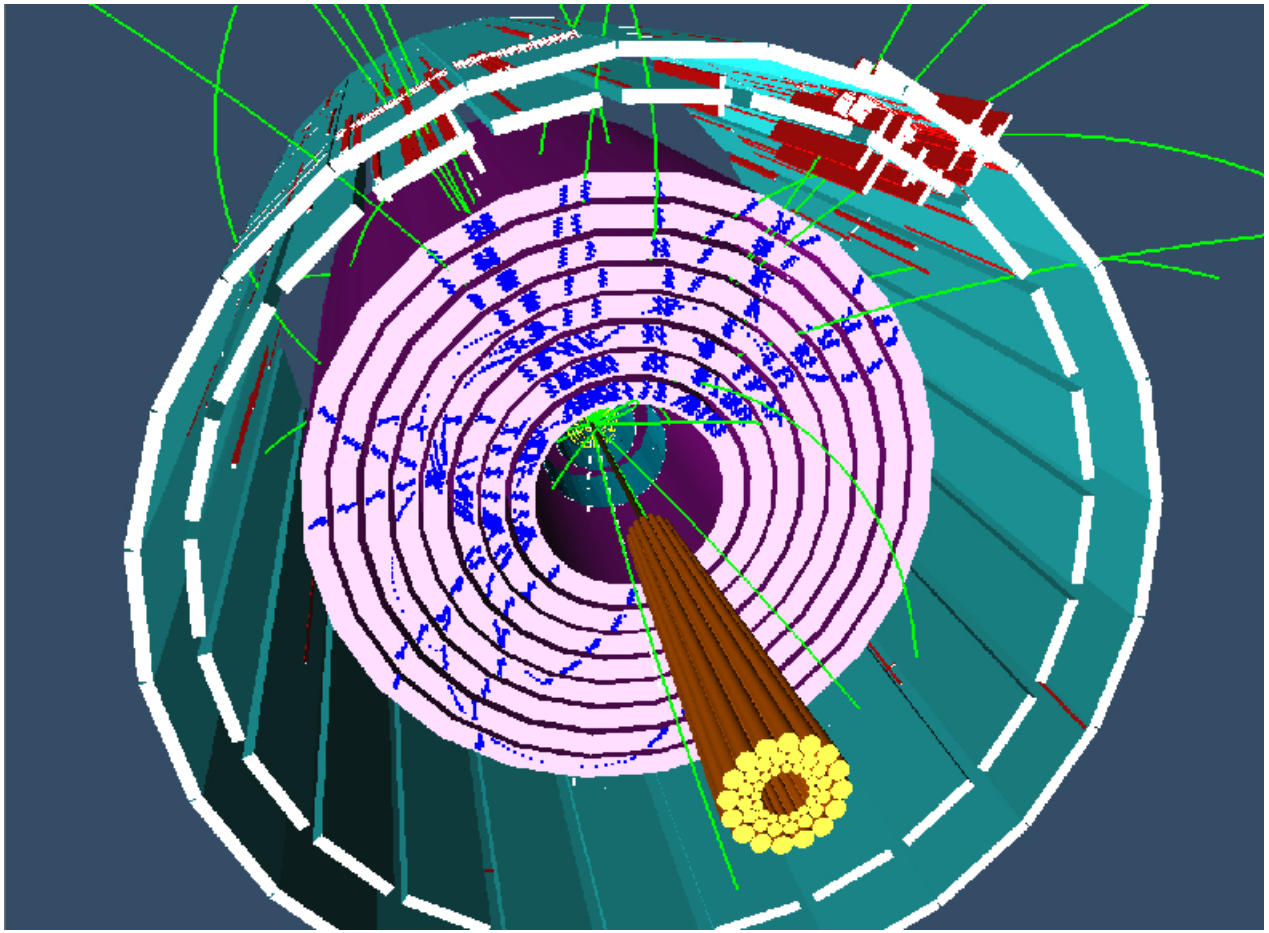
Measuring CDF's Run II Luminosity



- Introduction
- The CLC Detector
- Performance
- Measurements
- Summary / plans

People involved:

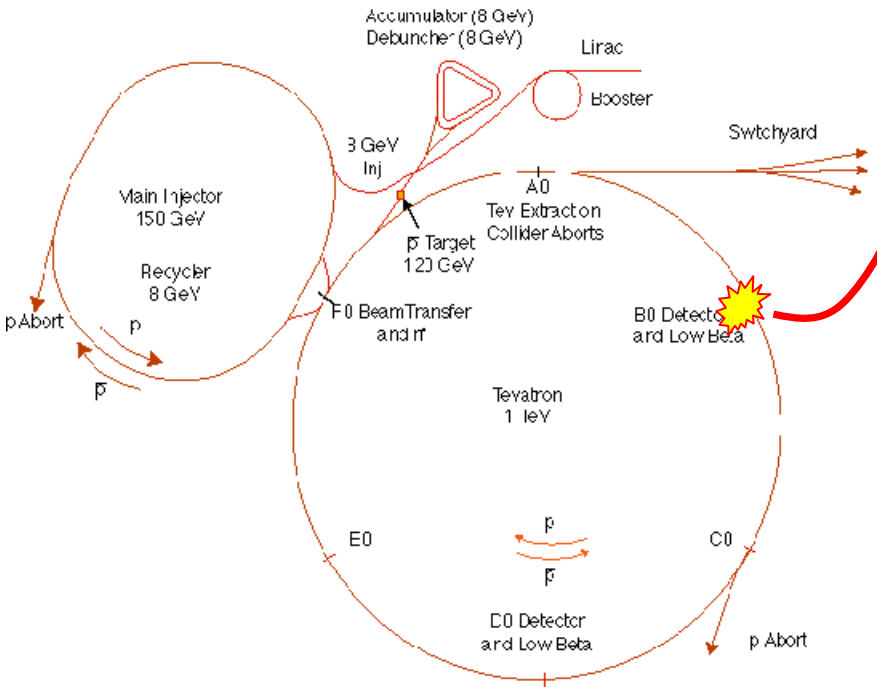
- *Univ. of Florida group ++*

Jacobo Konigsberg
U.C. seminar, 05/13/02

Collider Beam Luminosity

$$n\,(\text{top events}) = \sigma\,(p\bar{p} \rightarrow t\bar{t}) \cdot L \cdot \varepsilon$$

$$\varepsilon = \text{BR} \cdot \text{Acceptance} \cdot \text{Efficiency}$$



Instantaneous Luminosity:

$$\mathbf{L} = \frac{N_p \cdot N_{\bar{p}} \cdot B \cdot f_0}{4\pi\sigma^2} \sim 2\text{x}10^{32}\ \text{cm}^{-2}\text{s}^{-1}$$

(Run IIa goal)

N_p = protons/bunch ($\sim 3 \cdot 10^{11}$)

$N_{\bar{p}}$ = anti-protons/bunch ($\sim 4 \cdot 10^{10}$)

B = number of bunches in ring (36)

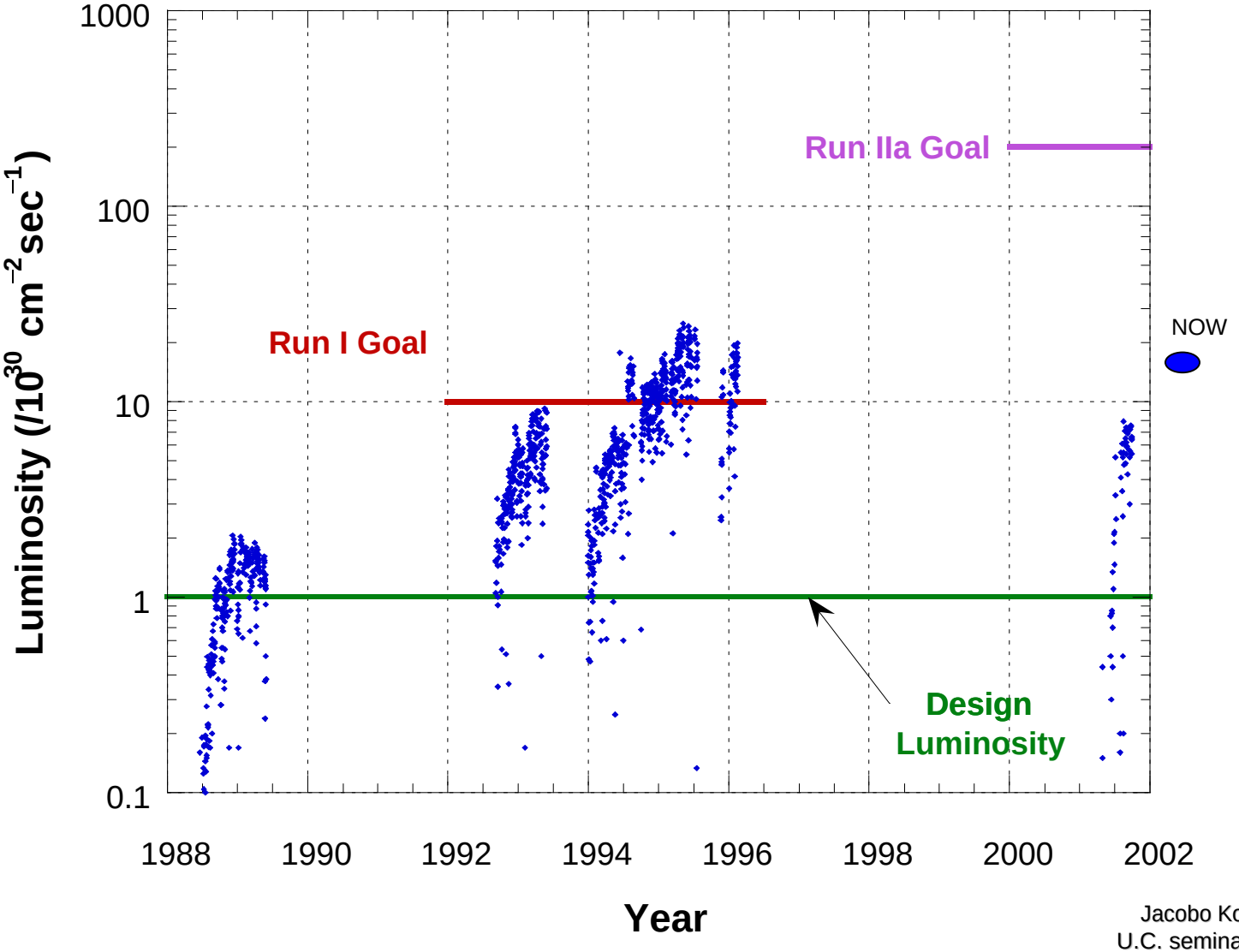
f_0 =~ 2 MHz (132 n sec bunch spacing)

$\sigma^2 \sim 3 \cdot 10^{-4}\ \text{cm}^2$ ($\sim 100\,\mu$ beam diameter)

Total Lum: $L = \int \mathbf{L} \cdot dt \sim 2\ \text{fb}^{-1}$ (Run IIa goal)

$$\mathbf{L} = \frac{3\gamma f_0}{\beta^*}\left(BN_{\bar{p}}\right)\left(\frac{N_p}{\varepsilon_p}\right)\frac{F\left(\beta^*, \theta_{x,y}, \varepsilon_{p,\bar{p}}, \sigma^L_{p,\bar{p}}\right)}{\left(1 + \varepsilon_{\bar{p}}/\varepsilon_p\right)}$$

Tevatron Luminosity History



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Run II Parameter List

RUN	Ib (1993-95) (6x6)	Run IIa (36x36)	Run IIa (140x103)	Run IIb (140x103)	
Protons/bunch	2.3×10^{11}	2.7×10^{11}	2.7×10^{11}	2.7×10^{11}	
Antiprotons/bunch*	5.5×10^{10}	3.0×10^{10}	4.0×10^{10}	1.0×10^{11}	
Total Antiprotons	**3.3×10^{11}**	**1.1×10^{12}**	**4.2×10^{12}**	**1.1×10^{13}**	
Pbar Production Rate	6.0×10^{10}	1.0×10^{11}	2.1×10^{11}	5.2×10^{11}	hr^{-1}
Proton emittance	23π	20π	20π	20π	mm-mrad
Antiproton emittance	13π	15π	15π	15π	mm-mrad
β^*	35	35	35	35	cm
Energy	900	1000	1000	1000	GeV
# p & p-bar Bunches	**6**	**36**	**103**	**103**	
Bunch length (rms)	0.60	0.37	0.37	0.37	m
Crossing Angle	0	0	136	136	μrad
Typical Luminosity	**0.16×10^{32}**	**0.86×10^{32}**	**2.1×10^{32}**	**5.2×10^{32}**	$cm^{-2}sec^{-1}$
Integrated Luminosity†	3.2	17.3	42	105	pb^{-1}/week
Bunch Spacing	**~3500**	**396**	**132**	**132**	**nsec**
Interactions/crossing	2.5	2.3	1.9	4.8	

†The typical luminosity at the beginning of a store has traditionally translated to integrated luminosity with a 33% duty factor. Operation with antiproton recycling may be somewhat different.

The luminosity goal for Run IIa is 2 fb^{-1}

- *Peak luminosity up to 2×10^{32} $cm^{-2}sec^{-1}$*
- *Switch to 103 bunches at 1×10^{32} $cm^{-2}sec^{-1}$*
- *Length of Run IIa is about <u>2 years</u>*

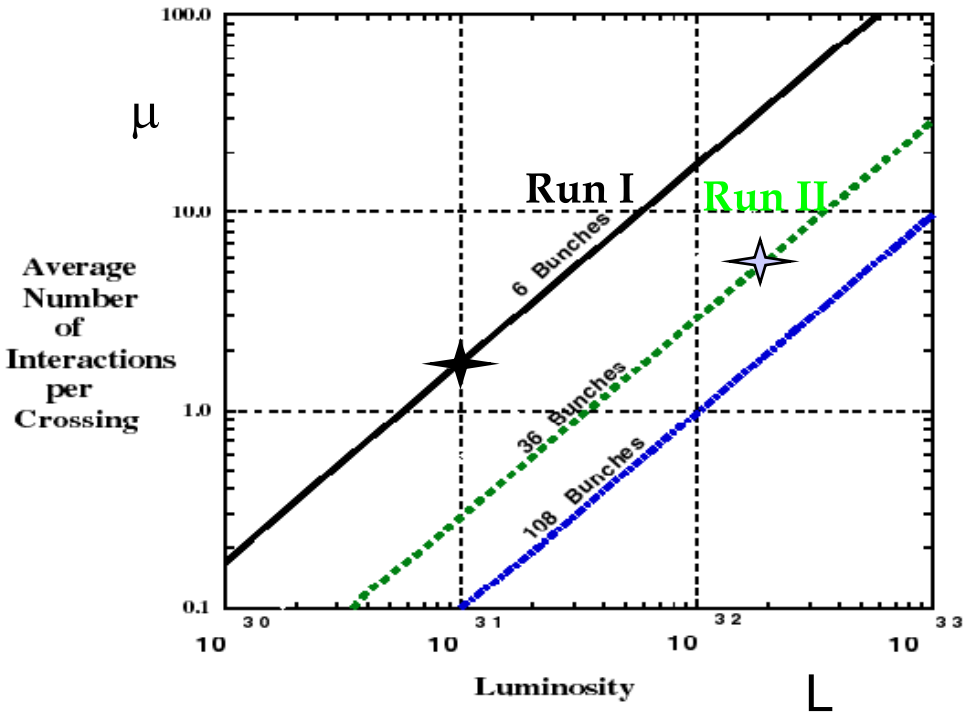
The luminosity goal for Run IIa+Run IIb is 15 fb^{-1}

- *Increase antiproton intensity by 2-3*
- *Peak luminosity up to 5×10^{32} $cm^{-2}sec^{-1}$*
- *103 bunch operation*
- *Length of Run IIb is about <u>4 years</u>*

Luminosity Detector in Run II

Operate at:

L ~$2*10^{32}cm^{-2}sec^{-1}$ μ ~6 **ppbar/b.c.**



- ***Measure instantaneous and integrated luminosity for CDF and Tevatron***
  - in real-time (~ 1 Hz), standalone, and offline for physics
  - delivered and live luminosity
  - bunch by bunch luminosity
  - keep good precision at high luminosity: < few %
- ***Measure z profile of collisions***
- ***Provide a minimum bias trigger for CDF.***

Linear, robust, and with many handles for very high Luminosity

Techniques for Luminosity measurements

- **Use a relatively well known, copious, process:**
  - ***Inclusive inelastic p-pbar cross-section***
    - large acceptance at small angles

$$\mu \cdot f = \sigma_{in} \cdot L$$

- μ = avg. # of interactions/b.c.
- f = frequency of bunch crossings
- σ_{in} = tot inelastic cross-section
- L = inst. luminosity

- **Use dedicated detector:**

$$\tilde{\mu}_{\alpha} \cdot f_{BC} = \sigma_{in} \cdot \varepsilon_{\alpha}^{clc} \cdot L$$

- **Use a good estimator**
  - ***Measure the fraction of crossings with p-pbar interactions (Run 1 "rate" technique)***
    - Use: $P_0(\mu) = e^{-\mu}$ prob. of no int.
  - ***Direct counting # of p-pbar interactions***
    - Counting particles
    - Counting time clusters

- **Cross- calibrate with rarer, clean, better understood process:**

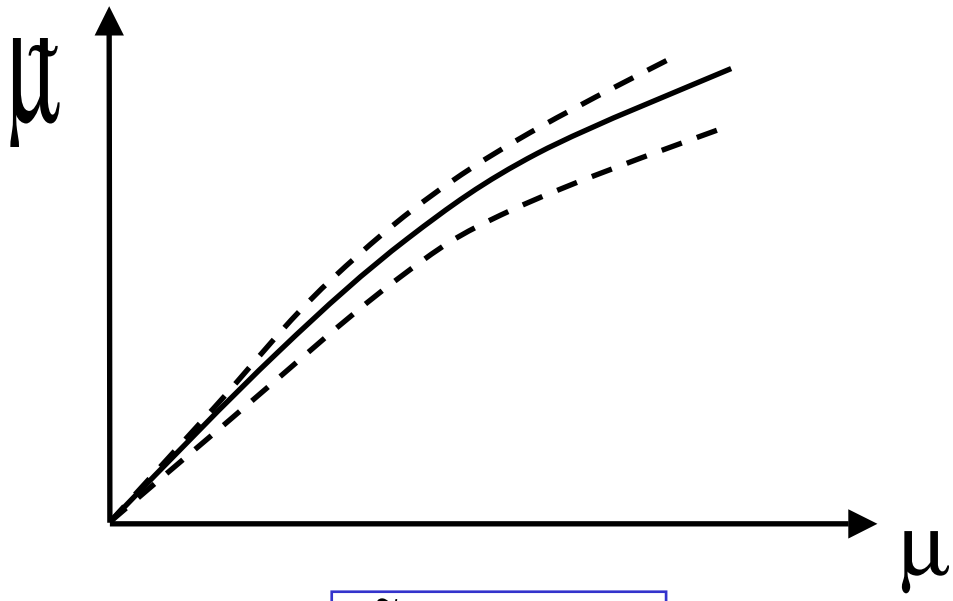
$$W \rightarrow lep, \nu$$

  - ***Need full understanding of tracking, particle-id, missing-Et,, trigger, NLO, bcknds etc.***
  - Useful for integrated lum abs. normalization

Luminosity estimators

$$\tilde{\mu}_\alpha \cdot f_{BC} = \sigma_{in} \cdot \varepsilon_\alpha^{clc} \cdot L$$

$$\tilde{\mu}_\alpha = s_\alpha(\mu) \cdot \mu$$

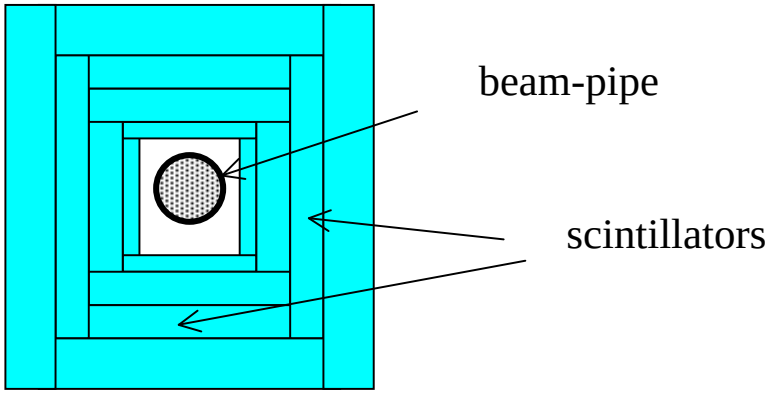


$$\delta\tilde{\mu} \rightarrow \delta\mu \rightarrow \delta L$$

➡ **Find device/estimator that has best chance at smallest:** $\frac{\delta L}{L}$

Scintillating counters for Luminosity

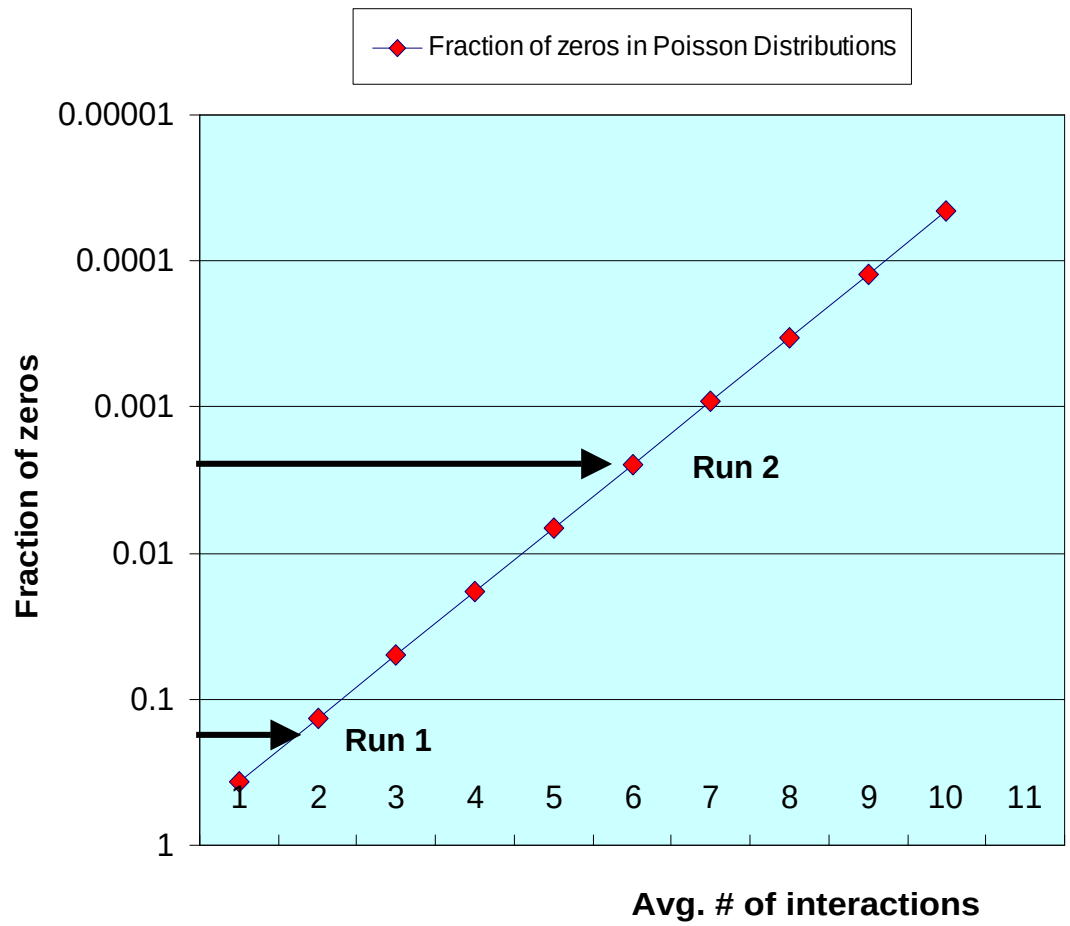
- **Beam-Beam Counters – used in Run 1:**
  - Segmentation too small for high lum
    - **16/side/2.6 units of rapidity**
  - Count "yes" or "no"
  - Counting rate saturated already @ 1.8 int./b.c.
  - Sensitive to all particles
  - Rate heavily dominated by secondaries
    - **Cal., beam-pipe, beam halo**
  - CDF's 10-degree hole now 3-degrees
    - **more backgrounds…**
  - Performed simulations w/ more segmentation + telescopes
    - **large systematics / random coincidences**
  - Will likely need more handles in Run II:



❖**Need new device…**

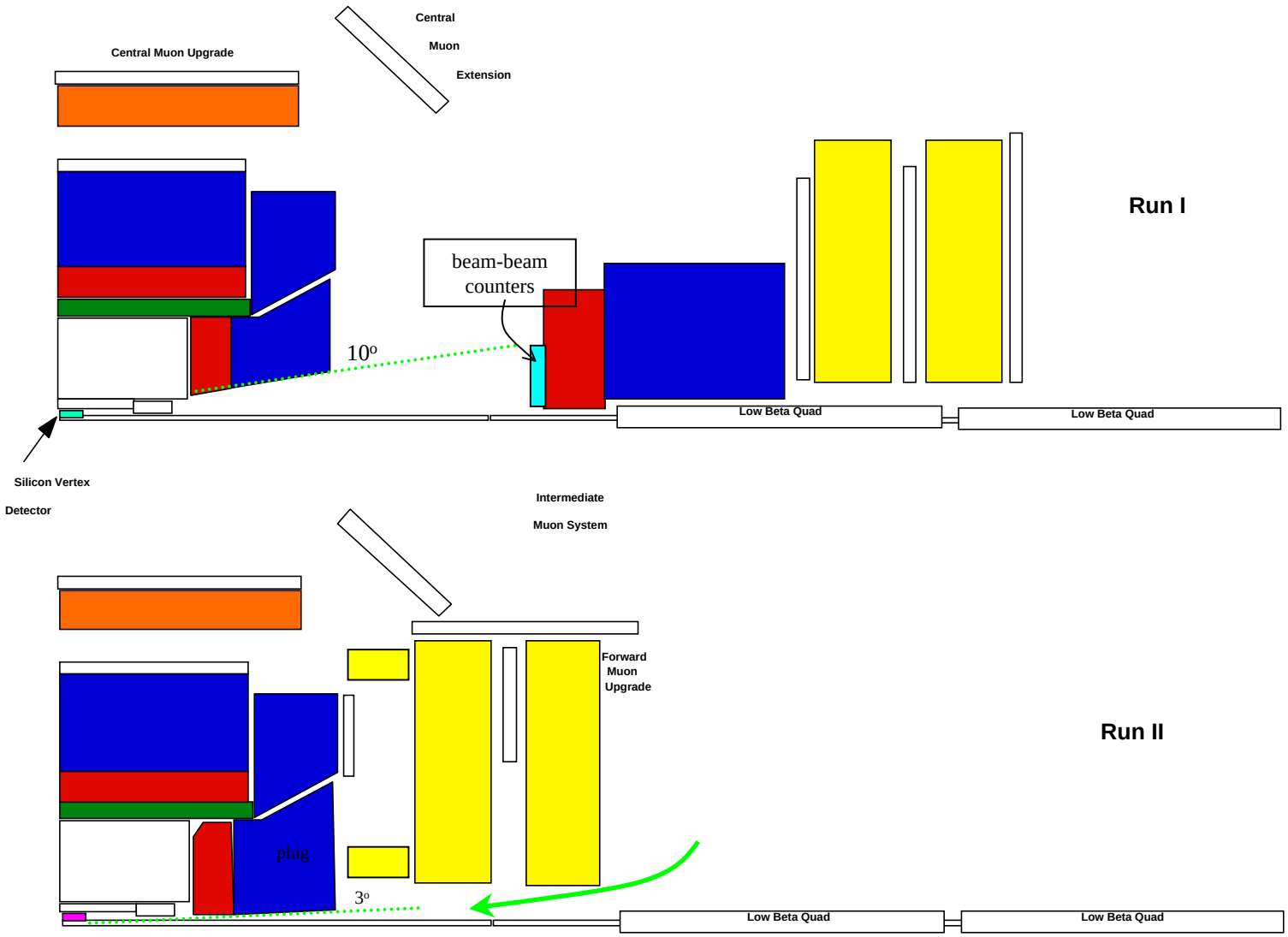
Luminosity for Run 2: measure μ directly

- Cannot measure rate (or "zeros") in Run 2 accurately enough
- Fraction is 0.25% for 6 int. avg:
- Systematics on acceptance only would make a precise measurement impossible

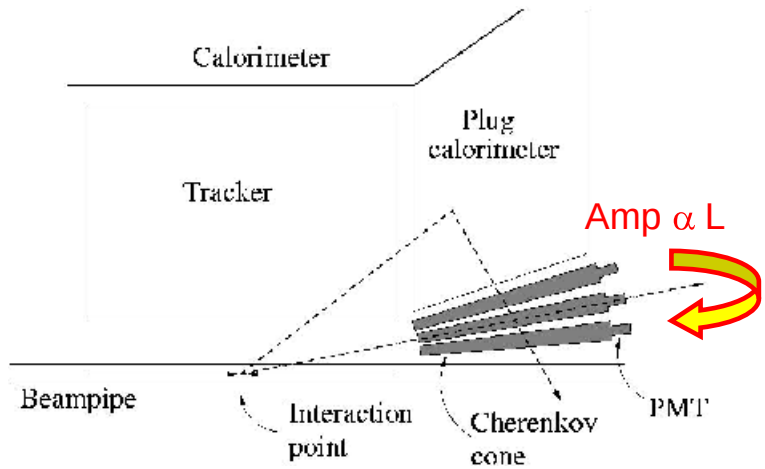


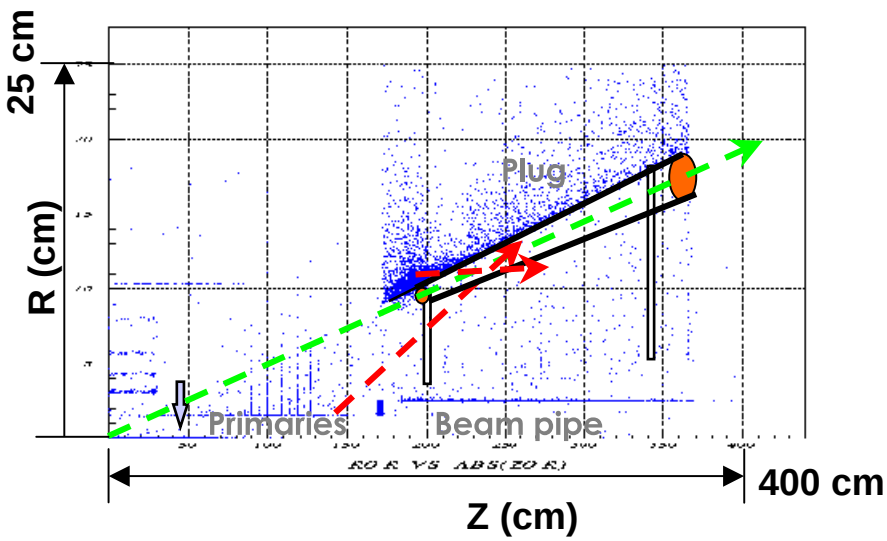
- **Need to measure the # of p-pbar interactions directly !**

Finding room in CDF II



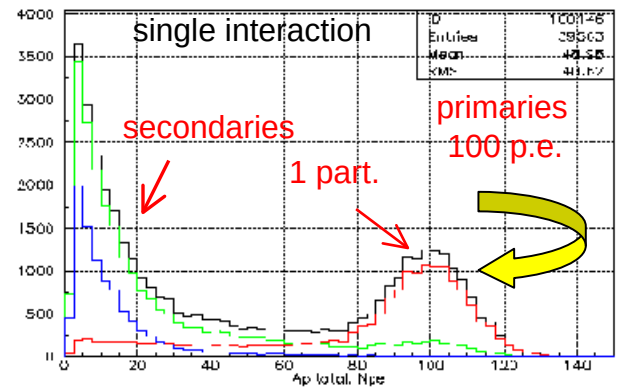
Gas Cherenkov Counters – basic idea

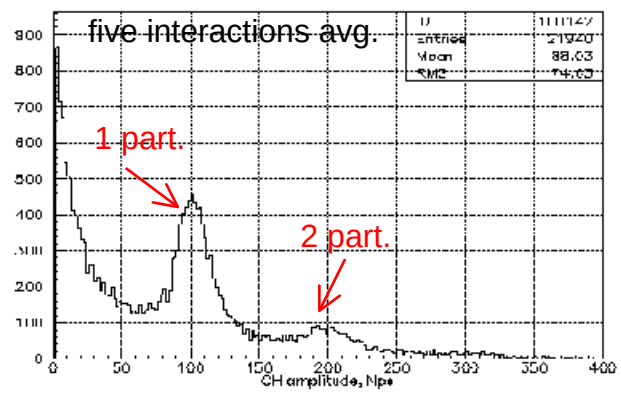




R vs Z for particles that traverse the counters

Measure the number of p-pbar interactions directly by counting <number> of primary particles

