Particle Therapy and accelerators:

part I: on reliability of accelerators

JUAS 2014

Here are the main slides used as support for the lecture

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Institut Curie

7th March 2014

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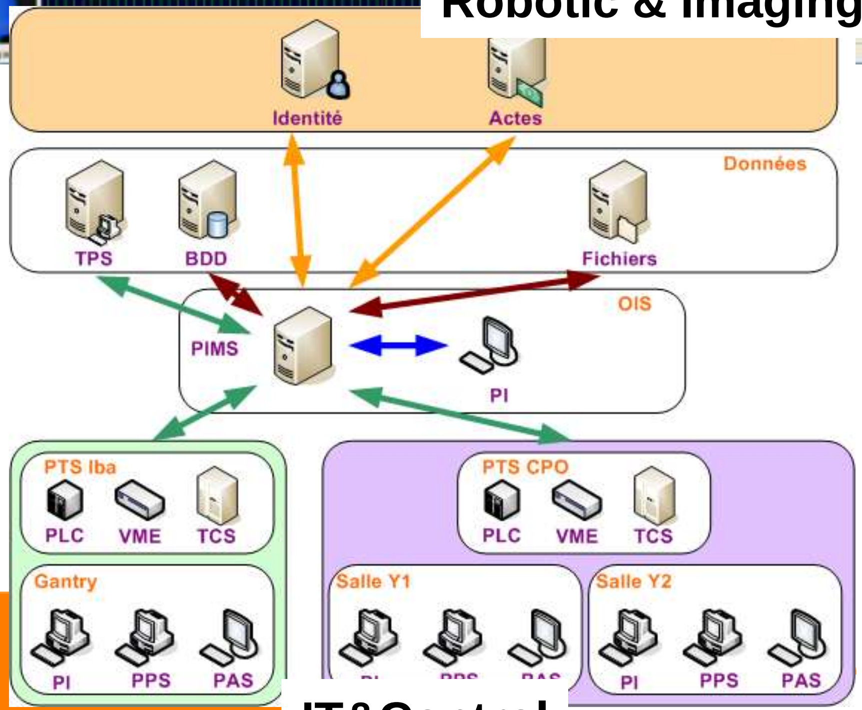
Centre de Protonthérapie d'Orsay

1991-2010: 5000 patient treatments
From 2010: treatments with an upgraded facility
2014: 30-40 patients treated per day

Gantry room

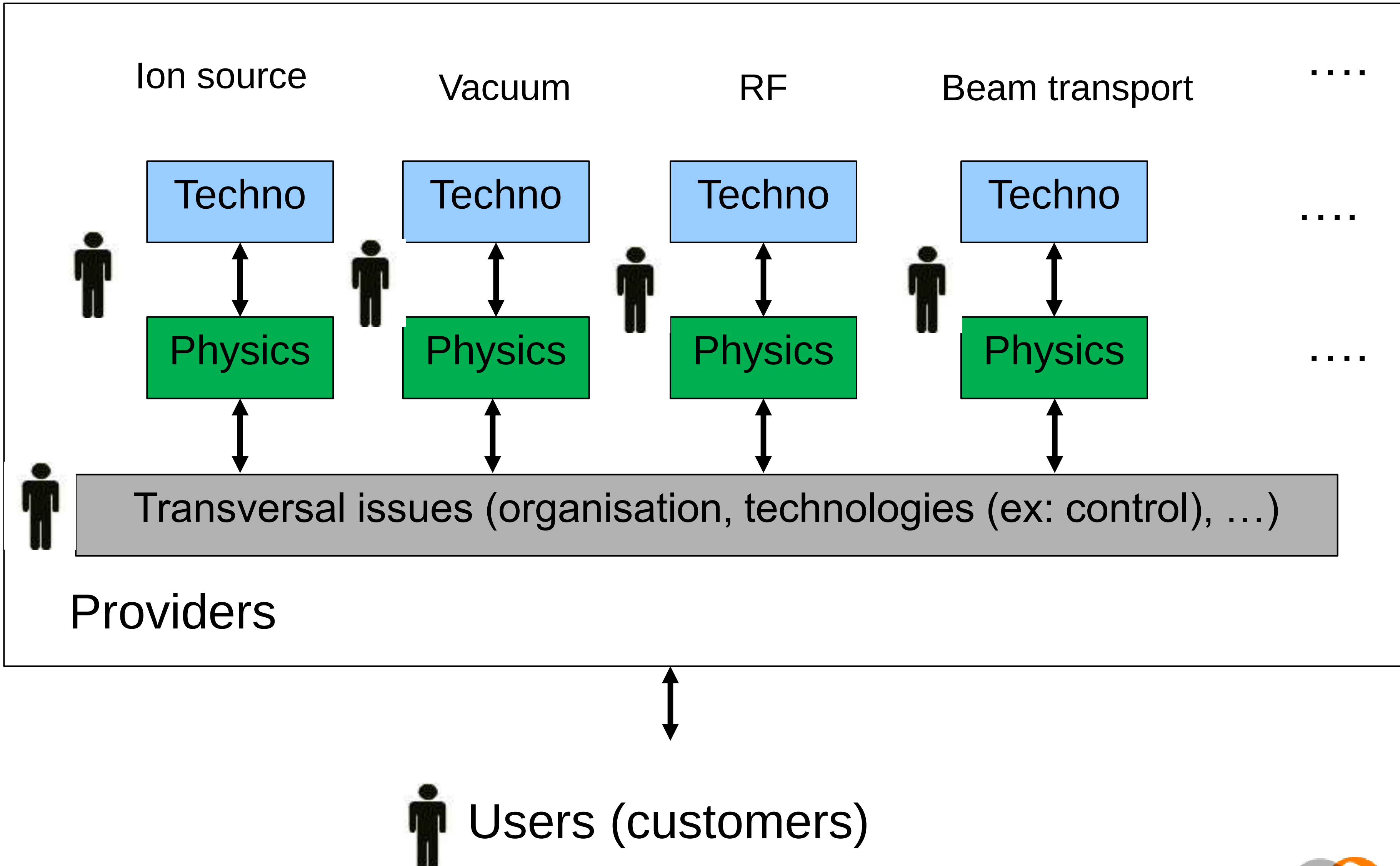
Cyclotron&Beamlines

Robotic & Imaging



R&D physics &Technology

IT&Control



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1st half: Life-cycle of an accelerator and reliability

2nd half: some cases of back and forth beetween an application and accelerator

(case of Particle Therapy)

on the dash board

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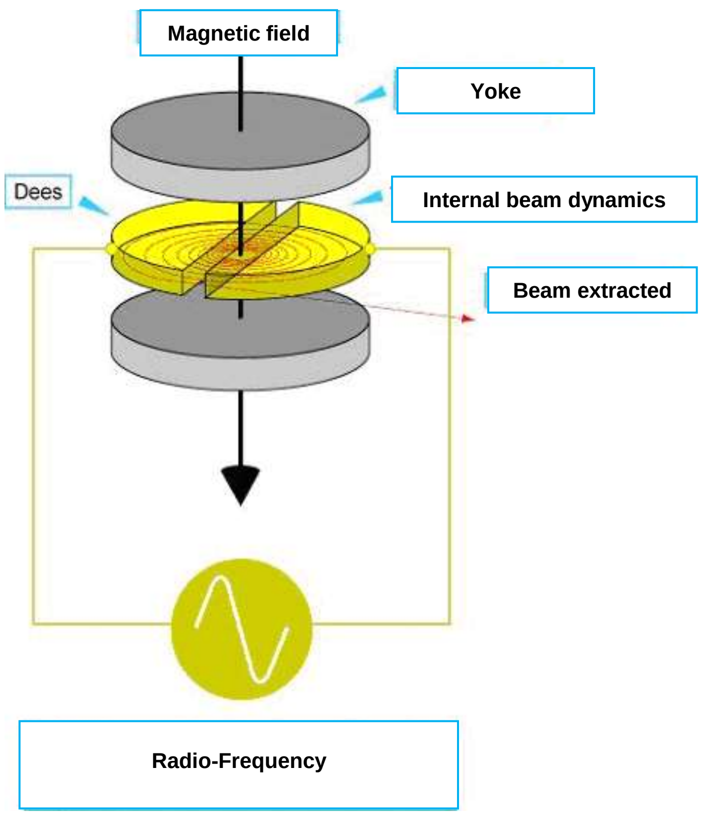
Accelerators as …

… systems



…stories

- **Let’s talk about reliability & life-cycle of accelerators**

summary

1. Reliability & Accelerators

2. Life-cycle of accelerators (towards reliability issues)

3.Paradoxes about reliability

4. Examples

Interactive
Questions / Answers

Definition of reliability

1st basic approach

$$\text{Reliability} = \frac{\text{Time the systems works – Time of breakdowns}}{\text{Time the system works}}$$

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Definitions of reliability

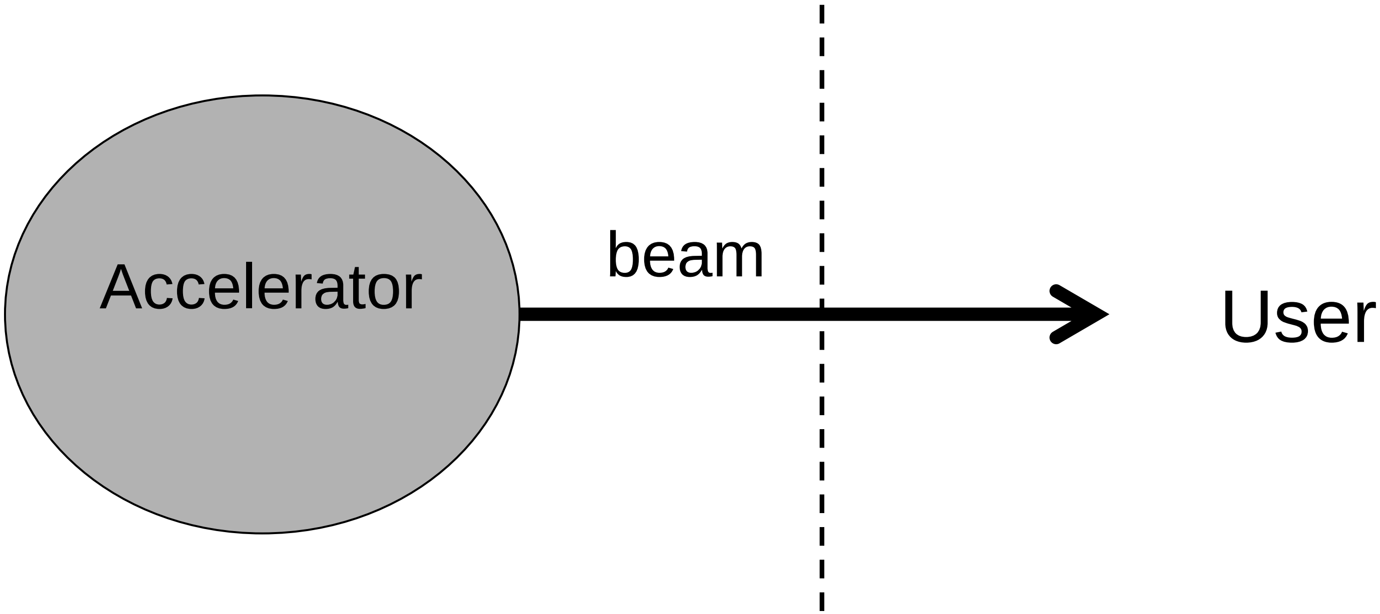
The reliability is the ability of a system or component to perform its **required functions** under stated conditions for a **specified period** of time

The reliability (R(t)) is the **probability** to have **no failure** at the time **t.**

MTBF: *Mean Time Between Failures*
MTTR: Mean Time To Repair

The **availibility** of the system is the ratio of the time when the system is operational by the time it was supposed to be operational

Availibility = MTBF / (MTBF+ MTTR)



What is the product (service) delivered ?
What is the quality defined ?
Who is defining the reliability ?

Reliability and Particle Accelerators

- **Power- Energy & Motion**

  Electricity, cooling, regular motion systems

- **Critical and/or sensitive Technologies**

  Radio-Frequency, vacuum, electronics, cryogenics, software, …

- **Risks**

  radiation-protection, costs, …

- **Complexity**

  mix of technologies, %research%production, regulations

- **Using &Users (Customers / Providers)**

  beams: current, energies, duration, …

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Reliability for synchrotron

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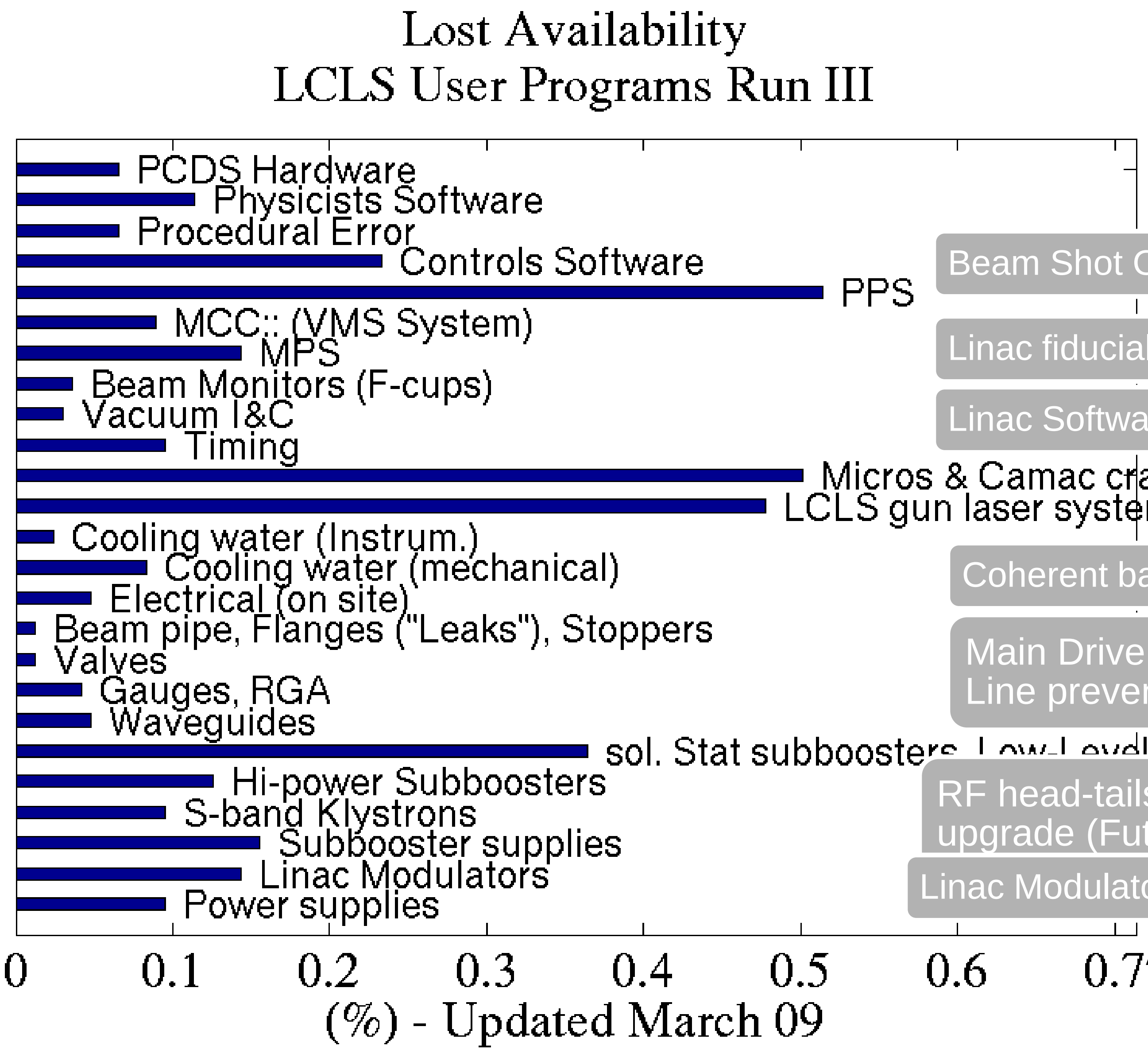
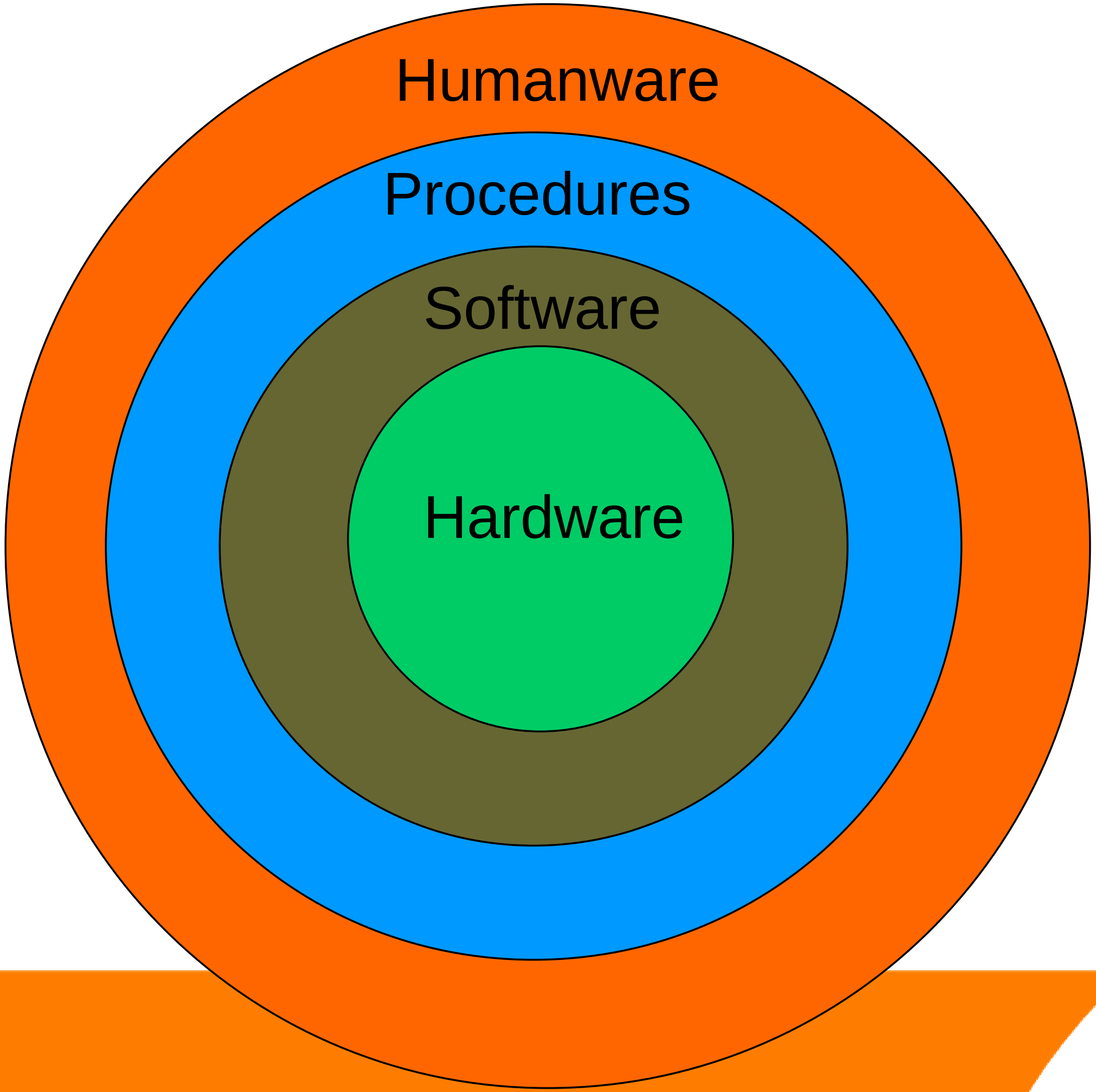
Downtime Statistics and future upgrades



