Luminosity determination at the TEVATRON

presented by:

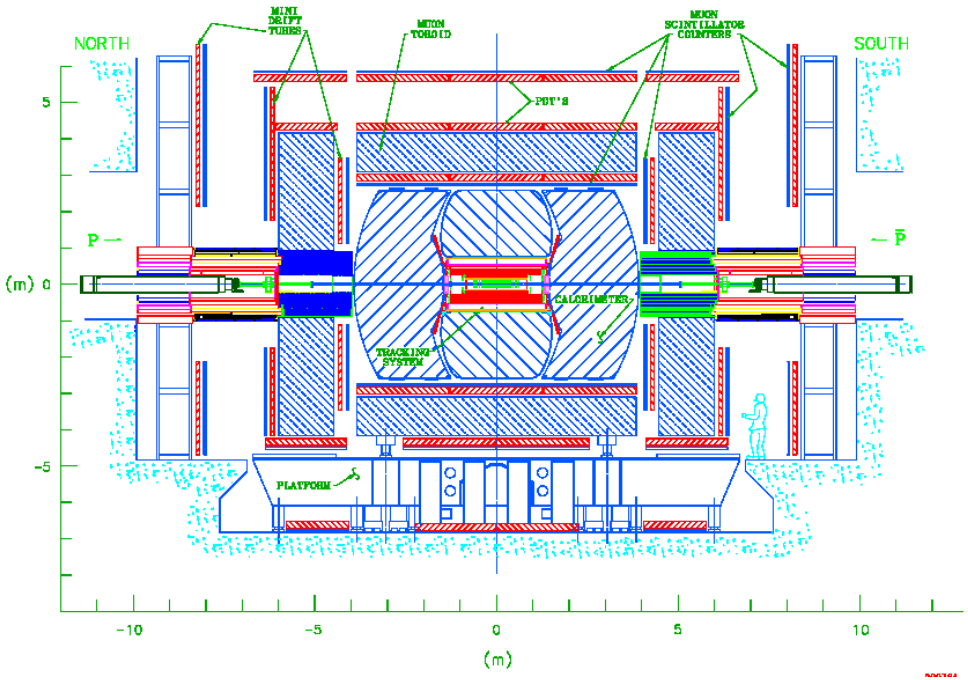
Sergey Klimenko

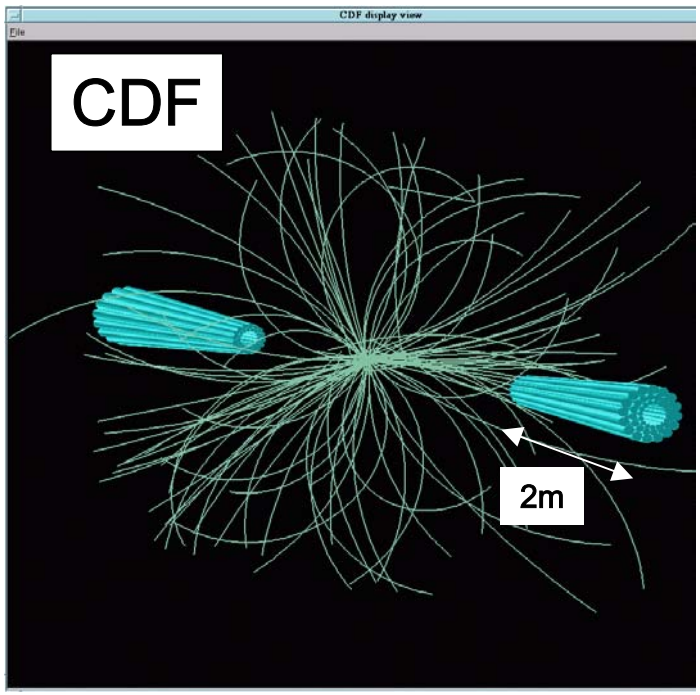
University of Florida

for CDF and D0 collaborations

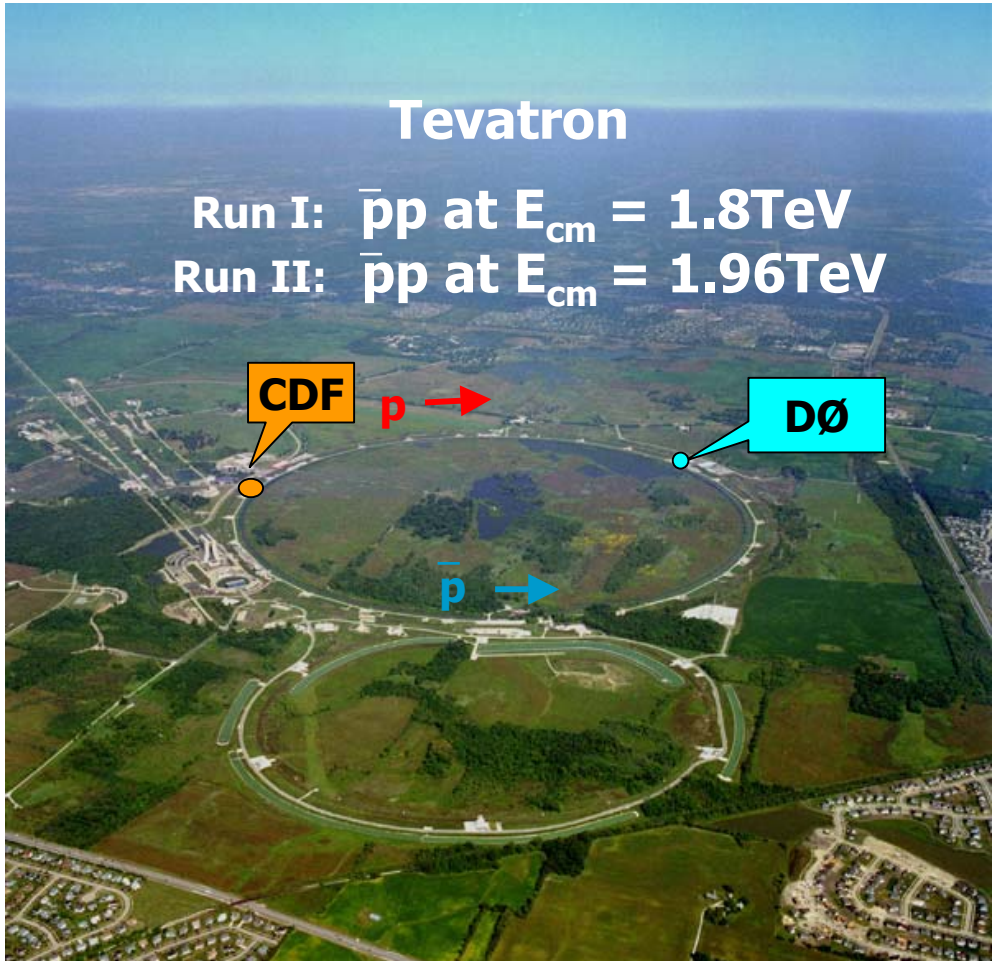
- Tevatron Luminosity
- Reference processes
- L measurement at B0 (CDF)
- L measurement at D0 (DØ)
- Summary

DØ

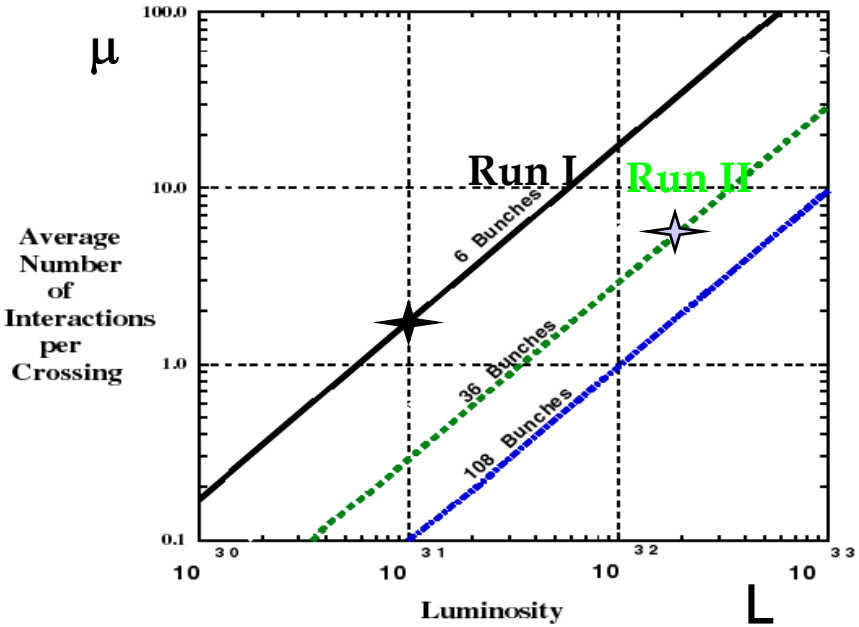




Tevatron Luminosity in Run II



Expected
$L \sim 2*10^{32} cm^{-2} sec^{-1}$
$\mu \sim 6$ PPbar/BC



Current peak Luminosity $\sim 3*10^{31} cm^{-2} sec^{-1}$

Reference Processes: inelastic p-pbar

- Inelastic cross-section
  - ✓ *55.50 ± 2.20* mb (E710: Phys.Rev.Let, 68, p2433, 1992)
  - ✓ *60.33 ± 1.40* mb (CDF: Phys.Rev.D, 50, p5550, 1994)
  - ✓ *55.92 ± 1.19* mb (E811: Phys.Let.B, 445, p419, 1999)

  measured @1.8TeV using the optical theorem, along with the total & elastic x-sections

  What σ_{inel} to use? Run I: CDF(BBC), DØ($\overline{\text{world}}$); Run II ($\overline{\text{CDF\&E811}}$?)

