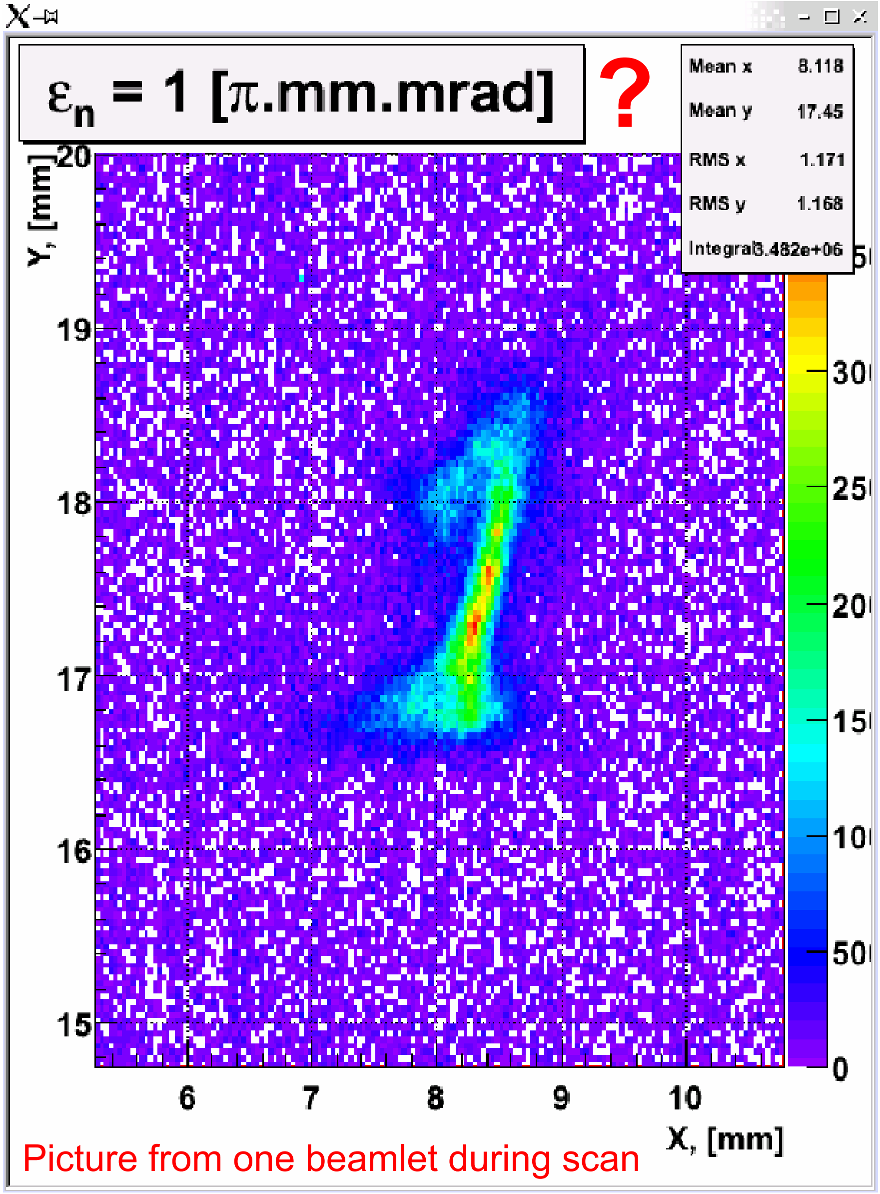
New Experimental Highlights from PITZ



Picture from one beamlet during scan

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

The PITZ collaboration

Colleagues actively participating in measurements / new design:

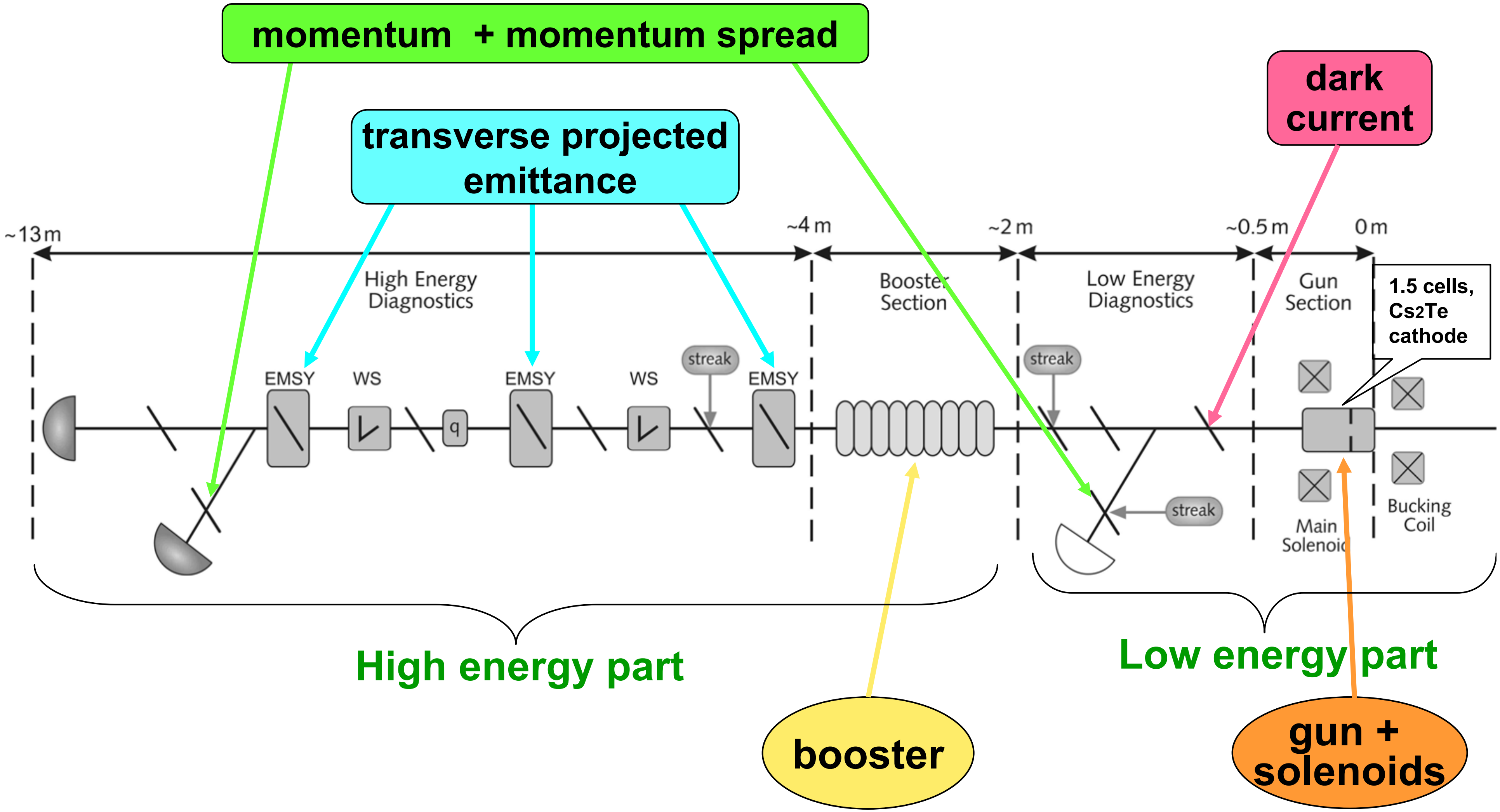
- **DESY, Zeuthen site:**
  F. Stephan, J. Bähr, C. Boulware, H.J. Grabosch, Y. Ivanisenko*, S. Khodyachykh**, S. Korepanov, M. Krasilnikov, A. Oppelt***, B. Petrosyan, S. Riemann, S. Rimjaem, K. Rosbach, A. Shapovalov****, T. Scholz, R. Spesyvtsev*****, L. Staykov
- **DESY, Hamburg site:**
  K. Flöttmann, 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. Skassyrskaia
- **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 Siemens Medical Solutions
*** now at PSI, Villingen,
**** on leave from MEPHI, Moscow,
***** on leave from NSCIM, Kharkov,
****** now at JLAB, Newport News

