EUROPEAN SPALLATION SOURCE

Neutron Sources

PART 2

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European Spallation Source

Outline

PART 1

- Background for neutron course
- Neutrons properties and their interactions
- Applications using Neutrons

PART 2

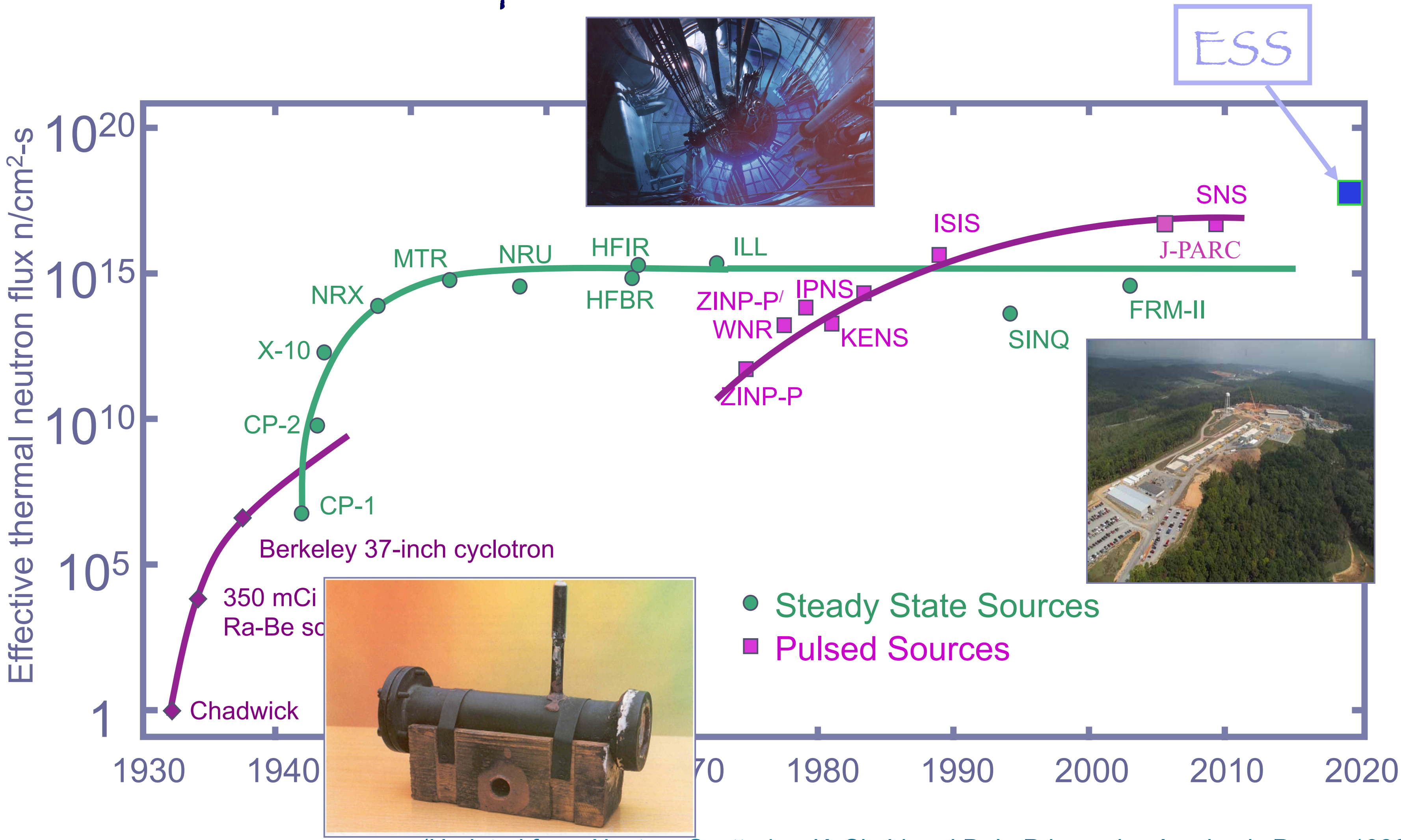
- How to generate intense neutron beams
- High power proton linear accelerator

PART 3

- Examples of world-wide neutron sources

High time average and peak flux

Evolution of the performance of neutron sources



(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

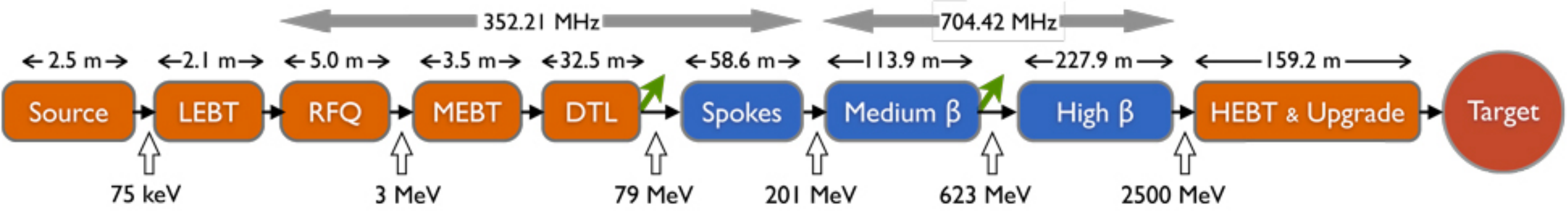
Example of the ESS accelerator

	Nominal	Upgrade
Average beam power	5.0 MW	7.5 MW
Macropulse length	2.86 ms	2.86 ms
Repetition rate	14 Hz	14 Hz
Proton energy	2.5 GeV	2.5 GeV
Beam current	50 mA	75 mA
Duty factor	4%	4%
Beam loss rate	< 1 W/m	< 1 W/m

Functional Requirements:

- Capacity to transfer energy from RF system to the beam,
- Capacity to confine the protons longitudinally,
- Capacity to steer the protons longitudinally,

The ESS accelerator



- Single pass linear accelerator
- Normal conducting
  - Electron cyclotron resonance source
  - Radio-frequency quadruple (RFQ)
  - Drift tube linac
- Superconducting
  - Double spoke resonator
  - Elliptical cavities (medium beta and high beta)

