HL-LHC cumulative IR7 losses and R2E

WP10
Energy Deposition & R2E

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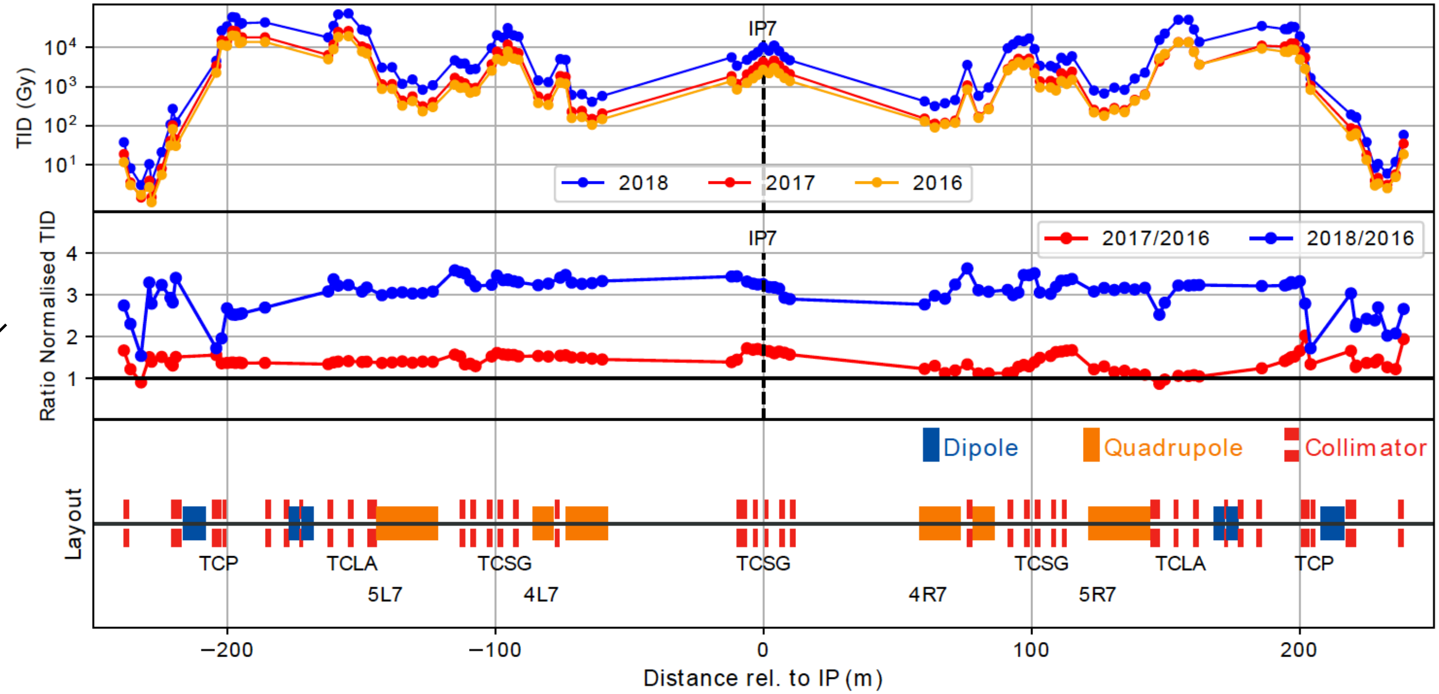
Content

- Cumulative TID levels measured by the BLMs in IR7 in Run 2 in the different years of operation.
- Measurement of the number of lost protons in the primary IR7 collimators, through a FLUKA-data BLM fit and a BCT-driven calculation.
- Summary of number of lost protons in Run 2 and HL-LHC predictions based on integrated intensity scaling.
- R2E implications in RR shielded areas.
- R2E implications in the DS, updated rack positions near the 11T magnets in half-cell 9.

Cumulative IR7 losses in Run 2

- Up to 2018, the BLM TID levels in IR7 scaled with integrated beam intensity (time-integral of the beam intensity in units of protons*seconds) with good approximation.
- **2018 saw an increase of normalised TID by a factor 2-3 in the whole LSS** (see slides at 116th HL-LHC WP15 meeting).

