QFT-HEP

nodes:

Bari
Catania
LNF: Maria Paola Lombardo –> large scale lattice QCD computations
Lecce
Napoli

Pietro Colangelo
INFN – Bari
on behalf of the IS QFT-HEP

QFT-HEP

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in-medium effects on heavy hadron masses and widths
QCD thermodynamics with N_f=2+1+1 Wilson fermions
topology in hot QCD
connection between the QGP and QCD conformal window

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nodes:

lattice vs analytic

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lattice vs analytic

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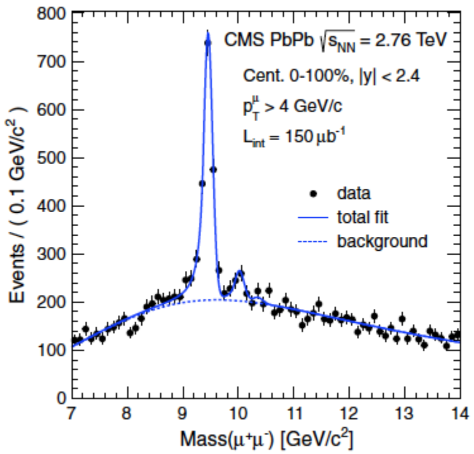
INFN Bari

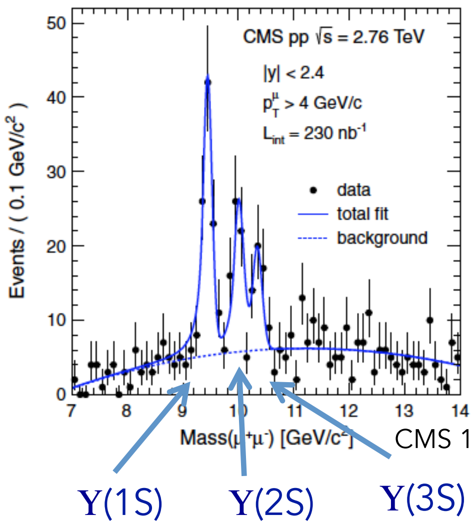
Transport and response properties of strongly interacting systems

heavy quarkonium in a thermalized medium

PbPb



pp

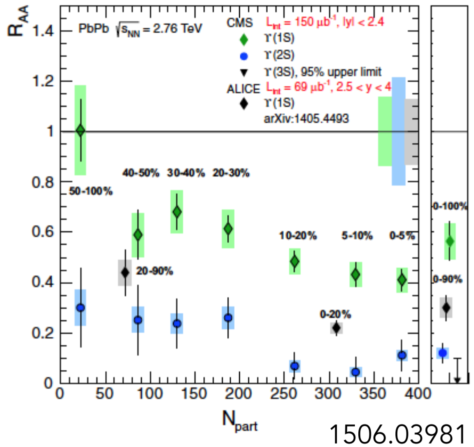


CMS 1208.2826

$$\frac{\Upsilon(2S)/\Upsilon(1S)|_{\mathrm{PbPb}}}{\Upsilon(2S)/\Upsilon(1S)|_{pp}} = 0.21 \pm 0.07(\mathrm{stat}) \pm 0.02(\mathrm{syst}),$$

$$\frac{\Upsilon(3S)/\Upsilon(1S)|_{\mathrm{PbPb}}}{\Upsilon(3S)/\Upsilon(1S)|_{pp}} = 0.06 \pm 0.06(\mathrm{stat}) \pm 0.06(\mathrm{syst})$$

$$< 0.17 (95\% \mathrm{CL}).$$



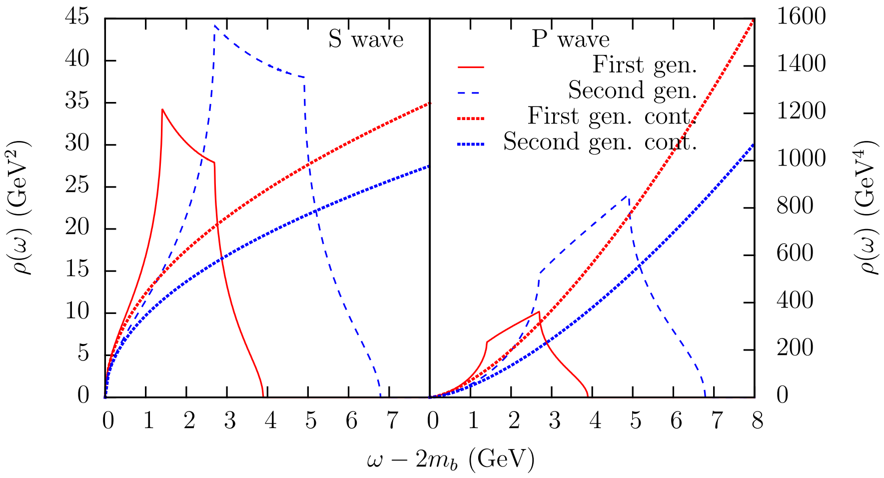
1506.03981

lattice calculation of spectral functions: issue of systematic errors
interplay with analytic methods (AdS/QCD)

ISSUES

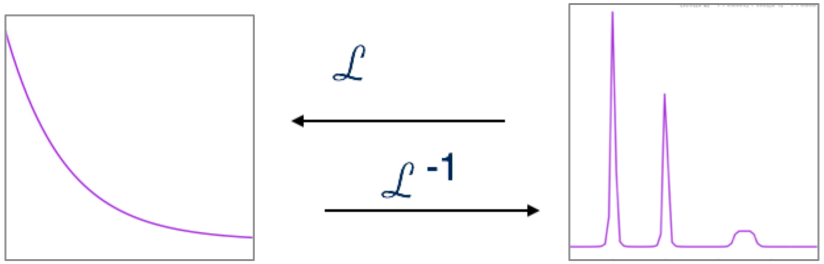
$$G(\tau) = \int_0^\infty \frac{d\omega}{2\pi} K(\tau,\omega)\rho(\omega), \qquad 0 \le \tau < \frac{1}{T},$$

finite lattice produces structures in spectral functions



transform acts as
a smoothing operator

inverse problem ill posed



relativistic vs nonrelativistic kernels

QCD: $$K(\tau,\omega) = \frac{\left(e^{-\omega\tau} + e^{-\omega(1/T-\tau)}\right)}{1-e^{-\omega/T}}.$$

NRQCD: $$K(\tau,\omega) \simeq \left(e^{-\omega\tau} + e^{-\omega(1/T-\tau)}\right);$$

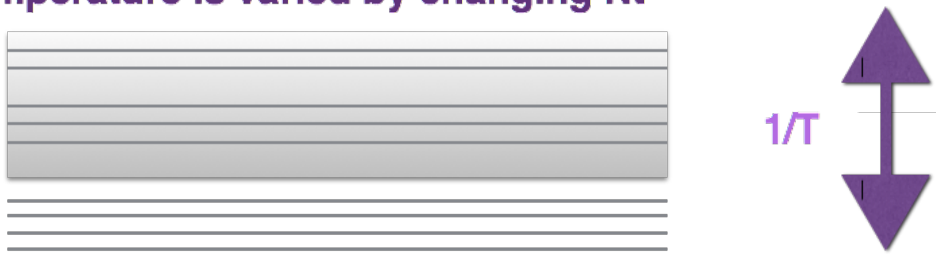
in NRQCD all the T dependence in the spectral function

FASTSUM Coll.

lattice setup: anisotropic lattice
Wilson clover fermions for the sea quarks, NRQCD for bottom quarks

