Collaborative planning and scheduling: towards an application of the ALARA principle in the intervention planning and scheduling phase.

Mathieu Baudin, CERN

20th January 2015

PURESAFE Final Conference, CERN, Geneva Switzerland
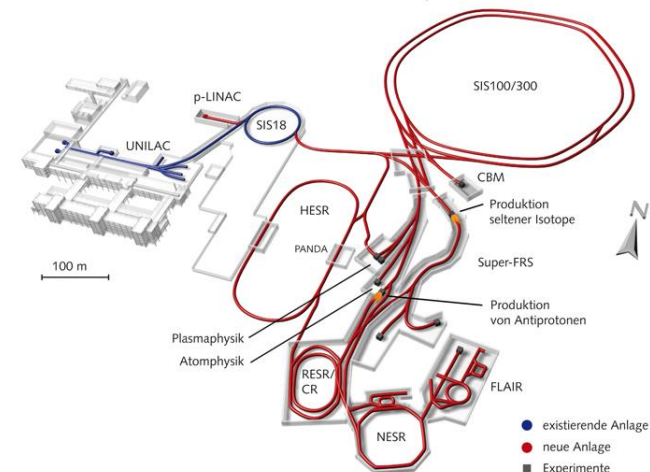
Table of content

I.1. Particle acceleration complexes

- Human interventions in particle acceleration complexes:
  - Preventive maintenance
  - Corrective maintenance
  - Inspection interventions
  - Consolidation interventions
  - Upgrade interventions

- Several hundreds of interventions per year

- Collaborative environment:
  - Several dozen scientific fields
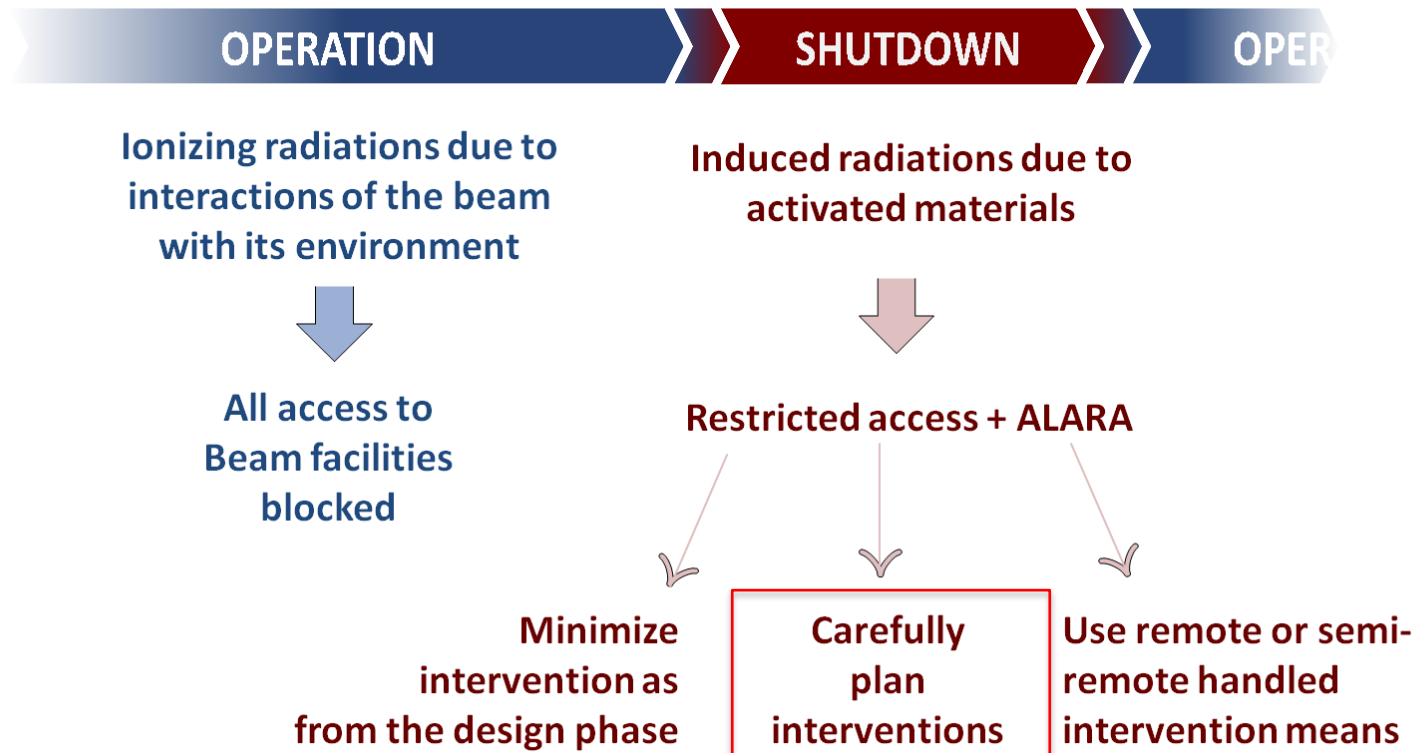 - Several dozen nationalities
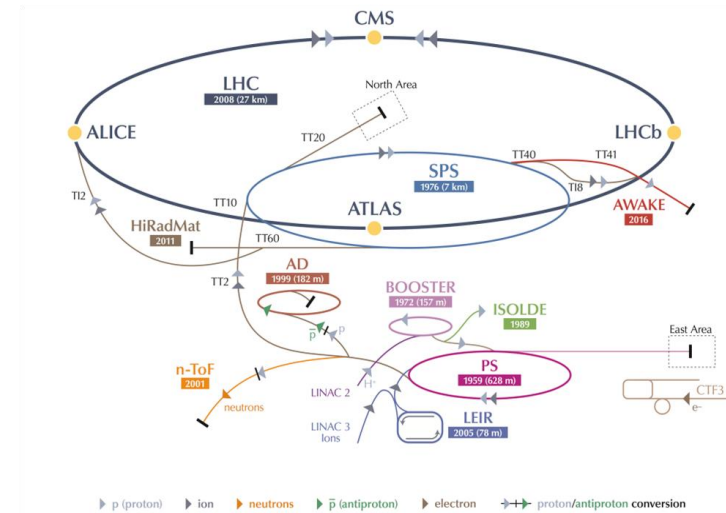
Schematic of CERN's beam installations

Schematic of future FAIR installations

I.2. The cycle of operations

OPERATION	SHUTDOWN	OPER...

