Preliminary gas target specification for the BGV (v1)

- What drives the gas target density requirement
- Gas types
- Densities
- Other requirements

For discussion

BGV for LHC

NB: it will measure beam **shapes** → must be able to measure accurately absolute value of β function at the device position!

Specifications:

- provide measurement of emittance
  - stat accuracy of <5% in ~~5~~ 3 min for 10^{11} p
  - syst uncertainty <5% (dominated by understanding of vtx resolution ?)
  - for $1.5 < \varepsilon_n/\text{um} < 4$ and $0.45 < E/\text{TeV} < 7$
  - bunch by bunch (max bunches per measurement to be defined?)
- should not affect beam operation

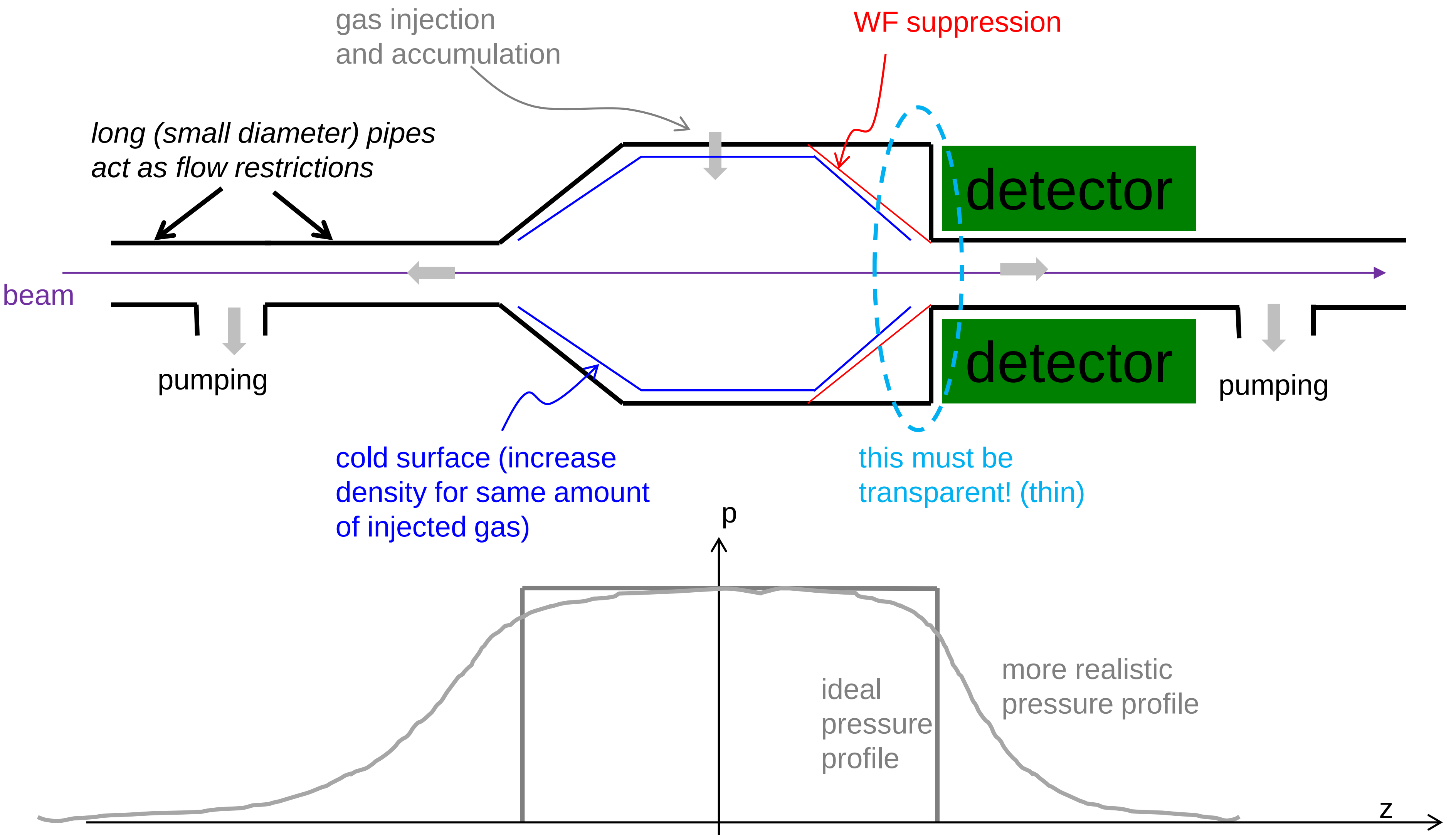
By-products:

- Measurements of beam positions and angles
- measurement of ghost charge (crucial for lumi calib)
  see A. Alici et al. (BCNWG note4), CERN-ATS-Note-2012-029 PERF
- measurement of relative bunch charges (to be normed by DCCT)
  see G. Anders et al. (BCNWG note3), CERN-ATS-Note-2012-028 PERF

Possible add-on: (not in baseline discussed here)

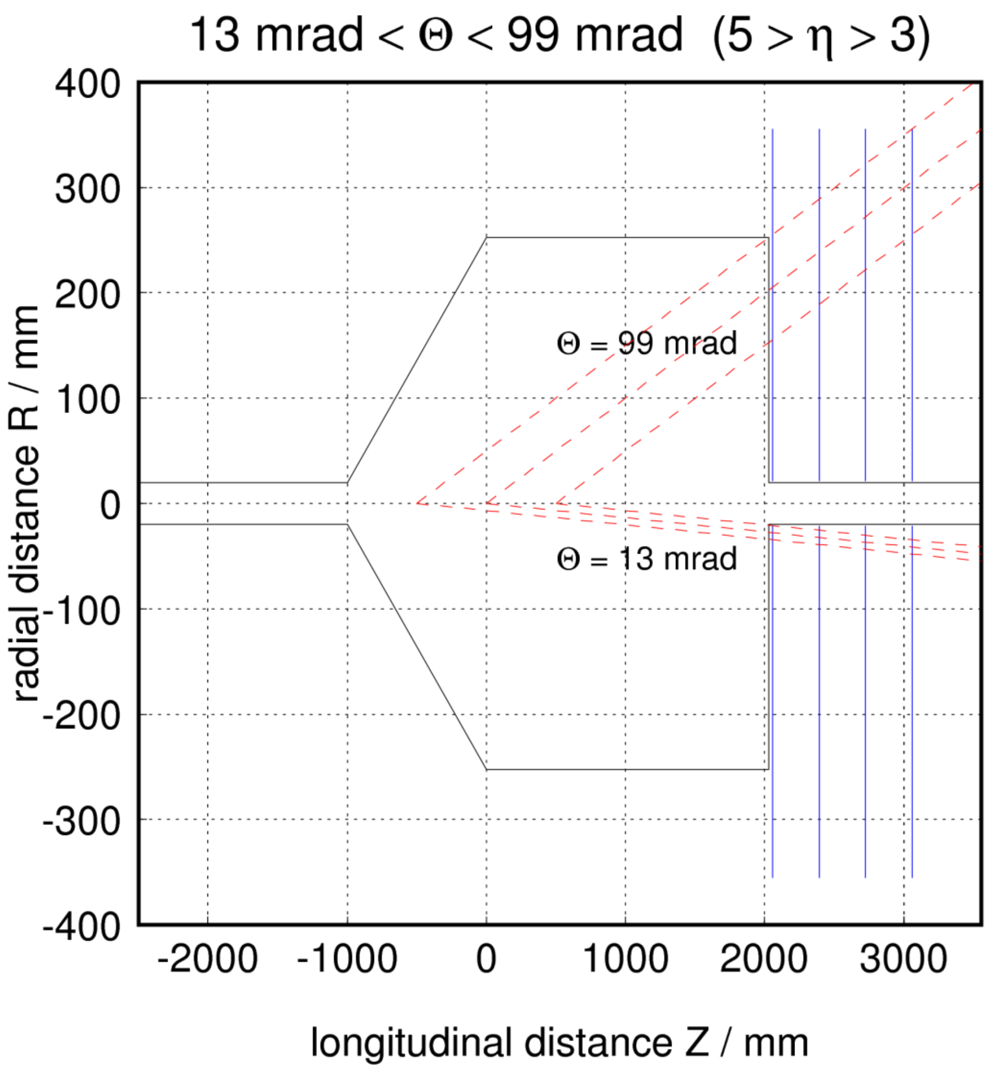
- timing detector with < ~100ps resolution, would provide longitudinal profile as well

Gas target (sketch!!)



