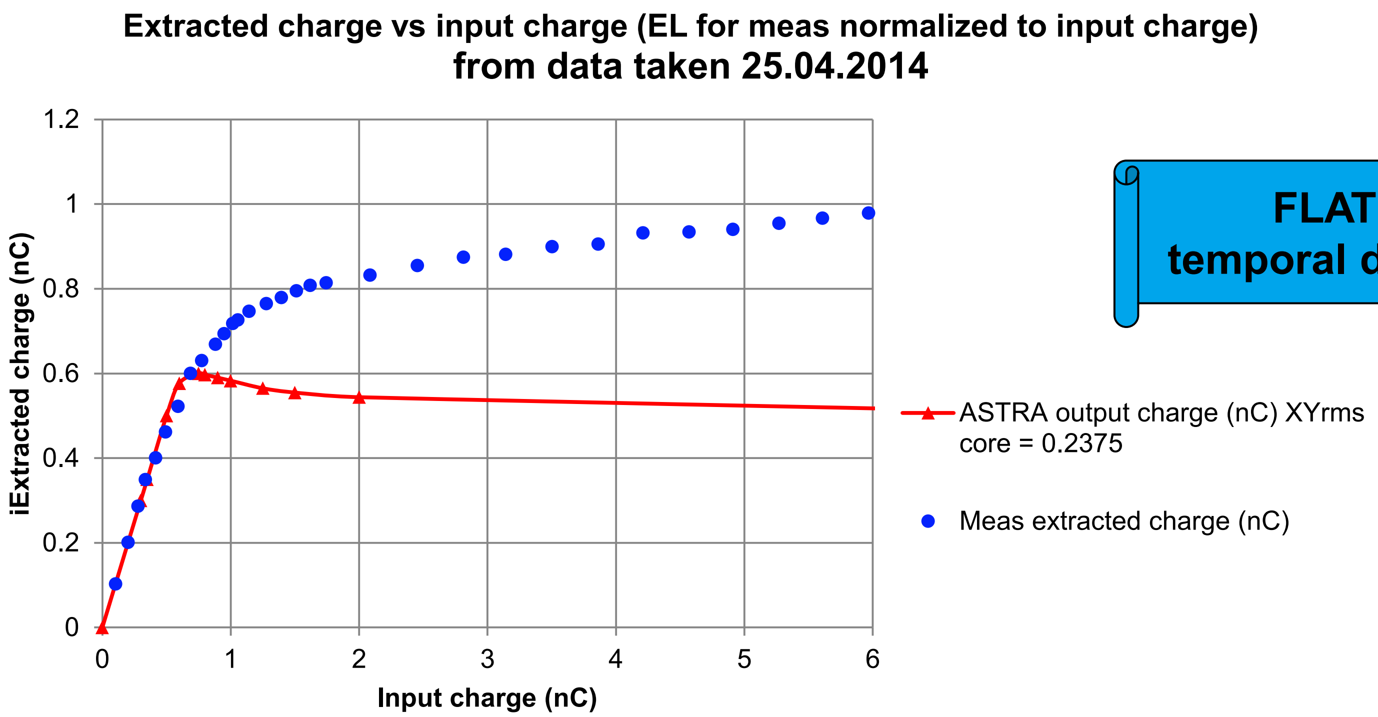
Emission studies, preliminary analysis from data taken in Feb-March 2015

- Why ASTRA output charge saturates while measured charge continues to increase with laser pulse energy?

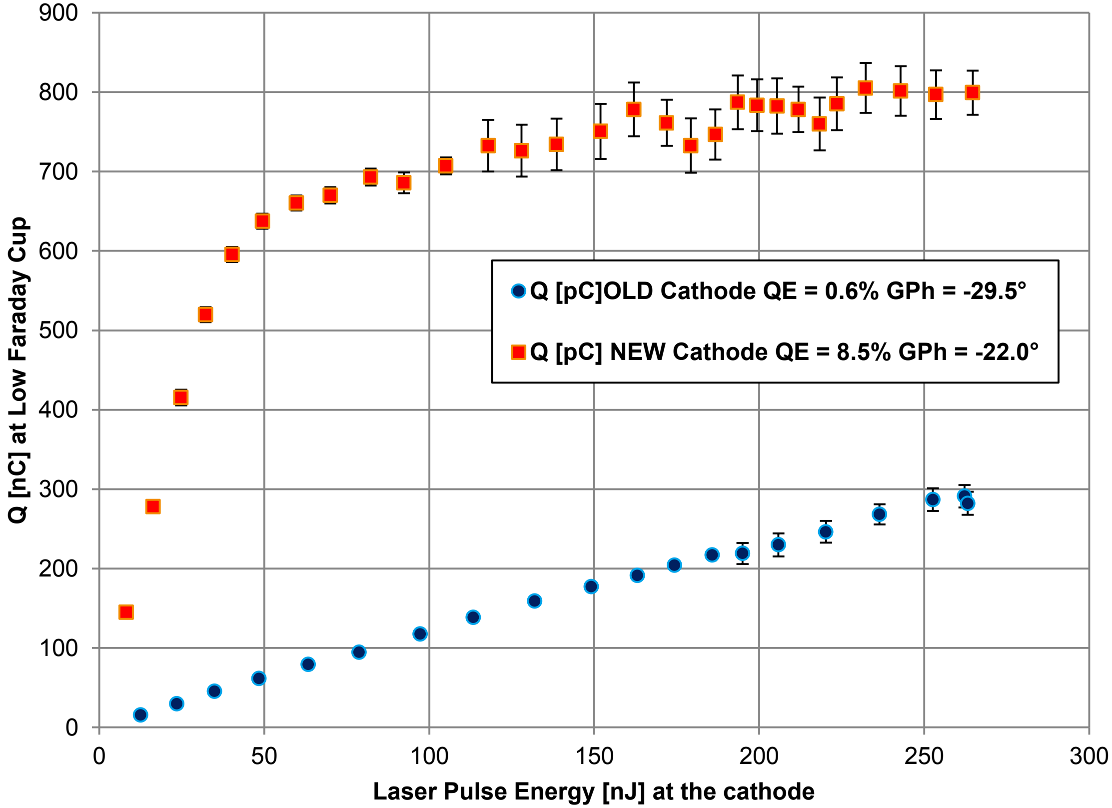


FLAT TOP temporal distribution

Carlos Hernandez-Garcia & Mikhail Krasilnikov
PPS Seminar

In addition, QE scans for old and new cathodes are drastically different.

- How to reproduce these measurements in simulations if machine parameters are the same for both?
- Pgun = 1.5 MW at Φ_0-90 and BSA = 1.8 mm



- Hypothesis: Transverse halo in the laser radial distribution

- Approach: Take charge vs laser energy scans for various gun and BSA settings, AND Virtual Cathode data to extract actual laser radial distribution and use as input parameter in ASTRA

- However, regarding the difference in emission between old and new cathodes: The input charge is Qbunch = 2xQEx$E_{L.}$ The product of QExE_L could be adjusted to match the low QE cathode, but the codes do not include input parameters for QE and laser energy, they use total input charge.

Measurements taken on Feb-Mar 2015 consists of 4 BSA settings, each with 9 different Gun power and phase settings = 36 QE scans

		BSA 1.8 mm	BSA 1.4 mm	BSA 1.0 mm	BSA 0.8 mm
	VC2 data taken on:	SHIFT:20150227N Comments:2015028M	SHIFT:20150227A Comments:____	SHIFT:20150227A Comments:____	SHIFT:20150227A Comments:____
P Gun (MW)	Gun SP Phase				
		Charge vs Laser Energy taken on:	Charge vs Laser Energy taken on:	Charge vs Laser Energy taken on:	Charge vs Laser Energy taken on:
1.5	ϕ_0-90°	SHIFT:20150227N Comments:10db scope att in	SHIFT:20150227A Comments:____	SHIFT:20150227A Comments:____	SHIFT:20150227N Comments:___
1.5	MMMG	SHIFT:20150227N Comments:10db scope att in	SHIFT:20150227A Comments:____	SHIFT:20150227A Comments:____	SHIFT:20150227N Comments:#1???
3.375	ϕ_0-90°	SHIFT:20150228M Comments:10db scope att in	SHIFT:20150301M Comments:10db scope att in	SHIFT:20150301A Comments:____	SHIFT:20150302M Comments:____
3.375	ϕ_0-42°	SHIFT:20150228M Comments:10db scope att in	SHIFT:20150301M Comments: Remeasured	SHIFT:20150301A Comments:____	SHIFT:20150302M Comments:_same as MMMG phase
3.375	MMMG	SHIFT:20150228M Comments:10db scope att in	SHIFT:20150301M Comments: Remeasured	SHIFT:20150301A Comments:____	SHIFT:20150302M Comments:____
6	ϕ_0-90°	SHIFT:20150228A Comments:10db scope att in	SHIFT:20150228A Comments:10db scope att in	SHIFT:20150301A Comments:____	SHIFT:20150301N Comments:____
6	ϕ_0-49°	SHIFT:20150228A Comments:10db scope att in	SHIFT:20150228A Comments:10db scope att in	SHIFT:20150301A Comments:____	SHIFT:20150301N Comments:____
6	ϕ_0-30°	SHIFT:20150228A Comments:10db scope att in	SHIFT:20150228A+N Comments:10db scope att in	SHIFT:20150301A+N Comments:____	SHIFT:____ Comments:_same as MMMG phase
6	MMMG	SHIFT:20150228A Comments:10db scope att in	SHIFT:20150228A+N Comments:10db scope att in, FC + ICT	SHIFT:20150301A+N Comments:_Data not taken	SHIFT:20150301N Comments:____

In addition, Virtual Cathode measurements were taken for each BSA as a function of LT.

