

# Powering Schemes for the Strip Trackers

Peter W Phillips  
*STFC Rutherford Appleton Laboratory*  
and ATLAS ITk Strip Community

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# Outline

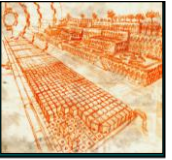
- Proposed CMS Tracker Distribution Scheme
  - Module concept & load
  - Conceptual LV distribution scheme
  - System Test with line drop recovery
- ATLAS ITk Strip LV
  - Strip Module Load
  - Internal Power Distribution
  - External Power Distribution
- Conclusions and Commonality

# Introduction

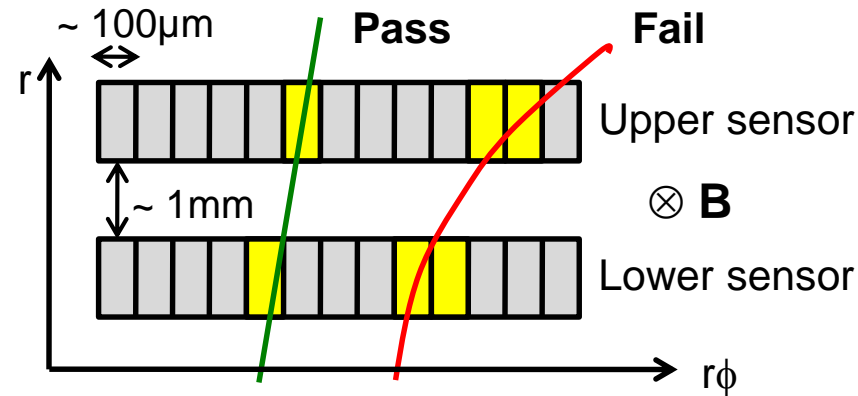
- Both ATLAS and CMS Strip Tracker upgrades foresee the use DC-DC point of load conversion (upFEAST)
  - LV power distributed to a group of modules at  $\sim 11\text{V}$  and converted locally to the required levels
  - Increased system efficiency
  - Reduced cable mass and cost
- Whilst conceptually similar other constraints may come into play. For instance:
  - CMS will use new cables
  - ATLAS ITk are reviewing the possibilities for cable reuse



# CMS $p_T$ Module Concept



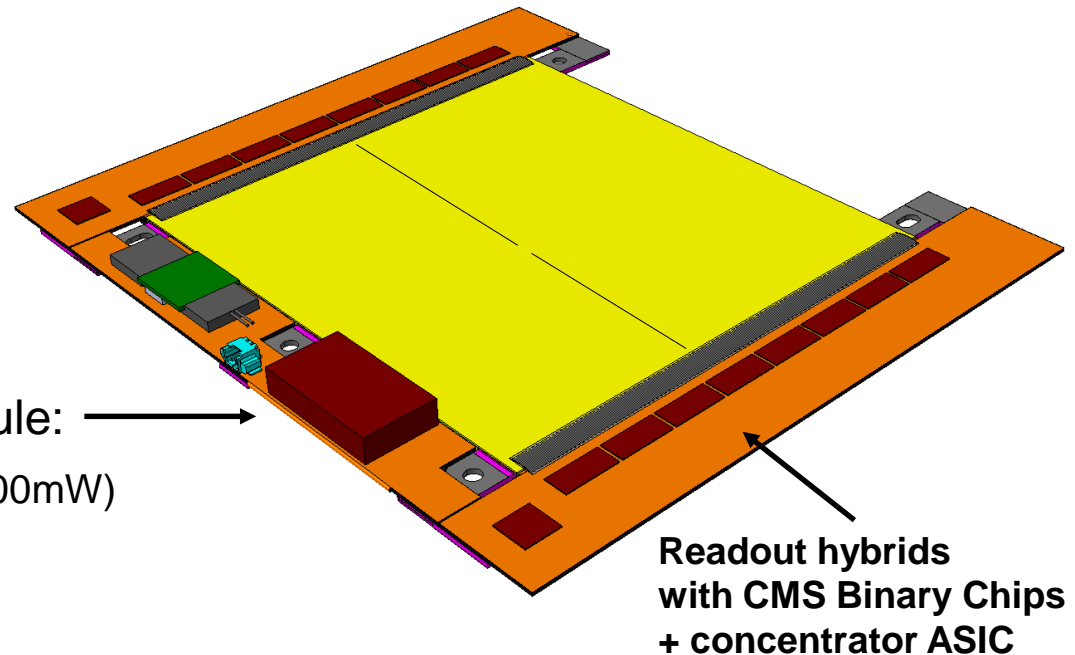
- Tracker contributes to L1 trigger @ 40MHz
- Data reduction by rejection of low  $p_T$  tracks exploiting bending in B field (3.8T)
- Compare hit patterns in closely spaced layers  $\rightarrow$  2-cluster tracklets ("stubs")
- Level 1 tracks with  $p_T > 2$  GeV formed at back-end



