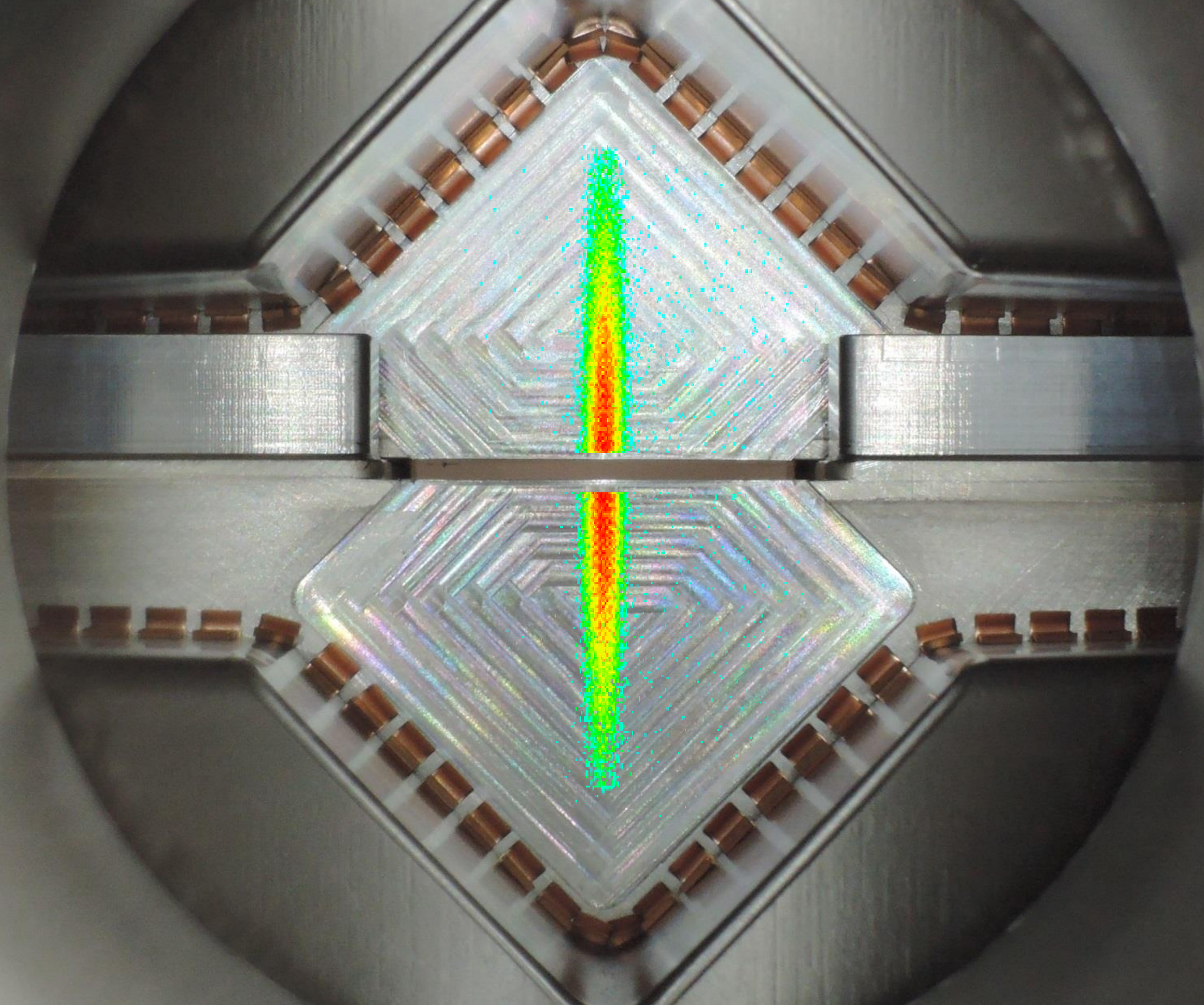
ALFA 900 GeV review



K.Hiller on behalf of the ATLAS/ALFA group

Why a low energy run ?