Data for the old cathode (QE = 0.6%) is also available for the set of parameters indicated by this color

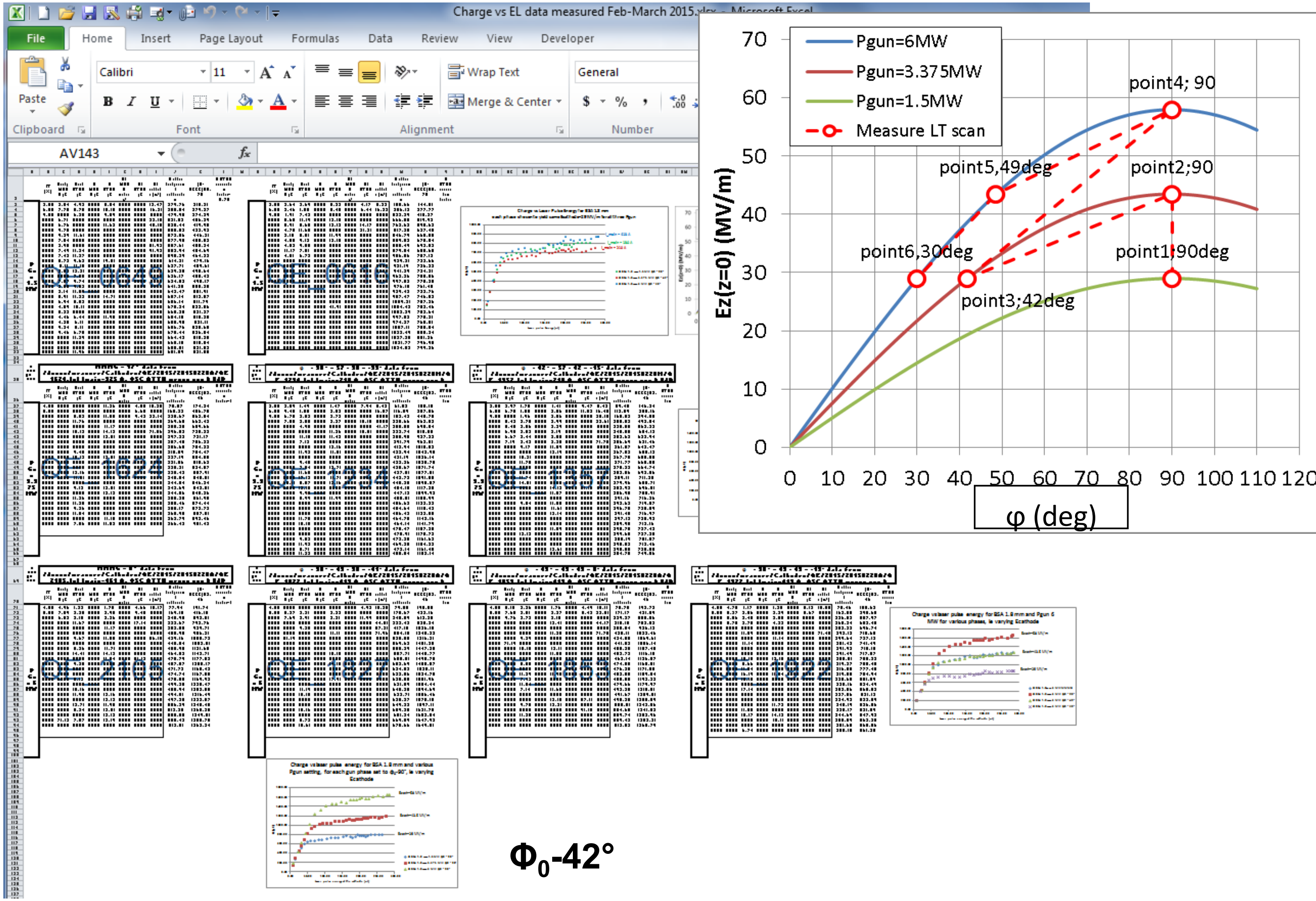
For each BSA, a total of 9 QE scans were taken at the indicated gun settings corresponding to different Ecath

P gun

1.5 MW

3.375 MW

6 MW



Φ_0-42°

Gun SPPhase

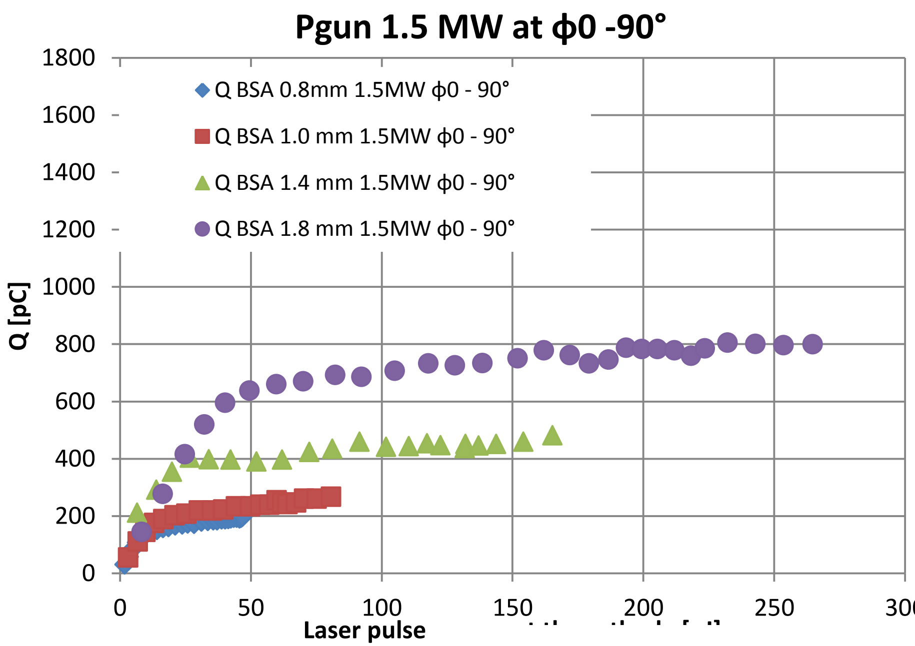
MMMG Φ_0-90° Φ_0-49° Φ_0-30°

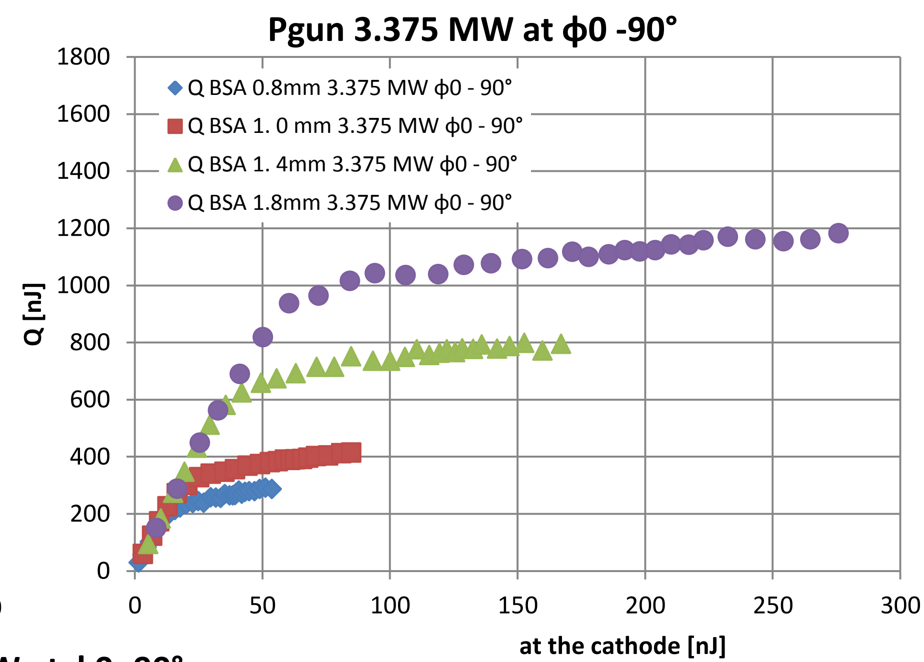
Each QE scan was captured and recorded in Excel with the information shown below