  What is the error for σ_{inel}? CDF&E811 combined: ~4% (PDG)

→ For Run II CDF & **DØ do not quote the error associated with σ_{inel}** yet

- Detected with dedicated L monitor at small angles
  - ✓ **real-time, instantaneous&integrated, delivered&live, bunch by bunch luminosity**
  - ✓ **z profile of collisions**
  - ✓ **minimum bias trigger**

inelastic p-pbar (continue)

- Luminosity measurement

$$R_{pp} = \mu_{pp} \cdot f_{BC} = \sigma_{inel} \cdot \varepsilon_{pp} \cdot \delta(L) \cdot L$$

σ_{LM}

L – luminosity
f_{bc} – Bunch Crossing rate
μ_a – # of pp /BC

σ_{inel} – inelastic x-section
ε_{pp} – acceptance for a single pp
$\delta(L)$ – detector non-linearity

- LM acceptance:

$$\sigma_{inel} \sim 60\,\text{mb} \rightarrow \begin{cases} \sigma_h & \text{hard core} \\ \sigma_{dd} & \text{double diffractive} \quad (\sigma_{dd} \sim \sigma_{sd}^2 / 2\sigma_{el}) \\ \sigma_d = 9.54 \pm 0.43\text{mb} & \text{single diffractive (CDF, E710)} \end{cases}$$

recent CDF measurement of *dd* x-section: PRL 87 141802 (2001) → σ_{dd} =7.5 ±2.0 mb

$$\varepsilon_{pp} = \frac{\varepsilon^h \cdot \sigma_h + \varepsilon^d \cdot \sigma_d + \varepsilon^{dd} \cdot \sigma_{dd}}{\sigma_{inel}}$$

→ requires large acceptance LM or
its normalization against large acceptance detector with $\varepsilon^h \sim \varepsilon^{dd} \sim 100\%$

→ ε_{pp} can be obtained from simulation with a few percent uncertainty
total expected δL due to uncertainty of $\sigma_{inel}\ \varepsilon_{pp}$ <5%

Methods of L measurement with inelastic PPbar

- Counting of BC with no interactions (zeroes):

$$P_0 = e^{-\mu}$$

  - *requires large acceptance detector*
  - *non-linear corrections due to pile-up of PPbar interactions at large μ.*
  - *Used both by DØ and CDF*

$$\mu = -\ln(N_{zeroBC} / N_{totalBC})$$

$$P_0 = 0.2\% @ \mu = 6$$

- Counting of hits

$$\mu = \langle N_{hits/BC} \rangle / \langle N_{hits/p\bar{p}} \rangle$$

  - *requires high granularity to achieve low occupancy*
  - *very non-linear for large μ*

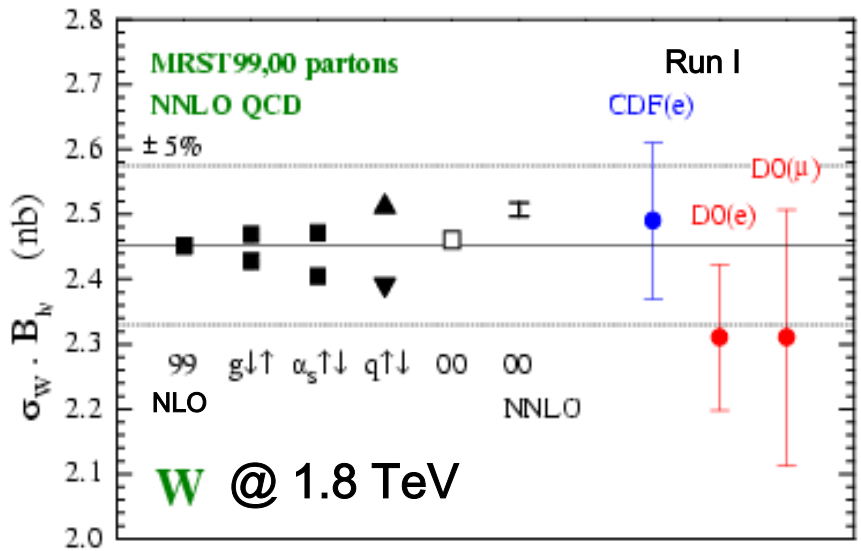
- Counting of "particles"

$$\mu = \sum A_i / \langle A_{p\bar{p}} \rangle$$

  - *Detector response proportional to energy flux or number of particles*
  - *best for high L (μ>>1)*
  - *Used by CDF Run II luminosity monitor CLC*

Reference processes: W→lep,nu

- **x-section @ 1.96 TeV ~2.73 nb**
  with ~4% theoretical uncertainty
  (Eur.Phys.J.C14 (2000) 133-145)
  - ✓ PDF, EWK param, scale variation, higher order corrections



- **Expected rate @L=2 10^{32} ~ 0.5Hz**
  - ✓ **good for off-line L**
- **Not trivial:**

$$N_W = L \cdot \sigma(p\bar{p} \to WX) \cdot B(W \to e\nu) \cdot \varepsilon_{\not{E}t} \cdot \varepsilon_{E_T,\eta} \cdot \varepsilon_{Trk} \cdot \varepsilon_{P_T} \cdot \varepsilon_{Iso} \cdot \varepsilon_{ID} \cdot \varepsilon_{Event} \cdot \varepsilon_{Trig}$$

- ✓ *Trigger+selection efficiency ~25%*
- ✓ *Background: QCD, Z→ll, W→τν,..*

} → 3%-4% sys. error

δL of 5% is feasible, which is comparable with the inelastic p-pbar

Luminosity measurements in Run I

CDF

CDF/PUB/Electroweak/4956 April 1999

- process: inelastic PPbar scattering
- detector: BBC
  - ✓ *16X2 scintillating counters*
  - ✓ *Rapidity coverage: $3.24<\eta<5.90$*
  - ✓ *BBC x-section: 51.15 ± 1.60* **mb**

    measured along with total, elastic and single diffractive x-section
- method: counting of zeroes
- δL: 3.6%(1a), 4.1% (1b)

DØ

IEEE Trans. Nucl. Sci. V41,1274(1994)

- process: inelastic PPbar scattering
- detector: LØ
  - ✓ *36X2 scintillating counters*
  - ✓ *Rapidity coverage: $2.2<\eta<3.9$*
  - ✓ LØ *x-section: 43.2 ± 2.5* **mb**

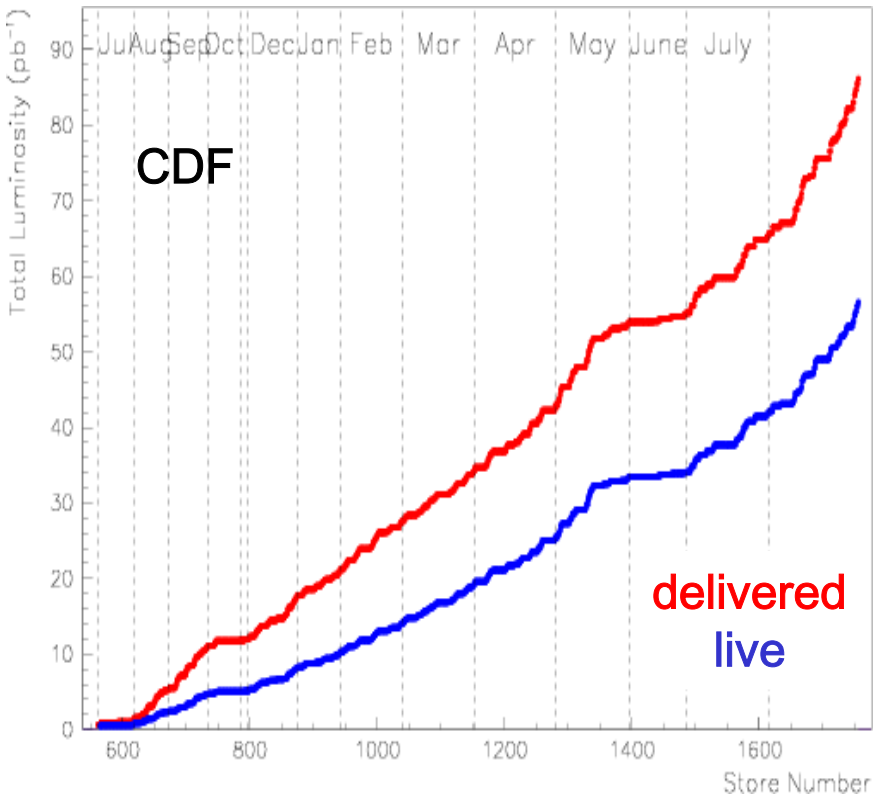
    determined from MC and world average of the inelastic x-section.
- method: counting of zeroes
- δL: 5.6%

