

The beam already knows what emittance it should deliver, we just have to measure it !

Content:

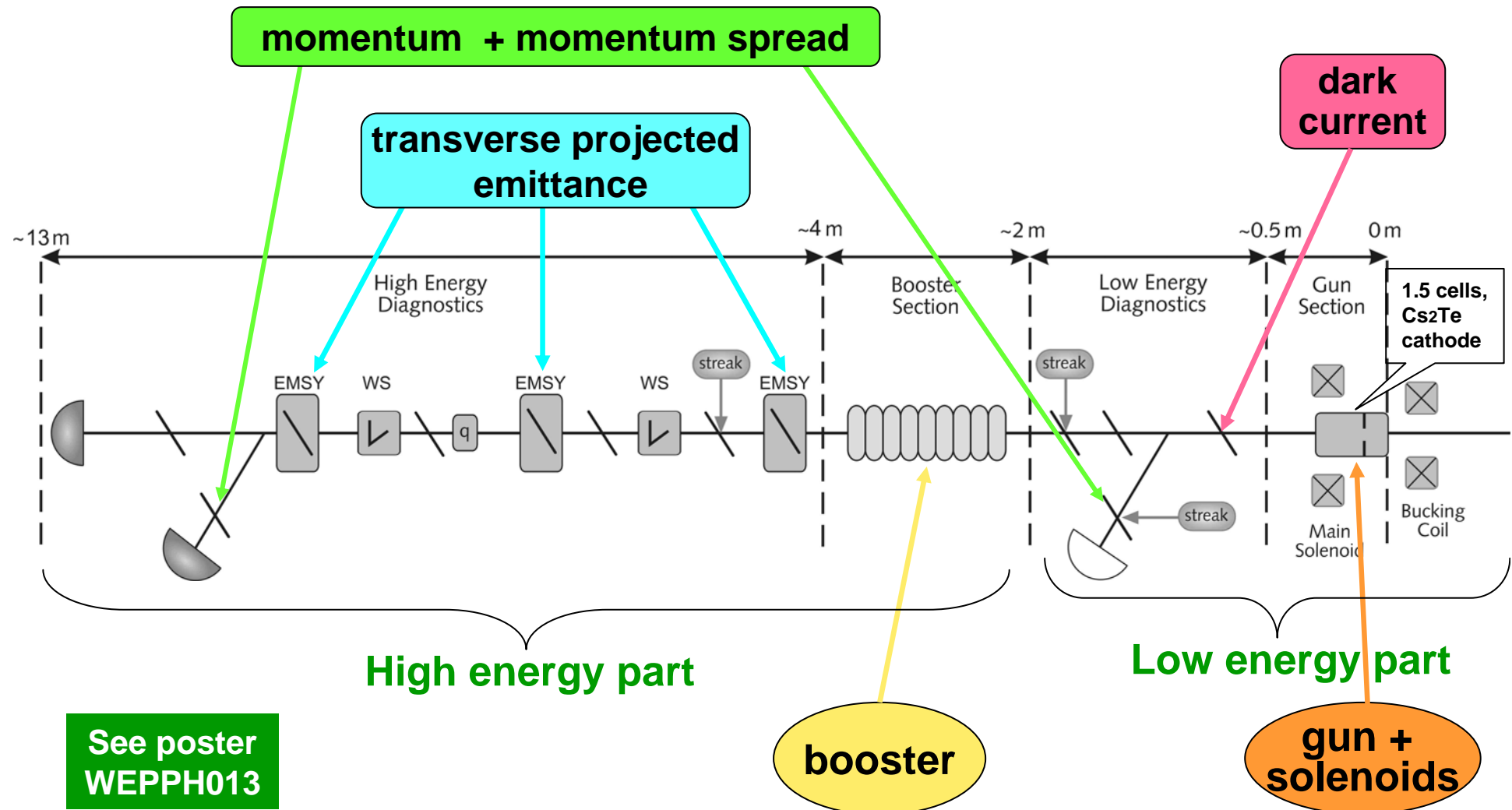
- measurement setup
- cathode laser
- different guns
- longitudinal phase space
- transverse projected emittance
- cathode studies
- future upgrades of the facility

Colleagues actively participating in measurements / new design:

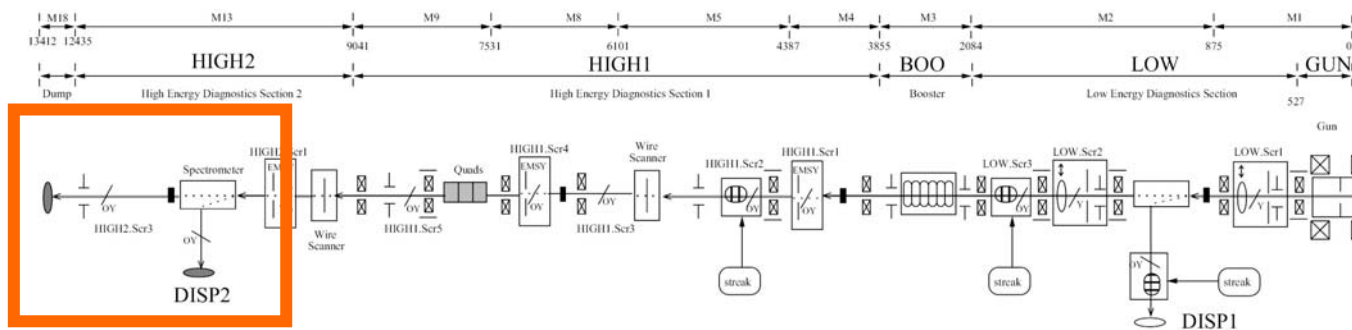
- **DESY, Zeuthen site:**
F. Stephan, J. Bähr, C. Boulware, H.J. Grabosch, Y. Ivanisenko*, S. Khodyachyk, S. Korepanov, M. Krasilnikov, A. Oppelt**, B. Petrosyan, S. Riemann, S. Rimjaem, K. Rosbach, A. Shapovalov***, T. Scholz, R. Spesyvtsev****, L. Staykov
 - **DESY, Hamburg site:**
K. Flöttmann, J.H. Han, S. Lederer, S. Schreiber
 - **BESSY Berlin:**
T. Kamps, F. Marhauser*****, R. Ovsyannikov, D. Richter, A. Vollmer
 - **CCLRC Daresbury:**
D.J. Holder, B.D. Muratori
 - **INRNE Sofia:**
G. Asova, K. Boyanov, I. Tsakov
 - **INR Troitsk:**
A.N. Naboka, V. Paramonov, A.K. Skassyrskaja
 - **LAL Orsay:**
T. Garvey**
 - **LASA Milano:**
P. Michelato, L. Monaco, D. Sertore
 - **LNF Frascati:**
D. Alesini, L. Ficcadenti
 - **MBI Berlin:**
G. Klemz, I. Will
 - **TU Darmstadt:**
W. Ackermann, E. Arevalo, W. Müller, S. Schnepp
 - **Uni Hamburg:**
J. Rönsch
 - **YERPHI Yerevan:**
L. Hakobyan
- * on leave from IERT Kharkov,
** now at PSI, Villingen,
*** on leave from MEPHI, Moscow,
**** on leave from NSCIM, Kharkov,
***** now at JLAB, Newport News
- **Acknowledgements:** R. Brinkmann, U. Gensch, E. Jaeschke, L. Kravchuk, V. Nikoghosyan, C. Pagani, L. Palumbo, J. Rossbach, W. Sandner, S. Smith, T. Weiland, G. Wormser

Present layout of PITZ

This setup was used for the measurements to be presented:

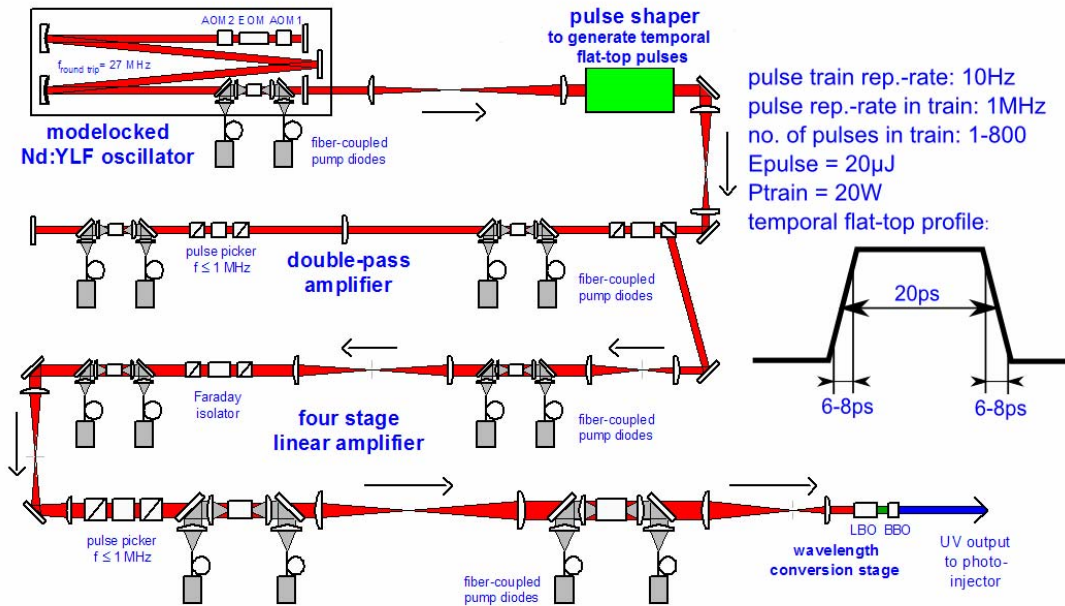


Present layout of PITZ

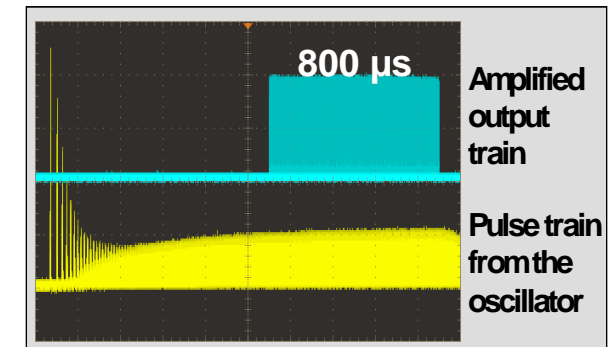


Version 6.2.07

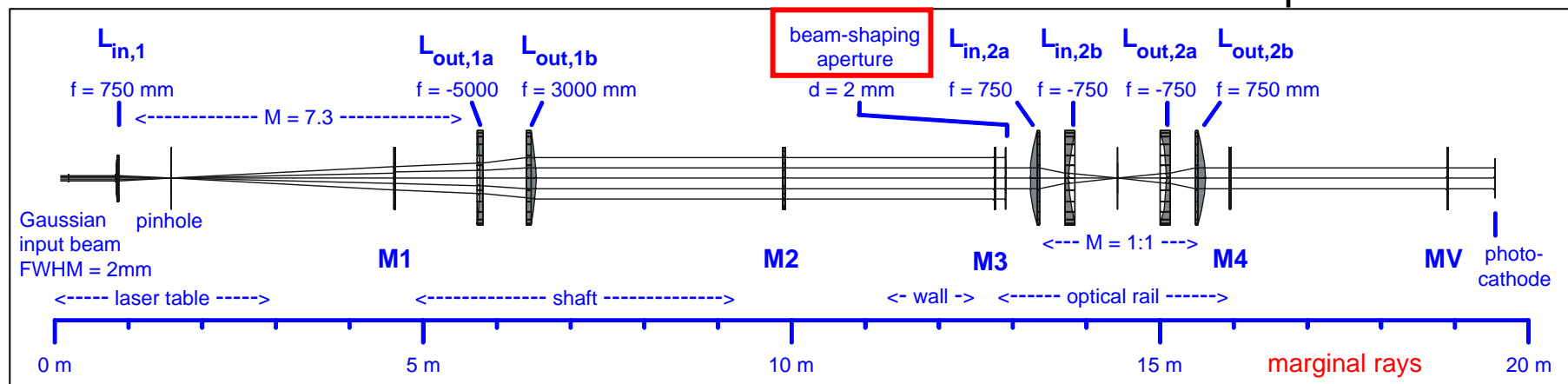
Photo cathode laser



Schematics of the diode-pumped Nd:YLF photo cathode laser system

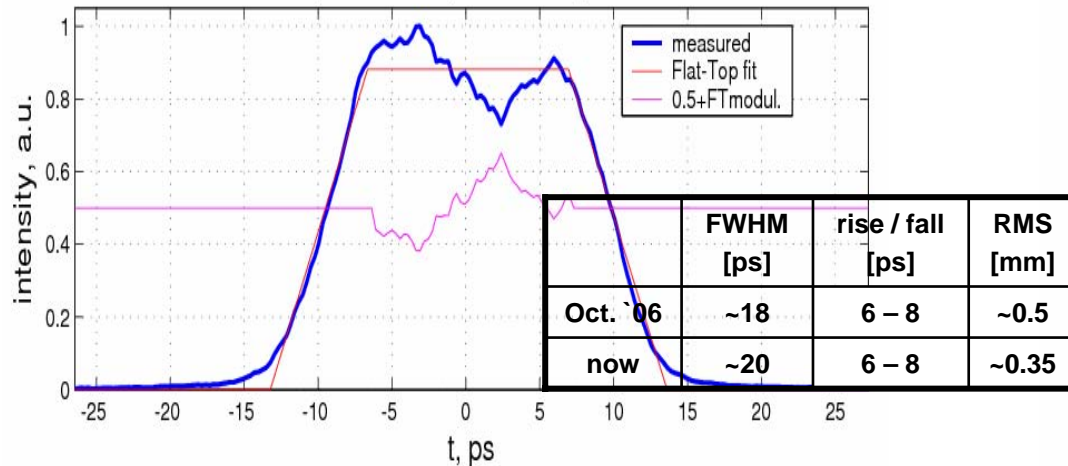


Beamline to photo cathode

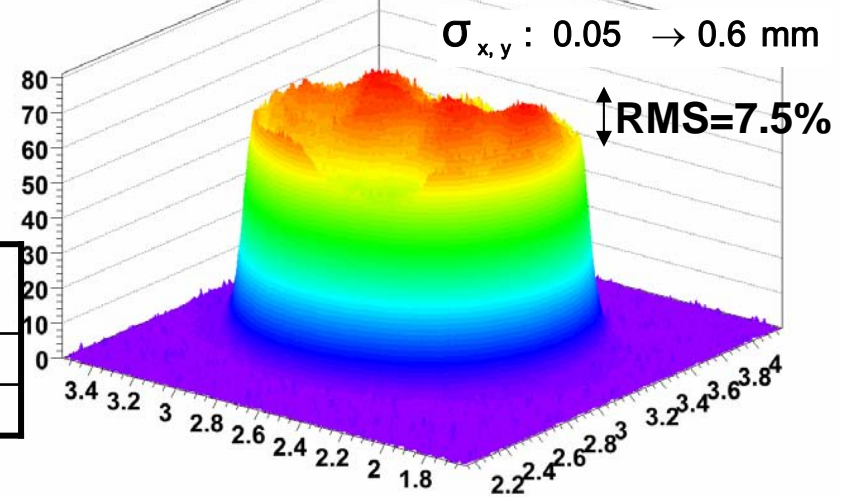


• longitudinal profile:

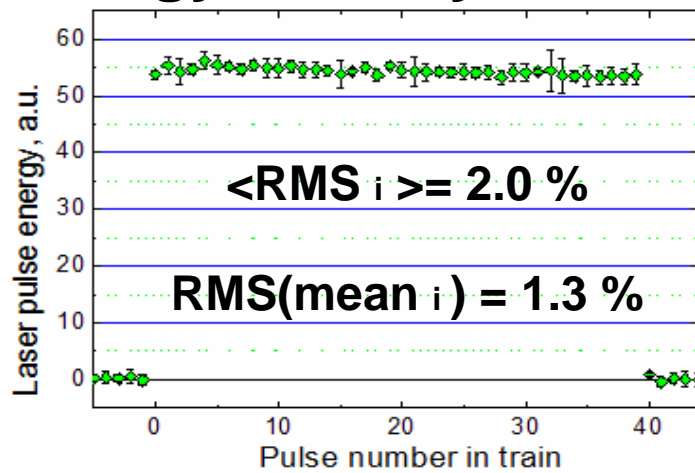
FWHM=20.22ps; rt1=6.58ps; rt2=6.67ps; FTmod=6.52%



• transverse profile:

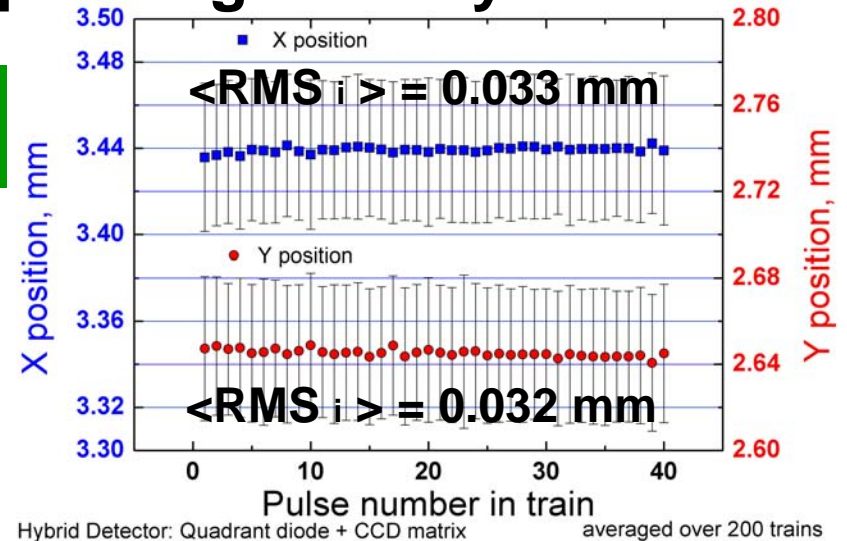


• energy stability:



See poster WEPPH011

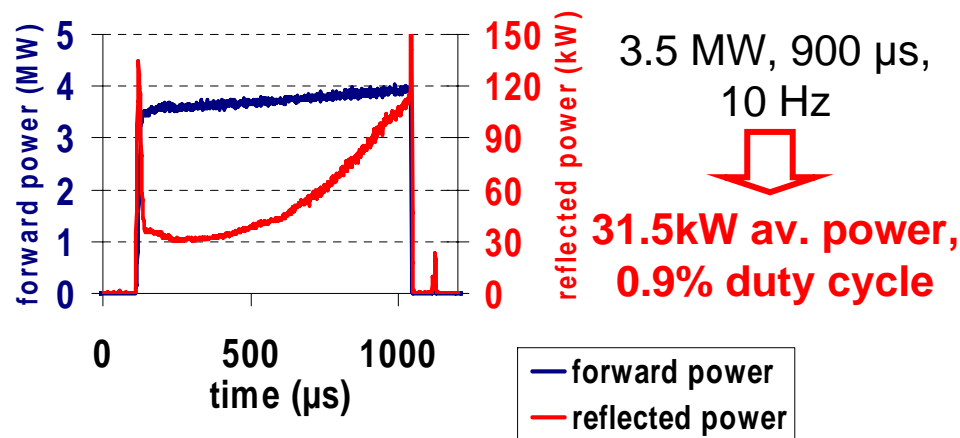
• pointing stability:



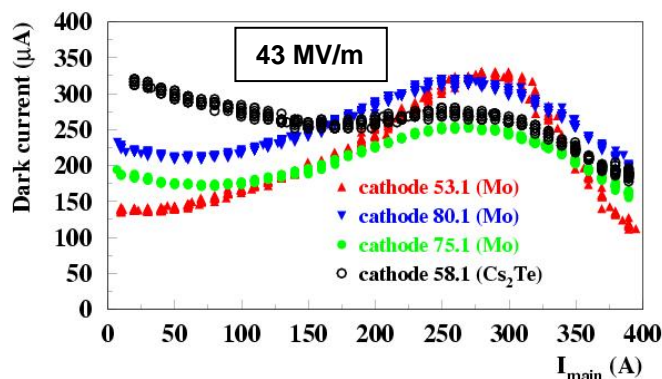
• Gun 3.1 –

characterized @ $\sim 40\text{MV/m}$ in Oct. '06
→ spare gun for FLASH

• Peak and average power:



• Dark current:

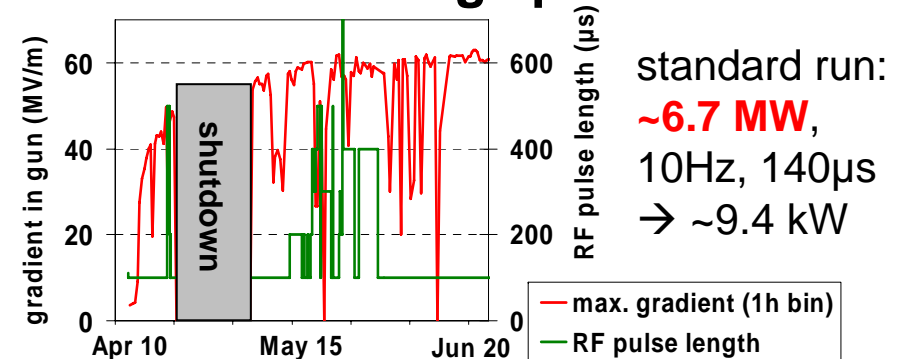


See poster
WEPPH013

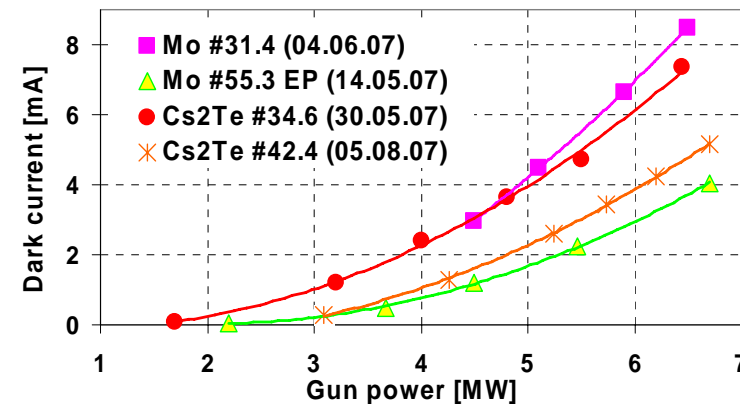
• Gun 3.2 –

characterized @ $\sim 60\text{MV/m}$ in summer '07
→ first experience with long RF at 60 MV/m

