Photoemission Studies of the PITZ Photoinjector: Bunch Charge Extraction

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- **Emittance studies (continuations)**
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  - Influence of laser spot size, laser transmission (LT) and RF field at the cathode
  - Discussions: Qmax (laser), LT (SCL), Schottky-like effect
  - Further photoemission studies: simultaneous variation of multi-parameters
- **Conclusions**

*CST Particle Studio
** Space Charge Limited

Emittance Studies (continuations)

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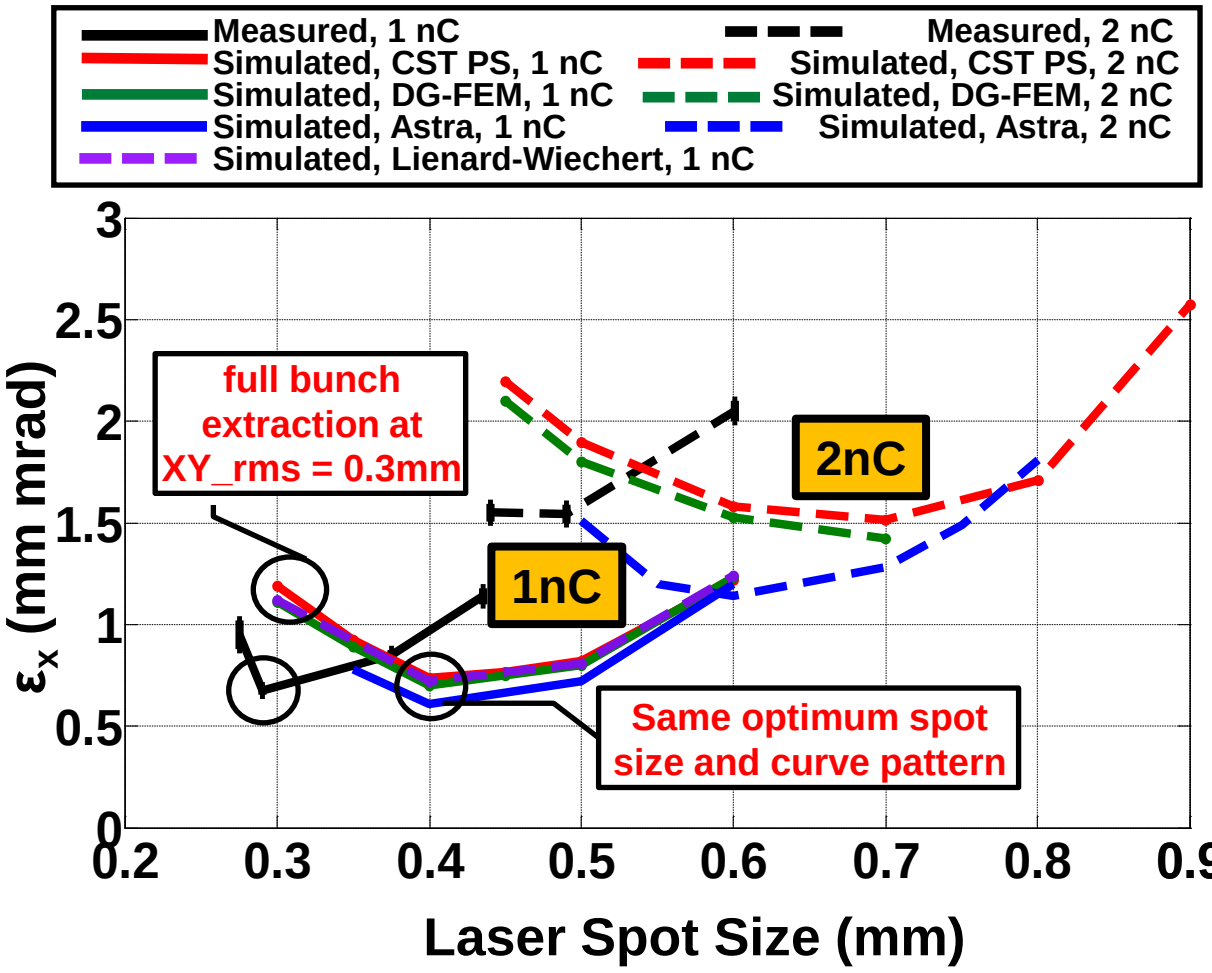
CST PS Simulations:

- Repeat all previous simulations up to EMSY1 using CST PS*
- Comparisons of emittance at EMSY1 between CST PS simulations, DG-FEM simulations, Astra simulations, and the measurement data
- Numerical procedures:
  - All bunches only tracked up to 3 cm behind cathode in CST PS, then continue tracking with Astra using the bunches obtained in CST PS

*CST Particle Studio

Emittance Studies (continuations)



Conclusions:

- There is a modeling error in Astra
- Still no explanation for the systematic shift w.r.t. laser spot size (observed in all simulations)

Probable causes for the shift:

- actual laser spot sizes smaller than reported in the literature
- bunch transverse size generated at the cathode ≠ laser spot size

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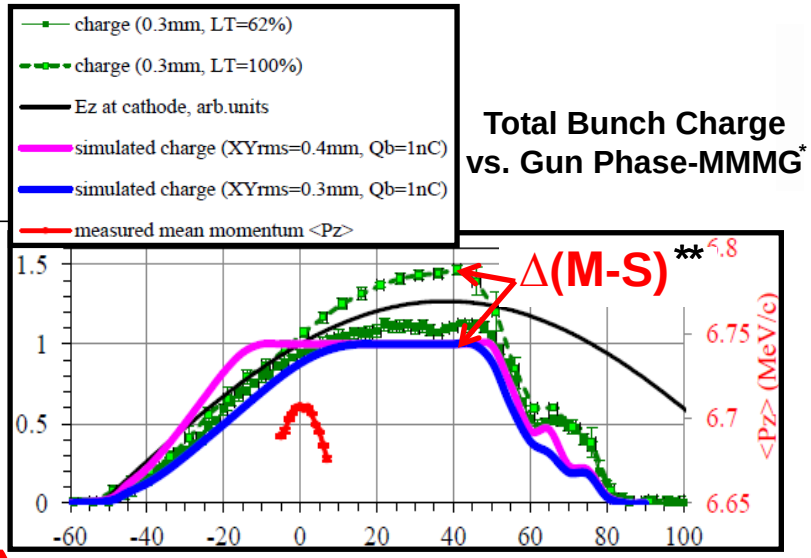
Photoemission Studies: Charge Extraction

- **Charge extractions in CST PS**
- **Comparisons: Simulations vs. Measurements**
- Influence of laser spot size, LT and RF field at the cathode
- Simultaneous variation of multi-parameters

Charge Extraction :

Motivation & Assumptions



Total Bunch Charge vs. Gun Phase-MMMG*

*M. Krasilnikov, PITZ: Simulations versus Experiment, 2013

** **M-S: Measurement-Simulation**

- **Motivation:** Astra simulations predict space charge limit at less than 1 nC for XY_rms = 0.3 mm, whereas 1 nC and even higher bunch charges were detected experimentally.
- **Assumptions (total charge calculation)**

I. Laser produced as more particles as one can inject at the cathode

⇨ Q_0=arbitrary, Q_b = ?

II. Laser produced just the maximum number of particles that can be emitted at the cathode without space charge limitations

⇨ $Q_b = Q_0$ = ?

- **Simulations based on assumption I**

Q_0 = arbitrary, Q_b = ?

Example: Q_0 = 2 nC, 1.2 nC, 1 nC
XY_rms = 0.3 mm

Main Simulation Parameters:

Q_0: initial total bunch charge, to be injected at cathode

Q_b: total emitted bunch charge

XY_rms = 0.3 mm, flat top, 2.2/21.46\2.2 ps

Charge Extraction —

CST PS Simulations (assumption I) (1)