Ionizing radiations due to interactions of the beam with its environment

Induced radiations due to activated materials

All access to Beam facilities blocked

Restricted access + ALARA

Minimize intervention as from the design phase

Carefully plan interventions

Use remote or semi-remote handled intervention means
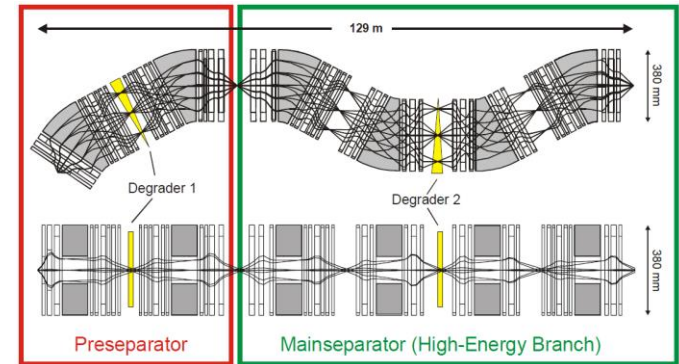
I.3. Ionizing radiation

Optics of FAIR's future Super-FRS
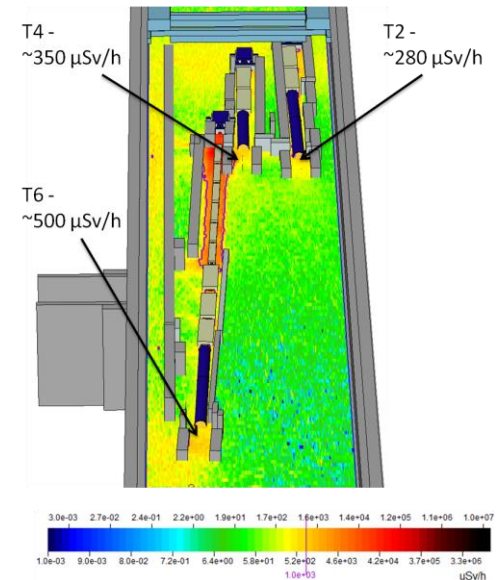
Production during operation:

- Activation of neighbouring materials (accelerators, water, dust, etc.)

- Activation of targets or beam inserts

Measurements and estimates:

- Manual surveys

- In situ detectors

- Monte Carlo Simulations (thin granularity, simulations on non-existing facilities, etc...)

CERN's TCC2 target area
Dose rates simulated using FLUKA

I.4. Optimizing the interventions

Temporal optimization :

- Demanding requirements for performance and operation time

- High number of requested works

- Resource constraints (limited space, human resources etc.)

ALARA Optimization
(**A**s **L**ow **A**s **R**easonably **A**chievable)

- Reduce the radiation dose

- A dose taken must be «JOLi» :
  - Justified
  - Optimized
    (trajectories, scheduling, etc.)
  - Limited
    (e.g. legal thresholds)

The ALARA optimization requires compromises between time, cost and received radiation doses

II. Planning and scheduling works

II.1. Working on both aspects

Aims:

- provide a collaborative planning and scheduling system
- Optimize interventions
  - Temporally
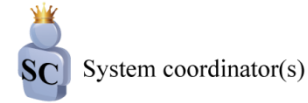 - In terms of received radiation doses (individual and collective)

This implies:

- Collaboration between participants
- Simulation of different scenarios
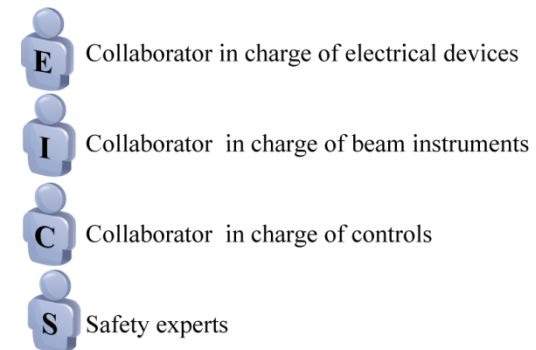- Optimization at both task and global levels

II.2. Collaborative planning and scheduling (1/2)

- Participants with specific roles submit activities and **temporal constraints:**
  - Sequential
  - Logistics (resources)

- The planning system :
  - May receive **conflicts**, **feedbacks** and **couplings** as input
  - Looks for **compromises** if necessary
  - Identifies and proposes solutions (if solutions exist)
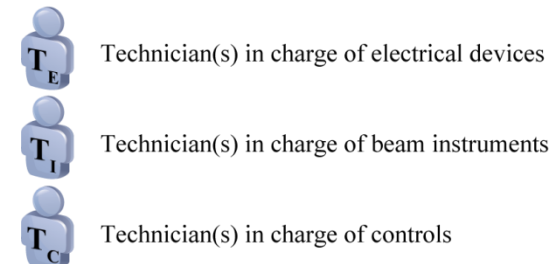 - **Optimizes** these solutions

Level 1: strategic

SC   System coordinator(s)

Level 2: tactical

E   Collaborator in charge of electrical devices

I   Collaborator in charge of beam instruments

C   Collaborator in charge of controls

S   Safety experts

Level 3: operational

T$_E$ Technician(s) in charge of electrical devices

T$_I$ Technician(s) in charge of beam instruments

T$_C$ Technician(s) in charge of controls

*Some of the roles encountered in the planning and scheduling system*

Needs:

- A mechanism to add new tasks and constraints in a previously existing schedule

- Detect conflicting submissions

- Solve conflicts when possible

- Optimize sequence
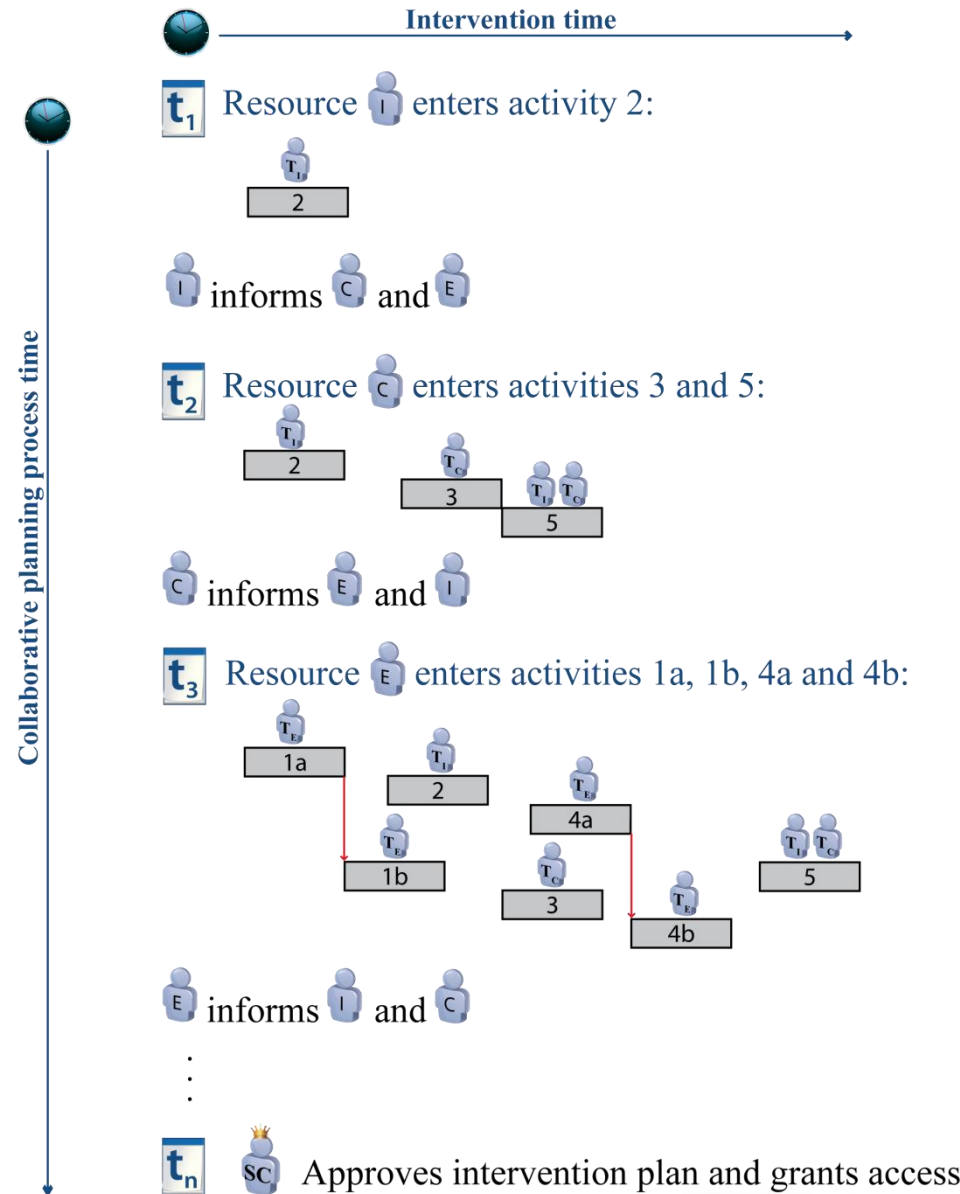
II.3. Proposed solution: constraint propagation

- **Constraint propagation** :
  - Not found in common approaches like PDM
  - Used since the 1980s in A.I.

- Advantages of A.I.:
  - Propagation
  - Equal treatment
  - Conflict detection

- Drawbacks:
  - Exponential algorithmic complexity (time and memory)
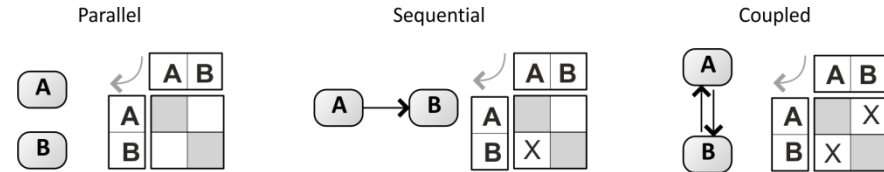 - Mostly unknown to practitioners
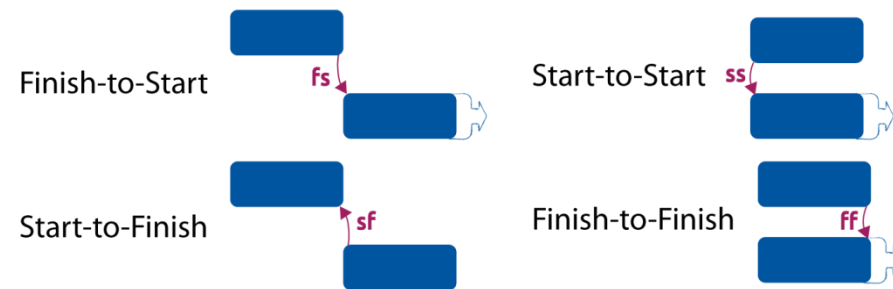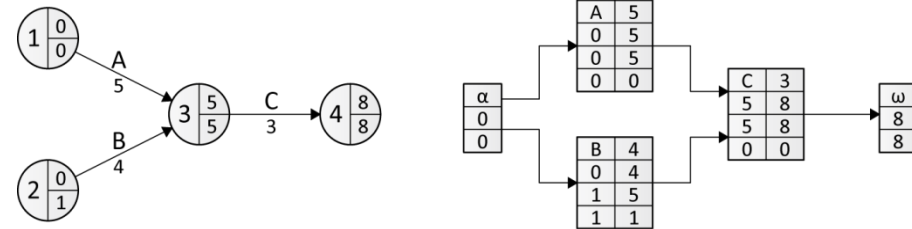
Generalized Precedence Relations (GPR)