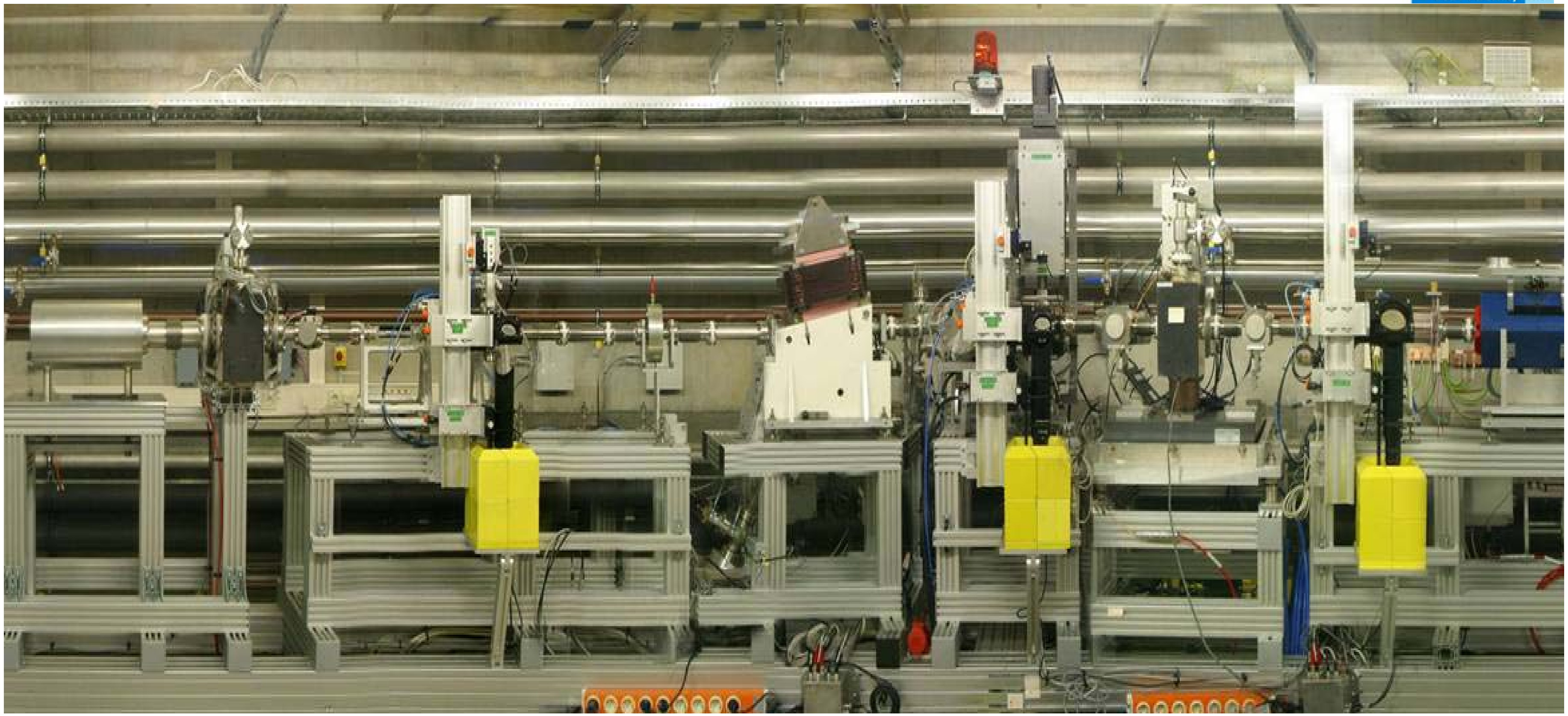
- **Acknowledgements:** R. Brinkmann, U. Gensch, E. Jaeschke, L. Kravchuk, V. Nikoghosyan, C. Pagani, L. Palumbo, J. Rossbach, W. Sandner, S. Smith, T. Weiland, G. Wormser

Present layout of PITZ

This setup was used for the measurements to be presented:



Present layout of PITZ



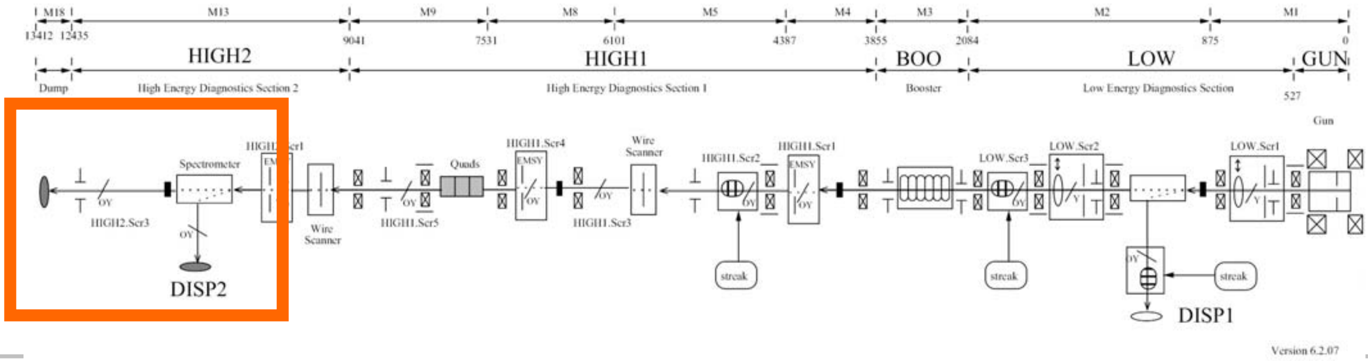
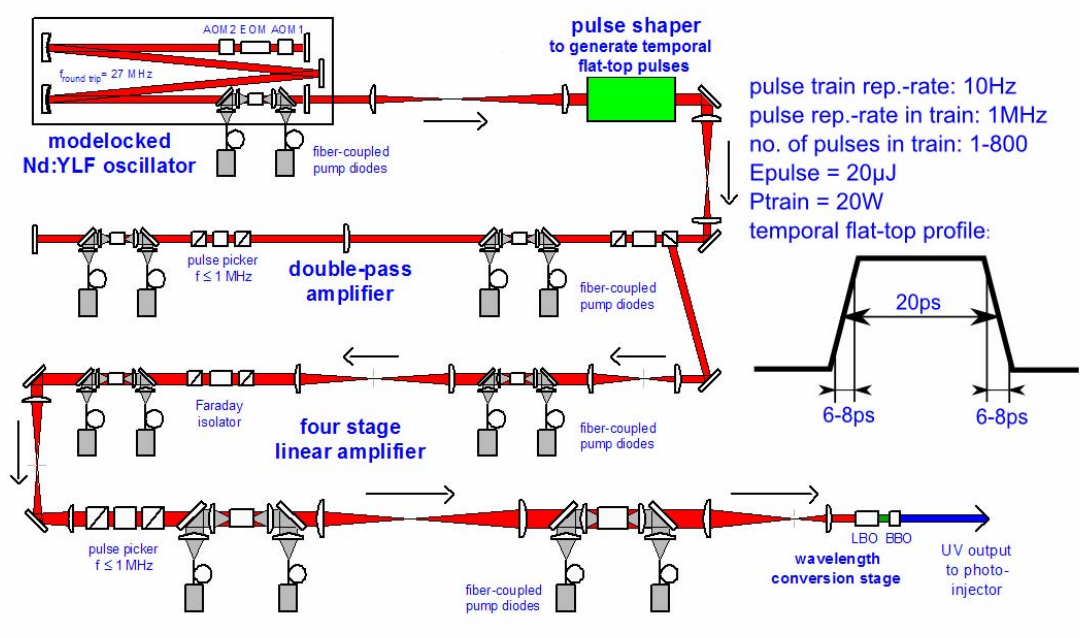
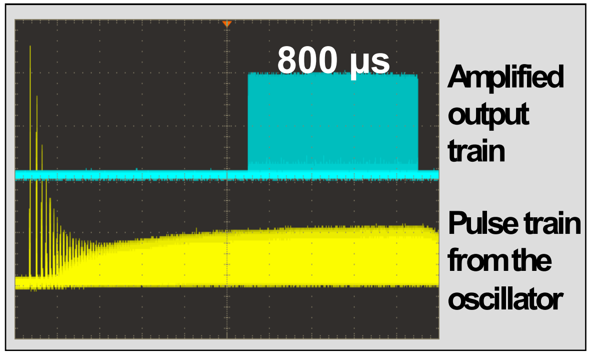