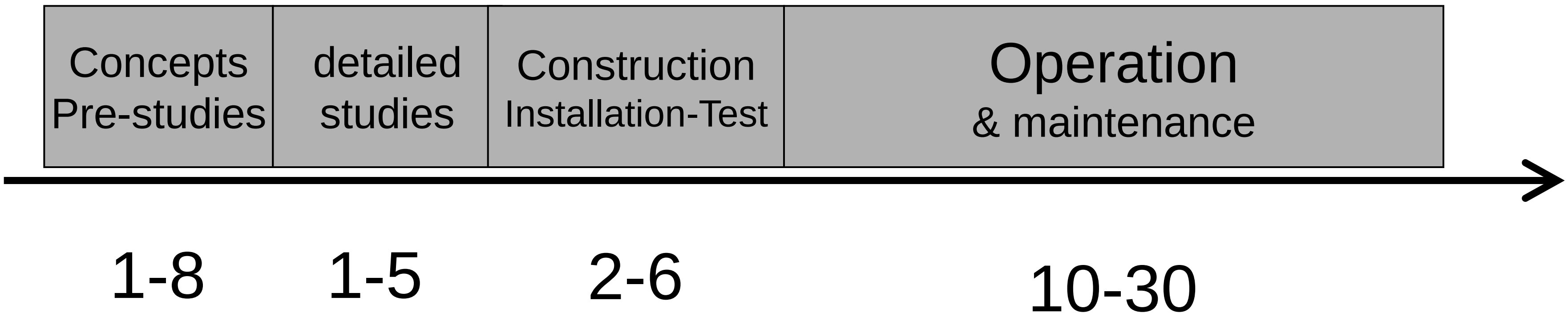
- Beam Shot Off Ion Chamber
- Linac fiducial distribution
- Linac Software Controls Conversion
- Coherent backup Laser
- Main Drive Line and Sub-Drive Line preventive maintenance
- RF head-tails phase monitor upgrade (Future)
- Linac Modulator Upgrade

the 4 layers of reliability



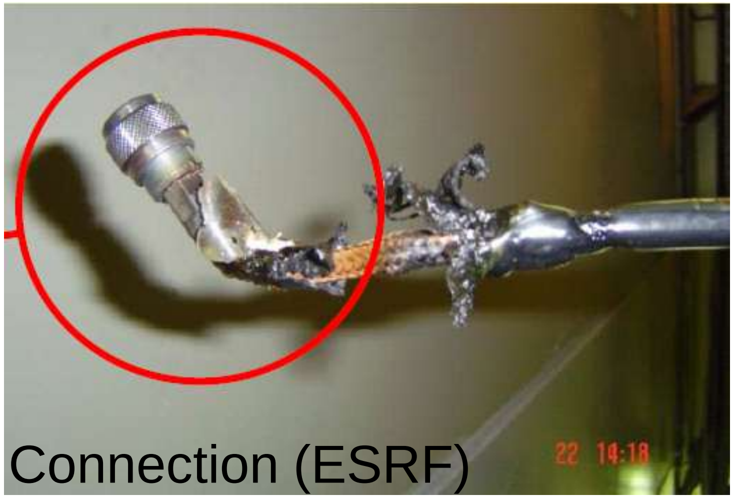
2. Life-cycle of accelerator

Life-cycle of an accelerator



Typical durations (in years)

A failure – a small (or big) death



Connection (ESRF)


Main coil (SC200-Orsay)


Turbo pump (Triumf)


Orphan system

Electromagnetic channel (with septum) of synchro-cyclotron of Orsay

7000 A 15V, vacuum 4.10-6, P= 18bars

« work of artist »

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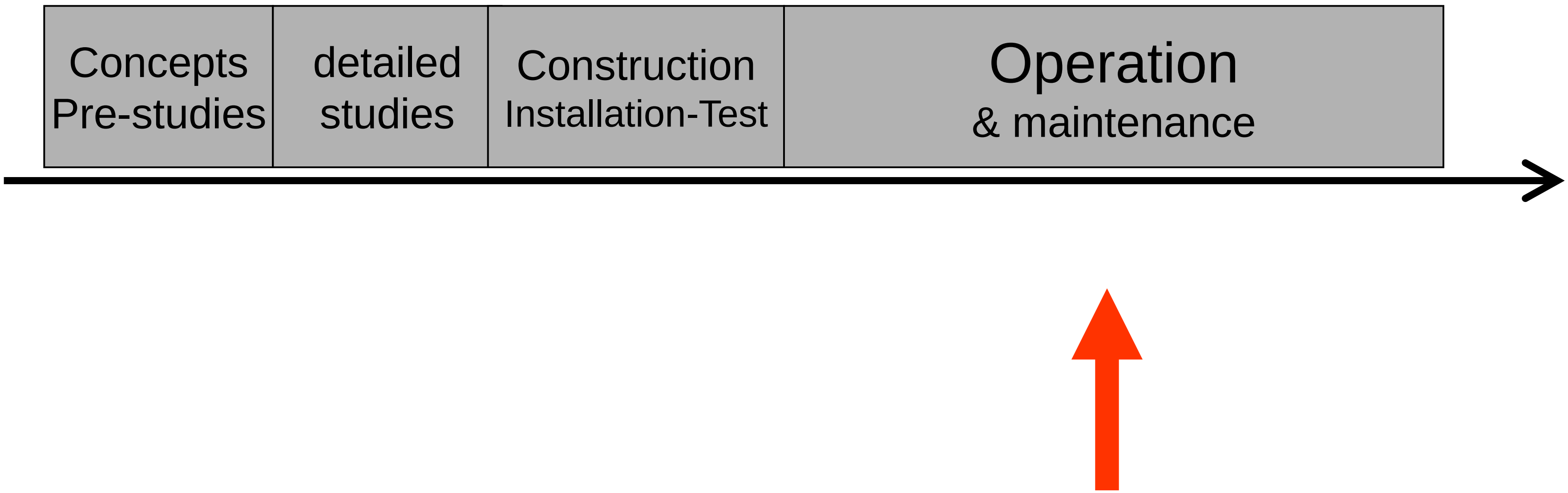
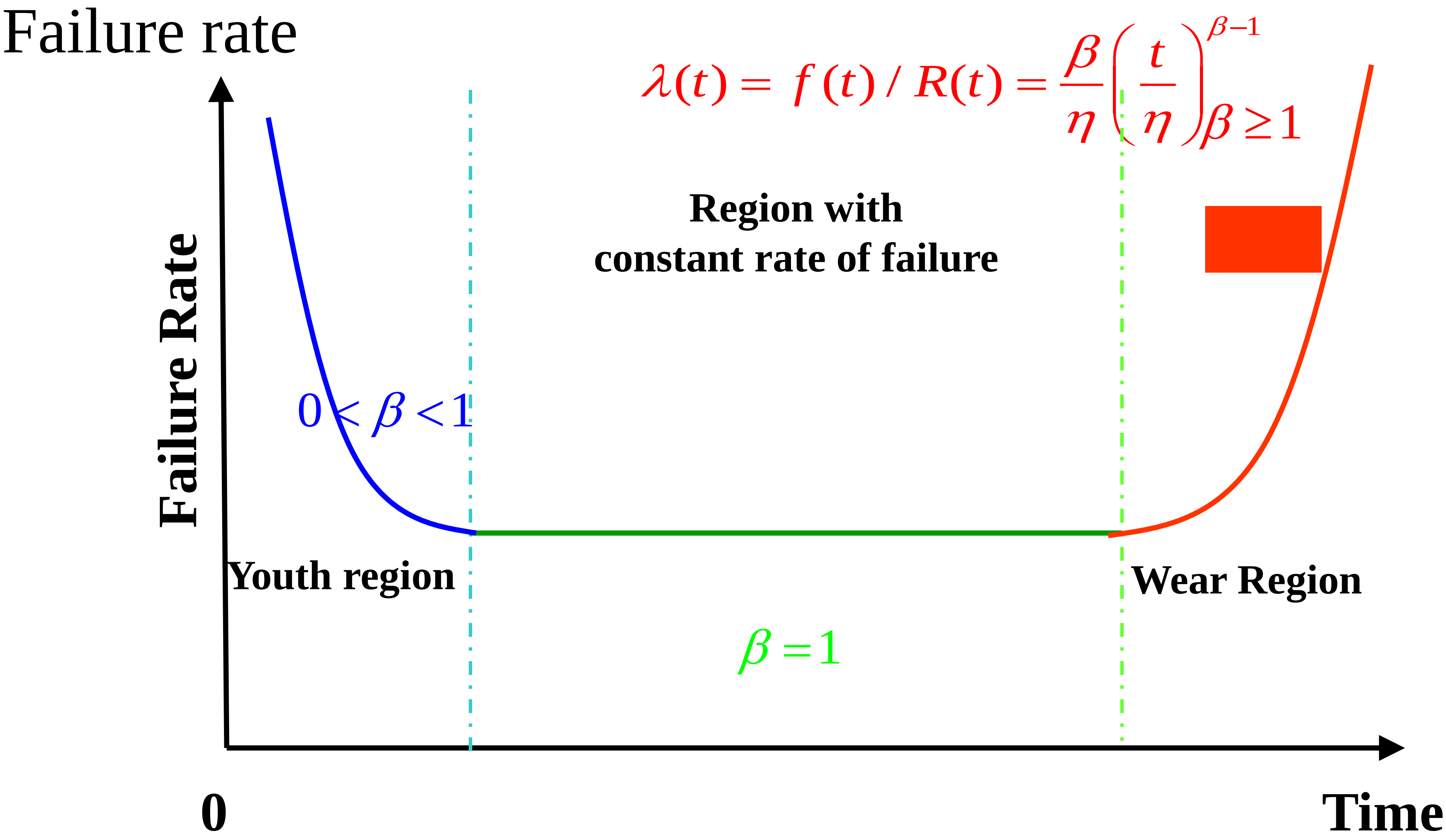
Life-cycle of an accelerator