II.4. The Design Structure Matrix (DSM)

- A binary matrix used to:
  - Model systems
  - Simulate processes

The 3 binary DSM dependencies

- Enables to represent:
  - Sequential constraints
  - Feedback, loops
  - Parallel tasks

- Sequence optimization is performed via the sequencing algorithm

- The binary DSM can be enhanced to give more details about constraints

Sequencing a DSM

II.5. Allen's Interval Algebra

- Tasks and events are represented through time intervals

- They are linked using a set of 13 constraints

- A constraint can be:
  - A single element of the set (e.g. A <m> B)

  - A vector of several constraints (e.g. A <b, o, m> B)

- Each new constraint is propagated using a transitivity table

Relation	Interpretation	Gantt chart-like illustration
A b B	A takes place before B	A
B bi A	B takes place after A	B
A m B	A meets B	A
B mi A	B is met by A	B
A o B	A overlaps B	A
B oi A	B is overlapped by A	B
A s B	A starts with B	A
B si A	B is started with A	B
A d B	A is during B	A
B di A	B contains A	B
A f B	A finishes with B	A
B fi A	B is finished by A	B
A = B	A equals B	A / B

Relations of Allen's interval algebra

B r2 C / A r1 B	b	bi	d
b before	b	no info	b, o ,m, d,s
bi after	no info	bi	bi, oi, mi, d, f
d during	b	bi	d

A small portion of Allen's transitivity table
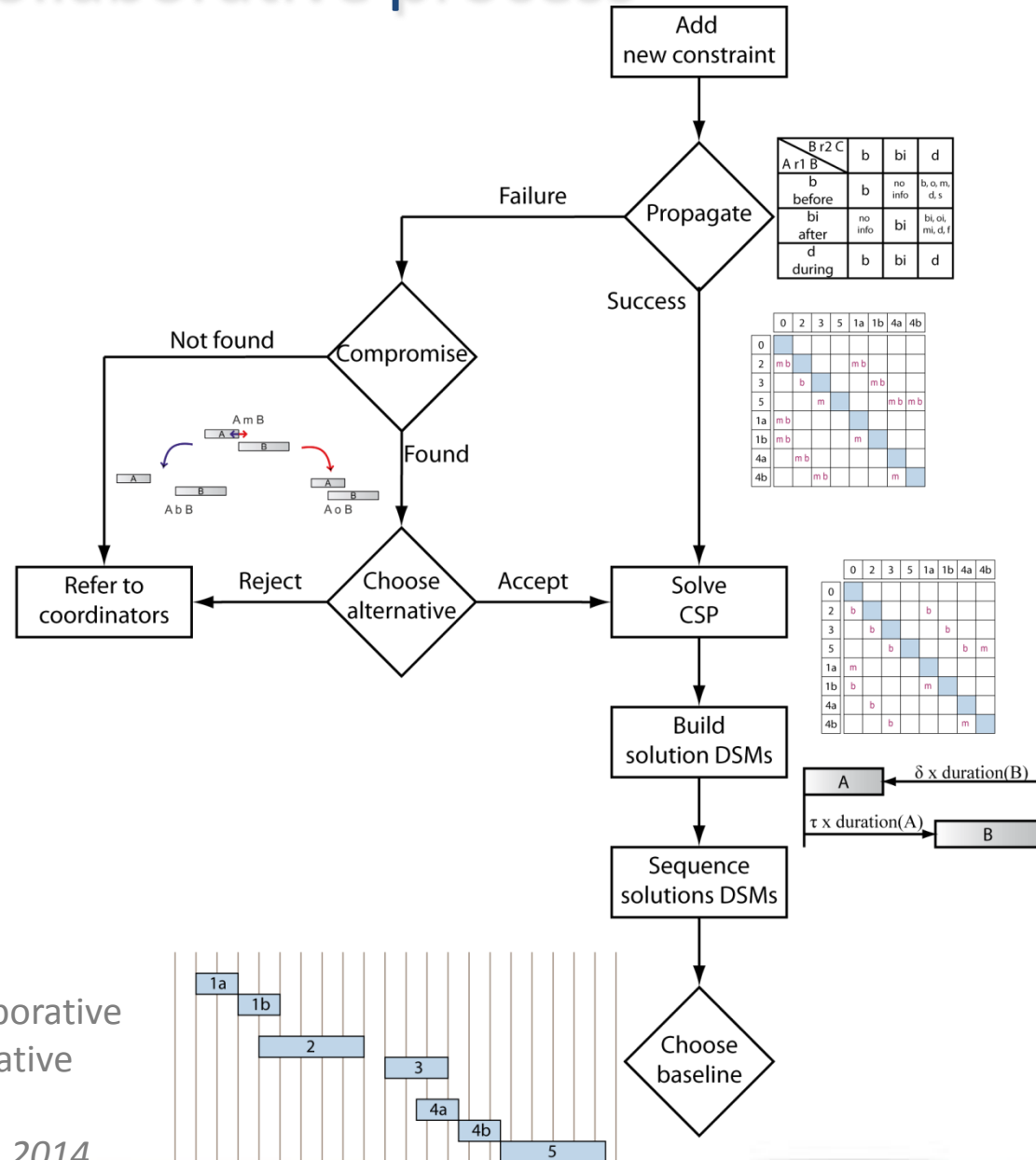
II.6. The collaborative process

- **Collaborative constraint submission process:**
  - Constraint submission
  - Constraint propagation
  - Compromise (optional)
  - CSP Solving (finding solutions)
  - Sequence optimization
  - Choice of baseline

- **Humans remains in the loop select the solutions**

- **Addresses mostly only temporal information**

- **Radiation protection data needs to be superimposed**

M. Baudin, P. Bonnal, J.-M. Ruiz, "The Collaborative DSM: a new way to handle complex collaborative planning and scheduling processes," *16th International DSM Conference, Paris, France, 2014*.

