IP-EUROTRANS
- INTEGRATED PROJECT ON EUROPEAN TRANSMUTATION -

SIXTH FRAMEWORK PROGRAMME

Status of the EUROTRANS R&D activities for ADS accelerator development

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Accelerator Driven Systems

1. **Overall purpose**
   - Reduce the nuclear waste radiotoxicity & volume before underground storage
   - 2500 tons of spent fuel are produced every year by the 145 EU reactors

2. **Available strategy**
   - Partitioning : chemical separation of Pu, MA & FP
   - Transmutation : use of the waste as a fuel in dedicated transmuter systems

3. **The ADS transmuter system**
   - A subcritical reactor (k<1), in which the chain reaction is not self-sustained
   - An intense spallation source, that provides the "missing" neutrons

From ETWG Report, 2001

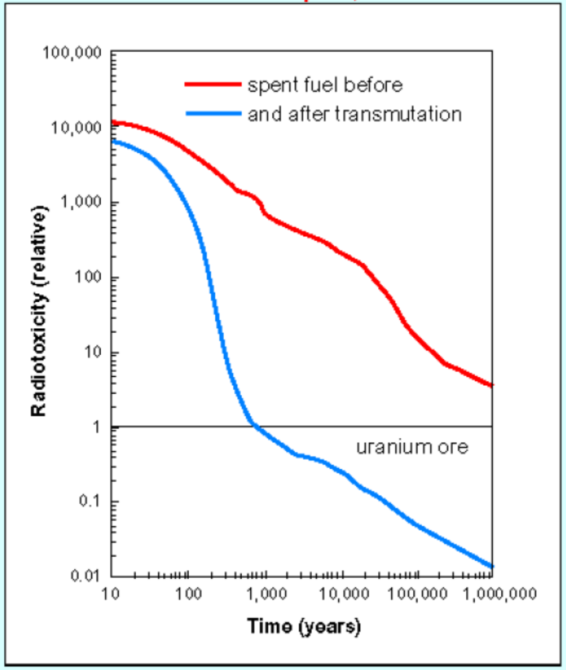


Fig. 1 – Ingestion radio-toxicity of 1 ton of spent nuclear fuel. With a separation efficiency of 99.9% of the long-lived by-products from the waste, followed by transmutation, reference radio-toxicity levels can be reached within 700 years

The EUROTRANS programme

- **EURopean research programme for the TRANSmutation of high level nuclear waste in an Accelerator Driven System**
- EU FP6 programme (2005-2009)
- 31 research agencies & industries, 16 universities
- Expands the EU FP5 project PDS-XADS (2001-2004)
- 5 Domains (DM1=Design, ...)

Main GOAL of the EUROTRANS programme

- Advanced design of a 50-100 MWth eXperimental facility demonstrating the technical feasibility of Transmutation on an ADS **(XT-ADS, short-term realisation)**
- Generic conceptual design (several 100 MWth) of a European Facility for Industrial Transmutation **(EFIT, long-term realisation)**

European Transmutation Demonstration

1. XT-ADS (ADS prototype)

- Goals:
  - **Demonstrate the concept** (coupling between accelerator, spallation target & reactor),
  - **Demonstrate the transmutation**
  - **Provide an irradiation facility** and an EFIT test bench
- Features:
  - 50-100 MWth power
  - Keff around 0.95
  - 600 MeV, 2.5 mA proton beam (or 350 MeV, 5 mA)
  - Conventional MOX fuel
  - Lead-Bismuth Eutectic coolant

2. EFIT (Industrial Transmuter)

- Goals:
  - Maximise the transmutation efficiency
  - Easiness of operation and maintenance
  - High level of availability for a cost-effective transmutation
- Features:
  - Several 100 MWth power
  - Keff around 0.97
  - 800 MeV, 20 mA proton beam
  - Minor Actinide fuel
  - Lead coolant (gas as back-up solution)

