Real Time Beam Position Monitoring at CDF
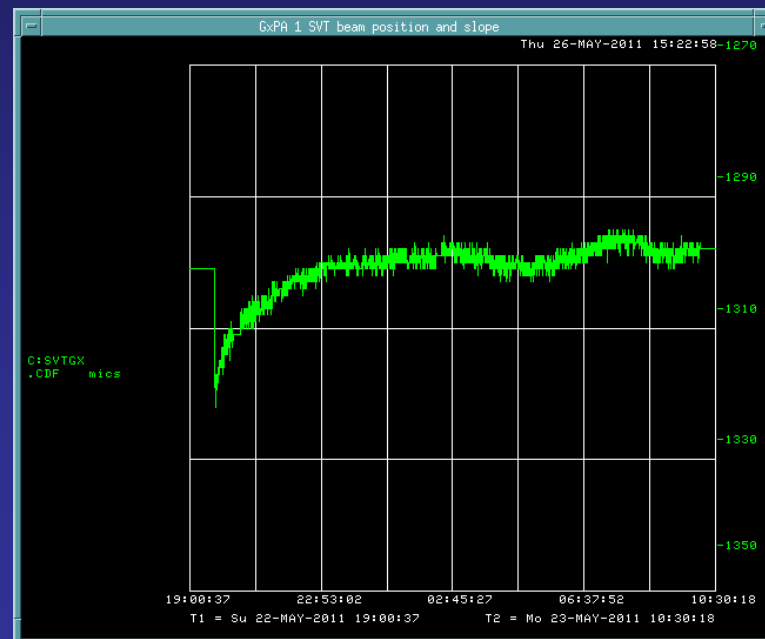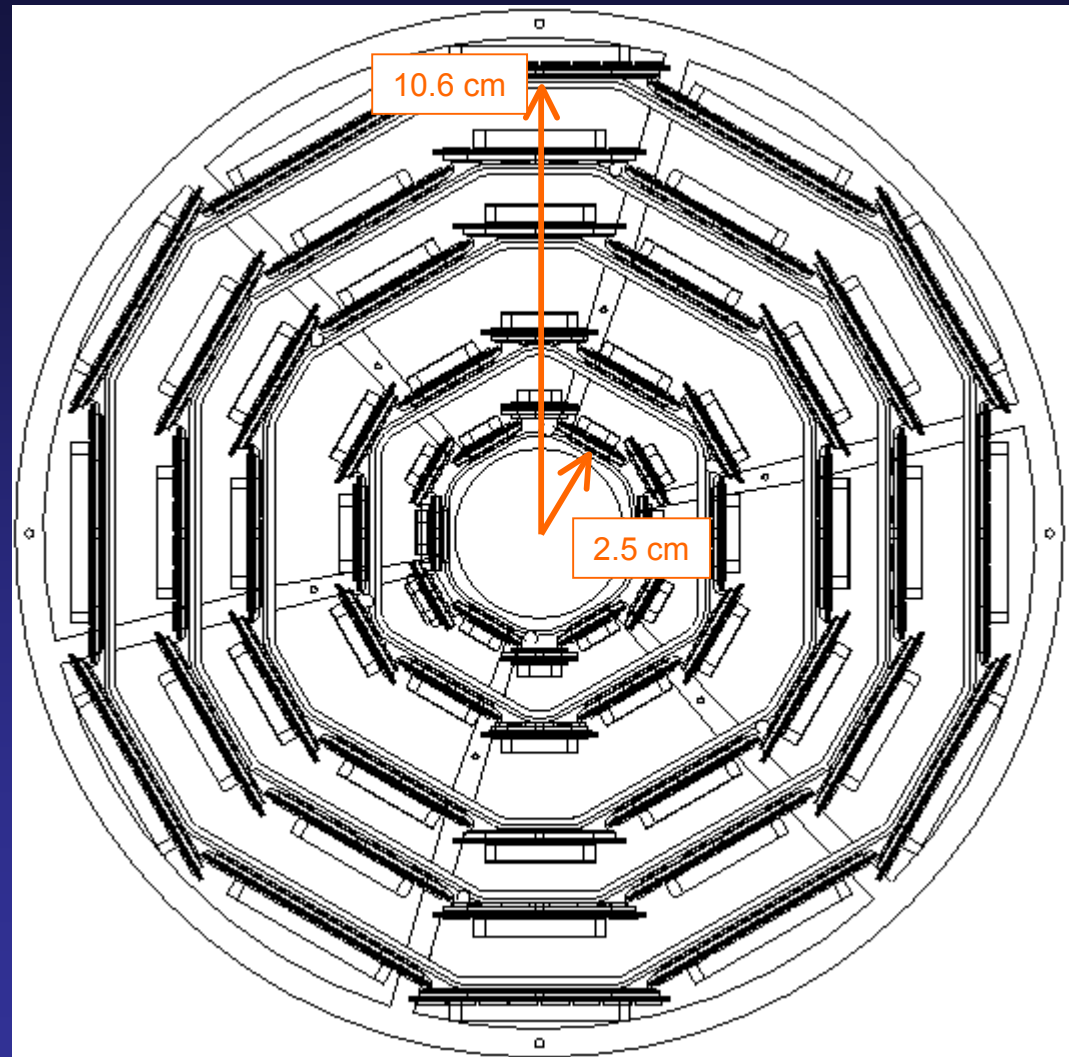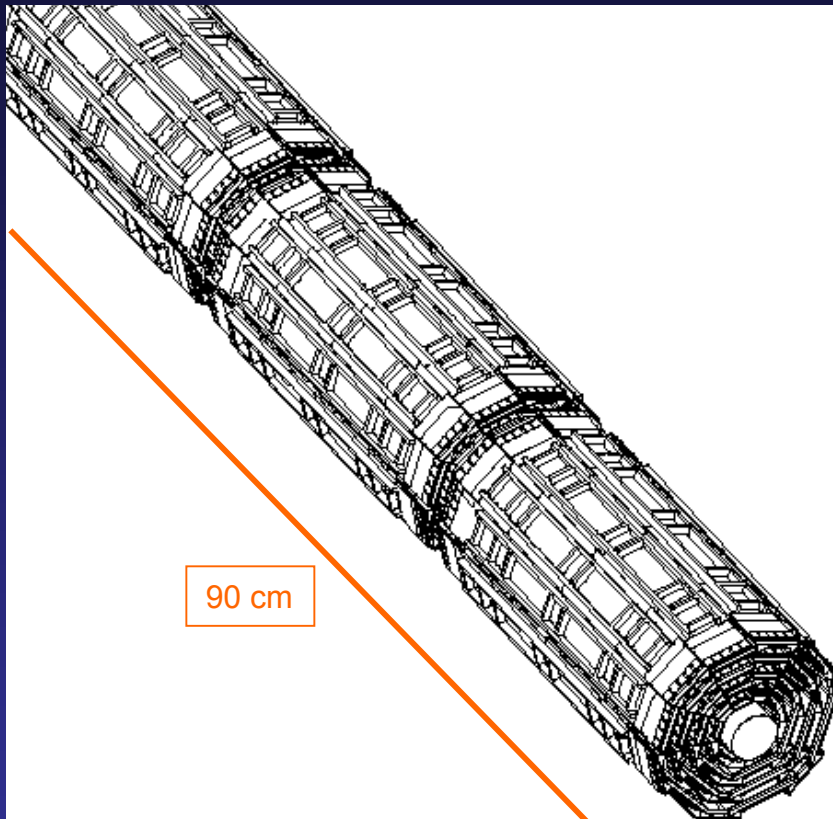
Luciano Ristori

INFN and Fermilab

SVX II

90 cm

10.6 cm

2.5 cm
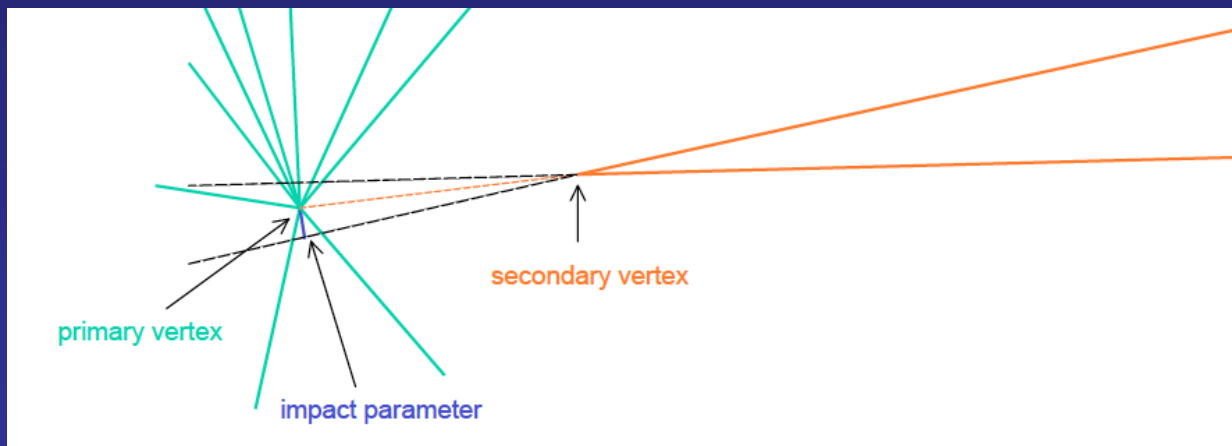
Silicon Vertex Trigger

- the capability of triggering on impact parameter and secondary vertices significantly expanded the physics reach of CDF in the sector of flavor physics, making it a competitor of B-factories in terms of yield of hadronic decays of Charm and Beauty

