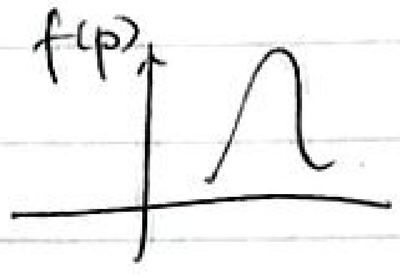
Lecture 2.

Following yesterday's discussions on oscillation.

subtleties of oscillation. example. decoherence

wave packet: 

→ Gaussian function with mean $\bar{p}$. width σ_p

$\sigma_p \ll \bar{p}$

→ position space $\psi_i(\vec{x},t) = \int \frac{d^3p}{(2\pi)^3} f(\vec{p}) e^{i\vec{p}\cdot\vec{x} - iE_i(p)t}$

repeat oscillation calculation

$$\Rightarrow P_{\alpha\beta} = \sin^2 2\theta \left\{ \frac{1}{2} - \frac{1}{2}\cos\left(\frac{\Delta m^2 L}{2E}\right) \exp\left\{ -\left(\frac{L}{L_{coh}}\right)^2 - \left(\frac{\sigma_x}{L_{osc}}\right)^2 \right\} \right\}$$

with $L_{coh} = \frac{4\pi E^2}{\Delta m^2}\sigma_x$ $\quad \sigma_x = \frac{1}{2\sigma_p}$.

oscillation.

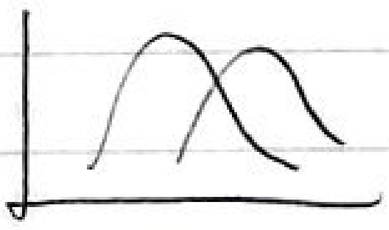
at production.

if $L \ll L_{coh}$ (terrestrial exp)

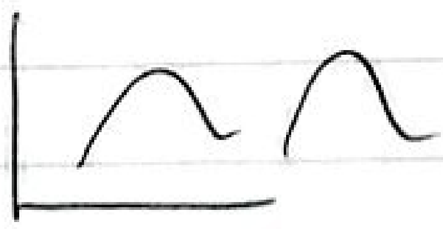
still significant overlap

$P \to \sin^2 2\theta \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$

if $L \sim L_{coh}$ (interesting!)



if $L \gg L_{coh}$. (astro neutrinos? can't tell)



$P \to \frac{1}{2}\sin^2 2\theta$

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to predict if we're ever in the situation of case 2.
we need to compute $\angle_{wh.} \to \sigma_x$.

What's σ_x ??

e.g. for reactor neutrinos. OoM estimates in literature.

$$\sigma_x \sim \frac{1}{E_\nu}$$

σ_x ~ the size of nuclei

σ_x ~ the mean free path of nuclei in reactor

$$10^{-12} \lesssim \sigma_x/\text{cm} \lesssim 10^{-5}$$

You should try to compute it!

ν-A cross section problem, mostly relevant for accelerator-based long-baseline oscillation exp.

In these exp. ν are detected through ν+A interaction.

Why not $\nu + e \to \nu + e$? known cross section, but much smaller than ν+A cross sections! :(

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why we need to compute it?

measure $P_{\alpha\beta}$. exapte $P_{\mu\mu}$.

$P_{\mu\mu}=1$ $(L\neq 0)$

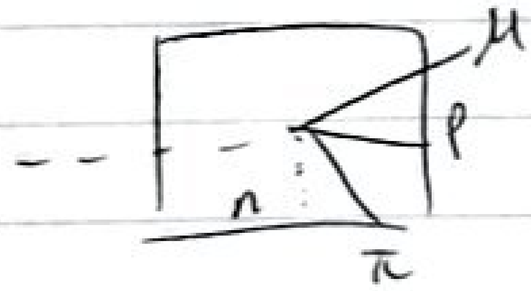
in general. hard
to predict ν fluxes
in any sources super precisely.

Naively. N at ND $(E_\nu) = f(E_\nu)\cdot\sigma(E_\nu)$
N at FD $(E_\nu) = f(E_\nu) P_{\mu\mu}(E_\nu)\sigma(E_\nu)$

$$\Rightarrow P_{\mu\mu} = \frac{N_{FD}(E_\nu)}{N_{ND}(E_\nu)}$$ don't need cross section!

↳ near-far cancellation

In reality: don't know E_ν ...



$E_\nu = E_\mu + E_p + E_n + E_\pi$
if perfect detector.

in practice. we need $\frac{d\sigma}{dE_\mu dE_p dE_n dE_\pi}$.

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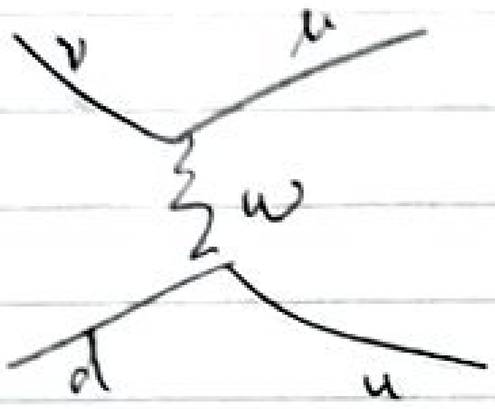
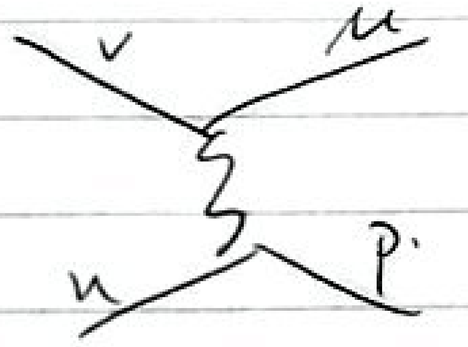
How do we capture it?



DIS interaction = ⟨ ⊗ PDF

factorization
valid at high Q^2 ($\gtrsim$ 10 GeV^2)

low energy, < 1 GeV

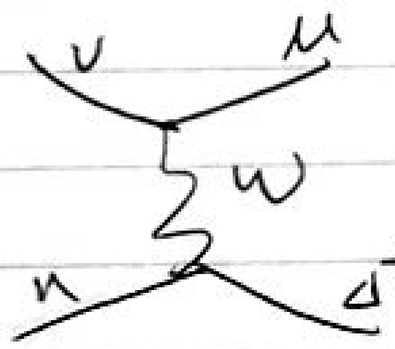


Quasi-elastic $\langle N' | J^\mu | N \rangle$

$= \bar{u} \left(\gamma^\mu F_1(Q^2) + \frac{i\sigma_{\mu\nu}}{2M} q_\nu F_2(Q^2) \right) u.$

↑ form factors, can measure.

intermediate energy 1-2 GeV.



→ Spin 3/2. Rarita Schwinger spinors.

$\langle \Delta | J^\mu | N \rangle$ = .. G_1, G_2 .. form factors.
there are many of them!

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