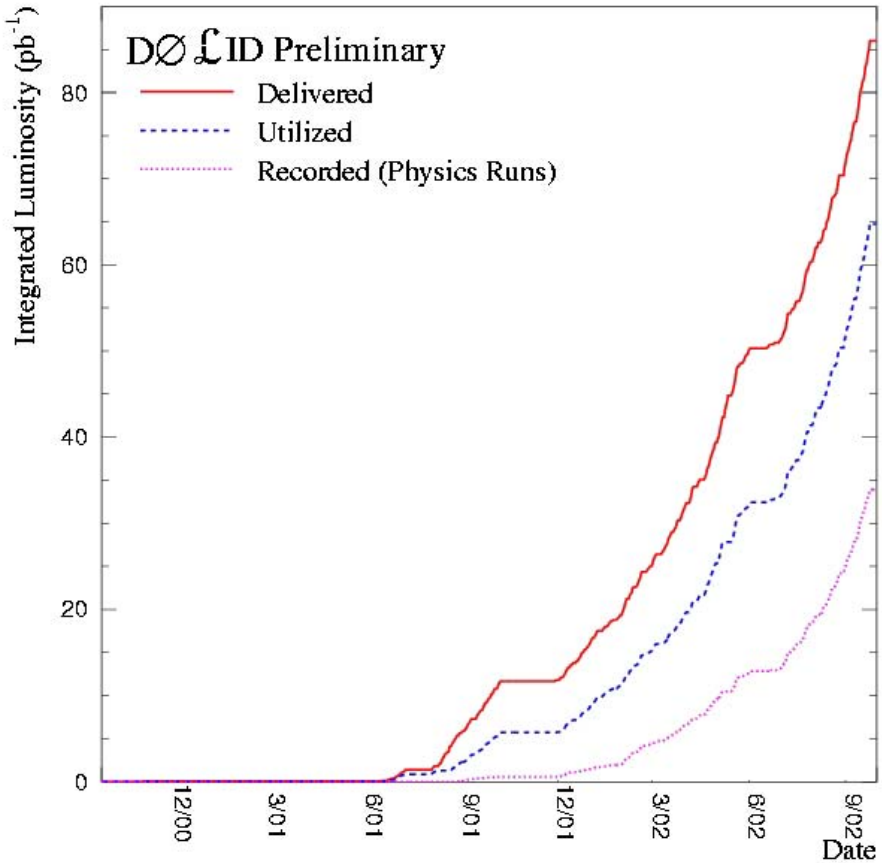
peak L: $\sim 3*10^{31} cm^{-2} sec^{-1}$

