Meson thermal masses at non-zero temperature

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1. Objectives of the project

1. What happens to the mesons when the medium is heated up?

2. Study melting/deconfinement of mesonic groundstates M_0 as a function of temperature.

3. Can we extract information about symmetry restoration and degeneracies?

2. Overview of the project (1)

Thermal correlation functions $C(\tau)$

Regression analysis using spectral decomposition in periodic lattices (2)

Ground state mass M_o

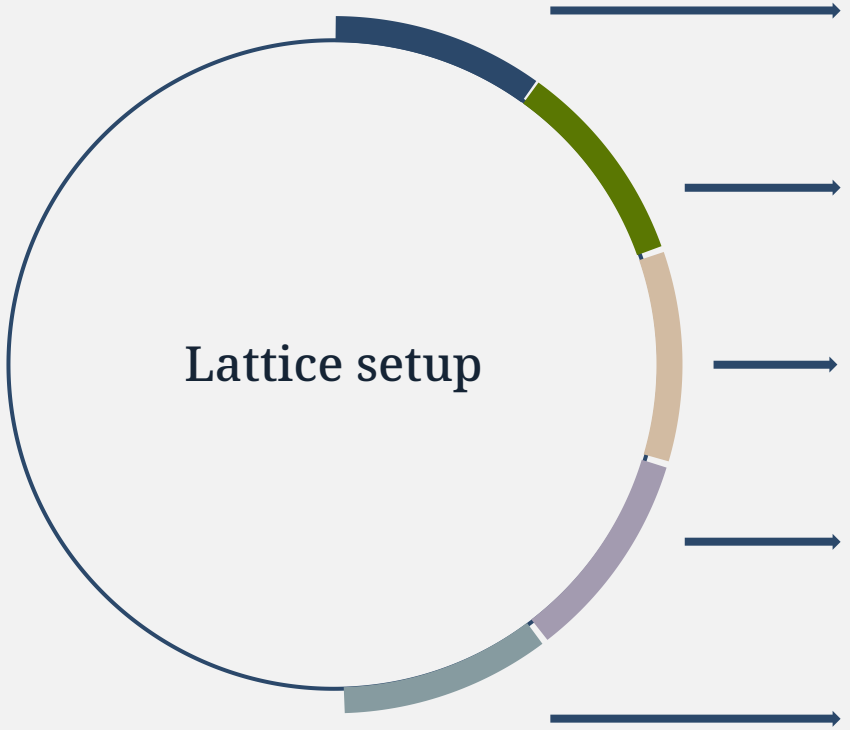
- Various $\mathrm{T} = \frac{1}{N_\tau a_\tau}$
- Various flavours
- Various operators

- Multistate analysis
- Variational fit windows

- Dependence $M_o(T)$?
- Symmetry restoration?

(1). The results presented correspond to finite lattice spacing. No continuum limit taken
(2). Difficult; states in spectrum are not described by simple delta-functions as $T \gg 0$

3. Setup of the project



Anisotropic action

Clover-improved Wilson fermions

Symanzik improvement

(2+1) flavours (1)

$46\ (\text{MeV}) \leq T \leq 300(\text{MeV})$

(1). FASTSUM collaboration GEN2L ensembles

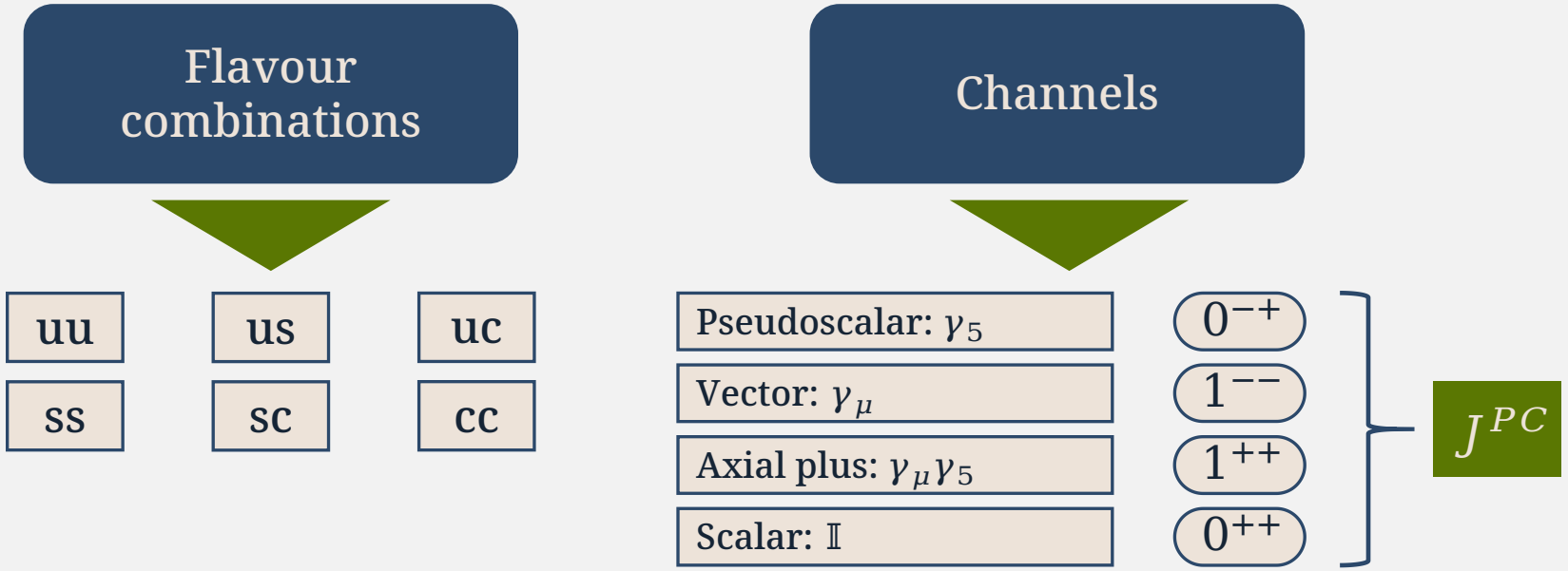
3. Setup of the project

Important lattice parameters (1)

a_τ[fm] (2)	a_s[fm]	$\zeta = a_s/a_\tau$	T_c[MeV] (3)	M_π[MeV]	N_s	m_πL
0.0030(2)	0.01136(6)	3.453(6)	164(2)	236(2)	32	4.36

