New Small Wheel Low-Voltage Power: Design Review

Jon Ameel[a], Dan Amidei[a], Karishma Sekhon Edgar[a], **Ryan Edgar**[a], Yunjie Yang[a], Paolo Cova[b,f], Nicola Delmonte[b,f], Agostino Lanza[b], Stefania Baccaro[c], Salvatore Fiore[c], Mauro Citterio[d], Stefano Latorre[d], Massimo Lazzaroni[d,e]

[a]University of Michigan, Ann Arbor

[b]Istituto Nazionale di Fisica Nucleare di Pavia

[c] ENEA and INFN Sez di Roma

[d]Istituto Nazionale di Fisica Nucleare di Milano

[e]Università degli Studi di Milano

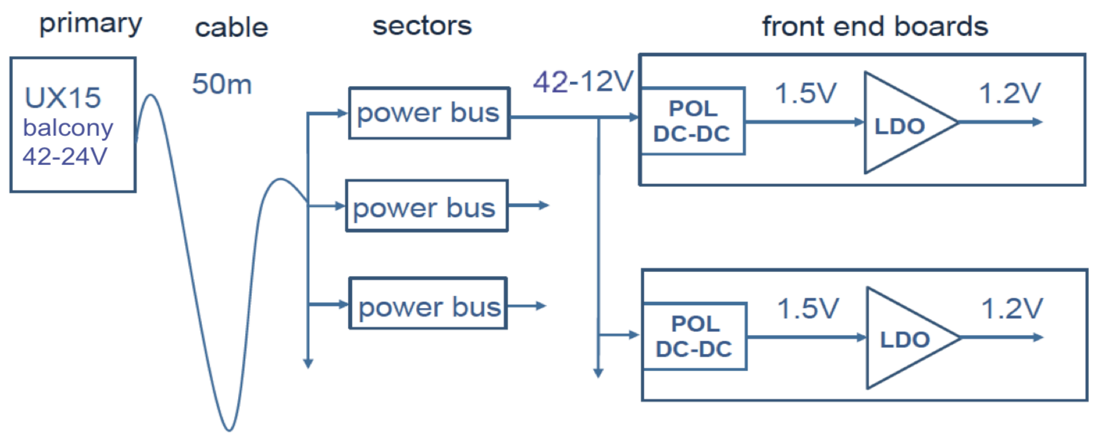
[f]Università degli Studi di Parma

Feb 9-10 2015 at CERN

Problem

- The NSW has
  - 2.5 M channels over 7400 FE boards
  - total system power 51KW, mostly at 1.2V

Proposal (TDR)



- Point-of-Load conversion
  - Phase II trk main option
- Transmit at 42-24V
- DCDC devices and linear regulators on FE boards
- Identify devices and propose design satisfying constraints on
  - environment: radiation + B field
  - space, cooling
  - noise
  - cost

Power Count

- assume efficiencies 80% DCDC, 80% LDO
- transmission efficiency = 64%*

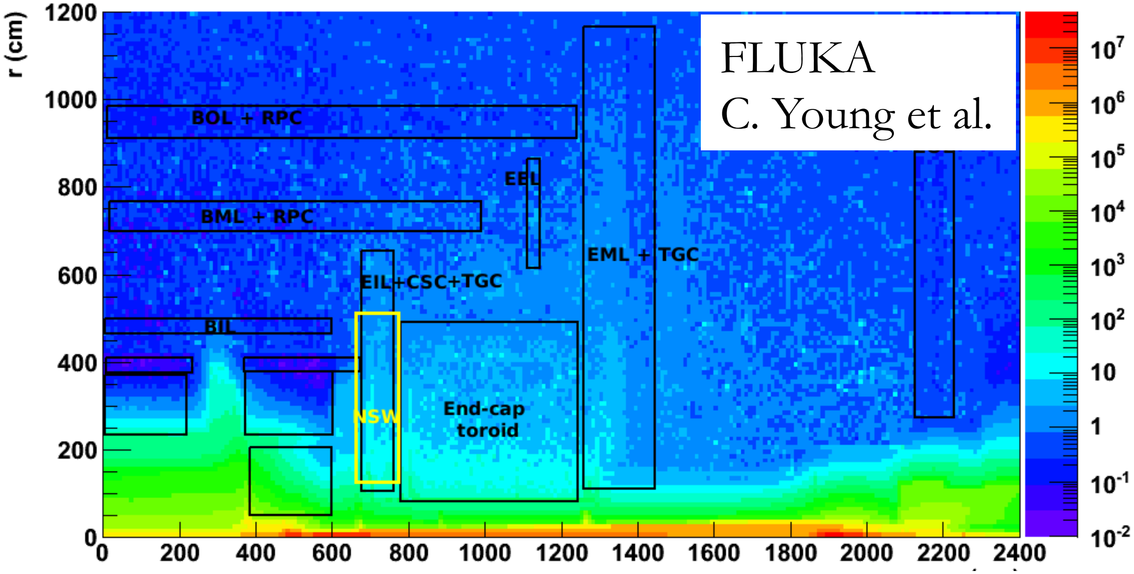
Per-Chip Supply Requirements

Part	Power (Watts)	Current at Voltage 1.2 V	1.5 V	2.5 V
VMM	0.840	0.700		
RO ASIC	0.630		0.420	
TDS ASIC	1.000	0.500		0.100
ART ASIC	0.500	0.417		
SCA	0.250		0.167	
GBTX	2.200		1.467	
GBTIA	0.250			0.100
GBTLD	0.325			0.130

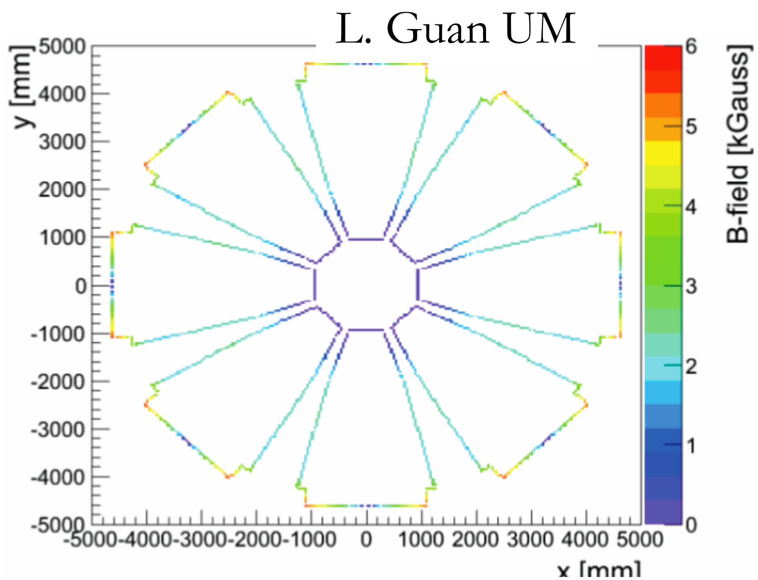
New Small Wheel Power Requirements

Device	Number of Devices	Power* (Watts)
MM		
MMFE	4096	11.88
ADDC	512	9.45
L1DDC	512	4.34
Total Power		**55700**
sTGC		
Strip (5 VMM)	128	11.47
Strip (6 VMM)	384	12.78
Strip (7 VMM)	256	15.08
Pad+Wire (2 VMM)	512	7.86
Pad+Wire (3 VMM)	256	5.56
L1DDC	512	4.34
Router	256	25.00
Pad Trigger	32	15.63
Total Power		**23716**

Environmental Constraints



Gy/year



large sector |B|; z =7.9m

Magnetic and Radiation Tolerance Criteria for COTS parts

		Inner Rim ($R = 1$ m)	Outer Rim ($R = 5$ m)
TID	(γ)	1740 Gy	84 Gy
NIEL	(fast neutrons)	2.1×10^{14} n/cm^2	7.1×10^{12} n/cm^2
SEE[1]	(protons)	4.3×10^{13} p/cm^2	1.4×10^{12} p/cm^2
B field		$\leq$1 kG	5 kG

[1] Simulated number of hadrons with $E > 20$ MeV

- 10 yr x 5E34 x ATLAS SF (COTS 3, NIEL 5, SEE 10)
- dose may increase 30-50% w/ new shielding design

