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ARIES

Efficient Energy Management for Particle Accelerators

Mike Seidel for WP4

PSI, CERN, CEA/Saclay, Univ.Uppsala, GSI, ESS

Workshop Energy for Sustainable Science at Research Infrastructures

23-24 November 2017, Magurele, Romania

Host: ELI-NP
[petawatt lasers, e-beam scattering, nuclear physics]

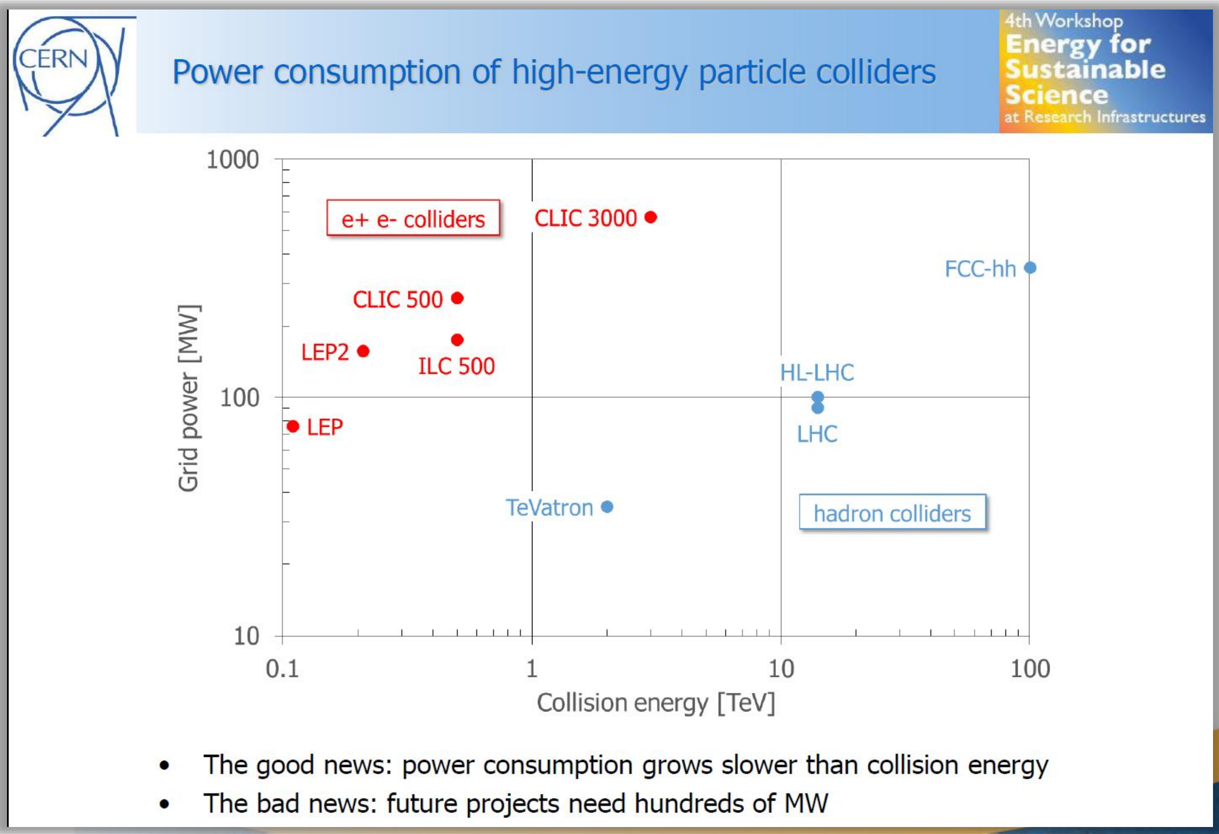
program:

- **large research facilities**, sustainable concepts
- energy consumption, energy recovery, **energy management**
- broad range of energy-efficient and **sustainable technologies for accelerators**
- https://indico.eli-np.ro/event/1/timetable/#all.detailed

Ph. Lebrun – Energy Efficiency of Colliders

Ph.Lebrun: Discussion of

- consumption and performance of collider facilities, suggested measures
- **Collider Coefficient of Performance**: CoCOP = 2EL, can be normalized to power consumption to compare facilities
- **Physics COP**: $2E'L^n$, aimed at appr. weighting Energy, Luminosity for physics reach
- **Grid to Beam Efficiency**, Efficiency of accelerator systems

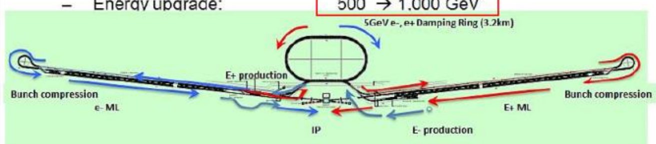


Takayuki Saeki (KEK): Challenge for the Efficient and Sustainable Design of ILC

Power Consumption of ILC

Requirements from Physics Exp.

- Basic requirements:
  - Luminosity : $\int Ldt$ = 500 fb^{-1} in 4 years
  - E_{cm} : 200 – 500 GeV and the ability to scan
  - E stability and precision: < 0.1%
  - Electron polarization: > 80%
- Extension capability:
  - Energy upgrade: 500 → 1,000 GeV



ILC (500 GeV) Total Power ~164 MW

The cost of energy consumption (electricity) is serious issue for the realization of ILC.

