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

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.

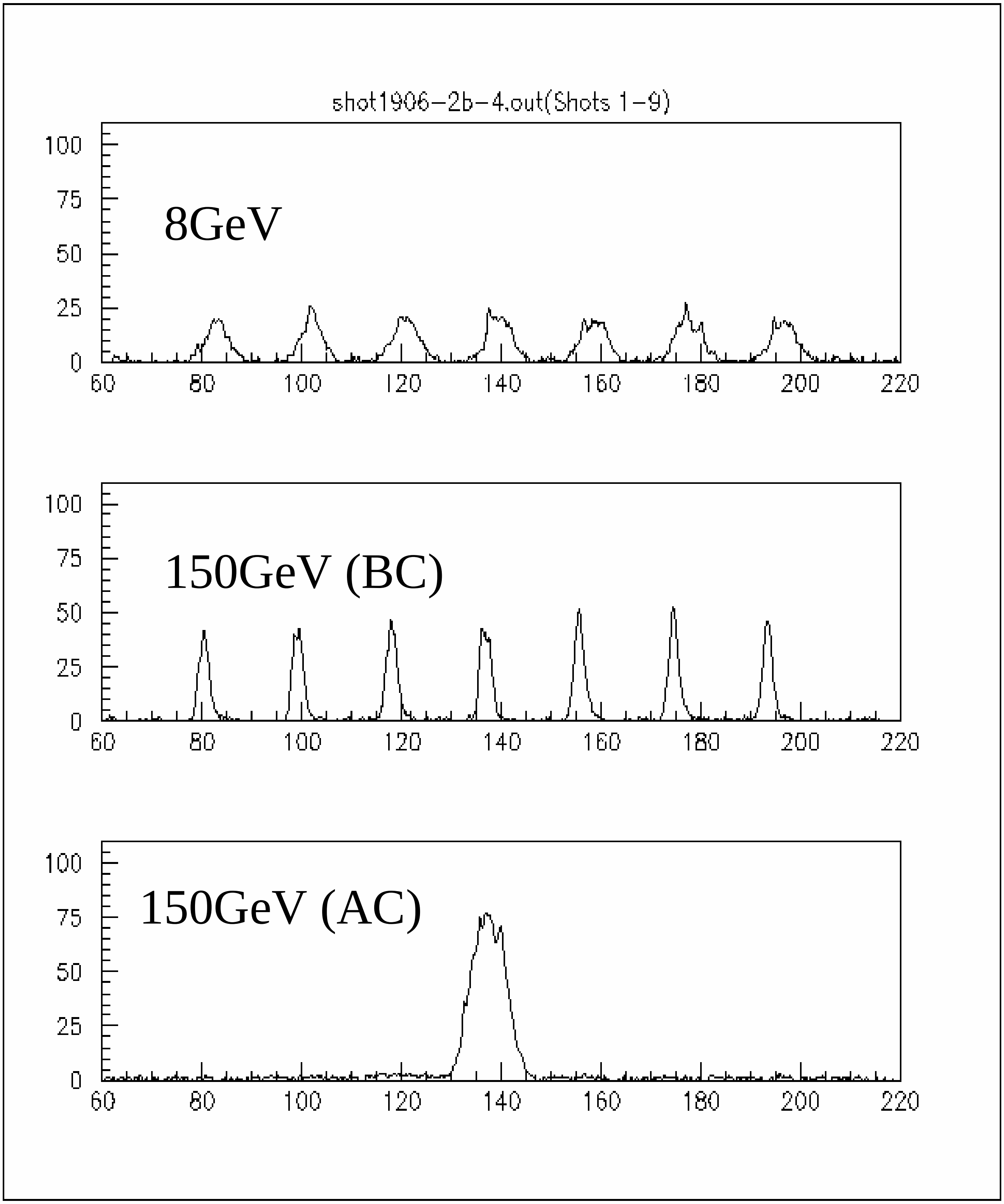
Description	Beam	Cycle & Beam Duration	# of Bunches	E-Range (GeV)
Pbar Stacking	**P 1E13 (max)**	**$29, 1.47 s <0.8 s**	**84**	**8-120**
NuMI	**P >3E13**	**$23, ~2 s <0.8 s**	**~508**	**,,**
Switchyard-120	**P Low int.**	**$21, ~3 s <0.8 s**	**??**	**,,**
Protons to Tev.	**P ~330E9**	**$2B, ~4 s ~2.7sec**	**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**