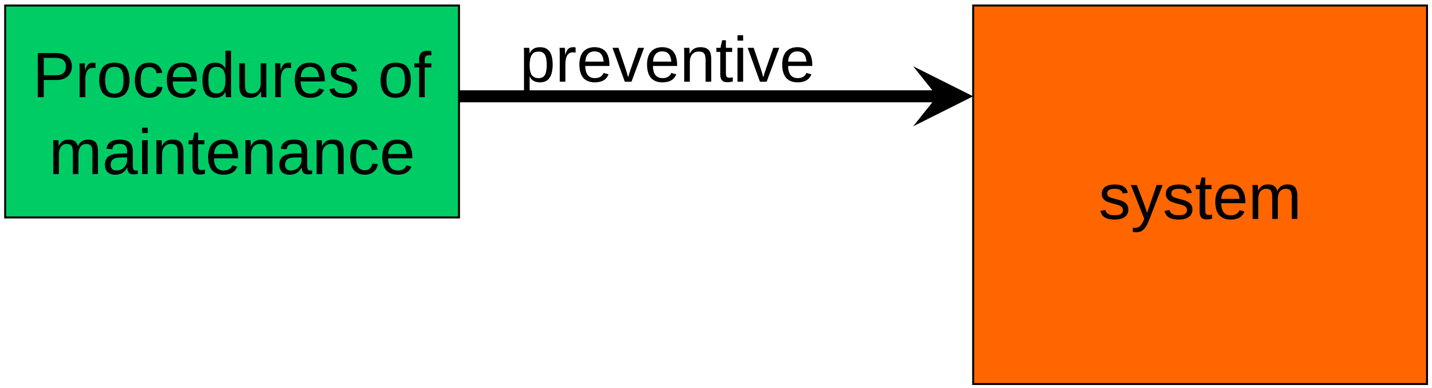


Weibull Model



Maintenances

Modelisation, experience

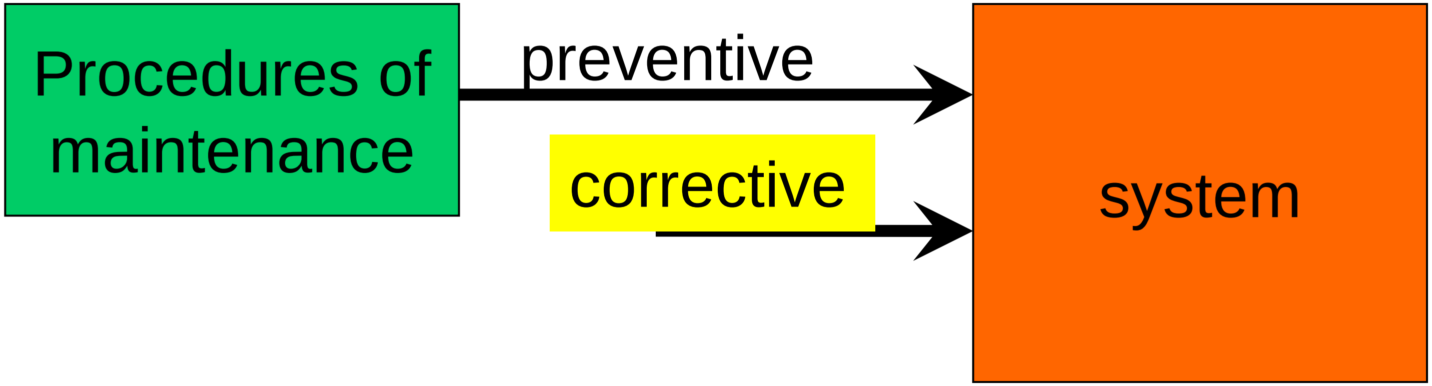


Inspect, clean, check, lubrify, calibrate, read, replace, test ,…

< 20% with high periodicity
Ex: Ions Sources

Maintenances

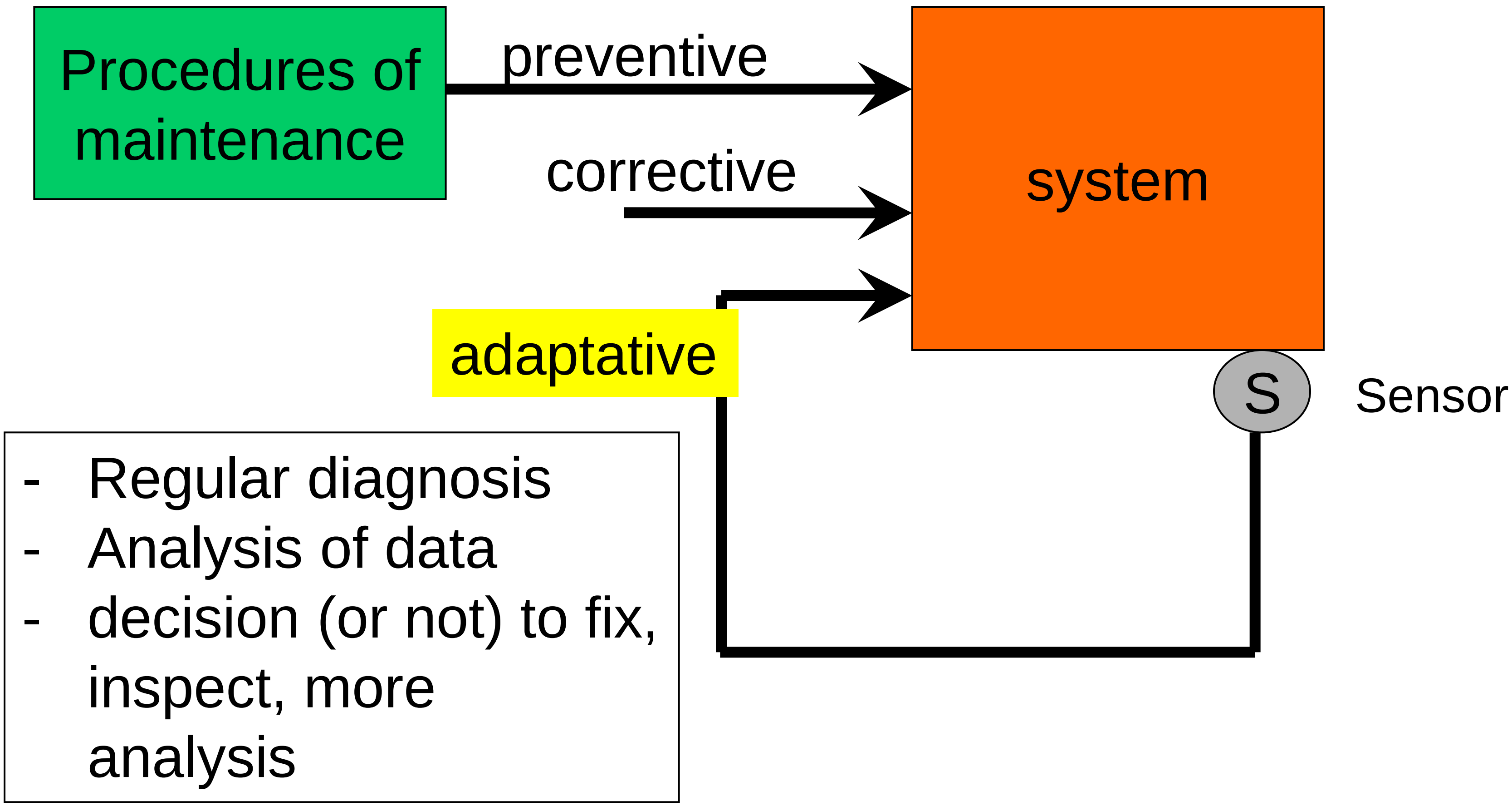
Modelisation, experience



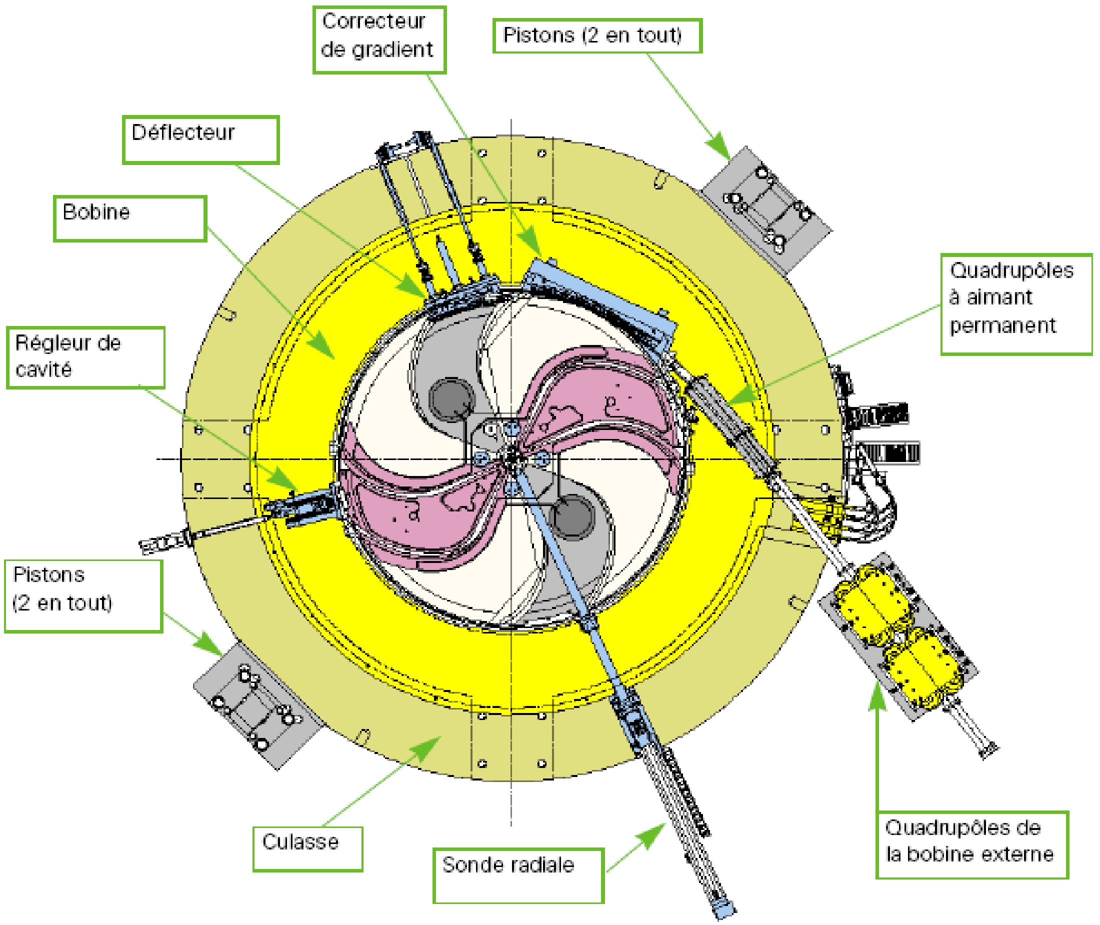
- Awareness of problem(s)
- Diagnosis
- Fix-replace
- test

Maintenances

Modelisation, experience



Diagnostic of beam inside cyclotron: the radial probe



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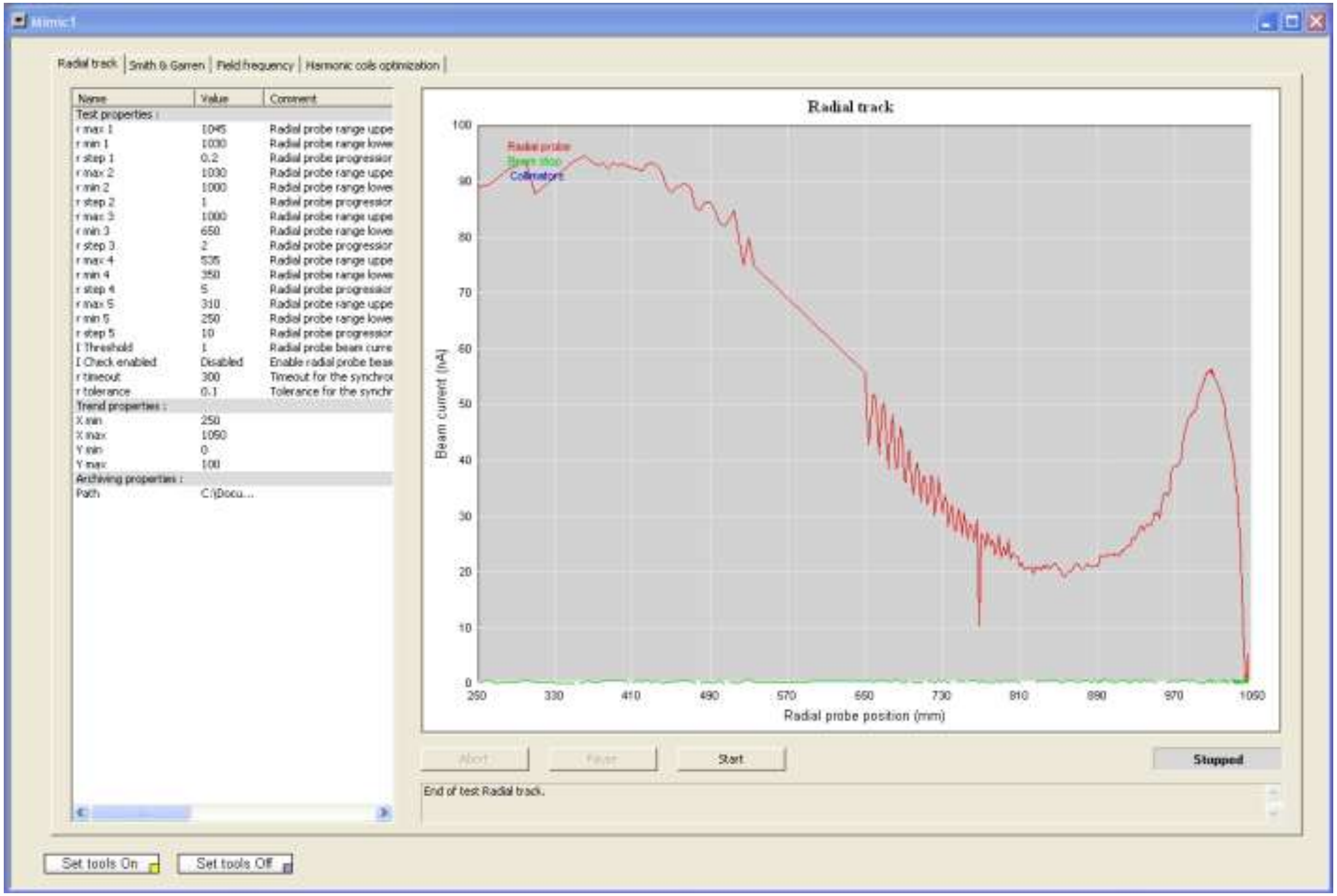
Example of result of radial track (C230IBA@CPO)



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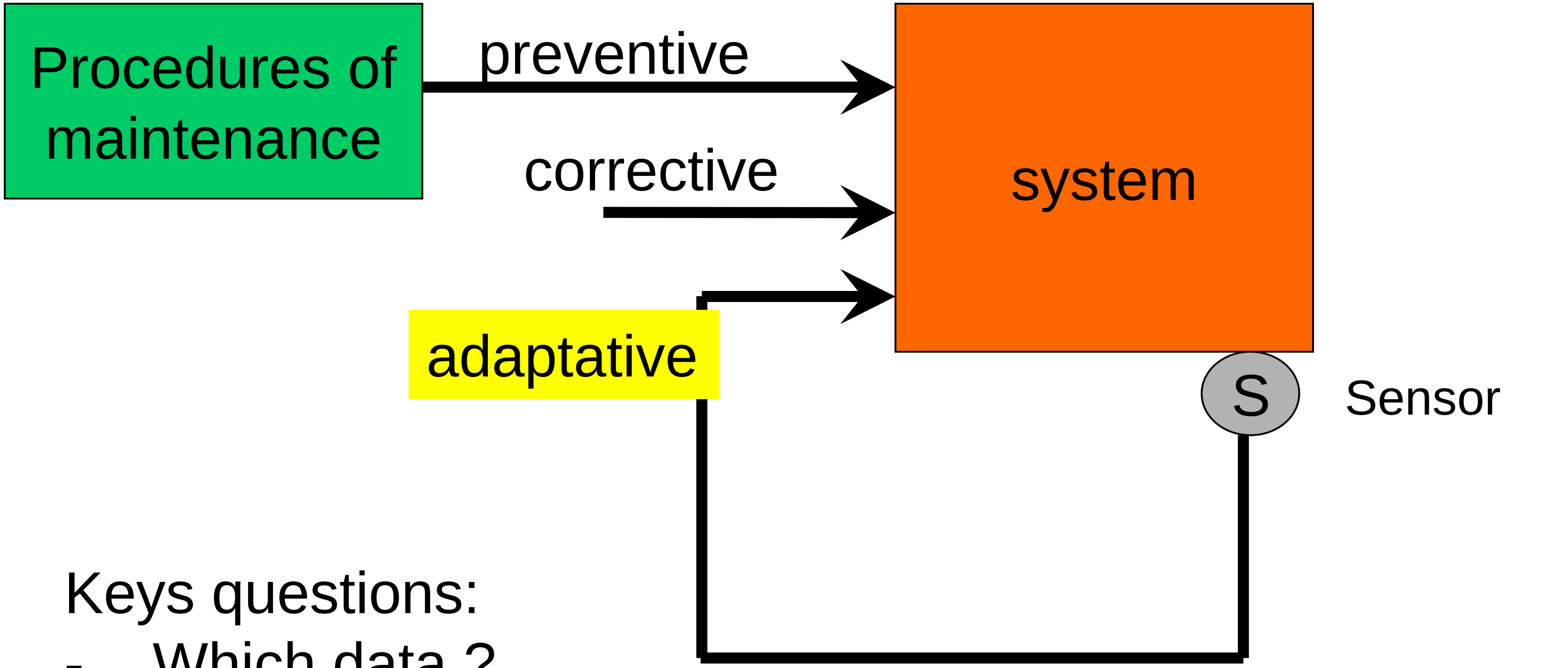
Maintenances

Modelisation, experience



Keys questions:

- Which data ?
- Which sensors ?

