



Longitudinal Emittance Measurement in MI SBD: How and why?

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Abstract

A sample bunch display (SBD) system has been used to monitor the longitudinal emittance of the beam in the MI for Run II and later part of the Run I operation of the collider complex. This uses wall current monitor data and a Lecroy scope for data collection. The data analysis is carried out using LABVIEW program. For the last two years we have made a few improvements in the data analysis. This report is intended to give an overview of the present system in use and how it can be improved.



Contents



Description	
Different MI operational cycles in use. We need to measure the longitudinal emittance and intensities of the bunches for all of them at different times in the acceleration cycle.	4
Typical proton SBD data used for off-line analysis. The traces are at 8 GeV, 150 GeV (before coalescing), 150 GeV (after coalescing) in the MI. The data are taken with 4GHz sample rate. The bunch separation is about 18.92 nsec.	5
Method of RMS estimation in MI SBD is outlined here.	6
Outline of the method of 95% width using the true rms width determination using a schematic picture.	7
Examples by using the SBD raw data after proton bunch coalescing.	8
ESME simulation to estimate constant of proportionality between true rms and 95% width. The cases illustrated are Gaussian, parabolic and elliptic distributions The 95% contours are also shown. The simulation results shown are for 3eVs bunches.	9
Same as previous, but, with bucket contours	10
Table summarizing the simulation results.	11
ESME simulation of 7 bunch coalescing and estimation of proportionality constant between true rms and 95% width.	12
Longitudinal emittance from SBD: formula and newly added lab-view routine.	13
Future plans.	14

Conclusions: The 95% longitudinal emittance measured using the present MI SBD is accurate to about 20%, out of which, about 15% error arises from the conversion from true rms to 95% emittance. In the case of MI a fast determination is also needed. Possible future improvements are suggested.



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MI Operating Scenario



MI is a rapid cycling proton synchrotron.

Description	Beam	Cycle & Beam Duration	# of Bunches	E-Range (GeV)
Pbar Stacking	P 1E13 (max)	\$29, 1.47 s <0.8 s	84	8-120
NuMI	P >3E13	\$23, ~2 s <0.8 s	~508	„
Switchyard-120	P Low int.	\$21, ~3 s <0.8 s	??	„
Protons to Tev.	P ~330E9	\$2B, ~4 s ~2.7sec	7	8-150
Pbar to Tev. ♦	P ~80E9- 680E9	\$2A, ~8 s ~7sec	20-60	8-150
P& pbars to RR	P& pbars Range of Int.	\$2D, ~5 s	4- 2.5MHz bunch	8
Other Studies	?	?	?	?



