Availability predictions for post LS1 operation and HL-LHC

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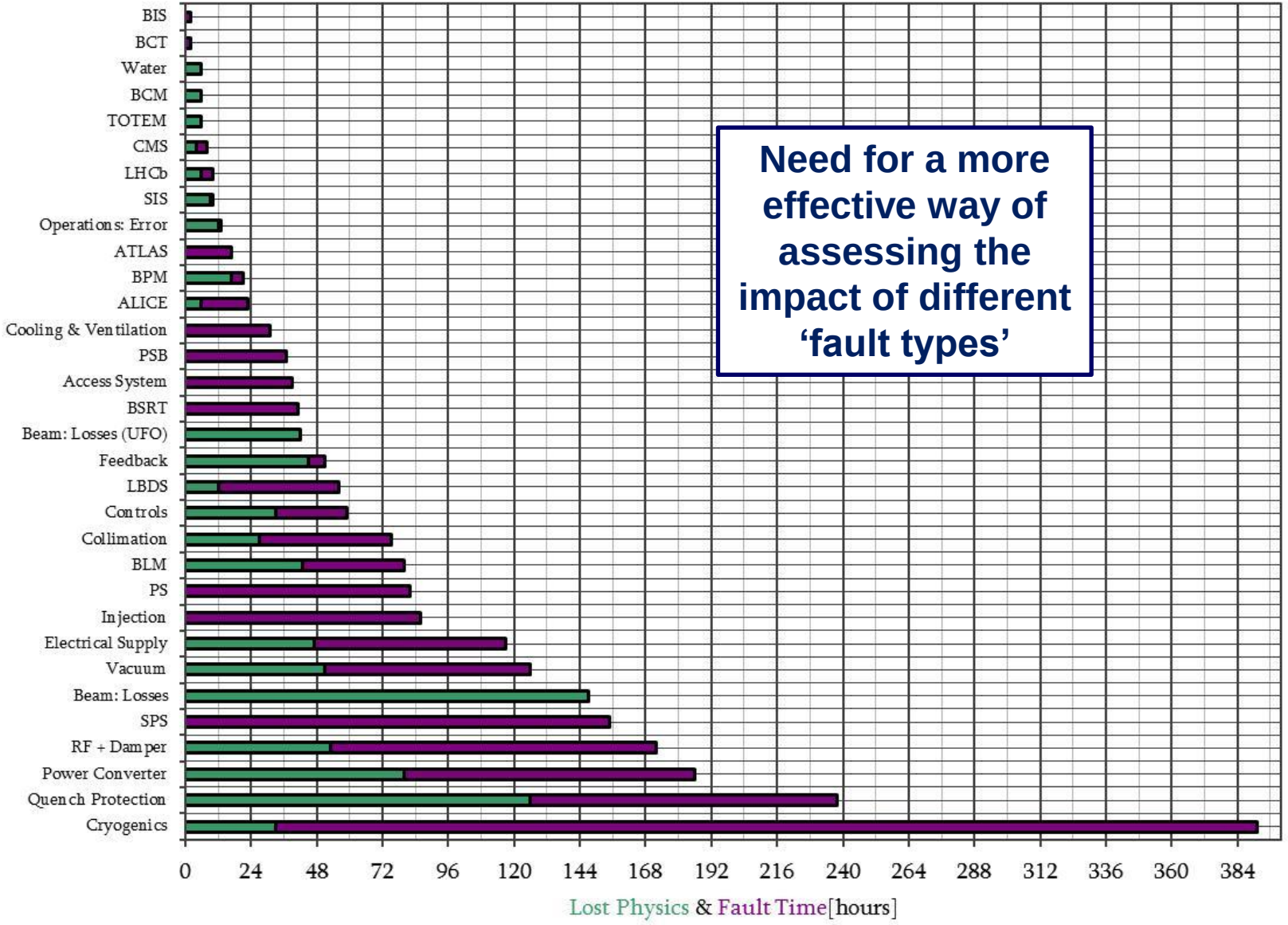
Acknowledgements: L. Ponce, B. Todd, J. Wenninger, D. Wollmann, P. Zeiler, M. Zerlauth

Motivation: Faults and Lost Physics



Outline

- Monte Carlo model for Availability predictions
- Predictions for Post-LS1 Operation
- Predictions for HL-LHC
- Potential of Petri-Nets for Availability predictions
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Baseline for Performance Evaluation

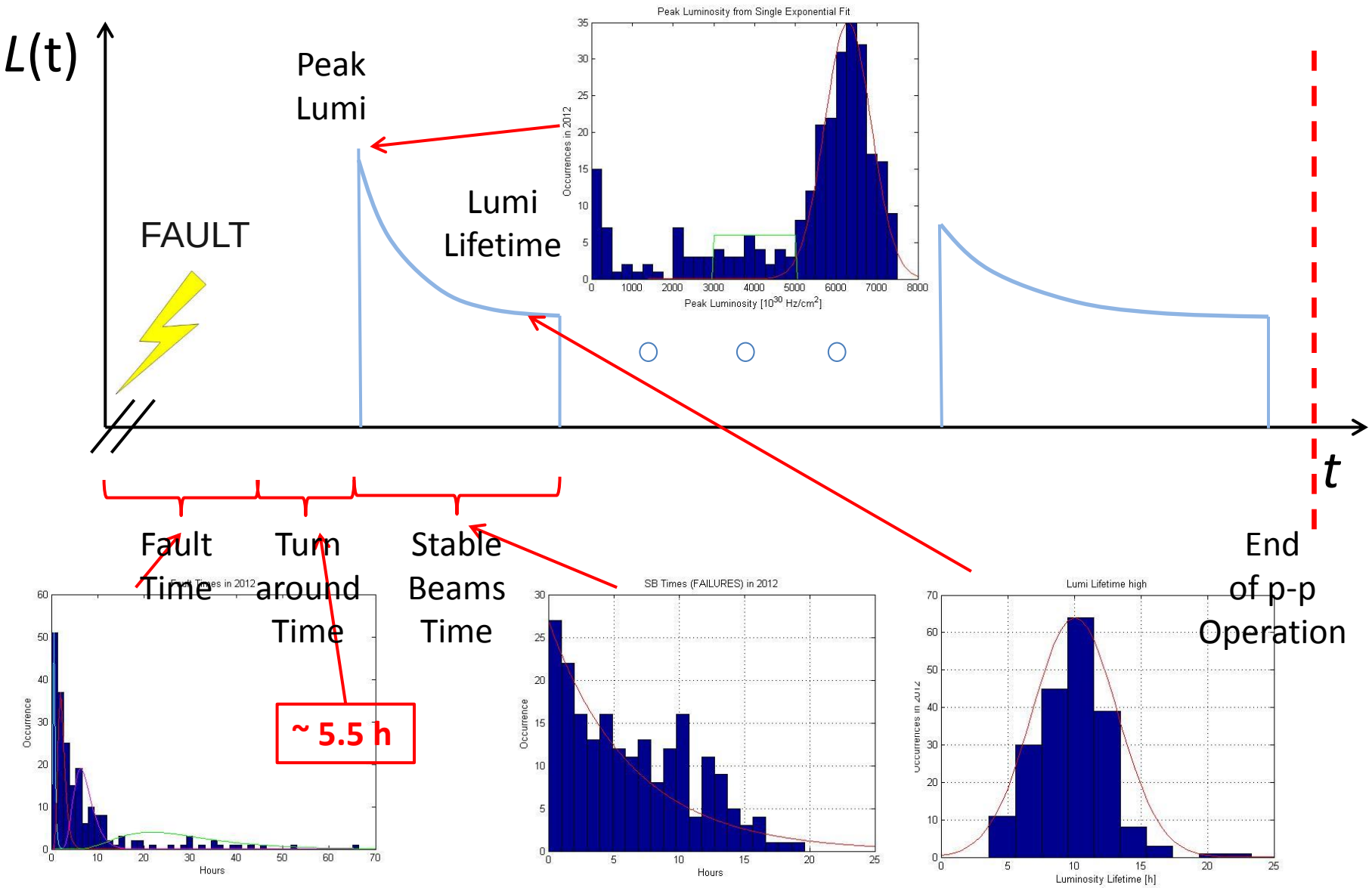
- Sequence of LHC Operational states:

- **2012 Observations** (average values):
  - Turnaround: 5.5 h
  - Fault time per fill: 4.8 h
  - Stable Beams: 6.1 h

- **Monte Carlo model** for performance evaluation (MATLAB):
  - Generation of random numbers based on 2012 distributions

- The model reproduces a **realistic timeline** of 1 year of LHC OP:
  - Assumes 2012 parameters as reference
  - Includes intensity Ramp-up
  - Allows for sensitivity analyses to relevant parameters

