COMPARISON BETWEEN MEASURED AND COMPUTED TEMPERATURES OF THE INTERNAL HIGH ENERGY BEAM DUMP IN THE CERN SPS

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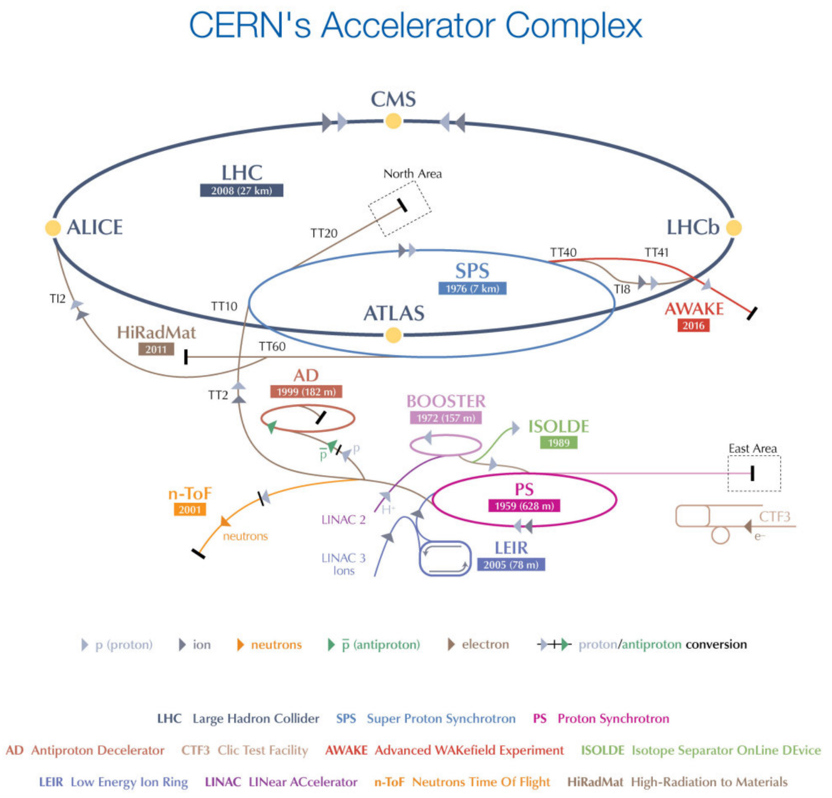
Introduction and background

Introduction to the SPS

- CERN's 2nd largest accelerator
- Switched on in 1976
- Serves as final link in injector chain for the LHC
- Simultaneously provides beams for other fixed target experiments

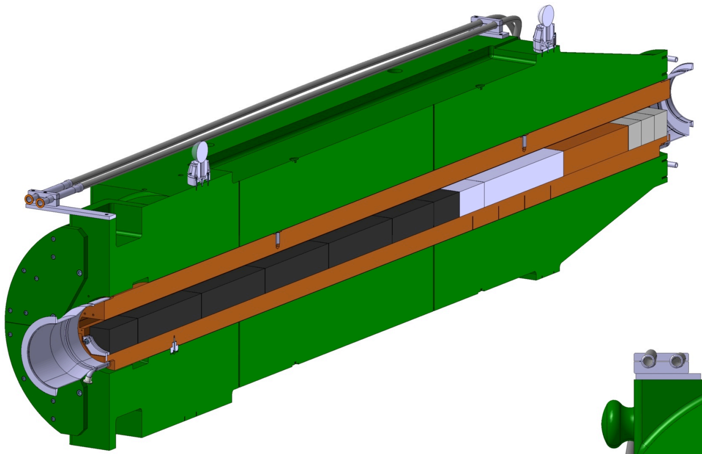


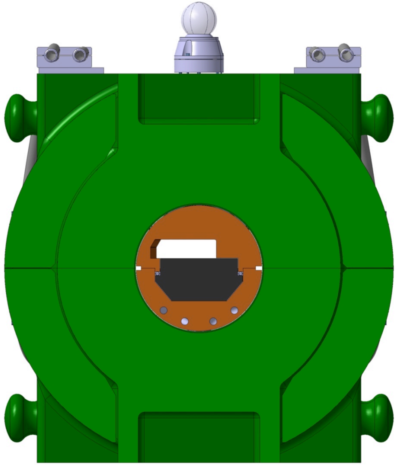
Introduction to the TIDVG

- Target Internal Dump Vertical Graphite (TIDVG)
- High energy dump for the SPS (102.2 to 450 GeV beams)
- Located in LSS1 of the SPS
- Must withstand all beams produced by the SPS e.g. LHC injection beams and fixed target experiment beams
- Combination of the waveforms from 2 vertical kickers and 3 horizontal sweepers spreads a dumped beam over a relatively large area on front face of dump
- 3 devices all based on same design:
  - TIDVG1: installed from 2000 until 2004
  - TIDVG2: installed from 2006 until 2013
  - TIDVG3: installed in 2014

