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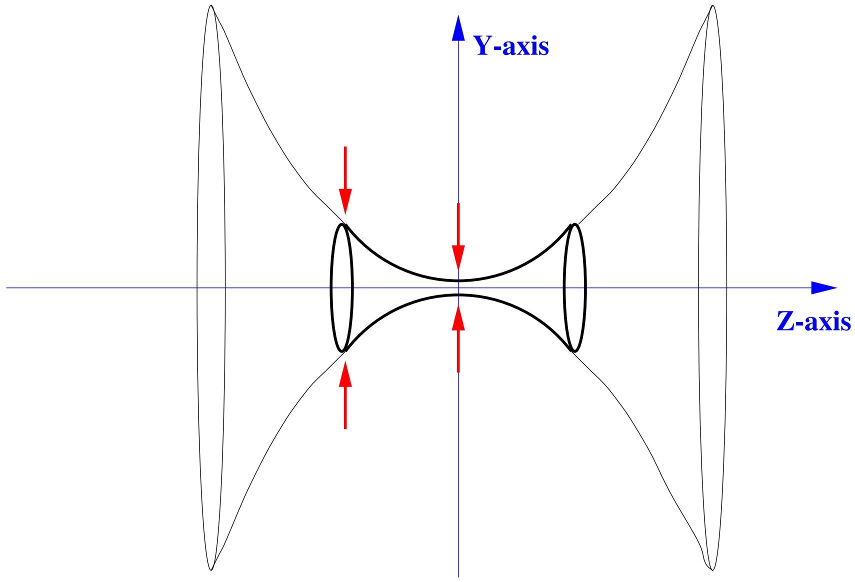
May 2000

Observation of the Hourglass Effect at CESR with CLEO

- Hourglass Effect
- Method of Analysis
- Results

Hourglass Effect

•Tight focusing of beams at the interaction point cause the transverse size of the luminous region to grow away from a waist

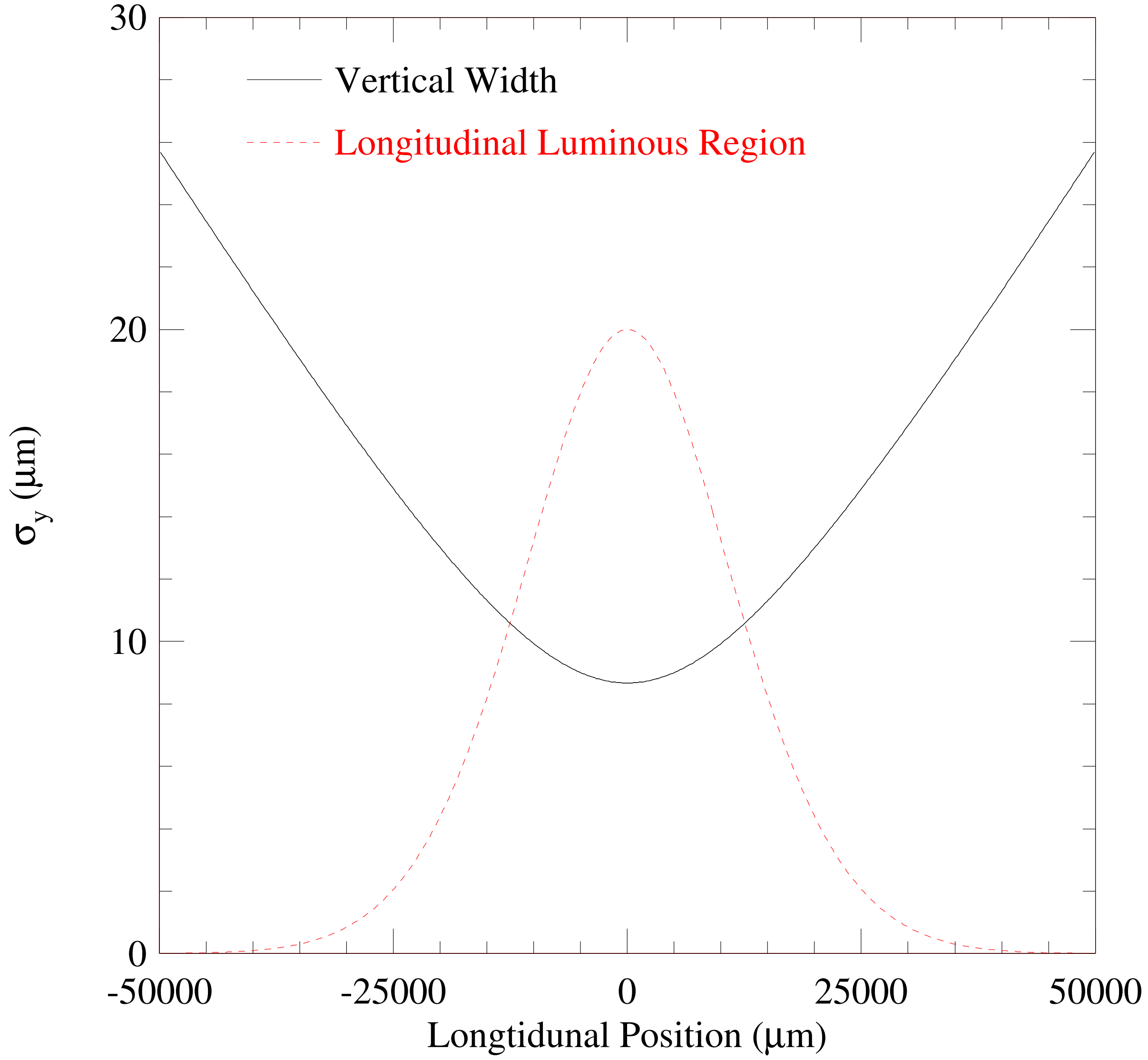


•Results in reduction of luminosity as $\beta*$ becomes smaller than bunch length (σ_z)

•Longitudinal width of the luminous region (assuming zero dispersion)

