HiLumi HL-LHC PROJECT

14th HL-LHC Collaboration Meeting

Genoa - 9th October 2024

Performance of the BGC in the LHC

D. Butti on behalf of the BGC collaboration

The Cockcroft Institute of Accelerator Science and Technology

GSI

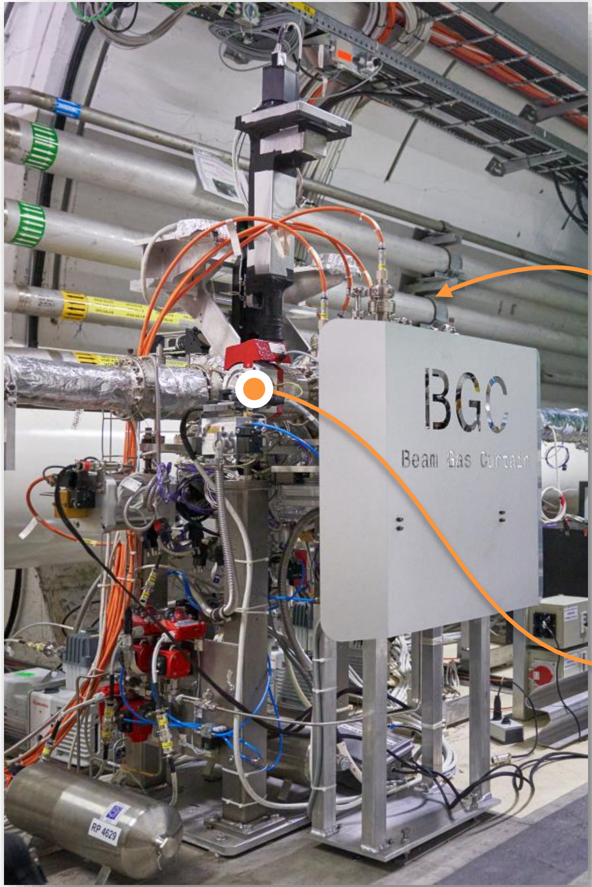
UNIVERSITY OF LIVERPOOL

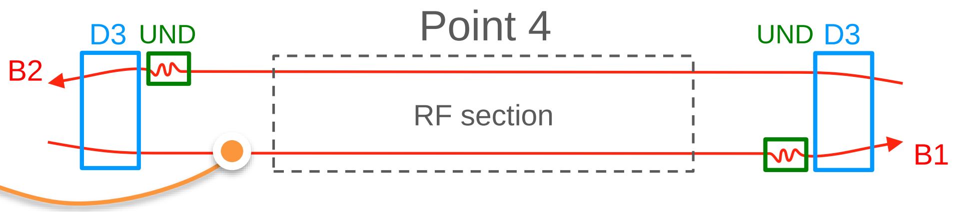
CERN

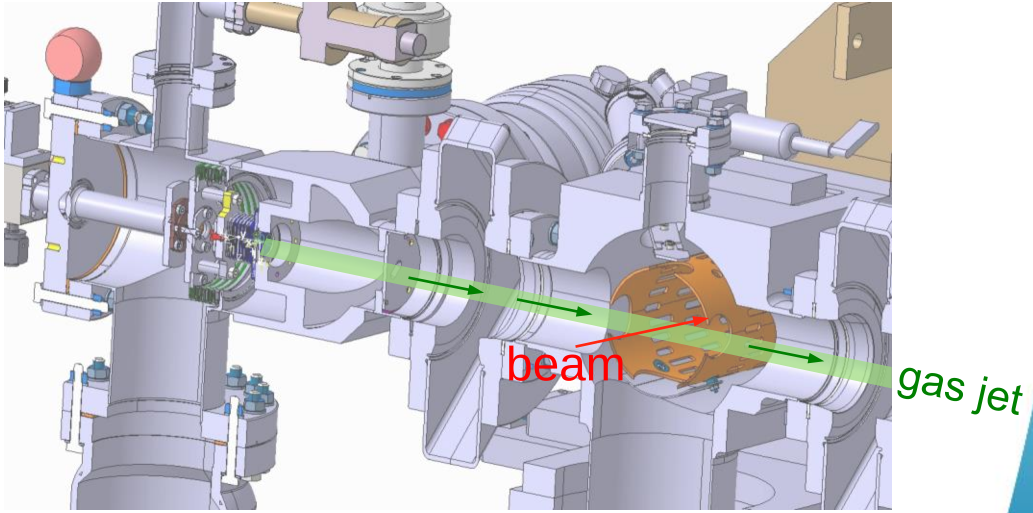
Outline

- **Introduction**
  - Beam Gas Curtain
  - BGC as beam size monitor
- **Results from BGC operation**
  - visible and ultra-violet configurations
  - emittance measurements
  - impact of jet thickness
  - ion run diagnostics
- **Beyond fluorescence**
  - losses-based diagnostics
- **Conclusion**

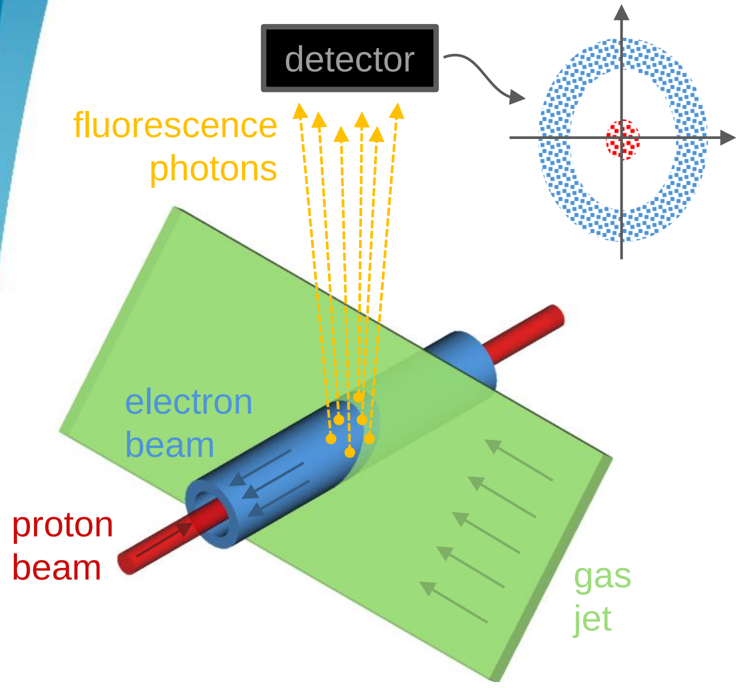
Beam Gas Curtain







Beam Gas Curtain principle



Conceived as overlap monitor for the Hollow Electron Lens

After HEL descoping, **reproposed as beam size monitor** for the main LHC beam:

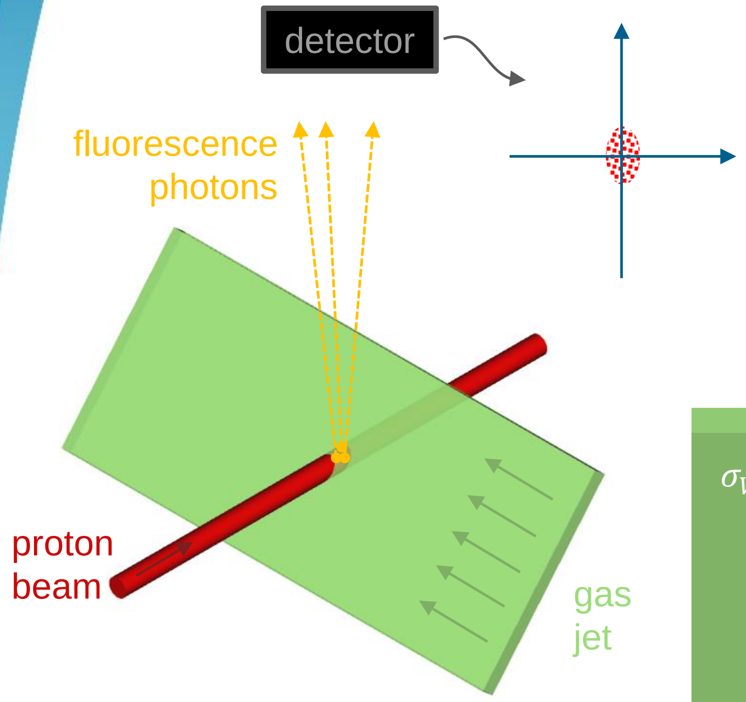
- ✓ **minimally-invasive**
- ✓ simple beam imaging
- ✓ only option for Pb @INJ

- ✗ **weak fluorescence signal**, only suitable for avg measurements
- ✗ jet thickness affects measurement in vertical direction

Promising measurements during 2023 run (with ions)
→ **ongoing effort to move towards an operational device**

BGC animation on YouTube

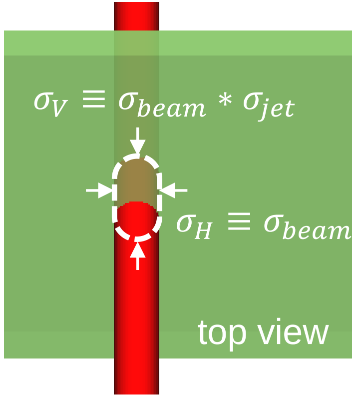
BGC as beam size monitor



Because of the gas jet finite thickness,
the **BGC output is different in the two directions**

Horizontal projection is unaffected
→ used as indicator of data quality

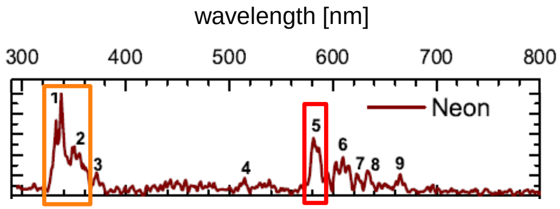
Vertical projection includes jet distribution
→ retrieving accurate beam size is more challenging



Horizontal
light profile = beam profile

Vertical
light profile = convolution of beam and jet profiles

Fluorescence signal



Non-destructive profile measurement of intensive heavy ion beams,
F. Becker 2010

BGC currently operates in two **spectral domains**

BGC VIS: visible line 585 nm

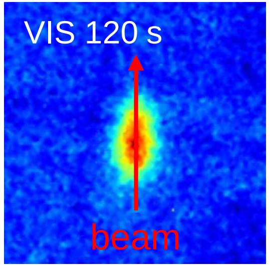
- lower light yield → longer integration times
- neutral transition Ne* → better resolution

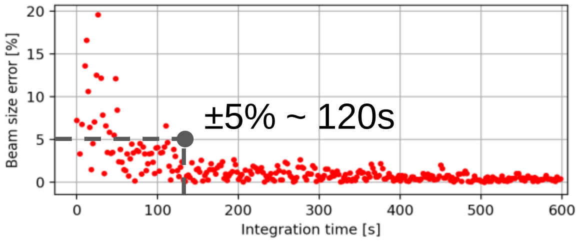
→ best for **accurate absolute measurements**

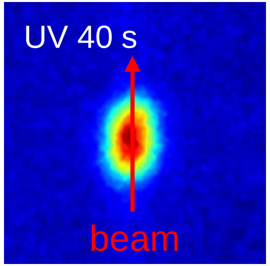
BGC UV: ultra-violet lines

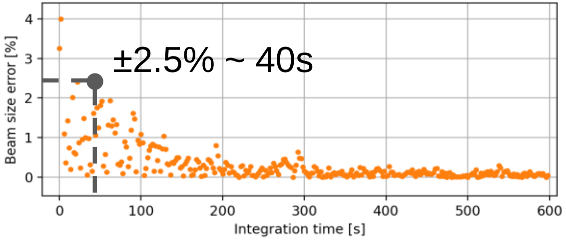
- better light yield → shorter integration times
- ionic transition Ne^+ → worse resolution

