

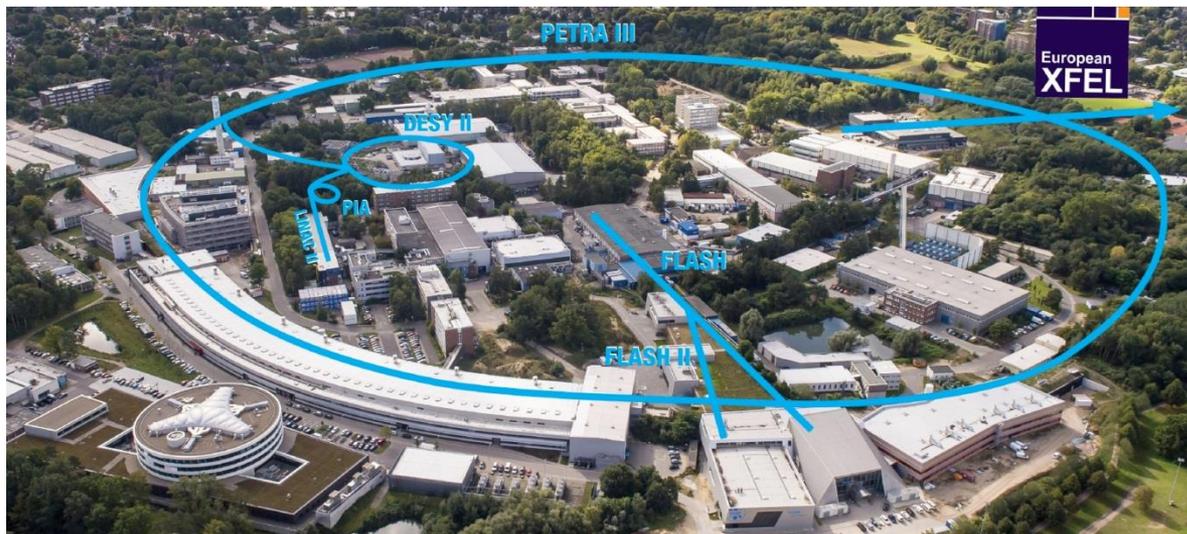


# PETRA III.

## Recent Studies of Injection System at PETRA III transport line and PETRA IV upgrade

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Topical Workshop on Injection and Injection Systems  
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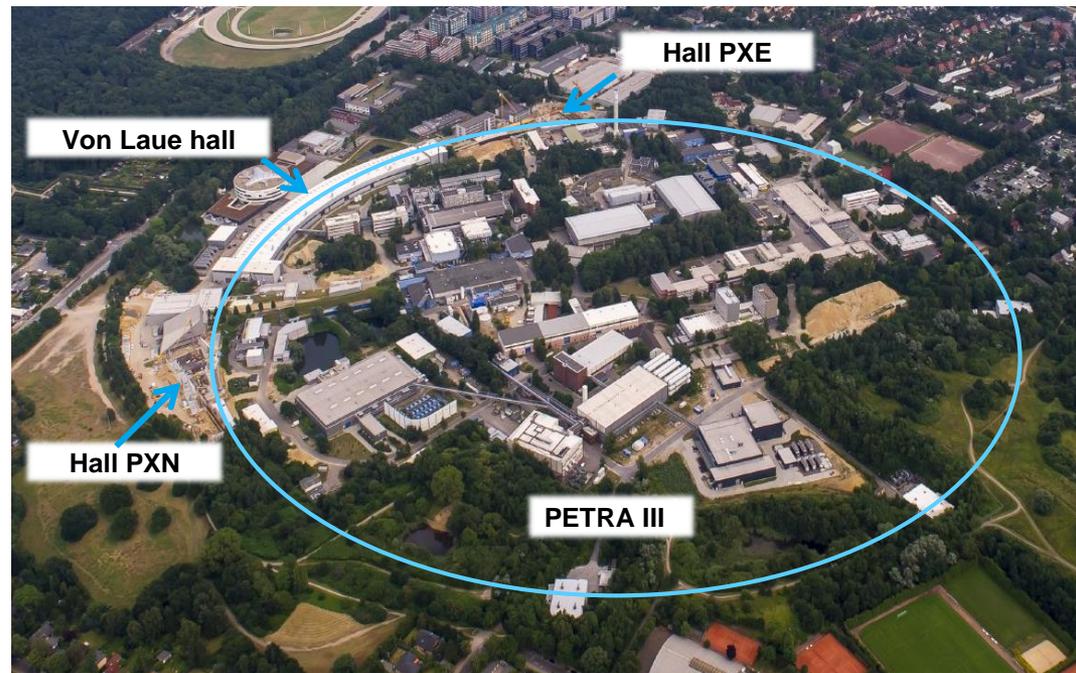
# Outline

- > Overview of PETRA III
  - Storage ring
  - Injection system
- > Upgrade strategy of PETRA IV
- > Recent studies
  - Measurement of emittance and optical functions on E-Weg
  - Reduce the emittance of DESY II
    - ❖ Increase the focusing and reduce the energy
    - ❖ Design a new PETRA IV-booster
- > Conclusions



