



UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

The heavy quark potential at finite T from quenched and dynamical lattice QCD

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in collaboration with:

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Strong and Electroweak Matter (SEWM14)
EPFL, Lausanne, Switzerland 2014-07-17 16:20h



Deutsche
Forschungsgemeinschaft

Heavy Quarkonium as probe of the QGP

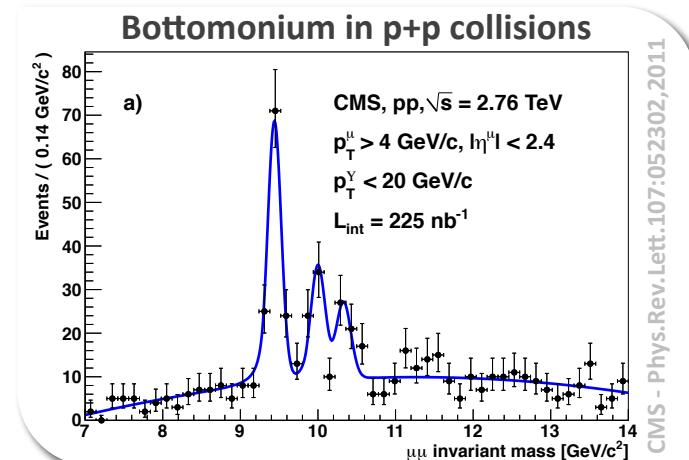


- QQbar pairs created in the partonic stage of a collision
- Non-thermal bound states traverse the bulk as probe

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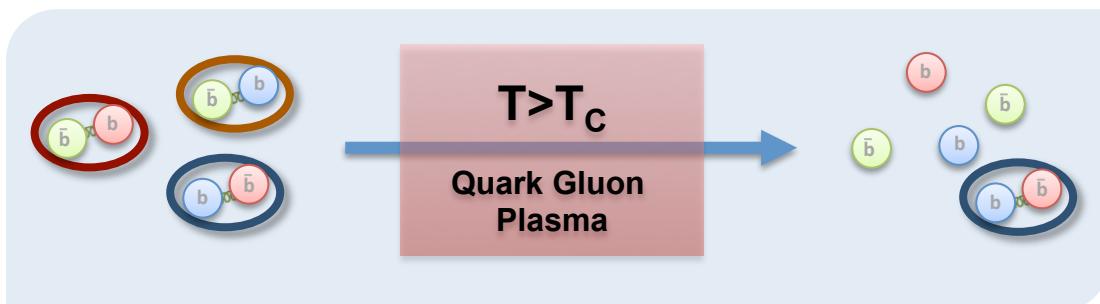
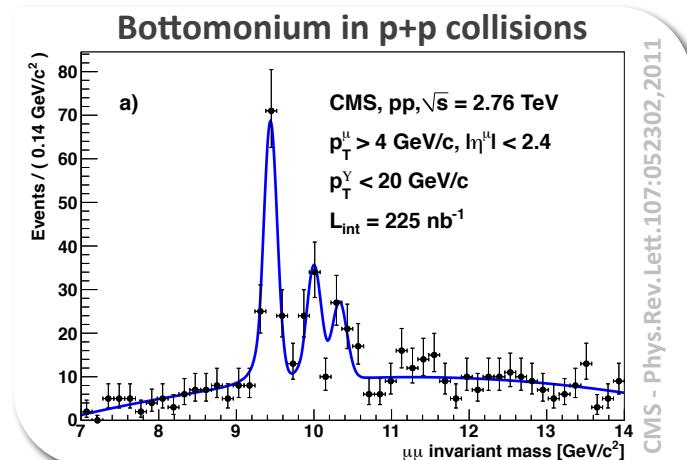
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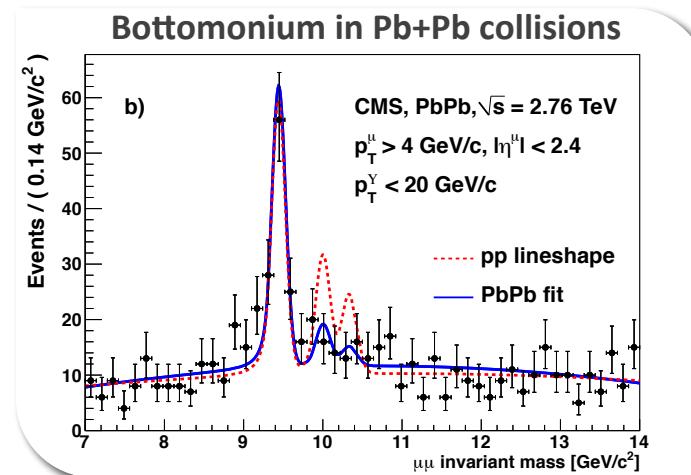
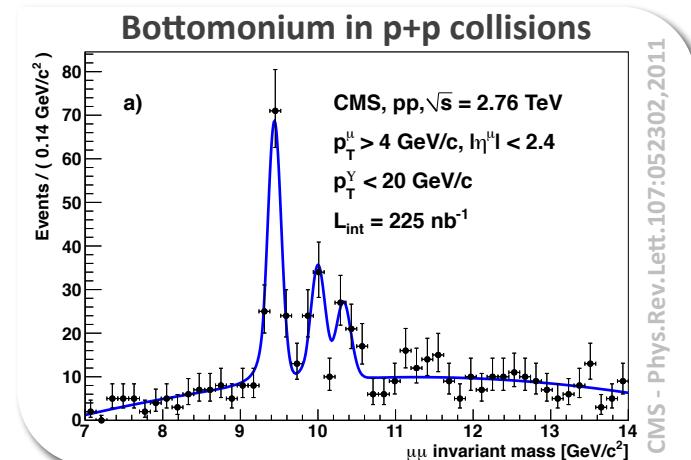
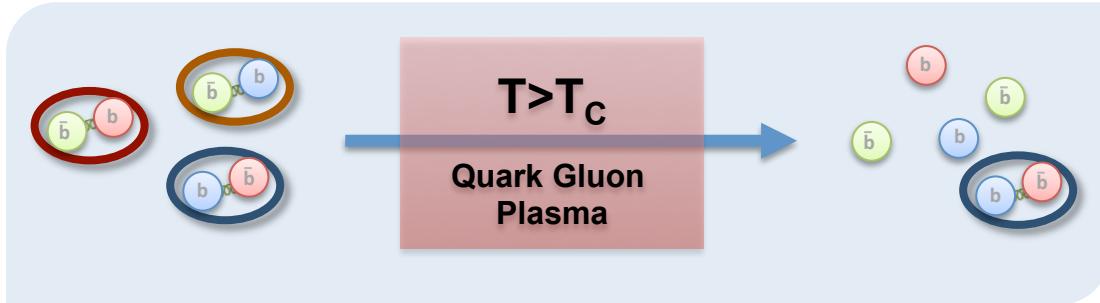
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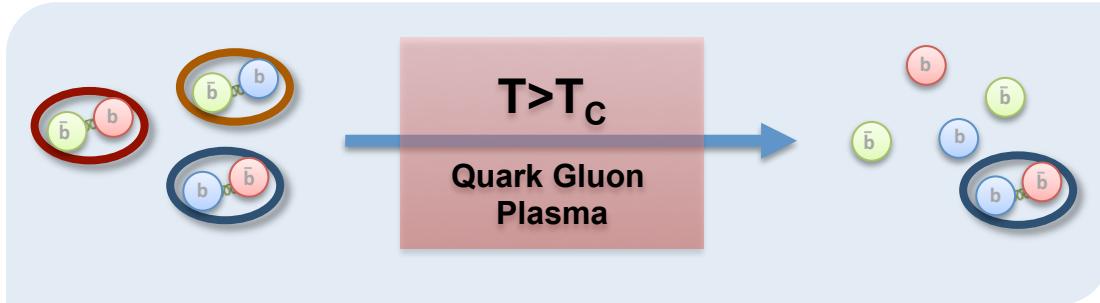
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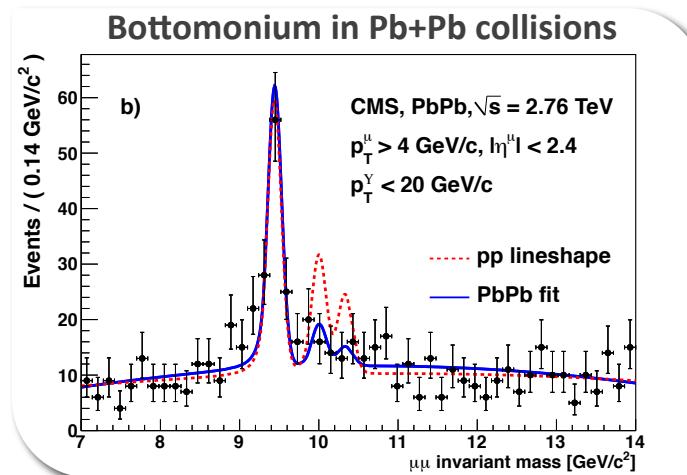
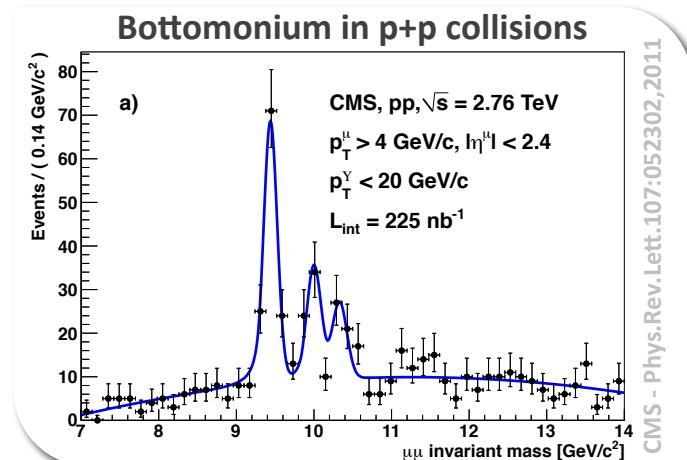
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- Goal: Real-time in-medium evolution of quarkonium



