SBD algorithms.

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I was studying algorithms of the base line subtraction and emittance and dp/p calculations in current versions of the Main Injector and Tevatron SBD Lab View programs. Following are results of my study for both of the programs. In general both program algorithms are 90% overlapping, nevertheless I will present them separately as corresponding vi's have different names.

1. The Main Injector SBD.

The main routine of MI SBD "SBDMIMainNew.vi" has several branches attempting to calculate the same values. It suffers from influence of different programmers and is messy. I will describe only one branch of the calculations that seems to be current algorithm. The main program "SBDMIMainNew.vi depending on the value in "Input" cluster calls either "SBD MI Single Turn.vi" or "SBD MI Event Delta"
The subset of hierarchy diagram of the current algorithm "SBD MI Event Delta" is shown on fig.1

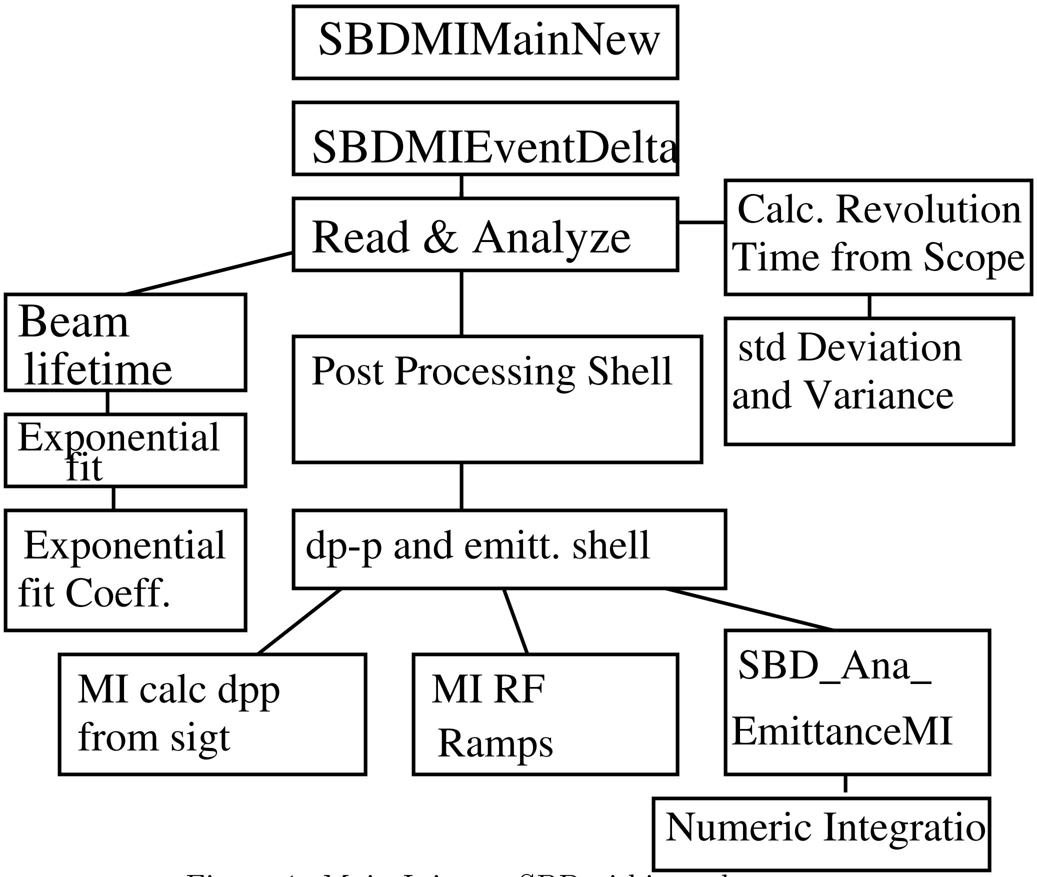

Figure 1: Main Injector SBD vi hierarchy.

1.1 "SBD MI Event Delta".

Input: "Mode" cluster and "Settings" cluster. Perform data acquisition from the scope calling following sub vi:

- "Read Acnet"
- "Update Camac"
- "Setup Seq. Scope"
- "Scope Gain"
- "Arm & Wait"
- **"Read & Analyze"**
- "Reset Gain & 3660"

1.1.1 "Read & Analyze".

Call following sub vi:

- "Revolt dt"
- **"SBD TurnProcess"**
- **"Post Proc. Shell"**

1.1.1.1 SBDTurn Process.

Take "Mode" cluster:

- #Batches
- Starting sample (index of the bucket start)
- #Samples/ns
- INJRevFreq. (kHz)
- Harmonic

Call sub-vis:

- **"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 $rms(\sigma_t) = \sqrt{\overline{X^2} - \overline{X}^2}$

1.1.1.2 Post Processing Shell.

Input:
Mode cluster;
Data cluster:

- centroids
- RMS sigmas (ns)
- widths (ns)

RampInfo:

- P (GEV/c)
- period (ns) 1000/period=RF(MHz)

Return "dp/p - Emit" cluster:

- dp/p
- Long Emit (eV*sec 95 %)
- Bucket Area (eV*sec)

Call "dp-p and emit shell" sub vi.

