Charm physics

DN interactions in nuclear matter

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I. Vidaña, A. Ramos

T. Mizutani, A. Ramos, hep-ph/0607257

J.Hofmann and M.F.M.Lutz, Nucl. Phys. A763, 90 (2005)

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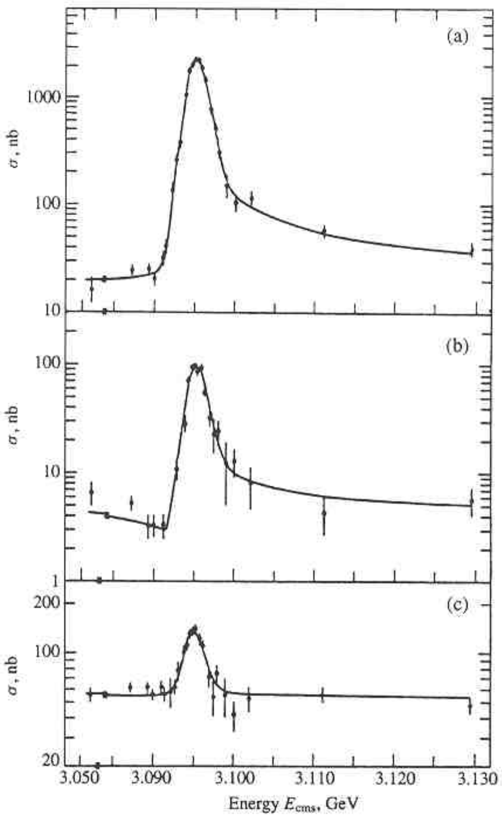
V. Panda experiment at GSI (if I have time)

Charmonium discovery

$J/\Psi: \; c\,\bar{c}$ $\qquad M(J/\Psi) \sim 3097 \text{ MeV}$

1976 Nobel prize in physics

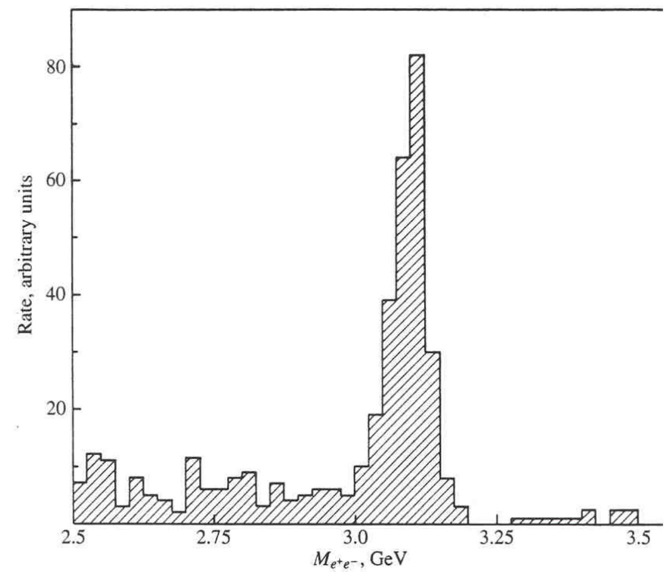


e^+e^- annihilation

October, 1974
Simultaneous discovery:

- Ting et al. at BNL AGS →
- Richter et al. at SLAC SPEAR ←

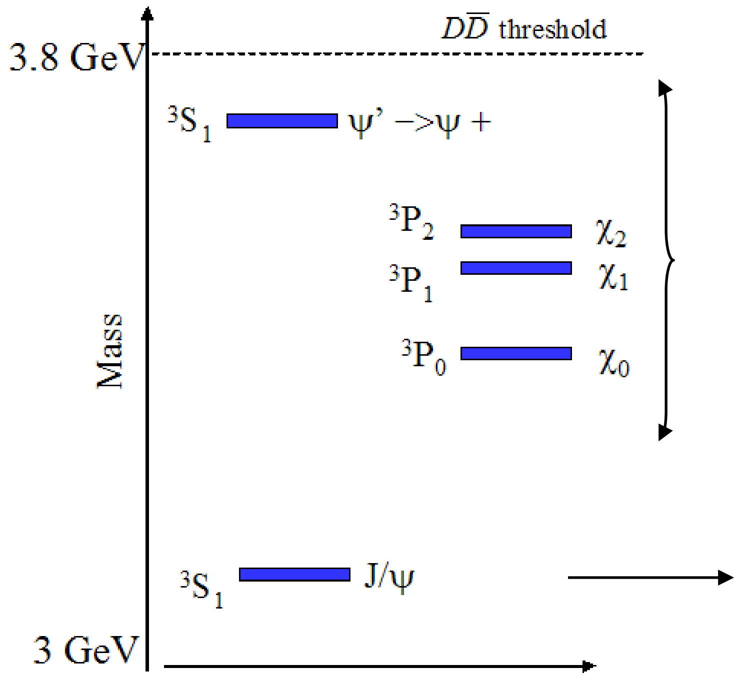
In both experiments a peak was found at 3.1 GeV

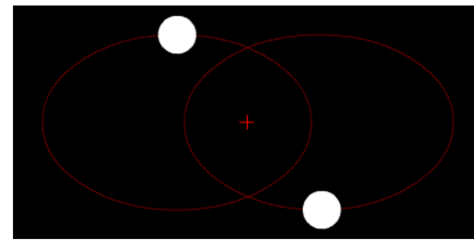


$p + Be \rightarrow e^+e^- + X$ at AGS

Very narrow peaks -> very long lifetimes (10^{-20}s): thousand of times longer than expected!