There are two main physics arguments:

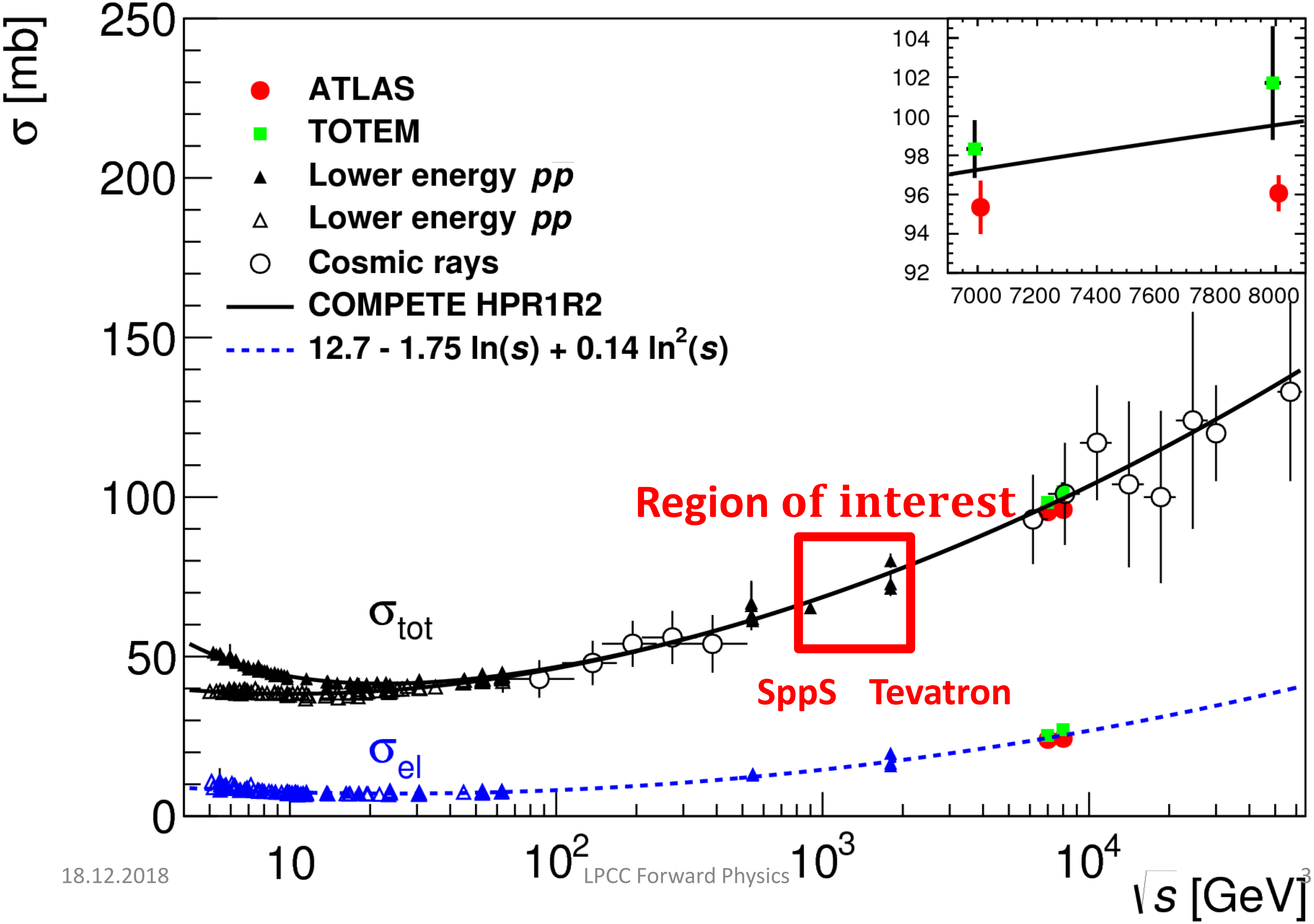
1) Perform the standard ALFA program (total & elastic & inelastic cross sections, B-slope of hadronic scattering) in a region where no pp data exist and with significant discrepancies between the experiments at the ppbar colliders.

- No pp data between ISR and LHC (60 GeV – 7 TeV)
- Large discrepancy in ppbar data at the Tevatron (2.8 sigma & 1.8 TeV)

2) Measuring the parameter ρ at low energy is an important ingredient to predict the total cross section beyond LHC energies based on dispersion relations.
Recall:
Dispersion relations are based on very general principles: analyticity, unitarity, crossing symmetry. They predict the energy evolution of σ_{tot} with the parameter $\rho = Re(f\_el)/Im(f\_el)$ measured at lower energies:

$$\rho_\pm \sigma_\pm = \frac{B}{p} + \frac{E}{\pi p} \mathrm{P} \int_{m_p}^{\infty} \left[\frac{\sigma_\pm}{E'(E'-E)} - \frac{\sigma_\mp}{E'(E'+E)} \right] p' \, dE'$$