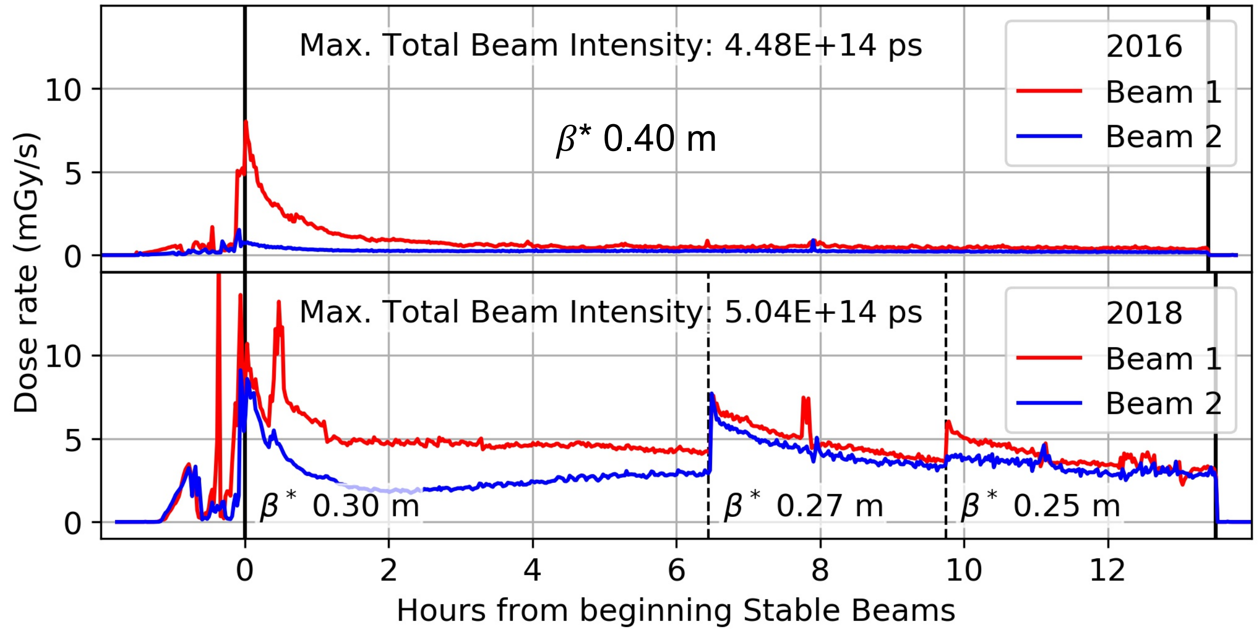
ratio of TID per unit integrated beam intensity



O.Stein et al., *"Run 2 prompt dose distribution and evolution at the LHC and implications for future accelerator operation"*, IPAC19

Cumulative IR7 losses in Run 2

- The observed increase of the cumulative losses in IR7 is visible by plotting the dose rate in the BLMs near the main TCP collimators in benchmark 2016 and 2018 fills.
- Dose rate peaks are clearly present in correspondence with the reduction of β^* in 2018 for both beam 1 and beam 2.
- The higher dose rate in 2018 fills can be attributed to different operating conditions of the LHC (lower β^*, reduction of β^* and crossing angle levelling during fills).