integrated L: $\sim 90 pb^{-1}$

Run II integrated luminosity

Delivered L = $90\ pb^{-1}$





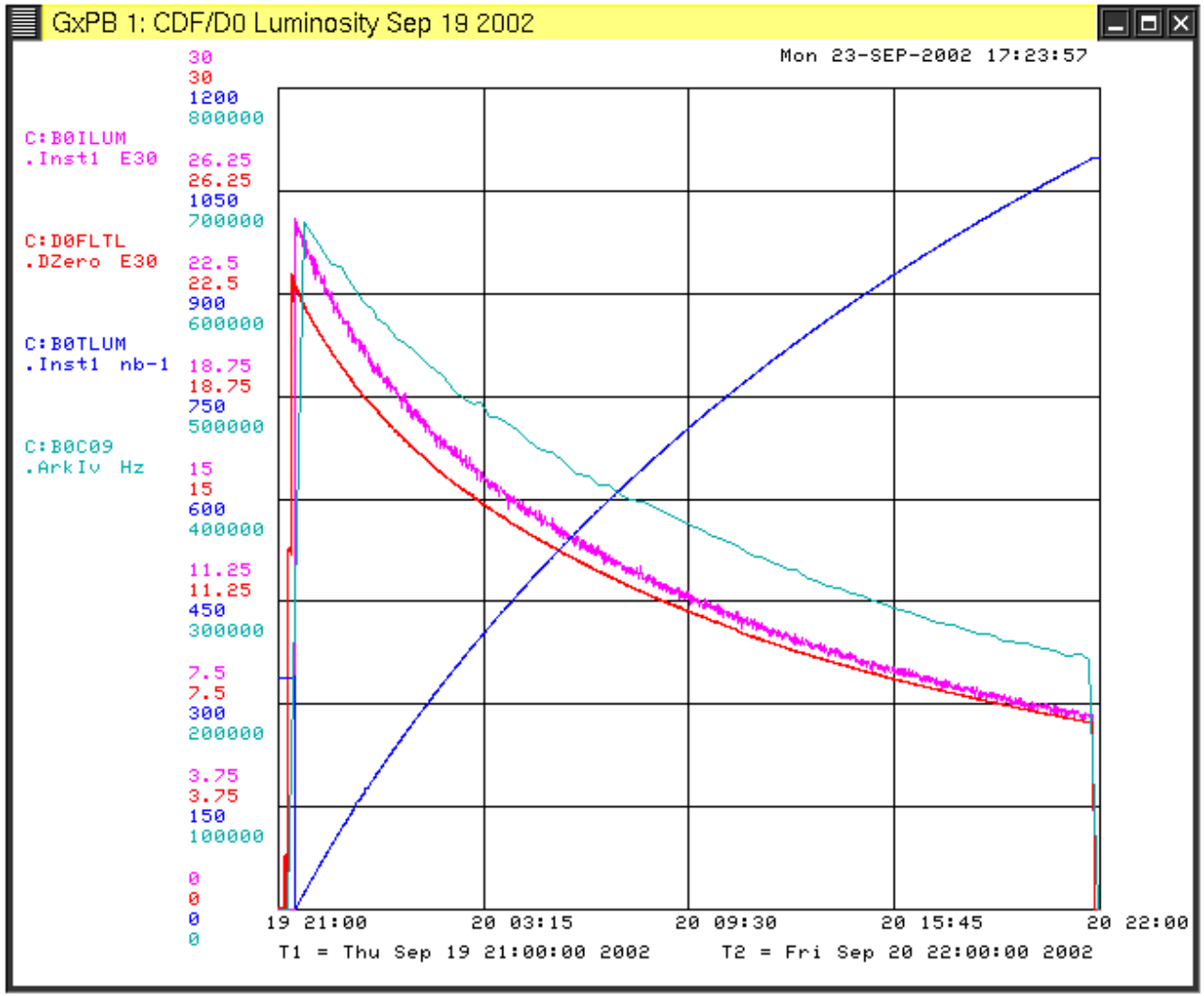
Run II instantaneous luminosity

CDF Delivered Inst. Lum

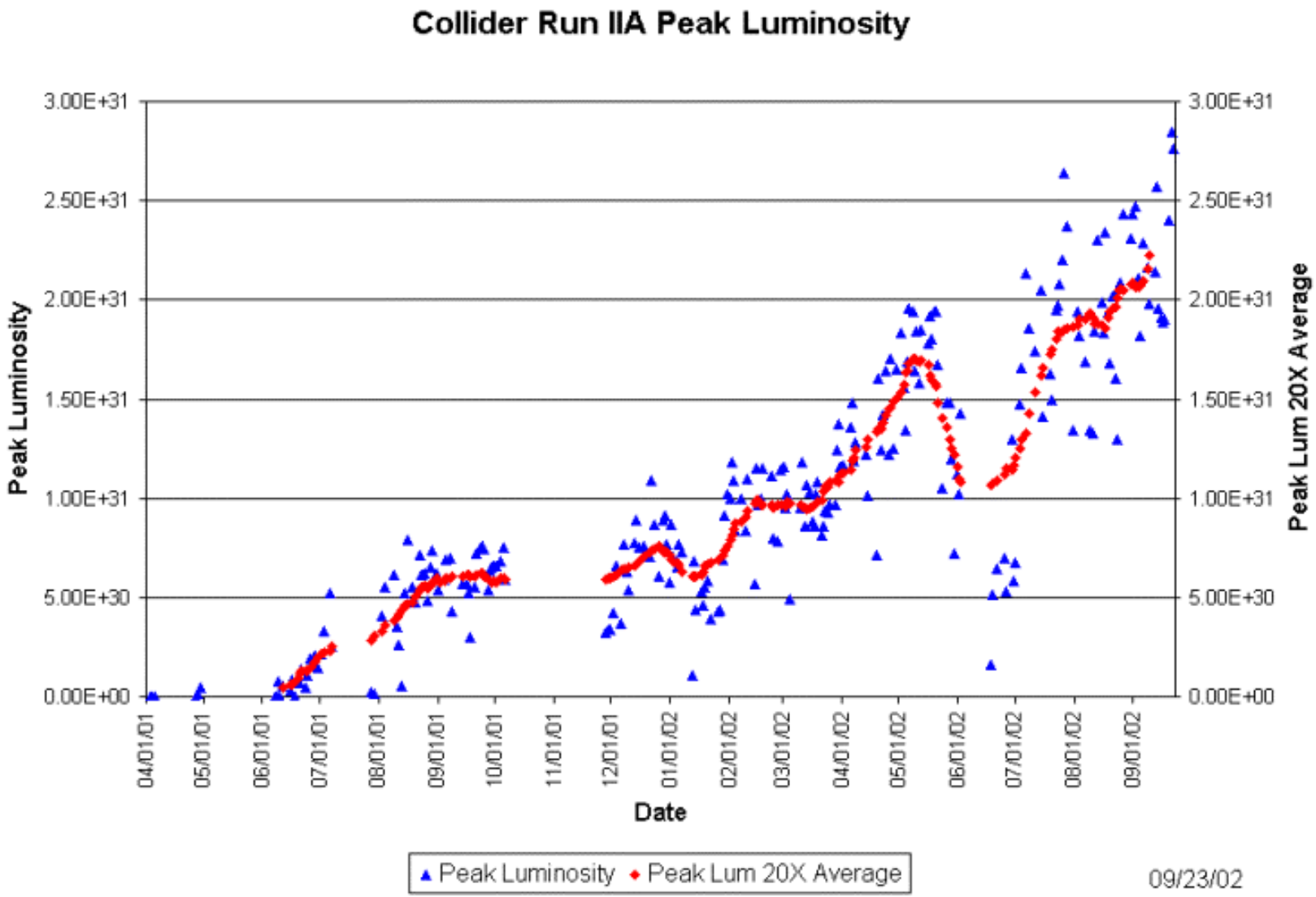
DØ Delivered Inst. Lum

Delivered Tot. Lum

CDF MB trigger rate



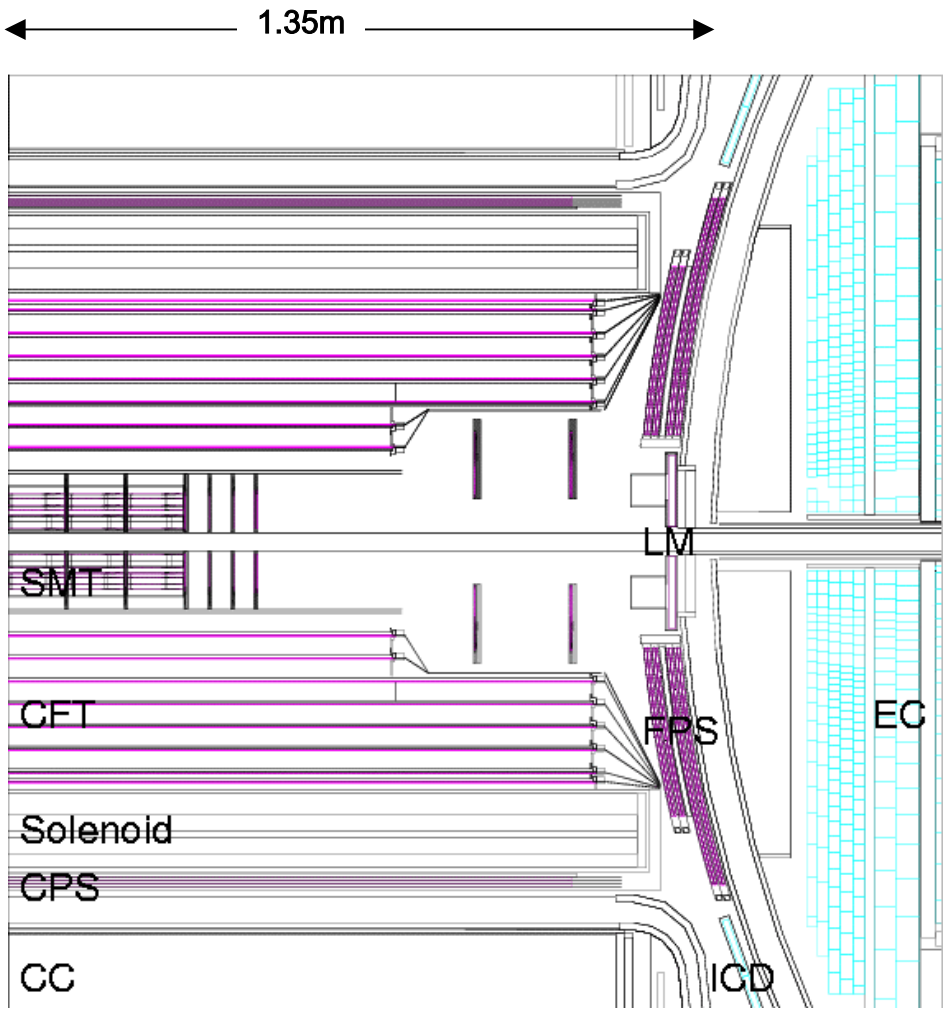
Run II peak luminosity



DØ Luminosity Monitor for Run II

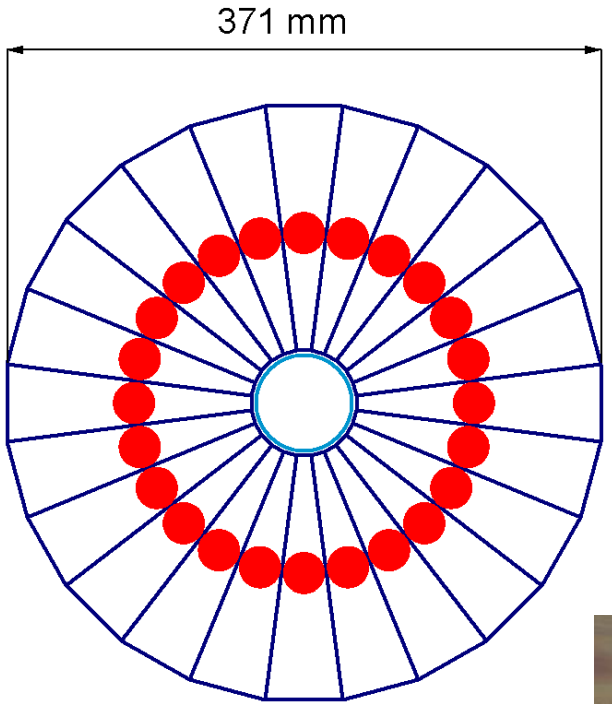
- LM detector:
  - ✓ *2 units at small angles*
  - ✓ *24 scintillating counters BC-408 per unit*
  - ✓ *Rapidity coverage: $2.7<|\eta|<4.4$*
  - ✓ *Mesh PMTs Hamamatsu R5505*
  - ✓ *Time resolution – 200ps*
- L measurement:
  - ✓ *counting of empty bunch crossings*
- Large acceptance
  - ✓ ε_{hc}=97%, ε_{sd}= 15%, ε_{dd}= 70%