→ best for **precise relative measurements**









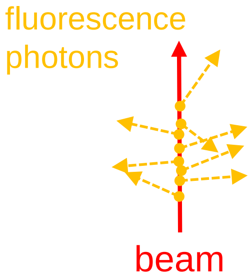
Resolution

Beam size inferred from image size, correcting for resolution $$\sigma_{beam}^2 = \frac{\sigma_{img}^2}{M^2} - \sigma_{res}^2$$

M = magnification
σ_{beam} = beam size
σ_{img} = fitted size
σ_{res} = resolution

BGC VIS

- neutral transition Ne* unaffected by beam field
- resolution only given by optics

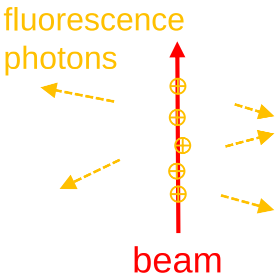


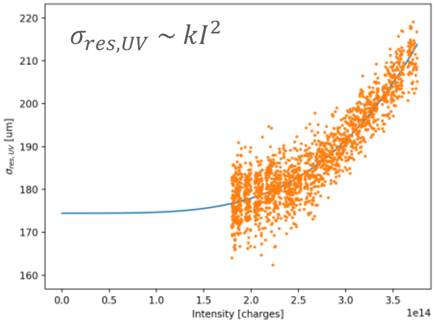
$\sigma_{res,VIS} \simeq 65$ μm

- measured a priori
- much smaller than any beam size

BGC UV

- ionic transition Ne^+ affected by beam field
- semi-empirical correction including beam current





BGC self-calibration → assume "true" value provided by BGC VIS and derive correction for BGC UV

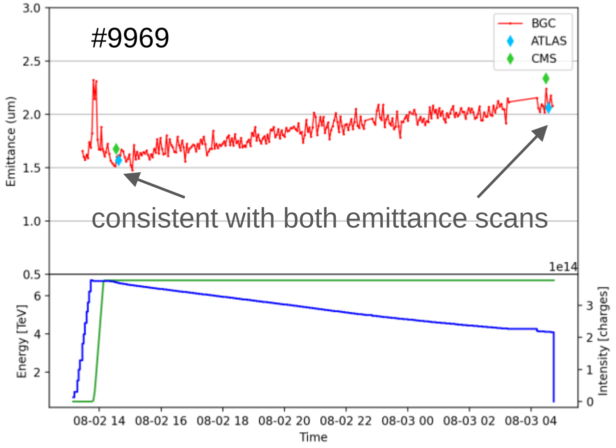
Accuracy of BGC VIS

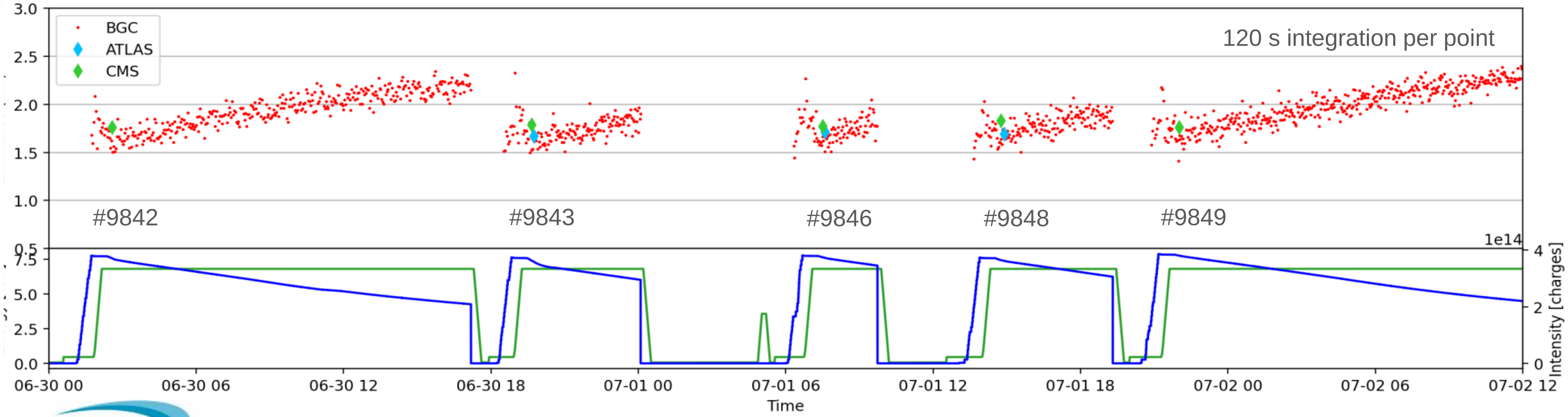
Resolution much smaller ($\sim 1/3$) than beam size

→ measurements look **accurate and reproducible** at flat-top

Low light yield with visible line

→ measurements **quite noisy** (±10% peak-to-peak in emittance)



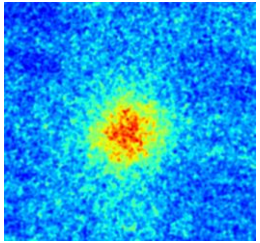


BGC VIS results during machine cycle

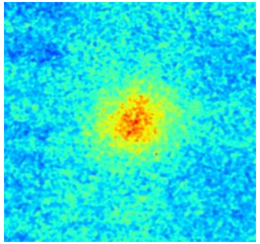
Some issues affect the measurement

- overestimation of injection size due to poor signal
- fluorescence easily overwhelmed by losses
- long integration time implies very few points

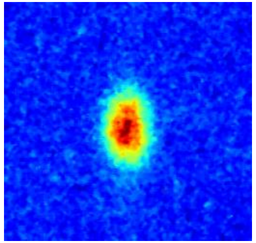
BGC VIS reliable reference in stable beams but not ideal to track beam size evolution



