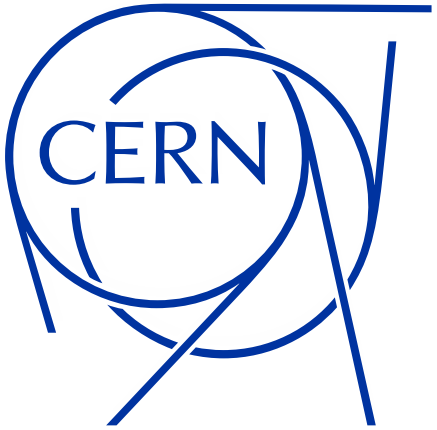
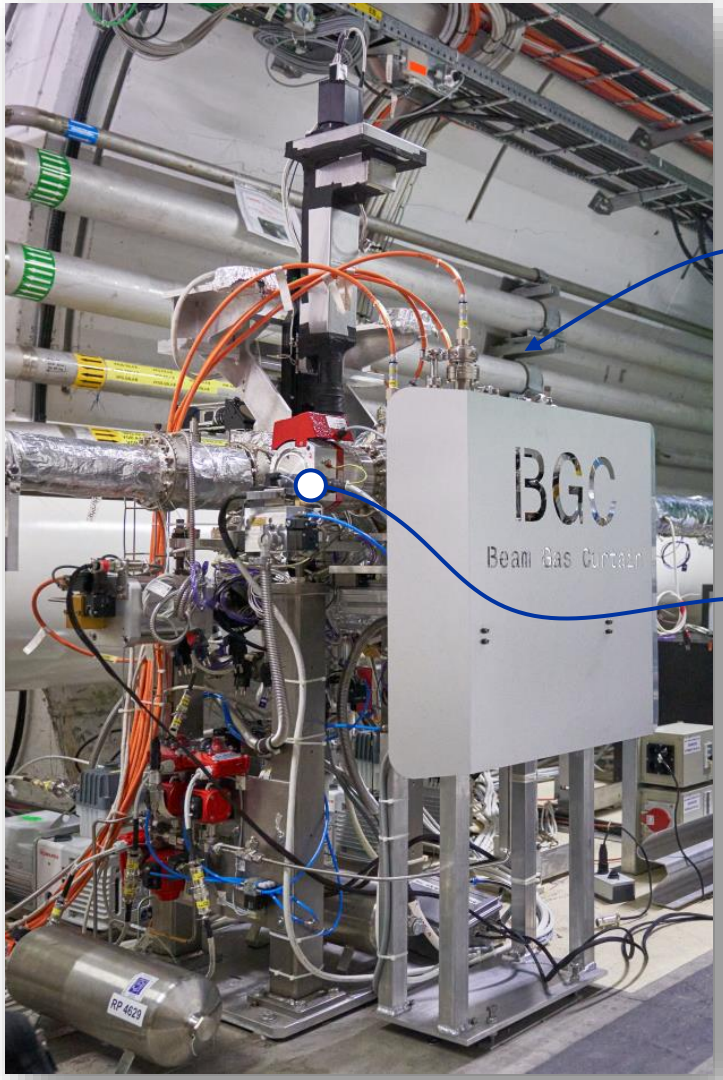
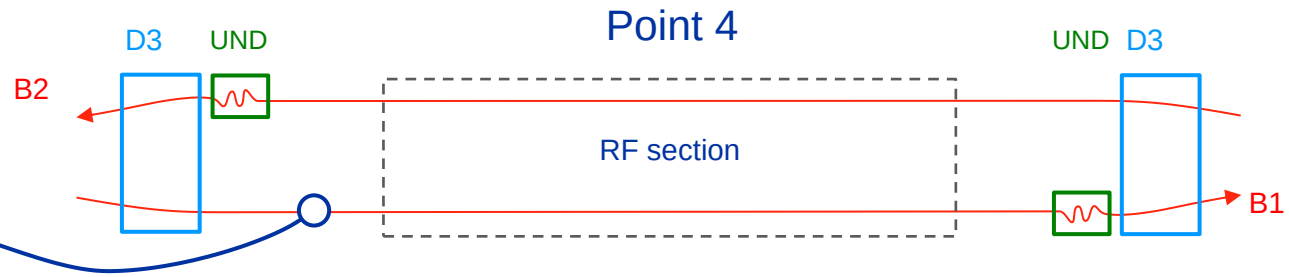


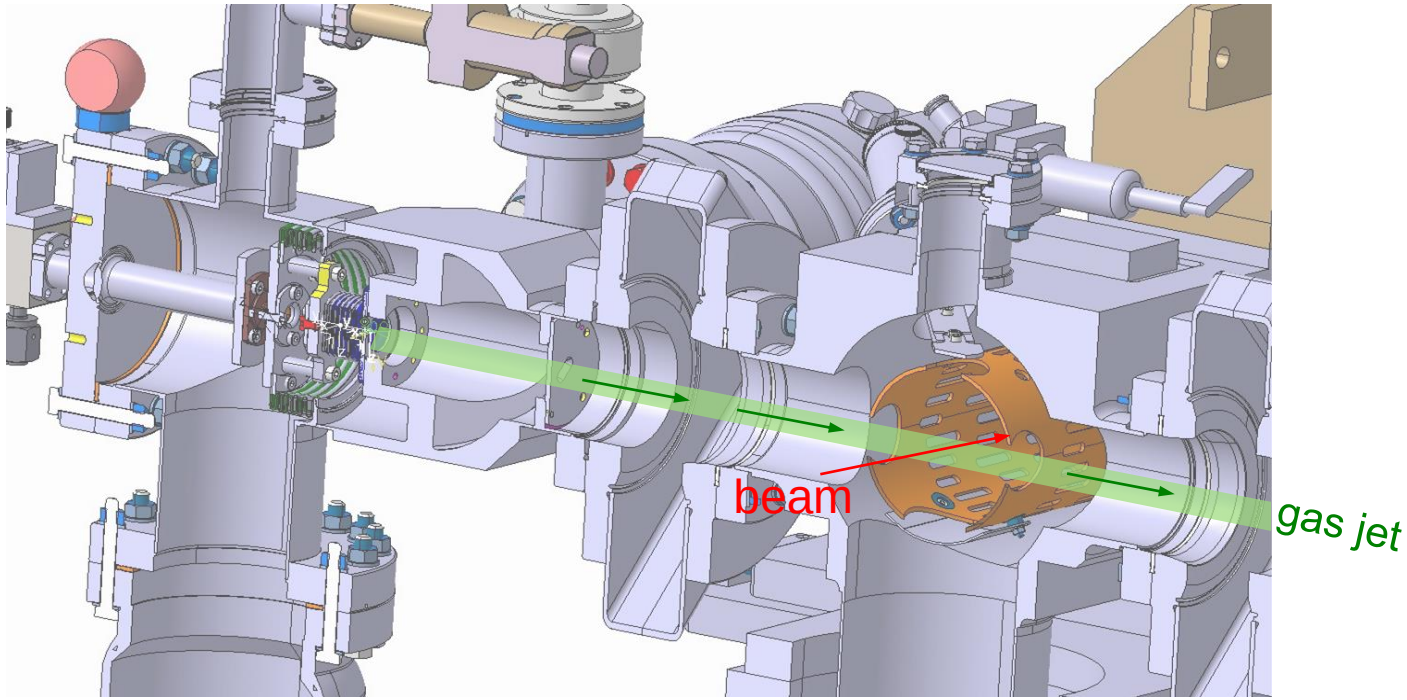
BGC: development in LHC and implementation study for LS3

