

Recent Results from the FASTSUM Collaboration

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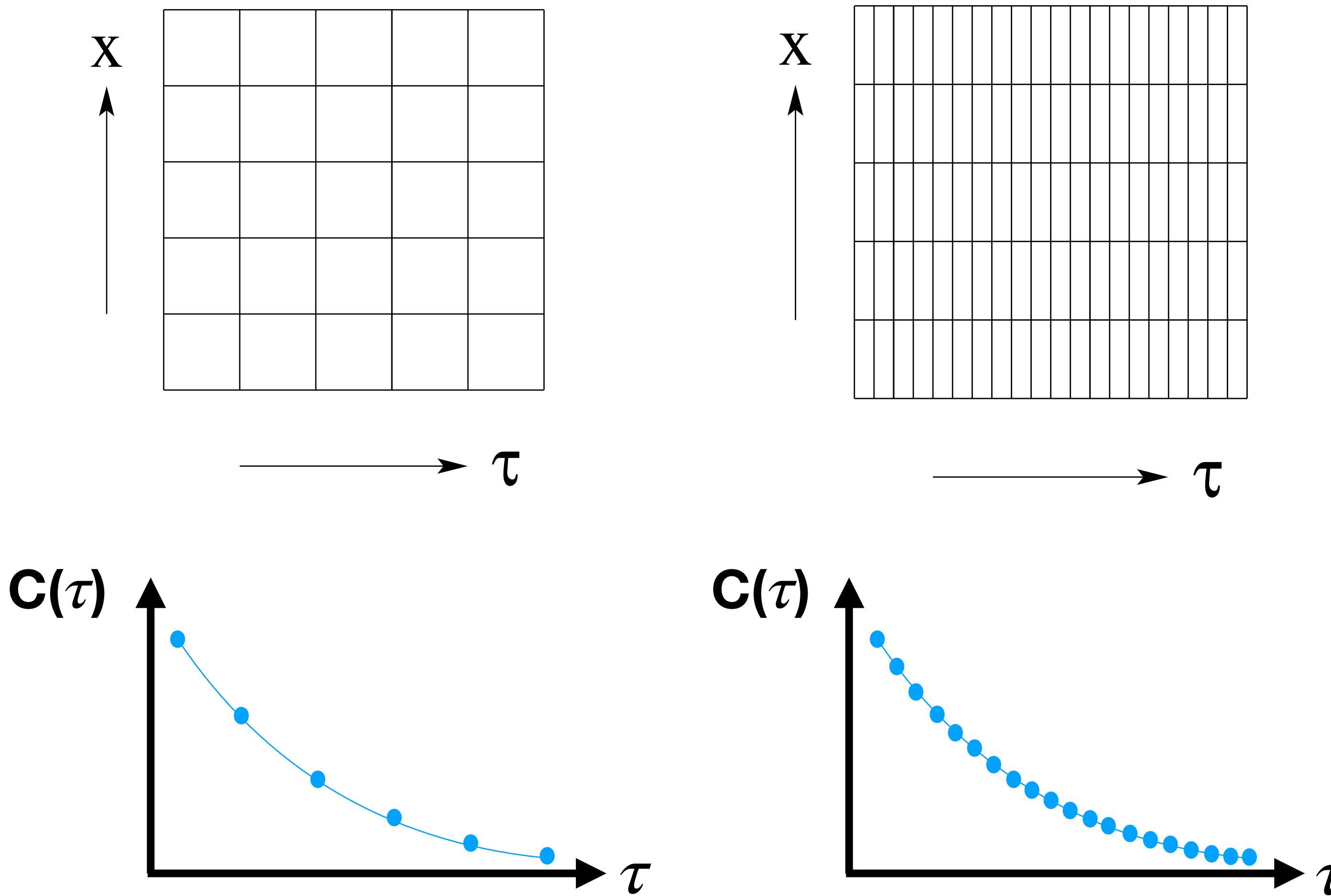
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Overview

- Overview of FASTSUM approach
- Charmed mesons
- Charmed baryonic spectrum (Ryan Bignell Wed 16:50)
- Bottomonium (NRQCD) spectrum (Benjamin Page Wed 14:20)
- Interquark potentials in Bottomonium (Thomas Spriggs Wed 14:40)
- Gen3 tuning

Our Lattice Setup: *Anisotropic*



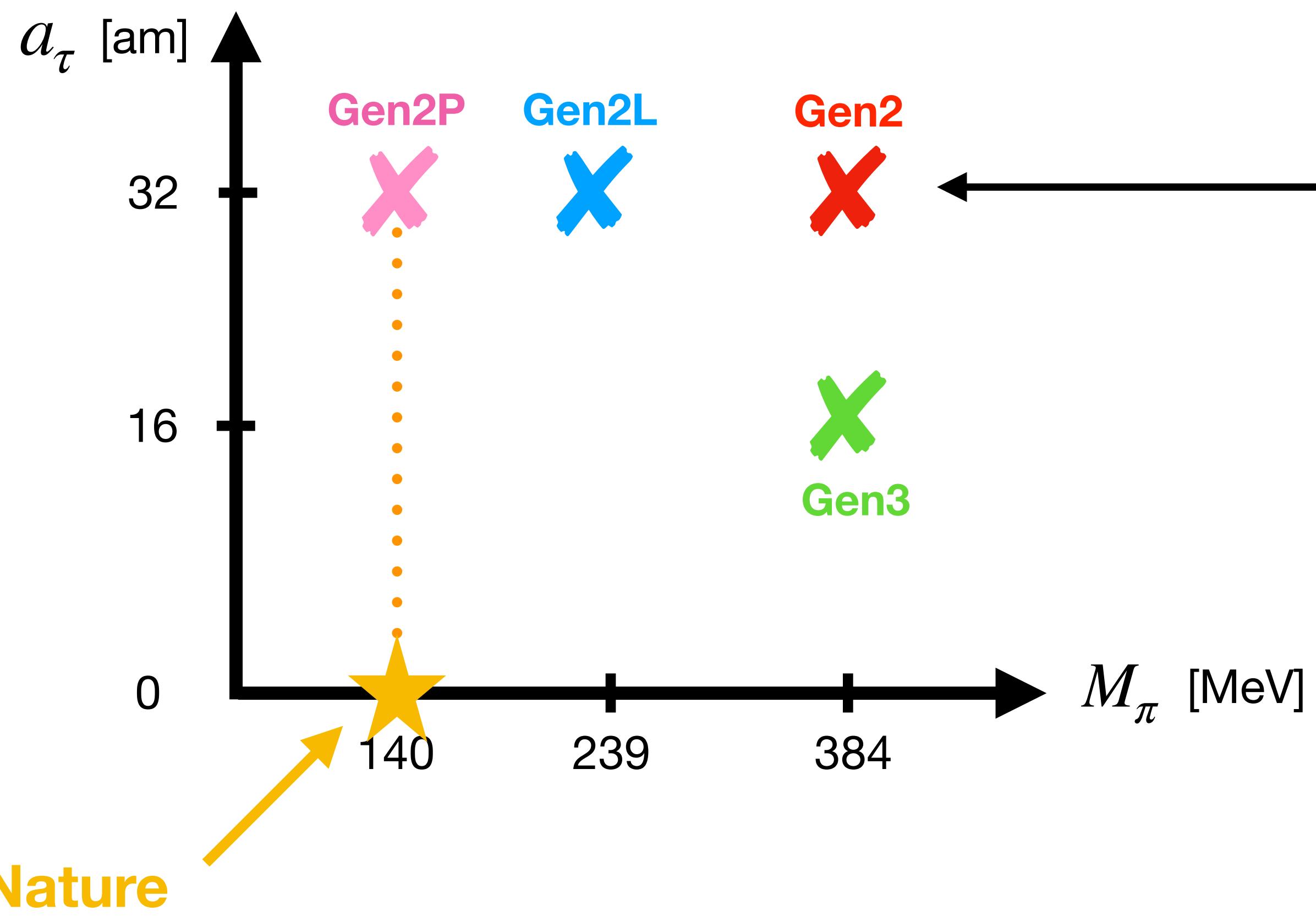
$$\begin{aligned} T &= 1/L_\tau \\ &= 1 / (a_\tau N_\tau) \end{aligned}$$

Spectroscopy:
Bottomonium
Charmed mesons
Heavy Baryons
Light Hadrons

Interquark potential
Conductivity

Lattice Parameters

(2+1) flavour
 $a_s \sim 0.112 \text{ fm}$



Parameters from **HadSpec Collaboration**
R. G. Edwards, B. Joo and H. W. Lin,
Phys. Rev. D 78 (2008) 054501

Gauge Action: Symanzik-improved anisotropic
Fermion Action: Wilson-clover, tree-level tadpole
with stout-smeared links

Generation 2L

a_τ [am]	a_τ^{-1} [GeV]	$\xi = a_s/a_\tau$	a_s [fm]	m_π [MeV]	$T_c^{\psi\psi}$ [MeV]
32.46(7)	6.079(13)	3.453(6)	0.1121(3)	239(1)	167(2)(1)

Generation 2L, $32^3 \times N_\tau$										
N_τ	128	64	56	48	40	36	32	28	24	20
T [MeV]	47	95	109	127	152	169	190	217	253	304
N_{cfg}	1024	1041	1042	1123	1102	1119	1090	1031	1016	1030

\uparrow
 $N_\tau^c \sim 37$

$T_c \sim 162$ MeV

- $a^{-1} = 6.079(13)$ GeV from HadSpec calculation of Ω baryon,
 D. J. Wilson, et al., Phys. Rev. Lett. 123 (2019)

