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A First Look at the CLC Luminosity Measurements

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Abstract

We take a first look at the CLC luminosity measurements for the first year or so of Run II data (between August, 2001, and August, 2002). We discuss the methodology used in the measurements, the problems encountered, the sources of systematic uncertainties and the plans for improvement.

Contents

1 Introduction

In Run II the Cherenkov Luminosity Counters (CLC) are being used by CDF to measure the luminosity by estimating the average number of $p\bar{p}$ interactions per bunch crossing: μ. The CLC was designed to measure μ with good accuracy ($< few$ %) all the way up to the high luminosity regime $L \sim 2 \times 10^{32} cm^{-2} s^{-1}$ expected in Run II [1, 2].

The total rate of $p\bar{p}$ interactions is given by:

$$\mu \cdot f_{BC} = \sigma_{tot} \cdot \mathcal{L}, \tag{1}$$

where the σ_{tot} is the total $p\bar{p}$ cross-section at $\sqrt{s} = 1.96$ TeV, L is the instantaneous luminosity and f_{BC} is the rate of bunch crossings in the Tevatron.

Processes resulting from $p\bar{p}$ interactions that satisfy a well defined **selection criteria,** $\{\alpha\}$, to be registered in the CLC will have an effective cross-section σ_α. The average number of such processes, per bunch crossing, μ_α satisfies:

$$\mu_\alpha \cdot f_{BC} = \sigma_\alpha^{CLC}(\mu_\alpha) \cdot \mathcal{L}, \tag{2}$$

with:

$$\sigma_\alpha^{CLC}(\mu_\alpha) = \sigma_{tot} \cdot \epsilon_\alpha(\mu_\alpha), \tag{3}$$

such that:

$$\mu_\alpha = \epsilon_\alpha(\mu_\alpha) \cdot \mu \tag{4}$$

is an "estimator" of the actual total number of interactions μ.

The probability to register such $p\bar{p}$ collisions in the CLC, ϵ_α, can be factorized as:

$$\epsilon_\alpha = \frac{\epsilon_\alpha^{in} \cdot \sigma_{in} + \epsilon_\alpha^{el} \cdot \sigma_{el}}{\sigma_{tot}} = \frac{\epsilon_\alpha^{hc} \cdot \sigma_{hc} + \epsilon_\alpha^{d} \cdot \sigma_{d} + \epsilon_\alpha^{dd} \cdot \sigma_{dd} + \epsilon_\alpha^{el} \cdot \sigma_{el}}{\sigma_{tot}} \tag{5}$$

with

$$\sigma_{tot} = \sigma_{hc} + \sigma_d + \sigma_{dd} + \sigma_d + \sigma_{el}, \tag{6}$$

where σ_{hc}, σ_d, σ_{dd}, and σ_{el} are the hard core inelastic cross section, the single diffractive inelastic cross section, the double-diffractive inelastic cross-section and the elastic cross section, respectively. Their corresponding acceptances in the CLC are: ϵ_α^h, ϵ_α^d, ϵ_α^{dd} and ϵ_{el}.

Table 1 lists the cross sections measured by CDF [3] at $\sqrt{s} = 1.8$ TeV and our approximate extrapolations to $\sqrt{s} = 1.8$ TeV using the formulas in there. We'll discuss these extrapolations in the future, elsewhere.

The CLC is most sensitive to hard core inelastic $p\bar{p}$ interactions, with small contributions from diffractive processes and no contributions from elastic ones, especially when East-West coincidences are required in selecting an "interaction". We therefore expect $\epsilon_\alpha^d, \epsilon_\alpha^{dd} << \epsilon_\alpha^h$ and $\epsilon_{el} = 0$ and can redefine ϵ_α and re-write equation 5, such that:

Process	$\sqrt{s} = 1.8$ TeV	$extrap. \sqrt{s} = 2.0$ TeV	comment on extrap.
σ_{tot}	80.03 ± 2.24 mB	81.90 ± 2.30 mB	from PRD formula
σ_{in}	60.33 ± 1.4 mB	60.4 ± 0.92 mB	assumed flat approx.
σ_{el}	19.7 ± 0.85 mB	21.5 ± 0.92 mB	the balance...
σ_{hc}	$[\sim 51]$ mB	$[\sim 51]$ mB	balance: not measured directly
σ_{d}	9.46 ± 0.44 mB	$\sim 10 \pm 0.5$ mB	guess...
σ_{dd}	$n.a. \pm xxx$ mB	$n.a.$ mB	included in h.c.

Table 1: $p\bar{p}$ cross sections for the various processes at the Tevatron.

$$\sigma_{\alpha}^{CLC}(\mu_{\alpha}) = \sigma_{in} \cdot \epsilon_{\alpha}(\mu_{\alpha}), \tag{7}$$

$$\epsilon_{\alpha} = \frac{\epsilon_{\alpha}^{h} \cdot \sigma_{h} + \epsilon_{\alpha}^{d} \cdot \sigma_{d} + \epsilon_{\alpha}^{dd} \cdot \sigma_{dd}}{\sigma_{in}}, \tag{8}$$

Once the $\{\alpha\}$ selection criteria is defined, the question is what CLC measurement is best to use to estimate and monitor μ_{α} as a function of luminosity ("the estimator").

For a good estimator $\epsilon_{\alpha}(\mu)$ should approximate a linear function of μ up to high luminosities (i.e. little saturation). For low luminosities we expect that $\mu_{\alpha} = \epsilon_{\alpha}^{1} \cdot \mu$ where ϵ_{α}^{1} is a factor that is related to the detector acceptance and efficiency to detect a **single $p\bar{p}$ interaction** as defined by the estimator. We can therefore re-write 4 as:

$$\tilde{\mu}_{\alpha} = \epsilon_{\alpha}^{1} \cdot \epsilon_{\alpha}^{m}(\mu_{\alpha}) \cdot \mu, \tag{9}$$

where the term $\epsilon_{\alpha}^{m}(\mu)$ describes the possible saturation of the estimator due to pileup from multiple interactions or other non-linear effects. The factors ϵ_{α}^{1} and $\epsilon_{\alpha}^{m}(\mu)$ need to be determined experimentaly, from data and/or from simulations.

Below we describe the two methods that we've used so far to measure luminosity during 2001:

- **The counting of the average number of hits per crossing.**
- **The counting of empty crossings.**

The particle counting method is relevant only for very high luminosity (with an avg. of more than 4 interactions per bunch crossing) where a significant fraction of counters have more than one primary particle traversing them. For the relatively low luminosities encountered in the period discussed here, hit counting is equivalent to particle counting.

2 Luminosity counting hits

2.1 Method

The **"hit counting"** method uses the average number of hits recorded in the CLC in zero-bias crossings, $< N_h >$, as an estimator of the average number of $p\bar{p}$ interactions μ and therefore of the luminosity.

In this case, when a specific definition of a collision $\{\alpha\}$ in which to count hits is made, we'll have:

$$\mu_\alpha = \frac{< N_H >_\alpha}{< N_H^1 >_\alpha}, \tag{10}$$

where $< N_H^1 >_\alpha$ is the average number of hits on the CLC for a single $p\bar{p}$ collision. Note that a "hit" may be defined arbitrarily as a counter with amplitude above a certain threshold which, for example, could be higher than the thresholds used to define a collision.

From 2 the luminosity will therefore be given by:

$$\mathcal{L} = \frac{f_{BC}}{\epsilon_\alpha(\mu_\alpha) \cdot \sigma_{in}} \cdot \frac{< N_H >_\alpha}{< N_H^1 >_\alpha} \tag{11}$$

The CLC acceptance $\epsilon_\alpha(\mu_\alpha)$ can be evaluated from Monte Carlo simulations of "minimum bias" event generators and also from real data provided that another detector determines that a collision has ocurred. The average number of hits for a single $p\bar{p}$ interaction, $< N_H^1 >_\alpha$, can be determined directly from data taken with a beam-crossing trigger ("zero bias"). These two quantities, in addition to the selection criteria $\{\alpha\}$, depend, of course, on the PMT gains, which need to be monitored closely.

3 Luminosity measurement with empty crossings

3.1 Method

A method equivalent to the counting of empty crossing, a rate measurement, was used to measure luminosity with the BBC [11] in Run I.

We consider an empty crossing as a $p\bar{p}$ crossing with no $p\bar{p}$ interactions as defined by a set of selection criteria α. In our case the criteria is to have at least one hit per CLC side.

The number of $p\bar{p}$ interactions (n), **of any kind**, per crossing follows Poisson statistics with mean μ:

$$\mathcal{P}_n(\mu) = \frac{(\mu)^n}{n!} \cdot e^{-\mu}, \tag{12}$$

so that probability to have zero such interactions would be

$$\mathcal{P}_o(\mu) = e^{-\mu}. \tag{13}$$

In principle by measuring the fraction of empty crossings in the CLC experimentaly, P_o^{exp}, we could obtain μ from equation 12 and the luminosity could then be derived from:

$$\mathcal{L} = \frac{f_{BC}}{\sigma_{tot}} \cdot \mu \tag{14}$$

However this will not work because the CLC acceptance to detect an interaction is not exactly 100% and P_o^{exp} differs from $\mathcal{P}_o$. One, of course, needs to calculate the experimental probability to see empty crossings with a real detector.

For a single interaction we define ϵ_0 as the probability to have no hits on the combined East and West modules, and ϵ_1 as the probability to have at least one hit exclusively on only one module (we assume East/West symmetry for now). We then compute the probability to see an empty crossing if there were k interactions, $\pi_o(k)$:

$$\pi_o(k) = 2 \cdot (\epsilon_0 + \epsilon_1)^k - (\epsilon_0)^k \tag{15}$$

This is not simply the one interaction empty crossing probability raised to the k power, $(\epsilon_0)^k$ because that would be an overestimation. For instance if we have two interactions in which the first one hits the West but not the East and the second one hits the East but not the West, the experimental result is a non-empty interaction, even if there were two empty ones.

The full probability to detect and empty interaction when the average number of interactions is μ is then obtained by summing over the Poisson distribution with mean μ but with weights given by eq. 15. We obtain:

$$P_o^{exp} = \sum_{k=0}^{\infty} \mathcal{P}_k(\mu) \cdot \pi_0(k) = (2e^{\epsilon_1 \cdot \mu} - 1) \cdot e^{-(1-\epsilon_0)\cdot\mu} \tag{16}$$

Note that equation 16 reduces to eq. 13 for a CLC with 100% acceptance. Also, in the low luminosity approximation, when $\mu << 1$, we obtain:

$$P_o \stackrel{\beta \to 0}{\to} e^{-\epsilon_\alpha \cdot \mu} \tag{17}$$

Where $\epsilon_\alpha = 1 - \epsilon_0 - 2\epsilon_{1x}$, is the probability of measuring a single interaction, defined by the criteria $\{\alpha\}$ as non-empty. This would be the same ϵ_α that goes into equation 11 above. Note that for a detector with only one module, or if no East-West coincidence requirement was made, $\epsilon_1 = 0$.

3.2 "Collision" and "hit counting" definitions

3.2.1 Online

Online we have real-time access for luminosity calculations to the signals coming out of the L1 trigger output of the ADMEM boards [4]. We've re-programmed the Xilinx chips on the ADMEM such that the "trigger" signals contain bits that represent the number of hits, per four channel group, in the counters.

A hit is counted if the number of ADC counts, after the CAFE card digitization, is above a fixed, pre-set, threshold, A_o in the Xilinx program. A collision is considered to have occurred if one or more hits are registered on both East and West CLC modules. We initially set the thresholds at 500 ADC counts and later changed to 250 to compensate for the lower PMT gains (see Appendix A).

These data is clocked into Dual Port Memories at the frequency of the CDF clock (132 ns) and a program running standalone in a dedicated 6U VME crate sorts through this memory and calculates luminosity. There is no timing requirement for a collision except that there is a coincidence of one or more hits in the East and West modules within the 132 ns gate.

3.2.2 Offline

Offline we have access to both the timing and the amplitude information in the CLC counters to establish the criteria $\{\alpha\}$ that a collision ocurred.

