Massimiliano Putignano

Development of a Beam Profile Monitor Based on a Supersonic Gas-Jet Curtain

Website: www.quasar-group.org
Email: massimiliano.putignano@quasar-group.org

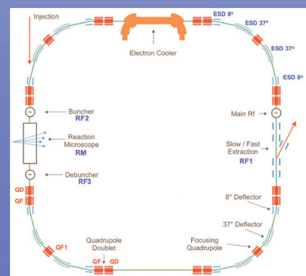
Overview

- Introduction
- Gas-Jet Simulations
- Experimental Setup
- Outlook

Why a Beam Profile Monitor using a Gas Jet?

• USR Project at FLAIR (FAIR facility, Darmstadt)

A. Papash and C. P. Welsch, Physics of Particles and Nuclei Letters, Vol. 6, No. 3. (2009), pp. 216-226.



- Ultra-low energy pbars (20-300 keV)
- Coasting/bunched beam
- Low pressure (10^{-11} mbar)

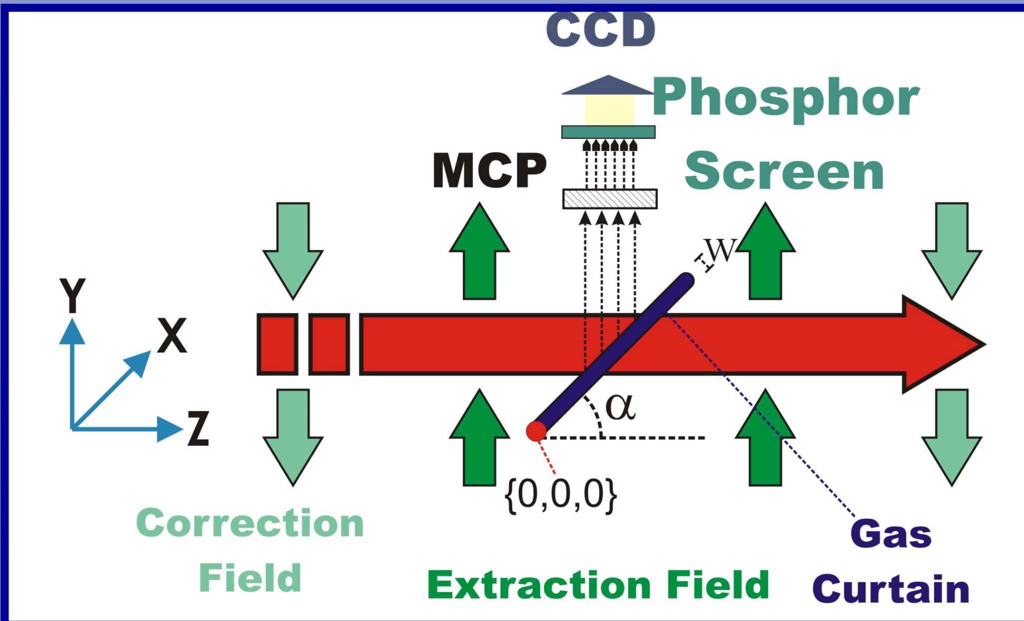
• Technical advantages

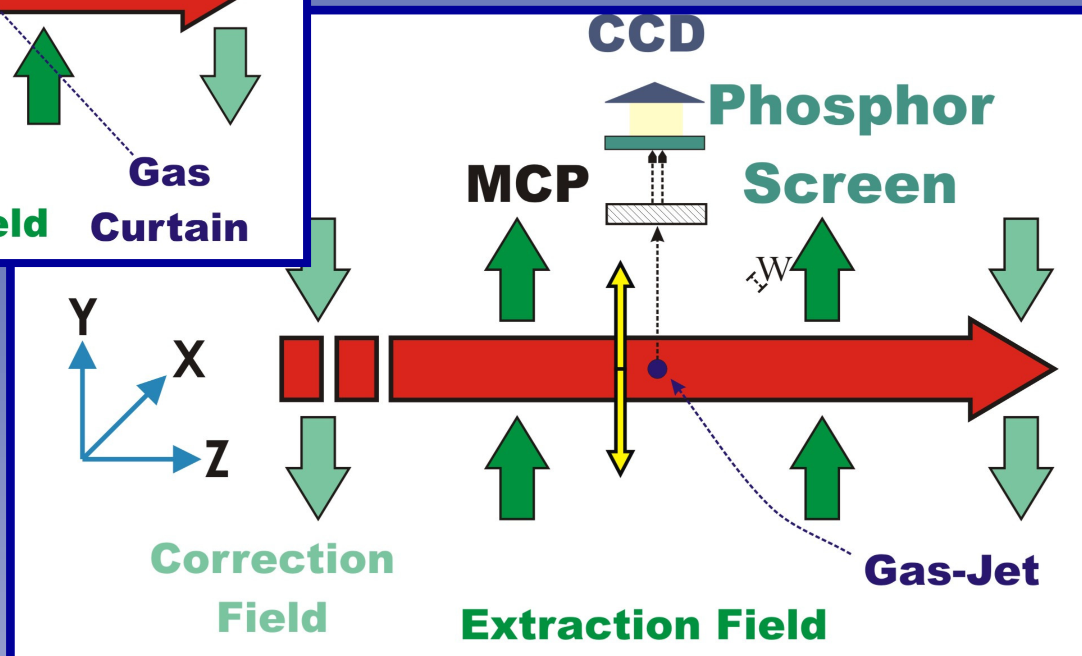
- Low perturbation to beam (storage ring!).
- Low perturbation to vacuum (directionality).
- Tunable count rate/perturbation.
- Simplicity and compactness!

• Inclusion in the Reaction Microscope

• Investigation of the Gas-Jet

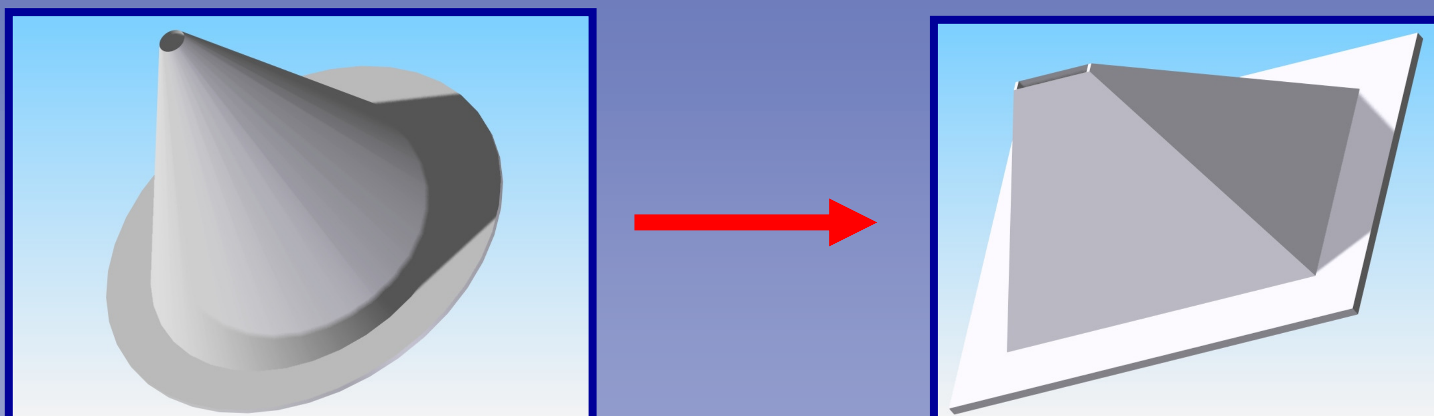
Working principle





What's so special about our particular monitor?

