CDF Luminosity Measurements

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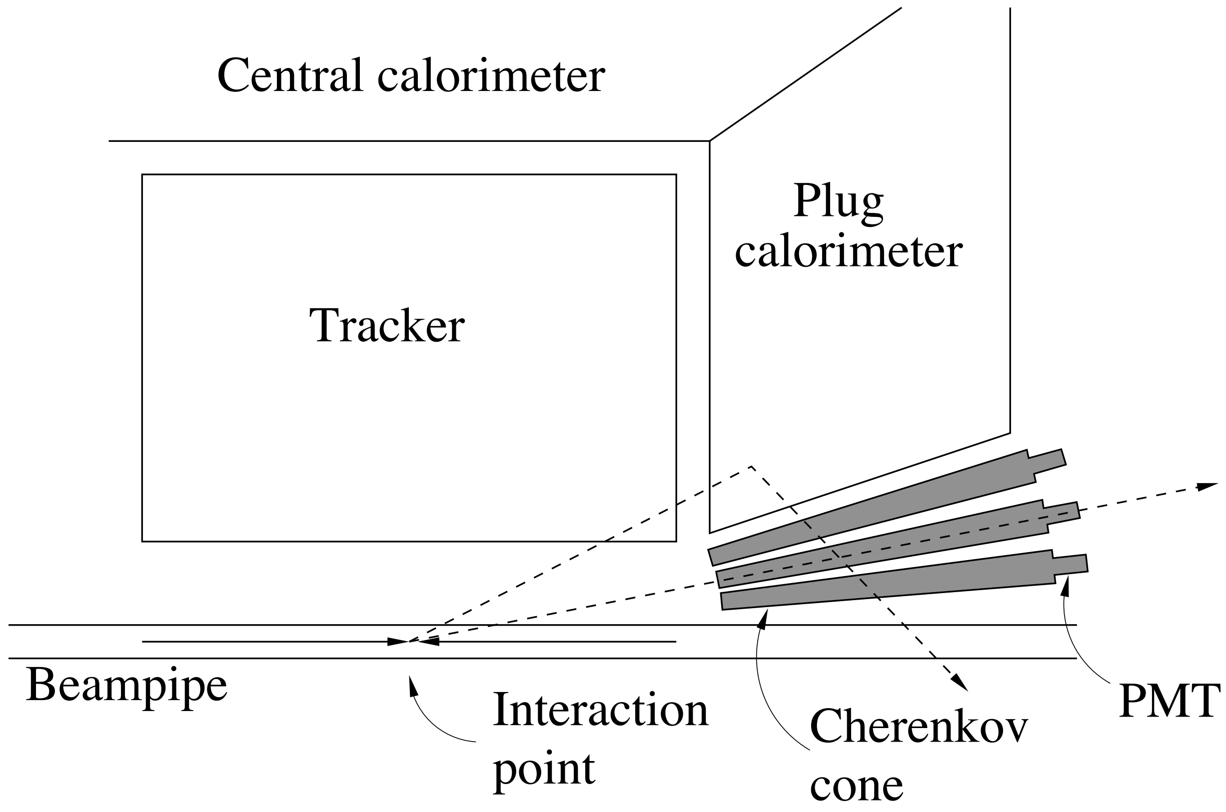
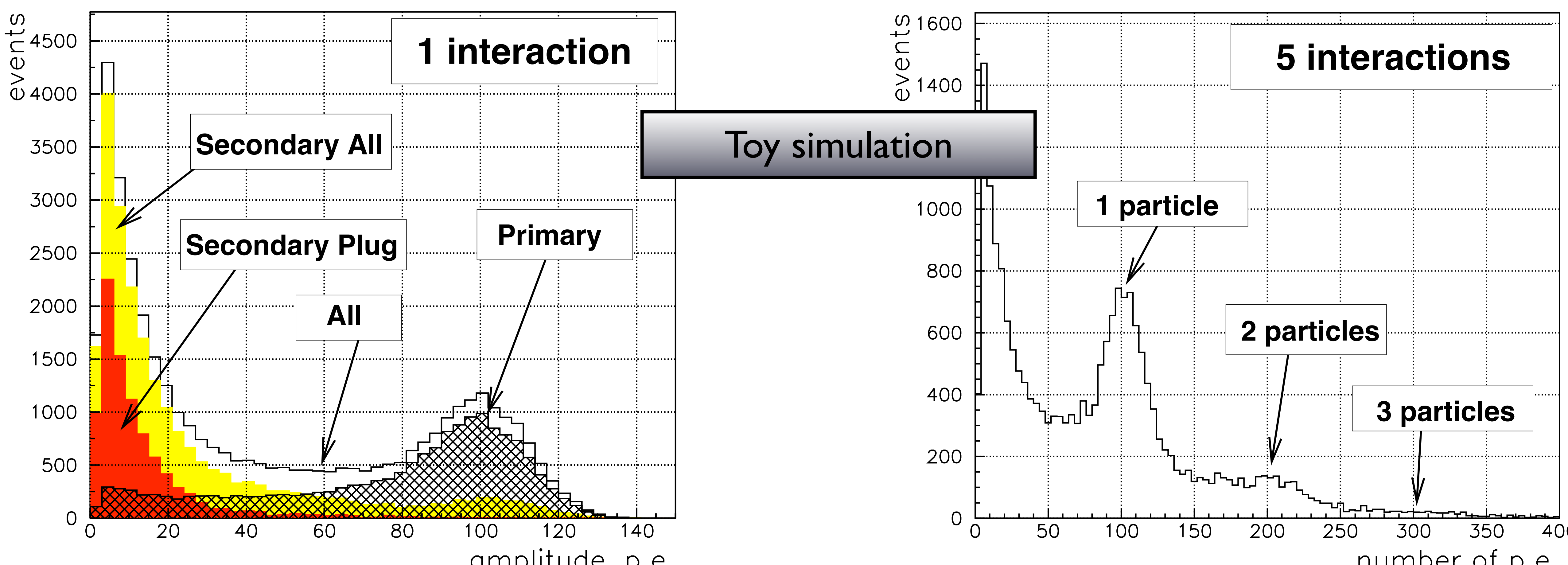
on behalf of the CDF Luminosity group

Joint Luminosity Meeting

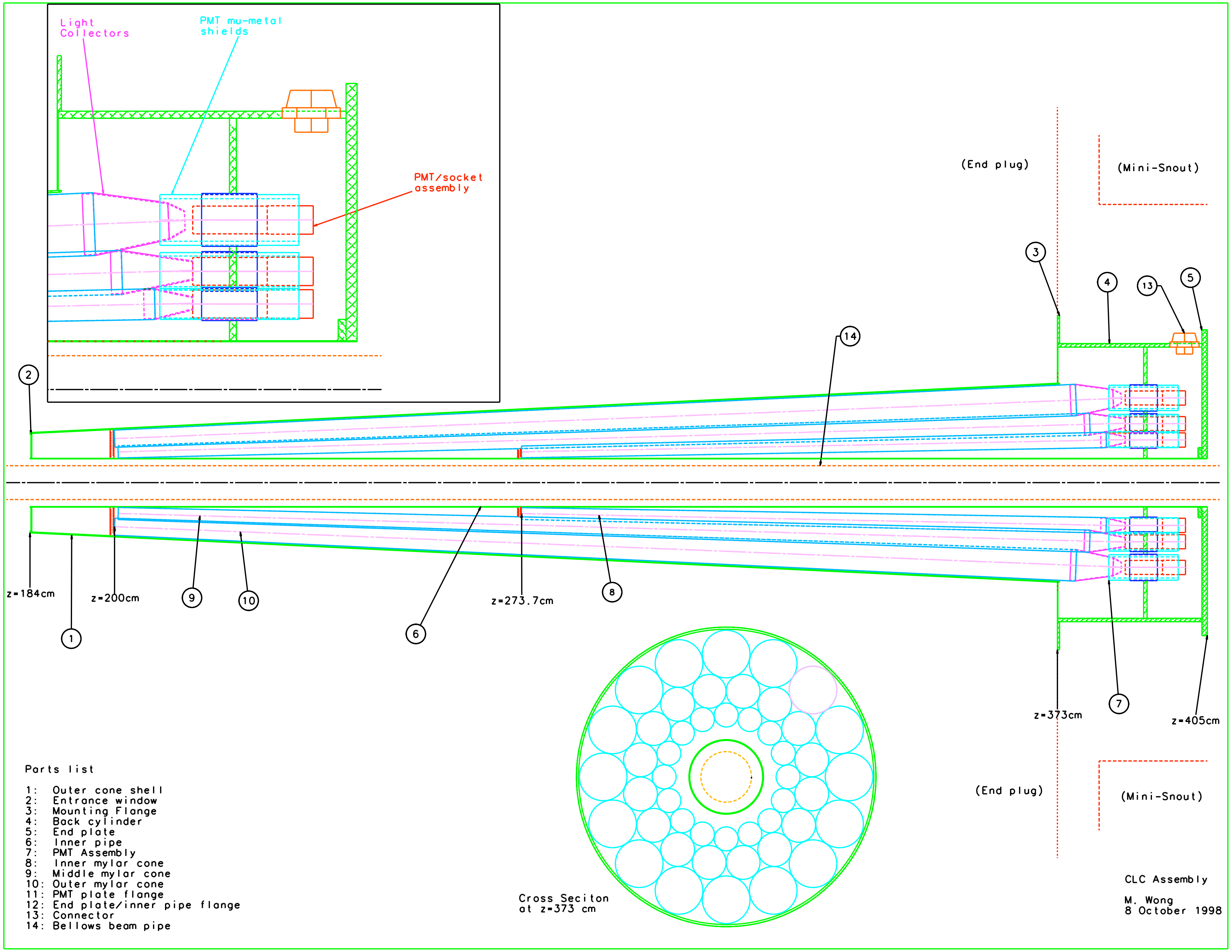
Cherenkov Luminosity Counters: Basic Ideas



