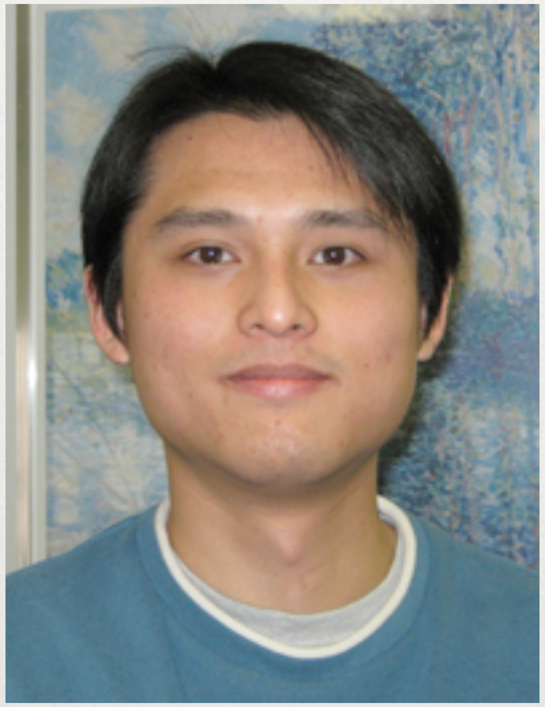
Confinement models

at finite temperature and density

Eric swanson



Pok Man Lo

P-M Lo and E.S. Swanson, 0908.4099

MOTIVATION

- do simple quark models explain lattice data at finite temperature (and density)?
- map the structure of the chiral phase transition
- investigate quarkyonic matter ideas

L. McLerran and R.D. Pisarski, NPA796, 83 (2007)

MOTIVATION...

$$H = \int \bar{\psi}(-i\vec{\gamma}\cdot\nabla + m)\psi + \frac{1}{2}\int \rho^a(x)V(x-y)\rho^a(y)$$

$$\delta^{ab}\,V(\vec{x}-\vec{y}) = \langle\Omega|(\vec{x}a|\frac{g}{\nabla\cdot D}(-\nabla^2)\frac{g}{\nabla\cdot D}|\vec{y}b)|\Omega\rangle.$$

$$\vec{D}^{ab} = \vec{\nabla}\delta^{ab} + g f^{acb}\vec{A}^c$$

$$V(\vec{q}) = \frac{6\pi b}{q^4}$$

$$V(\vec{q}) = \frac{3}{4}\frac{4\pi}{q^2\beta_0\log(1+q^2/\Lambda^2)}$$

$$\beta_0 = 11 - \frac{2}{3}N_f$$

$$\left[V(\vec{r}) = \frac{\lambda}{\Lambda^2}\delta(\vec{r}).\right]$$

$$\Lambda^2 = 2b\beta_0$$

FORMALISM

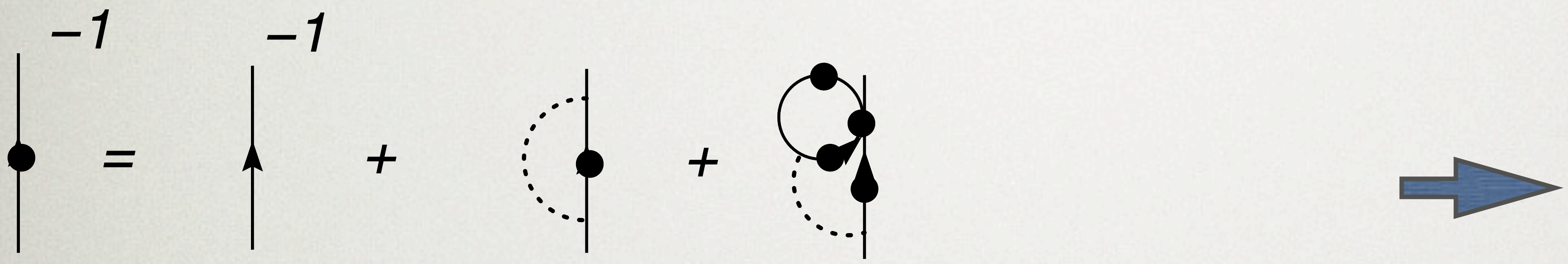
$$Z[\bar{\eta},\eta] = \int D\bar{\psi} D\psi \exp[-A + \bar{\eta}\psi + \bar{\psi}\eta]$$