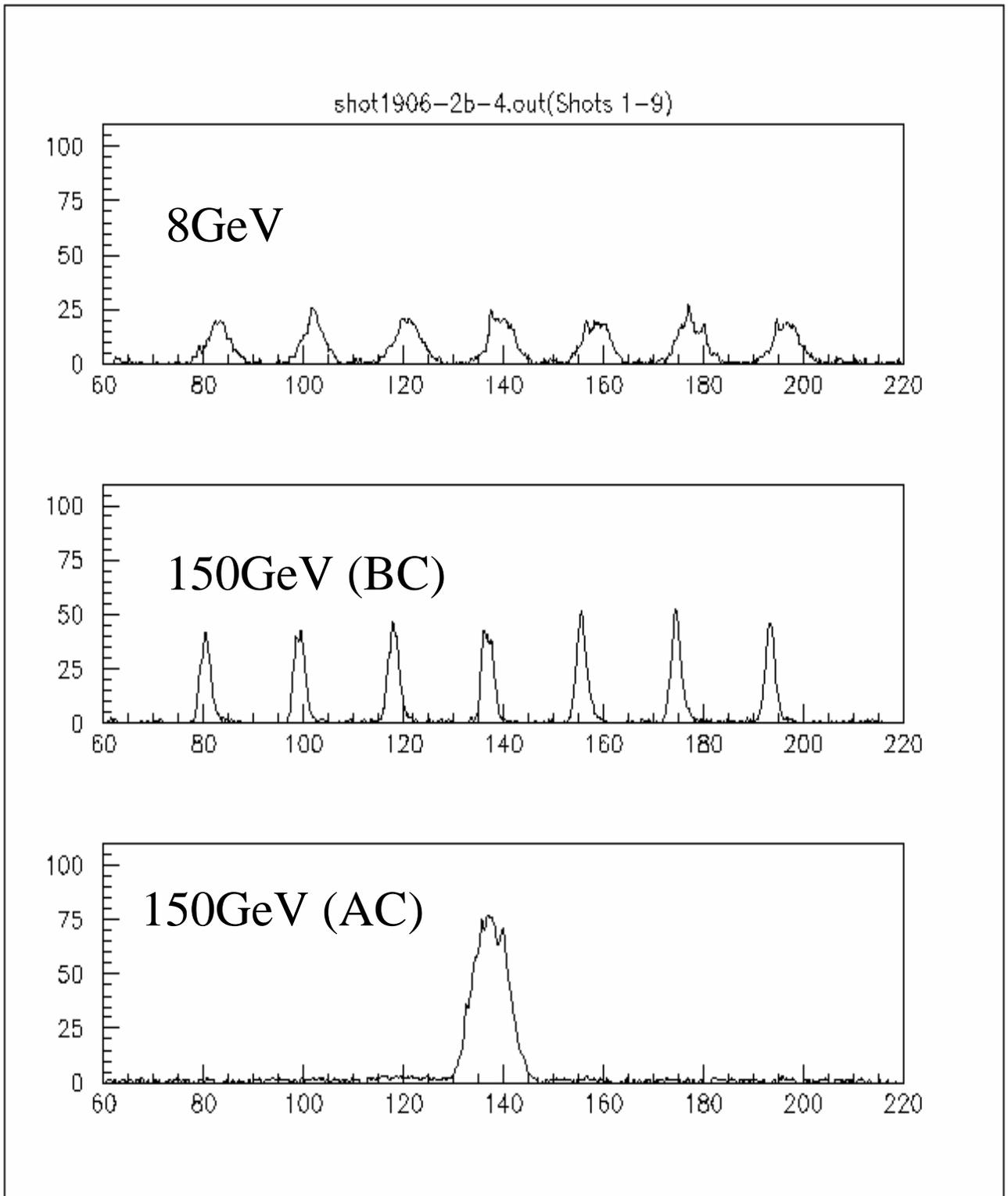
Capable of measuring

- **Long. Emittance**
- **Bunch Intensities**

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Sample of SBD Data (proton injection to the Tevatron)



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How do we estimate $rms(\sigma_t)$ of a bunch in MI SBD?

- "SBDMIBaseline Integer" - take 200 samples at the beginning and the end of turn, average them, and calculate the base line $ax + b$ Find the bucket width and calculate the bucket starting sample array. Calculate the background level (bg) in the middle of each bucket.
- "SBDMICalcCentIntFloatInteg" calculate bucket signal $\sum S = \sum I - \sum bg$ if $(\sum S)^2 > \sum bg^2 * (S/N)^2$ call "FindDataNewer"; here (S/N) stands for required Signal to Noise ratio;

- "FindDataNewer" calculate x and x^2 arrays; calculate number of samples under the bucket; calculate centroid

$$\bar{X} = \frac{\sum I * x - bg * \sum x}{\sum S};$$

iterate in both directions from the centroid by two samples until sum of the signal will reach 80% of the total bucket signal; find width of the 80% (width(80)) and calculate

$FWHM = width(80) * 0.75$; The other method used is by using the data from two times the width, where, the intensity is 1/2 of the peak intensity.

calculate the bucket width as $2 * FWHM$ and select samples covered by the width;

