11th BGC collaboration meeting
Liverpool
2nd December 2024

Summary of 2024 experimental results at LHC

D. Butti on behalf of the BGC collaboration

The Cockcroft Institute of Accelerator Science and Technology

Overview of 2024 run

YETS / machine commissioning

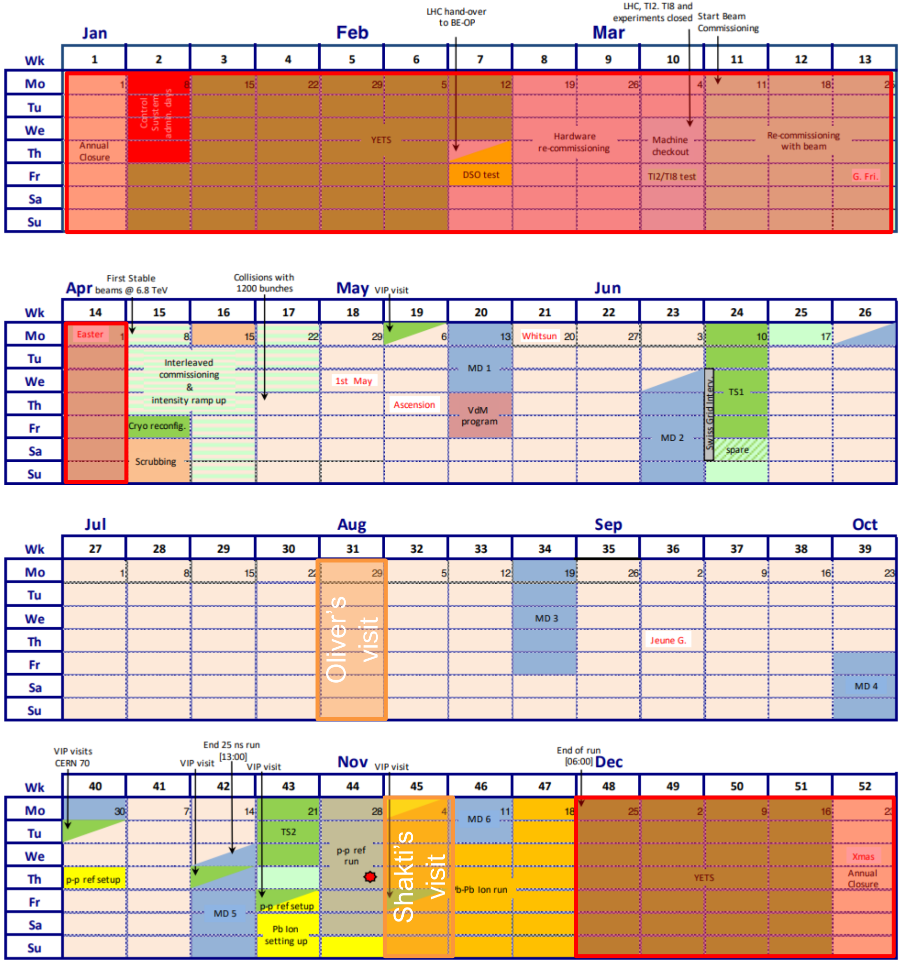
- resolution and focusing studies
- development of data processing tools

Proton run

- re-commissioning with beam, addressing open points from 2023
- systematic measurements

Ion run

- re-commissioning with ions
- systematic measurements with real time emittance monitoring