The $T>0$ $Q\bar{Q}$ potential from lattice QCD



- Complex in-medium heavy $Q\bar{Q}$ potential from effective field theory in **real-time**: NRQCD

$$\frac{\Lambda_{\text{QCD}}}{m_Q} \ll 1, \quad \frac{T}{m_Q} \ll 1 \quad V^{Q\bar{Q}}(r) = \lim_{t \rightarrow \infty} \frac{i \partial_t W(r, t)}{W(r, t)}$$

for a brief review see
A.R. MPLA 28 (2013) 133000
and references therein



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- Connection to Euclidean lattice QCD via **spectral functions**:

$$W(r, t) = \int_{-\infty}^{\infty} d\omega e^{-i\omega t} \rho(r, \omega) \quad \longleftrightarrow \quad W(r, \tau) = \int_{-\infty}^{\infty} d\omega e^{-\omega \tau} \rho(r, \omega)$$



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Bayesian spectral
reconstruction

A.R., T.Hatsuda & S.Sasaki PRL 108 (2012) 162001



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Y. Burnier, A.R. PRD86 (2012) 051503



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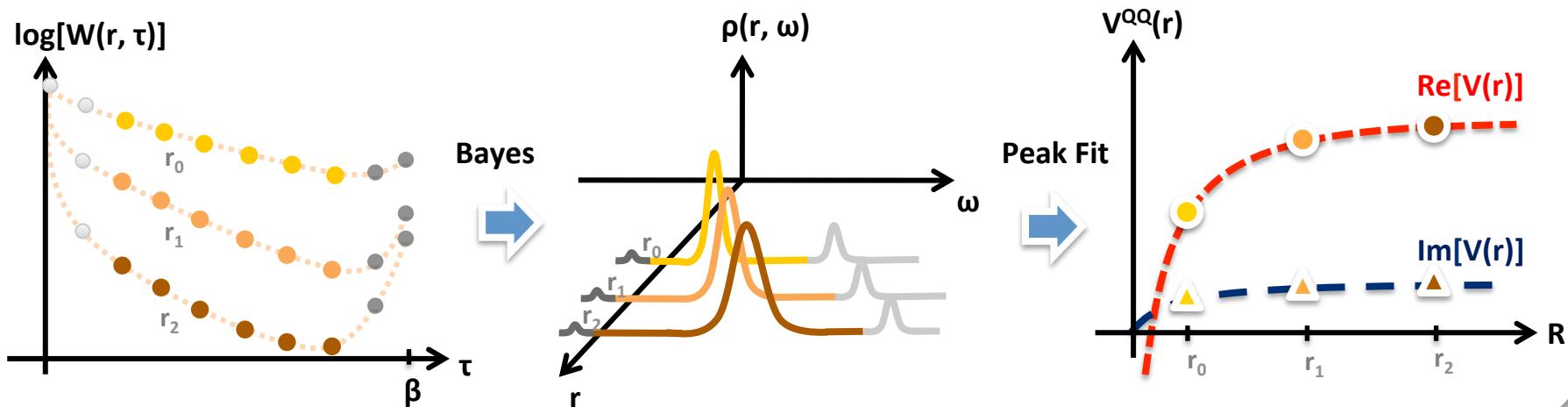
- Bayesian reconstruction challenging: Need prior information to regularize ill-defined χ^2 fit
- Recent improvement over Maximum Entropy Method: **new prior**, analytic treatment of α

$$S = \alpha \sum_{l=1}^{N_\omega} \Delta\omega_l \left(1 - \frac{\rho_l}{m_l} + \log \left[\frac{\rho_l}{m_l} \right] \right)$$

for more details see
Y.Burnier, A.R. PRL 111 (2013) 18, 182003
and POSTER by Y. Burnier

Extraction strategy summary

- From Euclidean lattice QCD correlators to the complex heavy quark potential



A.R. Mod. Phys. Lett. A, 28, 1330005 (2013)

- Technical detail: Wilson Line correlators in Coulomb gauge instead of Wilson loops
 Practical reason: Absence of cusp divergences, hence less suppression along τ



Two projects for V^{QQ} from the lattice

- Quenched lattice QCD: anisotropic lattices with naïve Wilson action $32^3 \times N_\tau$
with Y. Burnier
- Fixed scale approach: $\beta=7.0$ $\xi=a_s/a_\tau=4$ $a_s=0.039\text{fm}$

N_τ	24	32	40	48	56	64	72	80	96
T/T_c	3.11	2.33	1.86	1.55	1.33	1.17	1.04	0.93	0.78
N_{meas}	2750	1570	1680	1110	760	1110	700	940	690

- Focus: Achieve a large number of time steps for accurate spectral width reconstruction



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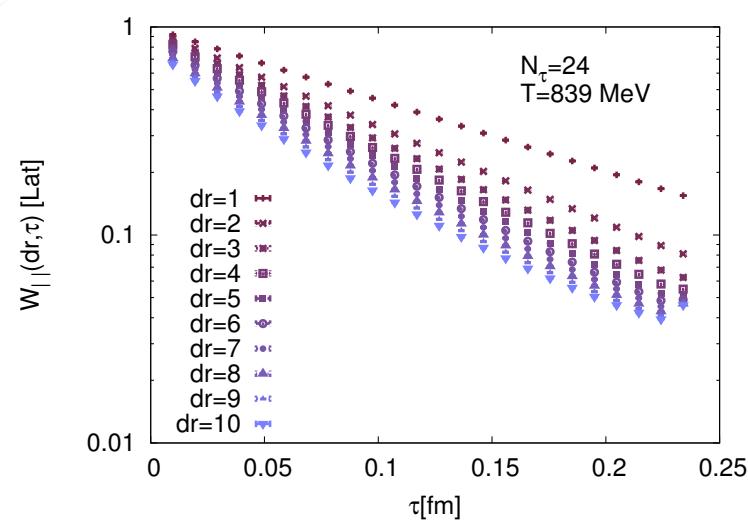
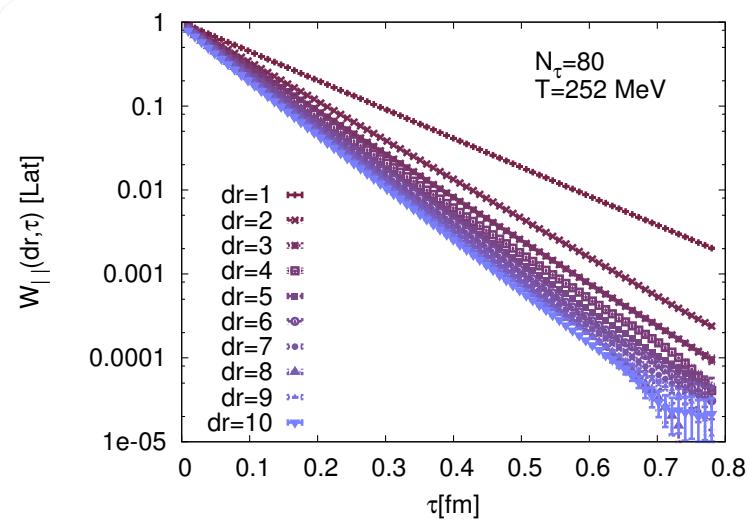
- Focus:** Achieve a large number of time steps for accurate spectral width reconstruction
- Dynamical lattice QCD: isotropic lattices with asqtad action $48^3 \times 12$ (HotQCD)
with O. Kaczmarek

β	6.80	6.90	7.00	7.125	7.25	7.30	7.48
T/T_c	0.85	0.94	1.04	1.18	1.33	1.39	1.64
a [fm]	0.111	0.100	0.090	0.080	0.071	0.068	0.057
N_{meas}	1295	1340	1015	840	1620	1150	1130

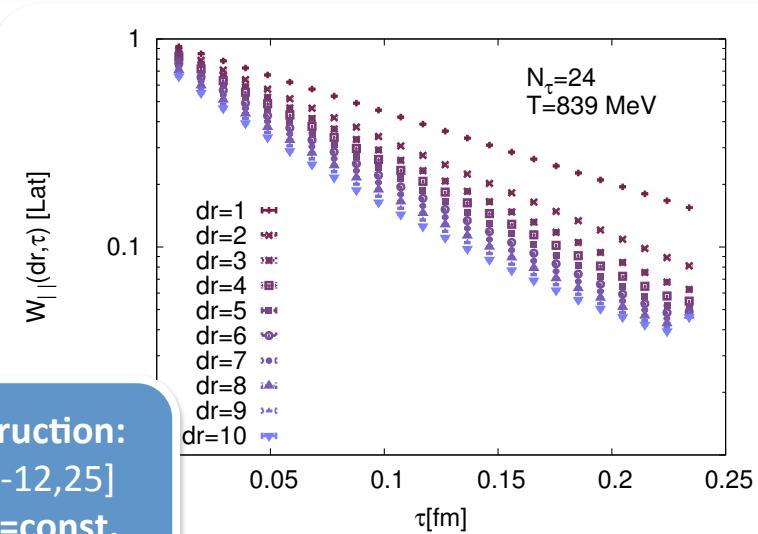
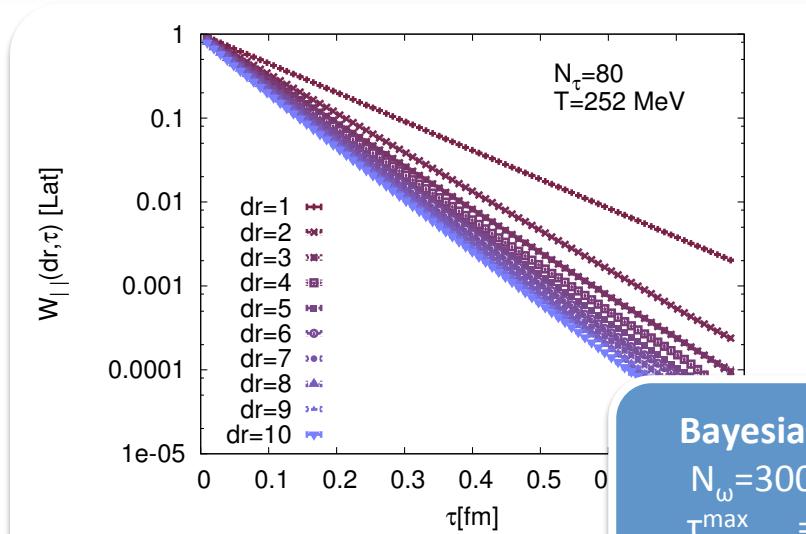
A. Bazzavov et. al.
PRD 85 (2012) 054503

- Focus:** Effect of light fermion on in-medium QQ interactions i.e. $\text{Re}[V]$

