FLAVOUR OsCilLaTioNs

in

Dense Baryonic Matter

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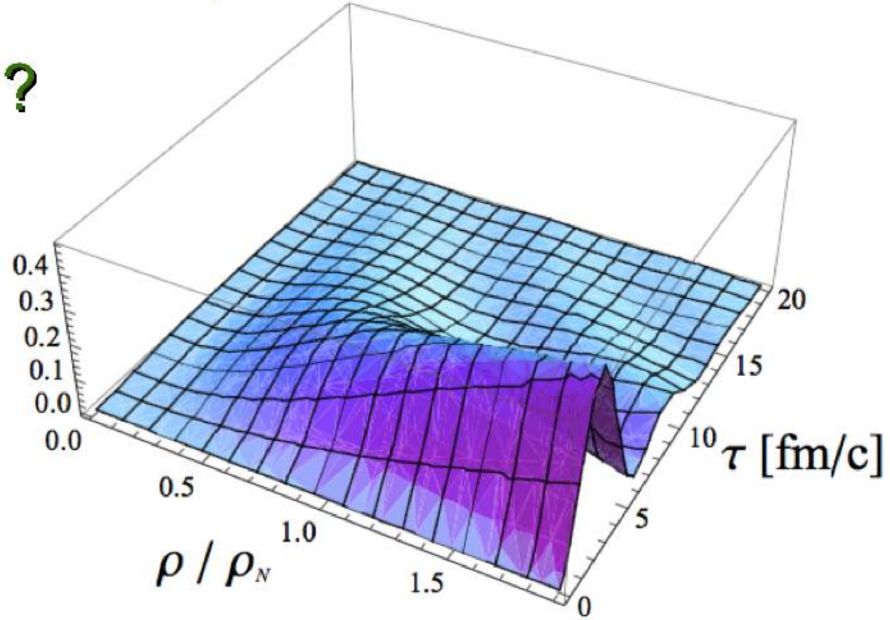
- Motivation: Ξ^-(dss) excess
- Strangeness in not conserved ?
- $K^0(ds') \rightarrow \overline{K}^0(d's)$
- $K^{0*}(896) \rightarrow \overline{K}^{0*}(896)$ [in medium]
- D^0 or D^{0*} oscillations ?
- Conclusions

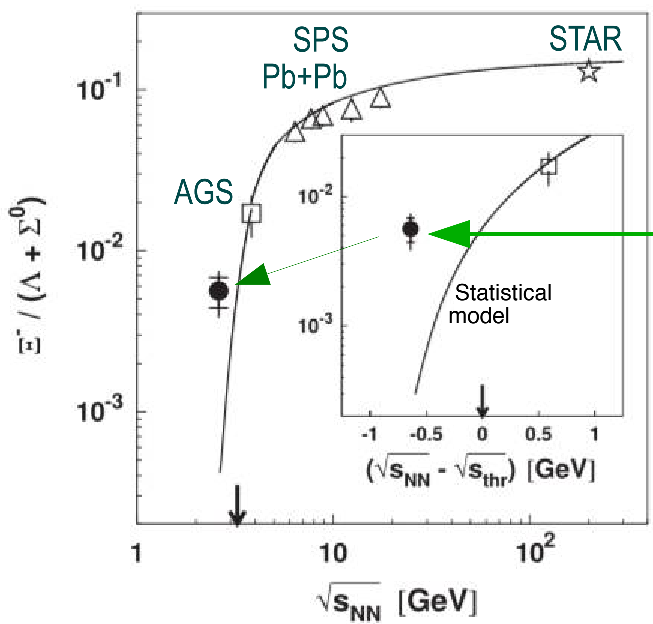
$$|g_-(\tau)|^2 = \frac{1}{4}[e^{-\tau\Gamma_1} + e^{-\tau\Gamma_2} - 2\mathrm{Cos}[\Delta M*\tau]\, e^{-\tau(\Gamma_1+\Gamma_2)/2}]$$



MOTIVATION: Ξ(ssd) excess

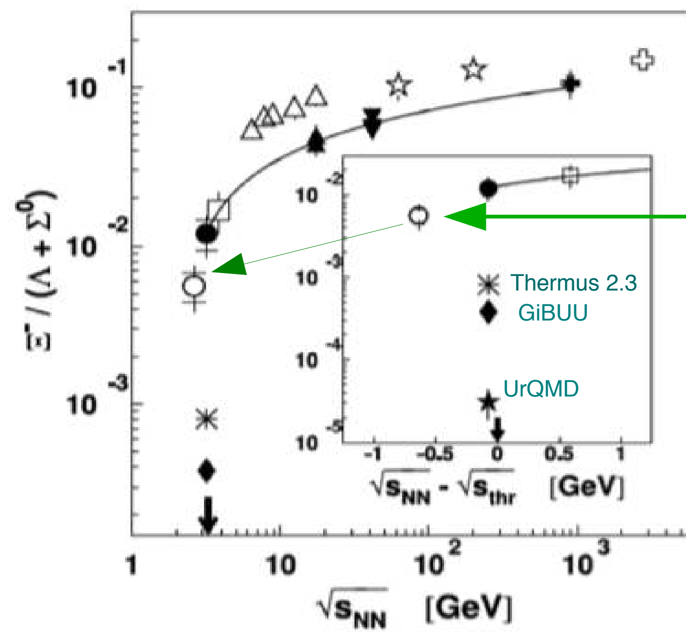
- There still is the unexplained puzzle of the strongly enhanced Ξ^- yield at the HADES

SQM2013: Jour. of Phys. Conf. Ser. 509 (2014) 012002



Ar+KCl
HADES

excess > 20x

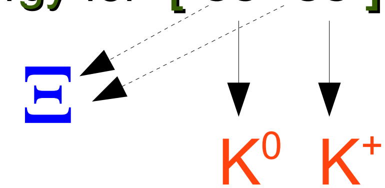


p+Nb
HADES

Ξ^-

subthreshold production of (ssd) means: not enough energy for [$s\bar{s}$+$s\bar{s}$]

- Production of (s s) pair requires ($\bar{s}$ $\bar{s}$) creation
- 2 kaons with 2x497MeV = 1GeV of Mass∗c^2
- Models + MC generators underestimate DATA



2x Kaons created for 1x Ξ

- Strangeness conservation means [$\bar{s}$ $\bar{s}$] = 2x K for every [s s] pair.

MOTIVATION: Ξ(ssd) excess

- There still is the unexplained puzzle of the strongly enhanced Ξ^- yield at the HADES

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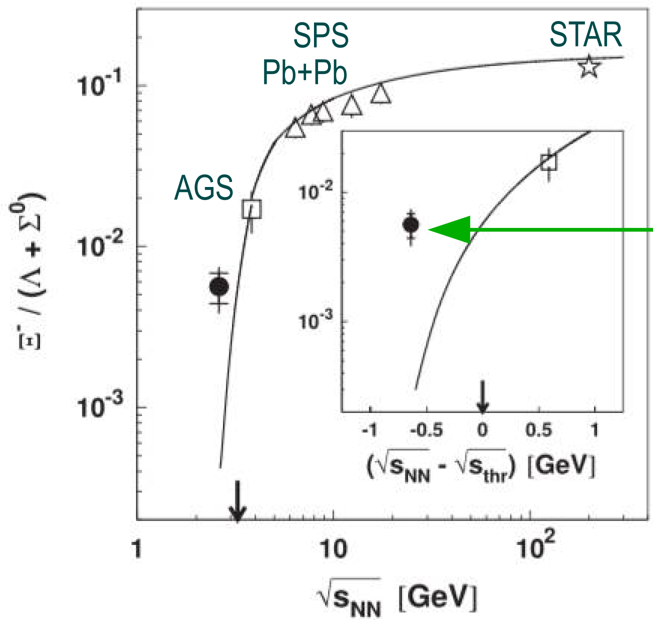
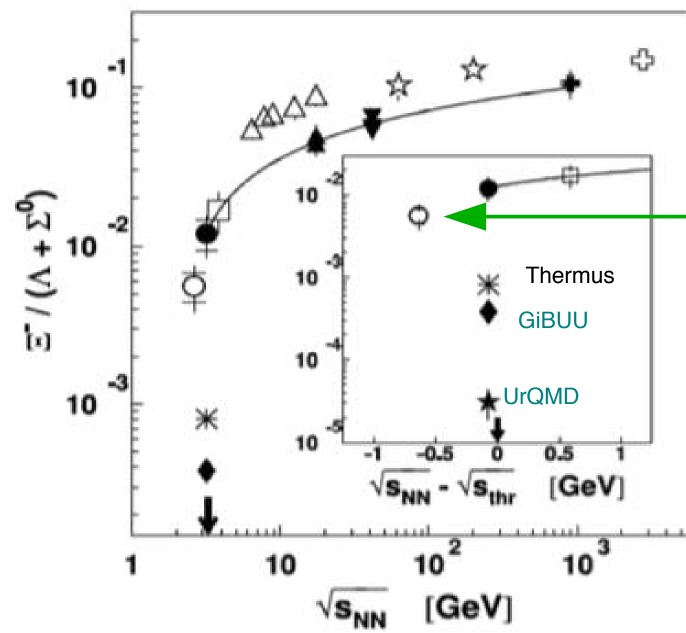


Ar+KCl
HADES

excess ≈ 20x



p+Nb
HADES

subthreshold production of Ξ^- (ssd) means: not enough energy for [$s\bar{s}$+$s\bar{s}$]

Ξ

K^0 K^+

1x Ξ and 2x Kaon

☼ **IDEA**:

oscillation

$(d\bar{s})\ K^0 \rightarrow \rightarrow (s\bar{d})\ \bar{K}^0$

- Produce only 1x $s\bar{s}$

$(sdu)\ \Lambda^0$, $(sdd)\ \Sigma$ $\rightarrow \rightarrow \Xi^- + \pi$

1x Ξ + Pion

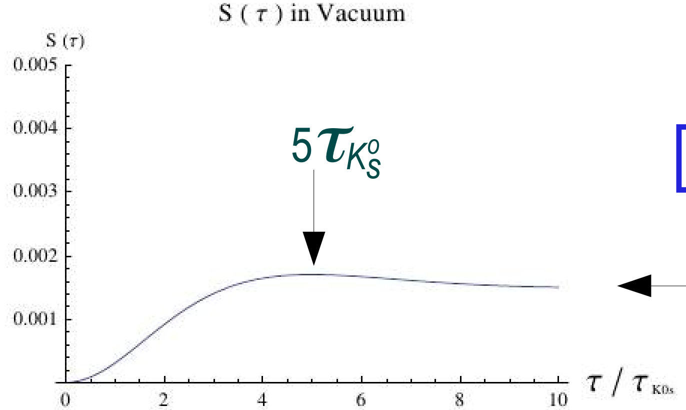
- Strangeness non-conservation ($K^0 \xrightarrow{\text{oscillation}} \bar{K}^0$) process in medium ?

Is strangeness conserved ? No!

Physical Review D2 (1970) 540, in Eq.(7)   CPT symmetry assumed

$|\langle K_2^0|K_1^0\rangle| = \delta_{cp} \approx 10^{-3}$

$$S(\tau) = \frac{\langle K_2{}^0|K_1{}^0\rangle[e^{-\gamma_1\tau}+e^{-\gamma_2\tau}-2e^{-(\gamma_1+\gamma_2)\tau/2}\cos(m_2-m_1)\tau]}{e^{-\gamma_1\tau}+e^{-\gamma_2\tau}-2e^{-(\gamma_1+\gamma_2)\tau/2}\langle K_2{}^0|K_1{}^0\rangle^2\cos(m_2-m_1)\tau}$$



Let us produce:

[$K^0 \bar{K}^0$] at $\tau = 0$

$$\frac{\rho(\bar{s}) - \rho(s)}{\rho(\bar{s}) + \rho(s)} = S(\tau)$$

- Small = 10^{-3} effect in Vacuum
- Takes long time $\tau = 5\tau_{K_S^0}$ >> 10fm/c $K_L \sim (1+\epsilon_L)K^0 - (1-\epsilon_L)\bar{K}^0$ $(d\bar{s})$
- Asymptotic value 1.5×10^{-3} due to K^0_L containing more $K^0(d\bar{s})$ than $\bar{K}^0(s\bar{d})$

when CP is violated: net-strangeness $\rho(\bar{s})-\rho(s)$ is not conserved

Is strangeness conserved ? No!

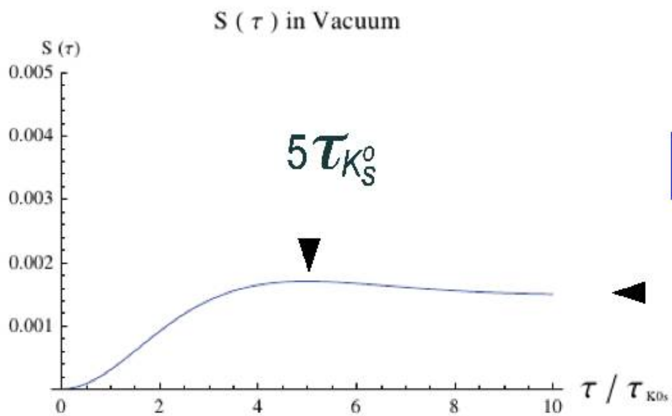
$|\langle K_2^0|K_1^0\rangle| = \delta_{cp} \approx 10^{-3}$

$$S(\tau) = \frac{\langle K_2{}^0|K_1{}^0\rangle[e^{-\gamma_1\tau}+e^{-\gamma_2\tau}-2e^{-(\gamma_1+\gamma_2)\tau/2}\cos(m_2-m_1)\tau]}{e^{-\gamma_1\tau}+e^{-\gamma_2\tau}-2e^{-(\gamma_1+\gamma_2)\tau/2}\langle K_2{}^0|K_1{}^0\rangle^2\cos(m_2-m_1)\tau}$$

$\Delta M_K = 3.48 \times 10^{-12}$ MeV

MASS: $(K_2 - K_1)$

Oscillation Length →



$5\tau_{K_S^0}$

$[K^0\,\overline{K}^0]$ at $\tau = 0$

$$\frac{\rho(\bar{s}) - \rho(s)}{\rho(\bar{s}) + \rho(s)} = S(\tau)$$

- Small = 10^{-3} effect in Vacuum
- Takes long time $\tau = 5\tau_{K_S^0}$ >> 10fm/c

$$K_L \sim (1+\epsilon_L)\overset{(d\bar{s})}{K^0} - (1-\epsilon_L)\bar{K}^0$$

- Asymptotic value 1.5×10^{-3} due to K^0_L containing more $K^0(d\bar{s})$ than $\overline{K}^0(s\bar{d})$

when CP is violated: net-strangeness $\rho(\bar{s})-\rho(s)$ is not conserved.

OSCILLATION LENGTHs in VACUUM

Table 1: Oscillation parameters of neutral K^0, D^0, B^0, and B_s^0 mesons in vacuum.

