
CERN

Availability Studies for LINAC 4

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Acknowledgments: M. Jonker, R. Schmidt, J. Uythoven

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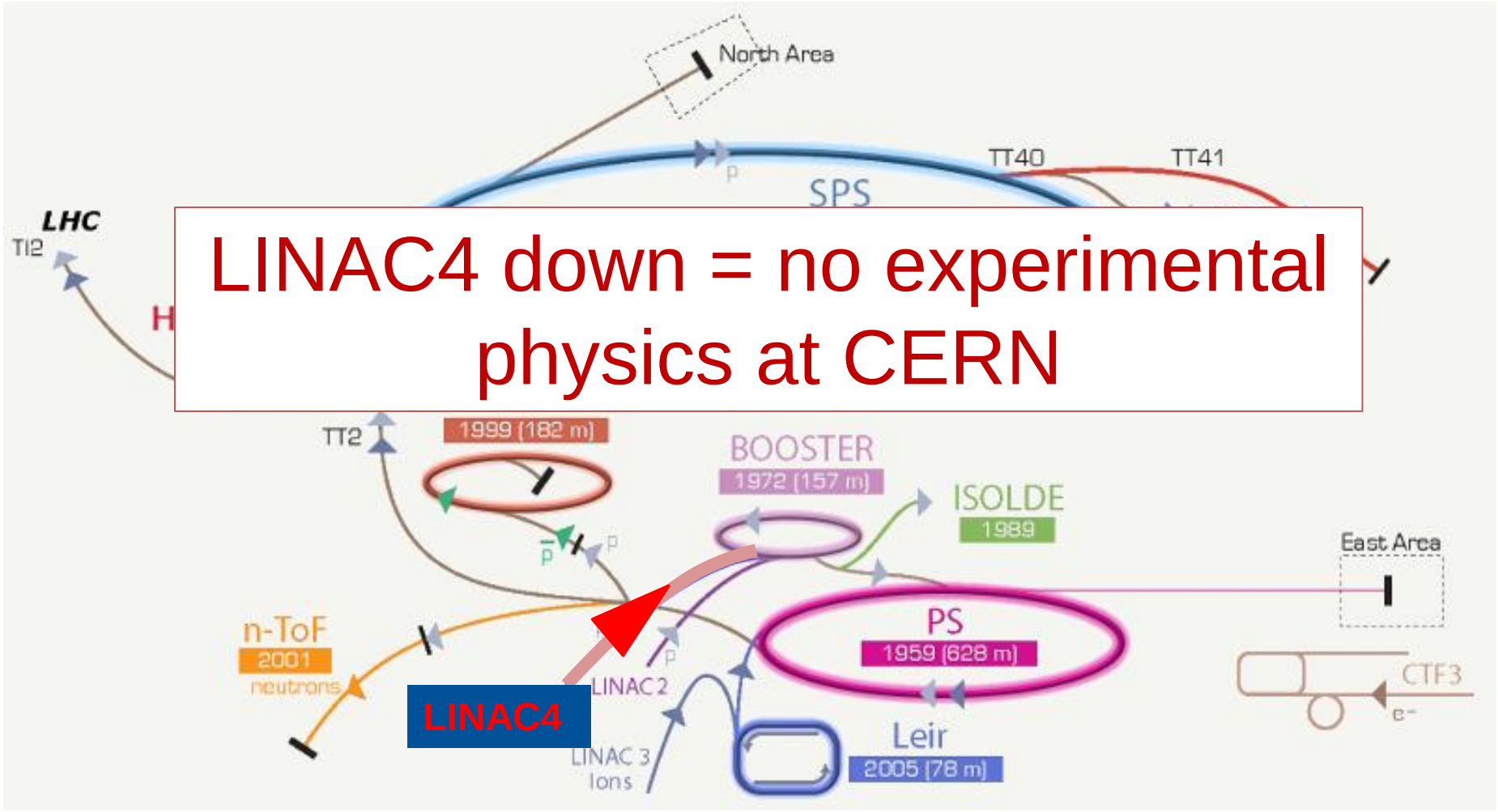
Introduction

CERN Injector Complex



LINAC4 down = no experimental physics at CERN

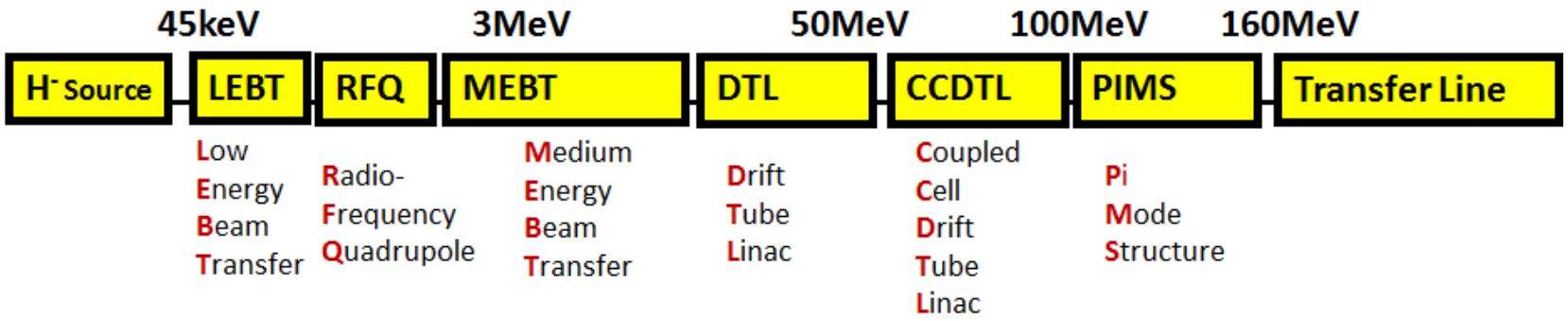
LINAC4 provides beam for LHC and several other experiments

