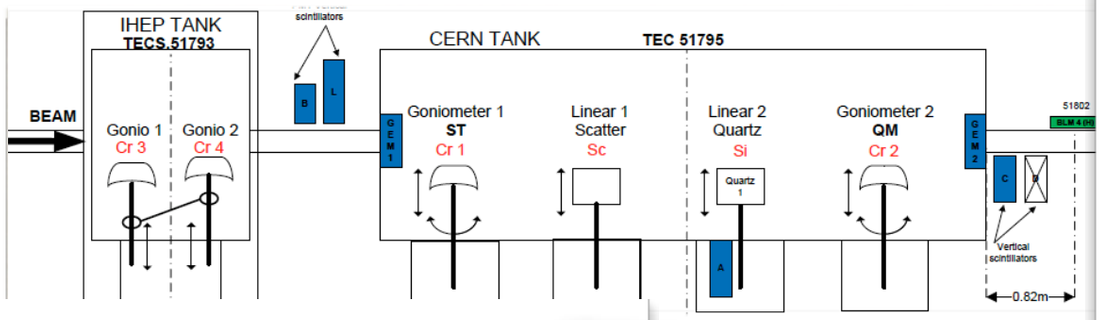
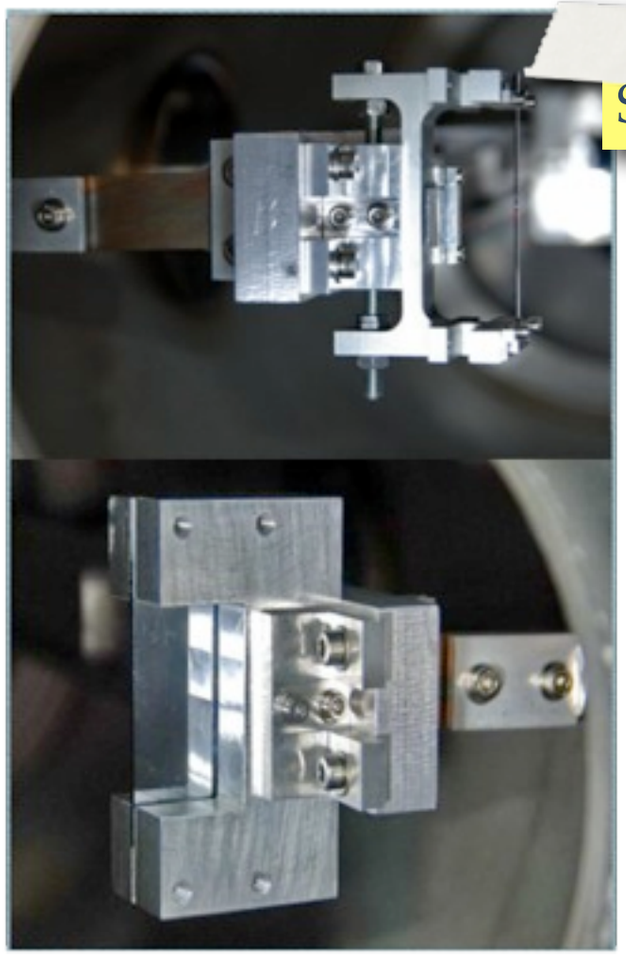
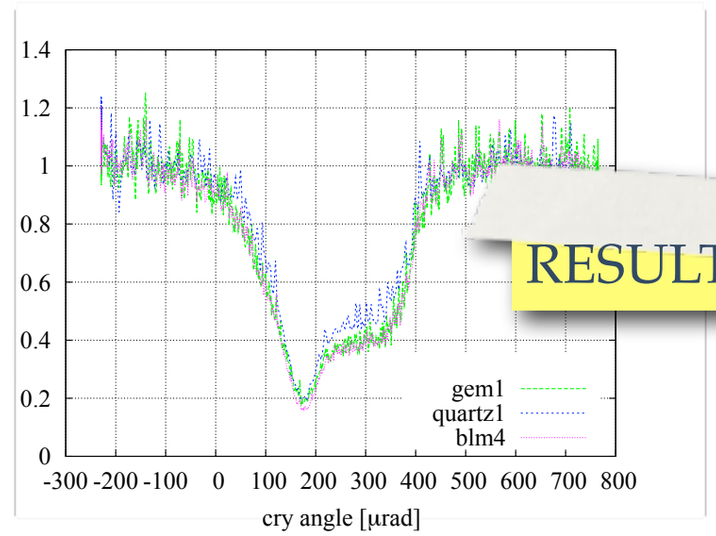
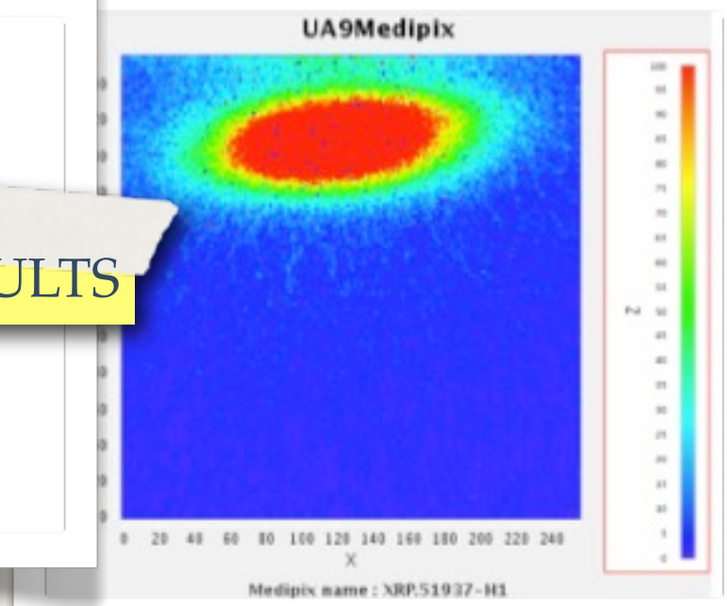


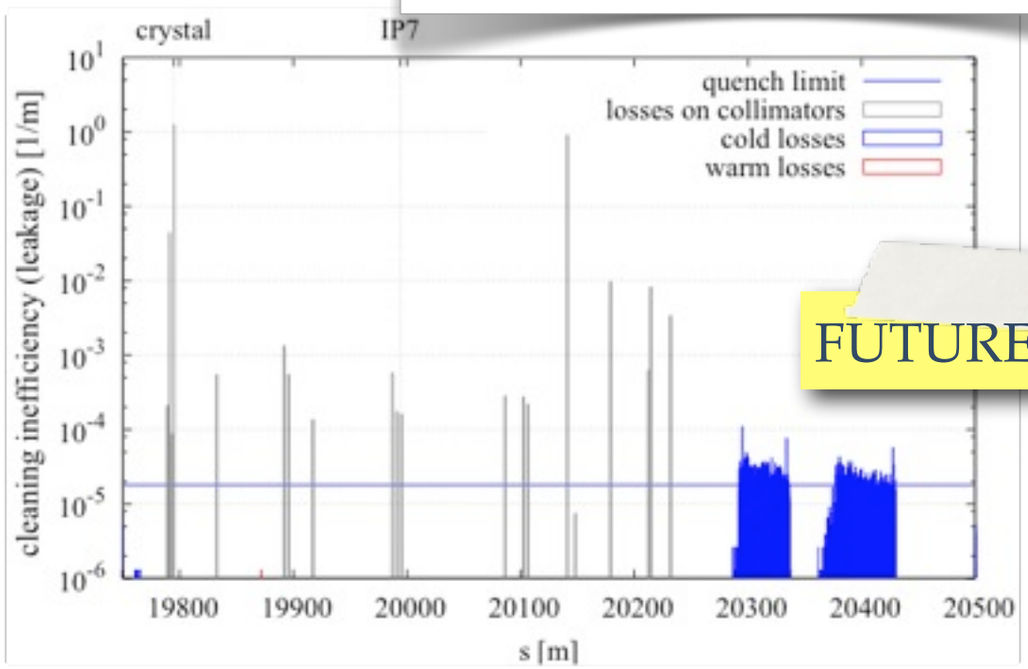


SETUP



RESULTS





FUTURE PLANS

Status and plans of the UA9 experiment

V.Previtali, on behalf on the UA9 collaboration

LARP CM16 - Montauk, NY
15-18 May 2011

Outline

INTRODUCTION

- UA9 experiment: how a crystal could help the LHC

DATA ANALYSIS RESULTS

1. angular scans
2. collimator scans
3. scraper scans

FUTURE PLANS

- future changes in the SPS layout
- from SPS to the LHC: letter of intents and ongoing studies

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starting from the end: crystal collimation in the LHC

INTRODUCTION

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- We want to prove the feasibility and the advantages of using a bent crystal as a primary collimator instead of a standard amorphous primary collimator.

Why are we studying the crystal collimation option?

starting from the end: crystal collimation in the LHC

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- UA9 is a Crystal Collimation experiment
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The Large Hadron Collider (LHC)

POWERFUL

total energy

360 MJ per beam

Losses cannot be (totally) avoided

Design loss rate (0.2h beam lifetime, 10 s)

$4.3\ 10^{11}$ p/s

=(480 KW per beam)

DELICATE

working temperature

1.9 K

superconducting magnets are very sensible to energy releases

Quench limit (energy release limit)

$7.8\ 10^{6}$ p/s/m

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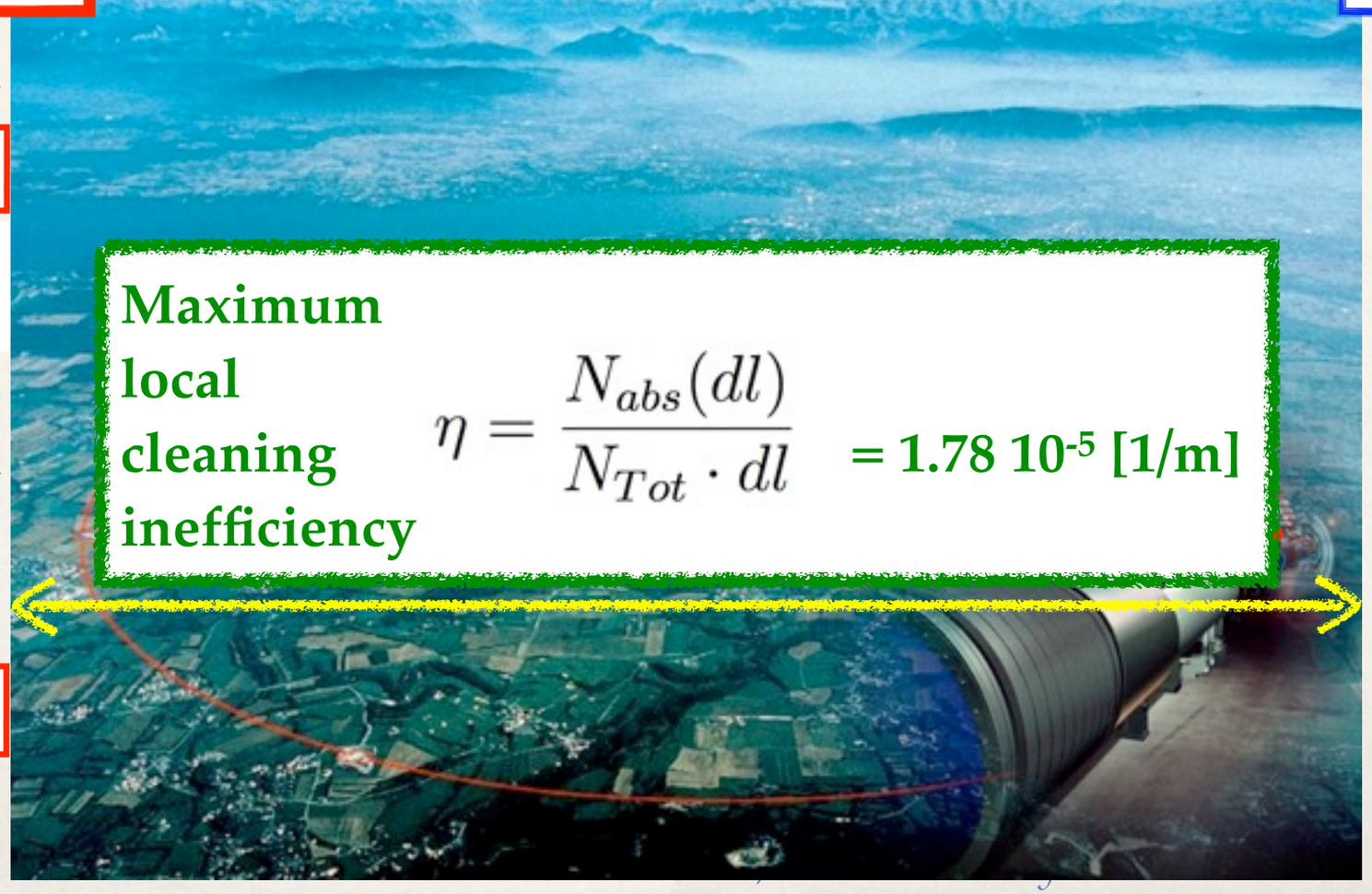

Maximum local cleaning inefficiency

$$\eta = \frac{N_{abs}(dl)}{N_{Tot} \cdot dl} = 1.78\ 10^{-5}\ [1/m]$$

starting from the end: crystal collimation in the LHC

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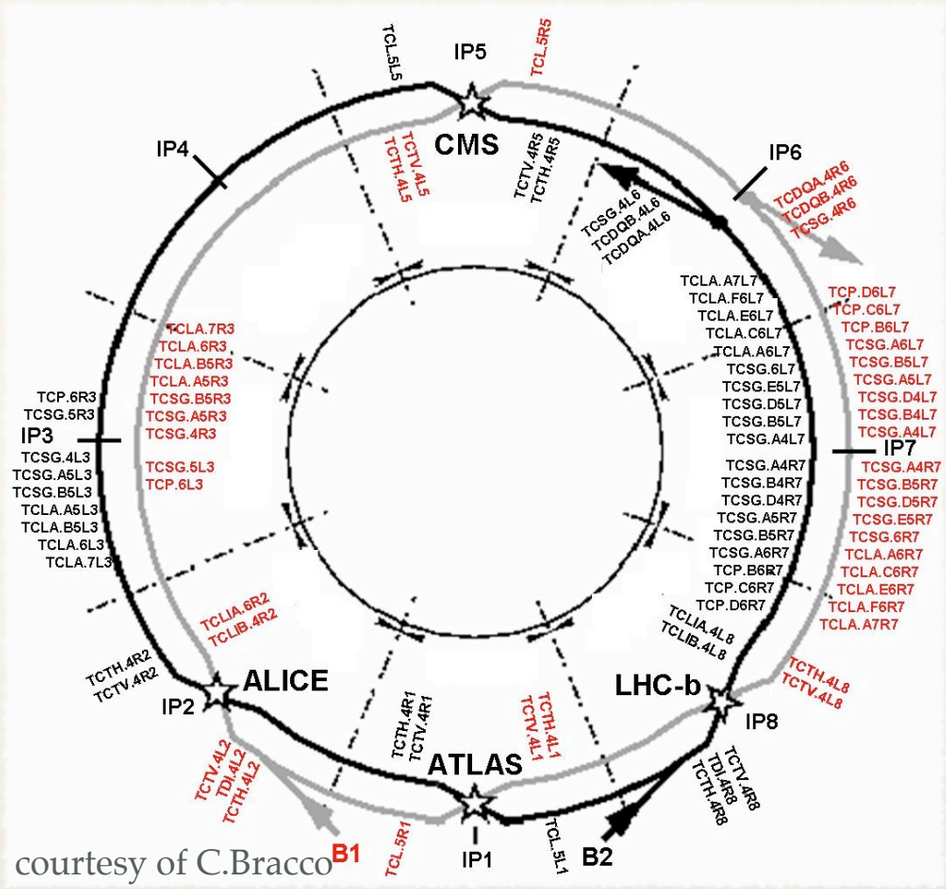
The Large Hadron Collider (LHC)

phase 1 system: the most sophisticated collimation system ever…

108 collimators and absorbers!

… but still limited!



courtesy of C.Bracco

single diffractive scattering

basic limitation of the collimation system: losses receiving a small kick but a non negligible $\Delta p/p$ escape the collimation insertion but are immediately lost at the first bending magnets

losses @ dispersion suppressor

starting from the end: crystal collimation in the LHC

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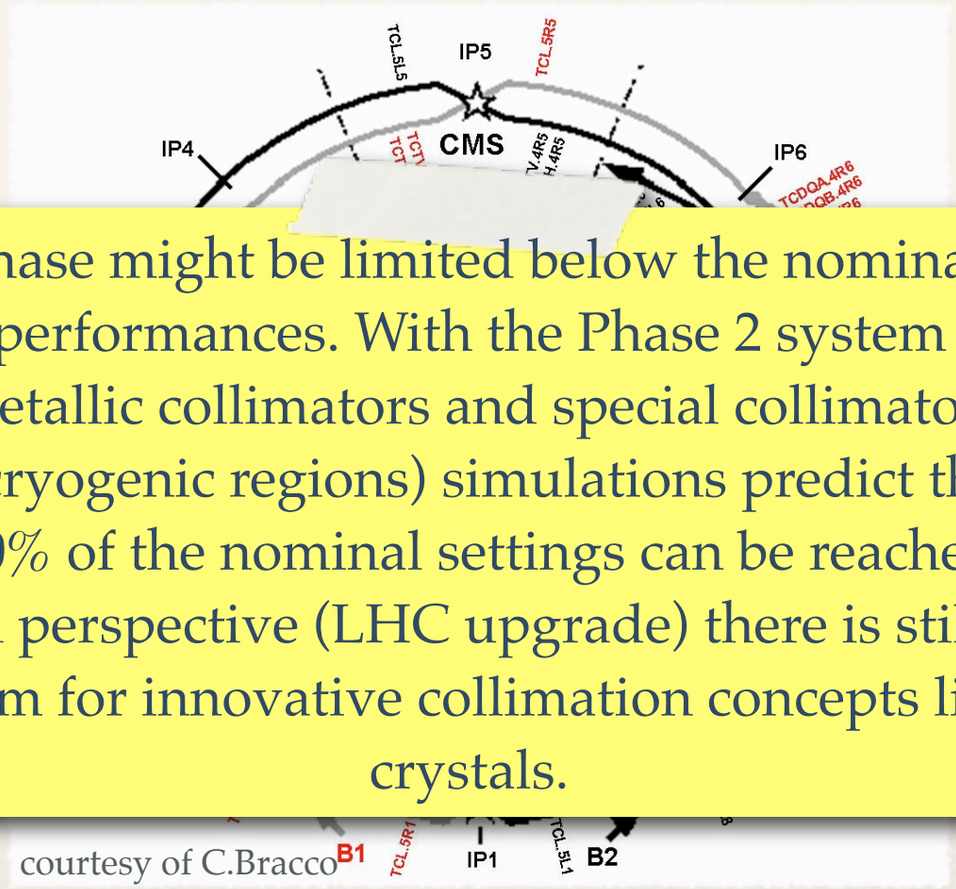


courtesy of C.Bracco

Phase might be limited below the nominal performances. With the Phase 2 system (metallic collimators and special collimators in cryogenic regions) simulations predict that 100% of the nominal settings can be reached. In perspective (LHC upgrade) there is still room for innovative collimation concepts like crystals.

single diffractive scattering

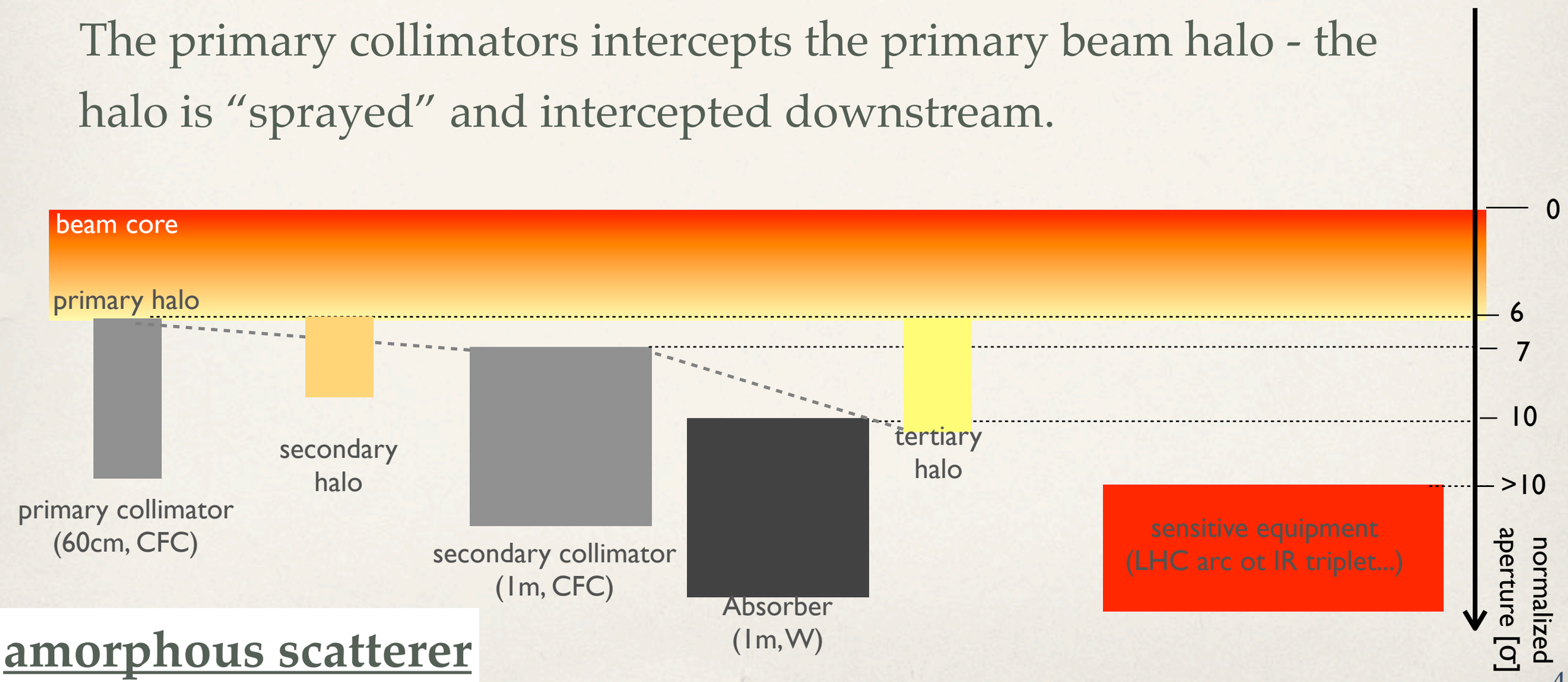
basic limitation of the collimation system: losses receiving a small kick but a non negligible $\Delta p/p$ escape the collimation insertion but are immediately lost at the first bending magnets

losses @ dispersion suppressor

A crystal for collimation: the idea

Present layout of the LHC collimation system: multi-stage cleaning.

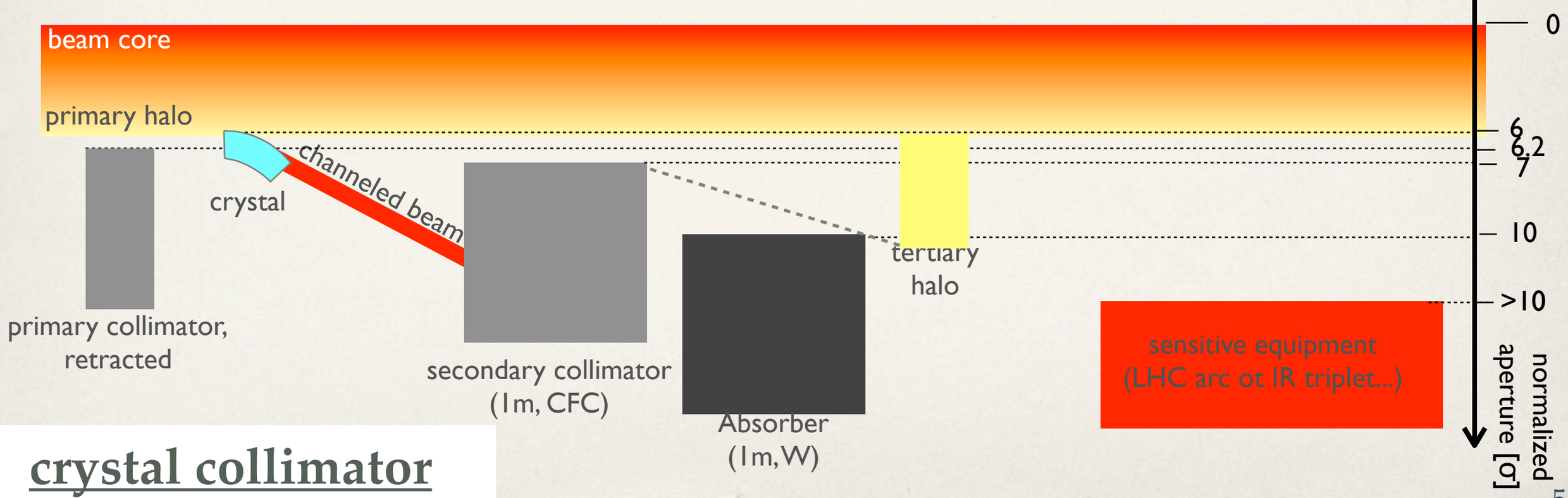
The primary collimators intercepts the primary beam halo - the halo is "sprayed" and intercepted downstream.



amorphous scatterer

A crystal for collimation: the idea

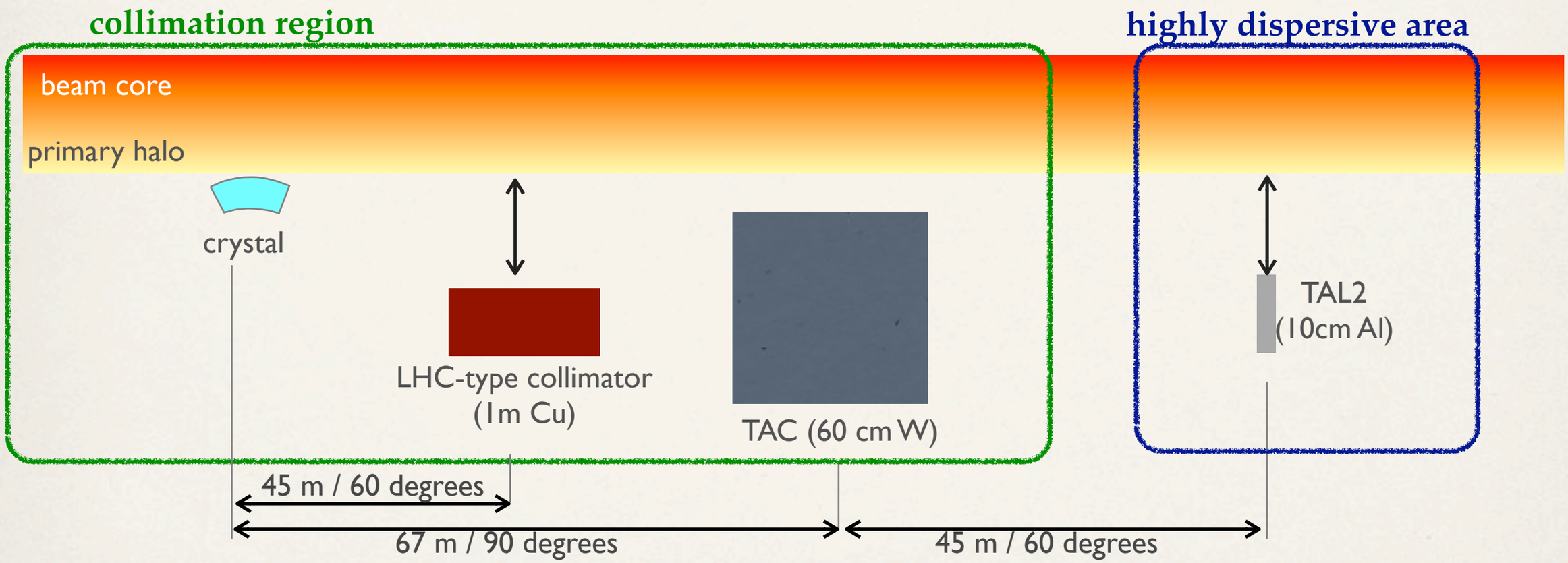
The idea: to use mechanically bent crystals (typically Si) as "**smart scatterers**" in replacement of primary amorphous collimators, to minimize the escaping particles. Primary collimator would be slightly retracted.



crystal collimator

UA9: SPS installation

- A crystal-based collimation insertion has been installed in the SPS LSS5 to test the crystal collimation concept.