	K^0	D^0	B^0	B_s^0
Δm [MeV]	3.5×10^{-12}	$\approx 6.3\times10^{-12}$	3.3×10^{-10}	11.7×10^{-9}
$\Delta m\ [\frac{10^{10}\hbar}{s}]$	0.529 ± 0.001	0.95 ± 0.44	51.0 ± 0.3	1776 ± 2
$\tau_0\ [10^{-12}\text{s}]$	89.5^*	0.401	1.52	1.51
$\tau_{osc}\ [10^{-12}\text{s}]$	1187	≈ 660	12.3	0.35
τ_{osc}/τ_0	13.1^*	≈ 1650	8.2	0.23
$c\cdot\tau_0$	2.7^*cm	0.123 mm	0.45 mm	0.45 mm
$c\cdot\tau_{osc}$	35 cm	≈ 20 cm	3.7 mm	0.11 mm

$$\cos(\Delta m\tau)$$

$$c\tau_{osc} = 2\pi\hbar c/\Delta m = 15\ \text{fm}$$

197 MeVfm

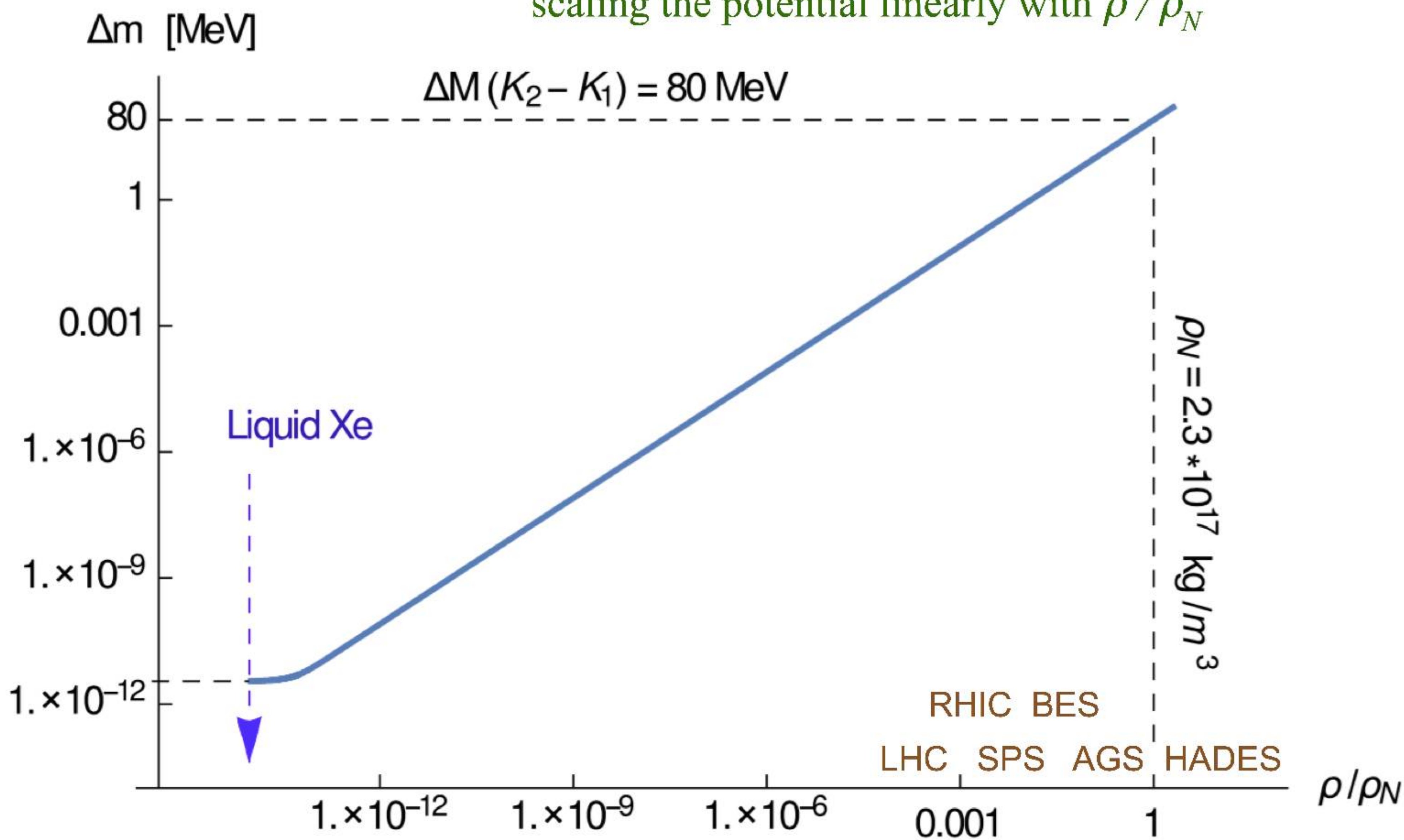
80MeV

} in Nuclei

Kaon Mass Difference in MEDIUM

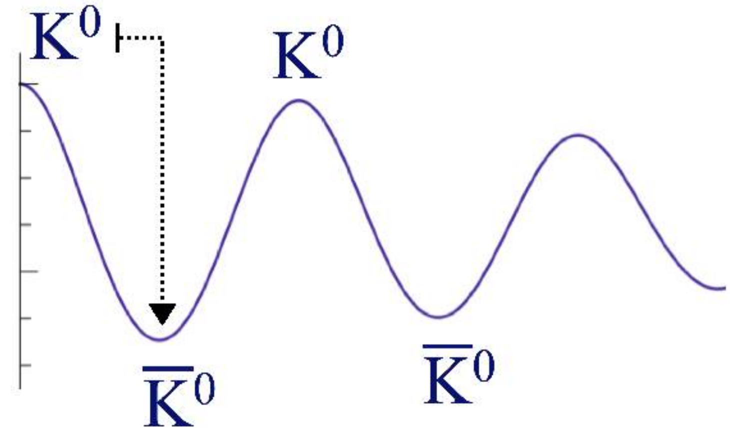
(assuming potential diff: $|\overline{K}^0 - K^0| = 80$ MeV at ρ_N)

scaling the potential linearly with ρ / ρ_N



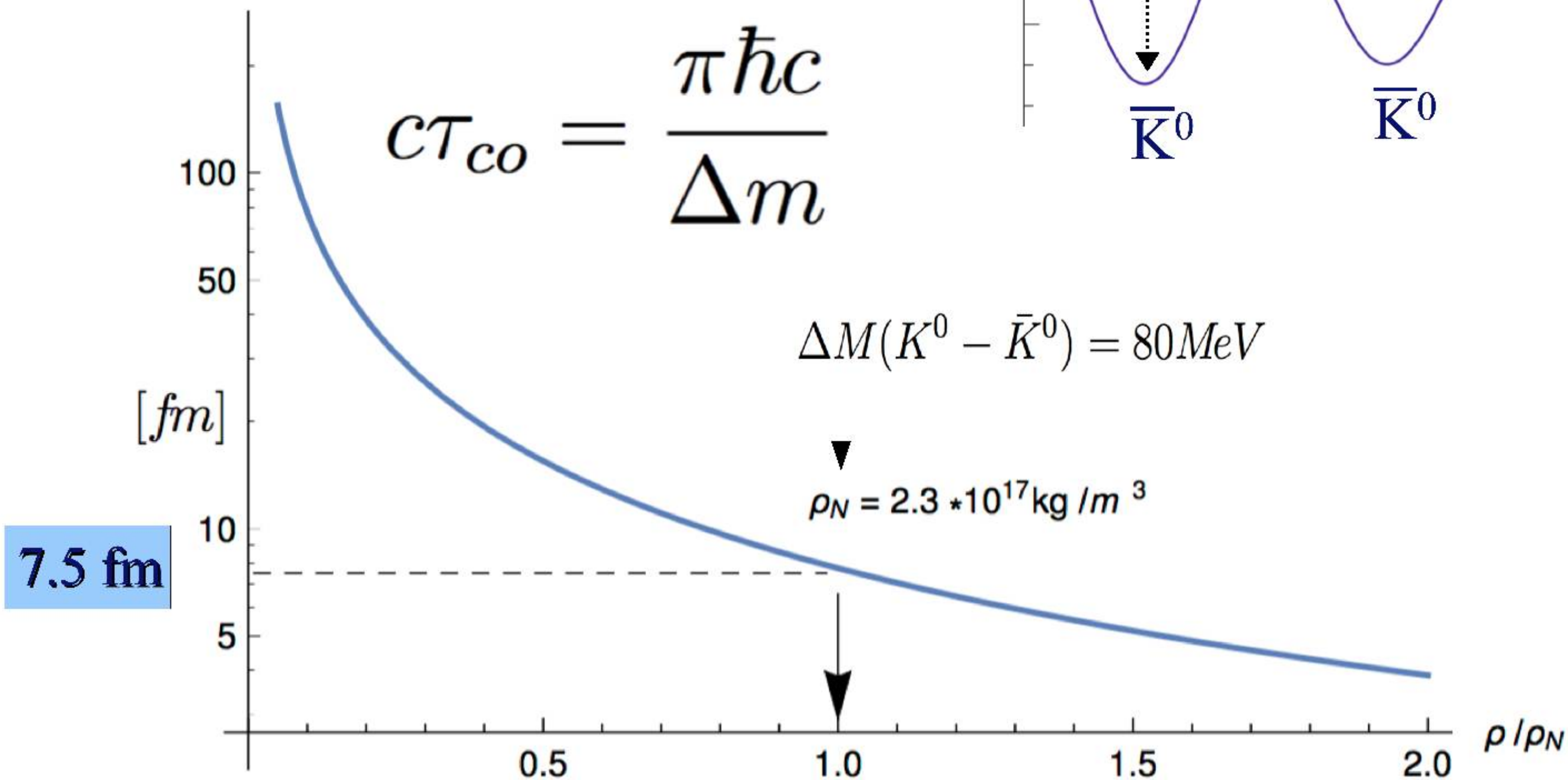
$K^0 \to \to \overline{K}^0$ conversion in dense Baryonic Matter

(assuming: $\Delta M = 80$ MeV at ρ_N)



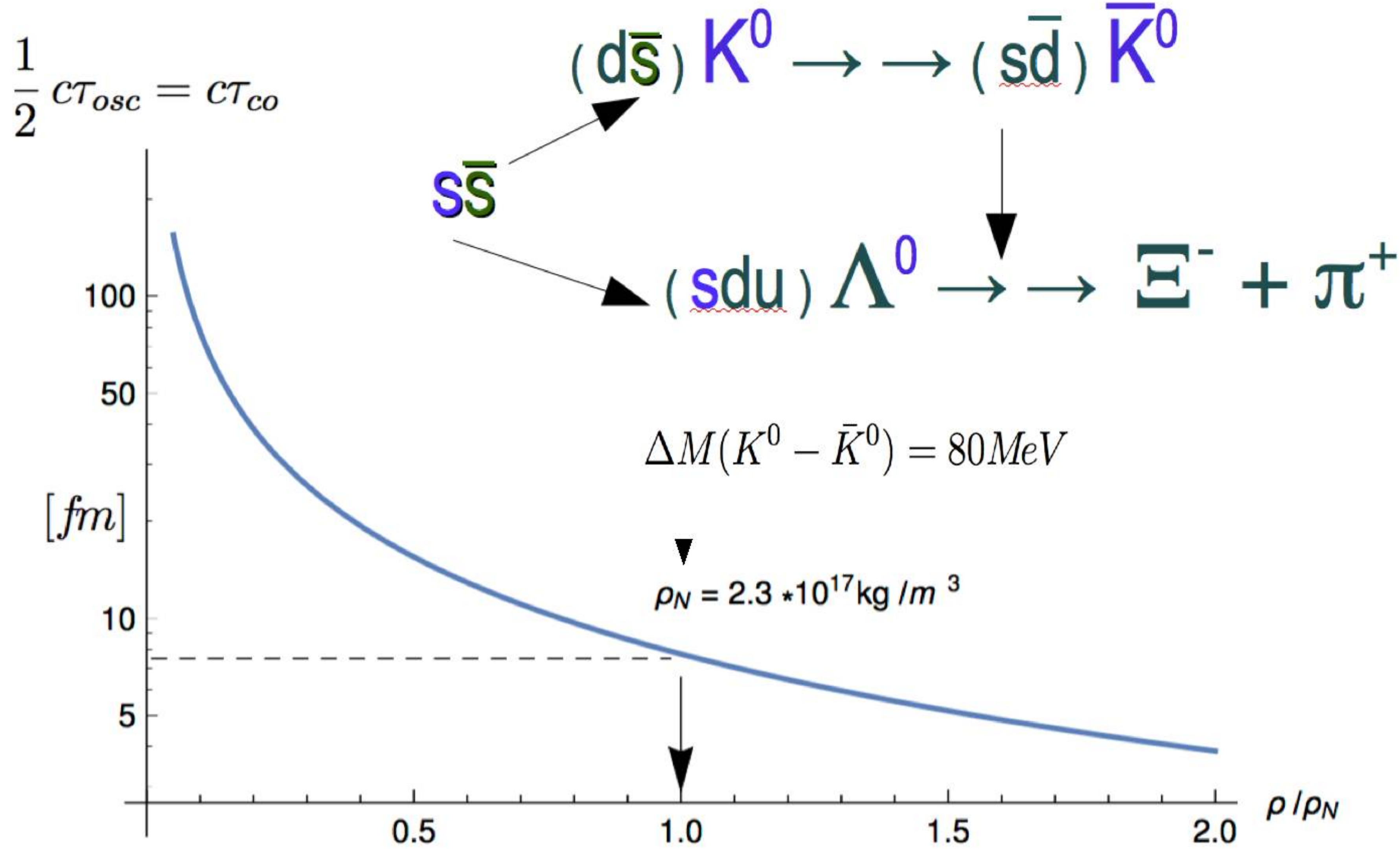
$$\frac{1}{2} c\tau_{osc} = c\tau_{co}$$

$$c\tau_{co} = \frac{\pi \hbar c}{\Delta m}$$



$K^0 \to \to \overline{K}^0$ conversion in Baryonic Matter

can be fast enough for $\Xi(ssd)$ to be created from 1x $(s\bar{s})$ pair.



Optimistic Observation:

1) K^0 oscillation is modified in medium (Δm_K)

at $\rho = \rho_N$ (dense baryonic matter) $\tau_o \approx 10$ fm/c

$\Rightarrow$ conversion $(d\bar{s}) \rightarrow (\bar{d}s)$ may be possible

within very short time during hadronic phase of HIC

2) It might be related to Ξ(ssd) excess

observed by HADES in Ar+KCl, p+Nb DATA

+ other anomalies in Kaon production at AGS, SPS, GSI

Calculation of $K^0 \to \overline{K}^0$ in Medium

$$\mathbb{H}' = \begin{bmatrix} \tilde{M}_{11} & M_{12} \\ M_{21} & \tilde{M}_{22} \end{bmatrix} - \frac{i}{2} \begin{pmatrix} \tilde{\Gamma}_{11} & \Gamma_{12} \\ \Gamma_{21} & \tilde{\Gamma}_{22} \end{pmatrix}$$

assuming CPT symmetry violation

$$\tilde{M}_{11} = M_{11} + V_{K^0}(\rho_B) \quad , \qquad \tilde{M}_{22} = M_{22} - \bar{V}_{\bar{K}^0}(\rho_B)$$

$$\tilde{\Gamma}_{11} = \Gamma_{11} + \gamma_{K^0}(\rho_B) \quad , \qquad \tilde{\Gamma}_{22} = \Gamma_{22} + \bar{\gamma}_{\bar{K}^0}(\rho_B)$$

absorption K^0 absorption $\overline{K}^0$

+ 20 MeV

$$\mathbb{M}_{K^0} = \begin{bmatrix} 497.7 + \underline{V_{K^0}(\rho_B)} & e^{i\xi_M} 1.74 \cdot 10^{-12} \\ e^{-i\xi_M} 1.74 \cdot 10^{-12} & 497.7 - \underline{\bar{V}_{\bar{K}^0}(\rho_B)} \end{bmatrix}$$

60 - 80 MeV at ρ_N

Calculation of $K^0 \to \overline{K}^0$ in Medium

assuming CPT symmetry violation

$$|\langle \tilde{K}_2^0 | \tilde{K}_1^0 \rangle| = \delta_{cp} \longrightarrow |\langle P_H | P_L \rangle|^2 = \frac{(1+\delta_{cp}^2)|1-\theta^2| - (1-\delta_{cp}^2)(1-|\theta|^2)}{(1+\delta_{cp}^2)|1-\theta^2| + (1-\delta_{cp}^2)(1+|\theta|^2)}$$

Eigenvectors:

$|P_L\rangle = p_L|P^0\rangle - q_L|\bar{P}^0\rangle$ $\qquad \frac{q_L}{p_L} = (1-\theta)\frac{\Delta\mu}{2H_{12}}$

$|P_H\rangle = p_H|P^0\rangle + q_H|\bar{P}^0\rangle$ $\qquad \frac{q_H}{p_H} = (1+\theta)\frac{\Delta\mu}{2H_{12}}$

$$\theta = \frac{M_{22} - M_{11} - \frac{i}{2}(\Gamma_{22} - \Gamma_{11})}{\sqrt{4H_{12}H_{21} + (H_{22} - H_{11})^2}}$$

CPT violation Complex parameter

see e.g. G. Branco et al. Book
"CP Violation" Eq.(6.25 - 6.32)

$$|K^0\rangle(t) = [g_+(t) - \theta g_-(t)]|K^0\rangle + \frac{q_H}{p_H}(1-\theta)g_-(t)|\bar{K}^0\rangle$$

$$|\bar{K}^0\rangle(t) = [g_+(t) + \theta g_-(t)]|\bar{K}^0\rangle + \frac{p_L}{q_L}(1-\theta)g_-(t)|K^0\rangle$$