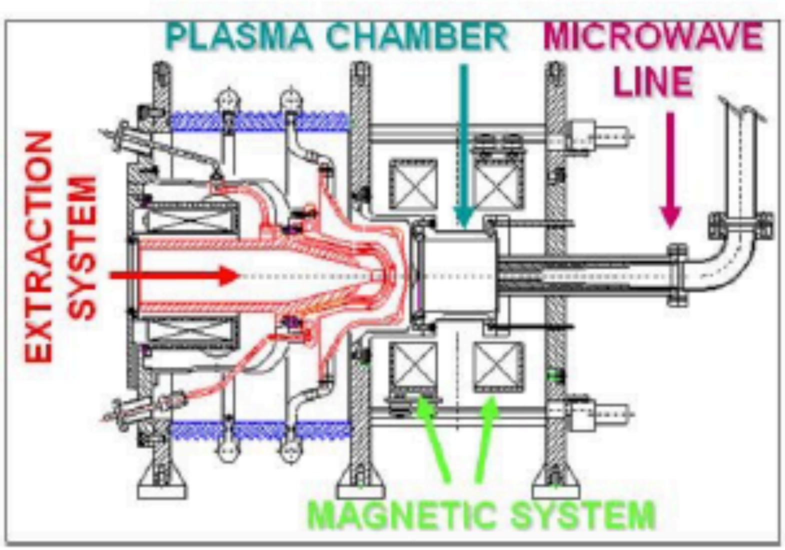
ESS beam parameters		
Beam current	I_b	50 mA
Pulse length	σ_p	$2.83*10^{-3}$ s
Pulse period	T_p	1/14 s
Number of bunches per pulse	N	$1.01*10^{6}$
Bunch frequency	F_b	352.21 MHz
Bunch period	T_b	$2.84*10^{-9}$ s
Charge per bunch	q_b	$1,42*10^{-10}$ C

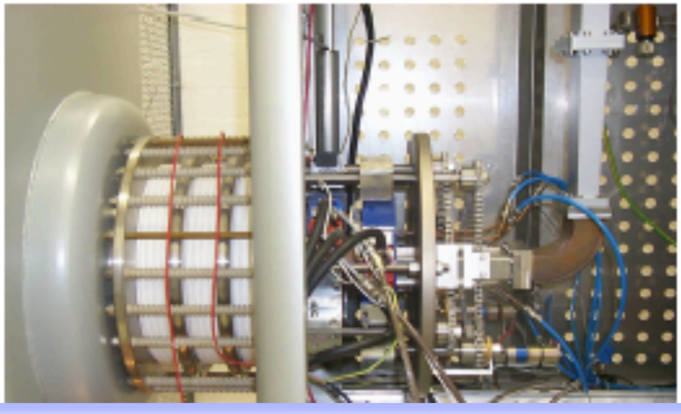
Proton source

Based on knowledge acquired with TRIPS, SILHI and VIS high intensity proton sources

	Status
Beam energy	80 keV
Proton current	55 mA
Proton fraction	≈80%
RF power, Frequency	Up to 1 kW @ 2.45 GHz
Axial magnetic field	875-1000 G
Duty factor	100% (dc)
Extraction aperture	6 mm
Reliability	99.8% @ 35mA (over 142 h)
Beam emittance at RFQ entrance	0.07πmmmrad @ 32 mA