1.1.1.2.1 dp-p and emit shell.

Call sub-vis:

- **MI RF Ramps** - calculate interpolated RF phase (radians) and RFHV.
- **MICalc dpp from sigt** OR (depending on mode)
- **SBD_Ana_Emittance MI**

1.1.1.2.1.1 MICalc dpp from sigt.

Calculate dp/p and longitudinal emittance ε_l using following formulas:

$$\frac{dp}{p} = \frac{\sin(\frac{\omega_0 \sigma_t}{2})}{\beta^2}\sqrt{\frac{4\beta V \cos(\phi_{RF})}{2\pi E_s h \mid \eta \mid}} \tag{1}$$

$$\varepsilon_l = \frac{6\pi\sigma_t \sin(\frac{\omega_0 \sigma_t}{2})}{\beta^2}\sqrt{\frac{2\beta V E_s \cos(\phi_{RF})}{\pi h \mid \eta \mid}} \tag{2}$$

Where $\omega_0 = 2\pi f_{RF}$

1.1.1.2.1.2 SBD_Ana_EmittanceMI.

Calculate dp/p and ε_l using real integration on bucket:

$$\frac{dp}{p} = \frac{const}{p} * \sqrt{\frac{\gamma V}{\mid \eta \mid}} * \sin(\frac{\delta}{4}) \tag{3}$$

$$\varepsilon_l = \sqrt{\frac{32R^2 m_0 c^2}{2\pi h^3 c^2}} * \sqrt{\frac{\gamma V}{\mid \eta \mid}} * \int_0^Q \sqrt{\cos(x) - \cos(Q)}dx \tag{4}$$

Here δ is bucket width in radians, and Q=$\frac{\delta}{2}$. And R is the Main Injector radius 528.3 meters.
There is also possibility to use following approximation equation to speed up the integral calculation:

$$I(x) = -0.02634836*x^4 - 0.00483797*x^3 + 0.5601463*x^2 - 0.0006670376*x + 2.19549*10^{-5} \tag{5}$$

TEV SBD

The Tevatron SBD program is more compact and well organized. The main program collect data and call **SBD_Ana_Main** The SBD_Ana_Main get all the data and perform analyses of each turn. It call **SBD_Ana_Turn** The subset of hierarchy diagram of the current algorithm "SBD_Ana_Main" is shown on fig.2

