

# Recent Results of Phase-Space Tomography in the EMMA Injection Line

Mark Ibison

Liverpool Group Meeting  
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# Goals for Tomography during ALICE Operations: Feb-Apr 2011

## 1) Demonstration of Consistency in Results:

- between tomographic methods
- with Quad-Scan/Beam-Size Method

## 2) Extension to Vertical Phase-Space:

- In addition to the Horizontal
- use specific input data sets

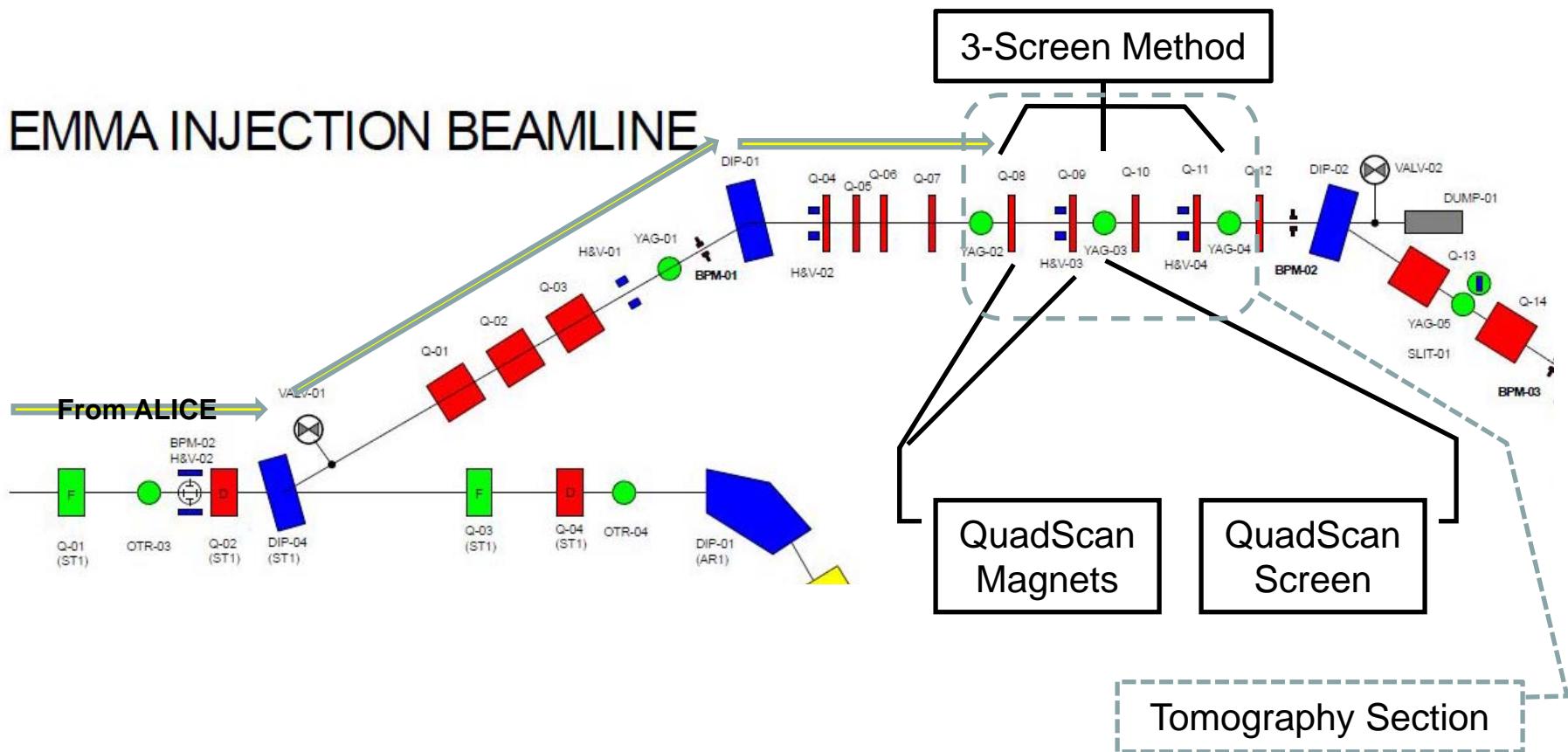
## 3) Variation of Bunch Charge

- Investigation of the effect of space-charge

# Elements of Experimental Plan

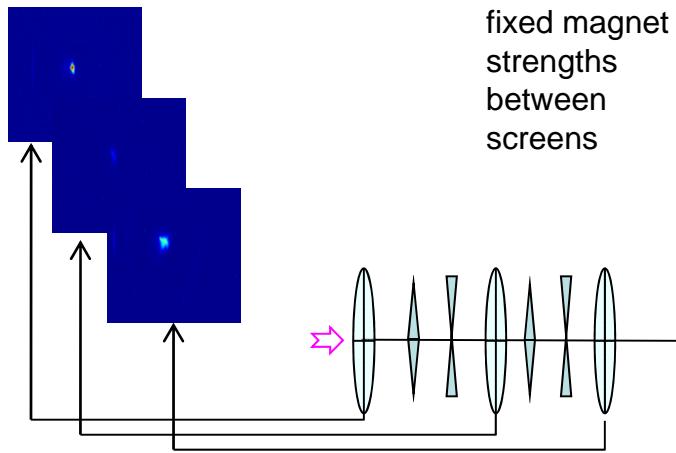
- Dispersion Check – in Tomography section
- Optimisation of ‘matching’ quadrupoles
- Adjustment of beam shape on Tomo screens
- Centring beam in scanning quadrupole(s)
- Tomography by ‘3-Screens’ & ‘Quad-Scan’
- Normalised Phase-Space measurements
- Space-Charge investigations