# Overview of PETRA III

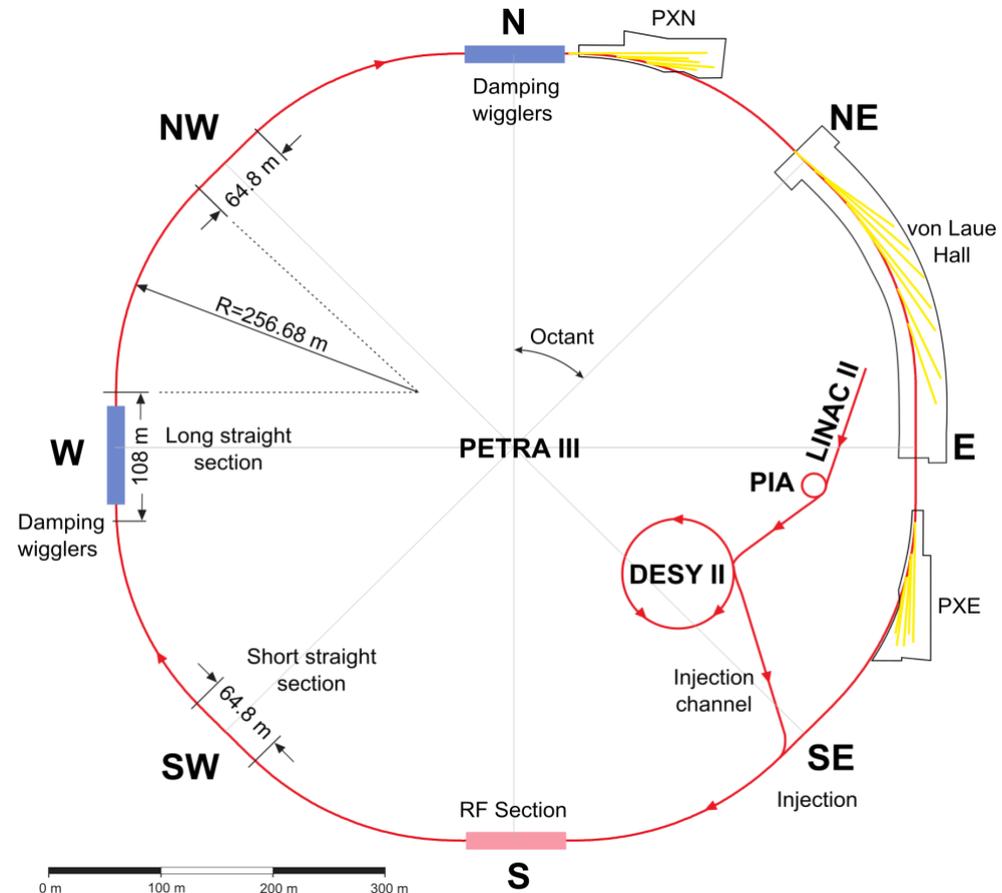
Parameter	Value
Energy	6 GeV
Current	100 mA, Top-Up
Hor. Emittance	1.2 nm·rad
Ver. Emittance	12 pm·rad
Bunches	40, 960
Circumference	2304 m
Harmonic number	3840
RF Voltage	20 MV
Energy loss/Turn	6.1 MeV



- > PETRA I:  $e^\pm$  collider (1978-1986), PETRA II: pre-accelerator for HERA (1990-2007)
- > PETRA III: commissioned 2009; in operation for users since middle of 2010
- > Max von Laue hall: 14 beam lines, PXE, PXN (2014): 7+5 beamlines -> **26 beam lines in total**

# Layout of PETRA III

- > Octagonal shape, circumference 2304 m, emittance 1.2 nm·rad
- > **Eight Arcs** (45°), 201.6 m long
  - 5 pure FODO-arcs
  - 2 modified FODO arcs with 2 DBA-like cells at the beginning (PXN, PXE)
  - One arc build from 9 DBA cells  
 $L_{\text{cell}} = 23 \text{ m}$ , 5 m ID straight sections
- > **Eight straight sections**
  - 4 long straights N,S,E,W (108 m)  
 20 damping wigglers in N and W;  
 RF cavities in S (20 MV)
  - 4 short straights NW,NE,SE,SW (64.8 m)
- > **Beamlines**
  - Max von-Laue Hall:14; PXN:5; PXE: 7



# Layout of PETRA III Injection System

## ➤ Linac II

S-Band Linac

$e^- \rightarrow e^+$  converter (presently not used)

two guns (bombarder type + triode)

## ➤ PIA

accumulator ring (originally designed for  $e^+$  operation)

## ➤ DESY II

450 MeV  $\rightarrow$  6 GeV (max. 7 GeV)

**Emittance** (6 GeV, PETRA III) x/y  $\sim$  350/15 nm.rad

Intensity (# particles): max.  $2 \times 10^{10}$ , typical  $1 \times 10^{10}$

## ➤ E-Weg: transport line DESY II $\rightarrow$ PETRA III

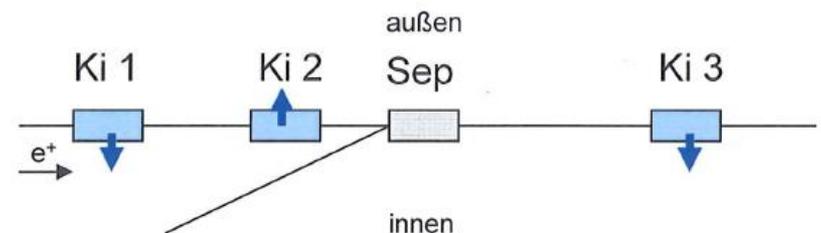
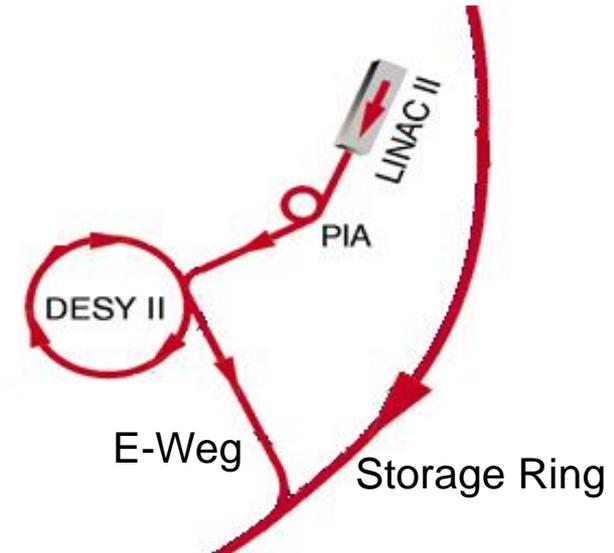
L = 203 m

