High rate studies of the ATLAS MDT chambers in LHC Run-2

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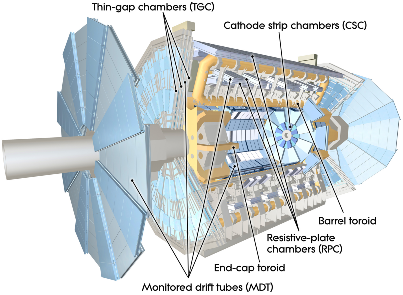
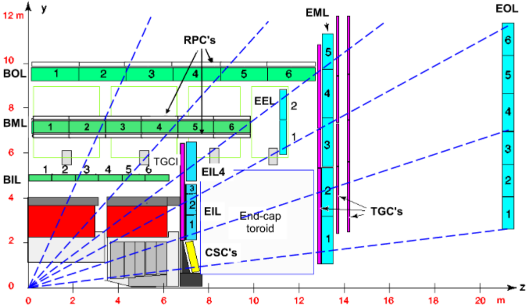
MAX-PLANCK-GESELLSCHAFT

The ATLAS muon system

- Consists of precision (MDT, CSC) and trigger (RPC, TGC) chambers
- Coverage up to $|\eta| < 2.7$
- Standalone muon reconstruction inside toroidal magnetic field





JINST 3 (2008) S08003

$\rightarrow$ High precision Monitored Drift Tube (MDT) chamber coverage up to $|\eta| < 2.0$ in **innermost end-cap** layer

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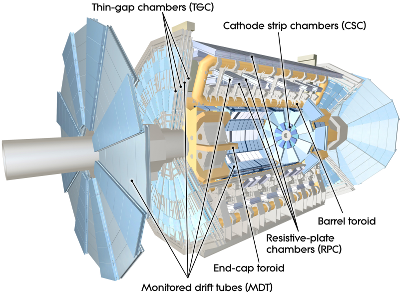

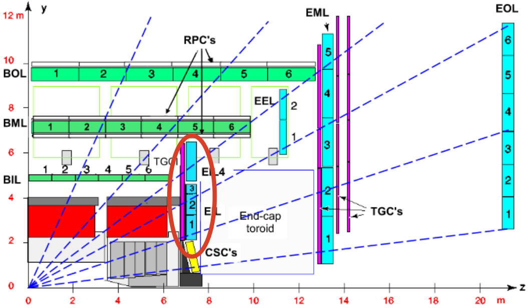

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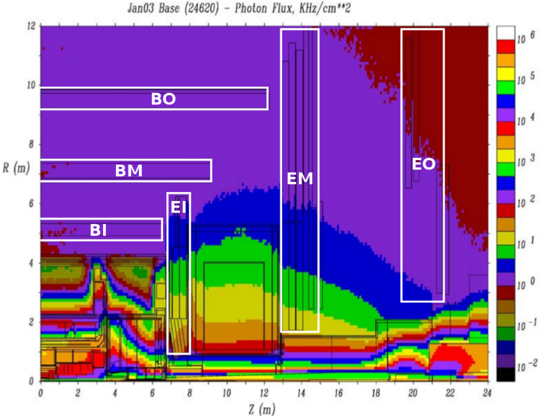
High-rate phenomena in MDT chambers

- Majority of hits in MDT chambers caused by the background radiation (γ/n) permeating ATLAS cavern
- Highest irradiation regions around the end-cap toroid magnets
- Innermost detector layer in end-cap region (**EI**) with MDT rate capability not sufficient for HL-LHC

Simulation of the photon flux



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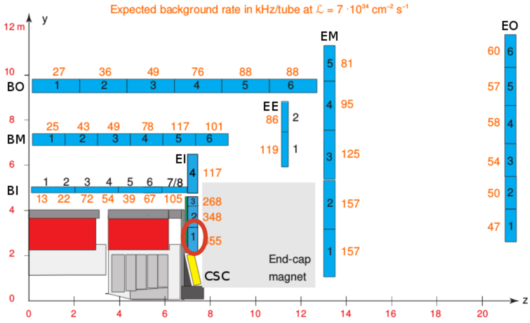
Expected background rates per drift tube at $\sqrt{s} = 8$ TeV and $L = 7 \cdot 10^{34}$ cm^{-2}s^{-1} in kHz/tube