- The element apertures depend on the measurement type
- For each element, **one or more detector are installed** to check the losses in the specific element.

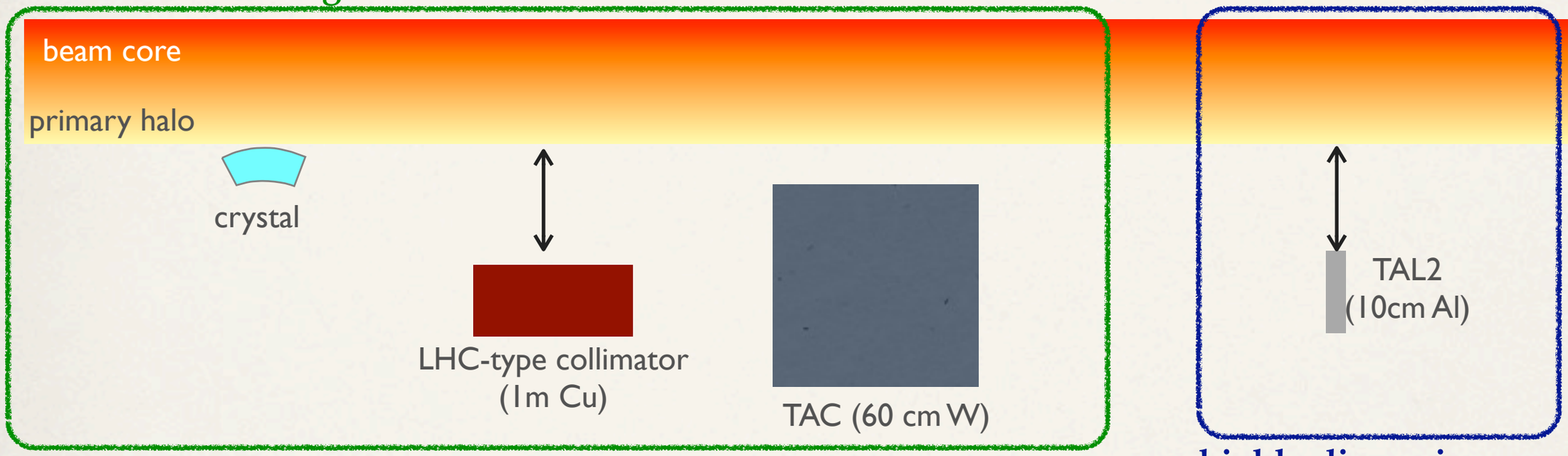
UA9: SPS installation

in this region we measure:

1- Reduction of inelastic interaction ratio at the crystal (**angular scan**)

2- multi-turn channeling efficiency (**collimator scan**)

collimation region



highly dispersive area

in this region we measure:

3- Tertiary halo reduction in highly dispersive area (**scraper scan**)

UA9: SPS installation

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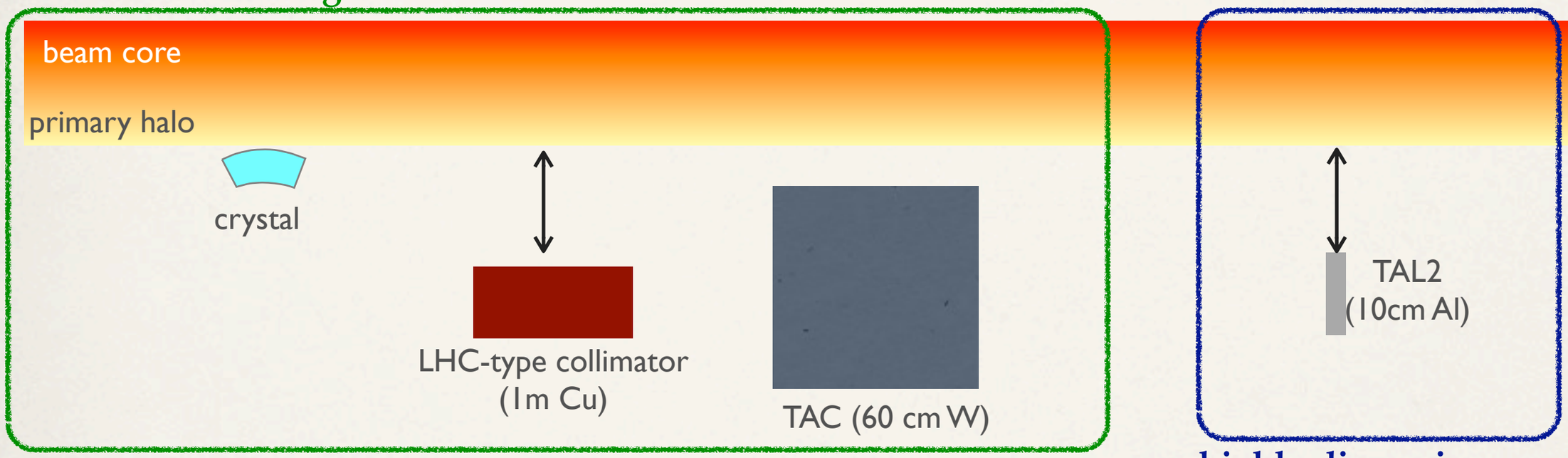

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3- Tertiary halo reduction in highly dispersive area (**scraper scan**)

3 fundamental measurements

Outline

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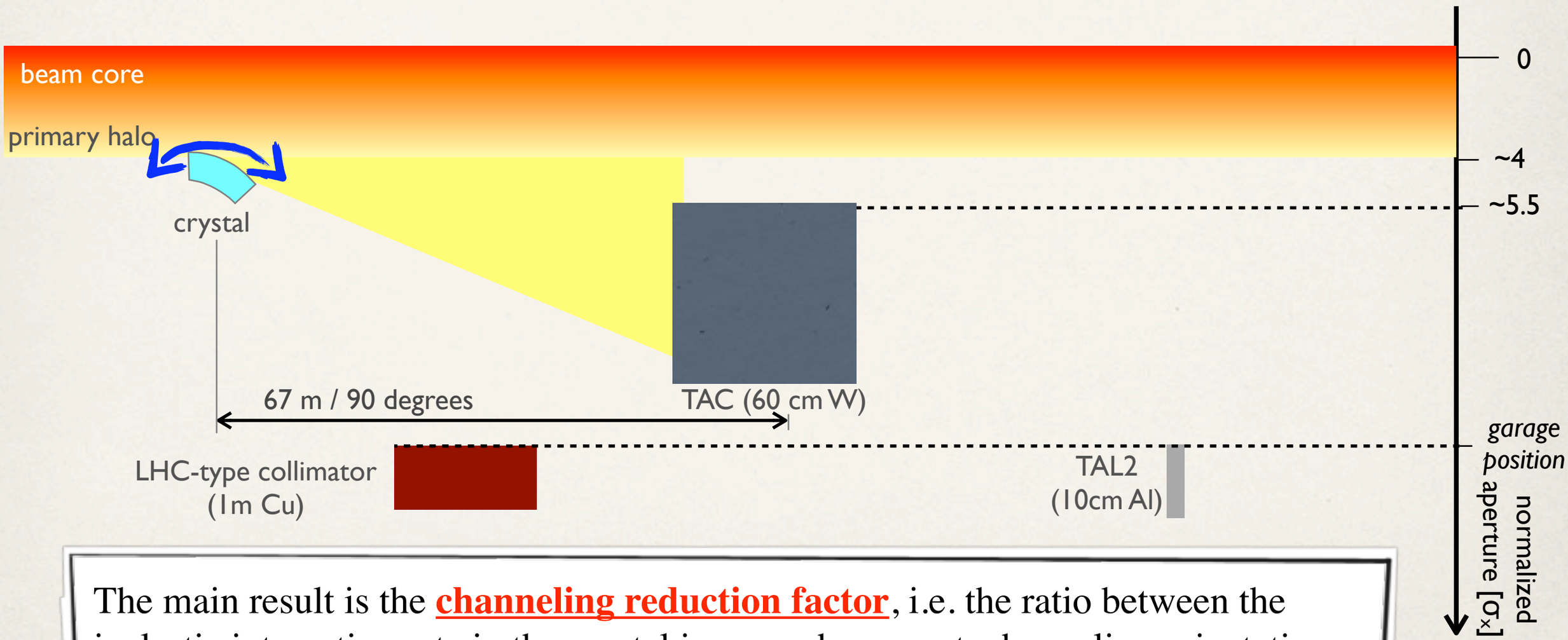
1- angular scans: layout

DATA ANALYSIS RESULTS

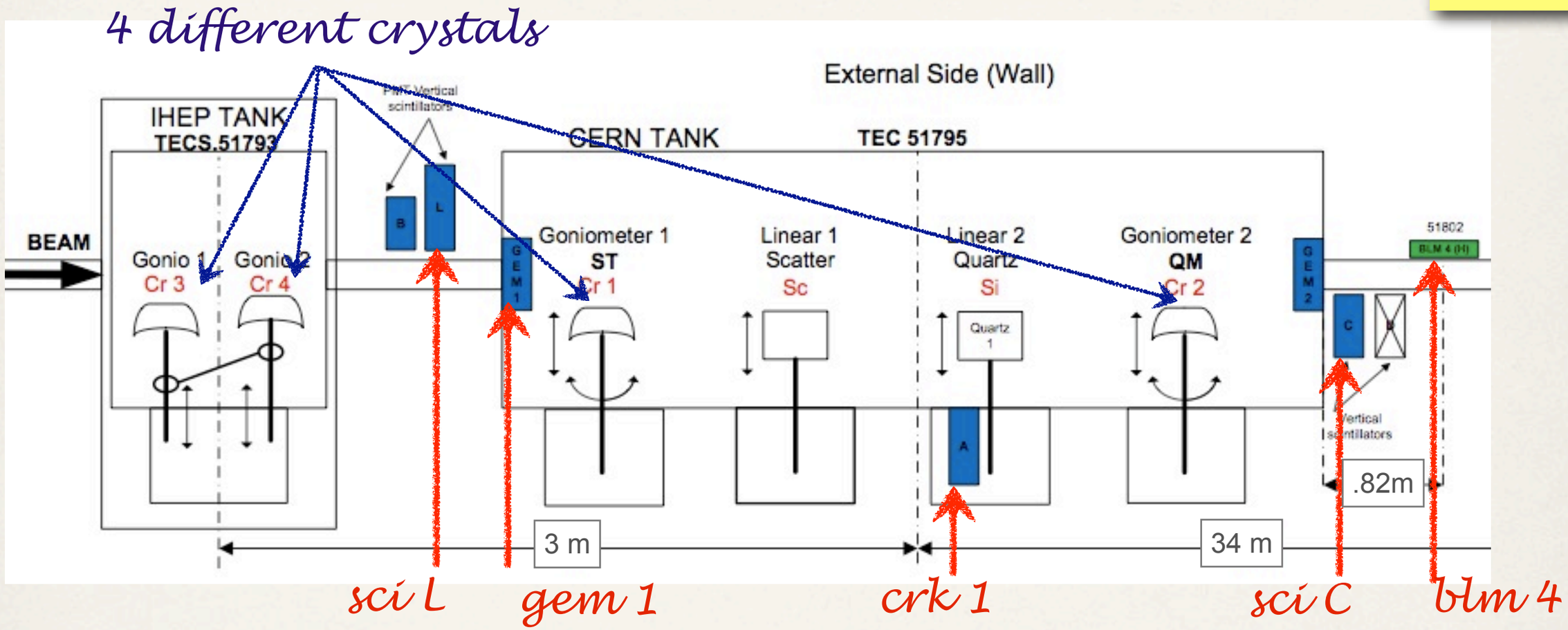
measurement concept: the transverse positions of the different elements are kept constant while the crystal orientation is changed. The rate of inelastic losses at the crystal is measured by downstream detectors.



The main result is the **channeling reduction factor**, i.e. the ratio between the inelastic interaction rate in the crystal in amorphous w.r.t. channeling orientation.

1- angular scans: detectors

DATA ANALYSIS RESULTS

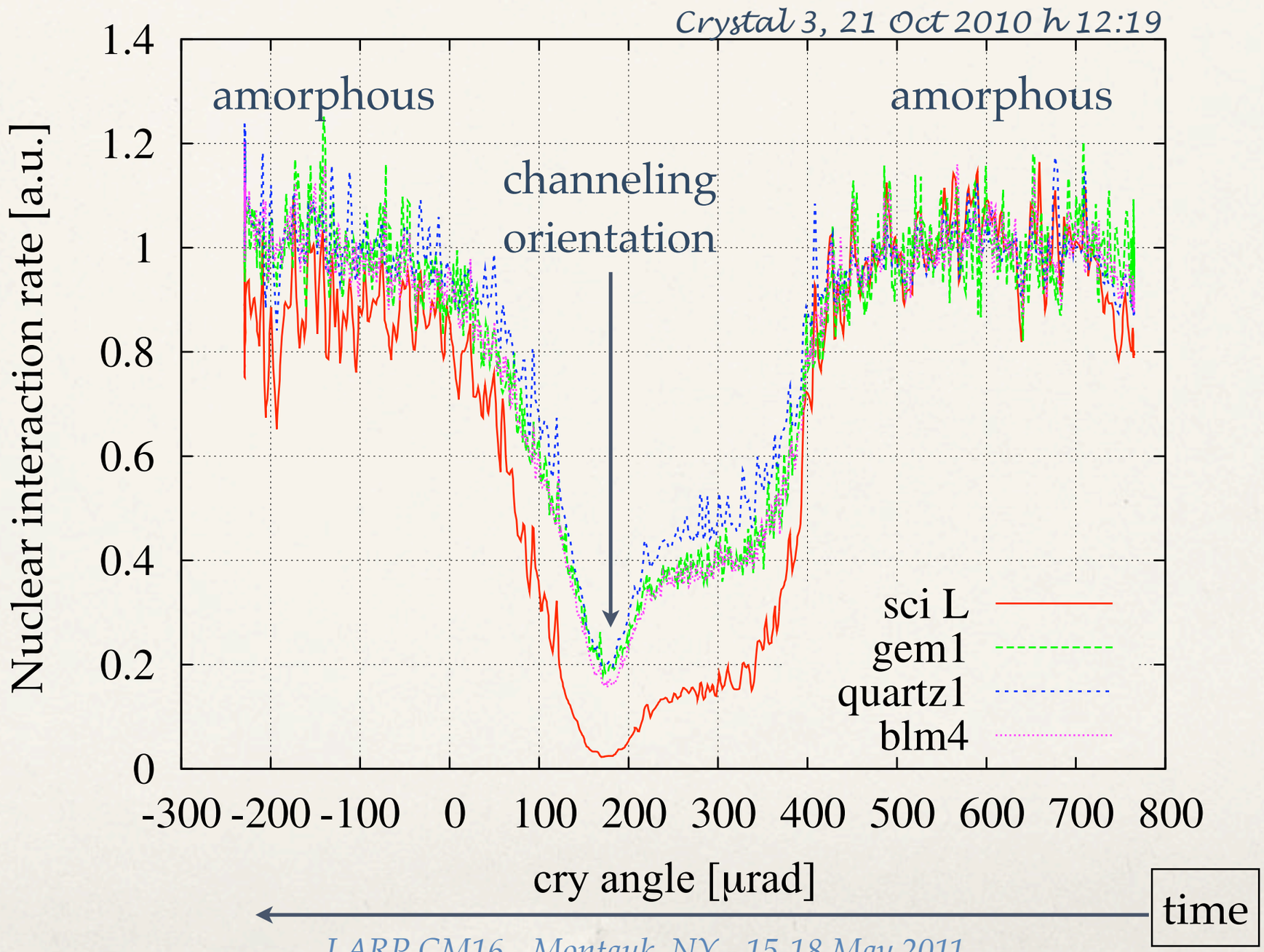


5 differerent detectors can be used to measure the inelastic interactions at crystal: 2 scintillators, 1 GEM,1 cherenkov and 1 BLM (ionization chamber).

the detectors data are normalized with respect to the flux of primary particles lost (BCT derivative)

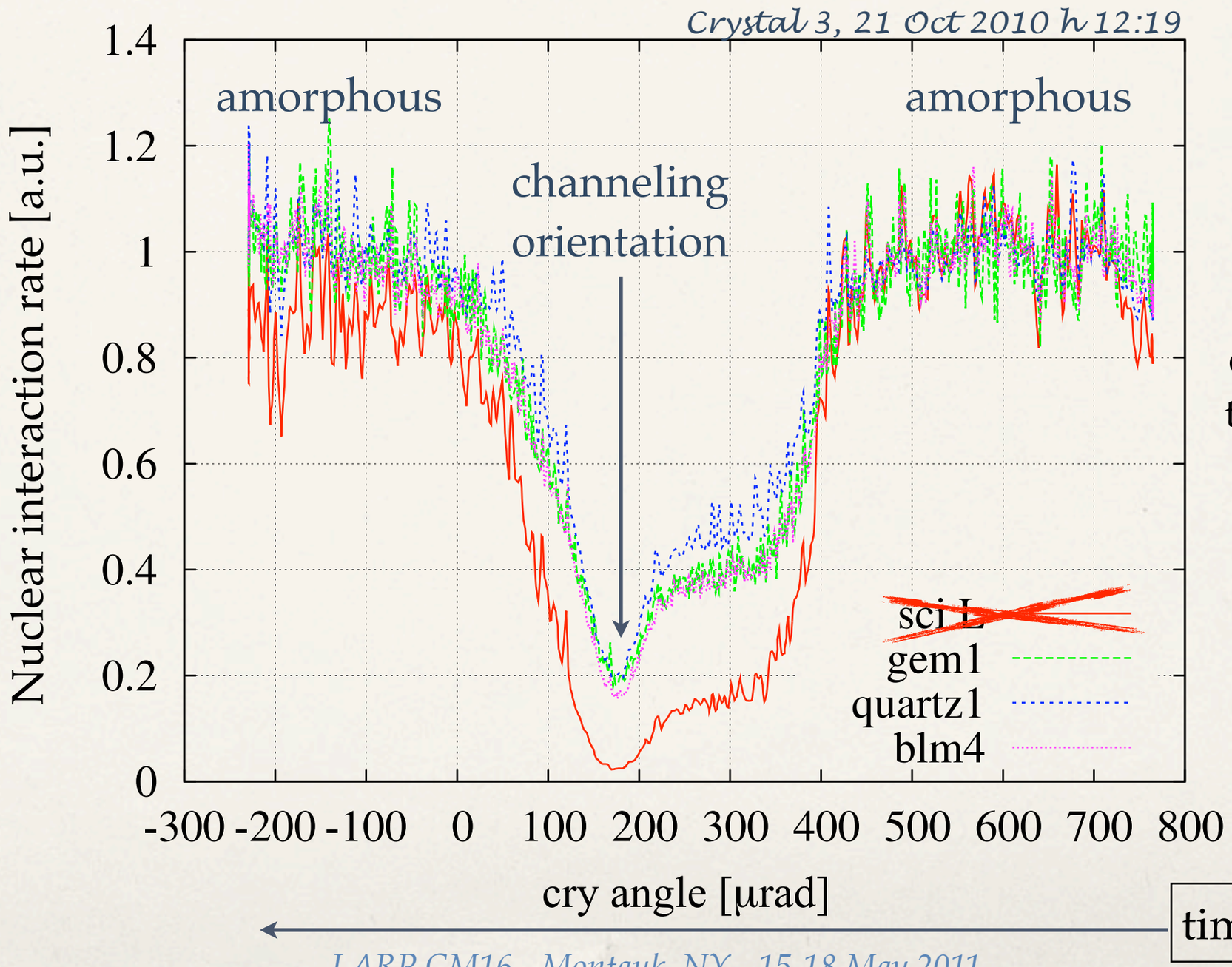
1- angular scans: measurement example

DATA ANALYSIS RESULTS



1- angular scans: measurement example

DATA ANALYSIS RESULTS



the scintillator gives consistently different results!

↓

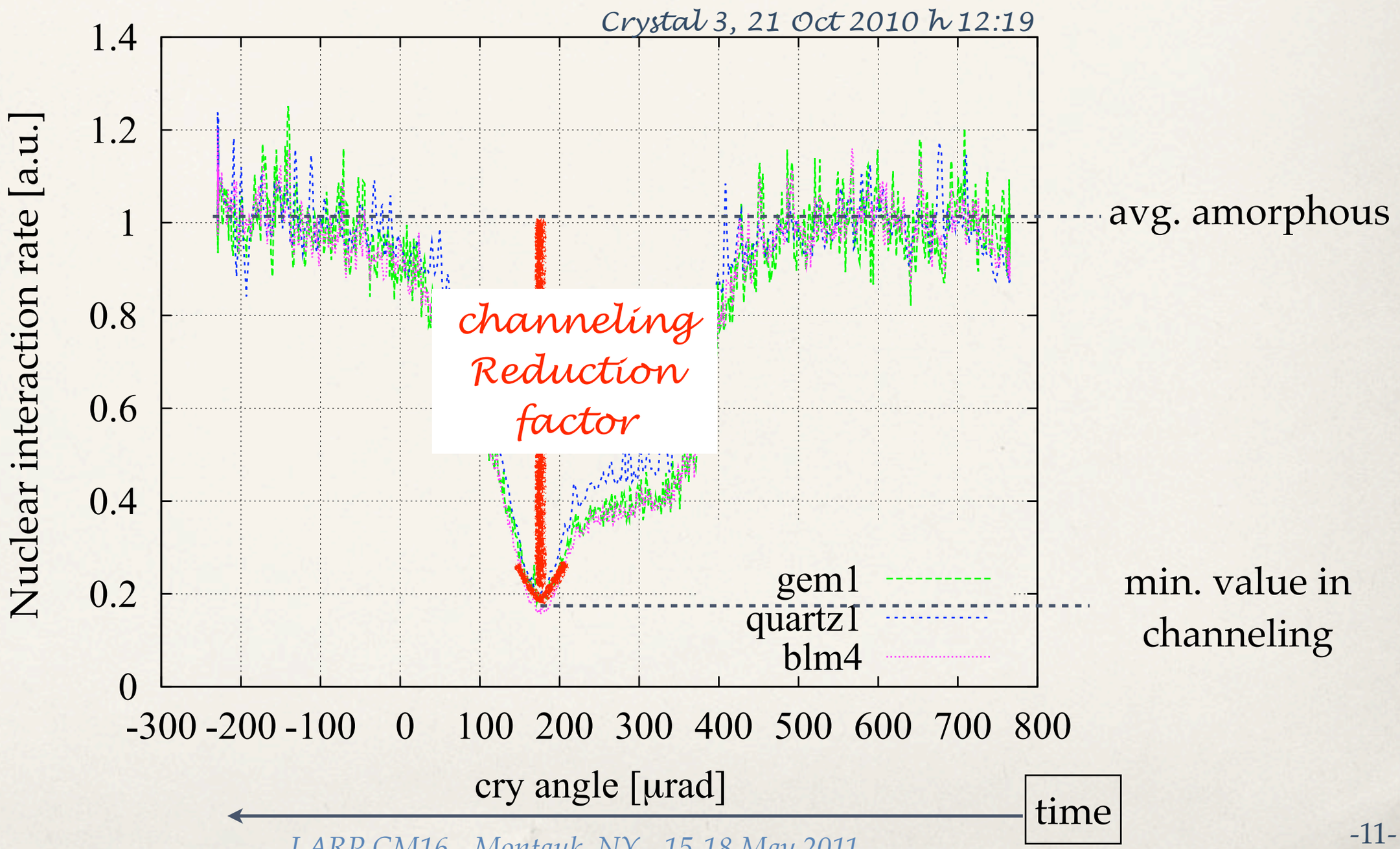
this triggered an extended study on the linearity region of the scintillator signal

↓

we had to reject the scintillator data for at high particle flux (dI/dt ~10^7 p/s)

1- angular scans: measurement example

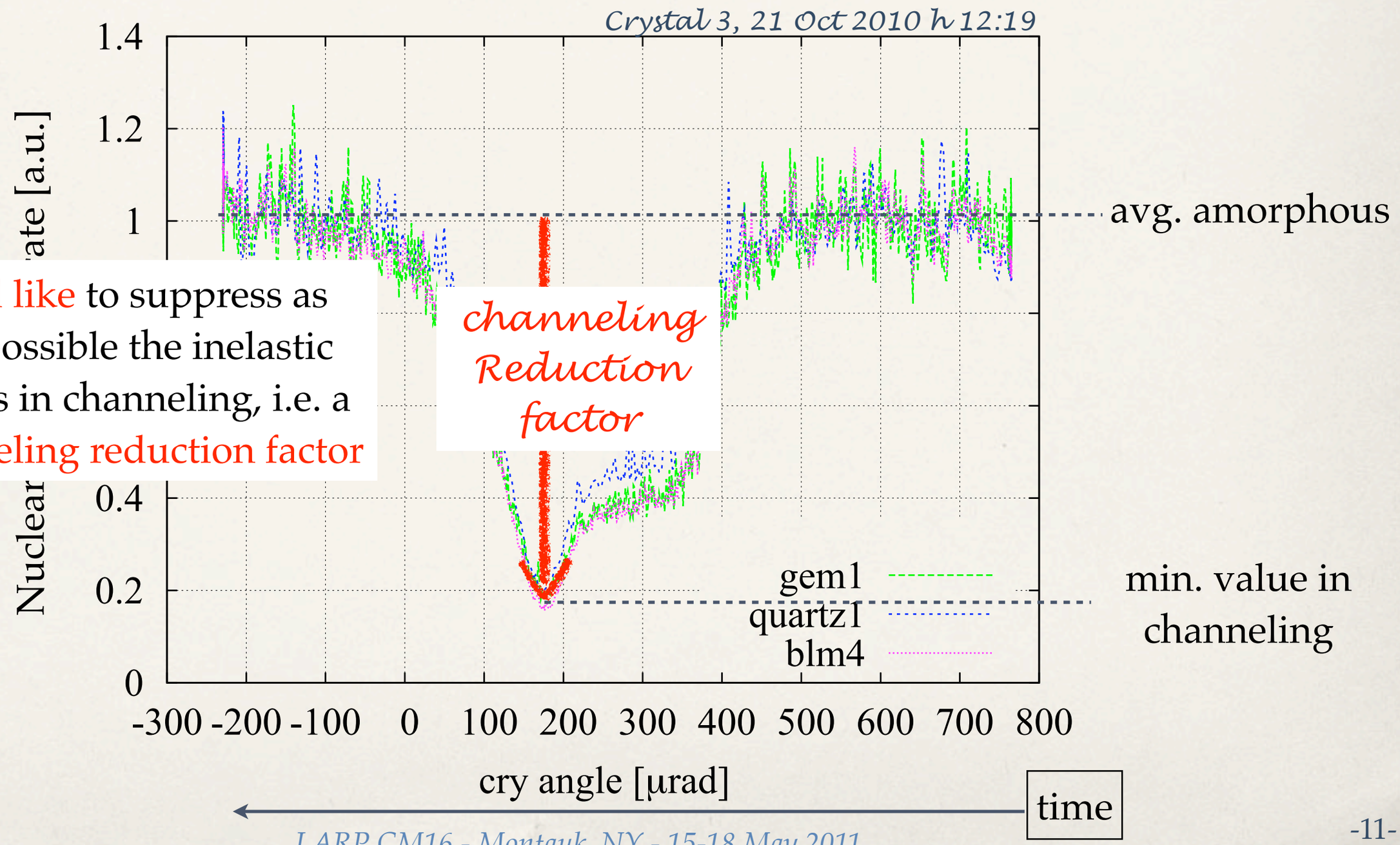
DATA ANALYSIS RESULTS



1- angular scans: measurement example

DATA ANALYSIS RESULTS

we would like to suppress as much as possible the inelastic interactions in channeling, i.e. a large channeling reduction factor



1- angular scans: summary

DATA ANALYSIS RESULTS

- the main results of the angular scan is the **reduction factor** i.e. the ratio between the inelastic interaction rate in the crystal in amorphous w.r.t. channeling orientation.