Accelerator main specifications

High-power proton CW beams

Table 1 – XT-ADS and EFIT proton beam general specifications

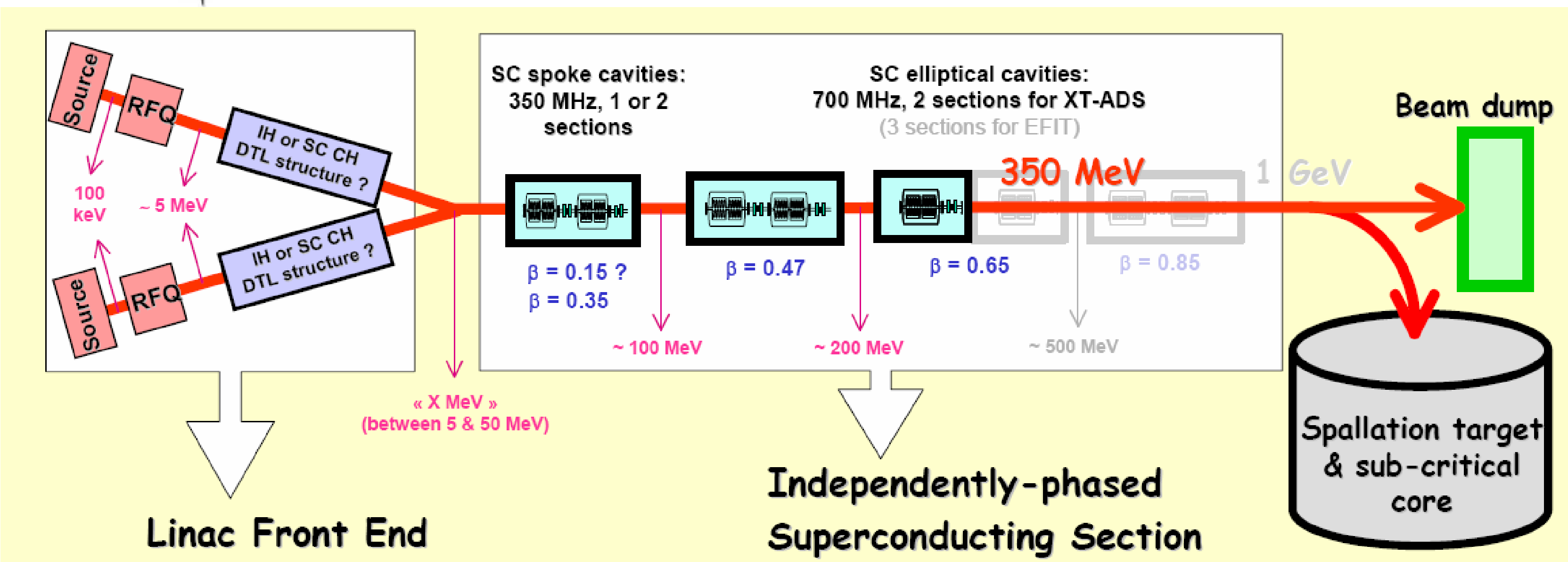
	XT-ADS	EFIT
Maximum beam intensity	2.5 – 4 mA	20 mA
Proton energy	600 MeV	800 MeV
Beam entry	Vertically from above	
Beam trip number	< 20 per year (exceeding 1 second)	< 3 per year (exceeding 1 second)
Beam stability	Energy: ± 1 %, Intensity: ± 2 %, Size: ± 10 %	
Beam footprint on target	Circular ∅ 5 to 10 cm, "donut-shaped"	An area of up to 100 cm² must be "paint-able" with any arbitrary selectable intensity profile
Beam time structure	CW, with 200 μs zero-current holes every 10^{-3} to 1 Hz, + pulsed mode capability (repetition rate around 50 Hz)	

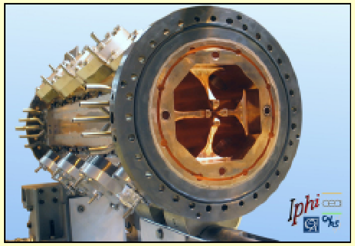
Extrememely high reliability is required !!!

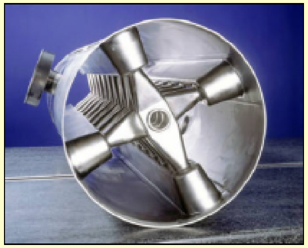
ADS accelerator reference scheme

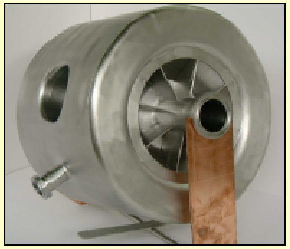
PDS-XADS

Superconducting linac: Highly modular and upgradeable (same concept for prototype & industrial scale) ; Excellent potential for reliability ; High efficiency (optimized operation cost)









Reliability aspects

- **Beam trips longer than 1 sec are forbidden** to avoid thermal stresses & fatigue on the ADS fuel & assembly : less than 5 per 3-month operation cycle (XT-ADS)