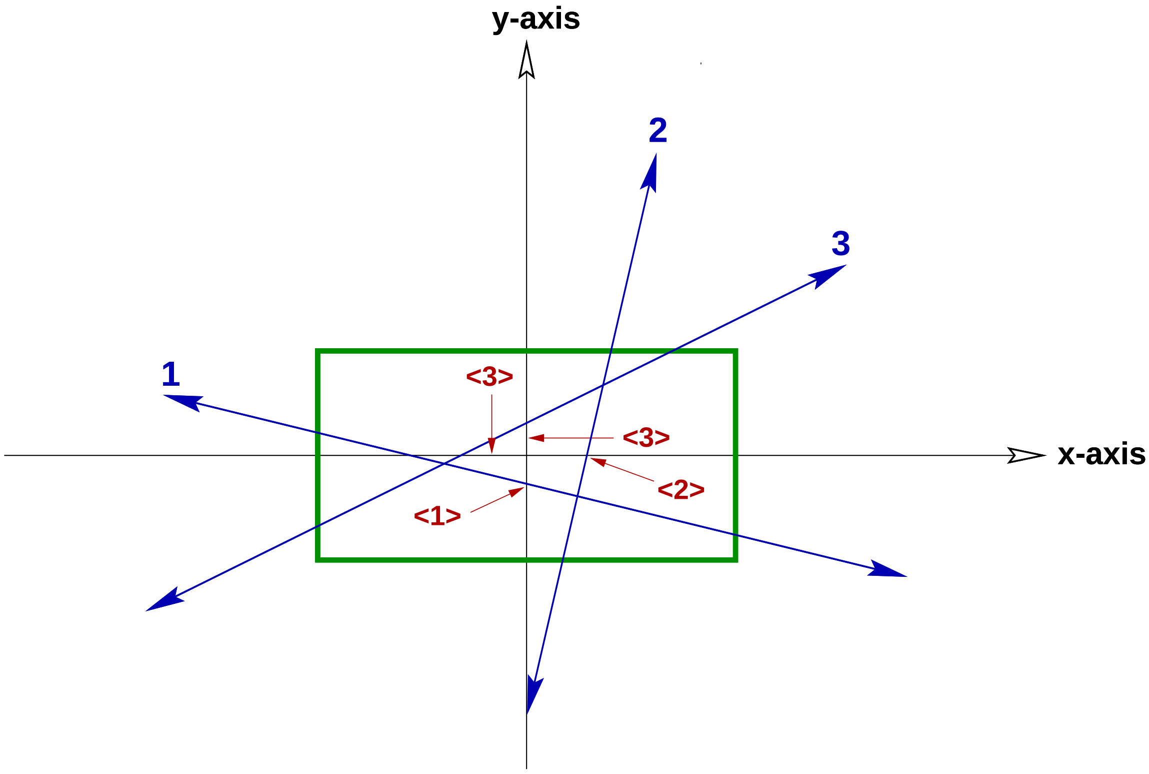
$$\sigma(z) = \sqrt{\frac{\epsilon}{2}\left(\beta^* + \frac{(z - z_0)^2}{\beta^*}\right)} \tag{1}$$

Expected Vertical Width of the Luminous Region



Box Technique

Use $e^+e^- \to \mu^+\mu^-$ events



- Box determined from independent measurement of position and shape of luminous region
- Average position of track is found to determine size and shape of luminous region
- Tracks with small direction cosines are most useful

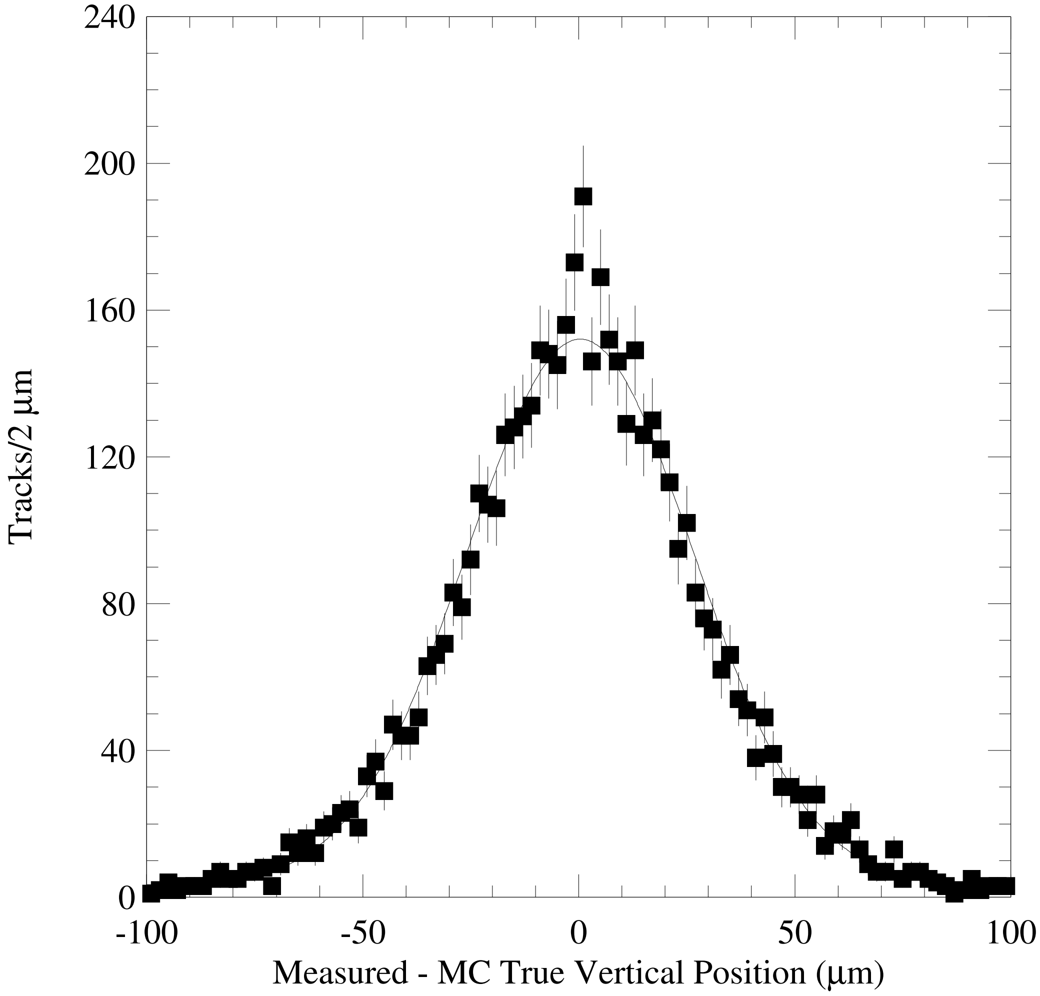
Resolution of Box Technique on the Vertical Position

MINUIT Likelihood Fit to Plot 307&1

File: */tem/cinabro/twolummc.rzn — 8-APR-2000 15:55
Plot Area Total/Fit 5249.0 / 5249.0 — Fit Status 3
Func Area Total/Fit 5249.0 / 5249.0 — E.D.M. 1.061E-06

Likelihood = 81.4
χ^2= 82.5 for 100 - 4 d.o.f., C.L.= 83.5%

Errors		Parabolic	Minos	
Function 1: Gaussian (sigma)				
AREA	4915.8	± 82.28	- 0.0000E+00	+ 0.0000E+00
MEAN	0.34528	± 0.3768	- 0.0000E+00	+ 0.0000E+00
SIGMA	26.370	± 0.4137	- 0.0000E+00	+ 0.0000E+00
Function 2: Polynomial of Order 0				
NORM	1.6700	± 0.2333	- 0.0000E+00	+ 0.0000E+00



Resolution = 26.4 μ m

Resolution of Box Technique on the Horizontal Position

MINUIT Likelihood Fit to Plot 1000&1

MC X-Pos Res: (3,3)