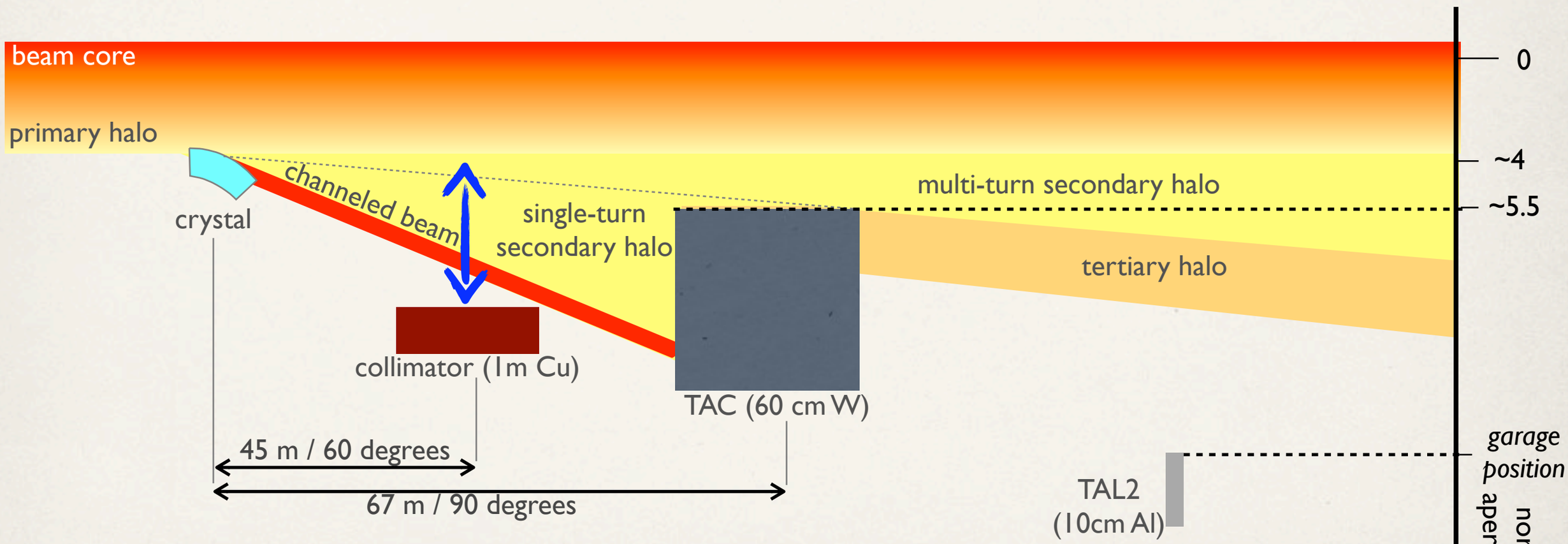
crystal	scan - time			emittance m rad	FLUX p/s	apertures crystal sx	apertures TAC sx	REDUCTION FACTOR SCI L	GEM1	CHER. 1	SCI C	BLM 4
3	2-Sep	14:21	14:27	1.6E-08	9.0E+06	-7.04	-8.40	9.7 ± 0.8	4.2 ± 0.2	5.7 ± 0.4	6.5 ± 0.2	6.8 ± 0.3
3	22-Oct	12:06	12:14	2.0E-08	1.3E+07	-4.57	-5.90	~~44.6~~ ± 2.5	5.4 ± 0.4	5.2 ± 0.3	~~12.9~~ ± 1.1	5.7 ± 0.3
3	22-Oct	12:19	12:37	2.0E-08	1.3E+07	-4.57	-5.90	~~42.7~~ ± 4.2	5.3 ± 0.4	5.0 ± 0.3	~~13.7~~ ± 1.2	6.2 ± 0.3
3	22-Oct	12:40	12:50	2.0E-08	1.1E+07	-4.57	-5.90	~~49.4~~ ± 4.1	5.5 ± 0.3	5.5 ± 0.3	~~12.8~~ ± 1.0	6.1 ± 0.4
3	22-Oct	12:55	13:04	2.0E-08	9.5E+06	-4.57	-5.90	~~46.8~~ ± 5.0	5.4 ± 0.5	6.5 ± 0.4	~~11.9~~ ± 1.2	6.8 ± 0.3
3	22-Oct	13:43	13:50	2.0E-08	2.7E+06	-6.19	-5.90	4.8 ± 0.4	2.8 ± 0.1	3.7 ± 0.3	4.7 ± 0.5	8.6 ± 2.3
3	22-Oct	13:57	14:07	2.0E-08	3.7E+06	-6.19	-5.90	6.4 ± 0.6	3.5 ± 0.2	4.7 ± 0.4	4.7 ± 0.3	6.8 ± 0.4
3	22-Oct	14:10	14:23	2.0E-08	3.8E+06	-6.19	-5.90	7.2 ± 0.8	3.4 ± 0.2	5.3 ± 0.5	5.6 ± 0.5	7.7 ± 0.8
3	22-Oct	15:40	15:50	2.0E-08	9.6E+06	-4.76	-5.95	~~40.8~~ ± 5.4	4.9 ± 0.5	5.3 ± 0.3	~~11.7~~ ± 1.2	6.5 ± 0.5
3	22-Oct	15:55	16:05	2.0E-08	9.6E+06	-4.76	-5.95	~~36.5~~ ± 5.4	5.0 ± 0.4	5.4 ± 0.4	~~11.5~~ ± 1.4	6.7 ± 0.5
4	3-Sep	7:25	7:28	1.50228E-08	9.0E+06	-7.4	-9.08	7.7 ± 0.8	5.4 ± 0.3	4.8 ± 0.1	8.0 ± 0.6	7.2 ± 0.2

- **Reduction factors between 5 and 8** have been measured for all crystals, all detectors (but scintillators)

2- collimator scans: layout

DATA ANALYSIS RESULTS

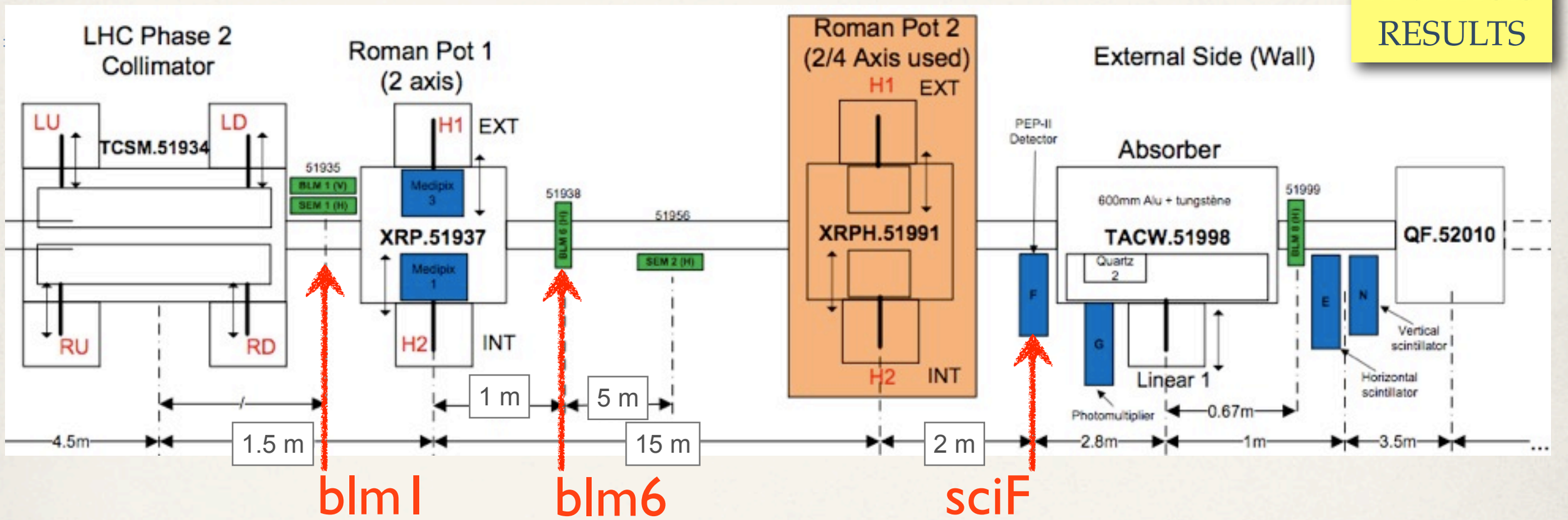
measurement concept: a 1m-Cu collimator is inserted gradually to intercept the secondary halo (directly scattered by the crystal) between the crystal and the W absorber. The inelastic interactions at the collimator are measured by downstream detectors.



The main results are the **channeling angle** and **the multi-turn channeling efficiency**, i.e. the probability for a halo particle in a circular machine to be, soon or late, channeled.

2- collimator scans: detectors

DATA ANALYSIS RESULTS



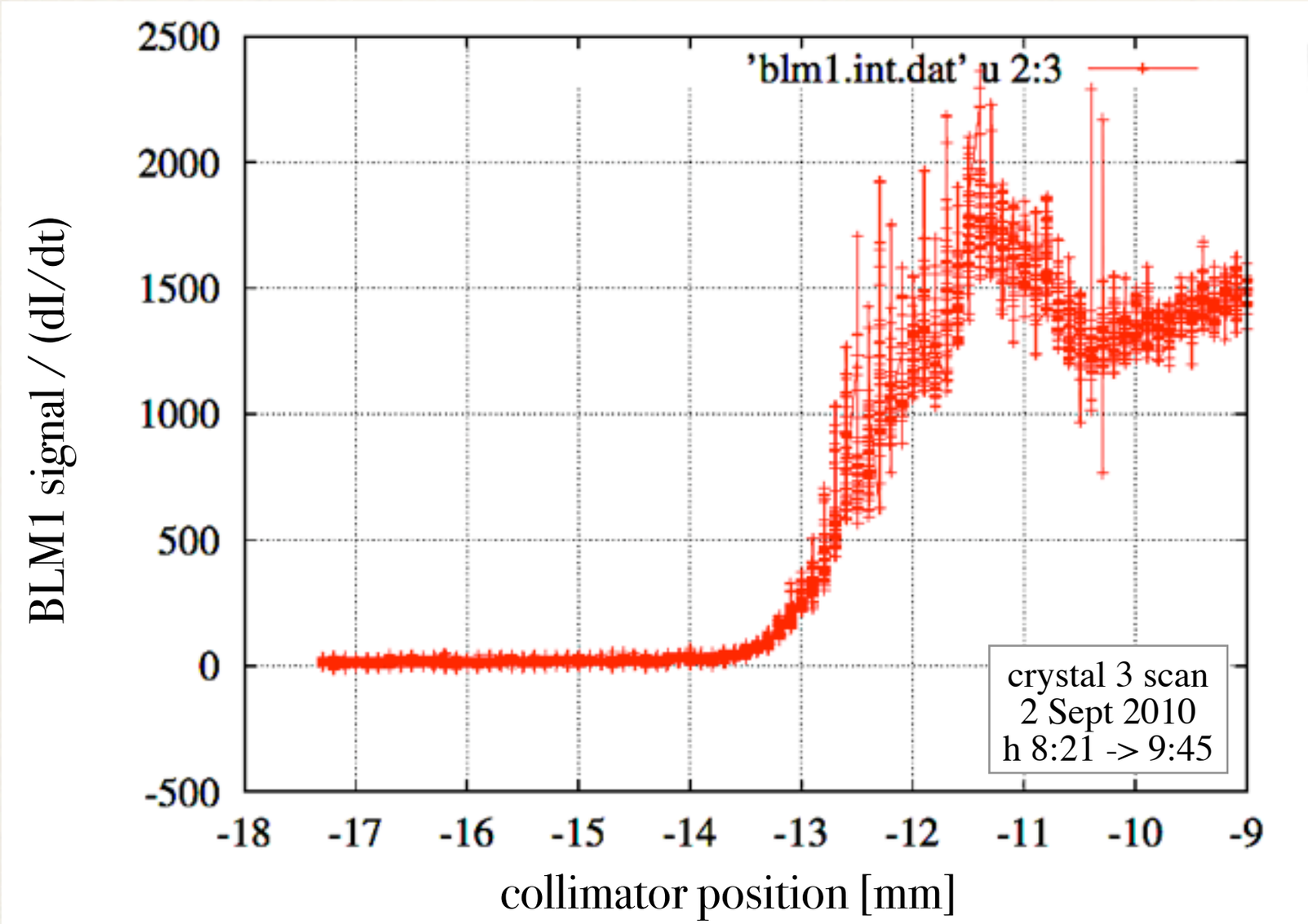
3 different detectors can be used to measure the inelastic interactions at crystal: 2 BLMs (ionization chamber) and 1 scintillator:

- BLM1 (ionization chamber) immediately downstream the LHC collimator
- BLM6 (ionization chamber) about 2.5 m downstream the LHC collimator
- sci F about 18.5 m downstream the LHC collimator center

the detectors data are normalized with respect to the flux of primary particles lost (BCT derivative)

2-collimator scans: measurement example

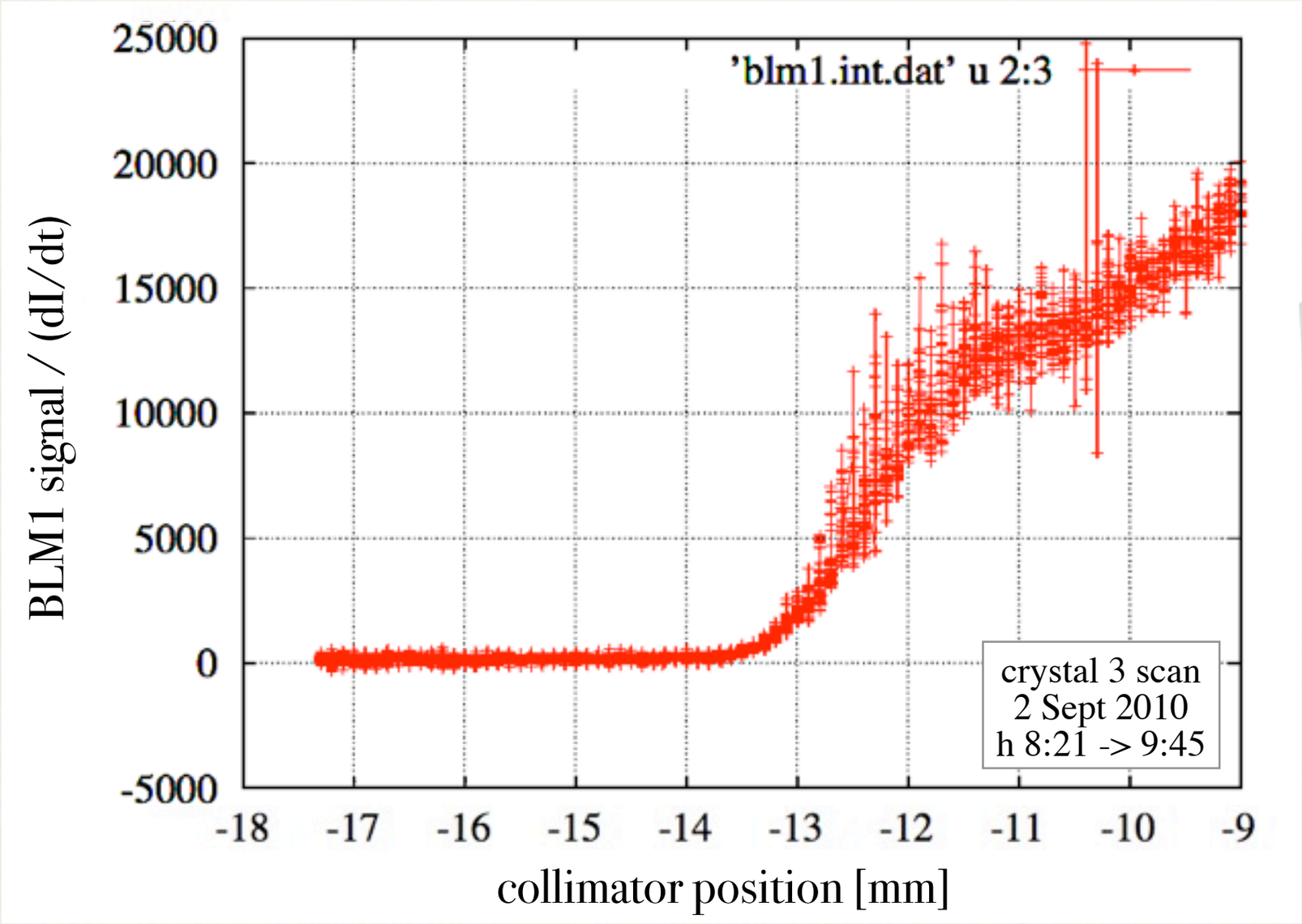
DATA ANALYSIS RESULTS



1. remove a "zero" offset to the detector signal
2. plot the detector reading vs collimator position
3. normalize the detector data with the flux of particles on the crystal
4. normalize w.r.t. the reading when the collimator is primary
5. express the collimator position in terms of equivalent crystal kick

2-collimator scans: measurement example

DATA ANALYSIS RESULTS



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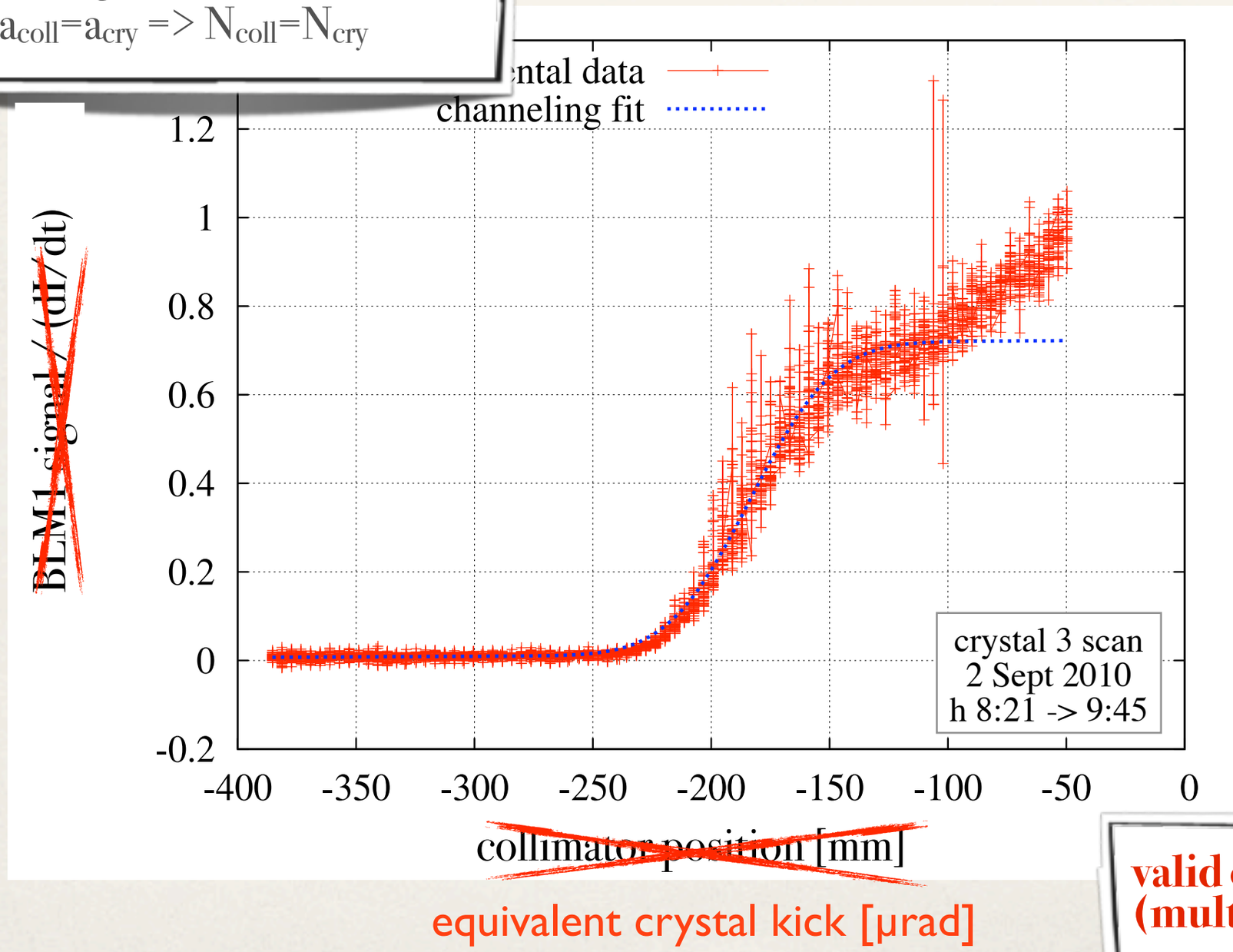
2-collimator scans: measurement example

DATA ANALYSIS RESULTS

valid only if we assume

1. BLM signal ∝ N_{coll}
2. If $a_{coll}=a_{cry}$ => $N_{coll}=N_{cry}$



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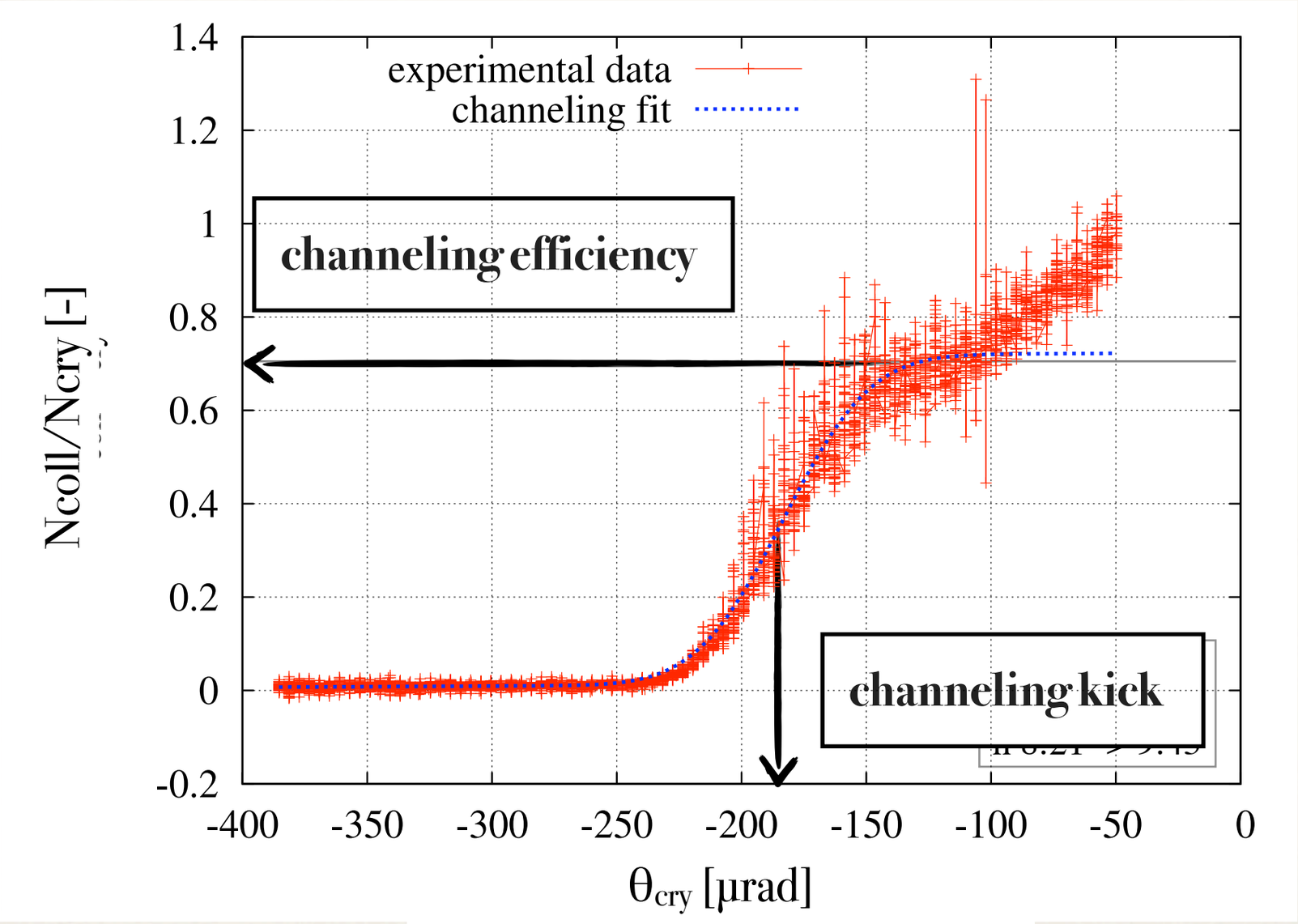
valid only for large kicks (multi turn limit)

2-collimator scans: measurement example

DATA ANALYSIS RESULTS



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5. express the collimator position in terms of equivalent crystal kick

