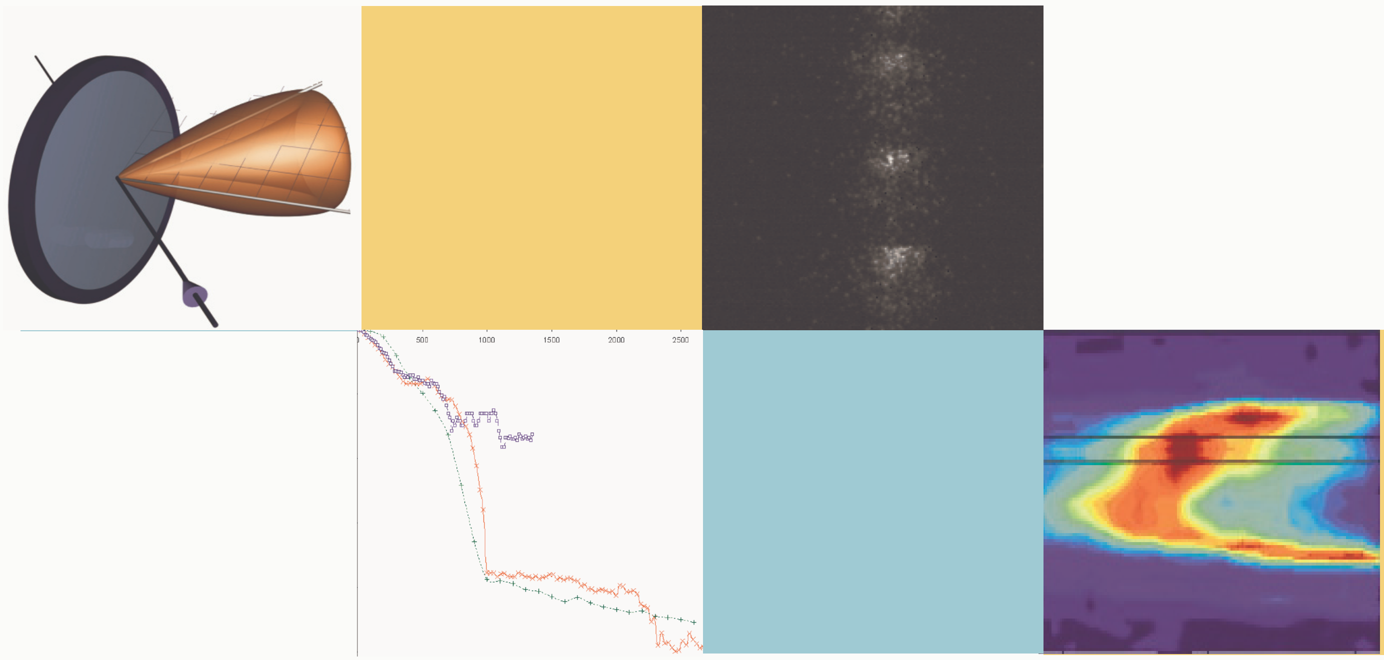
Beam Profile Measurements @ CTF3

Past, Present and Future



Carsten P. Welsch
AB/BI/PM

Outline

1. Transverse Beam Profiles

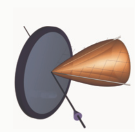
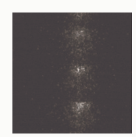
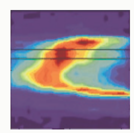
- General considerations
- OTR and SR as base for measurements
- Layout of the optical system *(optics, material choice, camera,…)*
- MTVs and Spectrometer Monitors *(Past, Present, Future)*
- Beam Halo Measurements
- Limitations

2. Longitudinal Beam Profiles

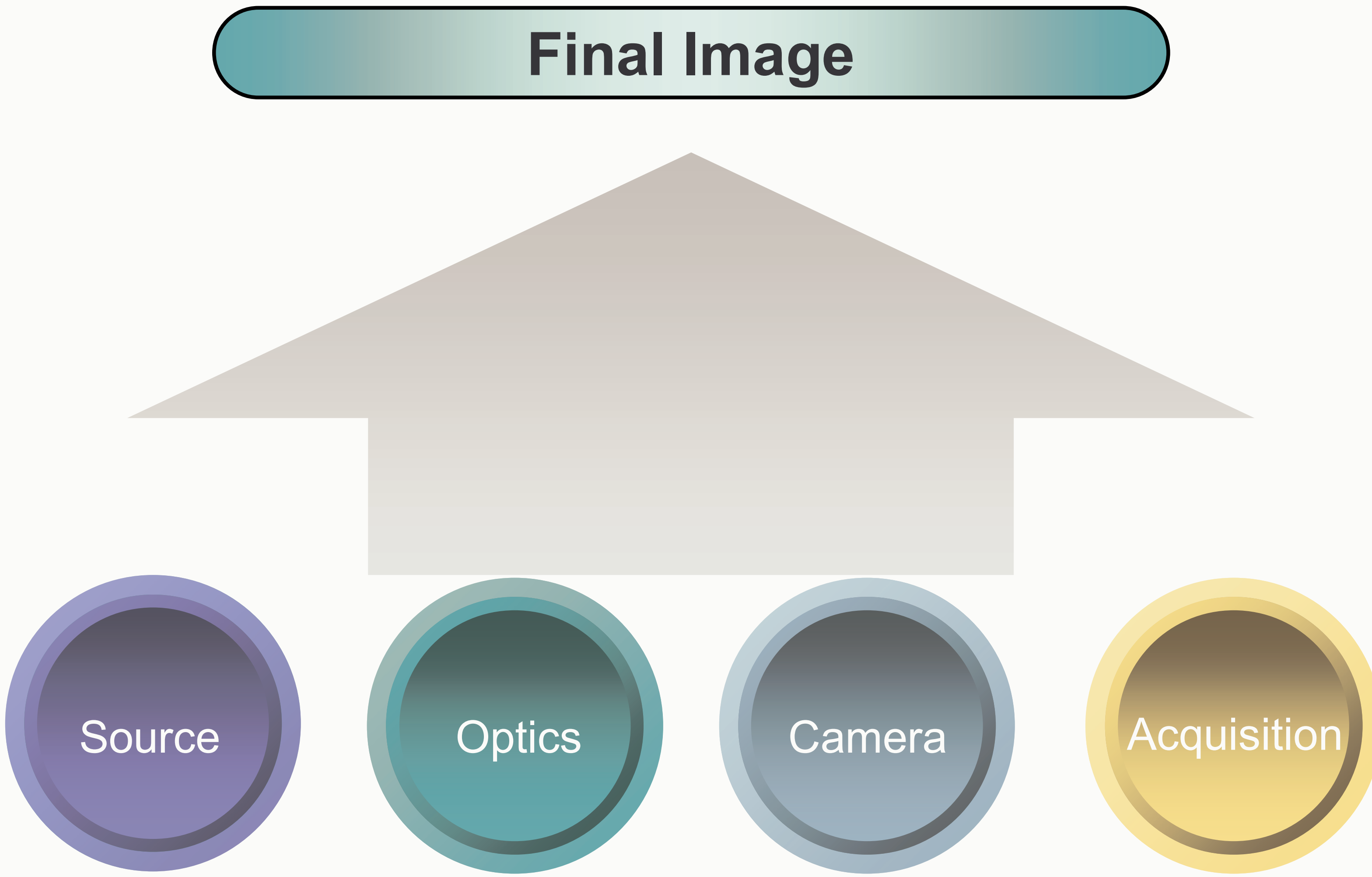
- Why do we care ?
- How to do the measurement ?
- Layout of long optical lines
- Results and Limitations
- Future Installations

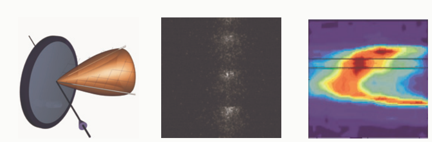
3. Time-resolved Energy Measurements

- How to do the measurement ?
- SEM Grid
- Segmented photomultiplier
- Segmented Dump

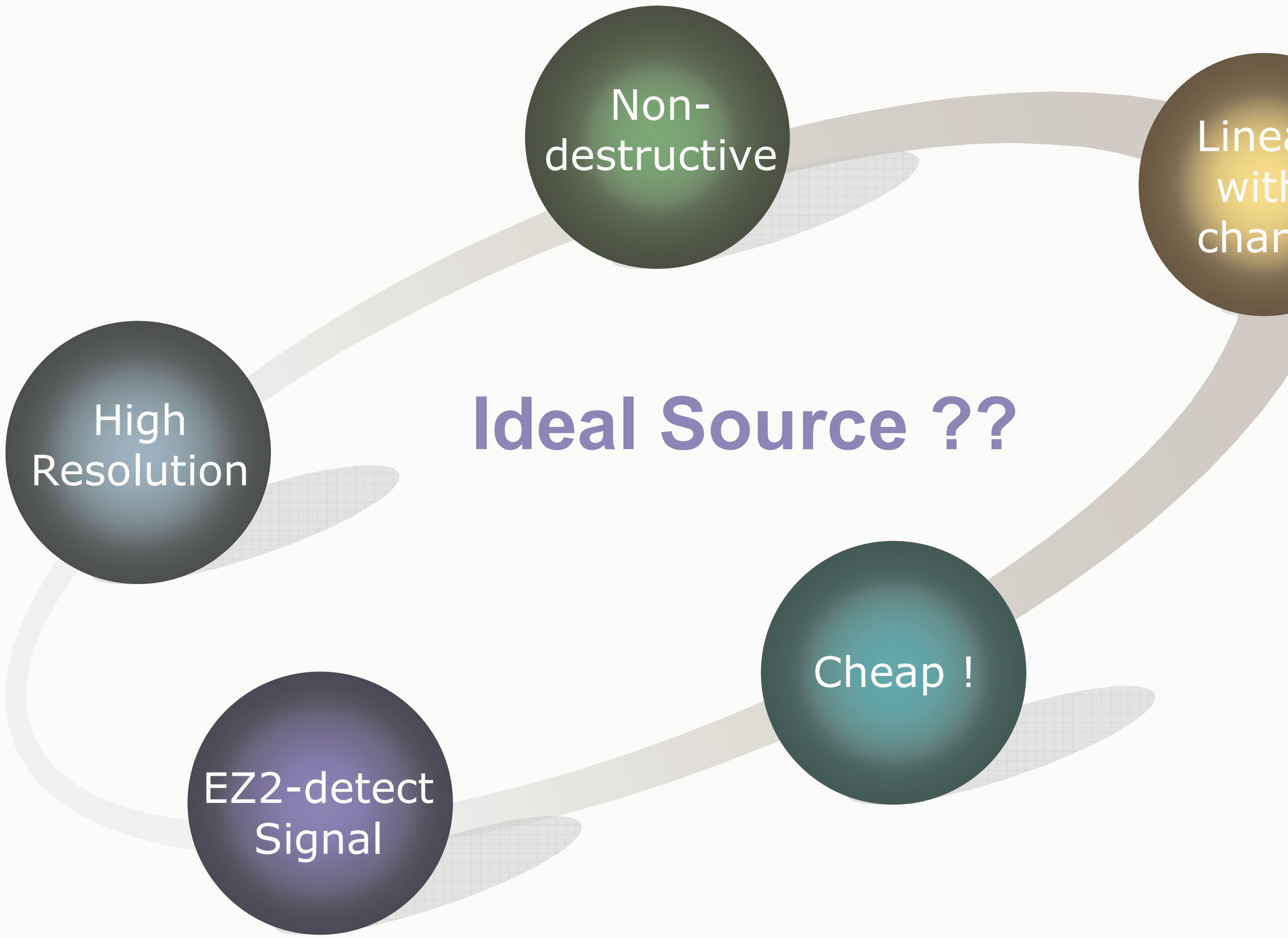




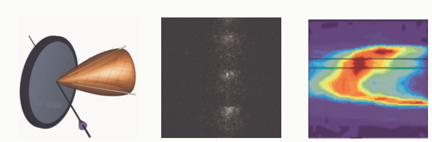
Defining the Image Quality



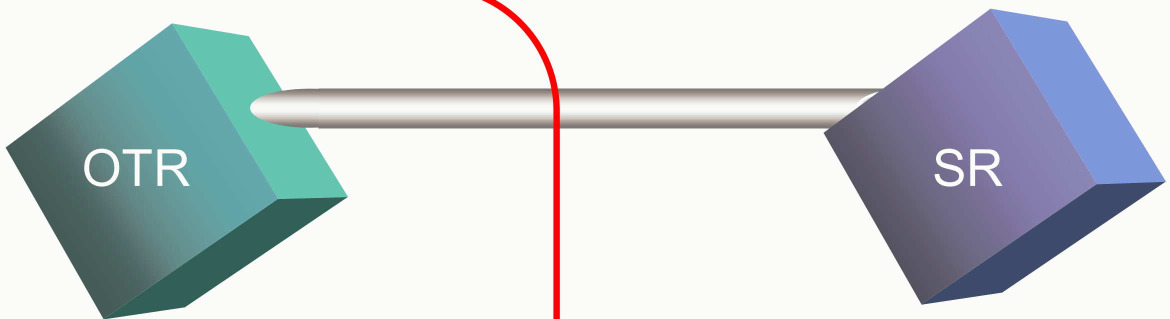


The Magic of So(u)rcery





A Brief *(incomplete)* Comparison



OTR

+

- Screen choice
- Linear, directive Signal
- Fast time response
- Add. Info *(E, x', y',..)*

–

- Destructive
- Installation/Maintenance

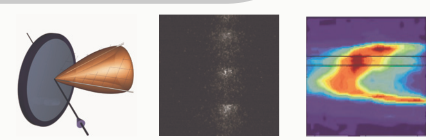
SR

+

- Non-destructive
- Highly directive
- Good signal if E~150 MeV

–

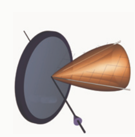
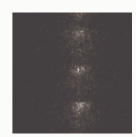
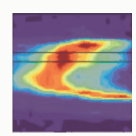
- Only in bends or chicane
- Alignment of line



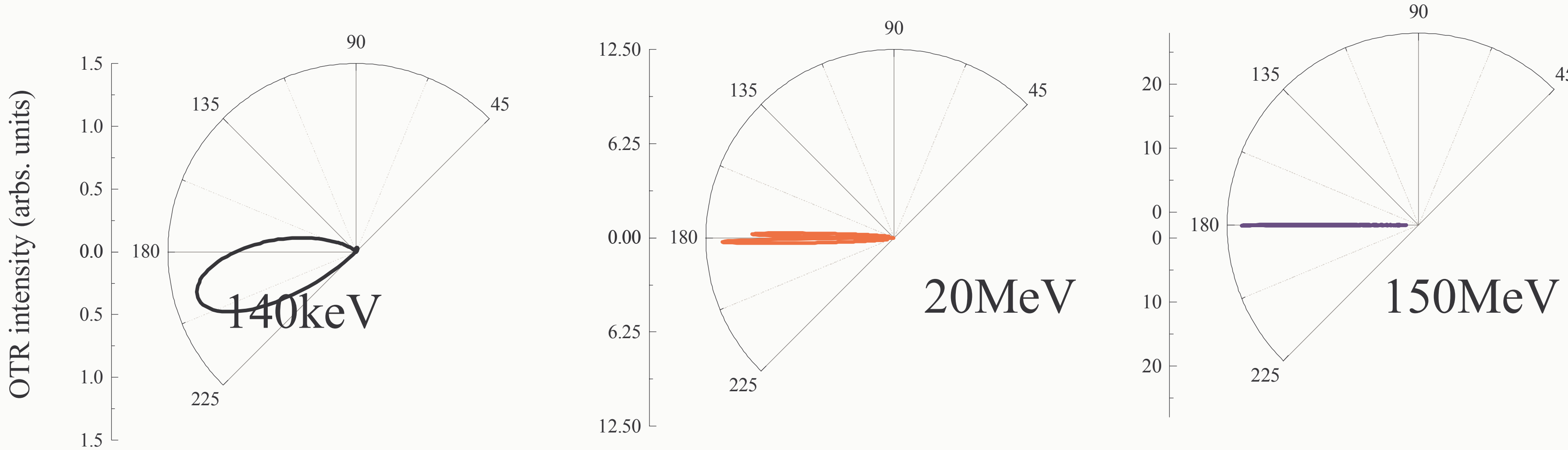
CTF3 Diagnostic Requirements

MTV's	Beam energy (MeV)	Beam charge (nC)	Beam size (mm)	Screen size (mm)	Spatial resolution (mm/pixel)
CL.MTV0165	0.140	10-7500[+]	>1	> Ø 50	0.2
CLS.MTV0440	20	7.5-5600[*]	>1	100x50	0.25
CL.MTV0500	20	-	>0.8	> Ø 30	0.1
CL.MTV1030	70	-	>0.4	> Ø 30	0.1
CLS.MTV1050	70	-	>1	100x50	0.25
CL.MTV0435	150	-	>0.15	> Ø 30	0.1
CLS.MTV0455	150	-	>1	100x50	0.25