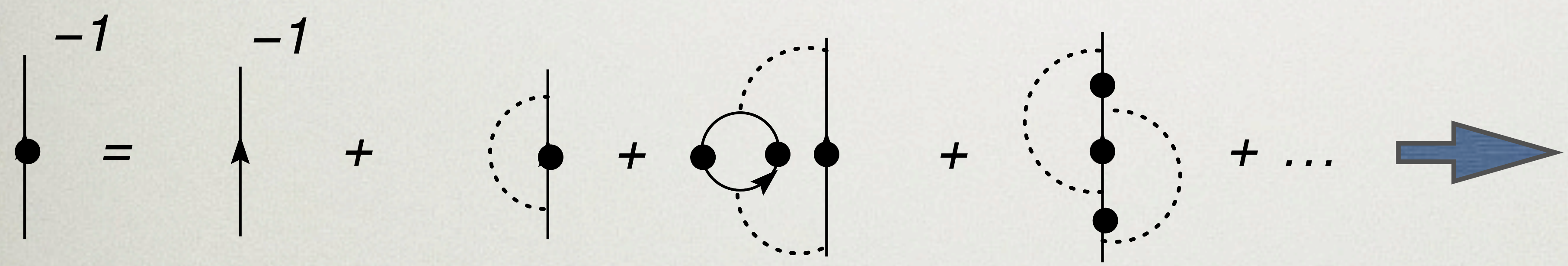
$$A \quad = \quad \int_0^{\beta} d\tau d^3x\, \bar{\psi}(\gamma_0(\partial_\tau - \mu) - i\vec{\gamma}\cdot\vec{\nabla} + m)\psi + \frac{1}{2}\int_0^{\beta} d\tau d^3x d\tau' d^3y\, \rho^a(x) V(\vec{x}-\vec{y})\delta(\tau-\tau')\rho^a(y)$$

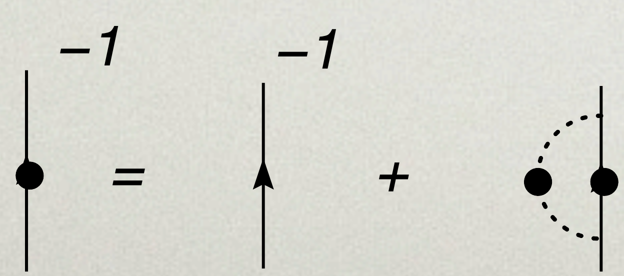
$$k^\mu = (i\omega_n + \mu, \vec{k})$$

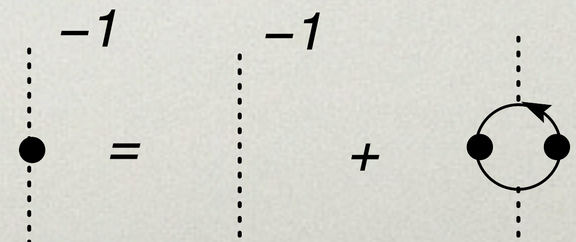
$$\Gamma^\mu = \sum_{n=1}^{12} c_n T_n^\mu \rightarrow \sum_{n=1}^{54} c_n T_n^\mu$$

FORMALISM...









FORMALISM...

$$S^{-1}(k) = i(\omega_n - i\tilde{\mu})\gamma_0 - \vec{\gamma}\cdot\vec{k}A - B$$

$$\begin{aligned}
A(\vec{p}) &= 1 + \frac{C_F}{2}\int \frac{d^3q}{(2\pi)^3} V_{\text{ring}}(\vec{p}-\vec{q})\frac{A_q}{E_q}\frac{\vec{p}\cdot\vec{q}}{p^2}\Theta(q) \\
B(\vec{p}) &= m + \frac{C_F}{2}\int \frac{d^3q}{(2\pi)^3} V_{\text{ring}}(\vec{p}-\vec{q})\,\frac{B_q}{E_q}\,\Theta(q) \\
\tilde{\mu}(\vec{p}) &= \mu + \frac{C_F}{2}\int \frac{d^3q}{(2\pi)^3} V_{\text{ring}}(\vec{p}-\vec{q})[n(q) - \bar{n}(q)] \\
E_p^2 &= A_p^2\, p^2 + B_p^2
\end{aligned}$$

FORMALISM...

$$\begin{aligned}\Theta(q) &= 1 - n(q) - \bar{n}(q)\\ n(p) &= \frac{1}{\exp(\beta(E_p - \tilde{\mu})) + 1}\\ \bar{n}(p) &= \frac{1}{\exp(\beta(E_p + \tilde{\mu})) + 1}\end{aligned}$$

$$E_p^2 = A_p^2 p^2 + B_p^2$$

A. Kocić, PRD33, 1785 (1986)

A. Le Yaouanc, L. Oliver, O. Pene, J.C. Raynal, M. Jarfi and O. Lazrak, PRD39, 924 (1989)

D. Blaschke, C.D. Roberts and S. M. Schmidt, PLB425, 232 (1998).

L.Y. Glozman and R.F. Wagenbrunn, PRD77, 054027 (2008);

P. Guo and A.P. Szczepaniak, PRD79, 116006 (2009)

A.V. Nefediev and J.E.F. Ribeiro, 0906.1288

FORMALISM...

$$S^{-1}(k) = i(\omega_n - i\tilde{\mu})\gamma_0 - \vec{\gamma}\cdot\vec{k}A - B$$

if the T=0 model has a phase transition -> Theta can drive this transition for T>0

$$\omega_n \qquad \frac{1}{\beta}\sum_m \qquad \omega_n - \nu_m \qquad \nu_m$$

$$A(\vec{p}) = 1 + \frac{C_F}{2}\int \frac{d^3q}{(2\pi)^3} V_{\rm ring}(\vec{p}-\vec{q})\,\frac{A_q}{E_q}\,\frac{\vec{p}\cdot\vec{q}}{p^2}\,\cancel{\Theta}(q)$$

$$B(\vec{p}) = m + \frac{C_F}{2}\int \frac{d^3q}{(2\pi)^3} V_{\rm ring}(\vec{p}-\vec{q})\,\frac{B_q}{E_q}\,\Theta(q)$$

$$\tilde{\mu}(\vec{p}) = \mu + \frac{C_F}{2}\int \frac{d^3q}{(2\pi)^3} V_{\rm ring}(\vec{p}-\vec{q})[n(q)$$

$$E_p^2 = A_p^2 p^2 + B_p^2$$

conf do NOT have T=0 transitions, here 1/q^4 -> 1/q^3...