DCDC options

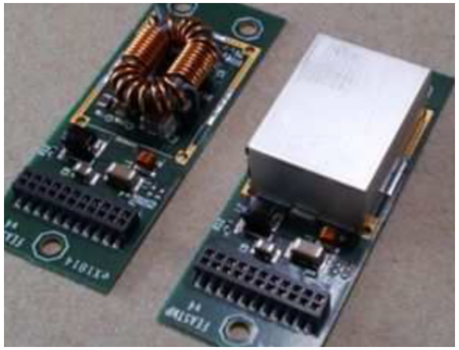
COTS

- Good
  - Inexpensive
  - small
  - optimized
  - 42V in, 8A out
- Issues
  - rad qualify
  - magnetics qualify
  - noise

CERN FEAST

- Good
  - rad hard 200Mrad
  - B tolerant
  - low noise
  - community
    - CMS: HCAL, Phase I pixels
- Issues
  - size: 44 l x 17 w x 9.4 h (CLP)
  - 10-12V input
  - cooling thru board !
  - < 4A
  - cost

FEASTMP CLP

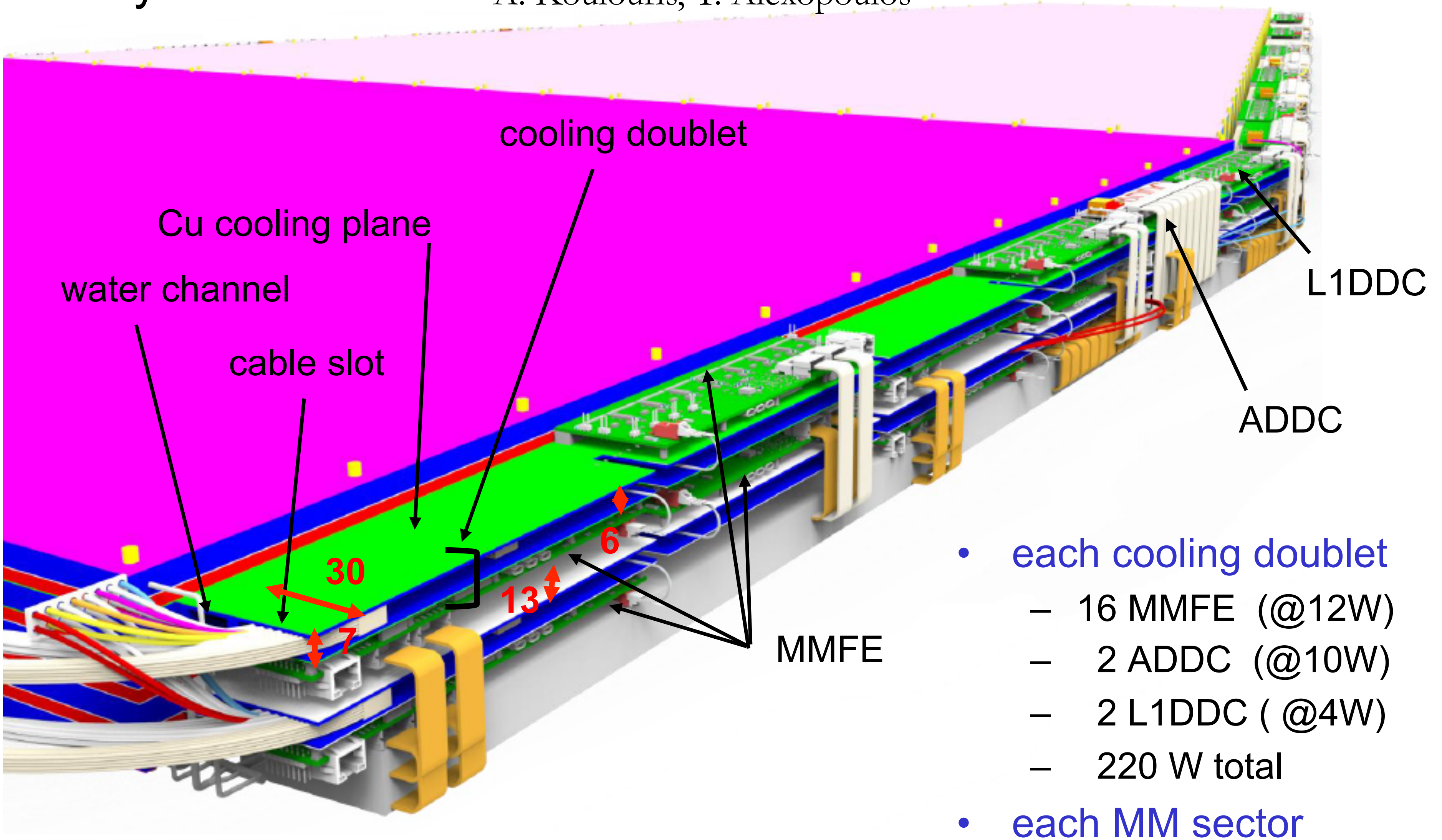


VR options

- COTS device
- Rad hard ST LDO: $16, min V_{out} = 1.25V, dropout @ 3A =1.5 V
- Rad hard TI: large footprint, price under discussion ($20)
- No VR

MM layout

A. Koulouris, T. Alexopoulos



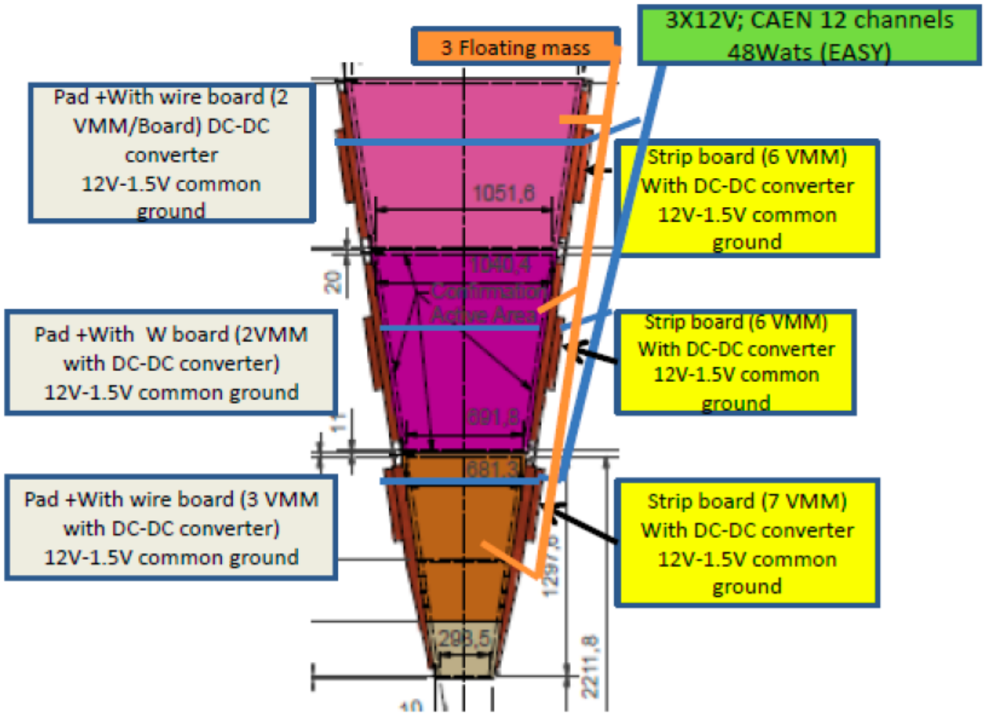
- each cooling doublet
  – 16 MMFE (@12W)
  – 2 ADDC (@10W)
  – 2 L1DDC (@4W)
  – 220 W total
- each MM sector
  – 4 doublets x 2 sides