We define a collision by requiring the following:

- At least one PMT per East/West side with start times $960\ ns < t_{i,j} < 977\ ns$ and with amplitude above a certain threshold $A_{i,j} > A_o$.
- At least one pair of PMT's (one on each side) with start times: $|t_i - t_j| < 8\ ns$

Note that in order for a hit to register a time its amplitude needs to be above the discriminator threshold in the transition board. Initially, for the runs discussed here, we set these thresholds to 10 mV, corresponding to approx. 250 ADC counts ($\sim$ 25 photo-electrons) [5]. When the PMT gains dropped due to Helium contamination (see Appendix A) we lowered the discriminator thresholds to 8.3 mV A_o can be chosen arbitrarily, but should be higher or equal to the amplitude needed to register timing information and lower or equal to the amplitude A_1 above which one decides to count hits offline. Offline we can reproduce the online measurements by setting $A_1 = A_o$.

Figure 1 shows the start time vs. channel and the start time distribution for all CLC channels for one of the 36x36 stores on April 27th, 2001 (inst. lum $\sim 5 \times 10^{29}$. The data in between the lines are the events selected as collisions. In the lower right plot (log scale) we can see events due to losses and satelite bunches. These amount to a fraction of a percent of the total.

Figure 2 shows the time differences between East and West PMT's for those channels with times in between 960 and 977 ns. This is for run 119333, with the T0 corrections shown in Fig. 3.

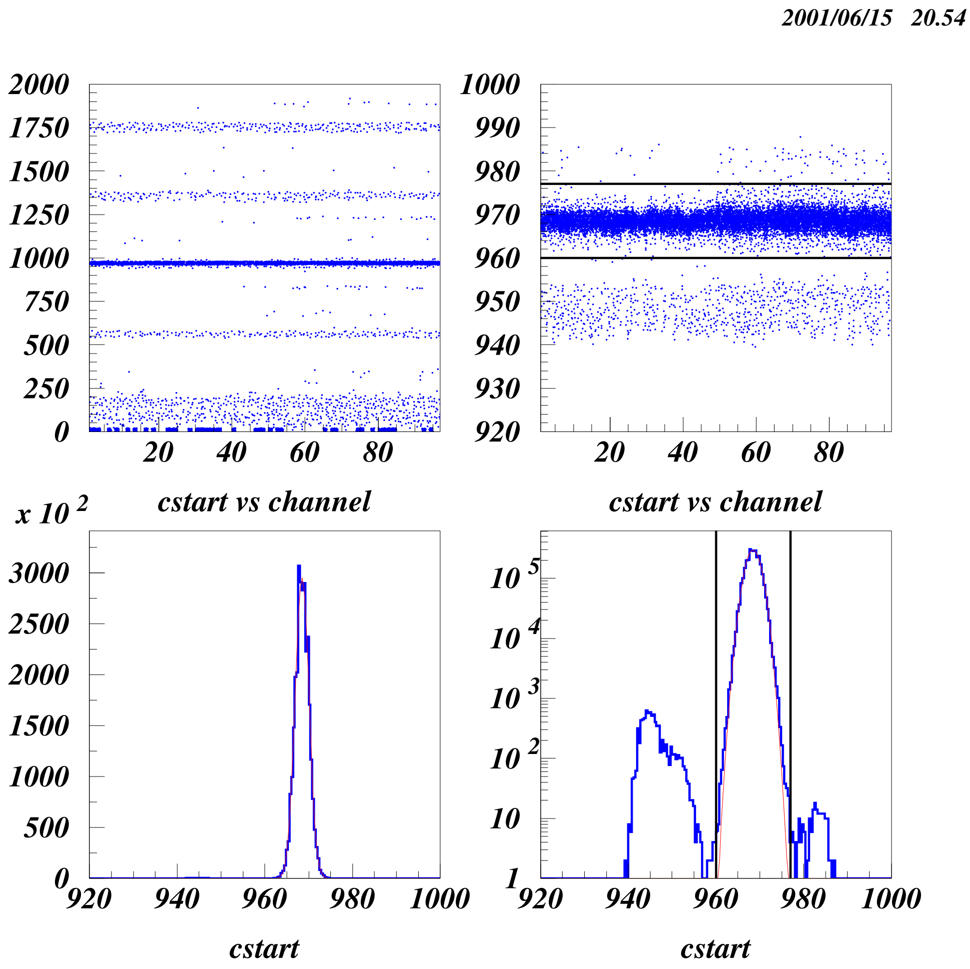

Figure 1: Start time vs channel number (top plots) and start times (bottom plots). The lines show the selection used to define a "collision".

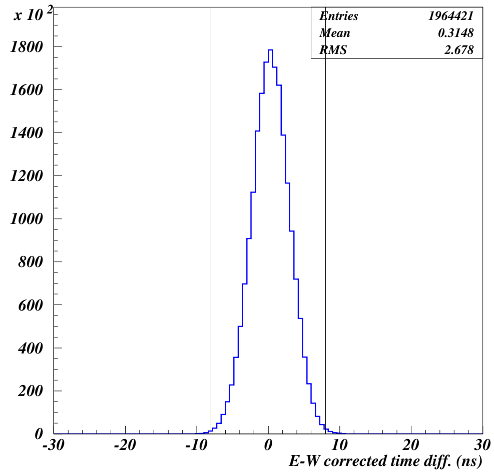

Figure 2: E-W T0 corrected time differences to determine “collisions”.

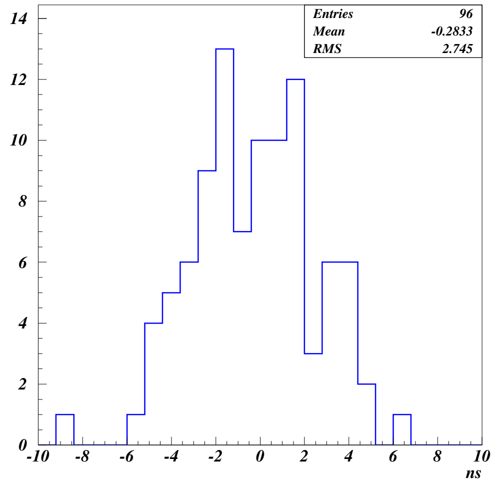

Figure 3: T0 corrections for July 3rdm 2001

To count hits offline we first fit the single particle peak, channel by channel, and then rescale the ADC amplitude distribution into units of “single particle peaks” or **spp**. We then count a hit in a particular channel if the amplitude is above a chosen percentage of the single particle peak.

3.3 A look at the data during April, 2001

Even though we started providing official luminosity numbers on Aug 8th, 2001 (see [**?**]) here we first take a quick look at **“zero bias”** data taken during the 36x36 store on April 27th. These data was taken before the PMT gains started to drop and it is important to document it here for future reference.

The CLC operation conditions were the following:

- The pressure was about $3.2PSI$ in the East module and $3.5PSI$ in the West module. Uncertain to ± 0.05.
- The nominal gains were approximately 4×10^5 for all PMTs (see Fig. 4).

Fig. 5 shows the instantaneous and integrated luminosity (delivered and live) for that store as measured by the standalone online CLC DAQ (more on this in a later section).

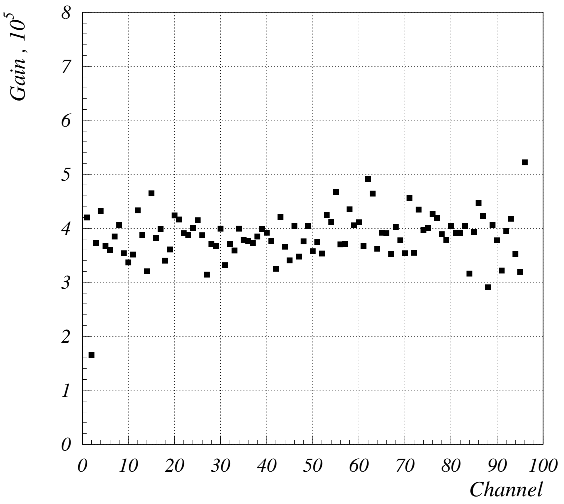

Figure 4: CLC PMT gains, per channel, for April 26th, 2001.

- <u>Measurement of $< N_H^1 >_\alpha$ and crude estimate of ϵ_α</u>

We first selected events that satisfy our collision definition. Then a set of different thresholds is applied to calculate the average number of hits per such interaction. Due to the luminosity being so low ($< L_{inst} >\sim few 10^{29}$ cm^{-2}s^{-1}) every crossing with collisions will have only single collisions.

Figures 6,7, and 8 show the hit multiplicity distributions for the West, the East, and the combined East and West modules, for various thresholds.

For a threshold of 75% of the single particle peak we find that:

$$< N_H^1 >_\alpha = 16.3 \pm \sim 0.4 \tag{18}$$

We notice that the zero bin in the first figure of 6 and 7 can be used to estimate the CLC acceptance for hits at this low threshold and therefore to estimate the acceptance

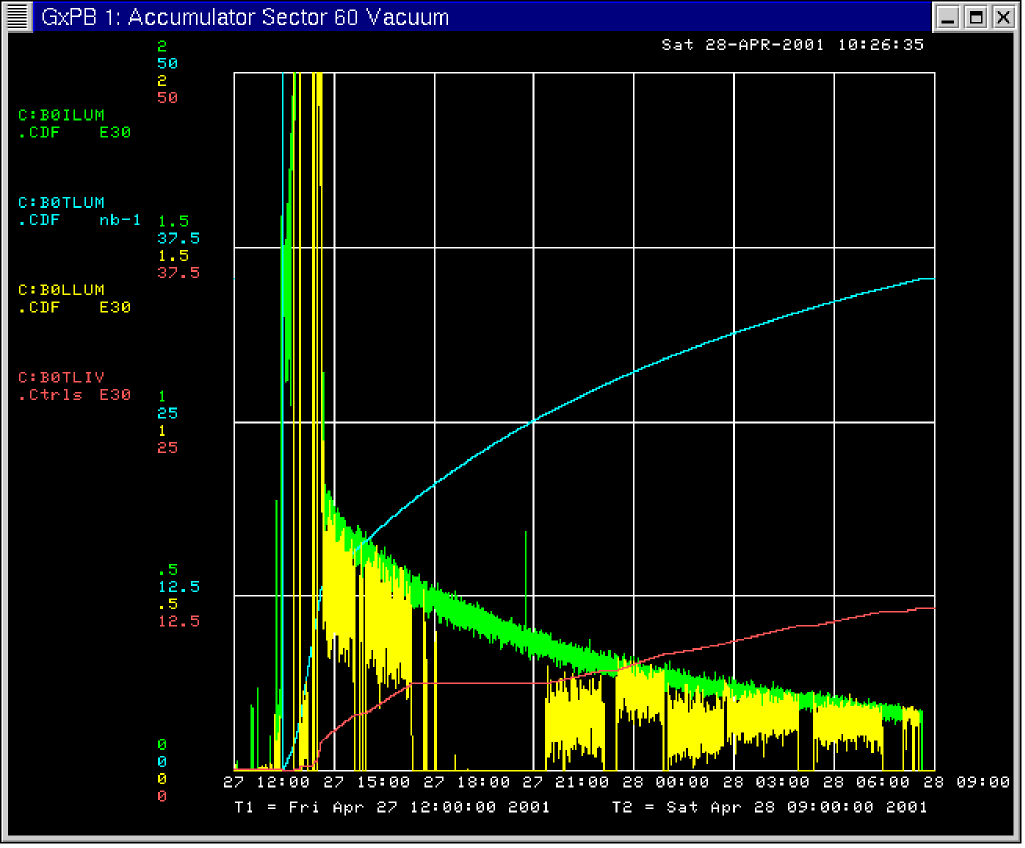

Figure 5: Online luminosity on ACNET for the 36x36 store in April 27th. The green trace is the instantaneous delivered luminosity, the yellow trace is the live instantaneous luminosity seen by CDF. The delivered and live integrated luminosities are given by the blue and red rising traces, respectively.

for the collision definition that we've adopted here. Assuming that the zero bin is not terribly discontinuous with the "1 hit" bin (not an unreasonable physical assumption) we can imagine it having somewhere between 10 and 50 entries. The mid range is 30 entries, which is approximately 5% of the 656 total entries in the histogram. So the single module acceptance would be 95(±3)%. Assuming the East/West acceptances are uncorrelated, the probablility of having hits in both modules would be between 83% and 96%. We can conclude that, from te data, the CLC acceptance for inelastic interactions is therefore $\epsilon_\alpha(data) \sim 90(\pm 6)\%$.