Photo cathode laser



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



Beamline to photo cathode

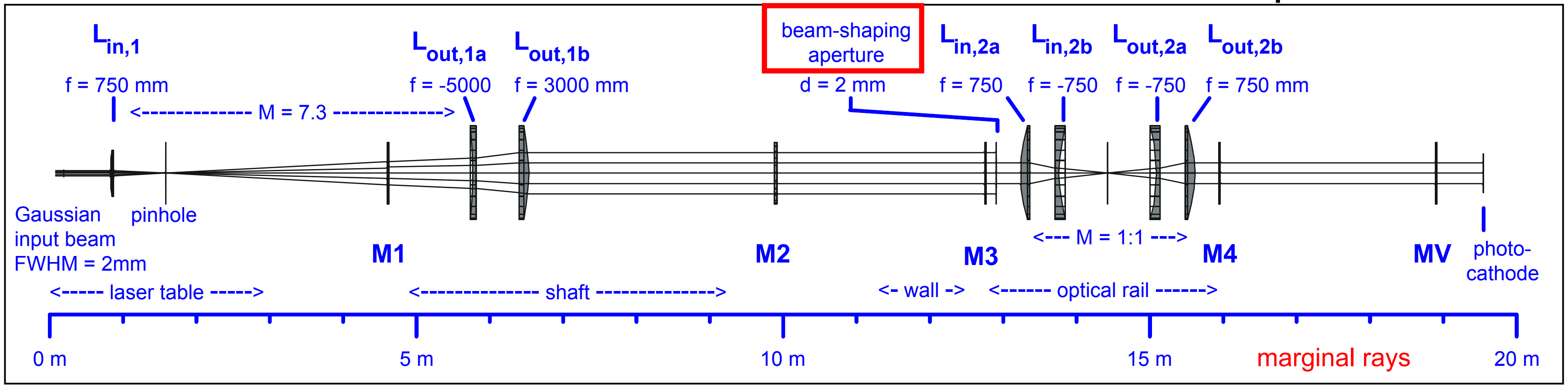
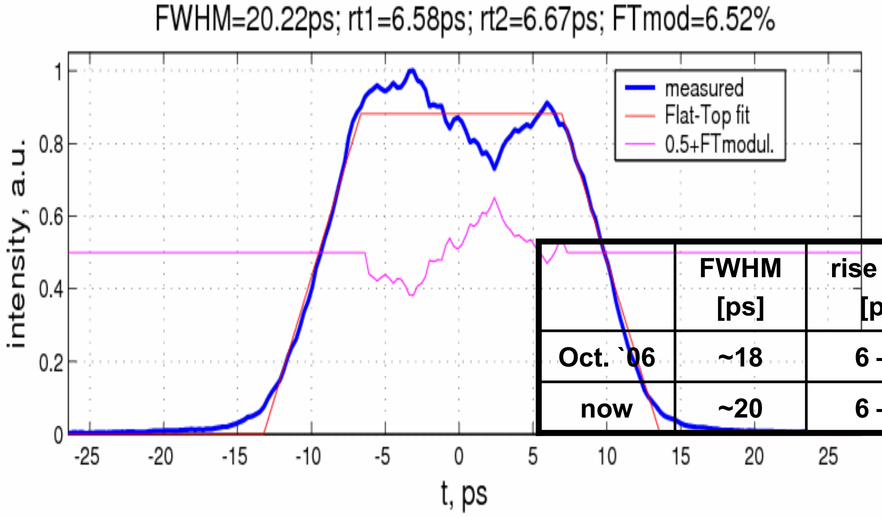


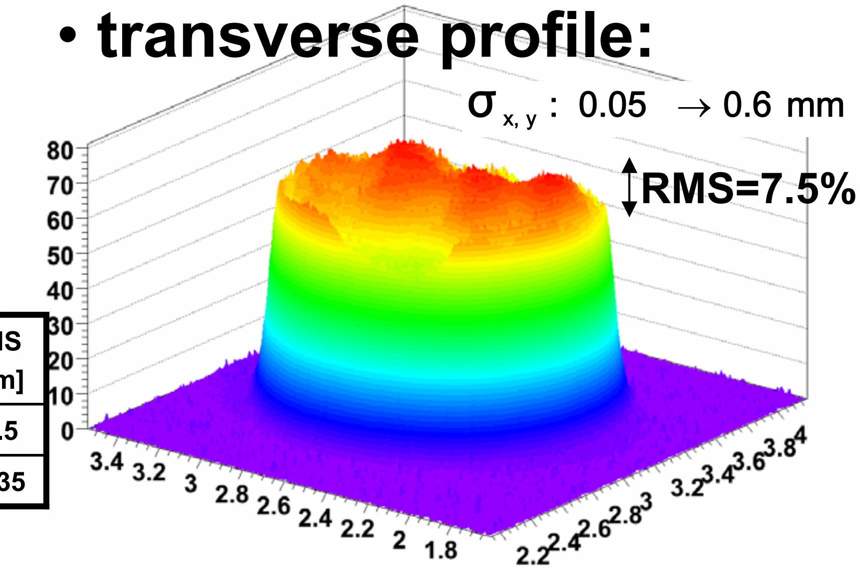
Photo cathode laser properties

- **longitudinal profile:**

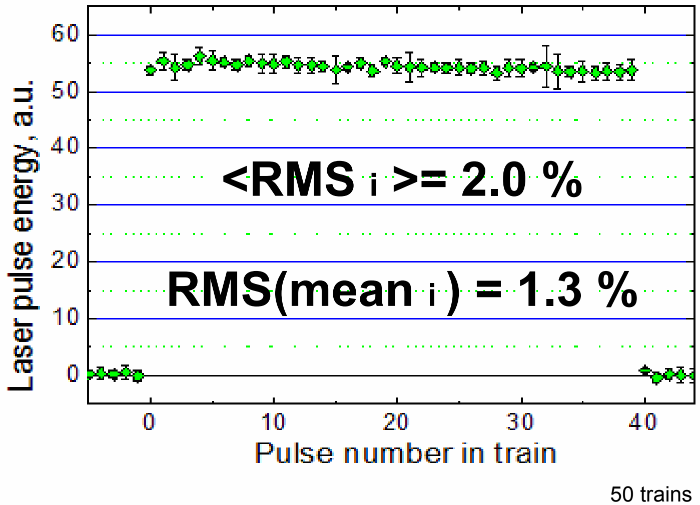


	FWHM [ps]	rise / fall [ps]	RMS [mm]
Oct. `06	~18	6 – 8	~0.5
now	~20	6 – 8	~0.35

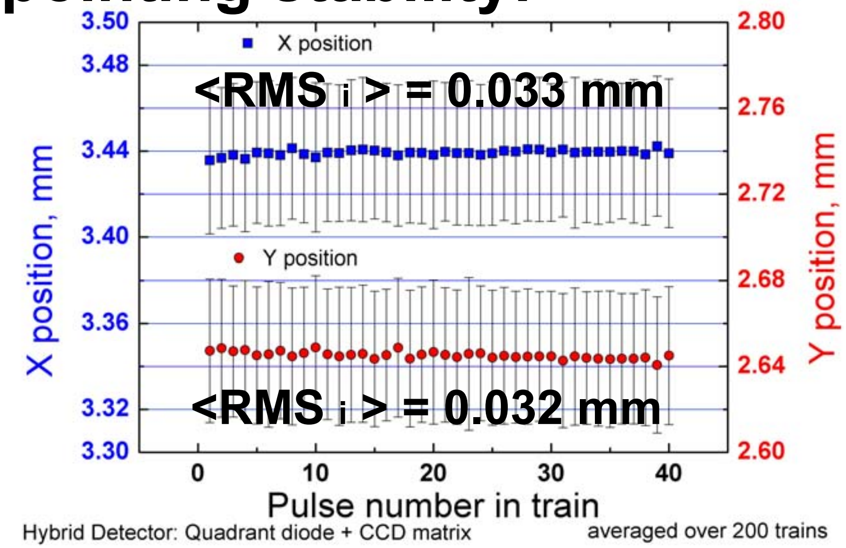
- **transverse profile:**



- **energy stability:**



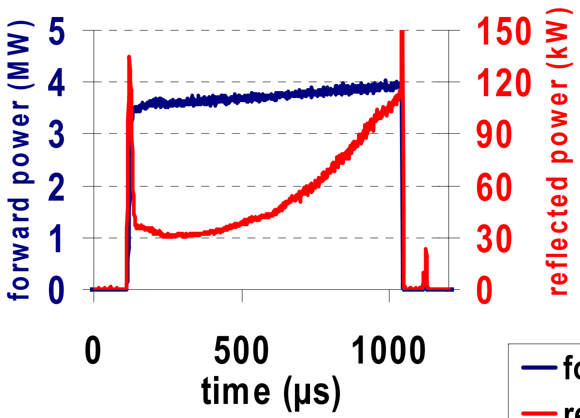
- **pointing stability:**



Guns, Gradients, Dark Currents

- **Gun 3.1** –
  characterized @ **~40MV/m** in **Oct.´06**
  → spare gun for FLASH