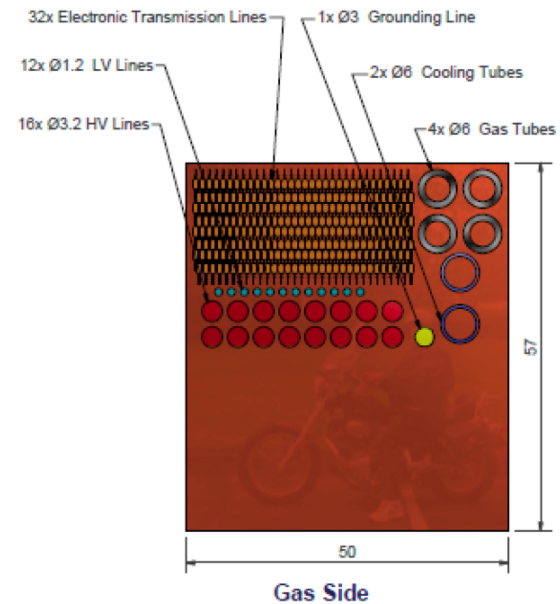
STGC layout

G. Mikenberg

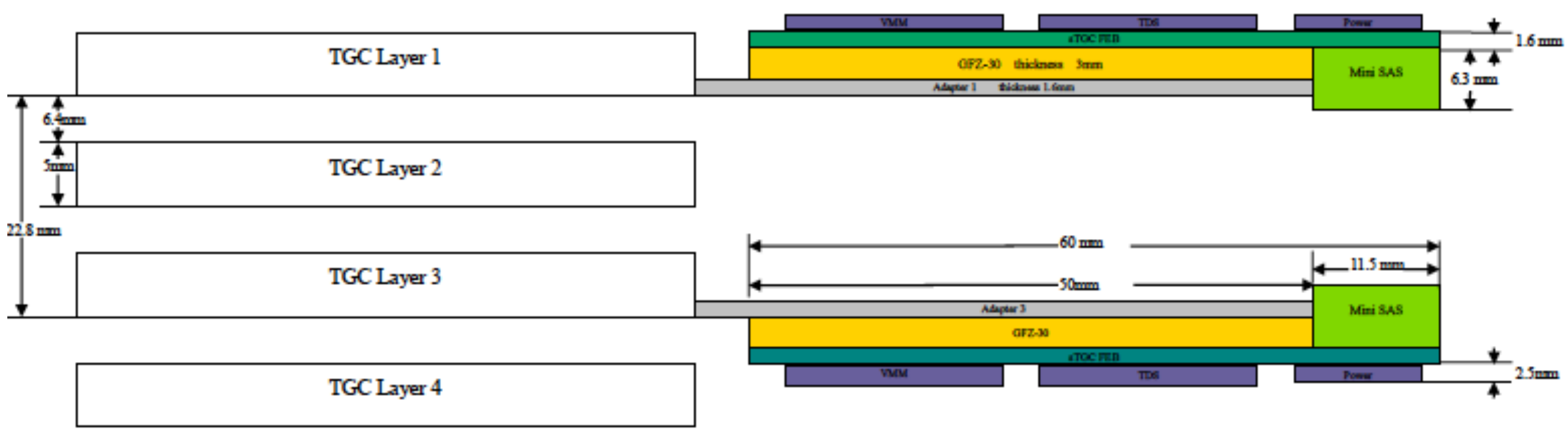
- already spec'ed for 12V inputs

12V cables fit in channel



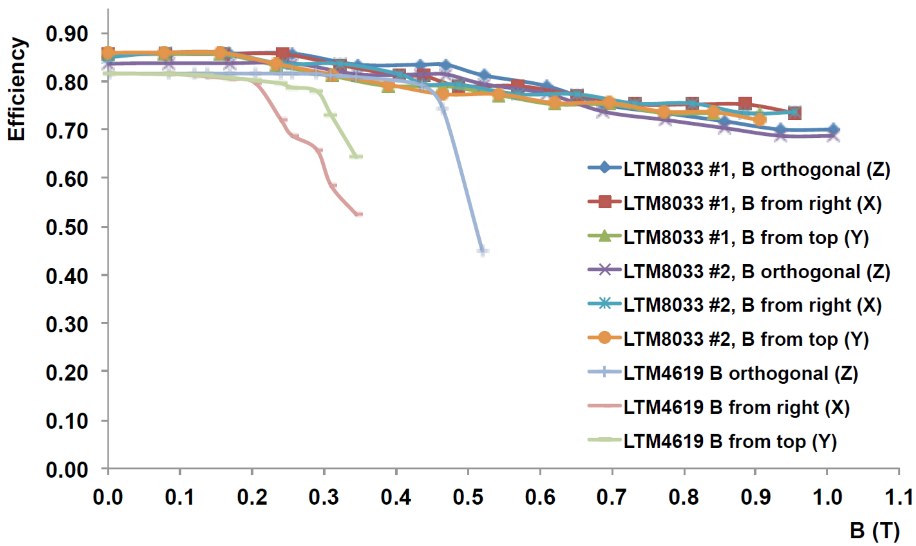


- DCDC location?

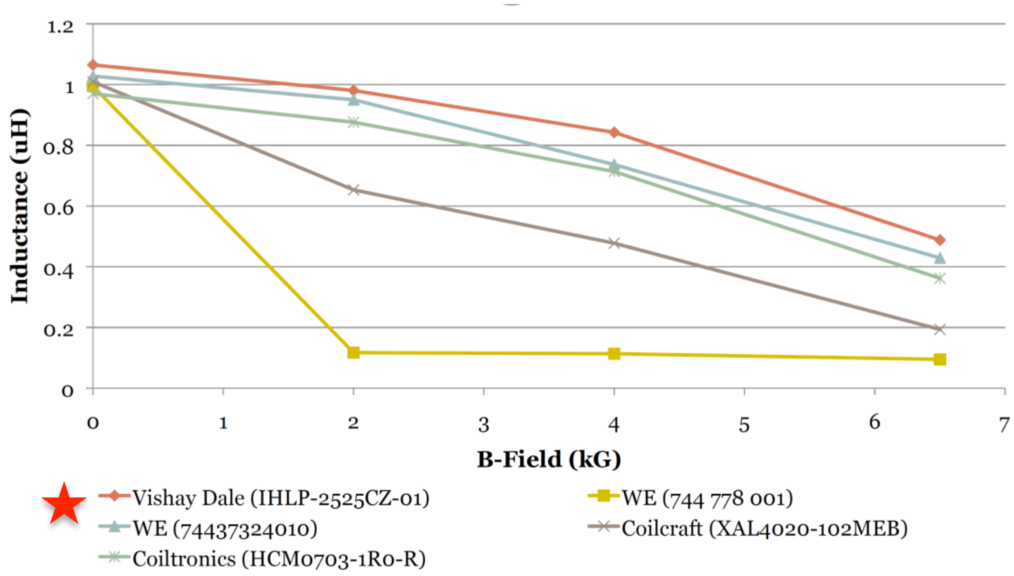


COTS Magnetics

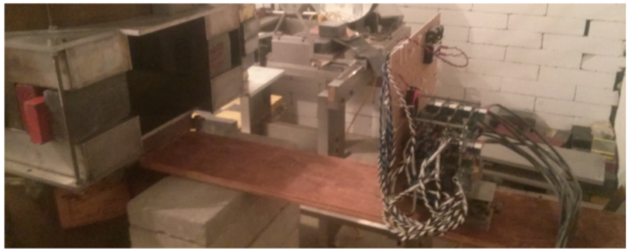
- COTS DC- DC vs orientation in large bore magnet at LASA (INFN)



- COTS inductors at UM
- NdFeB bench magnet
- 6.5kG with small gap
- tested 63 power inductors, chokes/beads

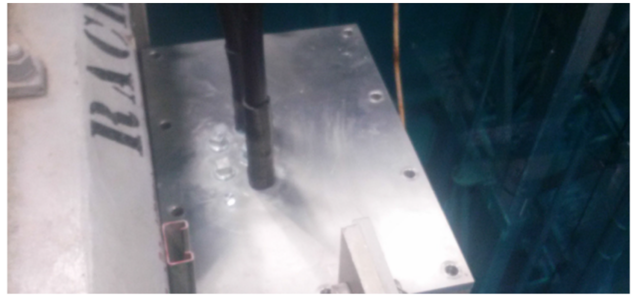


COTS radiation testing

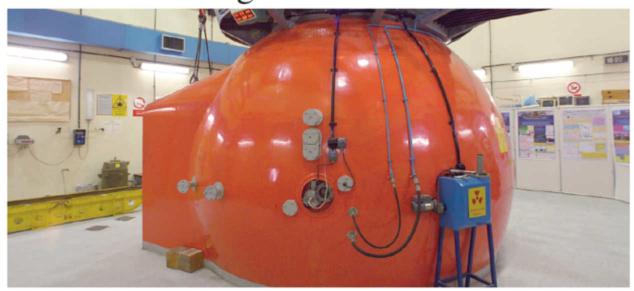


TID Testing at BNL SSIF

The Calliope ^{60}Co facility



NIEL Testing at UMass Lowell FNI



The TAPIRO reactor.

SE Testing at CDH Proton Center.