## ➤ Storage Ring

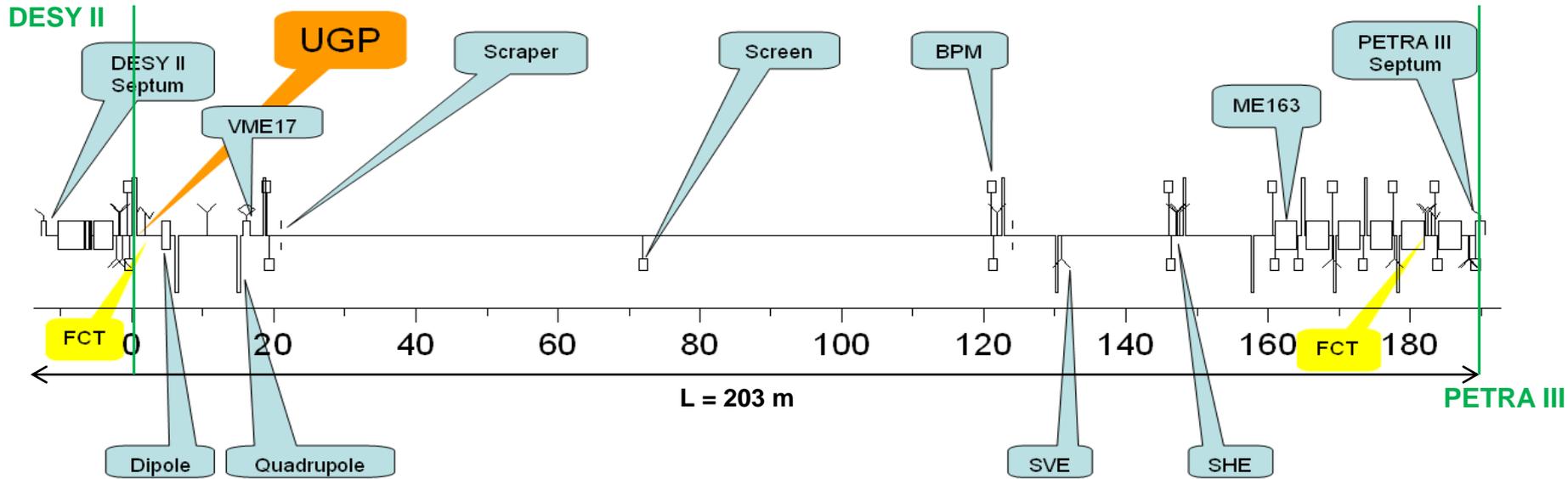
3 kickers (deflection = 2.88 mrad, L = 590 mm) +

1 septum (4 mm)

39 mm Kicker Bump



# E-Weg transport line



# Elements	Elements
12	Quadrupoles
7	H. dipoles
1	V. dipole
5	H. correctors
7	V. correctors
10	Screen Monitors
8	BPMs



To correct a difference in the vertical plane of 1.28 m between DESY II and PETRA III



To estimate beam spot profiles (emittance and dispersion measurements)