We can therefore calculate ϵ_α from:

$$\sigma_\alpha^{CLC}(data) = \sigma_{in} \cdot \epsilon_\alpha(data) \approx 54 \pm 4 \text{ mb} \tag{19}$$

Of course, this assumes that all inelastic interactions, including diffractive processes, have the same acceptance. We can take the other extreme, in which diffractive processes have zero acceptance. Then

$$\sigma_{\alpha}^{CLC}(data) = \sigma_{hc} \cdot \epsilon_{\alpha}(data) \approx 39 \pm 3 \text{ mB} \tag{20}$$

So approximately:

$$39 < \sigma_{\alpha}^{CLC}(data) < 54 \text{ mb} \tag{21}$$

The lower limit should be closer to the real cross section because, as we show in a later section, the diffractive processes have indeed significantly smaller acceptance than the hard-core.

The equivalent cross section for the BBC counters was measured to be [6]:

$$\sigma_{\alpha}^{BBC} = \sigma_{tot} \cdot \epsilon_{\alpha} = 51.1 \pm 1.7 \text{ mB} \tag{22}$$

Fig. 9 shows how the average number of hits, as a function of threshold, compares between the West and the East CLC modules. It also shows the dependance on threshold for for the combined hit counting.

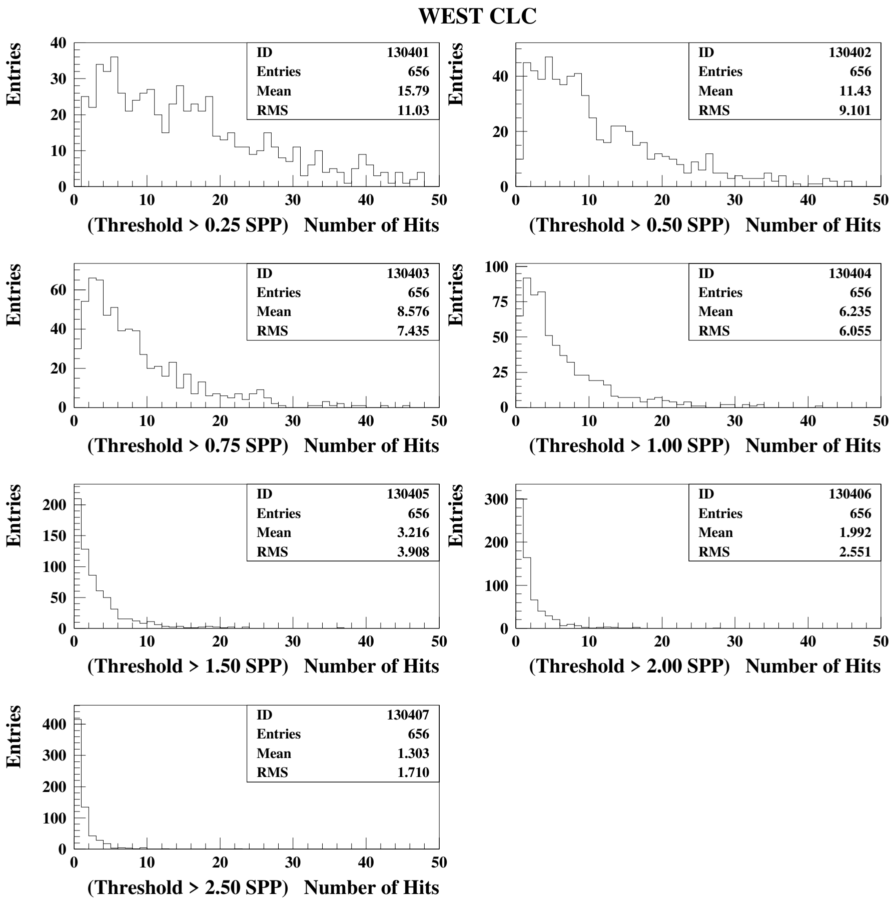

Figure 6: West CLC hit distributions for various thresholds (in units relative to the single particle peak or spp) - Apr. 2001

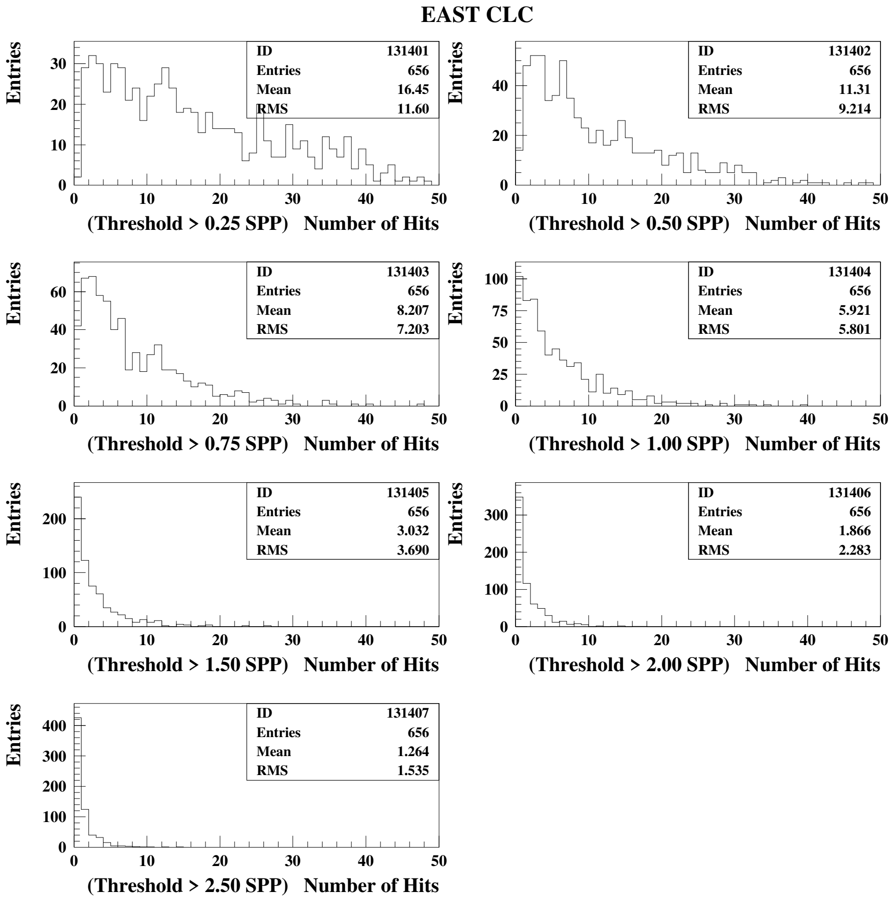

Figure 7: East CLC hit distributions for various thresholds (in units relative to the single particle peak or spp - Apr. 2001)

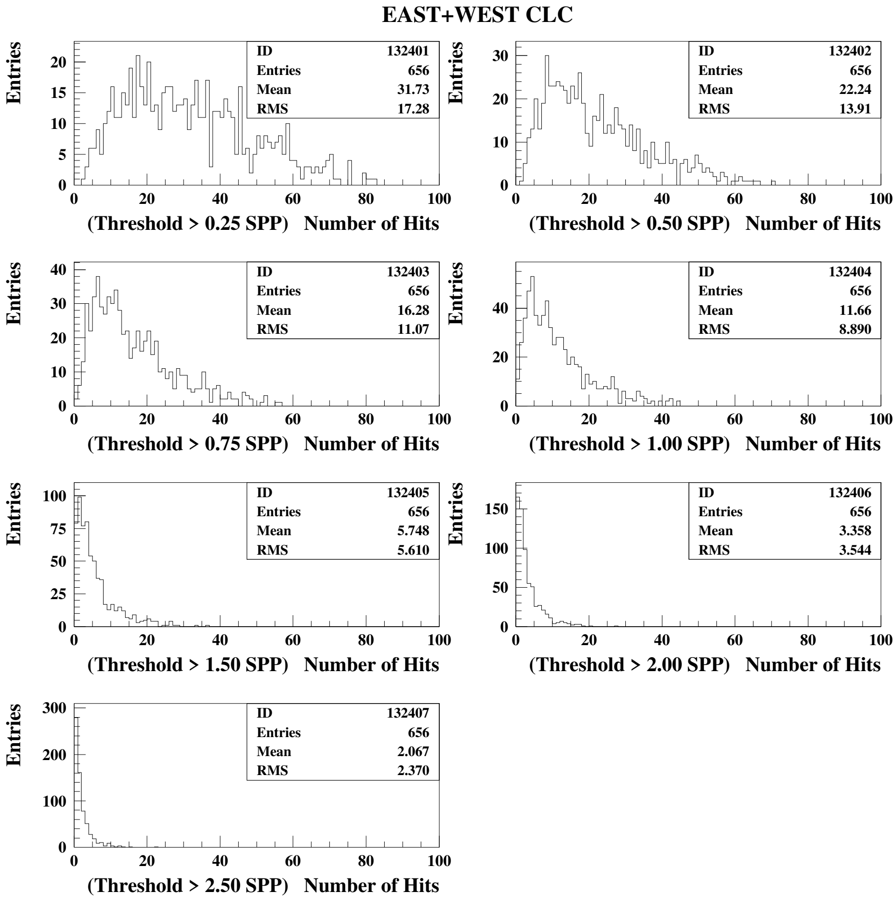

Figure 8: East plus West CLC hit distributions for various thresholds (in units relative to the single particle peak or spp) - Apr. 2001

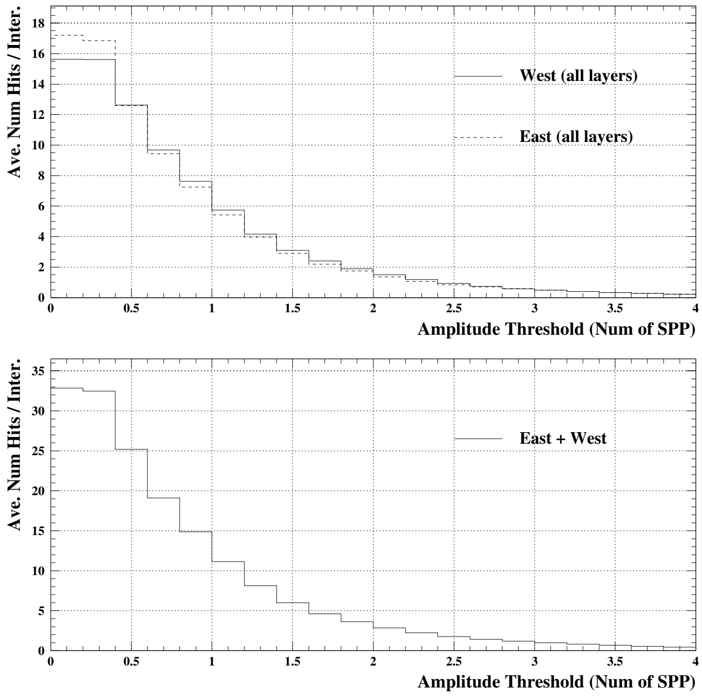

Figure 9: Top plot: Average number of CLC hits in the East vs. West CLC modules, as a function of threshold (in spp units). Bottom plot: Avg. number of hits vs threshold for the combined East and West modules - Apr. 2001

- First luminosity results

Having estimated ϵ_α and measured $< N_H^1 >_\alpha$, all from data, we were able to estimate the luminosity for the runs during the April 2001 period.

The uncertainty of the results, the first real measurements we attempted, was estimated to be of the order of $\pm 20\%$ and dominated by the uncertainty of the absolute normalization.