[+] Assuming commissioning conditions @100mA,100ns and nominal conditions @3.5A,1.56ms
[*] Assuming 25% beam loss in the 3GHz bunching mechanism

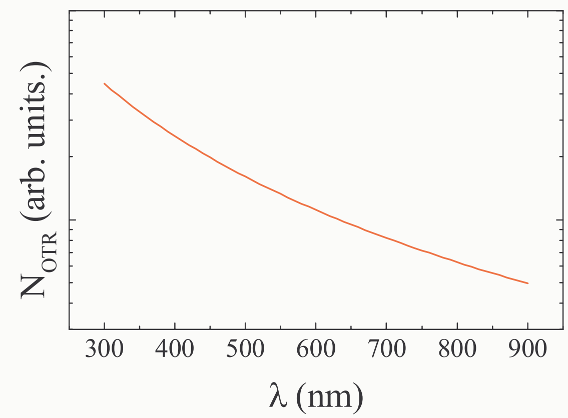
Electron – Photon Conversion



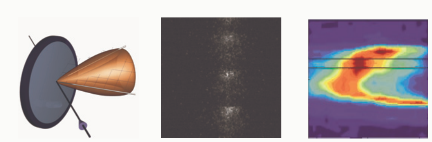
Number of OTR photons/electron in wavelength range [λ_a,λ_b]

(Ideal metallic surface)

$$N_{OTR} = \frac{2\alpha}{\pi}\left[\left(\beta + \frac{1}{\beta}\right)\cdot \ln\left(\frac{1+\beta}{1-\beta}\right) - 2\right]\ln\left(\frac{\lambda_b}{\lambda_a}\right)$$



Electrons energy (MeV)	0.14	20	40	150
[400,600]nm OTR photons / electron	7.2 10^{-4}	7.3 10^{-3}	8.6 10^{-3}	1.1 10^{-2}
[400,600]nm OTR photons on camera	4 10^{8}	6 10^{10}	7 10^{10}	9 10^{10}



Thermal Analysis: Material Study

$$\frac{\Delta T(r,t)}{\Delta t} = \frac{1}{c_p \rho}\left[\frac{dE}{dx}\rho e^{-\frac{r^2}{2\sigma^2}} N(t) - k\nabla^2 T(r,t) - \frac{2\varepsilon\sigma_s}{\delta}\left(T(r,t)^4 - T_0^4\right)\right]$$

Heating term — Cooling terms

Target :
- ε : Emissivity
- δ : Thickness
- c_p : Specific heat
- ρ : Density
- k : Thermal conductivity

Electron beam :
- σ : beam size
- $N(t)$: beam current

Material	c_p J/gK	k W/mK	T_{max} °C
Be	**1.825**	**190**	**1287**
C	**0.7**	**140**	**3527**
Al	0.9	235	660
Si	**0.7**	**150**	**1414**
Ti	0.523	22	1668
Mo	0.25	139	2623
W	0.13	170	3422

Thin foil of material with
- High fusion temperature
- High specific heat c_p
- High thermal conductivity

(for graphite ΔT=12% after 1ms)

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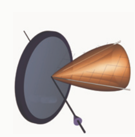
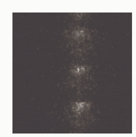
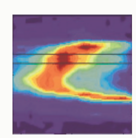




Examples from CTF3

Calculations for the injector profile monitor

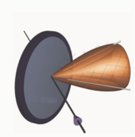
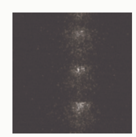
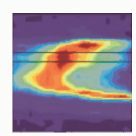
$I = 5.4A$, $E = 140keV$, $\sigma = 1mm$				
t_p (μs)	T (°C) @ 10Hz C	Al	T (°C) @ 50Hz C	Al
0.2	103	83	164	132
0.8	272	194	558	421
1.56	440	434	1003	*x*

Calculations for the linac profile monitors

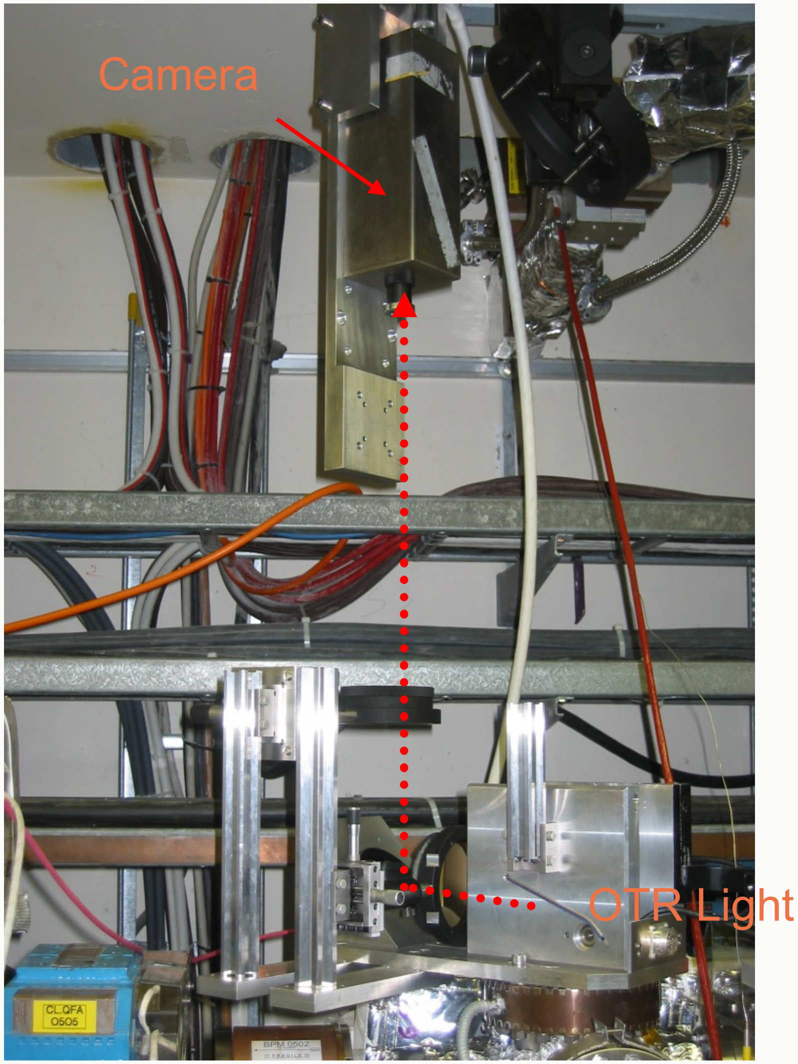
$I = 3.5A$, $E = 150MeV$, $t_p = 1.56\mu s$				
σ (mm)	T (°C) @ 10Hz C	Al	T (°C) @ 50Hz C	Al
0.25	1730	*x*	2250	*x*
0.5	-	*x*	-	*x*
0.6	-	510	-	*650*

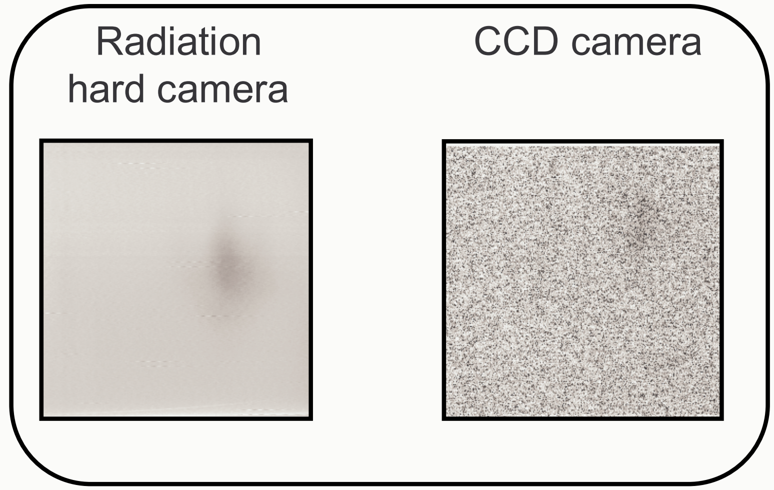
- **Carbon screens stand the full beam intensity for the maximum repetition rate at every energy.**
- Some alternatives for reduced bunch charge / lower repetition rate.

E. Bravin, T. Lefevre

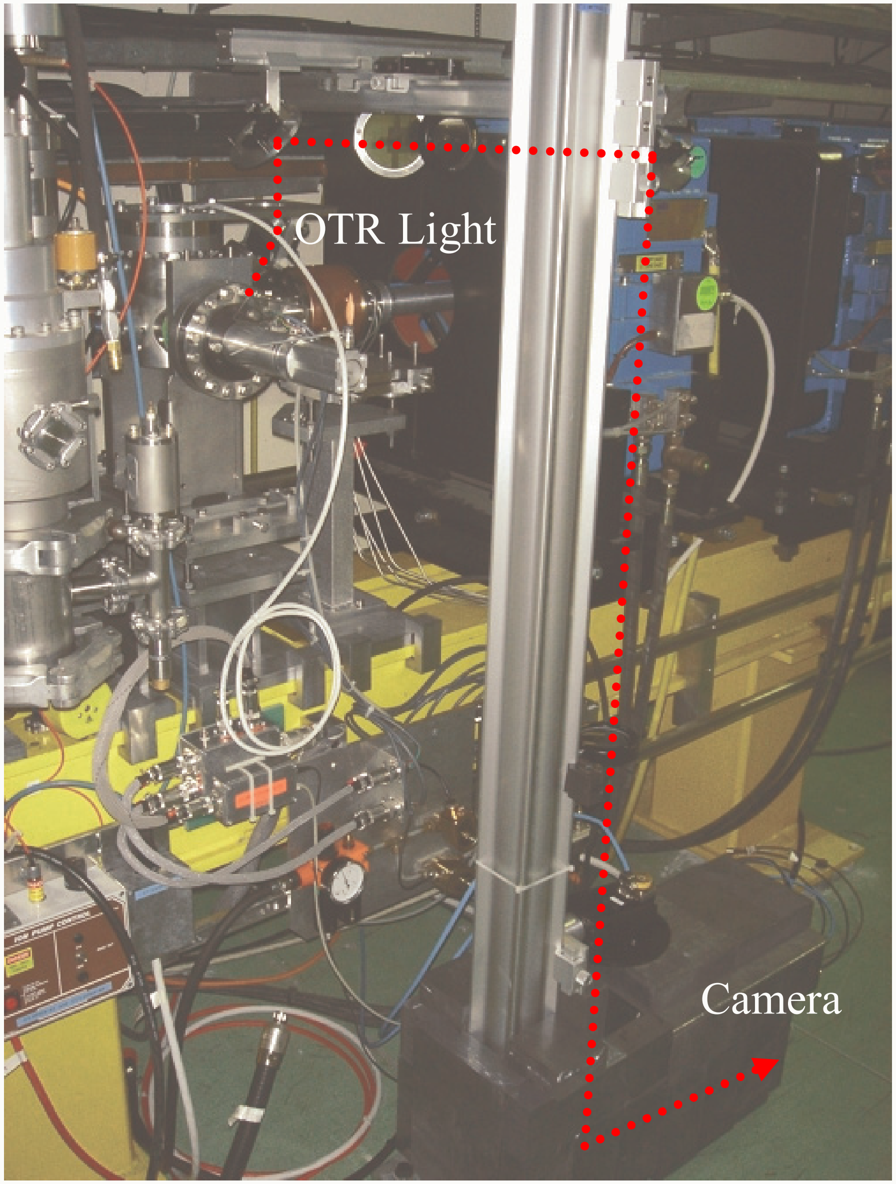




Past Installations





Present Layout

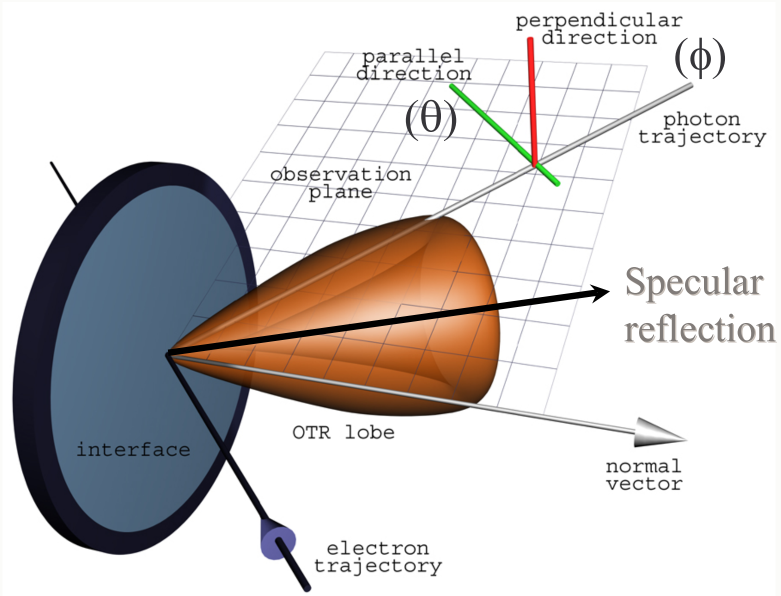


Design dominated by spatial constraints

Existing vacuum tanks used

Shielding of equipment

Simulation of OTR in ZEMAX



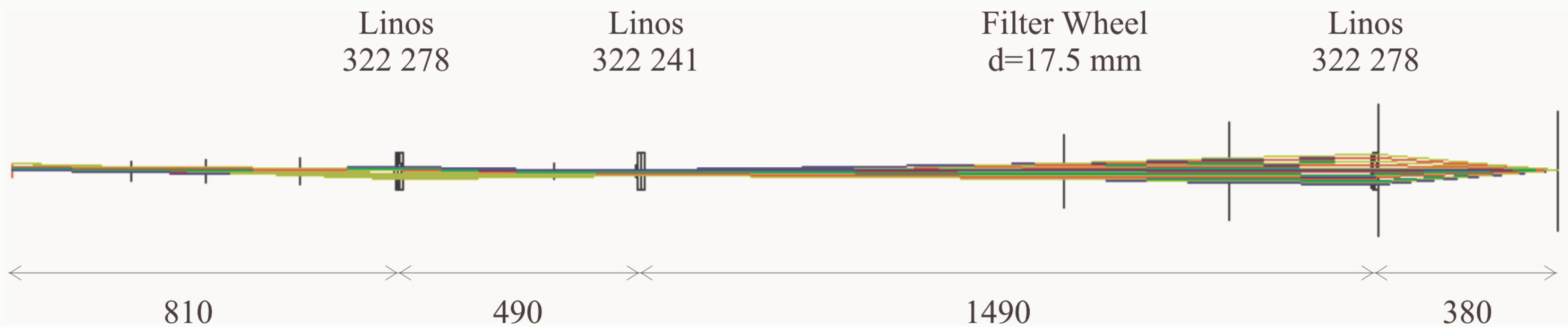
$$\frac{d^2W}{d\Omega d\omega} = \frac{d^2W_{\parallel}}{d\Omega d\omega} + \frac{d^2W}{d\Omega d\omega}$$

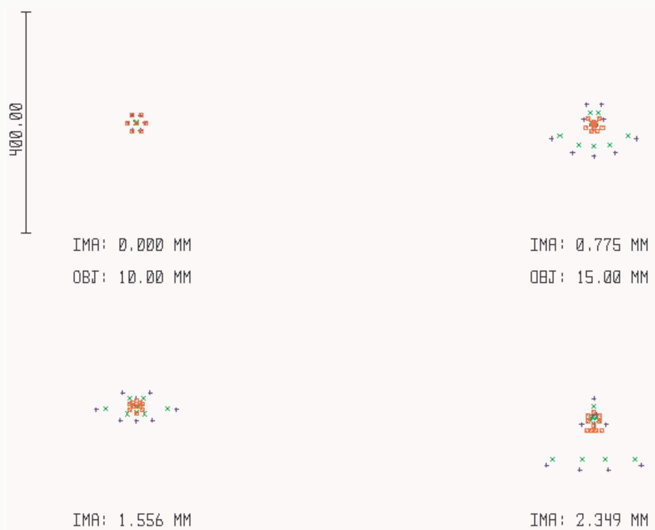
$$\approx \frac{q^2}{\pi^2 c} \frac{\theta^2}{\left(\gamma^{-2} + \theta^2\right)^2}$$

Maximum at $\theta_{max}=1/\gamma$ ⇨ Used in ZEMAX.

