Discussion Session #5, January 14, 2021

Thursday, January 14, 2021 2:14 PM

4-1. Analyze $pp \to W^{+/-}$, want to measure W mass.

first, $W \to jj$ is bad because:

$Z \to jj$ + $t\bar{t}$ + QCD dijets.

Even if you got rid of backgrounds, why is $W \to jj$ worse than $W \to \ell\nu$?

Jet resolution is not as good.

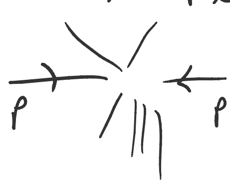
$p_T(j) \sim 10\%$ for jet $20\ \text{GeV} \lesssim p_T \lesssim 200\ \text{GeV}$

similar for jet energies $\Rightarrow$ M_W resolution $\sim 10\%$ or 10 GeV for $m_W \sim 80.4$ GeV

On the plus side, fully visible decay of W boson, in principle $m(jj) = m_W$.

Consider: leptonic decay.

E_ℓ, $\vec{P}_\ell$. Also infer $\vec{p}_T(\nu)$.



lab coincides with COM of partonic collision up to longitudinal boosts (boosts in $\pm\hat{z}$ direction).

$\xrightarrow{x_1 p}$ $\xleftarrow{x_2 p}$ vs $\xrightarrow{x_1 p}$ $\xleftarrow{x_2 p}$ vs. $\xrightarrow{x_1 p}$ $\xleftarrow{x_2 p}$

Transverse momenta in lab frame start as 0 as the initial condition. $0 = \sum \vec{p}_{T,i} = \sum \vec{p}_{T,f}$

So, when $\sum \vec{p}_{T,f}^{\,\text{observed}} \neq 0$, must be balanced by $\sum \vec{p}_{T,f}^{\,\text{unobserved}} = -\sum \vec{p}_{T,f}^{\,\text{obs.}}$

In $W \to \ell\nu$, assume the neutrino is only source of $\vec{p}_T^{\,\text{unobs.}}$

In $W \to \ell\nu$, assume the neutrino is only source of $\vec{p}_T$

Measured 4-momenta components of final state objects:

$E_\ell,\ \vec{p}_{T\ell},\ p_{z\ell},\ \vec{p}_{T\nu}$

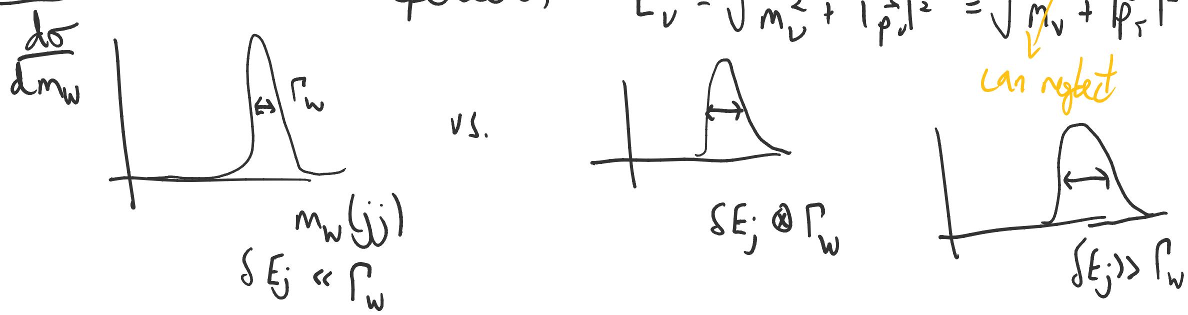
If we had all 4-momenta measured,

construct invariant mass of $\underline{(p_\ell+p_\nu)^2} = p_W^2 = m_W^2$.

In principle, E_ν + $p_{z,\nu}$ are unmeasured.

