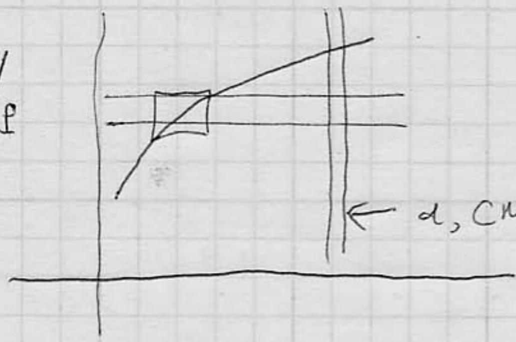
 Py229C. 10/13/2005.

Big Bang Nucleosynthesis

Is 4He really a problem?



Y_p appears to be too small

Possible Sol$^{\underline{n}}$

(1) Systematic error in observation?

(2) Change g_*

$g_* \uparrow$

$H_{BBN} \uparrow$

n freeze out happens earlier

$(n/p) \uparrow$

$Y_p \uparrow$ But wrong sign, we want to predict a smaller Y_p.

(3) Change $g_* \downarrow$

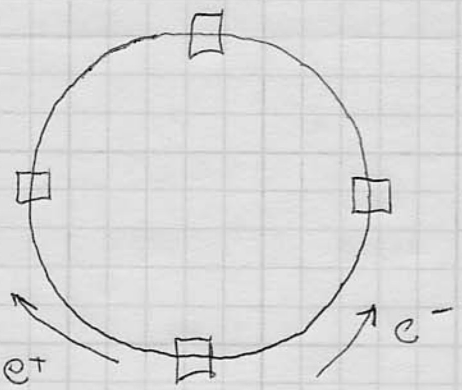
$Y_p \downarrow$

$$g_* = 2 + 4\left(\frac{7}{8}\right) + N_\nu \cdot 2 \cdot \left(\frac{7}{8}\right)$$

γ $\quad e^+e^-$ $\quad \nu\bar{\nu}$ $\implies N_\nu = 2.3 \pm 0.3$?

But we know from LEP $N_\nu = 3$.

LEP ↓ Large Electron-Positron Collider @ Cern.



$e^+e^- \to Z \to$ $u\bar{u}$, $d\bar{d}$, $b\bar{b}$, $s\bar{s}$, $c\bar{c}$, e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, $\nu\bar{\nu}$

$$\sigma = \frac{12\pi}{M_Z^2} \frac{\Gamma_{ee}\Gamma_f}{\Gamma_Z^2} \underbrace{\frac{\Gamma_Z^2}{(s-m_Z^2)^2 + s\Gamma_Z^2/m_Z^2}}_{\text{Breit Wigner}}$$

m_Z = mass of Z

$s = E_{cm}^2$ (Mandelstam variable).

Γ_Z = width of Z $= \hbar/\tau_Z$

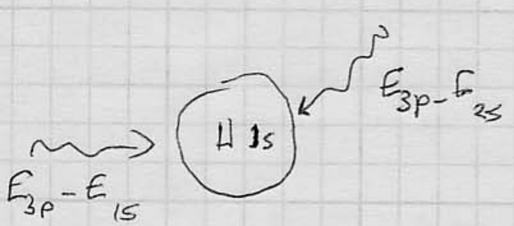
Γ_{ee}, partial width $Z \to e^+e^-$

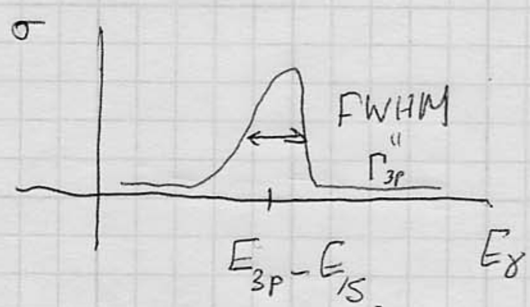
Γ_f " " $Z \to f$

Eg: Unstable stage eg 3p state of H.