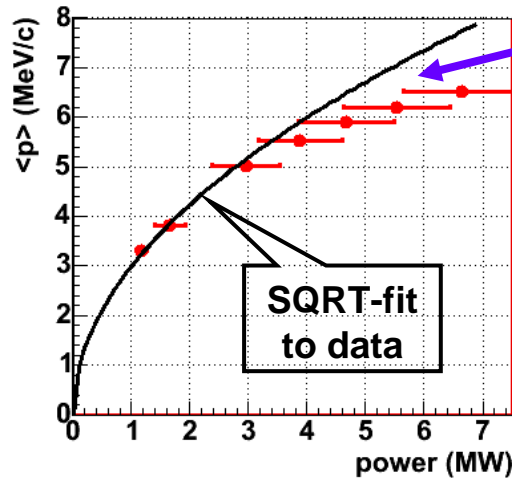
• Peak and average power:



• Dark Current:



→ very high ! → possible reason: cavity
fabrication error in cathode region

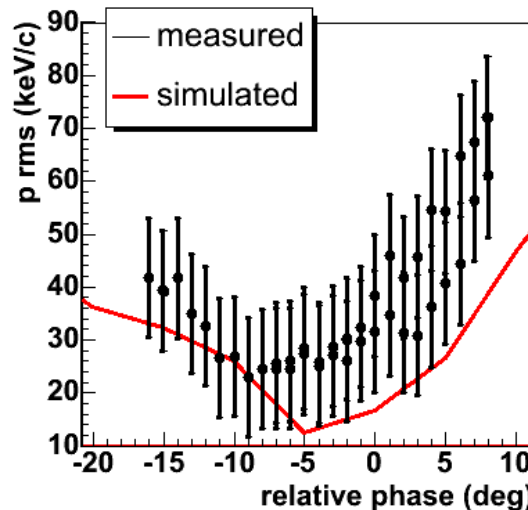
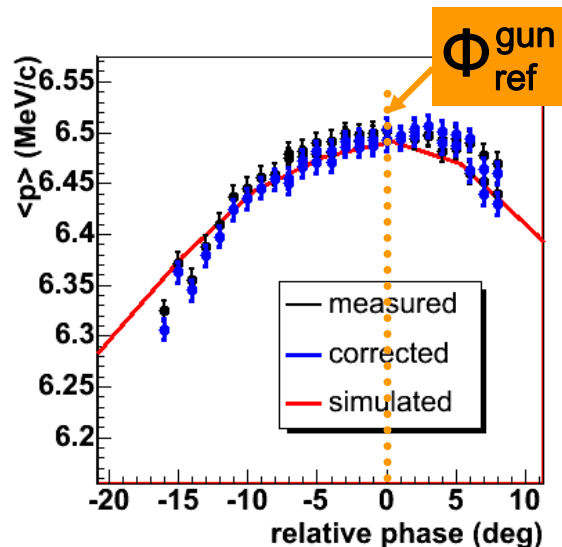


Problem with maximum momentum:

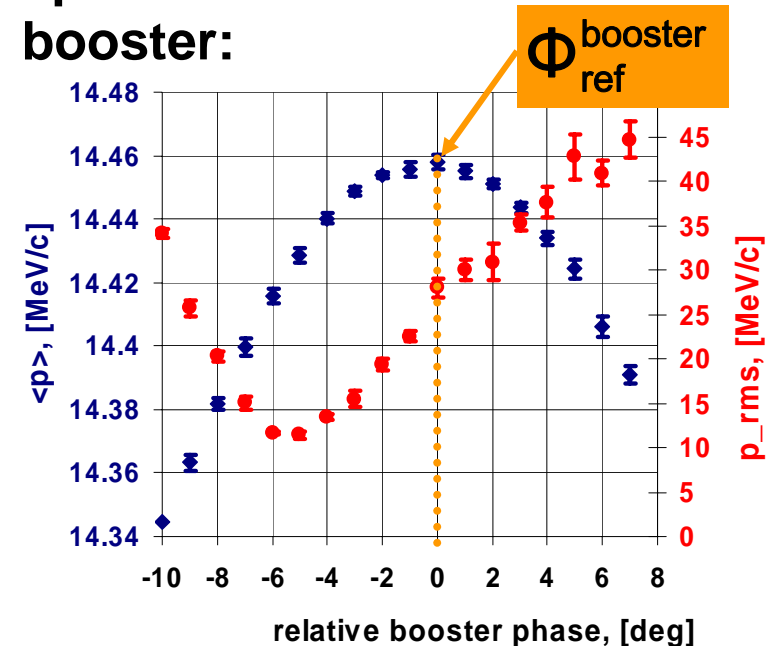
- measured momentum lower than expected from RF power readings
- possible reason:
→ power measurements

For more details
and bunch length
measurements
see poster
WEPPH09

Momentum and momentum spread downstream of the gun:



Momentum and momentum spread downstream of the booster:



Projected Emittance Measurements: → Slit Scan Technique

$$\mathcal{E}_{x,n} = \beta\gamma \cdot X_{rms} \cdot X'_{rms}$$

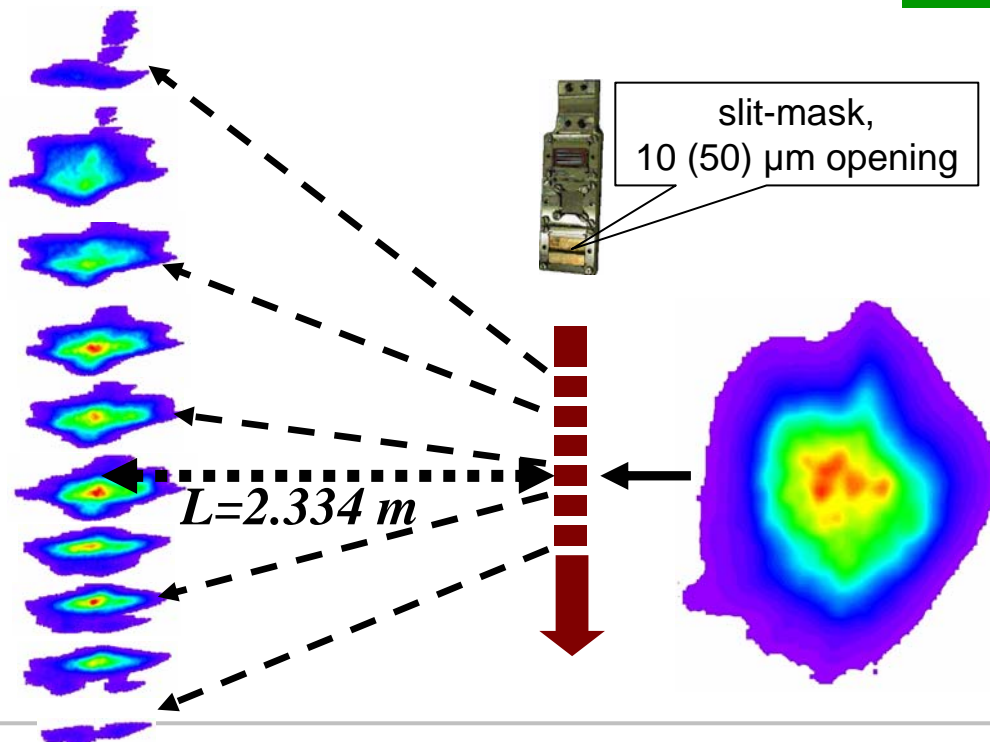
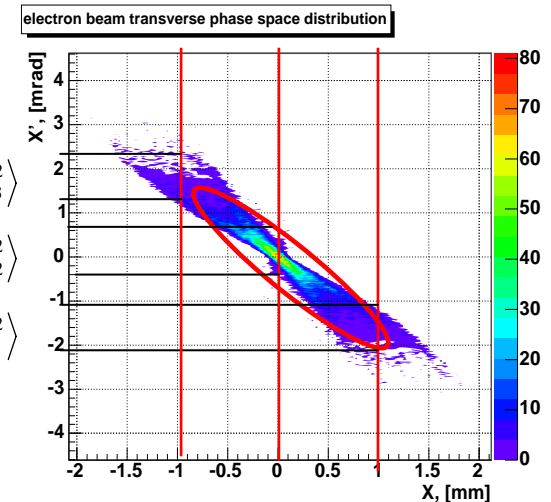
X_{rms} - RMS size of full beam at EMSY station (e.g. $z = 4.3\text{m}$)

