

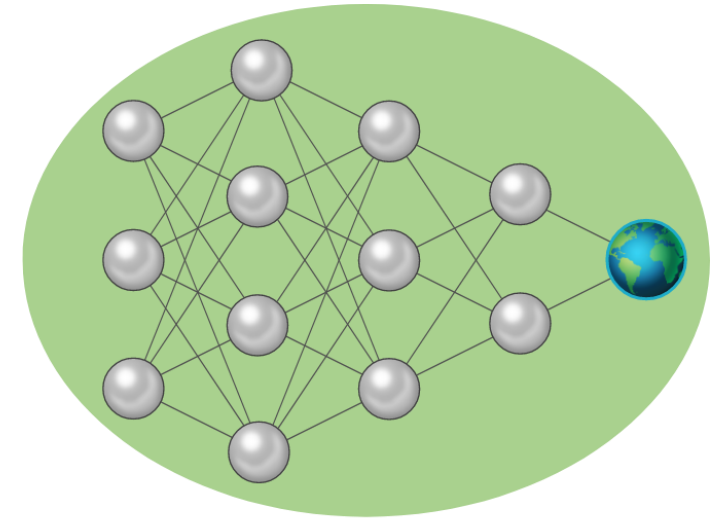
Measuring luminosity in ATLAS

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PEARLS

Precision in Energy-aware AI Research
for Low-carbon Solutions