Availability Model: Timeline

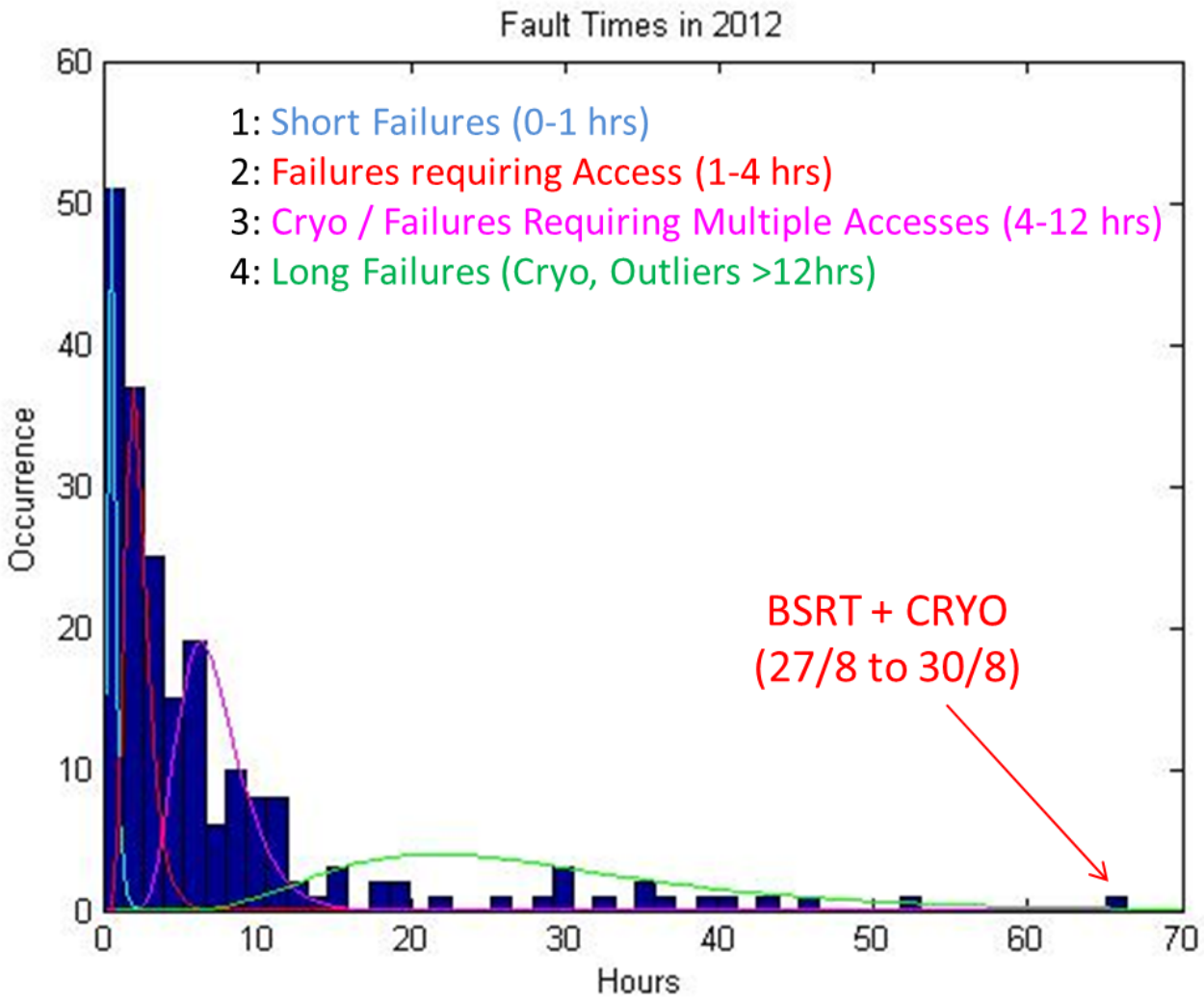


Availability Model: Input Parameters

- **Fault Time** distributions → from eLogbook
- **Turnaround Time** → only average value can be deduced from eLogbook and PM
- **Stable Beams Time** distributions → from PM
- **Peak Luminosity** distributions → from TIMBER (exponential fit)
- **Luminosity Lifetime** distributions → from TIMBER
- **Machine Failure Rate:** # fills with failures/ total # physics fills → deduced from PM

Fault time distributions in 2012

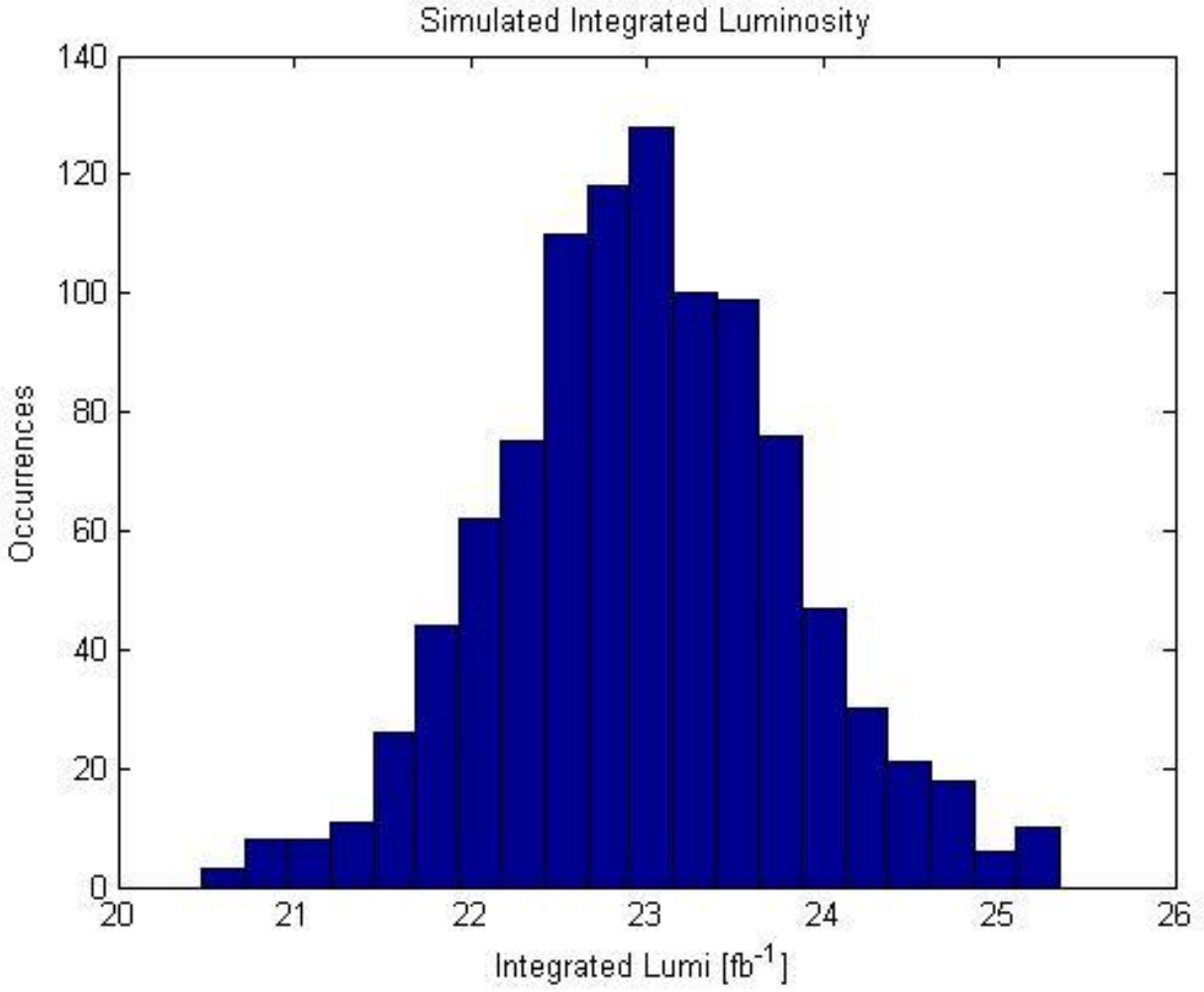
4 lognormal distributions were adopted to model the failures in 2012:



"Shaping" these distributions allows making predictions for possible future operational scenarios

Model Validation: 2012 Operation

The model was validated for 2012 operation (verifying Integrated Lumi, SB time, Fault Time, Turnaround time, number of fills,…):



AVG SIMULATED:

- 23.00 [fb^{-1}]

2012 MEASURED:

- 23.27 [fb^{-1}]

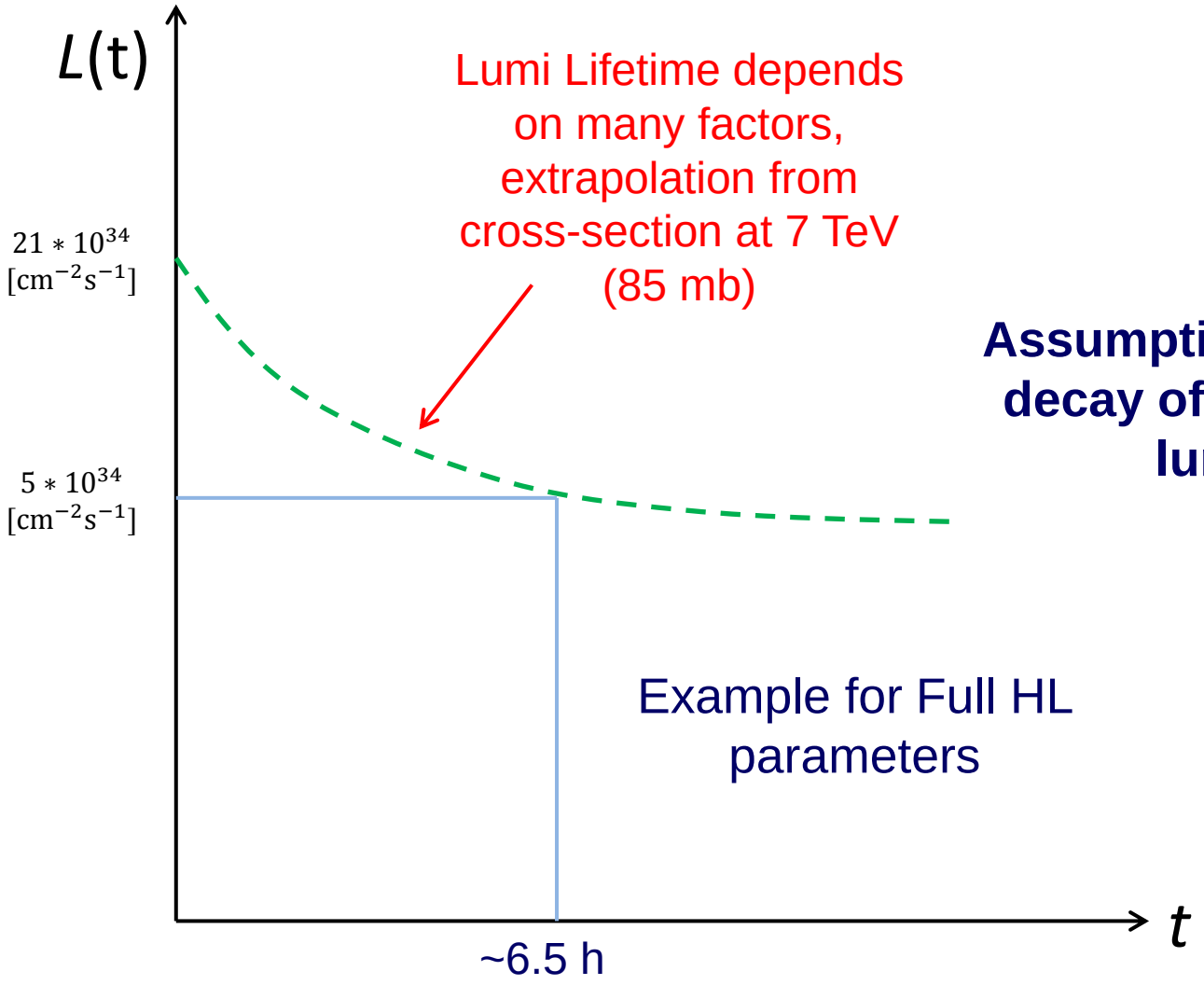
REL ERROR:

- 1.14%

Simulated years of operation: 1000, ~1.5 min Simulation Time

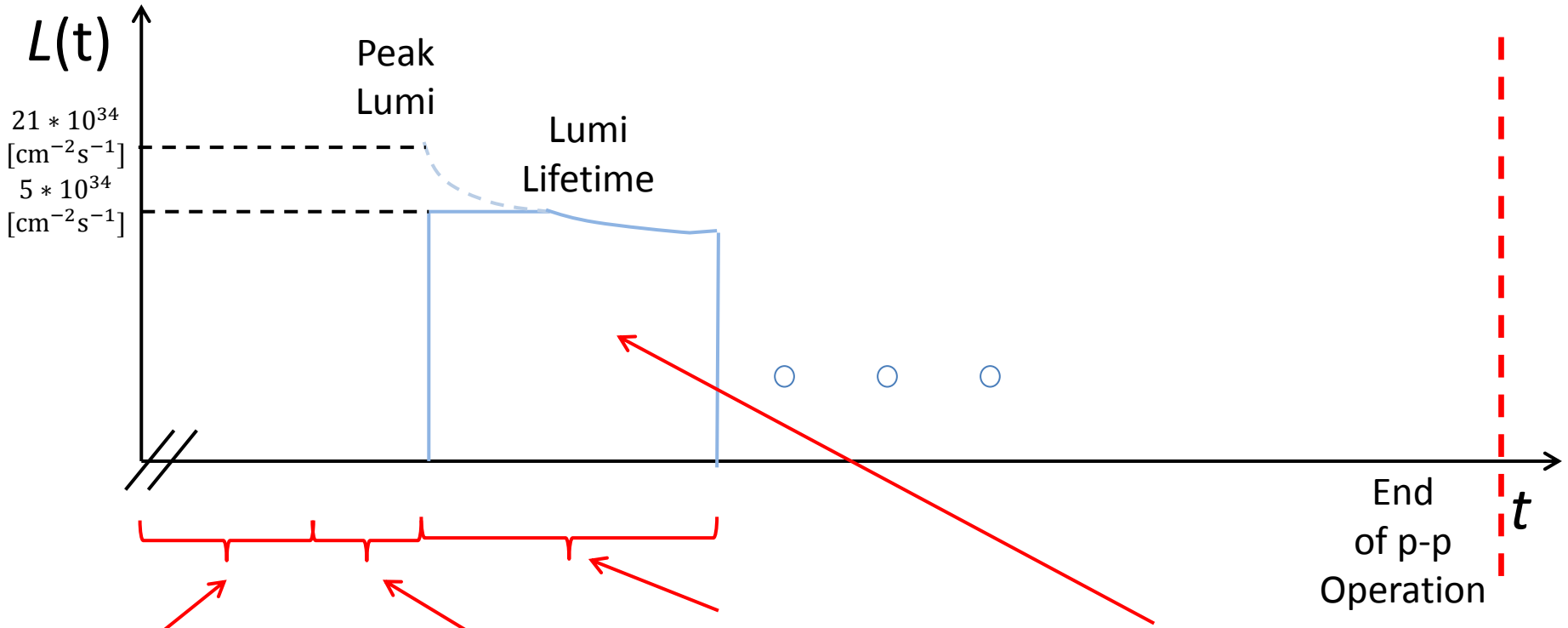
Model Extension: Levelling

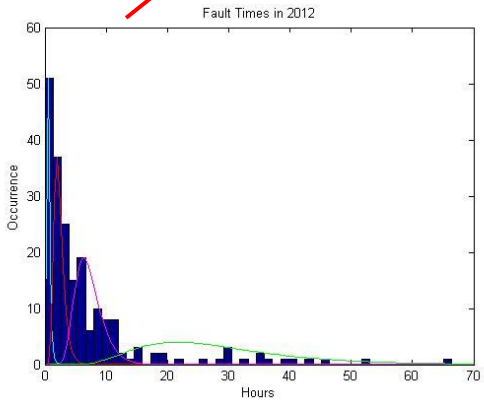
The model was then extended to include levelling:



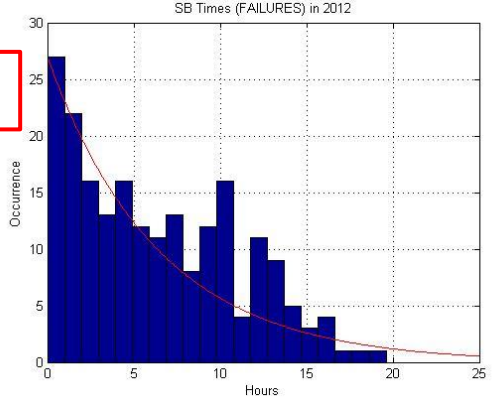
Assumption: exponential decay of instantaneous luminosity

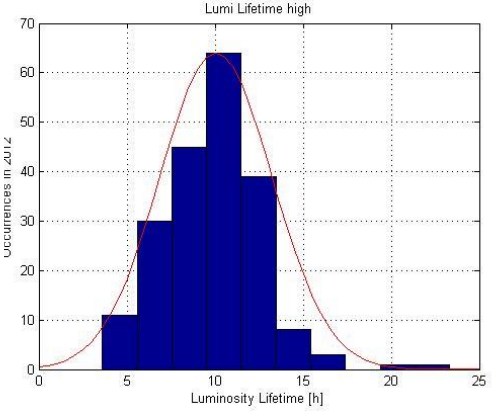
Model Extension: Levelling





~ 6.2 h





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Assumptions for post-LS1 LHC Operation

- **160 days of operation**
- **25 ns operation** with and without Linac4
  (BCMS and Standard + Linac4)
- **4.5 h average luminosity lifetime** (~10 h in 2012)
- **6.2 h average turnaround time** (5.5 h in 2012)
- **4 logn distributions for the fault time** + future scenarios
- **2 stable beams time distributions:**
  - END OF FILL: gauss(mean 9.6 h)
  - EMERGENCY DUMPS: exp(mean 4.6 h)

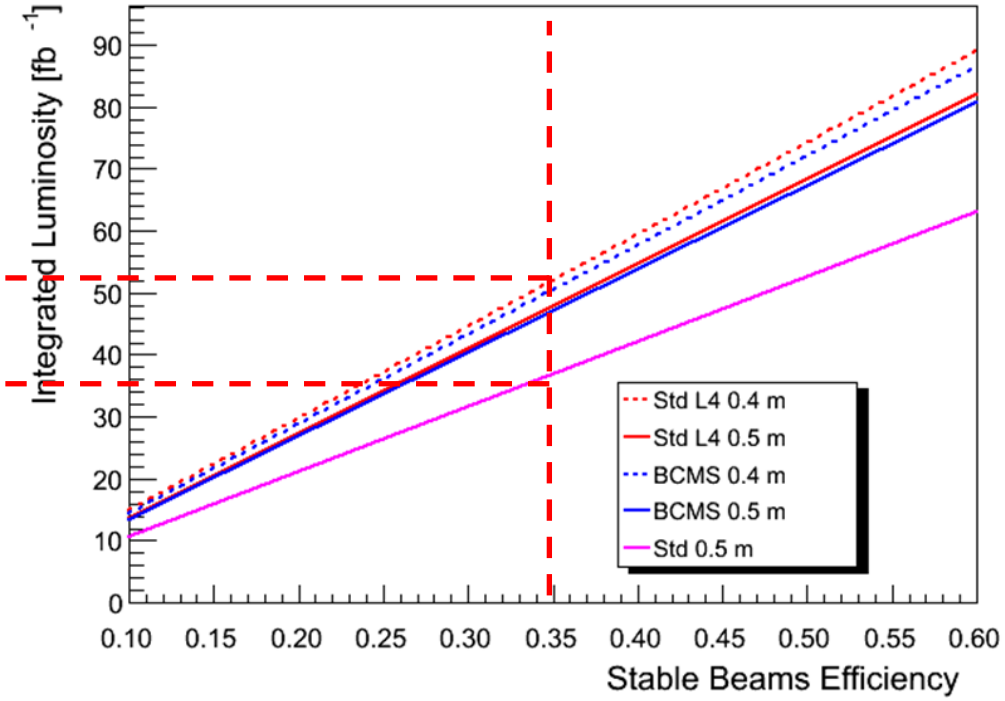
Post-LS1 Availability: Possible Scenarios

Possible future scenarios:

1. **Extension of 2012 fault distributions** to Post-LS1 operation
2. **Impact of UFOs** at 6.5/7 TeV
3. **Impact of increased BLM thresholds** and Beam-Induced Quenches (BIQ)
4. **Impact of LS1 mitigations wrt SEUs**
5. Possible **impact of increased energy on SEUs**
6. **Combination of 3 and 4:** Impact of increased BLM thresholds and Beam-Induced Quenches (BIQ)+ SEUs mitigations

Post LS1 LHC Operation

Beam	β* (m)	Leveled L (10^{34} cm^{-2}s^{-1})	Peak L (10^{34} cm^{-2}s^{-1})	Leveling time (h)
Standard L4	0.4	1.65	2.1	~1.4
BCMS	0.4	1.54	2.2	~2.1
Standard L4	0.5	1.65	1.9	~0.7
BCMS	0.5	1.54	2.0	~1.5
Standard	0.5	1.65	1.2	--



