ESS Klystron Modulator Workshop

CERN experience

David Nisbet
CERN

Intro

- Past and present
  - CERN accelerator complex
  - LINACs @ CERN
- Present : LINAC4
- Future : CLIC
- Strategy
- Conclusion

The CERN accelerators - past

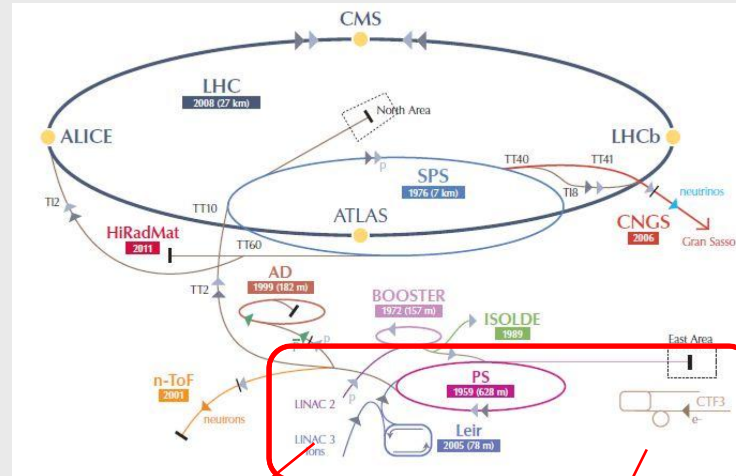
- LINAC1 and LINAC2
  - Cockcroft-walton generators
  - Used for CERN proton physics until 1993
  - (not recommended for new projects)

1959: [520kV, 135mA]

1973: [750kV, 150mA]

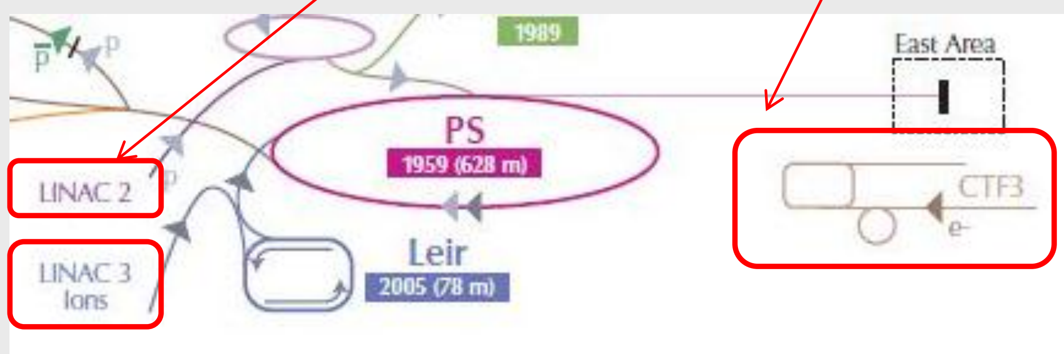
The CERN accelerators - today

- Operational pulsed RF power @ CERN
  - LINAC2 (triode)(1976)(x2)
  - LINAC3 (tetrode)(1994)(x2)
  - CTF3 (klystron)(1981)(x11)



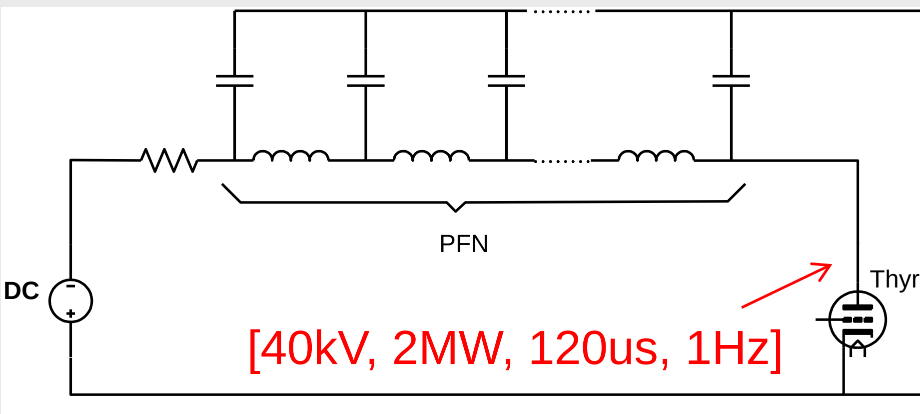
- Pulsed RF power has a modest (but important) presence