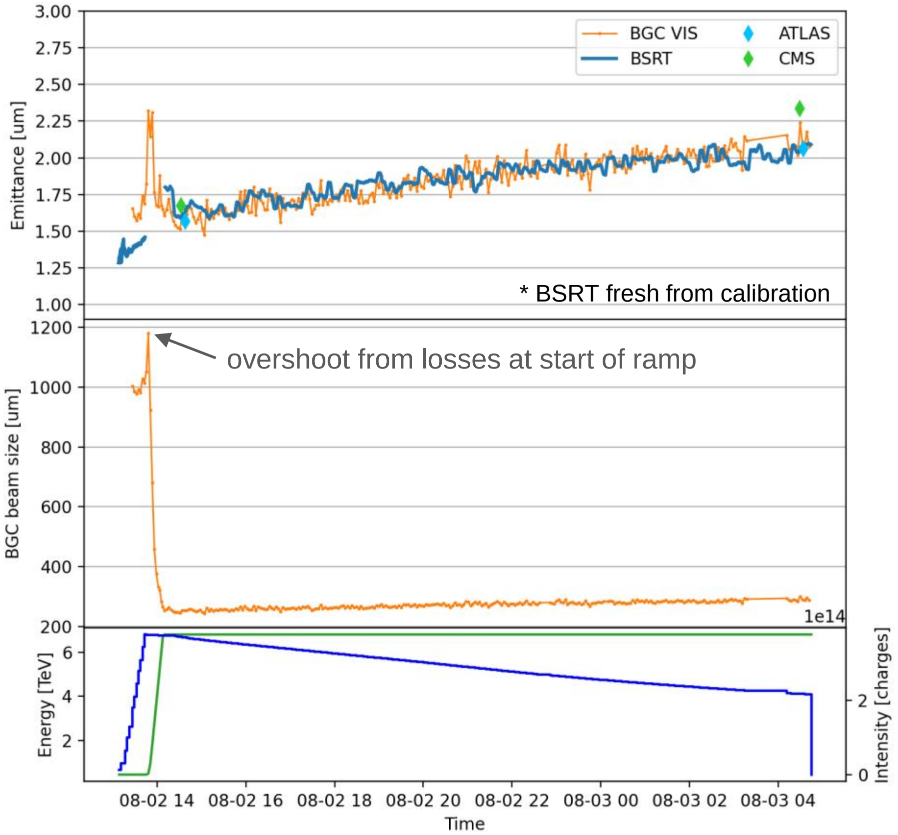
Injection



Start of ramp



Stable beams

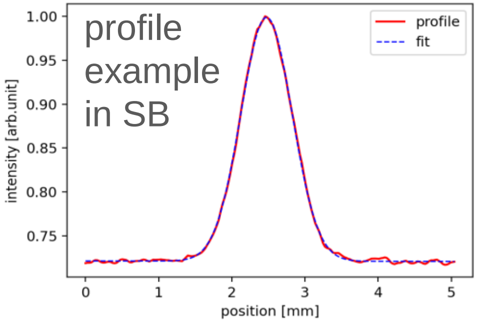


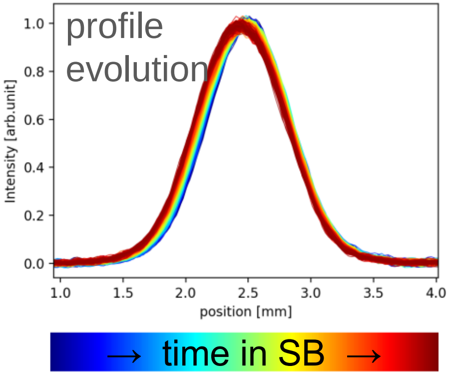
Combined BGC VIS + UV

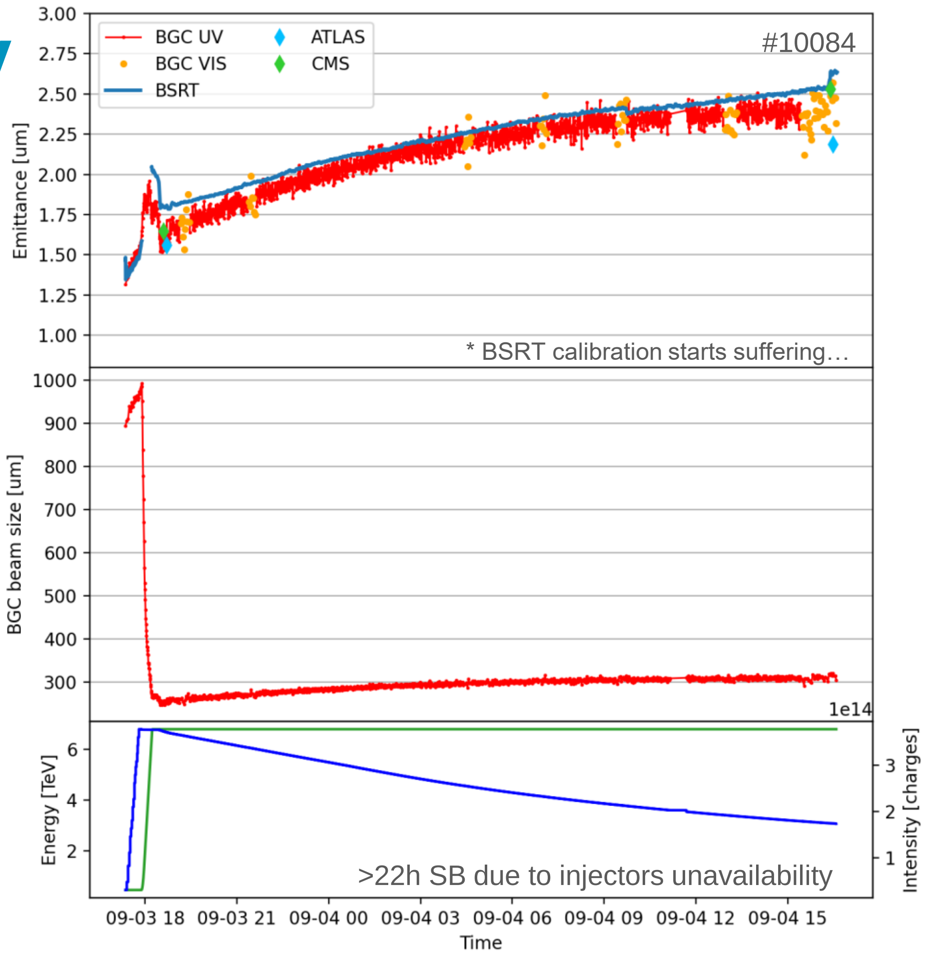
Measure fill using BGC UV, switching to BGC VIS for accuracy cross-checks

