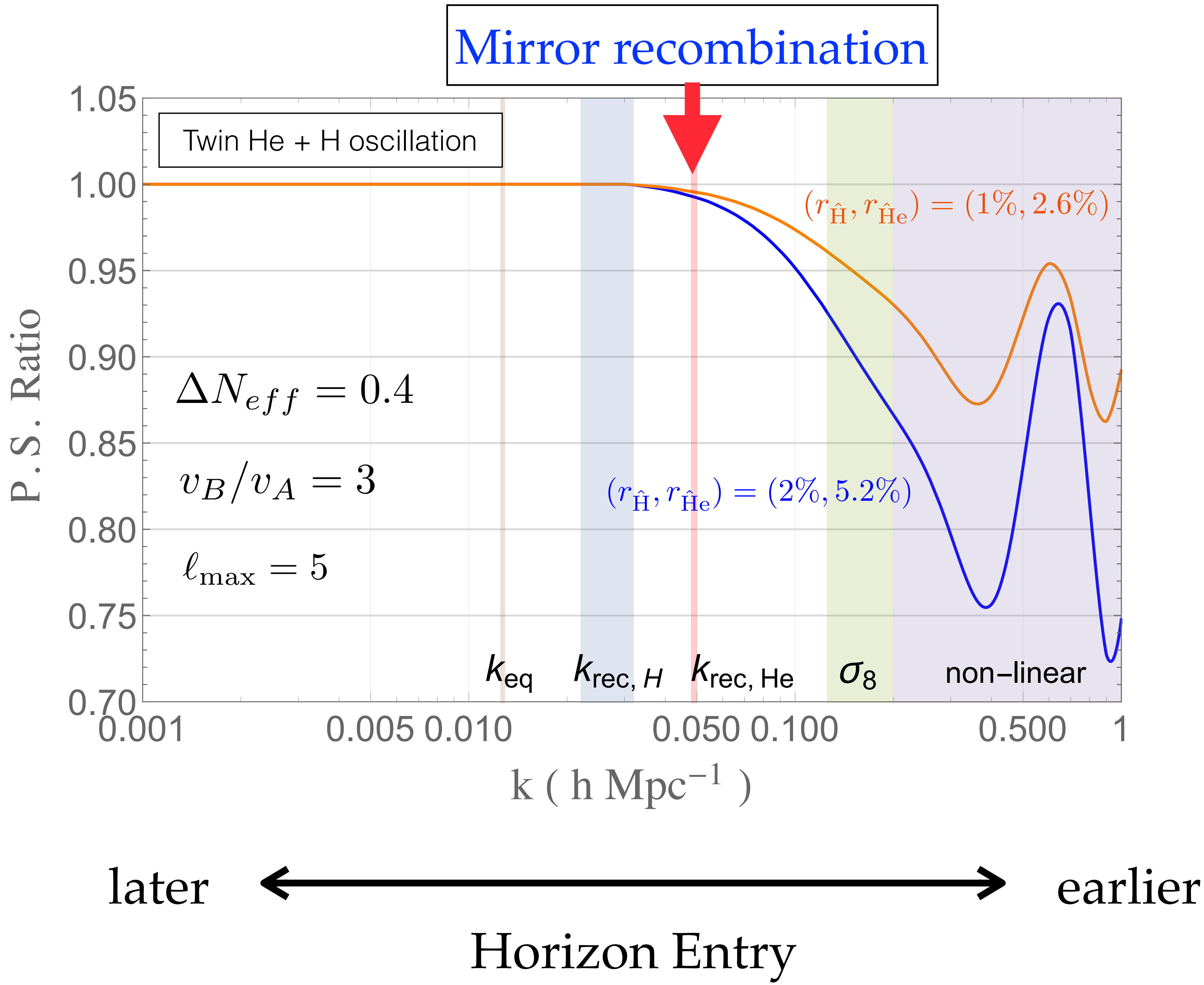


Inverse of sound horizon at recombination

later ⟷

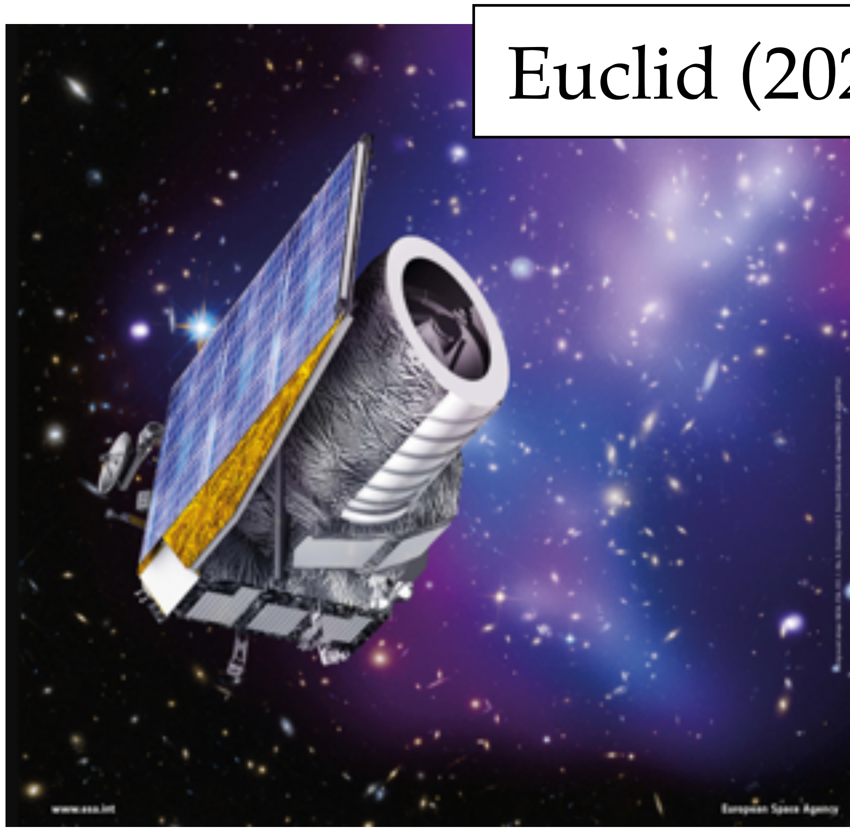
Horizon Entry