III. Theory and practice: example of FAIR's Super-FRS

III.1. Choosing solutions

- The DSM solutions provide different durations and different doses

- For more optimization:
    - Try different access paths
    - Optimize trajectories and procedures
    - Split radiation doses between several operators
    - Move equipment out of controlled areas

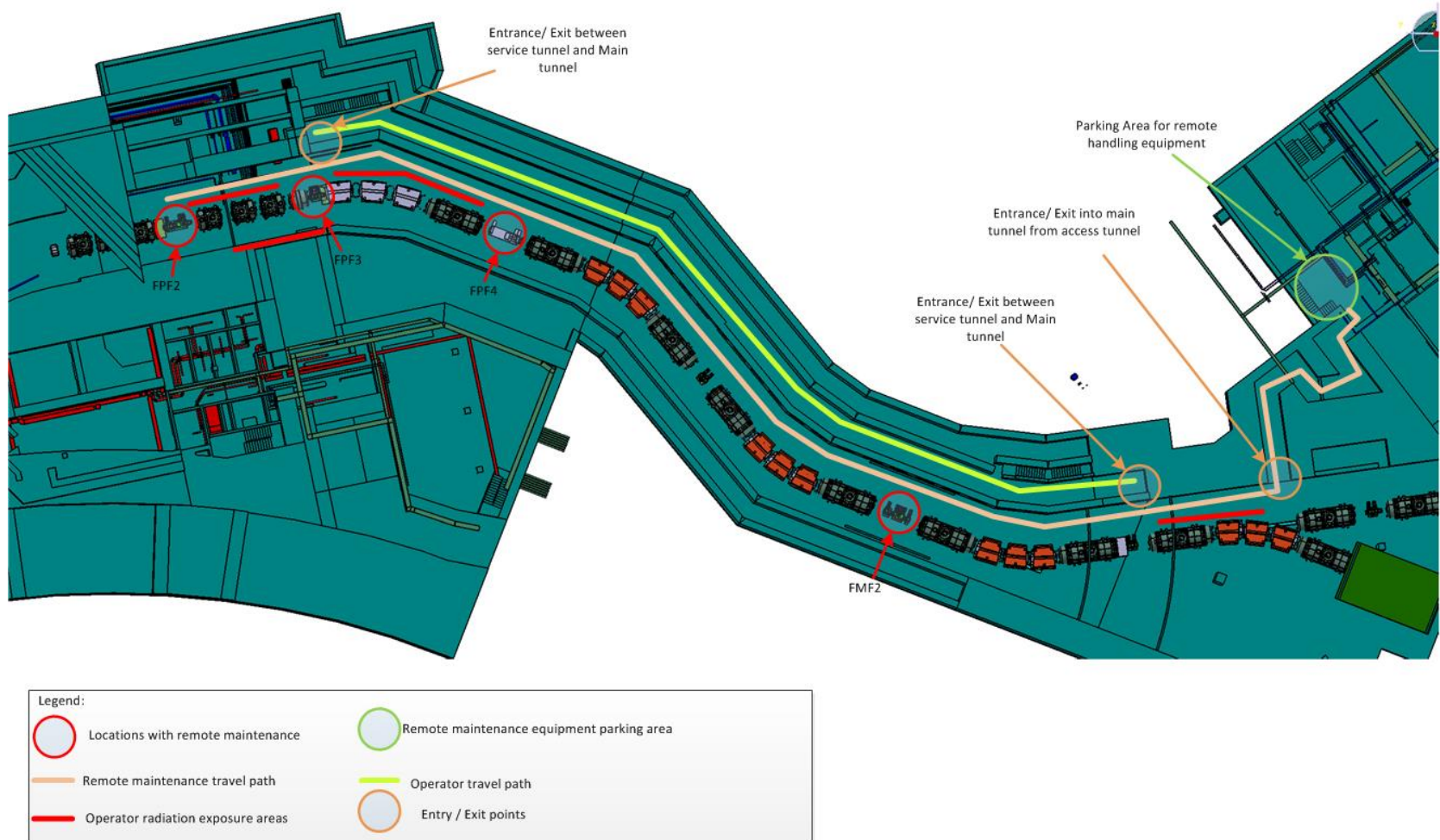- Optimal duration ≠ ALARA optimum
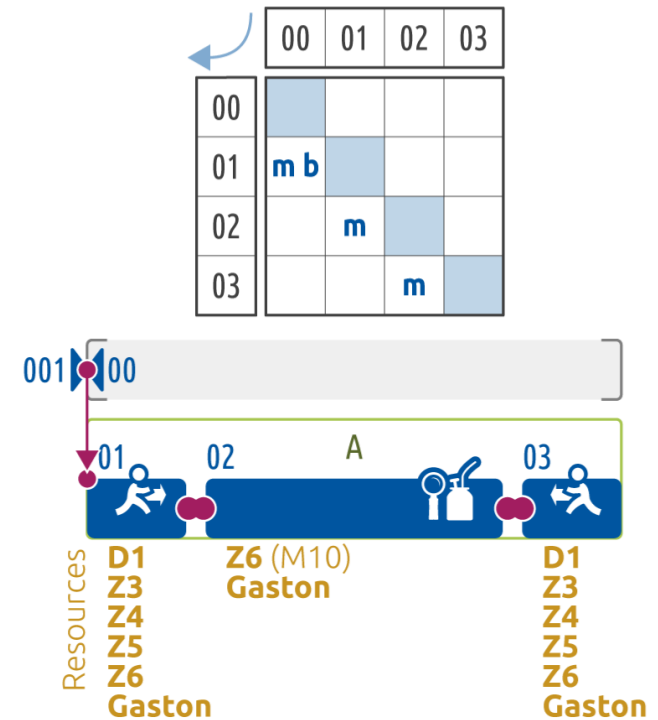
One scenario
=
One set of resources:
Human : Gaston
Locations: D1, Z3-6
Equipment: M10

