Quarkonium and B mesons at Non-Zero Temperature on Anisotropic Lattices

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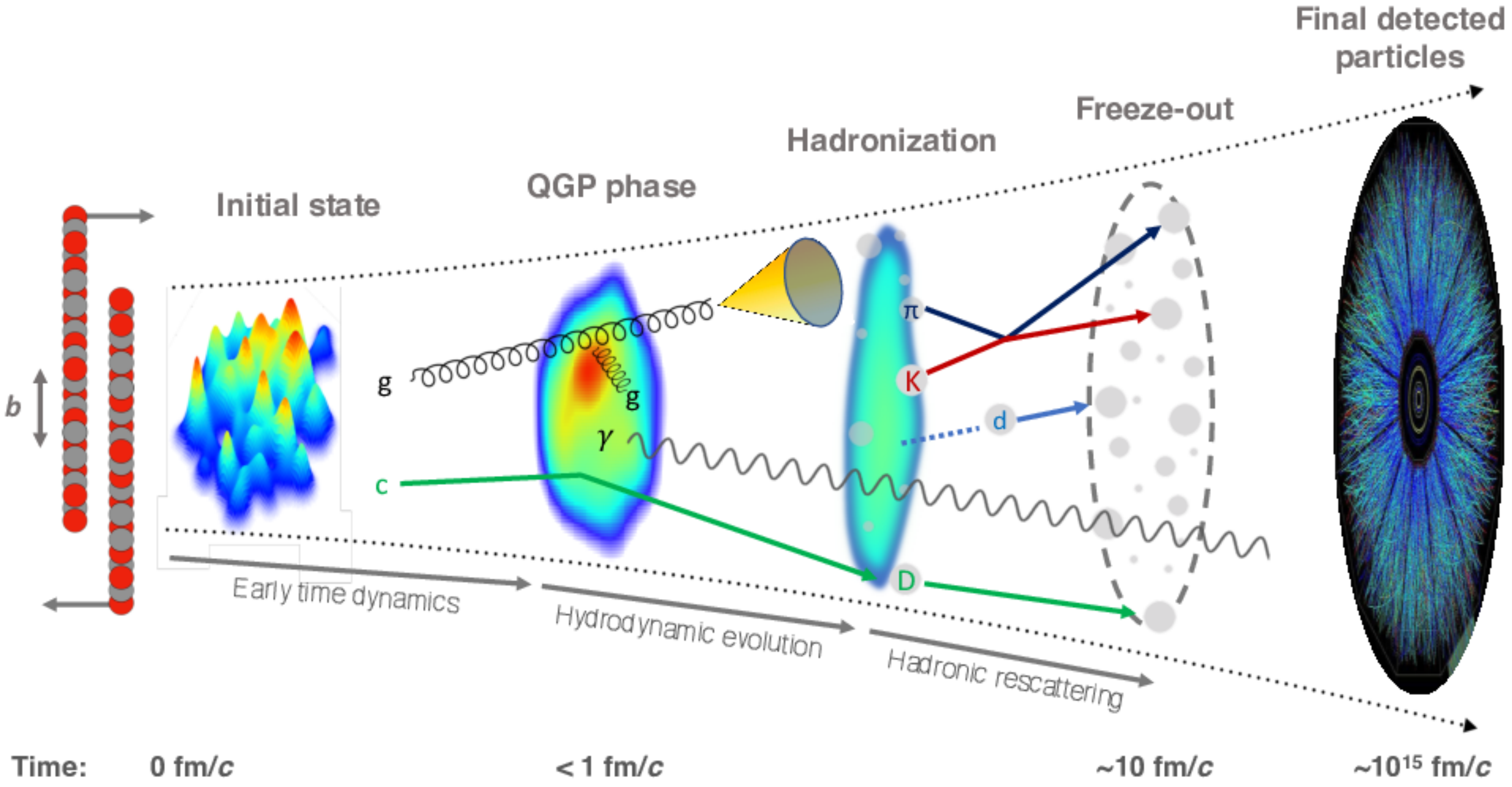
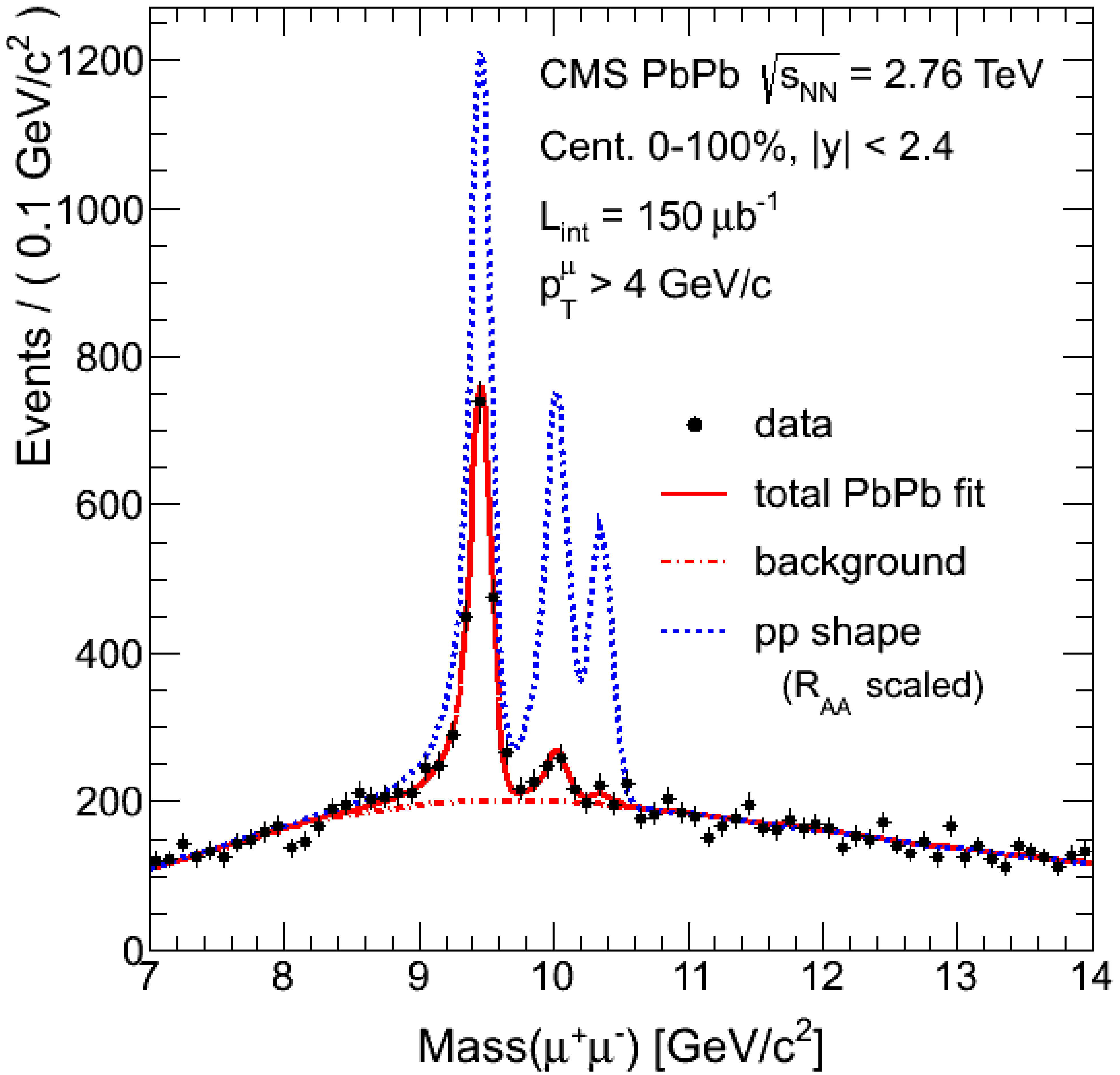
Work in progress
with FASTSUM collaboration, Rachel Horohan D'Arcy, Jon-Ivar Skullerud (B meson), Ryan Bignell, Sol Noh (Quarkonium)

