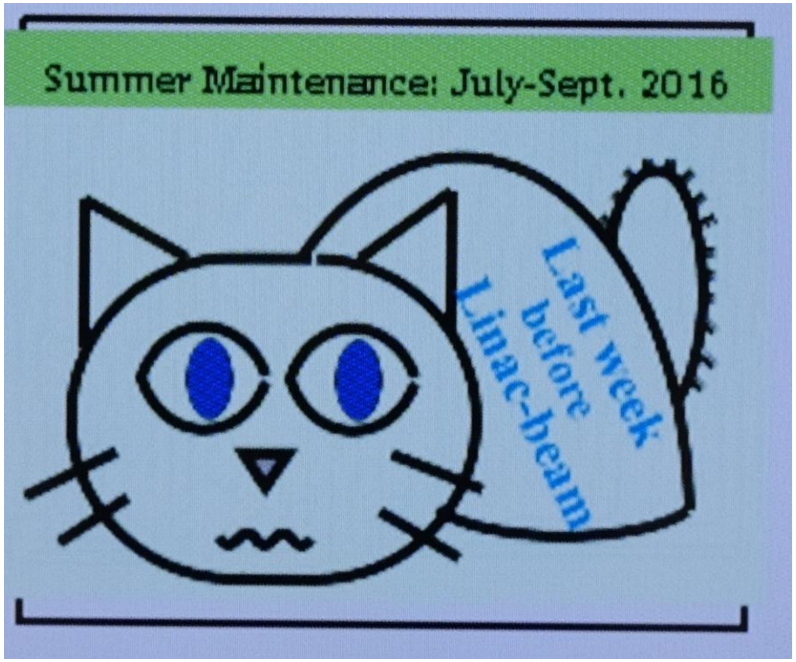
About GSI, thin target thermal simulations and Ionization Profile Monitors



Mariusz Sapinski, GSI

J-PARC seminar

October 12, 2016

Outlook

I will speak a bit about 3 different subjects:

1. GSI and machine data
    - GSI and FAIR project
    - Archiving and analysing machine data
    - Simple page1
2. Thermal simulations of thin targets
3. Ionization Profile Monitors – simulation community

GSI now

Main components:

1. Ion Sources

2. UNILAC (1975)

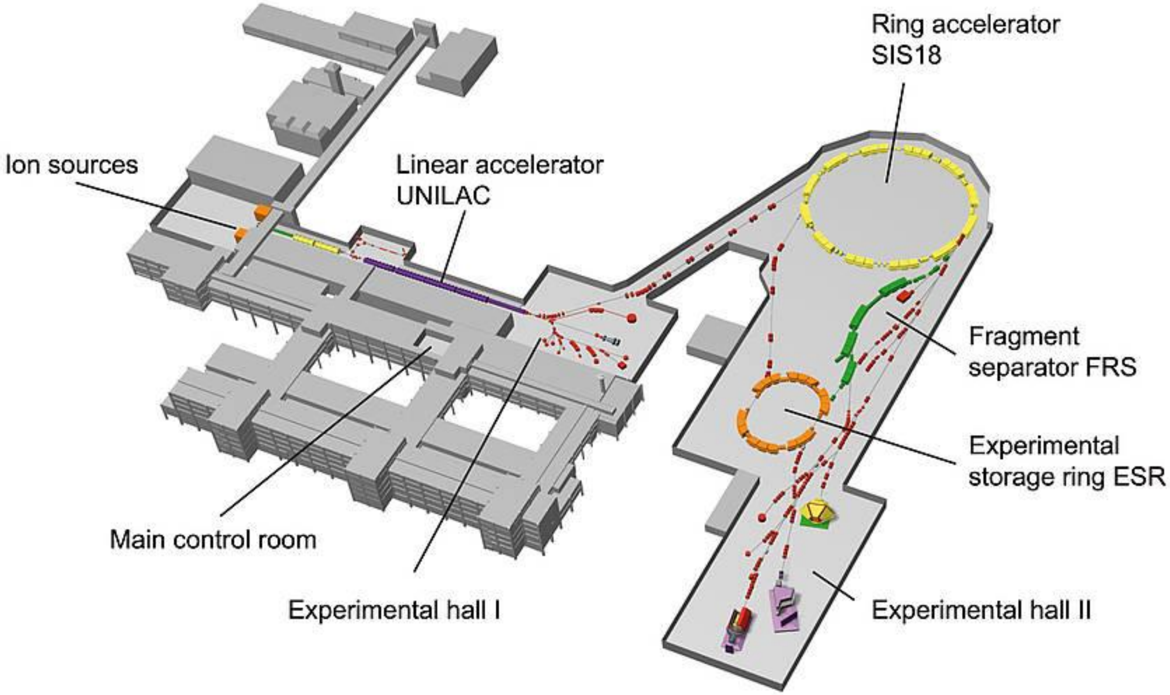
3. SIS-18

4. HEST

5. ESR (experiment)

6. CryRing (starting soon)

Currently: 2-year shutdown period.



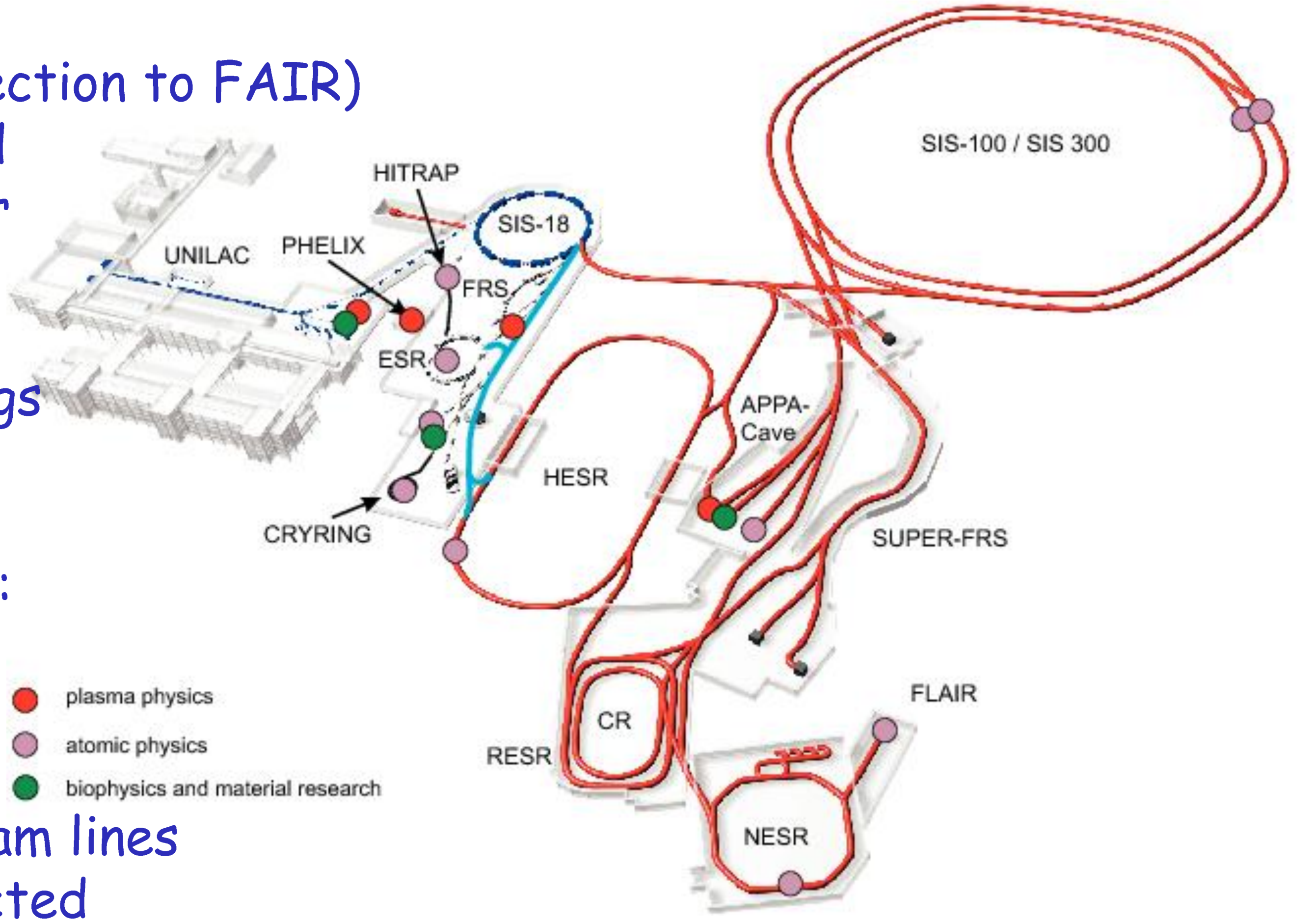
GSI now

Inside UNILAC Alvarez tank, (108 MHz), design optimized for U^{28+}

Accelerator complex growing by factor ~4

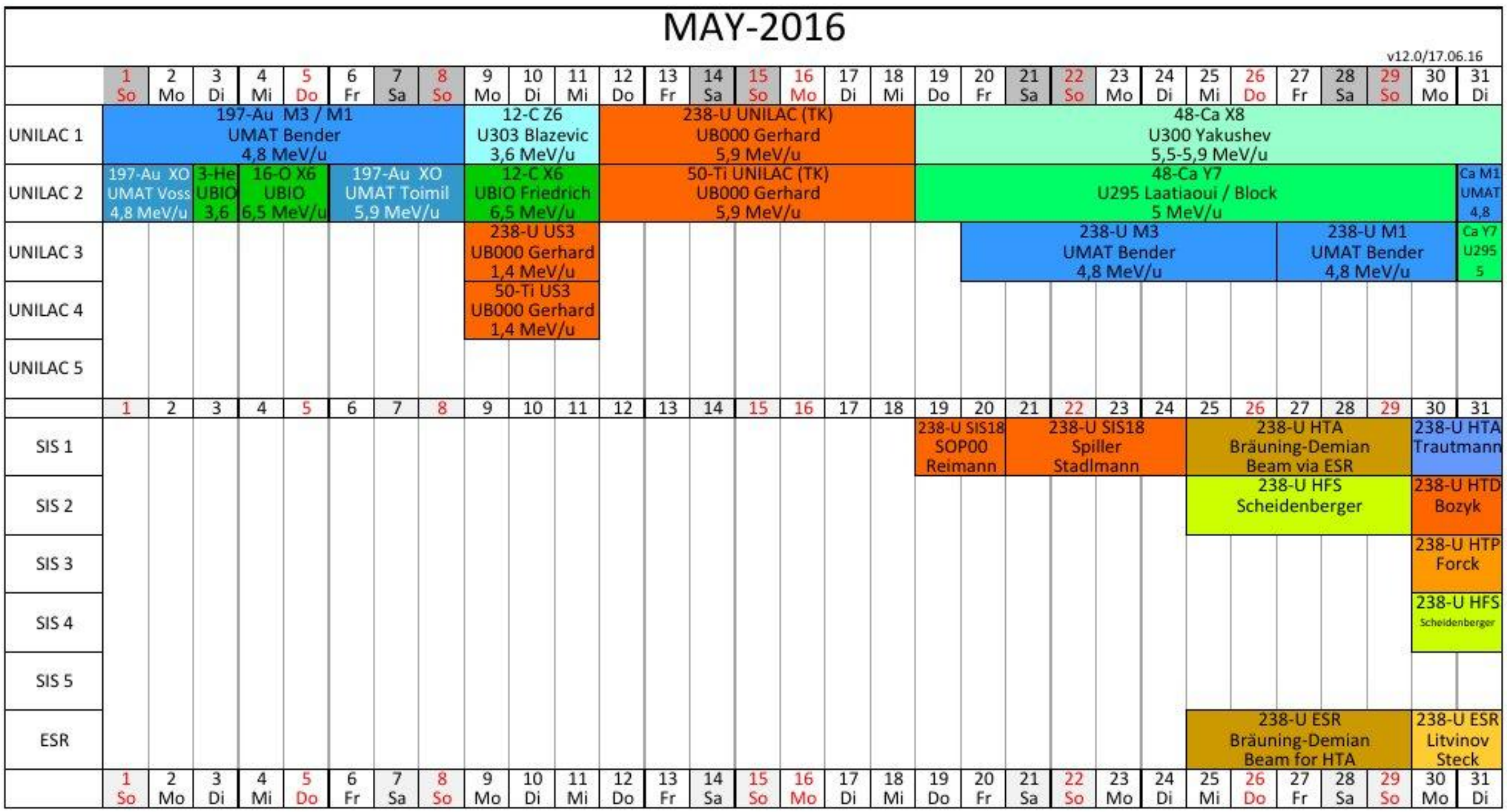
Status:

- GaF (GSI connection to FAIR) project started
- Calls for tender for SIS-100 excavation and tunnel + buildings construction works issued.
- Expected start: mid-2017
- Total 5 new machines and a few km of beam lines will be constructed



GSI-beamtime 2016

- 4-months of beam time: April 25 – July 21
- Example: May



GSI – machine data

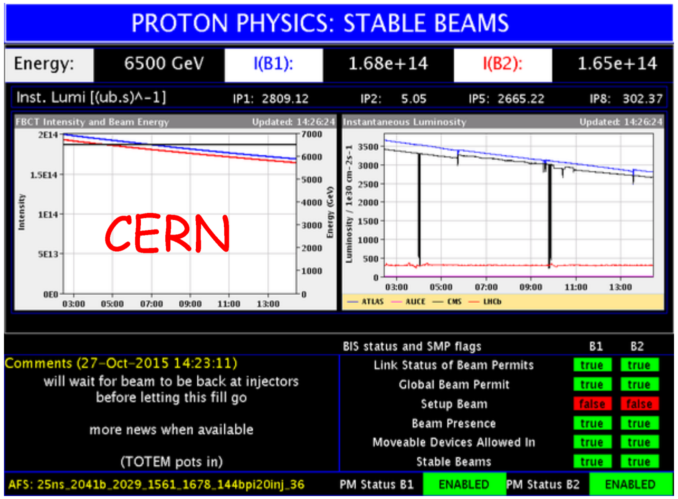
	Archived	Not archived	Remarks
Sources	Magnets, extraction voltages, etc...		Special format, one file per day per 3 sources
UNILAC	Magnets, RF (**machine settings**), intensity (1 shot every 100000)	Intensity, transverse profile, pulse shape	Settings are logged every hour + on demand
SIS18	High-level setting logged on change, Intensity (expert logging)	Transverse profiles, bunch shape, position, tune, beam loss	
HEST	Magnets (machine settings)	Intensity, transverse profiles, spill structure	As for UNILAC

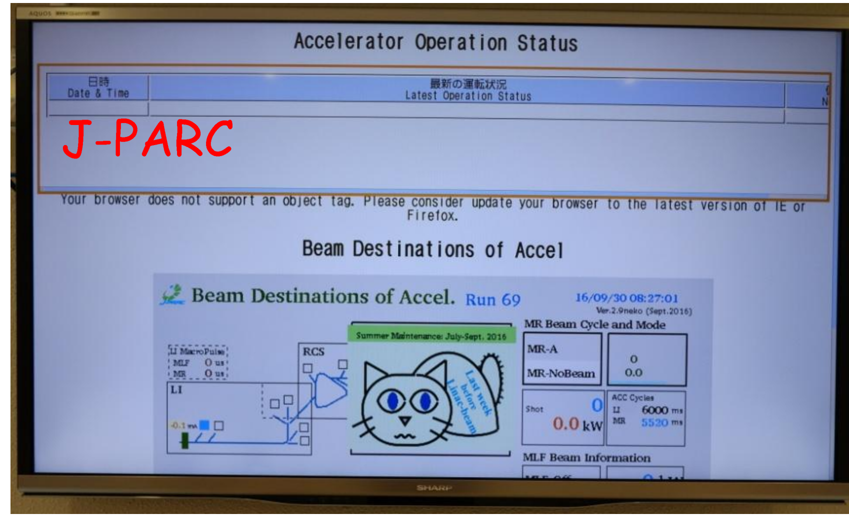
A lot of data are saved for machine experiments, but not archived regularly (eg. BPM raw data, beam profiles, etc.)

Machine data

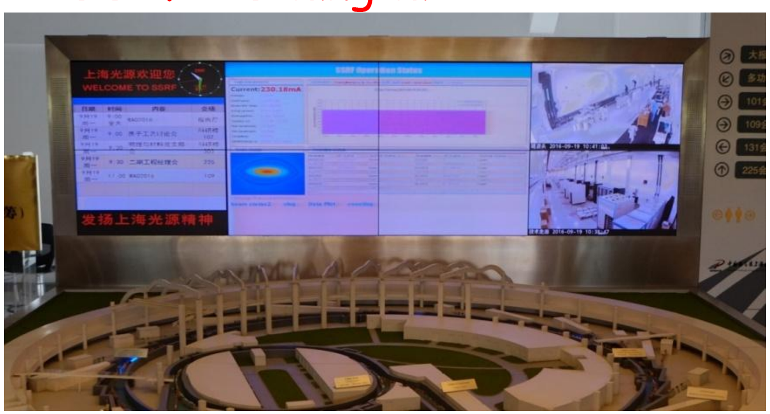
1. CERN central logging (archiving) service:
    - for LEP since 1992
    - for LHC (and the rest of the complex) since 2004
    - Only in 2013 about 1 million signals archived – total: 50 TB.
    - Very intense use of the data, online and offline
2. Other facilities also have large scale archiving (eg. Diamond, UK)
    - General Data Acquisition concept, 100,000 signals
3. J-PARC: EPICS-based system (how many channels?)
4. GSI – no central data archiving service.

Page 1 (I)





SSRF - Shanghai



GSI....

Page 1 (II)

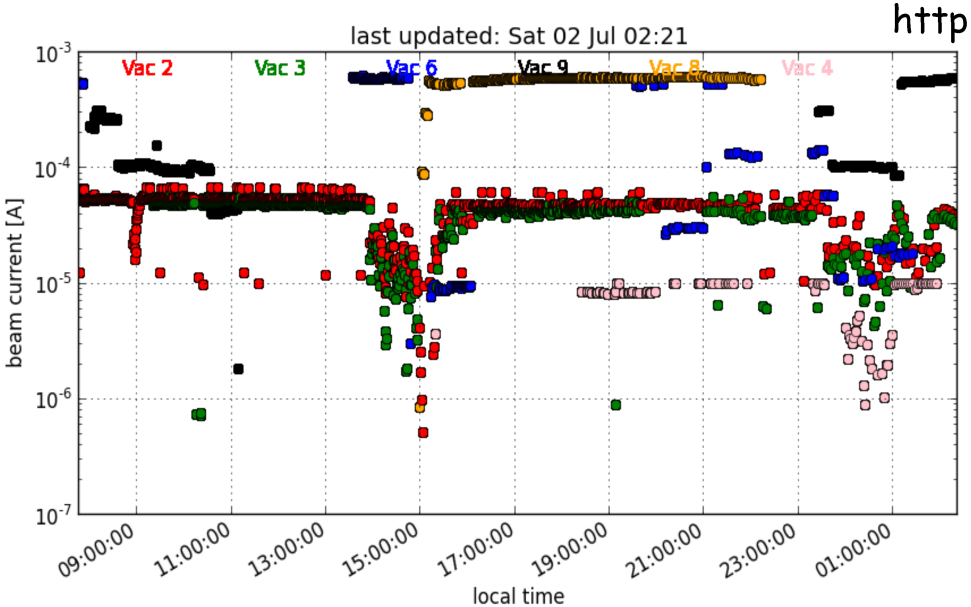
3. GSI: page 1 is planned (for 2018), but not existing.

Operation status is available in Electronic Logbook, but:

- not public
- difficult to access from outside GSI, so:

Using python it was easy to make a simple, 'private' page 1, showing evolution of various beams in UNILAC and SIS-18.

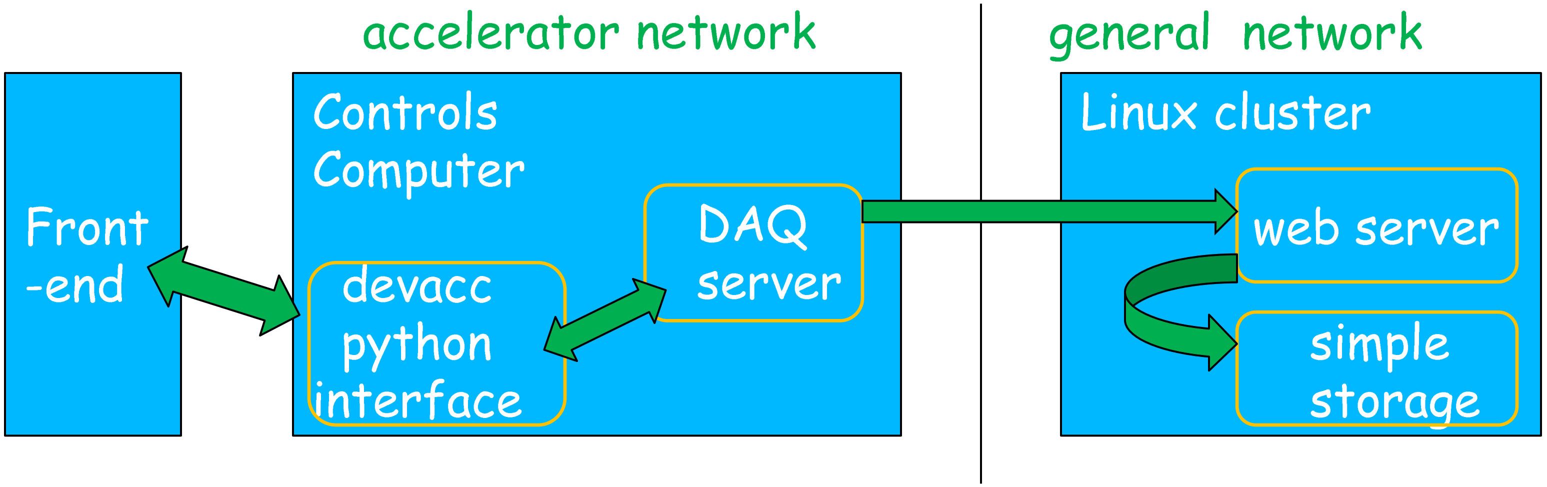
http://web-docs.gsi.de/~sapinski/page1.html



VA2: ^{48}Ca to UY7
VA3: ^{48}Ca to UX0
VA4: ^{48}Ca to UM1
VA5: ^{48}Ca to UN7
VA6,7,8,9:
^{15}CH->C to SIS-18

Data archiving for 2016 (I)

1. Schematics (for Beam Current Transformers):

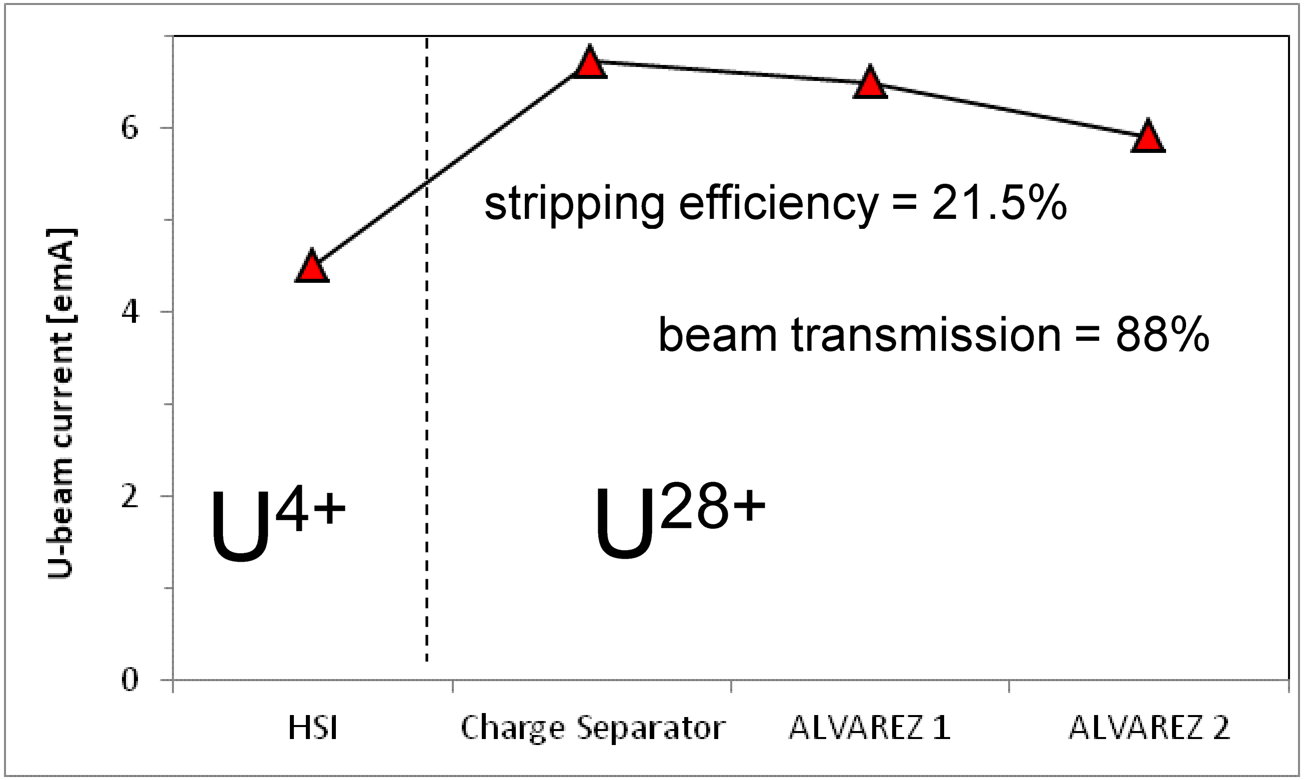


2. Outcome:

- about 2 million records in 3.5 months
- ~ two users (+ me):
  - Beam-time coordinator (sometimes).
  - Experimentator who later looked for good data.

