

# Non-Destructive Laser-based Emittance Measurement at LINAC4

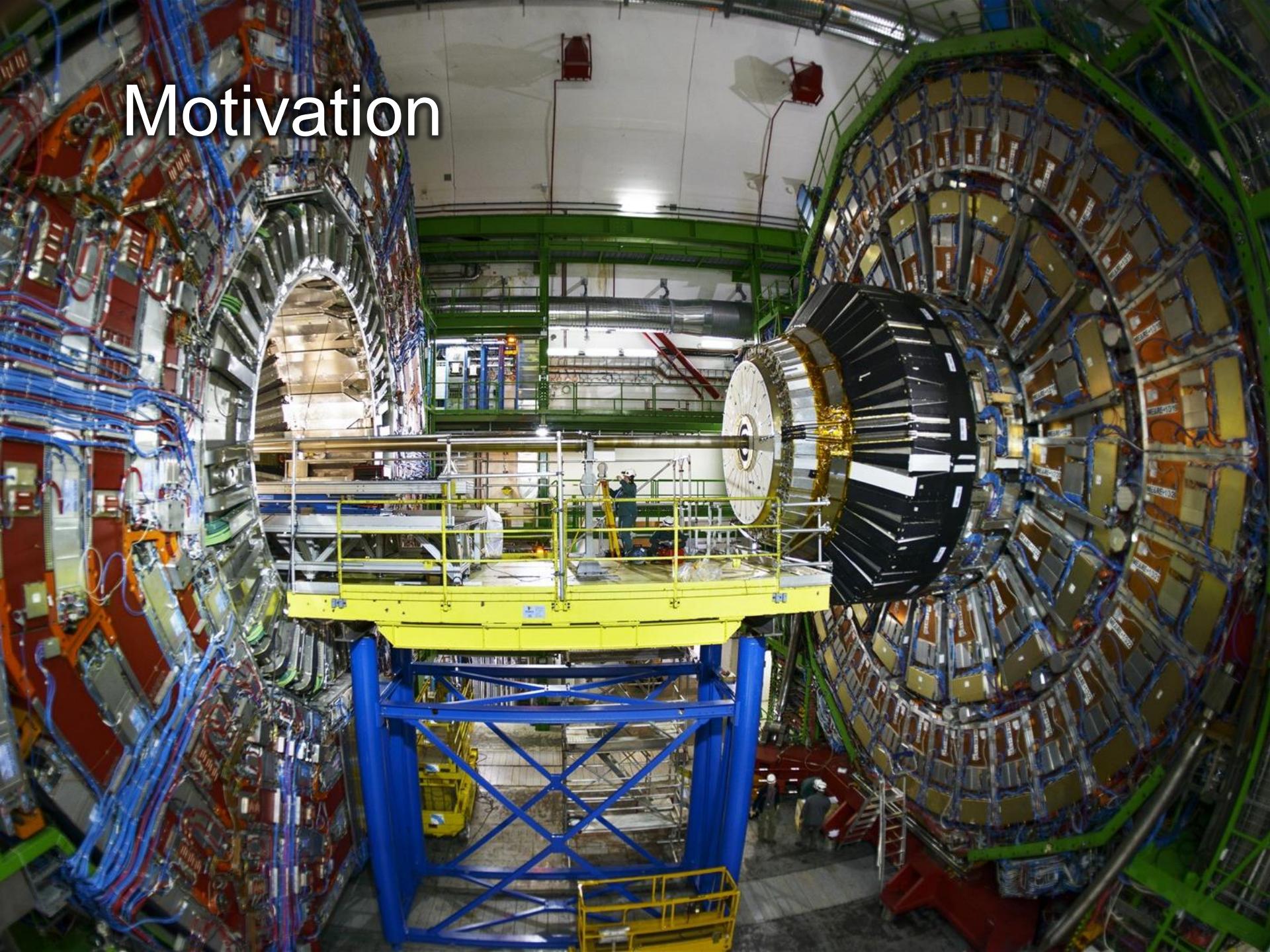
## Project Summary

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G. Boorman, A. Bosco, S. Gibson, K. Kruchinin (RHUL)  
B. Schmauss (FAU)

27.3.2015

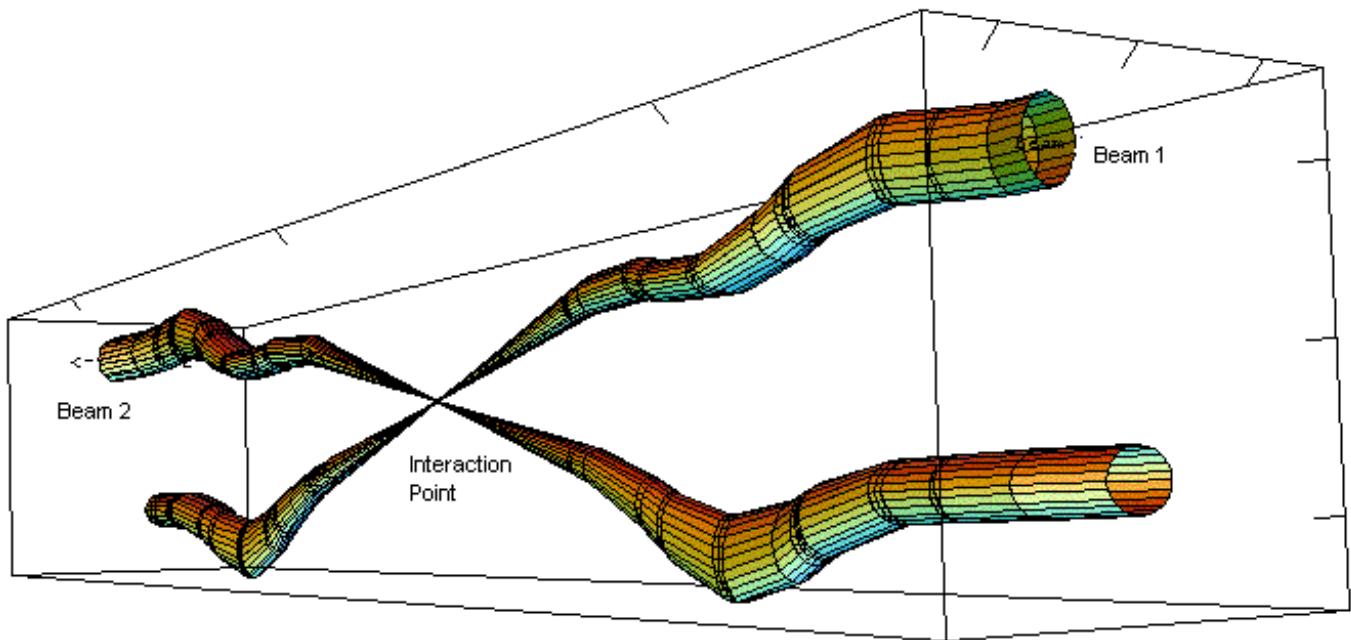
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# Motivation



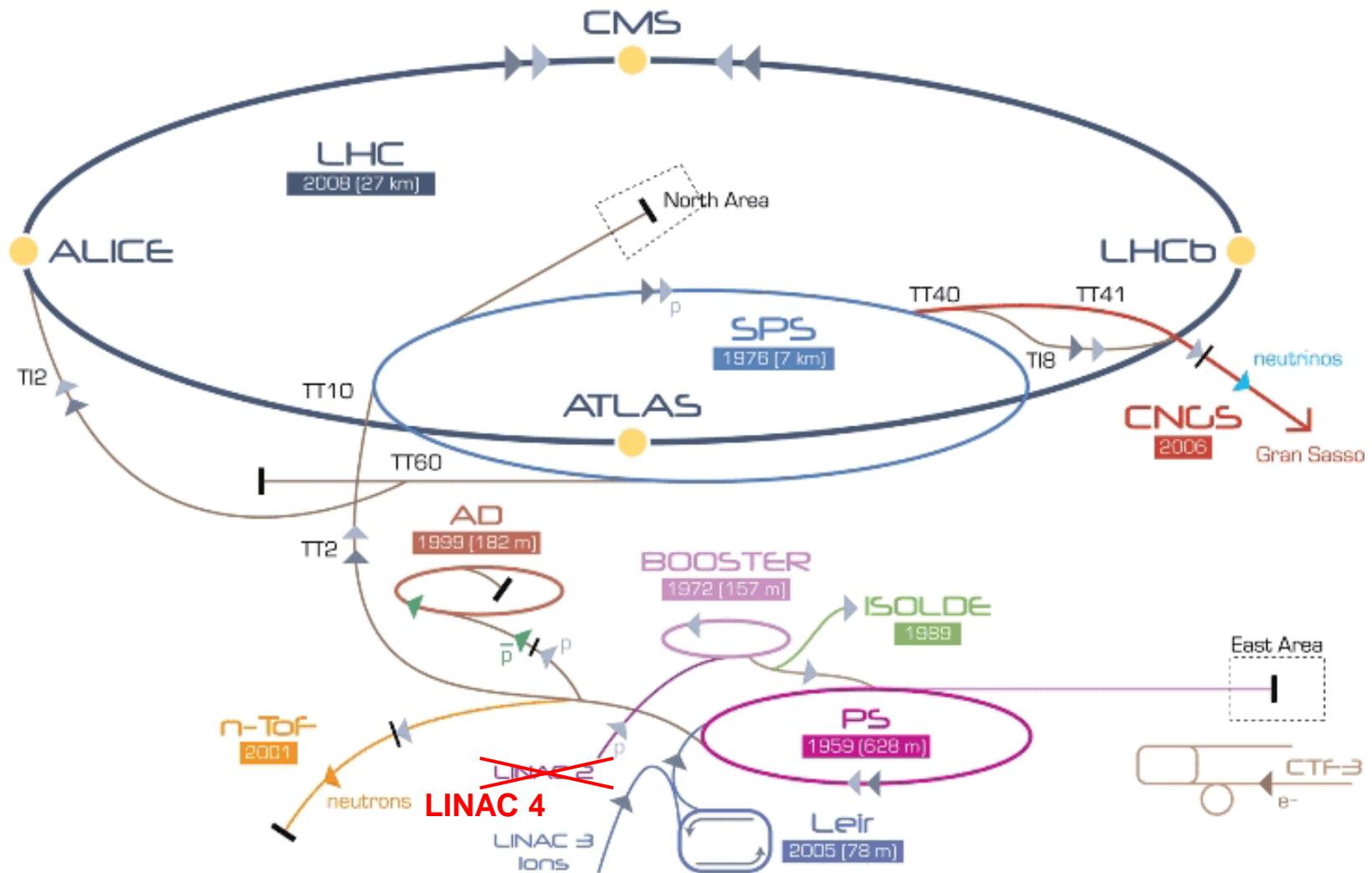
# High Luminosity LHC Project

- Luminosity:  $L = N^2 * f_b / (4\pi \sigma_x \sigma_y)$
- How to maximize the integrated luminosity?
  1. High brightness beams
  2. Minimize downtimes ( -> Non-destructive and reliable instruments!)