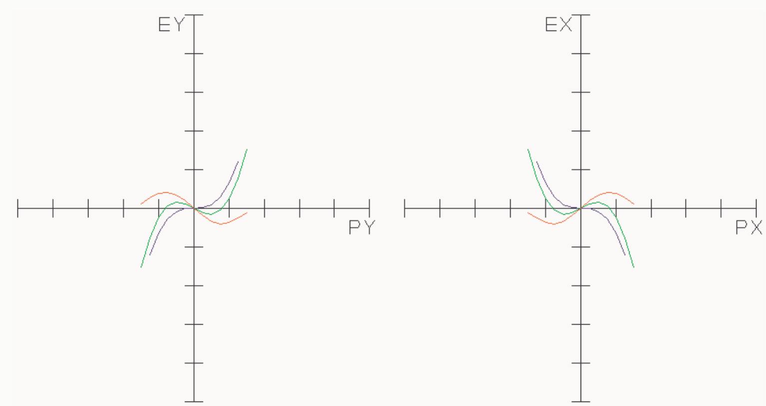
25 MeV	2.29°
80 MeV	0.73°
160 MeV	0.36°

Lens Configuration - ZEMAX





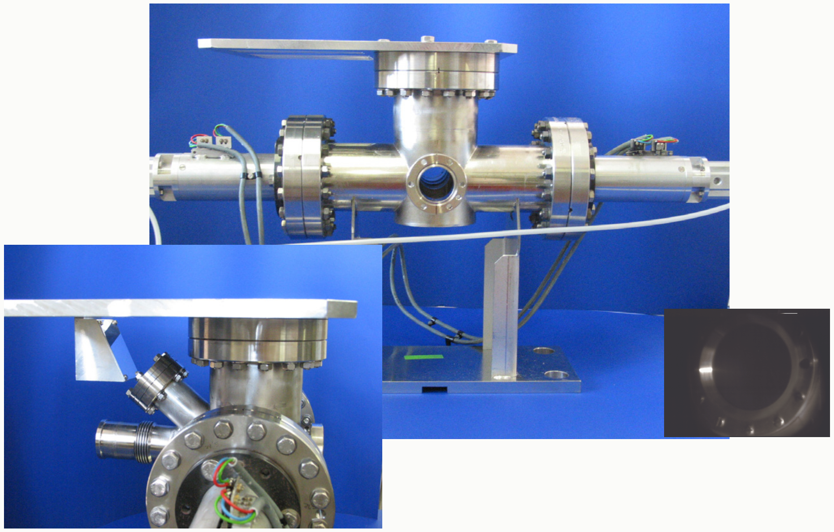
Spot diagram, max: 400μm



Ray aberrations, max: 400μm

Installed Screens at CTF3

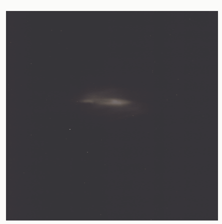
Linac *(Emittance)*



Backward OTR screens

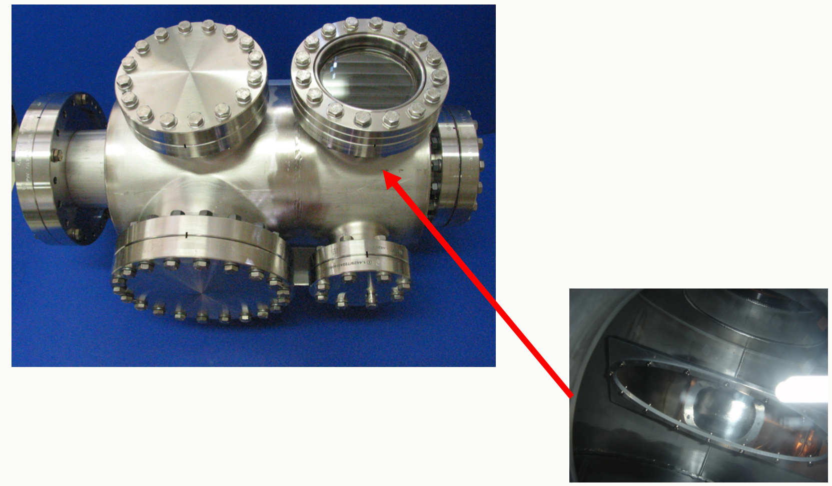
- Two screens at 20° *(observation at 40°)*
- 10µm thick Al-foil *(~90% reflectivity)*
- 100µm thick C / ~~SiC~~ foil *(~26% reflectivity)*
- Active Size : Ø 3cm

Scan in X



Scan in Y

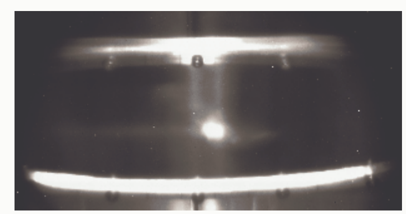
Spectrometer *(E,ΔE)*



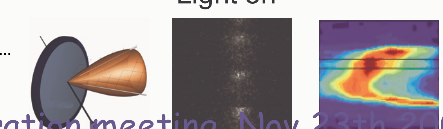
Backward OTR screen

- Fixed screen tilted at 45° *(observation at 90 °)*
- 10µm thick Al-foil *(~90% reflectivity)*
- Active Size : 10cm x 5cm

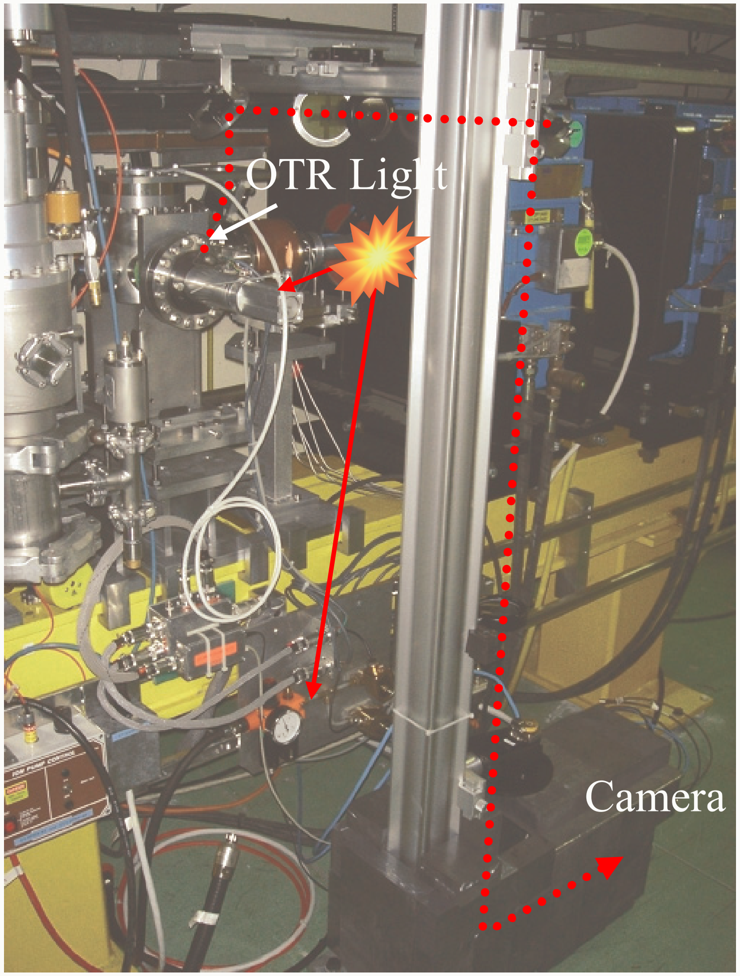
Light off



Light on



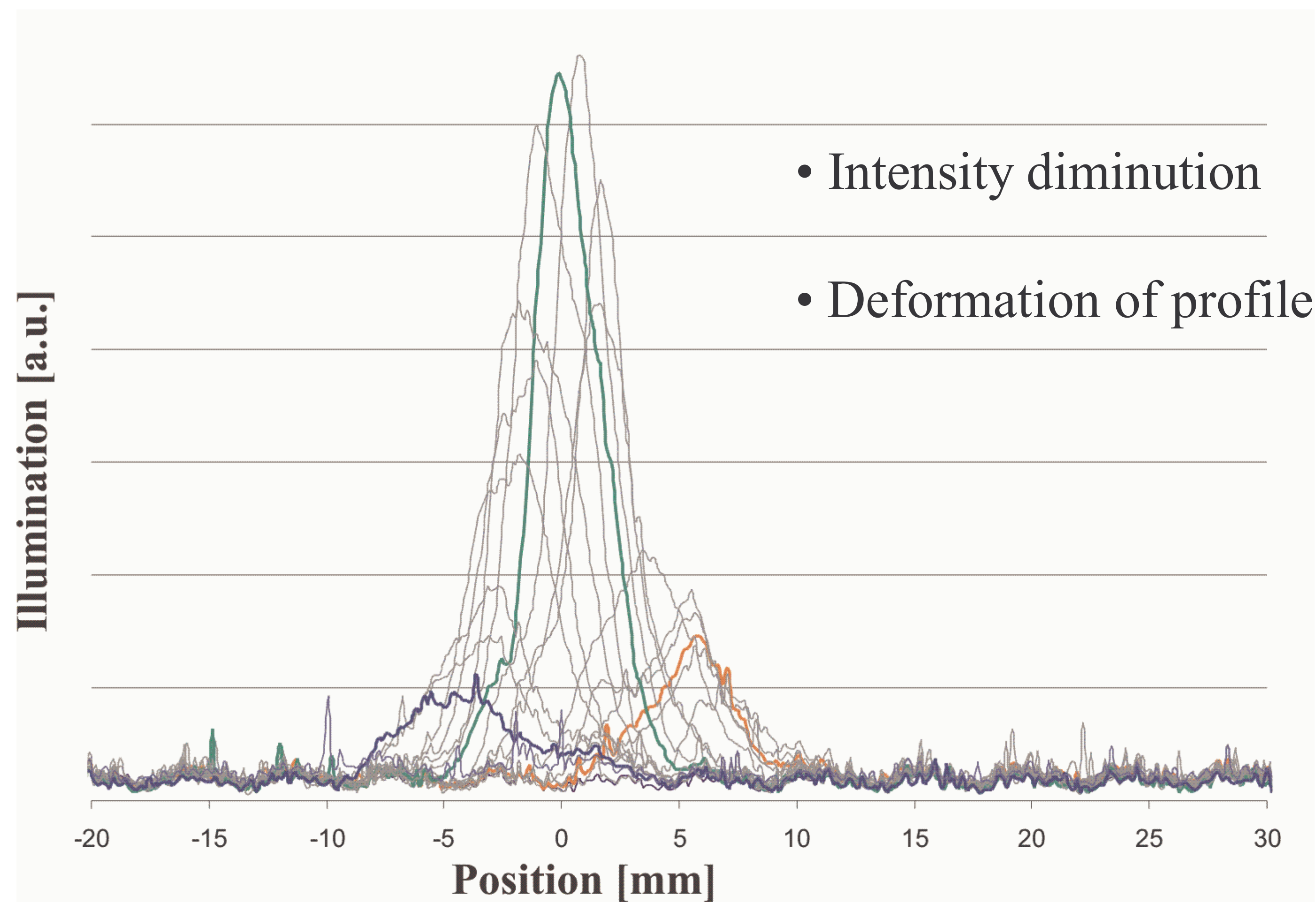
Linac: Radiation Issues



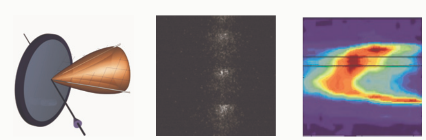
- CCD destroyed within weeks
- Lens darkening
- Damage to valves, cables and connectors

→ New (modular) rad-hard layout.

Problems in Spectrometer

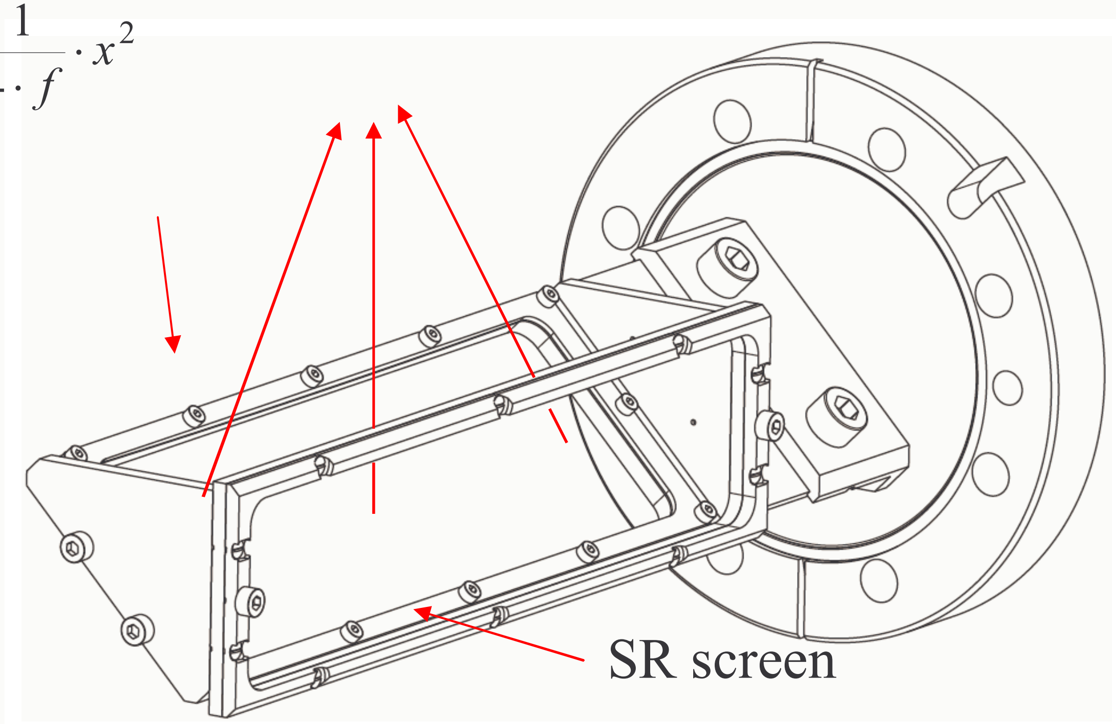


- Intensity diminution
- Deformation of profile



Solution: Parabolic Screen

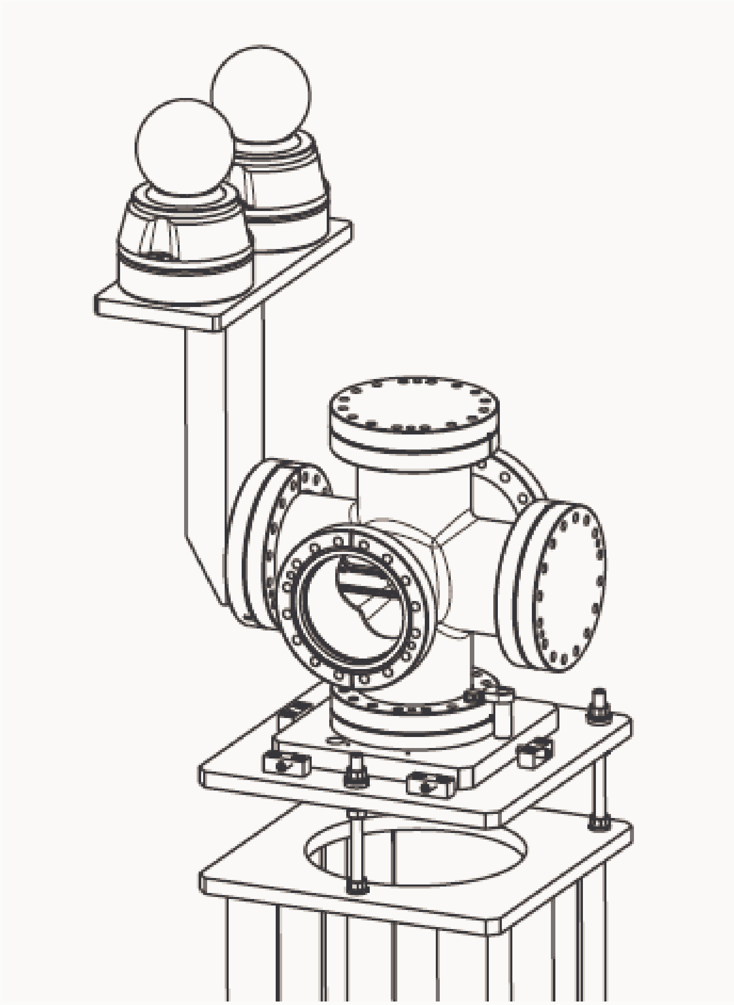
$$z = \frac{1}{4 \cdot f} \cdot x^2$$

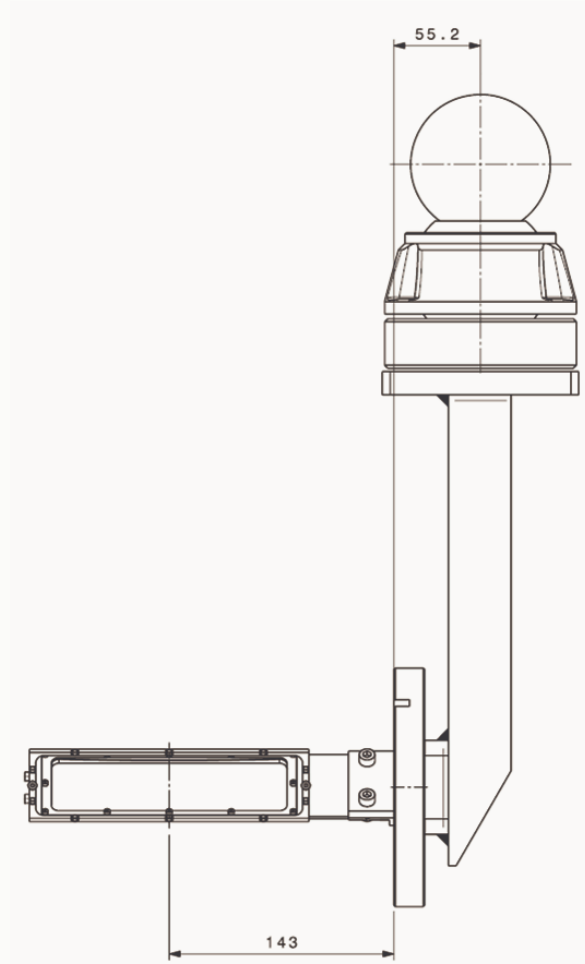


Proc. EPAC 06

Standard for future installations.