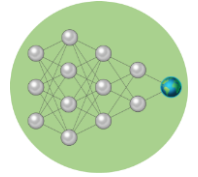
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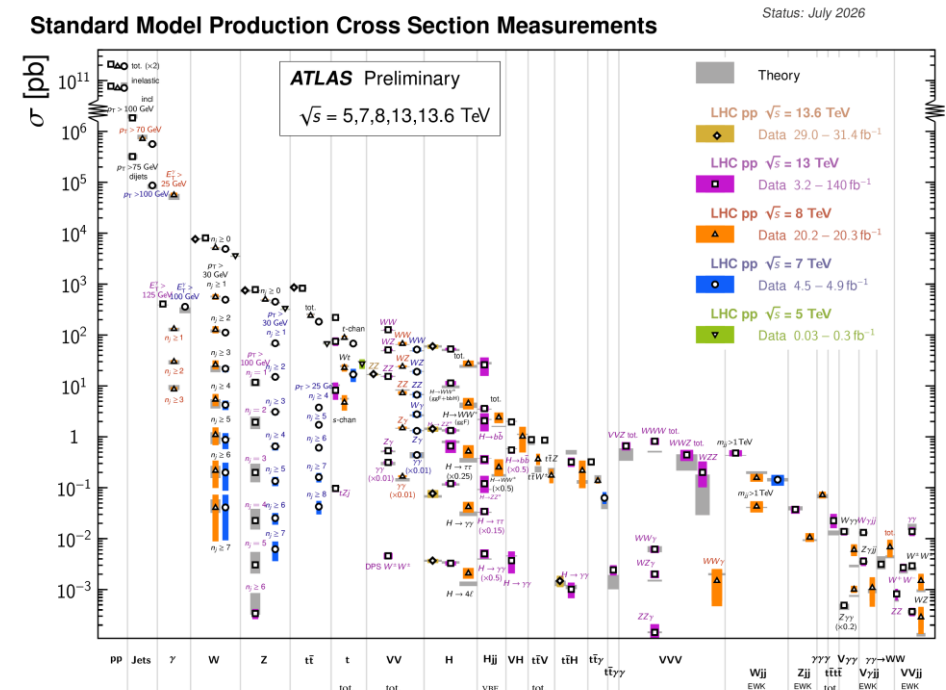
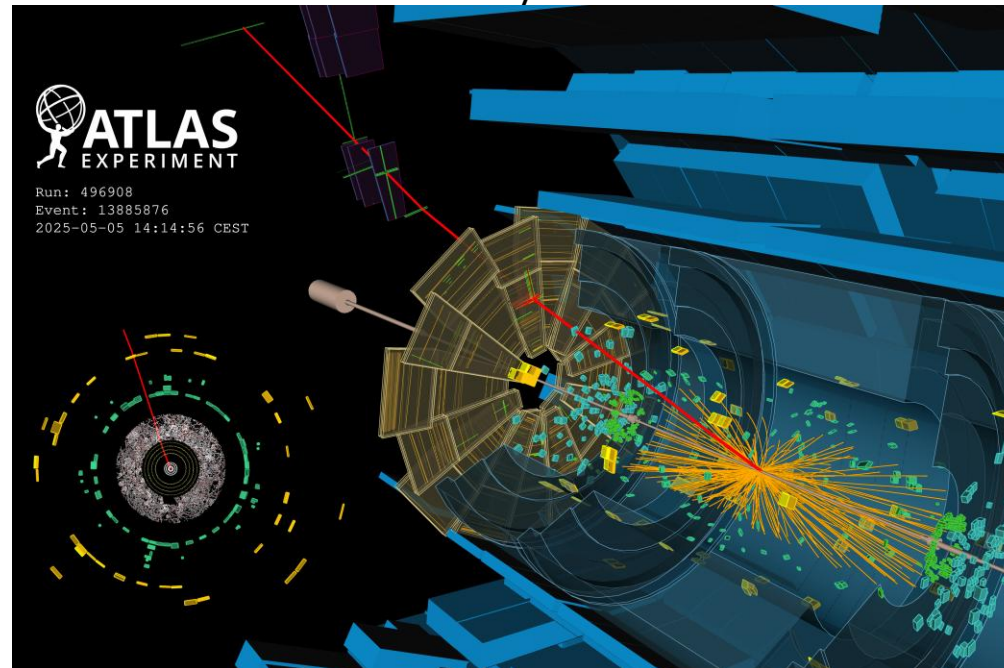
Proposed project in ATLAS