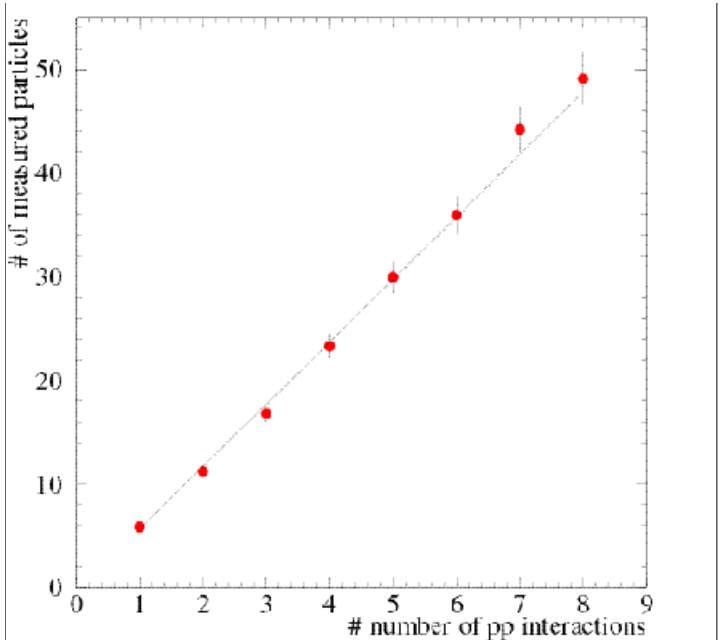




Pointing Gas Cherenkov Counters

- *Sensitive to the right particles!*
  - → **Much light for particles from interactions**
  - → **Little light from secondaries and soft particles**
    - ***Cherenkov thresholds***
    - ***Shorter paths***
  - → **Not too sensitive to particles from back (halo)**
- *Excellent amplitude resolution*
  - → **Count # hits and # particles**
  - → **No saturation → nice linearity**
- *Excellent time resolution*
  - → **Distinguish # of interactions by time**
- *Robustness*
  - → **Radiation hard / low mass**
- *Disadvantages:*
  - → **Needs gas system (small volume)**
- *New idea, more interesting....*

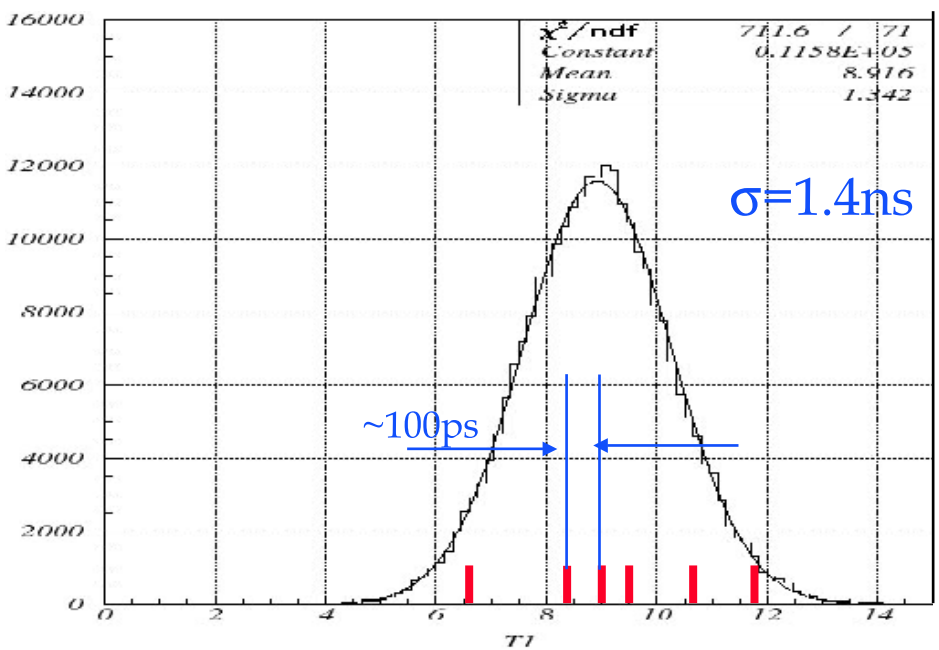
Operate @ L=2*10**32 @ ~6 interactions/beam crossing



From CDF II GEANT simulations w/ real geometry and Cherenkov light tracing

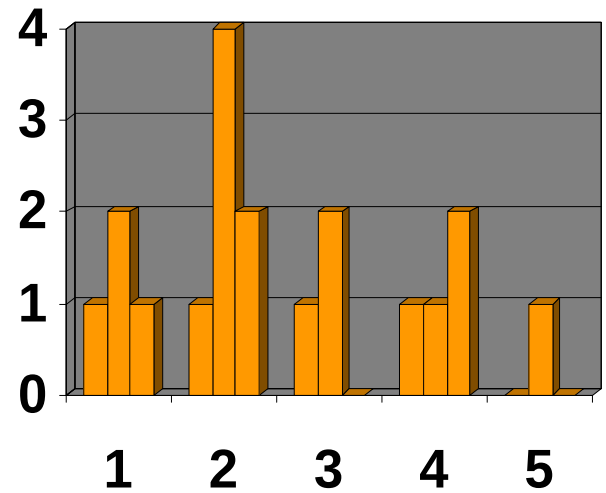
Luminosity counting time clusters

Measure the number of p-pbar interactions using precise timing



interaction time

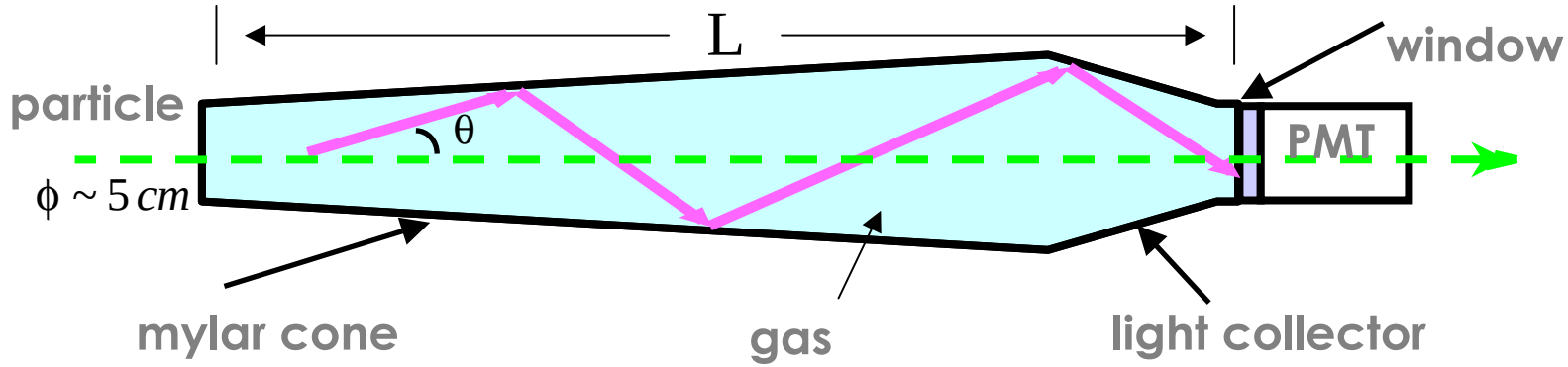
Time clusters



counter arrival times

Cherenkov Counters – prototype

Light emitted if $\beta > 1/n$ **UV dominated**



Cherenkov radiation

- $\cos\theta = 1/(n\beta)$
- $N_{pe} = N_o\ L\ \langle\sin^2\theta\rangle$
- $N_o = 370\ cm^{-1}\ eV^{-1} \int \mathcal{E}_{col}(E)\,\mathcal{E}_{det}(E)\,dE$

$\mathcal{E}_{col}$ - *light collection efficiency*

$\mathcal{E}_{det}$ - *PMT quantum efficiency*

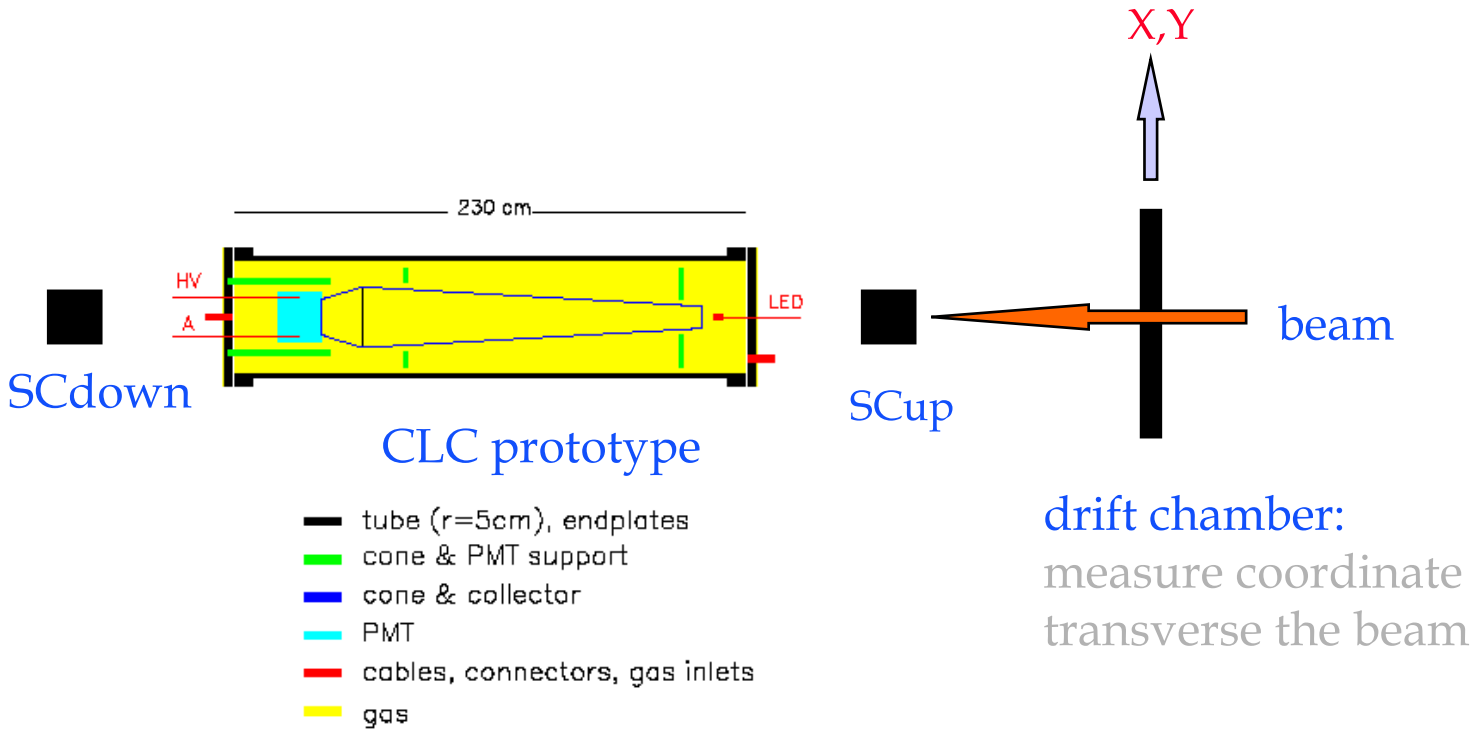
Isobutane @ 1atm

- $n=1.00143$
- $\theta = 3.1^o$
- $\sin^2\theta \sim 0.0027$
- $\langle\varepsilon_{col}\rangle \sim 0.80 \times 0.80 = 0.64$
- $\int \varepsilon_{det}(E)\,dE \sim 0.84$ *(quartz window)*
- $No \sim 200$

Pions > 2 GeV & Electrons > ~9 MeV ⇒ ***Np.e.~110*** *(L=200cm)*

CLC prototype - Testbeam

- *Testbeam studies @ Fermilab*



- ***main questions:***
  - radiator light yield and collection efficiency
  - timing resolution

PMT choice

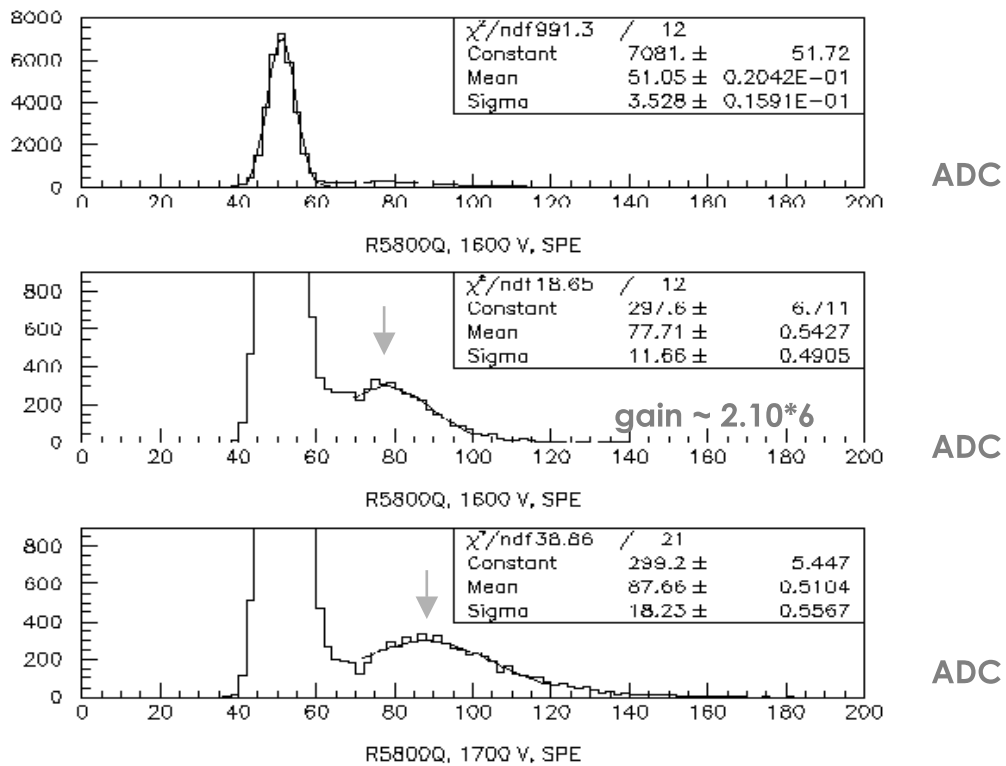
- **Geometrical constraints**
  - ***~ 25 mm diameter (all layers…)***
    - Larger doesn't fit
    - Smaller requires large angle collector (losses)
- **Performance**
  - ***Quartz window***
    - UV transparent
    - Rad hard
    - Thin
      - *Less light*
      - *Better timing resolution*
  - ***Timing resolution***
    - Sub 100 ps resolution
- **Cost**

…

R5800Q Hamamatsu
10-stage / 10^6 gain
0.8 mm concave-convex quartz window
25 mm x 60 mm
1.5 ns rise-time
~12 ns pulse width

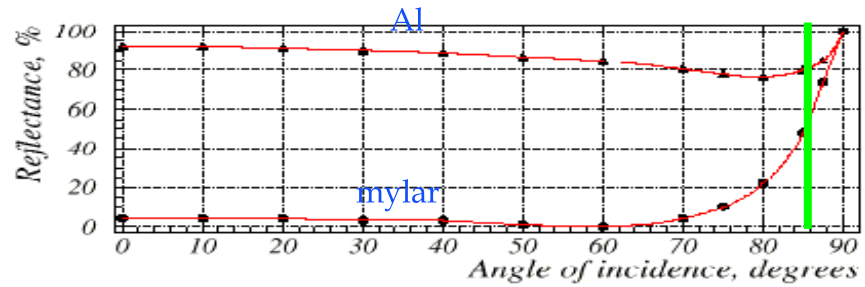
Single p.e. peak

- *60 m long cables, R5800Q PMT*

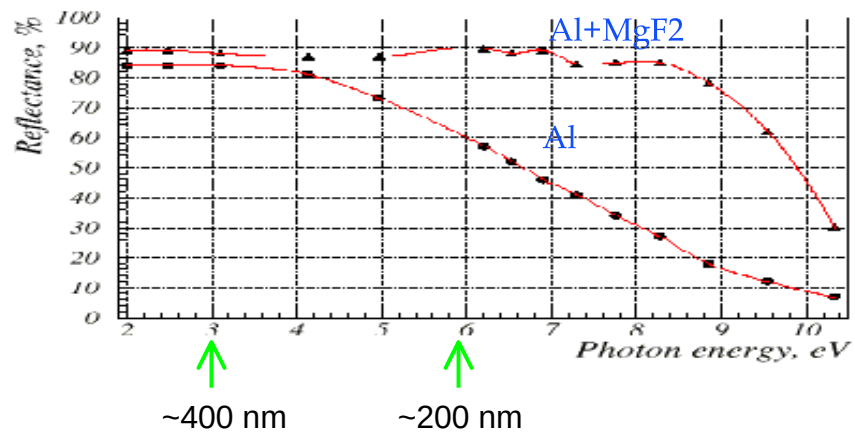


Collection Efficiency

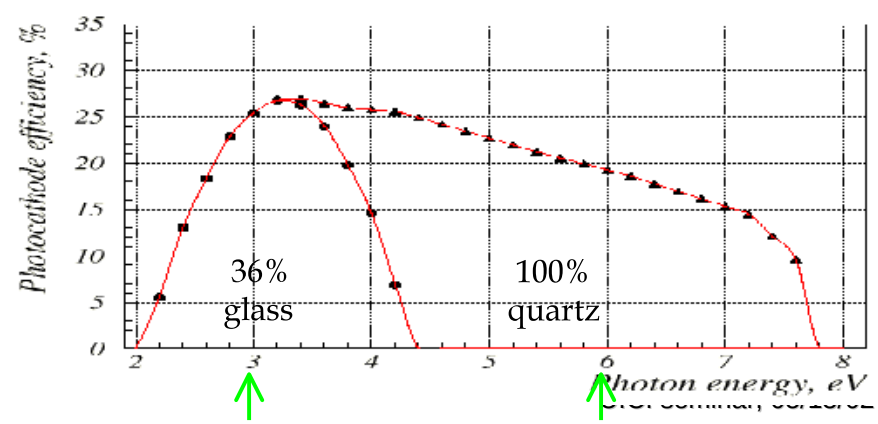
- Cone reflectivity ~80%
  - grazing angles < 4deg.
  - 2 reflections in average



- Collector reflectivity ~80%
  - large angles
  - one reflection

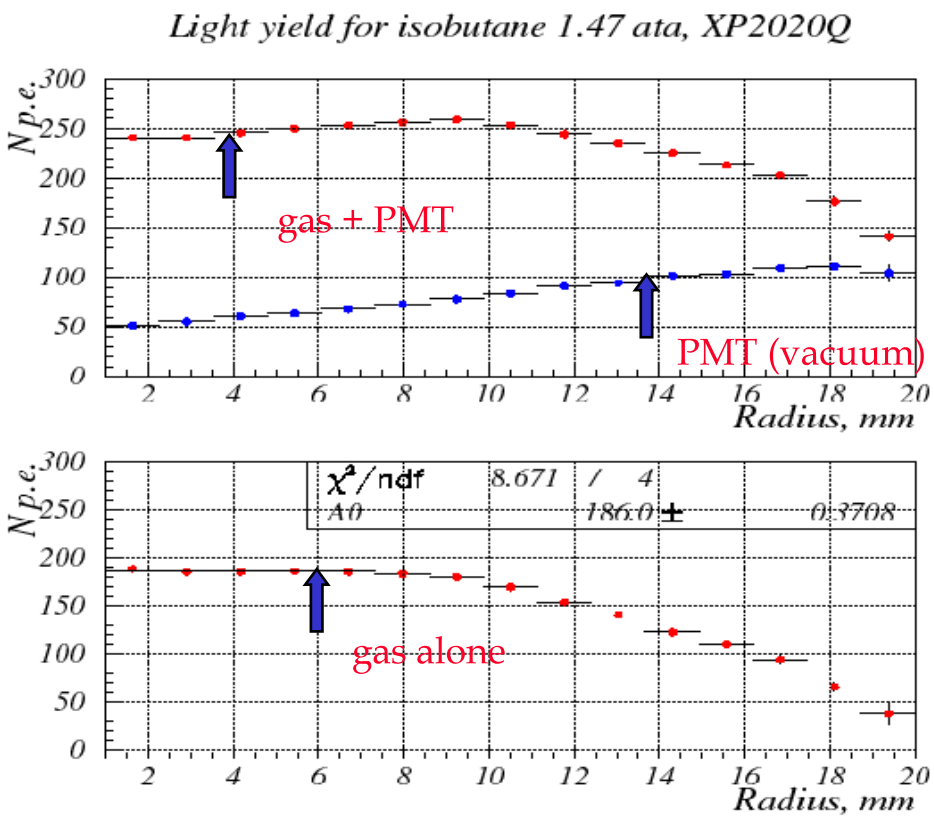


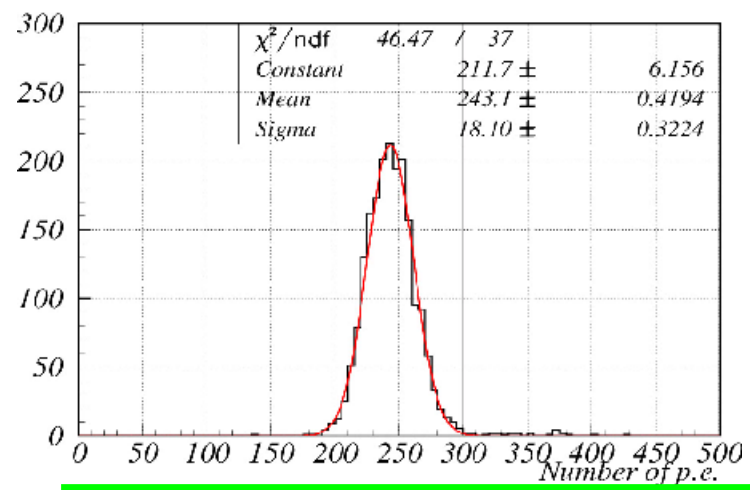
- Quartz window
  - x2-3 UV light collection (cutoff @ ~ 160 nm)
  - rad hard
  - ~ 25 p.e./mm (make thin)



Isobutane Light Yield - Testbeam

In isobutane, C_4H_{10}, (as a function of radius relative to the cone & PMT axis)





~ 7% resolution for r<6mm

126 photoelectrons @ 1atm.

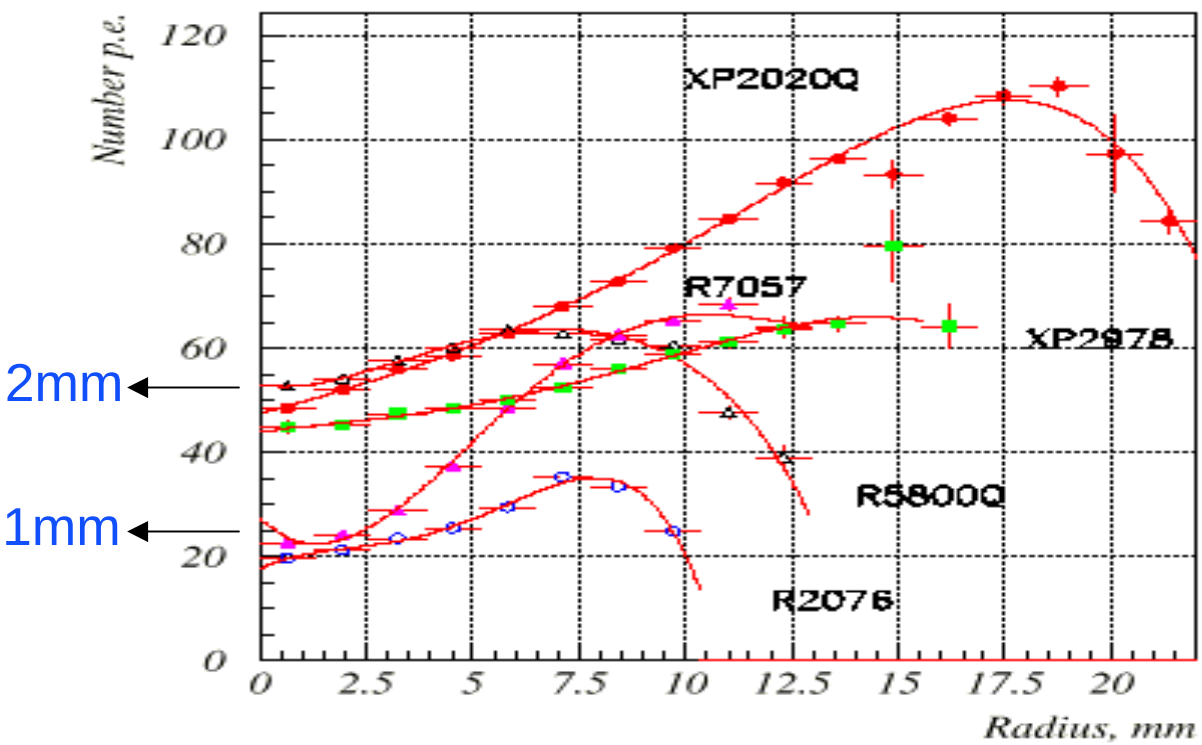
Isobutane

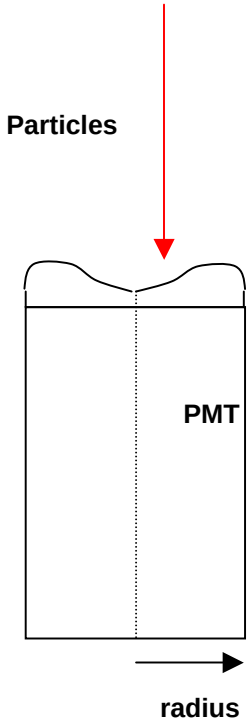
- *Good UV transparency*
- *Largest refractive index at normal P for common gases*
- *Tested other gases:*

C_2F_6 , C_3F_8 , C_4F_8, SF_6, N_2 etc.

PMT Window Light Yield - Testbeam

quartz → 25 p.e./mm

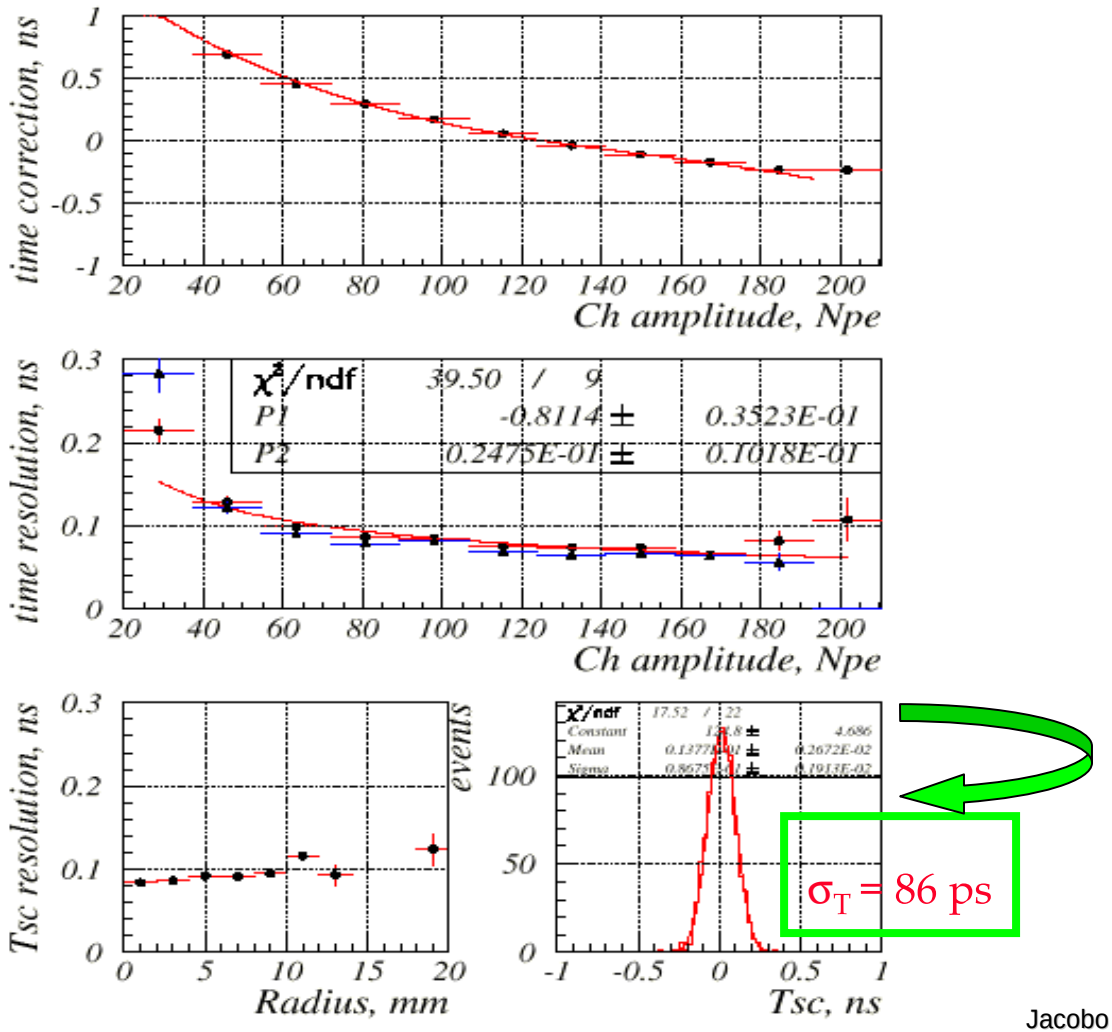




Time Resolution - Testbeam

For the R5800Q PMT

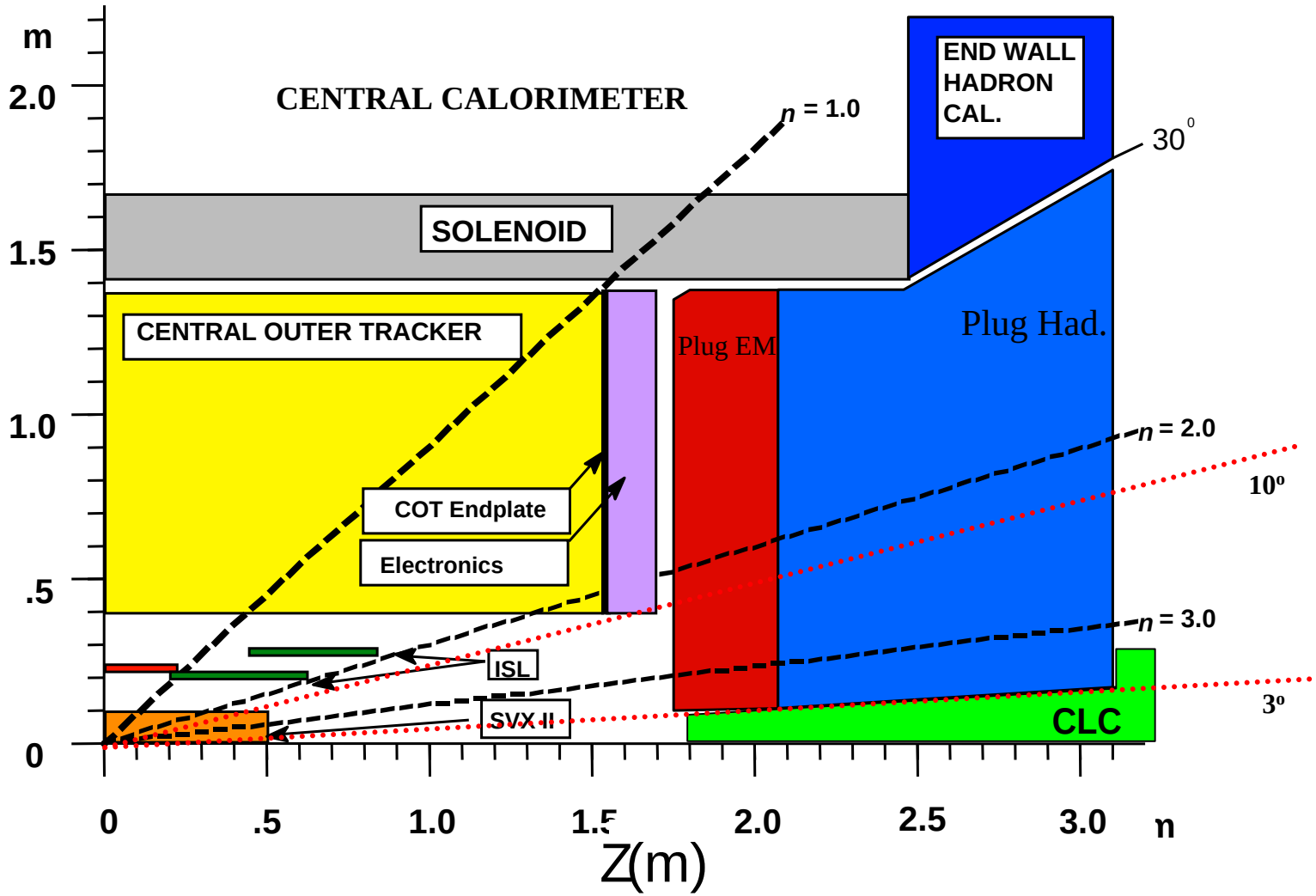
(75<Amp<125p.e.)