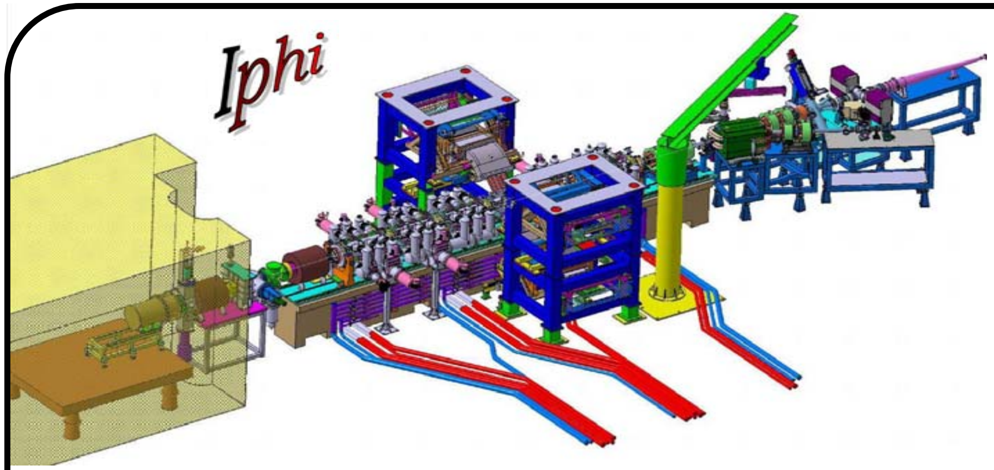
- **Reliability guidelines have been followed during the ADS accelerator design**

1. Strong component design & derating
   - All components are derated with respect to technological limitations
   - For every linac main component, a prototype is being designed, built and tested within the EUROTRANS programme
2. Inclusion of redundancies in critical areas
   - Front-end duplication, Solid-state RF power amplifiers where possible…
3. Capability of fault-tolerant operation
   - Expected in the highly modular superconducting RF linac (from ~20 MeV)
   - Implies reliable and sophisticated digital RF control systems with preset set points for implementation

5 reliability-oriented accelerator tasks

- **Task n°1 :** Experimental evaluation of the **proton injector** reliability
- **Task n°2 :** Assessment of the reliability performances of the **intermediate-energy** acceleration components
- **Task n°3 :** Qualification of the reliability performances of a **high-energy** **cryomodule** at full power and nominal temperature
- **Task n°4 :** Design of a prototypical **RF control system** for fault-tolerant operation of the linear accelerator
- **Task n°5 :** Overall coherence of the **accelerator design**, final reliability analysis, cost estimation for XT-ADS & EFIT

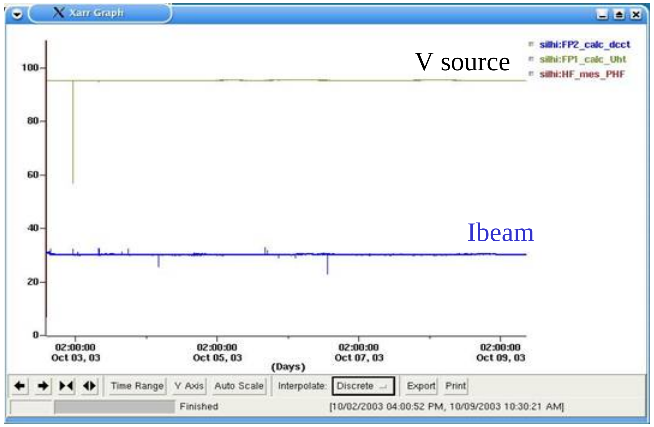
Task 1 – IPHI injector status



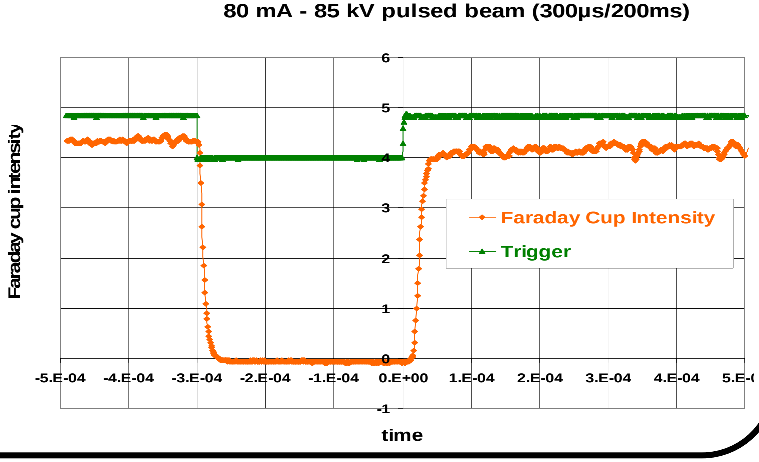
- SILHI Source operational (100 mA, 95 kV)
- LEBT tuned
- 3 MeV RFQ section 1 validated
- Fabrication of RFQ sections 2 to 6 on-going
- Installation of RFQ environment in progress
- Installation of diagnostic beam line in progress