System re-commissioning

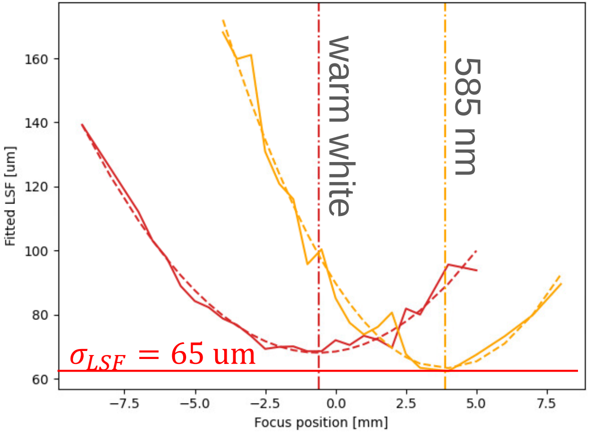
Focusing and resolution assessment

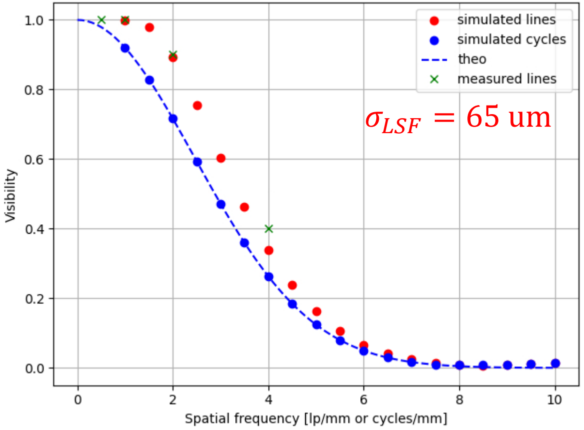
YETS 24

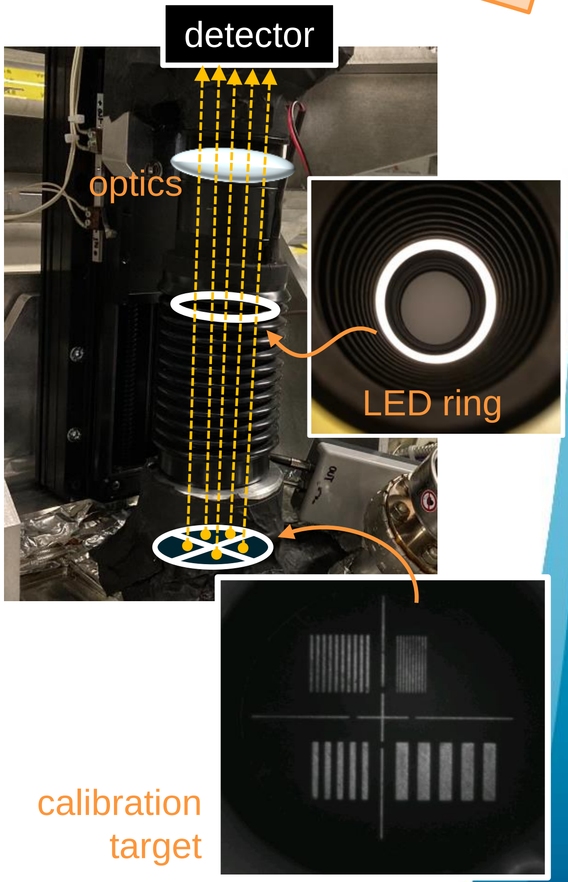
Magnification and resolution of the optics needed to get beam size from the image size

$$\sigma_{image} = \boldsymbol{M}\sqrt{\sigma_{source}^2 + \boldsymbol{\sigma_{res}^2}}$$

Several tests during YETS
→ independent techniques yield consistently **~65 um resolution**

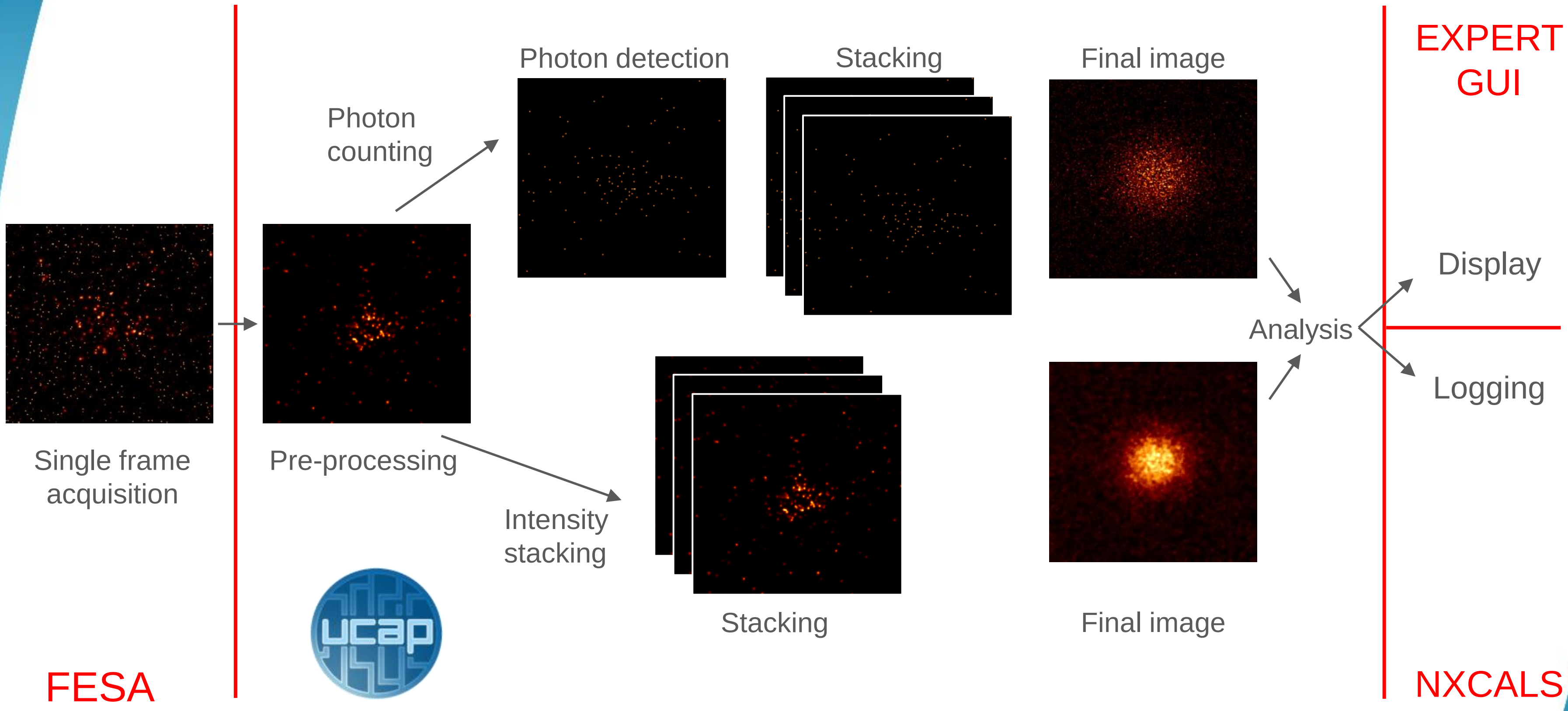






Data processing

YETS 24

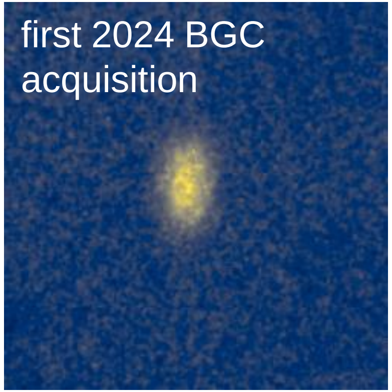


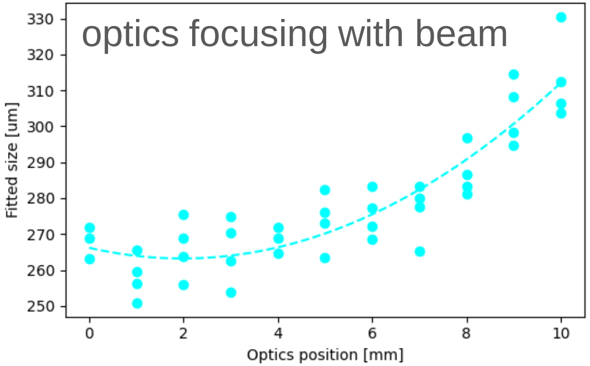
System re-commissioning

Intensity ramp-up

BGC re-commissioned during LHC intensity ramp-up

- optics centered and focused
- recommissioning of gas injection system in steps
- beam losses confirmed well within BLM limits



