Thermal QCD phase transition and its scaling window from Wilson twisted mass fermions

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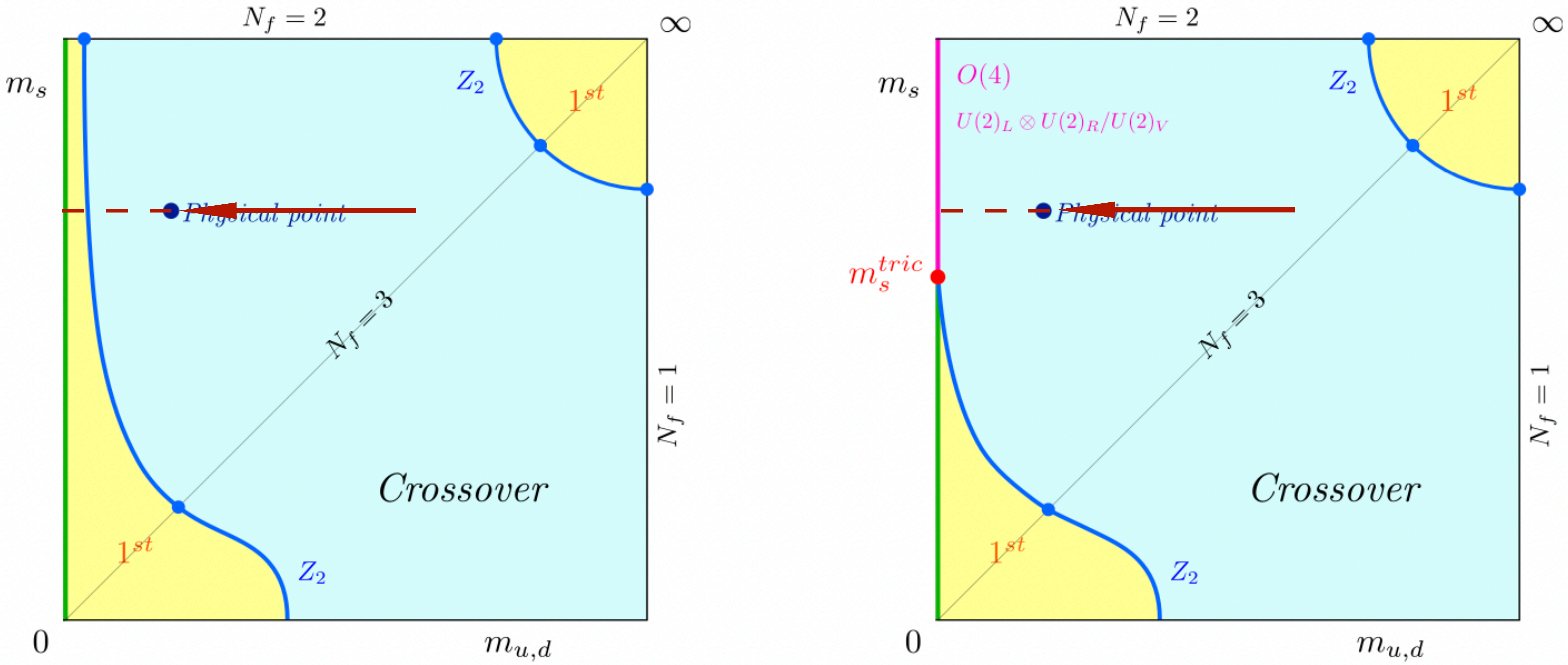
Lattice 2021

Columbia plot

From F. Cuteri



(a) First order scenario in the $m_s - m_{u,d}$ plane

(b) Second order scenario in the $m_s - m_{u,d}$ plane.