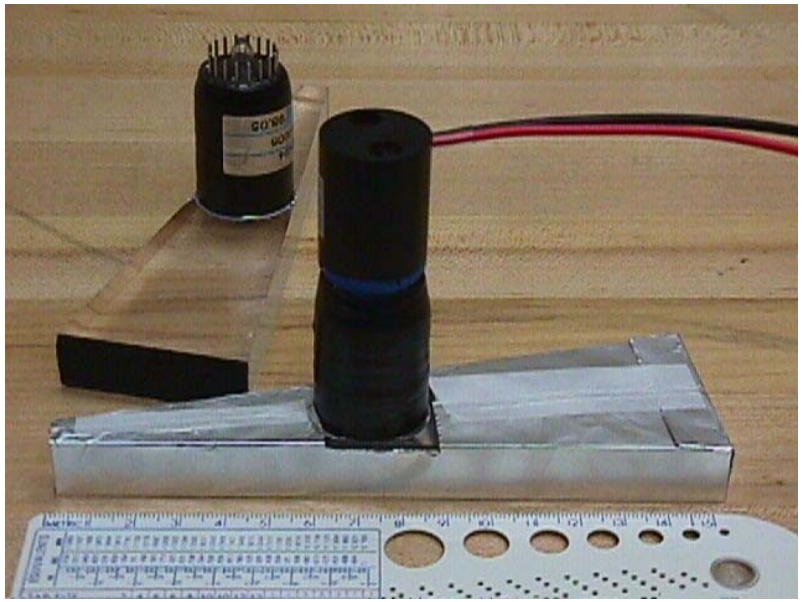
current DØ L uncertainty ~10%

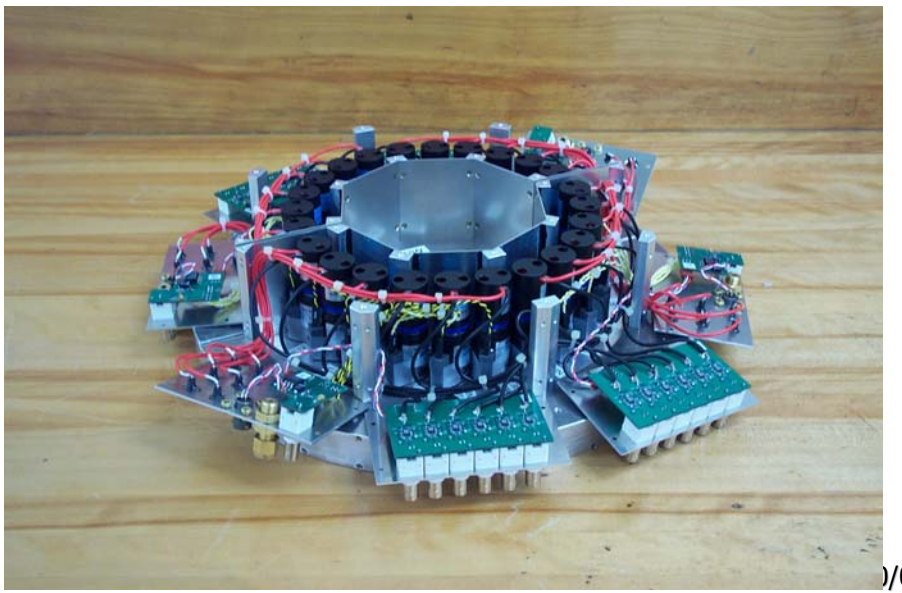


- *http://www.hep.brown.edu/lm/detector.htm*

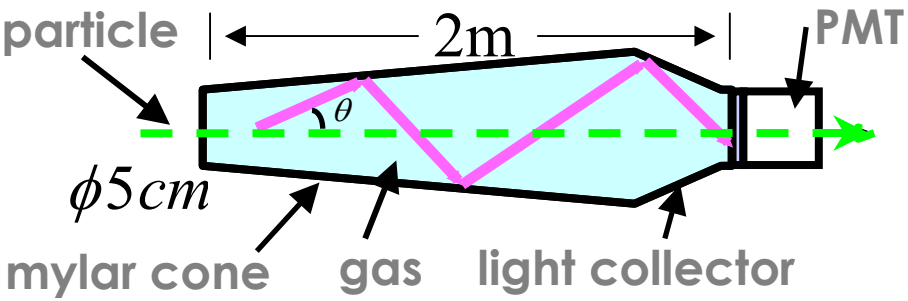
DØ Luminosity Counters





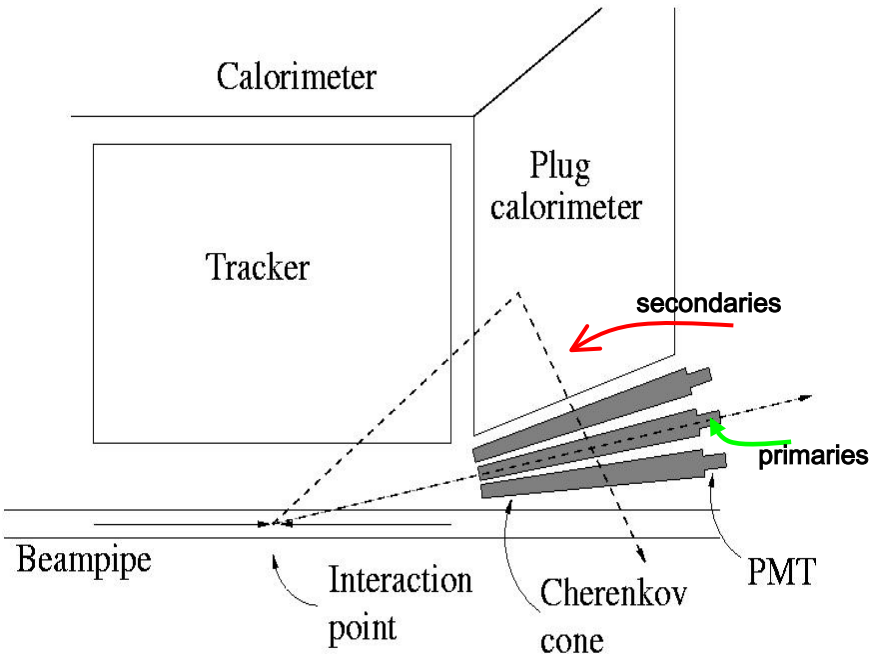


CDF Cherenkov Luminosity Counters



Isobutane @ 1atm

Light yield ~110 p.e.

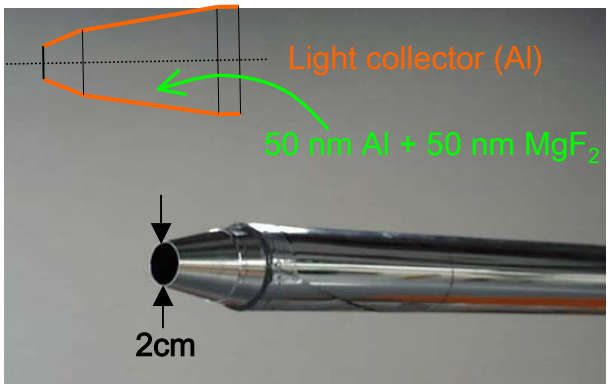


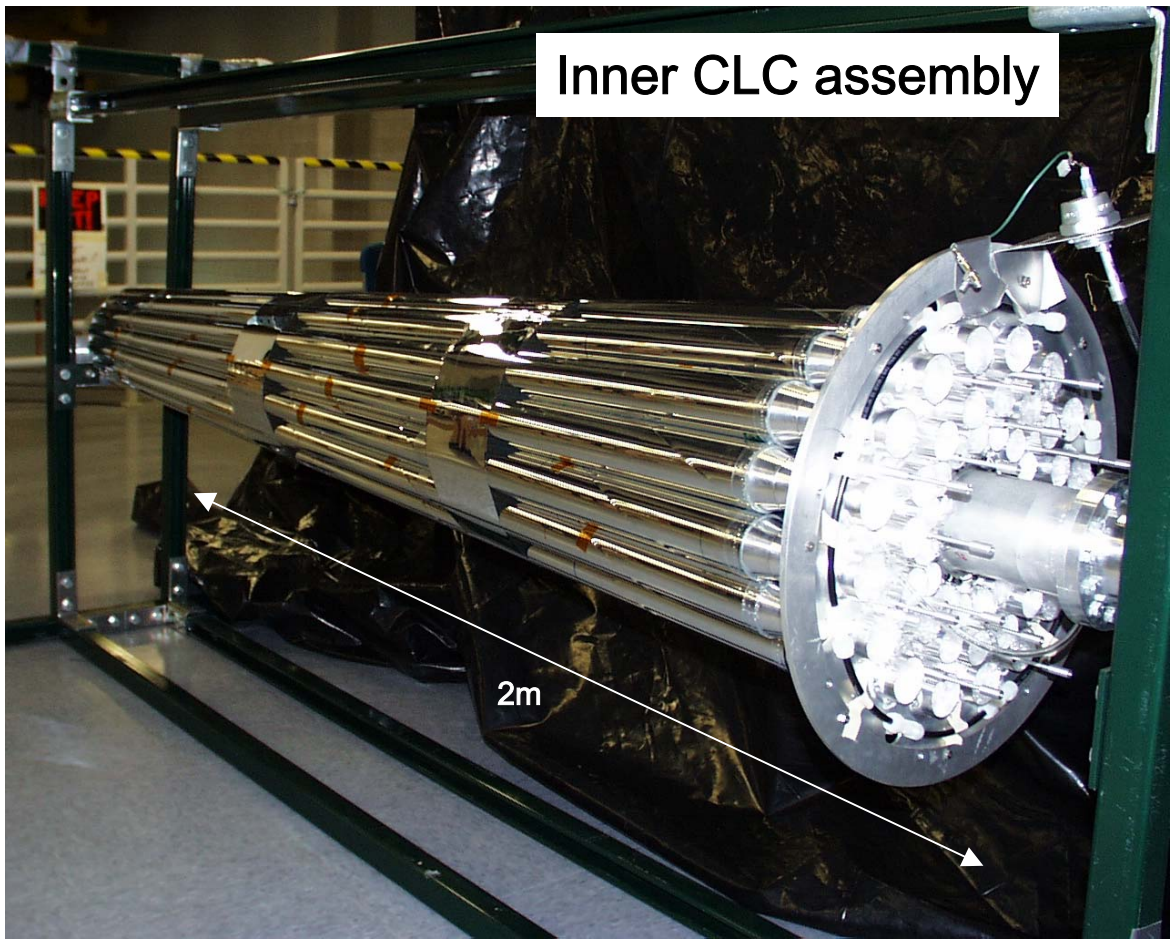
- low mass, radiation hard, fast
- insensitive to soft particles (Ch. threshold)
- less sensitive (then SC) to secondary particles
- Amplitude calibration using Ch peak
- rapidity coverage 3.7<h <4.7
- large acceptance for inelastic events
- Several methods of L measurement
  - *hits (rates)*
  - *"particles" (total amplitude/Ao)*
  - *empty crossings*