Linac4 at CERN

- Linac4 is the future linear accelerator that will replace Linac2 in the CERN injector complex
- Under commissioning
- **Availability-critical accelerator**: target > 95 % availability
- Linac4 will be in operation from 2019 (after LS2)
- Dedicated Reliability Run foreseen to start end of spring 2017

Goal of the availability study:
Predict the expected availability

Linac4 layout and Parameters



LINAC 4 PARAMETERS	
Ion species	H-
Output energy	160 MeV
Bunch frequency	352.2 MHz
Max. rep.-rate	2 Hz
Beam pulse length	400 us
Source current	80mA
RFQ output current	70mA
Linac current	40mA
Beam power	5.1kW
Linac transverse emittance	0.4 pi mm*mrad

Linac4 Availability Studies

Procedure:

Goal of the availability study:
Predict the expected availability

1.

- ✓ Together with system experts and data from Linac2 -> **Failure Catalogue**
- ✓ Data from the failure catalogue -> **Availability models**
- ✓ **First estimations**

2.

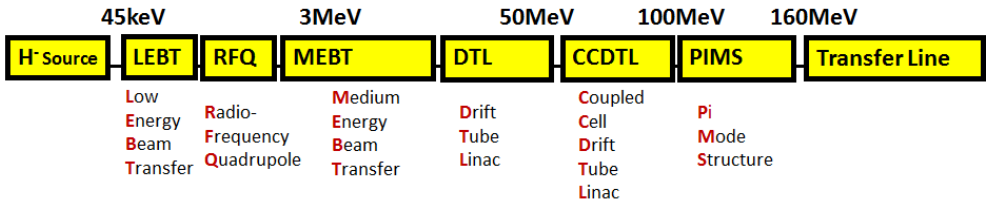
- ➢ Reliability run data -> **Refine models** and reproduce RR performance
- ➢ Predict Linac4 **future operation**
- ➢ **Provide guidelines for Linac4 performance improvement**

Failure Catalogue

Gathering data for availability models

Linac4 Failure Catalogue

- Failure Mode Analysis
- Based on
  - outcome of meetings with system experts
  - failure data from Linac2
- Identification of system components and failure modes
- Quantification of failure effects (mainly in terms of downtime)
- Link information with SNS Failure Catalogue

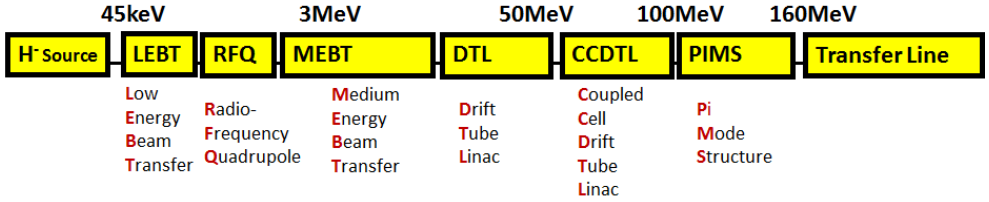


SECTION: Linac4	No. of components	BEAM CONDITION	FAILURE MODE	LOCATION OF BEAM LOSSES	MTTR (h)	COMMENTS *repair in the tunnel: venting incl. consign. 20', deconsign. 10'	MTBF (h)
1) SOURCE	1	80mA H-, 45keV, 0.25 umrad	H- source not availableor below nominal intensity	Source/LEBT			
1.1) HYDROGEN			Hydrogen delivery system	Plasma generator	3.00	3h*	2.60E+04
			Hydrogen pulser	Plasma generator	3.00	3h*	8.76E+03
1.2) RF-SOURCE			LLRF controller	Plasma generator	2.00	2 h	1.70E+04
			RF-amplifier	Plasma generator	2.00	6h	8.76E03
			Matching network connection	Plasma generator	1.00	1 h*	2.60E+04
			RF-antenna - air ionization	Source	24.00	24 h*	2.60E+04
1.3) PLASMA GENERATOR			Plasma generator leak	Plasma generator	24.00	24 h*	1.70E+04
			Plasma electrode Bias power supply		1.00	1 h*	1.70E+04
			Permanent magnets		24.00	24 h*	2.60E+04
			Vis ceramique		24.00	24 h*	2.60E+04
1.4) SOURCE HIGH VOLTAGE			10 kV Puller-dump transformer	Source	3.00	3 h*	2.60E+04
			45 kV HV transformer	Source	3.00	3 h*	2.60E+04
			25/45 kV Einzel Lens transformer	Source	3.00	3 h*	2.60E+04
			Fron-end insulator	Source	72.00	72 h*	2.60E+04
			10/25/45 kV converter	Source	3.00	3 h	8.76E03
1.5) CESIATION SOURCE			CS-heating system		1.00	1 h*	1.70E+04
			Air cooling system		1.00	1 h*	1.70E+04
			Cs-valve motorization		1.00	1 h*	8.76E03
1.6) SOURCE VESSELS			Flange leak	Source	24.00	24 h*	2.60E+04
			Front-end leak	Source	72.00	72 h*	2.60E+04
1.7) SOURCE VACUUM			TM pump		3.00	3 h*	1.70E+04

… **Continuously updated**
Started in 2012 and followed-up in the commissioning

Requirements for Linac4 Accelerator Fault Tracker:
- Categories based on failure catalogue structure

Linac4 Failure Catalogue



- More than **110 failure modes** considered
  - EM Magnets failures
    - Powering failure
    - Controls failure
    - Measurement failure
  - RF Cavities failures
    - Sparking
    - Movable tuners not working
    - Pressure on water system