D. Butti on behalf of the BGC collaboration

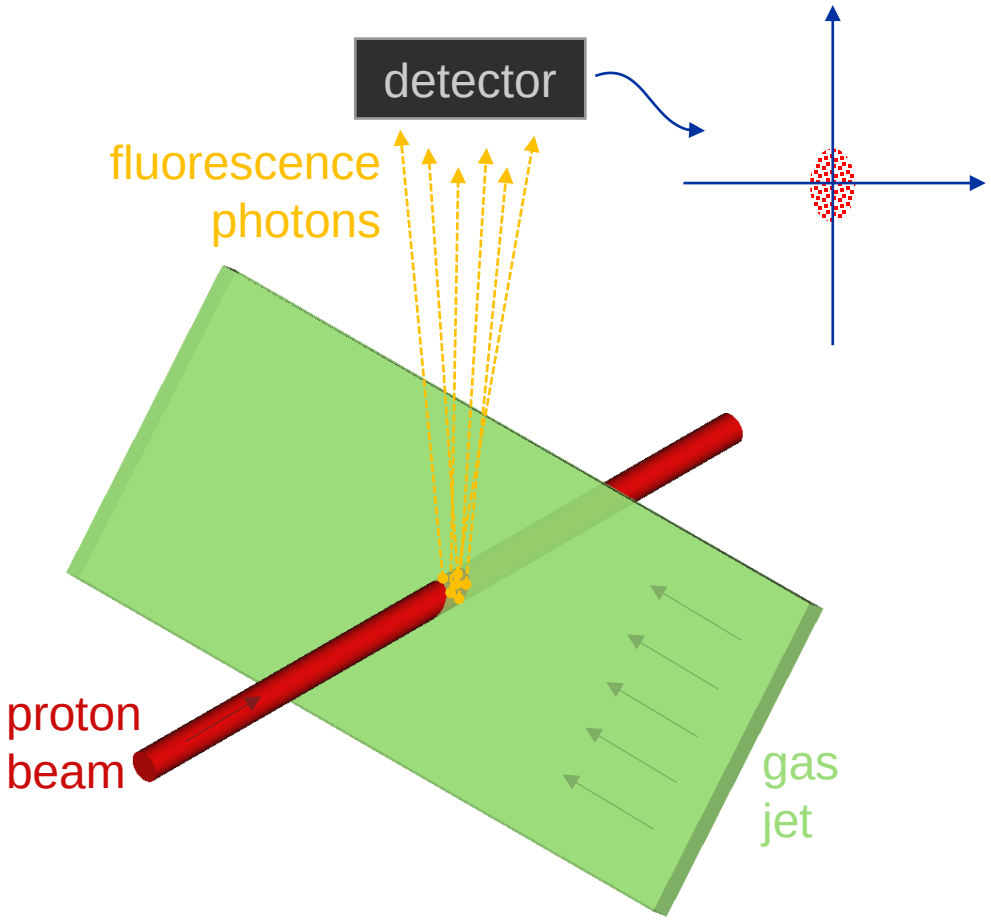
Beam Gas Curtain principle







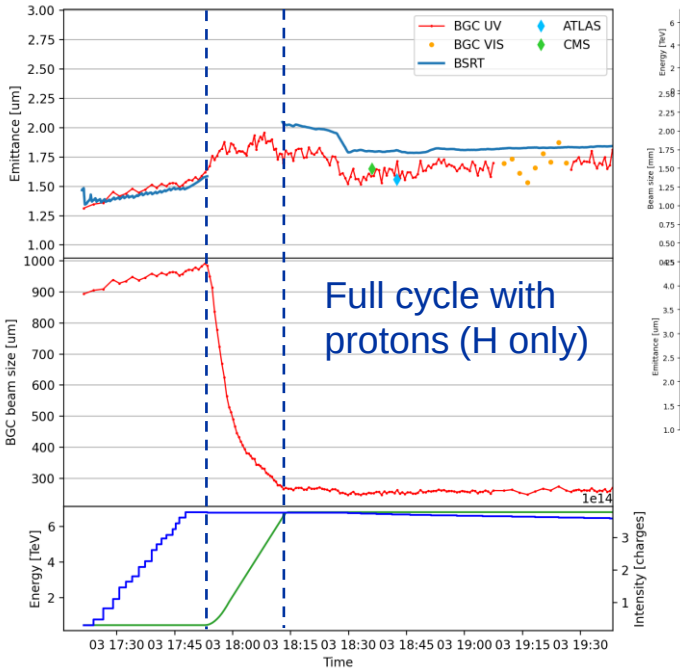
Beam Gas Curtain as beam imaging system

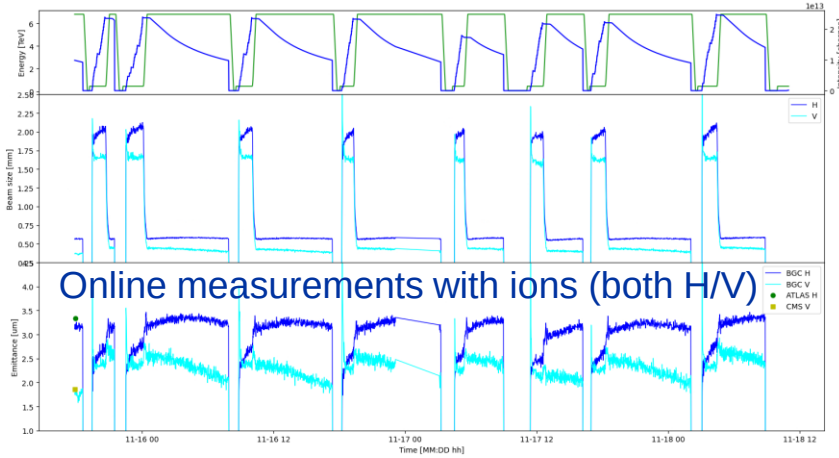


Conceived as overlap monitor for the Hollow Electron Lens, **reproposed as beam size monitor**:

- ✓ **minimally-invasive**
- ✓ simple beam imaging
- ✗ **weak fluorescence signal**, only suitable for avg measurements

Interesting emittance measurements in run 2024…

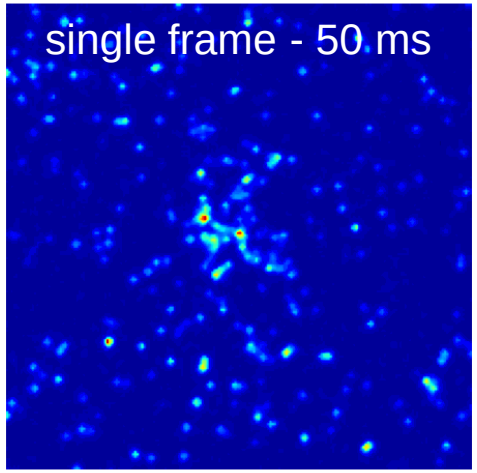




…can it be useful for halo measurements?

BGC animation on YouTube

Tail information in BGC images



Spatial resolution driven by system's optical resolution

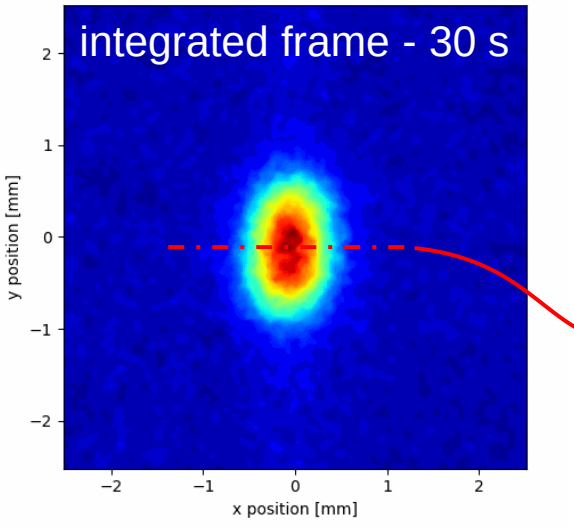
→ measured σ_{res}~200 μm consistent throughout the year

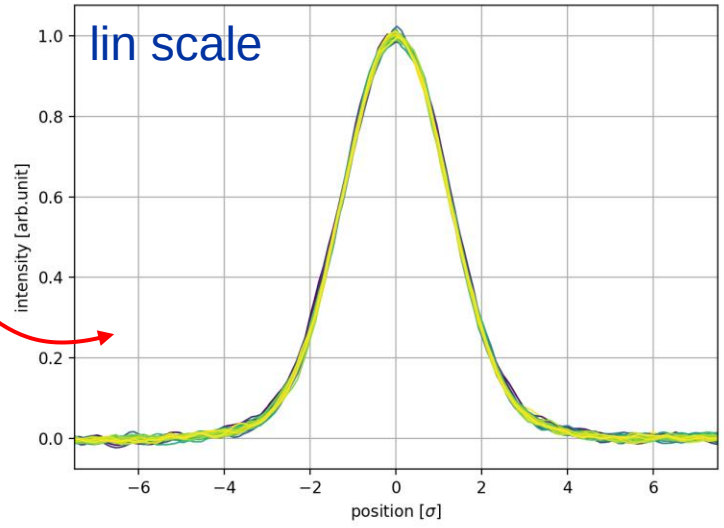
Dynamic range not an issue

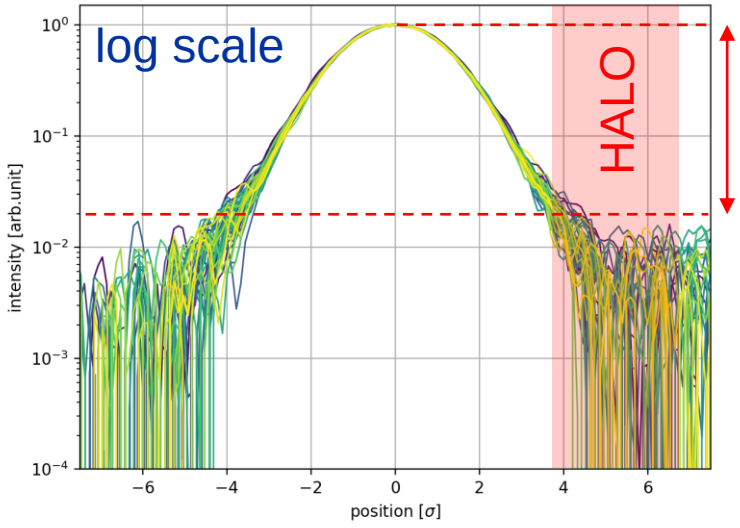
→ image build as (slow) sum of single photon frames