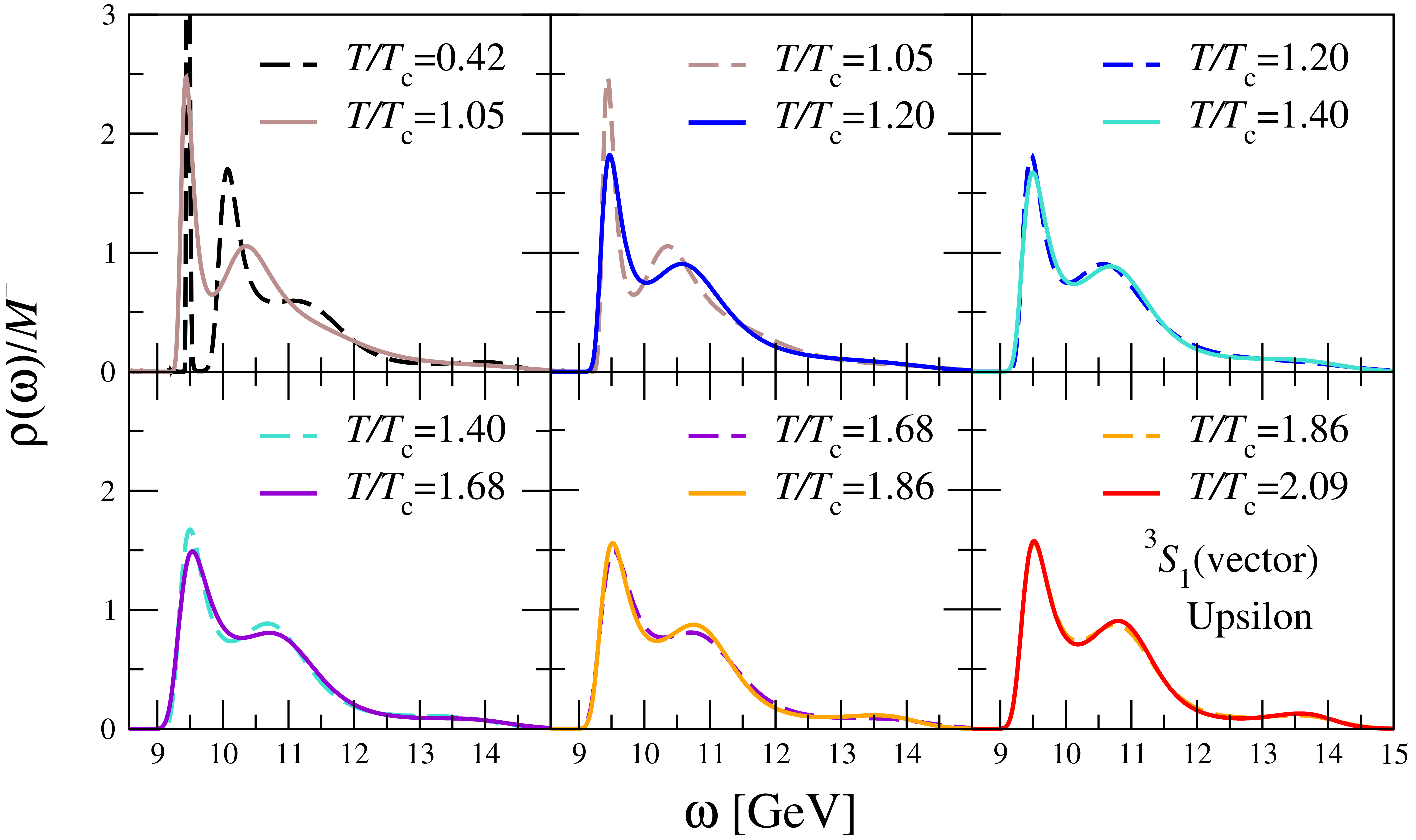


Hot QCD White Paper – Arslandok, M. et al – arXiv:2303.17254

Bottom quark is a “good” probe of QGP



CMS-collaboration, PRL 109 (2012) 222301



S-wave, Upsilon spectral function, FASTSUM collaboration, JHEP07 (2014) 097

FASTSUM (Frascati−Argonne−Swansea−Trinity−Sejong−Utah−Maynooth) collaboration

1. QCD Thermodynamics with Anisotropic lattices ($a_s \neq a_\tau$)
2. Symanzik improved anisotropic gauge action with tree−level mean−field coefficients
3. $N_f = 2 + 1$ flavors of mean−field improved Wilson−clover fermion with stout−smeared links
4. Fixed scale approach ($T = 1/N_\tau a_\tau$, a_τ fixed, N_τ changed)
5. Several sets of gauge field ensembles, Gen 1, Gen 2, Gen 2L, Gen 3

TABLE I. Details of the FASTSUM Generation 2, 2L and 3 ensembles with $n_f = 2+1$ flavours on $N_s^3 \times N_\tau$ lattices: the number of lattice points N_s in the spatial direction (*in Generation 3, $N_s = 24$ for $N_\tau = 256$); the lattice spacings a_s, a_τ; the renormalised anisotropy $\xi = a_s/a_\tau$; the pion mass m_π; the chiral transition temperature T_c determined using the renormalised chiral condensate. The strange quark mass is approximately at its physical value.

	Generation 2	Generation 2L	Generation 3
N_s	24	32	32 (*24)
a_s (fm)	0.1205(8)	0.1121(3)	0.1080(6)
a_τ^{-1} (GeV)	5.63(4)	6.079(13)	12.82(9)
$\xi = a_s/a_\tau$	3.444(6)	3.453(6)	7.02(3)
m_π (MeV)	384(4)	239(1)	380(1)
T_c (MeV)	181(1)	167(3)	182(1)
Refs.	[48, 49]	[50, 51]	[52, 53]

TABLE II. Temporal extent N_τ of the lattices in the three generations, with the corresponding temperature T expressed in MeV and in units of T_c.