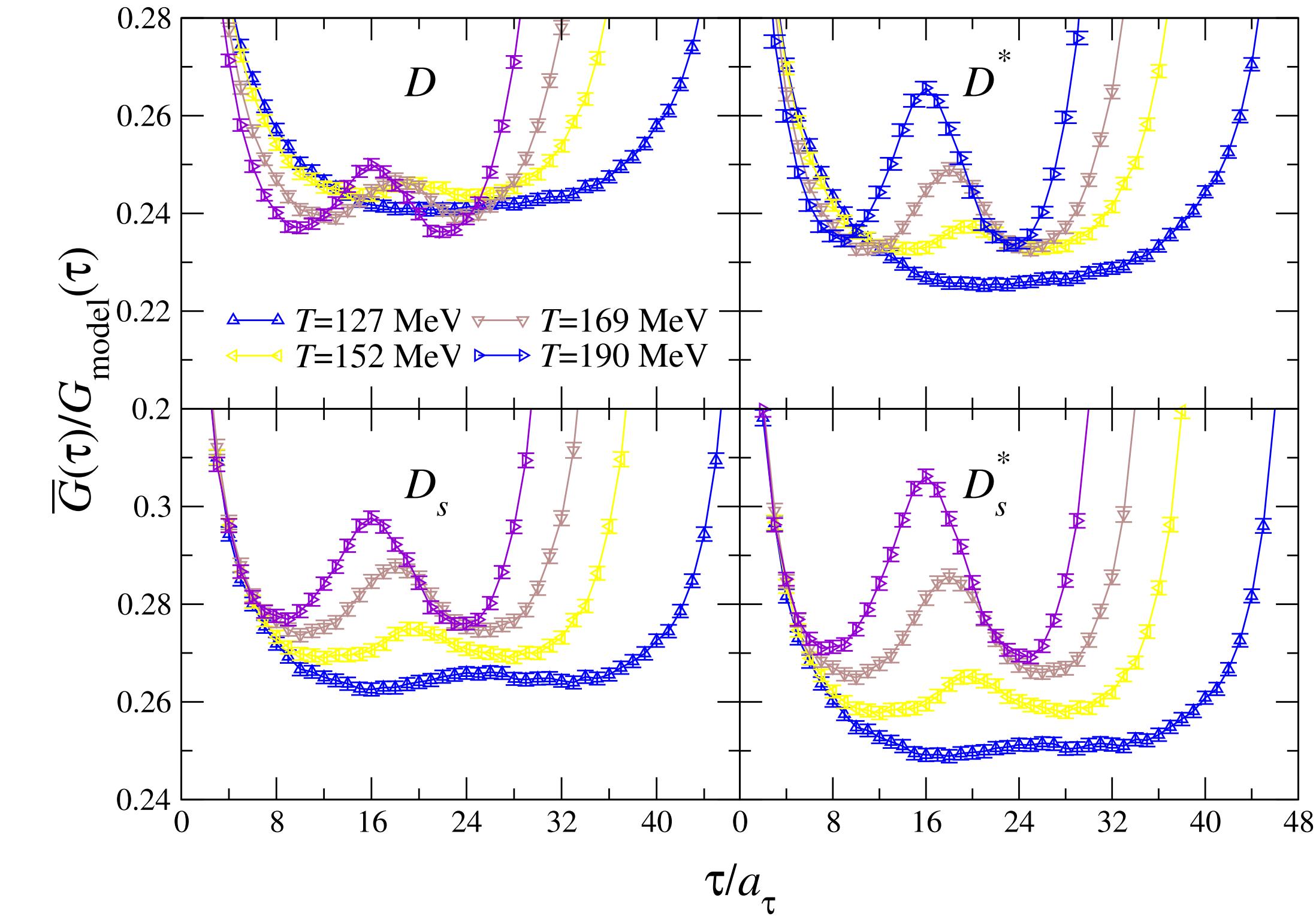
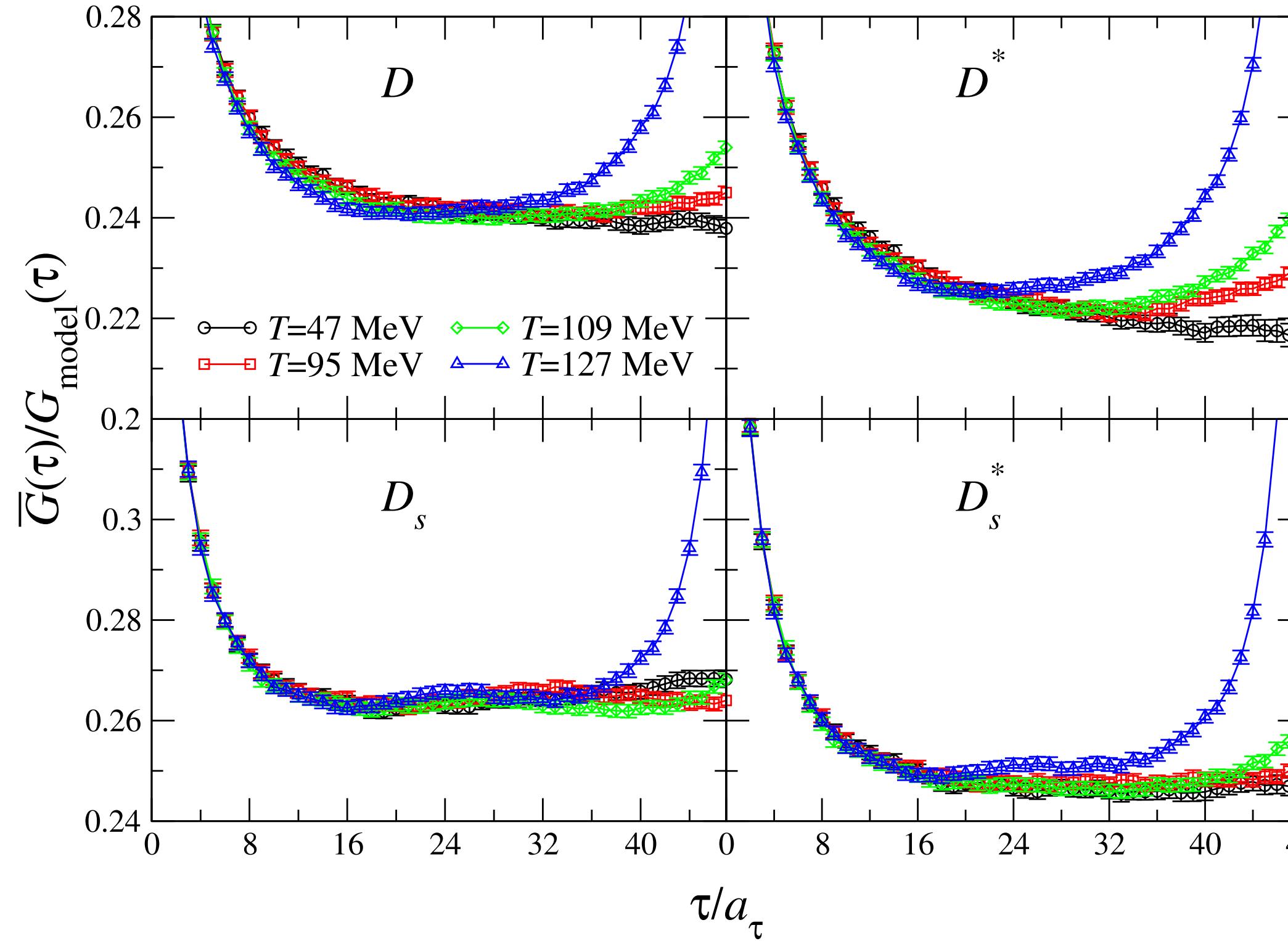
Charmed Mesons

Sergio Chaves

- Not studied at $T \neq 0$ before (Open Charm)
- Results obtained via a ratio $\rightarrow 5\text{MeV}$ accuracy

$$R(\tau; T) = \frac{G(\tau; T)}{G_{\text{model}}(\tau; T)}$$

$$G_{\text{model}}(\tau; T) = Z \frac{\cosh[M_{\text{model}}(\tau - 1/2T)]}{\sinh(M_{\text{model}}/2T)}$$

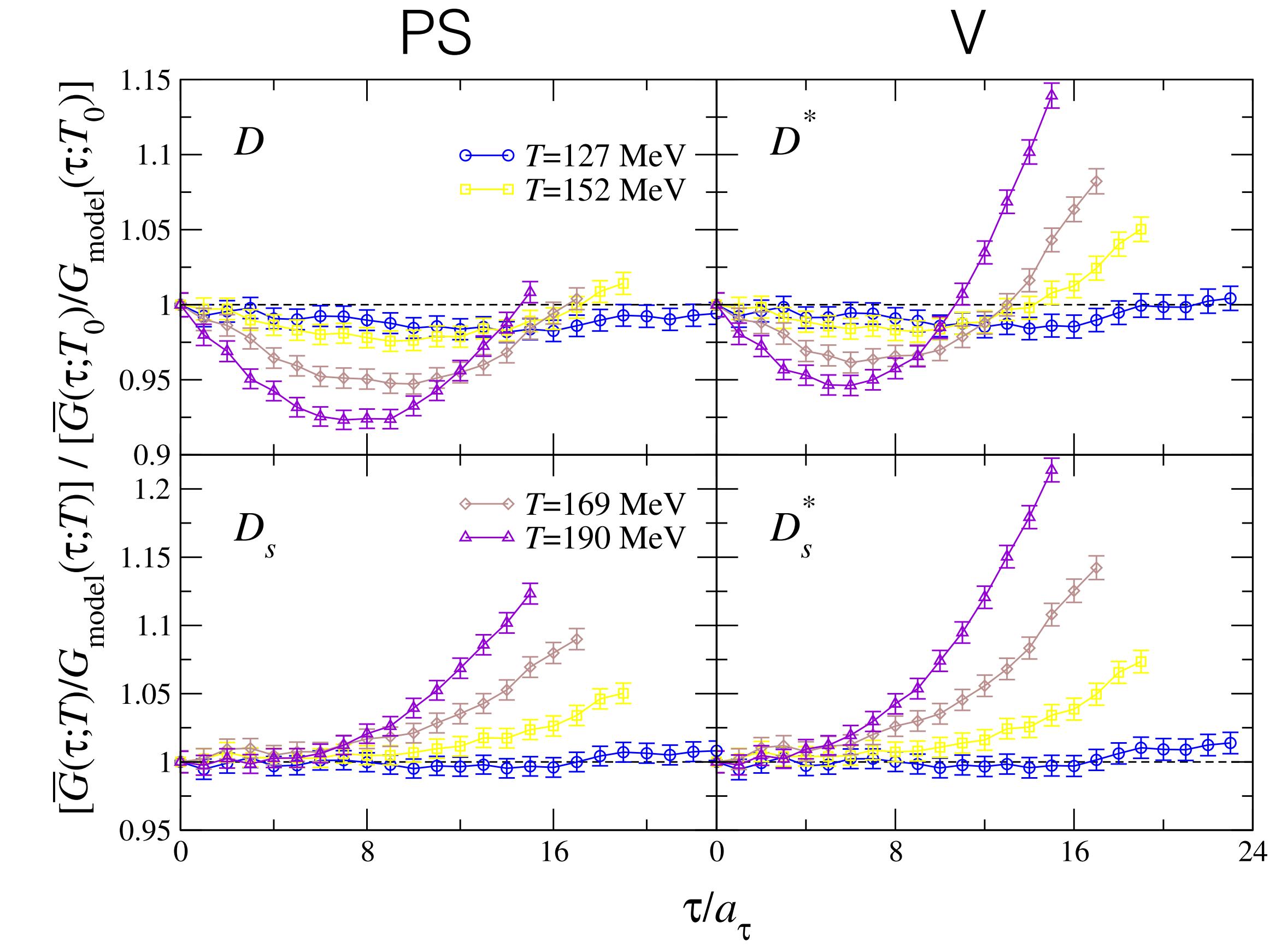
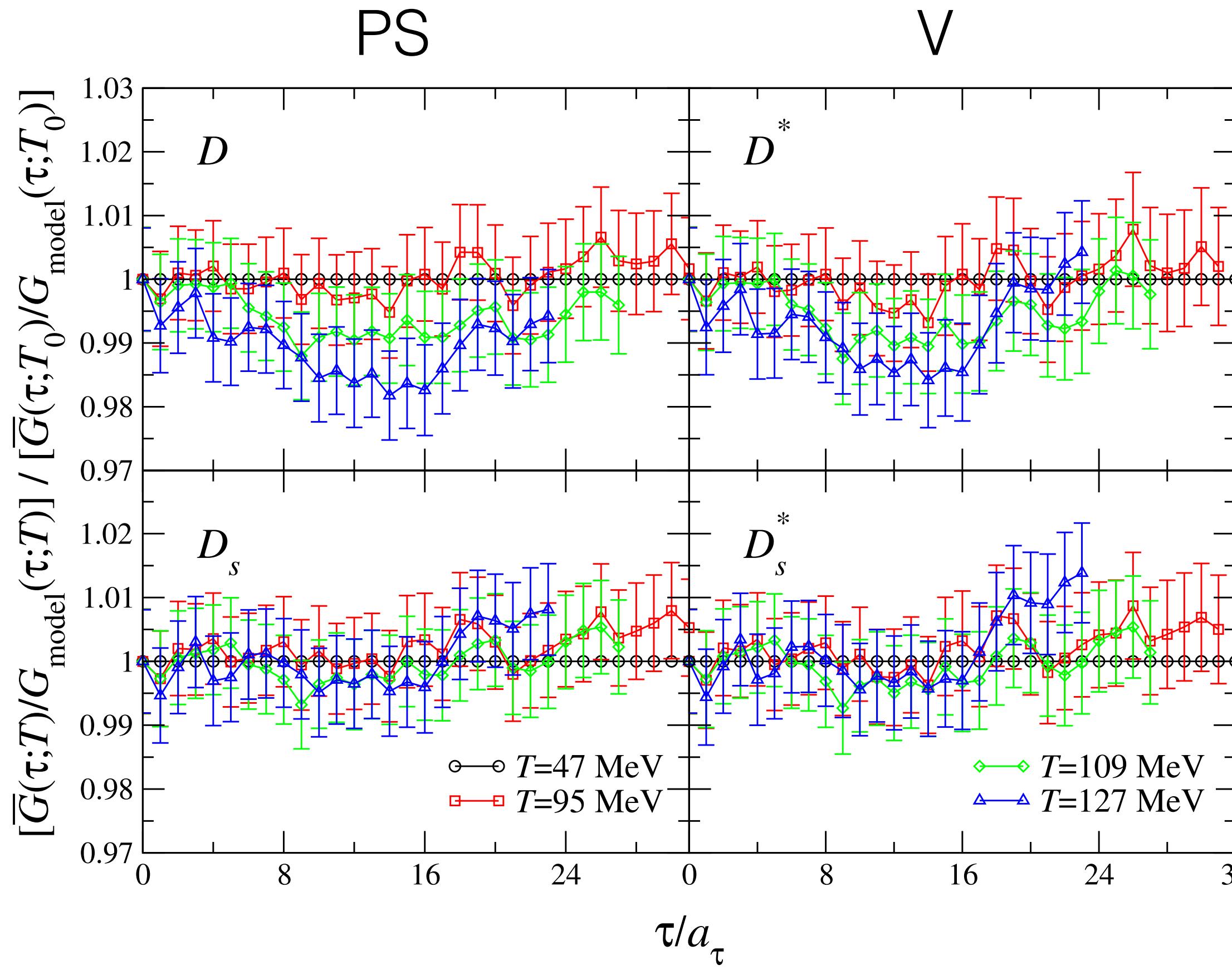