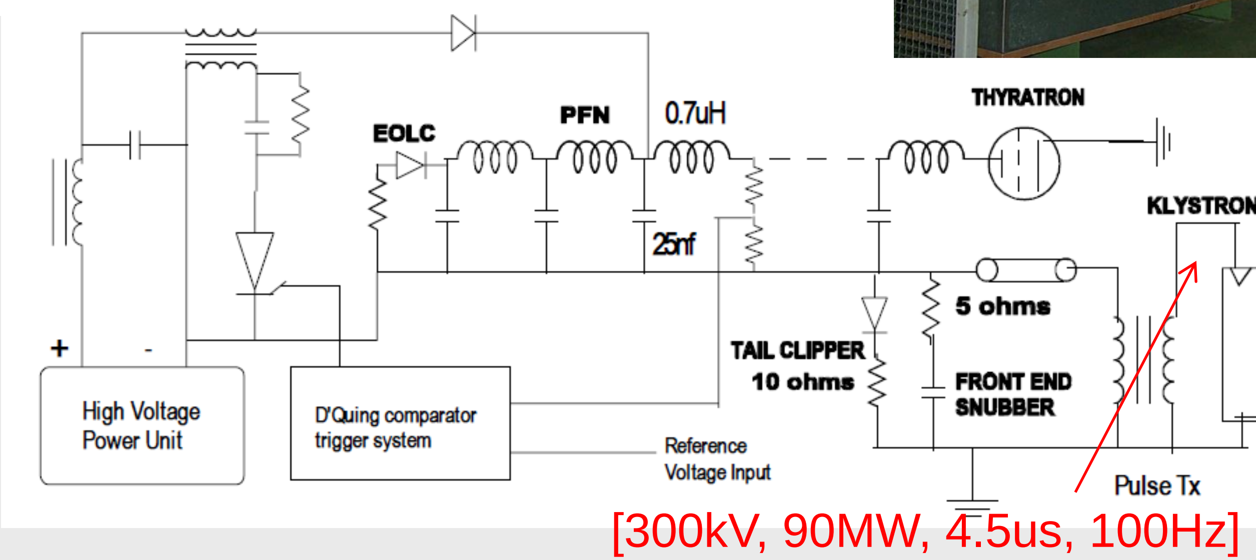
- Also several teststands
  - LINAC4
  - CTF3