Reminder: contrary to VELO/LHCb, here gas injection must be continuous (with beam)... Consider impact on machine!

Sketch of the system geometry (indicative, not final!)



How to specify the target density (thickness)

- Starting point: Assume we want 5% statistical uncertainty per bunch on the transverse sizes in 3 minutes for a bunch of charge $N=10^{11}$p.
  - 8 measurements over a 25 minutes ramp (0.45 to 6.5 TeV).
  - For 5% statistical uncertainty one needs about 200 good events.
  - This requires a rate of a bit more than 1 Hz of good events per bunch.

- The rate is

$$R \;=\; 1\,\text{Hz} \;=\; \rho\; n_A\; L\; N\; f\; A^{2/3}\; \sigma_{pp}\; F_{good}$$

- ρ: average gas density over L
- L: useful longitudinal length of target = 1 m (assumed/educated guess)
- f: revolution frequency = 11245 Hz
- F_{good}: fraction of good events (at least N_{tr} tracks reconstructible)
- n_A: number of nuclei of type A per molecule of gas
- N: bunch population = 1e11 p
- A: atomic weight (nucleons per nucleus)
- σ_{pp}: pp total cross section at 450 GeV (7 TeV). = 40 mb (45 mb)

- This gives the requirement

$$\rho = 2.3\cdot10^{8}\,\text{cm}^{-3} / \left(n_A\; A^{2/3}\; F_{good}\right)$$

Which is the worst case ?

- F_{good} is worst at 450 GeV (and with hydrogen gas), **but the beam size is about 4 times larger at 450 GeV than at 7 TeV**.
- Since the vertex resolution drops roughly with $N_{tr}^{-1/2}$ and F_{good} drops about exponentially as a function of the N_{tr} cut, it turns out that the **most stringent constraint on the gas target comes from 7 TeV** (if we request that the systematic uncertainty be also around 5%).
- We consider that **N_{tr} >9 is probably OK** for a **beam size > 150 um** though this needs confirmation by toy simulations.
- In case of **H_2 target, 7 TeV, small prototype detector, Ntr>9**, we estimate

  F_{good} = ~ 0.002 (see Plamen)