A couple of words about parameters

- $N_f = 2 + 1 + 1$ twisted mass Wilson fermions at maximal twist

- Fixed scale approach: $a =$ fixed, $T \leftrightarrow N_t$

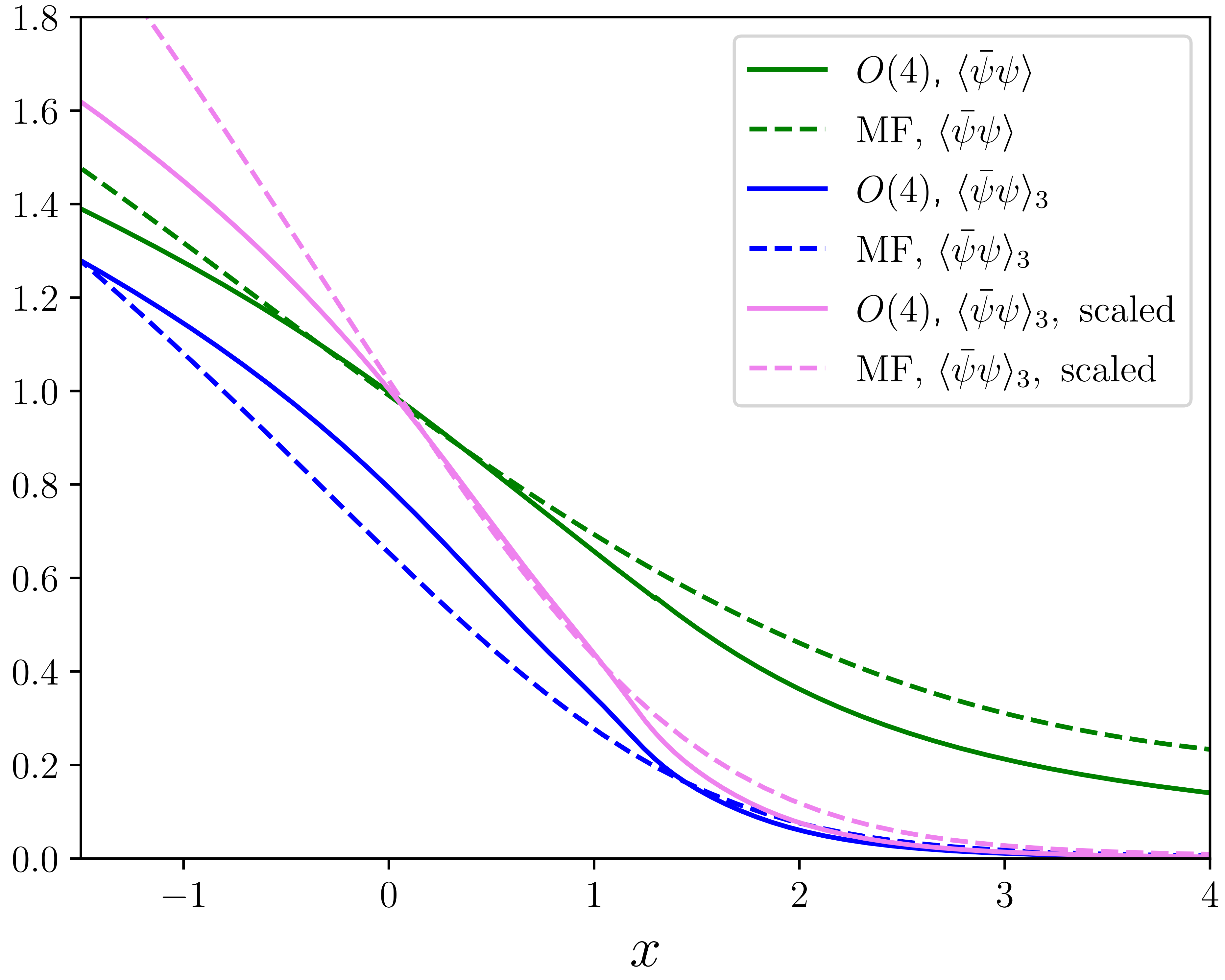
- Based on ETMC T=0 parameters

[C. Alexandrou et al., 2018]

m_π [MeV]	a [fm]
139.7(3)	0.0801(4)
225(5)	0.0619(18)
383(11)	0.0619(18)
376(14)	0.0815(30)