calculate $\bar{X} = \frac{\sum I * x - bg * \sum x}{\sum S}$

and $\bar{X}^2 = \frac{\sum I * x^2 - bg * \sum x^2}{\sum S};$

finally calculate $rms(\sigma_t) = \sqrt{\bar{X}^2 - \bar{X}^2}$



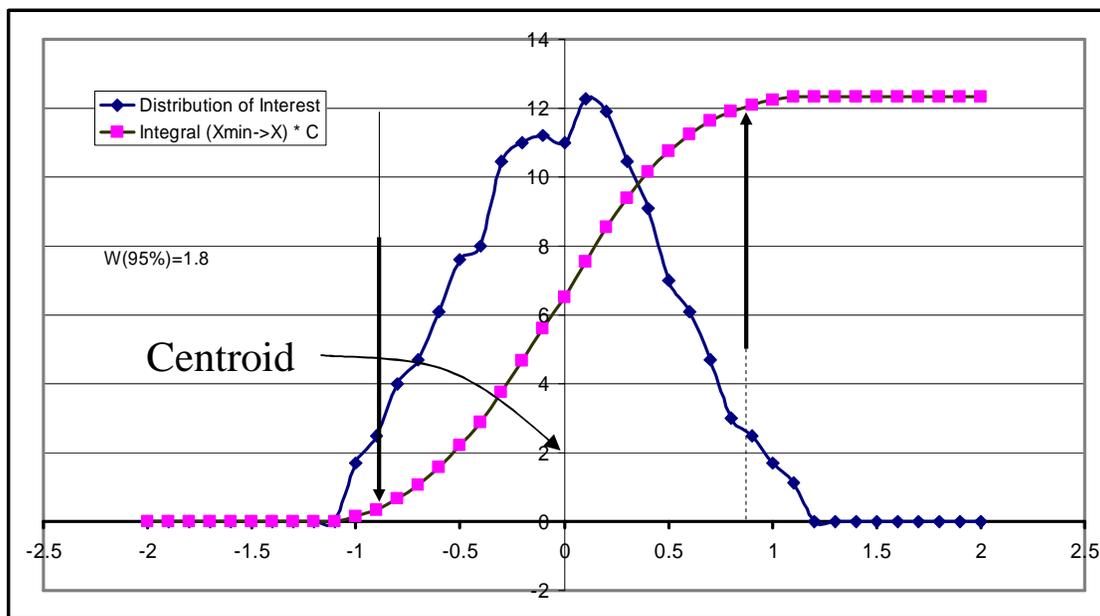
How do we estimate $W(95\%)$ for a bunch?

$$W(95\%) = \text{Constant} * \text{true-rms}(\sigma_t)$$

$\text{Constant} \approx 4.0$ for coalesced bunches at 150 GeV

How do we get the value of the *constant*?

The coalesced or un-coalesced bunches in the MI are not Gaussian in shape. Therefore, $W(95\%)$ is taken as the width of the distribution which encompasses 95% of the area about its centroid.