Facilities			
TID	^{60}Co γ	Brookhaven SSIF	4×10^{13} Bq
		ENEA Calliope	3×10^{15} Bq
NIEL	Reactor fast neutrons	UMass Lowell FNI	1 MW open-pool; submerged chamber
		ENEA-Casaccia TAPIRO	5 kW; dry irradiation channels
SEE	Protons	CDH Proton Center	220 MeV cyclotron
B		INFN LASA	10 kG electromagnet
		UMich	6.5 kG benchtop NdFeB

- devices tested under power
- 30 kHz monitor, 1 MHz triggerable window

COTS radiation results

Test Conditions

Buck Converters		
V_{in}	=	12 V/24 V (as appropriate)
V_{out}	=	1.5 V @ 1.6 A
Resistive loading of outputs		
Monitor V_{in} , V_{out} , I_{in}		
Regulators		
V_{in}	=	1.5 V
V_{out}	=	1.2 V @ 1.6 A
Powered *in situ* by LT8610/LT8612		

Monitor V_{in} , V_{out} , I_{in}

Test Notes

	Part	Limiting Tolerance	
	Candidate Buck Converters		
★	LTM4619	B	3 kG
		SEE	destructive
	LT8610	I_{out}	2 A
★	LT8612	SEE	$\sigma_S E = 6.8 \times 10^{-10}\ \text{cm}^{-2}$
	LTM4628	B	3 kG
	LTM8033	NIEL	$10^{13}\ \text{n/cm}^2$
	LTC3608	NIEL	$10^{13}\ \text{n/cm}^2$
	ADP5052	TID	750 Gy
	ADP1864	TID	630 Gy
	TPS53319	TID	260 Gy
	ST1S41	TID	240 Gy
	Candidate Low-Dropout Regulators		
	LT3080	NIEL	$5 \times 10^{13}\ \text{n/cm}^2$
	ADP1755	SEE	
★	MAX8556	viable?	
	TPS74201	engineering (V_{bias})	

Neutron dosages in 1 MeV (Si) equivalent.

COTS: SEE studies w/ protons

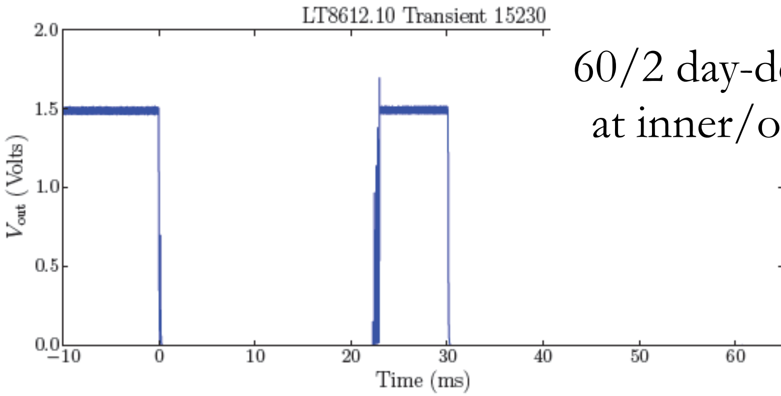
20- 220 MeV protons

Device	Proton Energy (MeV)	Cross-Section 10^{-12}cm^{-2}	Notes
ADP1755	220	277 ± 8	Short transients
	220	83 ± 4	Long transients
MAX8556	≥ 40[1]	71 ± 4	Short transients
	≥ 40[1]	0.50 ± 0.35	Long oscillations[3]
LTM4619	220	6[2]	Destructive
LT8612	220	680 ± 50	Multi-millisecond drops
MAX8556	220	2 ± 1	Long oscillations[3]
MAX8556	220	83 ± 8	Short transients
MAX8556	170	64 ± 9	Short transients
MAX8556	120	76 ± 9	Short transients
MAX8556	70	58 ± 10	Short transients
MAX8556	40	58 ± 10	Short transients
MAX8556	20	13 ± 3	Short transients

[1] Combined result from individual measurements in the second part of the table.
[2] One event; no error is assigned.
[3] These were observed only at 220 MeV, and not in lower-energy exposures.

SEE events in devices of interest

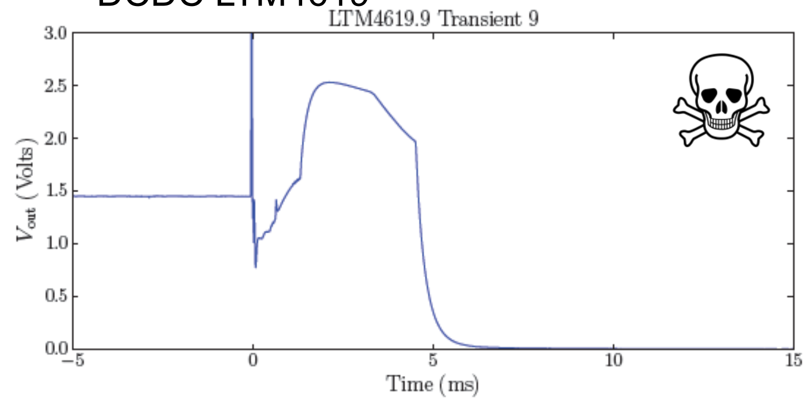
DCDC LT8612



60/2 day-device at inner/outer

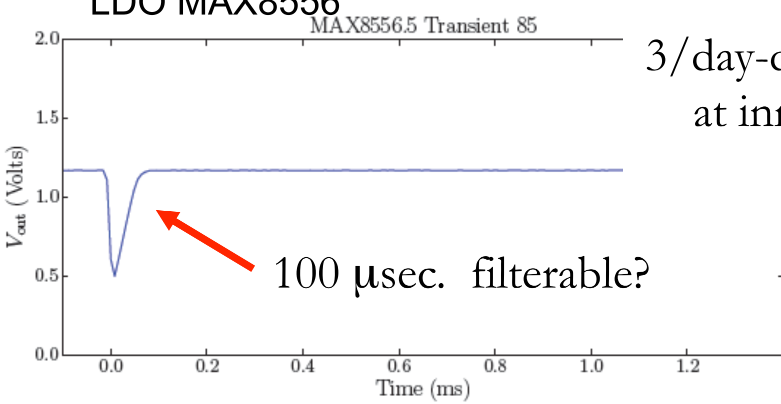
(a)

DCDC LTM4619



(b)

LDO MAX8556

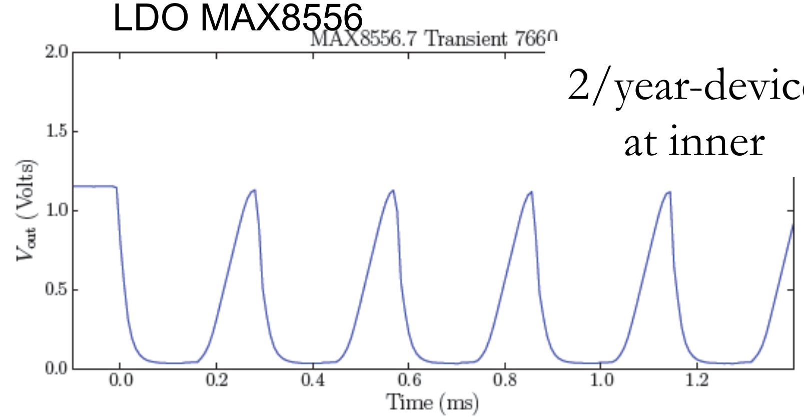


3/day-device at inner

100 µsec. filterable?

(c)

LDO MAX8556



2/year-device at inner

(d)