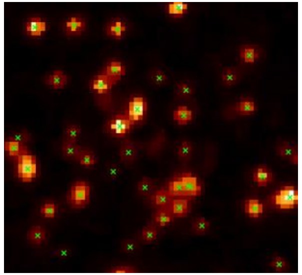


Photon counting vs frame stacking

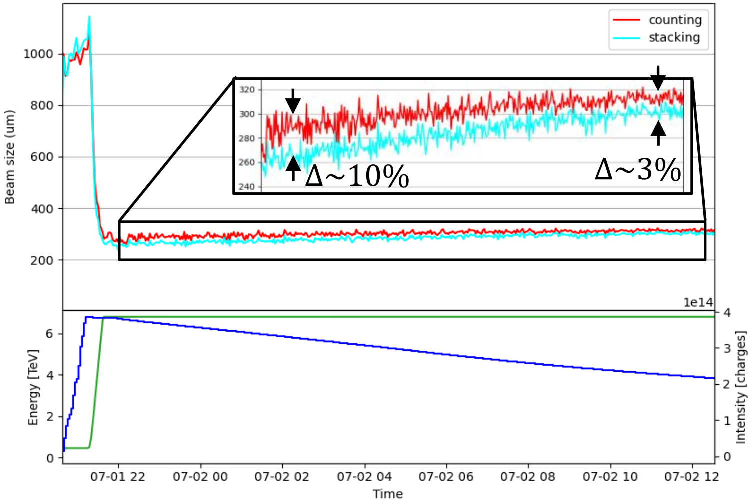
Intensity ramp-up

Photon counting and intensity stacking approaches compared

- **generally consistent**, except for counting failure due to clustering
- no evidence of major advantage with photon counting.
  Stacking used in regular operation (simpler and faster)



Example of photon detection in a single frame of 50ms exposure



For large beams, counting and stacking coincide (e.g. injection energy)

For small beams, counting is systematically larger, due to failure of photon counting at high photon density.

Exposure < 25 ms required in single photon studies.
Data recorded for offline analyses.

Highlights from proton run

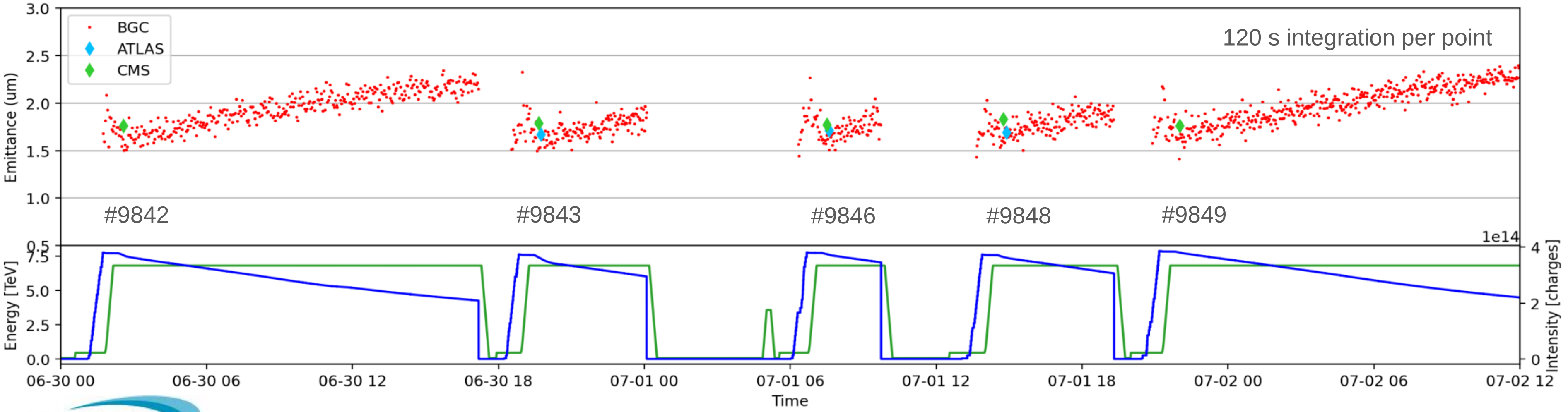
Accuracy validation

Proton physics

Assessing accuracy and reproducibility of absolute measurements

- observing **visible** neon transition (no space charge)
- considering **horizontal** direction (no jet thickness effect)

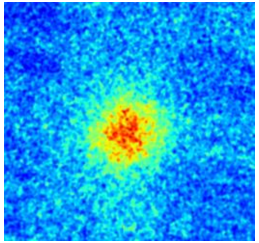
Noisy measurements (±10% peak-to-peak) but values **consistent** with emittance scans and **reproducible** over several fills