Sample of SBD Data

(proton injection to the Tevatron)



How do we estimate *rms*(σ_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
$\overline{X} = \frac{\sum I*x - bg*\sum x}{\sum S}$;
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
$FWHM = width(80) * 0.75$;
calculate the bucket width as 2*FWHM and select samples covered by the width;
calculate $\overline{X} = \frac{\sum I*x - bg*\sum x}{\sum S}$
and $\overline{X^2} = \frac{\sum I*x^2 - bg*\sum x^2}{\sum S}$;
finally calculate $rms(\sigma_t) = \sqrt{\overline{X^2} - \overline{X}^2}$

The other method used is by using the data from two times the width, where, the intensity is ½ of the peak intensity.

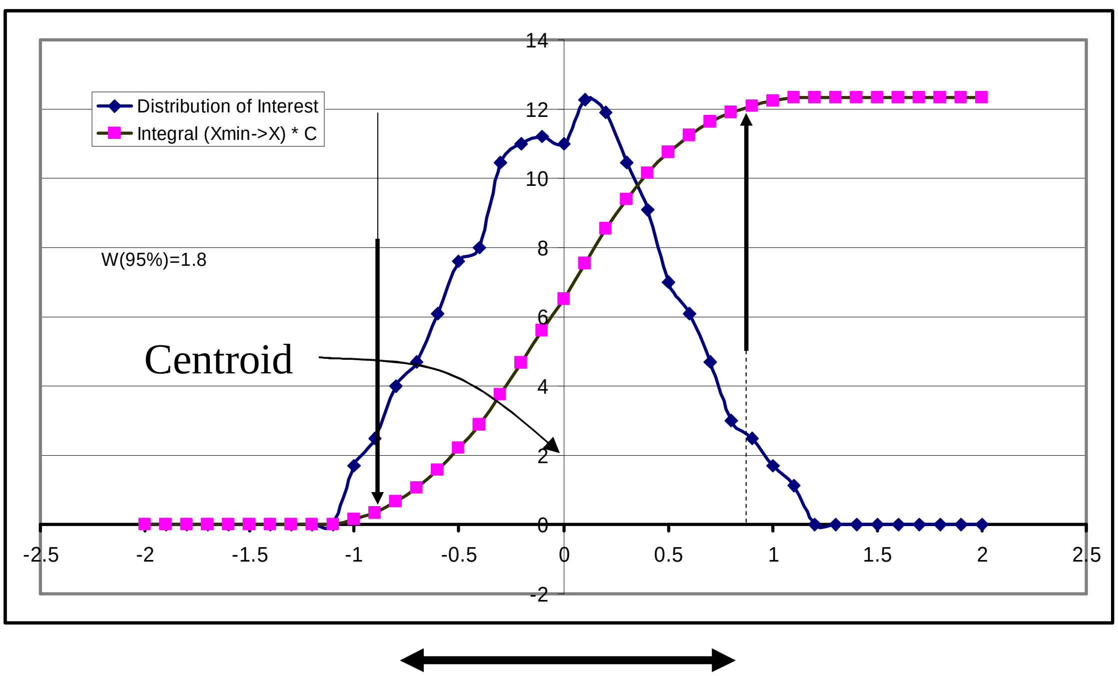
How do we estimate W(95%) for a bunch?