ATL-COM-MUON-2013-011, CERN-THESIS-2014-091

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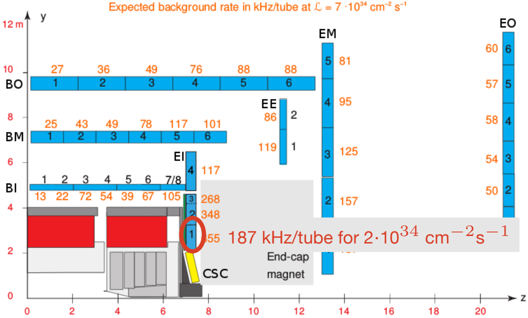


ATL-COM-MUON-2013-011, CERN-THESIS-2014-091

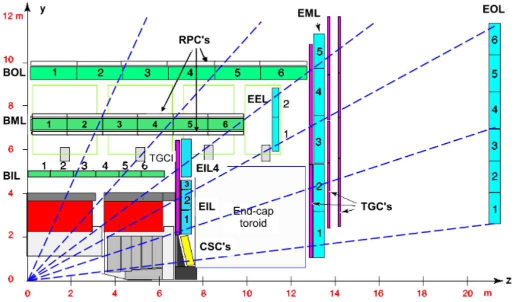
$\rightarrow$ Study MDT high-rate phenomena with *pp* collision data at $\sqrt{s} = 13$ TeV

High-rate phenomena in MDT chambers

Try to measure

- background rates in innermost end-cap chambers (e.g. chamber EIL1A01)
- spatial resolution of inner MDT chambers
- reconstruction efficiency of inner MDT chambers

in dependence of instantaneous luminosity



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$\rightarrow$ Require dataset covering a large range of instantaneous luminosities

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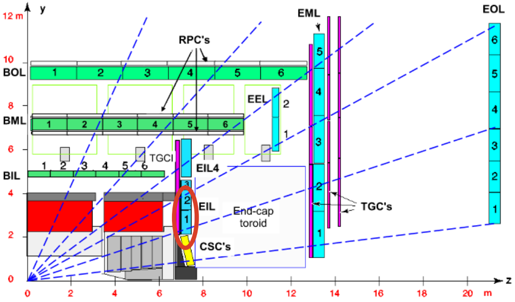

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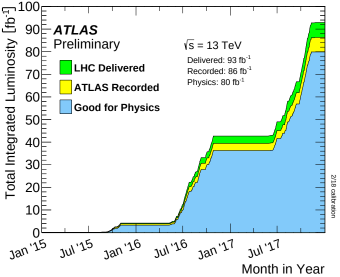
$\longrightarrow$ Require dataset covering a large range of instantaneous luminosities

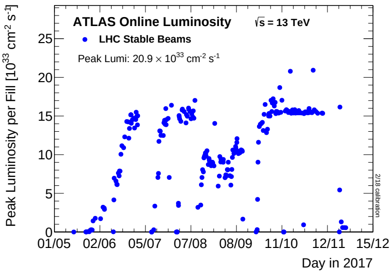
LHC Run-2 *pp* collision data

- The operation of the LHC in 2017 superseded its expectations
- Ideal preconditions for data-based studies of high-rate MDT phenomena

Ingegrated luminosity



Instantaneous luminosity



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2

$\rightarrow$ Reached peak instantaneous luminosity of $L = 2 \cdot 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$ on November 2nd, 2017