Temperature is varied by changing Nt

$0.4\,T_c < T < 2T_c$

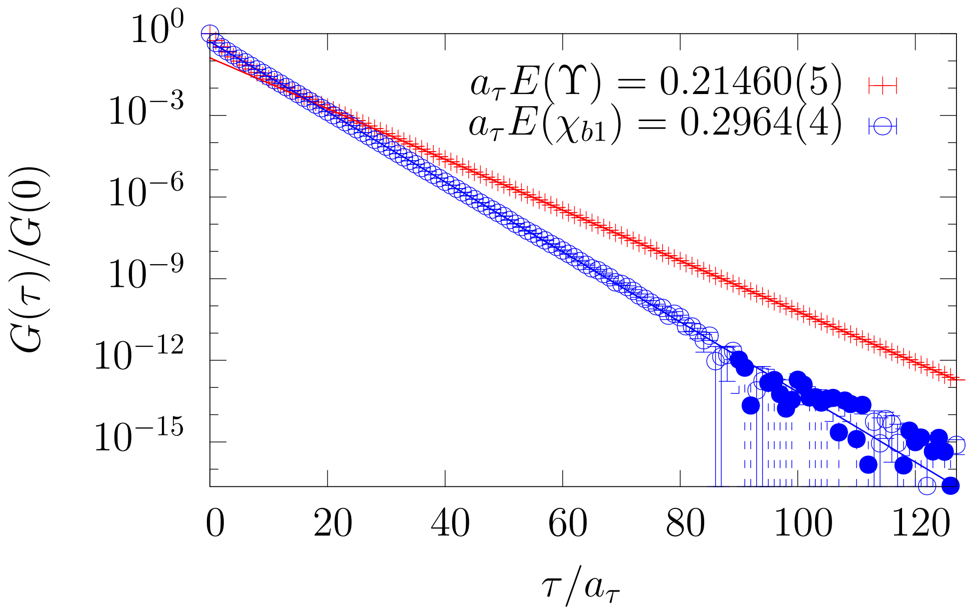


NRQCD evolution:

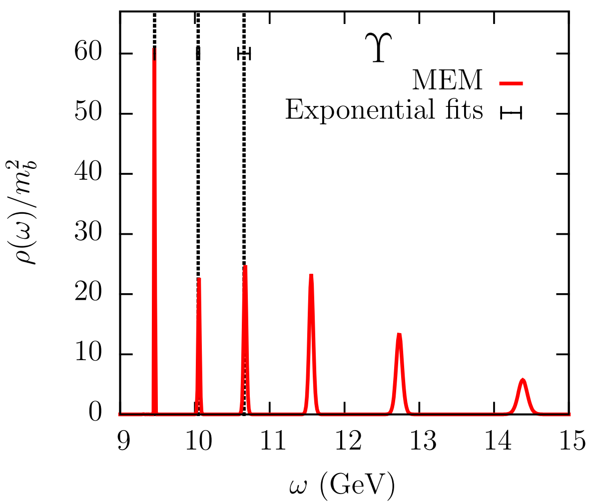
$$G(\boldsymbol{n}, n_\tau) = K_\tau G(\boldsymbol{n}, n_\tau - a_\tau \boldsymbol{e}_\tau),$$

M_π [MeV]	Anisotropy $= a_s/a_t$	a_s [am]	a_t [am]	
450	6	167	28	Completed
390	3.5	123	35	Completed
230	3.5	113	33	In progress
390	7	123	18	In progress

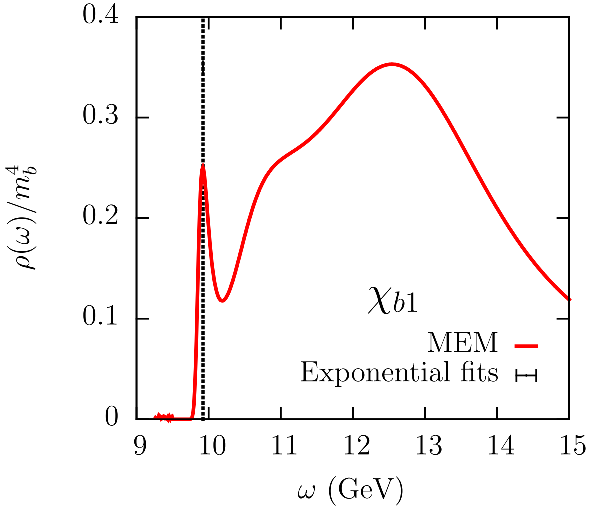
T=0



$a_\tau E(\Upsilon) = 0.21460(5)$
$a_\tau E(\chi_{b1}) = 0.2964(4)$
$G(\tau)/G(0)$
τ/a_τ

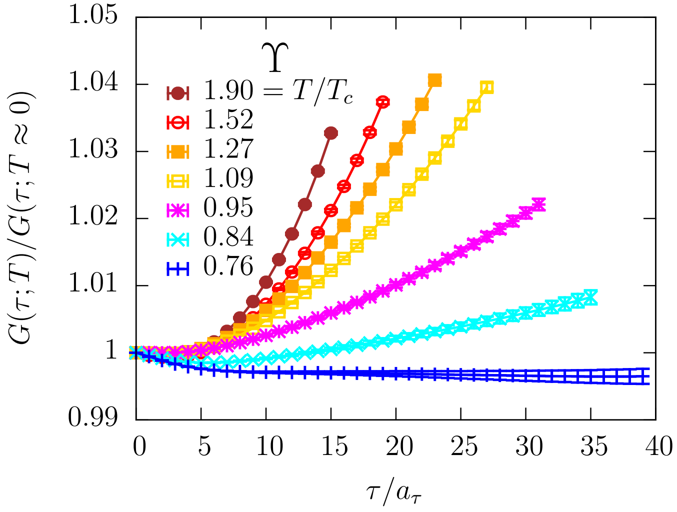


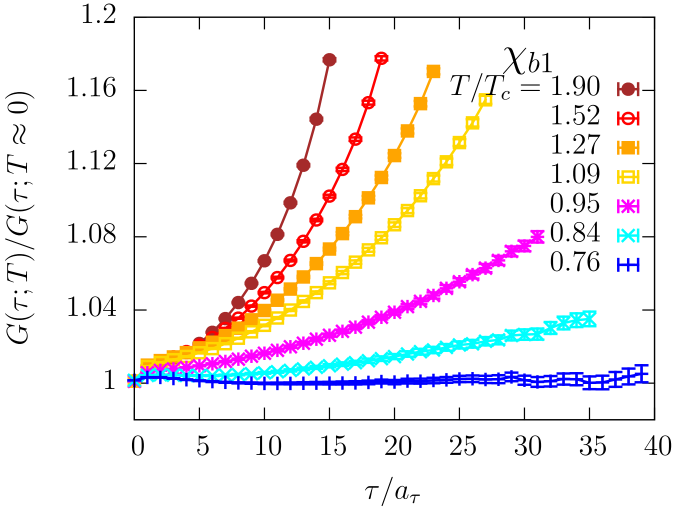
Υ
MEM
Exponential fits
$\rho(\omega)/m_b^2$
ω (GeV)



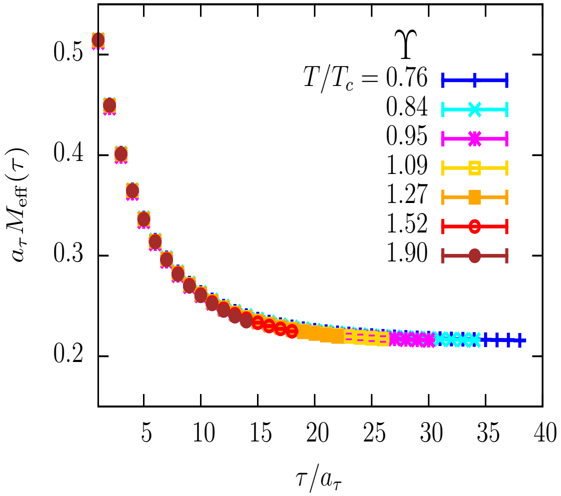
χ_{b1}
MEM
Exponential fits
$\rho(\omega)/m_b^4$
ω (GeV)

