Nuclear and Hadron Physics group at Yonsei University and our physics interests

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Research Interests

Research Topics	Collaborators
Light vector mesons in medium	T. Hatsuda (92−95) B. Friman, H. Kim(97−)
Form Factors	Y. Oh, T. Song, T. Barnes, C.Y.Wong
Pentaquarks	Y.Oh, H. Kim, A. Hosaka, Y. Kwon
Charmonim in medium and future GSI project	W. Weise(99), C.M. Ko(02) S.H.Lee (03)
QCD properties above T_c and charmonium states in QGP	T.H. Hansson, I. Zahed (88) S.H. Lee(89), T. Song, C. Y. Wong (04)

Some Historical Perspective on Strong coupling QCD above T_c

Manousakis, Polonyi, PRL 58 (87) 847

"Nonperturbative length scale in high T QCD"

Finite T Lattice result on $V_{s,t}(r) = \alpha_s \dfrac{e^{-mr}}{r} + \sigma_{s,t} r$

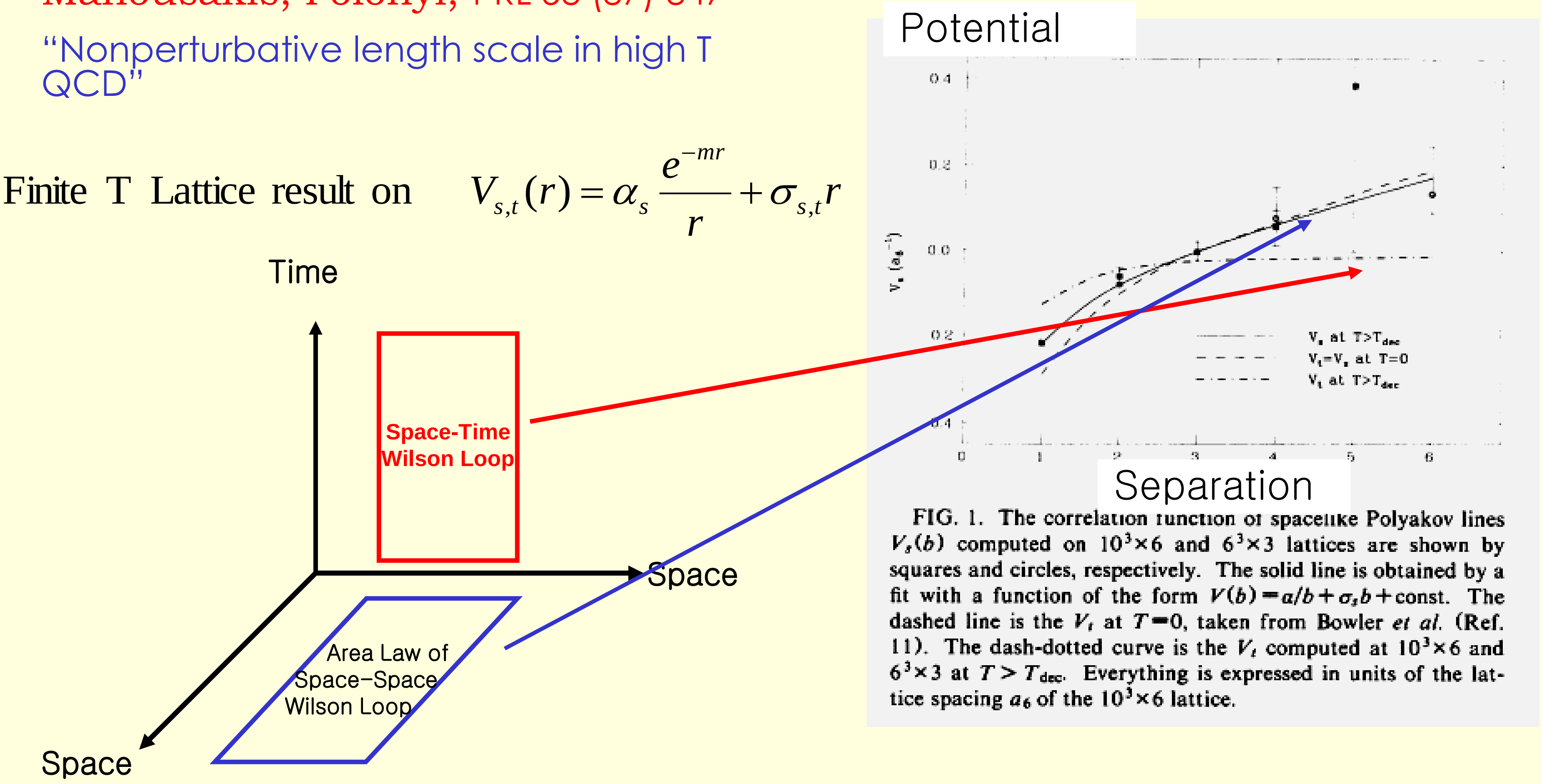


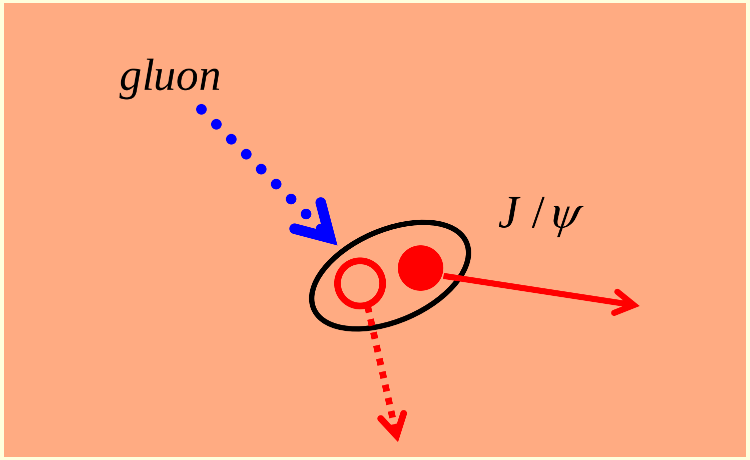
FIG. 1. The correlation function of spacelike Polyakov lines $V_s(b)$ computed on $10^3\times6$ and $6^3\times3$ lattices are shown by squares and circles, respectively. The solid line is obtained by a fit with a function of the form $V(b)=a/b+\sigma_s b+\text{const}$. The dashed line is the V_t at $T=0$, taken from Bowler *et al.* (Ref. 11). The dash-dotted curve is the V_t computed at $10^3\times6$ and $6^3\times3$ at $T>T_{\text{dec}}$. Everything is expressed in units of the lattice spacing a_6 of the $10^3\times6$ lattice.