Spectro Tank: New Layout



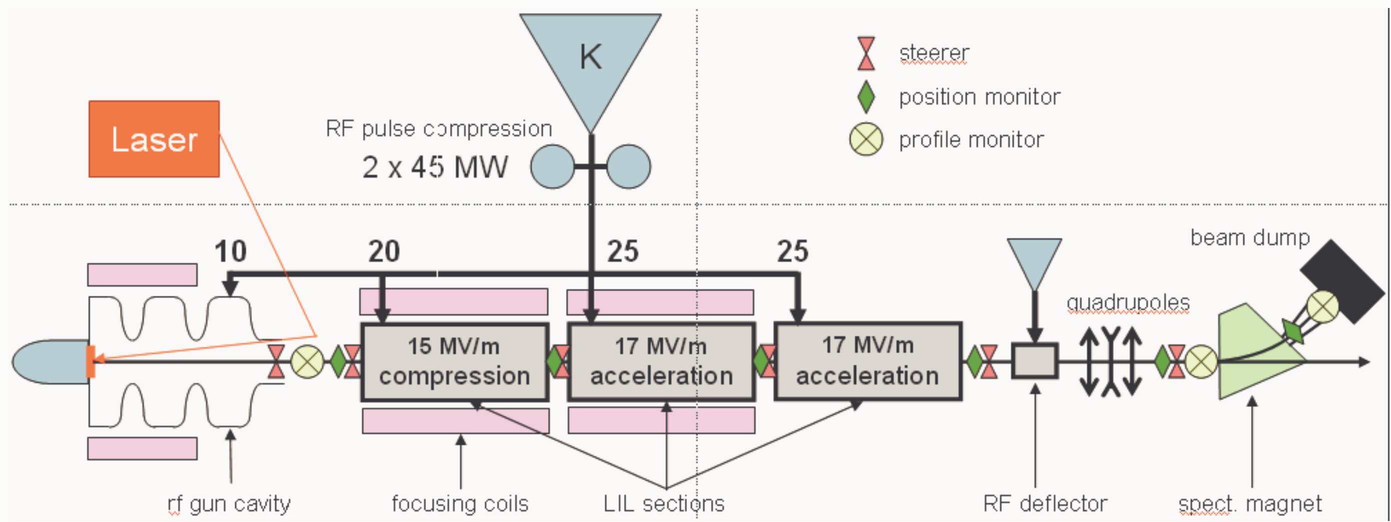


- Cheap, simple design,
- Screen can be aligned ex situ.

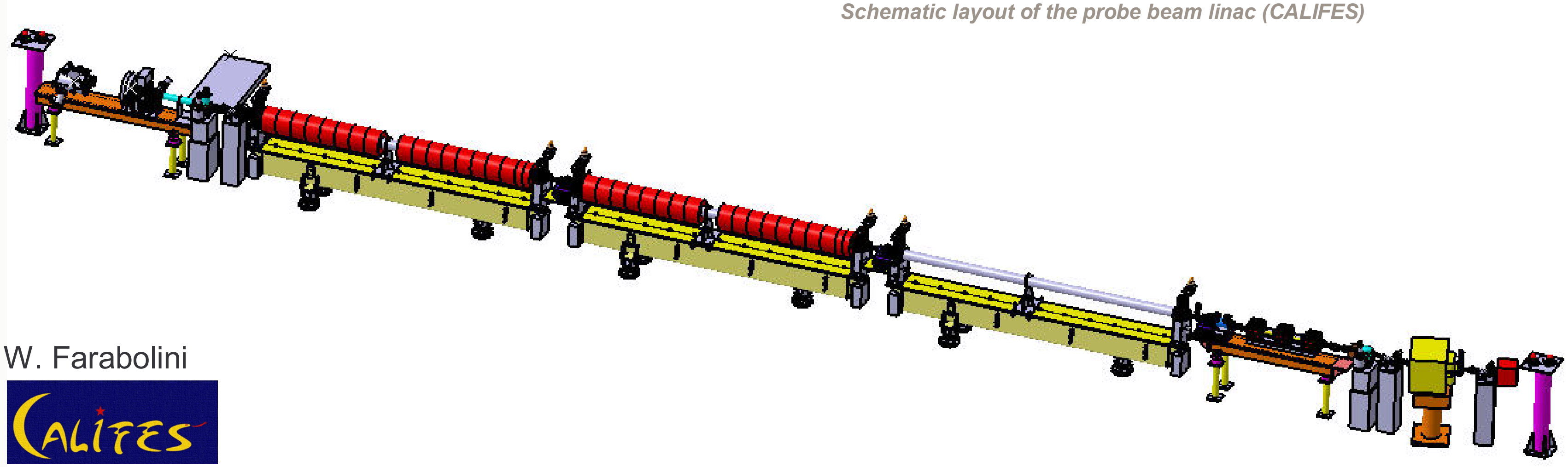
CALIFES *(guess !?)*

Concept d’Accélerateur Linéaire pour Faisceau d’Electrons Sonde

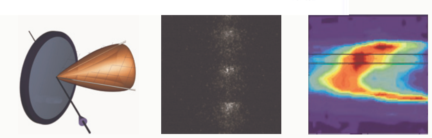
Energy	200 MeV
Emittance rms	< 20 π mm.mrad
Energy spread	< ± 2%
Bunch charge	0.5 nC
Bunch spacing	0.333 ns
Number of bunches	1 – 64
Bunchlength	< 0.75 ps



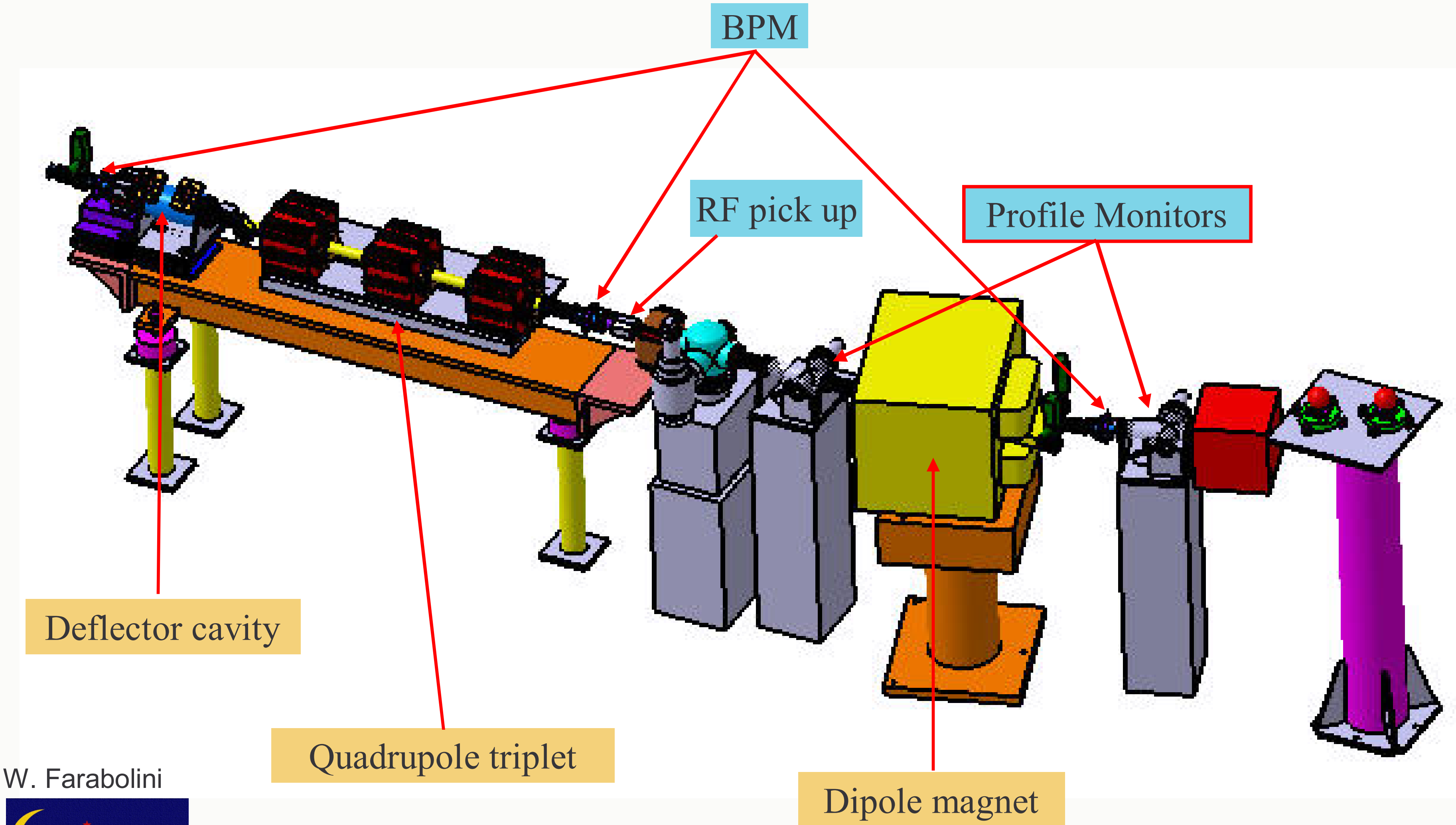
Schematic layout of the probe beam linac (CALIFES)



W. Farabolini



Diagnostic Installations



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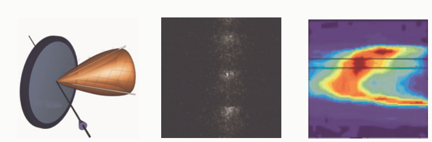
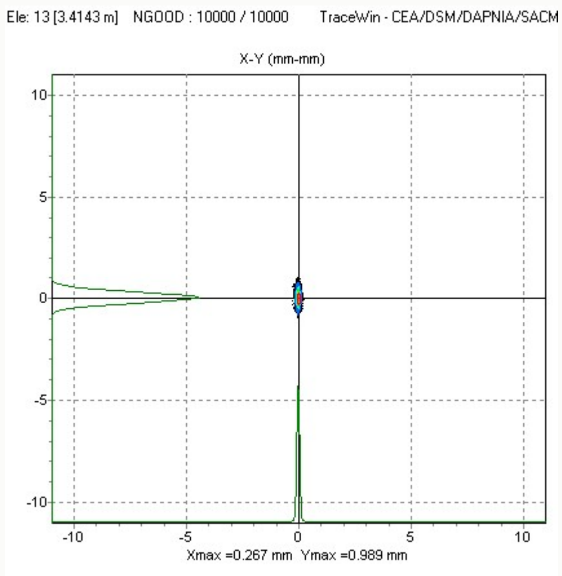
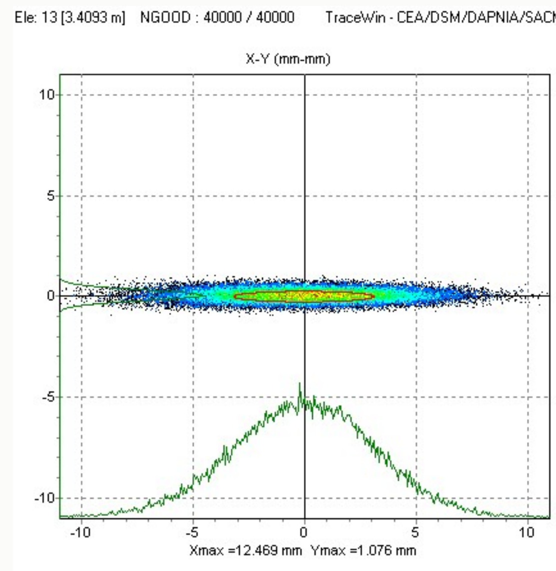


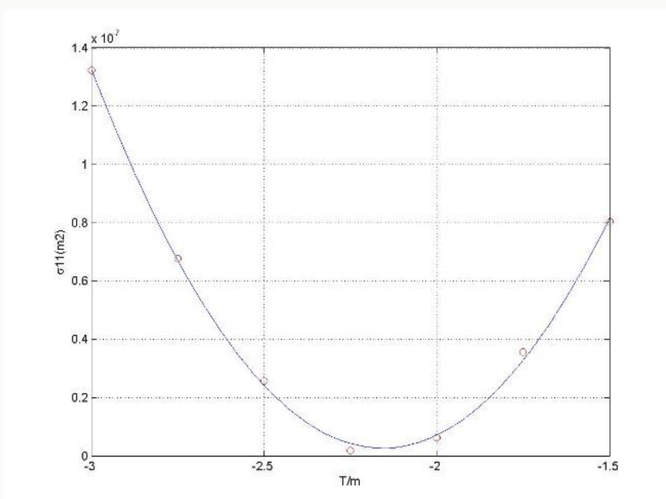
Simulation of e^- Beam Parameter





Quad scan simulation - Waist

Spectrometer line

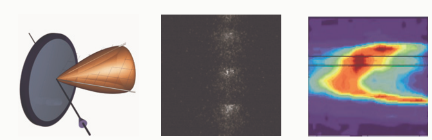


σ_{11} = $\langle x^2 \rangle$ vs. Quad gradient

Intensity between 10^8 - 10^{11} e^-

Spot between 0.01 et some mm^2

W. Farabolini

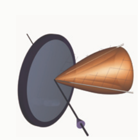
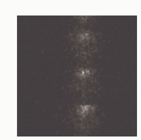
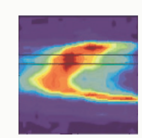


Different Characteristics

CCD camera 1/3'' (4.8 x 3.6 mm^2)
Frame grabber 416 x 312 pixels (pixels of 11.5 μm)

Position	After canon	After triplet	After Dipole
Aim	Check beam position and dimensions	Emittance measurement	Energy dispersion measurement
Specifications	None	Resolution ≤ 20 μm size 10 x 10 mm^2	Resolution $\Delta p/p \leq 1\%$ Precision < 2% of nominal energy
Energy	5 MeV	177-200 MeV	177-200 MeV
Beam size	2-3 mm rms	50 μm (waist) – 3 mm	20 x 0.5 mm
Magnification	0.2	1.73 and 0.36	0.18
Screen type	Phosphor or YAG	OTR and Phosphor	Phosphor
Resolution pattern	Engraved on screen	Movable or on dedicated optical line	Engraved on screen