INFRA-RED ISSUES

$$\int \frac{d^3q}{(2\pi)^3} \frac{f(q)}{(\vec{p}-\vec{q})^4} \to \frac{1}{\epsilon_{IR}^2} \qquad M(k) = B(k)/A(k)$$

no problem at zero temperature

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for T>0

$$\Theta \to n \to A$$

no way around it

INFRA-RED ISSUES...

$\Theta \rightarrow n \rightarrow A$ *no way around it*

resolutions

1. $E_q \rightarrow E_q - E_0$ A.C. Davis and A. M. Matheson, NPB246, 203 (1984)

2. $E_q^2 \rightarrow q^2 + M_q^2$ R. Alkofer, P.A. Amundsen and K. Langfeld, ZPC42, 199 (1989)

3. $V(\vec{q}) \rightarrow V(\vec{q}) - \delta(\vec{q}) \int d^3k V(\vec{k})$

4. $V(\vec{q}) \rightarrow V_{\text{ring}}$ M. Gell-Mann and K.A. Brueckner, PR106, 364 (1957)

INFRA-RED ISSUES...

$$V_{\text{ring}}(q_0,\vec{q}) = \frac{V(\vec{q})}{1-\Pi(q_0,\vec{q})V(\vec{q})}$$

$$\Pi(k_0,k) = \frac{1}{2\beta} n_f \sum_n \int \frac{d^3p}{(2\pi)^3} \mathrm{tr}[\gamma_0 S(k)\gamma_0 S(p+k)]$$

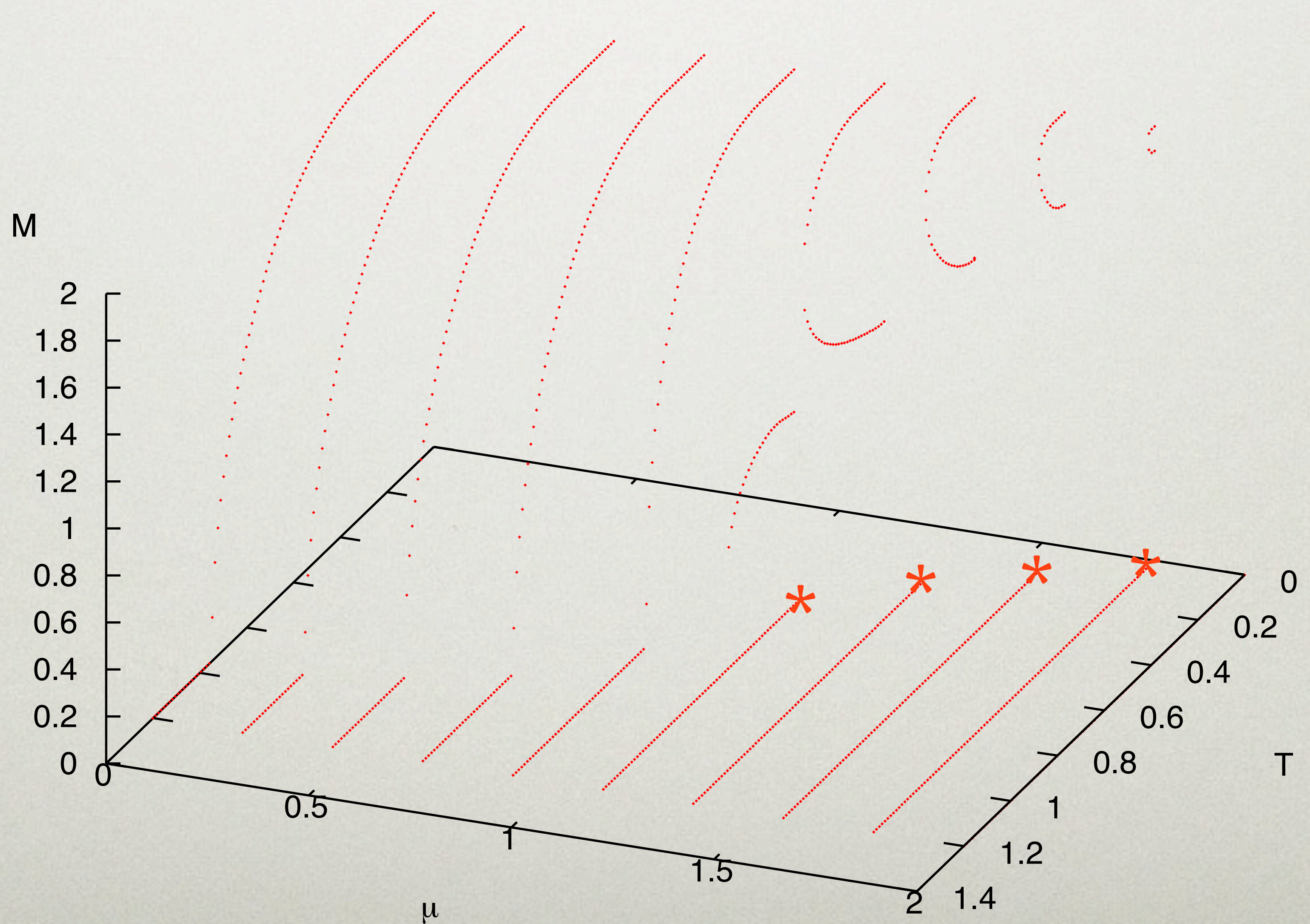
$$\lim_{p\to 0} \Pi(p_0=0,p) \equiv -m_g^2\, n_f = -\left(\frac{T^2}{6}+\frac{\mu^2}{2\pi^2}\right) n_f$$