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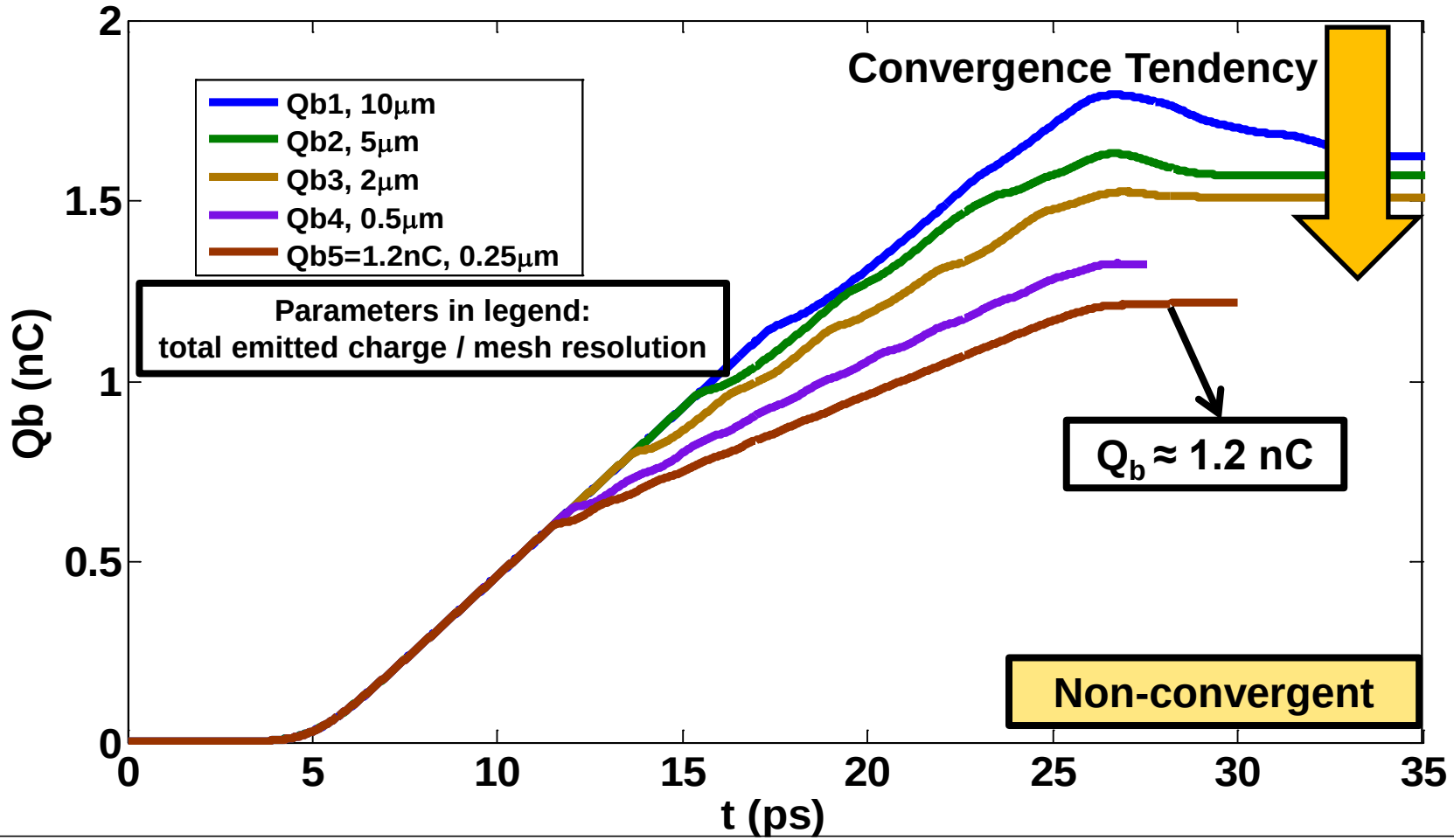
XY_rms = 0.3 mm, Q_0 = 2 nC



Charge Extraction —

CST PS Simulations (assumption I) (2)

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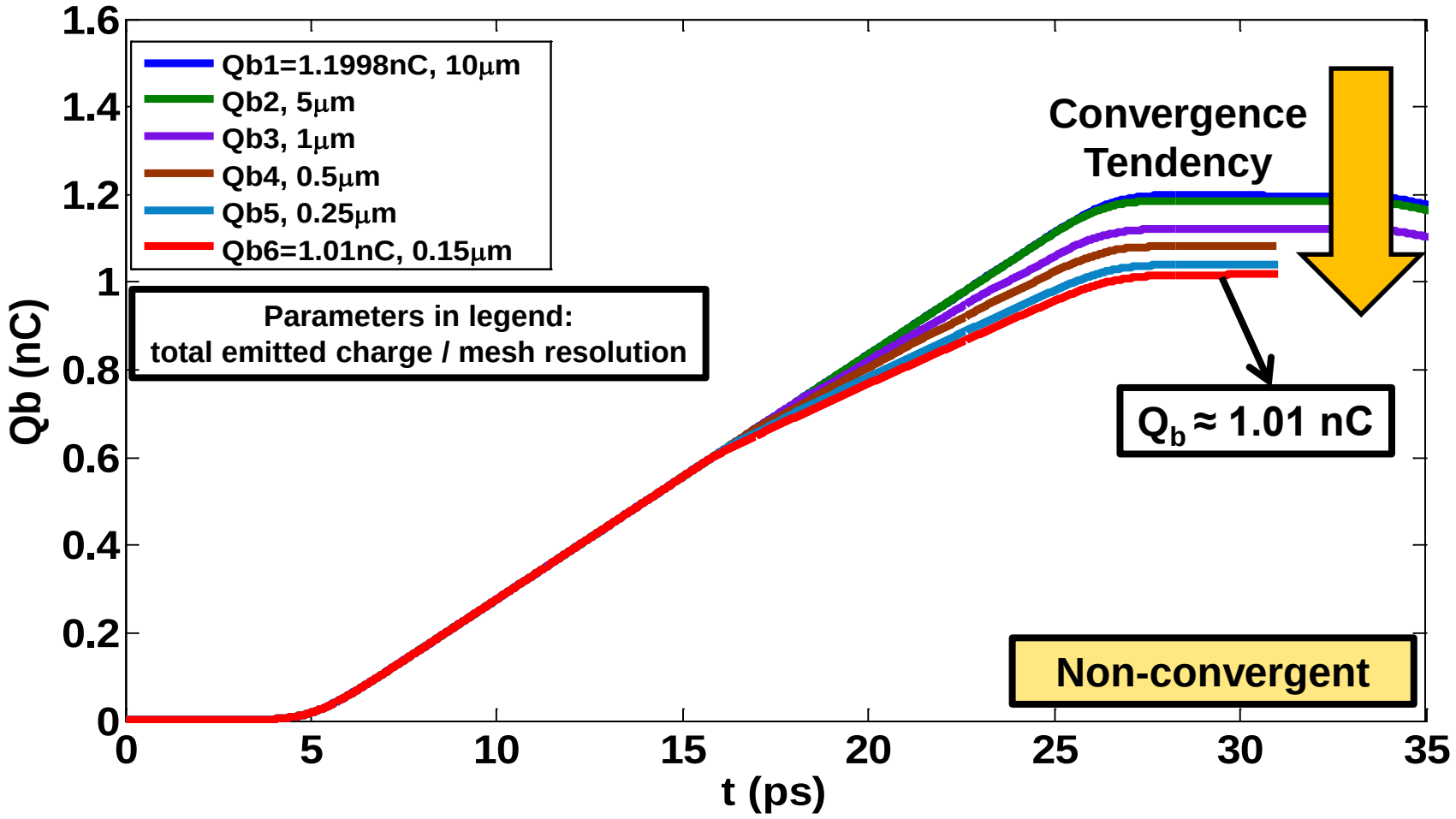
XY_rms = 0.3 mm, Q_0 = 1.2 nC



Charge Extraction —

CST PS Simulations (assumption I) (3)

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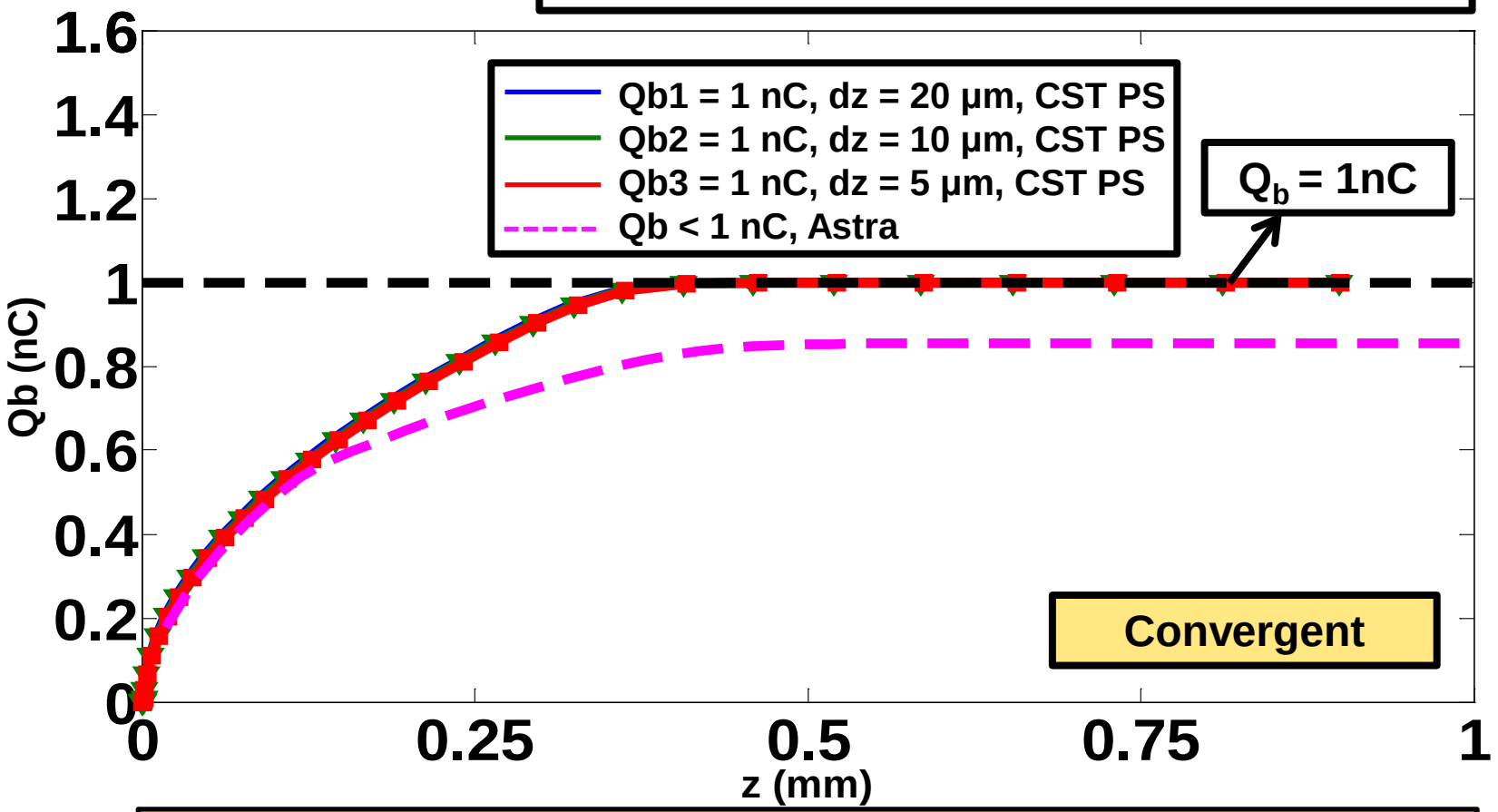
XY_rms = 0.3 mm, Q_0 = 1 nC