Charmed Mesons - Ratio of Ratios $D_{(s)} & D_{(s)}^*$

Sergio Chaves

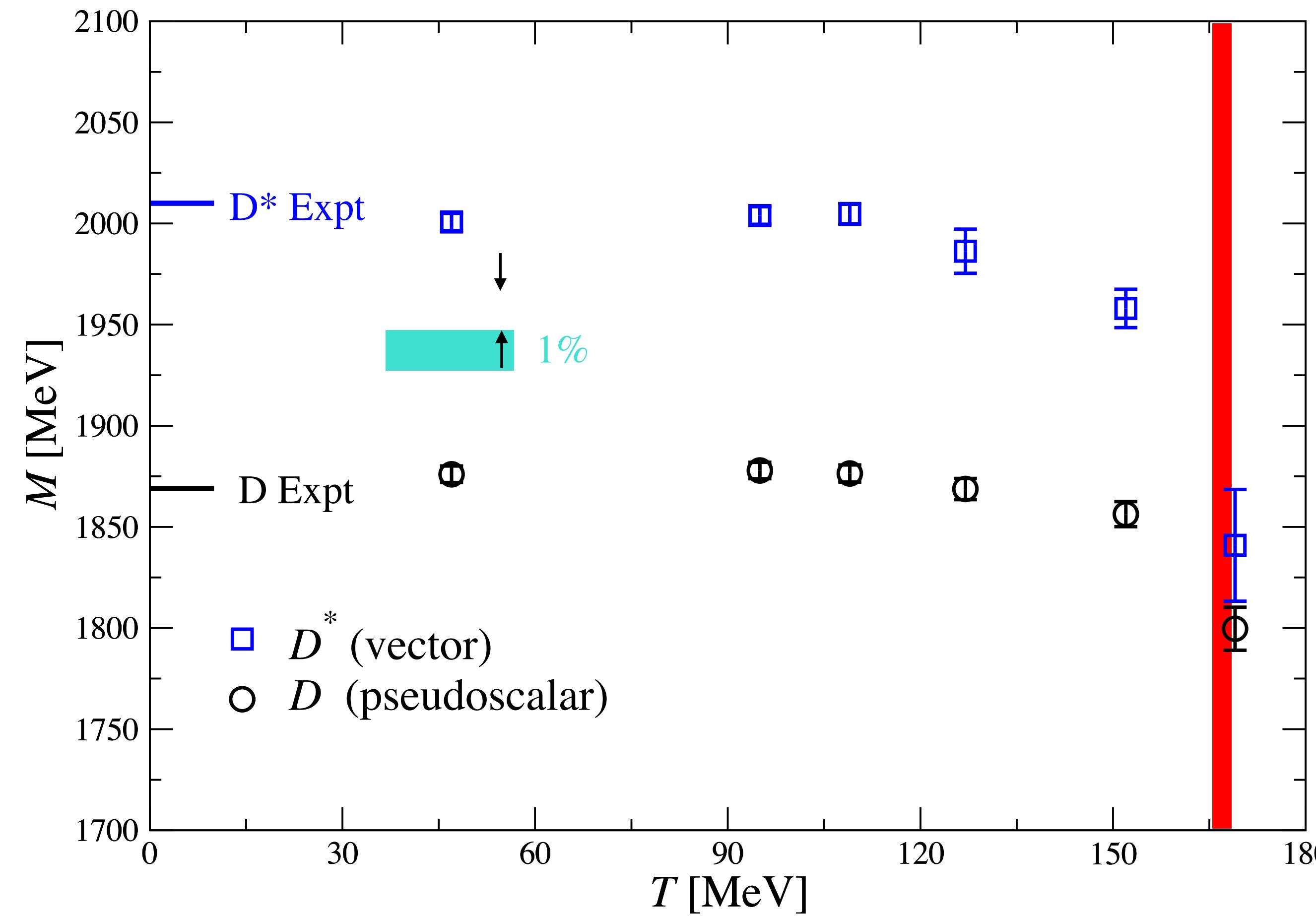
$$RoR(\tau; T, T_0) = \frac{R(\tau; T)}{R(\tau; T_0)}$$