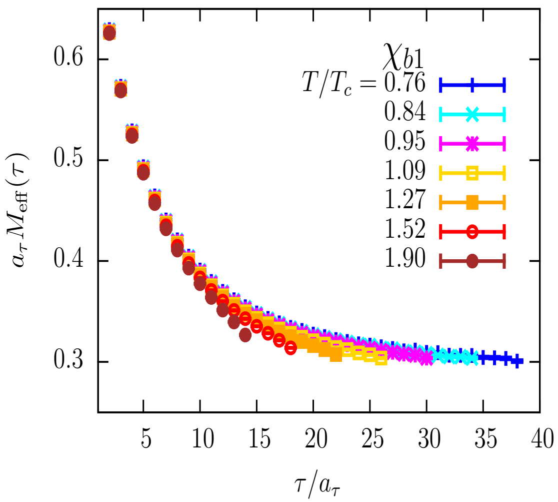
high T
Y(1S) correlators



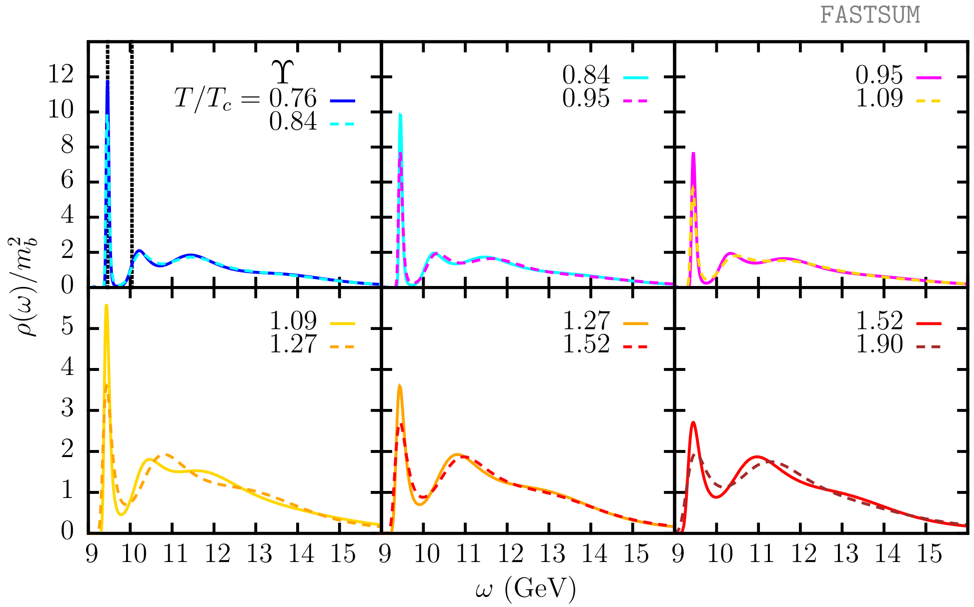


effective
masses



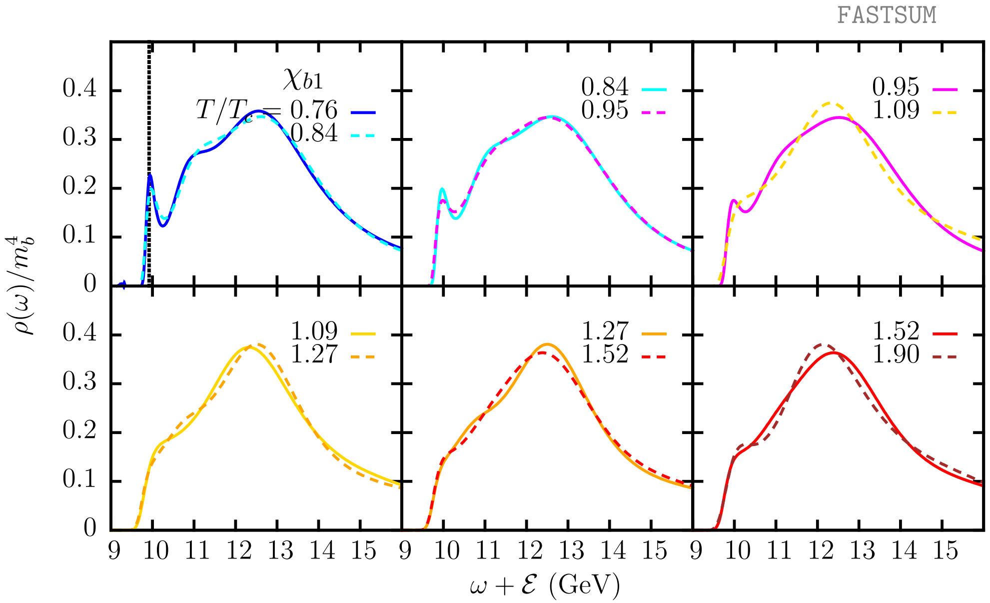


Υ spectral function



Υ(1S) survives up to ~1.9T_c

X_{b1} spectral function



X_{b1} melts at ~T_c

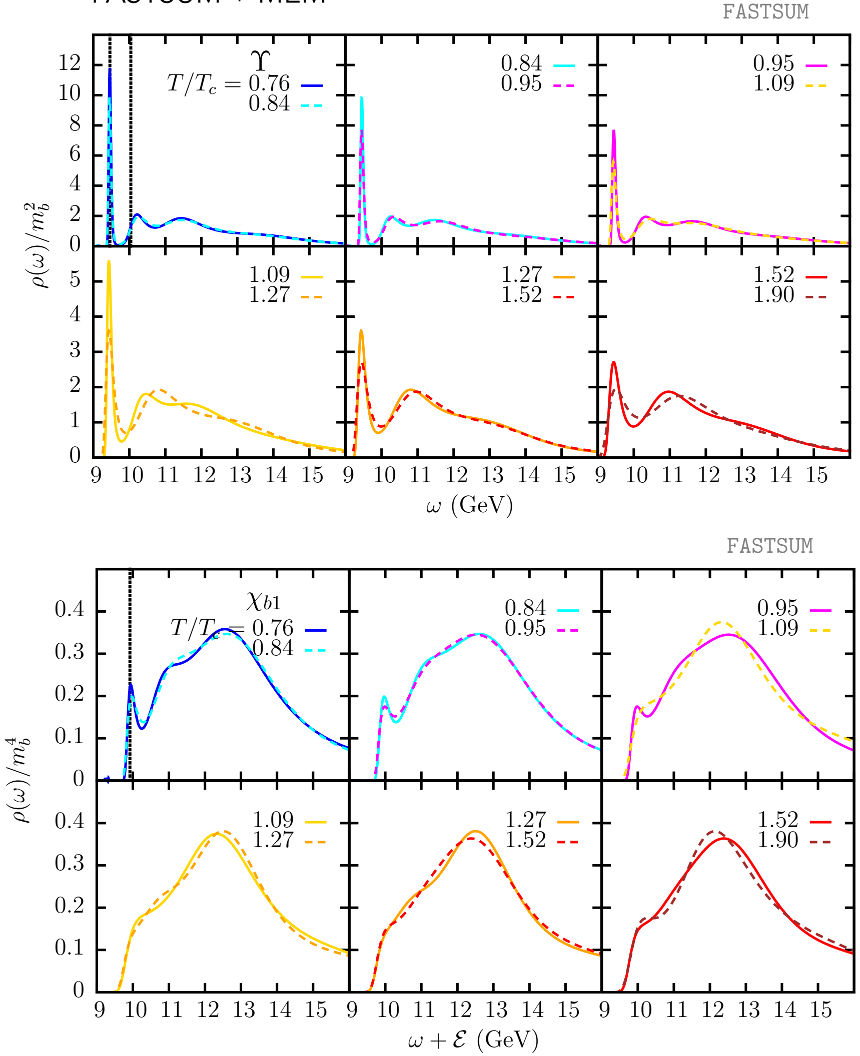
Aarts, Lombardo et al., NPA 956 (2016) 717