- *"Luminosity Monitor Based on Cherenkov Counters for P Anti-P Colliders"*, **Nucl. Instr. & Meth. A441 (266-373), 2000.**

The CLC modules

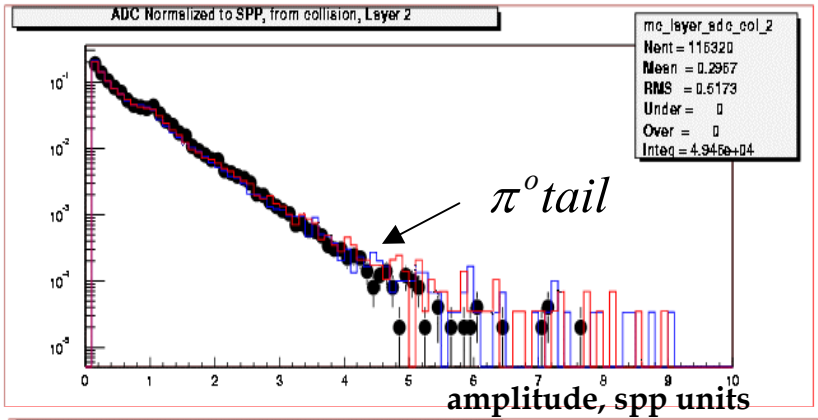
2 modules X 3 layers X 16 counters = 96 counters

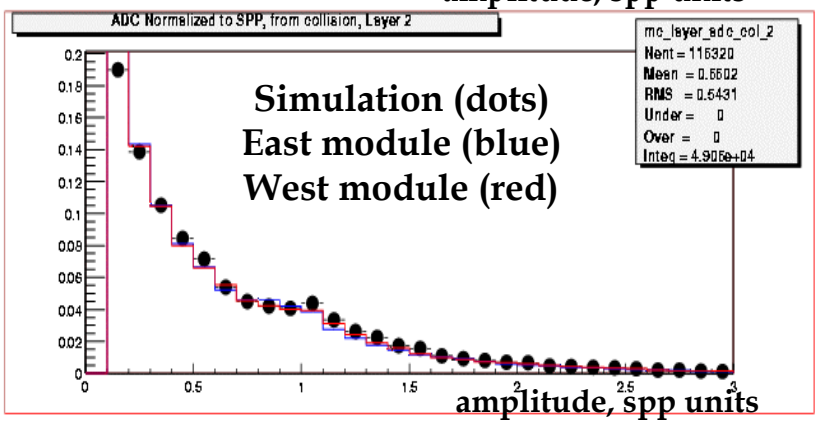


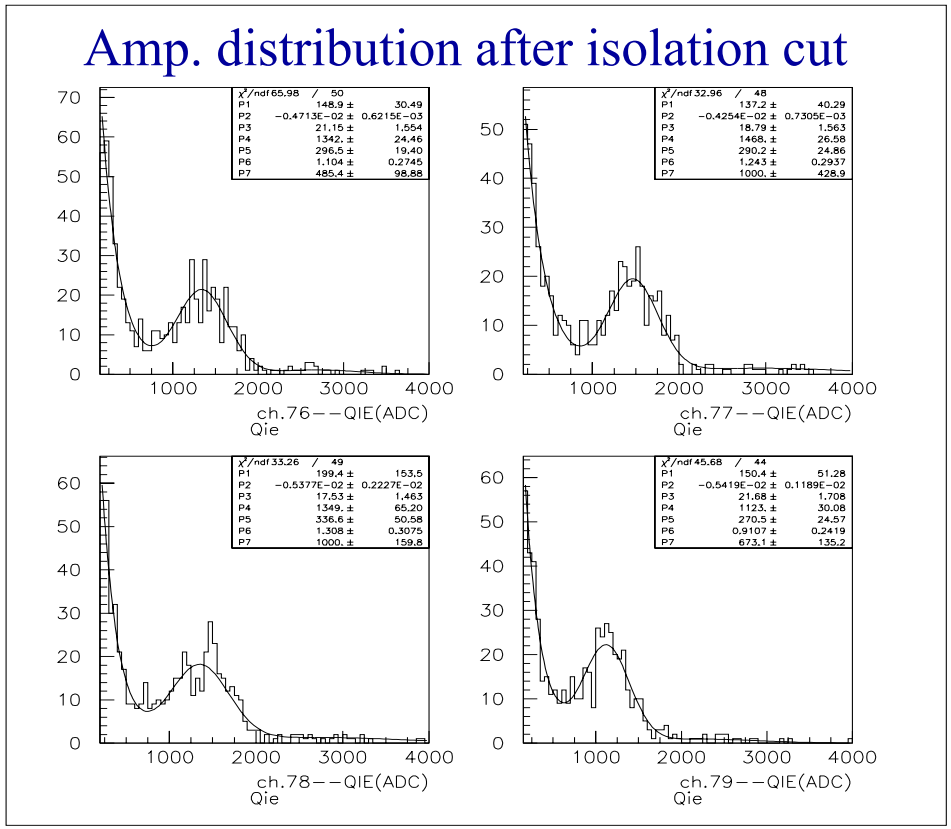


CLC amplitude distribution

- Single Particle Peak (spp)
  - *SPP clearly seen after isolation cut*
  - *Used for amplitude calibration of the counters*