Data archiving for 2016 (II)

September: analysis of July 18th data



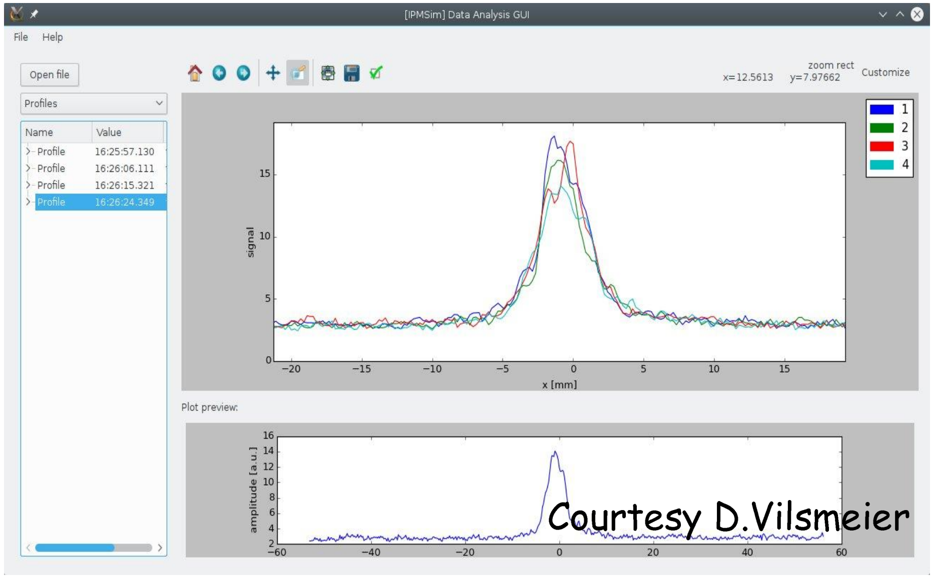
Courtesy W. Barth

Test of ion stripping using hydrogen gas stripper.

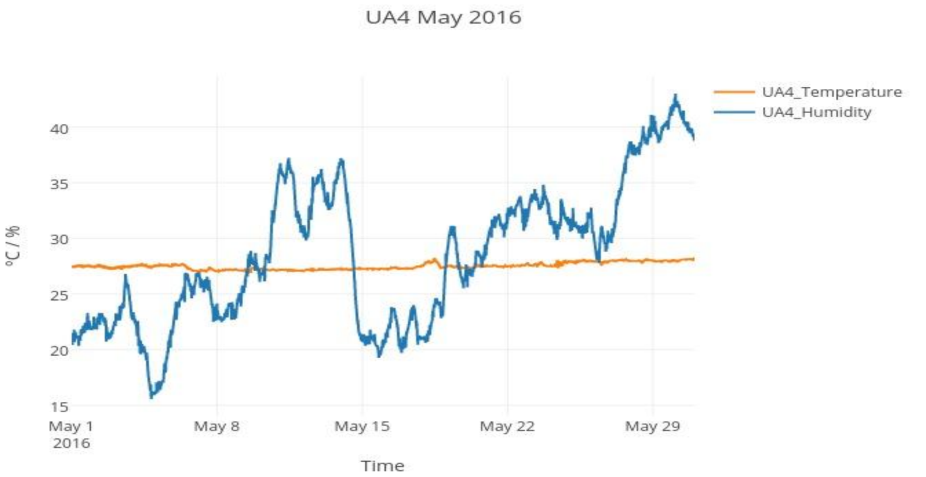
Data archiving for 2016 (III)

Other data:

- ~15,000 beam profiles using Beam Fluorescence Monitor
- ~200,000 records of tunnel temperature and humidity (sensors based on Raspberry Pi, *hobby project* of R.Haseitl)
- ~ 10,000 beam profiles using IPMs on SIS18
- Some BPM data
- A copy of machine setting data (saved by control system)
- All together: ~50 GB of data

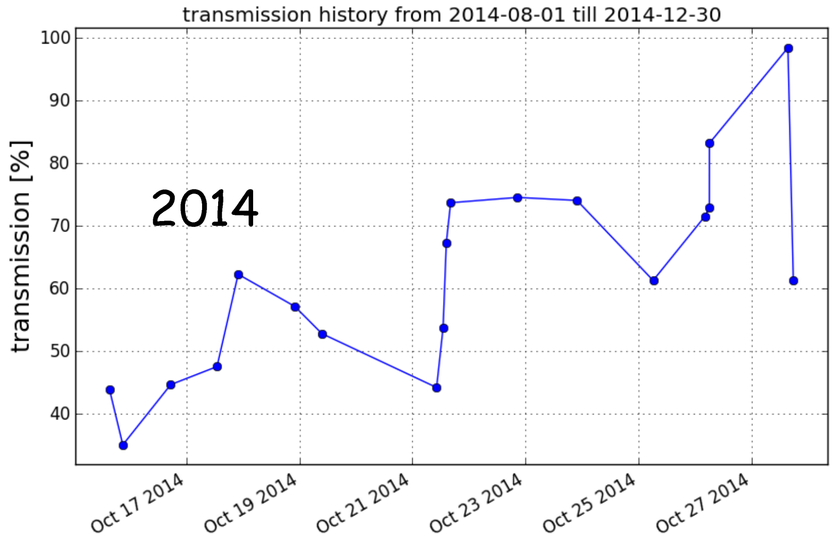


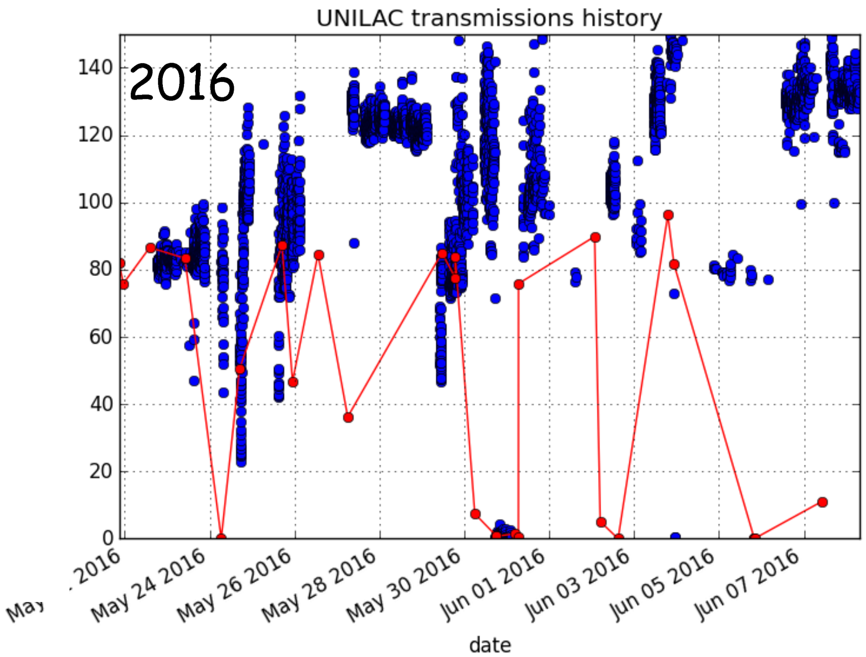
Courtesy D.Vilsmeier



Analyzing UNILAC setting of one of the most often used beams: ^{238}U to SIS18.

transmission evolution (GUS2DT5-GUA4DT5)





remarks:

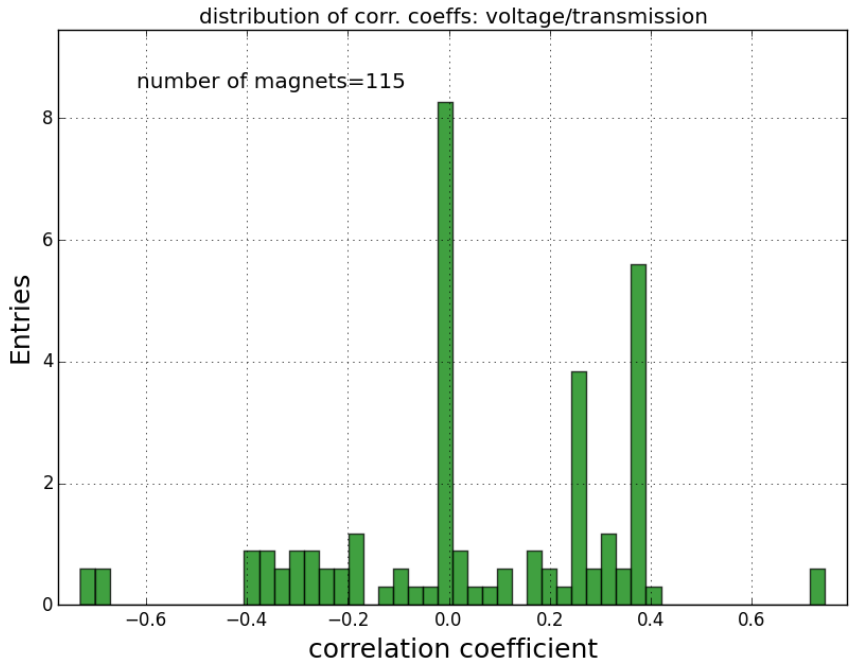
- in 2016 we have MUCH better data

Data analysis (II)

Analyzing UNILAC setting of one of the most often used beams: ^{238}U to SIS18.

Correlations between magnet field and transmission

example of study



Magnet	Corr.coeff
GUL4QT12	-0.725
GUL4QT13	0.719
GUL5QD21	0.744
GUL5QD22	-0.697
GUL5QT31	-0.729
GUL5QT32	-0.672

Interestingly magnets at the beginning of linac seem to have the largest impact on transmission downstream.

Data analysis (III)

There are various approaches to machine data analysis.

Some basic analysis can be done using GUIs (eg. CERN timber),

but for many tasks some kind of programing is needed.

python GSI Accelerator Data Analysis (pyGADA)

1. (another one) set of python modules to look at machine data.
2. Modular staructure, easy to use.
3. Continously in development (data-mining techniques).
4. Intended for wider use (not only personal).
5. Intended to be used in the future

   (with new, professional archiving system).

