ACTS for the Beam Gas Vertex (BGV) Monitor for Hilumi LHC

B. Kolbinger on behalf of the BGV team (CERN Beam Instrumentation Group)

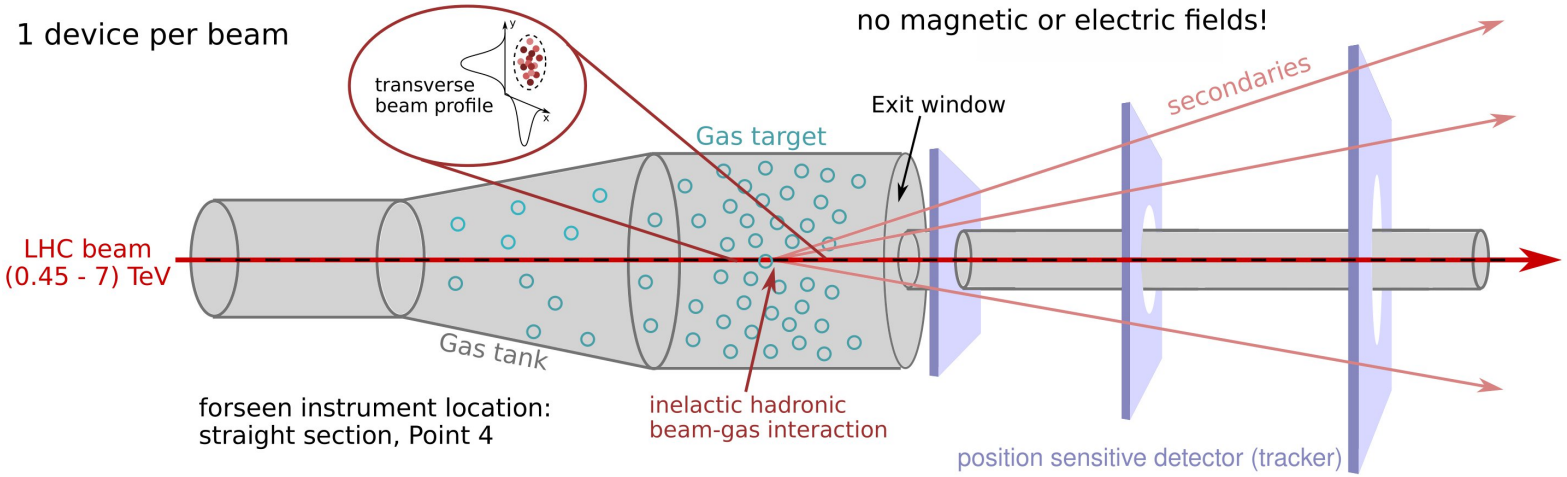
Acknowledgements:
BGV team: H. Guerin, J. Storey
With input from: **X. Ai**, **C. Allaire**, G. Bregliozzi, D. Hynds, R. Kersevan, R. De Maria, J. Oliveira, R. Plackett, D. Prelipcean, T. Ramos Garcia, B. Salvant, **B. Schlag**, G. Schneider, T. Lefevre, B. Salvant, **A. Salzburger**, H. Sandberg, R. Veness

Outline

- Introduction
- Simulations - Performance study & optimisation
  - ACTS for the BGV
  - Results of performance study with a generic BGV setup
- New BGV design
- Summary & conclusions

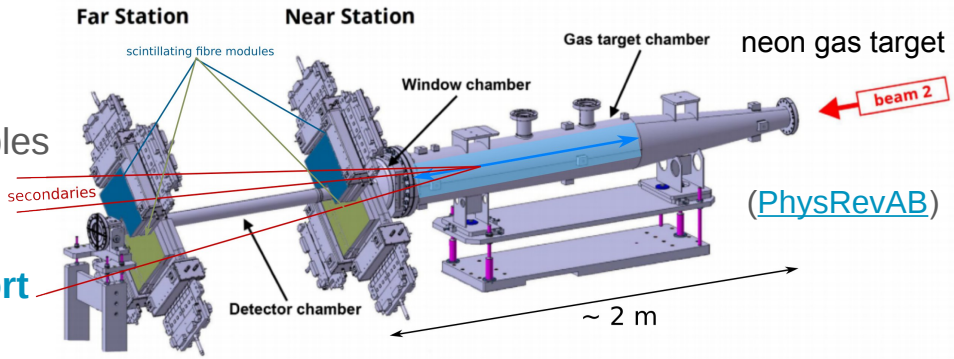
Introduction - principle

- **Noninvasive transverse beam profile monitor** based on the reconstruction of vertices of inelastic hadronic beam-gas interactions - **BGV (Beam Gas Vertex)** monitor.
- Part of Hilumi LHC upgrade.
- Provide **continuous emittance and transverse beam profile measurement** throughout the LHC accelerator cycle (450 GeV to 7 TeV).