TIDVG composition

- Absorbing core (TIDVG3 in brackets):
  - 2.5 (2.7)m graphite
  - 1.0 (0.8)m aluminium
  - 0.5m copper
  - 0.3m tungsten
- Copper jacket containing water-filled cooling pipes.
- Water cooled iron yoke.





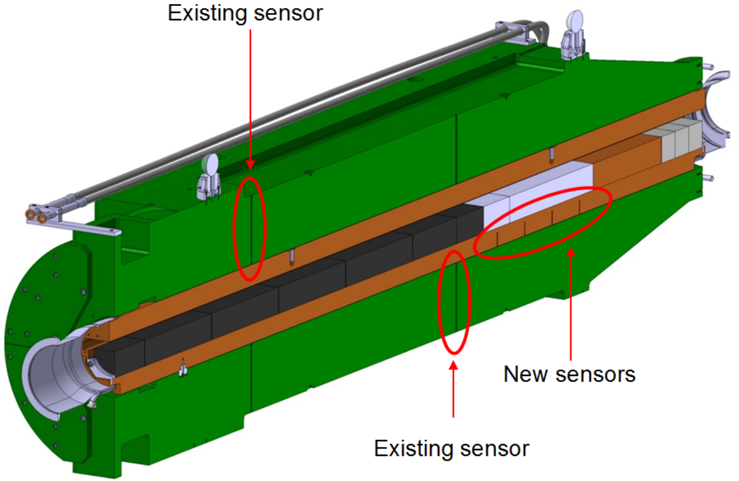
Motivation for studies

Damage sustained

- An endoscopy performed on TIDVG2 showed significant damage to the aluminium section

Response to damage

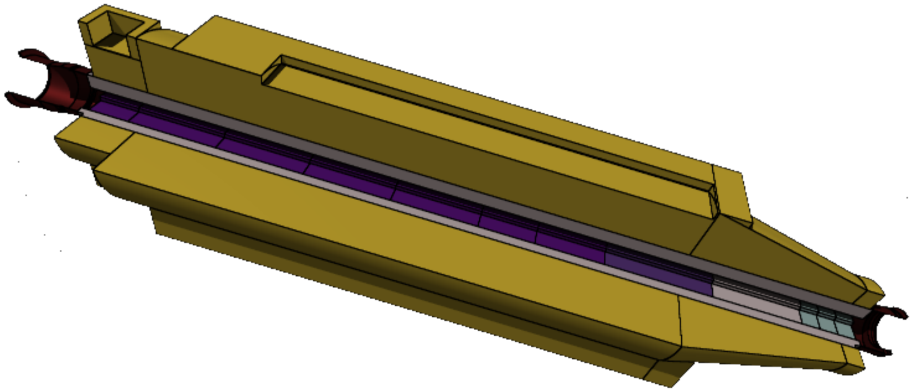
- Replacement of damaged device with TIDVG3 core (reuse of iron yoke)
- Installation of new temperature sensors
- Develop an improved thermo-mechanical model.
- Post-mortem analysis of when and how damage occurred (see *"Origin of the Damage to the Internal High Energy Beam Dump in the CERN SPS"* V. Kain et al.)
- Set limits on future operation to prevent damage to TIDVG3