- **Peak and average power:**

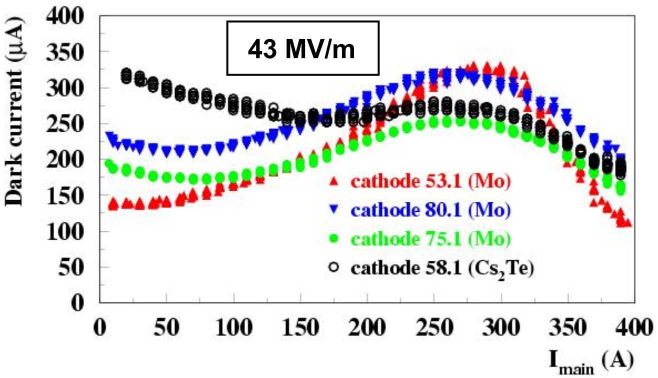


3.5 MW, 900 µs, 10 Hz

⇩

31.5kW av. power, 0.9% duty cycle

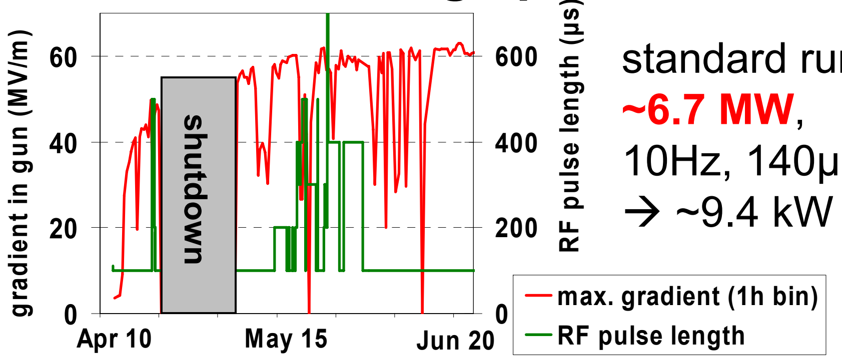
- **Dark current:**



Max.: 250-300 µA

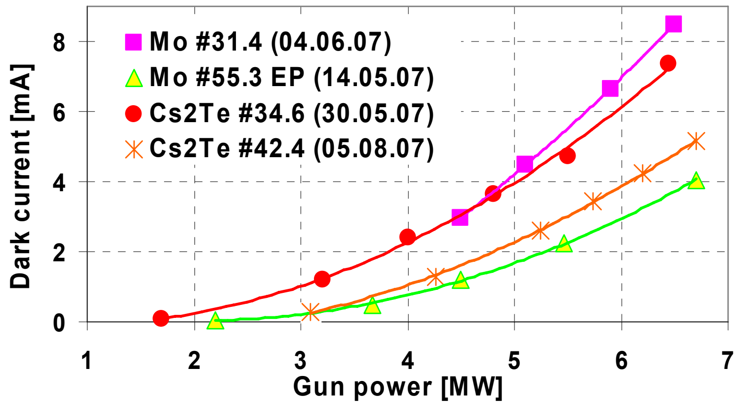
- **Gun 3.2** –
  characterized @ **~60MV/m** in **summer ´07**
  → first experience with long RF at 60 MV/m

- **Peak and average power:**



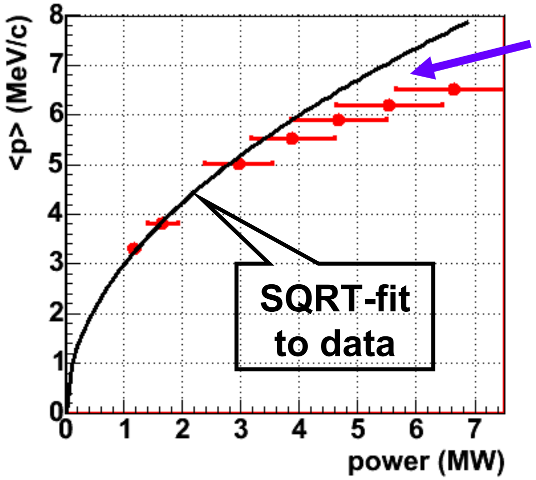
standard run:
~6.7 MW,
10Hz, 140µs
→ ~9.4 kW

- **Dark Current:**



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

Longitudinal phase space for gun3.2

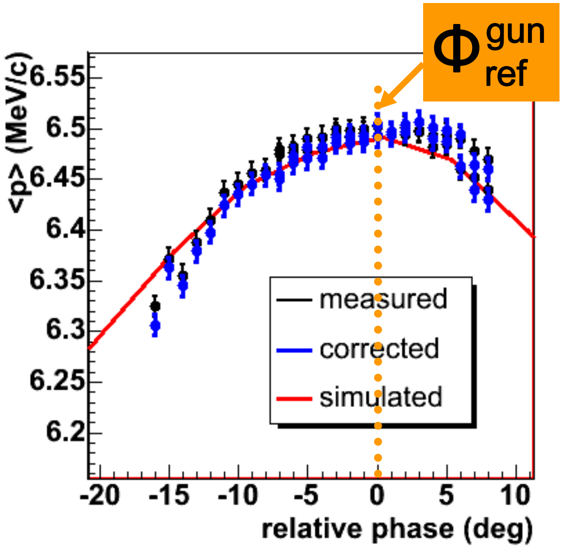


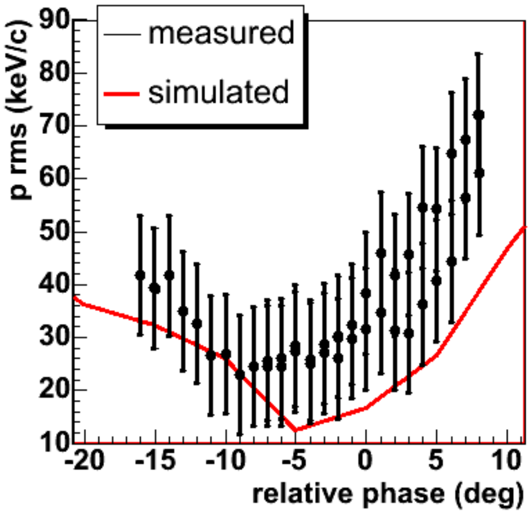
Problem with maximum momentum:

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

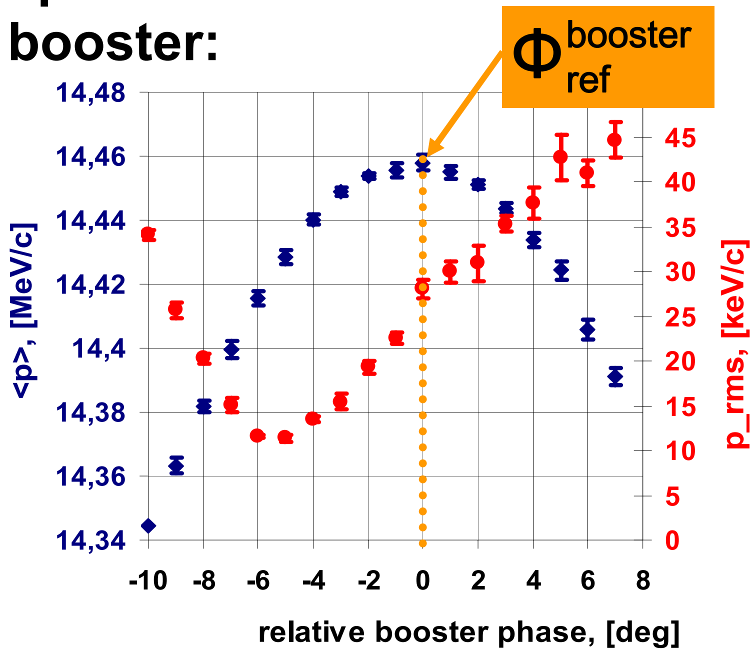
  → power measurements

Momentum and momentum spread downstream of the gun:





Momentum and momentum spread downstream of the booster:



Projected Emittance Measurements:
→ Slit Scan Technique

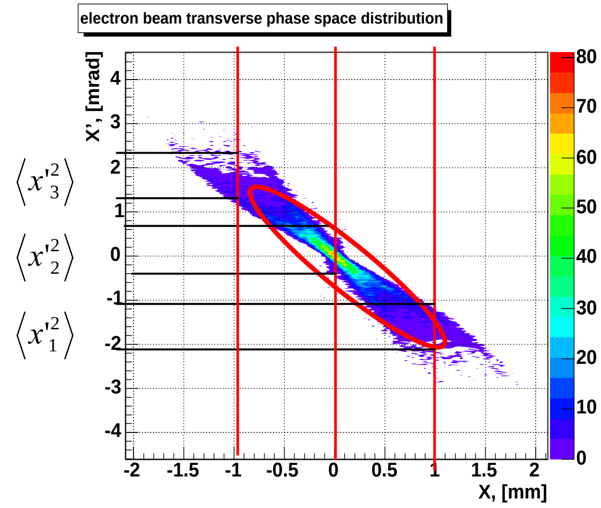
$$\varepsilon_{x,n} = \beta\gamma \cdot X_{rms} \cdot X'_{rms}$$

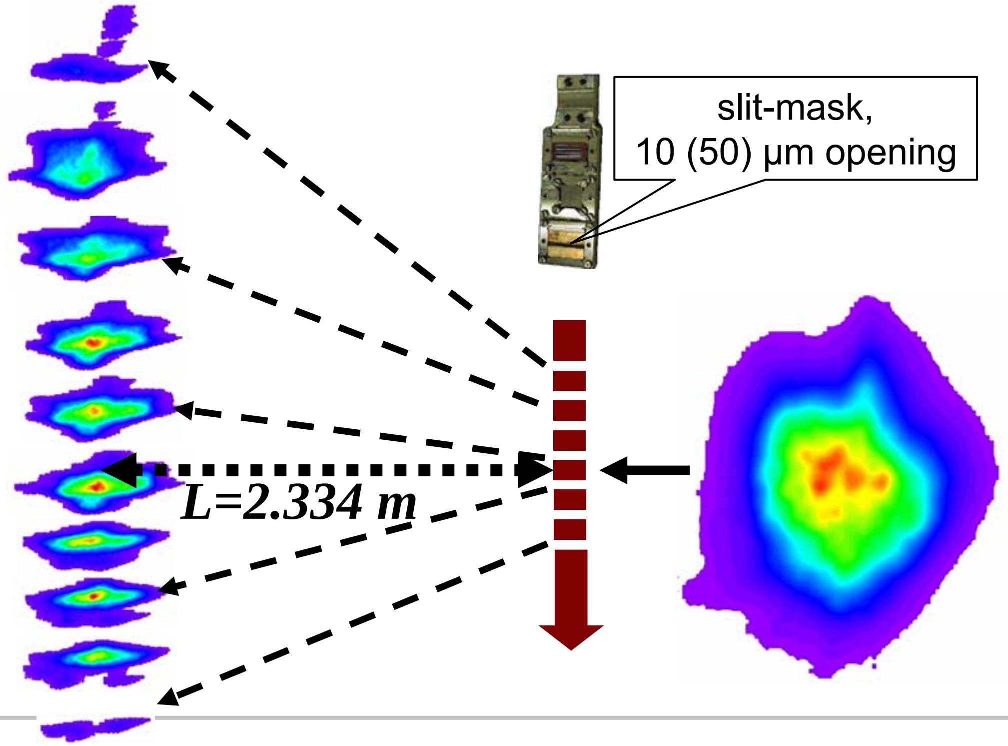
X_{rms} - RMS size of full beam at EMSY station (e.g. z = 4.3m)

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

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

L - distance from slit location to screen for beamlets



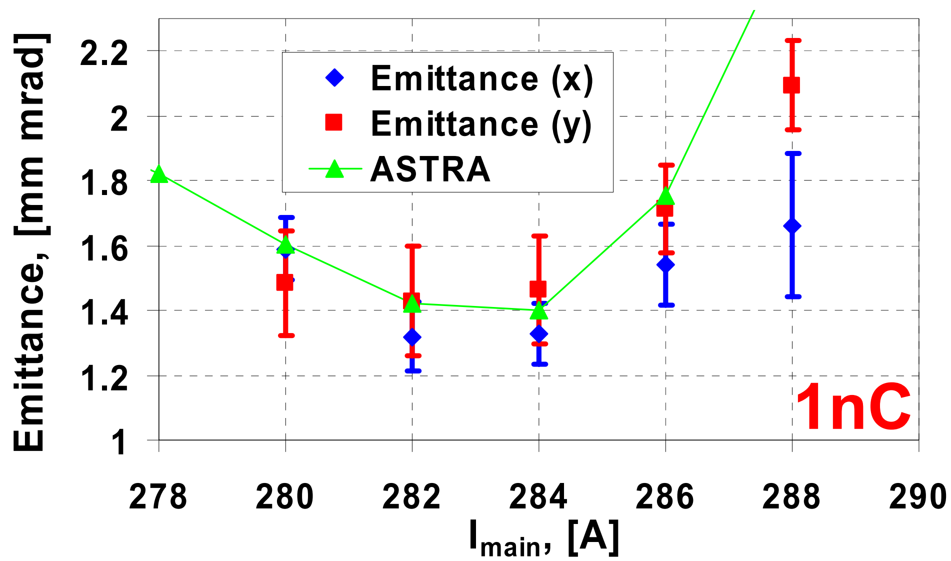


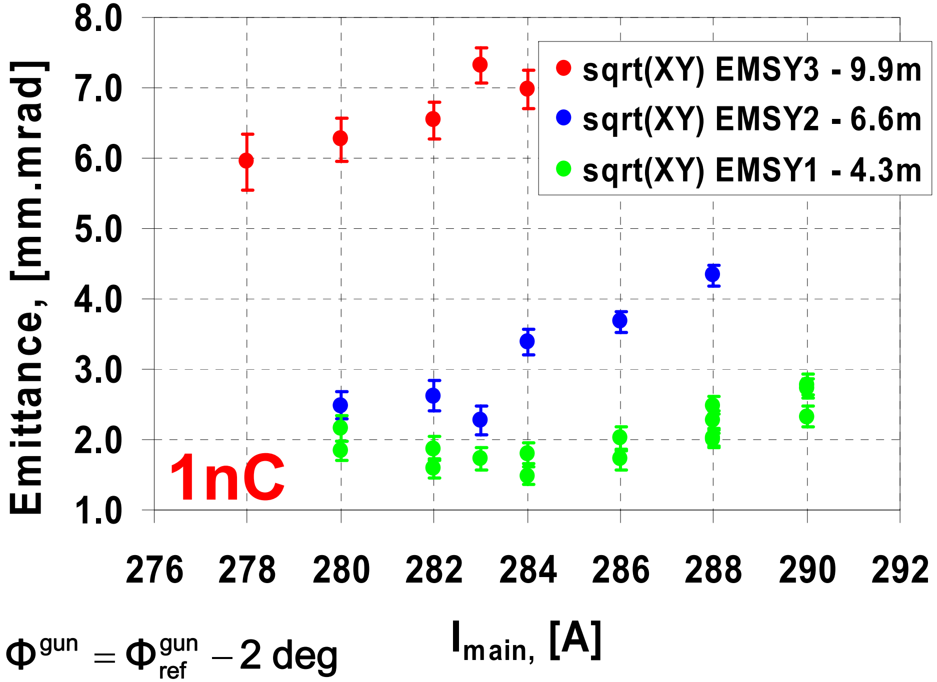
- **Current standard procedure:**
- take 11 equidistant beamlets over the full beam size
- use 10 µm slit opening
- ultimate resolution (current setup): → 36µm x 15.4 µrad
- use camera with 12 bit signal depth for beamlet measurements

Emittance results October 2006

Gun gradient: ~ 43MV/m
Gun phase: $\Phi^{gun} = \Phi^{gun}_{ref} - 2$ deg
Momentum from gun: ~ 5.0 MeV/c

Booster phase: $\Phi^{booster} = \Phi^{booster}_{ref} - 5$ deg
Total beam momentum: 12.8 MeV/c