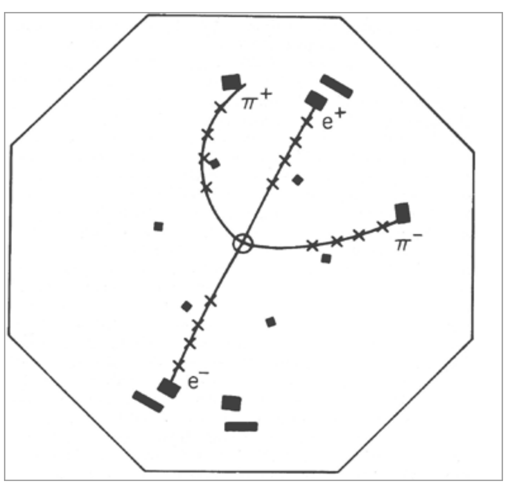
New kind of property → forth type of quark!





photons
pions
electrons
muons

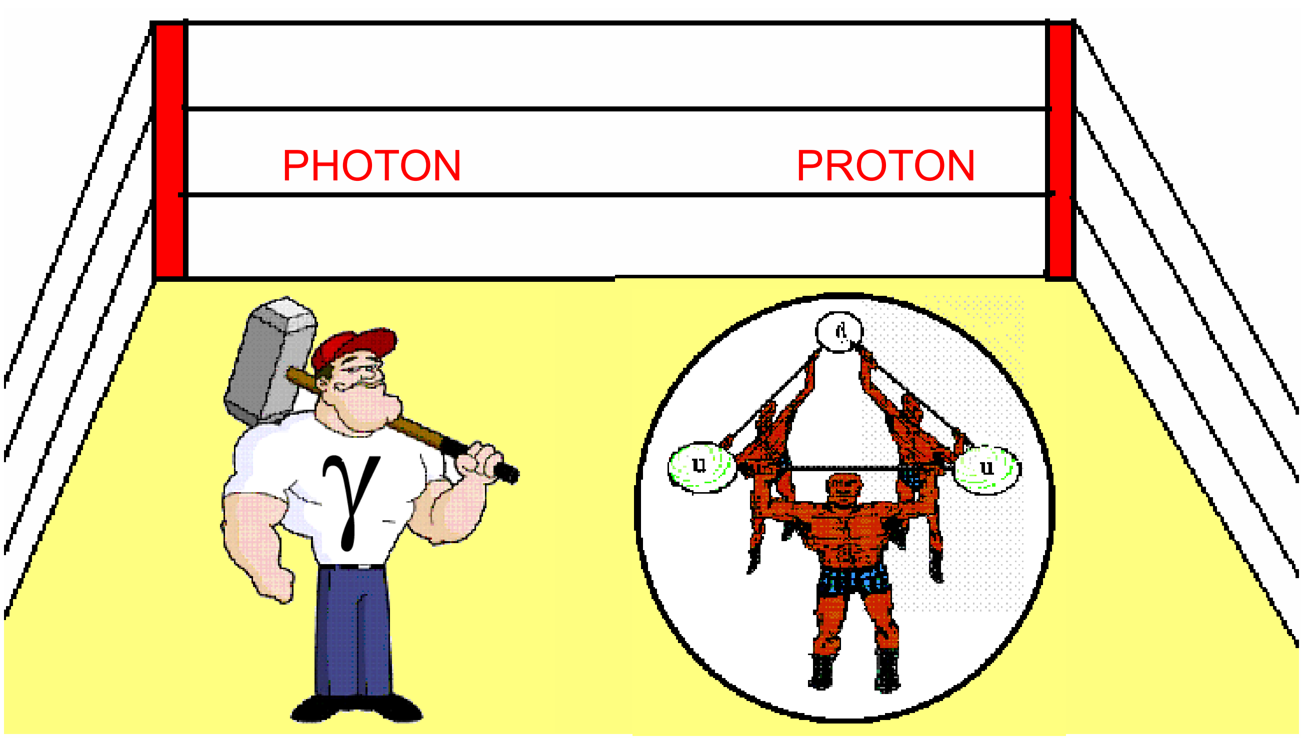
Decay of J/psi lowest level in lighter particles
-> 90% decay to lighter quark particles (pions, kaons)
-> Rarely decays to an electron and a positron (or muon and antimuon)



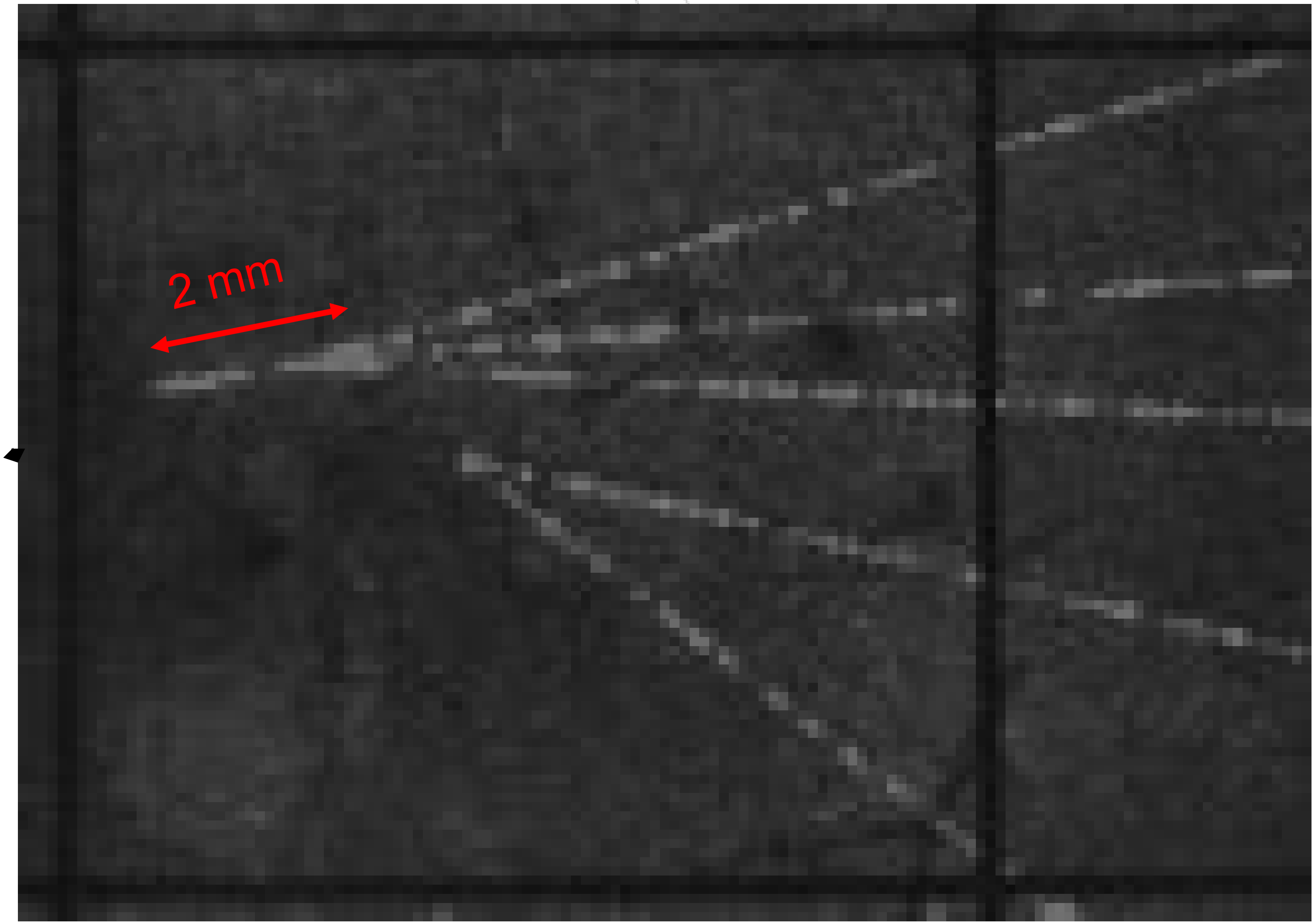
Example of decay
$\Psi' \rightarrow J/\psi + \pi^+ + \pi^-$
Followed by $J/\psi \rightarrow e^+e^-$