$$V_{\text{ring}}(q,T,\mu=0) \approx \frac{6\pi b}{q^4+\pi b T^2}$$

RESULTS-CONTACT

$V(\vec{q})$

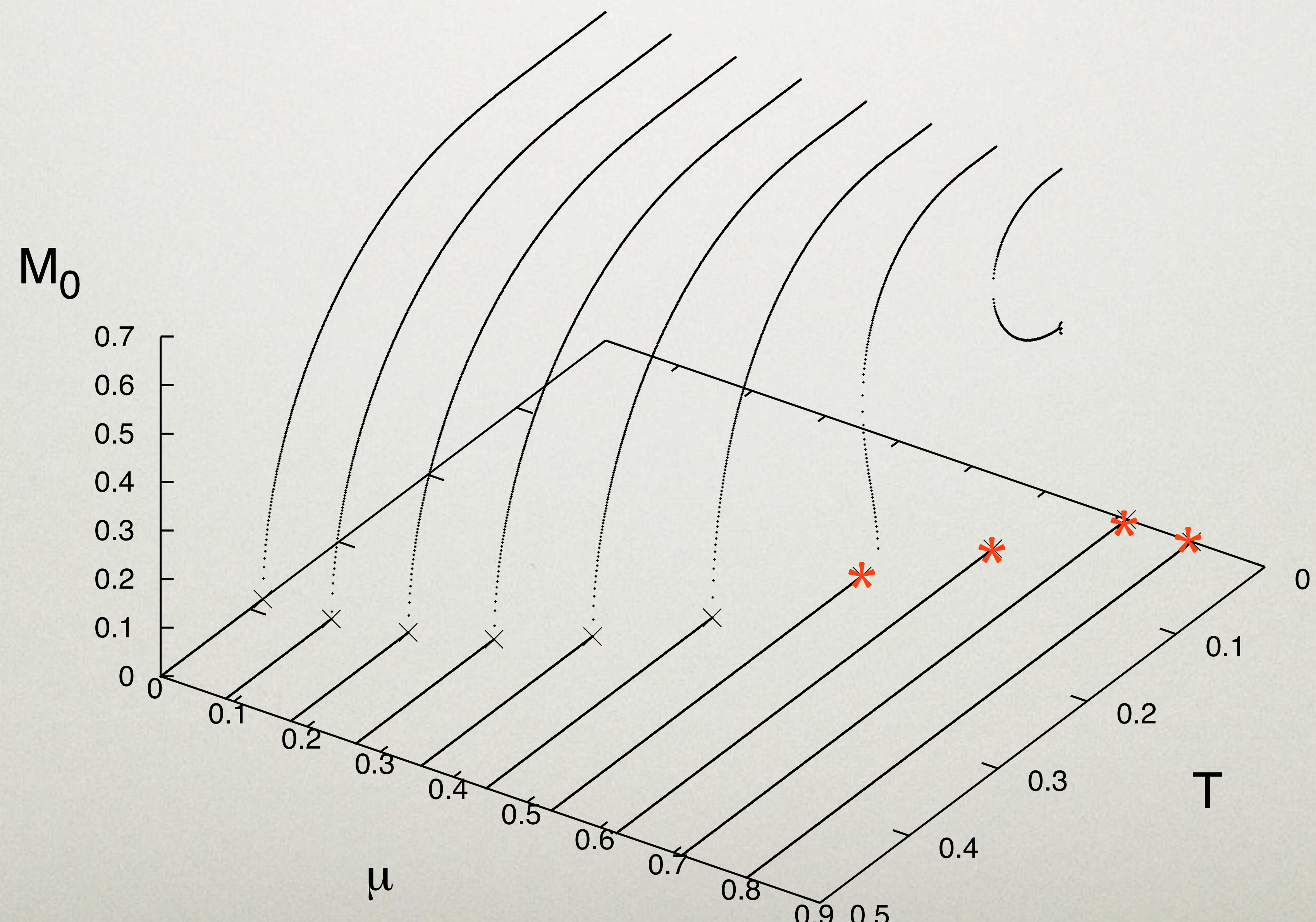
$\lambda = 4\lambda_c$

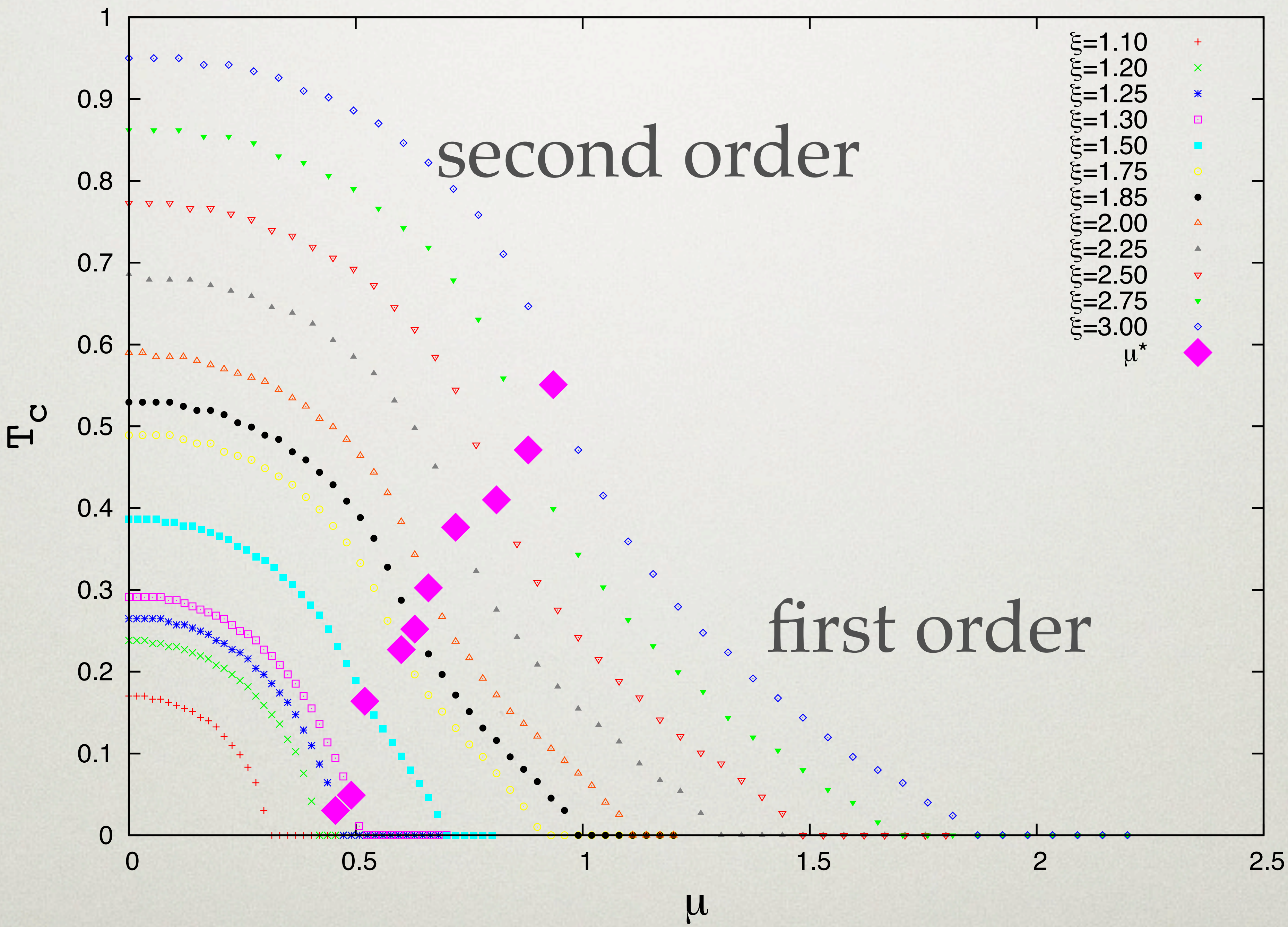


RESULTS-CONTACT

$V(\vec{q})$