Accelerator section	RF Power	Racks	NC magnets	Cryo	Conventional Normal	Conventional Emergency	Total
e^- sources	1.28	0.09	0.73	0.80	1.47	0.50	4.87
e^+ sources	1.39	0.09	4.94	0.59	1.83	0.48	9.32
DR	8.67		2.97	1.45	1.93	0.70	15.72
RTML	4.76	0.32	1.26		1.19	0.87	8.40
Main Linac	52.13	4.66	0.91	32.00	12.10	4.30	106.10
BDS			10.43	0.41	1.34	0.20	12.38
Dumps					0.00	1.21	1.21
IR			1.16	2.65	0.90	0.96	5.67
TOTALS	68.2	5.2	22.4	37.9	20.8	9.2	164 MW

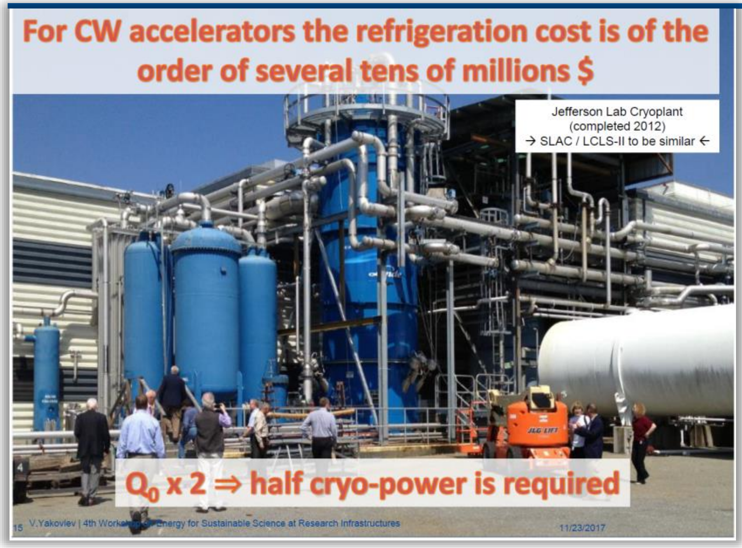
Efficiency from wall-plug to beam-power is ~10 %

We are challenging for higher efficiency

T.Saeki:

- Green ILC working Group, specific technologies:
  - high Q cavities, high Tc cavities
  - efficient cryo systems and energy recovery
  - efficient RF sources
  - smart grid, energy management
  - potentially interesting: Plasma beam dump

V.Yakovlev (Fermilab): high Q for CW Linacs



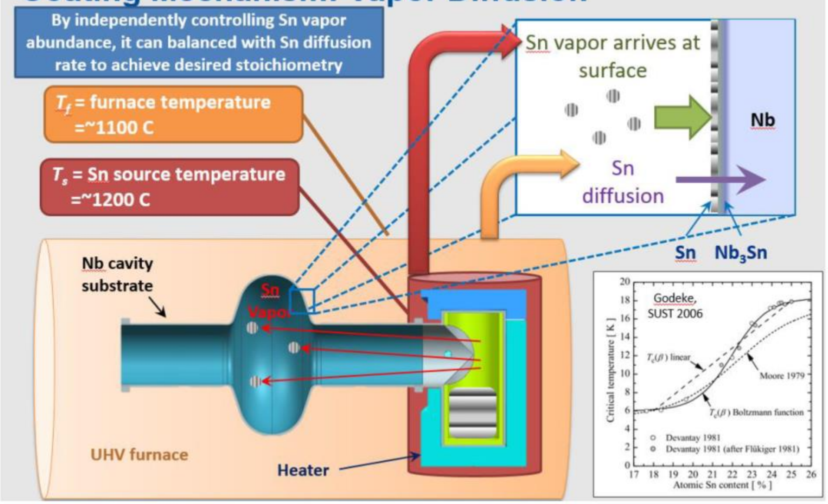
discussion of:

- high Q developments, N_2 doping
- Nb_3Sn: higher T → better cooling efficiency

→ **overall significant developments on s.c. resonators!**

Nb_3Sn: technology of the future*

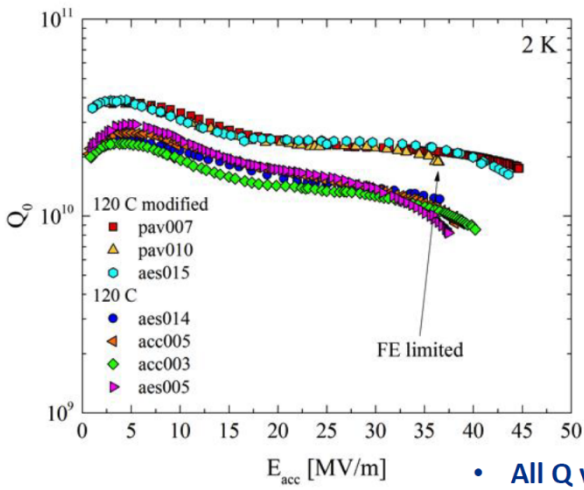
Coating Mechanism: Vapor Diffusion



*S. Posen and D.L. Hall, Supercond. Sci. Technol., 30 033004 (2017).

Technique development: Saur and Wurm, Naturwissenchaften 1962, Hillenbrand et al., IEEE Transactions on Magnetics 1977, Peinig...