Dynamical confinement

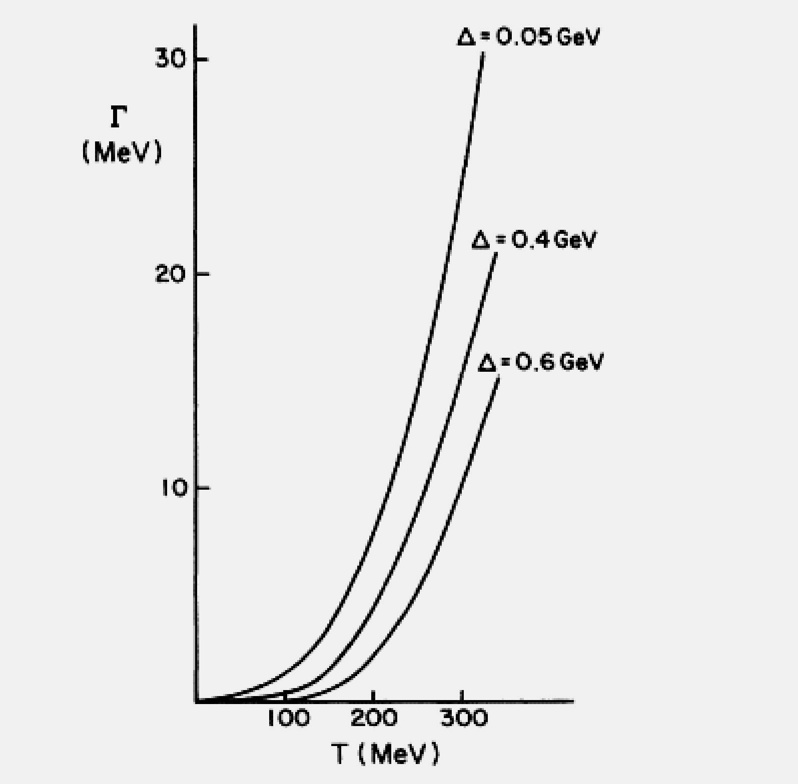
Charmonium states in QGP I

Hansson, Lee, Zahed, PRD 37 (88) 2672 "Charmonium states in QGP"

Due to non-perturbative nature of QGP, Charmonium states might survive at QGP. How big is the dissociation due to gluons?



We concluded that the Charmonium dissociation cross section by gluons is not large and charmonium, if bound, will survies above T_c



Thermal decay width of charmonium due to thermal gluons

Δ is binding energy

Charmonium states in QGP II

Spectral function for J/ψ

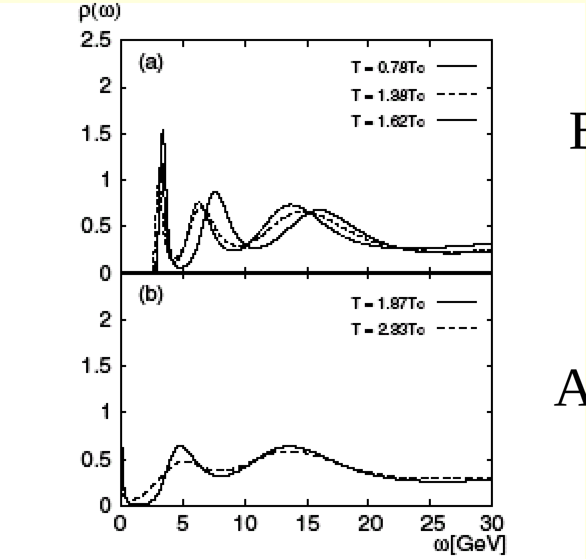


FIG. 1. Spectral functions for J/ψ (a) for $T/T_c = 0.78$, 1.38, and 1.62 and (b) for $T/T_c = 1.87$ and 2.33.

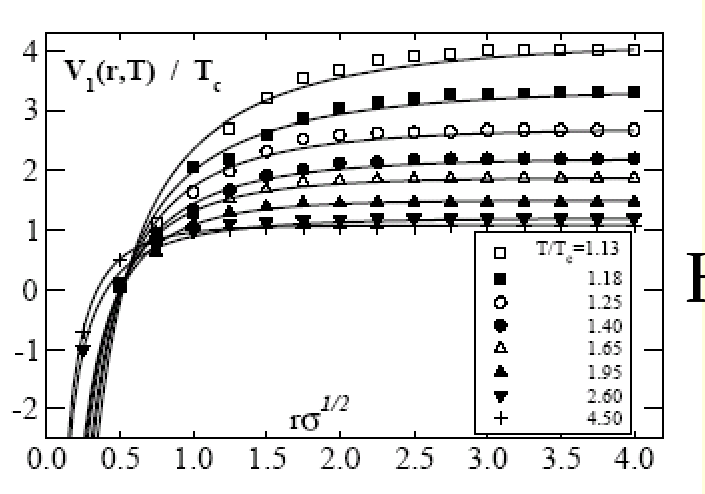
Below T_c

Above T_c

Asakawa, Hatsuda, PRL 92 (04) 012001

Qunched lattice QCD calculation shows Charmonium states survies up to 1.6 T_C

Due to Deby screened potential with **large coupling constant**. (Brown, Rho, C.H.Lee, Shuryak, Zahed, C.Y. Wong)



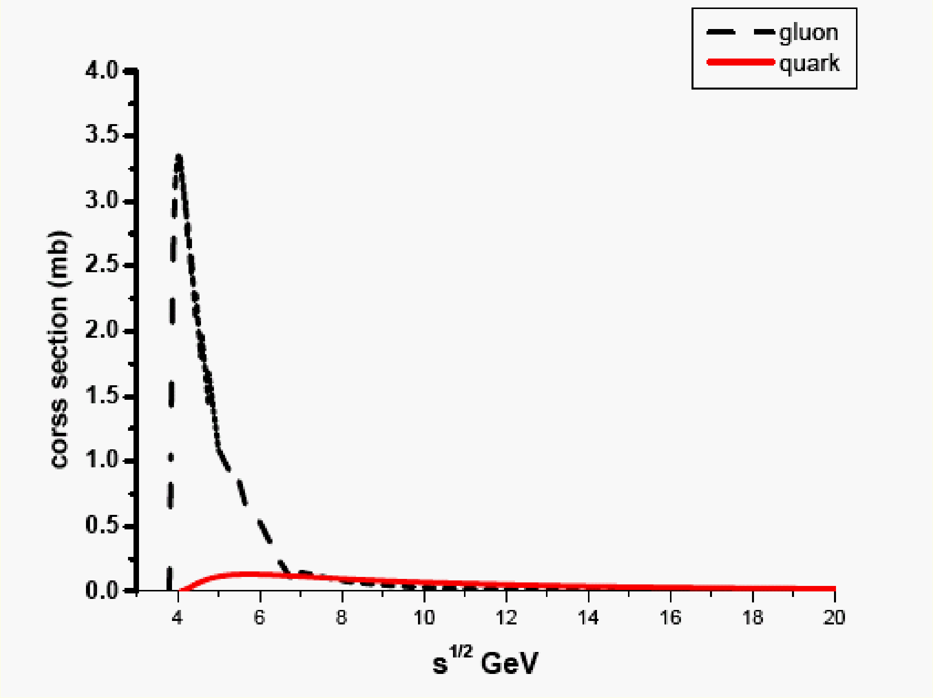
Heavy quark potential above T_c

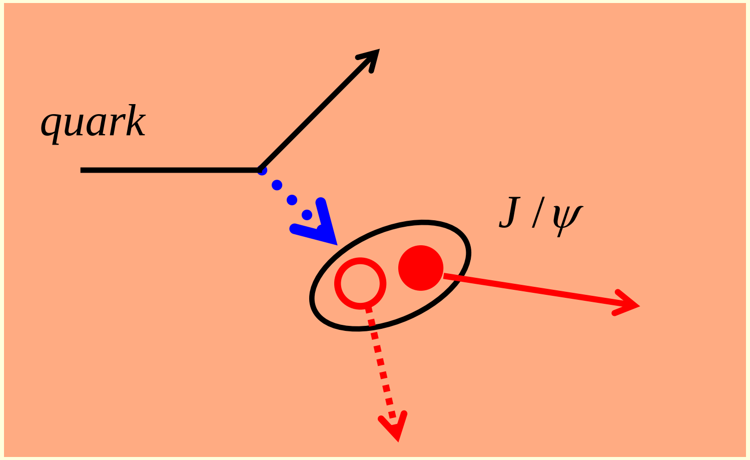
Charmonium states in QGP III

Lee, Song, Wong in preparation

Developed a formalism based on Bethe-Salpeter amplidude to handle such bound states at high Temperature