- Some data still missing
  - **RF Cavities LLRF and Interlock systems** components failure data
  - LEBT Chopper **synchronization failure**
  - **Vacuum failure behaviour** under discussion
  - **Beam Instrumentation** failure data
  - …

- 14 Main Categories
  - H- Source
  - LEBT
  - RFQ (RF System)
  - MEBT
  - DTL (RF System)
  - CCDTL (RF System)
  - PIMS (RF System)
  - *Vacuum*
  - *Electro Magnets*
  - *Dump*
  - *Technical Network**
  - *Machine Interlocks*
  - *Beam Instrumentation**
  - *Accelerator Controls**

* Failure data from Linac2 fault data 2007-2016

Availability model

Assumptions

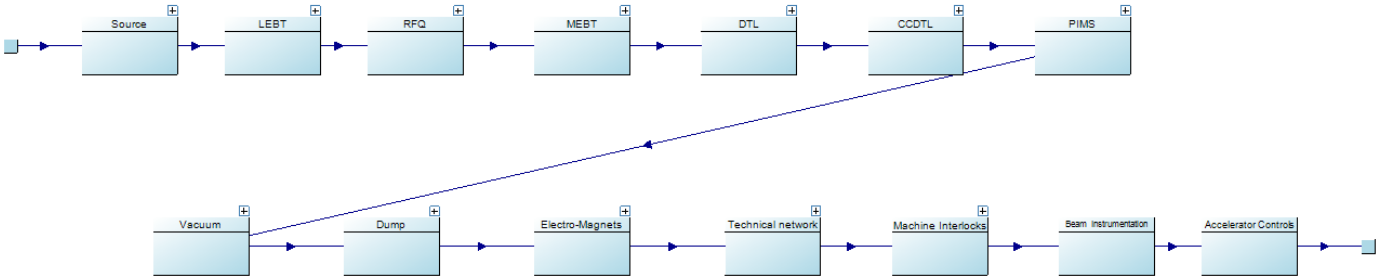
Linac4 Availability model: **Assumptions**

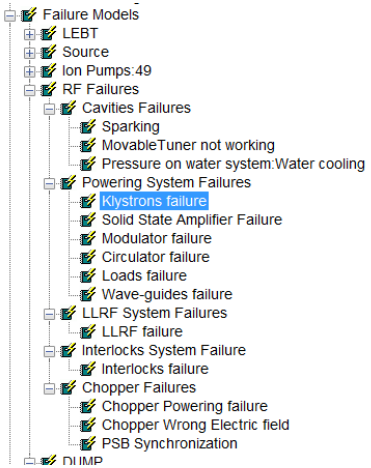
- Data from Failure Catalogue
- Simulation period: 1 year (operation 24/7)
- Components failure behaviour follow an exponential distribution
- Maintenance / repairs:
  - Only repairs when the system is down due to components failures
  - Repairs of different systems can be done simultaneously
  - All repairs must finished before restarting the Linac4
- The system is down after failure -> No components failure during repair

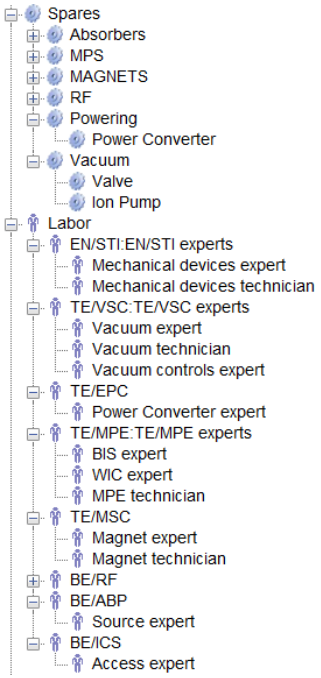
Availability model

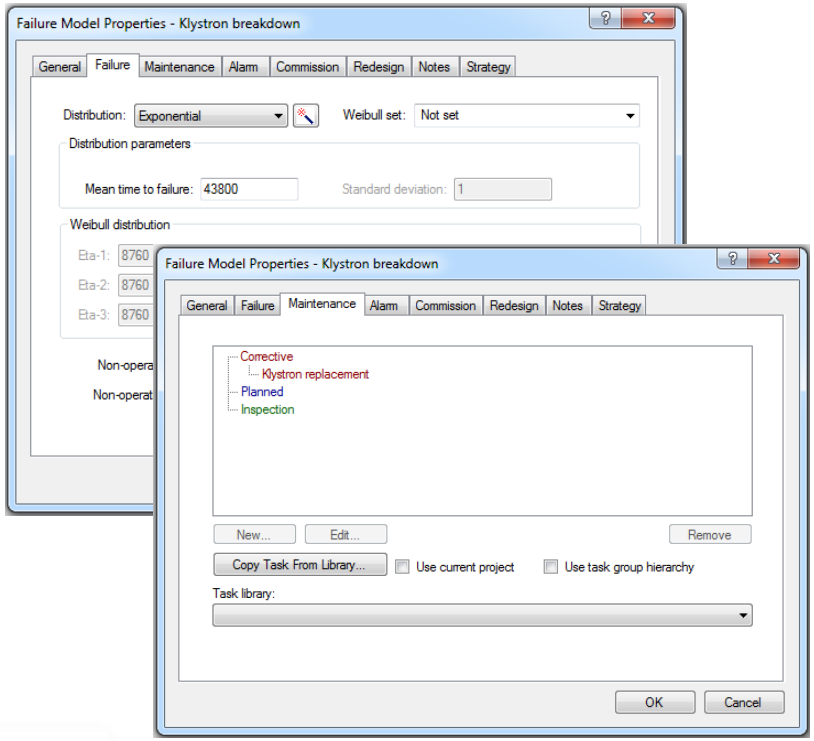
Implementation

Linac4 Availability model: **Implementation**









- Linac4 failure behaviour modelled by Reliability Block diagrams
- Each block can be assigned a failure mode…
  - Failure distribution
  - MTTF
  - Consequences
- …and a maintenance strategy

