Pile-up for physics: building a novel hadronic physics dataset

Antti Pirttikoski, Carlos Moreno Martínez, Mário Cardoso, Steven Schramm, Vilius Čepaitis

Swiss Physics Society Annual Meeting

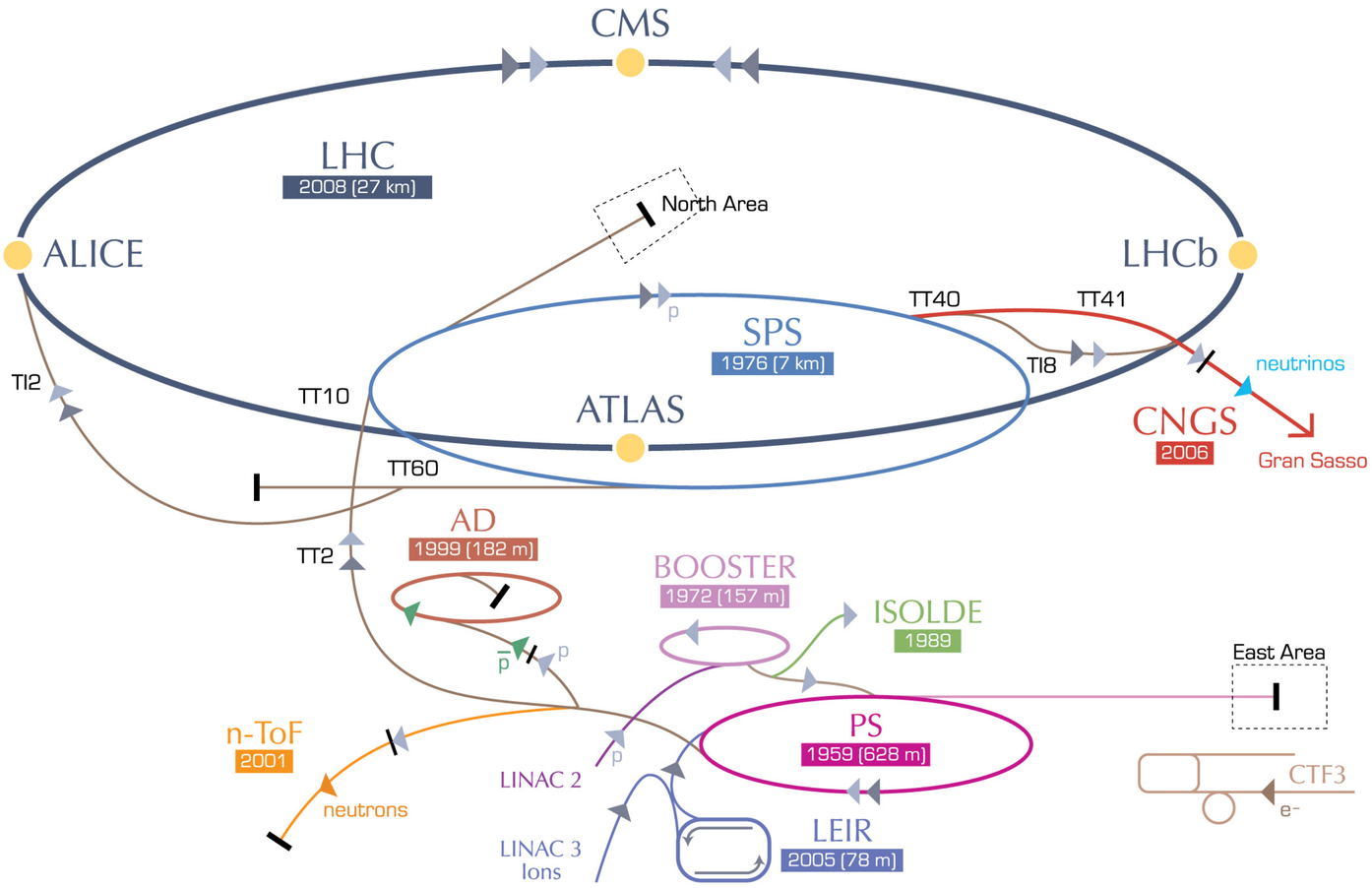
ETH Zürich - 12/Sep/2024

UNIVERSITÉ DE GENÈVE

This presentation is part of a project that has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 948254)

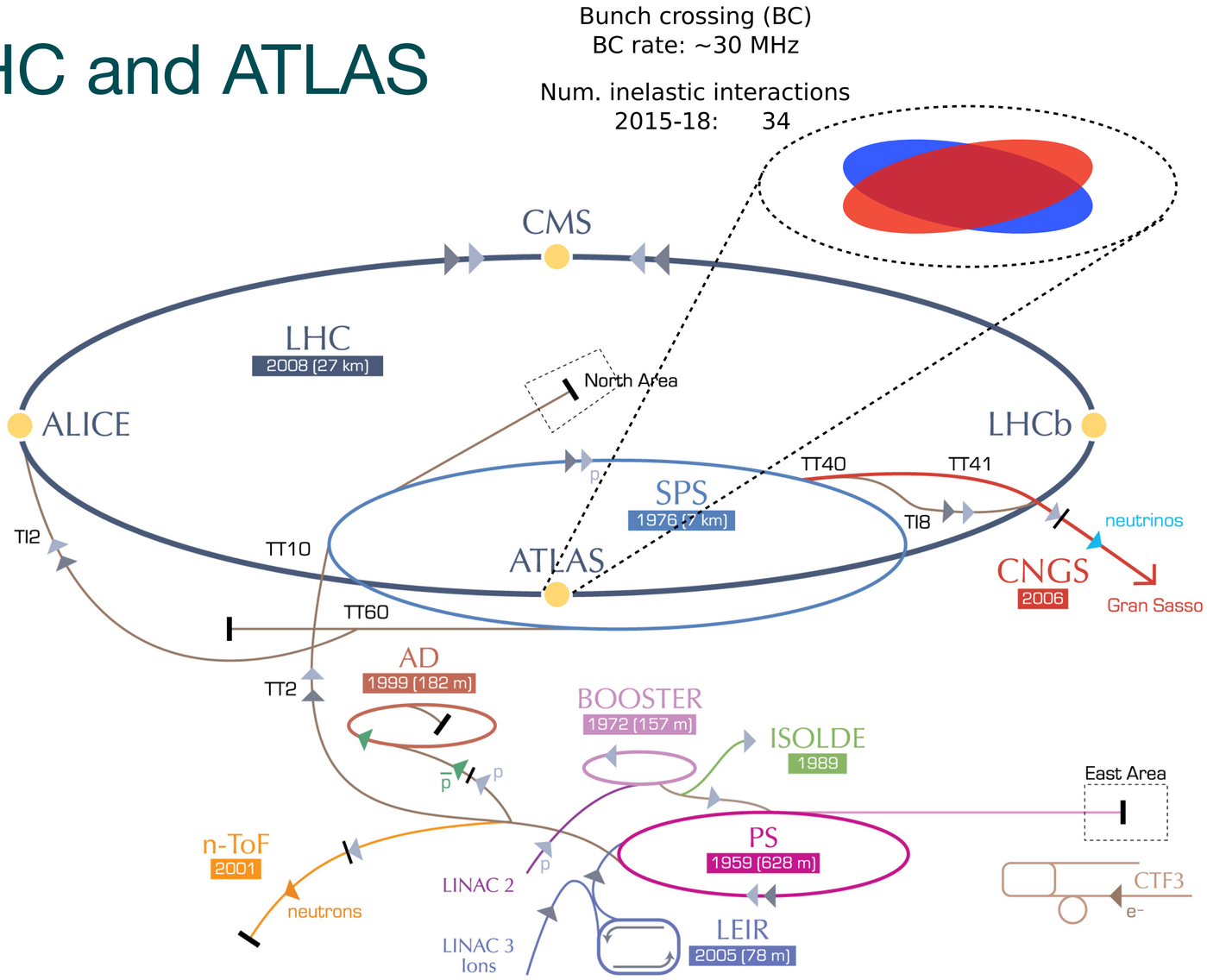
The LHC and ATLAS

- The Large Hadron Collider: unprecedented **energy** and **luminosity**
  - Up to 30 million pp collisions per second