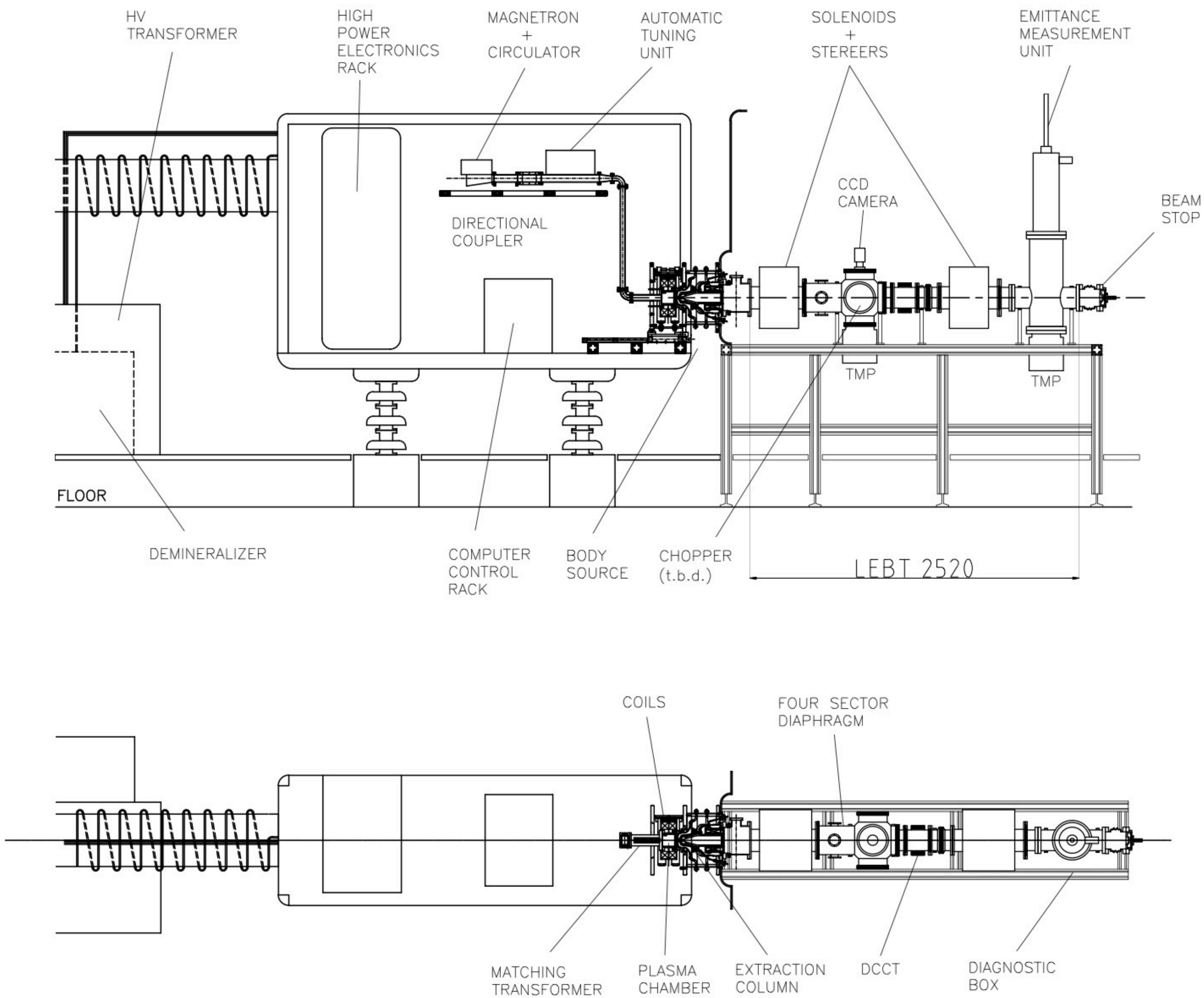
TRIPS



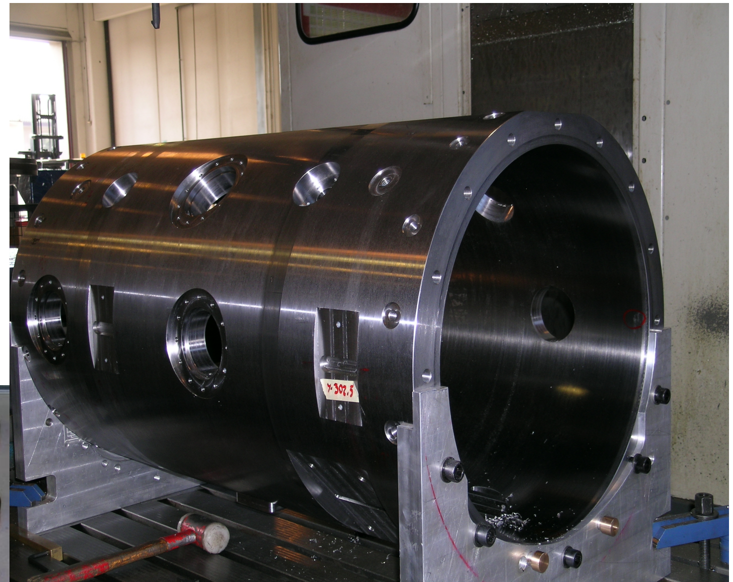


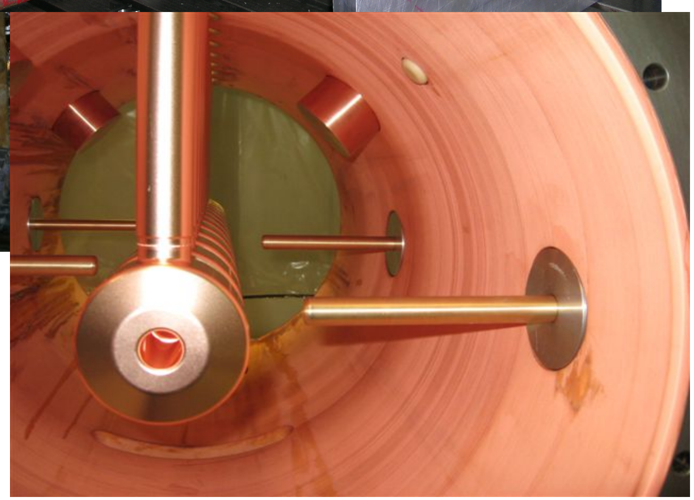
- Movable magnetic system composed by two solenoids
- Five electrodes extraction system

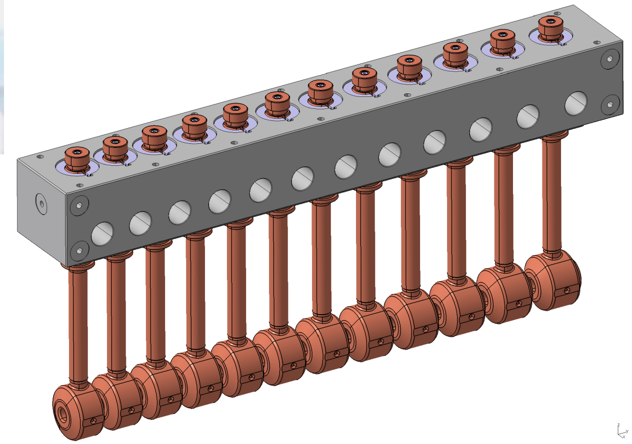
Proton source & LEBT

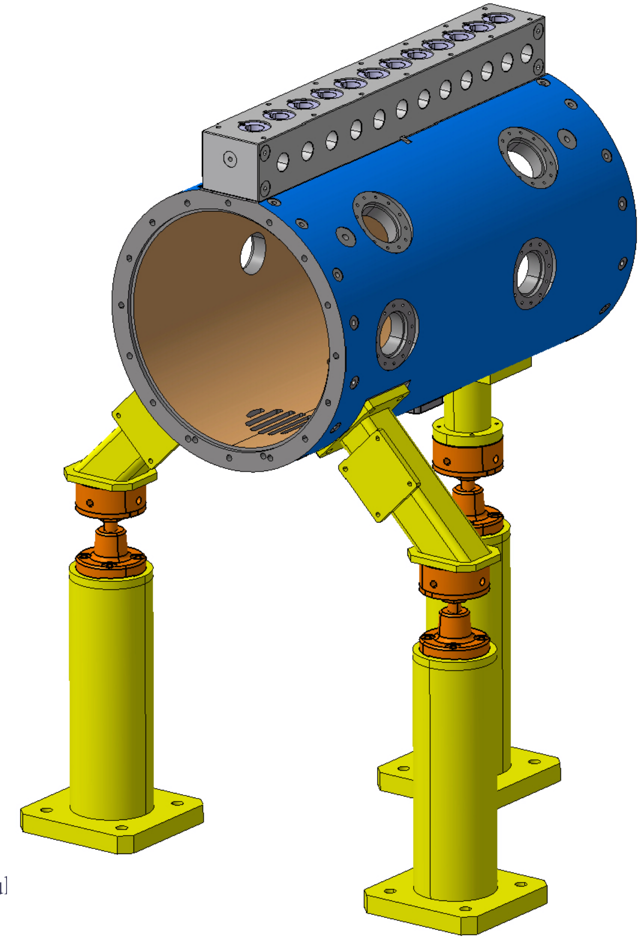


DTL prototype







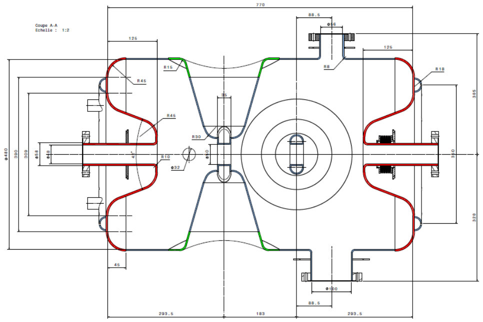


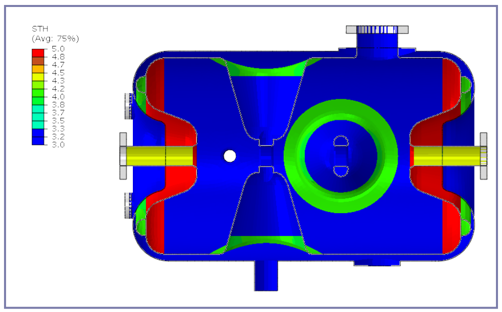
Tank machining at Cinel (Vigonza-Italy)