Task 1 – Injector reliability tests

- **Real scale long reliability test run**
  - Once IPHI fully commissioned (mid 2008), the 3 MeV beam will be continuoulsy operated over a period of **2 months** with beam intensity 20-40mA
  - Previous tests on the SILHI source in past years show encouraging results : 162 hours run (30mA, 95keV CW beam) => 1 spark, no beam off, +/-0.2mA stability

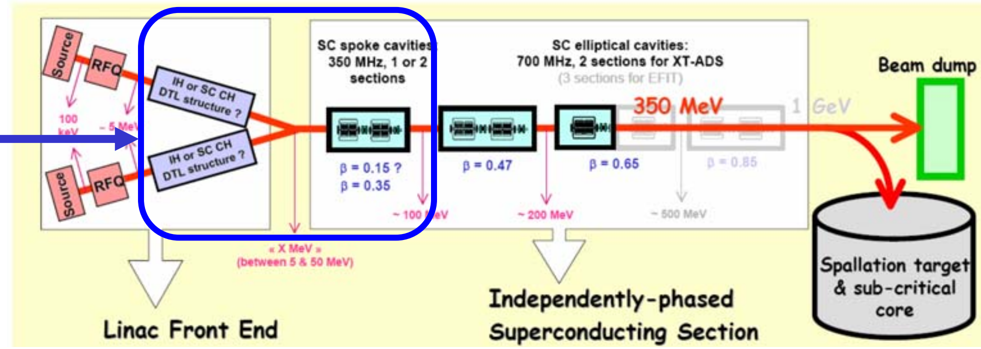


- **Short beam holes production**
  - Important issue for ADS technology = time structure with periodic 200us "beam holes" for on-line sub-criticality measurements
  - First successful tests on the SILHI source : Fall/Rise time: 20/30 us

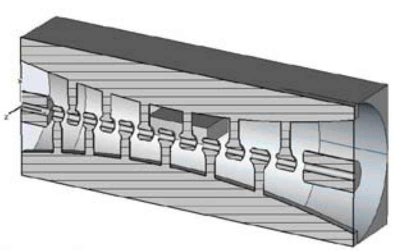


Task 2 – Intermediate-energy RF structures

Intermediate Energy Section
(3/5 MeV -> 100 MeV)



- **Several candidates to be tested & evaluated**
  - **Copper DTL IH structures** (front end) : high real estate (Konus BD)
  - **Superconducting multi-gap CH structures** (front end) : high real estate + RF efficiency
  - **Superconducting spoke cavities** (independently-phased linac) : modularity + RF efficiency
  - **Transition energy** to be optimised : 17 MeV ?



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Task 2 – Superconducting spoke cavities

Test of a fully equipped 350 MHz spoke cavity

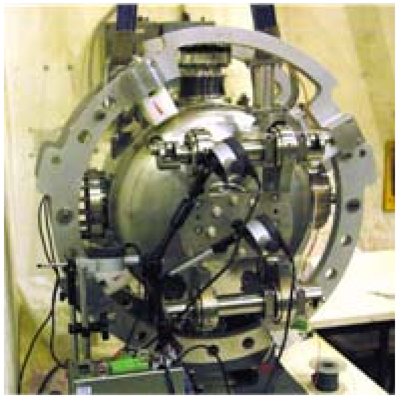
- β =0.15 spoke cavity prototype constructed and tested in vertical cryostat

- installation of the horizontal cryostat CM0 in progress

- power coupler ordered, tuner validated

- 10 kW solid-state RF amplifier ordered

- horizontal test in CM0 at high power in 2008



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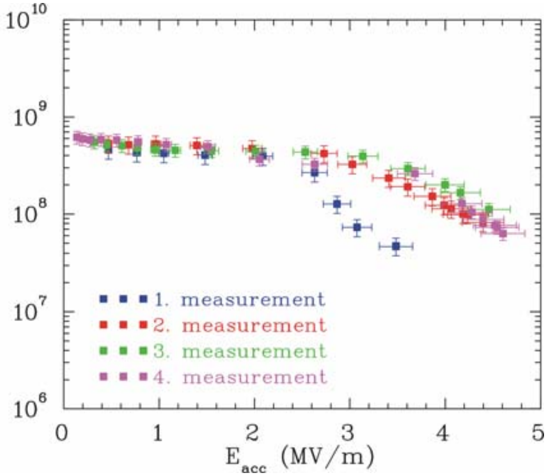
Task 2 – Superconducting CH structures