$$R(\tau; T) = \frac{G(\tau; T)}{G_{\text{model}}(\tau; T)}$$



Charmed Mesons $T \neq 0$ D & D^*

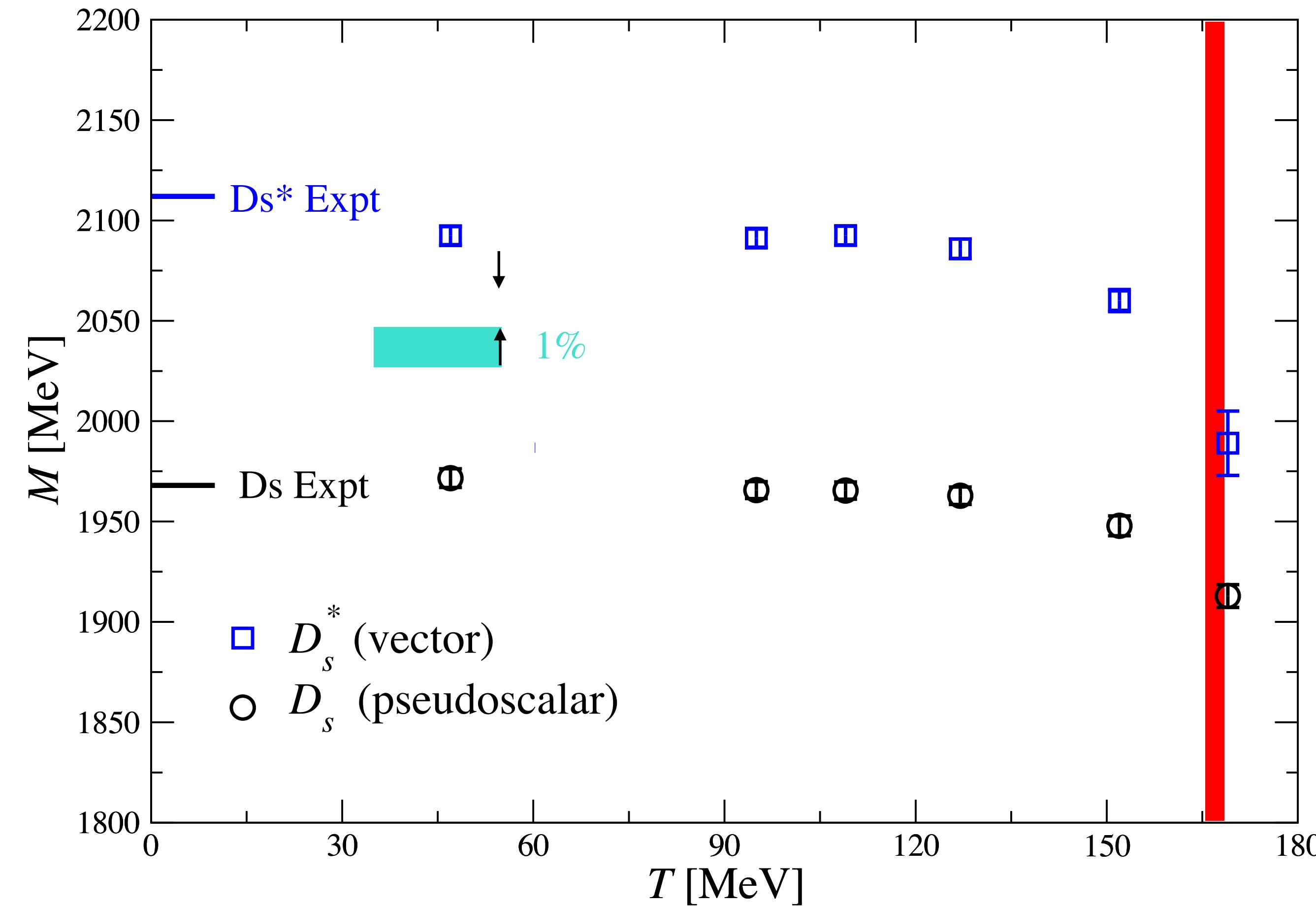
Sergio Chaves



- **temperature effects O(1%)**

Charmed Mesons $T \neq 0$ D_s & D_s^*

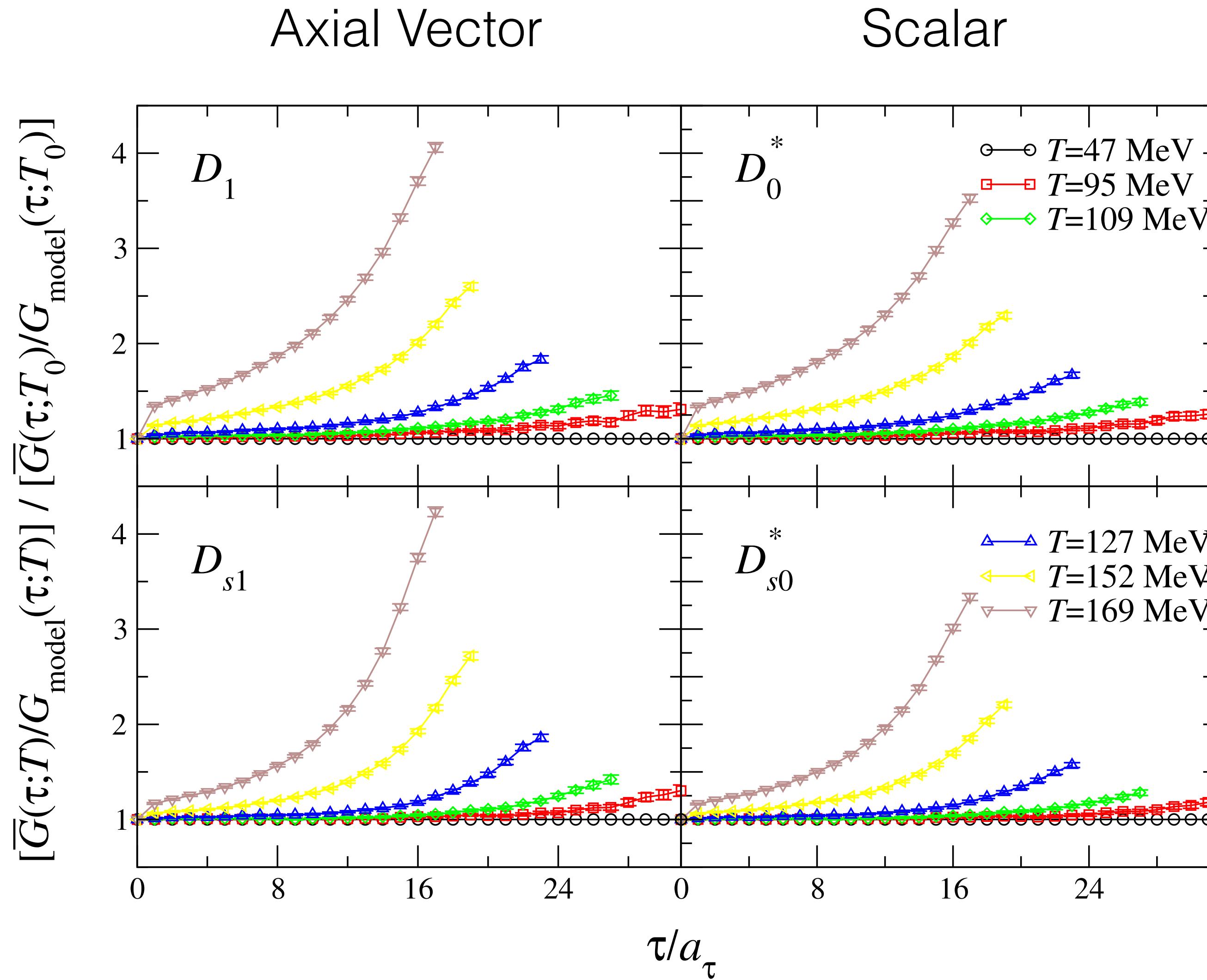
Sergio Chaves



- **temperature effects O(1%)**

Charmed Mesons - Ratio of Ratios $D^*_0(s) \& D_1(s)$

Sergio Chaves



- **Strong thermal effects**

$$RoR(\tau; T, T_0) = \frac{R(\tau; T)}{R(\tau; T_0)}$$

$$R(\tau; T) = \frac{G(\tau; T)}{G_{\text{model}}(\tau; T)}$$

Charmed Mesons - T=0

Sergio Chaves

		J^P	PDG [MeV]	$a_\tau m$	m [MeV]
D	pseudoscalar	0^-	1869.65(5)	0.3086(1)	1876(4)
D^*	vector	1^-	2010.26(5)	0.3291(1)	2001(4)
D_0^*	scalar	0^+	2300(19)	0.3656(14)	2222(10)
D_1	axial-vector	1^+	2420.8(5)	0.3823(70)	2325(43)
D_s	pseudoscalar	0^-	1968.34(7)	0.3243(3)	1972(5)
D_s^*	vector	1^-	2112.2(4)	0.3442(1)	2092(4)
D_{s0}^*	scalar	0^+	2317.8(5)	0.3479(46)	2115(29)
D_{s1}	axial-vector	1^+	2459.5(6)	0.3479(46)	2512(6)

- errors are combined statistical & systematic
- PS and V temperature effects are mild
- scalar and axial-vector temperature effects are significant

Charmed Baryonic Spectrum

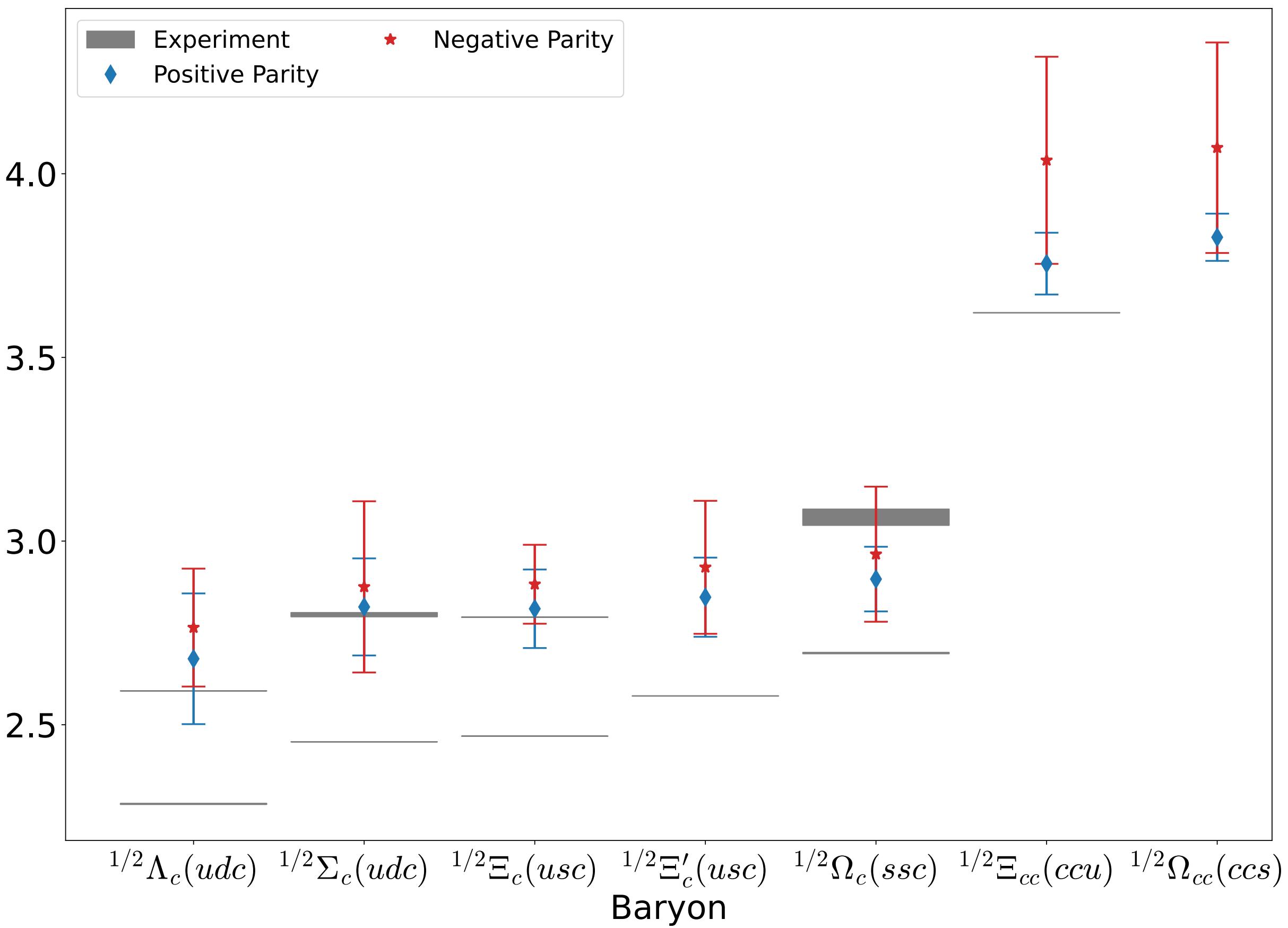
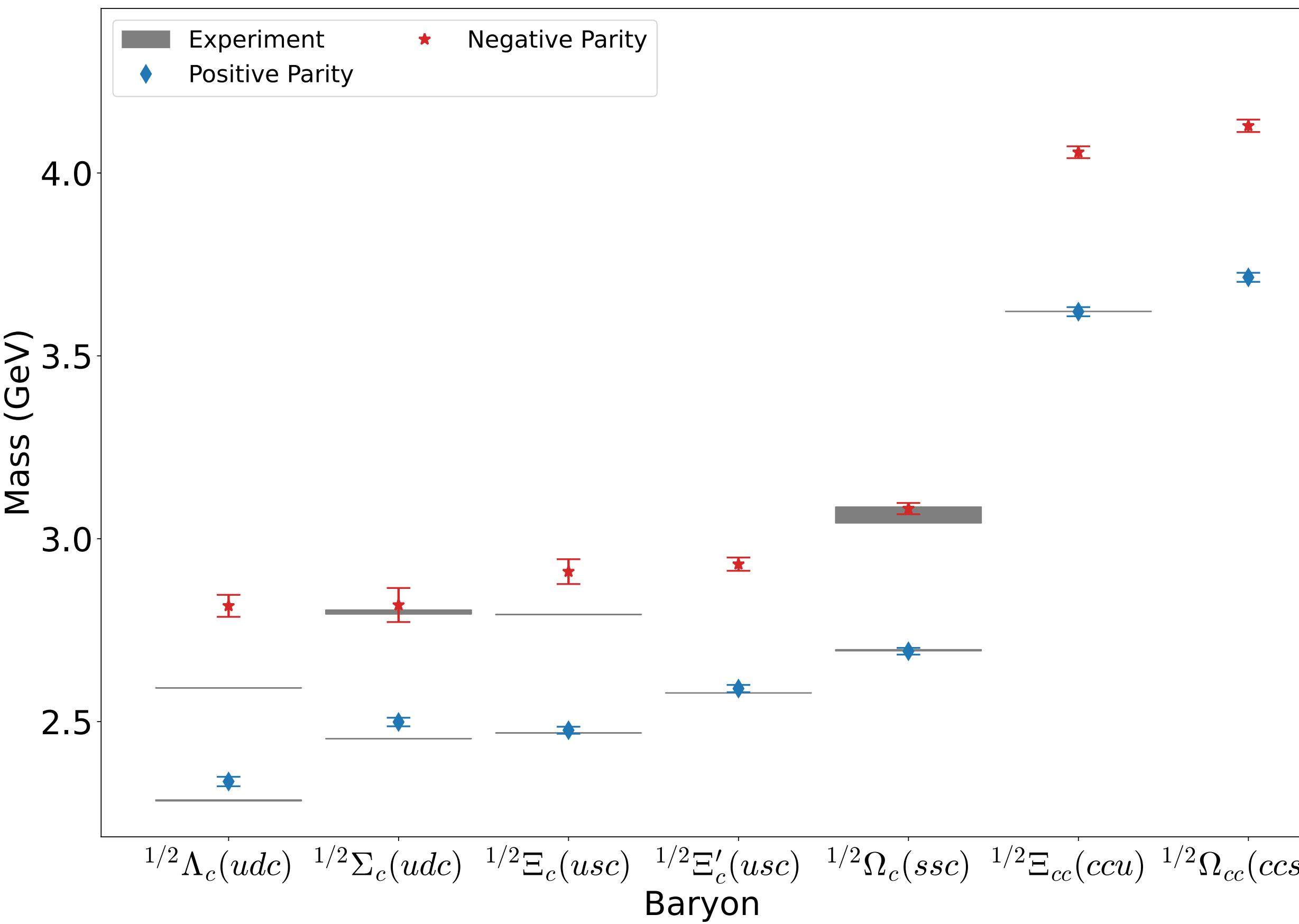
Ryan Bignell (Wednesday 16:50)