File: /tem/cinabro/twolummc.rzn 4-APR-2000 18:57

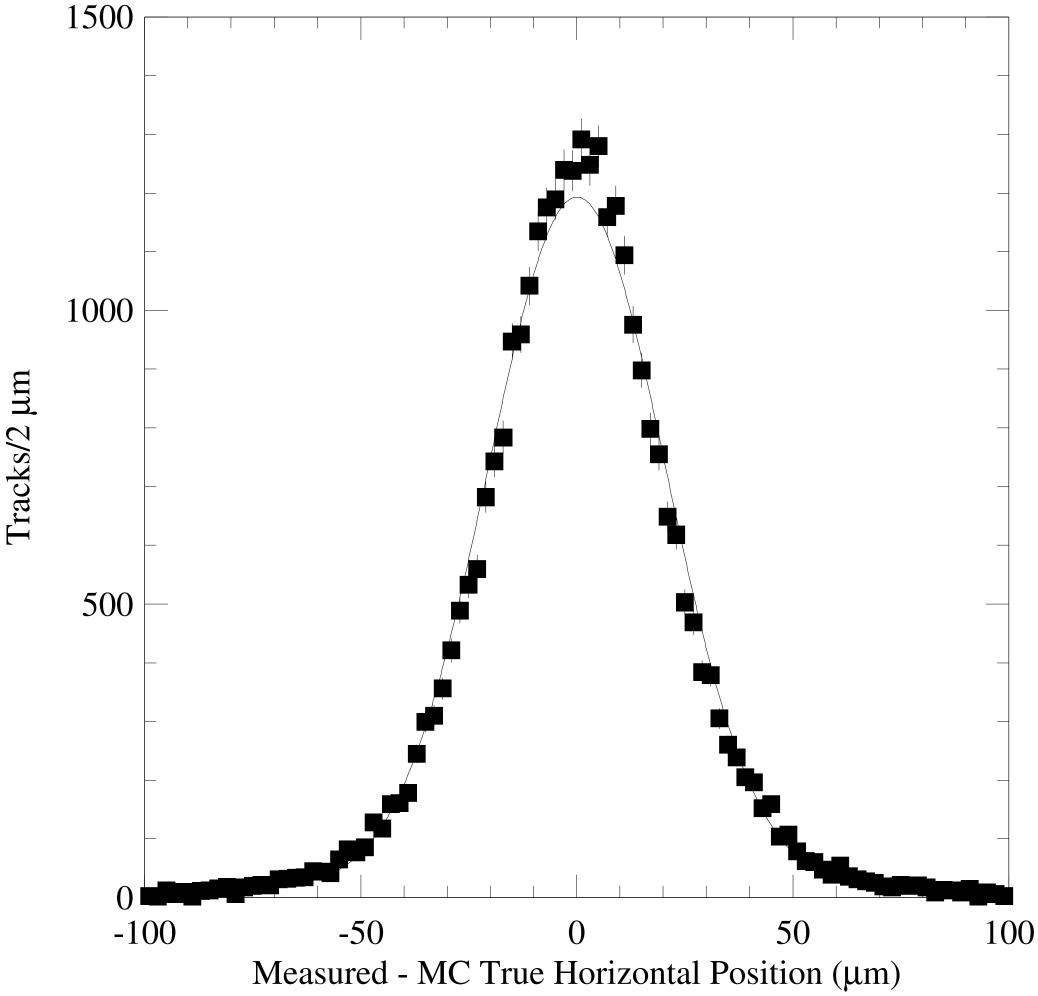
Plot Area Total/Fit 31905. / 31905. Fit Status 3

Func Area Total/Fit 31905. / 31905. E.D.M. 4.296E-06

Likelihood = 362.8

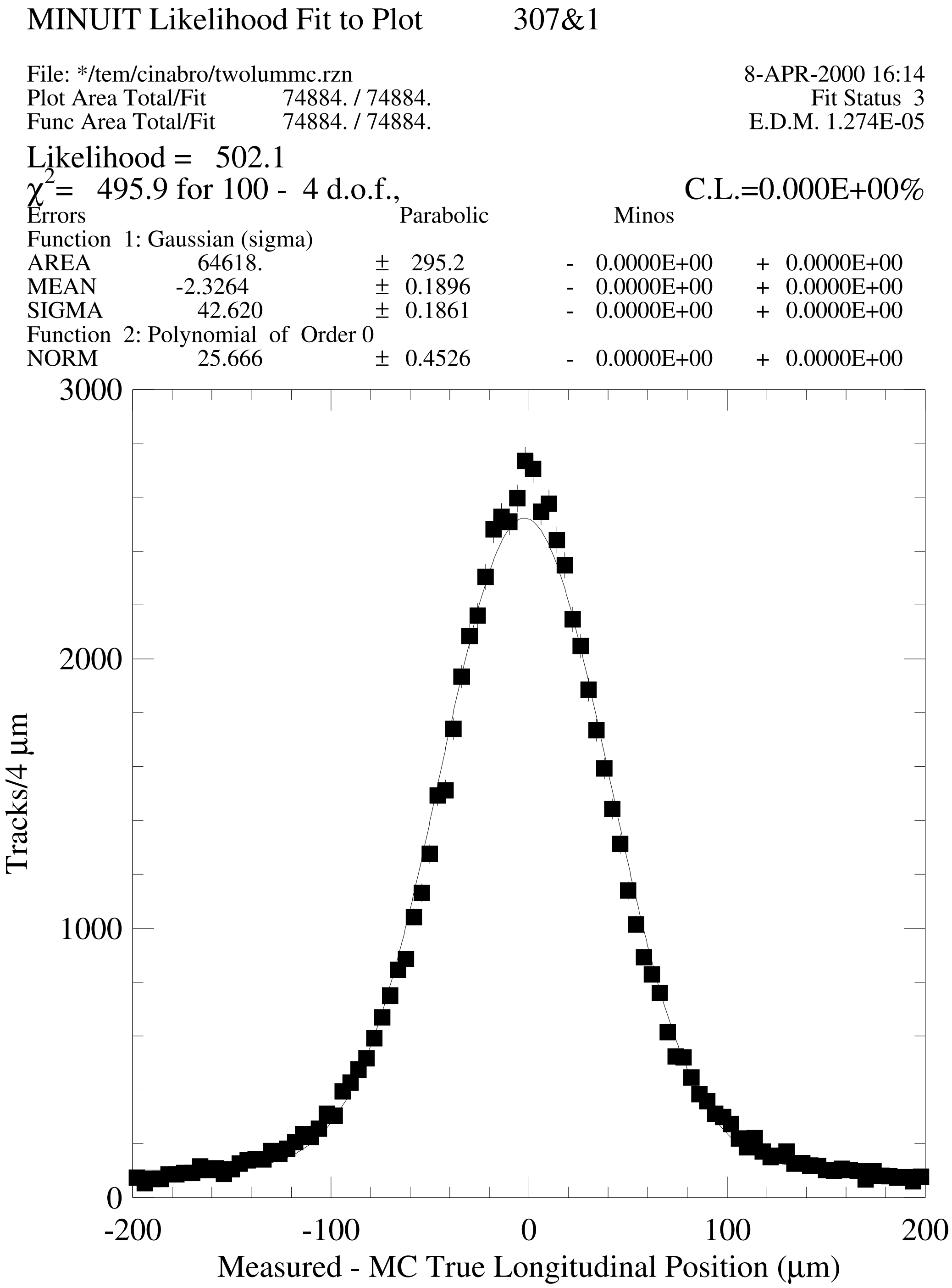
χ^2= 339.6 for 100 - 4 d.o.f., C.L.=0.624E-26%

Errors		Parabolic	Minos	
Function 1: Gaussian (sigma)				
AREA	30420.	± 185.5	- 0.0000E+00	+ 0.0000E+00
MEAN	5.46650E-02	± 0.1250	- 0.0000E+00	+ 0.0000E+00
SIGMA	20.601	± 0.1126	- 0.0000E+00	+ 0.0000E+00
Function 2: Polynomial of Order 0				
NORM	7.4249	± 0.3696	- 0.0000E+00	+ 0.0000E+00