Rates use FLUKA hadrons flux > 20MeV

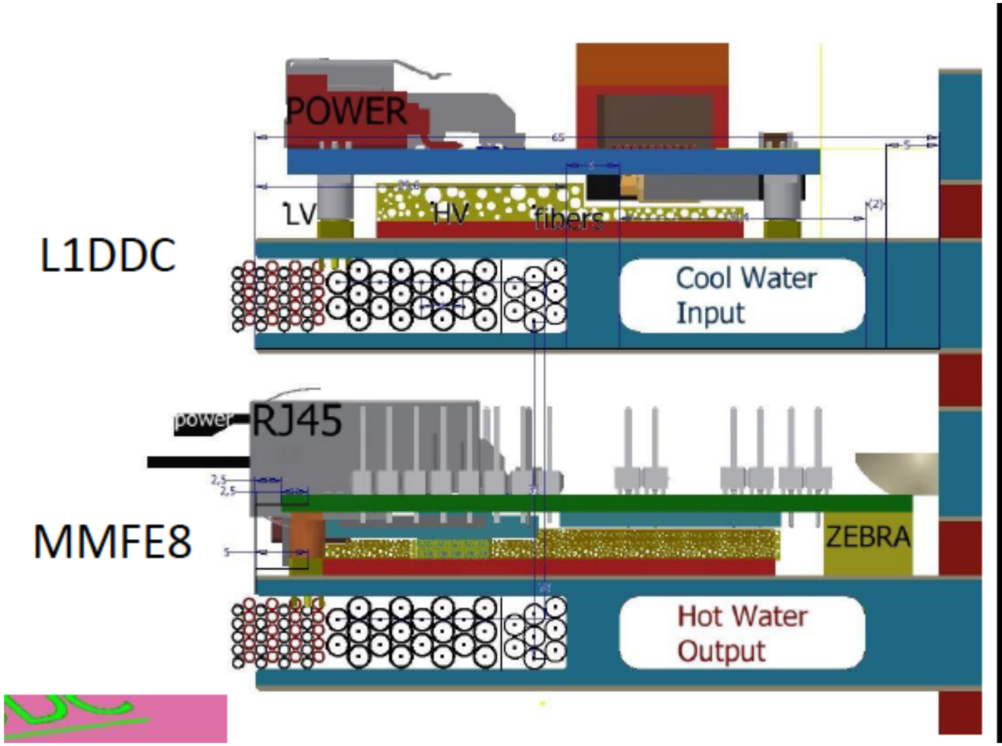
measured σ

SF = 10

Cables for 12V transmission from rim, in cooling slot

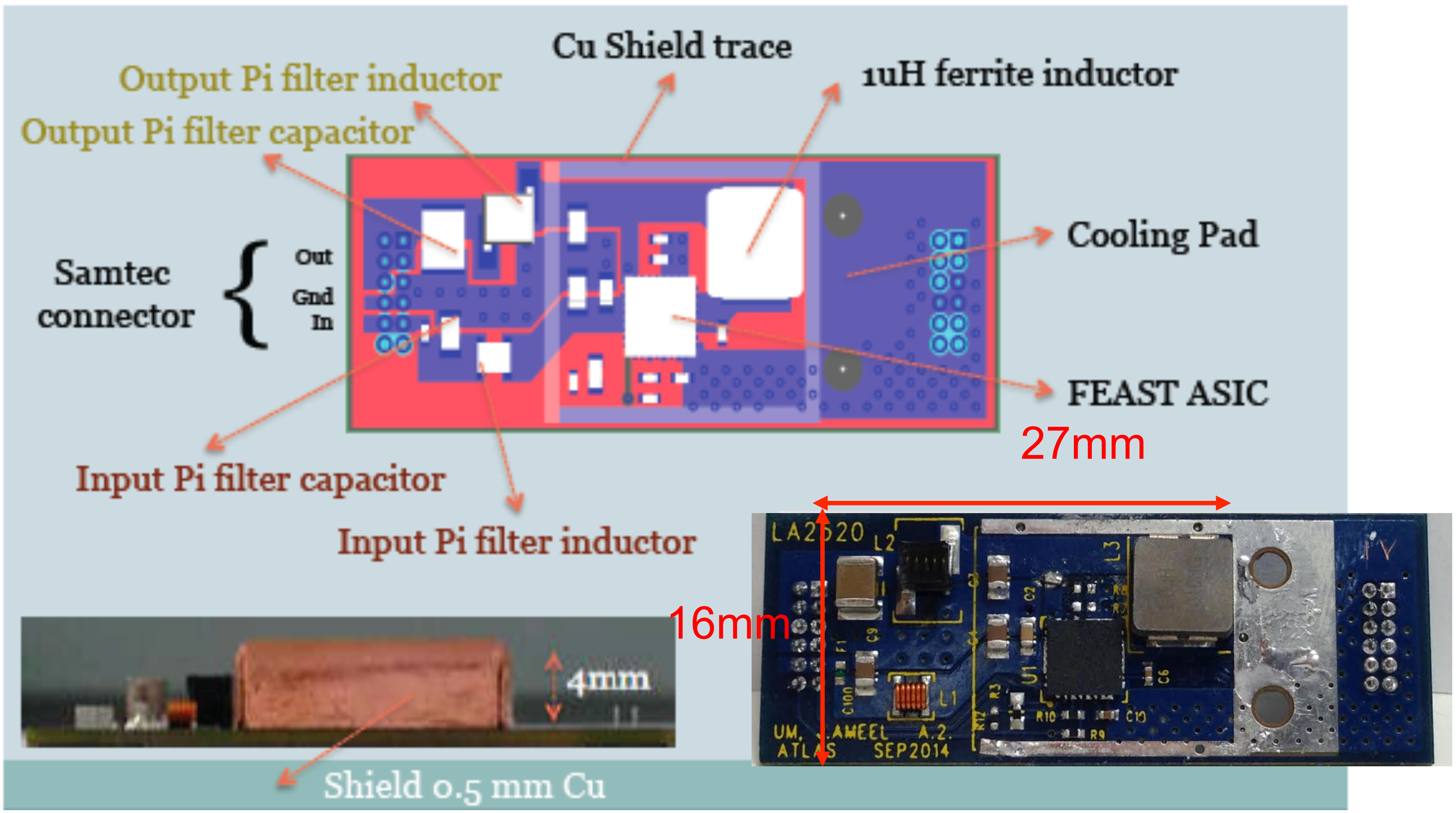
- MM model:
  - each cooling doublet = 16MMFE+2ADDC+2L1DDC
  - star topology: power and return = 40 cables.
- MMFE 11.9W ➔ 1.0A @ 12V
  - use 22AWG
- it fits

Star Power Distribution	
Design Power	150 W/layer (conservative)
Cabling	22AWG
Cable Resistance	210 mΩ per 4 m
Loss at 12 V	3.3 W/layer
	840 W/system
Efficiency (Rim to FEB)	$\sim$ 98%
Loss at 24 V	$<$ 1 W/layer
	210 W/system
Efficiency (Rim to FEB)	$\sim$ 99.5%



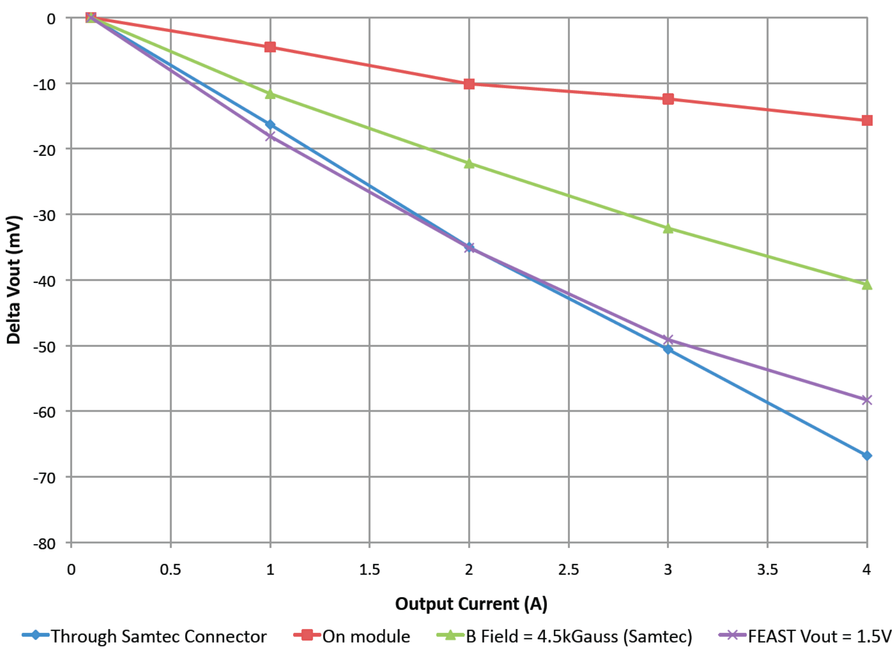
Custom FEAST

- FEAST ASIC + low profile ferrite + filters
- integrate directly on FEB
  - FEAST ASIC: 15Chf. Yield >98% (if omit power flag)
- build module to study layout, noise, cooling