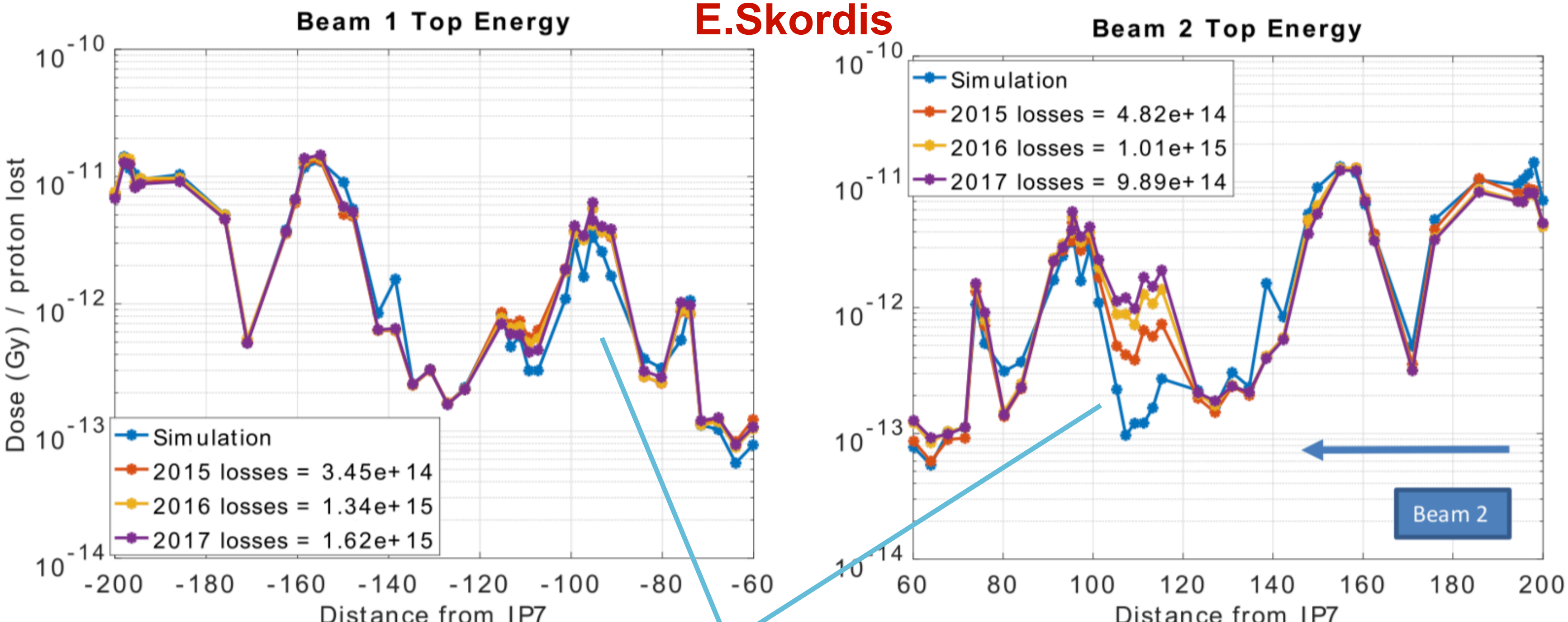


O.Stein et al., *"Run 2 prompt dose distribution and evolution at the LHC and implications for future accelerator operation"*, IPAC19

From TID to lost protons: FLUKA-BLM fit

- FLUKA simulations by E.Skordis (CWG, 12/12/18) with protons lost in the primary IR7 collimators as source.
- The profile of the BLM dose in the LSS is scaled to the data of each year to obtain the number of lost protons:

E.Skordis



Caveat: FLUKA-data disagreement caused by the TID contribution from the other beam, considered in the left plot but not in the right one

FLUKA-BLM fit at top energy

- FLUKA-BLM fit results for lost protons at top energy.
- Increase of lost protons per unit ps from 2016-17 to 2018.
- The lost protons per beam per year grew from ~$1.5 \cdot 10^{15}$ to ~$5 \cdot 10^{15}$ (with the known B1-B2 asymmetry).
- The number of lost protons at injection energy is similar (see backup) but not R2E-relevant because the TID per unit lost proton is more than 10 times lower than at top energy.

6.5 TeV collimation losses estimation, integrated intensity measurements and scaling factors.

Year		2015	2016	2017	2018
Beam 1	Estimated # of protons lost	0.4×10^{15}	1.4×10^{15}	1.7×10^{15}	5.1×10^{15}
	Integrated Intensity (ps)	0.254×10^{21}	1.17×10^{21}	1.03×10^{21}	1.36E+21
	Scaling factor (#p lost / ps)	**1.4×10^{-6}**	**1.2×10^{-6}**	**1.6×10^{-6}**	**3.8×10^{-6}**
Beam 2	Estimated # of protons lost	0.5×10^{15}	1.2×10^{15}	1.1×10^{15}	4.3×10^{15}
	Integrated Intensity (ps)	0.250×10^{21}	1.20×10^{21}	1.07×10^{21}	1.36E+21
	Scaling factor (#p lost / ps)	**2.0×10^{-6}**	**1.0×10^{-6}**	**1.0×10^{-6}**	**3.1×10^{-6}**