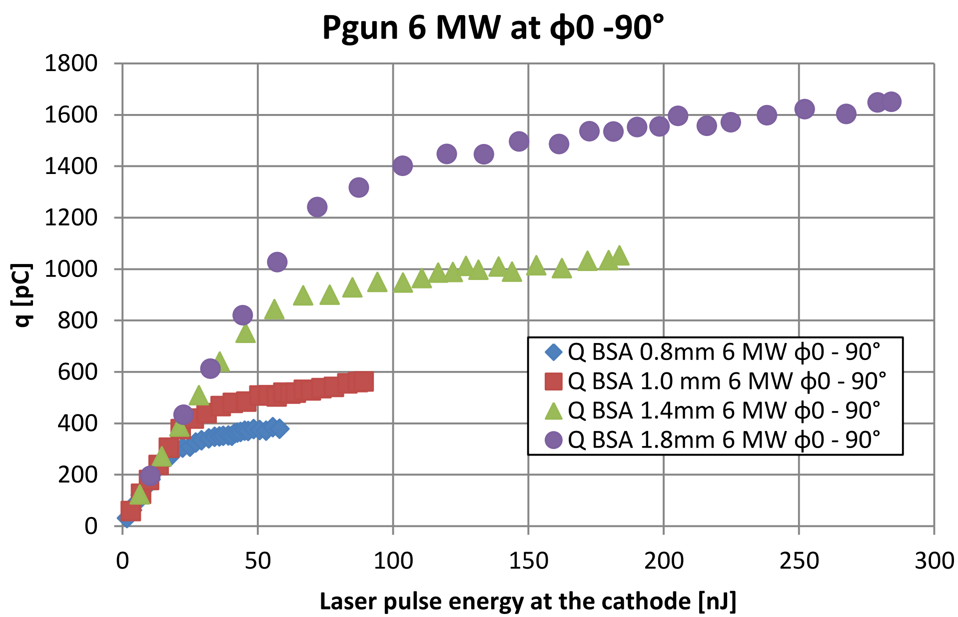
Q BSA 1.8 mm 1.5MW ϕ_0 - 90°	ϕ_0 - 90° = 68 - 90 = -22° data from /doocs/measure/Cathodes/QE/2015/20150227N/QE_0616.txt Imain=130 A, OSC ATTN wrong pos & 10dB selection in script-> corr factor =0.78

	LT (%)	Backg MEAN pC	Back STDV pC	Q MEAN pC	Q STDV pC	EL MEAN meter pJ	EL STDV pC	EL cathode [nJ]	Q after background subtraction	(Q-BCKG)X0.78
P Gun 1.5 MW	3.00	2.64	3.69	188.30	5.33	385.06	4.17	8.22	185.66	144.81
	6.00	3.46	1.50	359.58	5.40	764.33	6.44	16.32	356.12	277.77
	9.00	1.91	7.43	534.30	12.70	1161.14	10.47	24.79	532.39	415.27
	12.00	8.60	11.19	675.18	12.15	1509.82	10.40	32.23	666.58	519.93
	15.00	5.91	8.65	769.55	12.13	1884.71	14.17	40.24	763.63	595.63
	18.00	4.75	11.65	822.04	12.37	2316.20	21.31	49.45	817.28	637.48
	21.00	2.10	8.01	848.89	11.99	2798.70	23.30	59.75	846.79	660.50
	24.00	4.08	9.13	863.11	13.10	3279.80	26.51	70.02	859.03	670.04
	27.00	4.53	9.80	893.02	13.85	3851.70	22.43	82.23	888.49	693.02
	30.00	11.17	7.01	890.20	16.79	4324.20	29.82	92.32	879.04	685.65
	33.00	4.51	6.72	911.07	13.83	4921.10	35.36	105.06	906.56	707.12
	36.00	159.76	54.62	1099.07	41.65	5521.20	36.08	117.87	939.31	732.66
	39.00	176.90	34.73	1108.09	42.00	5994.40	48.67	127.97	931.19	726.33
	42.00	182.62	33.67	1123.91	41.76	6490.90	42.29	138.57	941.29	734.21
	45.00	171.58	21.54	1133.84	44.40	7116.10	46.45	151.92	962.26	750.56
	48.00	142.07	39.66	1139.89	43.53	7588.60	56.01	162.01	997.82	778.30
	51.00	159.63	45.41	1135.79	37.17	8054.60	51.24	171.95	976.15	761.40
	54.00	192.60	23.88	1132.03	43.83	8396.60	55.44	179.26	939.43	732.76
	57.00	181.96	33.29	1139.43	40.63	8745.80	55.16	186.71	957.47	746.83
	60.00	152.50	22.02	1161.81	43.45	9062.70	61.44	193.48	1009.31	787.26
	63.00	157.17	62.16	1161.60	41.91	9338.90	57.80	199.37	1004.43	783.46
	66.00	157.14	37.52	1160.53	44.72	9623.00	56.31	205.44	1003.39	782.64
	69.00	172.30	28.78	1170.13	36.47	9923.80	58.69	211.86	997.83	778.31
	72.00	176.22	23.53	1150.59	42.87	10224.60	56.84	218.28	974.37	760.01
	75.00	151.13	37.88	1158.24	42.65	10472.10	66.90	223.56	1007.11	785.54
	78.00	149.40	35.31	1181.89	40.35	10878.70	50.18	232.25	1032.49	805.34
	81.00	149.18	29.46	1176.56	40.00	11375.80	61.45	242.86	1027.38	801.36
	84.00	158.59	37.45	1180.36	39.39	11877.20	64.04	253.56	1021.77	796.98
	87.00	154.34	34.13	1179.17	35.59	12398.20	76.98	264.68	1024.83	799.36

QE scans for fixed gun power and phase are graphed for each BSA setting

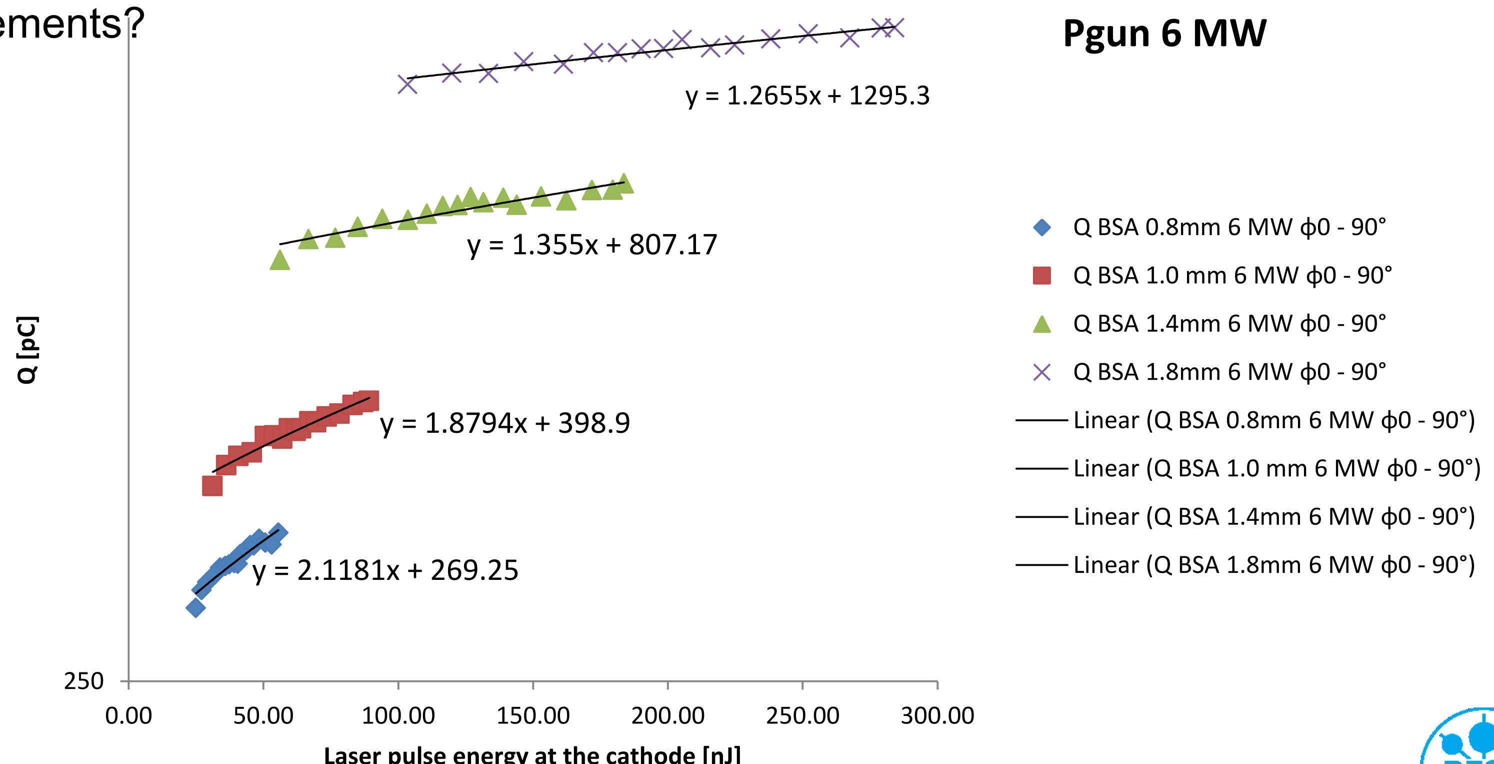






The slide in the saturated region:

- Indicates that charge continues to be extracted from halo regions even though charge from core has saturated
- Is higher for smaller BSA settings
- Higher slope means the charge contribution from halo is higher
- This indicates that there is more halo for smaller BSA settings
- Can we infer from these data the Qhalo/Qcore? And will this correlate with the VC2 measurements?