Parameters in legend:
total emitted charge / mesh resolution /simulation tool



- No numerical convergence unless the initial charge assumed to be close to the space charge limit

Charge Extraction :

Main Idea for Assumption II

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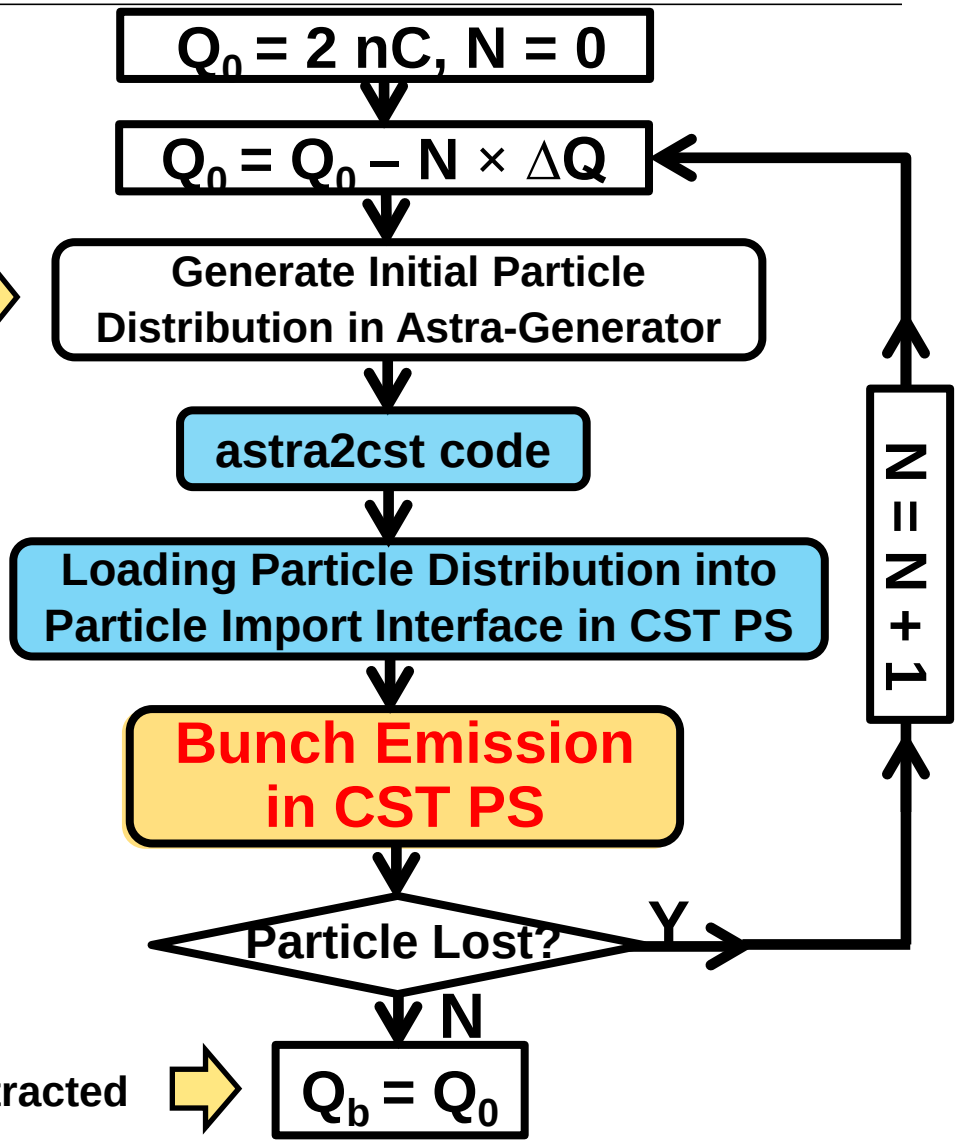
- **Assumption II: $Q_b = Q_0 = ?$**
  - **Simulation Scheme**

for comparison purpose

Main idea: calculate the maximum injected bunch charge which can be fully extracted (SPCH-Limited) using CST PS

Q_0: initial total bunch charge, to be injected at the cathode
Q_b: total emitted bunch charge
Charge scanning range: (0-2) nC
Charge resolution: ~ 50 pC
Laser spot size: XY_rms = 0.3 mm
Temporal Profile: flat top, 2.2/21.46\2.2 ps



the injected charge at cathode is fully extracted

Charge Extraction —

CST PS Simulation vs. Astra Simulation (1)

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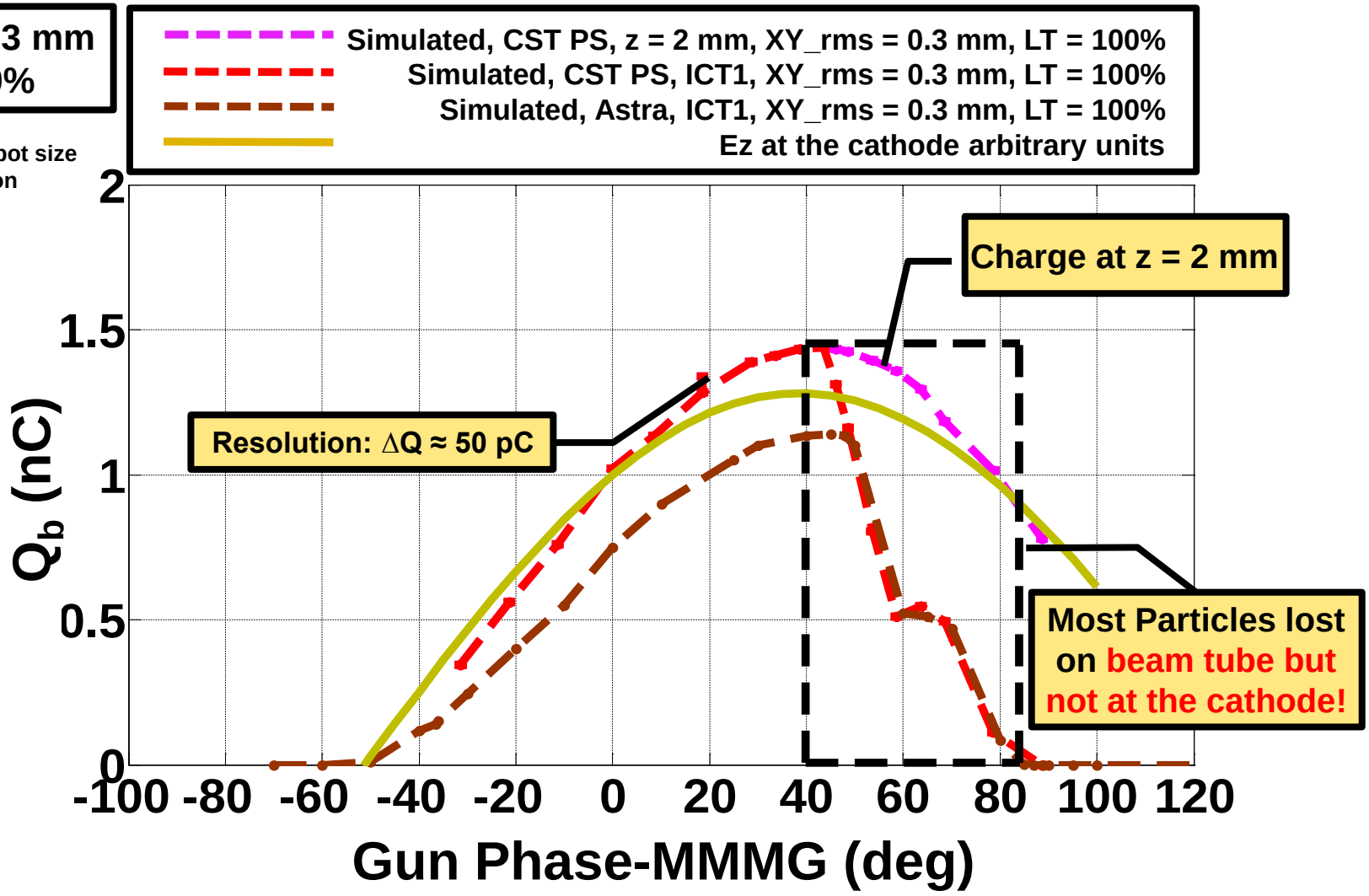
XY_rms = 0.3 mm
LT = 100%