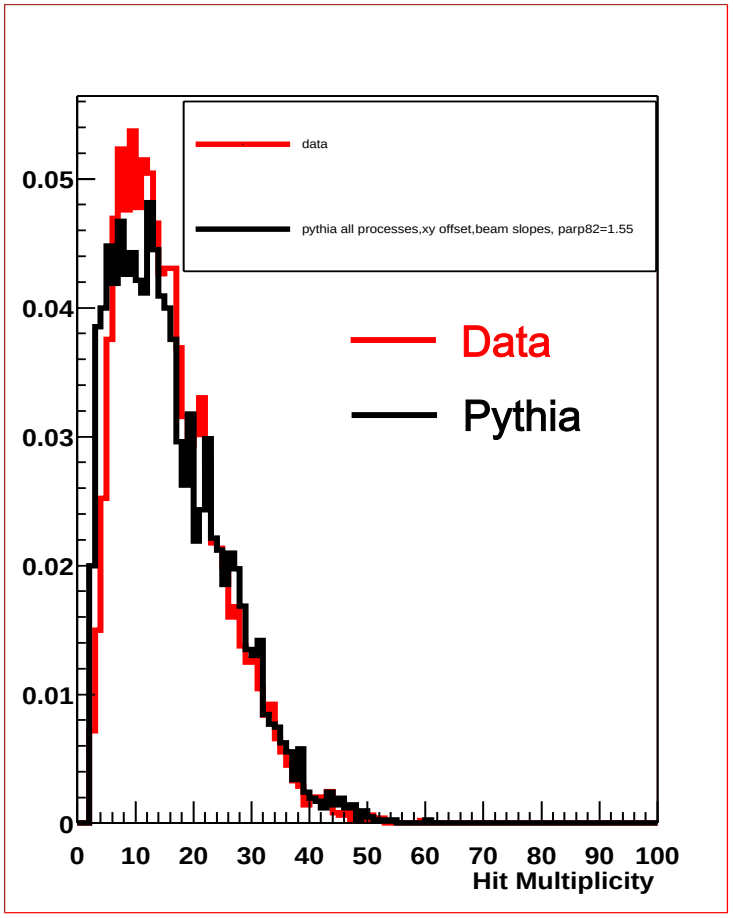


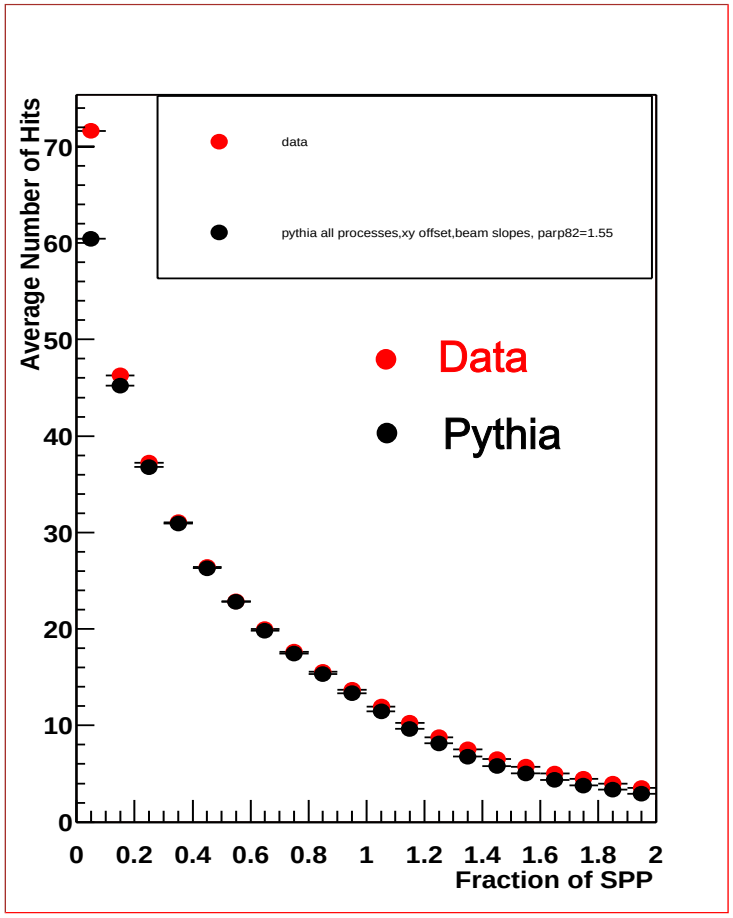


data & simulations (CDF)

Inelastic charge multiplicity ~5 per unit of η
Total hit multiplicity ~20/side (mainly electrons)

Tuned Pythia (full inelastic)





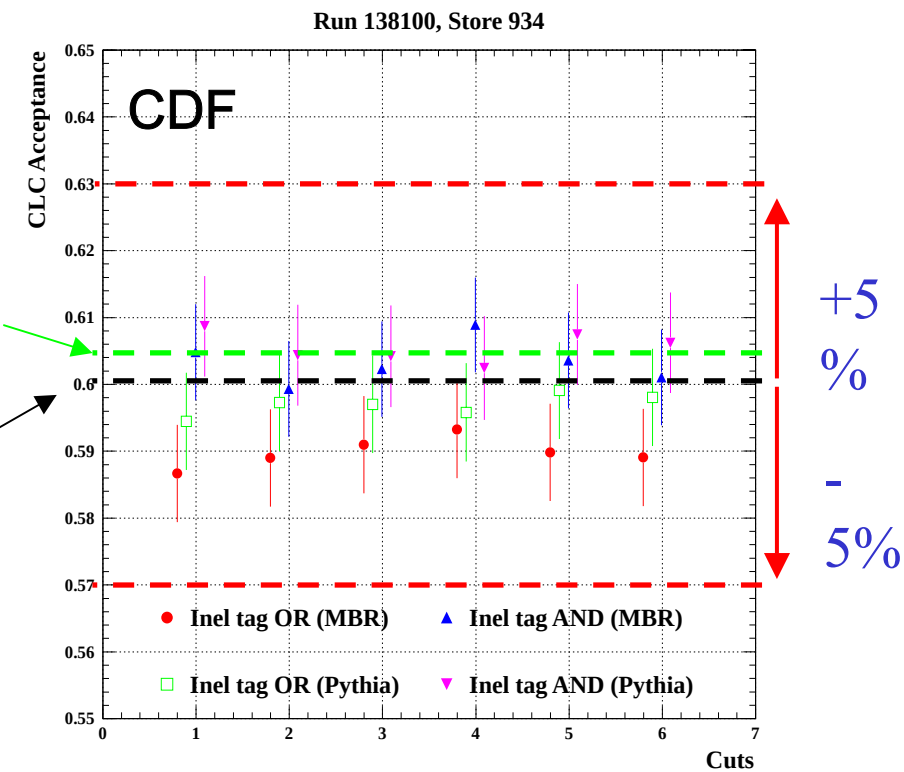
Summary: CDF Luminosity Uncertainty

Systematic error	2 layers
CLC acceptance (2 layers):	4.0 %
Geometry & material	3.0 %
Event generator	2.0 %
Beam	1.0 %
CLC simulation	1.0 %
amplitude calibration	1.0 %
Detector stability	1.0 %
Online → offline transfer (accounting)	~ 0 %
Luminosity method	1.0 %
Losses	<1.0 %
TOTAL	4.5 %

The error due to uncertainties in the inelastic x-section is not quoted.

acceptance from CLC+plug simulation and data

- **Measure CLC acceptance using a reference detector with large acceptance ($\varepsilon_h \rightarrow 100\%$) → less dependent on simulation**



$$\varepsilon_{clc} = \left(\frac{N_{clc}}{N_R} \right) \cdot \varepsilon_R$$

Measure experimentally

Find from simulation

Plug threshold:	3	5	10	20	5	5	(GeV)
CLC threshold:	250	250	250	250	200	225	(ADC)

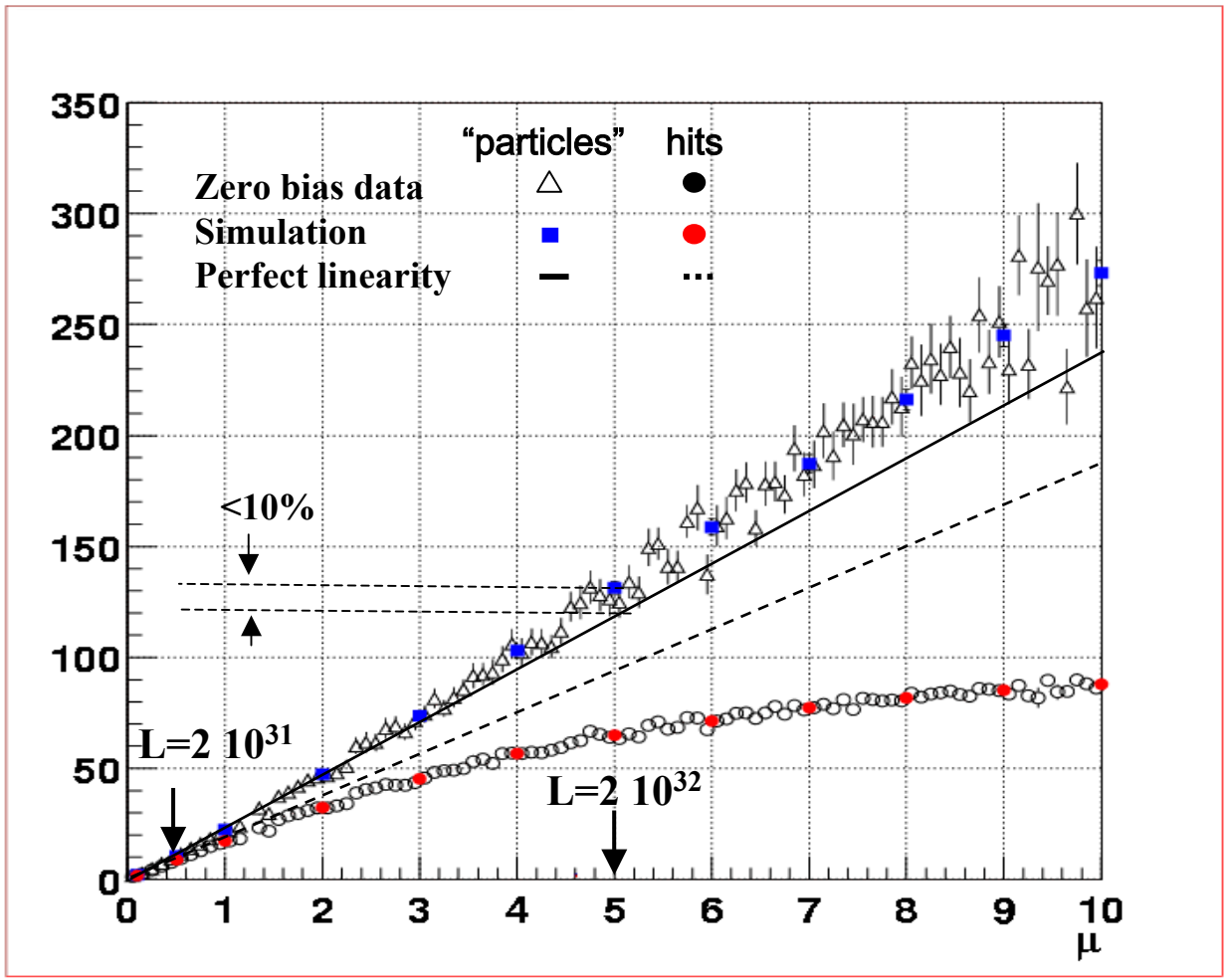
2% acceptance uncertainty is feasible !