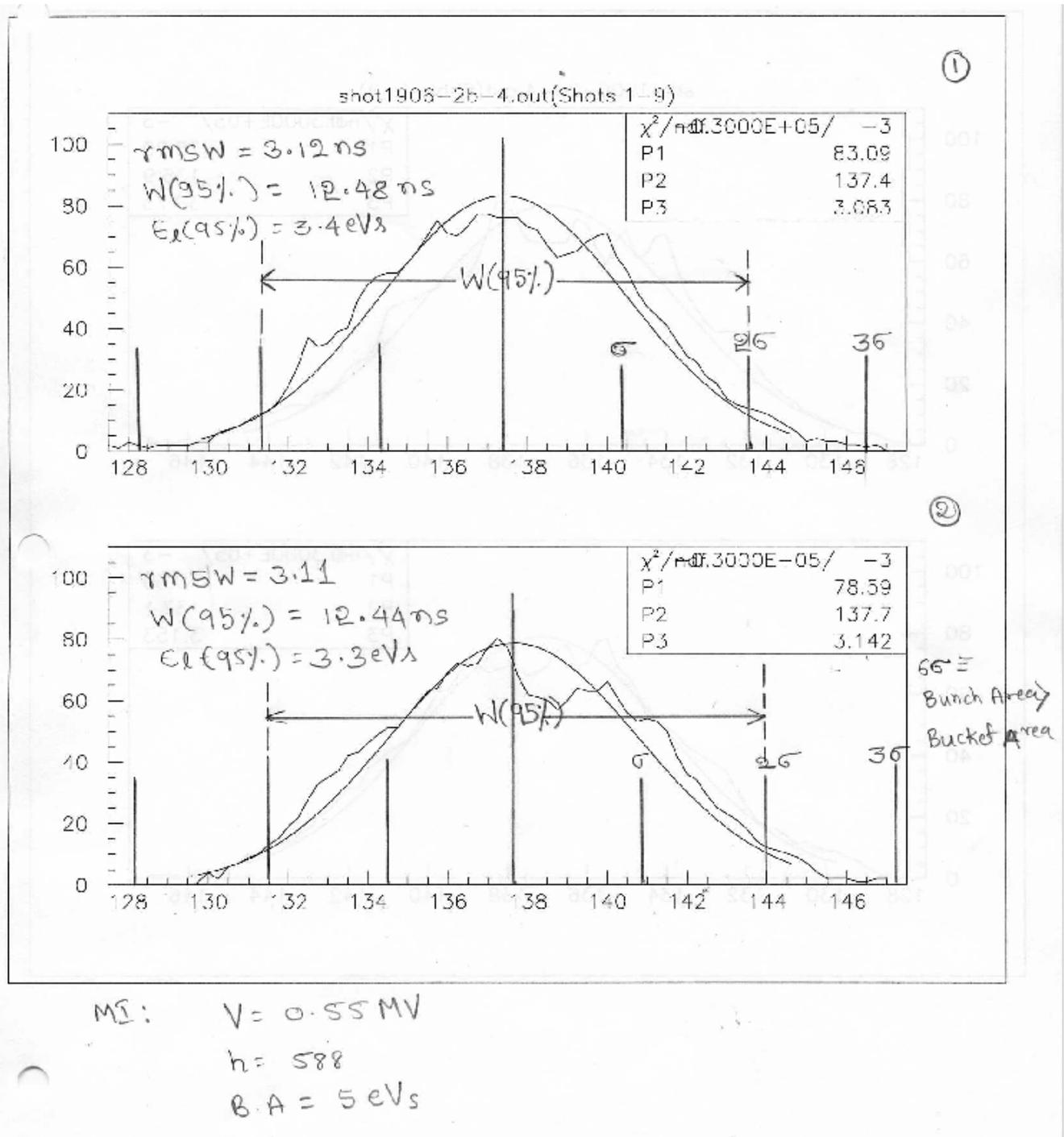


$W(95\%)$

$$\text{constant} = \langle W(95\%) / \text{true-rmsw} \rangle$$

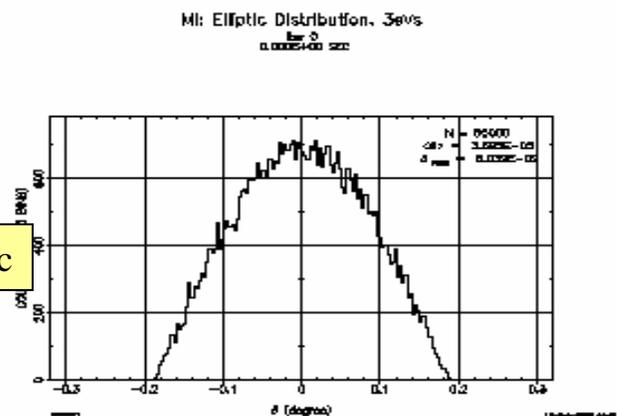
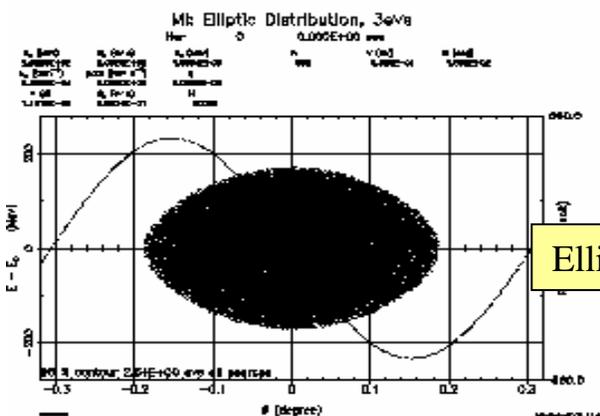
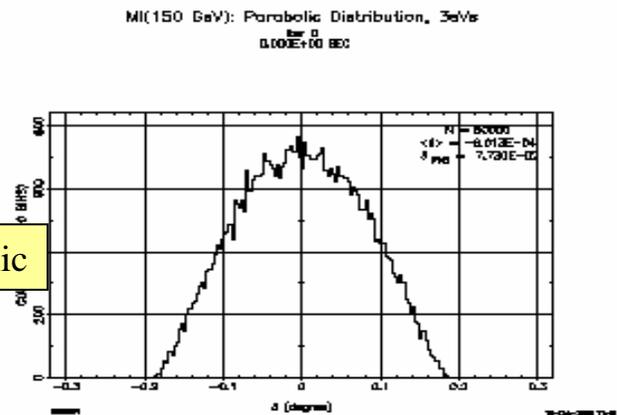
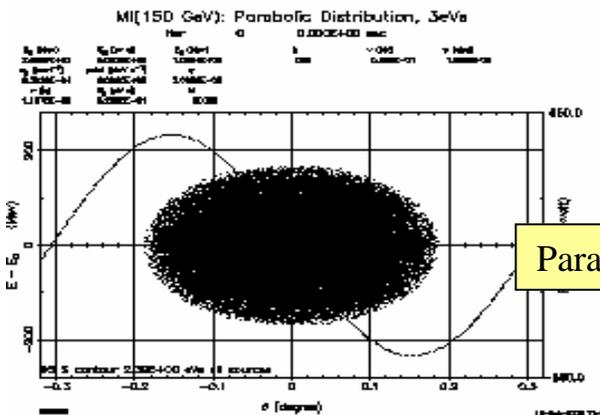
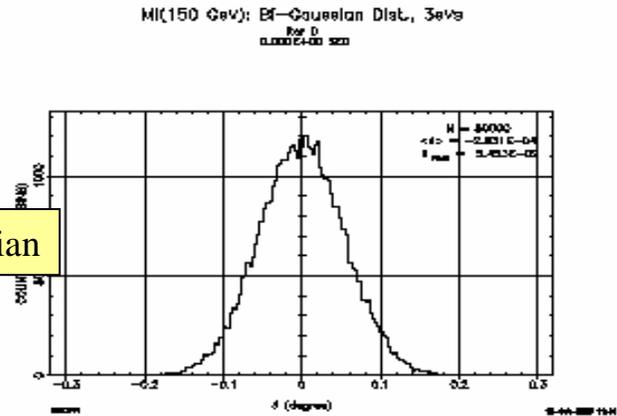
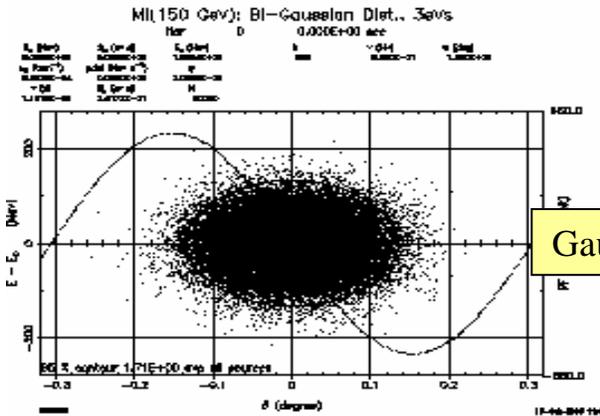