XY_rms: rms laser spot size
LT: laser transmission



Charge Extraction —

CST PS Simulation vs. Measurement (1)

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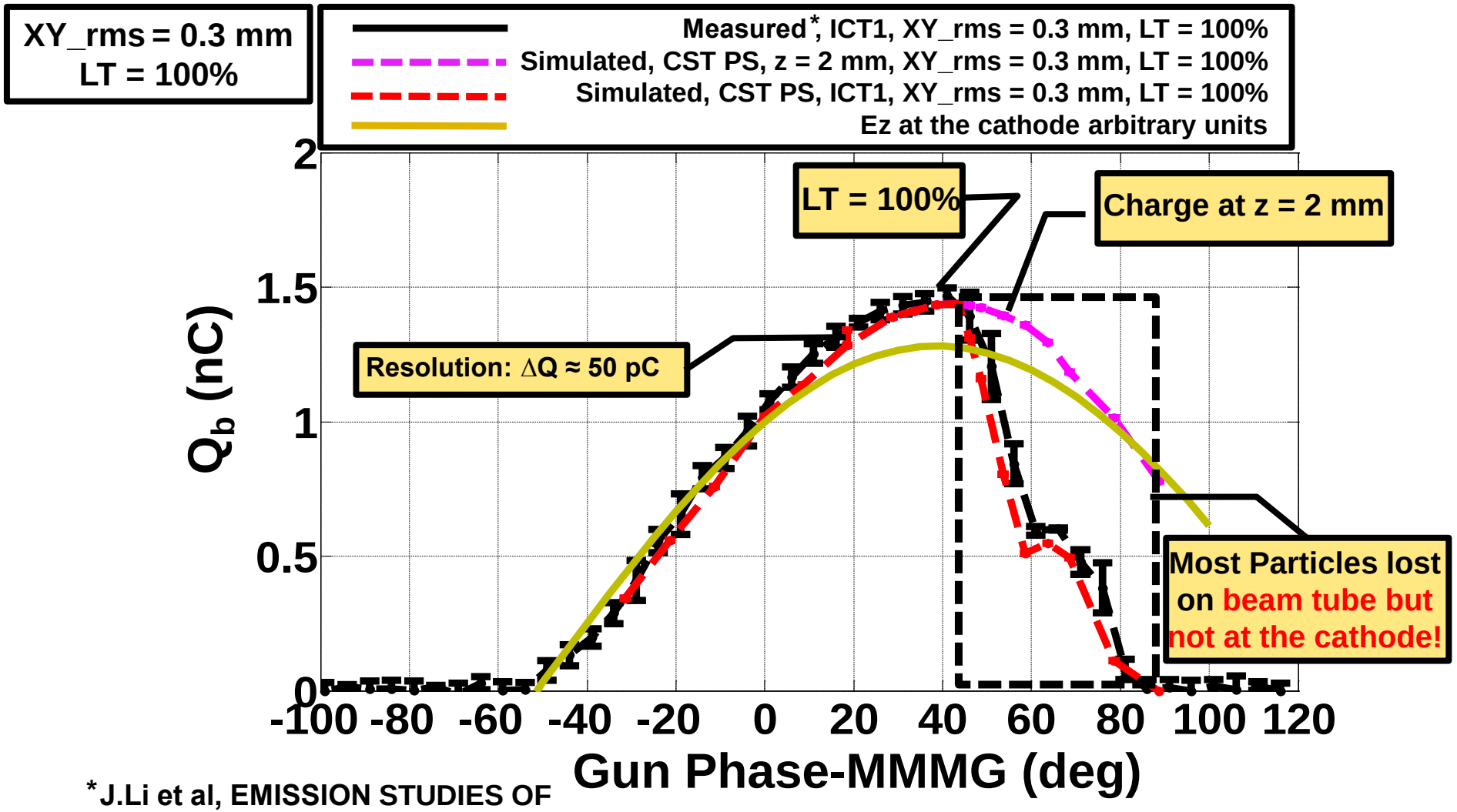

*J.Li et al, EMISSION STUDIES OF PHOTOCATHODE RF GUN AT PITZ, 2012

Charge Extraction —

Discussion (1): Schottky-like effect

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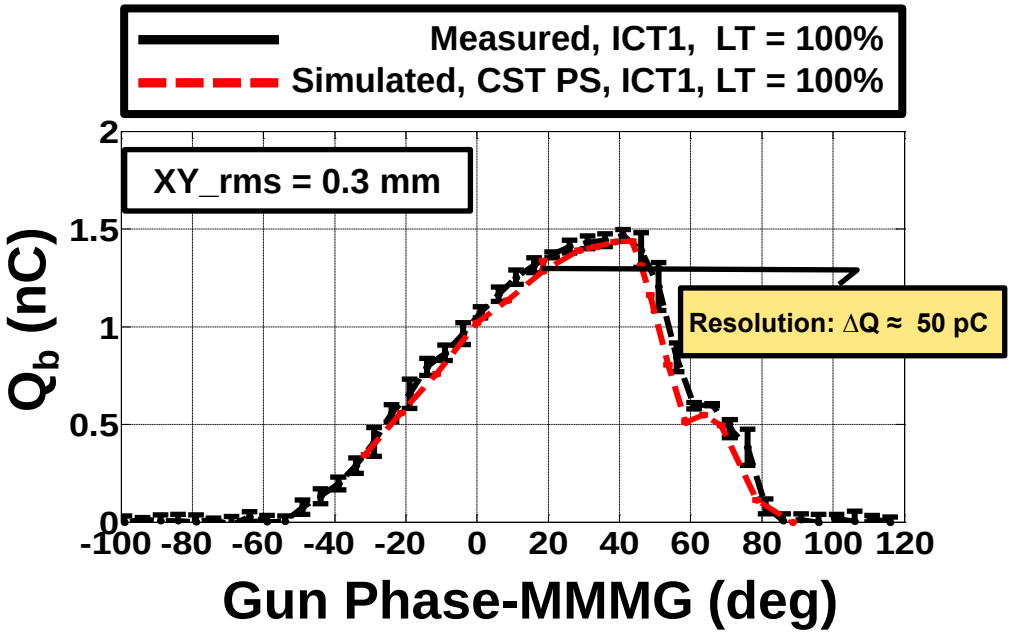
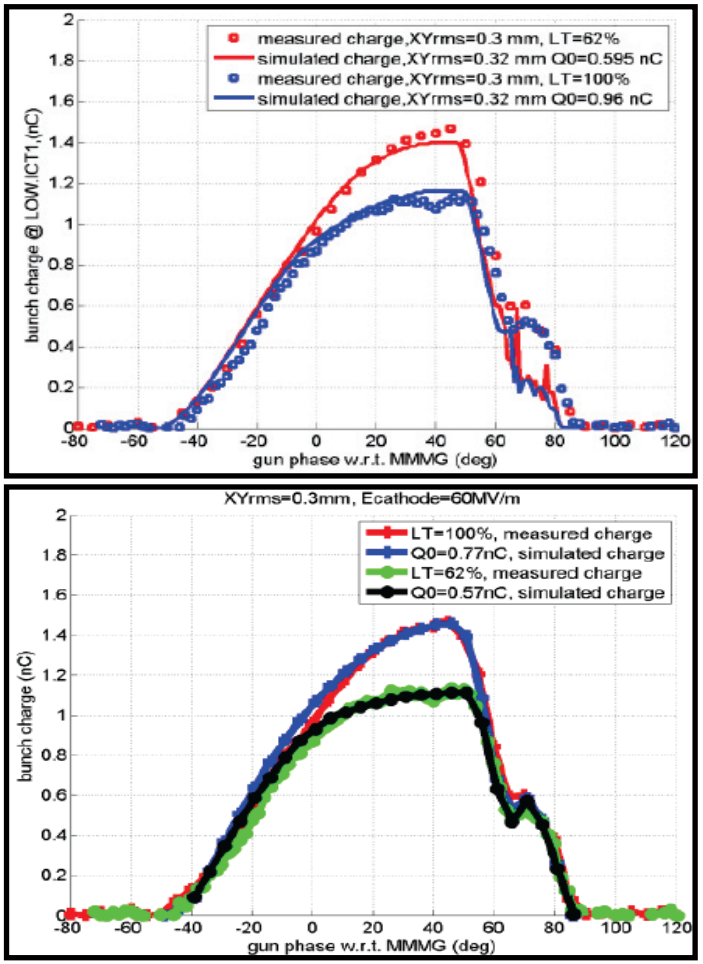
Without Schottky-like effect



- Total emitted bunch charge simulated with CST PS without Schottky-like effect can be very close to the measured total bunch charge.
- To explain the M-S difference in produced total bunch charge, Schottky-like effect probably not very important??