# EMMA Injection Line: Components

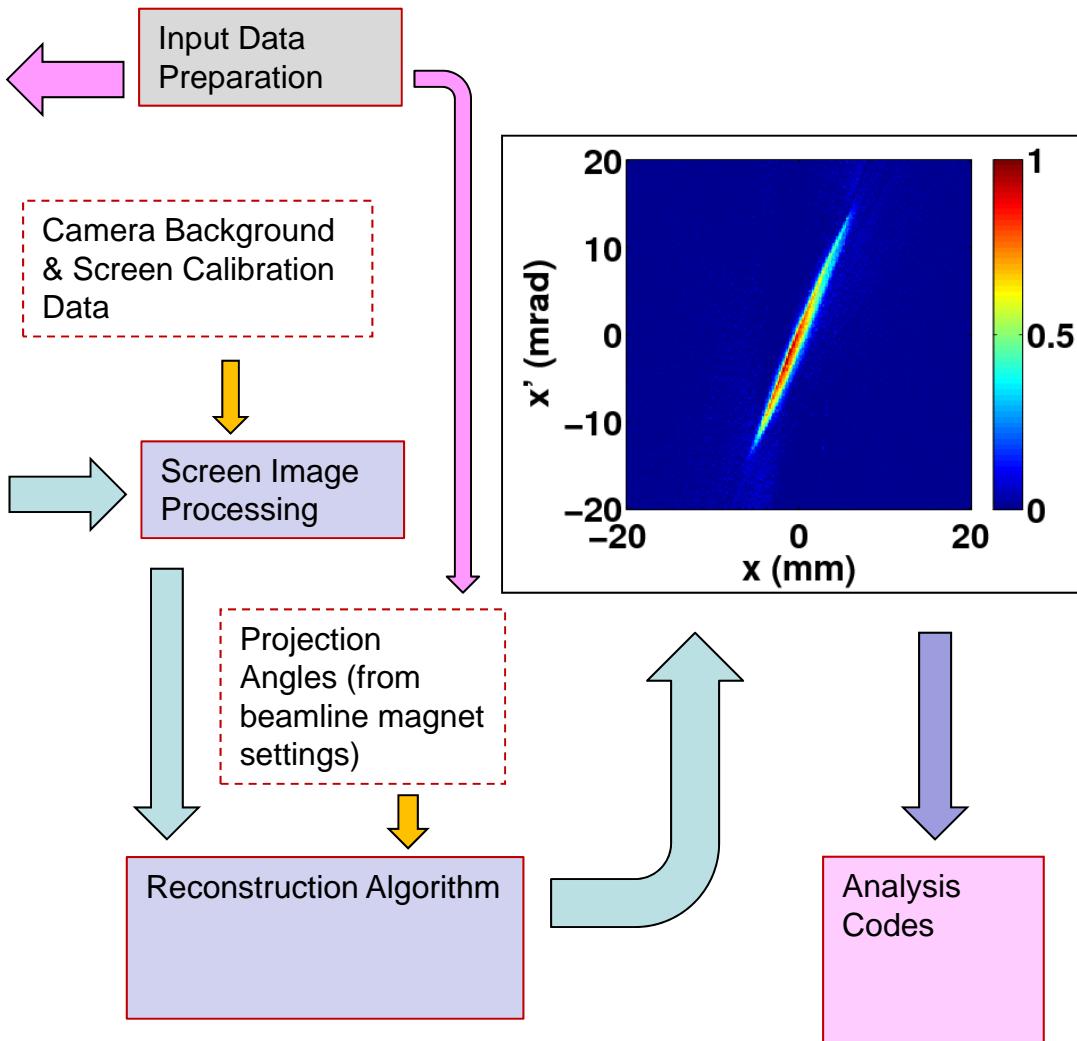
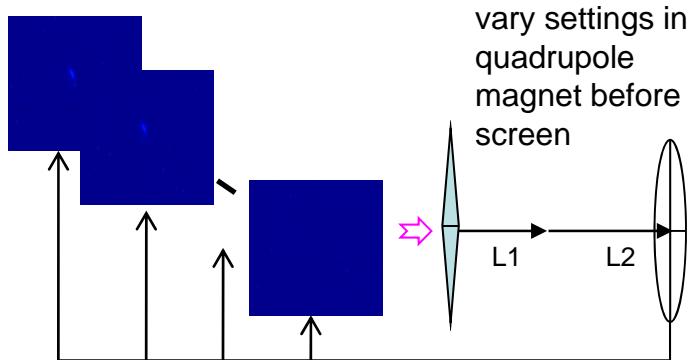


