Phi production at KEK

Meson Modification in Nuclear Media
&
QCD Chiral Symmetry Restoration

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- Discussion
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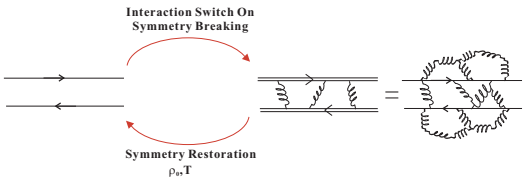
PHYSICS

Mass in QCD



Current quarks ($M_q \sim 0$) interacts with vacuum, gain an "effective mass", becomes valence quark.

As the consequence, mass of vector meson is described as

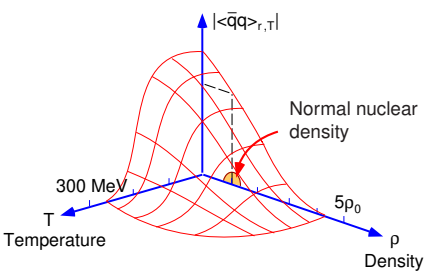
$$M_v = 2 \times M_q^{eff} + (small\, interaction\, term). \qquad (1)$$

Meson spectroscopy (in free space) can be considered as the mass spectroscopy for the valence quarks, with which it is difficult to answer "what is the origin of the mass".

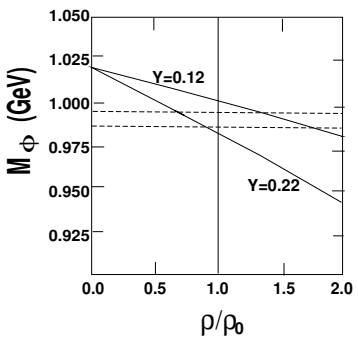
What happens if we changed the vacuum status ?

PHYSICS

Chiral Symmetry Restoration in Nuclear Media



Order parameter $< \bar{q}q >$ is supposed to change in $T \neq 0$ or $\rho \neq 0$ system.



Hatsuda & Lee's prediction. Mass shift and/or change in the decay ratios are expected.
→ Mass of vector mesons as a probe of $< \bar{q}q >$.

Hurdles

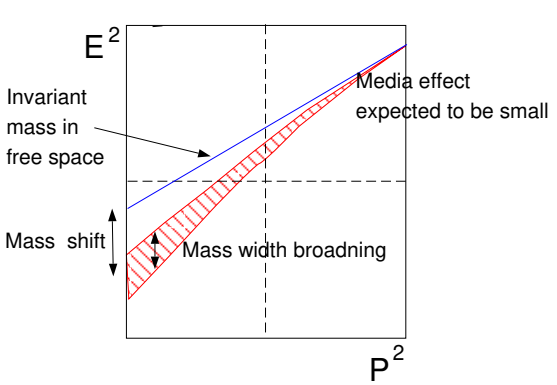
Many Unknown

$< \bar{q}q >$

Temperature	dependence of $< \bar{q}q >$
Temperature	time evolution → $(CERN/RHIC/LHC)$
Density	dependence of $< \bar{q}q >$
Density	time evolution → (BNL/JHF)

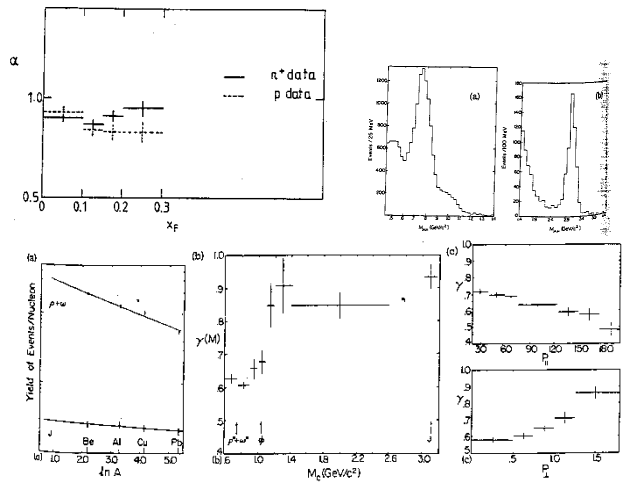
Invariant mass spectroscopy

In-media dispersion of meson mass
In-media mass broadening/narrowing
→ (Observed mass is not invariant in media)



A lot of inputs from experiments needed, even at the normal nuclear density.