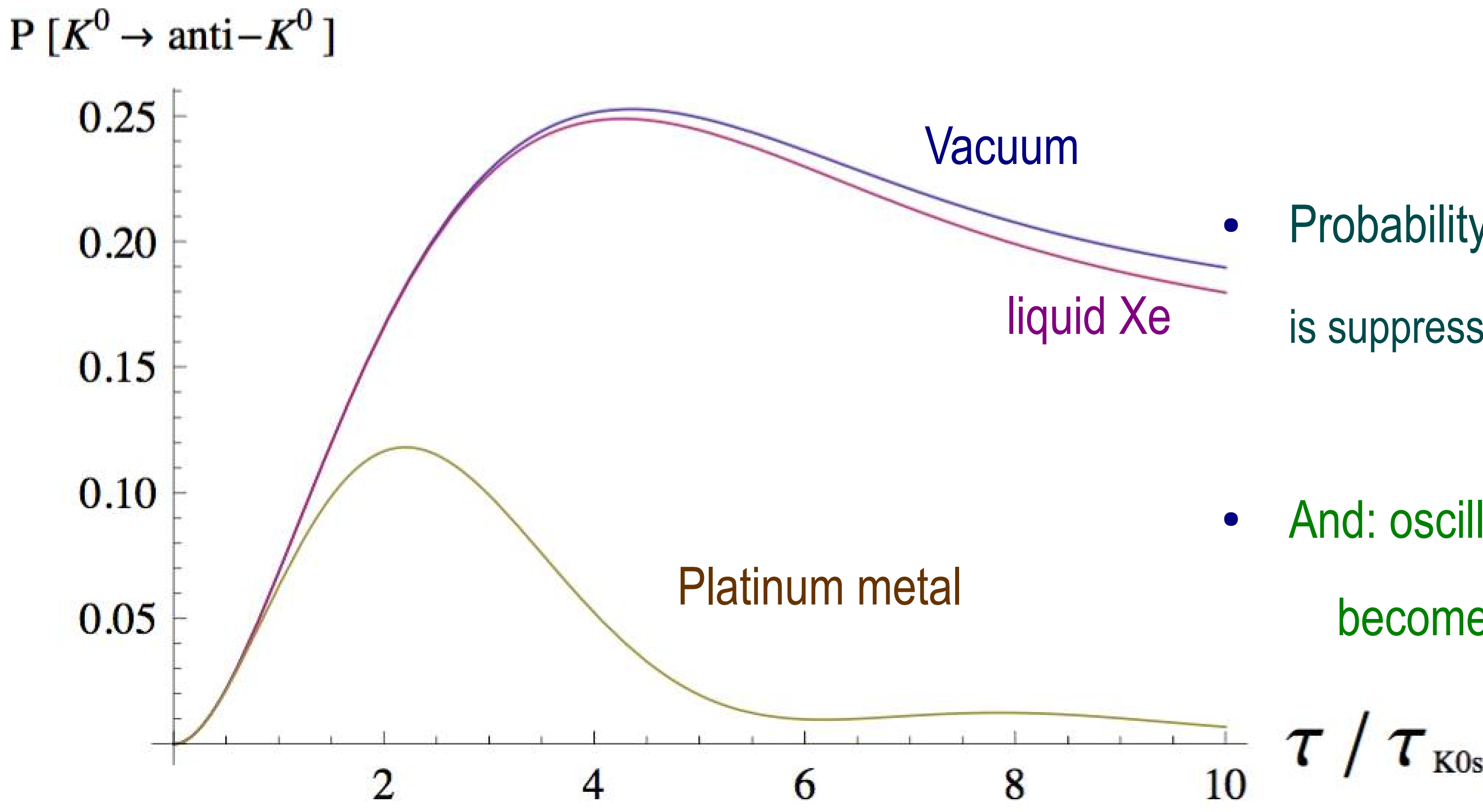
Time evolution of strong K^0 states

For eigenvalues one has: $\Delta\mu = M_H - M_L - \frac{i}{2}(\Gamma_H - \Gamma_L) = \sqrt{4H_{12}H_{21} + (H_{22} - H_{11})^2}$

Strangeness oscillation in medium:

$$[K^0 \rightsquigarrow \bar{K}^0]_{(\tau)} = \left|\frac{q_H}{p_H}\right|^2 |g_-(\tau)|^2 |(1-\theta)|^2$$

Branco et al.: CP Violation Eq.(9.8)

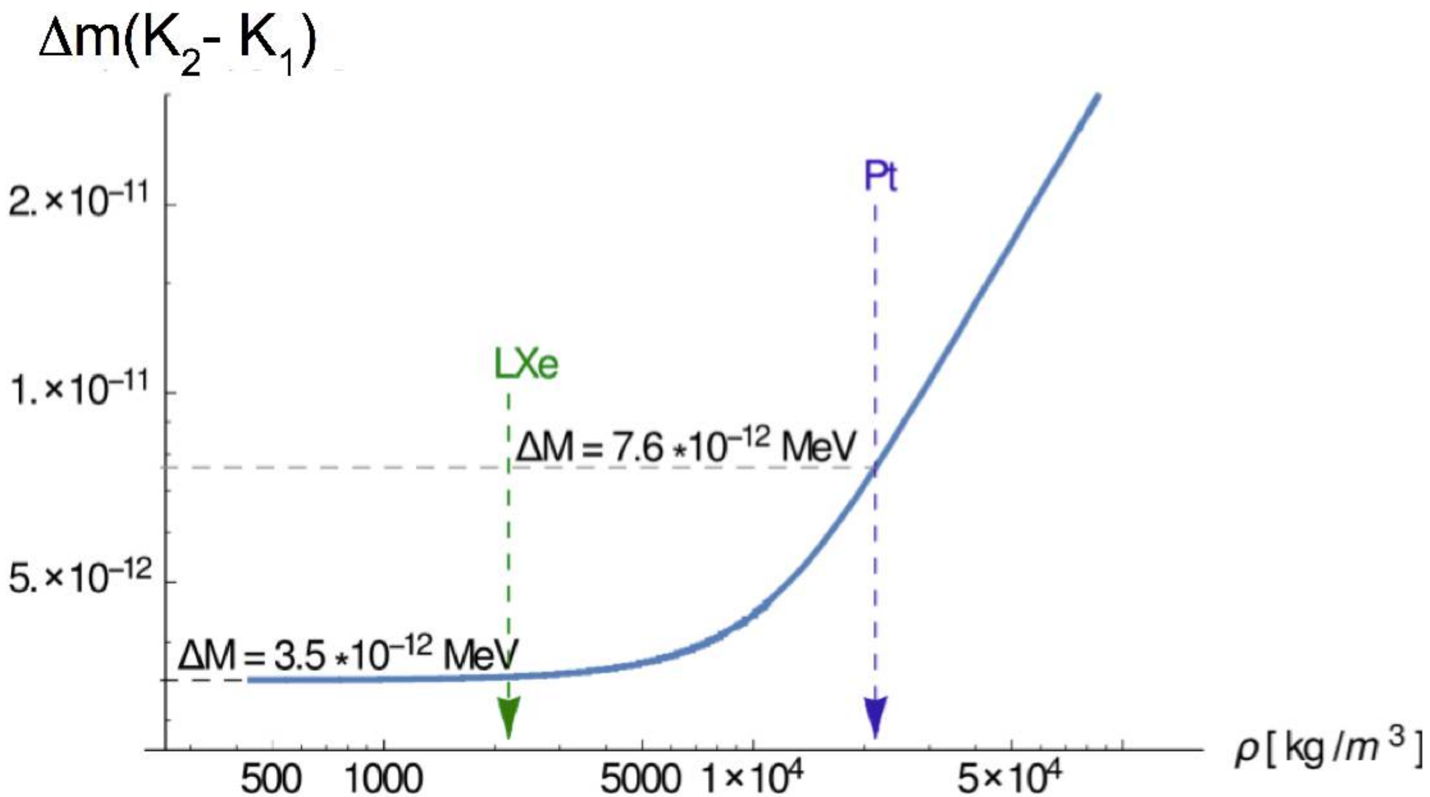


- Probability P[$K^0 \to \bar{K}^0$] is suppressed in medium
- And: oscillation length becomes shorter

- is weakly affected in Liquid detector media (compared to Vacuum)
- Relativistic γ factor neglected here (increases effective medium density)

(absorption neglected)

Mass difference $\Delta m(K_2 - K_1)$ in medium:



Absorption of kaons in medium not taken into account here

- Eigenvalues: $\Delta\mu = \underbrace{M_H - M_L}_{\Delta m(K_2 - K_1)} - \frac{i}{2}(\Gamma_H - \Gamma_L) = \sqrt{4H_{12}H_{21} + (H_{22} - H_{11})^2}$

$K^0 \rightarrow \overline{K}^0$ conversion in Nuclear Medium

$$[K^0 \rightsquigarrow \bar{K}^0]_{(\tau)} = \left|\frac{q_H}{p_H}\right|^2 |g_-(\tau)|^2 |(1-\theta)|^2$$

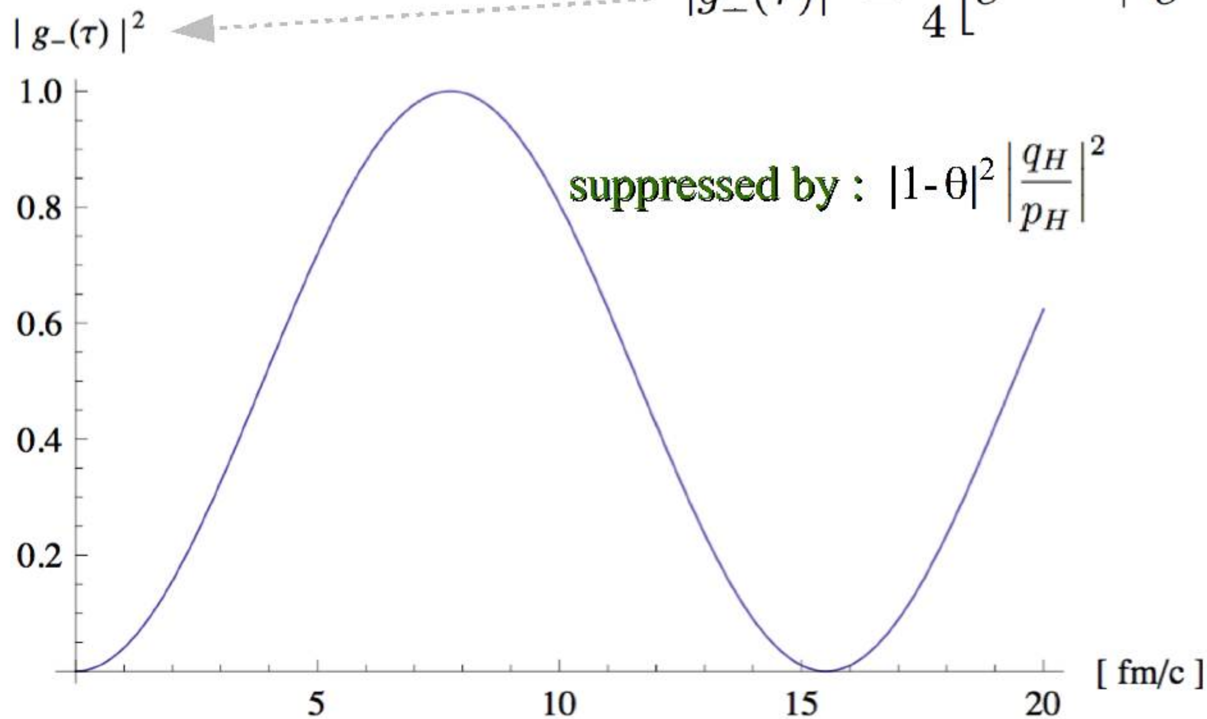
$$[\bar{K}^0 \rightsquigarrow K^0]_{(\tau)} = \left|\frac{p_L}{q_L}\right|^2 |g_-(\tau)|^2 |(1-\theta)|^2$$

if CP symmetry holds

$$\left|\frac{p_L}{q_L}\right| = \left|\frac{q_H}{p_H}\right|$$

oscillation

$$|g_-(\tau)|^2 = \frac{1}{4}\left[e^{-\tau\Gamma_H} + e^{-\tau\Gamma_L} - 2\cos(\Delta\tilde{m}\tau)e^{-\tau(\Gamma_H+\Gamma_L)/2}\right]$$



for dense Baryonic medium (e.g. Niobium nucleus)

Assuming potential difference $dV(K-\overline{K}) = 80$ MeV

$K^0 \rightarrow \overline{K}^0$ the same as $\overline{K}^0 \rightarrow K^0$
if
CP violation is neglected

it would modify $dN(\overline{K}^0)/dy$
only if
$N(K^0) >> N(\overline{K}^0)$

anyway would't be visible
in K^0_S spectra

SUPPRESSION FACTOR ESTIMATE

$$P(K^0 \to \bar{K}^0) = \left|\frac{q_H}{p_H}\right|^2 |1-\theta|^2 |g_-(\tau)|^2$$

see G.C. Branco et al.
in book: "CP Violation"
Eq.(9.8) Eq.(6.29-32)

$$\left|\frac{q_H}{p_H}\right|^2 = \frac{4|H_{21}|^2}{|\Delta\mu|^2} \frac{1}{|1-\theta|^2}$$

$$P(K^0 \to \bar{K}^0) = \frac{|2H_{21}|^2}{|4H_{12}H_{21} + (H_{22}-H_{11})^2|} |g_-(\tau)|^2$$

$$\approx \frac{|2H_{21}|^2}{|H_{22}-H_{11}|^2} |g_-(\tau)|^2 = \frac{4|M_{21} - i\Gamma_{21}/2|^2}{\Delta V^2} |g_-(\tau)|^2$$

10^{-12}

$(80\ \text{MeV})^2$

$\rho = \rho_N$

for $|H_{12}H_{21}| \ll |H_{22}-H_{11}|^2 \approx \Delta V^2$

$K^0 \to \overline{K}^0$ conversion in Nuclear Medium

$$[K^0 \rightsquigarrow \bar{K}^0]_{(\tau)} = \left|\frac{q_H}{p_H}\right|^2 |g_-(\tau)|^2 |(1-\theta)|^2$$

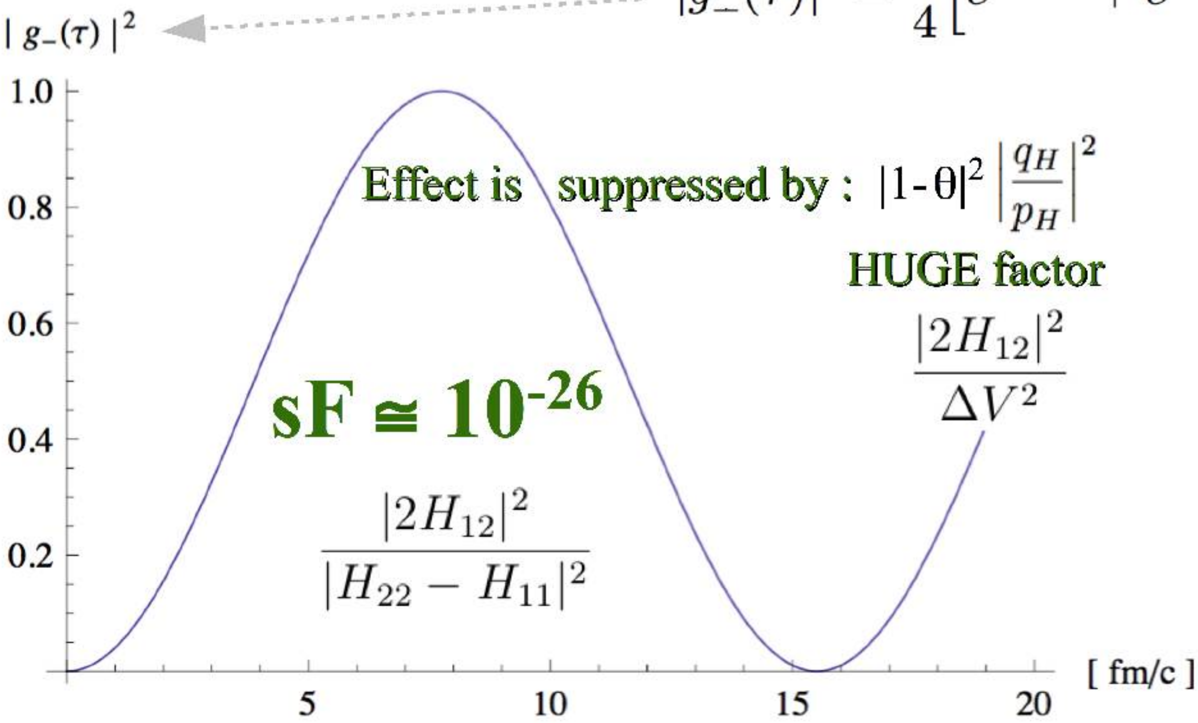
$$[\bar{K}^0 \rightsquigarrow K^0]_{(\tau)} = \left|\frac{p_L}{q_L}\right|^2 |g_-(\tau)|^2 |(1-\theta)|^2$$

if CP symmetry holds

$$\left|\frac{p_L}{q_L}\right| = \left|\frac{q_H}{p_H}\right|$$

oscillation

$$|g_-(\tau)|^2 = \frac{1}{4}\left[e^{-\tau\Gamma_H} + e^{-\tau\Gamma_L} - 2\cos(\Delta\tilde{m}\tau)e^{-\tau(\Gamma_H+\Gamma_L)/2}\right]$$