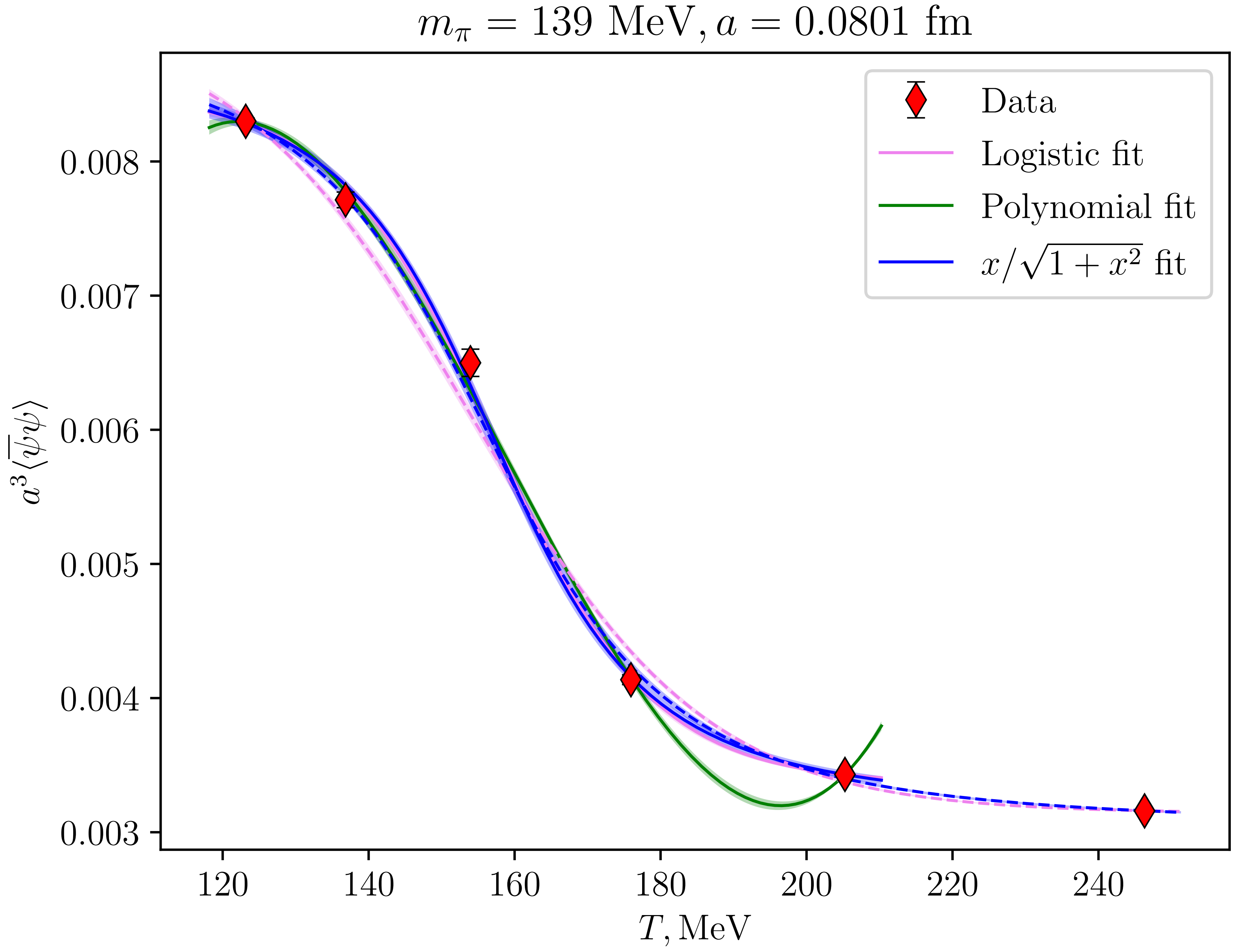
Observables and Equation of State

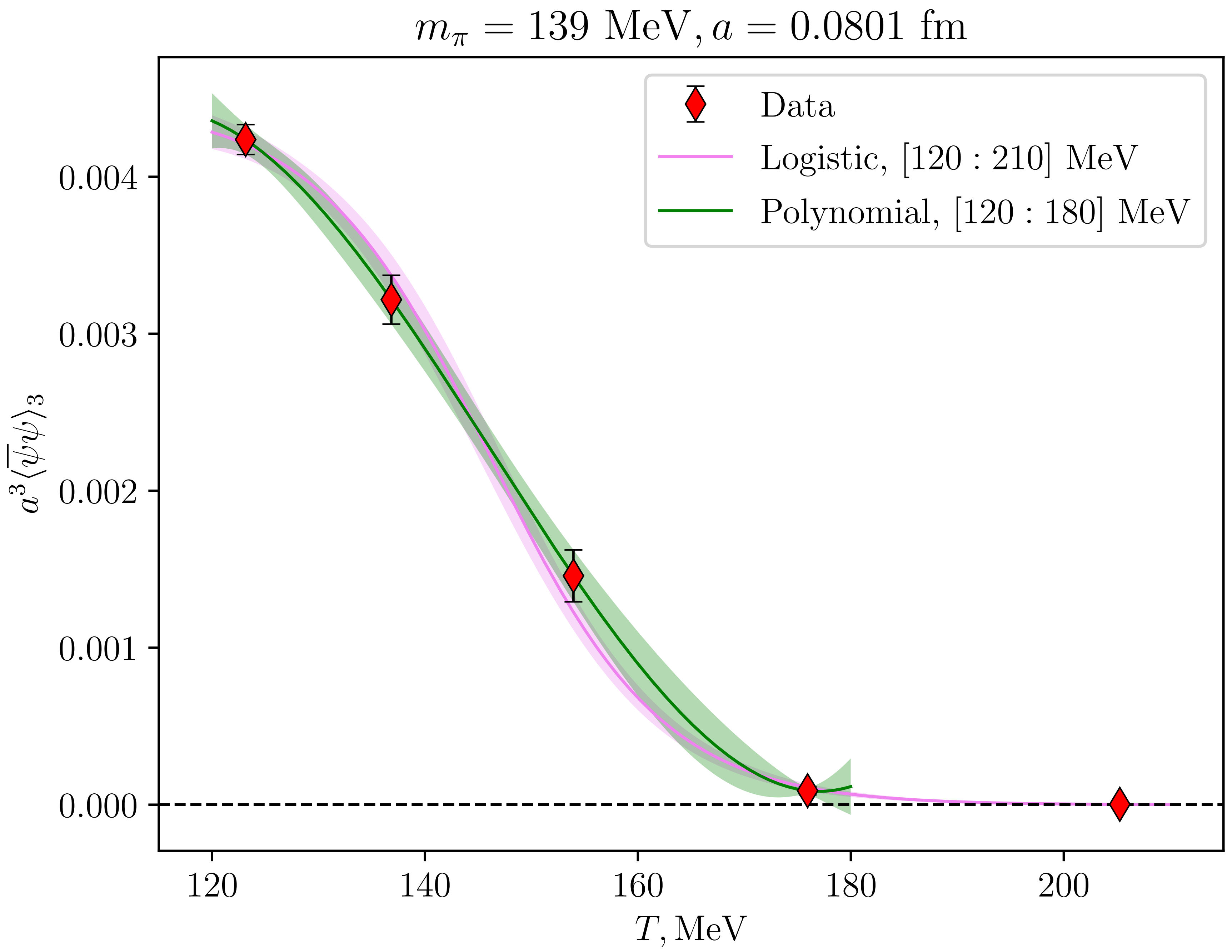
- Chiral condensate $\langle\bar{\psi}\psi\rangle$
- Chiral susceptibility $\chi = \partial\langle\bar{\psi}\psi\rangle/\partial m$
- New order parameter: $\langle\bar{\psi}\psi\rangle_3 = \langle\bar{\psi}\psi\rangle - m\chi$
    - ~m^3 (symmetric phase)
    - $1/a^2$ divergences cancel
    - $\langle\bar{\psi}\psi\rangle_3 \sim t^{-\gamma-2\beta\delta}$ vs $\langle\bar{\psi}\psi\rangle \sim t^{-\gamma}$ as $t \to \infty$

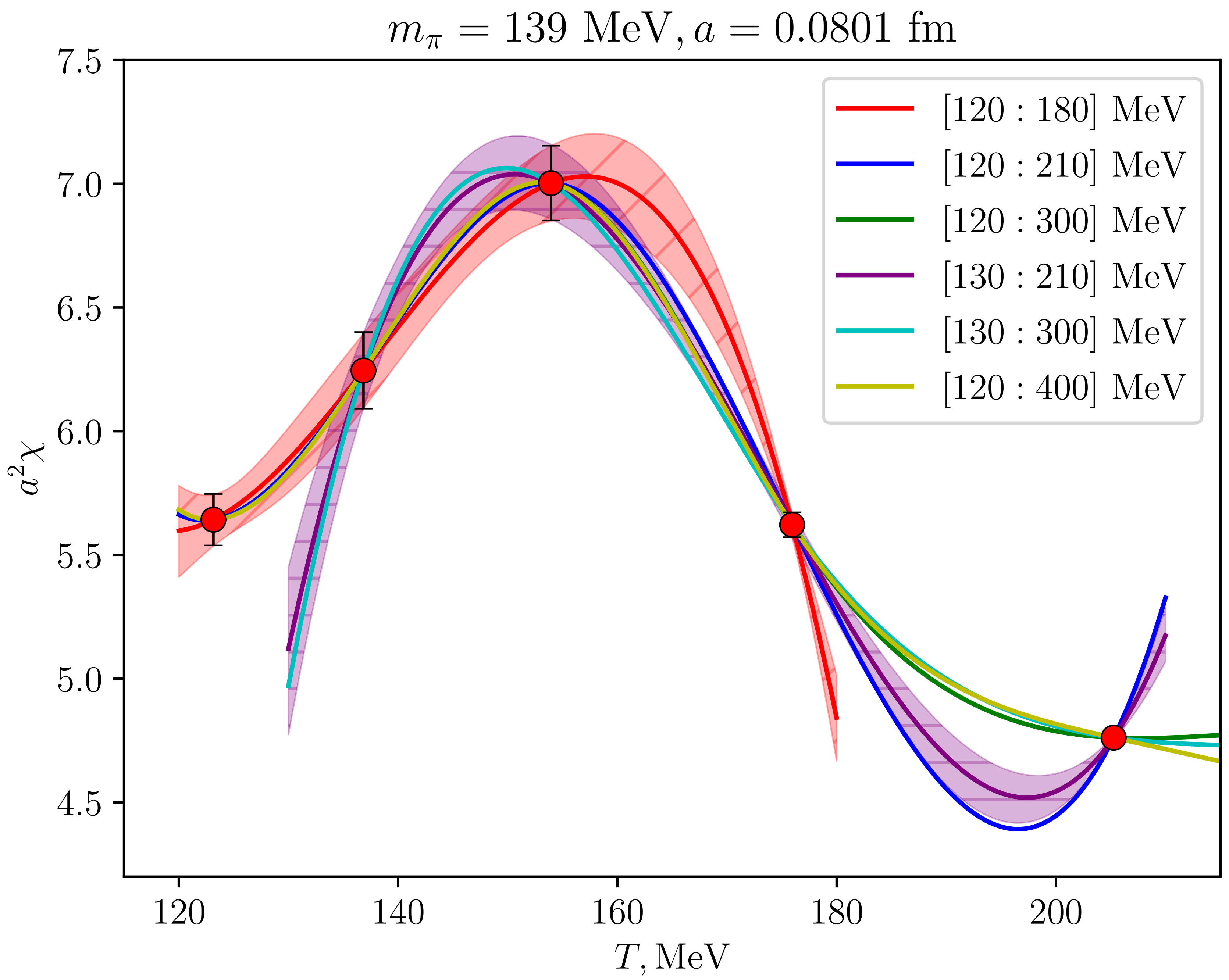


EoS: $$\frac{\langle\bar{\psi}\psi\rangle}{m^{1/\delta}} = f(x = t/m^{1/\beta\delta}) \longrightarrow \frac{\langle\bar{\psi}\psi\rangle_3}{m^{1/\delta}} = f(x)(1 - 1/\delta) + \frac{x}{\beta\delta}f'(x)$$