Test of a 350 MHz superconducting CH structure

- 19-gap prototype constructed
- several tests in vertical cryostat achieved
- tuner system development in progress
- horizontal cryostat adaptation in progress



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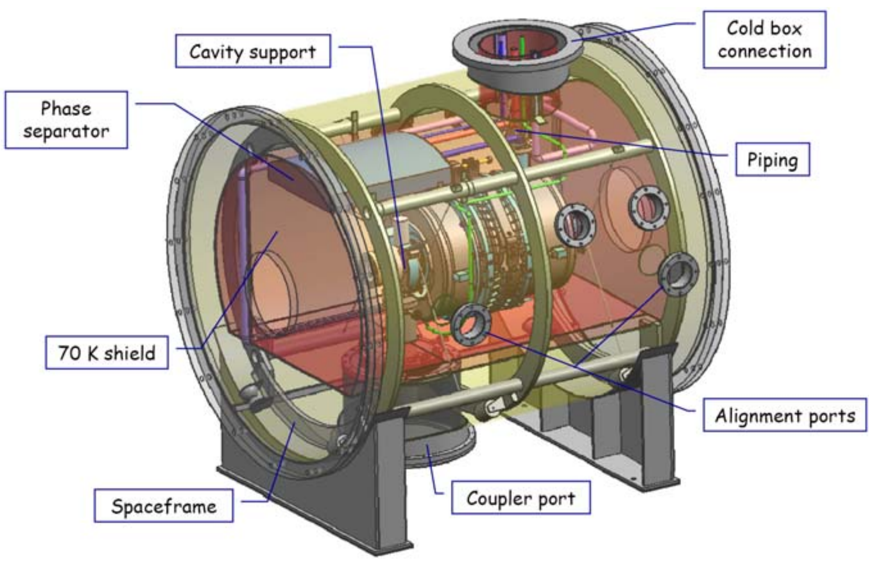
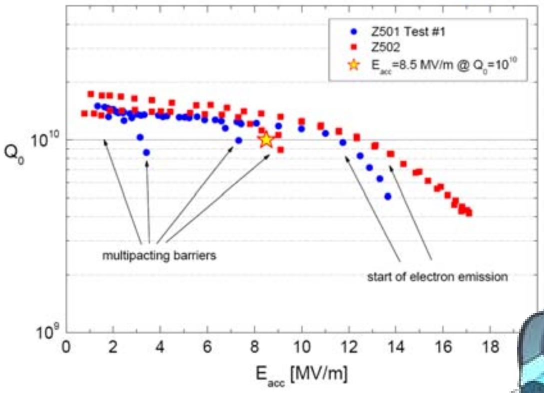
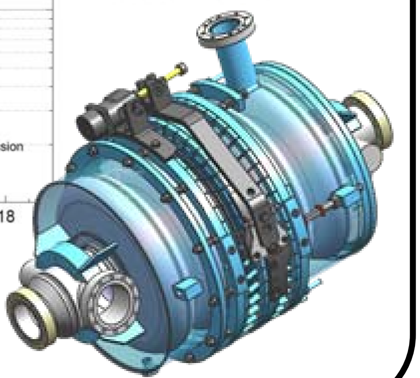
Task 3 – High-energy cryomodule

Design, fabrication & test of an elliptical module…

- β =0.47 prototype constructed and tested
- tuner system fabrication achieved
- cryomodule design in progress







Task 3 – High-energy cryomodule

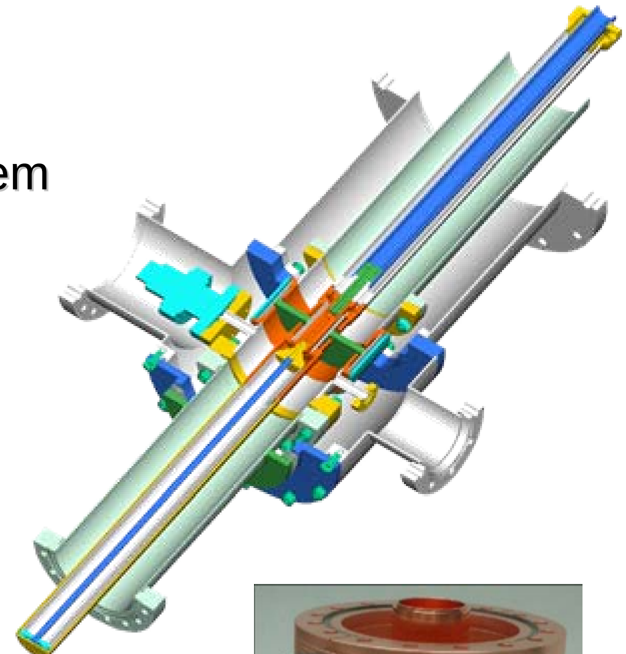
... at nominal power

- 150 kW CW RF power coupler under final design

- experimental validation of the coupler cooling system (He supercritical)