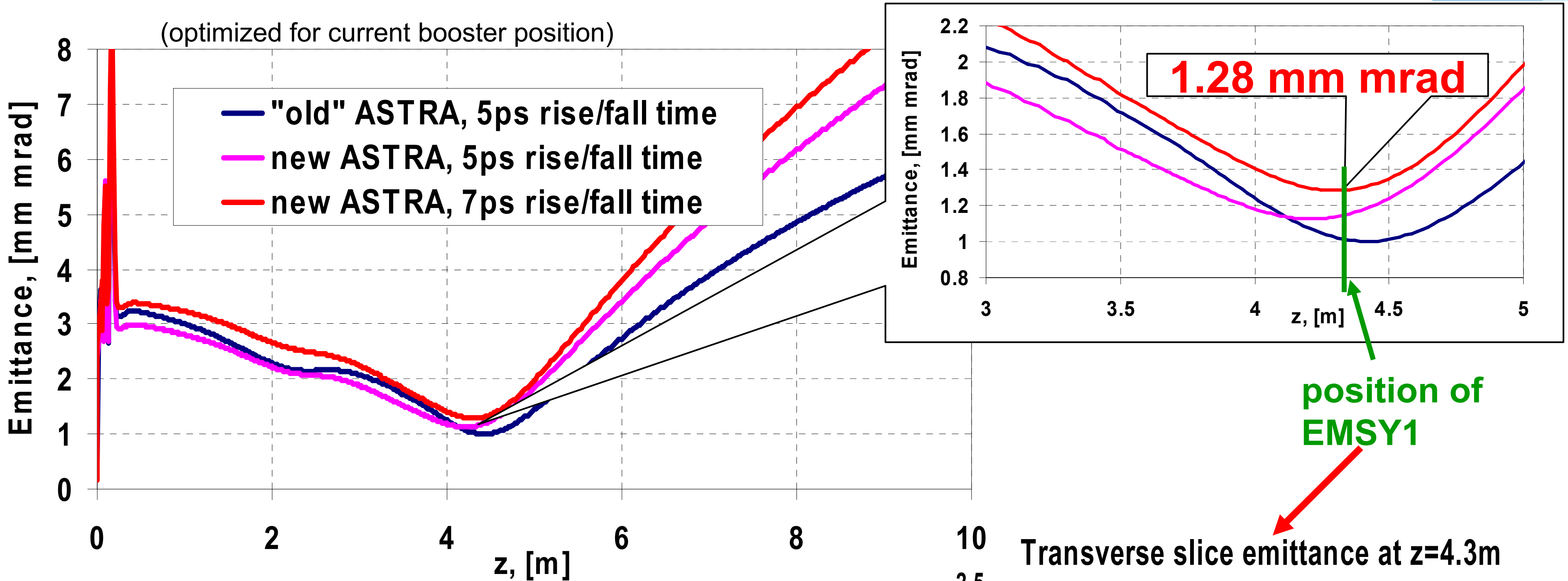
$\Phi^{gun} = \Phi^{gun}_{ref} - 2$ deg
$\Phi^{booster} = \Phi^{booster}_{ref} - 15$ deg

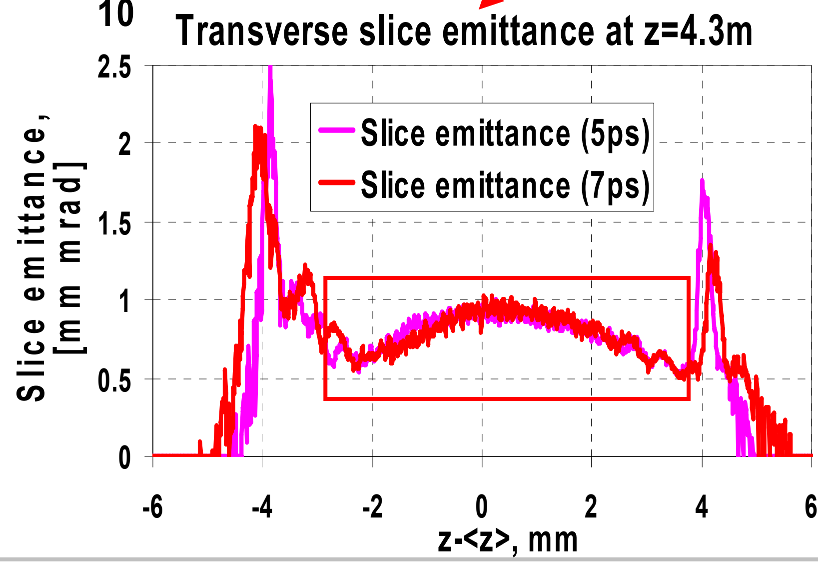
➔ for 43 MV/m we obtained

$\varepsilon_{x,n} = 1.32 \pm 0.11$ mm mrad
$\varepsilon_{y,n} = 1.43 \pm 0.17$ mm mrad
@1nC

➔ emittance strongly increases with distance from booster

Expectations for 60 MV/m



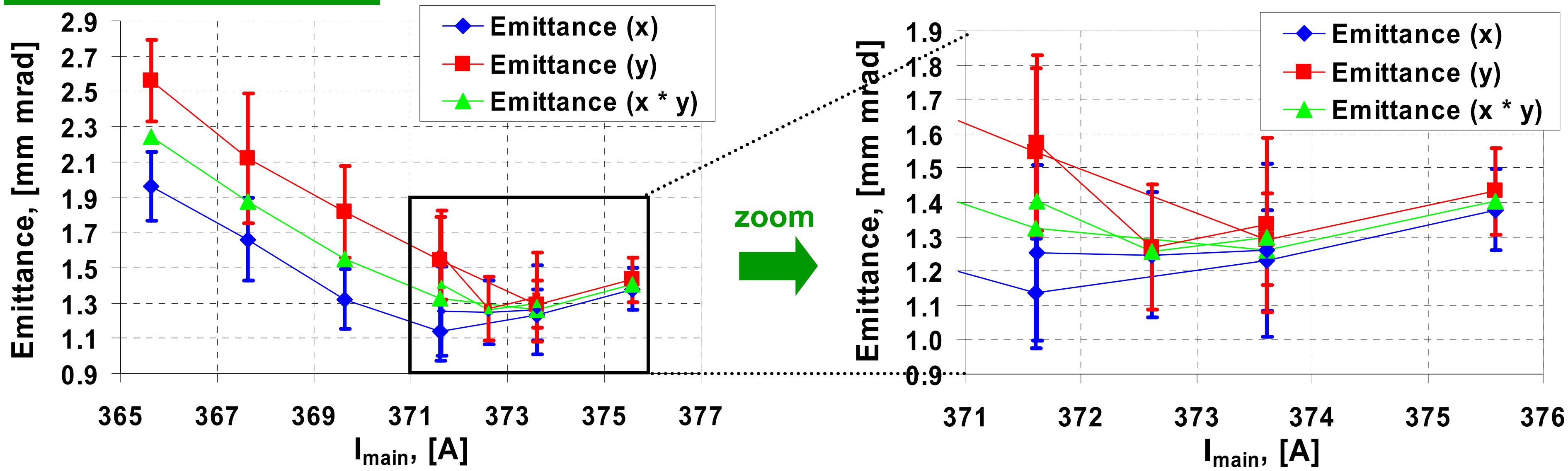


What`s new in new ASTRA (spring `07)?

- 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

Emittance for 1 nC and 60 MV/m

preliminary analysis



Cathode: # 90.1
Gun gradient: ~ 60 MV/m
Gun phase: $\Phi^{gun} = \Phi^{gun}_{ref}$
Momentum from gun: ~ 6.44 MeV/c

Booster phase: $\Phi^{booster} = \Phi^{booster}_{ref}$
Total beam momentum: 14.5 MeV/c

➔ for ~60 MV/m we obtained

$\varepsilon_{x,n} = 1.25 \pm 0.19$ mm mrad

$\varepsilon_{y,n} = 1.27 \pm 0.18$ mm mrad

@1nC

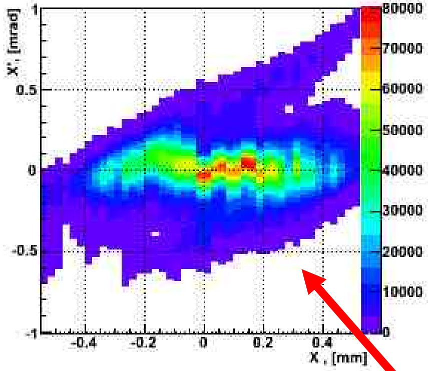
for 100 % RMS emittance !