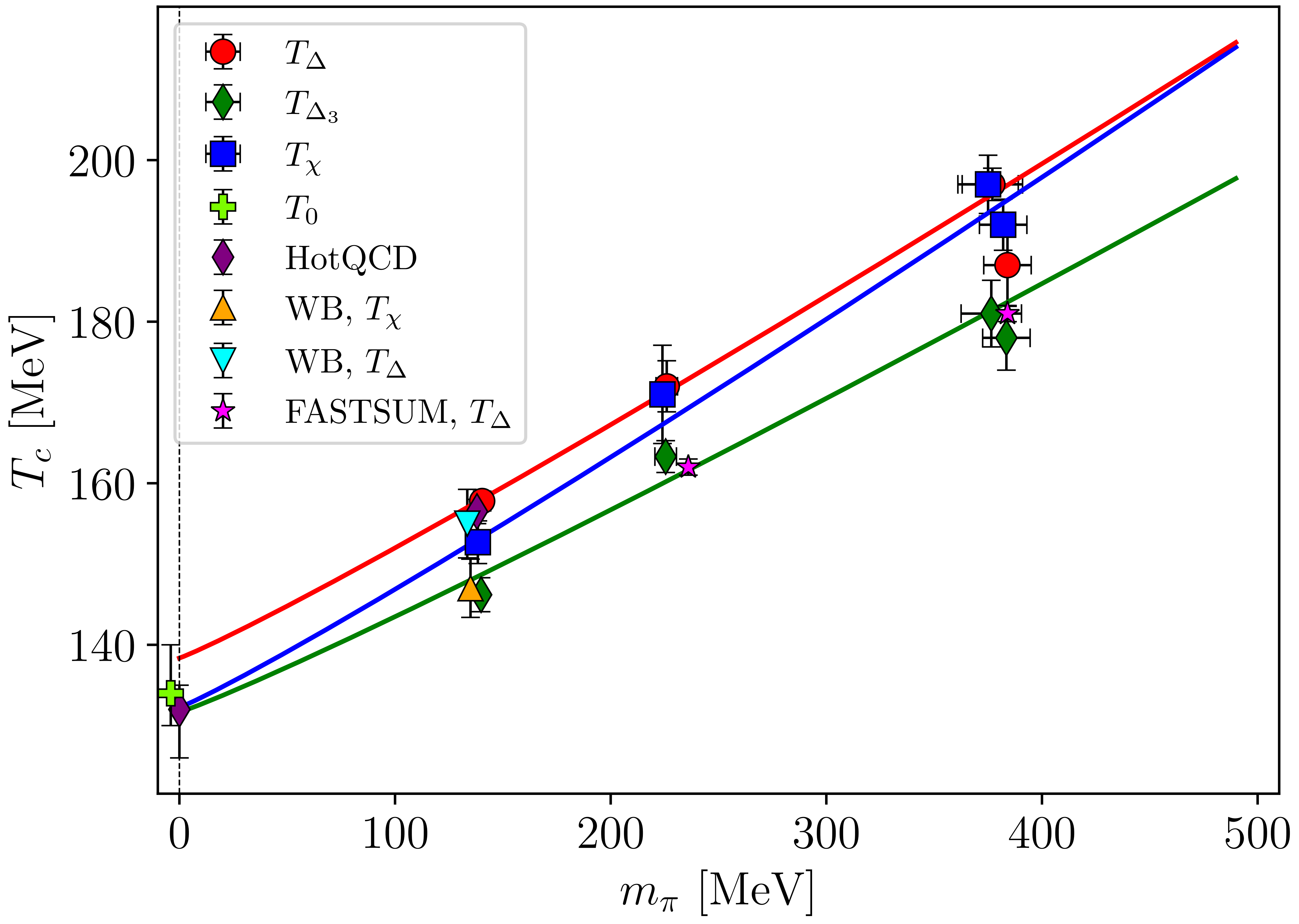
Physical pion mass







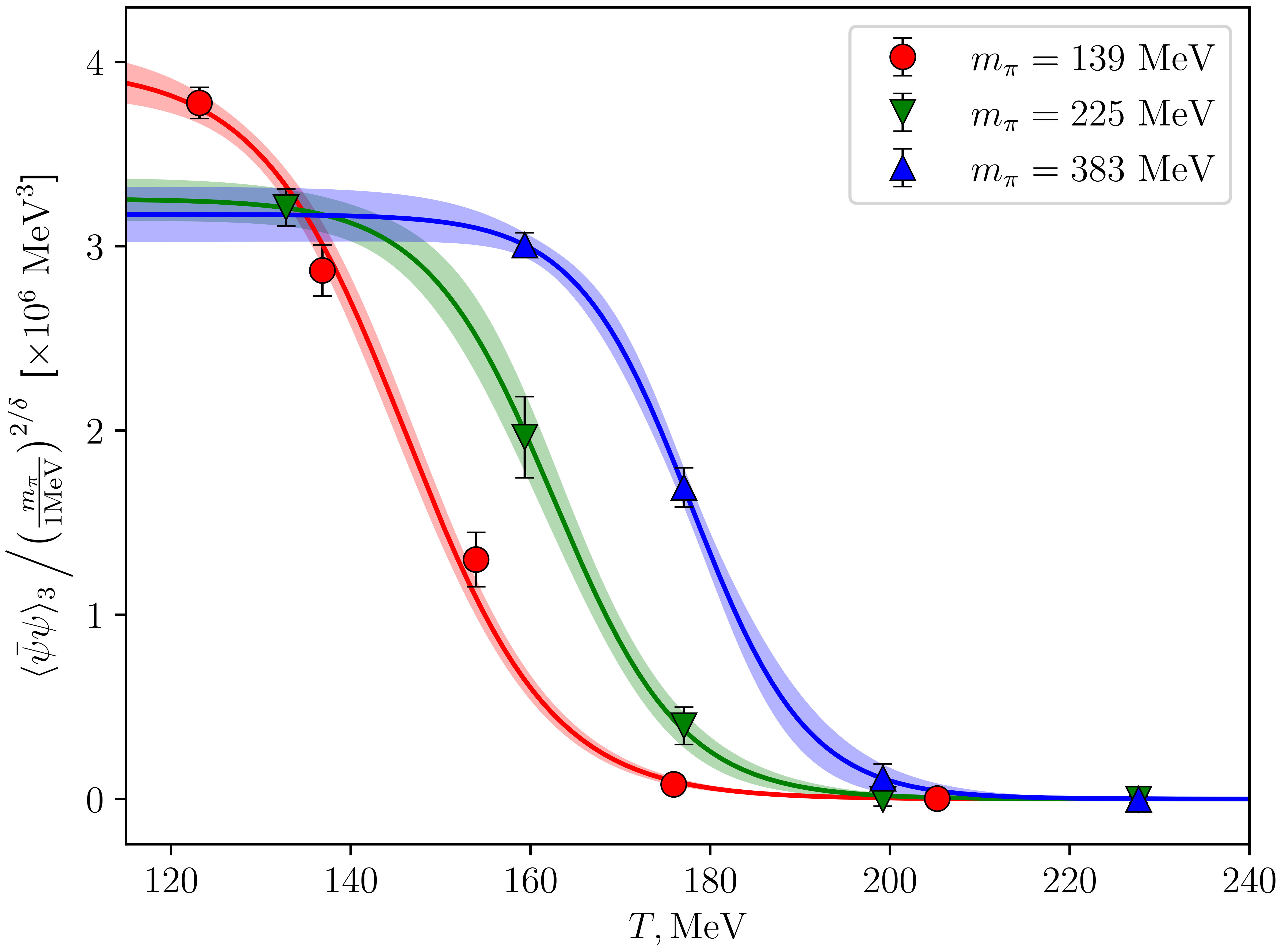
Critical temperature and the chiral limit