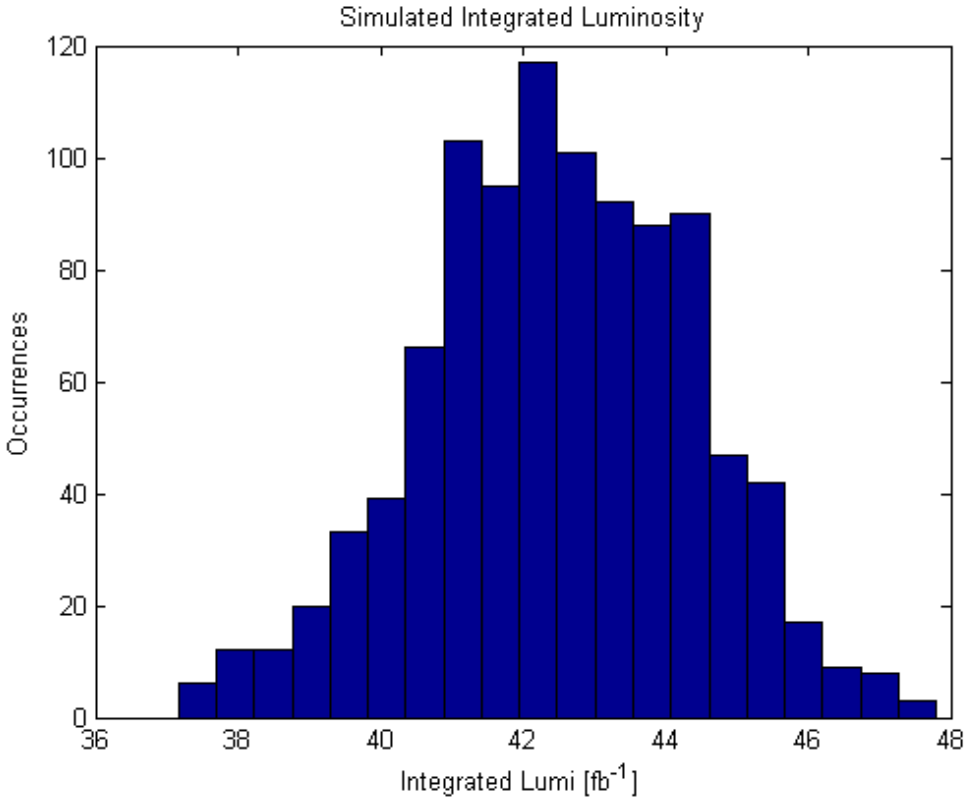
- BCMS & standard are very close in performance.
- Leveled L ~at the triplet limit, peak lumi BCMS / L4 above limit.
- With 2011 emittance model, values increase ~2%.

Add 5-10% to account for mixed fill length distribution

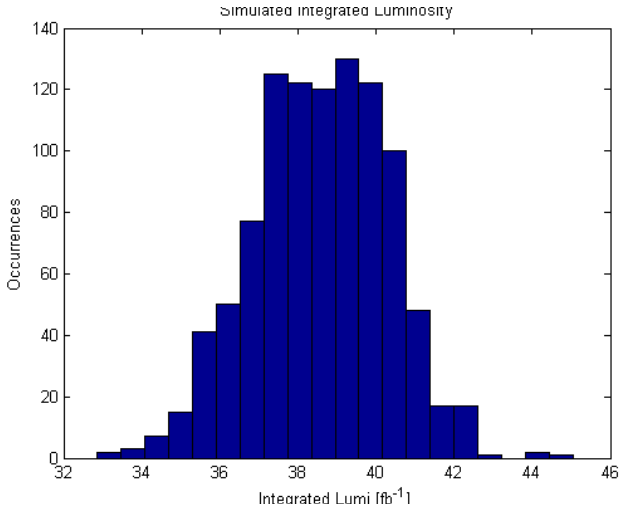
Courtesy J. Wenninger

Post-LS1 LHC: some results…

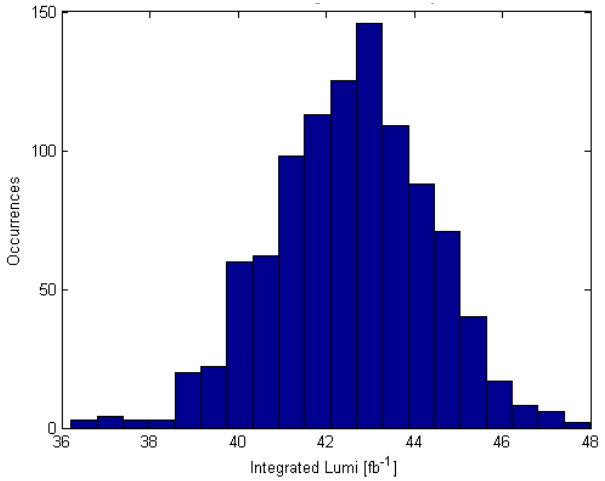
As 2012,
turnaround time 5.5 ➔ 6.2h
Avg: 42.5 [fb^{-1}] (*reference*)



100 UFO dumps due to 7TeV
Avg: 38.6 [fb^{-1}] (*-10%*)



SEU mitigation* (50 ➔ 20)
Avg: 43.3 [fb^{-1}] (*+1.8%*)



* Only SEU not requiring an intervention

Post LS1 LHC Operation and Availability

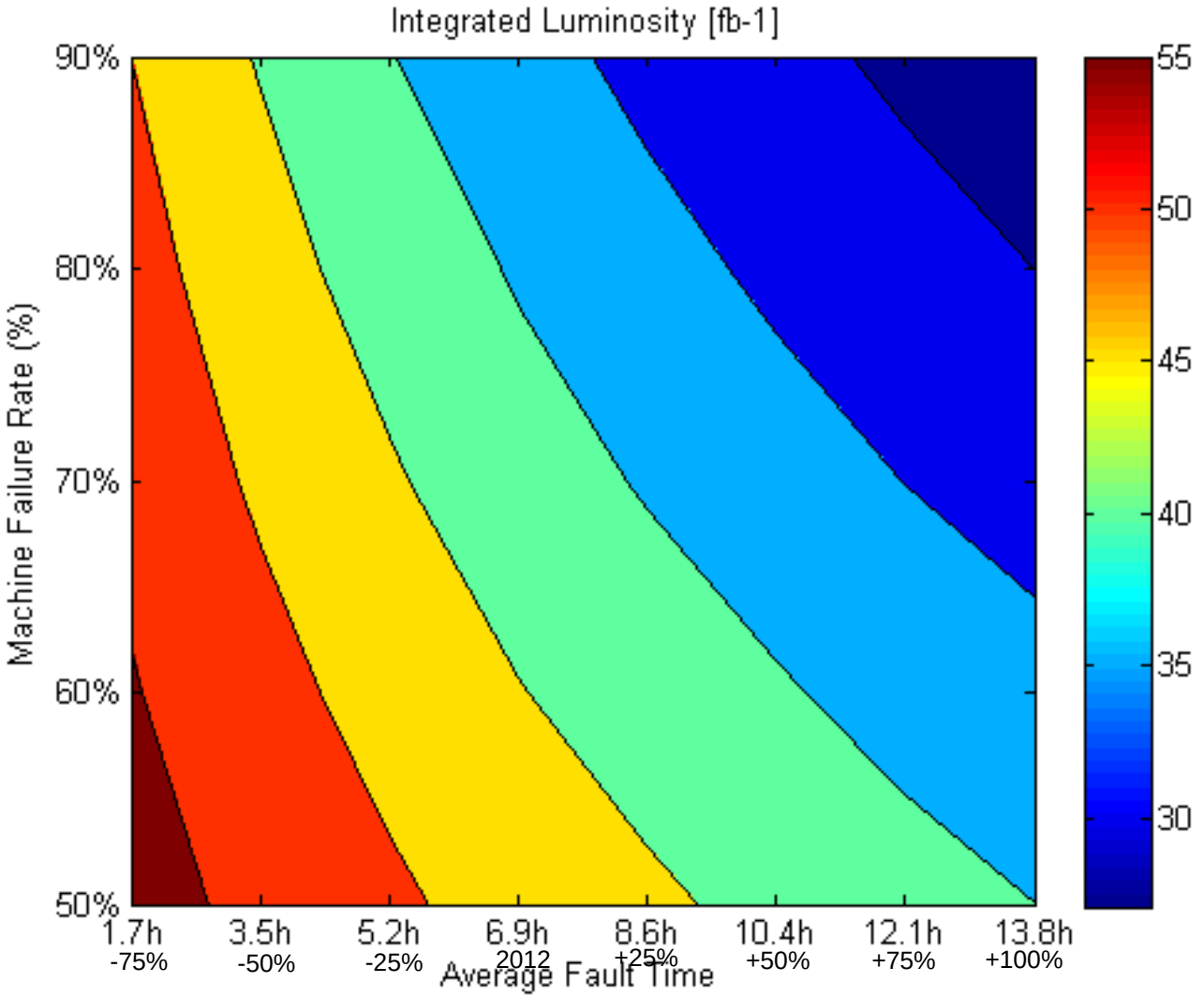
- Summary of fault scenarios and impacts:

Failure Scenario/ Mitigation	Assumption	Simulated impact on Integrated Luminosity (BCMS)	Simulated impact on Integrated Luminosity (LINAC4)
1. 2012 Fault distributions	-	42.5 [fb^{-1}] (*reference*)	42.7 [fb^{-1}] (*reference*)
2. UFOs (6.5/7TeV)	100 UFO dumps	38.6 [fb^{-1}] (*-10 %*)	39.0 [fb^{-1}] (*-10 %*)
3. UFOs + BIQ	Factor 3 higher BLM thresholds, 33 UFOs, 3 BIQ	41.4 [fb^{-1}] (*-2.6 %*)	41.5 [fb^{-1}] (*-2.8 %*)
4. SEU mitigations	20 SEU dumps	43.3 [fb^{-1}] (*+1.8 %*)	43.6 [fb^{-1}] (*+2.1 %*)
5. SEU increase due to higher energy	60 SEU dumps (+50% wrt 2012)	41.7 [fb^{-1}] (*-1.8 %*)	41.9 [fb^{-1}] (*-1.8 %*)
6. Combined impact of scenarios 3 and 4	-	41.8 [fb^{-1}] (*-1.6 %*)	42.1 [fb^{-1}] (*-1.4 %*)