2-collimator scans: results

DATA ANALYSIS RESULTS

- the main results of the collimator scan are the **channeling parameters:** channeling kick, width and efficiency

scan n.	θ_{chan} [μrad]	σ_{ch} [μrad]	η_{chan} [%]
C1.1	173±1	17±1	75±4
C1.2	199±1	40±1	65±3
C1.3	198±1	42±1	64±3

year 2009: crystal 1 and crystal 2 tested, efficiencies between 64 and 85%

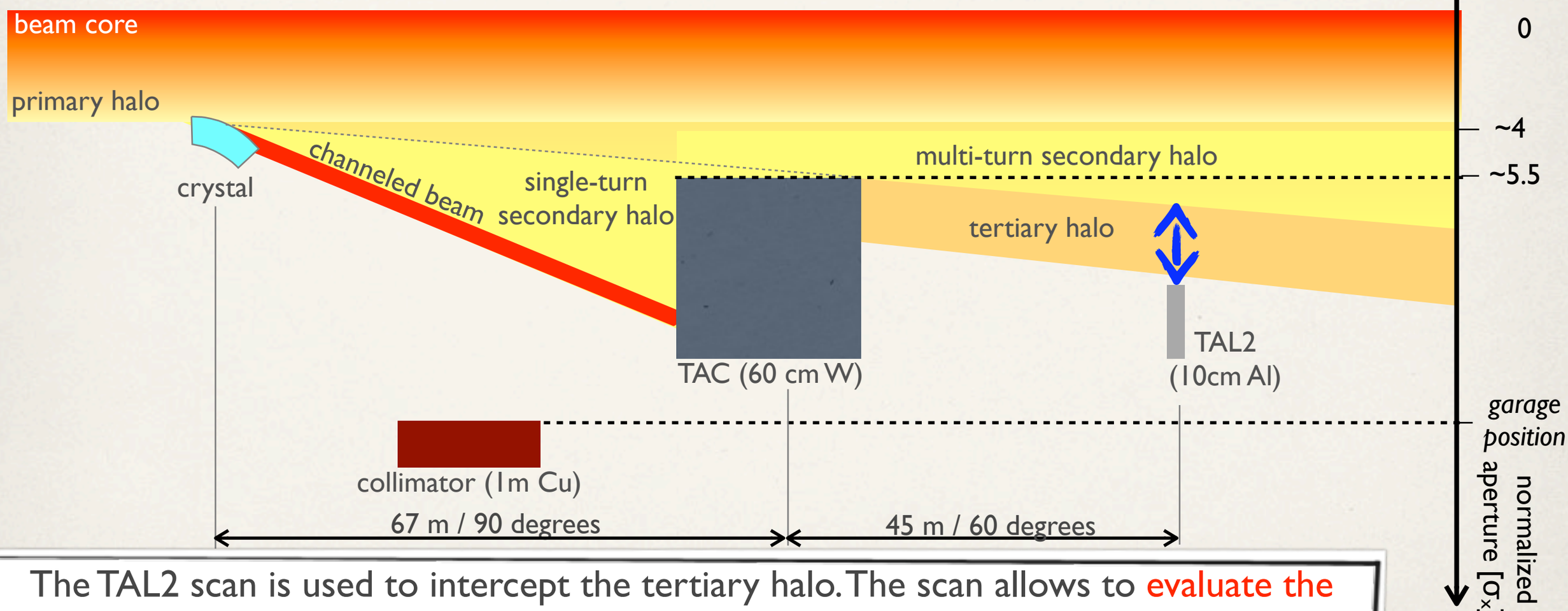
crystal	scan - time			emittance m rad	FLUX p/s	apertures crystal sx	apertures TAC sx	channeling parameters ch.kick µrad			ch.width µrad			efficiency %		
3	2-Sep	8:10	8:20	1.9E-08	8.0E+06	7.20	9.10	178	±	3	29	±	3	69	±	7
3	2-Sep	8:21	9:45	1.9E-08	6 to 16E+6	7.20	9.10	186	±	2	25	±	2	67	±	6

year 2010: collimator scans with protons have been done only with crystal 3. the results **confirm multi-turn channeling efficiency about 70**

3-scraper scans: layout

DATA ANALYSIS RESULTS

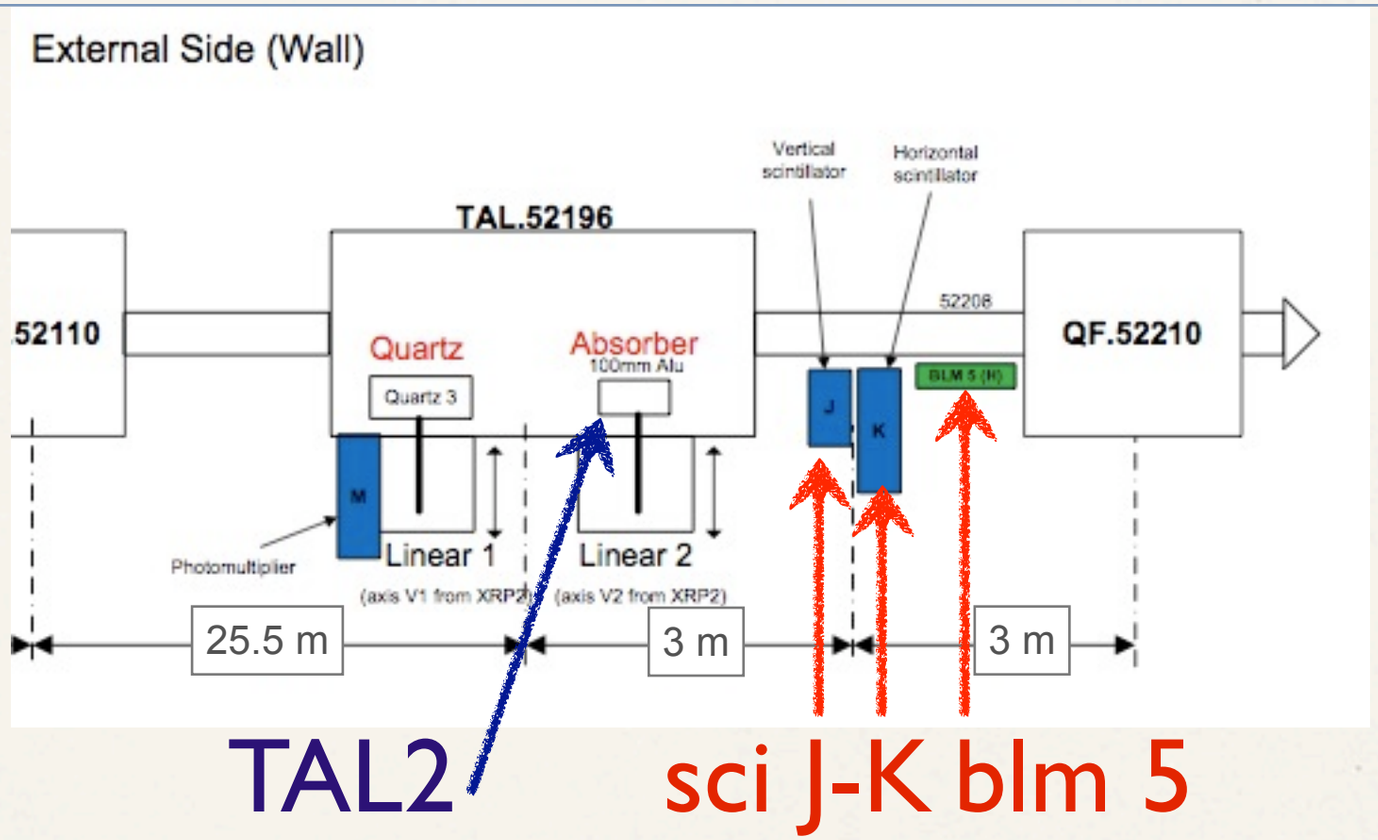
measurement concept: a 10 cm-Al scraper is inserted gradually to intercept the tertiary halo (leakage from the TAC) in a highly dispersive area downstream . The inelastic interactions at the TAL2 are measured by downstream detectors.



The TAL2 scan is used to intercept the tertiary halo. The scan allows to evaluate the leakage reduction factor the ratio between the population of the tertiary halo (meaning escaping to the W absorber) in amorphous and in channeling

3-scraper scans: detectors

DATA ANALYSIS RESULTS



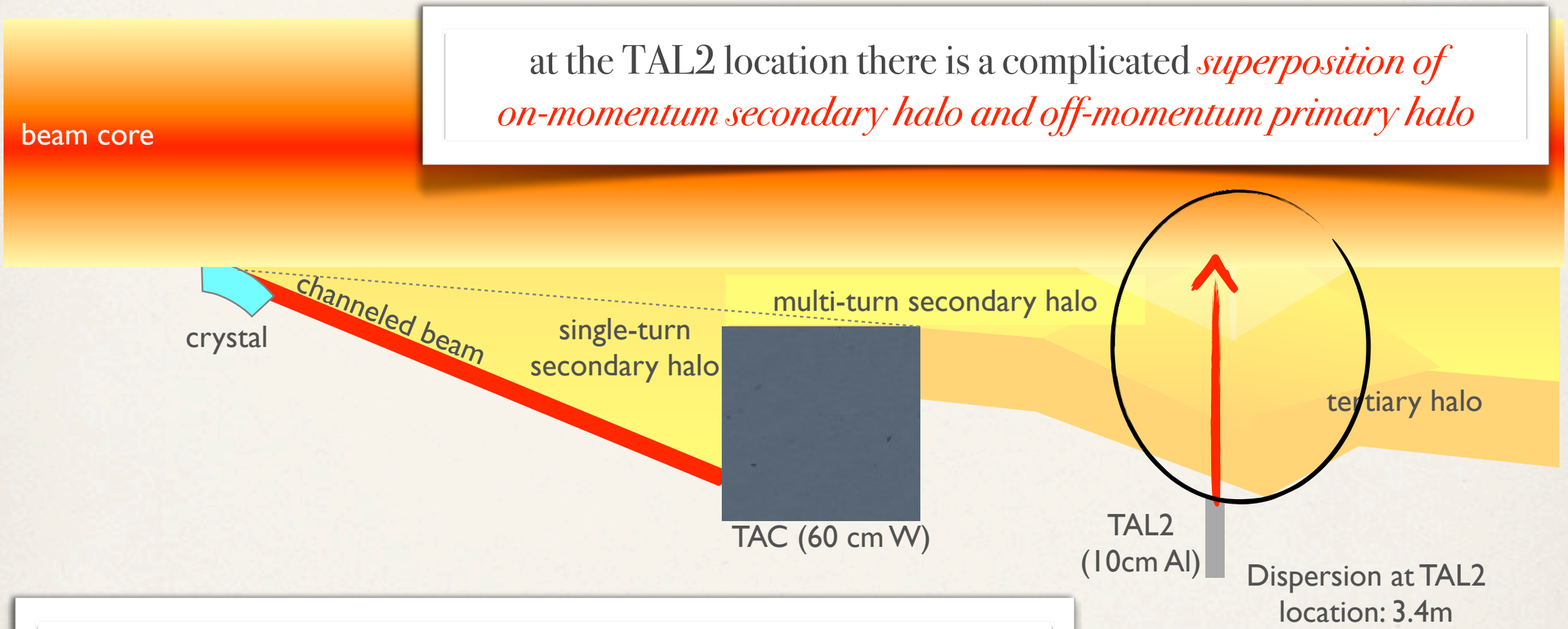
3 detectors can be used to measure the inelastic interactions at crystal: 2 scintillators and 1 BLM (ionization chamber) :

- sci J and sci K about 2 m downstream the scraper
- BLM6 (ionization chamber):immediately after sciK

The TAL2 scan is located in a *highly dispersive region* (meaning: particles are strongly sorted with respect to their momentum). e.g. :A particle with the designed momentum and a particle with the same betatronic amplitude but on the separatrix of the RF bucket (limit for stable particles) would have a transverse position (and then generate losses) about 4 mm more outward than an on momentum particle!!

DATA ANALYSIS RESULTS

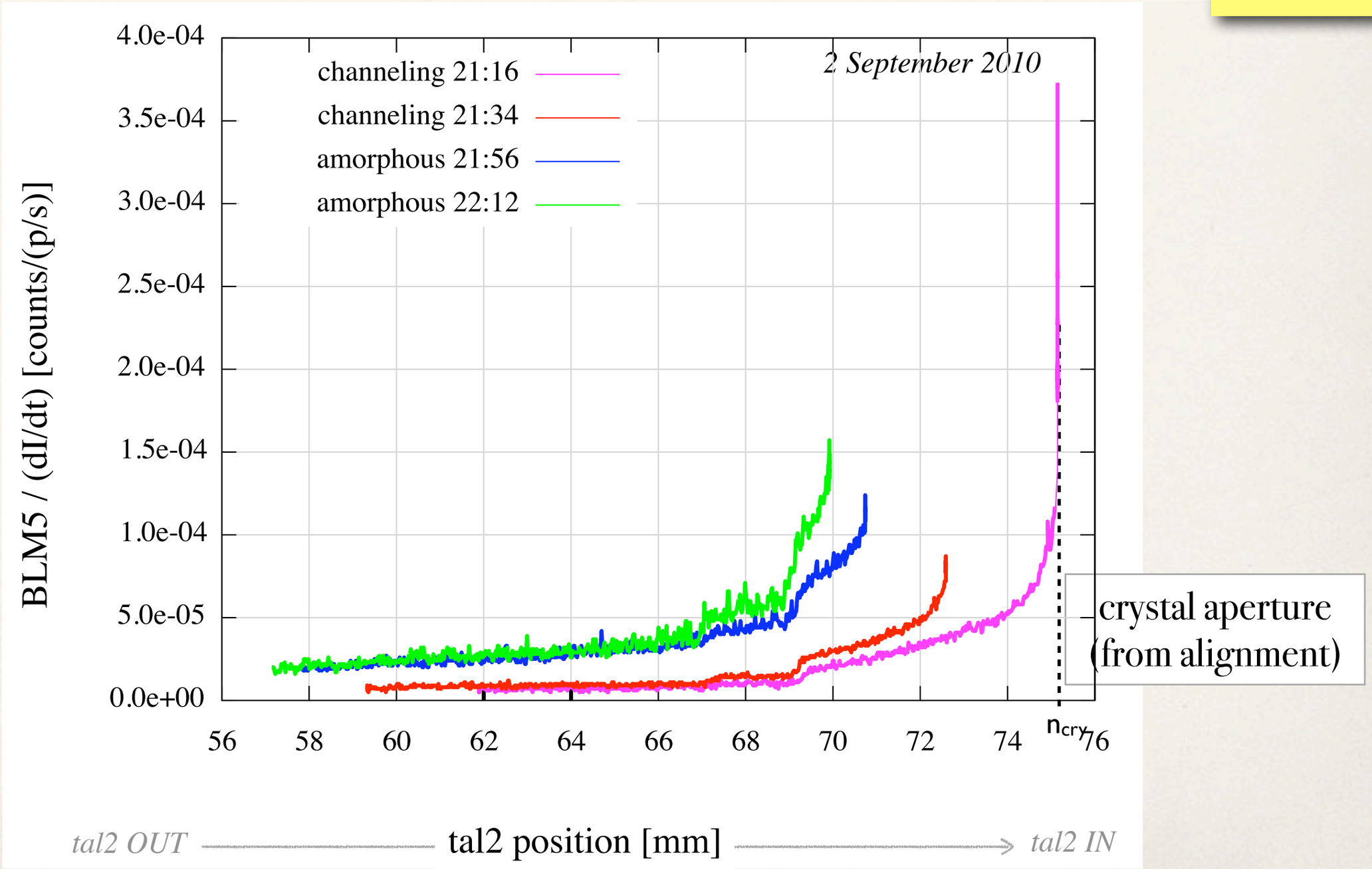
at the TAL2 location there is a complicated *superposition of on-momentum secondary halo and off-momentum primary halo*



it is very difficult to understand if the losses at the TAL2 location correspond to on momentum or off momentum particles, both during the TAL2 alignment and during a TAL2 scan

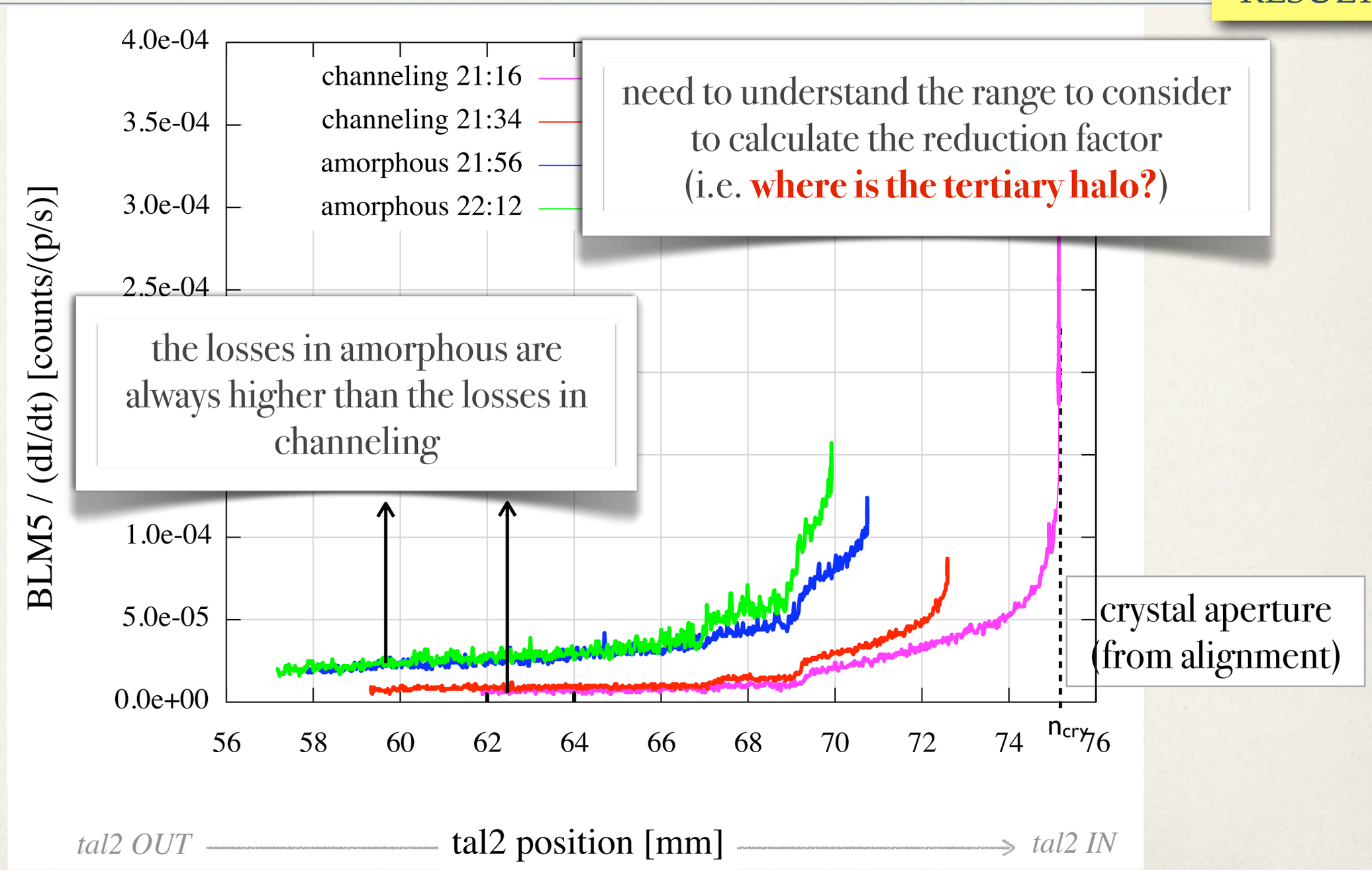
3- scraper scans: a full set

DATA ANALYSIS RESULTS



3- scraper scans: a full set

DATA ANALYSIS RESULTS



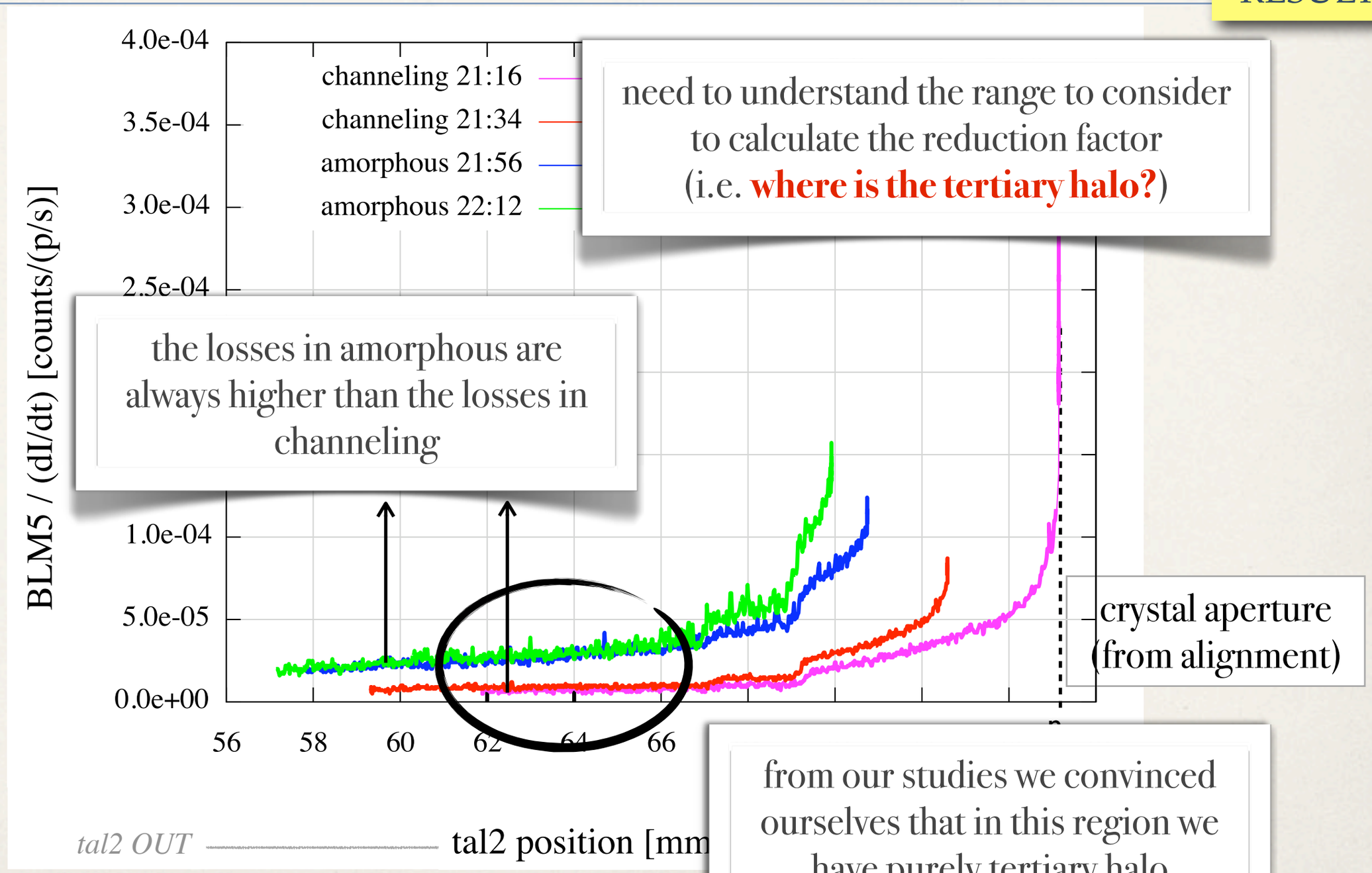
need to understand the range to consider to calculate the reduction factor (i.e. **where is the tertiary halo?**)

the losses in amorphous are always higher than the losses in channeling

crystal aperture (from alignment)

3- scraper scans: a full set

DATA ANALYSIS RESULTS



3- scraper scans: results

DATA ANALYSIS RESULTS

- the main result of the scraper scan is the **halo reduction factor**, i.e. the ratio between the population of the tertiary halo(meaning escaping to the W absorber) in amorphous and in channeling

Crystal	Time Channeling	Time Amorphous	Emittance m rad	Flux Channeling p/s	Flux Amorphous p/s	apertures Crystal sx	apertures TAC sx	halo reduction factor SCI K	halo reduction factor BLM5
3	2 Sept 21:18 → 21:29	2 Sept 22:13 → 22:23	1.9E-08	8.65e6÷16.15e6	7.60e6÷9.15e6	5.7	7.2	3.77÷3.97	3.70÷5.20
3	3 Sept 00:40 → 01:01	3 Sept 01:50 → 01:56	1.7E-08	7.45e6÷7.67e6	5.64e6÷6.24e6	6.7	8.3	1.34÷1.44	1.38÷1.54
3	3 Sept 00:03 → 00:14	3 Sept 01:50 → 01:56	1.7E-08	7.46e6÷7.92e6	5.64e6÷6.24e6	6.7	8.3	1.80÷2.10	2.08÷2.26
3	21 Oct 16:48 → 16:56	21 Oct 17:33 → 17:42	2.5E-08	7.02e6÷7.04e6	4.65e6÷6.10e6	4.1	5.5	3.10÷3.90	n.a

no discrepancy between scintillator and BLM data

- the amorphous losses are always larger than the channeling ones
- **halo reduction factors between 1.4 and 5.2** have been obtained for different system configurations

DATA ANALYSIS RESULTS

data analysis: comparison with simulation results

measurements:

1. **angular scans:**
   reduction of nuclear interaction rate when in channeling between 5 and 8
2. **collimator scans:**
   multi turn channeling efficiency of about 70%
3. **scraper scans:**
   tertiary halo reduction factors between 1.5 and 5

The fact that **crystal channeling collimation enhances the performances of a single-stage amorphous collimation system** is proved.

DATA ANALYSIS RESULTS

data analysis: comparison with simulation results

measurements:	simulations:

1. **angular scans:**
   reduction of nuclear interaction rate when in channeling between 5 and 8 — **factor 36 predicted!**
2. **collimator scans:**
   multi turn channeling efficiency of about 70% — **efficiency >95% predicted!**
3. **scraper scans:**
   tertiary halo reduction factors between 1.5 and 5 — **factor 10 predicted!**

The fact that **crystal channeling collimation enhances the performances of a single-stage amorphous collimation system** is proved.

However, the discrepancy between measurements and simulation is still under investigation; in particular the uniformity of crystal properties at the crystal edge is checked. Further test (especially in the extraction line) and dedicated simulations are foreseen.

Outline

INTRODUCTION

- UA9 experiment: how a crystal could help the LHC

DATA ANALYSIS RESULTS

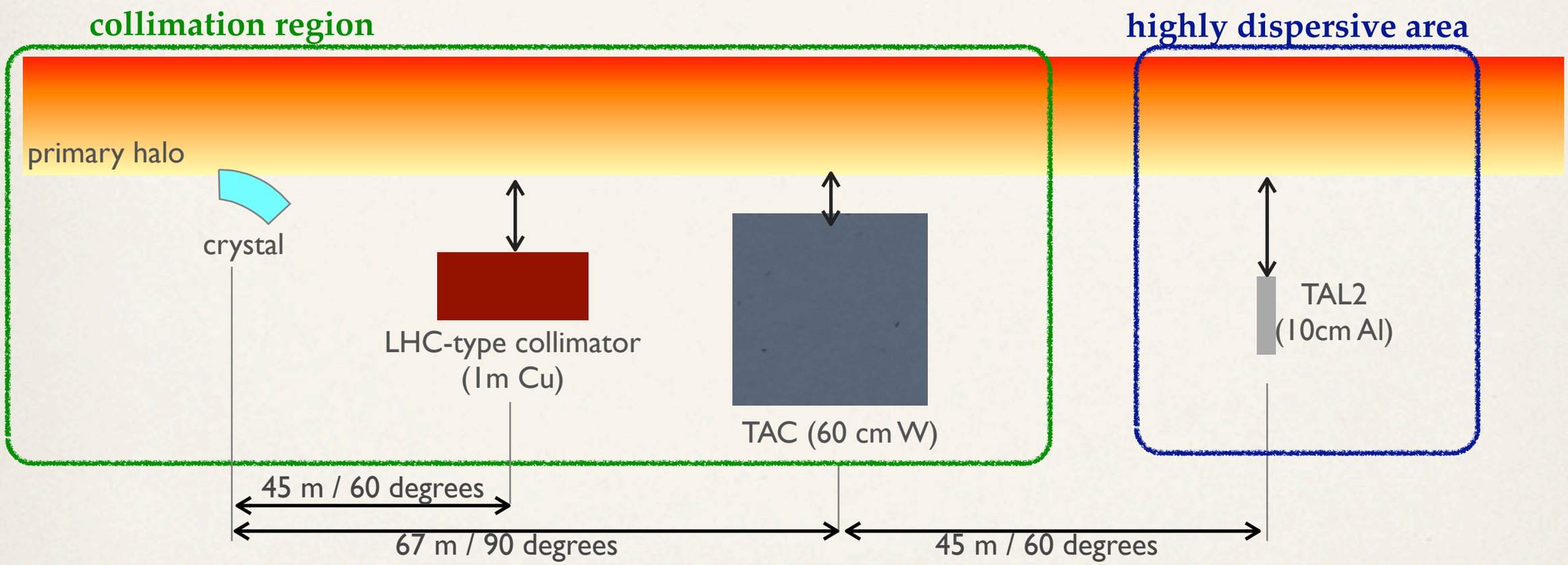
1. angular scans
2. collimator scans
3. scraper scans

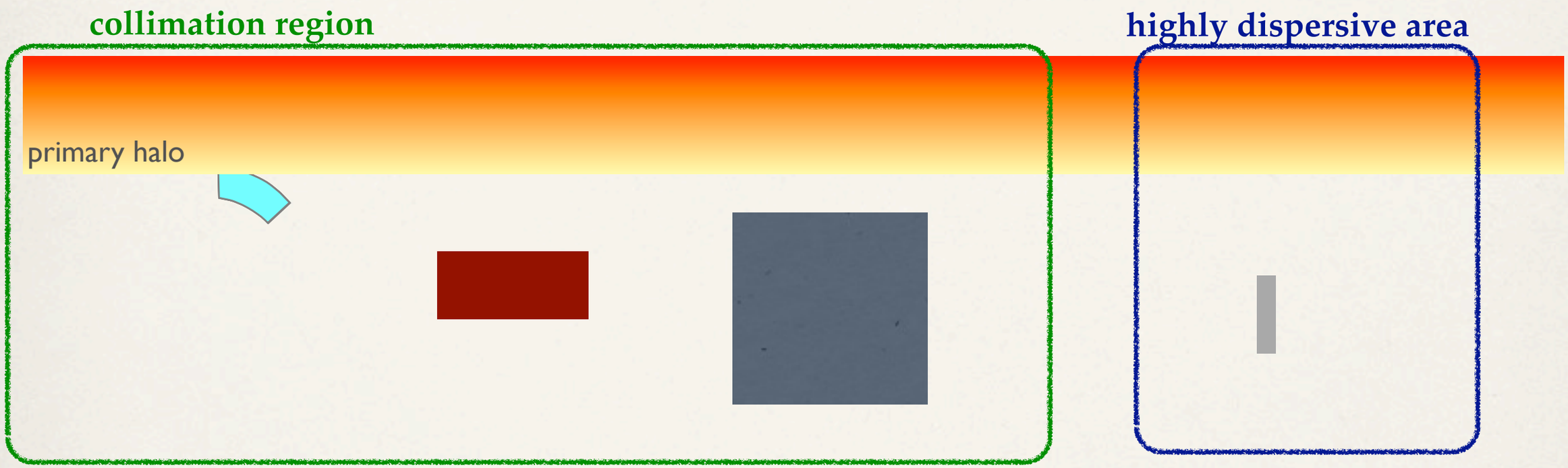
FUTURE PLANS

- future changes in the SPS layout
- from SPS to the LHC: letter of intents and ongoing studies

Changes in the SPS layout

- we have seen the conceptual layout...