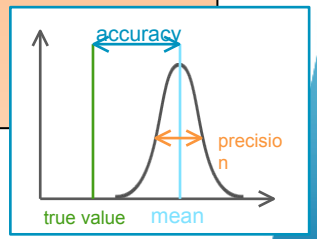
Status of the BGV

- **BGV demonstrator** device was installed, commissioned and operated during Run 2 - troubles reconstructing vertices, **no beam profile measurement possible**.
- Work on **new design - Conceptual design report** will be reviewed in **October 2022**.



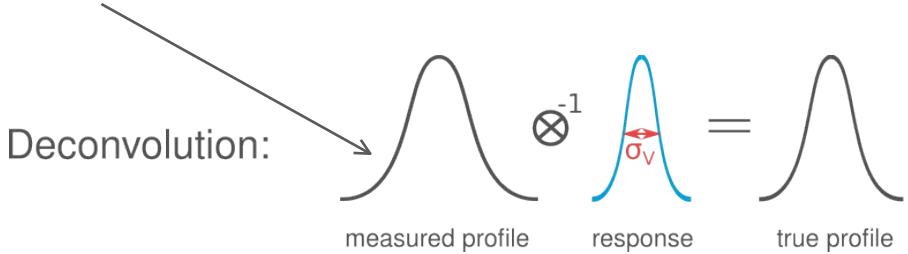
Requirements for the future HL-LHC transverse beam profile monitor:

- Emittance measurement with **accuracy** $\leq$ **10 %** (beam size $\leq$ 5%).
- Measurements of **beam size of individual bunches, with ~ 1 % precision after ~1 min** of accumulating data.
- Provide **transverse profile** measurements.



BGV performance - what's important?

- Method: deduce true beam profile from spatial distribution of reconstructed vertices.



the better we know the response function, the better we know the profile!

- Key performance measure = response function. Not easy to determine with high precision - keep its width (= vertex resolution σ_v) small!

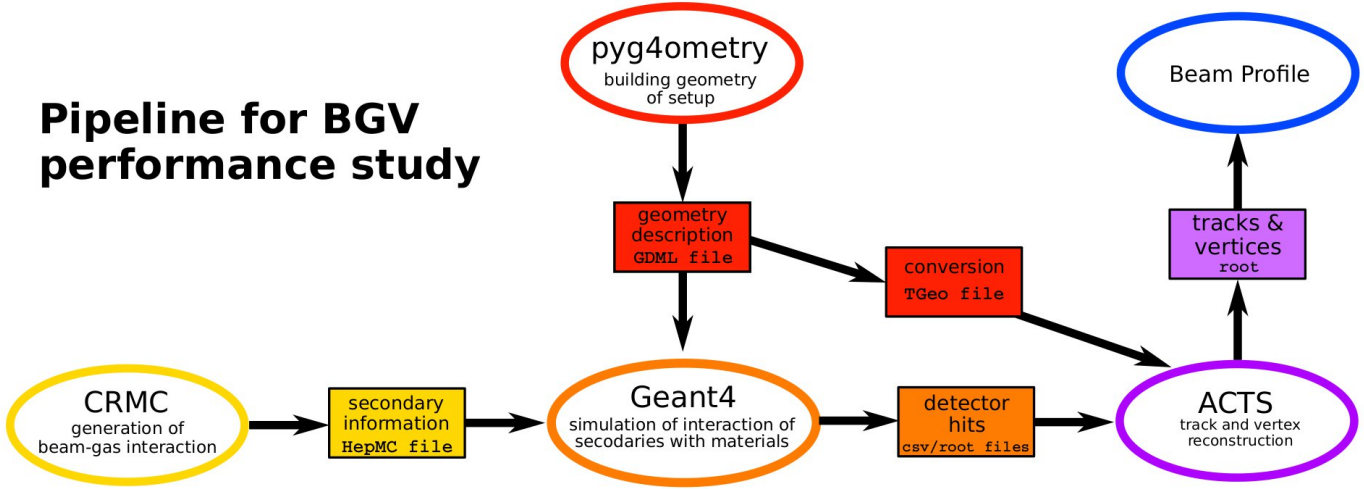
- **What σ_v do we need, to achieve a measurement of beam size with accuracy of $\leq$ 5 %?**
  - ➡ Depends on beam size and how well we know the vertex resolution!
  - **Minimum transverse beam size** at BGV locations is **235 µm (7 TeV)**. Assume knowledge of σ_v with 10 % accuracy ➡ **need $\sigma_v \leq$ 166 µm** (see calculation).

