Development of a Visualization Tool for the ARIES Systems Code to Explore the Parameter Space

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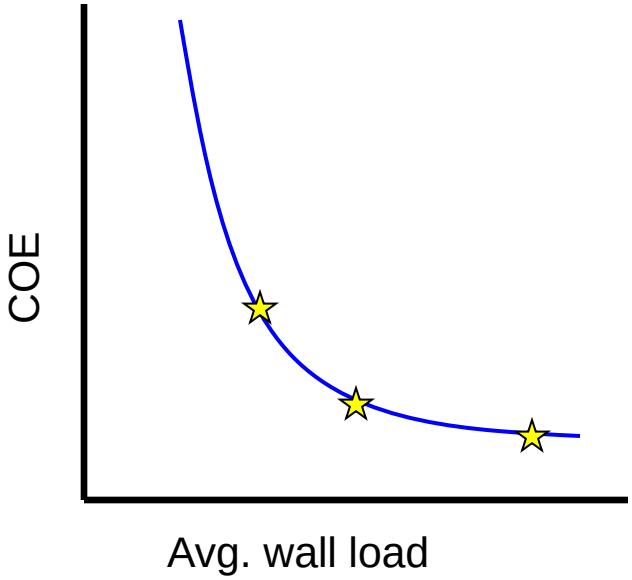
US/Japan Workshop on Power Plant Studies
NIFS, Japan
February 22-24, 2011

Systems code has evolved into a design space scanning tool

- Rather than optimize about a specific design point, new approach **scans** a wide operating space for a **range** of possible design points.
- It becomes necessary to **visualize** the large amount of data produced.

- We would like to better visualize tradeoffs and relationships between parameters.

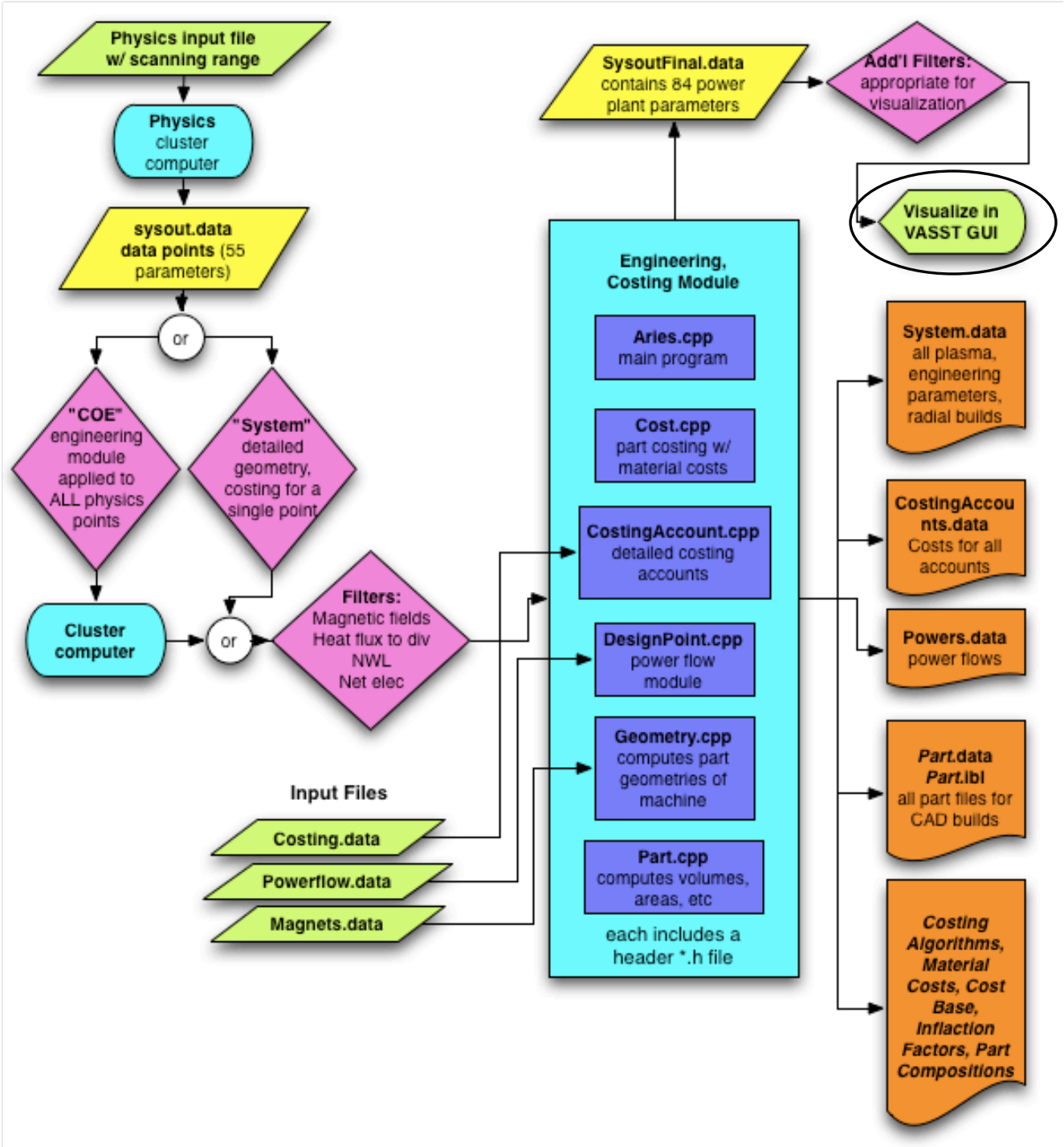
- By relaxing an “optimized” constraint, a larger design **window** may open up and give a more robust and credible design with minimal impact on COE.



ASC Flow Chart

(medium detail)

- Systems code consists of many modular building blocks



Now to visualize those points…

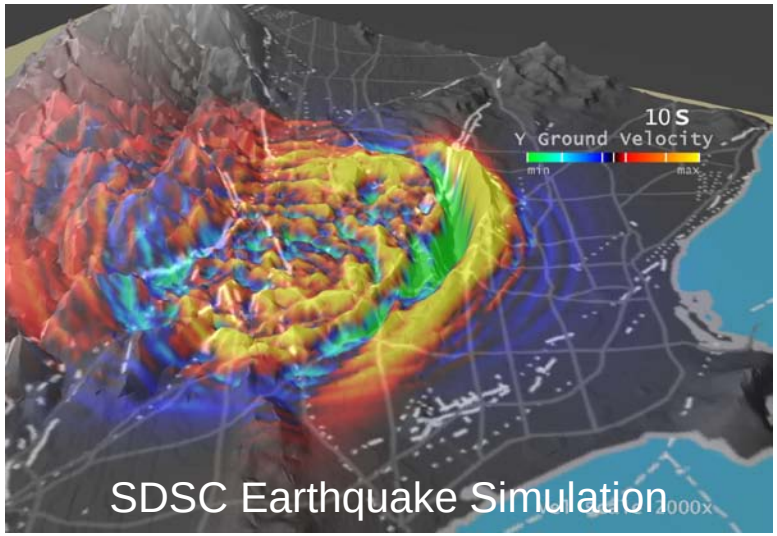
It is a challenge to visualize large data sets:

"Lots of numbers don't make sense to 'low-bandwidth' humans, but visualization can decode large amounts of data to gain insight."

- *San Diego Super Computer Center*

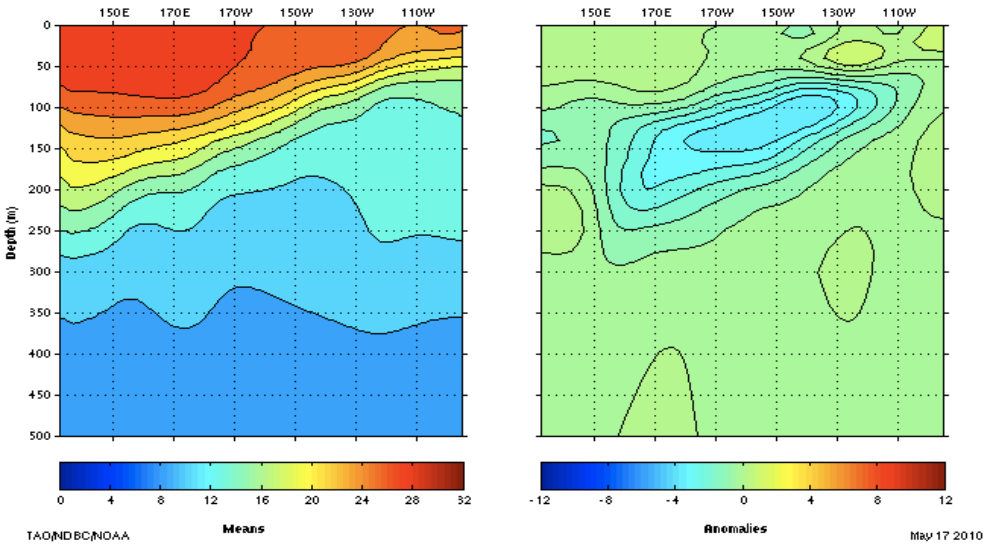
How do others visualize large data sets?

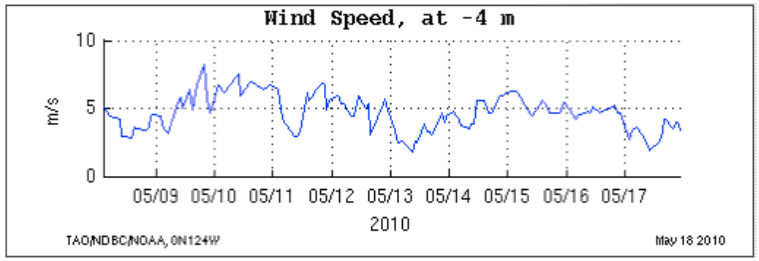
- Visualizing large datasets is a difficult task, almost an art.
- *Too much* information can be overwhelming/deceiving.
- 10^6 points exceed computer monitor real estate.

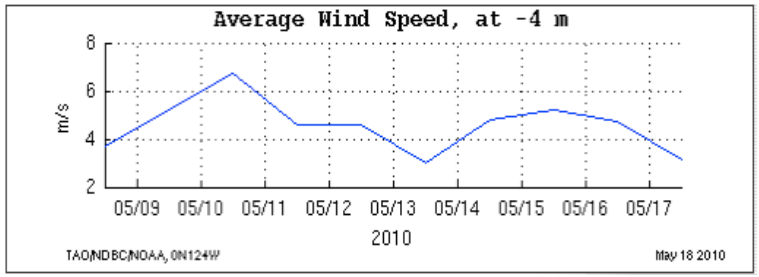


SDSC Earthquake Simulation

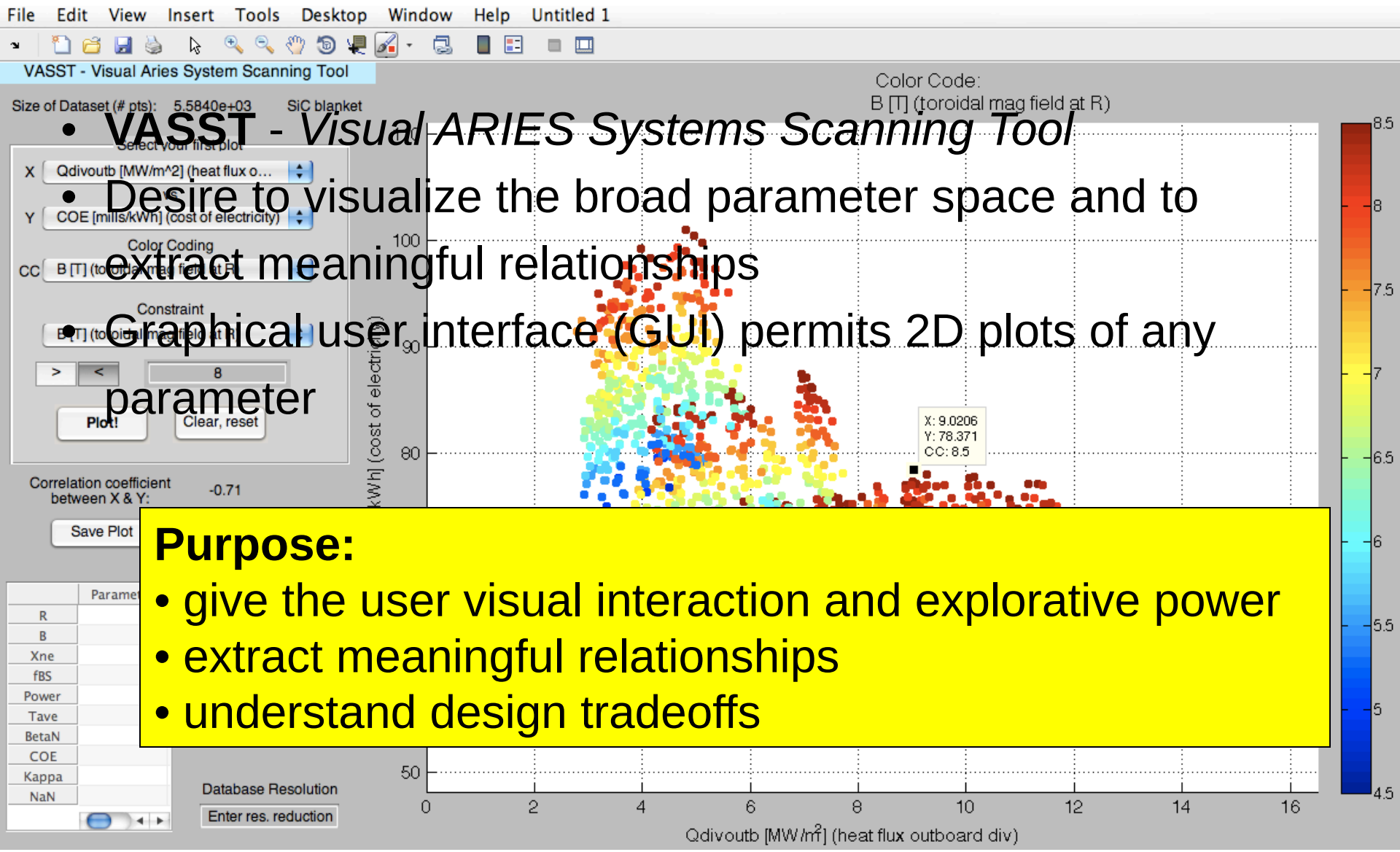
NOAA (National Oceanic and Atmospheric Admin.) data-logging buoys







