Electroweak Measurements at the Tevatron

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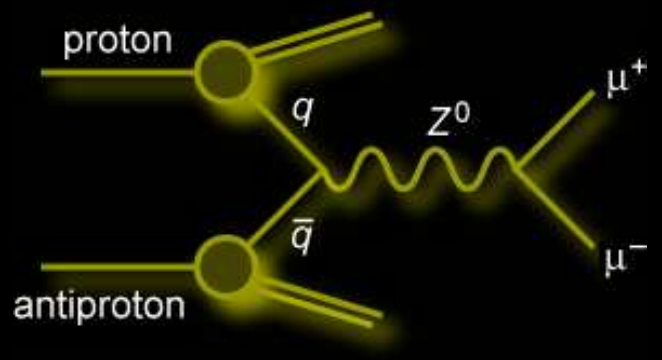
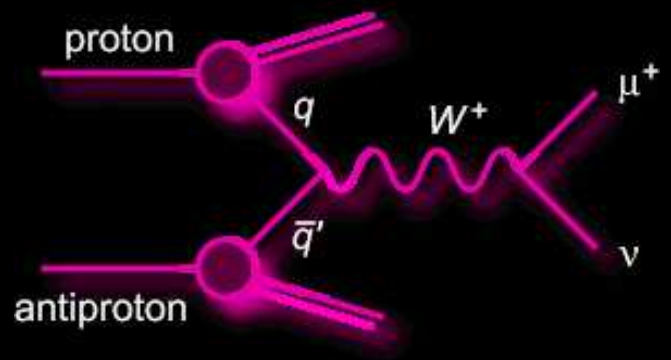
Why should you be here at 08:30 in the morning to listen to electroweak physics results?

Electroweak physics 101

Simplest tree-level diagrams to study at hadron colliders:





Z$\rightarrow \ell\ell$, W$\rightarrow \ell\nu$ reconstruction can be studied very well:

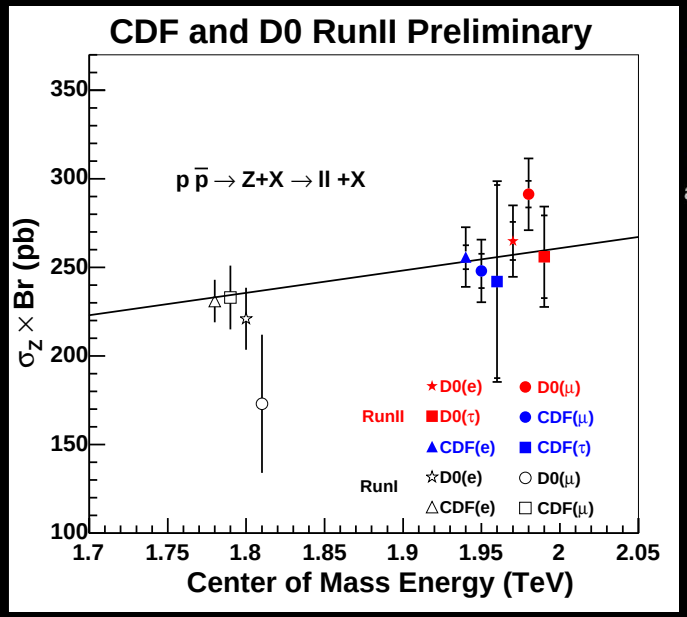
- clean signature (high p_t leptons)
- high rate (for single W,Z production)

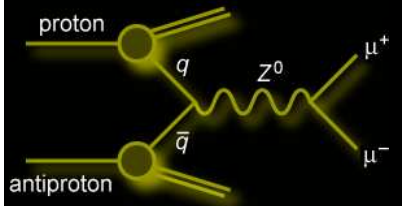
electroweak physics = excellent laboratory for precision studies!

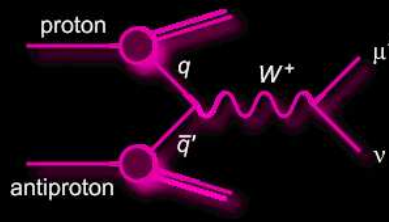
- testing the SM beyond leading order
- detecting non-SM contributions
- constraining PDFs

Tevatron Run I/II W/Z cross-sections

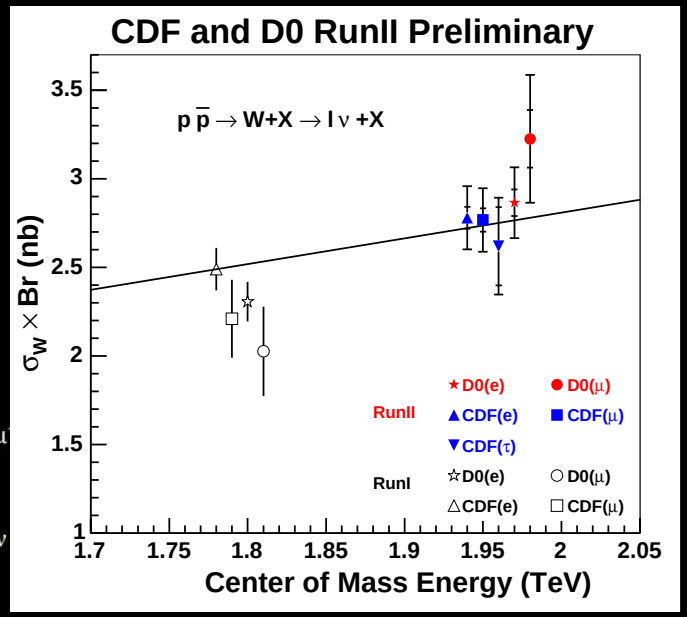
$p\bar{p} \to$ Z+X $\to \ell\ell$+X







$p\bar{p} \to$ W+X $\to \ell\nu$+X



total W, Z production cross-sections: good agreement with Standard Model

(at current precision!)

BUT: not the most sensitive observable to look at for SM checks!

anyone awake yet?

Electroweak topics of the day

Analyses presented in this talk:

differential Z cross sections (rapidity, transverse momentum)

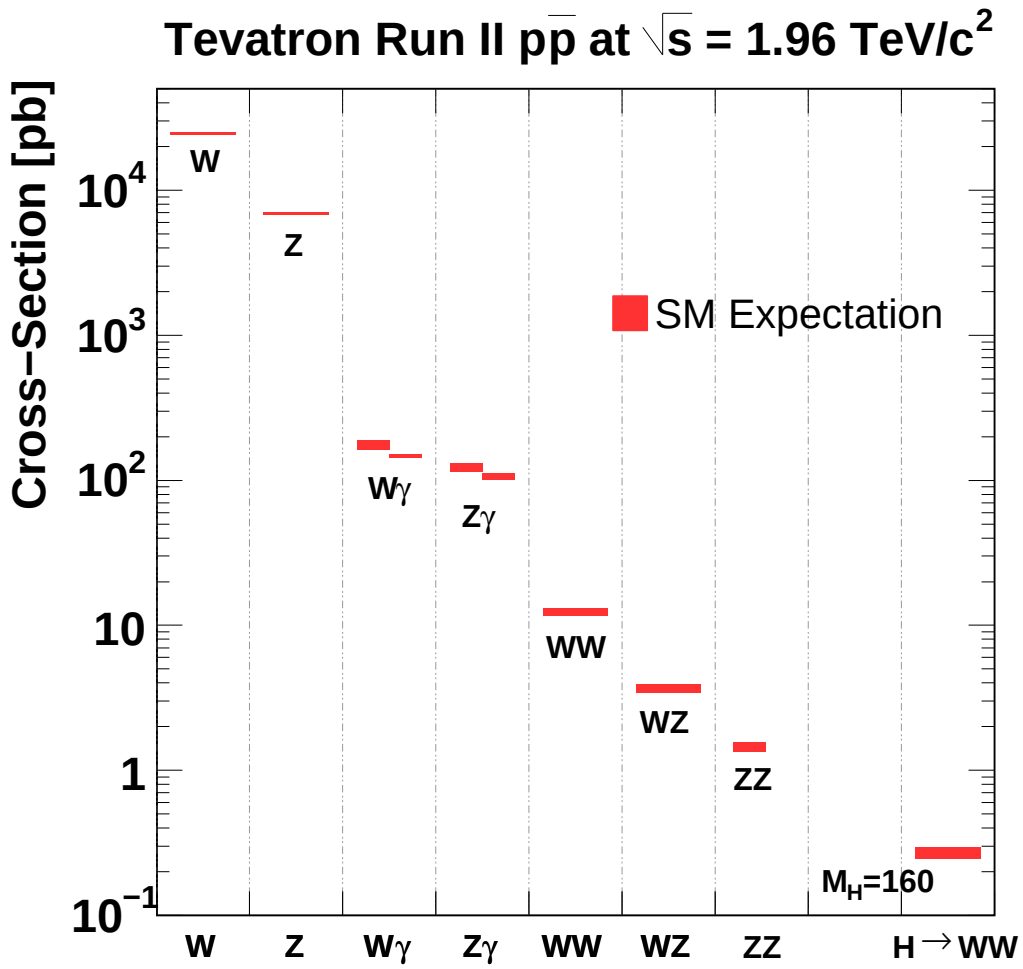
- better distinction of production mechanisms

diboson production (WW, WZ, ZZ, Wγ, Zγ)

- unknown loop contributions?
- anomalous triple gauge couplings?
- high mass particles decaying to two bosons? (Higgs?)

All these require a lot more integrated luminosity to study than $\sigma_{tot}(p\bar{p} \rightarrow$W+X) and $\sigma_{tot}(p\bar{p} \rightarrow$Z+X)

SM cross-section predictions



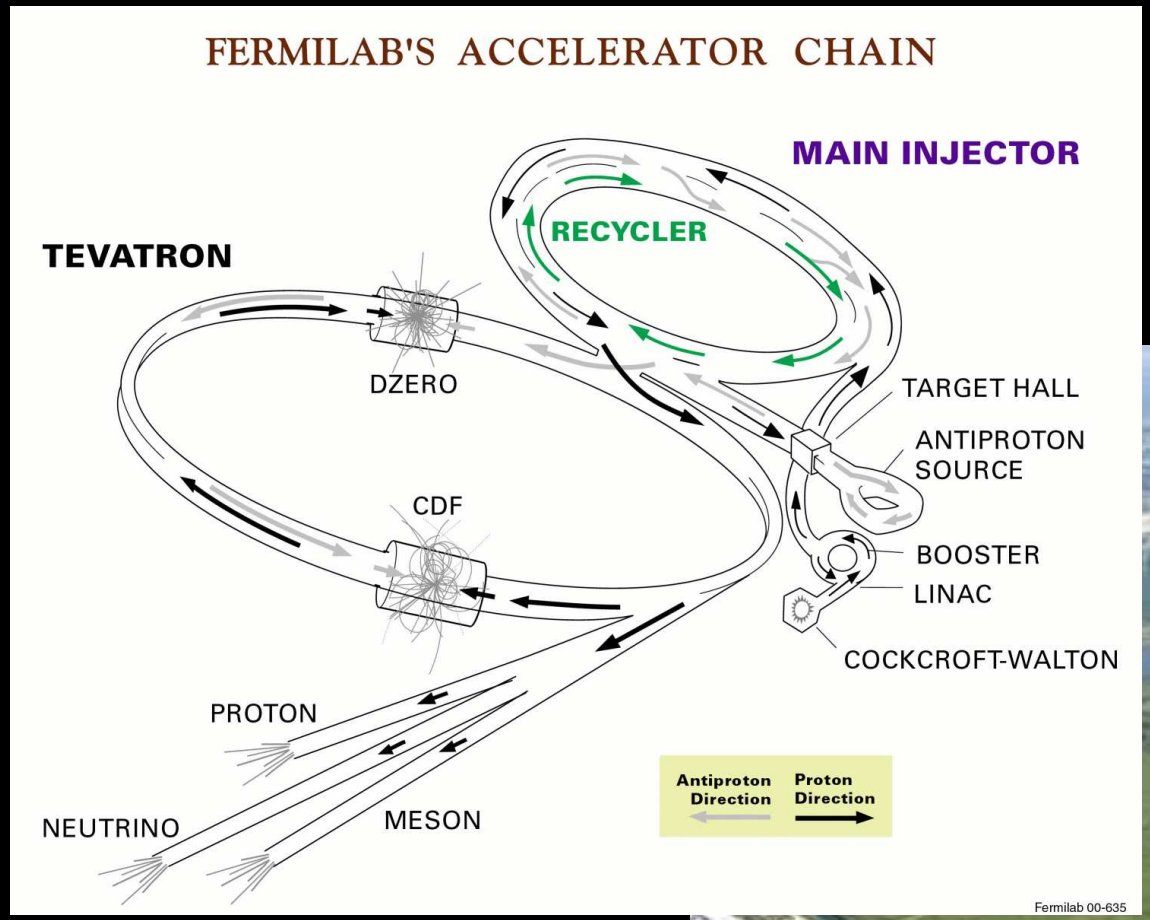
note: this is σ, not $\sigma \times$ BR

reconstructed events:

← O(100k) per fb^{-1} per final state

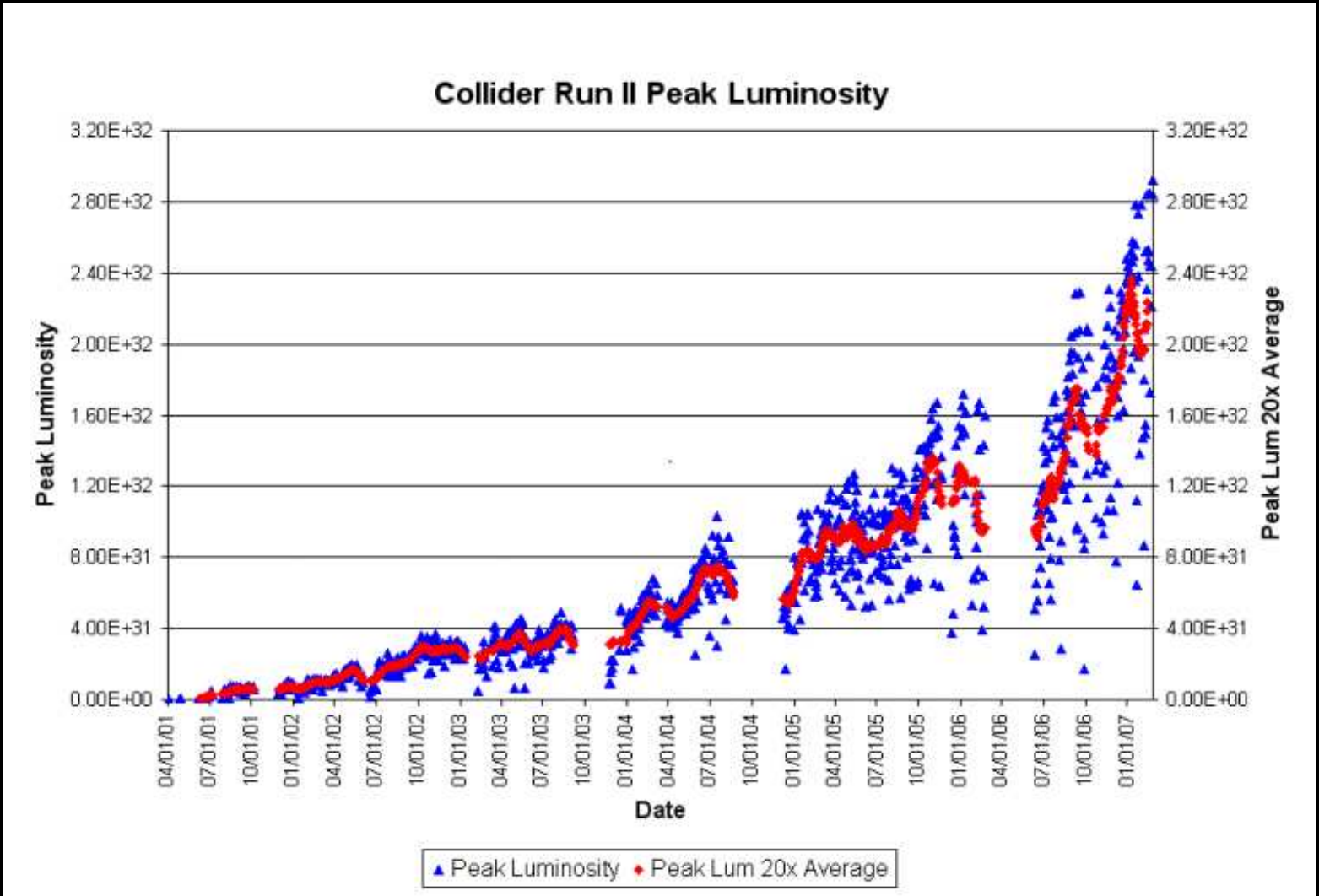
← O(1) per fb^{-1} per final state

Where the fb^{-1} are coming from



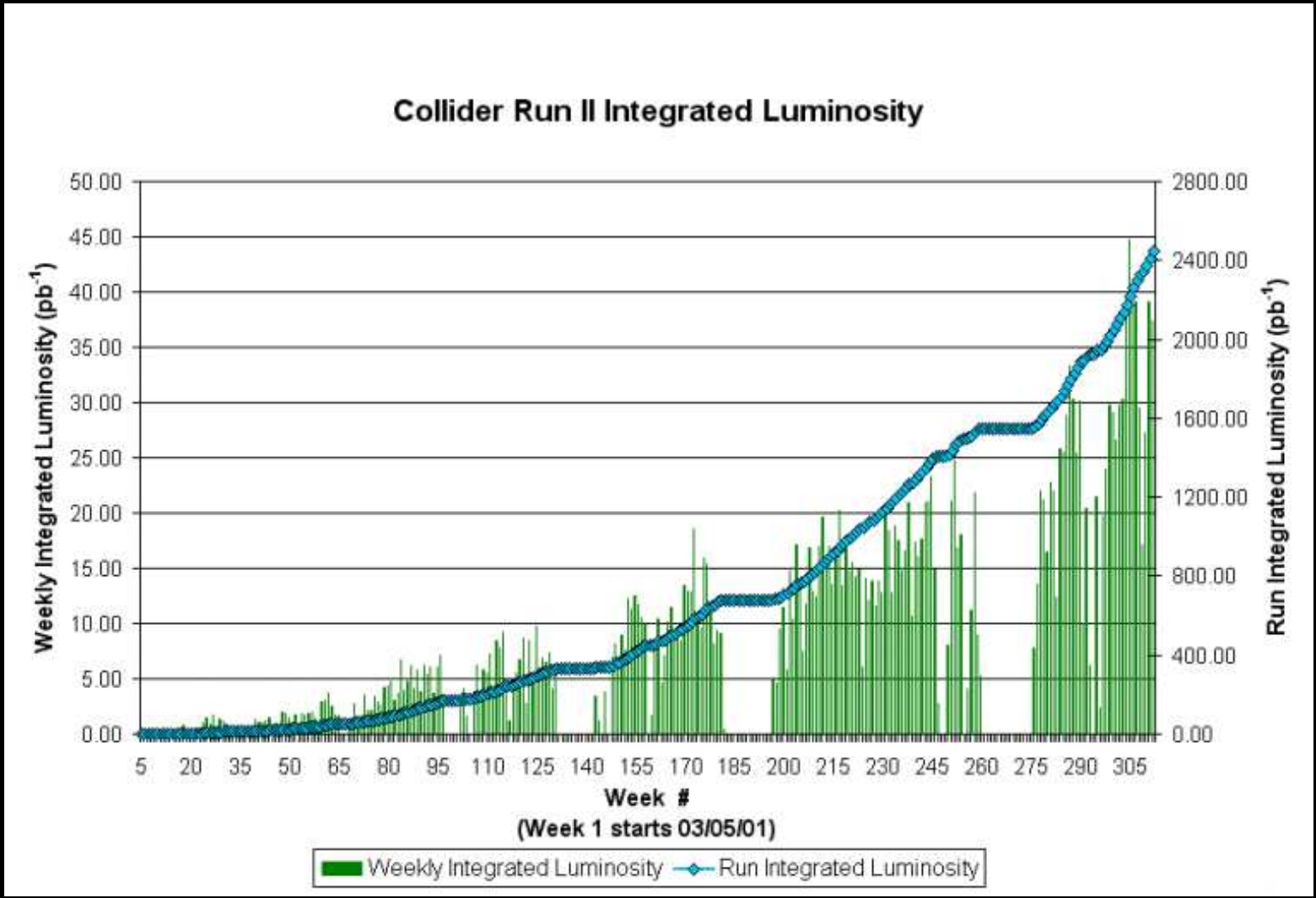
Fermilab's Tevatron:
2 km diameter $p\bar{p}$ collider
centre of mass energy 1.96 TeV