But only one is needed. E_ν + $p_{z,\nu}$ are not independent, $E_\nu = \sqrt{m_\nu^2 + |\vec{p}_\nu|^2} = \sqrt{\cancel{m_\nu^2} + |\vec{p}_T|^2 + p_z^2}$

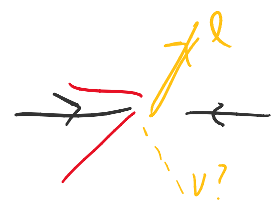
can neglect



$\vec{p}_{T,\nu} = -\sum_f p_{T,f}$ Since we cannot construct m_W^2 fully, but we

$\vec{p}_{T,\nu} \neq -\vec{p}_{T,\ell}$ can construct transverse variable.

Don't know E_ν: $m_W^2 = (p_\ell + p_\nu)^2 = (E_\ell+E_\nu)^2 - |\vec{p}_\ell|\, E_\nu \cos\Delta\phi$



$$(E_\ell+E_\nu)^2 - |\vec{p}_\ell|\, E_\nu \cos\Delta\phi$$

$$= \left(E_\ell + \sqrt{|\vec{p}_{T\nu}|^2 + p_{z\nu}^2}\right)^2 - \left(|\vec{p}_\ell| \sqrt{|\vec{p}_{T\nu}|^2 + p_{z,\nu}^2}\right)\cos\Delta\phi$$

suggestion: multiply out + drop terms not known to 1st order.

but, this breaks LI.

Keep LI in longitudinal direction: All observable components must be from scalars or transverse observables.

$$m_W^2 = (p_\ell + p_\nu)^2 = m_\ell^2 + m_\nu^2 + 2 \underbrace{p_\ell \cdot p_\nu}_{\text{scalar invariant}}$$

$$= 2(E_\ell E_\nu - |\vec{p}_\ell||\vec{p}_\nu| \cos\Delta\phi) + m_\ell^2 + m_\nu^2$$

If ignore m_ℓ, m_ν:

$$= 2(|\vec{p}_\ell||\vec{p}_\nu|)(1-\cos\Delta\phi)$$

Now, $|\vec{p}_\ell| \geq |\vec{p}_{T\ell}|$, $|\vec{p}_\nu| \geq |\vec{p}_{T,\nu}|$

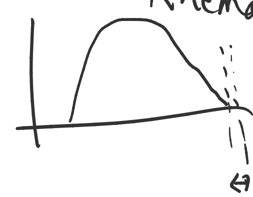
$$\geq 2|\vec{p}_{T\ell}||\vec{p}_{T,\nu}|(1-\cos\Delta\phi_1) \equiv m_{T,W}^2$$

$\dfrac{d\sigma}{dm_{T,W}}$

kinematic endpoint ✓

Analogous to ν-mass measurement

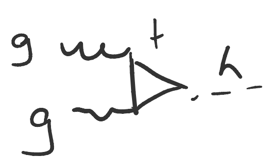
$n \to p \nu e \to$ endpoint of p_e kinematics.



0.1eV

4-2.

A. gg fusion: $\sigma_{gg} = 48.6\text{pb}$

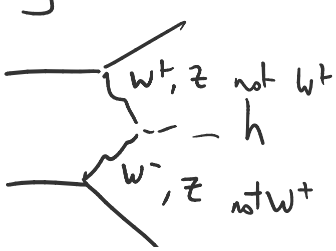


gg PDF dominant over qq' PDFs,

$\sigma(2\to2)_{1\text{loop}} \sim \frac{1}{16\pi}\sigma(2\to2)$

$\sigma(2\to3) \sim \frac{1}{8\pi}\sigma(2\to2)$

vector boson fusion



$\sigma_{VBF} = 3.78\text{ pb}$

PDFs: $(u,\bar{u})$, $(u,\bar{d})$, not (u,u)

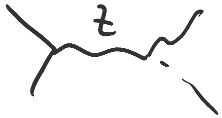
fusion 

PDFs: $(u,\bar{u})$, $(u,\bar{d})$, not (u,u)
not (u,d)

vector-boson association

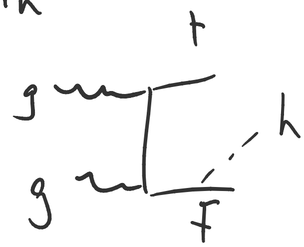
Wh 

$\sigma_{Wh} = 1.373\ pb$

Zh 

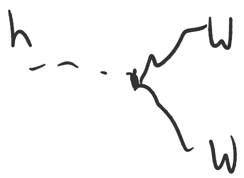
$\sigma_{Zh} = 0.88\ pb$

$t\bar{t}h$

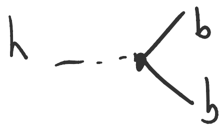
$t\bar{t}h$ 

$\sigma_{t\bar{t}h} = 0.5\ pb$

b.) In K-framework, artificially multiply every Higgs coupling by its own K.