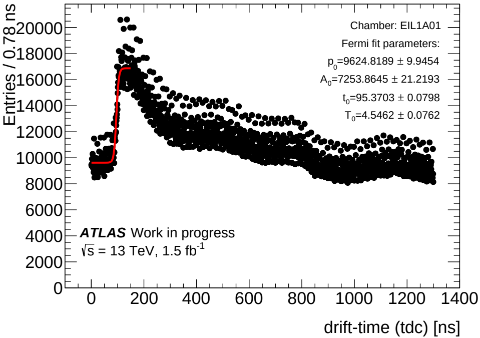
$\rightarrow$ Selected 1.5fb^{-1} of full Run-2 dataset covering the full range of instantaneous luminosities

Rate studies of MDTs - Background hit rate

- Background hit rate can be measured using side bands of the muon drift time spectrum
- Rising edge fitted with modified Fermi function

$$G(t) = p_0 + \frac{A_0}{1+\exp\left(-\frac{t-t_0}{T_0}\right)}$$

→ p_0 accounts for background caused by uncorrelated noise or background radiation

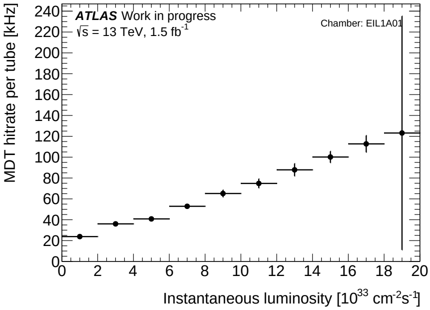


→ Divide p_0 by number of tubes of the chamber and by number of events to get hit rate per tube

Rate studies of MDTs - Background hit rate

- Background hit rate estimated by Fermi-Fit

Innermost end-cap chamber EIL1A01



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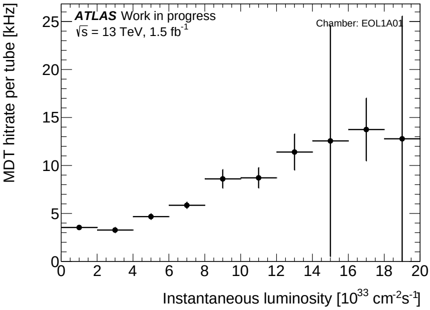


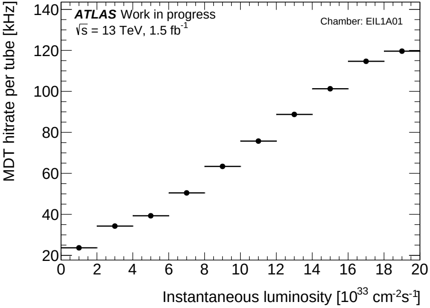
→ Depending on statistics, large fit parameter uncertainties are obtained

→ Try another estimation of the background hit rate

Rate studies of MDTs - Background hit rate

- Looking at drift time spectrum again
- Exclude all hits when a muon is extrapolated to the chamber
- Divide average height of drift time spectrum by number of tubes of the chamber and by number of events without muons extrapolated to the chamber

Innermost end-cap chamber EIL1A01



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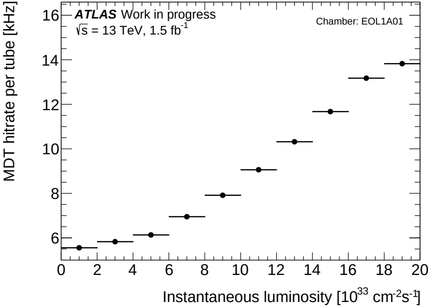
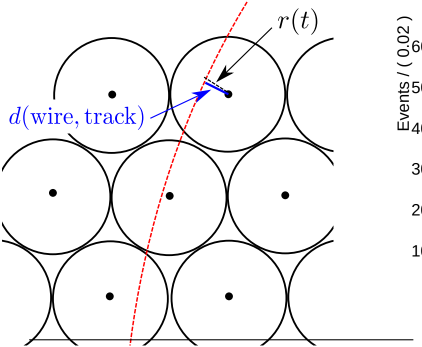