T = 47 MeV

$N_\tau = 128$

T = 152 MeV

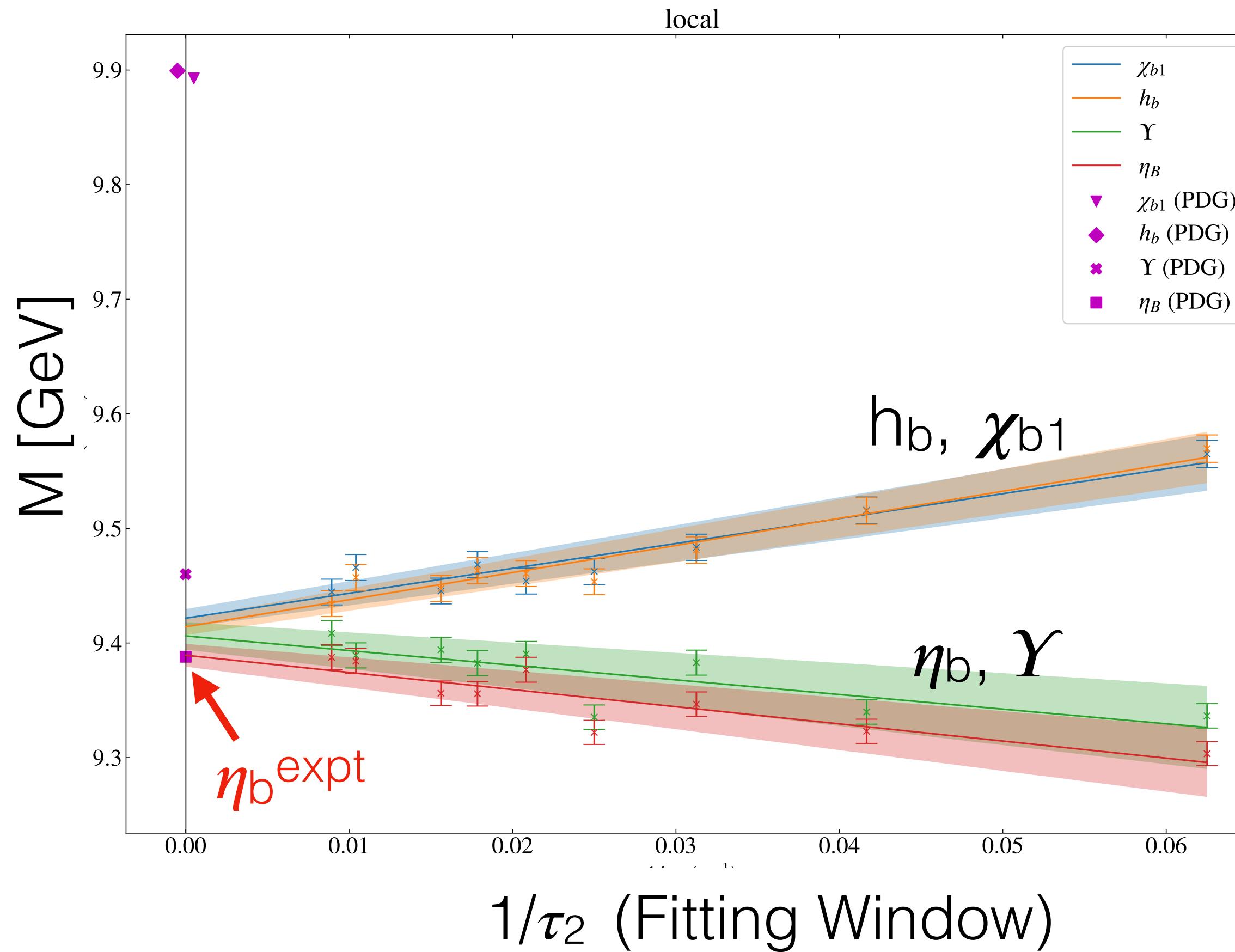
$N_\tau = 40$



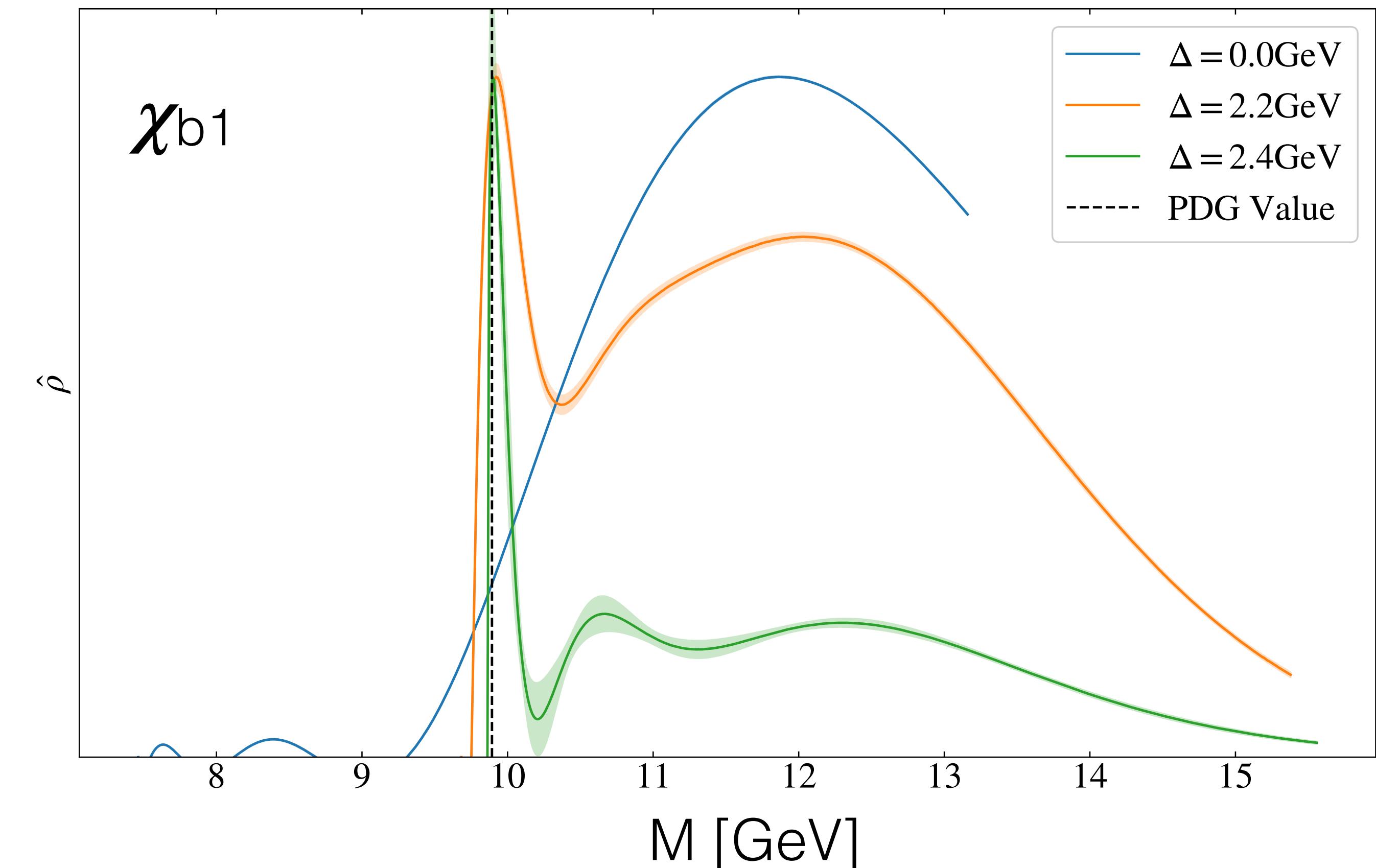
Bottomonium (NRQCD) Spectrum

Ben Page (Wednesday 14:20)

Analysis of **Covariance Mx** of η_b , χ_{b1} , h_b , γ
⇒ η_b mass (via Parisi-Lepage)