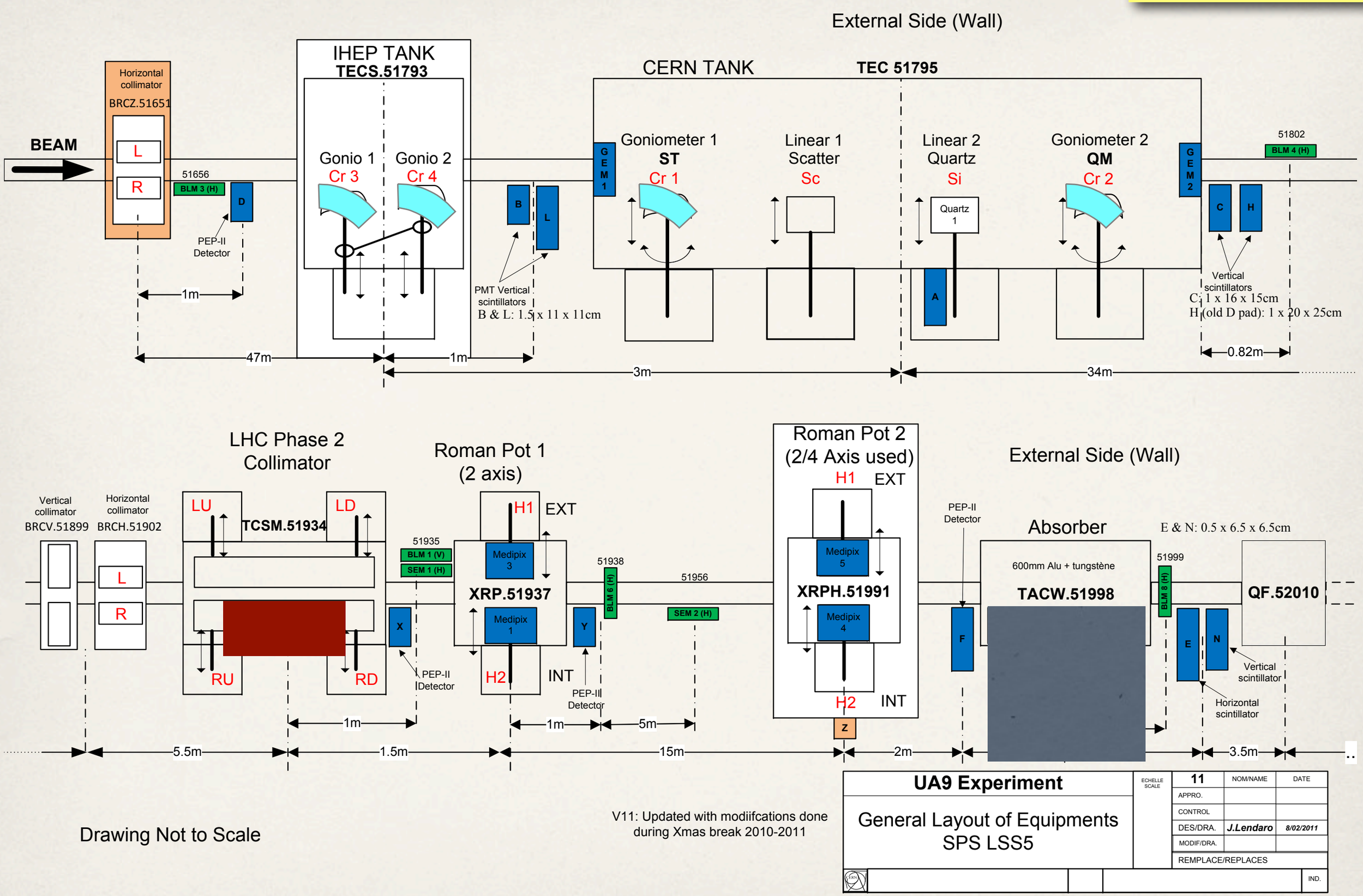




courtesy of S. Montesano

collimation region

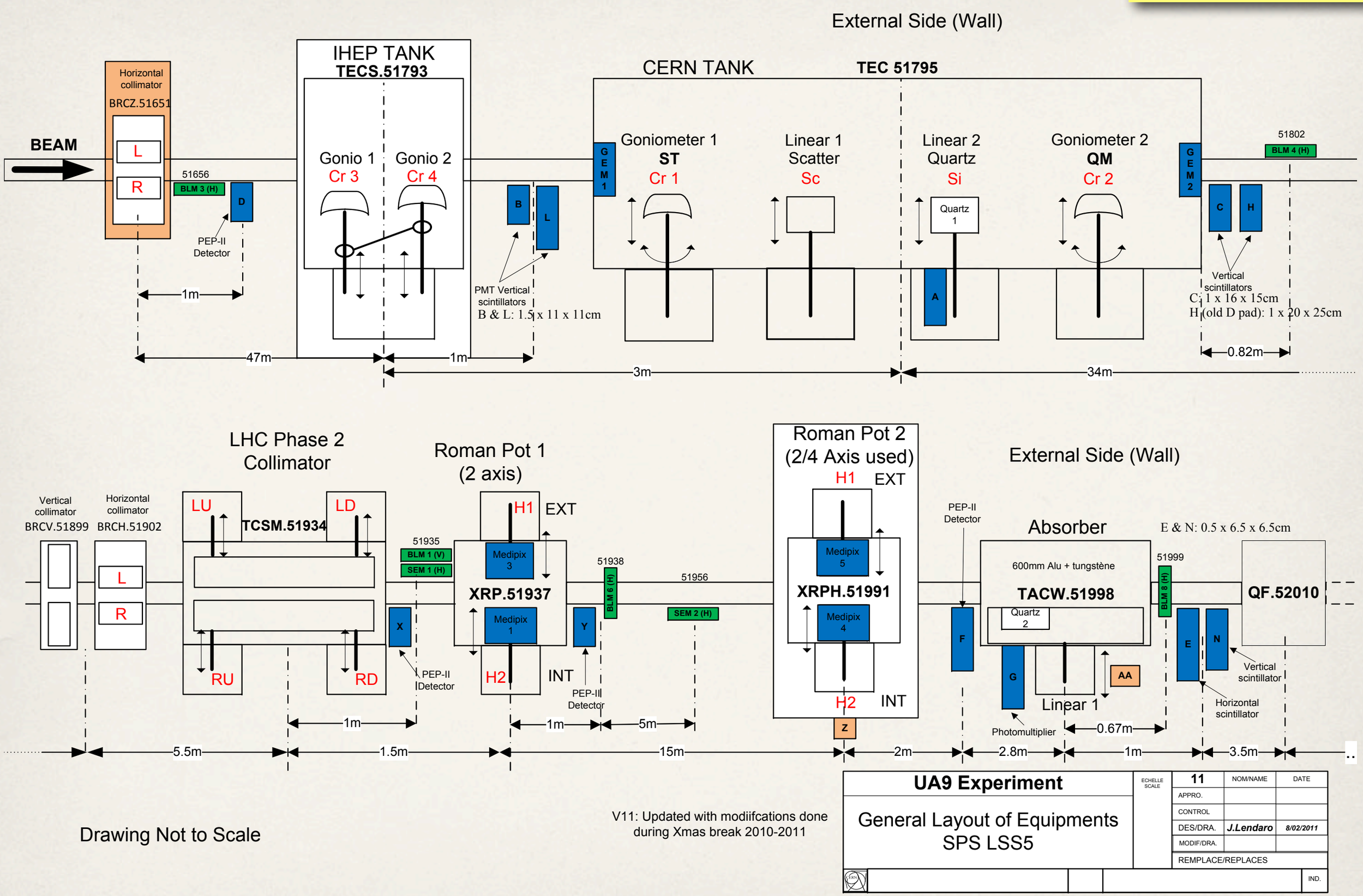
FUTURE PLANS



courtesy of S. Montesano

collimation region

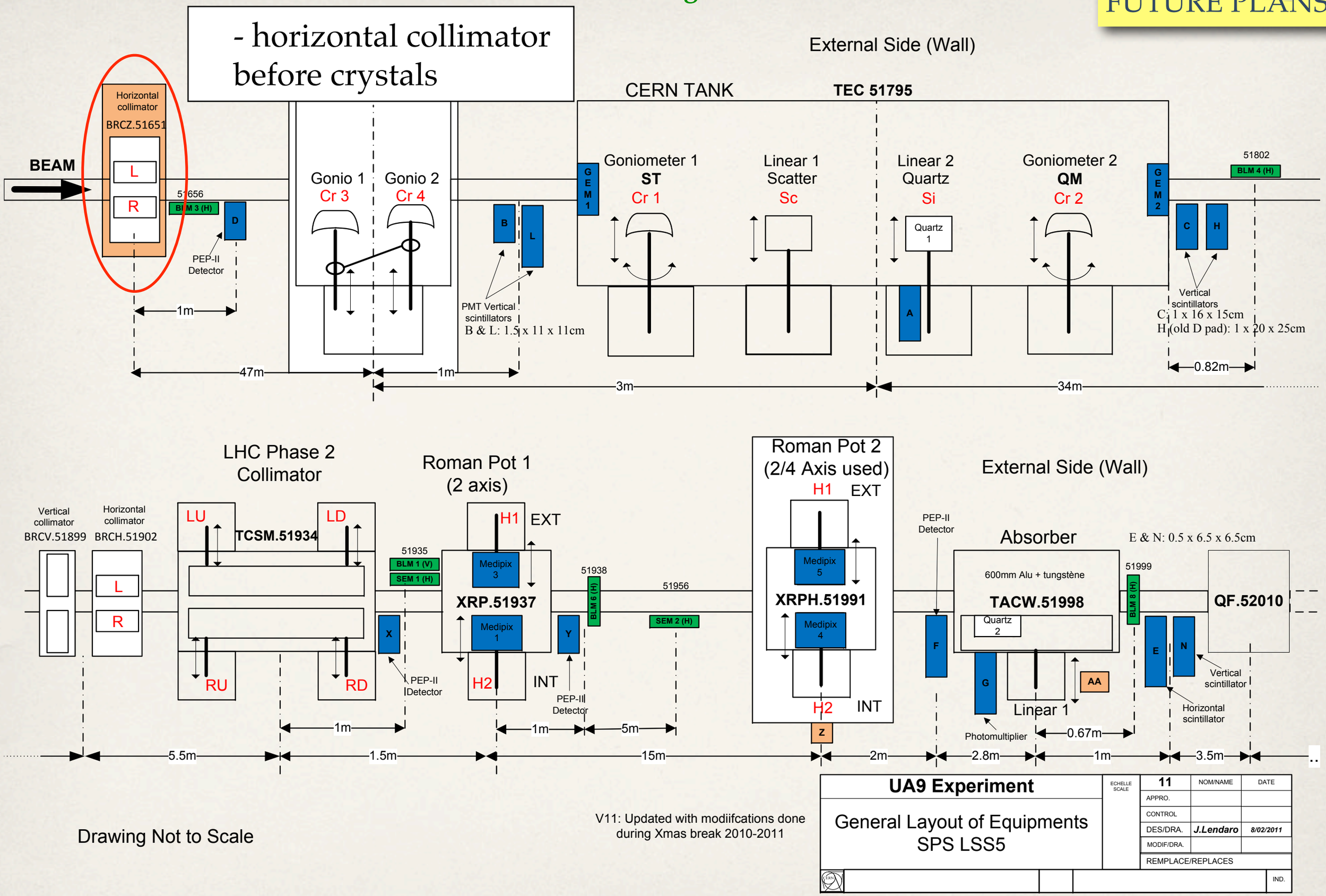
FUTURE PLANS



courtesy of S. Montesano

FUTURE PLANS

collimation region

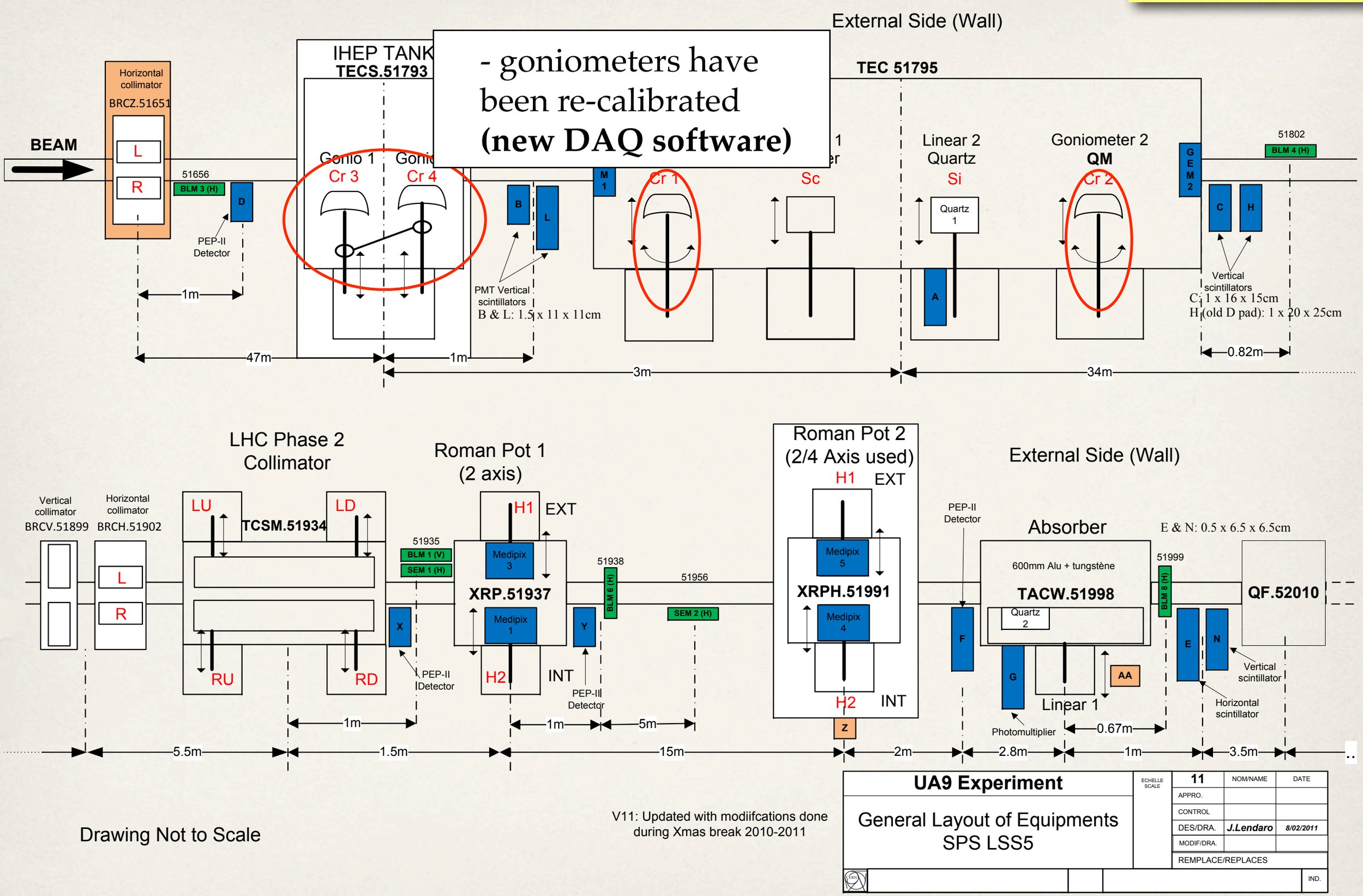


courtesy of S. Montesano

collimation region

FUTURE PLANS

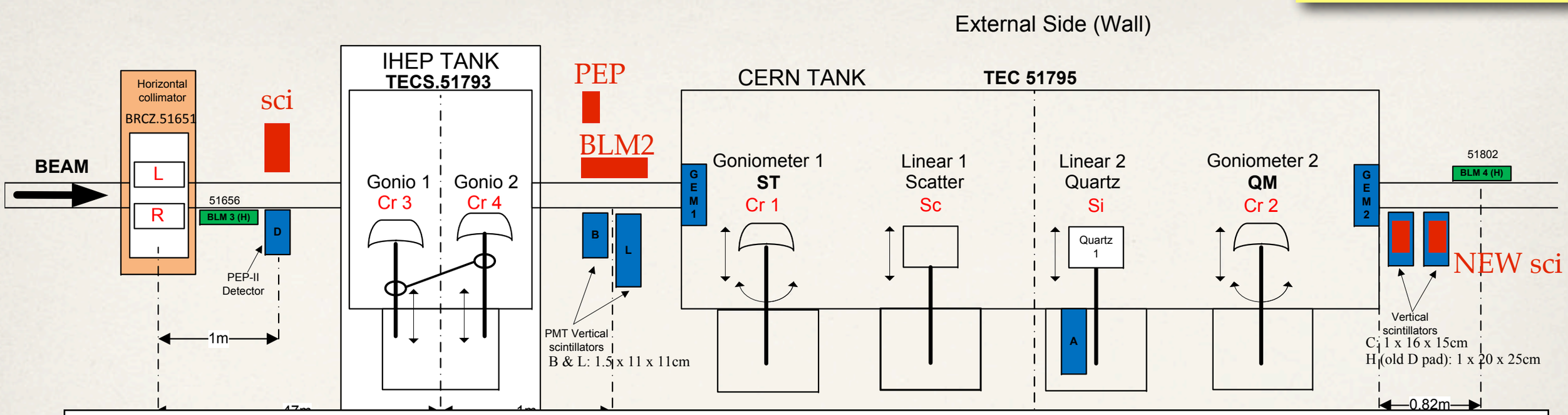
- goniometers have been re-calibrated **(new DAQ software)**



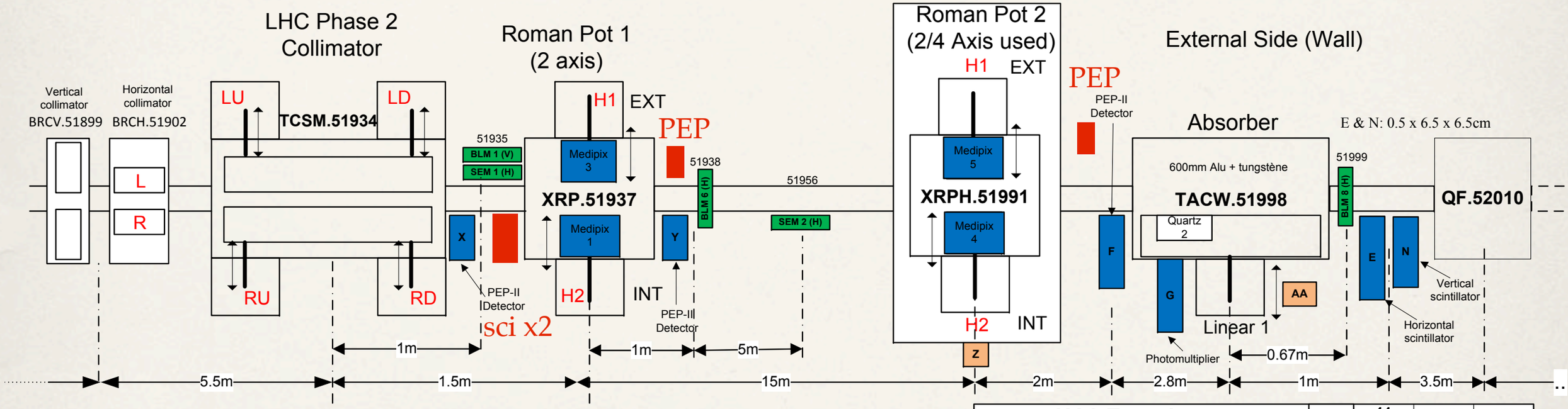
courtesy of S. Montesano

collimation region

FUTURE PLANS



- in critical points: **always 2 scintillators (in coincidence)+ 1 BLM + PEP detectors**



Drawing Not to Scale

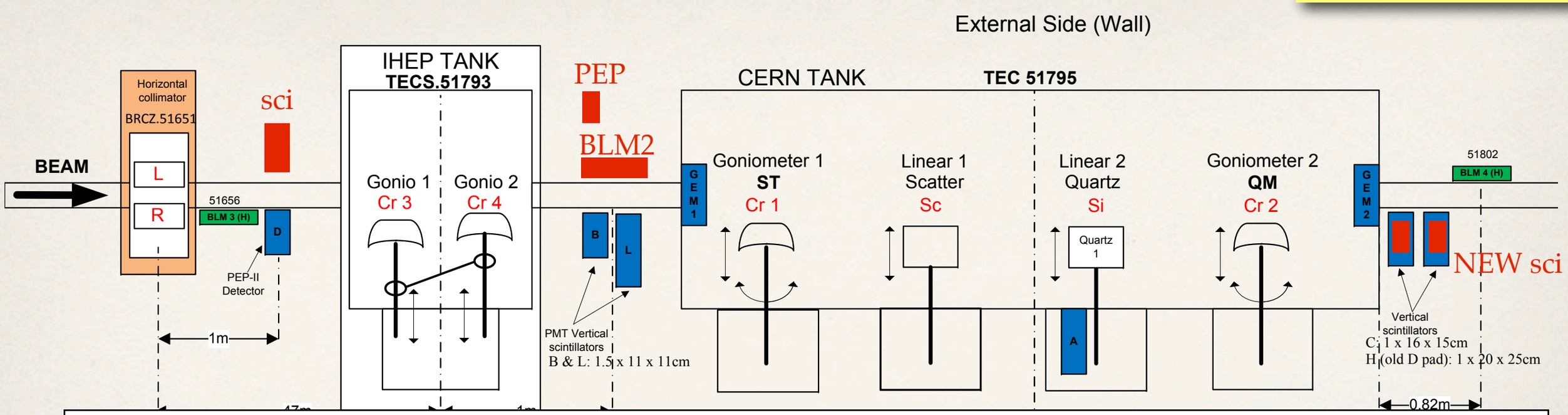
V11: Updated with modiifcations done during Xmas break 2010-2011

UA9 Experiment	ECHELLE SCALE	11	NOM/NAME	DATE
General Layout of Equipments SPS LSS5		APPRO.		
		CONTROL		
		DES/DRA.	J.Lendaro	8/02/2011
		MODIF/DRA.		
		REMPLACE/REPLACES		
		IND.		