BCMS Predictions: Sensitivity Analysis

- Impact of Average Fault Time:

$$MFR = \frac{\#\ OF\ FILLS\ TO\ SB\ WITH\ FAILURES}{TOT\ \#\ OF\ FILLS\ TO\ SB}$$



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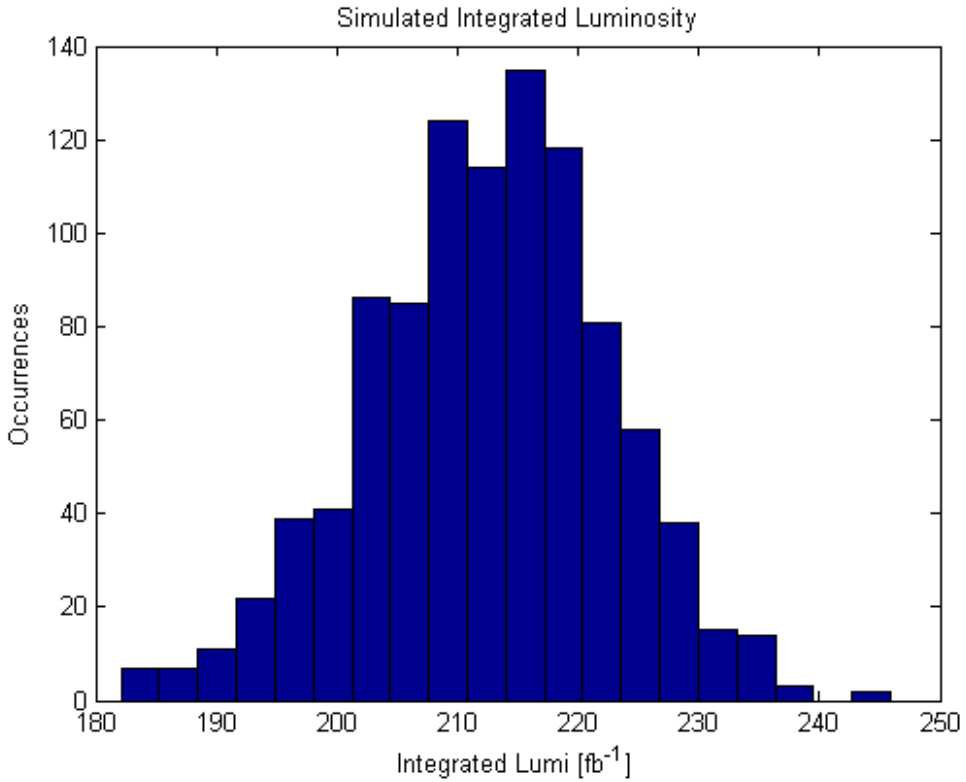
Assumptions for HL-LHC Operation

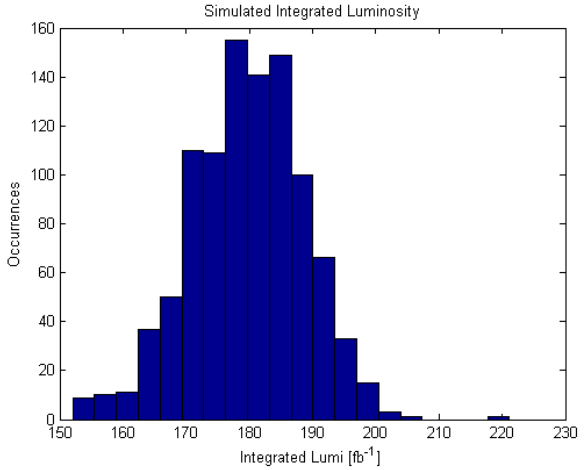
- **160 days of operation**
- 2.19*10^35 [cm-2s-1] **virtual peak luminosity (Full HL)**
- **Levelling** at 5*10^34 [cm-2s-1]
- **4.5 h average luminosity lifetime**
- **6.2 h average turnaround time**
- **4 logn distributions for the fault time** + scenarios
- **2 stable beams time distributions**
  - ❑ END OF FILL: gauss(mean 9.6 h)
  - ❑ EMERGENCY DUMPS: exp(mean 4.6 h)
- **Intensity ramp-up not included**

HL-LHC: some results…

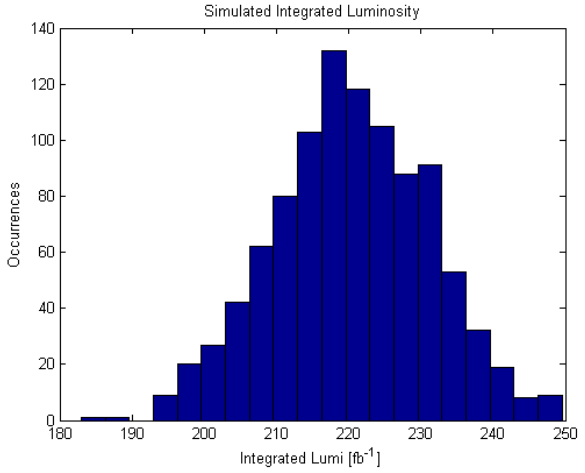
As 2012,
turnaround time 5.5 ➔ 6.2h
Avg: 213 [fb^{-1}] (*reference*)



100 UFO dumps due to 7TeV
Avg: 179 [fb^{-1}] (*-15%*)



SEU mitigation (50 ➔ 20)
Avg: 220.5 [fb^{-1}] (*+3%*)



* Only SEU not requiring an intervention

High-Luminosity LHC and Availability

- Summary of fault scenarios and impacts:

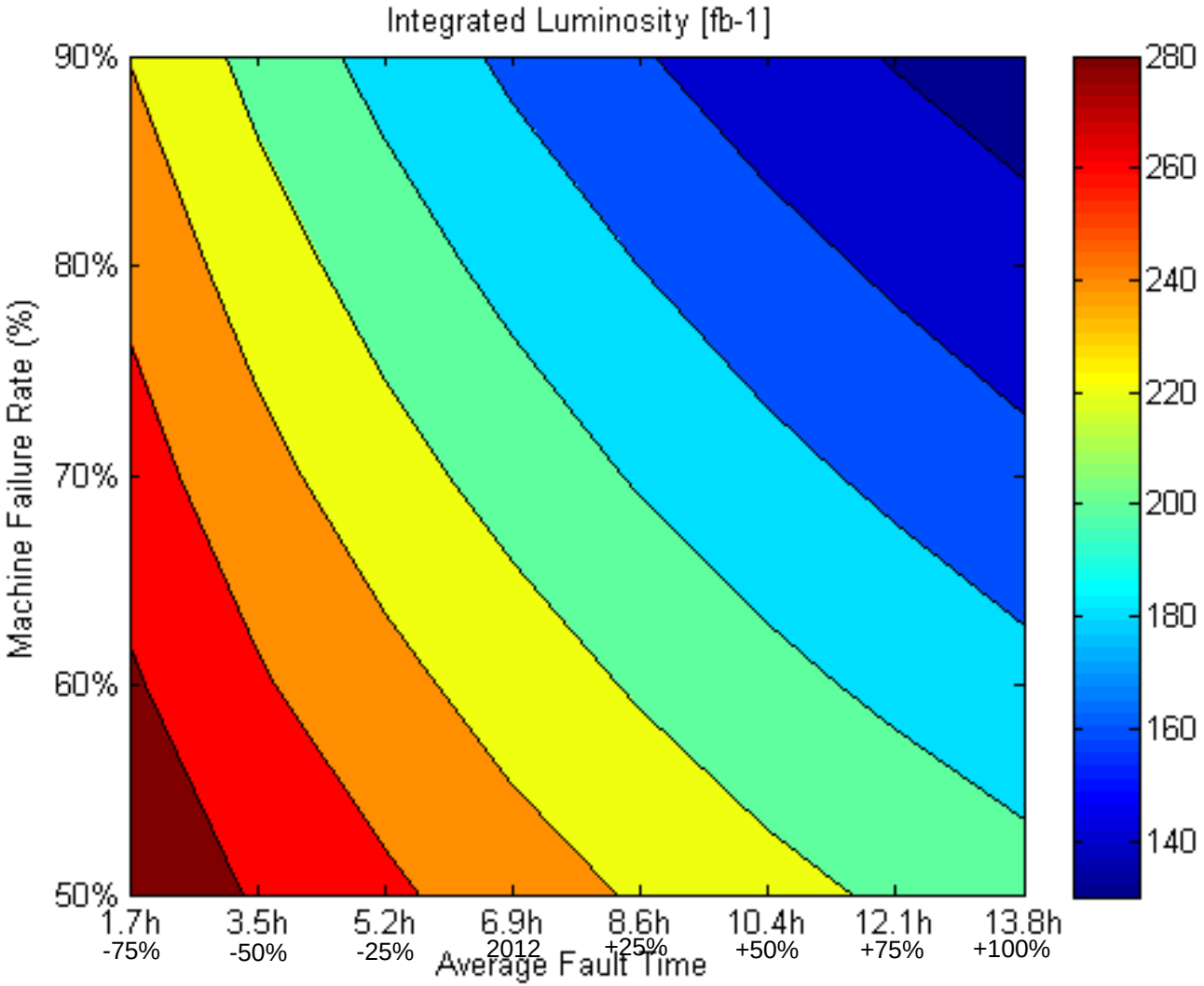
Failure Scenario/ Mitigation	Assumption	Simulated impact on Integrated Luminosity
1. 2012 Fault distributions	-	213 [fb^{-1}] (*reference*)
2. UFOs (6.5/7TeV)	100 UFO dumps	179.5 [fb^{-1}] (*-15%*)
3. UFOs + BIQ	Factor 3 higher BLM thresholds, 33 UFOs, 3 BIQ	203 [fb^{-1}] (*-5%*)
4. SEU mitigations	20 SEU dumps	220.5 [fb^{-1}] (*+3%*)
5. SEU increase due to higher energy	60 SEU dumps (+50% wrt 2012)	206 [fb^{-1}] (*-3%*)
6. Combined impact of scenarios 3 and 4	-	208.5 [fb^{-1}] (*-2%*)

- HL-LHC results are more sensitive to the selected fault scenarios given the longer levelling time
- Optimization of SB time can play a significant role for luminosity production