Energy deposition studies

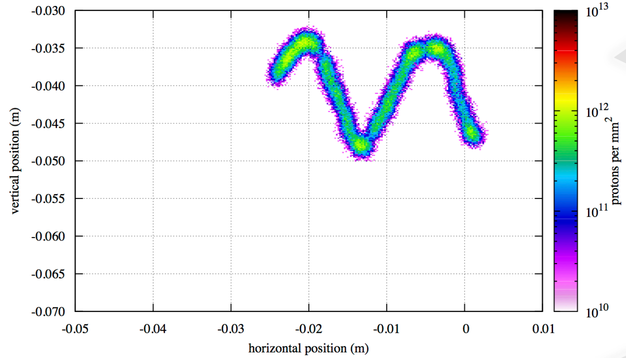
Energy deposition simulations

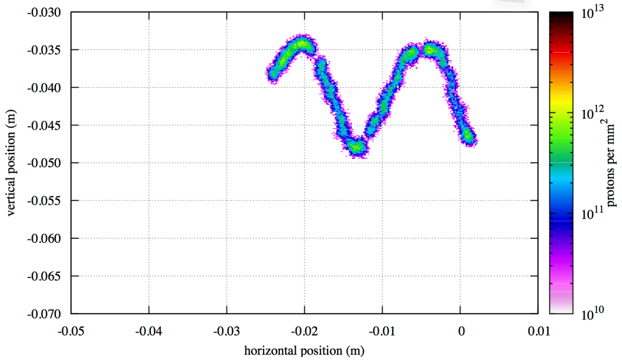
- FLUKA software used to produce energy density maps for different beam impacts.
- Detailed 3D model of TIDVG3 created
- 4 different beams considered - taken as being representative for immediate future running
- Beam particle density maps from tracking simulations used as input.

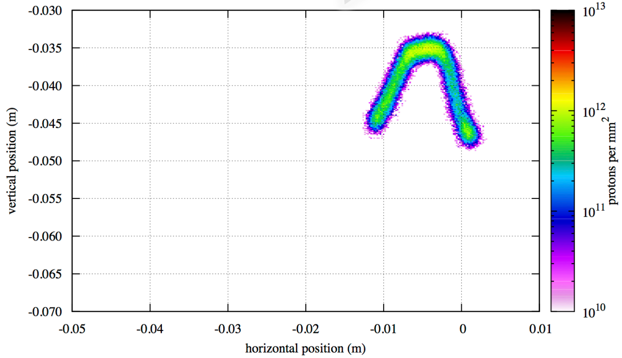


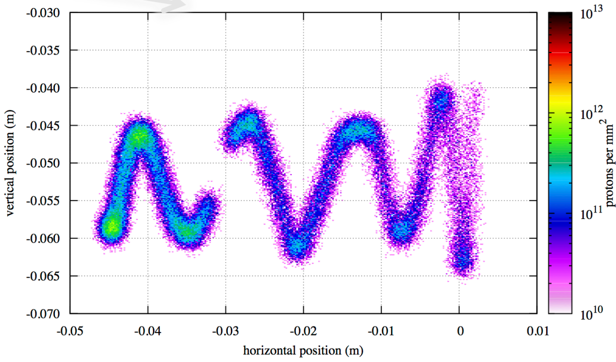
Input for simulations

Name	Energy [GeV]	Bunch intensity	Number of bunches	Total intensity
LHC 25ns	450.0	1.2e11	288	3.456e13
LHC 50ns	450.0	1.2e11	144	1.728e13
Dou-blet	450.0	1.6e11	144	2.304e13
Fixed target	400.0	9.52e9	4200	3.9984e13