E.Skordis

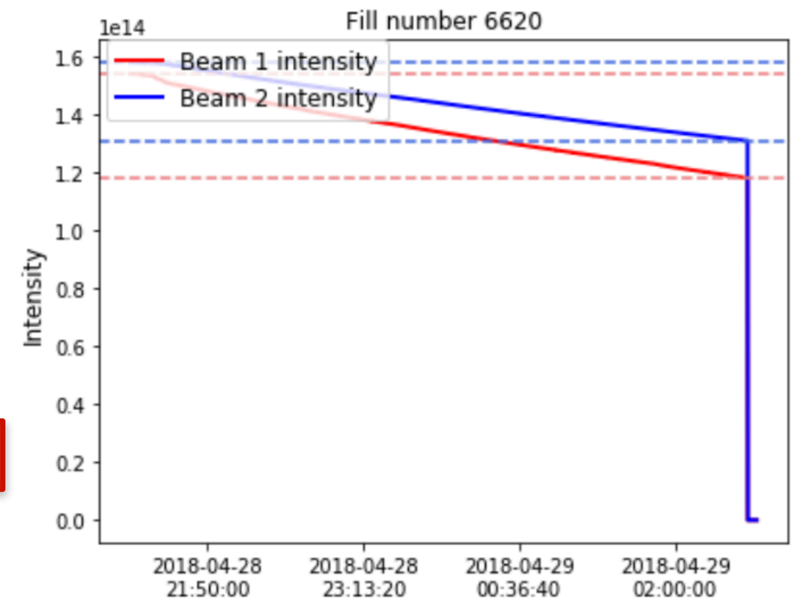
Lost protons in IR7: BCT-based measurement

- Alternative way to measure lost protons with BCT and luminosity:

$$N_{IR7}^{lost} = [\Sigma_i (I_{end}^i - I_{start}^i)] - \sigma_{inel} \cdot \mathscr{L}_{int}$$

Intensity difference between beginning of flat top and end of stable beams, summed over all fills in the year

Lumi burn-off



~20% agreement with FLUKA results!

#losses$_{IR7}$	2016	2017	2018
FLUKA B1	$1.4 \cdot 10^{15}$ p	$1.7 \cdot 10^{15}$ p	$5.1 \cdot 10^{15}$ p
BCT B1	**$1.7 \cdot 10^{15}$ p**	**$2.0 \cdot 10^{15}$ p**	**$6.1 \cdot 10^{15}$ p**
FLUKA B2	$1.2 \cdot 10^{15}$ p	$1.1 \cdot 10^{15}$ p	$4.3 \cdot 10^{15}$ p
BCT B2	**$1.0 \cdot 10^{15}$ p**	**$0.9 \cdot 10^{15}$ p**	**$4.2 \cdot 10^{15}$ p**

- Assumption for BCT measurement: non-lumi losses are concentrated in IR7 (i.e. we neglect losses in IR3).

Lost protons in IR7 in HL-LHC

- The number of lost protons in IR7 in HL-LHC can be predicted by scaling the Run 2 numbers with integrated beam intensity (see slides by R.García Alía).

	2016	2017	2018	Run 3	HL-LHC
$I_{int.}$ (10^{21} ps)	2.6	2.5	3.0	4.5	6.0
$\mathcal{L}_{int}^{ATLAS}$ (fb^{-1})	38.5	50.6	65.2	100	250
$\mathcal{L}_{int}^{CMS}$ (fb^{-1})	41.0	50.0	66.8	100	250
N_{lost}^{lumi} (10^{15}p)	12.4	15.6	20.4	34	85
N_{lost}^{coll} (10^{15}p)	2.9	3.0	10	15	20

**the table shows annual values for the sum of the two beams*

Run 3 and HL-LHC annual levels predicted with integrated intensity scaling **starting from the values measured in 2018**

10^{16} lost protons per beam per year, corresponding to around **$1.2 \cdot 10^{17}$** lost protons for the entire HL-LHC lifetime.

- Even with the updated prediction, the values are well below the safety margin considered for the IR7 warm magnets → **no impact on warm magnet replacement strategy**.

R2E impact - RR73-RR77 HEH fluence

- HL-LHC HEH fluence in the IR7 RRs (relevant for SEEs) given by 2018 RadMON levels at L0 and L1 scaled with integrated beam intensity. Observations:
  - Large L1/L0 HEH fluence ratio (shielding only effective at L0).
  - No factor 3 increase from 2017 to 2018 in RR77 (unlike RR73).
- Annual HEH fluence specifications for L0 (including safety margins): 10^8 cm^{-2}/y in Run 3, $2 \cdot 10^8$ cm^{-2}/y in HL-LHC.

>10 times lower than in the IP1-IP5 RRs!