In the following section we discuss how we've proceeded to improve the uncertainty on the absolute normalization by determining ϵ_α as best as possible from Monte Carlo and from data.

3.4 The CLC acceptance to inelastic collisions

In order to reduce the uncertainty of the luminosity absolute normalization we need to understand as best as possible the CLC acceptance for inelastic collisions. For this we need an accurate simulation that reproduces well the various aspects of the data that are relevant for the luminosity measurement.

In trying to estimate ϵ_{CLC} as accurately as possible we follow two strategies:

- Get ϵ_{CLC} from Monte Carlo simulations alone.
- Get from real, zero-bias, data the CLC acceptance relative to a "large acceptance" detector and use the Monte Carlo to determine "large acceptance" to inelastic interactions.

Below we discuss these two approaches.

3.4.1 ϵ_{CLC} from CLC simulations alone

Not until sometime in December, 2001, we were able to have a simulation that matched the data well enough [7]. This was due to missing material related to the silicon systems (such as cables and pipes) and due to a non accurate implementation of the details of the beam-pipe. This was fixed and we now have fairly good matching distributions. Work is ongoing trying to obtain an even better match and help reduce the systematics further. Here we summarize the studies we've done so far and the sources of systematics we've come up with. Details of these studies can be found in [8]

There are many parameters that drive the MC and the simulation that affect the comparison. Table 2 shows the "baseline" parameters used in the comparison between data and simulation in the plots that follow.

Parameter	Value used
Generator:	MBR
Hard-core x-section	44.54 ± 1.3 mb
single diff x-section	10.3 ± 0.5 mb
double diff x-section	7.0 ± 0.5 mb
Interaction z-profile Gaussian width:	= 30.0 cm
Beam offset in x, y:	= 0.0 cm in x and 0.0 cm in y
Belows beam-pipe thickness:	0.05 cm
Isobutane index of refraction:	= 1.00221 (22.5 psi)
CLC mylar walls reflection coefficient:	= 0.8
PMT quantum efficiency:	= 0.27 (specs curve)
Treshold to count hits in a collision:	= 250 ADC counts
Single particle peak matching to data?	yes

Table 2: Baseline MC simulation parameters

what data did we use here ???????????

Fig 10 shows the comparision between data and simulation for the amplitude distribution in a counter from particles from collisions. We see that the long tails, corresponding to multiple particles traversing the counter, are well matched. This was not the case when we did not have the right material in the simultion. Fig. 11 shows the same distribution on a linear scale.

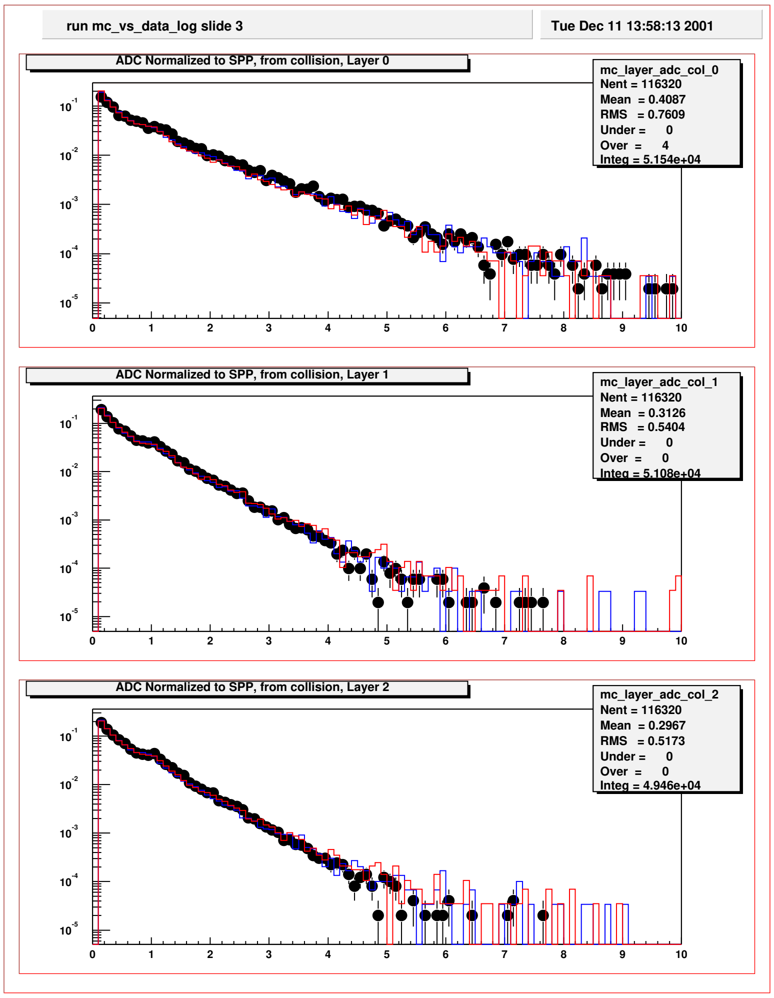

Figure 10: Data vs. simulation: amplitude distributions in the CLC counters. Dots are simulation, red and blue are West and East sides, respectively.

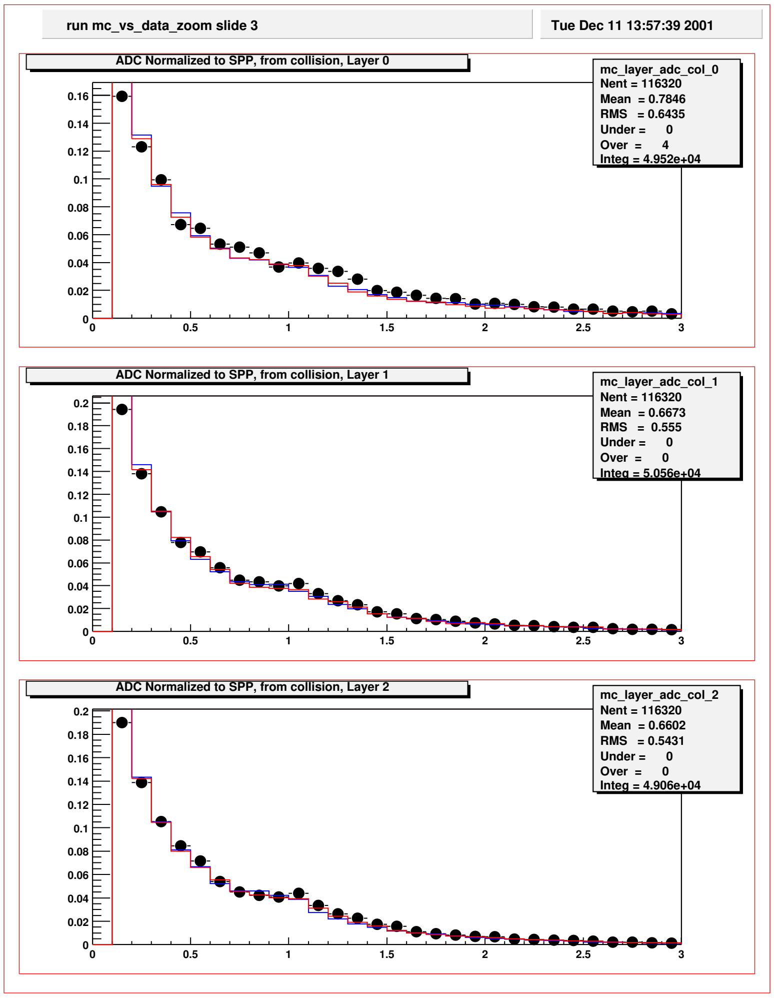

Figure 11: Data vs. simulation: amplitude distributions in the CLC counters. Dots are simulation, red and blue are West and East sides, respectively.

Figs. 12,13 show the dependance on the average number of hits in the CLC vs. the hit counting threshold. We see good agreement although some remaining discrepancies are still evident. Fig. 14 the ratio of simulation over data for the avg. number of hits as a function of threshold. Figs. 15 and 16 show the same but for the West and East modules, separated by layers.

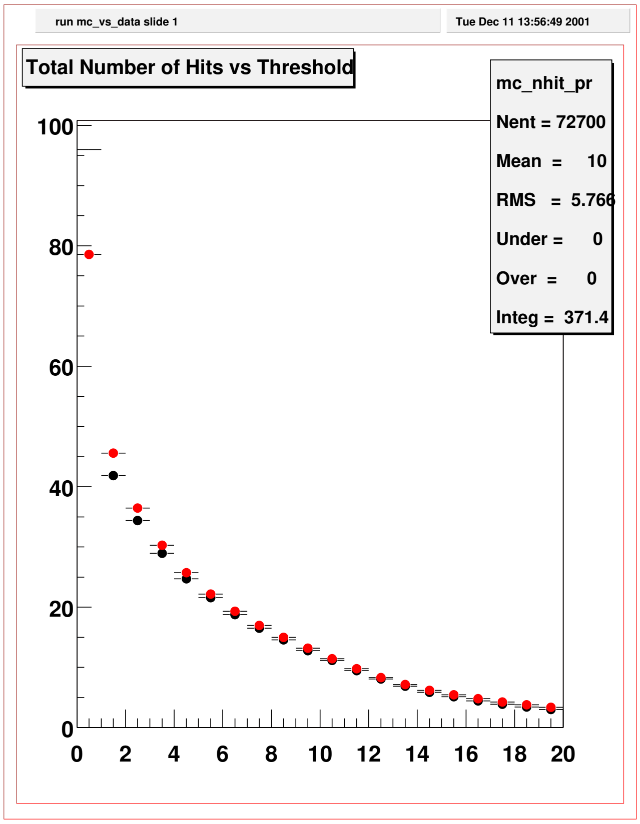

Figure 12: Data vs. simulation: Average number of CLC hit vs. the hit counting threshold. Dots are simulation, red and blue are West and East sides, respectively.

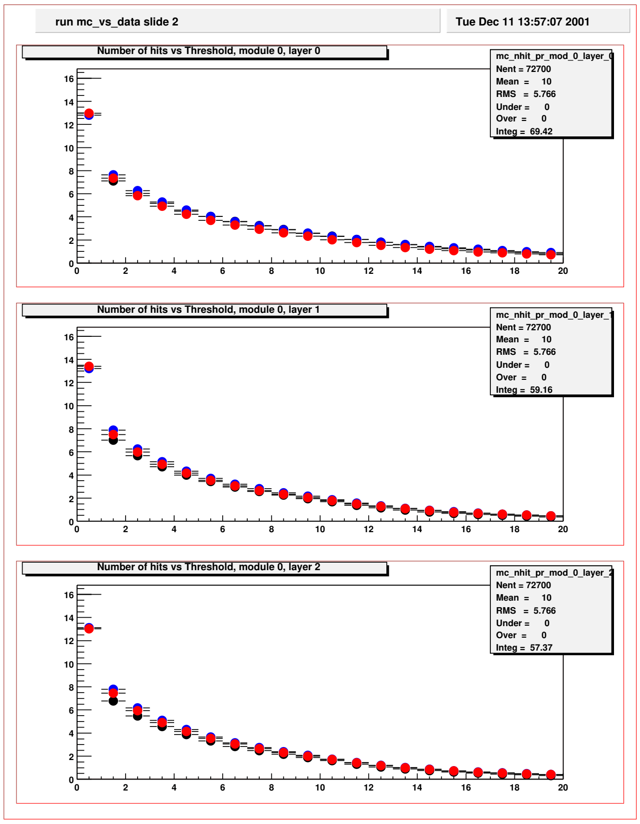

Figure 13: Data vs. simulation: Average number of CLC hit vs. the hit counting threshold. We show the three CLC layers separately. Dots are simulation, red and blue are West and East sides, respectively.