We have developed a visualization tool to utilize the scanning capability of the new systems code

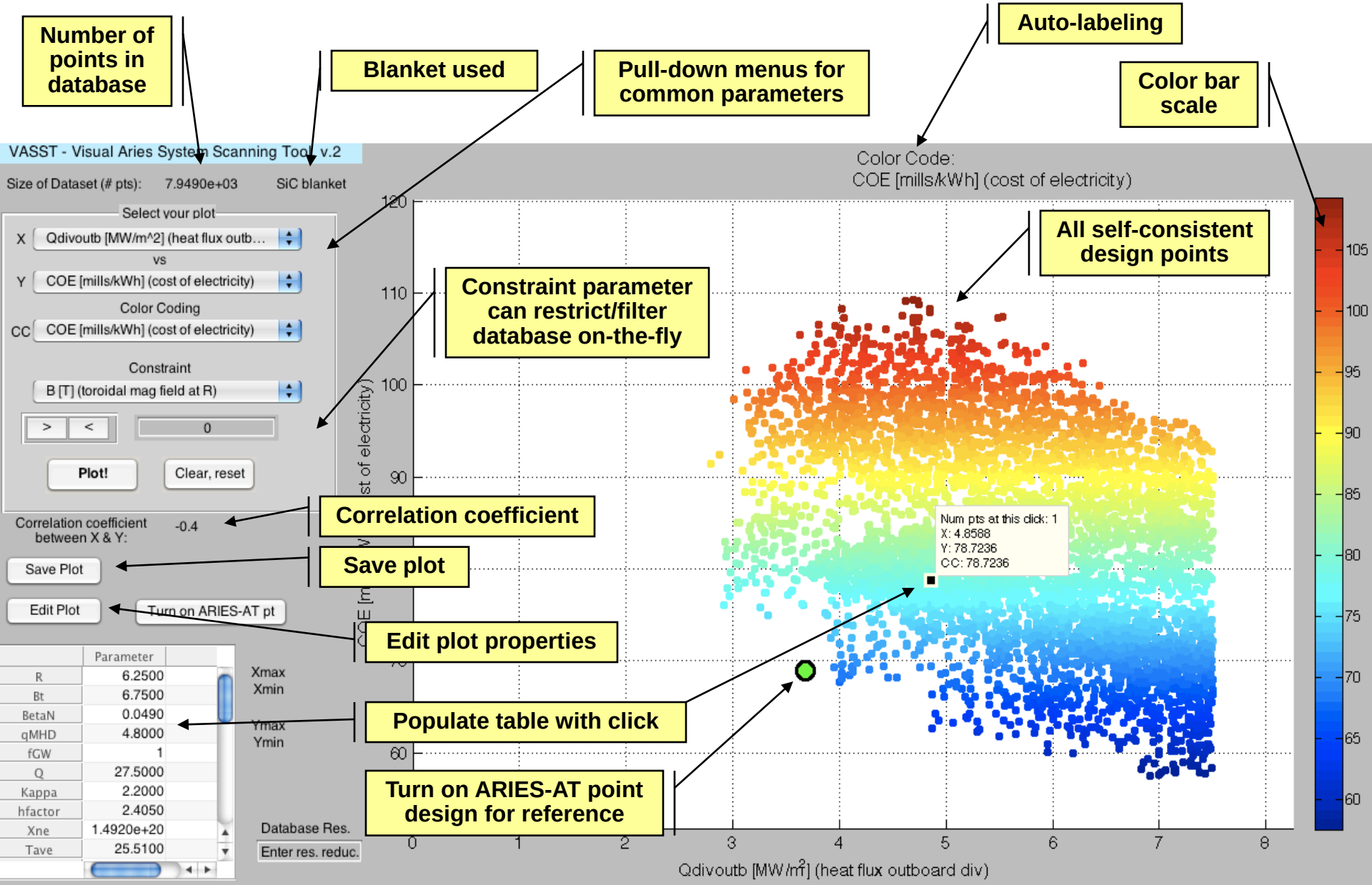


- **VASST** - *Visual ARIES Systems Scanning Tool*
- Desire to visualize the broad parameter space and to extract meaningful relationships
- Graphical user interface (GUI) permits 2D plots of any parameter

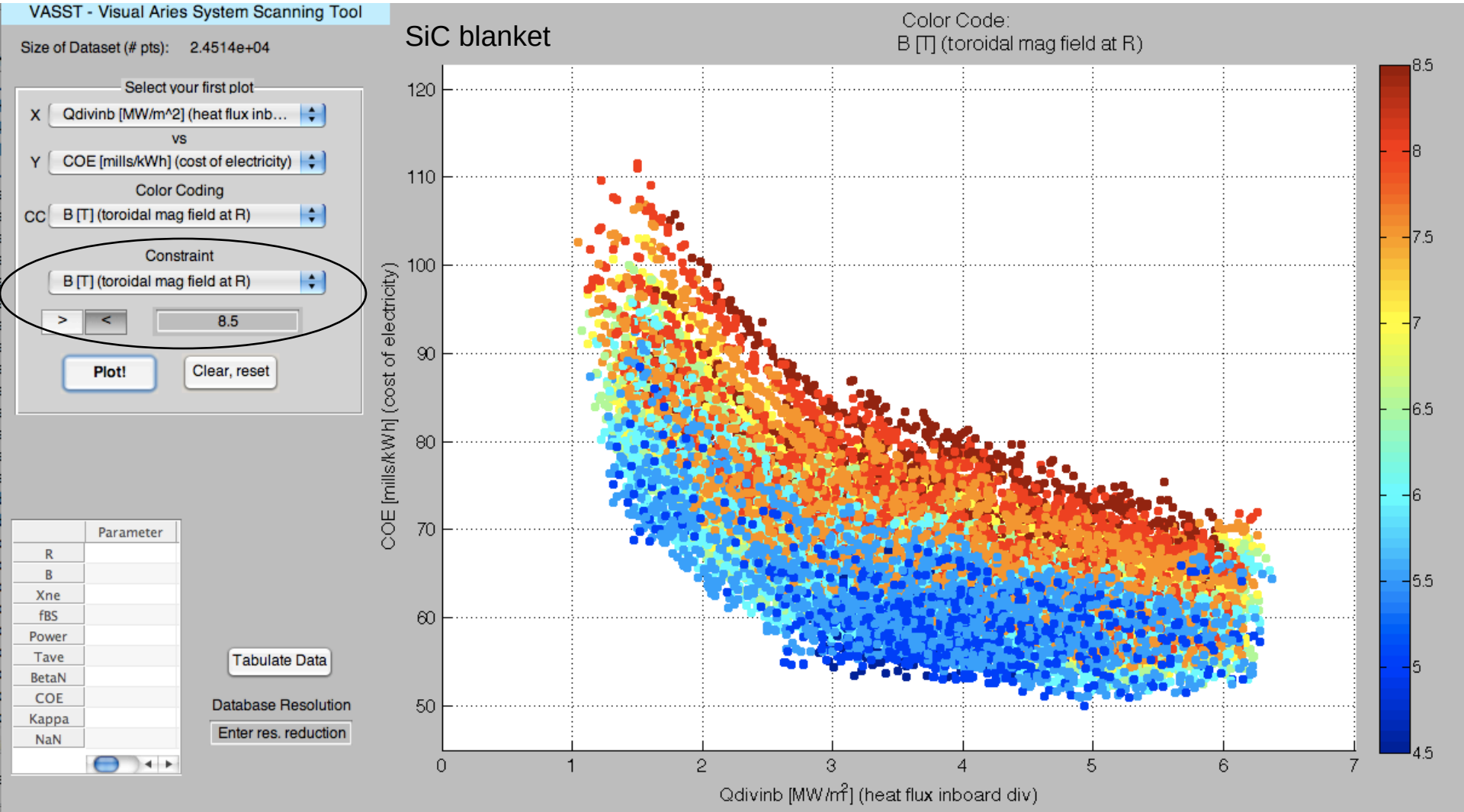
Purpose:

- give the user visual interaction and explorative power
- extract meaningful relationships
- understand design tradeoffs

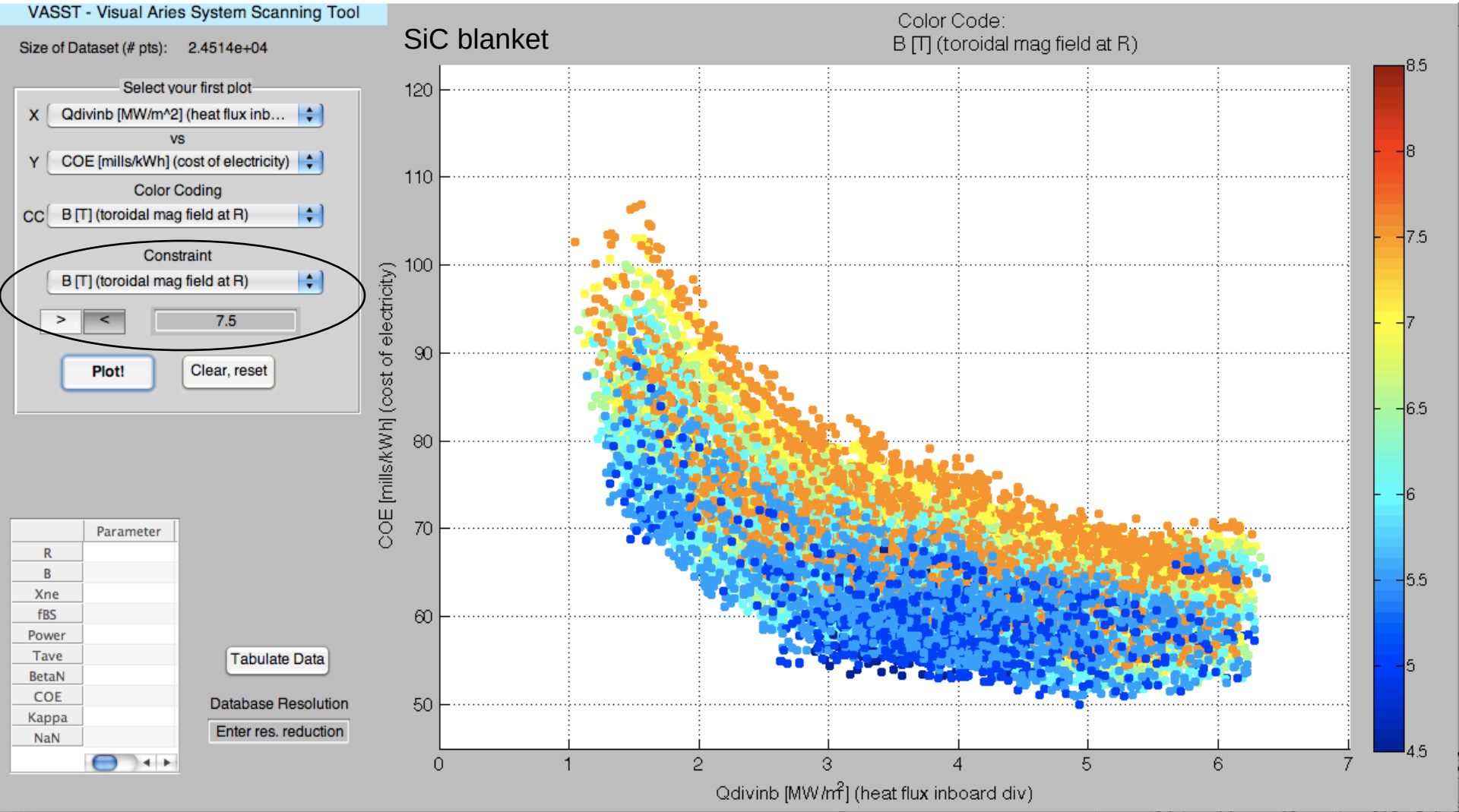
VASST - Visual ARIES Systems Scanning Tool