- thanks to SVT, CDF has perfomed many measurements otherwise impossible at a hadron collider

Silicon Vertex Trigger
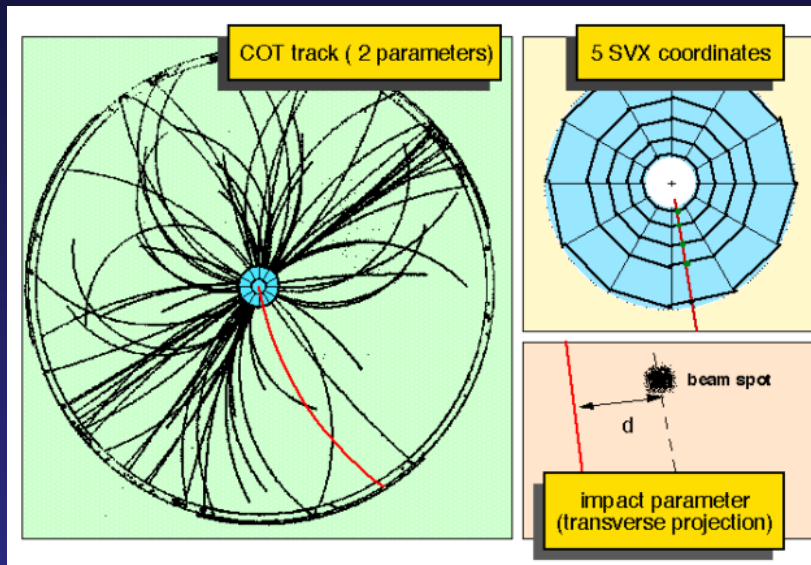
- knowing the exact position of the beam is very important
- beam moves around from store to store and drifts slowly within a store
- need to measure exact beam position in real time and feed back to SVT for impact parameter correction
- if the beam moves too much, new constants must be uploaded
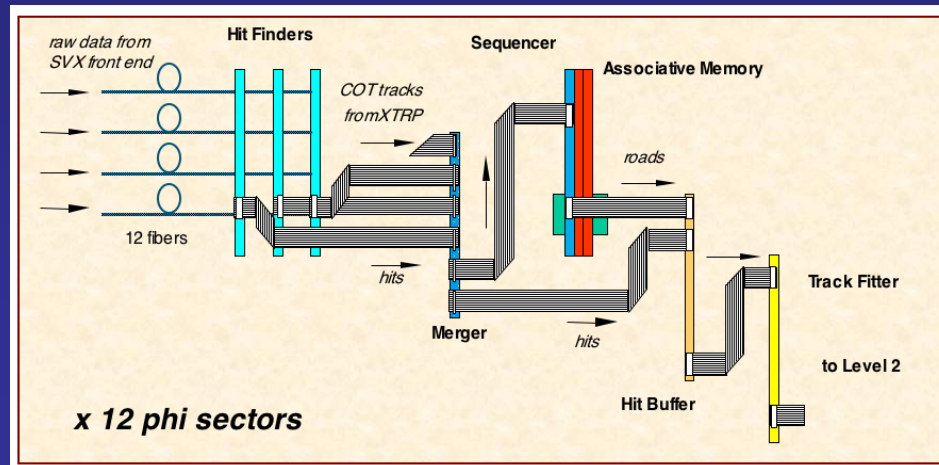
outline

- monitoring beam position in real time
  - crucial for SVT to work
  - performed continuosly and reliably in the last 10 years
- measuring beam spot size
  - done offline
  - never really managed to implement it reliably in real time
- beam spot tomography
  - just a cool idea

monitoring beam position in real time

some basic geometry: d vs. phi

$$d = y \cos(phi) - x \sin(phi)$$
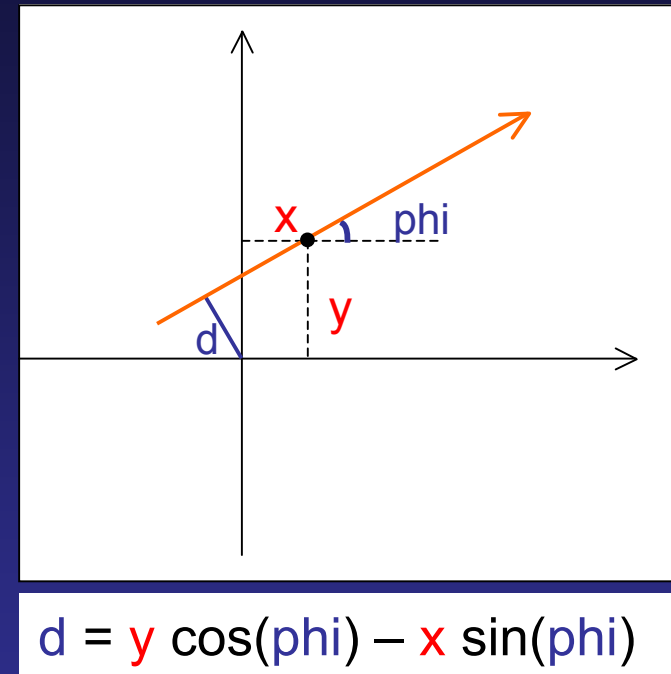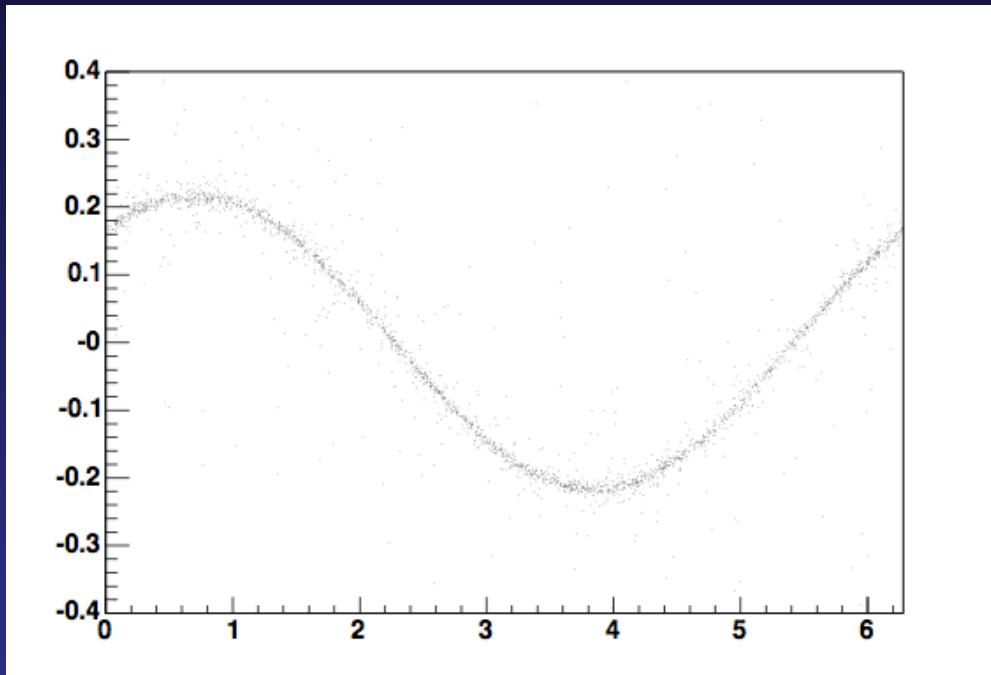
- simple least squares linear fit yields x and y
- analytical solution for minimum
- computationally very efficient
- performed in real time by CPU in a VME crate

some basic geometry: d vs. phi

d

Raw

d

Subtracted

phi

x phi
y
d

d = y cos(phi) – x sin(phi)