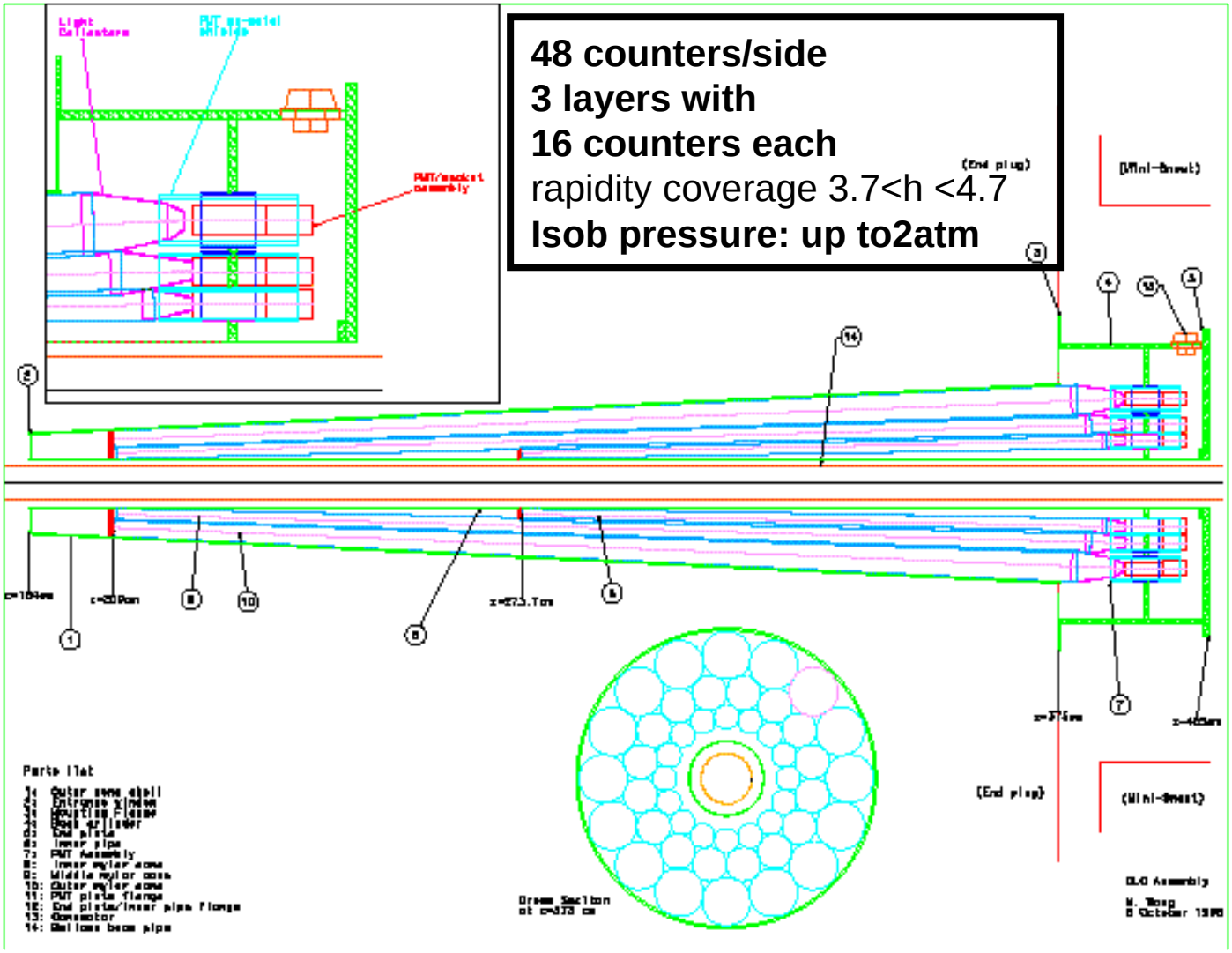
Detector design

Jacobo Konigsberg
U.C. seminar, 05/13/02

CDF II cross- section

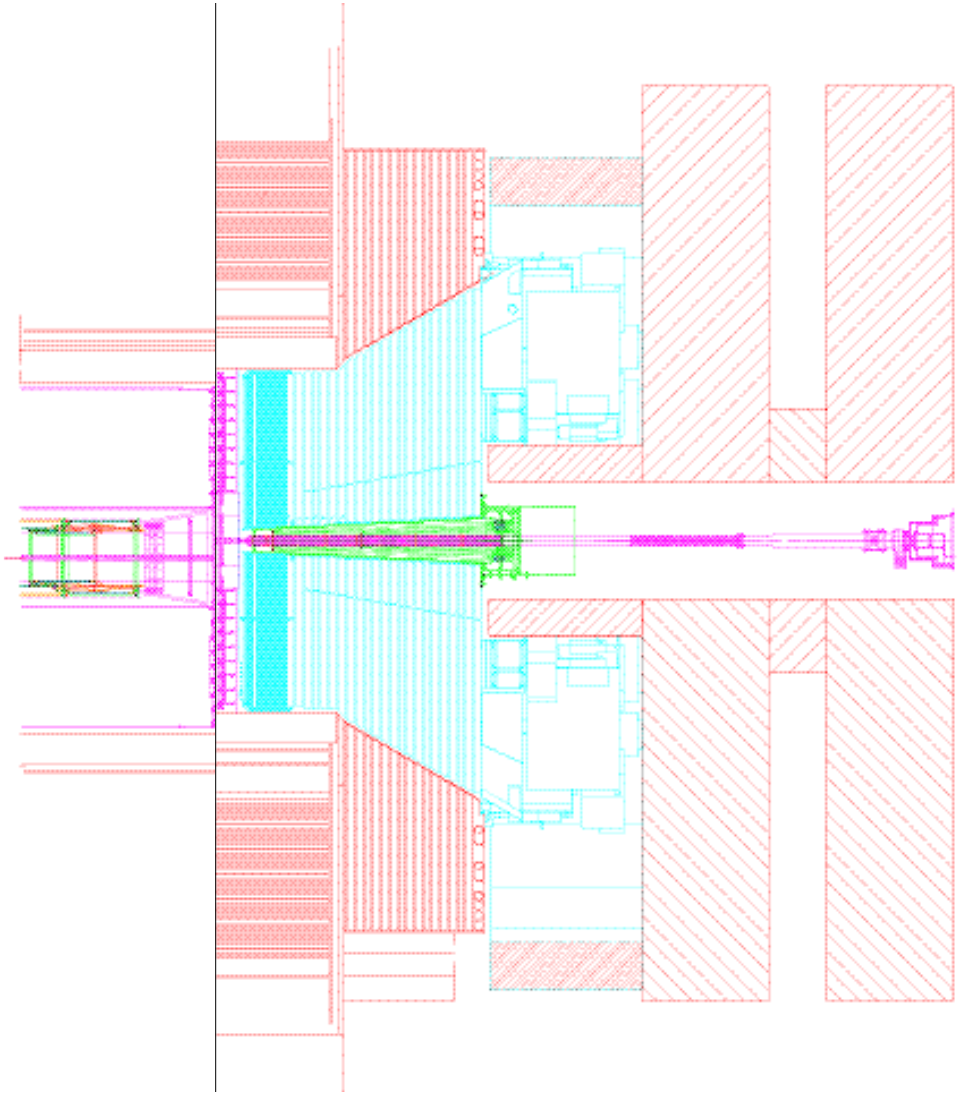


CLC Mechanical Design

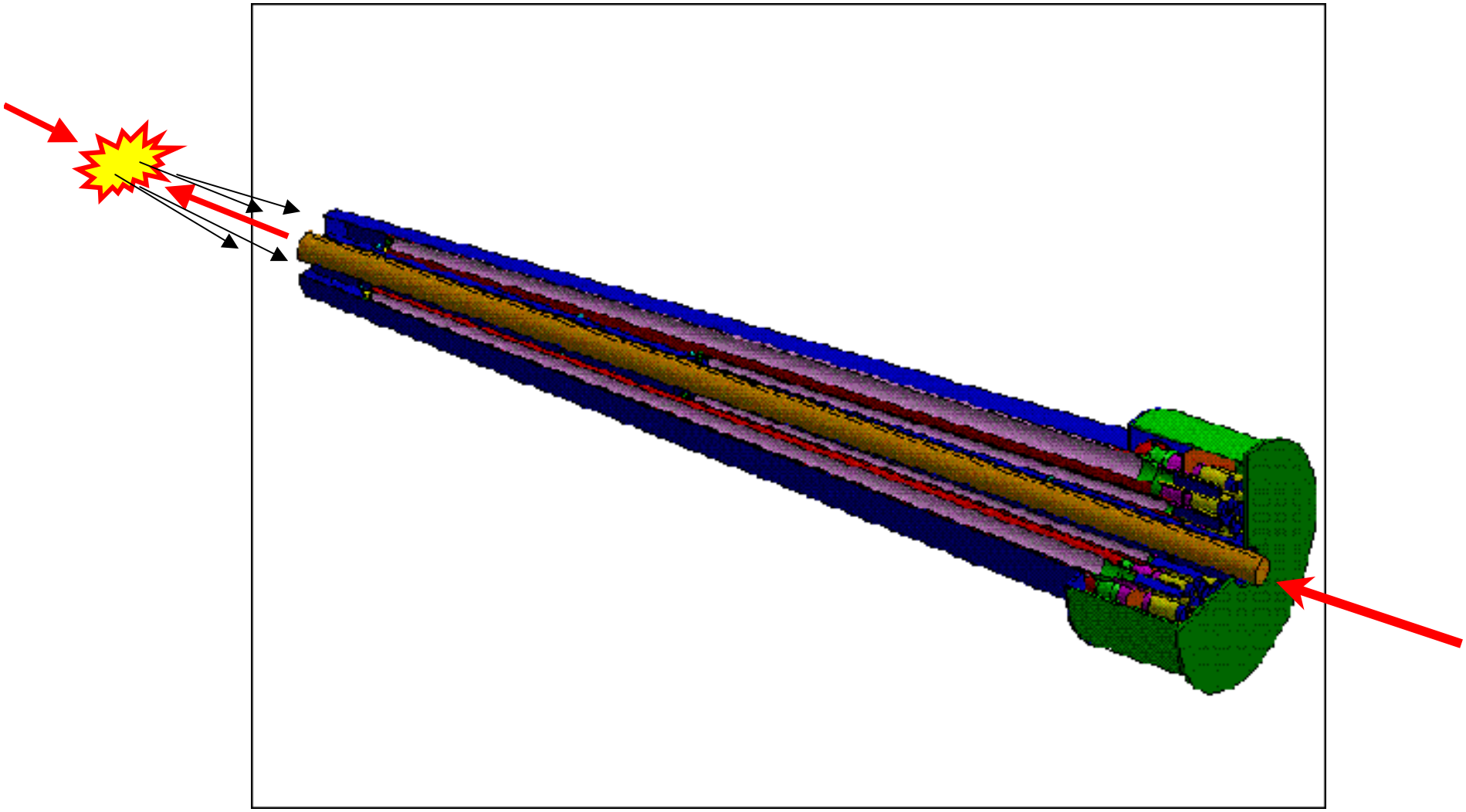


48 counters/side
3 layers with
16 counters each
rapidity coverage 3.7<h <4.7
Isob pressure: up to2atm

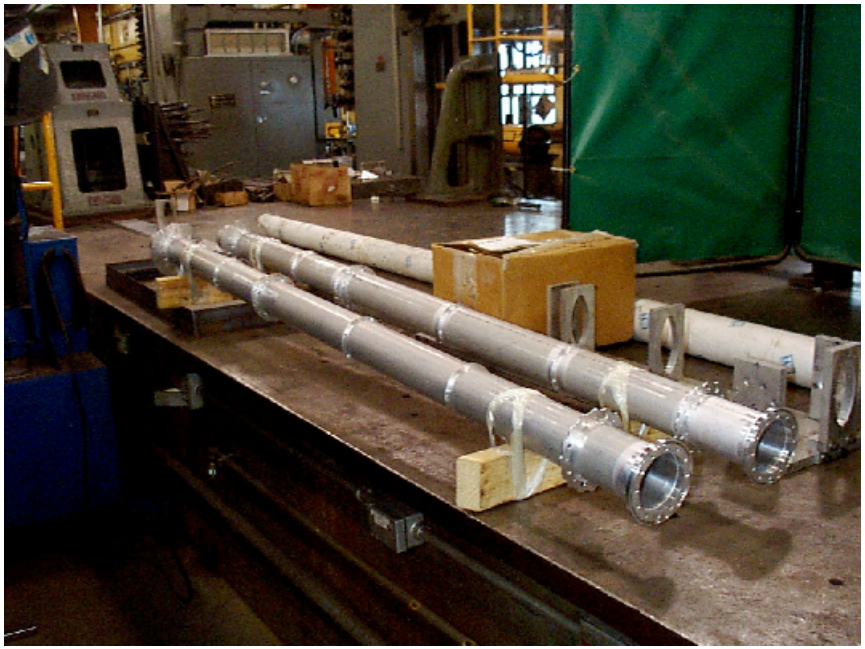
CLC location in CDF

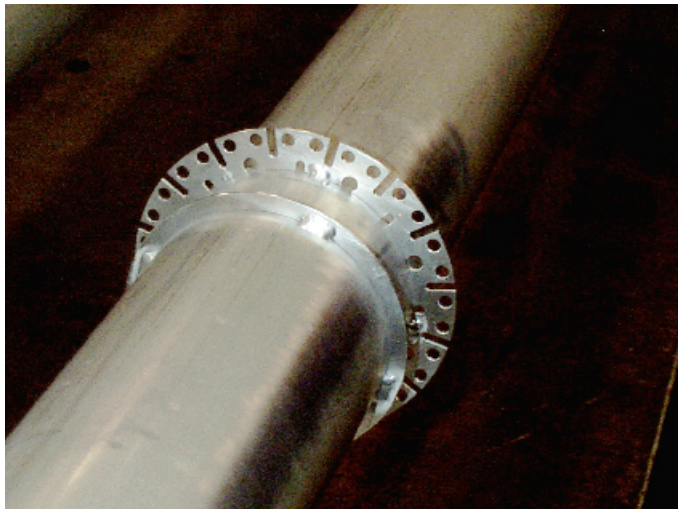


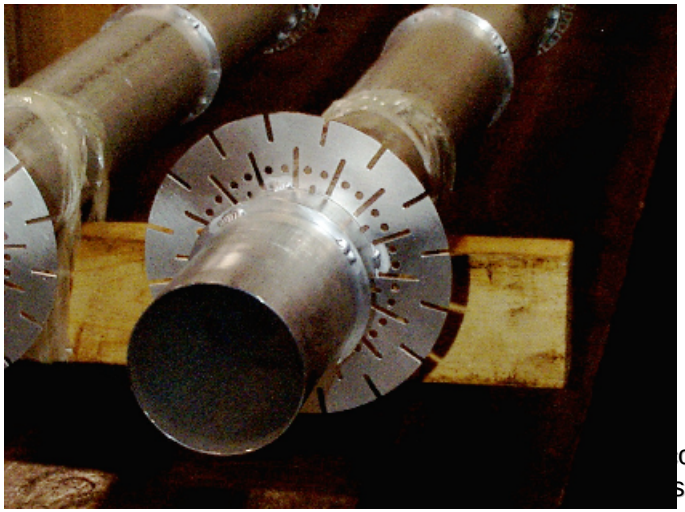
CLC Design



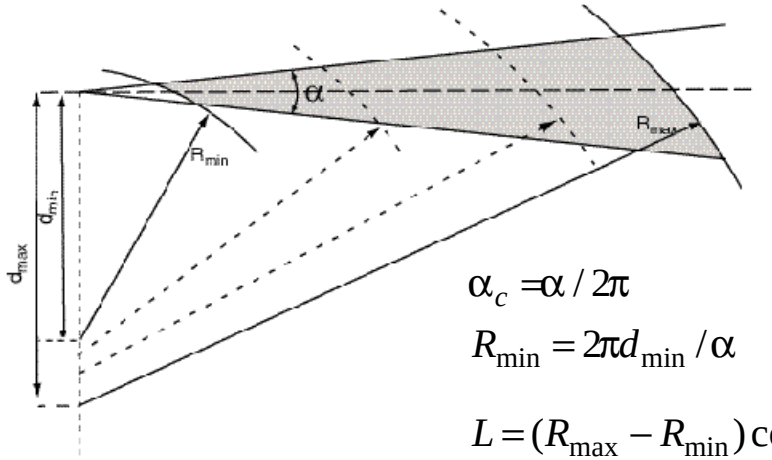
CLC support cylinder







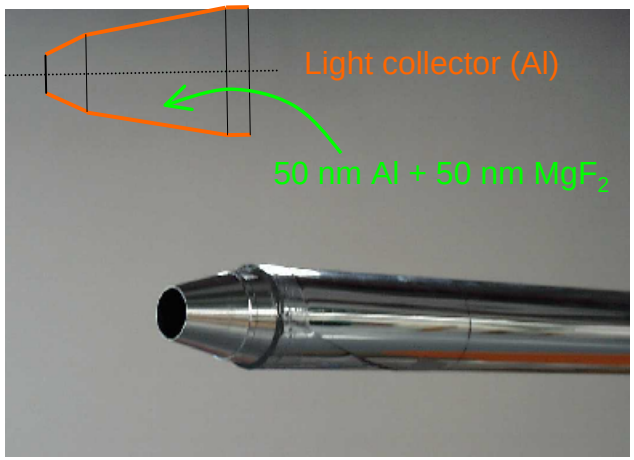
Aluminized Mylar cones - design

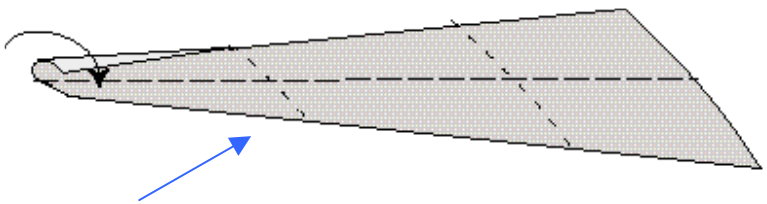


$$\alpha_c = \alpha / 2\pi$$

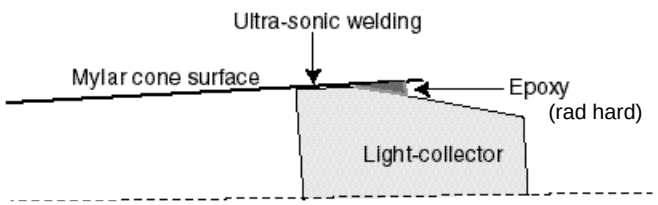
$$R_{\min} = 2\pi d_{\min} / \alpha$$

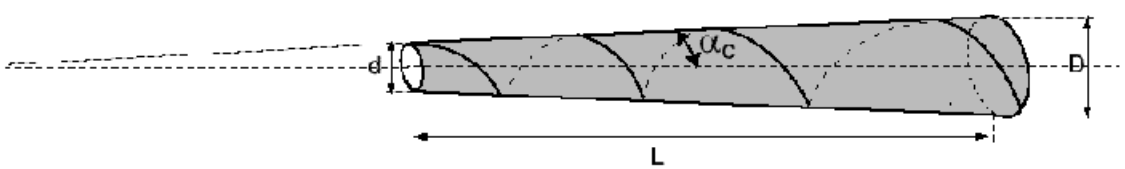
$$L = (R_{\max} - R_{\min}) \cos\frac{\alpha_c}{2}$$

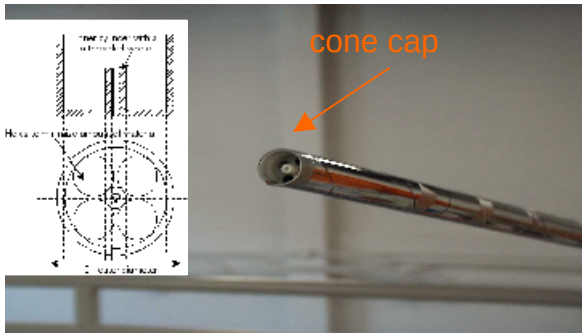




2 layers; 0.1 mm each; 60 nm Al coating

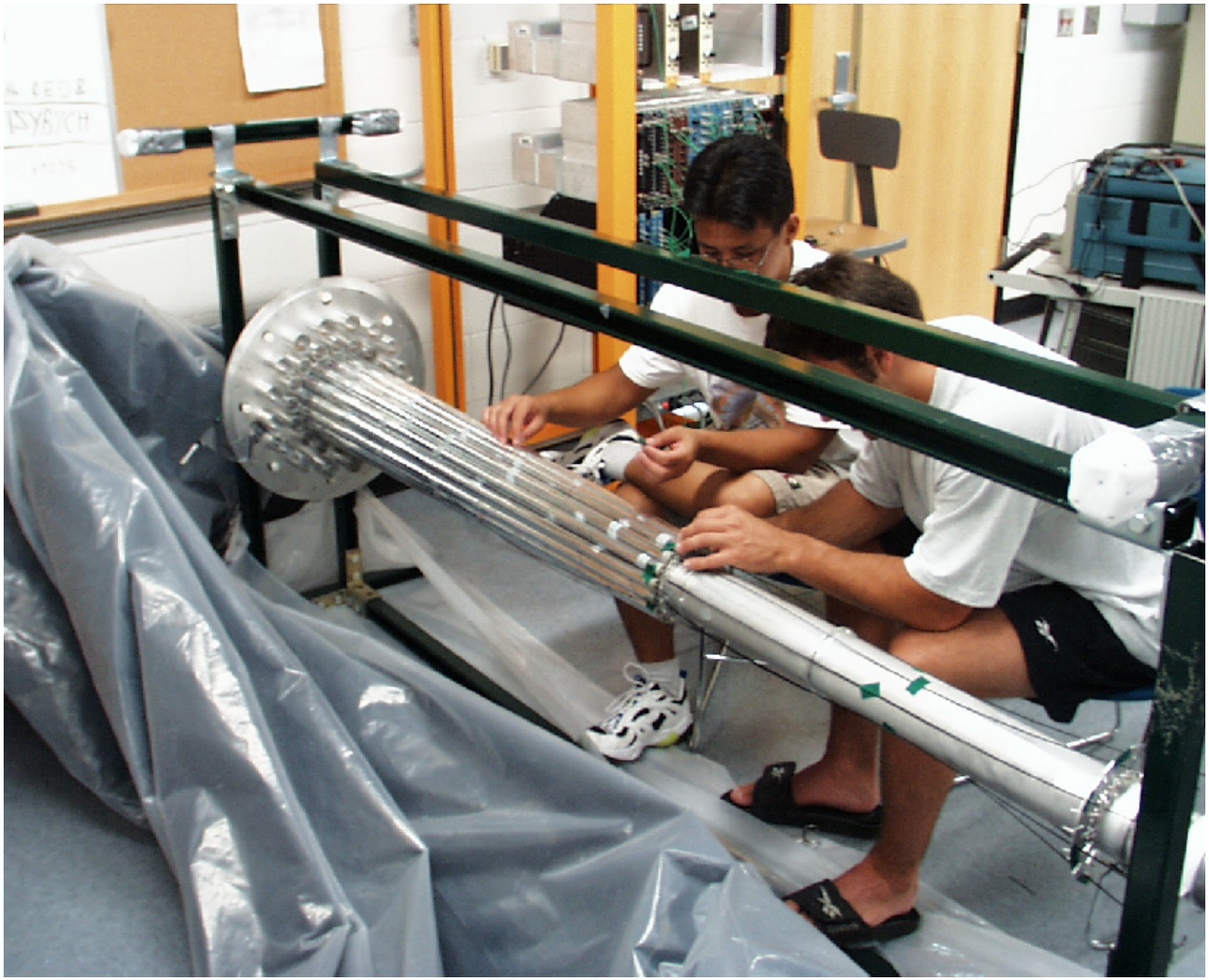




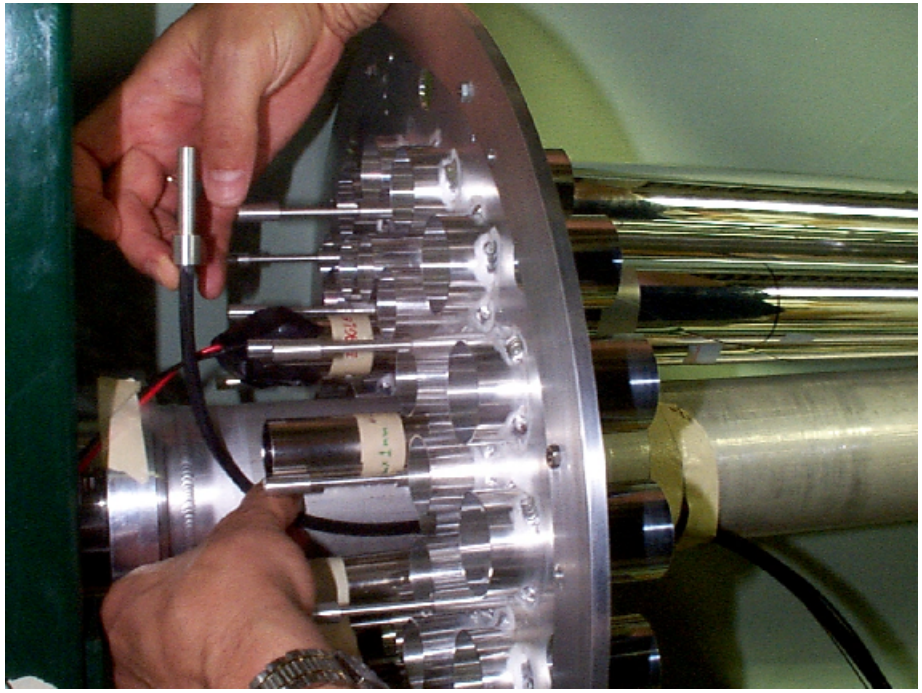


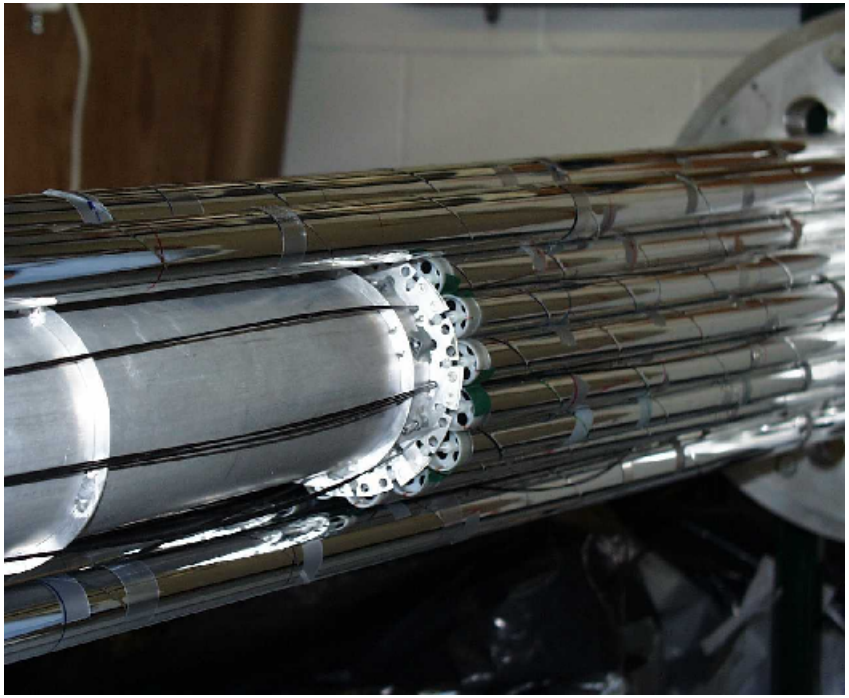
Outer layer cone + collector

CLC inner structure assembly (at UF)

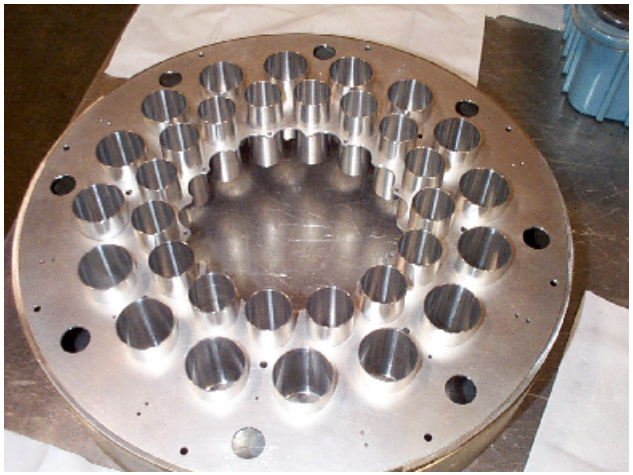


Quartz fiber bundles: LED calibration system





The CLC modules

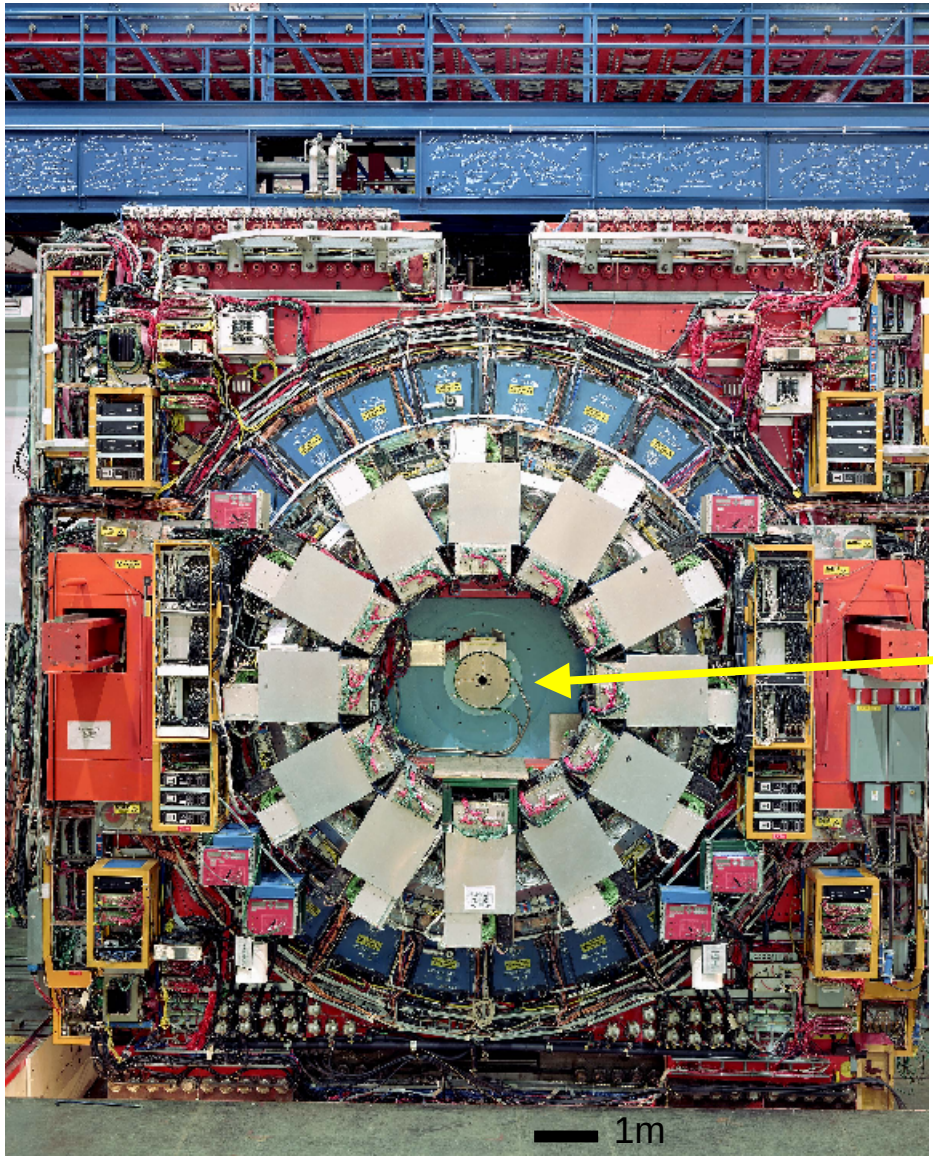


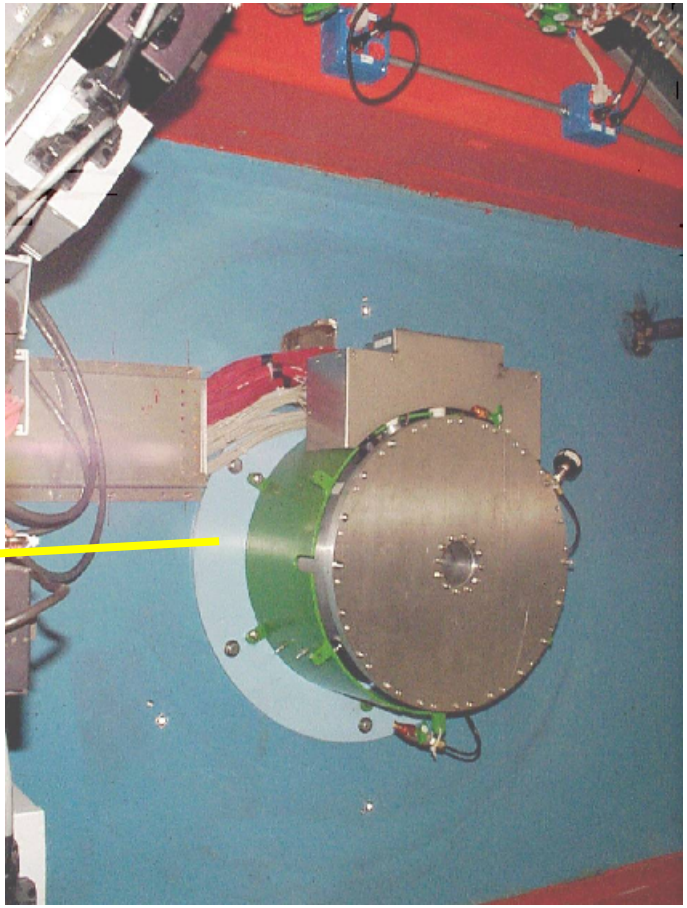
Installation into gas vessel

Completed PMT assembly

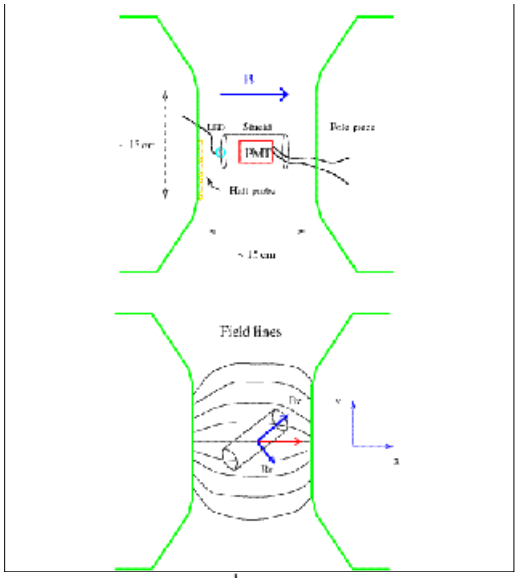
Completed modules

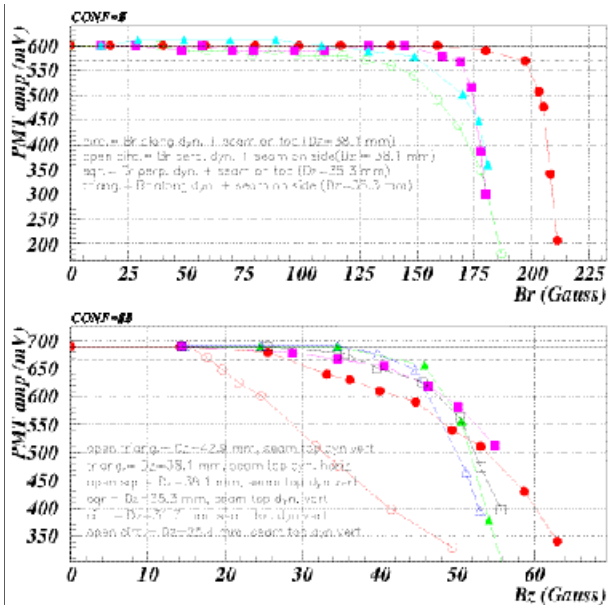
Installed in CDF !