(1). 2007.04188
(2). $1/a_\tau$ = 5.997(34) [GeV]
(3). Using inflection point of renormalised chiral condensate

4. Available mesons



Note:

1. No disconnected contributions calculated. We only have access to non-singlet flavour operators.
2. Local-local (ll) and smeared-smeared (ss) operators available. (1)

(1). 10.1103/PhysRevD.69.054501 ($\rho = 0.14$, isotropic, 2 steps)

5. Regression analysis (1)

Problems	Solutions proposed
Data is heavily correlated at different τ	Correlated fits
Single-state fits only valid in narrow window	Multi-state regression
No previous prior knowledge on parameters	Parameter initialisation; M_{eff} and fits
Fixing the fit window includes bias	Variable fit window FW

A fit window $FW(t_0, t_f)$ means that we fit using all *times* that fulfill $\tau \in FW(t_0, t_f) = [t_0, t_f]$

(1). Based on the procedure presented in 10.1103/PhysRevD.100.094510

6. Analysis at fixed window $FW(t_0, t_f)$

Define N_m models with different number of states

- $f_s(\tau; \vec{\theta}) = \sum_{i=0}^{s} A_i \cosh\left(M_i\left(\tau - \frac{N_\tau}{2}\right)\right)$

Perform N_m correlated fits

- $\chi^2 = \sum_{\tau_i, \tau_j = t_0}^{t_f} R(\tau_i)\sigma_{ij}^{-1}R(\tau_j)$

Compute Akaike for each model (AIC_c)

- Measures relative likelihood of data description among models

Use AIC_c to compute $M_0(FW)$ through weighted average

- No data is manually discarded
- More likely models will have more impact in result

Estimate errors in $M_0(FW)$

- Difficult task
- Computed using resampling of weighted average data

Residues: $R(\tau) = C(\tau) - f(\tau, \vec{\theta})$

(1). 10.1109/TAC.1974.1100705

7. Akaike Information Criterion (AIC_c)

Number of free parameters in the model ($2s$)

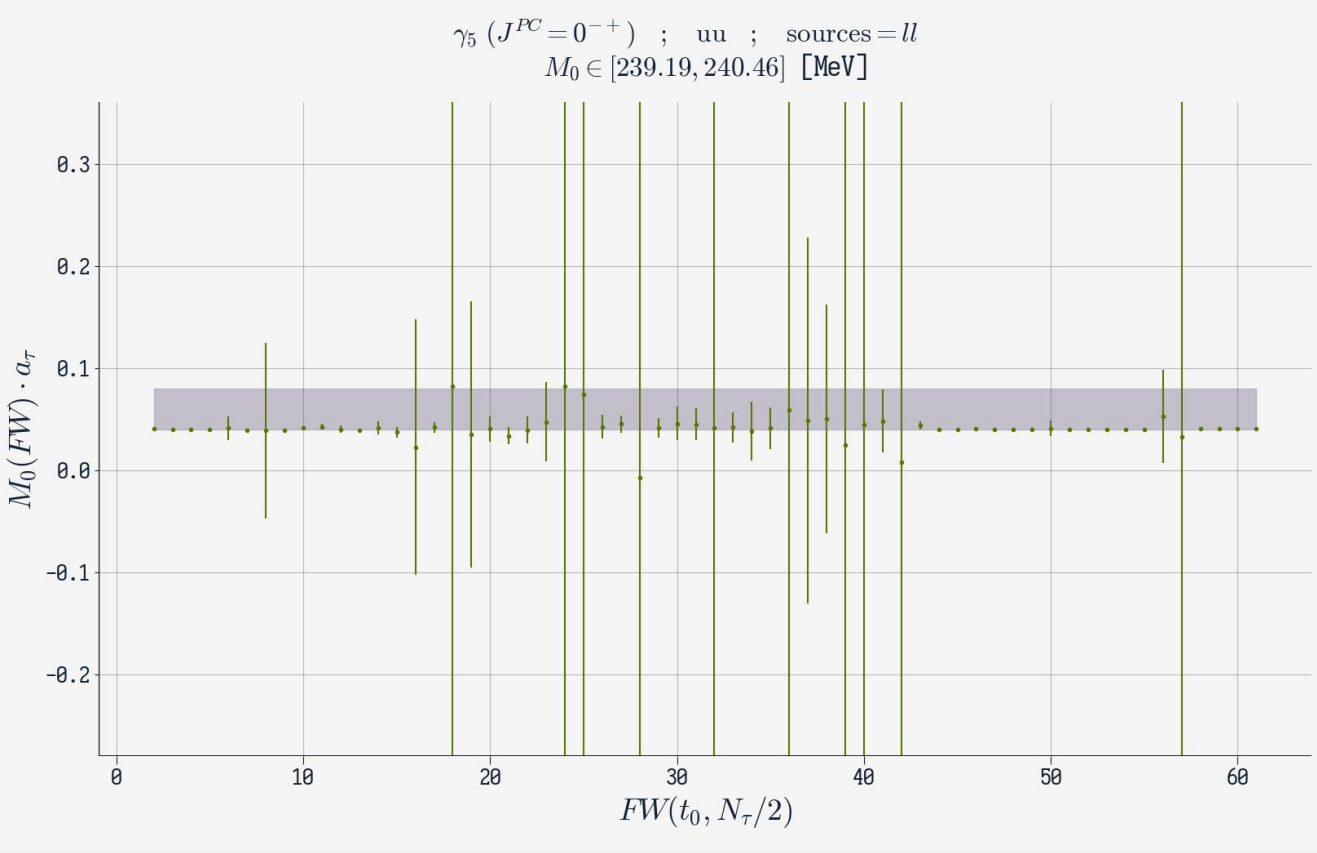
Log-likelihood of the model. (χ^2)

$$AIC_c = 2N_\theta - 2\log(\hat{L}) + \frac{2N_\theta^2 + 2N_\theta}{N - N_\theta - 1}$$