Thermography inspection C230 @ CPO

Cyclotron thermographie du 13 octobre 2011

°C

70°C

es

	0.95
	20 °C

nter bobines 3 et 4
rieures. Point chaud
n sp1 A surveiller

13/10/2011 06:32:34

IR_0069.jpg

13/10/2011 06:32:34

DC_0070.jpg

Sp1 54°C

Paramètres

Emissivité	0.95
Temp. réfl.	20 °C

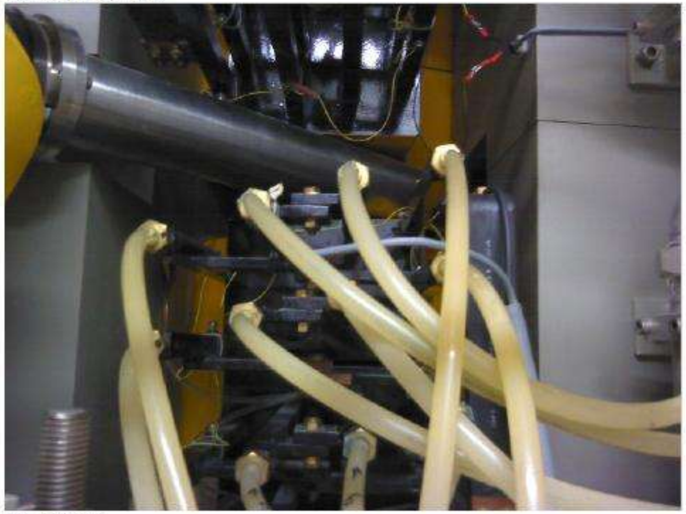
Bobines inferieurs 3 et 4

58,1

25,8

IR_0219.jpg

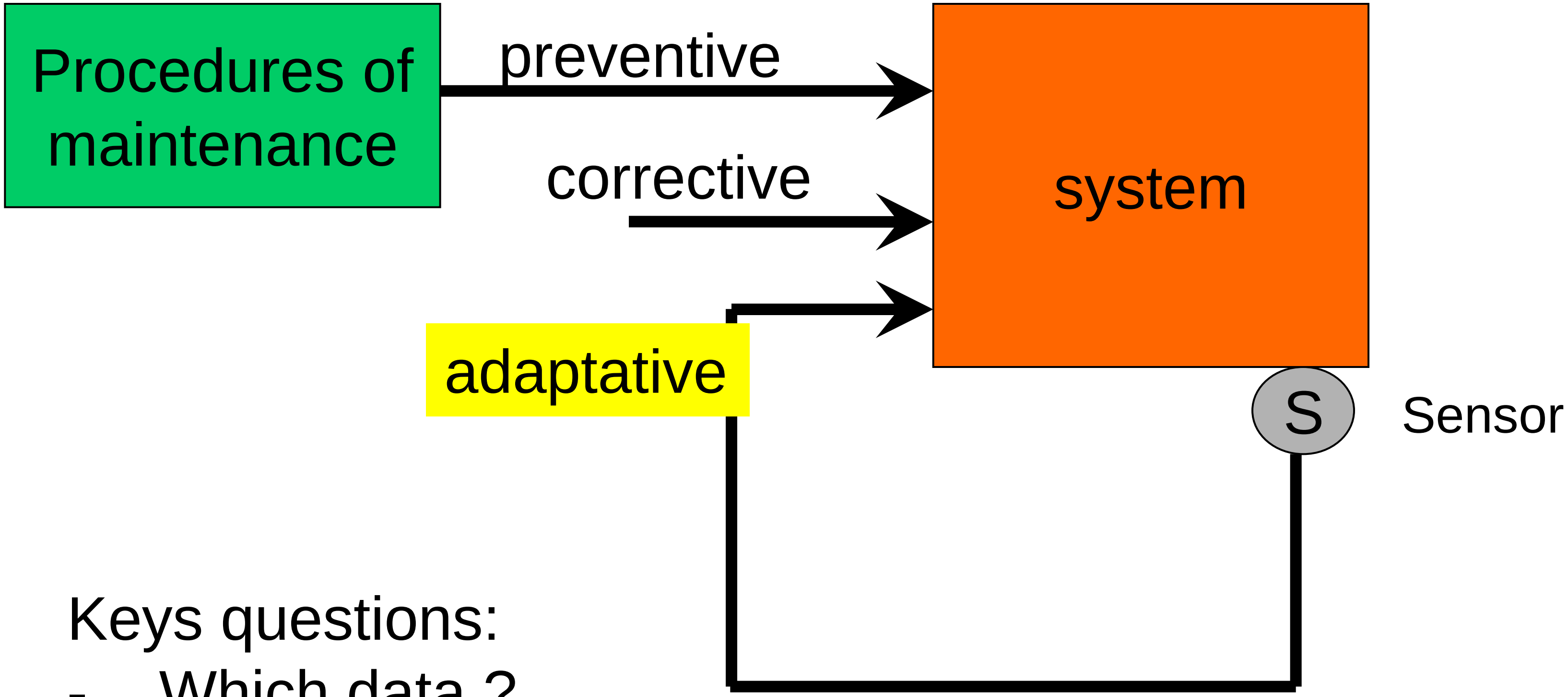
08/11/2011 07:15:17



DC_0220.jpg

Maintenances

Modelisation, experience

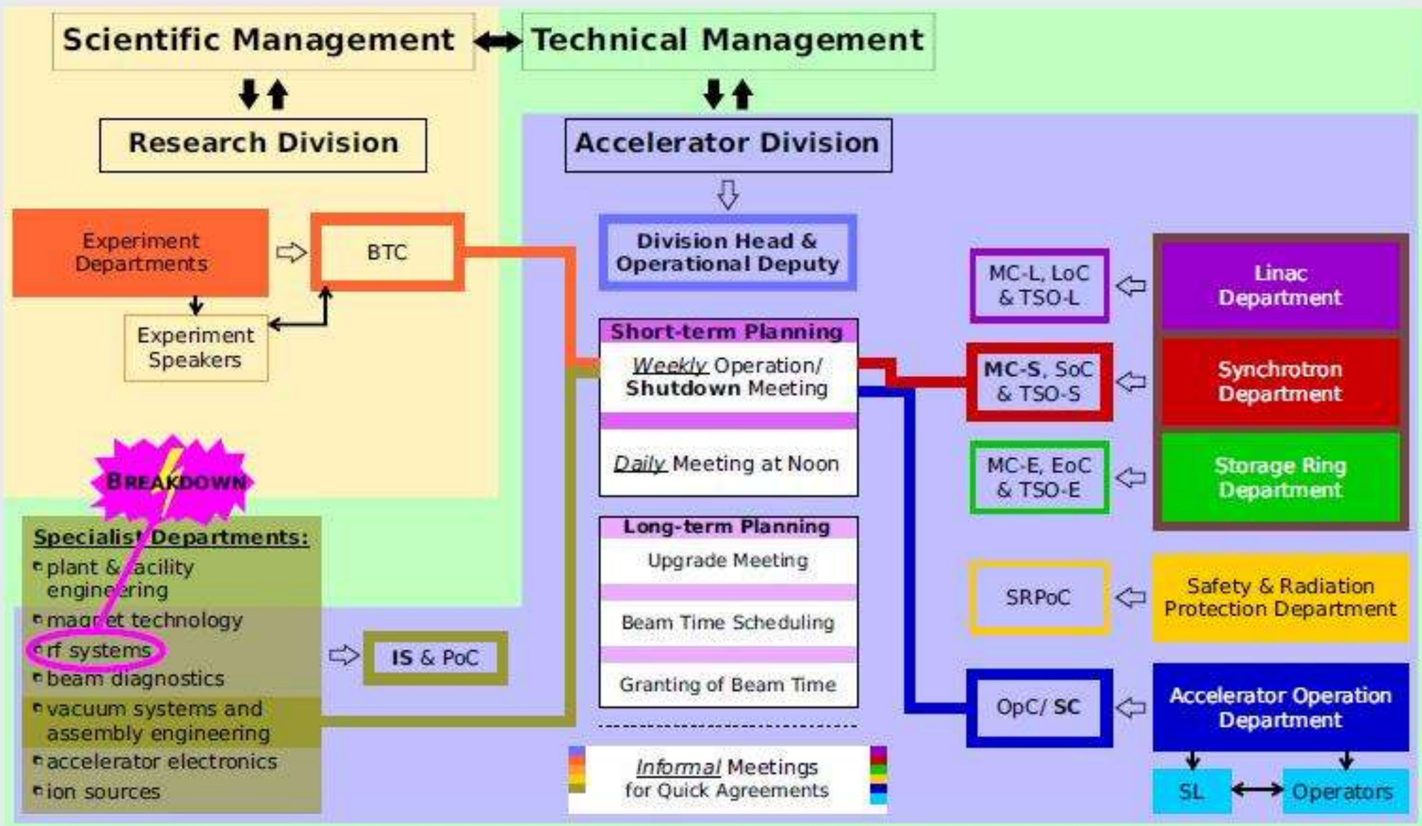


Keys questions:

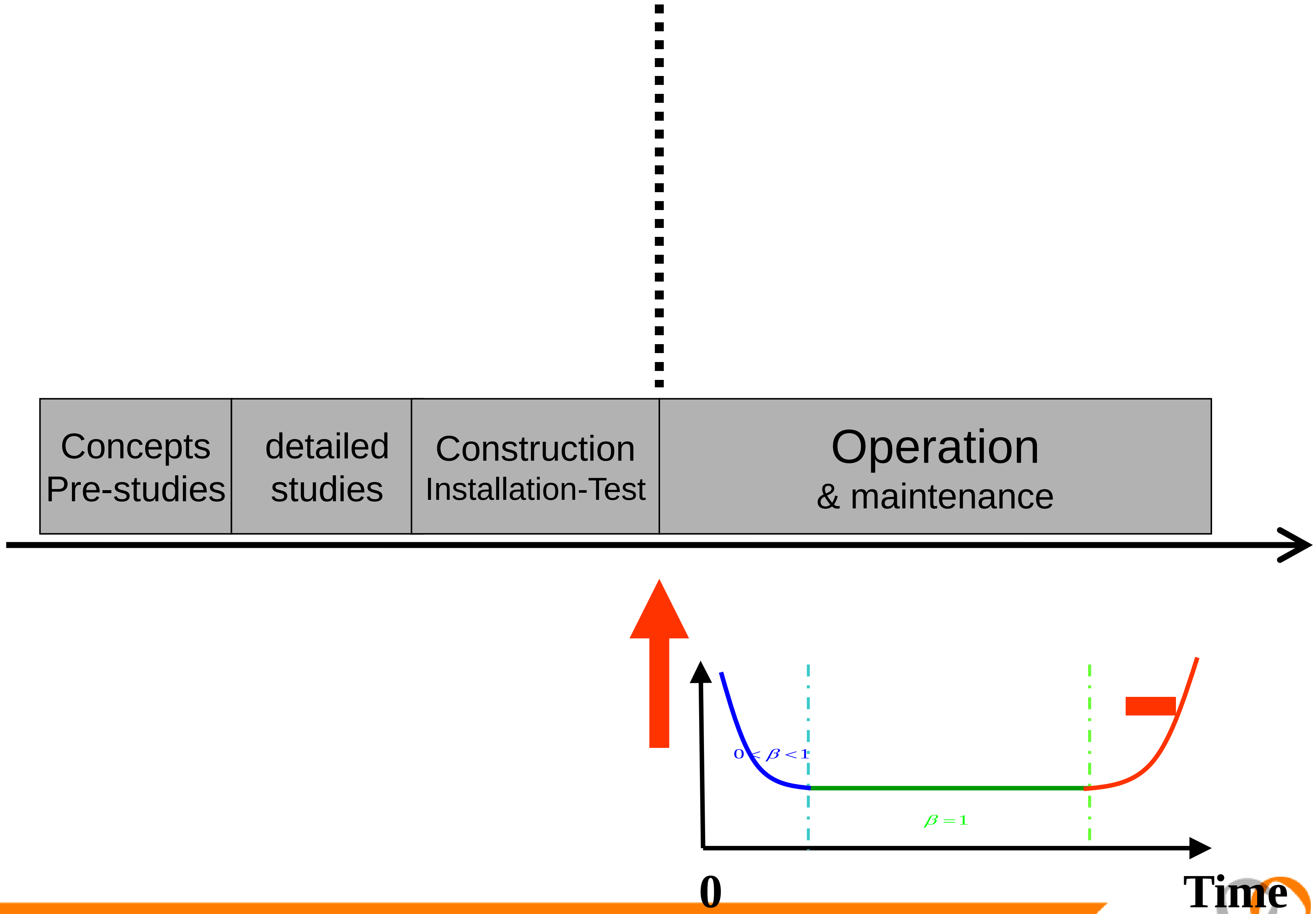
- Which data ?
- Which sensors ?

Reactivity of organisation–transmission of information

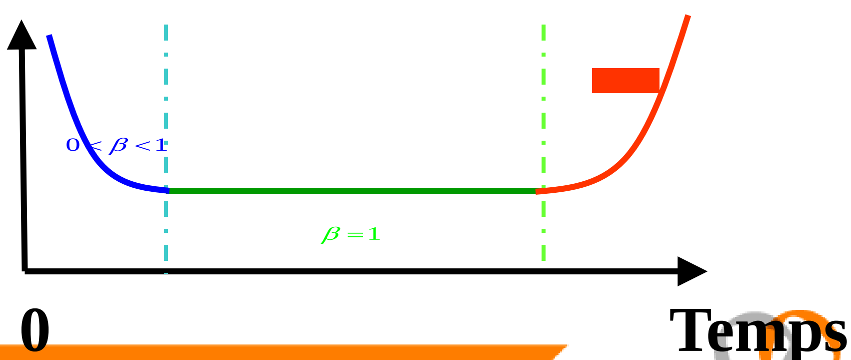
Example of Failure Handling – Short-term Planning



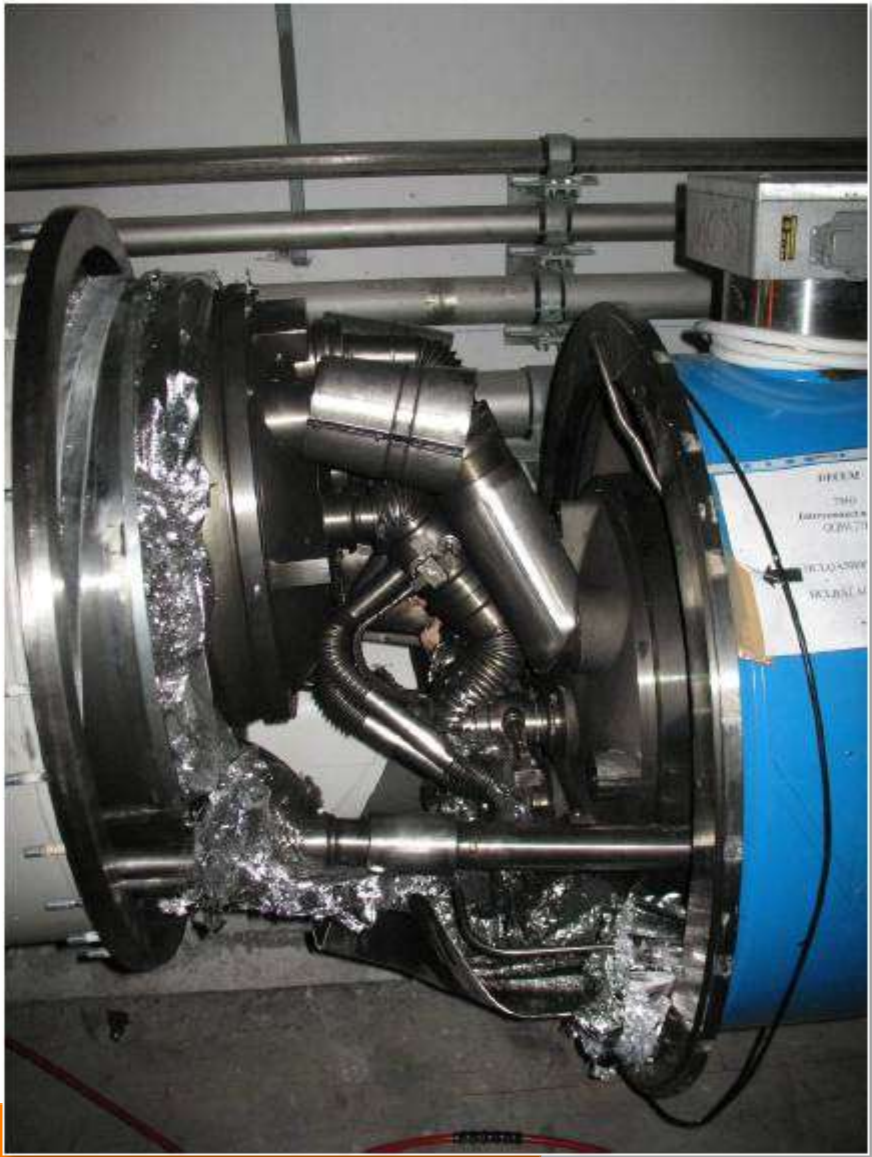
Updated shutdown schedule discussed in shutdown meeting, beam time coordinator informed


Concepts
Pre-studies
detailed
studies
Construction
Installation-Test
Operation
& maintenance
$0 < \beta < 1$
$\beta = 1$
0
Time

Concepts Pre-studies	detailed studies	Construction Installation-Test	Operation & maintenance



« the» CERN event (september 2008)



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Why transition « project » to « operation » so critical ?