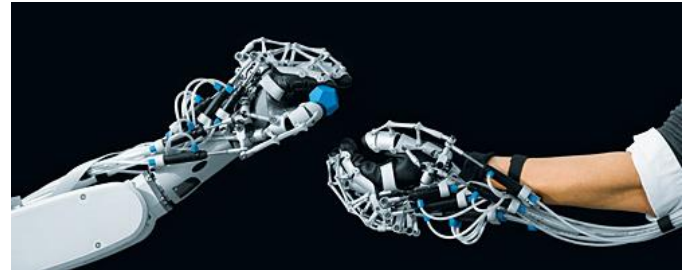# III.2. Example of FAIR's Super-FRS

Access paths for robots and operators in FAIR's Super-FRS from the tunnel entrance to the work station at focal point FPF2. (Courtesy of Faraz Amjad)

III.3. Comparison of scenarios

Automated scenario
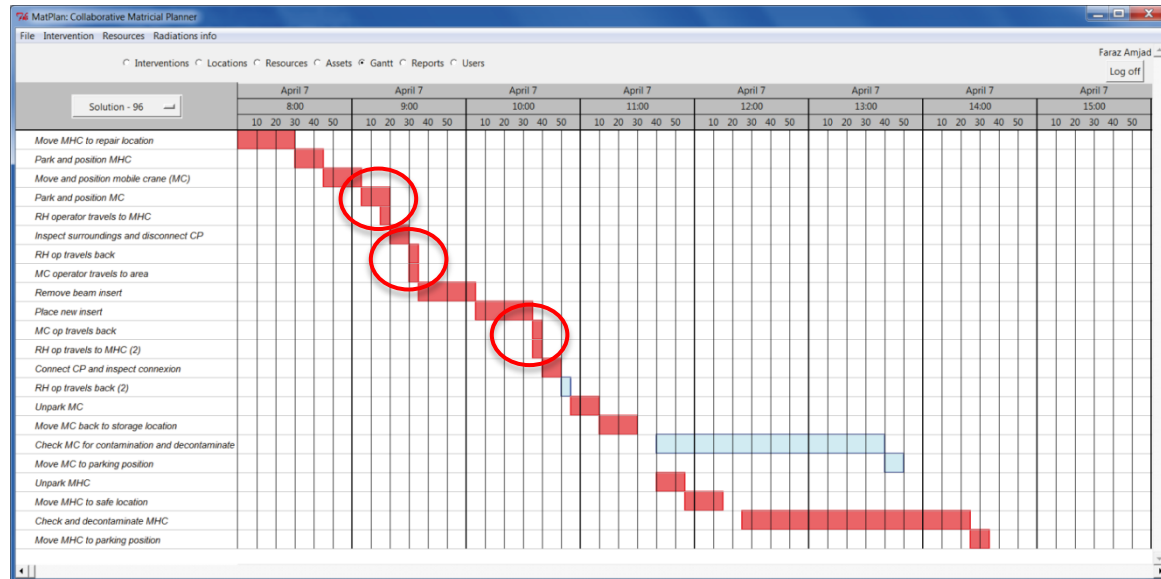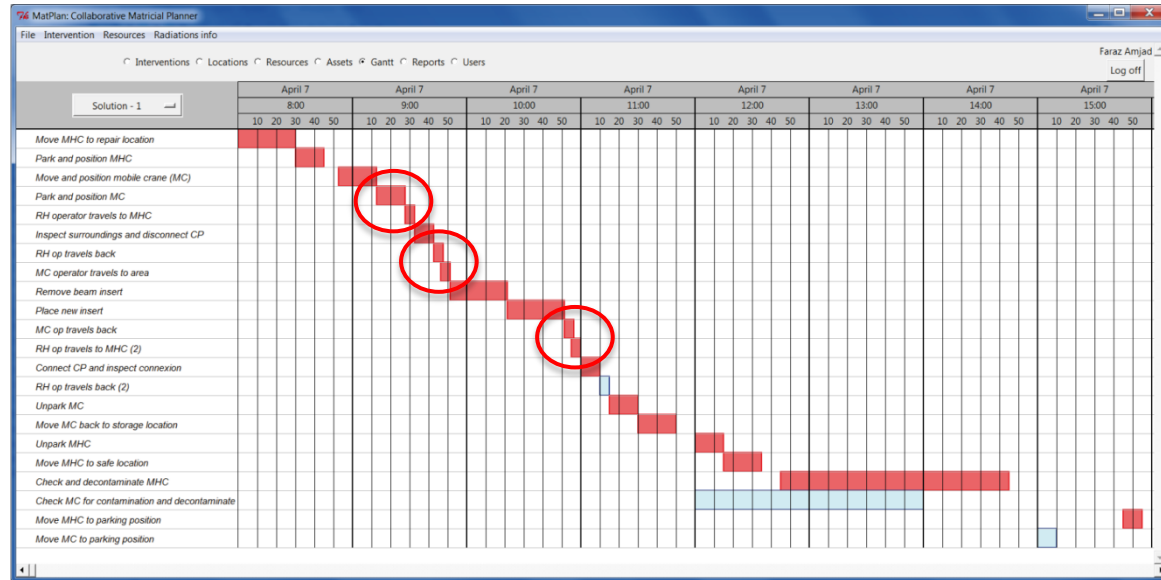
Remote-handled scenario