Number of data points available in the fit

8. Extraction of ground mass M_o

For each $FW[t_0, t_f]$ we do have an estimate of the ground mass



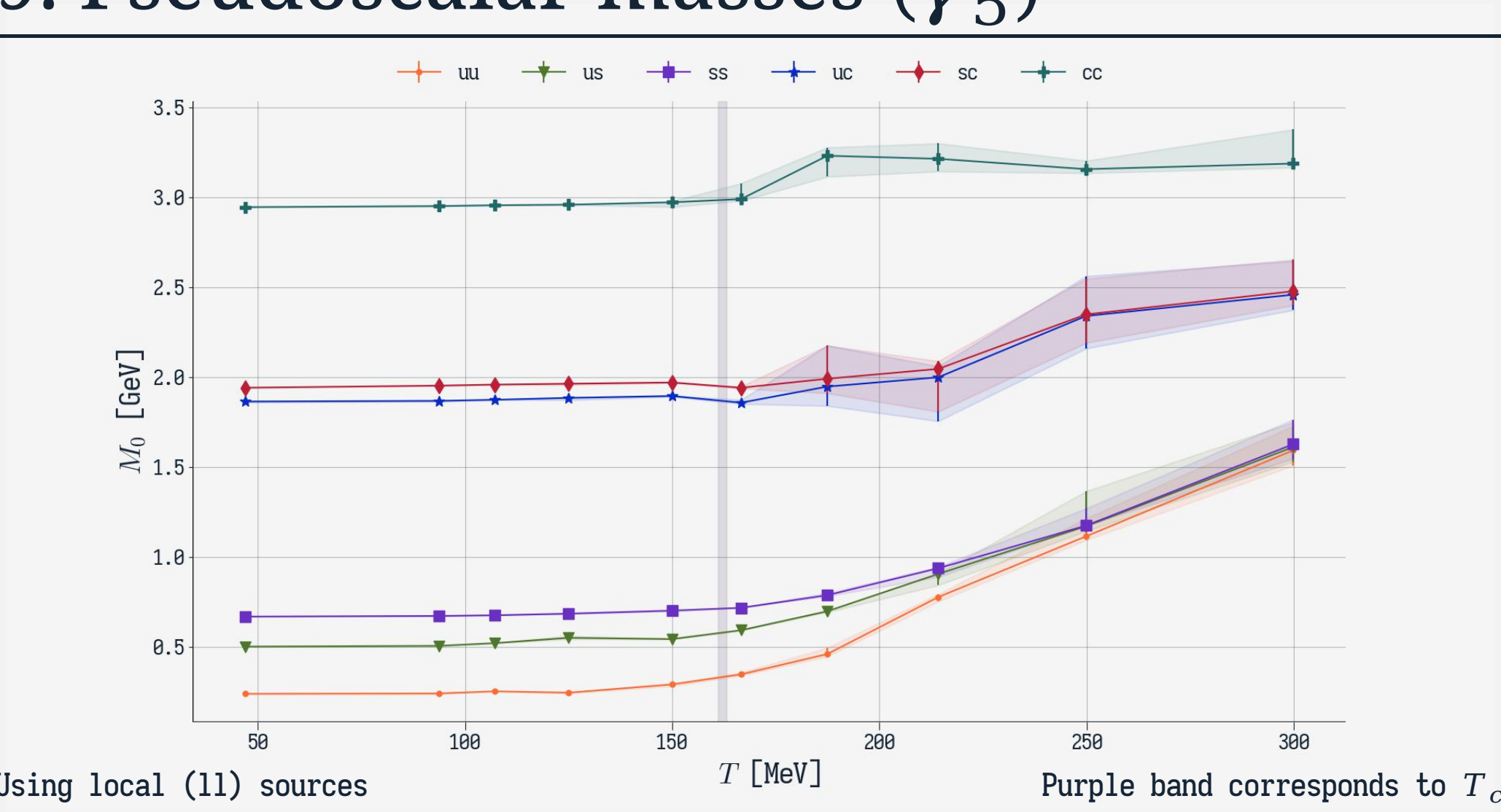
Assuming

All $M_o(FW)$ are estimates of M_o

M_o is the median of the data

Median confidence intervals extracted through resampling

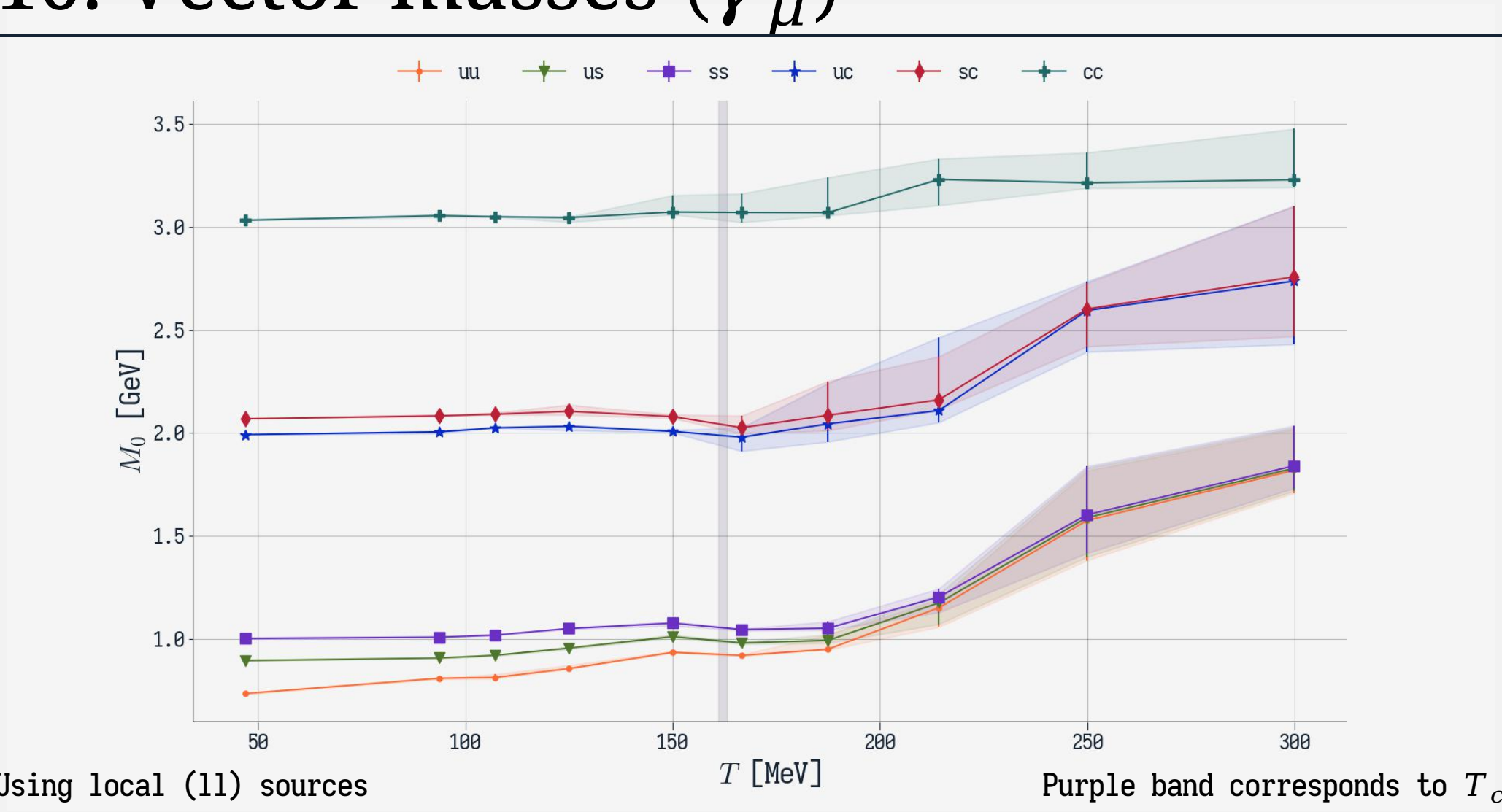
9. Pseudoscalar masses (γ_5)