Performance study & optimisation for new BGV design

- Guide choices of detector and gas target technology.
- **What are the requirements for BGV gas target and tracker**, to:
  - fulfilling performance specifications,
  - within the boundary conditions of: feasibility of integrating it into the LHC?

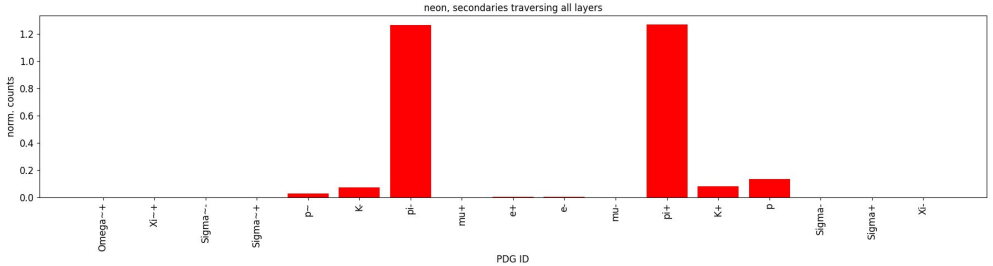
answer with simulation+reco study!

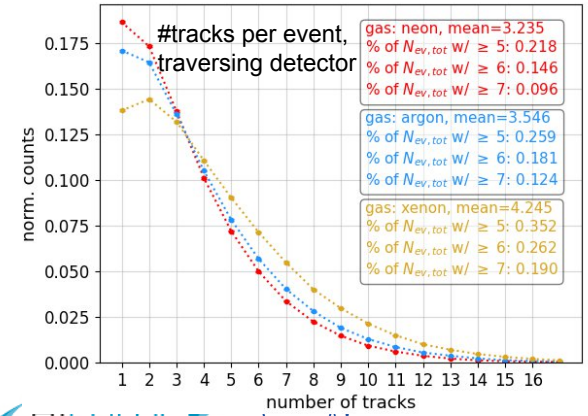
Pipeline for BGV performance study

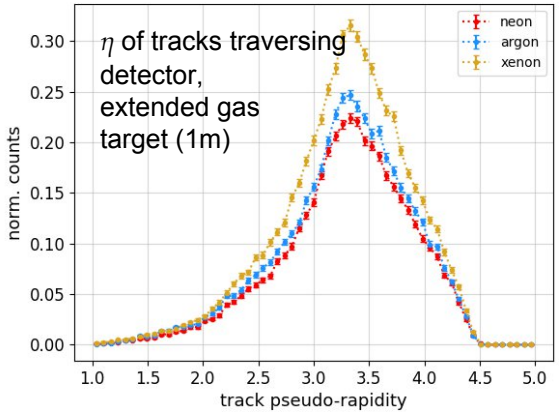


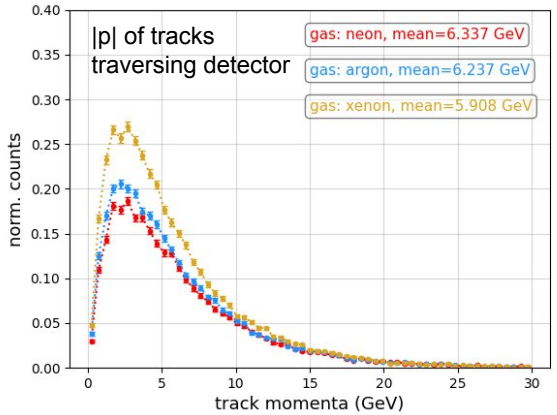
BGV - tracks, vertices & secondary properties

- Infer beam profile from **primary vertices of beam-gas interactions**.
  - Interaction rate is ~600 kHz (total, ~200 Hz per bunch).
  - Recording single collisions, pile-up very unlikely (one collision every 2 µs).
- Secondary species: mostly pions.
- No magnetic field - **straight tracks**.
- **Forward tracks** with relatively **low momentum**.