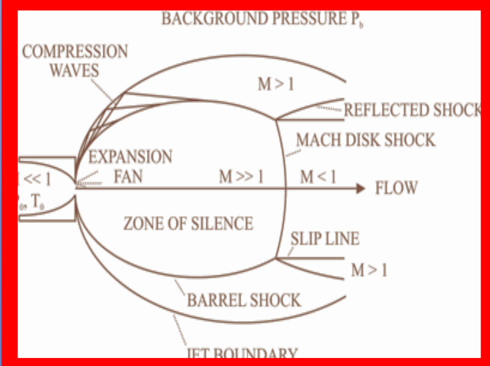
- Inclusion in the Reaction Microscope
- Optimized nozzle-skimmer system geometry
  - Minimize differential pumping (4 TMP used)
  - Compact setup (2 meters crossing the pipe)
  - Larger gas intensity in the reaction region



Estimated performances

- Low beam perturbation
  - All events useful + event rate tunable
  - Maintain beam lifetime in USR > 1 s
- Low pressure perturbation
  - Axis-symmetric jet -> vacuum unaffected at 10^{-11} mbar
- Tunable count rate
  - Up to 10^{8} events/sec

Why do we need numerical analysis?



- Governing equations
  - Continuity Equation
    - A statement of conservation of mass
  - Energy Equation
    - Resulting from neglecting thermal and viscous effects
  - Momentum Equation (Euler's Equation)
    - A statement of conservation of momentum
  - Equation of State
    - Ideal gas equation of state (from kinetic theory)
  - Thermal Equation of state
    - Definition of int. energy and measurement of specific heat.

Why do we need numerical analysis?

- Governing equations
  - Continuity Equation
    - A statement of conservation of mass

$$\nabla \bullet (\rho \cdot \vec{v}) = -\frac{\partial \rho}{\partial t}$$

  - Energy Equation
    - Resulting from neglecting thermal and viscous effects

$$h_0 = h + \tfrac{1}{2} q^2 = const$$

  - Momentum Equation (Euler's Equation)
    - A statement of conservation of momentum

$$\vec{a} = \frac{\partial \vec{v}}{\partial t} + \vec{v} \bullet \nabla \vec{v} = -\frac{1}{\rho} \nabla p - g \nabla h$$

  - Equation of State
    - Ideal gas equation of state (from kinetic theory)

$$p = \rho \frac{R}{W} T$$

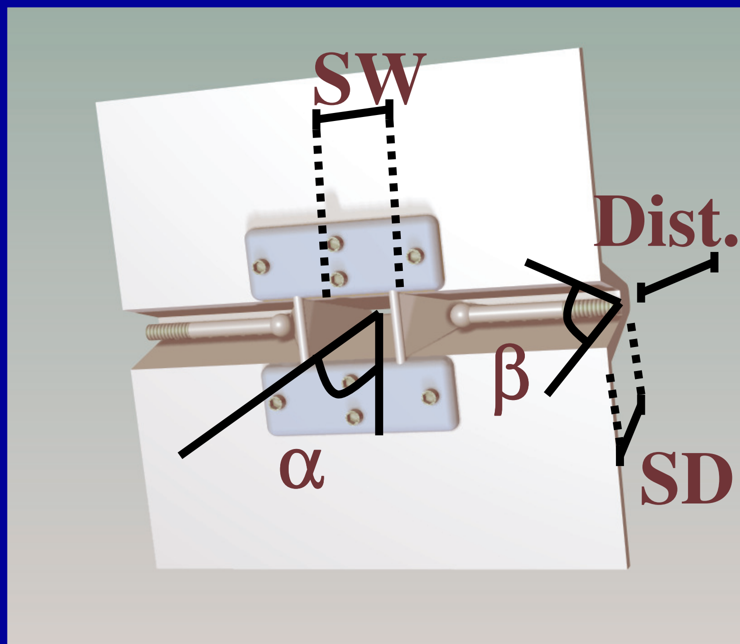
  - Thermal Equation of state
    - Definition of int. energy and measurement of specific heat.