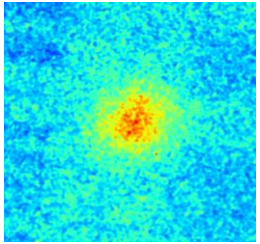


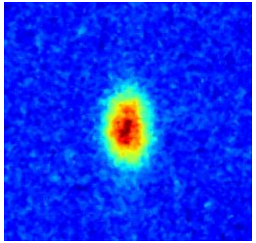
Limitations with visible fluorescence

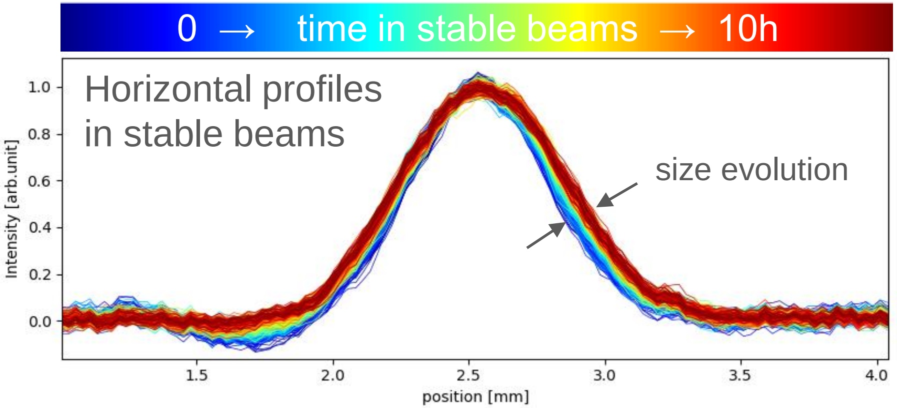
Working with the neutral line has drawbacks

- poor signal → noisy measurements
- long exposures → limited use for transients
- low profile quality → impossible to deconvolve


Injection


Start of ramp


Stable beams

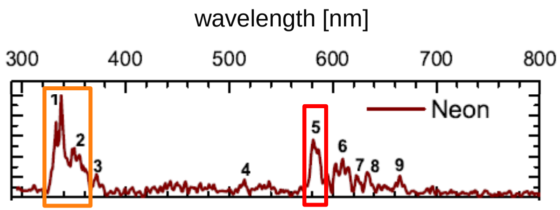


Using visible line with existing configuration, **BGC is effective mostly for accurate assessment of horizontal emittance in stable beams**

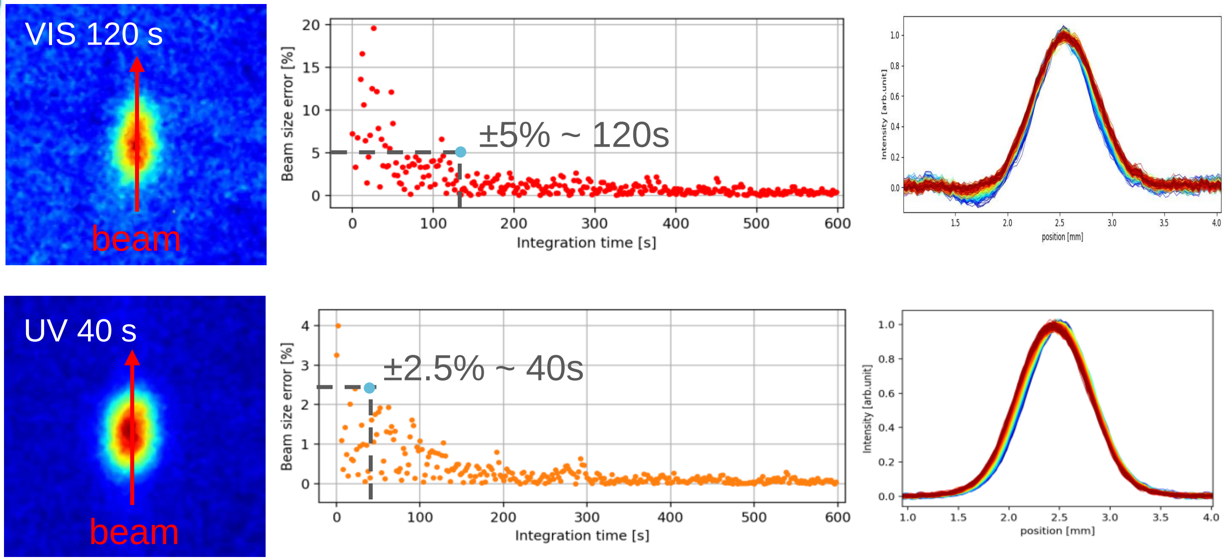
Combining visible and UV fluorescence

Proton physics

BGC optics allows observing the **more intense UV lines** of neon



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



Apparent **gain in signal quality**

- exposure time < 1 min
- lower statistical fluctuation of fitted size
- better profiles

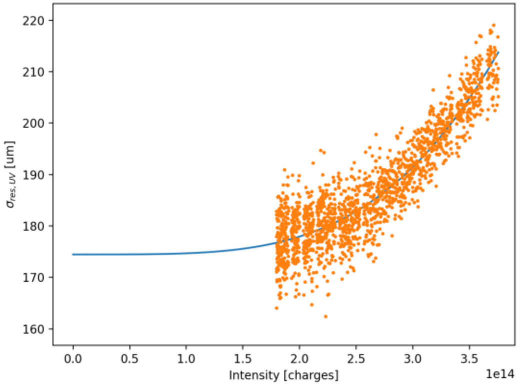
Combining visible and UV fluorescence

Proton physics

Better signal quality comes at the **cost of poorer resolution** due to space charge effects

Problem of **UV resolution handled in semi-empirical way**

- assume visible measurement provides “true” beam size
- derive UV resolution as a correction parameter, polynomial function of the beam current



Obtained resolutions in the order of 200 µm, vs 65 µm measured with visible light.