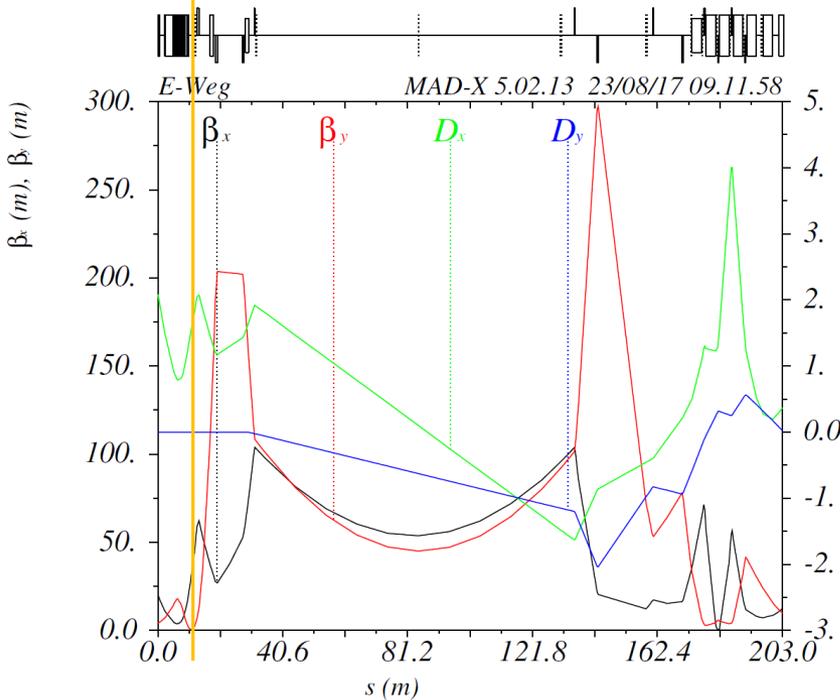


# E-Weg transport line

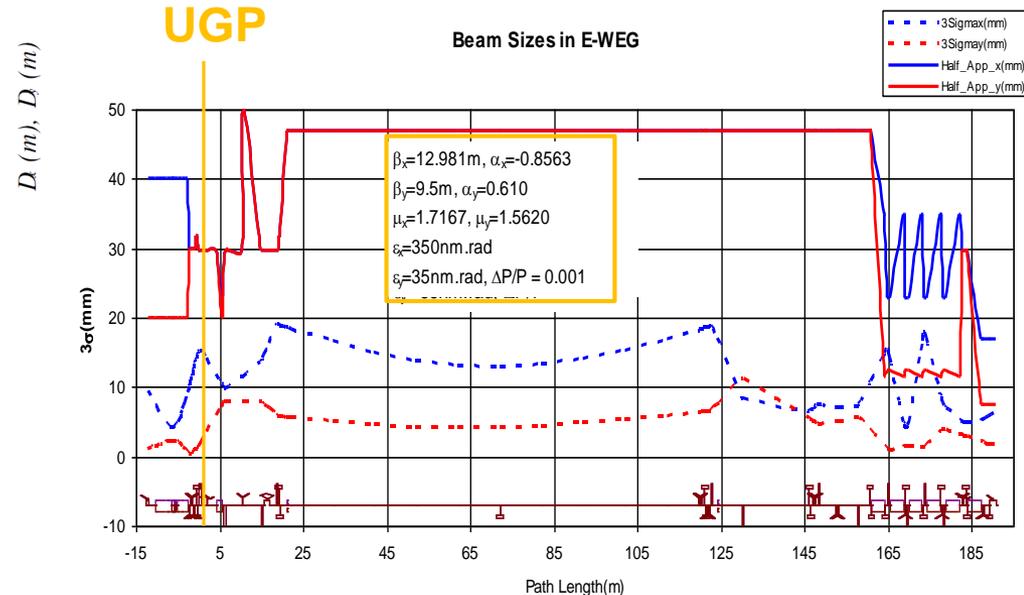
- Optical functions: matched at UGP point to take into account the effect of previous magnets of DESY lattice

- $3\sigma$  beam sizes in comparison to available physical aperture along E-Weg taking into account the beam emittances  $\varepsilon_x = 350 \text{ nm}\cdot\text{rad}$ ,  $\varepsilon_y = 35 \text{ nm}\cdot\text{rad}$

UGP



UGP



# PETRA IV upgrade: Parameters and time scale

PETRA IV Parameter		
Energy	6 GeV	(4.5 – 6 GeV)
Current	100 mA	(100 – 200 mA)
Number of bunches	~ 1000	
Emittance horizontal	10 pm.rad	(10 – 30 pm.rad)
vertical	10 pm.rad	(10 – 30 pm.rad)
Bunch length	~ 100 ps	
Number of beam lines	~ 30	

Investigate most challenging design parameters (6 GeV, 10 pm.rad) and determine the limits

- ❖ Improve dynamic aperture (2 mm.mrad) and momentum acceptance (2%) (MOGA, AT)
- ❖ Error studies

## > Started to investigate two different lattice types

1. Based on the ESRF-HMBA cell (H6BA, H7BA with different cell lengths)
2. Based on 4D-phase space exchange and MBAs with non-interleaved sextupoles

PETRA IV	Jan.	Feb.	März	April	Mai	Juni	Juli	Aug.	Sep.	Okt.	Nov.	Dez.
2016		Study group						Studies				
2017												Lattice Design
2018				CDR								
2019												TDR



# PETRA IV upgrade: Injection System

## > Design goal:

- to preserve as much as possible the current injector system.  
(at least an on-axis injection should be possible with the existing injector)
- an injection with accumulation in PETRA IV is highly desirable.

## > Recent studies and activities:

1. Measure the optical functions (dispersion and betas) and emittance of E-Weg (G.K. Sahoo, et al., Proc IPAC 2017).
2. We need to reduce the emittance of DESY II to inject in a storage ring of 10 pm.rad:
  - Increase the focusing and reduce the energy from 6 GeV to 5 GeV (J. Keil, et al., Proc IPAC 2017).
  - **Design a new booster of ~10 nm.rad** (I. Agapov, et al., Proc IPAC 2017).



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# Dispersion function measurement in E-Weg

- > Measurement of dispersion from the centroid shift of the screen beam spot by extracting beam from DESY II at different energies (neglecting the change in quadrupole strength)

$$\Delta x = D_x \cdot \frac{\Delta p}{p}$$

$\Delta p/p=0.6\%$ E=6.0493 GeV ( $\pm 0.0018$ GeV)				
	Theoretical		Measured	
Name	$D_x$ (m)	$D_y$ (m)	$D_x$ (m)	$D_y$ (m)
<b>M000</b>	1.8802	0.0000	-0.5216	0.0308
<b>M020</b>	1.9107	-0.0266	0.3603	0.0356
<b>M119</b>	-1.4793	-1.1492	0.007	0.2602
<b>M144</b>	-0.4561	-0.9784	-0.8741	-0.6193
<b>M161</b>	0.4727	-0.6235	-1.1326	-0.5737
<b>M169</b>	1.2715	0.2927	0.0000	0.0000
<b>M178</b>	1.6634	0.5213	1.0812	0.1890
<b>M185</b>	0.3439	0.3439	0.8062	-0.0808

- > Conclusion: the initial conditions of DESY II were not correct due to misalignment of magnets and resolution of BPMs that impacts the beam quality.



# Emittance and optics measurements in E-Weg

- Based in matrix formalism: the elements of the beam matrix at point 1 can be known measuring the Twiss parameters propagated by the transfer matrix between point 1 and point 2:

$$\text{beam matrix: } \Sigma = \begin{pmatrix} \langle x^2 \rangle & \langle xx' \rangle \\ \langle xx' \rangle & \langle x'^2 \rangle \end{pmatrix} = \epsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}$$

$$\text{Transport matrix from point 1 to point 2: } M = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}$$

$$\text{Beam matrix at point 2: } \Sigma_2 = M \Sigma_1 M^T$$

$$\text{Beam size at point 2: } \Sigma_{2,11} = M_{11}^2 \Sigma_{1,11} + 2M_{11}M_{12} \Sigma_{1,12} + M_{12}^2 \Sigma_{1,22}$$