Effect is suppressed by : $|1-\theta|^2 \left|\frac{q_H}{p_H}\right|^2$

HUGE factor $\frac{|2H_{12}|^2}{\Delta V^2}$

sF ≅ 10^{-26}

$$\frac{|2H_{12}|^2}{|H_{22}-H_{11}|^2}$$

for dense Baryonic medium (e.g. Niobium nucleus)

Assuming potential difference dV(K-$\overline{K}$) = 80 MeV

$K^0 \to \overline{K}^0$ the same as $\overline{K}^0 \to K^0$
if
CP violation is neglected

it would modify $dN(\overline{K}^0)/dy$
only if
$N(K^0) >> N(\overline{K}^0)$

anyway would't be visible
in K^0_s spectra

Realistic Observation:

1) $K^0 \rightarrow \overline{K}^0$ **oscillation is potentially fast enough**

in ($\rho = \rho_N$) dense baryonic medium: $\tau_o \approx$ 10 fm/c

2) Subthreshold production needed: $N(\overline{K}) << N(K)$

to violate strangeness conservation (if $\delta_{CP} = 0$)

$\Rightarrow$ **Suppression factor at $\rho \cong \rho_N$: sF ~ 10^{-26}**

makes $K^0(d\overline{s}) \rightarrow \overline{K}^0(\overline{d}s)$ process negligible

Don't Give UP for free!

Think about $K^{0*}(896)$ oscillations !

J = 1

$(d\bar{s}) \leftrightarrow (\bar{d}s)$

K_S^{0*} and its uses

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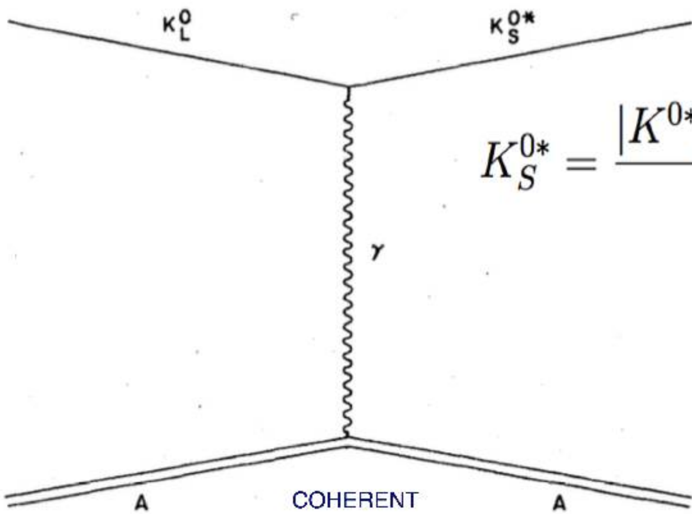
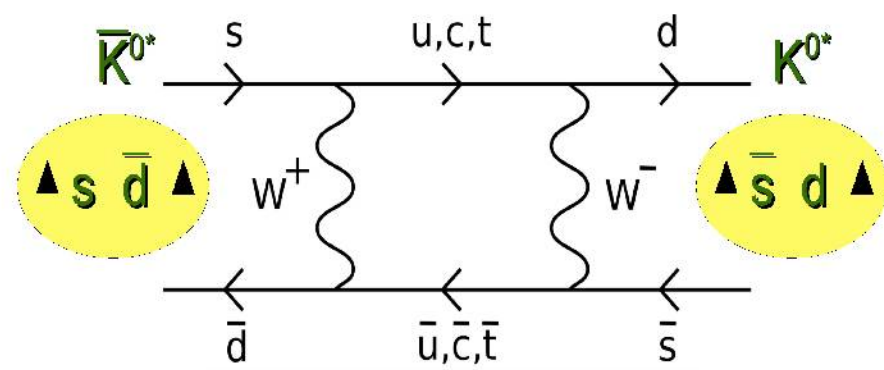
We point out that Primakoff conversion of K_L^0's produces K_S^{0*}'s.



$$K_S^{0*} = \frac{|K^{0*}\rangle + |\bar{K}^{0*}\rangle}{\sqrt{2}}$$

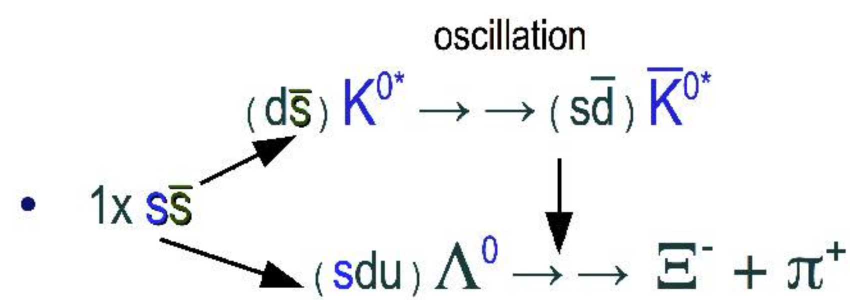
FIG. 1. Primakoff excitation of K^*.

PHYSICAL REVIEW D VOLUME 21, NUMBER 7



$$M_{21} = M_{21}^* = \langle \bar{K}^{0*} | H_{wk} | K^{0*} \rangle$$

assume M_{12} the same as for K^0(497)



- K_S^{0*} quantum state exists and it can be produced.

$K^{0*}(896)$ decay matrix (Hamiltonian)

Γ_{11} = 48 MeV $|\Gamma_{12}|$ = 16 MeV

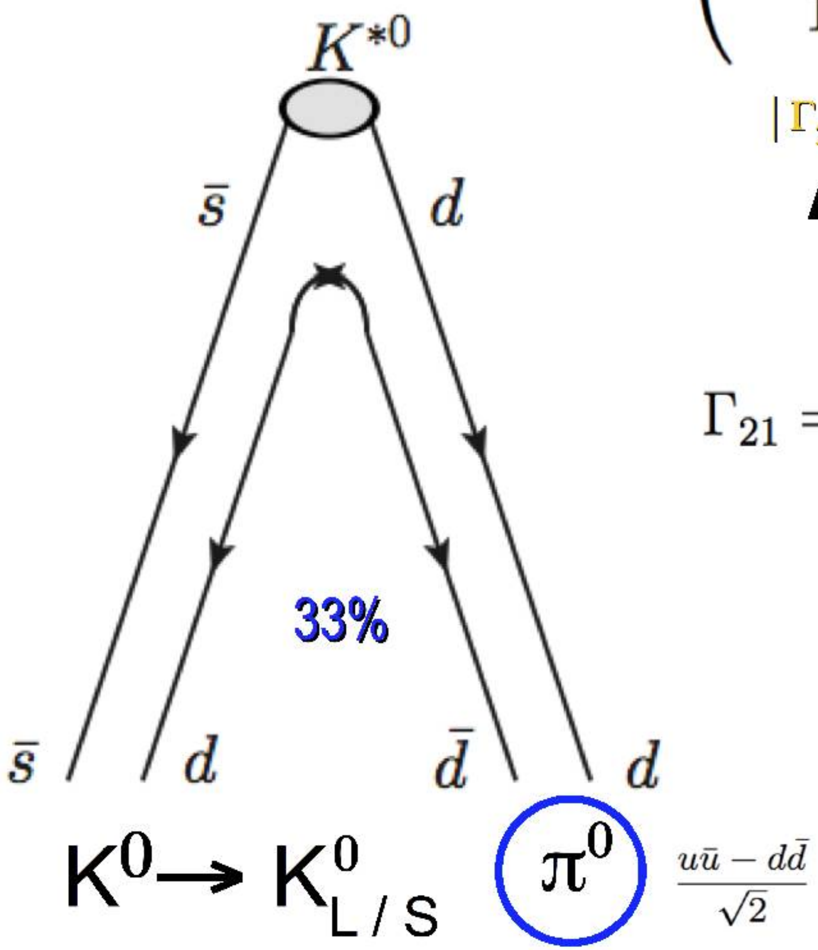
absorption

$$\mathbb{G}_{K^{0*}} = \begin{pmatrix} 48 + \gamma_{K^{0*}}(\rho_B) & 16\, e^{i\xi_{G^*}} \\ 16\, e^{-i\xi_{G^*}} & 48 + \bar{\gamma}_{\bar{K}^{0*}}(\rho_B) \end{pmatrix}$$

Absorption

$|\Gamma_{21}|$ = 16 MeV

Γ_{22} = strong decay width = 48 MeV



$$\Gamma_{21} = \Gamma_{21}^* = \pi \sum_F \rho_f \langle \bar{K}^{0*} | H_{wk} | F \rangle \langle F | H_{wk} | K^{0*} \rangle$$

$\pi^0 K^0_{L,S}$

8 MeV   8 MeV

$K^{*0} \Rightarrow K^0_L \pi^0$ or $K^0_S \pi^0$ 0.33 x 48 = 16MeV

$\bar{K}^{*0} \Rightarrow K^0_L \pi^0$ or $K^0_S \pi^0$ 0.33 x 48 = 16MeV

the same final states

Hamiltonian for K^{0*}(896)

K^{0*}(896)

$$\mathbb{G}_{K^{0*}} = \begin{pmatrix} 48 + \gamma_{K^{0*}}(\rho_B) & 16\, e^{i\xi_{G^*}} \\ 16\, e^{-i\xi_{G^*}} & 48 + \bar{\gamma}_{\bar{K}^{0*}}(\rho_B) \end{pmatrix}$$

$$\mathbb{G}_{K^0} = \begin{pmatrix} 3.7 \cdot 10^{-12} + \gamma_{K^0}(\rho_B) & e^{i\xi_G} 3.48 \cdot 10^{-12} \\ e^{-i\xi_G} 3.48 \cdot 10^{-12} & 3.7 \cdot 10^{-12} + \bar{\gamma}_{\bar{K}^0}(\rho_B) \end{pmatrix}$$

K^0(497)

SUBSTANTIAL decay width

K^{0*} differences K^0

observe: Γ_{12} of K^{0*} comparable to ΔV_{K^*}

+ 20 MeV

$$\mathbb{M}_{K^{0*}} = \begin{bmatrix} 896 + V_{K^{0*}}(\rho_B) & e^{i\xi_{M^*}} 1.7 \cdot 10^{-12} \\ e^{-i\xi_{M^*}} 1.7 \cdot 10^{-12} & 896 - \bar{V}_{\bar{K}^{0*}}(\rho_B) \end{bmatrix}$$

K^{0*}(896)

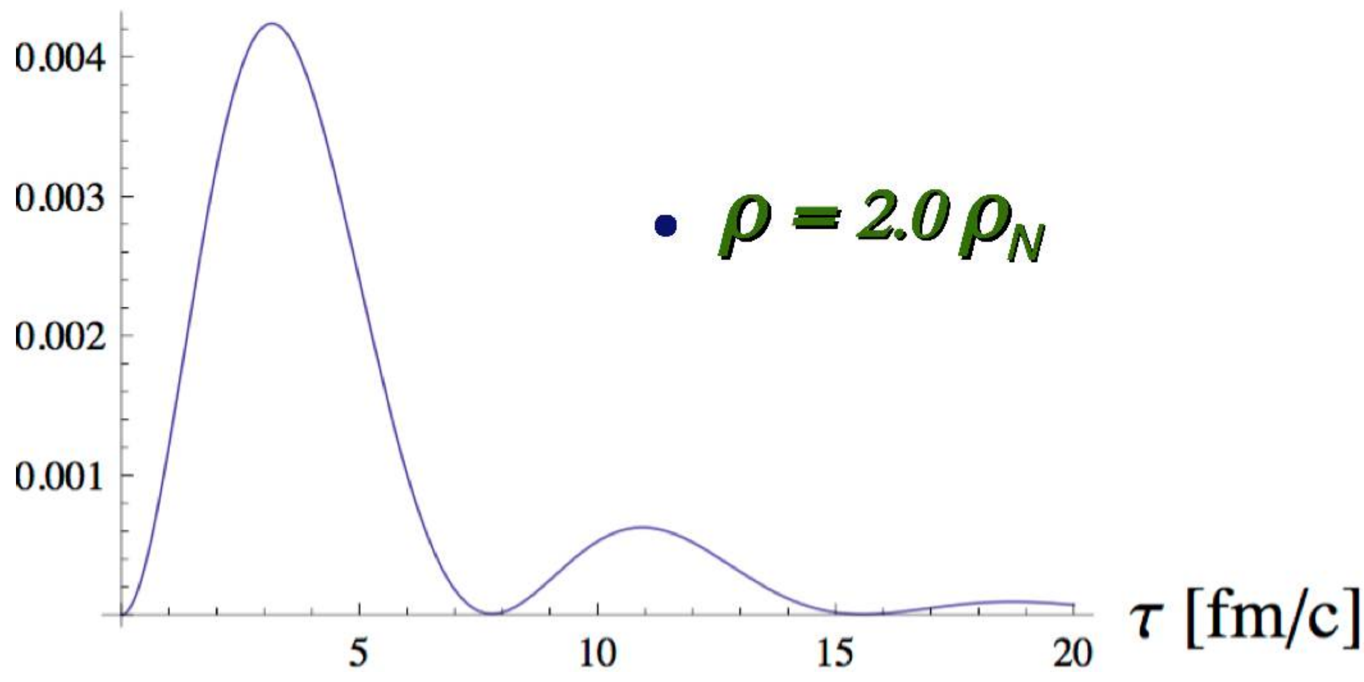
- 60 MeV

Assuming the same K^* in-medium potentials.