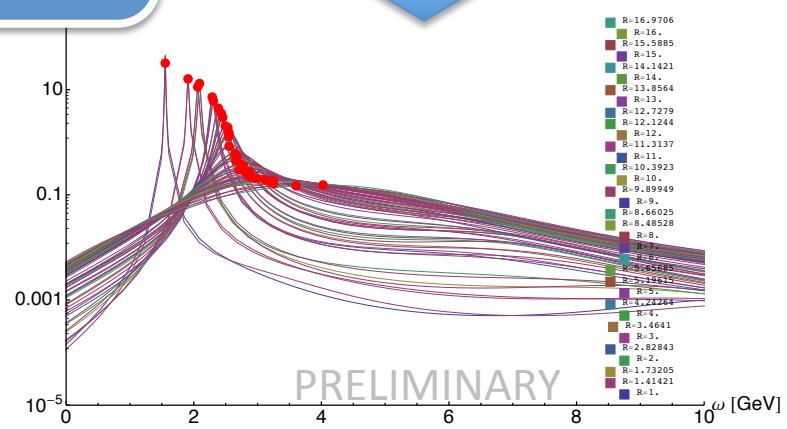
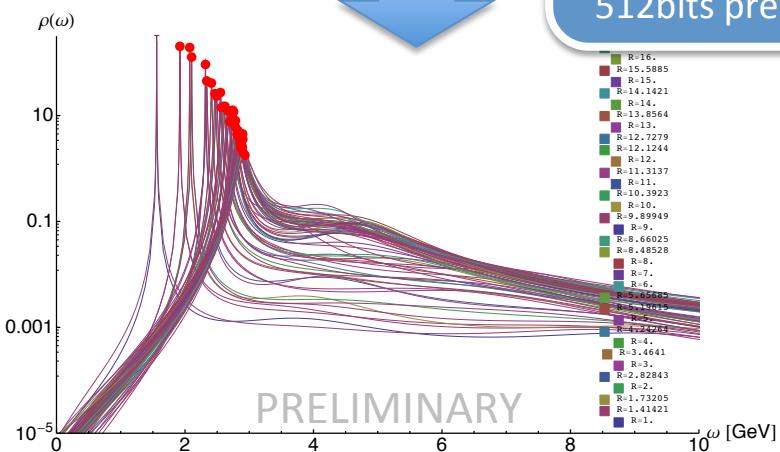
Towards $V^{QQ}(r)$ on quenched lattices



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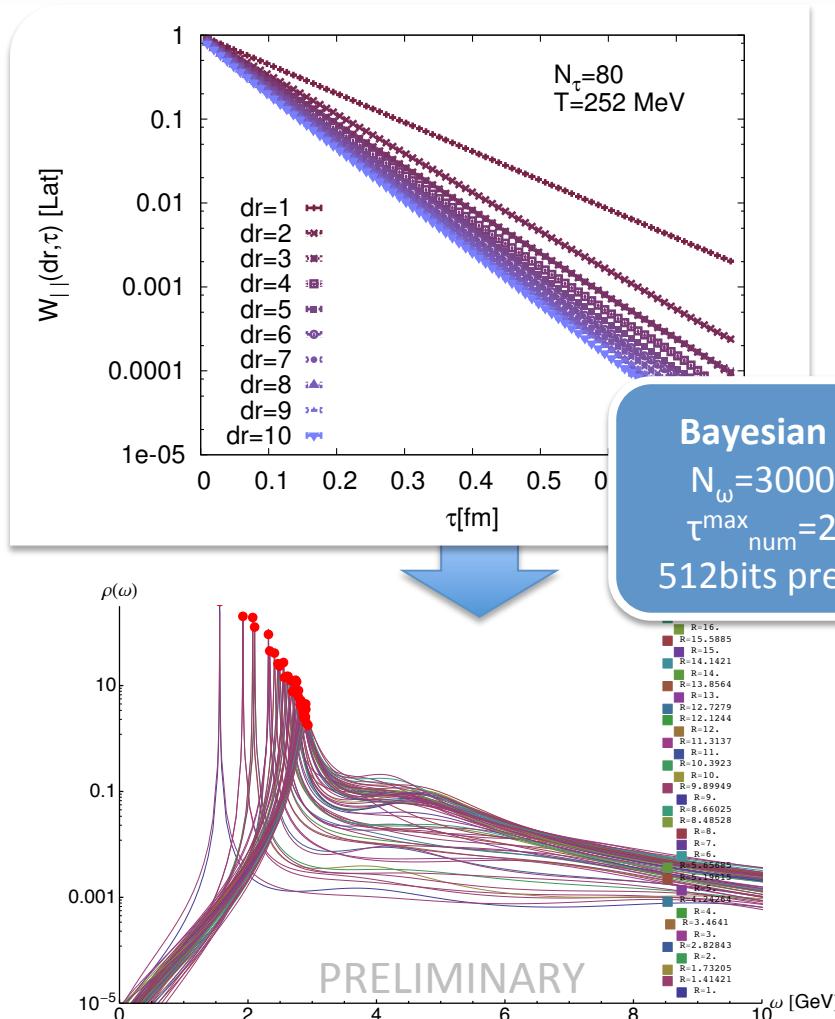


Bayesian reconstruction:
 $N_\omega = 3000$, $I_\omega^{\text{num}} = [-12, 25]$
 $\tau_{\text{num}}^{\text{max}} = 20$, $m(\omega) = \text{const.}$
512bits precision, $\Delta^{\text{min}} = 10^{-60}$

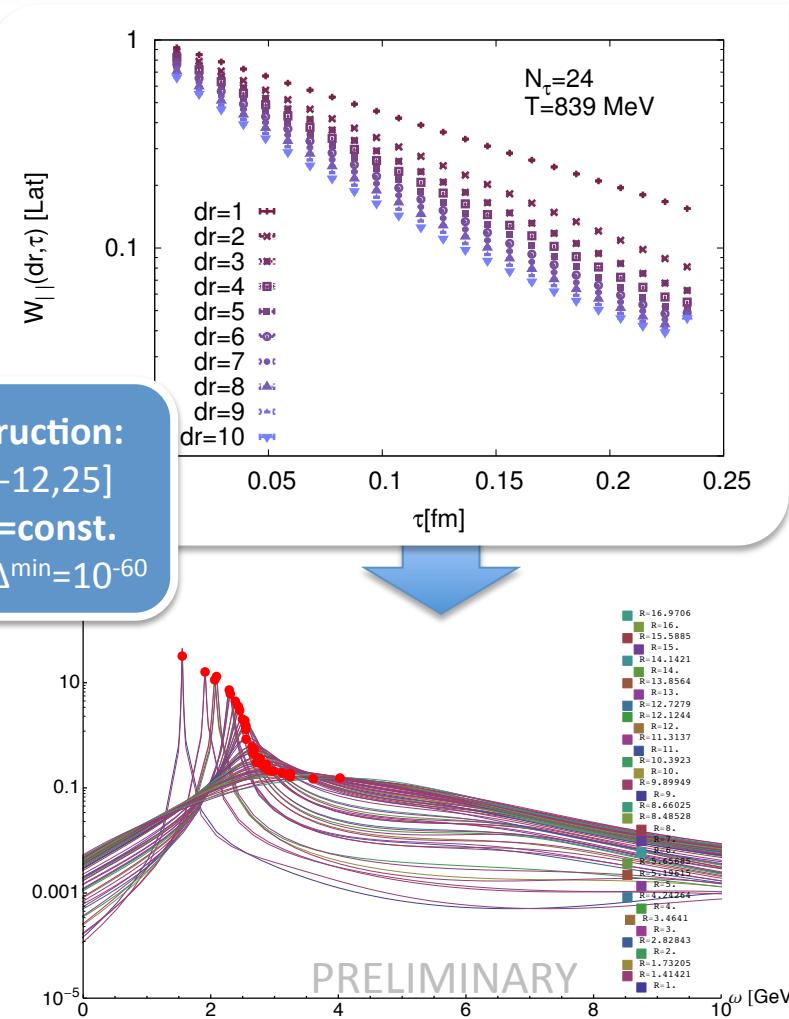




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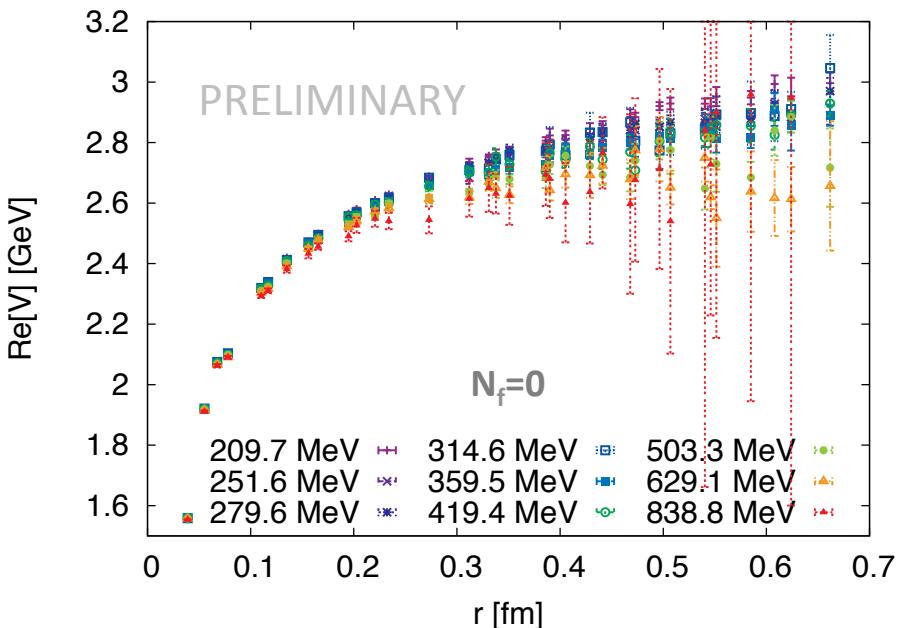