- Quadrupole Scan Method: fitting the beam size vs. the quadrupole strength just after the quadrupole

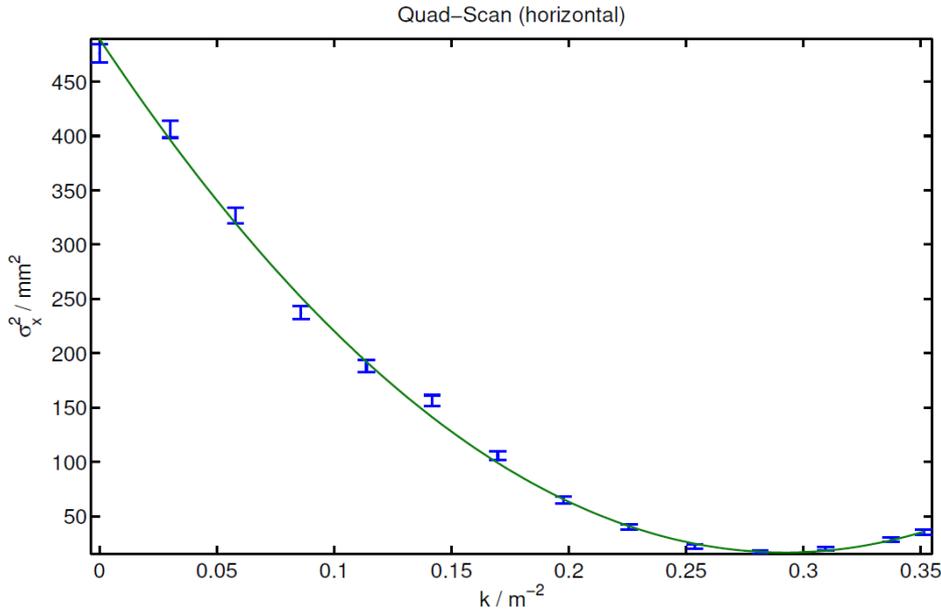
$$M = M_{quad}(k) \cdot M_{drift}$$

- Multiple Screen Method: using different screens to measure the beam size in the same drift space

$$M = M_{drift,1} \cdot M_{drift,2} \cdot M_{drift,3}$$



# Quadrupole Scan Method



> Example of fitting of the beam size vs. the quadrupole strength for 6 GeV

> Conclusion: the measured emittances agree with calculations.

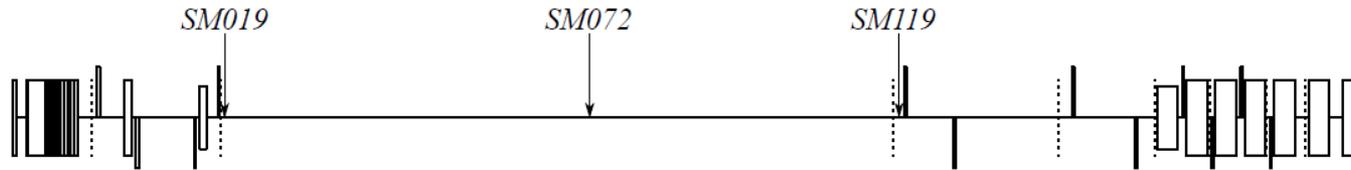
> Disagreement in betas and alphas caused by an incorrect model of the stray field of the DESY II dipole magnet which the beam has to cross when extracted

	Theory		Measurement	
	5 (GeV)	6 (GeV)	5 (GeV)	6 (GeV)
$\varepsilon_x$ (nm.rad)	241	331	$253 \pm 6$	$335 \pm 12$
$\varepsilon_y$ (nm.rad)	24	33	$10 \pm 0.5$	$15 \pm 0.5$
$\beta_x$ (m)	111	111	$53 \pm 2$	$56 \pm 2$
$\beta_y$ (m)	120	120	$56 \pm 4$	$56 \pm 3$
$\alpha_x$	-8.9	-8.9	$-3.8 \pm 0.1$	$-4.2 \pm 0.2$
$\alpha_y$	11.9	11.9	$6.2 \pm 0.4$	$5.9 \pm 0.3$



# Multiple Screen Method

- > Measurements done at screen monitors at 19 m, 72 m and 119 m from the beginning of E-Weg



Monitor	$\sigma_x$ (mm)	$\varepsilon_x$ (nm.rad)	$\beta_x$ (m)	$\alpha_x$
<b>SM019</b>	5.253482	357	77.3 (103)	0.83 (0.96)
<b>SM072</b>	4.337361	*	53 (54)	-0.39 (-0.02)
<b>SM119</b>	6.94860	*	135 (96)	-1.40 (-0.89)
Monitor	$\sigma_y$ (mm)	$\varepsilon_y$ (nm.rad)	$\beta_y$ (m)	$\alpha_y$
<b>SM019</b>	0.98797	12.5	78 (107)	1.05 (1.18)
<b>SM072</b>	0.74694	11.9	45 (45)	-0.45 (0.01)
<b>SM119</b>	1.344465	*	144 (92)	-1.70 (-1.03)

(\*) not enough BPMs resolution

- > Conclusion: disagreement caused by an incorrect model of the stray field of the DESYII dipole magnet which the beam has to cross when extracted

# PETRA IV upgrade: Injection System

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## > Recent studies and activities:

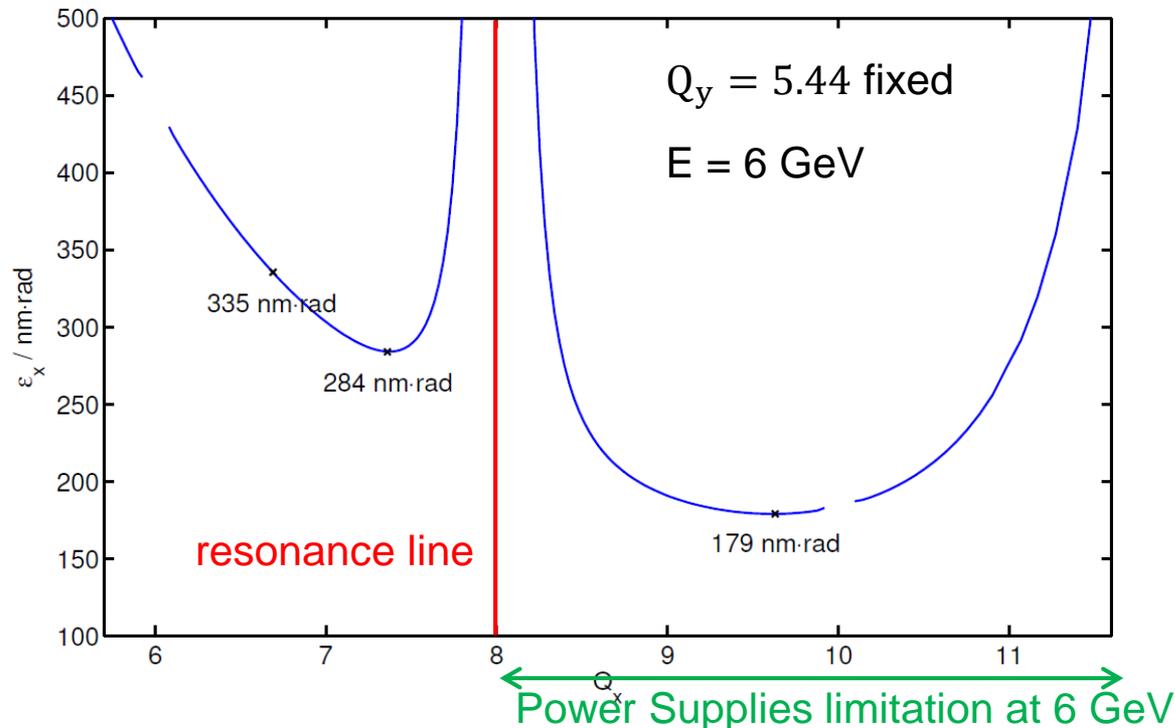
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- **Design a new booster of  $\sim 10$  nm.rad** (I. Agapov, et al., Proc IPAC 2017).



# Emittance reduction in E-Weg

- > DESY II consists of 8 supercells with  $L = 36.6\text{m}$  -> total  $L = 293\text{ m}$ .
- > Each supercell is made of 3 FODO cells.
- > Decreasing the energy from 6 GeV to 5 GeV, the emittance decreases from 330 nm.rad to 241 nm.rad (<10%).
- > Increase focusing also helps to reduce the emittance.



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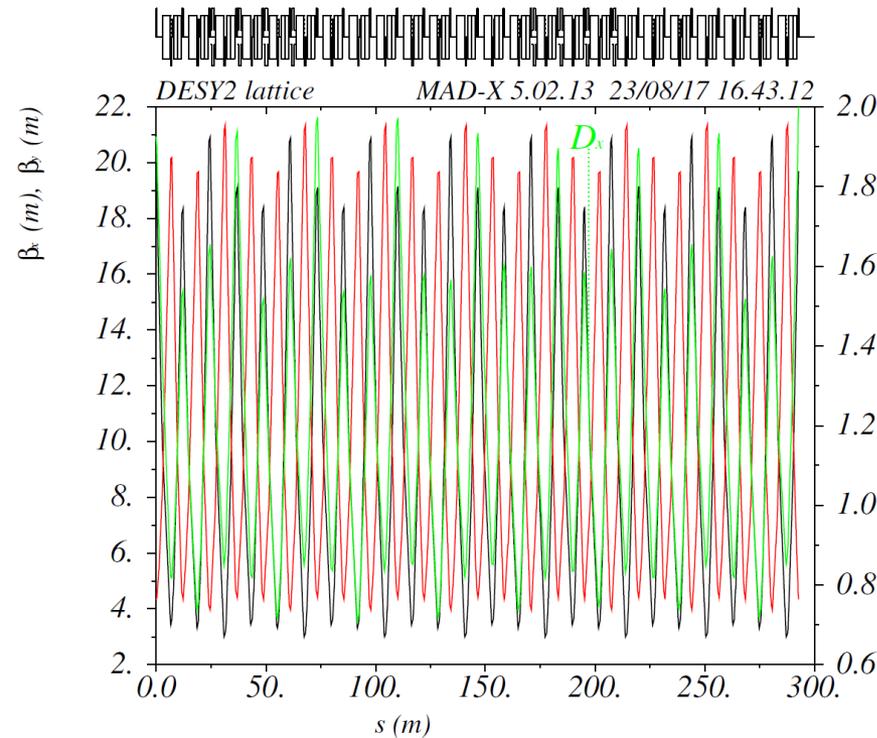
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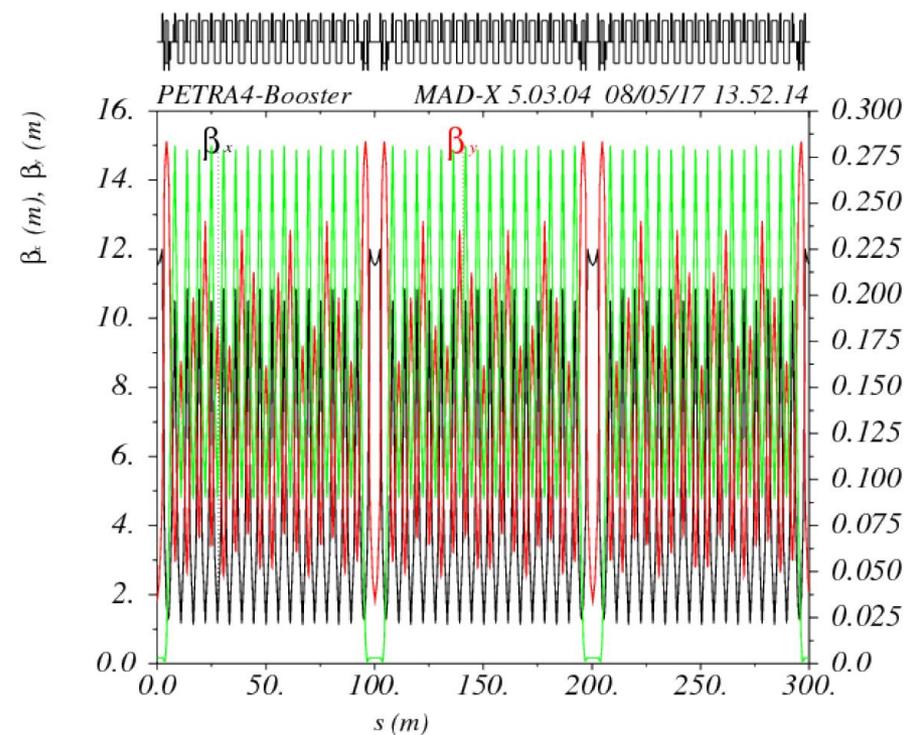
# New PETRA IV- Booster lattice