With Schottky-like effect*



*J.Li et al, EMISSION STUDIES OF PHOTOCATHODE RF GUN AT PITZ, 2012

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Photoemission Studies: Charge Extraction

- Charge extractions in CST PS
- Comparisons: Simulations vs. Measurements
- **Influence of laser spot size, LT and RF field**
- **Simultaneous variation of multi-parameters**

Charge Extraction —

CST PS Simulation vs. Astra Simulation (2)

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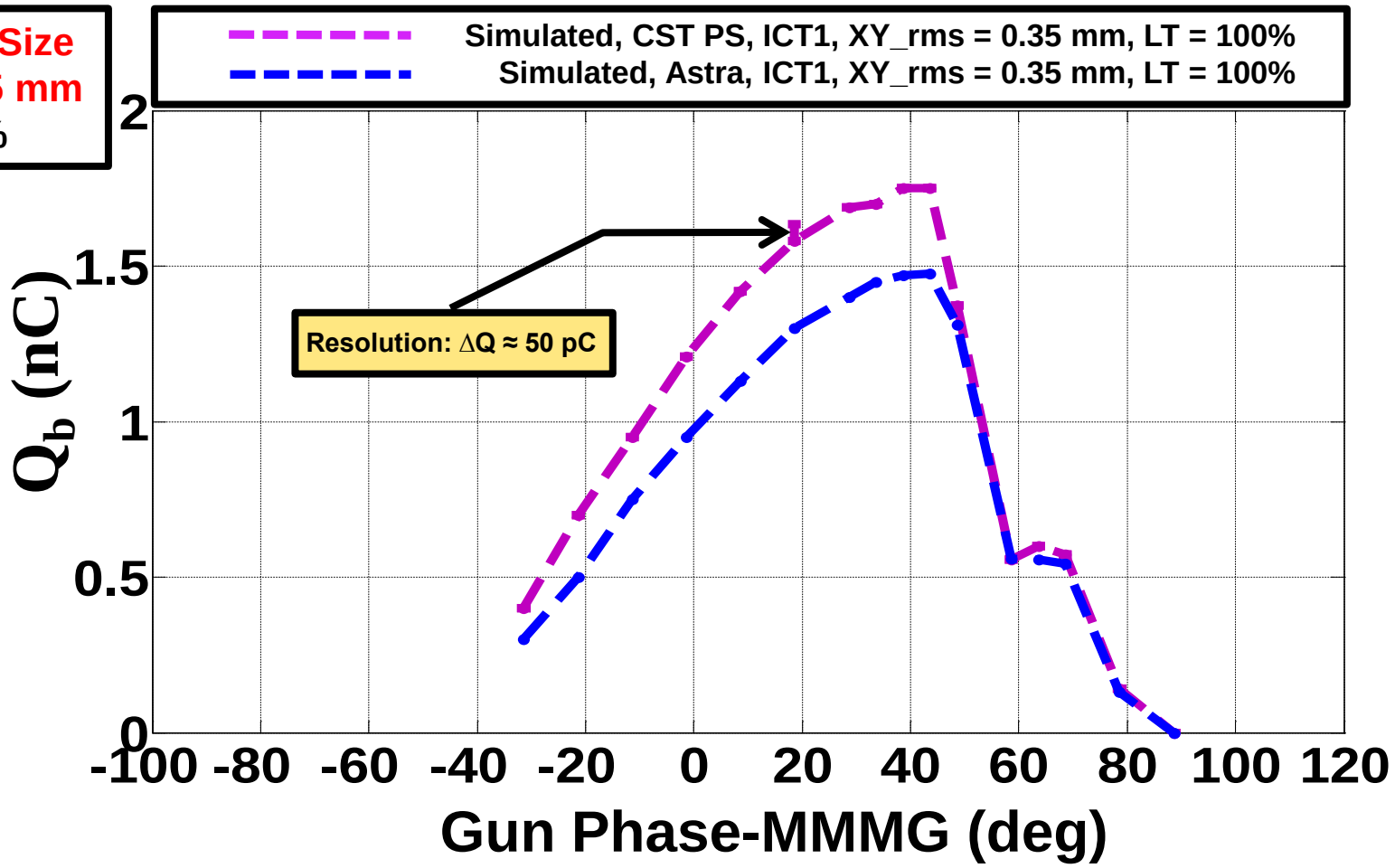
+ Laser Spot Size
XY_rms = 0.35 mm
LT = 100%



*missing corresponding measurement data

Charge Extraction —

Assumption for Lower-LT (<100%) case

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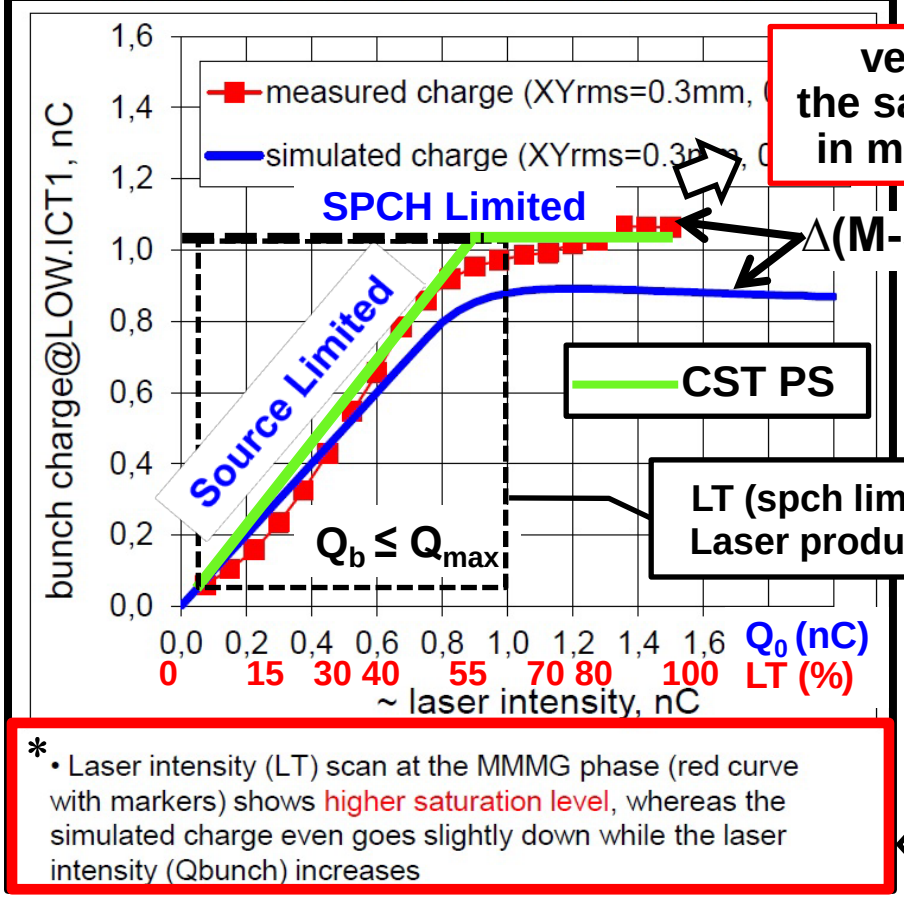
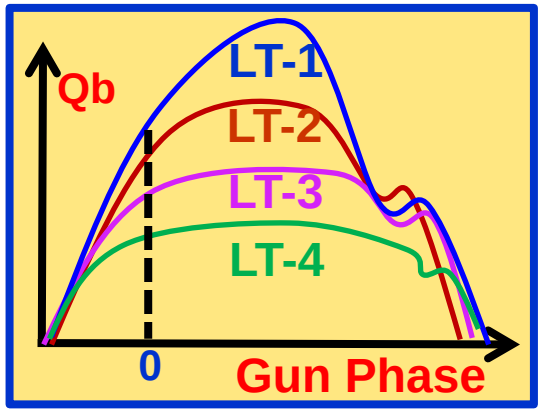
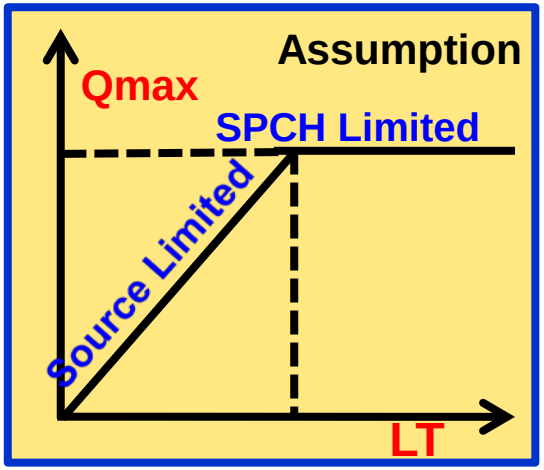
Measurement data for
XY_rms = 0.3 mm, MMMG Phase, various LTs







* • Laser intensity (LT) scan at the MMMG phase (red curve with markers) shows higher saturation level, whereas the simulated charge even goes slightly down while the laser intensity (Qbunch) increases

* M. Krasilnikov, ICFA Workshop on Future Light Sources, 2012

Charge Extraction —

CST PS Simulation vs. Measurement (2)