Dissociation of Charmonium due to thermal light quarks are small





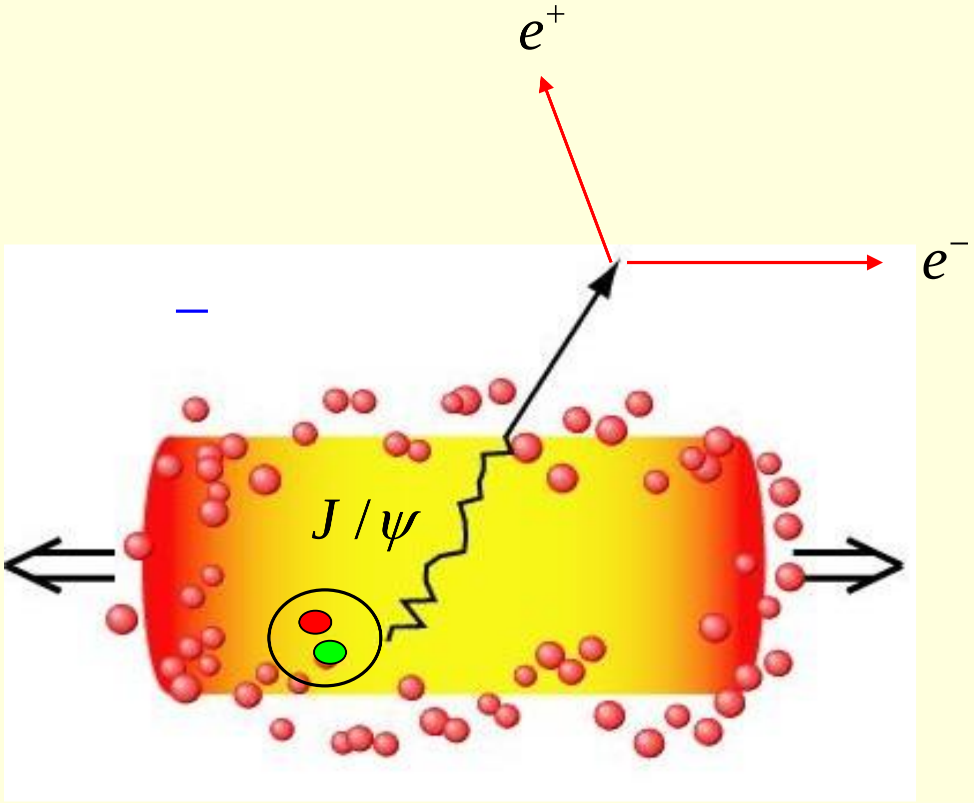
Charmonium states in QGP IV

Hence, in relation to charmonium suppression in RHIC,

More detailed theoretical and

experimental analysis is needed

in RHIC and **LHC (Alice),** where a more thermalized QGP is expected.



Theoretically relevant questions

Dissociation cross sections by partons vs. hadrons

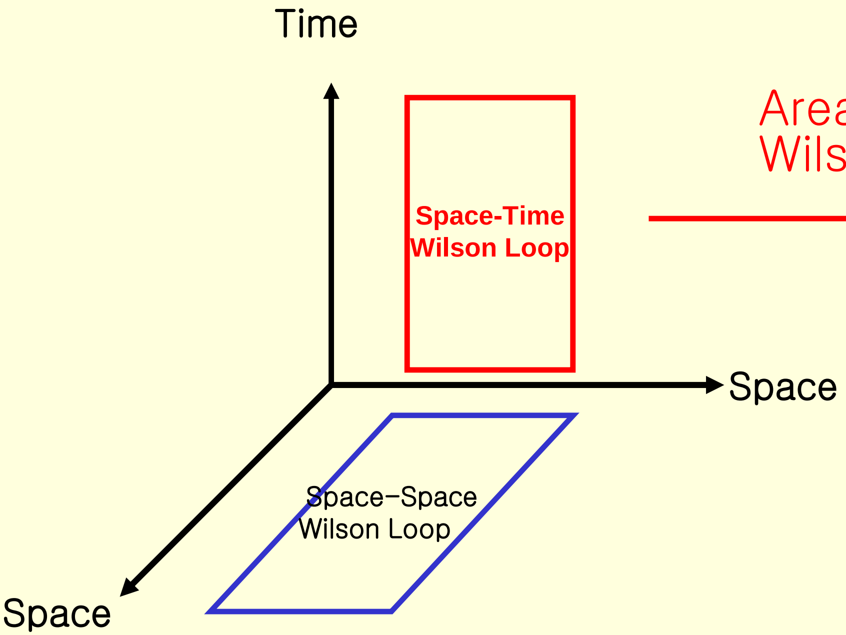
Realistic production Rate calculations. QGP vs. Hadron gas.

and so on

Some perspective on Wilson Loops and QCD Vacuum

Shifman, NPB 173 (80) 13

Area law of Wilson loops and gluon condensates "



Area law of Wilson loops →

$$\left\langle \frac{\alpha_s}{\pi} G^2 \right\rangle \neq 0$$

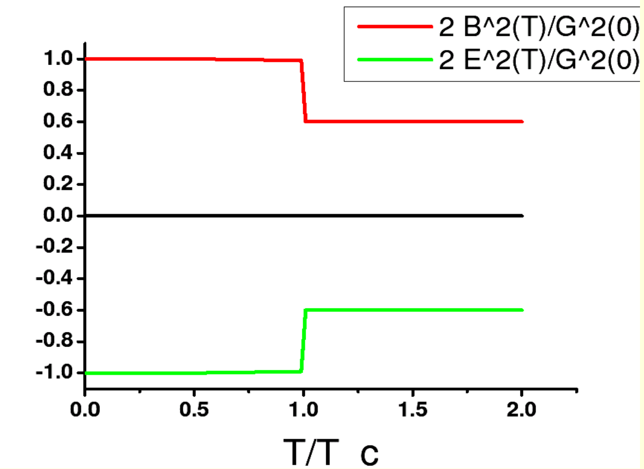
in QCD vacuum

Nonperturbative Length scale and Gluon condensate above T_c

S H Lee, PRD 40 (89) 2484 (later confirmed by Hatsuda, Koch , Brown)