Generation 2			Generation 2L			Generation 3		
N_τ	T (MeV)	T/T_c	N_τ	T (MeV)	T/T_c	N_τ	T (MeV)	T/T_c
128	44	0.24	128	47	0.42	256	50	0.28
			64	95	0.59	128	100	0.55
			56	109	0.67	112	114	0.64
48	117	0.63	48	127	0.78	96	133	0.73
40	141	0.76	40	152	0.94	80	160	0.88
						76	169	0.93
36	156	0.84	36	169	1.04	72	178	0.98
						68	188	1.04
32	176	0.95	32	190	1.17	64	200	1.10
28	201	1.09	28	217	1.34	56	229	1.26
24	235	1.27	24	253	1.56	48	267	1.47
20	281	1.52	20	304	1.87	40	320	1.76
						36	356	1.96
16	352	1.90	16	380	2.34	32	400	2.20
			12	507	3.12	24	534	2.93
			8	760	4.55			

B−meson
with Gen 2 and Gen 2L

CMS, JHEP02(202025)195

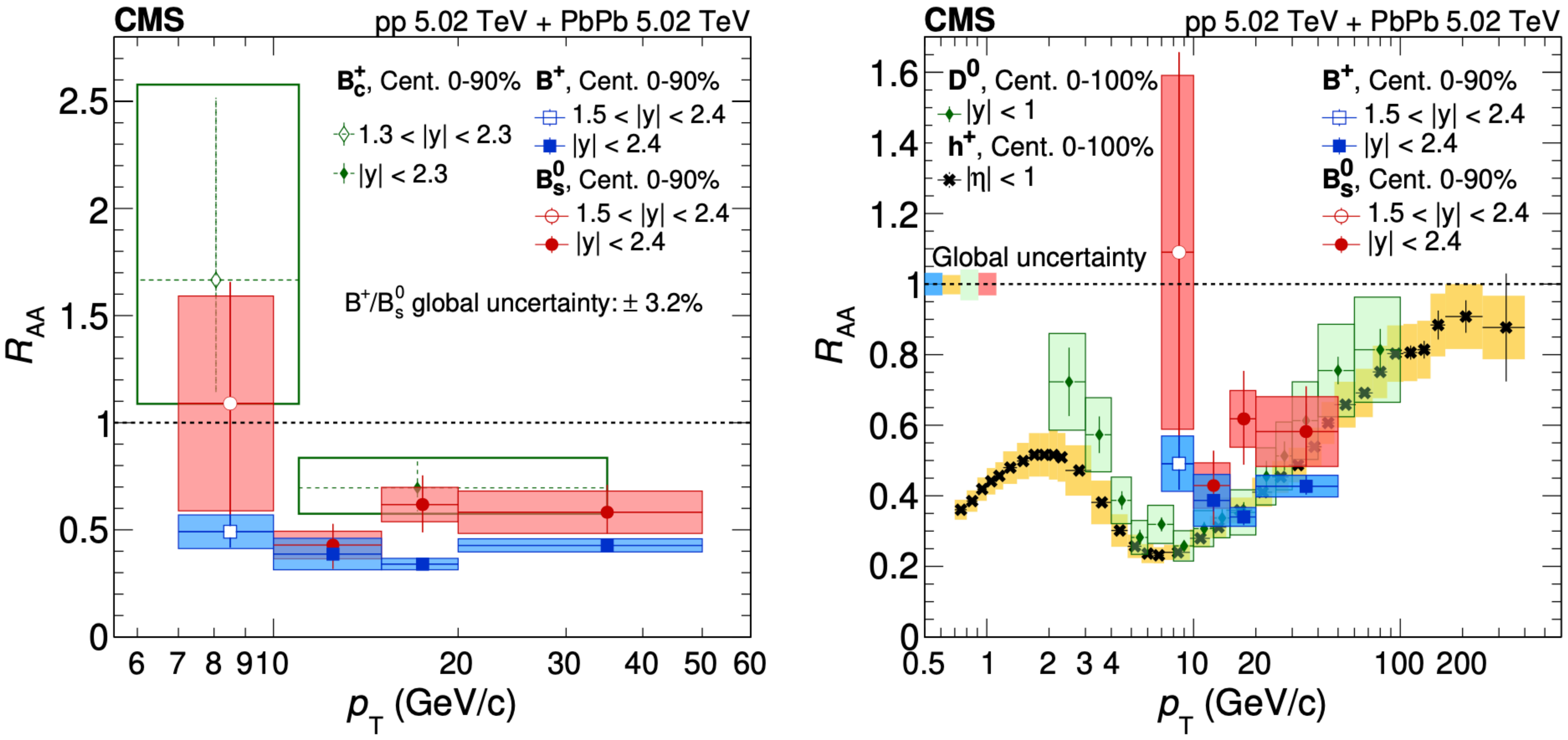


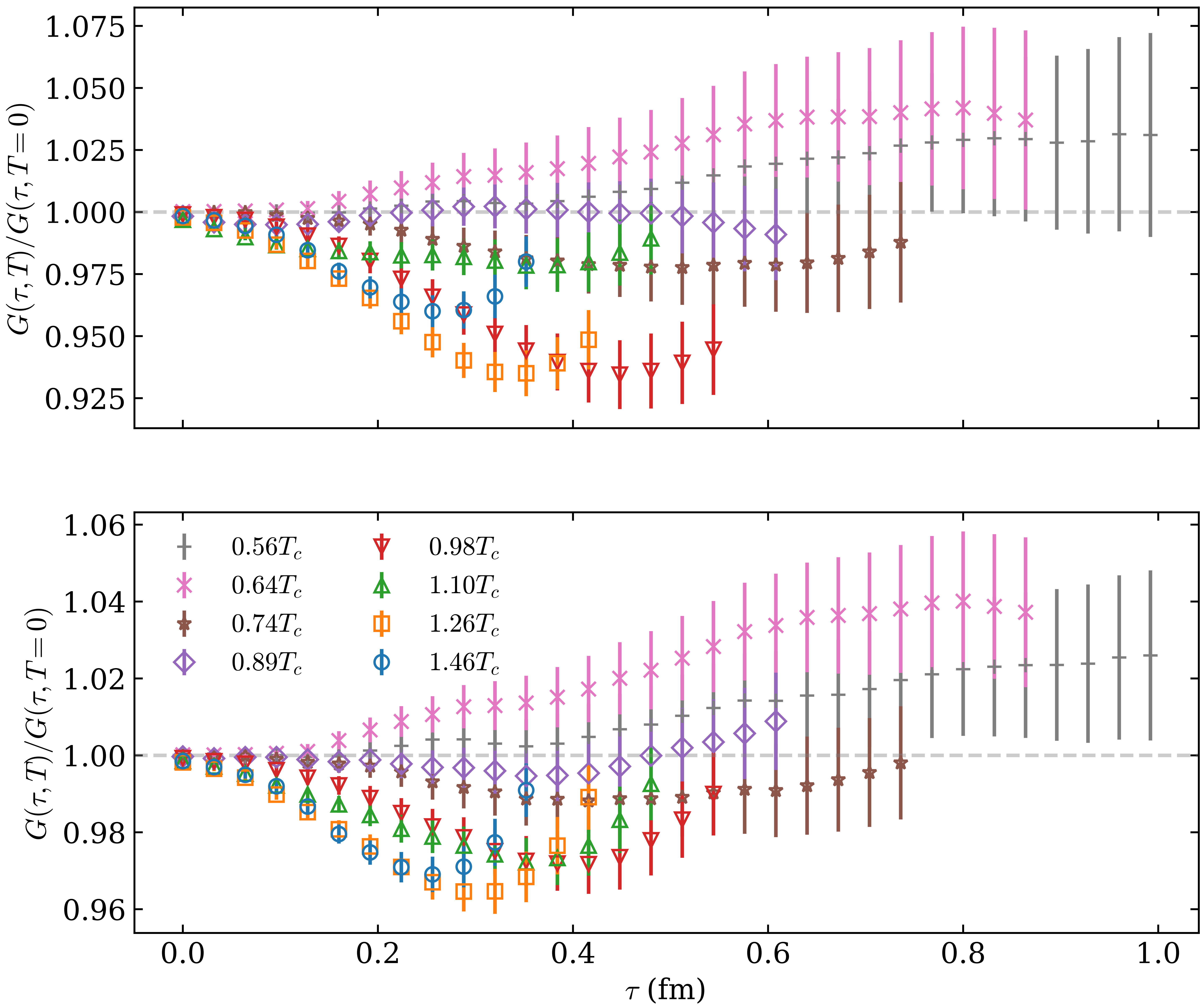
Figure 4. Comparison of the nuclear modification factor as a function of p_T of B^+ and B_s^0 mesons with B_c mesons [27] (left) as well as with D^0 mesons [88] and inclusive charged hadrons [60] (right) in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The vertical bars (boxes) correspond to statistical (systematic) uncertainties. The horizontal bars reflect the bin widths. The global systematic uncertainties, written in text on the left plot and depicted in shaded boxes around $R_{AA} = 1$ on the right plot, comprise the uncertainties in T_{AA}, the number of minimum-bias events, and the luminosity in ppcollisions. The dashed lines and the open boxes in the B_c data (left plot) represent bin-to-bin-uncorrelated and total uncertainties, respectively.