# Tomography Data Collection Techniques

## 3-Screen Method

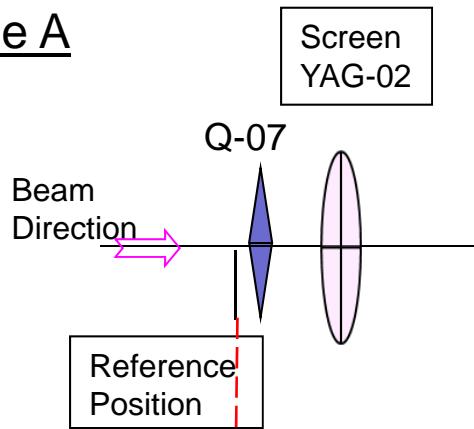


## Single-Screen (Quadrupole-Scanning) Method



# Tomography Configuration for Space-Charge Effects

## Case A

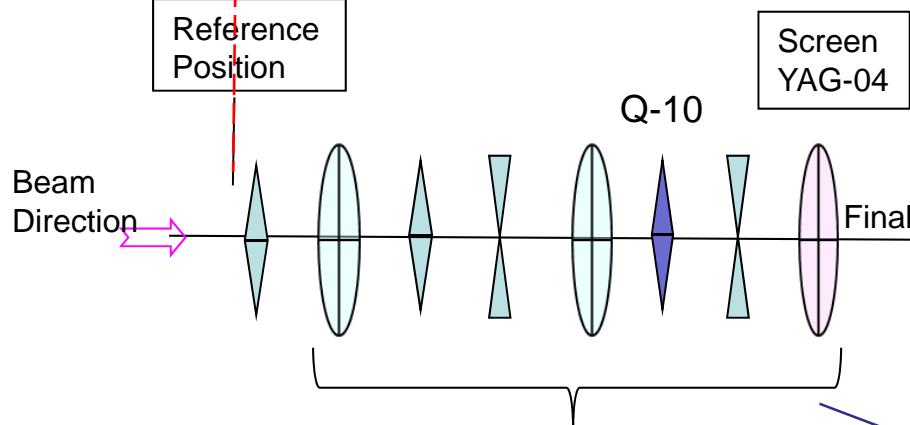


Reconstruction position - same for both Cases

Low charge  
High charge

- similar result expected
- space charge differences ?

