Z^0 production at the LHC

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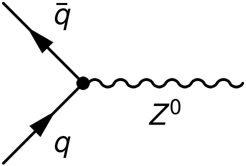
Drell Yan Process

for a real Z^0 boson

The Z^0 boson is produced via the DY process according to the following vertex:



The Z coupling to the quarks is described by a vertex factor of $-i\frac{g_z^2}{2}\gamma^\mu(c_V - c_A\gamma^5)$.
The matrix element is given by:

$$-i\mathcal{M} = \epsilon^{\mu\star}\overline{\upsilon(p_2)}\left(-i\frac{g_z}{2}\right)\gamma^\mu\left(c_V - c_A\gamma^5\right)u(p_1)$$

Invariant Amplitude

Squaring the matrix element and averaging over colors, spins and summing over all different colors gives:

$$|\mathcal{M}|^2 = -\frac{1}{2}\frac{1}{2}\frac{1}{3}\frac{g_z^2 e_f^2}{4} Tr\left[\not{p}_2\gamma^\mu\left(c_V - c_A\gamma^5\right)\not{p}_1\gamma_\nu\left(c_V - c_A\gamma^5\right)\right]\times$$

$$\left[-g^{\mu\nu} + \frac{q^\mu q^\nu}{{M_z}^2}\right] = \frac{g_z^2 e_f^2}{12}\left({c_A}^2 + {c_B}^2\right) s$$

The $\frac{q^\mu q^\nu}{M_z^2}$ term does not contribute by Ward Identity since we assume zero quark masses. The factor e_f corresponds to the fraction of the quark charge.

Partonic Cross Section

The cross section in the parton frame is given by integrating on the phase space:

$$\sigma = \frac{1}{2s} \int \frac{d^3 q}{(2\pi)^3 2q_0} (2\pi)^4 \delta^4 (p_1 + p_2 + q) \left| \mathcal{M} \right|^2$$

Using the amplitude derived above we get :

$$\sigma = \frac{\pi {g_z}^2 {e_f}^2}{12} \left({c_A}^2 + {c_V}^2 \right) \delta(s - M_z^2)$$

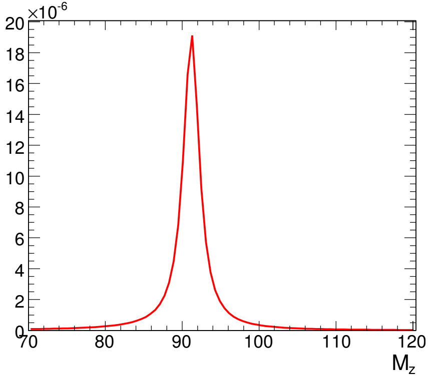
Hadron vs Lepton Colliders

- For a resonance to be produced, the invariant mass of the resonance should be equal to the partonic CM energy according to the formula derived above.
- A Hadron Collider in High Energies (LHC, Tevatron) can produce a huge range of partonic CM energies and give evidence for new physics
- The only way to search for resonances in a lepton collider is to scan the CM Energy range!
- This is easy and efficient if you know where the resonance is!
- Z and W discovery is a representative example
  - Z ,W discovered in proton-antiproton conditions (UA1,UA2)
  - However the best measurements of Z,W properties were done at LEP,SLC
  - A hadron collider discovers, A lepton collider measures

Z resonance

If we include the *Z* decay to fermions, the Z propagator contributes a Breit Wigner term in the cross section:

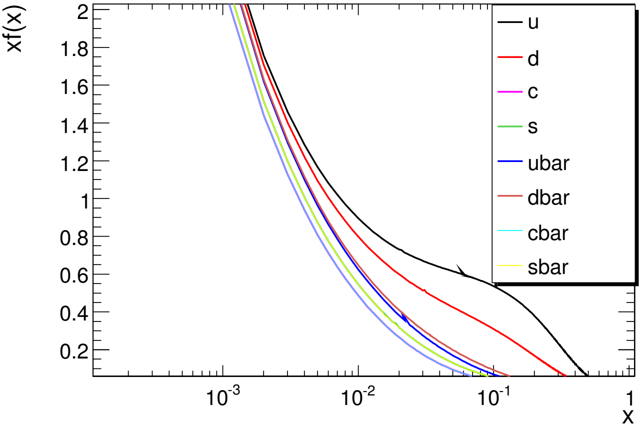
$$\sigma \sim \frac{1}{\left(s^2 - M_Z^2\right)^2 + M_Z^2\Gamma^2}$$



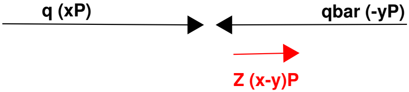
Parton Distribution functions

made by CTEQ

Those functions are taken from the PDF library and are used for calculations later:



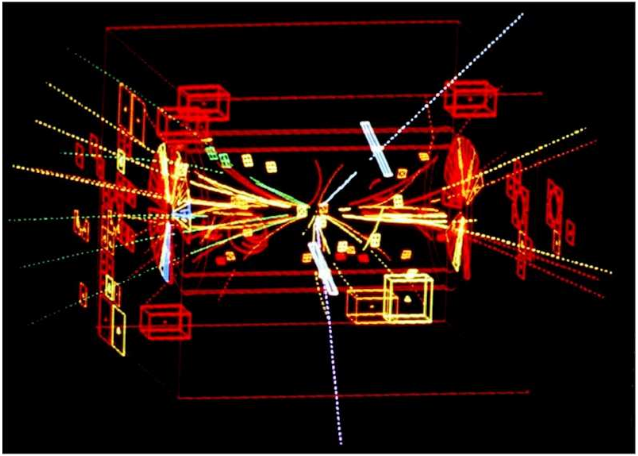
Drell Yan Kinematics in the pp frame



- Due to momentum conservation the Z has no p_t
- In the transverse plane, decay products are produced back to back
- However Z is boosted in the z direction