Duration estimates

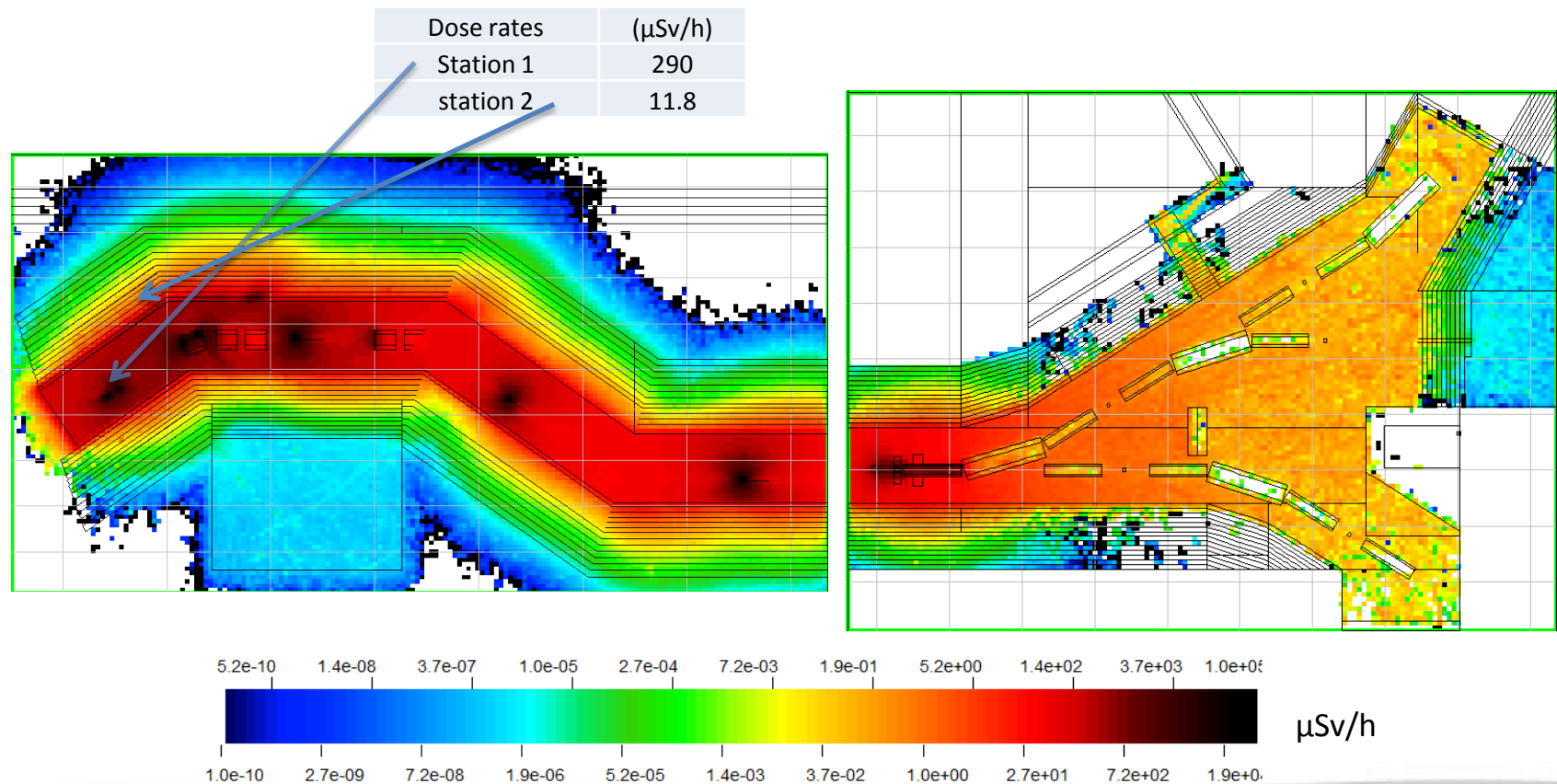| Scenario	Number of tasks	Constraints (multiple)	Shortest time	Longest time	Number of solutions
Remote-handled	22	24 (6)	6 h 58 min	8 h 14 min	96
Automated	19	20 (6)	7 h 30 min	9 h 15 min	64

III.4. Temporal optimization

- Some optimization possibilities and complex constraints are found

- The shortest scenario is not the most realistic

- Involvement of operators in the planning process can diagnose such problems

- In this case, more optimization can be achieved by:

    - comparing different scenarios

    - Adding radiation data

Radiation protection data comes from Monte Carlo simulations:
- 14 days of operation days and four different cooldown delays (12 h, 1 day, 7 days and 30 days)
- 4 months of operation with 2 weeks cooldown.
- 2 years of operation, 1week and 1 month cooldown

Dose rates	(µSv/h)
Station 1	290
station 2	11.8

| 5.2e-10 | 1.4e-08 | 3.7e-07 | 1.0e-05 | 2.7e-04 | 7.2e-03 | 1.9e-01 | 5.2e+00 | 1.4e+02 | 3.7e+03 | 1.0e+05 |

µSv/h

| 1.0e-10 | 2.7e-09 | 7.2e-08 | 1.9e-06 | 5.2e-05 | 1.4e-03 | 3.7e-02 | 1.0e+00 | 2.7e+01 | 7.2e+02 | 1.9e+04 |

III.5. Optimization at task level (2/2)

- Interactive dose optimization
- 2D or even 3D software tools
- Realistic trajectories and procedures
- Human validation