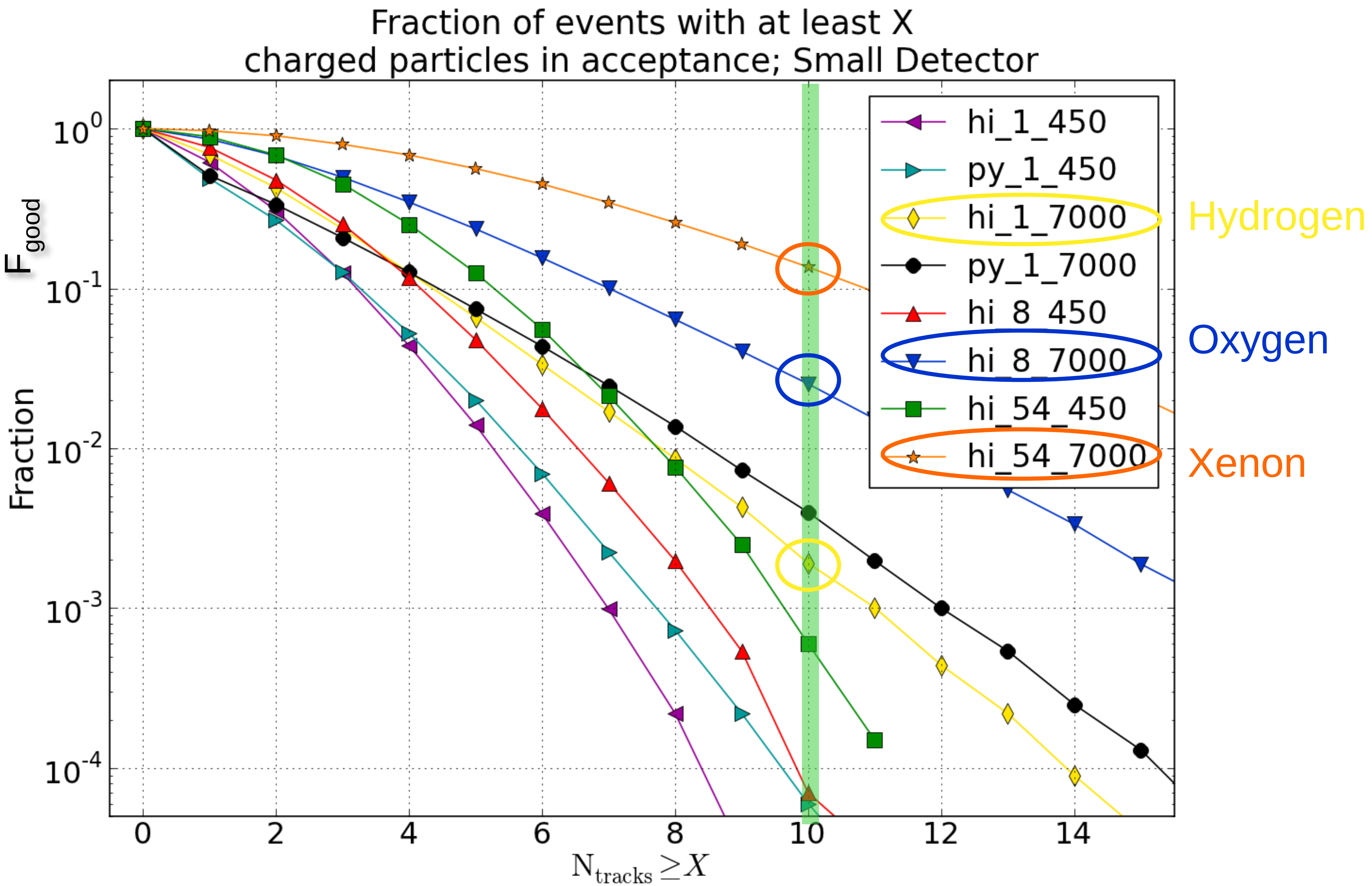
- Thus, (with n_A = 2 and A = 1), we need

  ρ = ~ $6 \cdot 10^{10}$ cm^{-3} <=> p = ~ $2.3 \cdot 10^{6}$ mbar at T_{gas} = 293 K

- This requirement can be alleviated if one uses heavier gases which give the factor $A^{2/3}$ and a larger F_{good}

Plamen's F_{good} for small detector

Consider most difficult case: 7 TeV (beams are 4 times smaller)



Required densities

- Densities (averaged over 1m) that would be needed for the BGV to work adequately for some representative gas types.

Gas type	A	F_{good}	ρ [10^7 cm^{-3}]	p at 293 K [10^{-9}mbar]
Hydrogen	1	0.002	5800	2300
Neon	20	~0.020#	160	64
CO_2	16*	0.020*	60	25
Xenon	131	0.140	7	2.6

Notes: since we only simulated H, O and Xe, we did this:

* A and F_{good} for CO_2 approximated by O_3

F_{good} for Ne assumed same as for O (should be slightly better)

- Can estimate performance of any other gas by estimating the F_{good} from the gas with the closest A and by scaling the density with $A^{2/3}$ (larger A, smaller density needed).
- Reminder 1: ρ is the molecular density, while the rate scales with the number of nuclei per cm^3 !
- Reminder 2: what really counts is the target thickness (ρ integrated along the useful z range)

Lessons

- One sees from this table that a large factor in density can be gained by using molecules containing **larger nuclei**. The requirement for hydrogen is quite elevated.

- A very small F_{good} also means that the bkg events and radiation to elements is much larger than with heavier gases.

- All this makes hydrogen not so attractive.