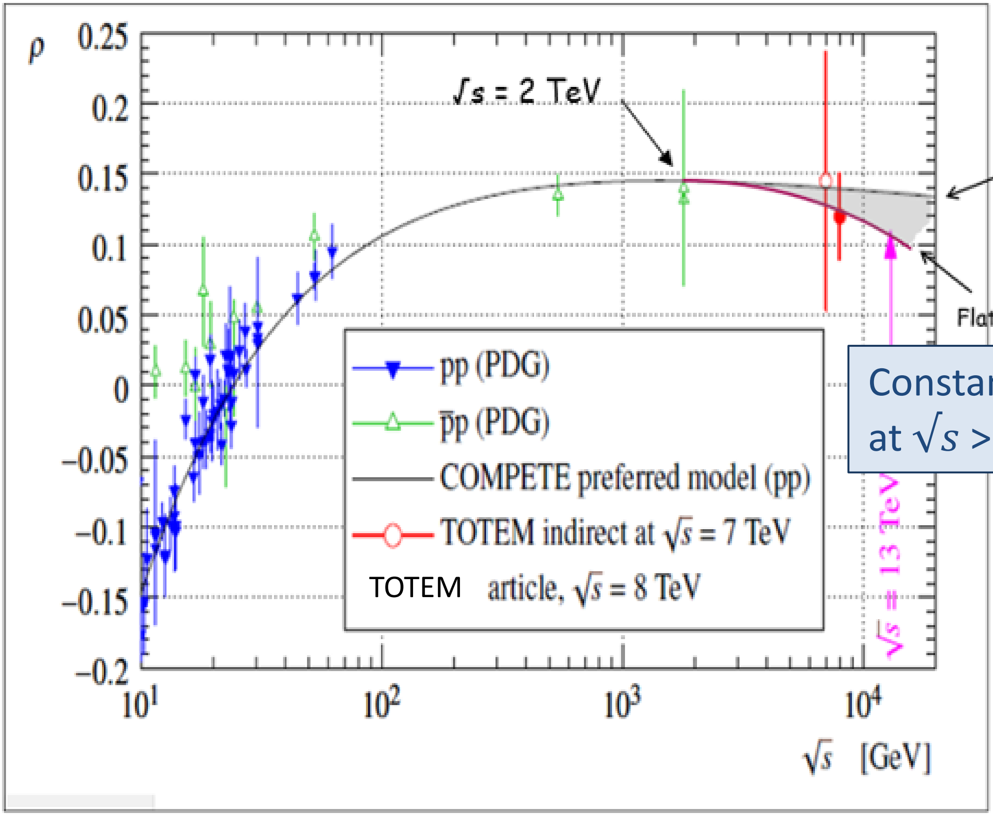
σ_{tot} – Region of interest



Impact of $\sigma_{tot}(s)$ on ρ

The point is illustrated in the figure (slide made before the measurement TOTEM's low ρ-value).

From P.Grafstrom



Constant X-section at $\sqrt{s}$ > 20 TeV

The grey area represents possible ρ- values for different high energy scenarios of σ_{tot}. At 2 TeV and below the value of ρ is independent of the different scenarios for σ_{tot}.