Fluctuations of BGC UV within ±5% in emittance

Trend from combined **BGC VIS + UV compatible with emittance scans** at start and end of fill



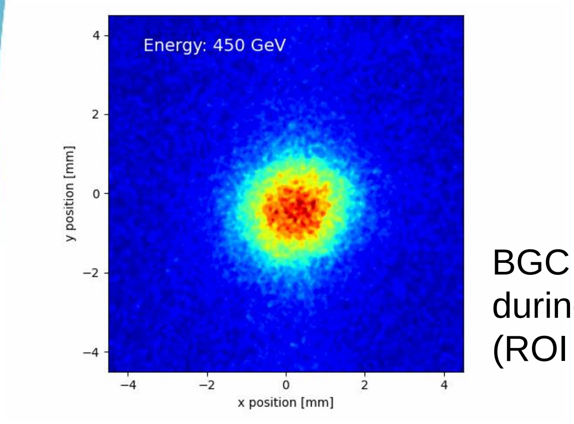




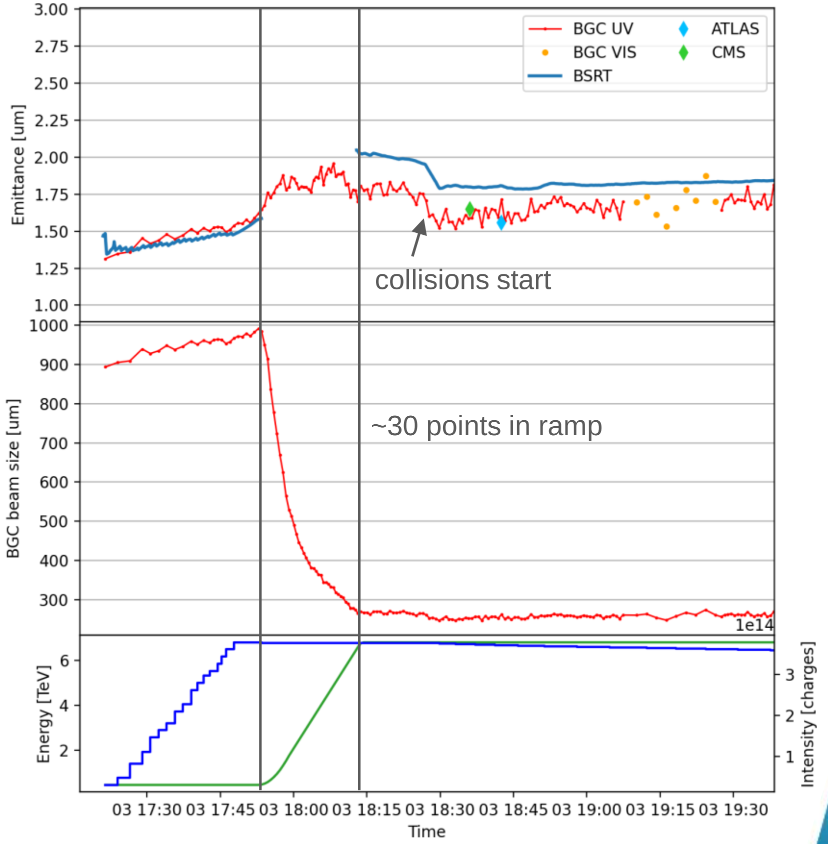
Combined BGC VIS + UV during ramp

Overall **positive results**

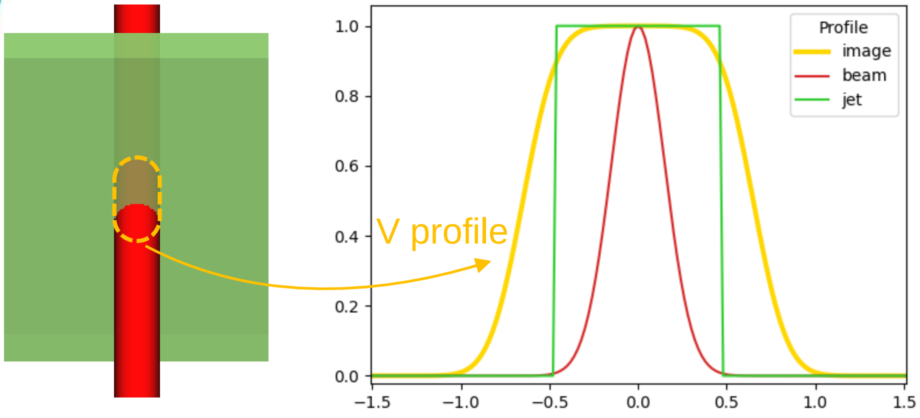
- quantitative agreement with BSRT at injection
- “smooth” behavior in ramp
- qualitative agreement with BSRT at FT
(e.g. dynamic beta effect on collision)
- quantitative agreement with emittance scan



BGC UV images
during energy ramp
(ROI follows beam size)



Vertical direction (perpendicular to jet)



Ideally, the vertical profile of the image has

- intensity plateau from uniform jet distribution
- Gaussian edges from beam distribution

→ beam size information only encoded in the edges, retrievable from **deconvolution**

If jet thin enough, deconvolution can be replaced by simple Gaussian fit and correction in quadrature

In reality,

- deconvolution works with low-noise profiles → **only BGC UV usable**
- real jet profile not perfectly rectangular → **jet edges further correction to beam size**