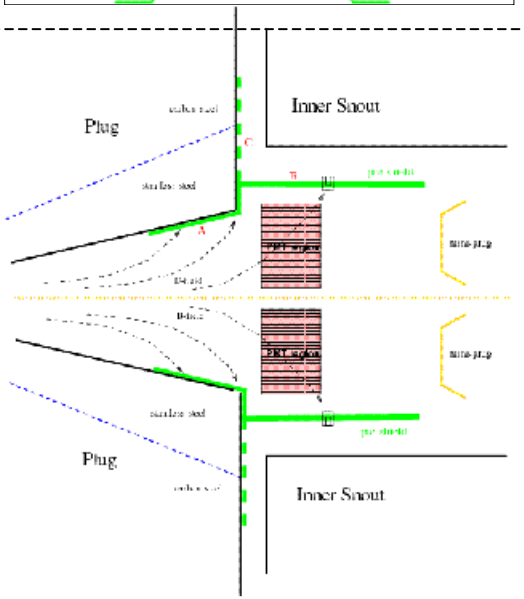


Magnetic Shielding

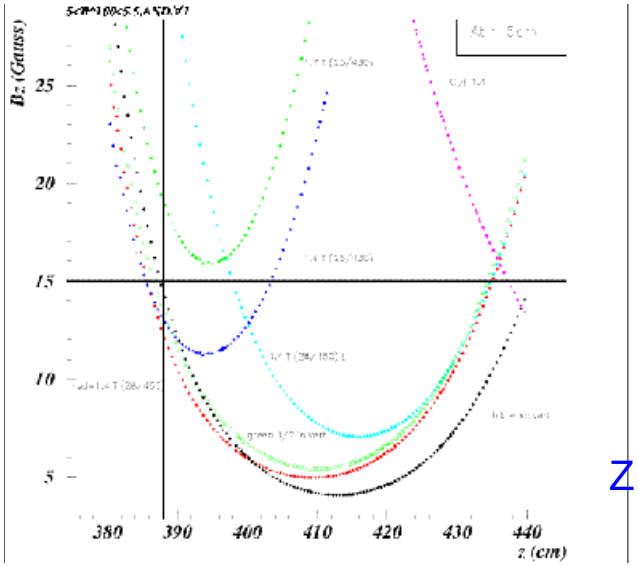




Individual
Mu-metal shields



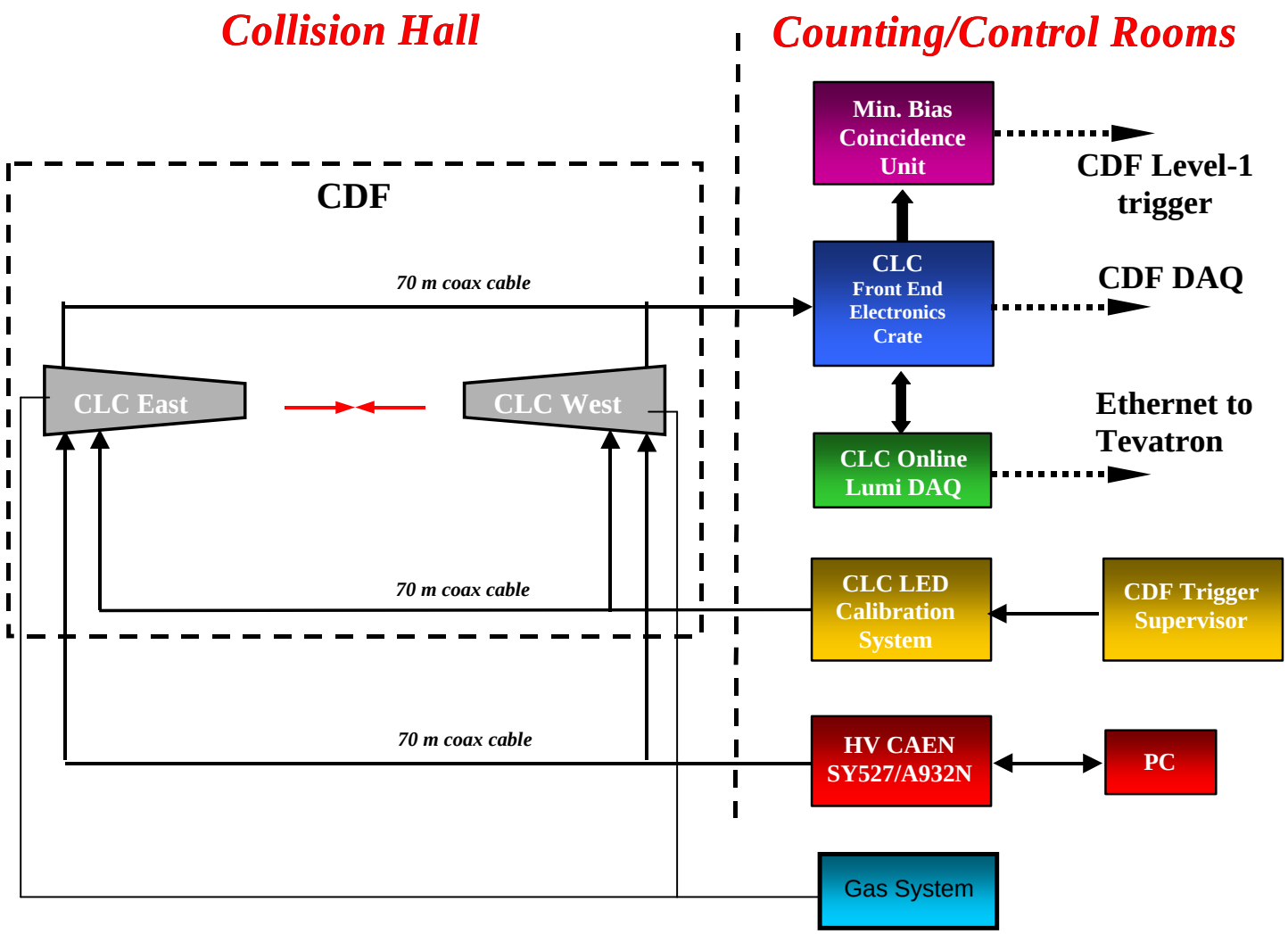
Bz (G)



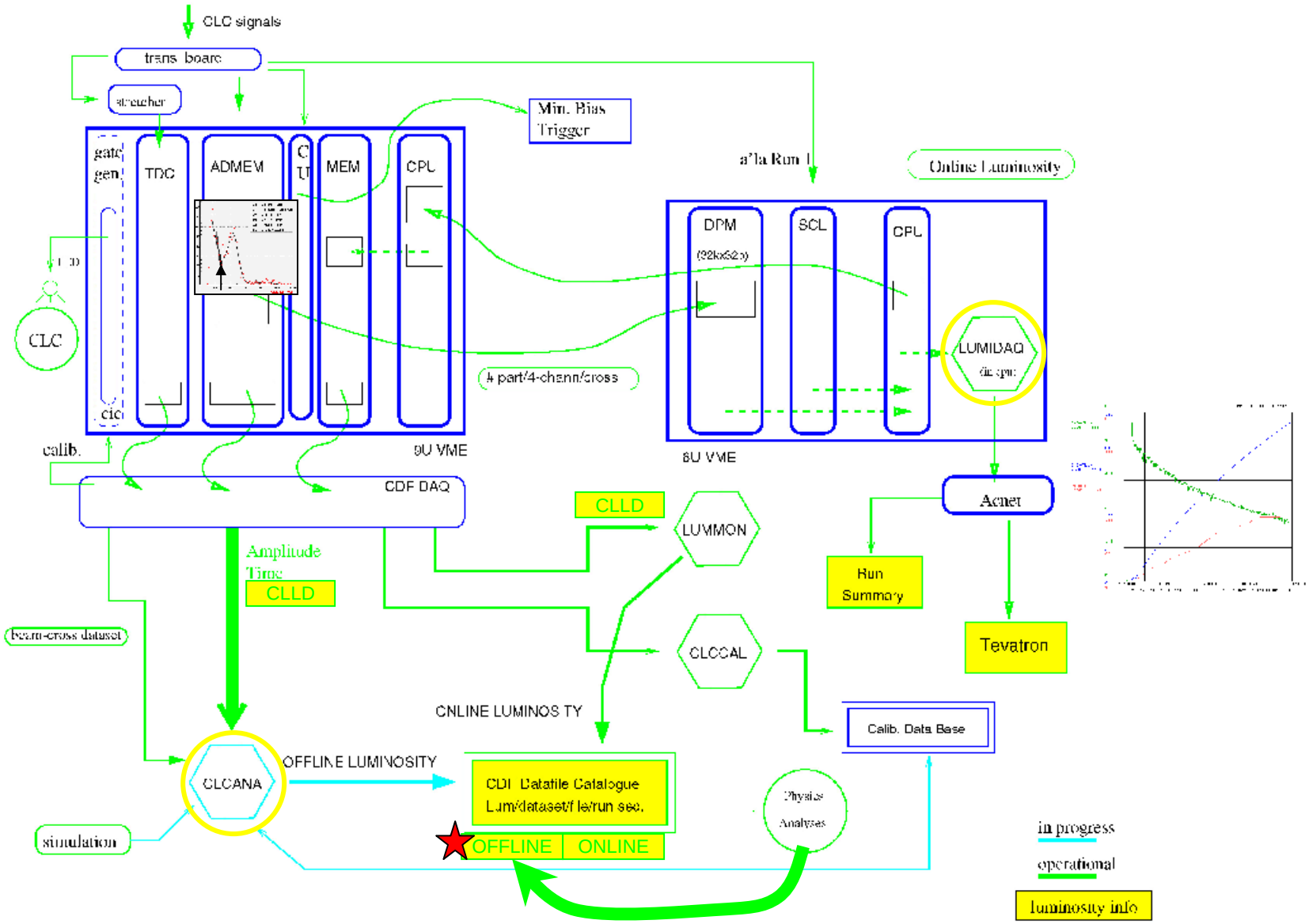
"pre-shield"
optimization

Z (cm)

CLC systems


Collision Hall
Counting/Control Rooms
CDF
70 m coax cable
CLC East
CLC West
70 m coax cable
70 m coax cable
Min. Bias Coincidence Unit
CDF Level-1 trigger
CLC Front End Electronics Crate
CDF DAQ
Ethernet to Tevatron
CLC Online Lumi DAQ
CLC LED Calibration System
CDF Trigger Supervisor
HV CAEN SY527/A932N
PC
Gas System

Luminosity Readout & Information Flow



Detector performance

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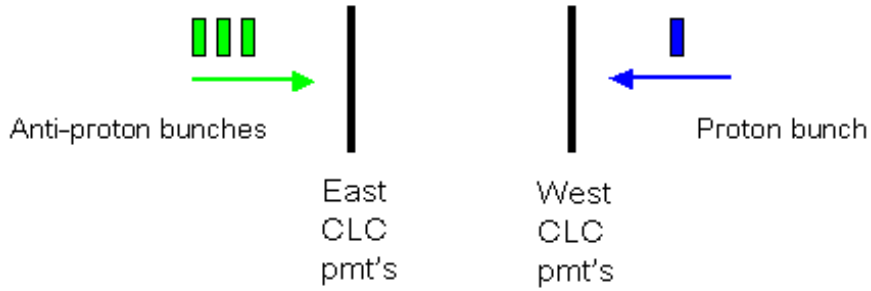
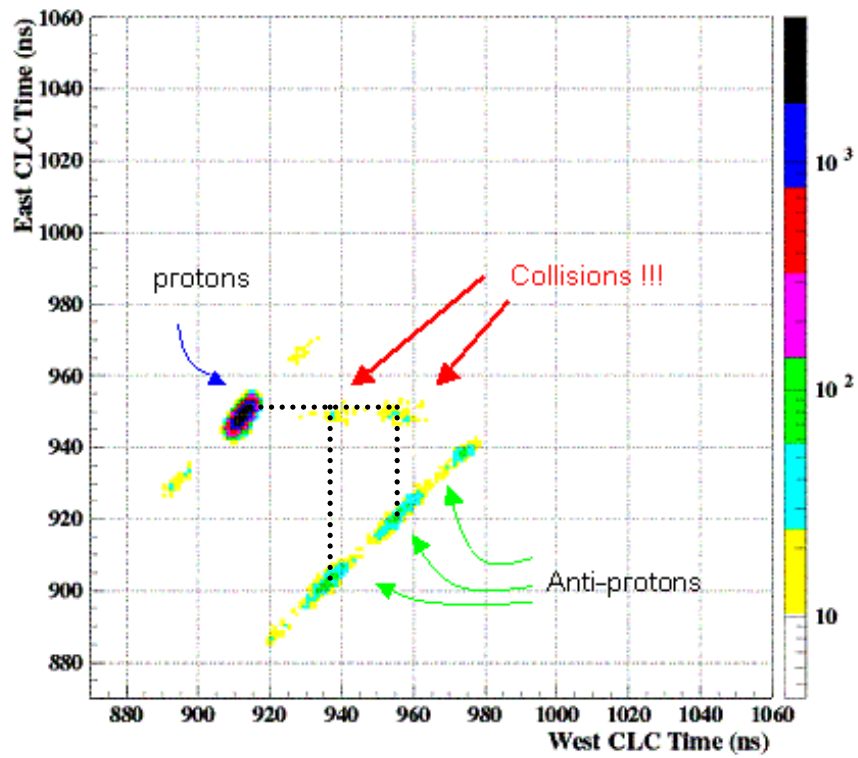
First Collisions at 1.96 TeV at CDF
(seen by the Cherenkov Luminosity Counters)

October 2nd, 2000





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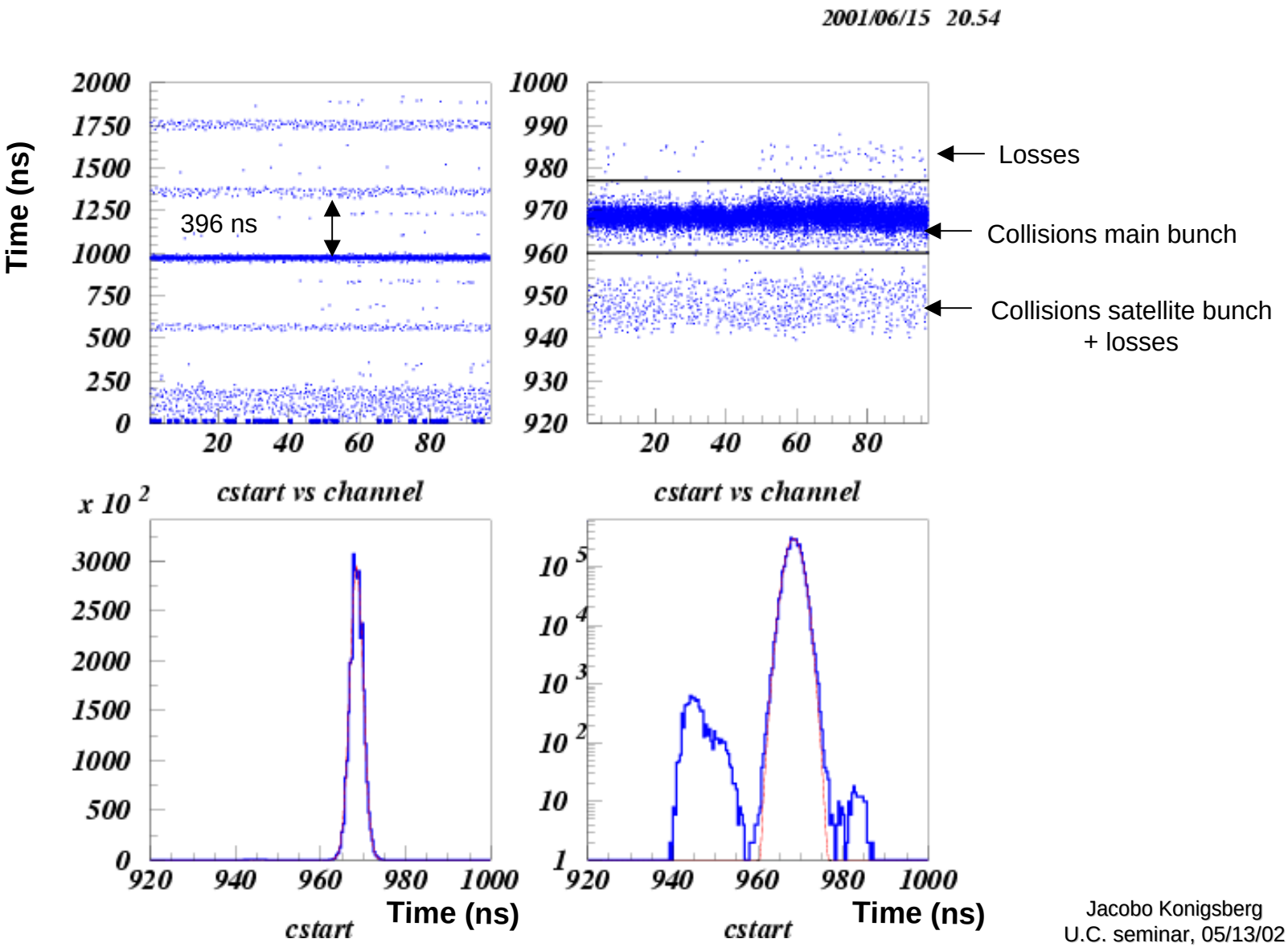
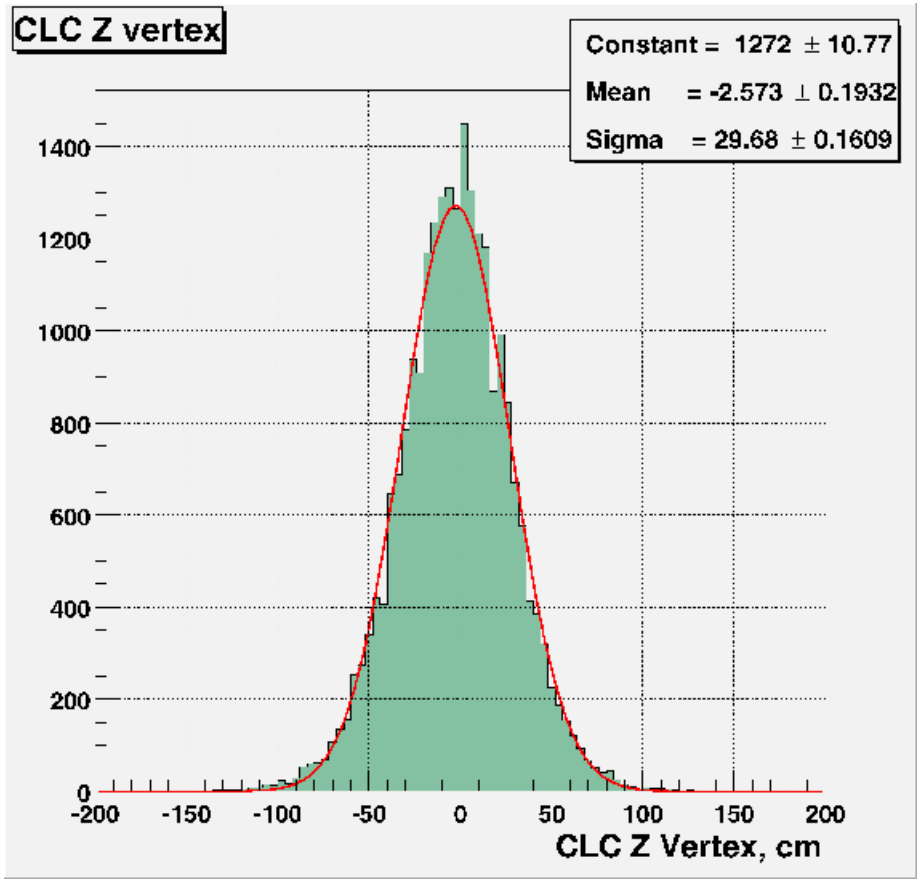
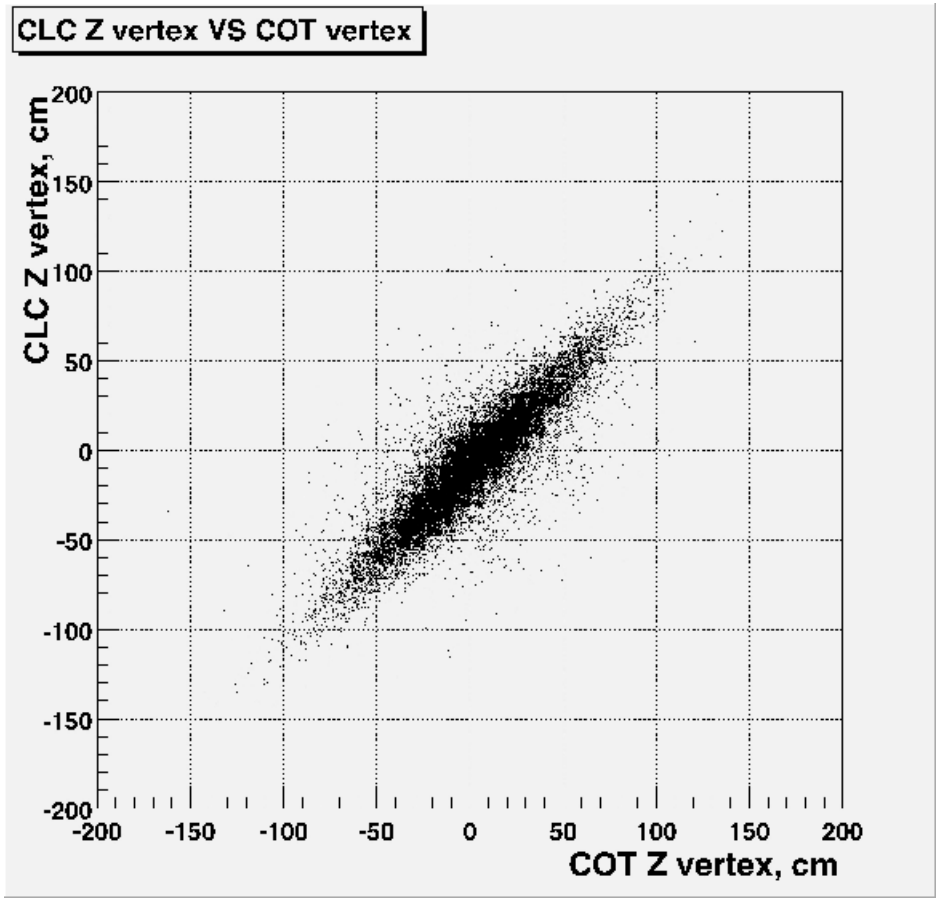
Beam structure: timing



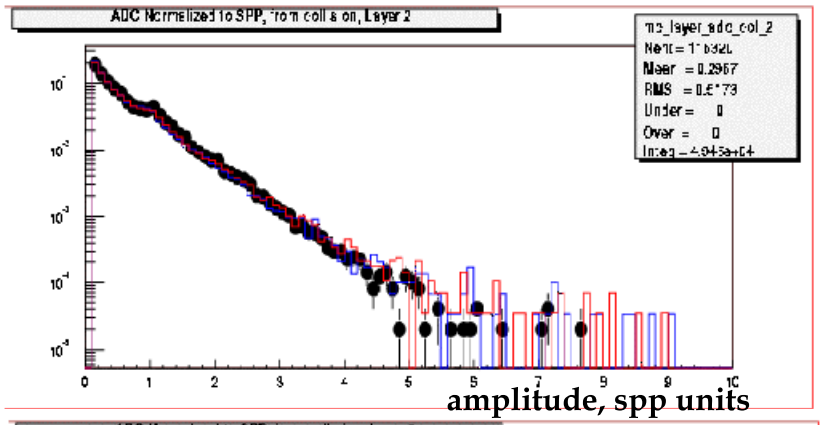
P- pbar interactions Z position

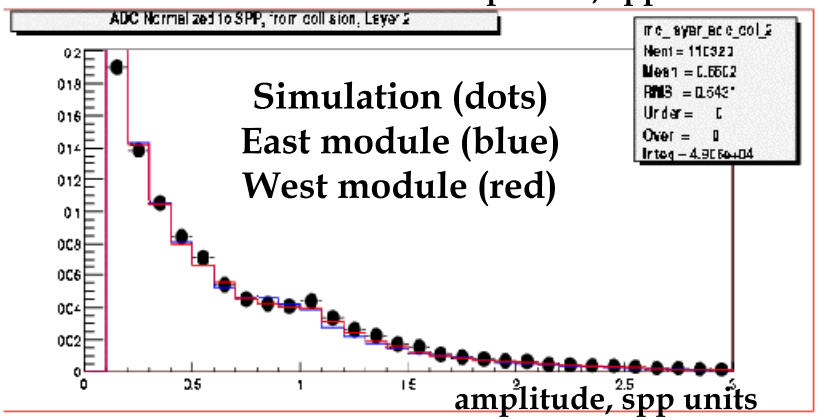


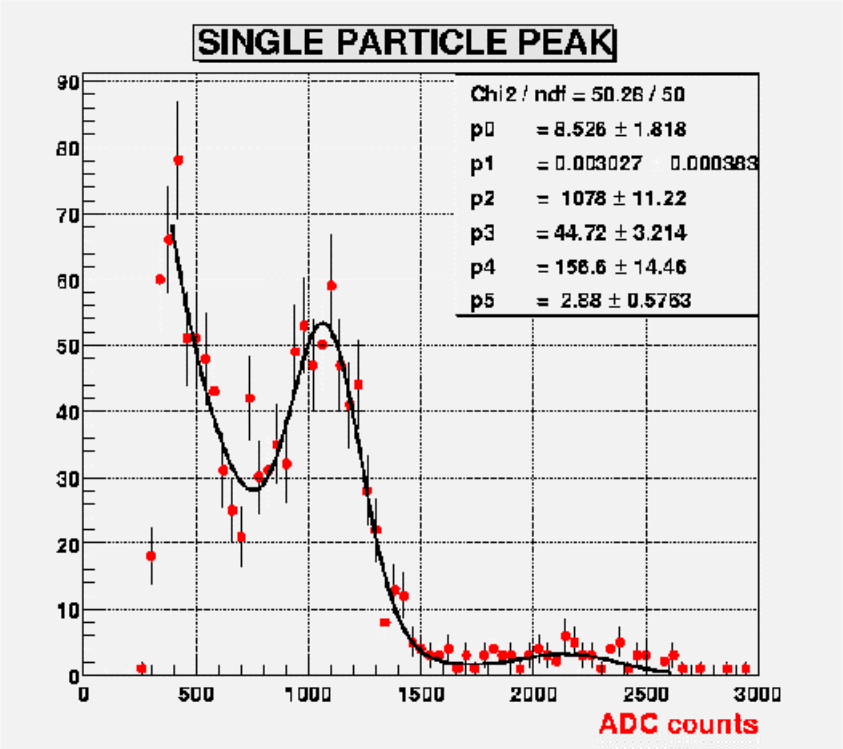


CLC amplitude distribution

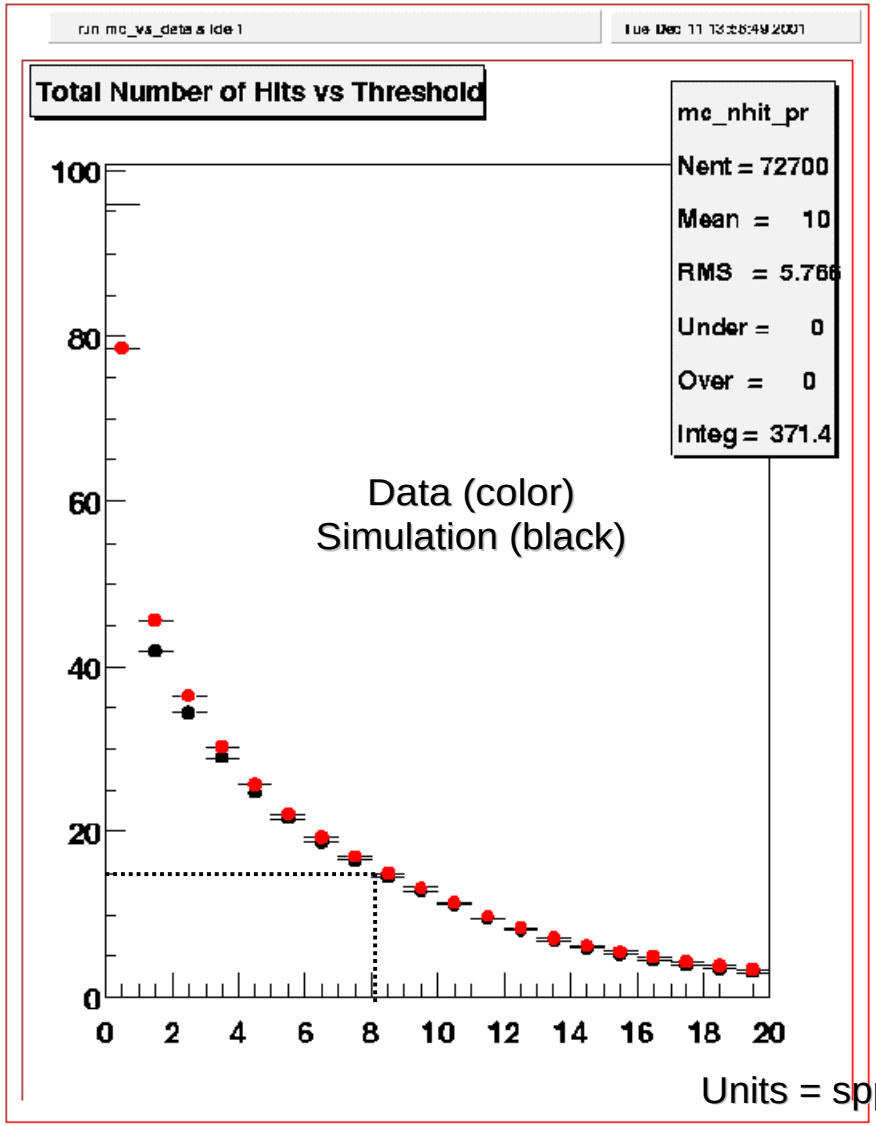
- **Single Particle Peak (spp)**
  - *Higher CLC occupancy due to more material close to beam*
  - *SPP clearly seen after isolation cat → useful for calibration !*
  - *Great agreement with simulation !*