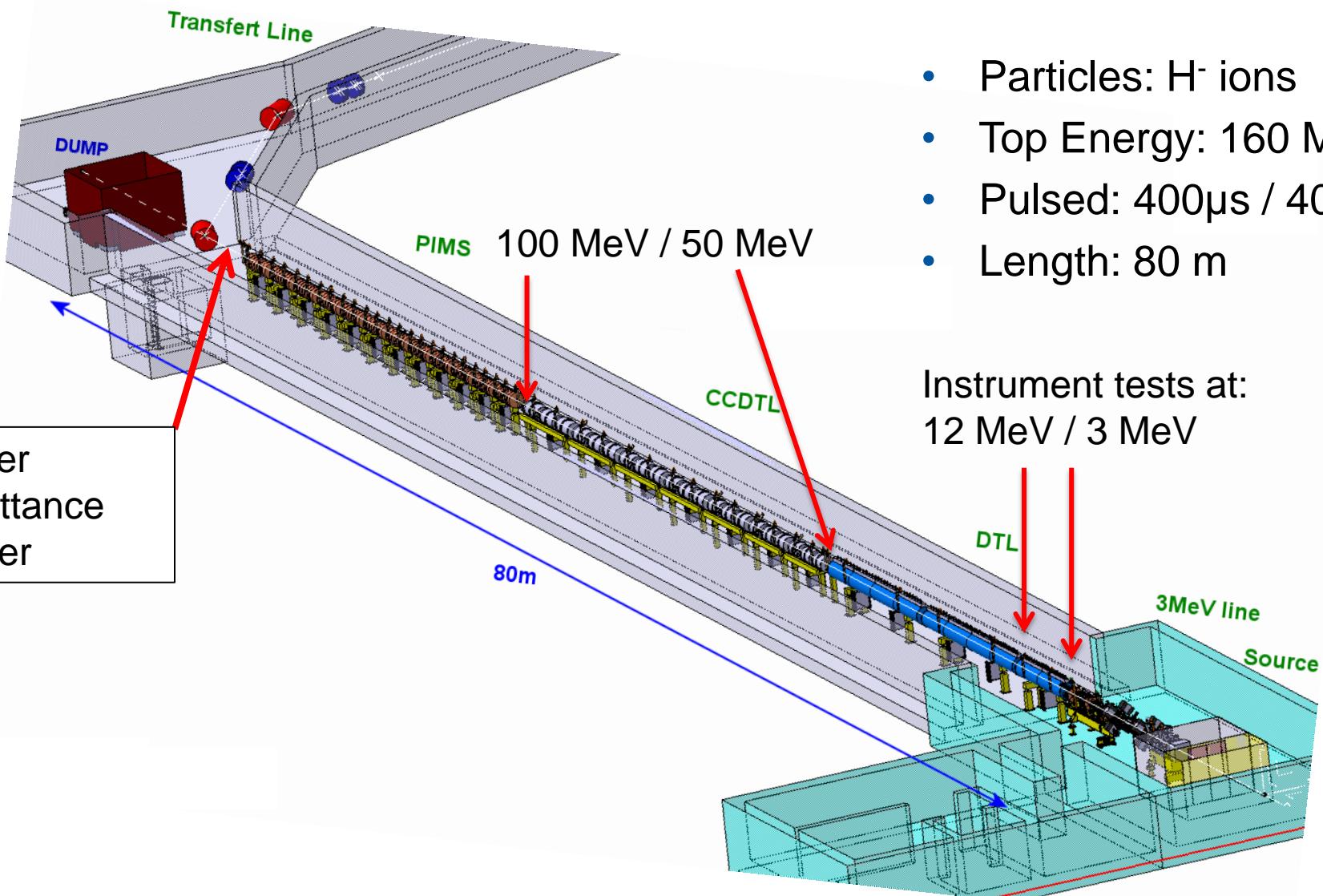


Relative beam sizes around IP1 (Atlas) in collision

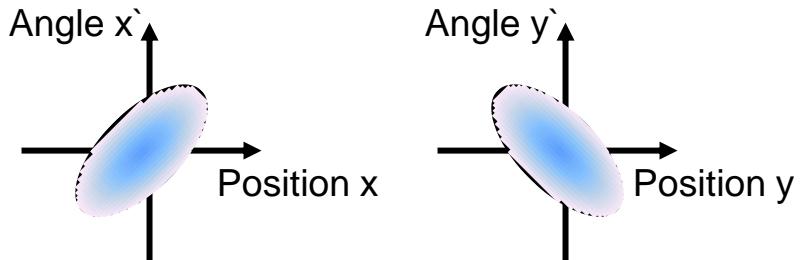
# CERN Accelerator overview



# LINAC 4 overview



- Transverse Phasespace
  - Position (x,y)
  - Angle ( $x'$ , $y'$ )
  - $\epsilon^2 = \langle x_i^2 \rangle * \langle x_i'^2 \rangle - \langle x_i x_i' \rangle^2$

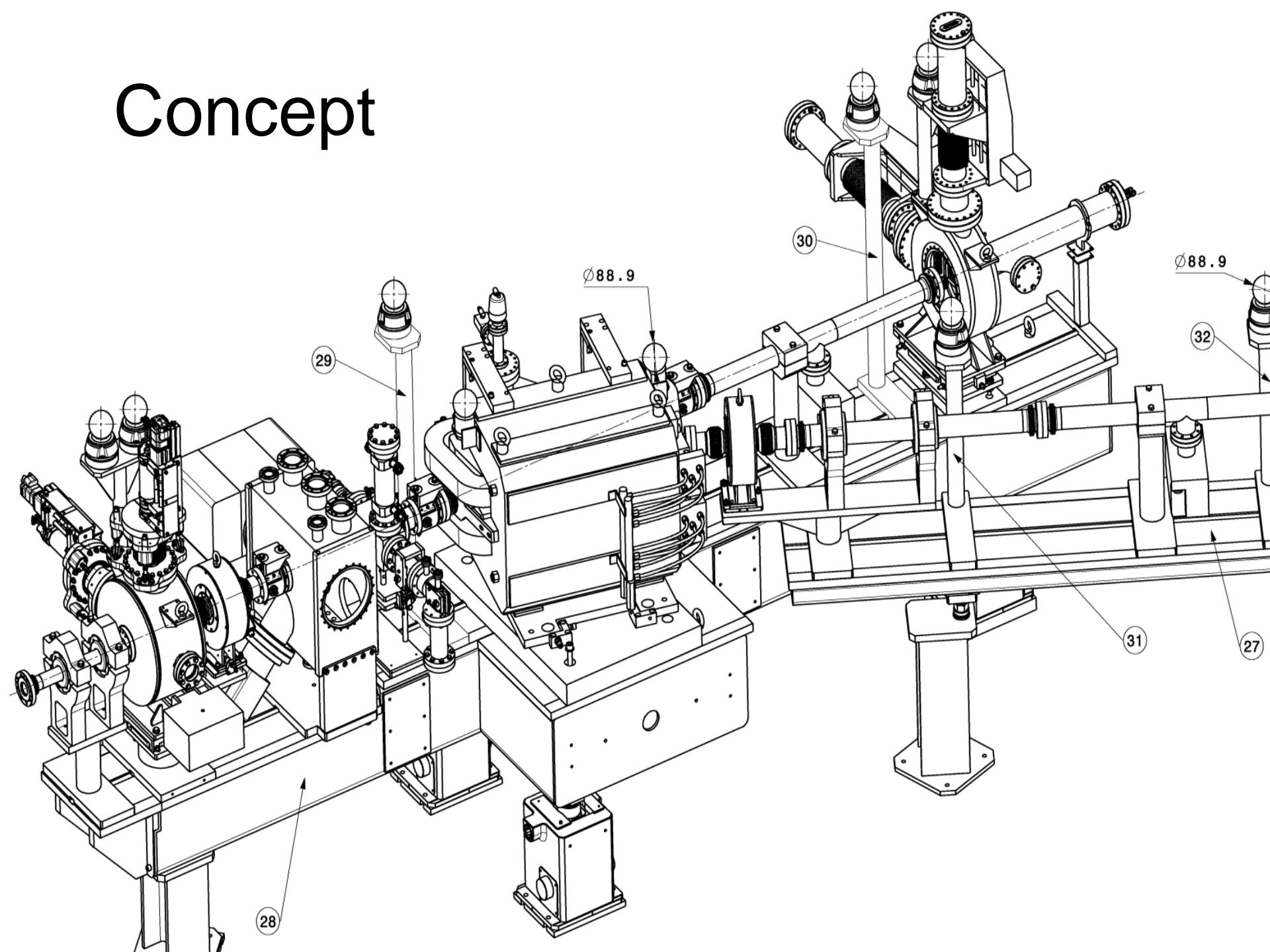


- Conventional Techniques
  - 3 Profile method
  - Quadrupol Scan
  - Pepperpot
  - Slit & Grid