Using local (ll) sources

Purple band corresponds to T_c

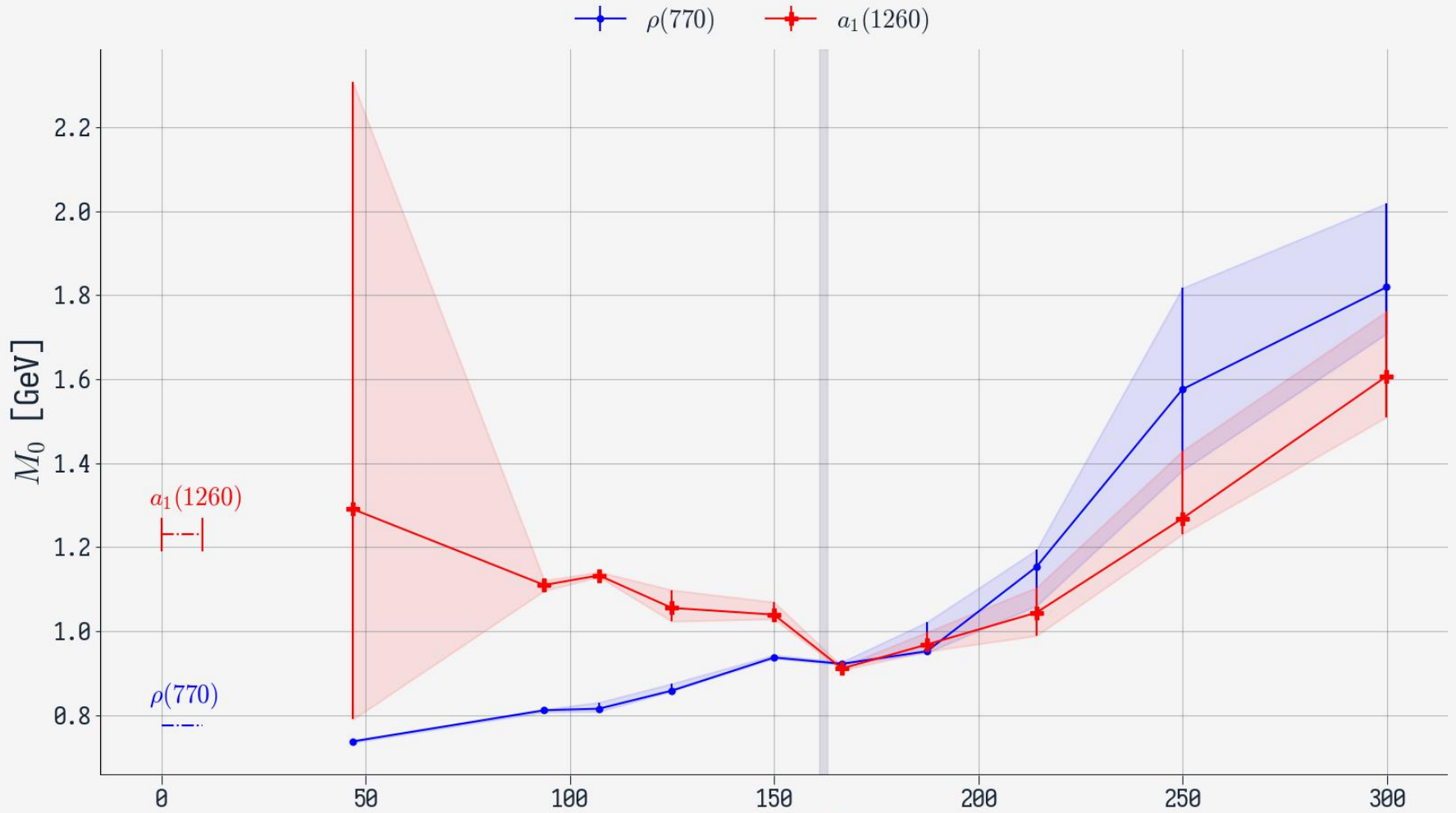
10. Vector masses (γ_μ)