$\lambda = 1.5\lambda_c$



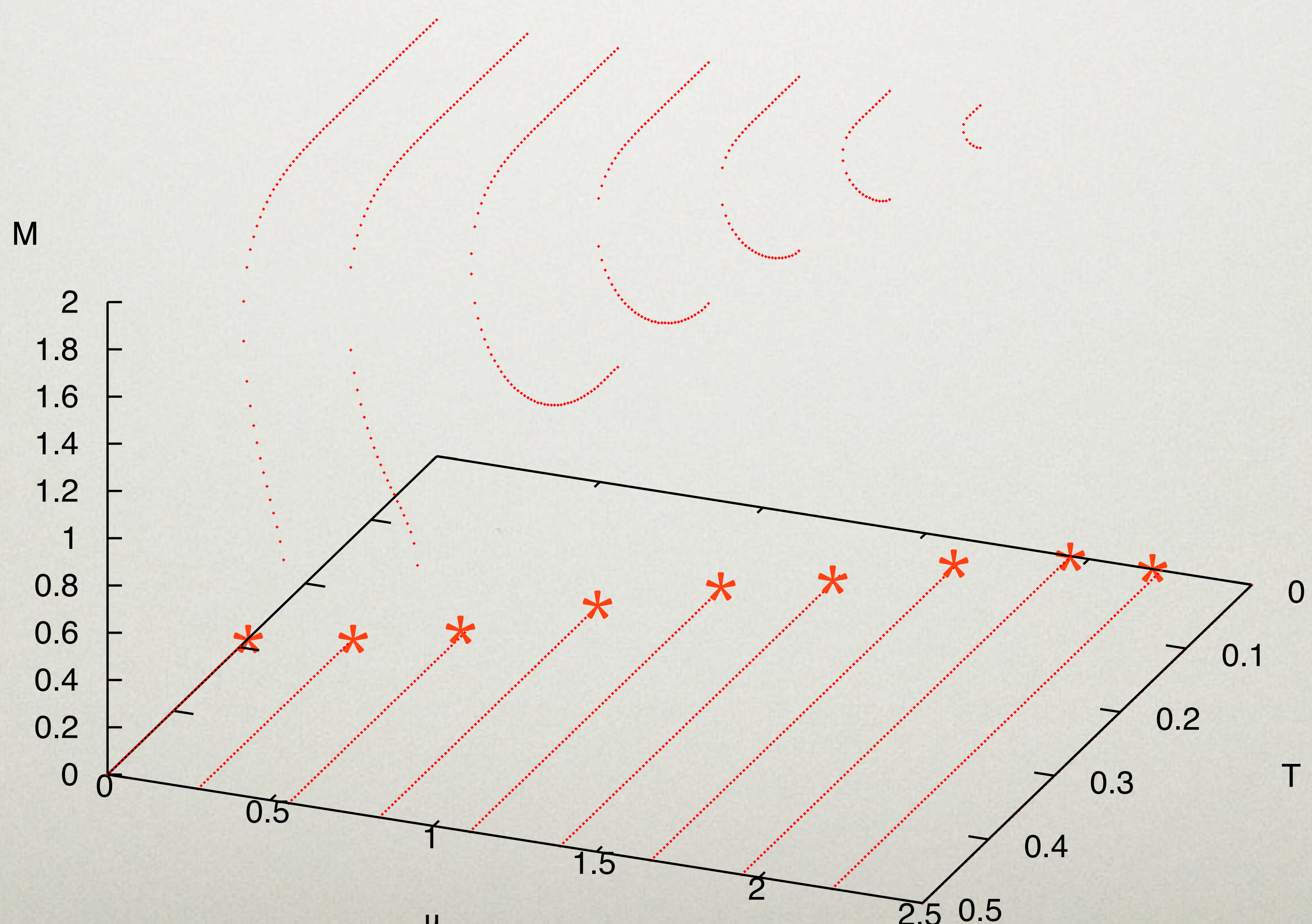


second order
first order
ξ=1.10
ξ=1.20
ξ=1.25
ξ=1.30
ξ=1.50
ξ=1.75
ξ=1.85
ξ=2.00
ξ=2.25
ξ=2.50
ξ=2.75
ξ=3.00
μ*
T_c
μ
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5