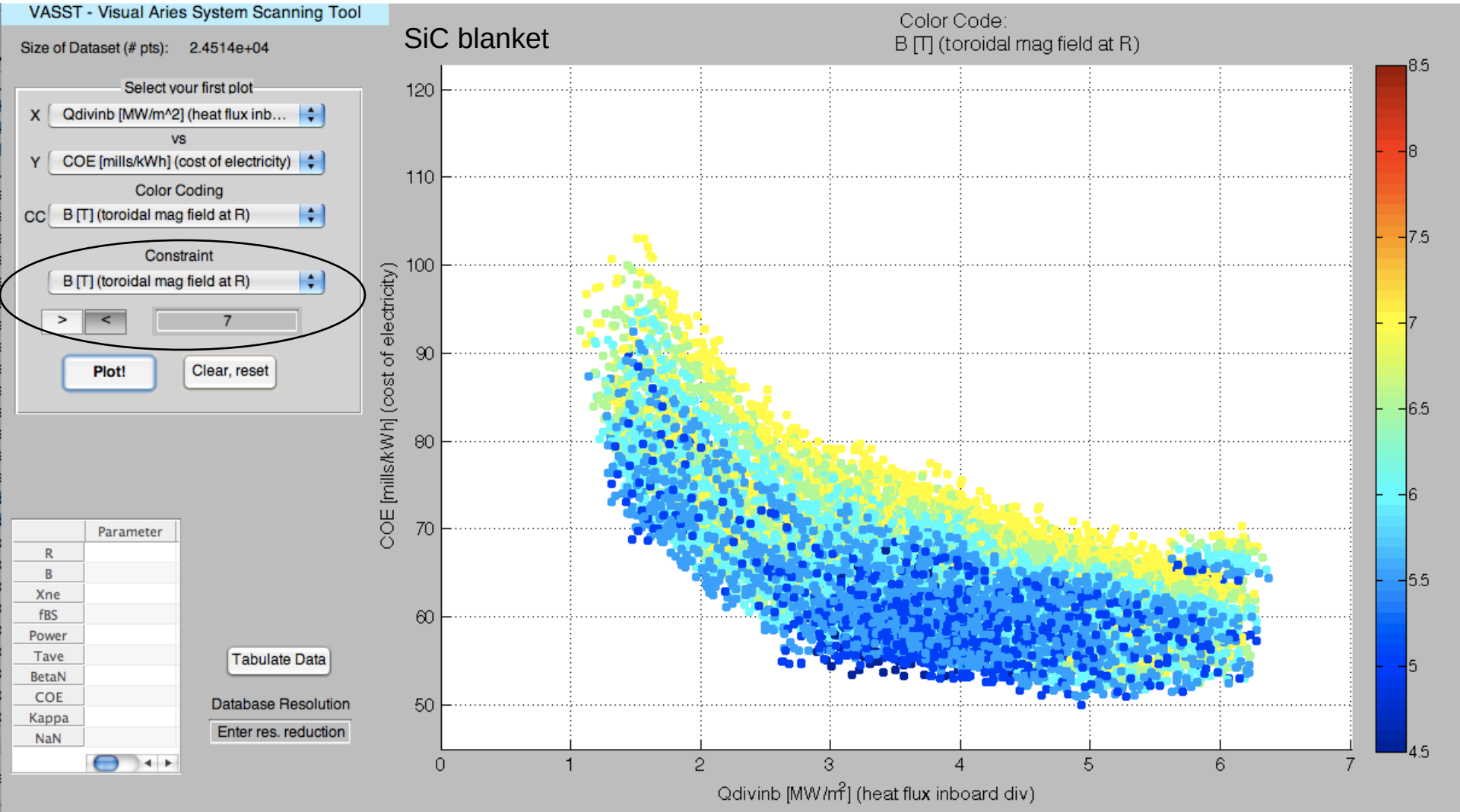
Example: Qdivinb vs COE, CC: B_T, constraint: B_T < 8.5 T



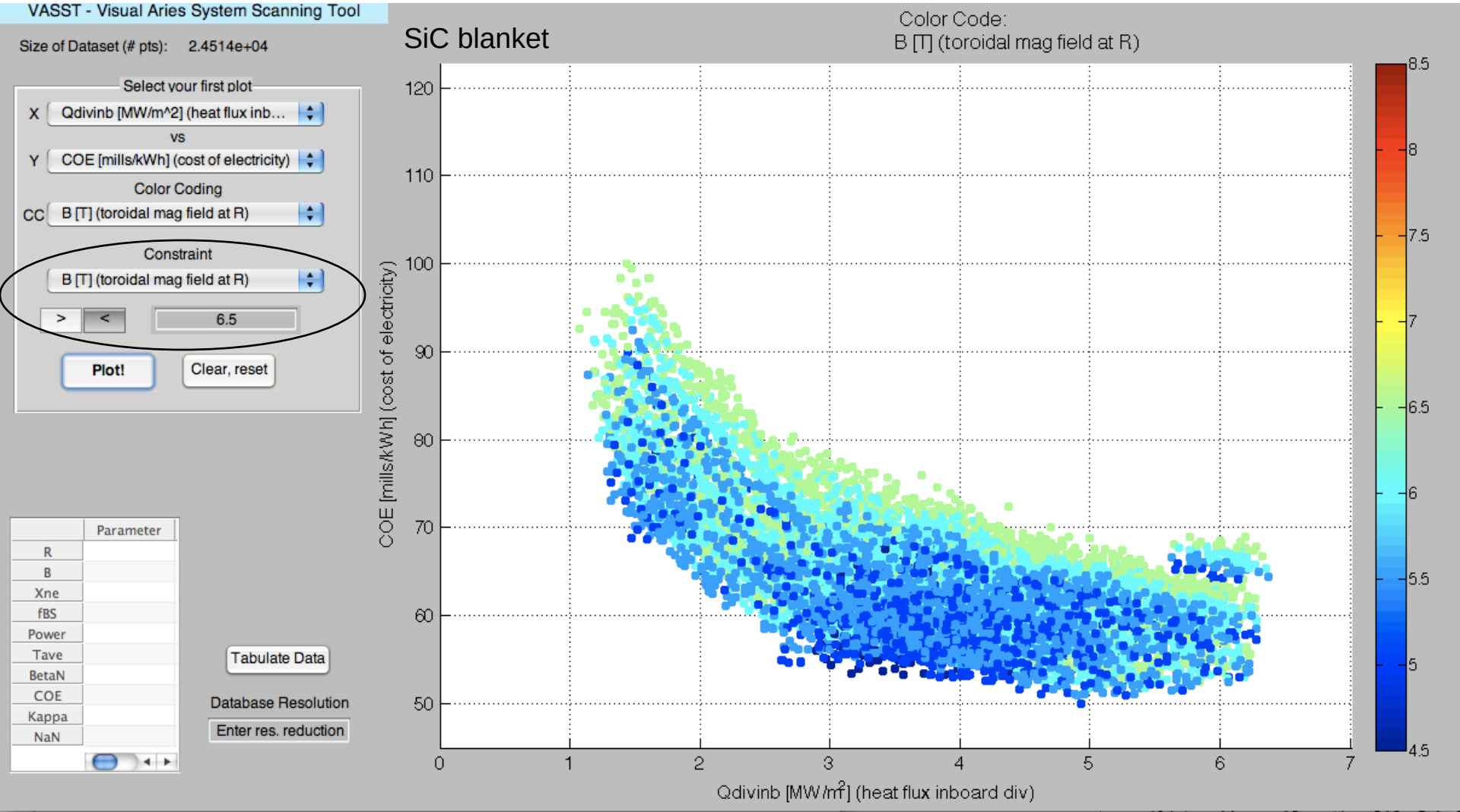
Example: Qdivinb vs COE, CC: B_T, constraint: B_T < 7.5 T



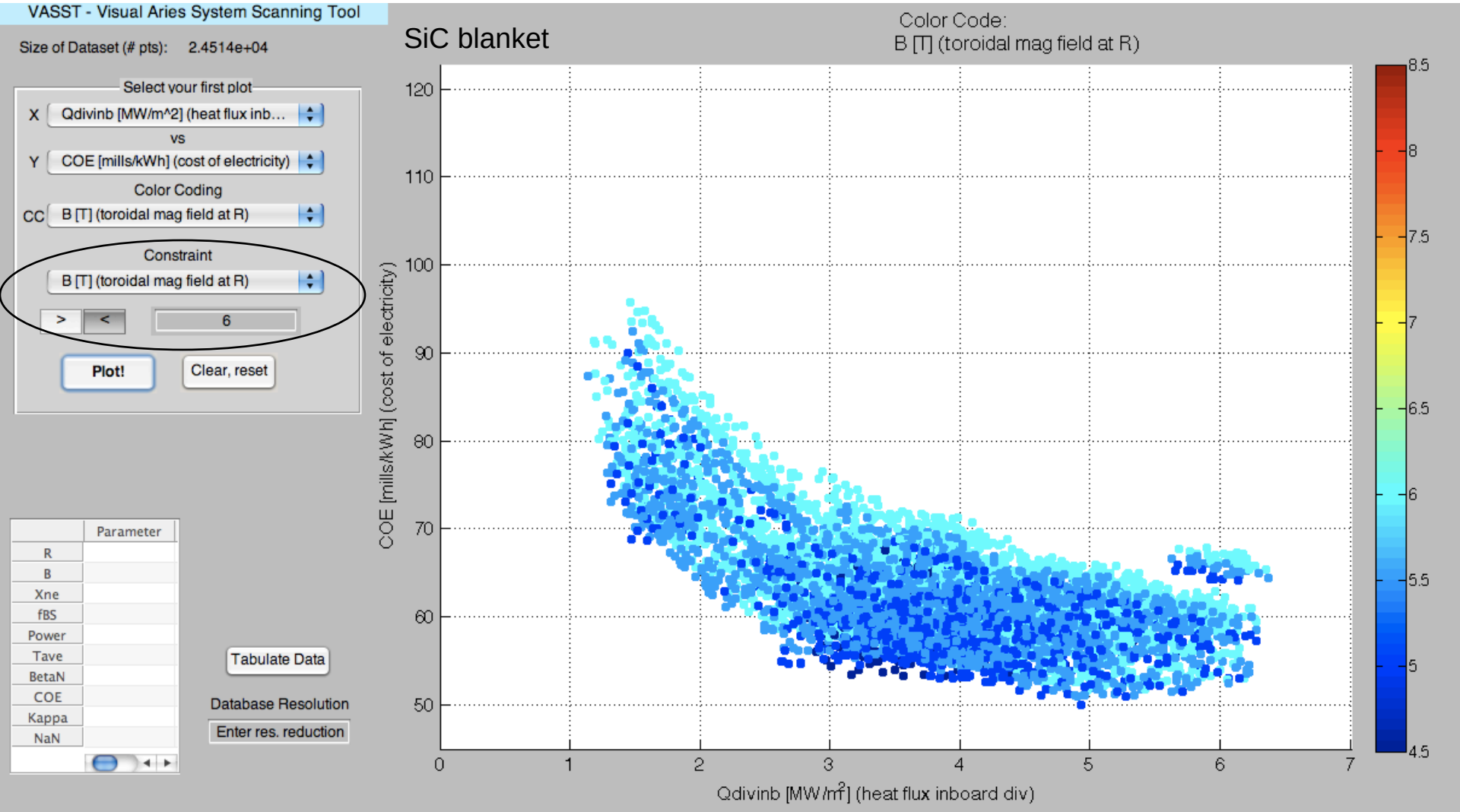
Example: Qdivinb vs COE, CC: B_T, constraint: B_T < 7.0 T



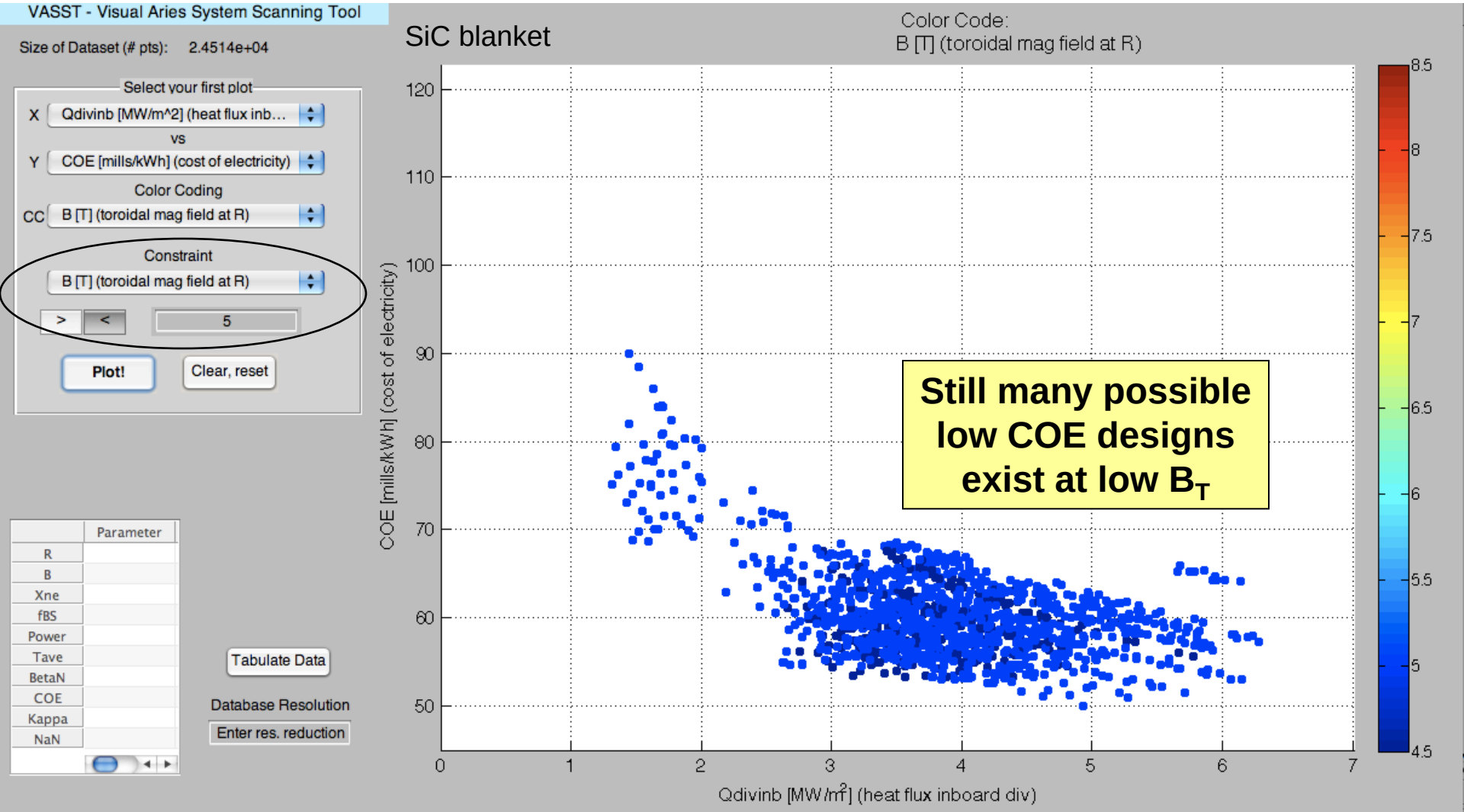
Example: Qdivinb vs COE, CC: B_T, constraint: B_T < 6.5 T