Measurements at high Luminosity (CDF)

Data:
Construct bunch crossings with large μ superimposing zero bias events at low μ.

Counting of hits:
<number> of hits /BC

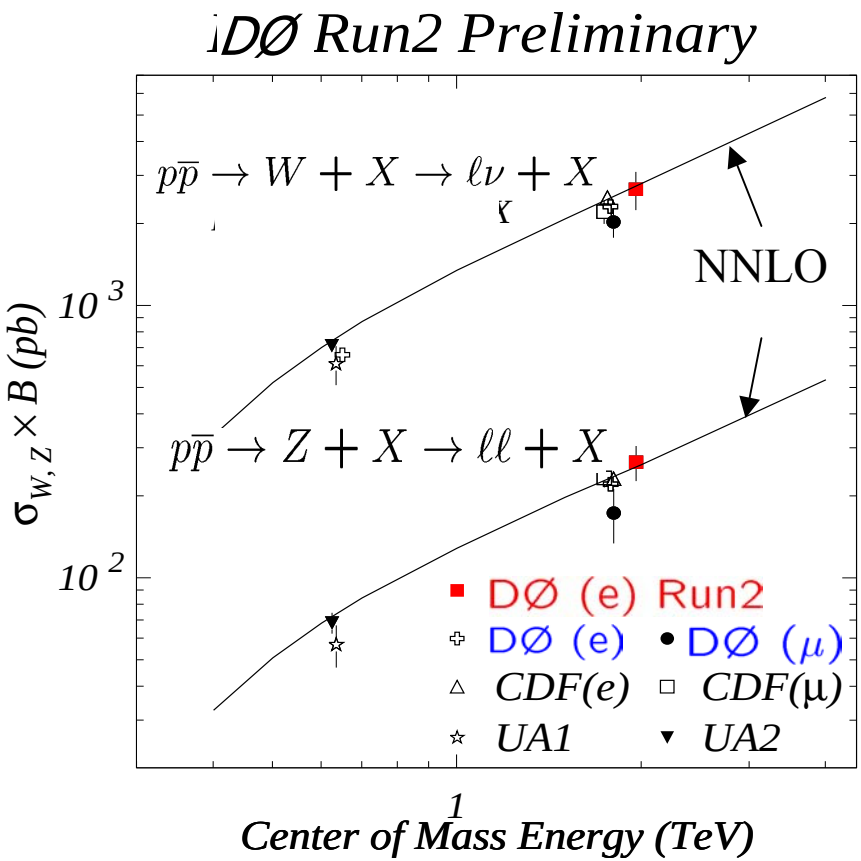
Counting of "particles":
Total amplitude / Ao
Ao = amplitude of single particle peak



Precise high luminosity measurement is feasible !

W and Z Production Cross Section (DØ)

- Data Sample:
  - *Luminosity ~ 7.5 pb^{-1}*
  - *No. of W→e: 3493±75±296*
  - *No. of Z →ee: 186±14±10*



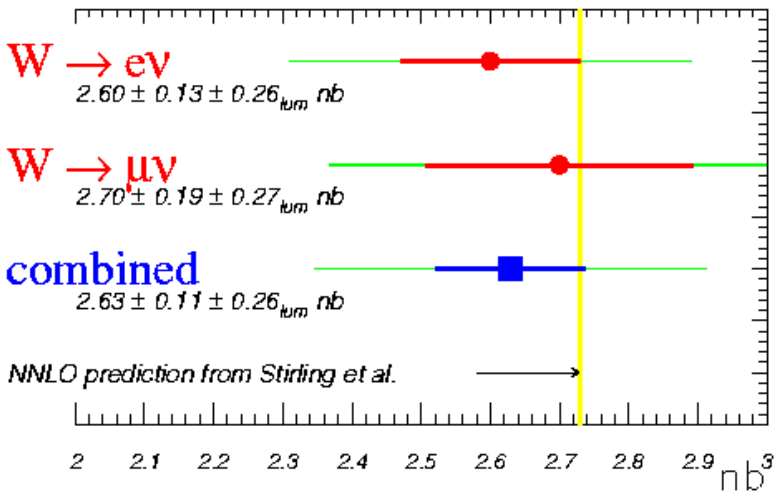
$$\sigma_Z \times B(Z \to ee) = 266 \pm 20_{stat} \pm 20_{syst} \pm 21_{lumi} \text{ pb}$$

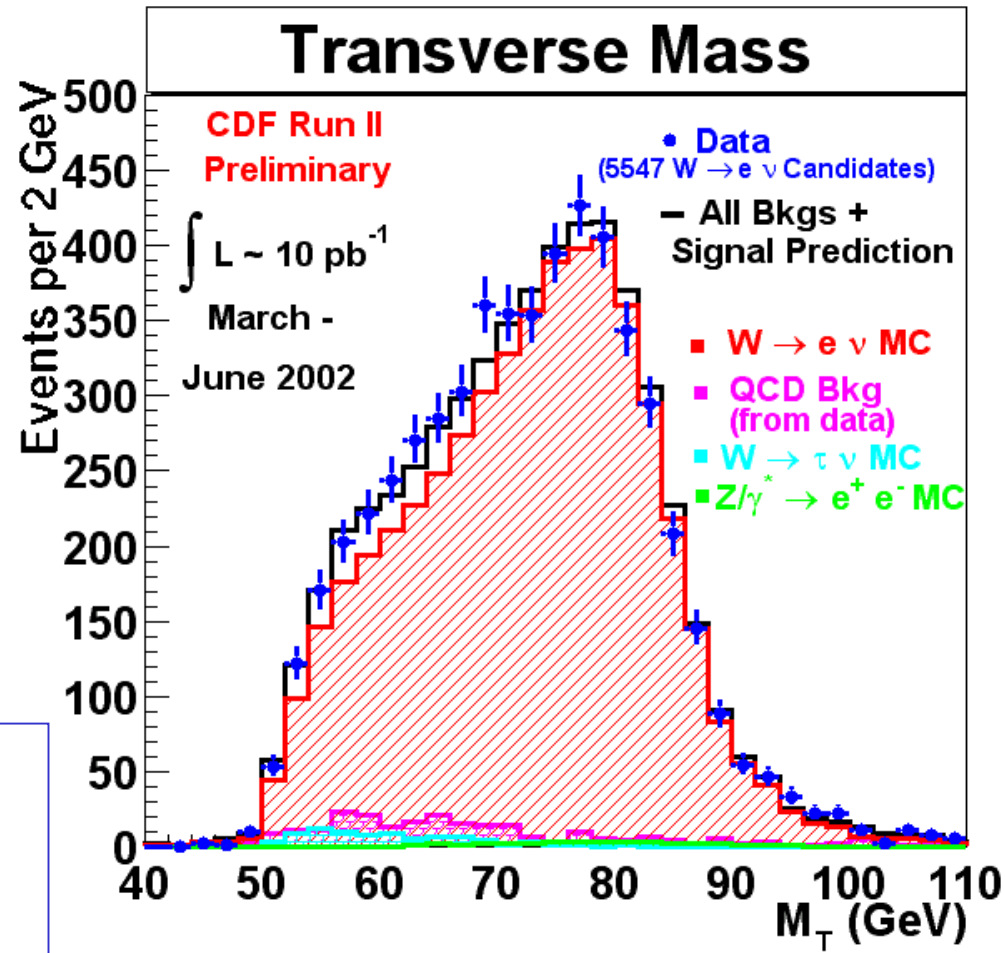
$$\sigma_W \times B(W \to e\nu) = 2.67 \pm 0.06_{stat} \pm 0.33_{syst} \pm 0.27_{lumi} nb$$

X-check with σ•B(W→lν) (CDF)

W cross section:

$$\sigma_W * BR(W \rightarrow e\nu)\ (nb) = 2.60 \pm 0.07_{stat} \pm 0.11_{syst} \pm 0.26_{lum}$$





Background (8%):

- **QCD:** 260 ± 34 ± 78
- **Z →ee:** 54 ± 2 ± 3
- **W→τν:** 95 ± 6 ± 1

5547 candidates in 10 pb^{-1}

Summary

- Run I luminosity uncertainty at ~**5%** level using inelastic PPbar scattering
- In Run II two methods of luminosity measurement are available
  - ***Inelastic Ppbar scattering (on-line, instantaneous, delivered, off-line,…)***
  - ***W production (off-line)***
  - ***Yield comparable uncertainty on luminosity of ~5%***
- Expected luminosity uncertainty in Run II **below 5%** level
- CDF&DØ are working on nailing down the systematic errors
  - ***Generators, Simulation, material, thresholds, etc. etc.***
- Tevatron luminosity is **$3*10^{31}$** and increasing
  - ***preparation for L measurement in the regime with multiple Ppbar interactions per bunch crossing.***