Examples of 150GeV Coalesced Proton Bunches in the MI



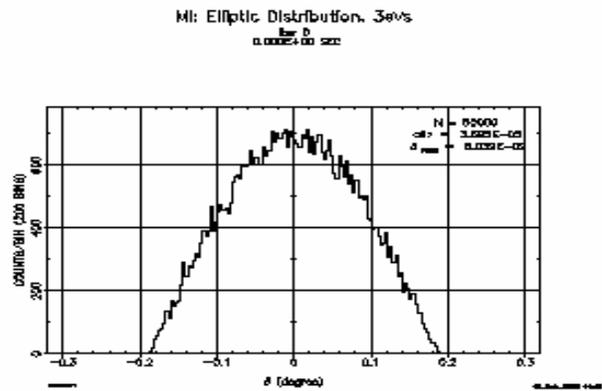
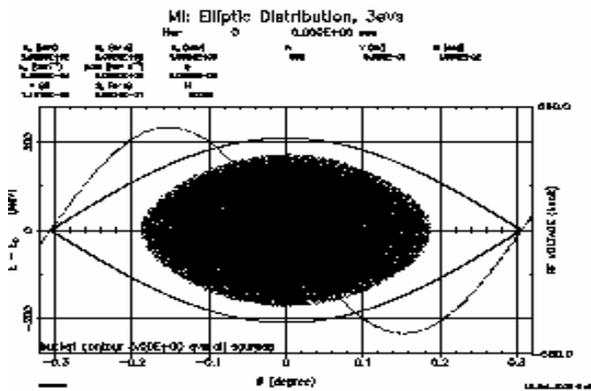
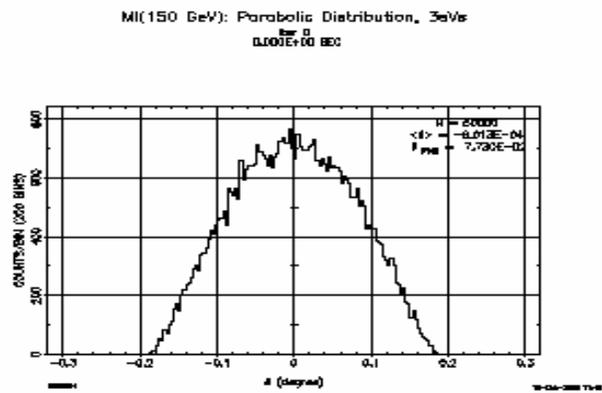
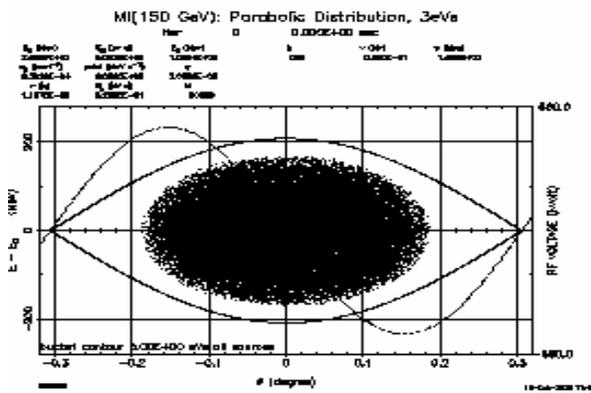
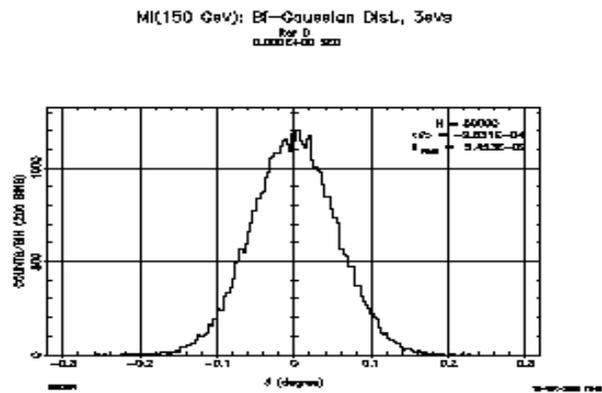
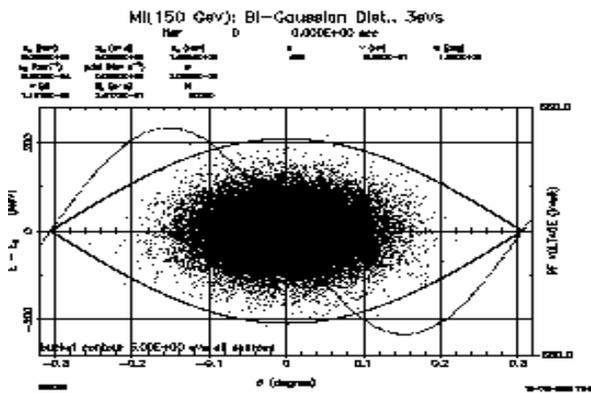