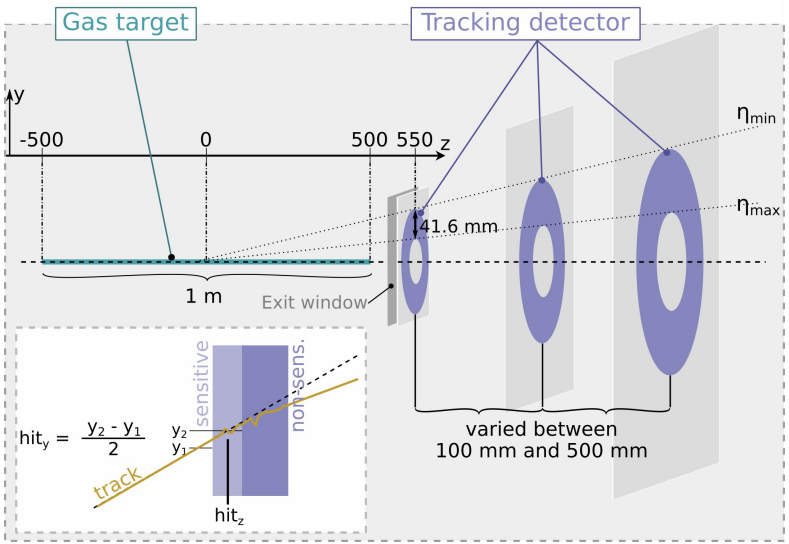




ACTS setup for the BGV

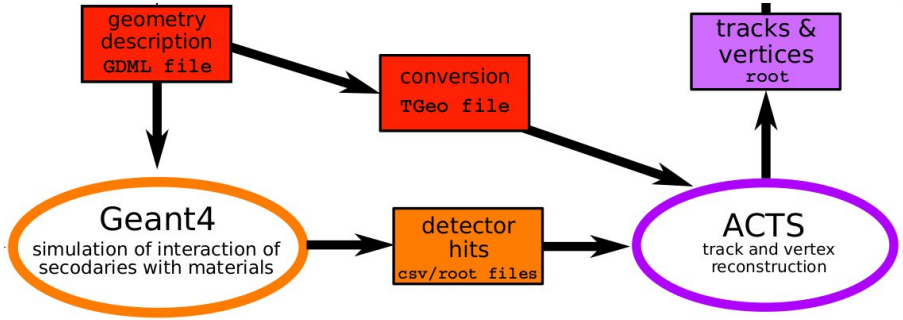
Initial ACTS setup:

- Using the framework of ACTS examples.
- Very basic geometry.
- Material mapping using **TGeo and GDML** files from Geant4.
- Read-in **event data from BGV Geant4** simulations via the **csv reader** (hits and initial particles).
- **Gaussian hit smearing**.
- Reconstruction **based on ACTS truth tracking examples**
- **with Kalman track fitting & Billoir vertex fitting.**
- Momentum input - **truth momentum**.



Add more details & realism step-by-step:

- ✓ Initial parameters for track fit:
  - ✓ First and last detector hit of tracks.
- ✓ Implement geometry specific technology/design (on-going).
- ▢ Momentum estimation for initial conditions and Kalman fitter (on-going).
- ▢ Digitisation, clustering, track finding, alignment...



Performance study - overview

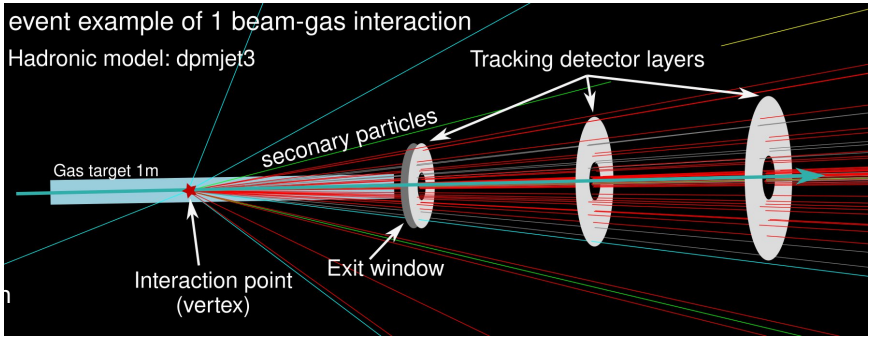
- **Initially: generic BGV**.
- **Goal**: efficiently identify impact of design parameters and provide **first estimates of promising setup's dimensions etc.**