Online 3D beam position

In each barrel

6 electrical barrels

z
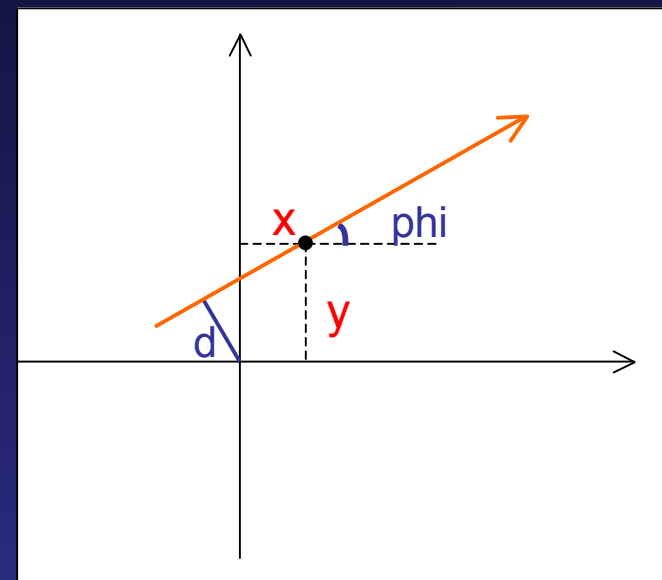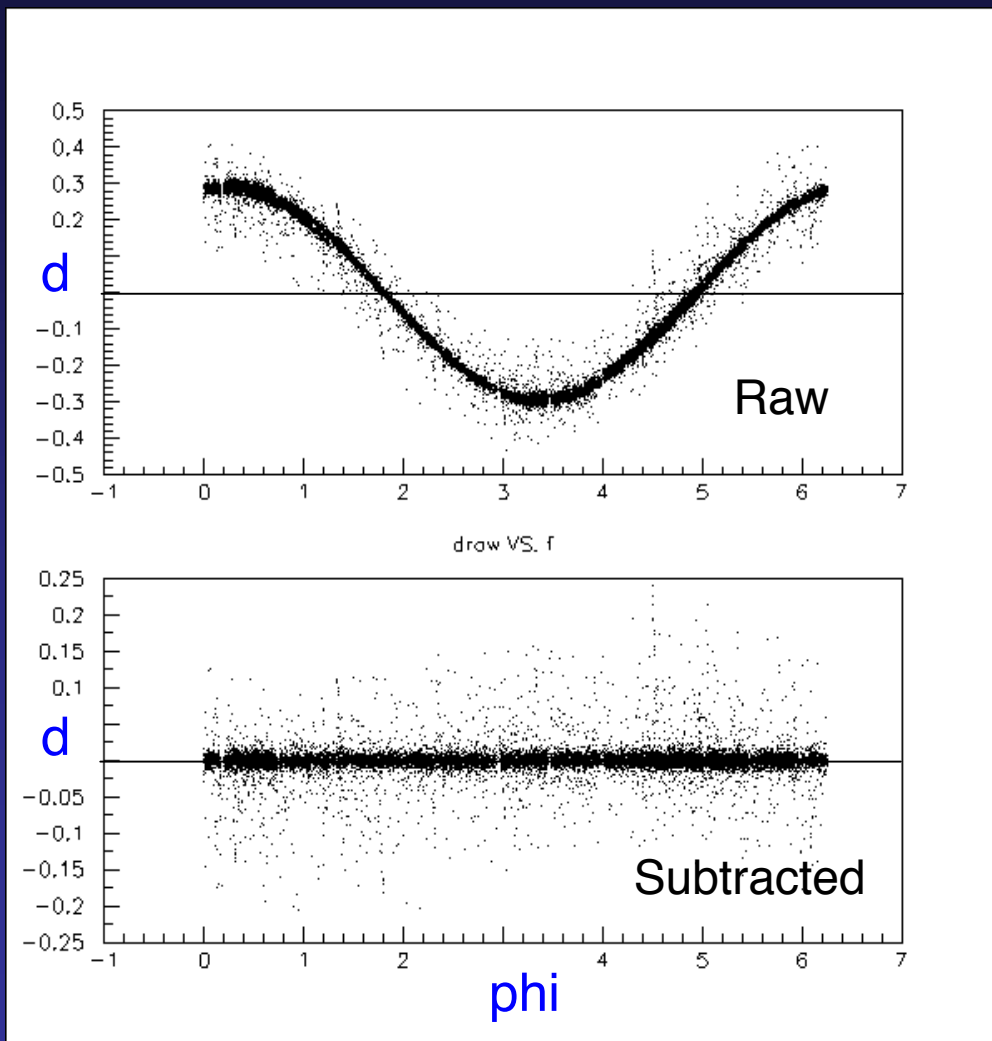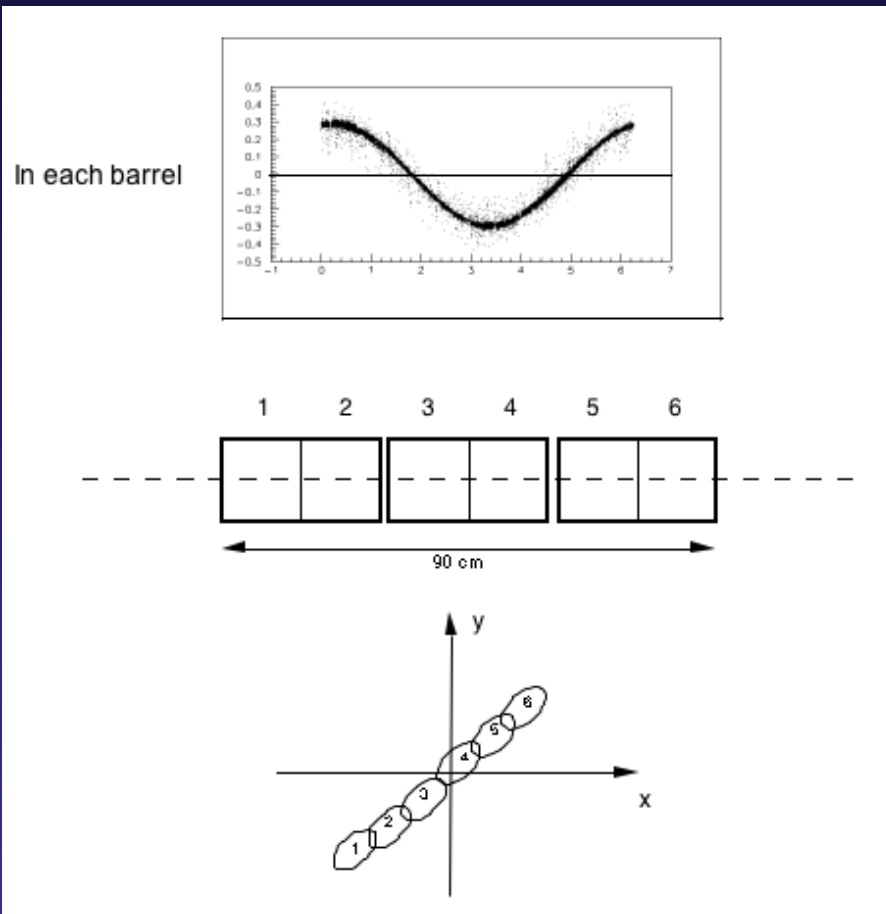
Compute x,y of beam spot at six positions in z using tracks from six distinct "electrical barrels"
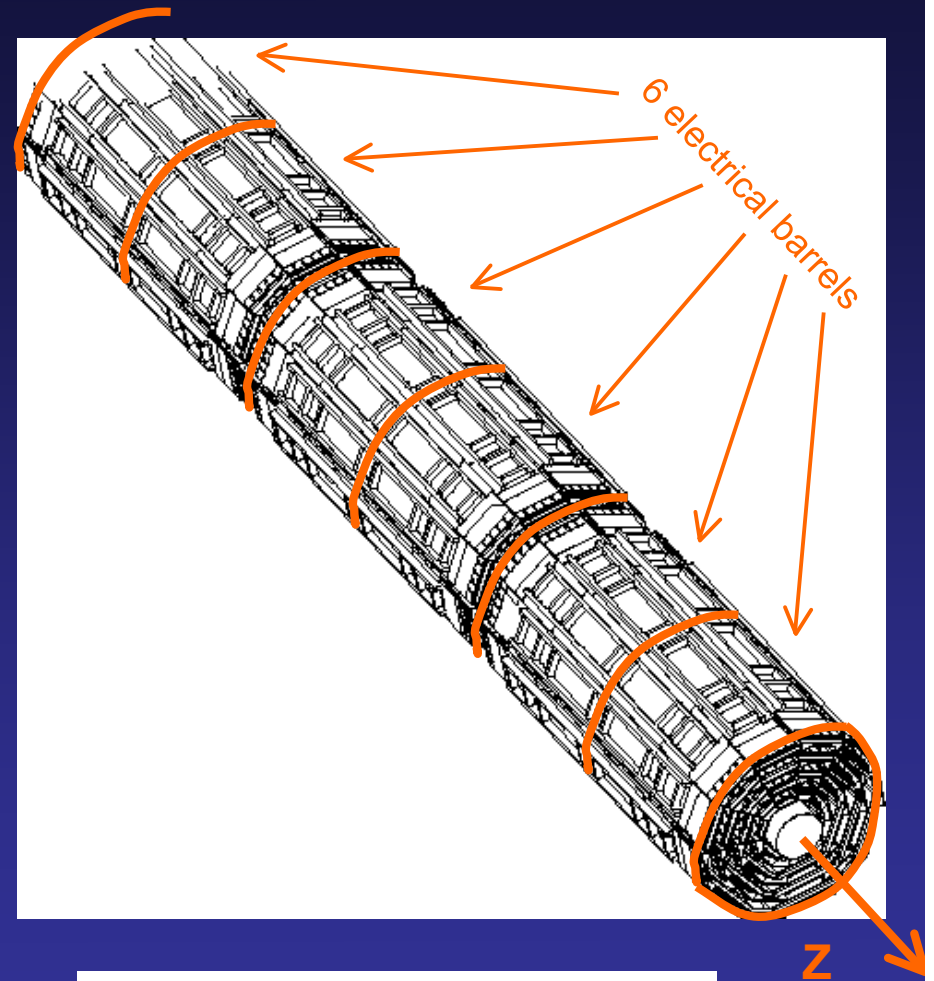
3D fit through 6 points yields
x_0, y_0, dx/dz, dy/dz

correcting the impact parameter in real time

x 12

tracks

i.p.
correction

FPGA board

L2
decision

tracks
(sample)