W(95%) = *Constant* ****true-rms*(σ_t)**

Constant ≈ 4.0 for coalesced bunches at 150 GeV

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

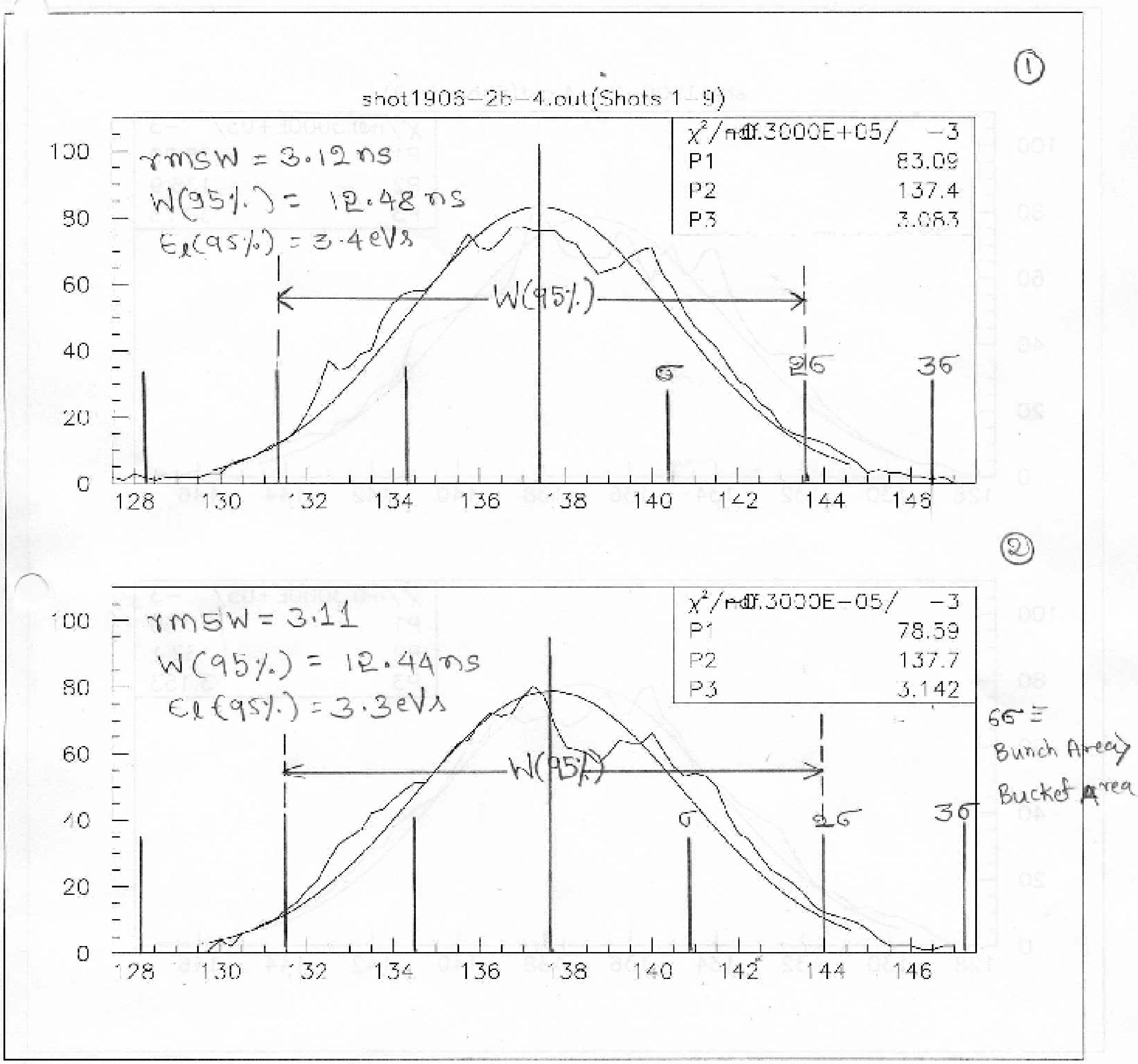
The coalesced or un-coalesced bunches in the MI are not Gaussian in shape. Therefore, W(95%) is taken as the width of the distribution which encompasses 95% of the area about its centroid.