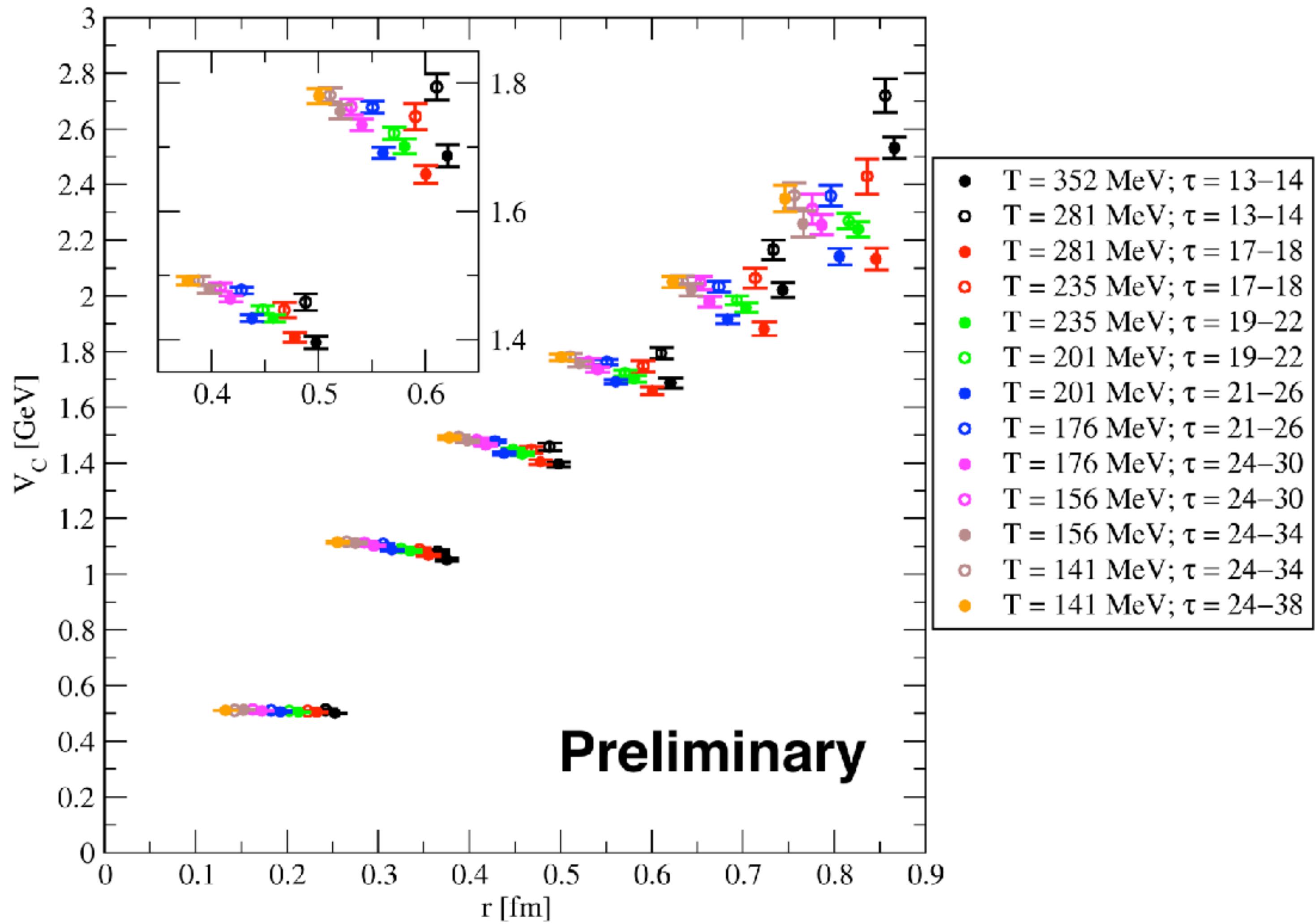


Spectral F'n of χ_{b1} using **Backus-Gilbert**
with **energy shift**



Quark-Antiquark Potentials in Bottomonium (NRQCD)

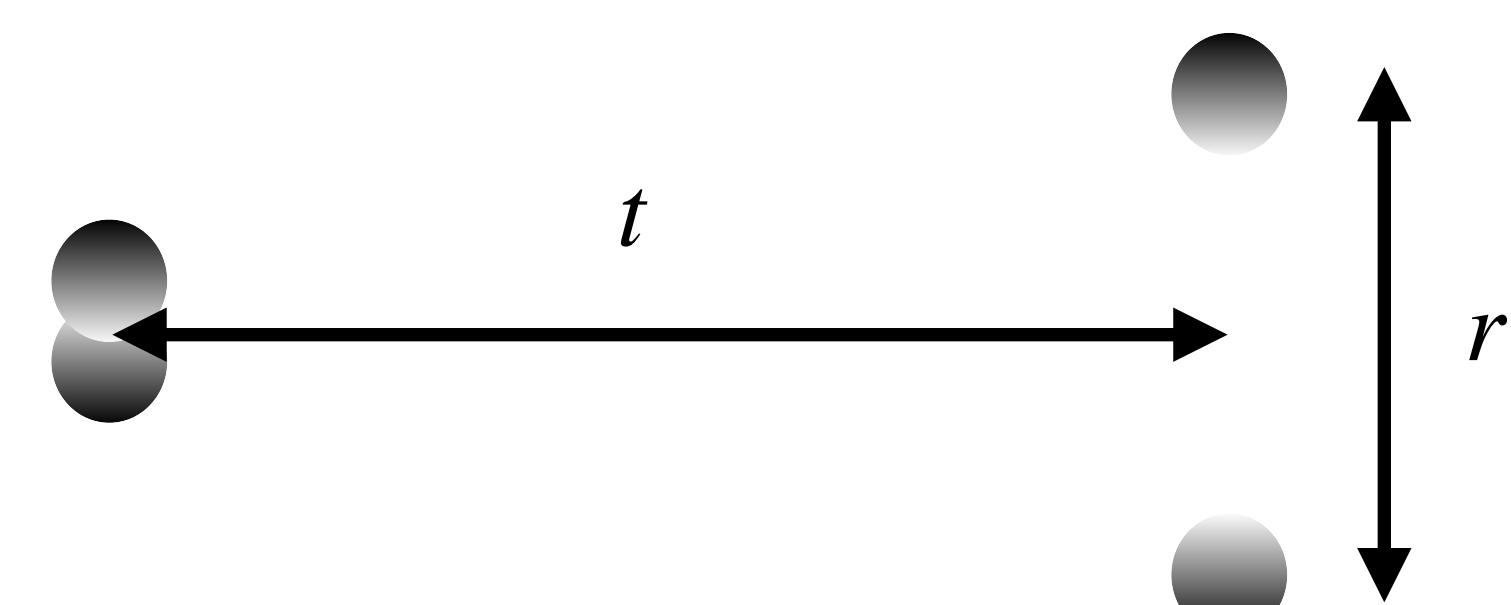
Thomas Spriggs (Wednesday 14:40)



HAL QCD Approach:

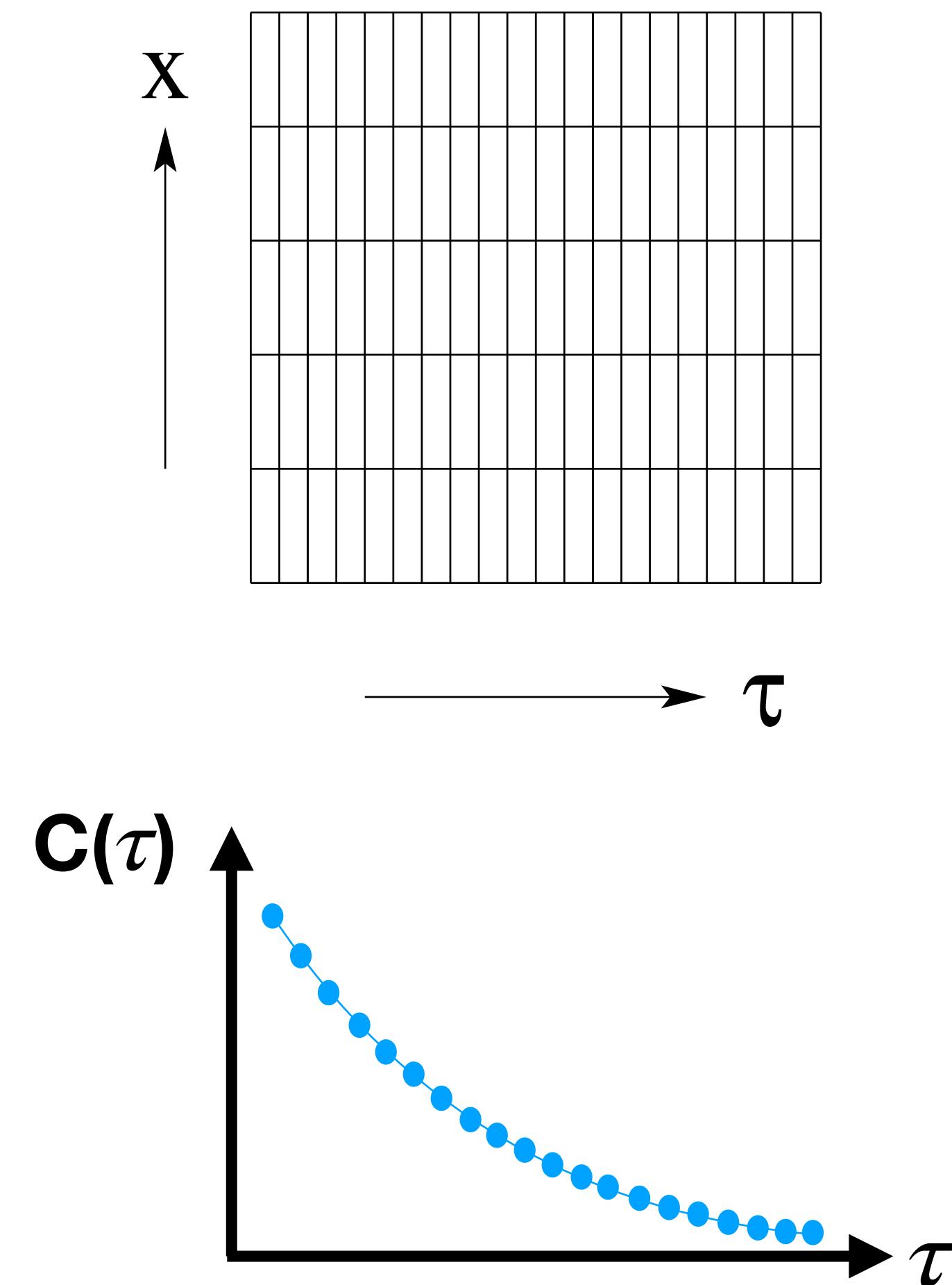
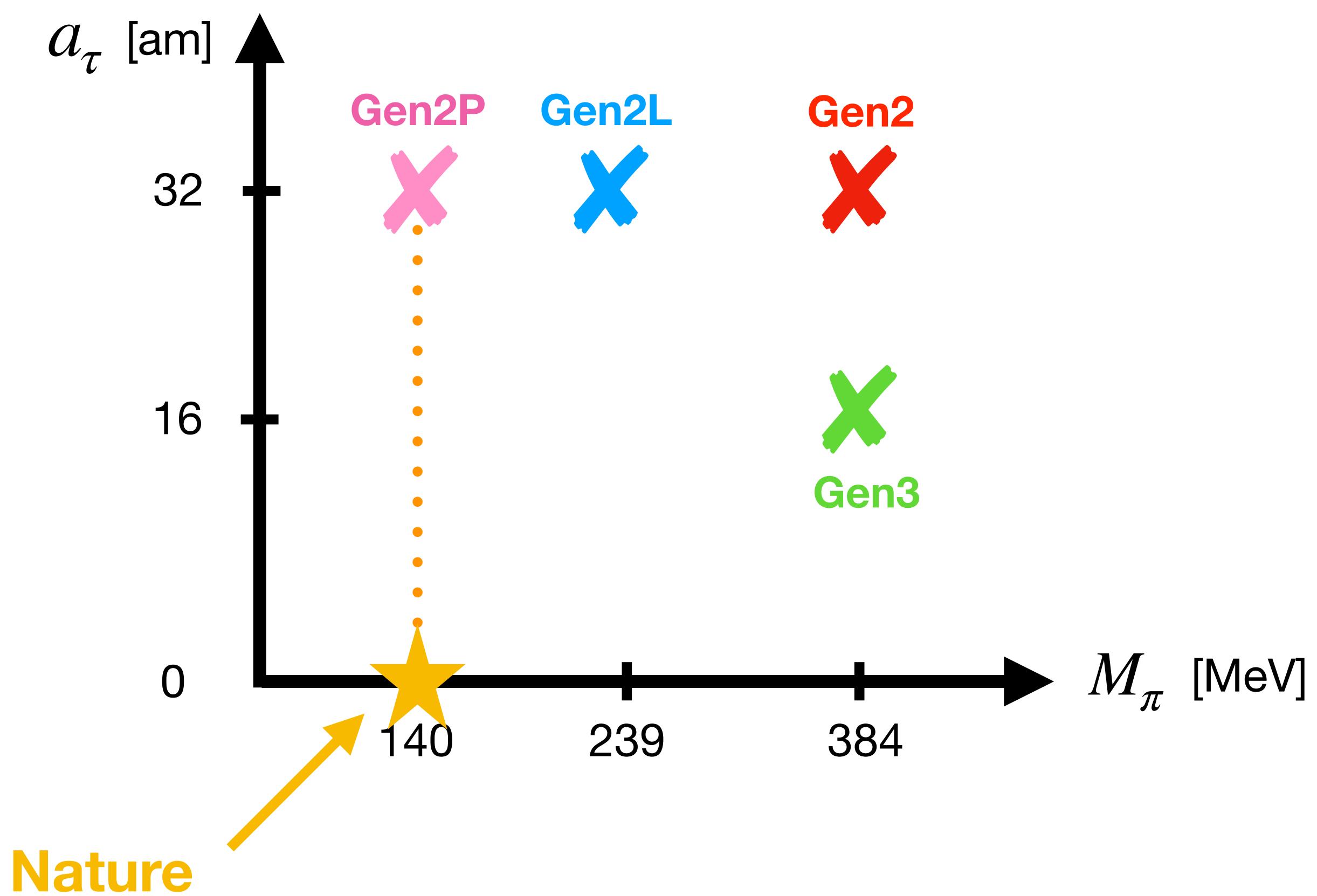
$$H\psi = \left[\frac{p^2}{2m} + V(r) \right] \psi = E\psi$$