beam
finder

CPU

beam position

beam position is updated every few seconds


```
SVT: Online Beam Position Monitor

This page updates automatically every 5 seconds

Last update : 2011/05/31 22:12:14

Coordinates are in microns

   z   ntrks     x        y       sigma   err x   err y   corr     width x        width y
-----------------------------------------------------------------------------------------------
  0:   3752 -1480.02  1810.21    74.26   1.647   1.877  -0.000    25.68 + 2.01    26.23 + 1.95
  1:   9640 -1402.98  1790.97    76.32   1.120   1.081  -0.000    20.34 + 1.85    21.90 + 1.53
  2: 20395 -1324.35  1764.85    76.53   0.759   0.759   0.000    18.63 + 1.59    16.34 + 2.20
  3: 15558 -1255.85  1756.51    72.78   0.854   0.801   0.000    20.23 + 1.25    14.26 + 1.88
  4:   9551 -1170.92  1736.31    74.08   0.999   1.181  -0.000    19.05 + 2.21    24.17 + 1.53
  5:   4950 -1102.15  1707.77    75.11   1.508   1.523  -0.000    26.14 + 2.24    24.70 + 2.35
-----------------------------------------------------------------------------------------------
```
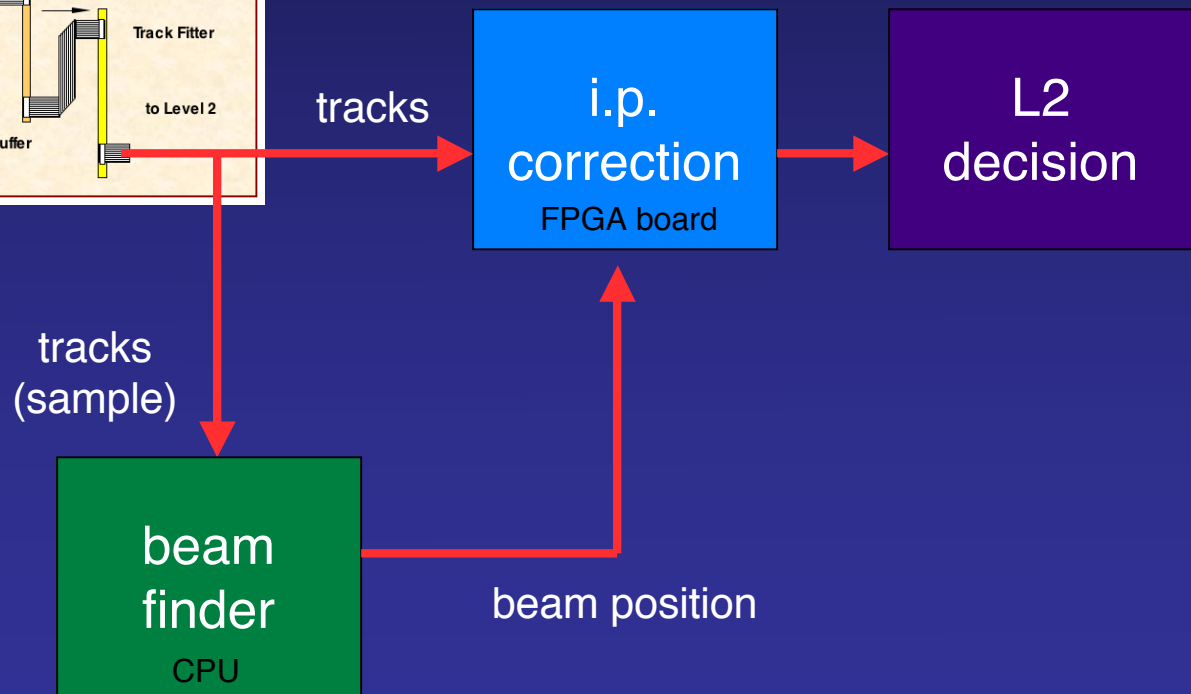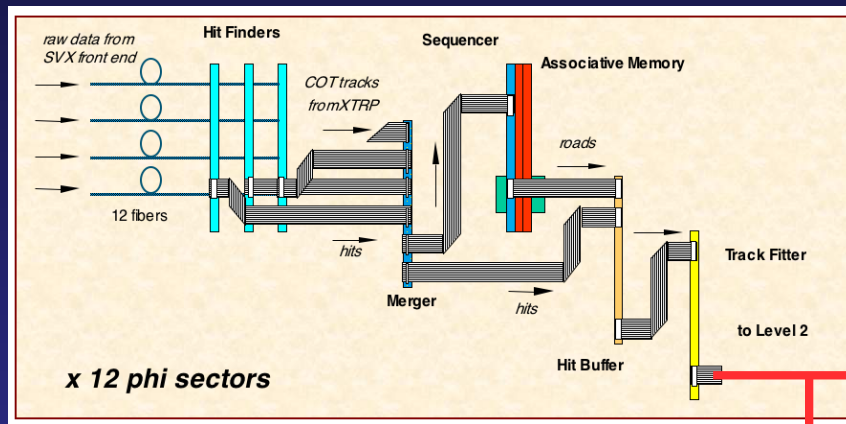
beam position is updated every few seconds

SVT: Online Beam Position Monitor

This page updates automatically every 5 seconds

Last update : 2011/05/31 22:12:28

Coordinates are in microns

z	ntrks	x	y	sigma	err x	err y	corr	width x	width y
0:	3637	-1477.96	1811.52	76.38	1.714	1.948	-0.000	25.68 + 2.01	26.23 + 1.95
1:	9483	-1406.24	1790.32	78.61	1.163	1.123	-0.000	20.34 + 1.85	21.90 + 1.53
2:	20497	-1325.53	1767.62	77.16	0.768	0.759	0.000	18.63 + 1.59	16.34 + 2.20
3:	15781	-1257.27	1756.84	74.39	0.870	0.812	0.000	20.23 + 1.25	14.26 + 1.88
4:	9765	-1172.12	1736.14	76.64	1.031	1.201	-0.000	19.05 + 2.21	24.17 + 1.53
5:	4860	-1101.49	1711.35	74.85	1.513	1.533	-0.000	26.14 + 2.24	24.70 + 2.35

beam position is updated every few seconds

SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

This page updates automatically every 5 seconds

Last update : 2011/05/31 22:16:45

Coordinates are in microns

z	ntrks	x	y	sigma	err x	err y	corr	width x	width y
0:	3721	-1479.20	1812.06	75.59	1.693	1.892	-0.000	25.68 + 2.01	26.23 + 1.95
1:	9287	-1401.28	1794.58	75.65	1.137	1.087	-0.000	20.34 + 1.85	21.90 + 1.53
2:	20227	-1324.08	1762.63	77.56	0.772	0.771	0.000	18.63 + 1.59	16.34 + 2.20
3:	15599	-1255.75	1756.22	73.92	0.875	0.808	0.000	20.23 + 1.25	14.26 + 1.88
4:	9635	-1169.20	1735.19	73.75	0.987	1.183	-0.000	19.05 + 2.21	24.17 + 1.53
5:	4769	-1100.14	1706.75	76.07	1.578	1.546	-0.000	26.14 + 2.24	24.70 + 2.35

beam position is updated every few seconds

SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

This page updates automatically every 5 seconds

Last update : 2011/05/31 22:16:59

Coordinates are in microns

z	ntrks	x	y	sigma	err x	err y	corr	width x	width y
0:	3537	-1479.45	1809.98	74.45	1.720	1.907	-0.000	25.68 + 2.01	26.23 + 1.95
1:	8674	-1402.72	1786.58	77.76	1.192	1.171	-0.000	20.34 + 1.85	21.90 + 1.53
2:	19118	-1321.69	1763.39	77.53	0.797	0.791	0.000	18.63 + 1.59	16.34 + 2.20
3:	14905	-1254.12	1756.48	74.75	0.896	0.844	0.000	20.23 + 1.25	14.26 + 1.88
4:	9013	-1169.99	1736.86	73.41	1.031	1.181	-0.000	19.05 + 2.21	24.17 + 1.53
5:	4567	-1098.23	1714.14	75.29	1.589	1.566	-0.000	26.14 + 2.24	24.70 + 2.35

beam position is updated every few seconds

SVT: Online Beam Position Monitor

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SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

This page updates automatically every 5 seconds

Last update : 2011/05/31 22:17:13

Coordinates are in microns

z	ntrks	x	y	sigma	err x	err y	corr	width x	width y
0:	3645	-1478.42	1811.82	74.91	1.687	1.919	-0.000	25.68 + 2.01	26.23 + 1.95
1:	8818	-1404.67	1787.36	75.93	1.177	1.120	-0.000	20.34 + 1.85	21.90 + 1.53
2:	19865	-1321.86	1765.20	76.78	0.769	0.774	0.000	18.63 + 1.59	16.34 + 2.20
3:	15243	-1254.96	1756.24	74.14	0.892	0.818	0.000	20.23 + 1.25	14.26 + 1.88
4:	9068	-1168.39	1735.48	76.34	1.070	1.238	-0.000	19.05 + 2.21	24.17 + 1.53
5:	4450	-1104.10	1710.19	76.37	1.635	1.614	-0.000	26.14 + 2.24	24.70 + 2.35

beam position is updated every few seconds

SVT: Online Beam Position Monitor

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SVT: Online Beam Position Monitor

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SVT: Online Beam Position Monitor

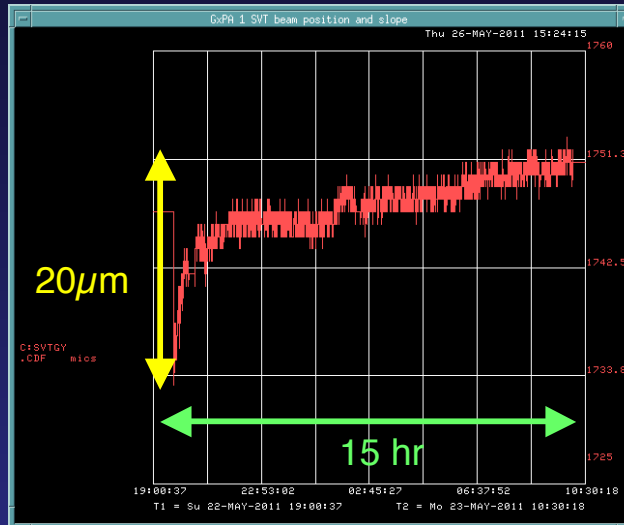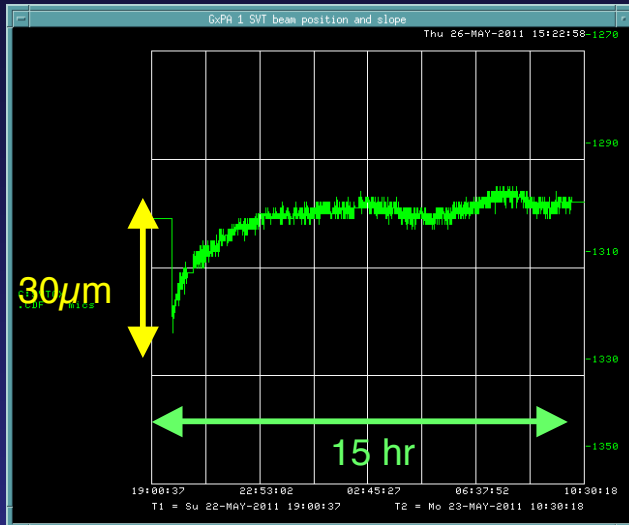This page updates automatically every 5 seconds