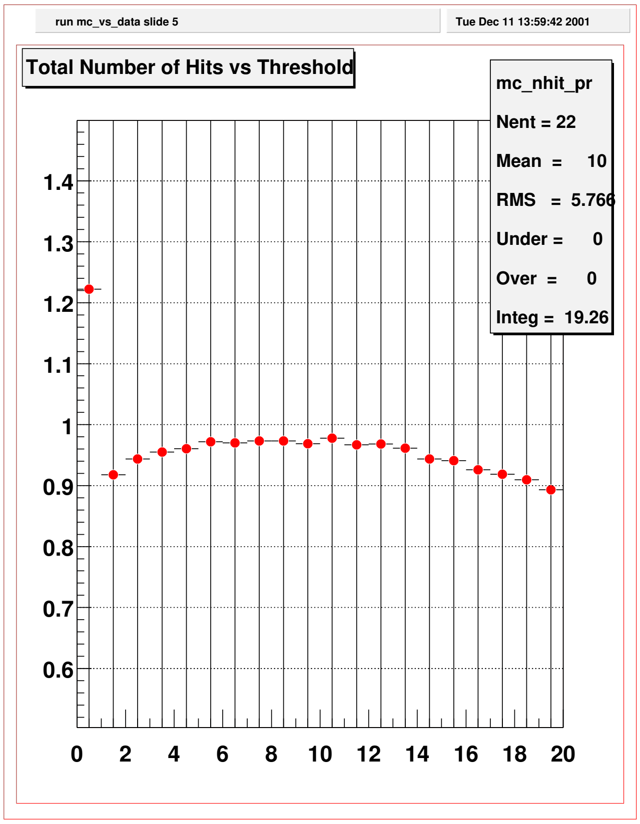

Figure 14: Data vs. simulation: Ratio of simulation over data for the avg. number of hit vs. threshold. The units on the x axis need to be divided by 10 in order to get "fraction of single particle peak".

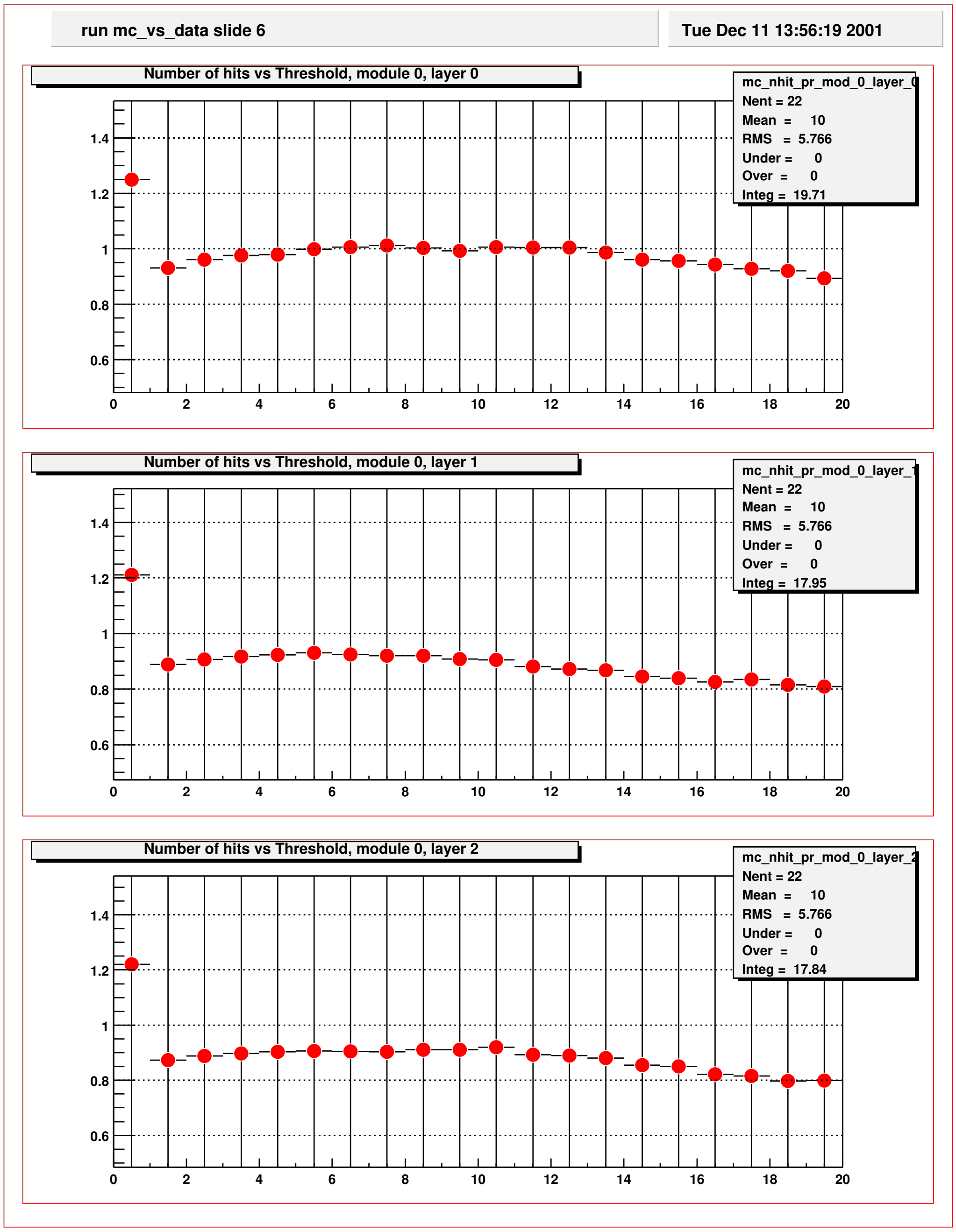

Figure 15: Data vs. simulation: Ratio of simulation over data for the avg. number of hit vs. threshold for the West CLC, by layer. The units on the x axis need to be divided by 10 in order to get “fraction of single particle peak”.

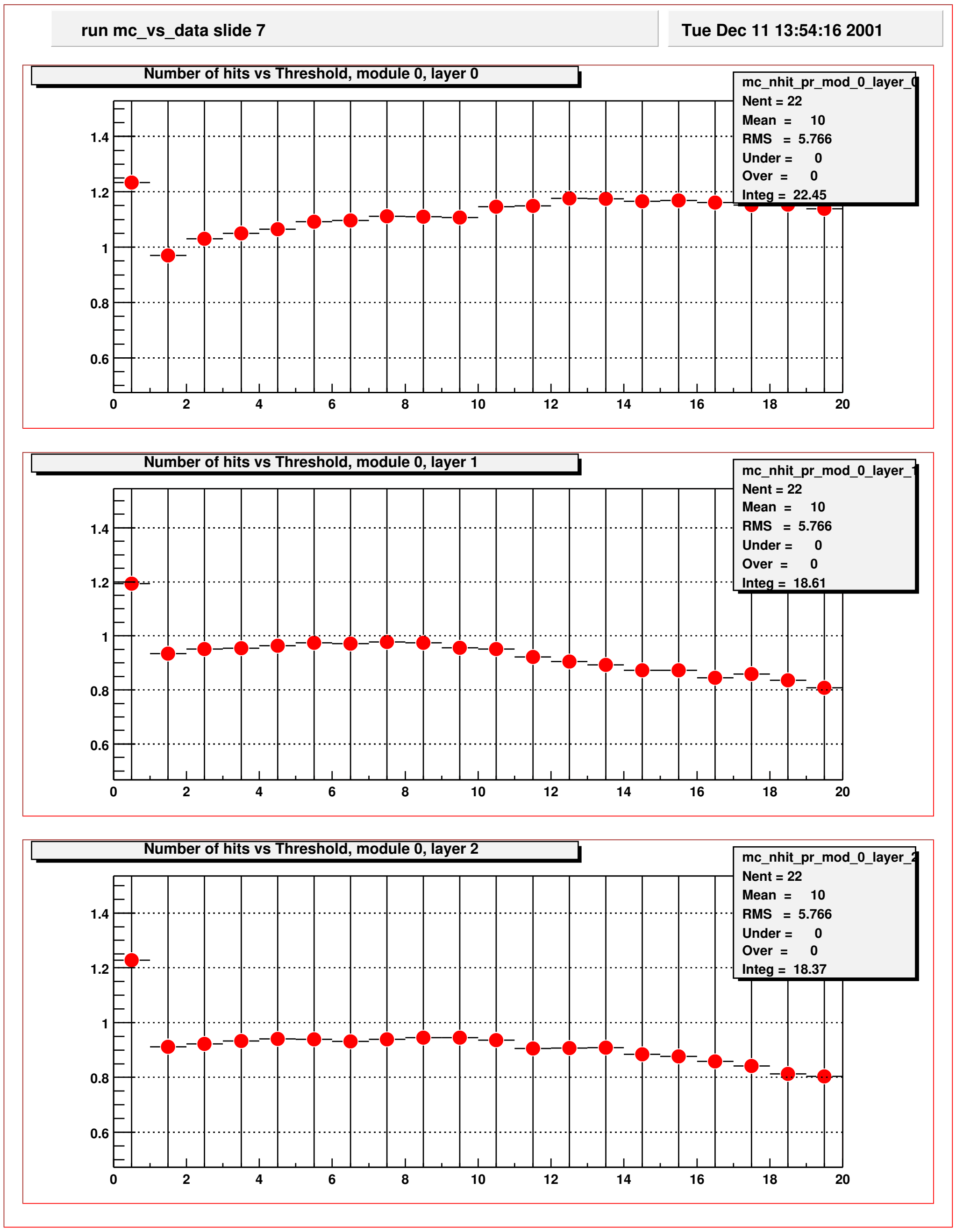

Figure 16: Data vs. simulation: Ratio of simulation over data for the avg. number of hit vs. threshold for the East CLC, by layer. The units on the x axis need to be divided by 10 in order to get "fraction of single particle peak".

Of course, the plots of avg. number of hits vs. threshold do not describe the full story. Fig. 17 shows the actual distributions from which these averages were taken. It is important that these distributions match well and we are getting closer.

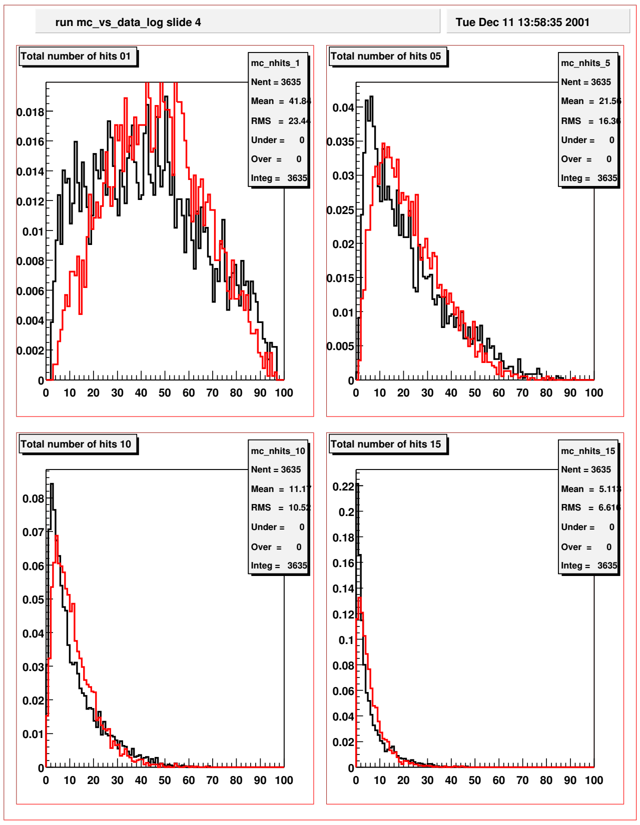

Figure 17: Data vs. simulation: Hit multiplicity distributions for simulation (black) and data (red) for hit counting thresholds of 10%, 50%, 100% and 150% - clockwise from top left.

Fig. 18 shows the hit multiplicity distribution comparison between data and simulation with only the “hard-core” part of the inelastic cross section included. We see an even better match. Part of the work that remains to be done is to tune the simulation, both in terms of material and in terms of the different components of the inelastic cross section in order to match the data as best as possible.