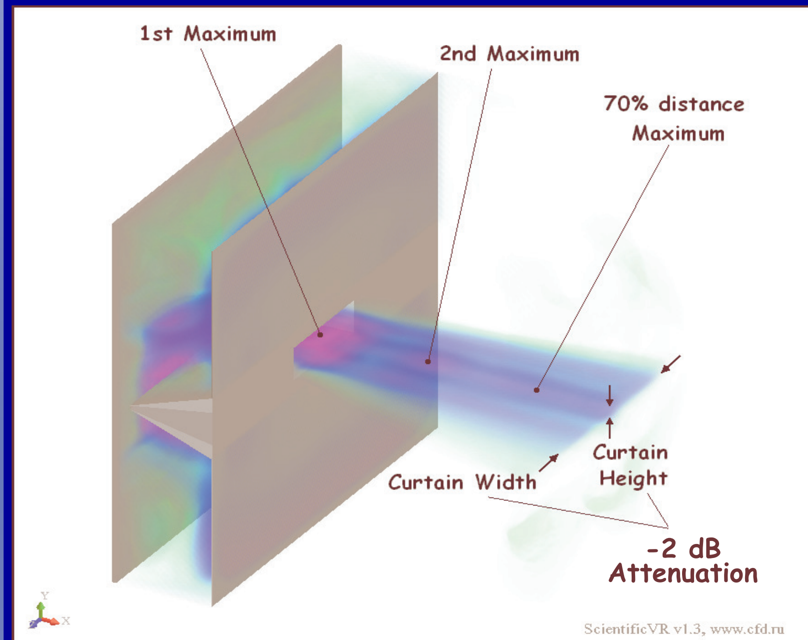
$$dh = \hat{C}_p dT$$

Thermodynamics of the Gas Jet

- **Energy equation:** $h_0 = h + \frac{1}{2} q^2$ → $C_p T_0 = C_p T + \frac{1}{2} q^2$
- **Specific Heat** $C_p = \frac{\gamma R}{\gamma - 1}$ → $T_0 = T\left(1 + \frac{\gamma - 1}{2} M^2\right)$
- **Mach Number** $M^2 = \frac{q^2}{a^2} = \frac{q^2}{\gamma R T}$ → $p_0 = p\left(1 + \frac{\gamma - 1}{2} M^2\right)^{\gamma/(\gamma-1)}$
- **Isentropic relation** $\frac{p}{p_0} = \left(\frac{T}{T_0}\right)^{\gamma/(\gamma-1)}$ → $\frac{\rho}{\rho_0} = \left(\frac{T}{T_0}\right)^{1/(\gamma-1)}$

Variables and Observables



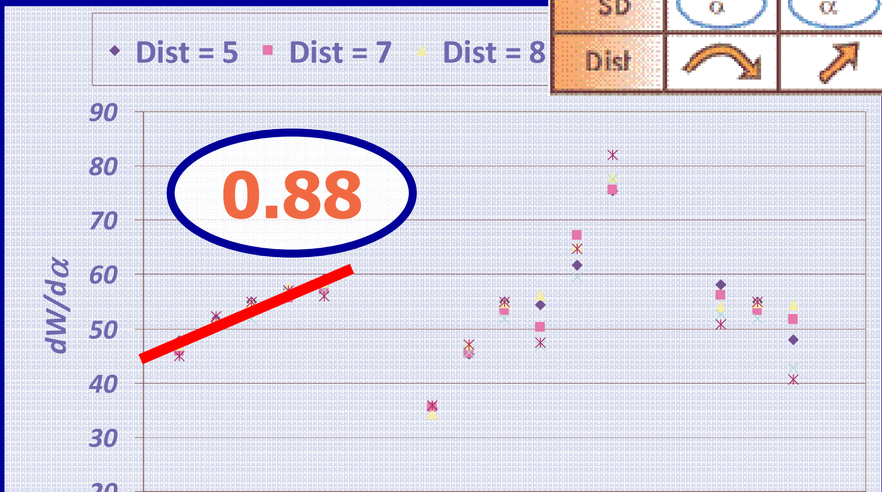


α – angle of skimmer aperture in the direction of curtain expansion;
β – angle of skimmer aperture in the direction perpendicular to curtain expansion
SW – skimmer slit width
SD – skimmer depth
Dist – nozzle-skimmer distance