## Case B



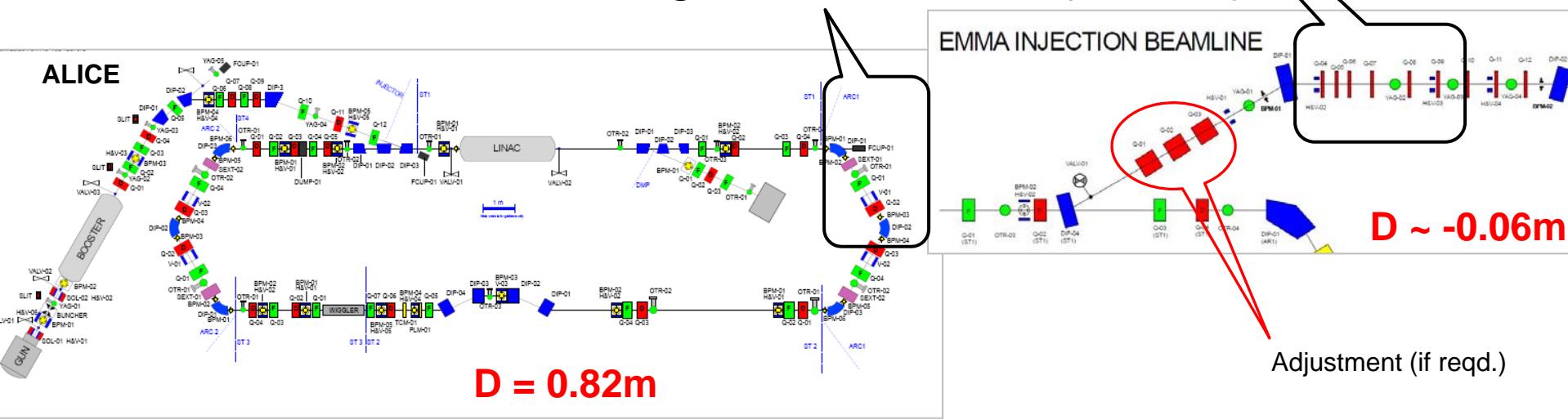
Tomography Section

# Experimental Shift Summary

Shift Date	pC	3-Screens	QuadScans		Notes & Other Measurements
			QUAD-08	QUAD-09	
16/02/11	40	✓	✓	✓	Try to <b>match images</b> on EMI-02, 03, 04
	40	✓	(✓)	(✓)	
27/02/11	40	<i>None taken</i>	✓	✓	[LINAC Grad vs. Energy change calibration]
	20		✓	✓	Confirm <b>measured dispersion</b> : $D \approx 0$ at EMI-03 (base on $D = 0.82\text{m}$ at AR1-1)
	20		---	✓	Fit <b>Optical filter</b> to EMI-03 camera lens
	40		✓	✓	
	50		✓	✓	
9/03/11	40	✓	✓	✓	<b>Space-Charge</b> – initial measurements
	50	✓	✓	✓	
	60	✓	✓	✓	Adjust Buncher Gradient for Charge $\geq 60\text{pC}$
	70	✓	✓	✓	
29/03/11	45	✓	✓	✓	<b>Normalised Phase-Space</b> (Predict Twiss params from <b>emittance</b> quad-scan data)
			(✓)	(✓)	
09/04/11	20	✓	✓	---	$E = 22.5\text{MeV}$ (AEMITR experiments - <i>by DJH</i> )
	20	✓	✓	---	
			QUAD-07	QUAD-10	
19/04/11	40	✓			
	20		✓	✓	Investigate <b>Space Charge</b> : Compared Quad-scans Q-07 on EMI-02, Q-10 on 04
	40		✓	✓	[ <b>Emittance</b> Quad-scans, equi-current steps)]
	60		✓	✓	[Slit scan of EMI-05 on screen EMI-06]
	70		✓	✓	
	80		✓	✓	

# Dispersion Measurement

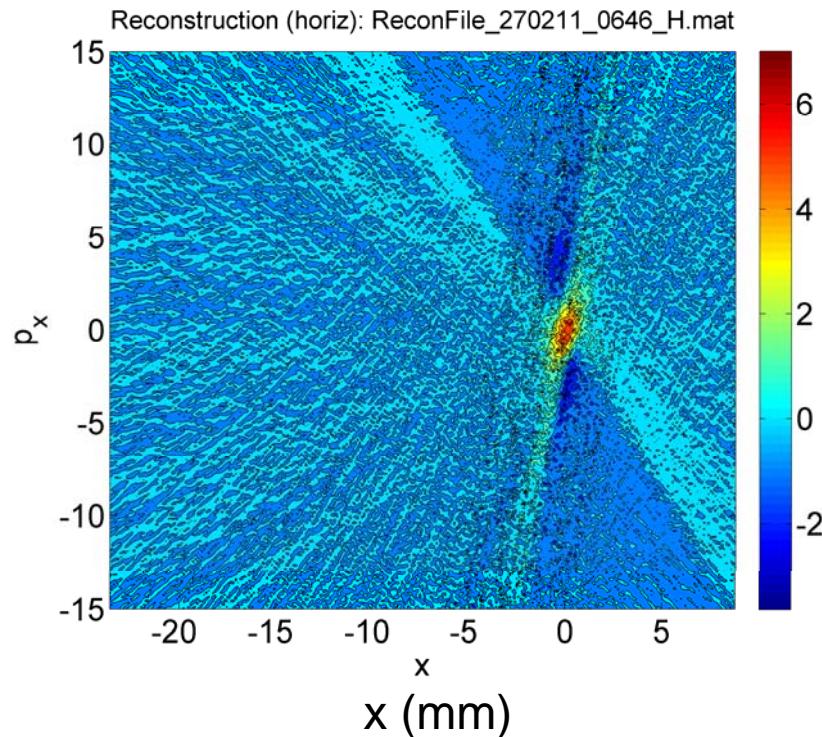
- Dispersion D leads to beam-size dependence on energy spread  $\delta E$
- Tomography section designed for low D
- Confirm by measurement:-
  - Observe displacement  $\delta x$  with E change
  - Calibrate  $\delta E$  in a region of known D (ARC-1)



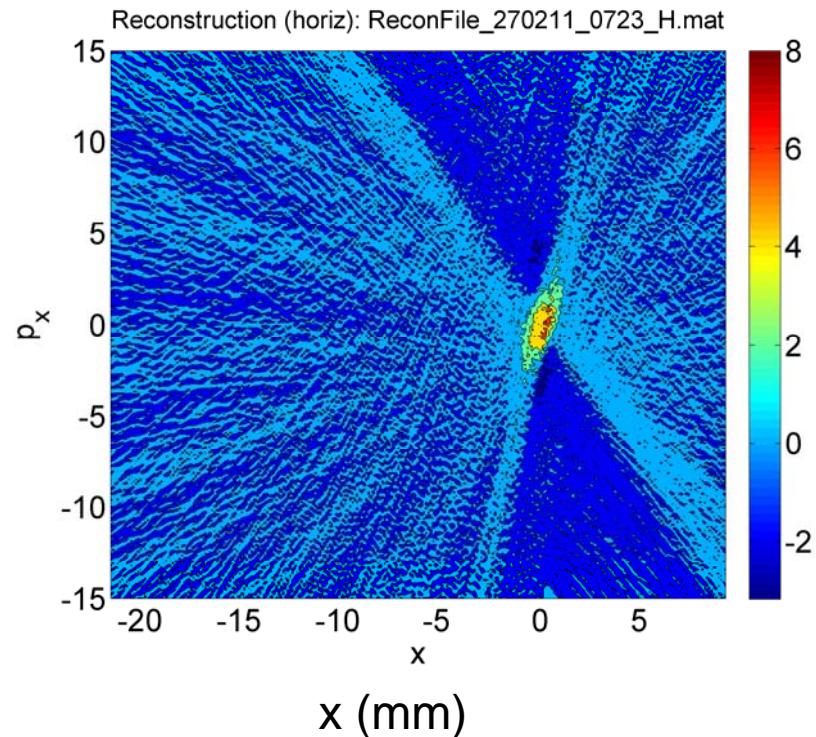
# Example Results (Horizontal)