FAIR Data Archiving System

1. New system, recently specified and send to external company for detailed evaluation and later implementation.

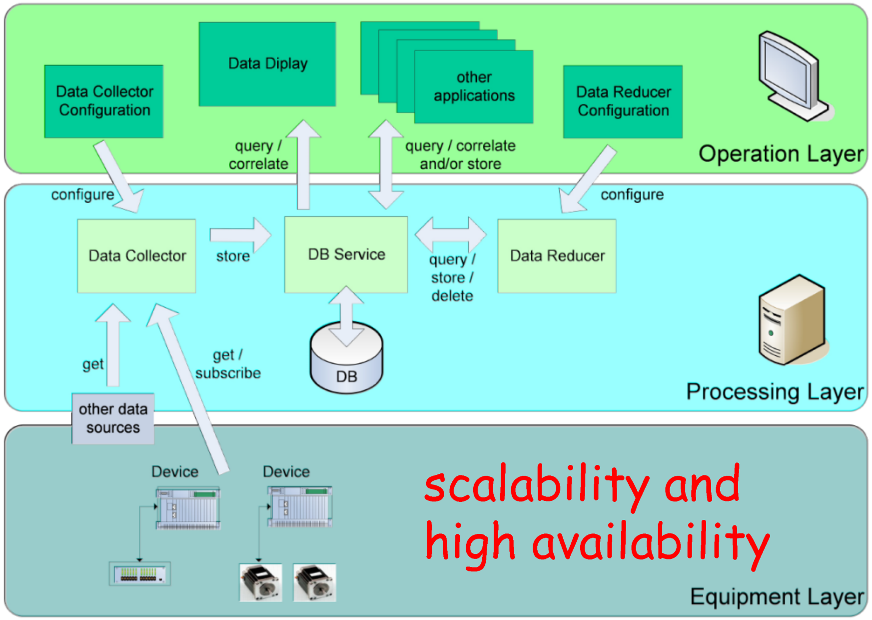


Figure 1: System Overview

2. Prototype should be ready for 2018 run.

(Apache Cassandra?)

Parameter	Value
Amount of monitorable devices	2032
Total amount of monitorable variables	~50000
Incoming data load	~10 MB/s
Required data buffer (short time storage)	~5 TB/week
Required data storage (long term storage)*	5 – 10 TB/year

Conclusions (part 1)

1. Machine data archiving is being developed for FAIR/GSI.

   Crucial for commissioning of large, complex machines!

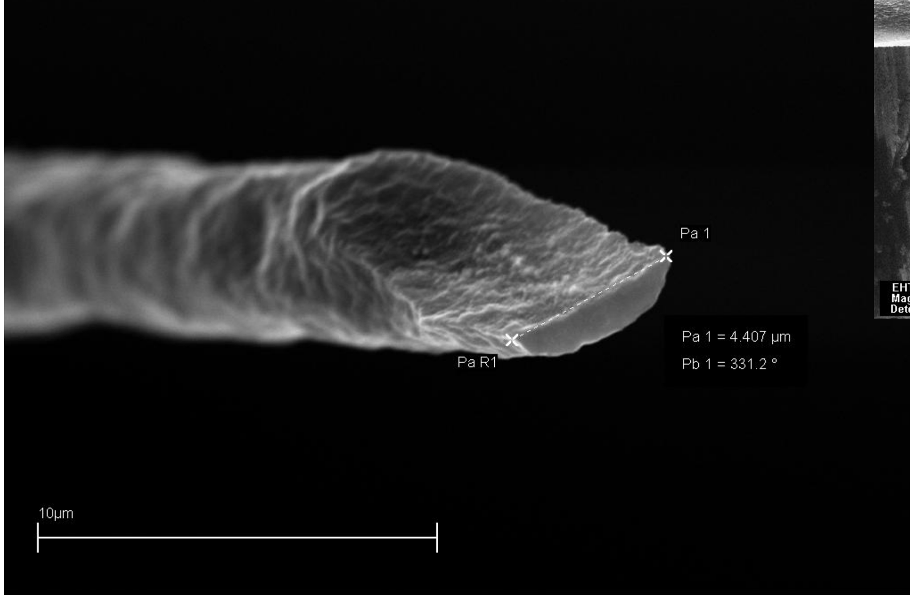
2. An attempt to archive some data in 2016 – partial success.
3. A set of python analysis modules prepared.
4. In the future some data analysis should be done by operators, so that they can better understand *their* machine.
5. page1 is an important operational tool – for 2018.

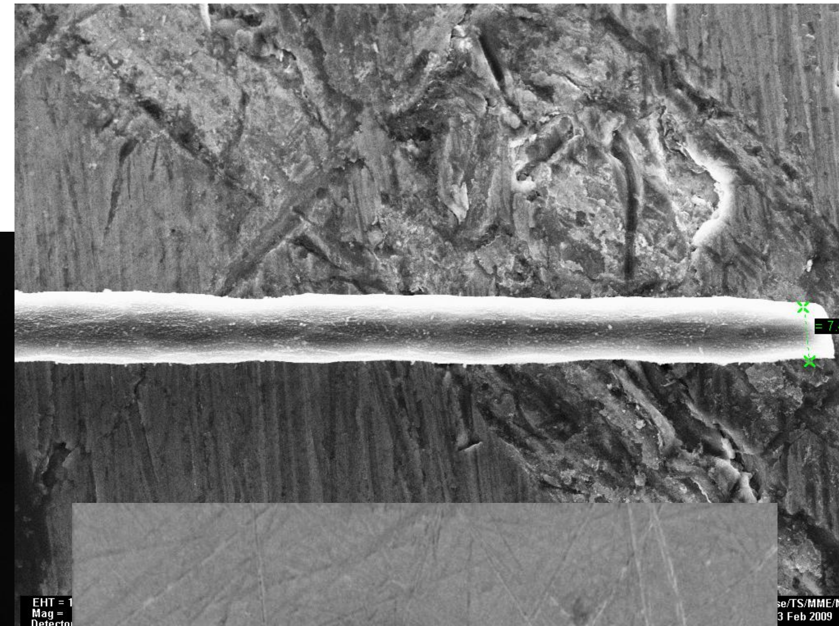
Heat transfer in thin targets

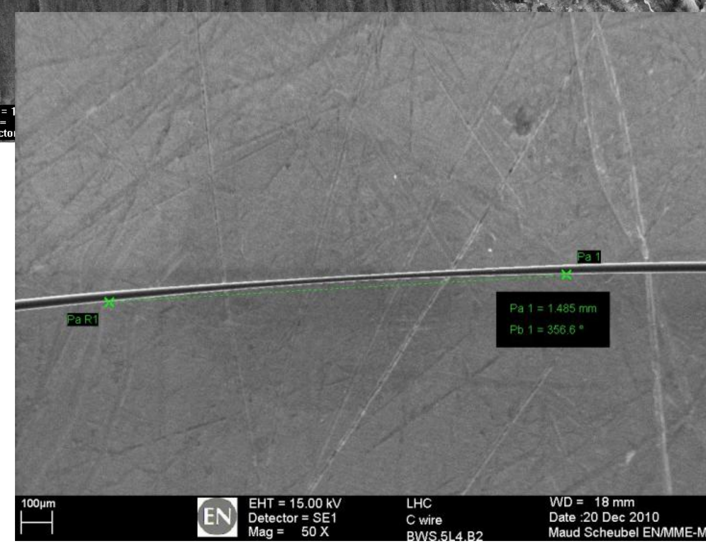
Heat transfer in thin targets

<u>Origin of the problem:</u>

Up to what beam intensity can we use wire scanners in LHC and SPS?







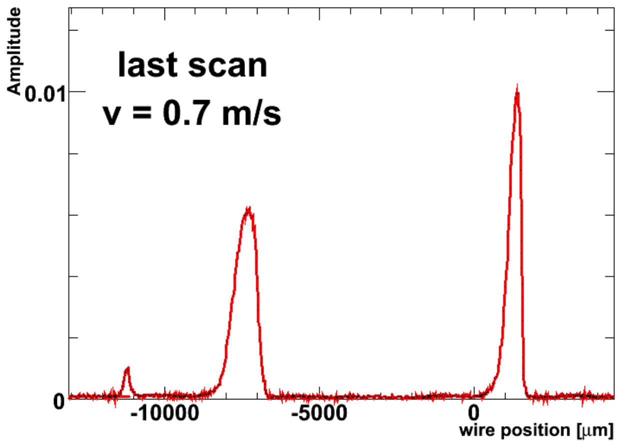
Wire breakage experiments

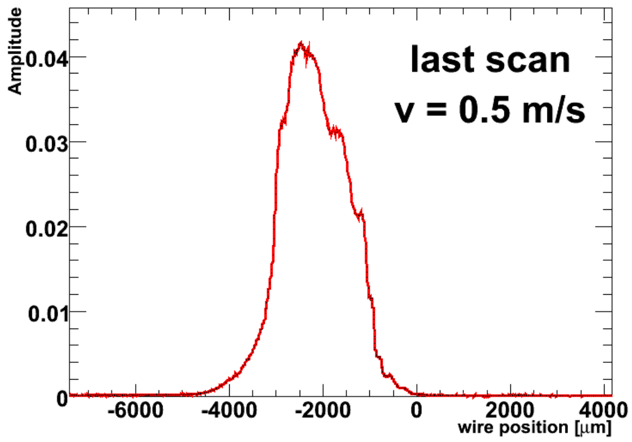
October 23rd, 2008, SPS beam

Special long cycle, coasting beam (reduce RF effect)

2 fibers broken

N_{ch}	σ_l [mm]	σ_t [mm]	E_{beam} [GeV]	v_{wire} [cm/s]
$2.4 \cdot 10^{13}$	0.57	0.73	400	50
$2.2 \cdot 10^{13}$	0.73	0.57	400	70





Heat transfer in thin targets

Questions:

1. What is the damage mechanism?
2. What is the maximum intensity?
3. How to improve?

CERN flying wire systems:

1. Wire 32 μm, imported from Los Alamos in 1980s'
   (no material data sheet)
2. In SPS – rotational scanners up to 10 m/s
3. In LHC – linear scanners 1 m/s

GSI:

No flying wires, but SEM grids

Heat transfer model

Heat transfer model:

beam

heat capacity

radiative cooling

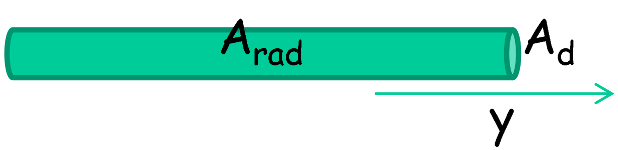
conductive cooling

thermionic cooling

reheating from compensation current

sublimation cooling

$$
\begin{aligned}
E_{dep}\frac{\Delta N_{hits}}{\Delta t} &= \rho_C V c_p(T)\frac{\Delta T}{\Delta t} \\
&- A_{rad}\epsilon\sigma(T^4 - T^4_{amb}) - \lambda(T)A_d\frac{\Delta T}{\Delta y} \\
&- A_{rad}(\phi + \frac{2k_B T}{q_e})J_{th}(y) + C(y)\Delta R J^2_{th-tot} \\
&- H_{sub}\frac{\Delta n}{\Delta t}
\end{aligned}
$$



CERN AB-2008-030-BI

Sublimation rate is also simulated!