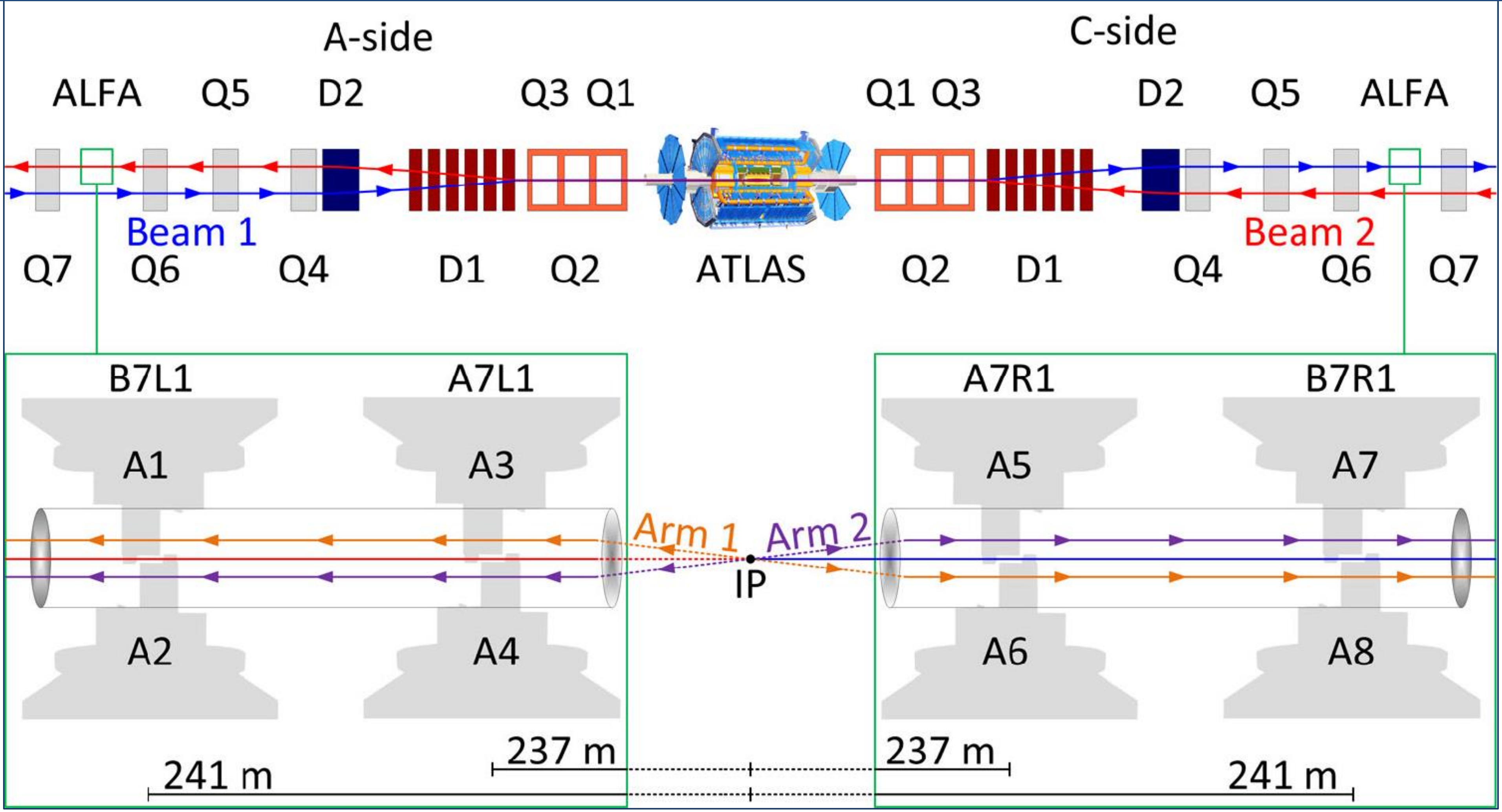
Motivation for ρ & low energy

A measurement at **low energy**, i.e. at √s= 900 GeV or 2 TeV, where the value of ρ is practically independent of σ_{tot} at energies beyond LHC, would allow us :

- to make sure that our experimental method and way of measuring ρ is correct.
- that dispersion relations are valid also in the TeV range.
- that there are no "odd" surprises… e.g. the existence of the up to now elusive Odderon that would modify the result of dispersion relation calculations via unexpected differences between p-p and p-pbar total cross section.

