Emission of Space Charge Dominated E-Beams in Pancake Regime

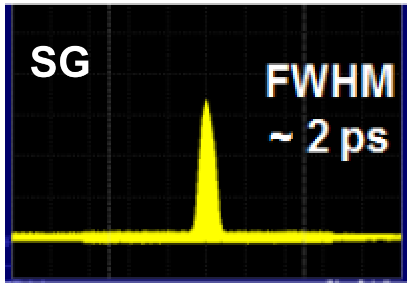
Y. Chen, PPS, DESY Zeuthen site, December 14th 2017

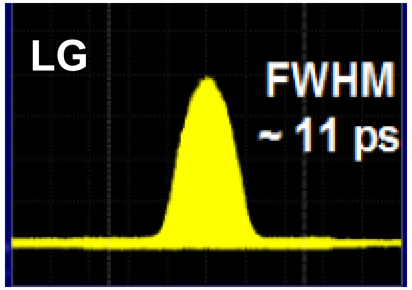
Content:

- Emission characterization with SG bunches
- Benchmark of simulation results
- Convergence studies
- Summary
- Tolerance studies (backup)
- Emittance comparison: trans. symmetric vs. trans. asymmetric (backup)

Cathode laser Gaussian temporal profiles at PITZ:

Short Gaussian (**SG**): **~2ps** FWHM
Long Gaussian (**LG**): **~11ps** FWHM





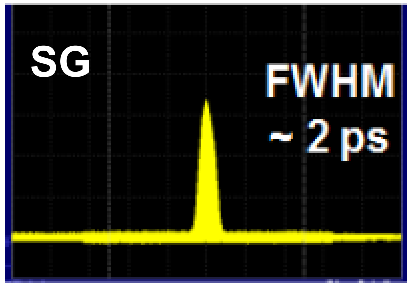
Introduction

Why and What

❑ Why Short Gaussian (SG)?

→ More confident about temporal cathode (laser) pulse shape

→ Impacts of pulse shape on emission presumably small



❑ Why different codes?

→ Benchmark available simulation tools

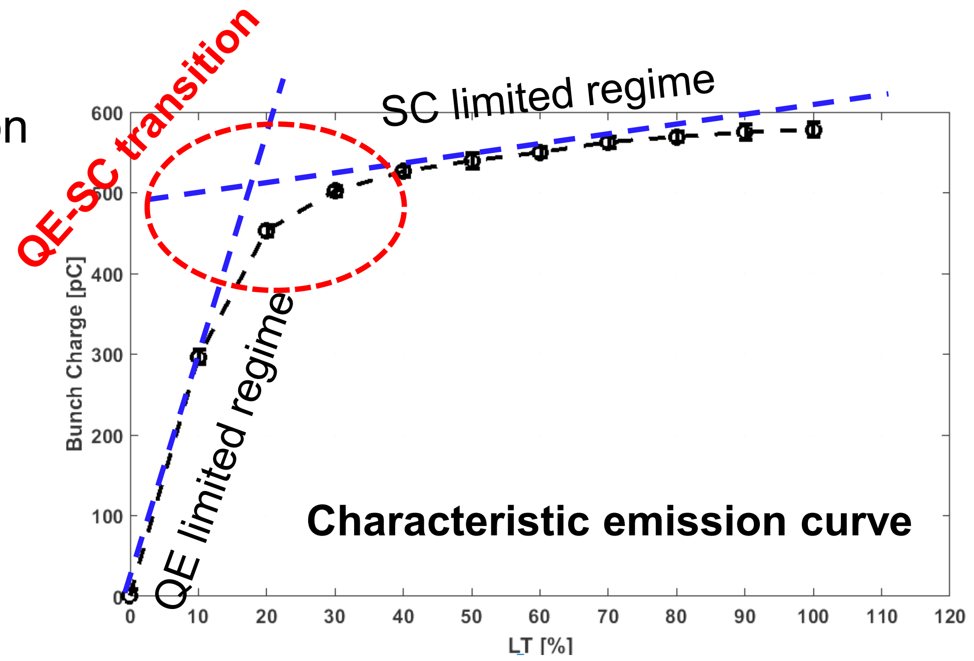
→ Try to "select" suitable one for further emission model implementation

❑ Why convergence studies?

→ Better time resolution needed for short bunches

→ Strong space charge effect numerically difficult to resolve

❑ Reminder: best emittance usually at QE-SC transition regime (one of the main goals for emission studies), not fully understood yet



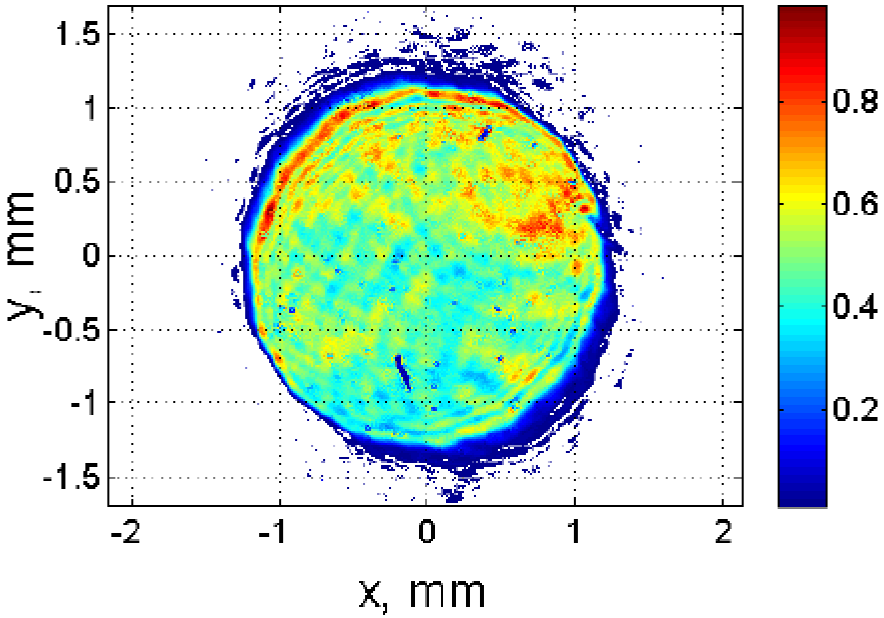
Measurements in October 2017

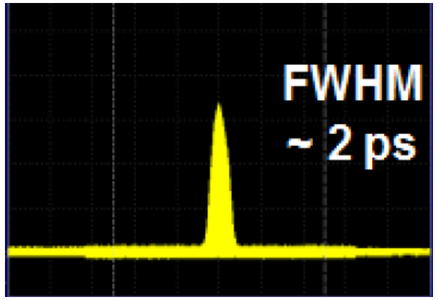
Raw Data

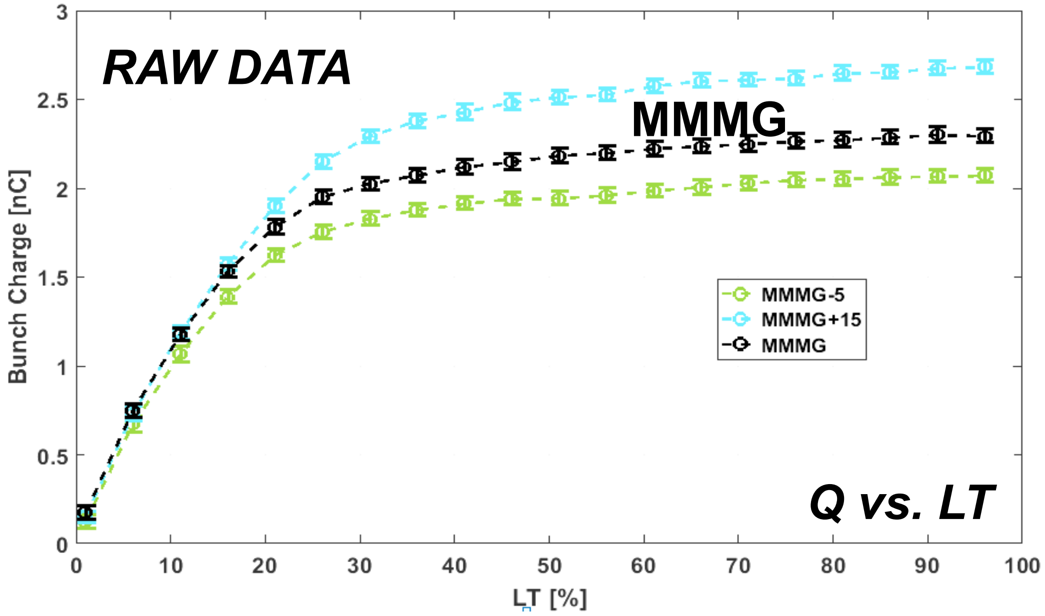
❑ Conditions:

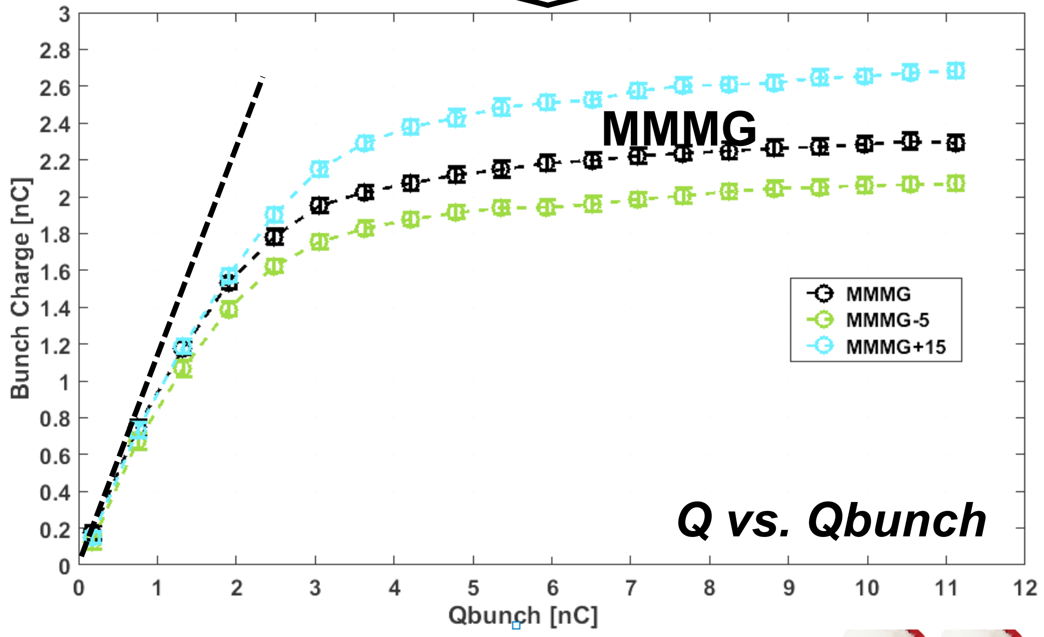
Cath Laser: MBI SG (2ps FWHM, 0.85ps RMS), BSA=2.4mm
RF: Ecath=60MV/m, Gun @ MMMG (0deg)