Gluon condensate changes to half of its vacuum value above T_c

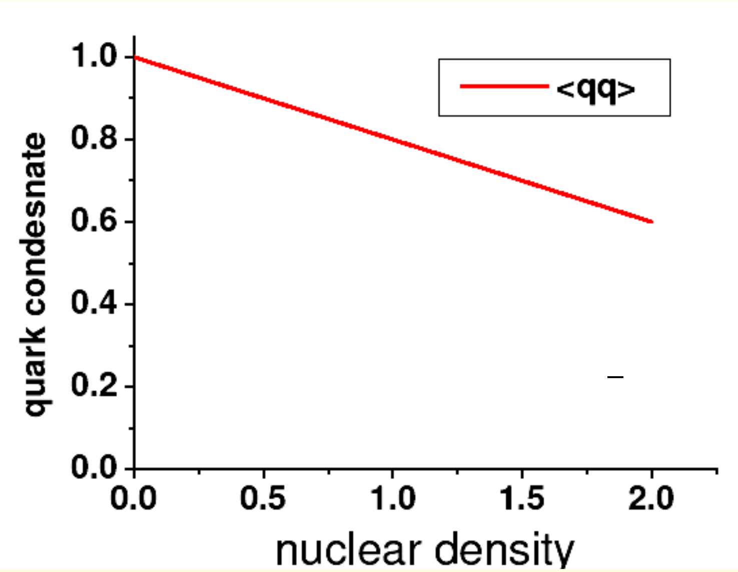
$$\left\langle \frac{\alpha_s}{\pi} G_{\mu\nu}^2 \right\rangle_T = 0.5 \left\langle \frac{\alpha_s}{\pi} G_{\mu\nu}^2 \right\rangle_{T=0}$$

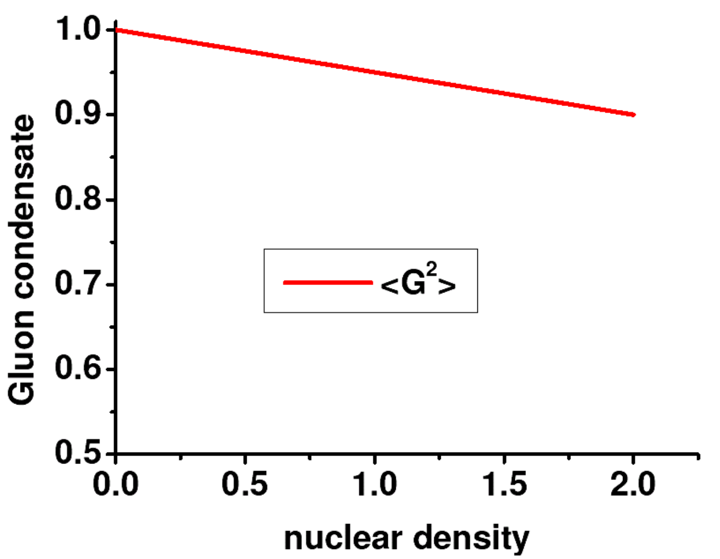


Reflects the QCD vacuum change near the phase transition.

Effects in Nuclear matter

On the other hand, heavy nuclei provide a constant density where QCD vacuum changes



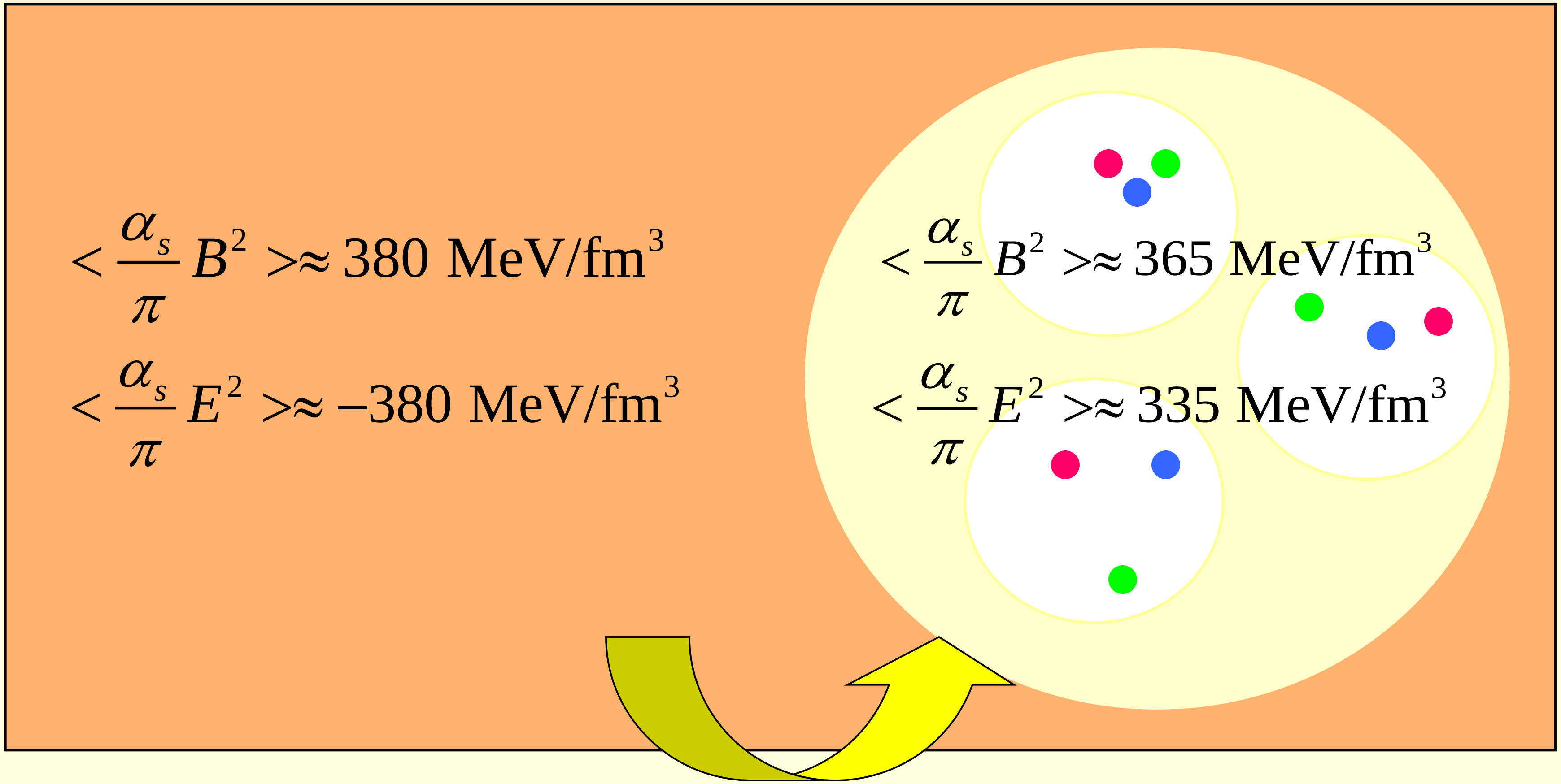


At nuclear matter density

$$\Delta < \bar{q}q > \approx 0.4\ /\text{fm}^3, \qquad \Delta < \frac{\alpha_s}{\pi} G_{\mu\nu}{}^2 > \approx 120\ \text{MeV/fm}^3$$