Creation of charmed particles

Charm quarks combine with lighter quarks (u, d, s) to form either barions or mesons



Production of charmed particles in the bubble chamber (SLAC) in 1980



… production of charm particles at present

Can be produced in pairs (D^+,D^-)

• in heavy ion experiments:

$$NN \longrightarrow NND^+D^- \quad E_{\mathrm{th}} = 2.8 \text{ GeV}$$

• or antiproton anhilation experiments (PANDA at FAIR) on protons and nuclei:

$$\bar{p}N \longrightarrow D\bar{D} \quad E_{\mathrm{th}} = 6.5 \text{ GeV}$$

Motivation

D and Dbar in the medium

Why is important to understand the interaction of charmed mesons in a hadronic medium?

If the mass of the D (and Dbar) mesons gets reduced appreciably in the medium (cold or hot), this would provide a conventional hadronic physics explanation to explain J/Ψ supression (attributed to be a signal for the formation of a Quark-Gluon Plasma)

$$J/\Psi \; N \longrightarrow D \; \bar{D} \; N \qquad\qquad J/\Psi \; \pi \longrightarrow D \; \bar{D}$$

Hints that a D Dbar meson-pair could feel attraction:
an open charm enhancement has been observed in nucleus-nucleus collisions by the NA50 Collaboration

$$N \; N \rightarrow N \; N \; D \; \bar{D}$$

Why do we believe in the "couple channel approach" model that we use?

- Other methods like QCDSR and NMFA become innapropiate when the 2-body interaction:
  →Strong
  →dominated by intermediate bound states or resonances and/or
  →strongly coupled to other channels

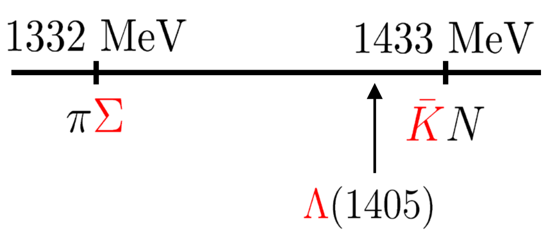
- KN and DN are "similar" systems:
  →Apparent similarity in their coupled channel nature
  by their association with the Lambda resonances:
  → Presence of the $\Lambda_c(2593)$ (udc)
  (plays a similar role as the $\Lambda(1405)$ (uds) in KN dynamics)

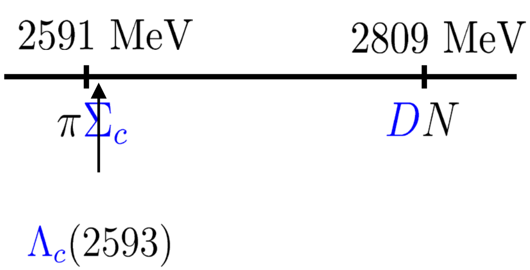
D and Dbar mesons:

$$D^+ : c\,\bar{d} \qquad \bar{D}^0 : \bar{c}\,u$$
$$D^0 : c\,\bar{u} \qquad D^- : \bar{c}\,d$$
$$M(D) \sim 1870 \text{ MeV}$$

Similar to Kbar K:

$$\bar{K}^0 : s\,\bar{d} \qquad K^+ : \bar{s}\,u$$
$$K^- : s\,\bar{u} \qquad K^0 : \bar{s}\,d$$
$$M(K) \sim 495 \text{ MeV}$$





D mesons in symmetric nuclear matter: DN couple-channel equations approach

- First step: (1)

-> Solving Bethe-Salpeter equation in free space

- Second step: (2)

-> Solving Bethe-Salpeter equation in nuclear medium.

$$\left.\begin{aligned} &(1) & T &= V + V\ G\ T \\ &(2) & \tilde{T}(\rho) &= V + V\,\tilde{G}(\rho)\,\tilde{T}(\rho) \end{aligned}\right\} \quad \tilde{T}(\rho) = T + T\,(\tilde{G}(\rho) - G)\,\tilde{T}(\rho)$$

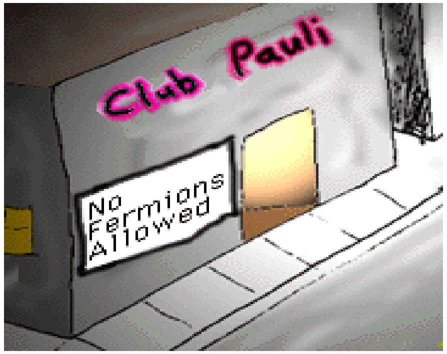
-> **T** is the transition operator matrix.
-> The propagator **G**, diagonal matrix in which every element is the product of single-particle propagator for a meson and a barion.
-> The potential **V**, whose elements are Weinberg-Tomozawa type meson-baryon interactions.