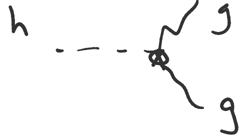


$\frac{i m_W^2}{v} \cdot g^{\mu\nu} K_W$ same for all others.



$\frac{i m_b}{v} \cdot K_b$ $\left(i \frac{y_b}{\sqrt{2}} K_b \right)$

$\Gamma(h \to b\bar{b}) = K_b^2 \cdot \Gamma_{SM}(h \to b\bar{b})$



$\# \cdot g^{\mu\nu} K_g$

$\Gamma_{tot} = \sum \Gamma_{partial}$

c.) xsec dependence on K_g + K_γ for $gg \to h \to \gamma\gamma$.

$$\sigma(gg \to h \to \gamma\gamma) \propto \frac{K_g^2\ K_\gamma^2}{[s - m_h^2 + i m_h \Gamma_{..}]^2}$$

$$\frac{}{\left[s - m_h^2 + i m_h \Gamma_{tot}\right]^2}$$

Narrow width

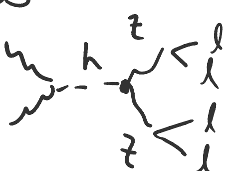
$$\propto \frac{K_g^2 K_\gamma^2}{\left[i m_h \Gamma_{tot}(K_i, \ldots)\right]^2}$$

σ measured.

$\exists$ Cannot determine either of these K_g or K_γ unambiguously.

Include another process:

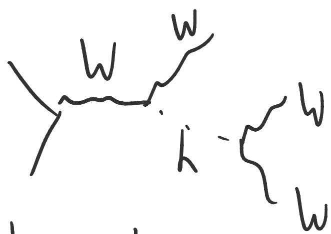
$gg \to h \to 4l$



$$\sigma \propto \frac{K_g^2 K_Z^2}{\left[i m_h \Gamma_{tot}(K_i, \ldots)\right]^2}$$

System of equations still has one overall unknown.

For another process, this is not improved.
Will have own production coupling + decay coupling.



$$\sigma \propto \frac{K_W^4}{\left[i m_h \Gamma_{tot}(K_i, \ldots)\right]^2}$$

Allows to determine ratios of xsecs + eliminates Γ_{tot}.

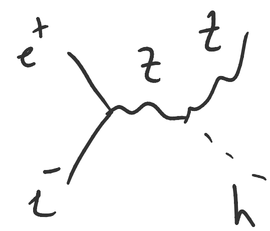
D.) Need: independent measurement of Γ_{tot}.

Alternatively, assume Γ_{tot} completely decomposition into known K. (See later)

E) κ_b to EFT.

$$y h \bar{b} b + y' \frac{h 3v^2}{\Lambda^2} \bar{b} b \Rightarrow \kappa_b = y_b \left(1 + \frac{2v^2 y'}{\Lambda^2 y_b}\right)$$

F.) $e^+e^- \to Zh$.



4-momenta of e^+, e^-, Z are known.

$$((p_{e^+} + p_{e^-}) - p_Z)^2 = m^2_{recoil}$$

Match (cut) only events with $|m_{recoil} - m_h| < 1\,\text{GeV}$.

This gives some # of events $\Rightarrow$ convert to xsec.

$\sigma(e^+e^- \to Zh, \text{inclusive on } h)$.

$$\sigma(e^+e^- \to Zh_{incl}) \propto \kappa_Z^2$$

$$\sigma(e^+e^- \to Zh,\ h \to 4\ell) \propto \frac{\kappa_Z^4}{(i m_h \Gamma_{tot})^2}$$

Can determine each unambiguously!