Nitrogen as a gas jet for the BGC

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- Why are we talking about this again?
- What is the interest in using N_2 as a jet?
- What are the issues?
- Possible options for use
- Associated ‘next steps’

What has changed since the GSI Meeting last year?

- Good analysis from Serban/Peter highlight the benefits of N_2, considering also the whole optical signal chain
  - Also validated by experimental results at CI and Munchen
- Experimental results with residual gas in the LHC from Stefano reveal the signal/noise issue that we will face, highlighting the importance of a strong signal
- Closer collaboration with the CERN vacuum group has allowed for a more open discussion on possible risks and benefits of different gasses in the LHC
- New simulation code at GSI gives hope that the e-m distortion of the N_2^+ ion can be understood (and even corrected-for?)

Fluorescence signal

Table 2: Average integration time $<t_i>_{MCP}$ for the detection of one emitted photon and total estimated integration time for the three working gases considered, using the parameters defined in Table 1.

Projectile	Emitter	λ [nm]	σ [cm²]	I [A]	η_{pc}	Estimated Integration time [s]	
						Single photon $<t_i>_{MCP}$	**Total** protons: 10^2 photons electrons: 10^4 photons
electron	N_2^+	391.4	$9.1\cdot10^{-19}$	5	0.19	$2.9\cdot10^{-7}$	0.003
proton	N_2^+	391.4	$3.7\cdot10^{-20}$	1	0.19	$3.6\cdot10^{-5}$	0.004
electron	Ne	585.4	$1.4\cdot10^{-20}$	5	0.09	$4.0\cdot10^{-5}$	0.4
proton	Ne	585.4	$4.7\cdot10^{-22}$	1	0.09	$5.9\cdot10^{-3}$	0.59
electron	Ar	750.4 & 751.5	$7.4\cdot10^{-20}$	5	0.02	$3.4\cdot10^{-5}$	0.34
proton	Ar	750.4 & 751.5	$3.3\cdot10^{-21}$	1	0.02	$3.8\cdot10^{-3}$	0.38
electron	Ar^+	454.5 & 476.5	$9.9\cdot10^{-21}$	5	0.20	$2.5\cdot10^{-5}$	0.25
proton	Ar^+	454.5 & 476.5	$1.7\cdot10^{-21}$	1	0.20	$7.4\cdot10^{-4}$	0.074

From our IBIC '18 paper (Serban/Peter)

We would expect **138x more signal** for 10 keV electrons and **164x more signal** for 7 TeV protons from N_2 than from Ne

Results from the CI test bench for 5 keV electrons (presented 29/3/2019) compare well with these numbers, with 10-40% differences, (which seem acceptable) considering assumptions and experimental errors

Results from the tests at Munchen with 13.8 MeV protons (presented by Serban on 27/11/18) also confirm these simulations