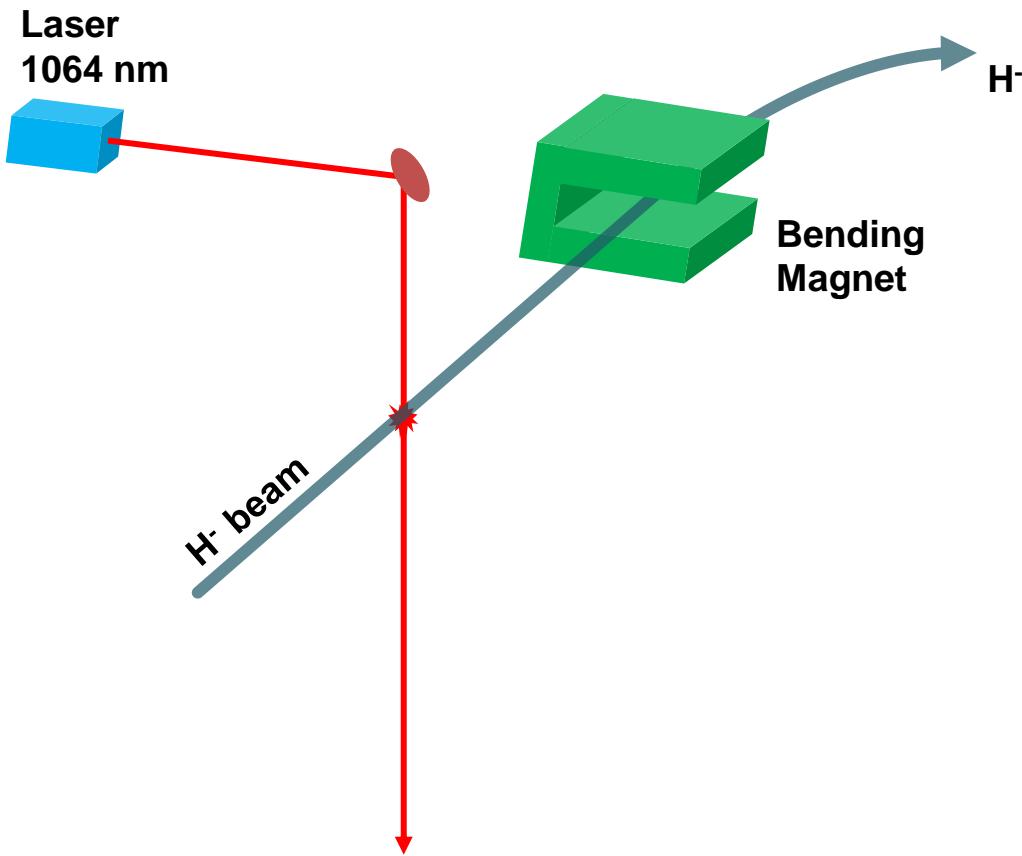


Destructive / invasive

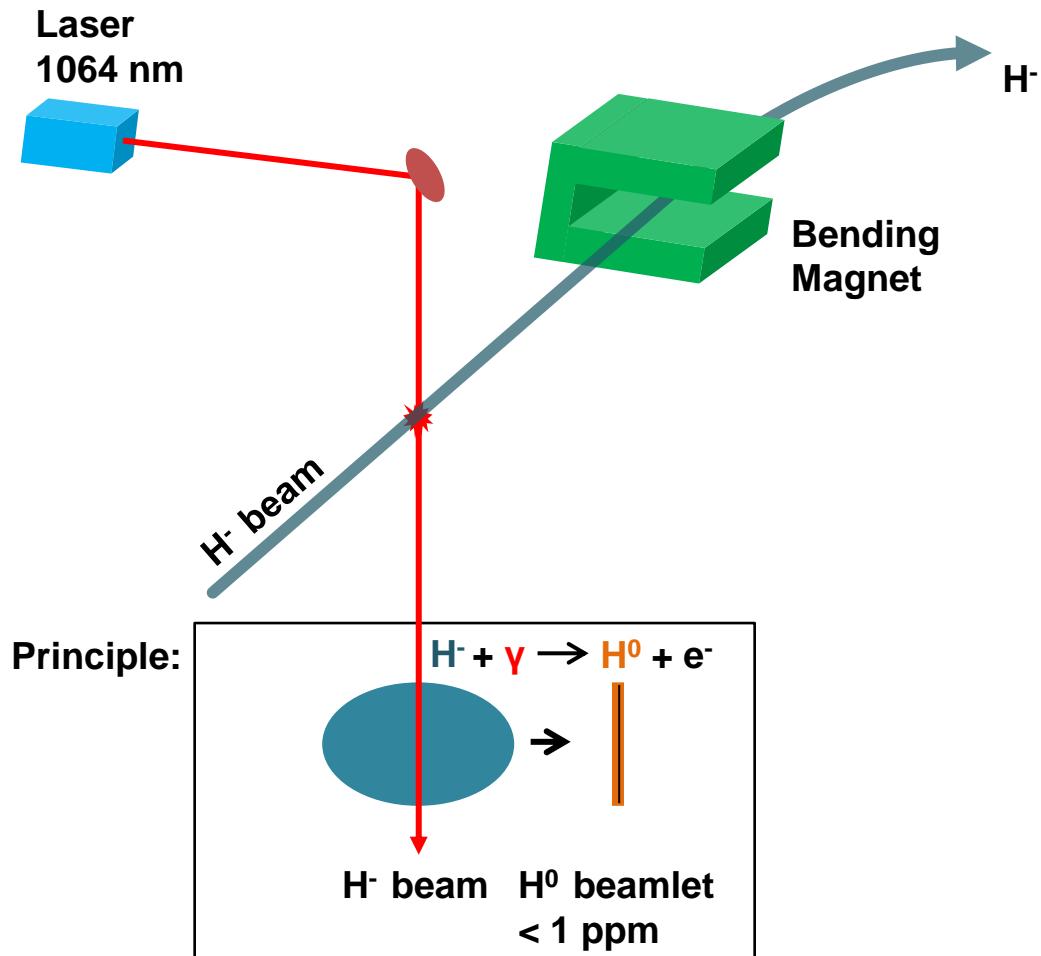
# Concept



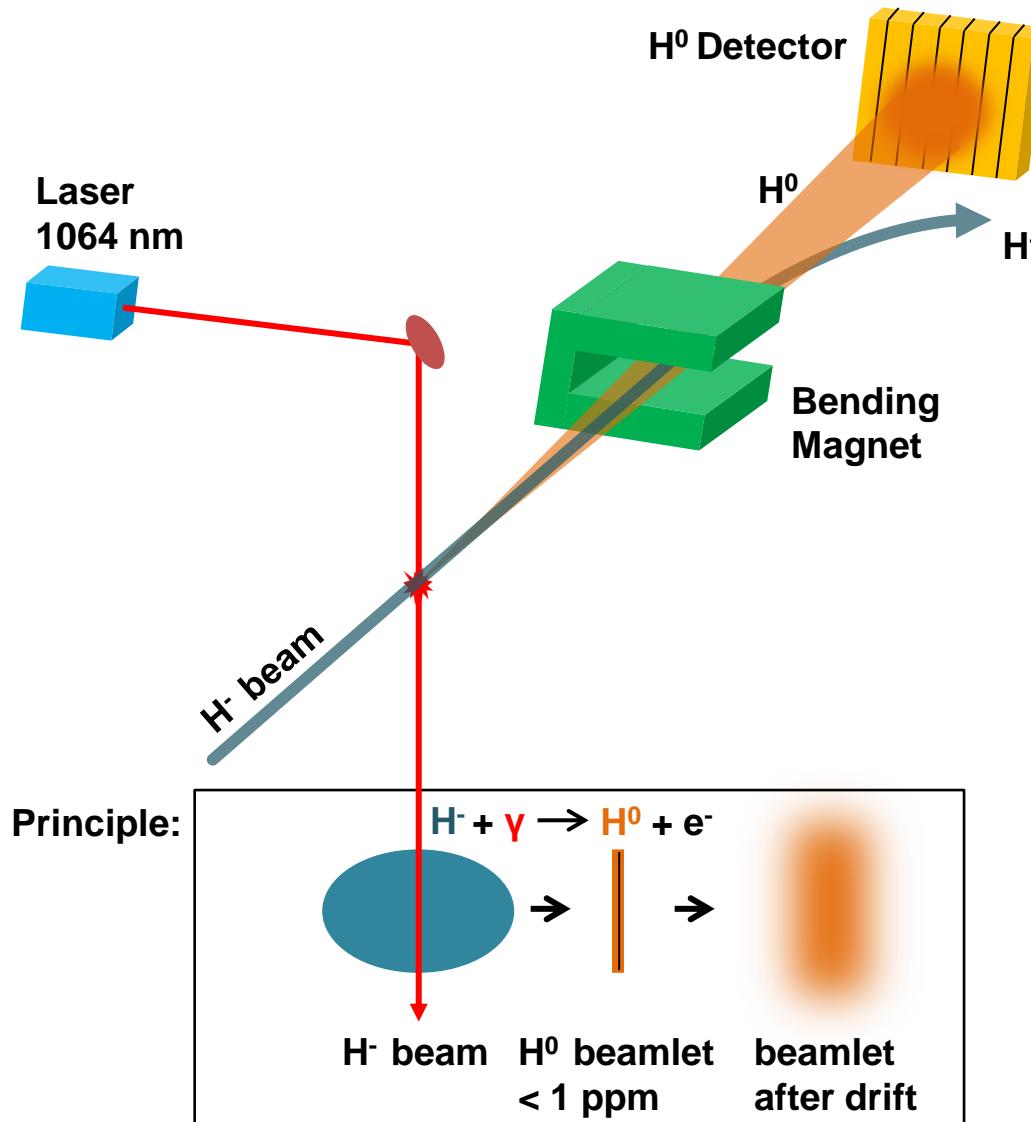
# Concept of Non-destructive Emittance Meter



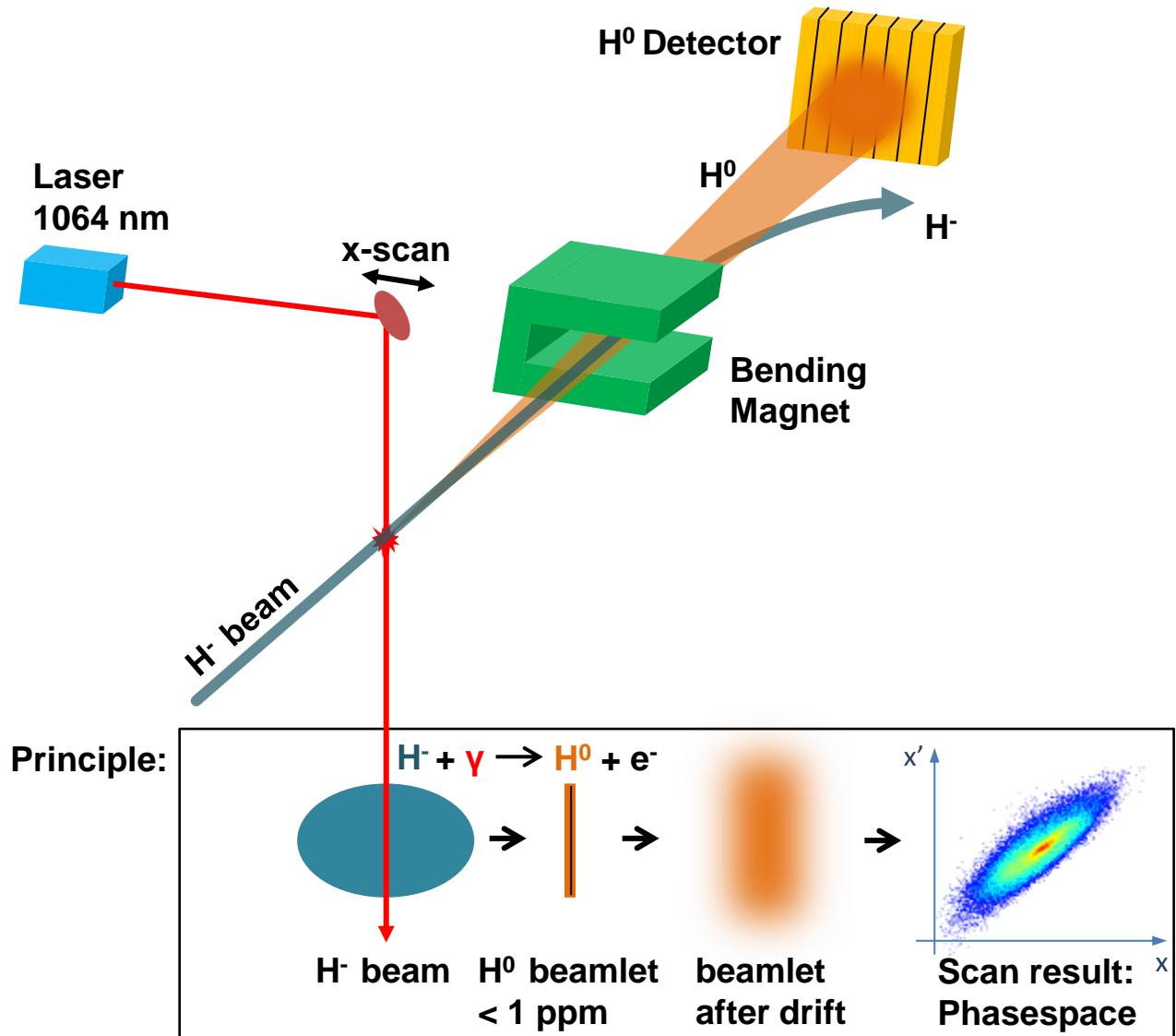
# Concept of Non-destructive Emittance Meter