W. Farabolini

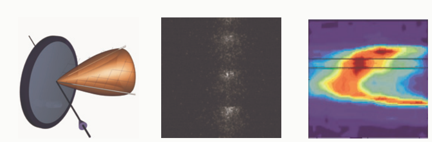
How to Decide for a Screen…

Phosphor or Chromox

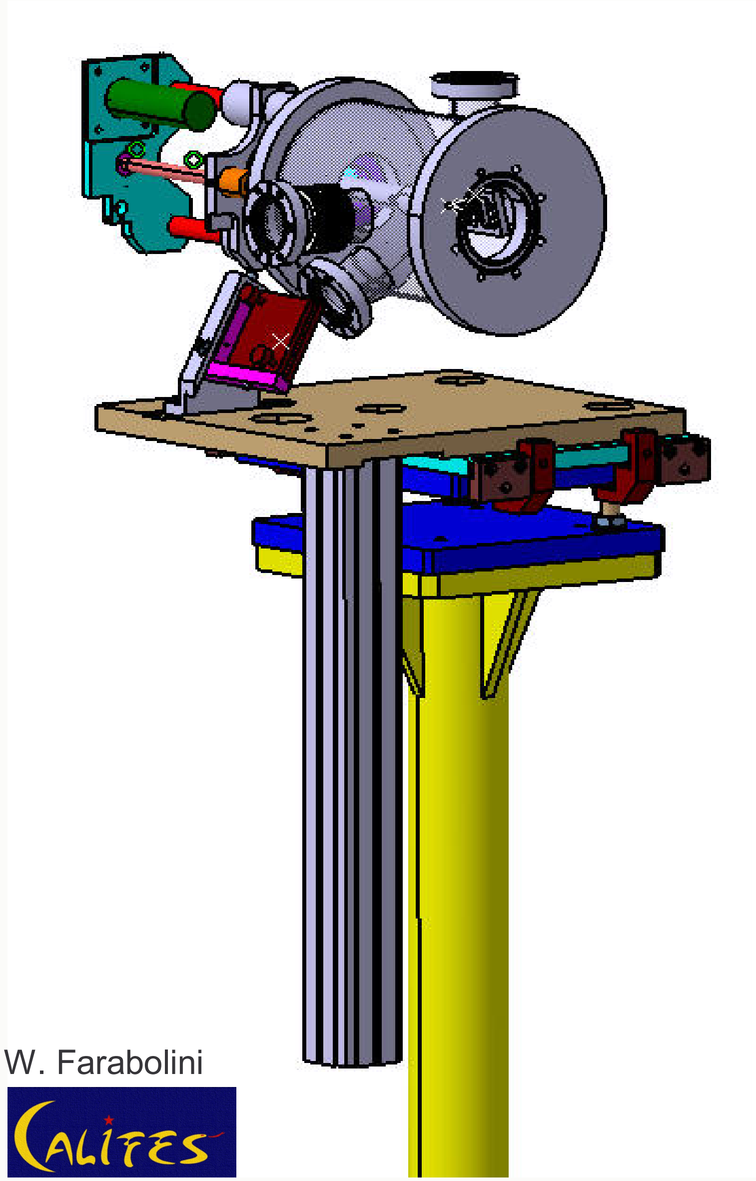
- Powder deposition (Y_2SiO_5:Ce,Tb) on substrate or Al+Ce,
- Omni directional emission,
- High gain *(P47: 630 ph/e^- @ 15 keV)*
- Monochromatic spectrum,
- Saturation and non-linear,
- Can be damaged if > 1 C/cm^2,
- Remanence *(0.1 µs - some ms)*,
- Spatial resolution is function of thickness.

OTR

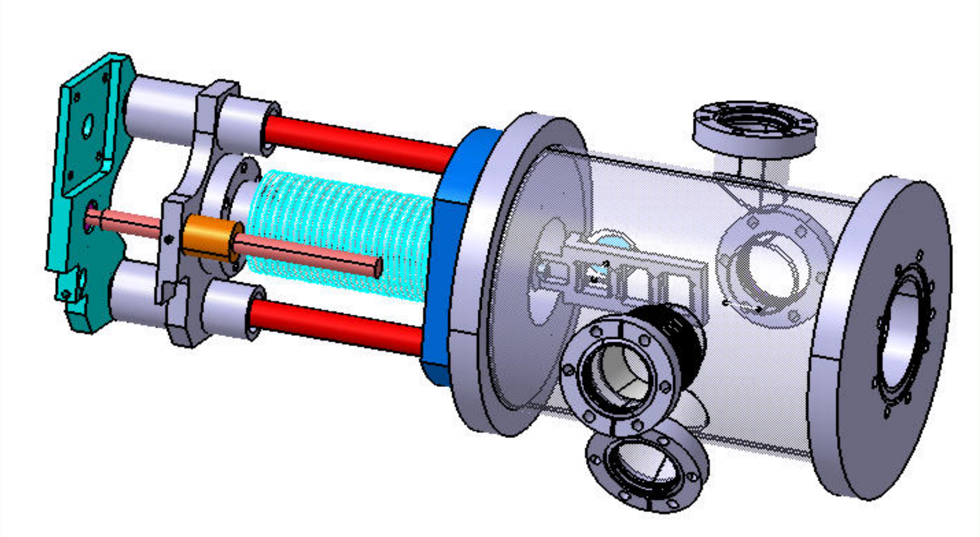
- Thin foil of Al, C, Si, SiC,…
- Narrow emission angle ($2/\gamma$),
- Weak gain *(0.015 ph/e^- @ 200 MeV)*
- Large spectrum,
- Very robust (see: thermal effects),
- No remanence,
- Very good spatial resolution.

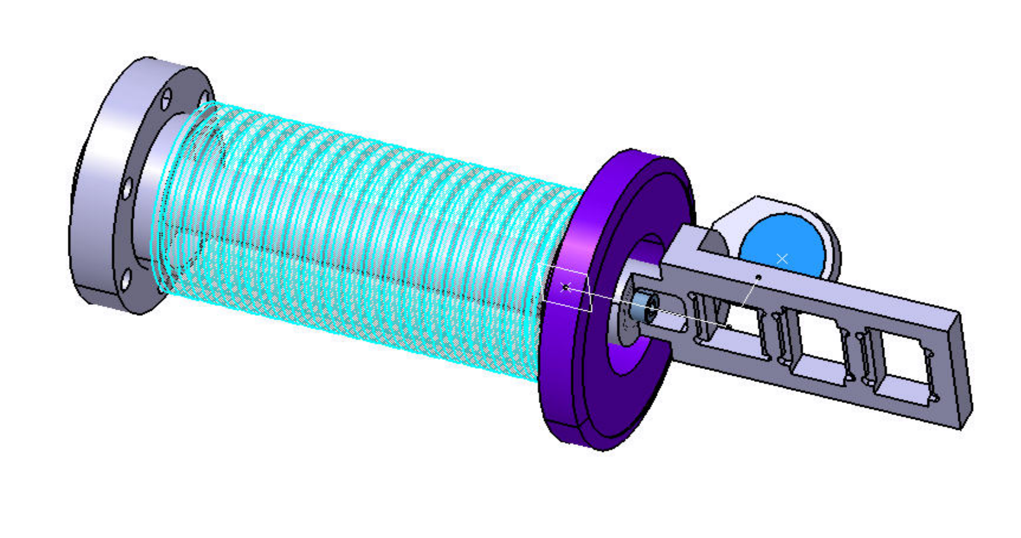


New Chamber Layout

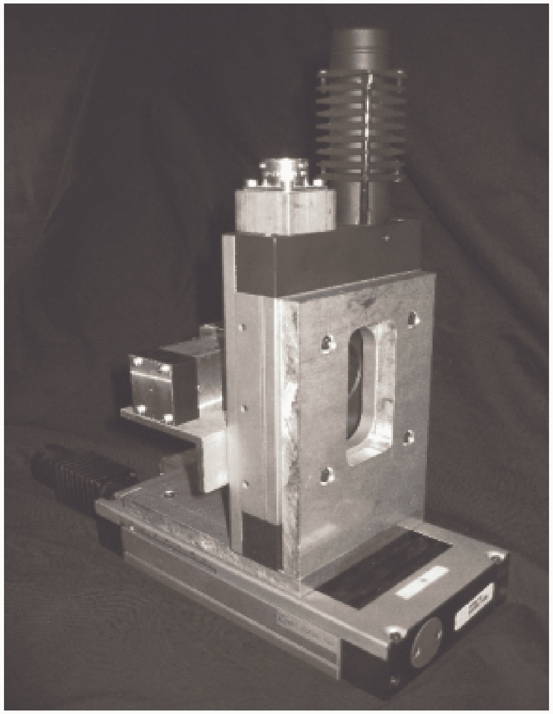


W. Farabolini





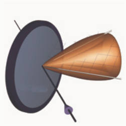
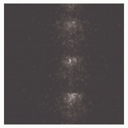
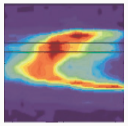
Halo Monitor



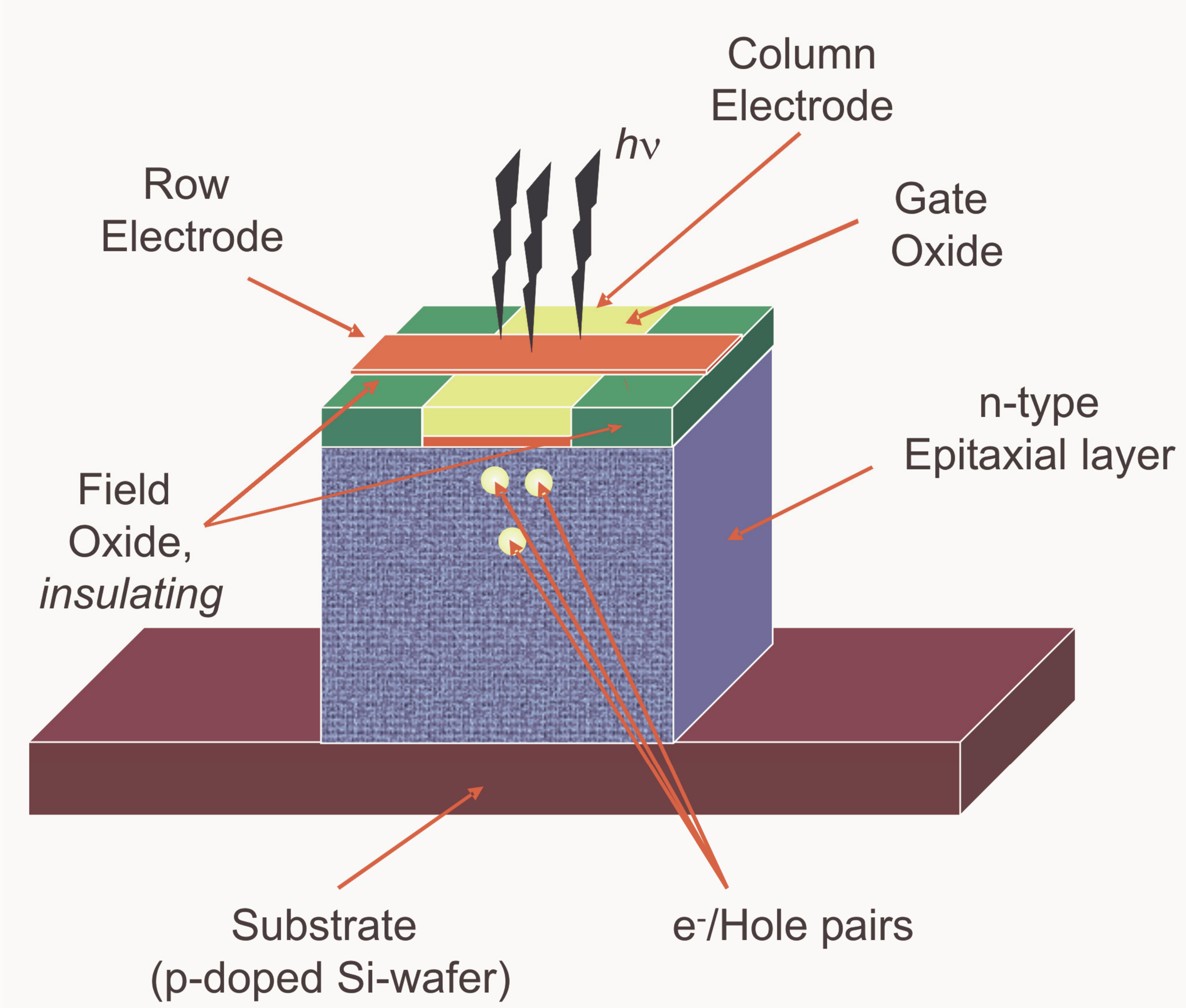
Meas. Sci. Technol. **17** (2006) 2035–2040

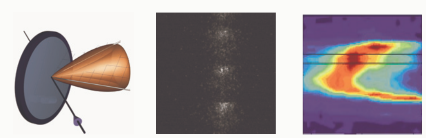
Under investigation:

- 2D PMT setup
- SpectraCAM CID camera
- Micro Mirror Array

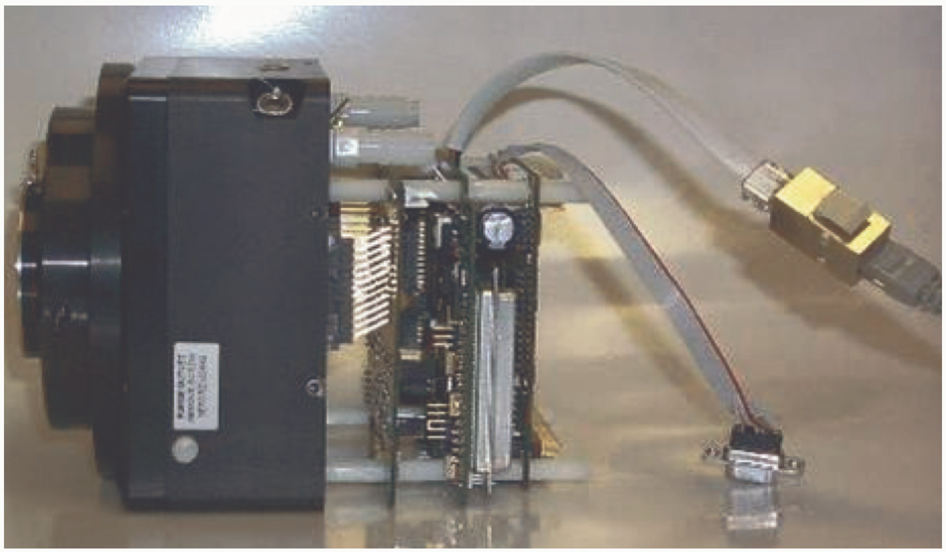




CID Technology





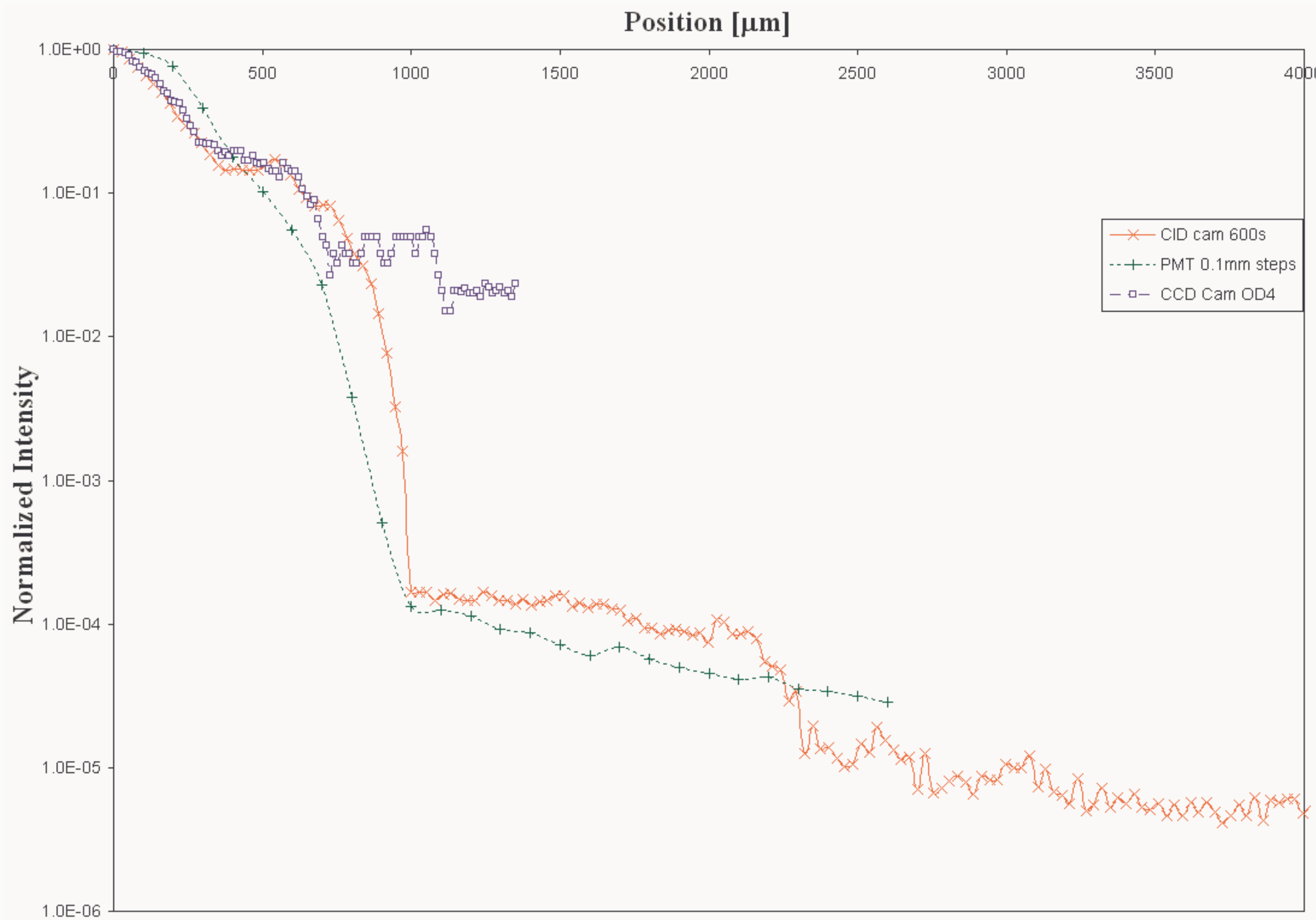
SpectraCAM System



Sealed camera head including read-out electronics

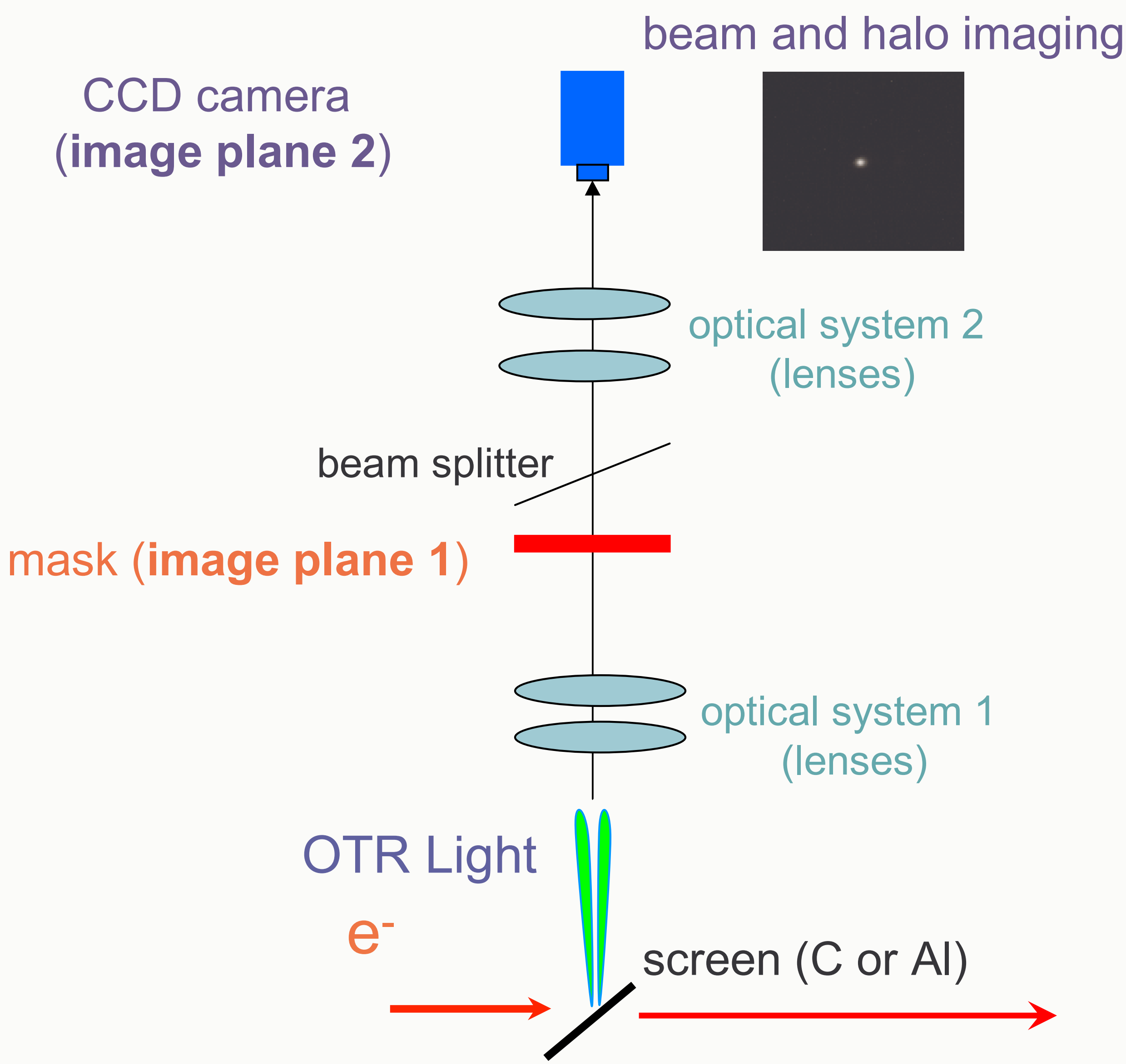
Water cooling system and integration electronics

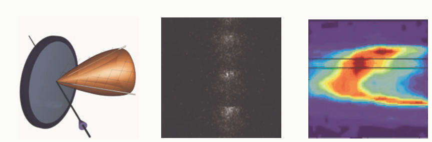
Halo Measurements



Meas. Sci. Technol. **17** (2006)

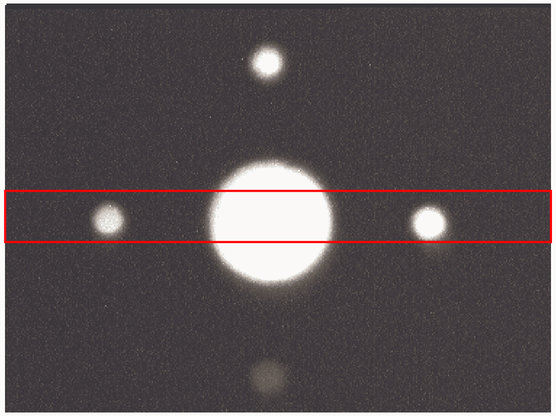
Core Masking Technique



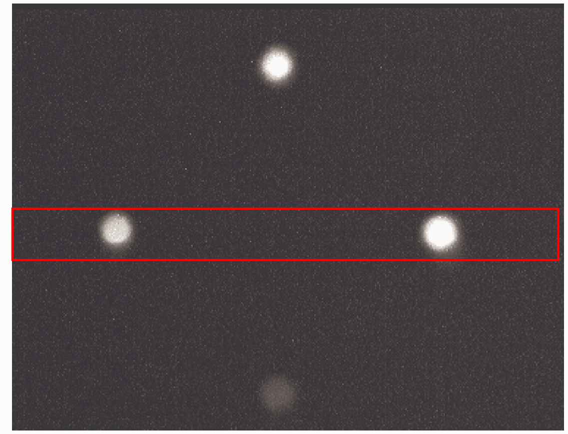


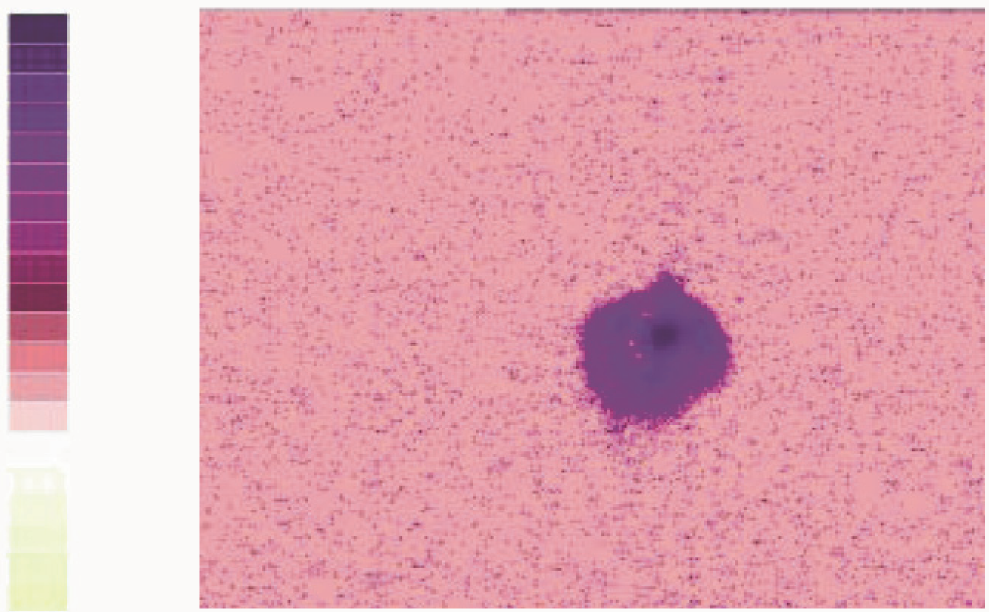
Callibration: Opacity

Phantom image without mask



Phantom image with mask



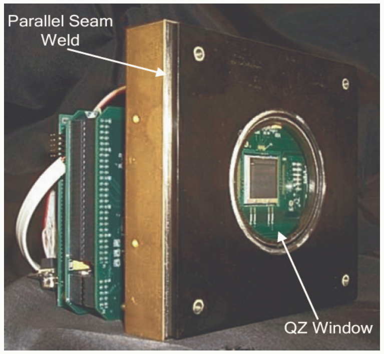


Factor 100
higher dynamic range.

Proc. EPAC04

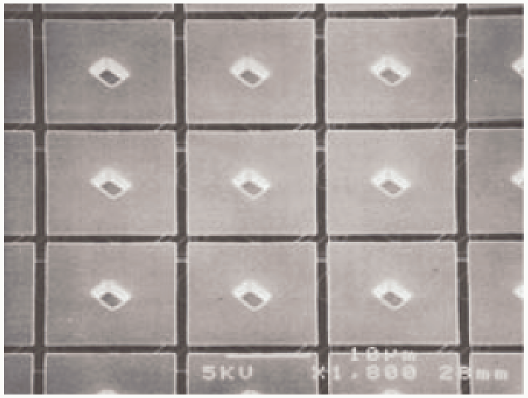
Future Perspectives

1. SpectraCAM XDR from Thermo



2048^2 pixels

2. Micro Mirror Array from Vialux



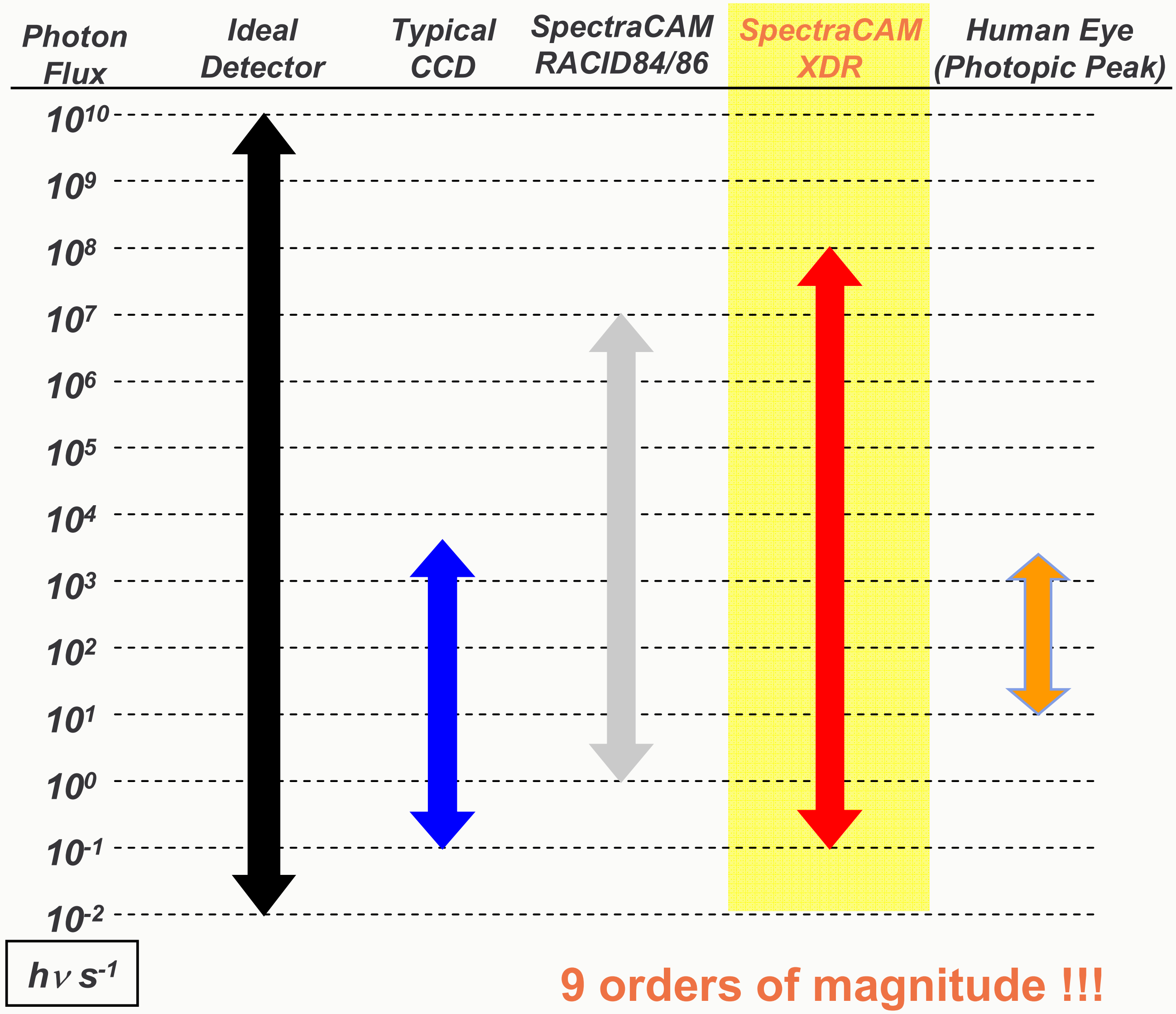
1024 x 768 pixels (XGA)

USB Interface

high-speed port 64-bit @ 120 MHz for data transfer

up to 9.600 full array mirror patterns / sec (7.6 Gbs)

Dynamic Range of New System



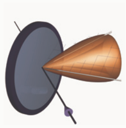
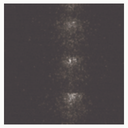
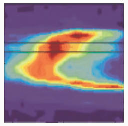
9 orders of magnitude !!!