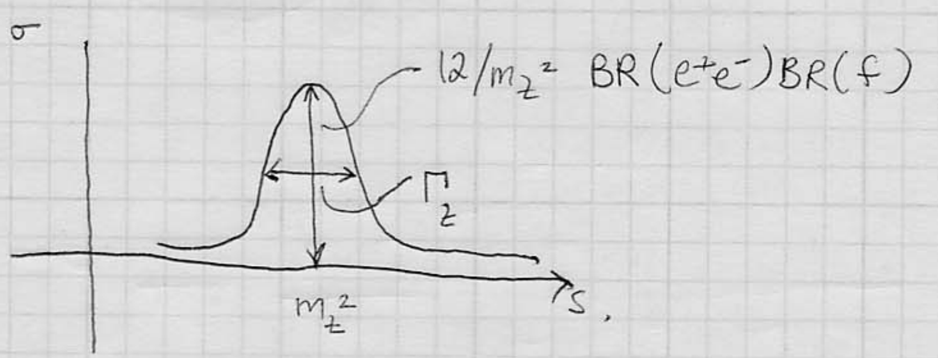
$$3p \to 1s + \gamma$$
$$3p \to 2s + \gamma$$

$$\tau_{3p} = \frac{\hbar}{\Gamma_{3p}} \qquad \sigma \propto \frac{1}{(E-E_\gamma)^2 + \Gamma^2/2}$$





$\sigma(e^+e^- \to Z \to f)$



By measuring ~~Breit Wigner curve~~ this curve for different visible final states we can measure $Br(f)$ for visible f.

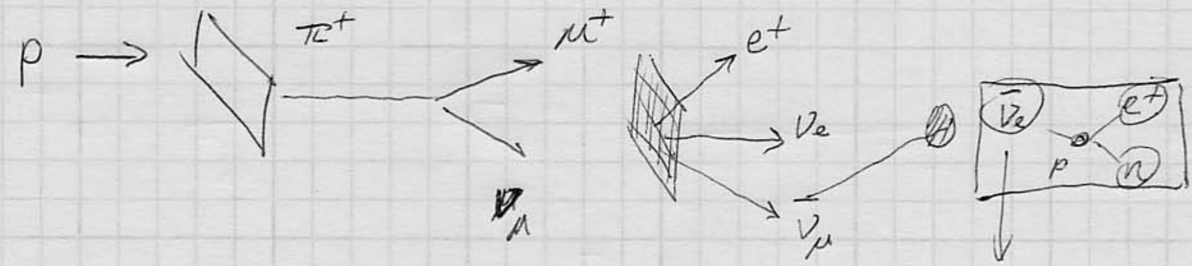
$$N_\nu = \frac{B(\nu\bar{\nu})\,\Gamma_Z}{\Gamma_{Z\to\nu\bar{\nu}}^{\text{calculated}}}$$

$$= 2.9840 \pm 0.0082 \quad (\text{hep-ex}/0509008)$$

So we have a N_ν puzzle

$$3 \leftrightarrow 2.3$$

LSND Los Almos Scintillator Neutrino Detector



But no source of $\bar{\nu}_e$

being tested / redone @ MiniBoone

Postulate Sterlire neutrinos

ν-like neutral fermions that don't couple to Z

$\Delta N_\nu = 1, 2, \ldots$

<u>Degenerate</u> BBN

$\xi_{\nu_e} = \frac{\mu_{\nu_e}}{T}$ chemical potential

we assumed $\mu_{\nu_e} = 0$ (or only with an ~~asyg~~ asymmetry comparable to η)

more ν_e less $\bar{\nu}_e$

$\nu_e n \longleftrightarrow e^- p$

$\Longrightarrow$ equlibrium shifts

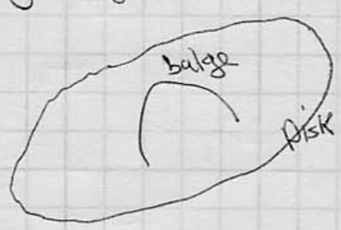
less n, $\Rightarrow n/p \downarrow$ $Y_p \downarrow$ See paper of linked from course website