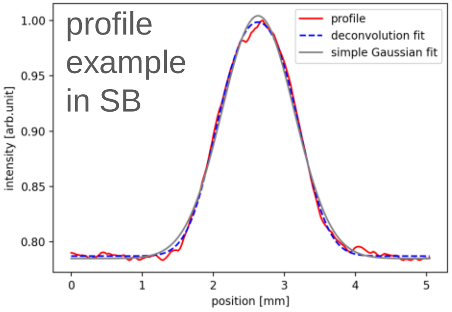
... these issues are mitigated if beam size is larger (low energy)

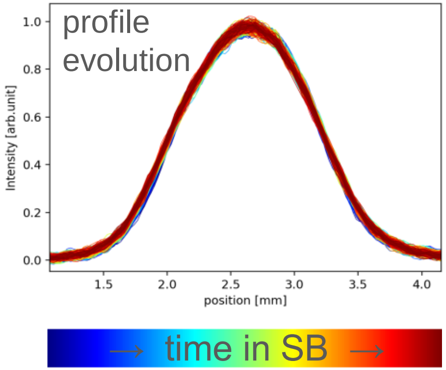
Vertical direction

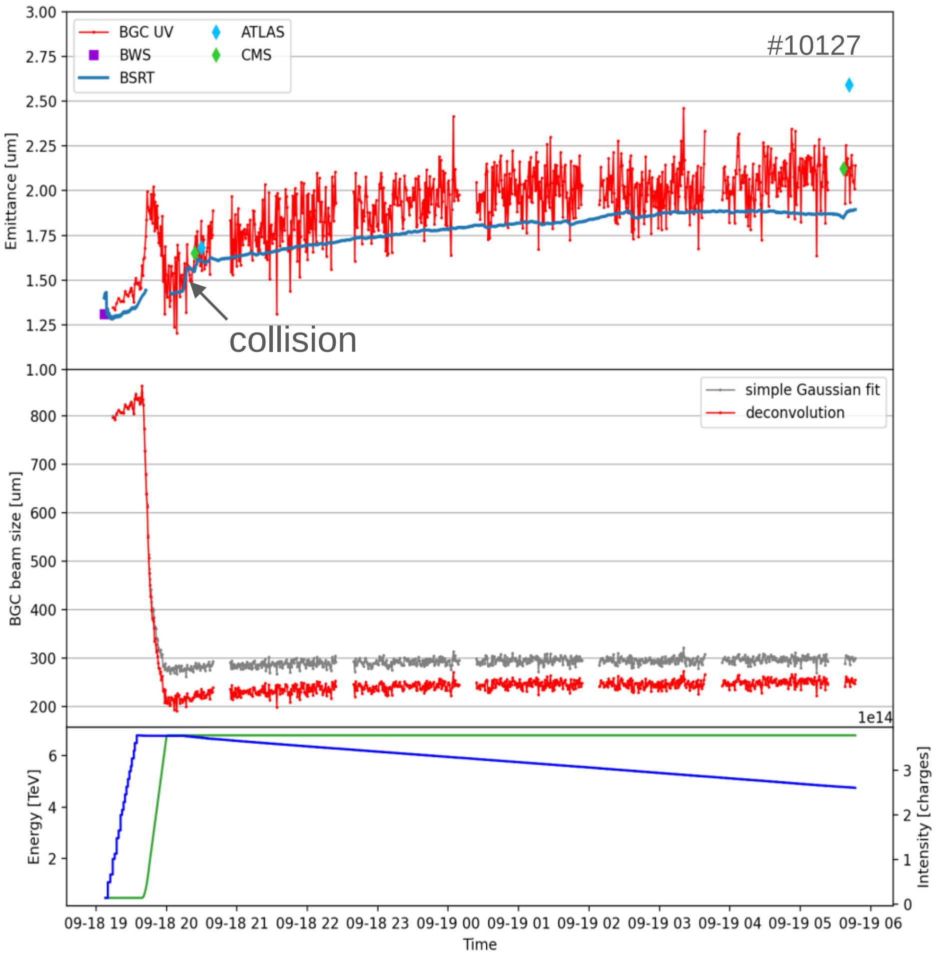
Deconvolve BGC UV profiles to assess beam size

Larger fluctuations at flat-top than horizontal, ±15% emittance, due to extra correction for jet thickness

No accurate reference from BGC VIS.
Deconvolution seems to match emittance scans but reproducibility to be assessed…