- **ALL** the systems must be ready **AND** OK (ancilaries, control system, …)

- often, the first time in « **REAL** » conditions

- Atmosphere of « **pressure** »:
  - Important milestone for contract (penalties)
  - users « wants » the beam

~~Maintenance~~ → Projects to set, keep, improve the operations

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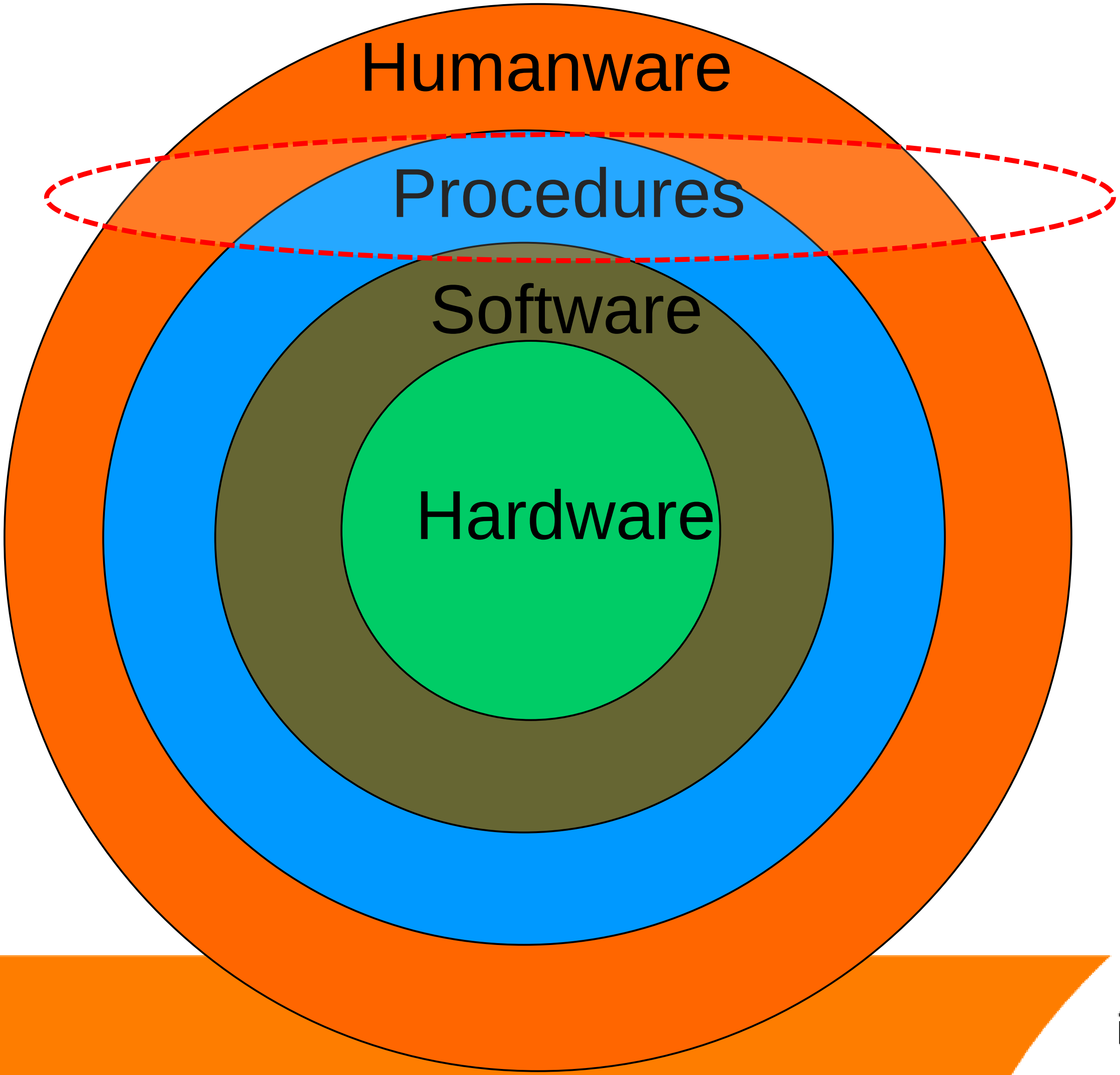
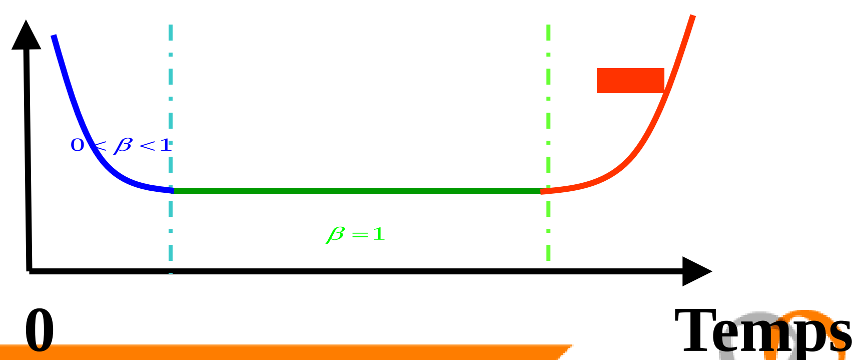
The 4 layers for reliability



Concepts Pre-studies	detailed studies	Construction Installation-Test	Operation & maintenance

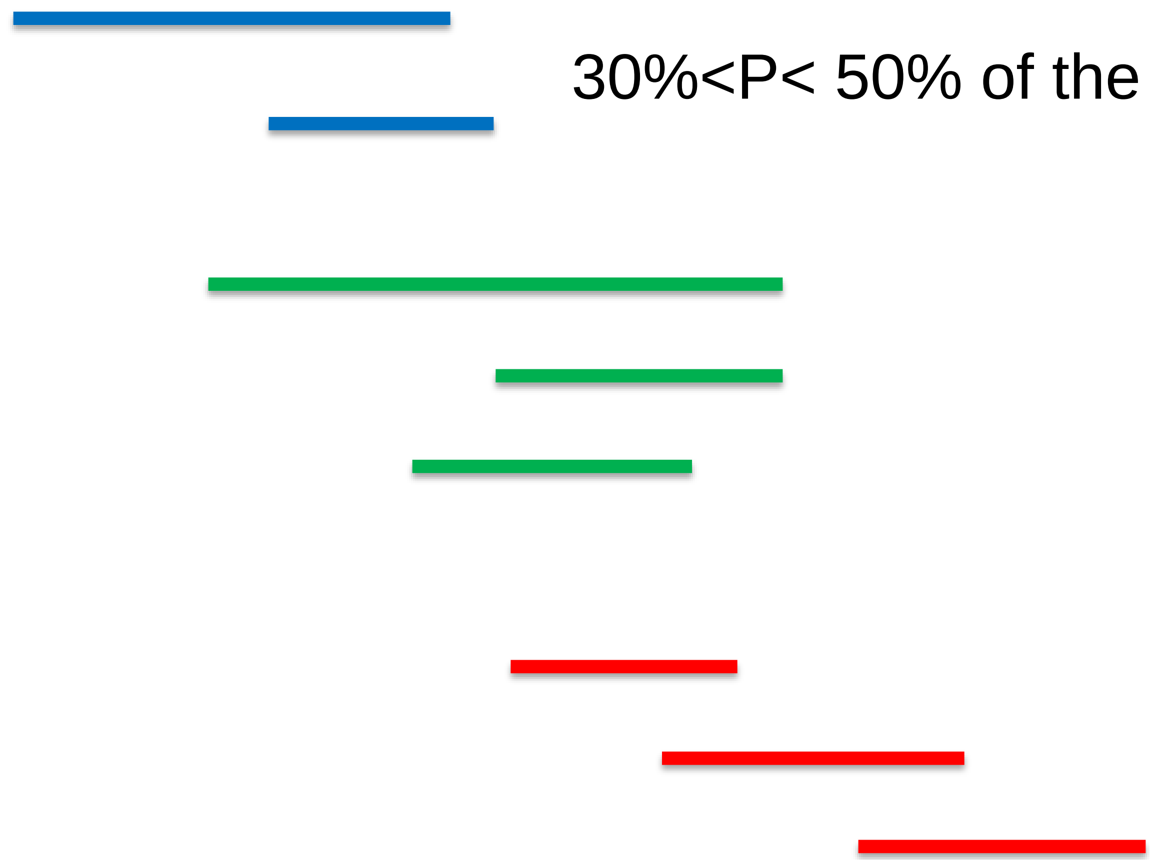


planning

Building
Ancilaries

Magnet
RF
Power Supplies

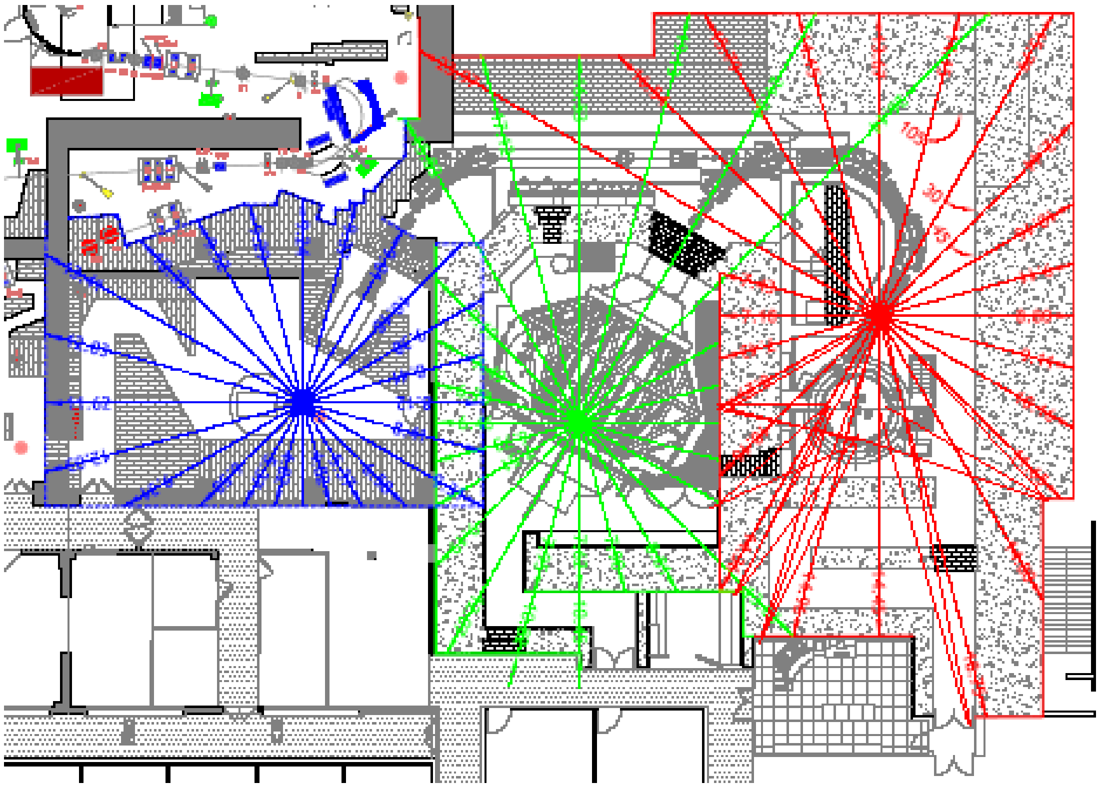
Integration
Test
Commissioning

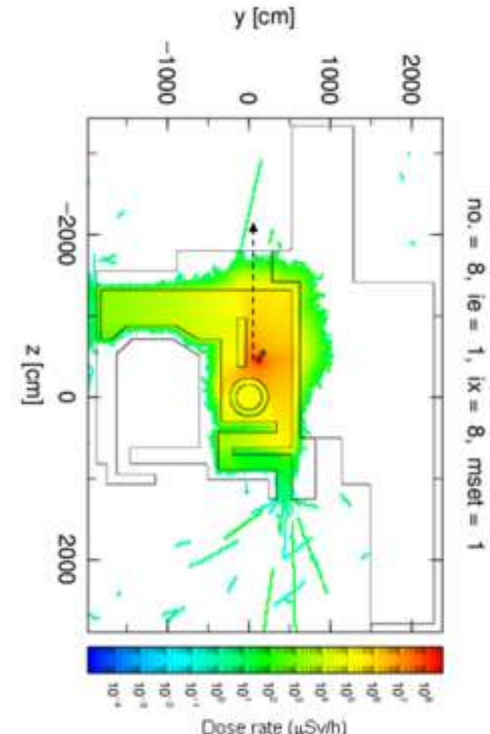


30%<P< 50% of the cos

Radiation – protection

- calculation of shieldings
- source points (to provide)
- proof of concept to dismantle





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planning

Building
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Magnet
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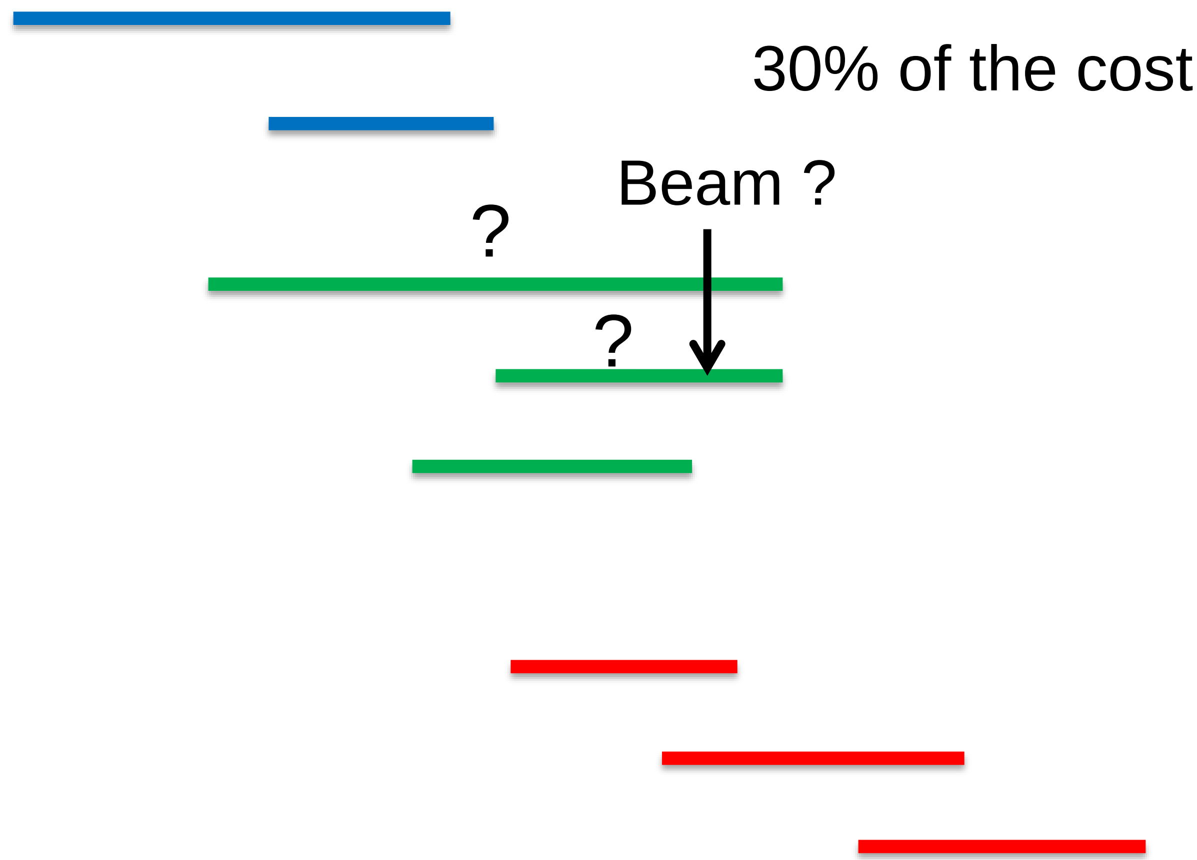
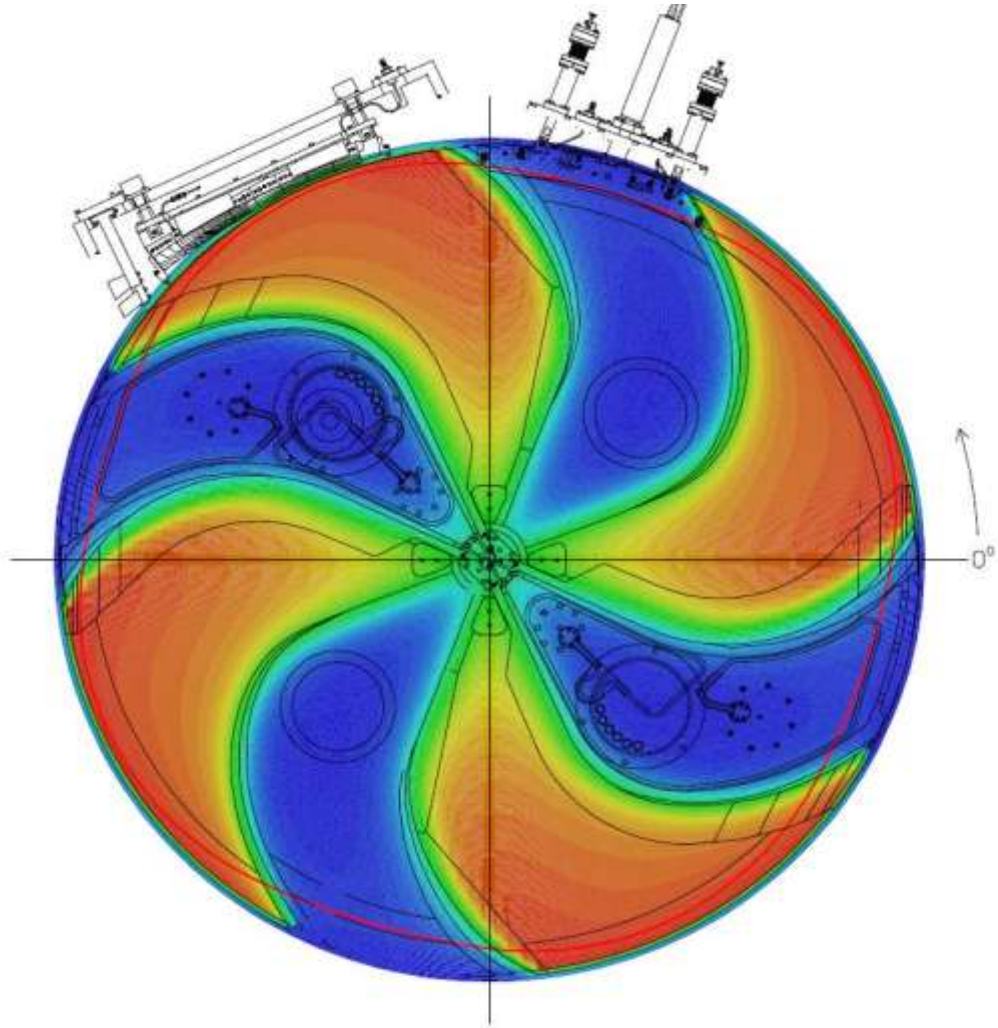