Resolution = 20.6 μ m

Resolution of Box Technique on the Longitudinal Position



Resolution $= 42.6\ \mu$ m

Vertical Distribution of Luminous Region

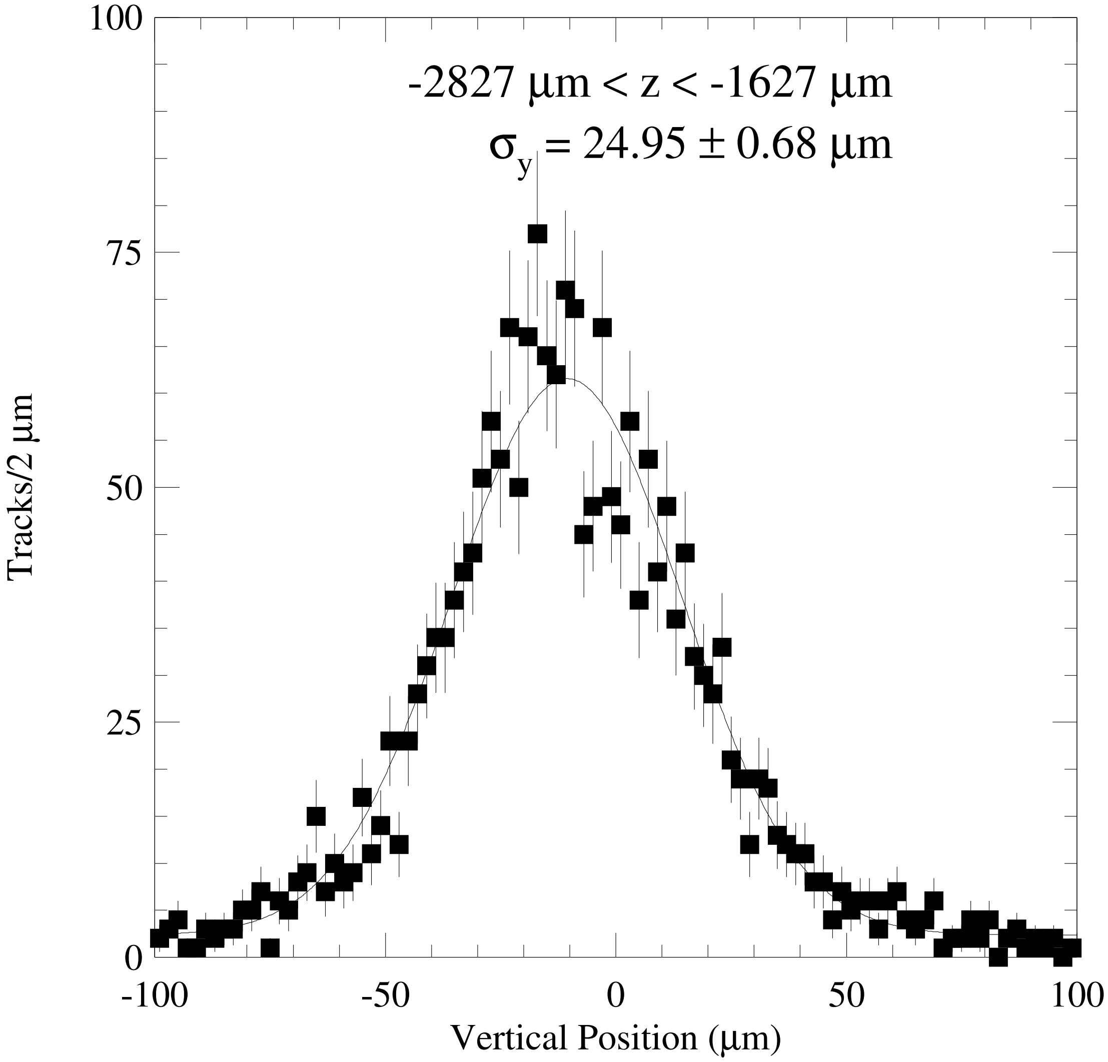
MINUIT Likelihood Fit to Plot 307&18

File: */stm/cinabro/twolum_307.rzn		6-APR-2000 10:28
Plot Area Total/Fit	2087.0 / 2087.0	Fit Status 3
Func Area Total/Fit	2087.0 / 2087.0	E.D.M. 1.675E-08

Likelihood = 94.4

χ^2= 89.2 for 100 - 4 d.o.f., C.L.= 67.5%

Errors		Parabolic	Minos	
Function 1: Gaussian (sigma)				
AREA	1850.6	± 53.70	- 0.0000E+00	+ 0.0000E+00
MEAN	-10.596	± 0.6518	- 0.0000E+00	+ 0.0000E+00
SIGMA	24.946	± 0.6816	- 0.0000E+00	+ 0.0000E+00
Function 2: Polynomial of Order 0				
NORM	1.1835	± 0.1681	- 0.0000E+00	+ 0.0000E+00



Range Near Center of Longitudinal Distribution

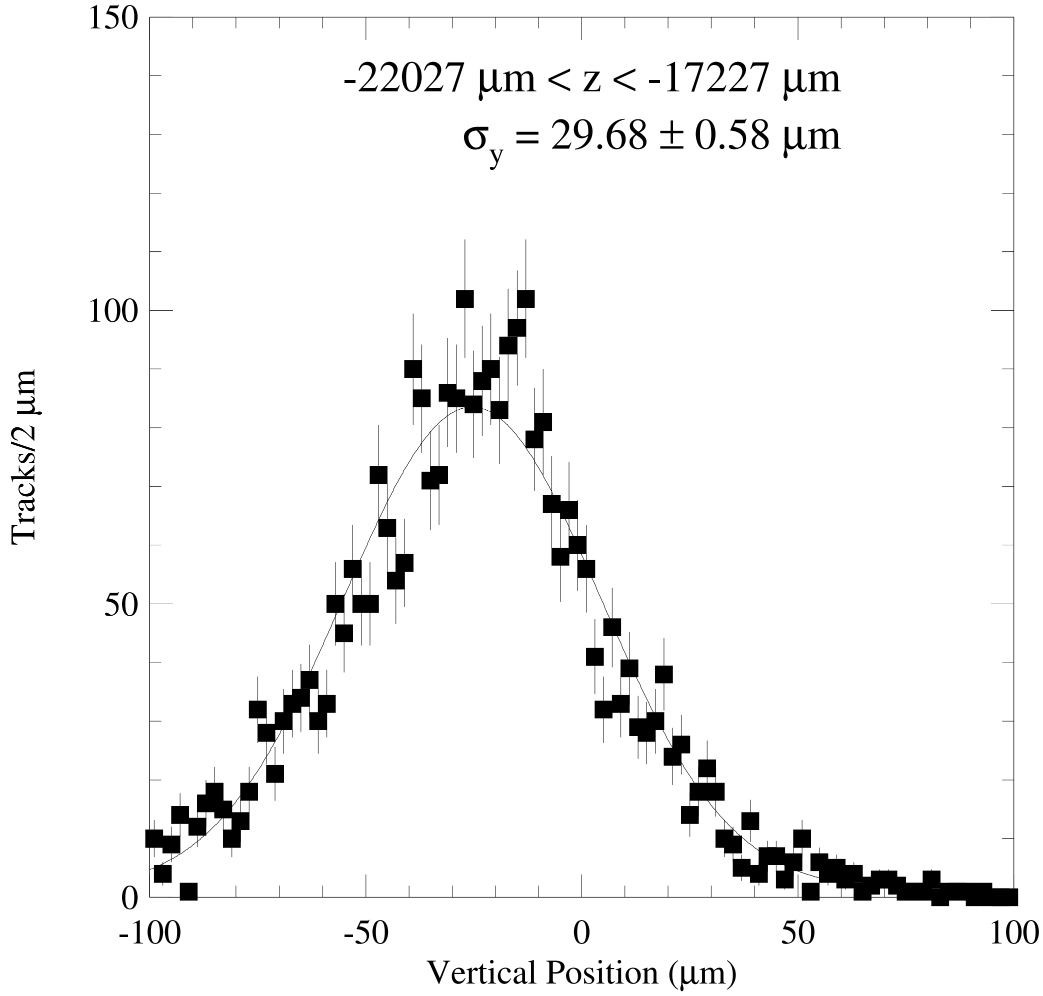
Vertical Distribution of Luminous Region