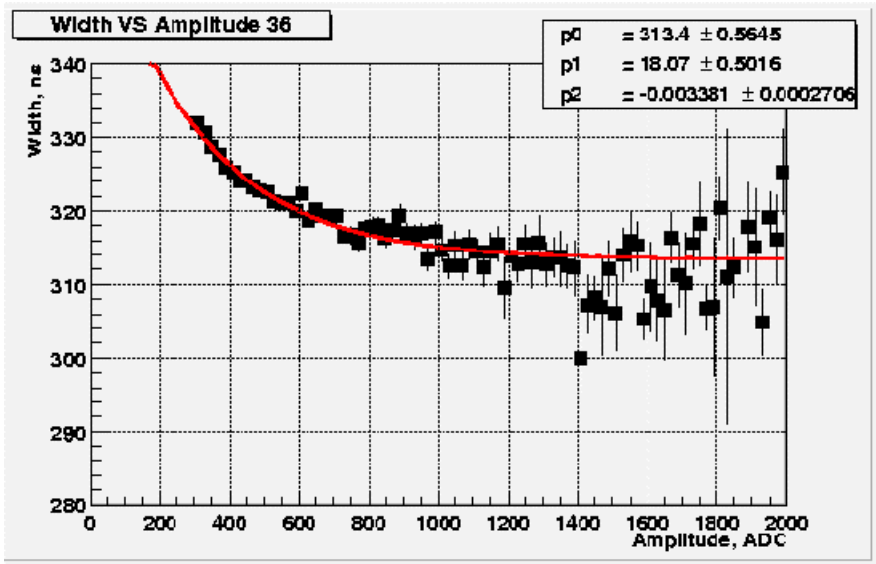


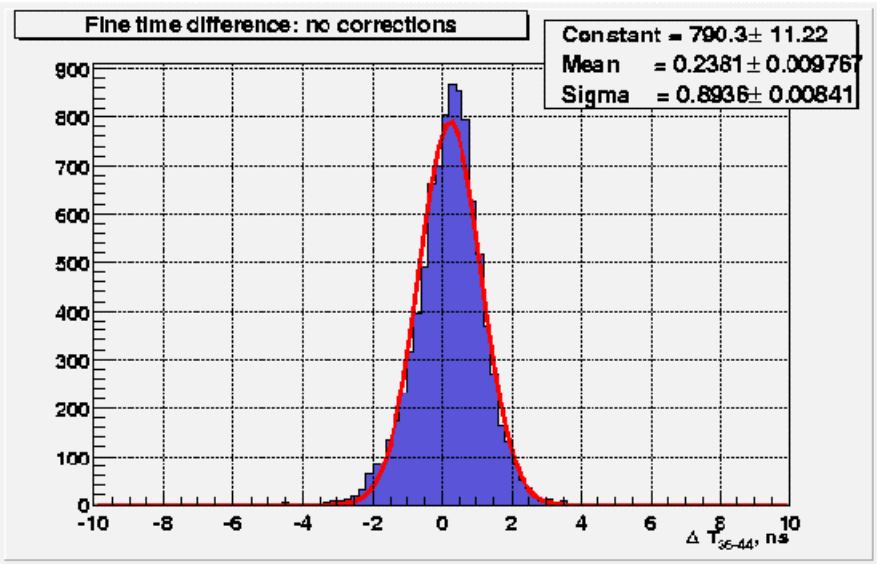
CLC <occupancy> vs. threshold

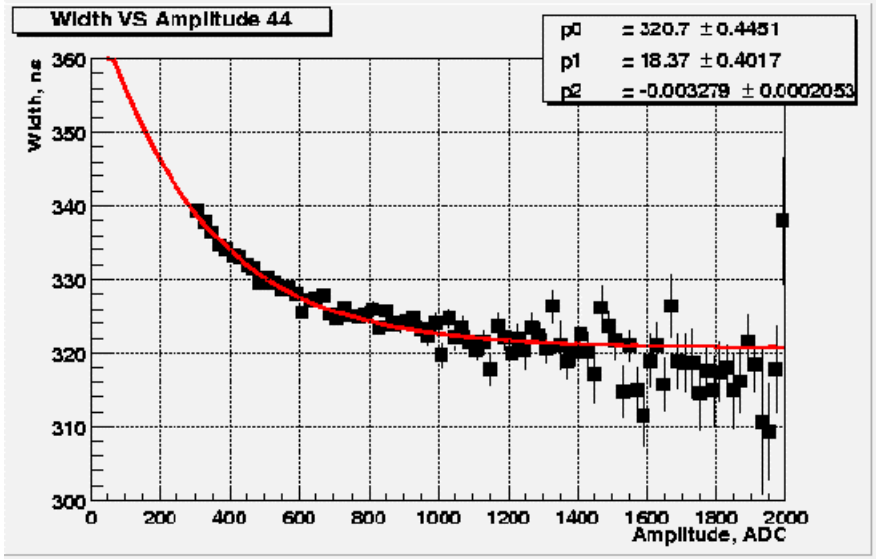


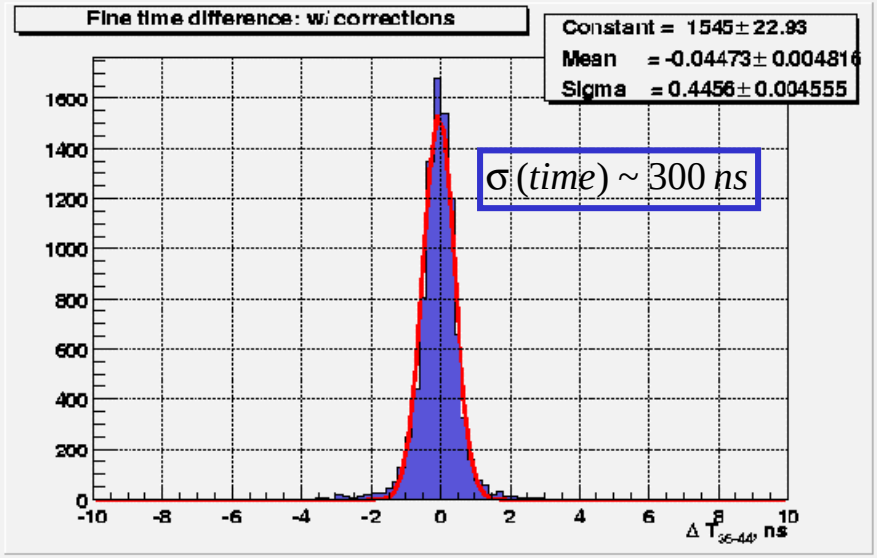
Units = spp x 10

Quick look at precise timing (low gain)

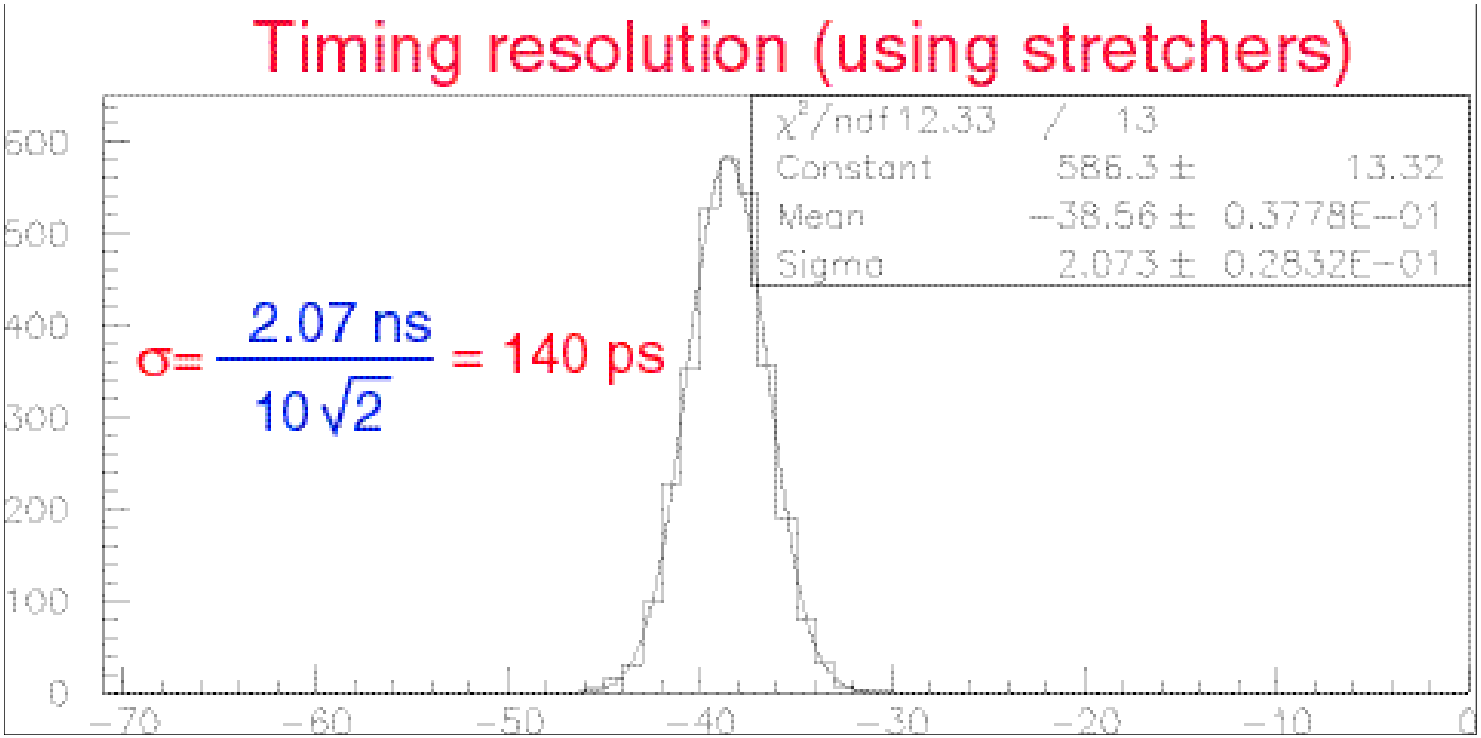




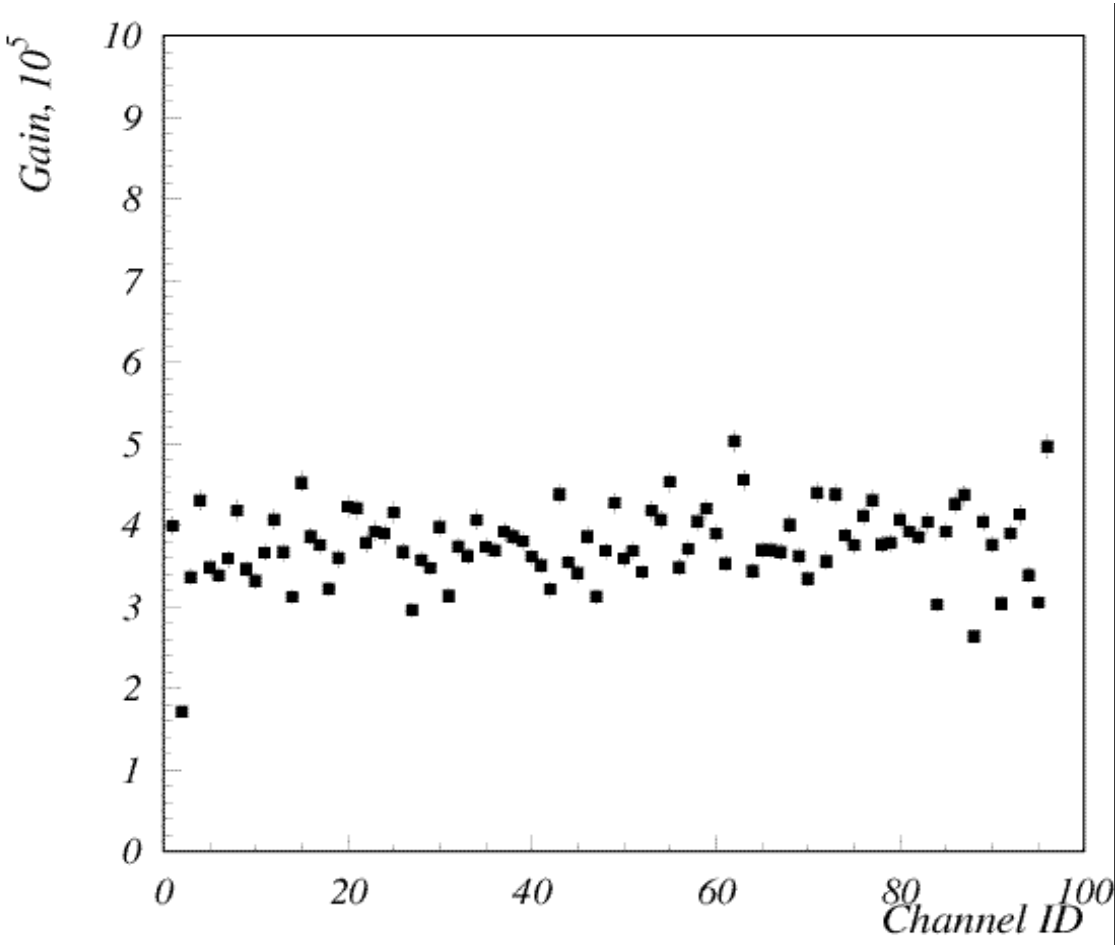




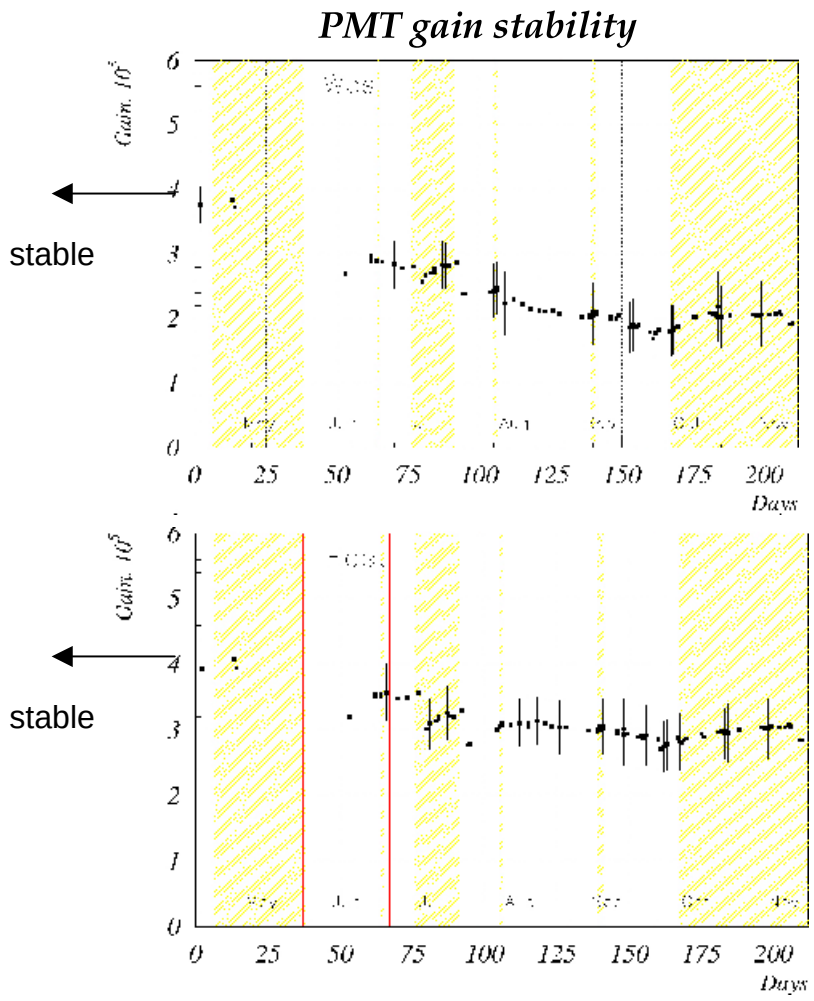
Quick look at precise timing (higher gain)

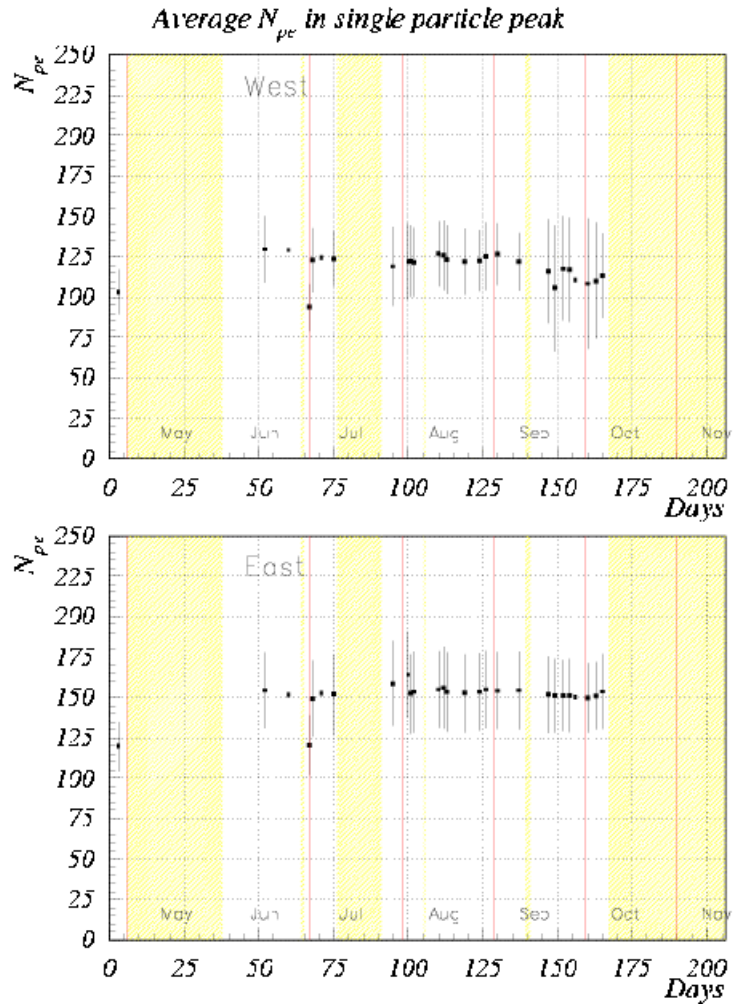


PMT gains



Gain Stability ☹

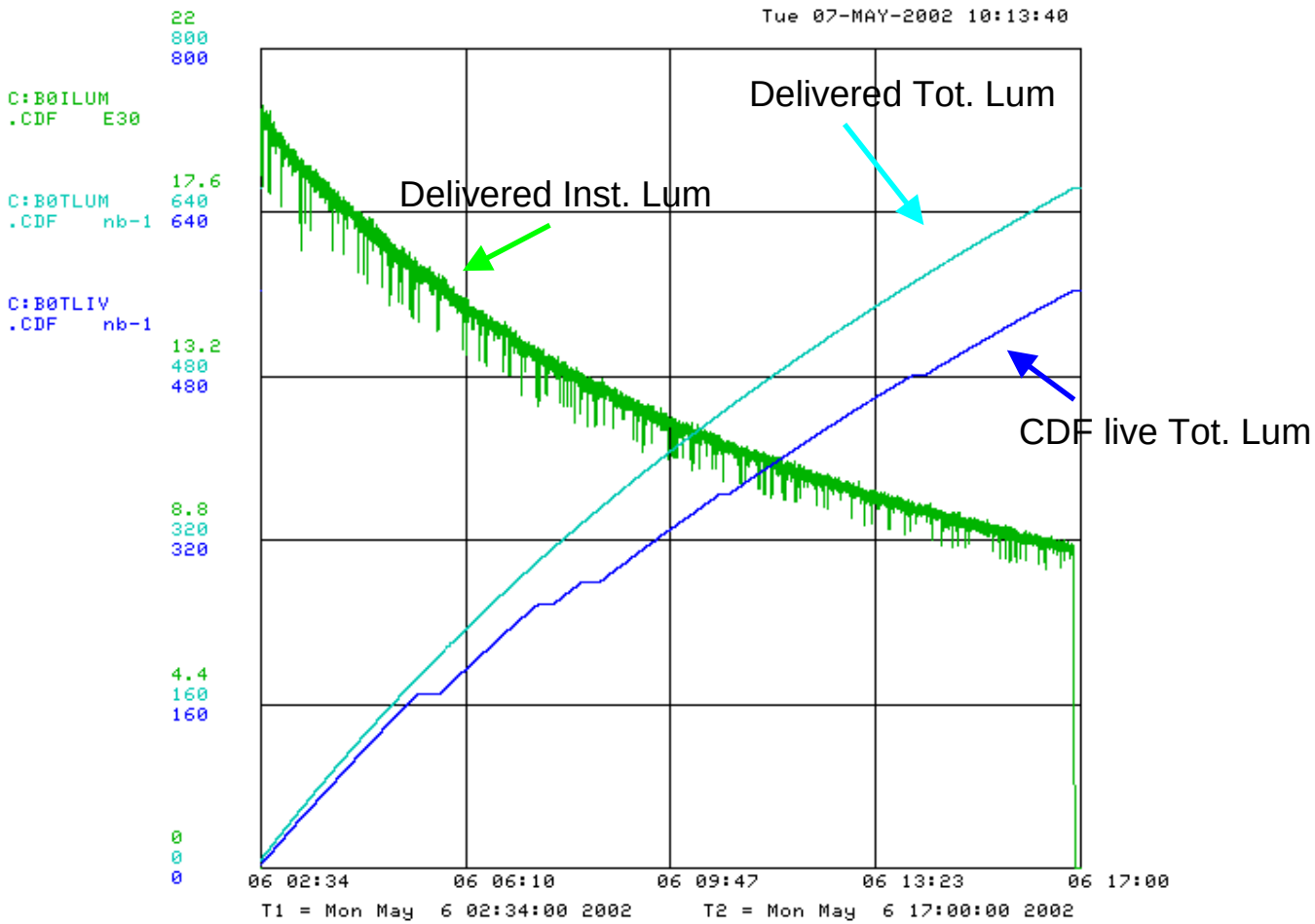




After much investigation→ Helium contamination… → reduced gain / new afterpulse-free PMT / lifetime tests

Lum measurements ok, just more work…

Real Time Luminosity



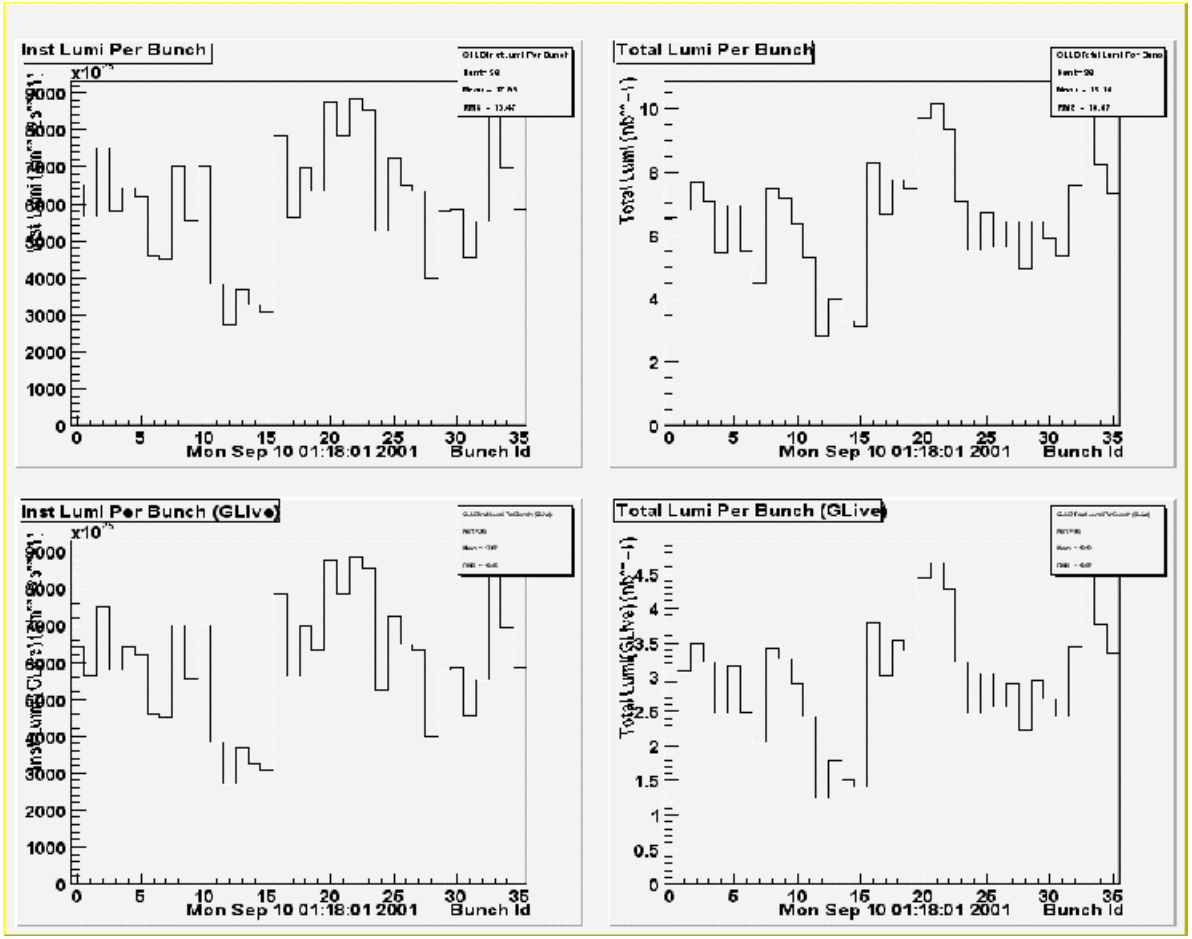
Best store so far….

Bunch by Bunch L

Instantaneous Total

Tevatron delivered

CDF live



Instantaneous Total

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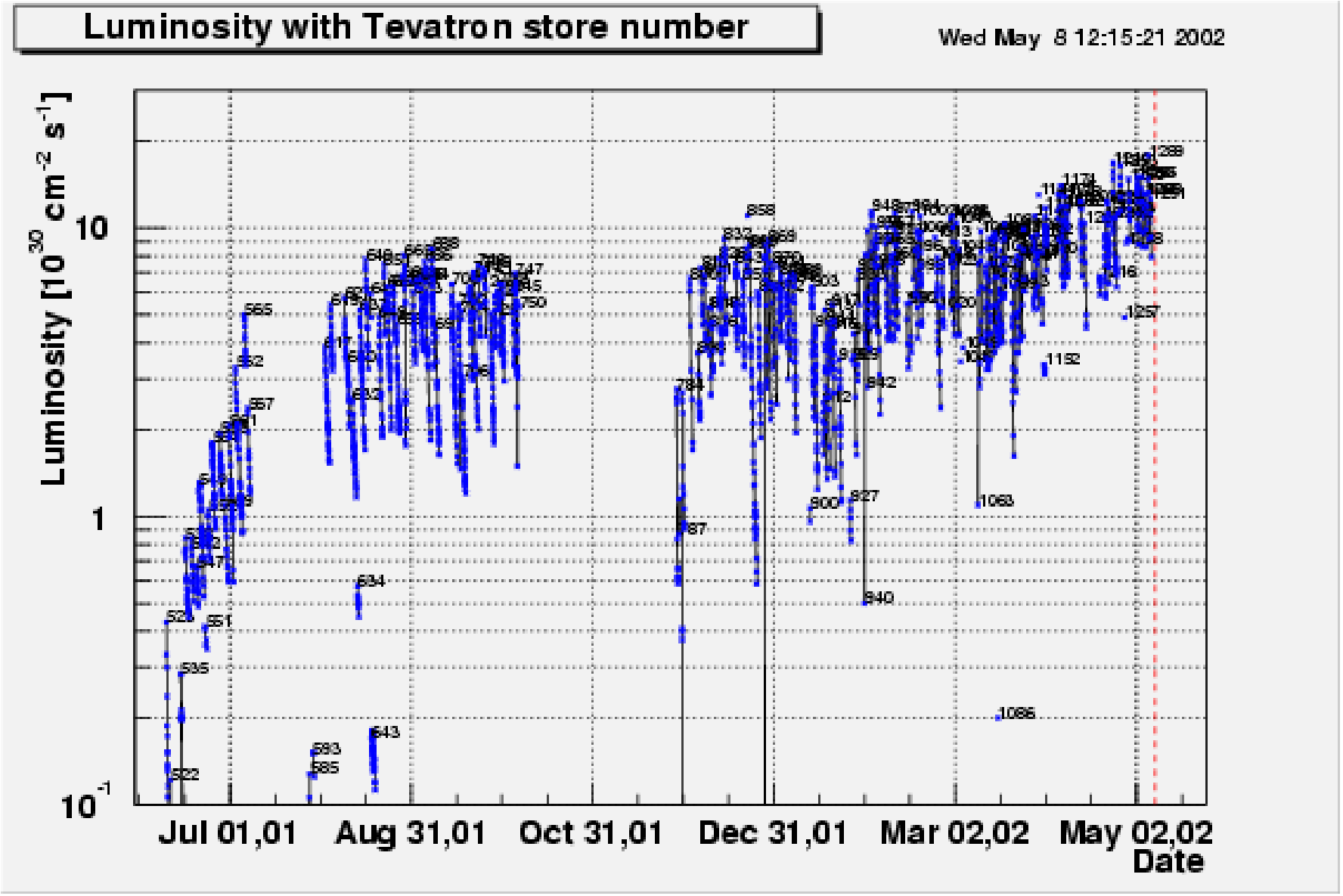
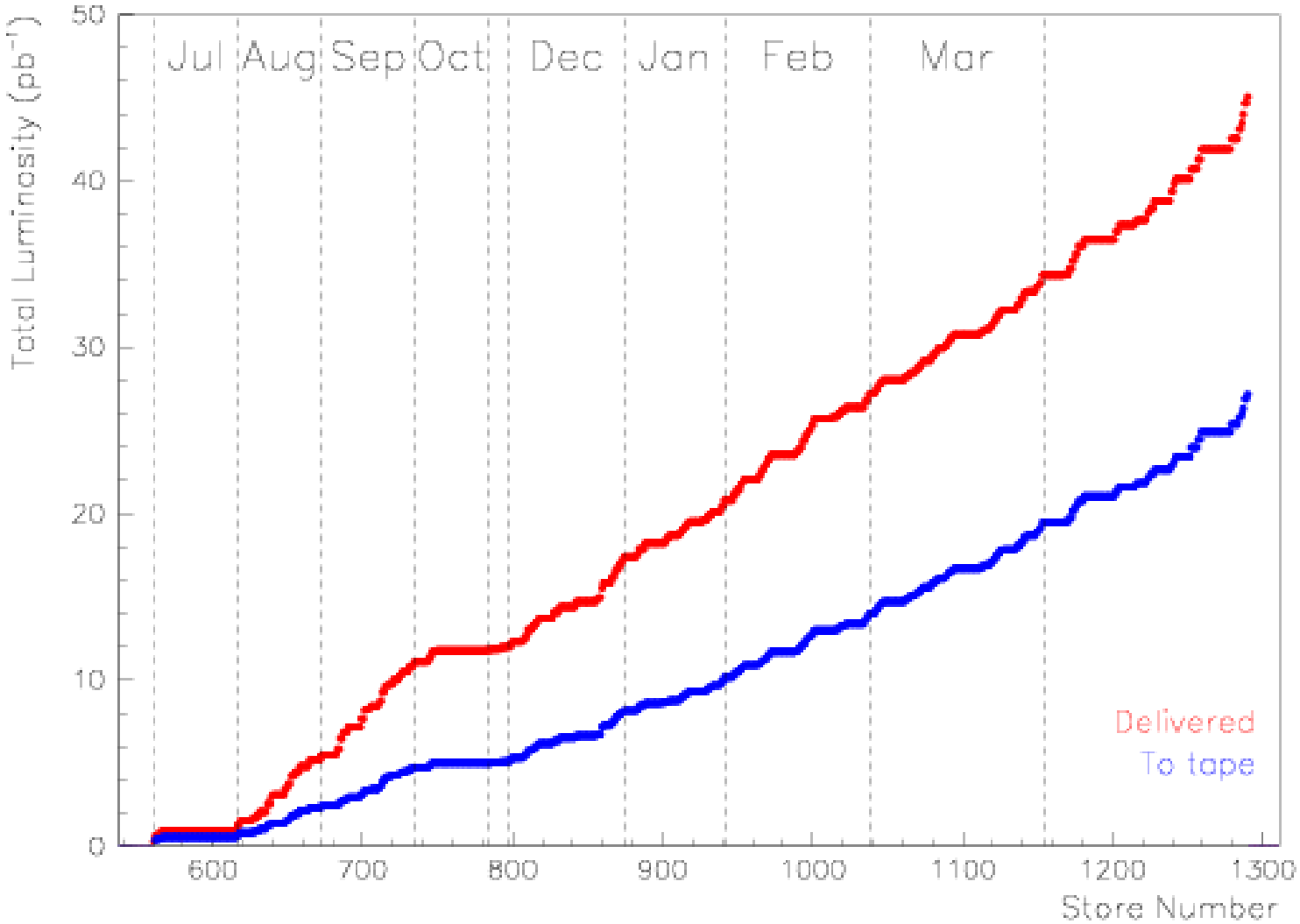
Run II store by Store Inst. Luminosity