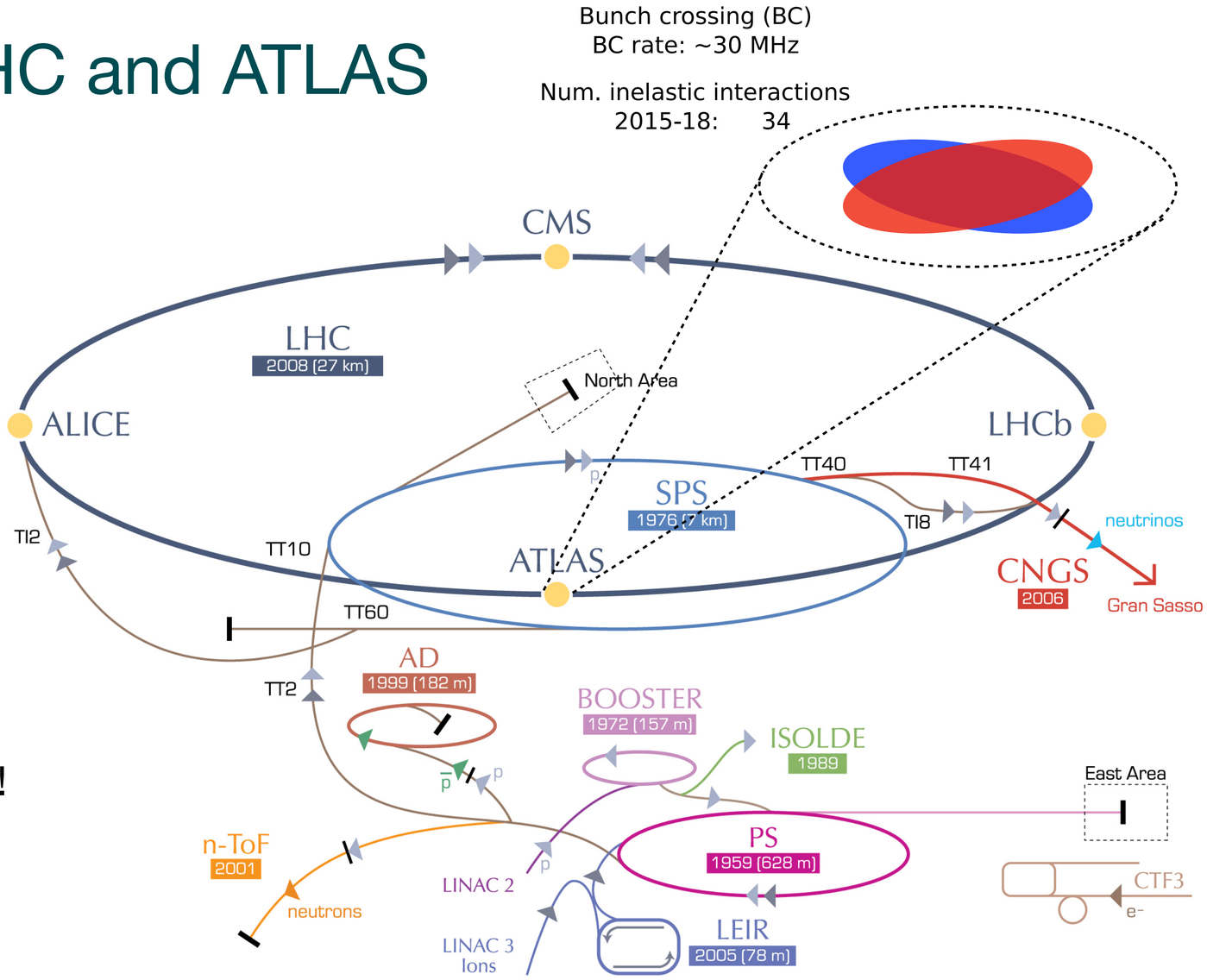
The LHC and ATLAS

- The Large Hadron Collider: unprecedented **energy** and **luminosity**
  - Up to 30 million pp collisions per second
  - Bunches of 10^{11} protons, with ~34 interactions per crossing



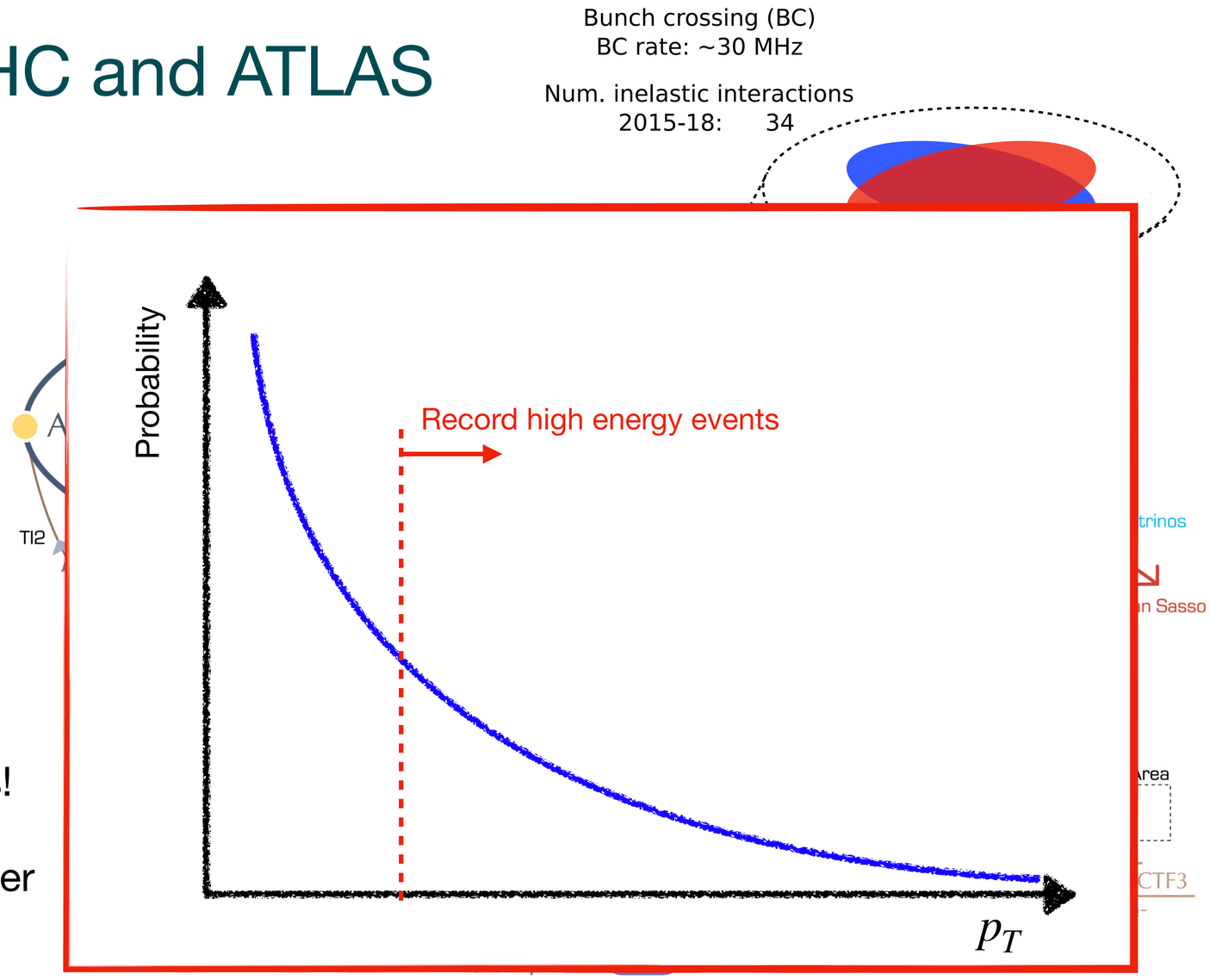
The LHC and ATLAS

- The Large Hadron Collider: unprecedented **energy** and **luminosity**
  - Up to 30 million pp collisions per second
  - Bunches of 10^{11} protons, with ~34 interactions per crossing
- Wide range of studies in ATLAS
  - General approach: record entire detector readout for offline reconstruction
  - Average size per collision: 1 MB → 30 TB/s!



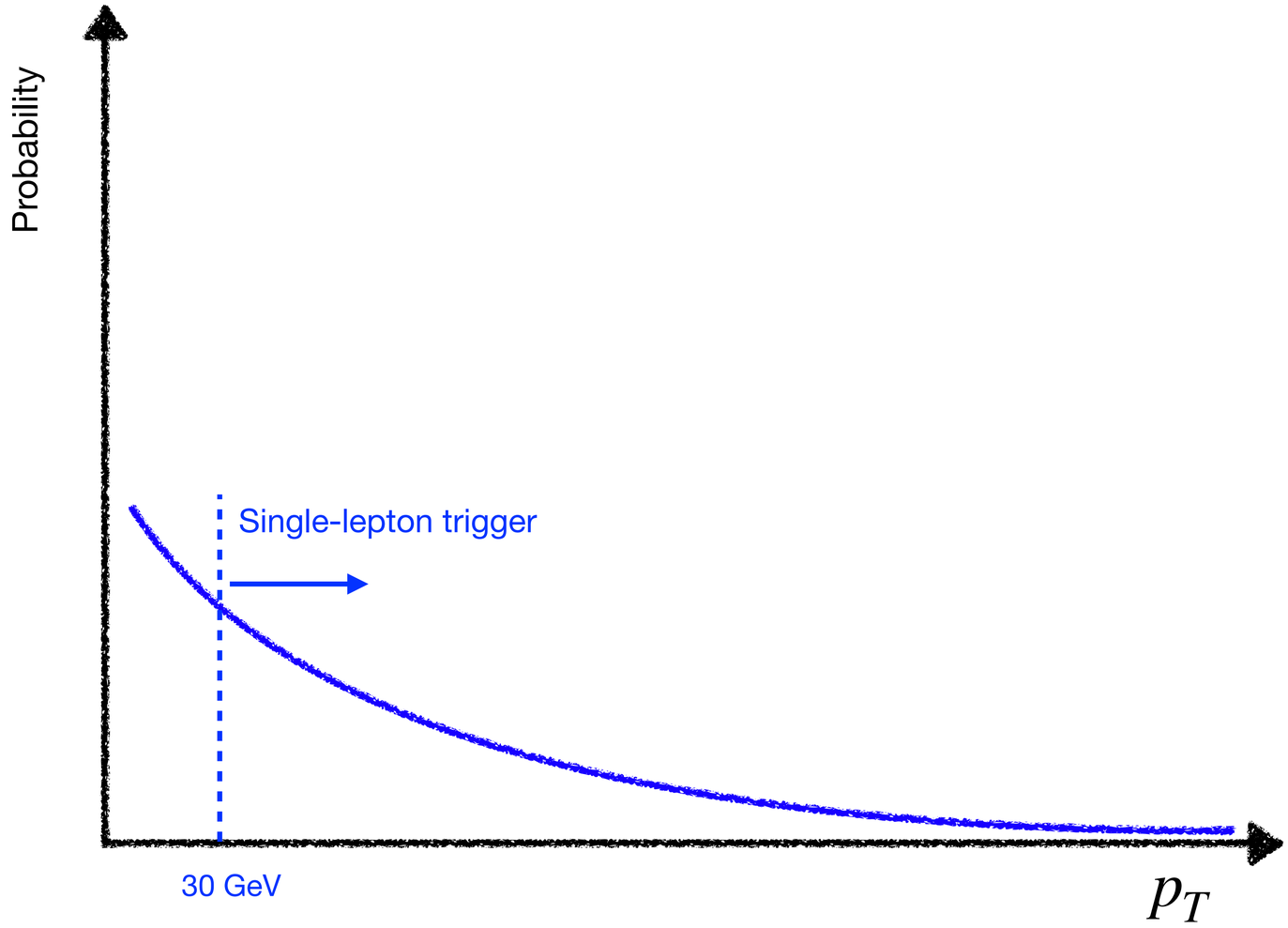
The LHC and ATLAS

- The Large Hadron Collider: unprecedented **energy** and **luminosity**
  - Up to 30 million pp collisions per second
  - Bunches of 10^{11} protons, with ~34 interactions per crossing
- Wide range of studies in ATLAS
  - General approach: record entire detector readout for offline reconstruction
  - Average size per collision: 1 MB → 30 TB/s!
- Filter out *uninteresting* collisions: ATLAS Trigger
  - Add a kinematic selection to record events