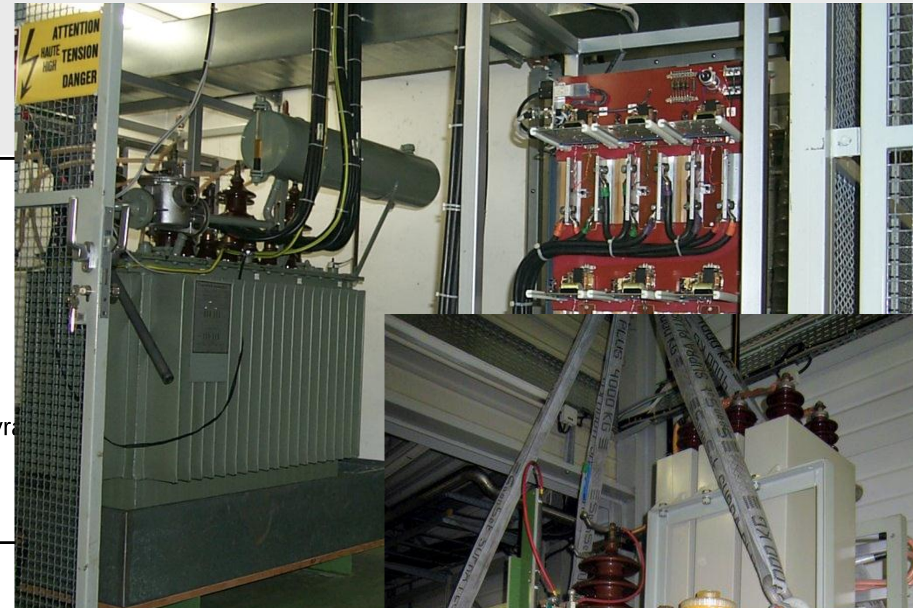


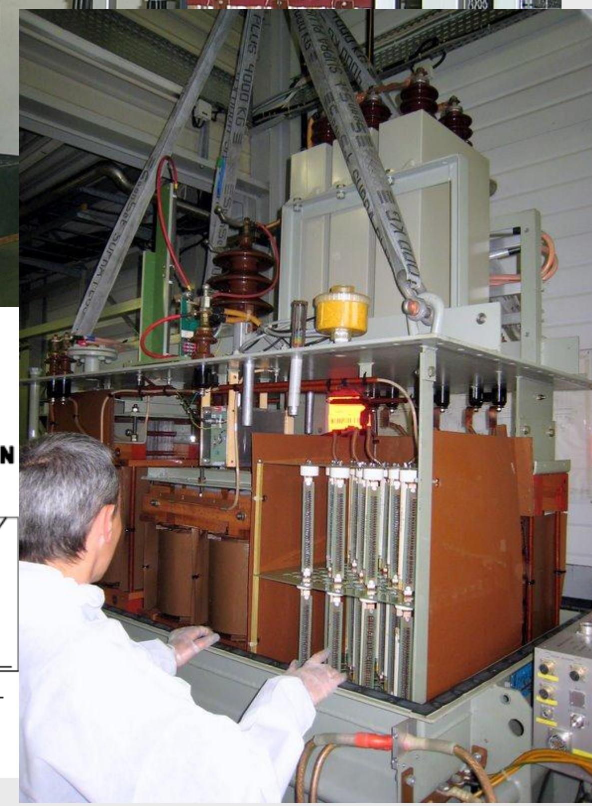
The CERN accelerators - today

- LINAC2, CTF3



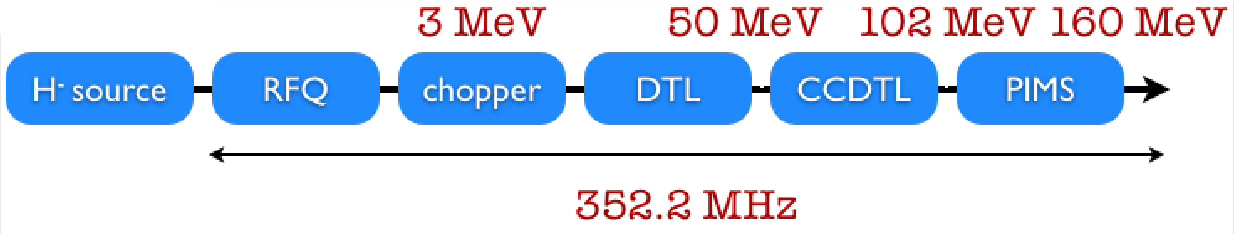






LINAC4

- Due to the age of LINAC2
  - Replace with an H- 'LINAC4'
  - Higher energy and beam intensity
  - Currently under construction