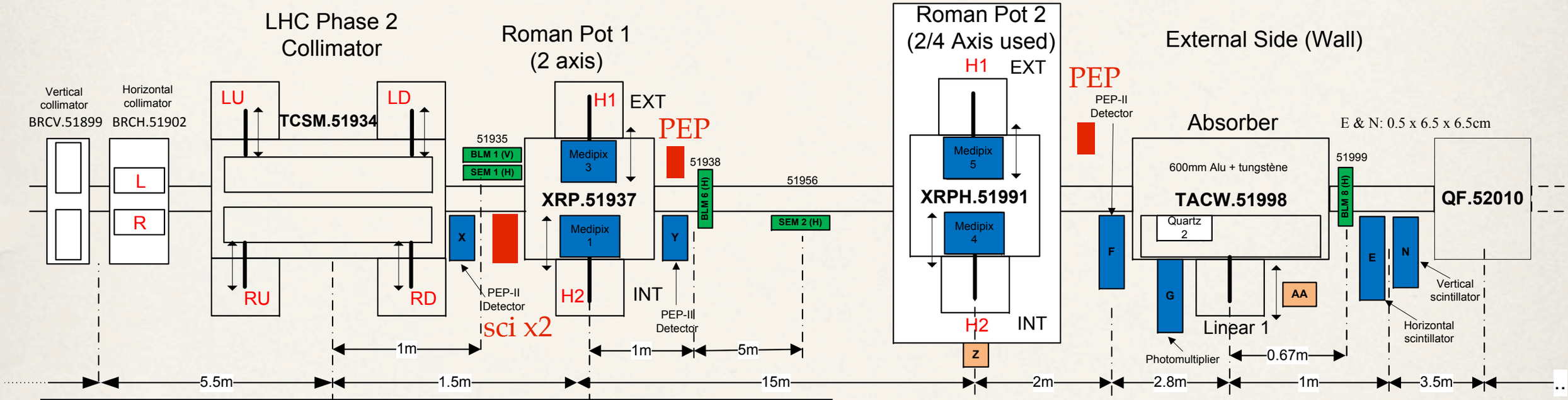
courtesy of S. Montesano

collimation region

FUTURE PLANS



- in critical points: **always 2 scintillators (in coincidence)+ 1 BLM + PEP detectors**



- all scintillators threshold has been re-calibrated with radioactive source - some of them substituted
- **for new scintillators, smaller active areas**

modiifcations done
eak 2010-2011

UA9 Experiment	ECHELLE SCALE	11	NOM/NAME	DATE
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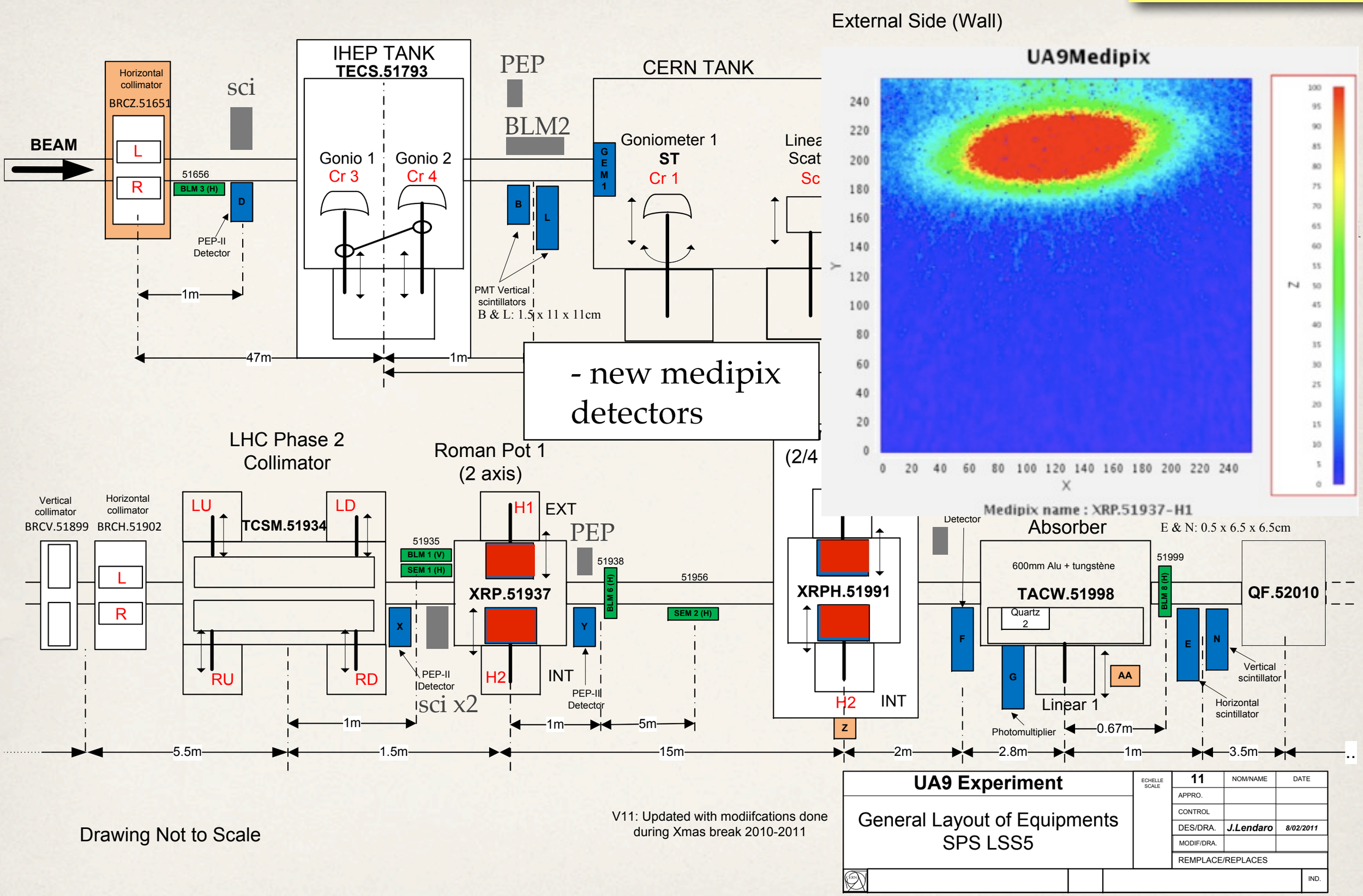
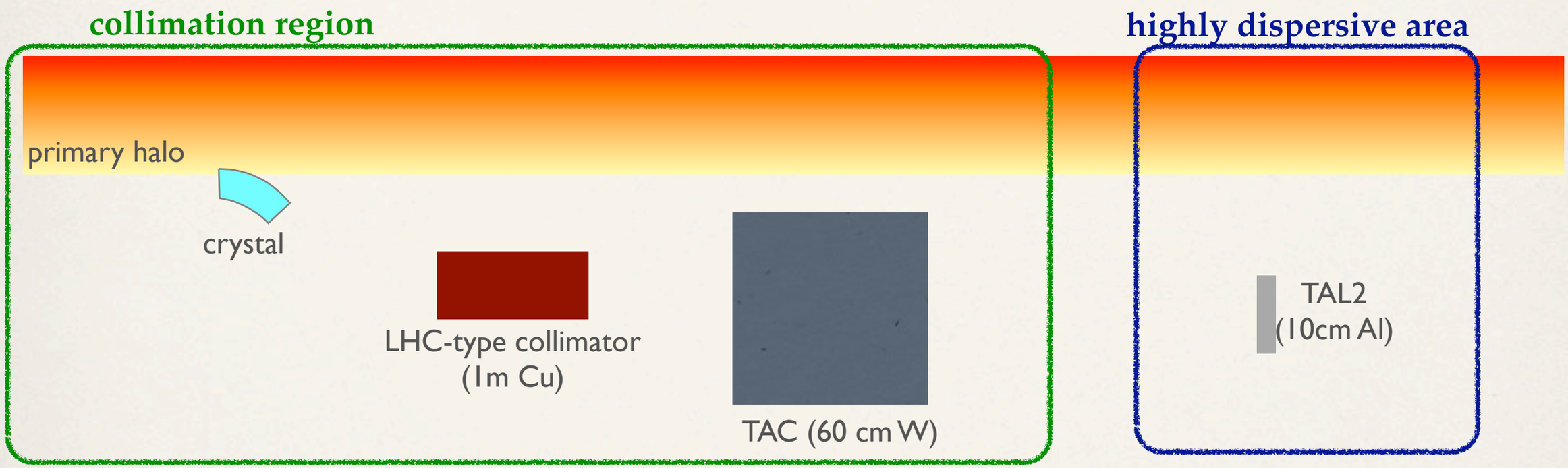
		CONTROL		
		DES/DRA.	J.Lendaro	8/02/2011
		MODIF/DRA.		
		REMPLACE/REPLACES		
				IND.

courtesy of S. Montesano

collimation region

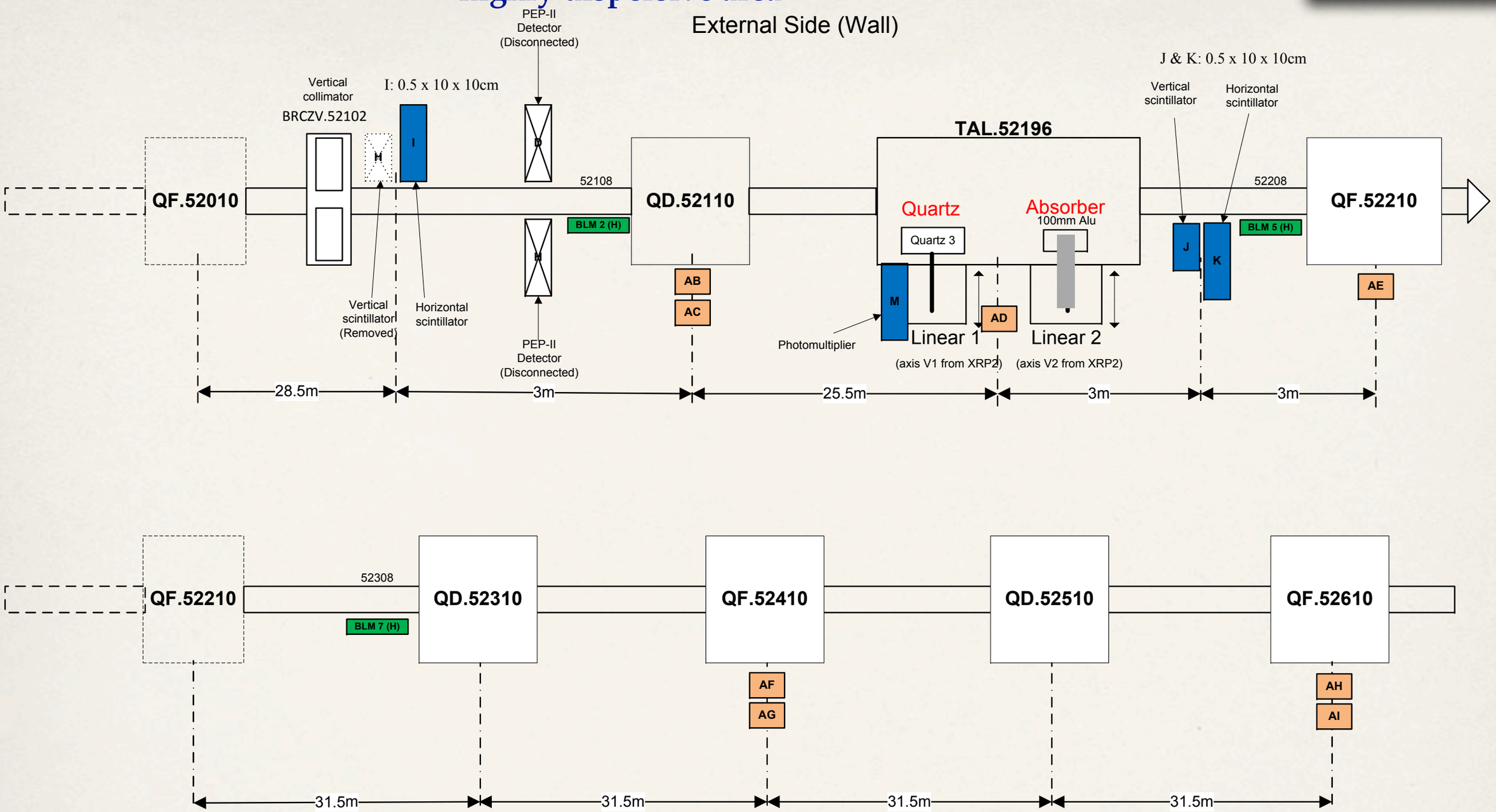


courtesy of S. Montesano



courtesy of S. Montesano

highly dispersive area



Drawing Not to Scale

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courtesy of S. Montesano

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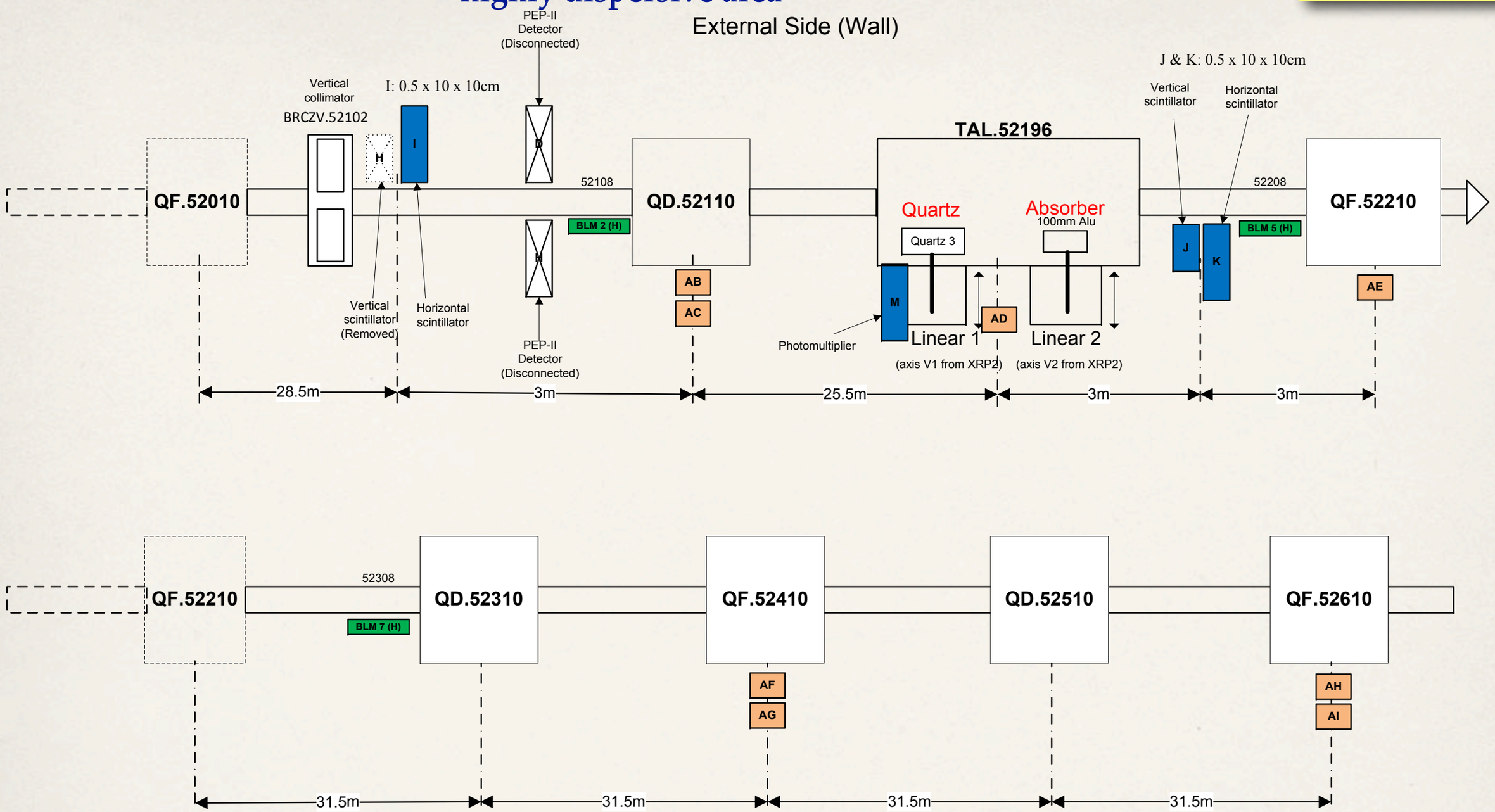

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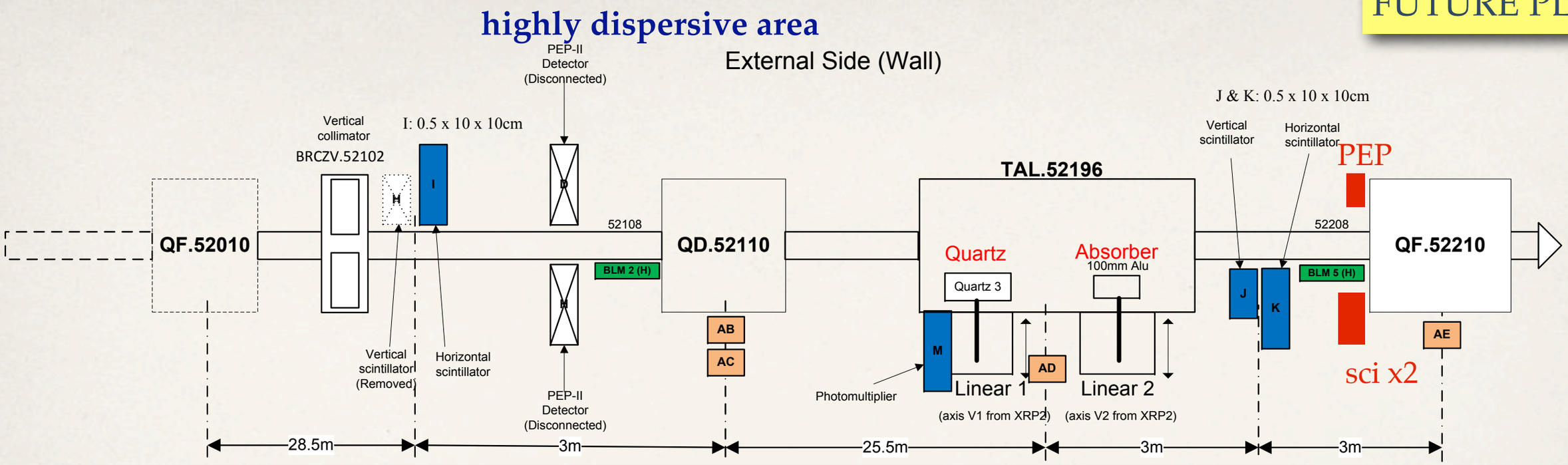
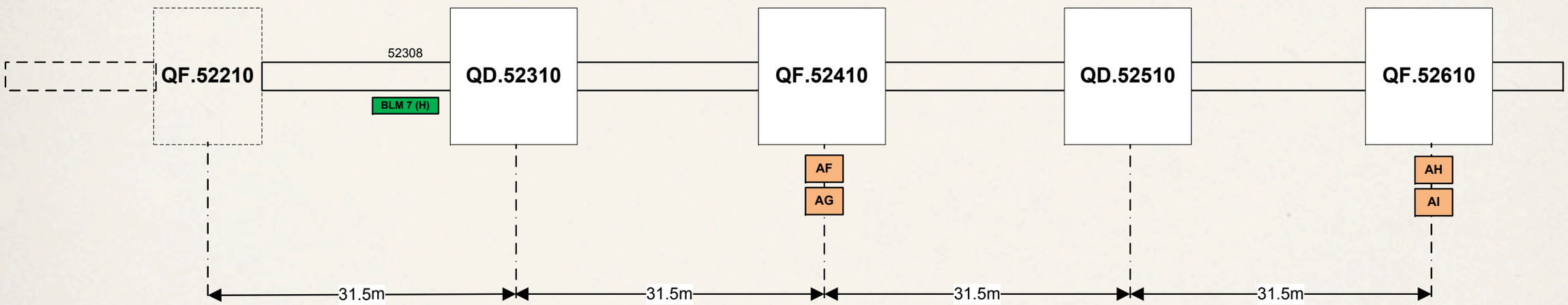
courtesy of S. Montesano



- in critical points: **always 2 scintillators (in coincidence)+ 1 BLM + PEP detectors**



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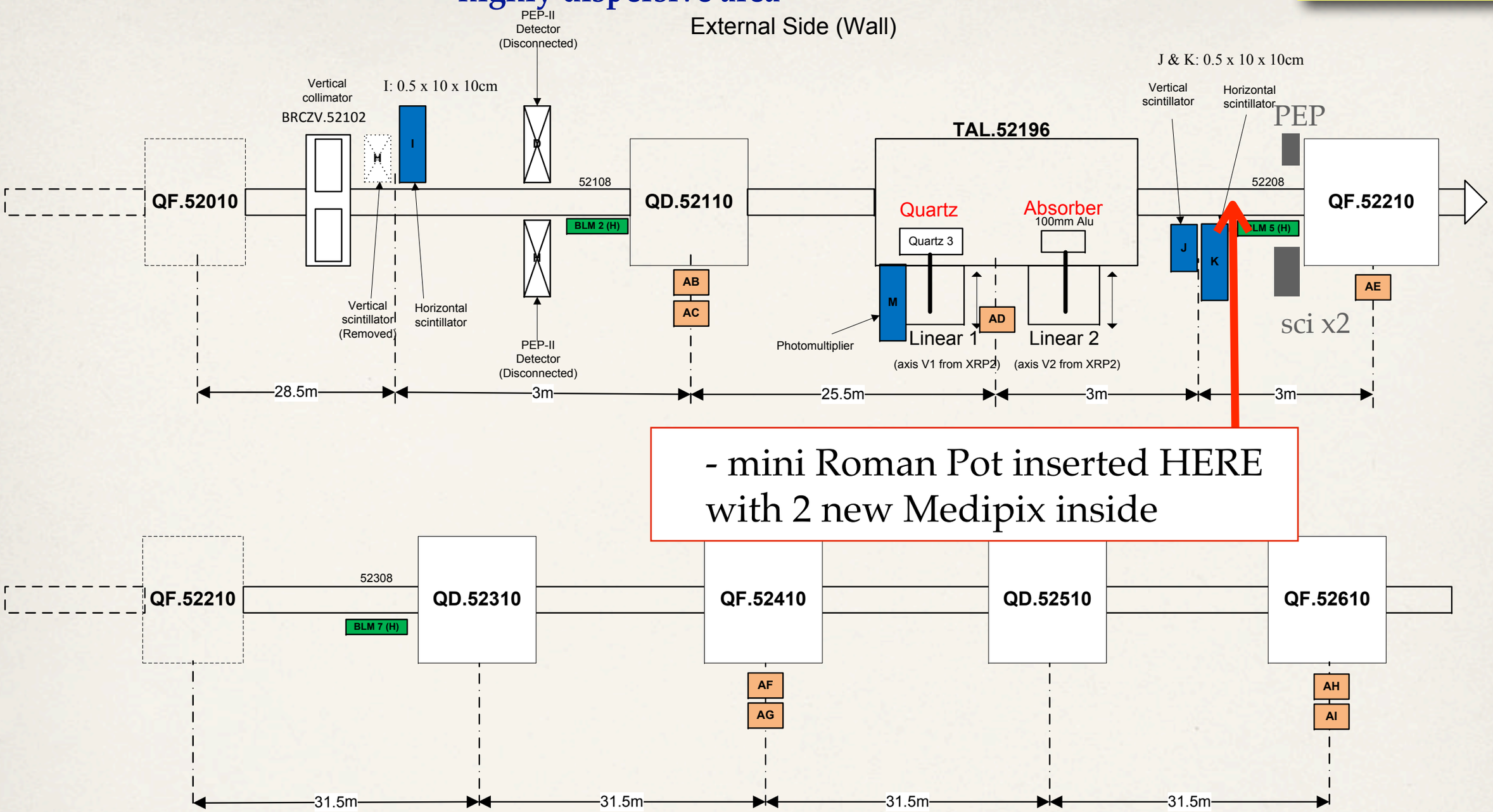
				IND.

courtesy of S. Montesano

highly dispersive area



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		CONTROL		
		DES/DRA.	J.Lendaro	8/02/2011
		MODIF/DRA.		
		REMPLACE/REPLACES		
				IND.

courtesy of S. Montesano

important changes in layout

for the 2011 MDs:

1. horizontal collimator before crystals
2. goniometers have been re-calibrated (-> new DAQ software)
3. in critical points: always 2 scintillators (in coincidence)+ 1 BLM + PEP detectors
4. new medipix (tot. 6 in H plane)
5. all scintillators threshold has been re-calibrated with radioactive source - some of them substituted
6. for new scintillators, smaller active areas
7. mini RP in dispersive areas

in future/ under discussion:
change crystals (single crystals), new scatterer in TAL2 location, fibrometer in vertical, test of new goniomenters types (in view of LHC requirements - one order of magnitude higher resolution/reproducibility...), new detector types...

… and channeling future measurements

- Use of newly installed **medipix detector in scraper scan** (analysis of the tertiary halo)
- Study of the effective rate of particles impinging on the crystal by using **Cherenkov detectors**
- **Measurements at high intensity: detecting change of losses along the machine (SPS blms)**
- Influence of off-momentum particles in our studies: **lifetime and debunching studies (mountain range...)**

different beam optics/set up

- different energies 120-270 GeV single bunch 1e11
- high intensity 48 or 12 bunches x1e11 (max 5e12)
- low intensity multi bunch 12 bunches *1e10
- low-gamma transition optics (higher dispersion for debunching studies)

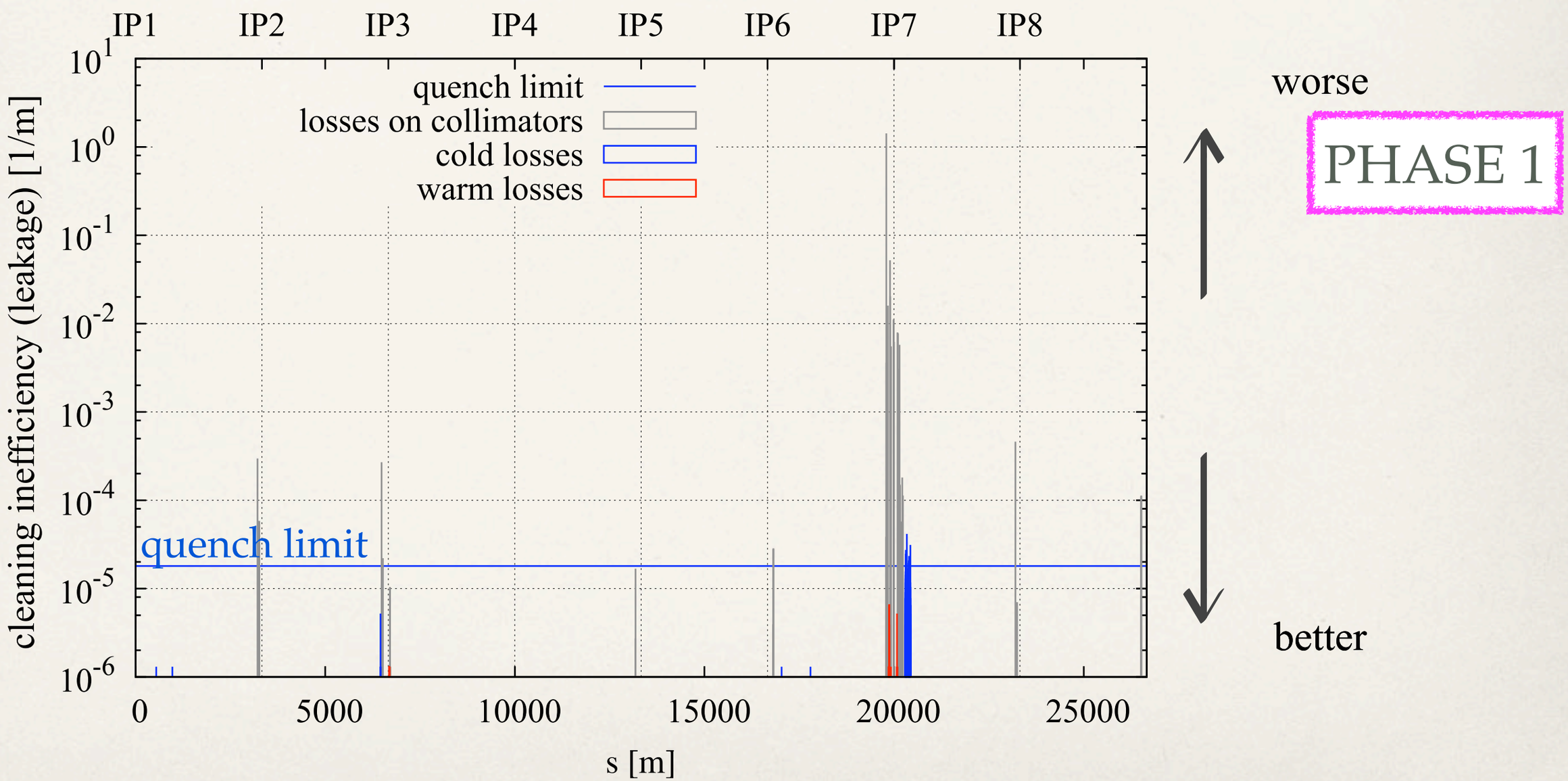
toward the LHC

- A LETTER OF INTENT is being prepared:
  the plan is to install a **3 primary crystal collimators for horizontal, vertical and skew orientation** during the long shutdown (currently scheduled beginning 2013)

- A first set of simulations of the crystal collimation system for the LHC (horizontal and vertical orientation) for the 7 TeV case have been already done by the collimation team.

toward the LHC: first simulations

first simulations/optimization studies performed with SixTrack for 7 TeV case (V.Previtali PHD Thesis)