Test important **design parameters and their impact on performance**:

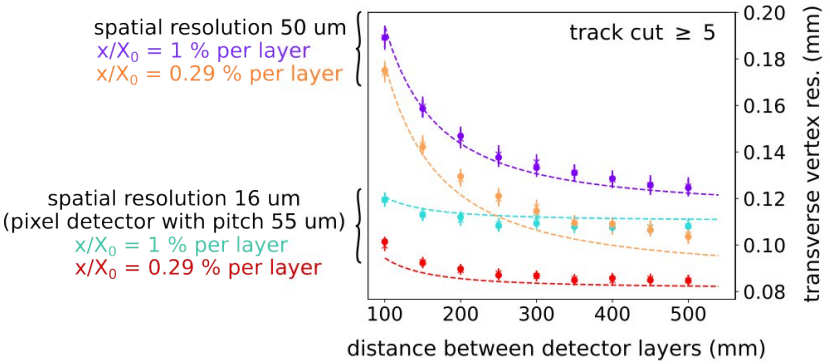
- Detector dimensions, material budget, position resolution etc.
- Gas target extension, pressure, gas species etc.

Conclusions

- Results point towards possibility of **compact tracker with a high spatial resolution.**
- **Extended gas target** not a show stopper - **~1 m neon, with ~10^{-7} mbar**.



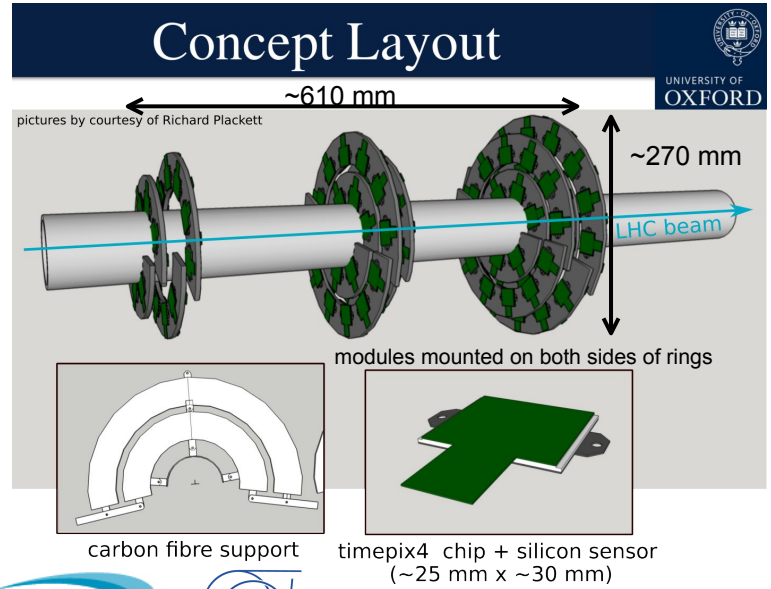
vertex resolution vs distance between detector layers:

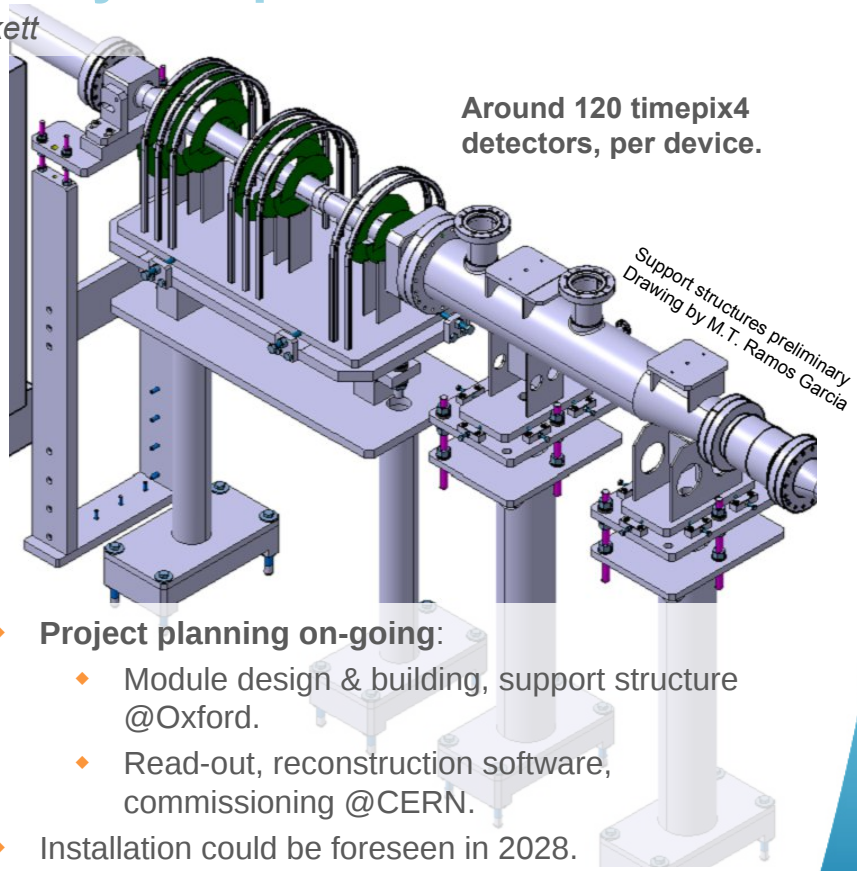


A BGV tracker based on silicon hybrid pixel detectors

Collaboration with Oxford University: D. Hynds and R. Plackett

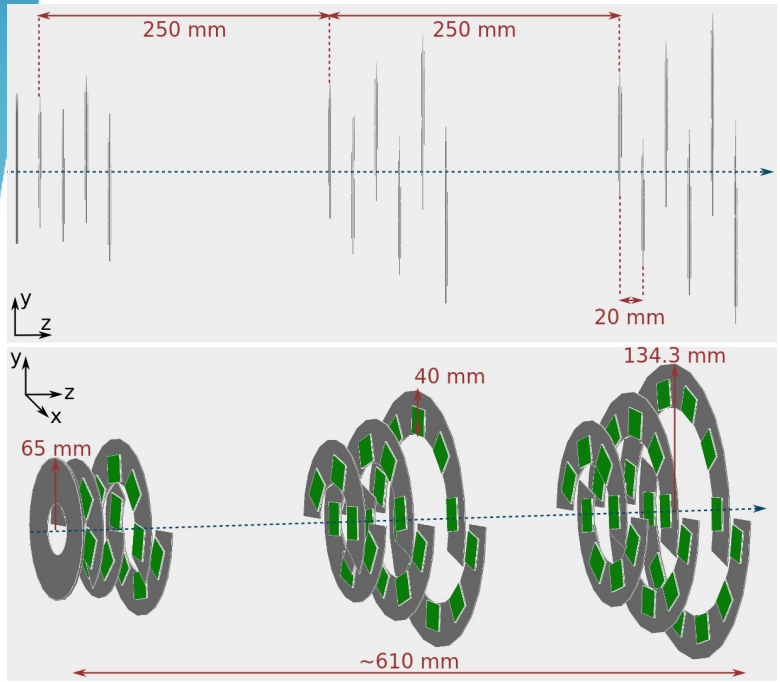
- Design based on the **ATLAS ITk HiLumi upgrade**.
- **Timepix technology**: well known, robust and widely used detectors. **XP within Beam Instrumentation** group.



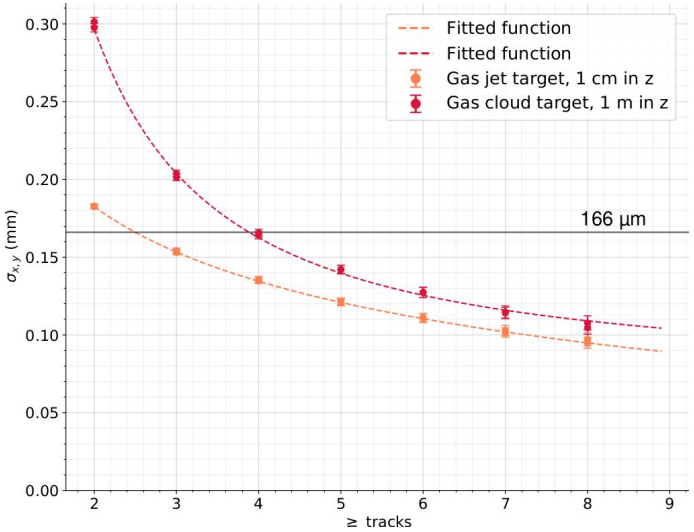


- **Project planning on-going**:
  - Module design & building, support structure @Oxford.
  - Read-out, reconstruction software, commissioning @CERN.
- Installation could be foreseen in 2028.