Using local (ll) sources

Purple band corresponds to T_c

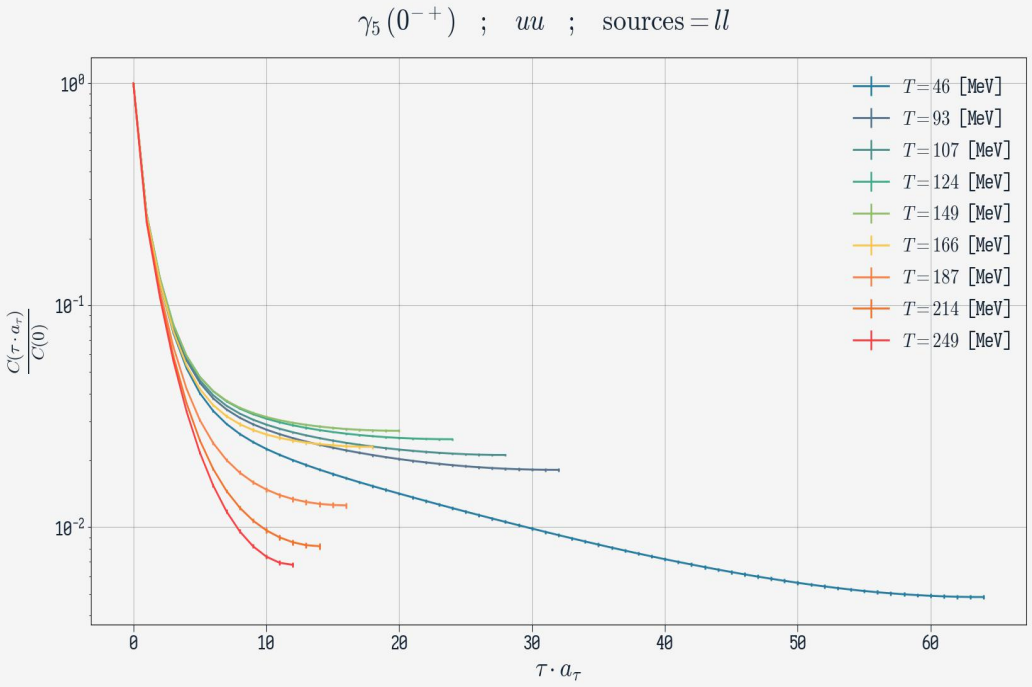
11. $SU(2)_A$ related mesons

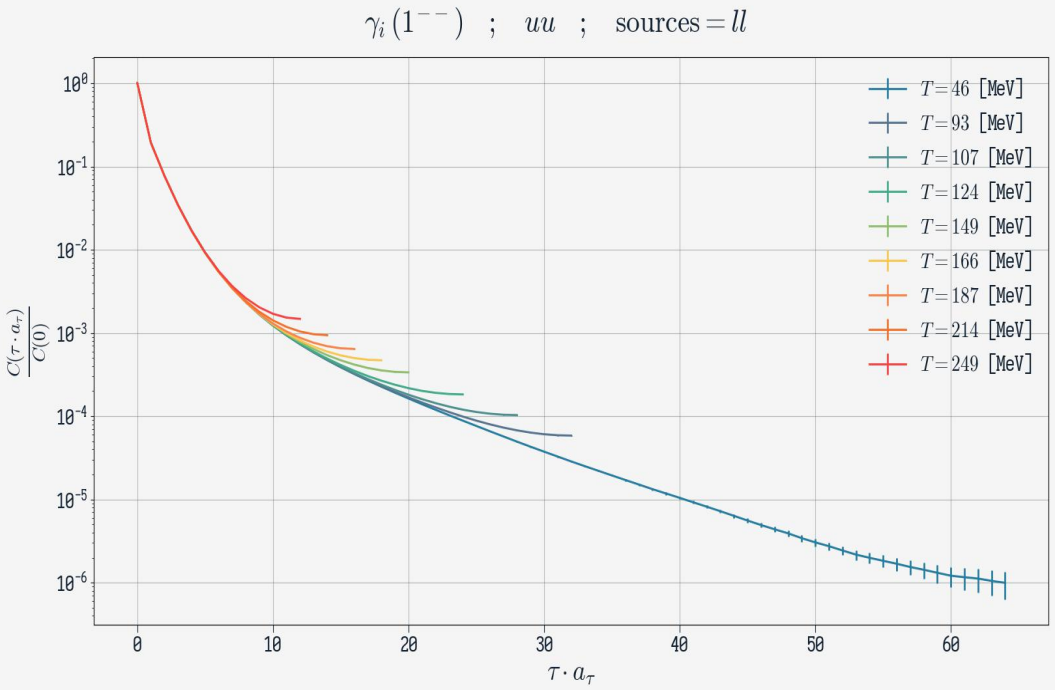


T = 0 values extracted from PDG
Using local (ll) sources

Purple band corresponds to T_c