Quad-Scan

40pC



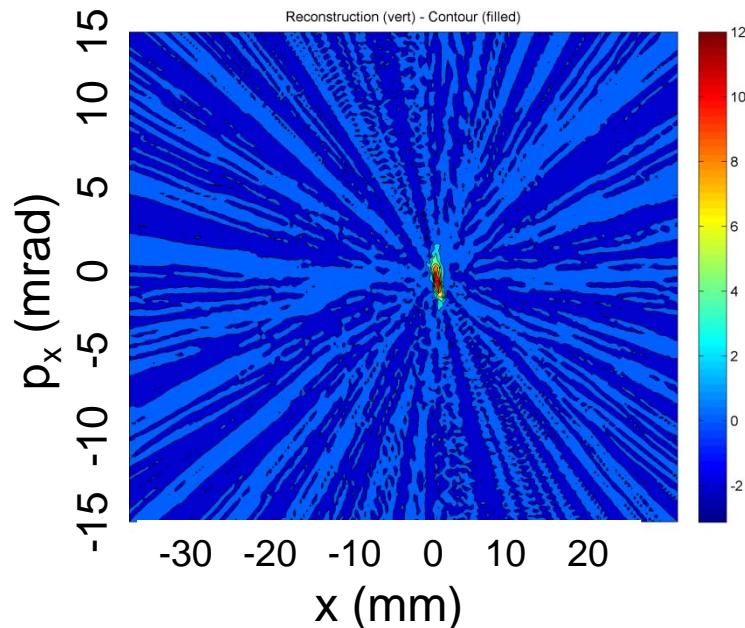
50pC



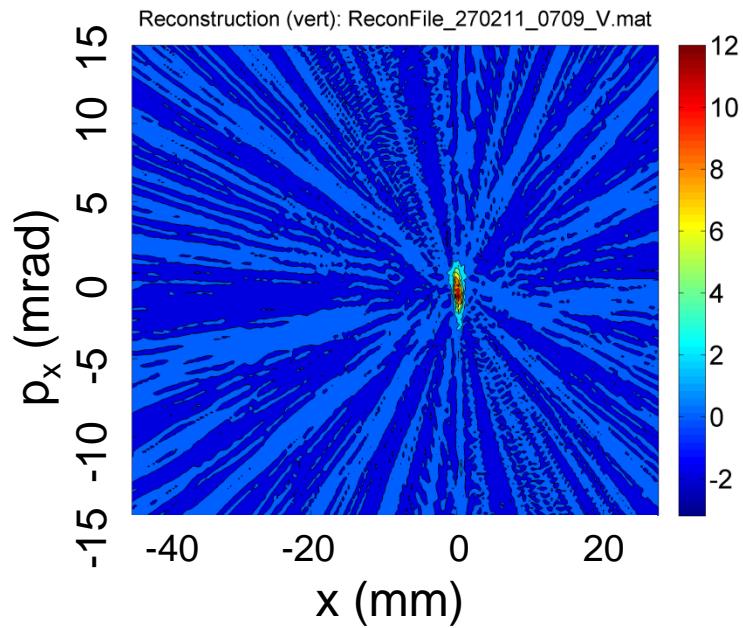
# Example Results (Vertical)