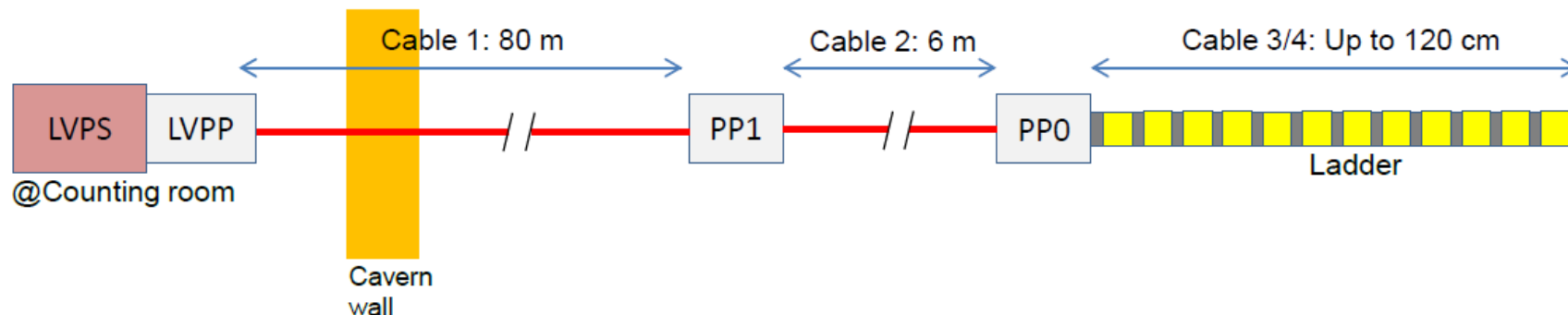
- 2S modules: 2 strip sensors
- PS modules:  
1 strip + 1 macro-pixel sensor

- 2-step DC-DC conversion on module:

- UpFEAST:  $12V \rightarrow 2.5V$  (VTRx+,  $\sim 300mW$ )
- DCDC2S:  $2.5V \rightarrow 1.2V$
- DCDC2S:  $2.5V \rightarrow 1.0V$  }  $\sim 3W$



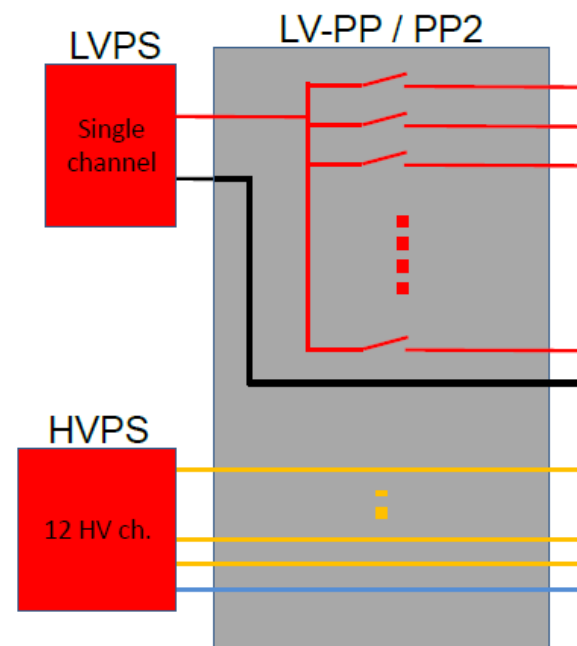
## Conceptual CMS LV distribution scheme



### 3 distinct building blocks can be considered

1. **LVPS**
  - In counting house
  - Output range: 15V max, 15-20A max
  - Relaxed noise/ripple characteristics TBC
  - Regulation mode TBD and tested, no sensing
2. **LVPP**
  - 12 out. channels, max: 15V/2A
  - Minimum control: Imon. and ON/OFF
3. **Cables**
  - Overall max Vdrop: 3V
  - Cross section should fit in existing cable channels
  - Material budget minimized from PP1 onwards

**New cables are foreseen throughout**





- The power chain has been set up with presently available prototypes
  - CAEN A1516B power supply
  - An 86m long cable from the pixel detector
  - The rigid SH prototype with a hand-made shield
  - A 2-CBC2 mini-module with two sensors, read out electrically
- Allows to study module noise with different powering schemes, and dynamic behaviour of power supply



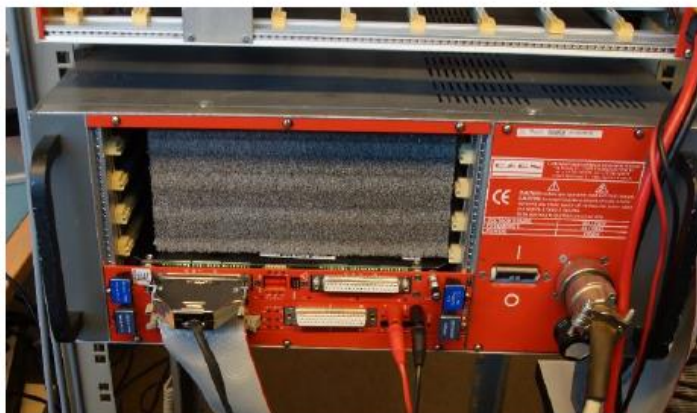




# CAEN A1516B Power Supply



- In the final system sensing should not be used (to reduce # of wires)
- Instead “line drop recovery” to compensate voltage drops on supply cables
  - Needs calibration of each channel, by tuning of a potentiometer
  - Need to connect final cable with a load and measure voltage at load
  - Works then for any load
  - Need mock-ups for cables of all lengths (cannot access load)
- Feature to be tested with A1513B, modified as A1516B (provided by Vincent)
  - 6 channels, each provides 1.5A at up to 15V
- Modularity in final system: 1 ladder (12 modules) per channel,  $I = \sim 8A$