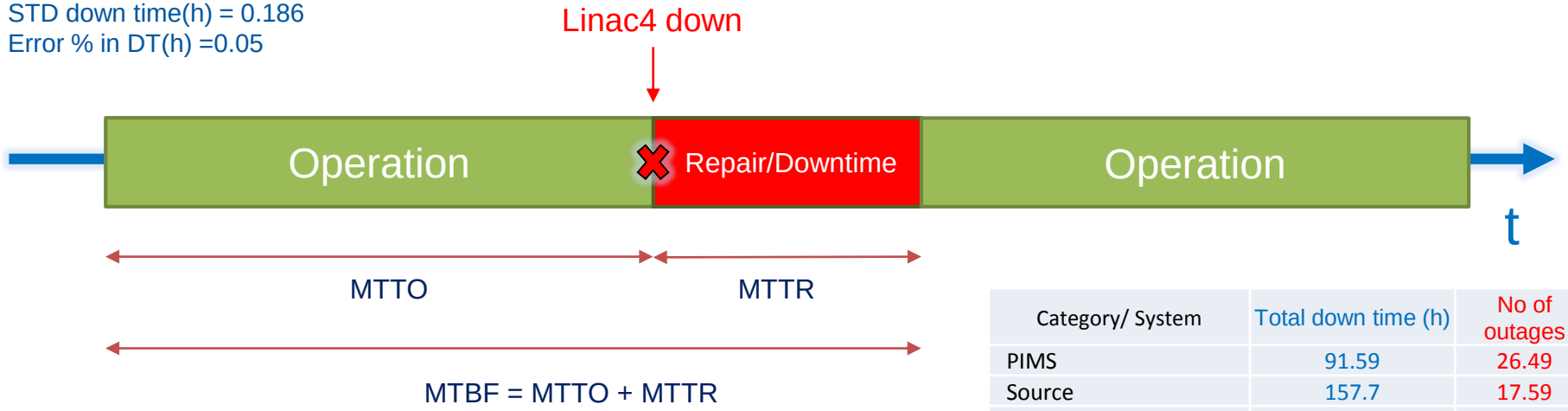
Availability model

First estimations

Linac4 Availability **estimations**

Availability	Mean down time	Failures	Mean time to operate (MTTO)	Mean time to repair (MTTR)	MTBF
95.8%	**15 days 3 h** / 1 year	**102**	**3 days 10h**	**3 h 30 min**	3 days 13.5h

Results from 300.000 simulations
STD down time(h) = 0.186
Error % in DT(h) =0.05



Category/ System	Total down time (h)	No of outages
PIMS	91.59	26.49
Source	157.7	17.59
CCDTL	20.36	10.08
Electro-Magnets	10.01	9.235
MEBT	17.05	7.056
DTL	18.08	6.76
Accelerator Controls	2.422	6.728
Technical network	1.825	6.531
Machine Interlocks	5.956	5.841
RFQ	6.679	2.466
Vacuum	5.163	2.208
LEBT	2.328	1.299
Beam Instrumentation	0.1398	0.2974
Dump	23.98	0.1441

DOWNTIME CONTRIBUTORS

- Which system failure contributed more to Linac4 downtime?

FAILURE ROOT CAUSE

- Which system failure caused the Linac4 to fail?

Linac4 Availability **estimations**

Downtime contributors

Results from 300.000 simulations
STD down time(h) = 0.186
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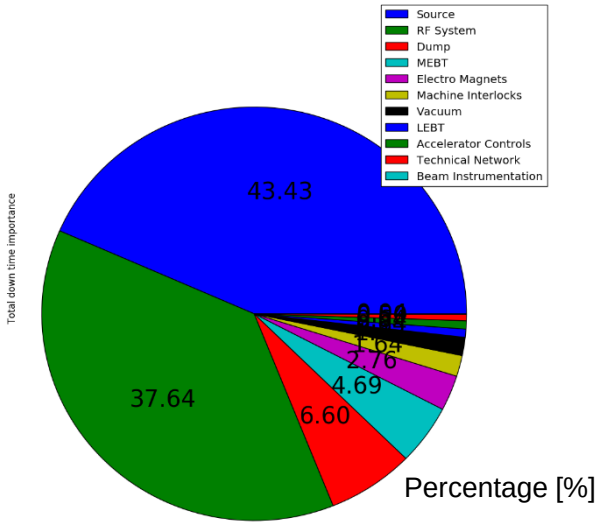