RESULTS-CONTACT

$$V(\vec{q}) = \frac{V(\vec{q})}{1 - \Pi(q_0 = 0, \vec{q} = 0)V(\vec{q})}$$

$$\lambda = 4\lambda_c$$



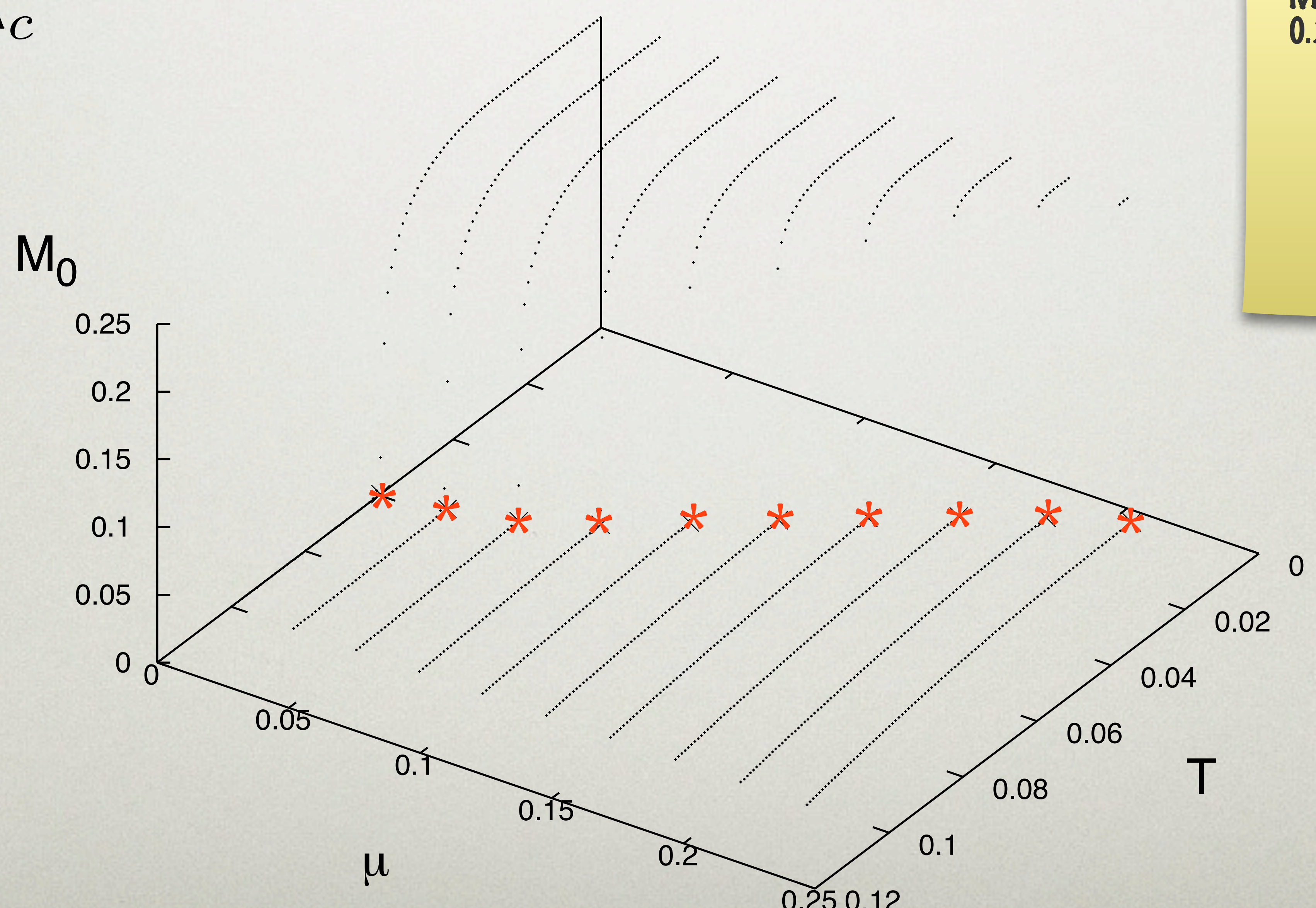
RESULTS-CONTACT

$$V(\vec{q}) = \frac{V(\vec{q})}{1 - \Pi(q_0 = 0, \vec{q})V(\vec{q})}$$

(NB: $\Pi_{\rm vac}$ contributes)