- Separate particle from primary interactions and sec. particles
- Good amplitude resolution
  - about 18% (photo stat, light collection, PMT resolution)
- Good timing resolution
  - separate collisions/losses
- Radiation hard, low mass



Cherenkov Luminosity Counters: Design

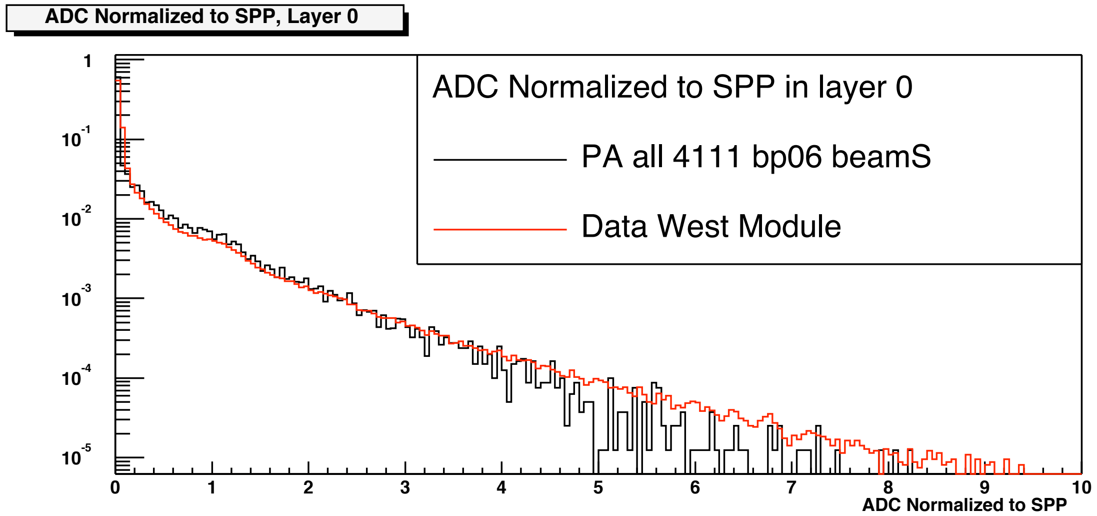


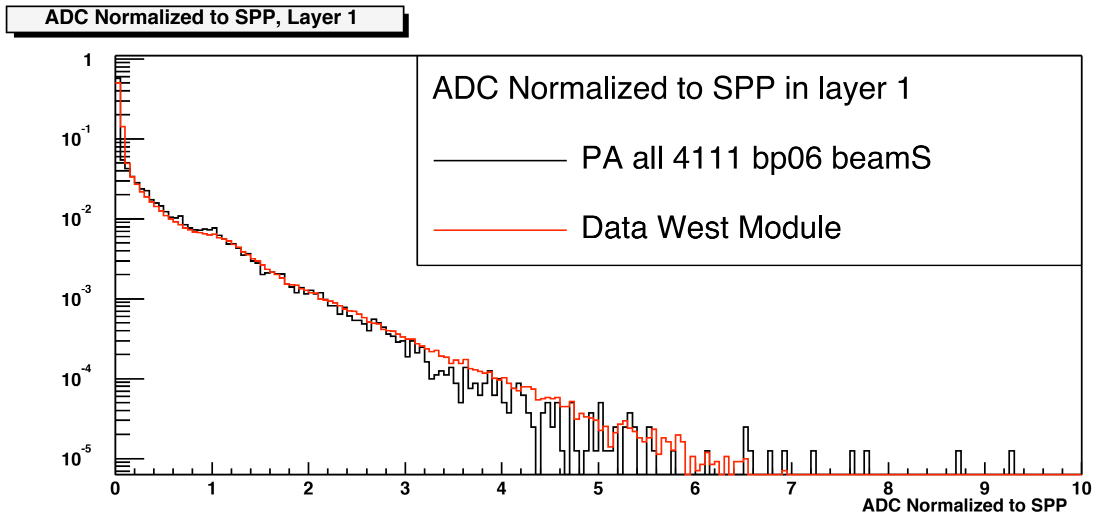
- 48 counters/side
- 3 layers × 16 counters
- Coverage: $3.7 \leq |\eta| \leq 4.7$
- Isobutane 2 atm, n = 1.000143, $\theta_C = 3.1^\circ$
- PMT Hamamatsu R5800Q CC quartz window, gain 10^5

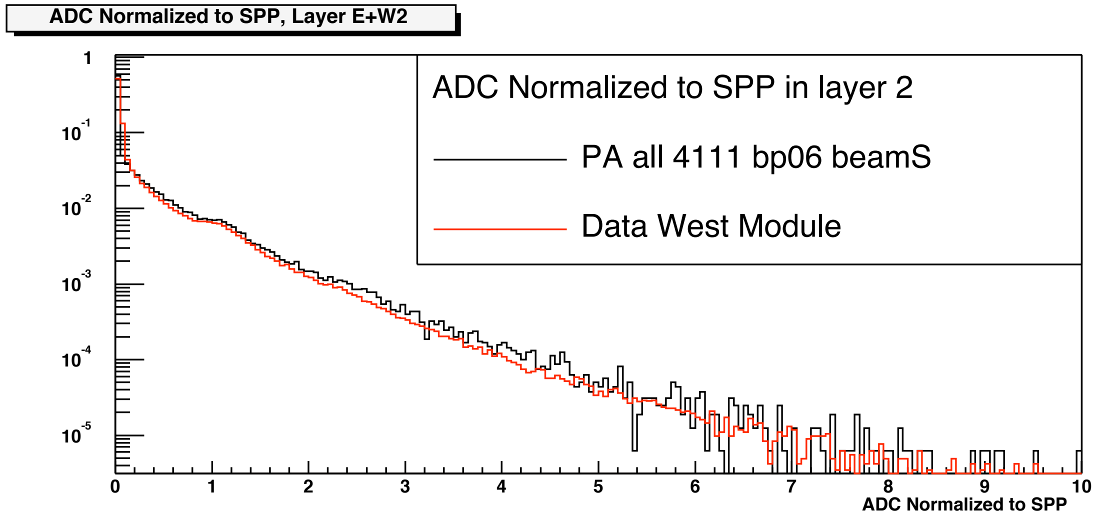
Systematic uncertainty of luminosity measurements is 4.5%