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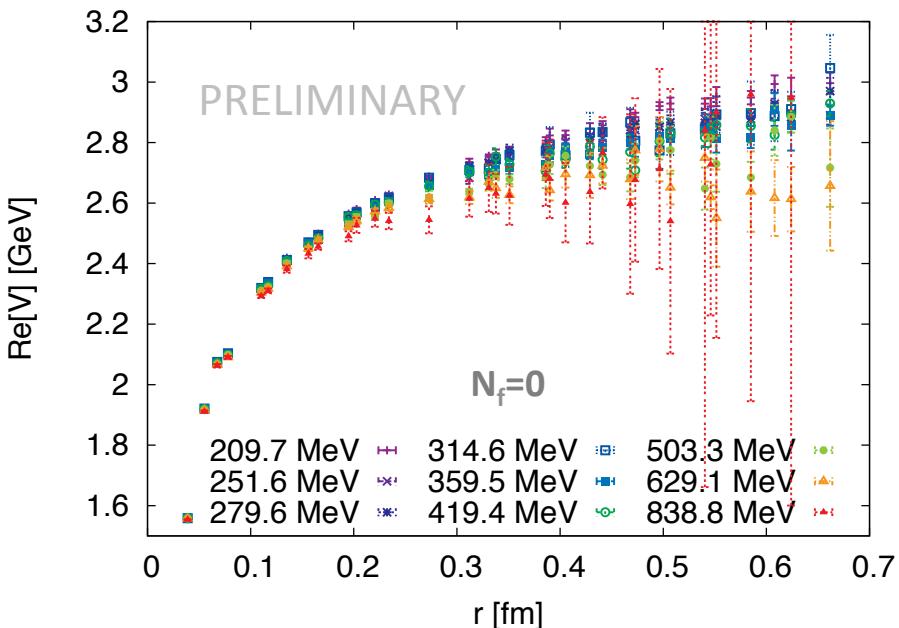


- Identify the lowest lying peak and fit its shape over the Full-Width at Half Maximum

Re[V] in quenched lattice QCD

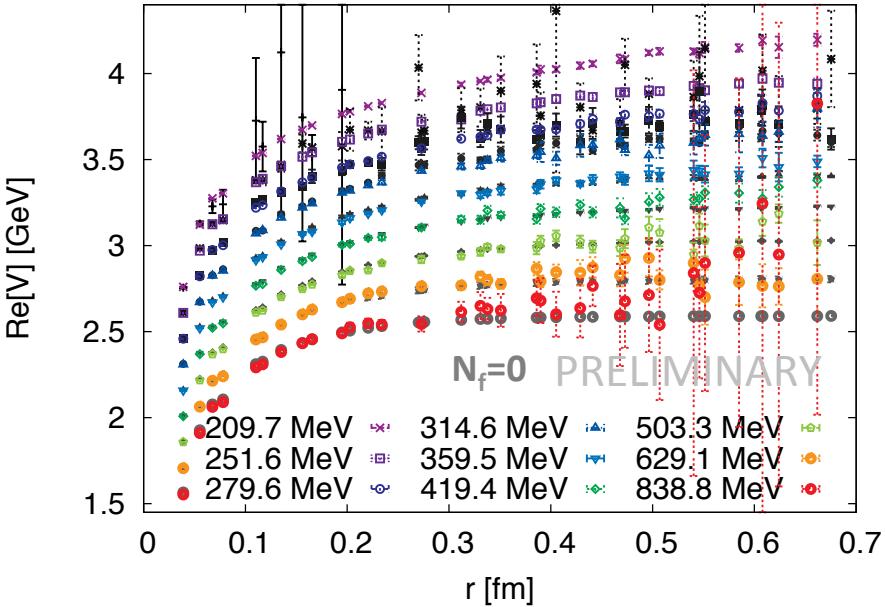
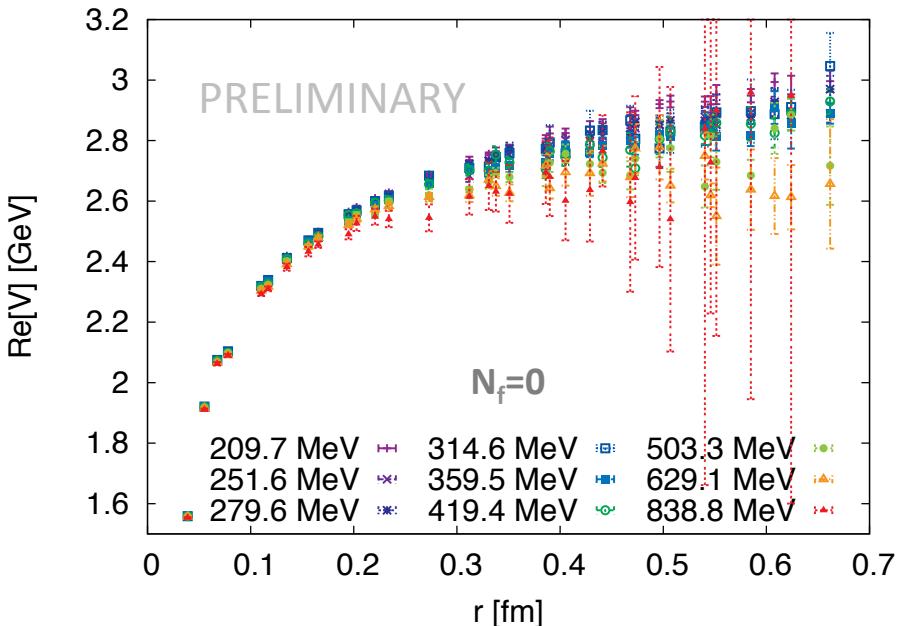


Re[V] in quenched lattice QCD



- Transition from a confining to a Debye screened behavior

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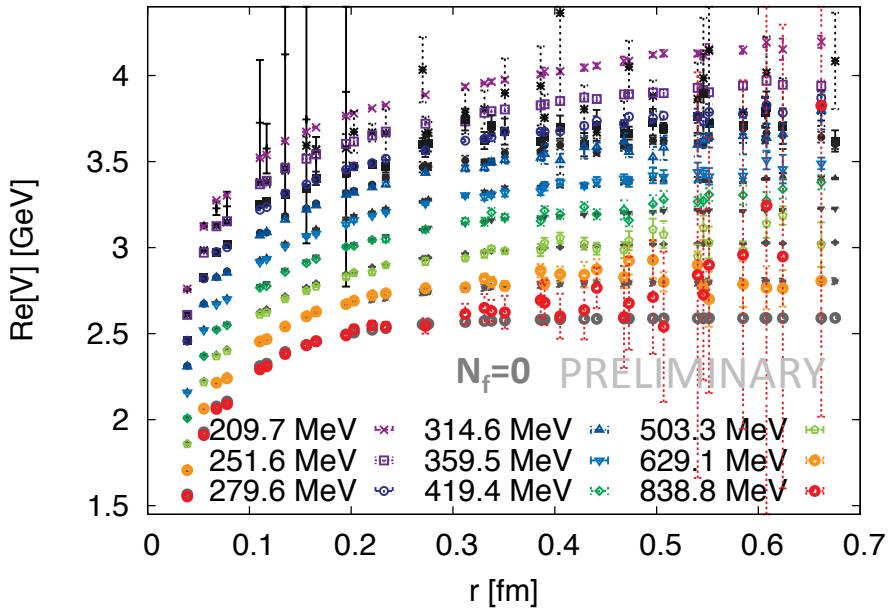
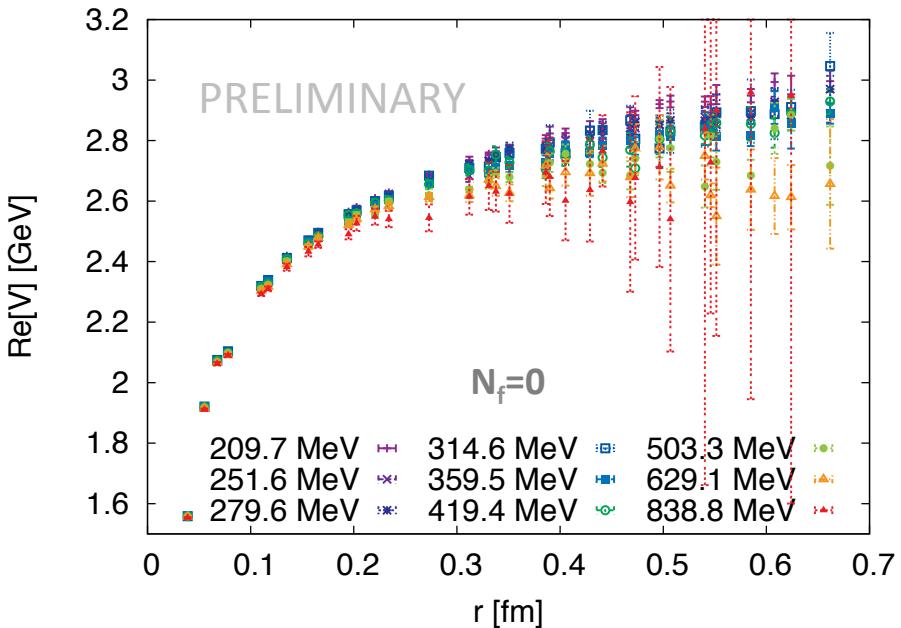


- Transition from a confining to a Debye screened behavior
- Comparison to color singlet free energies $F^1(r)$: agreement within errorbars

$$F^{(1)}(r) = -\frac{1}{\beta} \log [W_{||}(r, \tau = \beta)]_{CG}$$

Indication for this behavior seen in HTL
 Y. Burnier, M. Laine and M. Vepsäläinen,
 JHEP 1001, 054 (2010)

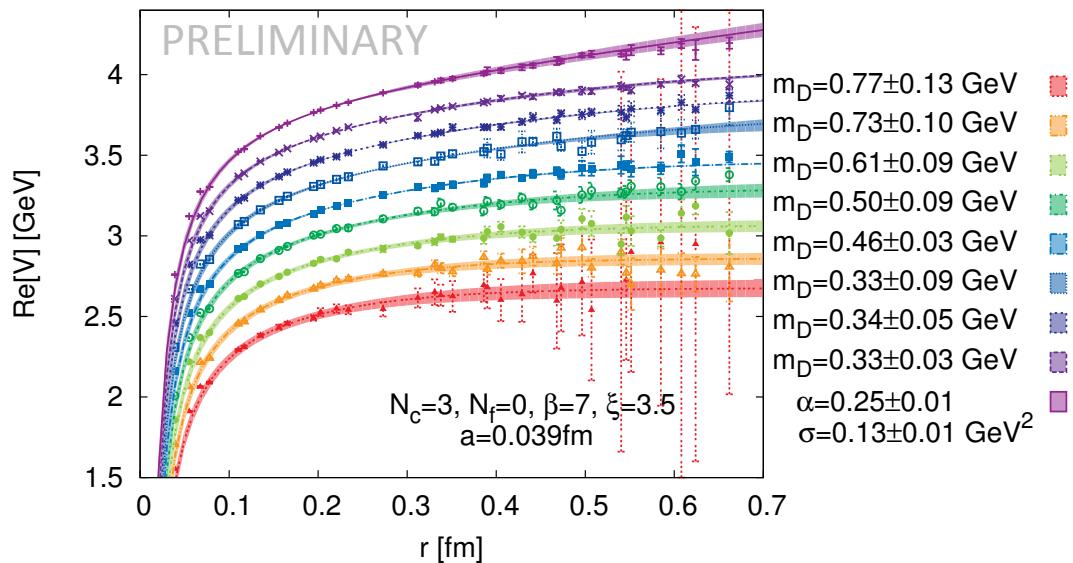
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- At $T \approx T_c$ extraction V^{QQ} benefits from using all datapoints instead of just $W_{||}(\tau = \beta)$