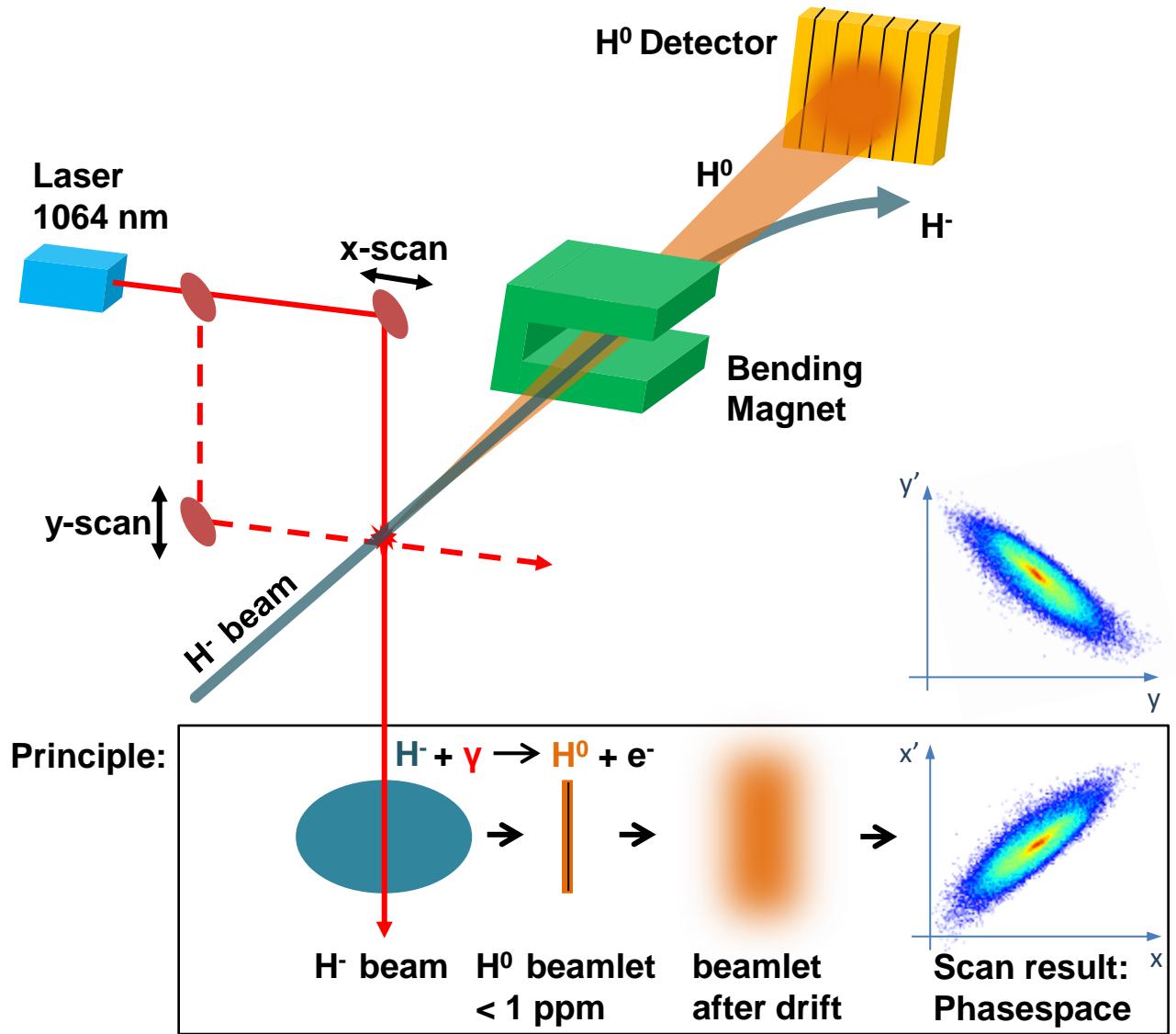
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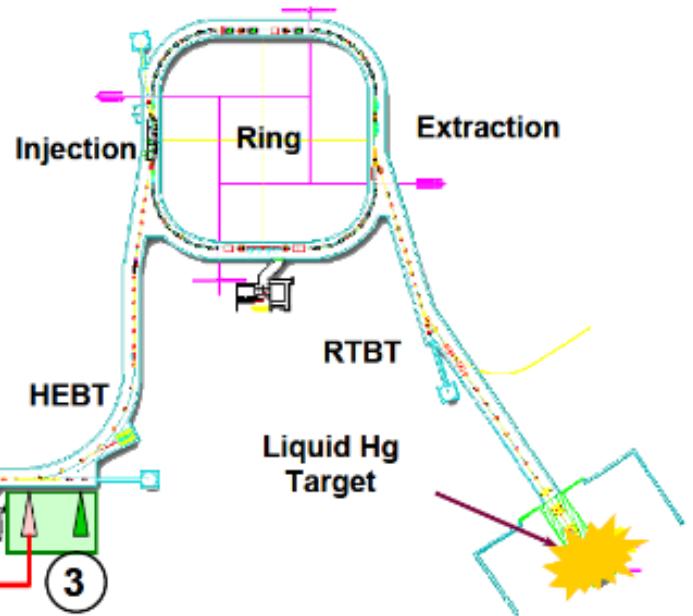
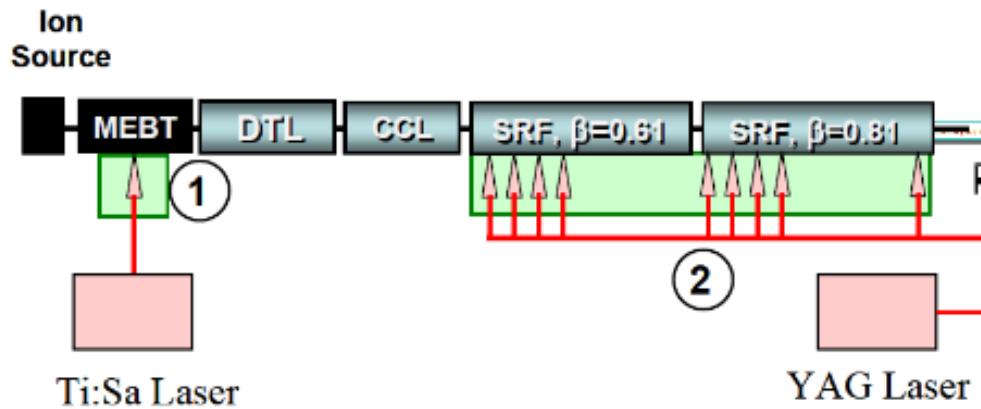


# Concept of Non-destructive Emittance Meter



## SNS: Operational Multi-Station Profile Measurement

- ① MEBT Laser Bunch Shape Monitor
- ② SCL Laser Wire Profile Monitor
- ③ HEBT Laser Emittance System



Y. Liu et al., Proc. PAC 2011

Challenge: Laser-Delivery!

250 m complex free space delivery line due to radiation environment!

# Challenge: Laser-Delivery

## Comparison of Laser Systems

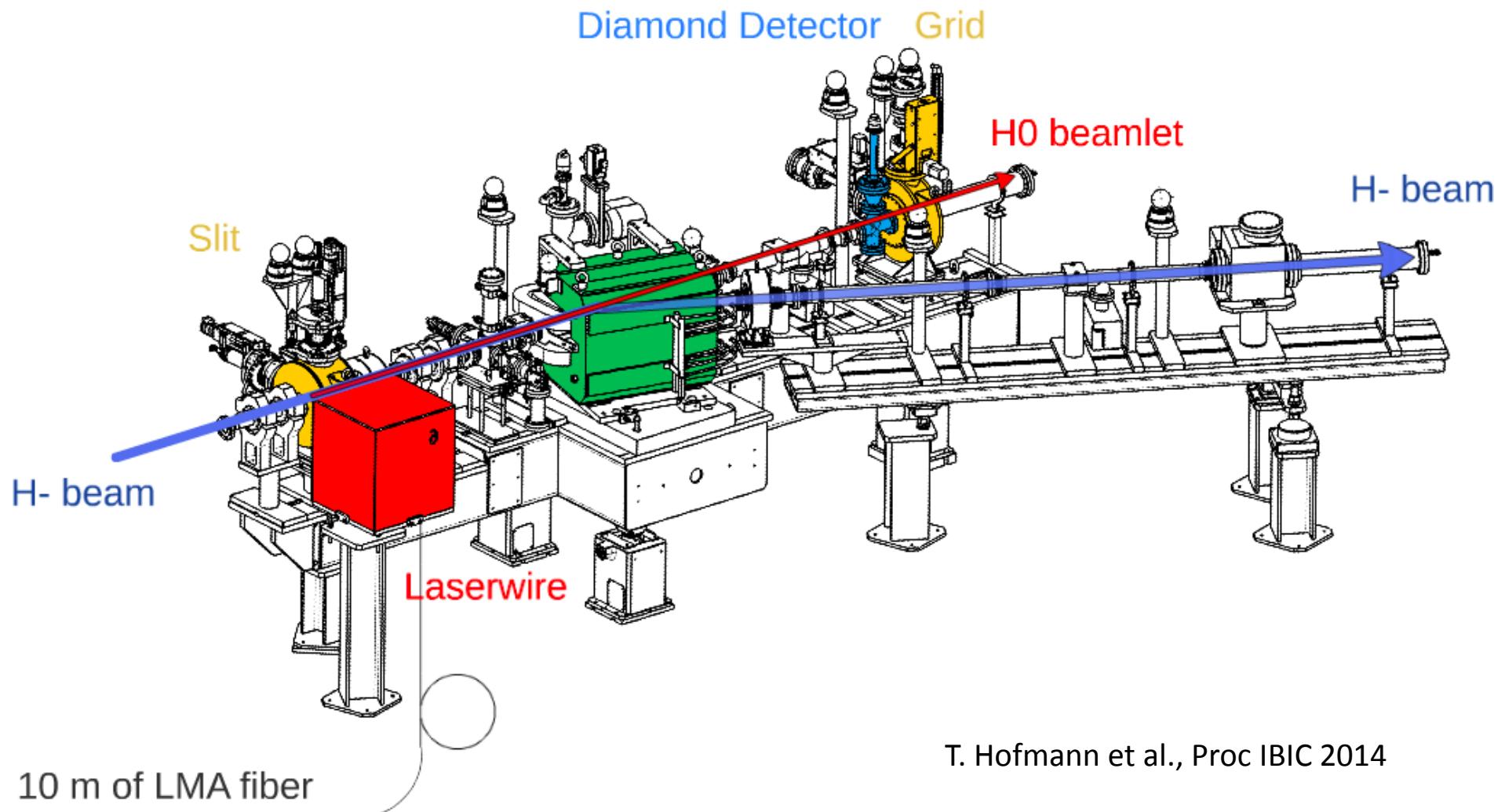
Laser	MOPA Fiberlaser (used at LINAC4)	Nd-YAG (used at SNS)
<u>Energy per pulse</u>	<u>0.1 mJ</u>	<u>50 mJ</u>
Diameter	$\sim 150 \mu\text{m}$	$\sim 200 \mu\text{m}$
$P_{\text{strip}}$ @ 160 MeV for H <sup>-</sup> crossing laser	0.1 %	> 99 %
t <sub>pulse</sub>	3...300 ns	5...10 ns
Repetition rate	10...500 kHz	< 20 Hz
<u>Beam transport</u>	<u>Fiber</u>	<u>Free Space</u>