µSv/h
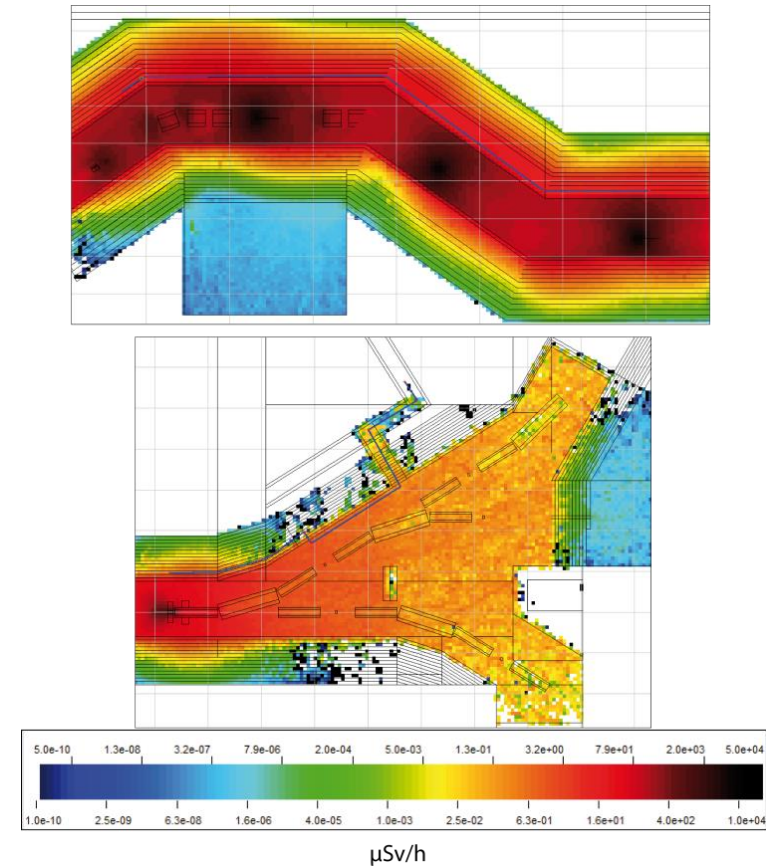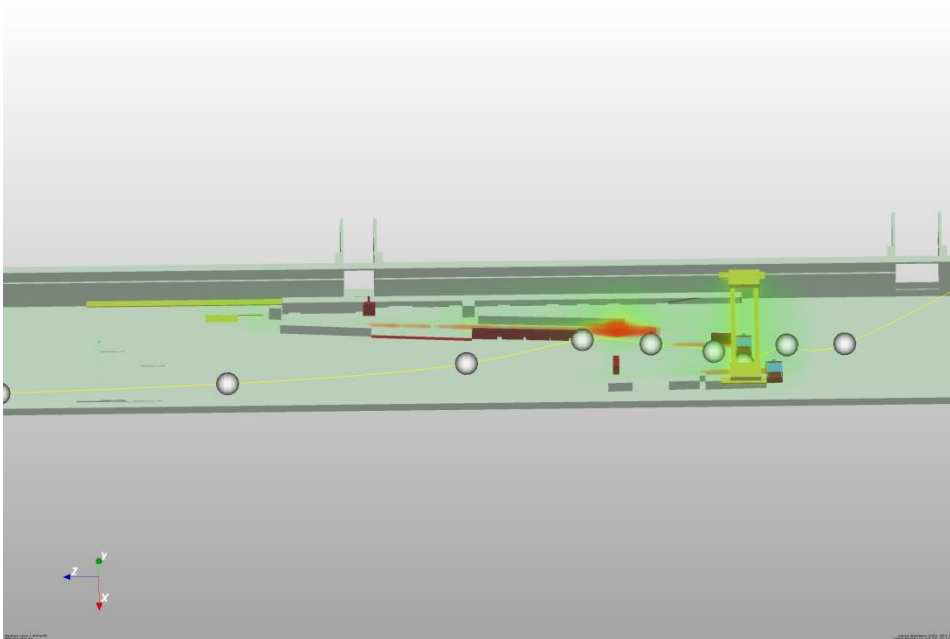
Top: IVPlanner, C. Theis, CERN

Left: RADIJS, Th. Fabry, CERN

III.6. Radiation doses and cost estimates

Estimates for anticipated radiation doses

	Station	Cooldown	MC Op.	MHC Op.	Collective
Remote-handled scenario	1	1 day	292.52 µSv	101.71 µSv	394.23 µSv
		1 week	140.49 µSv	47.65 µSv	188.14 µSv
	2	1 day	12.96 µSv	6.25 µSv	19.21 µSv
Automated scenario	1	1 day	0	0	0

Cost estimates (Courtesy of F. Amjad)

Scenario	Equipment	Cost estimates	Total cost estimate
Automated	2 omnimoves 1 robotic arm 1 mobile crane	1.25 M€ 200 k€	1.45 M€
Remote-handled	1 omnimove Extra shielding 1 Exo-Hands 1 mobile crane	500 – 600 k€ 200 k€	800 k€

IV. Conclusions and perspectives

IV.1. Conclusions

- The presented work proposes a collaborative planning and scheduling process, which:
  - is based on collaboration, constraints and compromises
  - is focused on simulation and comparison of scenarios in order to focus on feasibility rather than mathematical optimum
  - allows for non-temporal criticality, and places the engineer in a responsible, decision-making position.

- It needs to be completed using radiation protection data to properly integrate the ALARA approach in the intervention planning and scheduling phase

IV.2 Perspectives

- A prototype application has been developed
  - Still "confidential"
  - More development remains, e.g. to work on large schedules

- Work remains concerning the scenario selection:
  - Academic work: study the collaborative decision making (MCDA, Multi-objective optimization, etc.)
  - Practical work: integrate it in the tool

- In terms of practice, integration remains a challenge (1 intervention plan = 4 software tools)

cern.ch/puresafe

cern.ch