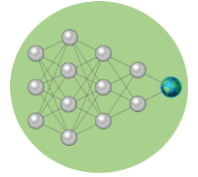
- Measurement of luminosity via track-counting at the HL-LHC with the ATLAS detector
 - In ATLAS: Collision of protons or lead ions produces signals of emerging particles at certain rates $\dot{N} = dN/dt$



Want to measure “interaction probabilities” σ for many processes



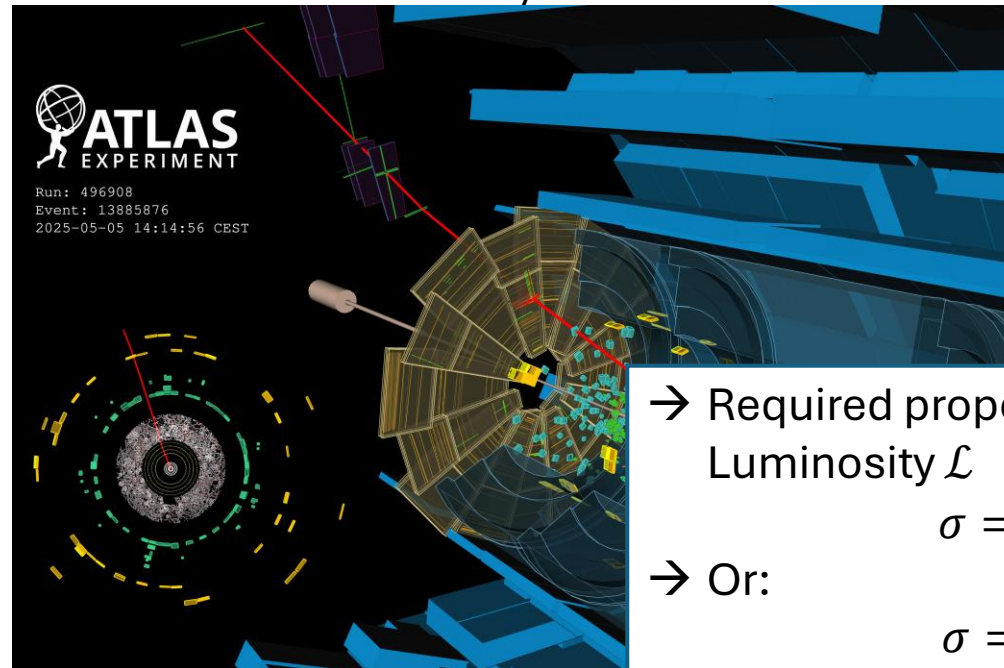
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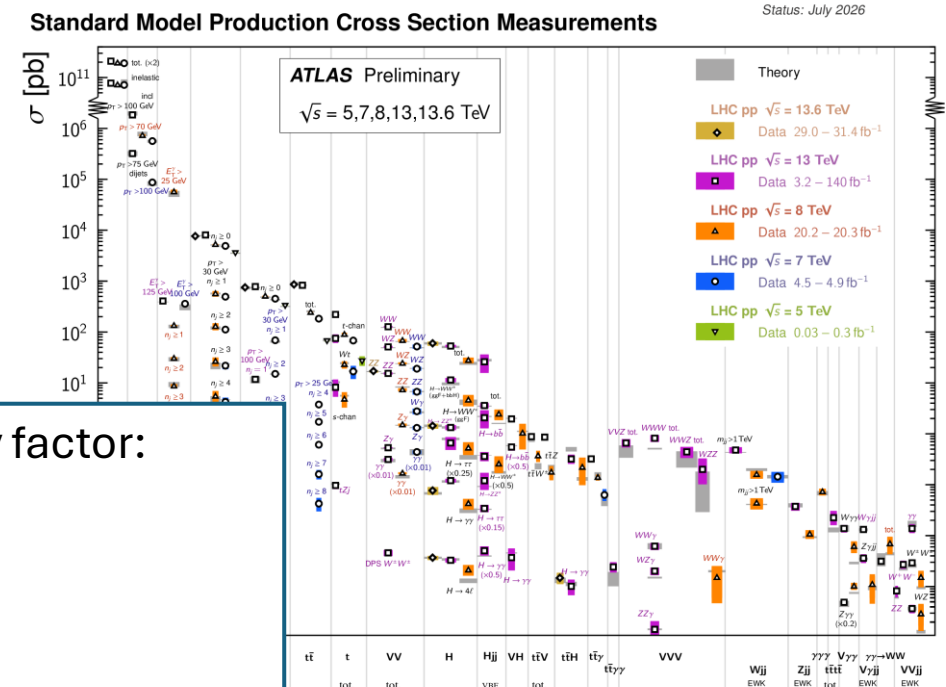


→ Required proportionality factor:
Luminosity $\mathcal{L}$

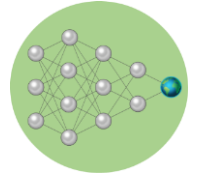
$$\sigma = \dot{N} / \mathcal{L}$$

→ Or:

$$\sigma = N / \mathcal{L}_{int}$$

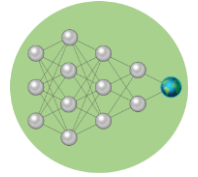


Luminosity measurement in ATLAS



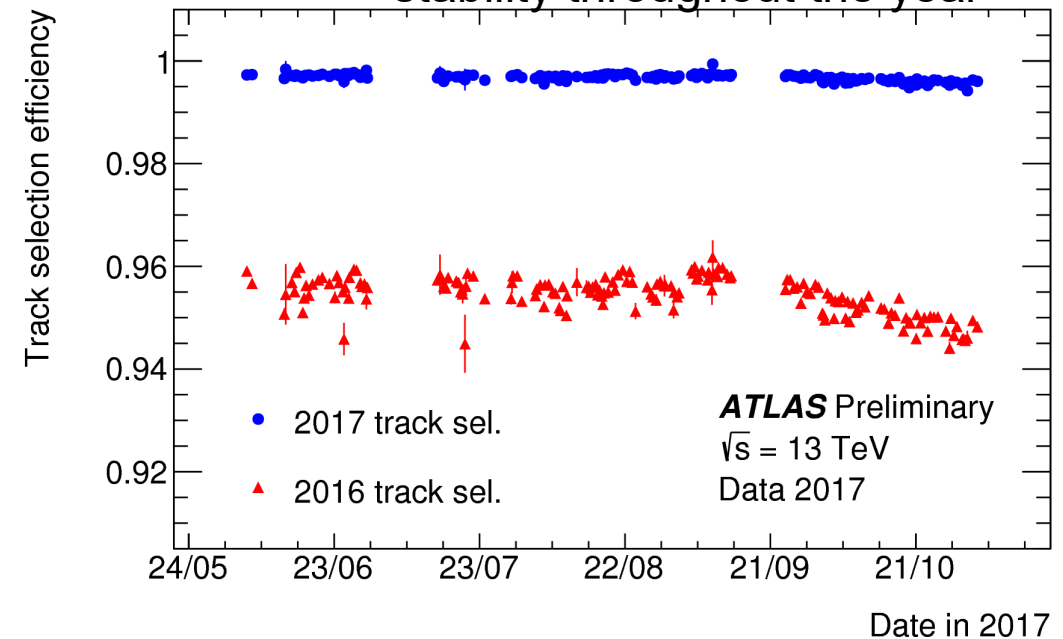
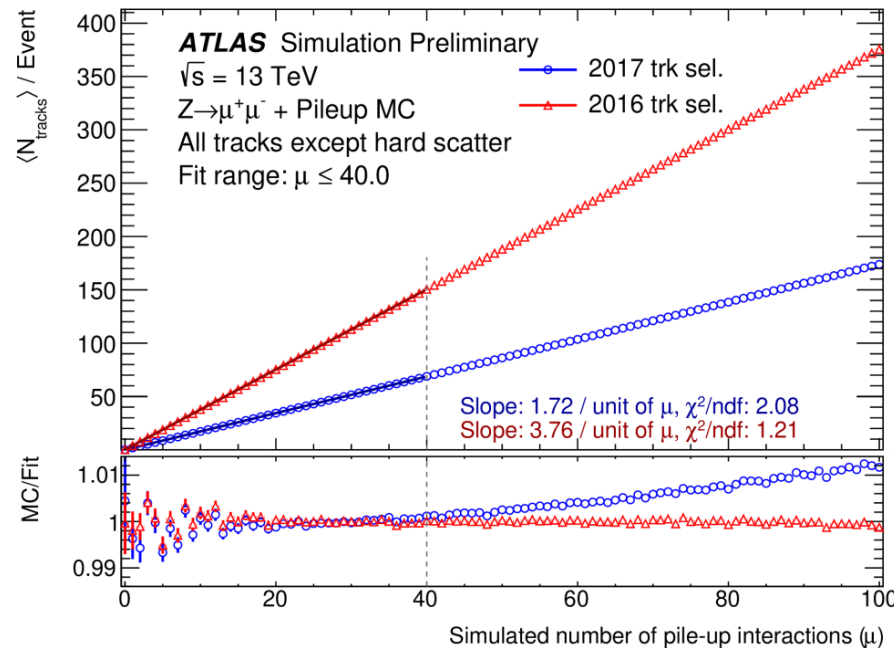
- Per colliding particle bunch pair
 - Solve for luminosity: $\mathcal{L}_b = \dot{N}/\sigma$
 - Using e.g. the cross section of inelastic pp collisions as reference: $\mathcal{L}_b = \mu \cdot f_r / \sigma_{inel}$
 - With μ = average number of inelastic pp collisions per bunch crossing, f_r = revolution frequency in the collider ($\sim 11\text{kHz}$ in the LHC)
 - Therefore: To measure luminosity, just need to measure μ
 - Dedicated detectors attempt to do that $\rightarrow$ Luminometers $\rightarrow$ Main ATLAS luminometer: LUCID
 - But: Every luminometer only “sees” part of μ , namely the visible part of μ , i.e.: $\mu = \mu_{vis} \cdot \frac{\sigma_{inel}}{\sigma_{vis}}$
 - With the visible cross section: $\sigma_{vis} \rightarrow$ Needs to be calibrated
 - Sophisticated three-step calibration procedure for σ_{vis}
 - Calibrate σ_{vis} under controlled experimental conditions via the van-der-Meer (vdM) method
 - Extrapolate the calibration to experimental conditions of physics data-taking
 - Monitor the calibration vs. other luminometers during the year
- } Important cross-check method:
Track counting