		Annual HEH fluence at RadMON location (cm^{-2}/y)				
		2016	**2017**	**2018**	**Run 3**	**HL-LHC**
RR73	L0	$1.6 \cdot 10^7$	$1.8 \cdot 10^7$	$6.6 \cdot 10^7$	$9.9 \cdot 10^7$	$1.3 \cdot 10^8$
	L1	n.a.	$1.9 \cdot 10^8$	$6.3 \cdot 10^8$	$9.5 \cdot 10^8$	$1.3 \cdot 10^9$
RR77	L0	$1.2 \cdot 10^7$	$1.4 \cdot 10^7$	$1.6 \cdot 10^7$	$2.4 \cdot 10^7$	$3.2 \cdot 10^7$
	L1	n.a.	$3.0 \cdot 10^8$	$4.9 \cdot 10^8$	$7.4 \cdot 10^8$	$9.8 \cdot 10^8$

*Run 3 and HL-LHC annual HEH fluences are obtained by scaling the 2018 values with integrated beam intensity

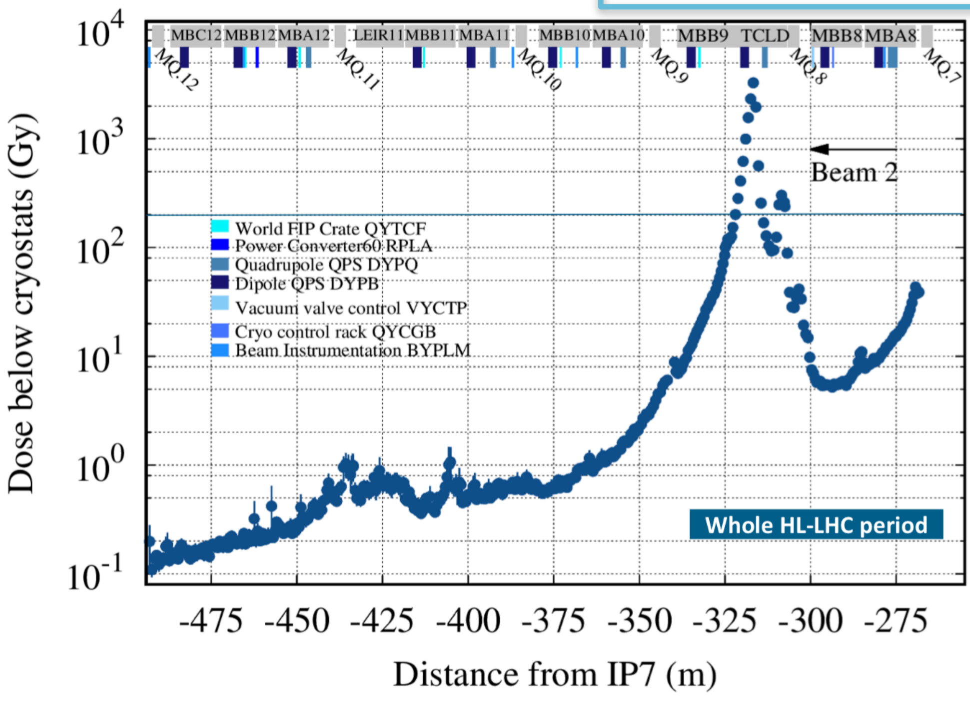
R2E impact - HL-LHC DS levels

- The radiation levels and profile in the DS will change due to the 11T magnets and TCLD collimator in half-cell 9.
- FLUKA simulation by C.Bahamonde Castro presented at the 62nd TCC meeting, showing peak power density and TID levels.

FLUKA settings:

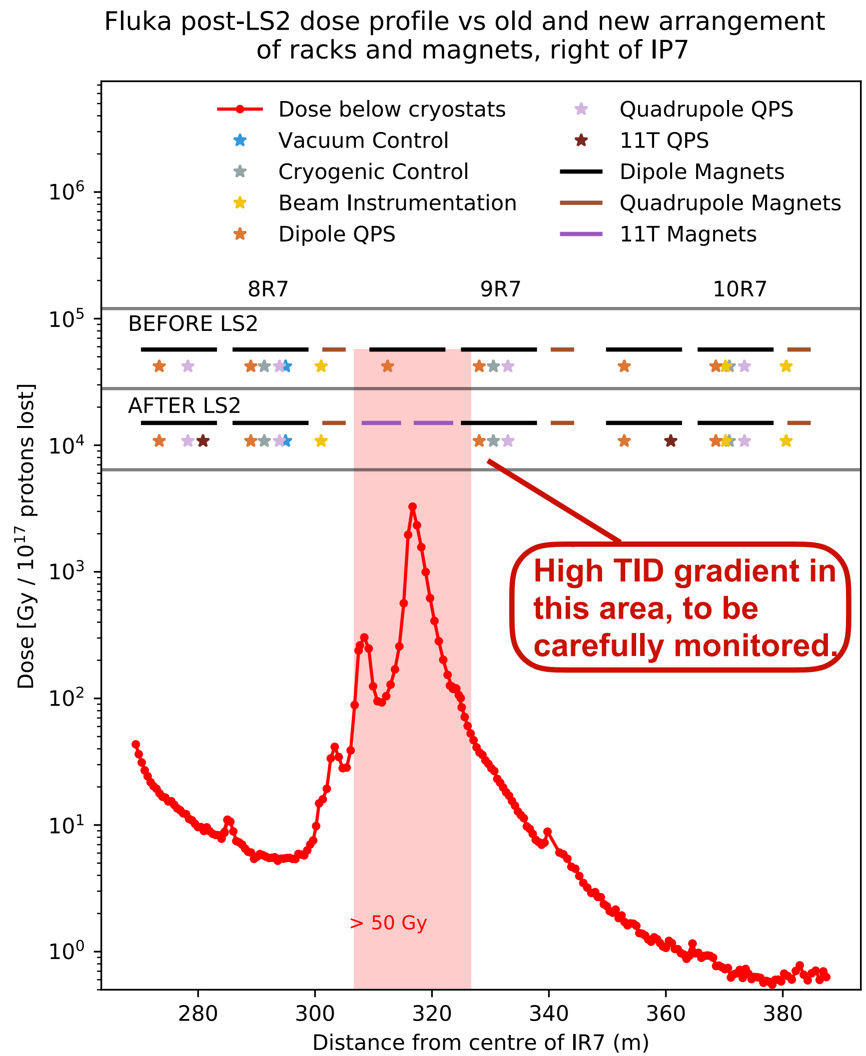
TCP	5.7 sigma
TCSG	7.7 sigma
TCLA	10 sigma
TCLD	14 sigma

- Simulation normalised to 10^{17} lost protons (the dose levels scale if this number changes).
- High TID peak next to the TCLD, lower levels further downstream.



Rack relocations near the TCLD (right of IR7)

- New positions of electronic racks defined by WP15 with input from equipment groups and R2E. New racks added (e.g. 11T QPS) and existing ones moved when needed.
- The racks below the MB.B magnet in cell 9 will be pushed as far away as possible from the TID peak.
- After the 11T installation, the TID peak will be monitored in data with different systems (e.g. BLMs, optical fibre).