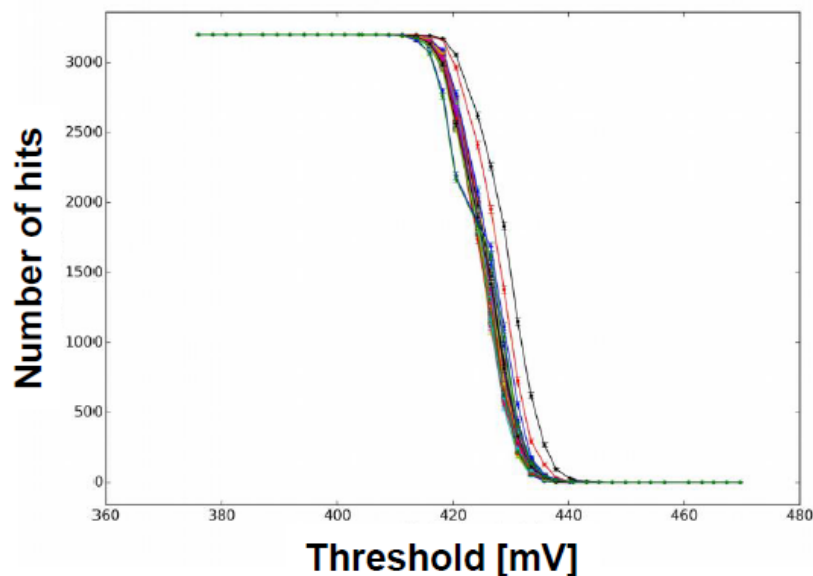


Board is plugged into SYx527 backside



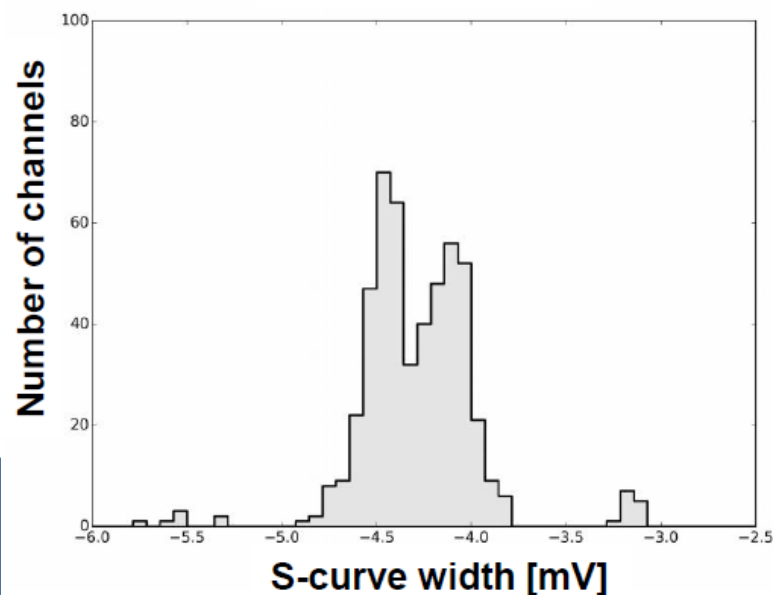
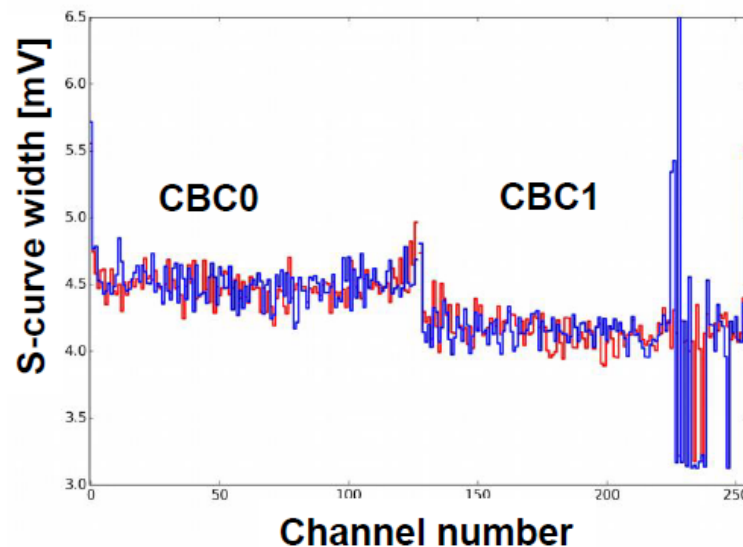


# Module Noise Measurement



- S-curves are taken for each strip (threshold scan with offsets tuned)
- Fit with error function and extract width at 50% occupancy point  
→ strip noise
- Noise of all strips is histogrammed

The line drop recovery scheme clearly works, but its use has not yet been confirmed.