$C(t; r)$



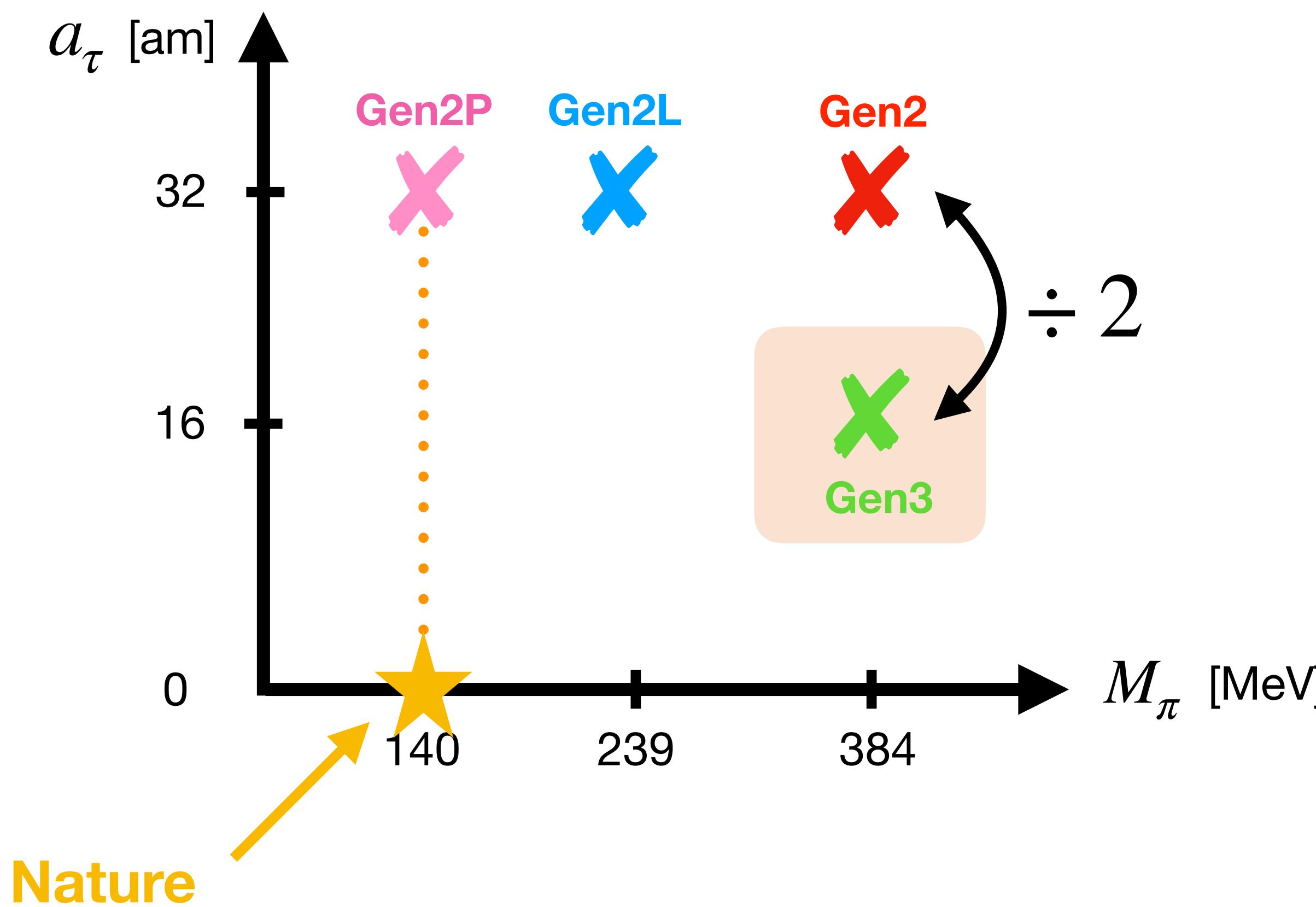
Generation 3 Tuning

Jon-Ivar Skullerud & Ryan Bignell



Generation 3 Tuning

Jon-Ivar Skallerud & Ryan Bignell



Physics motivation:
Doubles our temporal statistics

FOUR Lagrangian parameters:

$g_0^s \ m_0^s \ g_0^\tau \ m_0^\tau$

Spatial Temporal

Gauge Action: Symanzik-improved anisotropic
Fermion Action: Wilson-clover, tree-level tadpole
with stout-smeared links

Generation 3 Tuning

Jon-Ivar Skullerud & Ryan Bignell

FOUR Lagrangian parameters:

$$a_\tau (\text{Gen3}) = 1/2 a_\tau (\text{Gen2}) \quad (\text{from Wilson Flow})$$

$$a_s (\text{Gen3}) = a_s (\text{Gen2}) \quad (\text{from Wilson Flow})$$

$$\text{anisotropy: } \xi^{\text{fermion}} = \xi^{\text{gauge}} \quad (\text{from meson dispersion relation})$$

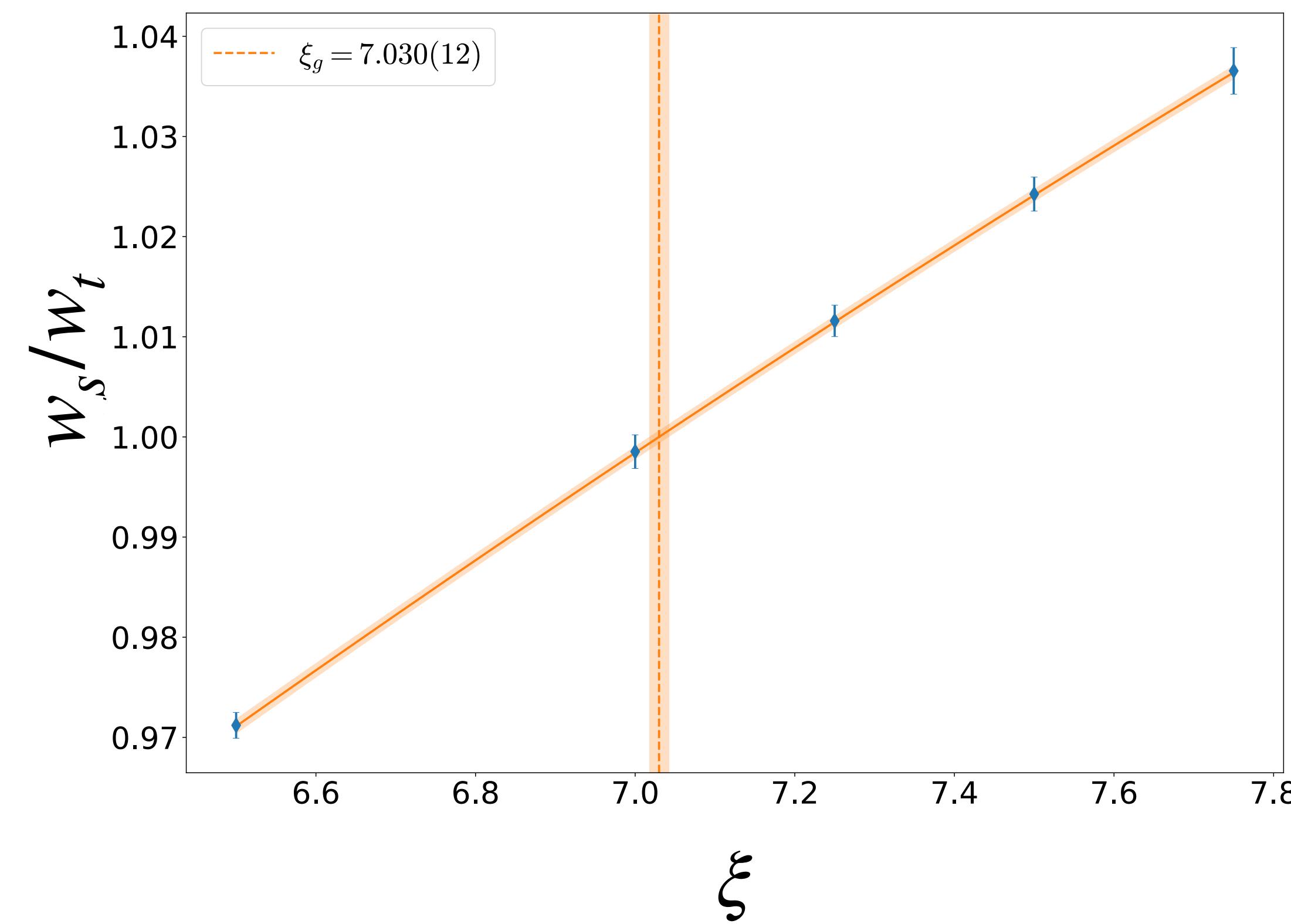
$$M_\pi (\text{Gen3}) = M_\pi (\text{Gen2}) \quad (\text{from } M_{\text{PS}} / M_V)$$