Tevatron performance: peak lumi



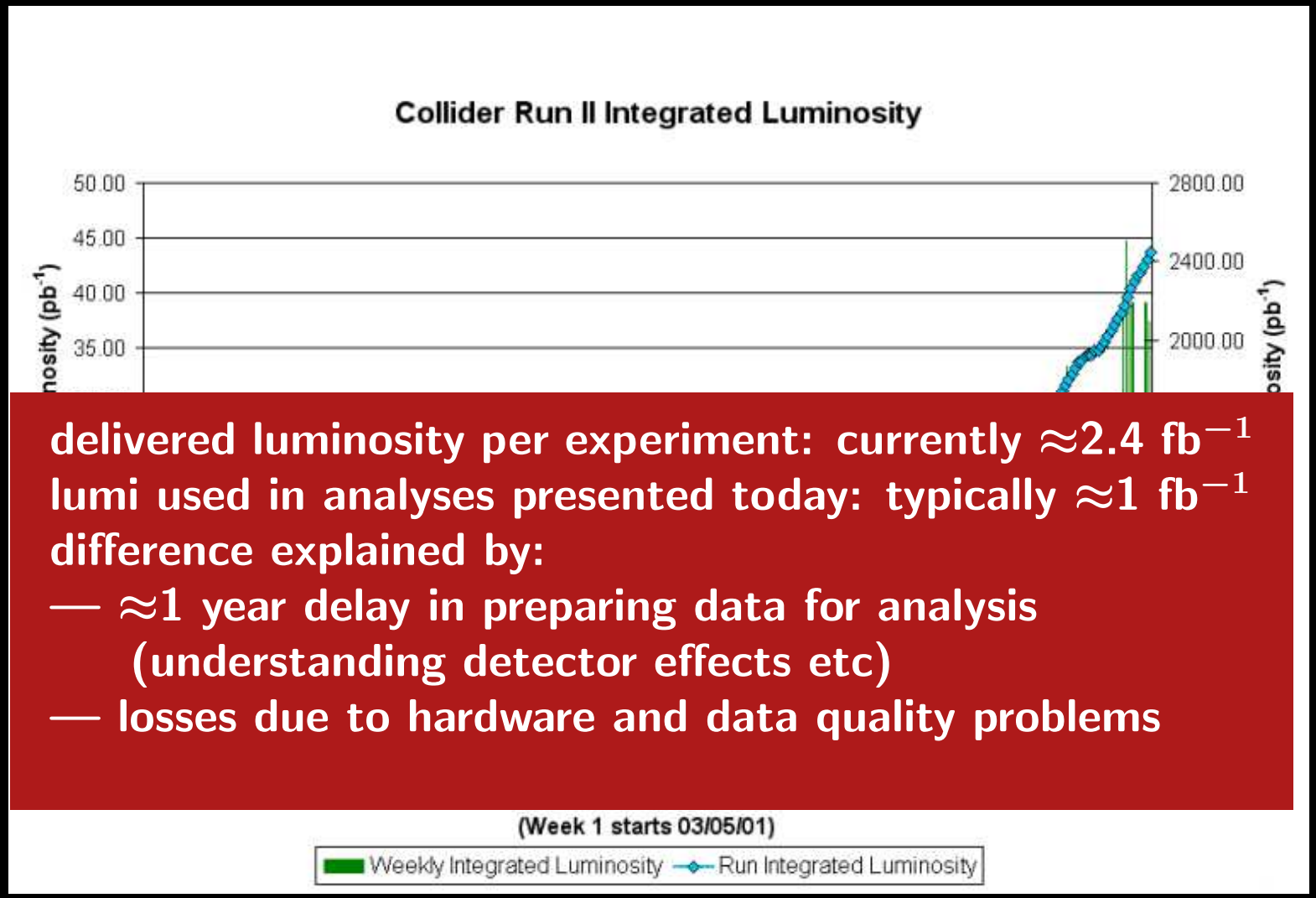
very close to the (revised) design luminosity!

Tevatron performance: integrated lumi



integrated lumi still falling short of 55 pb^{-1} per week expectation.
still problems with antiproton stacking rate!
BUT: delivered lumi per experiment growing quickly

Tevatron performance: integrated lumi



delivered luminosity per experiment: currently $\approx$2.4 fb^{-1}
lumi used in analyses presented today: typically $\approx$1 fb^{-1}
difference explained by:
— $\approx$1 year delay in preparing data for analysis
(understanding detector effects etc)
— losses due to hardware and data quality problems

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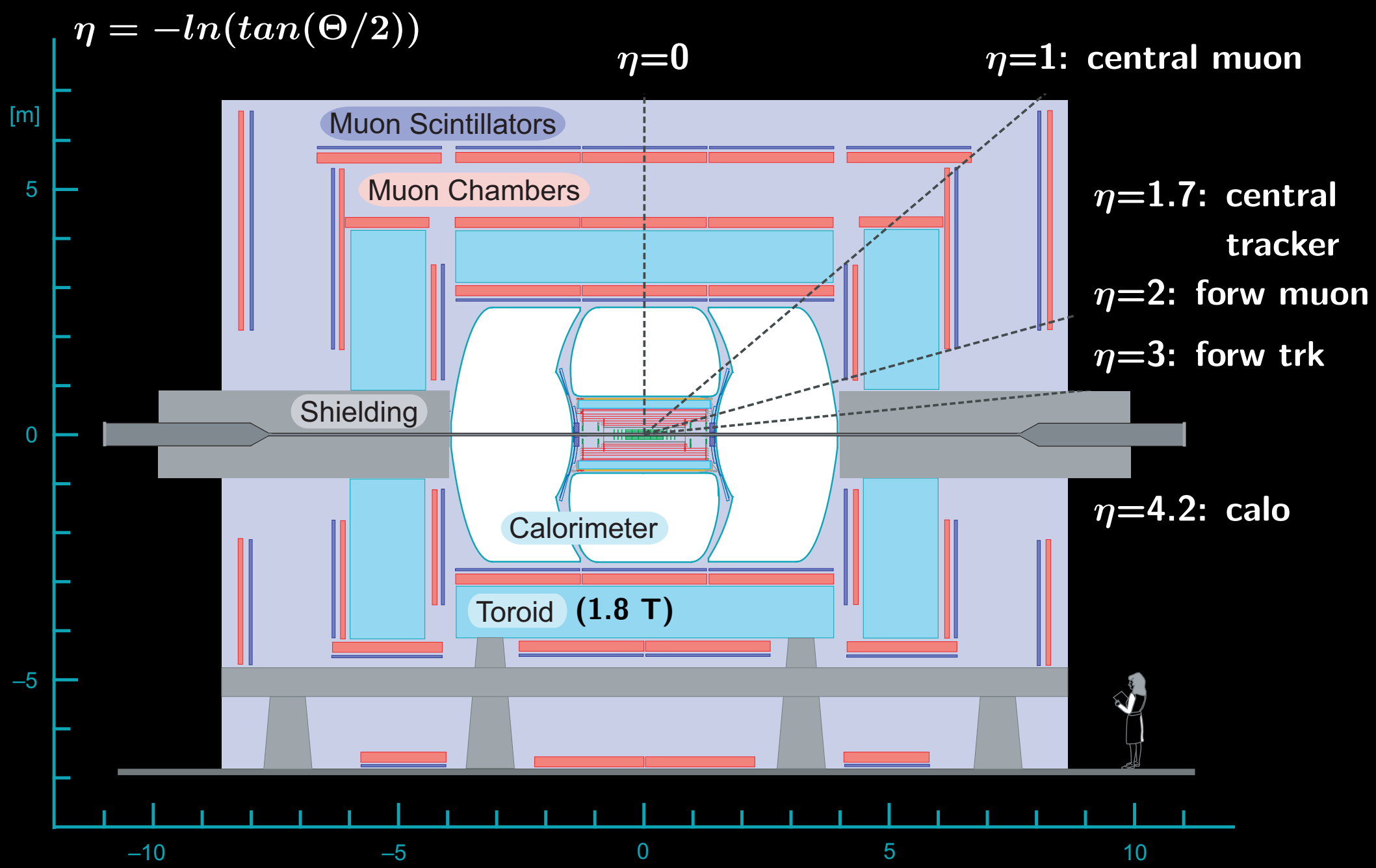
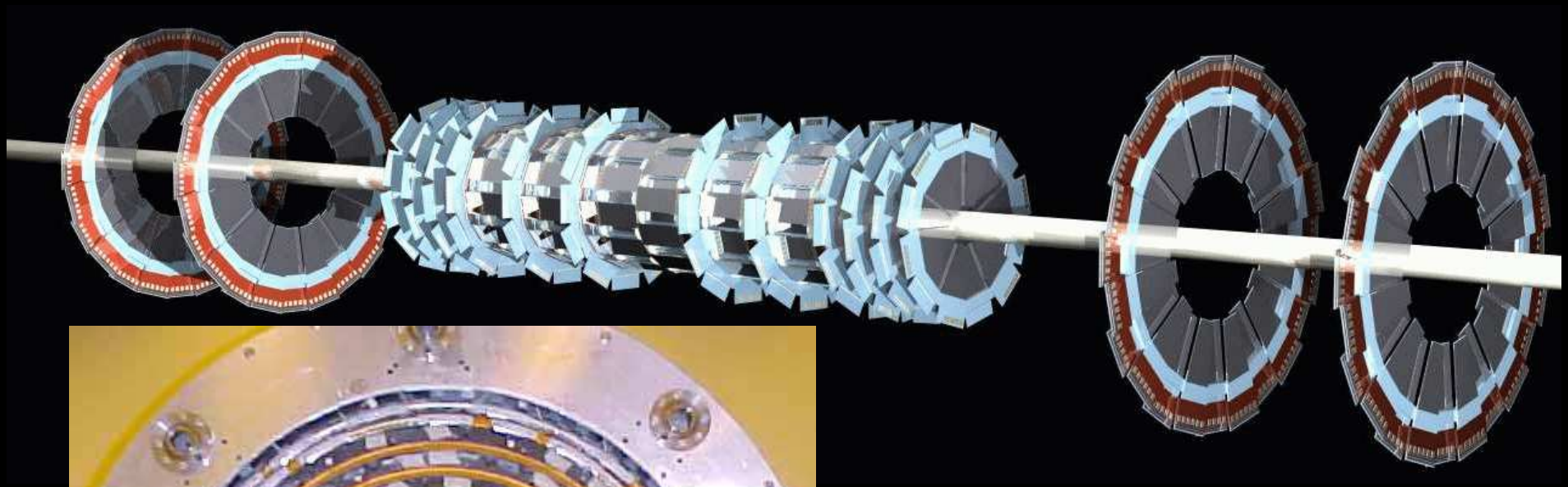
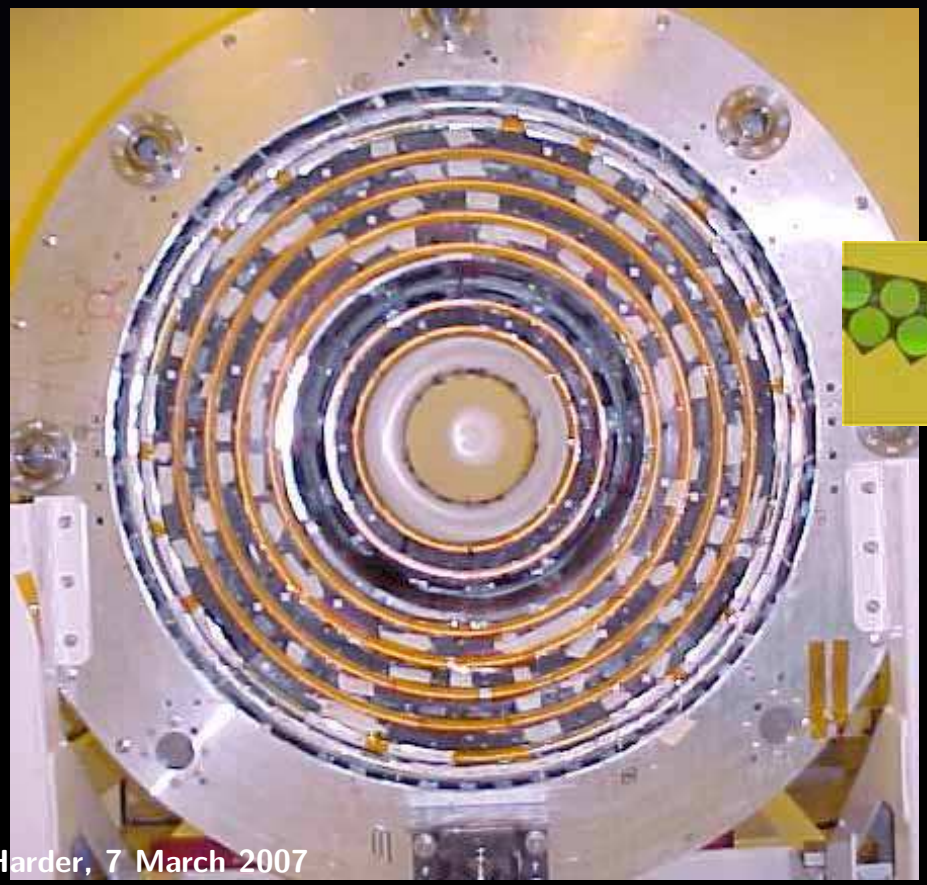
BUT: delivered lumi per experiment growing quickly