Example: Qdivinb vs COE, CC: B_T, constraint: B_T < 6.0 T

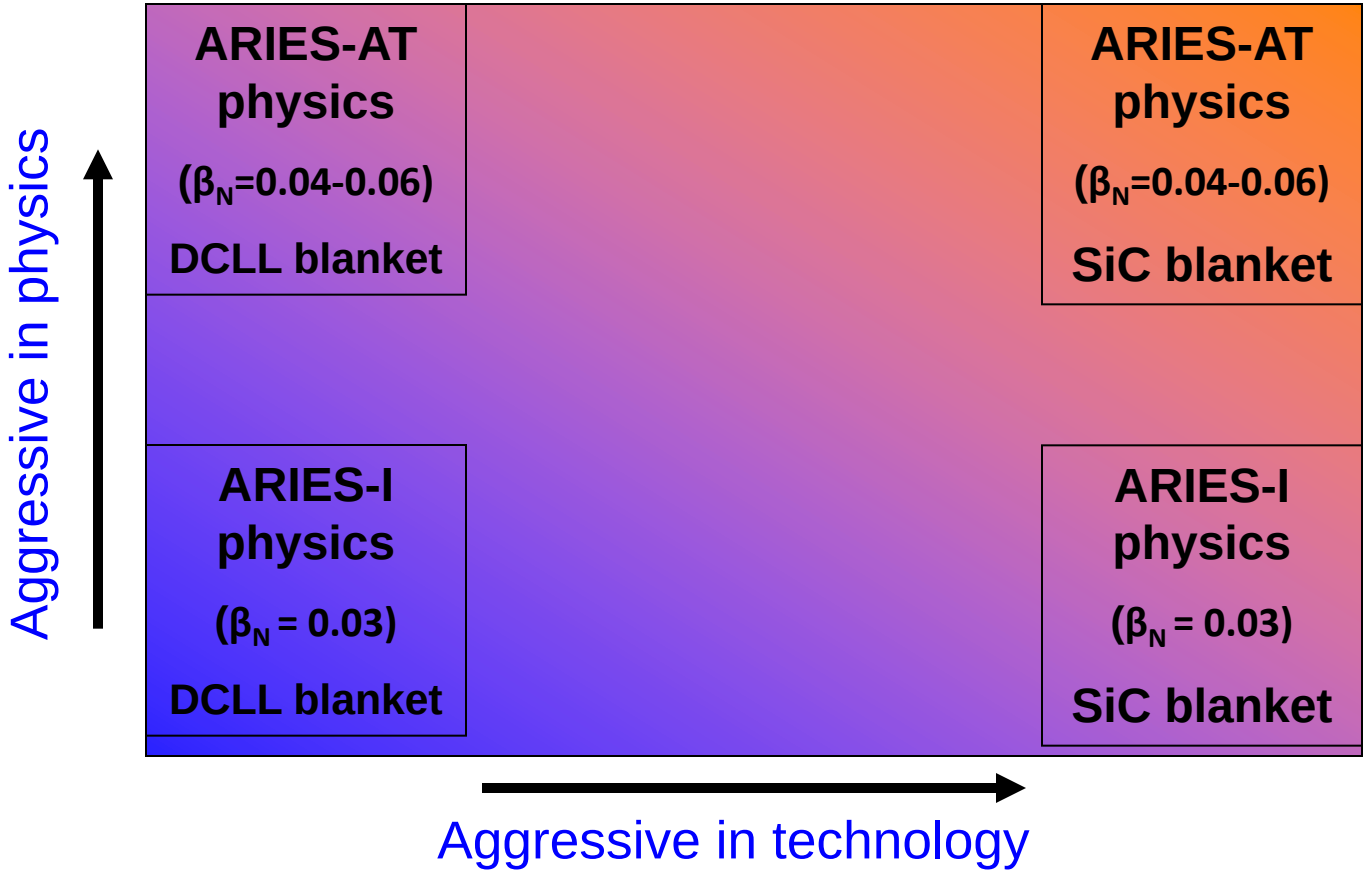


Example: Qdivinb vs COE, CC: B_T, constraint: B_T < 5.0 T



We have explored the "four corners" for current ARIES Physics & Technology Assessment

- Scans have been performed to span the 4 corners of the parameter space
- VASST GUI has helped visualize the effects of filtering data and identified design tradeoffs.



Some example systems code scanning parameters:

	Range	Resolution
R (m)	4.0 - 8.25	0.25
B_T (T)	4.5 - 8.5	0.25
BetaN	0.025 - 0.06	0.005
Q gain	15 - 40	5
n/n_{Gr}	0.7 - 1.3	0.1
P_{aux}	5 - 40	5
…		

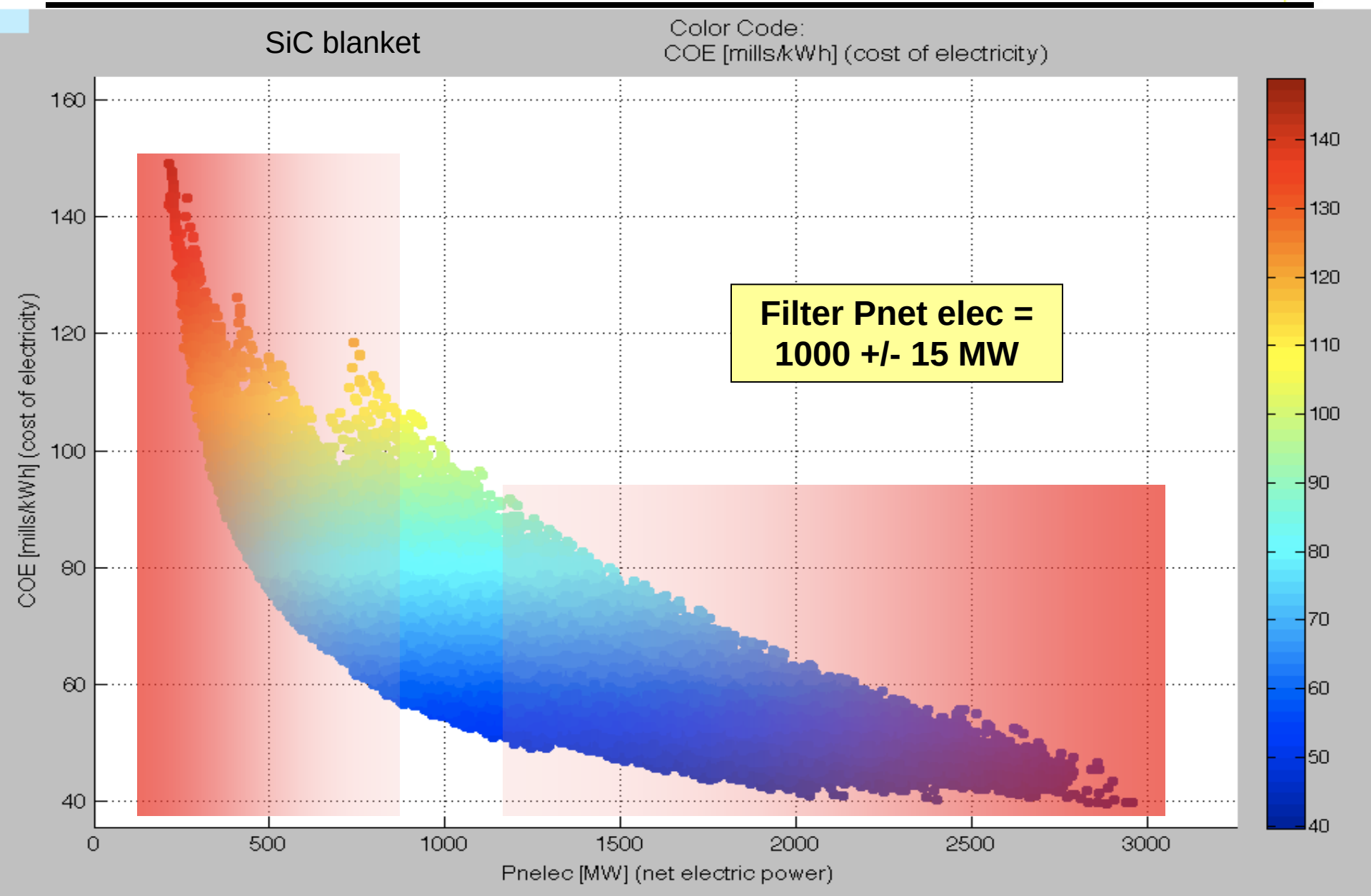
<u>Preliminary filtering:</u>

1. Pnelec = 1000 MW ± 15 MW
2. Divertor (in/outboard) limit < 15 MW/m^2
3. $B_T$max = 6 - 18 T

System scans done on cluster computer with 100's nodes

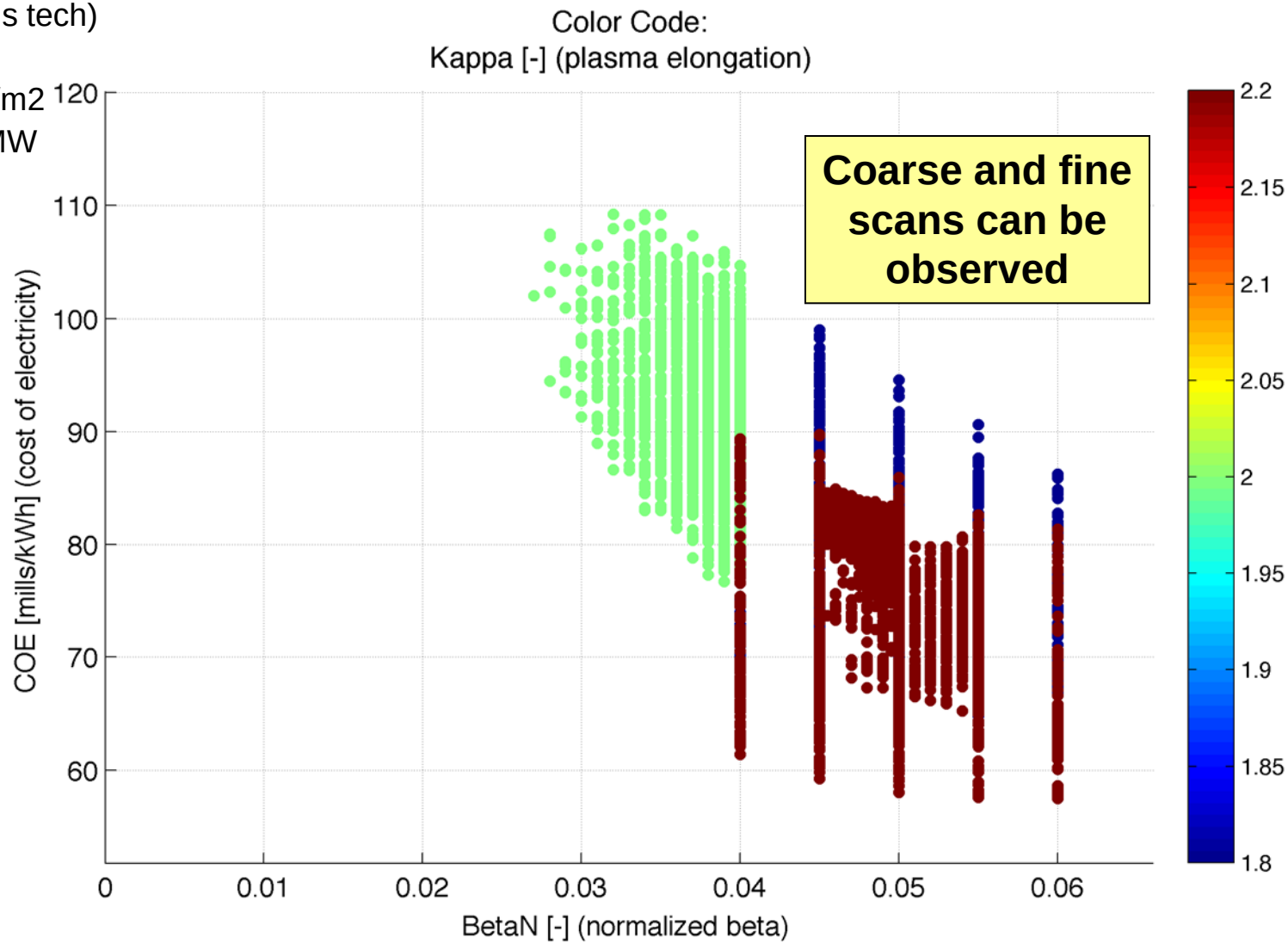
Large system scans can produce 10^6 - 10^8 points