MINUIT Likelihood Fit to Plot 307&29

File: */stm/cinabro/twolum_307.rzn 6-APR-2000 10:40
Plot Area Total/Fit 3166.0 / 3166.0 Fit Status 3
Func Area Total/Fit 3165.9 / 3165.9 E.D.M. 4.337E-07

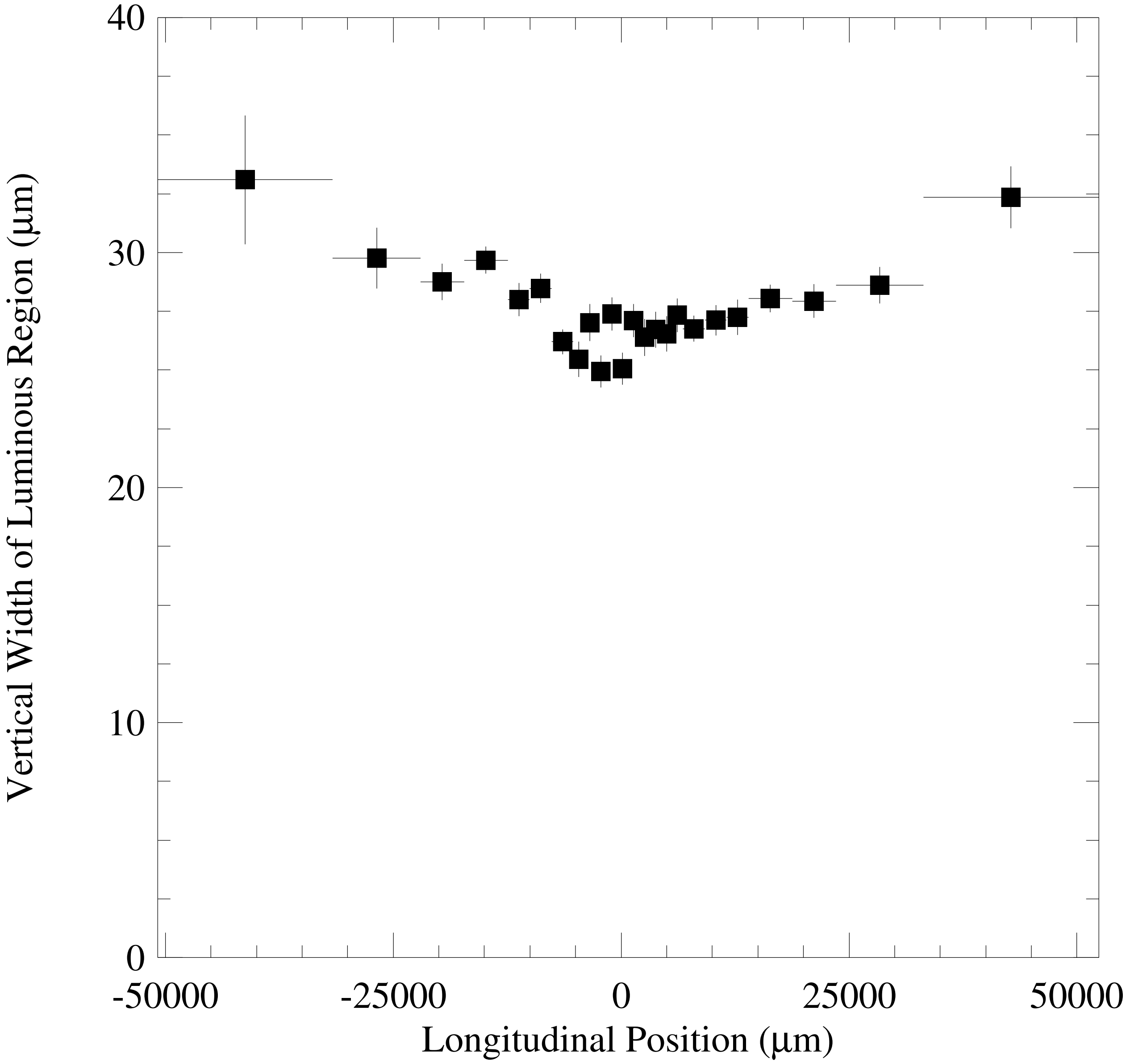
Likelihood = 147.9
χ^2= 142.0 for 100 - 4 d.o.f., C.L.=0.161 %

Errors		Parabolic	Minos	
Function 1: Gaussian (sigma)				
AREA	3062.0	± 64.64	- 0.0000E+00	+ 0.0000E+00
MEAN	-25.382	± 0.5728	- 0.0000E+00	+ 0.0000E+00
SIGMA	29.678	± 0.5842	- 0.0000E+00	+ 0.0000E+00
Function 2: Polynomial of Order 0				
NORM	0.61103	± 0.1628	- 0.0000E+00	+ 0.0000E+00