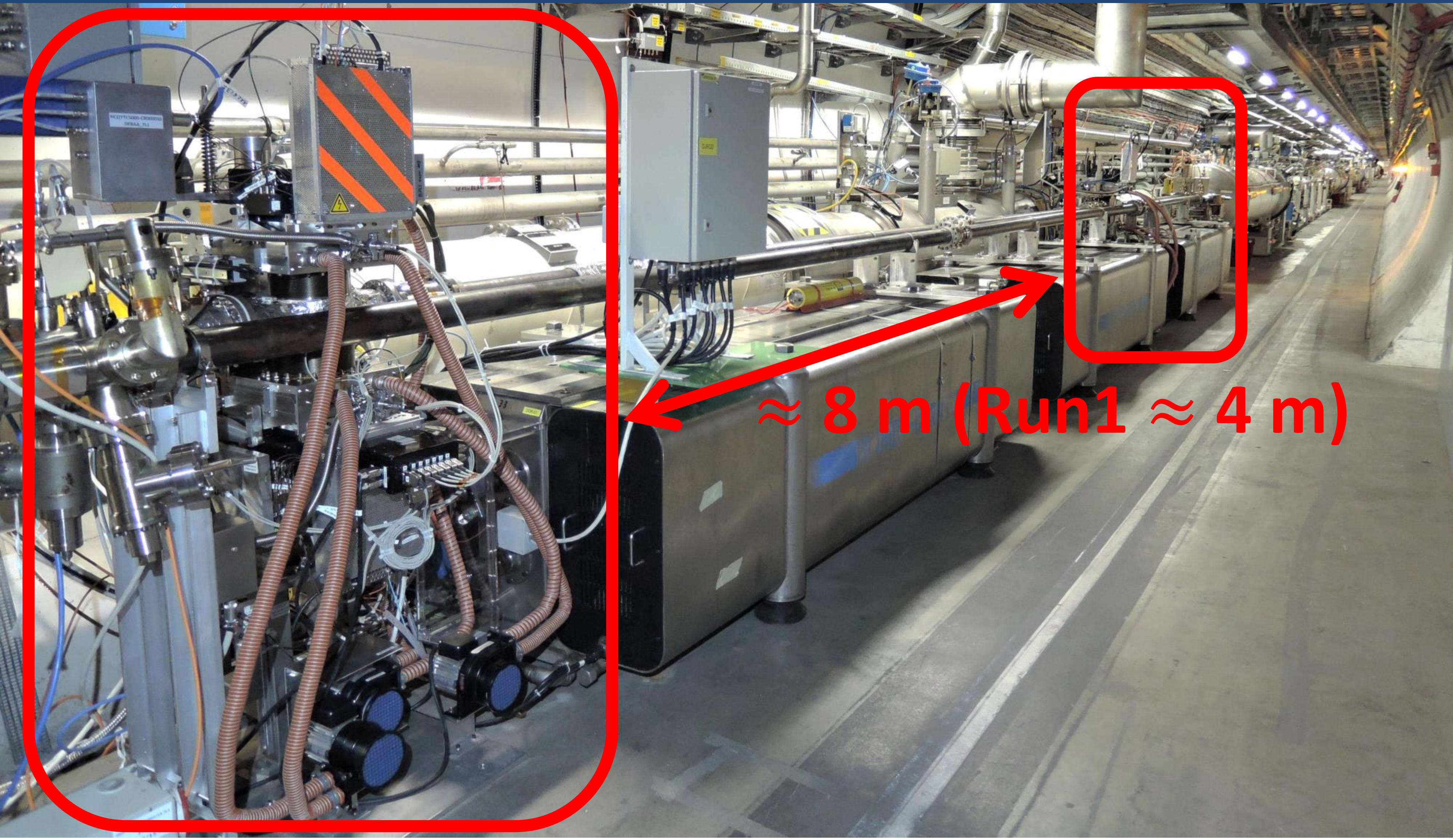
Bottom line:
A low energy point would be our **"anchoring" or *reference*** point giving us confidence that both experimentally and theoretically our prediction of the total cross section beyond LHC energies is standing on solid grounds.

ALFA setup



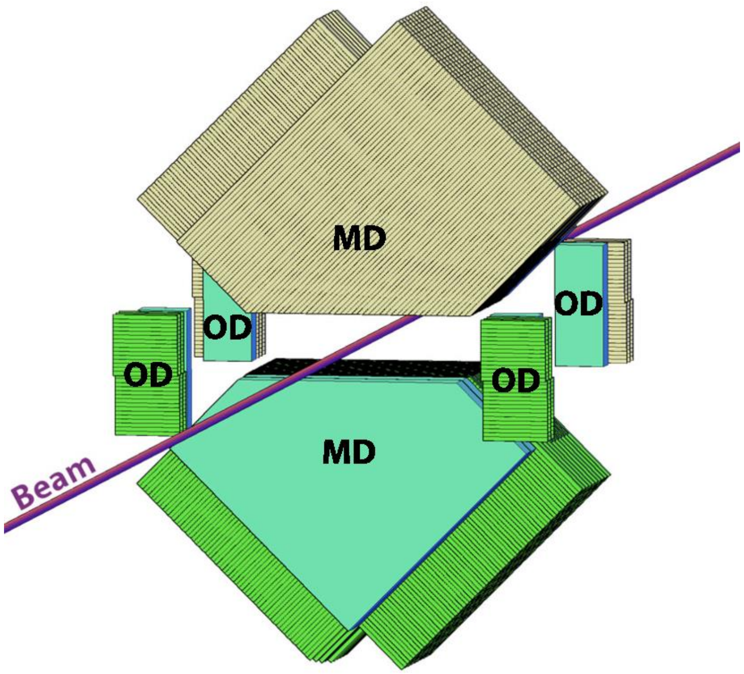
4 stations with 8 detectors at both sides of ATLAS provide 2 independent "elastic" arms.