Net electric (unconstrained) vs. COE, CC: COE



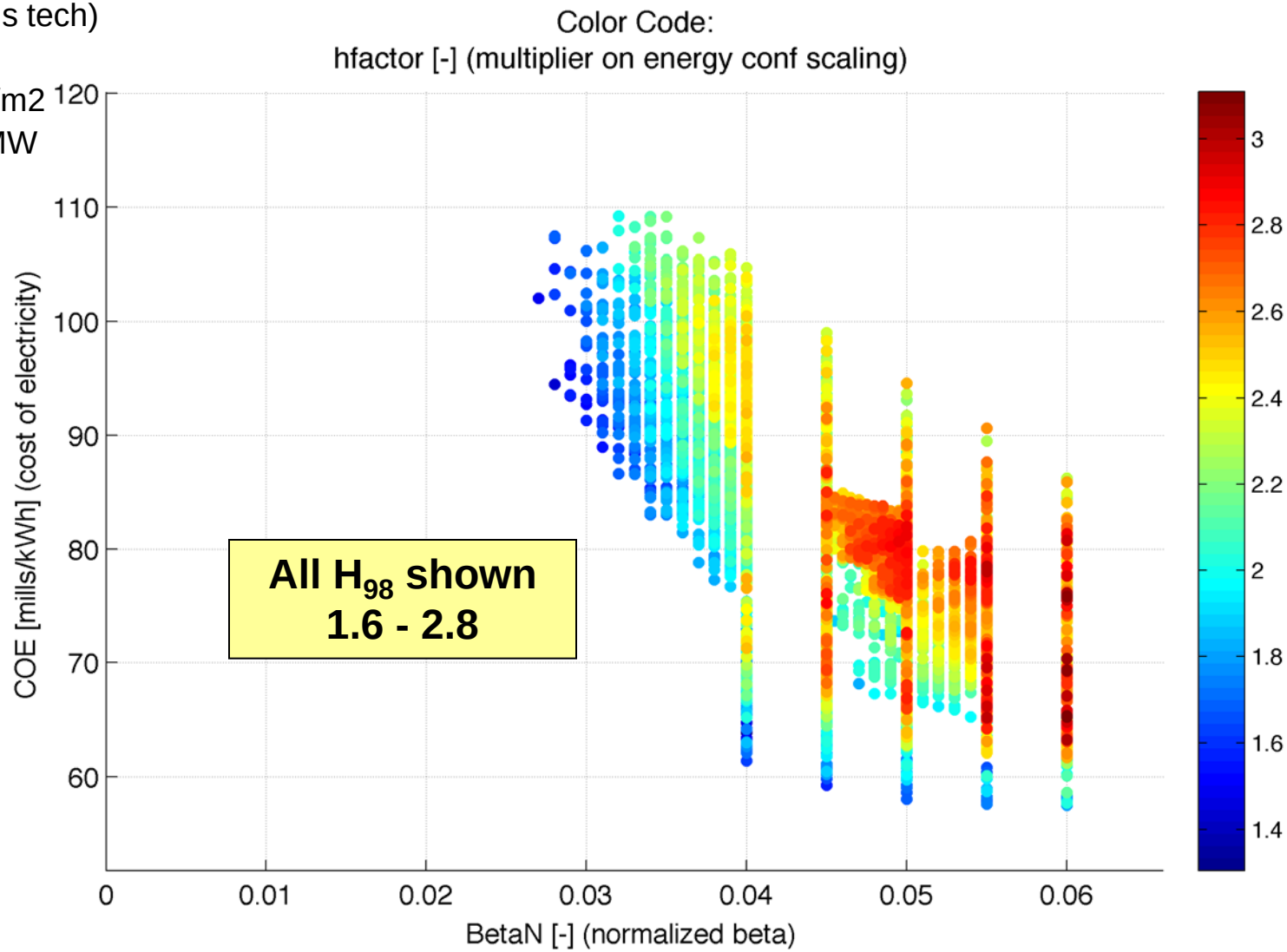
β_N vs COE, CC kappa

Database name: SysoutFinalsiccomb3
(aggr phys & aggr/cons tech)
Filters: Bt 6-18 T
div (in, out) < 7.5 MW/m2
Pnelec = 1000 ± 15 MW
COE real
n/nGr < 1
H98 < 1.9



β_N vs COE, CC H_{98}

Database name: SysoutFinalsiccomb3
(aggr phys & aggr/cons tech)
Filters: Bt 6-18 T
div (in, out) < 7.5 MW/m2
Pnelec = 1000 ± 15 MW
COE real
n/nGr < 1



β_N vs COE, CC H_{98}

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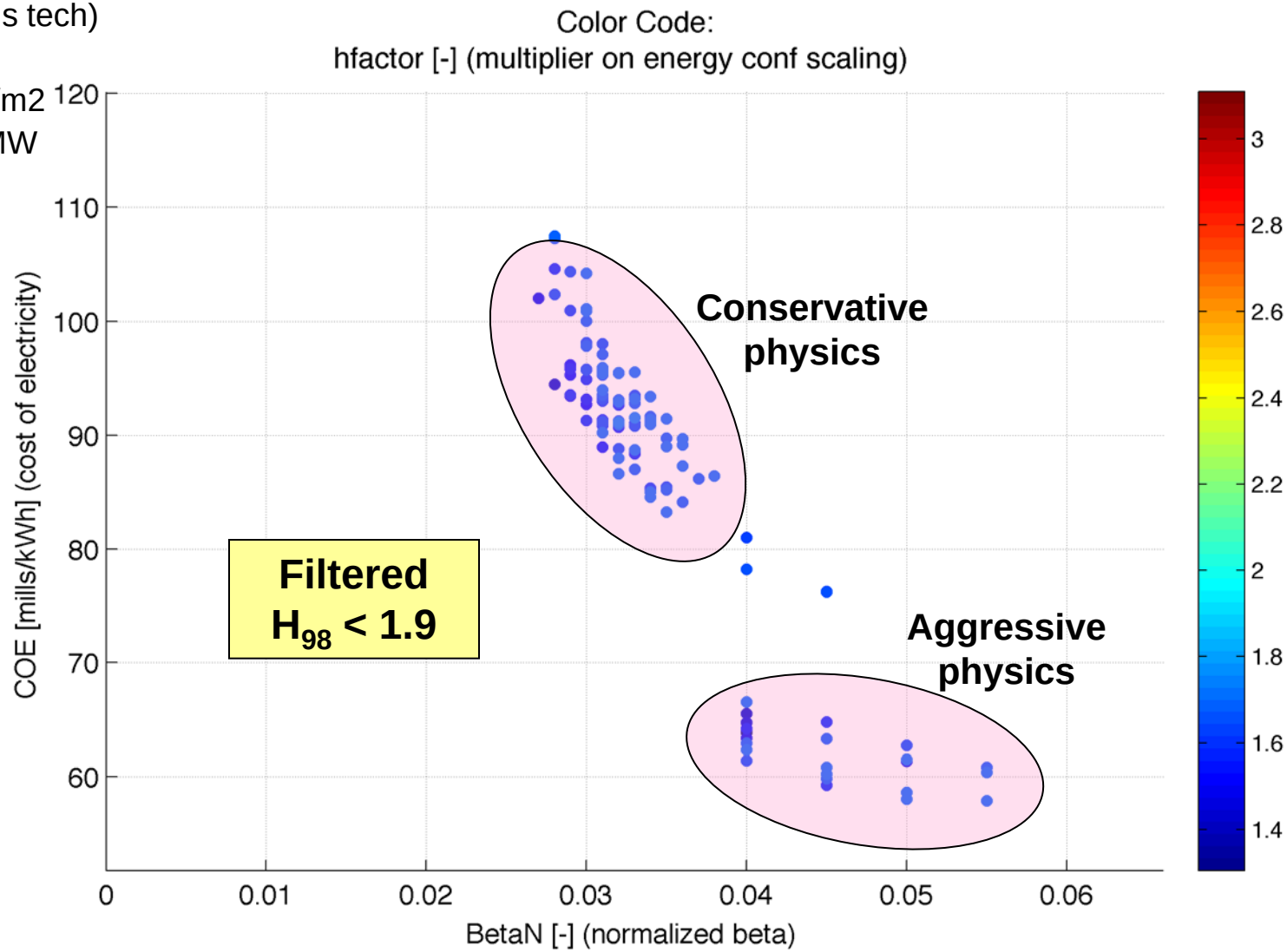
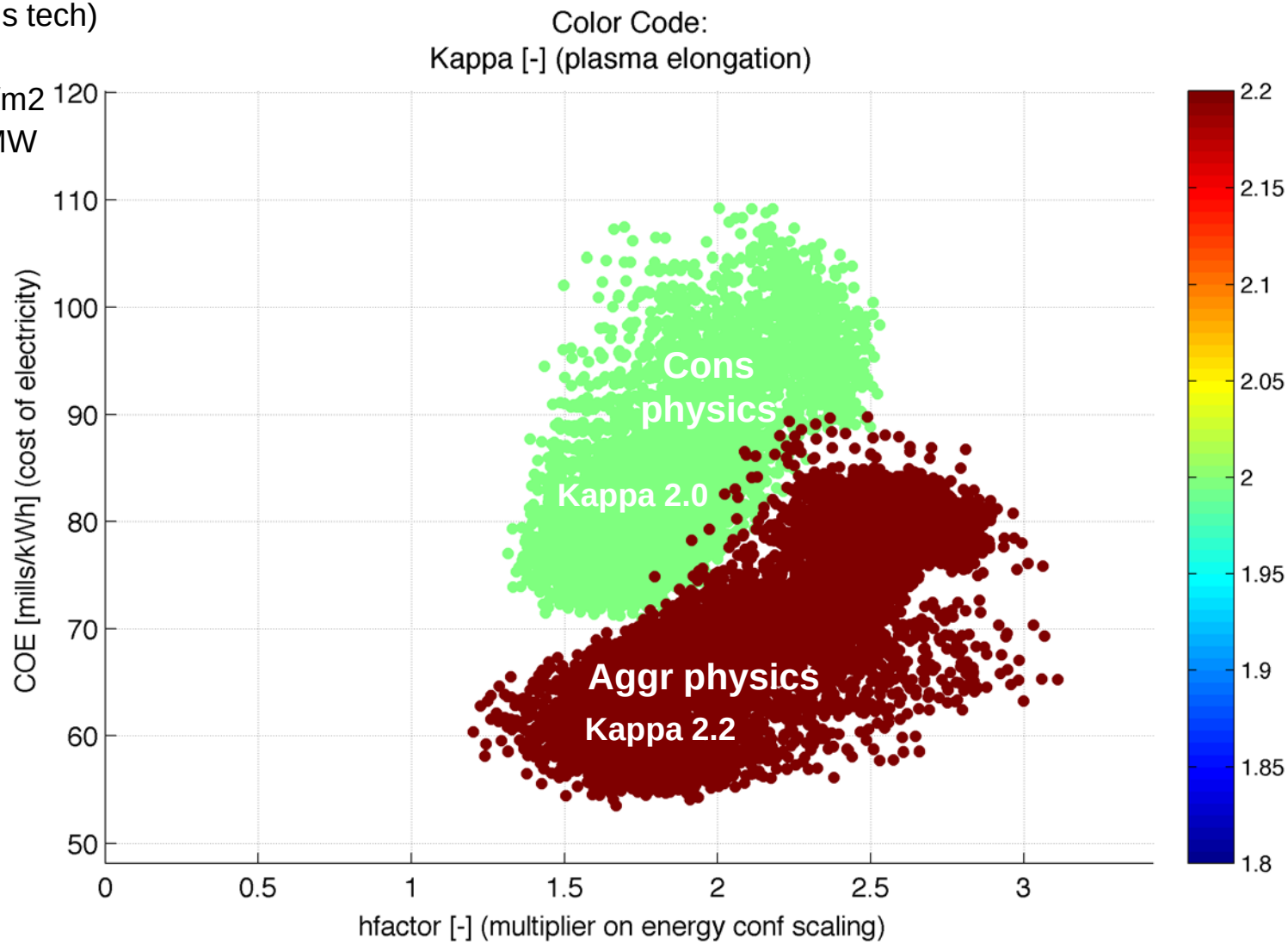


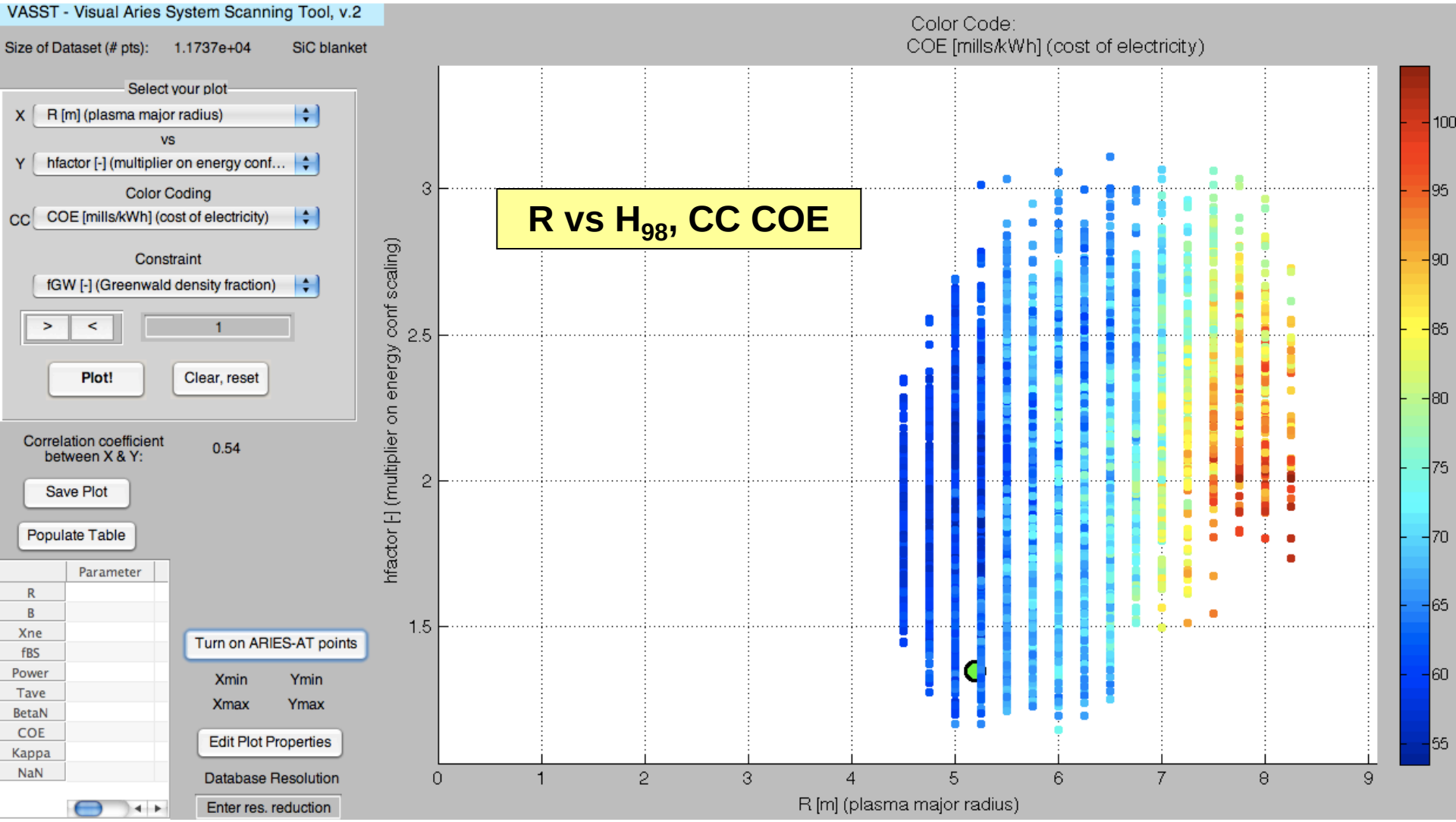
H_{98} vs COE, CC kappa

Database name: SysoutFinalsiccomb3
(aggr phys & aggr/cons tech)
Filters: Bt 6-18 T
div (in, out) < 7.5 MW/m2
Pnelec = 1000 ± 15 MW
COE real
n/nGr < 1