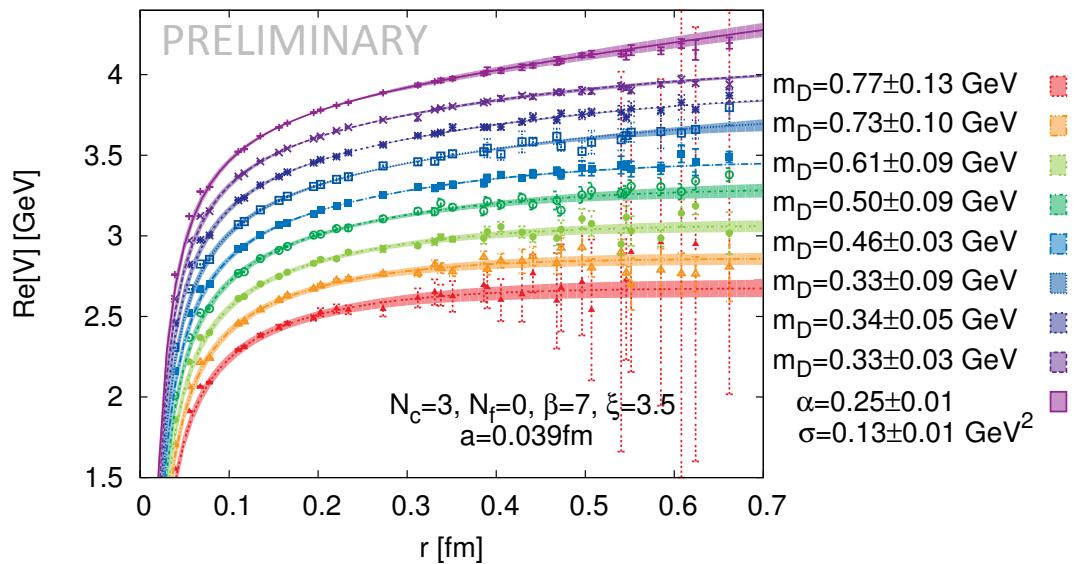


Debye-Hückel Fit of the Debye mass



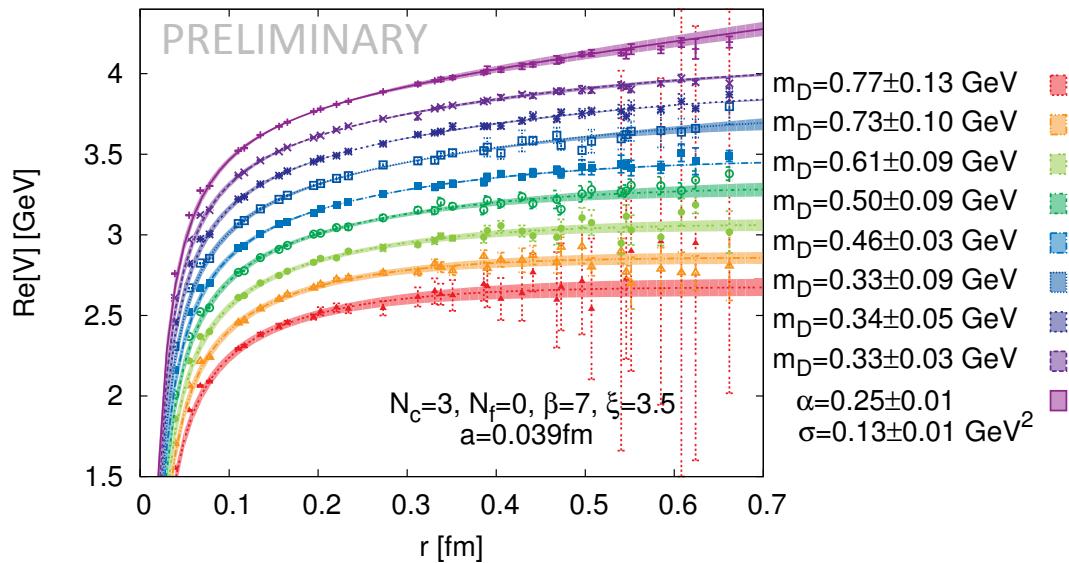


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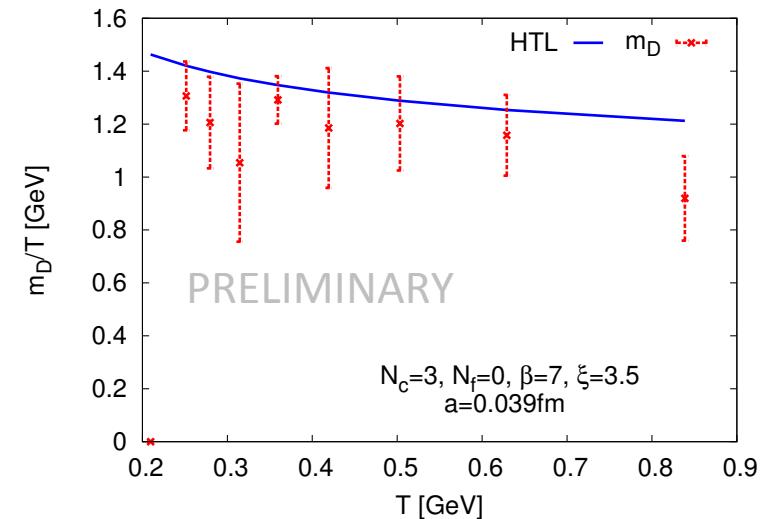
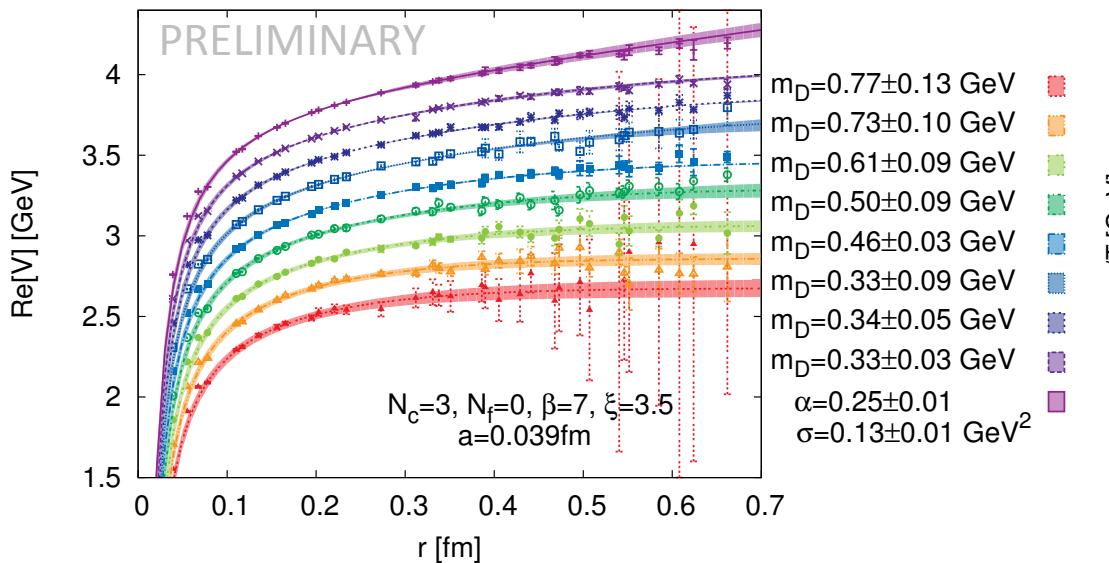


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- Phenomenological fit form for Coulomb and string screening S.Digal et.al. EPJ C43 (2005) 71-75

$$F^{DH}(r, T) = \frac{\sigma}{m_D(T)} \left[\frac{\Gamma(1/4)}{2^{3/2} \Gamma(3/4)} - \frac{\sqrt{m_D(T)r}}{2^{3/4} \Gamma(3/4)} K_{1/4}(m_D^2(T)r^2) \right] - \frac{\alpha}{r} [e^{-m_D(T)r} + m_D(T)r]$$

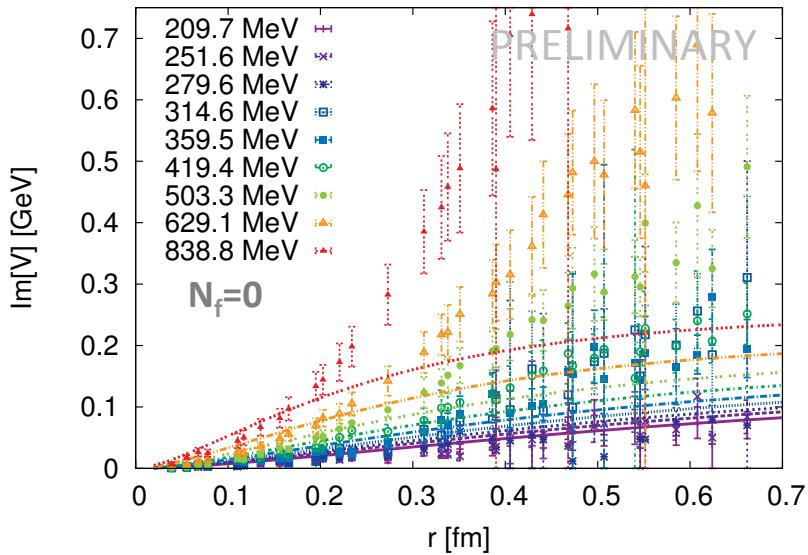


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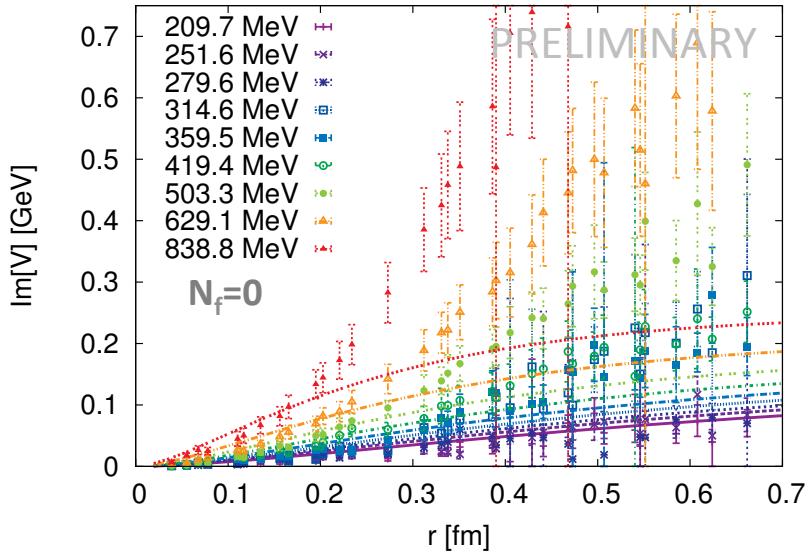
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 - Within the error bars, reasonable agreement with 1-loop HTL
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Imaginary part at finite temperature