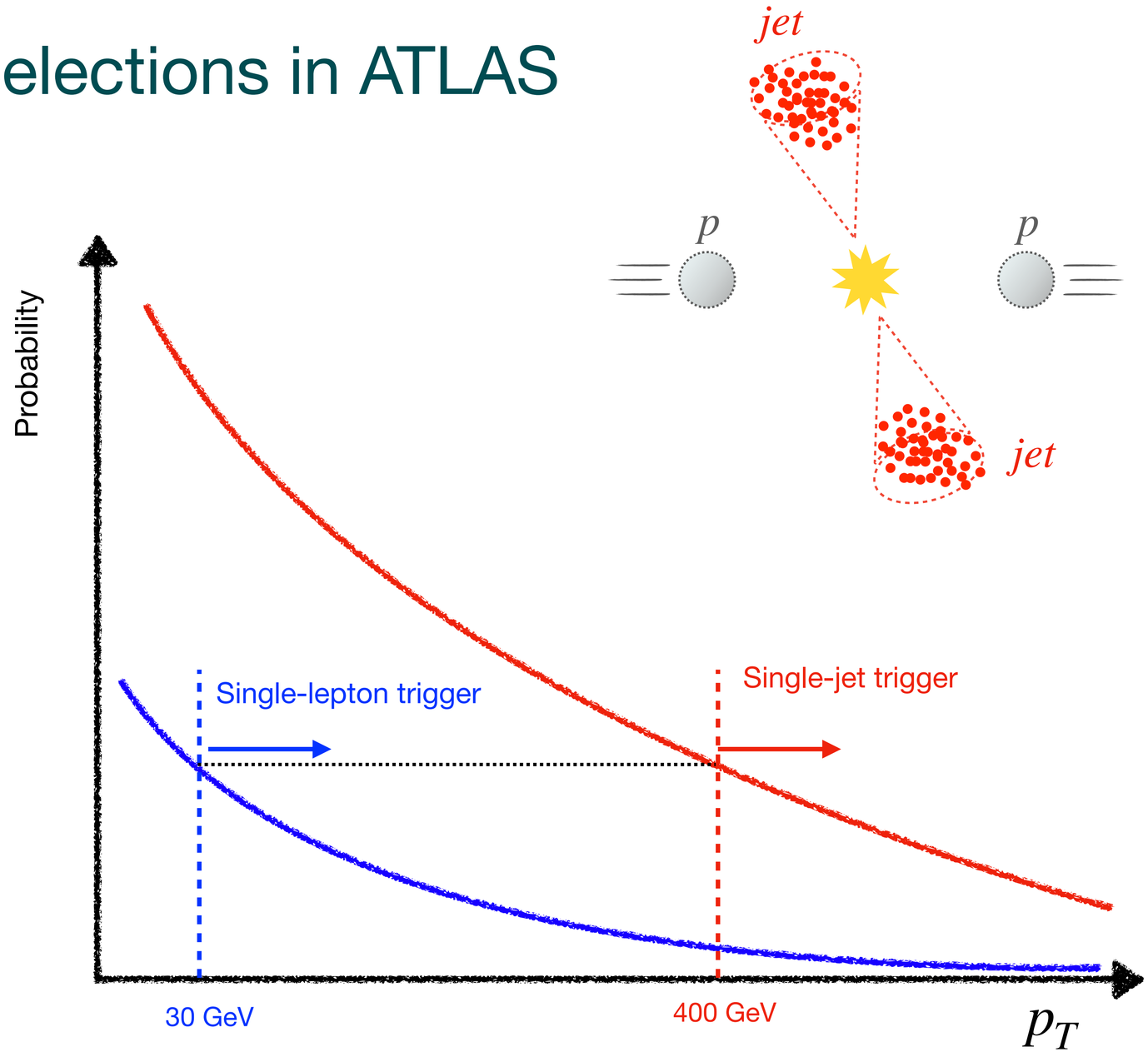
The trigger selections in ATLAS

- The selections applied at the trigger depend on the process targeted
  - **Electroweak processes** are rare
    - Single lepton threshold ~30 GeV



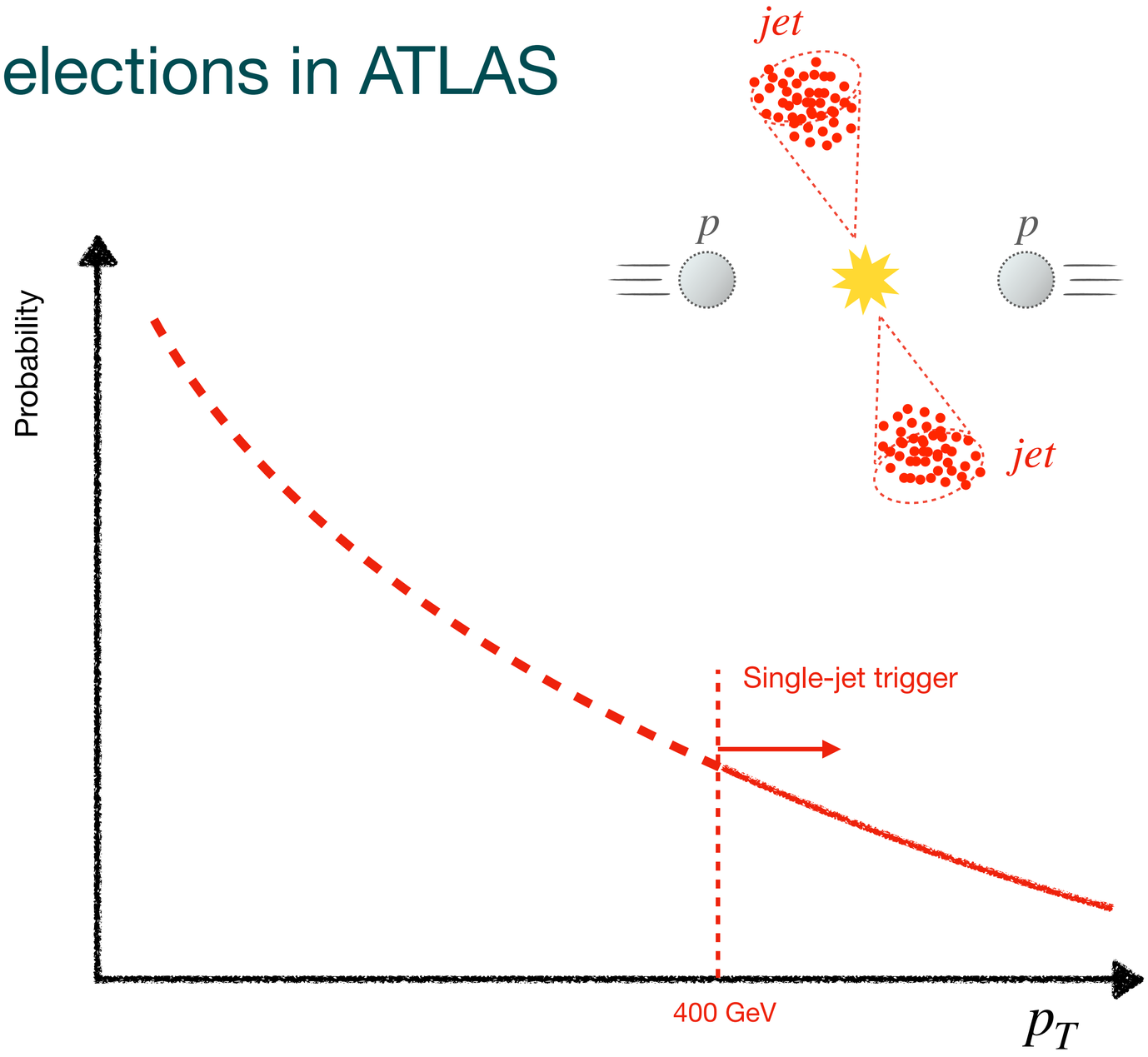
The trigger selections in ATLAS

- The selections applied at the trigger depend on the process targeted
  - **Electroweak processes** are rare
    - Single lepton threshold ~30 GeV
  - **Hadronic processes** are very common
    - Typical signature: jets
      - Collimated sprays of hadrons from quarks and gluons
    - Single jet threshold ~400 GeV