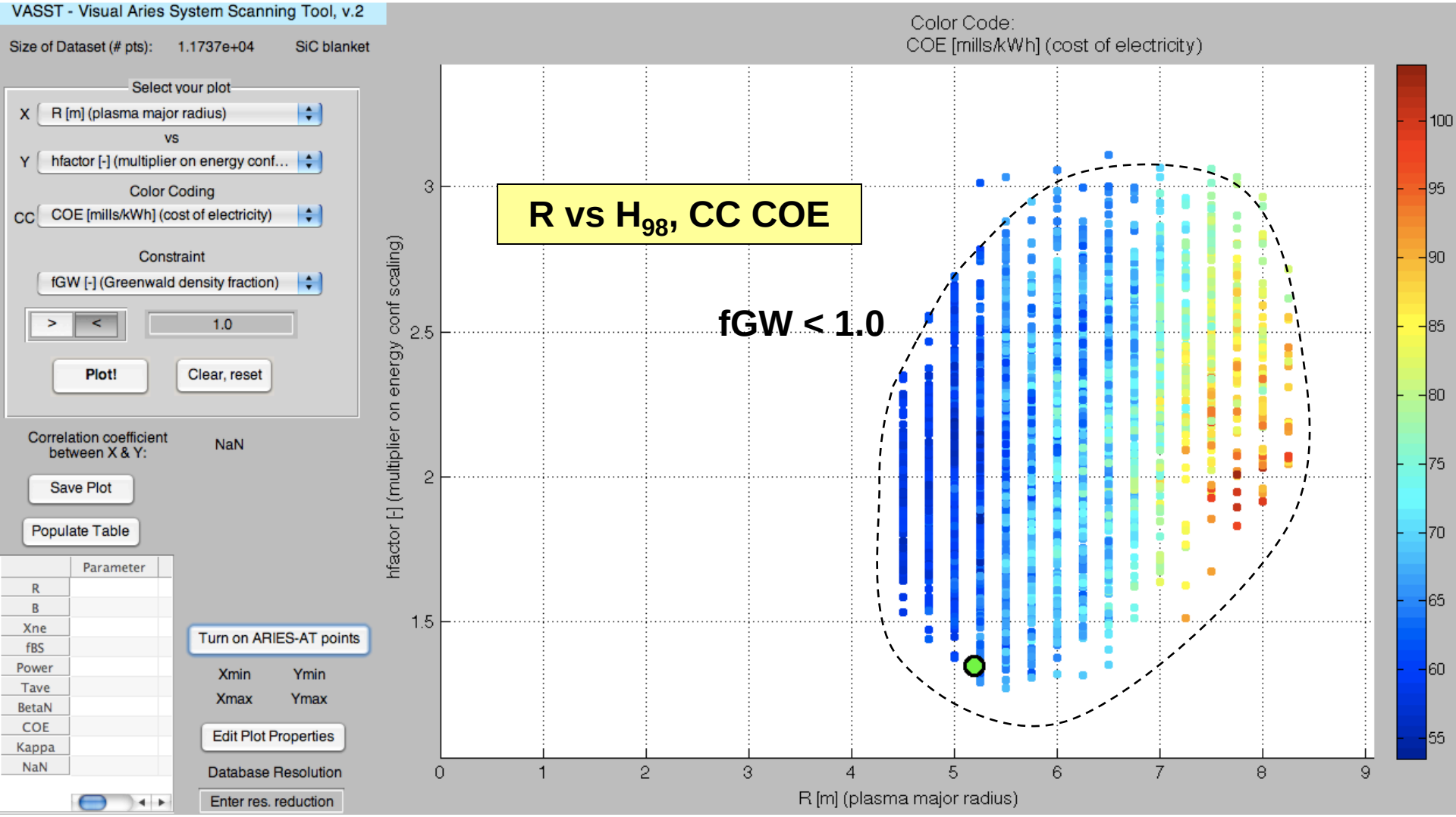
SiC	Value
H_{98}	< 1.9 aggr, < 1.6 cons



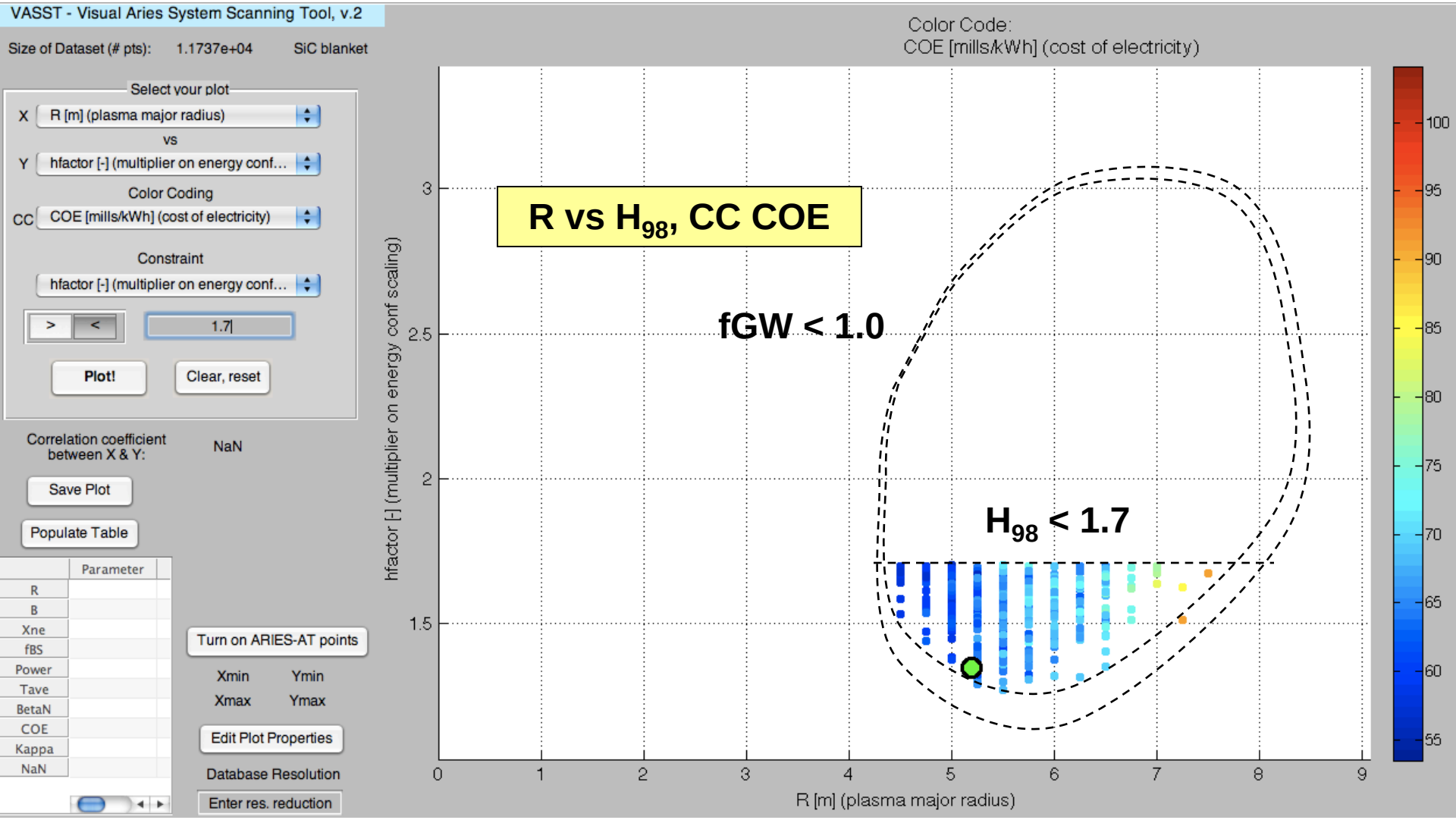
Aggr physics / aggr tech filtering (1/3)



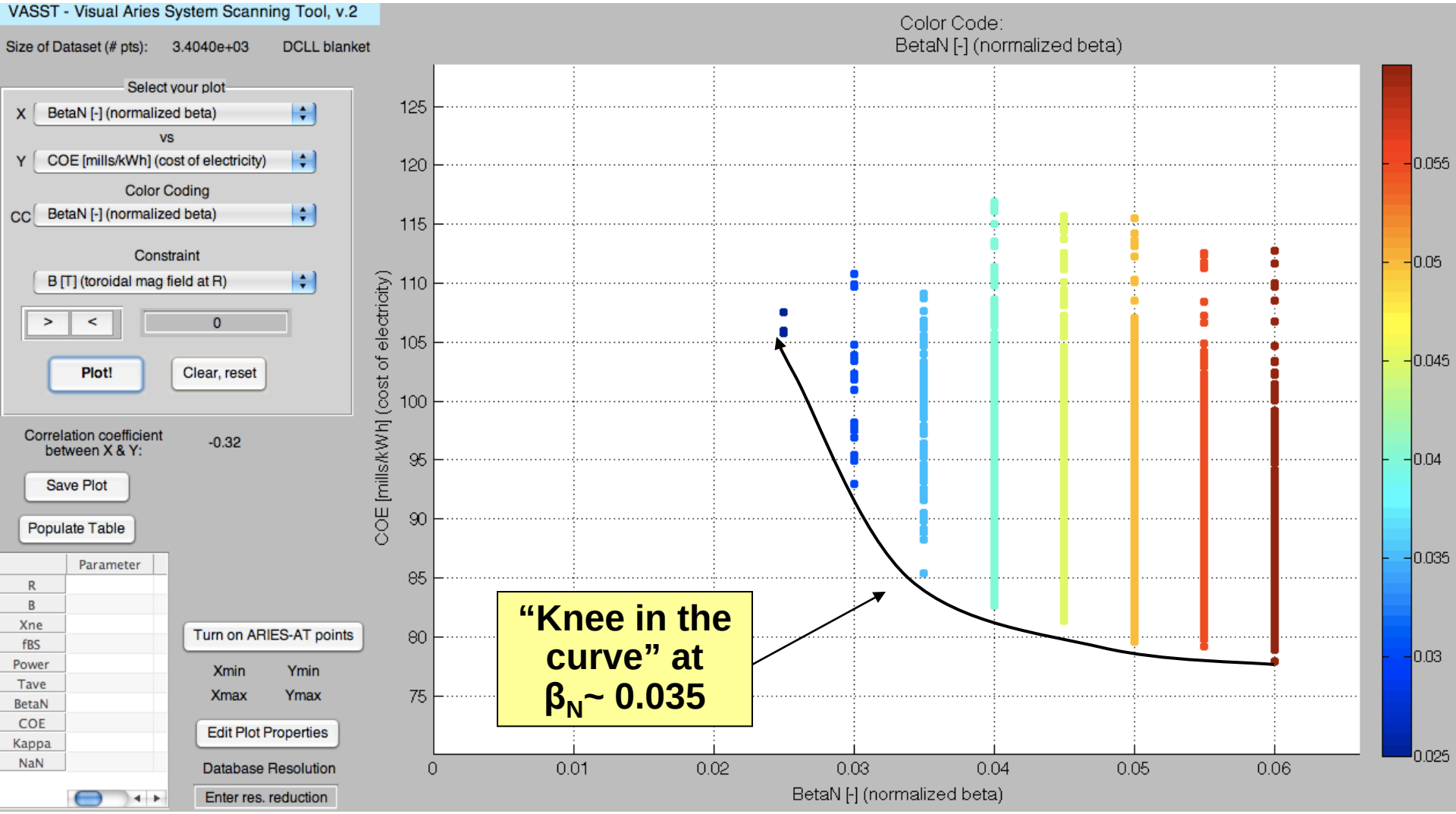
Aggr physics / aggr tech filtering (2/3)



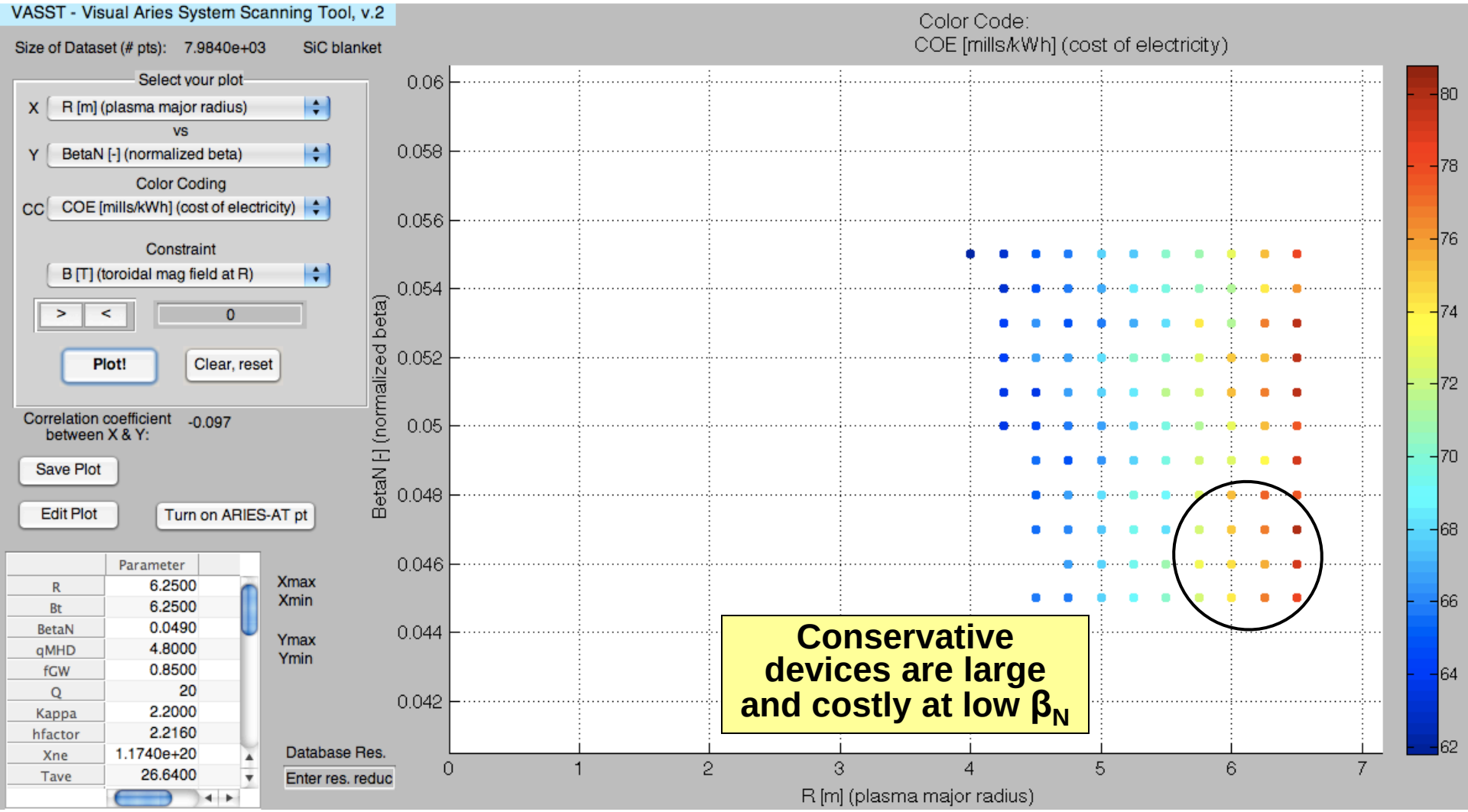
Aggr physics / aggr tech filtering (3/3)