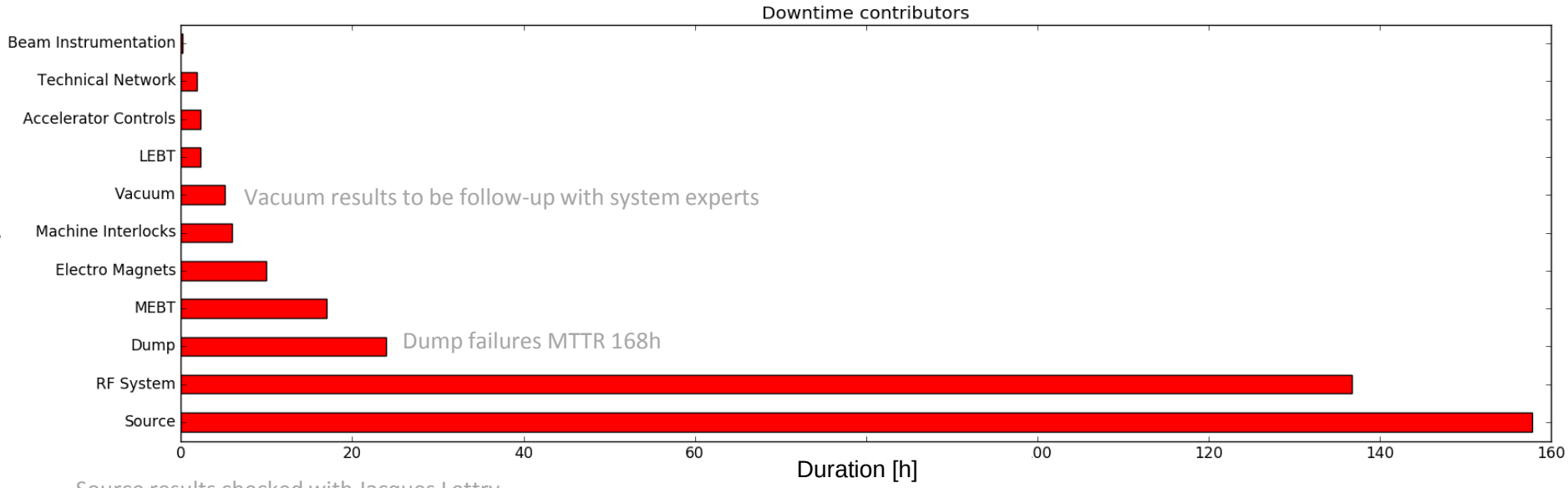

Source results checked with Jacques Lettry.
Consistent with their expectations

Linac4 Availability **estimations**

Downtime contributors

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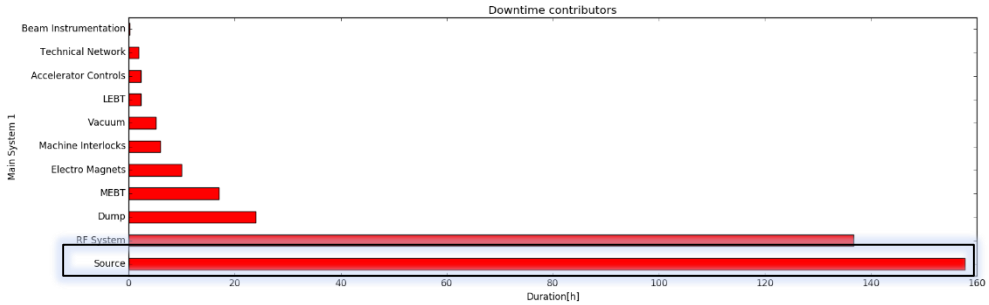
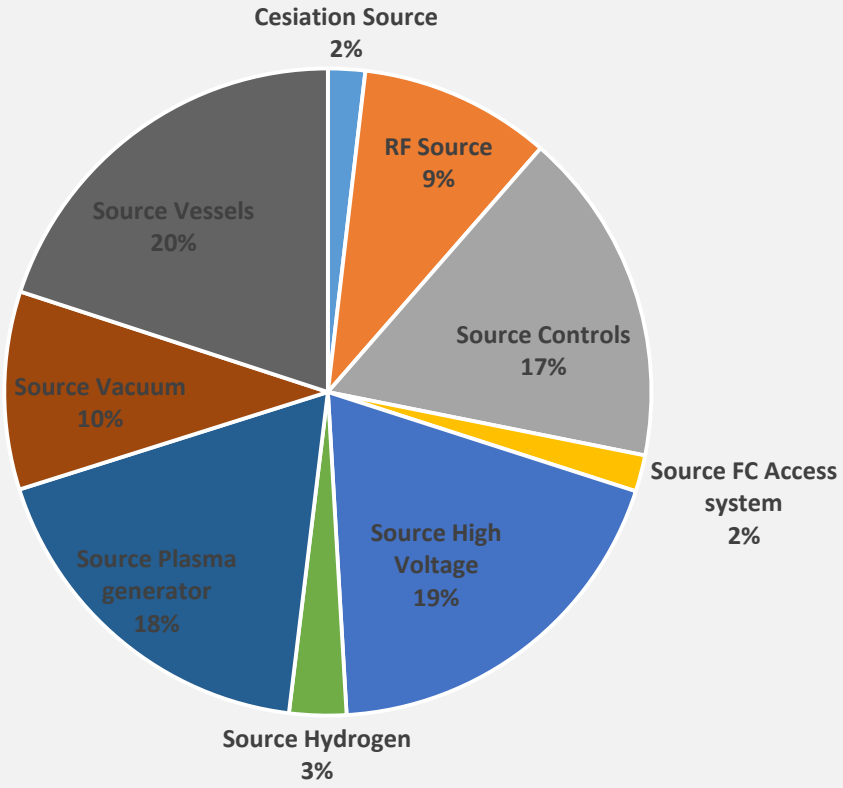


H- Source downtime contribution by subsystem



Major contributors to H- Source downtime:

- Source Vessels
- Source High Voltage
- Source Plasma generator
- Source Controls