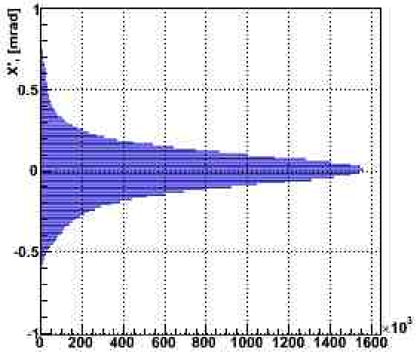
➔ good agreement with prediction from ASTRA

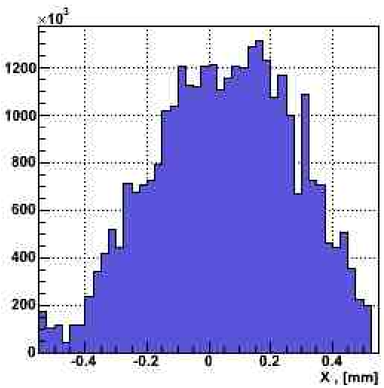
Signal / Noise ↔ RMS ↔ Core emittance

preliminary analysis

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

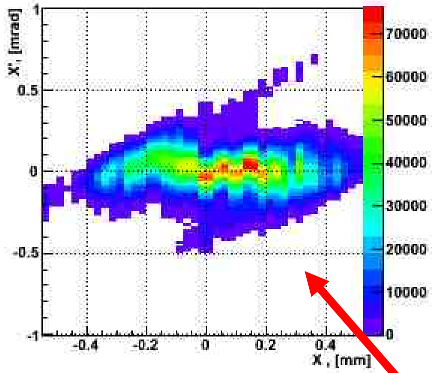


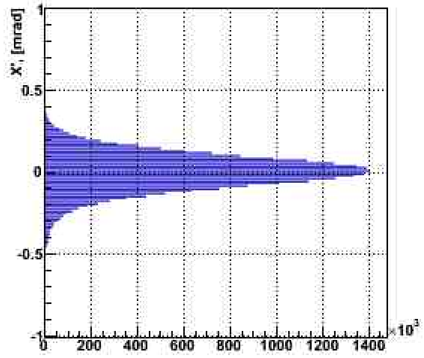


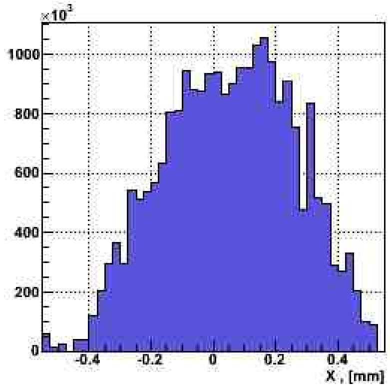


Emittance calculated purely from beamlet measurements, 100 % of data

➔ ε_n=1.1 mm mrad







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

➔ ε_n=0.69 mm mrad

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

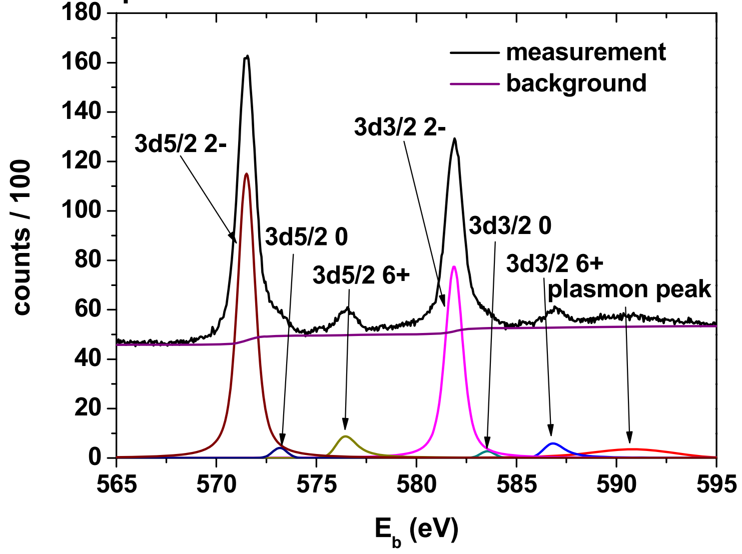
⇨ **projected emittance is reduced by 37 % !!**

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

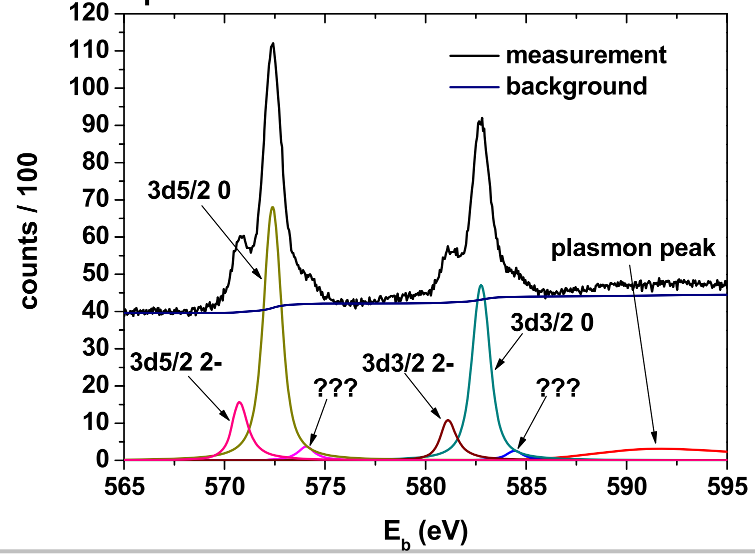
For 95% RMS ➔ $\varepsilon_{x,y,n} \approx 0.8$ mm mrad

XPS investigations on photo cathodes

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



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



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)

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**

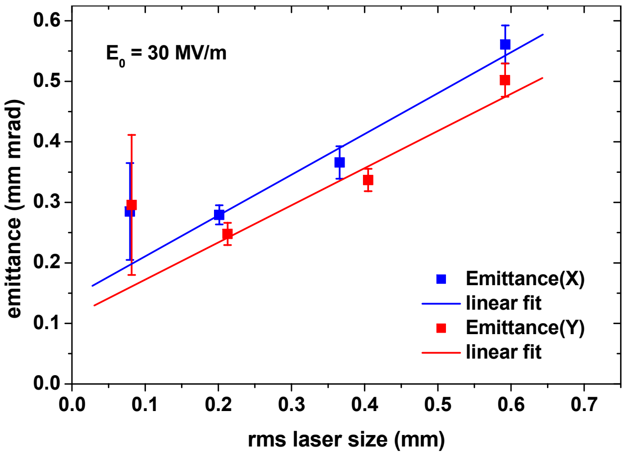
Thermal emittance measurements

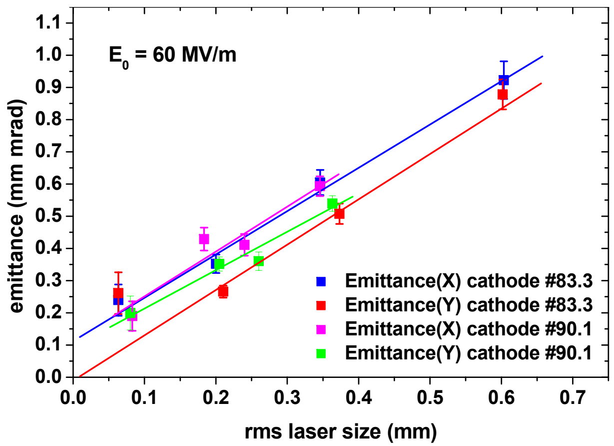
$$\varepsilon_{th} = \sigma_{cathode}\sqrt{\frac{2E_{kin}}{3m_0c^2}}$$

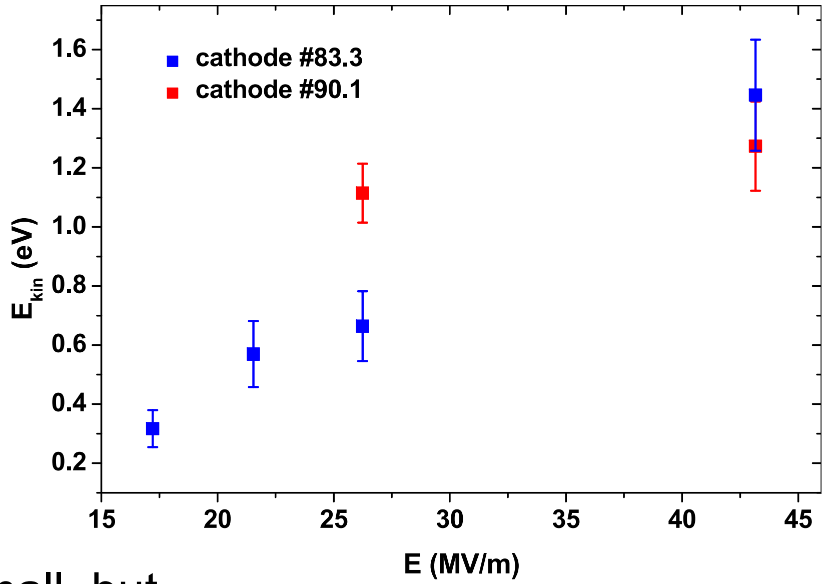
$$\varepsilon_{meas} \approx \sqrt{\varepsilon_{th}^2 + \varepsilon_{SC}^2 + \varepsilon_{RF}^2}$$

measure ε_{th} vs. $\sigma_{cathode}$ for low charge (≤6pC) and short pulse length (σ_{laser}≈3-4ps) ➔ **E_{kin}**