Idea of track counting



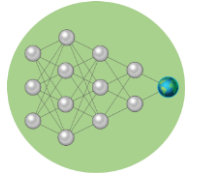
- Average number of tracks per event $\rightarrow$ Proportional to μ
 - Based on MC simulation
 - Use tracks reconstructed in the Inner Detector (no TRT)
 - Necessary to optimize selection for good proportionality

$\rightarrow$ But also need excellent stability throughout the year

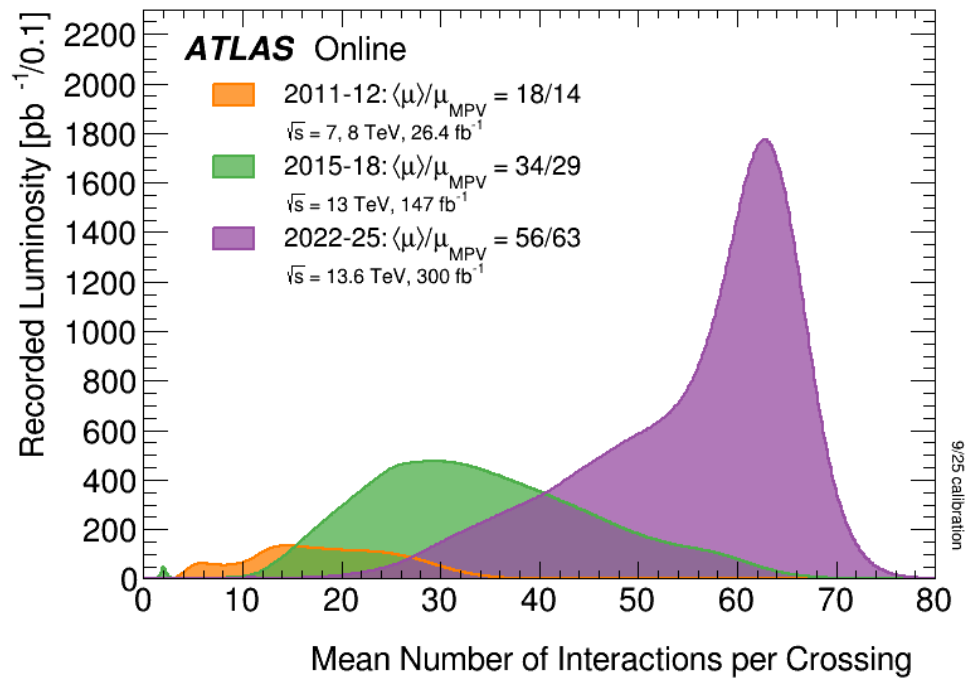


$\rightarrow$ 2017 track selection has been default since the optimization then

But what at HL-LHC?