	$T(m_\pi = 139$ MeV) [MeV]	$T(m_\pi = 0)$ [MeV]
$\langle \bar{\psi}\psi \rangle$	157.8(12)	138(2)
χ	153(3)	132(4)
$\langle \bar{\psi}\psi \rangle_3$	146(2)	132(3)

$$T_0 = 134^{+6}_{-4}\ \text{MeV}$$

Simple estimation of T_0 from EOS

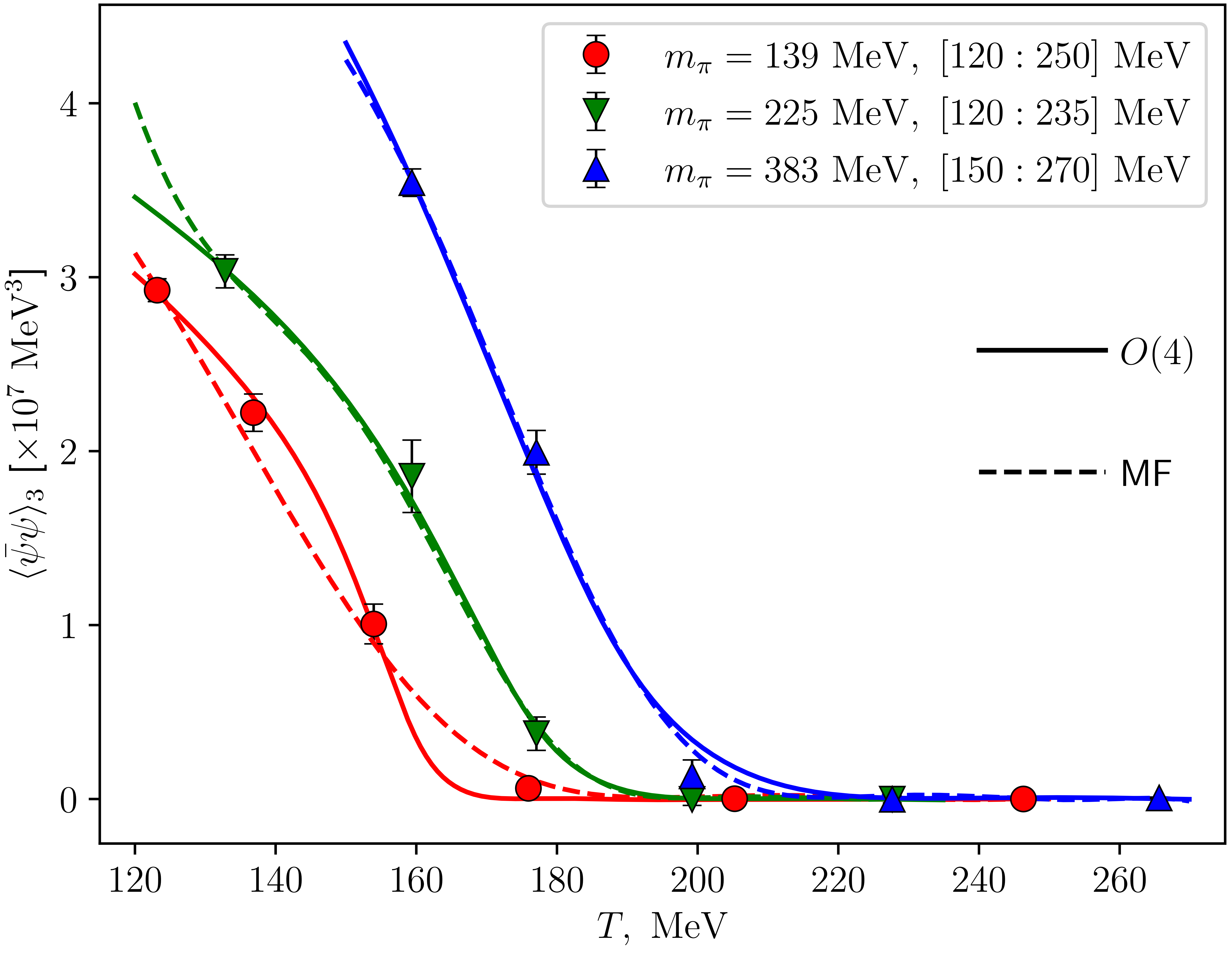


$$\frac{\langle\bar\psi\psi\rangle_3}{m^{1/\delta}} \sim \frac{\langle\bar\psi\psi\rangle_3}{m_\pi^{2/\delta}} = \text{const}$$