Amplitude Distributions in ppbar Collisions

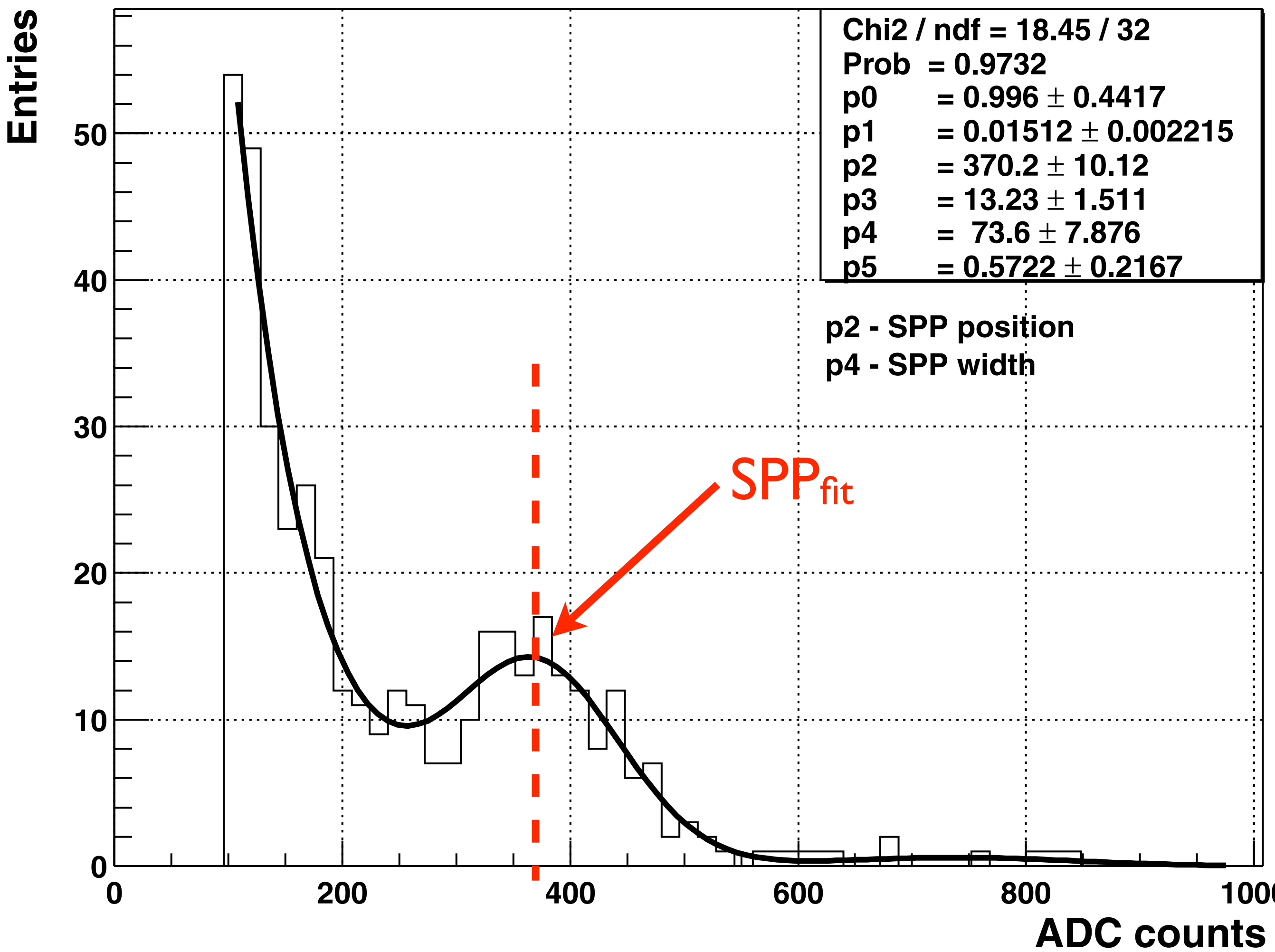
- Full Simulation *vs* Data





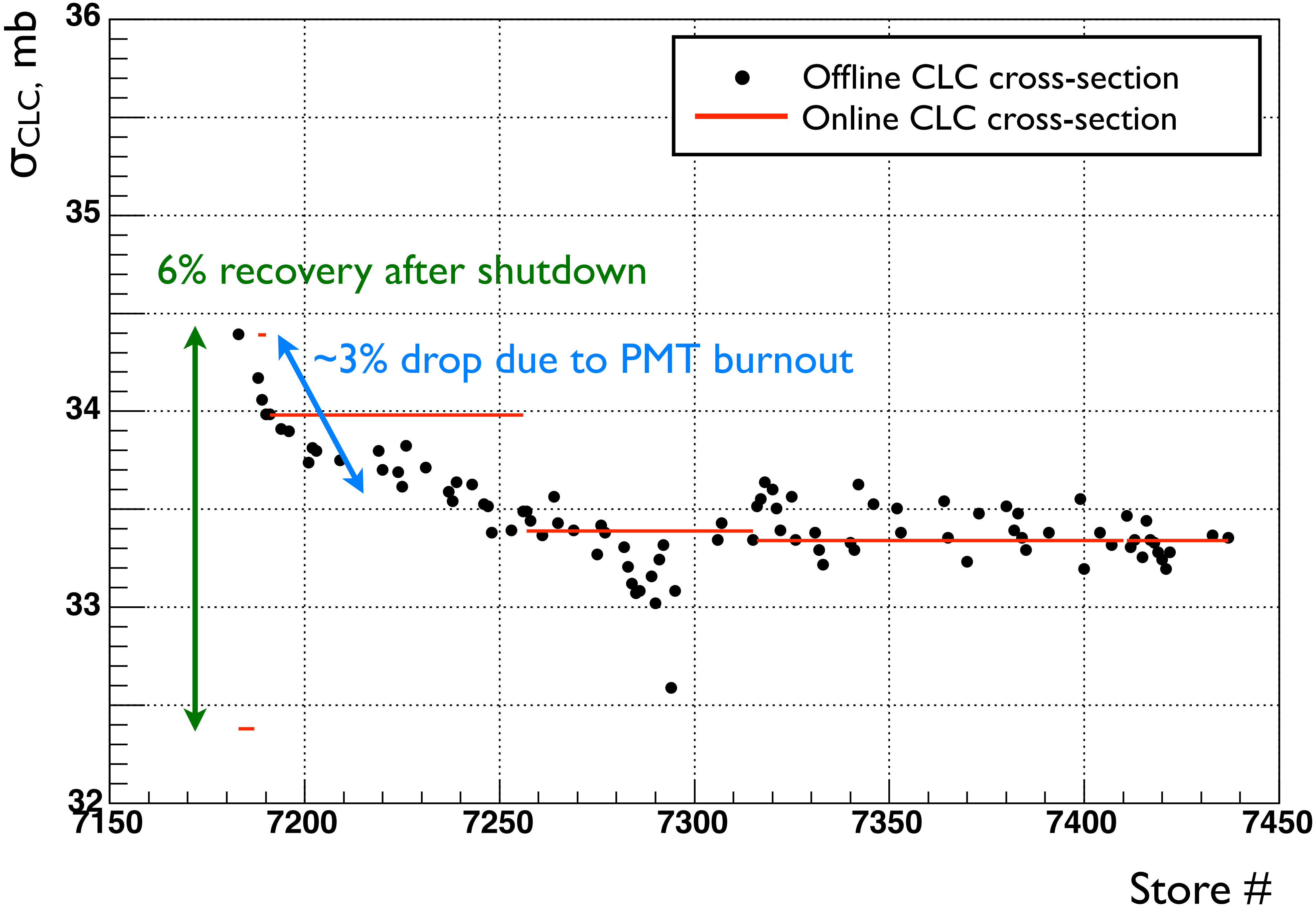


- Simulation agrees well w/ data
- Single particle peak buried under secondary interactons
- Clear peak after isolation requirement:
  - Amplitude < 20 p.e. in surrounding counters



CLC Effective Cross-section

- CLC cross-section *vs* store # (after 2009 shutdown)



In situ calibrations

- Use real data
- Fit SPP
- Feed SPP values to Monte-Carlo simulation
- Get new effective CLC cross-section
- Adjust online
- Apply offline corrections

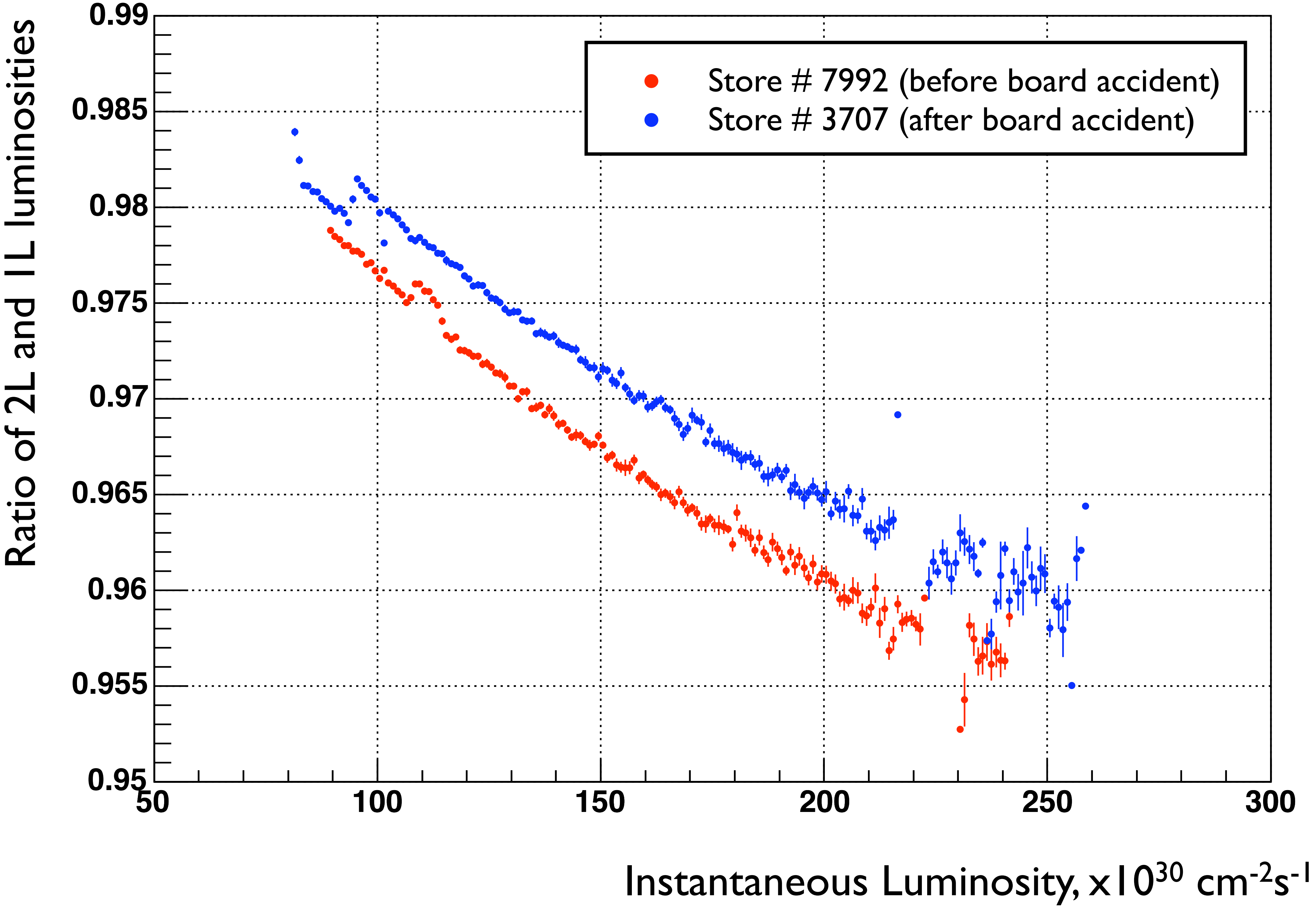
6% Recovery during shutdown. Stable operation after initial PMT burnout