Run II Integrated Luminosity



Luminosity Measurements

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Lum Measurements Methods

- **For any luminosity measurement method w/CLC**
  - ***For a defined selection criteria*** $\{\alpha\}$ ***for a p-pbar interaction to be registered in the CLC :***

$$\boxed{\tilde{\mu}_\alpha \cdot f_{BC} = \sigma_{in} \cdot \varepsilon_\alpha^{clc} \cdot L}$$

$\tilde{\mu}_\alpha$ = avg. # of int. $\{\alpha\}$/ bunch crossing

f_{BC} = bunch crossing frequency

L = inst. luminosity

$\sigma_\alpha^{clc} \equiv \sigma_{in} \cdot \varepsilon_\alpha^{clc}$ (effective σ)

- Define a collision $\{\alpha\}$
  - *{ >0 hits in E} .and. { > 0 hits in W} with amplitude > A_o*
    - *Online has fixed thresholds*
    - *Offline we can normalize to single particle peak (spp)*
  - *require hits to be in-time*
    - *Online can have gates*
    - *Offline can cut tighter*

Hit Counting Method

$$L = \frac{f_{BC}}{\sigma_{in} \cdot \varepsilon_{\alpha}} \cdot \frac{< N_H >_{\alpha}}{< N_H^1 >_{\alpha}}$$

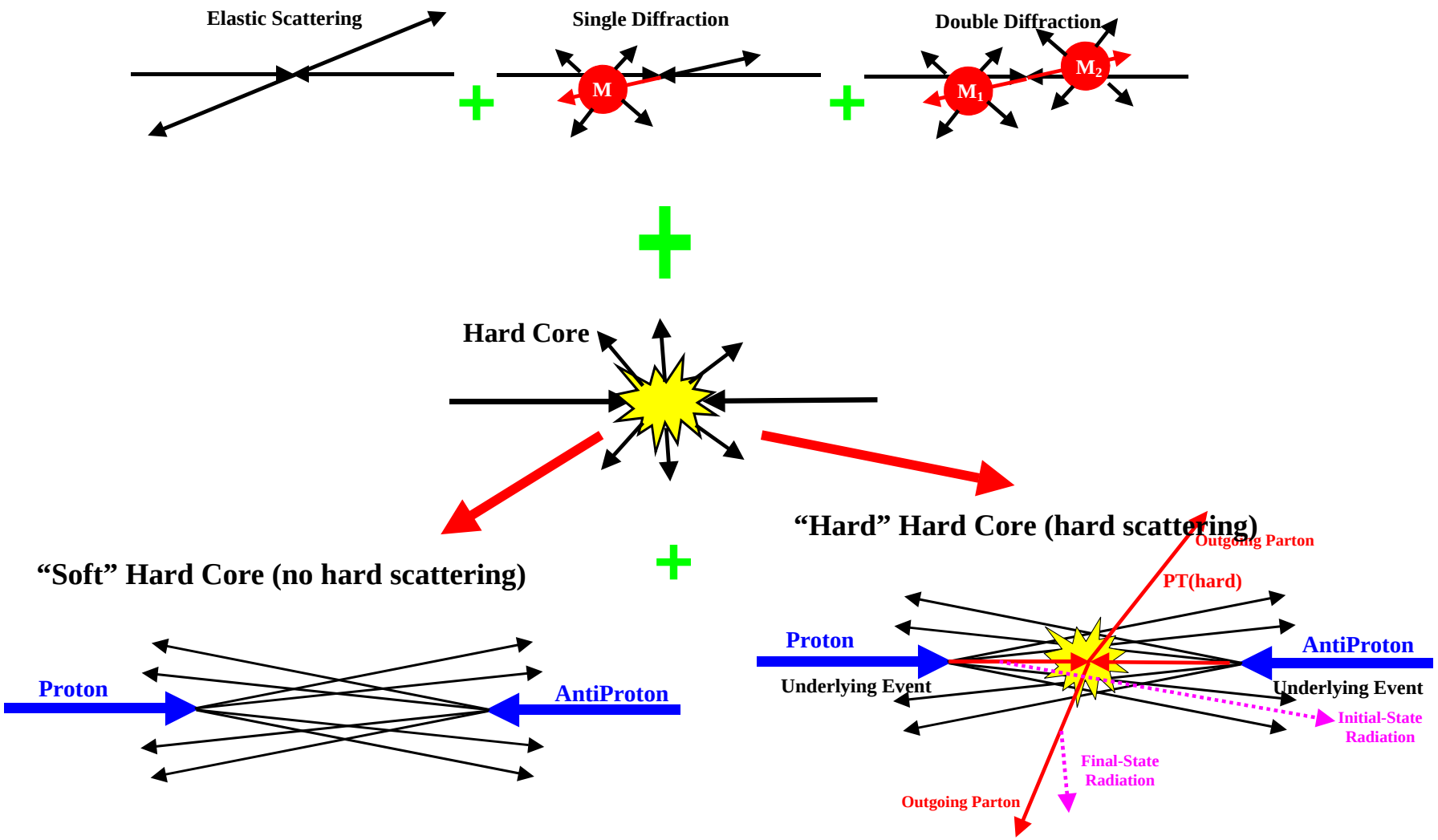
$< N_H^1 >_{\alpha}$ = avg. # hits for a single p-pbar interaction.

Measured at low luminosity from 0-bias data

$< N_H >_{\alpha}$ = measured avg. # hits/bunch crossing

- **We need to estimate ε_{α}**
- **From simulations**
  - ***Need all relevant material in CDF***
  - ***Need "correct" generator…***
- **From real data**
  - ***CLC vs. calorimeters / trackers***
  - ***W's (started !)***
- **Have preliminary estimates of uncertainties**

The total p- pbar cross- section



P- pbar cross- sections

Process (mb)	CDF meas. @ 1.8 TeV	E811 Exp.	D0 Exp.	CDF extrap. @ 2.0 TeV	New MBR MC
σ_{tot}	80.03 (2.24)	71.71 (2.02)	75.01 (2.85)	81.90 (2.30)	[81.9]
σ_{el}	19.70 (0.85)	15.79 (0.87)	17.67 (1.33)	21.50 (0.90)	[20]
σ_{in}	60.33 (1.40) 2% ← 8% →	55.92 (1.19) 2%	57.55 (1.56)	60.40 (1.40)	61.90 (1.40)
σ_{hc}	[51]		46.69 (1.63)	[51]	44.54 (1.30)
σ_{sd}	9.46 (0.44)	8.1 (1.7) E710	9.57 (0.43)	10.00 (0.45)	10.30 (0.50)
σ_{dd}	ϕ	ϕ	1.29 (0.20)	ϕ	7.00 (0.50)

CLC Absolute normalization

$\sigma_{tot} \sim 81.9 \pm 2.3\,\text{mb}$

- $\sigma_{inel} \sim 61.9 \pm 1.4\,\text{mb}$
  - $\sigma_h \sim 44.5 \pm 1.3\,\text{mb}$ hard core
  - $\sigma_d \sim 10.3 \pm 0.5\,\text{mb}$ diffractive
  - $\sigma_{dd} \sim 7.0 \pm 0.5\,\text{mb}$ double diffractive

  } MBR
- σ_{el} (0 acceptance)

- Acceptance: $$\varepsilon^{clc} = \frac{\varepsilon^h \cdot \sigma_h + \varepsilon^d \cdot \sigma_d + \varepsilon^{dd} \cdot \sigma_{dd}}{\sigma_{inel}}$$

- From CLC MC simulation alone:

$$\varepsilon^h = 88.6\,(0.5)\,\%$$

$$\varepsilon^d = 9.1\,(0.4)\,\%$$

$$\varepsilon^{dd} = 31.8\,(0.7)\,\%$$

$$\varepsilon_\alpha^{clc} \sim 68\ \%$$

$$\boxed{\sigma_\alpha^{clc} = \sigma_{in} \cdot \varepsilon_\alpha^{clc} \sim 42\ \text{mb}}$$

CLC Absolute normalization

- Reference detector ($\varepsilon_R \rightarrow 100\%$) CLC+PLUG: $\varepsilon_R \sim 94\%$
- CLC acceptance : $\varepsilon_{clc} = \left(\frac{\varepsilon_{clc}}{\varepsilon_R} \right) \cdot \varepsilon_R \sim$ 67% * 94% = 63 %

Measure experimentally Find from simulation

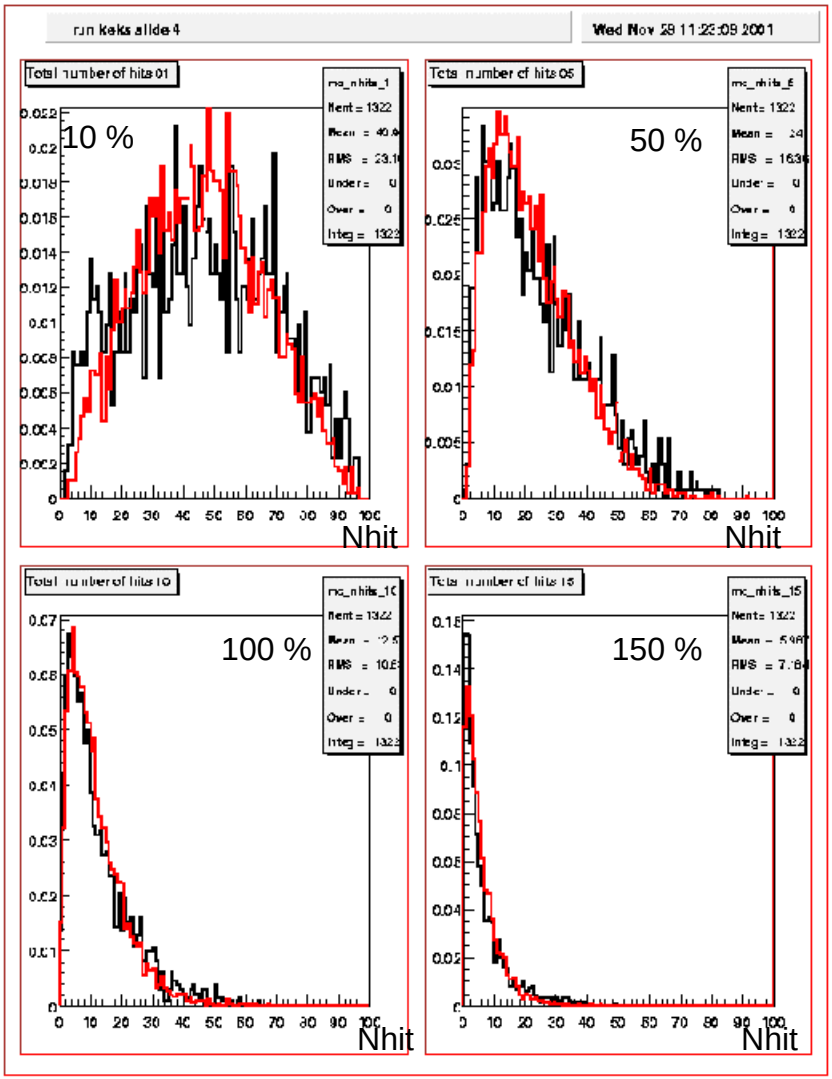
$$\sigma_{\alpha}^{clc} = \sigma_{in} \cdot \varepsilon_{\alpha}^{clc} \sim 39 \text{ mb}$$

- ~7 % difference with pure CLC simulation. But possibly more accurate…

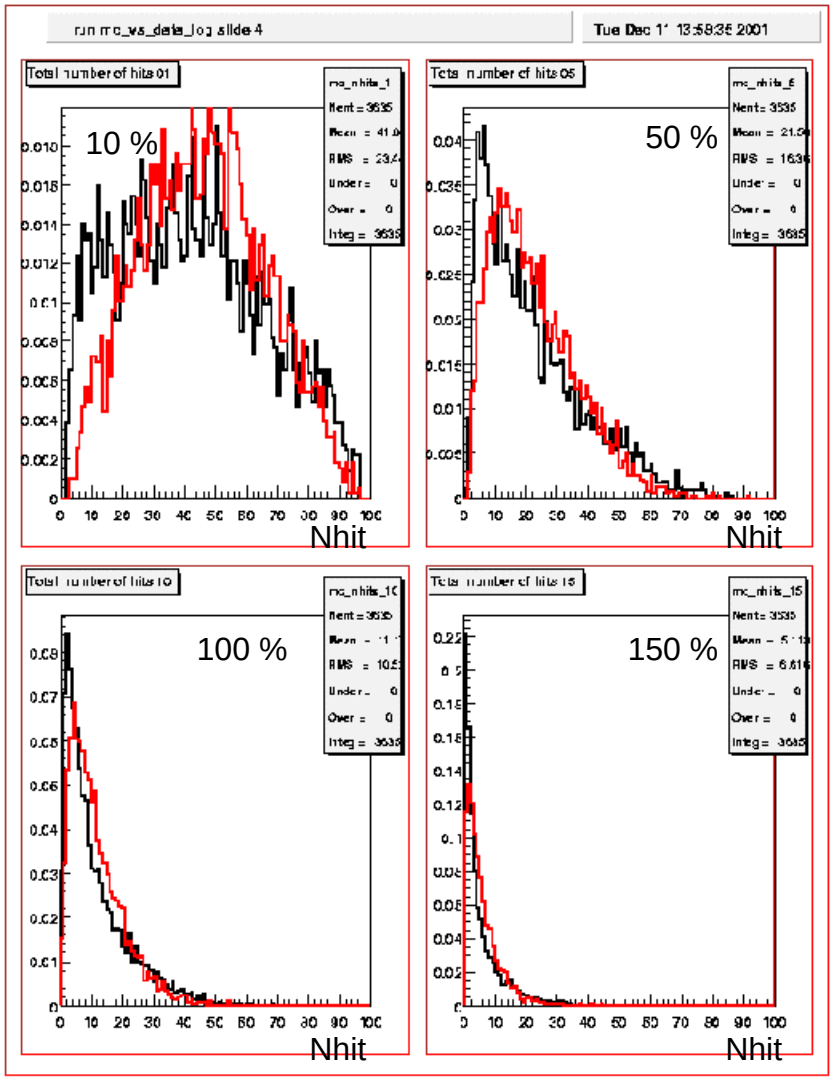
Nhit distributions vs. threshold

Data = red Simulation = black

MBR hard core only



MBR full inelastic



Luminosity Uncertainty – prelim.

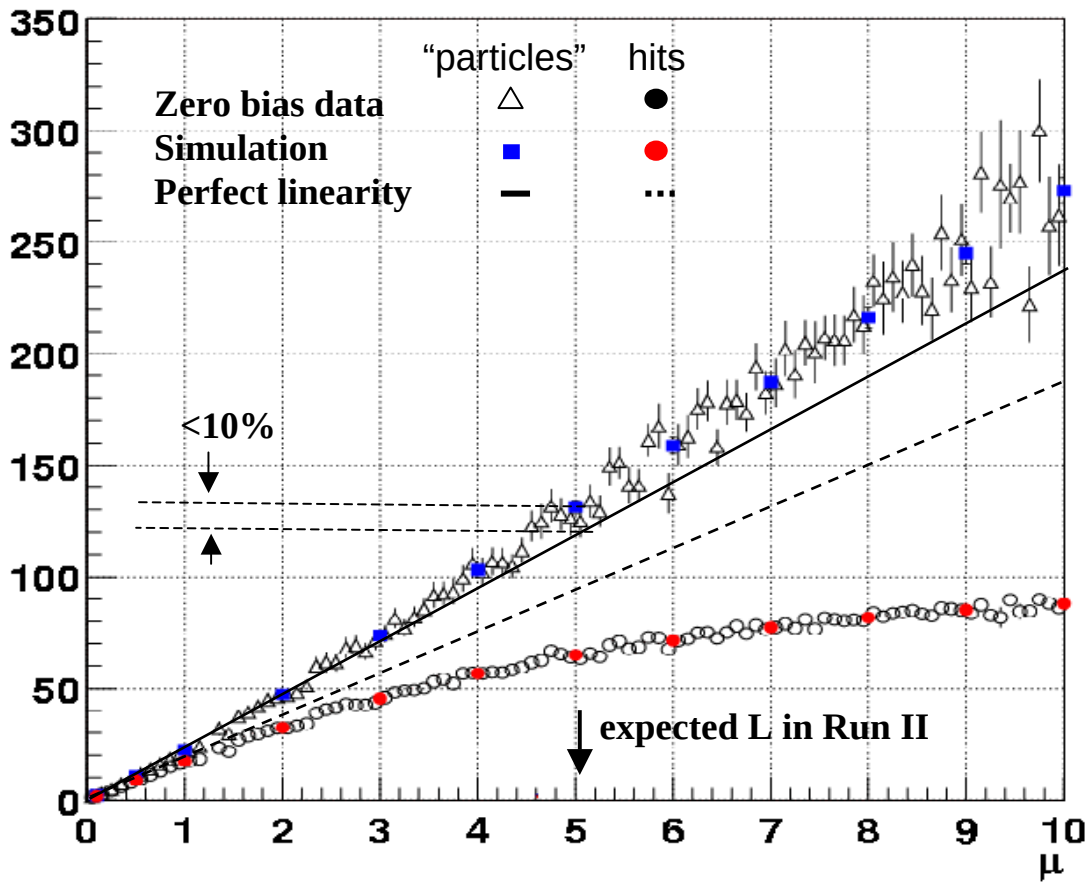
- Estimate CLC+PLUG uncertainty < 2% (changing cal thresholds)
- Estimate N_hit (single) uncertainty < 2% (from data extrapol.)
- Estimate uncertainty due to PMT gain changes < 2%
- CDF's uncertainty in inelastic cross section = 2.3 %
- Other ?
- Quote Luminosity uncertainty as <10% for now
- Target is < 5 % at all luminosities
- Plans:
  - Need to match simulation with data as well as possible & find the right mix
  - Above uncertainties are reducible, need more work.
  - Cross-check with W's

Measuring Luminosity at High Lum

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

Hits:
Average number of hits

"Particles":
Total amplitude / Ao
Ao = amplitude of single particle peak



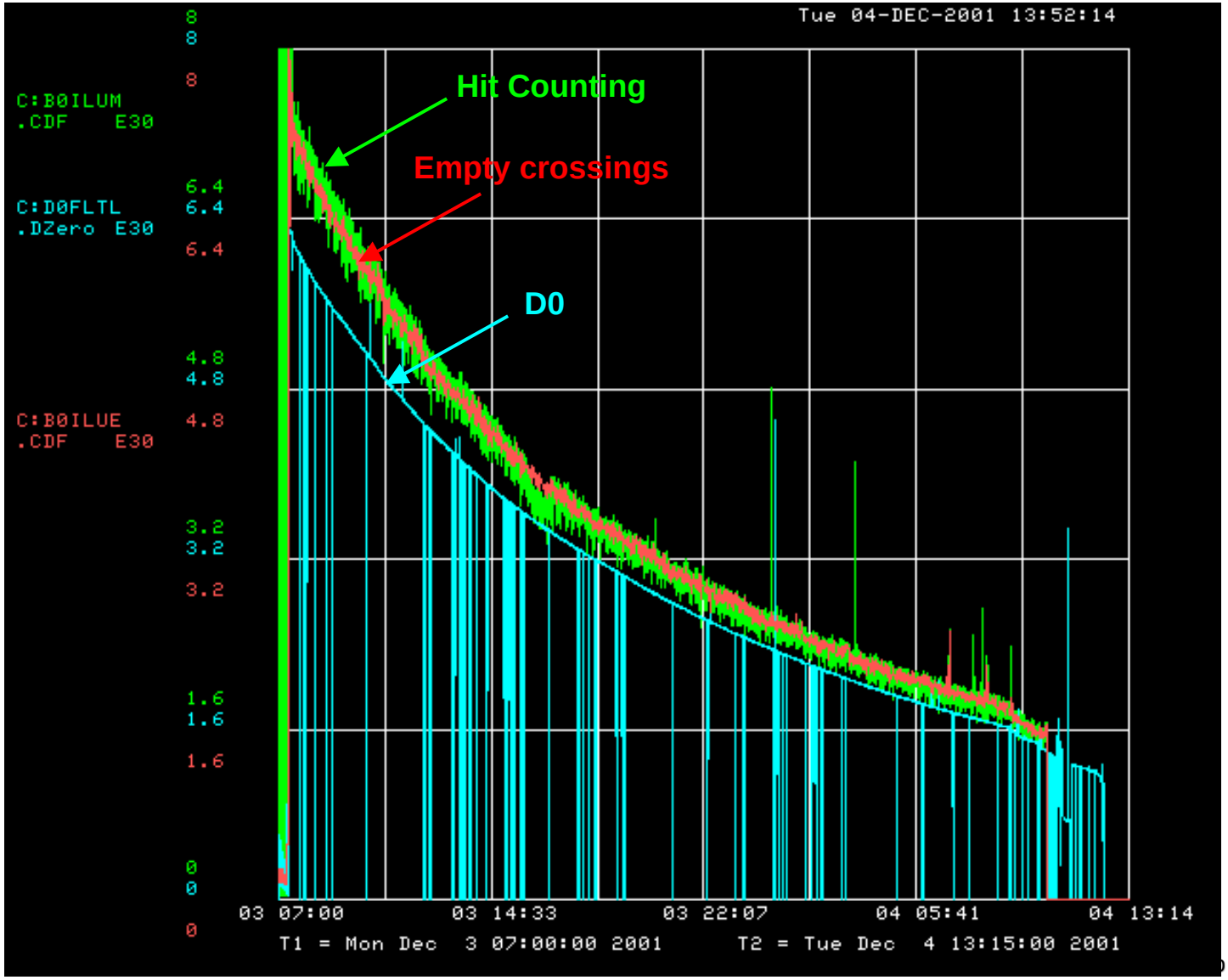
Precise high luminosity measurements are feasible !!!

Cross- check:
Luminosity by counting empty crossings

"empty" = bunch crossings with no PPbar interactions

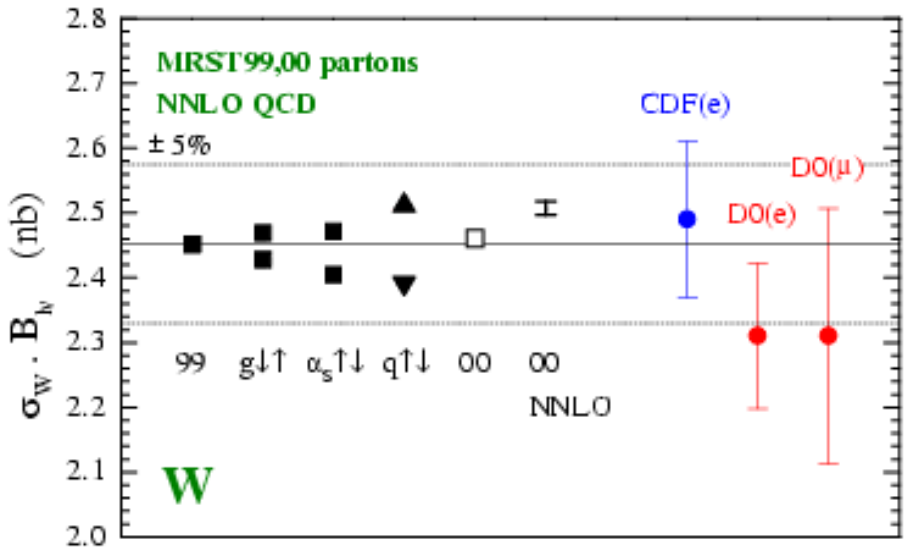
- probability of empty crossings:
  - *full acceptance detector:* $P_0(\mu) = e^{-\mu}$
  - *"real" detector:* $\tilde{P}_0(\mu, \varepsilon_0, \varepsilon_1) = e^{-\mu(1-\varepsilon_0)}(2 \cdot e^{\mu\varepsilon_1} - 1)$
    - ε_0 - probability to have no hits in CLC (~10%)
    - ε_1 - probability to have hits exclusively in one CLC module (~12%)
  - *More sensitive to beam losses*
  - *Sensitive to pileup at high lum*

Empty crossing method



Luminosity with W→lep, nu

- Complementary L measurement witl different systematic error
- Cross-section ~2.5 nb
- ~ Well known theoretically: 20%NLO,3%NNLO
- Expected rate (@L=2 10^{32}) 0.5Hz
- Trigger&selection efficiency ~25% → rate of ~0.1Hz
- Good for abs. normalization
- Not trivial:

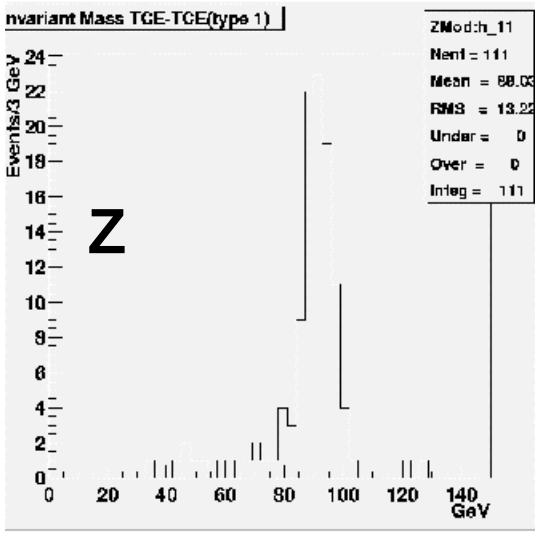


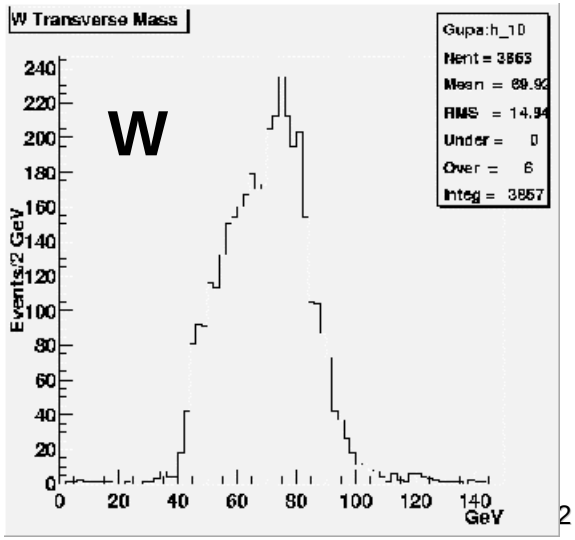
$$N_W = L \cdot \sigma(p\bar{p} \to WX) \cdot B(W \to e\nu) \cdot \varepsilon_{\not{E}t} \cdot \varepsilon_{E_T,\eta} \cdot \varepsilon_{Trk} \cdot \varepsilon_{P_T} \cdot \varepsilon_{Iso} \cdot \varepsilon_{ID} \cdot \varepsilon_{Event} \cdot \varepsilon_{Trig}$$

- + backgrounds …

Luminosity with W's

- **Preliminary results by Lum group:**
  - Selection criteria:
    - Central Et electron > 20 GeV
    - Met > 20 GeV
    - ~Standard electron ID
  - Pythia total accept ~ 25 %
  - Use only geom+kin from MC
  - electron-id, trk eff, from Z's
  - Trigger eff from missing ET trigger





Luminosity [W]	5.77 ± .50 pb-1
Luminosity [CLC]	5.53 ± .55 pb-1

Summary and plans

- **Established all Lum measurements and accounting**
- **Uncertainty below 10% level**
- **Working on absolute normalization systematics**
  - Generator, Simulation, material, thresholds, etc. etc.
- **Harder with changing gains**
  - Strong effort in calibrations and operations
  - Will replace PMTs with [hopefully] more robust ones
- **Working with W's for cross- checks**
  - Looks good so far
- **Expect absolute normalization uncertainty below 5%**
- **Implement and test high lum algorithms later on**
  - Particle counting
  - Time clusters

CLC Publications

- ☑ "Luminosity Monitor Based on Cherenkov Counters for P Anti- P Colliders"
  Nucl. Instr. & Meth. A441 (366-373), 2000.

- ☑ "The CDF Run II Luminosity Monitor"
  Nucl. Instr. & Meth. A461 (540-544), 2001.

- ☑ "The performance of the CDF Luminosity Monitor"
  Submitted to Nucl. Instr. & Meth. May, 2002.

- "The Run II Luminosity Measurement at CDF"
  To be submitted to Nucl. Instr. & Meth. May, 2002 + n.