Results for K^{0*} oscillations

Probability of $K^{0*} \Rightarrow \overline{K}^{0*}$ process:

$$|q_H/p_H|^2 |1-\theta|^2 | g_-(\tau) |^2 \quad \mathrm{K0} \to \mathrm{aK0}$$

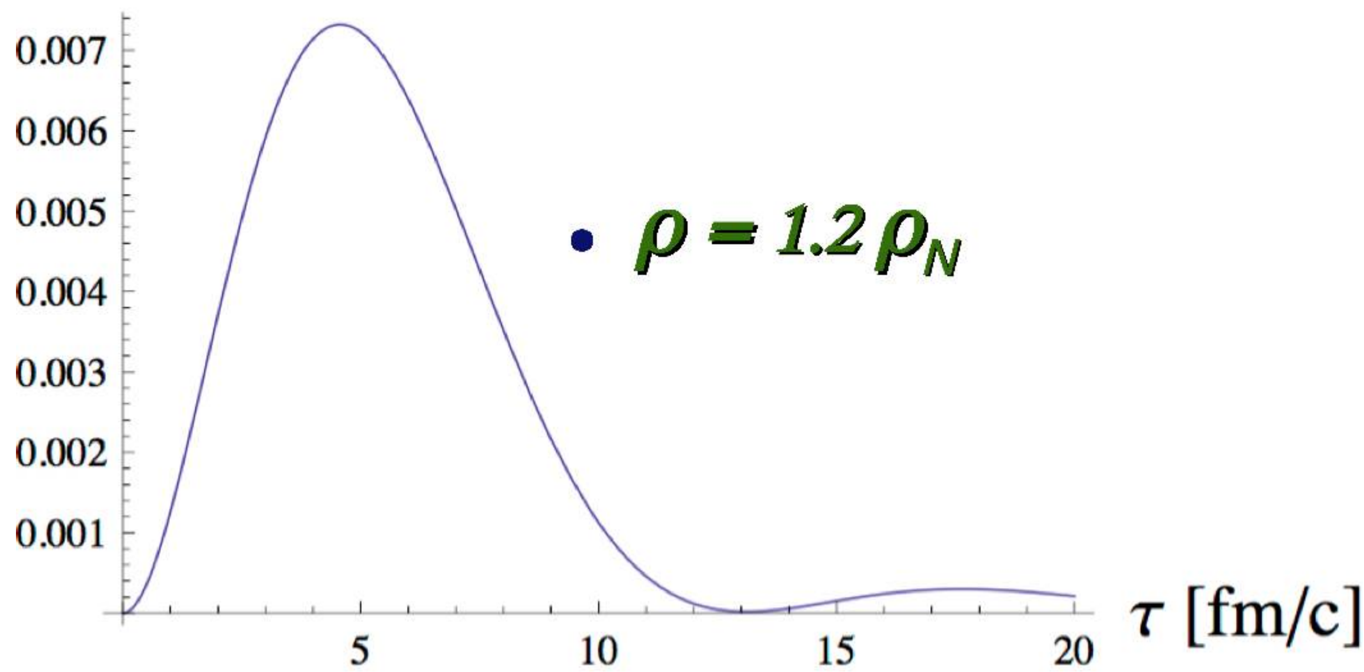


- With absorption: Γ_{22} = 48+12 MeV, Γ_{11} = 48+5 MeV

Results for K^{0*} oscillations

Probability of $K^{0*} \Rightarrow \overline{K}^{0*}$ process:

$$|q_H/p_H|^2 |1-\theta|^2 | g_-(\tau) |^2 \quad K0 \rightarrow aK0$$

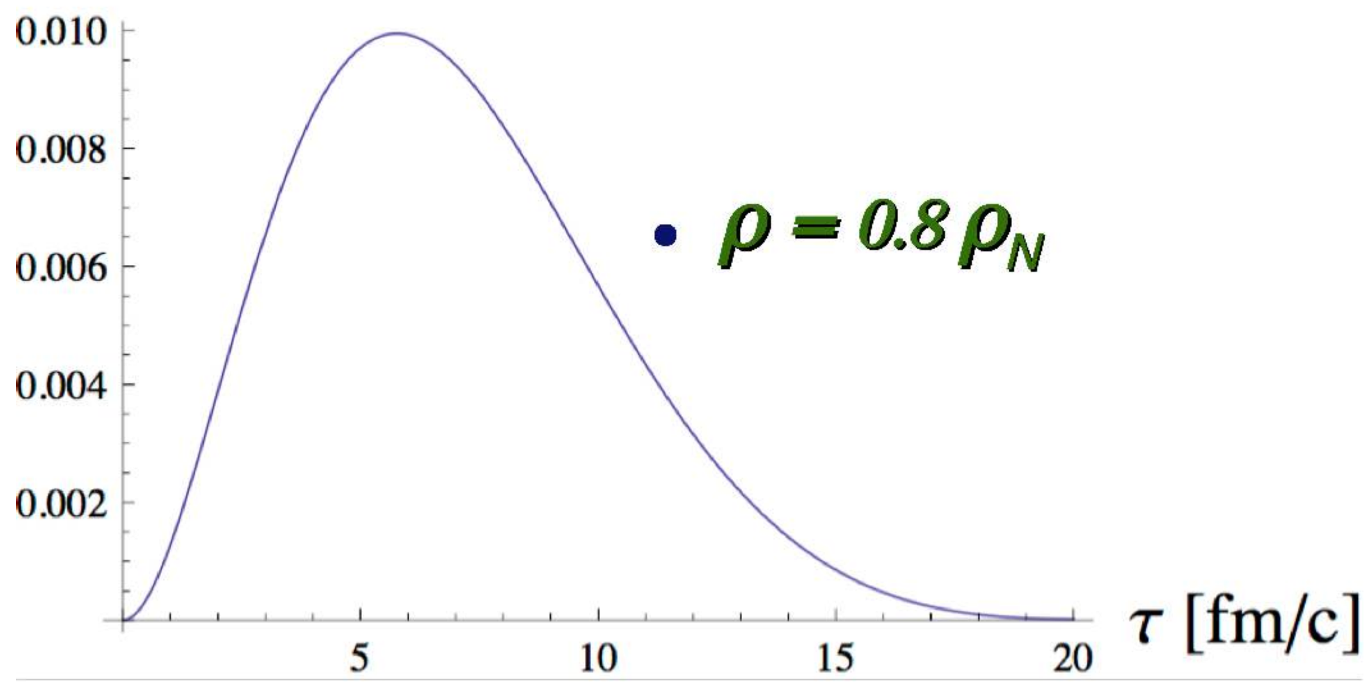


- With absorption: Γ_{22}= 48+12 MeV, Γ_{11}= 48+5 MeV

Results for K^{0*} oscillations

Probability of $K^{0*} \Rightarrow \overline{K}^{0*}$ process:

$$|q_H/p_H|^2 |1-\theta|^2 |g_-(\tau)|^2 \quad K0 \rightarrow aK0$$

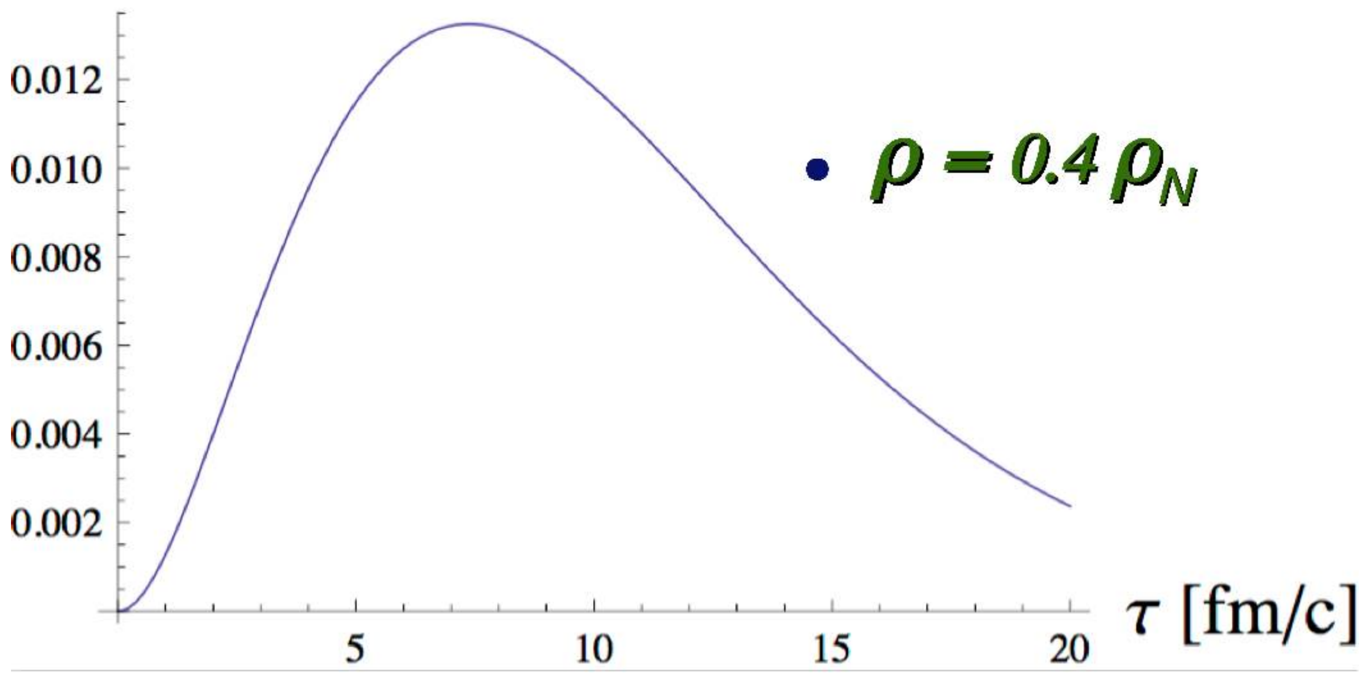


- With absorption: Γ_{22}= 48+12 MeV, Γ_{11}= 48+5 MeV

Results for K^{0*} oscillations

Probability of $K^{0*} \Rightarrow \overline{K}^{0*}$ process:

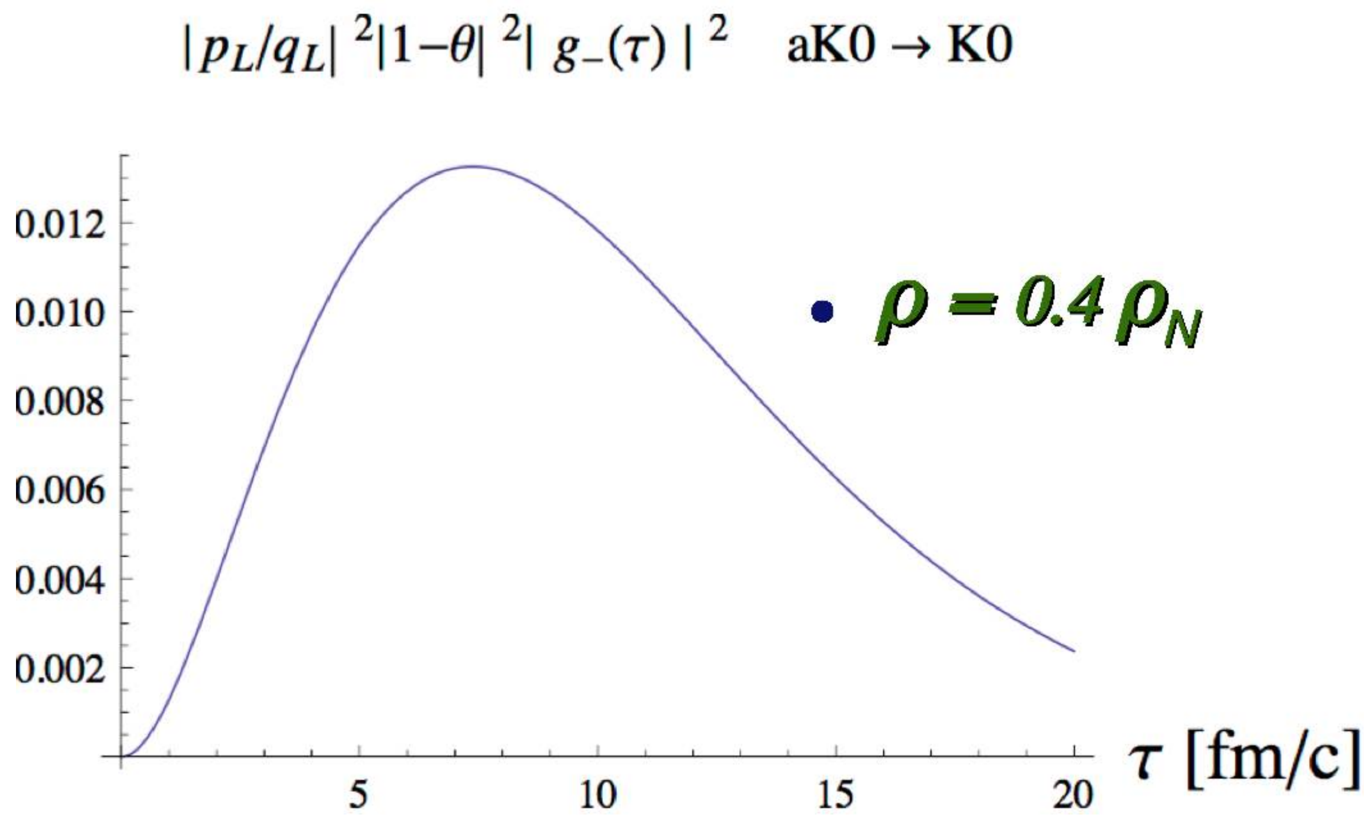
$|q_H/p_H|^2 |1-\theta|^2 |g_-(\tau)|^2$ K0 → aK0



- With absorption: Γ_{22}= 48+12 MeV, Γ_{11}= 48+5 MeV

Results for $\overline{K}^{0*}$ oscillations

Probability of $\overline{K}^{0*} \Rightarrow K^{0*}$ **reverse** process

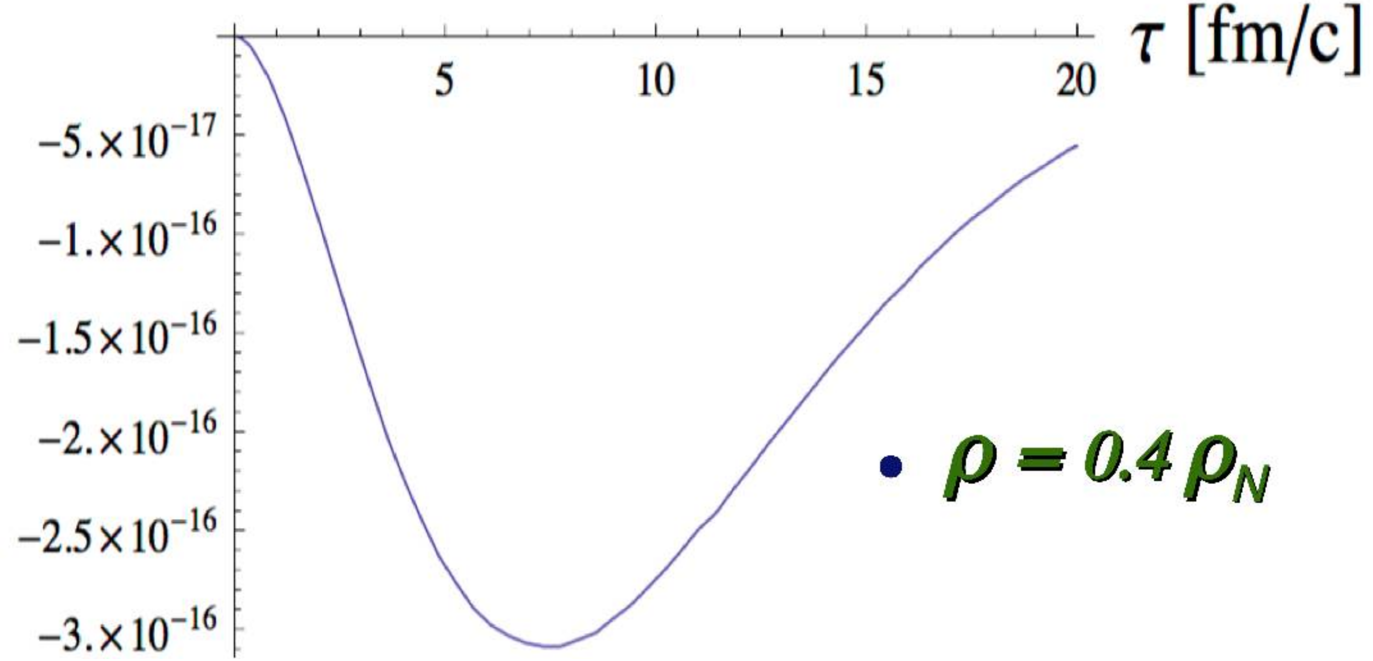


- With absorption: Γ_{22}= 48+12 MeV, Γ_{11}= 48+5 MeV

Results for K^{0*} oscillations

Difference between $\overline{K}^{0*} \Rightarrow K^{0*}$ **and** $K^{0*} \Rightarrow \overline{K}^{0*}$

$$(|p_L/q_L|^2 - |q_H/p_H|^2)|1-\theta|^2 |g_-(\tau)|^2$$



- With absorption: Γ_{22} = 48+12 MeV, Γ_{11} = 48+5 MeV

Observed Features:

1) **Probability of $K^{0*} \Rightarrow \overline{K}^{0*}$ is 0.5% - 1.5%**

2) **Process ($\bar{s} \rightarrow s$) occurs within $\tau = 4 - 10$ fm/c**

if net baryon density $\rho_B = [\,0.1 - 2.0\,]\rho_N$ [0.16 fm^{-3}]