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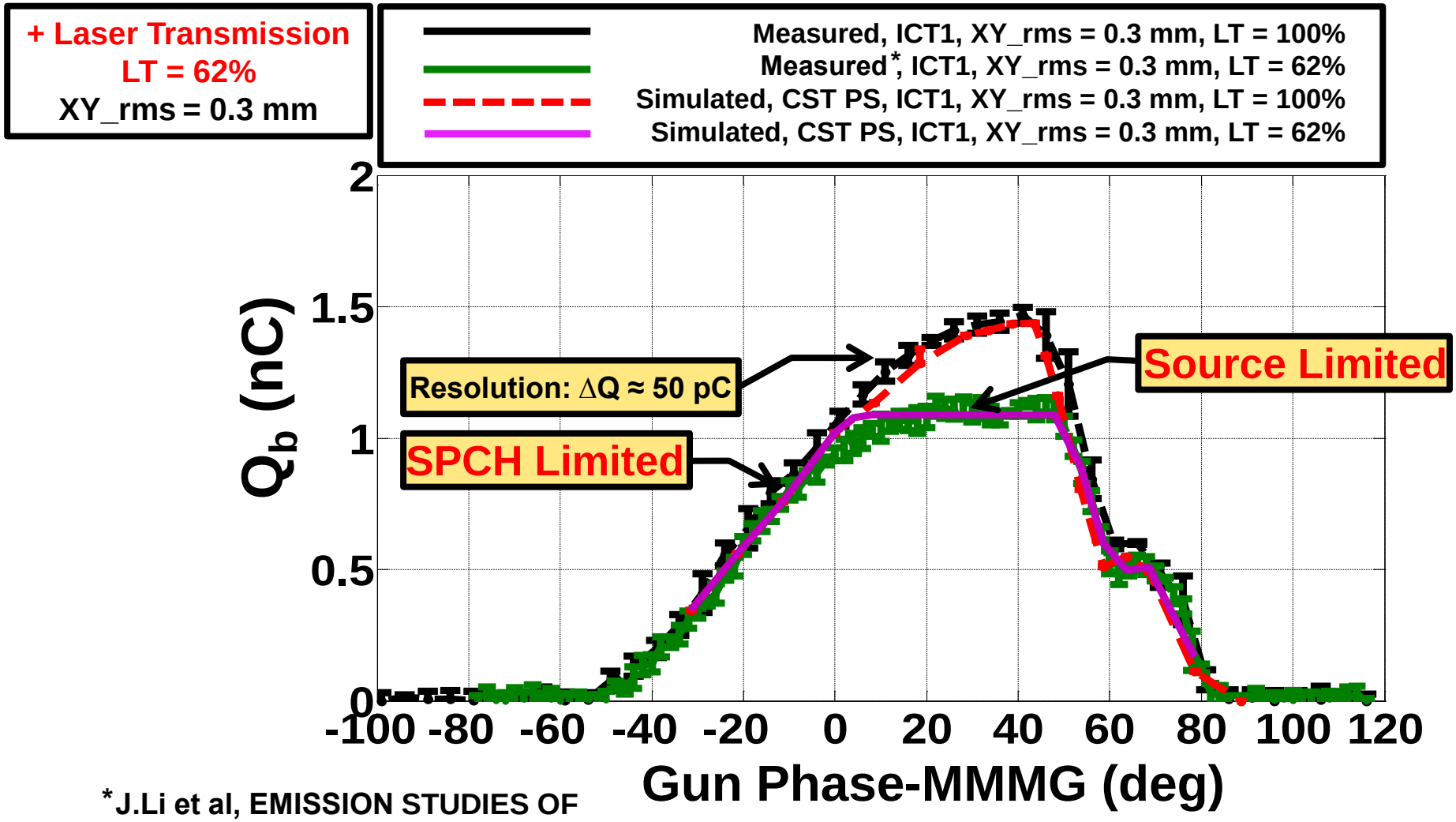

*J.Li et al, EMISSION STUDIES OF PHOTOCATHODE RF GUN AT PITZ, 2012

Charge Extraction —

CST PS Simulation vs. Measurement (3)

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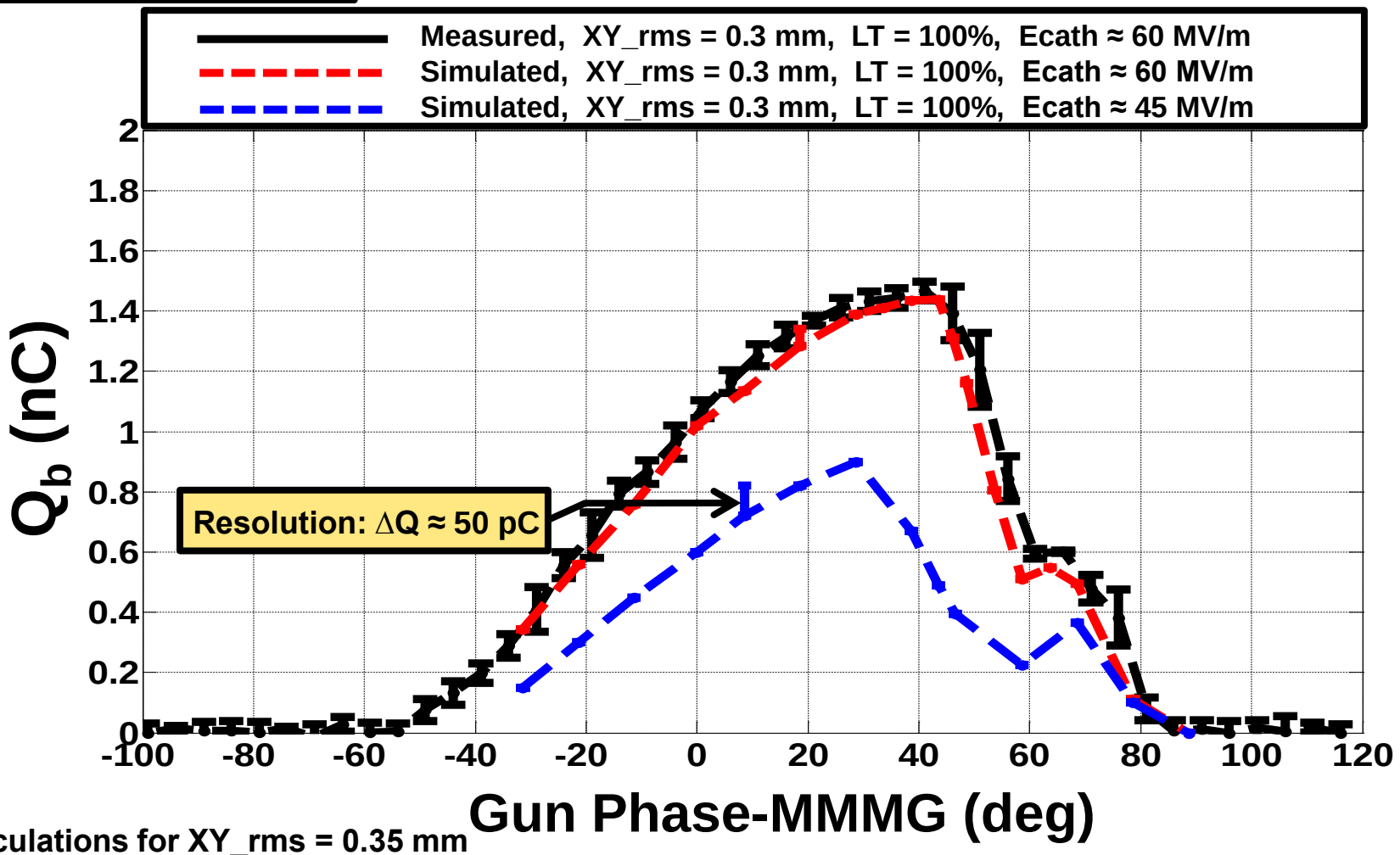
+ RF field, Ecath = 60, 45 (MV/m)
XY_rms = 0.3 mm, LT = 100%



*Ongoing calculations for XY_rms = 0.35 mm

Charge Extraction —

CST PS Simulation vs. Measurement (4)