ALFA stations in the tunnel

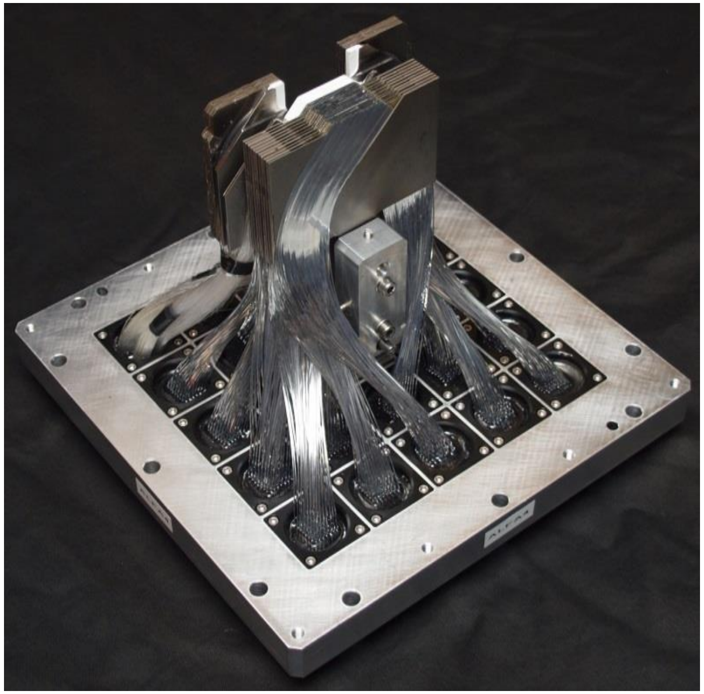


ALFA tracking detectors

Design principle



Real detector



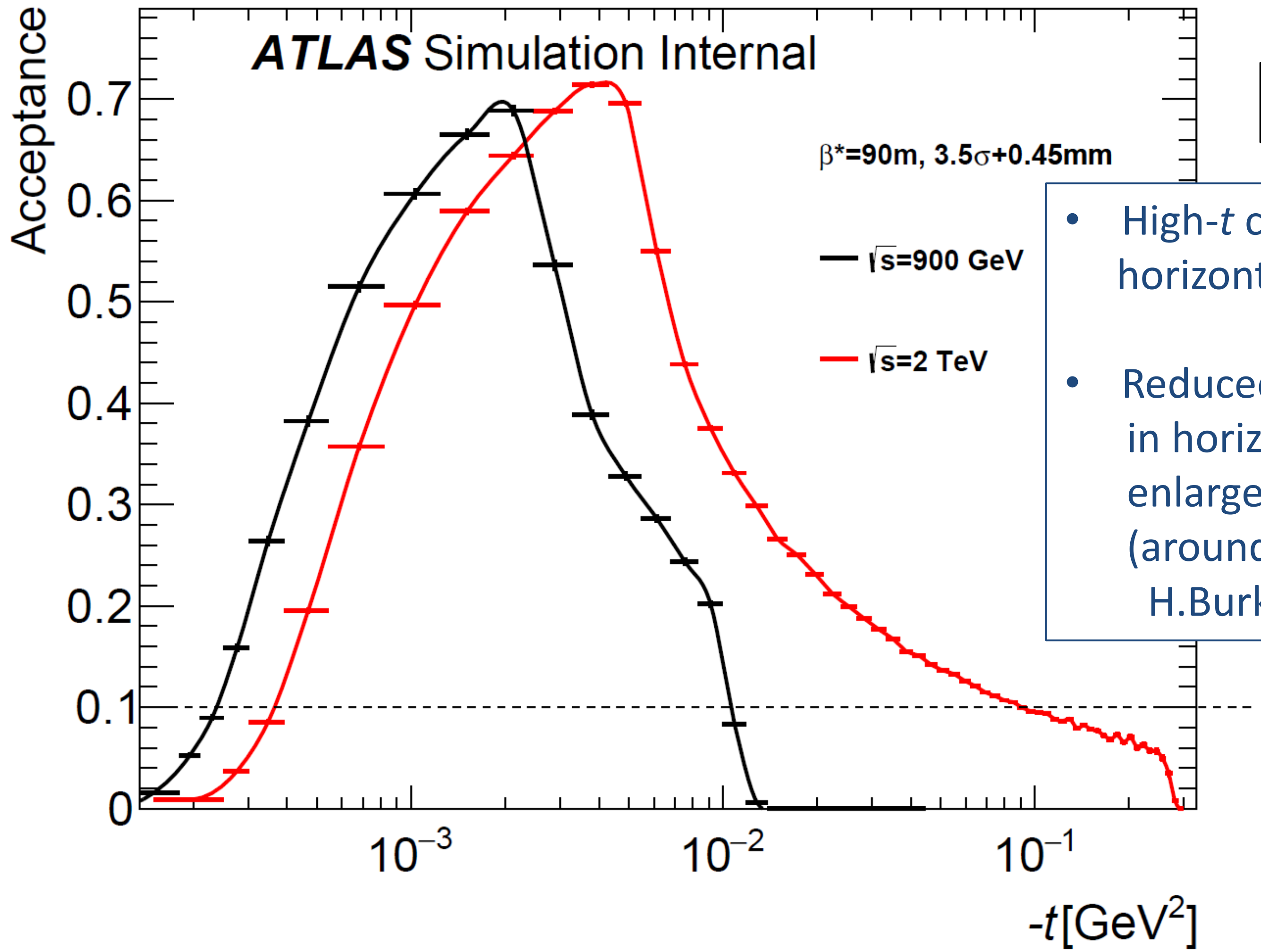
- Main detectors (MD): 2 x 10 layers of 0.5 x 0.5 mm^2 square fibers.
- Read out by Multi-Anode-Photomultilipliers with 64 channels.
- Light yield 4 -5 photo-electrons per fiber.
- Measured resolution ~ 35 µm.
- Special overlap detectors (OD) to measure the distance.