DØ Run II detector



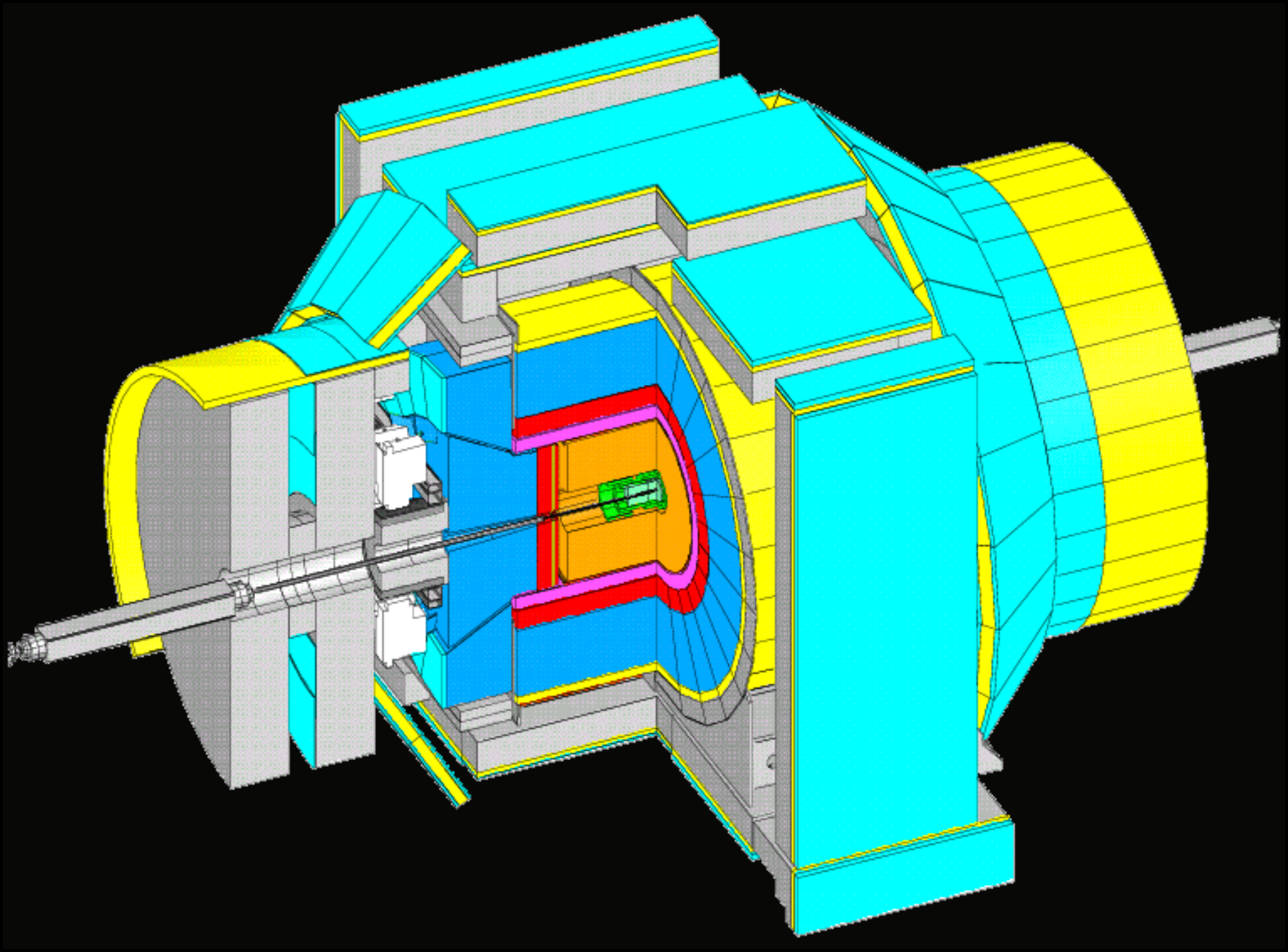
DØ tracking detectors



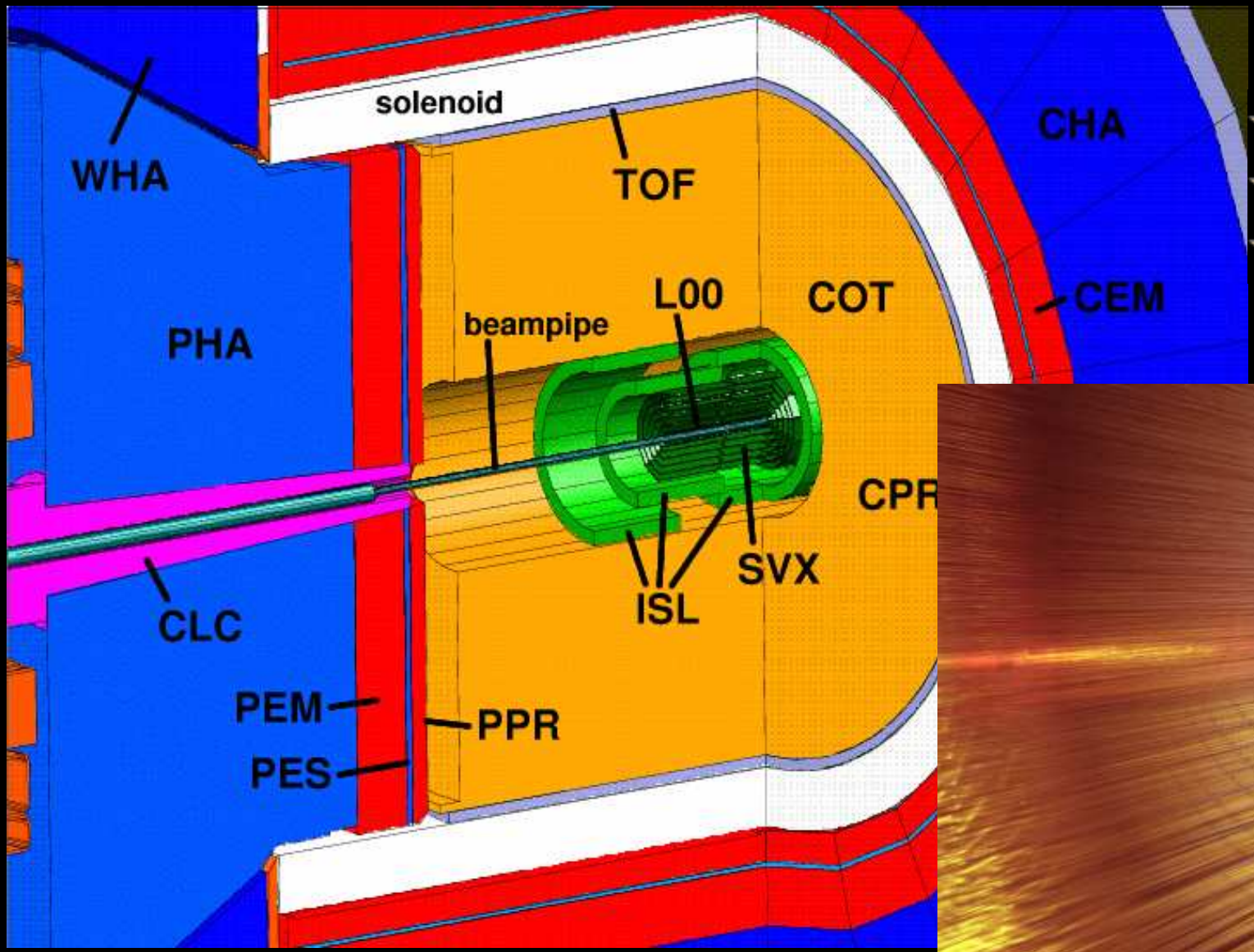


- 8 (+1) layers of silicon strips
- 16 (-2) silicon disks
- 16 scintillating fiber layers
- ≈2 T solenoid

CDF Run II detector



CDF inner detectors



- 6–7 layer silicon
- COT: 96 layer
- 1.4 T solenoid

Electroweak topics of the day

Analyses presented in this talk:

	CDF	DØ
Z rapidity distribution	1.1 fb^{-1}	0.4 fb^{-1} *
Z p_t distribution	—	1 fb^{-1}
Wγ	1.1 fb^{-1}	1 fb^{-1}
Zγ	1.1 fb^{-1}	1 fb^{-1}
WW	0.8 fb^{-1}	—
WZ	1.1 fb^{-1}	1 fb^{-1}
ZZ	1.1 fb^{-1}	—

* = final results,
everything else preliminary

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Wγ	1.1 fb	
Zγ	1.1 fb	
WW	0.8 fb	
WZ	1.1 fb	
ZZ	1.1 fb	

* = final results,
everything else preliminary

11 analyses in 10 minutes?

don't worry, they have a lot in common!

lepton identification

- **electrons**
  - E_t above $\approx$20 GeV
  - shower shape criteria
  - isolation requirement
  - $|\eta|$ coverage CDF $<$1.1 (central), 1.2–2.0 (forward)
    DØ $<$1.1 (central), 1.5–2.5 (forward)

- **muons**
  - p_t above $\approx$20 GeV
  - isolation requirement
  - $|\eta|$ coverage CDF $<$1.1/1.2 (central)
    DØ $<$1 (central), 1–2 (forward)

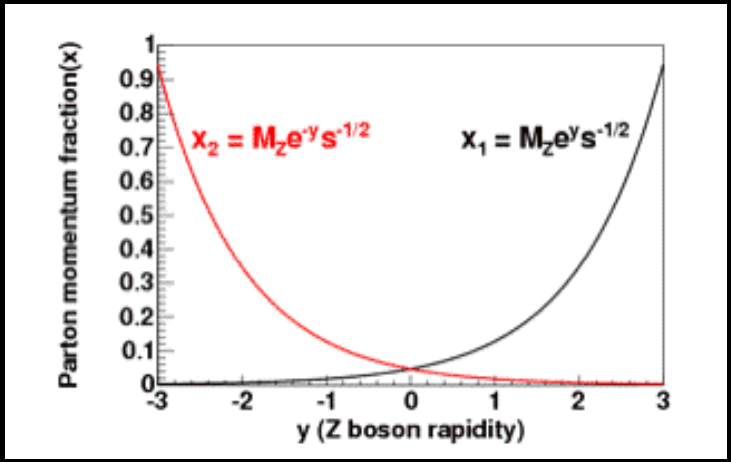
- tau not treated separately. $\tau \longrightarrow e$, $\tau \longrightarrow \mu$ included in e,μ channels