Linac4 Availability **estimations**

Downtime contributors

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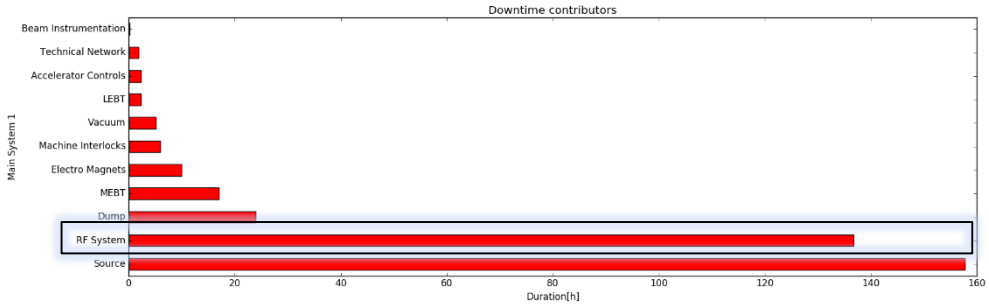
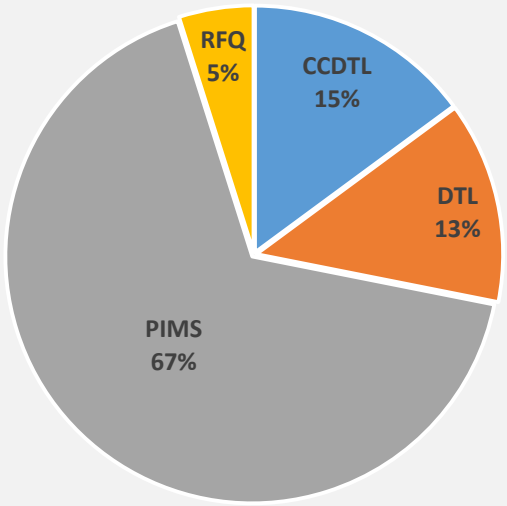
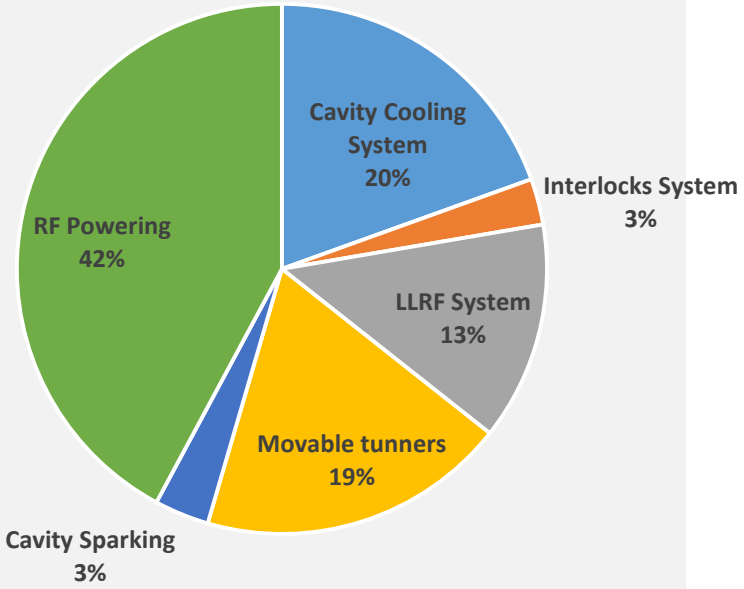


RF System downtime contribution by type



- Contribution proportional to the number of cavities
- Movable tuners redundancy

RF System downtime contribution by subsystem



- RF Powering System mayor contributors to RF System downtime

Linac4 Availability **estimations**

Failure root cause

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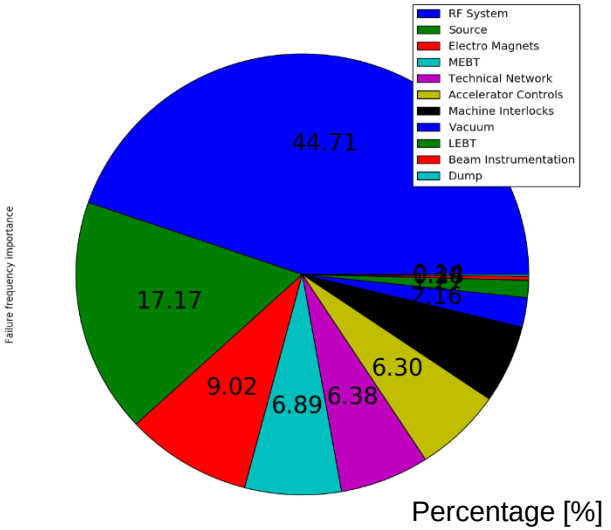