CLC Electronics Problems During Stores 7293-7306

- At EOS 7292 CLC West outer layer ADMEM card developed a problem
- Replaced with spare card before store 7293
  - Spare card appeared to be not properly functional. PPD electronics engineer was out of town for 2 weeks
  - Overestimated Luminosity during store 7293
- Switched to one layer luminosity measurements for Store 7294
  - Missed proper normalization, underestimated luminosity during store 7294
- One layer luminosity measurements during stores 7294, 7296
- Recovered and installed another spare card before store 7306
  - Card was not calibrated, underestimated luminosity during store 7306
- Switched back to standard luminosity measurements before store 7307
- At EOS 7414 put back fixed original card

Two Layers *vs* One Layer Luminosity Measurements

- L_{2L}/L_{1L} *vs* instantaneous luminosity



Two Layers and One Layer luminosity ratios agree better than 0.5%

Luminosity Corrections for Stores 7293-7306

- Use one layer luminosity measurements and correct reported luminosity

Store	Luminosity dependent correction	Average correction
7293	0.9478-0.1736*exp[-0.00632*L]	0.87
7294	1.13+0.1784*exp[-0.00786*L]	1.22
7295	0.9248+0.0756*exp[-0.00309*L]	0.98
7296	0.9162+0.0818*exp[-0.00253*L]	0.97
7306	1.0155+0.1034*exp[-0.00351*L]	1.10

- The above (multiplicative) luminosity dependent corrections should bring reported luminosity back to our standard values within 0.5% uncertainty
- Average corrections are the luminosity dependent corrections weighted with luminosity profiles

Summary

- No work has been done on CLC during shutdown
- Observed recovery in the PMT gain after shutdown
- Stable operation after a period of initial PMT burnout
  - CLC effective cross-section stability is better than 1%
- Electronics problem during stores 7292-7306
  - Only one layer of CLC was affected. Used other layers for luminosity measurements
  - Reported luminosity needs to be corrected with luminosity dependent corrections

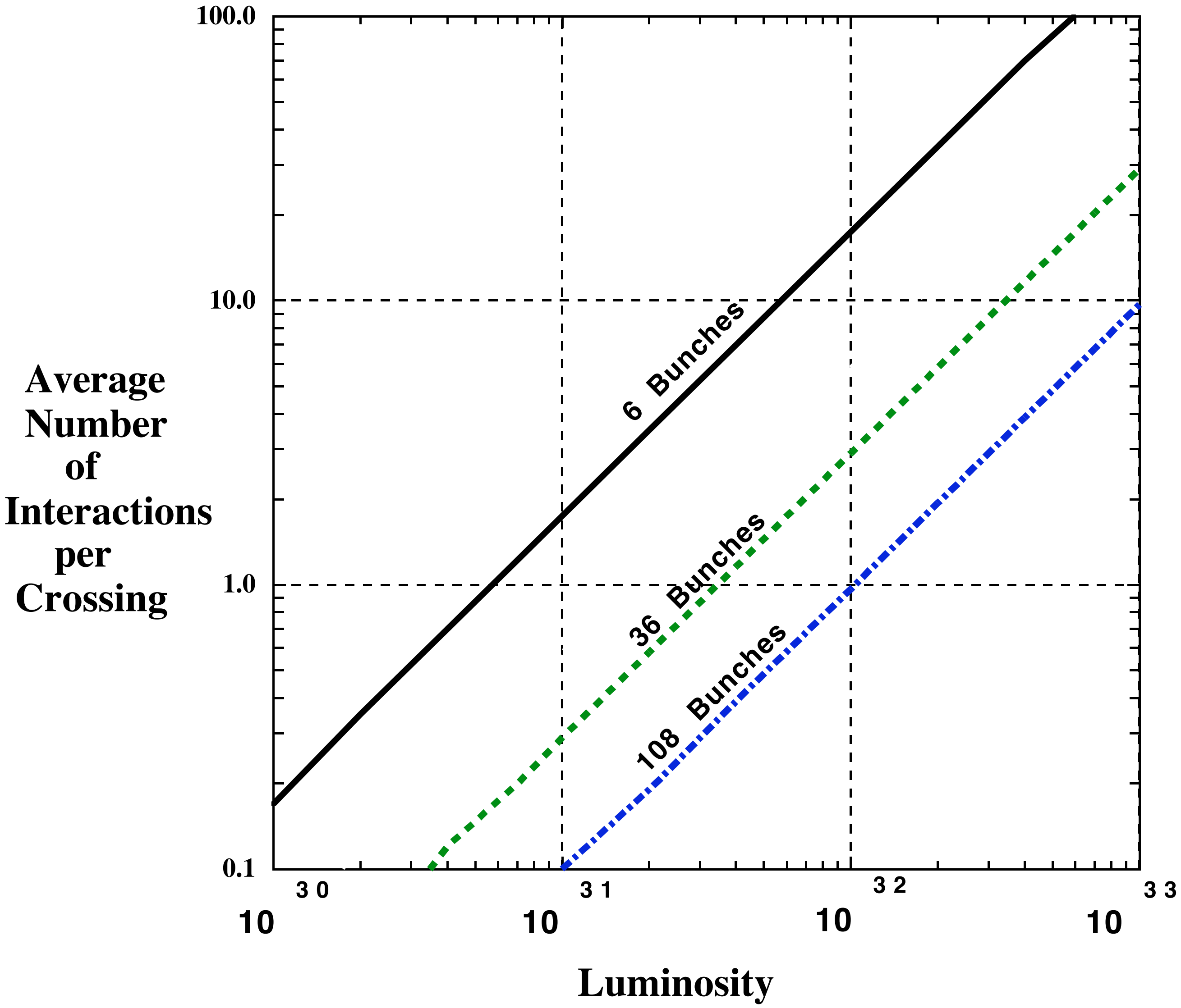
Backup slides

Specifications for CDF Luminosity Detector

- Precise absolute measurement of total luminosity is crucial for physics

- Rate of ppbar interactions

$$N_{pp} = \mu f_{BC} = \sigma_{in} L$$



- Operate at high luminosity (L ~ 4×10^{32} $cm^{-2}s^{-1}$, μ ~ 12 ppbar/BC)

- Measure Luminosity
  - Instantaneous and Total
  - Real-time
  - Bunch by bunch
  - Precise (few %)