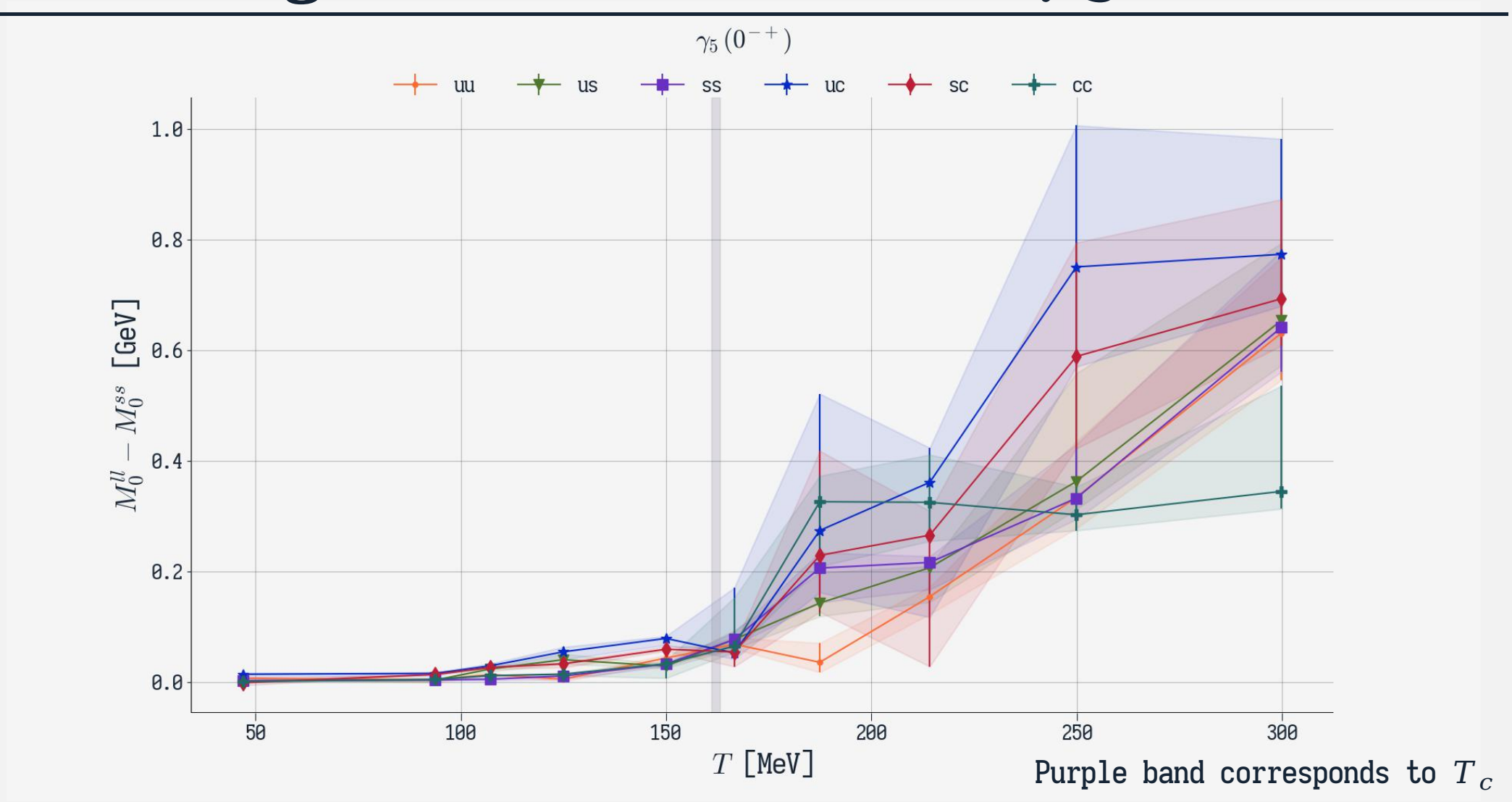
12. 2-point correlation functions





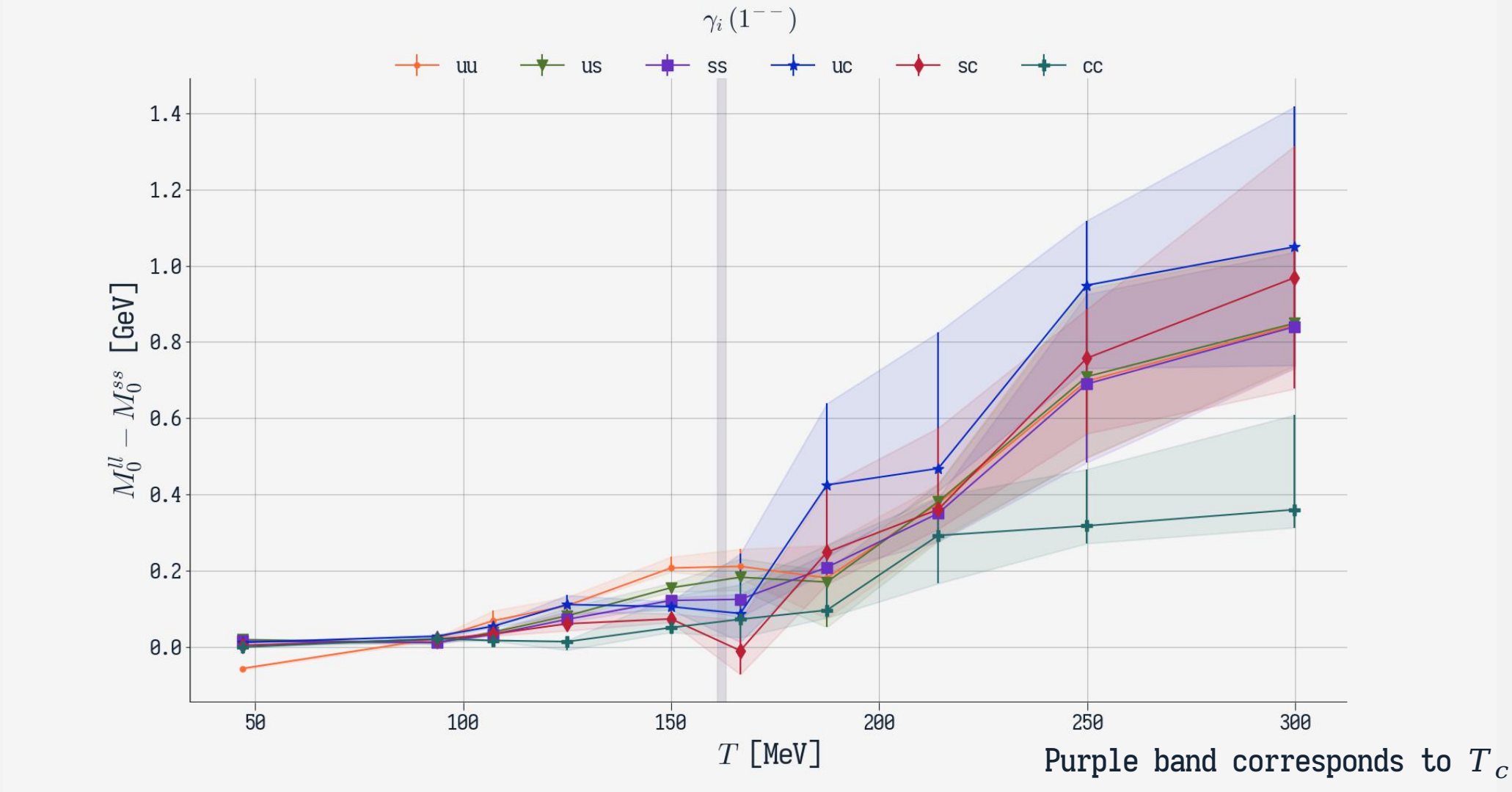
As T increases, defining M_0 becomes difficult → Regression using cosh functions becomes unreliable → Spectral function analysis might be needed