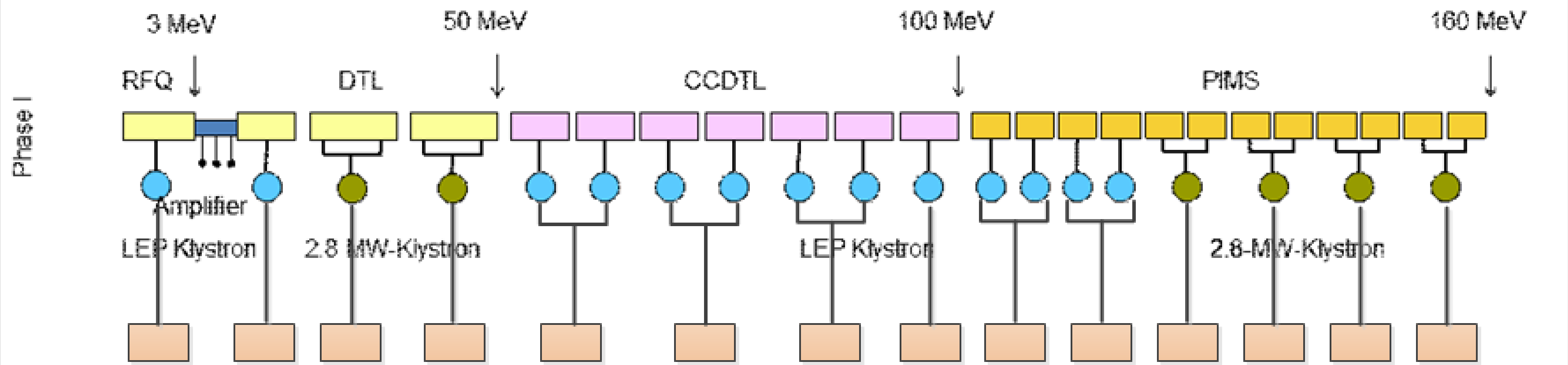


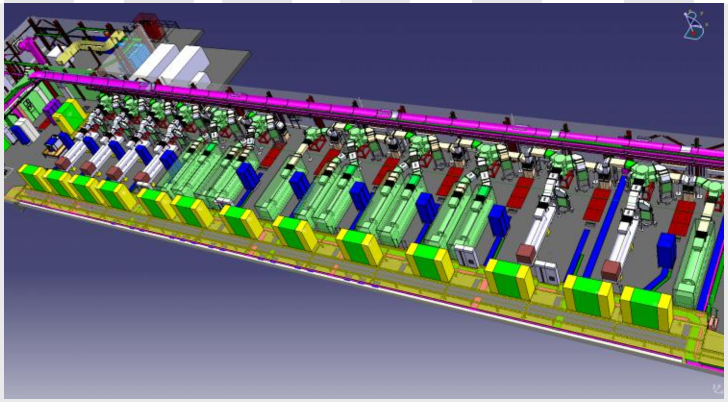
LINAC4

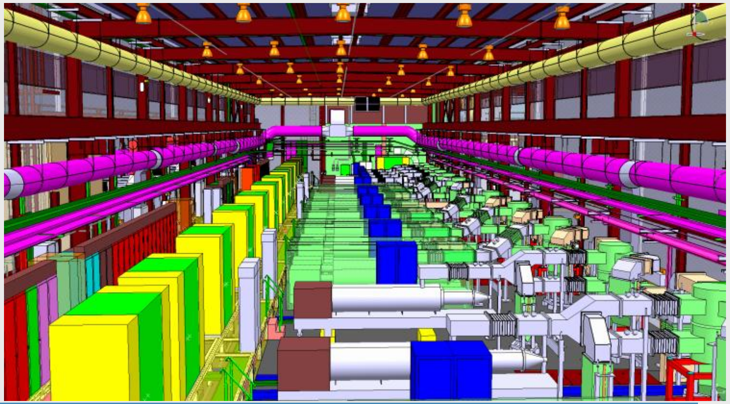
- Status Jan 2012

LINAC4

- 14 klystron modulators
  - 19 klystrons (13 'LEP' klystrons, 6 new klystrons)
  - 25 accelerating cavities