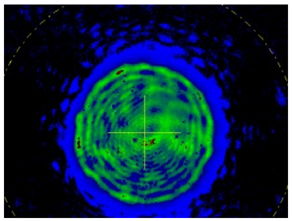


The analysis procedure basically consists of:

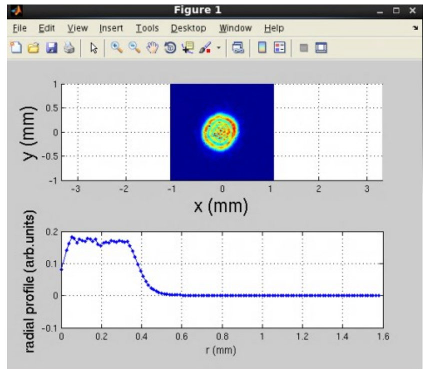
- Measuring charge vs Laser Energy for specific BSA
- Capturing Virtual Cathode Image for corresponding BSA
- Image processing for generating ASTRA input distribution
  - Utilizing MatLab script to read VC and obtain an averaged radial profile
  - Utilizing MathCAD to find a curve fit to the averaged radial profile
  - Utilizing a second MatLab script to generate an ASTRA input radial distribution with the values found
- Verify that generated input distribution for ASTRA matches the profile shown in VC2
- Utilize the generated input distribution to run ASTRA
- Compare ASTRA output charge with measured charge vs Laser Energy

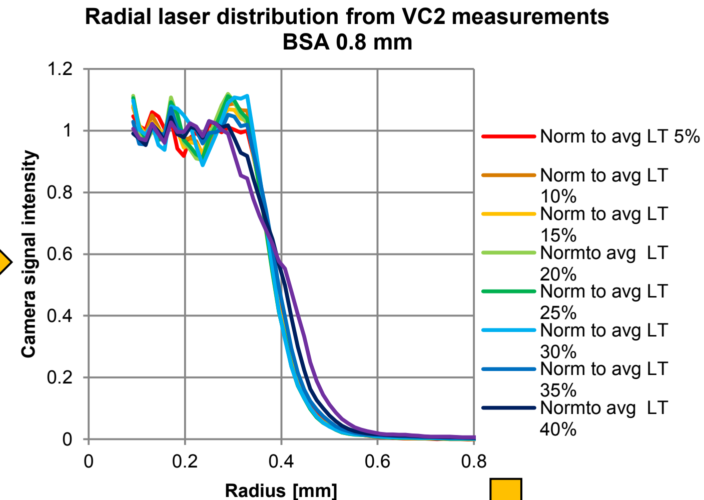
The procedure in pictures:

VC2 data image capture



VC2 data reproduced in MatLab





$$TG(r,\xi,\sigma,R_c) := \xi \cdot \exp\left(\frac{R_c^2 - r^2}{2\cdot\sigma^2}\right)$$

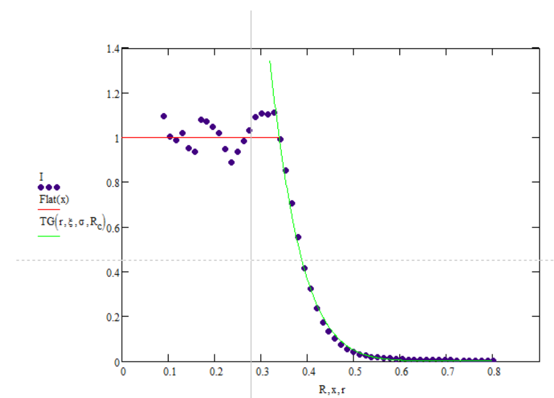
$\xi := 1$

$R_c := 0.34$

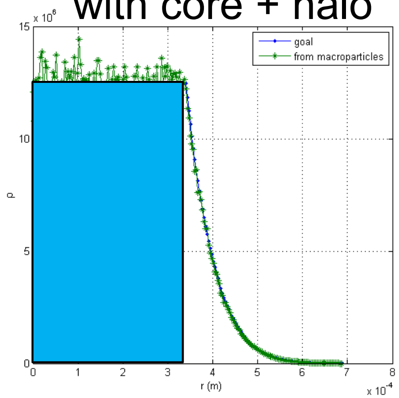
$\sigma := 0.15$

$r := 0.32, 0.321 .. 0.8$

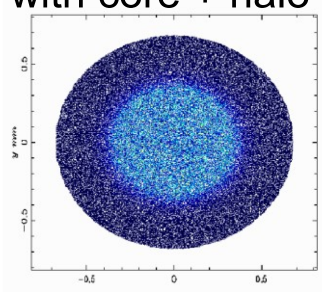
Curve fit to match laser distribution



MatLab-generated input distribution for ASTRA with core + halo



Input distribution shown by postpro with core + halo



To ASTRA

In the final part of the analysis we compare measured charge vs laser energy with ASTRA output charge…

Output charge from ASTRA

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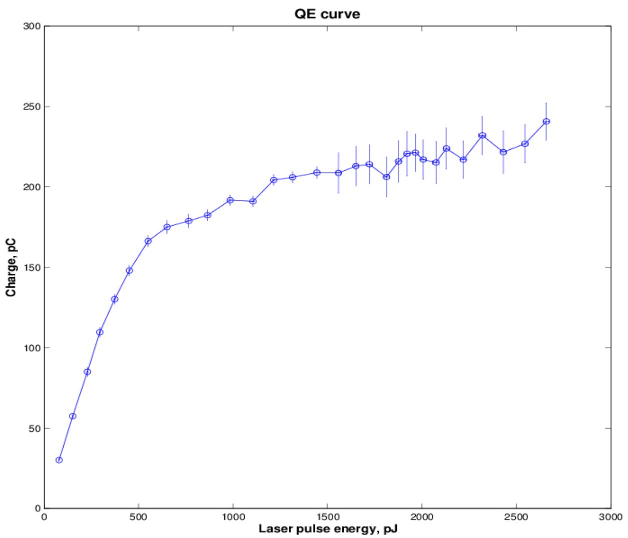
************************************************************************

Particles taken into account       N =      85575
total charge                       Q =     -1.284       nC
horizontal beam position           x =    -1.5121E-03 mm
vertical beam position             y =    -3.0764E-03 mm
longitudinal beam position         z =     0.5000       m
horizontal beam size           sig x =      3.055       mm
vertical beam size             sig y =      3.047       mm
longitudinal beam size         sig z =      2.167       mm
average kinetic energy             E =      5.924       MeV
energy spread                     dE =      38.72       keV
transverse beam emittance      eps x =      5.237       pi mrad mm
correlated divergence          cor x =     -3.312       mrad
transverse beam emittance      eps y =      5.235       pi mrad mm
correlated divergence          cor y =     -3.304       mrad
longitudinal beam emittance    eps z =      42.68       pi keV mm
correlated energy spread       cor z =      33.33       keV
emittance ratio eps y/eps x          =      1.000

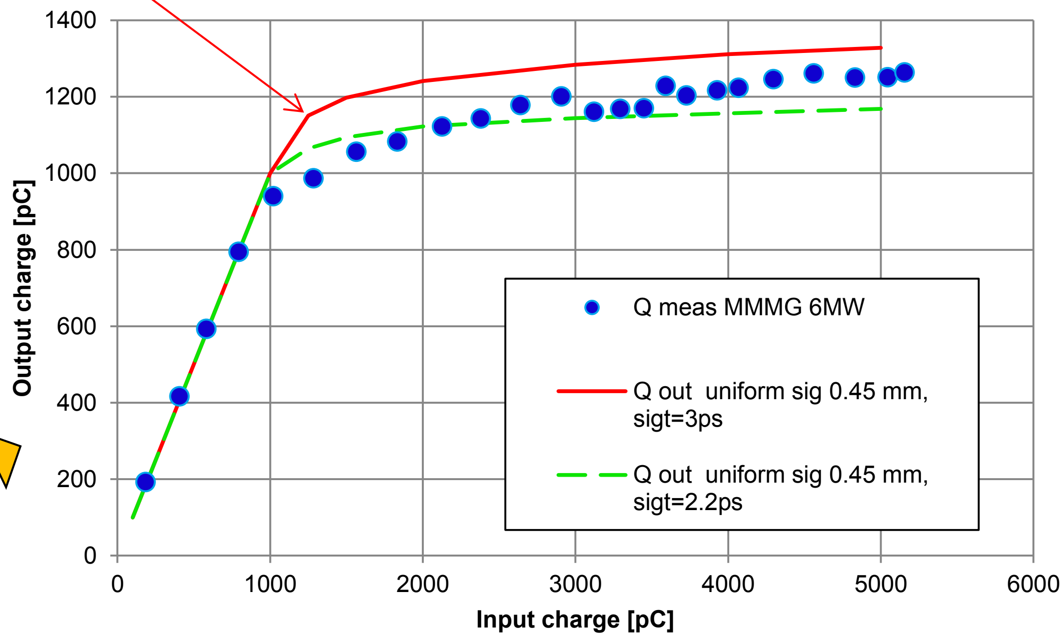
Particle Statistics:


Total number of particles on stack      =     200000
Electrons (total)                       =     200000
particles at the cathode                =          0
active particles                        =      85575
passive particles (lost out of bunch)   =          0
probe particles                         =          4
backward traveling particles            =          0
particles lost with z&lt;Zmin              =     114425
particles lost due to cathode field     =          0
particles lost on aperture              =          0
```

Measured charge vs laser energy



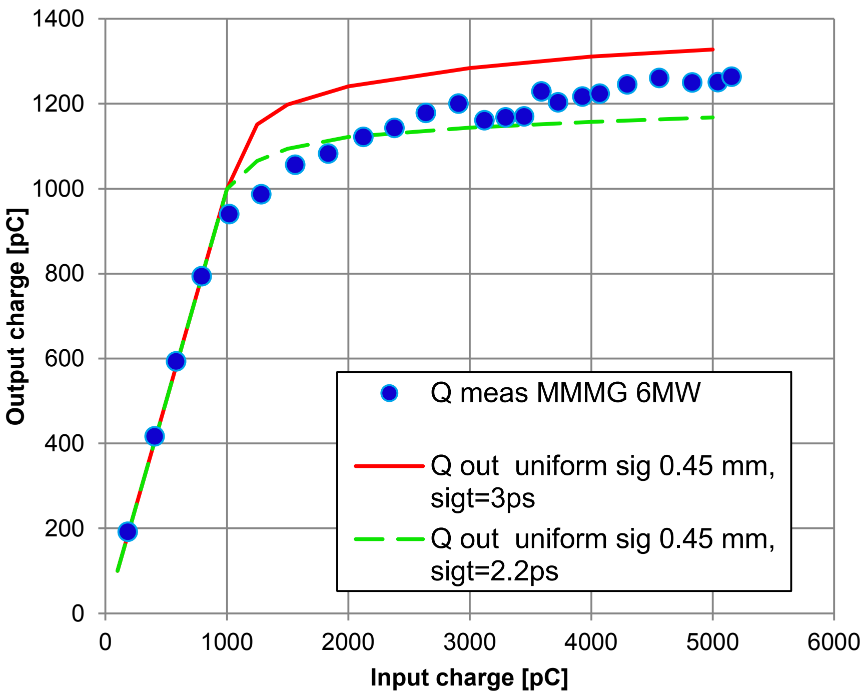
Comparison between measured and ASTRA extracted (MMMG) charge both with Gaussian temporal profile, and uniform radial profile BSA 1.8 mm



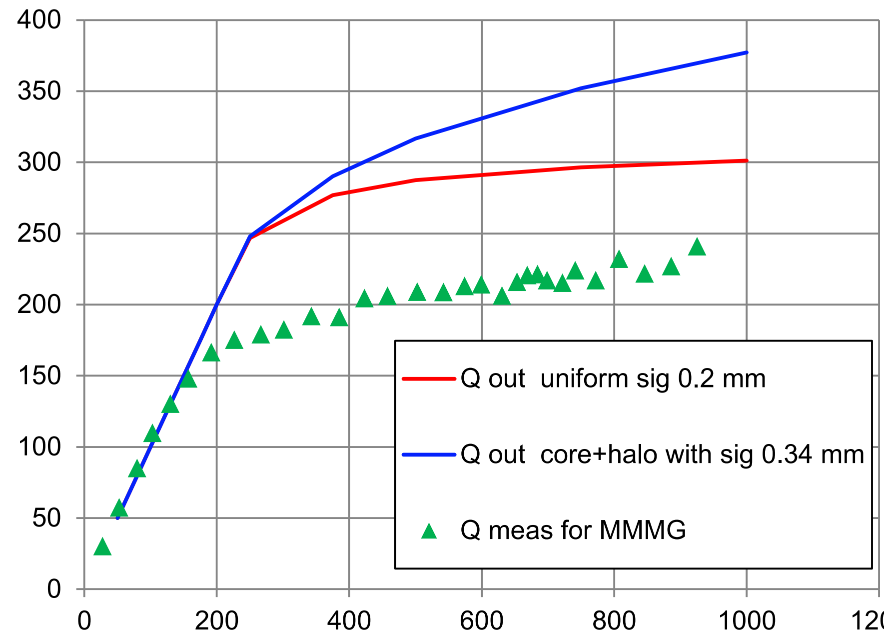
I started by comparing the Feb'15 data with ASTRA using core+halo and uniform distributions… BUT…

- It seems that the ASTRA output charge is actually larger than the measured charge <u>*when the 3 ps rms laser pulse length is used*</u>, independently of the BSA…
- WHY? Is the actual laser pulse length shorter????
- Am I totally confusing the gun phase, ie MMMG with phi0-90deg?

BSA = 1.8 mm



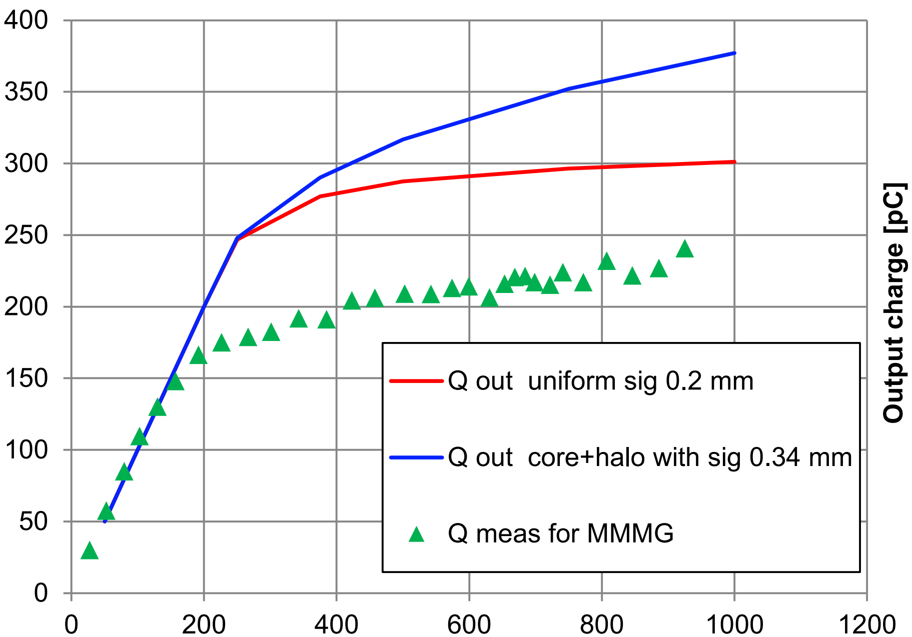
BSA = 0.8 mm



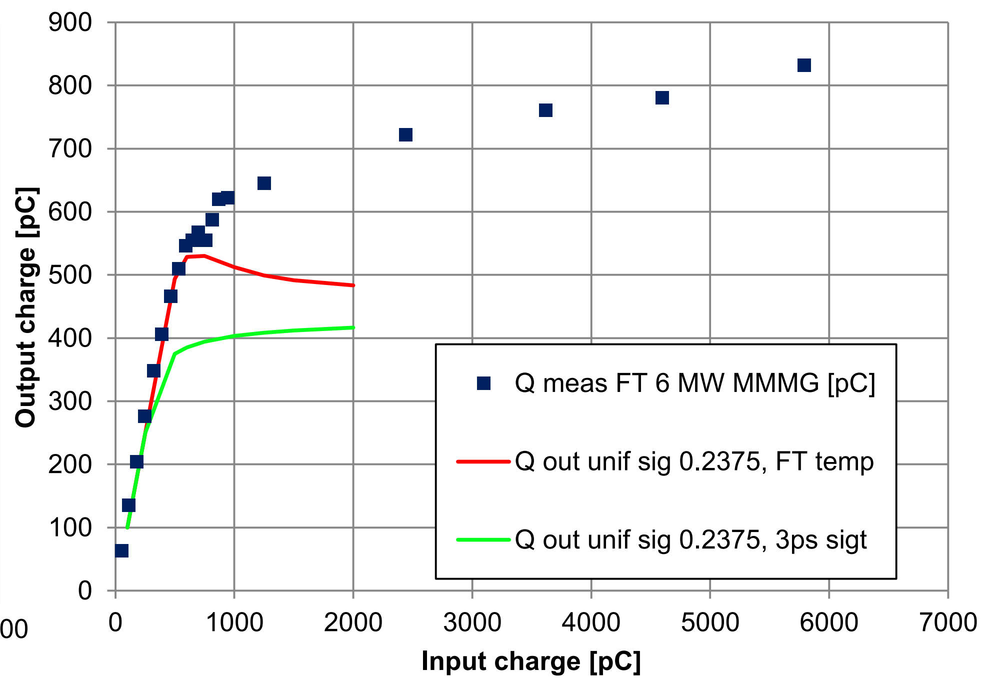
..when the temporal flat top is used in the simulation:

- ASTRA gives a lower charge than the measured one, but still higher than that for the temporal Gaussian as expected (for same BSA).

BSA = 0.8 mm, **temp Gaussian 3 ps rms**



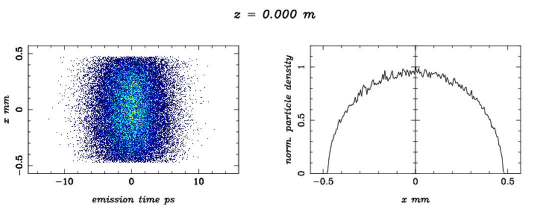