*left side of IR7 in backup

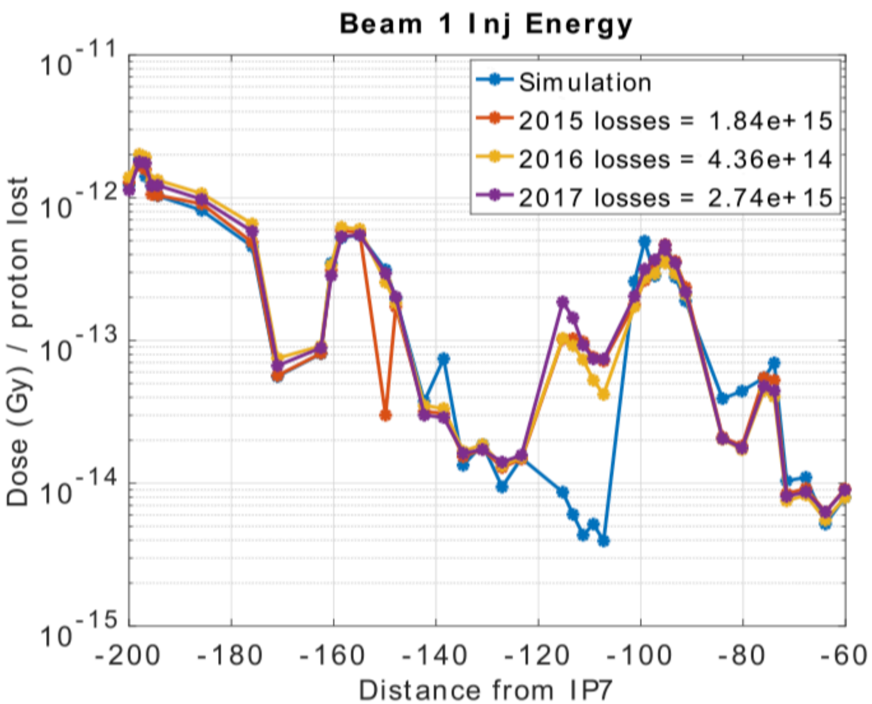
Summary

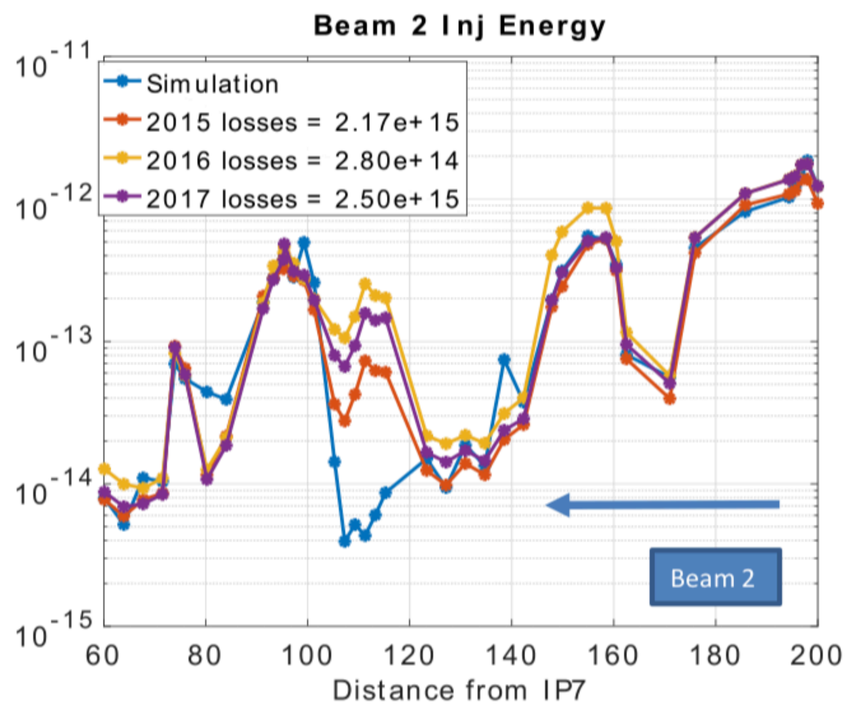
- I discussed the evolution of the cumulative IR7 losses in Run 2, in terms of TID levels and number of lost protons in the primary IR7 collimators (measured with two independent techniques that yield consistent results).
- The losses per unit integrated beam intensity increased by a factor ~3 from 2017 to 2018.
- The expected number of lost protons in IR7 in the whole HL-LHC period based on integrated intensity scaling from 2018 data is **$\sim 1.2 \cdot 10^{17}$p** per beam.
- The R2E implications in the RRs and DS were discussed. At present there are no critical issues, but we will continue to monitor the radiation levels in the upcoming years, particularly near the new 11T magnets.

BACKUP

FLUKA-BLM fit at injection energy

- FLUKA simulations by E.Skordis ([CWG, 12/12/18]) with protons lost in the primary IR7 collimators as source.
- Same plots shown in the [bulk of the presentation], now for injection energy. Note the lower TID per lost proton!