at

$$T = T_0(m_\pi = 0) = 138(2)\ \text{MeV}$$

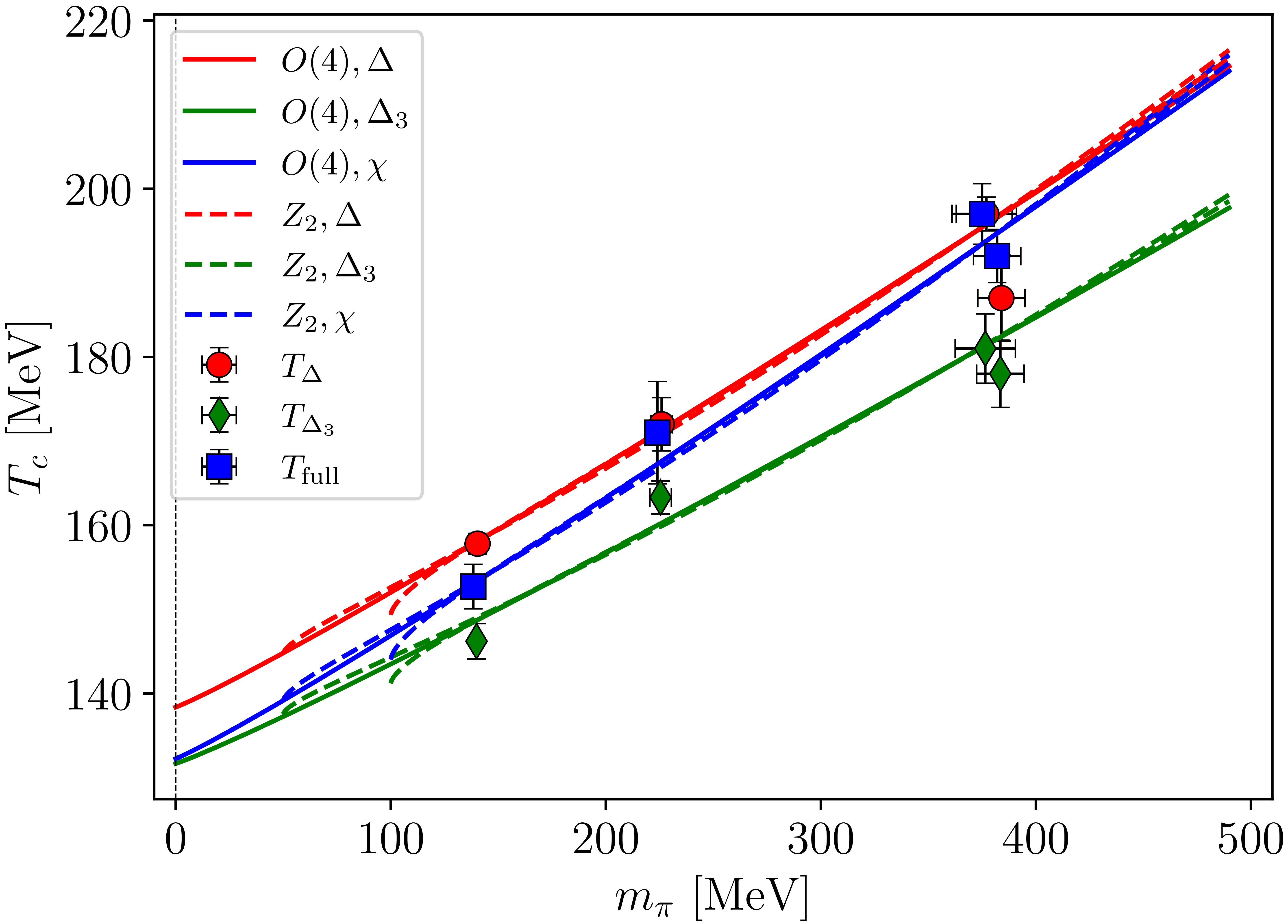
O(4) vs mean field



Mild tension between data and MF for m_π=139 MeV

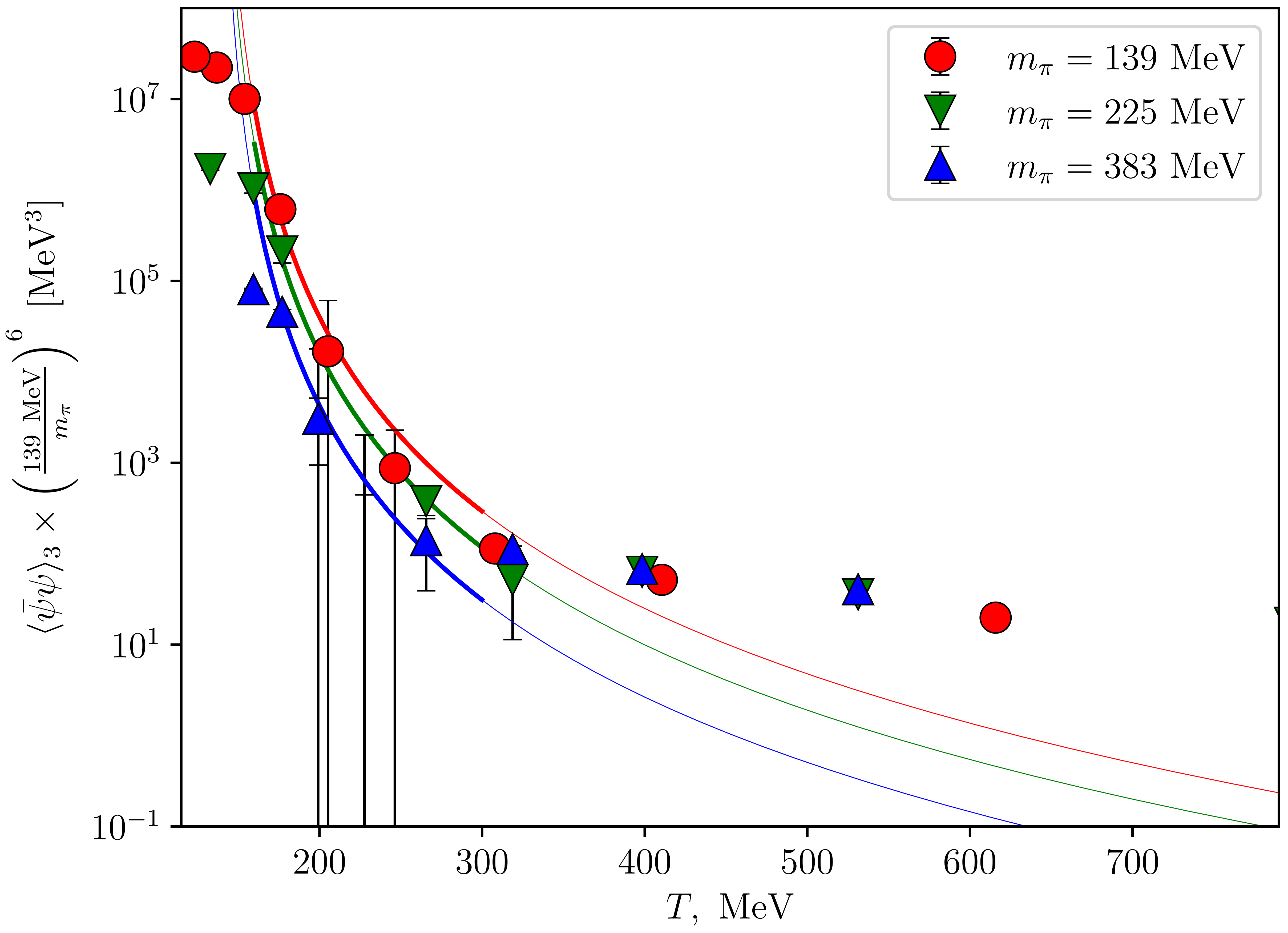
m_π [MeV]	T_0 [MeV]
139	142(2)
225	159(3)
383	174(2)