- $\text{Im}[V^{\text{QQ}}]$ related to width: need large # of datapoints and high signal/noise

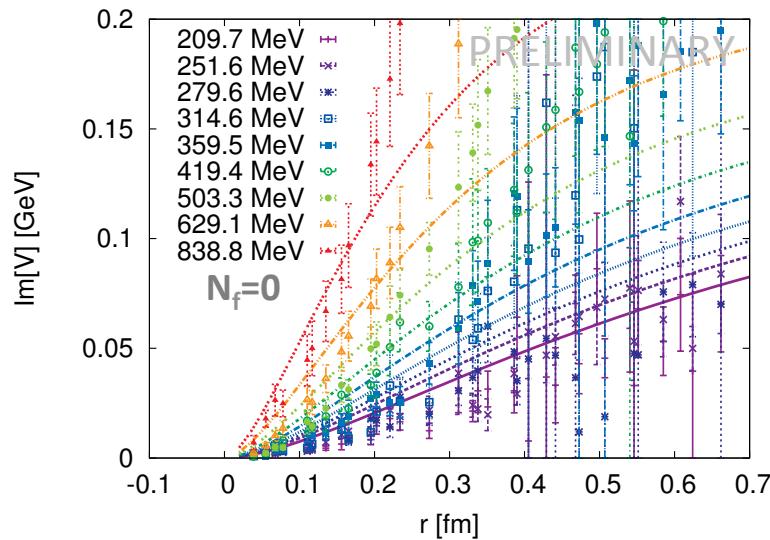
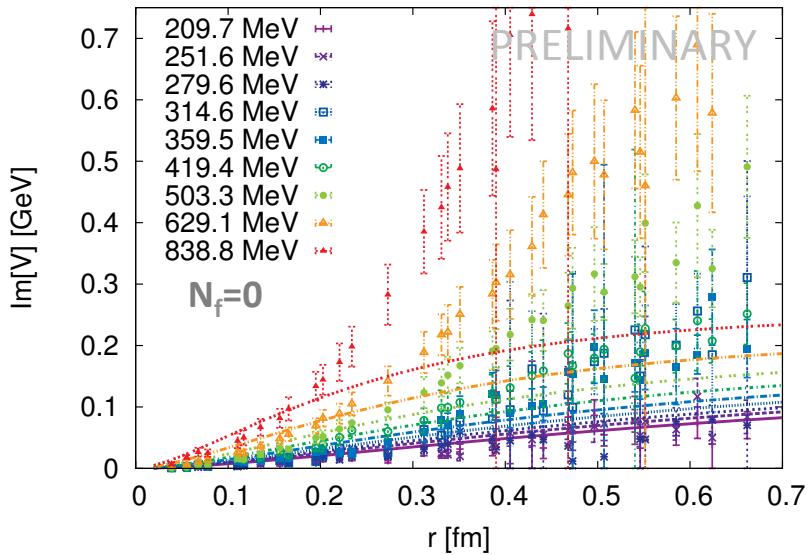
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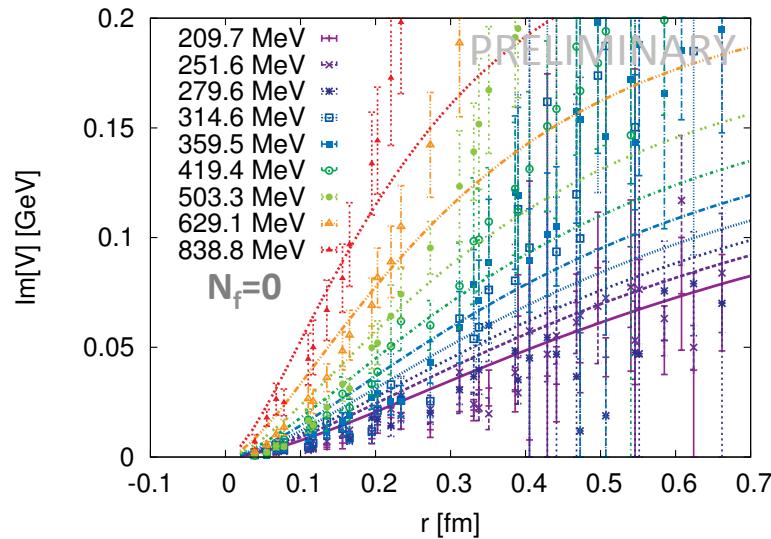
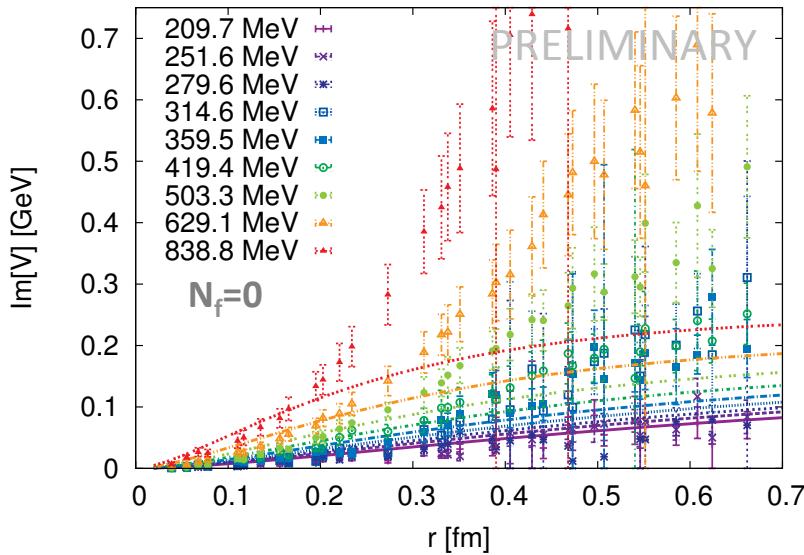
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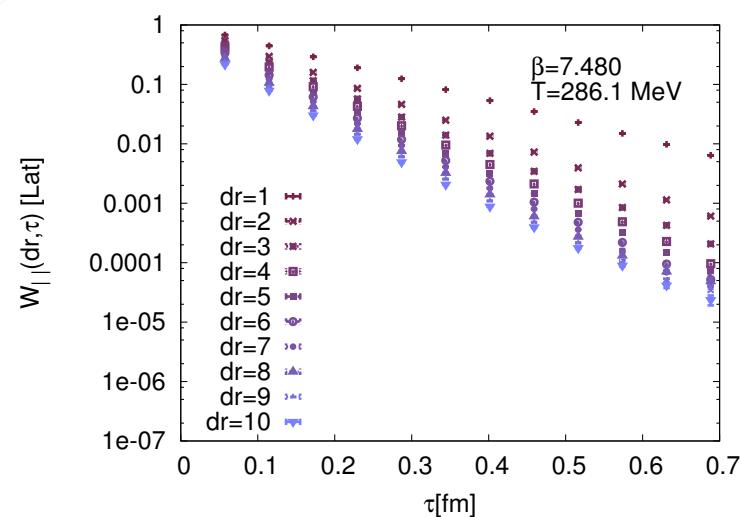
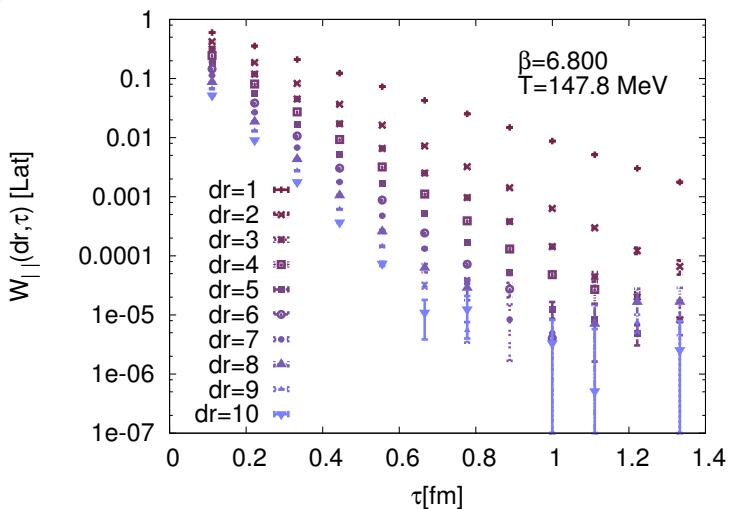