FLUKA-BLM fit at injection energy

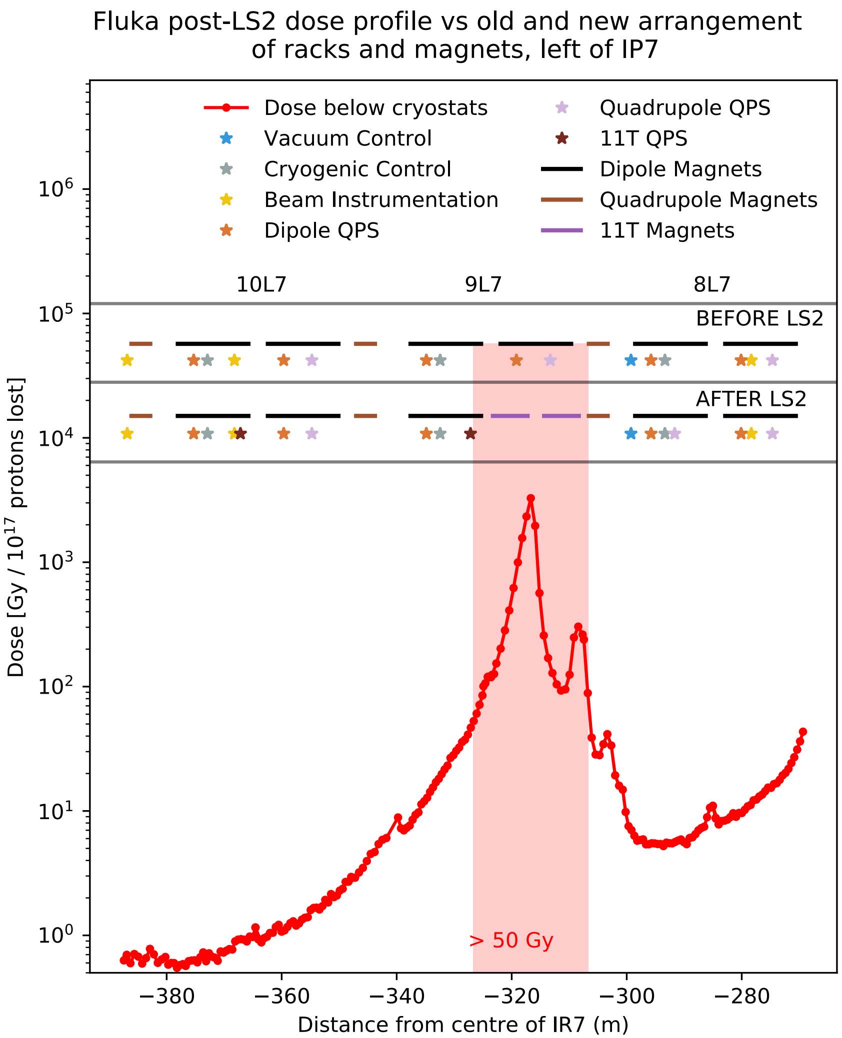
- Summary of FLUKA-BLM fit results for lost protons at injection energy.
- The number of lost protons at injection and top energy is similar (note: big impact of scrubbing runs).
- Injection losses are not critical for R2E, because the TID per unit lost proton is more than a factor 10 lower than at top energy.

450 GeV (injection) collimation losses estimation, integrated intensity measurements and scaling factors

	Year	2015	2016	2017	2018
Beam 1	Estimated # of protons lost	1.9×10^{15}	0.5×10^{15}	2.8×10^{15}	1.7×10^{15}
	Integrated Intensity (ps)	8.54×10^{19}	7.09×10^{19}	14.5×10^{19}	8.87×10^{19}
	Scaling factor (#p lost / ps)	**22×10^{-6}**	**7.0×10^{-6}**	**19×10^{-6}**	**19×10^{-6}**
Beam 2	Estimated # of protons lost	2.0×10^{15}	0.4×10^{15}	2.5×10^{15}	1.4×10^{15}
	Integrated Intensity (ps)	9.14×10^{19}	7.09×10^{19}	14.1×10^{19}	8.87×10^{19}
	Scaling factor (#p lost / ps)	**21×10^{-6}**	**5.3×10^{-6}**	**18×10^{-6}**	**15×10^{-6}**

E.Skordis

Rack relocations near the TCLD (left of IR7)



- Similar situation as on the right side of IR7 (backup).
- A new layout of electronic racks has been defined by WP15 to add the necessary new items (e.g. 11T QPS) and displace the existing ones where needed.
- The racks below the MB.B magnet in cell 9 will be pushed as far away as possible from the TID peak to mitigate the R2E risk.

Equivalent cross section

- The share of beam losses between luminosity and other loss sources (mainly IR7 collimators) can be expressed by the effective cross section:

$$N_{tot} = N_{lumi} + N_{IR7} = \sigma_{inel} \cdot \mathcal{L}_{tot} + N_{IR7} \quad \Rightarrow \quad \sigma_{eff} \equiv \frac{N_{tot}}{\mathcal{L}_{tot}} = \sigma_{inel} + \frac{N_{IR7}}{\mathcal{L}_{tot}}$$

- Numbers measured in Run 2 (for σ_{inel} = 76mb):

	2016 σ_{eq} [mb]	2017 σ_{eq} [mb]	2018 σ_{eq} [mb]
beam 1	97	96	122
beam 2	88	85	108

- For HL-LHC, σ_{eq} ~110mb would imply approximately 1.5-2·10^{17}p lost in IR7 for 12 years of operation assuming σ_{inel} ~80-85mb and 250fb^{-1} in ATLAS and CMS each year.

IR7 average beam lifetime (stable beams)

- The BLM TID levels are used to measure the IR7 beam lifetime, anti-correlated with the lost protons in IR7 (see slides by B.Salvachua).
- The scaling with integrated beam intensity of the cumulative BLM losses in IR7 holds if the IR7 beam lifetime during stable beams remains the same. From 2017 to 2018 it decreased significantly. For HL-LHC we assume that the average IR7 lifetime in stable beams will not be lower than in 2018.