$$X'_{rms} = \frac{1}{L} \sqrt{\frac{\sum_{i=1}^n w_i \cdot (X_{rms}^{beamlet})^2}{\sum_{i=1}^n w_i}} \quad \text{- uncorrelated local divergence}$$

$X_{rms}^{beamlet}$ - RMS size of the beamlet image

L - distance from slit location to screen for beamlets

See poster
MOPPH055



- **Current standard procedure:**
 - take 11 equidistant beamlets over the full beam size
 - use 10 μm slit opening
- ultimate resolution (current setup):
→ 36 μm x 15.4 μrad
- use camera with 12 bit signal depth for beamlet measurements

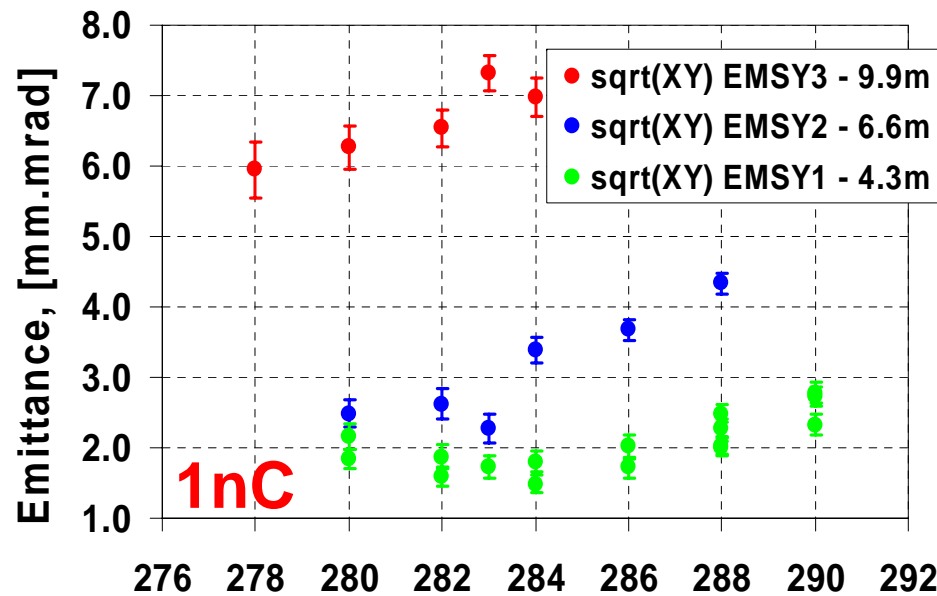
Gun gradient: ~ 43MV/m

Gun phase: $\Phi^{\text{gun}} = \Phi_{\text{ref}}^{\text{gun}} - 2 \text{ deg}$

Momentum from gun: ~ 5.0 MeV/c

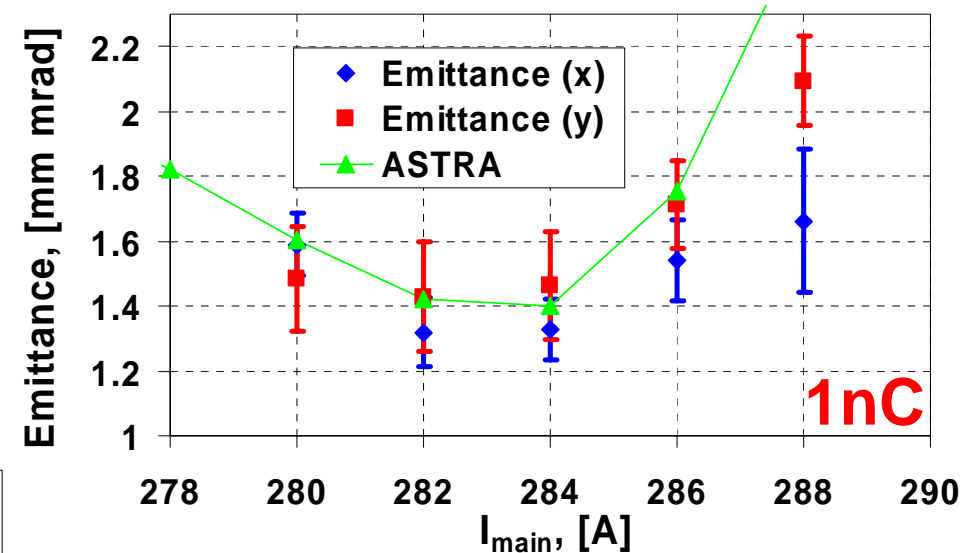
Booster phase: $\Phi^{\text{booster}} = \Phi_{\text{ref}}^{\text{booster}} - 5 \text{ deg}$