This is not ideal for flat-top beam size but **good for injection and ramp**, where the higher signal is actually demanded

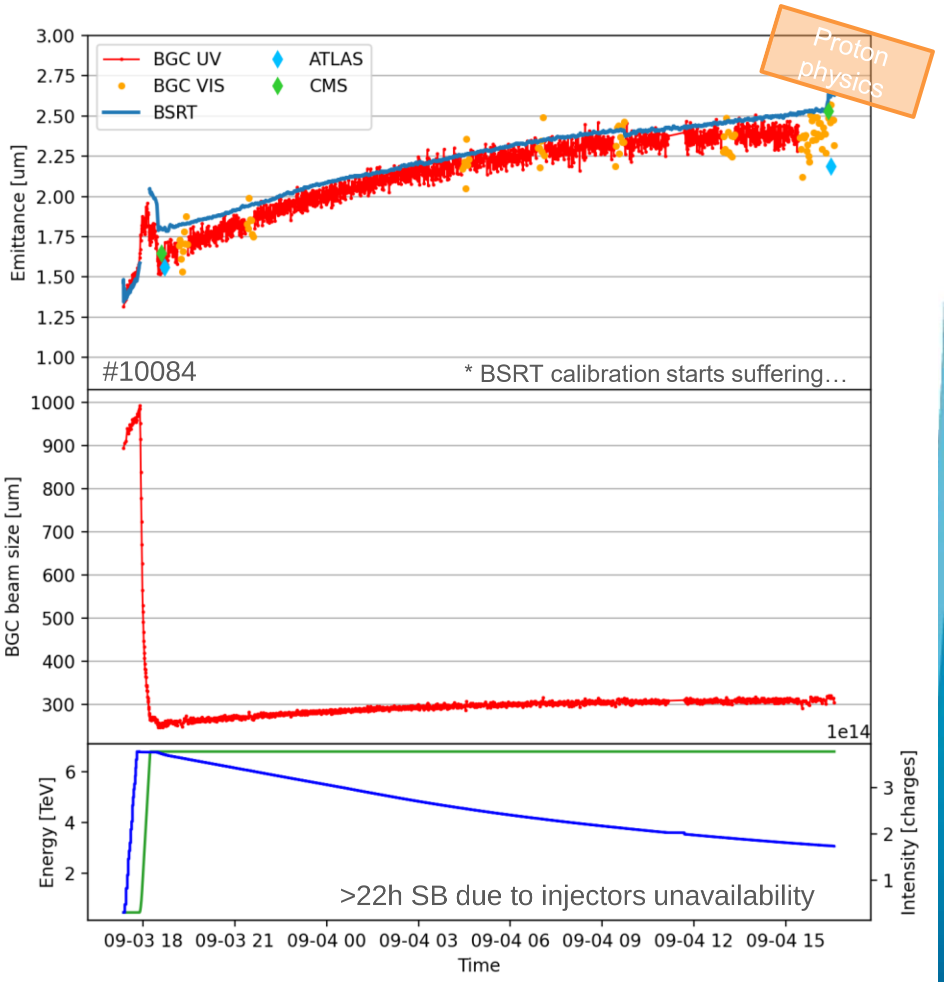
Combined results for horizontal plane

Combined UV and visible measurements allows **accurate measurements every 40s**

Fluctuations within **±5% in emittance**, compliant with specifications from operation

Absolute values still compatible with emittance scans at start and end of fill

This configuration was setup towards end of proton run, **long term reproducibility to be assessed**