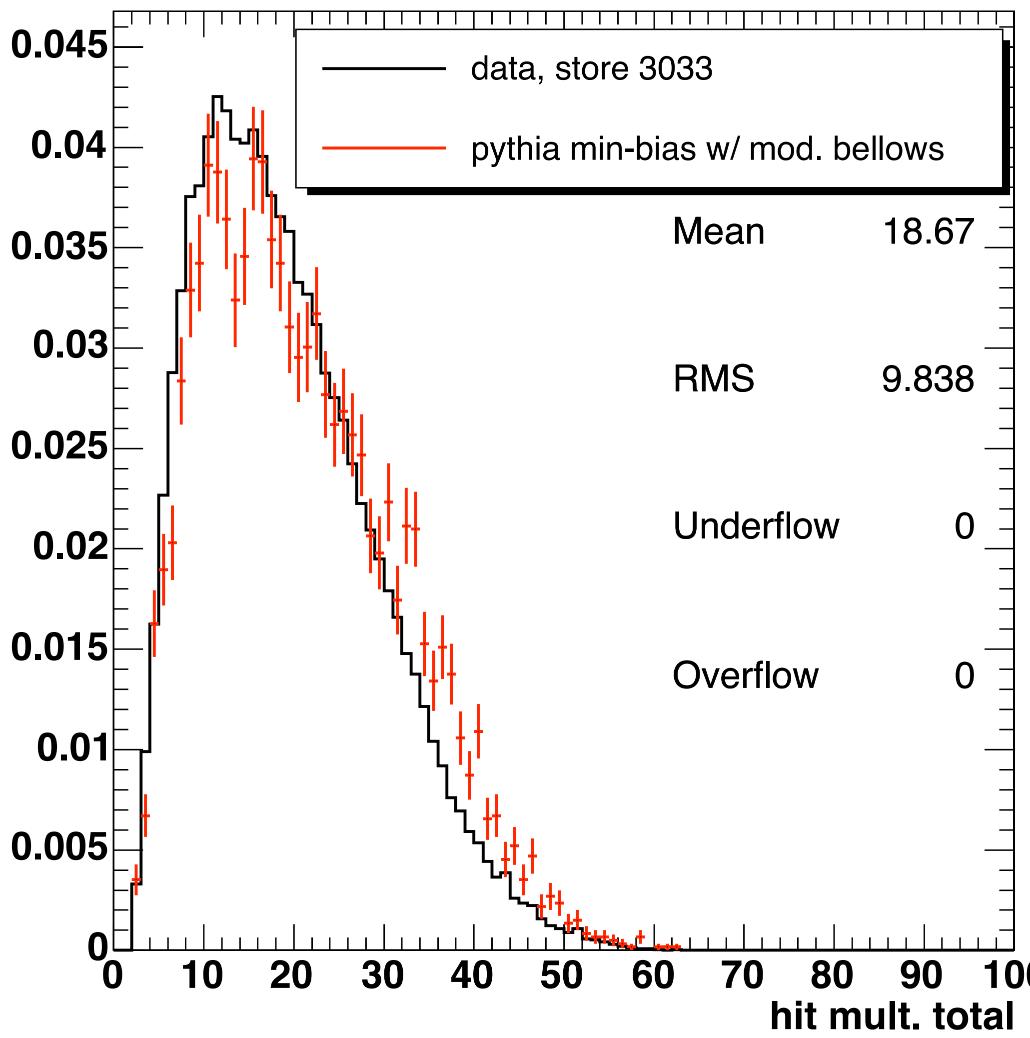
- Z-profile of collisions

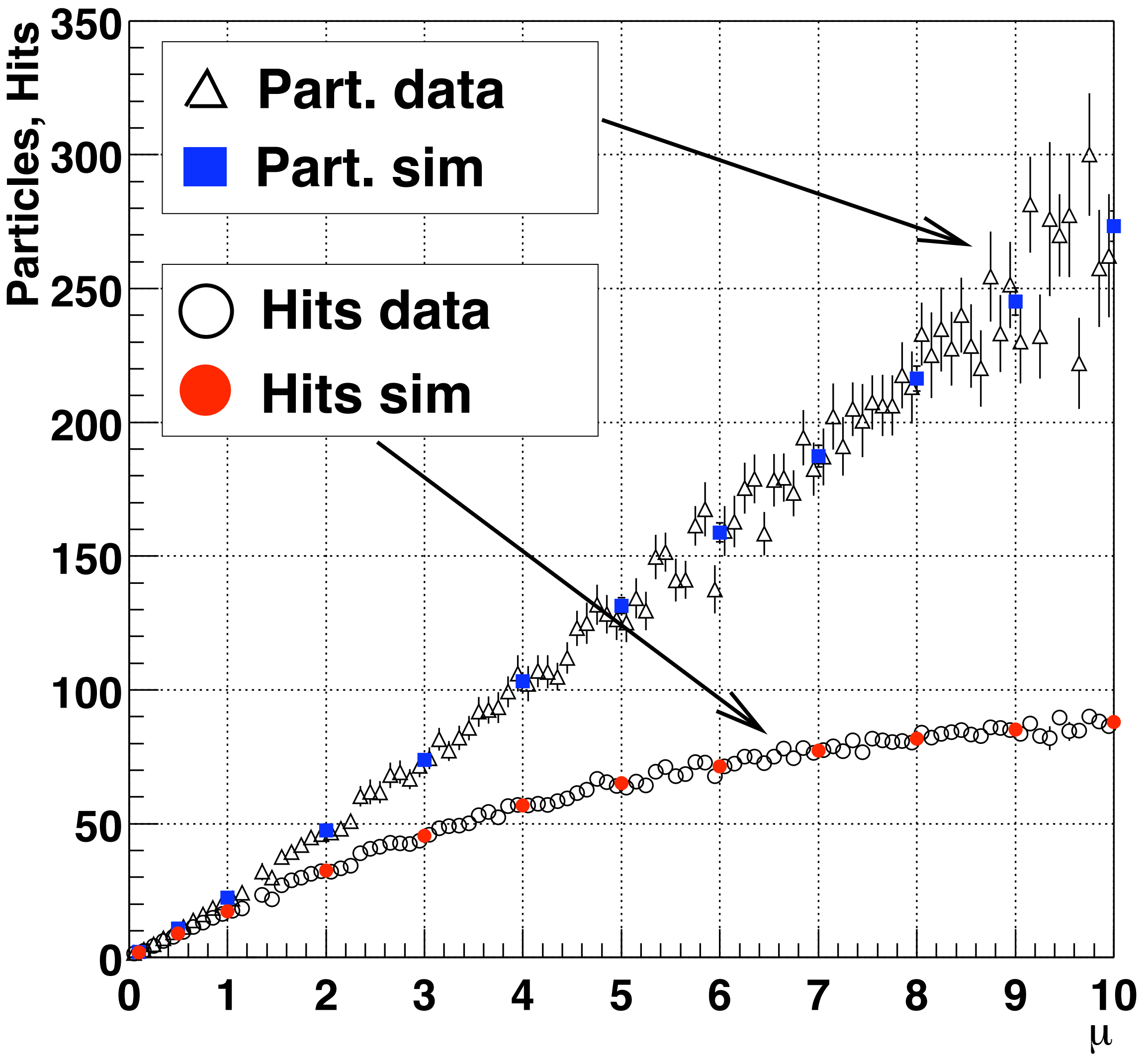
- Provide Minimum Bias Trigger

CDF: Gaseous Cherenkov Luminosity Counters

Multiplicity Distributions in ppbar Collisions

- Hits: counters with Amplitude > threshold (250 ADC, set in firmware)
- Particles: N_{part} = Amplitude / Amplitude_{SPP}





- Shape of multiplicity is more sensitive to variations in PMT gain (data) and accounting for all material in front of the detector (simulation)

Good agreement between data and simulation for average multiplicities

Luminosity Measurement Basics

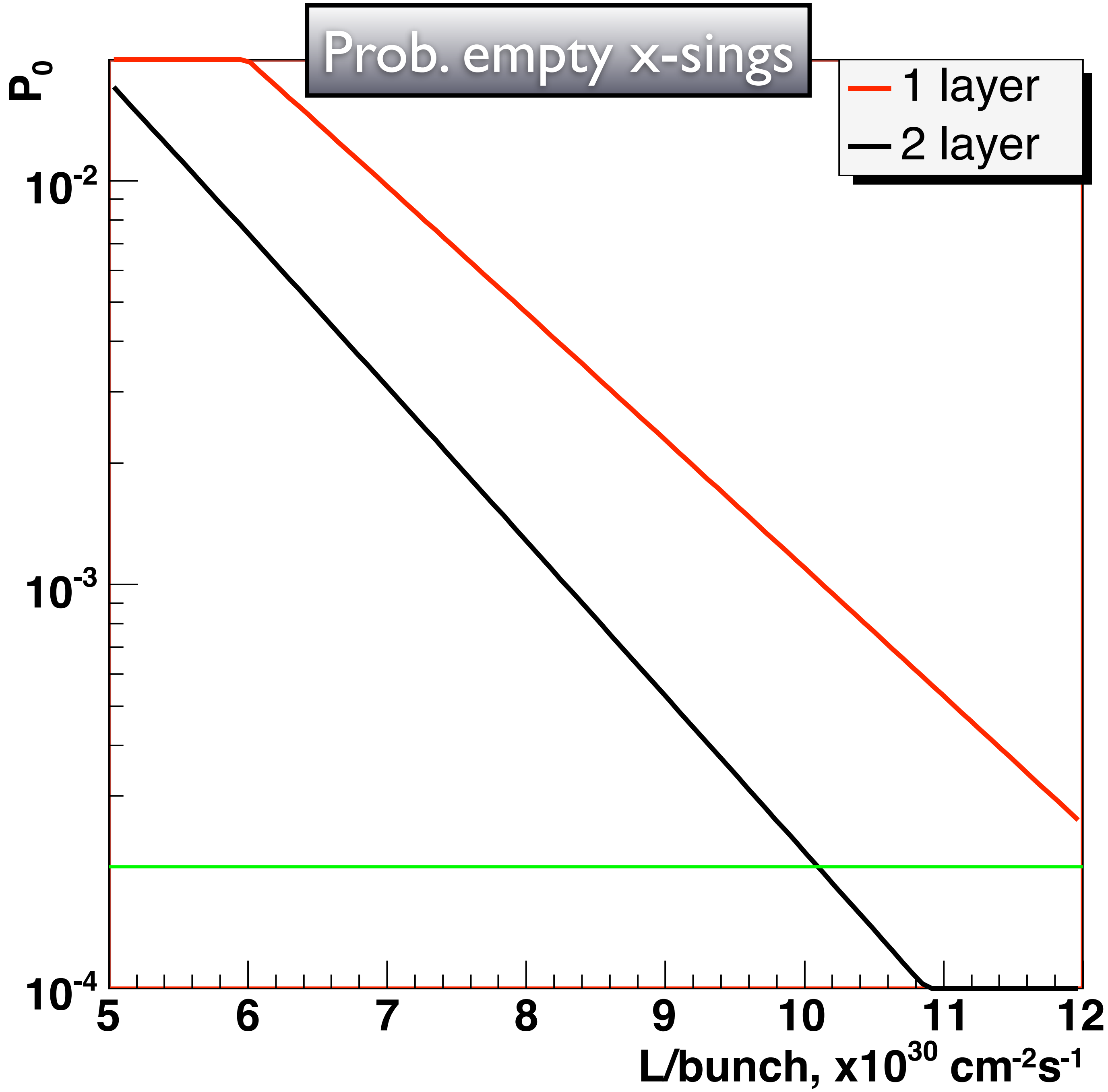
- Rate of ppbar interactions: $N_{pp} = \mu f_{BC} = \sigma_{in} L$, where
  - f_{BC} is freq. of bunch crossings
  - σ_{in}=61.7 mb is x-sec. of pp int.
  - μ is number of int./BC
- Instantaneous Luminosity