BSA = 0.95 mm **Data from April 2014 with FT 21 ps FWHM**

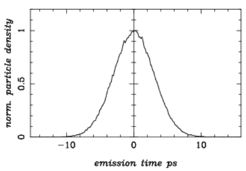


- Some good news: the core+halo distribution generated from laser data seems to yield higher charge than that from just uniform distribution, which is what we are looking for..at least for the FT case.

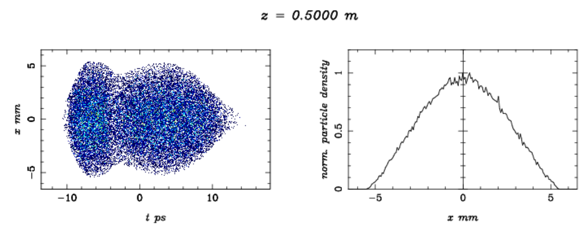
Can we explain the behavior of extracted charge between Gaussian and Flat Top? BSA = 0. 95 mmPgun 6 MW, MMMG for all cases shown

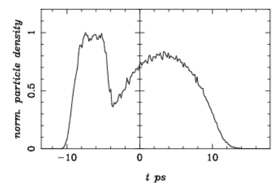
Gaussian temporal 3 ps rms



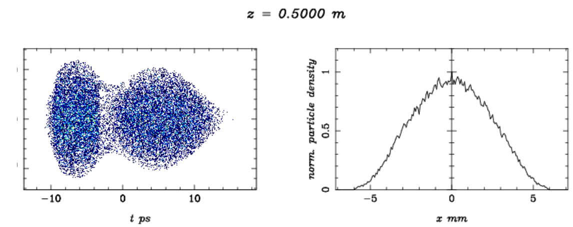


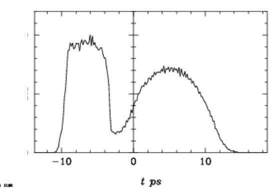
Initial distribution





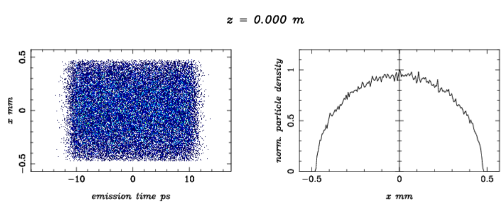
Input charge 500pC

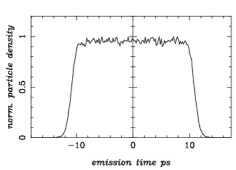




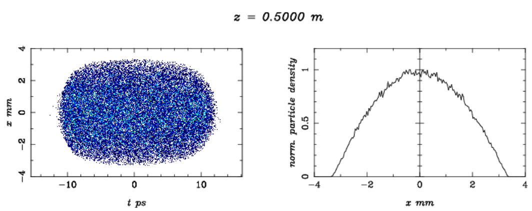
Input charge 750pC

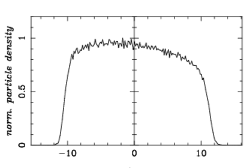
Flat Top Temporal 21 ps FWHM



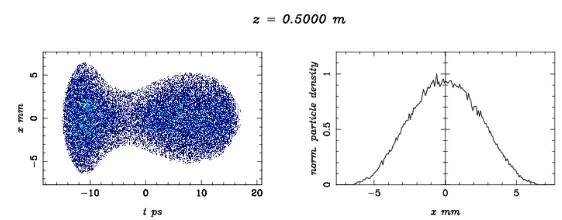


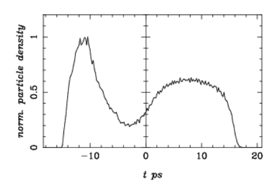
Initial distribution





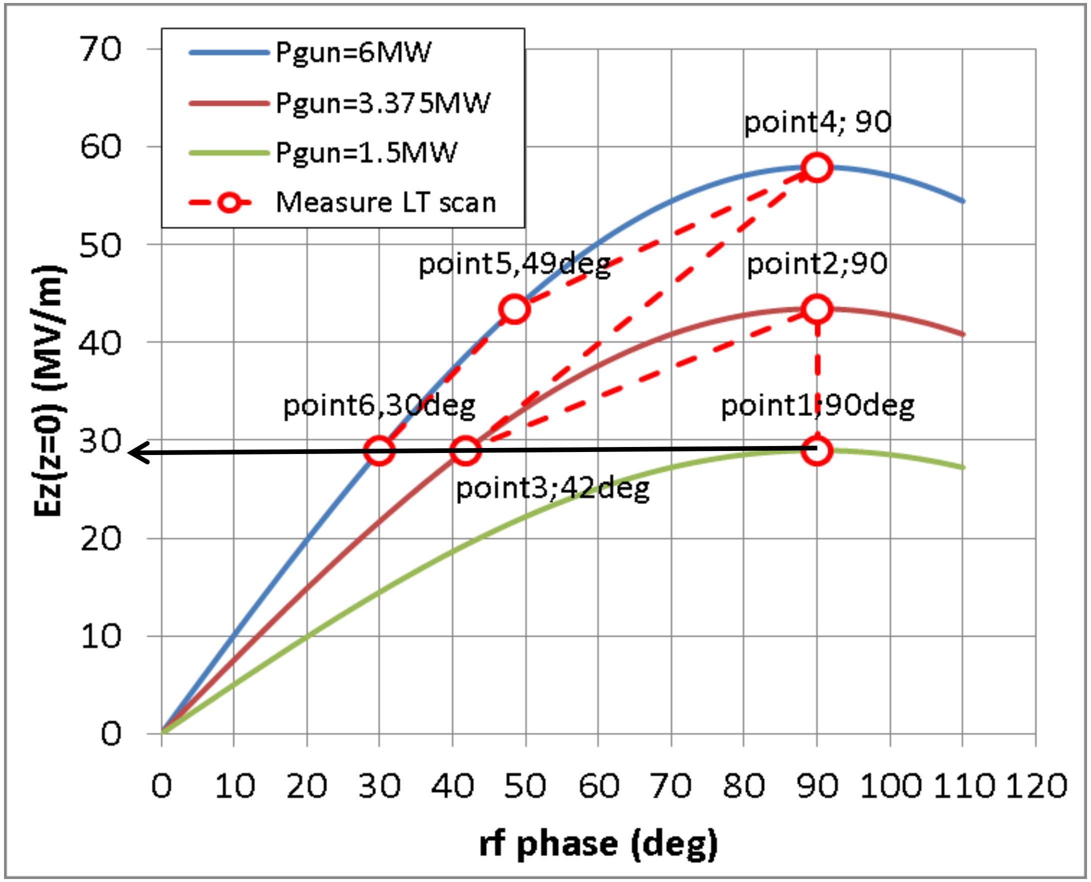
Input charge 500pC



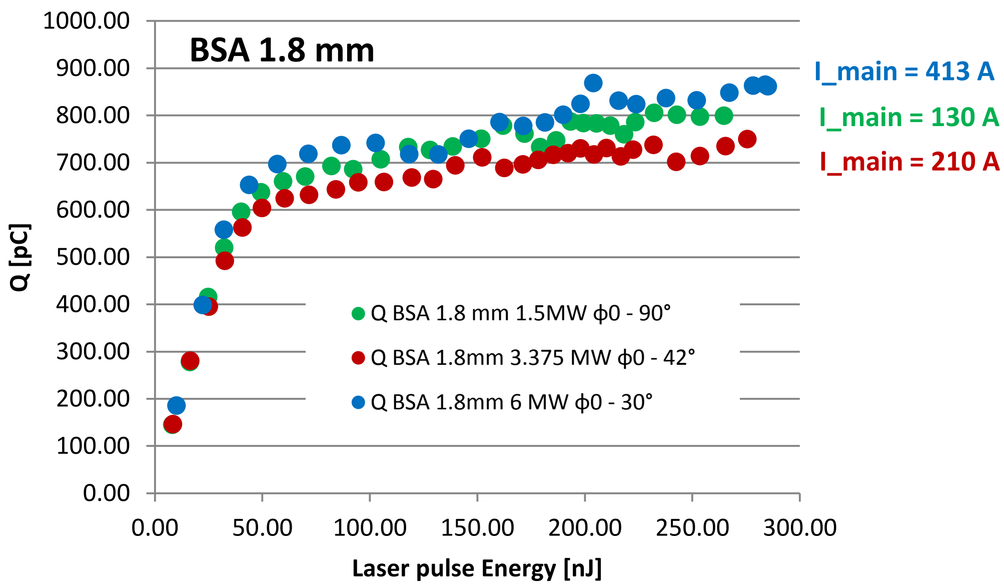


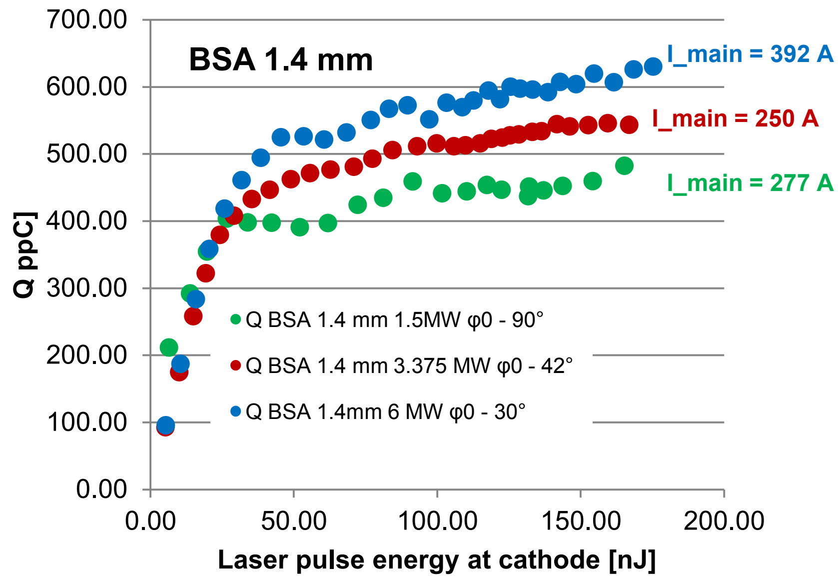
Input charge 750pC

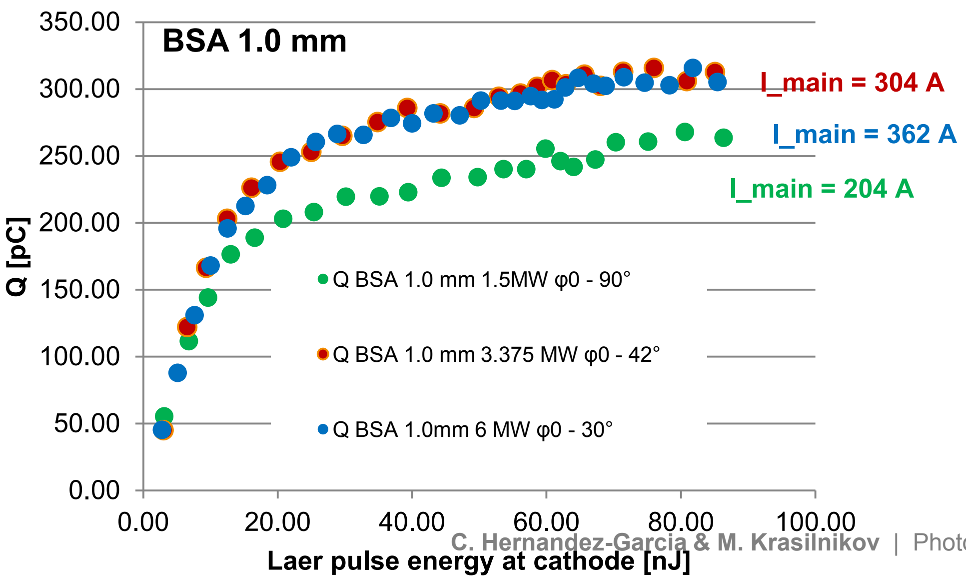
The extracted charge should be the same for the following gun parameter settings, since they all yield the same Ecathode, …

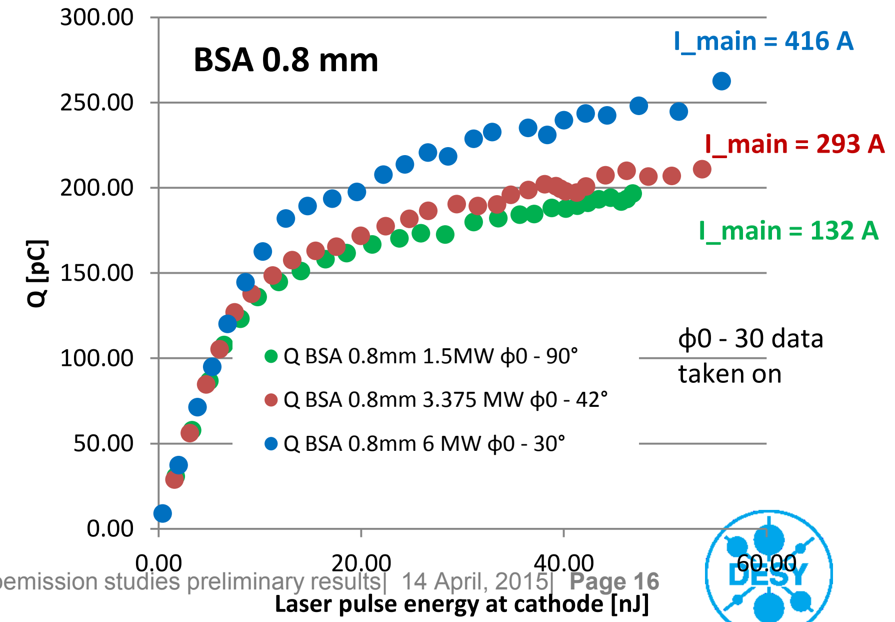


… but is not. Is because of solenoid settings? Or the gun phase is not what we think it is at the time of the QE scan?



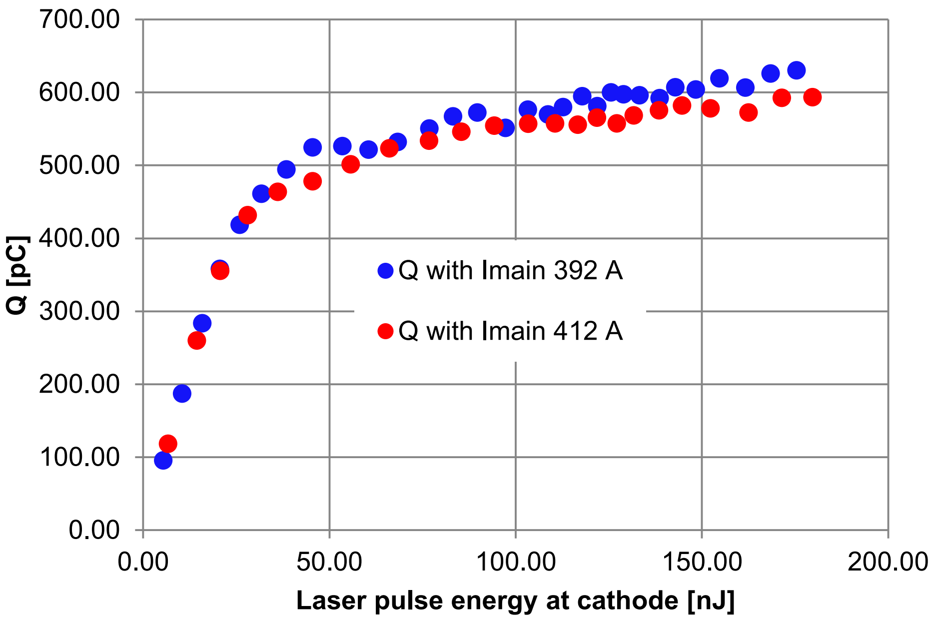






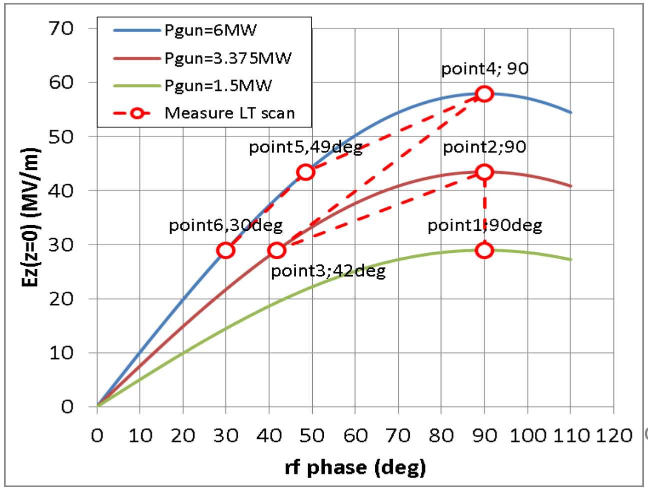