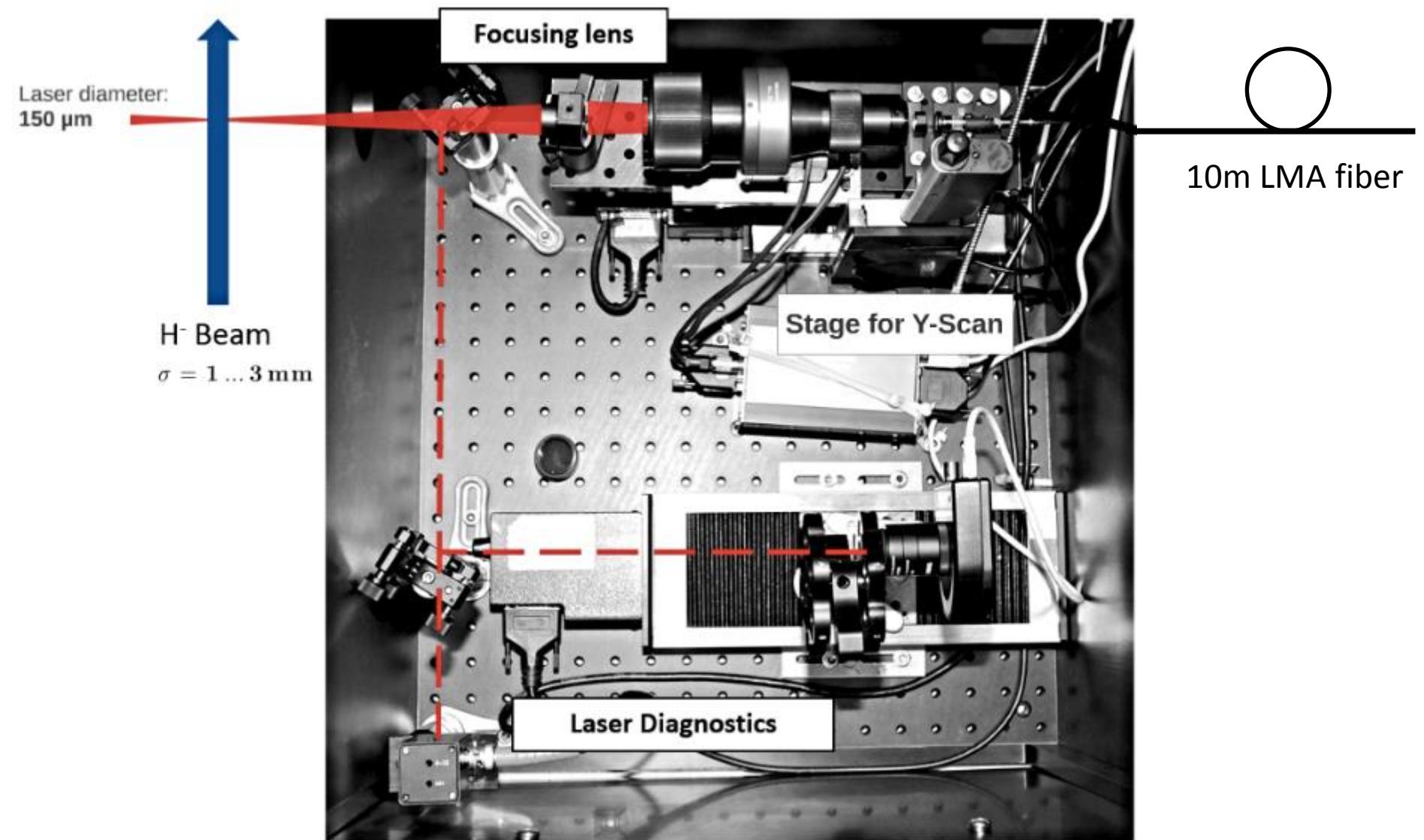
# Prototype Design & Tests



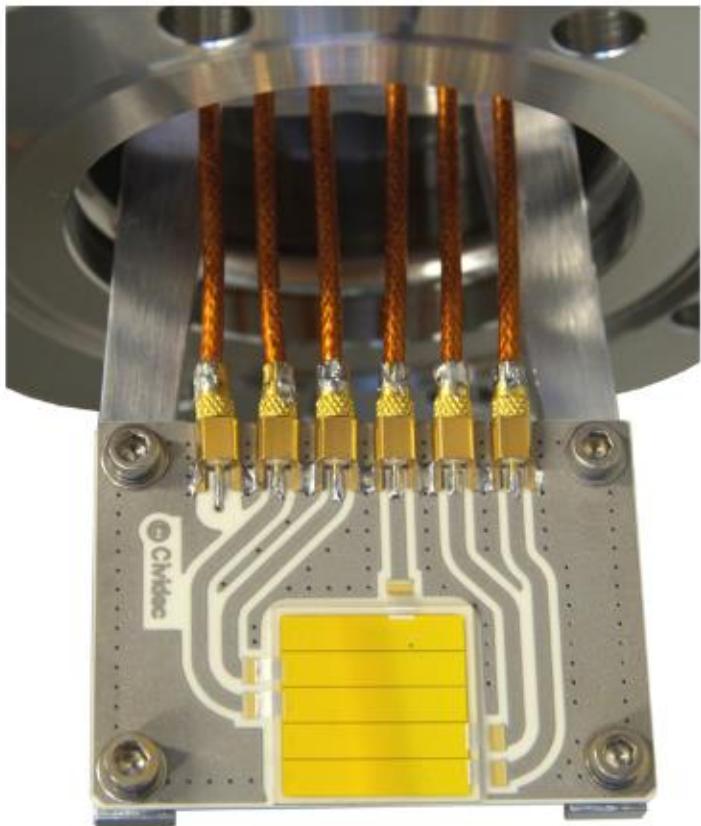
# 3 / 12 MeV Prototype Test Setup



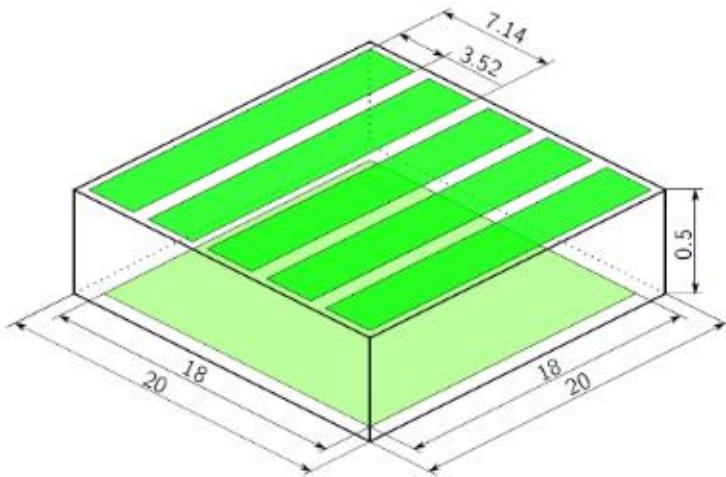
# Laser Focus / Scan / Diagnostics - Setup



# Diamond Strip Detector

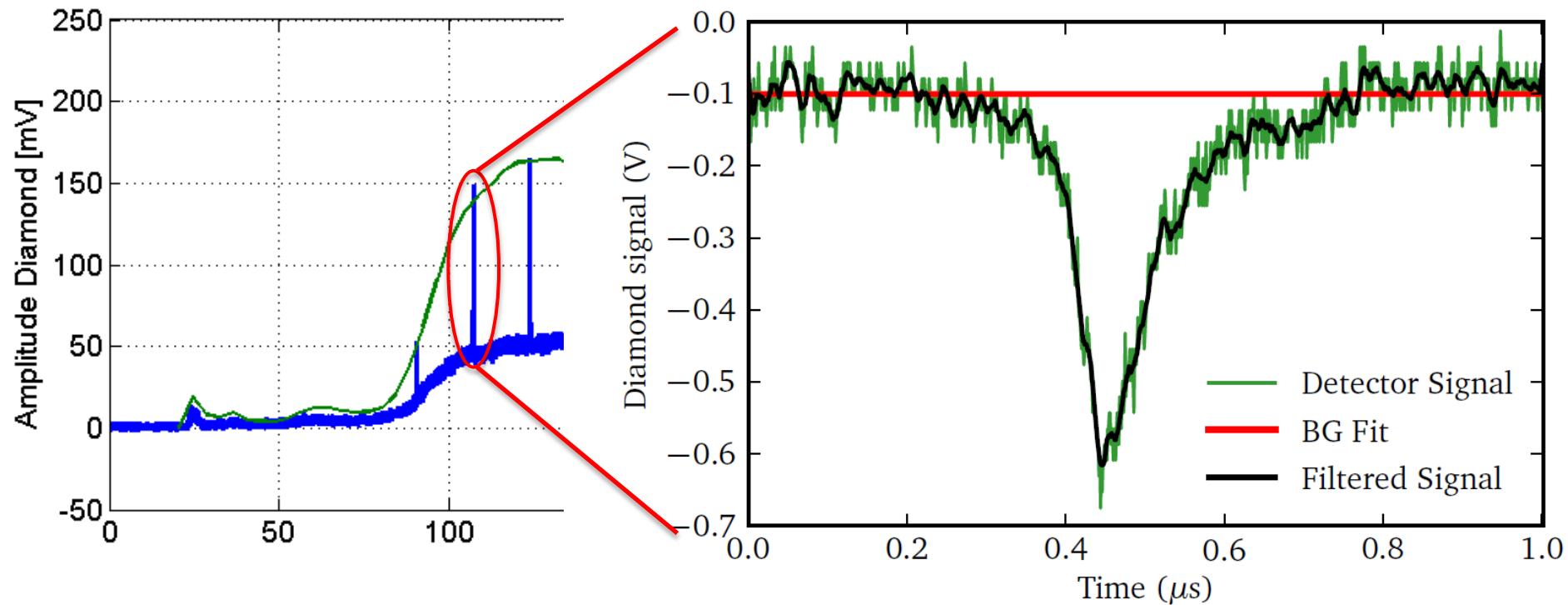


Ref: [CIVIDEC](#) Instrumentation, Austria



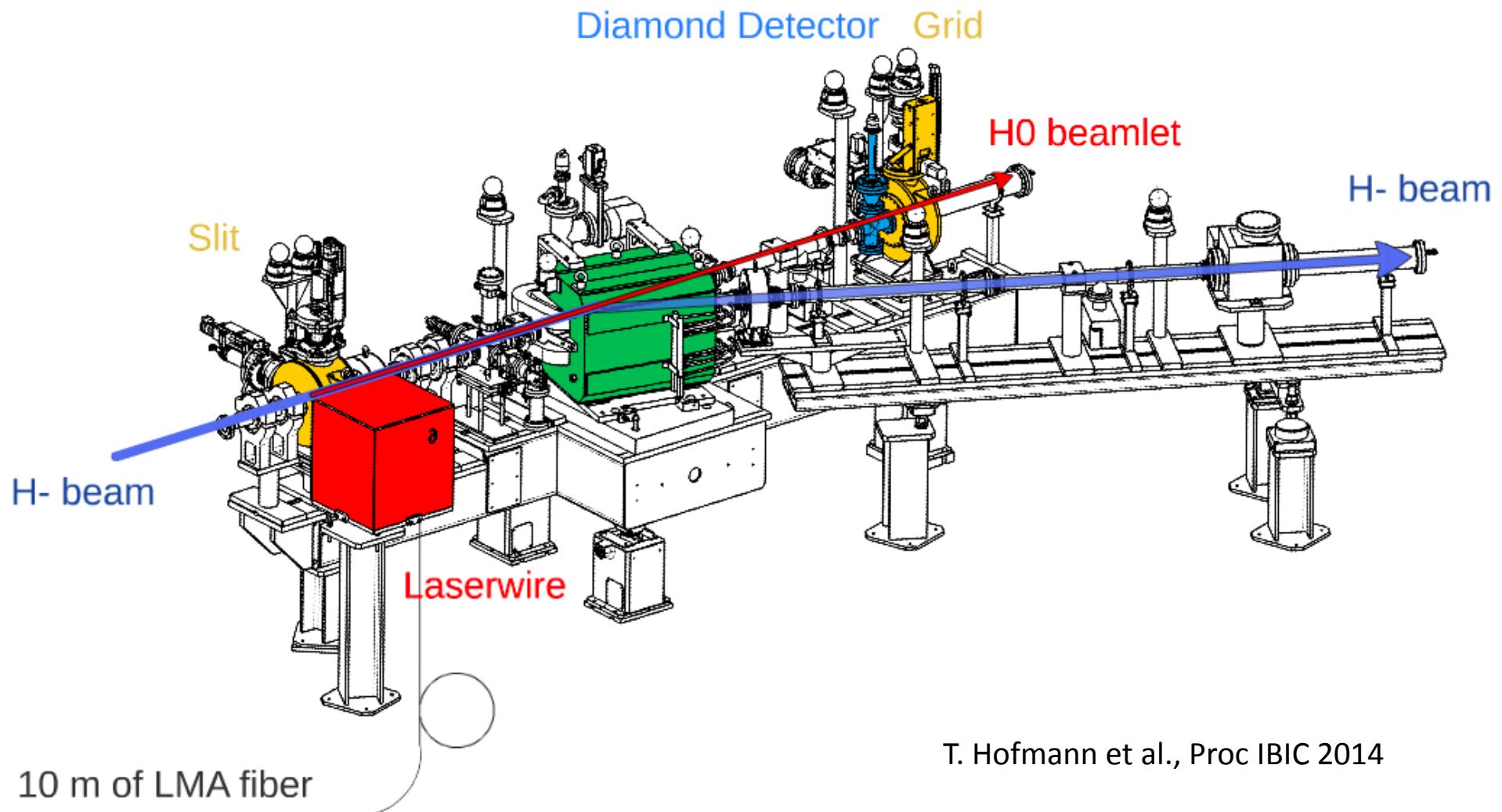
- High sensitivity ( $\sim 10^4 e^- / H^0$ )
- High bandwidth (< ns)
- Radiation tolerant ( $10^{15} cm^{-2}$ )
- Strip electrodes for spatial resolution