Reproducibility: repeatedly highest Q ever measured >2e10 at very high gradients > 40 MV/m!



Slide from A. Grassellino

- So far three out of 4 cavities processed with this regime have reached 45 MV/m with high Q
- Performed slow cooldown in 10mG and extracted very low sensitivity to B on order of 0.3 nOhm/mG -> very robust for Q preservation
- **All Q vs E curves shown are for 1.3 GHz single cells, T=2K**

Ben Shepherd (STFC Daresbury): Tunable permanent accelerator magnets

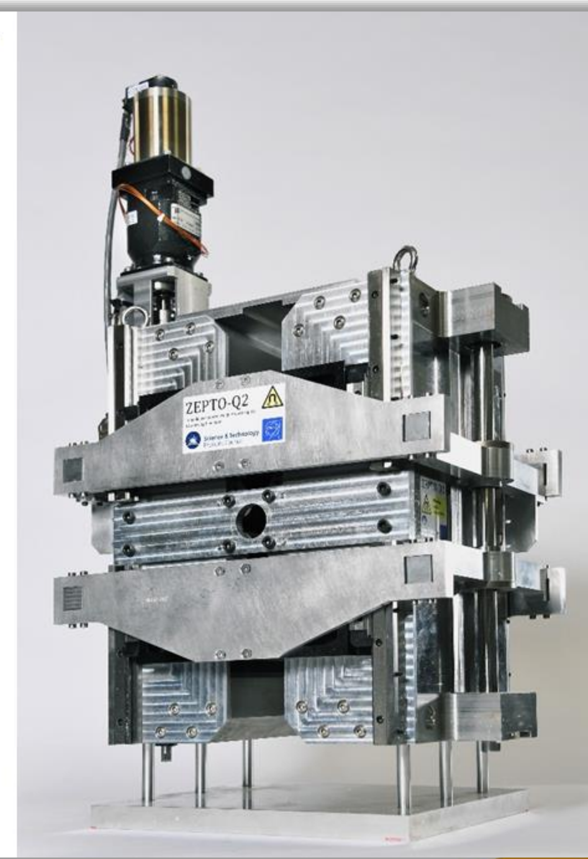
- Permanent magnets: **no power, no heat, no water/vibration, compact**
- innovative field and impressive range of examples from light sources, SIRIUS, ESRF, SPRING8 but also CLIC, NLC, some magnets licensed to industry

ZEPTO Q2 Prototype

- Prototype built at STFC Daresbury Laboratory and measured at CERN
- Confirmed gradient, field quality, tuning range
- Magnetic centre movement **80 µm**

- Patented design of both quadrupoles
- Licensed to Danfysik for production
- Ongoing collaboration with CERN to develop PM-based concepts for CLIC design study

Shepherd *et al* 2014 *JINST 9 T11006*
Clarke *et al*, *IEEE Transactions on Applied Superconductivity*, vol. 24, no. 3, pp. 1-5, June 2014
Clarke *et al*, patents WO2012046036, US8829462



ARIES

Rudolf Lohner (KIT): ForHLR II – energy and resource efficient computing at KIT

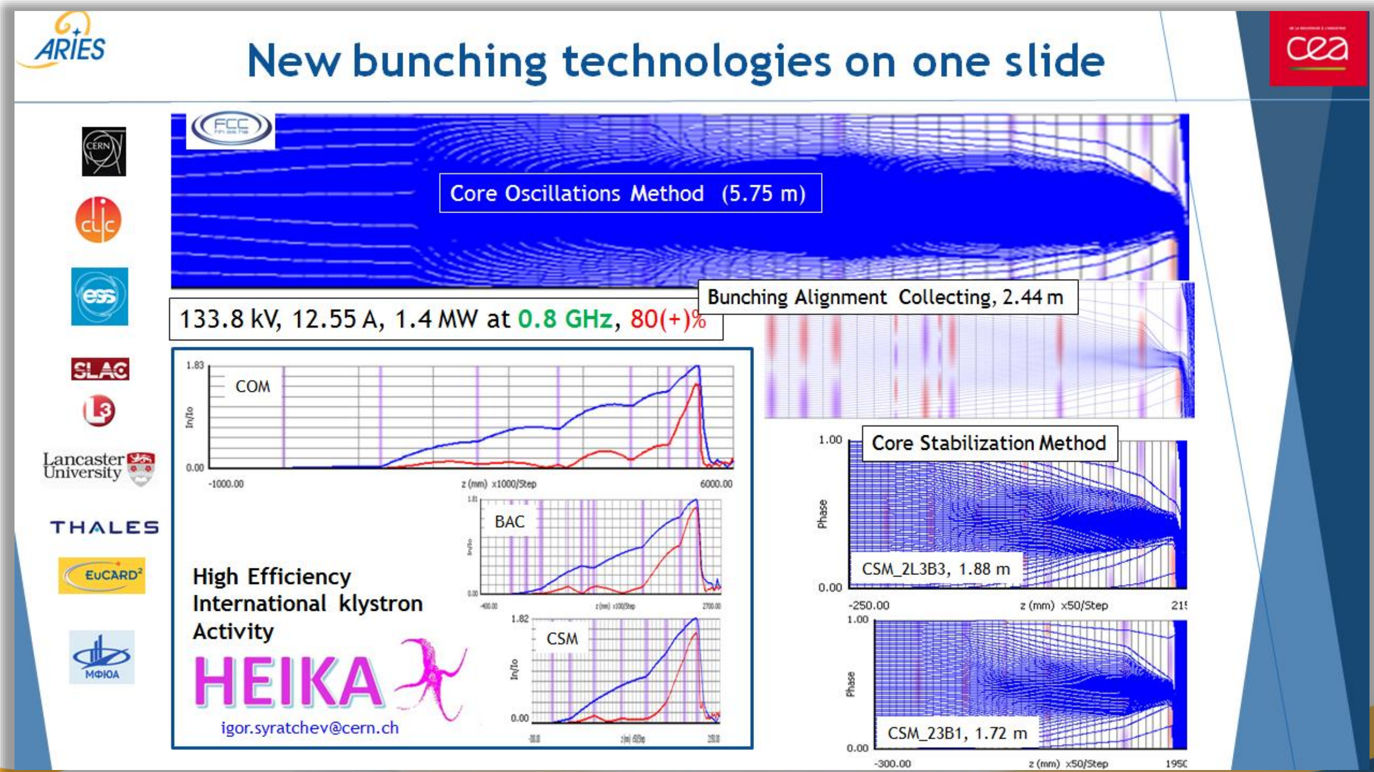
- ForHLR Project: example of sustainable HPC computer center; investment 26M€
- 1 Petaflop floating op; 1152 nodes; 236m^{2}x3.5m; 1MW electrical power; 750kW water cooling, 250kW air cooling-dry coolers on roof
- office heating up to 100kW at 40/45 degreesC, «concrete core» heating in ceiling plus small adjustment by radiator in offices