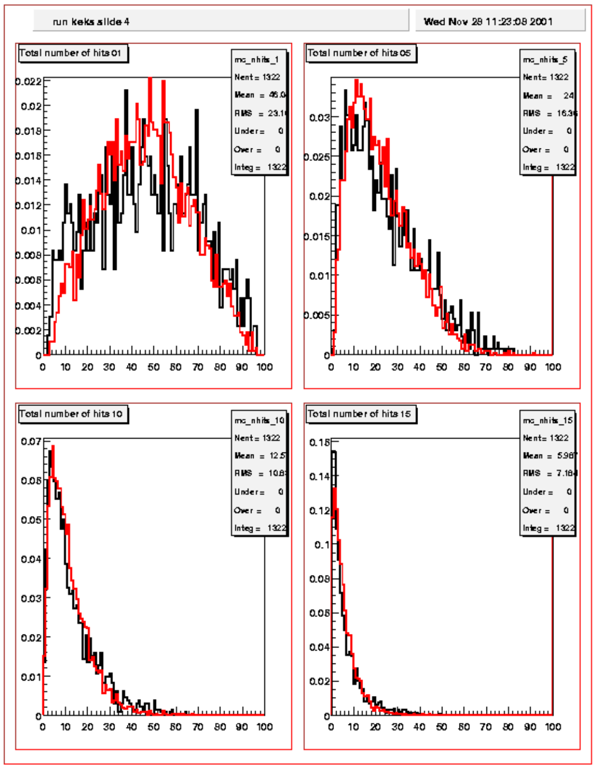

Figure 18: Data vs. simulation (“hard-core” interactions only!): Hit multiplicity distributions for simulation (black) and data (red) for hit counting thresholds of 10%, 50%, 100% and 150% - clockwise from top left.

Still, the figures above show that have a simulation that reproduces well the low luminosity data and we can proceed and estimate, with the appropriate systematic uncertainties, the CLC acceptance for a collision and therefore the CLC effective cross-section σ_{α}^{CLC} from equation 3.

For the "baseline" simulation and defining a collision as one or more hits above 250 ADC counts per side, in coincidence, we find:

$$\sigma_{\alpha}^{CLC} = 0.597 \pm 0.007 \quad and \quad < N_H^1 >_{MC} = 14.6 \pm 0.2$$

The uncertainties are statistical only. Table 3 show the results for the various other cases we studied. **The full spread is only 3%** with the baseline being close to the mean.

Case	Acceptance	Avg. num hits
Baseline	0.597 ± 0.007	14.6 ± 0.2
Change mean z beam	0.602 ± 0.007	14.4 ± 0.2
Change x, y beam offset	0.603 ± 0.007	15.4 ± 0.2
Beam z width=27 cm	0.596 ± 0.007	14.5 ± 0.2
Beam z width=33 cm	0.592 ± 0.007	14.6 ± 0.2
No beam-pipe sleave	0.587 ± 0.007	14.1 ± 0.2
Change mylar reflection	0.609 ± 0.007	14.8 ± 0.2
Change PMT quantum eff.	0.598 ± 0.007	14.9 ± 0.2

Table 3: The CLC acceptance and avg. number of hits for a single $p\bar{p}$ interaction, for various simulation cases.

- Systematics due to SPP measurement

The results above have been obtained by measuring, channel by channel, the single particle peak (spp) in the data and adjusting the MC simulation such that each channel has the same gain as the real detector. The spp is measured by selecting events in which the adjacent pmt's to the one that is being studied have very little light on them ("isolation"), in such cases the single particle peak is visible and a gaussian plus exponential (for the background) fit can be made. The uncertainty in this fit, which was found to be $\pm 3\%$ [?] can then be used to understand the effect on the CLC acceptance. Fig. **??** shows the change in acceptance as a function of changing the spp for all PMTs together. We see that a 3% change results in about a 1% change in acceptance. This is clearly an over-estimate since the uncertainties in the spp fit for all channels are not 100% correlated. For now, we conclude that the spp fit has a $< 1\%$ effect on the acceptance.

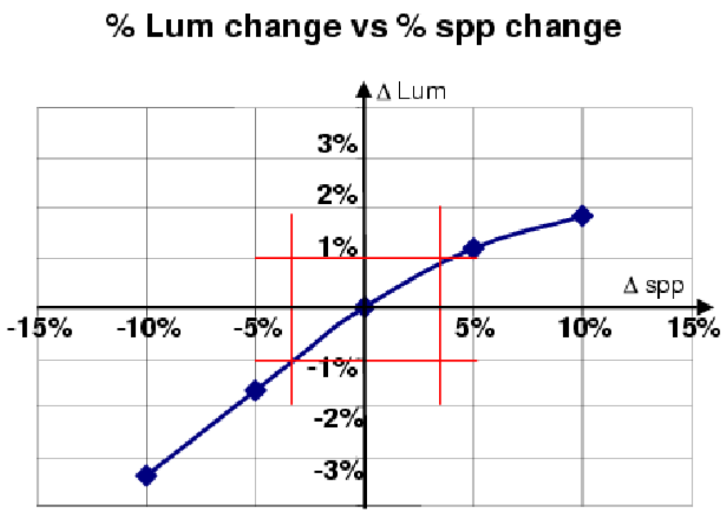

Figure 19: Systematics due to spp fit.

3.4.2 Summary of uncertainties in the CLC acceptance from MC alone

Since each of these effects studied above can in principle be uncertain independently we've grouped them by category in table 4 and computed the total in quadrature. We obtain that the total systematic uncertainty is 3.2%. There is additional evidence that this is a reasonable number. Previous simulations in the past had the amount of material significantly wrong and the effect on the CLC acceptance was relatively contained. For example, at some point the beam-pipe thickness (the "bellows" pipe) was approximated to 0.027 cm, instead of the baseline 0.050, and the number of hits was significantly lower than the data even after we added, artificially, material in front of the CLC (see Figs. **??**. However the acceptance was only 6% smaller. We also had, at some point, no flanges and the material due to the silicon was severly underestimated. Again, the acceptance was lower only by 5%. Since our simulation is now much better matched to the data, these variations would be considered way too large.

We still think that the measurement of these uncertainties can be improved upon after more studies and that the numbers quoted in the studies here reflect a realistic uncertainty.

??? point out that this is for the 2 layer blah blah, maybe early on say that for the period xxx we used 2 layers...???

We can also estimate other acceptances. The results are in table (5 and we use the following definitions:

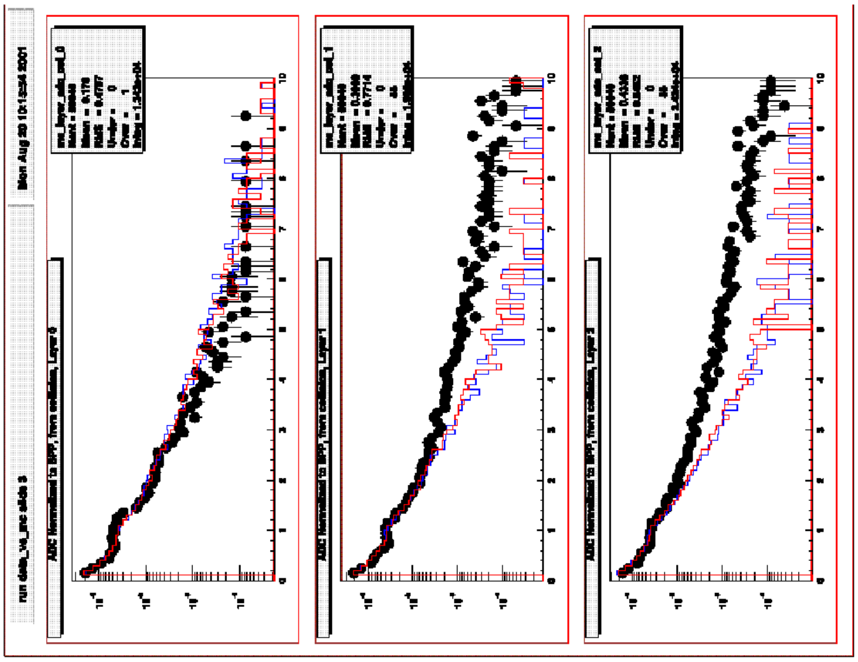

Figure 20: Amplitude distributions, data vs. simulation, for wrong material.

- ϵ_α = prob. to have an east-west hit coincidence.
- ϵ_0 = prob. to have zero hits above threshold on both modules combined.
- ϵ_{1x} = prob. to have at least one hit in only one of the CLC modules.

We present the acceptances separately for each of the inelastic cross section components.

- **Dmitri and Jim, can you fill these in?**

Systematic	% effect on CLC acceptance
Beam parameters	$\pm1\%$
Geometry material	$\pm2\%$
Min. bias generator	$\pm2\%$
Single particle peak	$\pm1\%$
Total ϵ_{CLC} uncertainty	$\pm3.2\%$

Table 4: Summary of systematic uncertainties for the CLC aceptance.

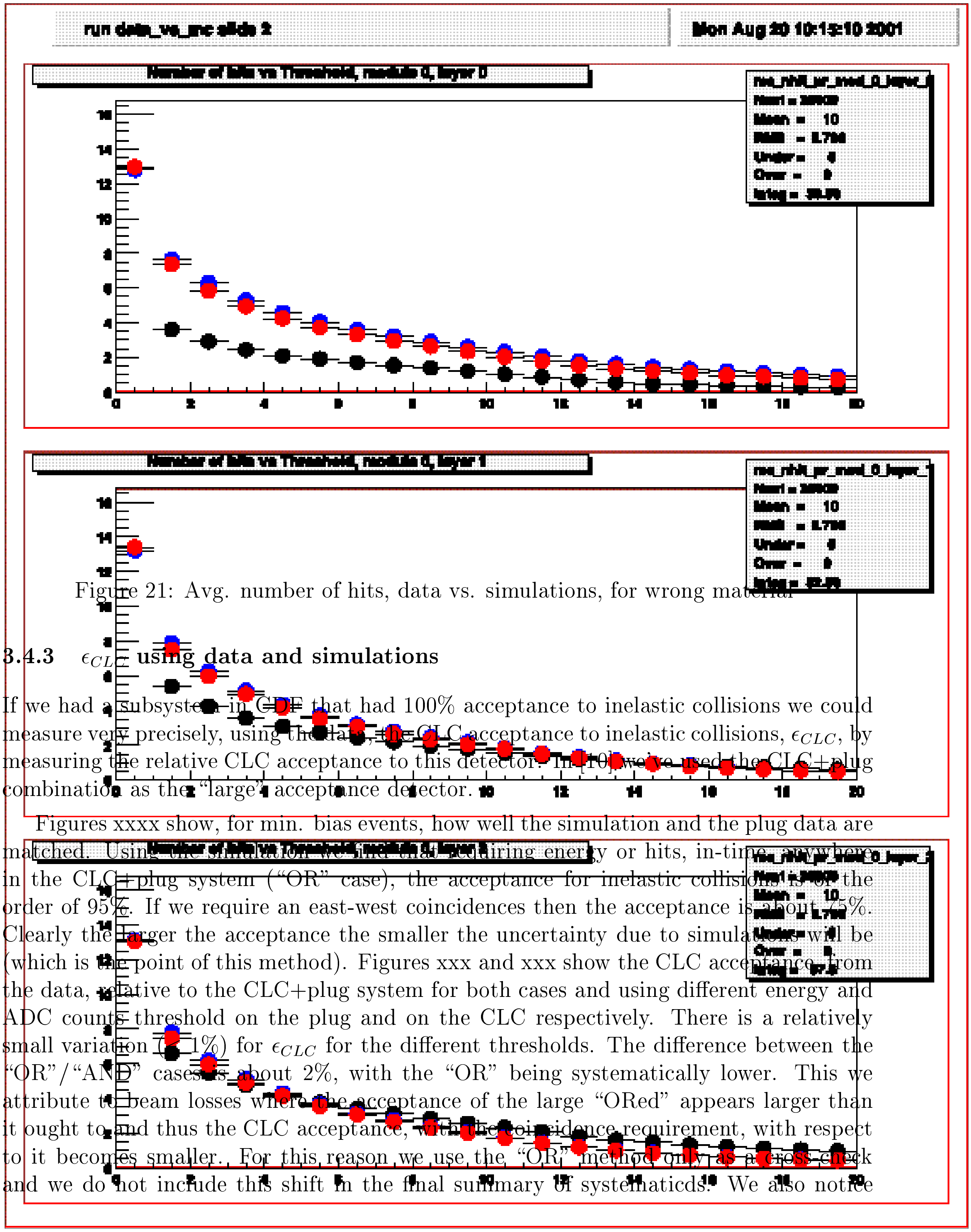

Figure 21: Avg. number of hits, data vs. simulations, for wrong material

3.4.3 ϵ_{CLC} using data and simulations

If we had a subsystem in CDF that had 100% acceptance to inelastic collisions we could measure very precisely, using the data, the CLC acceptance to inelastic collisions, ϵ_{CLC}, by measuring the relative CLC acceptance to this detector. In [10] we've used the CLC+plug combination as the "large" acceptance detector.