ϕ Productions Mechanism at 12 GeV



- Is the ϕ produced perturbatively or non-perturbatively ?
- Do the nucleon $s\bar{s}$ contents contribute to the ϕ production ?

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Present and Future Experiments

CLUES

Experiment	Measurements	Interests
CERES/HELIOS-3	ρ modification	Temperature dep.
KEK-TANASHI ES	ρ modification	Density dep.

The efforts to be continued at RHIC and LHC (temperature dependence)

Present & future experiments to measure the mass of vector mesons at normal nuclear matter density.

1. KEK(Tanashi)-ES: $\gamma + A \rightarrow \rho + A^*$ $(\rho \rightarrow \pi^+\pi^-)$ (Published, Analyzing)
2. KEK-PS: $p + A \rightarrow \phi + A^*$ $(\phi \rightarrow K^+K^-/e^+e^-)$ (Running)
3. SPring-8: $\gamma + A \rightarrow \phi + A^*$ $(\phi \rightarrow K^+K^-)$ (Preparation, 2000)
4. GSI: $d + A \rightarrow {}^3He + A^*$ to find a bound η and ω states (Approved, 1999)
5. GSI-HADES: $\pi + A \rightarrow \omega + A^*$ $(\omega \rightarrow e^+e^-)$ (Preparation, 2000 ?)

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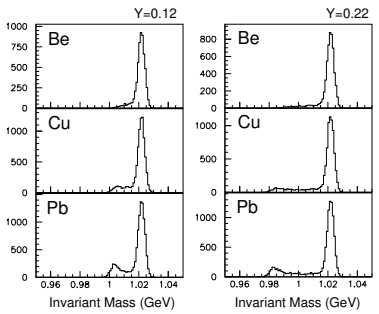
E325 PHYSICS

Expected Signal



- KEK-PS E325 to measure ϕ decays inside a nucleus
  - In $12GeV p + A(C/CH_2/Cu/Pb) \rightarrow \phi + X$
  - Observables
    - Invariant mass spectrum; $\phi \rightarrow K^+K^-/\phi \rightarrow e^+e^-$
    - Branching ratio; $Br(\phi \rightarrow K^+K^-)/Br(\phi \rightarrow e^+e^-)$
  - Focus on slowly moving ϕ's($1GeV/c_{lab}$)
  - 10^9/sec primary protons on thin (0.1%) nuclear target to suppress γ conversions.
- So:
  - Less ambiguous data on the ϕ modification
  - Also Sensitive to the production and interaction of ϕ in nucleus

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Some Tips of E325

- Expected mass shift is $20 \sim 40MeV$ (Hatsuda-Lee).
- About 10% ϕ's will decay inside a nucleus.
- Secondary peak may enhance when low β ϕ's are selected. gives the dispersion relation.
- If the ratio
$$\frac{\phi \rightarrow K^+K^-}{\phi \rightarrow e^+e^-}$$
increase with A → media modification of ϕ and/or K
decrease with A → nuclear rescattering of K
- natural width of ϕ is narrow (4.4MeV), but some broadening can happen.
Crude estimations (the worst case) exist;
  - $\Gamma_\phi = \sigma_{\phi N} \times \beta_\phi \times \rho_0$
    - $\sigma_{\phi N}$ <10mb, total cross section (elastic included from $\gamma + A \rightarrow \phi$)
    - $\beta_\phi = 0.7$, $\rho_0 = 0.16/fm^3$