→ advanced in cooling / recovering low grade heat for office buildings

ARIES

C.Marchand (CEA): Development of efficient klystrons

- efficient RF klystrons are important part of power conversion chain, especially for high intensity / collider projects
- **efficient bunching methods** discussed with Pro's and Con's (length, efficiency)
- S-BAND prototypes multi beam show good agreement with simulations, also SLAC result of modified klystron with more cells shows promising results; CERN/SLAC study on X-band klystron; ARIES/CEA study on 12GHz



note: some tubes are physically very long

Task 2: High Efficiency RF Power Sources (C.Marchand)

- **Objectives**:
  - Organize a workshop on efficient RF sources
    Tentative title: « Novel Energy Efficient RF Sources »
    Organizers: University of Uppsala, CEA Saclay
    Date: M25 = June 2019
  - Study the development of a very high efficiency klystron with adiabatic bunching
    Deliverable: Design study up to full 3D drawings
    Date due: M41 = October 2020

- **Manpower**:
  - Management: Claude MARCHAND (CEA)
  - Workshop: Roger RUBER (Univ. Uppsala)
  - Full time postdoc: Pierrick HAMEL (CEA)
  - Expertise: Juliette PLOUIN, Franck PEAUGER (CEA), *Igor SYRATCHEV (CERN)*

Task 2: HIGH EFFICIENCY RF POWER SOURCES

- Roadmap and status of klystron design study:

  - Define klystron specifications ✓:
    Choice has been made to design a 12 GHz klystron with about 70% efficiency for Compact Light project, with an output peak power of about 10 to 20 MW

  - Design interaction line using modern ParticleInCell codes:
    - First iteration with 1D/2D codes (AJDISK, KlyC) to get cavity parameters

    In progress. A preliminary study combining adiabatic bunching and COM gives the following design parameters for the tube:

    28 cavities, 52 cm long, 17 MW, $\mu K = 1.4\ AV^{-1.5}$, $\eta = 70\%$

    - Second iteration with 2D/3D codes (Magic 2/3D, CST) to refine the results, define cavities geometry and study stability of the beam