Behave as Cold DM after recombination

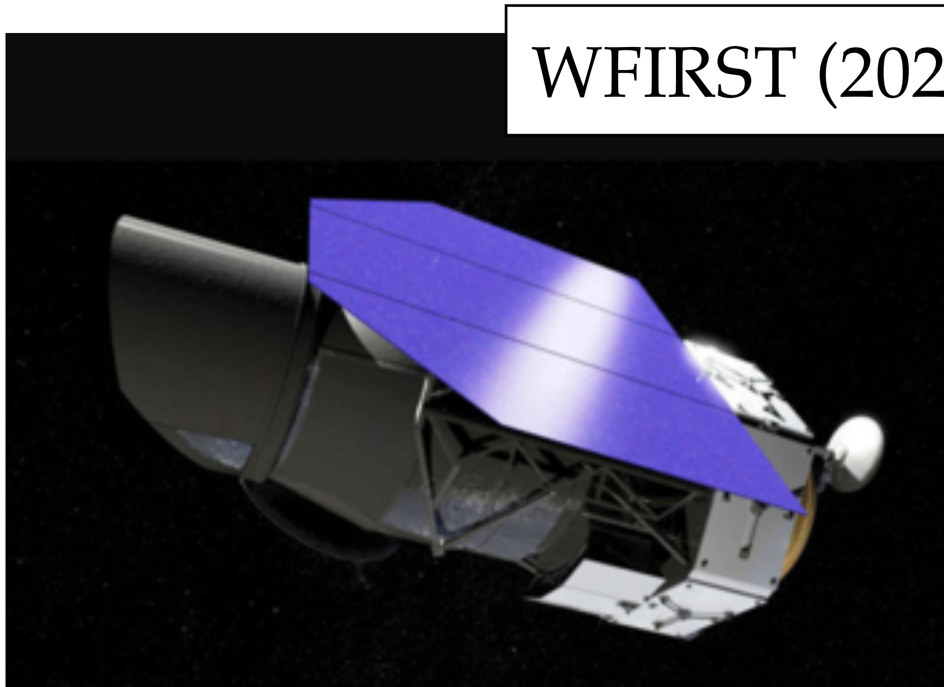


Precision measurement of the LSS

Euclid (2020)

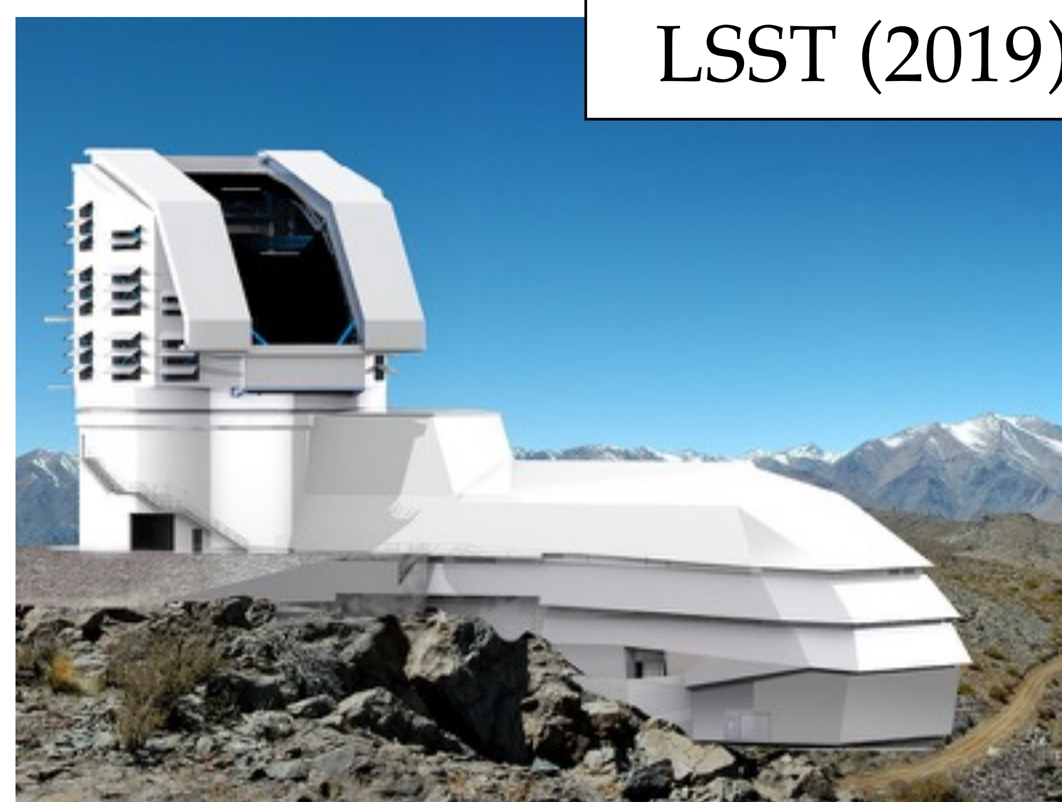


WFIRST (2020)