QCD Vacuum

Vacuum change inside nuclei



$$< \frac{\alpha_s}{\pi} B^2 > \approx 380 \text{ MeV/fm}^3$$

$$< \frac{\alpha_s}{\pi} E^2 > \approx -380 \text{ MeV/fm}^3$$

$$< \frac{\alpha_s}{\pi} B^2 > \approx 365 \text{ MeV/fm}^3$$

$$< \frac{\alpha_s}{\pi} E^2 > \approx 335 \text{ MeV/fm}^3$$

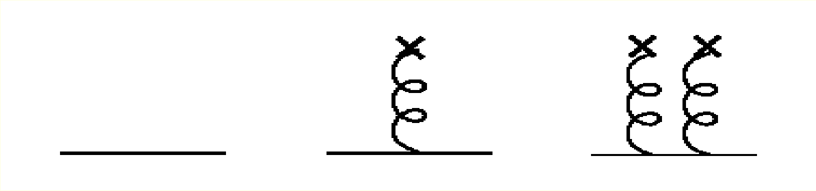
Change in external field

$$\Delta < \frac{\alpha_s}{\pi} E^2 > \approx +45 \text{ MeV/fm}^3$$

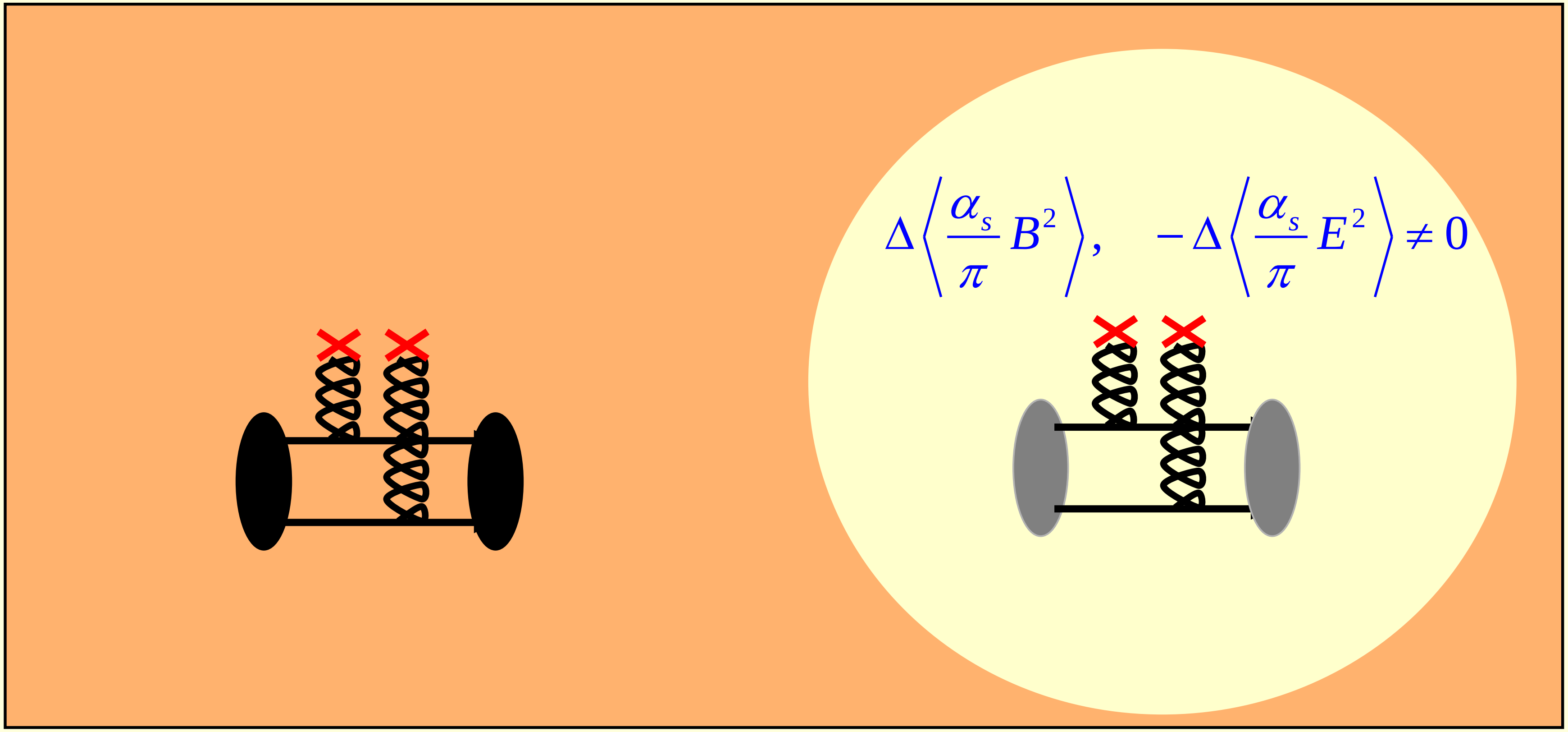
$$\Delta < \frac{\alpha_s}{\pi} B^2 > \approx -15 \text{ MeV/fm}^3$$

Heavy quark propagator is sensitive to only gluon fields

$$\frac{1}{\not{q} - m_H}$$



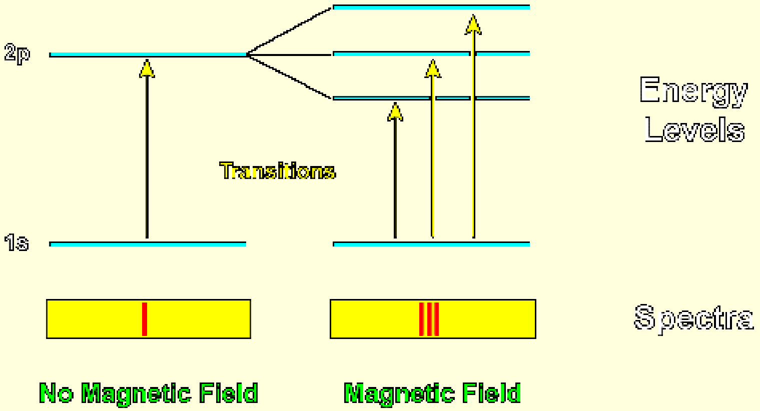
and therefore the mass of heavy quark system will change in nuclear medium



$$\Delta\left\langle \frac{\alpha_s}{\pi} B^2 \right\rangle, \quad -\Delta\left\langle \frac{\alpha_s}{\pi} E^2 \right\rangle \neq 0$$

Just like Hydrogen Atom in external E&M field

$$\Delta M_{Zeeman} \propto \frac{1}{m_H} \mathrm{L}\cdot\mathrm{B} \quad , \quad \Delta M_{Stark} \propto \mathrm{r}\cdot\mathrm{E}$$



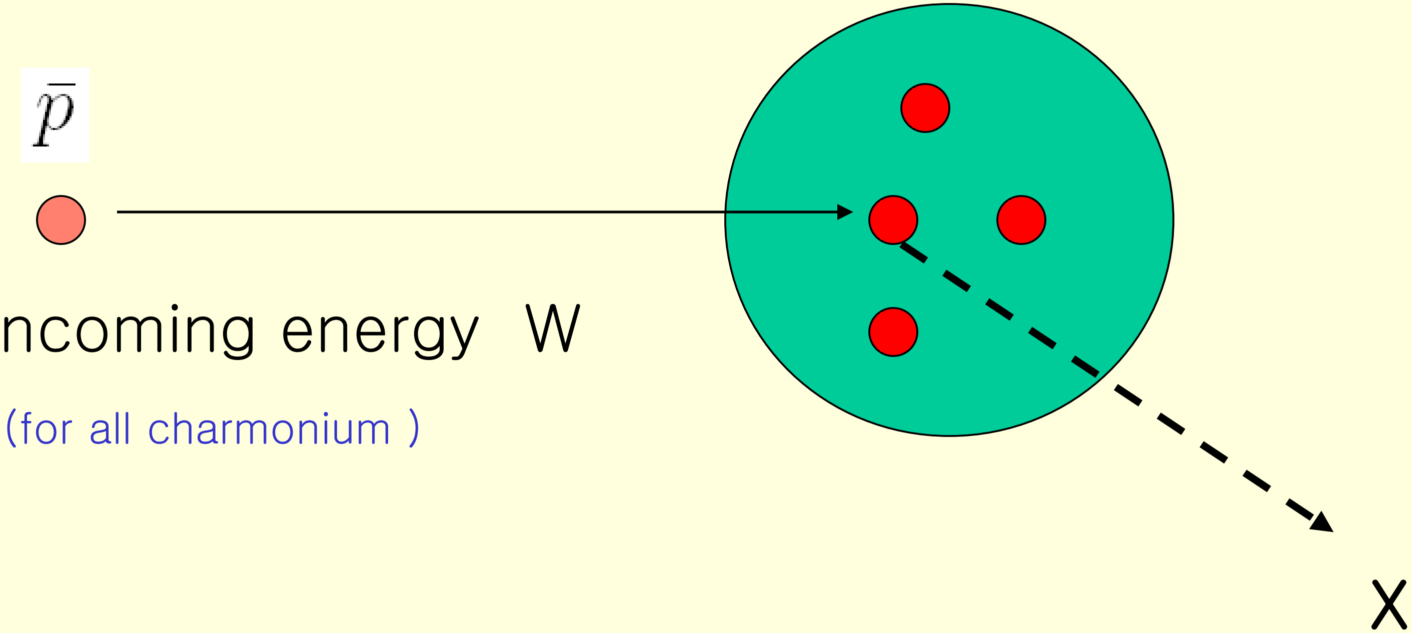
or in this case, **dominantly 2nd order Stark Effect**