Different distributions with 95% contours (ESME)





Different distributions with RF contours (ESME)





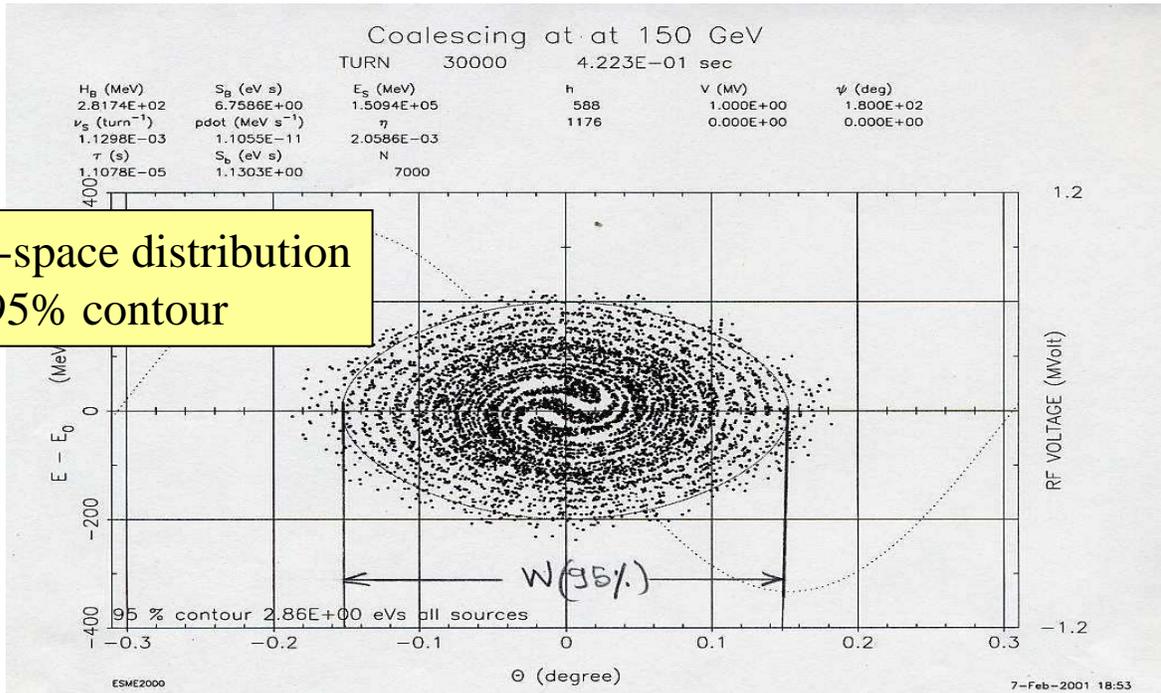
What are predictions from ESME?