Total beam momentum: 12.8 MeV/c



$\Phi^{\text{gun}} = \Phi_{\text{ref}}^{\text{gun}} - 2 \text{ deg}$

$\Phi^{\text{booster}} = \Phi_{\text{ref}}^{\text{booster}} - 15 \text{ deg}$



→ for 43 MV/m we obtained

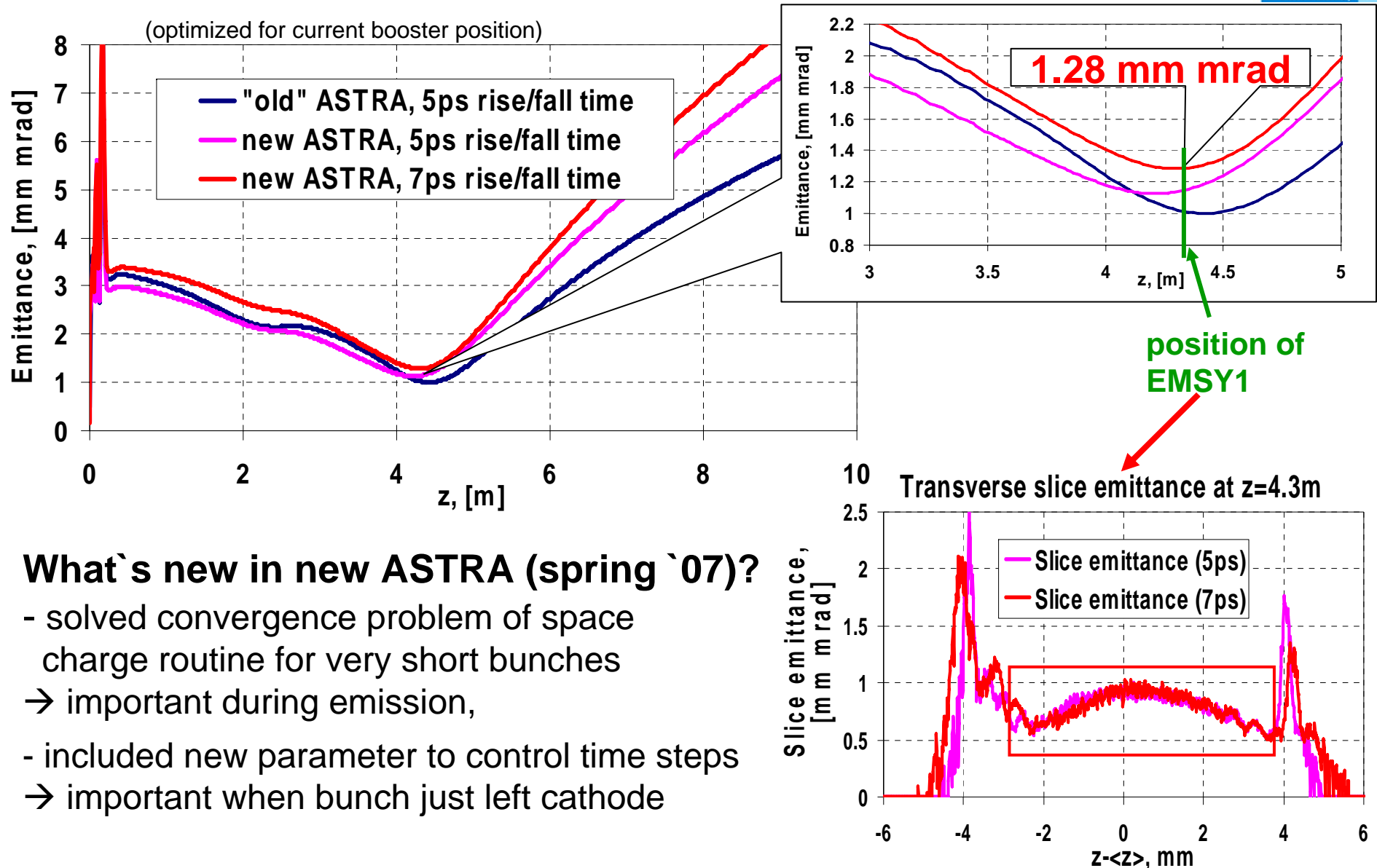
$$\epsilon_{x,n} = 1.32 \pm 0.11 \text{ mm mrad}$$

$$\epsilon_{y,n} = 1.43 \pm 0.17 \text{ mm mrad}$$

@1nC

→ emittance strongly increases with distance from booster

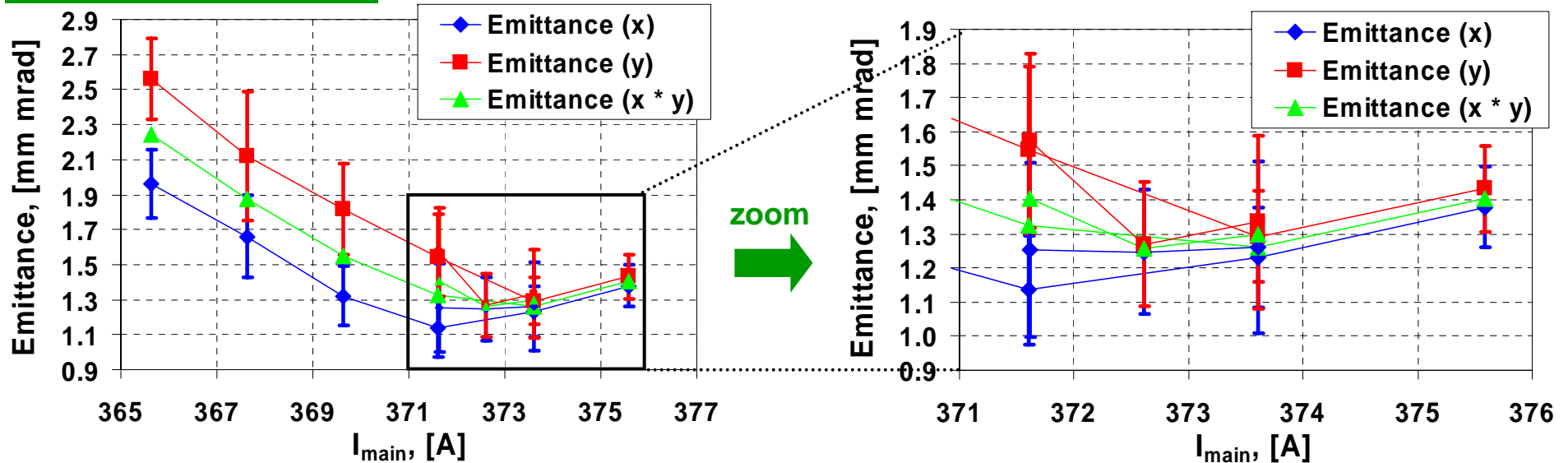
See poster MOPPH055



What's new in new ASTRA (spring `07)?

- solved convergence problem of space charge routine for very short bunches
→ important during emission,
- included new parameter to control time steps
→ important when bunch just left cathode

preliminary analysis



Cathode: # 90.1

Gun gradient: ~ 60 MV/m

Gun phase: $\phi^{gun} = \phi_{ref}^{gun}$

Momentum from gun: ~ 6.44 MeV/c

Booster phase: $\phi^{booster} = \phi_{ref}^{booster}$

Total beam momentum: 14.5 MeV/c

See poster MOPPH055

→ for ~60 MV/m we obtained

$$\begin{aligned} \epsilon_{x, n} &= 1.25 \pm 0.19 \text{ mm mrad} \\ \epsilon_{y, n} &= 1.27 \pm 0.18 \text{ mm mrad} \end{aligned}$$

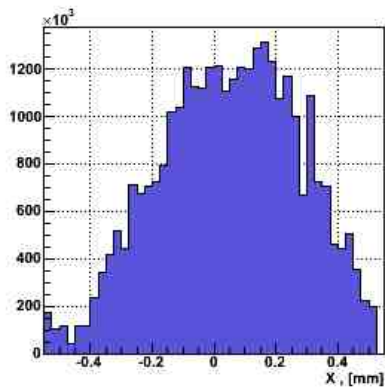
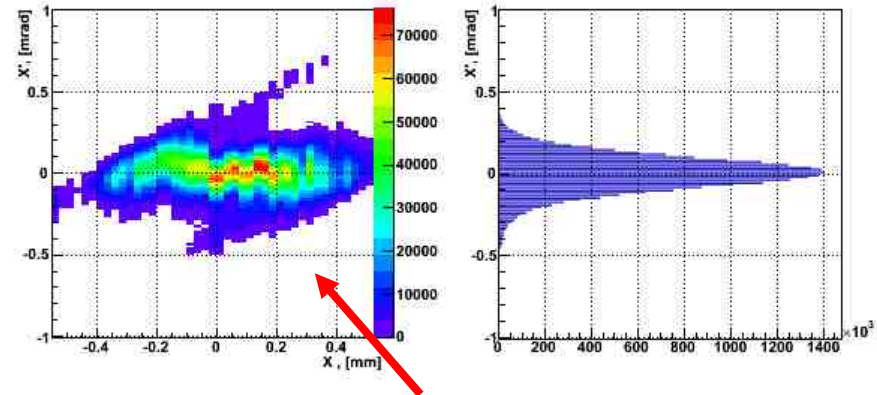
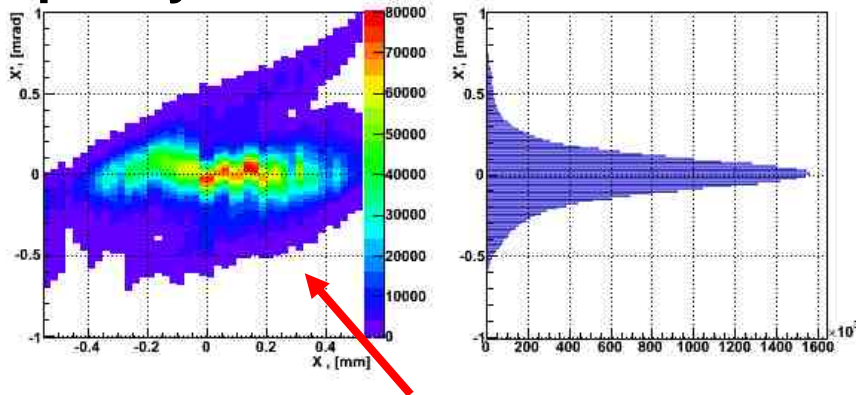
@1nC

for 100 % RMS emittance !