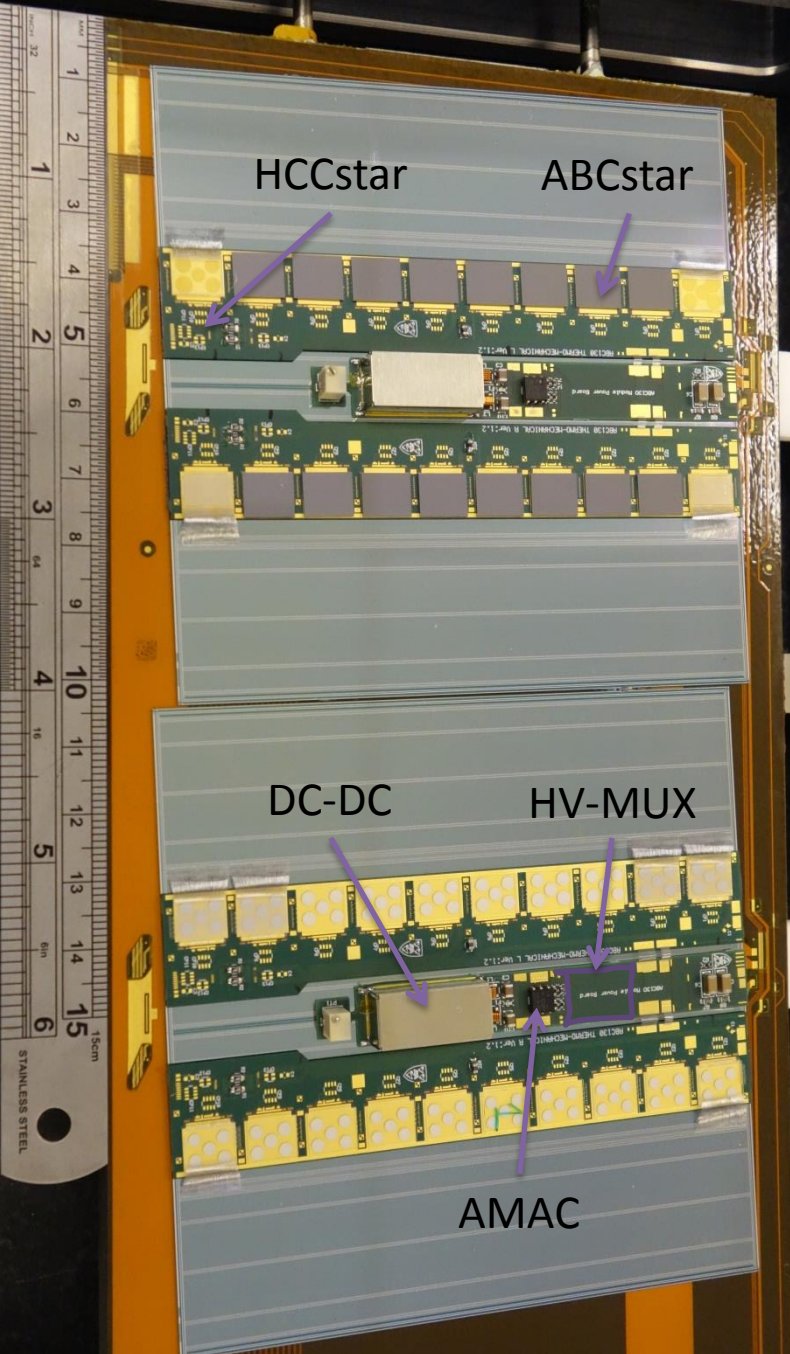
# ITk Short Strip Stave

The image shows two thermo-mechanical modules mounted on a stave. The labels show the final parts at each location. The hybrids are resistive loads but the DC-DC converters which power them are working devices with FEAST2.

Each stave will have 14 modules per side. Each short strip module comprises:

- 1 x Sensor
  - Maximum bias tbc ( $\geq 500V$ )
- 2 x Hybrid
  - 1 x HCCstar Hybrid Controller Chip
  - 10 x ABCstar front end chip
- 1 x Power Board
  - 1 x upFEAST DC-DC converter
  - 1 x High Voltage Switch (HV-MUX)
  - 1 x AMAC Autonomous Monitor And Control ASIC

The Long Strip Stave is similar but with one hybrid per sensor. In the forward region, the same electronics are assembled into several module types to form a petal geometry. All ASICs are in Global Foundries 130nm, so our powering scheme needs to carefully consider TID effects! <sup>9</sup>