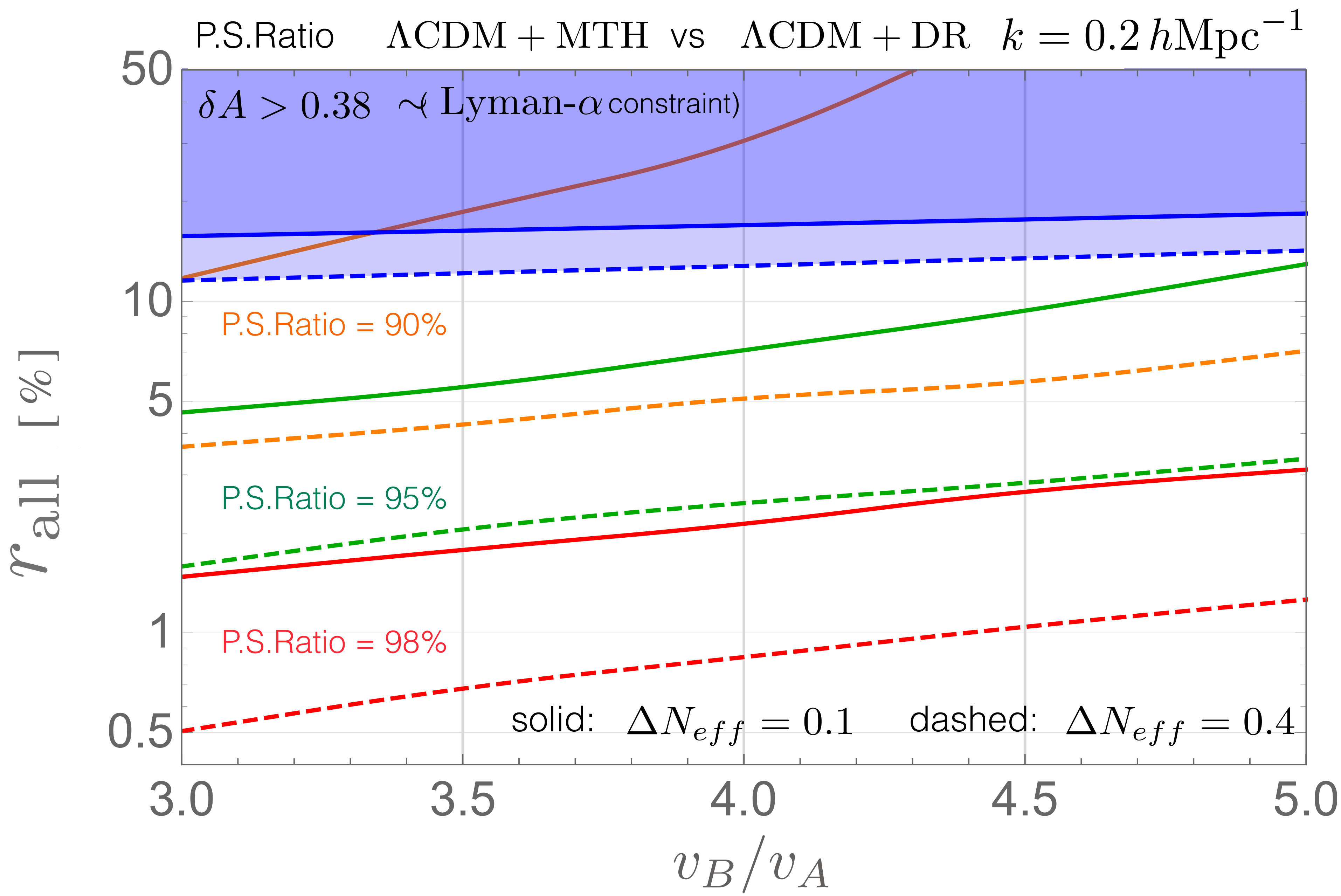


percent level precision
in ~ 10 years

LSST (2019)