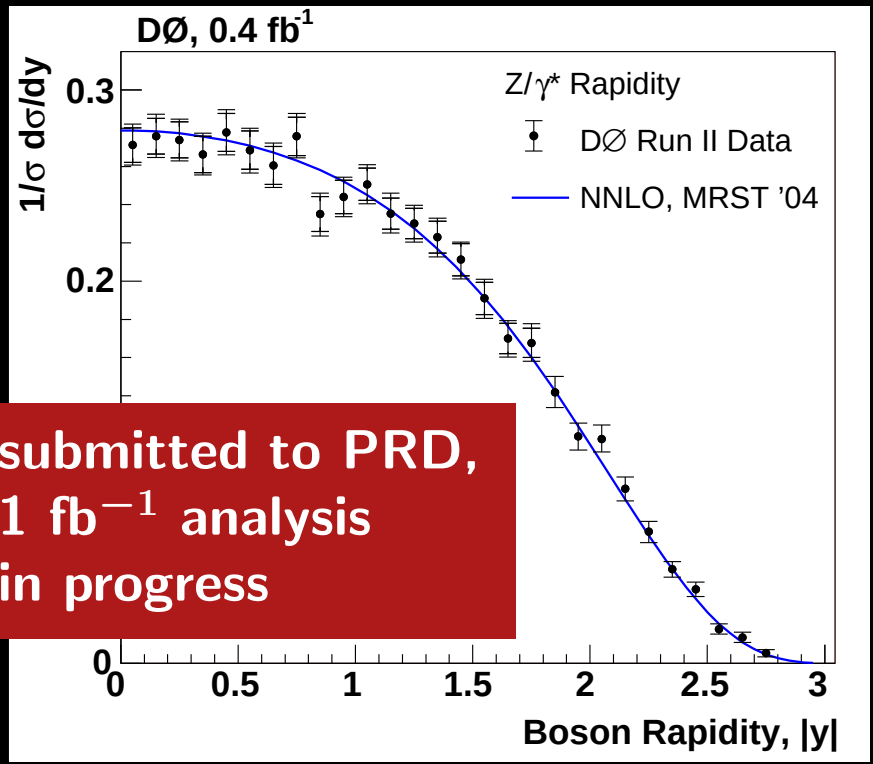
- **neutrinos**
  - missing E_t above $\approx$20 GeV
  - CDF: isolation requirement (angular distance)

differential Z cross sections

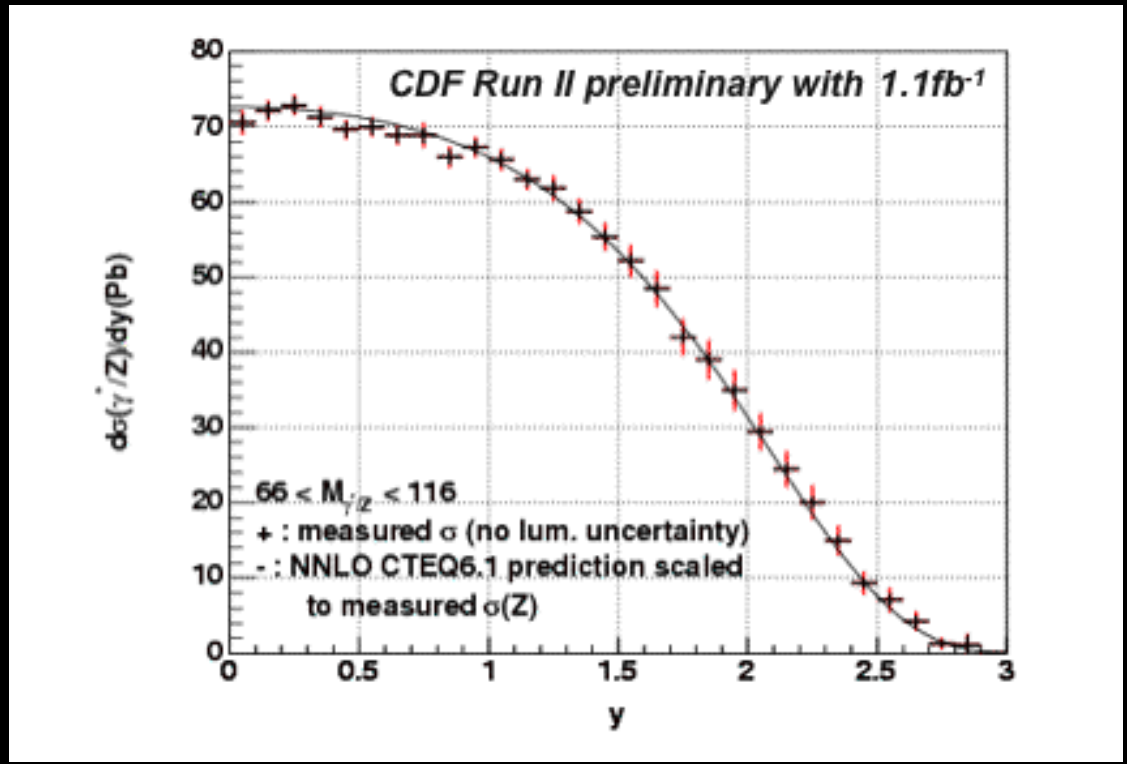
Z rapidity

- forward region probes PDF at low x + large Q^2, and at large x
- use Z$\rightarrow ee$ events: best η range — DØ: $|\eta| < 3.2$, CDF: $|\eta| < 2.8$



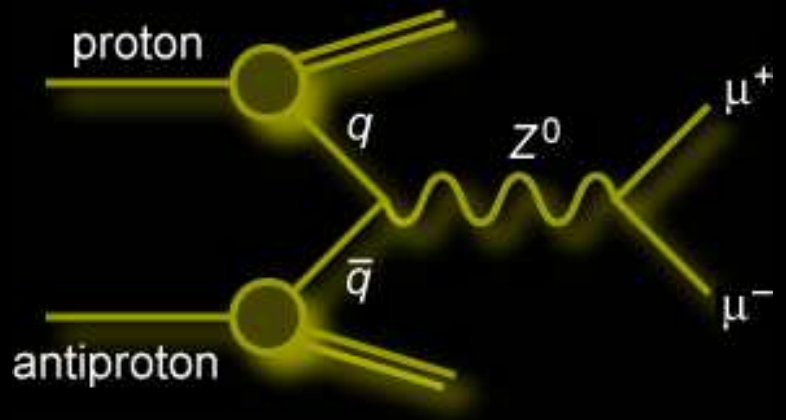


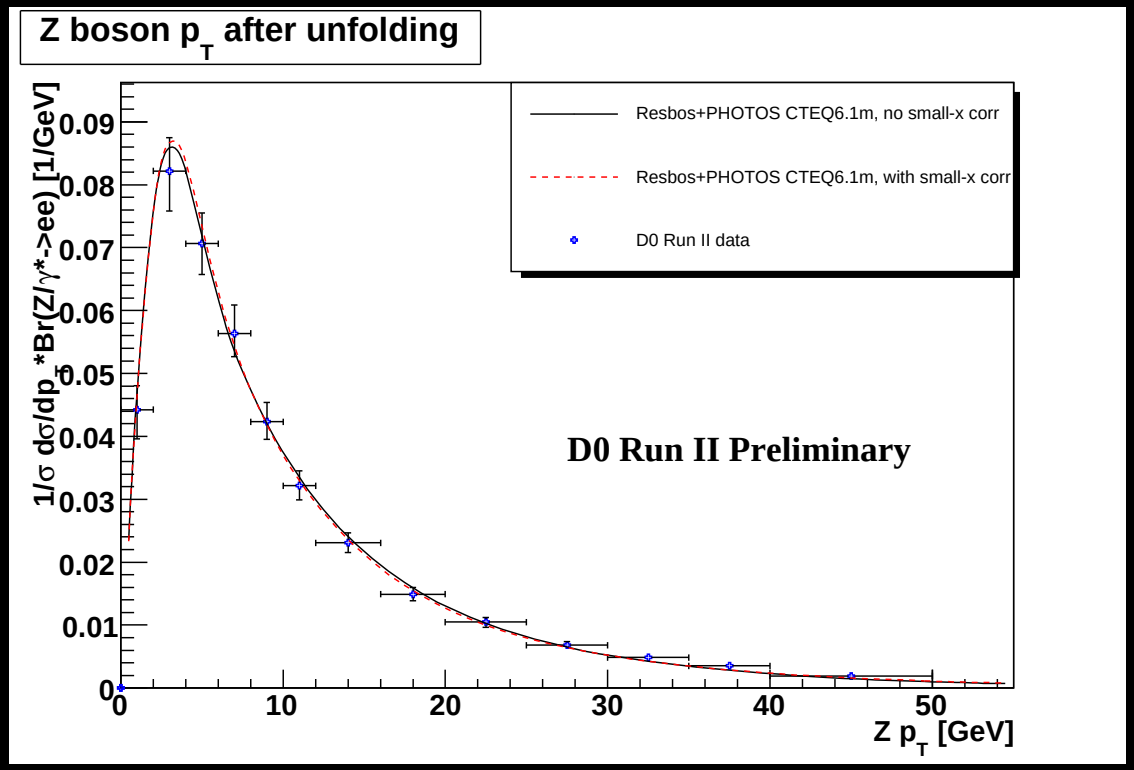
submitted to PRD, 1 fb^{-1} analysis in progress



Z transverse momentum

- boson p_t can be non-zero for NLO
- p_t shape predicted by resummation
- > 1 model for small x (=large rapidity)
  $\longrightarrow$ forward region very interesting!





tricky analysis:
- sensitive to electron energy scale
- p_t dependence of lepton ID

improving model sensitivity:
- more data
- plot in bins of Z rapidity

$\longrightarrow$ updated version due soon

diboson production

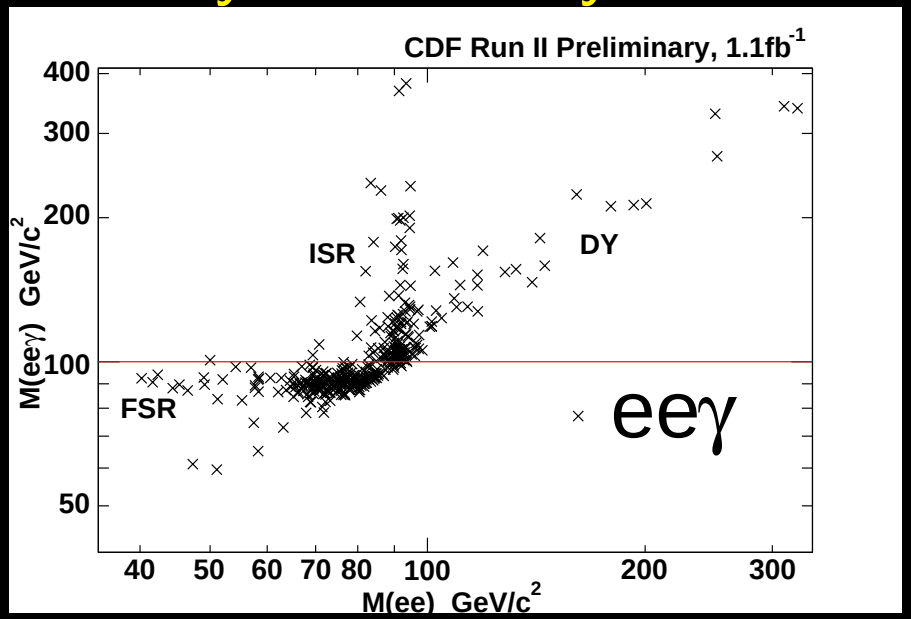
$Z\gamma$ production

no LO $ZZ\gamma$ and $Z\gamma\gamma$ vertices in SM $\rightarrow$ $Z\gamma$ production only as ISR or FSR