13. Using different sources (γ_5)



Purple band corresponds to T_c

13. Using different sources (γ_μ)



Purple band corresponds to T_c

14. Conclusions

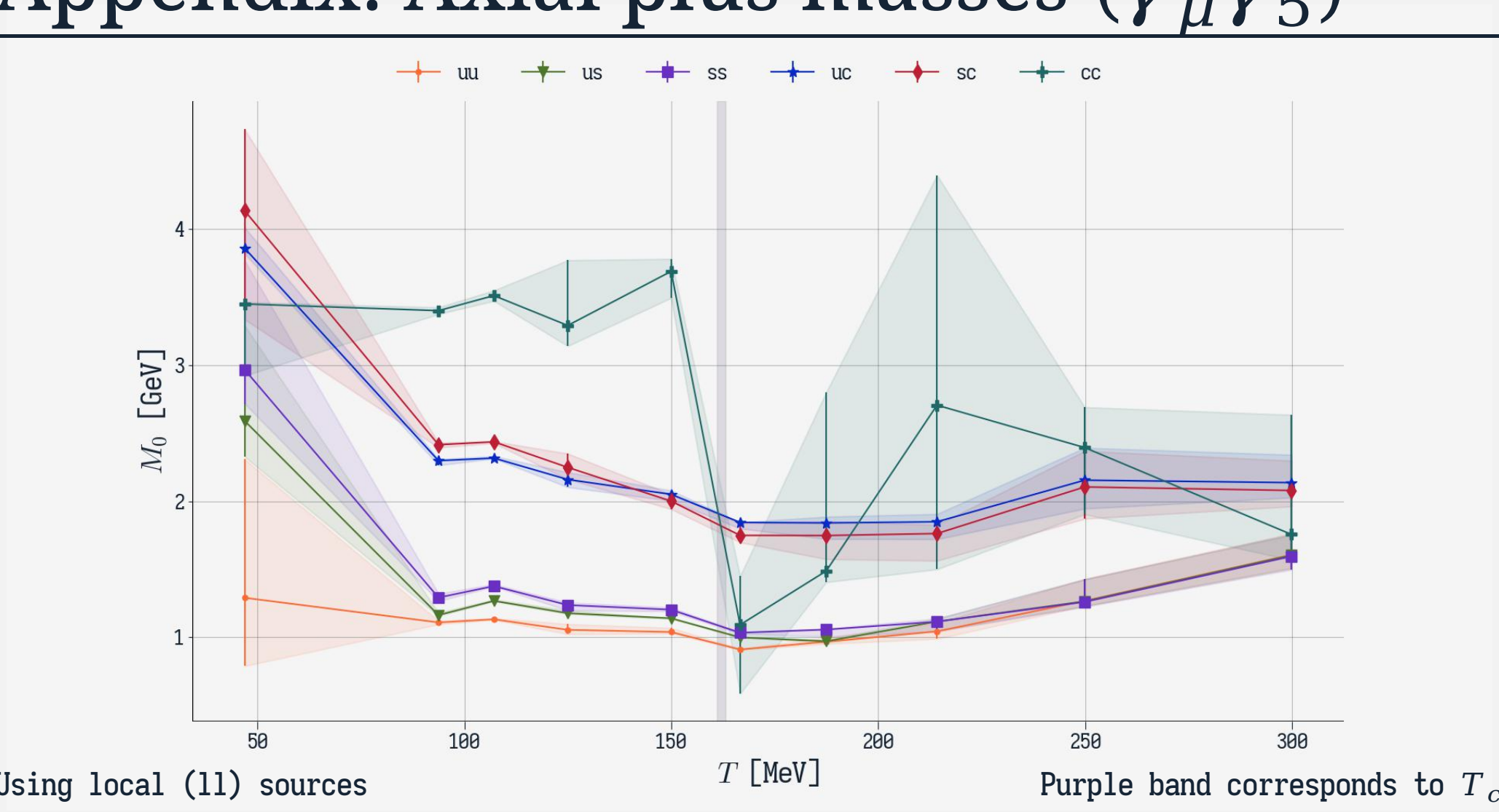
1. Above T_c defining M_0 is difficult
   - Spectral functions are required
   - Signal in QGP is (much) less reliable

2. $SU(2)_A$ symmetry recovered above T_c
   - $\rho(770)$ and $a_1(1260)$ become degenerate