ALFA setup: JINST 11 (2016) P 11013.

Operational conditions for

- 900 GeV and 2 TeV
- Various high-β^* values

Which energy: 900 GeV or 2 TeV ?

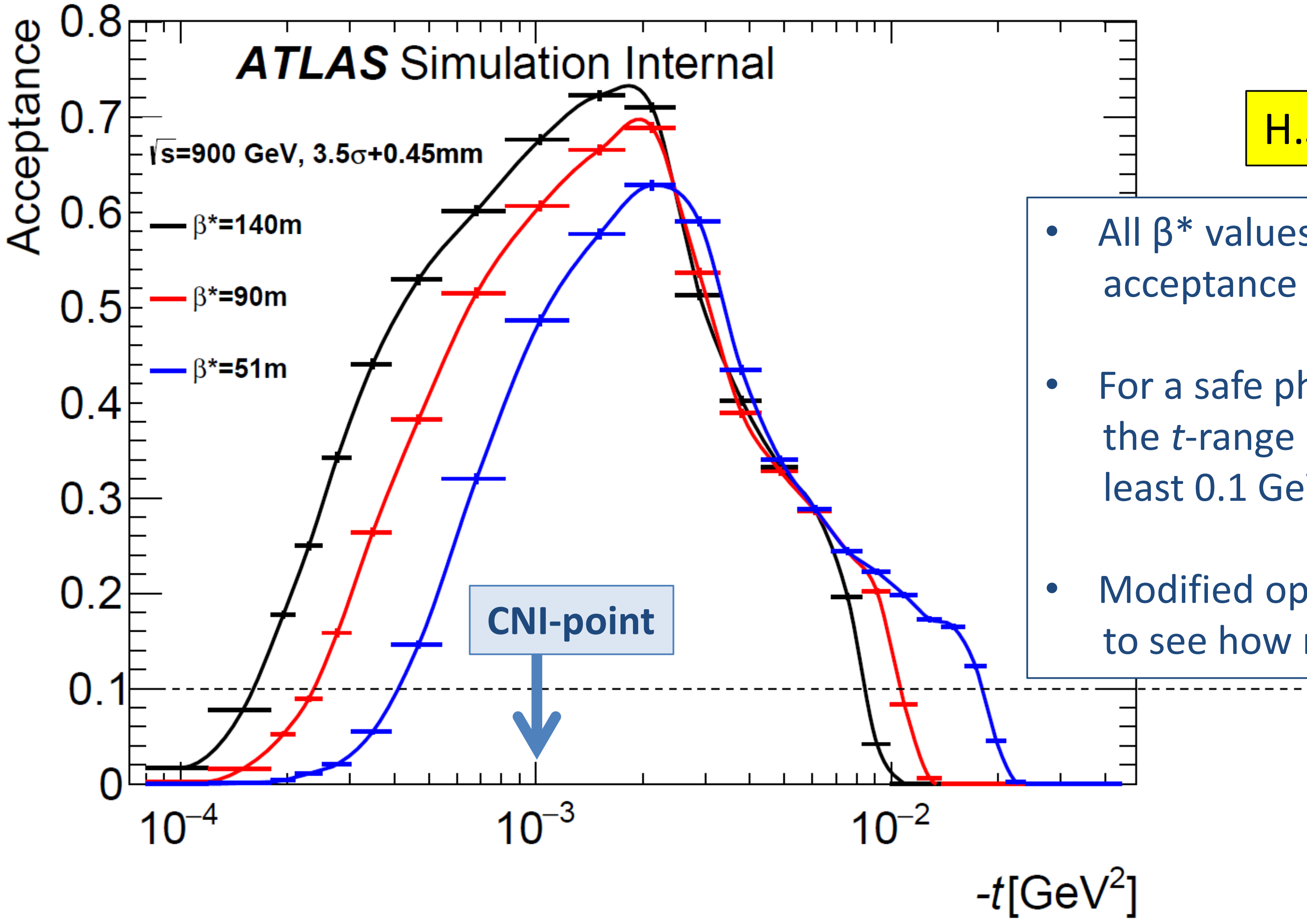


H.Stenzel

- High-*t* cutoff due to horizontal machine aperture.
- Reduced phase advance in horizontal plane can enlarge *t*-range. (around 175^o, in hands of H.Burkhardt)

900 GeV: cutoff at 1E-2 GeV2 hampers a fit in the nuclear region …

900 GeV versus β*(51/90/140m)



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- All β* values allow sufficient acceptance for a CNI fit.
- For a safe physics analysis the *t*-range needs reach at least 0.1 GeV2.