SC. Spoke Resonator and Elliptical Cavities

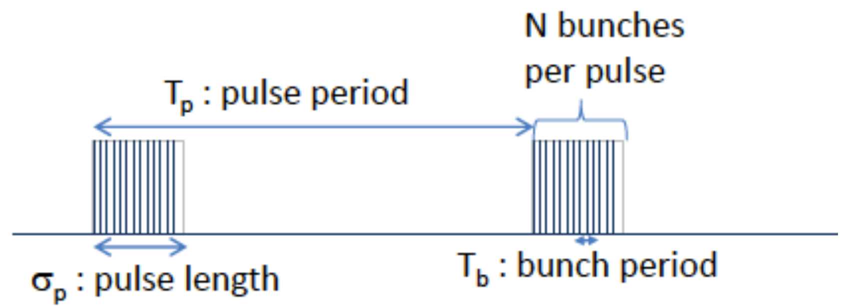
Spoke Resonator

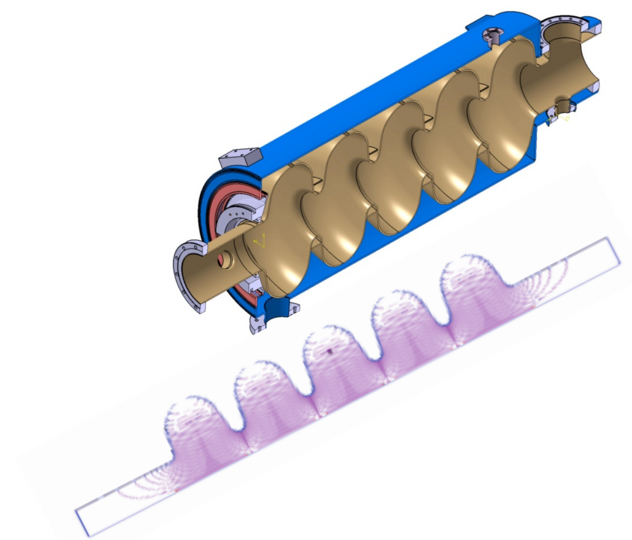
Cavity RF parameters	
R/Q	426 W
G	130 W
Q_o at 4K	2.6 10^9
Q_o at 2K	1.2 10^{10}
E_{pk} / E_{acc}	4.43
B_{pk} / E_{acc}	7.08



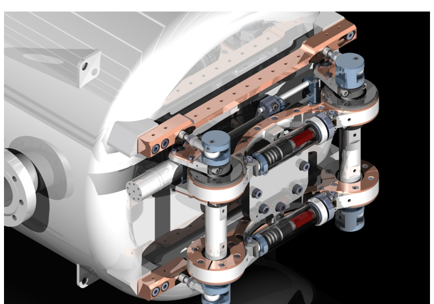


Elliptical Cavities



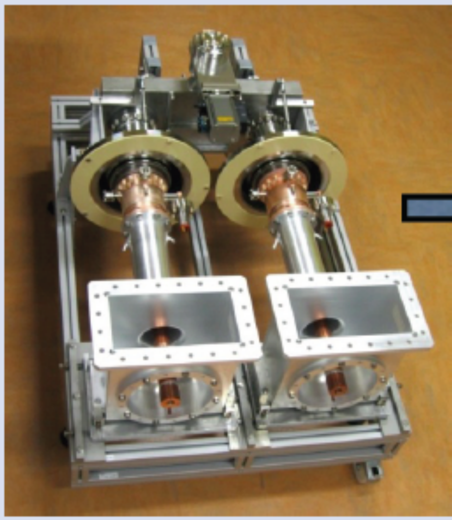


Tuning system

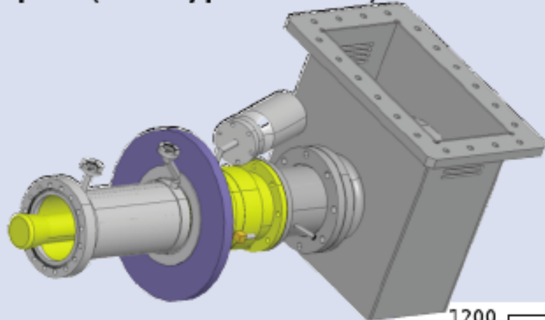


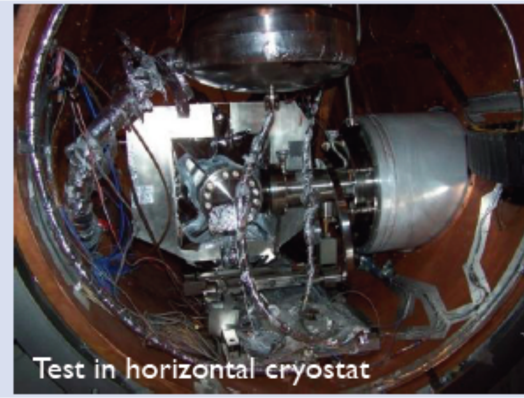
Power coupler

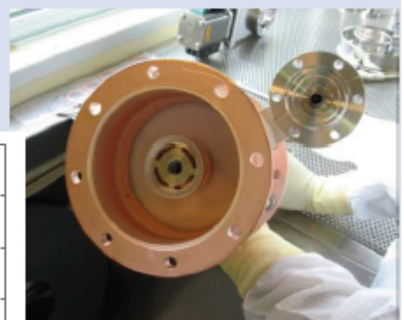
Power coupler design

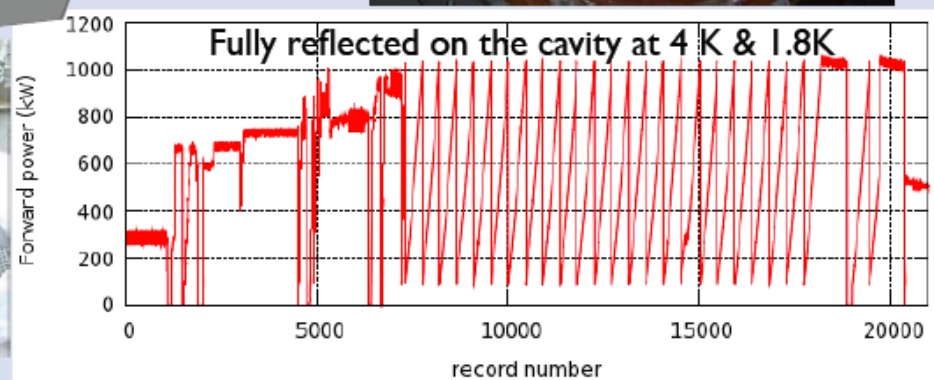


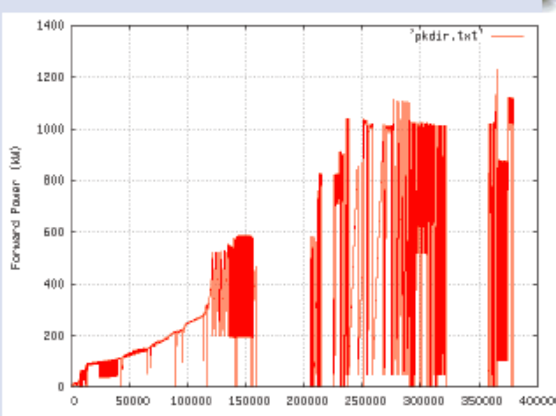
Starting from Saclay HIPPI 1MW 10%DC coupler (KEK type window)