BG = Bi-Gaussian, P= Parabolic, E = Elliptic

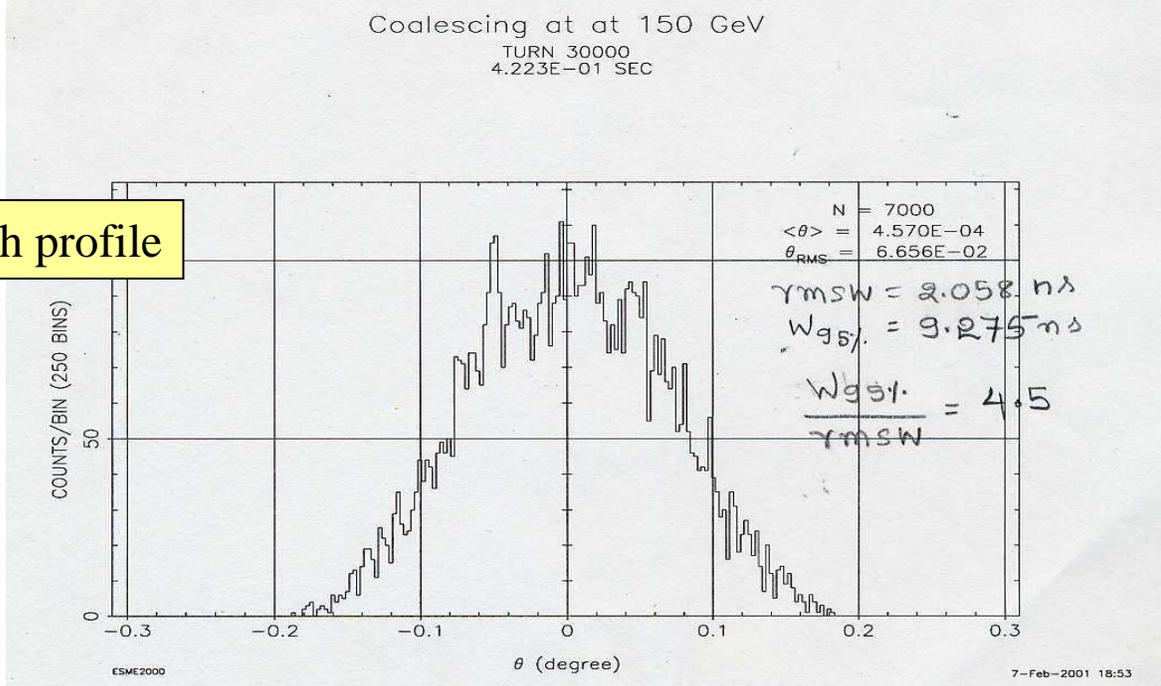
Long. Emit. (eVs)	Distribution	RMS (ns)	ϵ_l(95%) (eVs)	Factor
2	BG	1.32	1.4	6?
	P	1.87	1.64	4.36
	E	1.99	1.71	4.09
3	BG	1.64	1.71	6?
	P	2.38	2.39	4.24
	E	2.48	2.54	4.07
4	BG	2.06	2.12	6?
	P	2.91	3.19	4.15
	E	2.94	3.34	4.11
		Average<P> =		4.25
		Average<E> =		4.09
		Average(P&E) =		4.17