Imaginary part at finite temperature

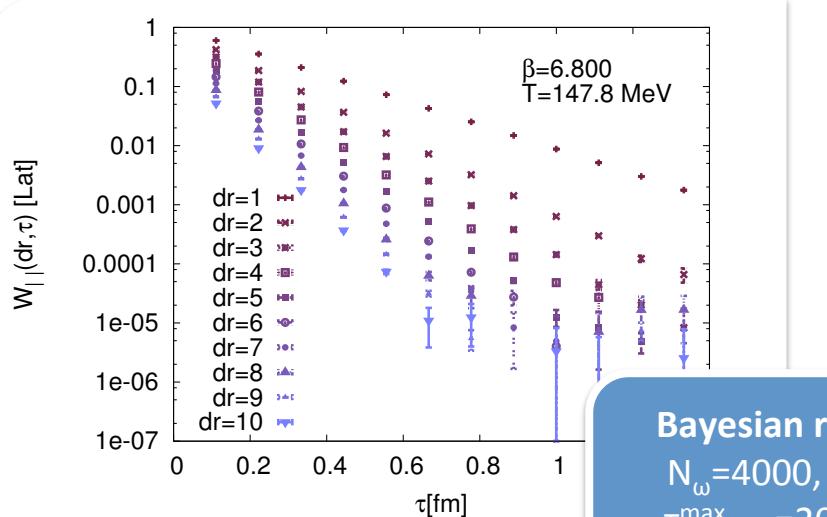


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- Rise above the HTL values might be related to diminishing number of datapoints
- For small r : good agreement with HTL prediction down to $1.17T_c$
- To improve the width reconstruction: better default model $m(\omega) \neq \text{const.}$

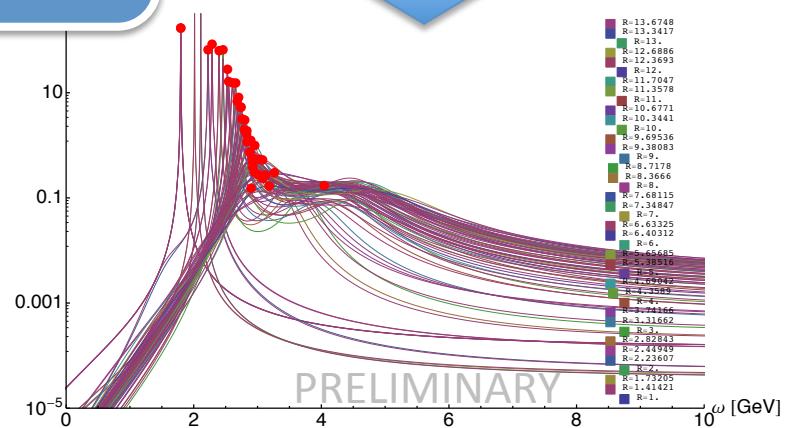
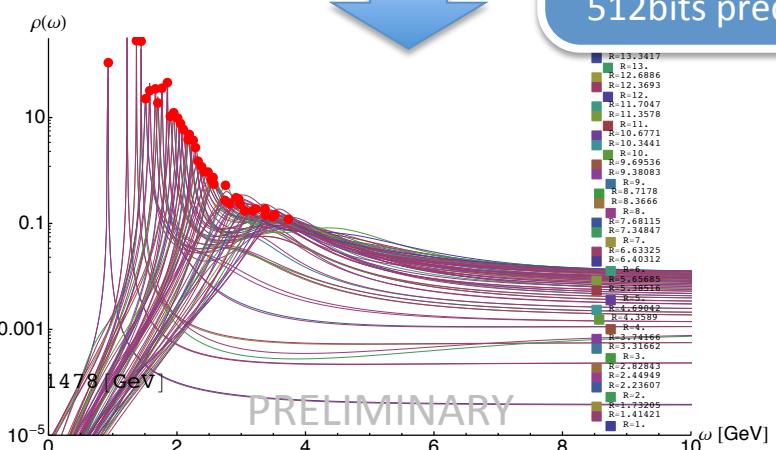
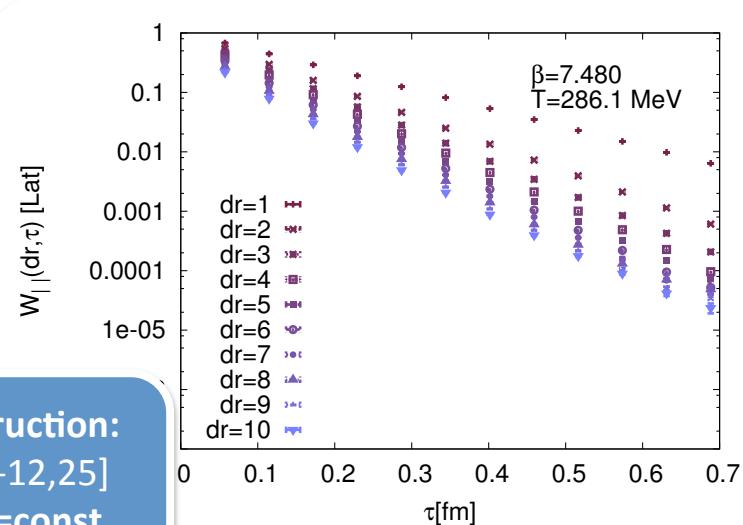
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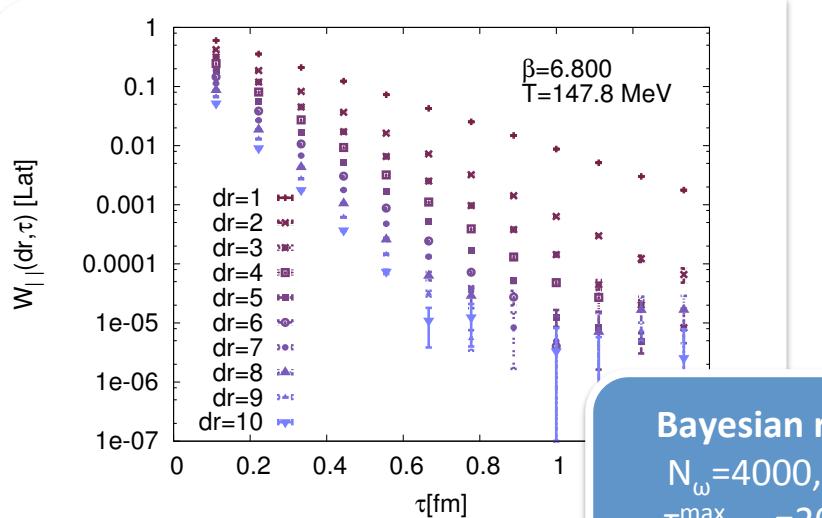
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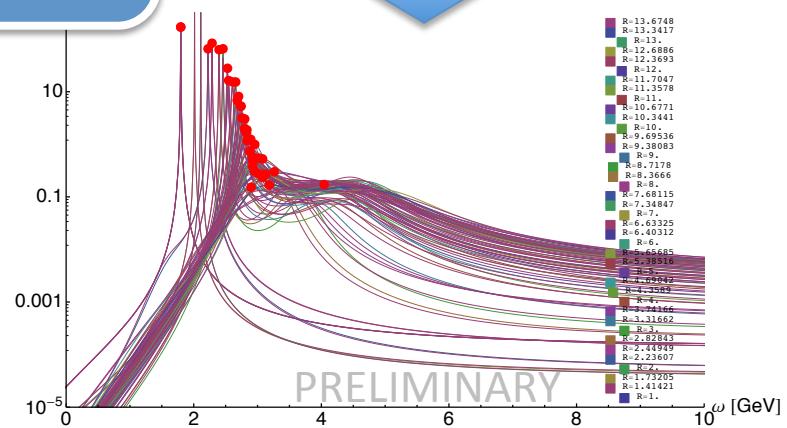
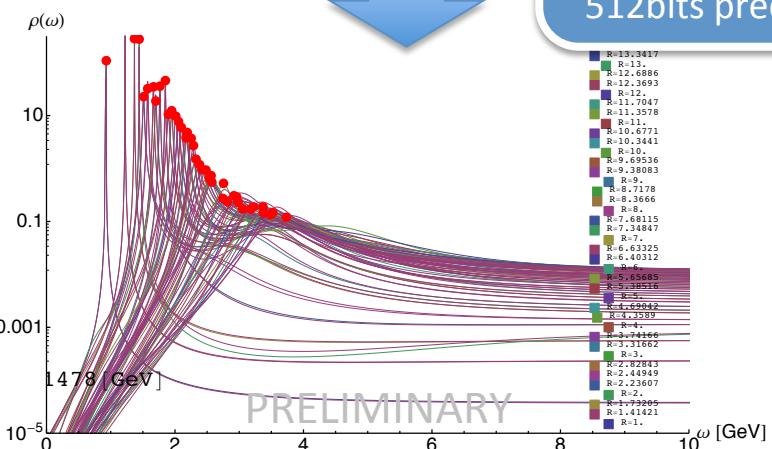
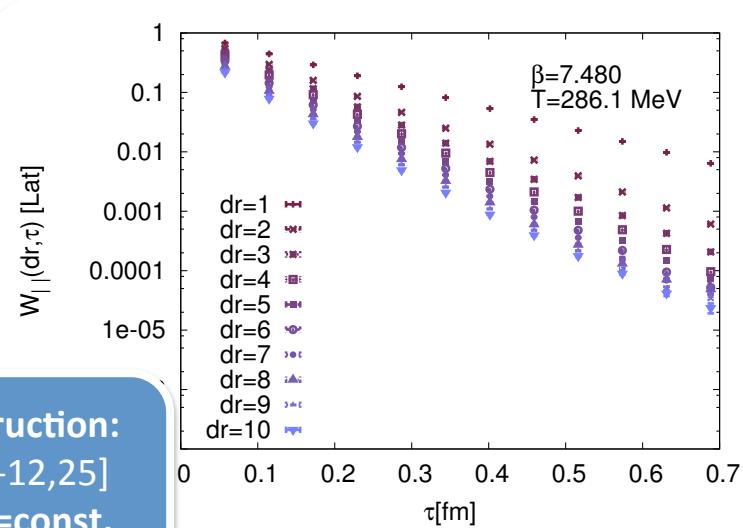
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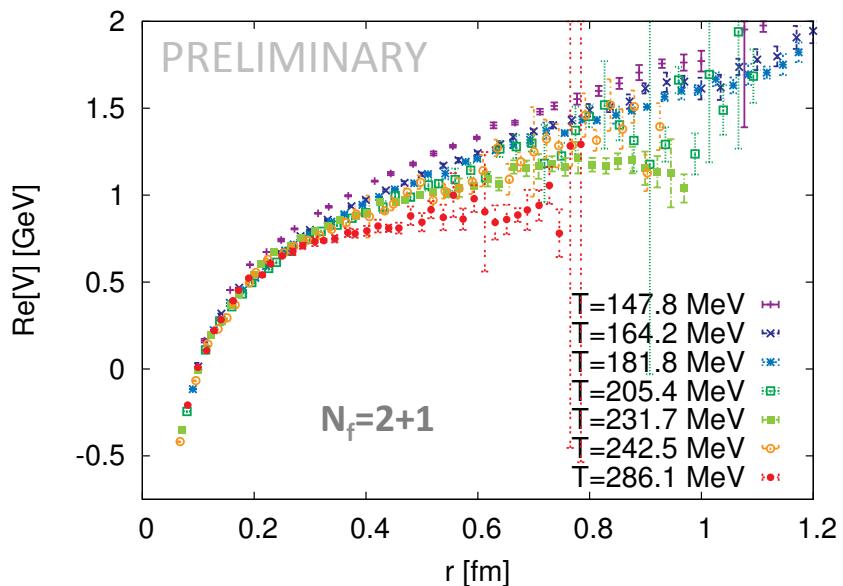