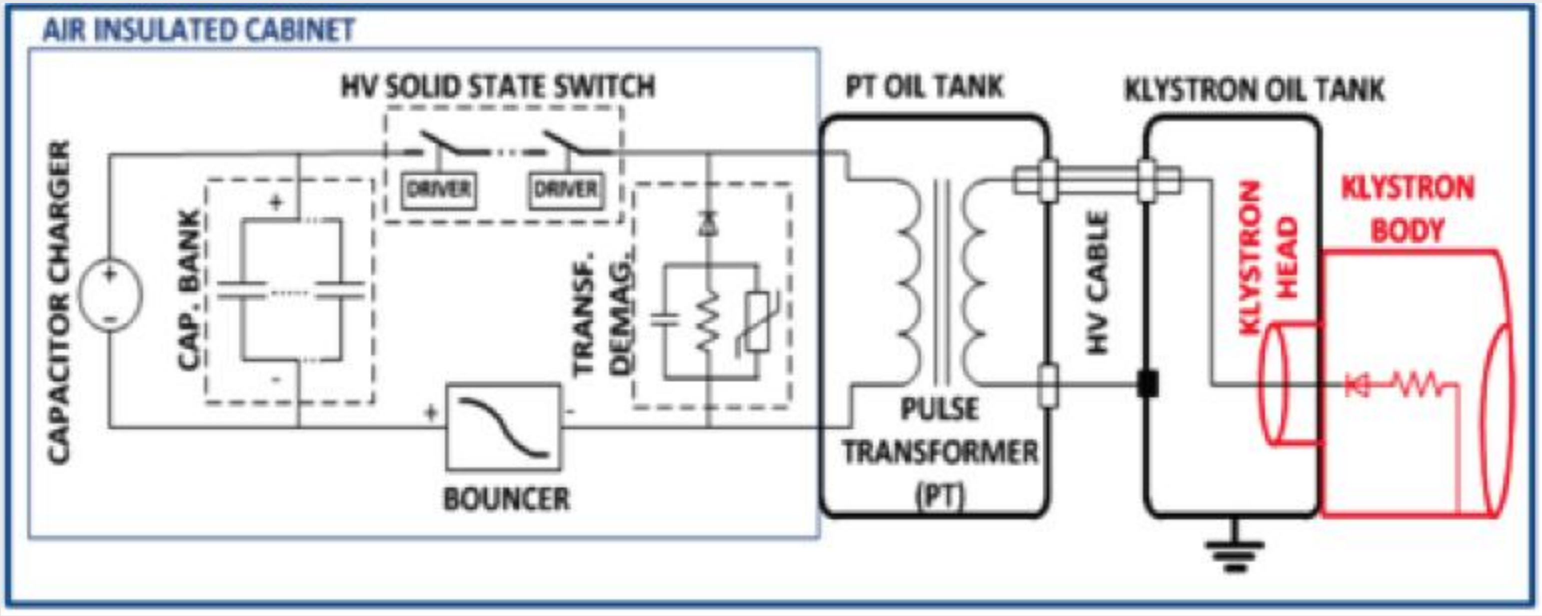
LINAC4

- CERN Modulator Strategy
  - LINAC will be part of critical accelerator infrastructure
  - Need internal competence in HV pulsed technology

  - CERN chose to make the modulator design with support of industry for the series manufacture
    - 800us prototype for RFQ teststand operational in 2008
    - 800us prototype for cavity teststand operational in 2010 (collaboration with RRCAT)
    - 1.8ms prototype for LINAC4 operational in 2011

    - Production contract awarded in February 2012

- Capacitor discharge with bouncer droop compensation
  - Switch: [4kV, 1.8kA] from ABB.
  - Pulse transformer: [110kV, 50A, 1.8ms, 2Hz] from Stangenes Industries inc.



LINAC4

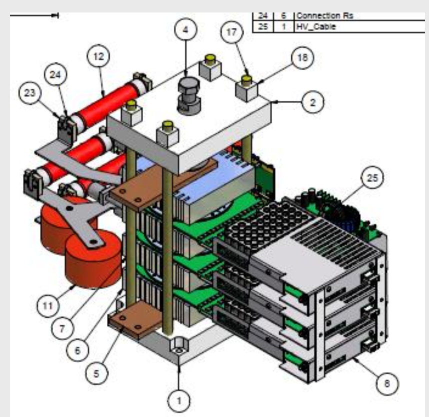
- Capacitor discharge with bouncer droop compensation

Advantages

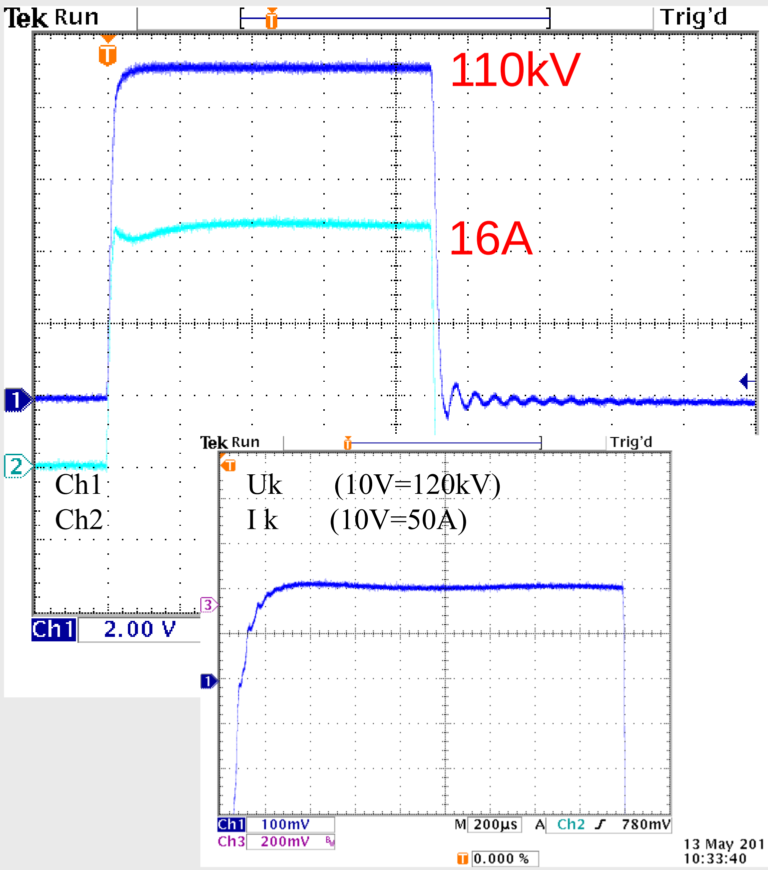
- The power circuit is simple and reliable.
- No voltage ripple on the flat-top
- All electronic active devices are at medium voltage level