→ good agreement with prediction from ASTRA

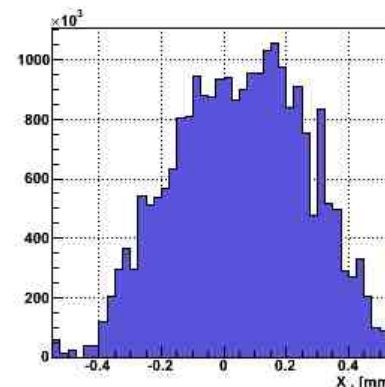
preliminary analysis

x-x'-phase space distribution for the best emittance measurement, purely reconstructed from subsequent beamlet measurements:



Emittance calculated purely from beamlet measurements, 100 % of data

→ $\epsilon_n = 1.1$ mm mrad



Cut at 5% of max. amplitude (i.e. 6.5% of “charge”) [reasons: noise, gain, sensitivity, bit depth, ...]

→ $\epsilon_n = 0.69$ mm mrad

Reminder: This $\epsilon_n \neq 1.25$ mm mrad because the separately measured beam size at the slit position is NOT taken into account here.

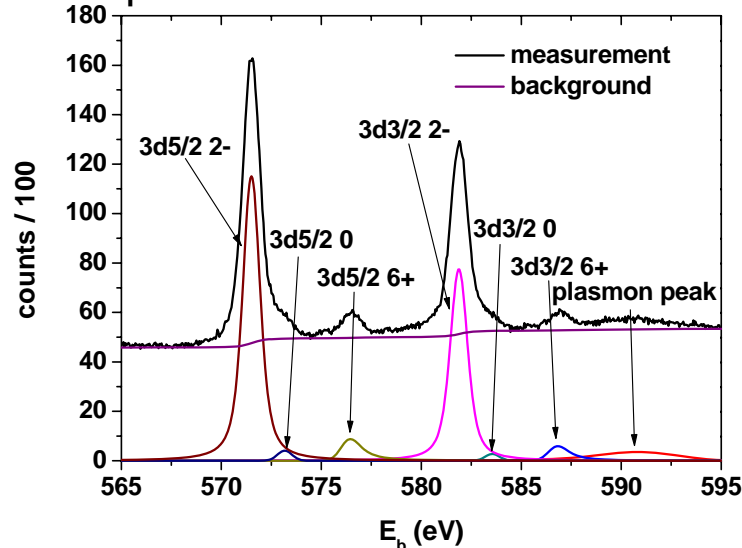
→ projected emittance is reduced by 37 % !!

ASTRA: - 5% in particles → -38% in proj. emittance

For 95% RMS → $\epsilon_{x,y,n} \approx 0.8$ mm mrad

Te 3d spectrum for **fresh** cathode #90.1

See poster WEPPH048



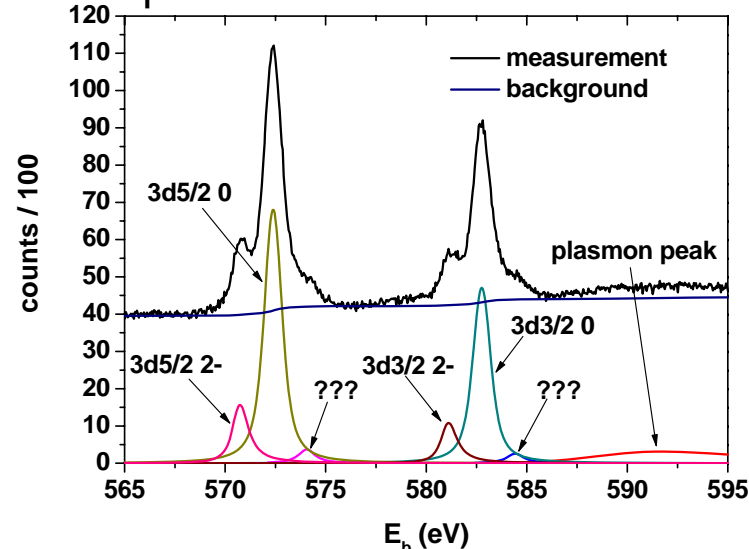
fresh cathode:

- dominant peaks for both spin-orbit couplings corresponding to Te^{-2} (Cs_2Te)
- small amounts of Te^0

used cathode:

- dominant peaks for both spin-orbit couplings corresponding to Te^0 (metallic tellurium)
- only small amounts of Te^{-2} (Cs_2Te)

Te 3d spectrum for **used** cathode #92.1



Confirmation from survey scan:

Te^{+6} visible (TeO_3) on fresh cathodes
but no oxidized states on used cathodes

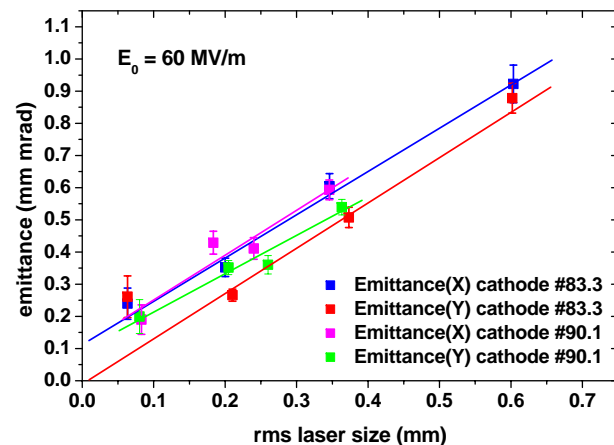
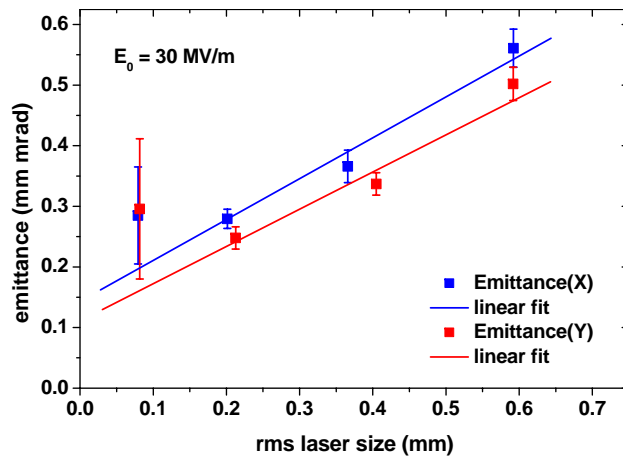
- **QE degradation during operation most probable related to change in chemical composition**
- **transition from Cs_2Te to metallic Te**