Backup Plots:

Cerenkov light

- **Light emitted if** $\beta > 1/n$ $\boxed{\cos\theta = 1/n\beta}$
- **At** $\beta \sim 1$ **n needs to be small for small angle emission**
- **The number of photons emitted per unith path lenght is:**

$$\frac{dN}{dx} = 2\pi\alpha \int_{\beta n>1} \left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right) \frac{d\lambda}{\lambda^2}$$

★ For $n(\lambda)$ const. over a relevant wavelength interval:

$$\frac{dN}{dx} = 2\pi\alpha \cdot \sin^2\theta \left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)$$

★ For smaller angles, smaller yields (UV dominated)

★ For wavelenghts between 350 to 500 nm: $\frac{dN}{dx} = 390 \sin^2\theta$ photons / cm

★ For scintillators ~ 170 photons / cm

Cerenkov light

➢ **The number of photoelectrons in a counter:**

$$N_{p.e.} = L\frac{\alpha^2 z^2}{r_e m_e c^2}\int \varepsilon_{coll}(E)\cdot\varepsilon_{det}(E)\cdot\sin^2\theta_c(E)\cdot dE \qquad \frac{\alpha^2 z^2}{r_e m_e c^2} = 370\ \text{cm}^{-1}\ \text{eV}^{-1}$$

★ n is usually const. over the useful range of photocathode sensitivity, therefore:

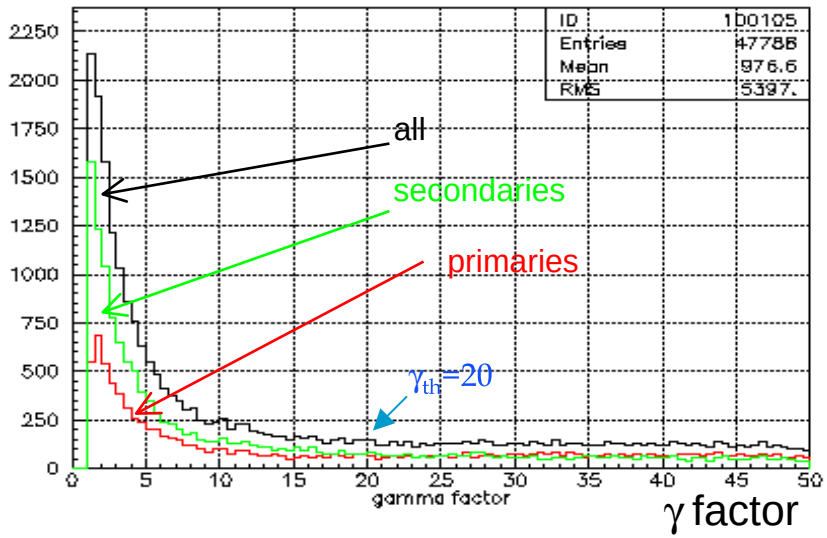
$$N_{p.e.} = 370\cdot L\cdot\langle\sin^2\theta_c\rangle\cdot\int\varepsilon_{coll}(E)\cdot\varepsilon_{det}(E)\cdot dE$$

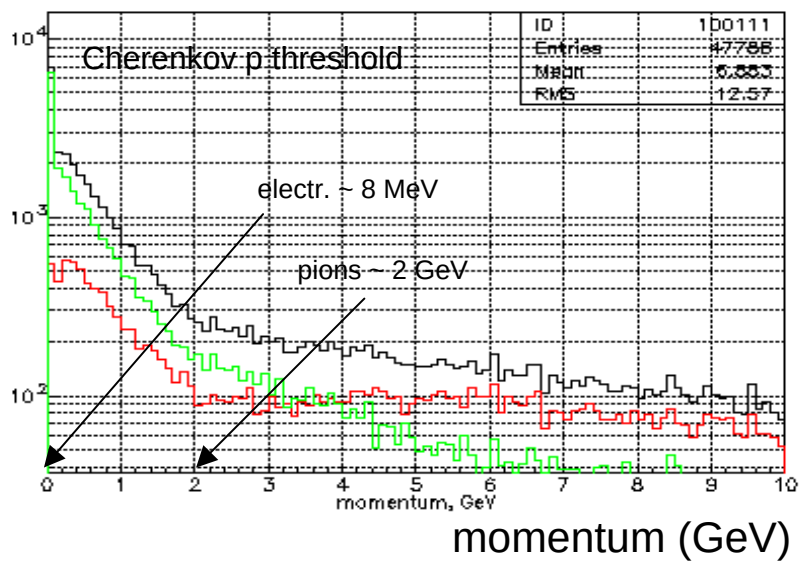
★ Using $\langle\sin^2\theta_c\rangle \approx 2(n-1)$ $\qquad \int\varepsilon_{det}(E)\cdot dE \approx 0.27$

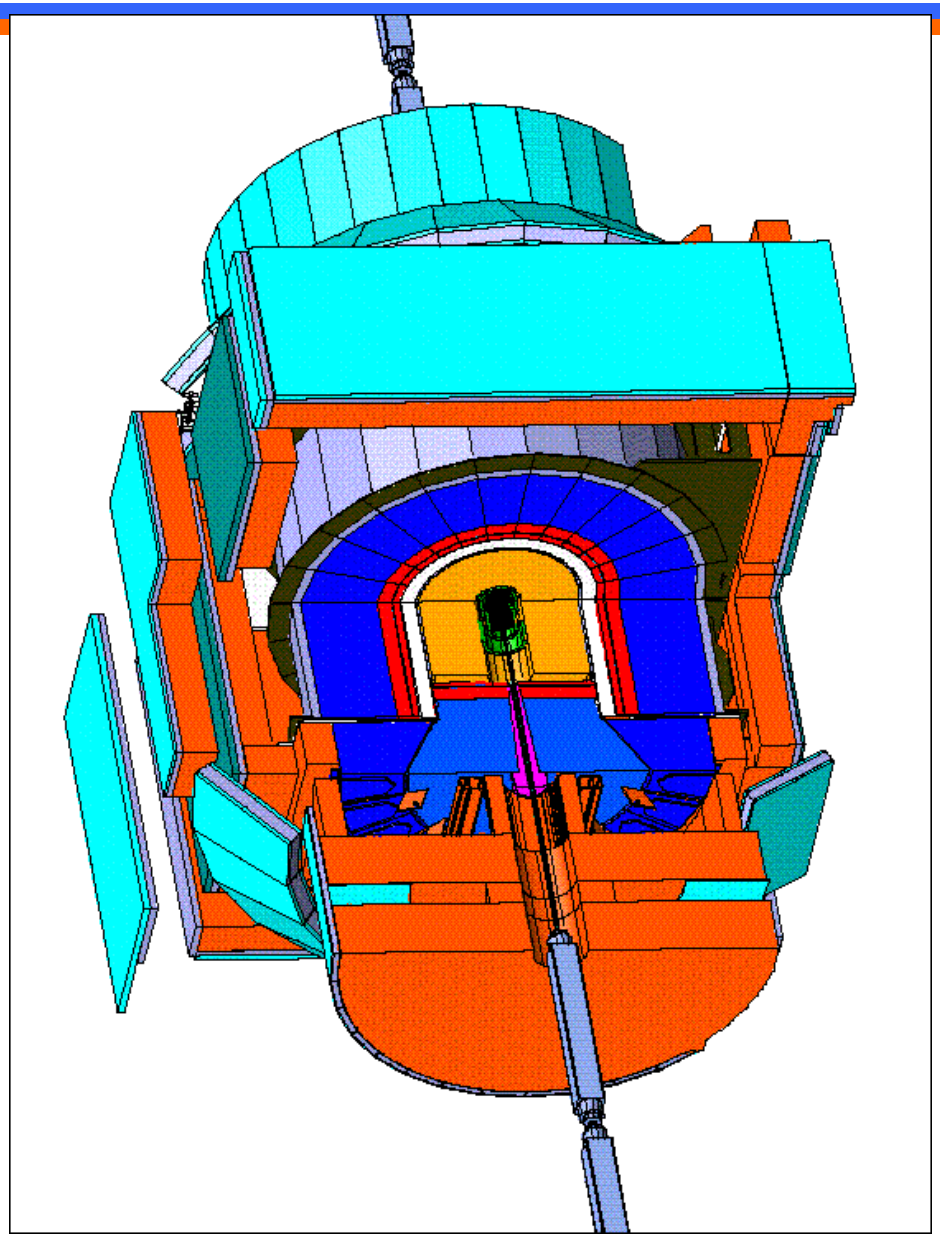
$$\boxed{N_{p.e.} \approx 200\cdot(n-1)\cdot L_{[cm]}\cdot\langle\varepsilon_{coll}\rangle}$$

★ Pressure dependence: $n-1 = (n_o - 1)\cdot\frac{P}{P_o}$

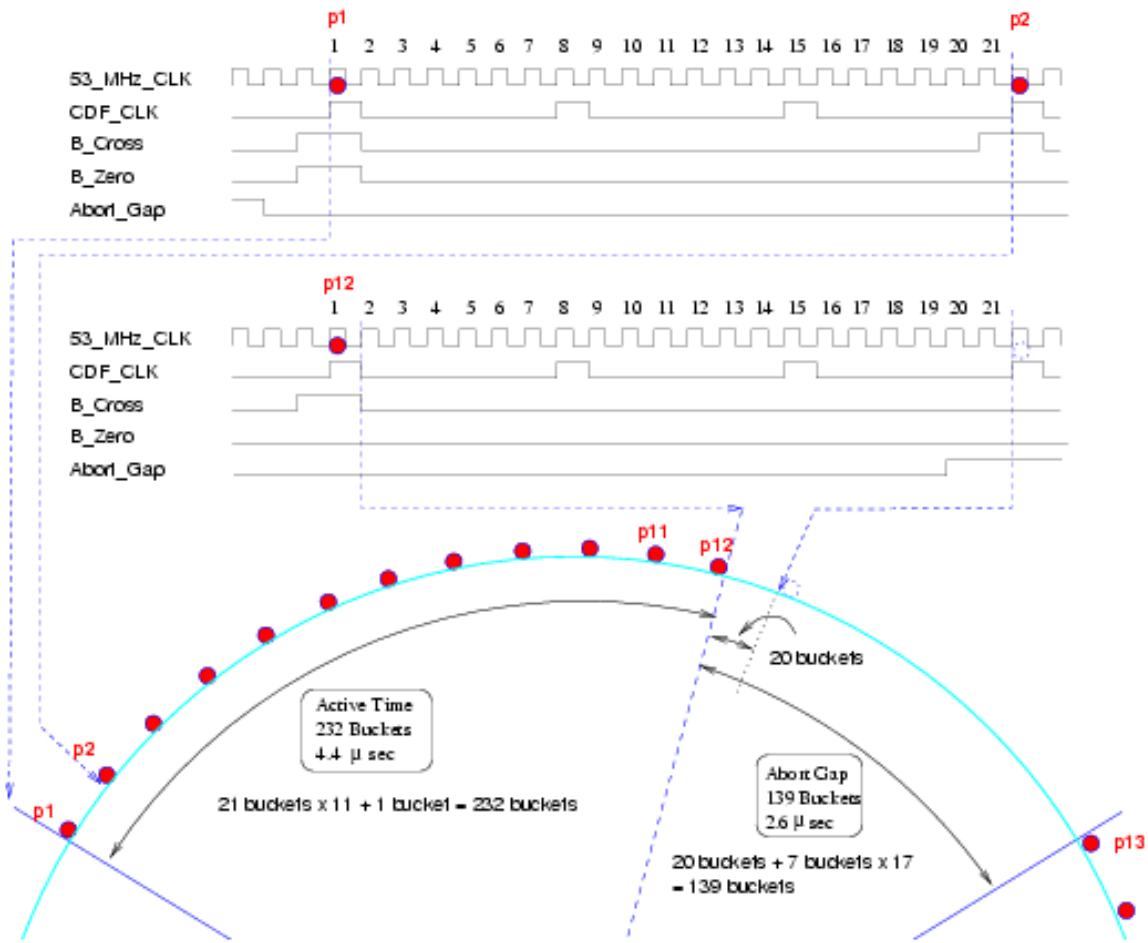
Cherenkov Momentum Threshold







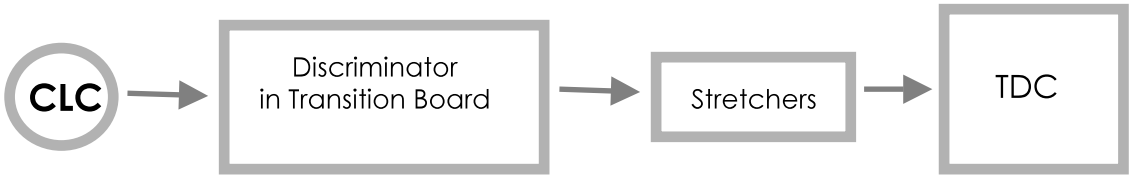
36x36 Bunch Structure

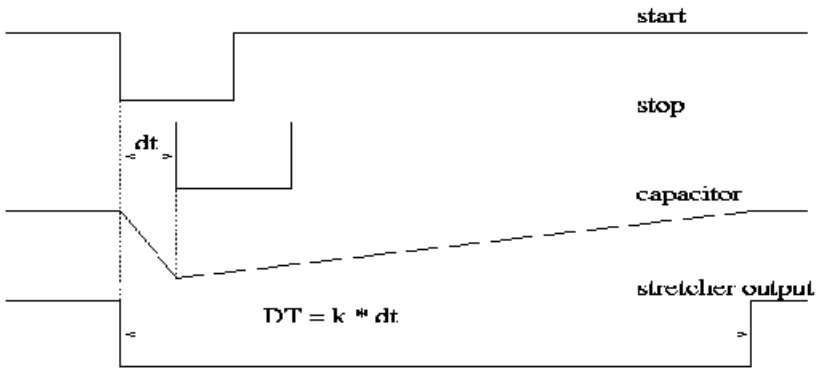


CLC timing

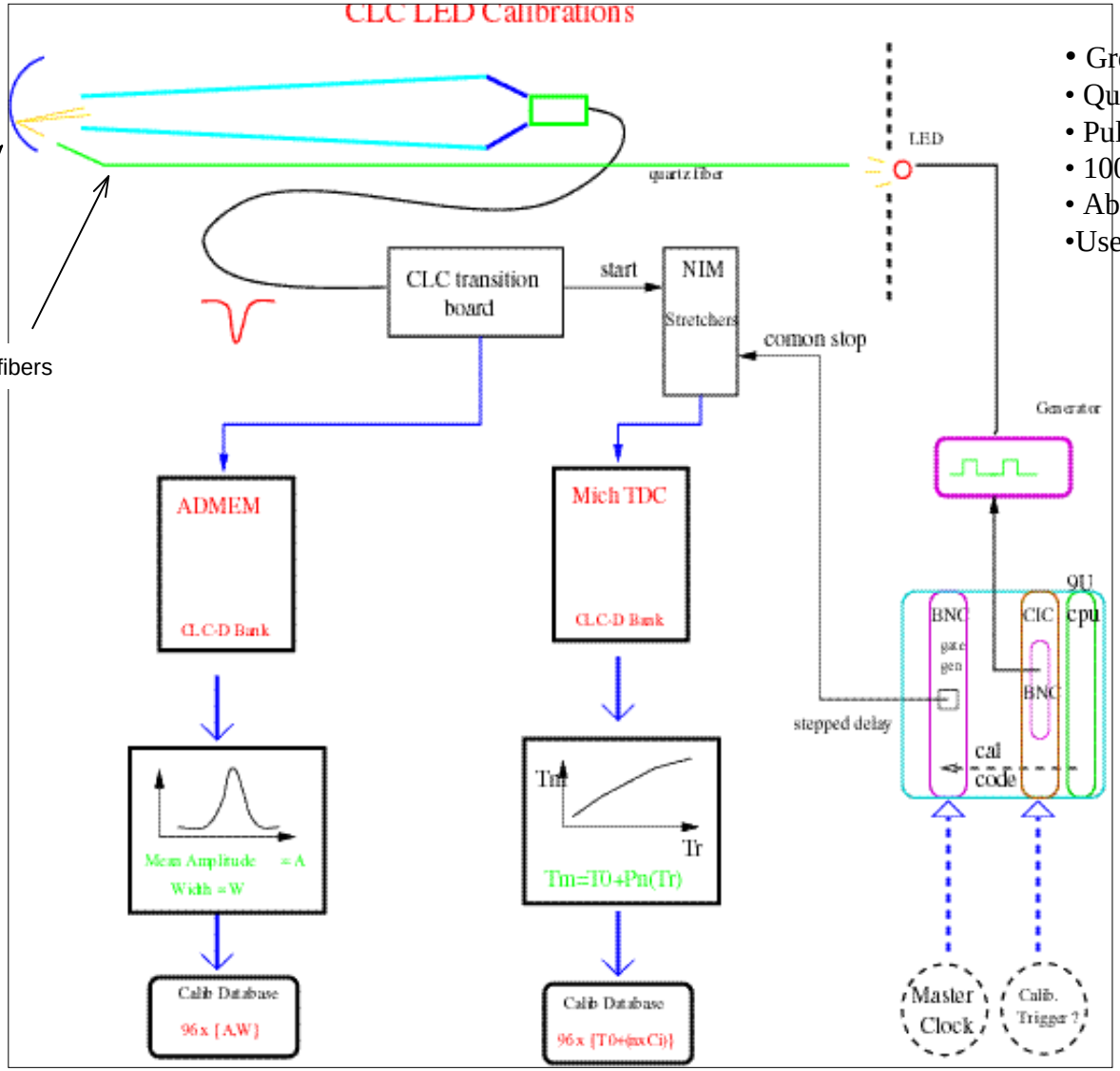
- **Precise Timing measurements:**
  - ***Use 1ns TDC (standard CDF)***
  - ***Use time stretcher circuitry***
    - ~ x 10 stretching factor

⇒ sub 100 ps resolution





Calibration system



white Tyvec

quartz fibers

- Green-blue bright LED from Ledtronics
- Quartz fiber + Tyvec reflector
- Pulse generator @ 8 V x ~40 nsec duration
- 100-500 mV signal for gain calibrations
- About 600 psec r.m.s. signal
- Use peak for initial timing calibration

Comparison to Run IIa Goals

$$\mathbf{L} = \frac{3\gamma f_0}{\beta^*}\left(BN_{\bar{p}}\right)\left(\frac{N_p}{\varepsilon_p}\right)\frac{F\left(\beta^*, \theta_{x,y}, \varepsilon_{p,\bar{p}}, \sigma^L_{p,\bar{p}}\right)}{\left(1+\varepsilon_{\bar{p}}/\varepsilon_p\right)}$$

Parameter	Value Achieved	Comparison to Run IIa Goal
f_0	47.713 kHz	OK
B	36	OK
β^*	35 cm	OK?
N_p	125×10^9	46%
$N_{\bar{p}}$	7×10^9	23%
$\varepsilon_p^H = \varepsilon_p^V$	~20π mm-mrad	100%
$\varepsilon_{\bar{p}}^H = \varepsilon_{\bar{p}}^V$	~20π mm-mrad	133%
F	0.63	85%
ε_p^L	~4 eV-sec	200%
$\varepsilon_{\bar{p}}^L$	~4 eV-sec	200%
L	7×10^{30} cm^{-2}sec^{-1}	8%
E	980 GeV	98%

Luminosity Formula

$$L = \frac{3\gamma f_0}{\beta^*}\left(BN_{\bar{p}}\right)\left(\frac{N_p}{\varepsilon_p}\right)\frac{F\left(\beta^*, \theta_{x,y}, \varepsilon_{p,\bar{p}}, \sigma^L_{p,\bar{p}}\right)}{\left(1+\varepsilon_{\bar{p}}/\varepsilon_p\right)}$$

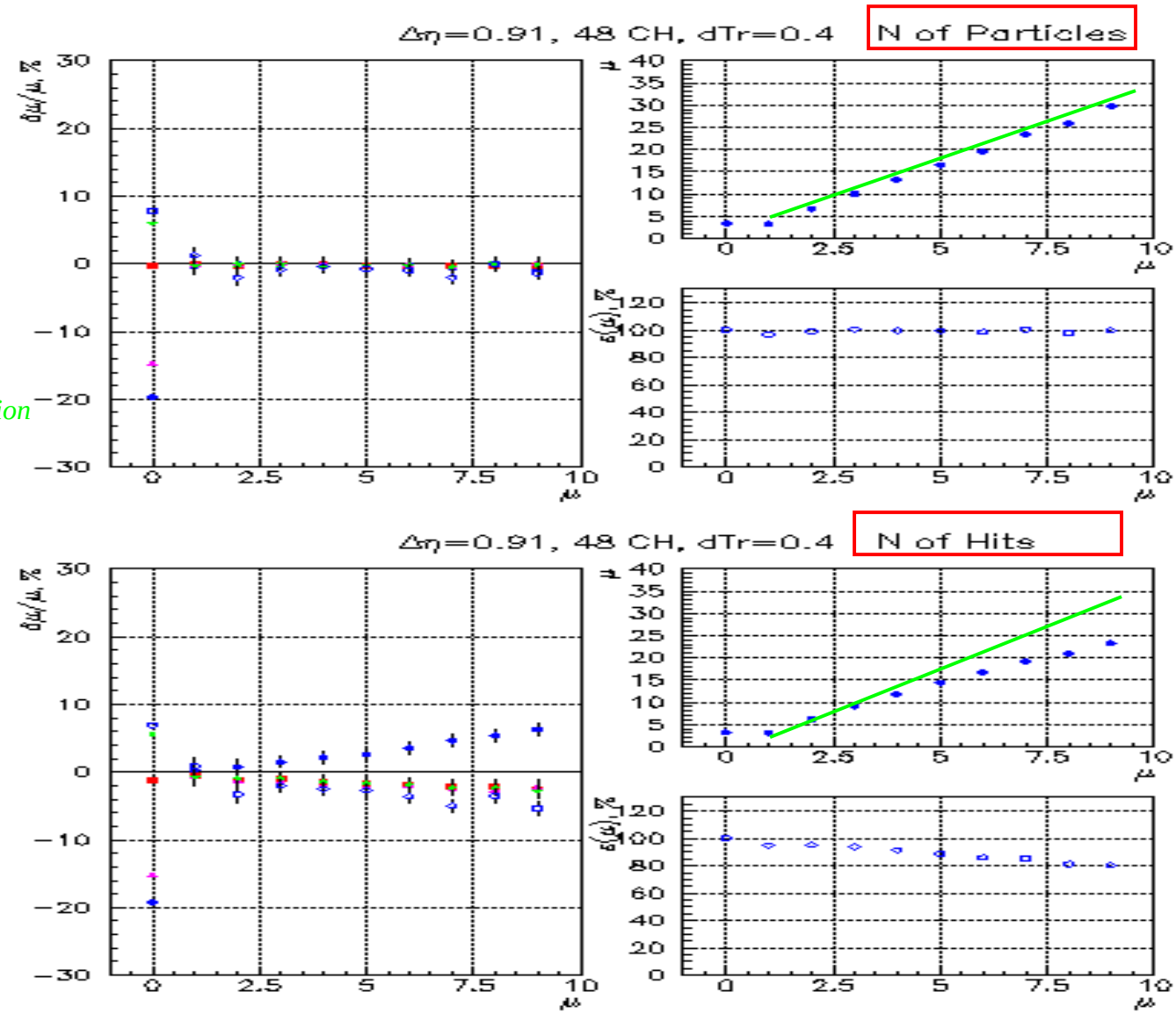
The major luminosity limitations are

- The number of antiprotons ($BN_{\bar{p}}$)
- The proton beam brightness (N_p/ε_p)
- $F<1$

Cerenkov - 48 chann.

★ Some sources of systematics:

- *Particle multiplicity/interaction*
- *Fraction of secondaries*
- *Source of secondaries*
- *PMT window thickness*
- *Gas index of refraction*

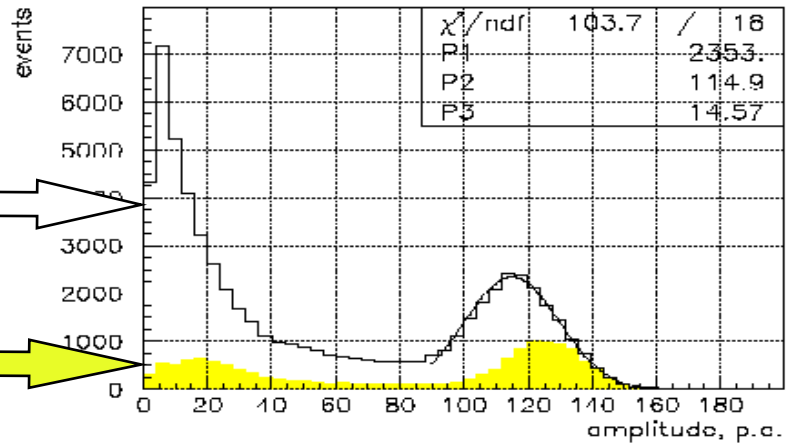


PMT window & electrons

- **Fraction of particles that hit window**

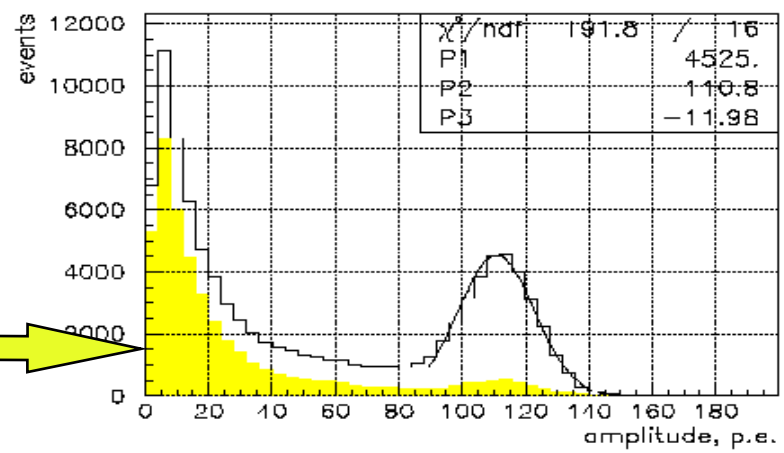
all particles

hit window

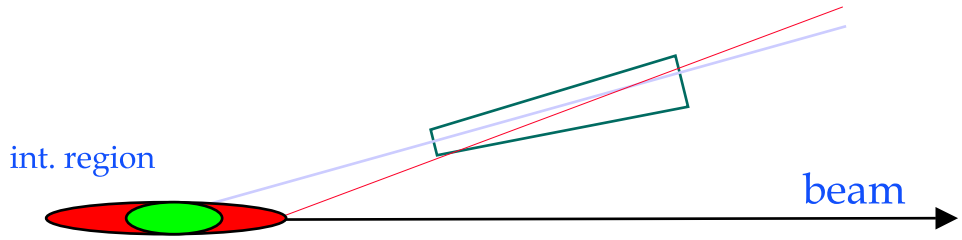


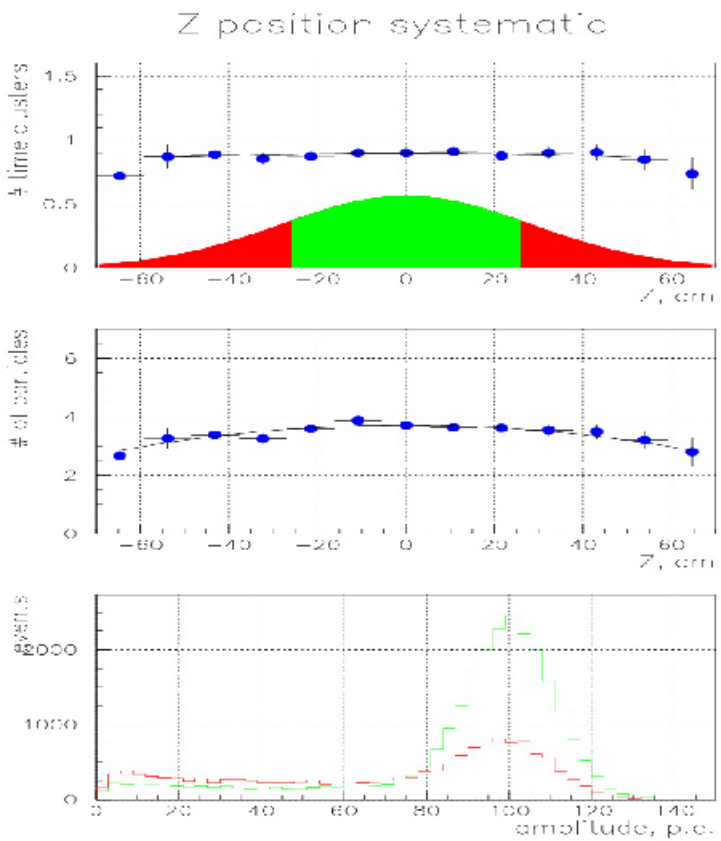
- **Electrons contribution**

electrons

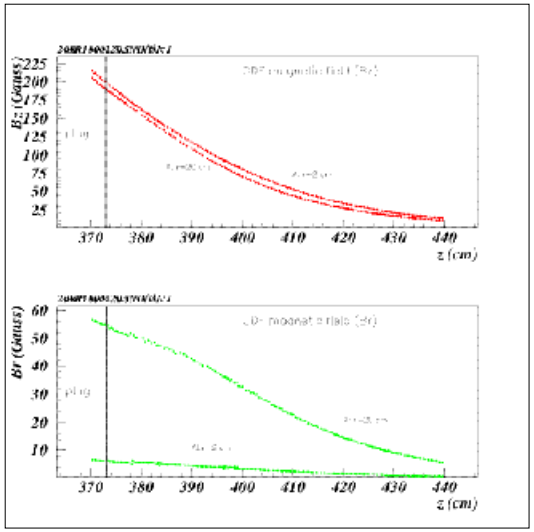


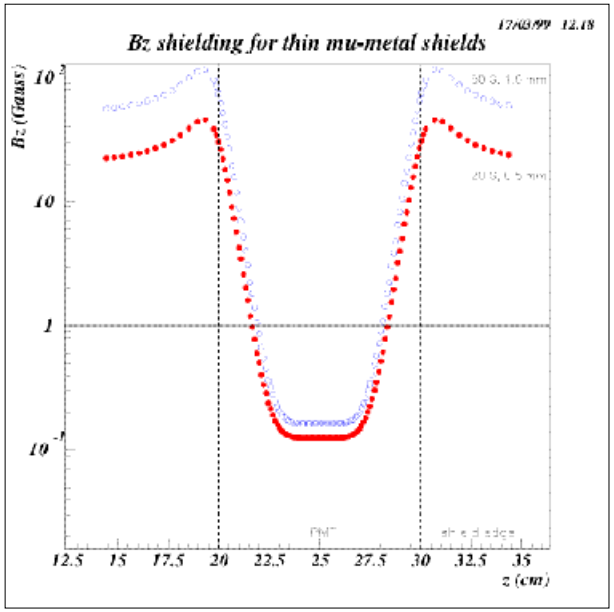
CLC parallax

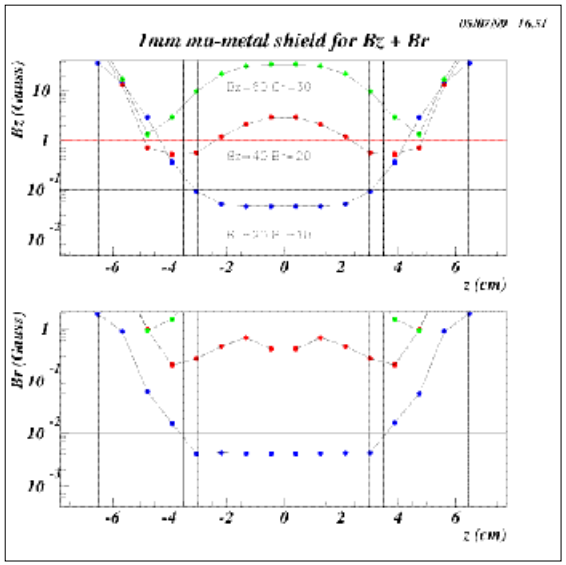




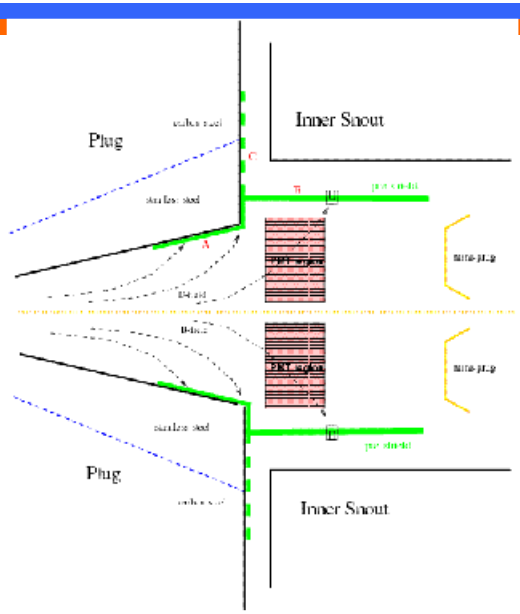
Magnetic Shielding

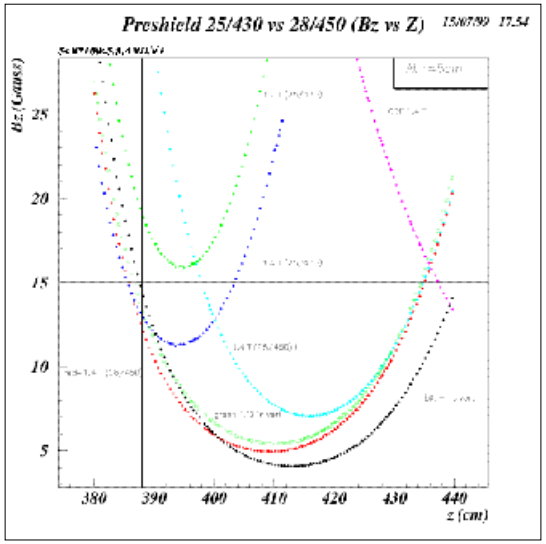




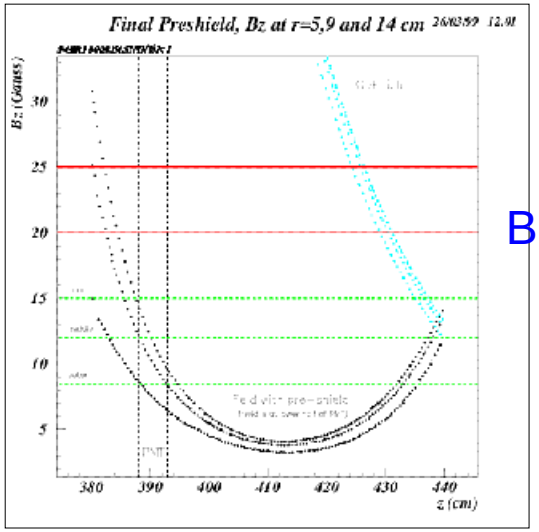


Magnetic Shielding – “pre- shield” simulation

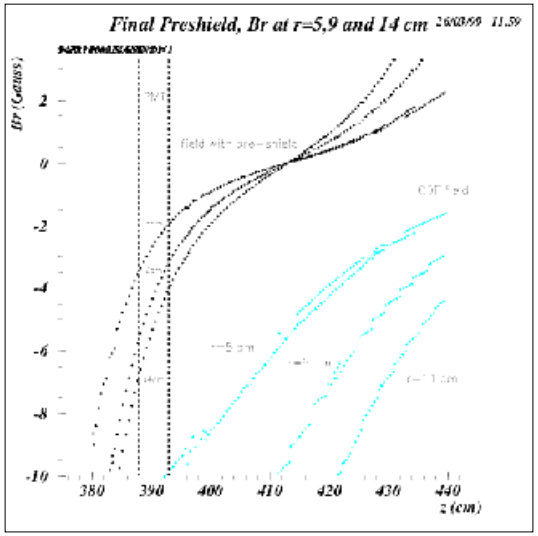




“pre-shield” optimization”



Bz

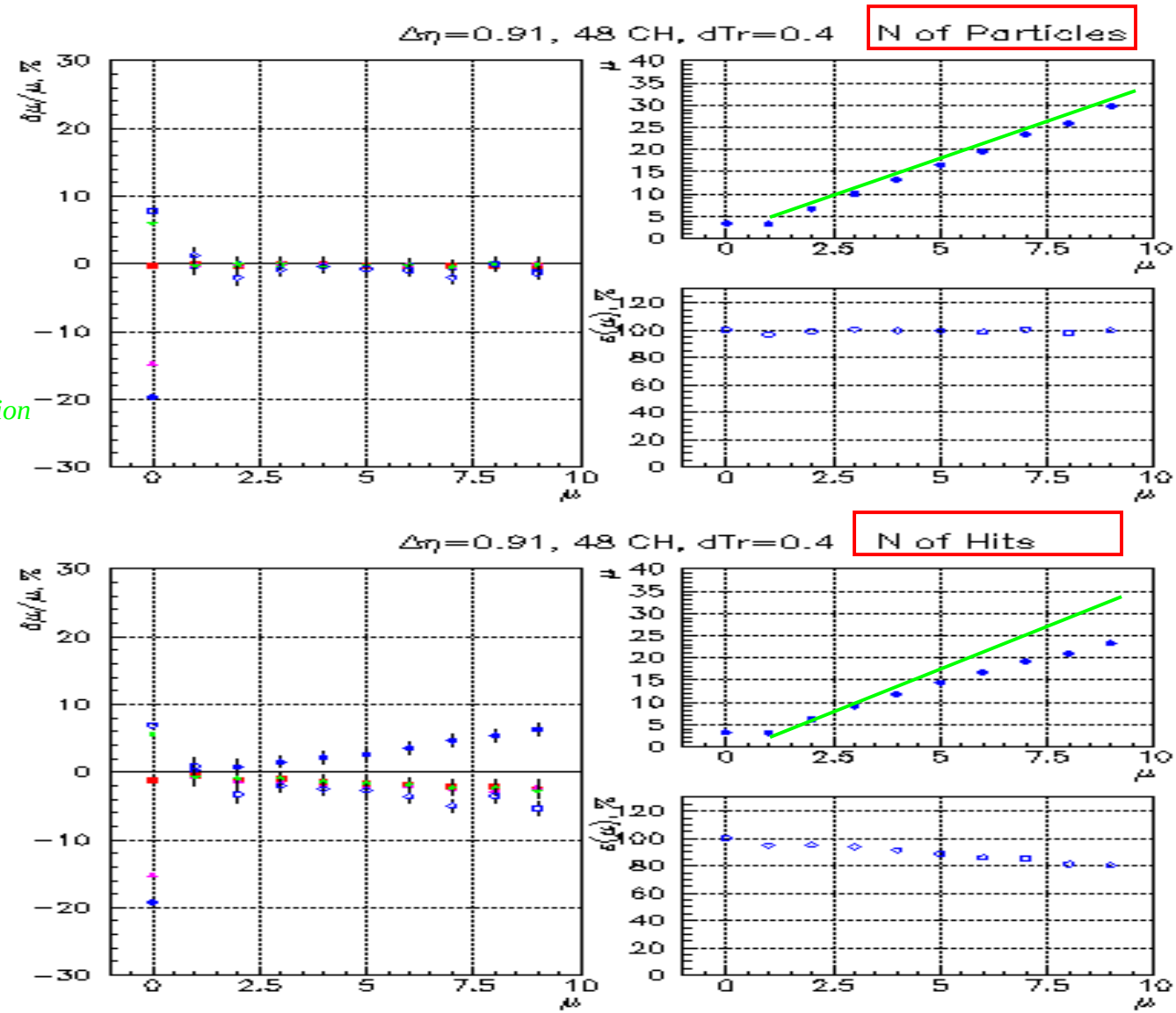


Br

Cerenkov - 48 chann.