4% increase in I_main yields ~6% less current at LOW.FC_1

6 MW, Φ_0 - 30° = 46 - 30 = +16° SPPhase



I_main captured from LOG

	1.5 MW	3.375 MW	6 MW
BSA	ϕ_0-90°	ϕ_0-42°	ϕ_0-30°
0.8	132	293	416
1	204	304	362
1.4	277	250	392
1.8	130	210	413



Solenoid settings should be the same for all these set points, since gun power and phase are set to yield the same E_cathode

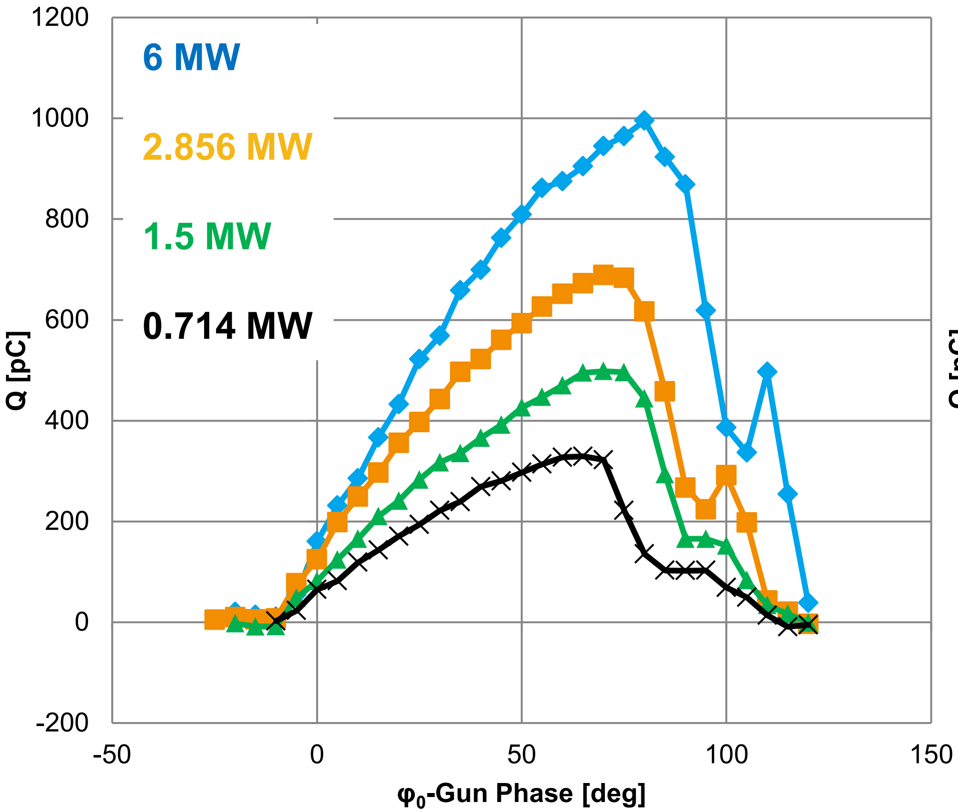
Additionally, Darmstadt request measurements were taken

- BSA = 1.4 mm (XYrms = 0.35 mm)
- Phase scans taken on shift 20150302A

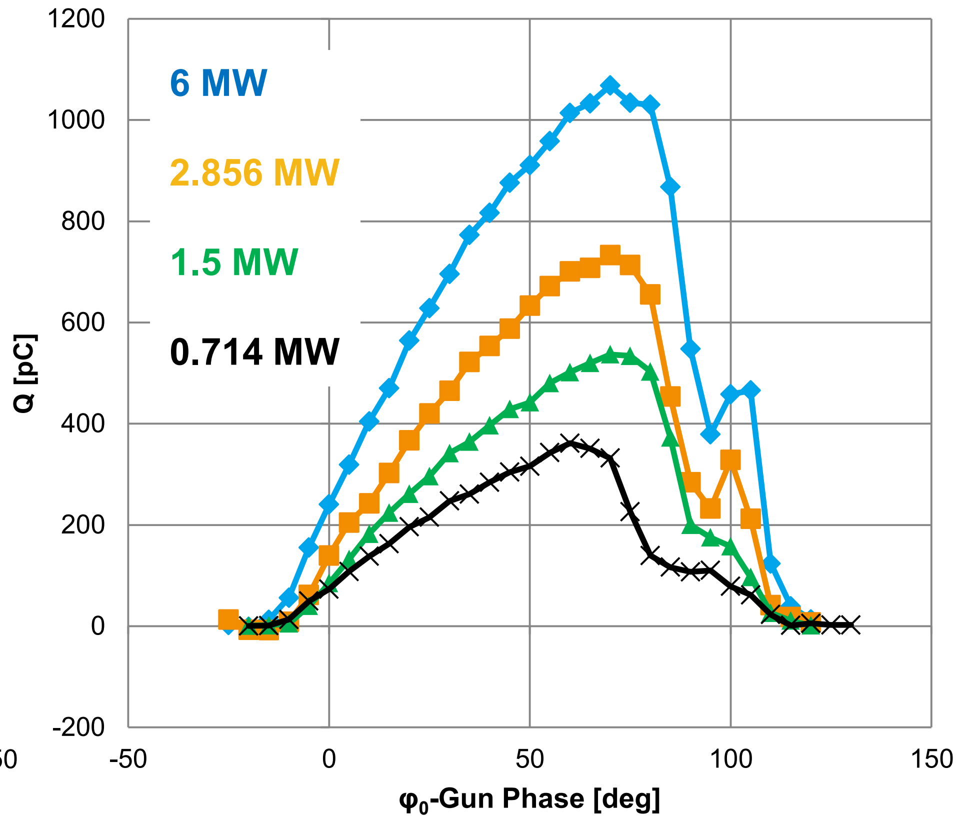
Ecath (MV/m)	Pgun (MW)	LT 100%, EL = 4.7nJ	LT = 50%, EL = 7.55 nJ
58	6.000	Imain=416 A	Imain=416 A
40	2.856	Imain=296A	Imain=296A
30	1.5	Imain=211A	Imain=211A
20	0.714	Imain=198A	

Phase scans taken for Darmstadt, BSA 1.4 mm

LT 50% = 97 nJ Laser pulse energy



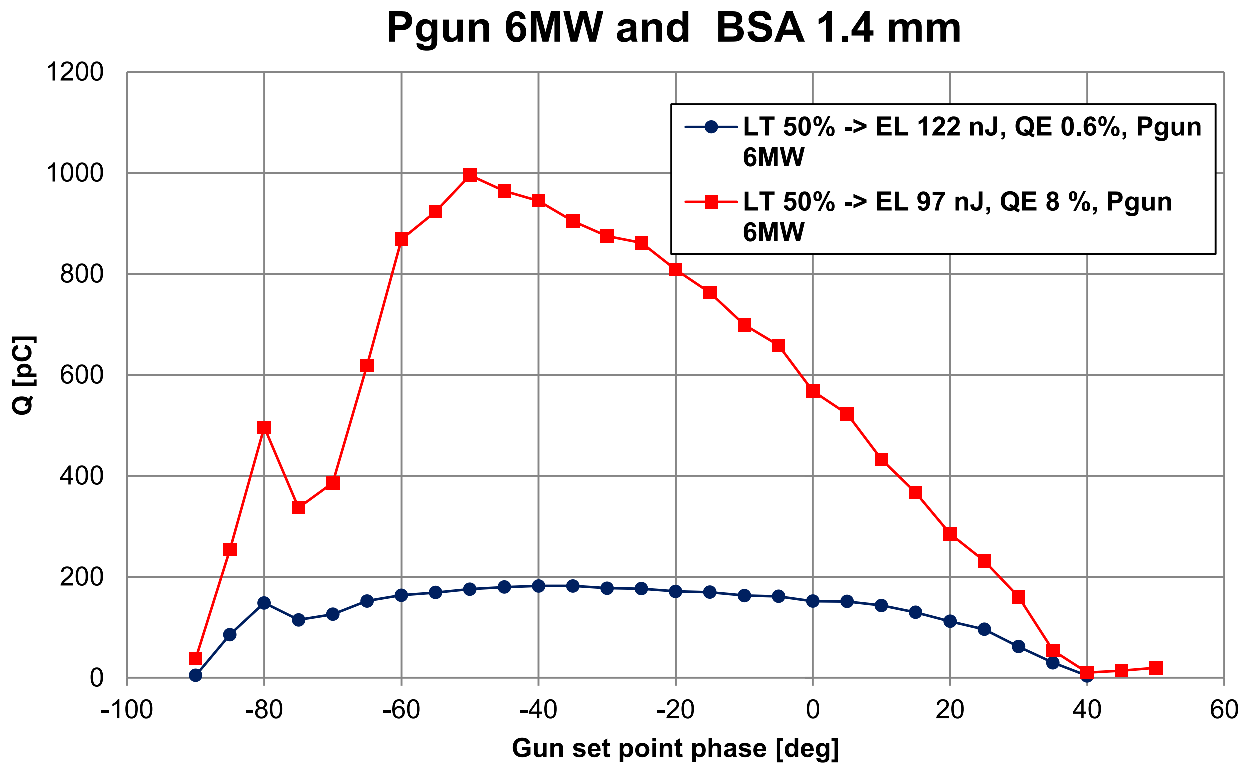
LT 90% = 118 nJ Laser pulse energy



The laser pulse energy is only 20% higher even though LT is two times higher

As expected, the phase scans for the old (QE 0.6%) and new cathode (QE 8%) are drastically different.

- How to reproduce these measurements in simulations if machine parameters are the same for both?
- The input charge is Qbunch = 2xQExE$_{L.}$ The product of QExE$_L$ could be adjusted to match the low QE cathode, but the codes do not include input parameters for QE and laser energy, they use total input charge.



Summary…

- We have charge vs laser energy for various BSA and gun settings for the fresh cathode, and some data for the worn cathode