$$\mathcal{E}_{th} = \sigma_{cathode} \sqrt{\frac{2E_{kin}}{3m_0c^2}}$$

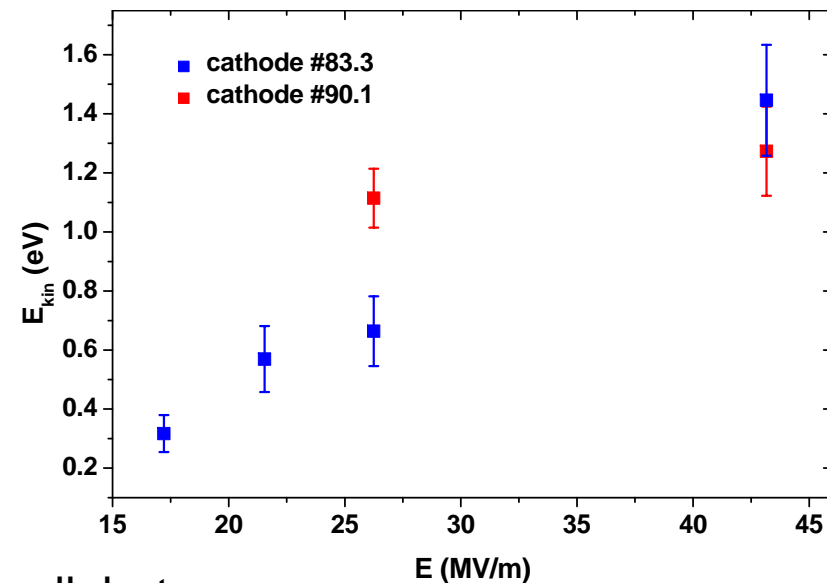
$$\mathcal{E}_{meas} \approx \sqrt{\mathcal{E}_{th}^2 + \mathcal{E}_{SC}^2 + \mathcal{E}_{RF}^2}$$

measure \mathcal{E}_{th} vs. $\sigma_{cathode}$ for low charge ($\leq 6\text{pC}$)
and short pulse length ($\sigma_{laser} \approx 3\text{-}4\text{ps}$) $\rightarrow E_{kin}$

Expected E_{kin} for Cs₂Te cathode and 262 nm laser: **0.55 eV**
(this does not consider: field on cathode, change of cathode properties during operation)



See poster
WEPPH012



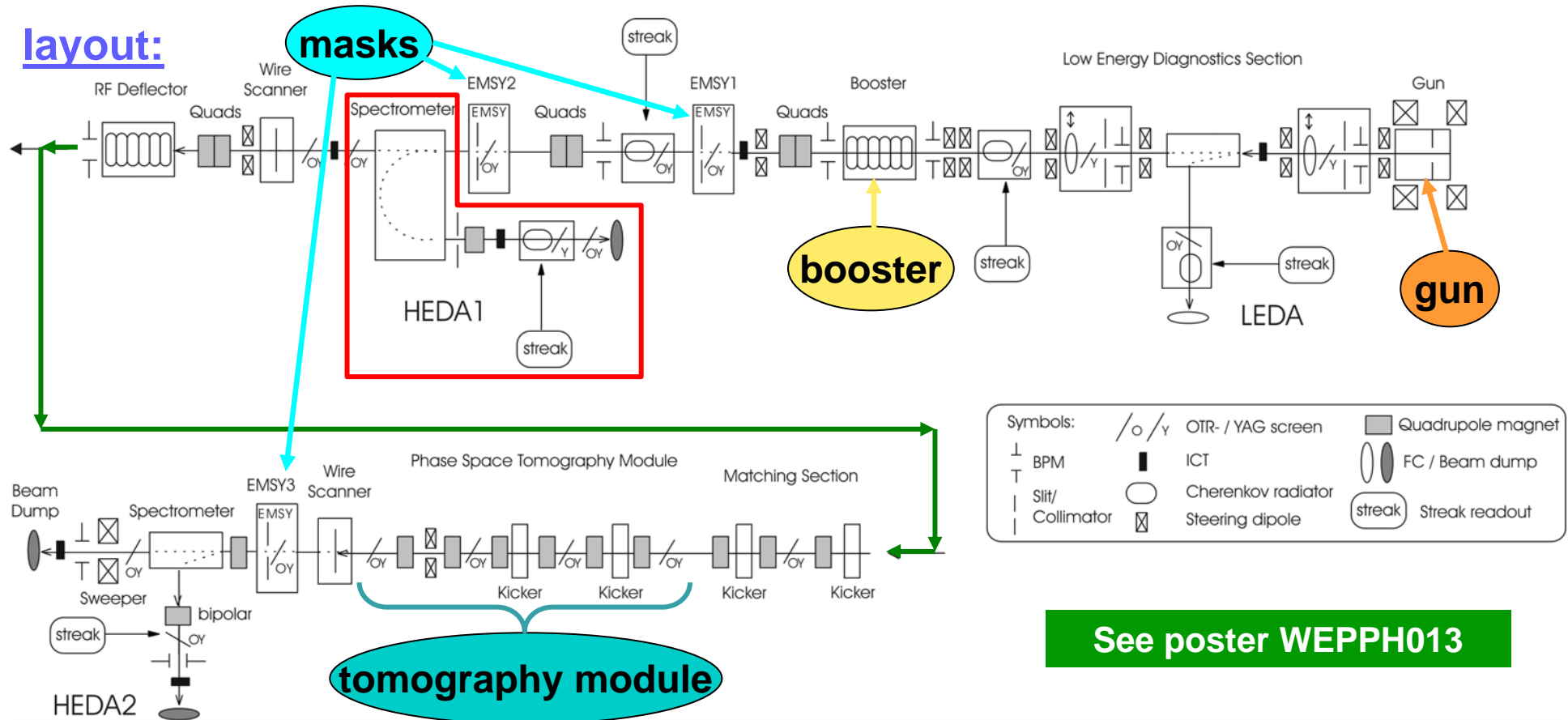
Error bars not small, but

- there is **increasing E_{kin}** with gradient at cathode !
- different **cathodes** can behave differently !
- **$E_{kin} \approx 1.4 \text{ eV} @ E_0 = 60 \text{ MV/m}$** \rightarrow 2 x larger than model
 \rightarrow for $\sigma_{cathode} = 0.35 \text{ mm}$ $\rightarrow \mathcal{E}_{th} = 0.47 \text{ mm mrad}$ (38%)

Future upgrades at PITZ

- this autumn:**
- install improved **laser** system (20 ps FWHM, **rise/fall time ≤ 2 ps**)
 - install improved dispersive arm downstream of booster (HEDA1)
 \rightarrow **slice emittance measurements**
 - condition **new gun** cavity to 60 MV/m
- 2008:**
- install new CDS **booster** and **tomography section**
 - start experimental optimization for **European XFEL baseline parameters**

layout:



See poster WEPPH013

- Gun3.1 characterized at **~40 MV/m**:
 - operated with up to 3.5MW, **900 μ s RF**, 10Hz
 - $\epsilon_{x,n} = 1.32 \pm 0.11$ mm mrad
 $\epsilon_{y,n} = 1.43 \pm 0.17$ mm mrad **@1nC, (100% RMS)**
- Gun3.2 characterized at **~60 MV/m**:
 - operated with up to **6.7MW**, 140 μ s RF, 10Hz
 - $\epsilon_{x,n} = 1.25 \pm 0.19$ mm mrad
 $\epsilon_{y,n} = 1.27 \pm 0.18$ mm mrad **@1nC, (100% RMS)**
 - (for 95% RMS: $\epsilon_{x,y,n} \approx 0.8$ mm mrad)
 - thermal emittance: **$E_{kin} \approx 1.4$ eV**
 - $\epsilon_{th} = 0.47$ mm mrad (38%)
- observed change of **chemical composition of Cs₂Te** cathodes using XPS
- upgrades at PITZ are ongoing → e.g. **new laser in 2007**