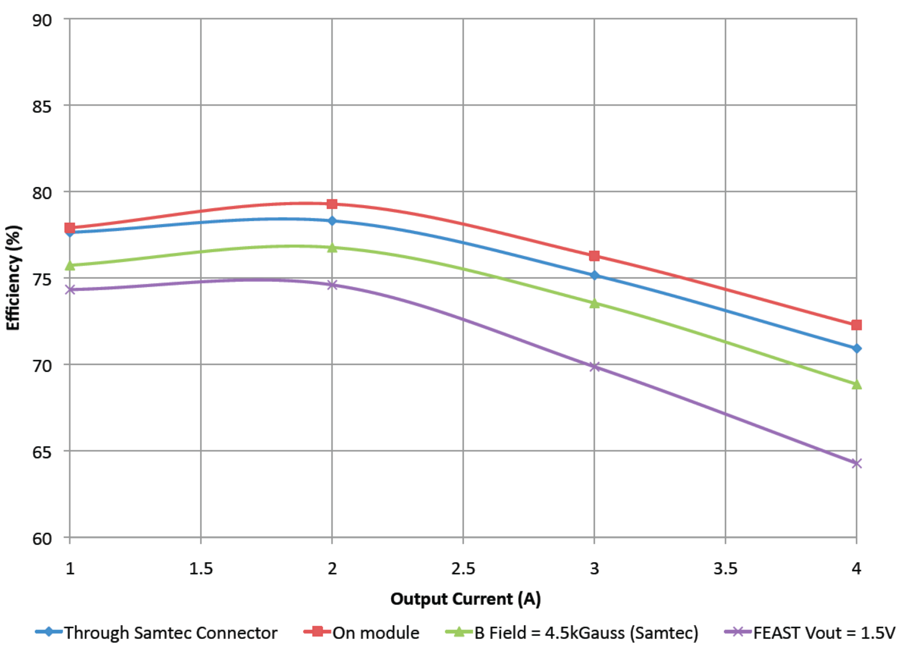


Custom FEAST performance

Regulation



Efficiency



- At 4.5kG slightly better than FEAST MP

Custom FEAST noise

- white noise < 20μV, spectral lines f ~ 1MHz ~ 1μV
- building on original work

C. Fuentes et al. Optimization of DC-DC Converters for Improved Electromagnetic Compatibility With High Energy Physics Front-End Electronics, Nuclear Science, IEEE Transactions on , vol.58, no.4, pp.2024,2031, Aug. 2011 + Ph.D.

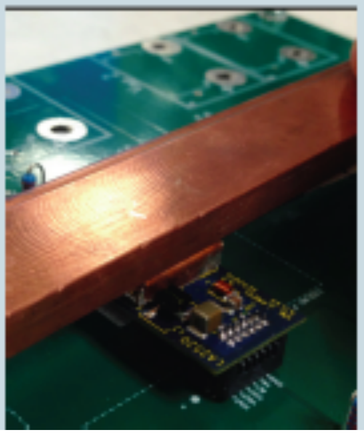
- We so far can get

FFT of input and output.

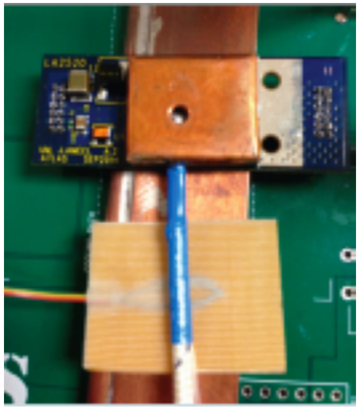
- Important to understand measure on board w/ VMM..

Custom FEAST cooling

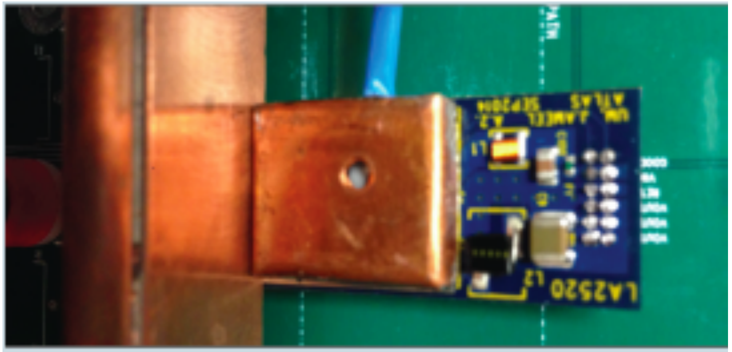
- Test 3 schemes



top (natural)



bottom (as intended)



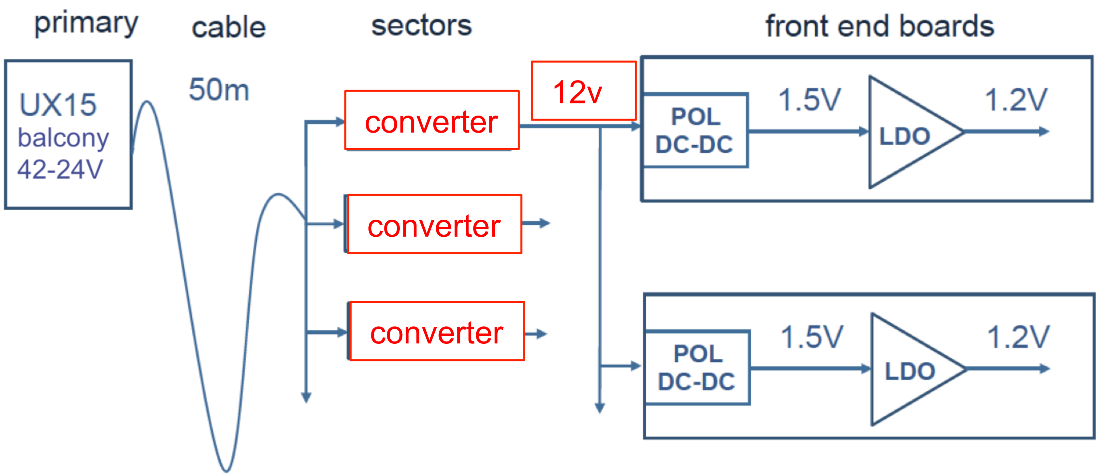
side pad (option?)

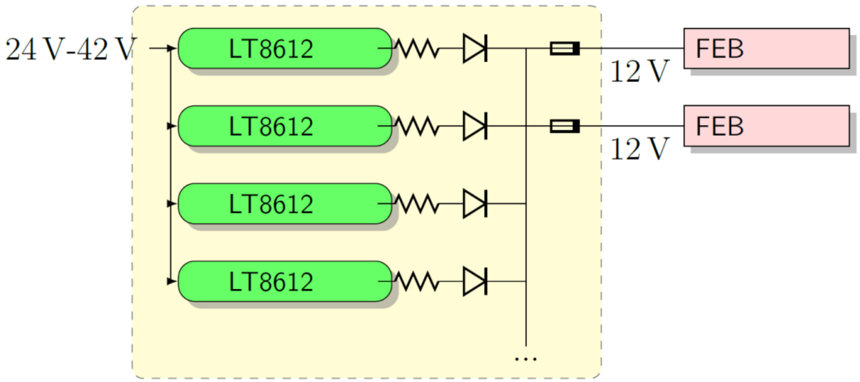
- $R_{thermal}$ in each instance
  - use case T
  - compare to FEAST standard
  - cooling from top, through shield + thermal paste, looks good

Cases	Thermal Resistance (˚C/W)	
	Shield on	Shield on + goo
Under side	7.8	3.9
Through shield	14.4	5.1
Side pad	19.6	10.8
FEAST under	5.3	

- need
  - peg to die T
  - neutron safe paste
  - production ready shield

Intermediate Conversion stage





On Rim

- natural place for fusing, ballast, channel-wise isolation
- per each MM half-doublet
  - 8MMFE,1 ADDC,1 L1DDC
  - 10 connectors, 1A each
  - 10A:12V out
  - 5A: 24V in
  - heat = 12W (at 90% eff)
- isolated converters?
- commercial vs COTS?
- 8612 solution?
  - SEE cross-section 1/day but redundancy

Regulator options

No VR

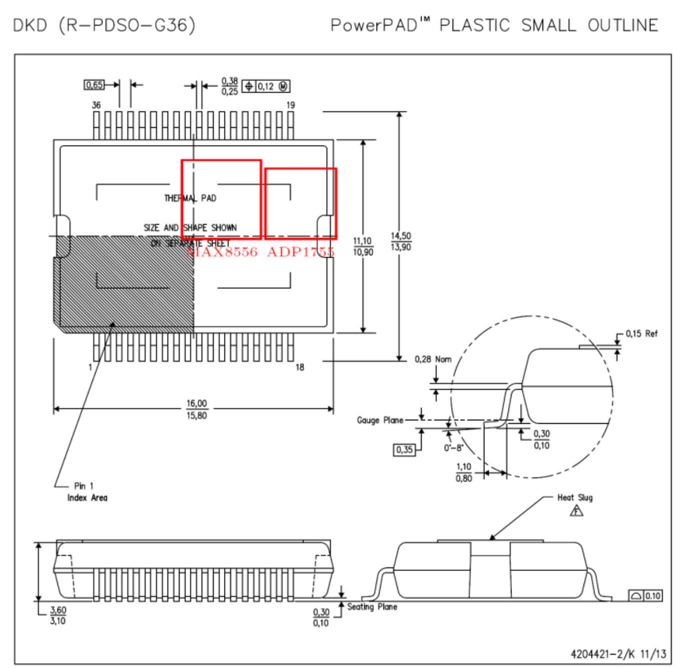
- GOOD
  - CMS Pixel FEAST adds <1% to noise (K. Klein)
- PENDING
  - keep working on FEAST noise levels
  - get noise measurements on FE boards