Photocathode laser at VC2 (cathode):
Xrms=0.618mm; Yrms=0.622mm





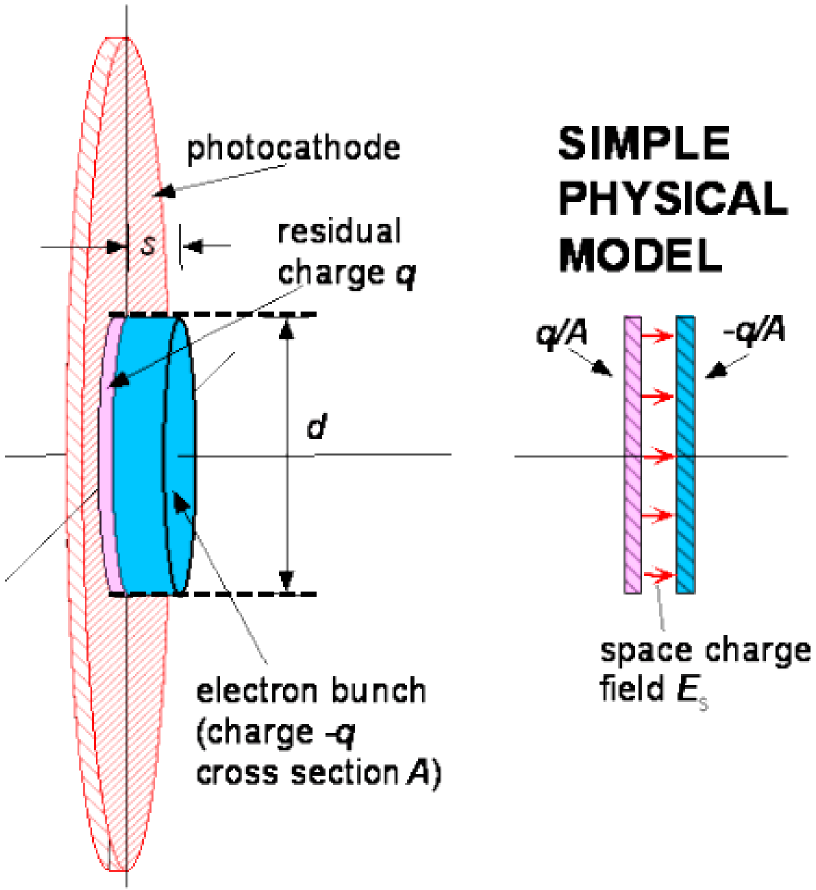




Measurements in October 2017

Beam Aspect Ratio and PPC model

❑ Extensively used PPC model for short bunches in RF gun



$$Q_{\rm sat} = \sigma_{\rm sat}\pi R^2 \cong \epsilon_0 E_0 \pi R^2$$

1. "capacity" of effective diode
2. 2 ps bunch shorter than 1 deg RF → constant E_0
3. R: emission radius, presumably R ~ laser spot size

By the end of the laser pulse the
beam extends a length Δz into effective diode:

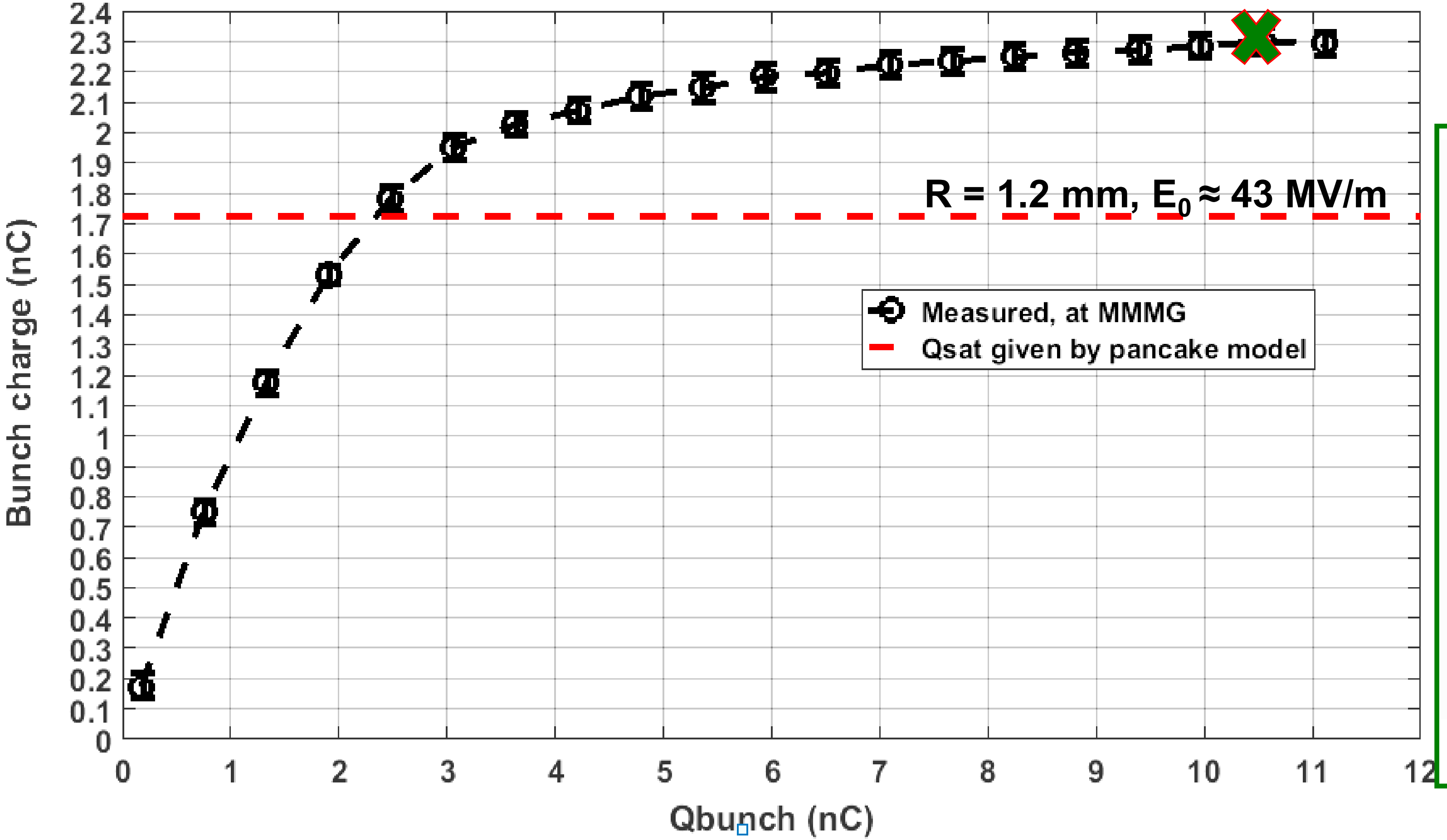
$$\Delta z_e = \frac{eE_0}{2m}\Delta t^2$$ ~1.5e-05 m

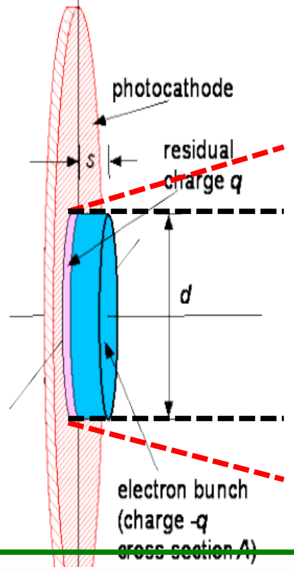
Δz_e << R → Pancake model applicable

Measurements in October 2017

Use PPC model for PITZ measurements

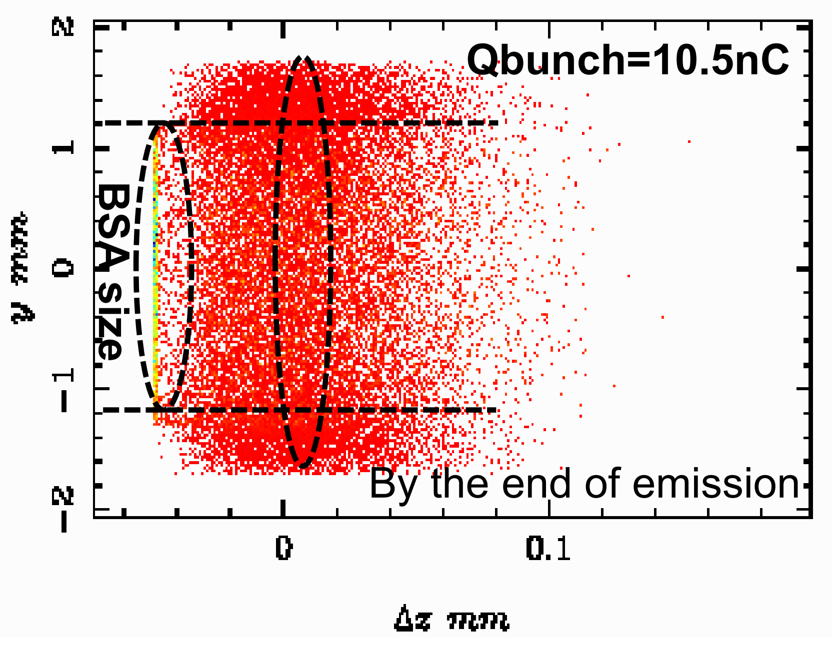
- ❑ Saturation charge by PPC lower than measured charge





Expansion by space charge

Emission radius ≠ laser spot size?