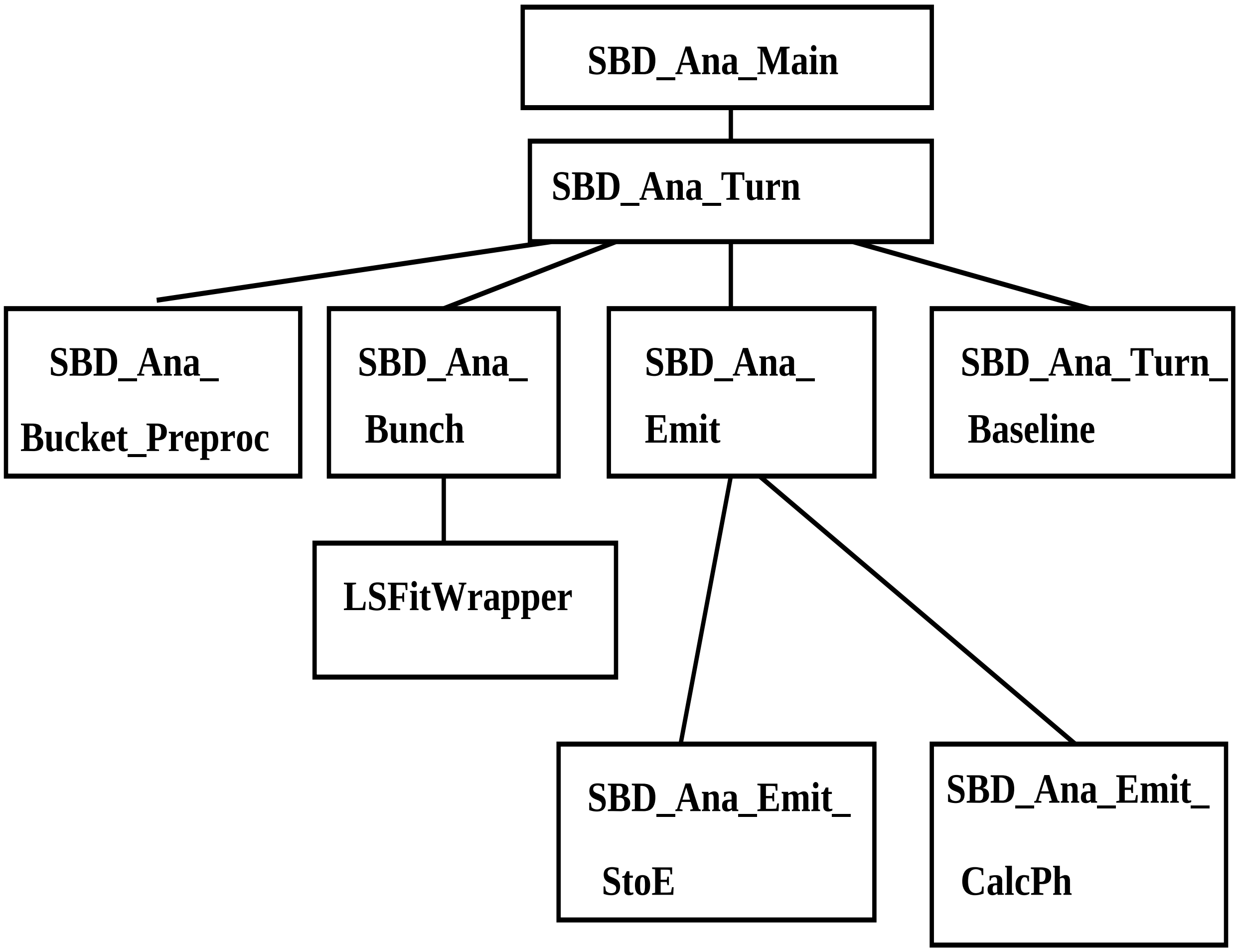

Figure 2: The Tevatron SBD vi hierarchy.

1.1 "SBD MI Event Delta".

1.1 SBD_Ana_Turn.

The vi call in a sequence following sub-vis:

- 1. **SBD_Ana_Turn_Baseline** - perform simple calculation of the baseline for a turn as (ax+b). It takes 200 samples at the beginning and the end of the turn average them and calculate base and slope. Parameters of the baseline (base, slope and error) are stored in the "Background Info" cluster.

- 2. **SBD_Ana_BucketPreproc** - for each bucket in the turn determine offset for the bucket and verify if the bucket has beam.

- 3. **SBD_Ana_Bunch** - Integer bunch processing followed by bunch fit.

- 4. **SBD_Ana_Emit** -calculate longitudinal emittance and dp/p

1.1.3 SBD_Ana_Bunch.

This vi consist of a sequence of 3 frames. It perform following operations: Initialization - calculate arrays of x and x^2.
Define bunch starting sample and width - There are five options to process the bunch: **FWHM - default**, **Area old** , **Area new** , **Do nothing** , and **FWHM new** . I will consider here only default mode. Perform calculation of the centroid $centr = \frac{\sum x*I-bg*\sum x}{\sum(I-bg)}$; calculate $halfmax = (I(centr) - bg) * 0.5 + bg$; iterate from the centroid by 1 sample in both directions until $I(x) < halfmax$; calculate full width of the bunch; calculate starting index.
Define bunch parameters - select data, x, and x^2 arrays under the bunch; calculate raw background and background rms using 10 samples at the beginning (will be used in the fit); calculate $signal = \sum I - \sum bg$; calculate first and second moments of the bunch

$$\overline{X} = \frac{\sum I * x - \sum bg * x}{\sum I - \sum bg} \tag{6}$$

$$\overline{X^2} = \frac{\sum I * x^2 - \sum x^2 * bg}{\sum I - \sum bg} \tag{7}$$

calculate $rms = \sqrt{\overline{X^2} - \overline{X}^2}$; fill first guess cluster with signal,centroid,rms,background and background rms; call **LSFitWrapper** to make Gaussian fit and return Area, centroid and sigma cluster. The sigma that will be used in following calculations is corrected on the scope resolution.

1.1.4 SBD_Ana_Emittance.

Call **SBD_Ana_Emit_CalcPh** to calculate absolute value of the RF Phase ϕ_{RF}. Call **SBD_Ana_Emit_StoE** where calculate dp/p and ε_l as:

$$\frac{dp}{p} = \frac{const}{\beta^2}\sqrt{\frac{4\beta V\cos(\phi_{RF})}{E_s \mid \eta \mid \omega_{RF} T}}\sin(\frac{\sigma_t \omega_{RF}}{2}) \tag{8}$$

$$\varepsilon_l = \frac{6\pi E_s \sigma_t}{\beta^2}\sqrt{\frac{4\beta V\cos(\phi_{RF})}{E_s \mid \eta \mid \omega_{RF} T}}\sin(\frac{\sigma_t \omega_{RF}}{2}) \tag{9}$$