# Diamond Raw Signal & Signal Analysis



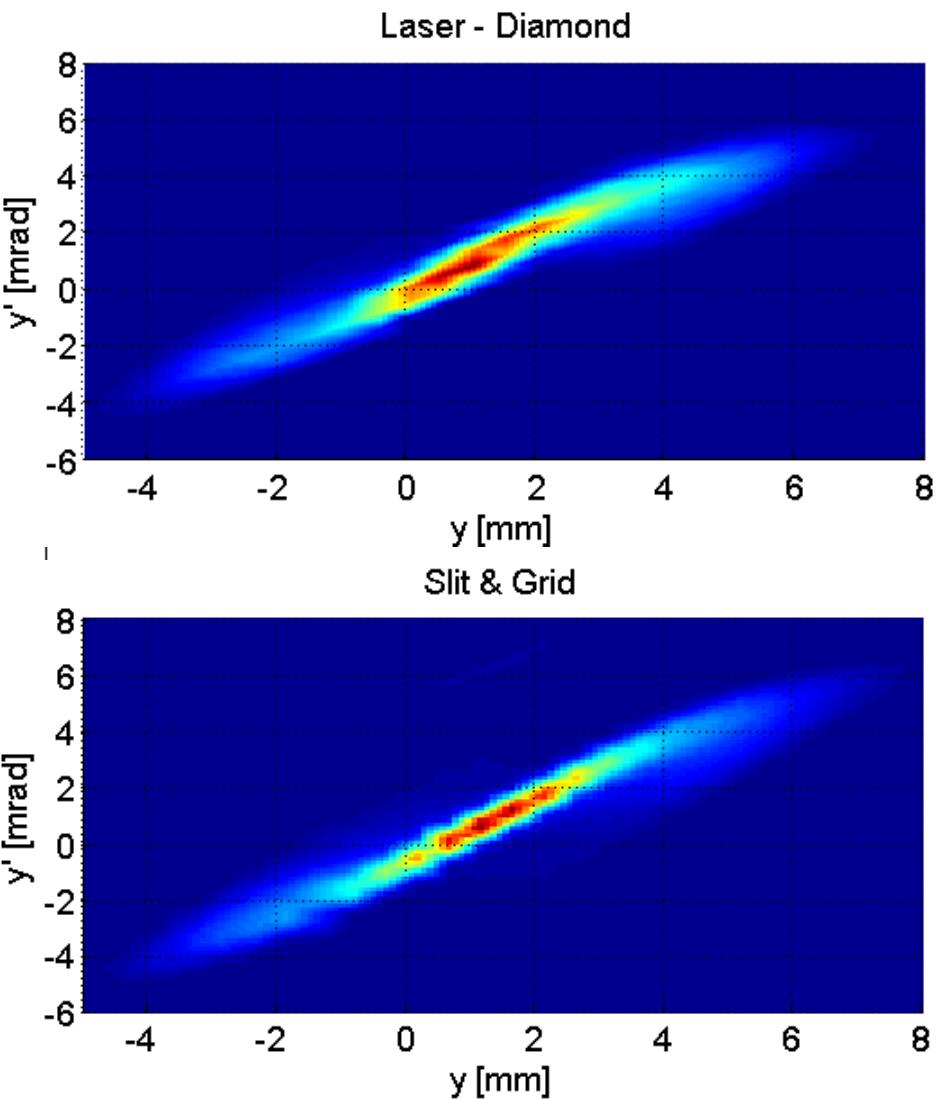
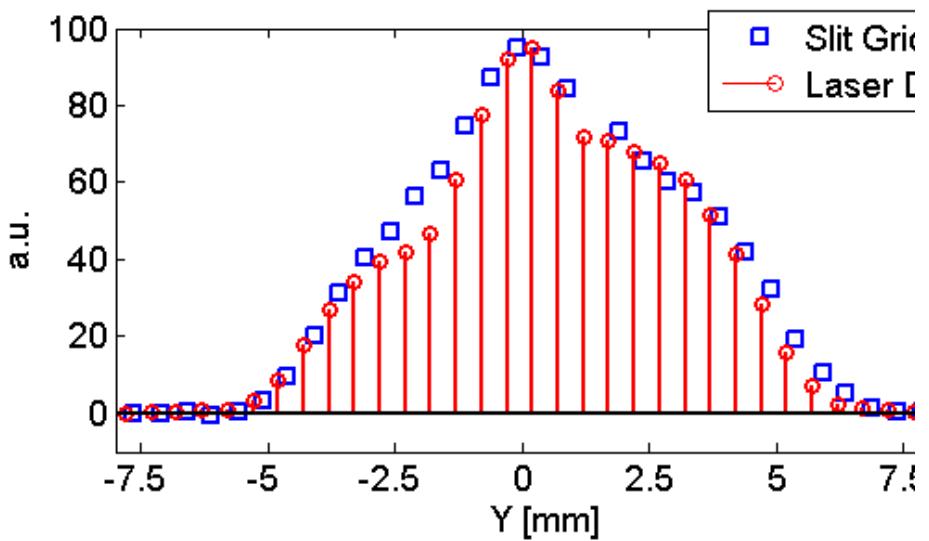
- $H^0$  particles originating from laserpulses
- Background from  $H^0$ , produced by residual gas collisions
- -> Diamond capable to detect  $H^0$  beamlets with high linearity and sensitivity

# 3 / 12 MeV Prototype Test Setup



# Results – Beam Profile and Phasespace

- Comparison with Slit & Grid
  - Beam Profile
  - Phasespace



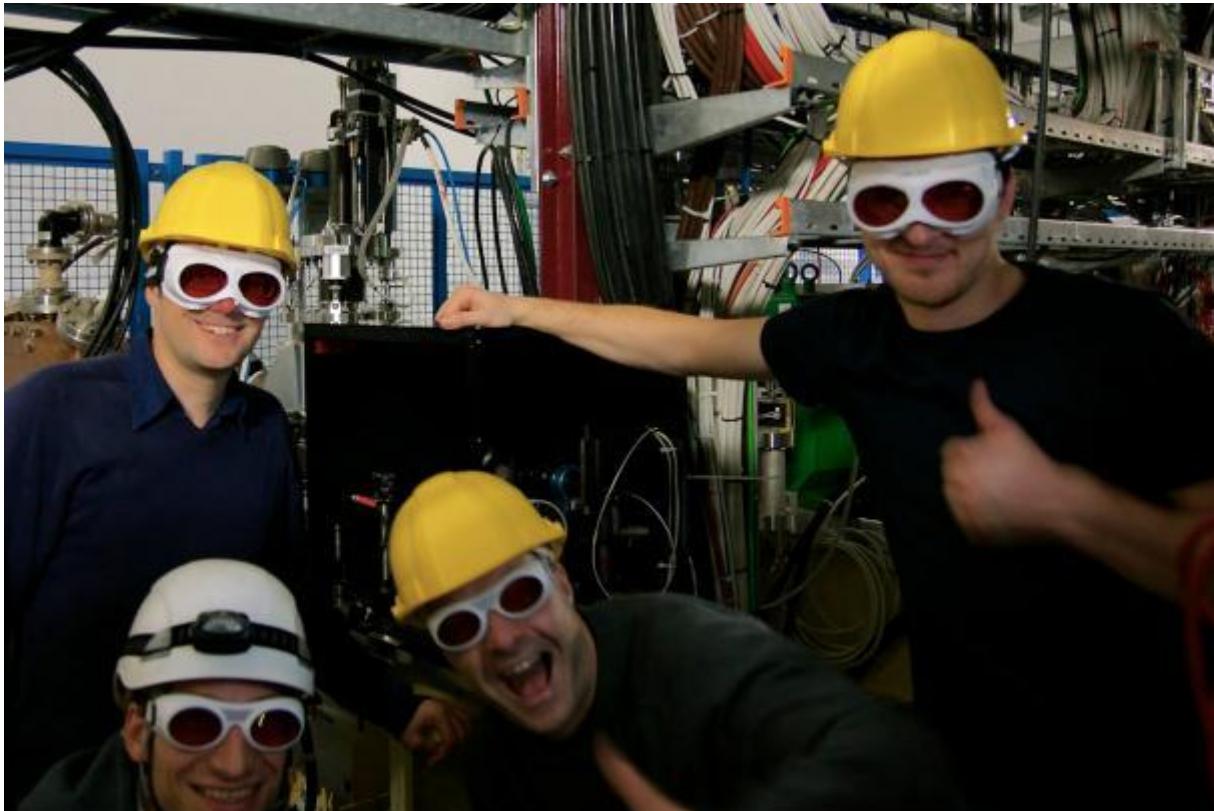
## What did we achieve?

- Prototype design
  - Simple fiber-based laser delivery
  - $H^0$  Detection based on a diamond detector
- Prototype test at 3 and 12 MeV  $H^-$  beam
  - Comparison with Slit&Grid as reference shows excellent agreement
- Proof of Principle for Non-Destructive Emittance Meter!
  - CERN approved installation for operational use at LINAC4

## What is to be done?

- Design for final location at 160 MeV
  - Longer Fiber delivery -> Non-linear effects?
  - High resolution diamond detector -> Readout scheme!
- Test of Non-destructive Profile Meter at 50 & 100 MeV beam

# Thanks for your attention!



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# Spare Slides

# Photo Neutralisation

- **Binding Energy: 0.75 eV**
- **Laser Stripping**

$$p_{strip} = 1 - e^{-\sigma(E) \cdot \rho_{pho} \cdot t}$$

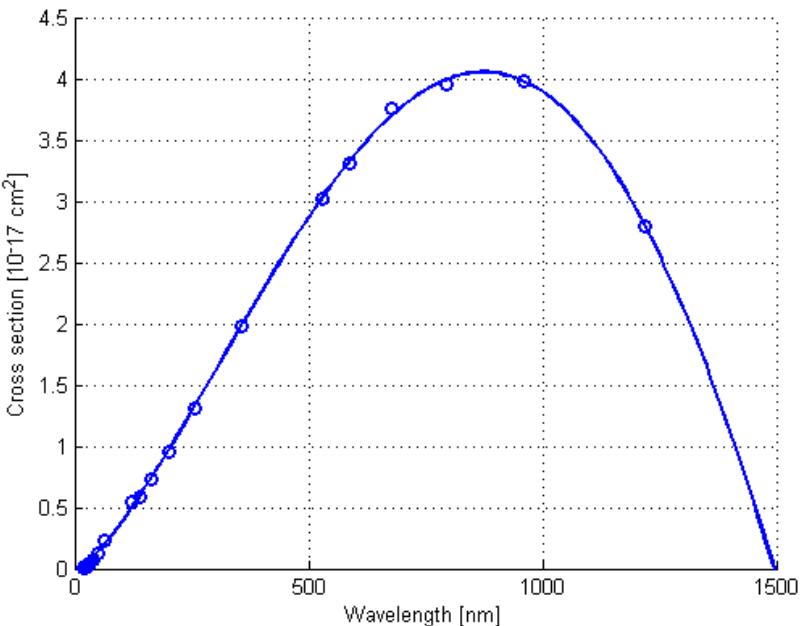


- Requirements for Laser:  
 $M^2 < 2$  for diameter  $< 200 \mu\text{m}$   
 $P_{\text{Peak}} > 1 \text{ kW}$
- Residual Gas Stripping Background

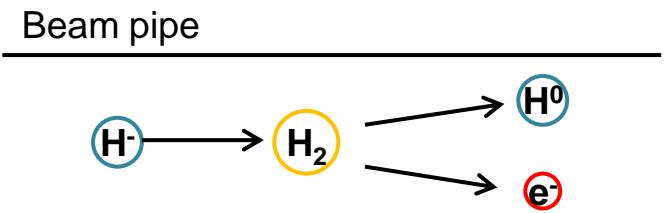
$$P_{strip} = 1 - e^{-l/\lambda}$$

$$l = \text{length}; \quad \lambda = \frac{kT}{\sigma P} \quad ; \quad \sigma \sim \frac{1}{\beta_{rel}^2}$$

- Stripping probability **rises with gas pressure**
- Stripping probability **decreases with particle energy**



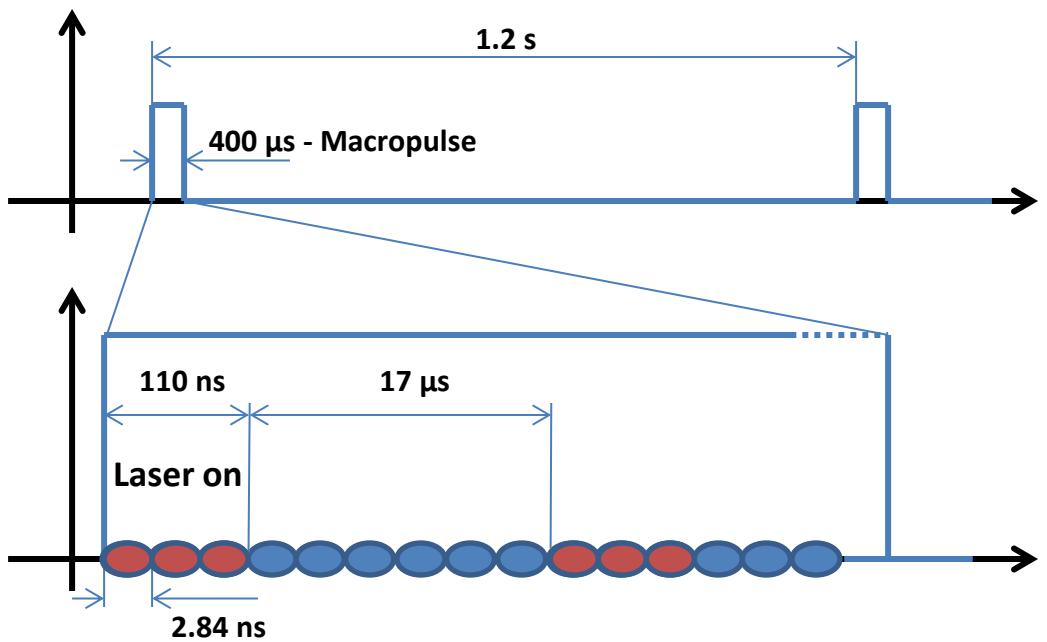
Ref: J.T. Broad and W.P. Reinhardt, Phys. Rev. A14 (6) (1976) 2159