- On the other hand, a good z-containment of the target would be advantageous. Better usage of the injected gas, less useless radiation, less background events

- CO_2 (or similar) with some strong local pumping seems quite attractive

Other requirements (to start the list…)

- The target gas density should be reasonably constant (i.e. vary by less than a factor of about 2) over the useful z range (about 1m). The z-integrated gas target density outside the useful z range should not be more than inside the useful z range.
  - Gas outside this range will cause unnecessary background rates, irradiation of nearby elements, etc.
  - For the same z-integrated density, the shorter the z extent of the target, the better it is for the detector (and for the machine).
- The target density transverse gradient (in x or y) should be less than $\Delta p / \sigma_{beam} < 0.0?$ p

  Yet to be estimated
  - One can assume σ_{beam} is between 0.1 and 1 mm.
- The BGV can be first installed in a single LHC ring, but it should be kept in mind when choosing the location and design that we ultimately want one BGV per ring.
- The smaller the ratio R_{pipe}/σ_{beam}, the better the performance of the BGV. For the time being, we (conservatively ?) assumed we can make R_{pipe} = ~20mm for a σ_{beam} > 0.15mm .
- The exit window must be thin enough for multiple scattering to be negligible. This must be discussed, but a vertical 1 mm Al thickness (for example) would be good enough.

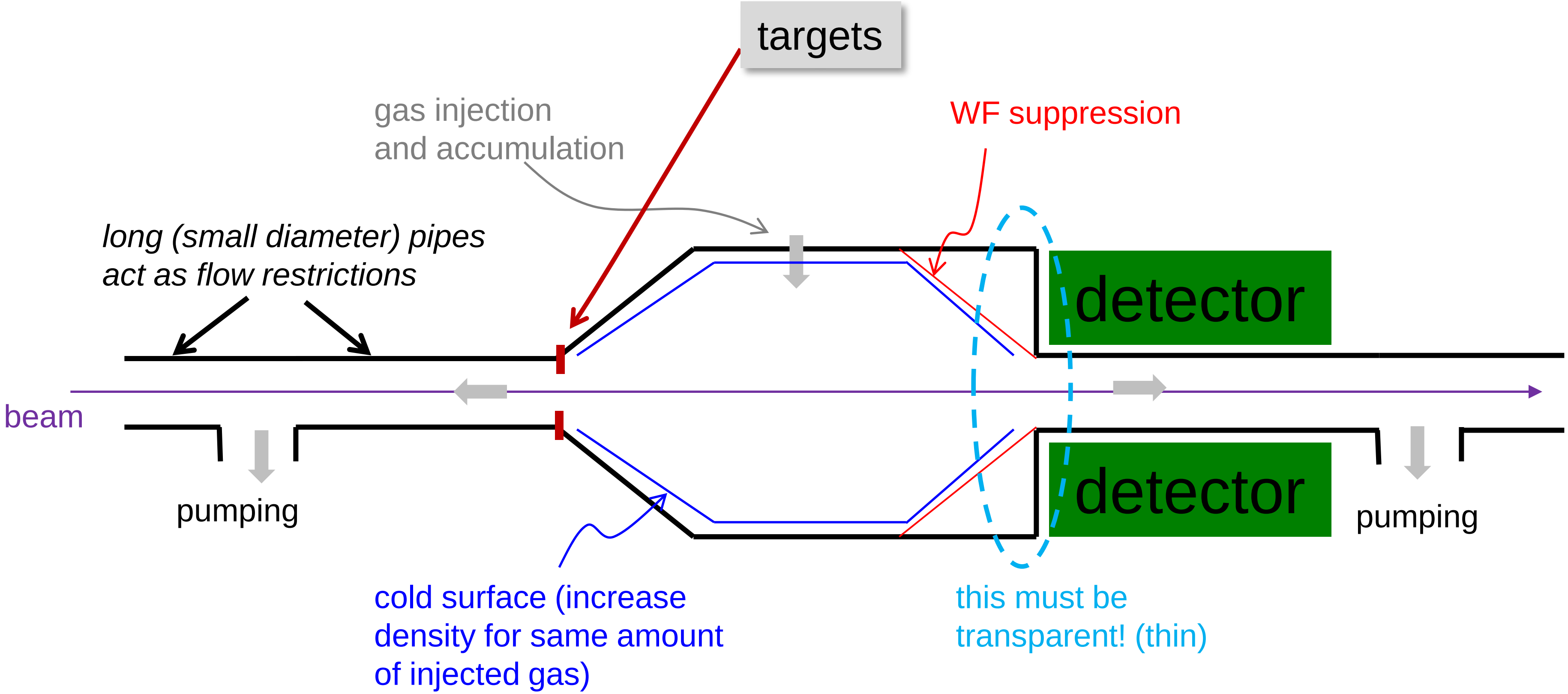
  Yet to be estimated
- The gas target should be available whenever there is beam (any energy, any mode). It is not required for the BGV that the gas be removed in the absence of beam. However, for reasons of irradiation of other elements, and integrity of the beams and beam pipe vacuum, it would be preferable if the gas target can be “switched off” on demand. Ideally, there should be a few settable levels of target density (like “low”, “medium” and “high”), but this is not needed from the start.
- Stability of the gas density is not so critical, though some side effects could appear if sudden and frequent “pressure spikes” take place. No specification other than “reasonable stability”...