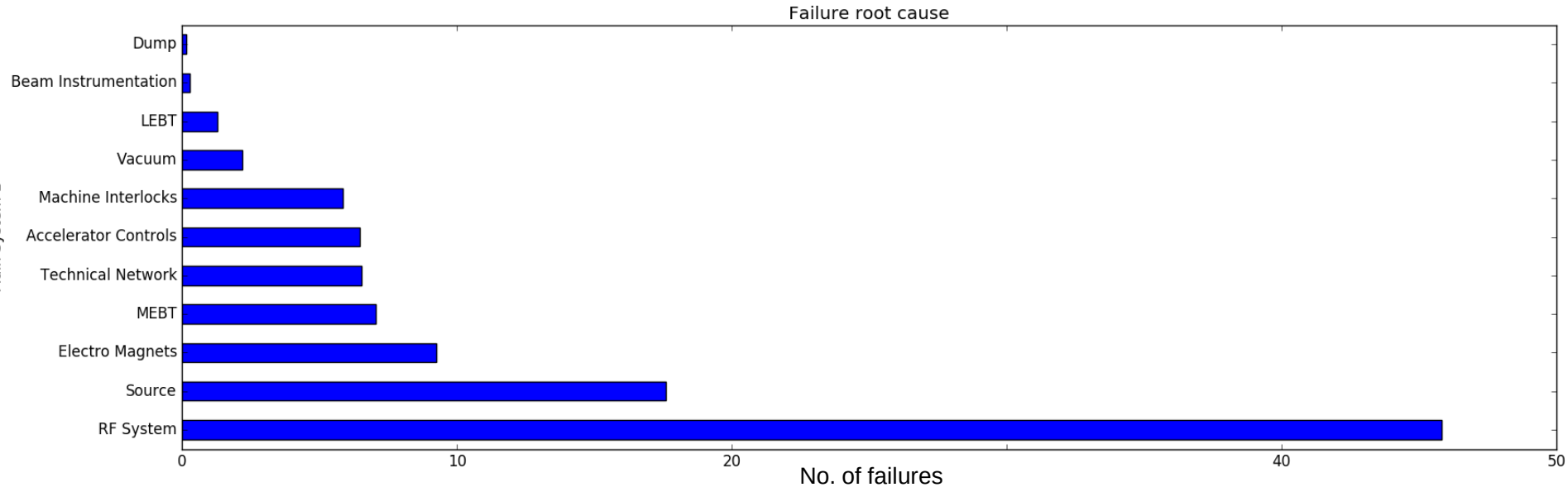

Linac4 Availability **estimations**

Failure root cause

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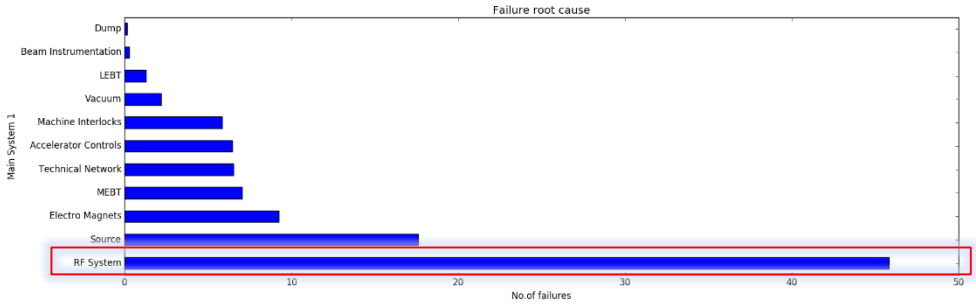
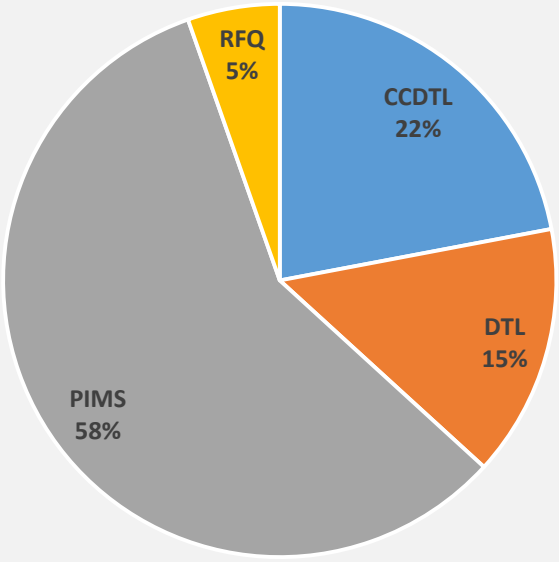
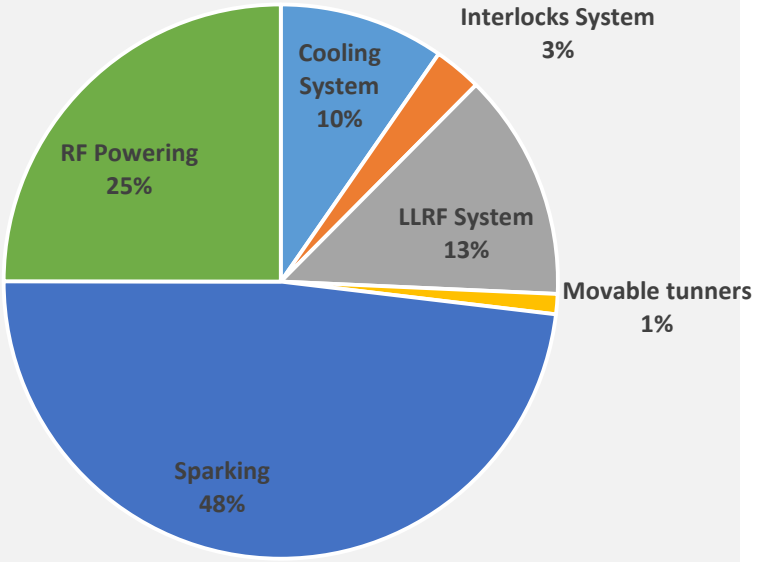


RF System failure contribution by type



- Contribution proportional to the number of cavities
- Movable tuners redundancy

RF System failure contribution by subsystem



- Cavity Sparking main failure causing the RF system failure

Linac4 Availability **estimations**

Failure root cause

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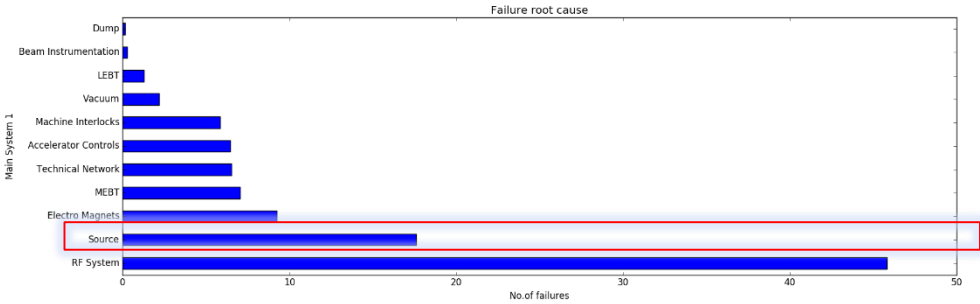