Disadvantages

- Large pulse transformer and LC resonant bouncer for long pulses
- Limited number of suppliers for pulse transformer
- Not a ‘modular’ topology



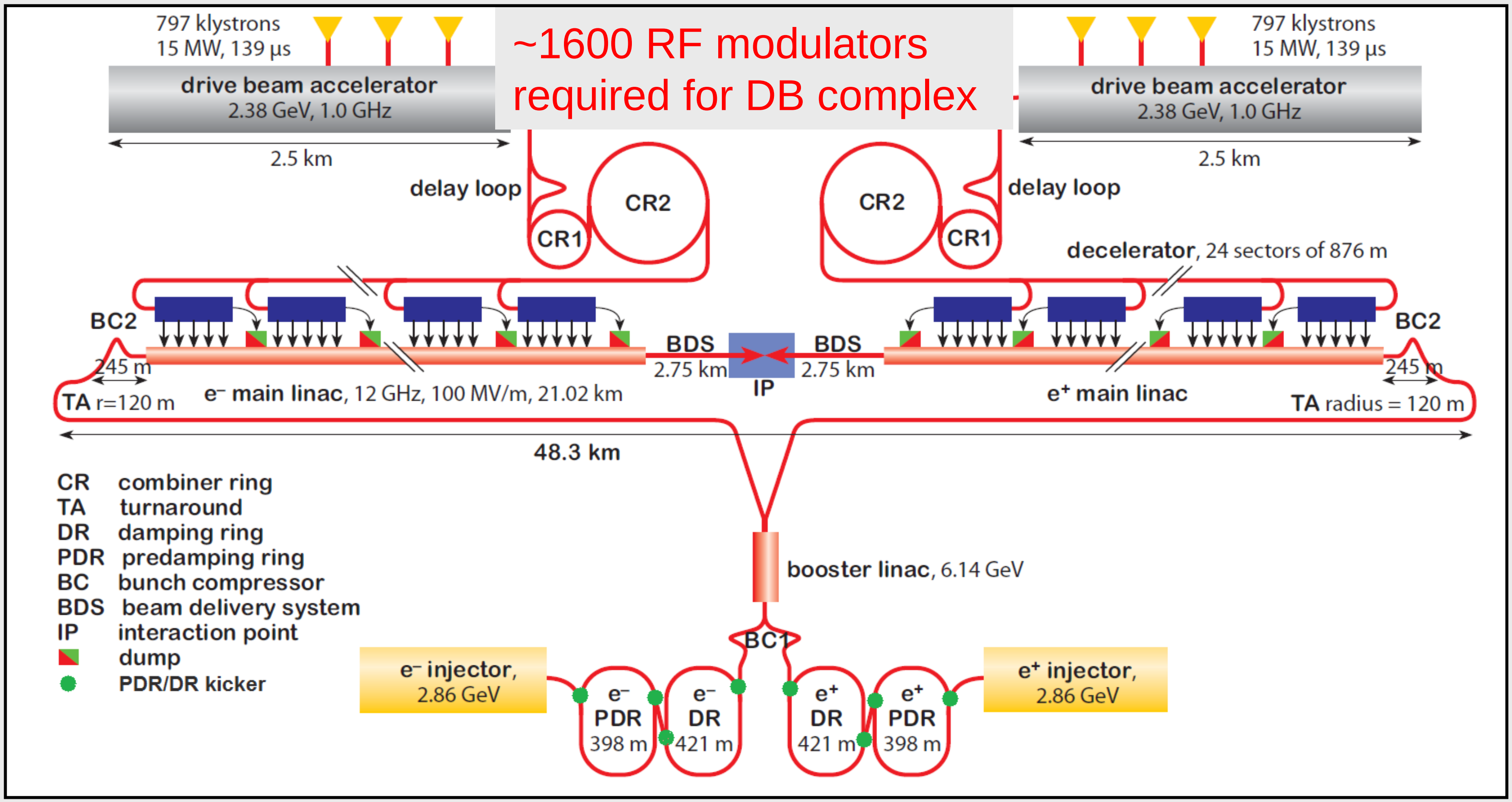
- Modulator prototype
  - [110kV, 50A, 1.8ms, 2Hz]