ISSUE OF THE RECONSTRUCTION METHOD

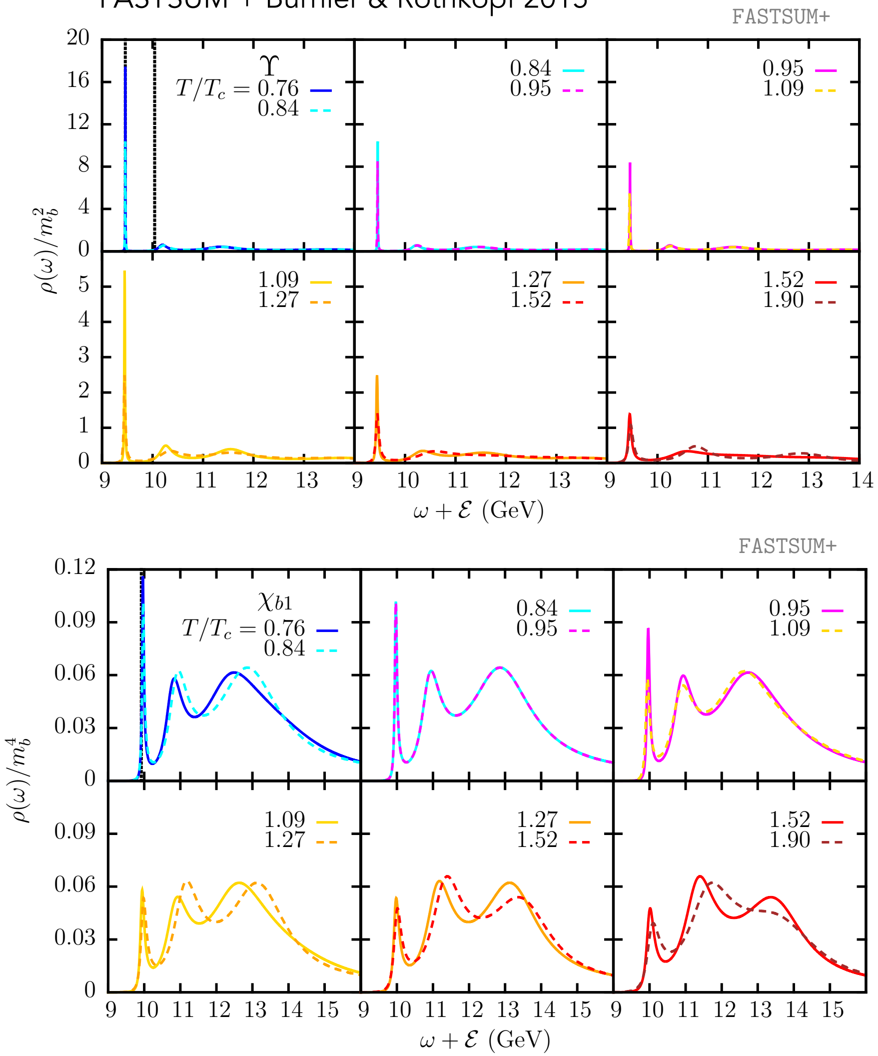
Υ

X_{b1}

FASTSUM + MEM



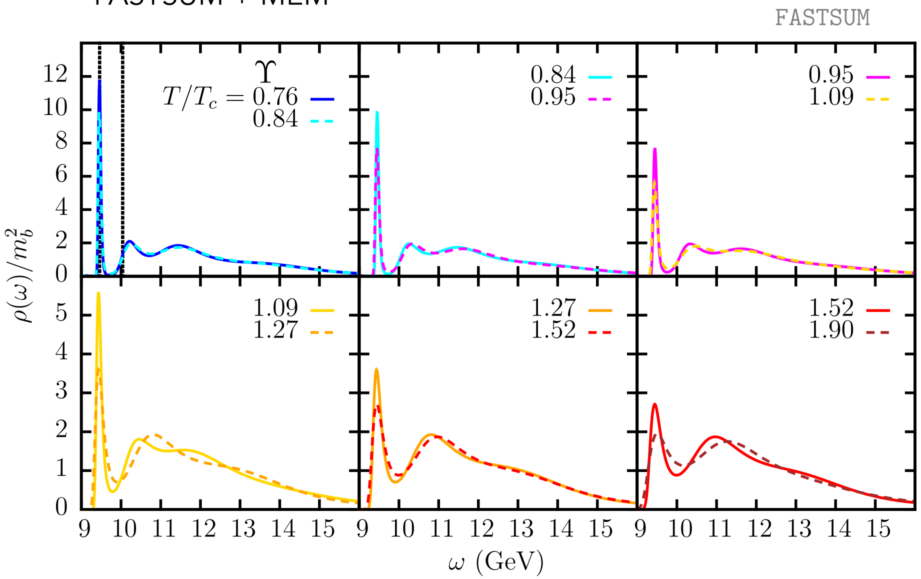
FASTSUM + Burnier & Rothkopf 2015



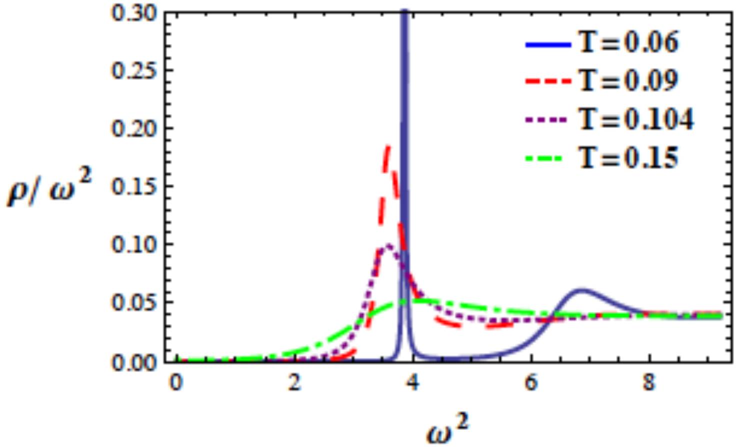
Aarts, Lombardo et al., NPA 956 (2016) 717