Vertex resolution results with new geometry

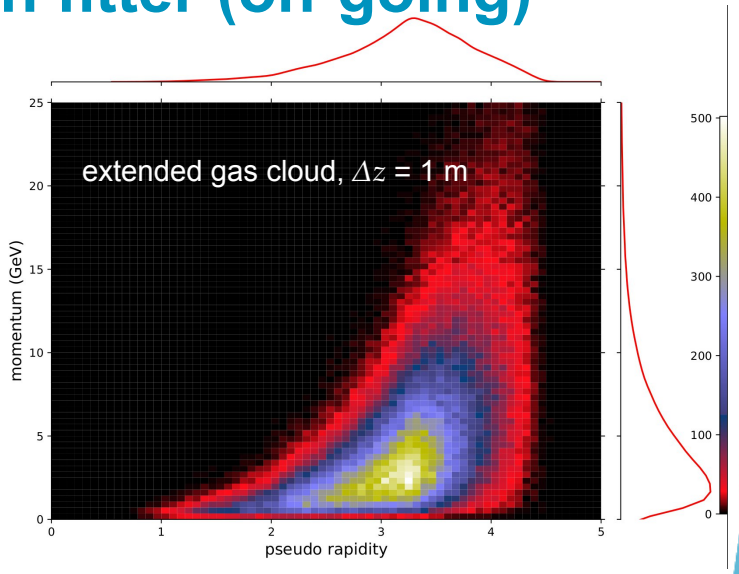


- **Simulation geometry update**: dimensions from generic BGV study & based on conceptual design.
- **Two types of gas targets - extension in z**:
  - 1 cm (gas jet-like target) and 1 m.
  - Constraint for vertex fit for Δz = 1 cm case.
- **Using truth momentum**.

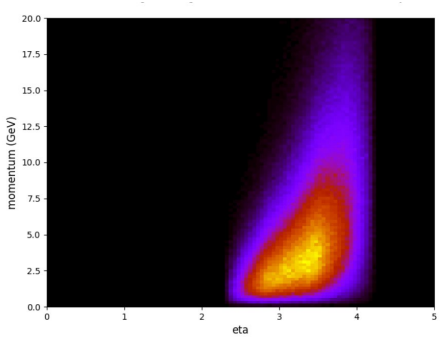


Momentum estimation for Kalman fitter (on-going)

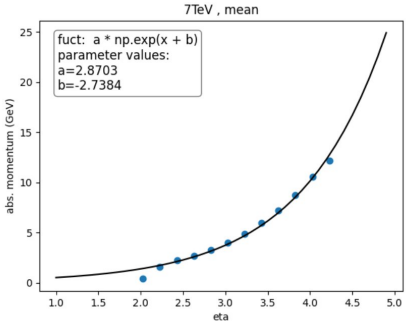
- **Straight tracks** - rely on estimation from simulations.
  - Constant momentum (average from simulations ~6 GeV),
  - Or exploit: correlation of p and pseudo-rapidity.
- How:
  - For testing: @PointwiseMaterialInteractor, add momentum estimation instead of truth momentum.



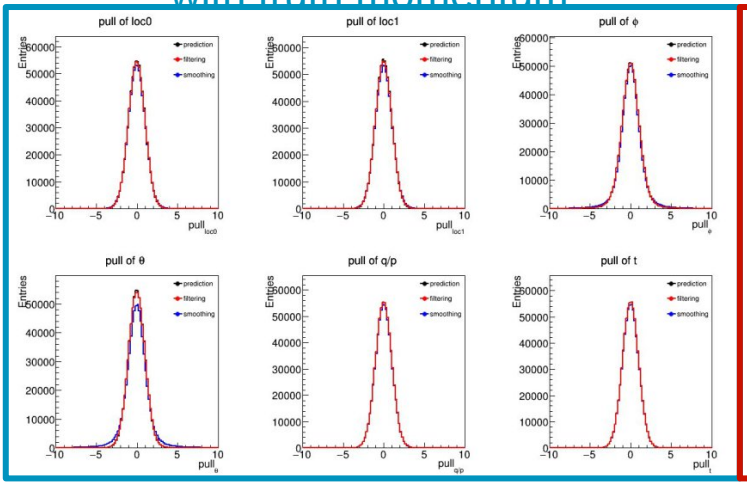
first tests with point source.