$$\lambda = 1.5\lambda_c$$

M0 goes from 0.7 ->
0.25 due to Pi_vac

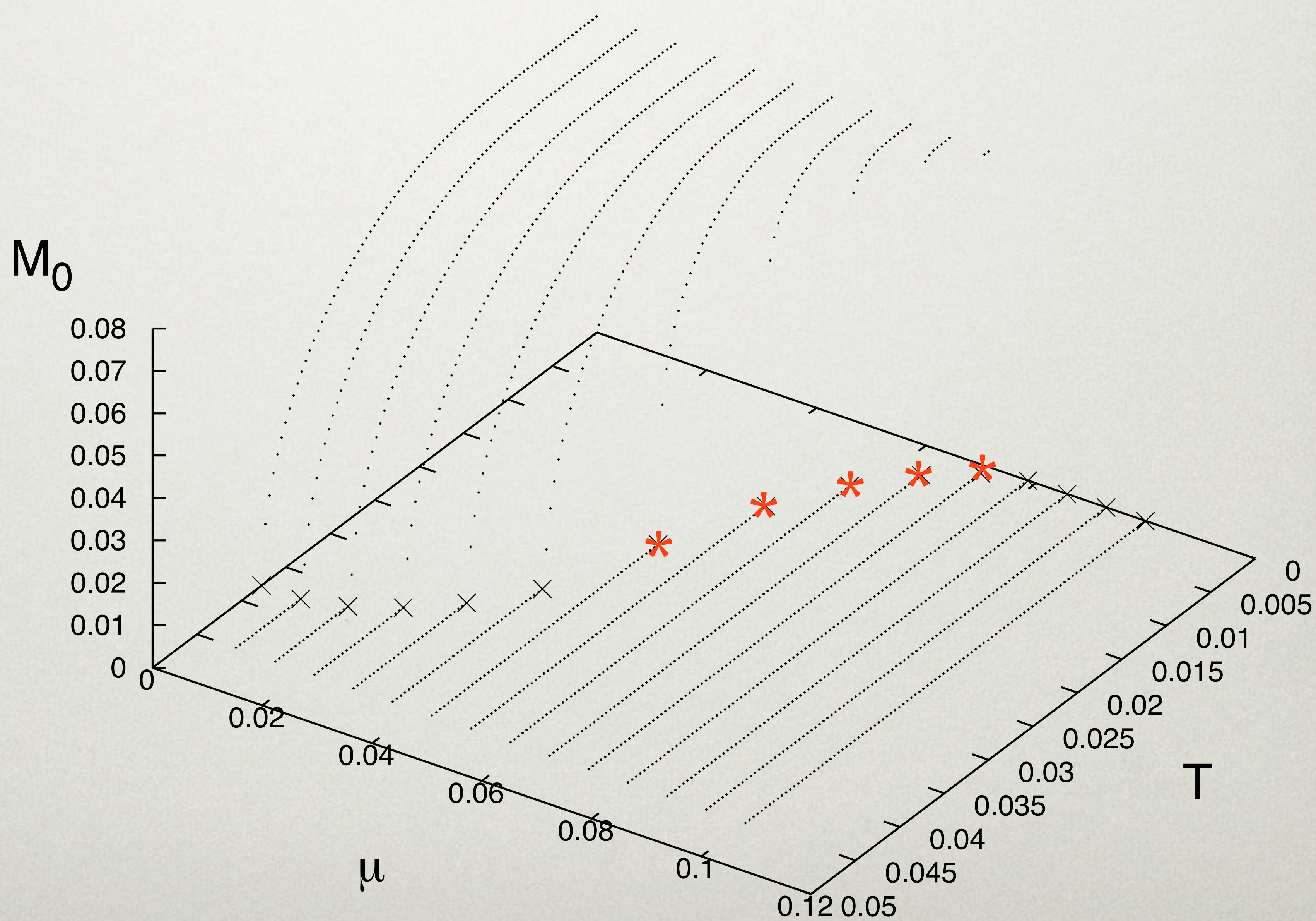


RESULTS-CONFINEMENT

$V(\vec{q})$

$b = 0.18\ \mathrm{GeV}^2$

AAL prescription



$T_c = 45\ \mathrm{MeV}$
$\mu_c = 85\ \mathrm{MeV}$

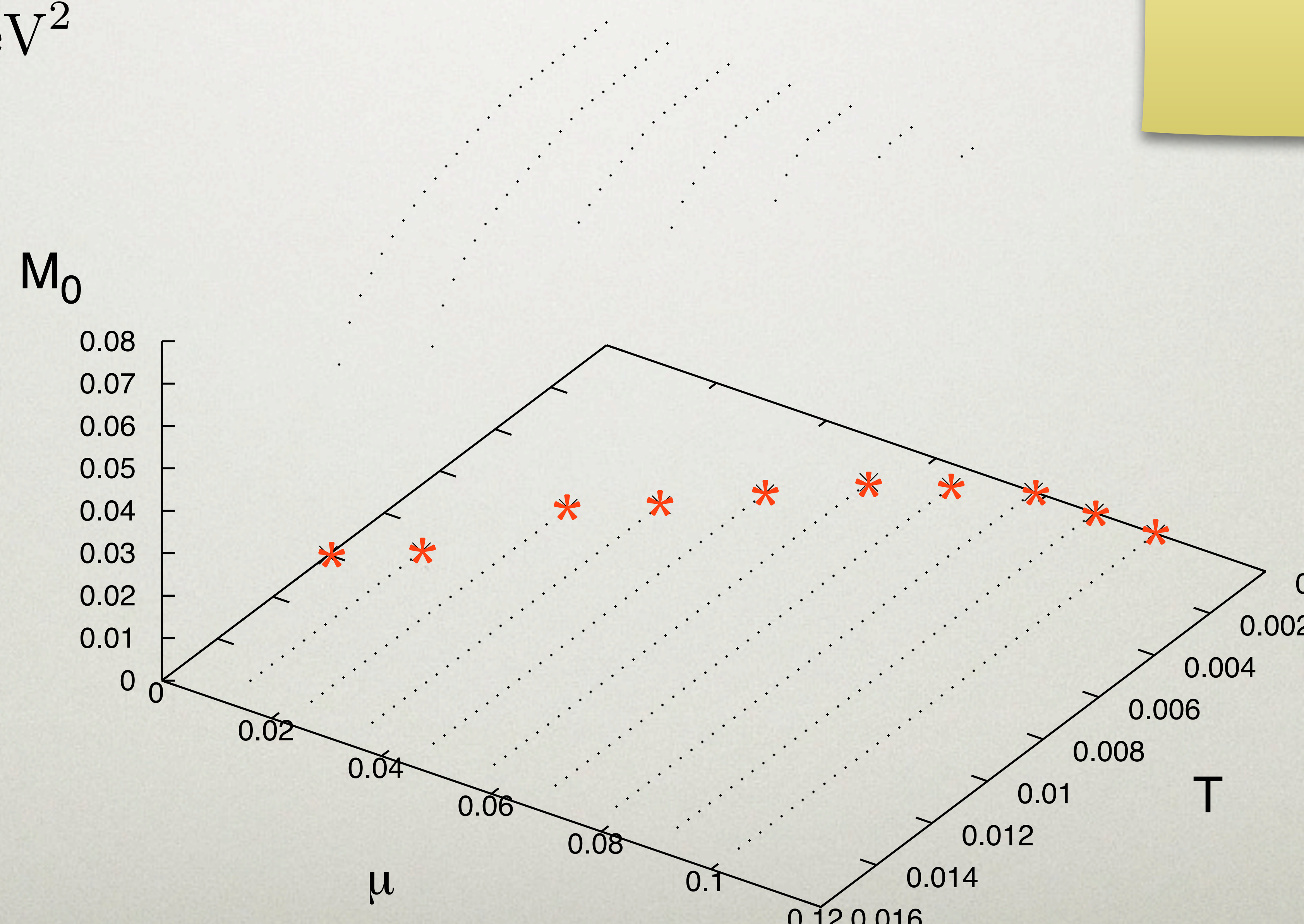
RESULTS-CONFINEMENT

RESULTS-CONFINEMENT

$$V(\vec{q}) = \frac{V(\vec{q})}{1 - \Pi(q_0 = 0, \vec{q})V(\vec{q})}$$

$$b = 0.18\ \mathrm{GeV}^2$$
$$\Pi_{\mathrm{mat}} = 0$$

absorb Pi_vac in the defn of the conf potl



$$T_c = 10\ \mathrm{MeV}$$
$$\mu_c = 80\ \mathrm{MeV}$$

CONCLUSIONS

- unquenching leads to strong effects in the phase diagram
- simple quark models do not successfully describe hadronic properties *and* in-medium properties
- quarkyonic matter is plausible, but not rigorously tested, in this approach
- studies of QED-3 under way

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