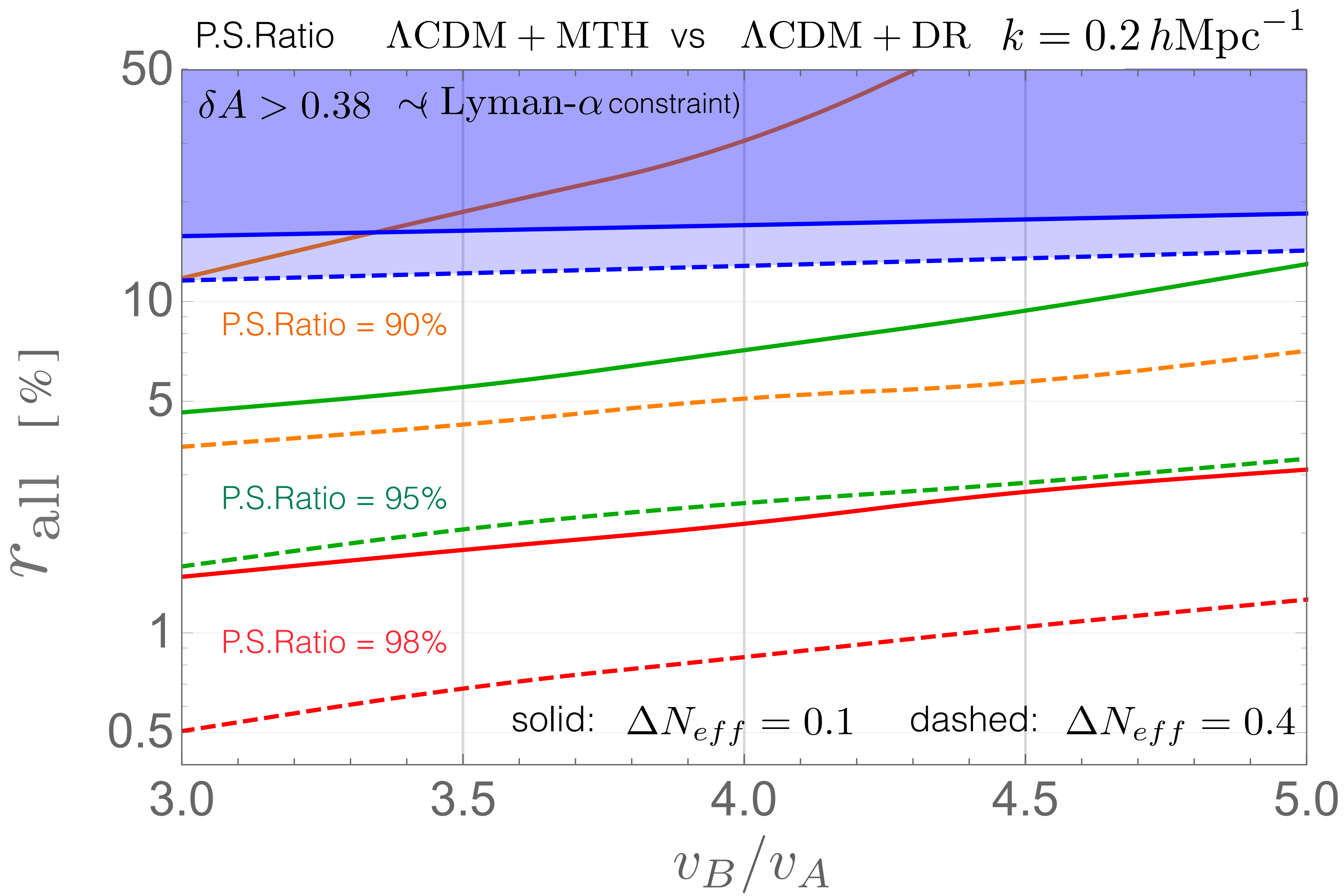


LSS constraint on mirror particle density



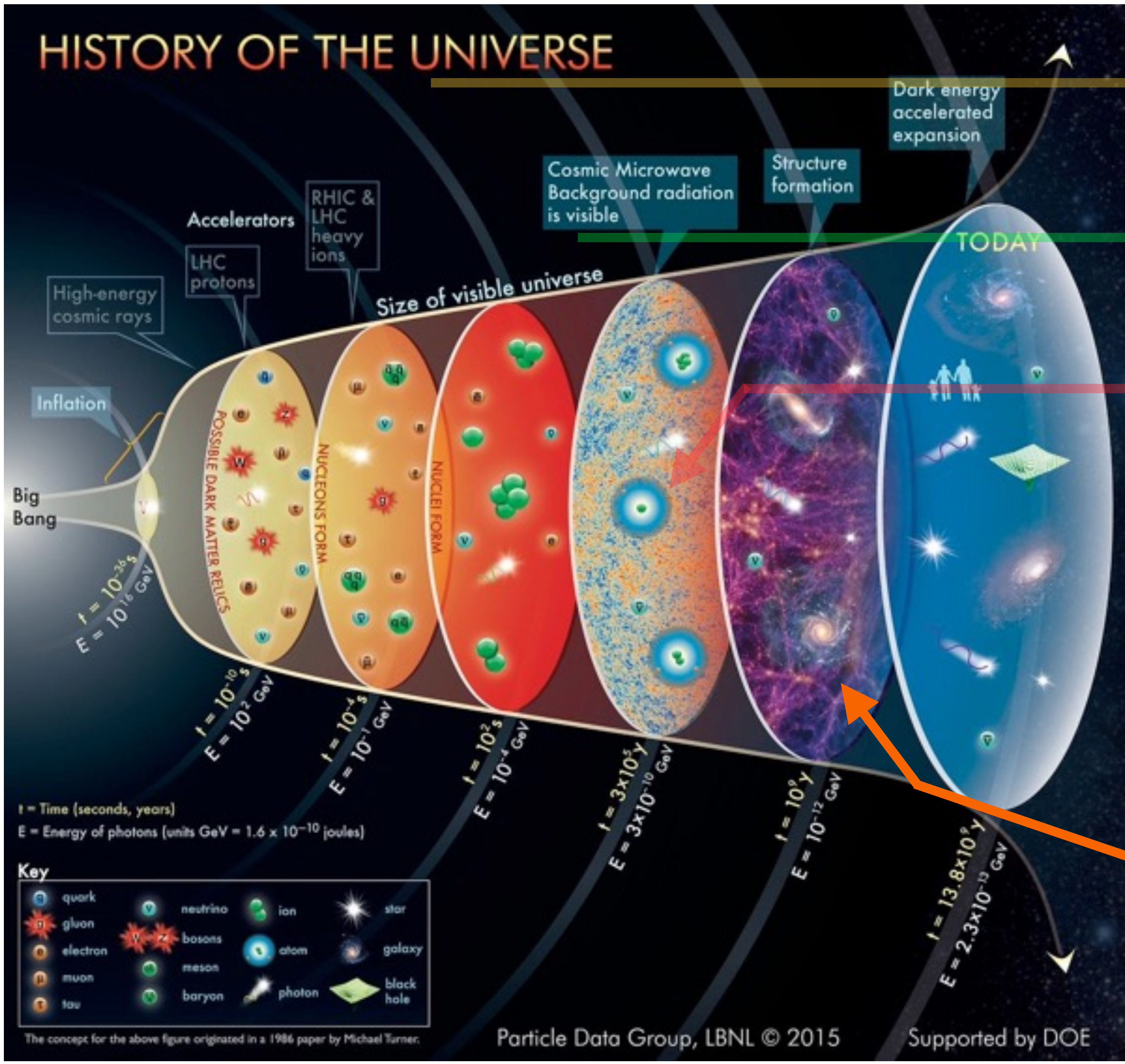
Current bound $\Omega_{\hat{\mathrm{H}}+\hat{\mathrm{He}}}/\Omega_{\mathrm{DM}} < 10\%$ Future bound, $< 1\ \%$