## ➤ New PETRA IV-Booster lattice scaling the **ALBA booster**



8 supercells (3 FODO cells with L=36.6m per supercell)

$$\epsilon_x = 330 \text{ nm.rad}$$



3-fold symmetry with 3 arcs and 3 straight sections

$$\epsilon_x = 7 \text{ nm.rad}$$



# Conclusions

- > The study of a new pre-accelerator of PETRA IV has already started thinking to reuse most parts of the current booster.
- > The measurements of the emittance agree with theoretical expectations. However, the measured optical functions at the transport line show a disagreement with the theoretical values due to a no precise model of the effect of magnets.
- > We must reduce the emittance of the PETRA IV pre-accelerator.
- > A different working point of DESY II can provide a smaller emittance (from 335 nm.rad to 284 nm.rad). Further improvements would require new power supplies.
- > A new booster lattice is also considered. First studies are based on a scaled version of the ALBA booster (7 nm.rad).
- > The final choice of new injector will depend on the new storage ring configuration.



# Thank you for your attention !!

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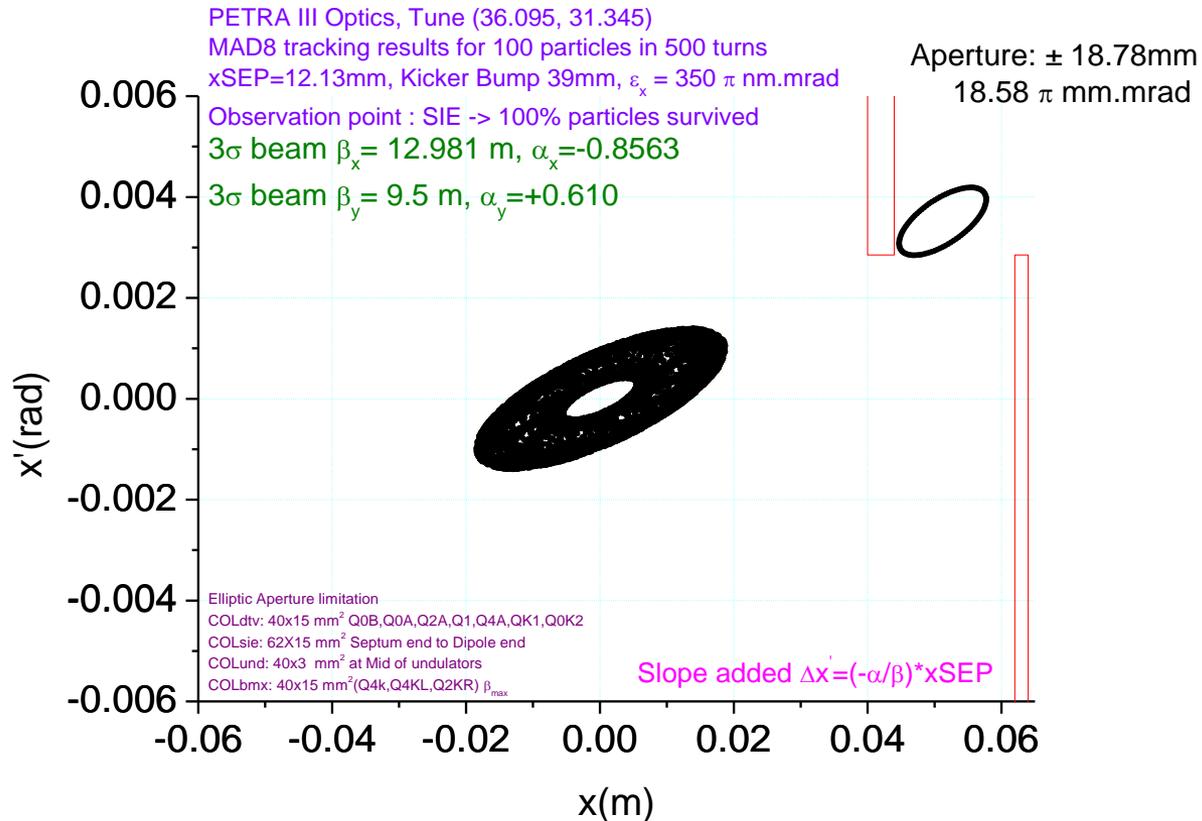