In-medium effects

In medium effects are contained in the propagator $\tilde{G}(\rho)$

Medium: isosymmetric nuclear matter (nucleons, Np=Nn)

- Pauli blocking on intermediate nucleons:
consequence of Pauli principle, prevents the scattering to intermediate nucleon states below Fermi momentum, pf.



- Dressing of mesons and baryons:
Non perturbative strong interaction at low energies -> particles of intermediate loops interact through strong force with the nucleons of the Fermi sea, and their properties are modified with respect to those in free space.

Self-consistent coupled channels method:

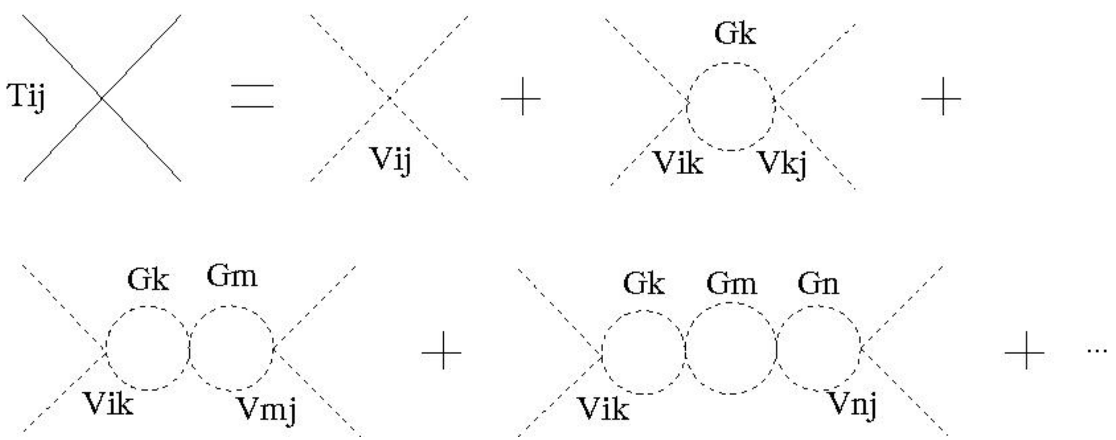
Bethe-Salpeter equation

$$T_{ij} = V_{ij} + V_{ik} G_k T_{kj}$$

$$T_{ij} = V_{ij} + V_{ik} G_k (V_{kj} + V_{km} G_m T_{mj})$$

$$T_{ij} = V_{ij} + V_{ik} G_k V_{kj} + V_{ik} G_k V_{km} G_m (V_{mj} + V_{\mathrm{ln}} G_n T_{nj})$$

$$T_{ij} = V_{ij} + V_{ik} G_k V_{kj} + V_{ik} G_k V_{km} G_m V_{mj} + V_{ik} G_k V_{km} G_m V_{\mathrm{ln}} G_n T_{nj}$$



$T = V + V \cdot GT \longrightarrow T = (I - V \cdot G)^{-1} \cdot V$ → V? / G?

The sectors of our interest: In S-wave and $J^P=(1/2)^-$, two different channels

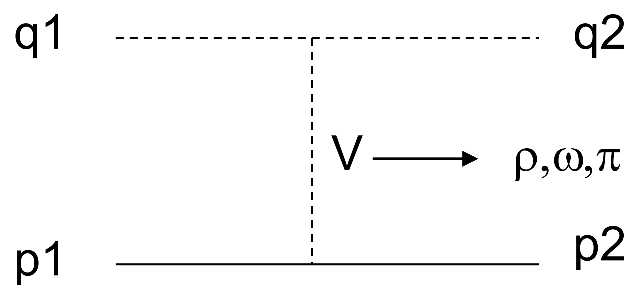
First channel with seven states:

$$(C=1, I=0, S=0): \pi\Sigma_c(2589), DN(2810), \eta\Lambda_c(2835),$$
$$K\Xi_c(2960), K\Xi_c^{'}(3071), D_s\Lambda(3085), \eta'\Lambda_c(3245)$$

Second channel with eight states:

$$(C=1, I=1, S=0): \pi\Lambda_c(2425), \pi\Sigma_c(2589), DN(2810), K\Xi_c(2960),$$
$$\eta\Sigma_c(3005), K\Xi_c^{'}(3071), D_s\Sigma(3160), \eta'\Sigma_c(3415)$$

$$\mathcal{L}_{\text{int}}^{\text{SU}(3)} = \frac{i}{4} h^{9}_{\bar{3}\bar{3}}\, \text{tr}\big((\partial_\mu \Phi_{[\bar{3}]})\Phi^{\dagger}_{[\bar{3}]} V^{\mu}_{[9]} - \Phi_{[\bar{3}]}\big(\partial_\mu \Phi^{\dagger}_{[\bar{3}]}\big) V^{\mu}_{[9]}\big)$$
$$+ \frac{i}{4} h^{1}_{\bar{3}\bar{3}}\, \text{tr}\big((\partial_\mu \Phi_{[\bar{3}]})\Phi^{\dagger}_{[\bar{3}]} - \Phi_{[\bar{3}]}\big(\partial_\mu \Phi^{\dagger}_{[\bar{3}]}\big)\big) \cdot \text{tr}\big(V^{\mu}_{[9]}\big)$$
$$+ \frac{i}{4} h^{9}_{99}\, \text{tr}\big((\partial_\mu \Phi_{[9]})\Phi_{[9]} V^{\mu}_{[9]} - \Phi_{[9]}(\partial_\mu \Phi_{[9]}) V^{\mu}_{[9]}\big).$$