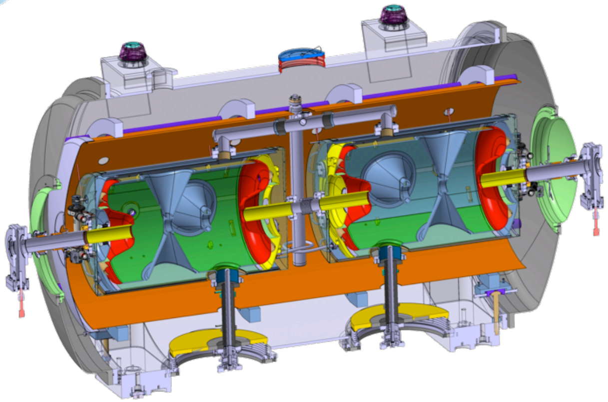


TW conditioning up to 1.2 MW 10%DC

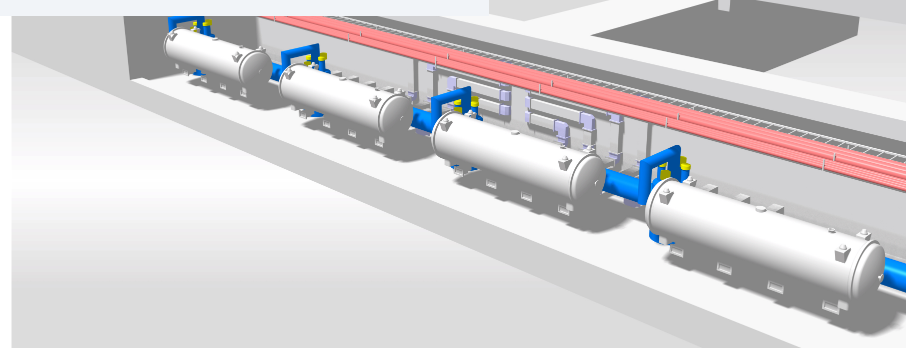
Current activities:

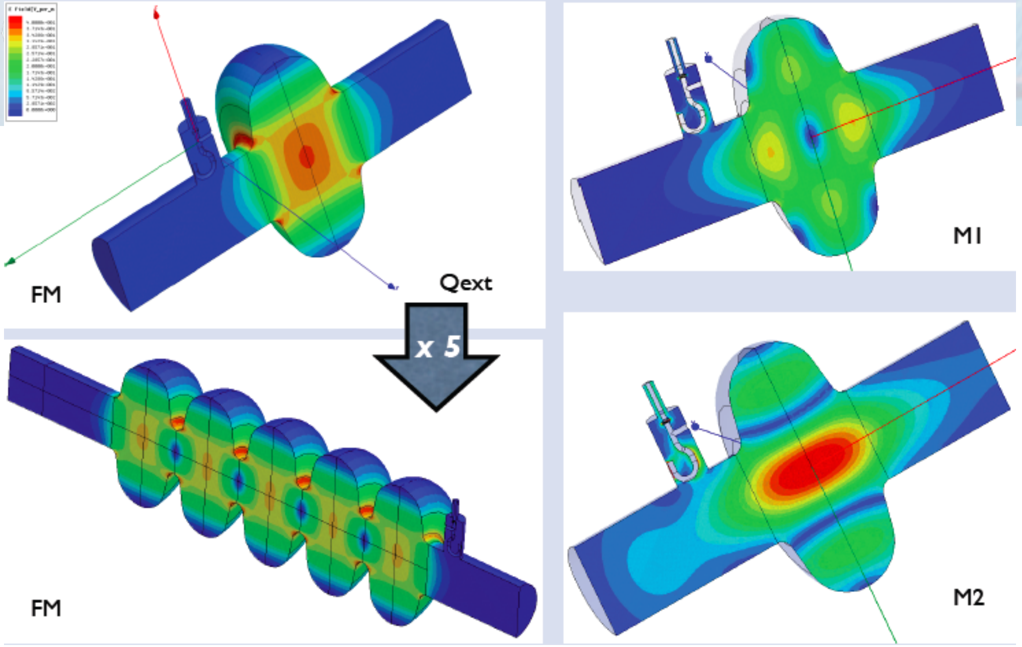
- Evaluation of maximum admissible peak power of Saclay HIPPI power coupler in SW and TW regime
- Study of antenna HV biasing started
- Starting thermo-mechanical calculations for air cooling assessment (tested up to 25kW average full reflection in horizontal cryostat)