N2 and the LHC Vacuum System

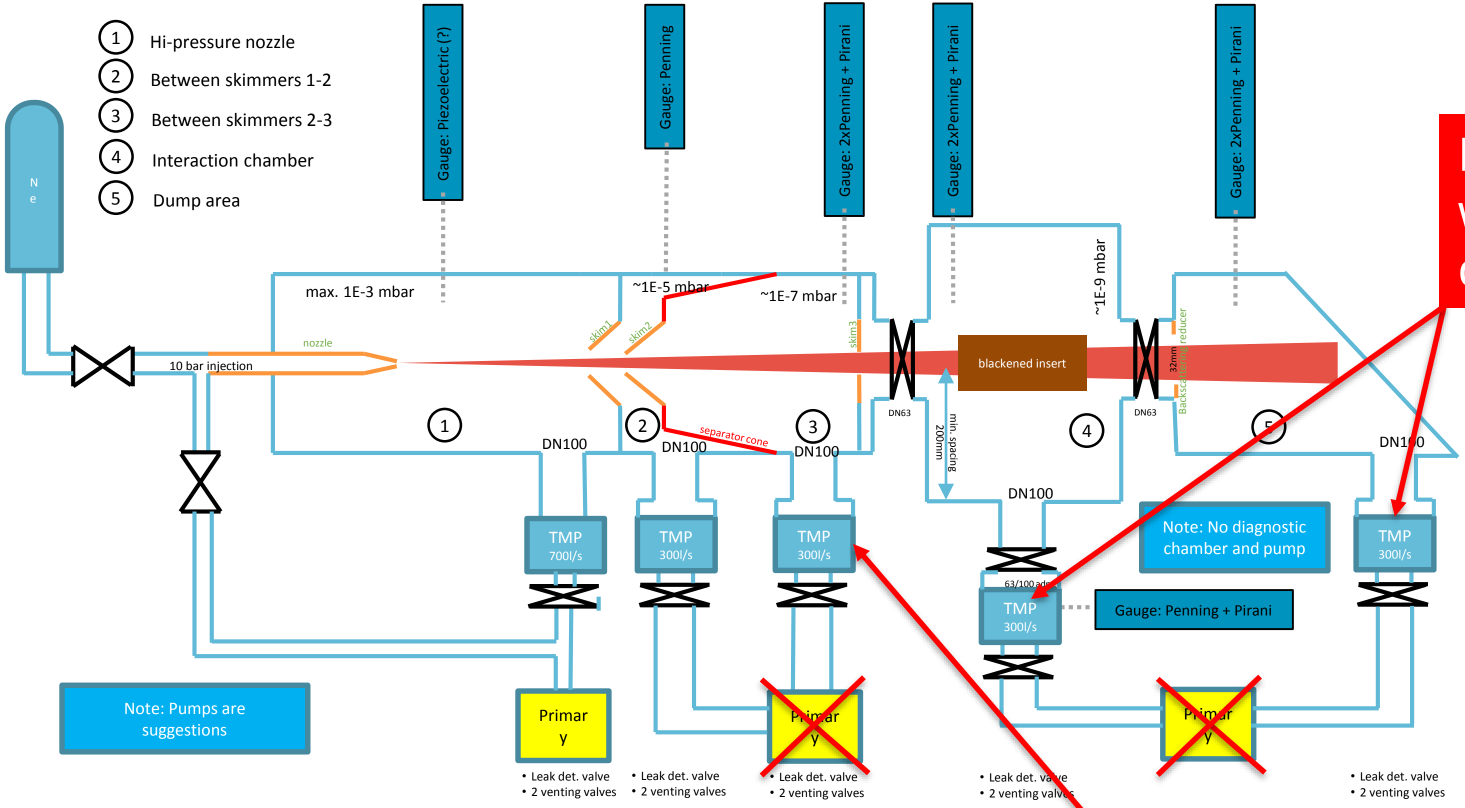
- Neon
  - Noble gas, not pumped by NEG (either on the LHC vacuum chambers, or in cartridges), or by ion pumps
  - Low condensation temperature (24 K) so not suitable for commercial cryo-pumps
  - Neon requires turbo pumps, which have unlimited capacity and good pumping speeds over a wide pressure range, but these do not work well in magnetic fields
  - Neon will not saturate local NEG surfaces (good), but can travel along the beampipe until it encounters cold surfaces (not good)
- Nitrogen
  - Good pumping speed with NEG, ion pumps and can be cryo-pumped (77 K condensation temp.)
  - Will saturate local NEG coatings (not good), so careful ‘inventory management’ may be needed, but effects should be local
  - Can use NEG cartridges but their capacity is limited. NEG cartridges are insensitive to magnetic fields, so no issue with solenoid stray field

Could we use NEG cartridges for Nitrogen?

- Estimated gas load in the interaction and dump chambers
  - IP pressure is 3.3e-10 and Dump is 3.4e10 mbar with effective pumping speed of 170 l/s
  - Corresponds to 6e-8 mbar.l.s^{-1} gas load
  - ‘Capacitorr’ HV 200/1600 NEG cartridges have N_2 capacity of more than 10 mbar.l and a similar size to a 300 l/s turbo pump
  - This gives a time between re-activation of more than 20 years of 24/365 operation
    - Could even imagine to use this in the Skimmer 2-3 region where pressures are 100x higher

CERN V3 Installation

Changes for a N_2 gas jet



Replace with NEG cartridge

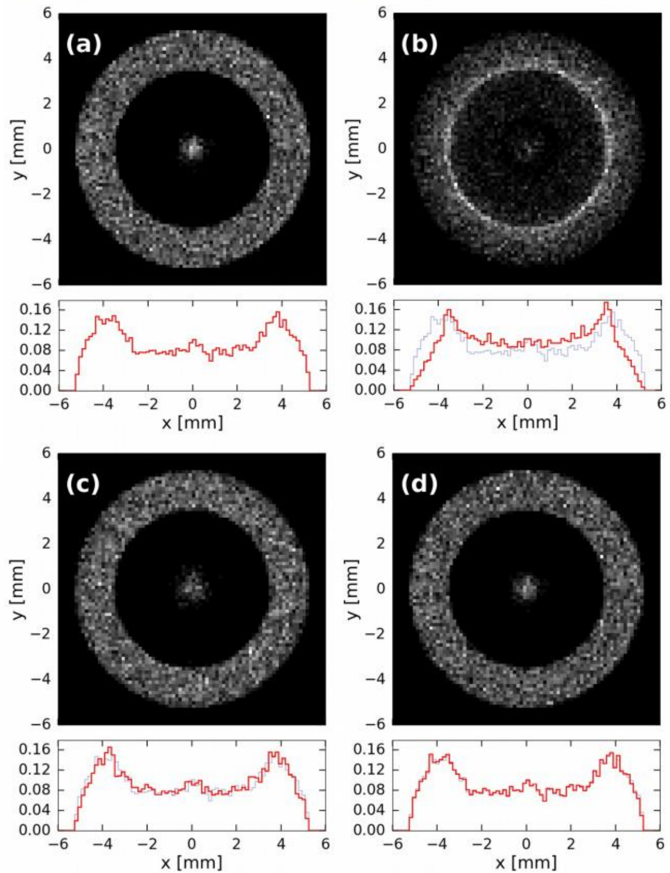
Perhaps also replace with NEG cartridge?