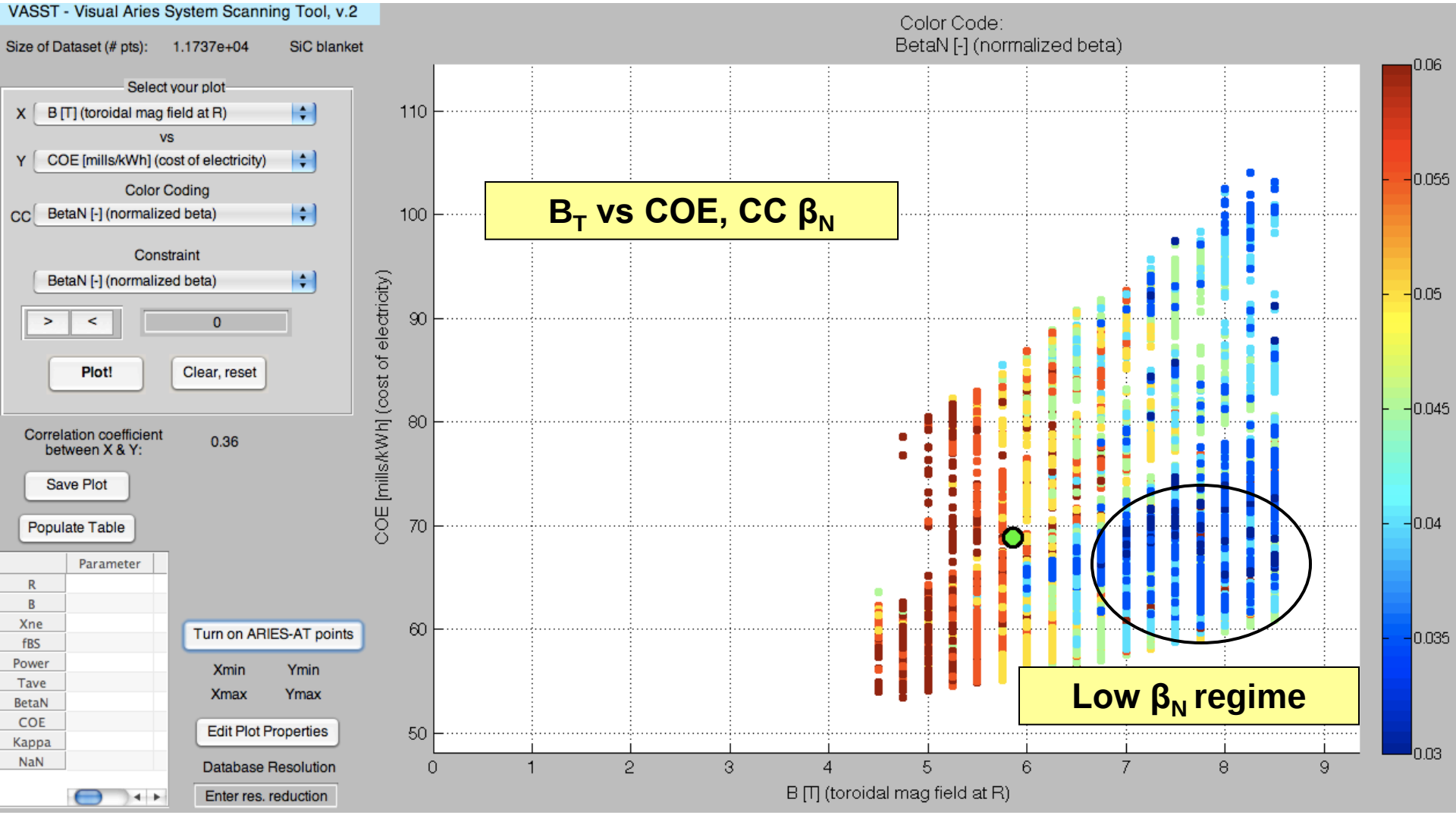
Aggr physics / cons tech



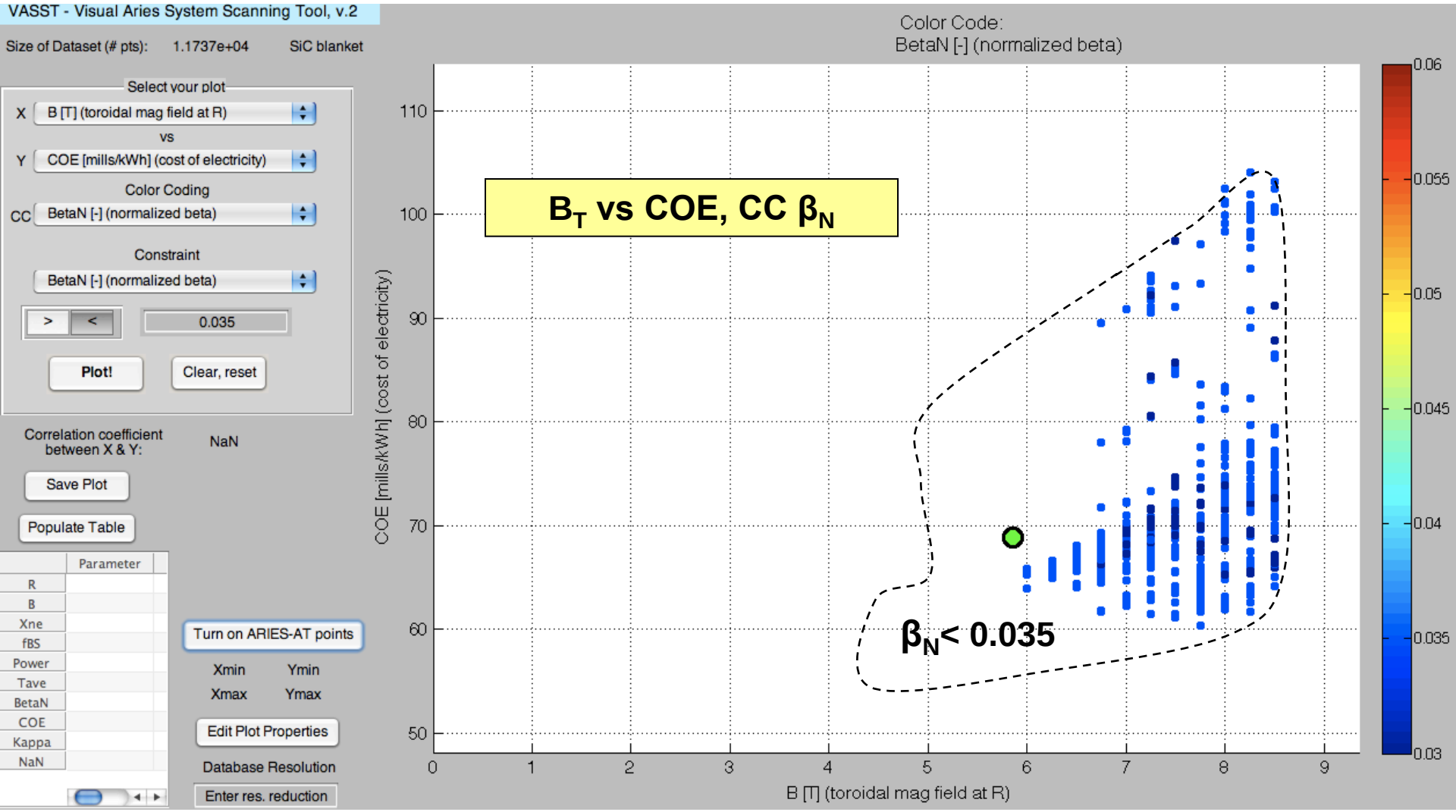
Example: R vs. β_N vs COE, CC H_{98}



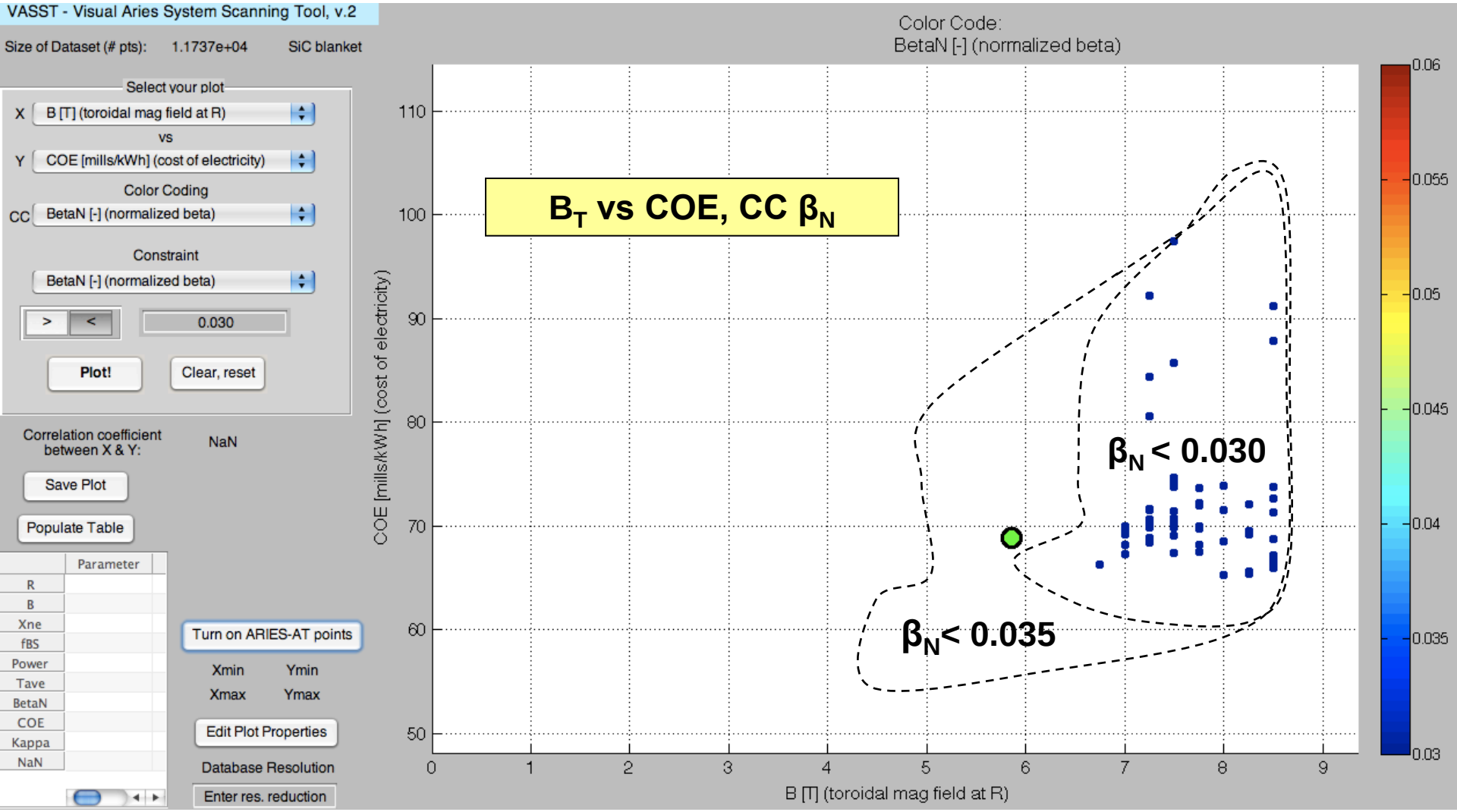
Example: Cons physics / aggr tech



Example: Cons physics / aggr tech



Example: Cons physics / aggr tech



Managing the ARIES systems code & VASST

Document error corrections & modifications to the systems code

- Mod #, date,
- Error correction or modification
- Lines of code affected
- Person responsible for input
- Status - complete, in progress, or pending
- Notes