LSS constraint on mirror particle density



$\Omega_{\hat{\mathrm{H}}+\hat{\mathrm{He}}}/\Omega_{\mathrm{DM}} \simeq 5\%$ may address the $(\sigma_8,\ H_0)$ puzzle ?

Formation of the small scale structures



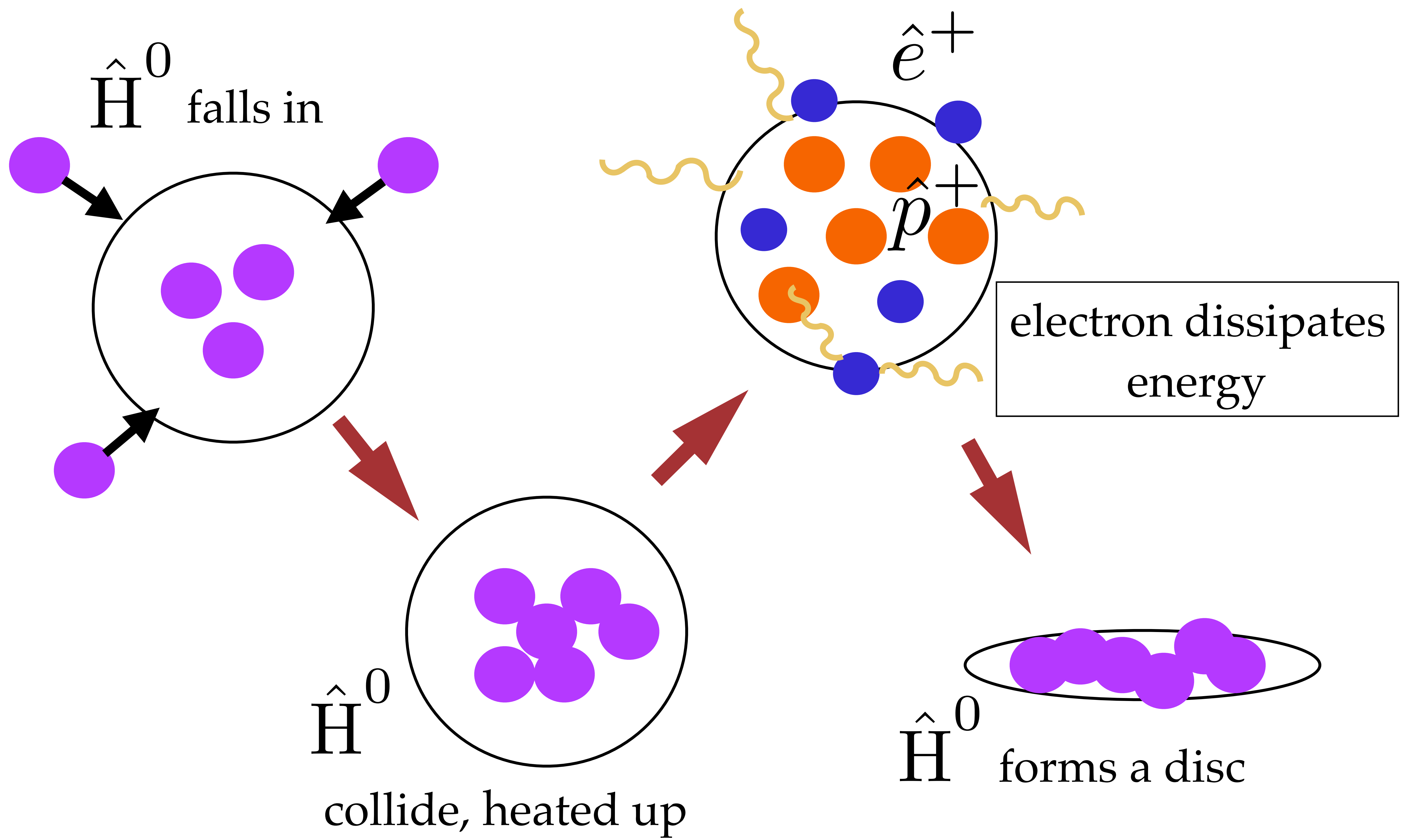
Nucleosynthesis
nuclei formation

Matter-radiation equilibrium
structure formation speeds up

Recombination
Ions become neutral atoms, baryon structure begins, CMB photons escape