- 700 MHz RF power source (IOT 80 kW) ordered

- cryomodule test at high power in end 2008 - 2009



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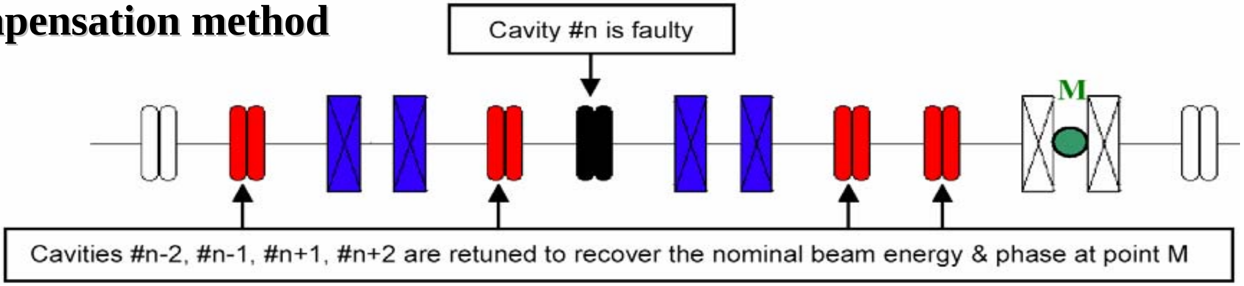
Task 4 – RF fault compensation

Fault-tolerance = ability to loose a RF cavity (or Q-pole) without loosing the beam

- Based on the local **compensation method**



- **Demonstrated** on the beam dynamics point of view in the **independently-phased linac**
- Requires up to 30% **margins** on fields and powers
- Need to identify & develop **fast failure recovery scenarios (<< 1 sec)**
  - Fast fault detection (and beam shut-down)
  - Fast communication between neighbouring LLRF systems
  - Fast update and tracking of the field/phase set-points (preset)
  - Adequate management of the tuner of the failed cavity
  - Beam recovery

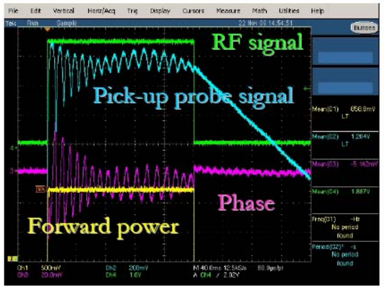
FPGA based

DIGITAL SYSTEM

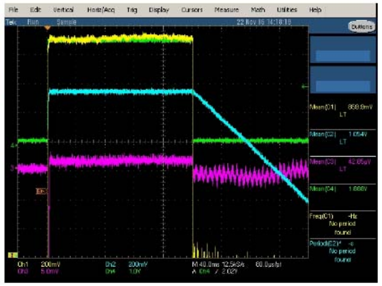
Task 4 – Digital LLRF control system

- It of course has also to reduce the effect of all perturbations (frequency fluctuations, beam loading transients…) below around **+/- 0.5% (fields) and +/- 0.5° (phase)**