3. Minimal T dependence of M_0 in hadronic phase

4. Local and smeared sources are not equivalent at high T

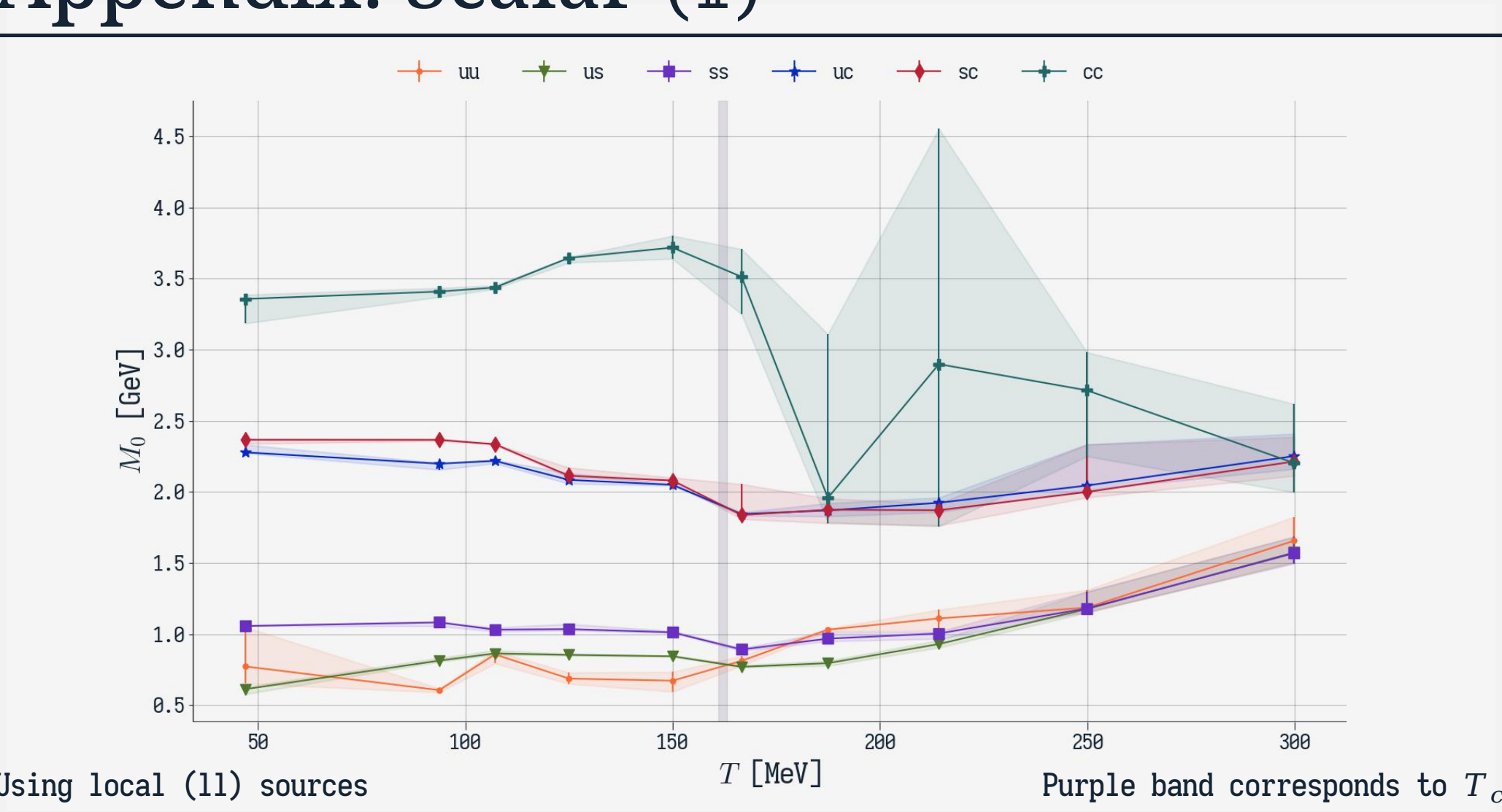
Appendix: Axial plus masses ($\gamma_\mu\gamma_5$)



Using local (ll) sources

Purple band corresponds to T_c

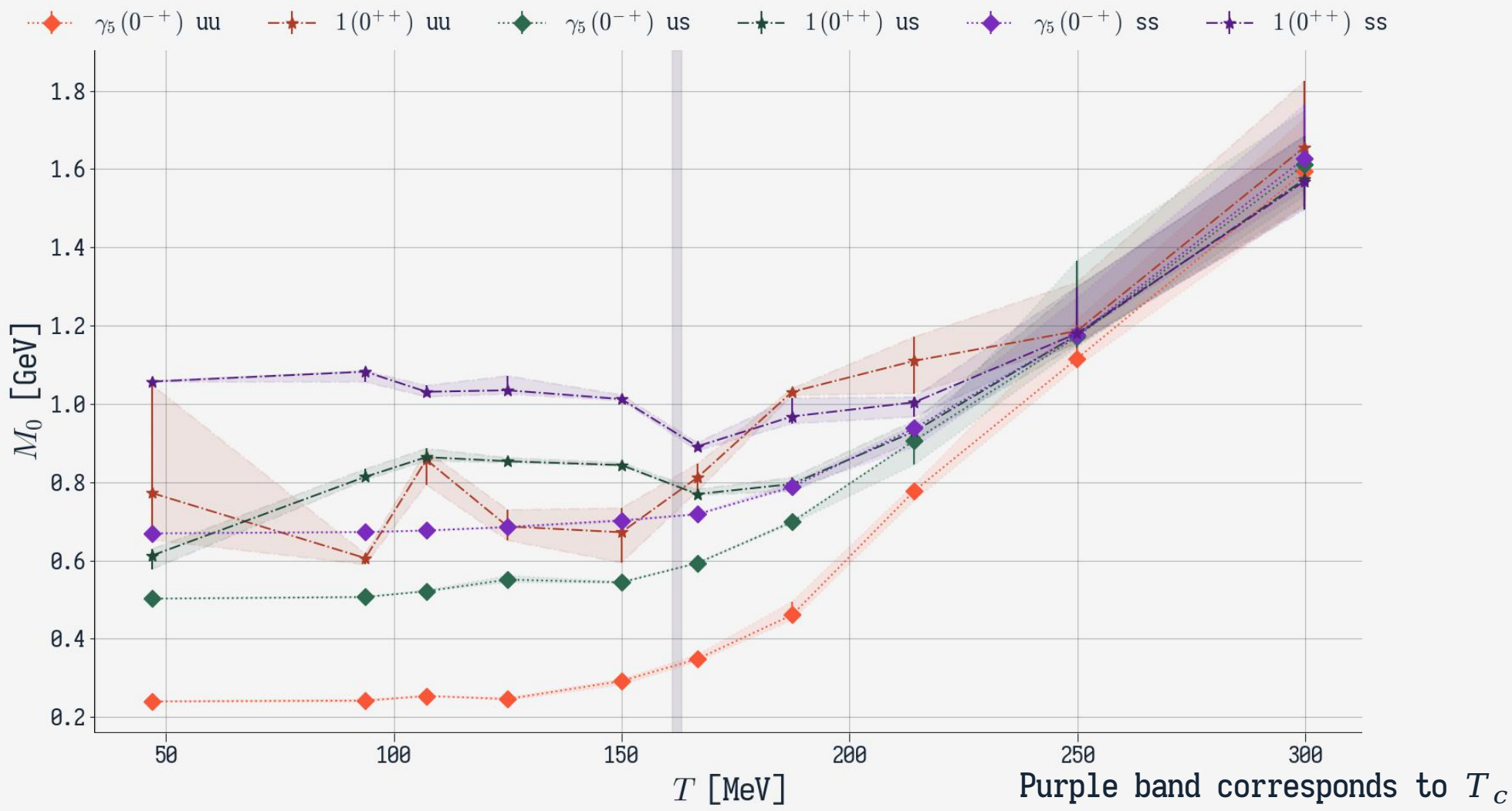
Appendix: Scalar (𝕀)



Using local (ll) sources

Purple band corresponds to T_c

Appendix: $U(1)_A$ related mesons



Purple band corresponds to T_c