Heat transfer model

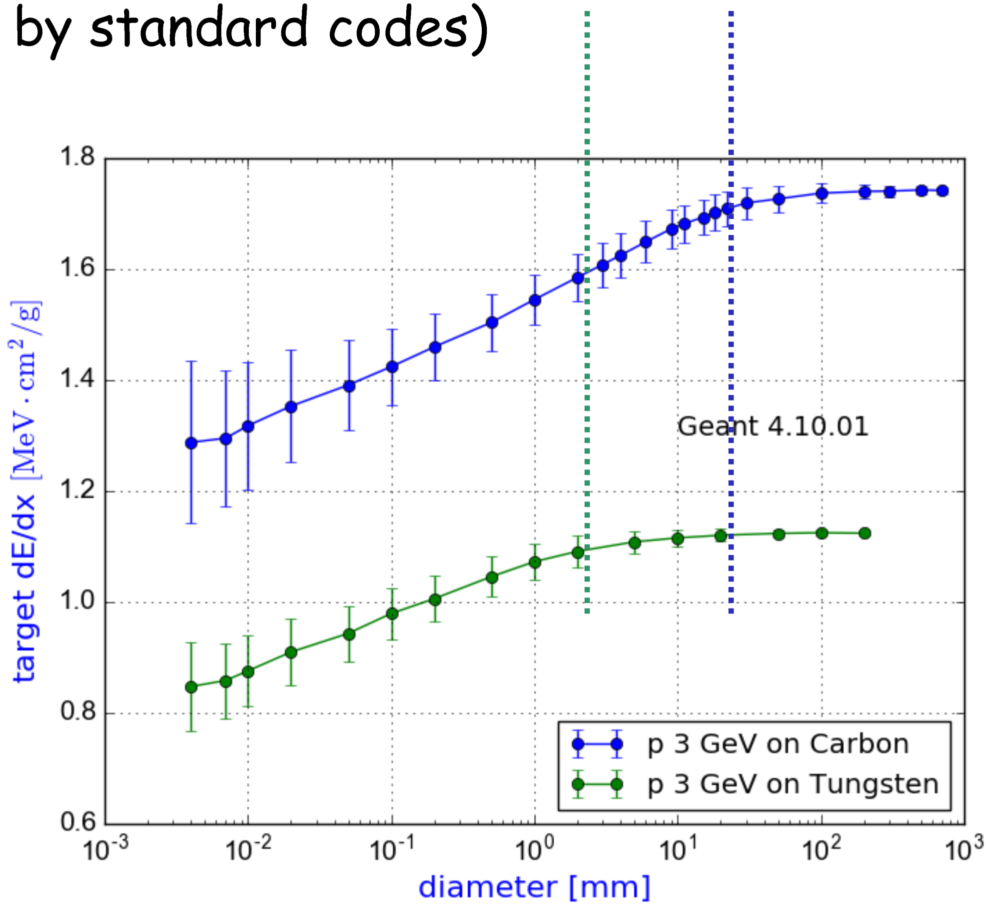
Heat transfer model:

1. Numerical solution necessary:
    - Initially a flat ROOT script created → now python (pyTT)
2. Several wire-damaging experiments:
    - *Carbon Fiber Damage in Particle Beam*, HB2010, CERN-BE-2011-03
    - *LHC magnet quench test with beam loss generated by wire scan* , IPAC11, WEPC173, CERN-ATS-2011-062
    - *Beam Interaction with Thin Materials: Heat Deposition, Cooling Phenomena and Damage Limits*, BIW12, CERN-ATS-2012-155
3. Other resources:
    - http://sapinski.web.cern.ch/sapinski/physics/thin/Wire.html
    - http://sapinski.web.cern.ch/sapinski/soft/pyTT/index.html

Beam heating

In thin targets the normal Landau deposited energy distribution (from Bethe-Bloch dE/dx) is altered:

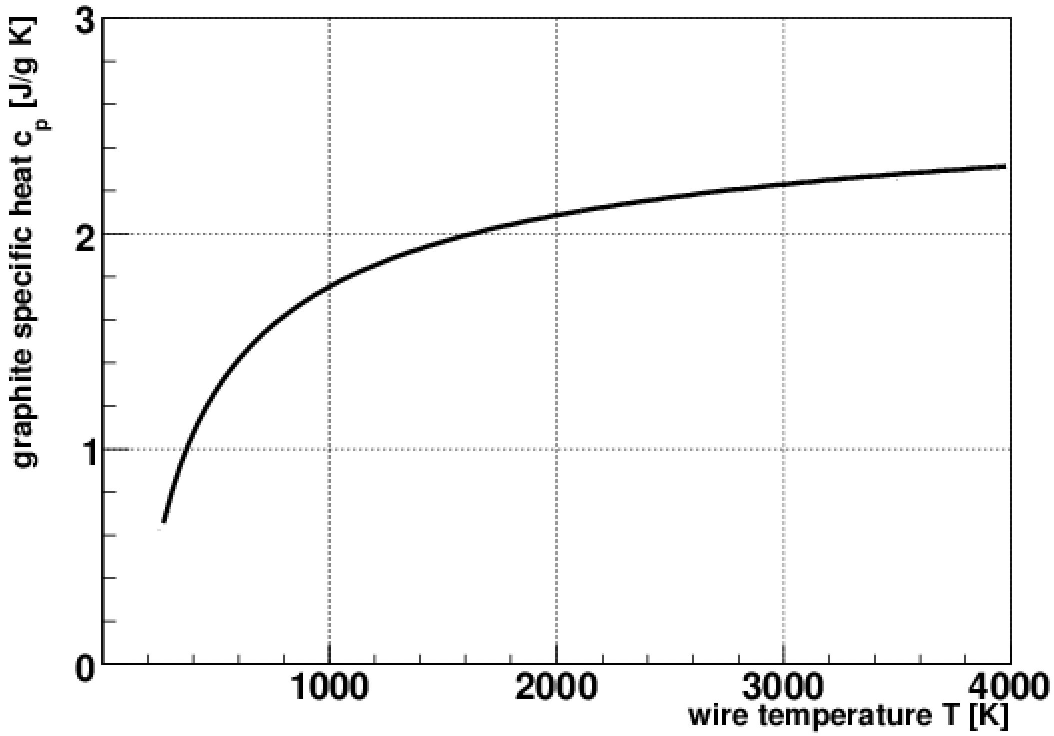
- Micrometer scale: significant fluctuations of energy deposit (usually not reproduced by standard codes)
- Up to mm scale: energy loss follows Bethe-Bloch, but energy deposit is affected by kick-off electrons



Specific heat

Specific heat as a function of temperature

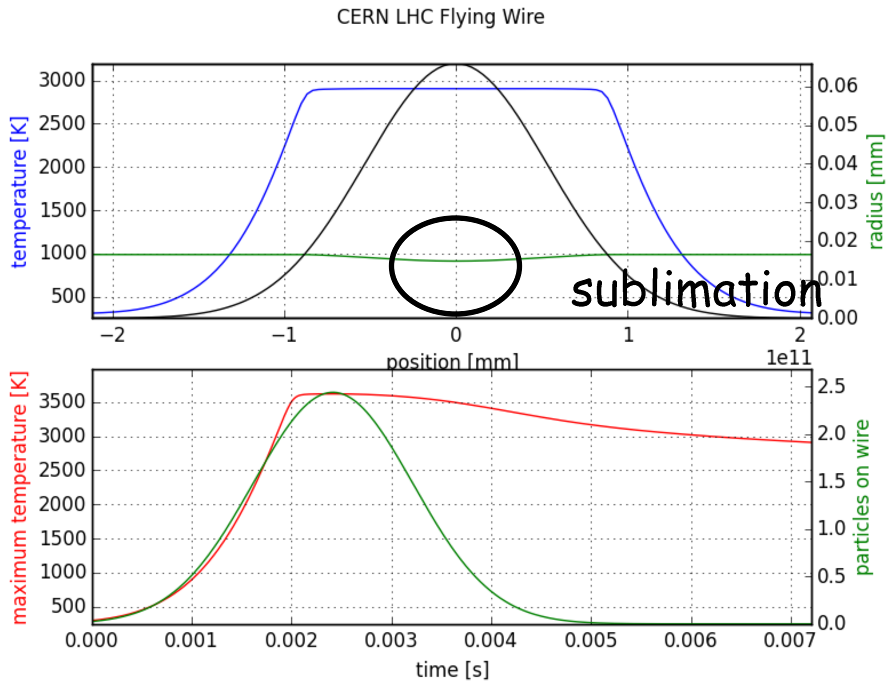
– important part of the model because heating is so fast that cooling processes are ineffective (up to ~ 3000 K maximum temperature defined by heat capacity)



Thermionic cooling

<u>Thermionic cooling is critical above ~3000 K.</u>

In case of carbon it *stabilizes* temperature at the point where slow sublimation of the material takes place.

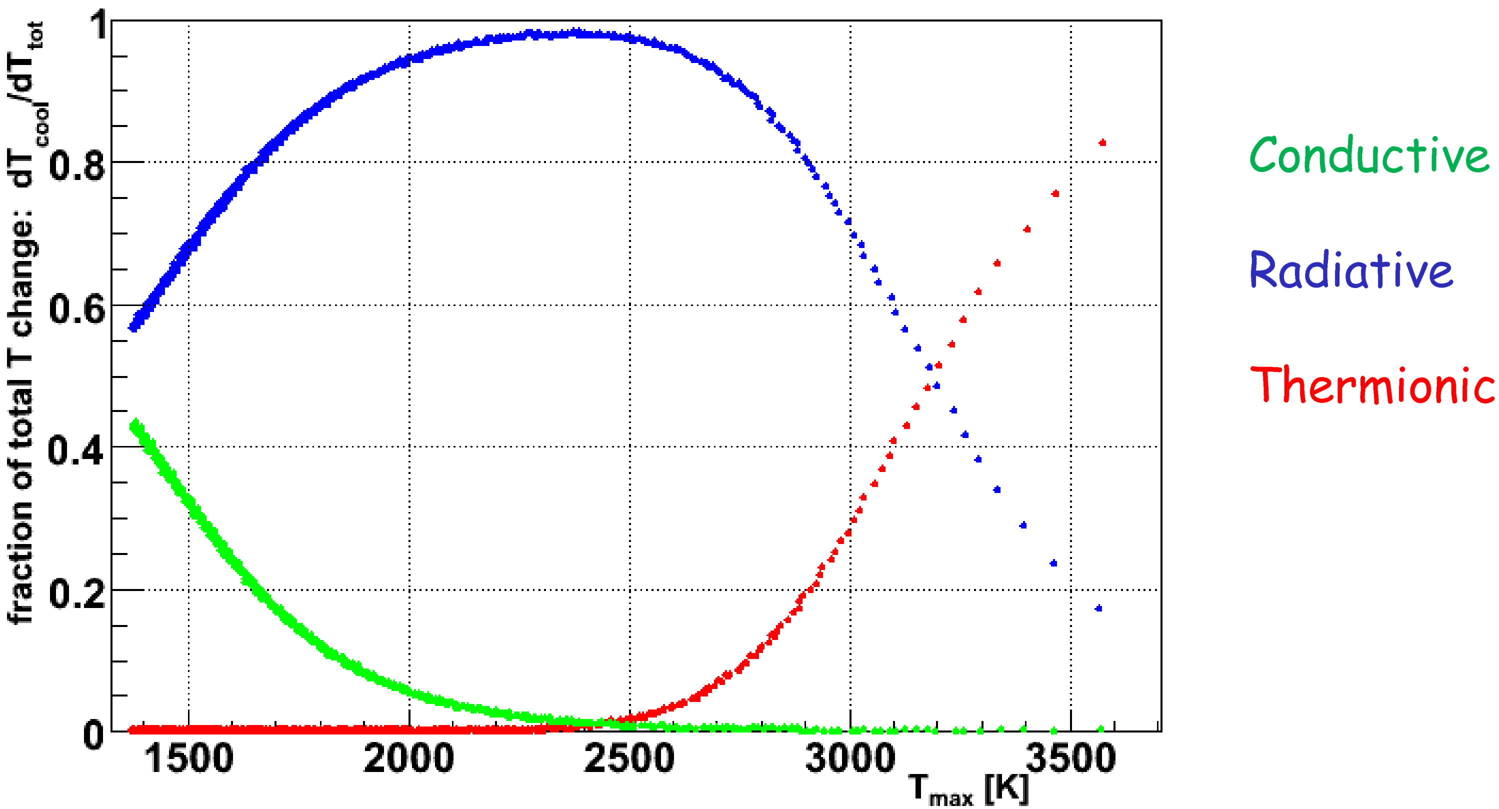


In LHC wire scanners operate in *controlled sublimation* mode.

Place for interesting optimization:

- Increase thermionic cooling by external field?
- Lower graphite work function by surface treatment?

Relative power of various coolings



Thermionic dominates at very high temperatures.