Last update : 2011/05/31 22:17:27

Coordinates are in microns

z	ntrks	x	y	sigma	err x	err y	corr	width x	width y
0:	3915	-1476.34	1812.35	76.94	1.685	1.849	-0.000	25.68 + 2.01	26.23 + 1.95
1:	9699	-1403.39	1788.71	77.38	1.137	1.089	-0.000	20.34 + 1.85	21.90 + 1.53
2:	20601	-1321.64	1766.22	76.84	0.763	0.755	0.000	18.63 + 1.59	16.34 + 2.20
3:	15629	-1252.76	1757.01	74.05	0.867	0.814	0.000	20.23 + 1.25	14.26 + 1.88
4:	10042	-1171.39	1736.71	75.89	1.001	1.176	-0.000	19.05 + 2.21	24.17 + 1.53
5:	4882	-1099.76	1709.18	75.75	1.547	1.527	-0.000	26.14 + 2.24	24.70 + 2.35

beam position is updated every few seconds

SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

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SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

SVT: Online Beam Position Monitor

This page updates automatically every 5 seconds

Last update : 2011/05/31 22:17:42

Coordinates are in microns

z	ntrks	x	y	sigma	err x	err y	corr	width x	width y
0:	3766	-1478.88	1811.32	76.79	1.693	1.913	-0.000	25.68 + 2.01	26.23 + 1.95
1:	9027	-1402.76	1792.14	77.34	1.195	1.115	-0.000	20.34 + 1.85	21.90 + 1.53
2:	19838	-1323.07	1766.63	78.20	0.792	0.779	0.000	18.63 + 1.59	16.34 + 2.20
3:	14718	-1254.77	1757.65	73.31	0.884	0.834	0.000	20.23 + 1.25	14.26 + 1.88
4:	8870	-1170.20	1735.44	74.17	1.039	1.218	-0.000	19.05 + 2.21	24.17 + 1.53
5:	4517	-1097.23	1712.87	75.98	1.606	1.607	-0.000	26.14 + 2.24	24.70 + 2.35

one Tevatron store

x

30μm

15 hr

y

20μm

15 hr

dx/dz

70 μrad

15 hr

dy/dz

50 μrad

15 hr

one week

Real Time Beam Position Monitoring at CDF - Luciano Ristori - TIPP - June 13, 2011

13
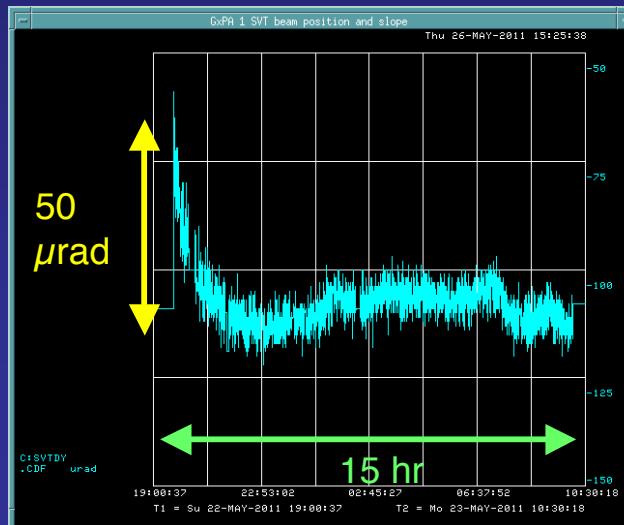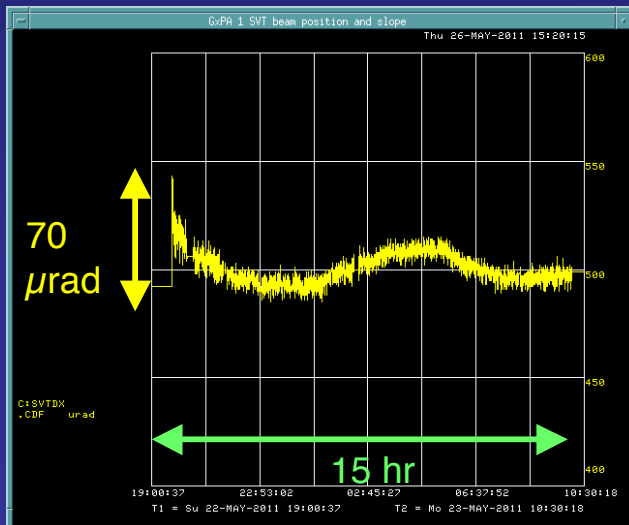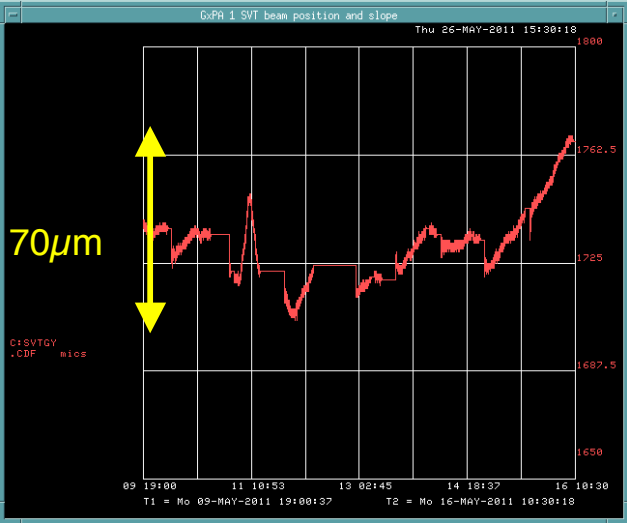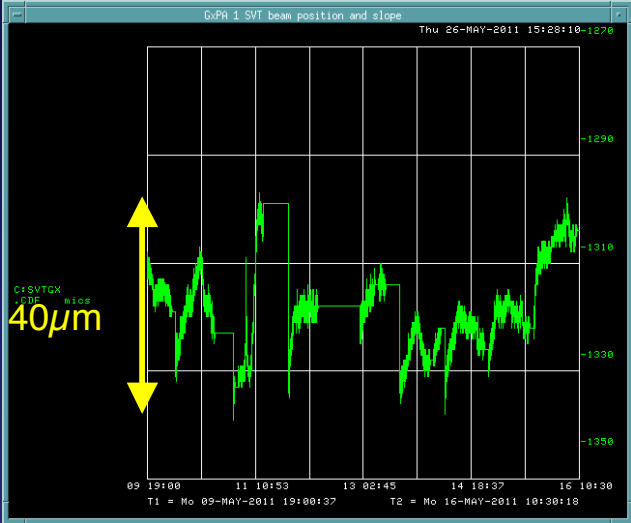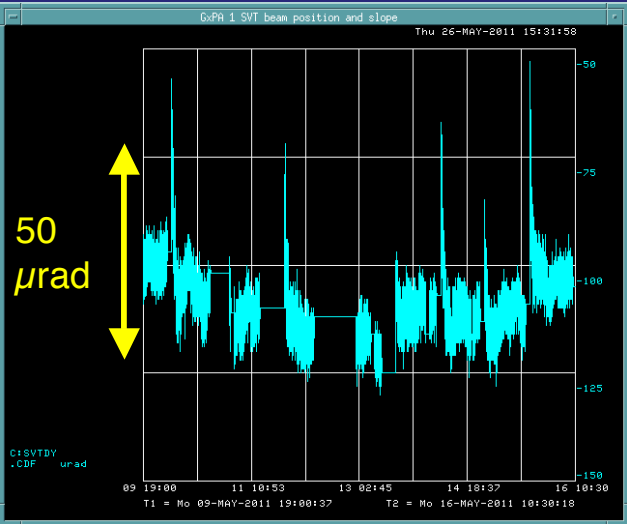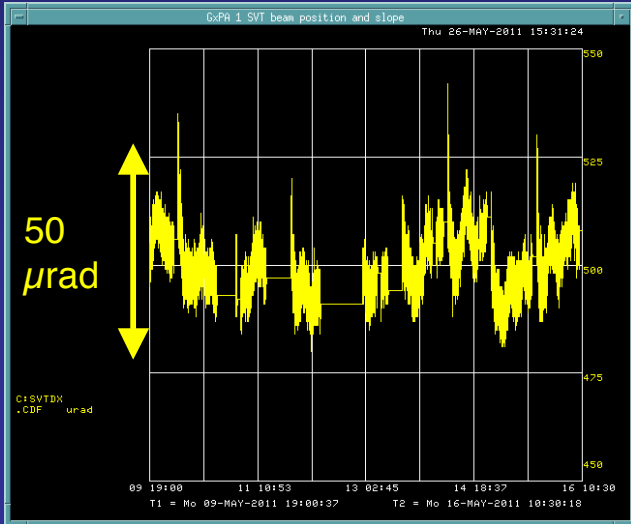
measuring beam spot size