Galaxy formation
Falling-in baryons scatter & re-ionized, later cools down forming a disc

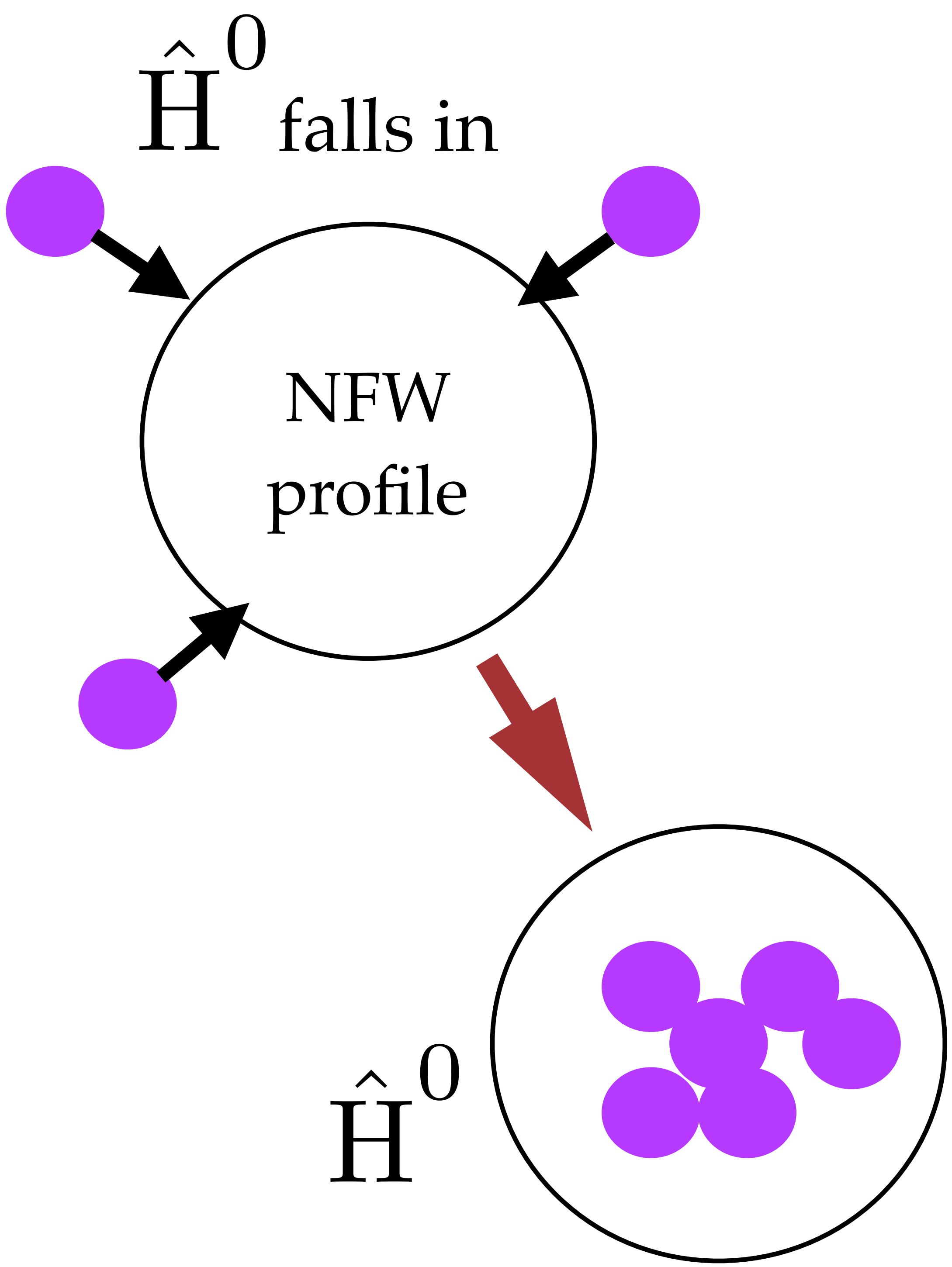
Re-ionization of twin atoms