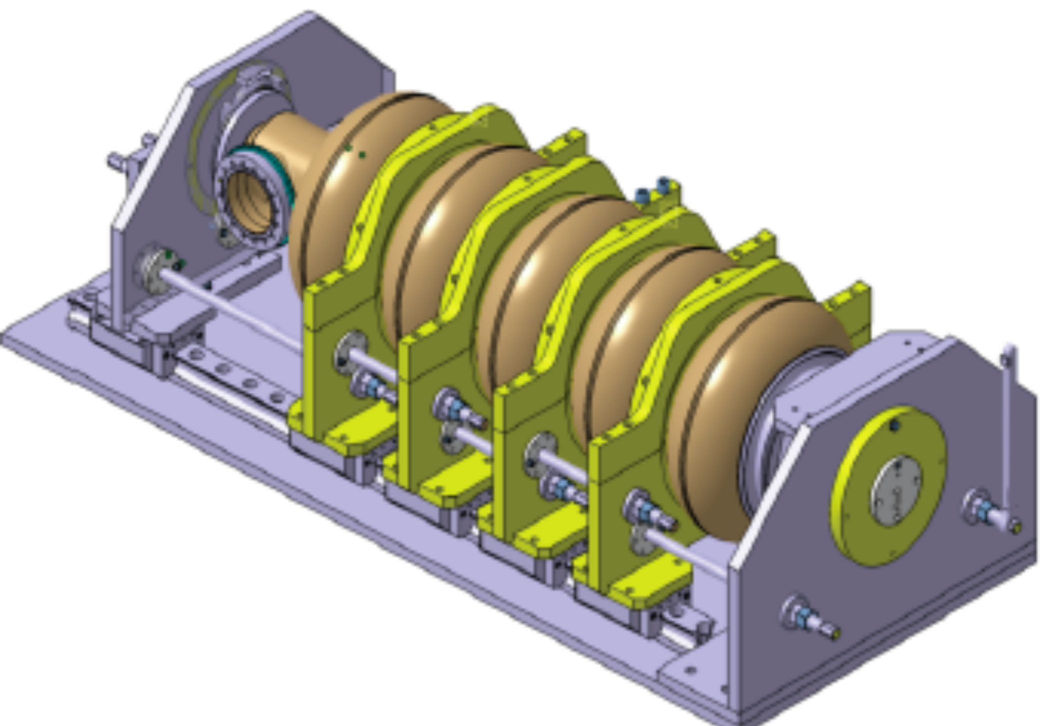
Cryomodules



	Length (m)	Input Energy (MeV)	Frequency (MHz)	Geometric β	# of Sections	Temp (K)
LEBT	2.05	75×10^{-3}	--	--	--	≈ 300
RFQ	4.95	75×10^{-3}	352.21	--	1	≈ 300
MEBT	3.53	3	352.21	--	--	≈ 300
DTL	32.58	3	352.21	--	4	≈ 300
Spoke	58.46	79	352.21	0.50	14 (2C)	≈ 2
Medium Beta	113.84	201	704.42	0.67	15 (4C)	≈ 2
High Beta	227.86	623	704.42	0.92	15 × 2 (4C)	≈ 2
HEBT (Projection)	158.66	2500	--	--	--	--

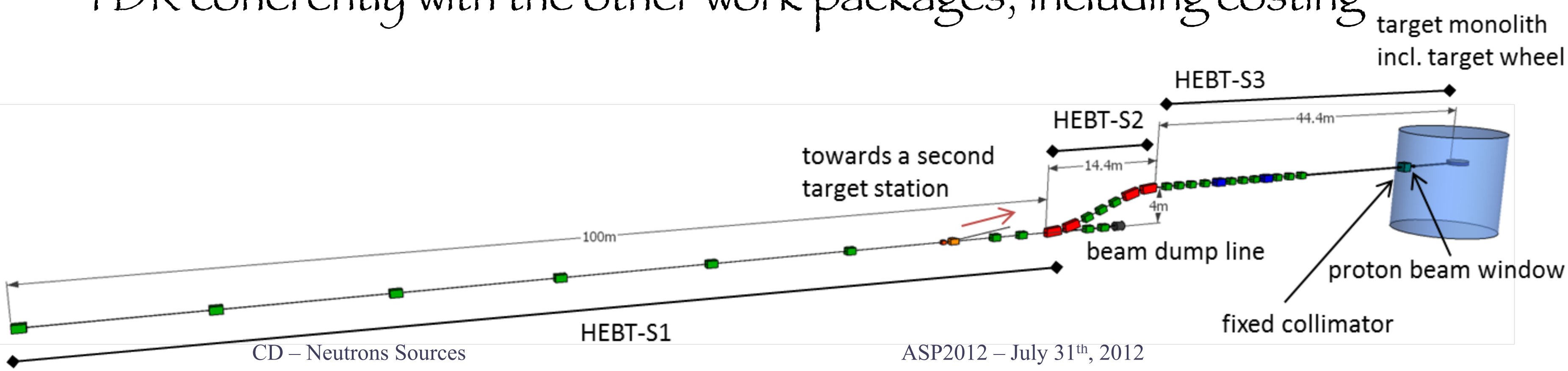



FM
Qext
x 5
M1
FM
M2

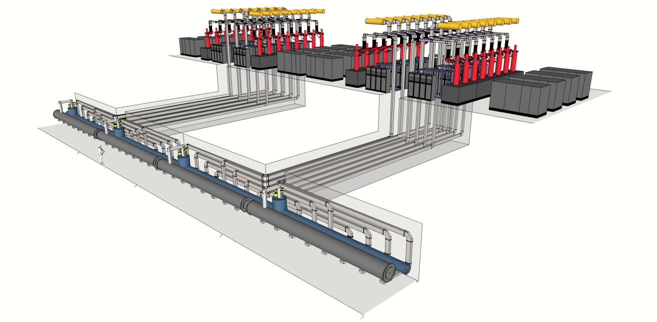


HEBT, magnets and power supplies

- Several optical designs of the High Energy Beam Transport system have been developed during the evolvement of the ADU project.
- The present design fulfill the requirements including layout geometry and the $6 \times 16 cm^2$ beam footprint on target with a sufficiently low maximum current density to ensure a long target lifetime.
- The technologies to be used for building the magnets and power supplies have been studied including aspects of handling and optimization of power consumption.
- The issues in 2012 consist of completing the many details to go into the TDR coherently with the other work packages, including costing



RF systems



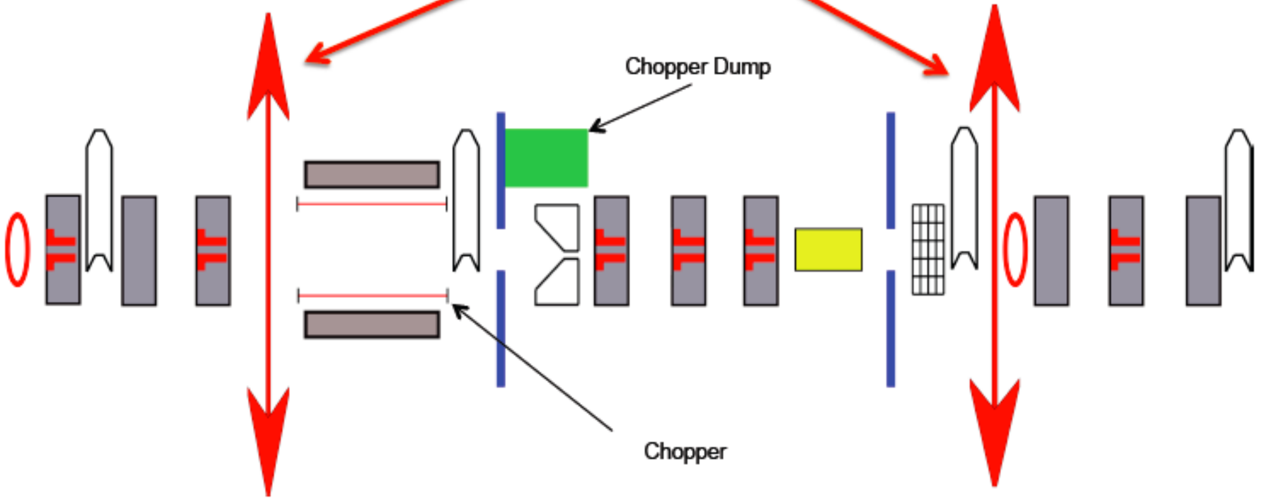
- Main Challenges
  - Large number or resonators (>200)
  - Large beam loading ($Q_L < 7x10^5$)
  - Large Lorentz de-tuning (>50 degrees)
  - Long Pulse length (3 mS ~3 Lorentz detuning time constants)
  - Large dynamic range in power (elliptical cavities range from 50kW – to 900kW)
  - Large average power (15 MW of AC power)