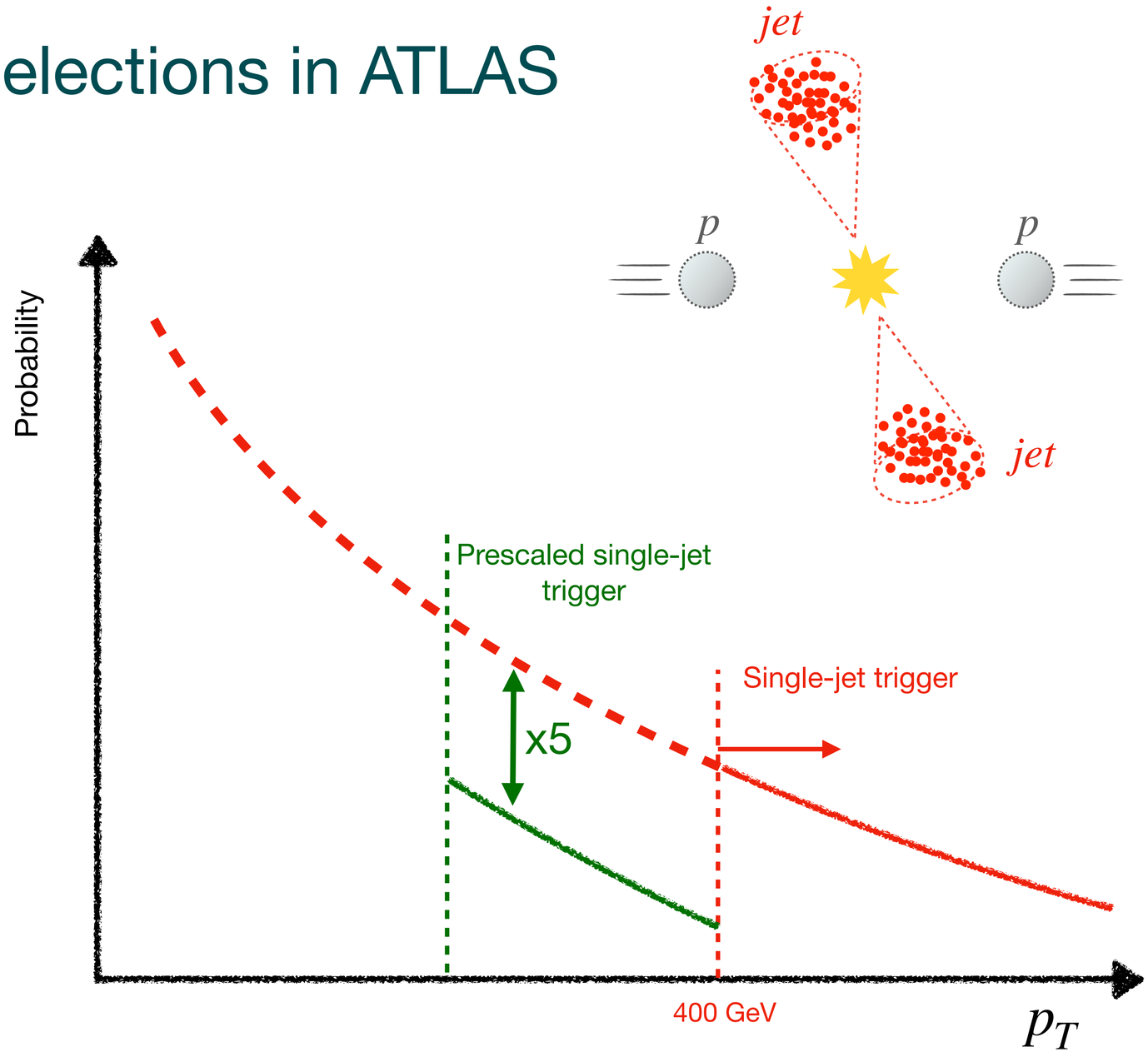
The trigger selections in ATLAS

- The selections applied at the trigger depend on the process targeted
  - **Electroweak processes** are rare
    - Single lepton threshold ~30 GeV
  - **Hadronic processes** are very common
    - Typical signature: jets
      - Collimated sprays of hadrons from quarks and gluons
    - Single jet threshold ~400 GeV
- One possibility: prescaling
  - Record only a fraction of the data with looser selection



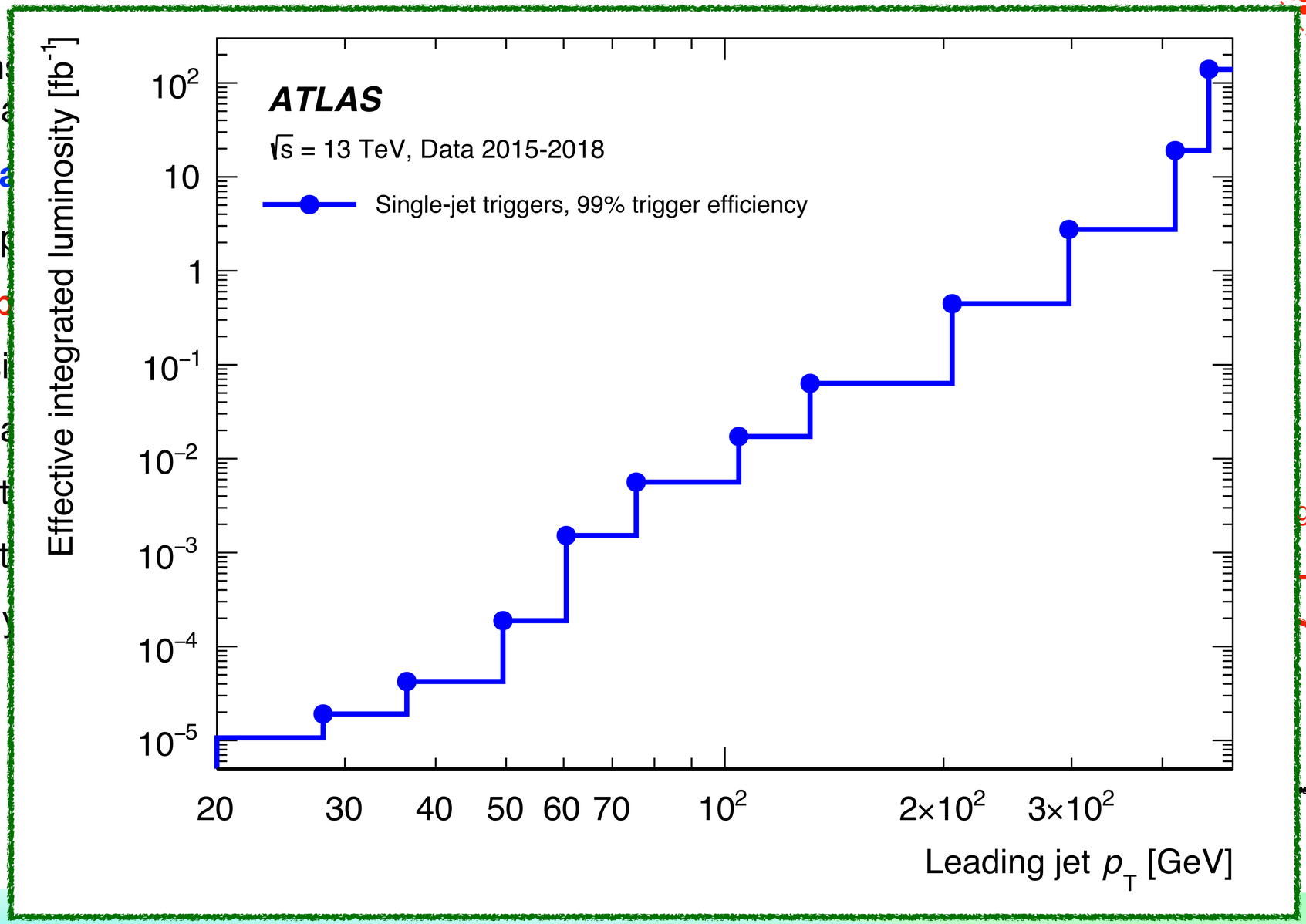
The trigger selections in ATLAS

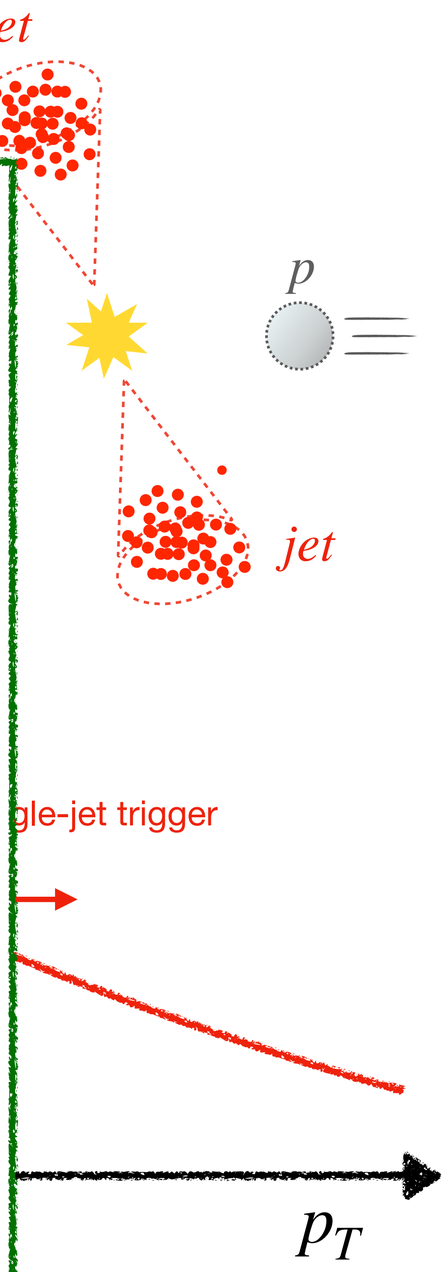
- The selections applied at the trigger depend on the process targeted
  - **Electroweak processes** are rare
    - Single lepton threshold ~30 GeV
  - **Hadronic processes** are very common
    - Typical signature: jets
      - Collimated sprays of hadrons from quarks and gluons
    - Single jet threshold ~400 GeV
- One possibility: prescaling
  - Record only a fraction of the data with looser selection