Light vector meson exchange

$$\mathcal{L}_{\text{int}}^{\text{SU}(3)} = \frac{1}{2} g^{9}_{33}\, \text{tr}\big(\bar{B}_{[3]}\gamma_\mu B_{[3]} V^{\mu}_{[9]}\big) + \frac{1}{2} g^{1}_{33}\, \text{tr}\big(\bar{B}_{[3]}\gamma_\mu B_{[3]}\big)\, \text{tr}\big(V^{\mu}_{[9]}\big)$$
$$+ \frac{1}{2} g^{9}_{\bar{3}\bar{3}}\, \text{tr}\big(\bar{B}_{[\bar{3}]}\gamma_\mu V^{\mu}_{[9]} B_{[\bar{3}]}\big) + \frac{1}{2} g^{1}_{\bar{3}\bar{3}}\, \text{tr}\big(\bar{B}_{[\bar{3}]}\gamma_\mu B_{[\bar{3}]}\big)\, \text{tr}\big(V^{\mu}_{[9]}\big)$$

$$+ \frac{1}{2} g^{9}_{66}\, \text{tr}\big(\bar{B}_{[6]}\gamma_\mu V^{\mu}_{[9]} B_{[6]}\big) + \frac{1}{2} g^{1}_{66}\, \text{tr}\big(\bar{B}_{[6]}\gamma_\mu B_{[6]}\big)\, \text{tr}\big(V^{\mu}_{[9]}\big)$$
$$+ \frac{1}{2} g^{9-}_{88}\, \text{tr}\big(\bar{B}_{[8]}\gamma_\mu \big[V^{\mu}_{[9]}, B_{[8]}\big]_{-}\big) + \frac{1}{2} g^{9+}_{88}\, \text{tr}\big(\bar{B}_{[8]}\gamma_\mu \big[V^{\mu}_{[9]}, B_{[8]}\big]_{+}\big)$$
$$+ \frac{1}{2} g^{1}_{88}\, \text{tr}(\bar{B}_{[8]}\gamma_\mu B_{[8]})\, \text{tr}\big(V^{\mu}_{[9]}\big)$$
$$+ \frac{1}{2} g^{9}_{\bar{3}6}\, \text{tr}\big(\bar{B}_{[\bar{3}]}\gamma_\mu V^{\mu}_{[9]} B_{[6]} + \bar{B}_{[6]}\gamma_\mu V^{\mu}_{[9]} B_{[\bar{3}]}\big).$$

$$\begin{aligned}
&\Phi_{[9]} = \tau \cdot \pi(139) + \alpha^{\dagger} \cdot K(494) + K^{\dagger}(494) \cdot \alpha + \eta(547)\lambda_8 + \sqrt{\frac{2}{3}}\mathbf{1}\eta'(958), \\
&\Phi_{[\bar{3}]} = \frac{1}{\sqrt{2}}\alpha^{\dagger} \cdot D(1867) - \frac{1}{\sqrt{2}}D^{t}(1867) \cdot \alpha + i\,\tau_2 D^{(s)}(1969), \\
&\Phi_{[1]} = \eta_c(2980), \\
&\quad \tau = (\lambda_1, \lambda_2, \lambda_3), \qquad \alpha^{\dagger} = \frac{1}{\sqrt{2}}(\lambda_4 + i\lambda_5, \lambda_6 + i\lambda_7).
\end{aligned}$$

Pseudoscalar meson fields

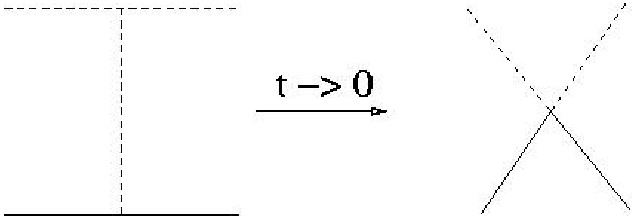
$$\begin{aligned}
V_{\mu}^{[9]} &= \tau \cdot \rho_{\mu}(770) + \alpha^{\dagger} \cdot K_{\mu}(894) + K_{\mu}^{\dagger}(894) \cdot \alpha \\
&\quad + \left(\frac{2}{3} + \frac{1}{\sqrt{3}}\lambda_8\right)\omega_{\mu}(783) + \left(\frac{\sqrt{2}}{3} - \sqrt{\frac{2}{3}}\lambda_8\right)\phi_{\mu}(1020).
\end{aligned}$$

vector meson fields

$$\begin{aligned}
&\sqrt{2}B_{[8]} = \tau \cdot \Sigma(1193) + \alpha^{\dagger} \cdot N(939) + \Xi^{t}(1318) \cdot \alpha + \Lambda(1116)\lambda_8, \\
&\sqrt{2}B_{[6]} = \frac{1}{\sqrt{2}}\alpha^{\dagger} \cdot \Xi_c(2576) + \frac{1}{\sqrt{2}}\Xi_c^{t}(2576) \cdot \alpha + \Sigma_c(2452) \cdot (i\,\tau\,\tau_2) \\
&\qquad + \frac{\sqrt{2}}{3}\left(1 - \sqrt{3}\lambda_8\right)\Omega_c(2698), \\
&\sqrt{2}B_{[\bar{3}]} = \frac{1}{\sqrt{2}}\alpha^{\dagger} \cdot \Xi_c(2469) - \frac{1}{\sqrt{2}}\Xi_c^{t}(2469) \cdot \alpha + i\,\tau_2 \Lambda_c(2285), \\
&\sqrt{2}B_{[3]} = \frac{1}{\sqrt{2}}\alpha^{\dagger} \cdot \Xi_{cc}(3440) - \frac{1}{\sqrt{2}}\Xi_{cc}^{t}(3440) \cdot \alpha + i\,\tau_2 \Omega_{cc}(3560).
\end{aligned}$$