Outline

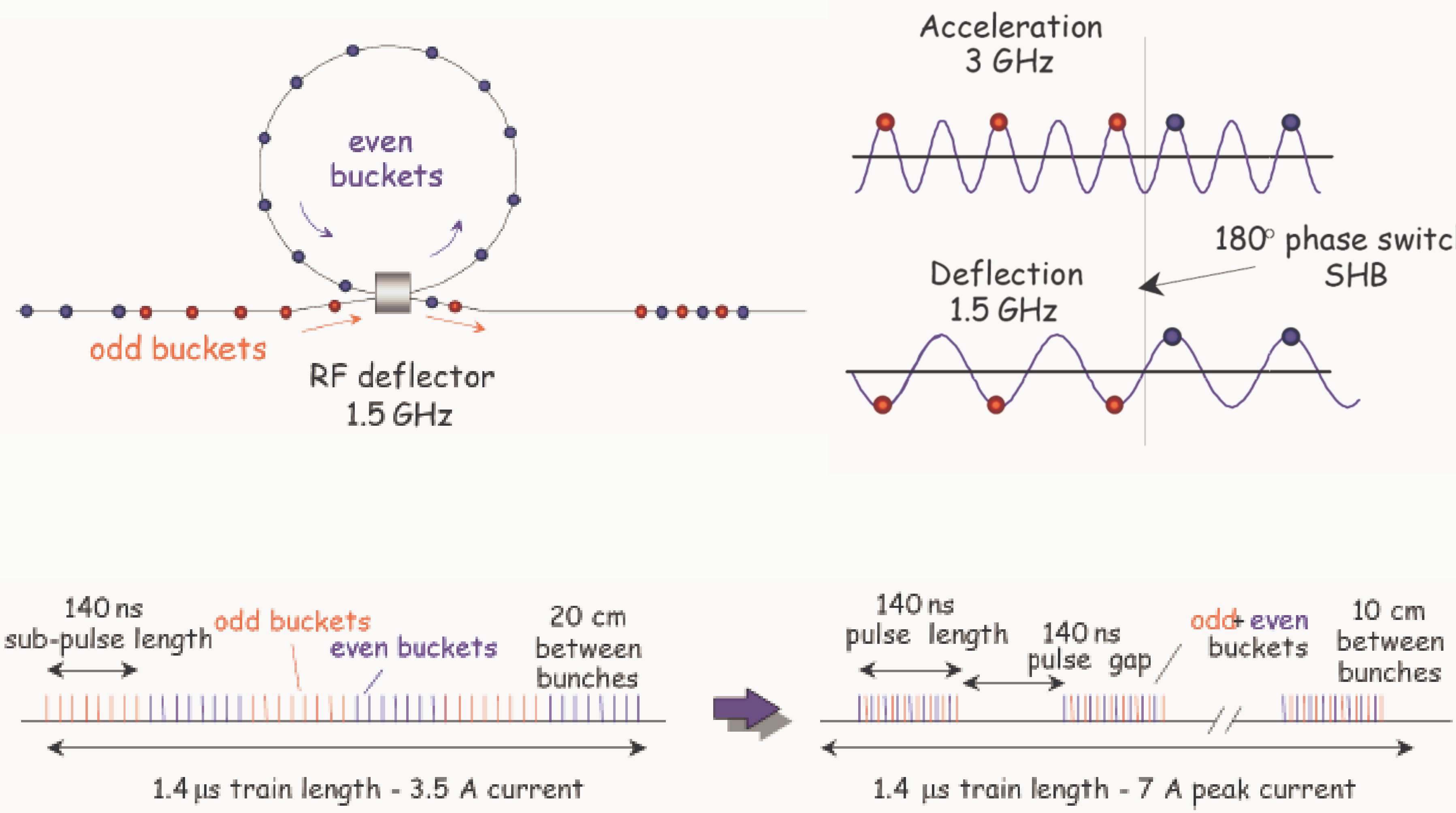
1. Transverse Beam Profiles

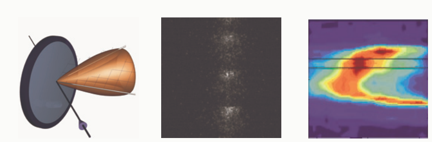
2. Longitudinal Beam Profiles

3. Time-resolved Energy Measurements

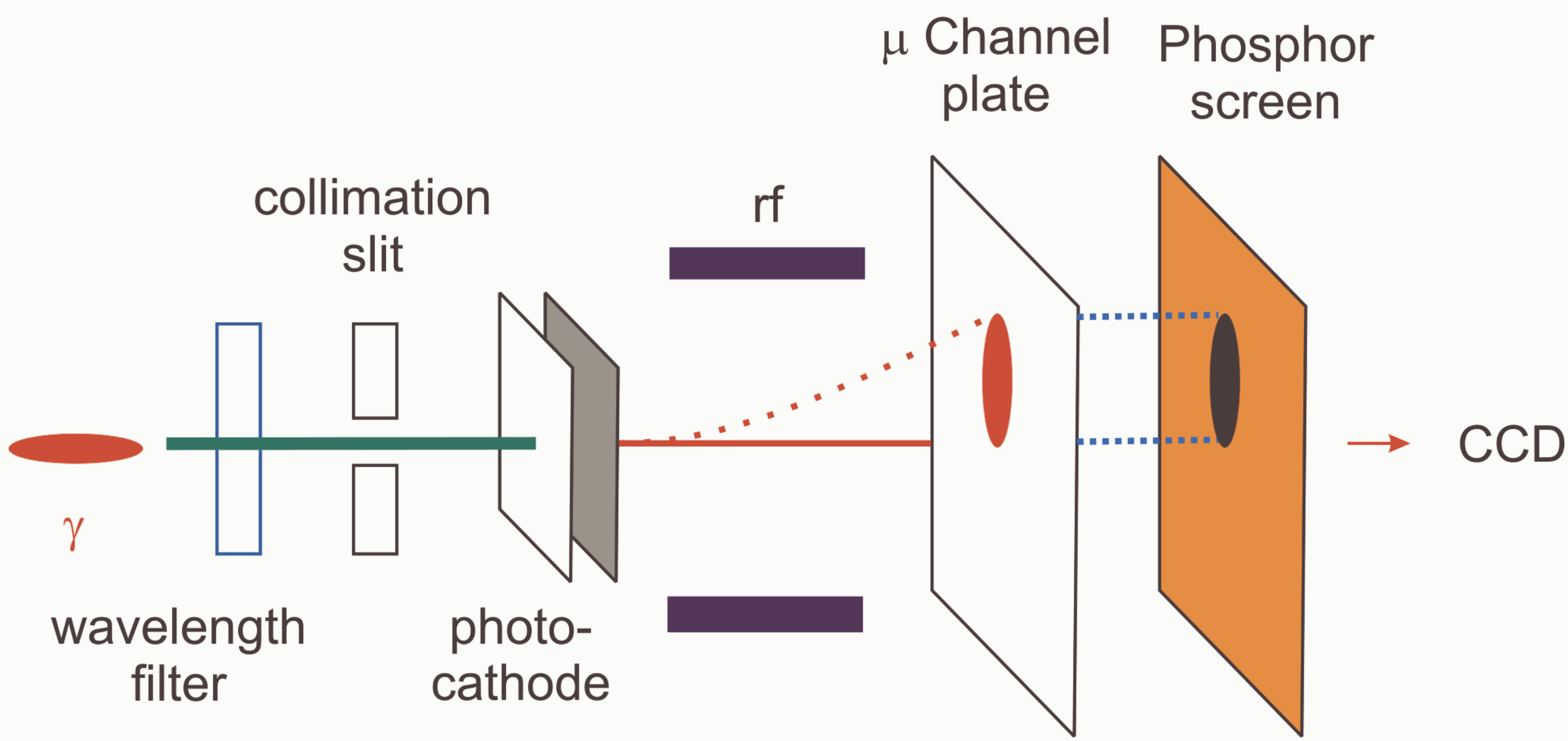




Longitudinal Measurements

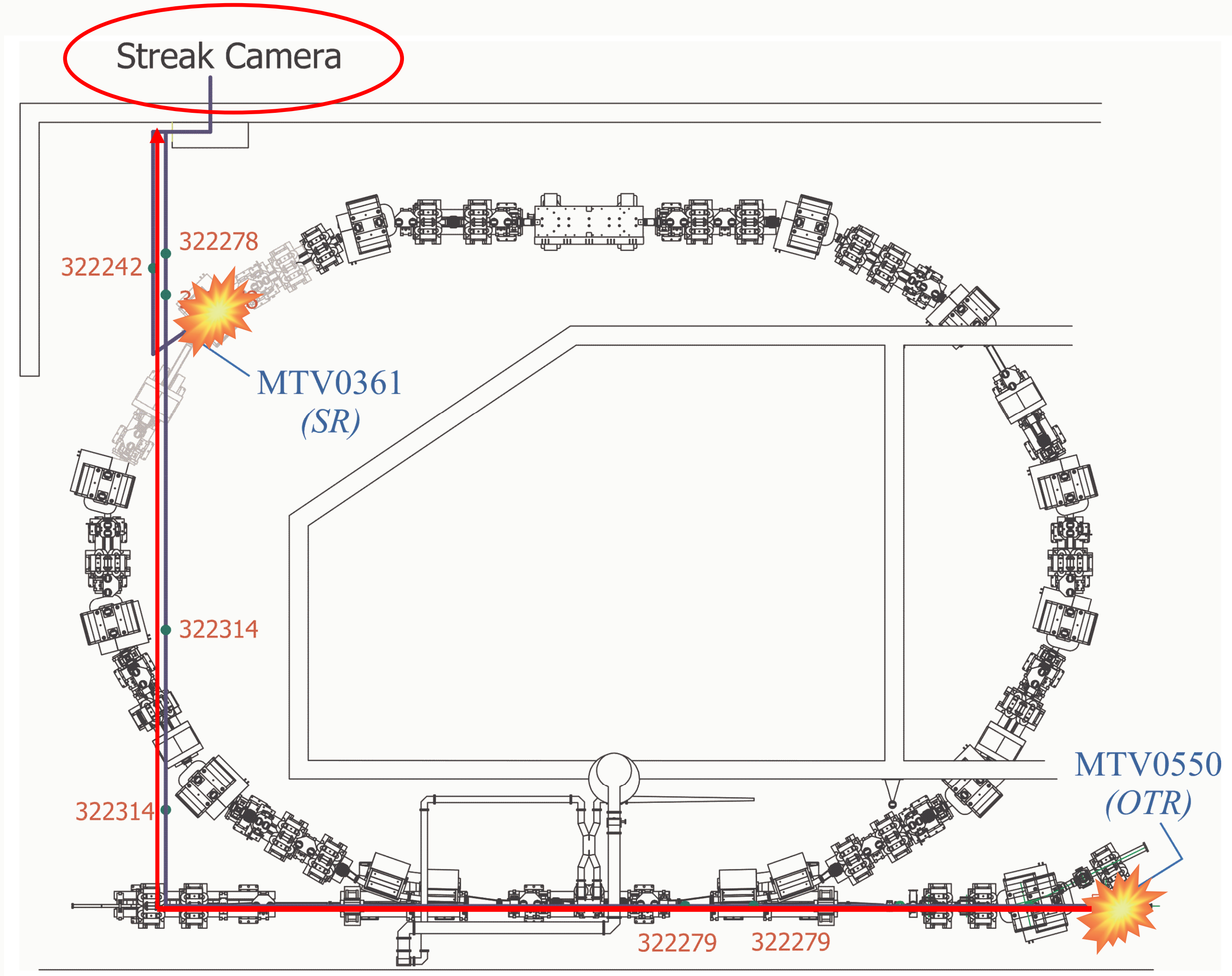




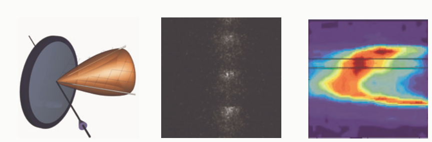
Principle of a Streak Camera



Long Optical Lines



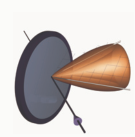
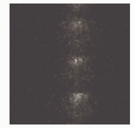
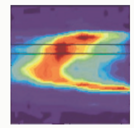
CTF3 Note 072



Design – Overview of Tasks

- Transmit the light using telescopic arrangements.
- Optimize between collecting, transmitting and demagnifying optics.
- Minimize the number of optical elements.
- Optimize optical resolution.

→ **ZEMAX.**

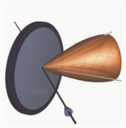
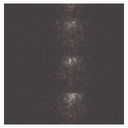
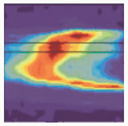




Used for…

- Monitoring of phase switch using sub-harmonic bunchers
- Monitoring of the RF bunch combination
- Monitoring of track length modification with a wiggler
- Bunch length measurements

  (compare to rf pickup)

J. of Instr. **1** P09002 (2006)
CLIC-Note 681

Limitations

- Both, light intensity and aberrations at limit.

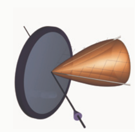
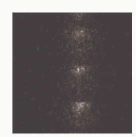
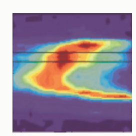
- Even longer lines (CR) no feasible option with present layout.

Will now be used as Cherenkov detector.

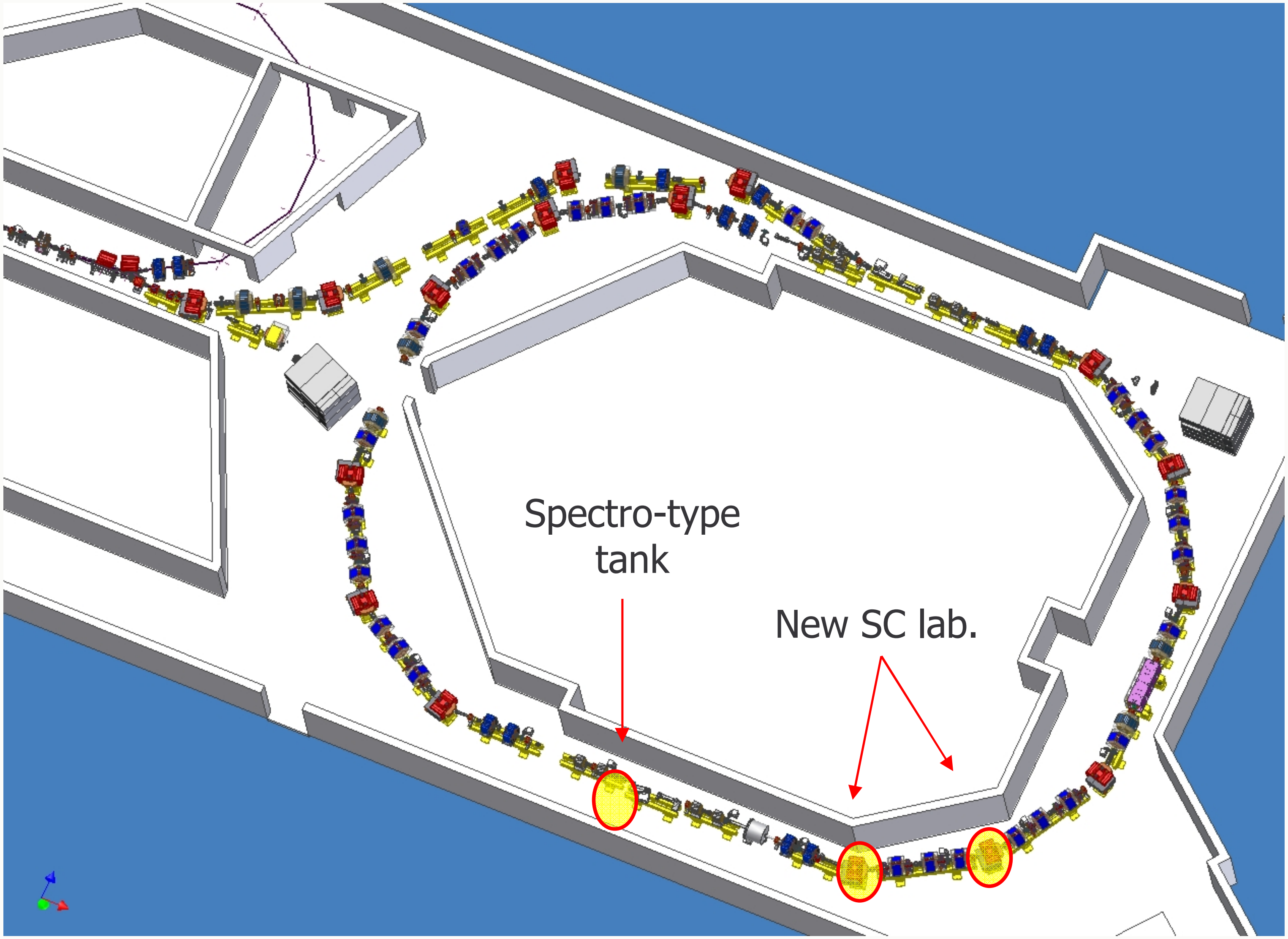
- Test with optical fiber not successful.

⇨ Second SC lab in 2012.

Building,...not year !