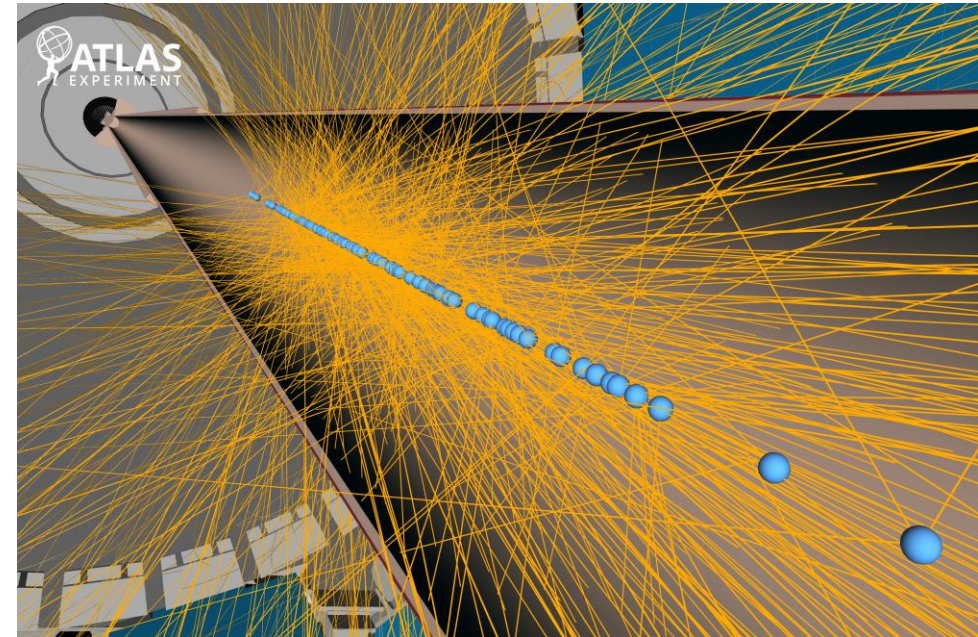


- At LHC



→ μ between ~10-70

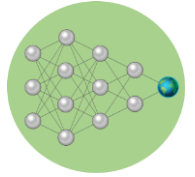
At High-Luminosity (HL-) LHC



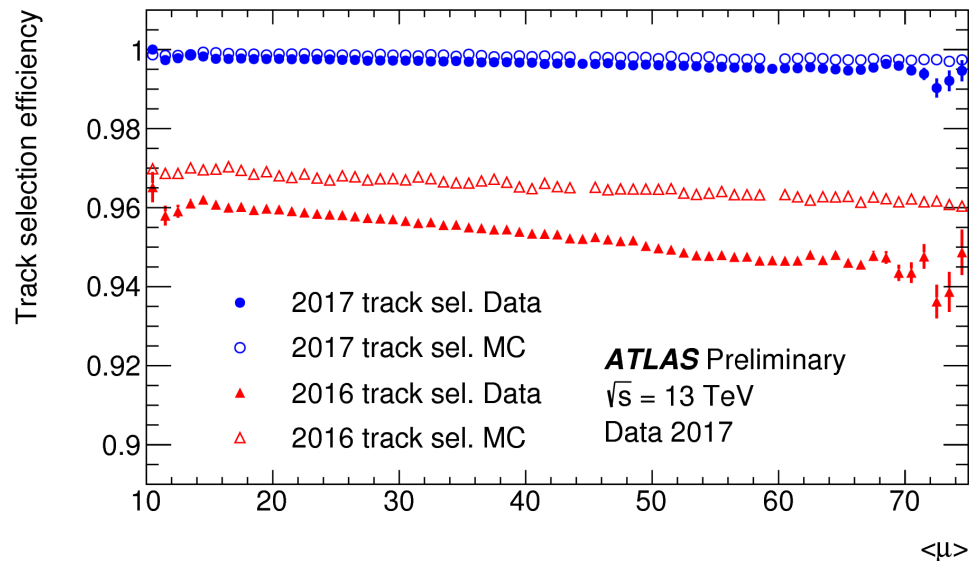
→ Standard μ of 140

→ Maximum μ of 200

Will track counting still work?