    $< 20MeV$
  - $\phi \rightarrow K^{+*}K^{-*}(K^-N \rightarrow \Sigma X)$

    $< 30MeV$

Brief Mile Stones and Status

- PreHistory
  - 1994 March KEK-PS PAC conditionally approved
  - 1995 March KEK-PS PAC approved
  - 1996 July- Construction started
  - 1996 November Engineering Run
- 1997 June, First Physics Run with K^+K^-. 17days
  - Data accumulation mainly with K^+K^- channel trigger
  - Beam Intensity $1 \sim 2 \times 10^8$ protons/spill
  - 0.6% interaction target (10^6 interaction/spill)
  - $C/CH_2/Pb$ 3 targets in-line
  - 165GByte Data (160M events) collected in 50 shifts
- 1998 March, Completion of Spectrometer,
- 1998 April -May: Production Running of 85 shifts (29 days)
  - Parallel Trigger (K^+K^- / e^+e^-)
  - Beam Intensity $1 \sim 2 \times 10^9$ protons/spill
  - 0.1% interaction target (10^6 interaction/spill)
  - $C/CH_2/Cu$ 3 targets inline
  - 502GByte Data (180M events) collected in 85 shifts
- 1999 June 60 shifts Data Taking performed
  - Parallel Trigger (K^+K^- / e^+e^-)
  - Beam Intensity 1×10^9 protons/spill
  - 0.2% interaction target (10^6 interaction/spill)
  - $C/CH_2/Cu$ 3 targets inline
  - 360GByte Data (180M events) collected in 85 shifts
- 2000 Jan 80-100 shifts Data Taking Expected

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E325 collaboration

note: students presently working hard and students used to be working hard & left

- Kyoto-Univ
  H.Enyo, H.Funahashi, T.Haseyama, M.Ishino, H.Kanda, M.Kitaguchi, S.Mihara, M.Miyabe, T.Miyashita, K.Miyazaki, T.Murakami, R.Muto, M.Naruki, K.Ozawa, H.D. Sato, T.Tabaru, S.Yamada, S.Yokkaichi, Y.Yoshimura
- CNS,Univ.of Tokyo
  H.Hamagaki
- KEK
  J.Chiba, M.Ieiri, O.Sasaki, M.Sekimoto, K.Tanaka
- RCNP
  M.Nomachi
- T.I.T.
  K.Hamada, Y.Sakemi, T.A.Shibata
- Tsukuba-Univ.
  K.Yagi

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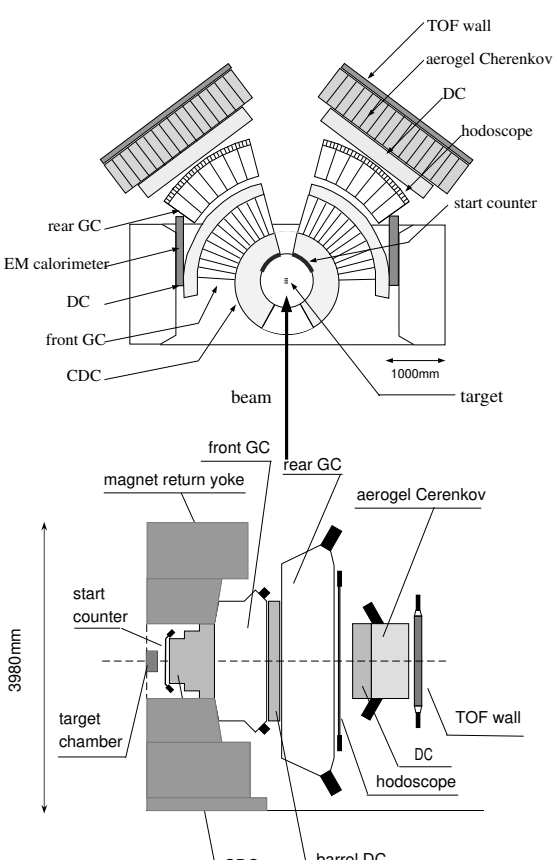
E325 SETUP