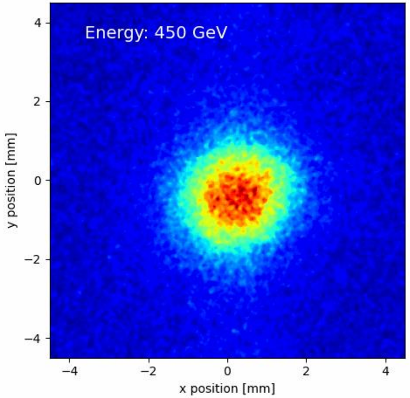


Combined results for horizontal plane

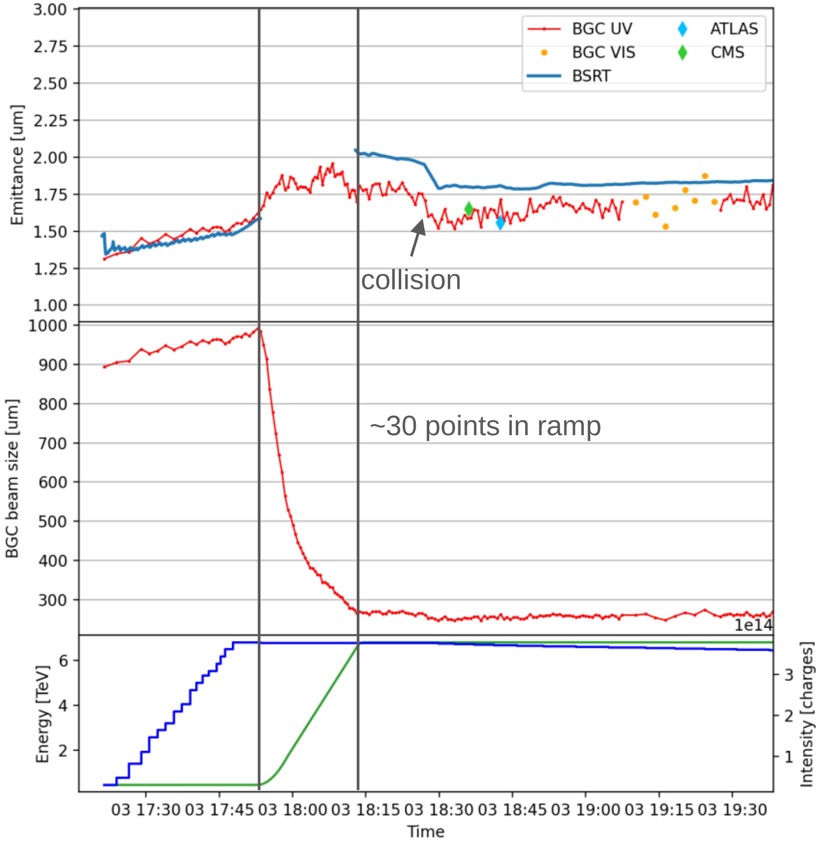
Proton physics

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

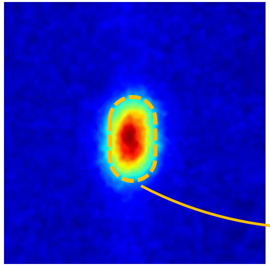


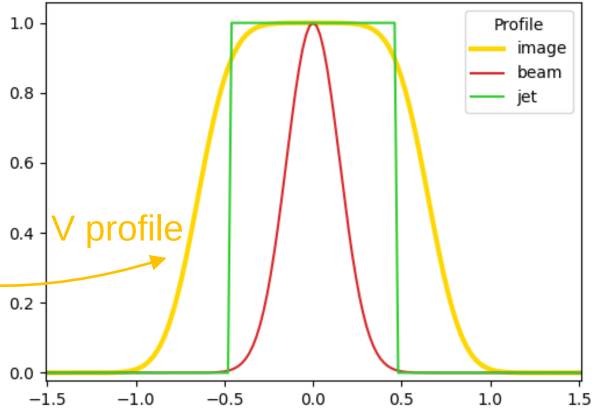
BGC UV acquisition during energy ramp (ROI follows beam size)



HiLumi HL-LHC PROJECT

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**

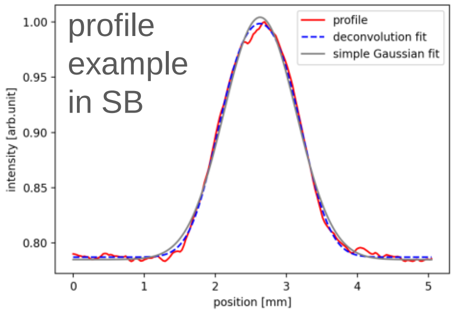
... these issues are mitigated if beam size is larger (low energy)

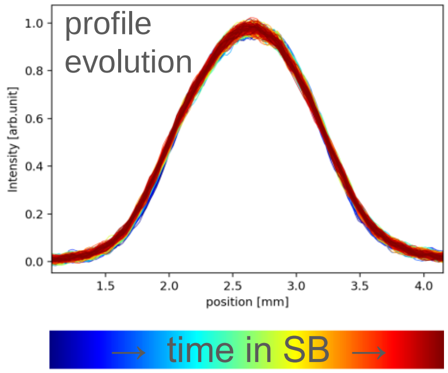
Vertical direction

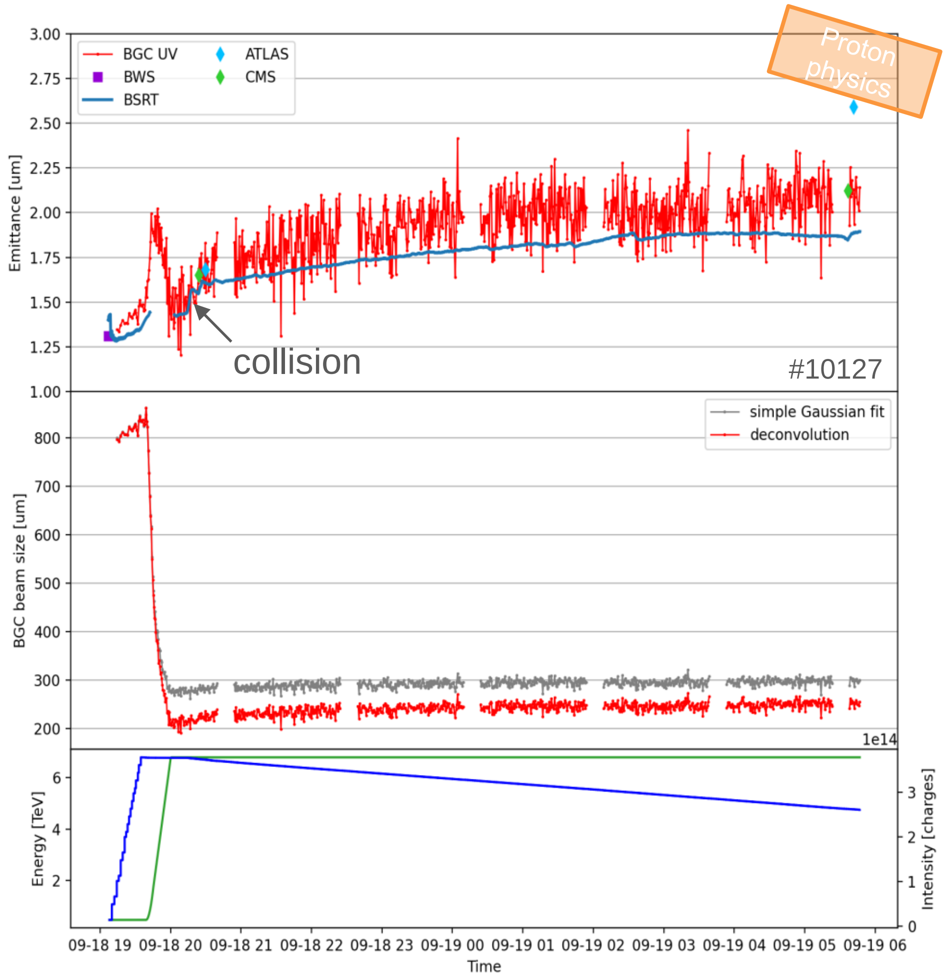
Deconvolve BGC UV profiles to assess beam size