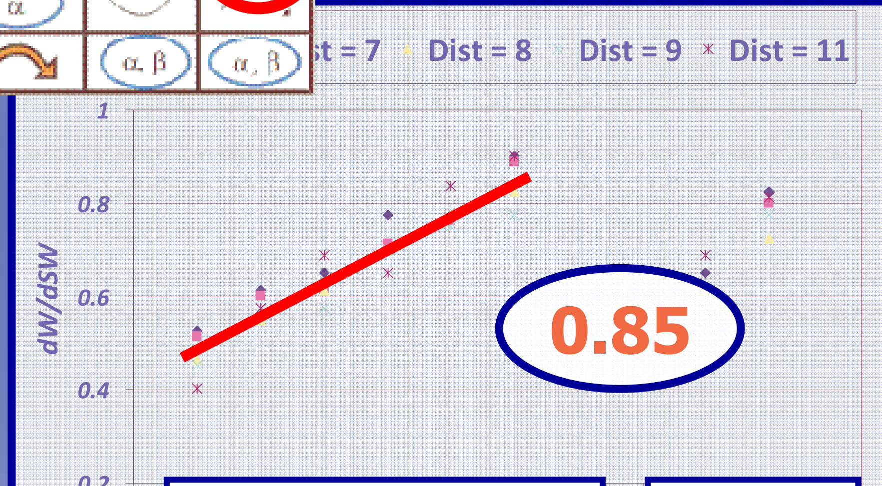
M_{max} – Maximum Mach Number
CM_{max} – Coordinates maximum M
$M_{max70\%}$ - Maximum M at 70% simulation domain distance from nozzle
W – Curtain width (at -2 dB attenuation);
D – Curtain depth (at -2dB attenuation);

Curtain behavioral trends – Self consistency tests

	M_{max}	CM_{max}	M_{max} 70%	D	W
α	(β, SD)	(β, SD)	↘	↘	↗
β	(α)	(α)	↘	◡	
SW	↗	↗	↘	↘	↗
SD	(α)	(α)	(α)	◡	
Dist	↷	↗	↷	(α, β)	(α, β)



- SW -	- β -	- SD -
10-14-18-22-26	0-5-10-15-20-25	15-22-29
β = 10, SD = 22	SW = 18, SD = 22	β = 10, SW = 18



- α -	- β -
0-5-10-15-20-25	10-15
β = 10, SW = 18	α = 10, SW = 18

Curtain behavioral trends – Self consistency tests

$$W = f_1(SW, \beta, SD, Dist)\cdot \alpha + f_2(SW, \beta, SD, Dist)$$
$$W = f_3(\alpha, \beta, SD, Dist)\cdot SW + f_4(\alpha, \beta, SD, Dist)$$

	M_{max}	CM_{max}	M_{max} 70%	D	W
α	(β, SD)	(β, SD)	↘	↘	↗
β	(α)	(α)	↘	∪	
SW	↗	↗	↘	↘	↗
SD	(α)	(α)	(α)	∪	↗↘
Dist	↷	↗	↷	(α, β)	(α, β)

$$\frac{\partial W}{\partial \alpha} = f_1(SW,\ldots) \Rightarrow \frac{\partial^2 W}{\partial \alpha \cdot \partial SW} = f_1'(SW,\ldots)$$
$$\frac{\partial W}{\partial SW} = f_3(\alpha,\ldots) \Rightarrow \frac{\partial^2 W}{\partial SW \cdot \partial \alpha} = f_3'(\alpha,\ldots)$$

$$W = g_1(\beta, SD, Dist)\cdot \alpha + g_2(\beta, SD, Dist)\cdot SW + g_3(\beta, SD, Dist)\cdot \alpha \cdot SW + g_4(\beta, SD, Dist)$$