Mapping C230



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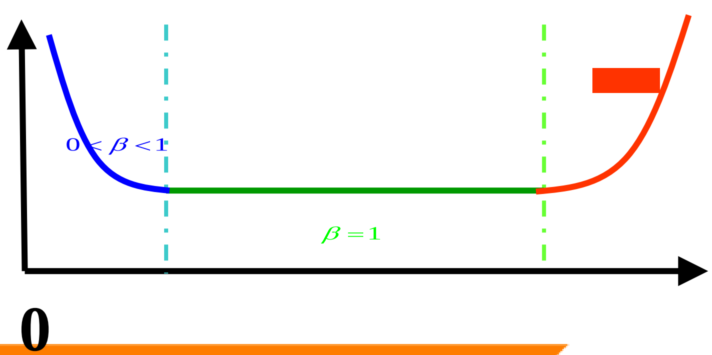
Concepts Pre-studies | detailed studies | Construction Installation-Test | Operation & maintenance



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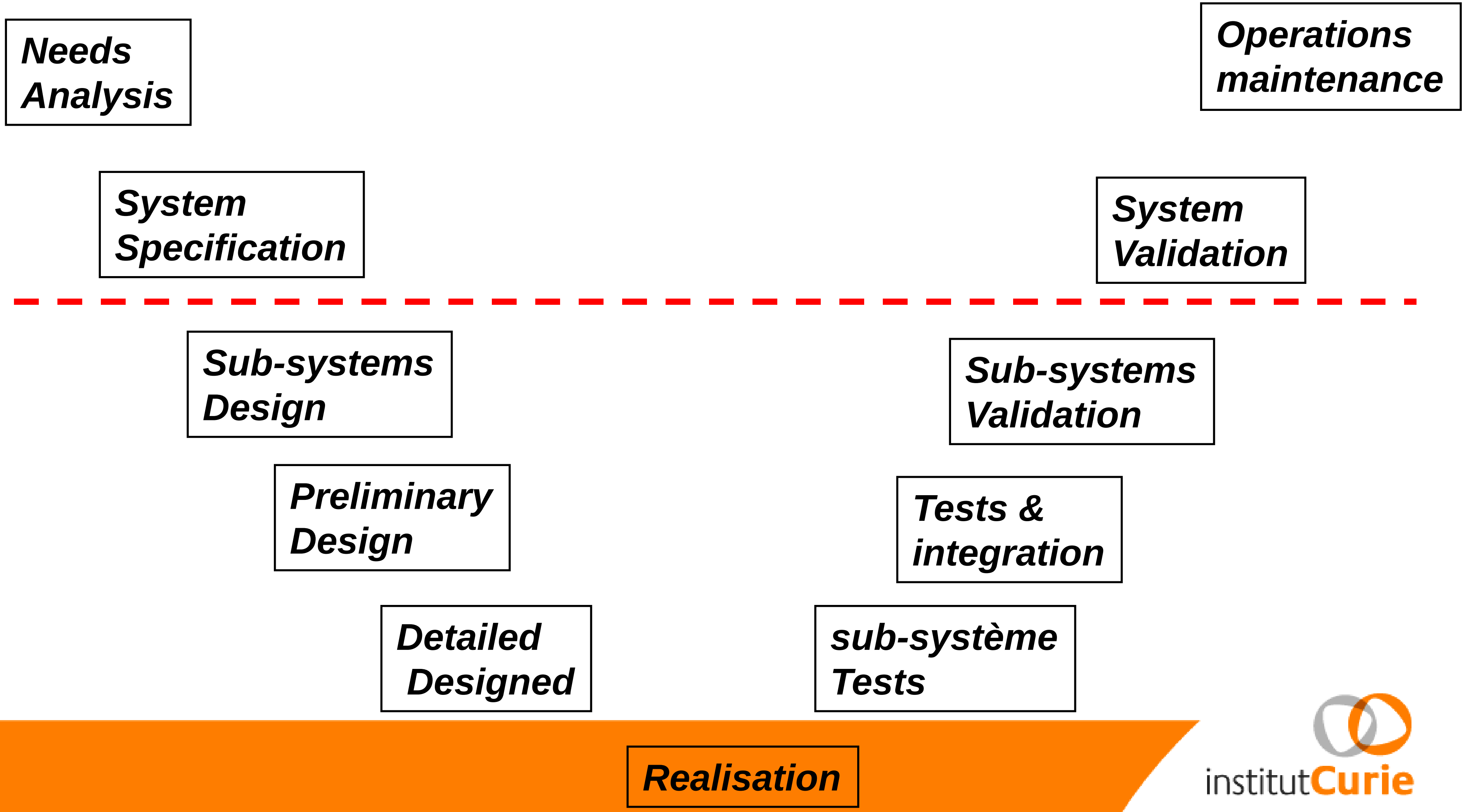
Development – the V cycle



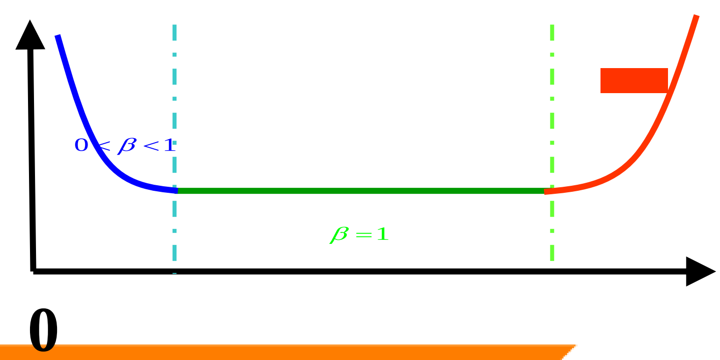
Concepts
Pre-studies

detailed
studies

Construction
Installation-Test

Operation
& maintenance

contract



Contracting with

With the provider of the accelerator

- performances and acceptance tests (conservative / innovation)
- contents and limits of interface (beam, building , control, …)
- training - documents
- budgets (bonus / penalties)
- maintenance

With the provider of building and ancilaries

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Contracting with

With the provider of the accelerator

- performances and acceptance tests (conservative / innovation)
- contents and limits of interface (beam, building , control, …)
- training - documents
- budgets (bonus / penalties)
- maintenance

With the provider of building and ancilaries

With the users (« real » needs, constraints, freedoms, evolutions…)

With the payers (budget and resources)

- for investment
- for ramp-up and contengencies
- for operations, maintenance, …

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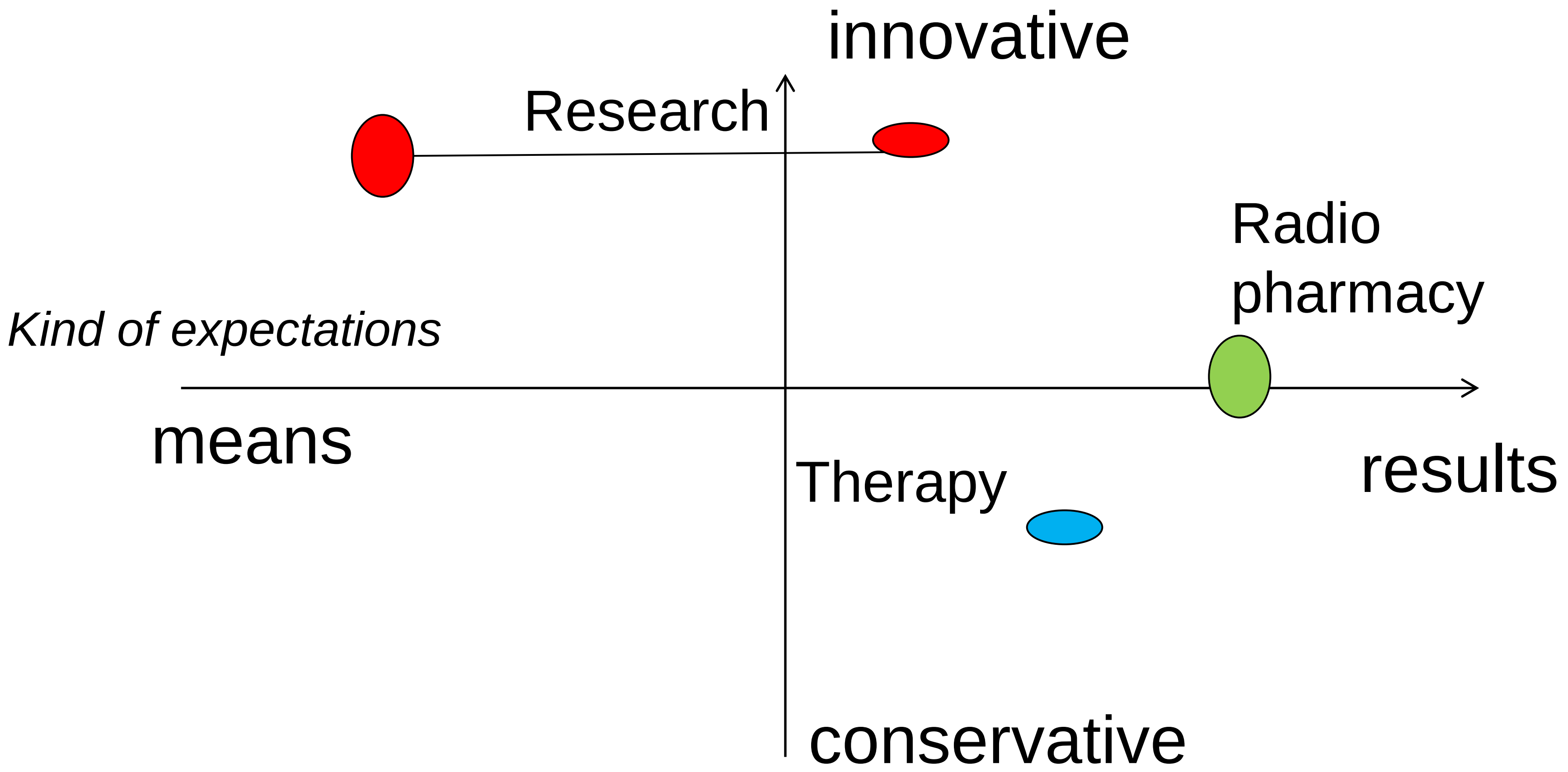
Science of Organisations

Henry Mintzberg: different kinds of coordination

- **Mutual adjustment**
- **Direct supervision**
- **Standardization of work processes**
- **Standardization of outputs**
- **Standardization of skills**
- **Standardization of norms**



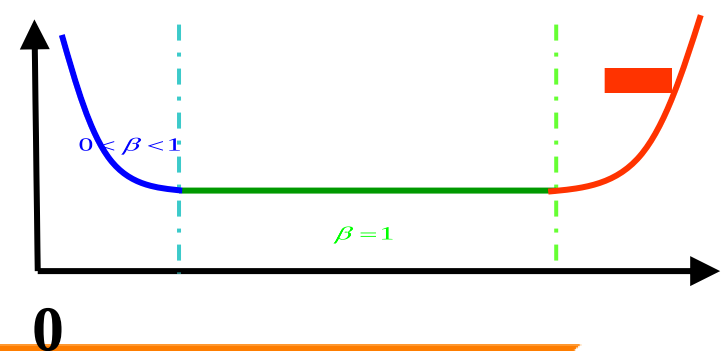
Kind of project

+

Quality Assurance

Concepts Pre-studies	detailed studies	Construction Installation-Test	Operation & maintenance

contract

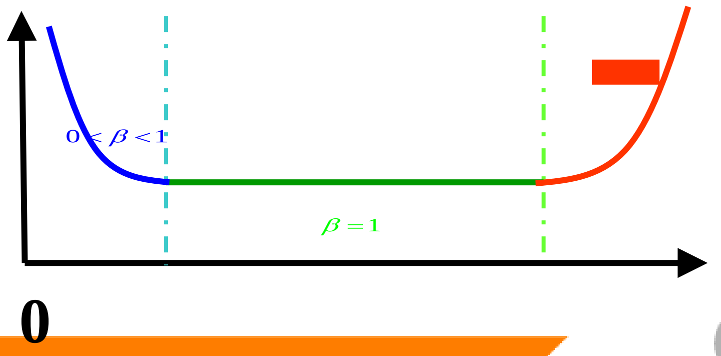


SSC: The Super Superconducting Collider

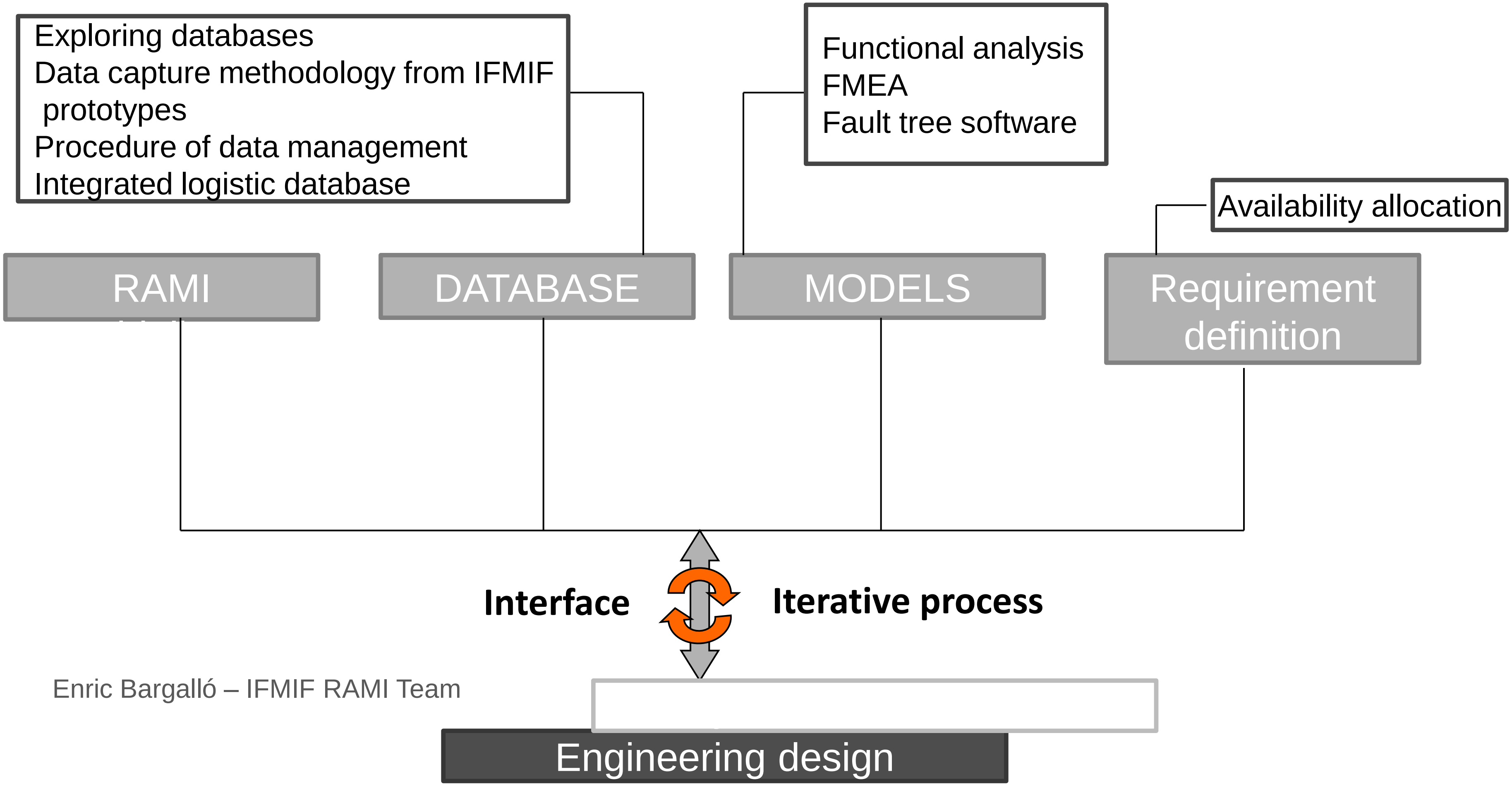
South of Dallas - 89 km – 80 TeV protons

Starts 1991-1993
Then cancelled

Life-cycle of an accelerator



RAMI approach (Reliability, Availability, Maintainability, Inspectability) for project IFMIF



Enric Bargalló – IFMIF RAMI Team

Concepts and reliability

Principles to increase reliability:

- Redundancy
- accessibility
- over -engineering
- maintainability
- …

Parameters increasing **risks** on reliability

- Technological innovations
- Lonely experience
- Number of specific interfaces
- pressure on quality, budget, delay
- …