$$\Delta M_{Stark} = \sum_n \frac{|\langle i \,|\, z\mathrm{E} \,|\, n\rangle|^2}{E_i - E_n} = -\alpha\ \mathrm{E}^2$$

Approaches for charmonium mass shift in nuclear matter:

	Quantum numbers	QCD 2nd Stark eff.	Potential model	QCD sum rules	Effects of DD loop
η_c	0^{-+}	–8 MeV		–5 MeV (Klingl, SHL ,Weise)	No effect (SHL, Ko)
J/ψ	1^{--}	–8 MeV (Peskin, Luke)	−10 MeV (Brodsky et al).	–7 MeV (Klingl, SHL ,Weise)	<2 MeV (SHL, Ko)
$\chi_{0,1,2,}$	$0,1,2^{++}$	−40 MeV (SHL)		−60 MeV (SHL)	No effect on χ_1
$\psi(3686)$	1^{--}	−100 MeV (SHL)			< 30 MeV (SHL, Ko)
$\psi(3770)$	1^{--}	−140 MeV (SHL)			< 30 MeV (SHL, Ko)

Can we observe this?



Anti-Proton **Nucleus**

$\bar{p}$

Incoming energy W

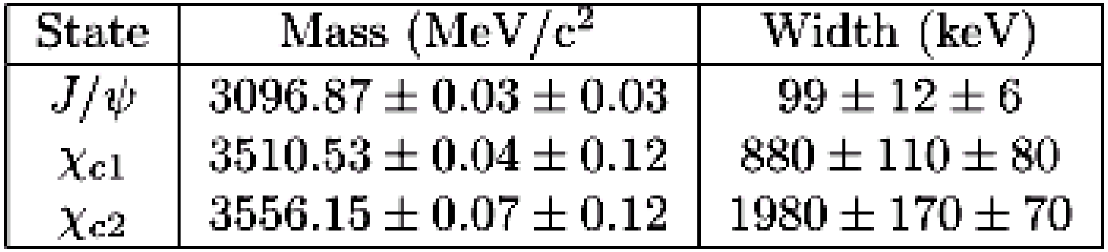
(for all charmonium)

X

(for all vector state) $e^+ e^-$ invariant mass M

(for all χ states) or $J/\psi - \gamma$ invariant mass

First method has been used at Fermilab



State	Mass (MeV/c^2)	Width (keV)
J/ψ	$3096.87 \pm 0.03 \pm 0.03$	$99 \pm 12 \pm 6$
χ_{c1}	$3510.53 \pm 0.04 \pm 0.12$	$880 \pm 110 \pm 80$
χ_{c2}	$3556.15 \pm 0.07 \pm 0.12$	$1980 \pm 170 \pm 70$

Table 1: Mass and width results from E760

E835

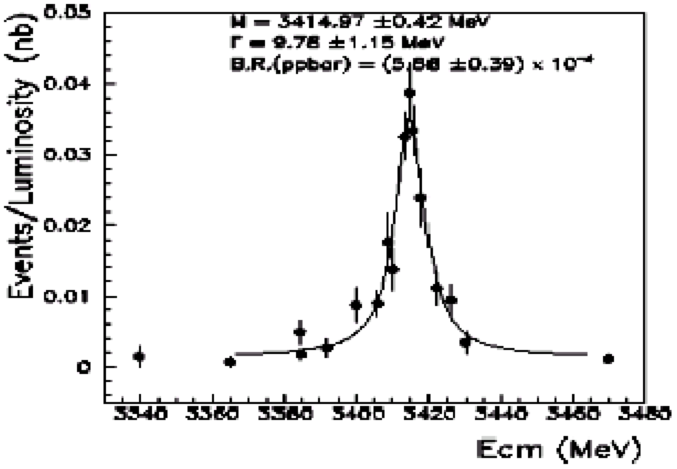
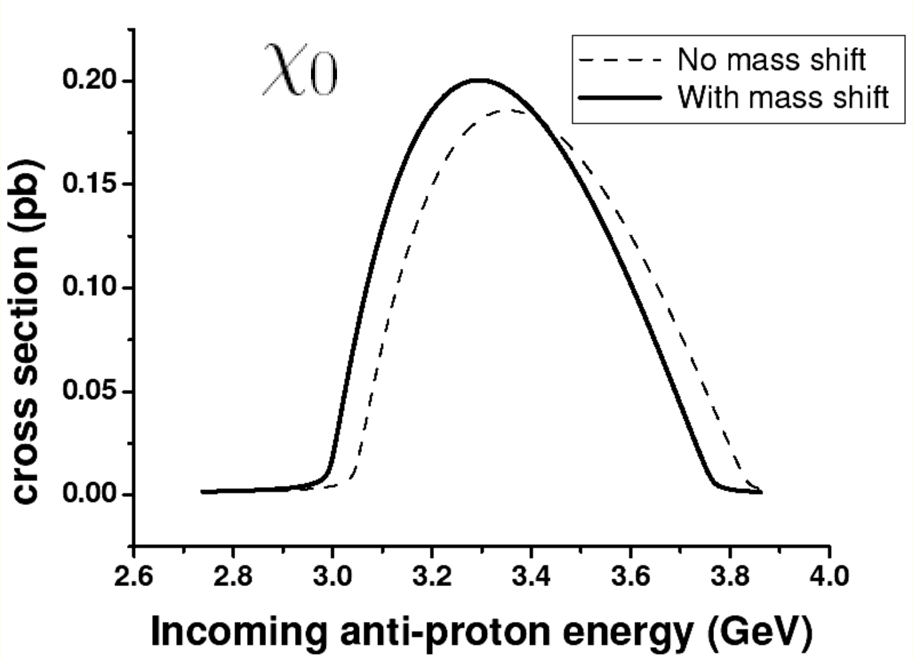