$$\Psi_q = \begin{pmatrix} \psi_q^f \\ \psi_q^b \end{pmatrix}, \quad \Psi_Q = \begin{pmatrix} 0 \\ \psi_Q^b \end{pmatrix}$$

$$G(\tau, T) = -Tr\left(\Gamma S_q(m,n)\Gamma S_Q^\dagger(m,n)\right)$$

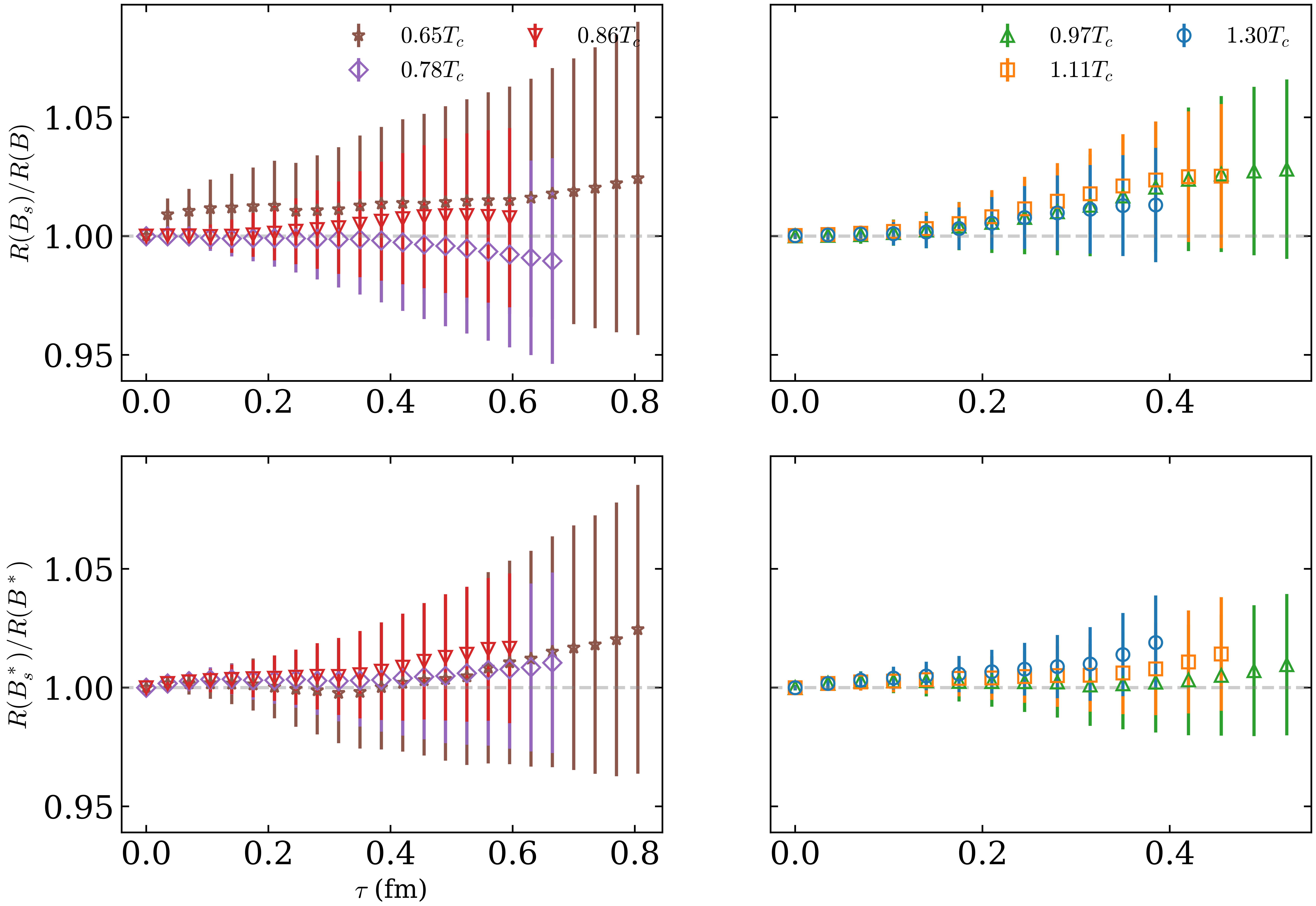
cf. $T = 0$ relativistic light quark propagator + NRQCD heavy quark study, HPQCD collaboration, arXiv:1010.3848