barion fields

t-channel exchange of vector mesons:



$$V_{ij}(q_i, q_j; \sqrt{s}) = \sum_{V \in [16]} g^2 C_{ij}^V \bar{u}(\vec{p}_i)\gamma^\mu \left[g_{\mu\nu} - \cancel{\frac{k_\mu k_\nu}{m_V{}^2}} \right] \frac{1}{\cancel{t} - m_V{}^2} (q_i + q_j)^\nu u(\vec{p}_j),$$

universal vector coupling constant

- chiral symmetry in the light sector imposed → $g^2 = \frac{m_V^{\text{light}}}{2f^2}$

$$m_V \sim 1 \text{ GeV} \sim m_\rho, m_\omega, m_{K^*} \quad \text{in non-charm exchange transitions } (DN \to DN,\ D_s Y)$$

$$m_V \sim 2 \text{ GeV} \sim m_{D^*}, m_{D_s^*} \quad \text{in charm exchange transitions } (DN \to \pi\Sigma_c,\ K\Xi_c)$$

-> With these approximations and projecting in s-wave:

$$V_{ij}^I(\sqrt{s}) = -\frac{\kappa C_{ij}}{4f^2}(2\sqrt{s} - M_i - M_j)\left(\frac{M_i + E_i}{2M_i}\right)^{1/2} \times \left(\frac{M_j + E_j}{2M_j}\right)^{1/2}.$$

$$\begin{aligned} \kappa &= 1 \text{ (non-charm exchange)} \\ &= 1/4 \text{ (charm exchange)} \end{aligned}$$

→ W.T interaction

Coefficients C=0, S=0

I=0

	$\pi\Sigma_c$	DN	$\eta\Lambda_c$	$K\Xi_c$	$K\Xi'_c$	$D_s\Lambda$	$\eta'\Lambda_c$
$\pi\Sigma_c$	4	$\sqrt{\frac{3}{2}}\,\kappa$	0	0	$\sqrt{3}$	0	0
DN		3	$-\frac{1}{\sqrt{2}}\,\kappa$	0	0	$-\sqrt{3}$	$-\frac{1}{\sqrt{3}}\,\kappa$
$\eta\Lambda_c$			0	$-\sqrt{3}$	0	$-\sqrt{\frac{2}{3}}\,\kappa$	0
$K\Xi_c$				2	0	$-\frac{1}{\sqrt{2}}\,\kappa$	0
$K\Xi'_c$					2	$-\sqrt{\frac{3}{2}}\,\kappa$	0
$D_s\Lambda$						1	$-1\,\kappa$
$\eta'\Lambda_c$							0

I=1

	$\pi\Lambda_c$	$\pi\Sigma_c$	DN	$K\Xi_c$	$\eta\Sigma_c$	$K\Xi'_c$	$D_s\Sigma$	$\eta'\Sigma_c$
$\pi\Lambda_c$	0	0	$\sqrt{\frac{3}{2}}\,\kappa$	1	0	0	0	0
$\pi\Sigma_c$		2	$1\,\kappa$	0	0	$\sqrt{2}$	0	0
DN			1	0	$\frac{1}{\sqrt{6}}\,\kappa$	0	-1	$-\frac{1}{\sqrt{3}}\,\kappa$
$K\Xi_c$				0	0	0	$\sqrt{\frac{3}{2}}\,\kappa$	0
$\eta\Sigma_c$					0	$-\sqrt{3}$	$\sqrt{\frac{2}{3}}\,\kappa$	0
$K\Xi'_c$						0	$-\frac{1}{\sqrt{2}}\,\kappa$	0
$D_s\Sigma$							1	$\frac{1}{\sqrt{3}}\,\kappa$
$\eta'\Sigma_c$								0

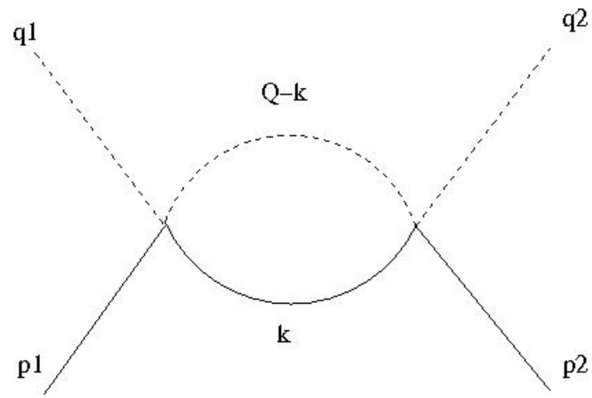
$$L_i \cdot L_j = [\text{kinetic term}] \cdot \mathbf{C}_{i,j}$$

… solving T matrix in the free space …

Propagator in free space

$q1=(q1^0,\mathbf{q1})$

$q2=(q2^0,\mathbf{q2})$



$p1=(p1^0,\mathbf{p1})$

$p2=(p2^0,\mathbf{p2})$

$$G_i(\sqrt{s}) = i\int \frac{d^4k}{(2\pi)^4}\frac{M_i}{E_i}\left(\frac{1}{k^0 - E_i(k) + i\varepsilon} - \frac{1}{k^0 - E_i(k) - i\varepsilon}\right)$$

$$\times \frac{1}{((Q^0 - k^0)^2 - (\vec{Q} - \vec{k})^2 - m_i^2 + i\varepsilon)}$$