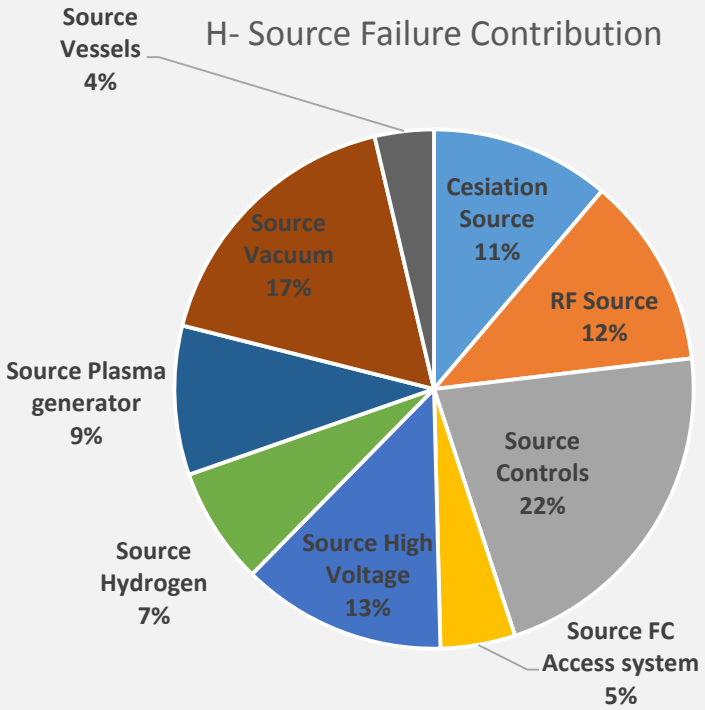

Major contributors to H- Source failure:

- Controls
- Vacuum
- High Voltage
- RF Source
- Cesiation Source

Linac4 Availability **estimations**

Failure root cause

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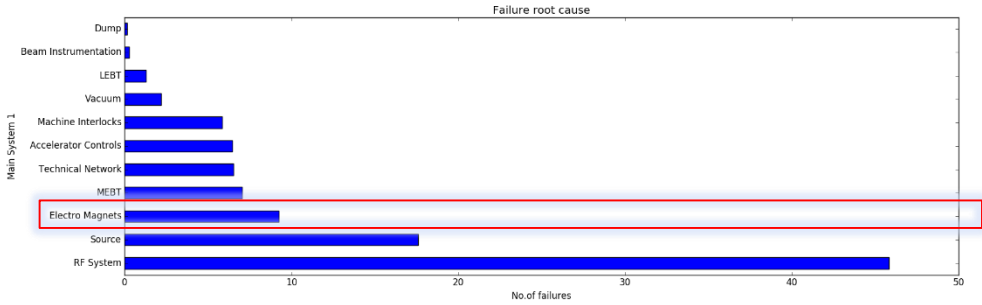
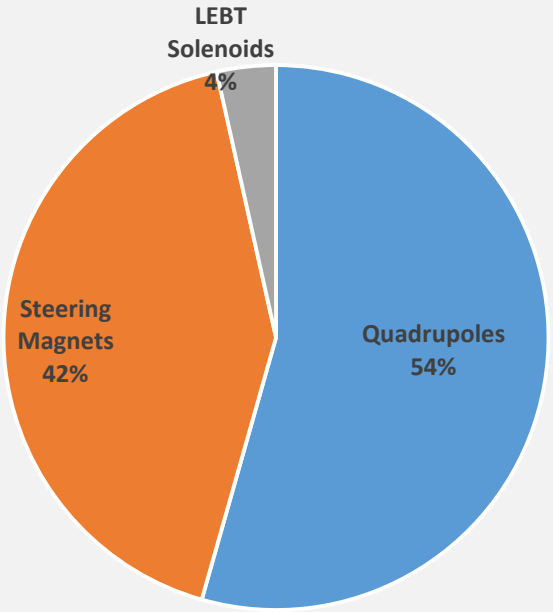
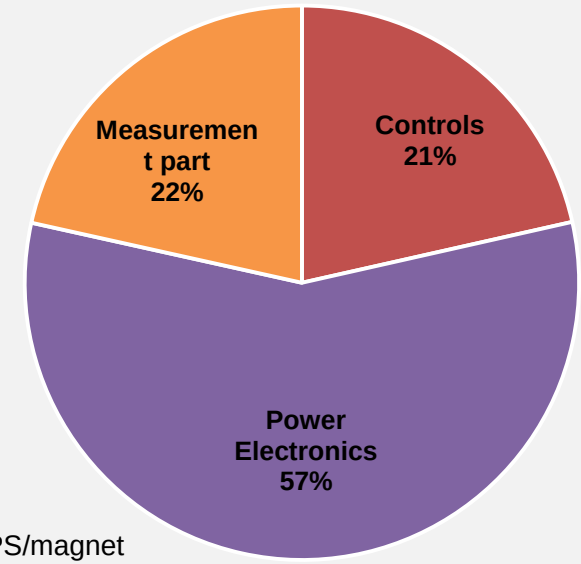


EM failure contribution by magnet type



EM failure contribution by component



	#	PS/magnet
Solenoids	2	1
Quadrupoles	31	1
Steering magnets	16	2

Linac4 Availability **estimations**

Availability	Mean down time	Failures	Mean time to operate (MTTO)	Mean time to repair (MTTR)	MTBF
95.8%	**15 days 3 h** / 1 year	**102**	**3 days 10h**	**3 h 30 min**	3 days 13.5h

Results from 300.000 simulations
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Downtime contributions	Failure root cause
H- Source (43.4%)	RF System (44.7%)
RF System (37.6%)	H- Source (17.7%)
Dump (6.6%)	Electro Magnets (9%)

Conclusions and future plans

Conclusions and future plans

- Based on system experts estimates
  - the target of 95% availability seems to be in reach
  - the H- Source is the biggest contributor to downtime
- Fault tracker important for gathering real data

- Implementation of the model in AvailSim (under development)
- Review of Failure Catalogue on-going (Vacuum System)

After the RR….

- Refine models using the Reliability Run data as input
- Predict Linac4 **future operation**
- **Provide guidelines for Linac4 performance improvement**

Thank you!