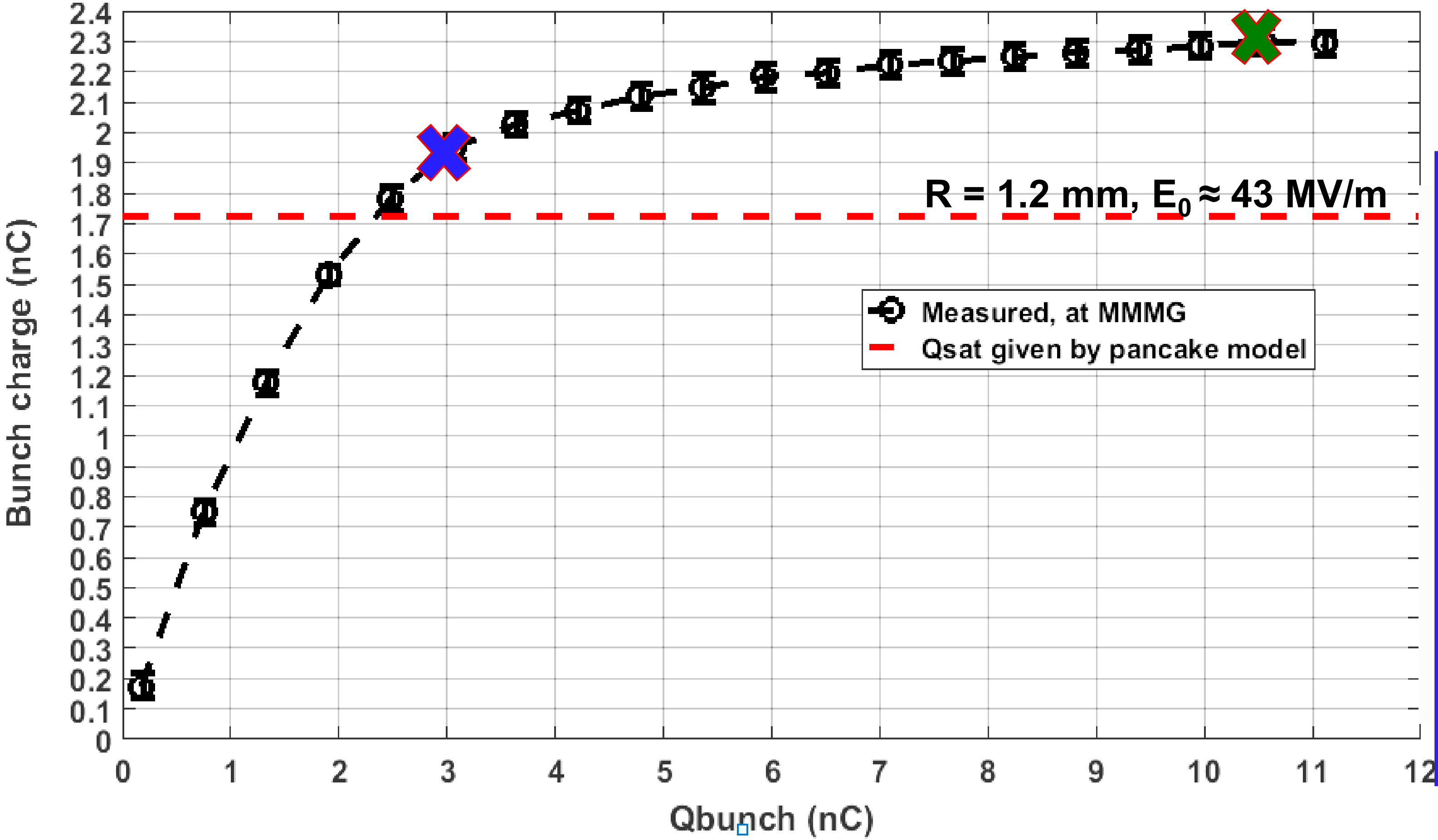


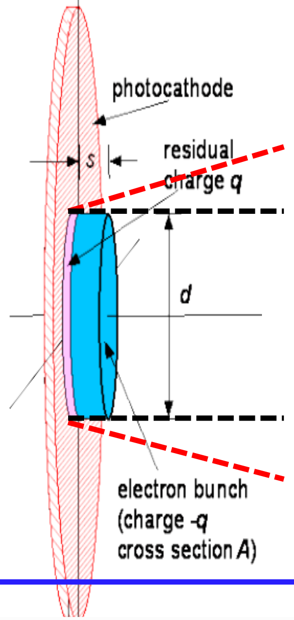
$\Delta XY_{rms}/XY_{rms}(initial)\% \approx 6.3\%$

Measurements in October 2017

Use PPC model for PITZ measurements

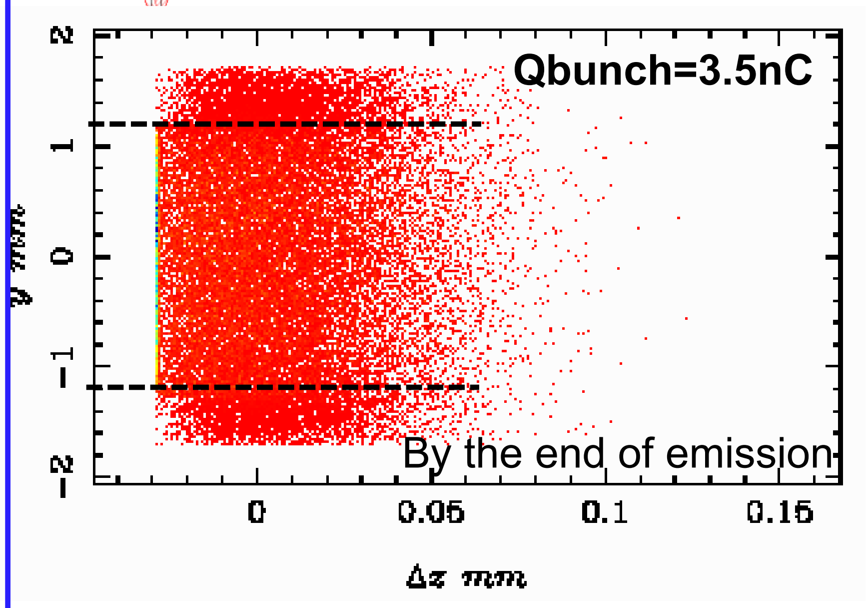
- ❑ **Saturation charge by PPC lower than measured charge**





Expansion by space charge

Emission radius ≠ laser spot size?



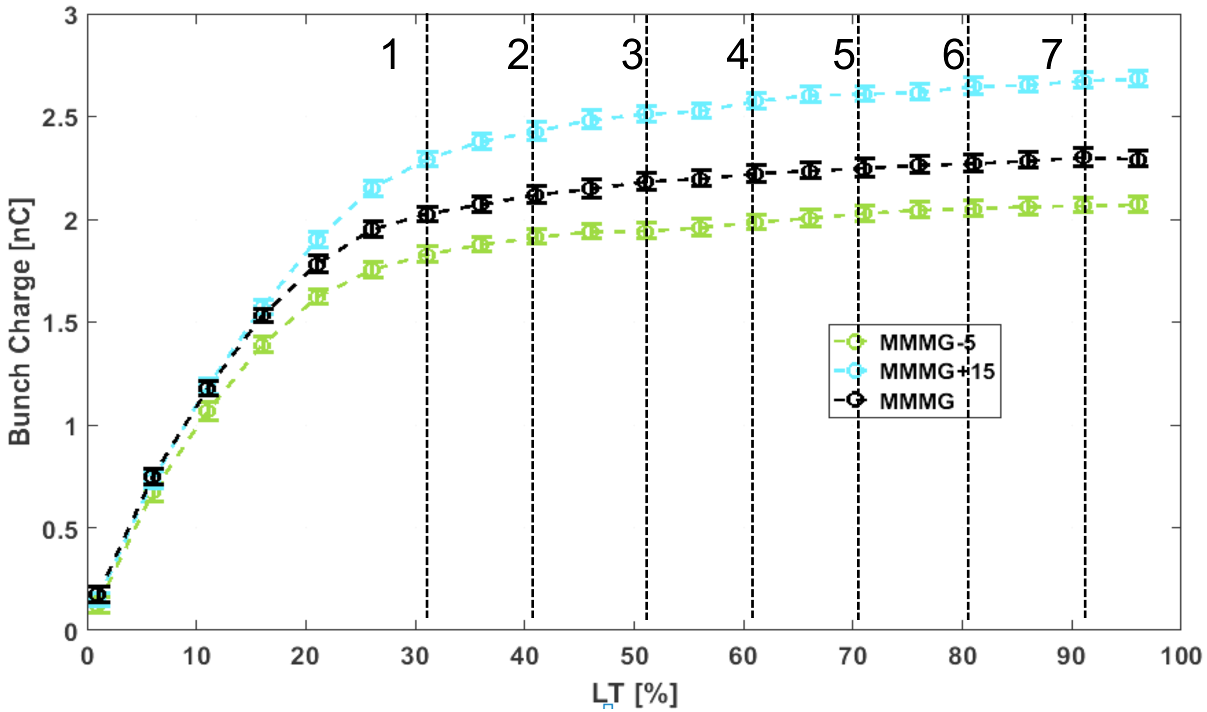
$\Delta XY_{rms}/XY_{rms}(initial)\% \approx 2.6\%$