Outlook: 2007



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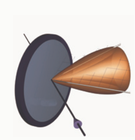
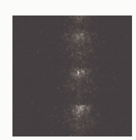
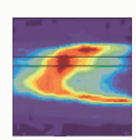
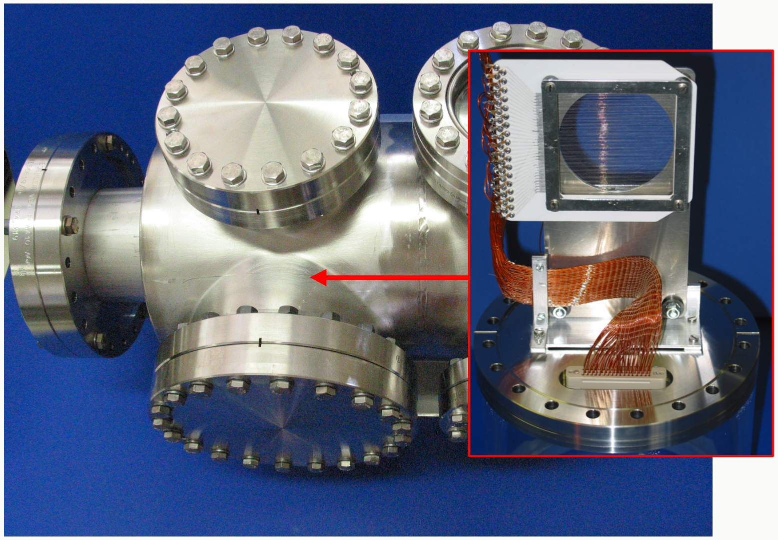
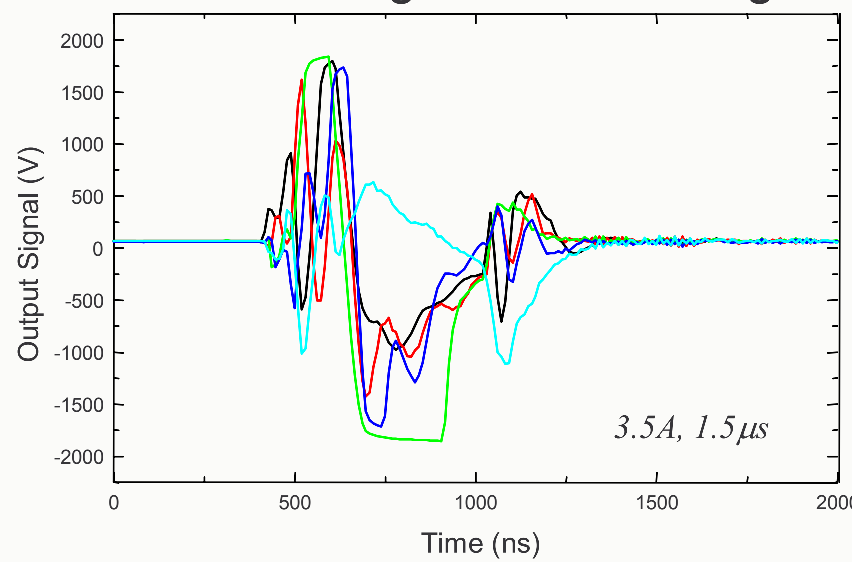




Time Resolved Measurements

In 2003: SEM-Grids (two were installed), 2004 with modifications.

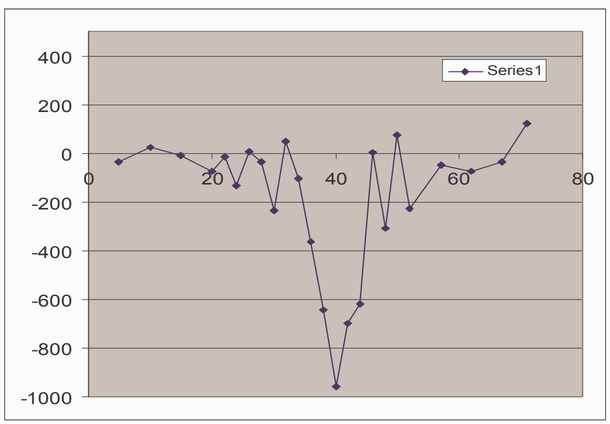


Problems at higher beam charges



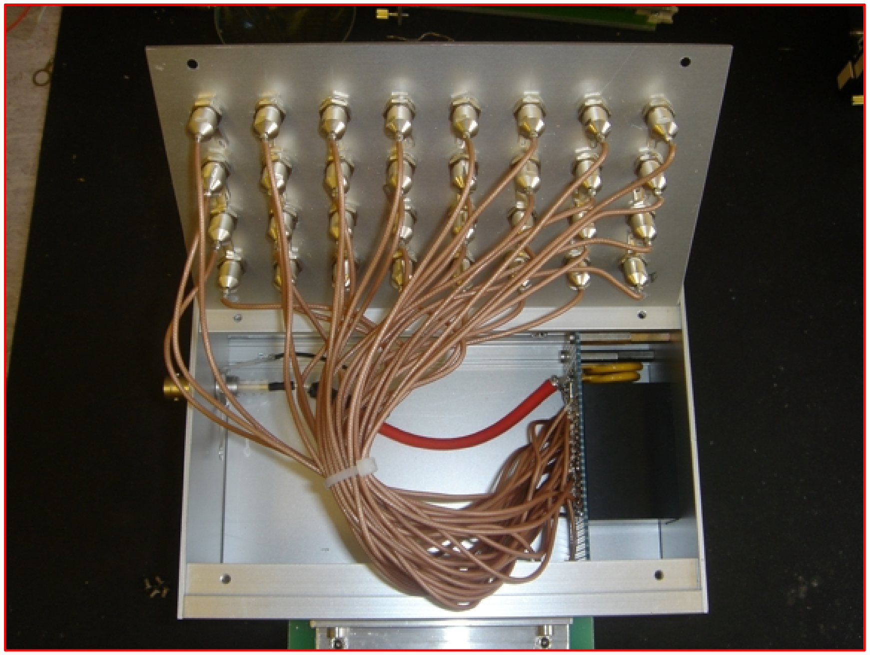
SEMgrid profiles

~ 1 A – 320 ns – 25.5 MeV

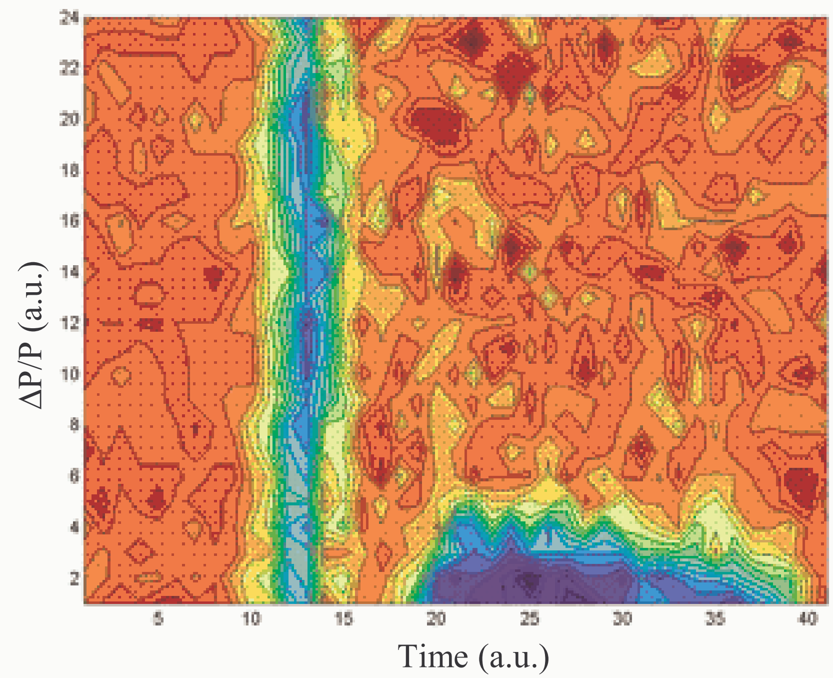


➡ Method abandoned.

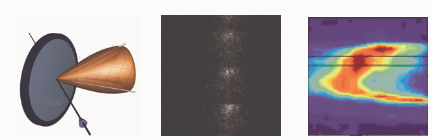
Time Resolved Measurements



- 32 channel segmented PMT from Hamamatsu Corp.
- OTR light from Al screen
- Use beam splitter

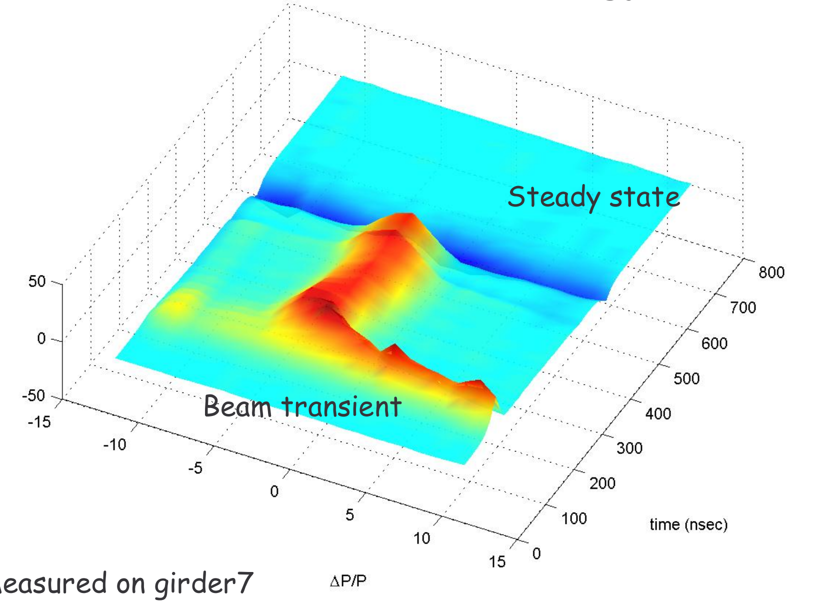


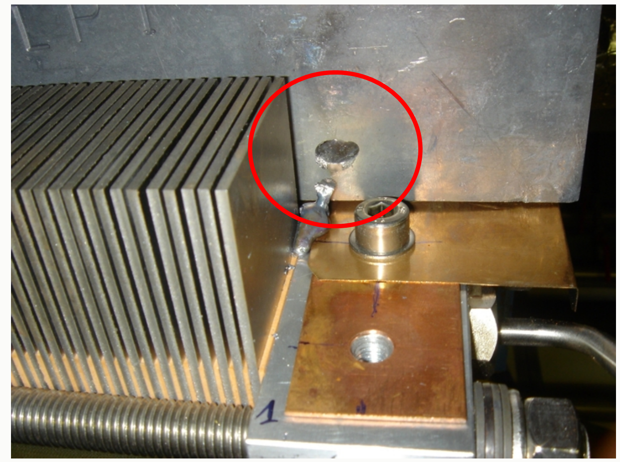
- Good time resolution [ns]
- Amplified to get good s/n ratio
- Screen quality / optics acceptance



Seg. Dump: $\Delta p/p$ (t)

Time evolution of the beam energy spread

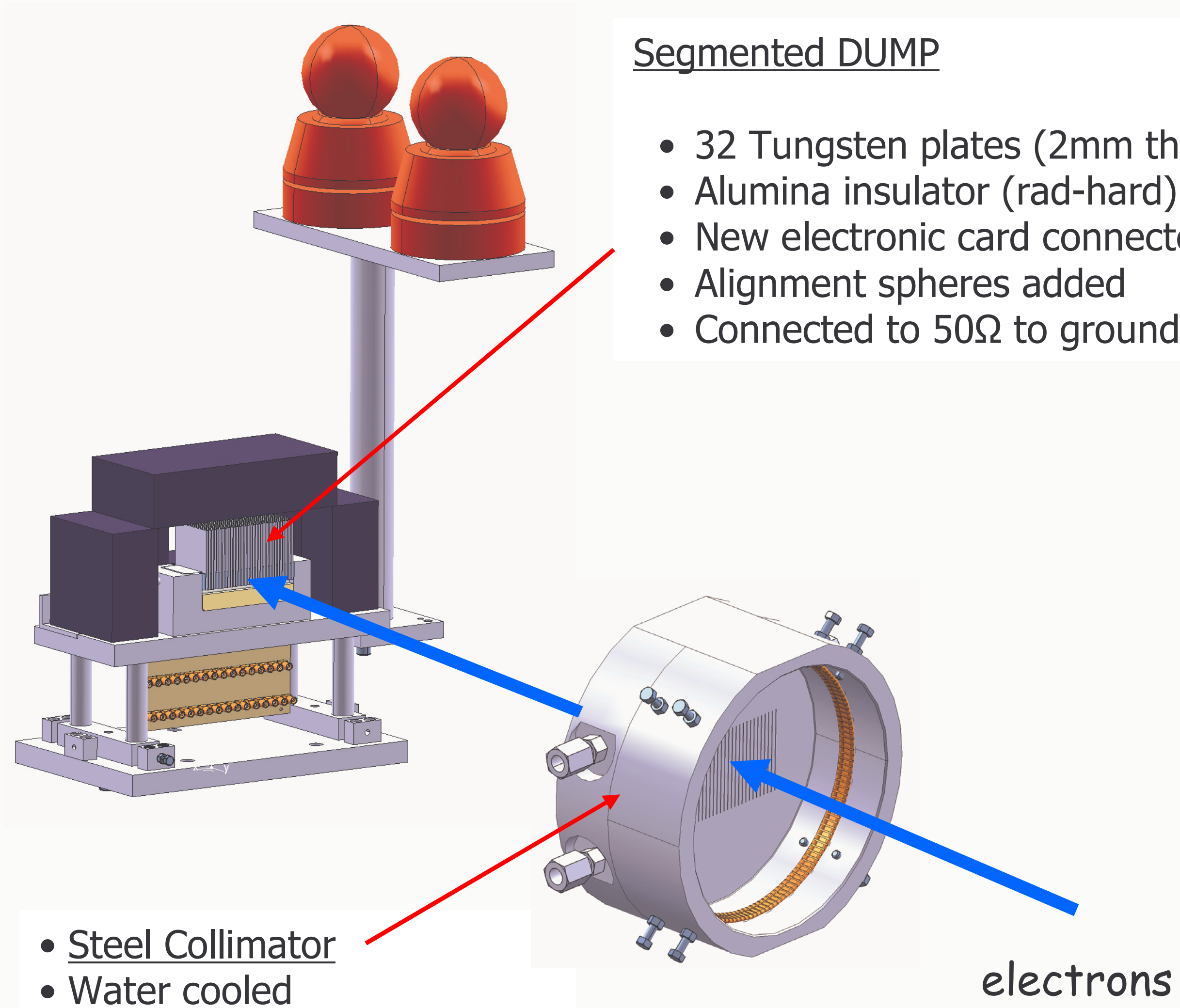




- Bandwidth limited (parasitic noise)
- Destructive method (long term reliability)
- Non-radiation hard insulator

T. Lefevre

Seg. Dump: New Layout



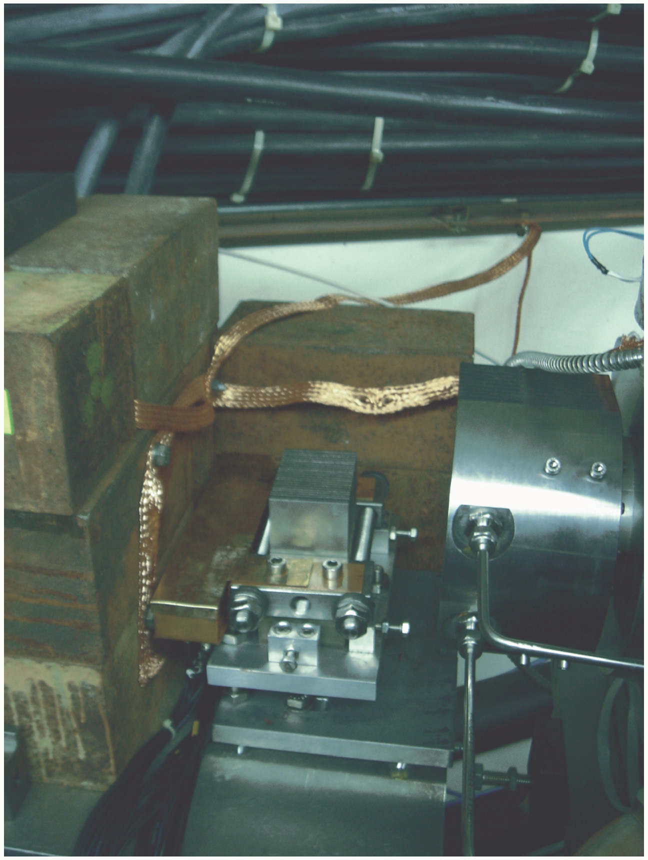
Segmented DUMP

- 32 Tungsten plates (2mm thick) spaced by ~ 1mm
- Alumina insulator (rad-hard)
- New electronic card connected to dump segments
- Alignment spheres added
- Connected to 50Ω to ground

- Steel Collimator
- Water cooled
- Mounted on the beam tube
- 32 vertical slits 400μm thick

T. Lefevre

Seg. Dump: New Installation, G. 4



Ready for this run.

T. Lefevre

Conclusion

- Transverse profile monitors can be designed for a wide range of specifications,
- Beam halo monitoring showed promising results,
- Streak camera proved powerful tool for longitudinal beam profile measurements,
- Segmented monitors in spectrometer lines now finalized.