Working gases overview

	N_2	Ne	Ar
General remarks	Fluorescence almost exclusively due to N_2^+ at λ around 391 nm. Highest photon yield.	Strong fluorescence due to Ne at λ > 580 nm relatively strong emission due to Ne^+.	Strong Ar lines at λ > 700 nm, relatively strong Ar^+ lines for 400 < λ < 500 nm.
Life times (τ)	The relevant transition of N_2^+ has τ ≈ 60 ns. Cascades seem to play no role. No branching.	The relevant Ne^+ transitions have τ ≤ 10 ns, unknown cascade influence. The $2p_1$ Ne level has τ ≈ 15 ns, negligible branching and cascade influence.	Relevant Ar^+ transitions have 10 < τ ≤ 20 ns, little cascade influence, branching can be advantageous(*). Ar lines have 20 ≤ τ ≤ 40 ns, cascades are not expected to significantly influence image quality.
Mass	28 u	20 u	40 u
$τ^2/m$	129 ns²/u	≤ 5 ns²/u, if no cascades!	(*)2 ≤ τ ≤ 10 ns²/u
Exp. data availability for σ	Up to 1 keV for e^-, up to 450 GeV for p.	Ne: up to 1 keV for e^-, up to 1 MeV for p. Ne^+: no data identified yet.	Ar: up to 1 keV for e^-, none for p. Ar^+: up to 1 keV for e^-, none for p.
γ-cathode efficiency	Good for the strongest N_2^+ lines.	Poor for main Ne lines, good for Ne^+ lines.	Very poor for main Ar lines, good for Ar^+ lines.
e.m. fields influence	Relatively strong distortion expected due to large $τ^2/m$	None for Ne, relatively low distortion expected for Ne^+ because of low $τ^2/m$	None for Ar, relatively low distortion expected for Ar^+ because of low $τ^2/m$
Integration time	Very low for e^-, low for p, as estimated for the N_2^+ 391.4 nm line.	Low for e^-, large for p, as estimated for the Ne 585.4 nm line.	Lower than for Ne but large as compared to N_2^+. Integration over 400 < λ < 500 nm may be useful!

Simulations of expected images for N_2^+, Ne^+ and Ar^+

Simulations performed with the **virtual-ipm** code
pypi.org/project/virtual-ipm



2D and 1D histograms of the detected photons assuming **ideal gas curtain and optics with unit magnification**. The bin size is 0.15 mm. The 1D histograms are normalized.

(a) No distorsions
(b) N_2^+, τ_{BIF} = 60 ns
(c) Ne^+, τ_{BIF} = 11 ns
(d) Ar^+, τ_{BIF} = 9 ns

The 1D histogram from (a) is reproduced in grey in all the others.

Simulation parameters

B_{sol} = 1 T
I_e = 5 A
D_e = 10.5 mm
d_e = 7 mm
$\langle I_p \rangle$ = 1 A
σ_{tp} = 0.3 mm
$4 \cdot \sigma_{lp}$ = 1.01 ns
$N_\gamma^e \approx 12500$
$N_\gamma^p \approx 250$

Such simulations should be performed with a realistic gas curtain too for a better reproduction of the image to be expected.

Possible options for using N_2

- Use N_2 jet for post-LS2 fluorescence tests
  - Should give significant improvement in p+ signal for these early tests (enough even for a profile?)
  - No issue with solenoid field distortion
  - Should be compatible with existing pumping solutions. Could imagine to switch between gases?
  - Would need discussion with VSC and a new gas system (purification?). N_2 already injected in LHCb?
  - Gas volume injected for these background tests is higher than for the final BGC instrument – how could we maintain a stable pressure without significant saturation of NEG coated surfaces?
- Use a N_2 jet to fully replace Ne for the BGC
  - Give improvement for both e- and p+ signals
  - Could implement NEG cartridge option for e-lens
  - Would need to resolve the field distortion issue

Key questions

- Which is more of an issue for the CERN vacuum group:
  - Gas migration on non-NEG gasses (Ne) into cold sectors, or possible saturation of NEG coated surfaces by pumped gasses (N_2)
- Can we measure profiles (or at least ensure a correct overlap measurement) for N_2, either:
  - In the presence only of the p^+ beam
  - With both P^+ and e^- (and associated solenoid field)

Possible next steps

- Simulations of e-m distortion of a N2 gas jet in the presence of (only) the LHC p+ beam
- Discussions with VSC on the pro’s and con’s of these gases
  - Should we be planning to use this for the LHC background gas test in Run 3? This could be more ‘delicate’ than the final BGC instrument
- Tests with NEG cartridge pumps?
  - Do we need to qualify their performance?
- Investigate integration with NEG cartridges
  - Should be easier than a turbo…
- Will we need to wait until we can take data from the HEL Test Stand?
  - This could be quite late for a project decision. How could we work with this?

Discussion?

Special thanks to Serban, Hao and Gerhard for their valuable input