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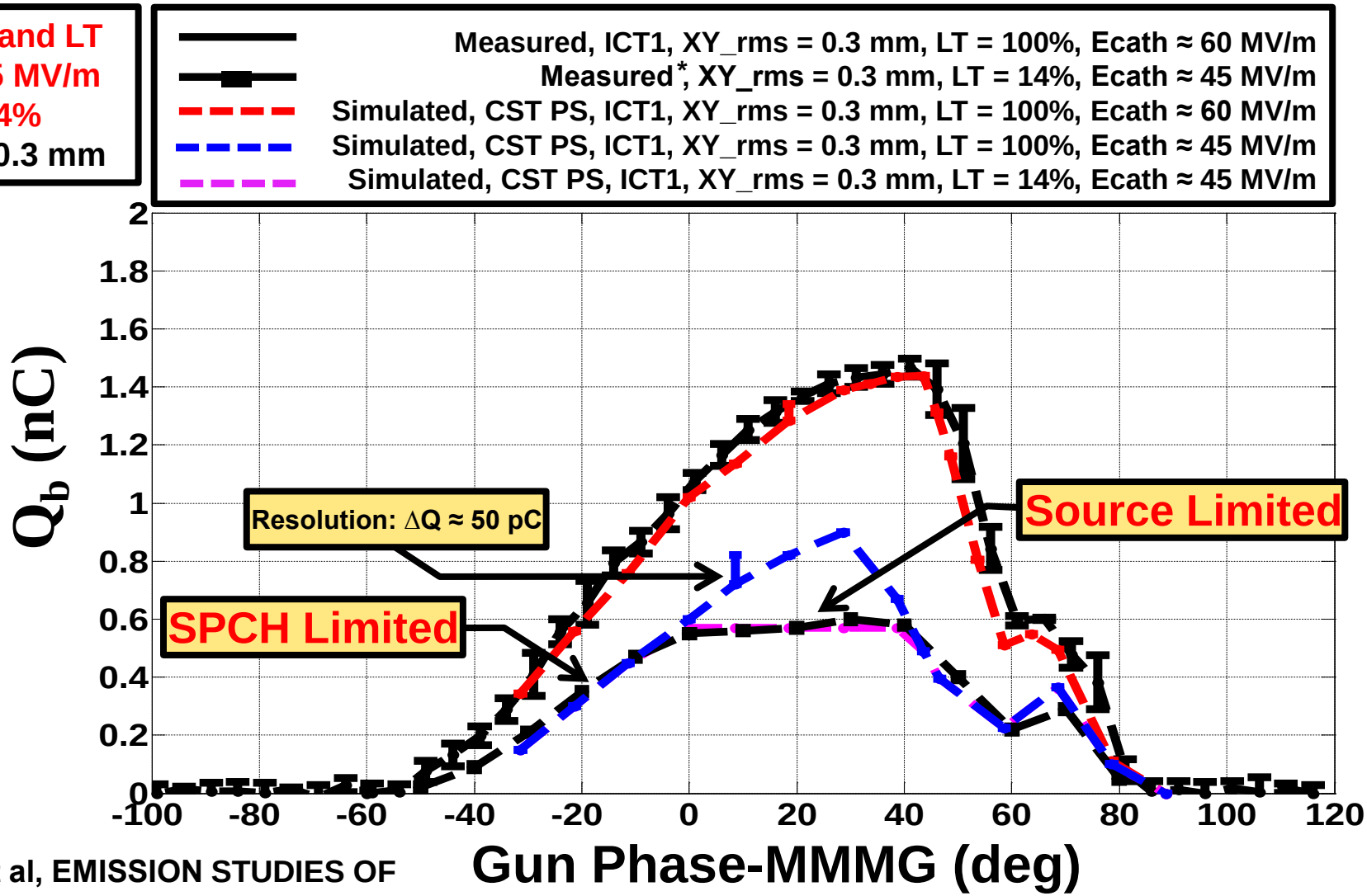
+ RF field and LT
Ecath = 45 MV/m
LT = 14%
XY_rms = 0.3 mm



*J.Li et al, EMISSION STUDIES OF PHOTOCATHODE RF GUN AT PITZ, 2012

Charge Extraction —

Test Results with Assumption I: RF Field Impact

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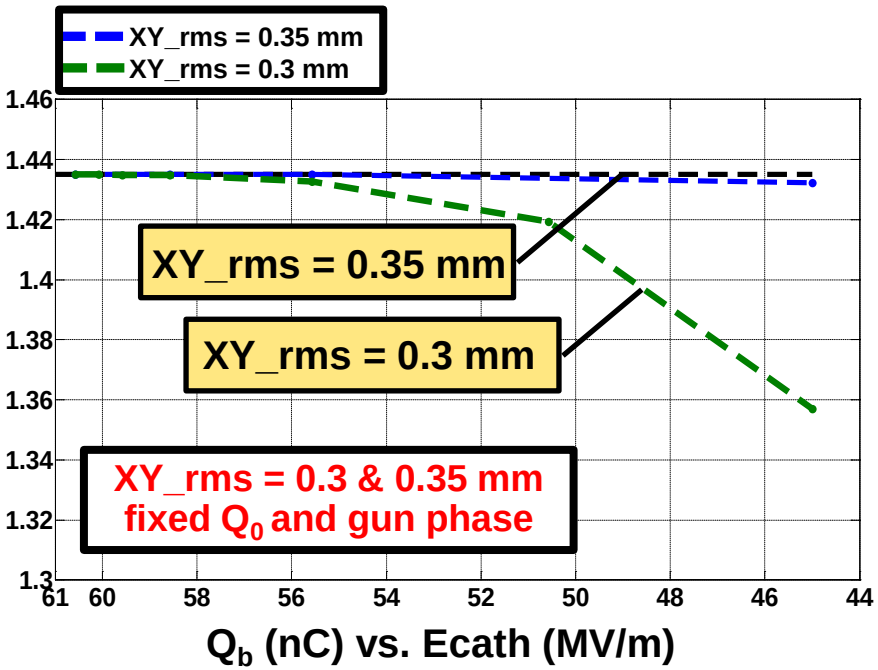
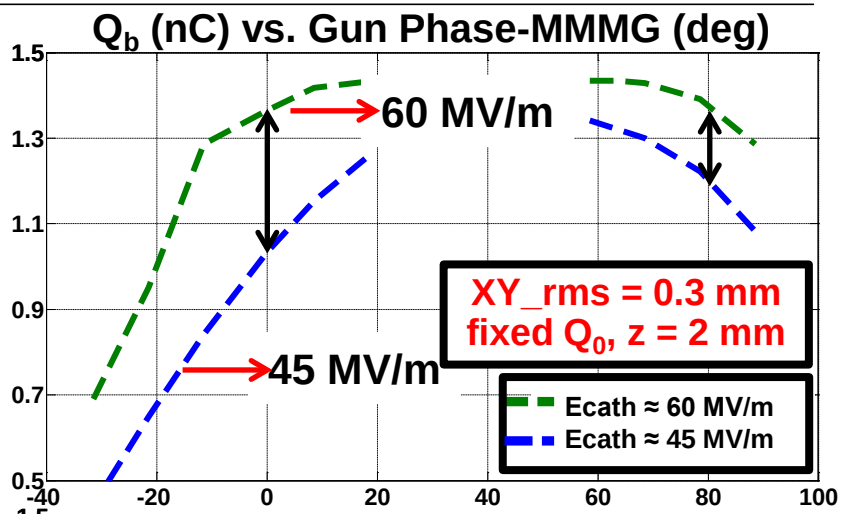
- **Preliminary results**

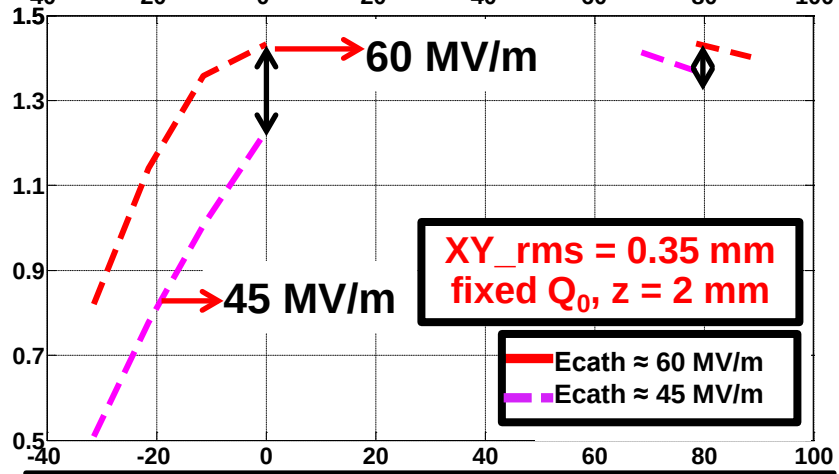
– RF field impacts for two cases: **XY_rms = 0.3 mm and 0.35 mm by applying different voltages**

– **Tests based on assumption I**: no numerical convergence

– Calculations with assumption II still in progress







- **Relative changes in total bunch charge showed stronger RF field impact for XY_rms = 0.3 mm (testing).**

Further Photoemission Studies (ongoing)

Simultaneous Variation of Multi-Parameters
RF power + laser spot size + laser pulse energy