The trigger selections in ATLAS

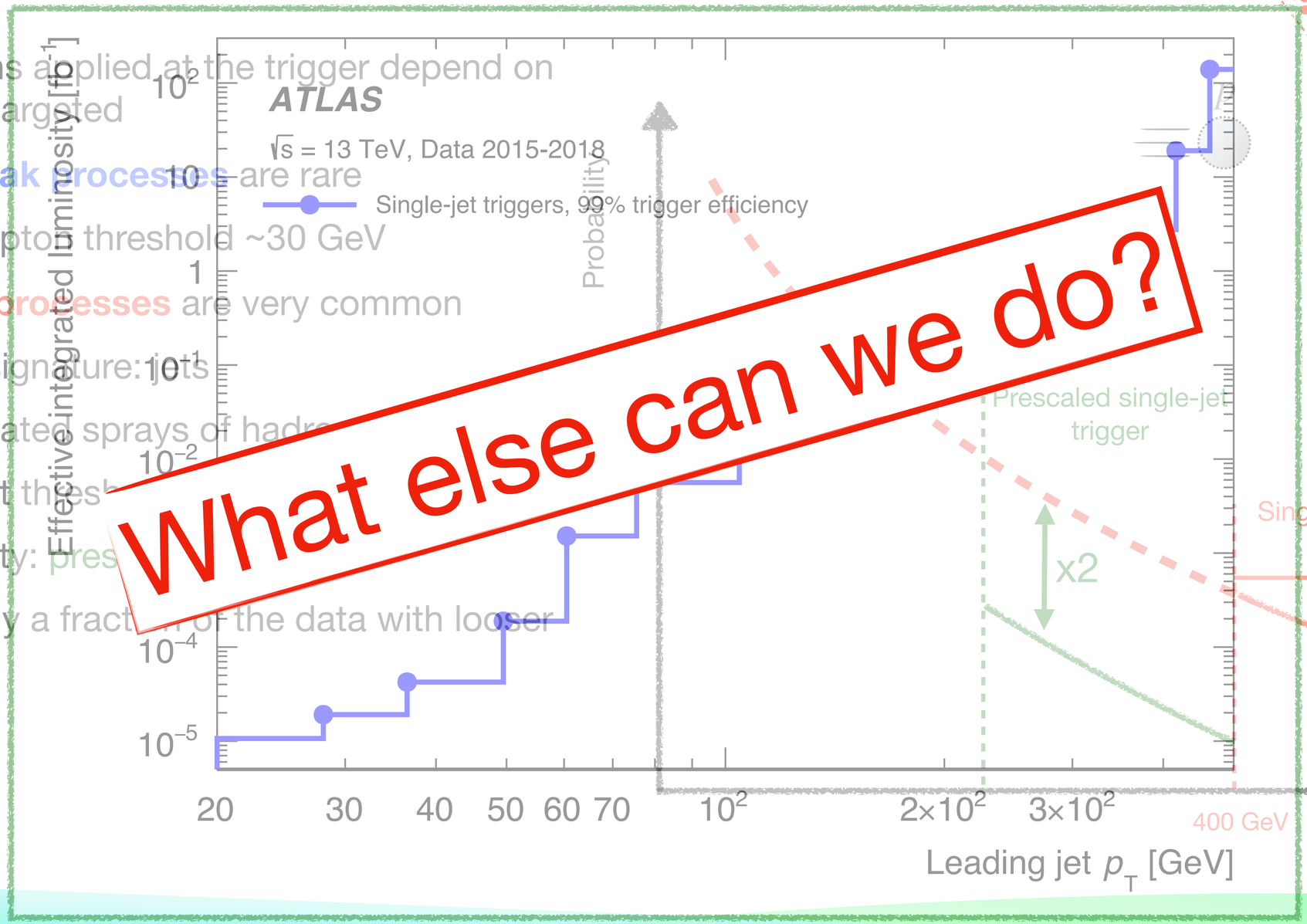
- The selections
  the process ta
  - **Electrowea**
    - Single lep
  - **Hadronic p**
    - Typical si
      - Collima
    - Single jet
- One possibilit
  - Record only
    selection

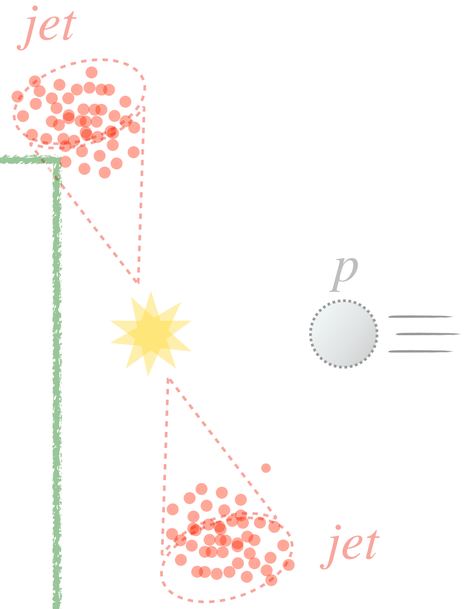




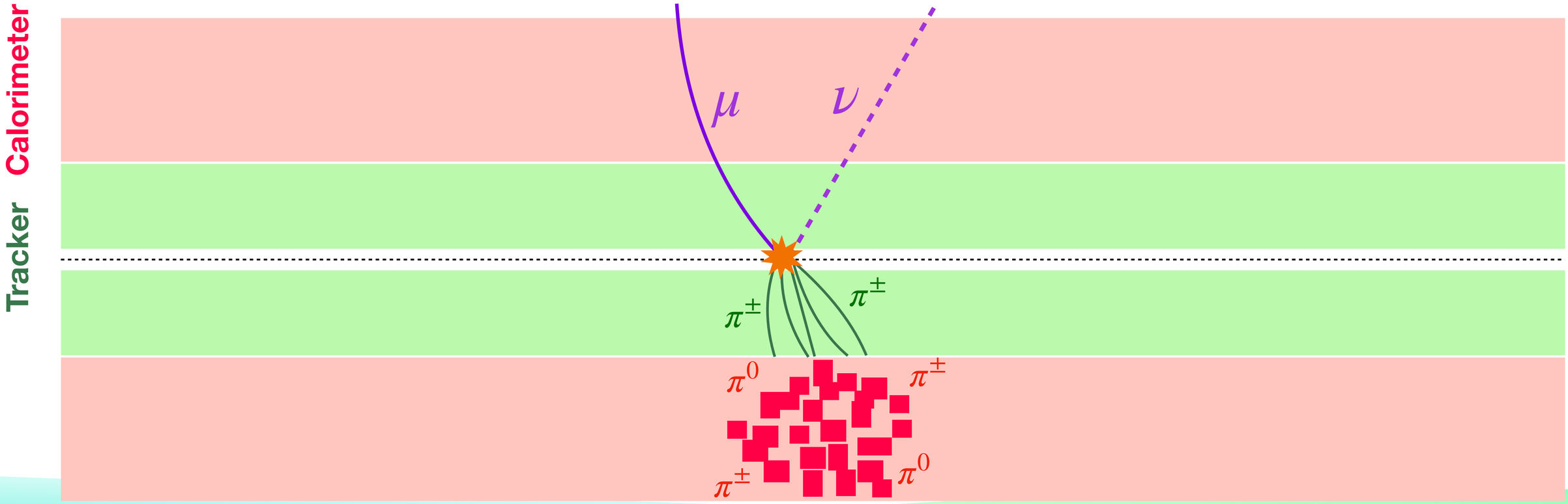
The trigger selections in ATLAS

- The selections applied at the trigger depend on the process targeted
  - **Electroweak processes** are rare
    - Single leptons threshold ~30 GeV
  - **Hadronic processes** are very common
    - Typical signature: jets
      - Collimated sprays of hadrons
    - Single jet thresholds
- One possibility: prescale jets
  - Record only a fraction of the data with looser selection