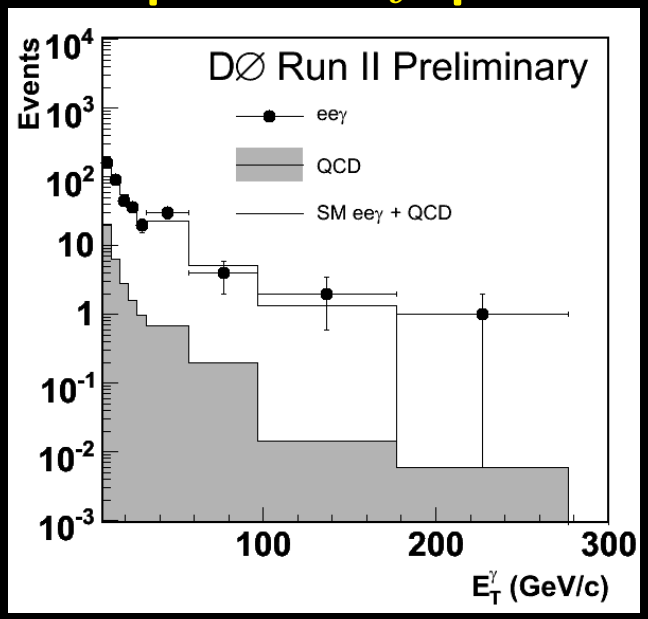
new physics could be found
- as additional $ZZ\gamma$ or $Z\gamma\gamma$ contribution
- potentially with high E_t photons

CDF and DØ analyses: $Z \rightarrow ee$ selection
photon with $E_t > 7$ GeV (angular separation)

two-body vs three-body mass



photon E_t spectrum



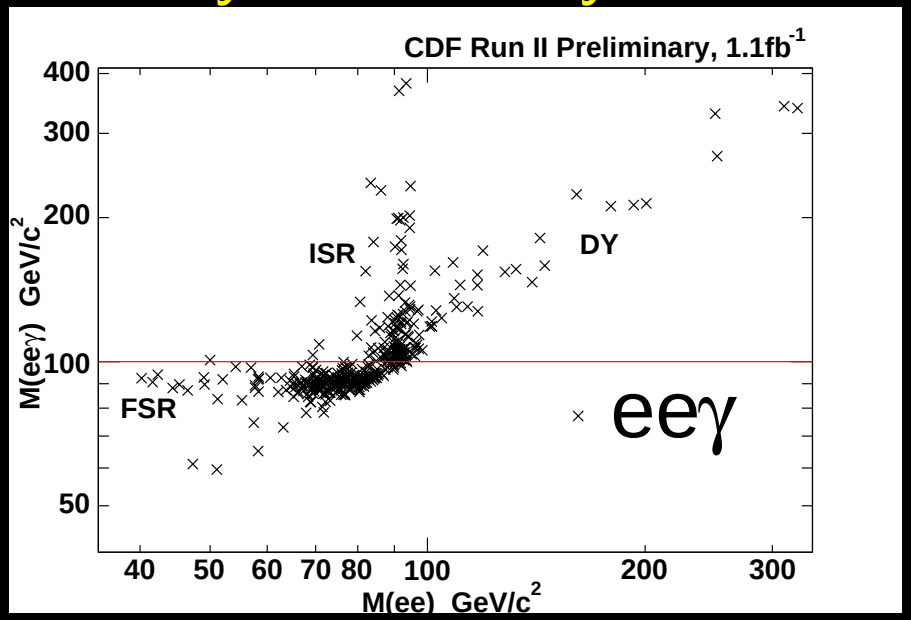
$Z\gamma$ results

	candidates	$Z\gamma$ cross section $\times$ BR	SM prediction
DØ	387	4.51±0.37(stat+syst)±0.27(lum) pb	4.2±0.2 pb
CDF	390	4.9±0.3(stat)±0.3(syst)±0.3(lum) pb	4.7±0.4 pb

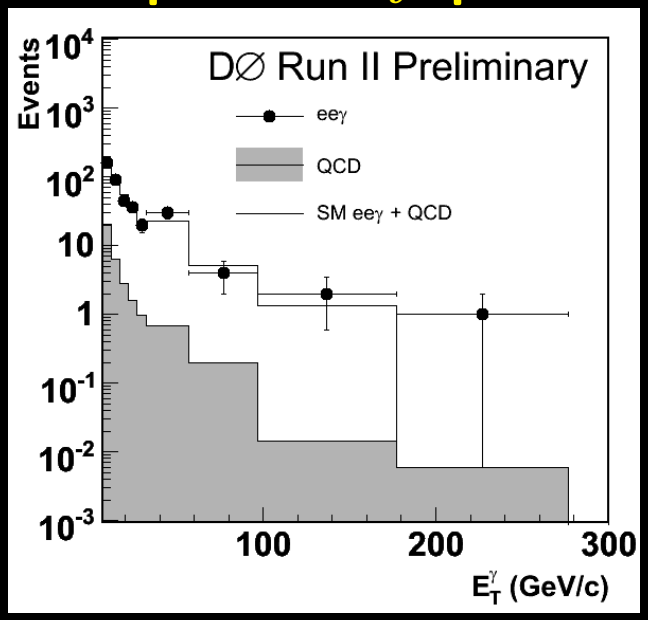
NB: different SM predictions due to different kinematic region

good agreement with Standard Model!

two-body vs three-body mass



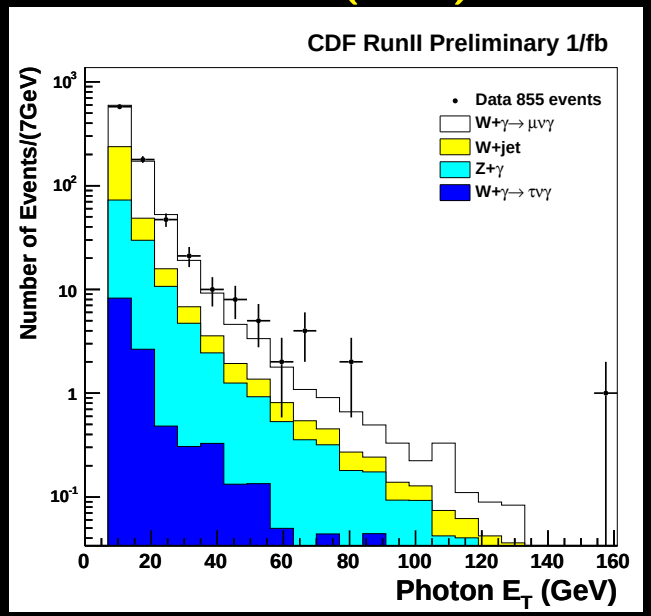
photon E_t spectrum

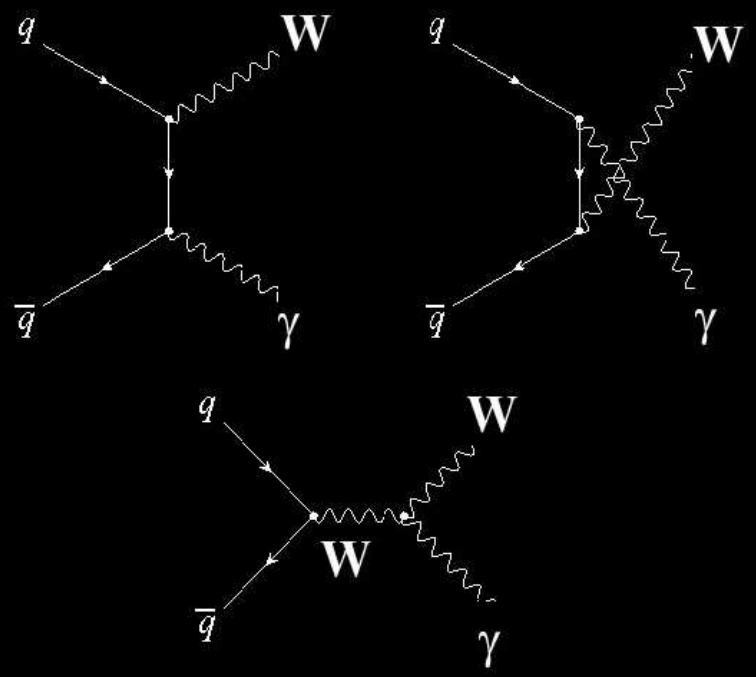


Wγ production

Now *with* LO diagrams:

similar analysis to Zγ,
but W$\rightarrow \mu\nu$ (CDF+DØ),
W$\rightarrow e\nu$ (DØ)





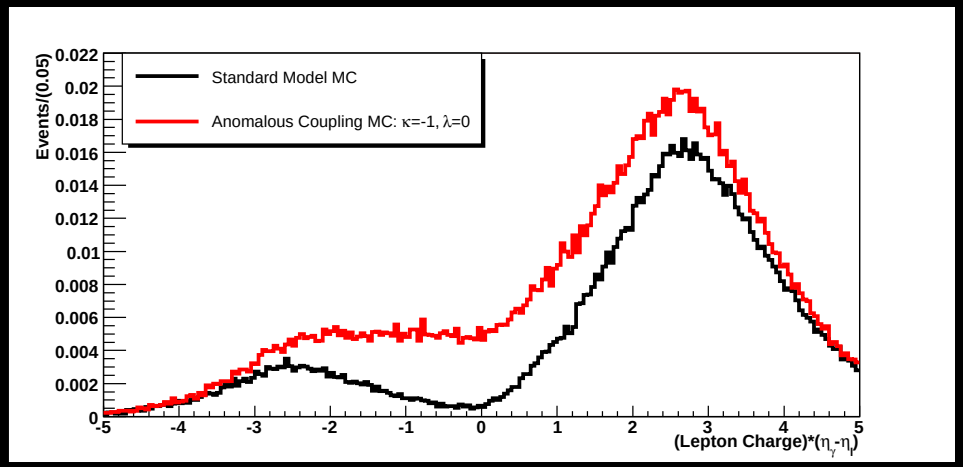
DØ uses tight FSR veto:
$M_t(W\gamma) > 110$ GeV

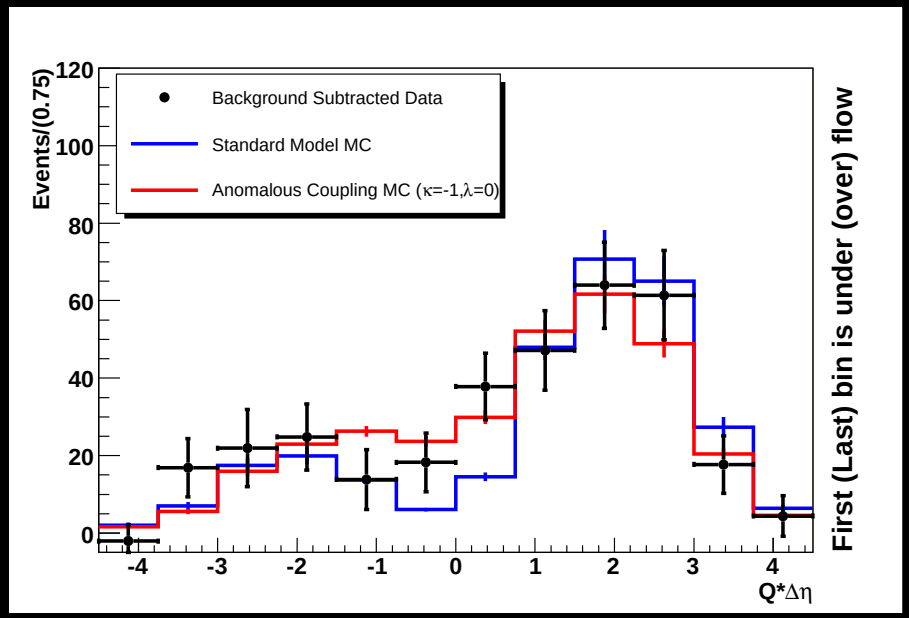
	cands	Zγ cross section $\times$ BR	SM prediction
CDF μ	855	19.11$\pm$1.04(stat)$\pm$2.40(syst)$\pm$1.11(lum) pb	19.3$\pm$1.4 pb
DØ μ	245	3.21$\pm$0.49(stat+syst)$\pm$0.20(lum) pb	3.21$\pm$0.08 pb
DØ e	389	3.12$\pm$0.49(stat+syst)$\pm$0.19(lum) pb	3.21$\pm$0.08 pb

DØ Wγ ++

increased sensitivity to anomalous couplings through
charge-signed rapidity difference:

interference between tree-level diagrams
➡ dip in $Q_\ell \times [y(\gamma) - y(\ell)]$





prediction (SM vs example anom TGC) data

good agreement with Standard Model
...and with many other scenarios...
clearly need more data for this measurement!