  - Detailed design of the cavities, the diode gun and the collector

  - Provide a preliminary 3D model

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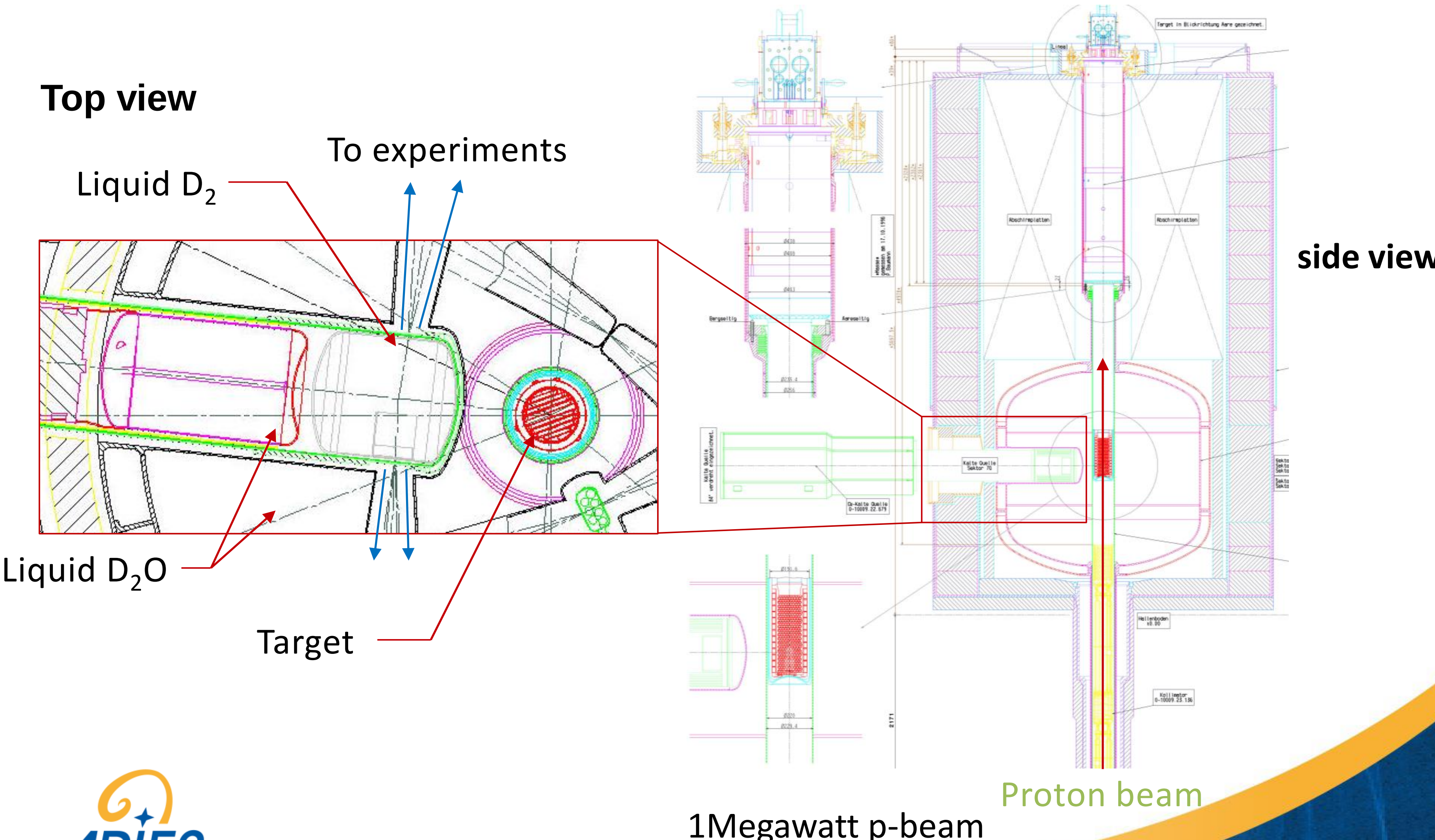
Task 3: Neutron moderation (Y.Charles, M.Wohlmuther)



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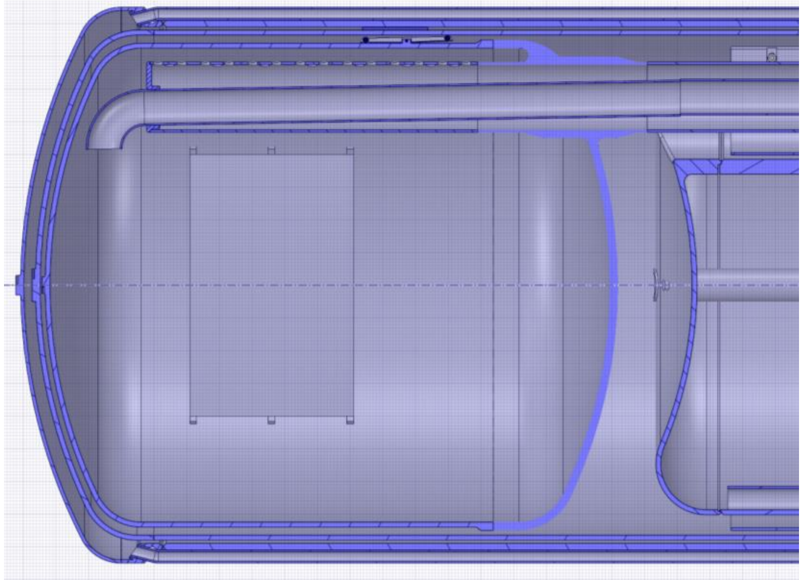
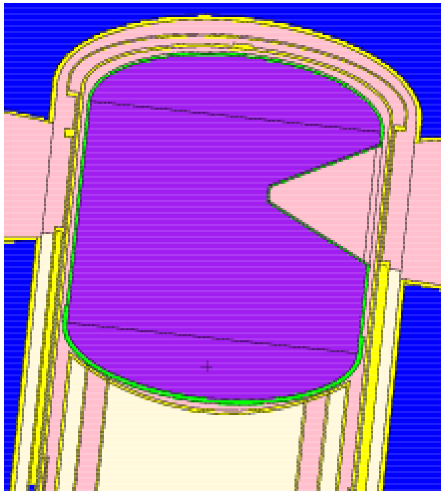
Task 3: Improvements on the moderator design

New design will provide 1.3 – 1.6 increase in cold neutron flux



Liquid deuterium moderator, current design, side view.



New design for the deuterium moderator, top view.