$$L = \mu f_{BC}/\sigma_{in}$$

- How to measure μ?

- Empty Crossings: BC w/o int.
  - probability: $P_0 = N_0 / N_{BC}$
  - naively: $P_0 = e^{-\mu} \Rightarrow \mu = -\log P_0$
  - need to take into account detector acceptance: $P_0=(2e^{\mu\varepsilon 1}-1)\cdot e^{-\mu(1-\varepsilon 0)}$
    where $\varepsilon 0$ is prob. of no hits in detector and $\varepsilon 1$ is prob. of hits only in one side
  - systematic uncertainty 4.5%
    - dominated by acceptance (4%)
- Other methods:
  - Hits: $\mu = N^{hits}_{BC} / N^{hits}_{1}$
  - Particles: $\mu \sim \sum_i A_i$

High Luminosity: Rare Empty Crossings

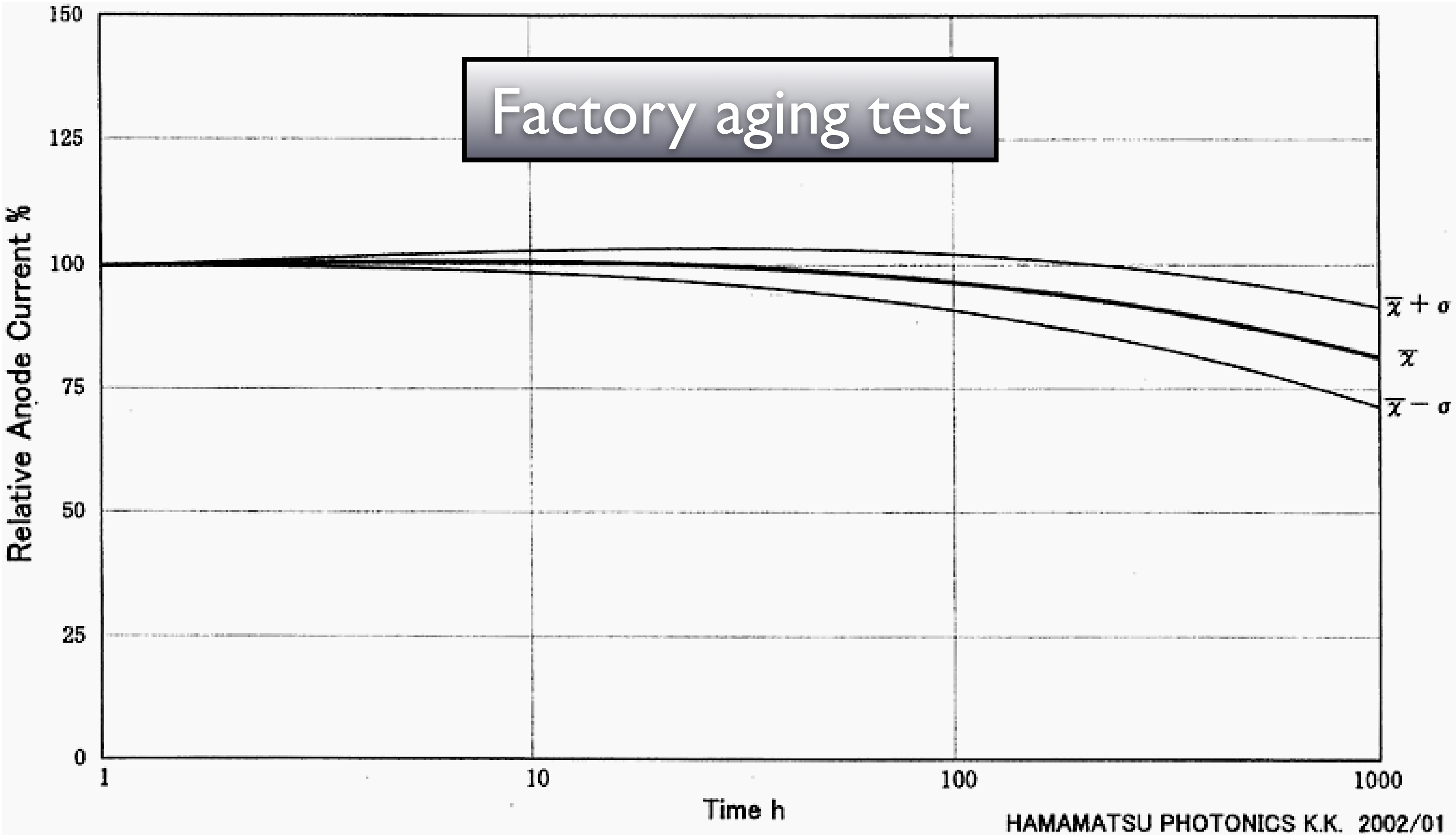


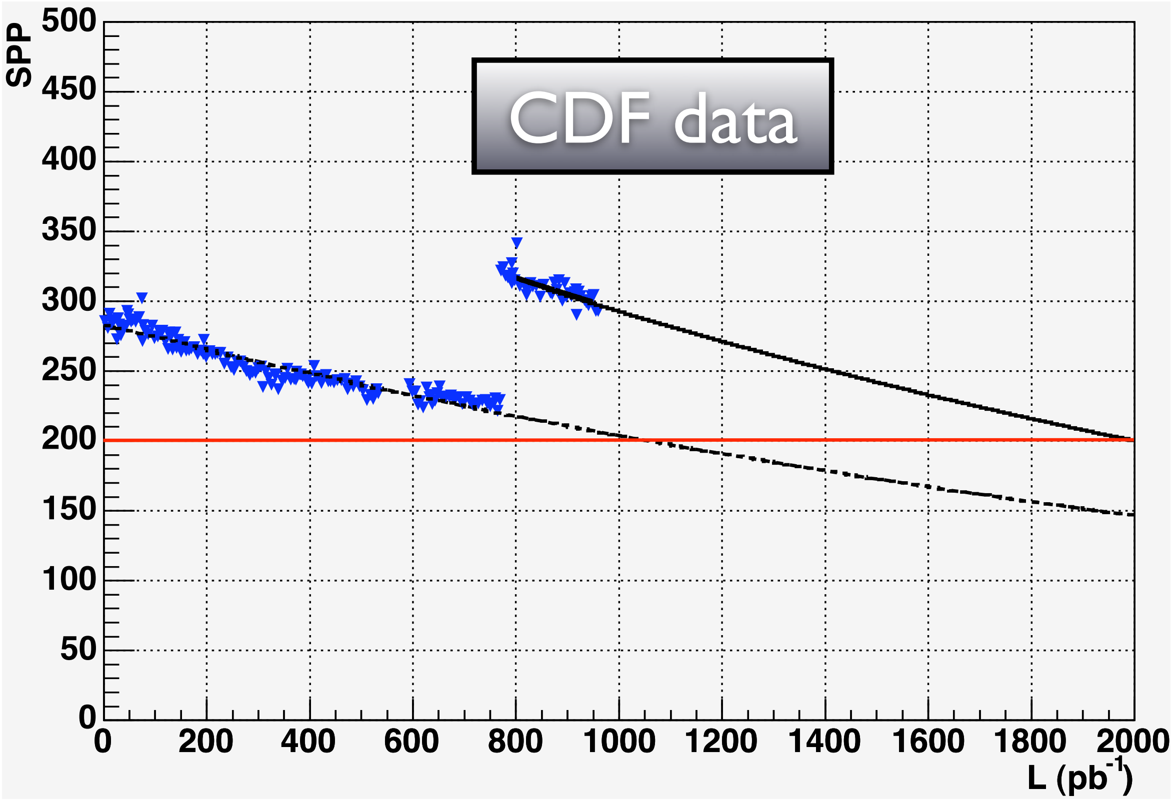
- Typical acceptances
  - 2 Layers: $\varepsilon 0 \sim \varepsilon 1 \sim 15\%$, acc ~ 55%
  - 1 Layer: $\varepsilon 0 \sim \varepsilon 1 \sim 20\%$, acc ~ 40%
- $N_{BC} \approx 20000$ per measurement
  - limited by h/w DAQ
- Cutoff (adjustable in s/w)
  - $N_0 < 4$, $P_0 < 2 \cdot 10^{-4}$
- Cutoff Luminosity (assuming equal luminosity per bunch)
  - using 2 Layers: ~ $360 \cdot 10^{30}$ cm^{-2}s^{-1}
  - using 1 Layer: ~ $400 \cdot 10^{30}$ cm^{-2}s^{-1}