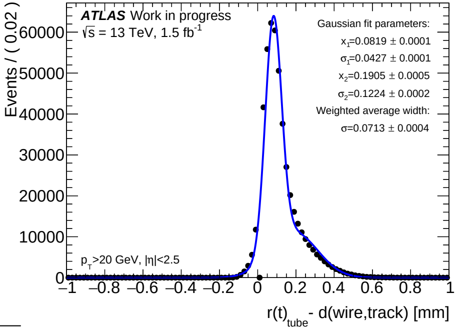
$\rightarrow$ Comparable rates with smaller errors

Rate studies of MDTs - Resolution

- Looking at innermost end-cap chamber EIL1A01
- Calculating difference between measured drift radius $r(t)$ per tube and distance between fitted muon track and wire inside tube $d(\text{wire,track})$

→ Fit sum of 2 Gaussians[1] and take weighted average of σ_1,σ_2 as resolution

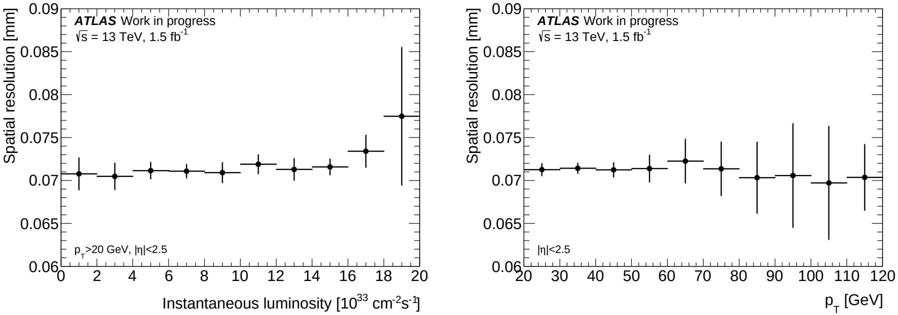




[1] used for modelling asymmetry correctly

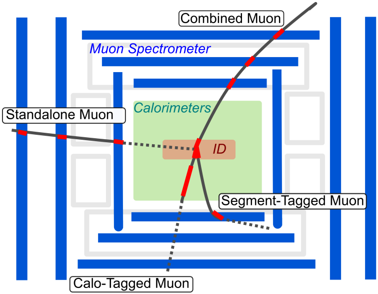
Rate studies of MDTs - Resolution

- Looking at innermost end-cap chamber EIL1A01
- Plot measured resolution σ vs. instantaneous luminosity L and muon transverse momentum p_T



$\rightarrow$ Spatial resolution flat in instantaneous luminosity and muon transverse momentum

Rate studies of MDTs - Efficiency



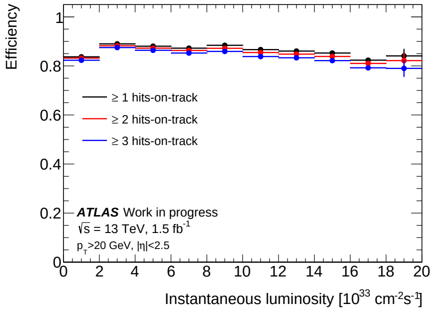
- Combined muon: Combine track from MS and ID (standard method)
- Calorimeter-tagged (CaloTag) muon: Track in ID with small characteristic energy deposit in calorimeter

- Define reconstruction efficiency per chamber as $\epsilon = N_{\text{Matches}}/N_{\text{Probes}}$
  - -- Probe = Number of CaloTag muons extrapolated to chamber
  - -- Match = Number of Combined muons with hits on muon track in chamber within $\Delta R = 0.05$ of CaloTag muon