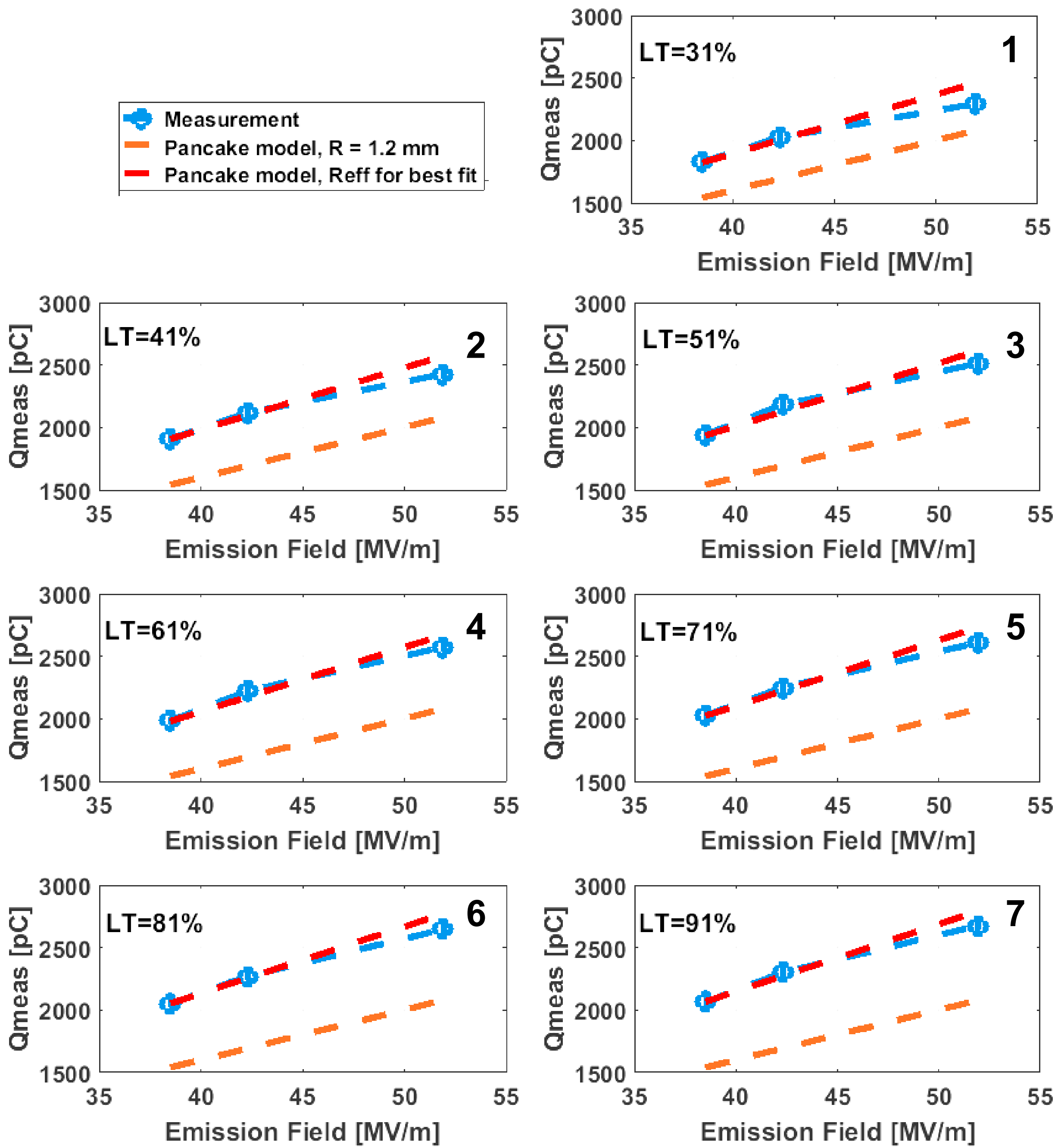
Measurements in October 2017

Use PPC with variable radius of emission layer

- ❑ Apply PPC model with **space charge modified emission radius** for the best fitting to the measurement data

Fit measurements @ 3 different gun phases simultaneously





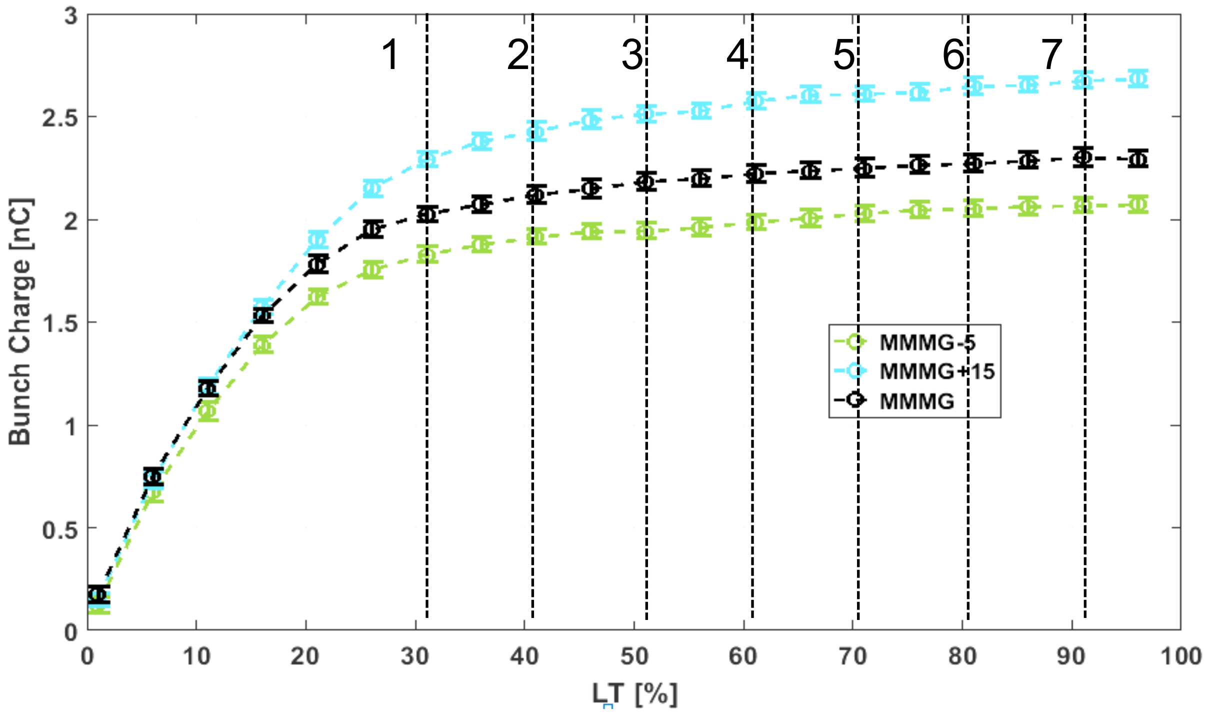
Measurements in October 2017

Use PPC with variable radius of emission layer

- ❑ **Apply PPC model with space charge modified emission radius for the best fitting to the measurement data**

$$\text{Error} = \sum_k \frac{abs(Q_{fit,k} - Q_{meas,k})}{Q_{meas,k}}$$

Fit measurements @ 3 different gun phases simultaneously



LT	Reff [mm]	Error
31%	1.305	0.0892
41%	1.335	0.0769
51%	1.345	0.0670
61%	1.360	0.0597
71%	1.375	0.0568
81%	1.385	0.0517
91%	1.390	0.0556

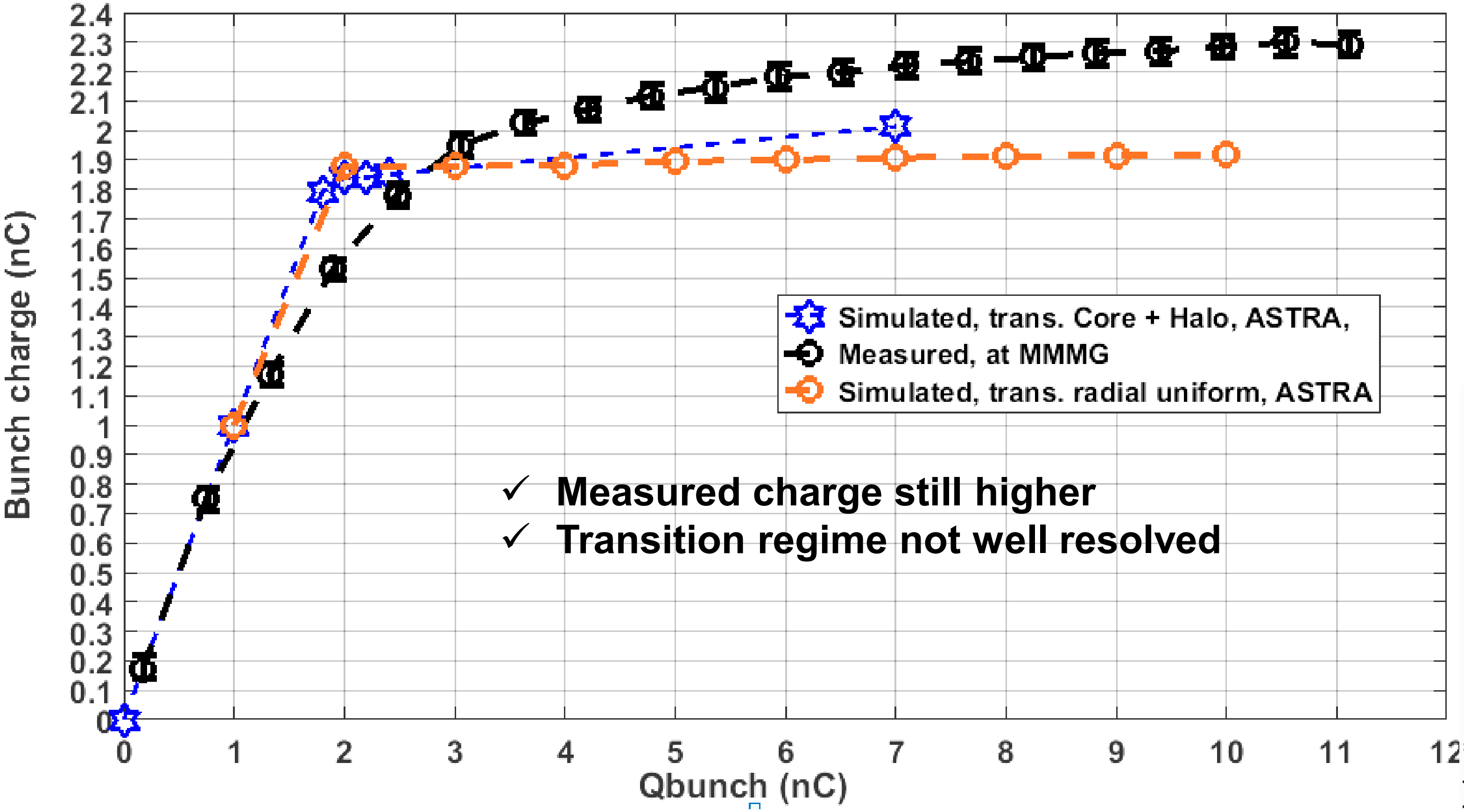
~6.5% change in emission radius while varying LT

- ❑ **If one considers variable sizes of space charge layer formed in front of cathode, PPC model may explain the short bunch case**
- ❑ To be checked for different BSA sizes
- ❑ Cross checking with simulated beam sizes for different injected bunch charges