Tasks

- Ongoing: numerical modelling of fluid and heat flows to understand the limitations of the current design
- Planned: hydro-thermo-mechanical analysis of the new design to assess feasability

Task 4.4: High efficiency SRF power conversion (F.Gerigk)

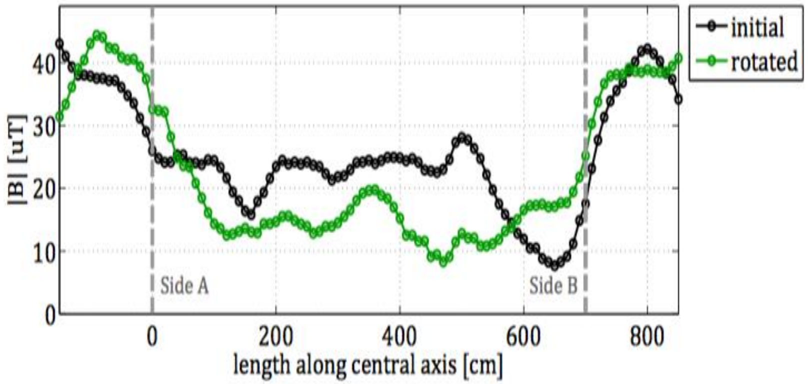
Goal: *improved Q-value (and lower cooling power) by minimising the trapped magnetic flux during cool-down and maximising the magnetic shielding.*

- 1st Fellow, S. Papadopoulos: 1.5.2017 – 31.1.2018: magnetic measurements on existing vacuum vessel for a cryo-module.
- 2nd Fellow, A. Ivanov: 1.5.2018 – 30.10.2020: flux trapping during cool-down and magnetic shielding.
- 8-9 November 2018: ARIES topical workshop on flux trapping at CERN, has also been accepted as TTC topical workshop (no additional funding but distribution to wider audience).

Magnetic measurements on vacuum vessel

- After the re-design of warm and cold magnetic shielding for a vacuum vessel that will house 4 x 704 MHz 5-cell Nb cavities, the influence of the vessel had to be assessed.
- A measurement system was set up and the magnetic field on the cavity was measured with a 3-axis fluxgate magnetometer.
- Shielding factor and magnetisation of the vessel were identified (measurement in 2 position). ARIES report in preparation.

Measurement with magnetometer on a stick

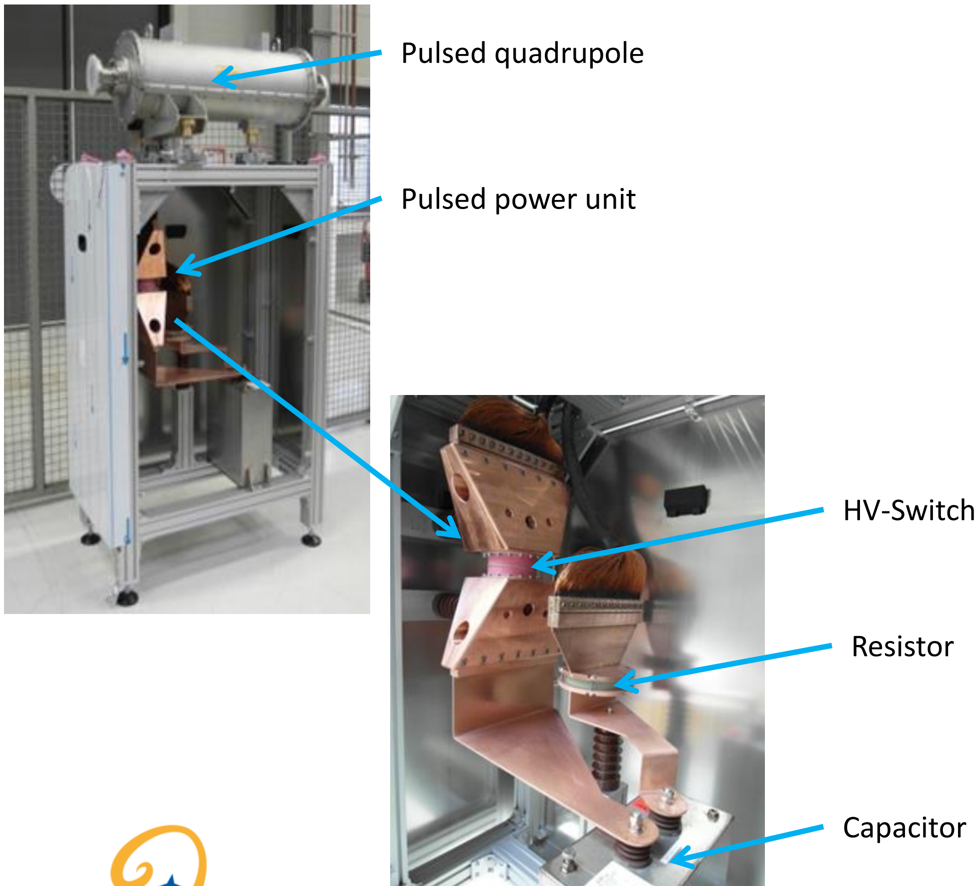


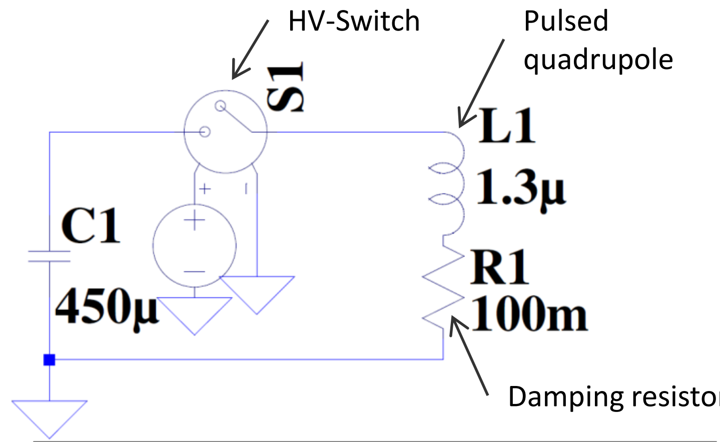
Absolute magnetic field in initial and rotated (180 deg) position