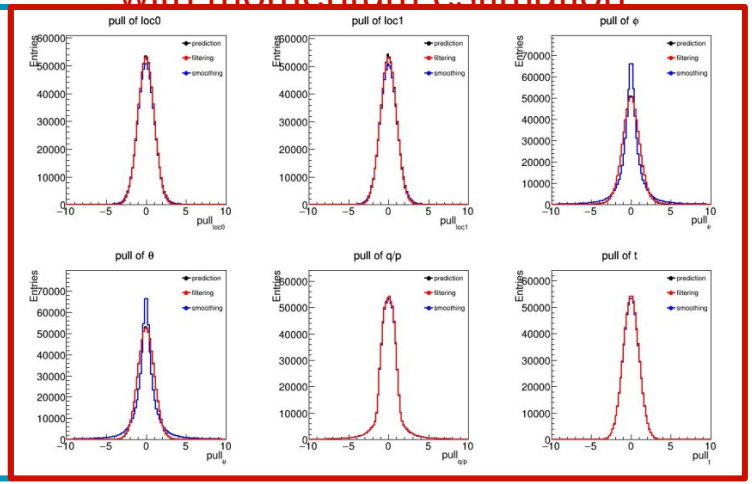
average p. in eta intervals.



with truth momentum

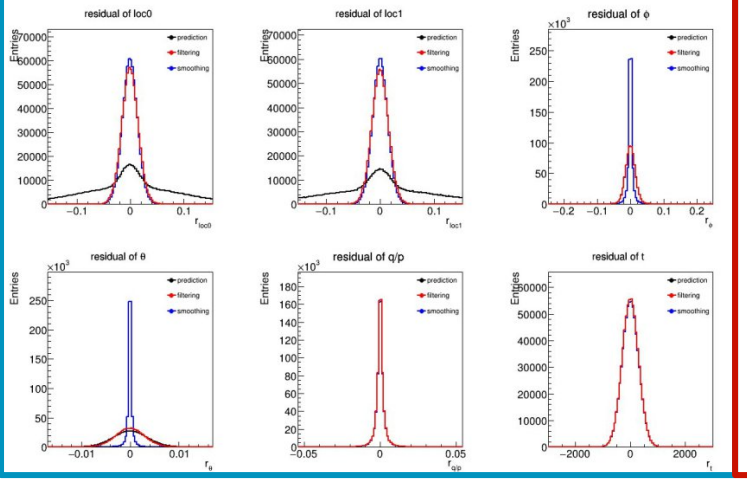


with momentum estimation

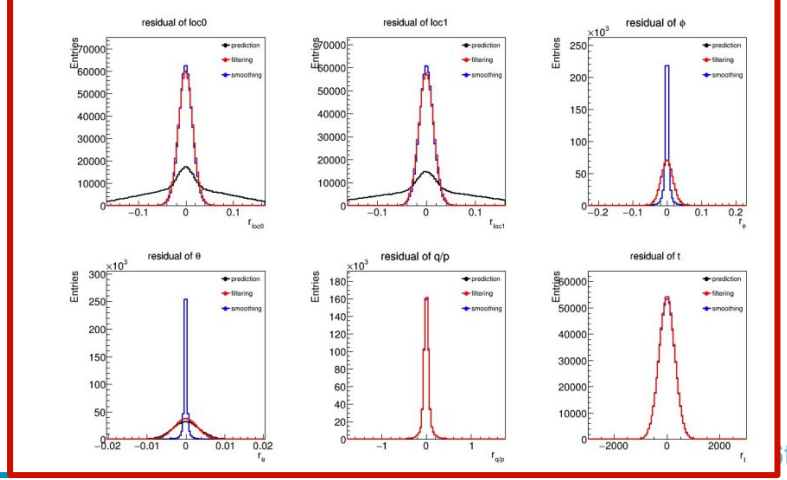


pull distributions at first measuring plane.

with truth momentum



with momentum estimation



residual distributions at first measuring plane.

Summary & outlook

- The BGV is a transverse beam profile monitor based on inelastic hadronic collisions, currently being **optimised for the HL-LHC**.
- **Design is based on performance study** using G4 simulations & reconstruction via ACTS.
- **More work on track and vertex reconstruction necessary**. Future steps/interests:
  - **Momentum estimation** – investigate issues with pull distributions.
  - More **geometry details** – use cone shape for gas target's exit window and add beam pipe.
  - Use ACTS for **the future measurement, real time analysis?** 53 kHz Event rate.
  - **Track finding**/pattern recognition - small number of hits per track (CKF not suitable?), but low track multiplicity.
  - **Alignment -** no experience in BI.
- Thanks very much to ACTS team for their support!

Thank you for your attention!