Gen 2L



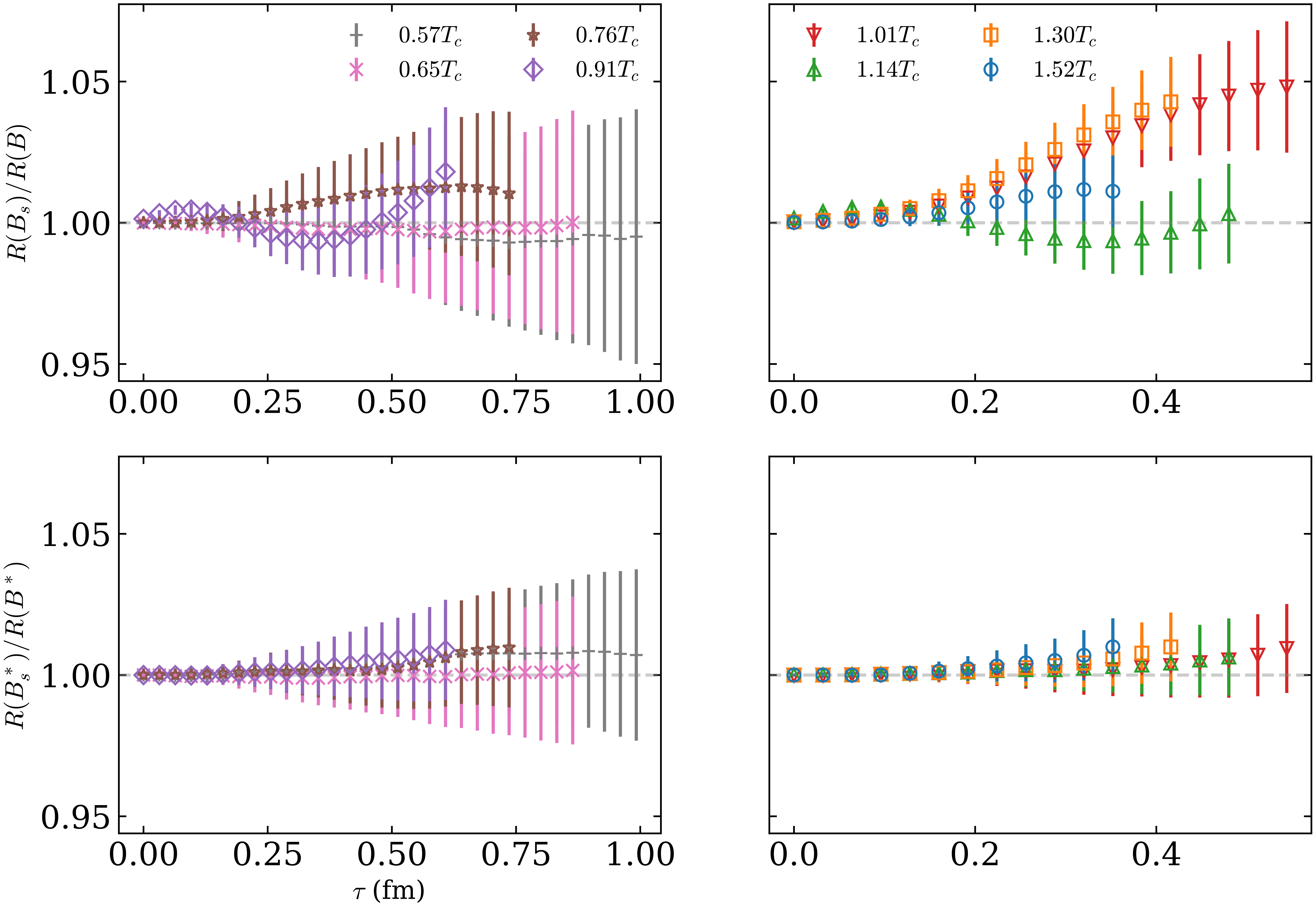
1.075
1.050
1.025
1.000
0.975
0.950
0.925
$G(\tau,T)/G(\tau,T=0)$
1.06
1.04
1.02
1.00
0.98
0.96
$G(\tau,T)/G(\tau,T=0)$
$0.56T_c$
$0.64T_c$
$0.74T_c$
$0.89T_c$
$0.98T_c$
$1.10T_c$
$1.26T_c$
$1.46T_c$
0.0
0.2
0.4
0.6
0.8
1.0
τ (fm)

Gen 2



$0.65T_c$
$0.86T_c$
$0.78T_c$
$0.97T_c$
$1.30T_c$
$1.11T_c$
$R(B_s)/R(B)$
$R(B_s^*)/R(B^*)$
1.05
1.00
0.95
0.0
0.2
0.4
0.6
0.8
τ (fm)

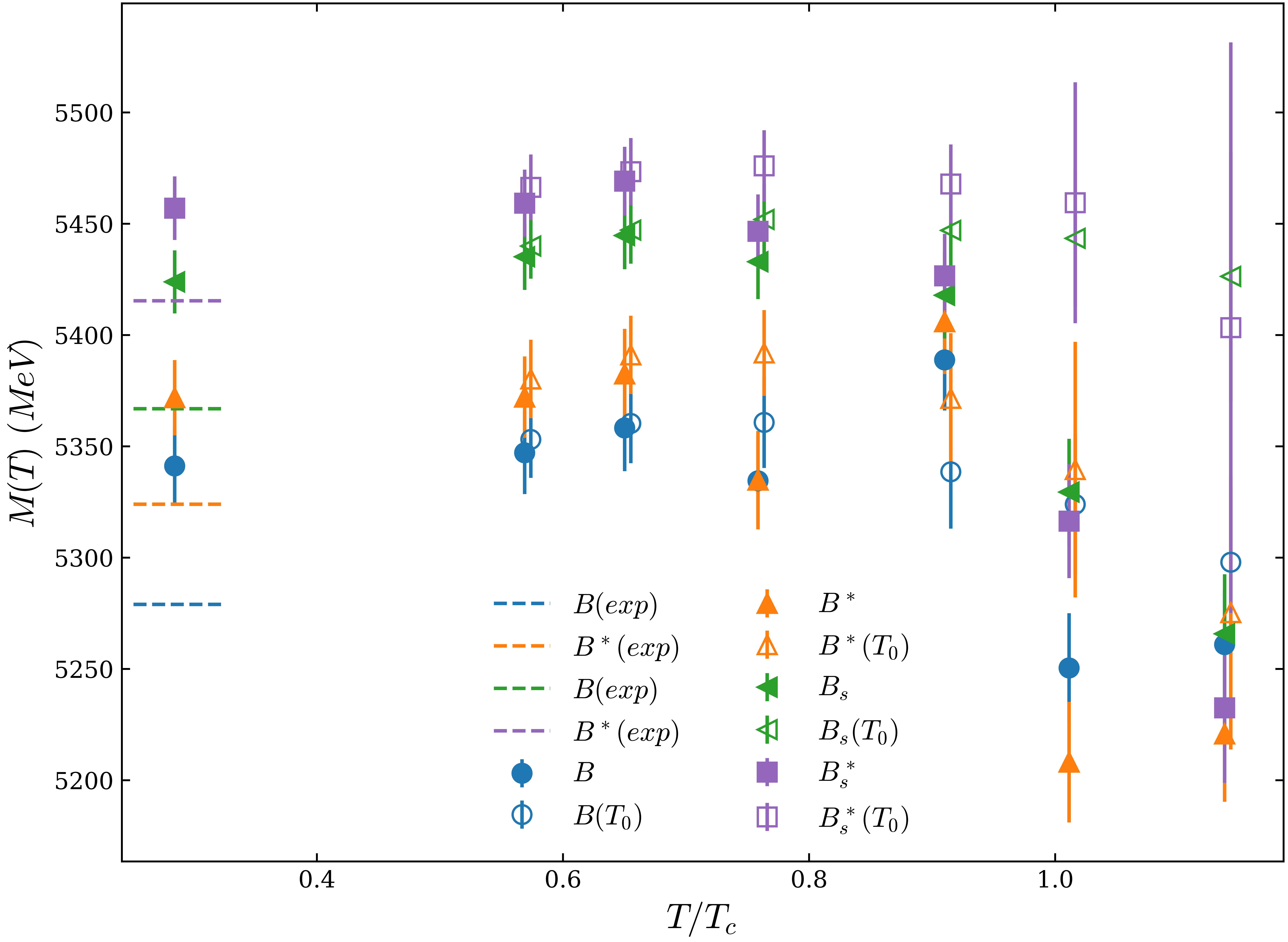
Gen 2L



0.57T_c
0.76T_c
0.65T_c
0.91T_c
1.01T_c
1.30T_c
1.14T_c
1.52T_c
$R(B_s)/R(B)$
$R(B_s^*)/R(B^*)$
1.05
1.00
0.95
0.00
0.25
0.50
0.75
1.00
0.0
0.2
0.4
τ (fm)