Stave with 2 Mechanical Modules

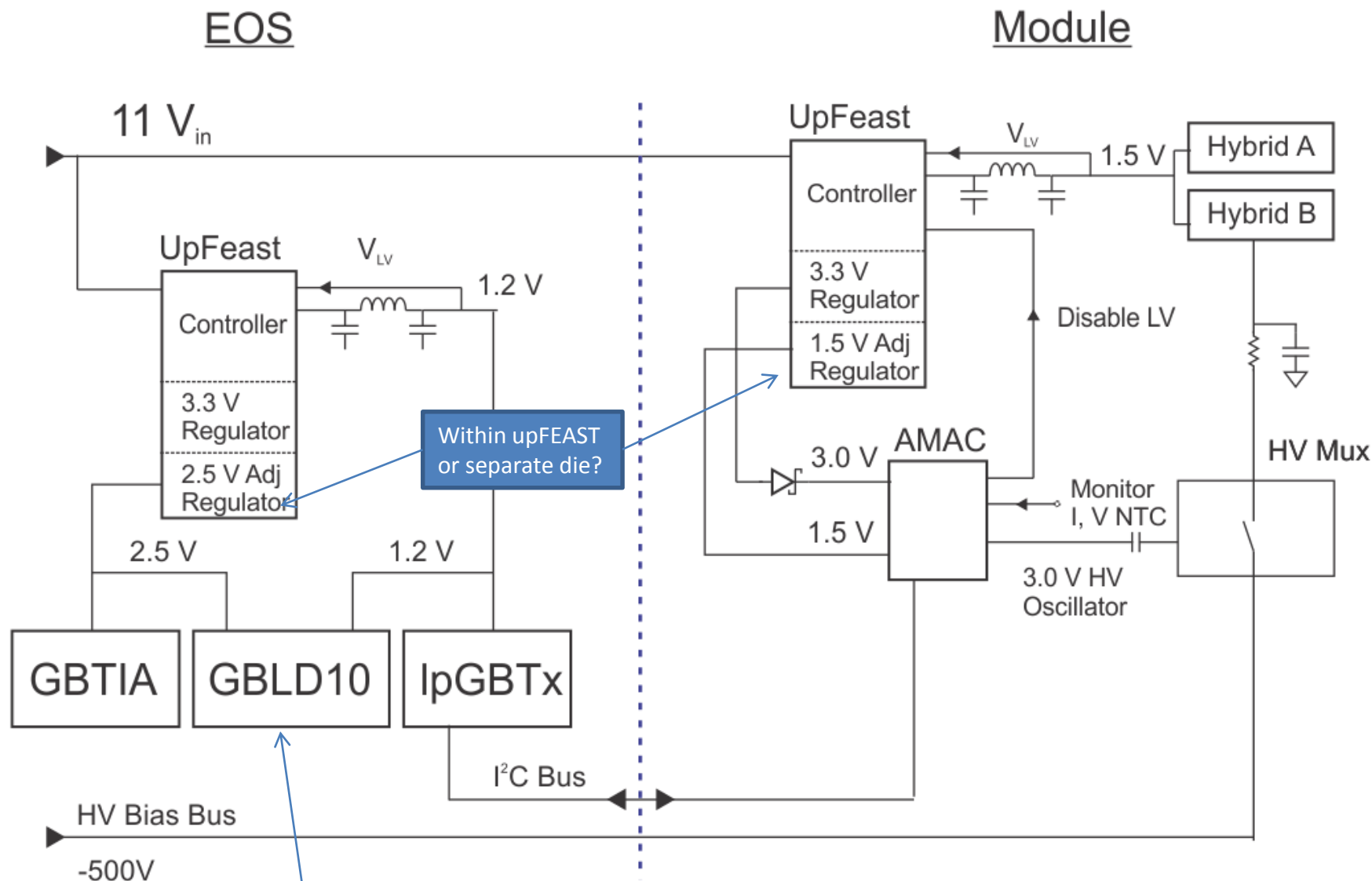


# ITk Short Strip Stave Module Load

Module	n	V	I <sub>typ</sub>	ΣI <sub>typ</sub>	I <sub>max</sub>	ΣI <sub>max</sub>
HCC*	2	1.5	300	2400	750	4700
ABC*	20	1.5	90		160	
AMAC core	1	1.5	30	30	30	30
AMAC HV osc	1	2.5/3.3	1	1	1	1
		V	mA	mA	mA	mA

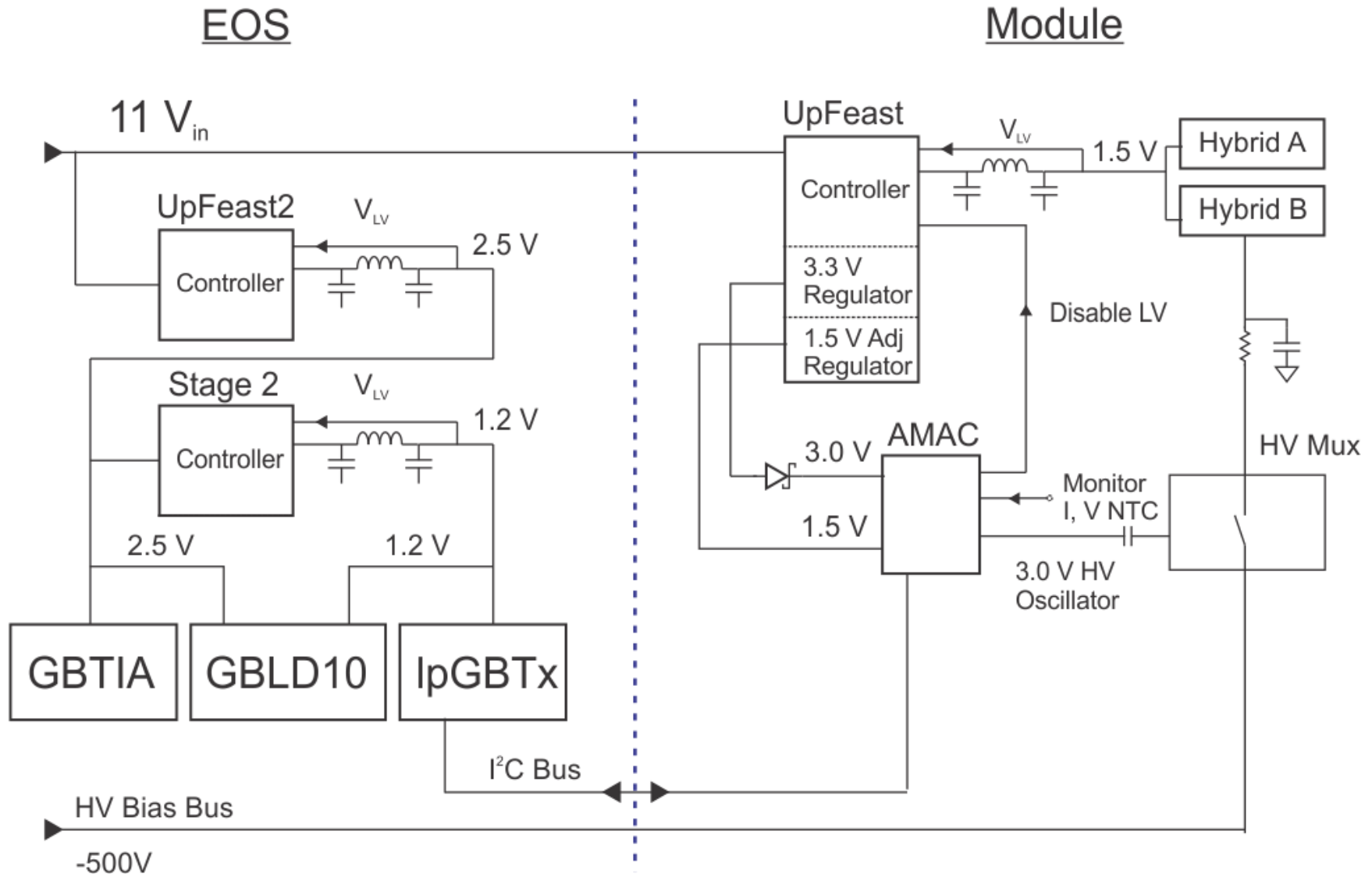
- The projected peak demand of 4.7A at 1.5V exceeds the recommended mean load for upFEAST
  - **Subject to ongoing TID studies**, we may need to request a revised limit
- AMAC has important control functionality
  - It enables DC-DC and autonomously monitors temperature and currents to interlock module power
  - Its supply must be separate from the module's 1V5 and "always on"
- We are considering several options for powering AMAC
  - Local regulation minimises voltage drop issues. Currents are low: linear regulators are appropriate.
  - 3V3 @1mA may be supplied from the regulator which powers the upFEAST core
  - 1V5 @30mA may be supplied by a second regulator, ideally in the same process as upFEAST
- Assuming AMAC is powered by 100% efficient linear regulators and that the low mass upFEAST converter has 70% efficiency
  - Short Strip Module draws 0.5A typical (0.92A max) at 11V
  - Long Strip Module (not shown, half as many FE channels) draws 0.25A typical (0.45A max) at 11V