Contrast driven by signal-to-noise ratio

→ values ~2% peak-to-tail in present BGC configuration

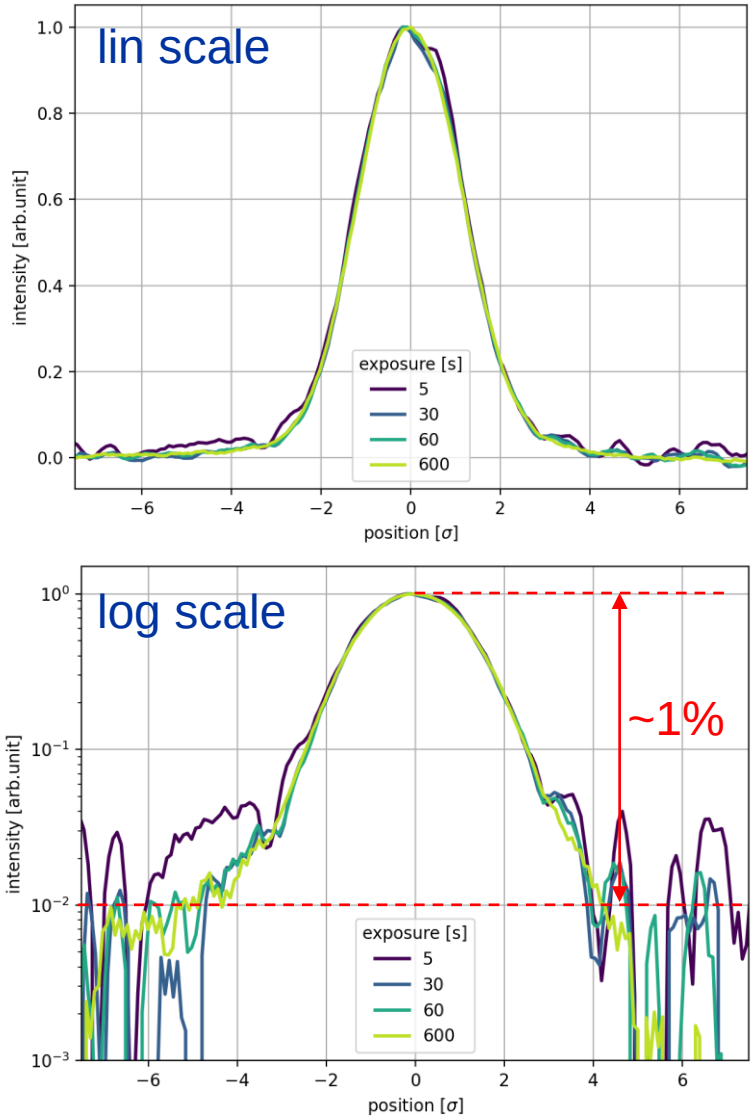






~2% peak-to-tail

Improving image contrast



Longer exposure times increase beam and background signals

→ less noisy profiles but no exceptional contrast gain

Some **options available** to improve contrast

- increase light collection efficiency → under study, may gain factor 4
- increase jet density/active volume → under study
- reduce dark counts and light background → already pushed, little margin
- reduce losses background → requires dedicated shielding
- advanced denoising techniques → to be studied
- use alternative gas species (e.g. N_2) → gain/feasibility to be tested

Margin to reach stable ~1% contrast with exposure ~1 min, feasibility of exceeding this requires further investigation and testing

Summary of BGC imaging

Contrast: ~1% likely feasible in halo, margin for improvement but feasibility to be studied

Halo integral: requires experiments to assess sensitivity to actual halo population change (e.g. EoF scraping)

1D/2D information: likely 1D (jet much thinner than beam size needed for 2D beam image)

Acquisition rate: slow ~1 min, average measurements only

Interlock: only software (image processing required)

Full cycle: mildly affected by beam energy

Ad-hoc optics: larger size improves spatial resolution, not too much (i.e. < 2σ) to avoid signal dilution

Take-home message for BGC imaging:

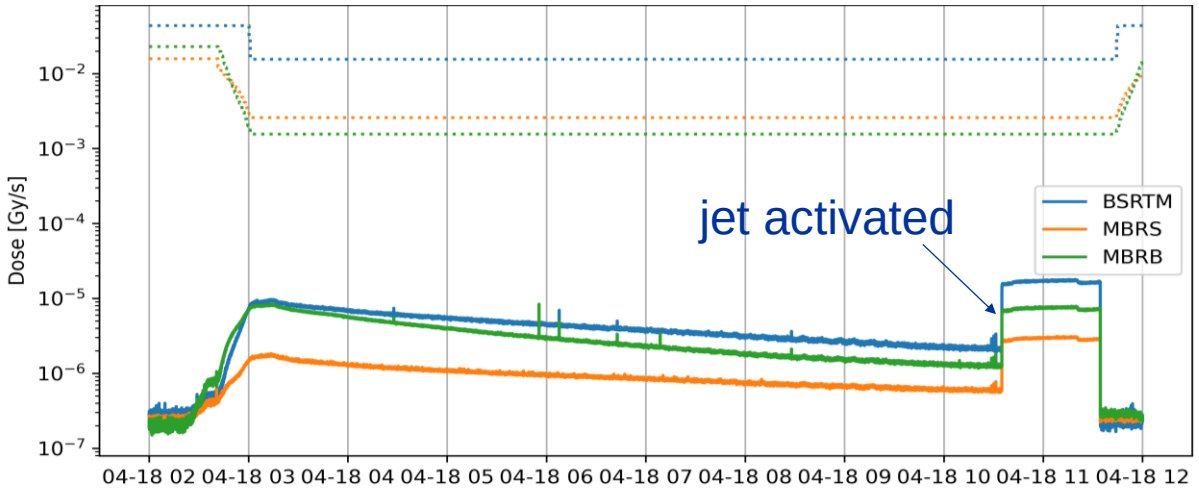
✗ limited performance in acquisition rate and contrast

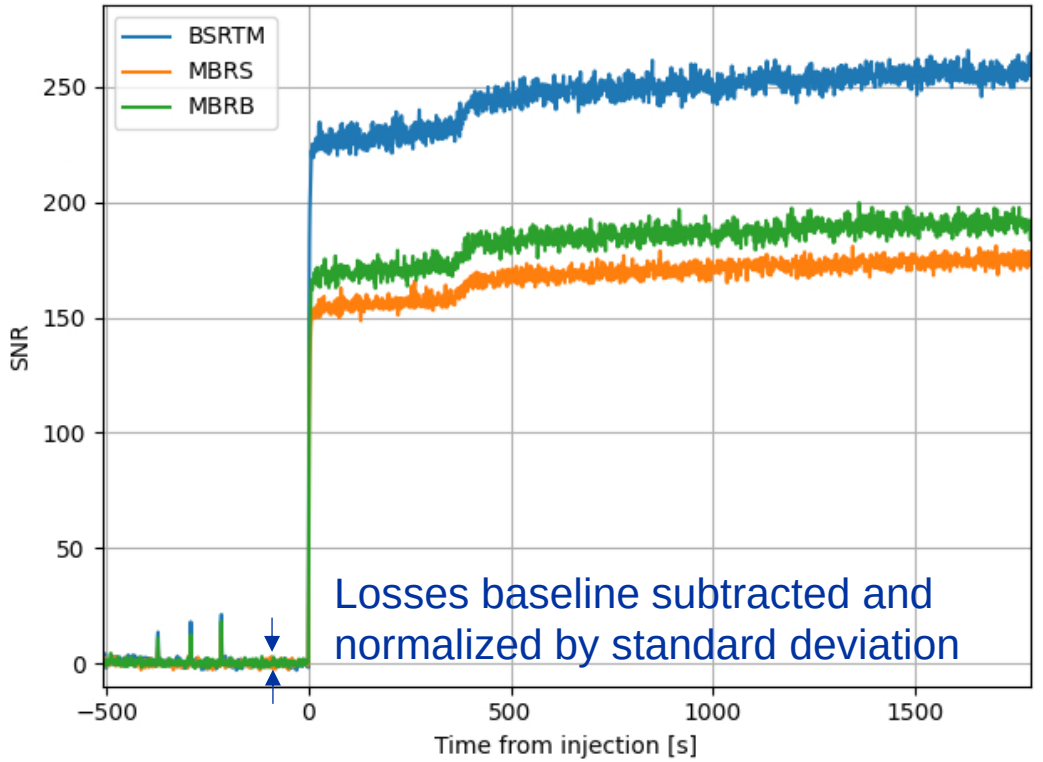
✓ robust and reproducible thanks to its simplicity