Rate studies of MDTs - Efficiency

- Plot measured efficiency σ vs. instantaneous luminosity L

Innermost end-cap chamber EIL1A01



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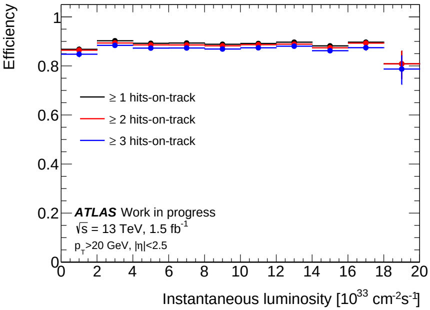
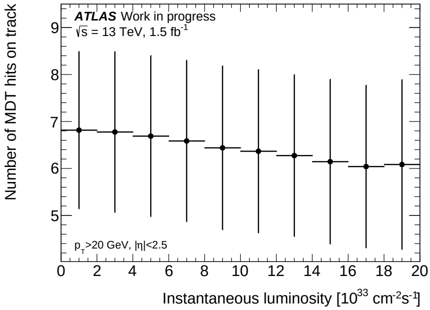


$\rightarrow$ Efficiency slightly decreasing (flat) with instantaneous luminosity for innermost (outermost) end-cap chamber

Rate studies of MDTs - Efficiency

- Plot number of hits-on-track (mean value and RMS) vs. instantaneous luminosity *L*

Innermost end-cap chamber EIL1A01



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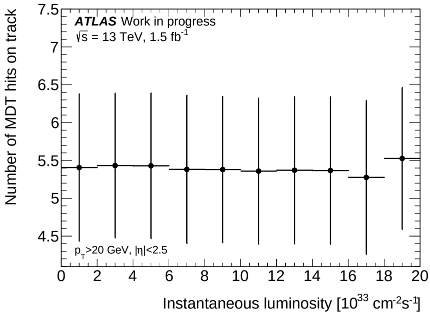


$\rightarrow$ Average number of hits on muon track slightly decreasing with instantaneous luminosity for innermost end-cap chamber

$\rightarrow$ Hit requirement in efficiency definition leads to decreasing efficiency

Summary

- Studied resolution and efficiency of MDT chambers as a function of background rates using LHC Run-2 data

→ Instantaneous luminosities up to $L = 2 \cdot 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ similar to HL-LHC conditions

- Background rates observed in innermost end-cap chambers agree with expectations
- Spatial resolution is independent of instantaneous luminosity up to $L = 2 \cdot 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Slightly decreasing efficiency with increasing instantaneous luminosity for innermost end-cap chamber

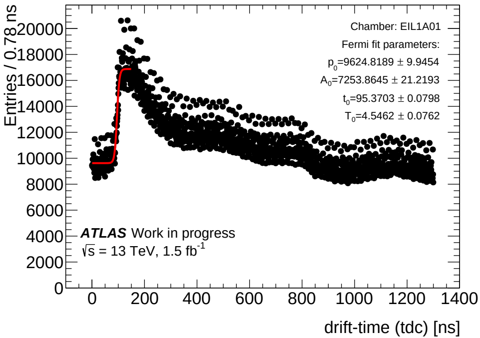
→ Separate hit efficiency from reconstruction efficiency

BACKUP

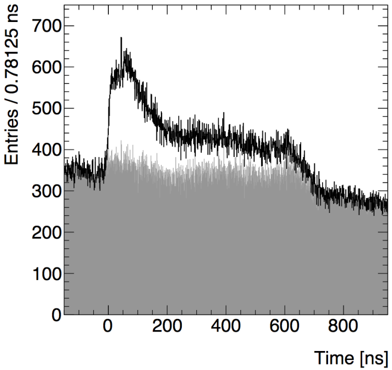
The shape of the drift time spectrum

- Compared to an ideal drift time spectrum, a band-like structure is observed
- The spectrum shows a period structure (in 16 of the 25ns/32 bins)