# ITk Stave/Petal LV: LDO option



GBLD10 has a single 2.5V power rail, expect future versions to have 2.5V and 1.2V rails

# ITk Stave/Petal LV: Dual DC-DC Option





# Estimating Stave and Petal Loads

## End of Sub-structure Loads (SS Stave)

EoS	n	V	I <sub>typ</sub>	I <sub>max</sub>	ΣI <sub>typ</sub>	ΣI <sub>max</sub>
GBTIA	1	2.5	52	52	52	52
GBLD10	2	2.5	34	46	68	92
IpGBT	2	1.2	625	625	1000	1000
		V			mA	

## Linear Option (SS Stave)

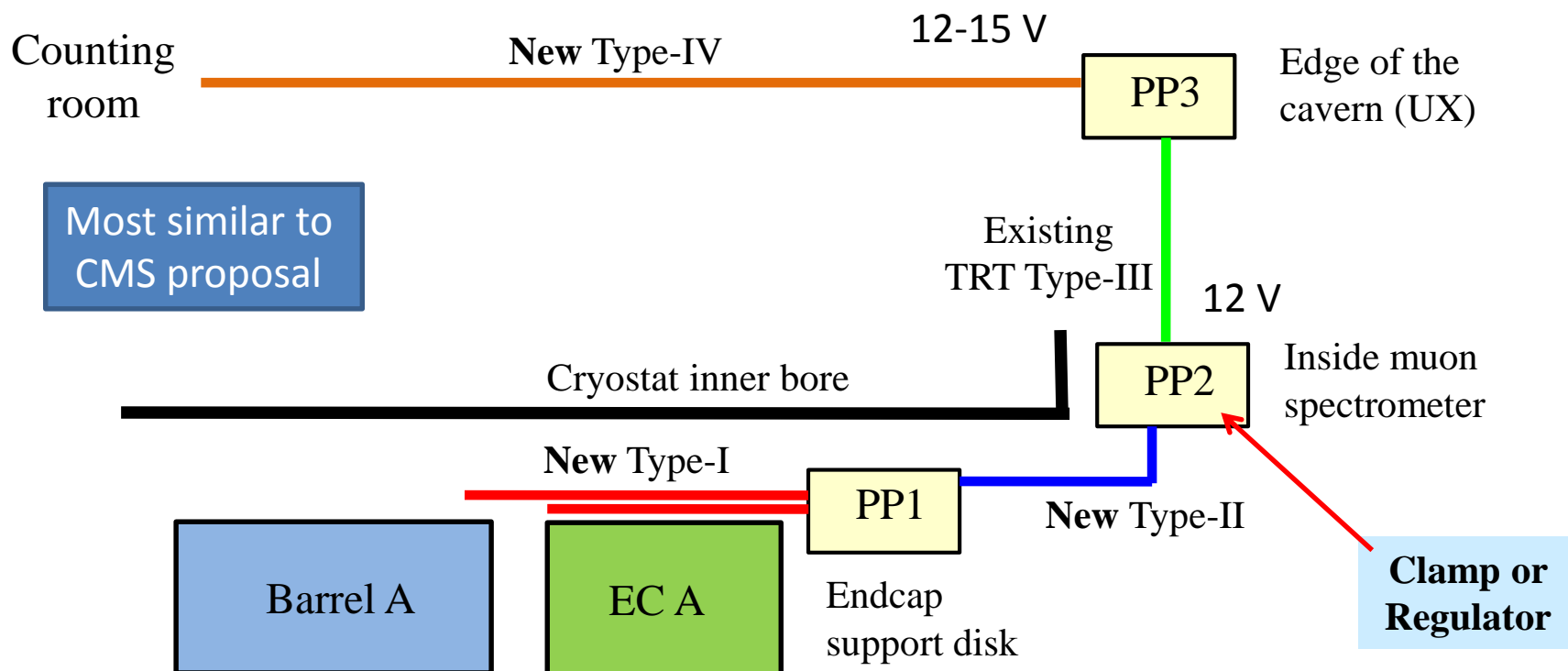
DC-DC	V <sub>in</sub>	V <sub>out</sub>	Efficiency	I <sub>typ</sub>	I <sub>max</sub>
upFEAST	11	1.2	0.7	212	212
linear	11	2.5		120	144
	V	V		mA	mA