ISSUE OF THE RECONSTRUCTION METHOD: use info from AdS/QCD

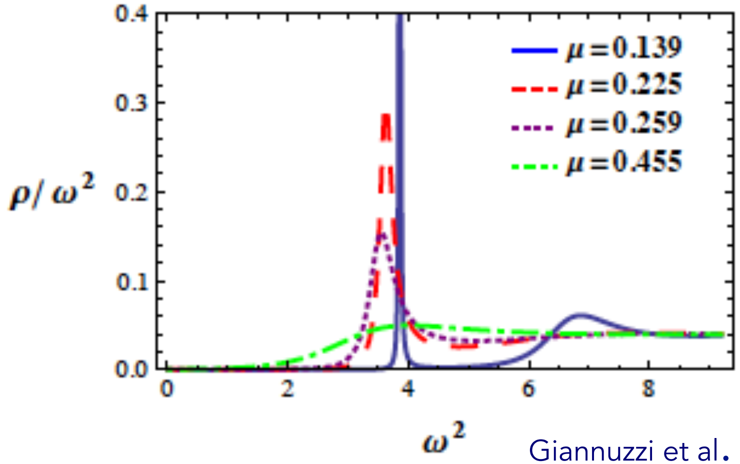
FASTSUM + MEM



μ fixed



T fixed

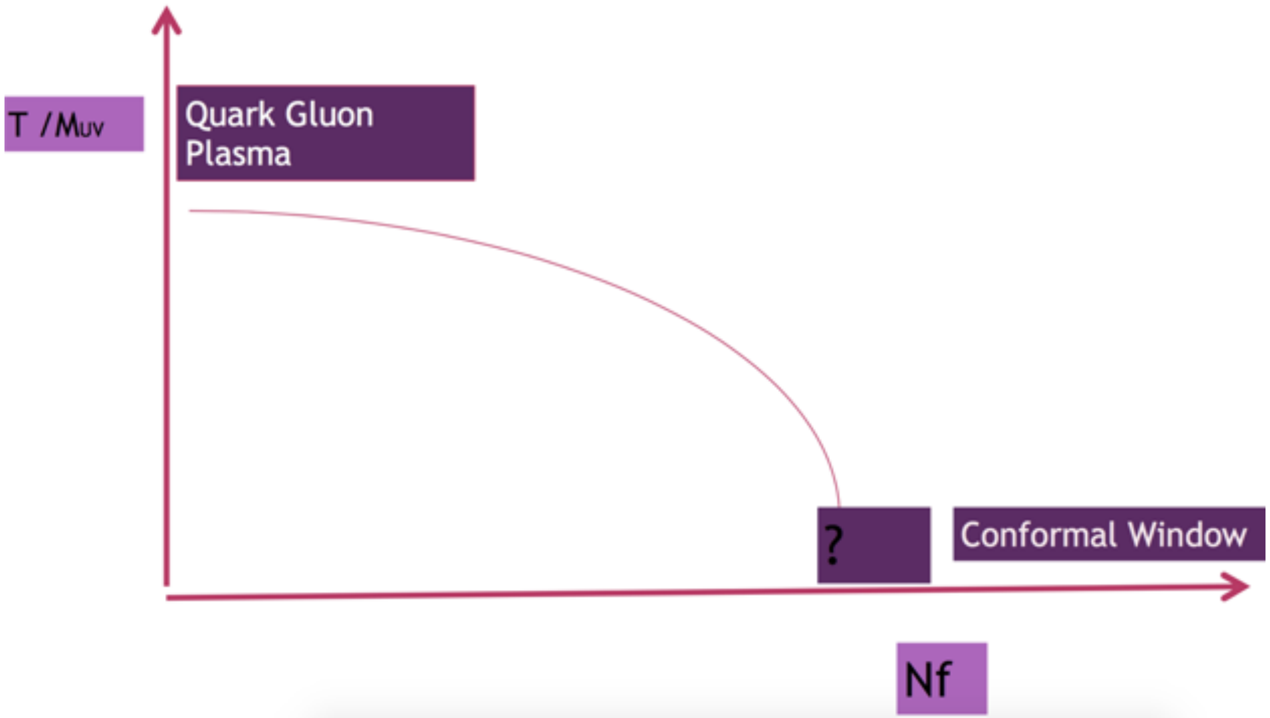


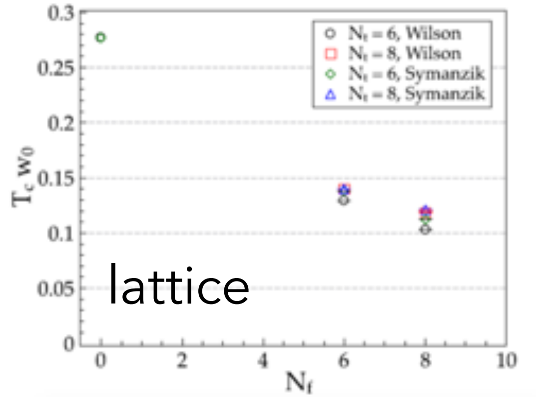
Giannuzzi et al.

- different priors
- dependence on the input data set features

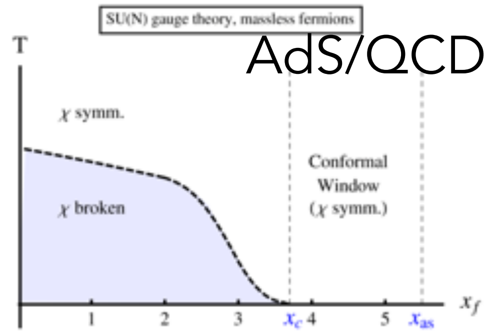
QGP continuously connected to conformal QCD

$$G_H(t) = \tilde{c}_H \frac{\exp(-\tilde{m}_H t)}{t^{\alpha_H}}$$





Lombardo, Pallante et al.



Kiritsis

from free correlators to quasi-conformal behaviour

fits: include a T dependence in the coefficients

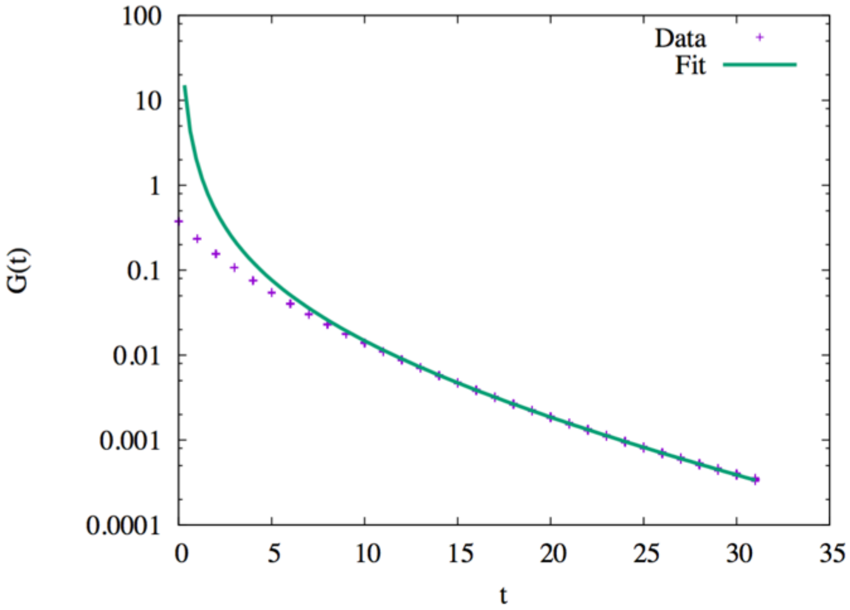
$$G(\tau) \to \frac{e^{-\omega_0(T)\tau}}{\tau^{\alpha(T)+1}}$$

in a quasi-conformal theory

$$G(\tau) \to \frac{e^{-\omega_0(T)\tau}}{\tau^{\alpha_H(T)}}$$

$$\alpha_H = 3 - 2\gamma$$ Iwasaki 2013

χ correlator fit to quasi-conformal behaviour

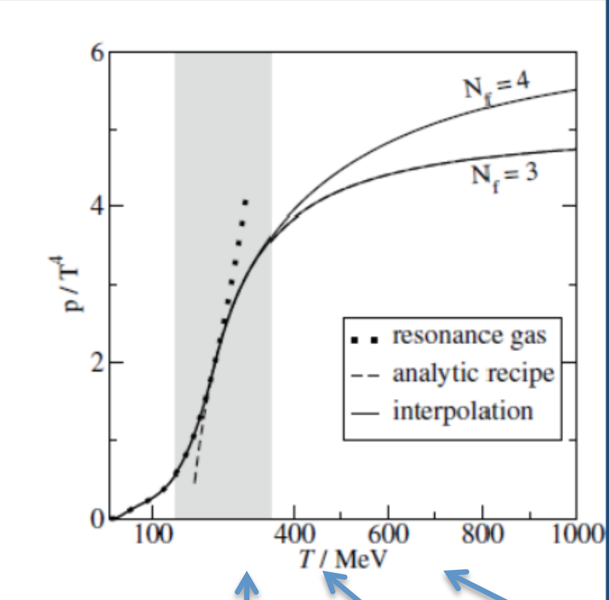


preliminary

HOT QCD and Nf=2+1+1 twisted mass Wilson fermions

u, d in the isospin limit | physical s | physical c

Quark Gluon Plasma @ Colliders



Analytic studies suggest that a dynamical charm becomes relevant above 400 MeV, well within the reach of LHC