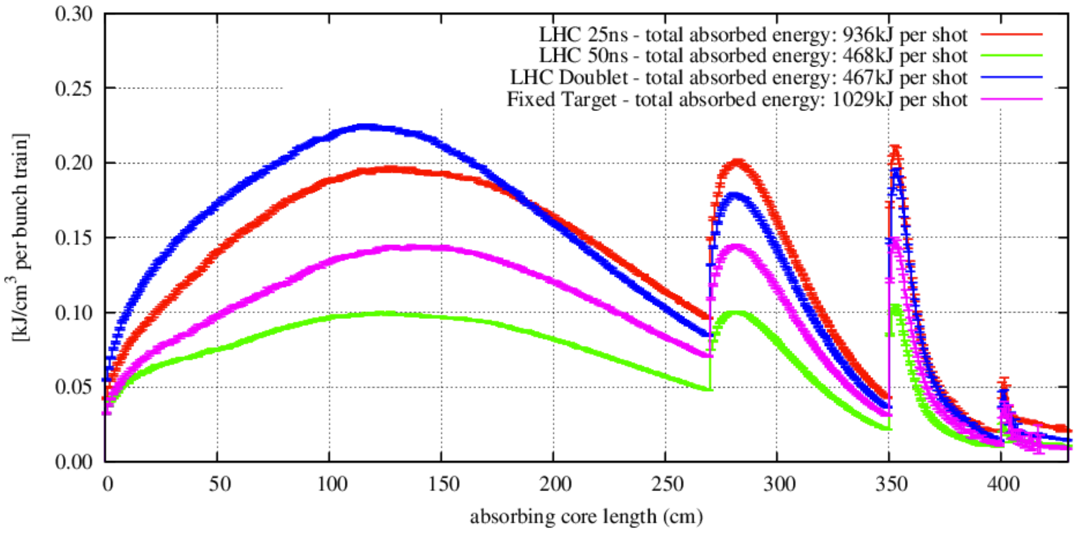






Peak energy deposition

- Difference between LHC 25 and 50 ns beams due solely to different total intensity.
- Higher proton density of doublet beam on front face means it is most severe initially.
- Further along the device doublet beam also scales w.r.t. total intensity.
- Even though fixed target has the greatest total intensity, the significantly larger sweep is the dominating variable along entire length.



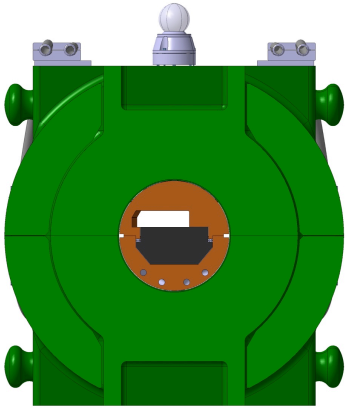
Thermo-mechanical simulations

Initial setup

- FLUKA results used as input for ANSYS simulations
- Focus predominantly on absorbing core and copper jacket
- Affect of thermal radiation discounted after investigation
- Since absorbing blocks do not have any direct cooling the Thermal Contact Conductance (TCC) is a key parameter for simulations and difficult to define precisely.
- Ideally a strongly coupled model (thermal-structural) would be used - not feasible.

TCC

- Calculated using the Mikic or Marotta model depending on materials at boundary
- Only the lower faces of the absorbing blocks are in contact with the copper jacket.
- TIDVG design includes two springs to exert a downward force on the absorbing blocks increasing contact pressure and thus TCC
- Observation of removed Al section showed spring imprints in material.
- This led to a revised estimate of the load now ~50% of the design value.



Heat exchange surface

- Investigations of TCC and heat exchange surface showed that an increased TCC did not compensate for a reduced heat exchange surface.
- Further investigations studied pressure profiles due to beam induced heating to ensure the smallest area was taken for simulations

Material properties

- All devices undergo a bakeout procedure (250°C for 350 hours)
- Leads to the ‘aging’ of the aluminium which corresponds to a reduction in strength
- Max temp during operation set to be 250°C to prevent further degradation

Simulations performed

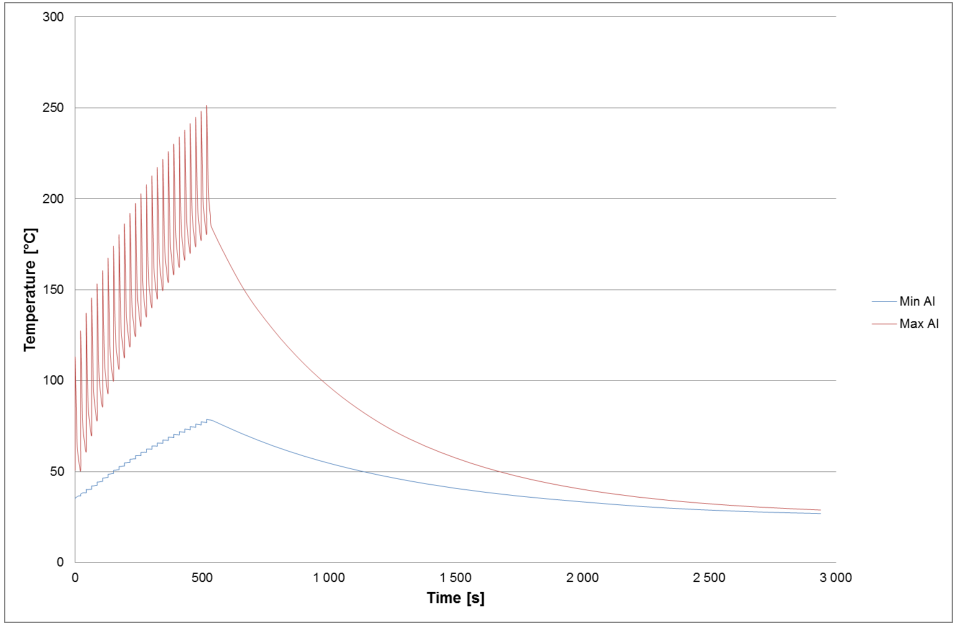
- Repeated dumping of all 4 beam types with timings as shown in table
- 5th scenario intended to reflect an SPS supercycle:
  - 1 pulse of LHC 25ns
  - 15 seconds of cooling time
  - 1 pulse of 5% of fixed target
  - 20 seconds of cooling time
  - repeat to achieve steady state
  - after LHC 25ns pulse 6 seconds of cooling
  - 1 pulse of 100% of fixed target