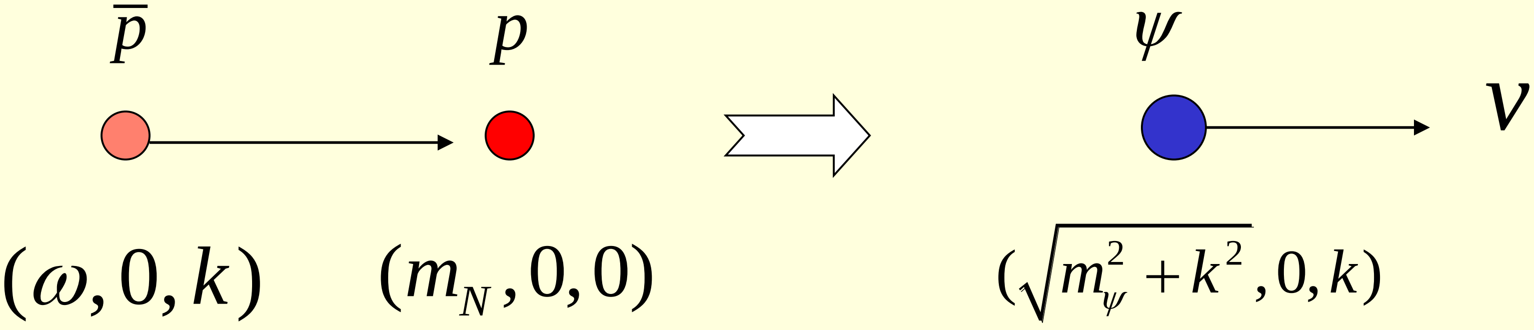
Figure 6: Measured cross section of $\bar{p}p \to J/\psi\gamma$ in the χ_{c0} region

Expected shifts from a nuclear target including Fermi momentum of the nucleons



Will Charmonium be formed inside the nucleus?

1. Kinematics



$\bar{p}$ $(\omega, 0, k)$

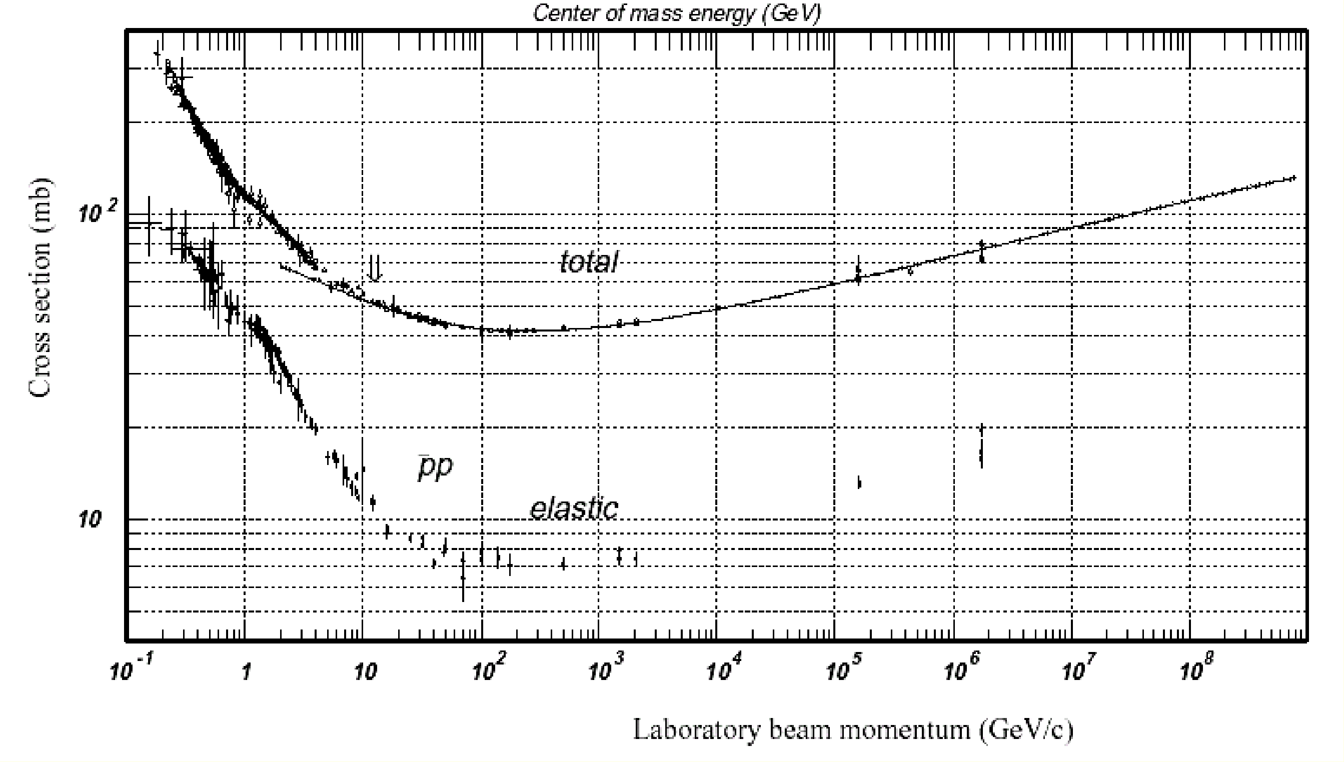
p $(m_N, 0, 0)$

ψ v $(\sqrt{m_\psi^2 + k^2}, 0, k)$

	η_c	J/ψ	χ_0	χ_1	χ_2	$\psi(3686)$	$\psi(3770)$
k	3.7 GeV/c	4.1	5.2	5.5	5.7	6.2	6.5
ω	3.8 GeV	4.2	5.3	5.6	5.8	6.3	6.6
v	0.78 c	0.80	0.83	0.84	0.85	0.86	0.87

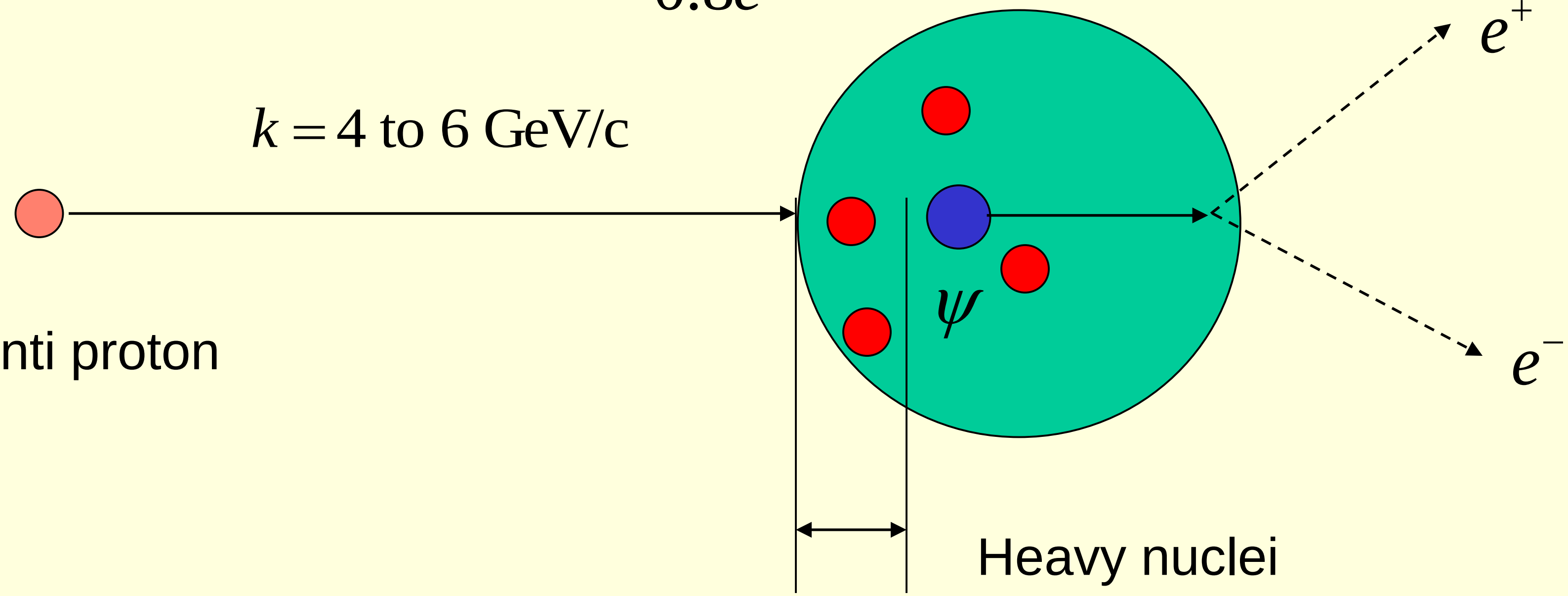
Will charmonium be formed inside the nucleus?