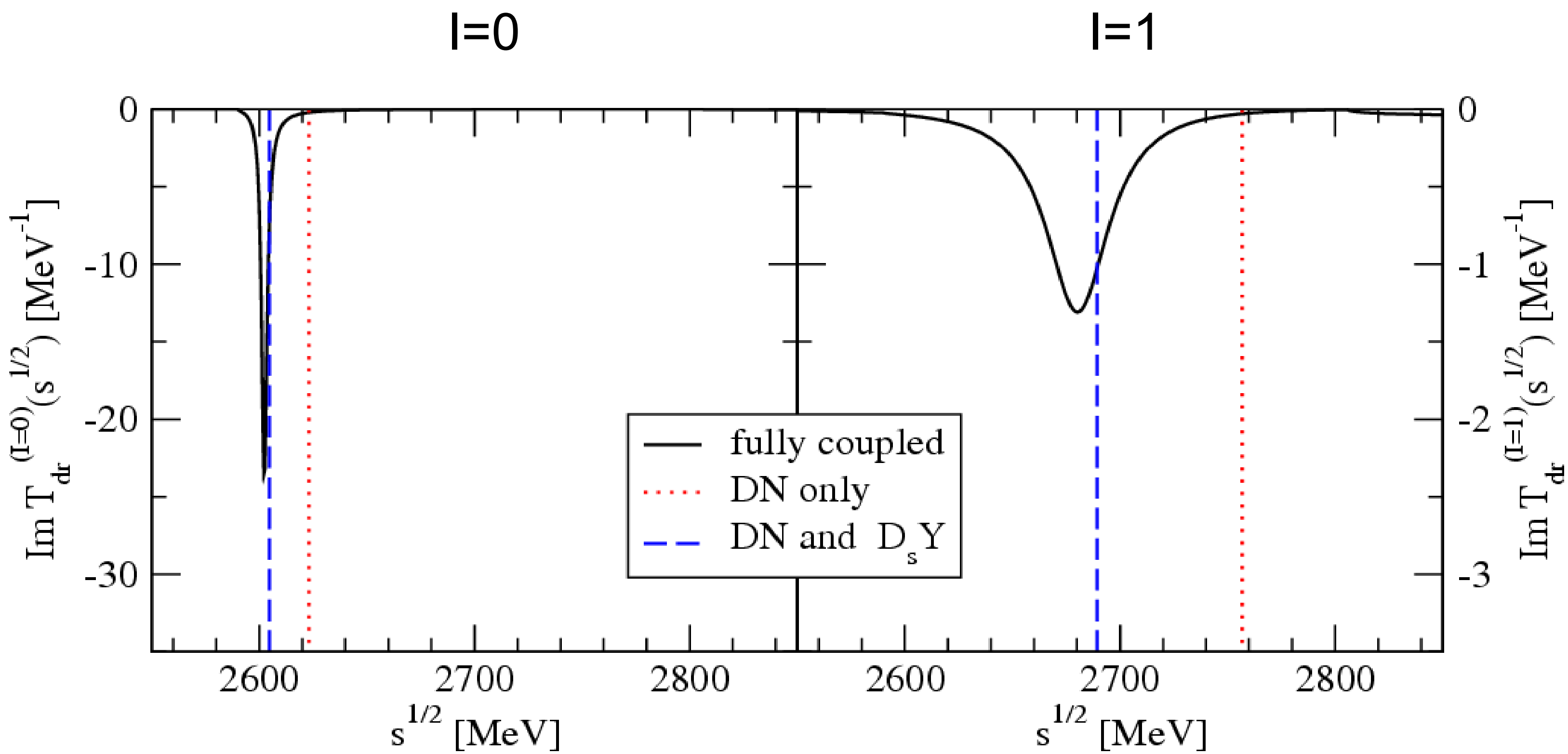
all 4-momenta are given in the lab frame

$s = (Q^0)^2 - (\mathbf{Q})^2$ → Energy of mass frame

E_i and M_i is the energy and mass of the baryon

m_i the mass of the meson

Free space DN amplitudes



Λc(2595)

Σc(2770)

T matrix in the nuclear matter …

Summary

D N → Intermediate states → DN

$T = V + V \cdot GT$

$\boxed{T = (I - V \cdot G)^{-1} \cdot V}$

$V \leftarrow \mathbf{C_{i,j}} \leftarrow (L_i \cdot L_j = [\text{kinetic term}] \cdot \mathbf{C_{i,j}})$

G

G in free space

↓

G in nuclear matter

Conclusions …

-> DN interaction in coupled channels from a model (inspired on the work of Hofmann and Lutz)

-> In free space, we generate the Λ_c(2595) dynamically in I=0. The same interaction generates a I=1 wide resonance which we denote as Σ_c(2770)

… and Future

-> We will implement the medium effects on the DN amplitudes (Pauli blocking, self-consistent dressing of D meson, dressing of π) self-consistently.