Name	Bunch spacings [s]	Pulse duration [s]	Pulse period [s]
LHC 25 ns	25.0e-9	7.2e-6	21.6
LHC 50 ns	50.0e-9	7.2e-6	43.2
Doublet	25.0e-9	3.6e-6	43.2
Fixed target	5.0e-9	21.0e-6	14.4

Results

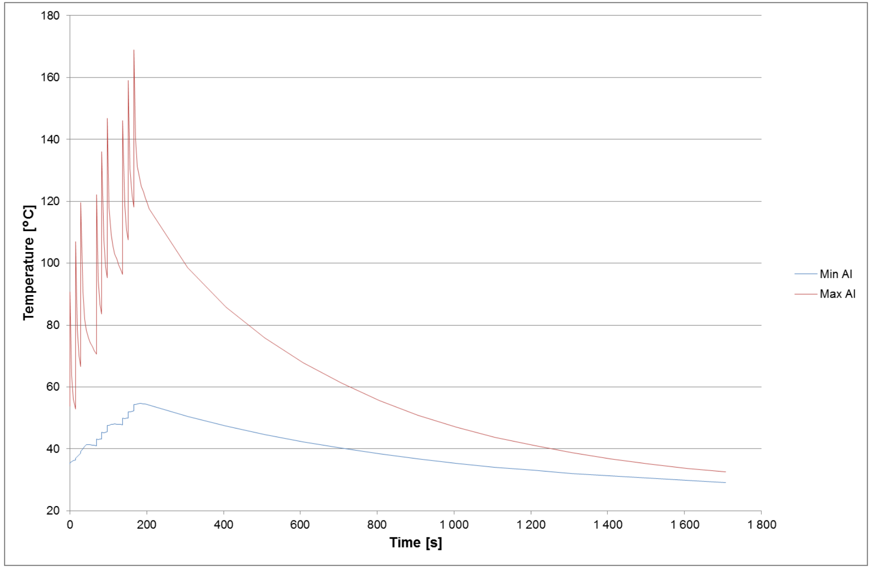
LHC type beams

- LHC 25ns beam reaches Al temperature limit after 25 shots.
- Requires 30 minutes of cooling to return to start temperature
- Addition of 15 seconds of cooling between shots gives steady state below temperature limit
- LHC 50 ns and doublet beams achieve steady state (at 121 and 164°C respectively) without any additional cooling time.