W(95%)

constant = <W(95%)/ture-rmsw>

Examples of 150GeV Coalesced Proton Bunches in the MI

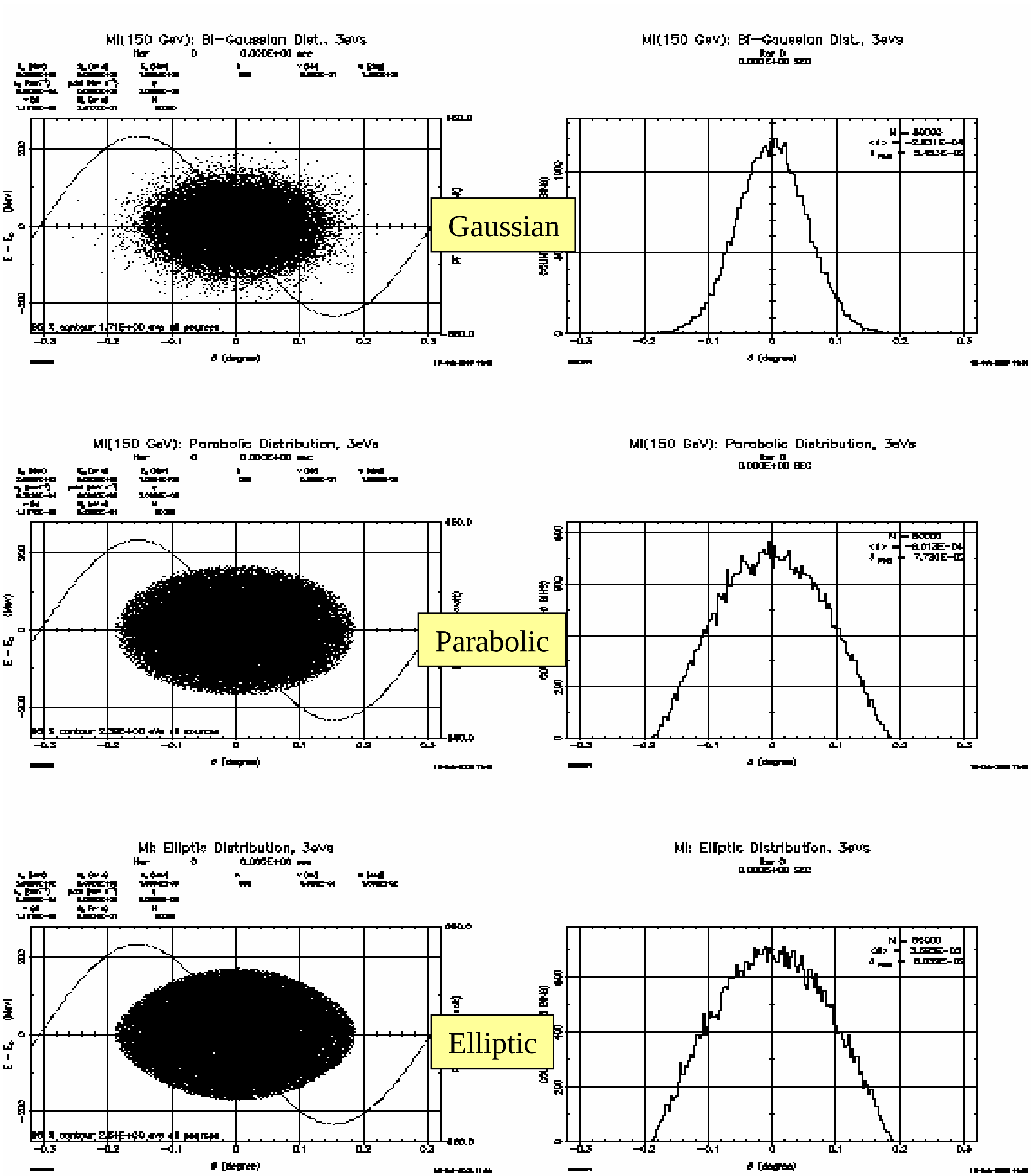


MI: V = 0.55 MV

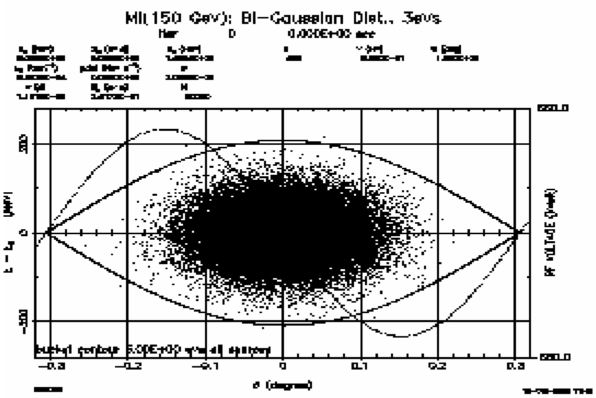
h = 588

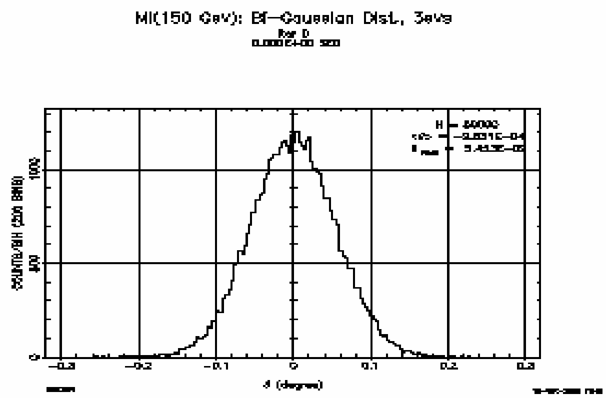