Quad-Scan

40pC

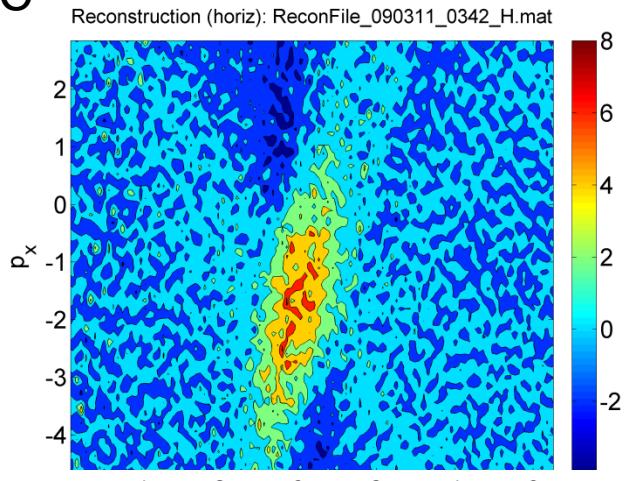


50pC

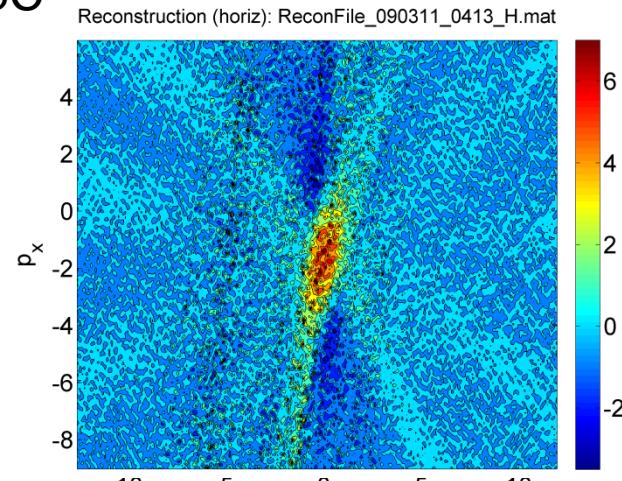


# Example Results (Space Charge)

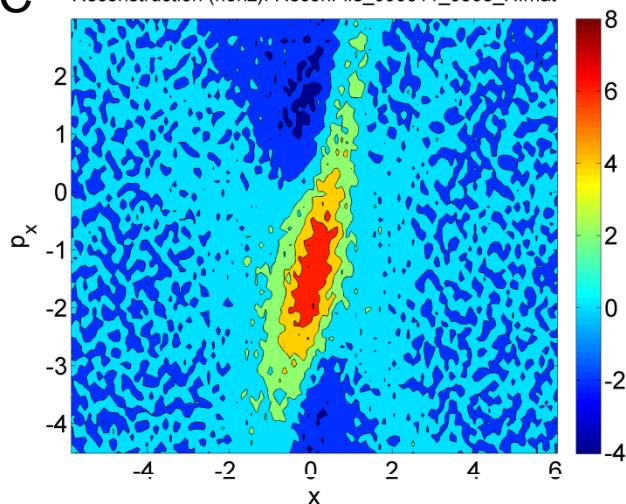
40pC



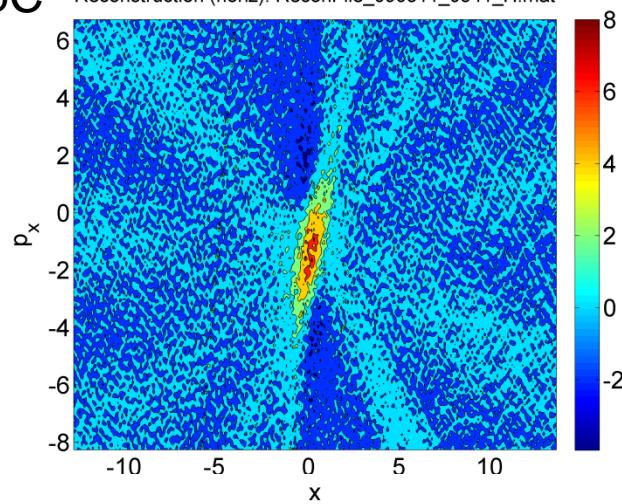
50pC



60pC



70pC

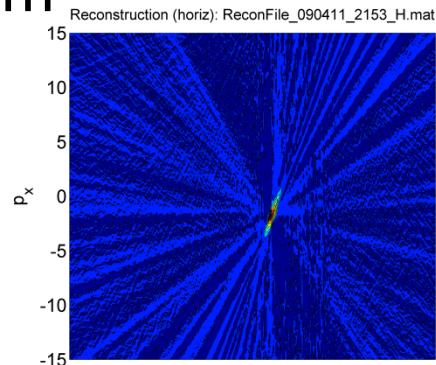


# Analysis: Summary of Methods

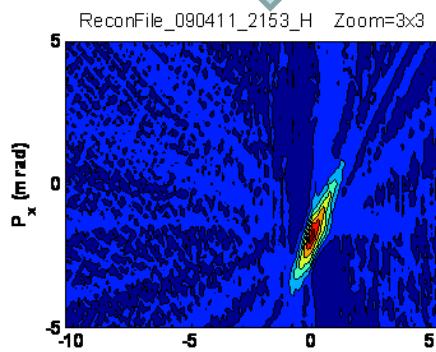
- Median Filtering
  - Reduce noise, smooth ‘negative’ regions
- Windowing (Zoom) – with centring
  - Select an optimum ‘region of interest’
- Gaussian Fitting in 2-D
  - Removes subtle features in distribution
- 2<sup>nd</sup> Moments Calculation
  - For Emittance/Twiss Parameters

# Analysis Methods

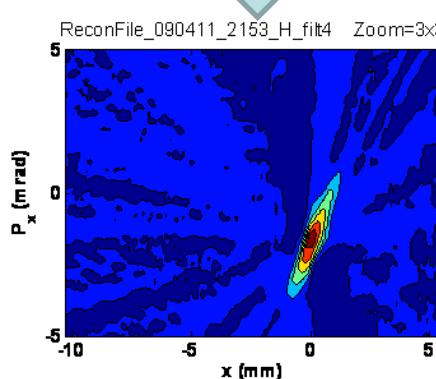
Zoom



Filtering

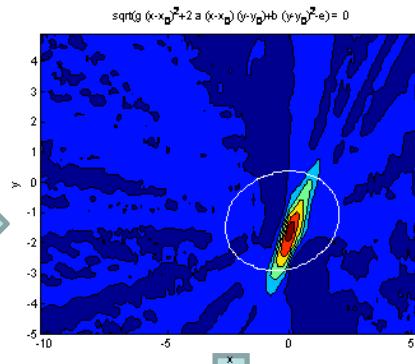


4x 4 Median

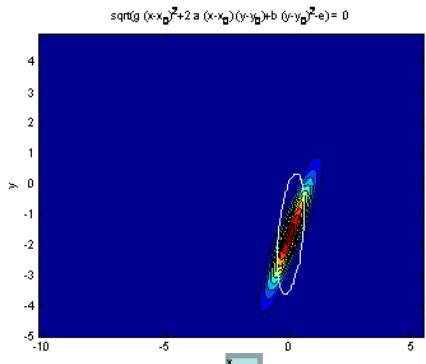


## Fitting Parameters

Unfitted



2-D Gaussian Fit



2<sup>nd</sup> Order Moments

Emittance (geometric) = 1.3831  
beta Function = 0.44565  
alpha Function = -0.63746  
gamma Function = 3.1557