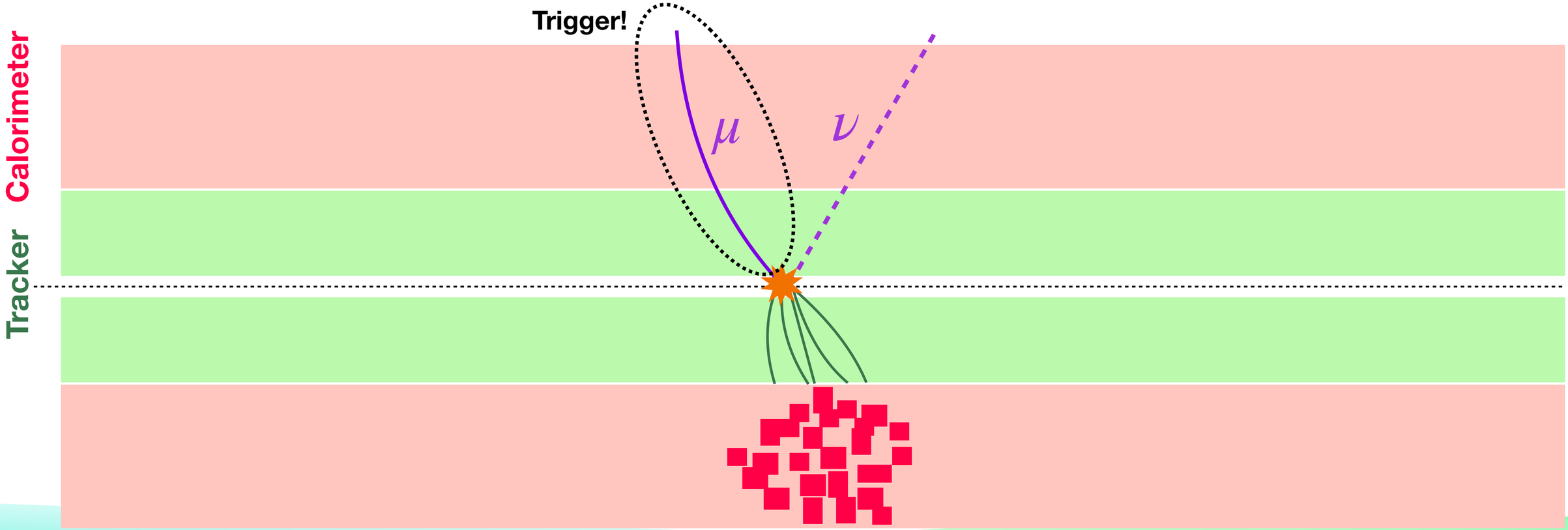


Back to basics: *pp* collisions in ATLAS



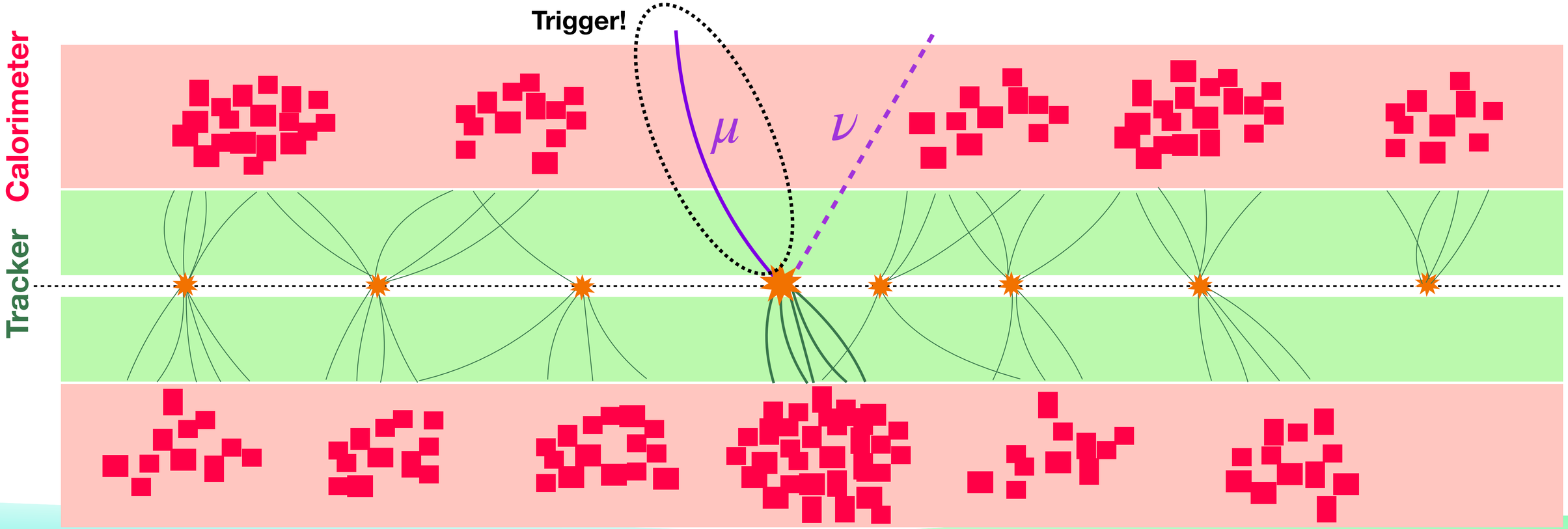
Back to basics: *pp* collisions in ATLAS

- Interesting collision! → Record *full* detector readout



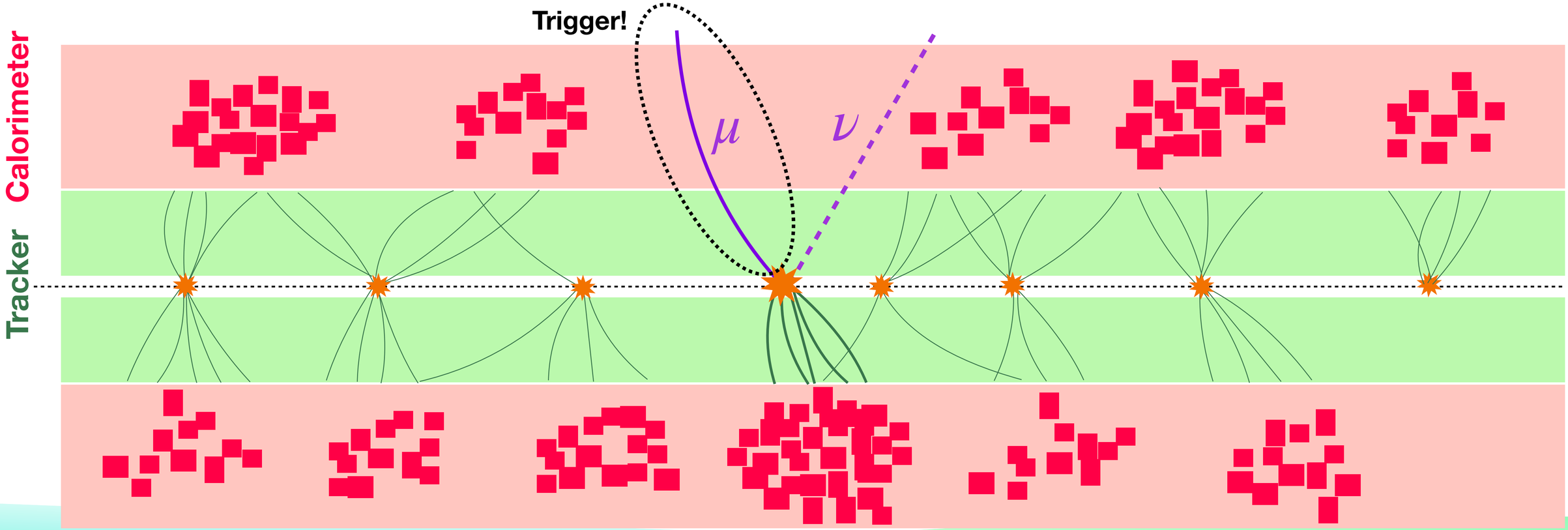
Back to basics: *pp* collisions in ATLAS

- Interesting collision! → Record *full* detector readout
- Real <u>recorded</u> collisions are more complex
  - Pile-up interactions fill the detector with low-energy hadronic activity…



Back to basics: *pp* collisions in ATLAS

- Interesting collision! → Record *full* detector readout
- Real <u>recorded</u> collisions are more complex
  - Pile-up interactions fill the detector with low-energy hadronic activity…
  - Pile-up interactions fill the detector with low-energy hadronic activity!

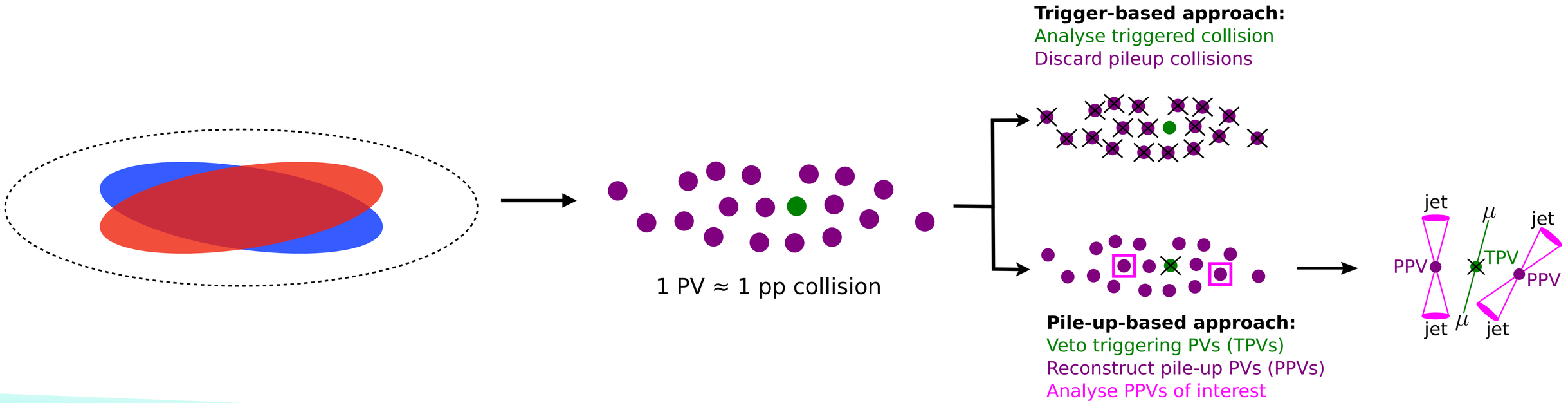


arXiv:2407.10819

Using pile-up collisions for physics

- In each Bunch Crossing (BC) there are multiple *independent* hard scatterings
- Once the data is recorded, we reconstruct each *pp* interaction in a BC as Primary Vertices (PVs)
  - Standard ATLAS approach: find the PV that fires the trigger, suppress everything else
  - Alternative approach: find the PV that fires the trigger, remove it and use everything else for physics
- All interactions in a given BC are uncorrelated: pile-up interactions are not biased by the trigger selection

  ➡ Access to low-momentum jets for physics studies! See A. Pirttikoski's talk for more!