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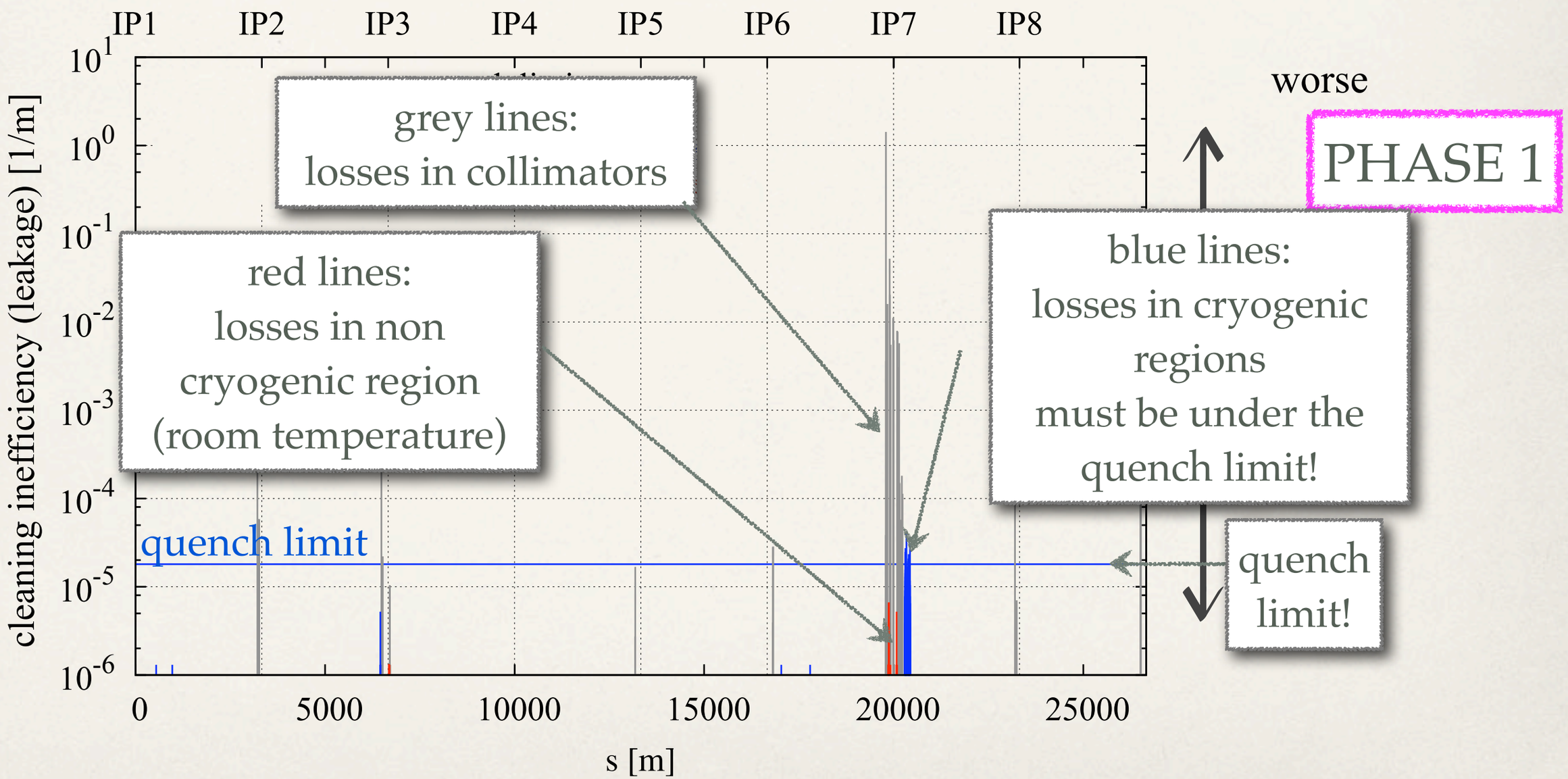

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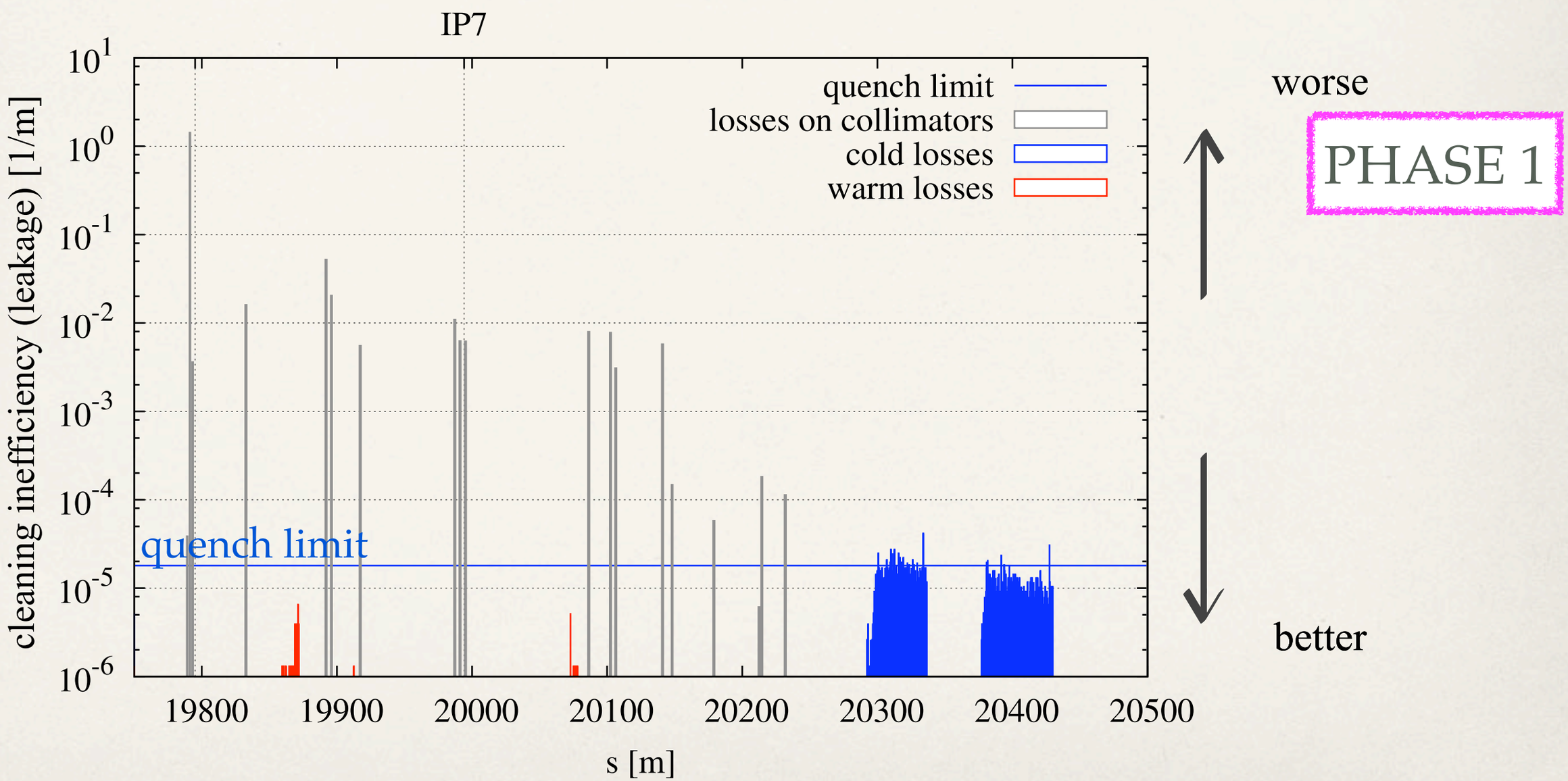

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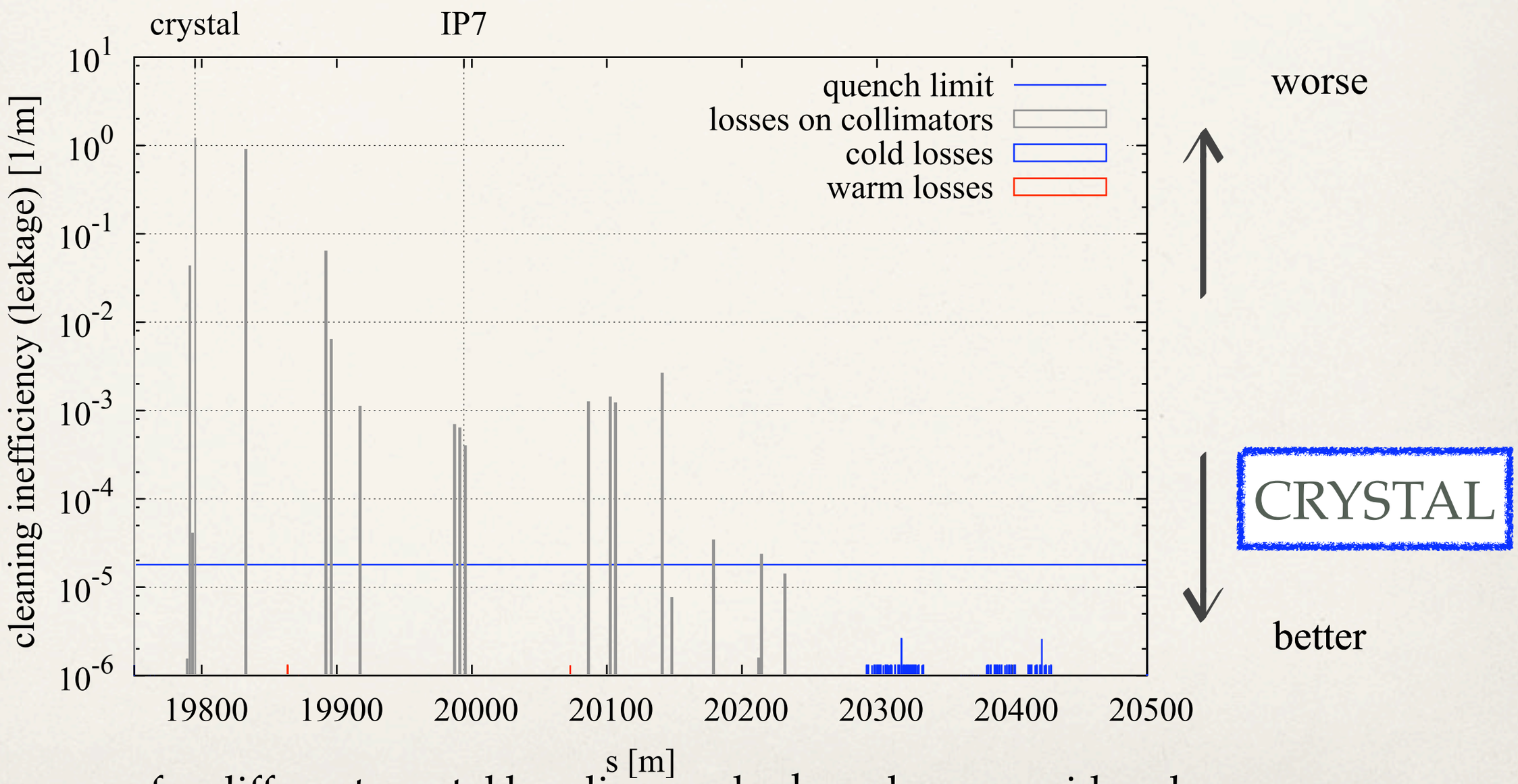
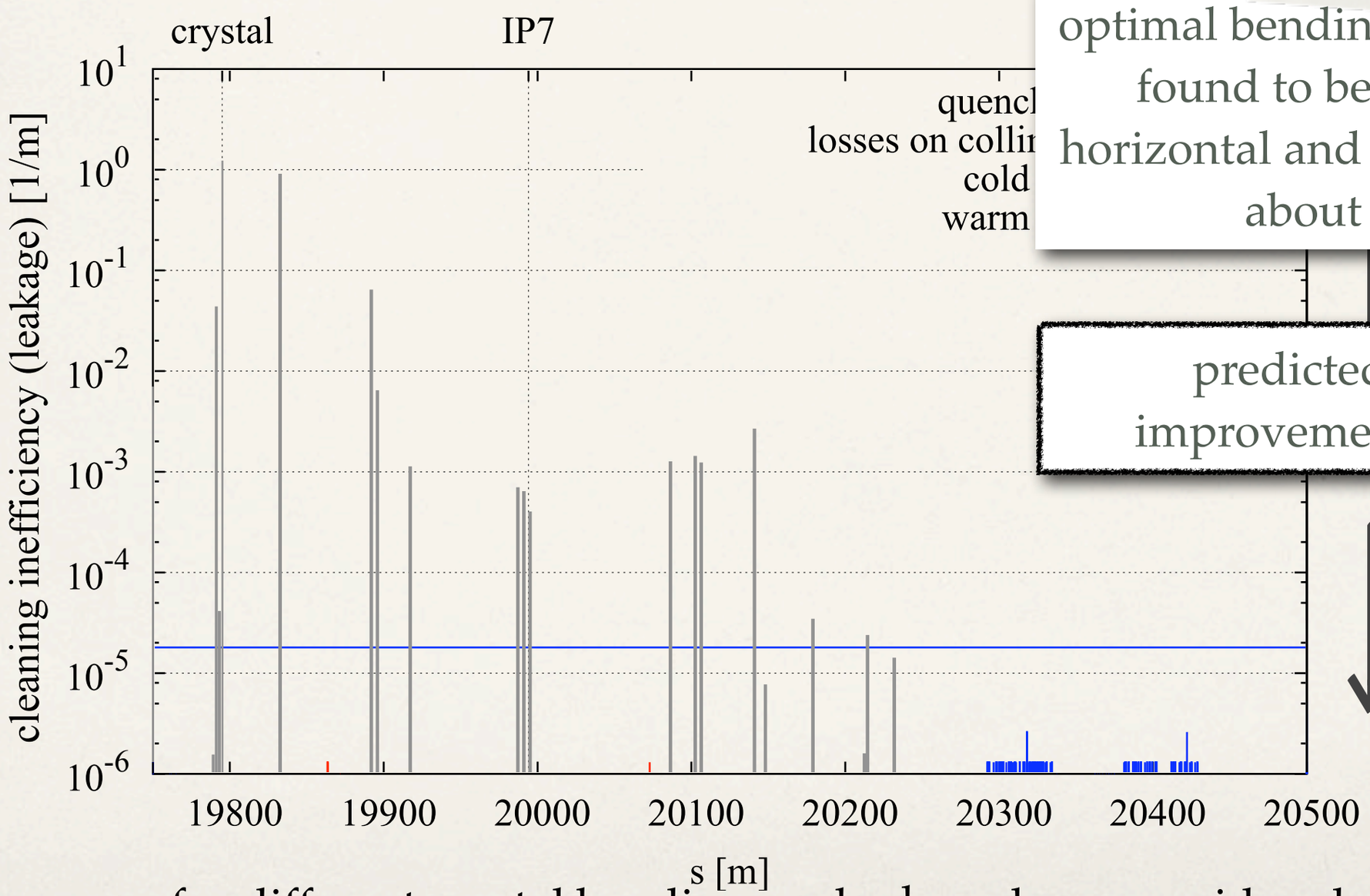


- Loss maps for different crystal bending angles have been considered

toward the LHC: first simulations

first simulations/optimization studies performed with SixTrack for 7 TeV case (V.Previtali PHD Thesis)



optimal bending angle has been found to be, both for the horizontal and the vertical case, about 40 μrad

predicted efficiency improvement: ~ factor 15

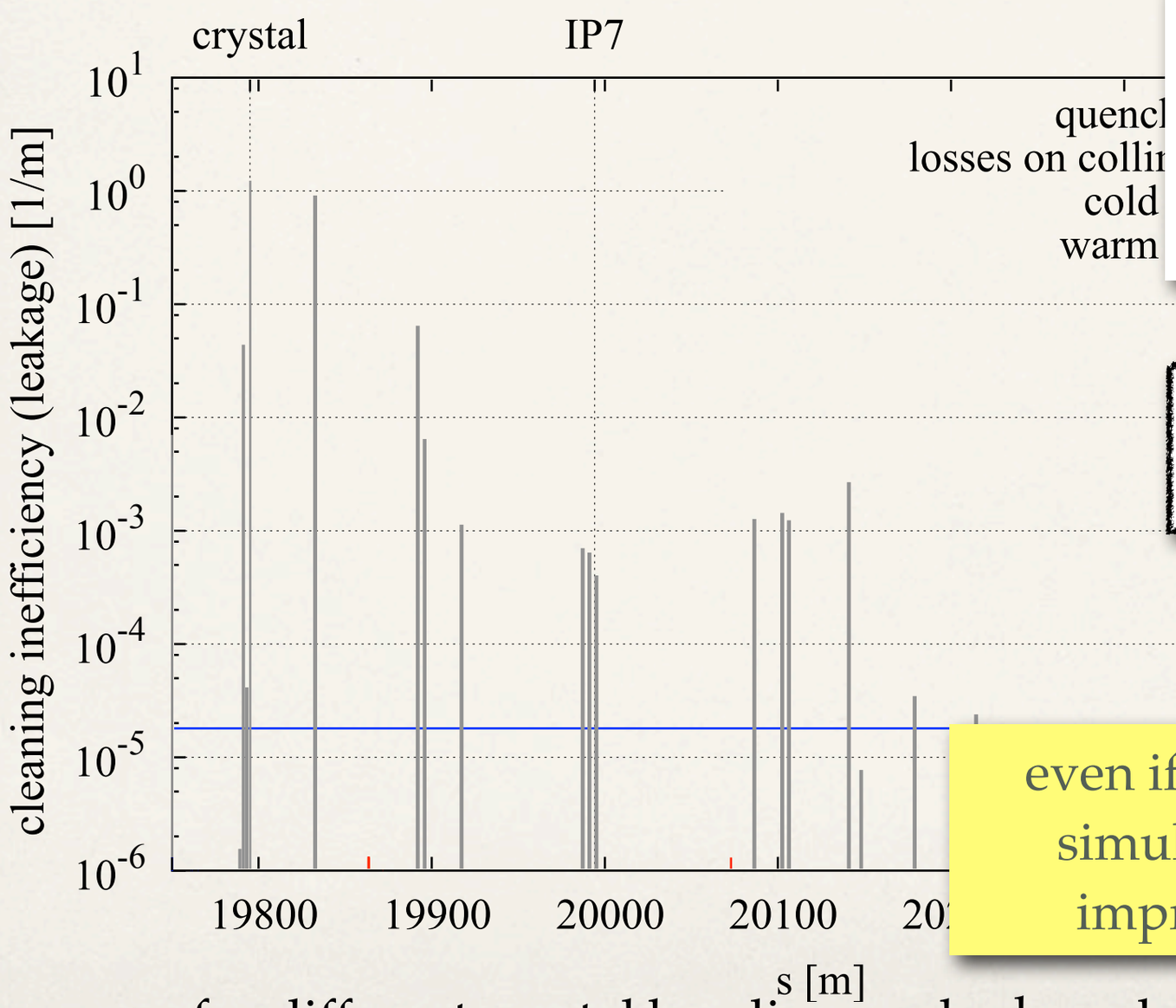
CRYSTAL

better

- Loss maps for different crystal bending angles have been considered

toward the LHC: first simulations

first simulations/optimization studies performed with SixTrack for 7 TeV case (V.Previtali PHD Thesis)



optimal bending angle has been found to be, both for the horizontal and the vertical case, about 40 μrad

predicted efficiency improvement: ~ factor 15

CRYSTAL

even if the same discrepancy with simulation is found, a factor ~5 improvement is still expected

- Loss maps for different crystal bending angles have been considered

… but still a long way!

- Simulation studies for the optimal crystal collimation scenario in one LHC ring relying on three crystal/goniometer setups and three roman-pots. -> Fix the locations of the three crystals.
- Infrastructure needed asap: additional cables, segmented pipes with vacuum valves where the installation of crystals and roman pots can be made with a minimal impact on vacuum in a minimal time.
- Three crystal/goniometer setups based in the IHEP/PNPI technology or some other industrial solution (under evaluation) and three mini-roman pots based on CERN technology already available.
- Tests with beam at the earliest in 2013! Mechanical studies (thermal stability, robustness..) of the crystal and the crystal holder.
- Energy deposition studies (usually performed with FLUKA/ANSYS) to compute the secondary losses downstream the collimators.
- Mechanical studies (FLUKA+ANSYS) on the secondary collimator which receive the channeled beam.
- Possible improvements for ion collimation (studies on ion fragmentation in crystal).
- Possible use of Multiple Volume Reflection for collimation.

conclusions

DATA ANALYSIS RESULTS

- complete characterization of the crystal collimation system is made by angular scan, collimator scan, scraper scan measurements.
- crystal collimation works and is proved to reduce the tertiary halo of up to a factor 5.
- discrepancies with the simulated results will be further investigated with:
  1. future measurements (also in the H8 extraction line).
  2. dedicated simulations.

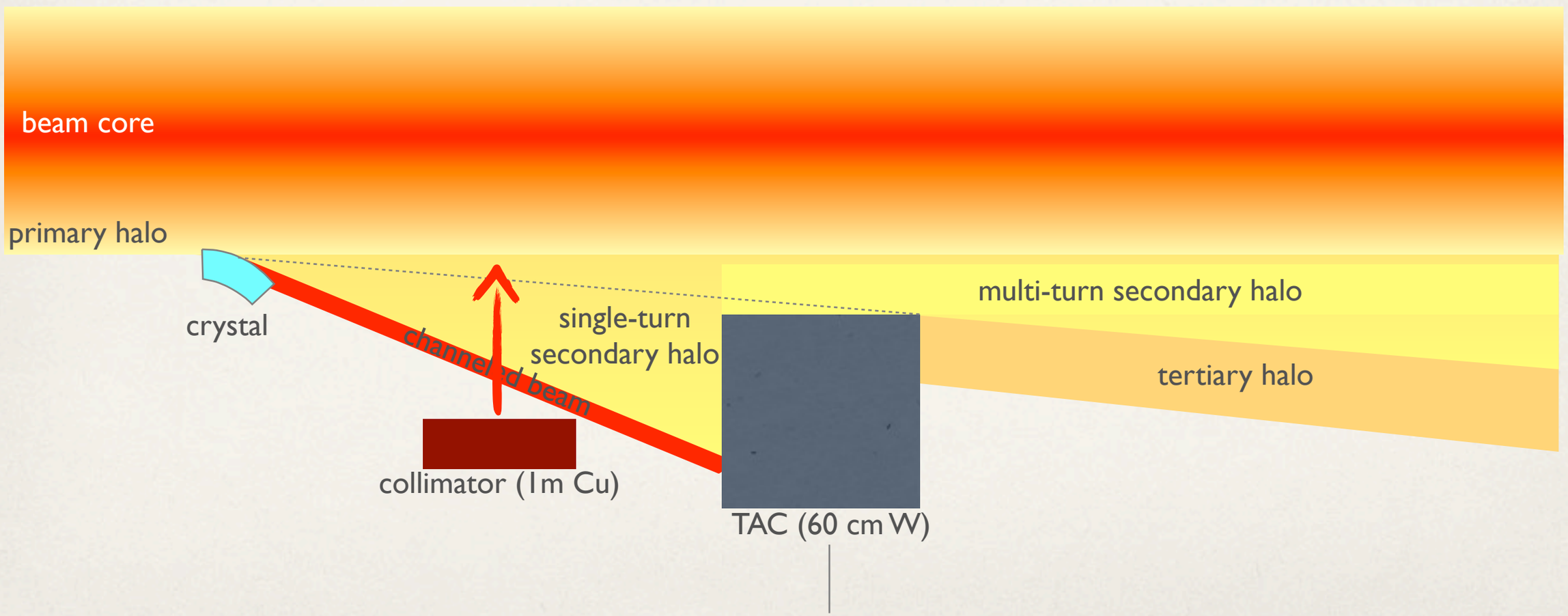
FUTURE PLANS

- a full set of layout changes are foreseen to be completed by the next experimental campaign: this will allow us to understand beam (and crystal) features.
- a high intensity beam is being prepared to measure the effective change of losses along the machine with the SPS BLMs.
- a letter of intent is being prepared for asking the insertion of three crystals in the existing collimation system, in the LHC IP7, by the end of 2012.
- on the simulation side, a wider campaign of Sixtrack simulations is foreseen to study optimal setting for the crystal collimation option.

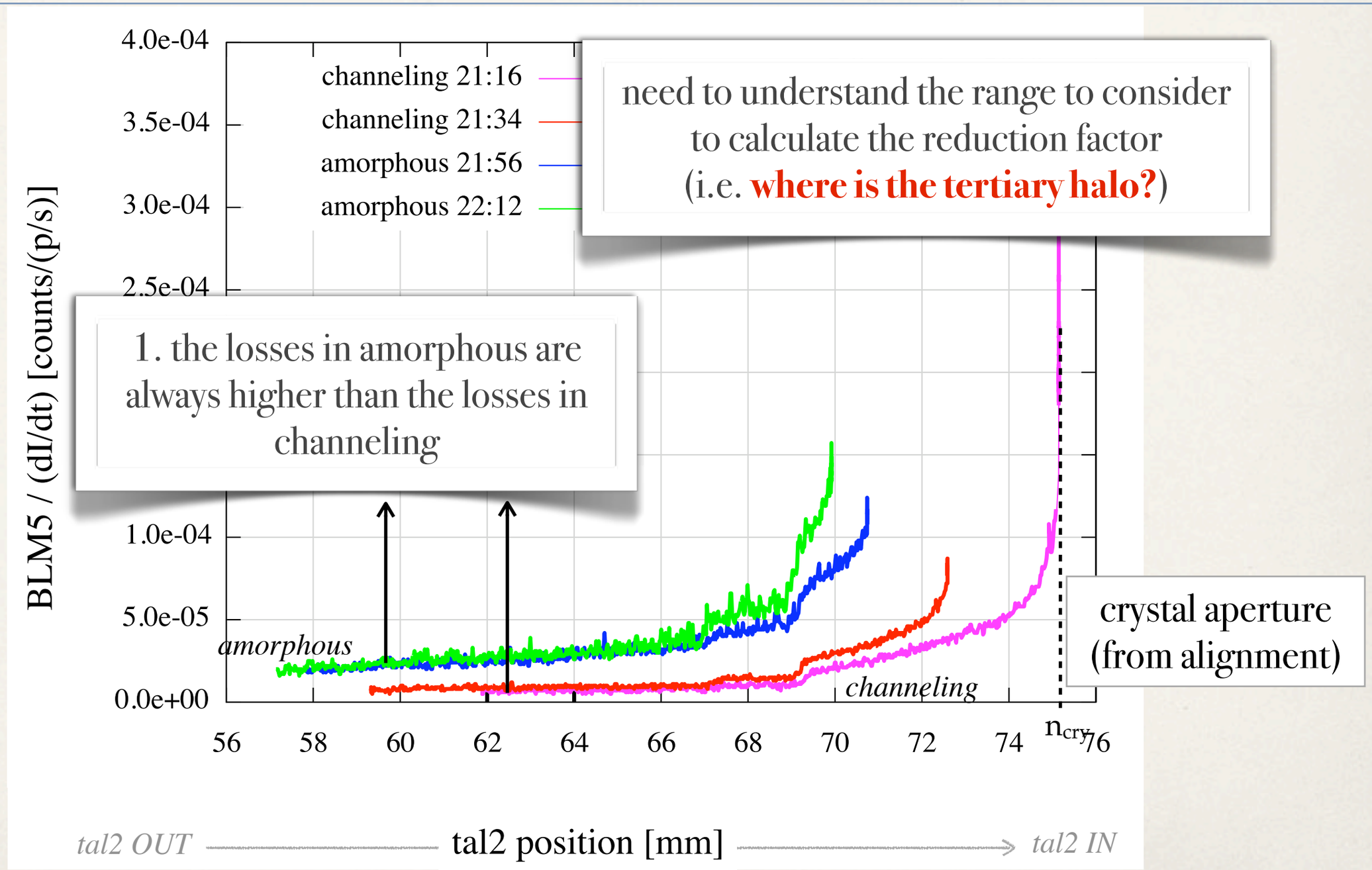
thank you!

… but still a long way!