Innermost end-cap chamber EIL1A01



Testbeam data



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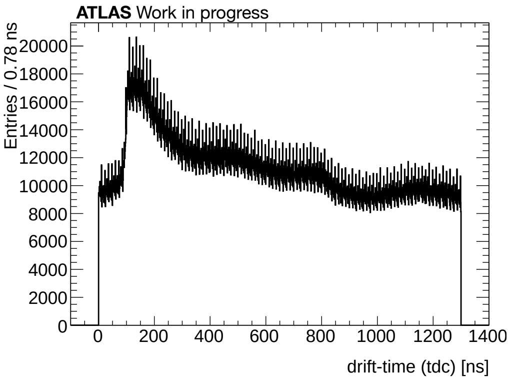

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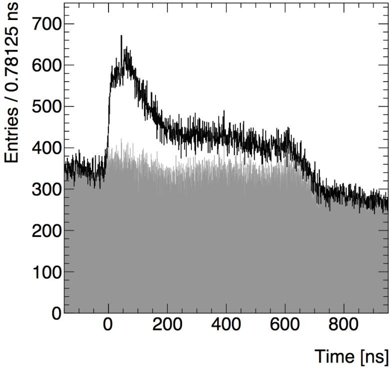

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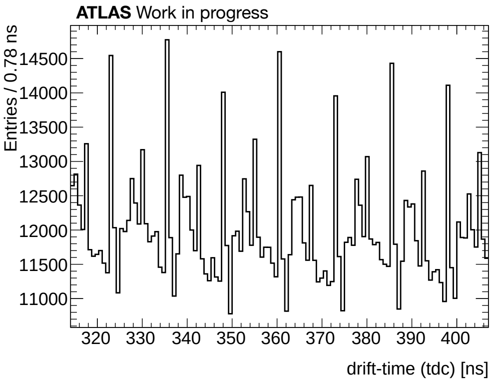

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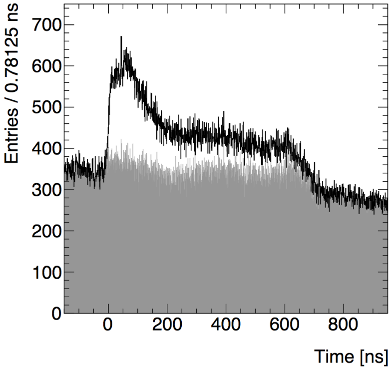

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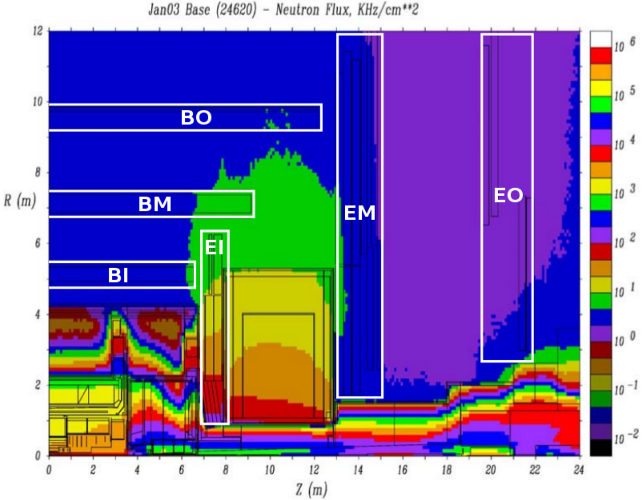
High-rate phenomena in MDT chambers

Simulation of the neutron flux



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Used pp collision data for studies

Run	Date	Inst. L $[10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	Integr. $\mathcal{L}$ [pb^{-1}]
276262	2015, August 16th	356 - 419	6.2
297730	2016, April 28th	150 - 198	3.4
300415	2016, May 28th	3343 - 4562	94.4
309759	2016, October 2nd	5001 - 12658	347.7
325713	2017, June 4th	1757 - 3216	76.3
325790	2017, June 5th	2204 - 2925	40.3
338349	2017, October 16th	6917 - 15696	462.3
339849	2017, November 2nd	6151 - 20614	456.1
			1486.7

$\rightarrow$ Covering the full range of instantaneous luminosities up to

$$L = 2 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$