- Charge vs laser energy is drastically different between the fresh and worn cathodes, even though the laser and gun settings are almost identical. The cathode QE and laser energy are not integrated into simulation codes.
- We have captured laser radial profile data and can now use it to generate input distributions in ASTRA.
- The obtained data set was taken with laser temporal profile Gaussian, but if we use the inferred 3 ps rms pulse length, ASTRA gives higher charge than the measured charge.
- However, ASTRA is still consistent about showing less charge for the Gaussian temporal pulse than for the Flat top temporal pulse, when the same BSA is assumed in the calculations.
- We also measured gun phase scans for various gun RF powers as requested by Darmstadt
- TU Darmstadt is now analyzing the data

…and more work to do…

- Using laser radial distributions generated from virtual cathode data gives in fact higher charge than using just inform distributions, indicating the procedure is going in the correct direction.
- This needs to be applied to the March 2013 data taken with the flat top temporal profile to confirm if indeed reproduces the observed charge vs laser energy behavior.
- We need to understand why ASTRA gives higher charge than the measured one for the 3 ps rms Gaussian temporal profile. Once we understand this:
- There are another ~30 charge vs laser energy scans that need to be studied (taken March 2015 with Gaussian 3 ps rms), including virtual cathode data that needs to be processed to generate ASTRA input distributions.
- Need to derive some conclusive results for preparing journal manuscript…soon.