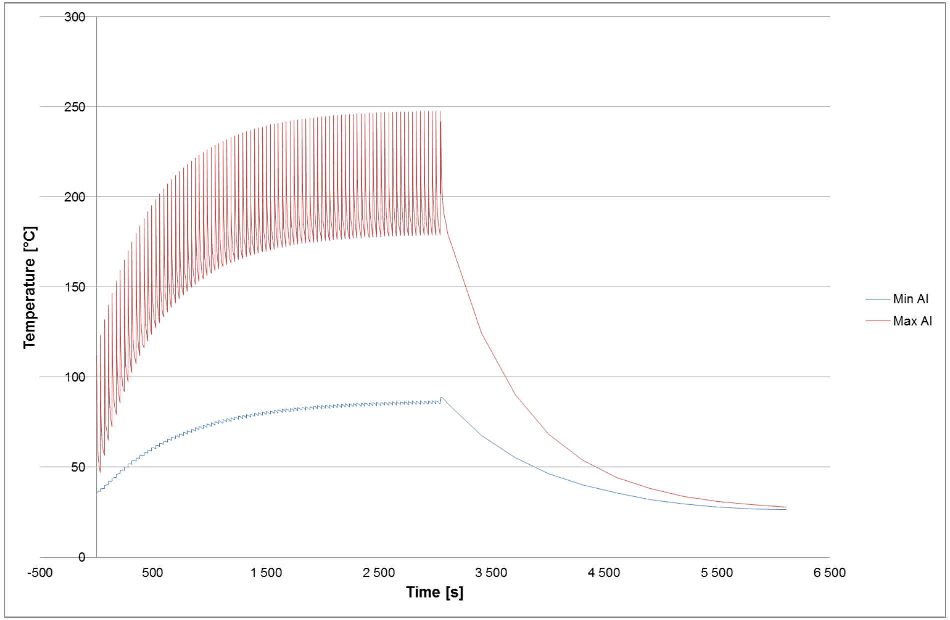
Fixed target beams

- Worst case 3 series of 3 pulses rather than continuous dumping separated by 40 seconds cooling time
- Steady state not achieved but peak temp is 205°C
- Time taken to return to initial temperature around 24 minutes



5th scenario

- Steady state achieved at just under 250°C
- Since peak temp is just for short time - still acceptable.
- After full shot of fixed target beam need to return to 179°C to recommence steady state running.
- Return to acceptable level takes 70 seconds



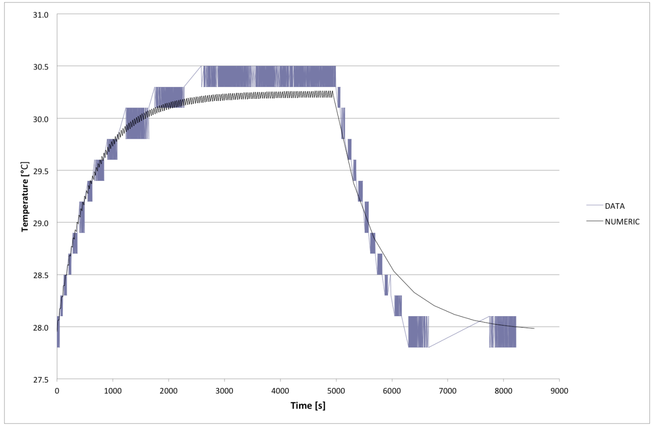
Data-simulation comparisons

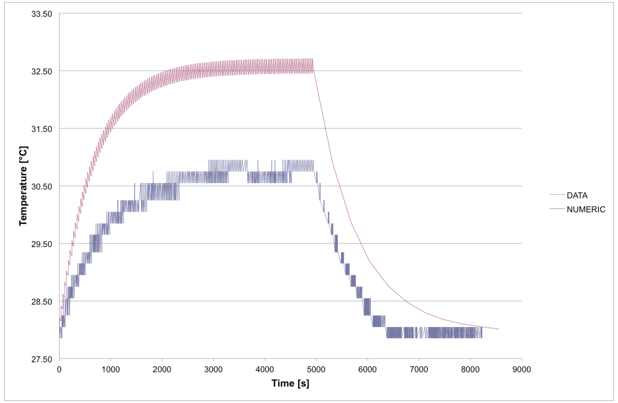
Data collected

- Restart of the SPS allowed for the collection of new temperature data.
- Data set for the time being restricted to low intensity beams
- Can still be compared to simulations performed using all latest assumptions for the equivalent scenario.

Temperature comparisons

- Good agreement for total power transfer as shown by water pipe measurements.
- Also good agreement in iron yoke
- Observable difference for temperature in copper jacket around Al section.
- This indicates a lower TCC than anticipated, implying the possibility of higher temperatures in the Al section
- Possible explanation due to non flatness of copper jacket surfaces
- To be verified with higher intensity beams and if necessary re-set limits





Conclusions and outlook

Thermo-mechanical model

- Simulation model has been carefully re-considered
- As far as possible assumptions have been investigated to ensure they are conservative
- Further data analysis will reveal if the assumptions have to be reconsidered

TIDVG device and operation

- Aim of the study was to provide safe operation limits for TIDVG3
- Limits need to be verified, monitored and, if necessary, adjusted with further data taking
- Long term, the current internal dump design becomes increasingly unsuitable.
- HL-LHC will require a new device

Questions?