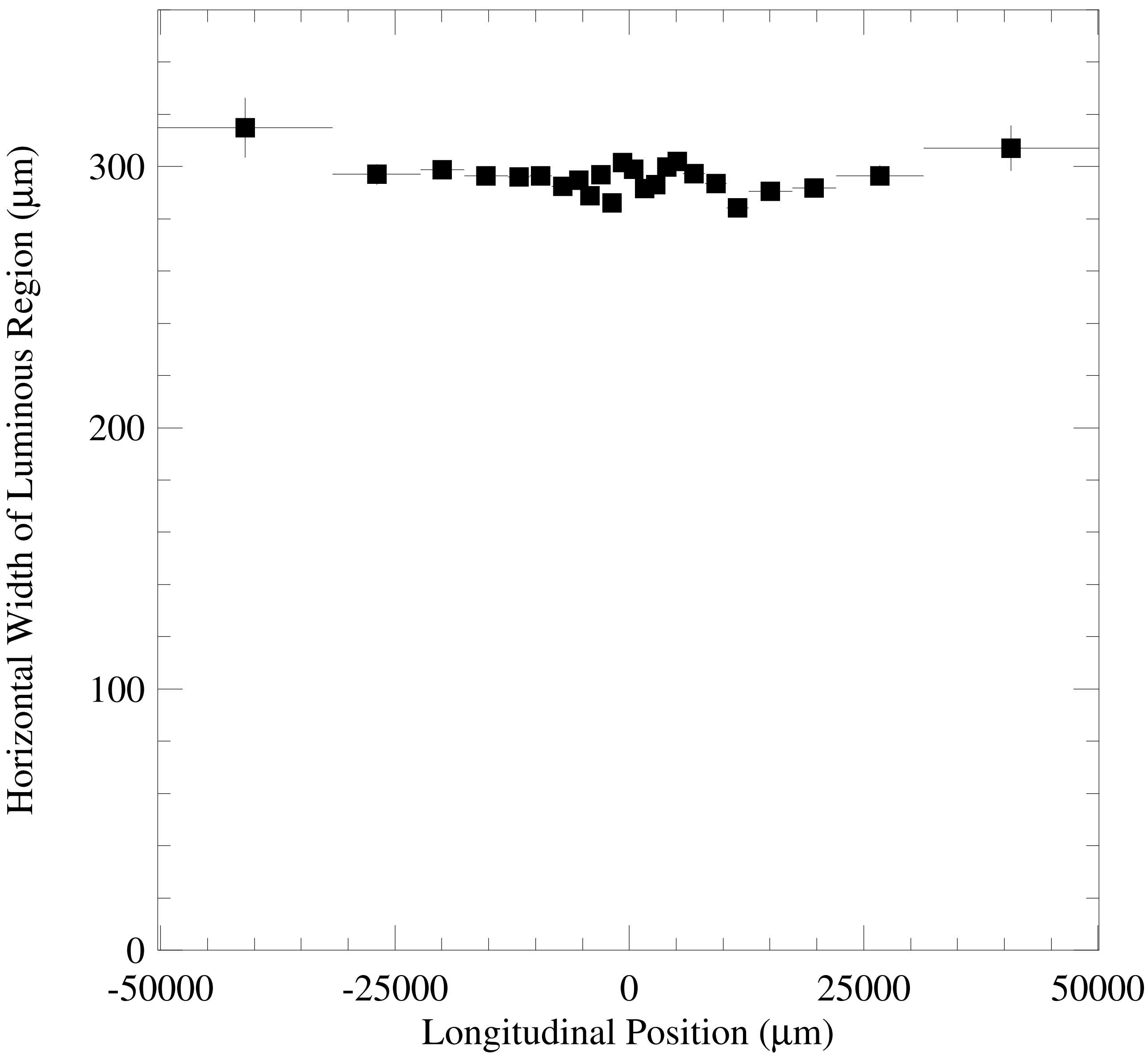
Range Near Edge of Longitudinal Distribution

Vertical Width of the Luminous Region v Longitudinal Position



Hourglass effect clearly visible

Horizontal Width of the Luminous Region v Longitudinal Position



No hourglass effect is visible

Extraction of Beam Parameters

- Fit distributions for:

  Beta β

  Emittance ϵ

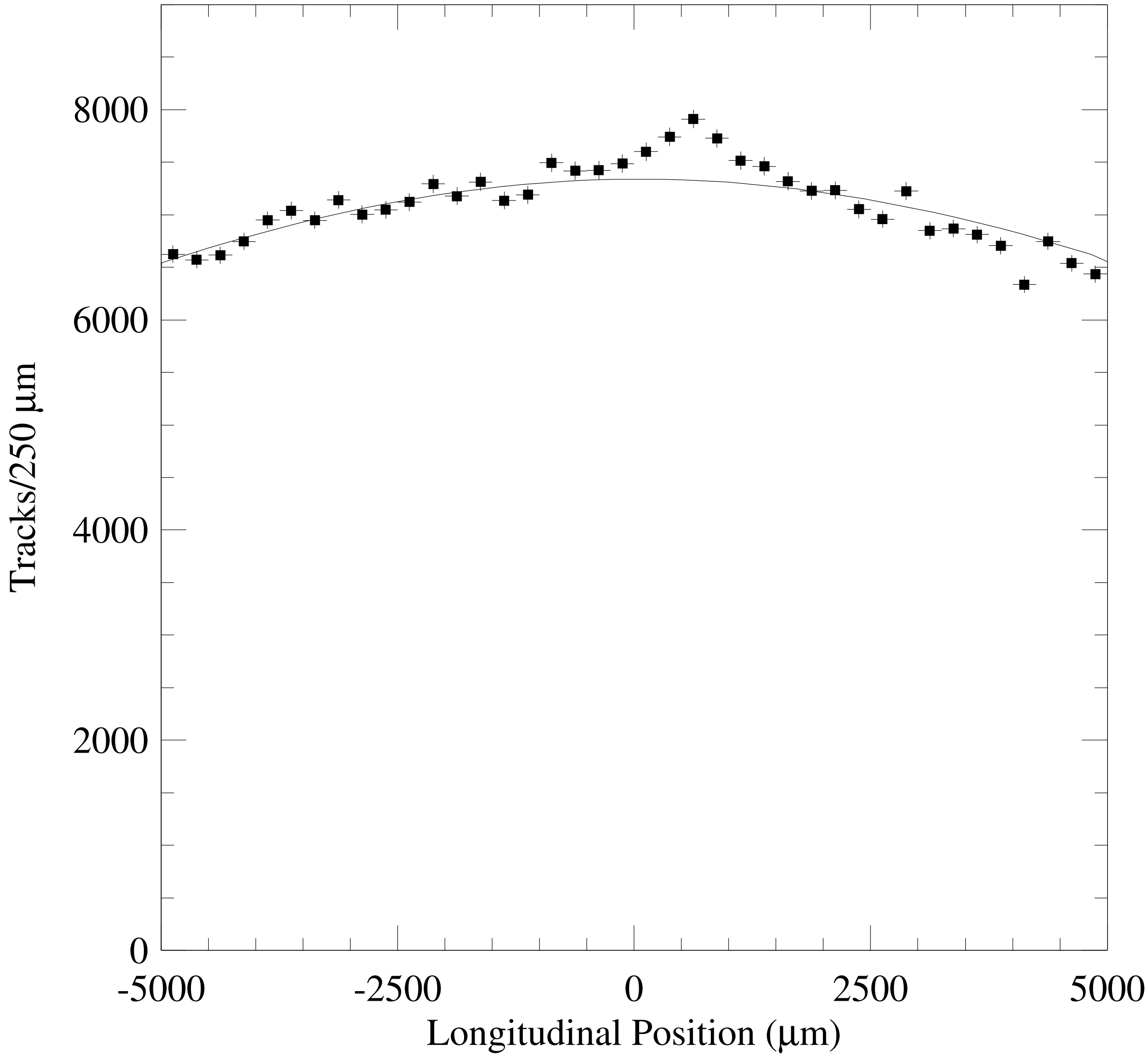
  Resolution

$$\sigma_y(z) = \sqrt{\left[\frac{\epsilon_y}{2}\left(\beta_y^* + \frac{(z - z_0)^2}{\beta_y^*}\right)\right] + \mathrm{yres}^2} \quad (2)$$