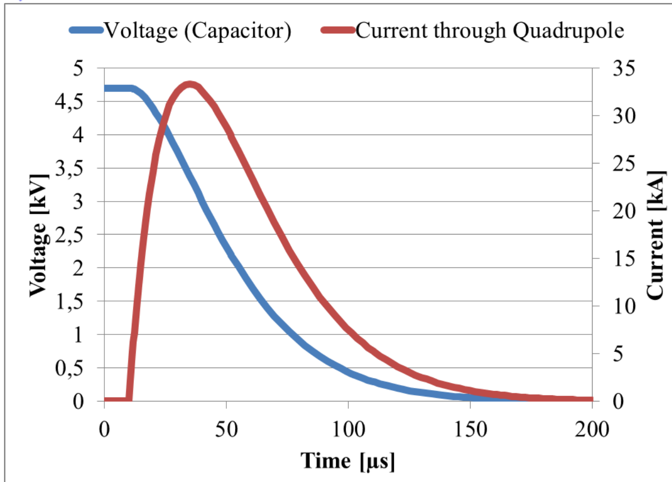
Task 5: Pulsed Quadrupole Prototype (P.Spiller, S.Heberer)

- Design parameter: up to 400 kA, up to 25 kV 75 T/m

Tested: 30 kA, 4 kV, 5.5 T/m (high damping resistance to avoid voltage reversal)