ASC Modifications

implemented by Lane Carlson — **SiC blanket ONLY so far, comparing ACT**

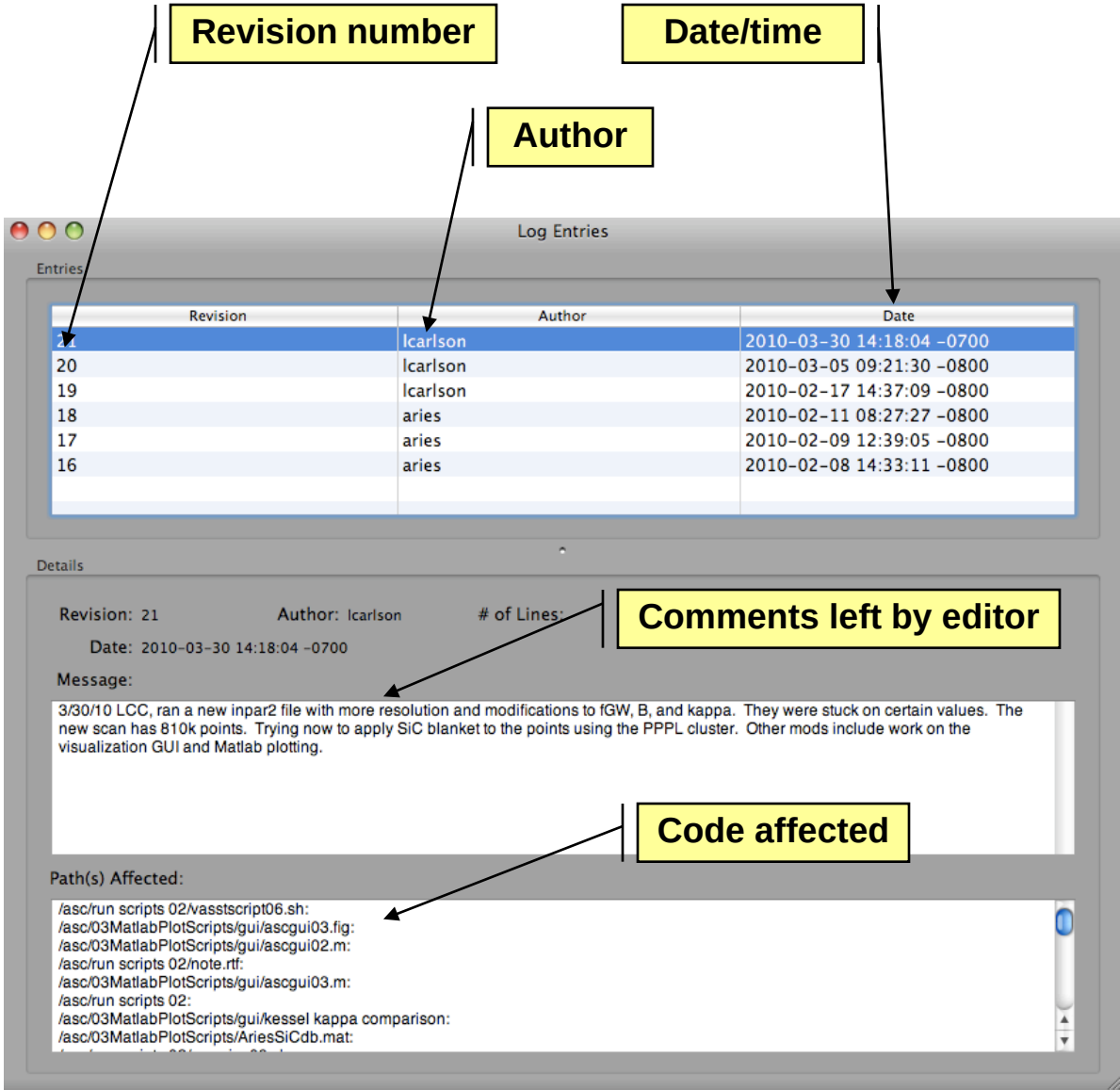
Chronicle started 8/26/10 — included in pres?

Mod #	Date	Type of mod.	SiC Code affected	~line #	Responsible for input	SVN version	Status	Notes:
1	8/26/10	error correction	SiC DesignPoint.cpp, CostingAccount.cpp, Cost.cpp	300, 1200, 89	L. Carlson	21	complete	SiC divertor module was changed from **PbLi-cooling to He-cooling** since we routinely exceed 5 MW/m^2 in the divertor; this is taken from DCLL DesignPoint.cpp
2	8/26/10	error correction	DCLL designpoint.cpp	800	L. Carlson	21	complete	DCLL **He-pumping efficiency** changed from a table with low (~40%) pump efficiency to a set value of 90% in input file powerflow.data
3	11/17/10	modification	Aries.cpp	240	L. Carlson	21	complete	**Cost base year** changed from 2010 to 2009, for easier data comparison
4	11/17/10	error correction	CostingAccount.cpp	1216	L. Waganer, L. El-Guebaly	21	complete	**PbLi costing** was too low. *A factor of 2.5 was missing: 2.5 x inside power vol = total coolant (to account for coolant in plumbing and outer loop)*
5	12/2/10	modification	Part.cpp, CostingAccount.cpp	1122, 1619	L. Waganer	21	complete	Modified **inflation factors** after new GDP input effective Nov 2010. See *"GDP current(103010)(2005 basis).xls"*
6	12/2/10	error correction	Part.cpp	981	L. Carlson	21	complete	Corrected **material densities** (PS from 789 to 7800 kg/m^3)
7	11/23/10	error correction	DesignPoint.cpp	610	M. Tillack	21	complete	Concluded that we can continue to use R. Raffray's NW. vs **gross cycle efficiency** for the new term since our NW. and q' are low (~3 MW/m^2, ~0.25 MW/m^2 for ~AT).
8	12/7/10	modification	DesignPoint.cpp, powerflow.data input	196, 36	L. El-Guebaly	21	complete	Recommends combining cryo and aux powers, scale **Paux** (50 MW) from ITER (30 MW misc, 25 Lhe cryoplant, 10 LM cryoplant) = 63 MW (still have low temp SC cryo power separate, 2MW)
9	12/7/10	modification	Aries.cpp	208	X. Wang		complete	Left scrap off layer **(SOL)** at 7 cm. Has negligible effect on COE ($0.01 change) if we go to 5 cm (like AT).
10	12/10/10	error correction	DesignPoint.cpp	1070-1190	L. Carlson	21	complete	Multiplied all **volume** printouts by **16x.** Need to do this since volumes are calculated on a unit/contour basis in Geometry.cpp
11	12/7/10	modification	CostingAccount.cpp	1058	L. Waganer	21	complete	**New turbine-generator** plant equipment costs *"Algorithm Comparison RevC (112510).xls"* 46.3% increase in acct C23, 3.3% increase in COE
12		modification	Aries.cpp, DesignPoint.cpp, DesignPoint.h	(173,205,225), (51,1050), 98	L. Carlson	21	complete	Radial build is not given for SiC as it is for DCLL in **"TETRA"** format. Need to include in readout.
13	12/8/10	modification	CostingAccount.cpp	all	L. Waganer	21	complete	**All** costing algorithms updated per *"Algorithm Comparison (Rev C 112510).xls"*
14	1/3/11	modification	Geometry.cpp	2583	L. Carlson	22	complete	Change **TF current table (Jsc)** into a polynomial for better fitting. Prior version just used the nearest entry in the table.
15	11/23/10	error correction	DesignPoint.cpp, CostingAccount.cpp	1239, (349, 409)	L. Carlson	21	complete	**Bucking cylinder** was too costly ($500M). The cost was redundantly multiplied by 16 in CA.cpp. Other costs fixed as well.
19	12/13/10	error correction	DesignPoint.cpp	258, 301, 488, 491, 558, 559	L. El-Guebaly	21	complete	**f_geo_div.** This over-estimates power flow into the divertor. Better estimate is theta/pi (look angle). Laila: P_neutron divides 10% div, 25% IB, 65% OB. Changed f_geo_div to f_div (0.1) and (1-f_geo_div) to f_blanket_ob + ib
21	1/10/11	error correction	DesignPoint.cpp	220-245	L. Carlson, C. Kessel	21	complete	**Plasma surface area** erroneously included divertors so removed them. Changed "A_plasma_facing" to "A_plasma_surface". BEST SA is plasma + **SOL**. This raised NW. appropriately. It also raised f_geo_div (=divSA / A_plasma_facing). So modified f_geo_div = theta/pi (~0.109).
16	12/14/10	modification	DesignPoint.h, DesignPoint.cpp	105, (319-356, 540), 595-606, 820-859	X. Wang, J. Burke, M. Yoda	21	in progress	**Divertor pumping power** polynomials for T-tube, plate, finger div designs. *Uses old P_pump_divertor to get P_thermal needed for new P_pump_divertor. Uses **P_thermal_div (check)** to find pumping power, not P_thermal_total (see other entry.)*
17	1/14/11	modification	DesignPoint.cpp	315-360, 1007	M. Tillack, X. Wang	21	in progress	**FW/blanket pumping power (DCLL)** polynomials. INCLUDES: He + MHD Pb-Li pumping powers all included. See "Tillack - Pumping power DCLL blanket.xls" **NEED** SiC (Mark getting)
18		modification	Part.cpp	791	L. Waganer	21	in progress	Update this material properties table with new **fabrication costs** per *"Fabrication costs per kg RevM 112520 10.xls"* **MORE** coming from Les. Some 10x off, others don't utilize Les' available detailed costing.
20	1/22/11	error correction					in progress	**P_thermal total (FWBS+div)** was used for calculating blanket and div pumping power. Changed so that P_pump_div uses ONLY P_thermal_div.
22	11/29/10	modification	DesignPoint.cpp	449, 584	M. Tillack, N. Morely	21	pending	**LM MHD pumping powers**, see "LMpowers, Tillack, Morely.ppt" **IMPLEMENT.** Thermal recovery of LM.
23		modification	DesignPoint.cpp	630	L. Carlson, M. Tillack	21	pending	**Thermal heat recovery:** Add difference between He-pump (90% efficient) and LM pump (40%, but can recover thermal heat)
24		modification	DesignPoint.cpp	892, 1544, 1737	L. Carlson	21	pending	**data_point_filter** - what does it do???
25		modification			L. El-Guebaly	22	pending	Waiting for list of ideal **output formatting from Laila.** LW: It would be useful to have all the **independent variables in the costing algorithms** printed out so we have a way to double check the results.
26		modification	throughout all modules		L. Carlson	22	pending	Would like to make the number of **TF coils an input variable** that can be changed. Right now it is hardwired as 16 everywhere and difficult to track (costing, volumes, surface areas, etc.)
27		modification	DesignPoint.cpp	154	L. Carlson	22	pending	**Pumping efficiency** needs distinction between He pump and LM pump. Right now 90% for both from input file.
28		modification	CostingAccount.cpp	675	L. Carlson	22	pending	Work on account **22.05 primary support structure.** The costing is zero.
		modification	DesignPoint.cpp, Geometry.cpp	1393, 1833	L. Carlson	22	pending	Figure out **vacuum vessel volume.** VVMain.data exactly = VVOutboard.data in Matlab, yet volumes for the two are different in sysout.data. Where is the seam?

Lock code revision here as #21. all updates afterwards will be #22 and tracked with SVN

Revision control is necessary and helpful

- Must track and control revisions to the code.
- Subversion (SVN) software maintains the code centralized in a server repository.



The database chronicle contains important details

- What input parameters were scanned?
- What version of the systems code was used? Any changes? Version #
- What blanket/divertor were implemented?
- What were the assumptions applied in the code?
- What filters were implemented? (Pnetel, Qdiv, B, etc.)
- What costing algorithms were used, year$, material properties ?

> ⇒ ***Every result/picture/graph must be traceable and backed up with specifics of its origin***

Database Chronicle

Log #	Date	Blanket	# points	Pysics output file size (MB)	Output file after eng module (MB)	Output file file name (named by # data pts)	Input files inpar	Input files inpar2	Plasma physics folder	Engineering filters applied	Systems code rev	VASST Rev #	Notes1
1	20100407	SiC	282,866	178	311	SysoutFinalsic282.data	&inpar	&inpar2	inpar06	apply as needed,	21	0	
2	20100407	DCLL	282,866	178	314	SysoutFinaldcll282.data	&inpar	&inpar2	inpar07	apply as needed,	21	0	
3	20100412	SiC	810,303	510	897	SysoutFinalsic810.data	&inpar	&inpar2	inpar05	apply as needed,	21	0	
4	20100412	DCLL	810,303	510	900	SysoutFinaldcll810.data	&inpar	&inpar2	inpar05	apply as needed,	21	0	
5	20100528	SiC	60,412	38	49	SysoutFinalsic60.data	&inpar	&inpar2	inpar08	usually: Bt 6-18,	22	1	*Took 282k inp*
6	20100528	DCLL	60,412	38	49	SysoutFinaldcll60.data	&inpar	&inpar2	inpar08	usually: Bt 6-18,	22	1	"
7	20100614	SiC	1,136,792	-	763 (122 .m	SysoutFinaldsiccombined.d	-	-	database0	Bt 6-18, deviatior	-	-	*Combined dat*
8	20100614	DCLL				SysoutFinaldcllcombined.da	-	-			-	-	"
9	20100614	SiC	280,444	176	309	SysoutFinalsic280.data	"	&inpar2	inpar09	Bt 6-18, deviatior	22	1	*After C.K. cor*
10	20100616	SiC	20,466	12.9	22.8	SysoutFinalsic20.data	"	&inpar2	inpar10	Bt 6-18, deviatior	22	1	
11	20100616	SiC	16,473	10.4	18.5	SysoutFinalsic16.data	"	&inpar2	inpar11	Bt 6-18, deviatior	22	1	
12	20100616	SiC	252,803	159	283	SysoutFinalsic252.data	"	&inpar2	inpar12	Bt 6-18, deviatior	22	1	
13	20100616	SiC	18,255	11.5	20.5	SysoutFinalsic18.data	"	&inpar2	inpar13	Bt 6-18, deviatior	22	1	
14	20100621	SiC	1.7M			SysoutFinaldsiccombined2.	-	-	database0	Bt 6-18, deviatior	-	2	*Combined dat*
15	20100701	SiC	280,444	176		SysoutFinalsic280magx3.da	"	&inpar2	inpar09	Bt 6-18, deviatior	22	1	*Reduced mag*

Summary

- ✓ New VASST visualization tool provides visual interaction with systems code database and gains insight into design tradeoffs.
- ✓ Utilized VASST to help define preliminary strawmen for ARIES Physics & Technology Assessment.
- ✓ Continuing chronicle and documentation of systems code
- ✓ Thicken database to encompass 4-corners design space to issue refined strawmen for detailed design.