Reliable Luminosity measurements up to L ~ $400 \cdot 10^{30}$cm^{-2}s^{-1}

Large Total Luminosity: Aging

- Factory aging test
  - 1000 h at 10 μA
  - ΔI / I = 10 - 35%
- Corresponds to 30 - 80 % per fb^{-1}





- PMT aging in detector
  - hard to calibrate Ampl. < 200
  - aging rate aprox. 35% per fb^{-1}
  - agrees well w/ Hamamatsy spec.
- HV/gain adjustments:
  - same aging rate

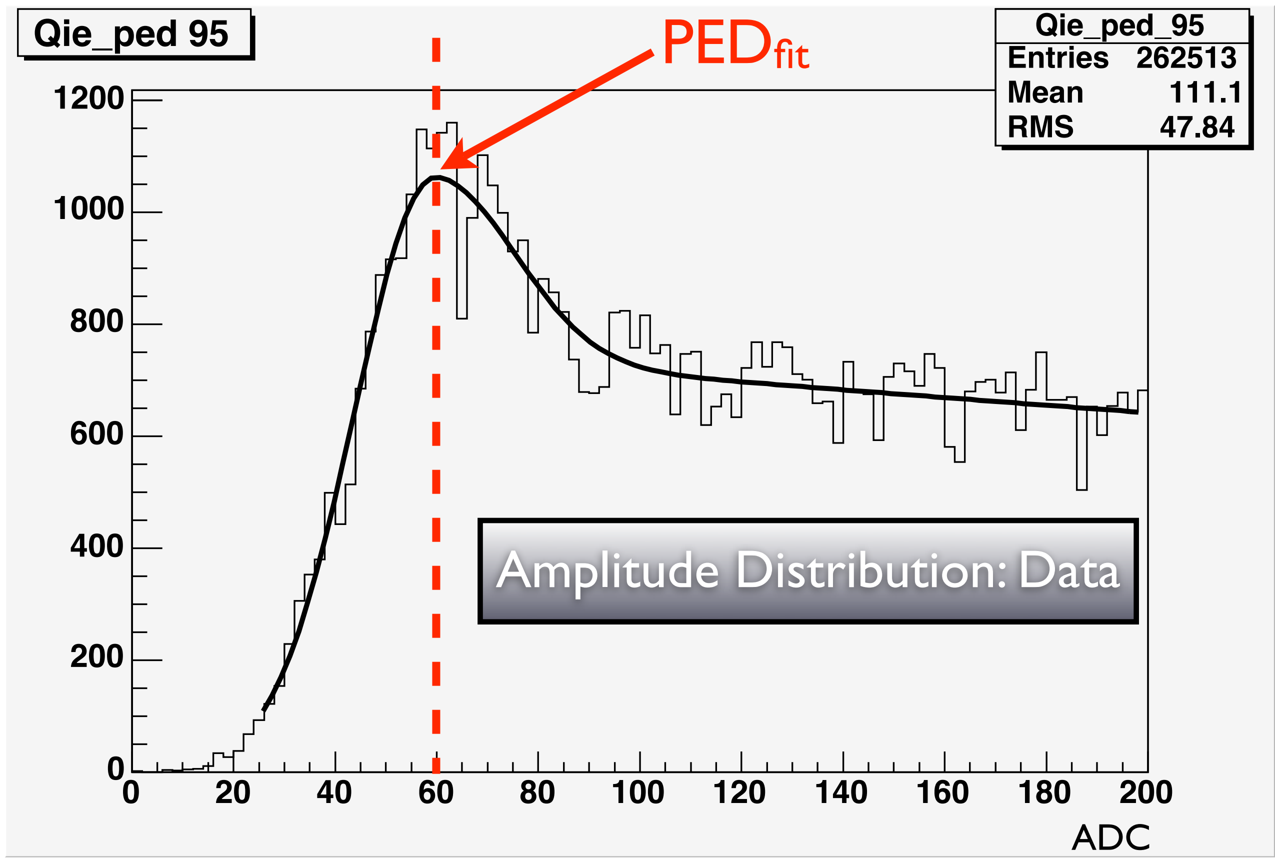
Survive few fb^{-1}

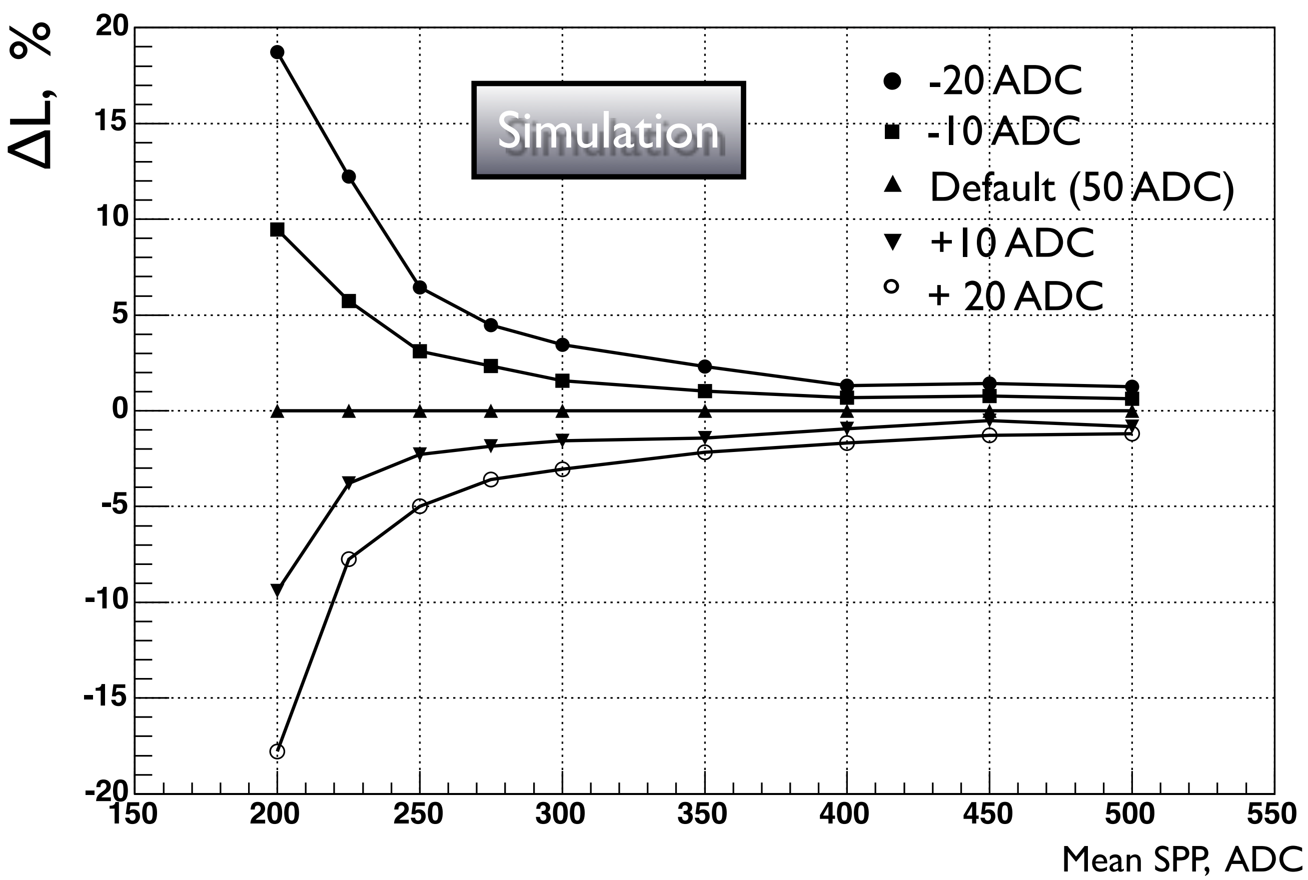
Pedestal Effect on Luminosity Measurement