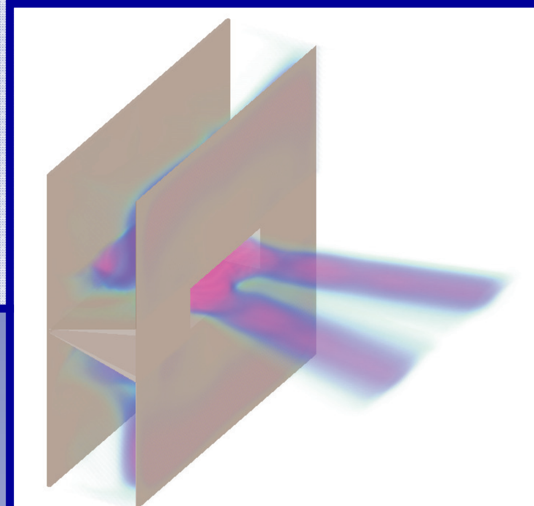
$$\frac{\partial W}{\partial \alpha} = g_1(\beta, SD, Dist) + g_3(\beta, SD, Dist)\cdot SW$$
$$\frac{\partial W}{\partial SW} = g_2(\beta, SD, Dist) + g_3(\beta, SD, Dist)\cdot \alpha$$

- System can be optimized through nozzle-skimmer geometry.
- Slit nozzle (instead of circular nozzle)
- Nozzle and skimmer slits have to be perpendicular

Actual value of quality ratio: W/D.
Decreases of a factor of 2-3 moving from *Slit nozzle to Circular nozzle.*
Homogeneity of curtain at 70% distance (over W): ΔM/M =

Nozzle-Skimmer system:

Perpendicular	Parallel
12%	31%



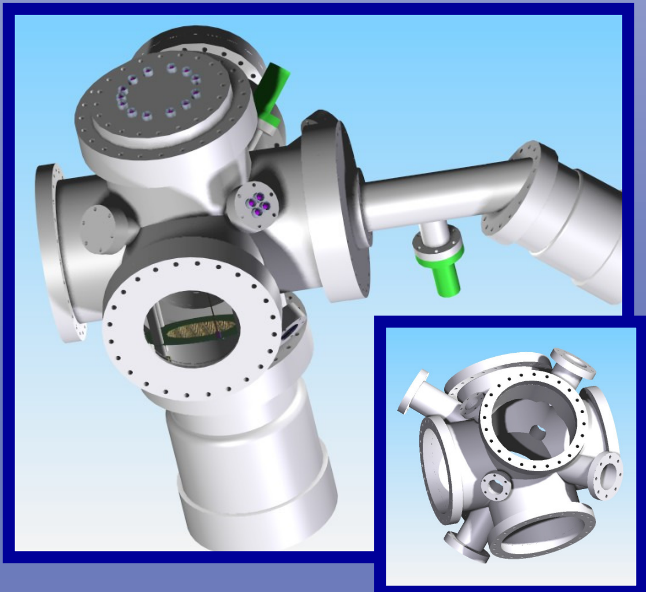
- Shaping of the gas curtain is feasible.
- Behavioral trends (see table)