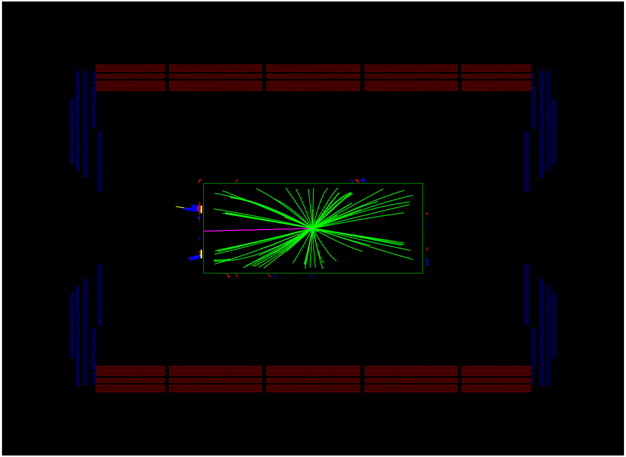
One of the first Zs

in the UA1 Detector



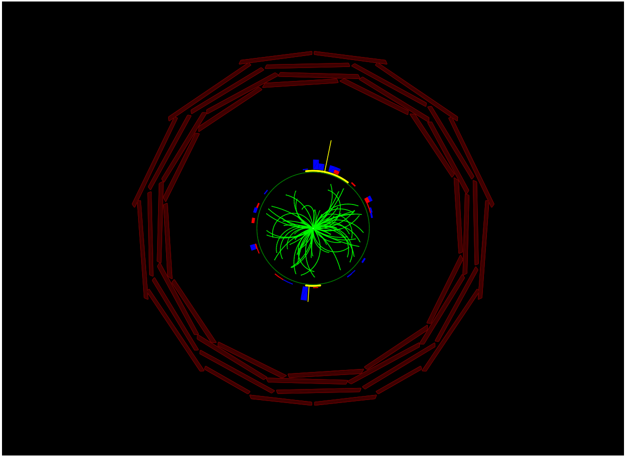
Example from CMS - Simulation

$Z \to \tau\tau$, (ρ, z) plane



Same example

$Z \to \tau\tau$, (x, y) plane



Calculation of the leading order Cross Section

The total cross section in the *pp* frame is given by:

$$\sigma = \sigma_p \sum_{quarks} \int dx dy f_q(x) f_{\bar{q}}(y) =$$

$$= \frac{\pi g_Z^2}{12} \sum_{quarks} e_f^2 \left(c_A^2 + c_B^2 \right) \int dx dy f_q(x) f_{\bar{q}}(y) \delta \left(xyS - M_Z^2 \right)$$

$$= \frac{\pi g_Z^2}{12} \sum_{quarks} e_f^2 \left(c_A^2 + c_B^2 \right) \int dx dy \frac{f_q(x) f_{\bar{q}}(y)}{|xS|} \delta \left(y - \frac{M_Z^2}{xS} \right)$$

$$= \frac{\pi g_Z^2}{12S} \sum_{quarks} e_f^2 \left(c_A^2 + c_B^2 \right) \int dx \frac{1}{x} f_q(x) f_{\bar{q}} \left(\frac{M_Z^2}{xS} \right)$$

where $S = 14 TeV$.

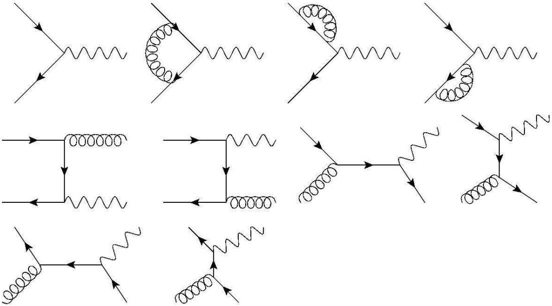
Cross Section at 14 TeV

- Performing the PDF Integral numerically and using *u*, *d*, *c*, *s* PDFs we get :

$$\sigma = 13.2\ nb$$

- A calculation of the DY process (Z contribution) using Pythia Monte Carlo gives a cross section of 15.8*nb*
- We are not so far away :-)

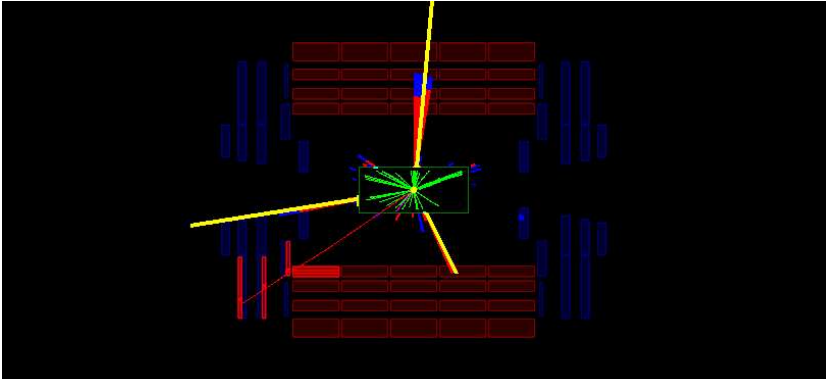
More Terms!



- Some are trivial to calculate (e.g. the ones with an outgoing quark/gluon)
- The ones with a gluon /quark + Z in the final state are interesting (Z+Jets)

$Z \to \tau\tau + 2$*jets* in CMS

ρ, z view



$Z \rightarrow \tau\tau + 2$*jets* in CMS

x, *y* view