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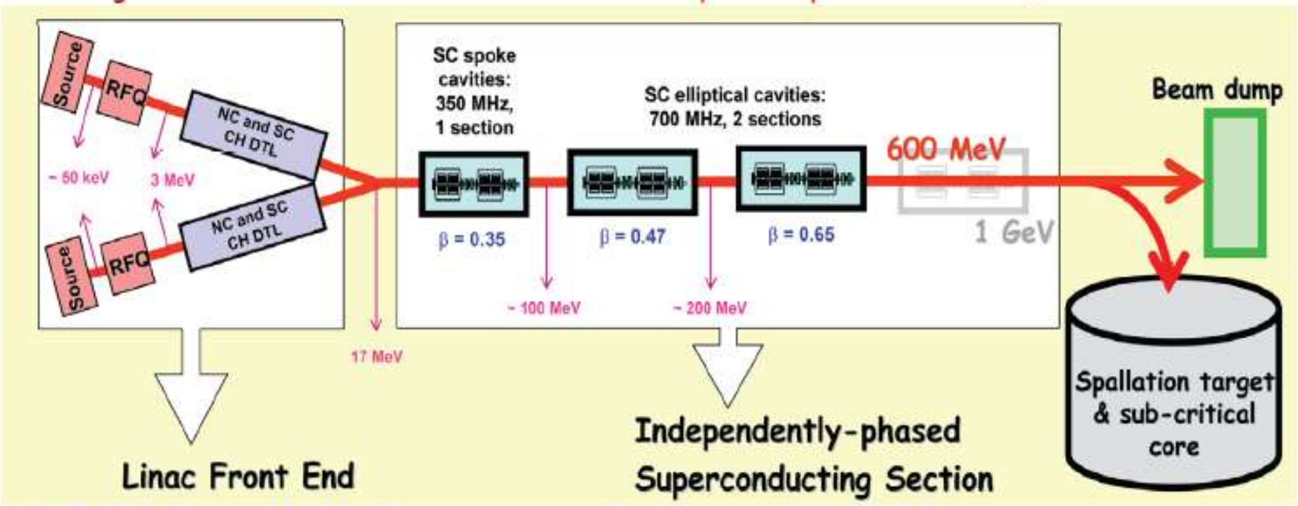
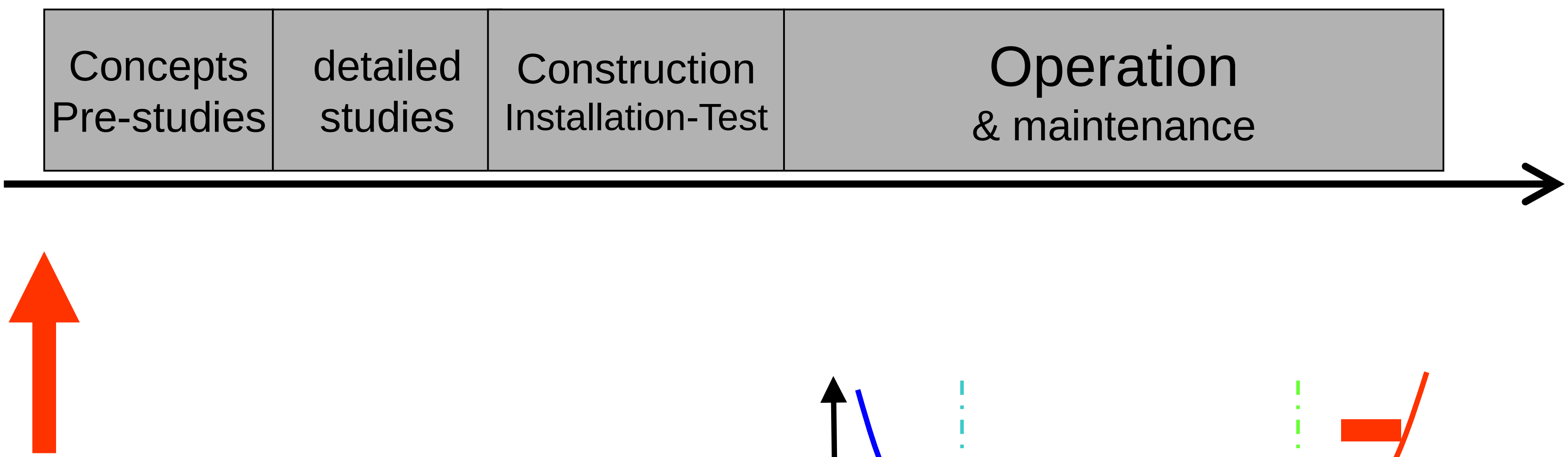
MYRRHA

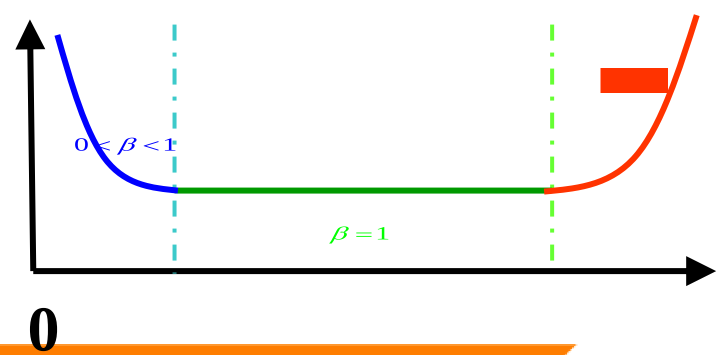
- ADS (Accelerator Driven System) pour la transmutation des déchets radioactifs
- Multi-Purpose hYbrid Research Reactor for High-tech Applications (SCK), horizon ~2023
- Challenge #1 : faisceau CW multi-MW : 2.5 mA (4 mA to compensate burn-up), 600 MeV
- Challenge #2 : fiabilité extrême : moins de 10 trips > 3 s pendant 3 mois !!



- **Injecteur redondant**
  - "fault-tolerance" non applicable
  - nb éléments minimisé
  - injecteur "spare" avec aiguillage rapide
- **Linac supra modulaire**
  - concept valable demo→transmuter
  - éléments contrôlés indépendamment
  - fault-tolerance : élt défaillant remplacé par ses voisins

Life-cycle of an accelerator





The (wellknown) recipes for a good reliability

A system (hardware & software) well designed

- specifications, model of developpement, tests
- principles of reliability, a lot of diagnosis

A well-maintained system

- Preventive, real, adaptative, reactivity for corrective
- Spare parts (a lot, ready for use)
- time dedicated for operations

Human resources and good organization

- people trained, skilled, enough, here when required
- efficient and clean organization, data-base, Knowledge Management

Briefly: resources (men, budget), consistency, willingness…

The (wellknown) recipes for a good reliability

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Example on life-cycle

the AGOR cyclotron

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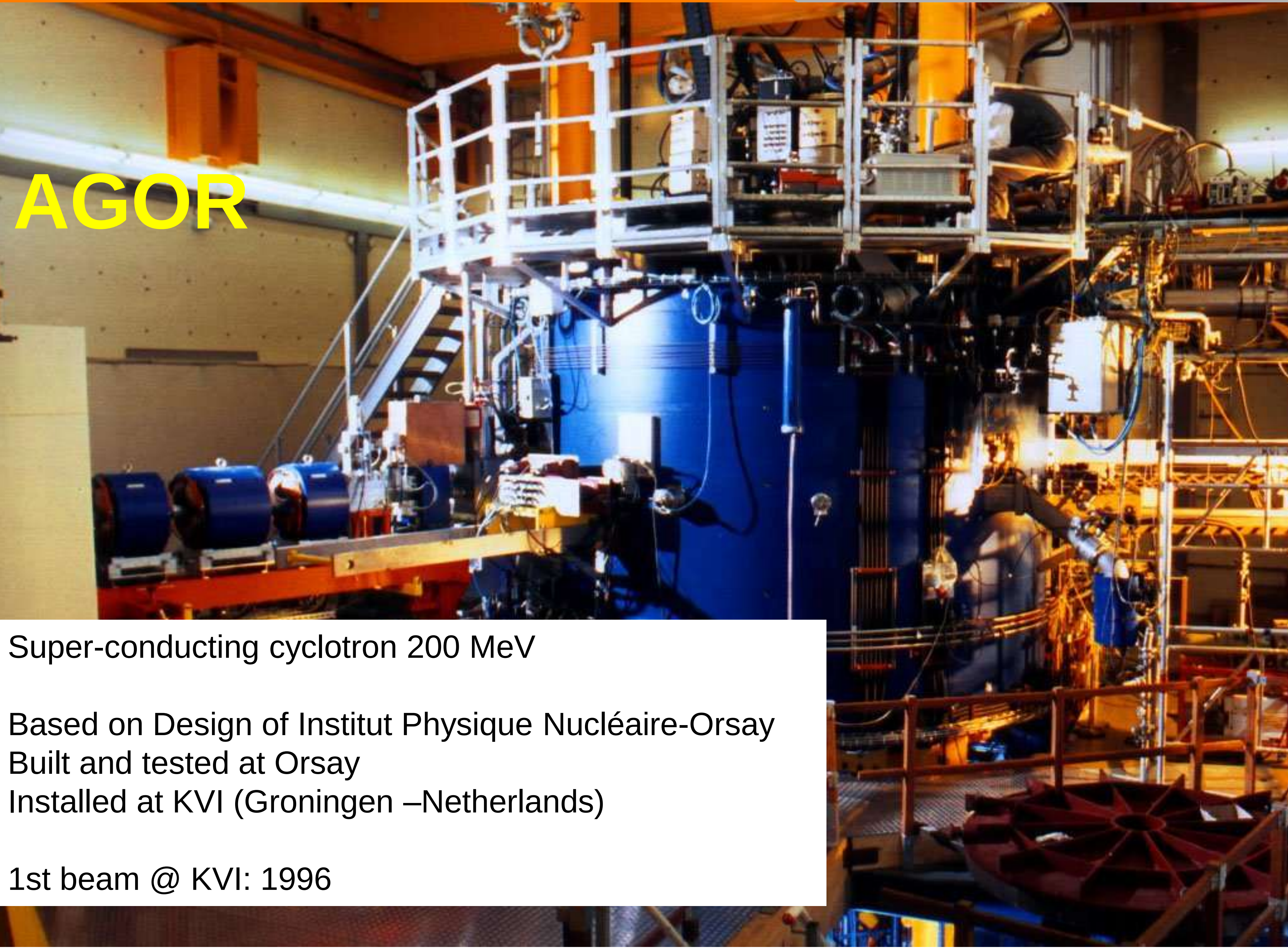
AGOR



Super-conducting cyclotron 200 MeV

Based on Design of Institut Physique Nucléaire-Orsay
Built and tested at Orsay
Installed at KVI (Groningen –Netherlands)

1st beam @ KVI: 1996

Basic design:All ions
200MeV pol p and d
100MeV/n Z/A=0.5

10 MeV/n Z/A=0.1

AGOR
Few numbers

Weight	320 T
Height	4 m
Diameter	4.4m
Magnetic field	4.05 - 1.75 T
RF	Amplitude 50 KV to 90 KV

33 Kms of supraconducting wires

250 l of liquid He (-269°c)

50 Millions Joules stored energy in SC oils

1 MW Installed power

400 T Attracting force on the poles (2/10 mm) at 4T

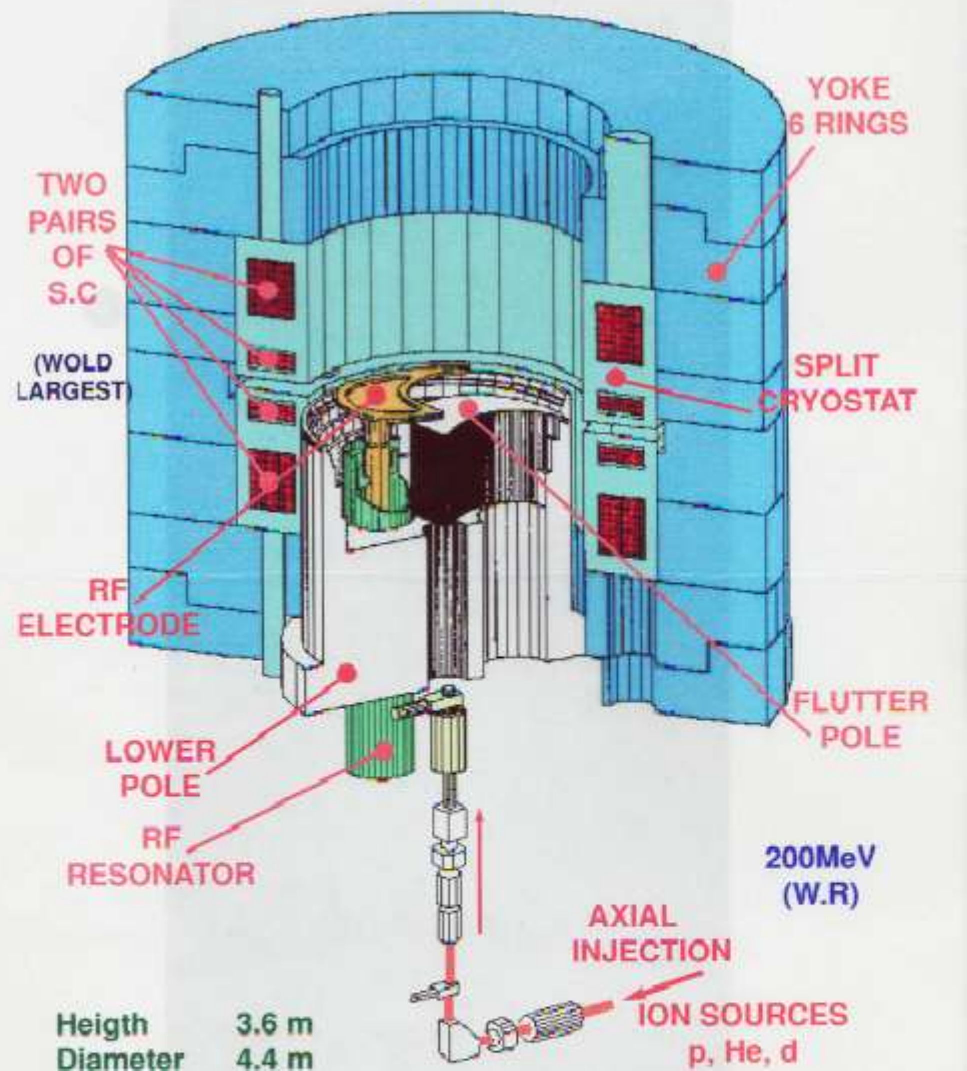
Protons beam at 200 MeV

$V = {}^{1}/_{4}\, C$

1.2 km

AGOR K600

3 sectors, 3 dees Compact Superconducting Cyclotron



Some features of the project

1. Expected results in terms of range of particles

2. Cyclotron built at Orsay and re-installed at KVI

3. Small leak in the cryostat

4. New concept: coils + vacuum systems (Heat pipes)

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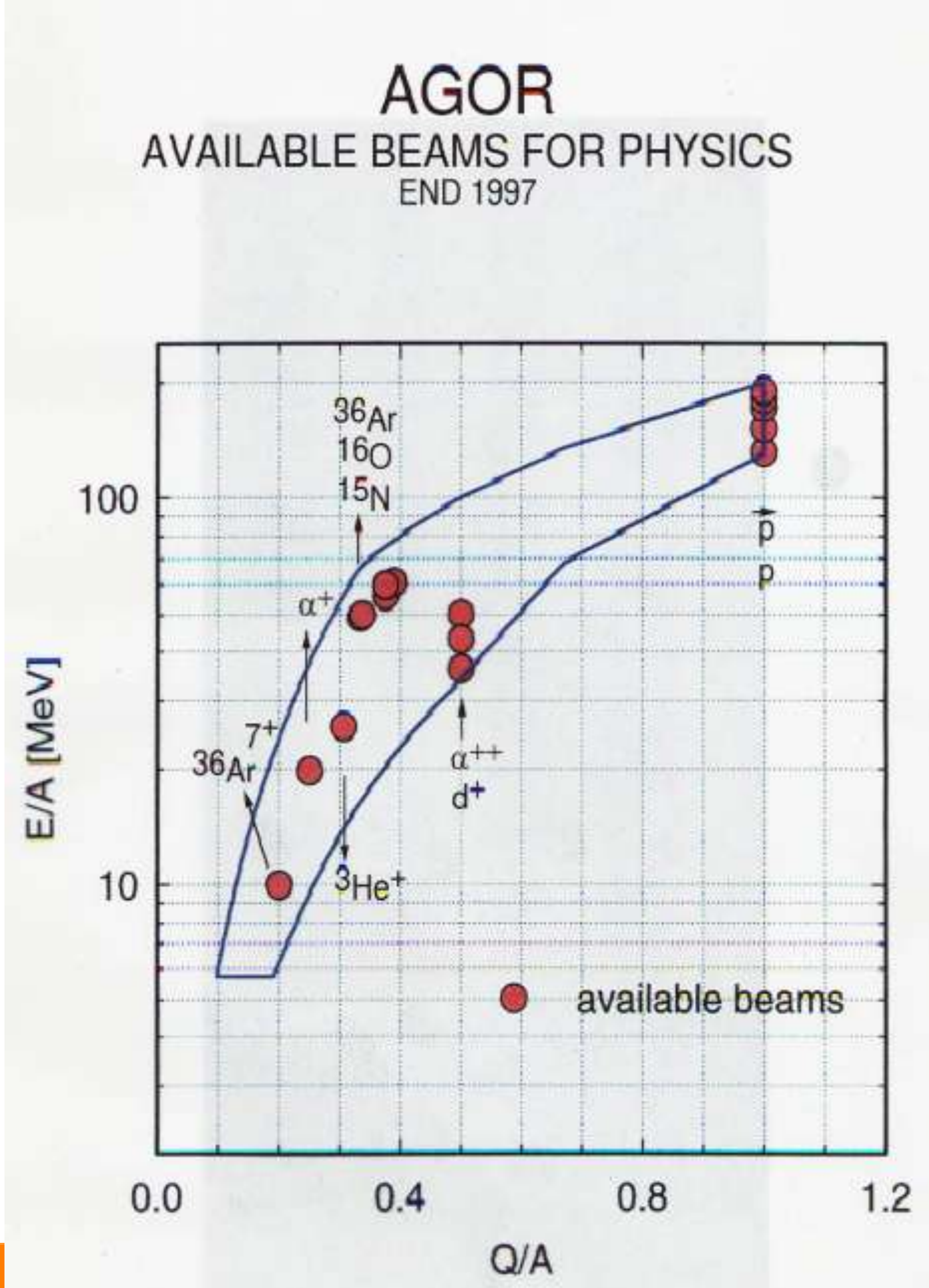