arXiv:2407.10819

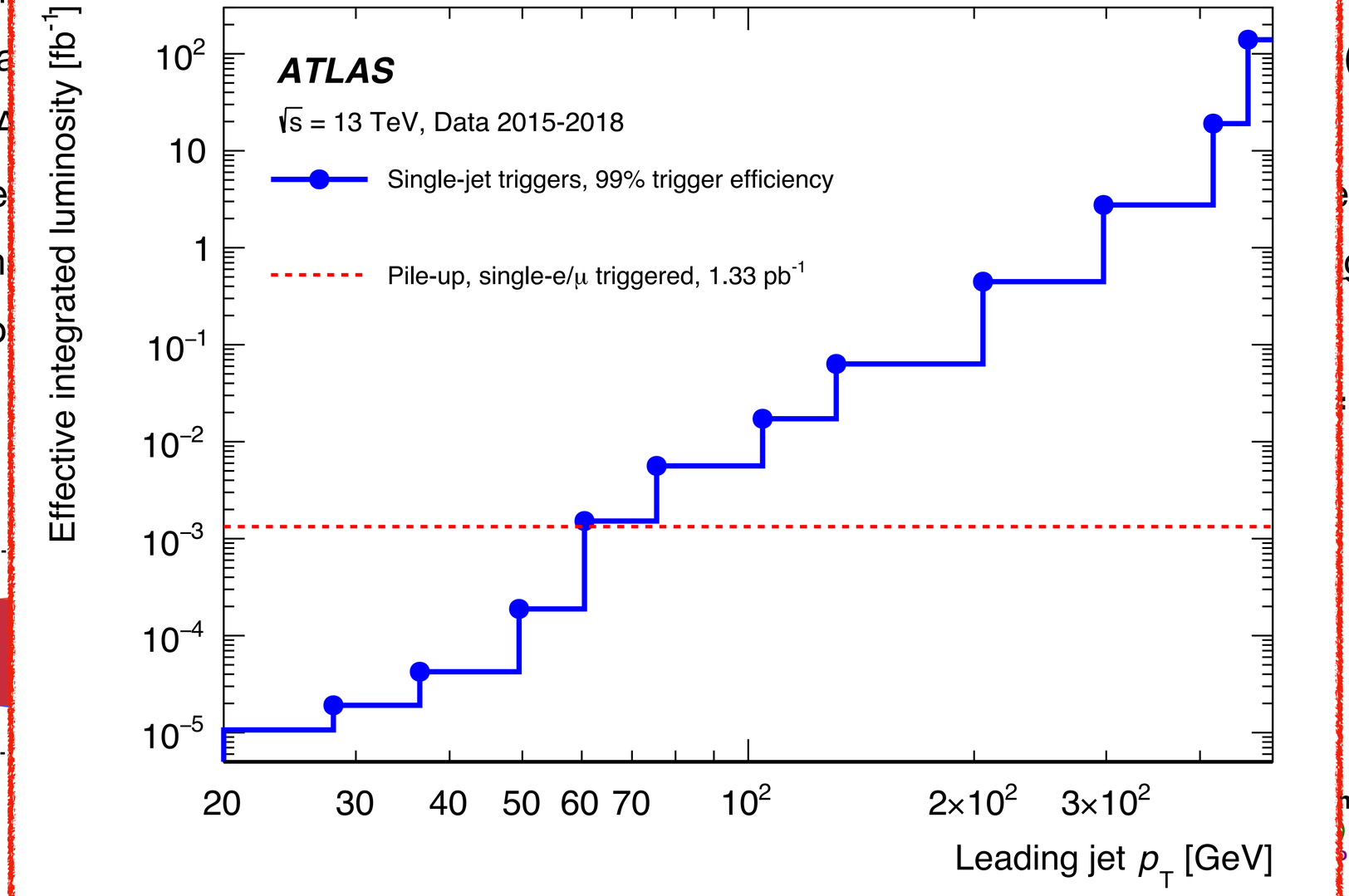
Using pile-up collisions for physics

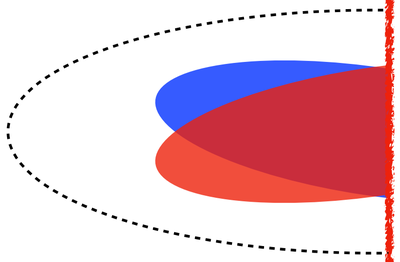
- In each Bunch
- Once the data
  - Standard A
  - Alternative
- All interaction
  - ➡ Access to

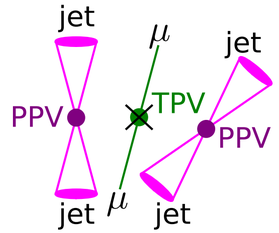
(PVs)

for physics

gger selection



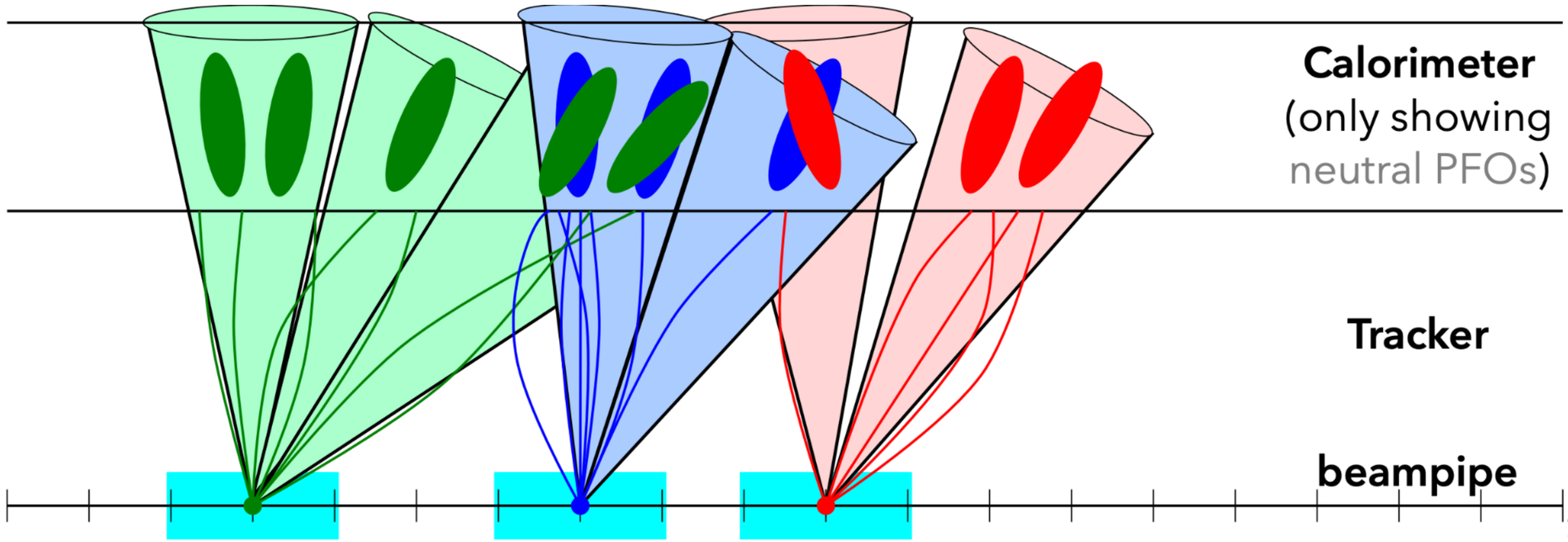




arXiv:2407.10819

By-vertex jet reconstruction

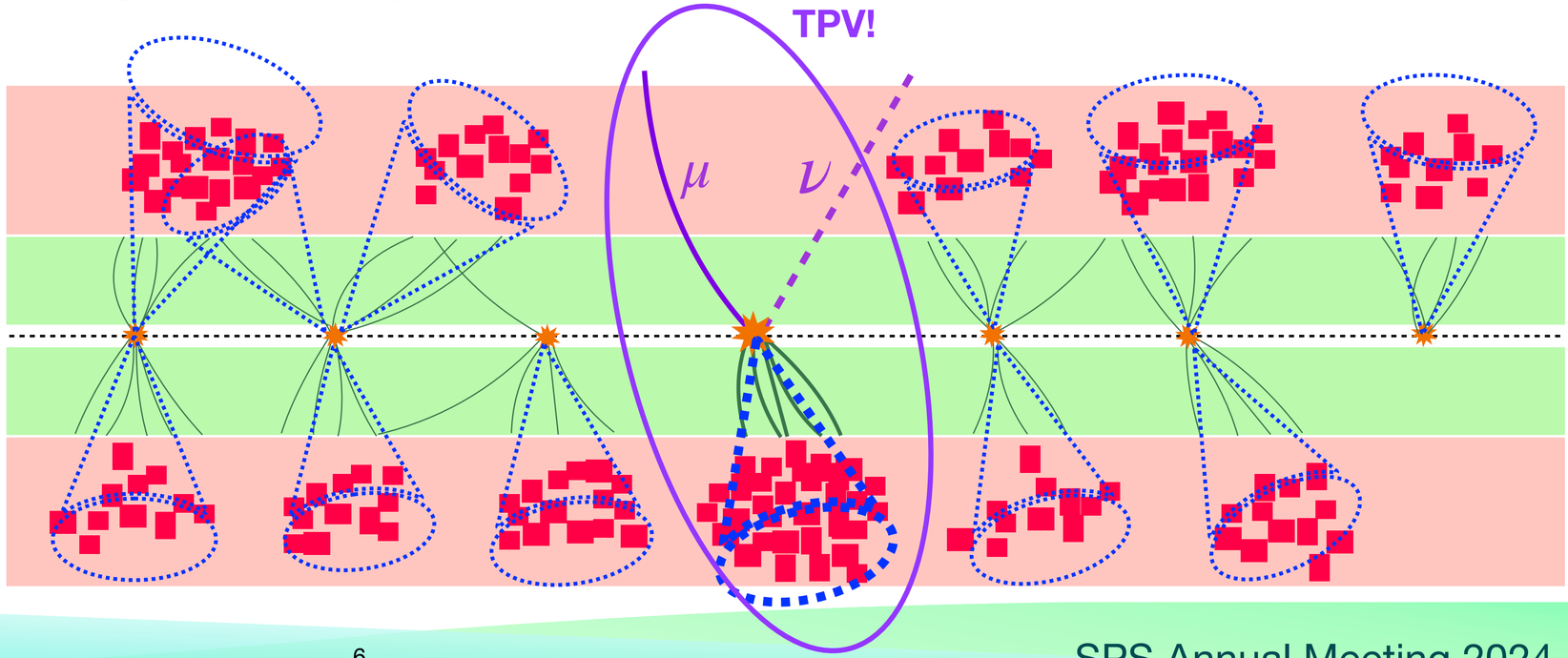
- Problem: reconstruct jets originating from different collisions
- Solution: vertex-aware (Particle Flow) jet reconstruction algorithm
  - For each PV, reconstruct jets with the associated charged activity + all neutral contributions
  - Needs careful treatment of “origin-less” neutral component — See M. Cardoso’s talk