Laine Schroeder 2006

Tc ≈200MeV

340 –380 MeV
RHIC AuAu
200 GeV

420-480 MeV
LHC
2.76 TeV

500- 600MeV
LHC hot spots
2.76 TeV

FCC

Setup Nf=2+1+1

Number of flavours	$m_{\pi^\pm}$
$N_f = 2+1+1$	210
	260
	370
	470
$N_f = 2$	360
	430

$T=0$ (ETMC) nomenclature	β	a [fm] [6]	N_σ^3	N_τ	T [MeV]	# confs.
A60.24	1.90	0.0936(38)	24^3	5	422(17)	585
				6	351(14)	1370
				7	301(12)	341
				8	263(11)	970
				9	234(10)	577
				10	211(9)	525
				11	192(8)	227
				12	176(7)	1052
			32^3	13	162(7)	294
				14	151(6)	1988
B55.32	1.95	0.0823(37)	32^3	5	479(22)	595
				6	400(18)	345
				7	342(15)	327
				8	300(13)	233
				9	266(12)	453
				10	240(11)	295
				11	218(10)	667
				12	200(9)	1102
				13	184(8)	308
				14	171(8)	1304
				15	160(7)	456
				16	150(7)	823
D45.32	2.10	0.0646(26)	32^3	6	509(20)	403
				7	436(18)	412
				8	382(15)	416
				10	305(12)	420
				12	255(10)	380
				14	218(9)	793
				16	191(8)	626
			40^3	18	170(7)	599
			48^3	20	153(6)	582

fermionic action

$$S_f^{\text{light}}[U,\chi_l,\overline{\chi}_l] = \sum_{x,y} \overline{\chi}_l(x)\left[\delta_{x,y} - \kappa D_{\text{W}}(x,y)[U] + 2i\kappa a\mu_l\gamma_5\delta_{x,y}\tau^3\right]\chi_l(y)\,, \quad (1)$$

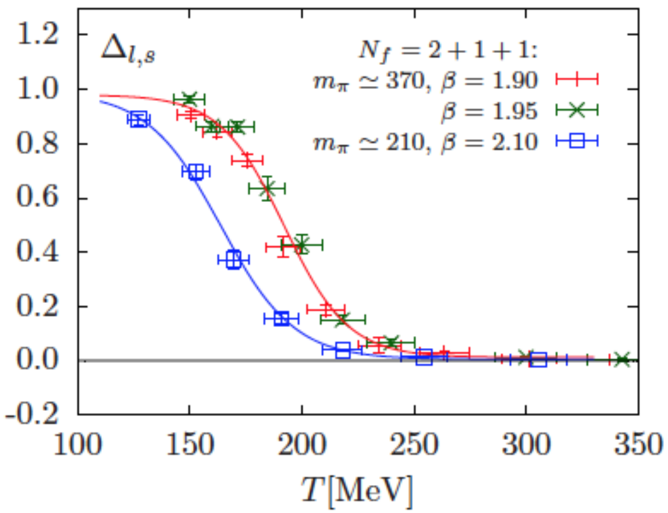
$$S_f^{\text{heavy}}[U,\chi_h,\overline{\chi}_h] = \sum_{x,y} \overline{\chi}_h(x)\left[\delta_{x,y} - \kappa D_W(x,y)[U] + 2i\kappa a\mu_\sigma\gamma_5\delta_{x,y}\tau^1 + 2\kappa a\mu_\delta\delta_{x,y}\tau^3\right]\chi_h(y),$$

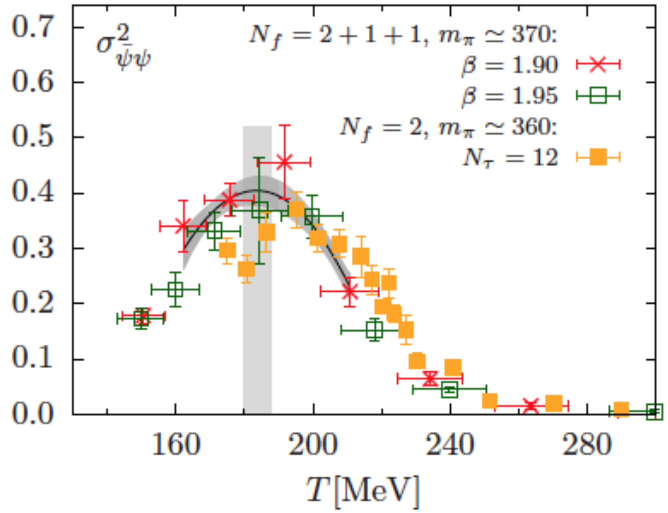
renormalized subtracted chiral condensate

$$\Delta_{l,s} = \frac{\langle\bar\psi\psi\rangle_l - \frac{\mu_l}{\mu_s}\langle\bar\psi\psi\rangle_s}{\langle\bar\psi\psi\rangle_l^{T=0} - \frac{\mu_l}{\mu_s}\langle\bar\psi\psi\rangle_s^{T=0}}\,,$$

disconnected chiral susceptibility

$$\sigma^2_{\bar\psi\psi} = \frac{V}{T}\left(\langle(\bar\psi\psi)^2\rangle_l - \langle\bar\psi\psi\rangle_l^2\right), \qquad V = a^4N_\sigma^3N_\tau.$$

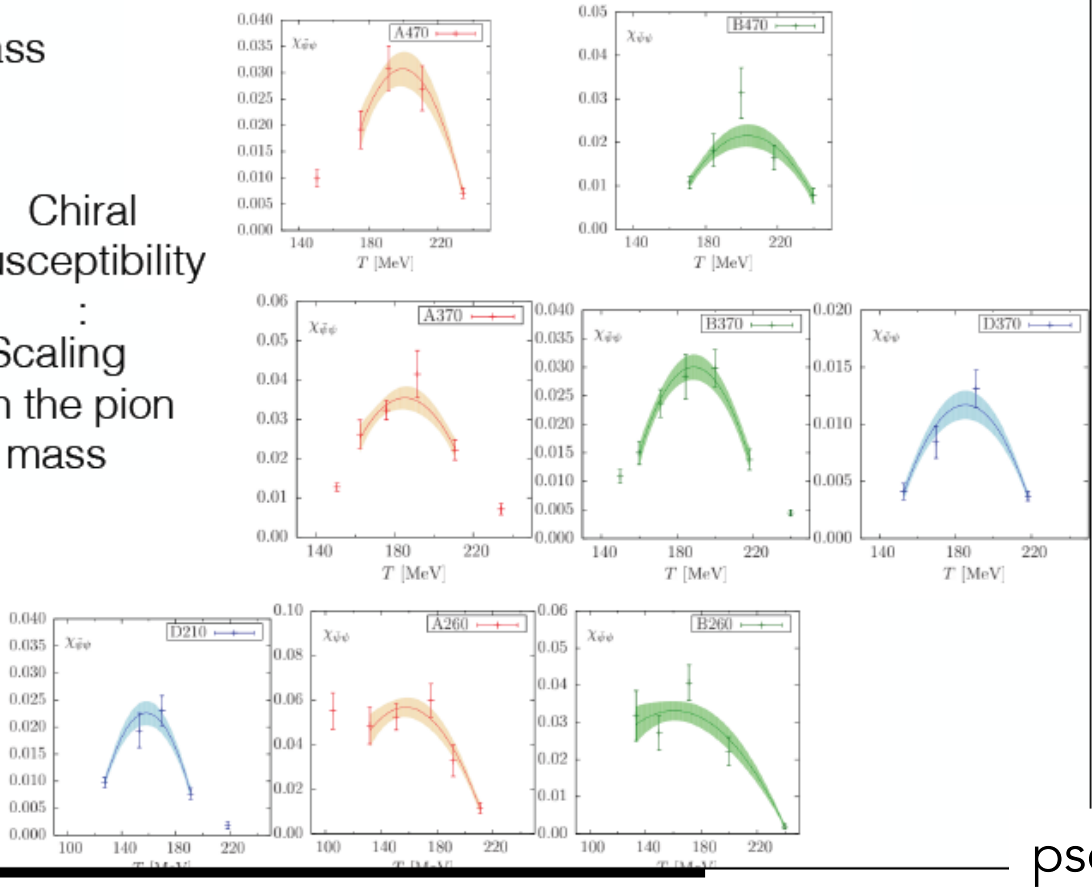




Burger, Lombardo et al., J. Phys. Conf. Ser. 668, no.1 012123 (2016)
Trunin,, Lombardo et al., J. Phys. Conf. Ser. 668, no.1 0122092 (2016)