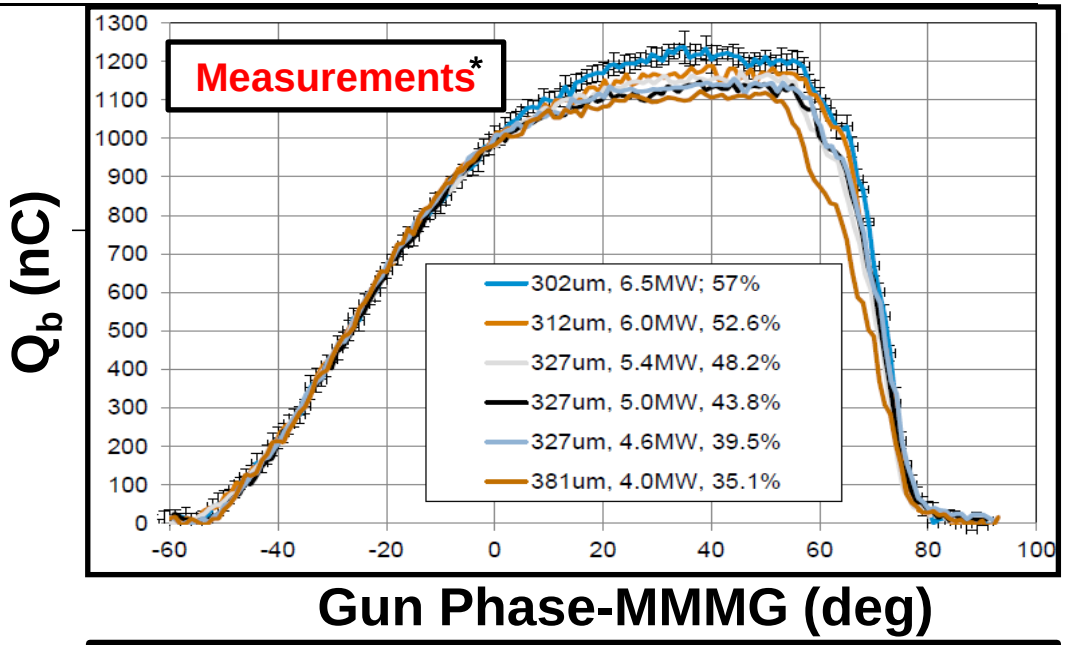
Keeping Ecath·LaserSpotSize = const

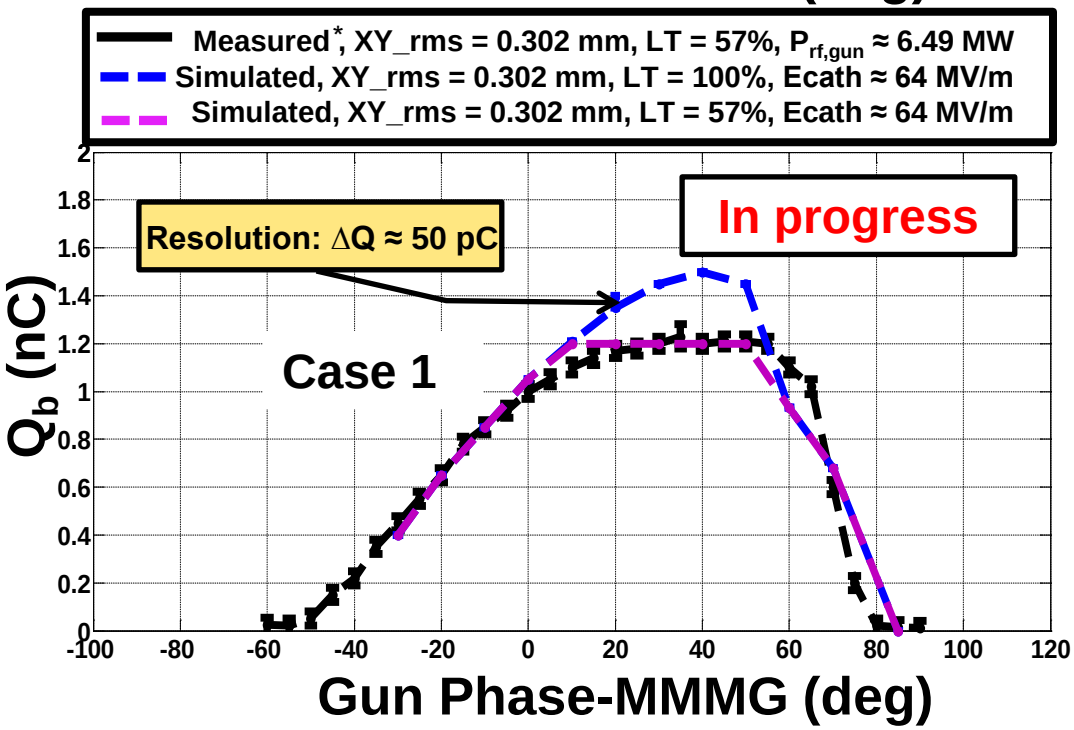
Measurements by Simultaneous Variation of Multi-Parameters*

#	σ_{xy} /mm	LT**	$P_{rf,\,gun}$/MW	$\sqrt{P_{rf,\,gun}} \times \sigma_{xy}$
1	0.302	57%	6.49	0.769
2	0.312	52.6%	5.99	0.764
3	0.327	48.2%	5.45	0.763
4	0.341	43.8%	5.00	0.762
5	0.361	39.5%	4.55	0.770
6	0.382	35.1%	3.99	0.762

*M. Krasilnikov, Simulations at PITZ, DESY 2012
**LT was tuned to keep laser pulse energy constant

$$Q = \pi R^2 \varepsilon_0 E_0 \sin\varphi_0$$





Further Photoemission Studies (ongoing)

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Testing:

$$Q_b = \pi R^2 \varepsilon_0 E_0 \, sin\varphi_0 = \pi R^2 \varepsilon_0 E_{cath}$$

XY_rms = 0.3 mm
LT = 100%
Gun phase: (-40deg ~ +50deg)

Fitting Result:

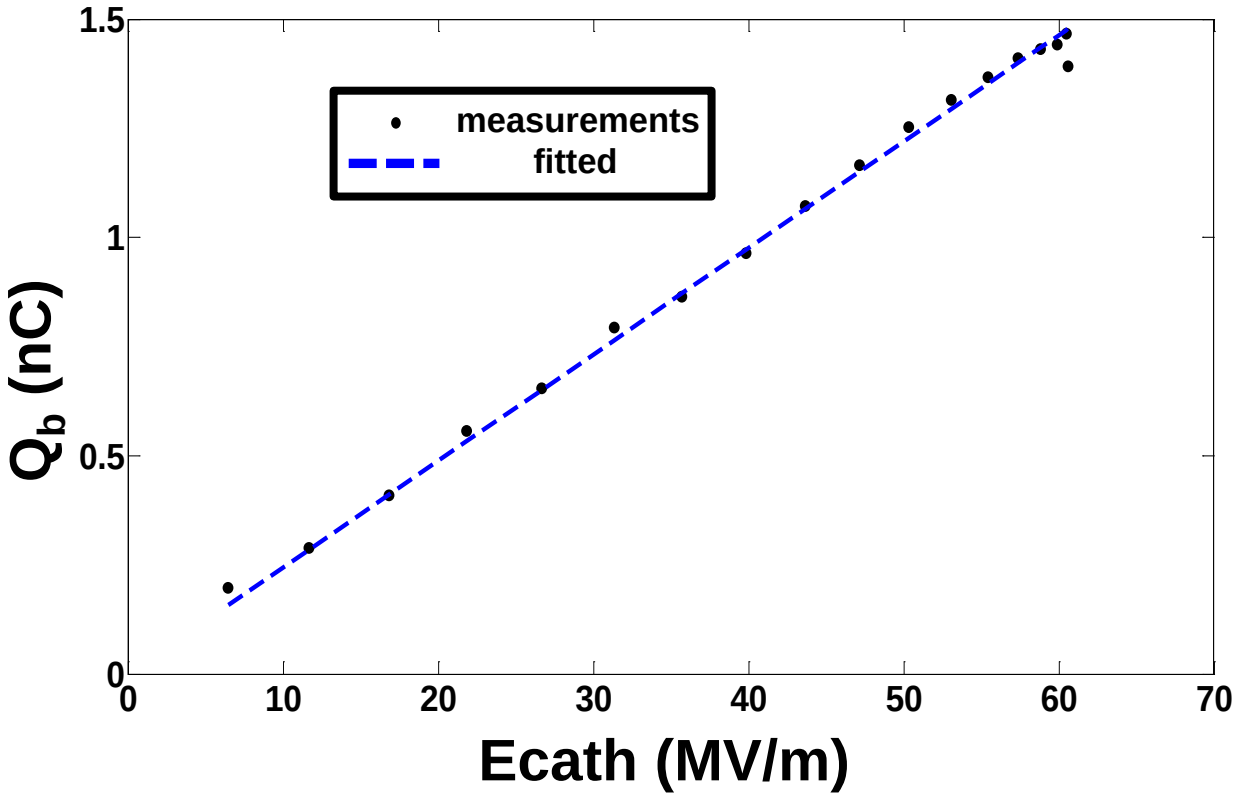
- R = 0.0009365 m (0.0009306, 0.0009424)
- R-square: 0.9959

Effective Radius:

R = 0.9365 mm

σxy = 0.46825 mm >

XY_rms = 0.3 mm



Conclusions

- **Emittance studies (continuations)**
  - There is a **modeling error** in Astra.
  - Still no explanation for the **systematic shift** w.r.t. laser spot size (observed in all type of simulations).
- **Photoemission studies: bunch charge extraction (new)**
  - Total emitted bunch charge simulated with CST PS **fits the measurement data** well at XY_rms = 0.3 mm for different gun phases.
  - M-S* comparisons for **lower laser transmissions** and **different RF fields** showed **good agreements.**
  - Schottky-like effect may not be very important for explaining the M-S discrepancy in produced bunch charge.
  - Preliminary tests showed stronger RF impact for higher space charge density.
  - **Next steps:**
    - Interpolation of laser transmission and maximum charge produced by the laser to space charge limits?
    - Further photoemission studies: **simultaneous variation of multi-parameters**.

* M-S: Measurement and Simulation

Thank you for your attention!

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