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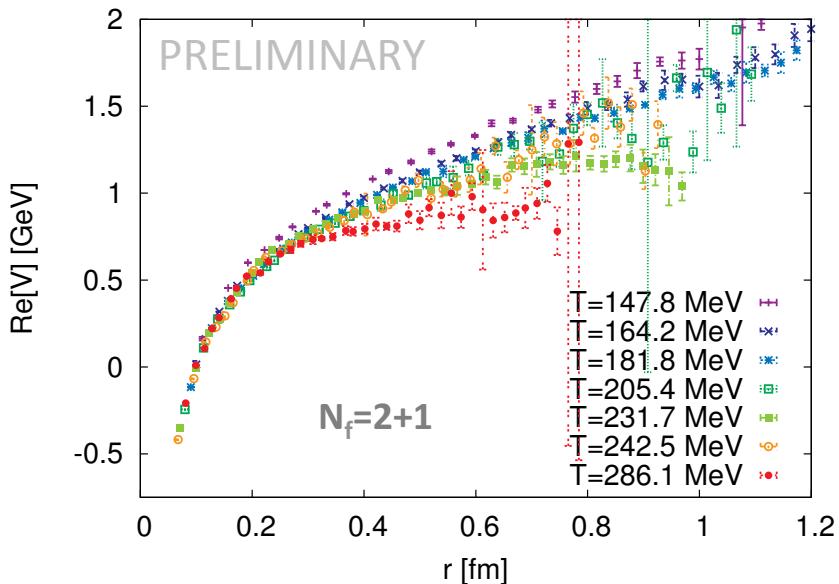


- Identify the lowest lying peak and fit its shape over the Full-Width at Half Maximum

The real part in dynamical lattice QCD

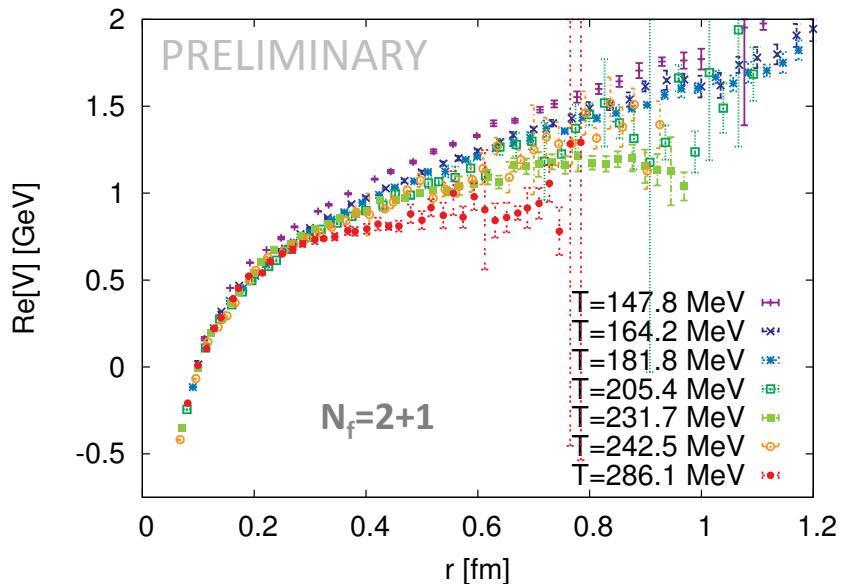


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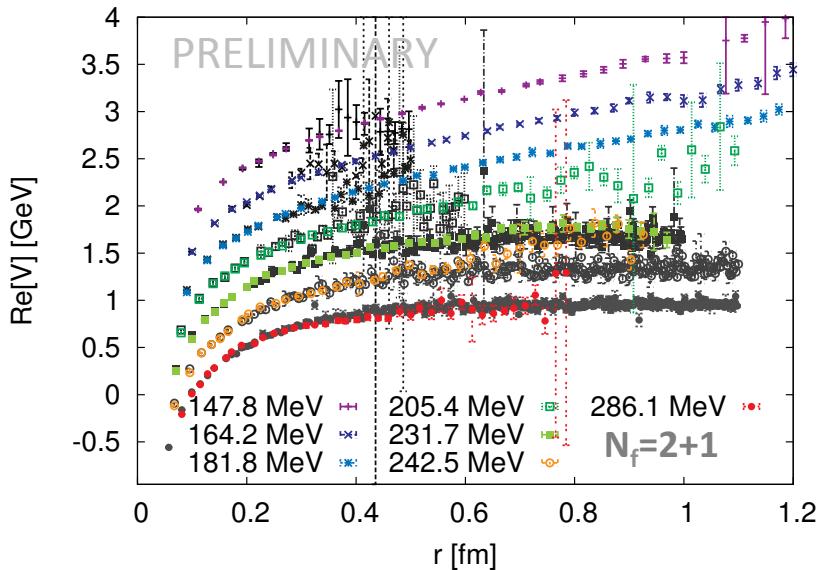
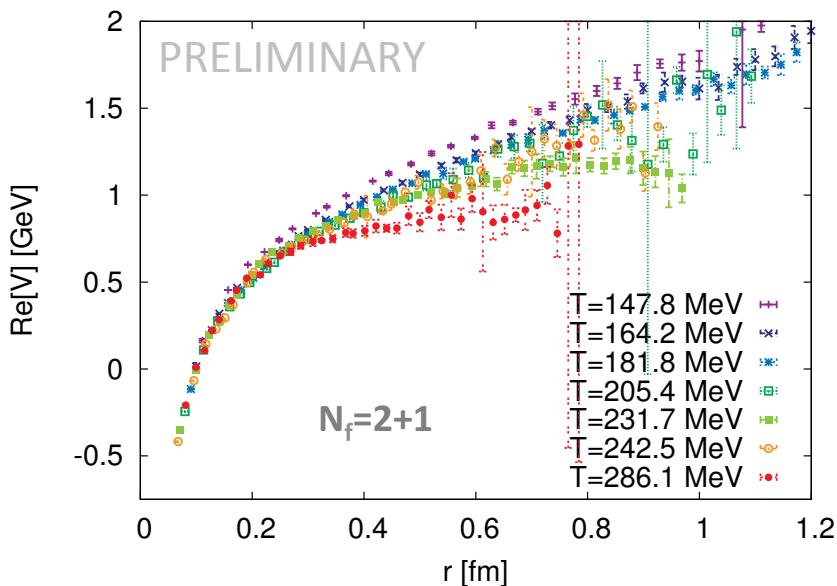
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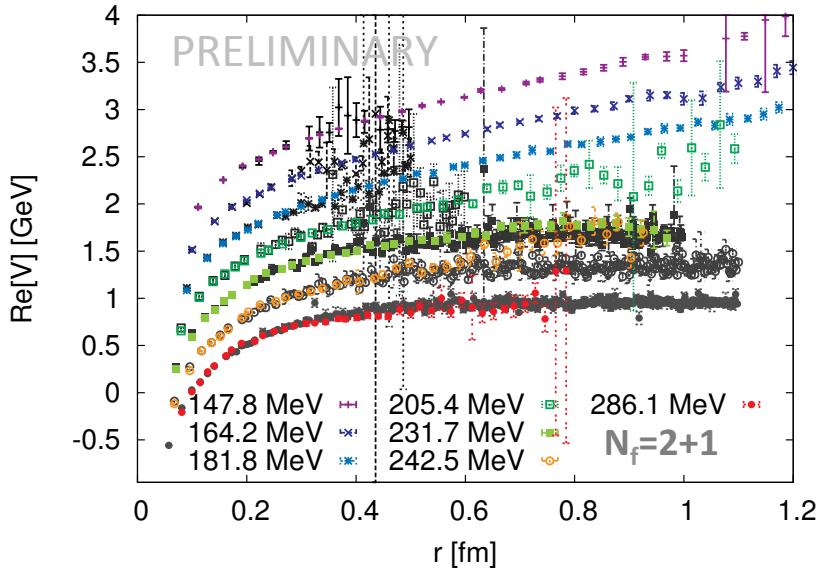
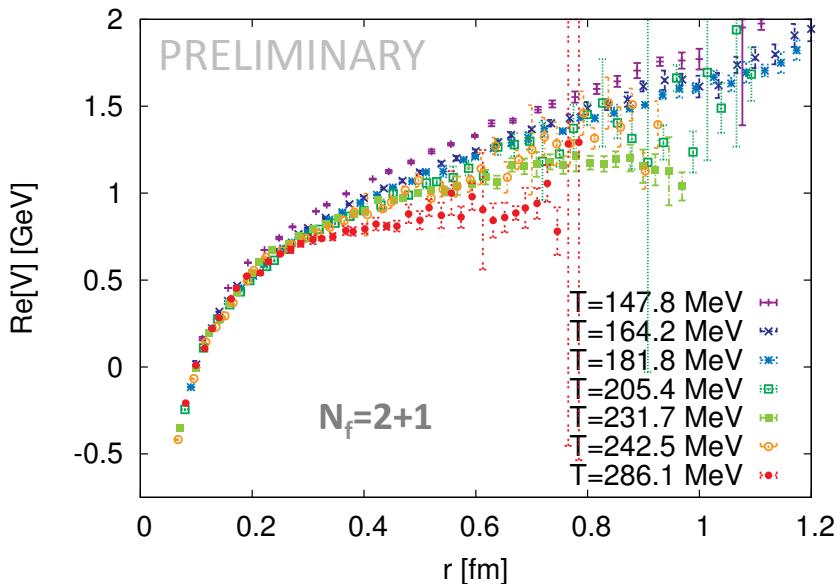
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Conclusion



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- Definition from QCD via effective field theory NRQCD: Wilson loops/lines at late real-time
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Thank you for your attention