- Search in **FOUR** dimensional parameter space: each point from Monte Carlo
- Clover coefficients are tadpole improved and therefore require plaquette
- Initial parameter search with 3 degenerate quark flavours
- Move to 2+1 flavour with strange = physical and 2 light given by $M_\pi (\text{Gen3}) = M_\pi (\text{Gen2})$
- Thermalisation is short because starting config is at neighbourhood parameter value.
- ~100 parameter choices so far (!!)

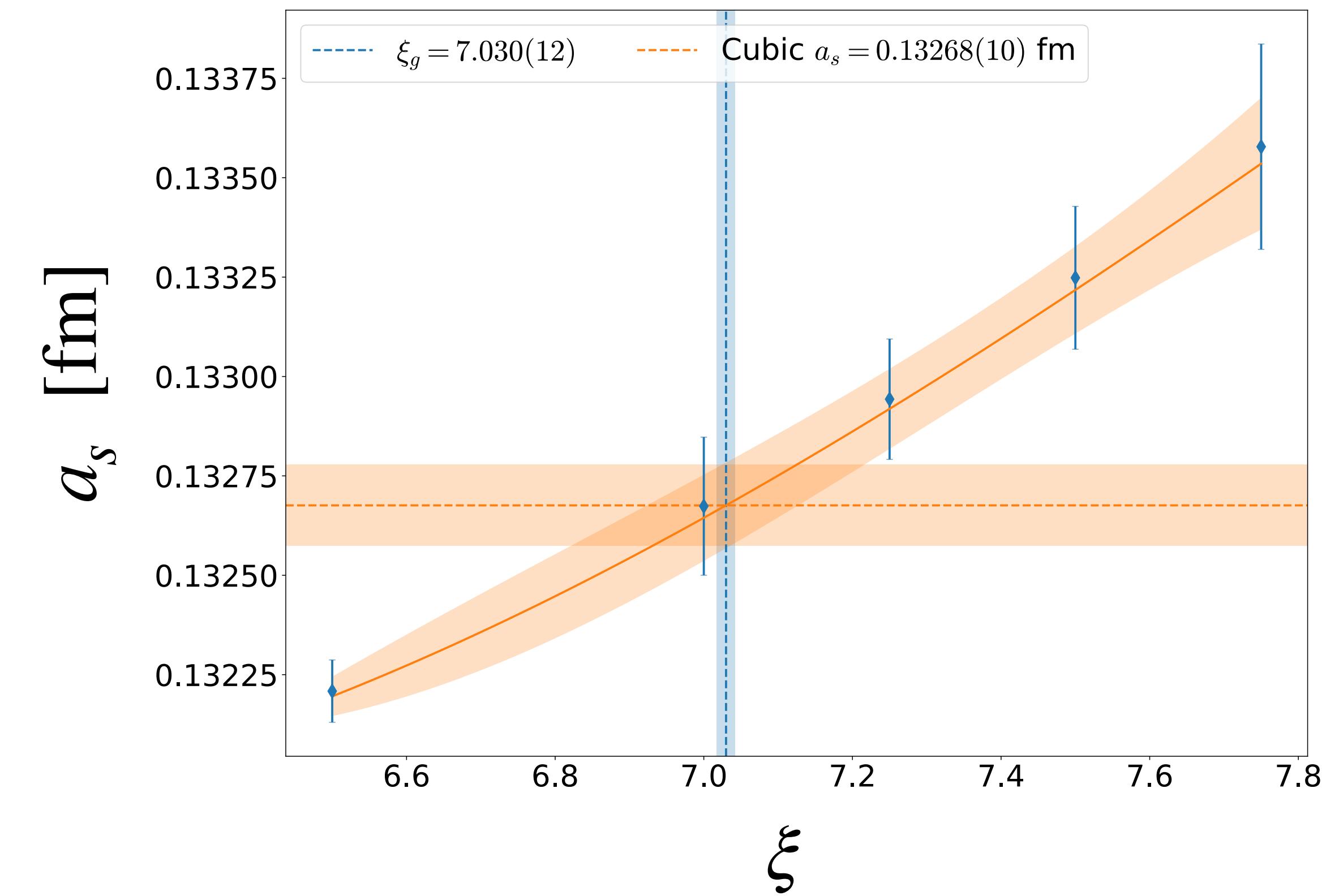
Generation 3 Tuning - Wilson Flow

Jon-Ivar Skullerud & Ryan Bignell

$$a_\tau (\text{Gen3}) = 1/2 a_\tau (\text{Gen2})$$



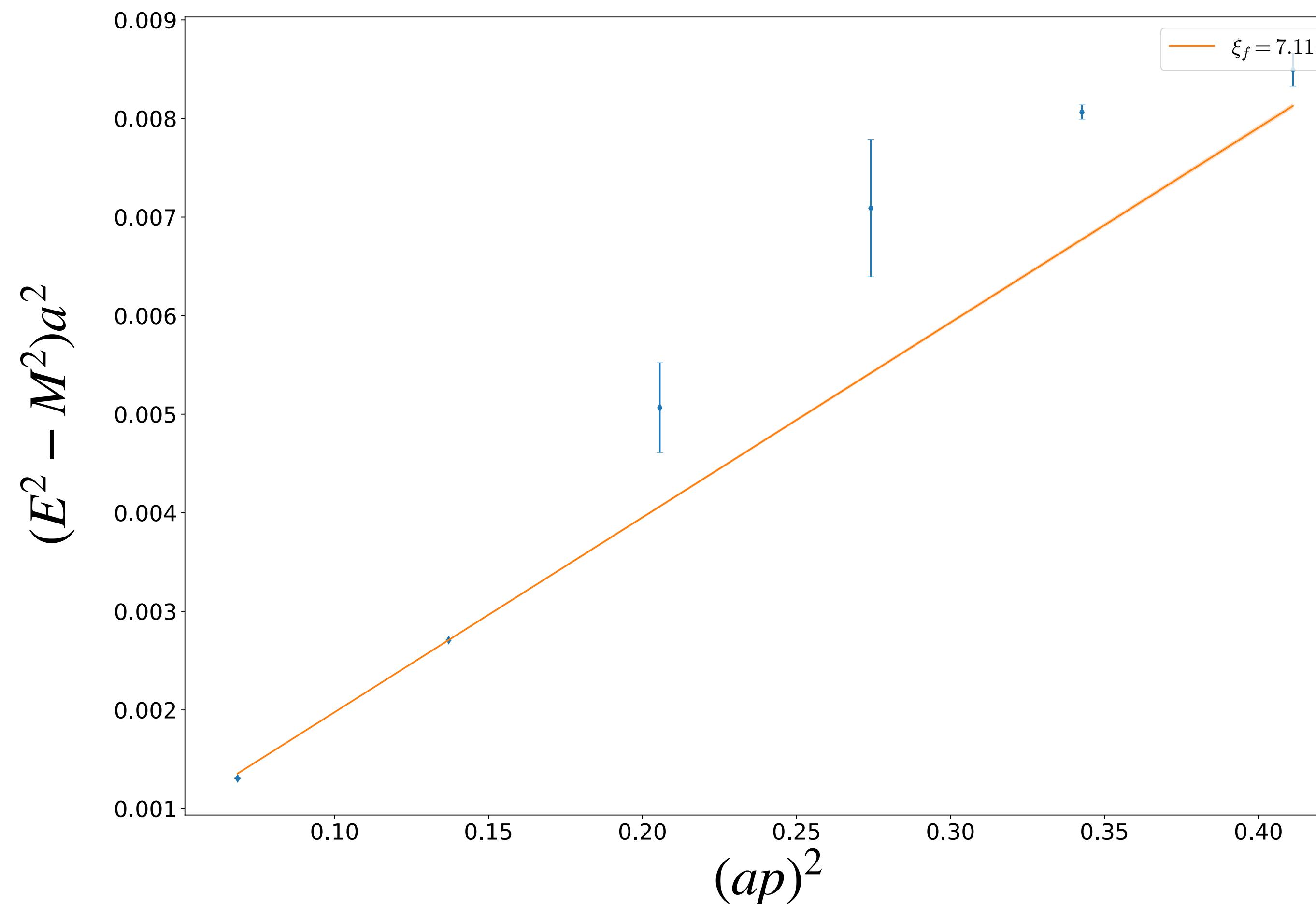
$$a_s (\text{Gen3}) = a_s (\text{Gen2})$$



Generation 3 Tuning - Dispersion Relation

Jon-Ivar Skullerud & Ryan Bignell

anisotropy: $\xi^{\text{fermion}} = \xi^{\text{gauge}}$



Summary

- Overview of FASTSUM approach
 - anisotropic, designed for spectroscopy
- Charmed mesons
 - PS & V have little thermal effect, Scalar & Axialvector much more
- Charmed baryonic spectrum (Ryan Bignell Wed 16:50)
- Bottomonium (NRQCD) spectrum (Benjamin Page Wed 14:20)
- Interquark potentials in Bottomonium (Thomas Spriggs Wed 14:40)
- Gen3 tuning
 - 1/2 temporal lattice spacing

Spare Slides

Study of Numerical Methods

- | | | |
|---|---|--|
| 1. Exponential (Conventional δ f'ns) | } | Maximum Likelihood
(Minimise χ^2) |
| 2. Gaussian Ground State (+ δ f'n excited) | | |
| 3. Moments of Correlation F'ns | | Direct Method - “no” fit |
| 4. BR Method | } | Bayesian Approaches |
| 5. Maximum Entropy Method | | |
| 6. Kernel Ridge Regression | | Machine Learning |
| 7. Backus Gilbert | | from Geophysics |