Simulations

ASTRA, Trans. Uniform and Asymmetric Particle Distributions

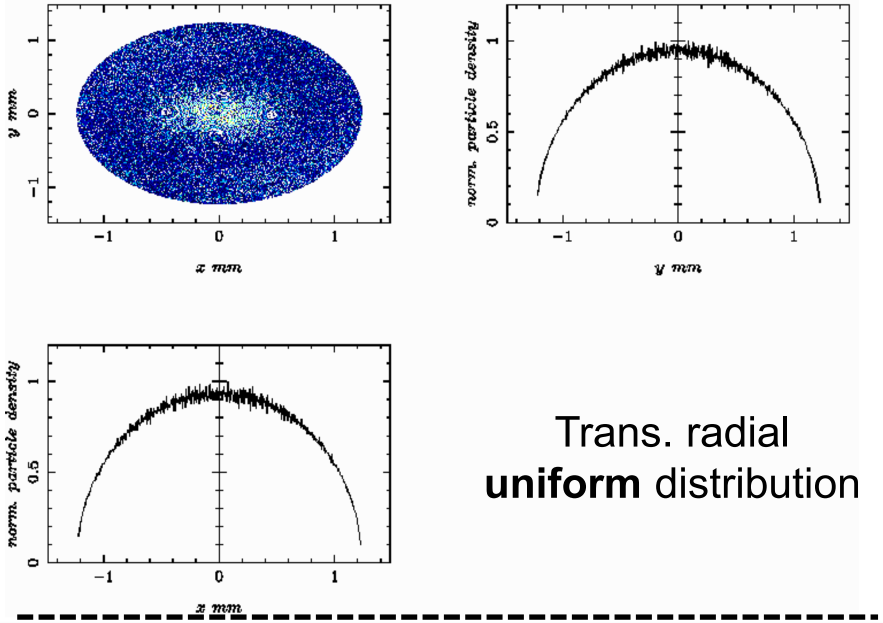
❑ **ASTRA using trans. uniform and asymmetric distributions**



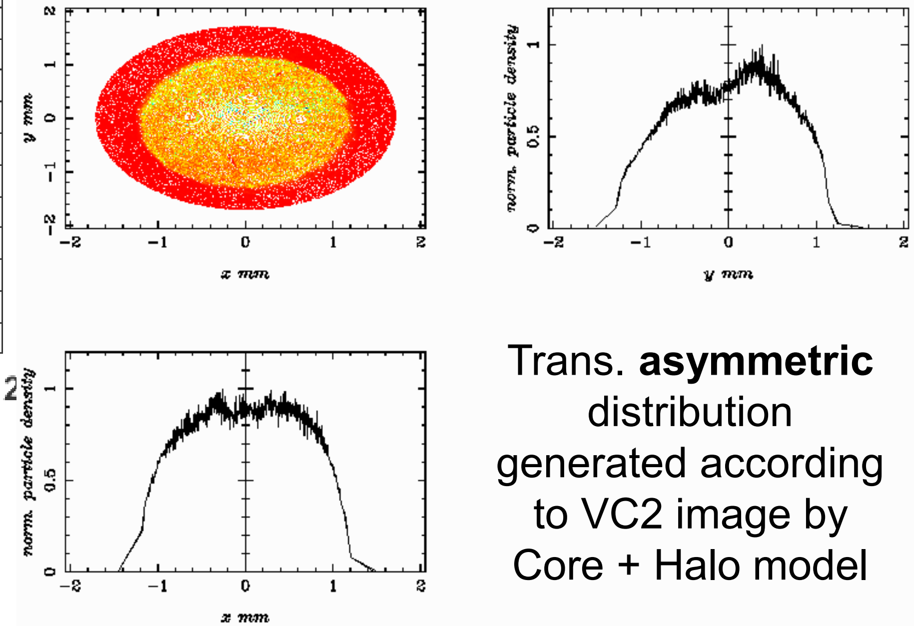
✓ **Measured charge still higher**
✓ **Transition regime not well resolved**

Convergence issues for short bunch?

Initial Trans. Particle distributions



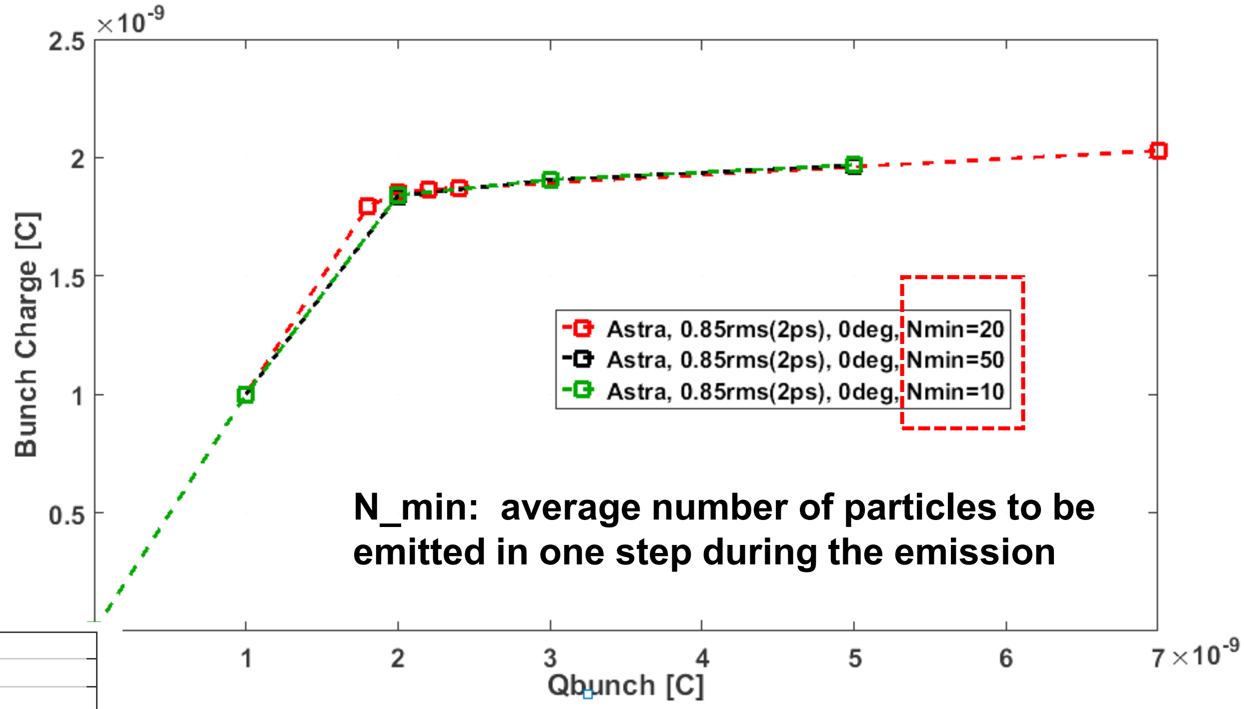
Trans. radial **uniform** distribution



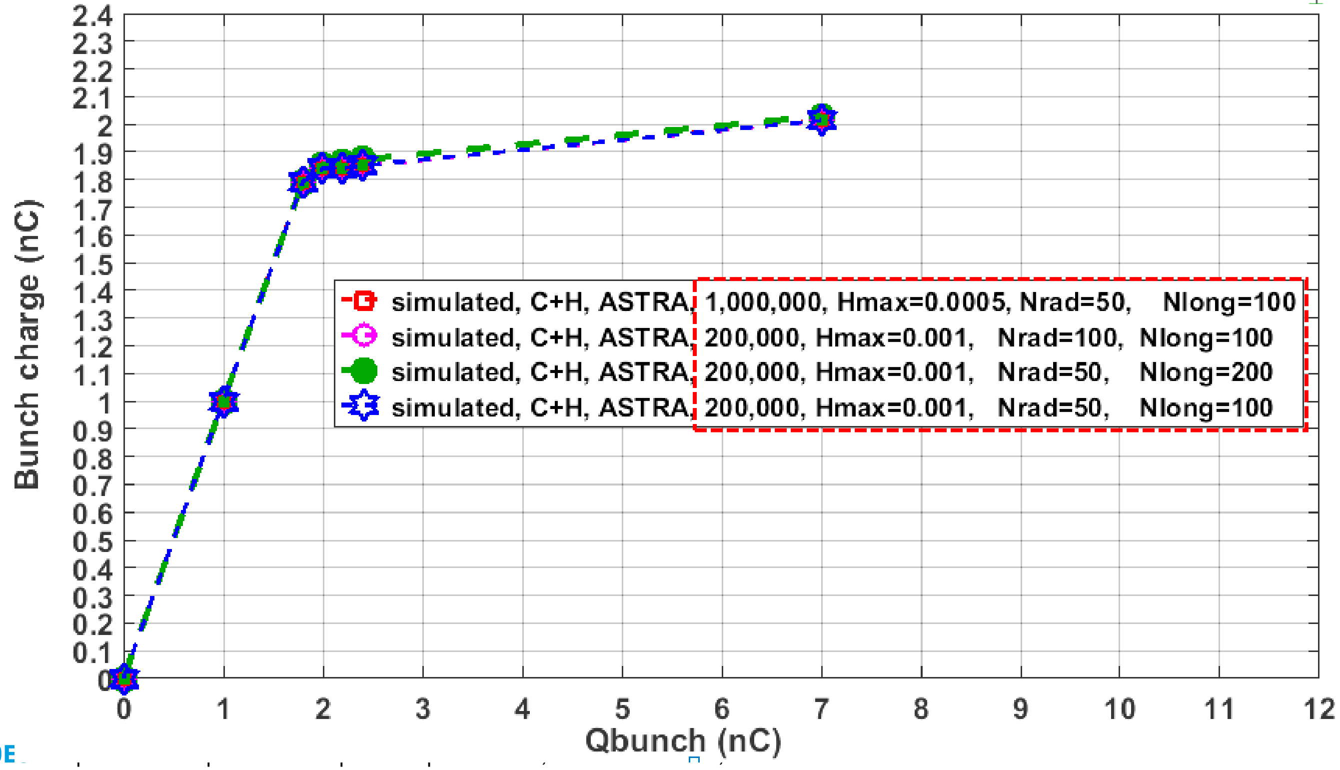
Trans. **asymmetric** distribution generated according to VC2 image by Core + Halo model

Simulations

ASTRA convergence



- **Convergence w.r.t.**
  - Time step
  - Number of macro particles
  - Number of emitted particles per time step / per grid
  - Spatial resolution: trans. Grid + long. Grid
  - Possible combinations of those parameters…