New Topic: Dark Matter
↓
Component of matter in universe which is non-luminous, non-relativistic particles

$\rho \to \frac{1}{R^3}$

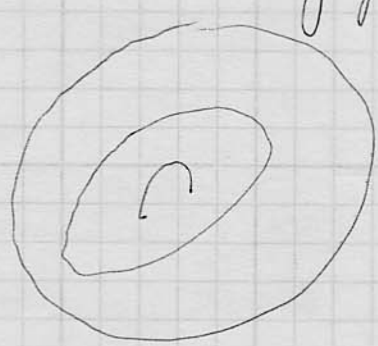
Where does it come from:

Early arguments:
galaxy



Zwicky showed this configuration is gravitationally unstable

$\Rightarrow$ other source of gravity, unseen

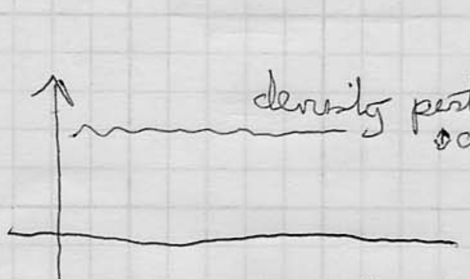


spherical halo

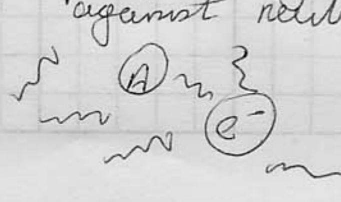
Another Argument:

Ω_B from BBN, assume no other Ω_M

$\Rightarrow$ matter-radiation eq, decoupling

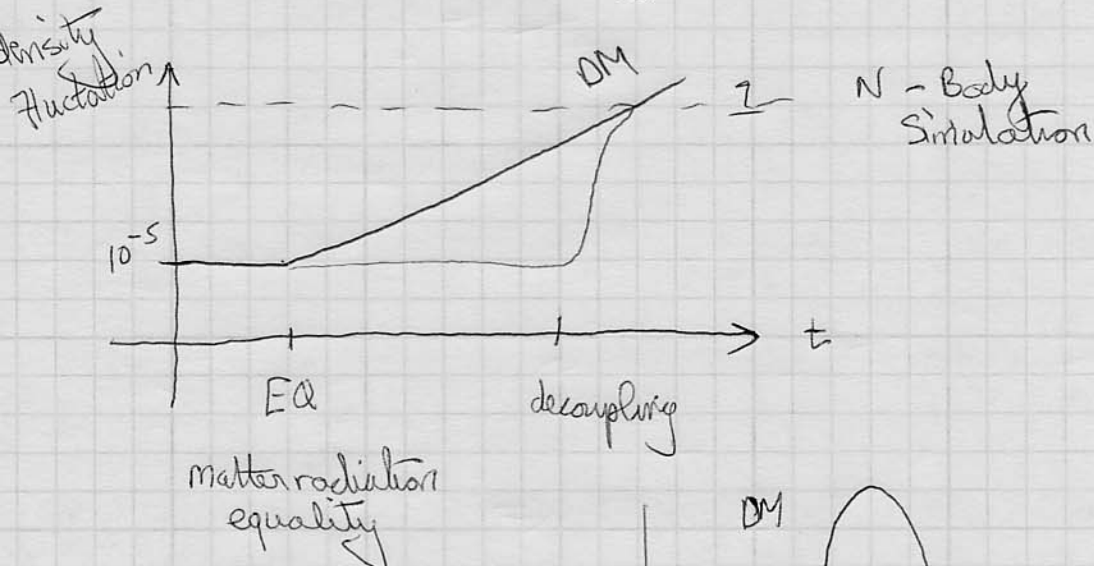


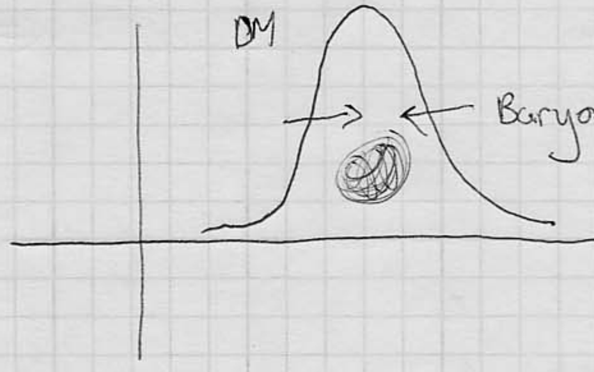
photons no longer provide pressure against neutral atoms



If baryon dominated universe ⇒ not enough time for the structure (galaxies, clusters etc) to form

∃ dark matter (non-rel, neutral) starts to cluster before photon decoupling

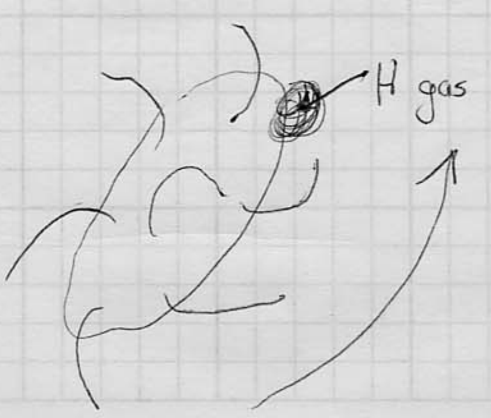




More Recent Stuff:

Observational evidence:

1) Galatic Rotation Curves.



Spiral Galaxy, everything is rotating

How do we see the hydrogen gas

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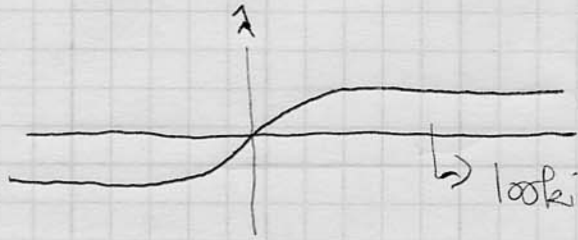
hyperfine splitting $\Rightarrow$ 21cm line

$\sim 10^{-7}\,eV \ll kT_{CMB}$

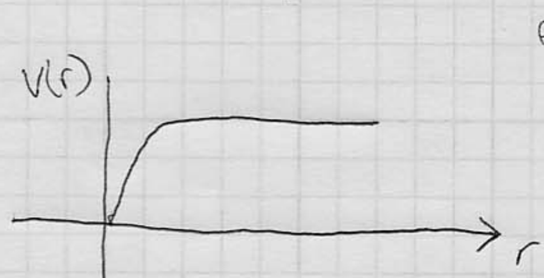
So this excited state is all over the place

Then combine Doppler effect:

$v \sim 10^{-3} c$.



↳ looking at this curve can extract ~~the~~ velocity profile



$$\frac{G_N M m}{r^2} \simeq \frac{m v^2}{r} \quad \text{So } v^2 \propto \frac{1}{r}$$

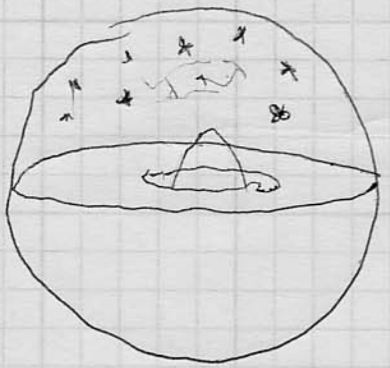
So Problem! Measured curve is essentially flat halo profile (ansatz)

$$\rho(r) = \frac{v_\infty^2}{4\pi G_N r_c^2} \frac{r_c^2}{r_c^2 + r^2}$$

r_c = core radius

v_∞ = asymptotic rotation velocity

- typically called Thermal sphere.



Massive compact halo objects eg "jupiter"