B.A = 5 eVs

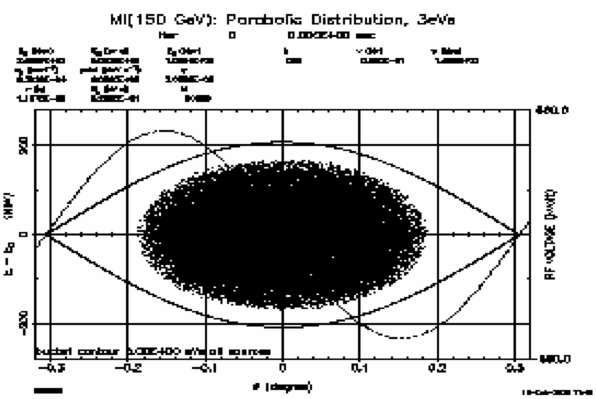
Different distributions with 95% contours (ESME)

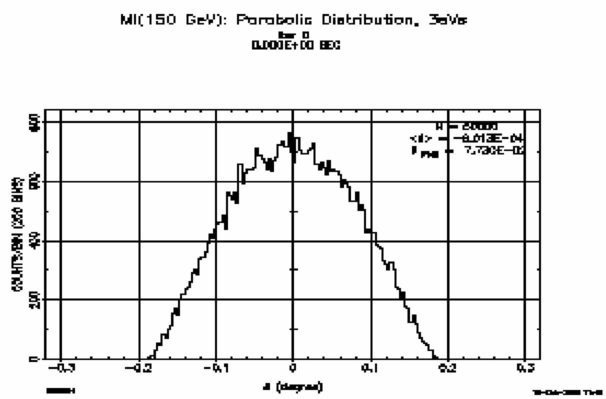


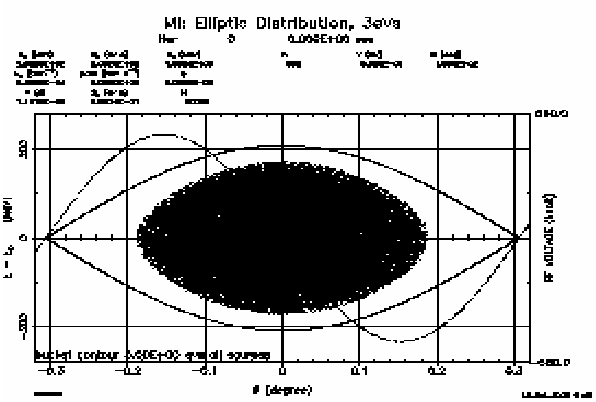
Different distributions with RF contours (ESME)