Figures xxxx show, for min. bias events, how well the simulation and the plug data are matched. Using the simulation we find that requiring energy or hits, in-time, anywhere in the CLC+plug system ("OR" case), the acceptance for inelastic collisions is of the order of 95%. If we require an east-west coincidences then the acceptance is about 75%. Clearly the larger the acceptance the smaller the uncertainty due to simulations will be (which is the point of this method). Figures xxx and xxx show the CLC acceptance from the data, relative to the CLC+plug system for both cases and using different energy and ADC counts threshold on the plug and on the CLC respectively. There is a relatively small variation ($\approx 1\%$) for ϵ_{CLC} for the different thresholds. The difference between the "OR"/"AND" cases is about 2%, with the "OR" being systematically lower. This we attribute to beam losses where the acceptance of the large "ORed" appears larger than it ought to and thus the CLC acceptance, with the coincidence requirement, with respect to it becomes smaller. For this reason we use the "OR" method only as a cross-check and we do not include this shift in the final summary of systematicds. We also notice

Process	% prob. 2L 25% spp	% prob. 3L 25% spp	% prob. 2L 50% spp	% prob. 3L 50% spp	% prob. 2L 75% spp	% prob. 3L 75% spp
ϵ_{α}^{hc}	~ 90	$\sim xxx$	-	-	-	-
ϵ_{0}^{hc}	???	???	-	-	-	-
ϵ_{1x}^{hc}	???	???	-	-	-	-
ϵ_{α}^{d}	~ 10	???	-	-	-	-
ϵ_{0}^{d}	???	???	-	-	-	-
ϵ_{1x}^{d}	???	??	-	-?	-	-
ϵ_{α}^{dd}	~ 30	???	-	-	-	-
ϵ_{0}^{dd}	???	???	-	-	-	-
ϵ_{1x}^{dd}	???	???	-	-	-	-

Table 5: The CLC acceptances, from simulation.

that there is a small store-to-store variation for the “AND” method, ¡2% for the stores studied so far. We conservatively assign a 3% uncertainty to the CLC acceptance using this method. We therefore obtain:

$$\epsilon_{CLC} = 0.61 \pm 3\%$$

This result is very consistent (although quite correlated) with those described above using the CLC simulation alone ($\epsilon_{CLC} = 0.597$) and show that a small systematic on the acceptance is possible. Here, and until more studies are performed, we set the uncertainty at the 3% level. This is consistent with the 3.2% uncertainty from the CLC alone method and we therefore conclude, for now, that 3.2% is a reasonable number.

??? figure showing plug data and sim ???
??? figure showing

3.5 Avg. number of hits per interaction from the data

Fig. 22 shows, for a store in September, 2001, the dependance of $< N_H^1 >$ on the instantaneous luminosity. From here we can try to estimate its value at the lowest luminosities, which would correspond to cases where only one interaction is present.

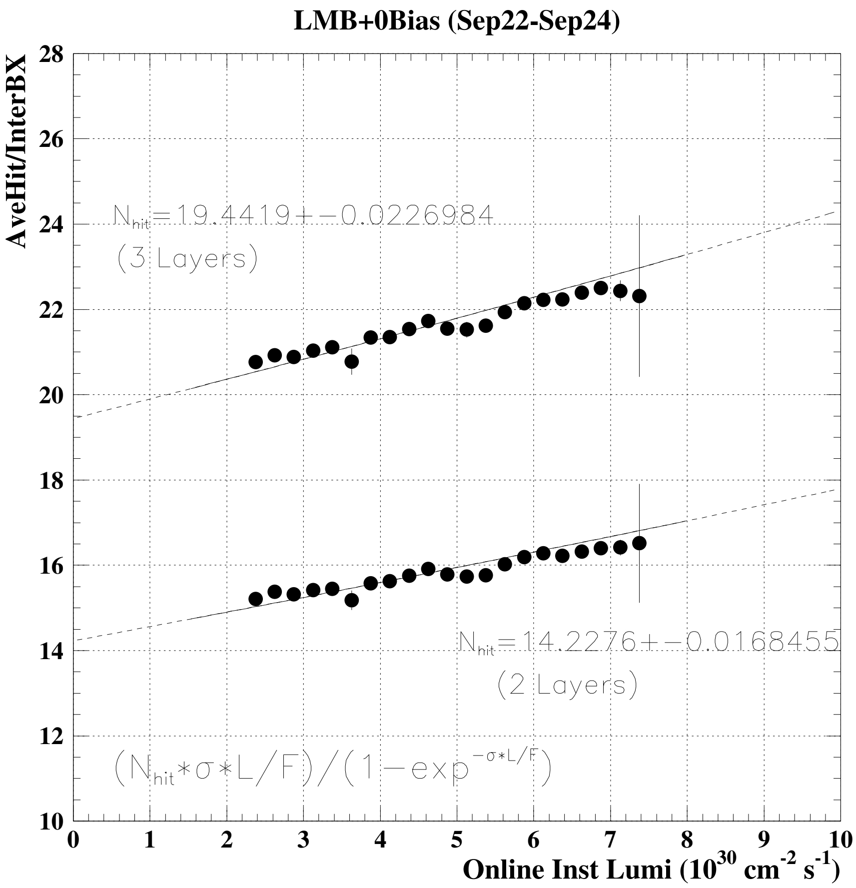

Figure 22: $< N_H^1 >$ from the data....

3.6 Detector Stability

??? discuss the 2% uncertainty due to the detector stability ???

3.7 Online to Offline transfer

??? discuss the 1% uncertainty in the online to offline transfer???

3.8 Luminosity measurements at high luminosity

All the plots shown above comparing the simulation with the data have been for low enough luminosity such that there is very little contamination from multiple interactions. However, the simulation needs to reproduce well the change in the hit multiplicity distributions as a function of the average number of $p\bar{p}$ interactions, μ.

Sasha's work here....

Fig. 23 shows, from the simulation, how the average number of CLC hits varies with the avg. number of $p\bar{p}$ interactions. The error bars represent the r.m.s. of the distributions. We can see that the relation is quite linear up to about 4 interactions on avg. per bunch crossing. For the $36x36$ configuration this corresponds to a intantaneous luminosity of about 10^{32}. At the highest luminosities the particle counting algorithm is more linear, as shown in Fig. 24.

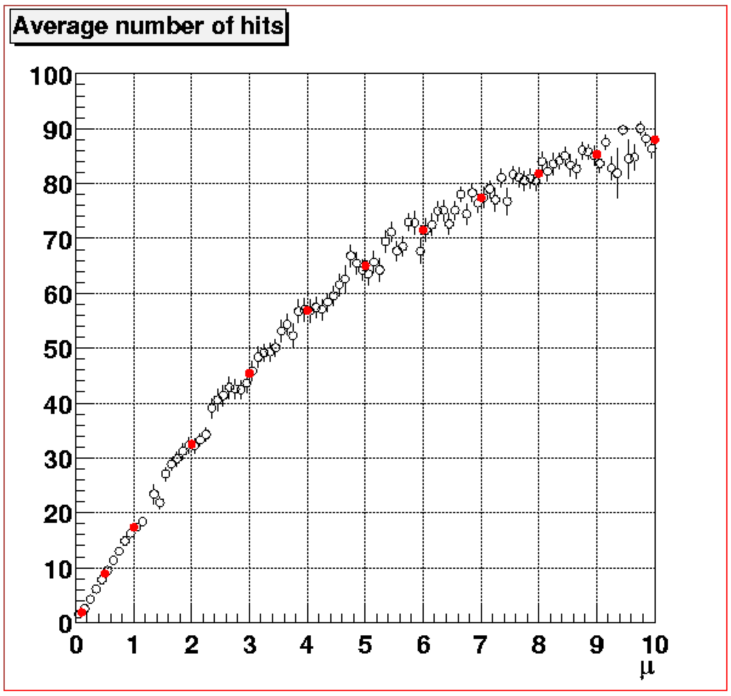

Figure 23: Data (empty circles) vs MC Simulation (filled circles): Avg. number of hits vs. avg. number of $p\bar{p}$ interactions.

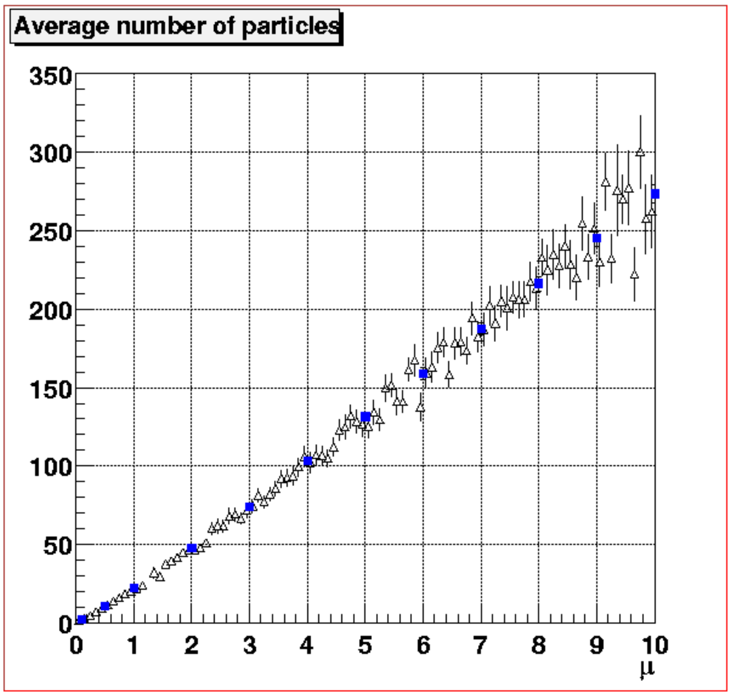

Figure 24: CLC simulation: Avg. number of particles vs. avg. number of $p\bar{p}$ interactions.

xxx put here plot of Nhit for 1,3,5,7,9 interactions all in one plot xxx

3.9 Luminosity for the Aug. 8th to Oct. 6th, 2001, period

In this section we describe the details that went into the calculation of the luminosity for the Aug 8th to Oct 6th, 2001, period. The following deails and other information can be found in our Official Luminosity web page: **http://www-cdf.fnal.gov/internal/people/links/JacoboKonigsberg/lum_official_page.html**.

Procedure:

- Based on the Online "hit counting" measurements done in the standalone CLC 6U crate which are read out into the CLLD bank
- Lummon looks at the CLLD bank for events within 1 run section and takes the difference in live integrated luminosity between the 1st and last event to calculate the total integrated luminosity per run section. This value is then entered into the Online Luminosity column in the CDF II Datafile Catalogue.
- We apply corrections to the Datafile Catalogue Online values, as described below, and fill the Datafile Catalogue Offline values.
- These Offline values are what users should access to calculate their dataset luminosity
- We estimate the uncertainty in the total integrated luminosity for this version to be ±10% dominated by the absolute nromalization. This will be reduced in future versions with better MC simulation and further data studies.

Details on the Online "hit counting method" :

- Used the two CLC outer layers
- Used Xilinx code with 500 ADC counts as the hit counting threshold
- Required at least one hit per CLC module (East/West) in coincidence before counting
- Used the following calculation:

$$\mathcal{L} = \frac{f_{BC}}{\sigma^{CLC}} \cdot \frac{< N_H >}{< N_H^1 >} \tag{23}$$

- f_{BC} is the tevatron's frequency = 36/(159*132 ns) = 1.715 MHz
- $< N_H >$ = measured number of hits in a time period of ?????seconds/periods???