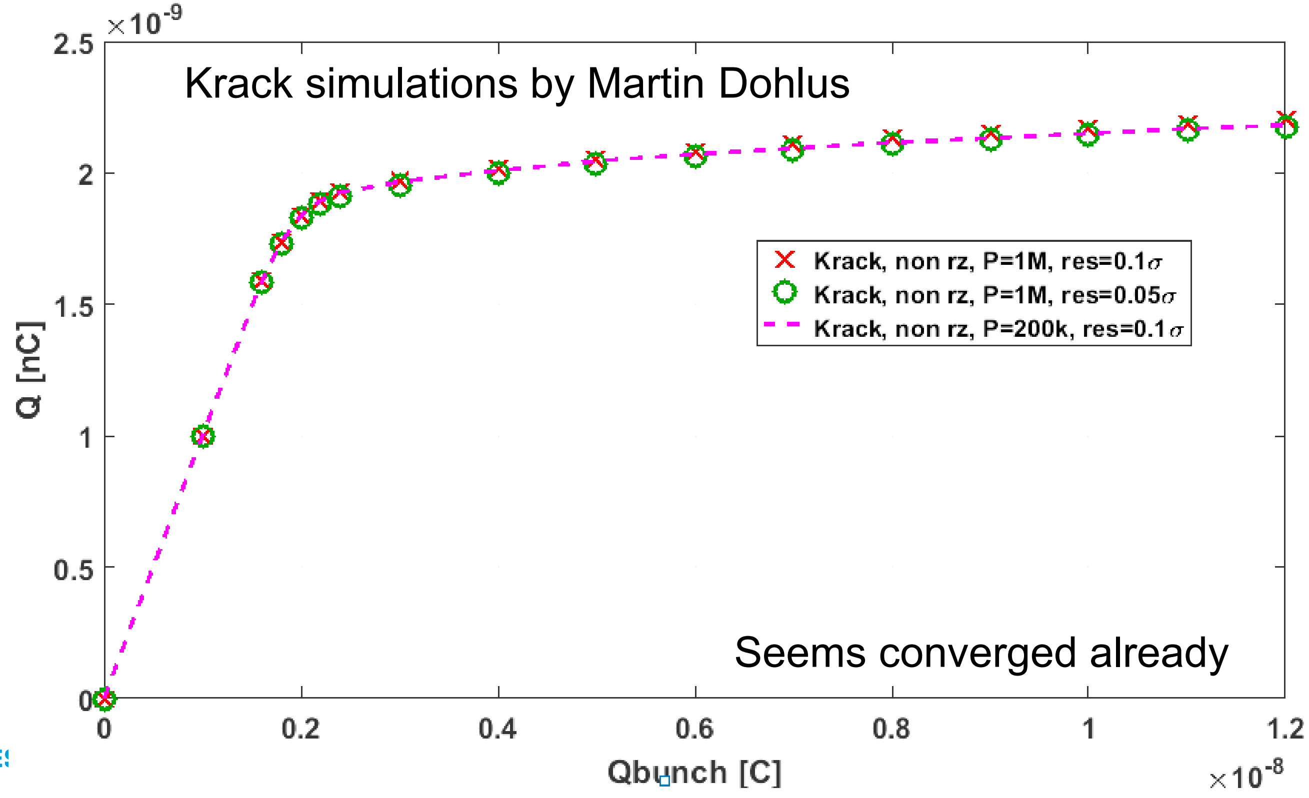
- **Seems not an obvious convergence issue**
- **Combinations of numerical parameters can be further checked…**

Simulations

KRACK code written by Martin Dohlus, DESY Hamburg

❑ KRACK code

→ see **http://www.desy.de/fel-beam/data/talks/files/2017.00.31_11_26_26_53_1_NonUnifCathode.pdf**
→ see **http://www.desy.de/fel-beam/data/talks/files/2017.10.15_13_34_34_49_1_Dohlus_problem_with_poisson_S.pdf**

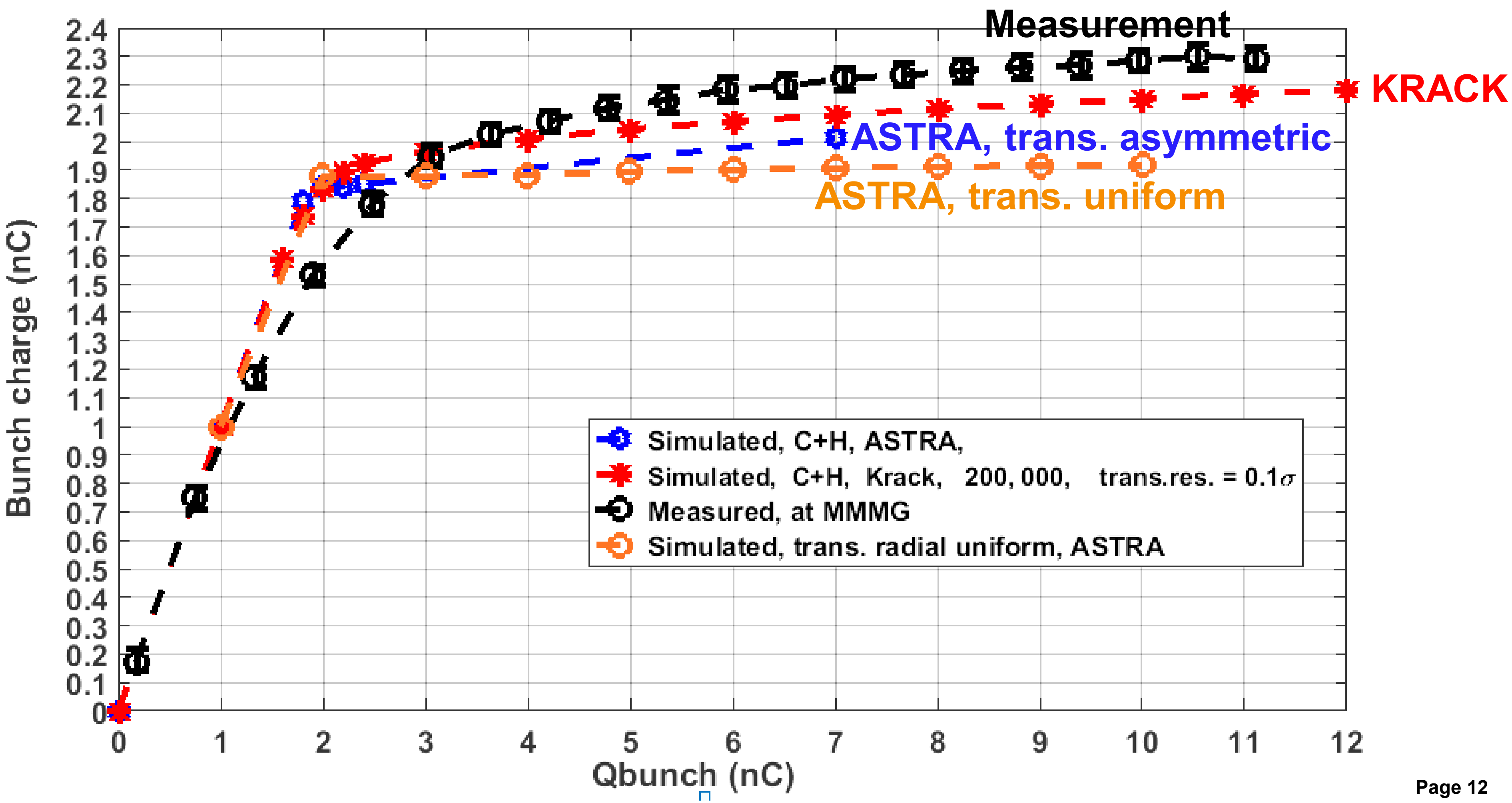


- **3D emission**
- **Planar image charge**
- **Poisson solver**
- **PIC code**
- **Written in Matlab**
- **…**