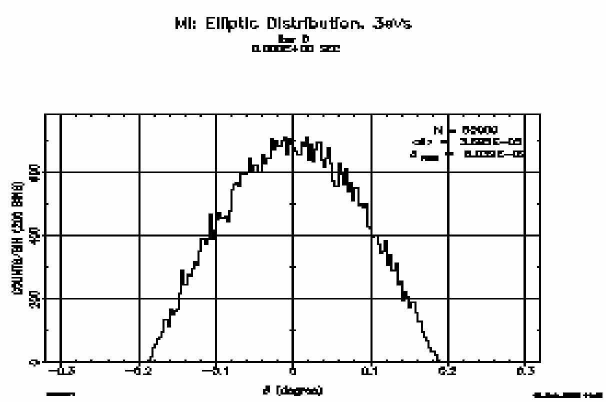










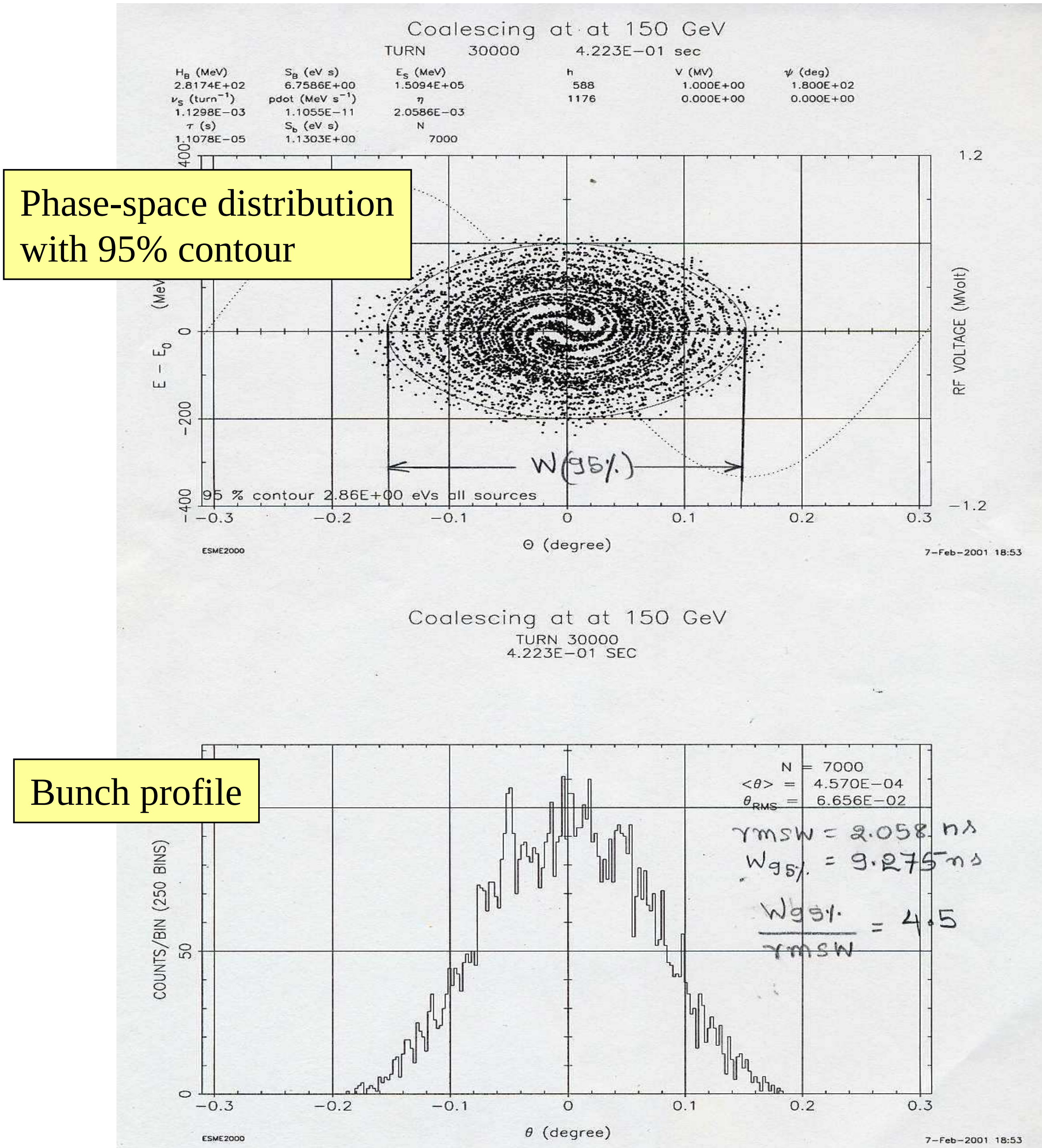


What are predictions from ESME?