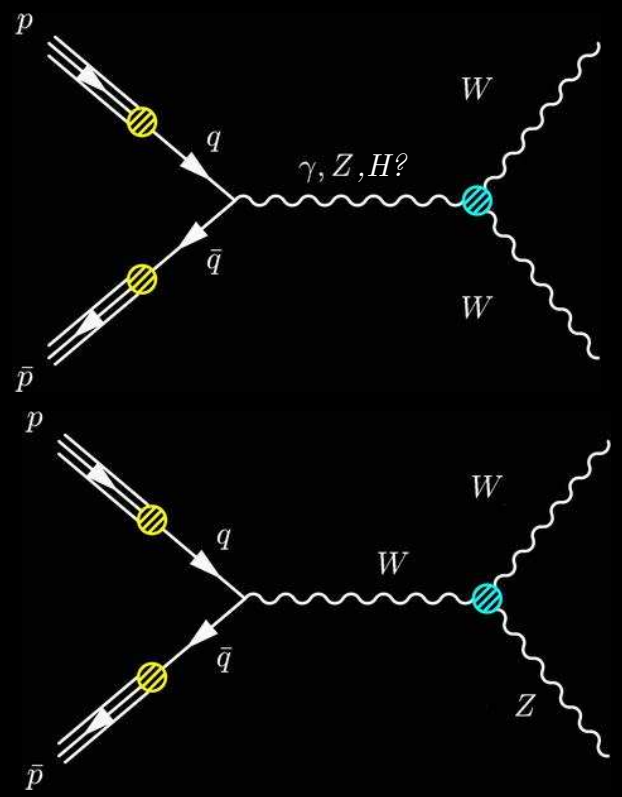
WW, WZ, ZZ

WW
(SM: 12.4±0.8 pb)

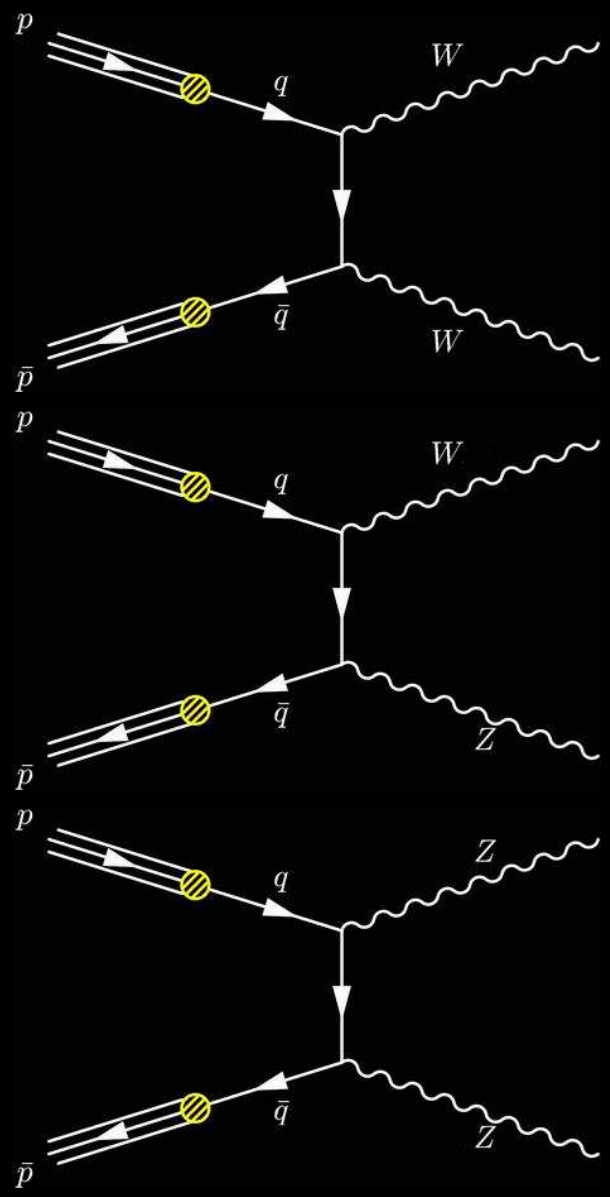
WZ
(SM: 3.7±0.3 pb)

ZZ
(SM: 1.4±0.1 pb)

s-channel

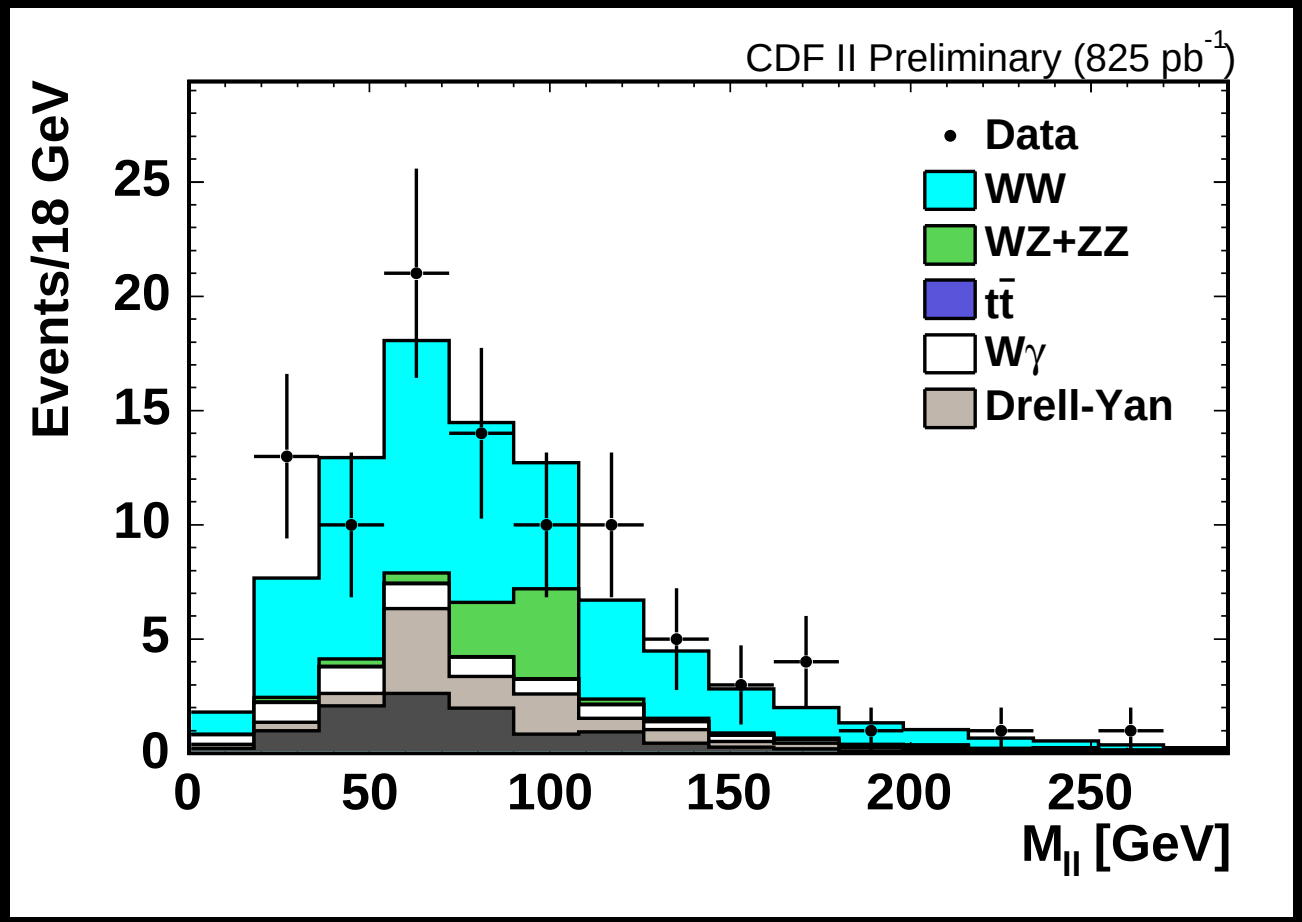


t-channel



CDF WW with 0.8 fb^{-1}

WW$\rightarrow \ell\ell\nu\nu$ with $\ell\ell = ee,\ e\mu,\ \mu\mu$
$\approx$ std lepton selection, missing E_t, jet veto, opposite charge, $|\Delta z| < \pm 4$ cm



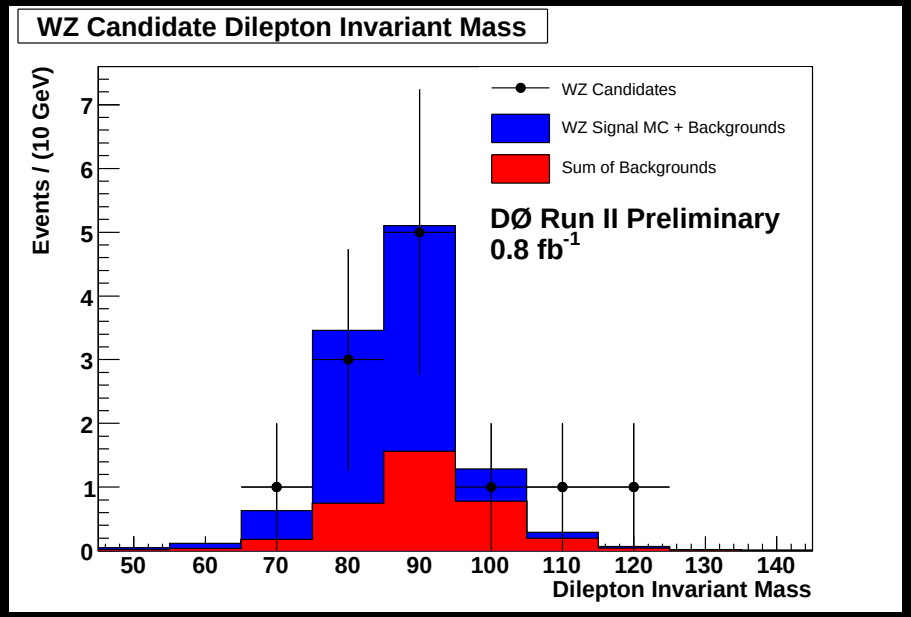
95 events, cross section 13.6$\pm$2.3(stat)$\pm$1.6(syst)$\pm$1.2(lumi) pb,
SM prediction 12.4$\pm$0.8 pb

WZ observation

WZ$\rightarrow \ell\ell\ell\nu$, with eee, $ee\mu$, $e\mu\mu$, $\mu\mu\mu$ (total BR $\approx$1.5%)
again, standard lepton and missing E_t selection.
require two leptons in Z mass window.