- Current drawn at 2.5V worst case of order 150mA
  - Three options under evaluation: Dual Stage Buck DC-DC, Switched Capacitor DC-DC or LDO.
- Short Strip Stave Side: 14 modules plus EoS with two IpGBT/IpGBLD (neglecting resistance)
  - Typical:  $14 \times 0.50 + 0.31 \Rightarrow 7.4A$
  - Maximum:  $14 \times 0.92 + 0.32 \Rightarrow 13.2A$
- Long Strip Stave Side: 14 modules plus EoS with one IpGBT/IpGBLD (neglecting resistance)
  - Typical:  $14 \times 0.25 + 0.20 \Rightarrow 3.7A$
  - Maximum:  $14 \times 0.45 + 0.23 \Rightarrow 6.6A$
- Petal Side: 6 modules of varying types plus EoS with two IpGBT/IpGBLD (neglecting resistance)
  - Typical:  $2.9 + 0.31 \Rightarrow 3.3A$
  - Maximum:  $5.4 + 0.32 \Rightarrow 5.8A$
- The ITk cable task force is reviewing the possibility of cable reuse with these loads
  - Two options for LV power supplies under consideration (next slides)



# Power Distribution: Single Stage DC-DC

- **COTS LV in US(A)15?**
- **New** Type IV cables to TRT PP3
- Reuse existing TRT cables between PP2 and PP3 (least accessible part)
- **Radiation Hard** voltage clamp or regulation at PP2
  - If turn off all the modules on SS stave, maximum dl  $\sim 12A$ . Must control dV to avoid damage!
- New Type-II and Type-I

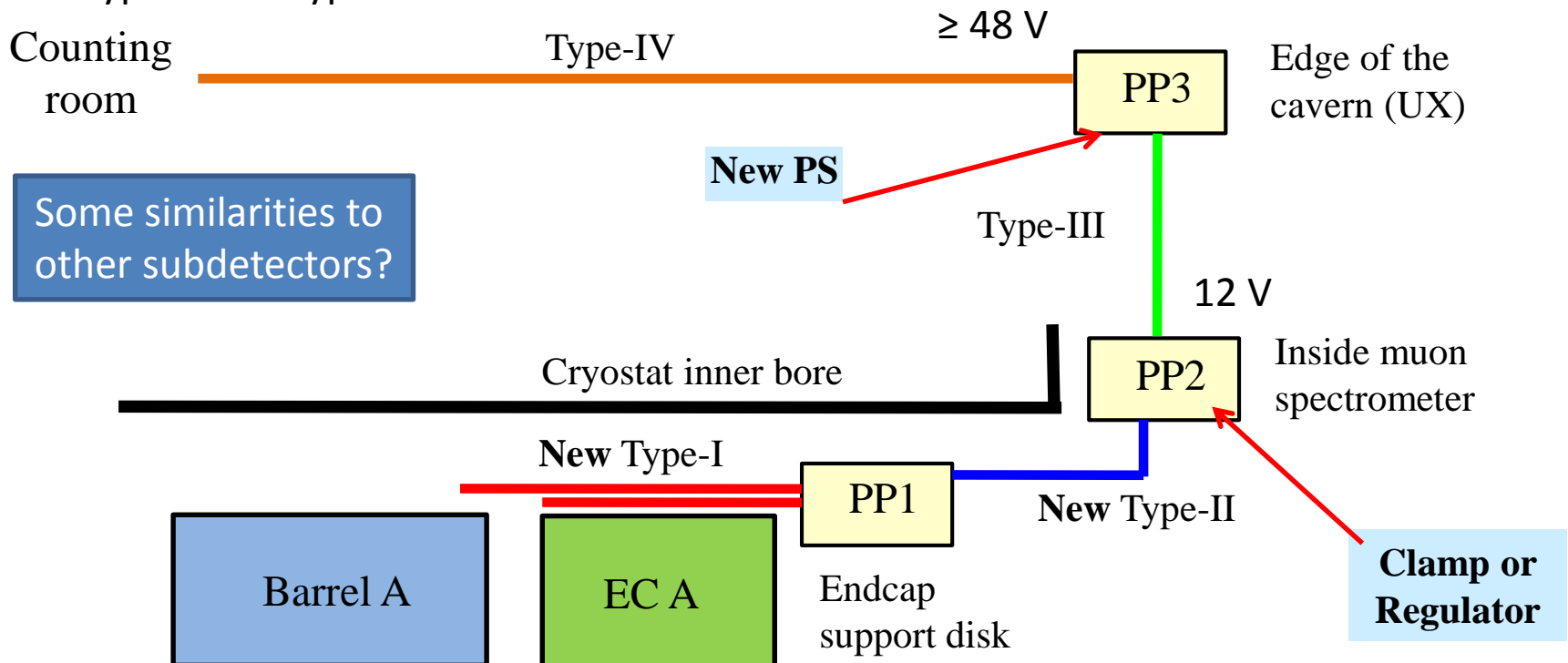






# Power Distribution: Dual Stage DC-DC

- **Radiation Tolerant** power supply at PP3
  - Essentially a second DC-DC converter stage *(Could be PP2 if sufficiently radiation hard)*
  - Radiation Levels? Space? Segmentation?
- Possible cable reuse to SCT PP3 or TRT PP2
- **Radiation Hard** voltage clamp or regulation at PP2 if power supply at PP3
  - If turn off all the modules on SS stave, maximum dl  $\sim 12\text{A}$ . Must control dV to avoid damage!
- New Type-II and Type-I