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

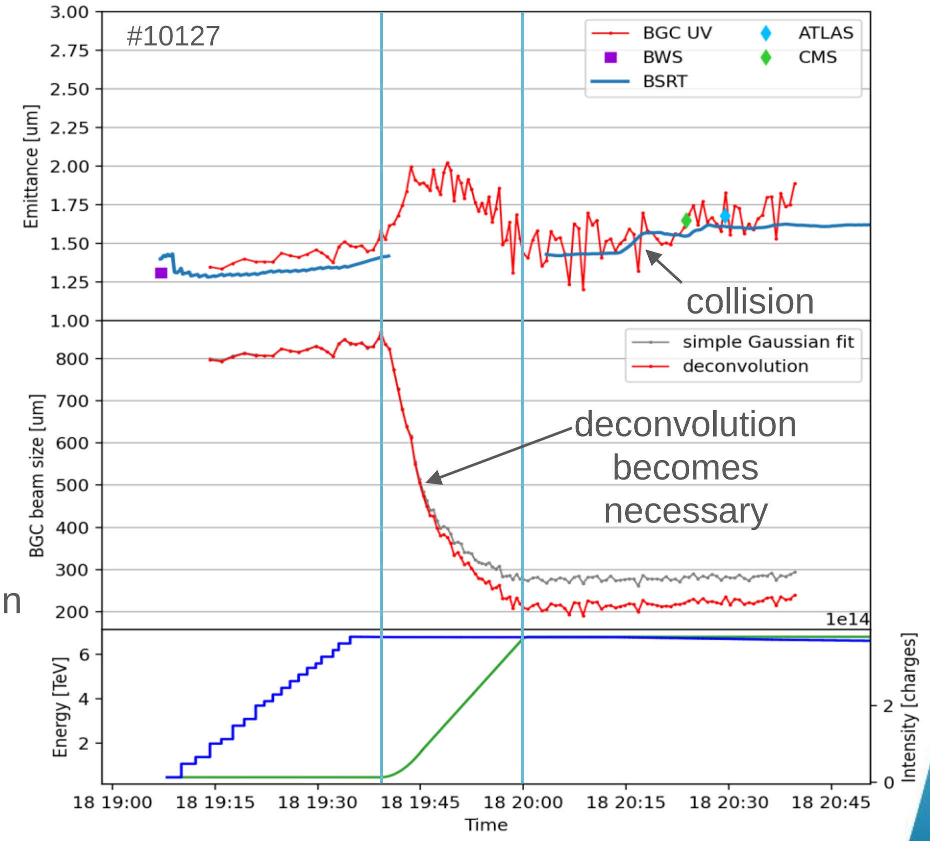
Proton physics

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



HiLumi HL-LHC PROJECT

Highlights from ion run

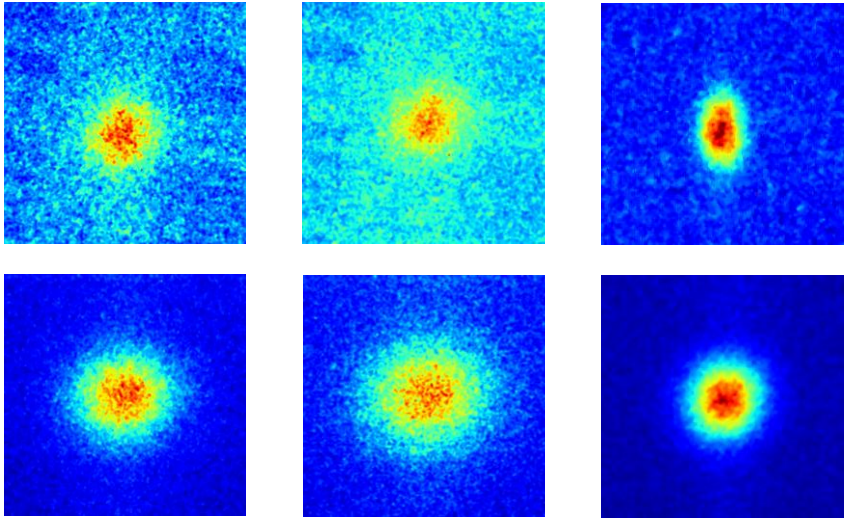
Performance with ion beams

Ion physics

More favorable conditions with ion beams

- stronger fluorescence signal
- larger beam sizes

sufficient signal with visible configuration, no need to combine UV signal



Limited availability of BSRT with ions:

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

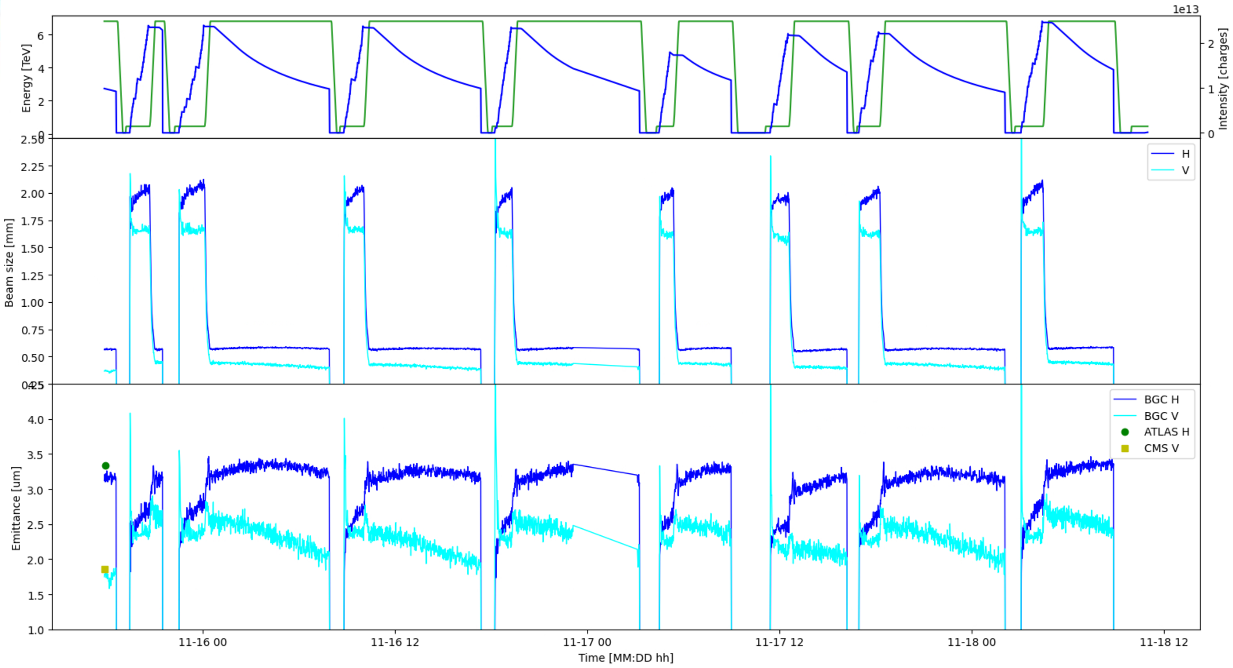
there is already the case for extra diagnostics