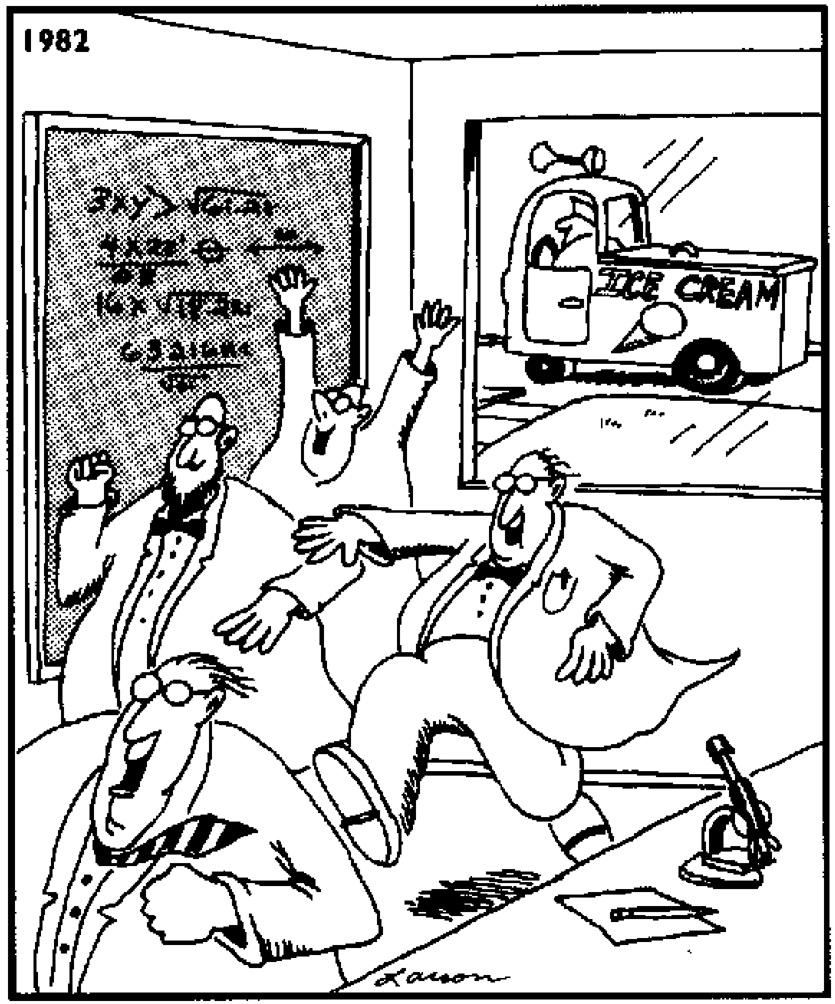
D_s also develops a self-energy

[M.F.M.Lutz, and C.L.Korpa, Phys. Lett. B 633,43 (2006)]

-> Solve C=1 S=1 D_sN problem in the medium and incorporate D_s self-energy in our coupled-channel problem (DN strongly coupled to D_sY)

Question time

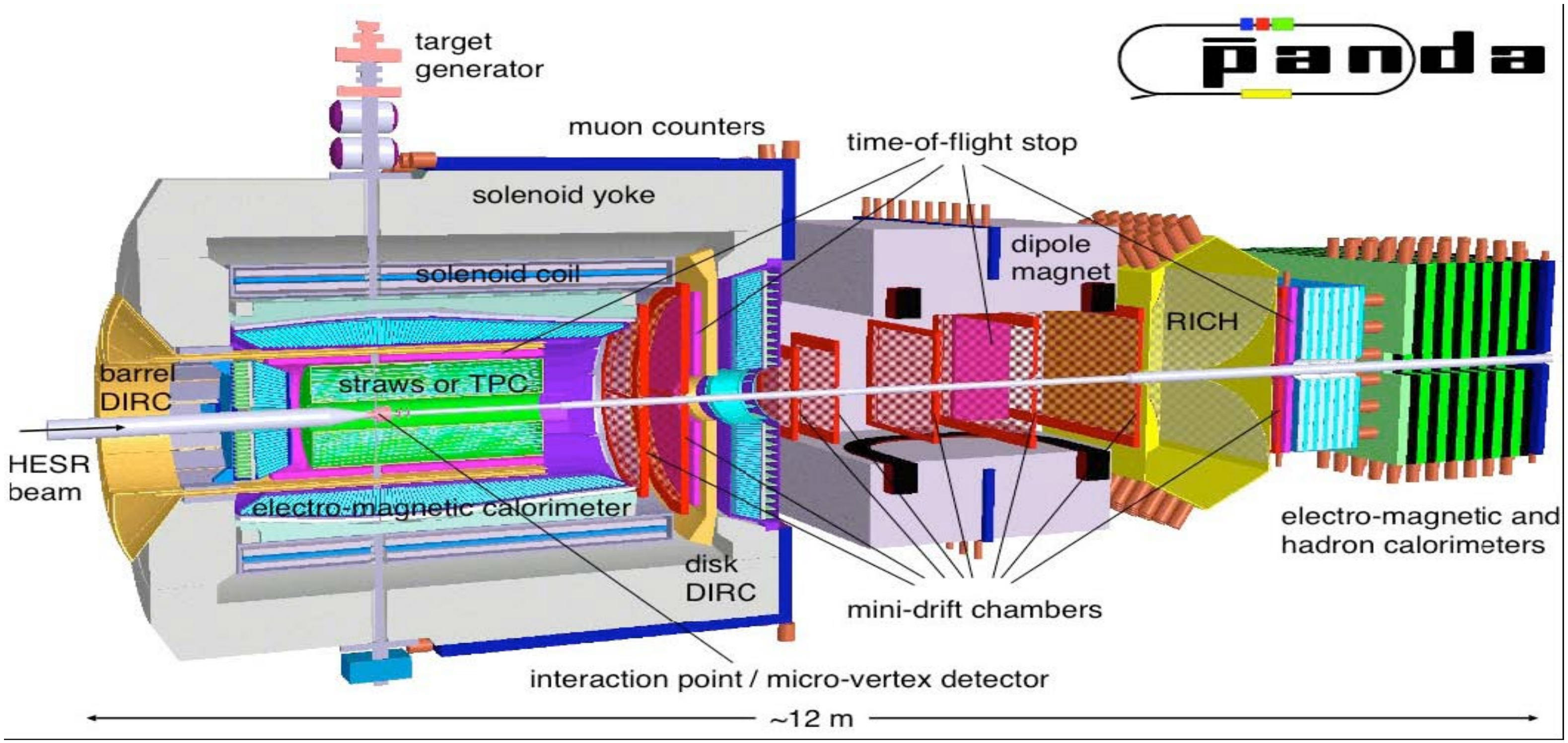
thanks for your patience …



… so early in the morning

Panda menu

- Charmonium spectrospcopy
- Gluonic excitations (hibrids, glueballs)
- Open and hidden charm in nuclei
- γ-ray spectroscopy of hypernuclei



http://www-panda.gsi.de/auto/_home.htm

Characteristics **HESR**
10^11stored antiprotons
1.5 -14.5 GeV**L**= 2 x 1032cm-2s-
1δp/p ≥ 10-5σx≥ 50 μm