Expected E_{kin} for Cs_2Te cathode and 262 nm laser: **0.55 eV**
(this does not consider: field on cathode, change of cathode properties during operation)







Error bars not small, but

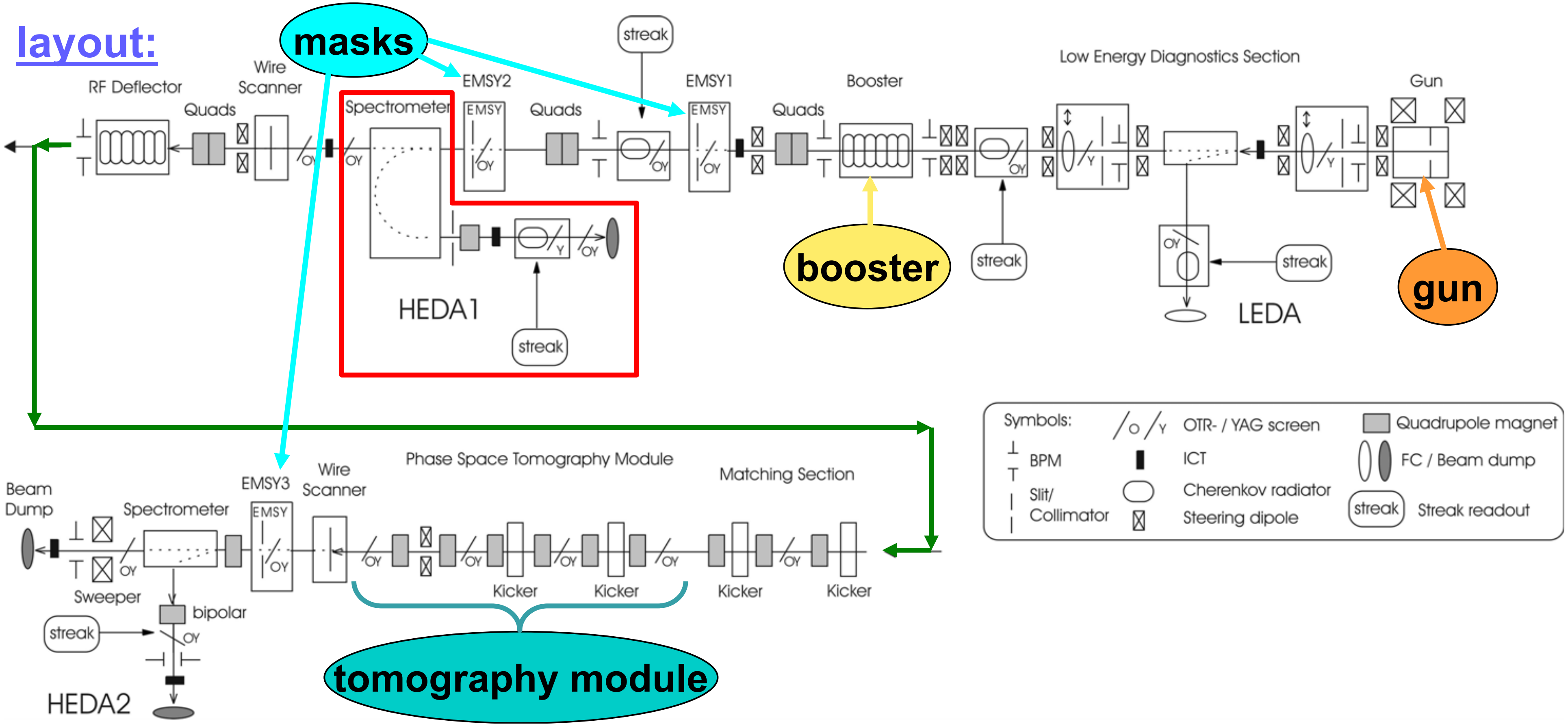
- there is **increasing E_{kin}** with gradient at cathode !
- different **cathodes** can behave differently !
- **E_{kin} ≈ 1.4 eV @E_0=60MV/m** ➔ 2 x larger than model
  → for $\sigma_{cathode}$= 0.35mm → ε_{th} = 0.47 mm mrad (~50%)

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)
  → **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:



Work to be done, problems during run (1)

- **Dark current from cavity 3.2:** although dark current was reducing during conditioning/operation → **still very high at 60 MV/m**. We assume that one main reason is a **fabrication error** which did not happen again at later cavities. **New cavity 4.2** was **cleaned with CO_2** and **conditioning** will start on a separate test stand in **November 2007**.

- **Life time of photo cathodes:** only up to **~1 week** in last run period. Reason not clear. Might be related to high **level of dark current**, may be in addidion related to **Flour** impurities in the vacuum system.

- **Comparison simulation ↔ measurements:** although value for absolute minimum emitttance agrees very well, **dependencies on operation parameters** (e.g. energy gain in booster) are very different. → studies have to be continued.

- **Laser system:** up to now rise/fall time of **6-8 ps** was possible → one of the reasons why **tails** in distributions dominate emittance number. This autumn, a **new laser system** will be installed which should allow **2 ps** rise/fall time. **Stability and usability** of the new system has to be observed during real operation.

Work to be done, problems during run (2)

- **RF system (llrf and total power):**
  - up to now **only feed-forward** is possible (no regulation) → instabilities.
  - currently, 60 MV/m only reached with **saturated klystron** → no hat-space for regulation.

  → Several approaches ongoing to allow llrf regulation and higher total power at the gun. (klystron with > 10 MW ???)

- **„Core emittance“:** to measure / optimize it → particles in **tails of PHASE SPACE** distributions have to be cut (not in coordinate space). This measurements require **very long & stable measurement time** → can only be done for **individual cases** at the moment. **Next year** we plan to install a tomography module which allows **phase space tomography** as standard measurement operation.

- **Slice emittance:** what finally counts is slice emittance in high current part of electron bunch. According to our current knowledge, the only way to **measure it with the required accuracy** is the usage of an **RF deflector.** E.g. also LCLS is intensively using their RFD to characterize their injector. Therefore, the development of the **RFD for PITZ** (e.g. pre-test of XFEL version) **should be continued**.

Outlook

- **Optimize injector for XFEL baseline parameters:**

  Ingriedients:
  - laser upgrade this year
  - the installation of the CDS booster next year
  - extension of the diagnostics beamline now and in next year(s)

→ we will be able to study the **evolution of the emittance for the full XFEL baseline parameters**:

- do experimental optimization
  (full variation of experimental parameters,
  systematic cathode studies, …, 1-2 years)
- in parallel also requires further development of the simulations.

Summary

- Gun3.1 characterized at ~**40 MV/m**:
  - operated with up to 3.5MW, **900µs RF**, 10Hz
  - $\varepsilon_{x,n} = 1.32 \pm 0.11$ mm mrad
    $\varepsilon_{y,n} = 1.43 \pm 0.17$ mm mrad **@1nC, (100% RMS)**
- Gun3.2 characterized at ~**60 MV/m**:
  - operated with up to **6.7MW**, 140 µs RF, 10Hz
  - $\varepsilon_{x,n} = 1.25 \pm 0.19$ mm mrad
    $\varepsilon_{y,n} = 1.27 \pm 0.18$ mm mrad **@1nC, (100% RMS)**

  → **for 95%-RMS:** $\varepsilon_{x,y,n} \approx 0.8$ mm mrad **!!**

  → first demonstration of emittance required for European XFEL
  - thermal emittance: **$E_{kin} \approx 1.4$ eV**

  ➔ ε_{th} = 0.47 mm mrad (~50%)
- observed change of **chemical composition of Cs_2Te** cathodes using XPS
- upgrades at PITZ are ongoing → e.g. **new laser in 2007**