HL-LHC Predictions: Sensitivity Analysis

- Impact of Average Fault Time:

$$MFR = \frac{\#\ OF\ FILLS\ TO\ SB\ WITH\ FAILURES}{TOT\ \#\ OF\ FILLS\ TO\ SB}$$



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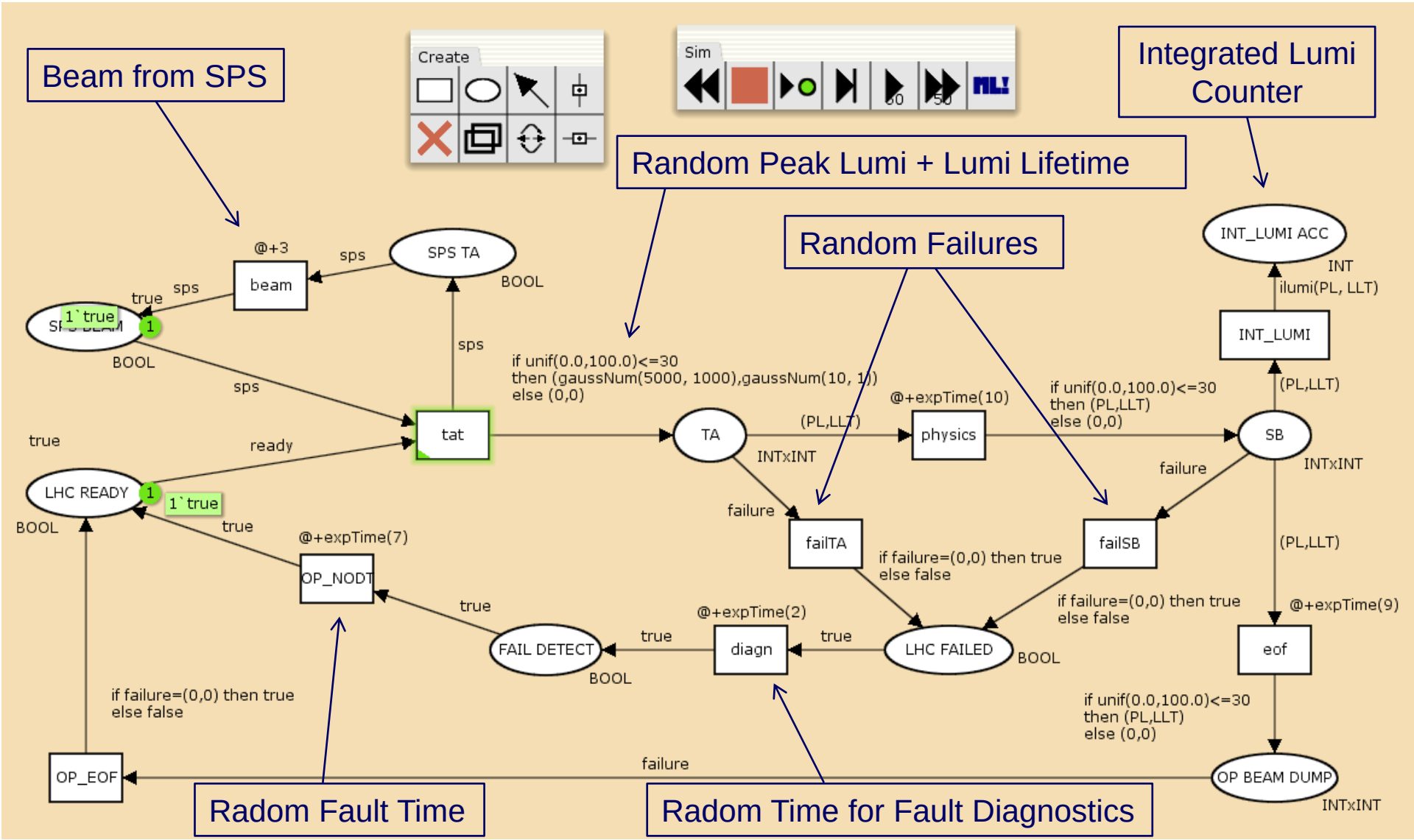
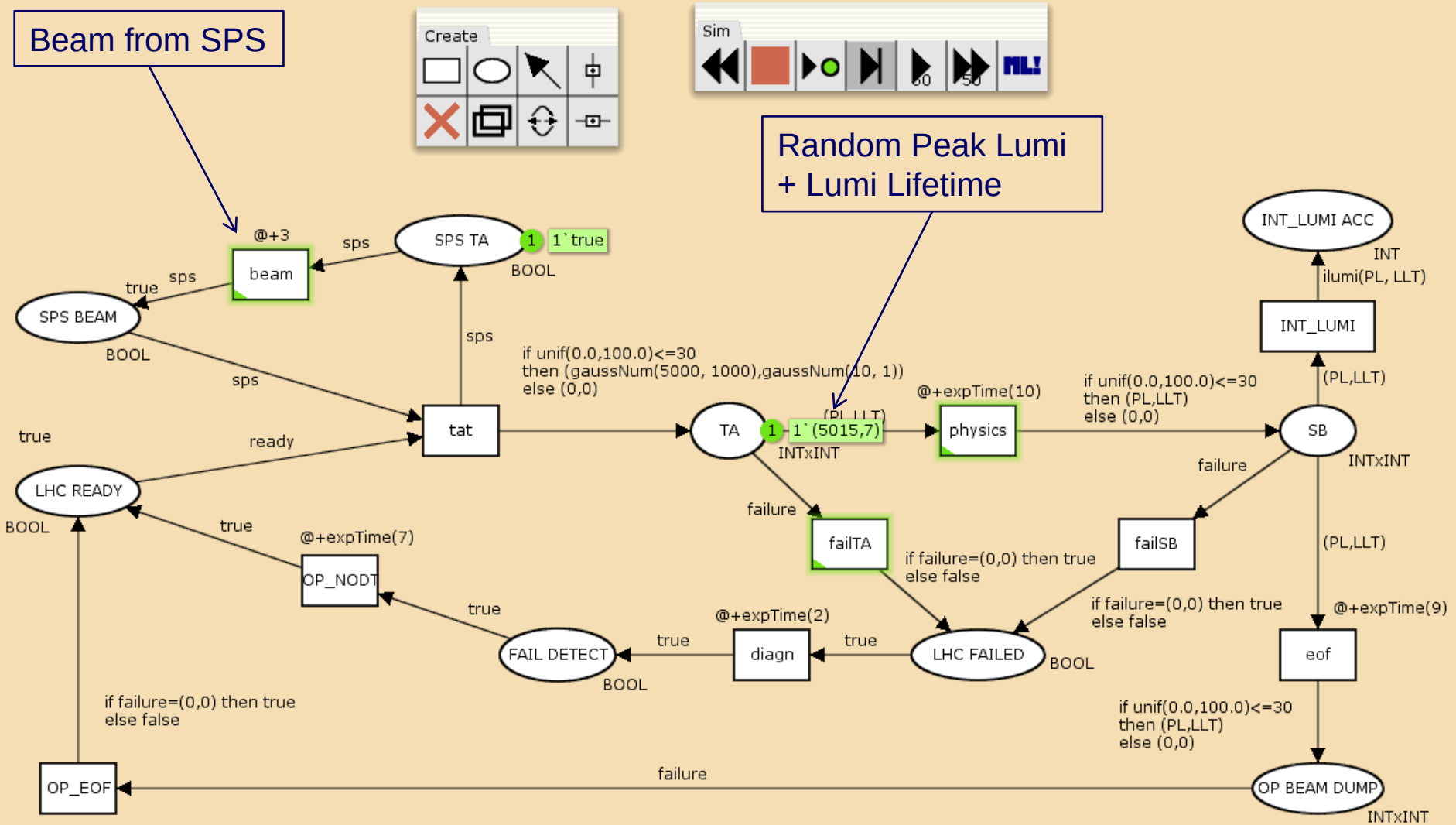
Preliminary Petri Net Model of LHC Operation*



* Using CPN Tools

Preliminary Petri Nets Model of LHC Operation*



* Using CPN Tools

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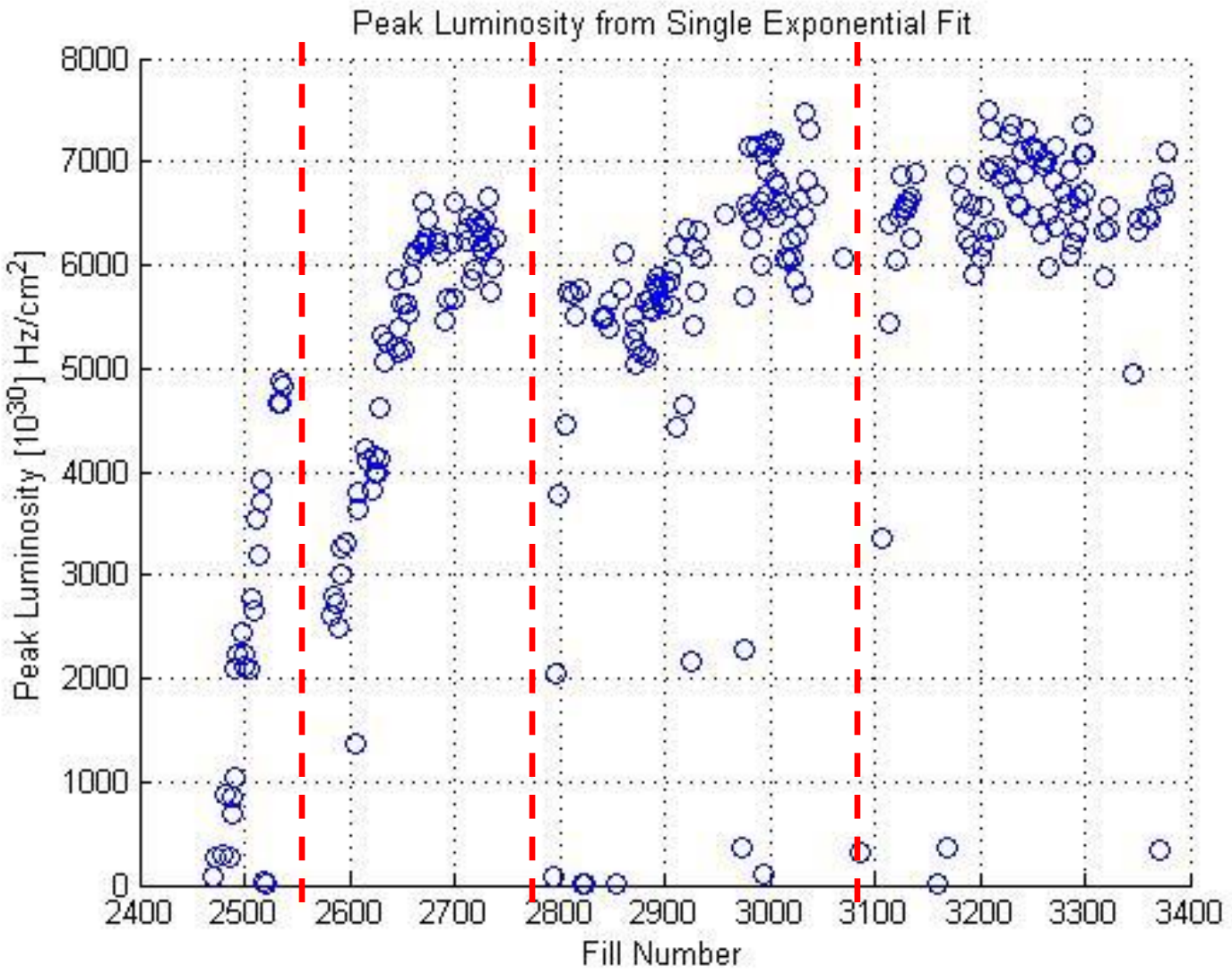
Conclusions and Outlook