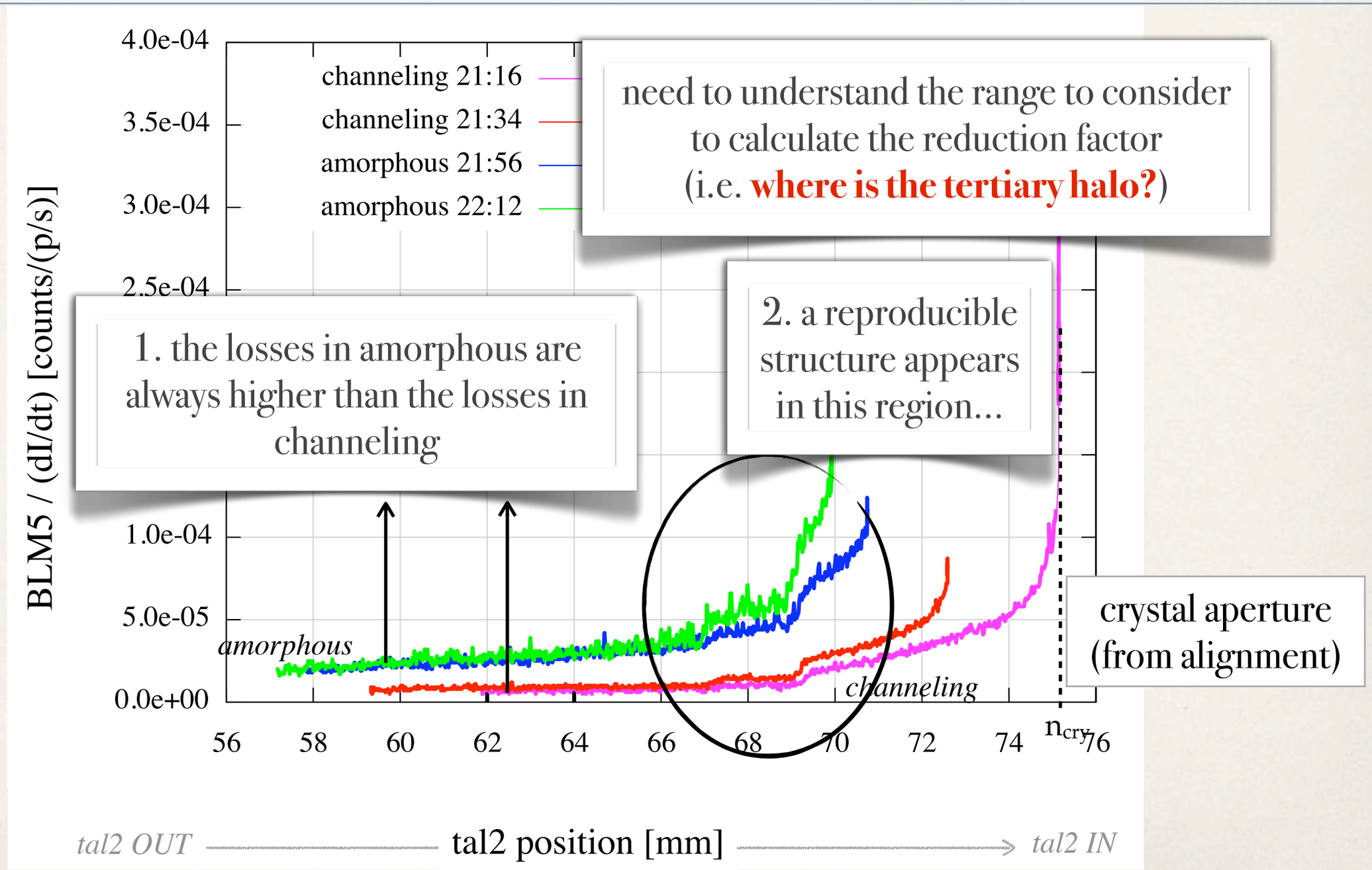
- ☑ Technicalities: precision, reproducibility and stability of the goniometer.
- ☐ Mechanical studies (thermal stability, robustness..) of the crystal and the crystal holder.
- ☐ Energy deposition studies (usually performed with FLUKA/ANSYS) to compute the secondary losses downstream the collimators/
- ☐ Mechanical studies (FLUKA+ANSYS) on the beam dumper: study a dedicated absorber capable of managing high power depositions.
- ☐ Simulation studies for the skew orientation (changes in the code).
- ☐ Simulation studies for intermediate energies (only the 7 TeV case has been studies).
- ☐ Possible improvements for ion collimation (studies on ion fragmentation in crystal).
- ☐ Possible use of Multiple Volume Reflection for collimation.


beam core
primary halo
crystal
channeled beam
single-turn
secondary halo
multi-turn secondary halo
tertiary halo
collimator (1m Cu)
TAC (60 cm W)

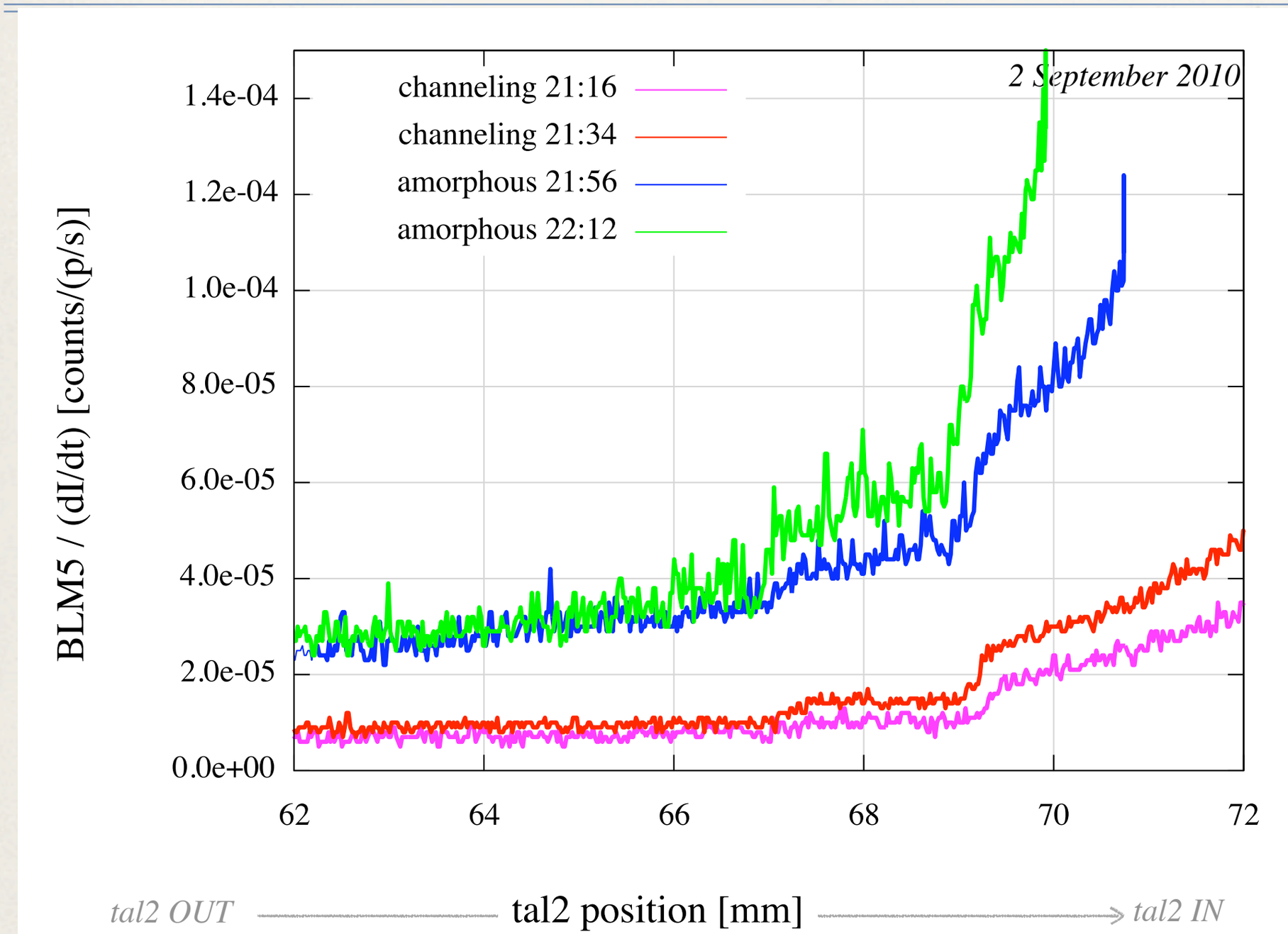
a full set of scraper scans

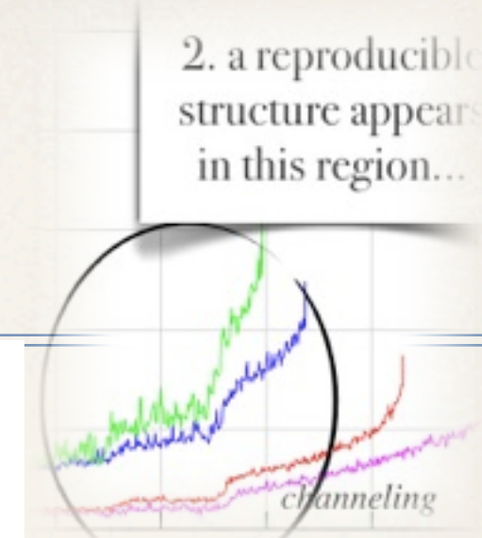


a full set of scraper scans



a closer look...

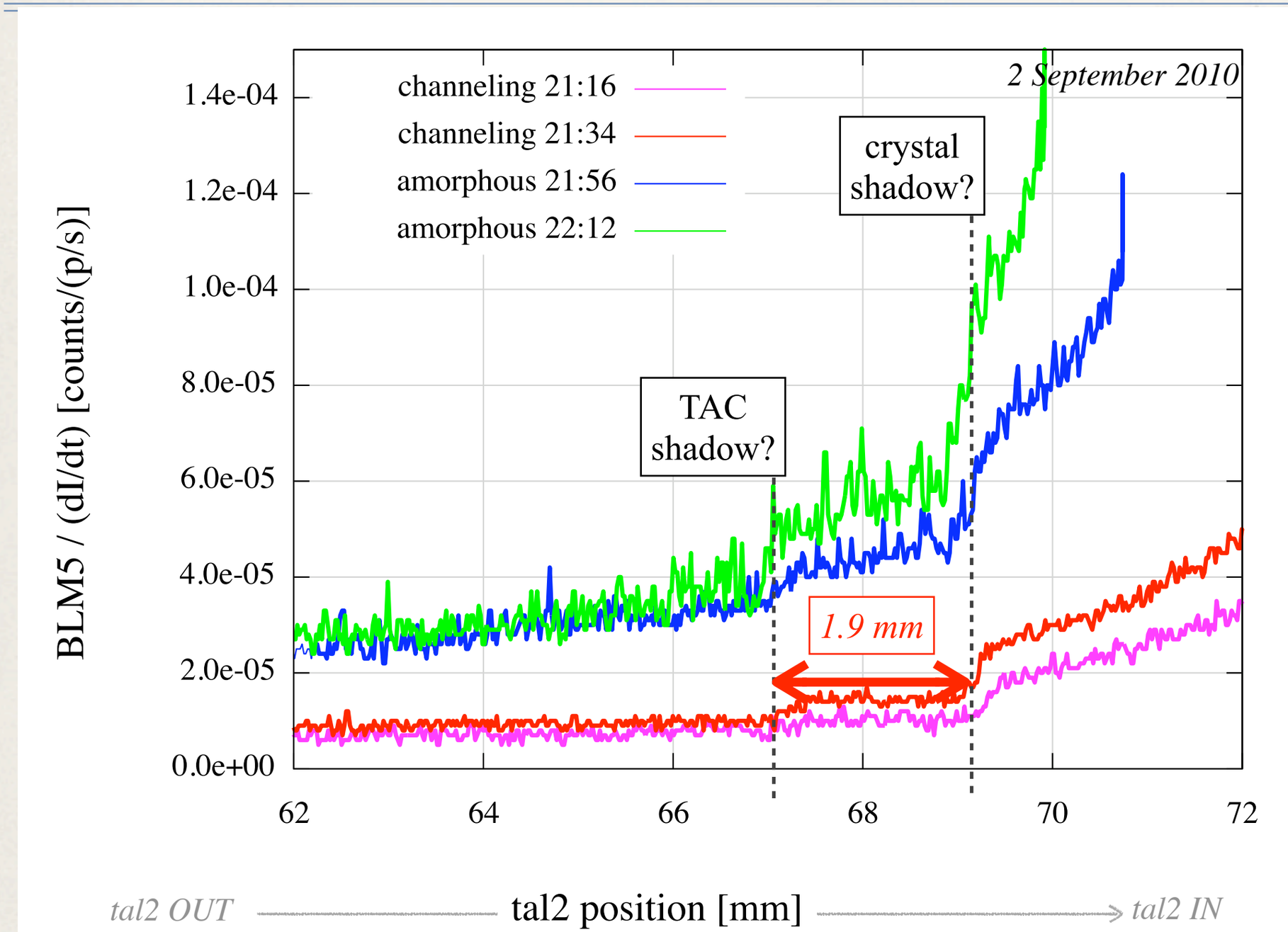


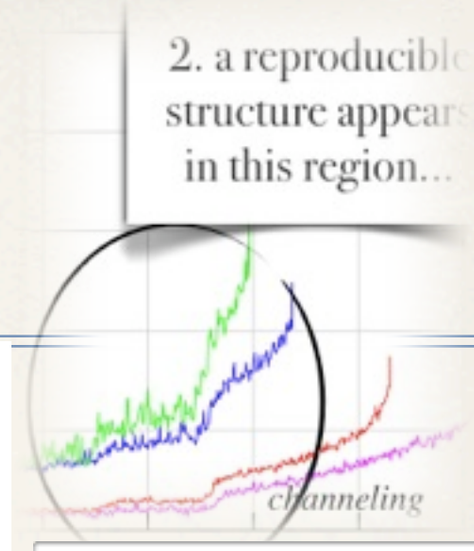


two shoulders always observed

are these correlated to the crystal and TAC positions?

a closer look...



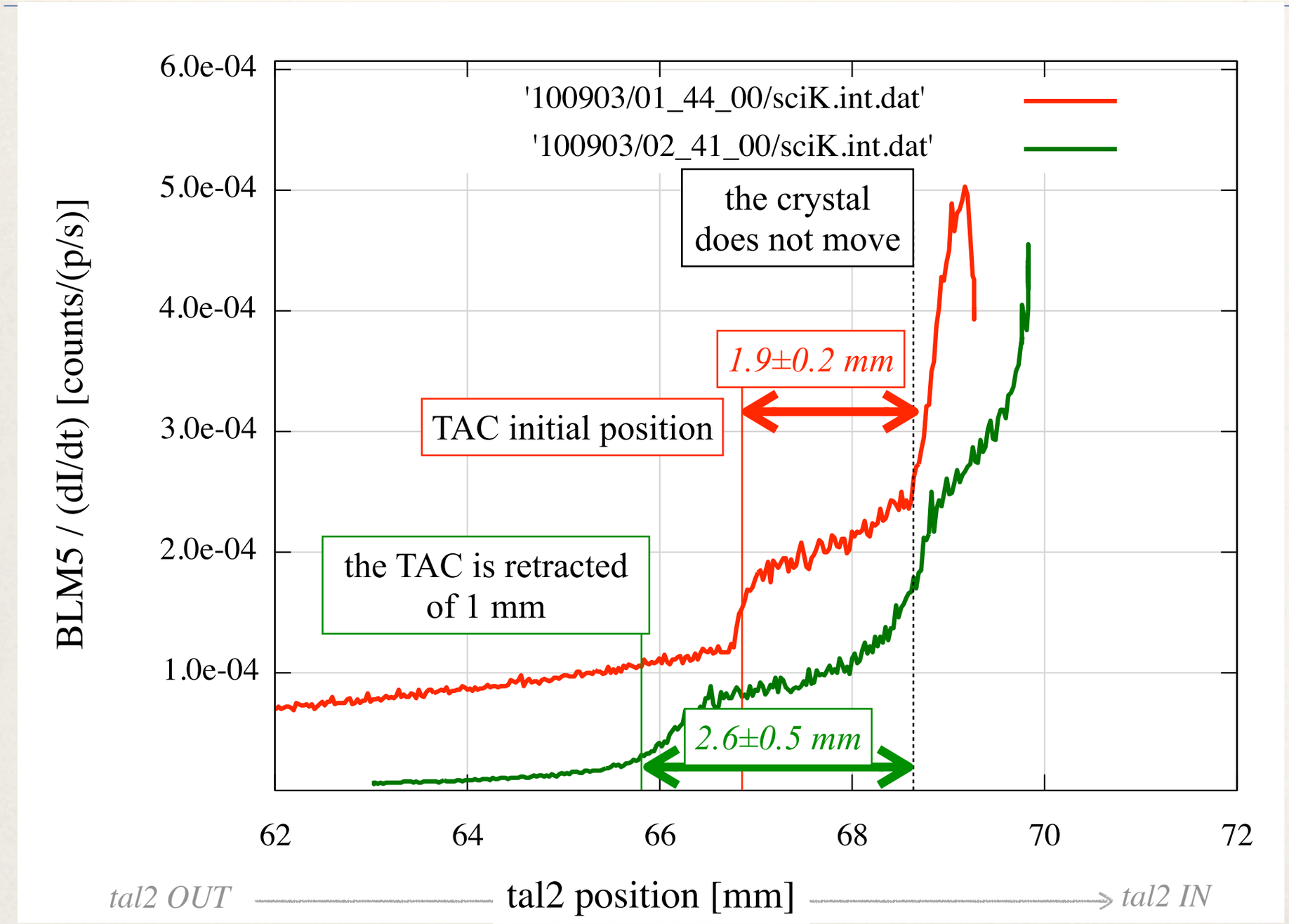


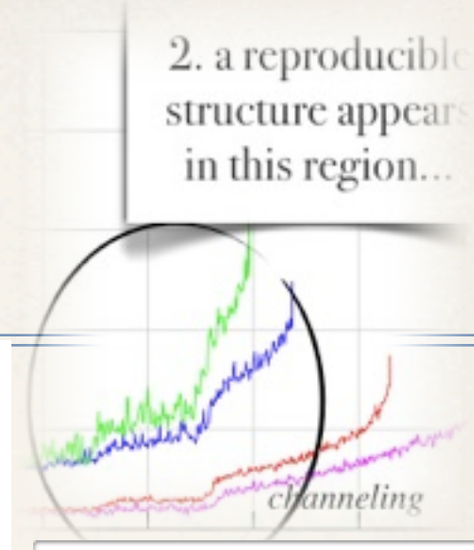
two shoulders always observed

are these correlated to the crystal and TAC positions?

1- the distance between the two "shadows" is the expected one

a closer look...





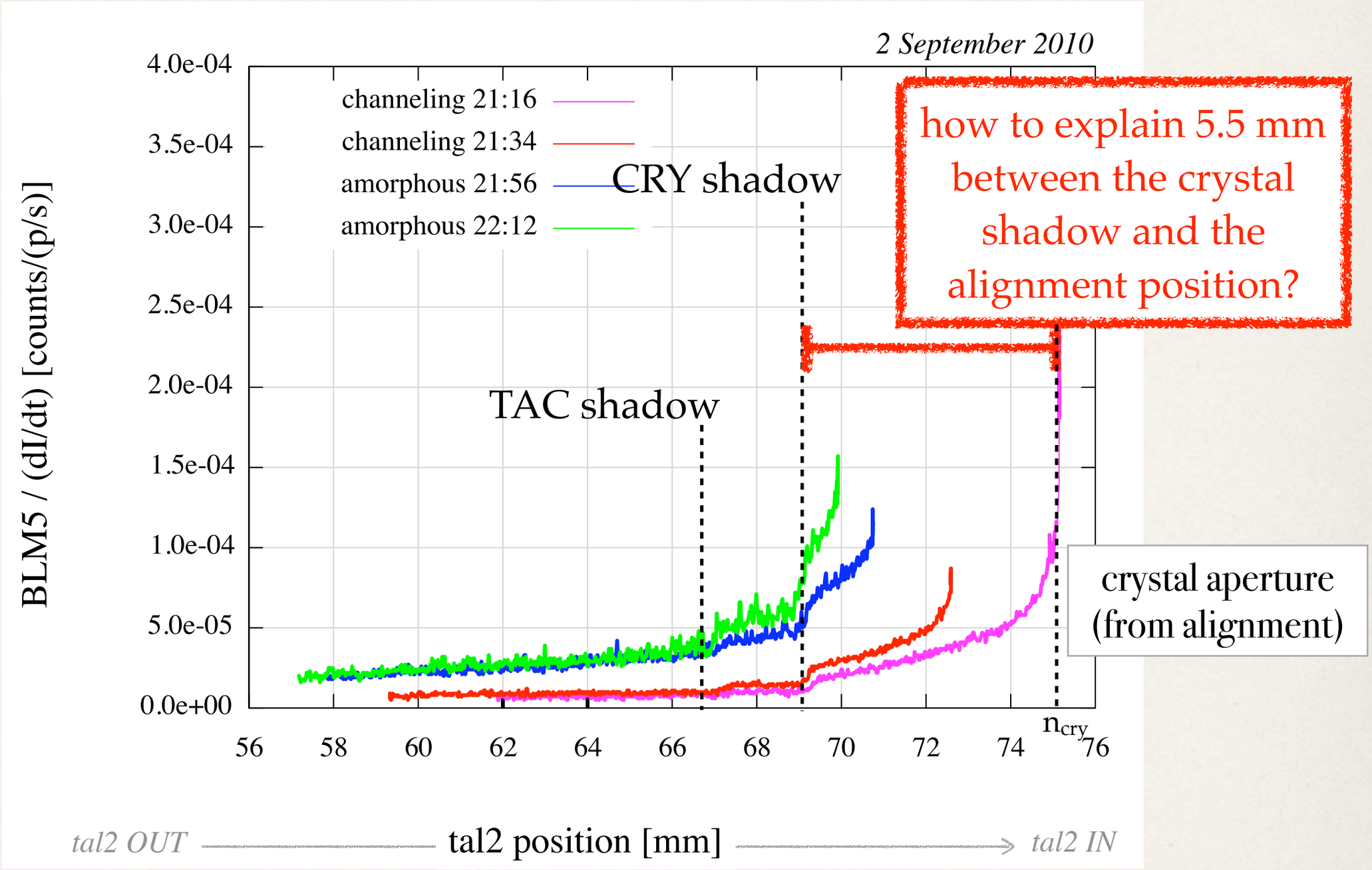
two shoulders always observed

are these correlated to the crystal and TAC positions?

1- the distance between the two "shadows" is the expected one

2- when the TAC is retracted, the second shoulder moves accordingly

however...


2 September 2010
channeling 21:16
channeling 21:34
amorphous 21:56
amorphous 22:12
CRY shadow
TAC shadow
how to explain 5.5 mm between the crystal shadow and the alignment position?
crystal aperture (from alignment)
BLM5 / (dI/dt) [counts/(p/s)]
4.0e-04
3.5e-04
3.0e-04
2.5e-04
2.0e-04
1.5e-04
1.0e-04
5.0e-05
0.0e+00
56
58
60
62
64
66
68
70
72
74
76
n_{cry}
tal2 OUT
tal2 position [mm]
tal2 IN

off-momentum halo: the hypothesis

- if the shoulders were generated by on-momentum particles:
  - we should find the alignment position for the crystal

1.the distance between the alignment position and the cry shadow is > 5 mm

  - after the crystal shadow we should scrape the primary beam

2.channeling and amorphous curves do not overlap
3.the losses downstream the crystal do not decrease
4.there is no variation in the beam intensity (BCT) even entering 5 mm more than the crystal shadow

1.the distance between the two "shadows" is the expected one
2. the "shadows" move when we move the elements

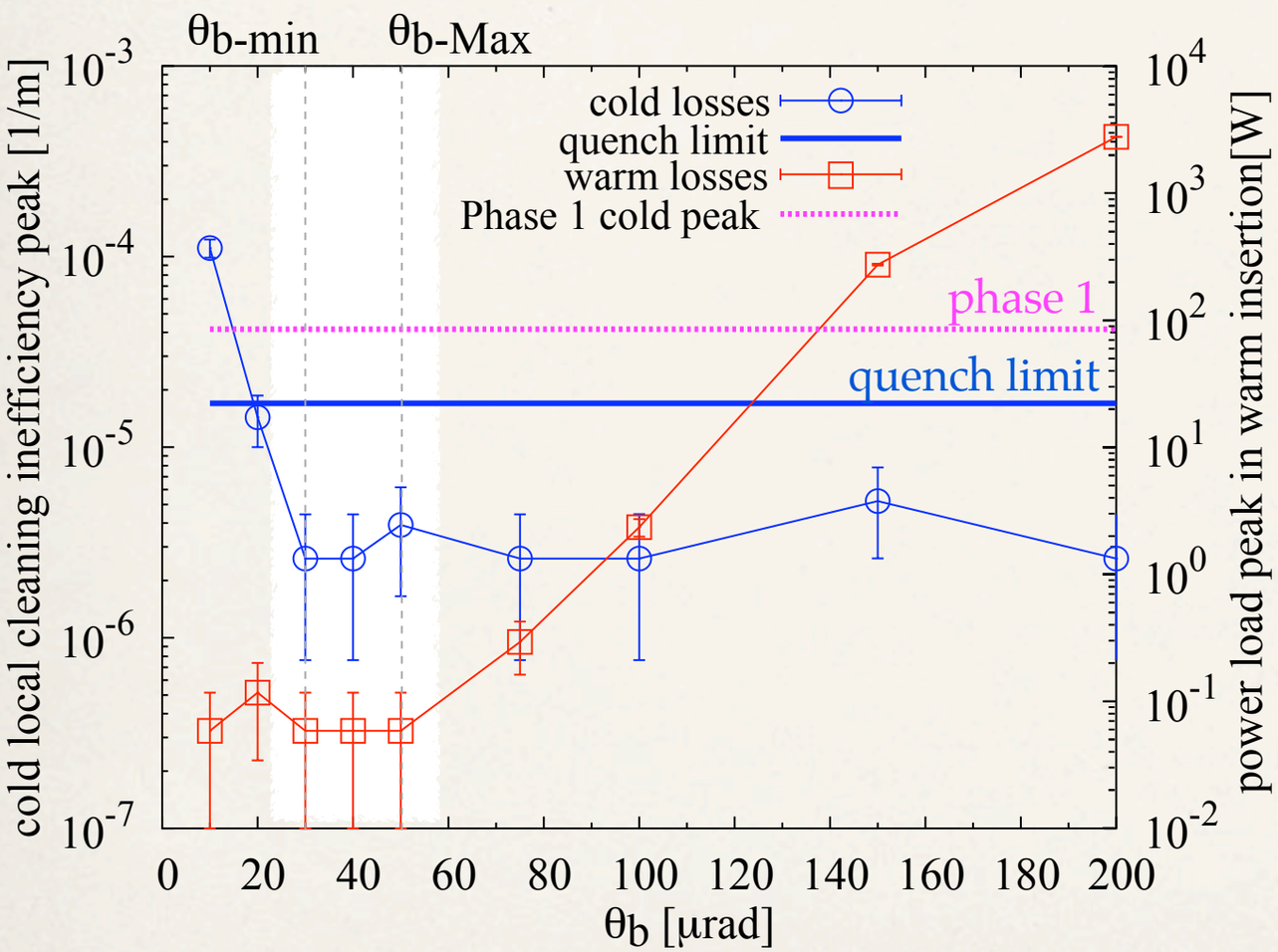
considering the dispersion value at TAL2 (3.4m) and the distance

further detailed studies next year on buch population and debunching

the shadows must be generated by particles with a dp/p =1.6E-5 = 4σp

toward the LHC: first simulations

- first simulations/optimization studies have been performed with SixTrack by the Cern Collimation Team (V.Previtali PHD Thesis)



channeling angle

optimal bending angle has been found to be, both for the horizontal and the vertical case, about 40 μrad

predicted efficiency improvement: ~ factor 15

- Loss maps for different crystal bending angles have been considered