ESME Simulation of 7-bunch coalescing



Phase-space distribution with 95% contour



Bunch profile



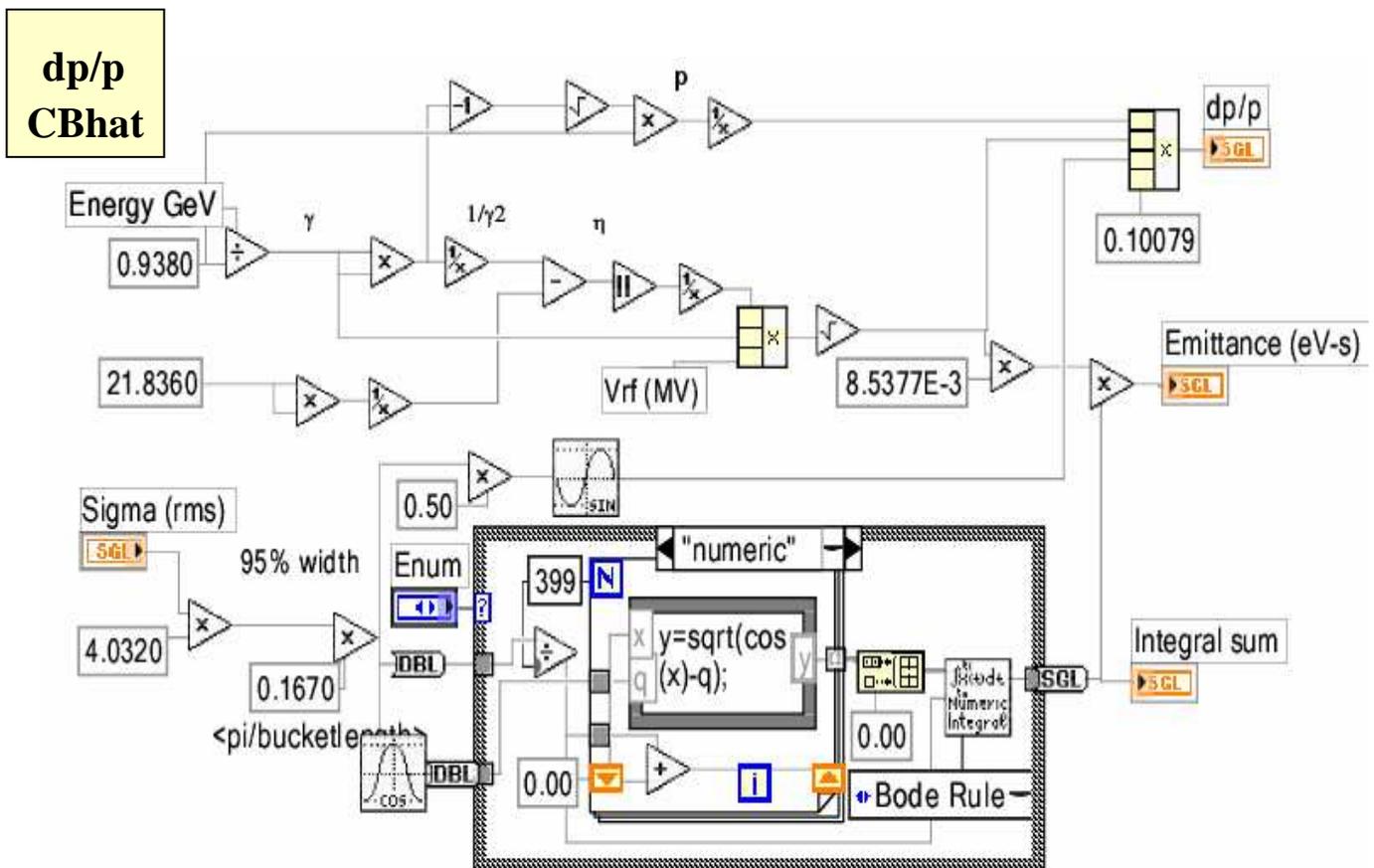
Long. Emit. From MI SBD

$$\frac{dp}{p} = \frac{const}{p} * \sqrt{\frac{\gamma V}{|\eta|}} * \sin\left(\frac{\delta}{4}\right)$$

Where δ is bunch width in rf radian and $Q = \delta/2$

$$\epsilon_l = \sqrt{\frac{32R^2 m_0 c^2}{2\pi h^3 c^2}} * \sqrt{\frac{\gamma V}{|\eta|}} * \int_0^Q \sqrt{\cos(x) - \cos(Q)} dx$$

$const = 0.10079$
Which is a function of proton mass, harmonic number etc.





Suggestions and future plans



- The present method of measuring long. emittance is distribution dependent. So we need a better method. I propose the following:
 - Use Alvin’s “Constant Phase Space Expansion” method. ← Very promising. This needs further study on MI bunches. We need beam tomography. We need to understand robustness of the method.
 - Do more simulations, beam tomography studies and extract better values for *constants* and use it in SBD. ← this is relatively easy and fast, computation-wise
- The bunch length is ~ 1 nsec close to transition and 150 GeV before coalescing. ← this needs cable dispersion and scope response be deconvoluted.
- **Baseline detection** ← particularly difficult for stacking +NuMI operations. This needs further study.