Mass

Chiral susceptibility : Scaling with the pion mass



pseudocritical temperature

Ensemble	a [fm]	m_π [MeV]	T_χ [MeV]	T_Δ [MeV]	T_{deconf} [MeV]
D210	0.065	213	158(1)(4)	165(3)(1)	176(8)(8)
A260	0.094	261	157(8)(14)	172(2)(1)	188(6)(1)
B260	0.082	256	161(13)(2)	177(2)(1)	192(9)(2)
A370	0.094	364	185(5)(3)	191(2)(0)	202(3)(0)
B370	0.082	372	189(2)(1)	194(2)(0)	201(6)(0)
D370	0.065	369	185(1)(3)	180(5)(1)	193(13)(2)
A470	0.094	466	200(4)(6)	193(5)(2)	205(4)(2)
B470	0.082	465	203(2)(2)	202(7)(1)	212(6)(1)

Topology (N_f = 2+1+1)

$$\mathcal{L}_{QCD}(\theta) = \mathcal{L}_{QCD} + \frac{g^2\theta}{32\pi^2}\epsilon^{\mu\nu\rho\sigma}F^a_{\mu\nu}F^a_{\rho\sigma}.$$

Ammitted but $\theta < 10^{-9}$

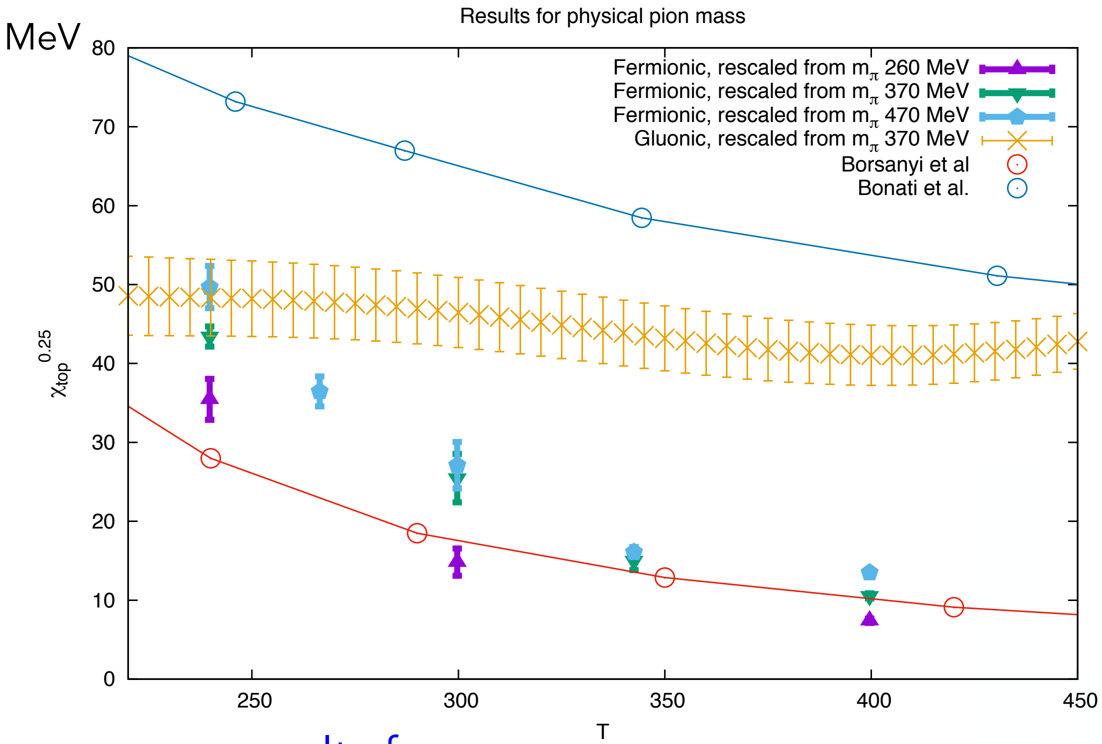
$$Q = \int d^4x \, \frac{g^2}{32\pi^2}\mathrm{tr}F\tilde{F}$$

$$Z_{QCD}(\theta,T) = \int [dA][d\psi][d\bar{\psi}] \exp\left(-T\sum_t d^3x \, \mathcal{L}_{QCD}(\theta)\right) = \exp[-VF(\theta,T)$$

$$\left.\frac{\partial^2 F(\theta,T)}{\partial\theta^2}\right|_{\theta=0} \equiv \chi(T) = (< Q^2 > - < Q >^2)/V$$

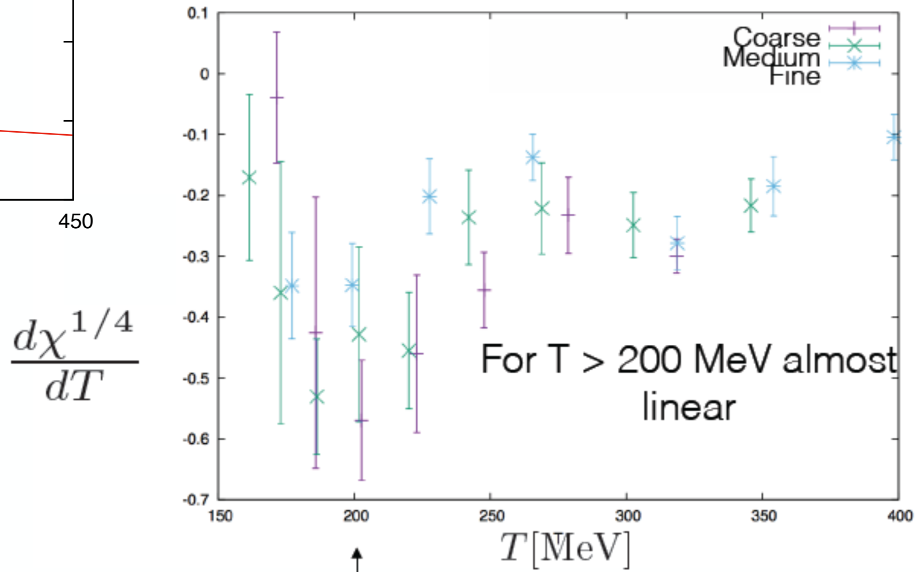
$$\chi_{top} = < Q^2_{top} > /V = m_l^2 \chi_{5,disc}$$