SPL Testbench

- CERN R&D in superconducting 704MHz cavities
  - Synergy with ESS requirements
  - ESS is contributing the modulator to the teststand
    - Industrial supply according to ESS/CERN specification
  - Contract awarded in Jan 2012 for supply of modulator
    - Capacitor discharge with bouncer droop compensation topology
    - [115kV, 25A, 2.8ms ,20Hz]
    - Specified to operate at [1.1ms ,50Hz] (constant average power)
    - Detailed design study ongoing
    - Delivery and commissioning expected in 2013

- CLIC : Drive Beam modulators



CERN Future projects - CLIC

- Drive Beam RF requirements

Peak power/klystron	15 MW
Train length after injection	140 μs
Repetition rate	50 Hz
Klystrons efficiency	65% (70% target)
Phase precision	0.05° @ 1 GHz (first 10% of the DB linac) 0.2° @ 1 GHz (next 90% of the DB linac)
Nb of klystrons (DB linac)	2x 797 = 1594

- Leads to demanding modulator requirements
  - pulse reproducibility (<10ppm) and its measurement
  - efficiency and low pulse rise time (>300MW total power in best case)
  - reliability (modular topologies with redundancy and low MTTR)

- R&D program to demonstrate technical solutions

CERN Future projects - CLIC

- Features of CLIC R&D program
  - Initiating collaboration with several institutions
  - Intend to build 2 full scale prototypes for 2017
  - The prototypes will use different modulator topologies

  - Important to have the right to use intellectual property for subsequent production for CERN use

Modulator's output pulse specification			
Nominal pulse voltage	V_{kn}	150	kV
Nominal pulse current	I_{kn}	160	A
Pulse peak power	P_{mod_out}	24	MW
Rise & fall times	t_{rise}, t_{fall}	3	μs
Settling time	t_{set}	5	μs
Flat-top length	t_{flat}	140	μs
Repetition rate	$REPR$	50	Hz
Voltage overshoot	V_{ovs}	1	%
Precisions			
Flat-Top Stability	FTS	0.85	%
Reproducibility (6kHz-4MHz)	PPR	10	ppm
Efficiencies			
Charger electrical efficiency	η_{ch}	96	%
PFS electrical efficiency	η_{pfs}	98	%
Pulse efficiency	η_{pulse}	95	%
Modulator global efficiency	η_{mod_global}	90	%

Comparison of Modulators

- ESS requirements v CERN long-pulse requirements

	ESS	SPL	LINAC4	CLIC
Max power/modulator	5 MW	2.9 MW	5.5 MW	23 MW
Average Power	270 kW	180 kW	20 kW	200 kW
Nominal voltage	100 kV	115 kV	110 kV	>150 kV
Pulse length	3.5 ms	2.8 ms (1.1ms)	1.8 ms	0.15 ms
Repetition rate	14 Hz	20 Hz (50 Hz)	2 Hz	50 Hz
Droop	1%	3%	1%	<1%
Nb of modulators	~110	1	14	~1600

In-house v commercial development

- In-house development allows CERN to confidently maintain and operate equipment for the long term
  - Enables personnel to be highly knowledgeable of technology in operation
  - Requires investment in people and test facilities

- When opting for industry solutions then important to be cautious of intellectual property and 'black box' approach
  - Can be problematic for long term operation of specialized equipment
  - However allows optimization of design for cost and production facilities

- LHC R&D and production model
  - Impose general topology
  - Purchase prototypes developed according to guidelines
  - Competitive tender on validated prototypes
  - All design data made available to CERN for long term support

Conclusion

- The ESS modulator requirements represents a similar financial investment as the power systems for the entire LHC!
  - The LHC powering was a 10year project from conception to installation
  - Due to good concept and design, excellent availability of power systems

- Experience both from CERN and other installations identify the modulator as an important contributor to machine reliability/availability
  - Appropriate topology choice and design effort is a good investment

- CERN is reviving competence in the design and specification of high voltage long-pulse modulators
  - LINAC4 facility will start beam commissioning in 2013
  - CLIC R&D will push specification and measurement boundaries
  - We look forward to following and supporting the ESS adventure, which has synergies with potential future projects (for example an SPL)