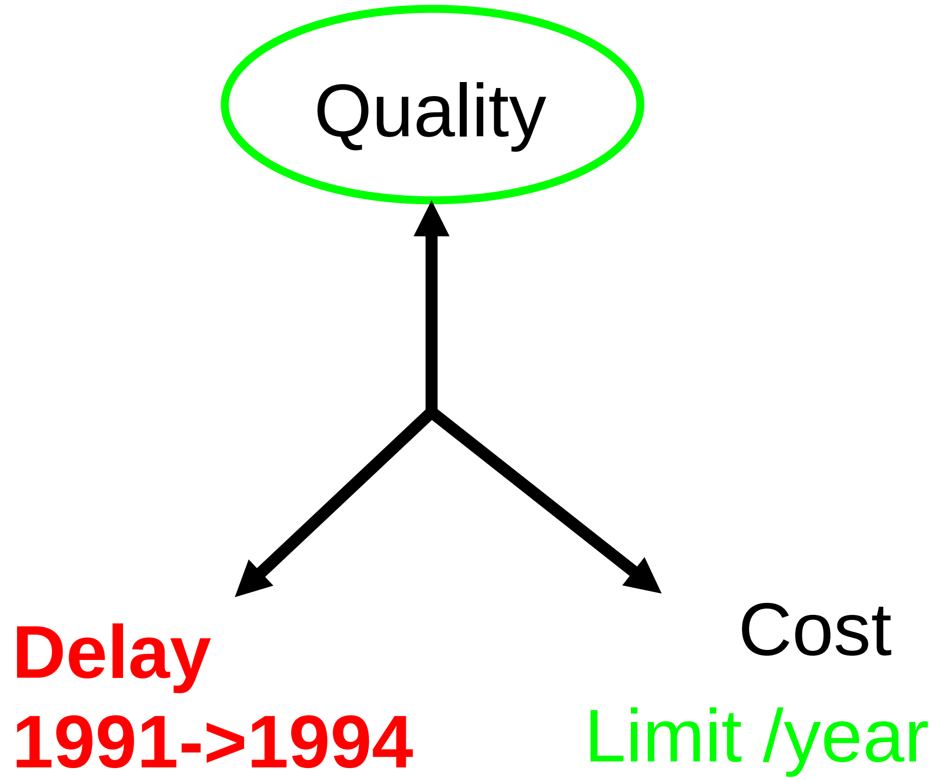

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Some features of the project

1.Expected results in terms of range of particles
OK for results – 3 years of delay

2. Cyclotron built at Orsay and re-installed at KVI
OK : mix team IPNO-KVI from the begining

3. Small leak in the cryostat
NOK : a persistent trouble during first years

4. New concept: coils + vacuum systems (Heat pipes)
OK : good management of R&D on innovation

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3. some paradoxes about reliability (for accelerators)

Some paradoxes about reliability

In order to obtain the **maximal** reliability, this thematic must be considered by **all**.

A **permanent** and **rational** approach will permit to reach the **expected** results.

Some paradoxes about reliability

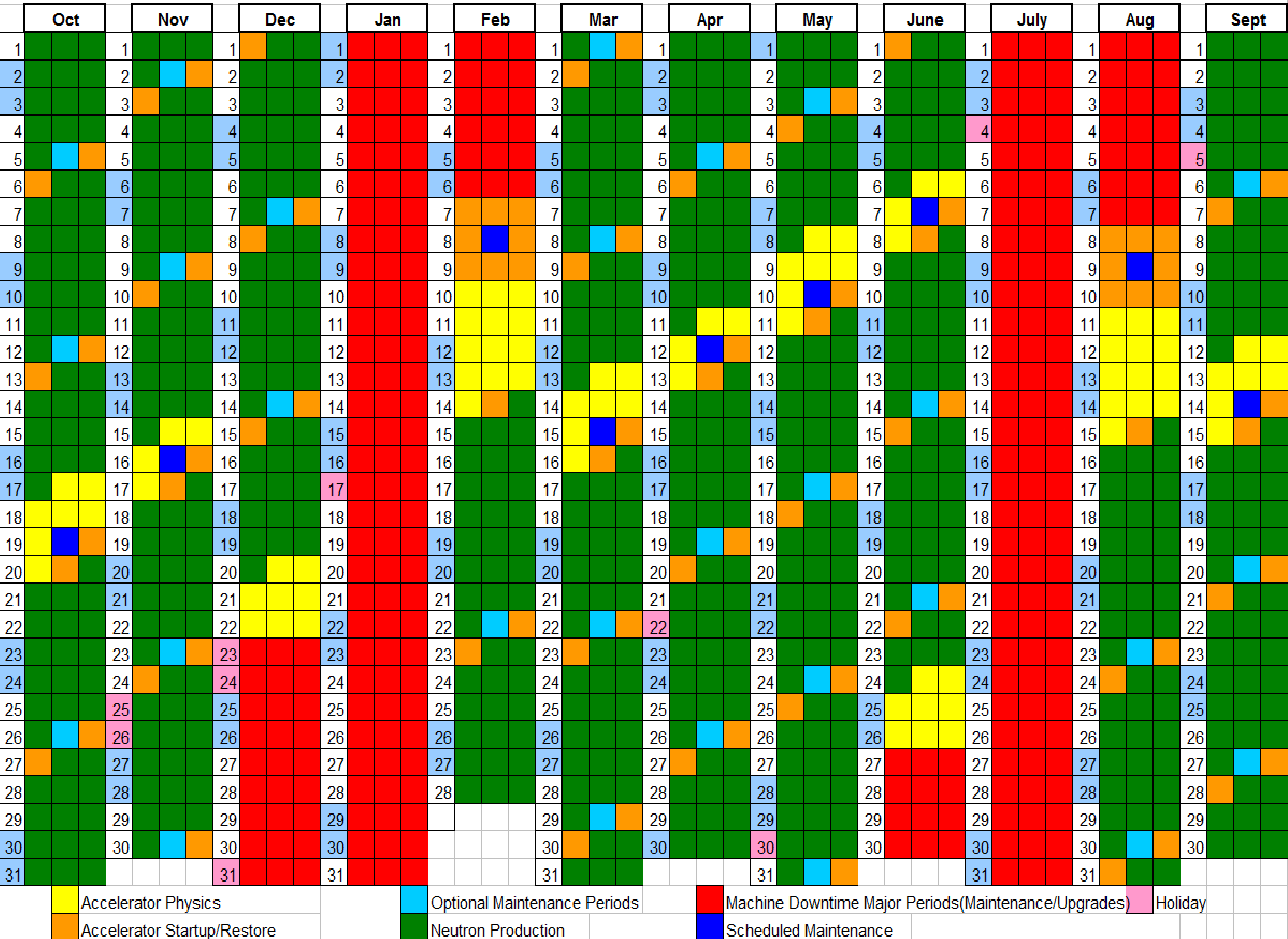
In order to obtain the ~~maximal~~ reliability, this thematic must be considered by **all**.

A … **nal** approach will … **xpected** results.

The maximal reliability
is an utopia

To be defined, means necessaries, associated costs…

Run Schedule for FY 2011



Some paradoxes about reliability

In order to obtain the ~~maximal~~ reliability, this thematic must be considered by ~~all~~.

A permanent and rational approach will … ed results.

Who is responsible of what ?
Are the guilties the payers ?

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Some paradoxes about reliability

In order to obtain the ~~maximal~~ reliability, this thematic must be considered by ~~all~~.

A ~~permanent~~ and rational approach will permit to reach the expected results.

Access difficult during operations
No mobilisation if all run well

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Some paradoxes about reliability

In order to obtain the ~~maximal~~ reliability, this

Durable effects obtained on long-term
Budget often discussed during crisis

~~all~~.

A ~~permanent~~ and ~~rational~~ approach will permit to reach the expected results.

Some paradoxes about reliability

In order to obtain the ~~maximal~~ reliability, this thematic must be considered by ~~all~~.

A ~~permanent~~ and ~~rational~~ approach will permit to reach the ~~expected~~ results.

Reliability is measured a posteriori

Some paradoxes about reliability

In order to obtain the ~~maximal~~ reliability, this thematic must be considered by ~~all~~.

A ~~permanent~~ and ~~rational~~ approach will permit to reach the ~~expected~~ results.

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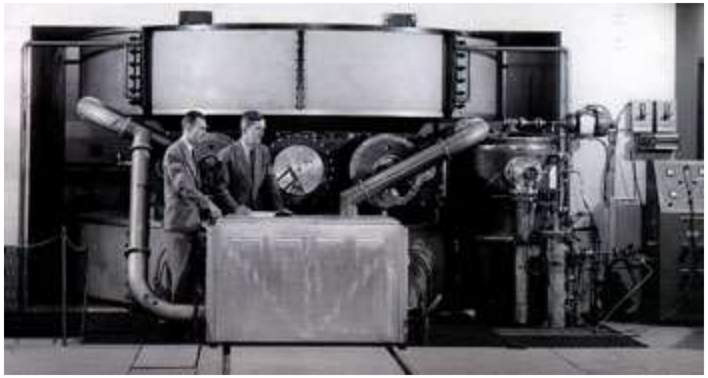
Salutations

Synchro-cyclotron - HCL
Harvard (1949-2003)



Cyclotron 88 inch - LBL
Berkeley (1961 - …)

Cyclotron PSI (590 MeV)- CH
designed for 100 µA (1974)
an now at 2,2 mA (2012)

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Summary

Reliability and accelerators

- **Concepts**: principles to increase reliability, risks to consider

- **Definition** : Importance to agree on (what, how, mode, constraints/freedoms, …)

- **Maintenance**: % determinist (mechanical, cooling, …) % based on monitoring (systems + organisations)

- **Responsabilities**: to etablish and clarifiy (systems, organization, Quality assurance, test, …)

- **Information**: how to get as soon as possible (other experiences, test, …), how to keep during the life of accelerator.

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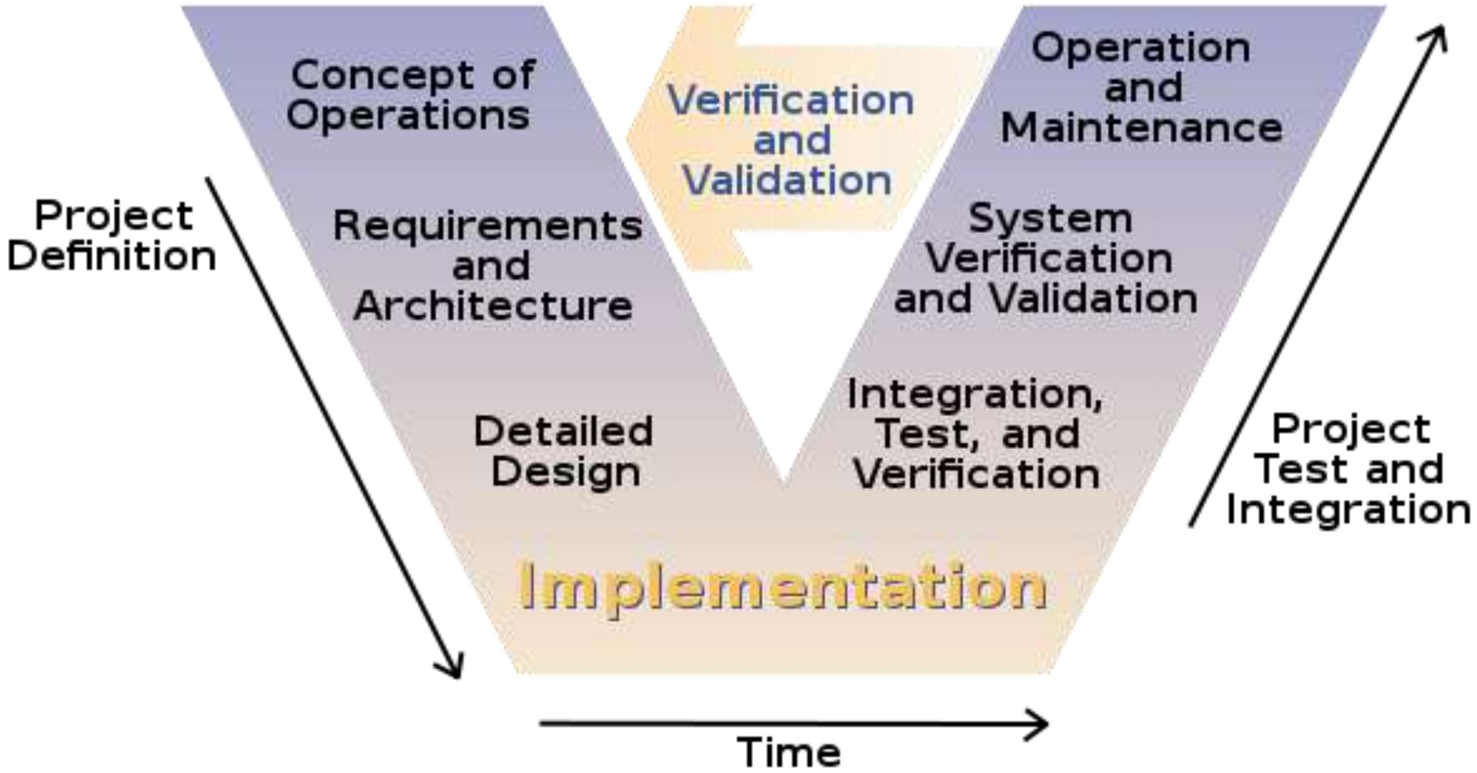
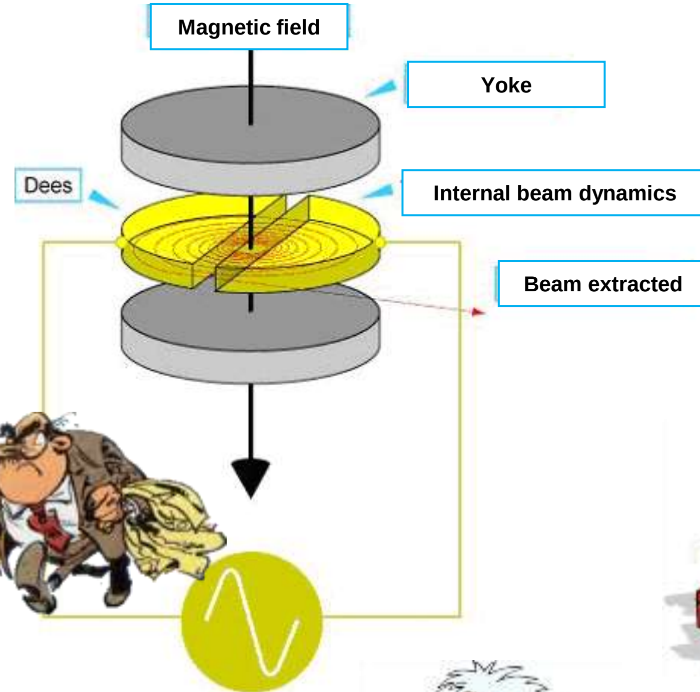
The V cycle of development



Building

THANK YOU !



Concepts Pre-studies	detailed studies	Construction Installation-Test	Operation & maintenance

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