Topology (N_f = 2+1+1) gluonic operator m_π=370 MeV
fermionic operator m_π=210-470 MeV



new results from fermionic method

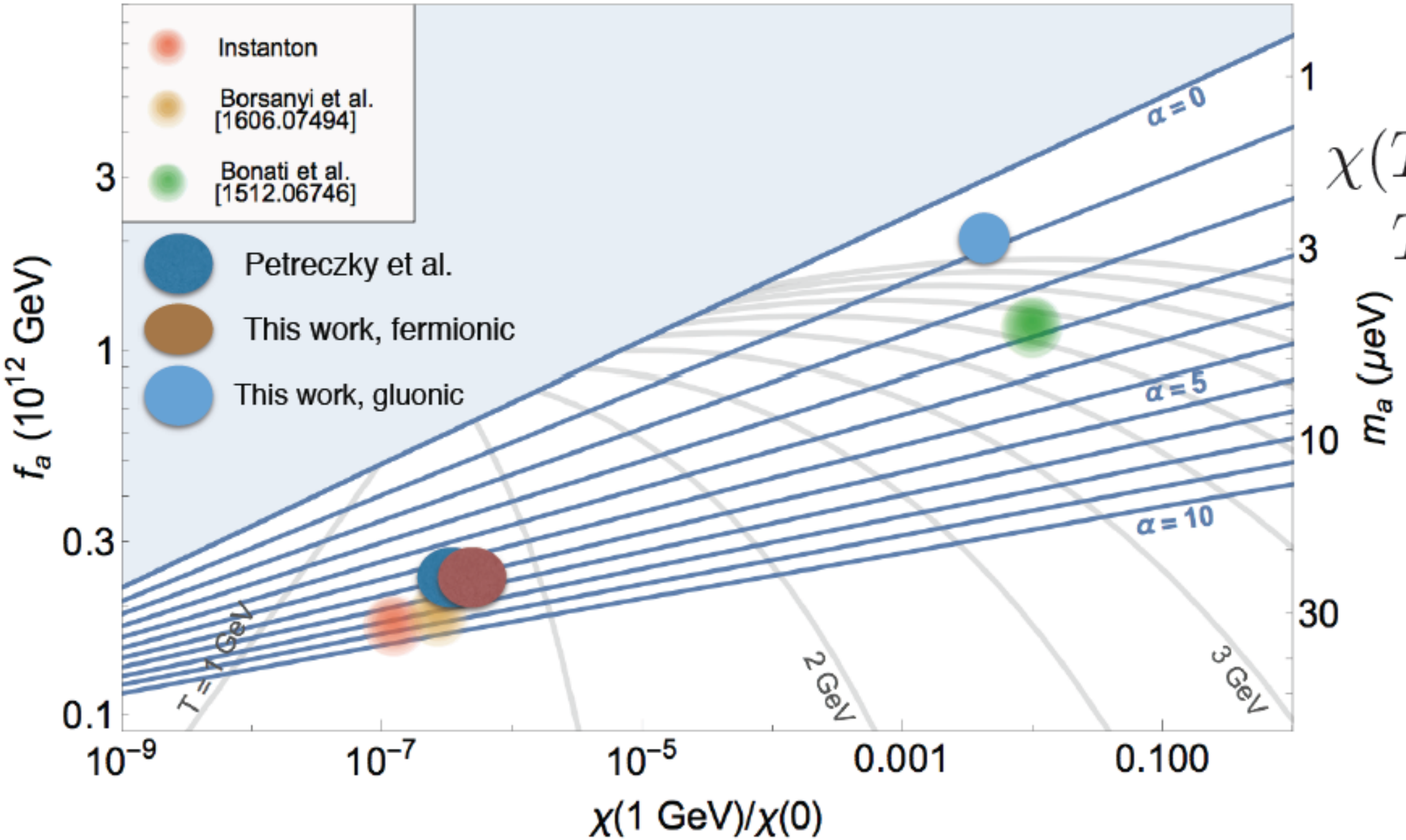
puzzling features of gluonic method



Inflection point around 200 MeV

Needed assumption on fraction of DM made of axions

Assume: Axions make all of Dark Matter



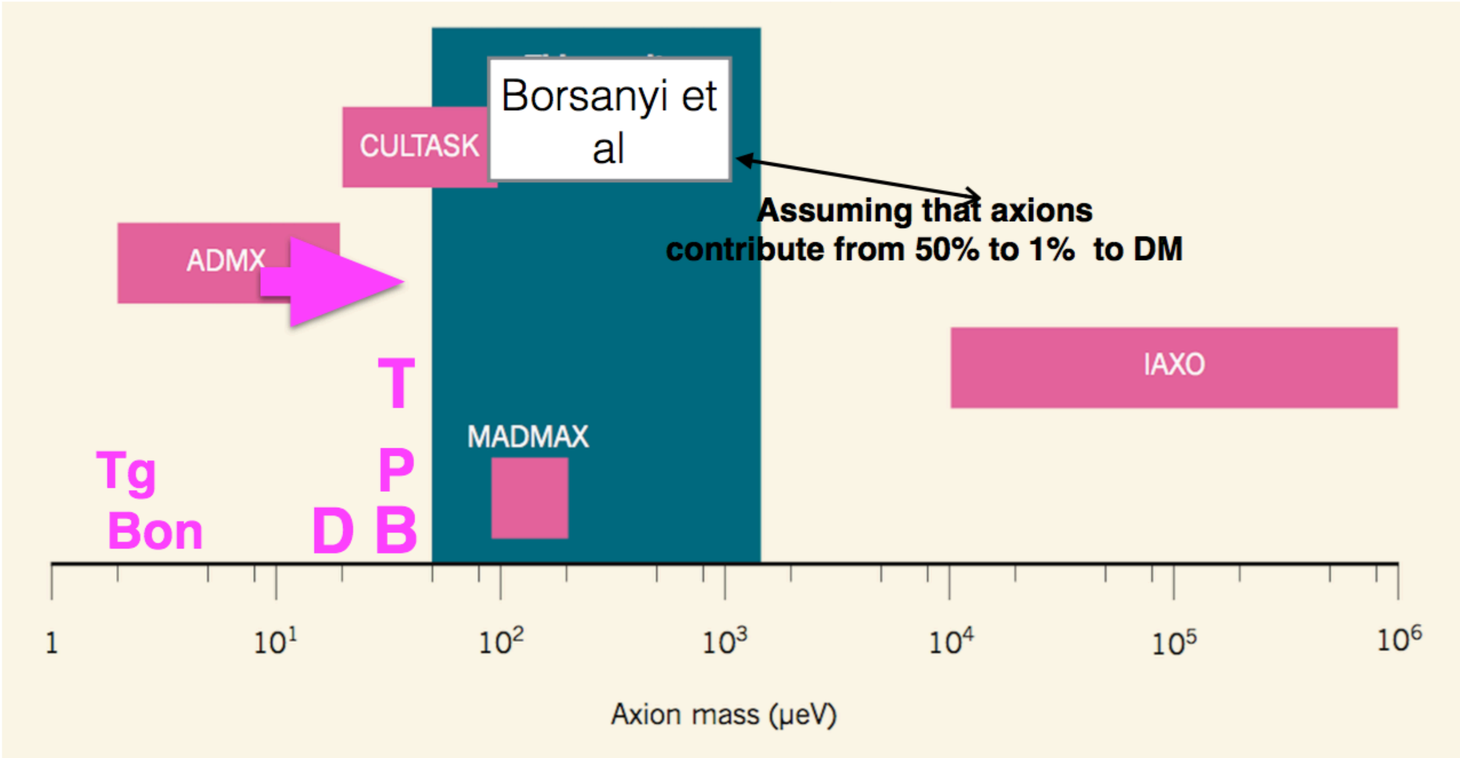
$$\chi(T) \propto 1/T^{\alpha}$$
$$T > 1\ \mathrm{GeV}$$

$$m_a^2(T) f_a^2 = \left.\frac{\partial^2 F(\theta, T)}{\partial \theta^2}\right|_{\theta=0} \equiv \chi(T),$$

PhD Thesis, G. Grilli di Cortona, Sissa 2016

Lower limits on the axion mass assuming that axions make 100% of DM:

Tg: This work, gluonic; Bon: Bonati et al.; D: DIGA, B: Borsanyi et al.,
P: Petreczky et al., T: this work, fermionic



Updated from Nature N&V

computing needs

at present:
FASTSUM (spectral functions) -> DIRAC UK (400 Mio core hours up to 2018)
hot QCD with Wilson fermions -> Dubna+Berlin facilities

needs (next 3 years)
10 Mio core hours -> participation in computational activity (not only design and analysis)

(hopefully) 100 Mio core hours -> simulations not included in already funded projects (e.g. finite volume effects for topology at high T)