Simulations

ASTRA Trans. Uniform vs. ASTRA Trans. Asymmetric vs. KRACK

- ❑ **Comparisons (first results)**

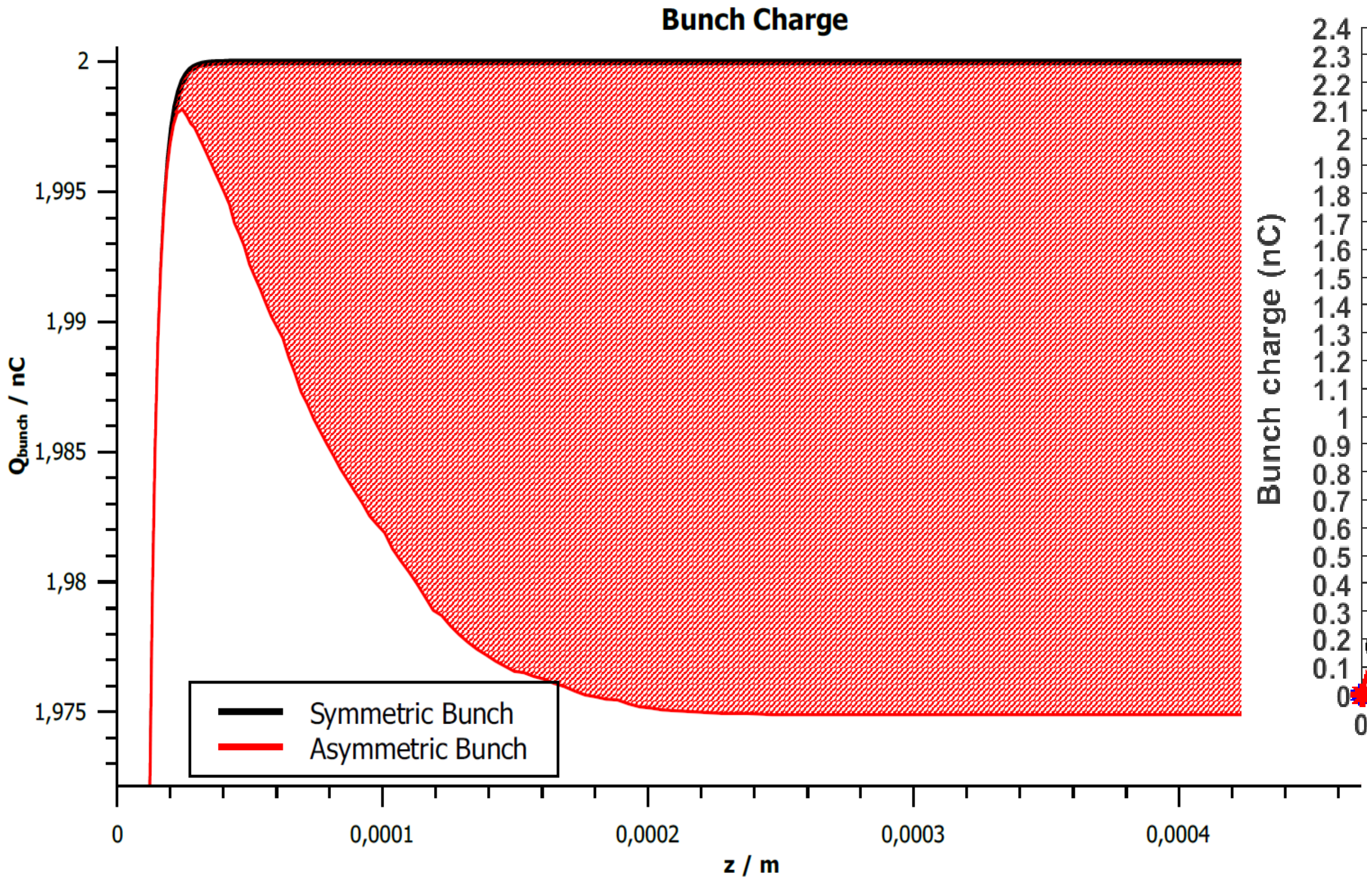


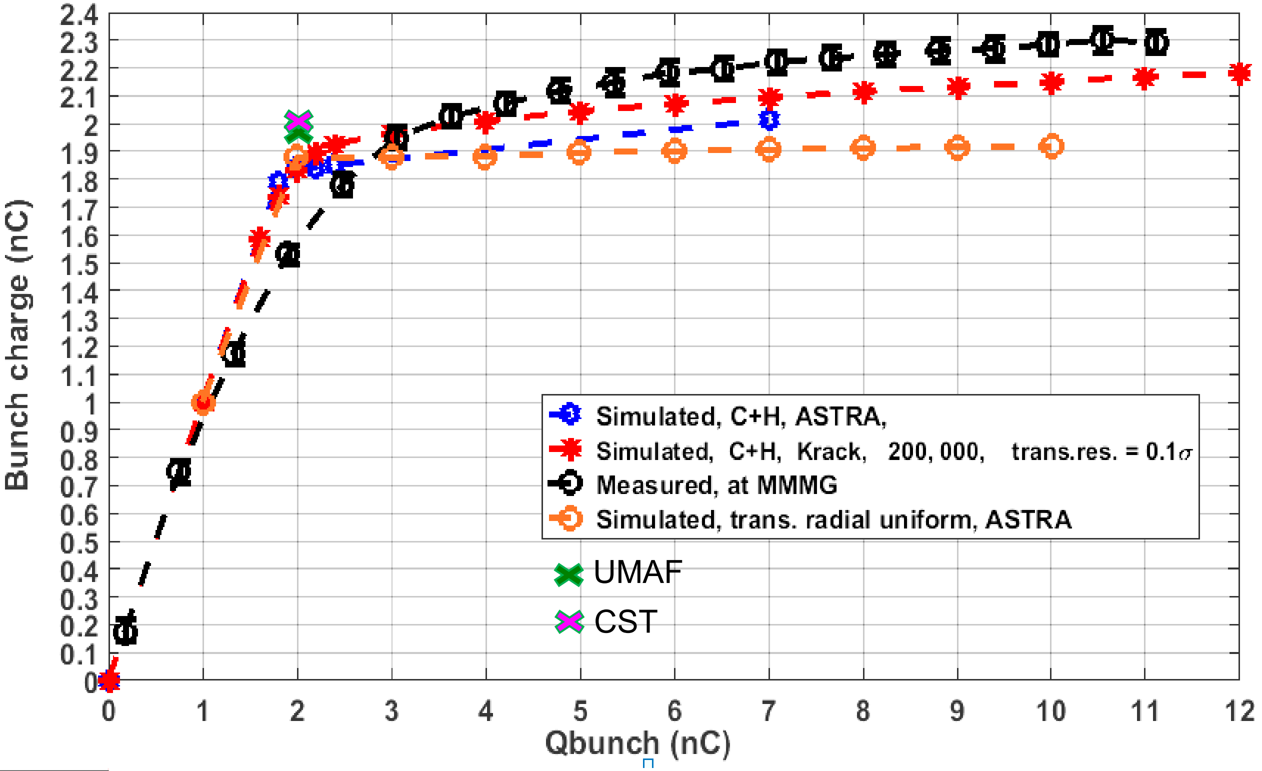
Simulations

Uniform motion average frame (UMAF) simulations

UMAF simulations by Steffen Schmid, TEMF

Qbunch	Trans. Symmetric	Trans. Asymmetric
2 nC	2 nC	~1.975 nC





Simulations

Codes

❑ General features of interests

CODE		Space Charge	Image Charge during emission	RF fields and static magnetic fields	Numerical approx.
ASTRA	2D		Yes	Paraxial approx. (field map possible)	Poisson solver, β constant, particle-in-cell…
	3D		No		
KRACK	3D		Yes	(not sure) Paraxial approx. (field map possible)	(not sure) Similar to ASTRA
CST Particle Studio	3D	Yes	Yes	Full fields	Maxwell solver, full EM fields, particle-in-cell…
UMAF	2D		Yes	Paraxial approx. (field map possible)	Particle-particle / particle-mesh, β constant…
Lienard-Wiechert	3D		Yes	Paraxial approx. (field map possible)	Full Lienard-Wiechert fields, retarded interaction, particle-particle/particle-mesh…