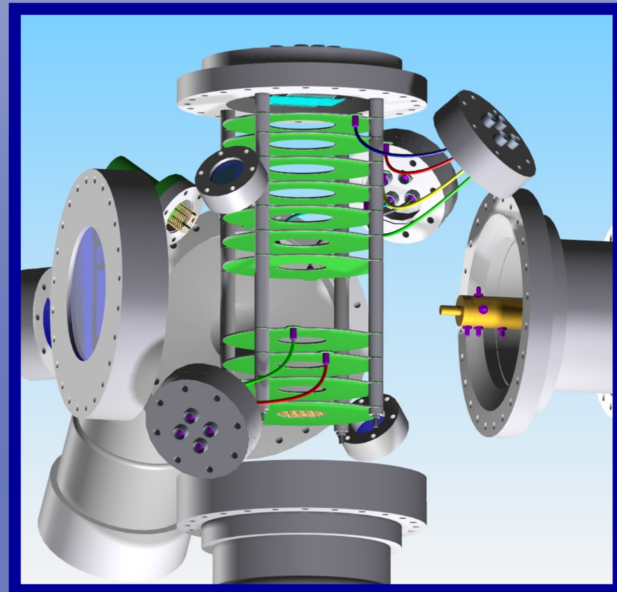
Experimental plan

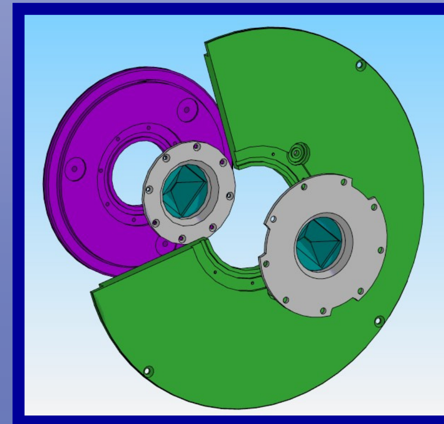
- Characterization of the gas curtain
  - Curtain density mapping (benchmarking of simulations)
  - Curtain velocity mapping

    (after development of Self Mixing velocimeter)
- Operation of the profile monitor
  - Test of basic operation (e^- @ ALICE, pbars @ AD)
  - Test of the modified version (axis-symmetric jet)

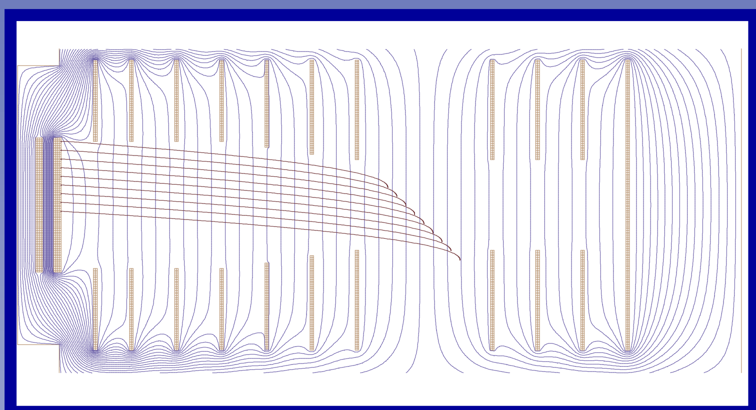
Experimental Chamber







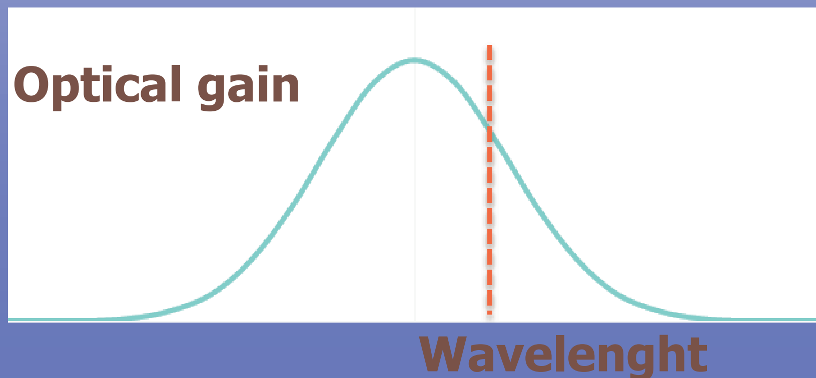
- Differential Pumping
- Longitudinal (20 mm range) and angular (5° range) fine tuning.