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

Long. Emit. (eVs)	Distribution	RMS (ns)	εl(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 Simultion of 7-bunch coalescing



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Long. Emit. From MI SBD

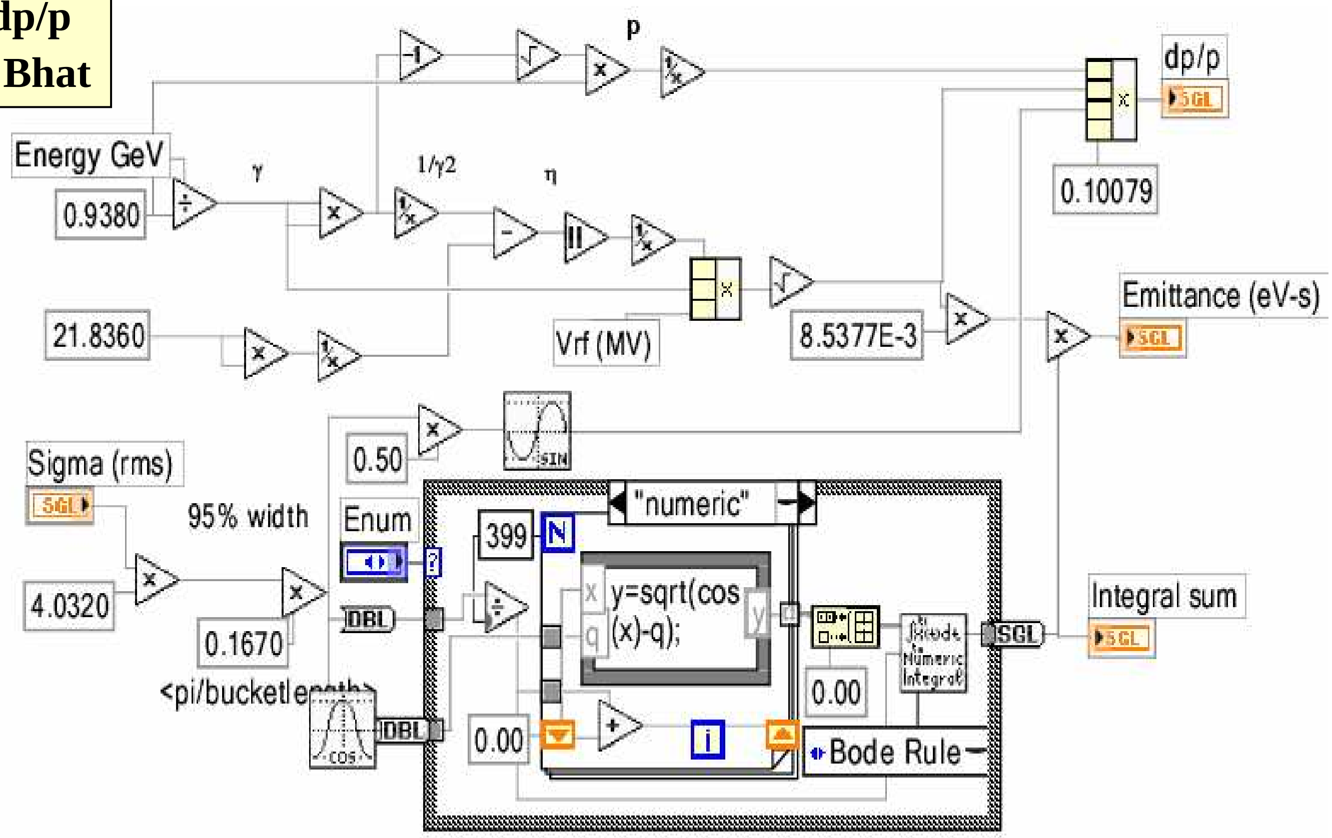
$$\frac{dp}{p} = \frac{const}{p} * \sqrt{\frac{\gamma V}{|\eta|}} * \sin\left(\frac{\delta}{4}\right)$$

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

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

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

dp/p
CBhat



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 de-convoluted.
- Baseline detection ← particularly difficult for stacking +NuMI operations. This needs further study.