- Main Features
  - One RF power source per resonator
  - RF Sources
    - Pulsed cathode klystrons for elliptical, DTL, and RFQ
    - Gridded tube for spokes (IOTs)
  - Two klystrons per modulator for elliptical
  - 30% overhead for RF regulation
    - Adaptive low level feed-forward algorithms and Low gain feedback
    - High bandwidth piezo tuners on superconducting cavities
  - Bundled waveguide stub layout

Integrated Control System for ESS

- Decision to have a single integrated control system for ESS
  - EPICS based
  - ITER control box concept
- Achievements:
  - Control Box prototype running at ESS
  - Naming Convention with tools implemented
  - Working Development Environment and prototype ESS CODAC
  - Well defined Safety / Protection system architecture
  - Parameter List tools developed
  - Interfaces with the Instrument Controls defined
  - BLED database for parameters
- Issues:
  - Target Safety System and Infrastructure Controls requirements immature
  - Fast data acquisition for Accelerator AND Instruments?
  - ICS scope not resourced

ESS Instrument



	BPM (position and TOF)		SEM grid
	Wire scanner		BCT
	BSM		Slit
	Collimator		Quad

Beam Diagnostics

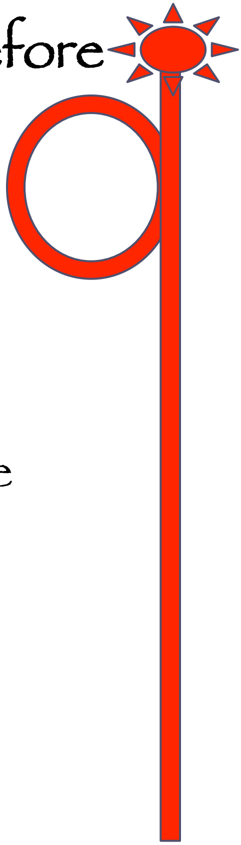
Main topics addressed: modeling codes, radiation issues, longitudinal and transverse measuring techniques

Main message: more diagnostic equipment than envisaged

- ✓ The primary linac diagnostic needs include **beam position**, **beam arrival time** (or phase), **beam bunch length**, **beam transverse profiles**, and **beam loss**.
- ✓ Especially important for high power operation are **sensitive beam loss measurement** and **profile resolution** over a wide dynamic range.
- ✓ Techniques for **halo measurement** in a superconducting environment need to be developed.

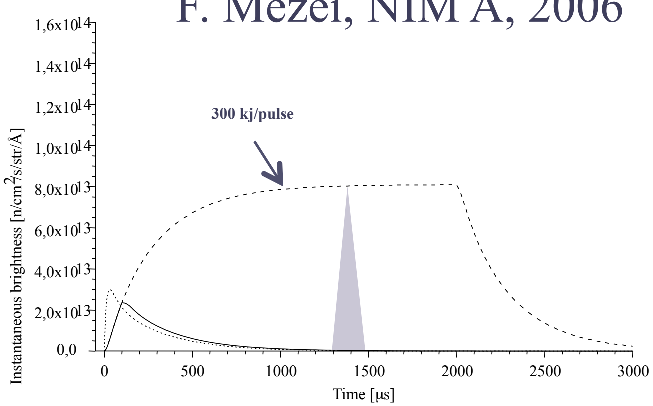
Long Pulse and cold neutrons

- Many research reactors in Europe are aging and will be closed before 2020
  - Up to 90% of the use is with cold neutrons
- There is a urgent need for a new high flux cold neutron source in Europe
  - The vast majority of users will profit from a pulsed structure
  - A large fraction of the users are fully satisfied by a long pulse source (approx 2 ms, 20 Hz)
  - Existing short pulse sources (ISIS, JPARC and SNS) can supply the present and imminent future need of short pulse users

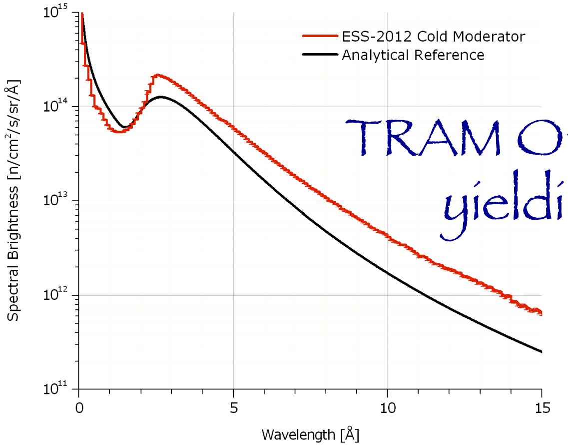


> "Pulsed cold neutrons will always be long pulsed as a result of the moderation process"