E_x = 1kV/m

Homogeneity: $E_y/E_x < 2.5\%$

Over 40mm range

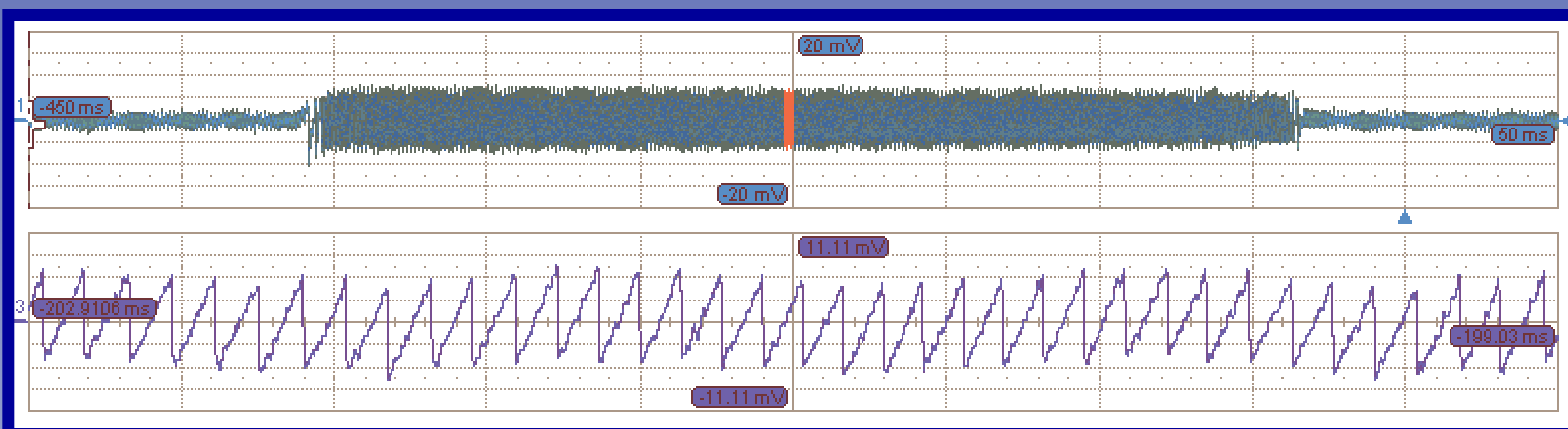


- Mie Scattering

  (Rayleigh)

- Seeding needed

  ≈ 100 nm seeds at
  10^{-5} mbar gas pressure



- Self-Mixing Interferometry
  - Used for measurement of
    - Displacement
    - Velocity
    - Vibrations
  - Targets used:
    - Solids
    - Liquids
  - Information on direction with a single interferometric channel
  - Low intensity backscattered light needed (-90 dB)
  - High Resolution (≈1 μm)
  - Low cost (≈1k€)

Thank you for your attention

- Acknowledgements:
  - Kai-Uwe Kühnel
  - Angela Intermite
  - Carsten P. Welsch

- References:

1. M.Putignano *et al*: A Fast, Low Perturbation Ionization Beam Profile Monitor Based on a Gas-jet Curtain for the Ultra Low Energy Storage Ring - Hyperfine Interaction, accepted.
2. M.Putignano *et al*: Design of a nozzle-skimmer system for a low perturbation ionization beam profile monitor – DIPAC09 Proceedings.
3. M.Jugroot *et al*: Numerical investigation of interface region flows in mass spectrometers: neutral gas transport – J. Phys. D: Applied Physics, vol. 37 (2004) pp 1289.
4. Y. Hashimoto *et al*: Oxygen gas-sheet beam profile monitor for the synchrotron and storage ring - Nucl. Instr. Meth. Phys. Res. A 527 (2004) 289.