Centroid = [0.069242 -1.2395]

Tomography Progress

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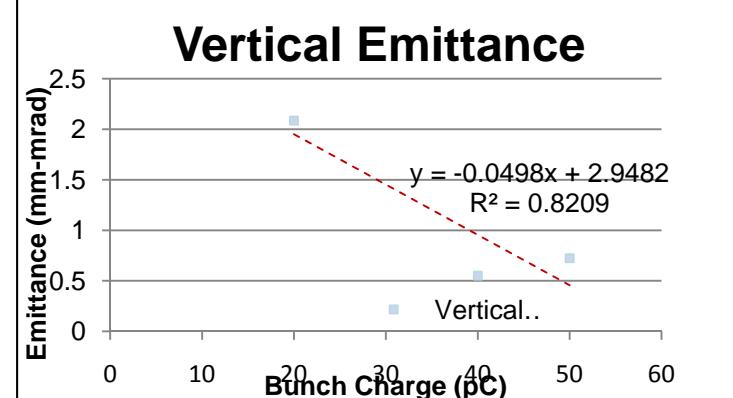
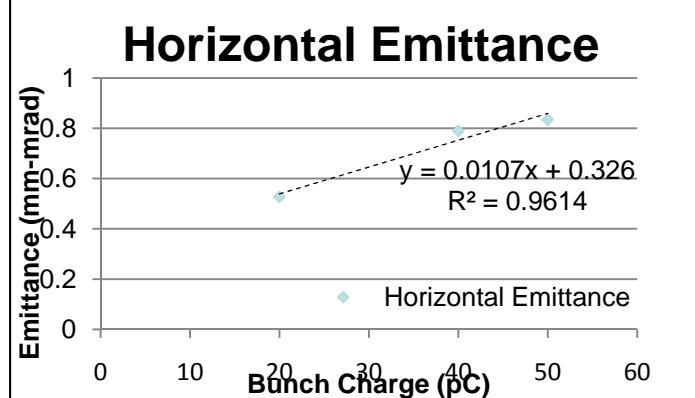
# Analysis: Parameter Values

Date	Bunch Charge	PHASE_SPACE	Screen	Emittance (geom)	Beta	Alpha	Gamma
16/02/2011	40	H	EMI-3	1.7027	1.2939	-0.28942	0.83757
	40	V	EMI-3		1.5499	1.1286	2.3018
<b>27/02/2011</b>	20	V	EMI-3	2.0857	1.0346	2.5291	7.1492
	20	H	EMI-3	0.5269	0.35829	-0.68273	4.092
	40	V	EMI-3	0.55112	0.65534	0.40001	1.7701
	40	H	EMI-3	0.78944	0.65464	-0.87695	2.7023
	50	V	EMI-3	0.72475	0.51231	0.15151	1.9967
	50	H	EMI-3	0.83436	0.64918	-0.95143	2.9348
<b>09/03/2011</b>	40	H	EMI-3	1.6929	0.39992	-0.52026	3.1773
	40	V	EMI-3	3.2929	0.5178	0.83508	3.278
	50	H	EMI-3	1.6809	0.43654	-0.57922	3.0593
	50	V	EMI-3	2.2135	0.33249	0.2249	3.1597
	60	H	EMI-3	1.3241	0.49094	-0.71934	3.0909
	60	V	EMI-3	2.6627	0.51366	-0.27594	2.095
	70	H	EMI-3	1.3831	0.44565	-0.63746	3.1557
	70	V	EMI-3	2.1067	0.46268	-0.79524	3.5282
29/03/2011	45	V	EMI-3	1.4225	0.52822	0.18733	1.9596
	45	H	EMI-3	0.50165	2.3441	-1.2412	1.0838
09/04/2011	20	H	EMI-3	1.033	0.48591	-0.84428	3.5249
	20	H	EMI-3	1.0799	0.31994	-0.43295	3.7114
<b>19/04/2011</b>	20	H	EMI-2	0.60151	0.77023	-1.6075	4.6532
	20	H	EMI-4	1.8326	0.34796	-0.76811	4.5694
	40	H	EMI-2	0.79656	0.89327	-1.1843	2.6896
	40	H	EMI-4	0.97724	1.0756	-2.0713	4.9185
	60	H	EMI-2	1.0525	0.98737	-1.1451	2.3409
	60	H	EMI-4	1.3729	1.2494	-2.2773	4.9514
	70	H	EMI-2	1.1252	0.99586	-1.1269	2.2794
	70	H	EMI-4	1.2717	1.163	-2.0311	4.4069
	80	H	EMI-2	1.3007	0.99294	-1.0867	2.1965
	80	H	EMI-4	1.2278	1.138	-2.1267	4.853