UMAF: uniform motion average frame code

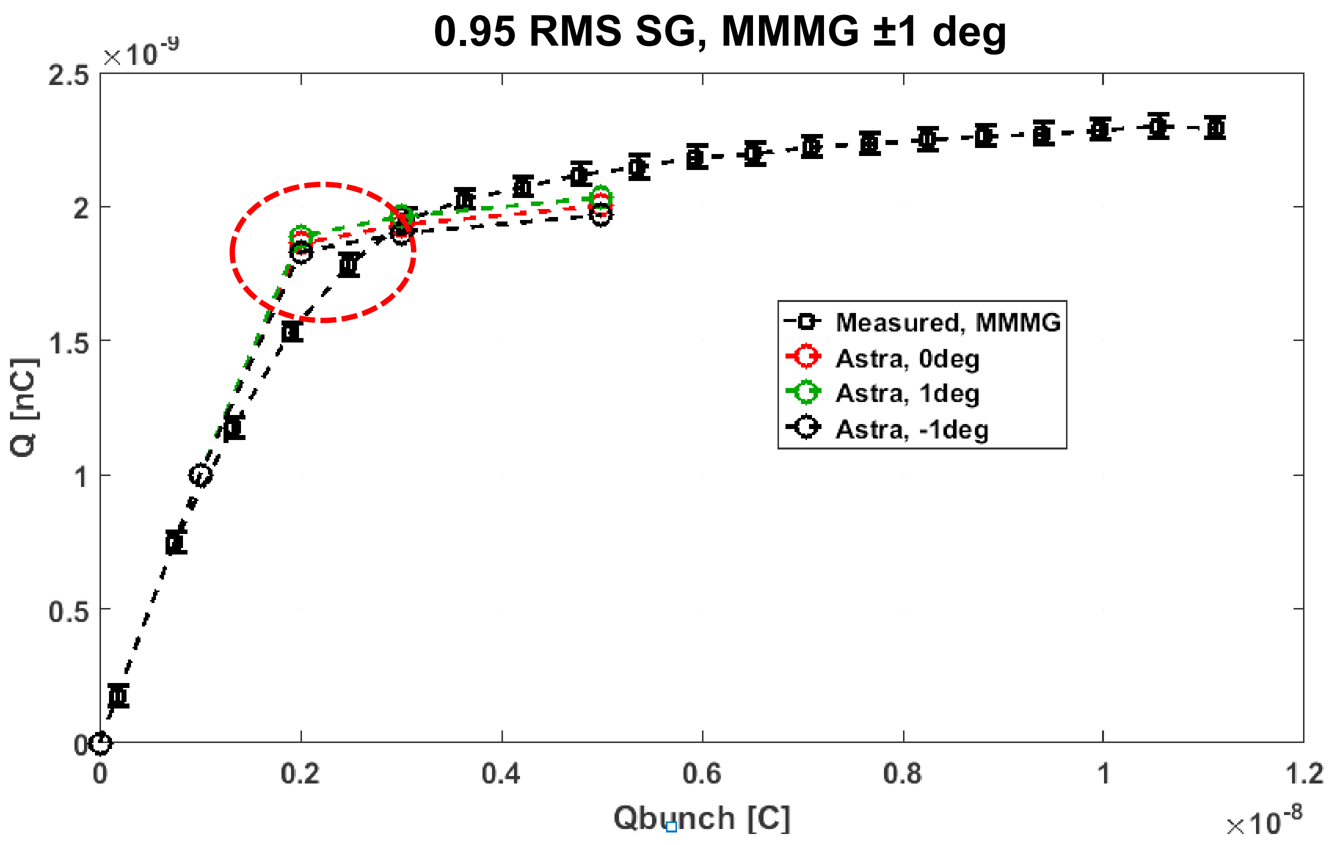
Summary

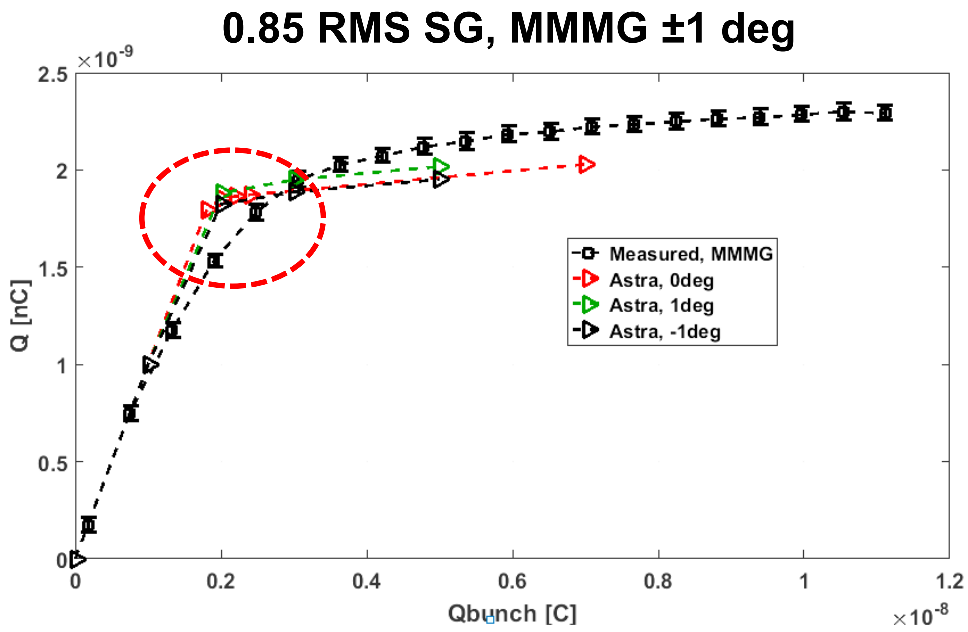
- ✓ Saturation charge predicted by **PPC** model **lower than measured charge in pancake regime**
- ✓ **Strong space charge induced bunch expansion may vary effective emission radius** of PPC model
- ✓ **PPC model with variable emission radius may explain** the measurements for SG cases
- ✓ Effective emission radius grows by ~6% as Qbunch increasing; Seems comparable with simulated beam size growth tendency; To be checked for other measurement data
- ✓ Simulations with different codes (without emission model) could not yet explain the emission curve, especially in the QE-SC transition regime
- ✓ **If transverse beam dynamics is fine, can we suspect longitudinal dynamics might not be fully modeled by the codes?**
- ✓ Convergence of ASTRA, KRACK simulations done; Results of other codes to be further checked vs. numerical parameters
- ✓ Tolerance studies (pulse shape/length/RF phase) did not show improvements on the nonlinear dependency of emission curve on the laser pulse energy

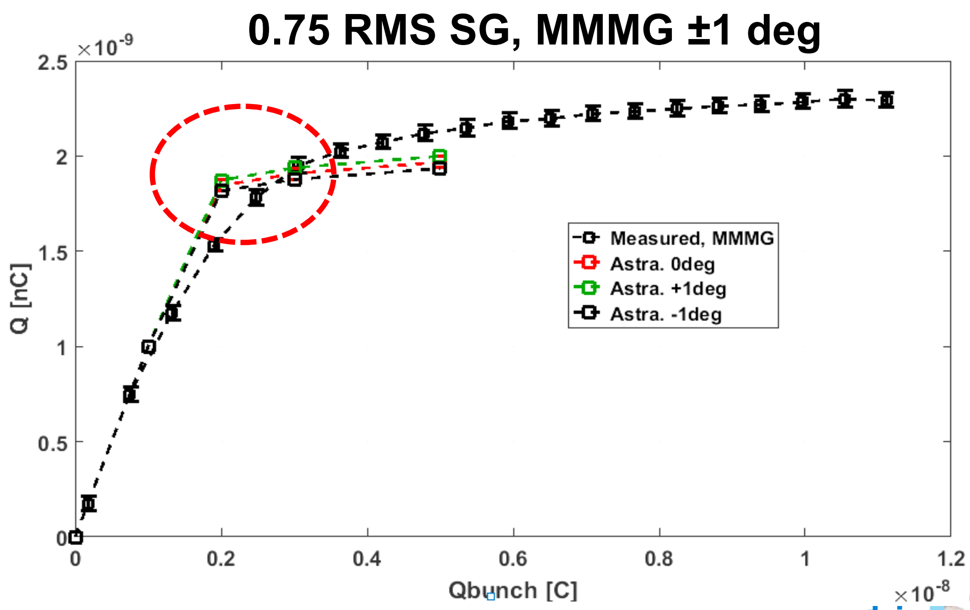
Backup

Tolerance Studies

Varying RF phase by ±1deg at 3 laser pulse lengths



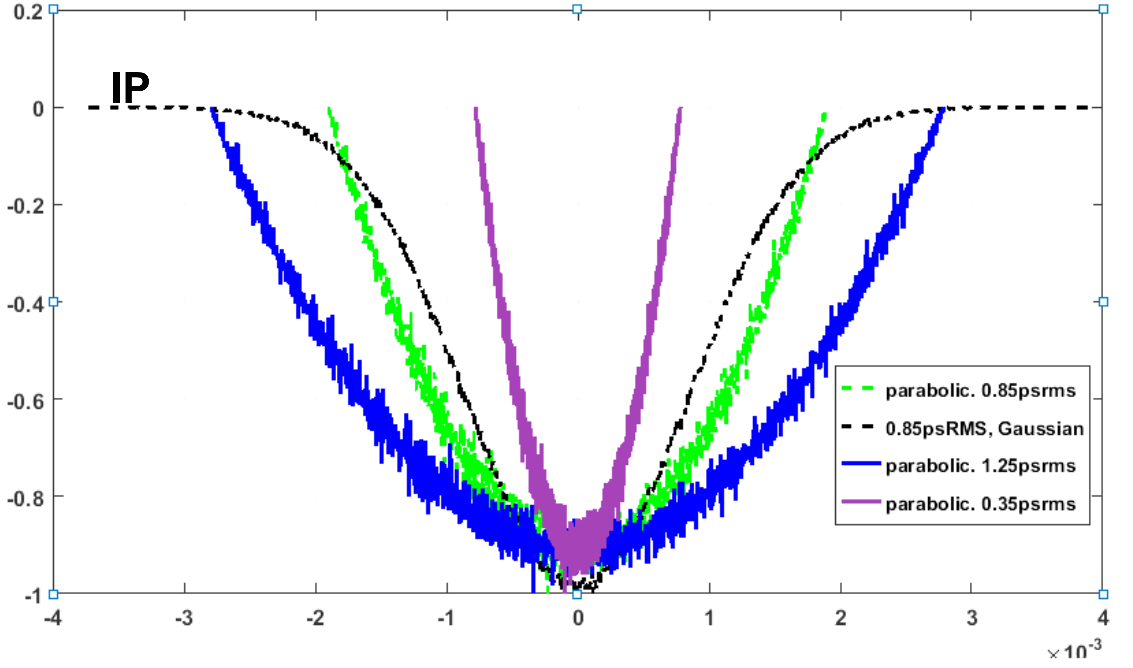


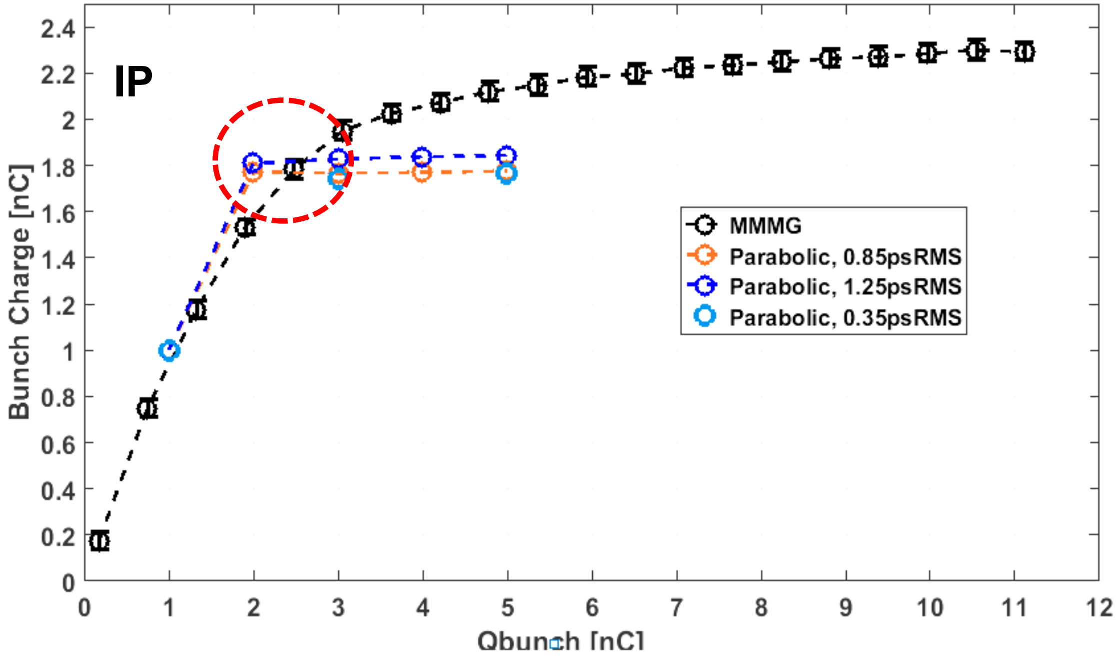


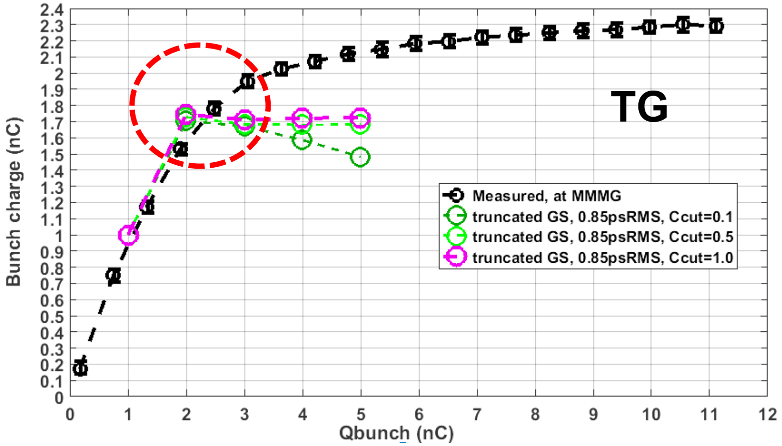
Tolerance Studies

Varying temporal pulse shapes

❑ Using inverted parabola (IP) and truncated Gaussian (TG) profiles







$$f(x) = \frac{1}{\sqrt{2\pi}\sigma_{inp}} \exp\left(-\frac{1}{2}\frac{x^2}{\sigma_{inp}^2}\right) \quad \text{for} \quad |x| \le C_{Cut}\sigma_{inp}$$

UMAF simulations by Steffen Schmid, TEMF

Emittance comparison

Trans. Symmetric Bunch vs. Trans. Asymmetric Bunch