$$M_B = (E_B - \frac{1}{n}E_{ref})a^{-1} + \frac{1}{n}M_{ref}$$

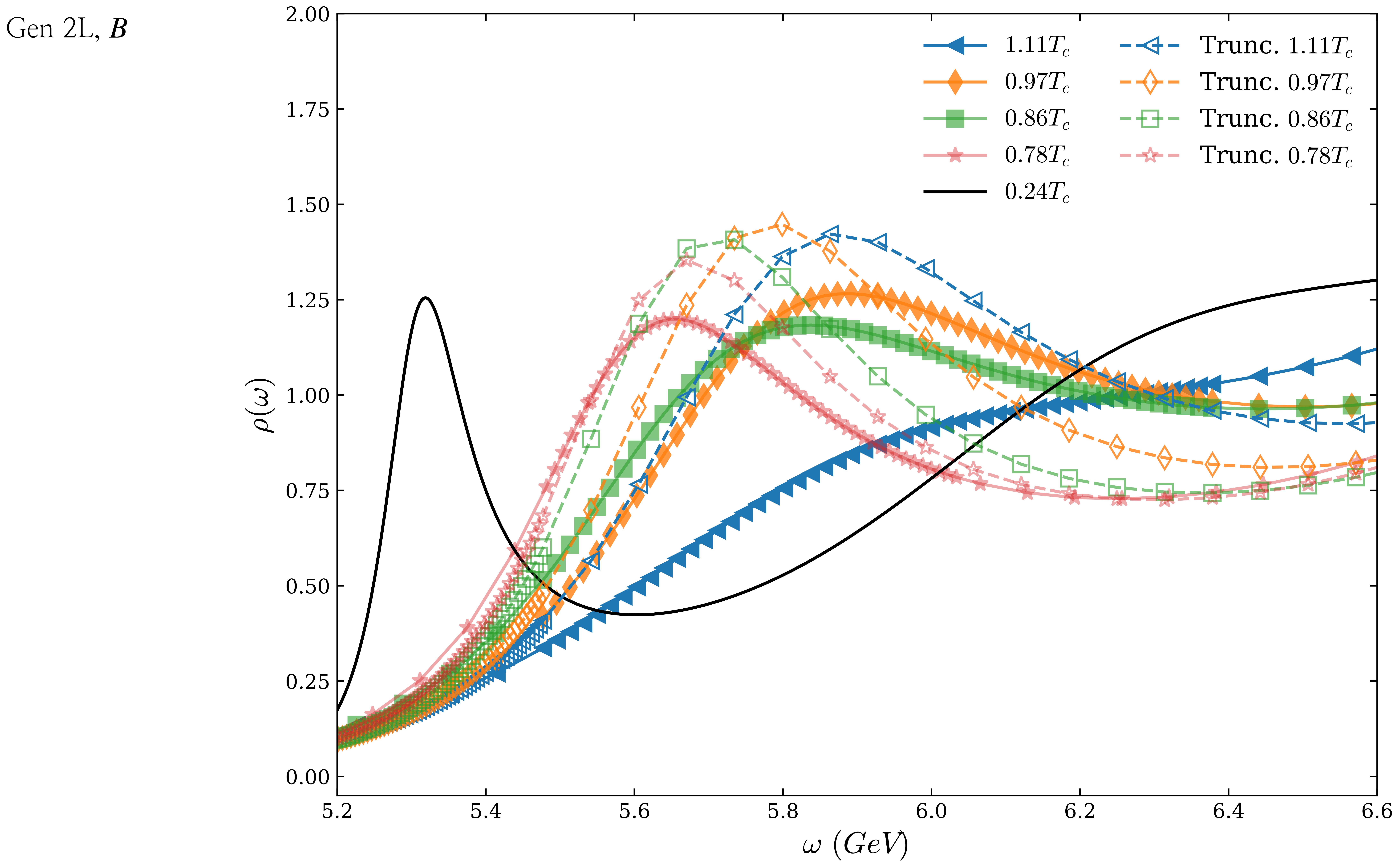
Gen 2L



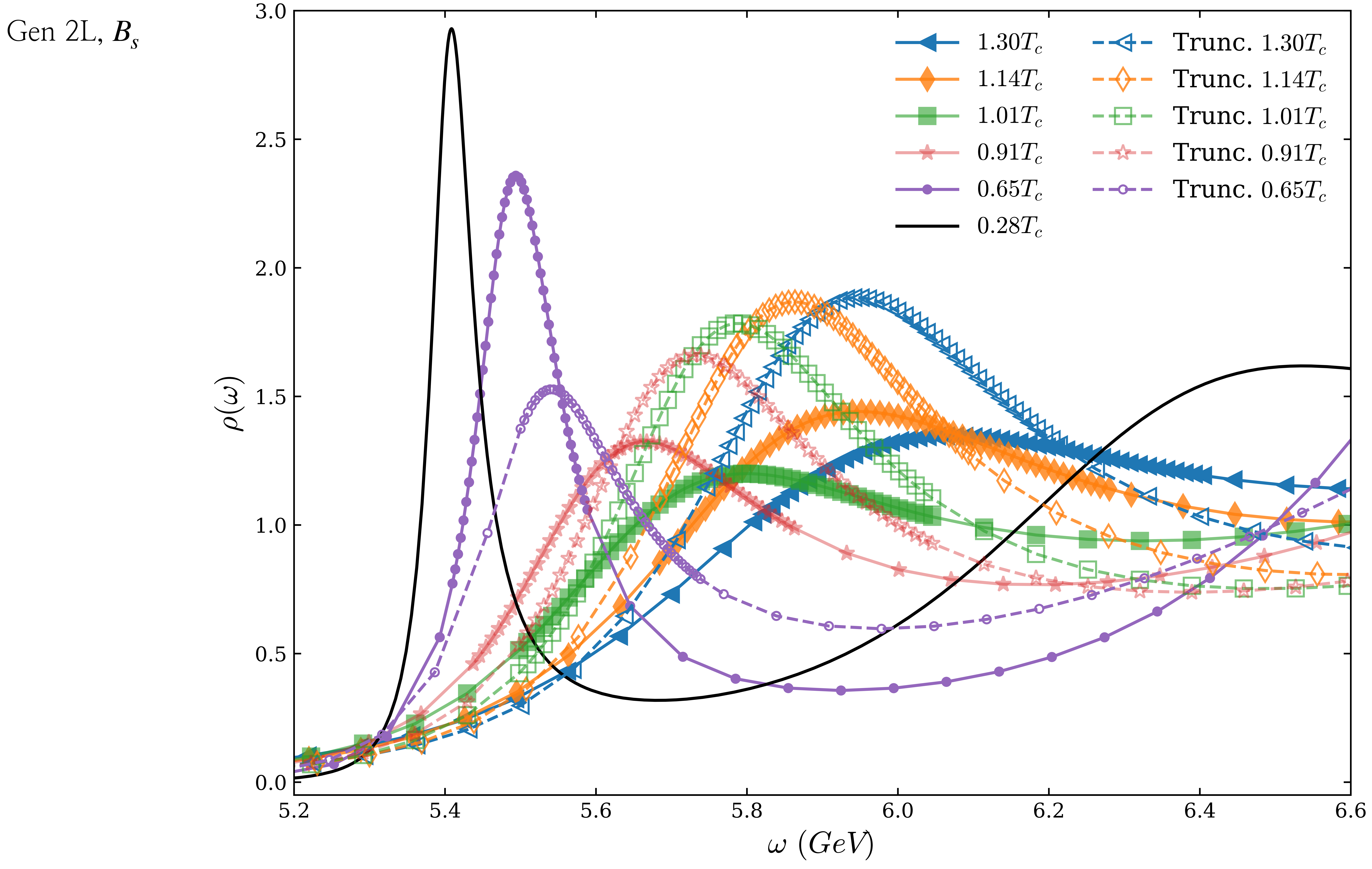
$M(T)\ (MeV)$
5500
5450
5400
5350
5300
5250
5200
T/T_c
0.4
0.6
0.8
1.0
$B(exp)$
$B^*(exp)$
$B(exp)$
$B^*(exp)$
B
$B(T_0)$
B^*
$B^*(T_0)$
B_s
$B_s(T_0)$
B_s^*
$B_s^*(T_0)$