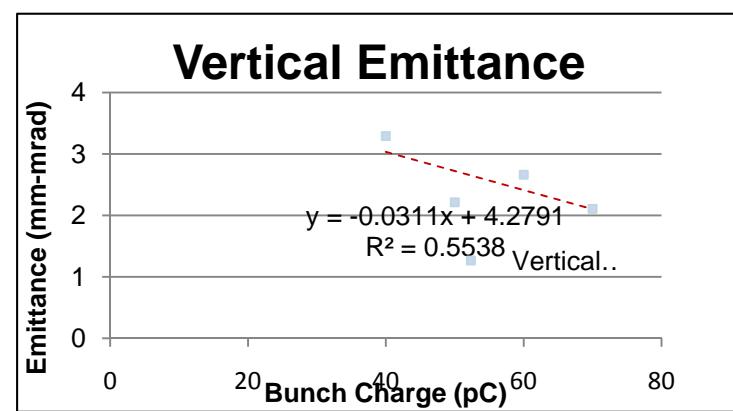
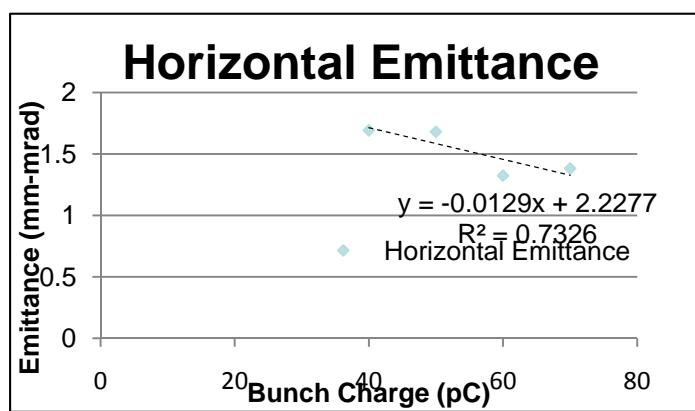
# Analysis: Trends

## Space-Charge Effects

27/02/11

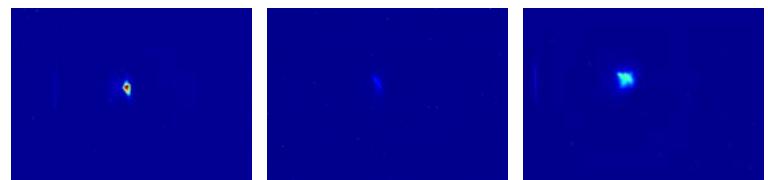
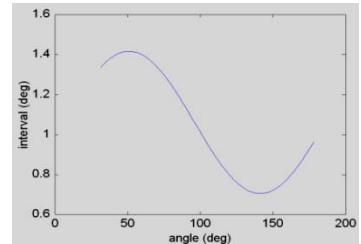
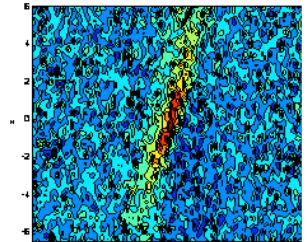


09/03/11



# Some Outstanding Issues

- Reconstruction Noise
  - Use of smoothing/filtering/thresholding methods
- Uniformity of Projection Angular Intervals
  - Use of ‘weighting’ factors
- Screen Image Intensity Variation
  - Effectiveness of normalisation
- Reconciling 3-Screen & Quad-Scan Reconstructions
- Camera Noise & ‘Background’



# Further Work Planned

## Detailed Data Analysis:

- ‘Space-Charge’ data (collected April 2011)

## Reconstruction Methods:

- Explore the limitations of the MENT algorithm

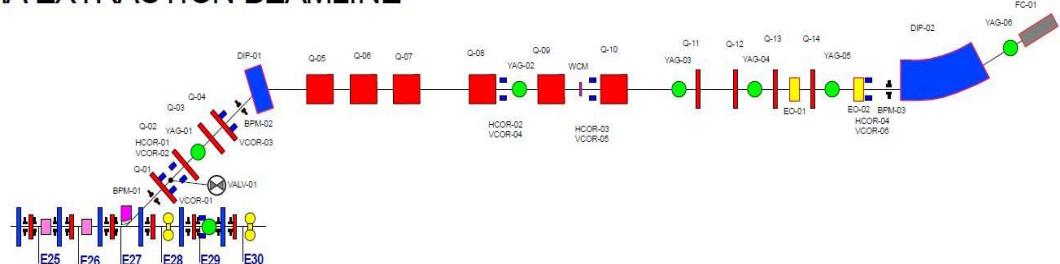
## Simulation:

- Use GPT to predict phase-space distributions in the presence of space-charge

## Experimental (possible):

- Tomography in the EMMA Extraction Line

EMMA EXTRACTION BEAMLINE



# Acknowledgements

- David Holder
- Kai Hock
- Andy Wolski
- EMMA Team