- Successful preliminary tests at 350 MHz



Without regulation



With regulation

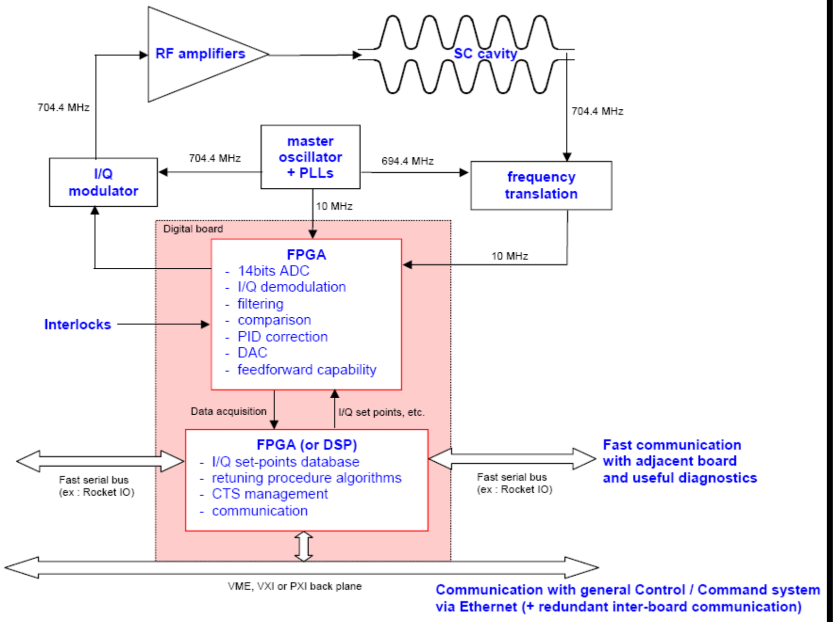
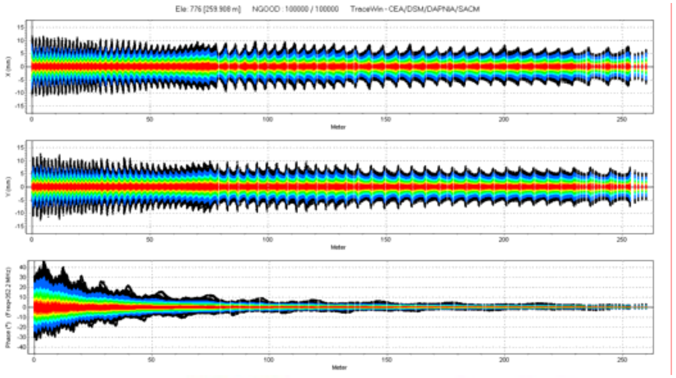


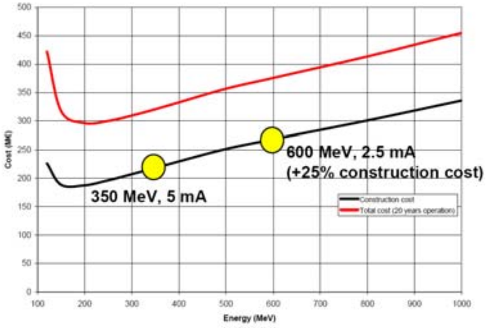
Figure 2 – Possible generic scheme for the XT-ADS digital RF feedback system.

Task 5 – Accelerator design

- **GOAL of this task**
  - Supervise the **overall coherence** of the accelerator design
  - Reach an **“as much as possible” frozen design with assessed reliability figure and costing in 2009**



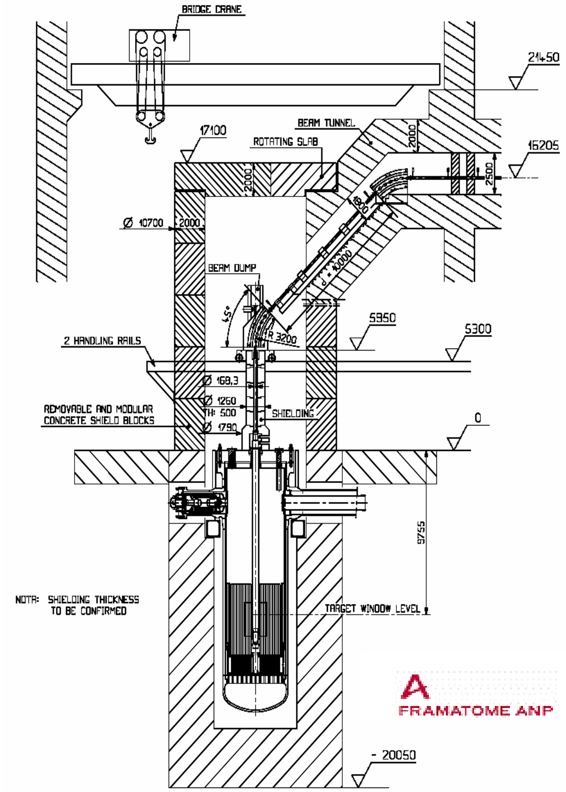
- **Beam dynamics simulations**
  - start to end simulations of different options for the intermediate-energy structures
  - modeling of beam transients induced by RF faults (implementation in TraceWin)



- **Preliminary costings**
  - Parametric study to test the energy dependance

Task 5 – Interface with the reactor

- **<u>Final beam tranport line</u>**
  - Connects the linac to the LBE spallation target
  - Guarantees the position of the beam spot and ensures that only particles of nominal energy are delivered (doubly-achromatic line)
  - Guarantees the shape and required distribution at the target (redundant beam scanning)



- **<u>Beam transients effect on fuel claddings and target</u>**
  - Preliminary studies show that beam holes up to 1 sec (from faults or for sub-criticality monitoring) have **negligible effects on core claddings**