MAX8556

- GOOD
  - small
  - cheap
  - TID
- PENDING
  - neutrons
  - SEE triple check
  - Do we understand all effects, rates?
  - Lot control

TI Rad Hard

- GOOD
  - TID, SEE
- PENDING
  - NIEL
  - $20. need ~10K
  - 16 x 14 mm

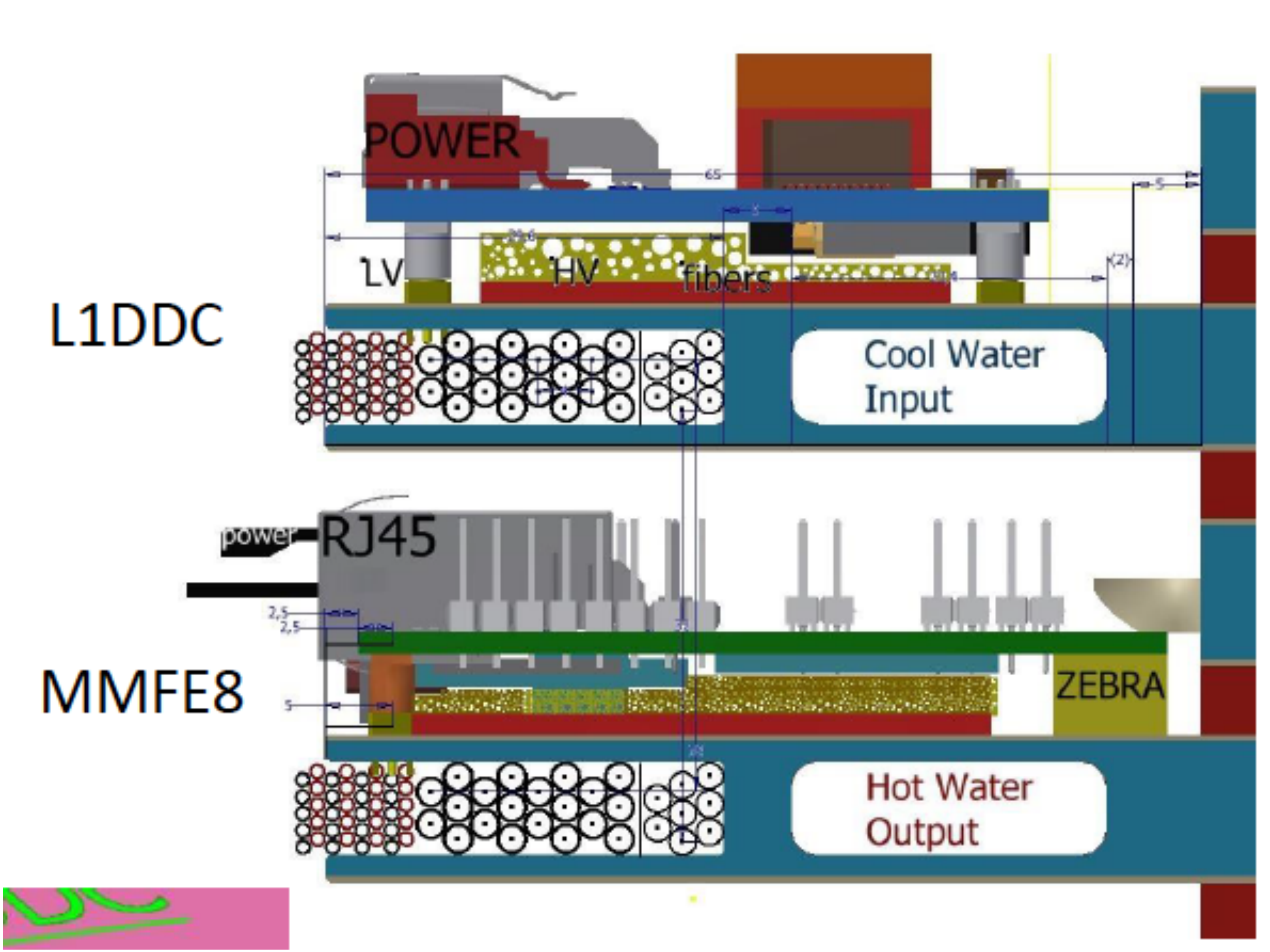


Plan

- use FEAST for DCDC conversion
  - settle remaining implementation issues by summer 2015
    - cooling design
    - mass produced shield
    - improved noise performance
    - rail trimming?
- resolve VR choice by summer
  1. none: test noise on boards
  2. MAX556: rad qualify next level
  3. TI: resolve now
- close loop w/FE boards
  - footprint exercise for FEAST and TI options asap
  - integrate FEAST on Mini-1 to test function and noise
- intermediate stage
  - need it? would 12V from balcony fit? (5.5kA (MM) + 2.kA(sTGC))
  - design. electrical, placement, cooling
- system design

Backup

MM envelope


POWER
LV
HV
fibers
L1DDC
Cool Water Input
power
RJ45
MMFE8
ZEBRA
Hot Water Output

Power Count

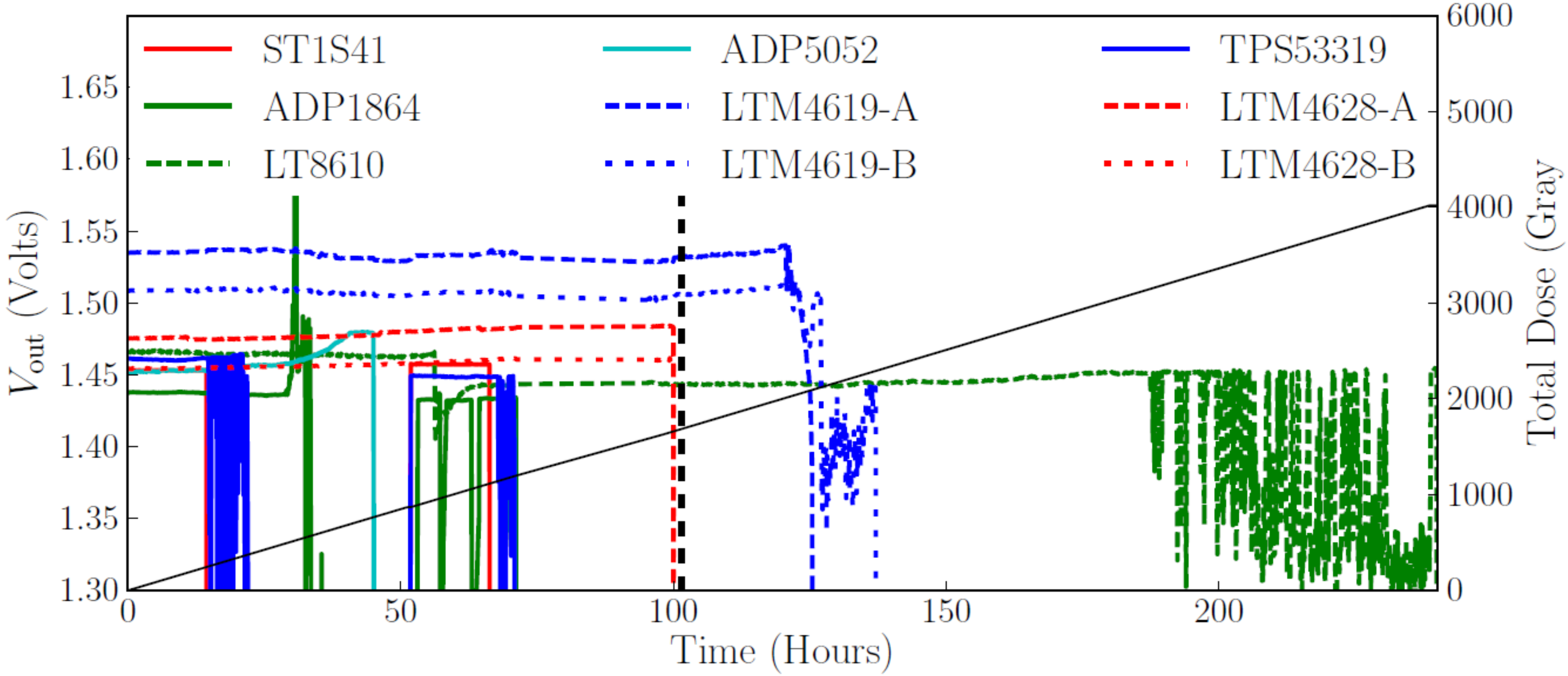
Assumed Board Composition for Power Estimates