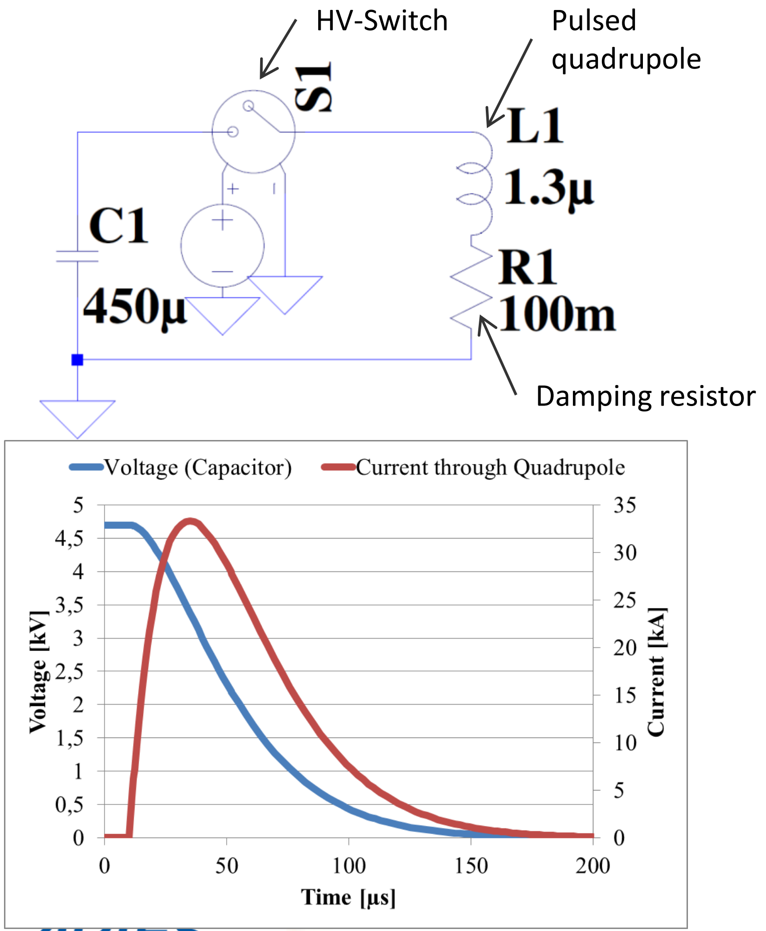


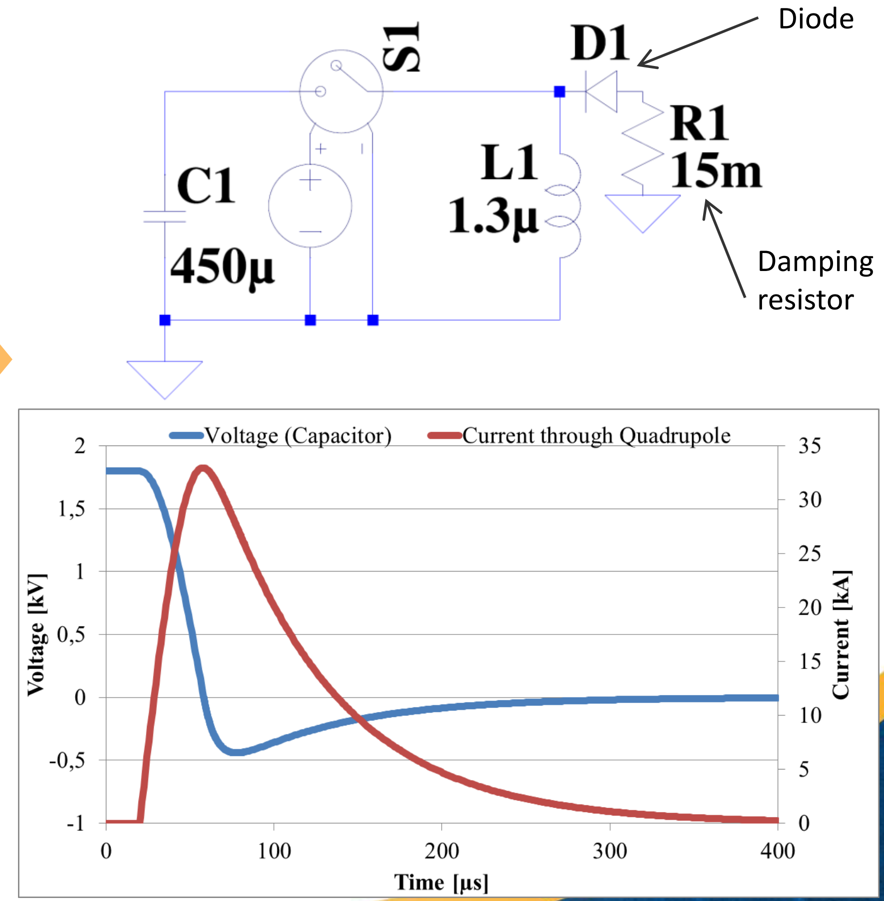




Task 5: Prototype and Improved Circuit Design

- Improved circuit: Smaller damping resistor, not in main circuit
  → same current at a significantly lower voltage
  - Voltage reversal has to be avoided with diode





Task 5: New Hardware Acquired For Improved Pulse Circuit

Pseudospark Switch TDI1-200K/25
max. 200 kA and 25 kV

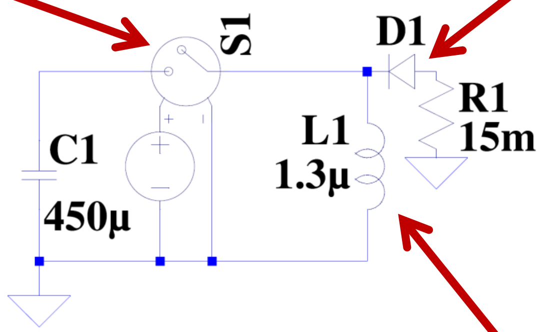
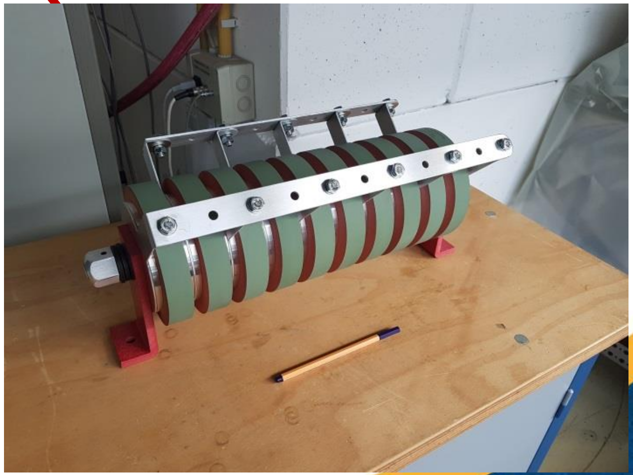


ABB D2601N Diode
max. surge current 52 kA, max. 9kV



HVR Pulse Resistor
max. 80 kA

Next Steps:

- Assemble new components in pulse circuit
- First tests and measurements up to 30kA
- Increasing the current stepwise to 50kA with this assembly

Summary Efficient Energy Management

- EEM: all workpackages on track, co-funded manpower hired, first general workshop held, next specialized workshop planned for Nov 18 on s.c. cavities: flux trapping & magnetic shielding
- Another general workshop “sustainable research facilities” in Nov 2019 at PSI
- Hot topics in accelerator field:
  - **Collider studies** and their power consumption: ILC, FCC-hh, FCC-ee, CLIC
  - **New Technologies**:
    - Efficient RF generation
    - Permanent accelerator magnets
    - High Q s.c. cavities
    - Energy recovery and overall management

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EEM: Workshops & Deliverables

Task	Workshops / Deliverables
#1: coordination	**MS17**: co-organize workshop on Energy for Sustainable Science, M7: **done!** + another workshop 2019 at PSI
#2: efficient RF sources	**MS19: workshop on simulations and prototyping of novel energy efficient RF sources, M13, Univ. Uppsala, CEA Saclay; shifted to 18 - 20 June 2019** **D4.2: 3d design of efficient klystron, M41**
#3: neutron production	**MS20**: workshop on efficient n-production targets and moderators, M31, ESS, PSI **D4.4**: report on the optimization procedure and technical layout of efficient moderator assemblies, M46
#4: high efficiency SRF power conversion	**MS18**: workshop on low loss superconducting RF, M19; (**workshop "Flux trapping & magnetic shielding" planned for Nov 8/9, 2018**) **D4.1**: report on magnetic shielding for high quality superconducting resonators, M35
#5: pulsed magnets	**MS21**: workshop on efficient magnets/beam transport, M37, GSI **D4.3**: Report on pulsed magnets, M43

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