Z_2 scaling



Can also describe data for $m_\pi^c \in [0, m_{\text{phys}}]$

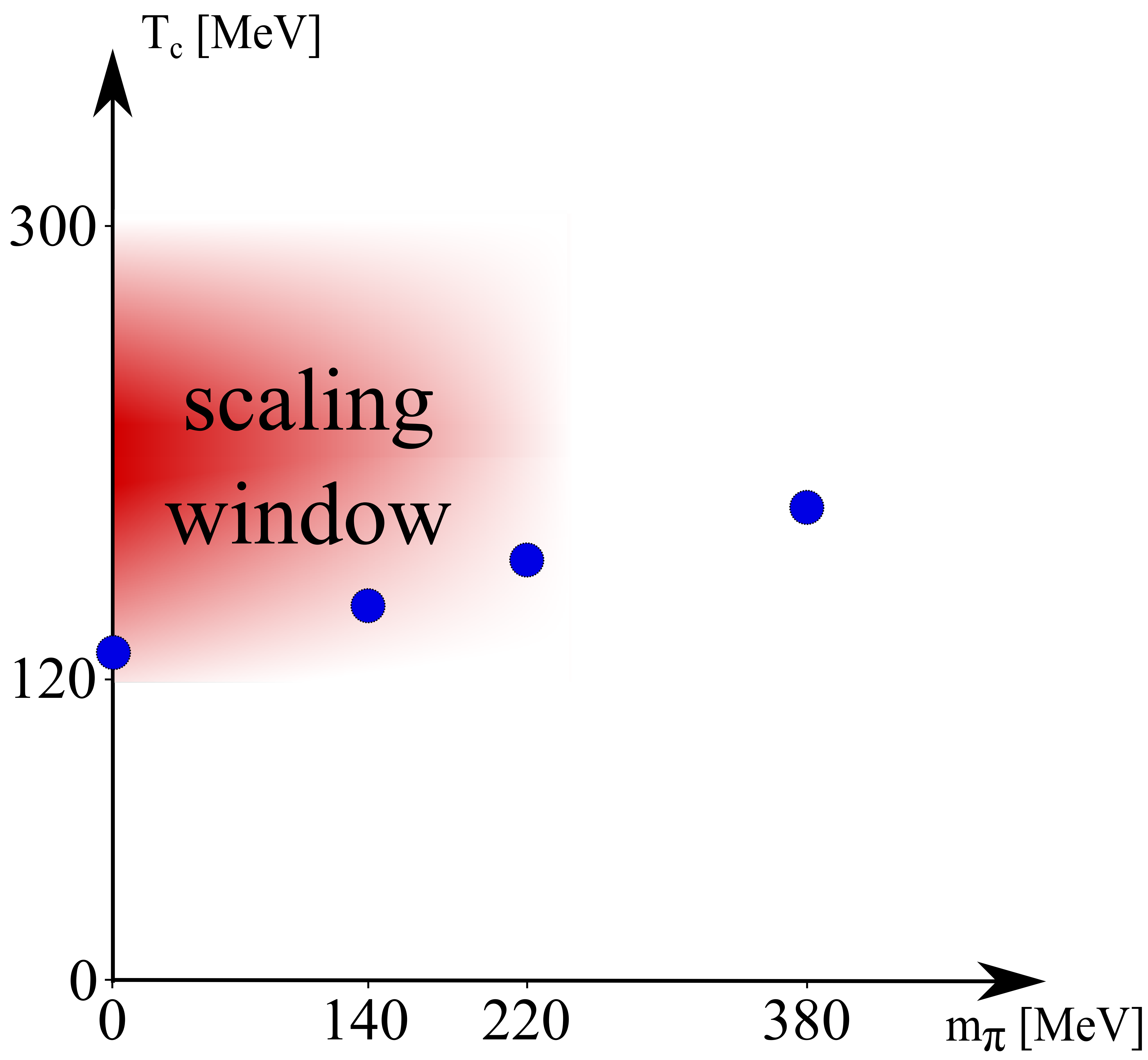
Large temperature behaviour



- O(4): $\langle\bar{\psi}\psi\rangle_3 \sim t^{-\gamma-2\beta\delta}$
- Griffith analyticity: $\langle\bar{\psi}\psi\rangle_3 \sim m^3 \sim m_\pi^6$
- $T \sim 300$ MeV