- **Increasing machine availability** towards better LHC performance will be one of the **big challenges** of the Post-LS1 era
- A model to **quantify the potential gain/loss** of integrated luminosity in different operational scenarios was developed in MATLAB
- Predictions could be improved with more **reliable data sources**, allowing for more accurate **data correlation**
- **UFOs** have the potential to be one of the **main limitations** for future LHC operation
- **Petri-Nets** could be exploited for Availability predictions and further modelling

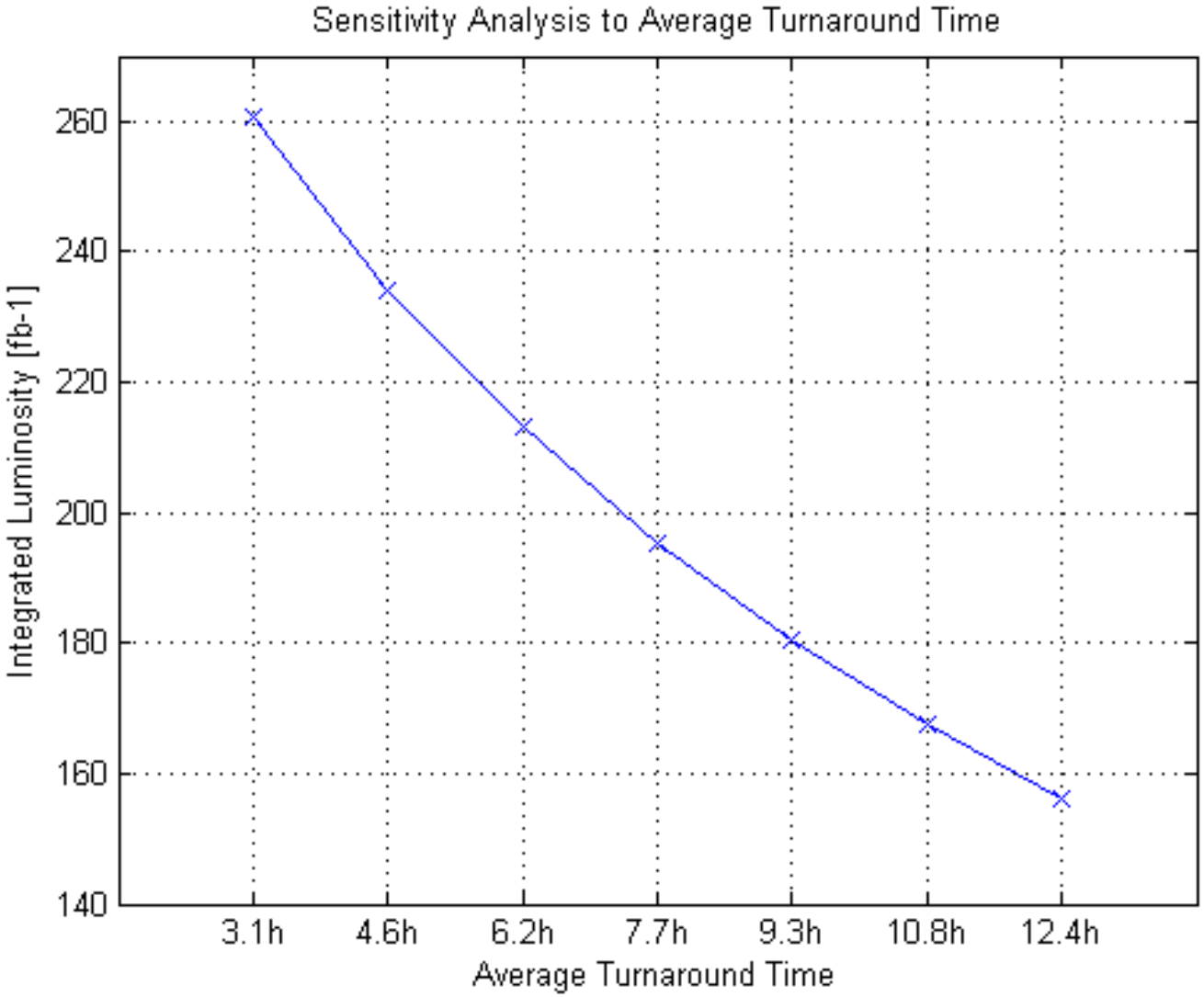
THANKS A LOT FOR YOUR ATTENTION!

Peak Lumi distributions in 2012

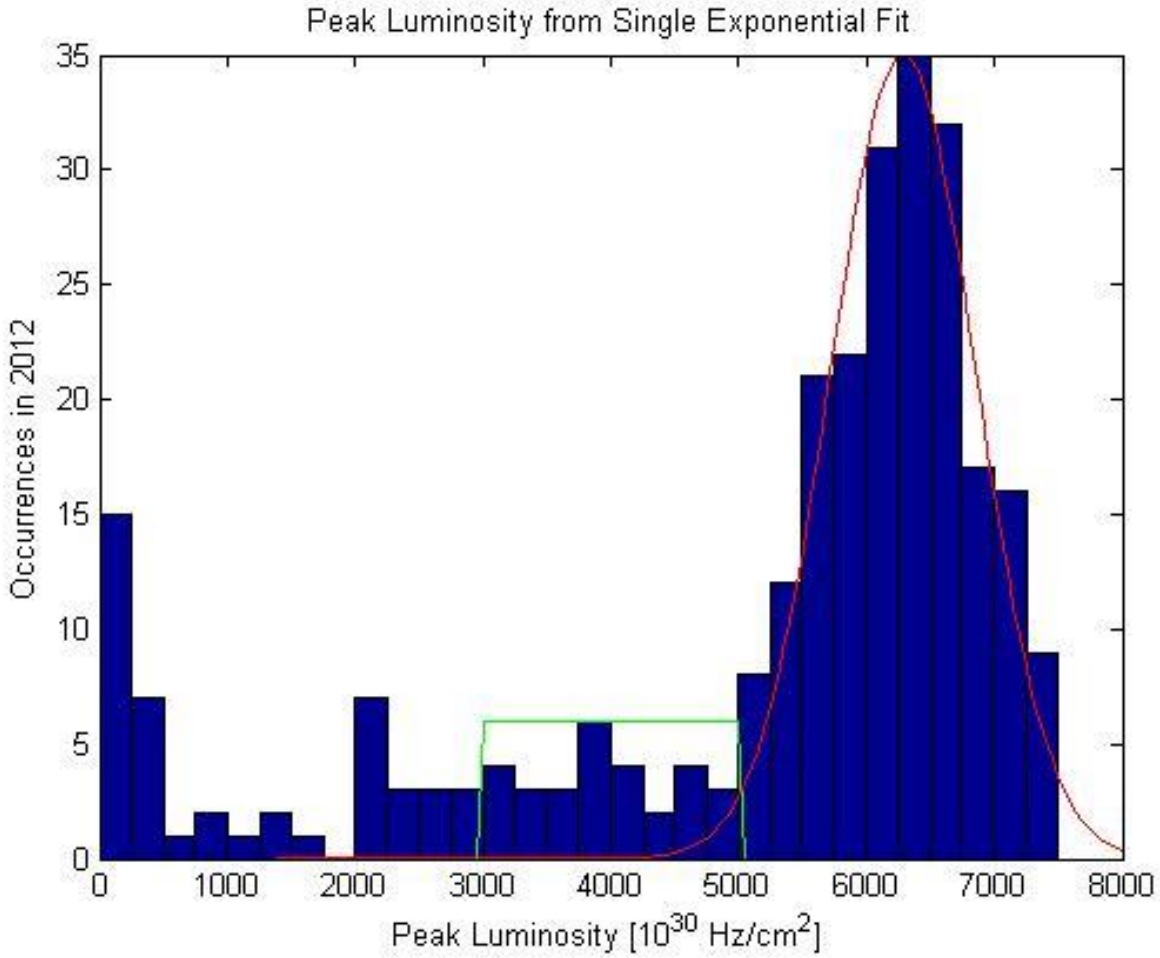


High-Luminosity LHC and Availability

- Impact of Turnaround Time, assuming 2012 fault distributions:



2012 Peak Luminosity



Unif Distribution:

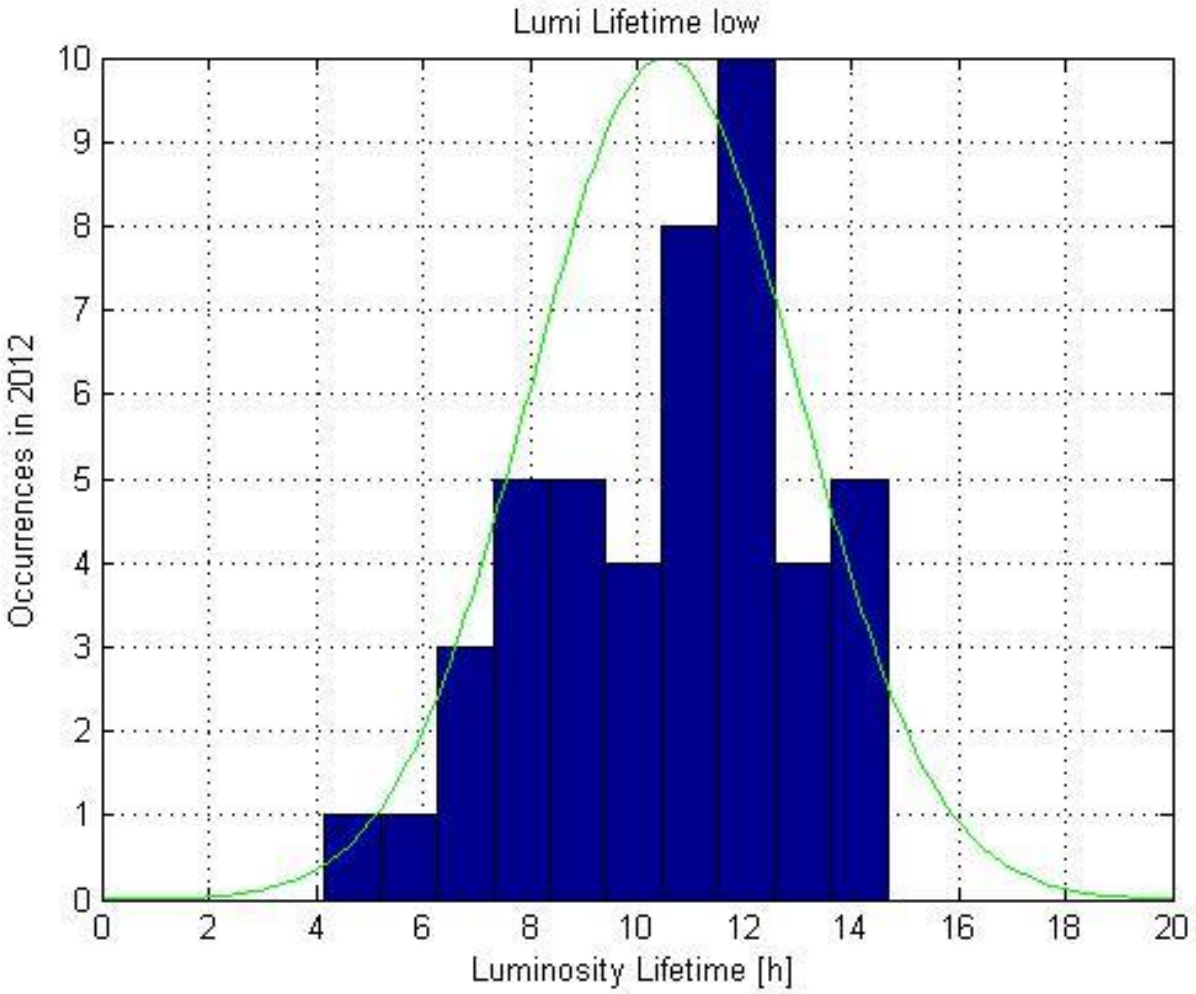
- a = 3000 [Hz/cm2]
- b = 5000 [Hz/cm2]

Norm Distribution:

- μ = 6285 [Hz/cm2]
- σ = 569

"Low" Peak Lumi
"High" Peak Lumi

2012 Luminosity Lifetime (Low)

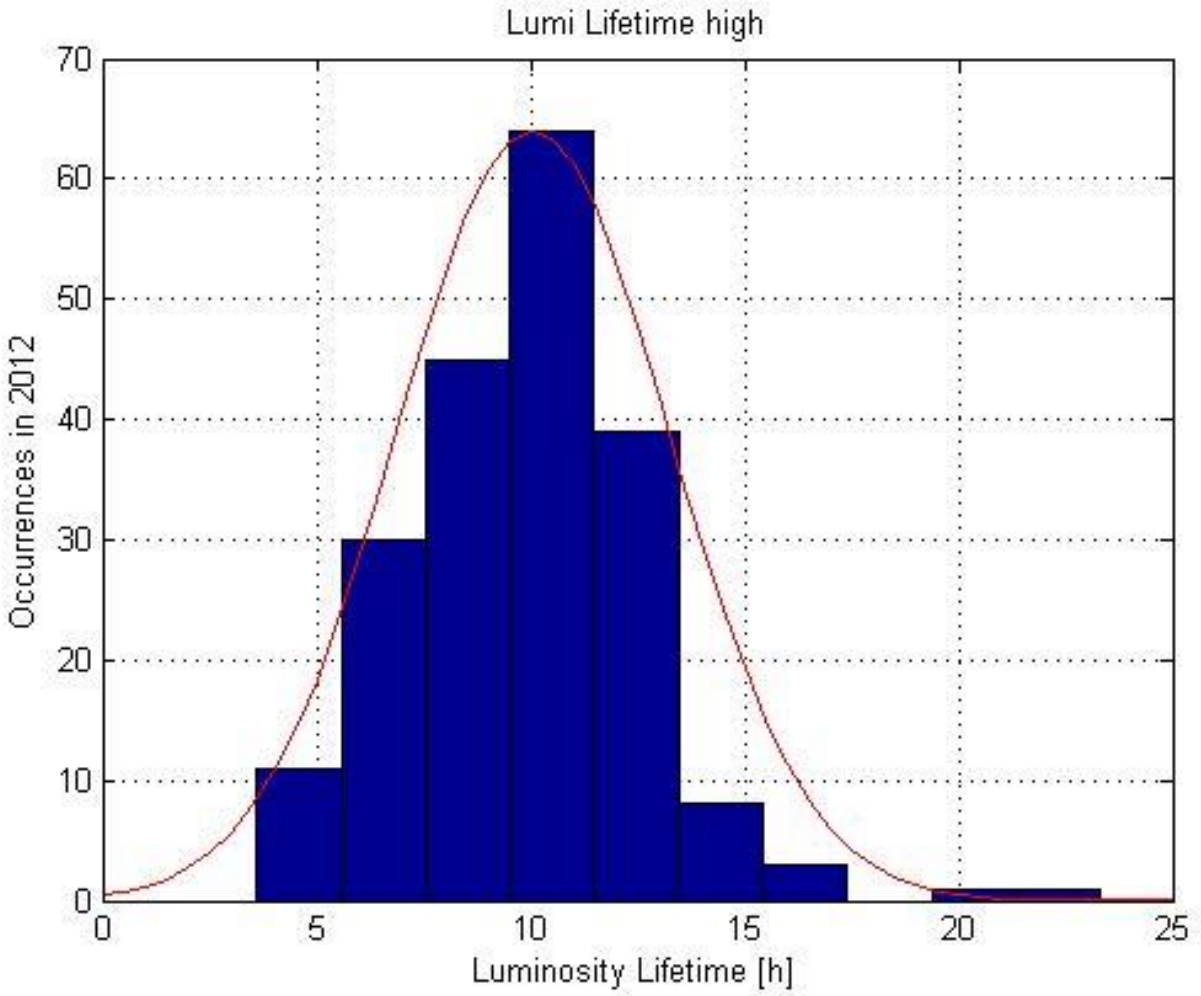


Norm Distribution:

- $\mu = 10.5$ [h]
- $\sigma = 2.5$

"Low" Peak Lumi
"High" Peak Lumi

2012 Luminosity Lifetime (High)

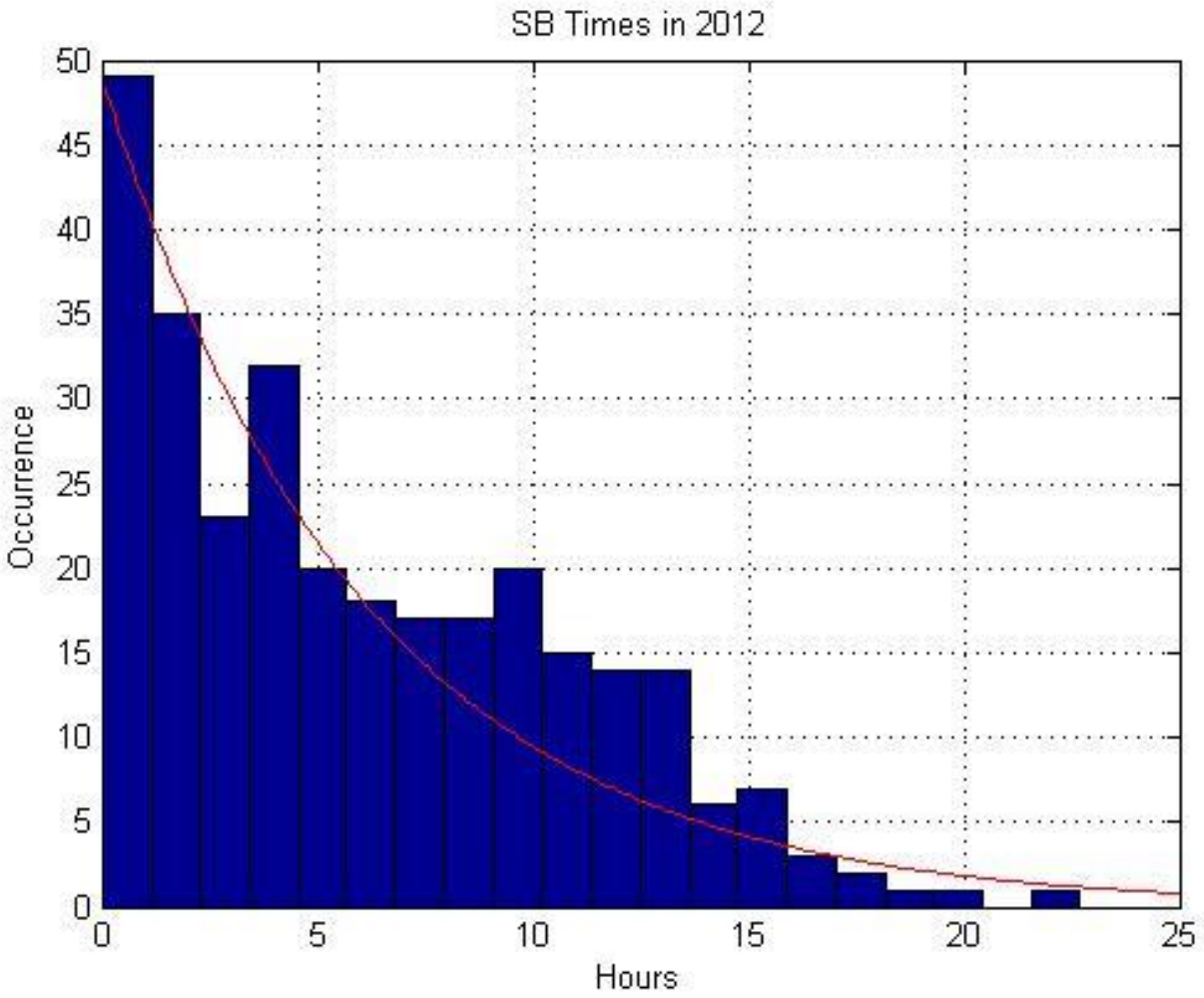


Norm Distribution:

- $\mu = 10.05$ [h]
- $\sigma = 3.2$

"Low" Peak Lumi
"High" Peak Lumi

2012 SB Distribution



Exp Distribution:

- $\mu = 6.0809$ [h]