- Parameters are correlated and errors large
- Z distribution also depends on β

$$\frac{d\mathcal{L}}{dz} = \mathcal{L}_0 \frac{\exp\left(\frac{-z^2}{\sigma_z^2}\right)}{(1 + \frac{z^2}{\beta_x^{*2}})^{1/2}(1 + \frac{z^2}{\beta_y^{*2}})^{1/2}} \quad (3)$$

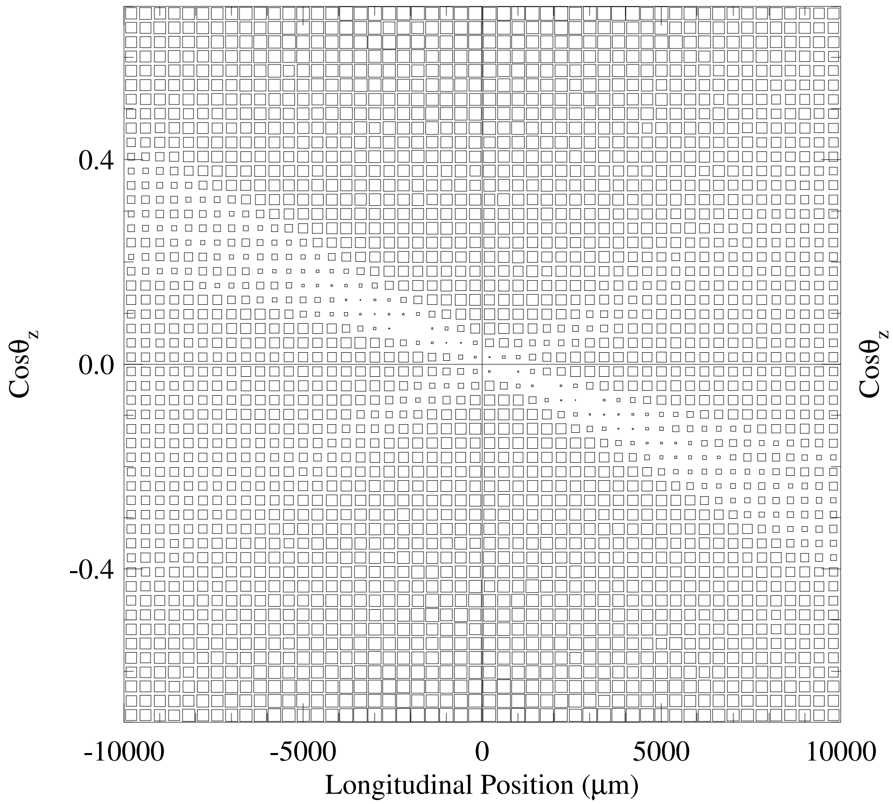
The Central Region of Raw Longitudinal Distribution of the Luminous region