	M_{eff}		BR		
	Gen2	Gen2L	Gen2	Gen2L	PDG [12]
B	5335(41)	5341(16)	5319(40)	5321(18)	5279.72(8)
B^*	5376(42)	5371(17)	5392(43)	5377(20)	5324.75(20)
B_s	5386(41)	5423(14)	5374(40)	5409(24)	5366.93(10)
B_s^*	5435(41)	5457(14)	5428(41)	5443(13)	5415.4(1.4)
$B^* - B$	41(20)	30(20)	72(44)	55(18)	45.18(20)
$B_s - B$	51(18)	82(18)	55(41)	87(18)	87.45(44)
$B_s^* - B_s$	47(17)	33(15)	54(40)	35(14)	48.5(1.4)

TABLE III: T_0 effective mass values compared the BR results and the experimental values.

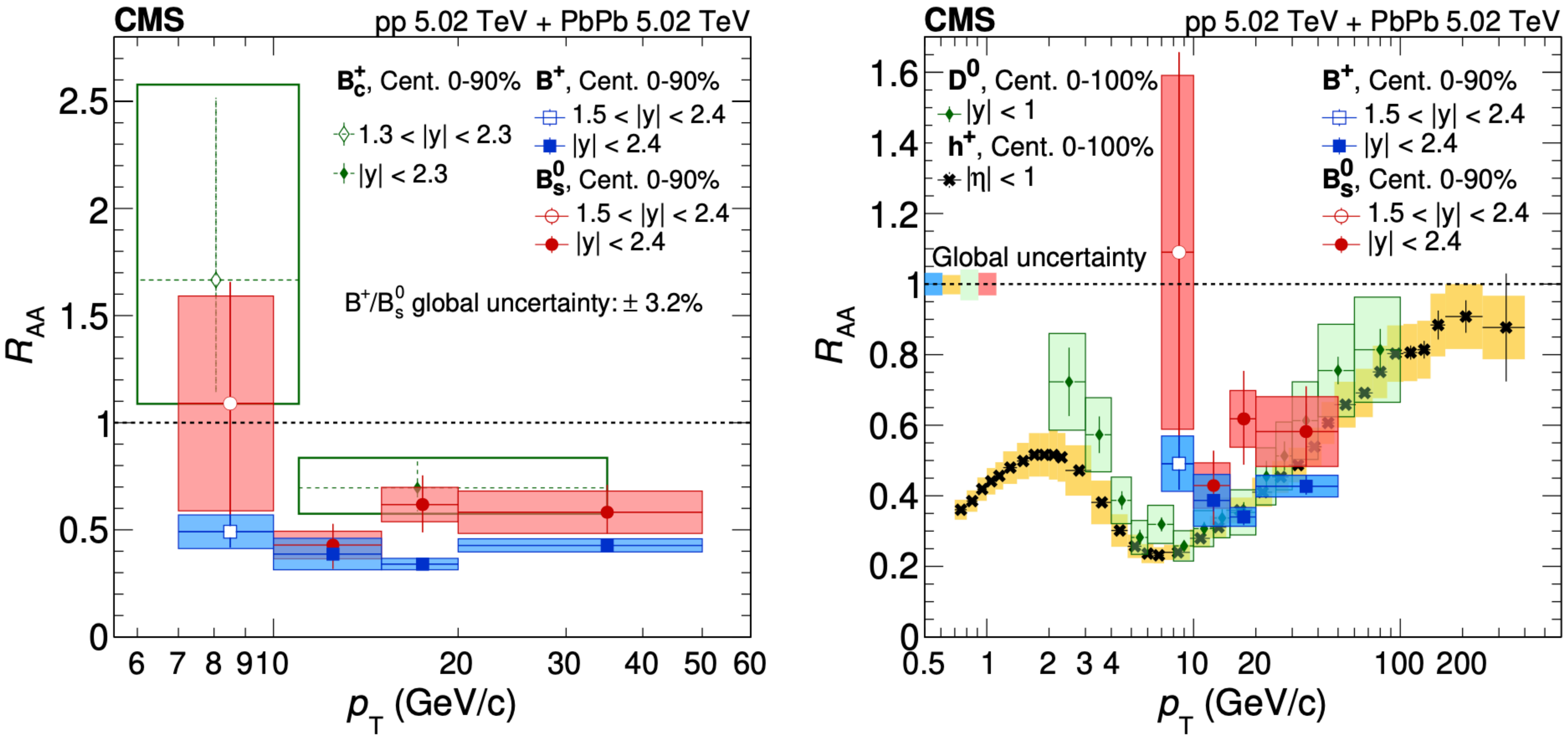


Gen 2L, $\boldsymbol{B}$
$1.11T_c$
$0.97T_c$
$0.86T_c$
$0.78T_c$
$0.24T_c$
Trunc. $1.11T_c$
Trunc. $0.97T_c$
Trunc. $0.86T_c$
Trunc. $0.78T_c$
$\rho(\omega)$
ω (GeV)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6



Gen 2L, B_s
$\rho(\omega)$
ω (GeV)
$1.30T_c$
$1.14T_c$
$1.01T_c$
$0.91T_c$
$0.65T_c$
$0.28T_c$
Trunc. $1.30T_c$
Trunc. $1.14T_c$
Trunc. $1.01T_c$
Trunc. $0.91T_c$
Trunc. $0.65T_c$