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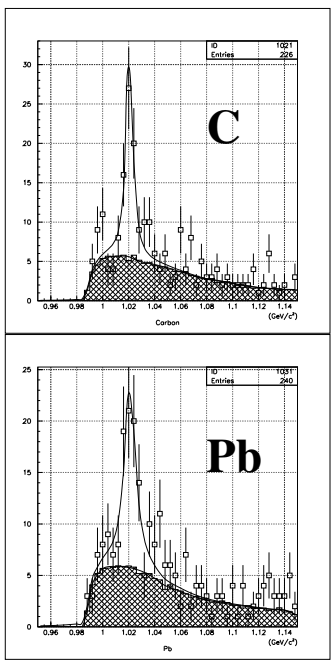
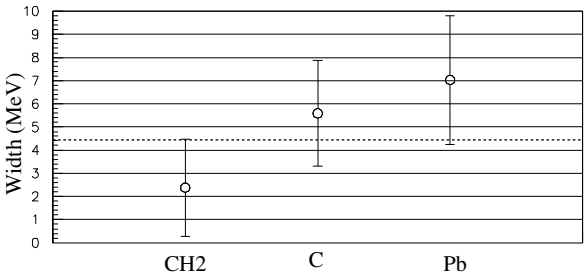
K^+K^- invariant mass spectrum



- Two kaons are in the same arm.
- TOF consistency in the Hodoscope and the TOF counters.
- Mixed event background is overplotted (shaded area).

Mass and Width of Observed $\phi \to K^+K^-$



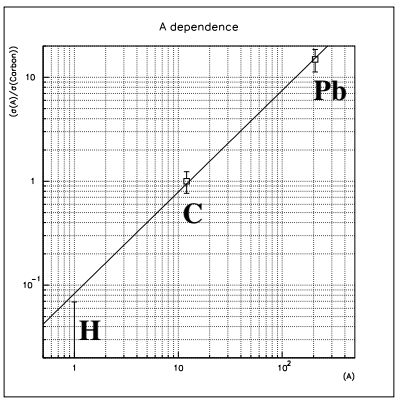
- Within the statistics so far analyzed, the mass and the width are consistent with the free decay parameters
- Further data acumulation and analysis are under way

Summary and Outlook

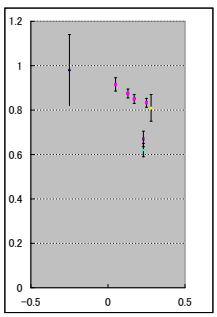
- The experiment, E325, at KEK 12GeV PS measures 12 GeV $p+A \to \phi + X$ reactions in both $\phi \to K^+K^-$ and $\phi \to e^+e^-$ channels. Especially we put an emphasis on the detection of slowly moving ϕ mesons ($\sim$ 1-2GeV/c in lab., thus decay in Nuclear Media).
- To observe a possible change of the ratio, $Br(\phi \to K^+K^-)/Br(\phi \to e^+e^-)$, and of the shape of the mass peak are to be compared under the normal nuclear density ($\rho = \rho_0$ and $T = 0$).
- The data $\phi \to K^+K^-$ have been analyzed so (1/5 of the data already collected, 1/10 of data to be acquired). The results shows
  - No statistical significance on the mass shape deformation (YET)
    - deformation can be attributed to mass shift and/or K scattering
    - comparison to the electron pair channel is indispensable
  - Strong A dependence ($\alpha = 0.97 \pm 0.17$ in the production)
    - consistent with the high energy date ($E_{inc} > 100GeV$) where the ϕ is produced somewhat perturbatively.
    - Surprising that similar production mechanism even at 12GeV
- Further data analysis and data taking still going on

- Some hints already exist for the mass modification of vector mesons.
- Many experimental results including this experiment will be available in year 2000 and later.

Target Mass Dependence of $\phi \to K^+K^-$



- $17\mu b \times A^{\alpha}$ ($\alpha = 0.98 + -0.17$) Absolute cross section is not well determined yet.
- α is surprisingly large
- multiple production of ϕ does not contribute in this energy
- May suggest the partarvative production of ϕ even at 12 GeV



The α parameters as a function of x_F