3) **CP violation is not important = not needed**

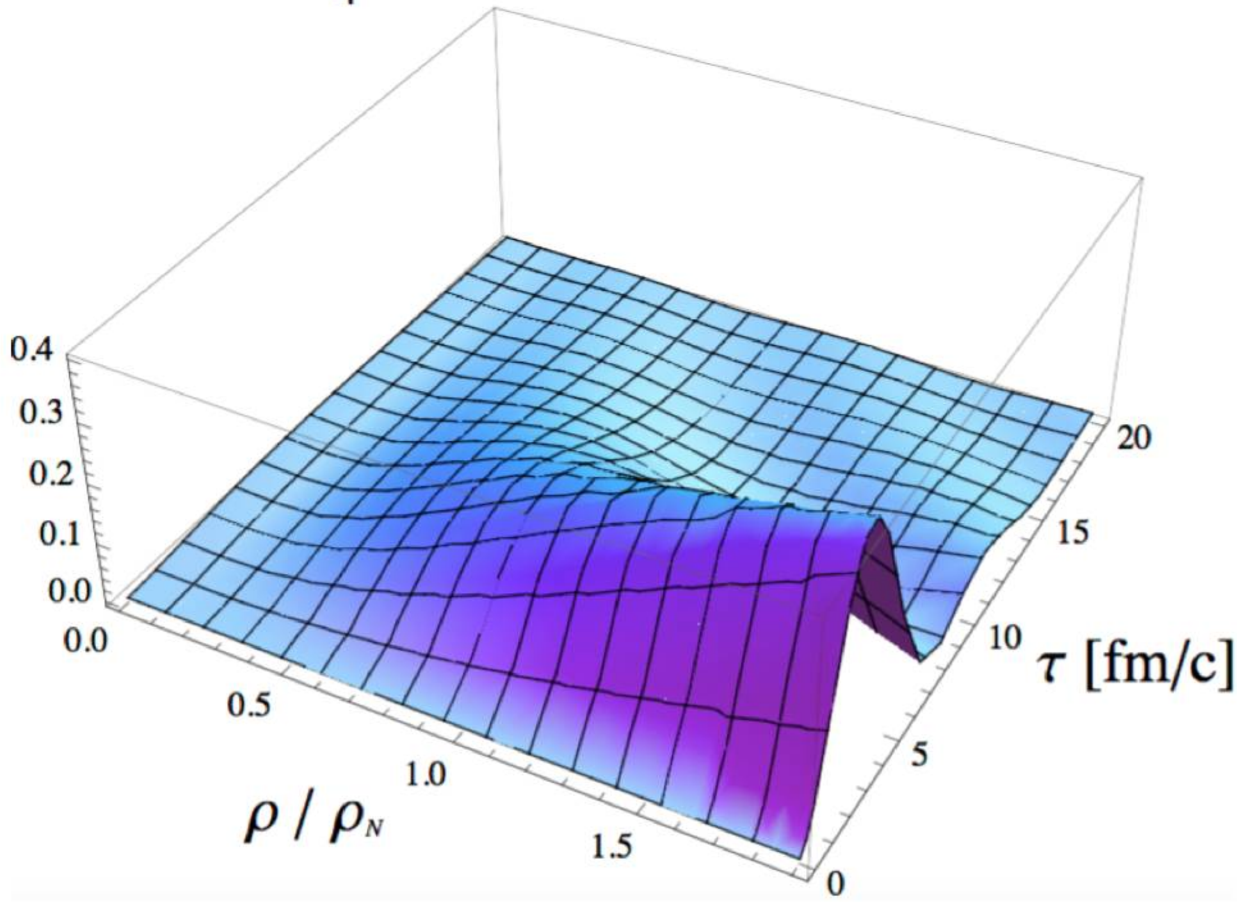
(opposite process $\overline{K}^{0*} \Rightarrow K^{0*}$ has the same probability)

process ($\bar{s} \rightarrow s$) becomes relevant = IF primordial $N(K^{0*}) >> N(\overline{K}^{0*})$

More results for K^{0*} oscillations

Oscillation term for $K^{0*} \Rightarrow \overline{K}^{0*}$ process:

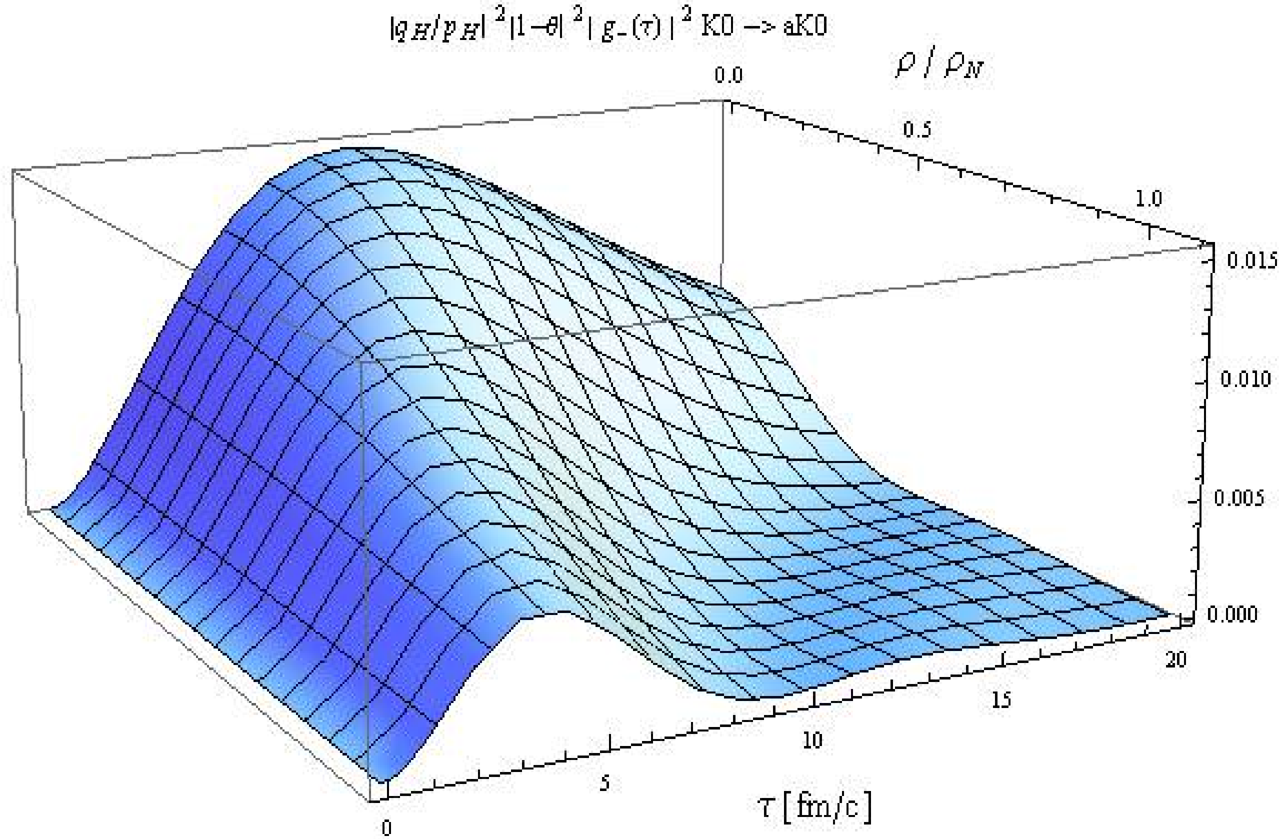
$$|g_-(\tau)|^2 = \frac{1}{4}\left[e^{-\tau\Gamma_1} + e^{-\tau\Gamma_2} - 2\mathrm{Cos}[\Delta M * \tau]\, e^{-\tau(\Gamma_1+\Gamma_2)/2}\right]$$



Suppression factor not shown.

More results for K^{0*} oscillations

Transition probability $K^{0*} \Rightarrow \overline{K}^{0*}$:



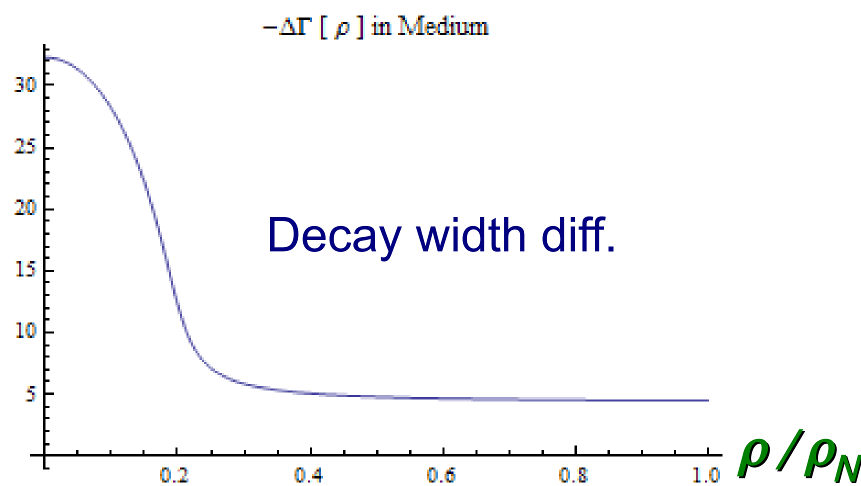
1.5%

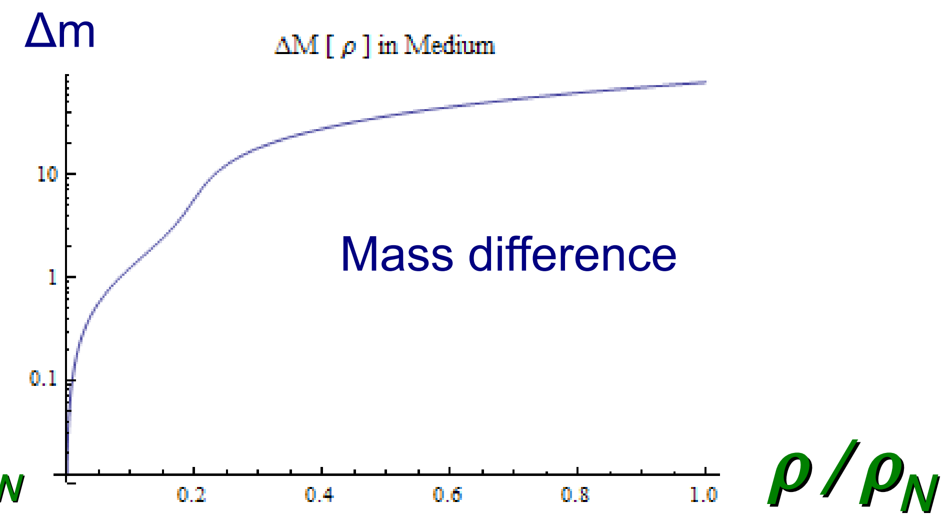
However: $N(K^*)/N(\overline{K}^*)$ is smaller.

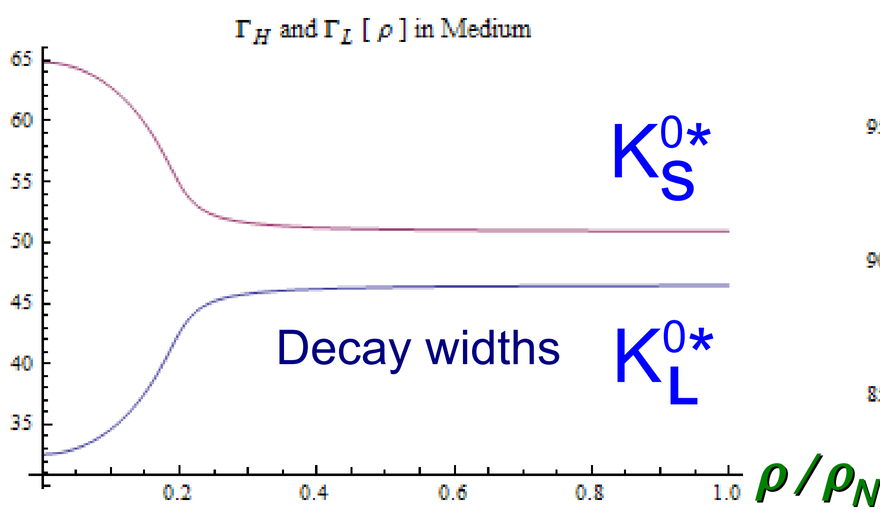
If suppression factor is included, at small ρ_B we have larger Probability.

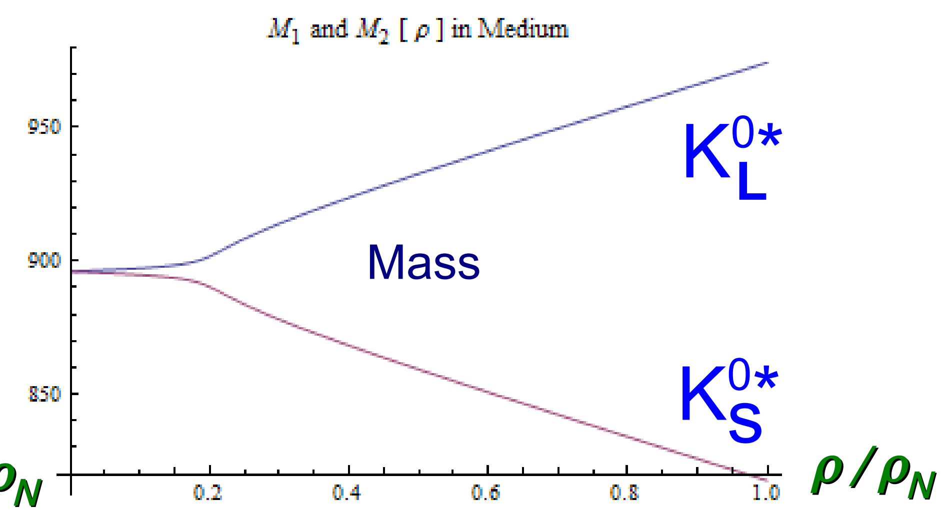
More results for K^{0*} , $\overline{K}^{0*}$ in medium

Decay widths and Masses of eigenstates K_L^{0*}, K_S^{0*}









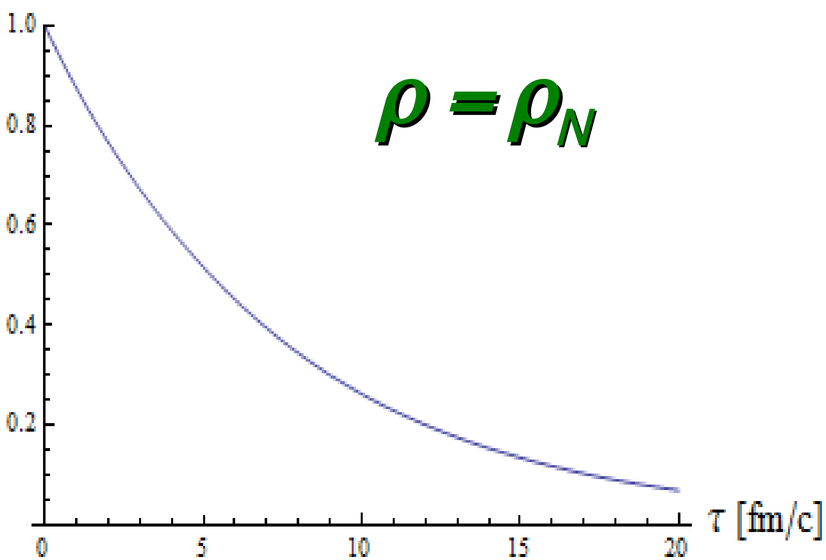
Γ_{22}= 49+7.4 MeV, Γ_{11}= 49+3 MeV, ΔV = 80 MeV at ρ_N

Survival $K^{0*} \Rightarrow K^{0*}$ and $\bar{K}^{0*} \Rightarrow \bar{K}^{0*}$ probability:

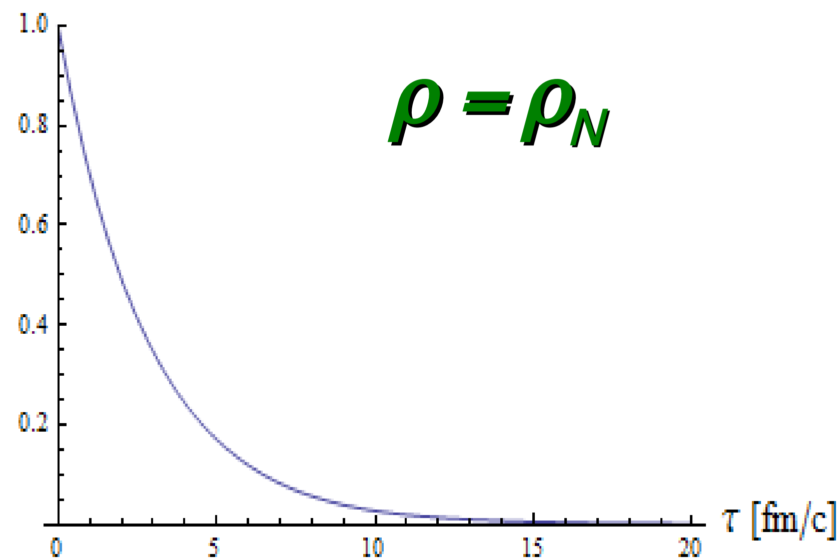
$$[P^0(t) \to P^0]_{(\tau)} = |\langle P^0|P^0(\tau)\rangle|^2 = \left|g_+(\tau) - \theta g_-(\tau)\right|^2$$

$$[\bar{P}^0(t) \to \bar{P}^0]_{(\tau)} = |\langle \bar{P}^0|\bar{P}^0(\tau)\rangle|^2 = \left|g_+(\tau) + \theta g_-(\tau)\right|^2$$

$|g_+(\tau)-\theta g_-(\tau)|^2$ $K^{0*}(t)$



$|g_+(\tau)+\theta g_-(\tau)|^2$ $\bar{K}^{0*}(t)$



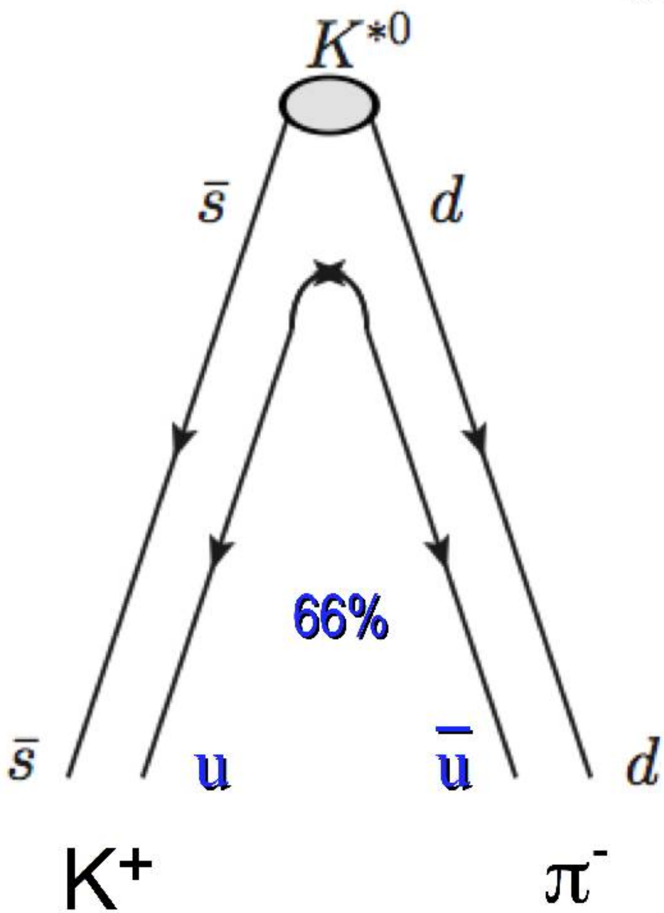
Substantially different absorption cross sections assumed here.

Γ_{11} = 48+30 MeV, Γ_{22} = 48+74 MeV at $\rho = \rho_N$

$K^{0*} \rightarrow \overline{K}^{0*}$ oscillation: CONSEQUENCE 1.

For a sub-threshold $\overline{K}^*$ production: $100 \cdot N(\overline{K}^*) < N(K^*)$

$\rightarrow$ more $\overline{K}^{0*}$ observed than expected:



$\overline{K}^{0*} \rightarrow K^-\pi^+$ channel

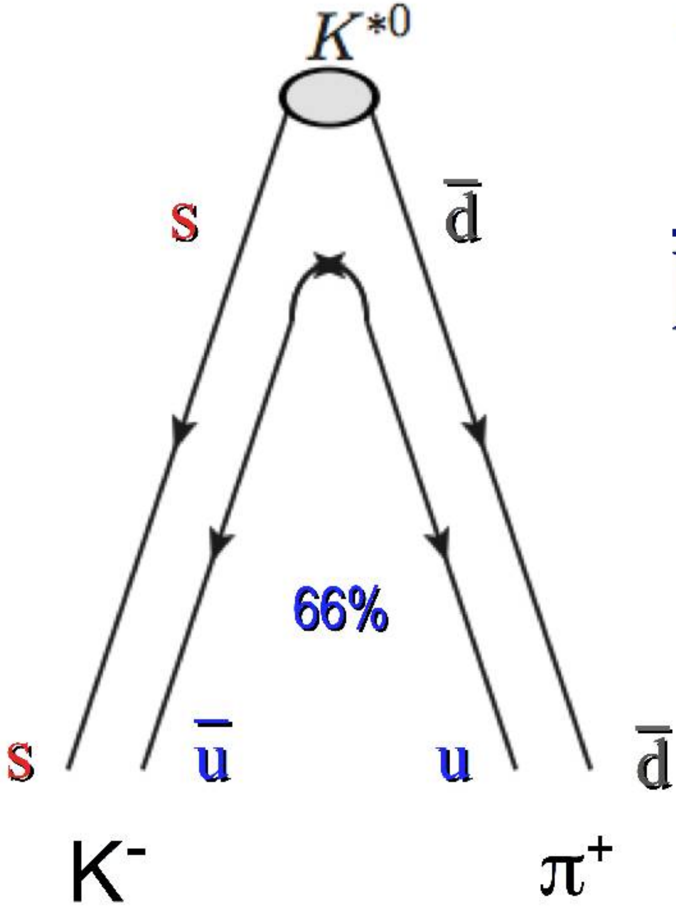
$K^{0*} \rightarrow K^+\pi^-$ channel

Can be distinguished

Note: no AGS data were published on K^{0*} / $\overline{K}^{0*}$

$K^{0*} \rightarrow \overline{K}^{0*}$ oscillation: CONSEQUENCE II

Assume sub-threshold $\overline{K}^*$ production: $N(\overline{K}^*) << N(K^*)$



$\rightarrow$ more $\overline{K}^{0*}$ than expected

$\overline{K}^{0*} \rightarrow K^- \pi^+$ gives excessive K^-

K^-/K^+ or K^-/π anomaly may appear in exp. Data.

SUMMARY Ia

1) $K^0 \rightarrow \overline{K}^0$ in A+A , p+A collisions is negligible

suppression factor ≤ 10^{-26}

2) $K^{0*} \rightarrow \overline{K}^{0*}$ oscillation can be significant + fast enough

→ it may affect $\overline{K}$ yields and ratios

(just in case of sub-threshold anti-K^* production)

3) Production of (2ss) hyperons may thus be enhanced

via secondary strangeness-exchange reactions.

$$\Lambda^0 + \overline{K}^{0*} \rightarrow \Xi^- + \pi^+$$

D^o-$\bar{D}^o$ oscillation in Vacuum

PHYSICAL REVIEW LETTERS

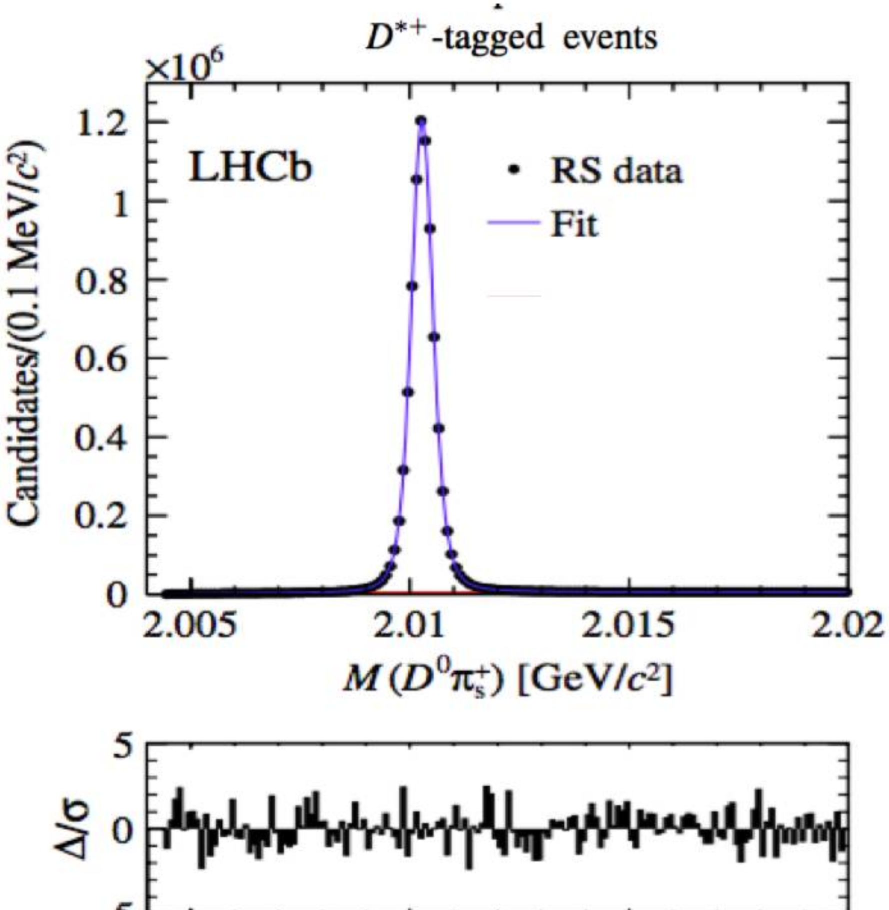
Observation of $D^0 - \bar{D}^0$ Oscillations

(LHCb Collaboration)
(Received 6 November 2012; published 5 March 2013)

$$c\tau_{osc} = 2\pi\hbar c/\Delta m$$

D^0, $\bar{D}^0$ decay too fast, for typical oscillation pattern in vacuum to be clearly visible. Instead, LHCb measures rising Ratio of "WS/RS" decays.

probability corresponding to 9.1 standard deviations



PRL **110,** 101802 (2013)

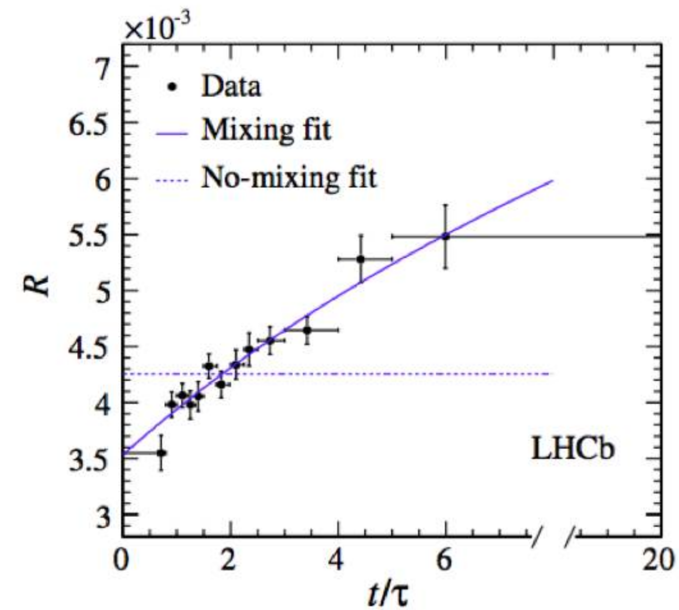


FIG. 2 (color online). Decay-time evolution of the ratio, R, of WS $D^0 \to K^+\pi^-$ to RS $D^0 \to K^-\pi^+$ yields (points) with the projection of the mixing allowed (solid line) and no-mixing

D^{0*}(2007) and D^0 behavior in Medium

Table 1: Oscillation parameters of neutral K^0, D^0, B^0, and B_s^0 mesons in vacuum.

	K^0	D^0	B^0	B_s^0
Δm [MeV]	3.5×10^{-12}	$\approx 6.3\times10^{-12}$	3.3×10^{-10}	11.7×10^{-9}
$\Delta m\ [\frac{10^{10}\hbar}{s}]$	0.529 ± 0.001	0.95 ± 0.44	51.0 ± 0.3	1776 ± 2
$\tau_0\ [10^{-12}\mathrm{s}]$	89.5^*	0.401	1.52	1.51
$\tau_{osc}\ [10^{-12}\mathrm{s}]$	1187	≈ 660	12.3	0.35
τ_{osc}/τ_0	13.1^*	≈ 1650	8.2	0.23
$c\cdot\tau_0$	2.7^*cm	0.123 mm	0.45 mm	0.45 mm
$c\cdot\tau_{osc}$	35 cm	≈ 20 cm	3.7 mm	0.11 mm

D^0, $\overline{D}^0$ decays too fast, for typical oscillation pattern in vacuum to be clearly visible. **Eigenstate D^0_1 or D^0_2 exists virtually, but it has no time to be formed.**

$$c\tau_{osc} = 2\pi\hbar c/\Delta m$$ **= 30 fm** } **in Nuclei**

$\hbar c$: 197 MeVfm

Δm: **40MeV**

optical potential difference $\overline{D}^0$ - D^0

Oscillation of D^0(1865) in Medium

- 20 MeV

$$\mathbb{M}_{D^0} = \begin{bmatrix} 1865 + V_{D^0}(\rho_B) & e^{i\xi_M}\, 3.1 \cdot 10^{-12} \\ e^{-i\xi_M}\, 3.1 \cdot 10^{-12} & 1865 - \bar{V}_{\bar{D}^0}(\rho_B) \end{bmatrix}$$

assuming M_{12} and Γ_{12} are not changed in hadronic medium

$$\mathbb{G}_{D^0} = \begin{pmatrix} 1.58 \cdot 10^{-9} + \gamma_{D^0}(\rho_B) & e^{i\xi_G}\, 1.04 \cdot 10^{-11} \\ e^{-i\xi_G}\, 1.04 \cdot 10^{-11} & 1.58 \cdot 10^{-9} + \bar{\gamma}_{\bar{D}^0}(\rho_B) \end{pmatrix}$$

SMALL decay constants compared to ΔV

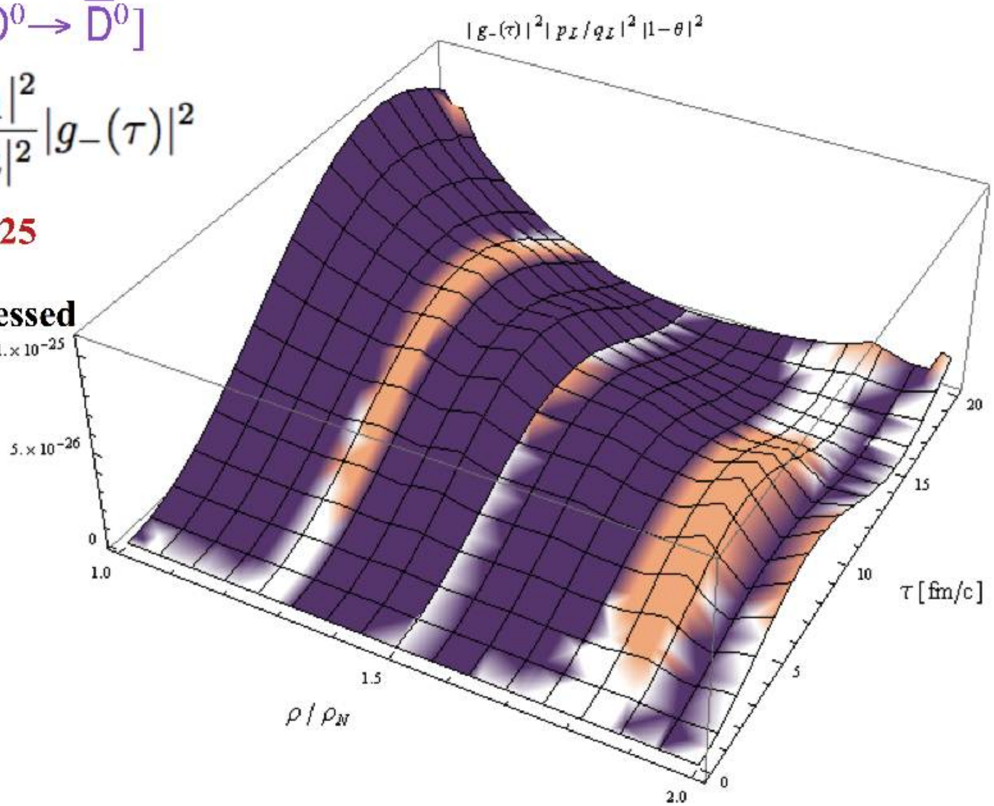
$\Delta V\ [\rho = \rho_N] \cong 40$ MeV