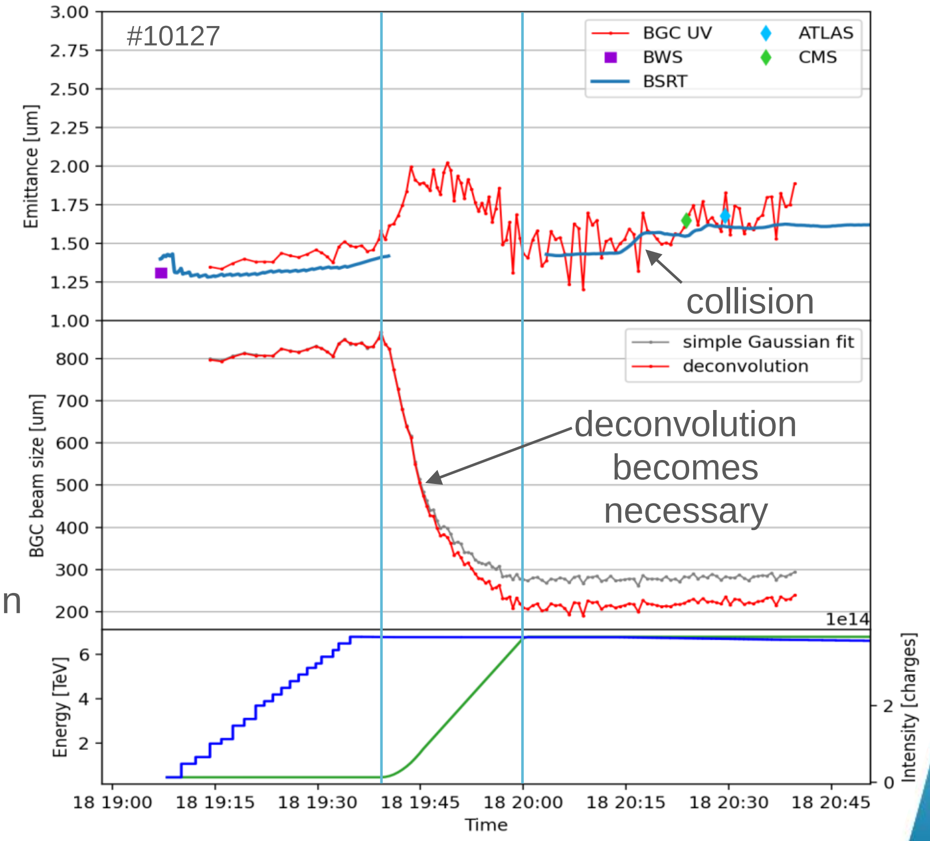
Vertical direction during ramp

Still **some positive results**:

- BGC, BSRT and BWS are compatible within 10% at injection
- "smooth" behavior in ramp, not so different from horizontal case
- within larger BGC fluctuations, good agreement with BSRT and emittance scan at FT

As size decreases, **jet thickness effects** appear

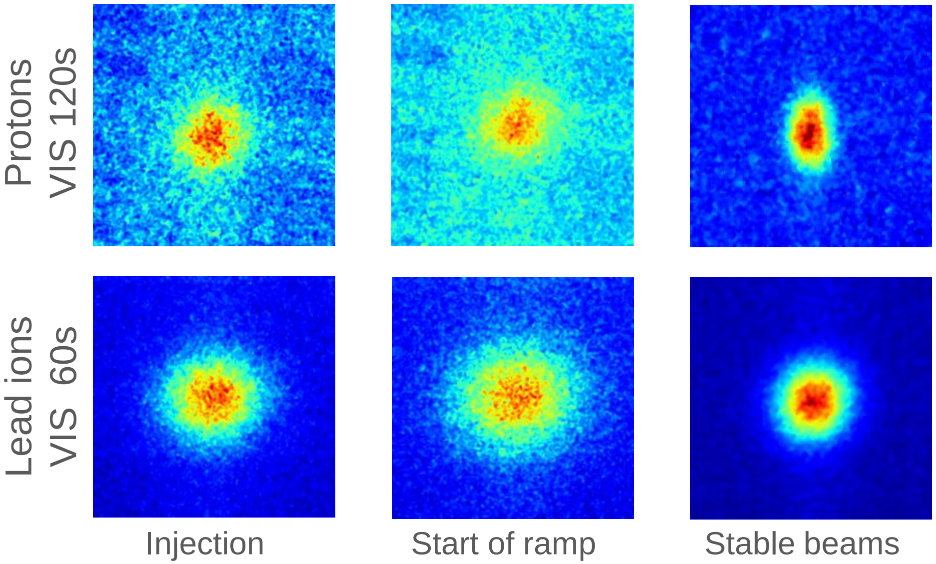
- simple Gaussian fit deviates from deconvolution
- measurements become noisier



Performance with ion beams

More favorable conditions with ion beams

- stronger fluorescence signal
- larger beam sizes



Limited availability of BSRT with ions:

- no light at injection
- rarely calibrated at flat-top

Promising results from last year ion run, re-commissioning with ions still pending

Summary of experimental results

Horizontal measurements (i.e. parallel to jet)

- BGC VIS configuration provides accurate and reproducible measurements in stationary beam conditions
- BGC VIS and BGC UV combined best option for beam size monitoring over full machine cycle

Vertical measurements

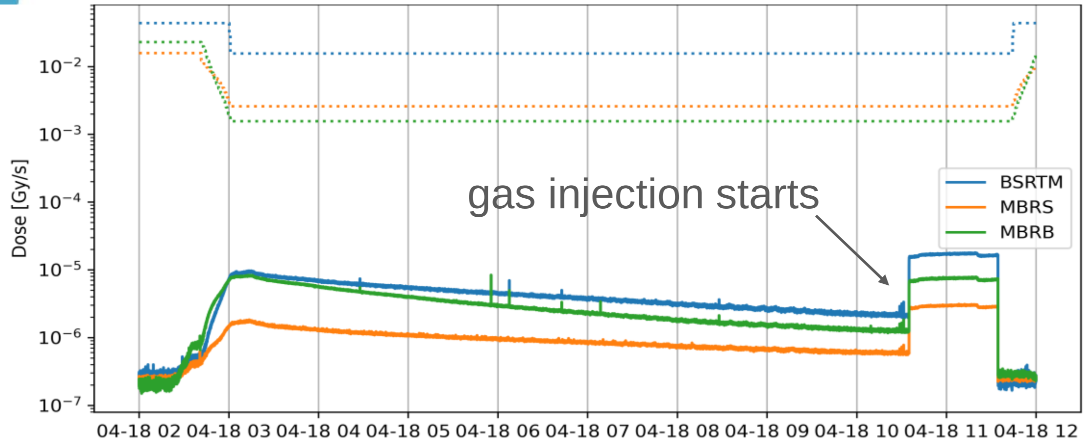
- BGC UV still OK at injection, flat-top performance affected by jet thickness
- improvable by reducing jet thickness and/or de-squeeze to increase flat-top beam size

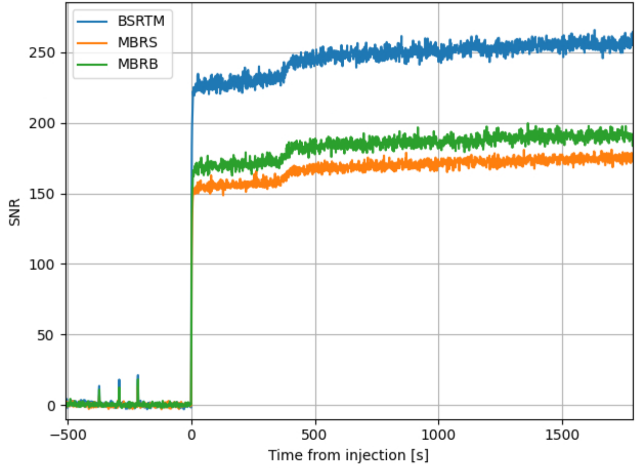
Promising measurements from last year's **ion run**