- is the effective CLC cross section for an East-West coincidence (500 ADC counts)
- $< N_H^1 >$ = Avg. number of hits (East+West) in a single p=pbar interaction
- We used the following values for σ^{CLC} and $< N_H^1 >$:
  For $122255 < run < 126686$: $< N_H^1 > = 13.8$ and $\sigma^{CLC} = 36.5$ mb
  For $run >= 126686$: $< N_H^1 > = 16$ and $\sigma^{CLC} = 37.78$ mb

Corrections to the Online measurement:

- Filled gaps for run sections with zero online luminosity due to Lummon failure:
  - If for a given run more than 10% of the runsections in the Online Datafile Catalogue were zero then the Offline value of these runsections is set such that the total run luminosity is in agreement with the ACNET value (taken from the Run Configuration database). This happened for 25% of the runs that had a luminosity greater than 1 nb in ACNET.
  - If less than 10% of the runsections are zero we used a linear interpolation from adjacent non-zero runsections to compute the Offline luminosity for these runsections. If the run starts(ends) with runsections having zero luminosity then these are set to the value of the first(last) non-zero runsection.
- For runs between 122255 and 126686 (between July 31st, 2001 and Sept 14th, 2001) we had an effective cross section such that the Online luminosity was measured 20% higher than it should have been:
  - We multiplied the Online Data catalogue values by 0.83 for these runs
- Correction due to CSL not sending all events to Lummon. Lummon needs the first and last event of a runsection to calculate the full integrated luminosity. The CSL in many cases does not send these events and on average Lummon underestimates the luminosity by 2%.
- Correction due to PMT gain drift between Sept 14, 2001, and Oct 6, 2001
  - The effective CLC cross-section and the number of hits per single interaction change if the PMT gain changes (due to the fixed Xilinx thresholds in the Online measurement). Offline corrected for this by looking at the single particle peak and applying thresholds relative to these peaks. We find a correction in the form of: L(offline) = 1./(1.035 - 0.0062 * t (days)) * L(online)

Figs. 25 shows the luminosity calculated per store for the Oct-Aug period considered here. Fig 26 shows the integrated luminosity as a function of store.

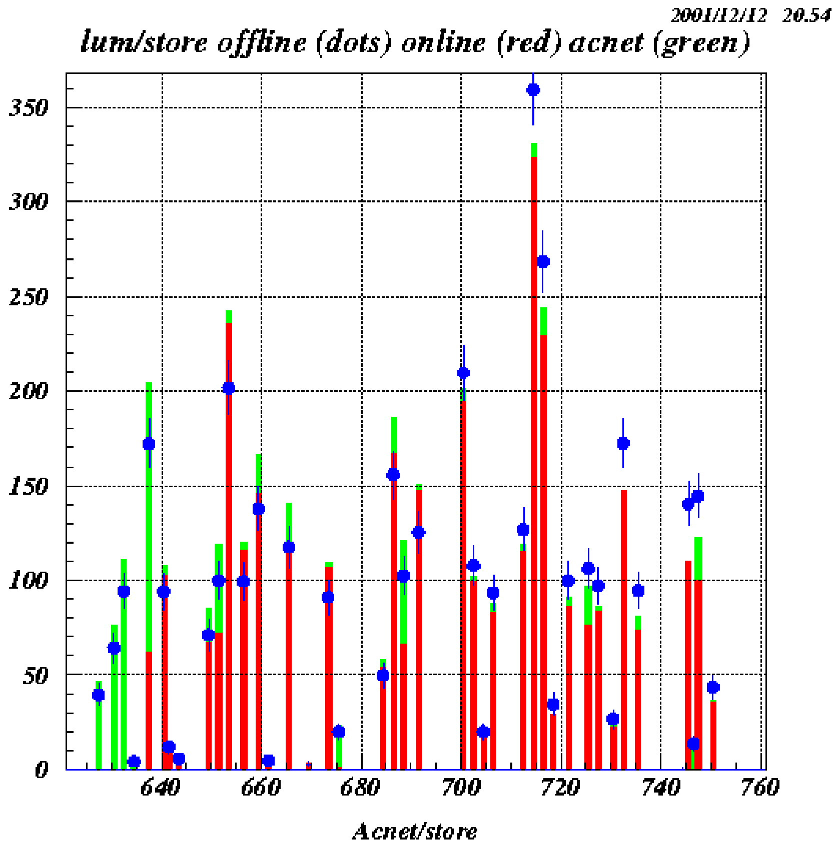

Figure 25: Luminosity per store. We shos the difference in the online, acnet and the official offline calculations.

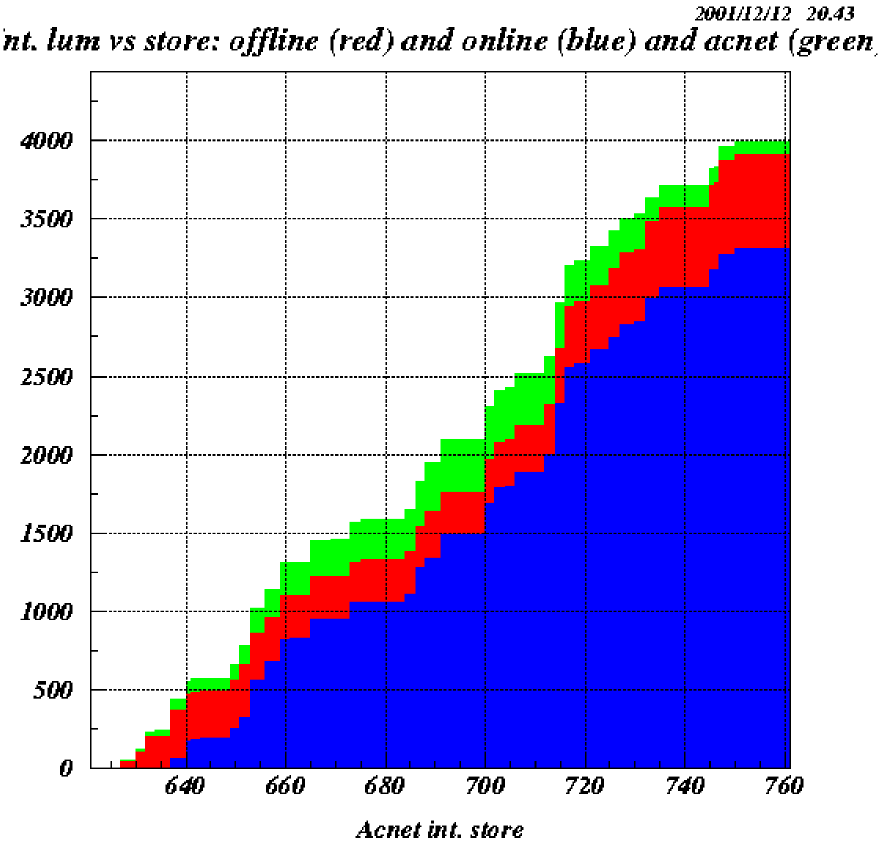

Figure 26: Integrated Luminosity as a function of store.

3.10 hit counting vs. empty crossing

Fig. 27 shows a comparison between the online luminosity measurements using the hit-counting (magenta) and the empty-crossing (blue) methods, for a store in Dec 3rd, 2001. The agreement is very good as a function of instantaneous luminosity.

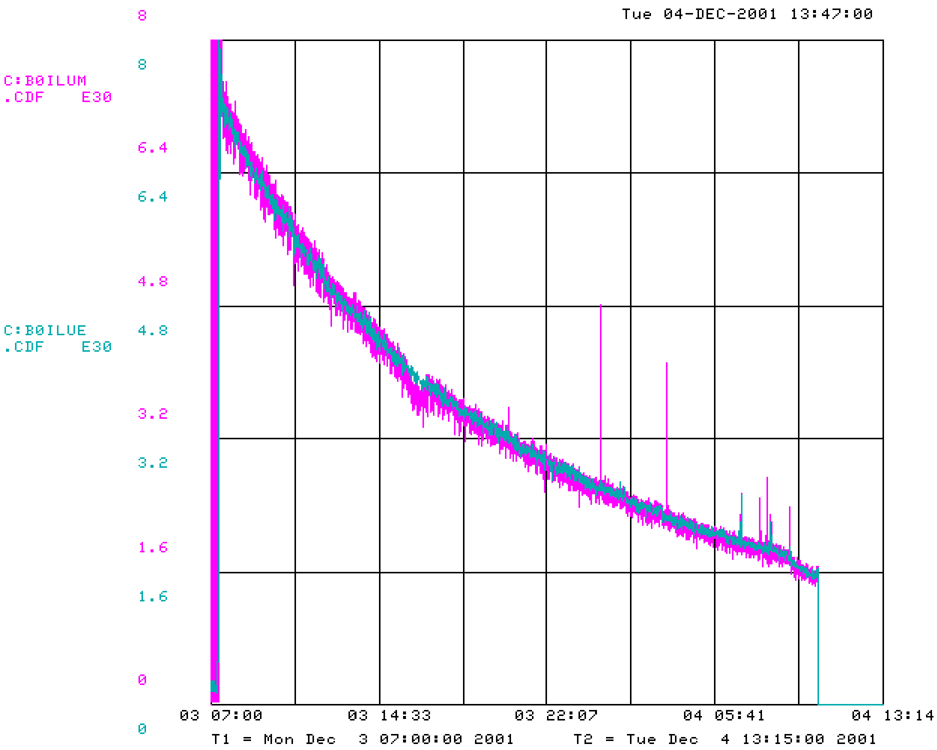

Figure 27: Online luminosity: comparison between the hit-counting (magenta) and the empty-crossing (blue) methods.

3.11 Offline results

Used same datased at for hit counting.....

In each run we select events that satisfy our definition of collision and measure $\tilde{P}_o$, we then estimate μ from equation 4 and finally obtain the the average instantaneous luminosity according to equation 1 using $f_{BC} = xxxxx$ for the 36x36 run and $\sigma_{tot} = xxx \pm yyy$.

XXX This should propagate all uncertainties correctly XXX

4 Cross-check with W's

5 Conclusions and plans

We have established the CLC luminosity measurements and accounting and have released a first version of the official luminosity for the Aug-Oct, 2001, period. The estimated uncertainty is of the oder of 10% and is due to the uncertainty in the absolute normalization, mostly. The official numbers are stored in the Data File Catalogue and can be accessed according to the instructions found in: http://www-cdf.fnal.gov/internal/people/links/JacoboKonigsberg/lum_official_page.html

- **Plans:**
- Work on the reduction of the absolute normalization uncertainty by studying the effect of using different generators, CDF simulation, material, thresholds, gas pressure etc.
- Given the unstable gains this requires more effort in calibrations, opertation and accounting
- We are considering switching to make the "empty-crossing" method to be the official method since it is more robust to PMT gain changes and will be ok for luminosities up to xxx
- Working with Hamamatsu to resolve the gain question
- We are looking at W's to help with the abs. normalization
- Working on automatization of the offline reconstruction
- Expect to be able to get below 5% in the next major version
- Also working on implementation of "particle counting" and "time cluster counting"

6 Appendix A: PMT gain drop

7 Acknowledgements

- Paolo Giromini for cross-section discussions...
- Elena Gershtein+Silicon+french guy for simulations and material
- Who else????

References

[1] CDF-xxx sim note

[2] CDF-xxx CLC proposal

[3] PRD's with cross sections - Giromini et al

[4] J. Konigsberg *et. al*, "Luminosity Information in Run II"

[5] clc-comm note

[6] S. Belforte *et. al*, "σ_{BBC} Derivation and Results"

[7] E. Gershtein *el. al*, "CLC Simulation User's Guide"

[8] Dima and Jim's note

[9] Sasha's note

[10] Note on CLC+PLUG studies

[11] Note on luminosity meas. w/BBCs

[12] CDF-xxx