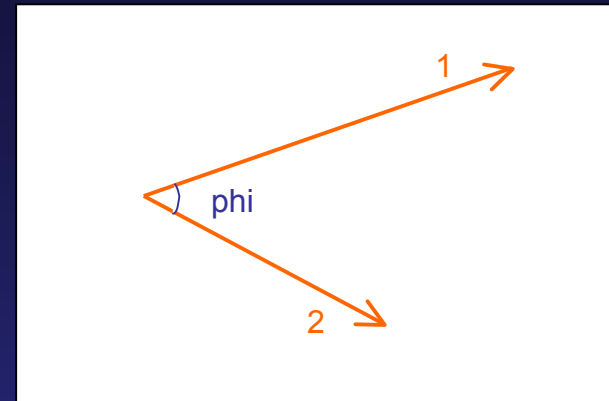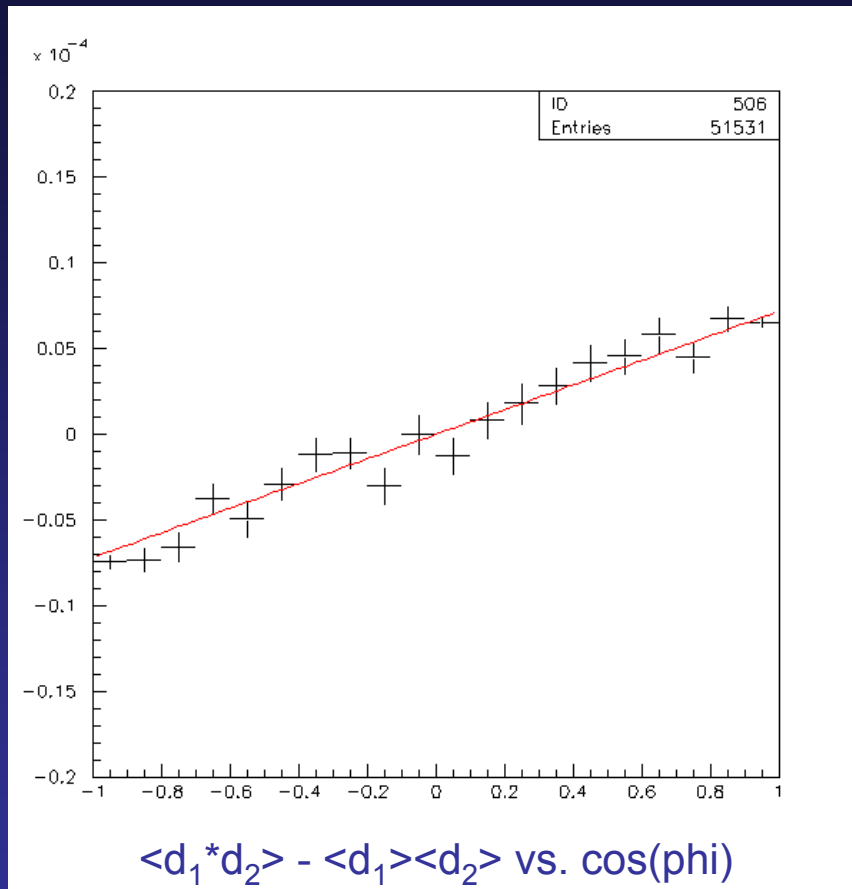# measuring beam spot size

Impact parameter distribution
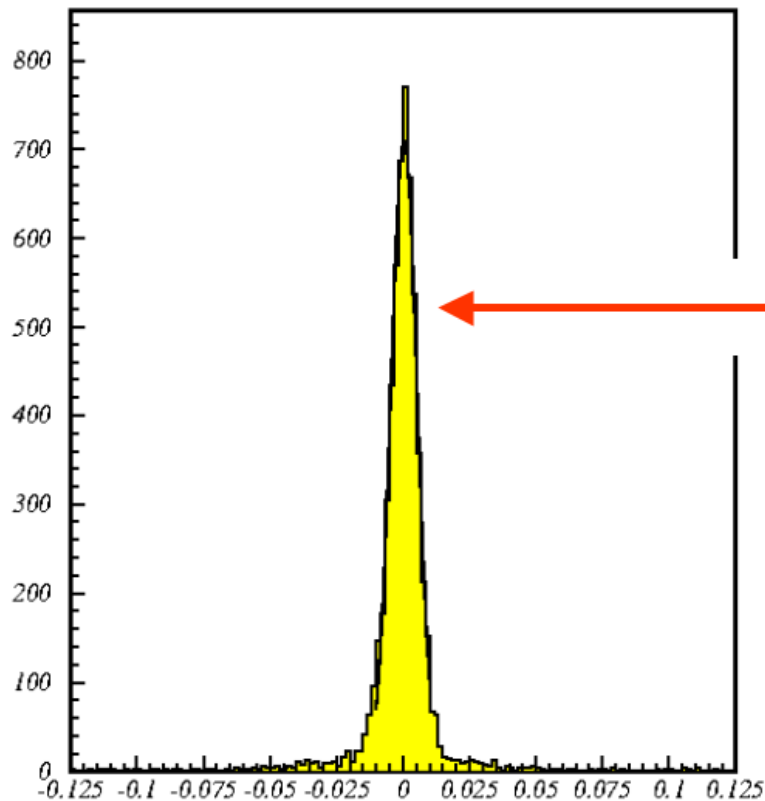
This distribution is interpreted as the convolution of the actual transverse size of the beam spot with the impact parameter resolution of the SVT

sigma ~ 48 um ~ 42 um $\oplus$ 23 um

SVT resolution   beam spot size

	beam	SVT	Total
sigma	23	42	48
rms	23	51	56

two track impact parameter correlation

$\langle d_1*d_2 \rangle - \langle d_1 \rangle \langle d_2 \rangle$ vs. cos(phi)

information on the intrinsic beam spot size can be extracted from the correlation between impact parameters of pairs of tracks coming from the same primary vertex

$$\langle d_1*d_2 \rangle - \langle d_1 \rangle \langle d_2 \rangle = \sigma^2 \cos(phi)$$

Intrinsic beam width

two track impact parameter correlation
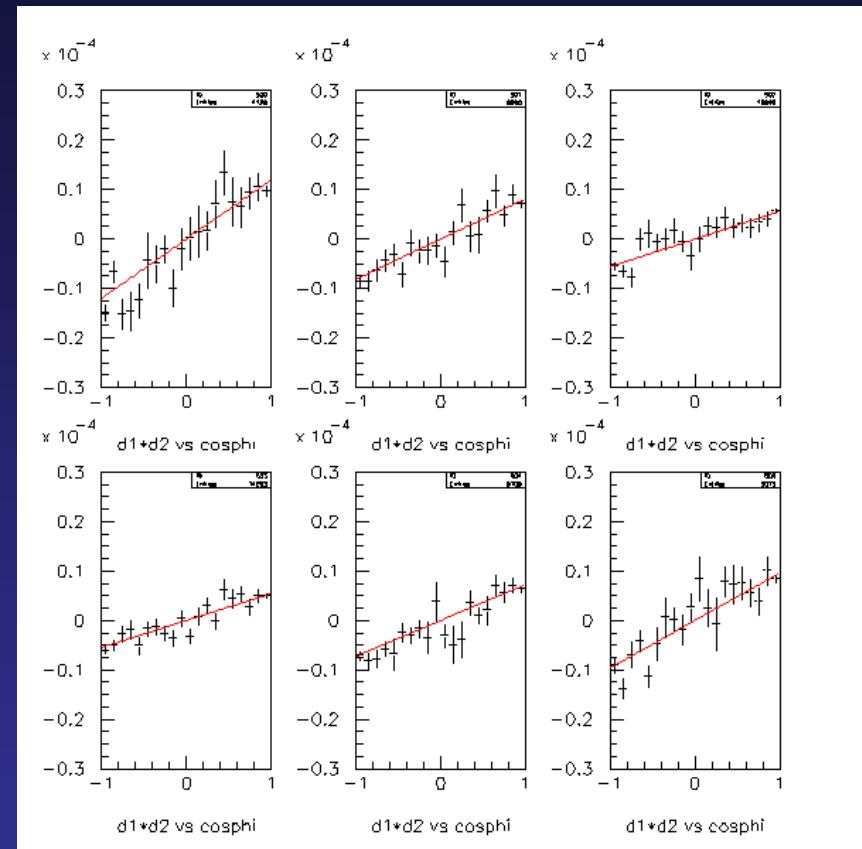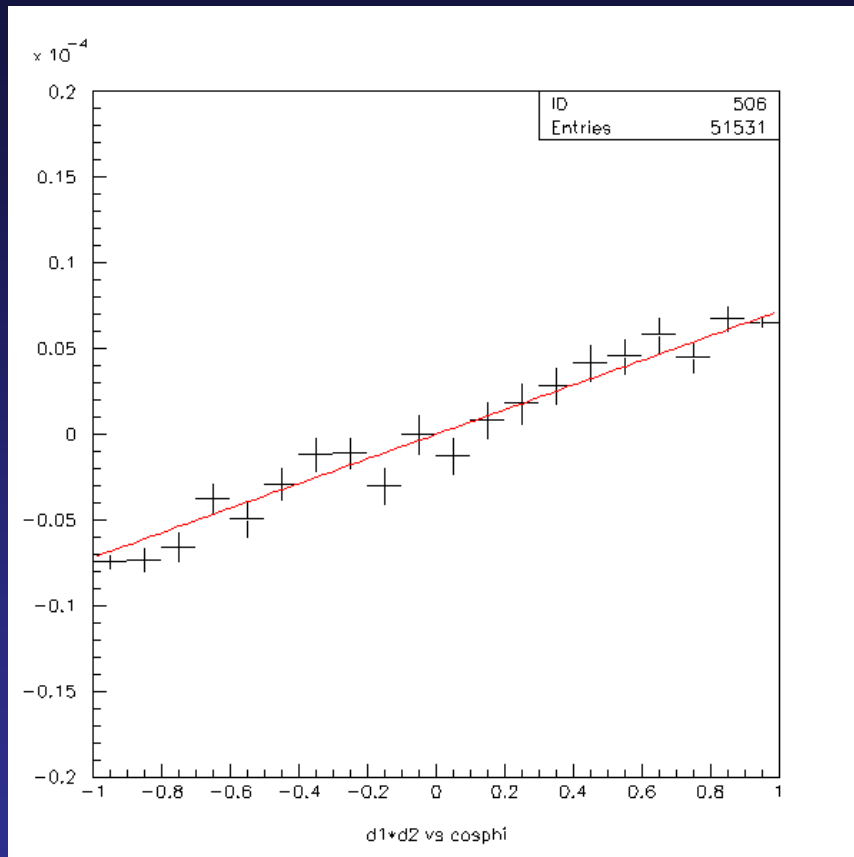
measure beam width in six z segments