→ insufficient as single halo monitor, might provide a solid cross-reference for other monitors

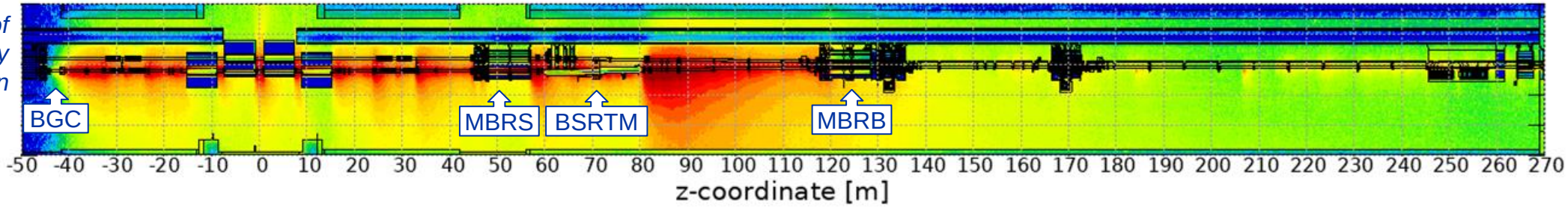
Beyond fluorescence: losses-based diagnostics

Fluorescence is not the only signal produced by the BGC, **jet-induced losses clearly detectable downstream**

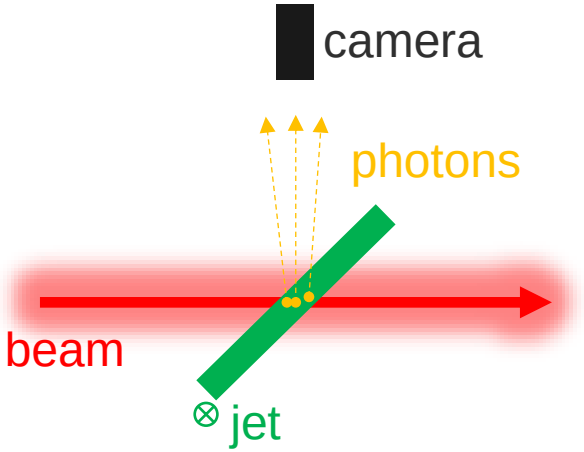




FLUKA simulation of BGC induced dose by D. Prelipcean



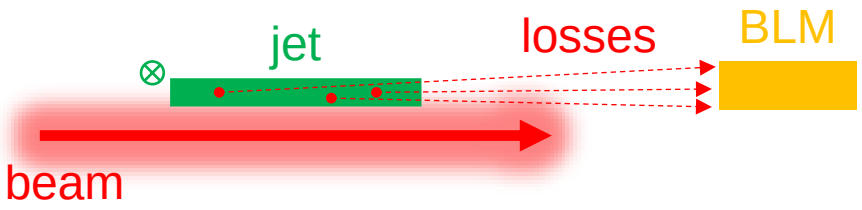
Concept of BGC as beam profiler



Present BGC configuration as beam imaging system

→ **jet is “gas screen”** and detect fluorescence photons

- info about 2D beam distribution
- low fluorescence cross-section, limited halo performance

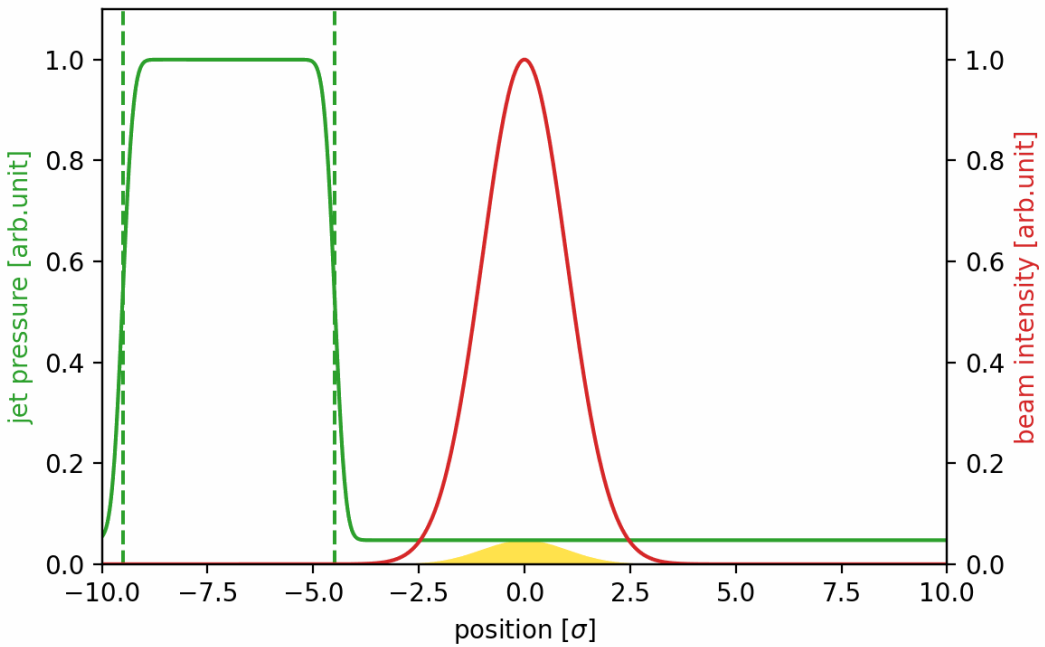


System can be converted into a beam profiler

→ use **jet as “gas collimator”** and detect losses

- intrinsically a 1D instrument
- measures integrated population within jet, profile obtained by scanning jet position