# HV-MUX

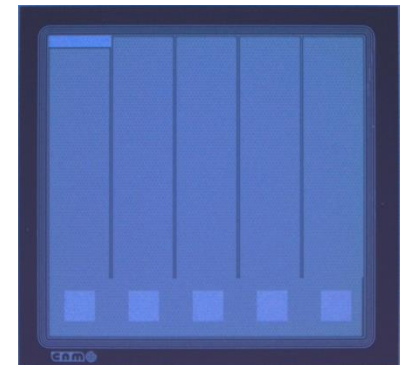
- Concept
  - connect sensors to HV bus through a radiation hard HV switch
  - Permits faulty sensors to be disconnected from the bus
- We have irradiated and tested small batches from several vendors covering GaN, SiC and Si technologies
  - GaN FETs from two vendors, each rated in excess of 500V, switching 550V with acceptable leakage after  $1 \times 10^{16} \text{ n/cm}^2$
- Alternate candidate: custom Si V-JFET from CNM
  - Recently manufactured, working but evaluation continues
- Next Steps
  - Irradiation of larger batches of GaN FETs (bare die)
    - Select preferred GaN option this year
  - Further irradiation & reliability studies of CNM V-JFET and selected GaN FET
    - Final selection 2017
  - Procurement



GaN FET "A"



GaN FET "B"



CNM V-JFET

# Conclusions and Commonality

- Both strip trackers *may* be able to use bulk supplies to a common design
  - This is dependent upon the conclusion of the ATLAS ITk cable task force, who are reviewing the possibilities for cable reuse in the light of the latest power projections.
- A standalone linear regulator in the same technology as upFEAST would be a useful addition to our tracker powering toolkit
  - This could be integrated within upFEAST or a separate die
- A radiation tolerant 48V to 12V converter may help reduce the number of new cables needed
  - GaN FET technology may be useful for this
- The “line drop recovery” technique may be used to reduce wire counts by the omission of sense lines
  - The CMS system test indicates this may work well in a system with Point of Load DC-DC
- HV-MUX is a useful concept to reduce HV cable counts whilst retaining the possibility to isolate faulty sensors
  - Radiation tolerance of GaN FET devices is promising.
  - Studies of larger samples are now beginning.
  - Alternate technology: custom silicon V-JFET.

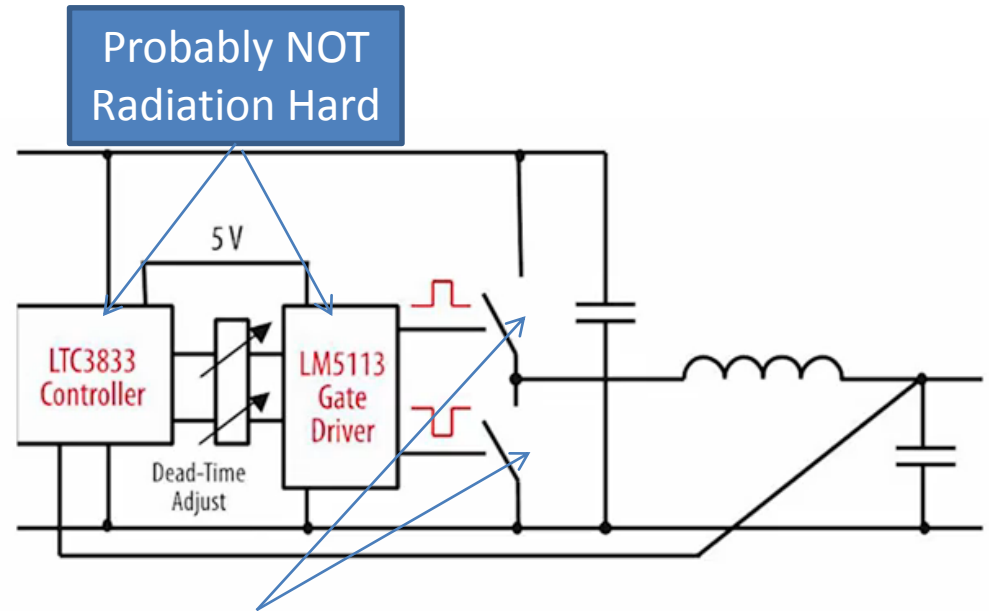
**BACKUP**

# Buck Converter with GaN Technology?



EPC9101

$V_{IN}$  8V-19V  
 $V_{OUT}$  1.2V  
 $I_{OUT}$  18A  
270nH @ 1MHz



***GaN FETs: Probably Radiation Hard***

Whilst the ATLAS ITk HV-MUX community have been testing irradiated GaN FETs at low currents, Giulio Villani has tested one sample of “GaN FET A” irradiated to  $6e15$  neutrons, at 1.5A: overall it seems that the device can operate at high current. It may be interesting to make a demonstration DC-DC PCB to explore this possibility further.