the "hourglass"
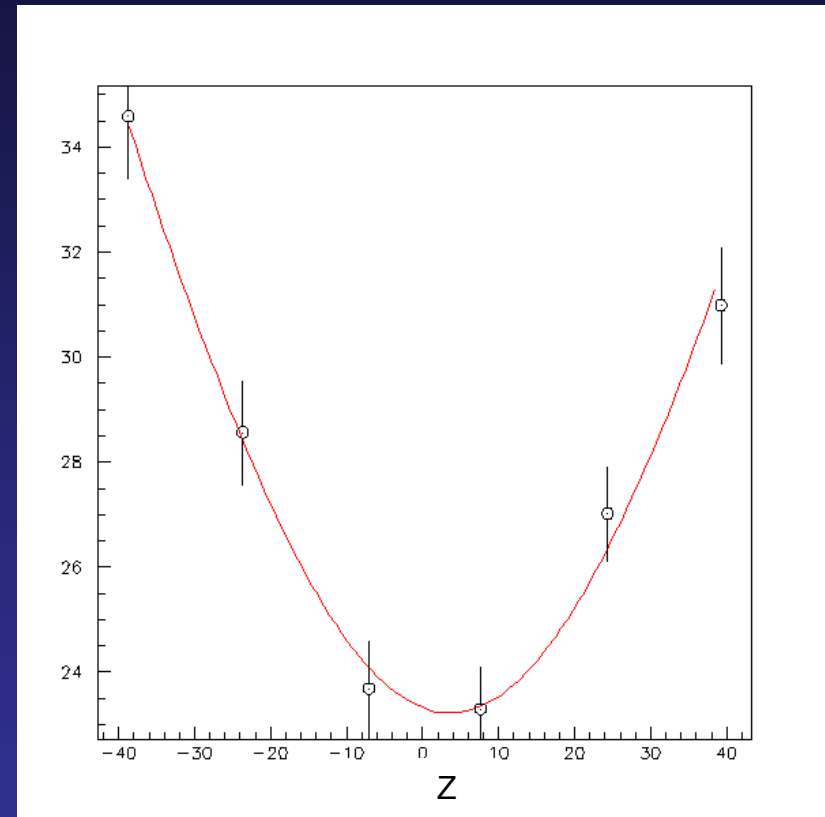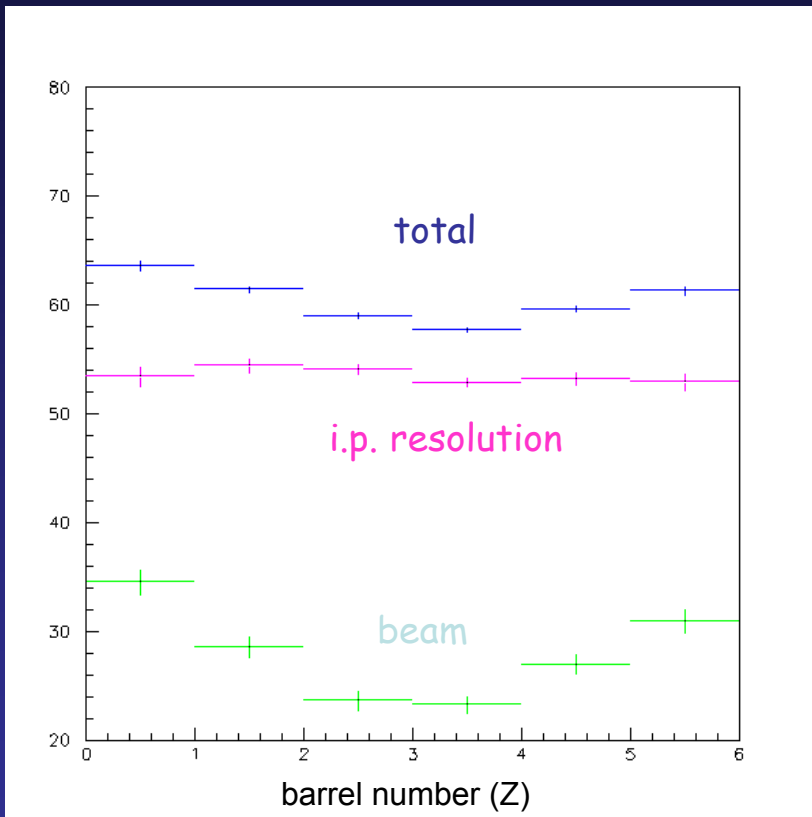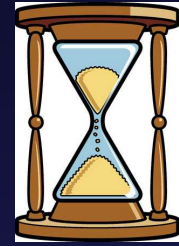
Emittance: 0.279E-08 +- 0.125E-09 m
    Beta*: 0.387E+00 +- 0.297E-01 m
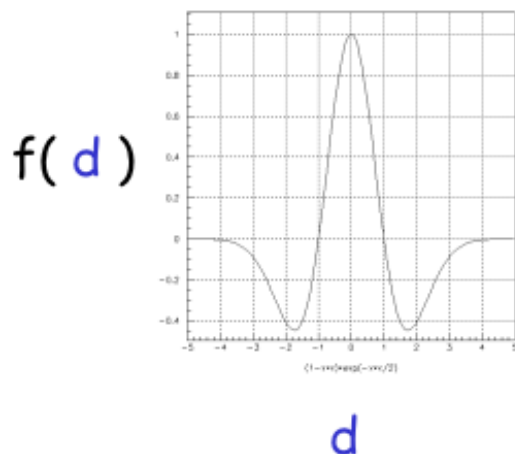   Z0: 0.359E+01 +- 0.141E+01 cm

beam spot tomography

beam spot tomography

To reconstruct x-y density of track vertices we can use the same imaging algorithm as used in Positron Emission Tomography.

$$\rho(\underline{x}) = \Sigma_k \, f(d(\underline{x}, t_k))$$

sum is over all tracks t_k

$d(\underline{x}, t_k)$: distance between point $\underline{x} = (x,y)$ and track t_k
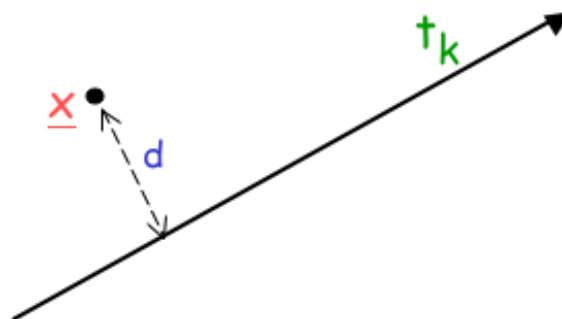
the mexican hat

Weighting Function for the tomography method:

$(1-x^2)*e-(x^2/2)$

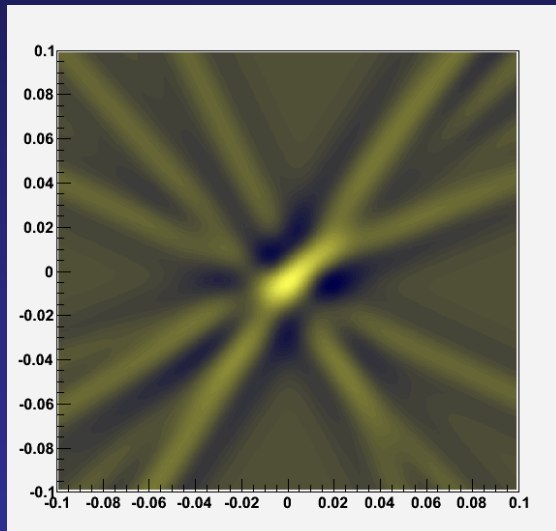Width determined by measurement resolution and desired precision…