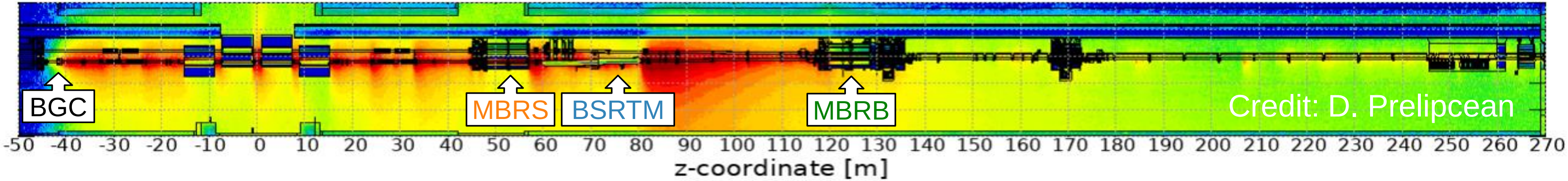
- re-commission BGC for ions and validate results

Beyond fluorescence

Fluorescence is not the only signal, **gas-induced losses detectable downstream**

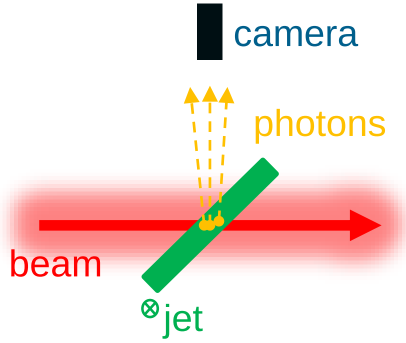






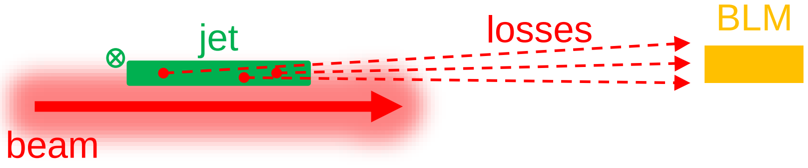
Concept for a BGC-based beam profiler

Present BGC → jet is “gas screen” and detect fluorescence photons



- 2D image very efficient to detect centroid
- info about beam profile (emittance)
- very low fluorescence cross-section, limited dynamic range

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
- if jet is moved, measures profile (emittance)

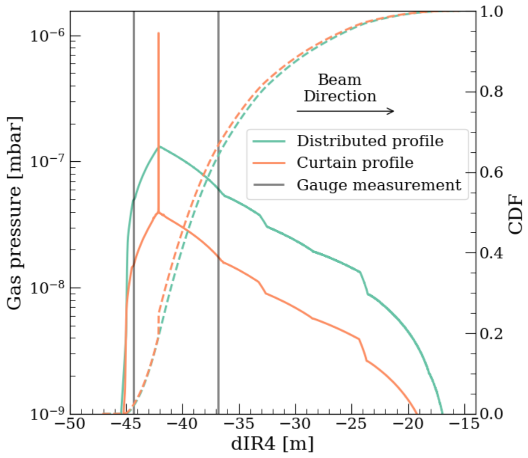
Optimizing jet-induced losses

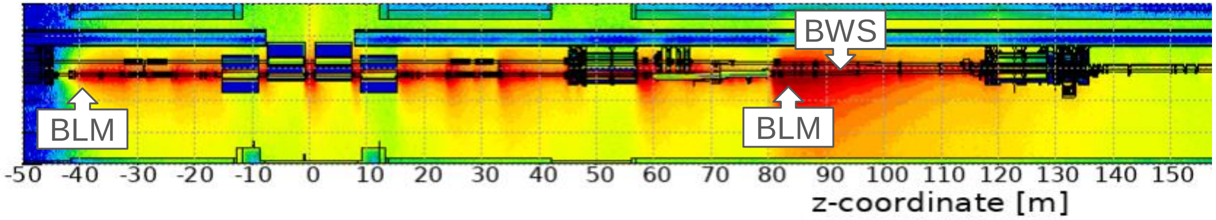
Jet is only a part of the gas distribution created by BGC

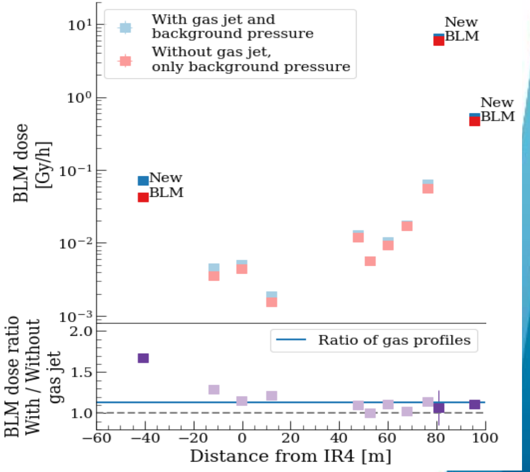
- need to maximize sensitivity to jet versus background (jet shape/aspect ratio, reduce pressure background..)

Existing BLMs not optimized for BGC losses

- install additional BLM in BGC radiation hotspot
- install additional BLM close to BGC to enhance jet sensitivity
- test BGC-induced signal on new BWS scintillators







Conclusion and outlook

- BGC performance as average emittance monitor assessed with protons
  - successfully validated in the direction of the gas jet
  - perpendicular direction more challenging but margin for improvement

- re-commissioning with ions pending in 2024
  - encouraging results from 2023 ion run
  - could mitigate lack of emittance monitoring at injection energy

- investigations ongoing to exploit jet-induced losses as stronger signal for transverse beam diagnostics

Thank you for your attention!

Spares

Image processing