arXiv:2407.10819

Finding the triggering process

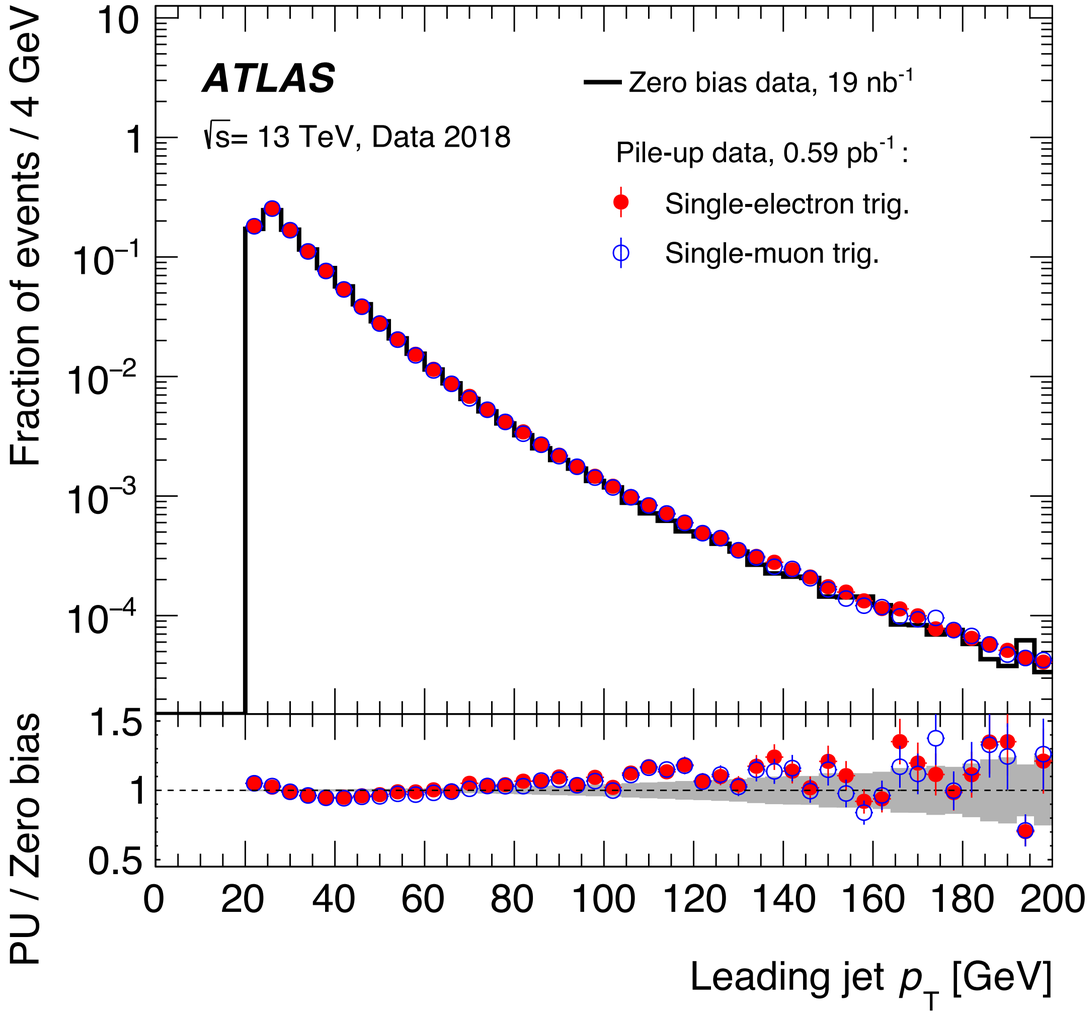
- Next step: identify and remove the **Triggering Primary Vertex (TPV)** and all objects associated to it
- TPV identification depends on the signature triggered on
  - We have to be able to find a single responsible physics object for firing the trigger
  - It must be possible to match the triggering object to a PV — charged objects
- Example of bad signature: total energy deposited in the calorimeter
- Perfect signature: single-electron and single-muon triggers!



arXiv:2407.10819

Are pile-up collisions really independent?

- TPV and pile-up PVs should be independent
  - TPV-removal process is essential for trigger-unbiased data!
- **Dataset validation:** compare the pile-up data to *zero bias* data
  - Study single-electron and single-muon triggered-data independently
  - Good agreement with reference
  - Excellent agreement between them
- **Within stat uncertainties, the pile-up data is trigger unbiased!**
  - Access jet p_T down to 20 GeV (vs 400 GeV trigger threshold!)

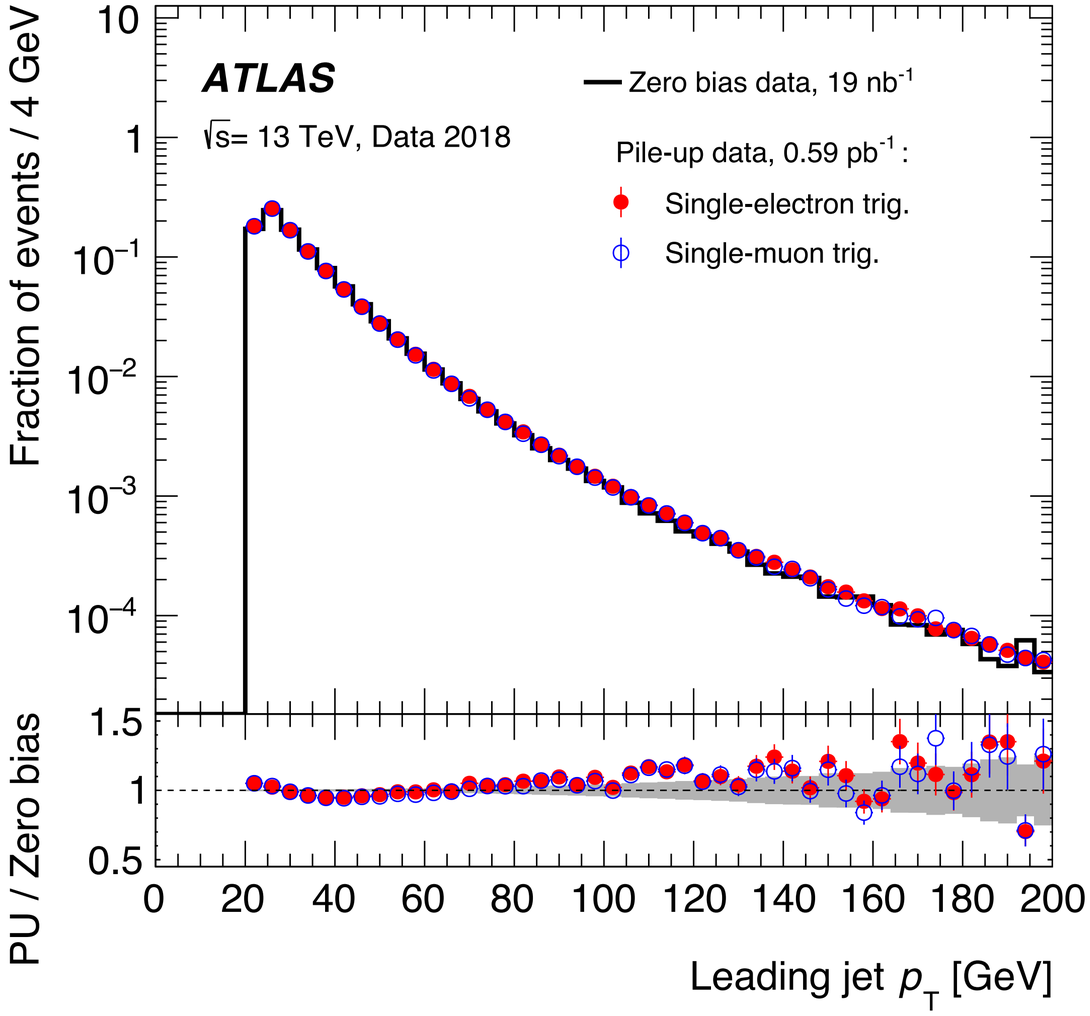


arXiv:2407.10819

Are pile-up collisions really independent?

- TPV and pile-up PVs should be independent
  - TPV-removal process is essential for trigger-unbiased data!
- **Dataset validation:** compare the pile-up data to *zero bias* data
  - Study single-electron and single-muon triggered-data independently
  - Good agreement with reference
  - Excellent agreement between them
- **Within stat uncertainties, the pile-up data is trigger unbiased**
  - Access jet p_T down to 20 GeV (vs 400 GeV trigger threshold!)

So… what now?



Summary and outlook

- Developed a novel approach to access low-energy hadronic data beyond trigger-imposed limitations
- Two key ingredients to build the pile-up dataset
  - Improved standard ATLAS jet reconstruction to be vertex-dependent
  - Finding and removing the process responsible for firing the trigger
- This was an introductory talk to discuss the technique, more on the
  - Challenges arising from the pileup dataset creation/usage: talk by M. Cardoso
  - Physics applications of the pile-up data: talk by A. Pirttikoski

Thanks for your attention!