  Yet to be estimated
- No effect on beam operation (lifetime >100h, acceptable contamination of nearby section, …)

Further design considerations

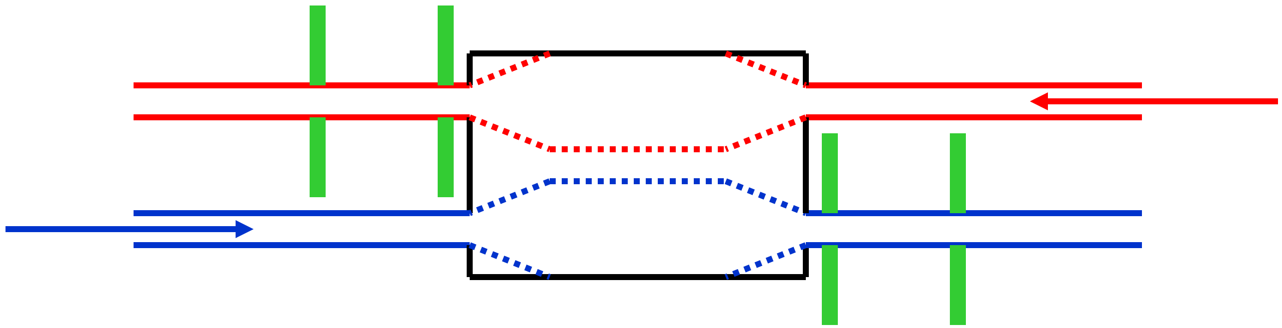
For alignment / resolution studies

- Consider putting some edge target upstream of gas target for determination of detector position relative to machine XY frame
- Move a 450 GeV pilot bunch locally toward the edge targets and reconstruct edge image



How many targets ?

- Can one use a single target for both rings ?



- Advantages:
  - Simpler gas target setup
  - Easier maintenance, possible sharing of cables and spares
  - Can easily move detector from one ring to the other if needed
- But:
  - Beam-gas interactions of one ring should not cause background to the BGV of the other ring
    - Only works if target is well contained in z (not much gas upstream of chamber)
  - Beam sizes in H/V and ring1/2 should be of comparable value

To be done

- Fluence due to beam-gas interactions
- Freeze R_pipe and sigma_beam, then optimize detector geometry
- Design detector station
- Design target

backup

Which gas ?

Inelastic cross section

$$\sigma_{pA} \approx \sigma_{pp} \cdot A^{2/3}$$

Charged pion multiplicities

$$M_{pA} \approx M_{pp} \cdot (a + b \cdot A^{1/3})$$

$a \approx 0.65$, $b \approx 0.3$

MG, DR, Z. Phys C65, 215-223 (1995)

Larger A → larger cross section and larger multiplicity per vertex

Getterable / non-getterable ? (or cryosorption ?)

- getterable: e.g. CO_2, N_2, O_2 ...
  - Very local pressure bump
  - Requires regenerating (changing ?) the NEG sporadically
- non-getterable: e.g. Ne, Xe, …
  - Longer pressure bump, requires differential pumping around the target
  - Some contamination of nearby cryo section surfaces ?