# Backup Slides



# Injector with 39 mm Kicker Bump

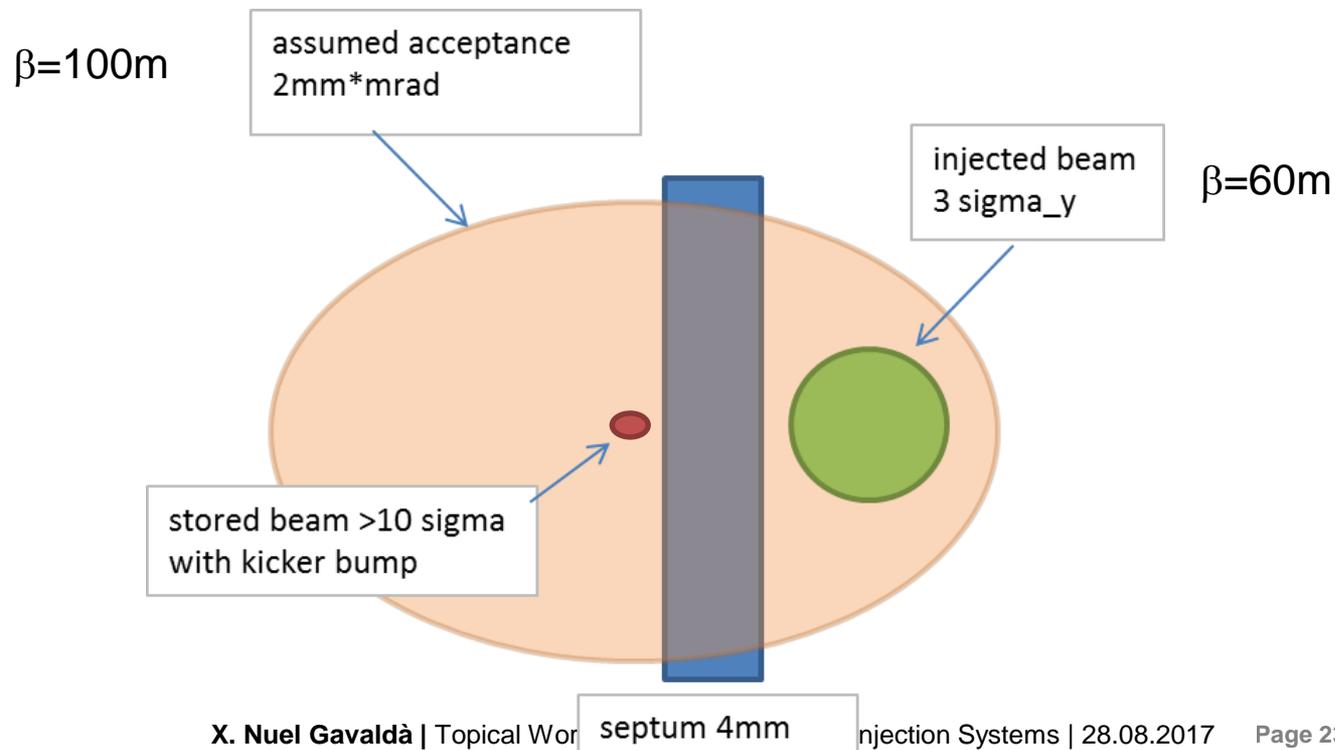
- > An aperture of  $\pm 18$  mm is enough to inject  $3\sigma$  beam



# Recent idea: accumulation in the (y-) plane of smaller emittance from injector

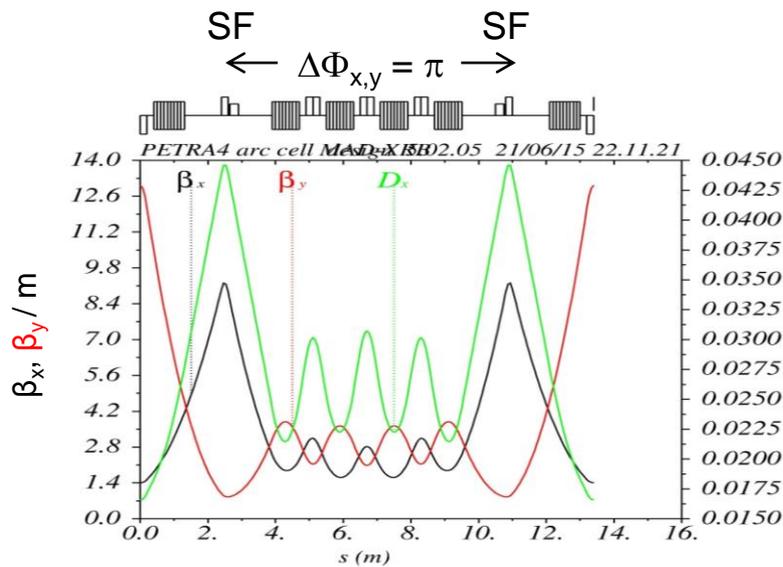
(Similar concept pursued at HZB/BESSY2, P. Kuske, Proc. IPAC 2016)

- Either inject vertically into PETRA III ring or perform a 90° x-y phase space twist in the transfer line
- Dynamic acceptance of 2 mm\*mrad would be safely sufficient for accumulation
- On-axis injection in the other plane with ~200nm emittance no problem



# Phase Space Exchange Lattice (TMBA Lattice)

- > Lattice with **significantly more dynamic aperture**
  - Arc cells with non-interleaved sextupoles pairs and  $\pi/\pi$  phase advance
  - Enough DA to allow off-axis injection
- > Provides **equal emittances** by using two *Twists*
  - *Twists*: Two x-y phase space exchange insertions in straight sections (“Double Möbius”) – full coupled only within the twists
  - Horizontal natural emittance  $\epsilon_0$  is equally distributed in both planes  $\rightarrow$  round beam
- > The sum chromaticity of two half-arcs is corrected
- > In addition cells for arcs without IDs are necessary



Non-interleaved arc cell