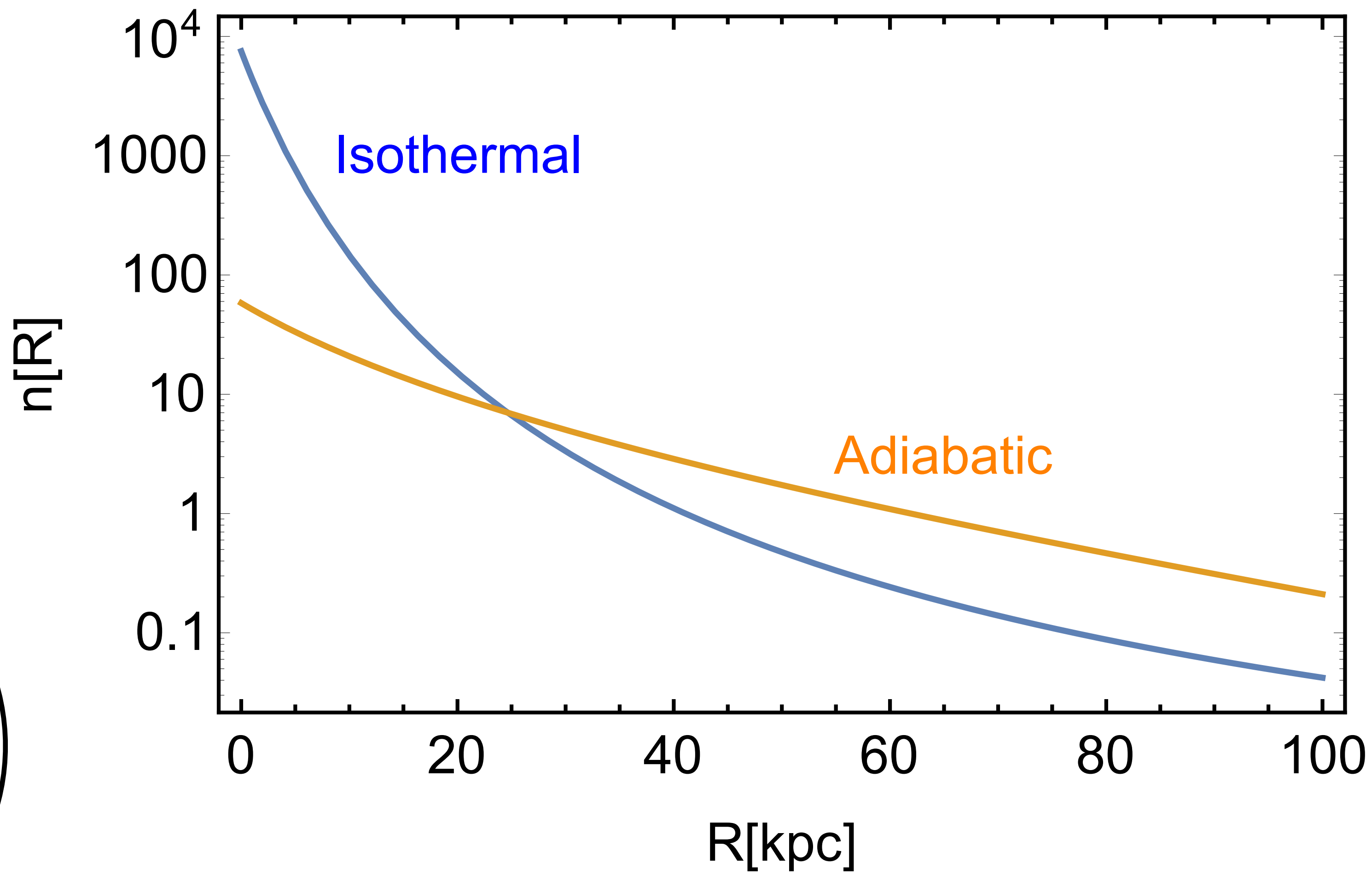


Twin baryon profile before cooling

Chacko, Curtin, Geller, YT (in preparation)

(preliminary)