$(1-x \cdot x) \cdot \exp(-x \cdot x/2)$
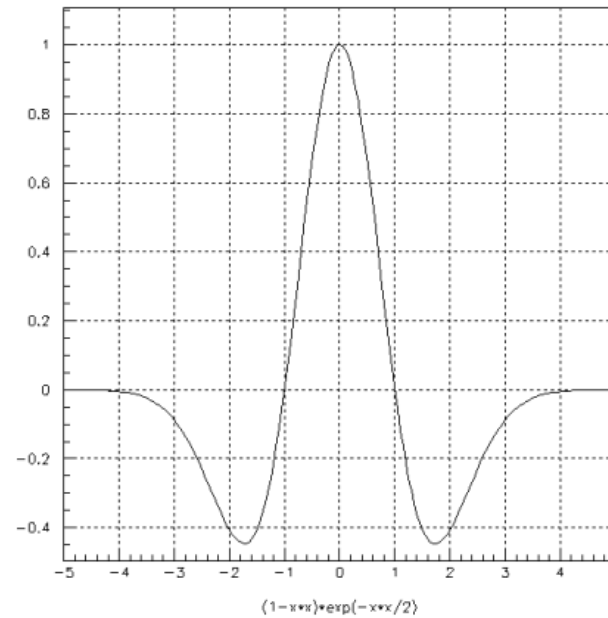
second derivative of a gaussian
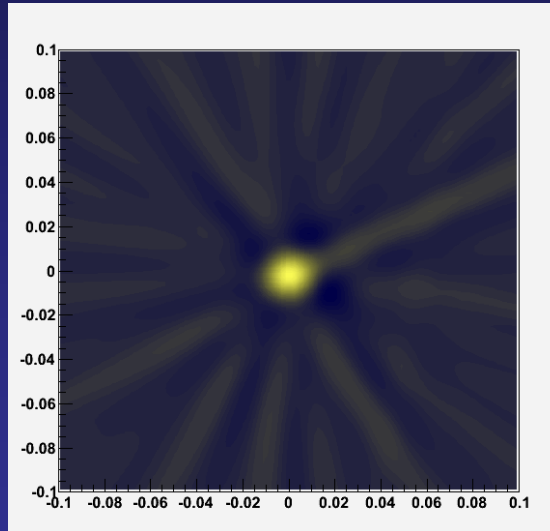
width must be optimized for the problem at hand
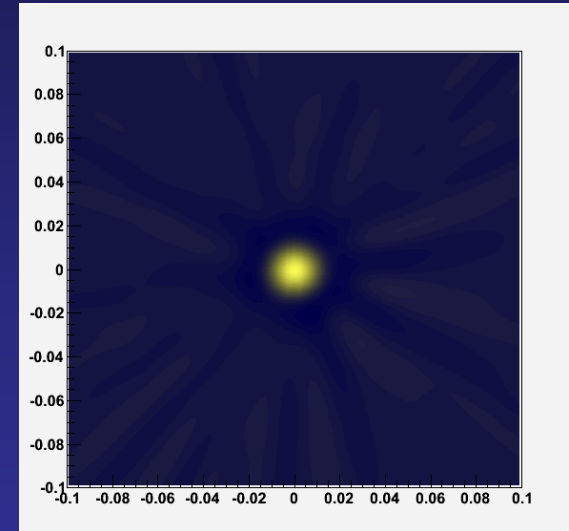
reconstructing a 2D image

2 x 2 mm^2

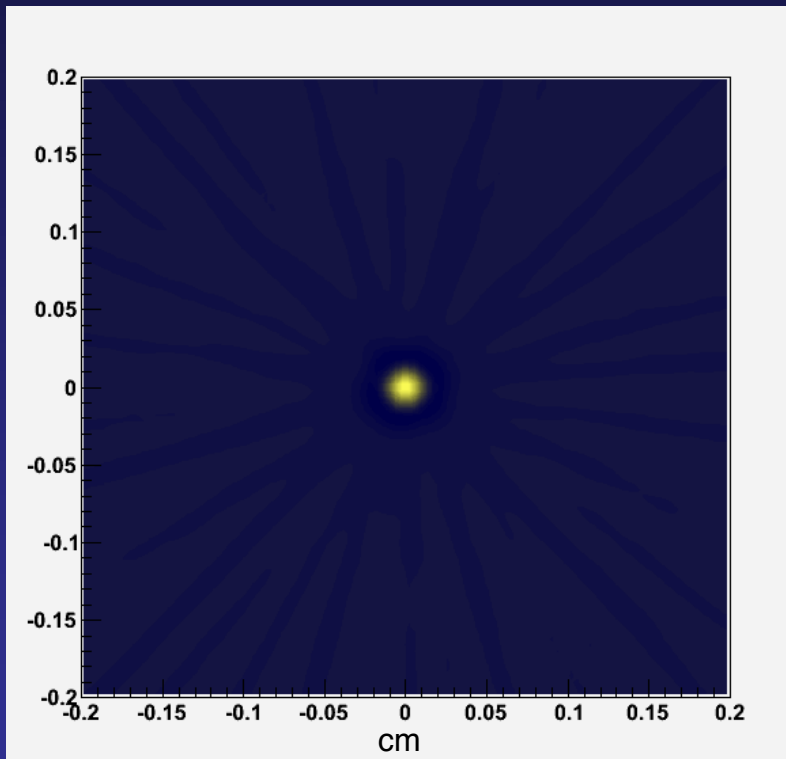10 tracks   100 tracks   1000 tracks

what if the beam moves?

4 x 4 mm^2
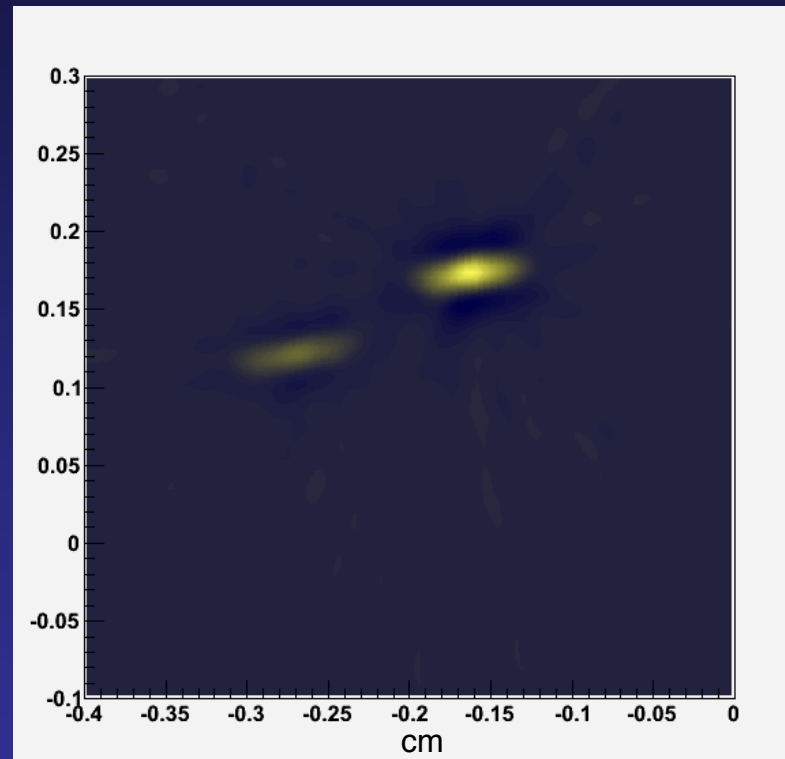
i.p. corrected   100,000 tracks   i.p. uncorrected
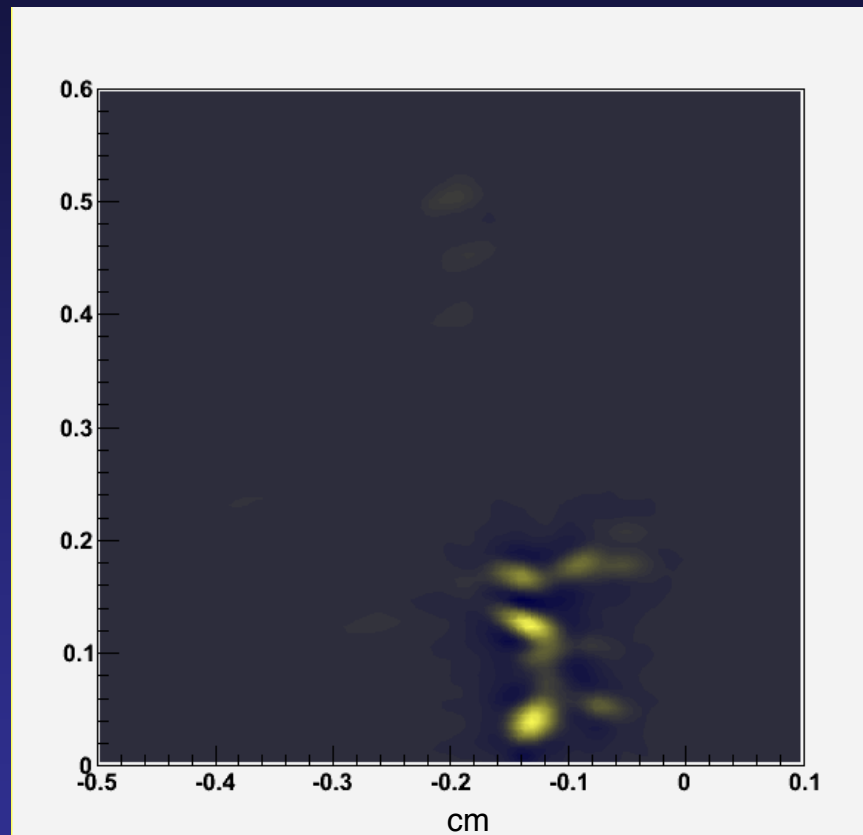
footprints of the Tevatron beam

6 x 6 mm^2

17 million tracks - uncorrected

Feb 2002 - Feb 2010

summary

- ## monitoring beam position in real time
  - crucial for SVT to work
  - performed continuosly and reliably in the last 10 years

- ## measuring beam spot size
  - done offline
  - never really managed to implement it reliably in real time

- ## beam spot tomography
  - just a cool idea