Concept of BGC as beam profiler



Jet used as a **probe to scan the beam**

Measurement principle

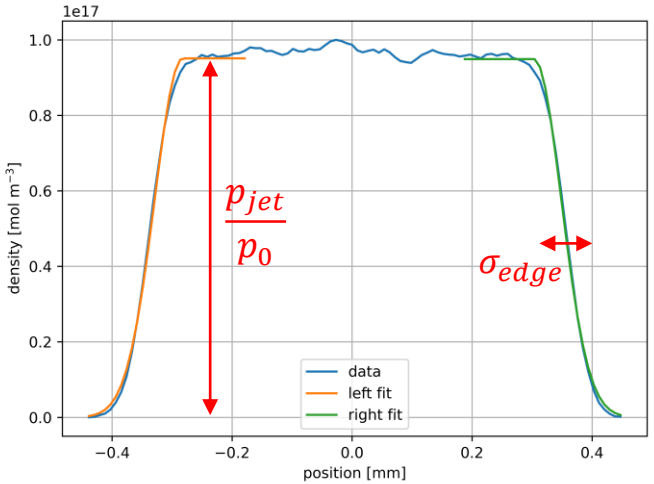
1) full transverse scan of the beam. Beam distribution obtained by deconvolution of losses signal and jet profile
2) take background reference with jet away from beam
3) approach jet to beam to monitor evolution of tail population

Scan repeated whenever full-profile is requested and to adjust jet position

Background subtraction can be regularly adjusted by displacing jet but **very high sensitivity required to resolve halo signal**

Gas distribution: jet

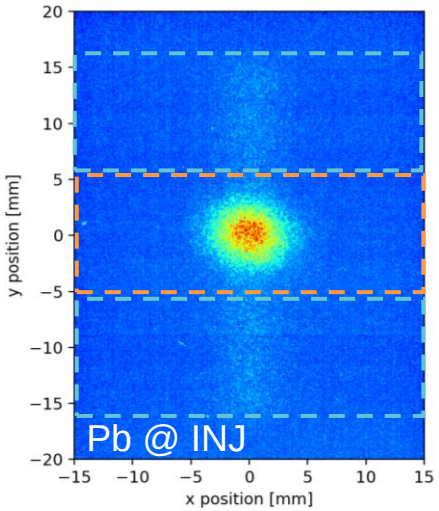
Real jet profile not an ideal rectangle but has **finite edge sharpness** and **pressure gap**

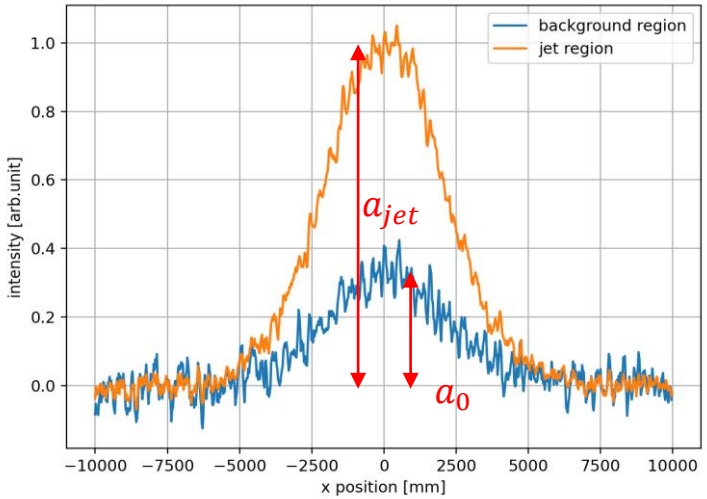


Edge sharpness measured by movable gauge

$\sigma_{edge} \simeq 100\ \mu m$

Finite edge sharpness → **ultimate limit for spatial resolution**





Pressure gap can be estimated from fluorescence emission

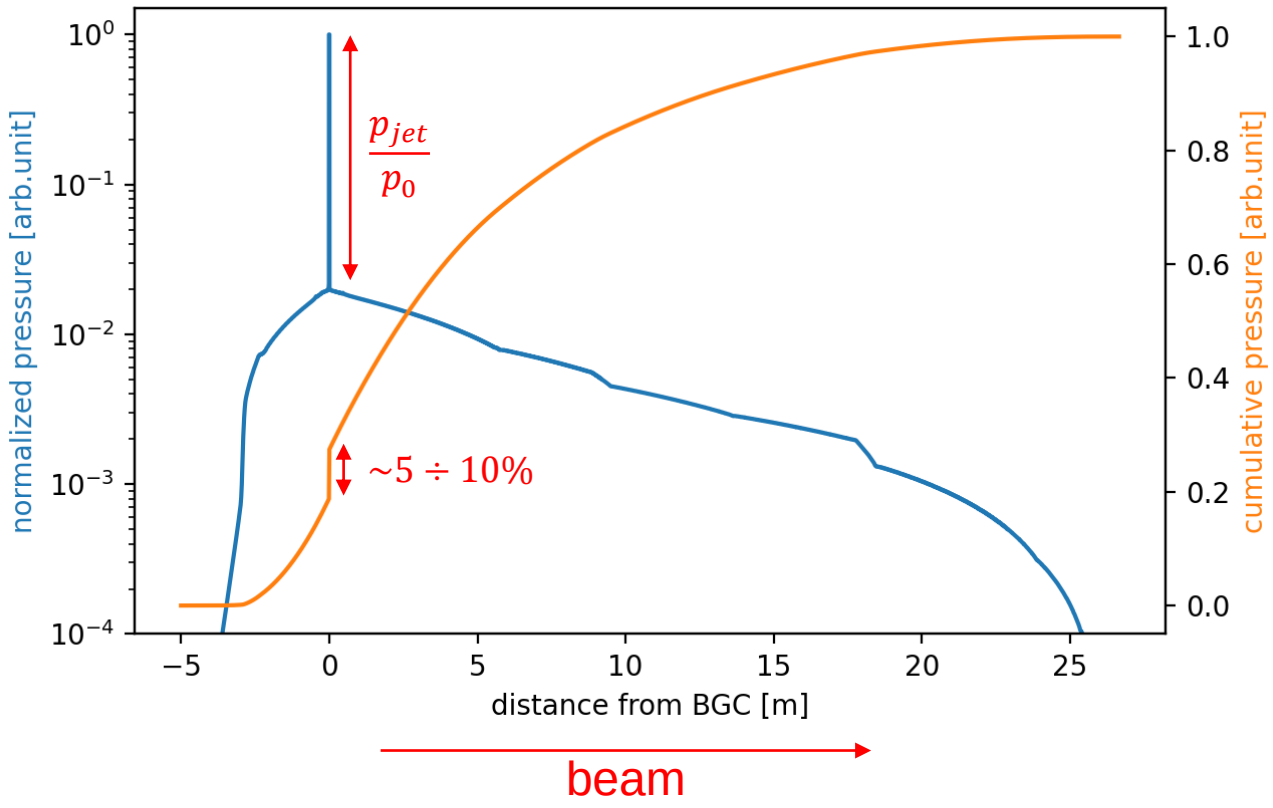
$$\frac{p_{jet}}{p_0} \sim \frac{a_{jet}}{a_0} + [geom.\,factors] \simeq 50$$