# LINAC4 & Laser Timing

- **LINAC4**

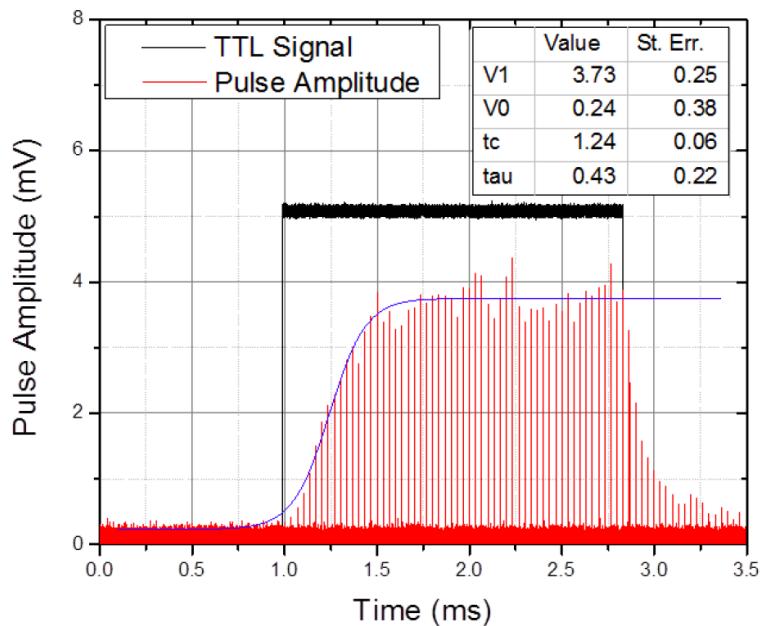
- 1.2 s Period length
- 400  $\mu$ s Macropulse
- 352 MHz RF-System



24 Laserpulses per 400  $\mu$ s Macropulse

- **MOPA Fiberlaser**

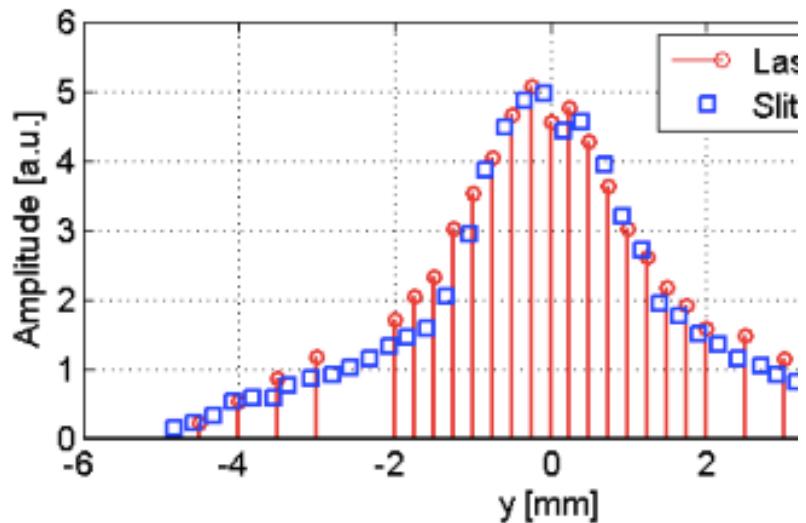
- 60 kHz Master Oszilllator
- 110 ns Pulsewidth
- Modulation via Power Amplifier



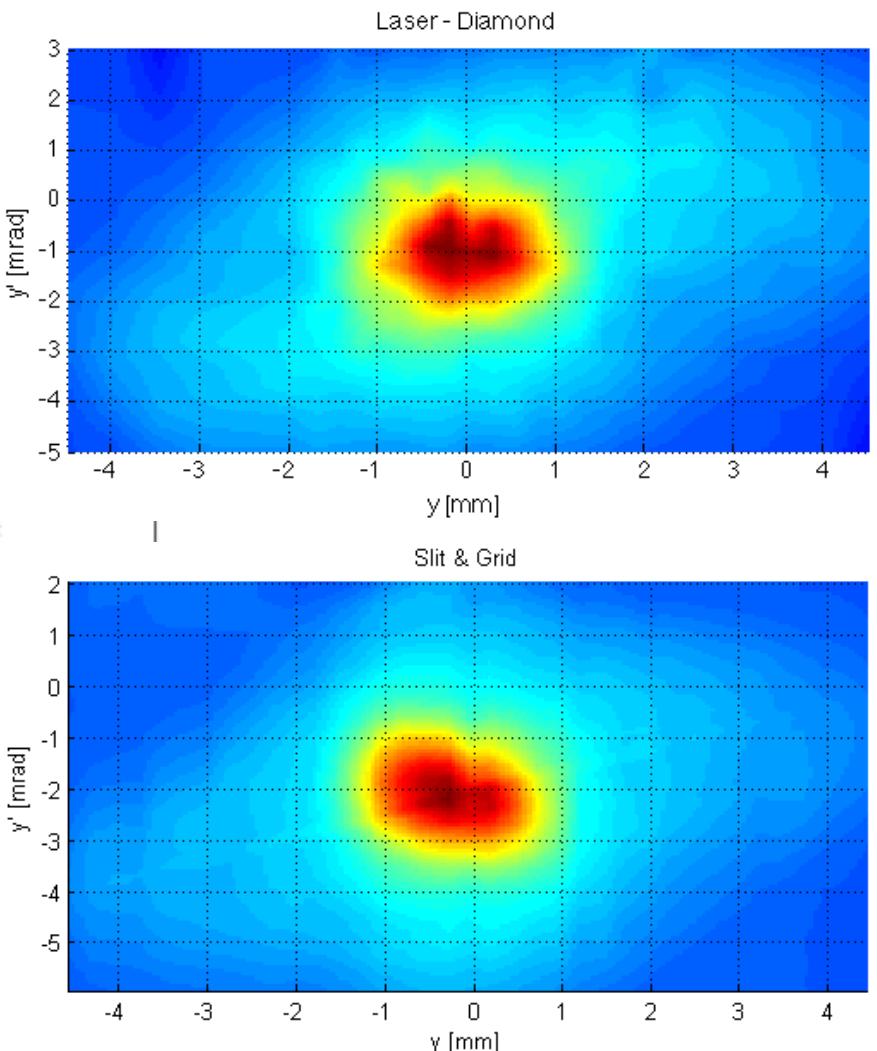
# 3 MeV Results - Comparison with Slit & Grid



- Beam Profile
- Phasespace



$$\sigma_{Laser} = 1.49 \text{ mm} \quad \sigma_{Slit/Grid} = 1.36 \text{ mm}$$



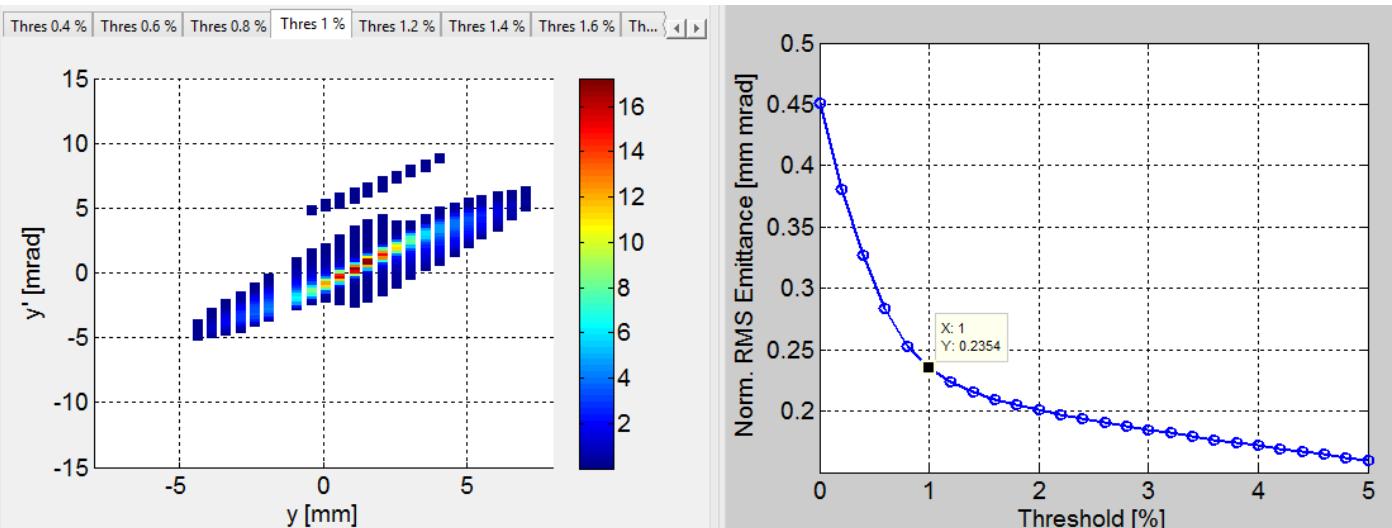
Ref: F. Roncarolo et al., Transverse profile and emittance measurements with a laser stripping system during the CERN LINAC4 commissioning at 3 and 12 MeV, Proc. LINAC14, Geneva, Switzerland

# Emittance Value at 12 MeV

- Slit & Grid

Emittance:

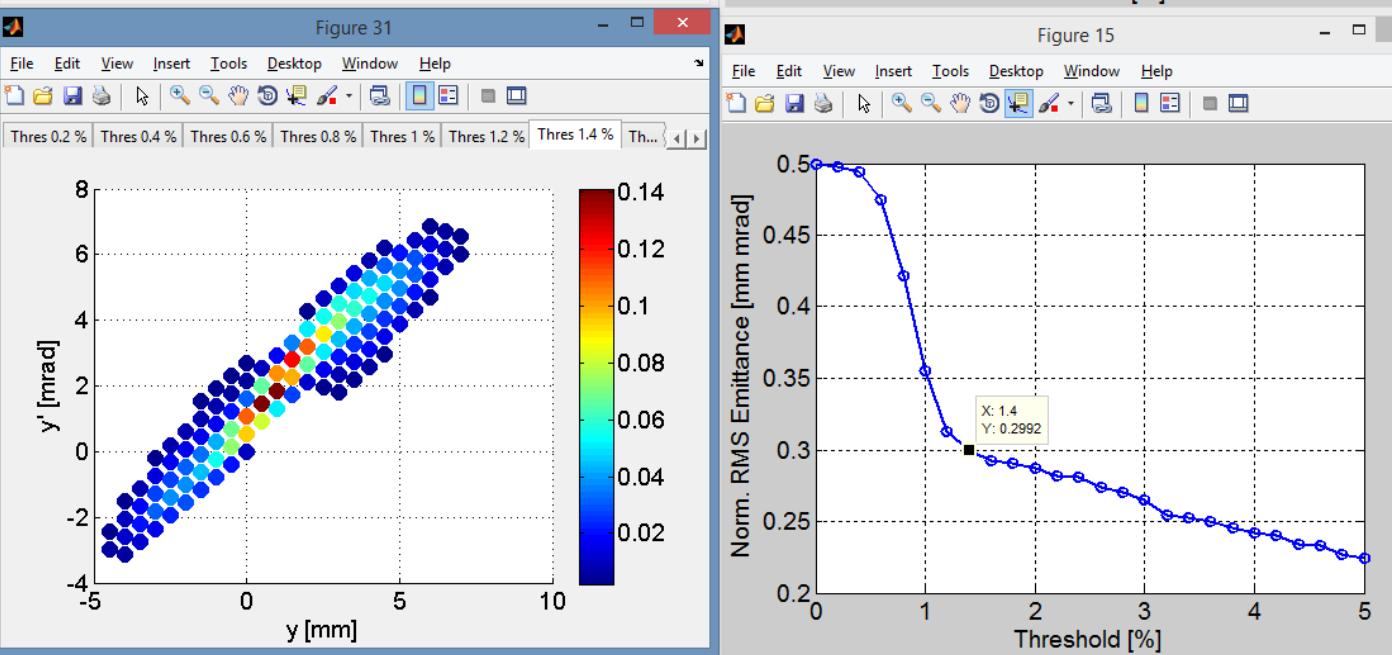
0.235 mm mrad



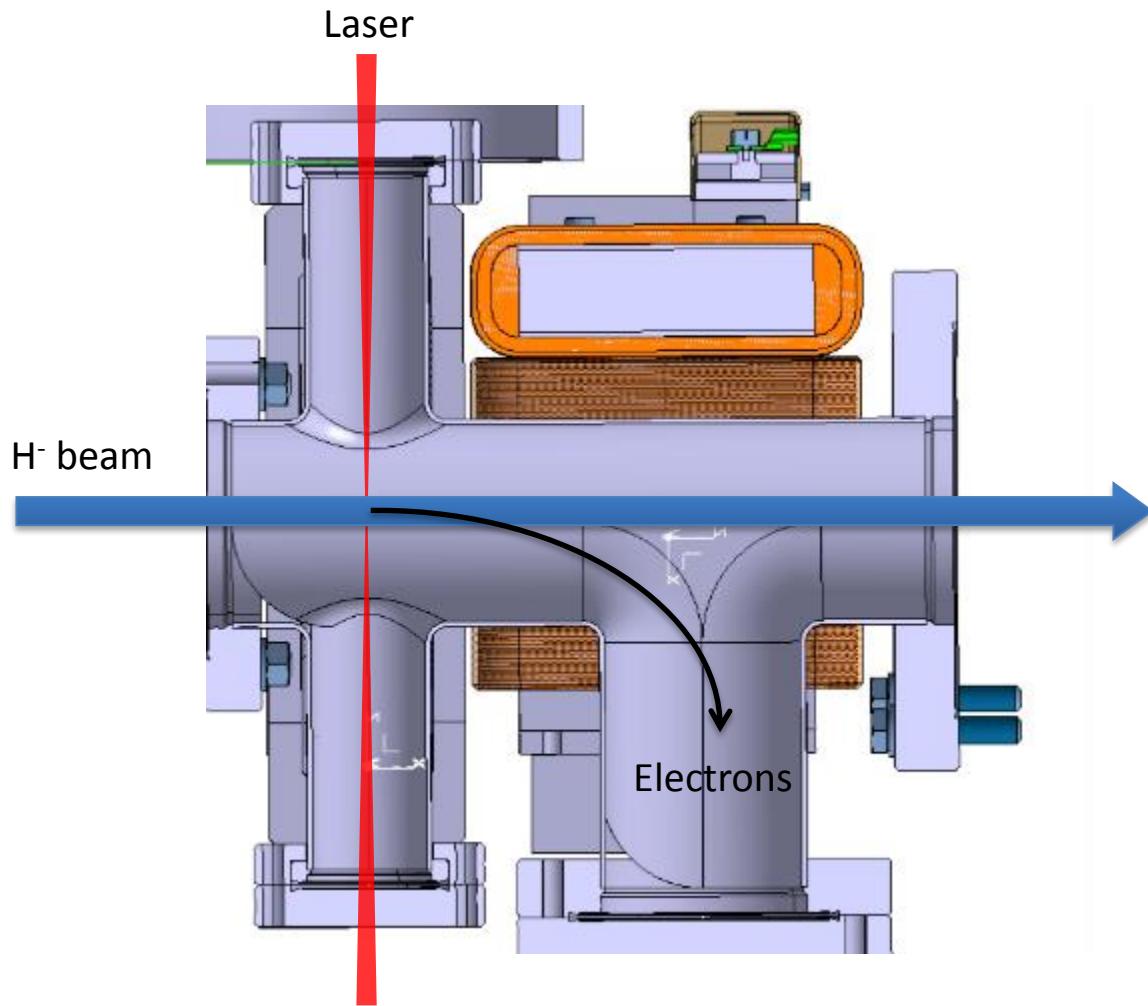
- Laser Diamond

Emittance:

0.299 mm mrad



# Concept Profile Meter

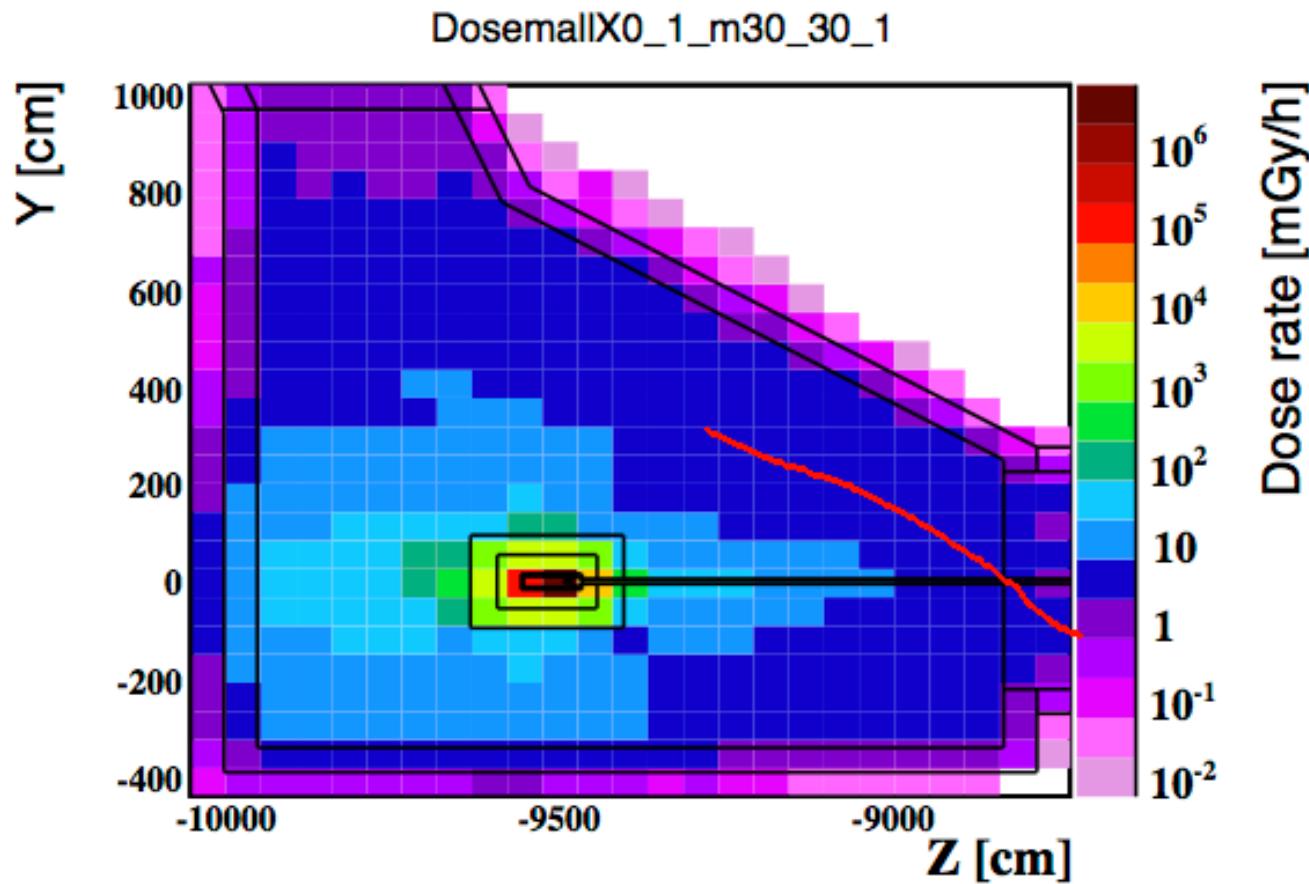


# Detector Possibilities for Electron Collector



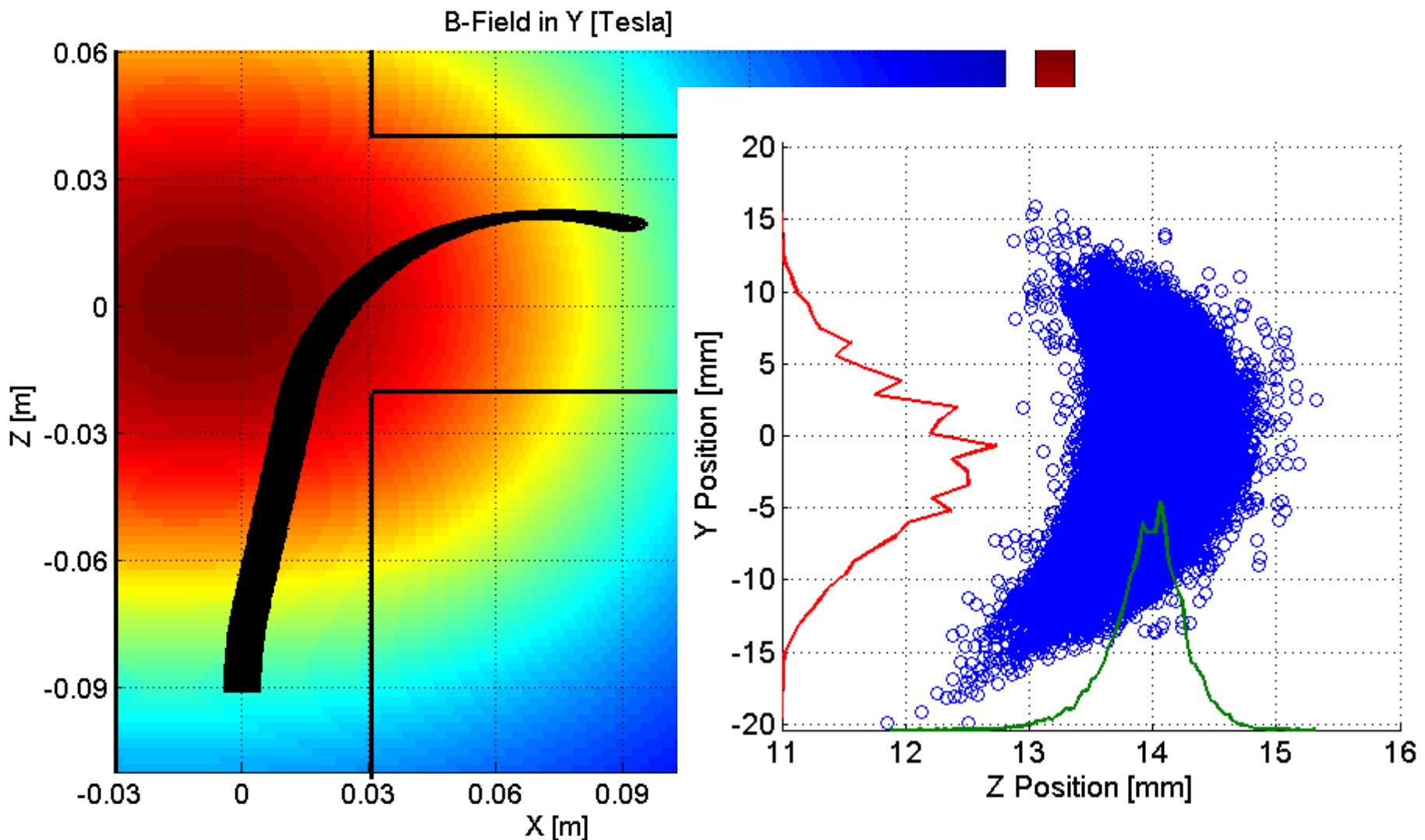
Type	Faraday cup	Diamond detector	Silicon PIN Diode	Electron Multiplier
Sensitivity	1	$10^4$	$10^5$	$>10^6$
Rad. Hardness	+++	++	+	+++
Time constant	High!	ps	16ns	2ns
Homogeneity	+++	-	+++	+++
Saturation	No limit	No limit	2...3mA	10mA
Vacuum	good	good	diffcult	good

# Radiation environment at LINAC4 160 MeV area



- Dose over lifetime of LINAC4 (red: path of fiber)
- -> ca. **50Gy** will be radiation load of fiber over whole lifetime

# Simulation – Electron Collection



# Beam at 160 MeV