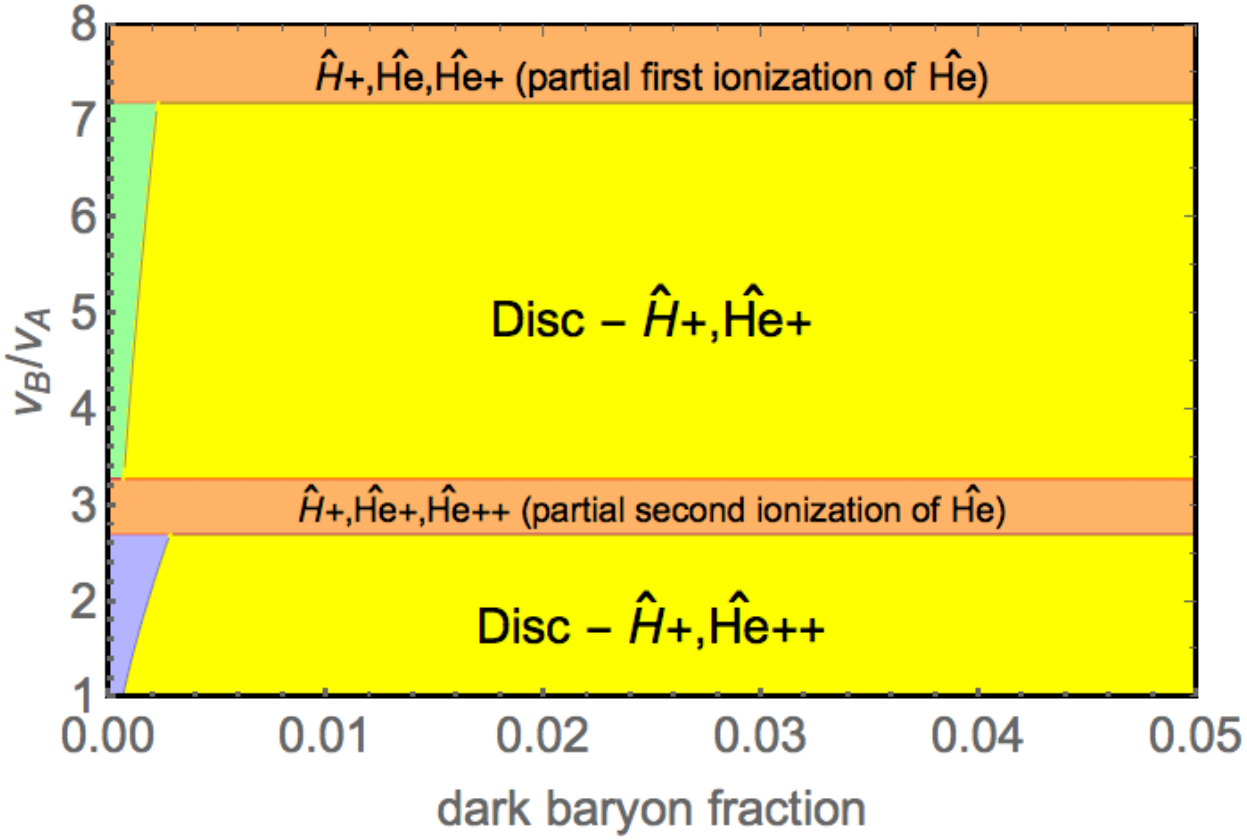




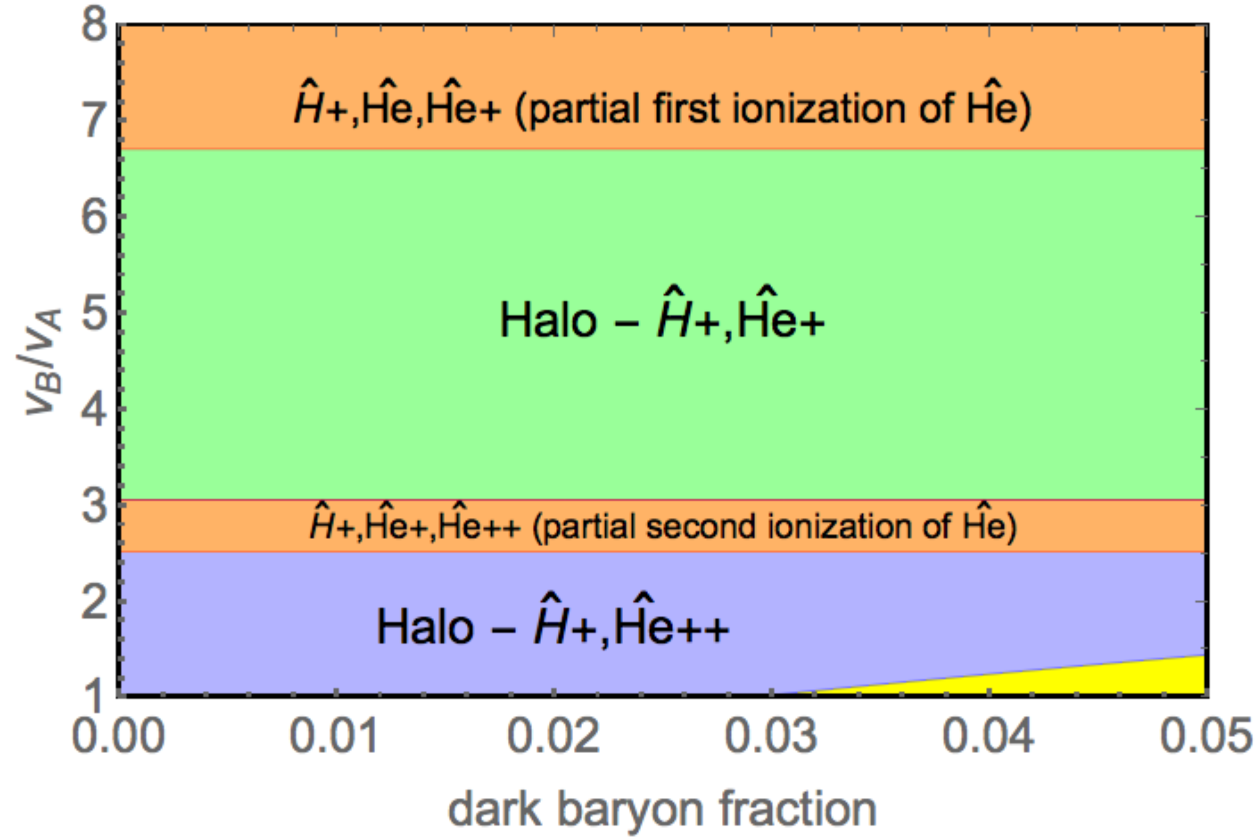
either adiabatic or isothermal distribution

Small scale structure, mirror disc? (preliminary)

Isothermal



Adiabatic



There is a chance to form a Twin disc

Gaia survey only allows 1% of DM forming a disc

More study is needed to see if twin disc can form

Schutz et. al. (2017)

Conclusion

- **Twin Higgs** scenarios solve **little hierarchy problem** with a dark sector that contains **dark QCD**

- We can use **cosmological data** or **Long-lived Particle searches** to examine the idea

- **Mirror Twin Higgs** model gives predictable signatures in Large Scale Structure, CMB, Small Scale Structure observations