Finite background pressure → **parasitic losses from core**

Gas distribution: background

Gas injected by BGC not fully confined within to jet but spans over several meters

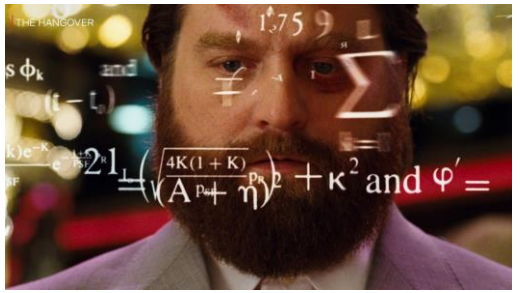
At present, a fraction of the gas load belongs to the jet while the majority remains as background



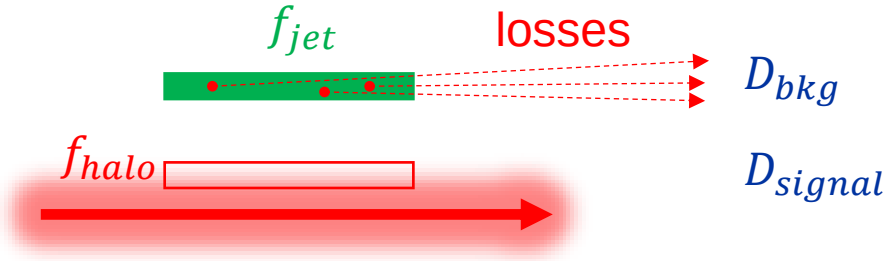
A fraction of the losses f_{jet} **is the useful signal** produced by the jet

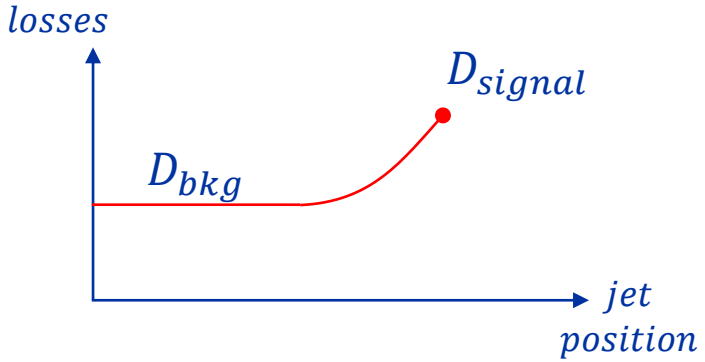
Fraction f_{jet} **depends on detection location** (e.g. higher jet sensitivity closer to jet)

Contrast of BGC as beam profiler



How to quantify the contrast of the BGC profiler?

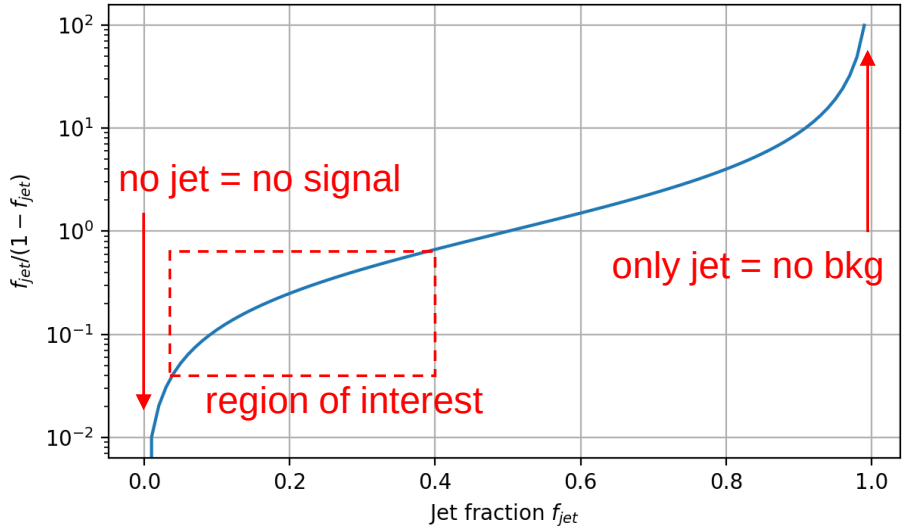




$$\frac{D_{signal} - D_{bkg}}{D_{bkg}} \simeq \frac{f_{jet}}{1 - f_{jet}} f_{halo}$$

Basic model where signal depends only on geometric overlap between jet and halo

Proportionality between **contrast to integrated population and sensitivity to losses**, with jet fraction as modulating function



Improving contrast

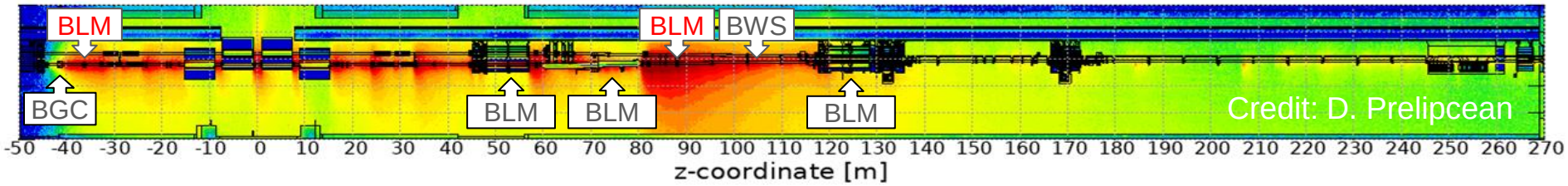
Optimizing contrast requires maximizing production and detection of losses created by the jet