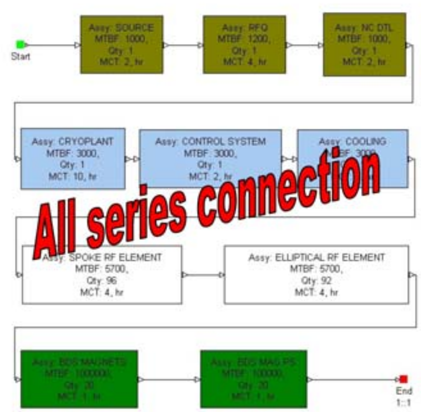
Task 5 – Integrated reliability analysis

- **Standard reliability analyses performed on the design**
  - **Failure Modes and Effect Analysis** (FMEA) performed on the whole linac to assess critical areas in the design with a bottom-up approach
  - **Reliability Block Diagram** (RBD) analysis to derive reliability estimations of different configurations from top-down, varying in the degree of redundancy and fault-tolerance

A preliminary reliability analysis of the system (PDS-XADS) shows that **the "less than a few beam trips per year" goal is REACHABLE**

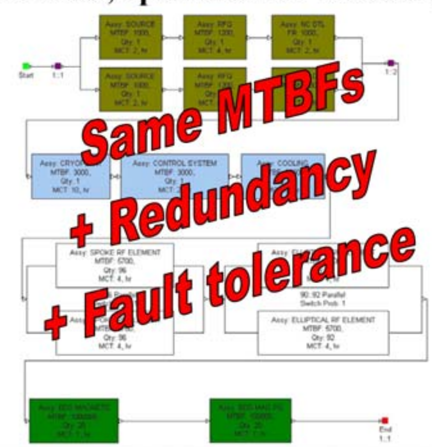
INFN

Classical linac



System MTBF	31.19 hours
Nb of failures (3 months)	**70.23**
Steady State Availability	86.6 %

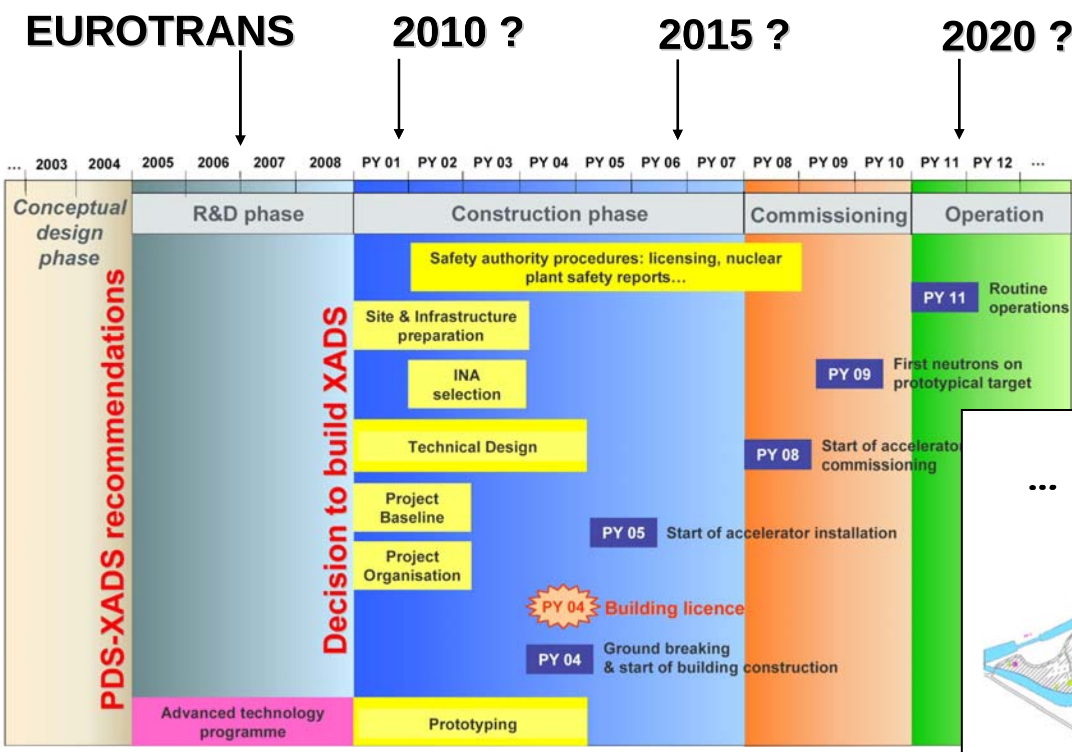
ADS linac, optimized for reliability



System MTBF	757.84 hours
Nb of failures (3 months)	**2.89**
Steady State Availability	99.5 %

Preliminary reliability estimations by P. Pierini, INFN

Beyond EUROTRANS…



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