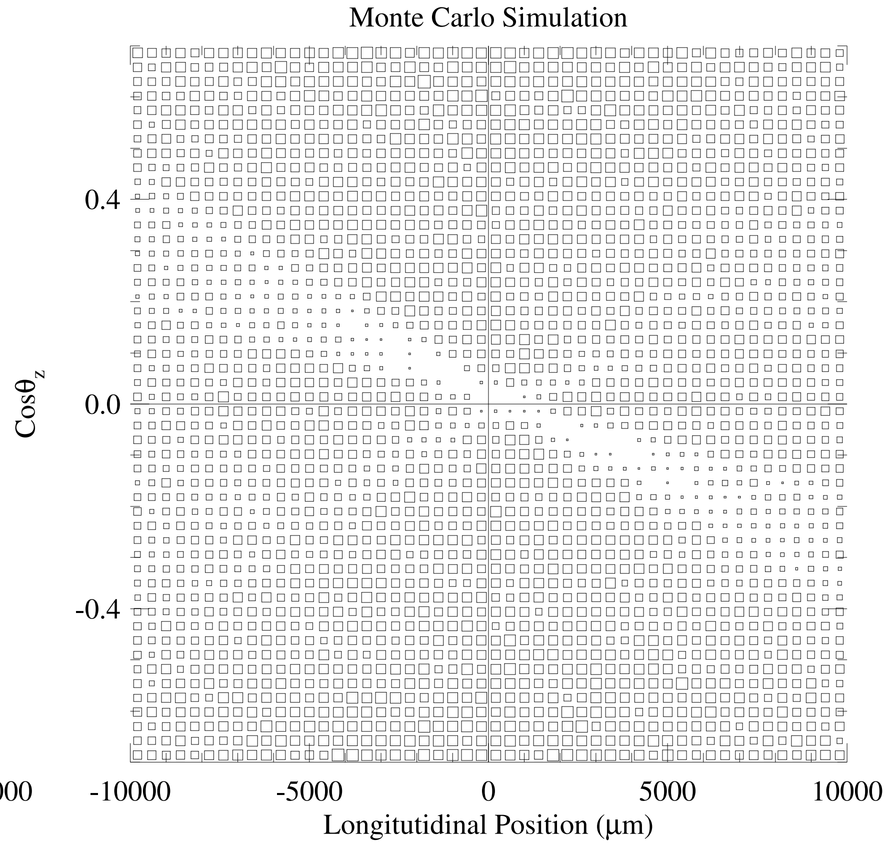


Known efficiency effect

z Direction Cosine v Longitudinal Position

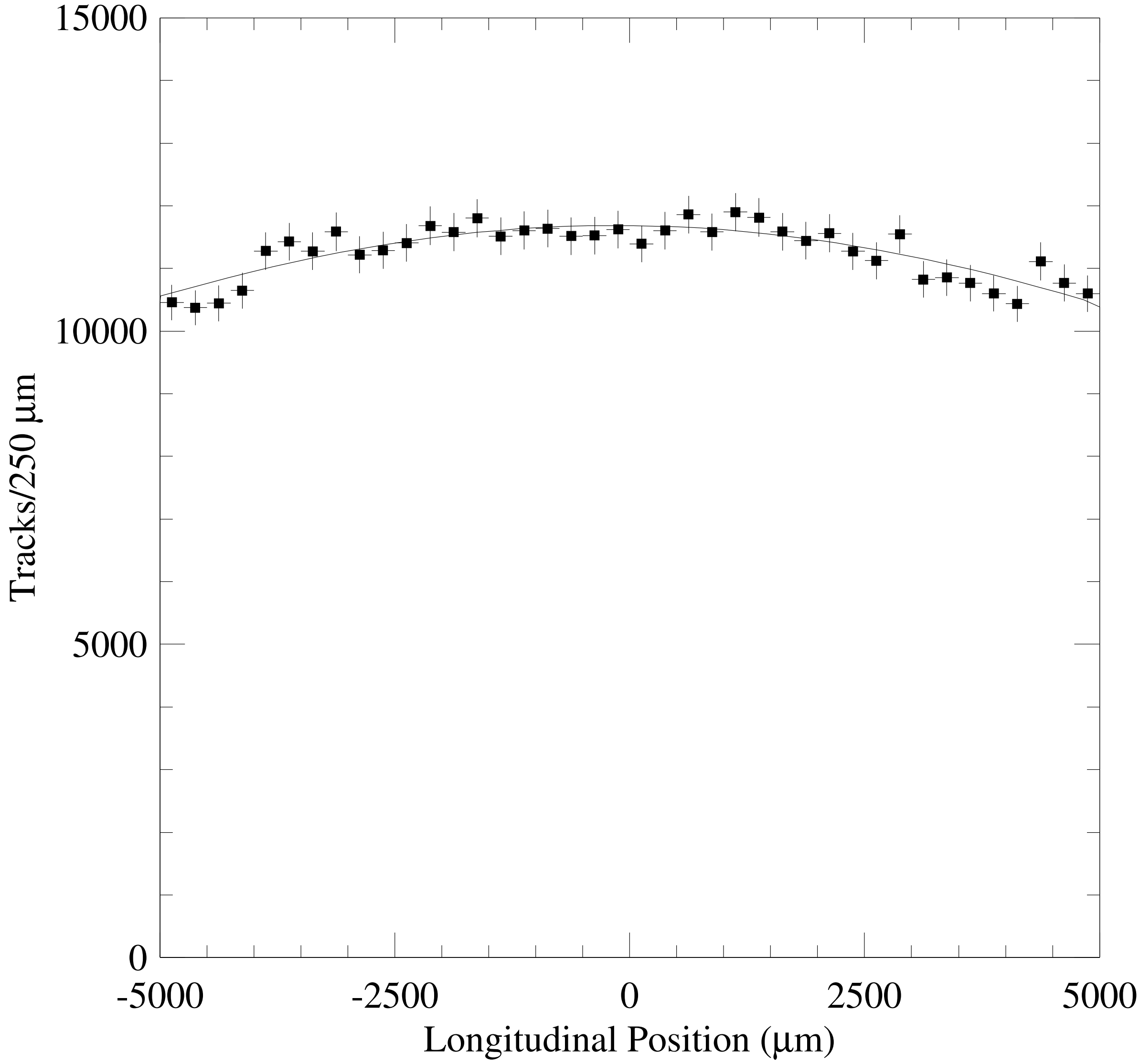
Real Data & MC Simulation





Effect is well modeled by the simulation

After Efficiency Correction



Combined Fit for the Vertical Region

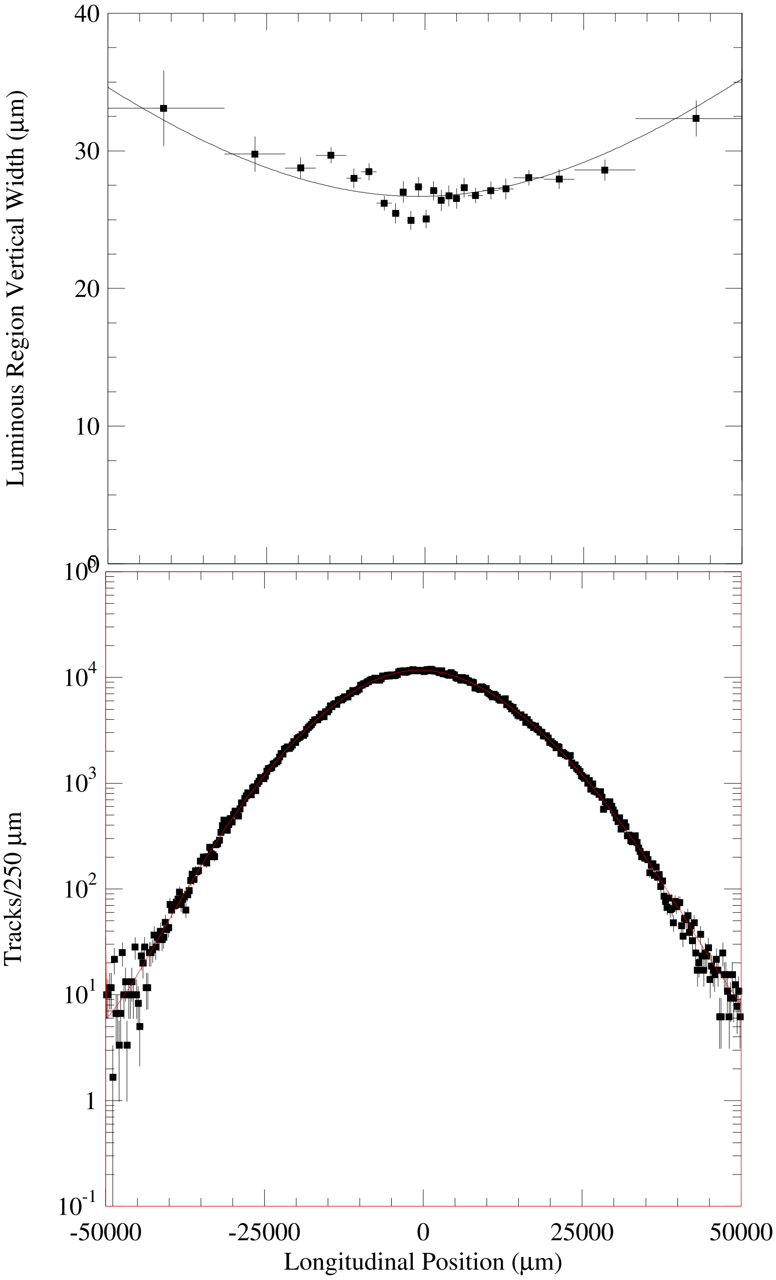
MINUIT Likelihood Fit to Plot 40&0

File: /home/cinabro/analysis/bmspot/hourglass/test.dat — 10-APR-2000 16:40
Plot Area Total/Fit 1.33249E+06 / 1.33249E+06 — Fit Status 3
Func Area Total/Fit 7.01171E+05 / 7.01171E+05 — E.D.M. 6.063E-08

Likelihood = 1592.0

χ^2= 1592.8 for 424 - 8 d.o.f., C.L.=0.000E+00%

Errors		Parabolic	Minos	
Function 1: Hourglass				
BETAY	17330.	± 172.9	- 172.1	+ 176.9
EMITY	7.02223E-03	± 5.0056E-03	- 4.7135E-03	+ 5.3656E-03
Z0	-1076.4	± 34.28	- 0.0000E+00	+ 0.0000E+00
RESO	25.529	± 1.888	- 1.958	+ 1.843
NORM	11703.	± 16.58	- 0.0000E+00	+ 0.0000E+00
ZSIG	19052.	± 38.12	- 38.52	+ 38.34
* BETAX	4.17500E+05	± 0.0000E+00	- 0.0000E+00	+ 0.0000E+00
ASYM	-6.17615E-02	± 2.2818E-03	- 2.2745E-03	+ 2.2725E-03
BACK	3.0722	± 0.4854	- 0.0000E+00	+ 0.0000E+00
* BREAK	52373.	± 0.0000E+00	- 0.0000E+00	+ 0.0000E+00



Conclusions

- Novel box technique measures luminous region with a resolution of $\sim$25 μm.

- Resolution is measured from the data; not taken from simulation

- First direct observation of the hourglass effect

- Including longitudinal distribution, we can measure

Parameter	**CESR Lattice (μm)**	**Measurement (μm)**
β_y^*	**17900**	**17330 $\pm$ 170 $\pm$ 460**
ϵ_y	**0.0084 (rad)**	**0.0070 $\pm$ 0.0054 $\pm$ 0.0019 (rad)**
σ_z	**19100**	**19050 $\pm$ 40 $\pm$ 200**