CMS, JHEP02(202025)195



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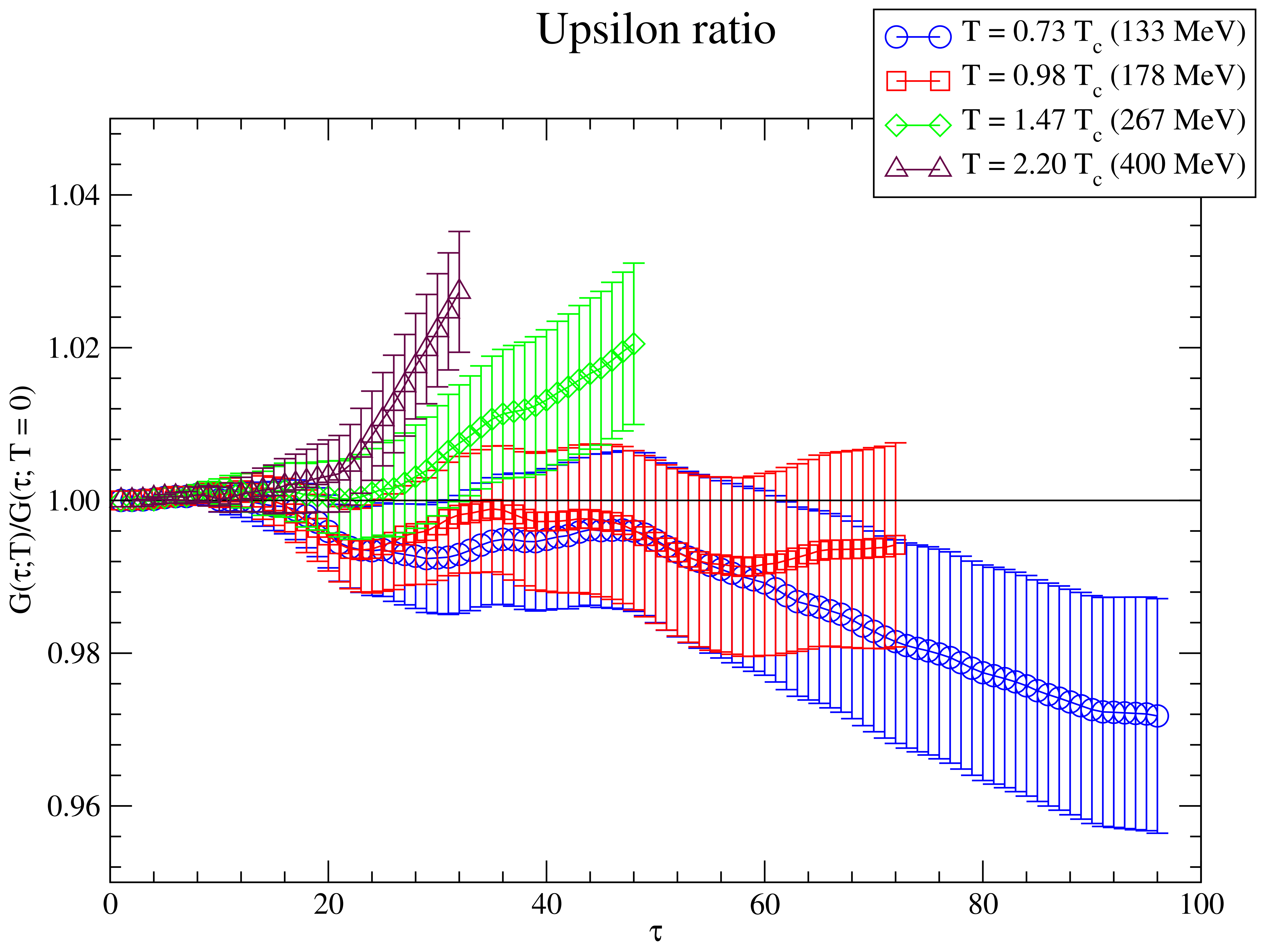
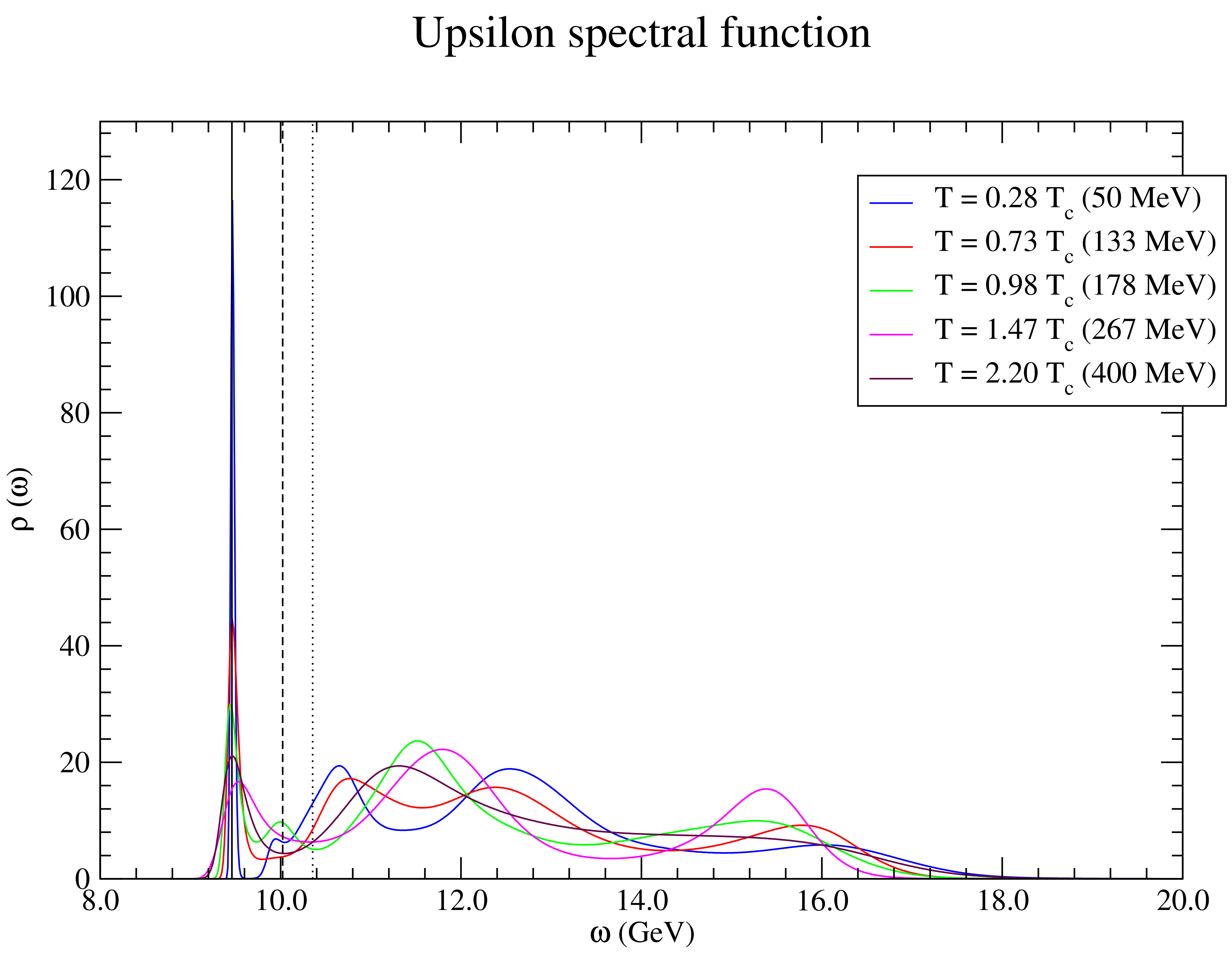
Quarkonium
with Gen 3 (pre–preliminary)

Gen 3



Upsilon ratio
T = 0.73 T_c (133 MeV)
T = 0.98 T_c (178 MeV)
T = 1.47 T_c (267 MeV)
T = 2.20 T_c (400 MeV)
G(τ;T)/G(τ; T = 0)
1.04
1.02
1.00
0.98
0.96
0
20
40
60
80
100
τ

Gen 3



Upsilon spectral function
T = 0.28 T_c (50 MeV)
T = 0.73 T_c (133 MeV)
T = 0.98 T_c (178 MeV)
T = 1.47 T_c (267 MeV)
T = 2.20 T_c (400 MeV)
ρ (ω)
ω (GeV)
0
20
40
60
80
100
120
8.0
10.0
12.0
14.0
16.0
18.0
20.0

Discussion

1. We study B−mesons and bottomonium at $T \neq 0$ using anisotropic lattices
2. Based on Gen 2 and Gen 2L with relativistic light quarks and NRQCD bottom quark, we show that B−meson in QGP doesn't survive above T_c
3. Bottomonium on Gen 3 configuration ensembles is progressing
4. Further work is needed