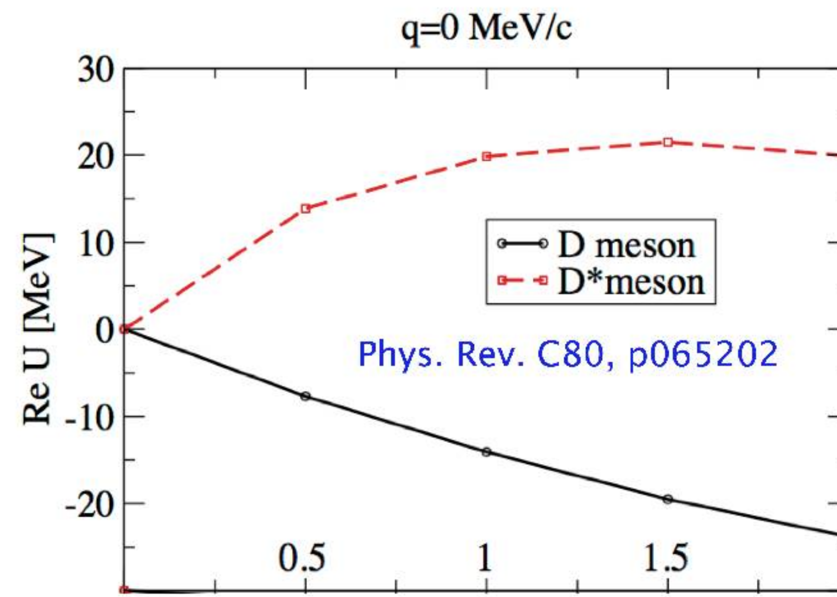
P [$D^0 \rightarrow \bar{D}^0$]

$$4\frac{|H_{21}|^2}{|\Delta\mu|^2}|g_-(\tau)|^2$$

×10^{-25}

suppressed





D and D^* optical potentials as a function of ρ/ρ_0

Oscillation of D^{0*}(2007) in Medium

40 MeV

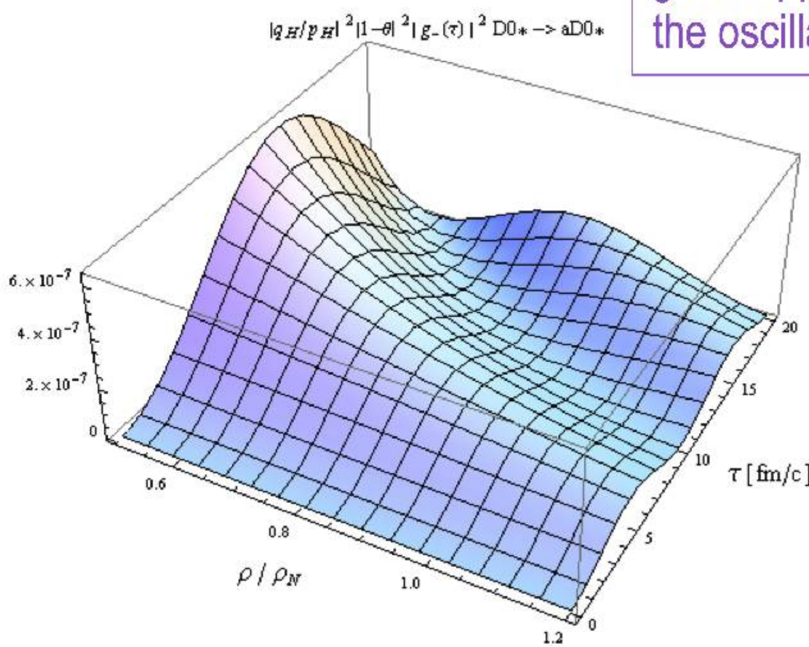
$$\mathbb{M}_{D^{0*}} = \begin{bmatrix} 2007 + V_{D^{0*}}(\rho_B) & e^{i\xi_{M^*}} 3 \cdot 10^{-12} \\ e^{-i\xi_{M^*}} 3 \cdot 10^{-12} & 2007 - \bar{V}_{\bar{D}^{0*}}(\rho_B) \end{bmatrix}$$

assuming M_{12} and Γ_{12} are not changed in hadronic medium

$$\mathbb{G}_{D^{0*}} = \begin{pmatrix} 0.04 + \gamma_{D^{0*}}(\rho_B) & 0.04 e^{i\xi_{G^*}} \\ 0.04 e^{-i\xi_{G^*}} & 0.04 + \bar{\gamma}_{\bar{D}^{0*}}(\rho_B) \end{pmatrix}$$

Γ_{21} → maximal possible value: gives upper estimate for the oscillation probability

$P [D^{0*} \to \bar{D}^{0*}]$



$\bar{D}^{0*} \to$ → D^0_1, D^0_2

$D^{0*} \to D^0 + \pi^0$ 62%

$D^{0*} \to D^0 + \gamma$ 38%

$\Gamma_{D^{*0}} \approx$ 40 keV and hence

Physics Letters B 418 (1998) 383–388

$$\Gamma_{D^{*+}} \approx 3\, \Gamma_{D^{*0}} \left| \frac{P_{\pi(D^{*+})}}{P_\pi D^*_o} \right|^3 \approx 90 \text{ keV}.$$

small
decay widths
compared to ΔV

ΔV [ρ = ρ_N] ≅ 80 MeV

TABLE II. The shifts of the masses and decay constants of the heavy mesons in nuclear matter, where NLO (LO) denotes that contributions up to the next-to-leading order (leading order) are included; the unit is MeV.

	δm_D	δm_{D^*}	δm_{D_0}	δm_{D_1}	δm_B	δm_{B^*}	δm_{B_0}	δm_{B_1}
NLO	−72	−102	80	97	−473	−687	295	522
LO	−47	−70	54	66	−329	−340	209	260
[13]	−48							
[16]	+45				+60			
[15]	−46							

PHYSICAL REVIEW C **92**, 065205 (2015)

Oscillation of D^{0*}(2007) in Medium

40 MeV

$$\mathbb{M}_{D^{0*}} = \begin{bmatrix} 2007 + V_{D^{0*}}(\rho_B) & e^{i\xi_{M^*}} 3 \cdot 10^{-12} \\ e^{-i\xi_{M^*}} 3 \cdot 10^{-12} & 2007 - \bar{V}_{\bar{D}^{0*}}(\rho_B) \end{bmatrix}$$

assuming M_{12} and Γ_{12} are not changed in hadronic medium

$$\mathbb{G}_{D^{0*}} = \begin{pmatrix} 0.04 + \gamma_{D^{0*}}(\rho_B) & 0.04 e^{i\xi_{G^*}} \\ 0.04 e^{-i\xi_{G^*}} & 0.04 + \bar{\gamma}_{\bar{D}^{0*}}(\rho_B) \end{pmatrix}$$

Γ_{21} → maximal possible value: gives upper estimate for the oscillation probability

D_1^0, D_2^0

$D^{0*} \to D^0 + \pi^0$ 62%

$D^{0*} \to D^0 + \gamma$ 38%

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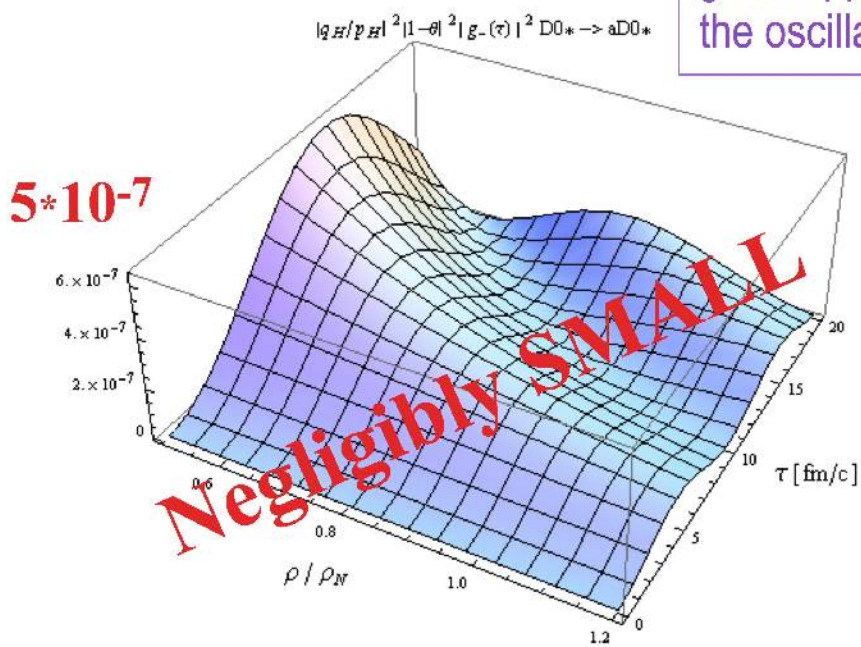
Physics Letters B 418 (1998) 383–388

$\Gamma_{D^{*+}} \approx 3\, \Gamma_{D^{*o}} \left|\frac{P_{\pi(D^{*+})}}{P_\pi D_o^*}\right|^3 \approx$ 90 keV.

small decay widths compared to ΔV

ΔV [ρ = ρ_N] ≅ 80 MeV

P [$D^{0*} \to \bar{D}^{0*}$]



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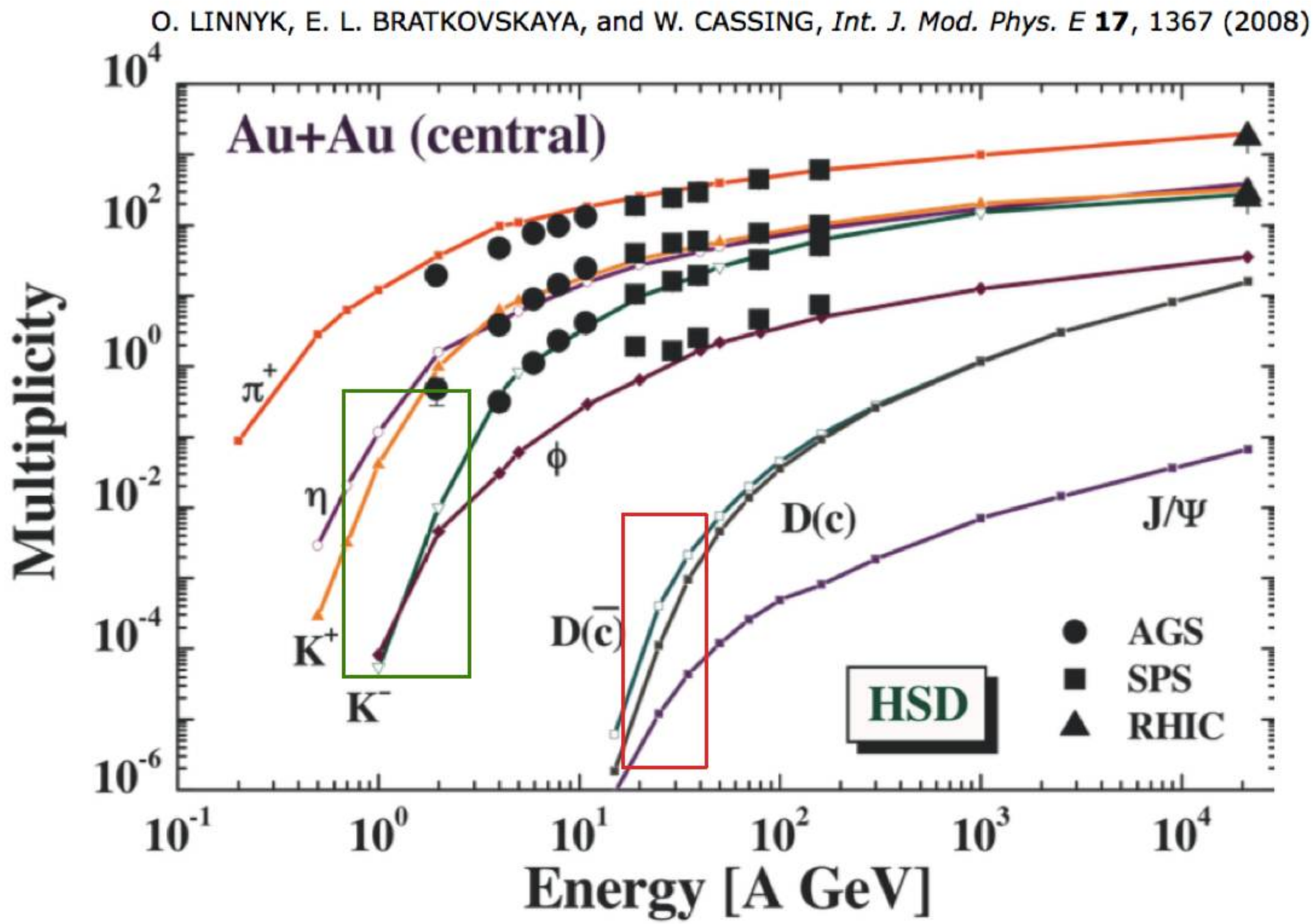
[13]	−48							
[16]	+45				+60			
[15]	−46							

PHYSICAL REVIEW C **92**, 065205 (2015)

$_{\text{(sub)}}$Threshold D, K meson Production Ratios



Charm is conserved

because $\bar{D}$ / D < 10 makes $\bar{c} \rightarrow c$ negligible

when $K^* / \bar{K}^* \geq 10^2$, process $\bar{s} \rightarrow s$ is significant

CONCLUSIONS.

1) oscillation $\overline{K}^{0*} \leftrightarrow K^{0*}$ in dense baryonic matter possible (processes $s \rightarrow \bar{s}$ and $\bar{s} \rightarrow s$ having same probability)

2) if $N(K^0, K^{0*}) >> N(\overline{K}^0, \overline{K}^{0*})$ due to s quarks taken by Λ, Σ

real or virtual $K^{0*}(\bar{s}d) \rightarrow \overline{K}^{0*}(s\bar{d})$ transitions may:

- **enhance the Yields of $\overline{K}^{0*}$ and K^- in A+A, p+A coll.**
- effectively violate strangeness conservation at high ρ_B

3) Ξ^-(dds) sub-threshold production may be explainable using strangeness exchange reaction $\Lambda + \overline{K}^{0sc} \rightarrow \Xi + \pi$

4) Charm is conserved ! Strangeness is not at high ρ_B

THANK YOU

FOR

hospitality

SQ

Berkeley 2016

ATTENTION

SUPPRESSION FACTOR ESTIMATE

$$P(K^0 \to \bar{K}^0) = \left|\frac{q_H}{p_H}\right|^2 |1-\theta|^2 |g_-(\tau)|^2$$

see G.C. Branco et al.
in book: "CP Violation"
Eq.(9.8) Eq.(6.29-32)

$$\left|\frac{q_H}{p_H}\right|^2 = \frac{4|H_{21}|^2}{|\Delta\mu|^2}\frac{1}{|1-\theta|^2}$$

K^{0*} → (16 MeV)^2

$$P(K^0 \to \bar{K}^0) = \frac{|2H_{21}|^2}{|4H_{12}H_{21} + (H_{22}-H_{11})^2|}|g_-(\tau)|^2$$

$$\approx \frac{|2H_{21}|^2}{|H_{22}-H_{11}|^2}|g_-(\tau)|^2 = \frac{4|M_{21} - i\Gamma_{21}/2|^2}{\Delta V^2}|g_-(\tau)|^2$$

→ (80 MeV)^2
$\rho = \rho_N$

for $|H_{12}H_{21}| \ll |H_{22}-H_{11}|^2 \approx \Delta V^2$