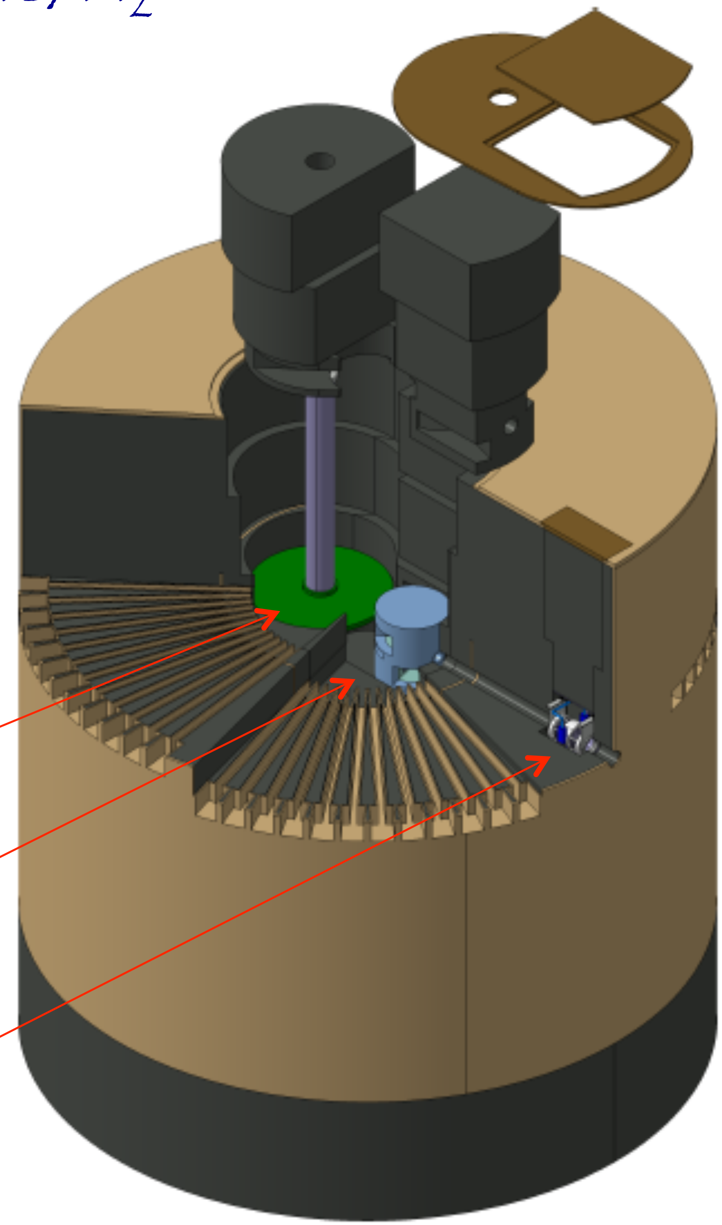
F. Mezei, NIM A, 2006



Target Station W/He/H_2



TRAM Optimization yielding gains



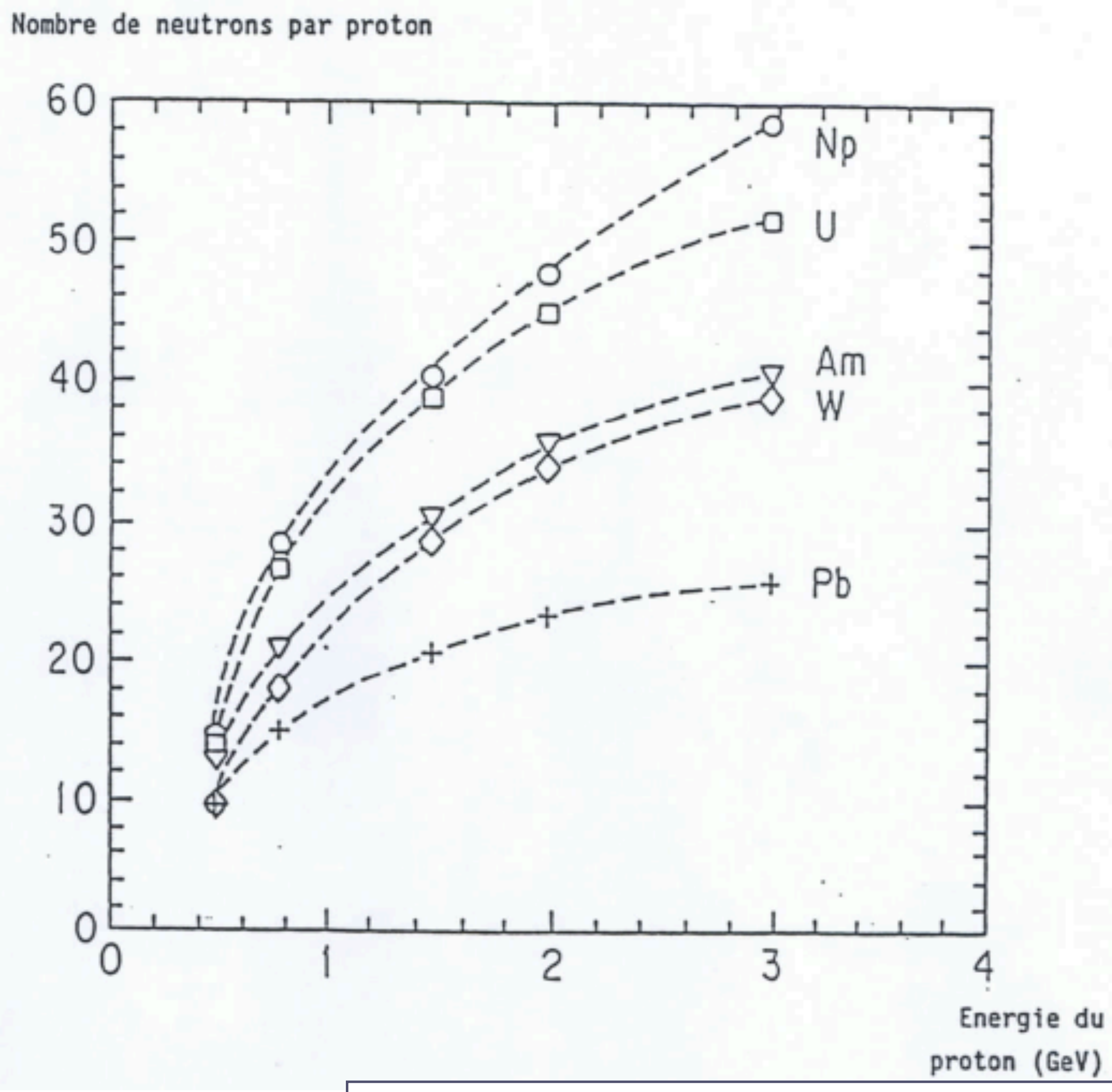
Target monolith during target change

Target wheel

Moderator-reflector plug

Accelerator proton beam window

Spallation : choice of target materials



$$Y(E,A)=0.1\ [A+20]\ [E\ (GeV)\ -0.12)]\ \ n/p$$

Rotating tungsten target with He cooling

- Lower radioactive inventory than for water (^{7}Be, ^{3}H, Ta cladding, W activation,…)

- Proven passive cooling capability of afterheat in case of power loss (even for earthquake and 10 MW power)

- Passive backup shutdown of accelerator: better chance for He

- Lower risk for being qualified as nuclear facility than for water

→ He gas cooling is the prime candidate for the legally mandated choice of adopting the environmentally most favourable of the viable options.