Case 1: MR flying wire at injection

σ_x= 8.8 mm

σ_y= 8.9 mm

E_{beam}=3 GeV

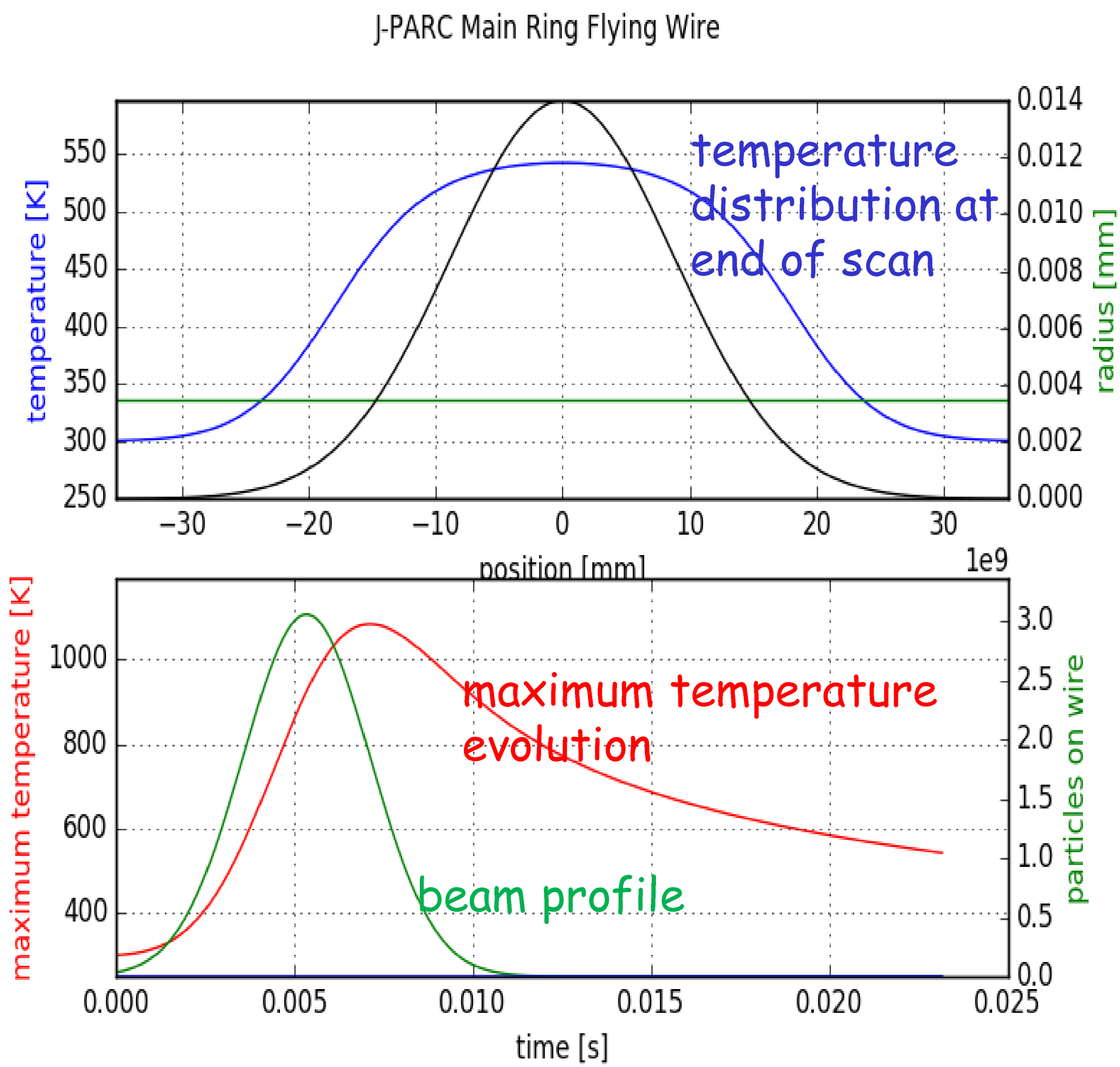
N= $3.48 \cdot 10^{13}$ p

τ_{rev}= 5 µs

d_{wire}= 7 µm

v_{wire}= 5 m/s

No sublimation



Case 2: MR flying wire at 30 GeV

σ_x= 3.09 mm

σ_y= 3.12 mm

E_{beam}=30 GeV

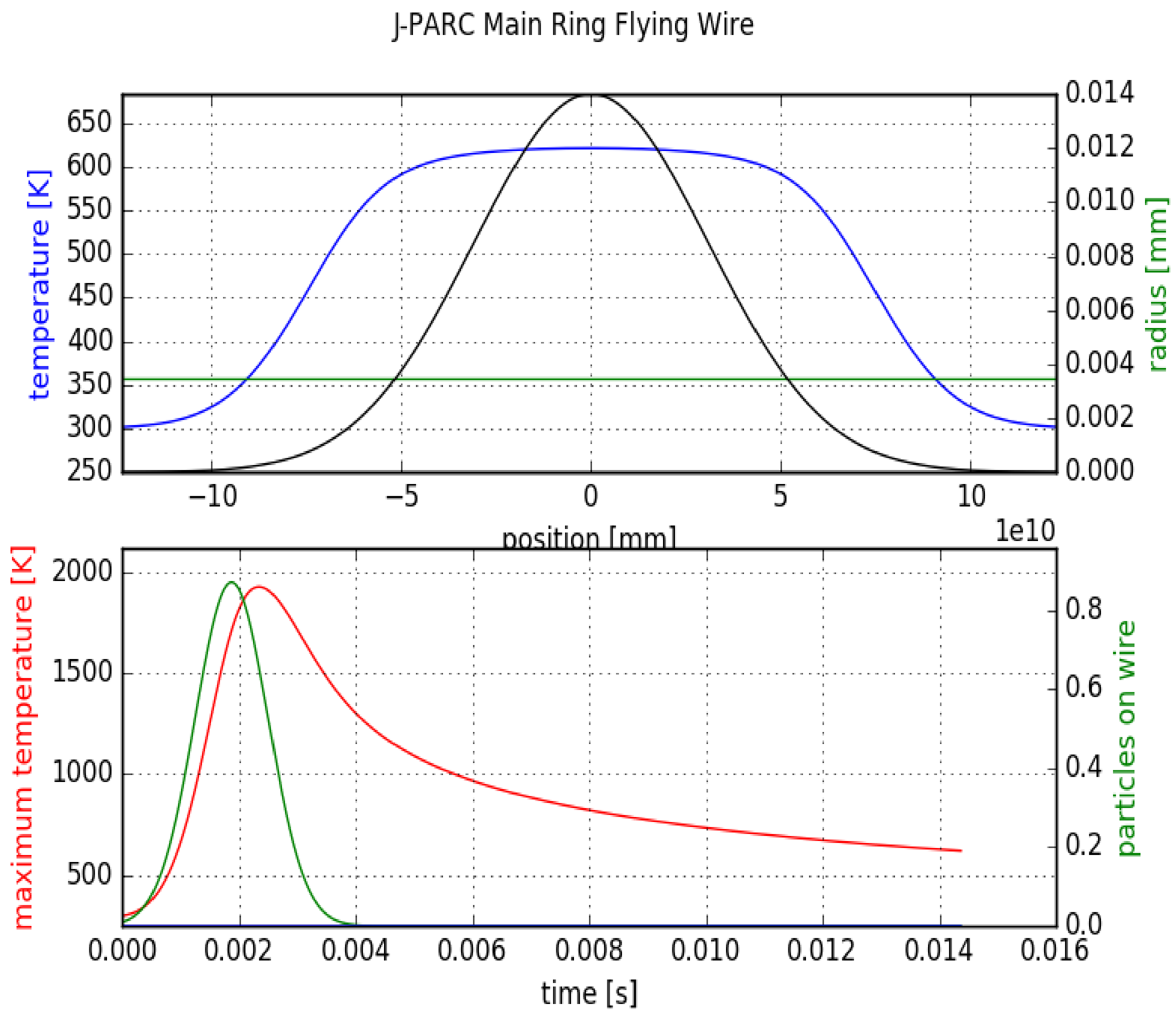
N= $3.48 \cdot 10^{13}$ p

τ_{rev}= 5 µs

d_{wire}= 7 µm

v_{wire}= 5 m/s

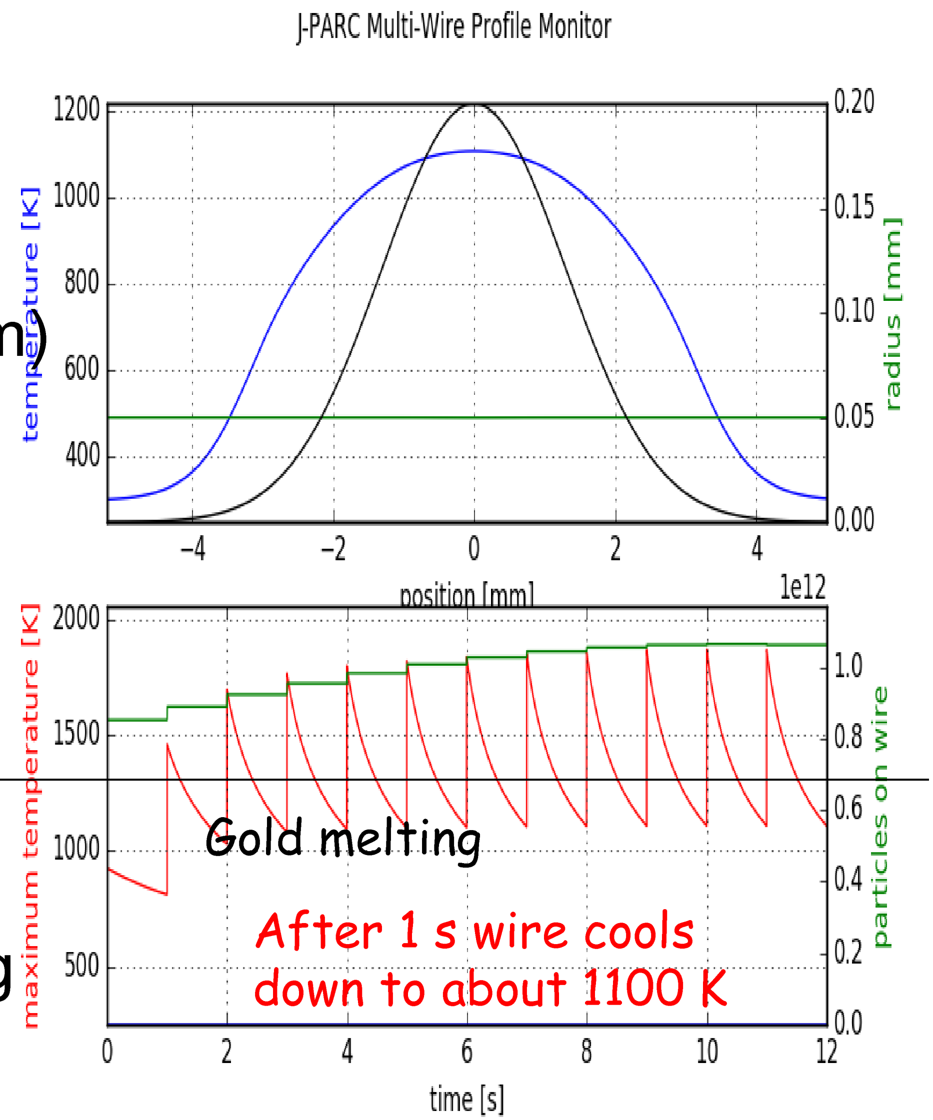
Safe as well, according to this model at CERN we reach 3500 K!



Case 3: MWPM at linac extraction

σ_x= 1.3 mm
σ_y= 1.5 mm
E_{beam}=400 MeV
N= $4 \cdot 10^{13}$ p (half of maximum)
One pulse every 1 s
Simulation: (-1 σ_y , 0.1 σ_y)
d_{wire}= 100 µm, W
Au on surface (why?)
v_{wire}= 0.1 mm step every second

Remarks: conductive cooling off, simulation started at -1 mm from the beam center

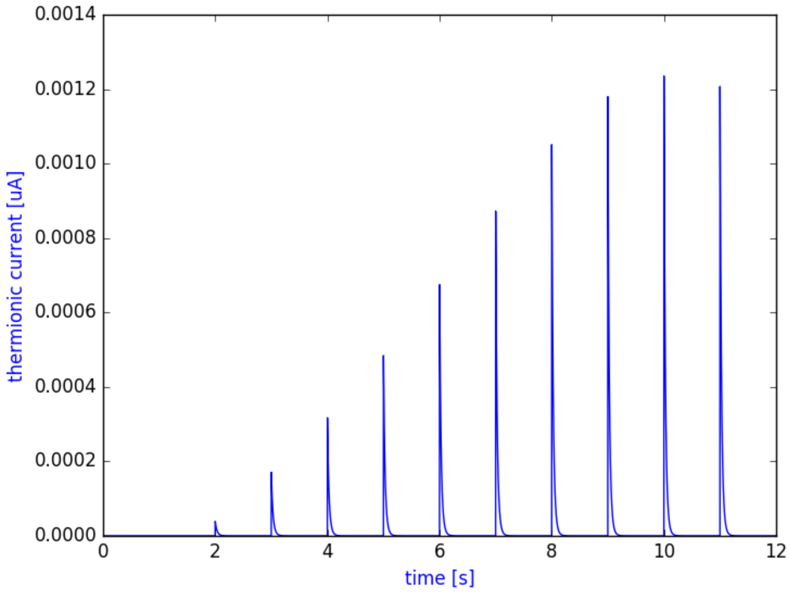


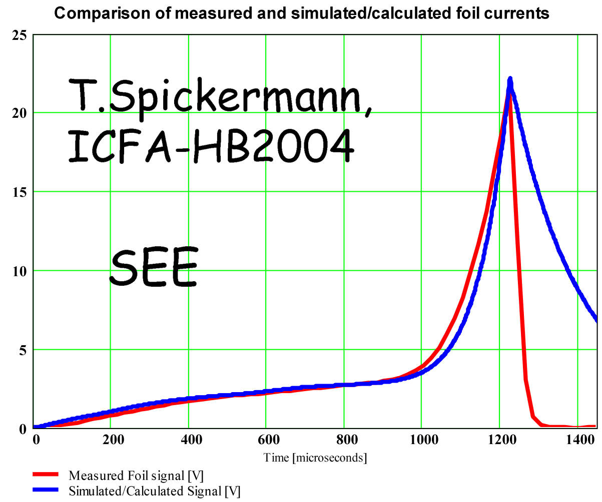
Safe intensity: < $2 \cdot 10^{13}$ p.