Part	Power (Watts)	MMFE	ADDC	L1DDC	Strip	Pad	Router[1]	Pad Trigger
VMM	0.840	8			5-7	2-3		
RO ASIC	0.630	1			1	1		
TDS ASIC	1.000				3-4	1-2		
ART ASIC	0.500		2					
SCA	0.250	1			1	1		
GBTX	2.200		2	1				
GBTIA	0.250			1				
GBTLD	0.325		2	1				
Current at 1.2 V		5.60	0.83	-	3.50	1.40		
					4.90	2.10		
Current at 1.5 V		0.59	2.93	1.47	2.09	1.25		
					2.51	1.67		
Current at 2.5 V		?	0.26	0.23	?	?		
Total Power (Watts)		**7.60**	**6.05**	**2.78**	**7.34 -9.65**	**3.56 -5.03**	**16.00**	**10.00**

[1] Voltage rails for router: 1.0 V (x3), 1.2 V, 1.8 V, 2.5 V, 3.3 V

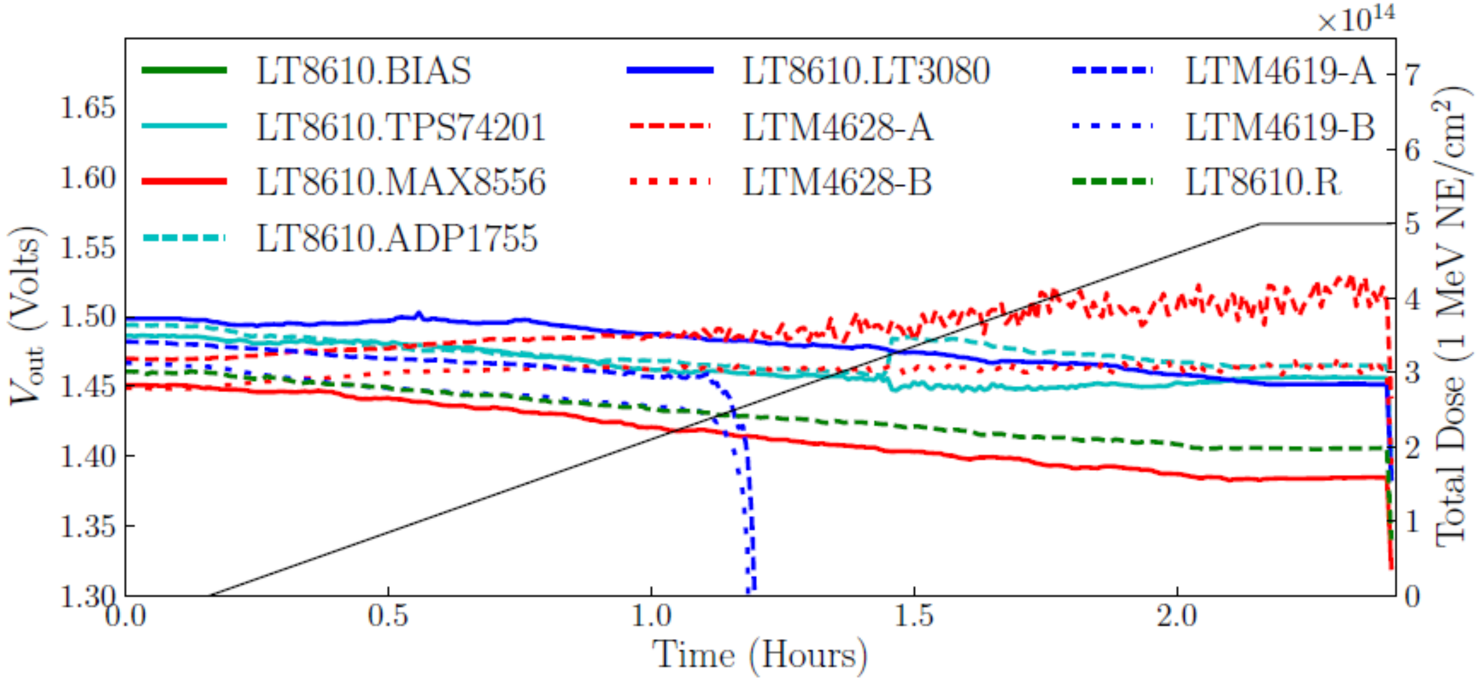
(a)

COTS testing



Output voltage of DC-DC converters.

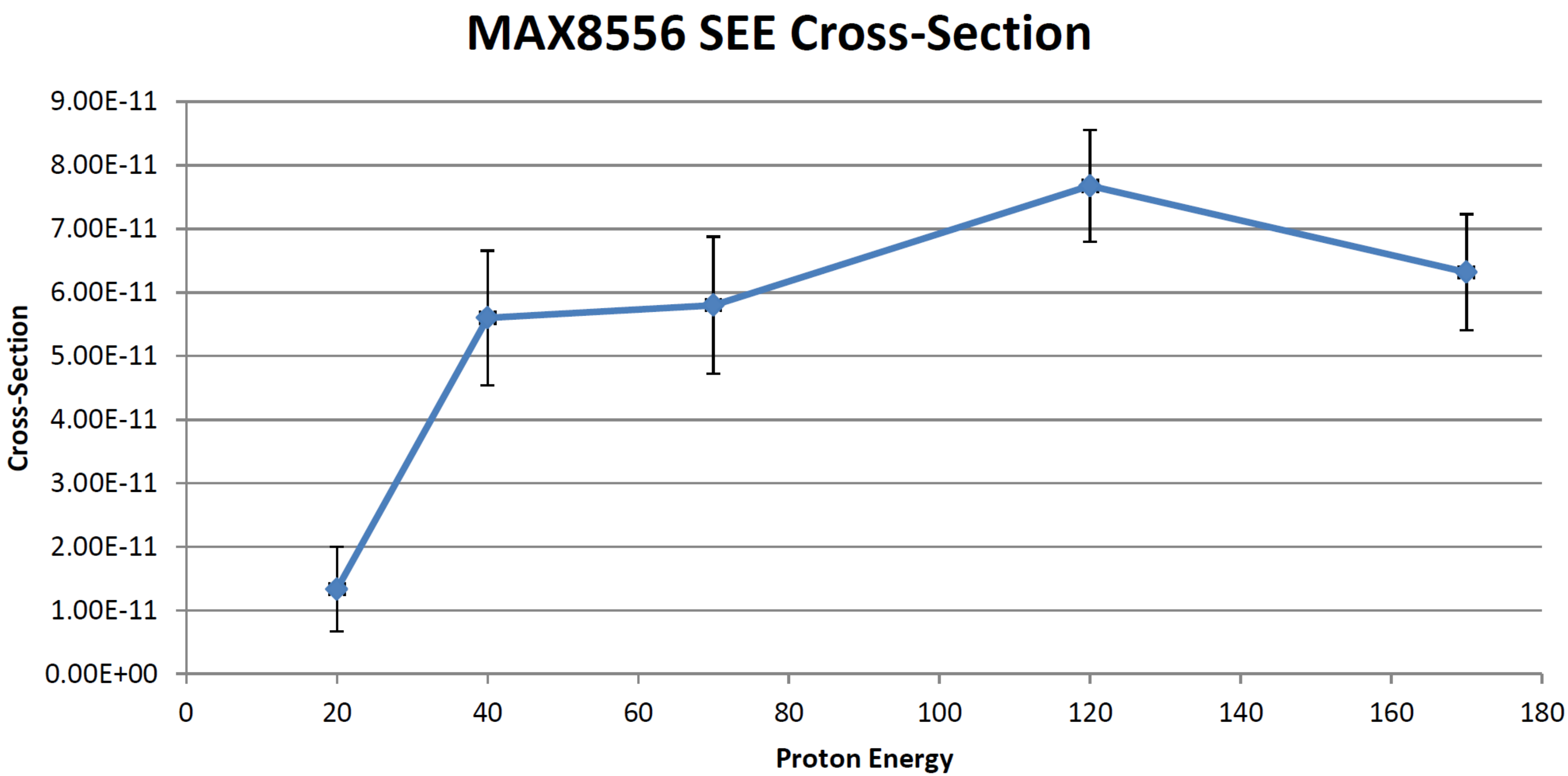
COTS testing



Output voltage of DC-DC converters.

- From 6 May 2014 exposure at FNI.
- Total fluence: 5×10^{14} n/cm^2 1Mev(Si)-equivalent.

COTS testing: SEE



FEAST circuit