1. For anti proton momentum between 3- 6 GeV/c, the inelastic cross section on a proton is 50 mb=5 fm^2



Anti proton project at GSI

$$t = \frac{2\times 1.3 A^{1/3}\gamma^{-1}}{0.8c} = 10\, fm/c \quad \text{for} \;\; \text{A=125}$$



$k = 4$ to 6 GeV/c

Anti proton

ψ

e^+

e^-

Heavy nuclei

$$\frac{1}{0.17\, fm^{-3} \times 5\, fm^{2}} = 1.2\, fm$$

Anti proton will be absorbed at surface and

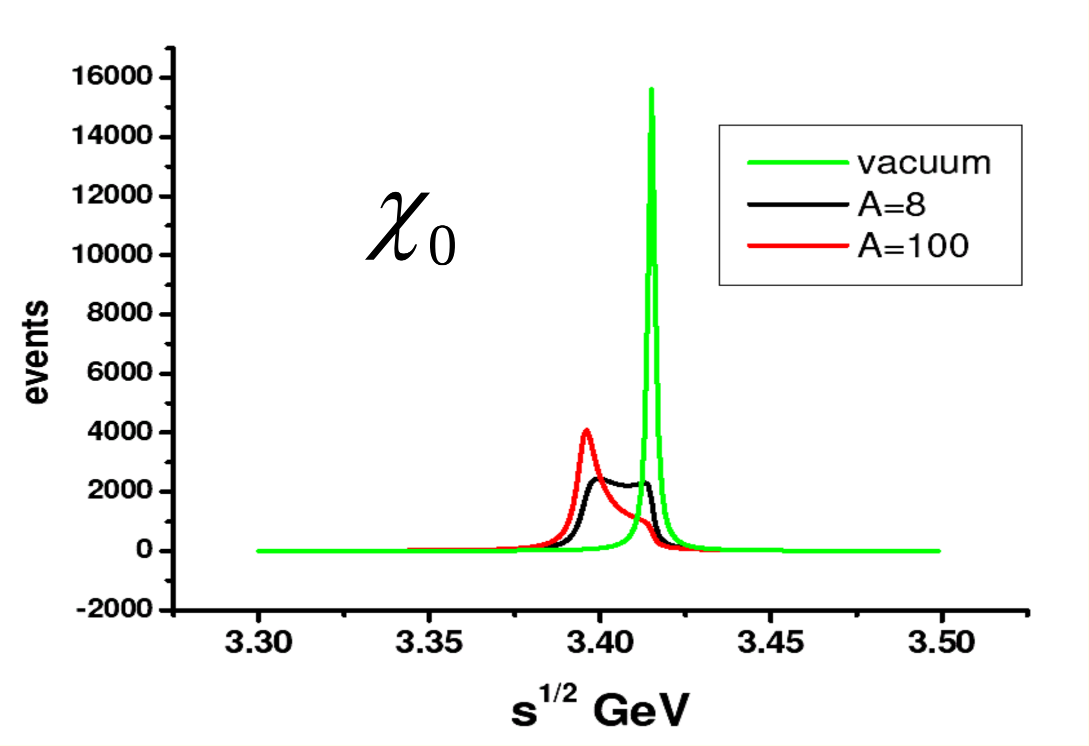
Charmonium will decay inside the heavy nuclei

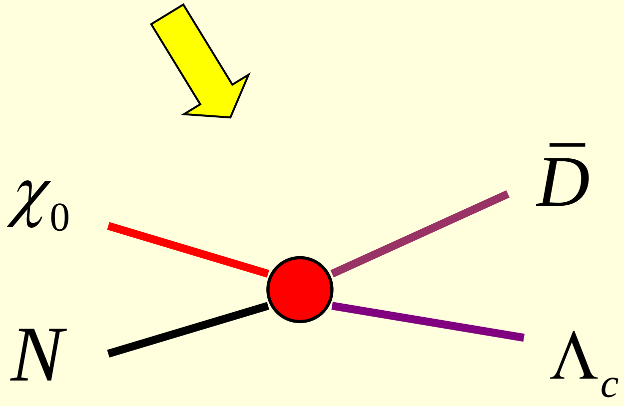
Expected shifts in the invariant mass spectrum from a nuclear target including collision broadening

$$\rho(r) = \frac{\rho_0}{1 + e^{\frac{r-R}{a}}}$$

$$M_\chi(\rho) = M_\chi(0) - 50\ \text{MeV}\ \rho/\rho_0$$

$$\Gamma_\chi(\rho) = \Gamma_\chi(0) + 20\ \text{MeV}\ \rho/\rho_0$$





Typical collision broadening

Production rate:

$\text{Luminosity} = 2\times10^{32}\,cm^{-2}s^{-1}$

$$\sigma_{BW} = \frac{2J+1}{(2s_1+1)(2s_2+1)}\frac{\pi}{k^2}\frac{B_{in}B_{out}\Gamma^2_{Total}}{(E-E_R)^2+\Gamma^2_{Total+medium}/4}$$

	J^{PC}	Mass shift	Final state	σ to final state	Events per day
J/ψ	1^{--}	–8 MeV	$e^+ + e^-$	6 pb	100
$\psi(3686)$	1^{--}	–100 MeV	$e^+ + e^-$	0.6 pb	10
$\psi(3770)$	1^{--}	−100 MeV	$e^+ + e^-$	1 pb	17
χ_0	0^{++}	−50 MeV	$J/\psi + \gamma$	200 pb	3400
χ_1	1^{++}	−50 MeV	$J/\psi + \gamma$	80 pb	1360
χ_{12}	0^{++}	−50 MeV	$J/\psi + \gamma$	350 pb	5950

Such experiment can be done at

1. GSI future accelerator facility

⇒ anti proton project (1-15 GeV)

SIS100/200

HESR

Conclusion

1. **Charmonium states seems to survive up to 1.6 Tc and is not easily dissociated by thermal quarks and gluons. But nevertheless provides an extremely useful observable.**

⇒ Detailed theoretical and experimental analysis is needed.

2. **Precursor effects of QCD phase transition can be observed through QCD 2nd order Stark effect by PANDA**

⇒ Changes of QCD vacuum in nuclear matter and generation of QCD masses

$$\Delta M_{2nd-Stark} = -\alpha \, \Delta \mathrm{E}^2$$