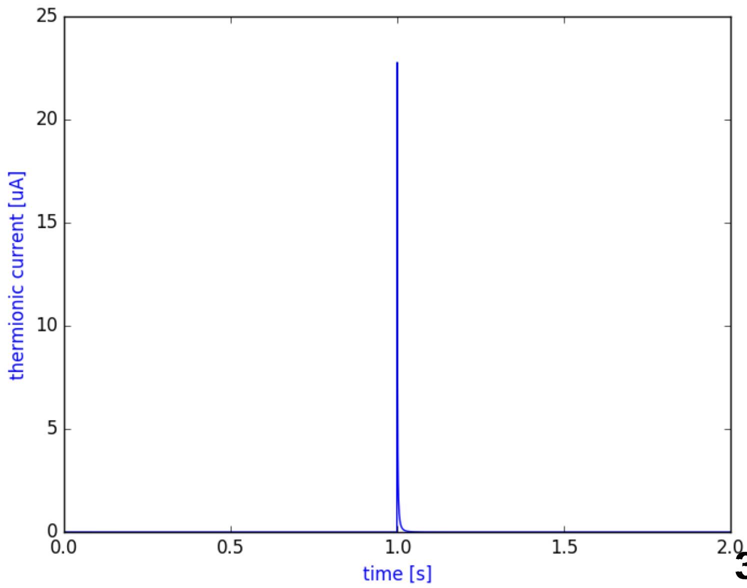
Thermionic current:

- At half intensity thermionic current reaches 1.2 nA.
- At full intensity temperature

should reach 2500 K and thermionic current 20 µA!

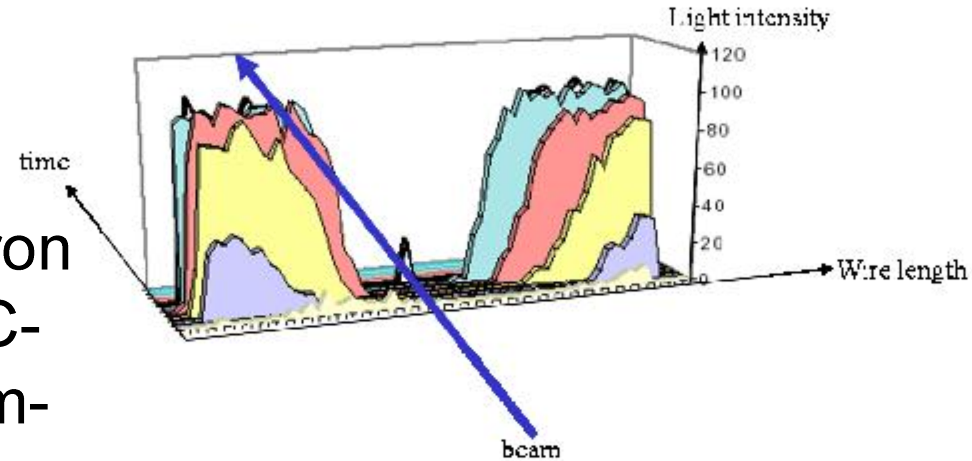






RF-heating

- Interest in RF-heating was expressed.
- CERN experience: wire breakage in LEP (electron beam) and in SPS (LHC-type beam) due to beam-wire coupling.
- Remedy: installation of ferrites to dump RF power



In SPS with LHC beam: CERN-AB-2003-067-BI

- Measurements with antenna and Spectrum Analyzer:

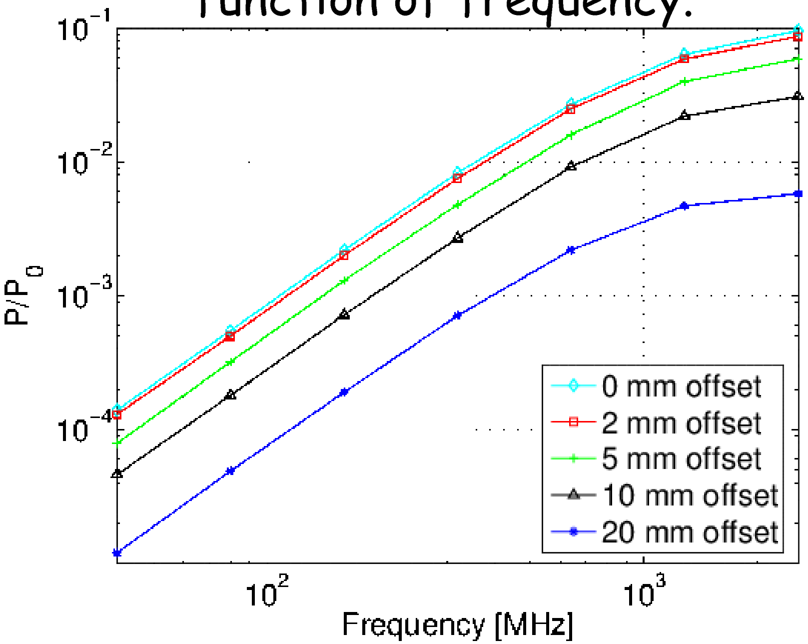
F.Roncarolo et al., Proceedings of DIPAC 2003

- Wire Scanner tank acts as a cavity with high impedance close to beam spectrum maximum.

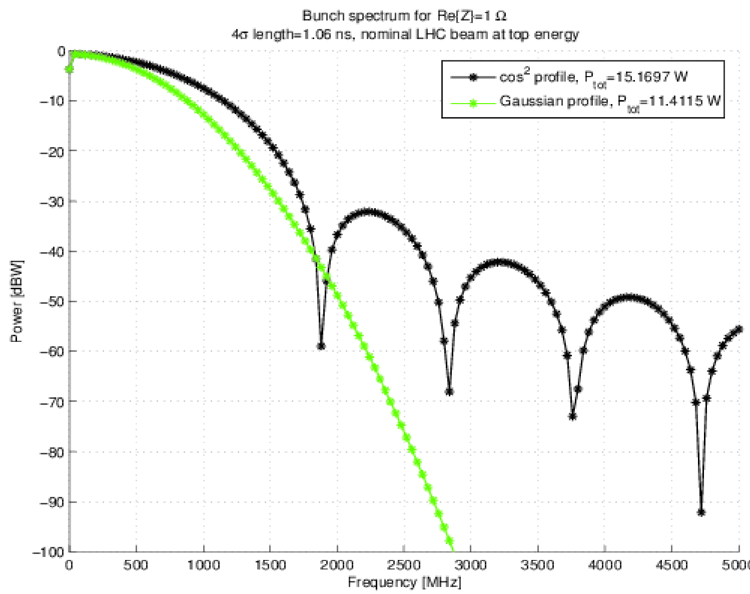
RF-heating

- Heating due to RF coupling affects also LHC beams (CERN-AB-2003-067-BI)
- The effect can be calculated using Ansoft HFSS.

Total relative loss as a function of frequency.



Power distribution



M. S., T. Kroyer, "Operational limits of wire scanners on LHC beam", BIW2008

Conclusions (part 2)

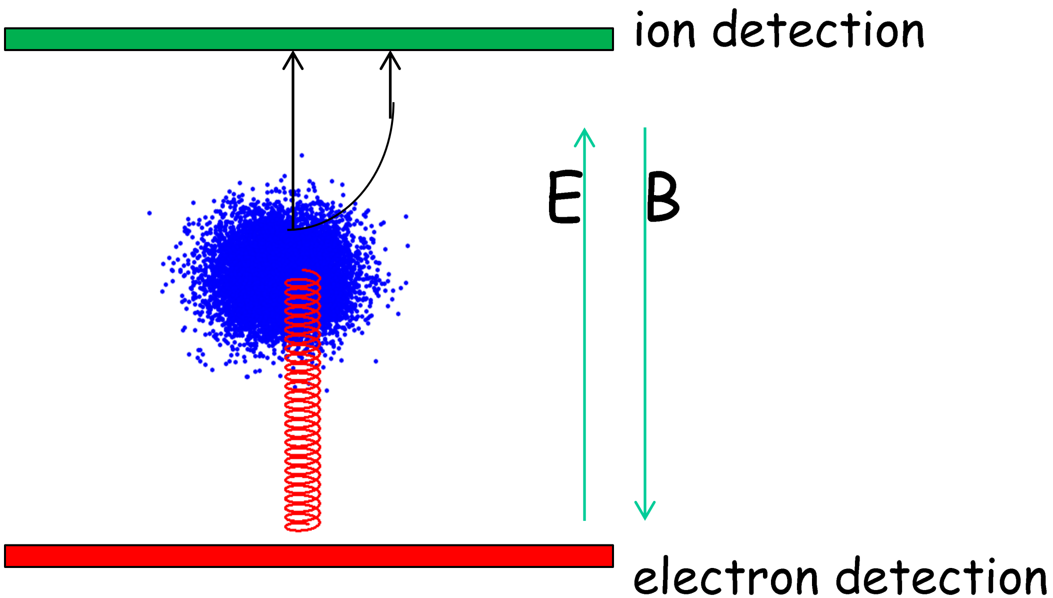
1. Wire scanners, SEM-grids, foils often operate at extreme conditions.
2. The maximum temperature depends on beam pulse intensity and heat capacity of the target.
3. In extreme cases thermionic emission is a main, very powerful cooling mechanism.
4. A python code to investigate heat transfer and sublimation has been developed (1D case for now).

Ionization Profile Monitor simulations

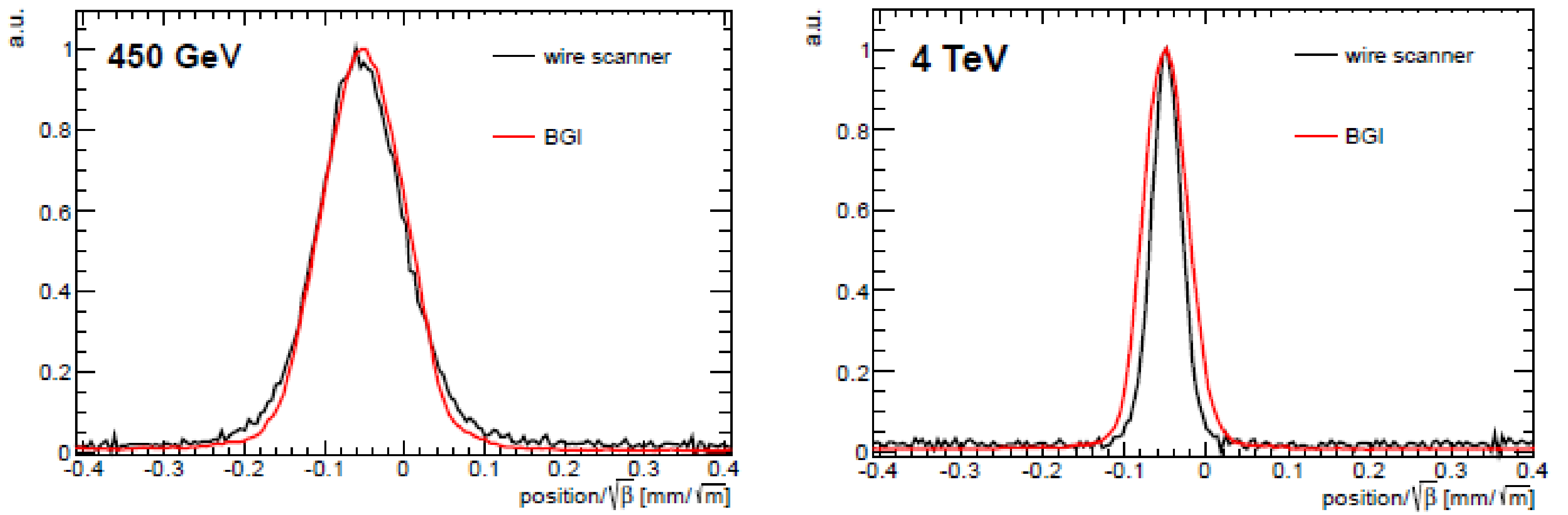
IPM simulation

Simulations of Ionization Profile Monitor:

- Effect of beam space charge on measured profile
- Effect of electric and magnetic field uniformity
- Effect from background electrons



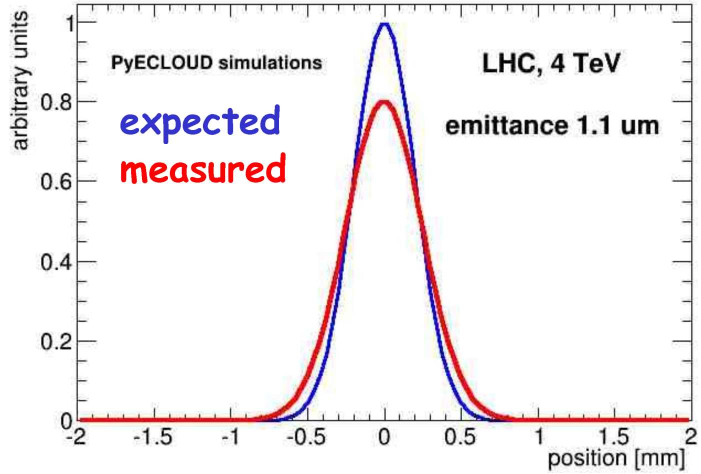
Signal distortion in LHC IPM due to space charge:

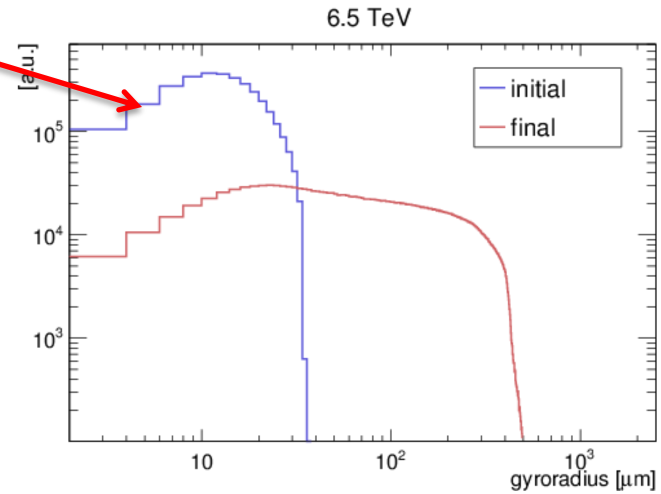


LHC and ion beam: good agreement with the Wire Scanner at injection, at 4 ZTeV additional broadening due to beam space charge not compensated by 0.2 T magnetic field.

IPM simulations – space charge

- Observed beam profile is broader than expected.
- The **beam space-charge kicks electrons** increasing their gyroradius.
- The gyroradius depends on the location of the electron inside the beam.
- Magnetic field increase, from 0.2 T to 1 T solves the issue but is expensive (large aperture strong dipole).

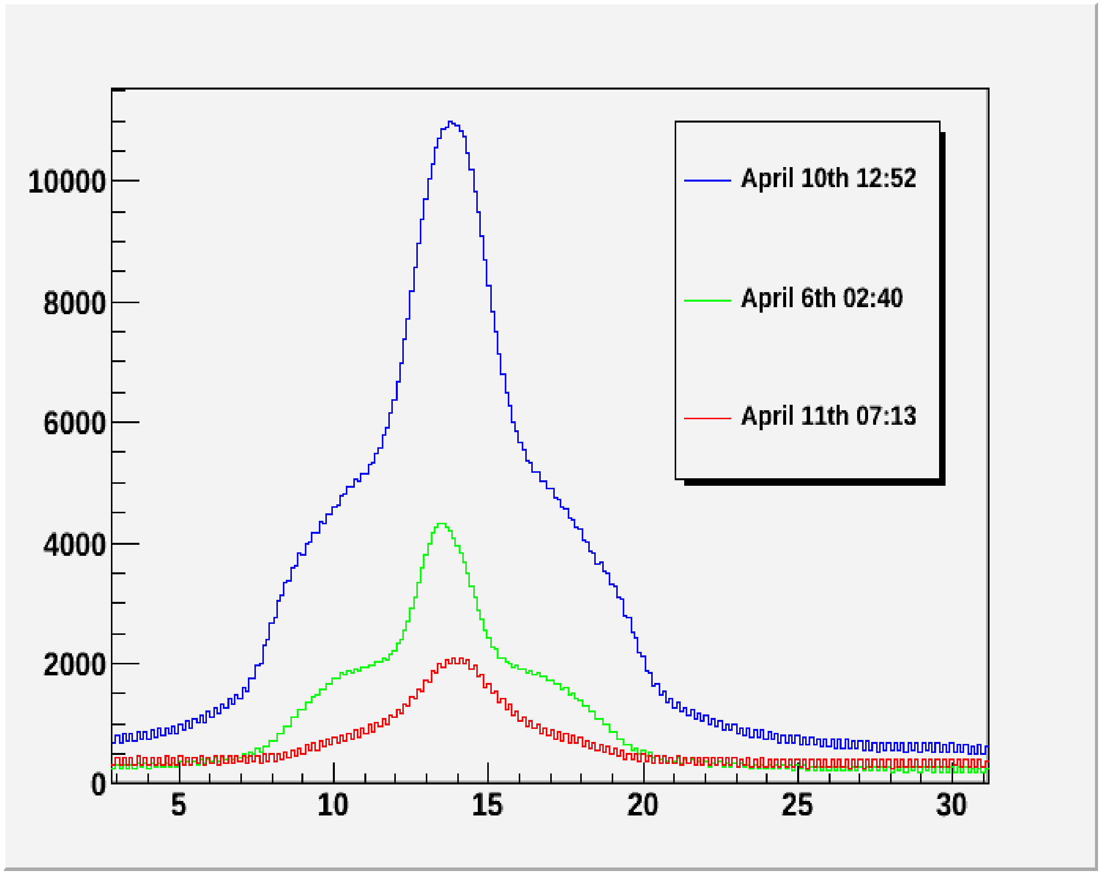




IPM background electrons

Signal in LHC IPM during scrubbing

– large electron cloud effect:



IPM simulation codes

Several simulation codes have been written to account for various effecs in IPMs (see D. Vilsmeier et al., IBIC16, TUPG71 and https://indico.cern.ch/event/491615/).

Name/Lab	Language	Ionization	Guiding field	Beam shape	Beam field	Tracking
GSI code	C++	simple DDCS	uniform E,B	parabolic 3D	3D analytic relativ.	numeric R-K 4th order
PyECLOUD-BGI /CERN	python	realistic DDCS	uniform E,B	Gauss 3D	2D analytic relativ. only	analytic
FNAL	MATLAB	simple SDCS	3D map E,B	arbitrary	3D numeric relativ. (E and B)	num. MATLAB rel. eq. of motion
ISIS	C++	at rest	CST map E only	arbitrary (CST)	2D numeric (CST) non-relativ.	numeric Euler 2nd order
IFMIF	C++	at rest	Lorenz-3E map E only	General. Gauss	numeric (Lorenz-3E) non-relativ.	
ESS	MATLAB	at rest	uniform E,B	Gauss 3D	3D numeric (MATLAB) relativ.	numeric MATLAB R-K
IPMSim3D /J-PARC	python	realistic DDCS	2D/3Dmap E, B	Gauss 3D	2D numeric (SOR) relativ. only	numeric R-K 4th order

IPM simulation collaboration

Participants from all main laboratories:

- J-PARC
- CERN
- GSI
- ISIS (UK)
- ESS/IFMIF
- Fermilab
- BNL (new)
- Liverpool (Quasar)

Yearly meetings:

- 2016/03-CERN
- 2017-Liverpool or GSI

Goals:

- Exchange experience
- Compare various simulation approaches
- Preparation of common program

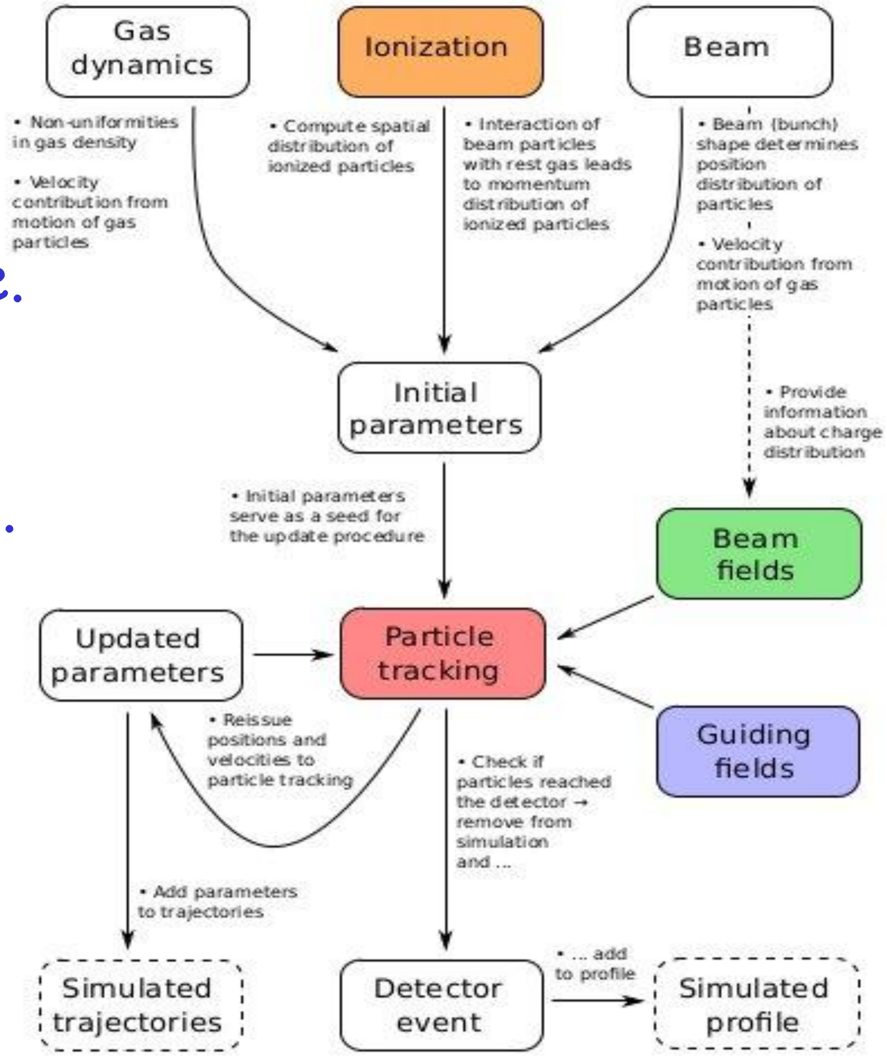
Wiki:
https://twiki.cern.ch/twiki/bin/view/IPMSim

On Wiki
https://twiki.cern.ch/twiki/bin/view/IPMSim:

1. Description of a common profile format (XML)
2. Selection of example beam profiles in this format
3. Python GUI to look at these profiles and compare them
4. Source code for pyECLOUD-BGI and IPMSim3D.
5. Description of various simulation aspects.
6. Collection of bibliography.

New IPM simulation code

1. IPMSim3D from Kenichiro as a backbone.
2. Modular approach.
3. Object-oriented design.
4. Manpower: D. Vilsmeier - master student.



Conclusions (part 3)

1. Several IPM simulation codes were independently written over the years.
2. We established a collaboration to exchange experience in IPM simulation and to understand better the various phenomena within IPM.
3. The goal of the collaboration is also to create a common, modular simulation code.

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and thank you all for your attention !

Extra slides