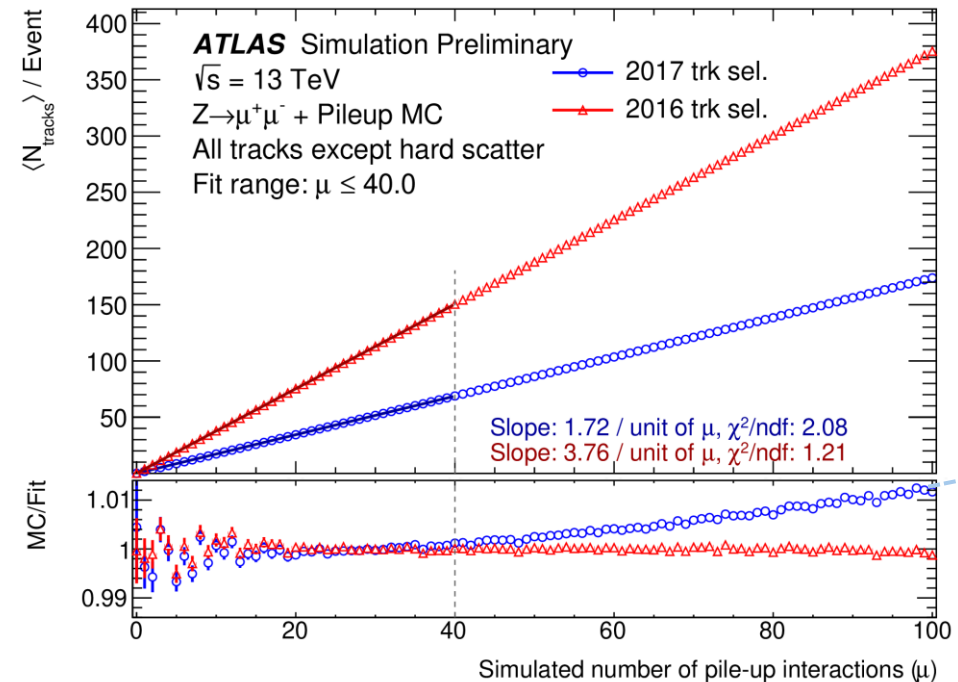


- Track selection efficiency

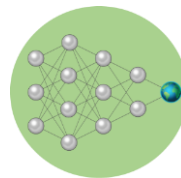


→ Very stable within so far relevant μ range for default 2017 track selection

→ But based on MC predictions ...



... expect increasing differences from linear relation due to fake tracks



How to suppress fake tracks?

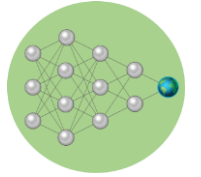
- So far used track selection

Criterion	Selection A	Selection B	Selection C
p_T [GeV]	> 0.9	> 0.9	> 0.9
$ \eta $	< 1.0	< 2.5	< 1.0
$N_{\text{hits}}^{\text{Si}}$	≥ 9	≥ 9 if $ \eta < 1.65$ else ≥ 11	≥ 10
$N_{\text{holes}}^{\text{Pix}}$	≤ 1	$= 0$	≤ 1
$ d_0 /\sigma_{d_0}$	< 7	< 7	< 7

- This corresponds to “2017 selection”
- Can this be improved to suppress fake tracks further, while maintaining good and stable selection efficiencies?

- Proposed STA with PEARLS
 - Investigate track selections in MC simulation for HL-LHC using the most recent ITk detector simulation
 - Test whether machine-learning (ML) based approaches can improve the fake suppression
 - Quantify the CO₂ costs of the algorithms
 - What are good metrics to decide on a new track selection (in- or excluding ML), taking into account the CO₂ footprint
 - Publish track-counting optimization and CO₂ footprint

Conclusion



- Luminosity = very important quantity for any physics measurement at ATLAS
 - Proportionality factor betw. counted events and cross section, i.e. “interaction probability”
 - Requires dedicated calibration procedure which uses the track-counting algorithm as important reference
- Track-counting luminosity measurement
 - Count the number of tracks reconstructed in the Inner Detector in ATLAS
 - Optimized track selection for good linearity and excellent stability during the year
 - Expect fake track contributions to rise significantly for experimental conditions at HL-LHC
- ATLAS STA within PEARLS
 - Investigate track-counting at HL-LHC
 - Optimize track selection to suppress fake tracks further – testing machine-learning approaches
 - Investigate and optimize carbon footprint when developing the new algorithms