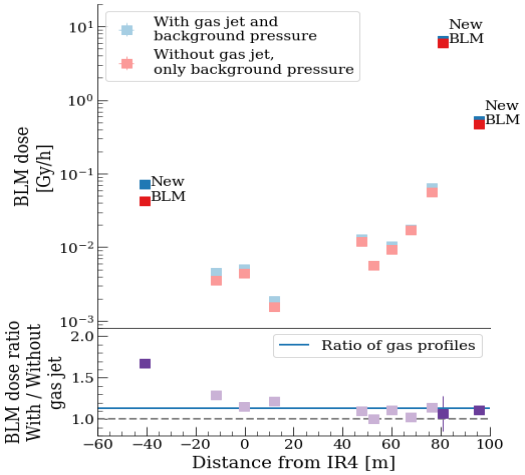
Options available to **improve jet losses** (vs background)

- optimize jet aspect ratio for maximum jet-beam overlap → under study
- increase gas pressure in jet → to be studied, limited margin
- increase pumping to reduce background → under study (helpful also to reduce gas load)

Options available to **improve losses detection** (vs background)

- optimize detection location → dedicated IC BLMs installed in YETS2425
- maximize detection sensitivity → best detector technology to be studied





Summary of BGC profiler

Contrast (integral): to be quantified depending on achievable sensitivity to jet losses

1D/2D information: intrinsically 1D

Acquisition rate: potentially bunch-by-bunch, integration time depends on achieved sensitivity to jet losses

Interlock: potentially HW, if interlock on simple loss threshold is reliable

Full cycle: not affected by beam energy

Ad-hoc optics: larger size improves spatial resolution, not too much (i.e. < 2σ) to avoid signal dilution

Take-home message for BGC profiler:

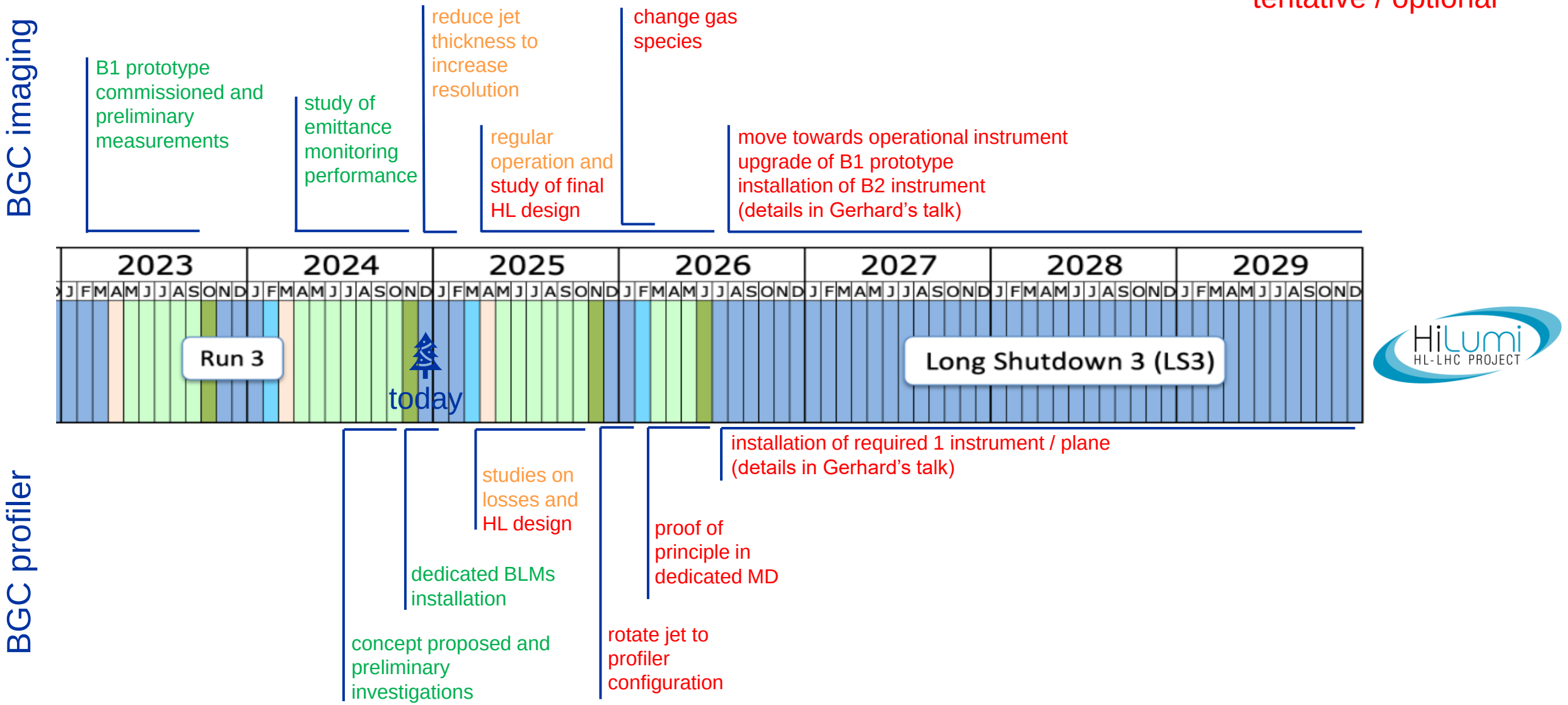
✘ using BGC as beam profiler is a very recent concept

✓ BGC profiler configuration very similar to existing one, already validated in the machine

→ instrument has potential, but further investigations needed (before LS3) to quantify performance

Timeline for BGC development

done
planned
tentative / optional



Conclusion

Beam Gas Curtain is an **R&D instrument with demonstrated potential as average emittance monitor**

Two candidate configurations for halo monitoring

Beam imaging based on fluorescence

- principle and implementation validated
- requires optimisation for halo measurements

→ known limitations but little uncertainty on implementation by HL-era

Beam profiler based on losses

- new concept, proof of principle possible before LS3
- performance and limitation still to be assessed

→ principle more suitable for halo measurement but exploitation is more challenging

Primarily work as **emittance monitors**, halo measurements would come as additional feature

Tests and studies planned for next year will provide estimate of ultimate performance of both configurations

Thank you for your attention!