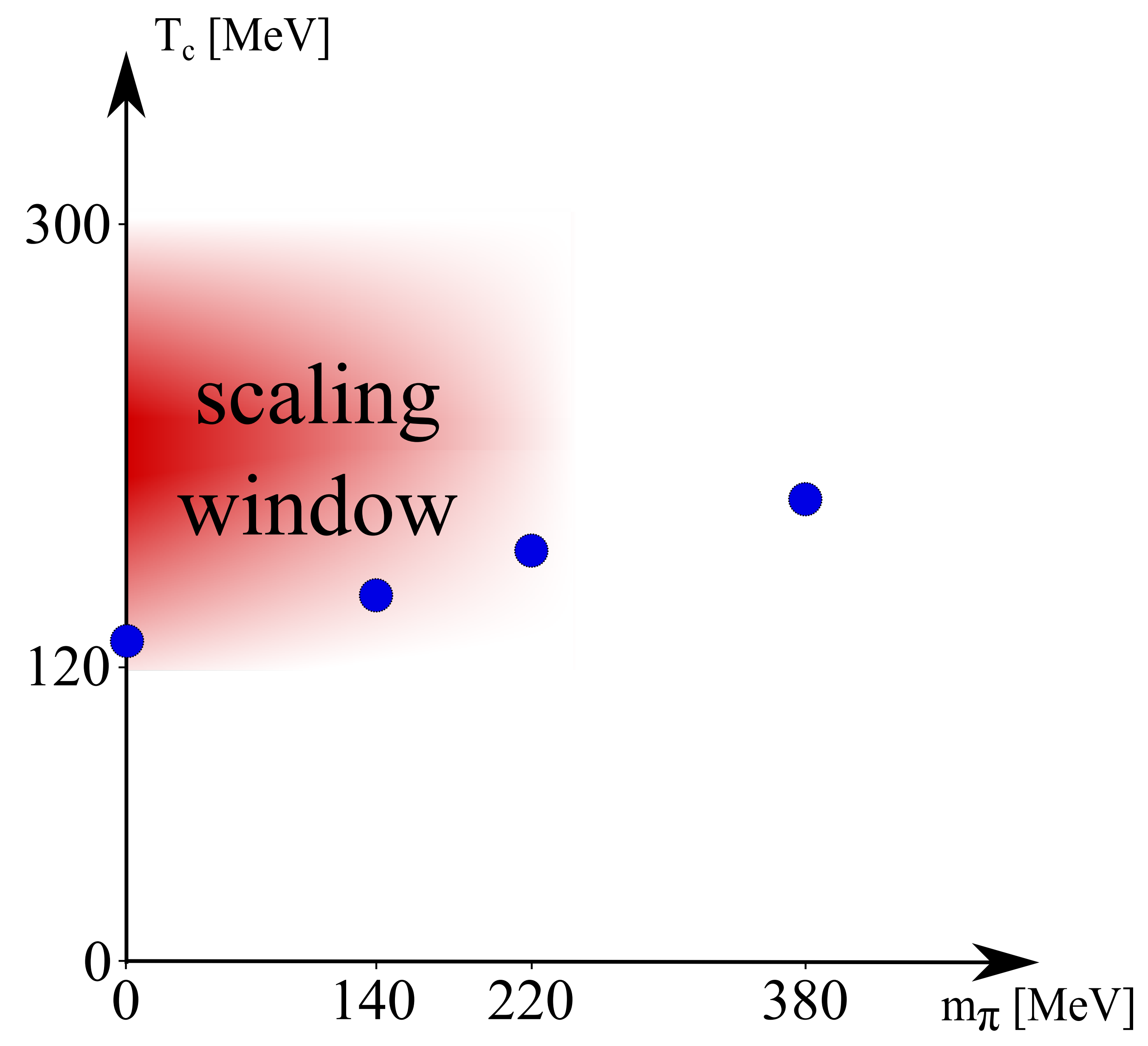
[Poster by A.Trunin]

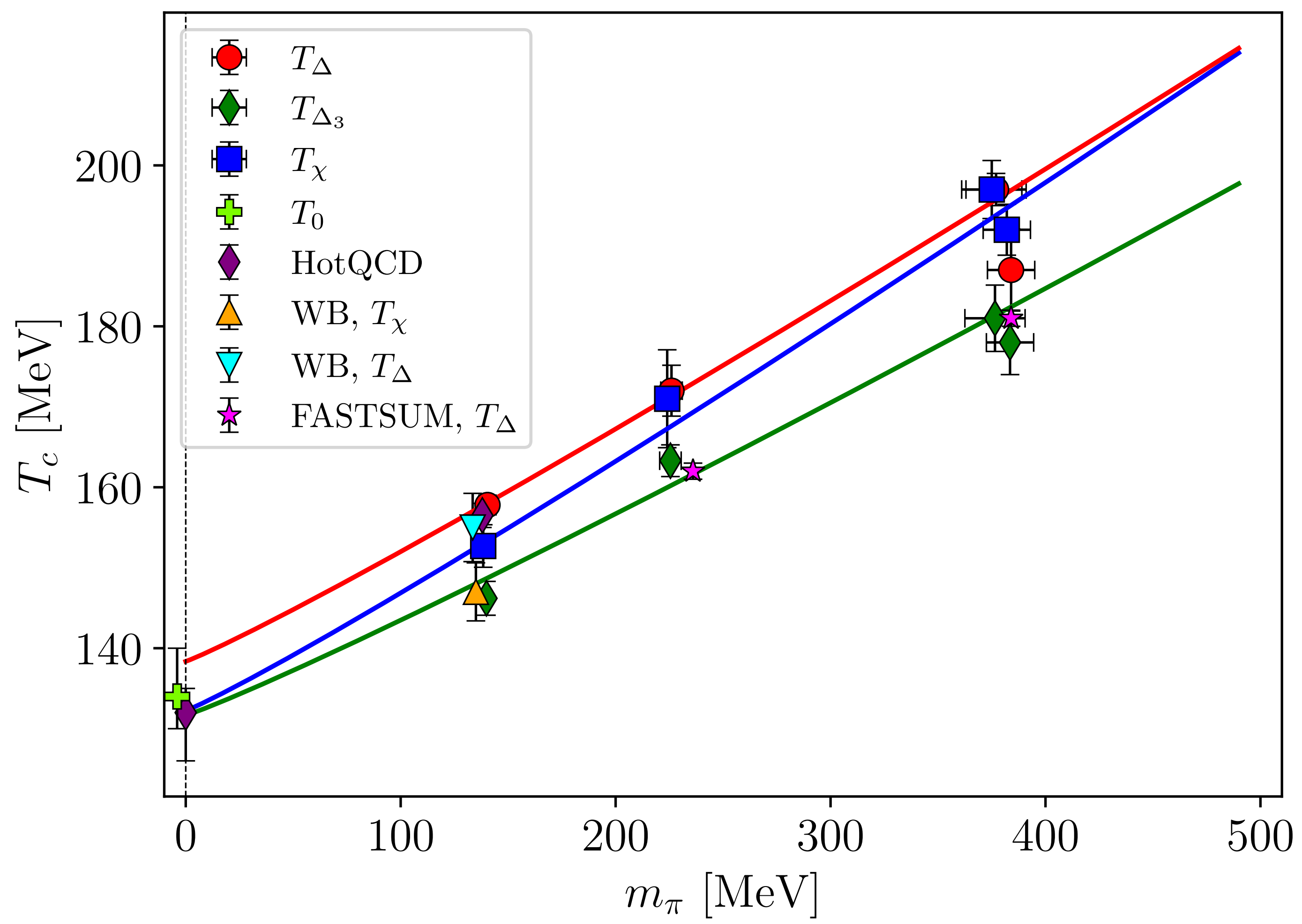
Scaling window



Conclusions

- $\langle \bar{\psi}\psi \rangle_3 = \langle \bar{\psi}\psi \rangle - m\chi$ is useful to study scaling
- $T_0 = 134^{+6}_{-4}$ MeV in the chiral limit
- $O(4)$ scaling for $m_\pi \lesssim 140$ MeV, $T \in [120,\ 300]$ MeV
- Z_2 scaling with any $m_\pi \lesssim 140$ MeV cannot be excluded
- $T \geq 300$ MeV: leading order Griffith analyticity





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