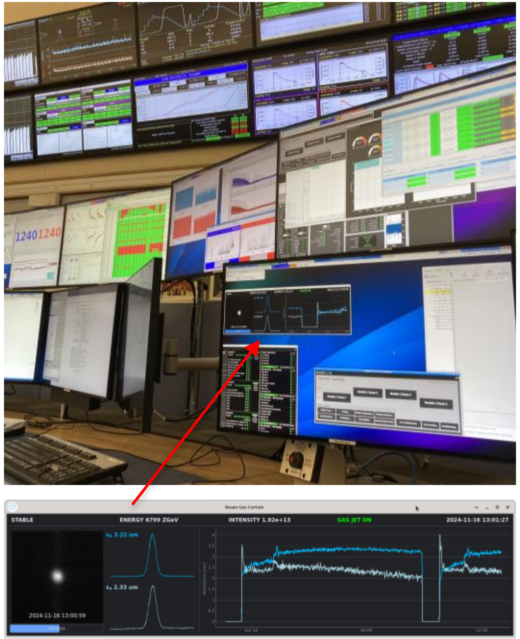
Highlights from 2024 ion run

Ion physics

BGC continuously running throughout 2024 ion run, close to an operational way

Average emittance measurements available online





Conclusion

BGC performance as emittance monitor thoroughly assessed in 2024

Achievements with **proton beams**

- accurate and reproducible measurements for horizontal direction in stable beams
- combined UV-visible operation best option for injection and ramp
- reducing jet thickness beneficial for vertical direction in stable beams

Achievements with **ion beams**

- stronger fluorescence and larger sizes simplifies BGC operation
- effective online emittance monitoring during ion physics production

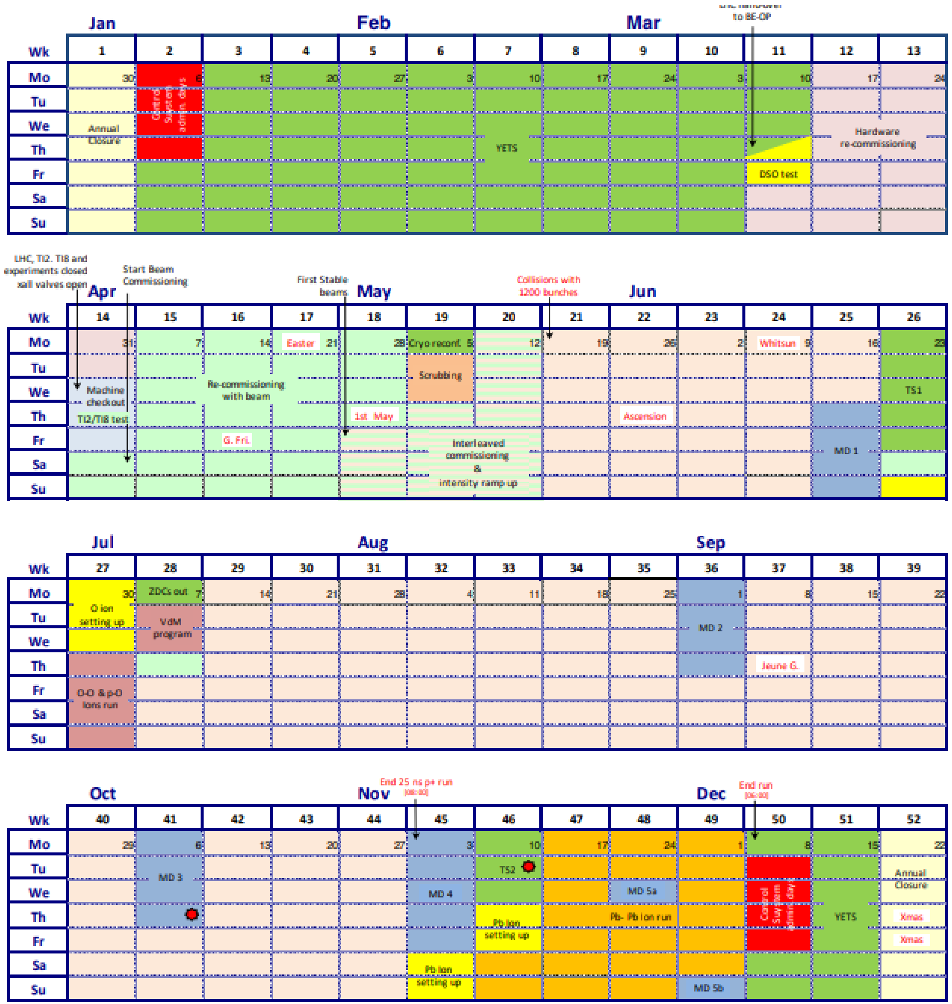
Towards 2025…

2025 run will be shorter due to the extended YETS 24-25

Yet, dense program for BGC

- assessment of long term stability
- operational implementation of combined UV-visible operation
- improve vertical measurements with thinner jet (hopefully)
- extra O-O ion run planned
- studies to upgrade to loss-based diagnostics
  (but this is another story…)

…stay tuned!



Thank you for your attention!