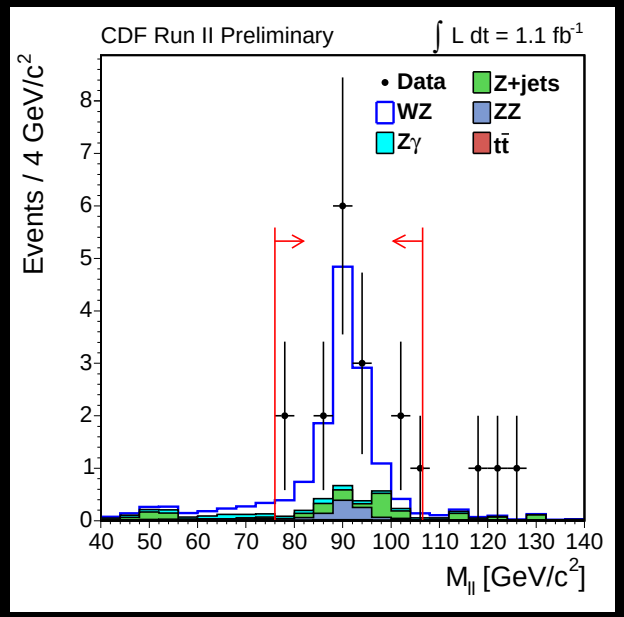
selection results:

	candidates	background	signal significance
DØ:	12	3.61$\pm$0.20	3.34σ
CDF:	16	2.65$\pm$0.28$\pm$0.33$\pm$0.09	6.0σ



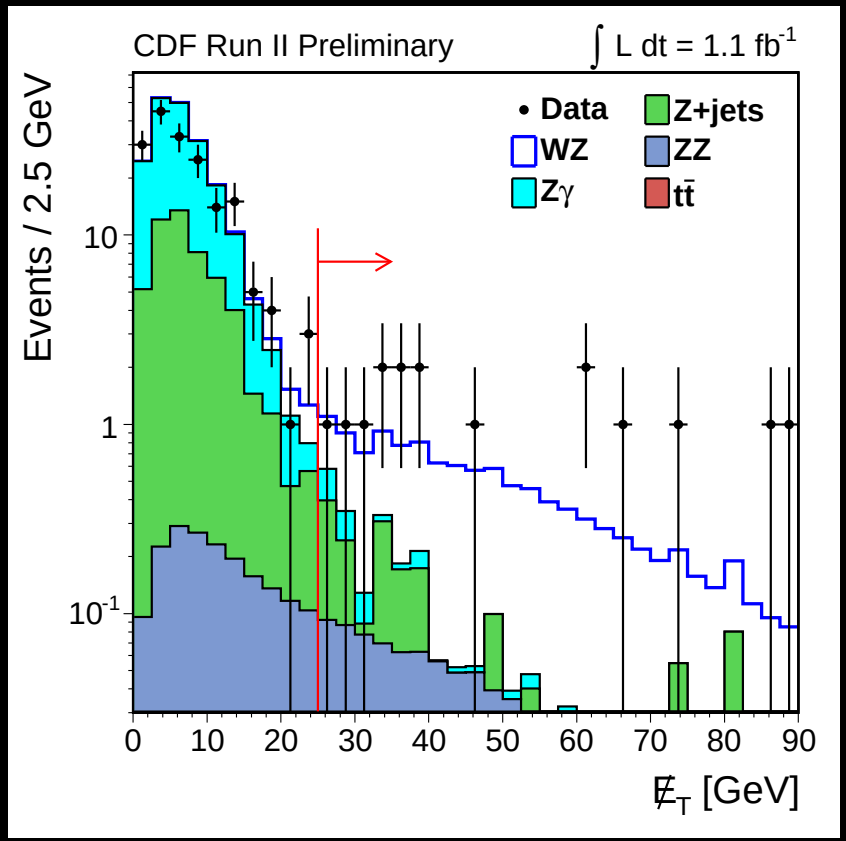
Z mass

background composition similar, just overall worse S/B ratio for DØ



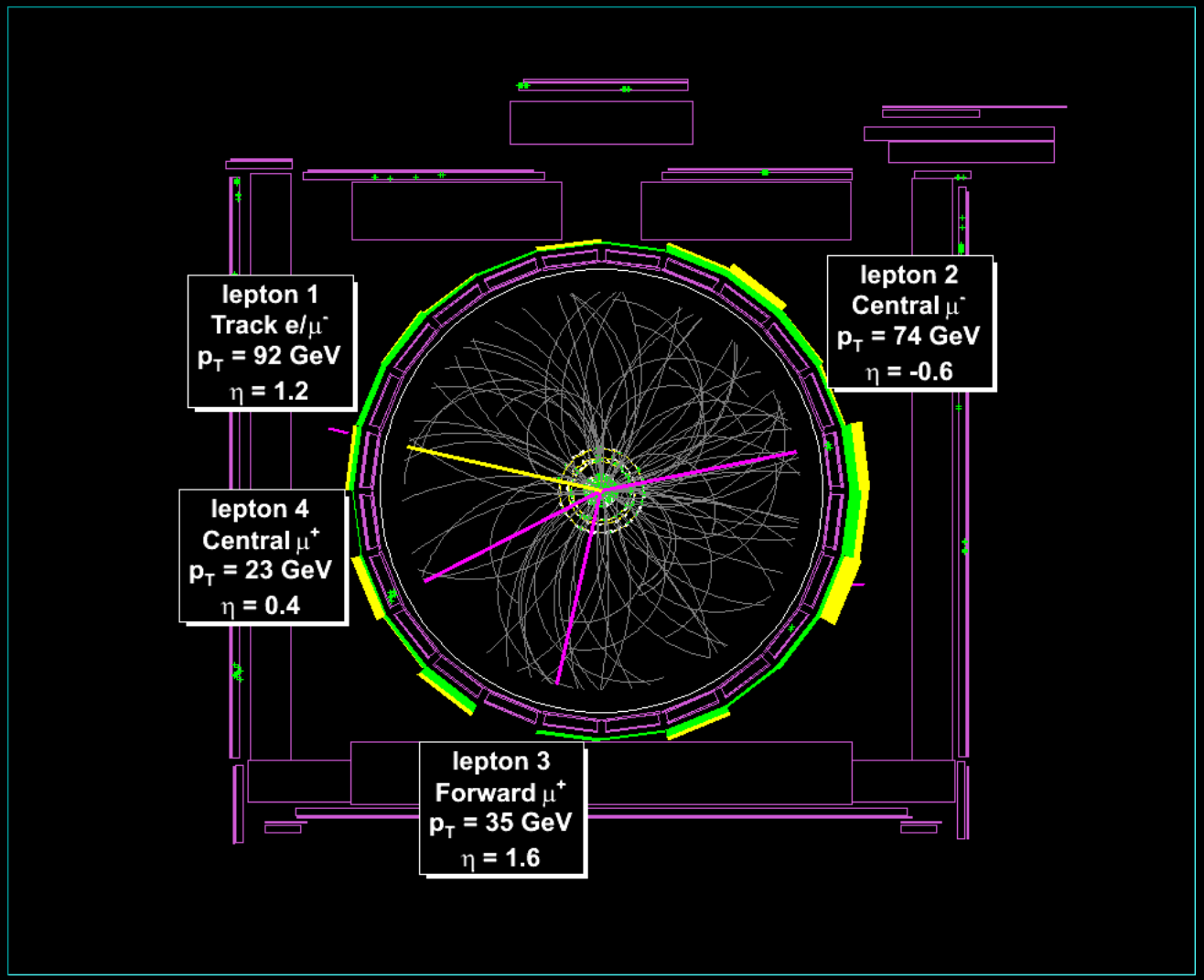
WZ cross section

	measured	predicted
CDF	$5.0^{+1.8}_{-1.4}$(stat)$\pm$0.4(syst) pb	3.7$\pm$0.3 pb
DØ	$4.0^{+1.9}_{-1.5}$(stat+syst) pb	3.7$\pm$0.3 pb



CDF ZZ search

How about events with 4 leptons? SM predicts ≈2 events in 1 fb^{-1}...



Here is a candidate.

The only one so far.

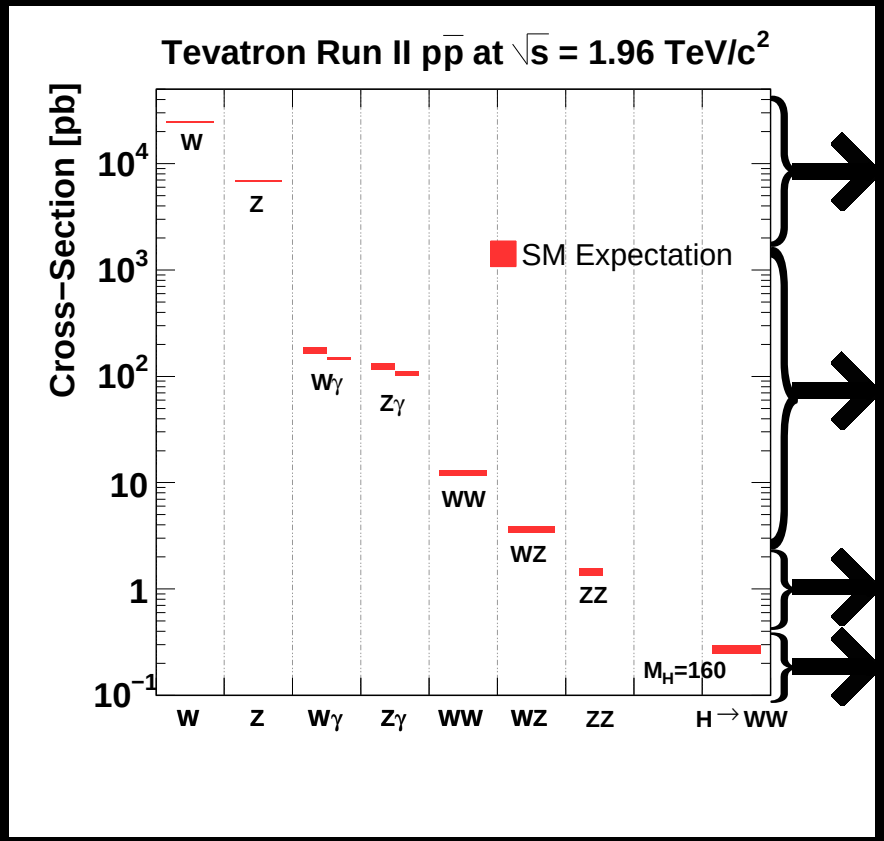
$\sigma(ZZ)<3.8$ pb
(95% C.L.)

(SM: 1.4±0.1 pb)

With 4–8 fb^{-1}, this could become another first observation.

Summary

- DØ+CDF data samples increase quickly
- understanding of detector response improving as well
- bringing electroweak precision physics to the ~~next~~ next-to-next level!



precision physics playground

established signals —
more data should help to improve those!

promising searches

acts of desperation → LHC?

Acknowledgments

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Assessorat de l'Éducation et de la Culture

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(content providers)

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