- SPP_{fit} and PED_{fit} are obtained from data
- Acceptances are calculated using Monte-Carlo simulation
- SPP are corrected for pedestal and then we add default constant term of 50 ADC:

$$SPP_{acc} = SPP_{fit} - PED_{fit} + 50$$

- Method is fine for PMTs working at high gain. As PMTs age and gain drops, effect of deviation of pedestals from default value become more evident

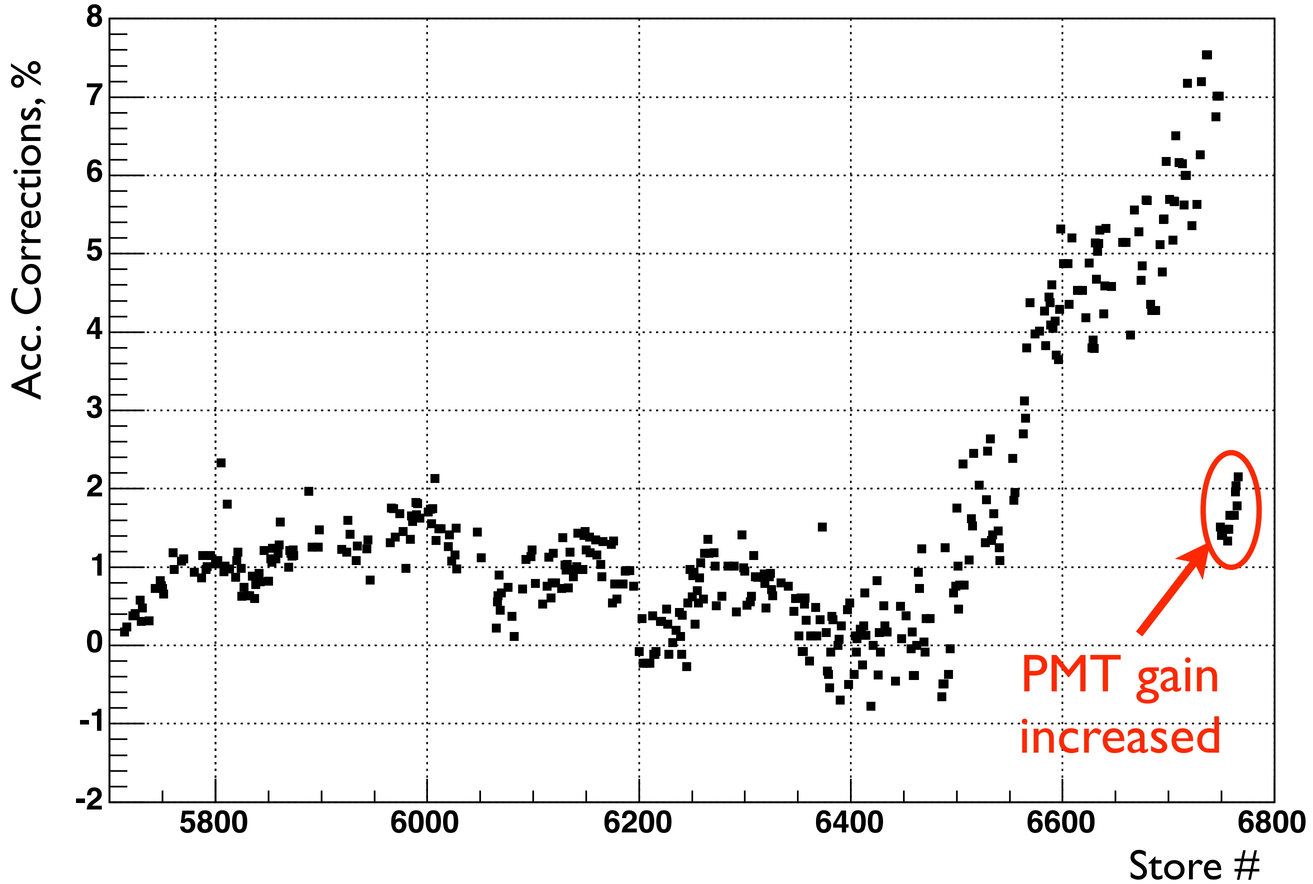


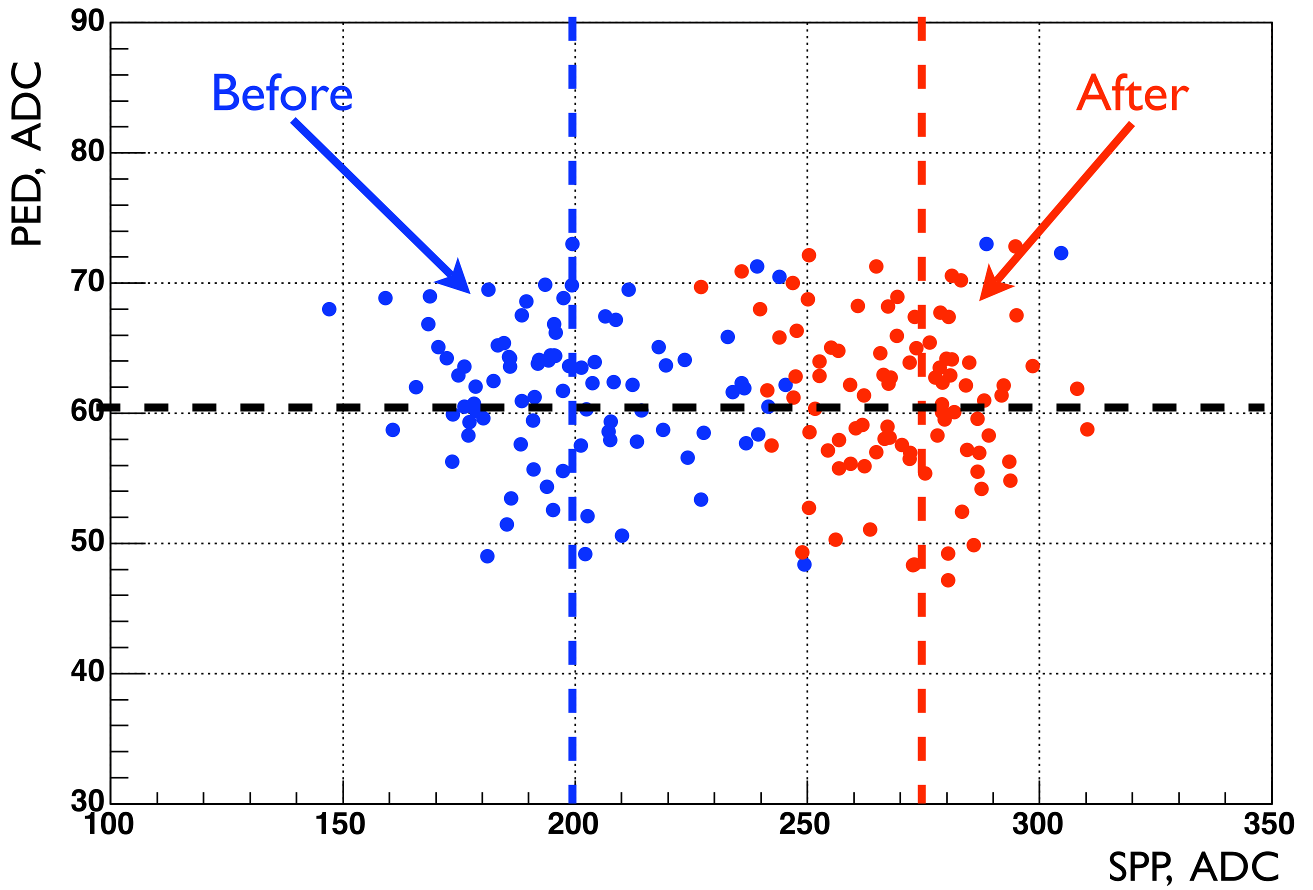


Easily fixed by offline corrections

Recent Pedestal Effect on Luminosity Measurement

- After October 2008 shutdown gain of our PMTs reached critical region and we begun gradually underestimate acceptance due to pedestal shift effect
- It is directly translated into Luminosity overestimation
- Increased PMT gain beginning Store 6749: reduced pedestal effect to 1.5-2%
  - We will use real pedestal values for *online* acceptances calculation: further eliminates these 1.5-2%





Pedestal effect is easily taken into account by offline corrections: Physics will not be affected