★ Some sources of systematics:

- *Particle multiplicity/interaction*
- *Fraction of secondaries*
- *Source of secondaries*
- *PMT window thickness*
- *Gas index of refraction*

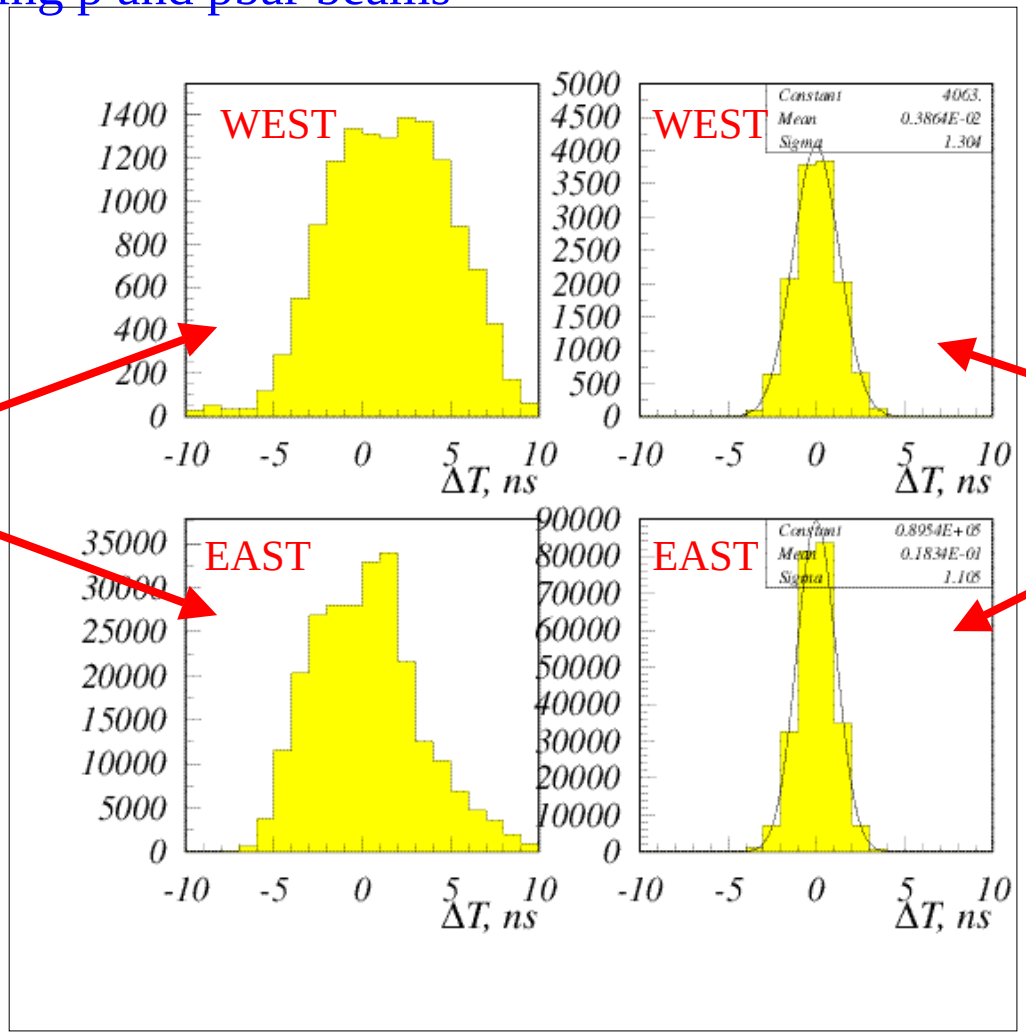


T0 Calibration

•Calibration using p and pbar beams

Time offset w.r.t. a reference channel

(before applying T0 correction)



Time offset w.r.t. a reference channel

(after applying T0 correction)

Reference Processes

➢ Process of inelastic PPbar scattering

- ***Large x-section:*** $\sigma_{inel} = 60.4 \pm 1.4 mb$ **(CDF)**
  - *Total x-section is measured also by E710 and E811 (2.8σ discrepancy with CDF)*

$$R_{pp} = \mu \cdot f_{BC} = \sigma_{inel} \cdot \varepsilon_{clc} \cdot L$$

L – luminosity
μ– # of interactions /BC
σ_{inel} – inelastic x-section
ε_{clc} – CLC acceptance
f_{bc} – Bunch Crossing rate

➢ Process: W → *lν*

- ***Complementary L measurement with different systematic error***
- ***Cross-section ~2.5nb (well known theoretically:20%NLO,3%NNLO)***
- ***Expected rate (@L=2 10^{32}) 0.5Hz (good for integrated L)***
- ***Trigger&selection efficiency ~25% (rate of ~0.1Hz after cuts)***

$$R_{W \to l\nu} = \sigma_{W \to l\nu} \cdot \varepsilon_{W \to l\nu} \cdot L$$

$R = rate$

CLC effective inelastic x- section

Method	CLC X-sec (mb) 2 layers	CLC X-sec (mb) 3 layers
Old simulation MBR + 3 Xo Straight acceptance	36.9	40.5
Old simulation MBR+3 Xo CLC/(CLC+plug)	35.2	38.6
Data (CLC+plug accept from old sim.) CLC/(CLC+plug)	35.8	38.3
New Simulation Straight acceptance	38.2	42.4

- Used 500 ADC thresholds in CLC
- Used 3 GeV threshold in plug
- East and West coincidence in both
- CLC+ plug acceptance in MC = 94%

Notes:

- Span in x-sec is 10%
- So maybe error is ~ +-5 % ?
- Needs more time to settle and to decide what's "more correct"
- MBR inelastic is 44.4 mb ~ measured by CDF
- Pythia gives ~9% smaller
- CLC acceptance for hard-core (@500 ADC) is ~90%. Is ~95% for lower threshold.
- Need to match simulation with data as well as possible & find the right mix →

Real Time Luminosity

Delivered Inst. Lum

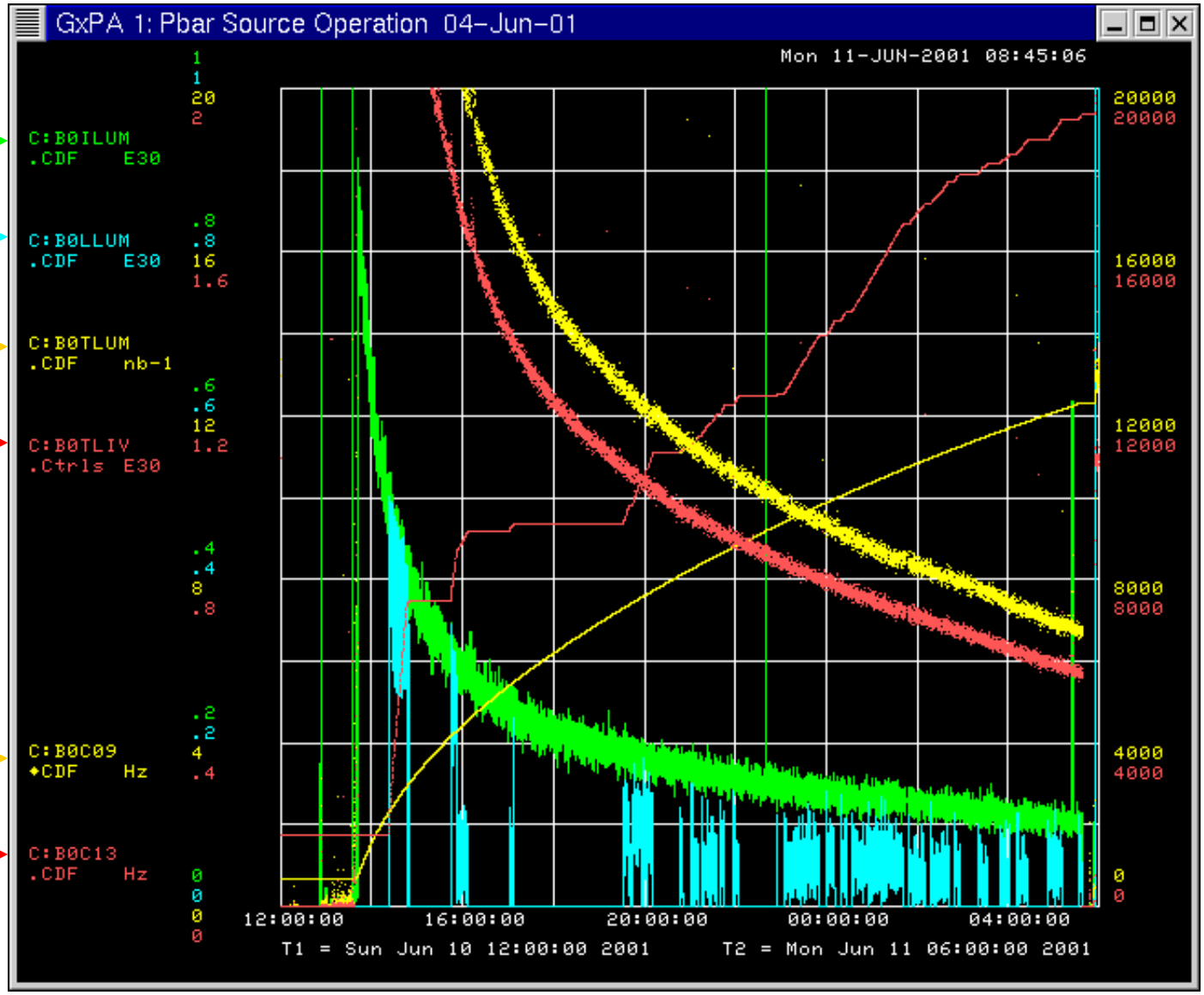
CDF live Inst. Lum

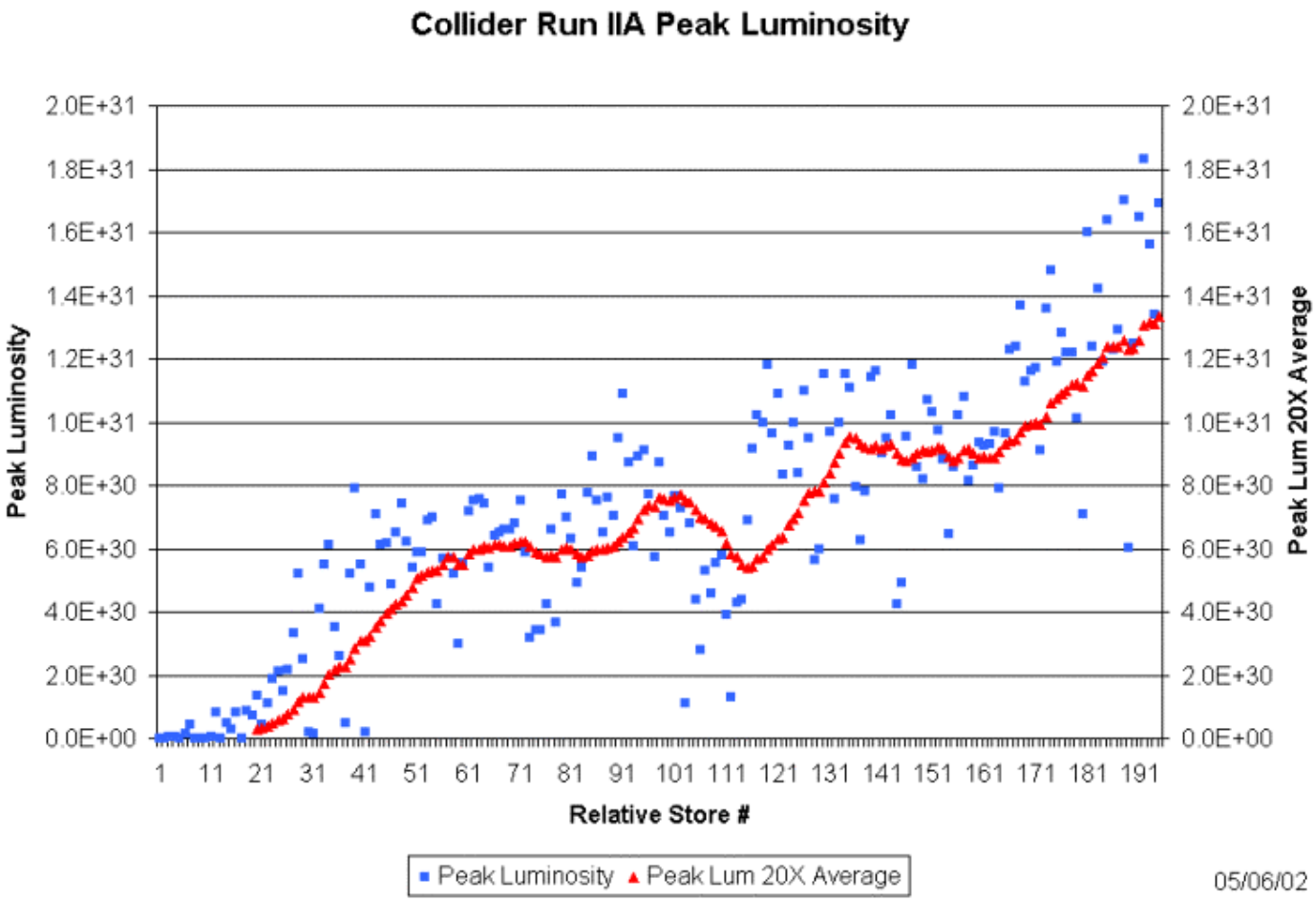
Delivered Tot. Lum

CDF live Tot. Lum

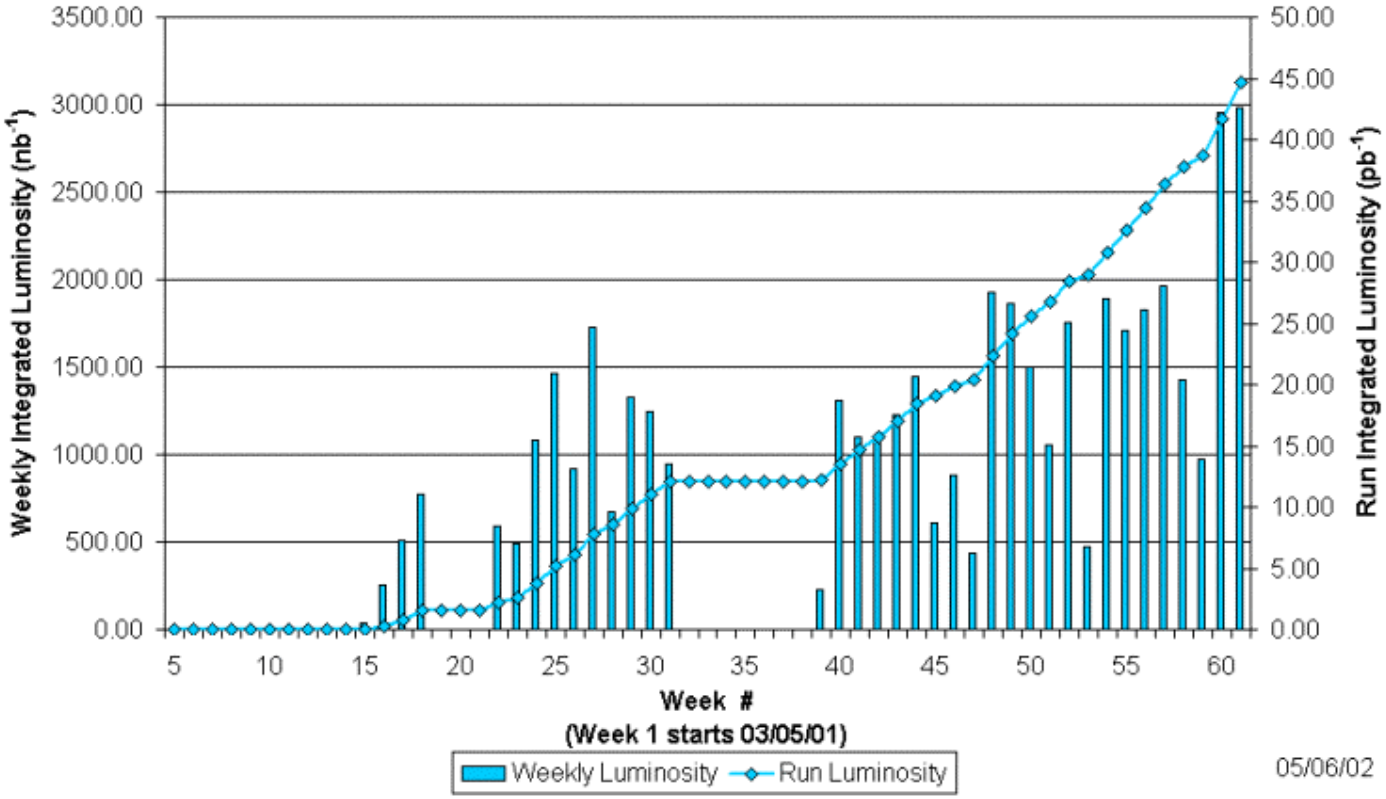
Loose min bias rate

Tight min bias rate




Collider Run IIA Peak Luminosity
Peak Luminosity
Peak Lum 20X Average
2.0E+31
1.8E+31
1.6E+31
1.4E+31
1.2E+31
1.0E+31
8.0E+30
6.0E+30
4.0E+30
2.0E+30
0.0E+00
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191
Relative Store #
Peak Luminosity
Peak Lum 20X Average
05/06/02

Collider Run IIA Integrated Luminosity



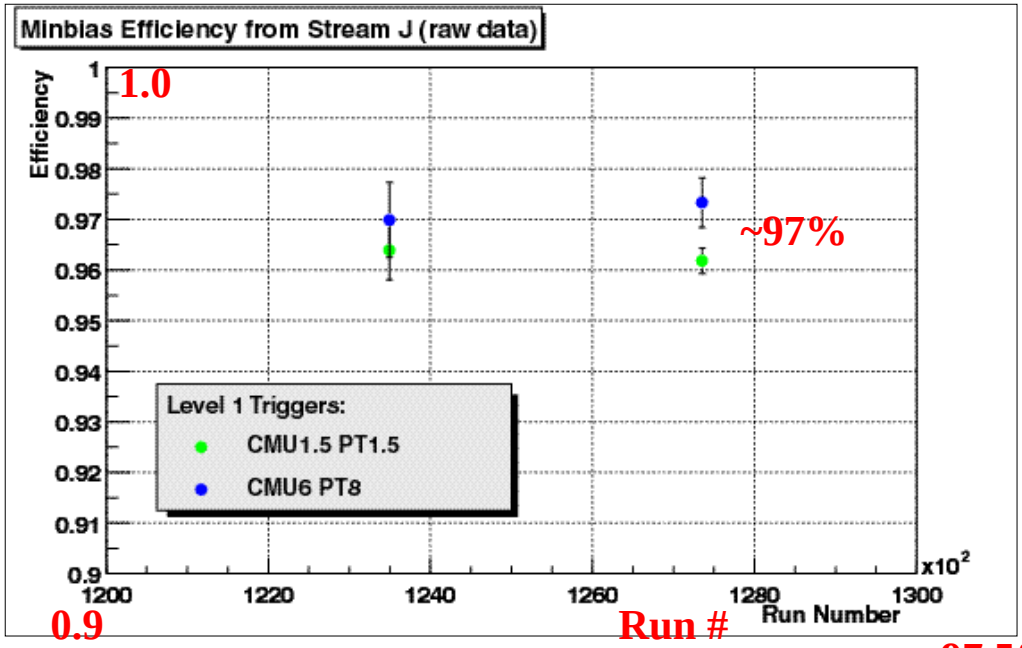
05/06/02

CLC Min. Bias Trigger

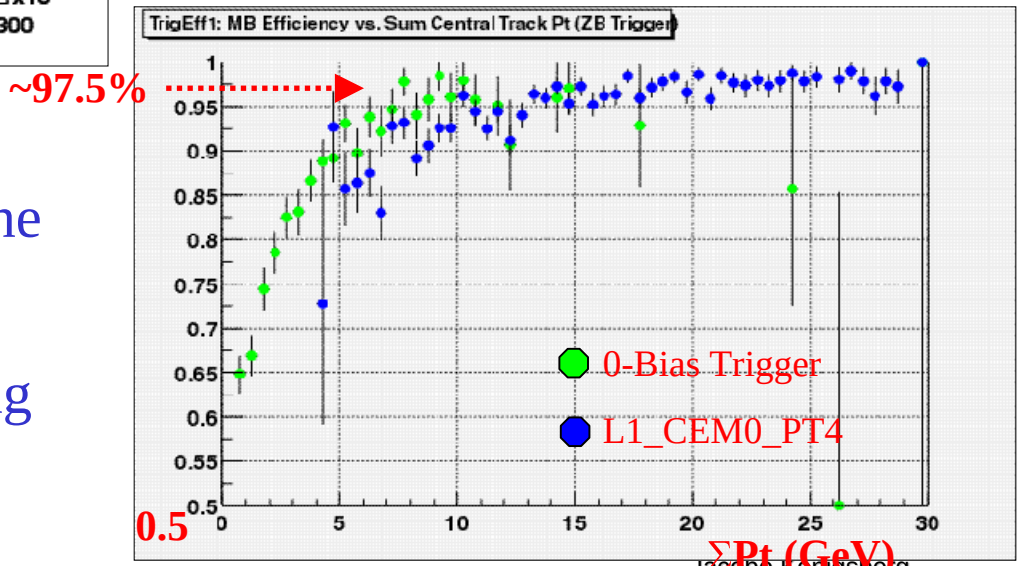
- Min. bias trigger requires at least 1 hit from East AND West CLC modules
- Loose time gate used to reduce losses contributions
- CLC min. bias trigger efficiency is studied with using orthogonal triggers to tag min. bias events
  - L1_CEM0_PT4, L1_CMU0_PT8
  - L1_CEM4_PT4, L1_CEM8_PT8
  - L1_CMU1.5_PT1.5, L1_CMU6_PT8
- $\varepsilon^{meas}_{tag} = N_{trig*tag}/N_{tag}$
- $\varepsilon^{hc}_{trig} = \varepsilon^{meas}_{tag}/(1 - f^{loss}_{tag} - f^{non\text{-}empty}_{tag})$

Efficiency for tagging on hardcore events (corrected for losses and non-collision events, and assuming negligible diffractive contributions in tagged events)

CLC Min. Bias Trigger

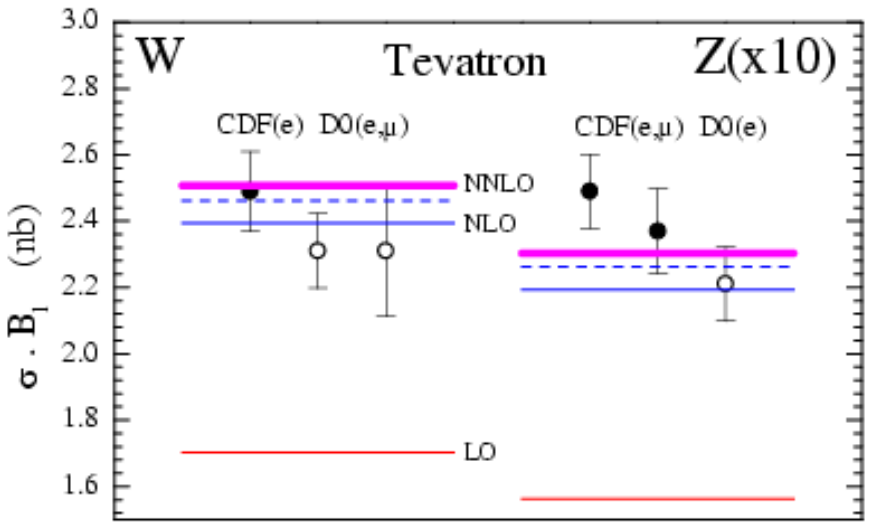


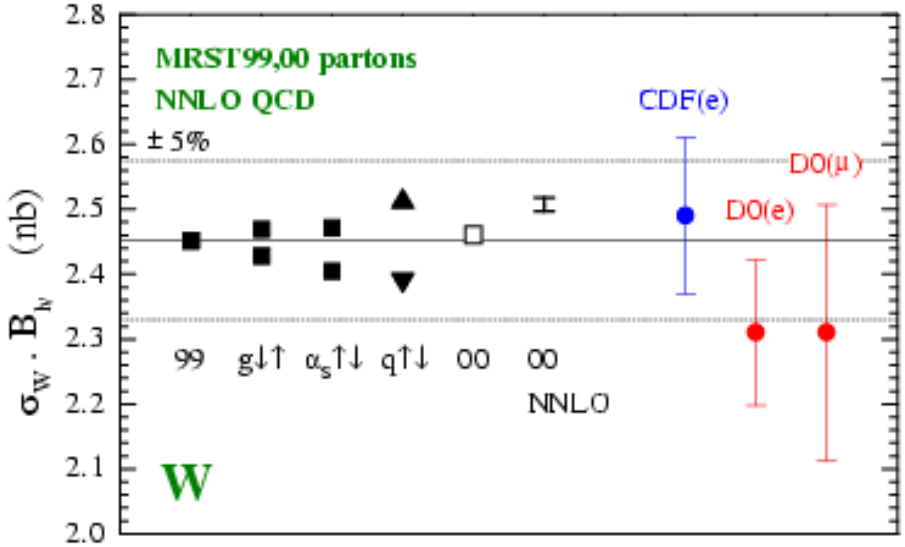
- Min. bias trigger efficiency determined from samples of events passing Level-1 muon triggers



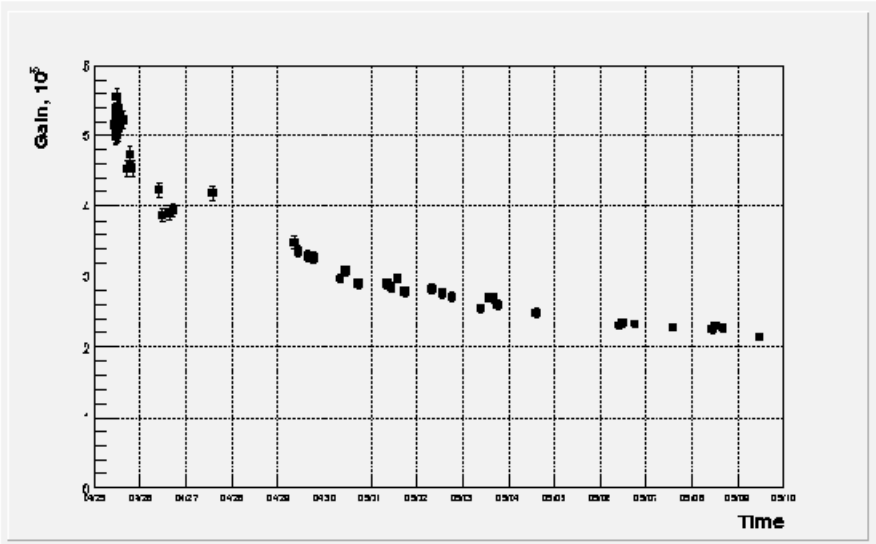
- Min. bias trigger efficiency as function of the sum of track Pt in the central region (-1< η <1)
- Simulated trigger efficiency (req tag in CCAL > 10 GeV) is ~98%

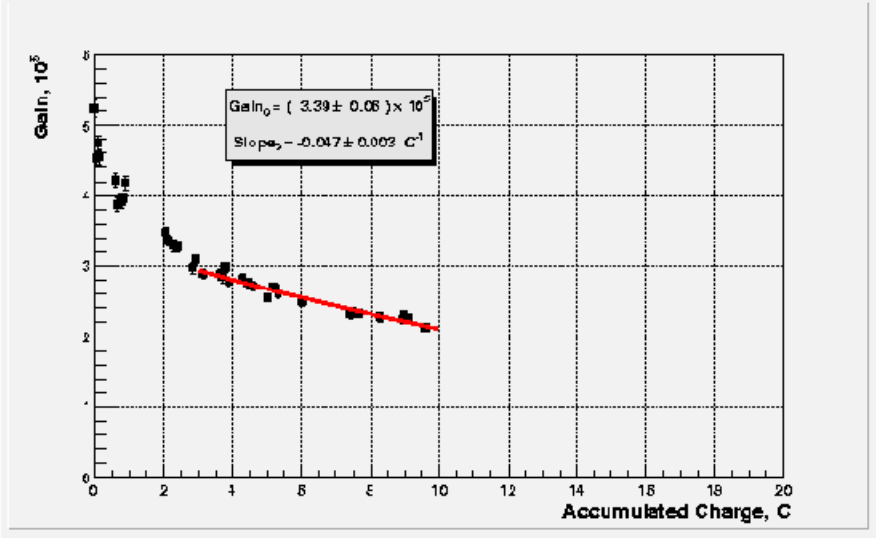
W cross- sections





PMT lifetime tests





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