- Modified optics file needed to see how much it helps.

Naturally, for larger β* lower *t*-values are accessible. The high-*t* cutoff is critical.

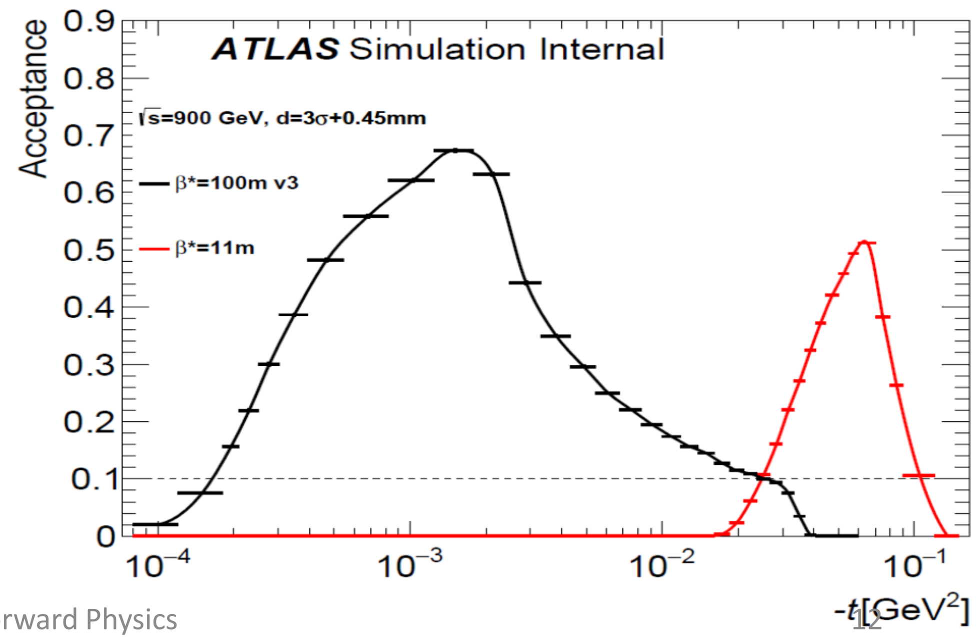
900 GeV optics V4

H.Burkhardt

- Naturally, the 450 GeV beams allow smaller t_min for same β*.
- To extend the high-t range the β* in the horizontal plane was set to 50m.
- As usual: phase advance Ψ_y close to 90°, Ψ_x a few degrees away from 180°.

β*y=100m, β*x=50m	Inner Station B1	Outer Station B1
βx	158.3	160.2
βy	346.5	264.4
ψx	173.7°	176.6°
ψy	89.4°	91.0°
M12x	9.8	5.2
M12y	186.2	162.6

- For a better coverage of the high-*t* range some data taking at β* = 11m was foreseen.



The 900 GeV tests

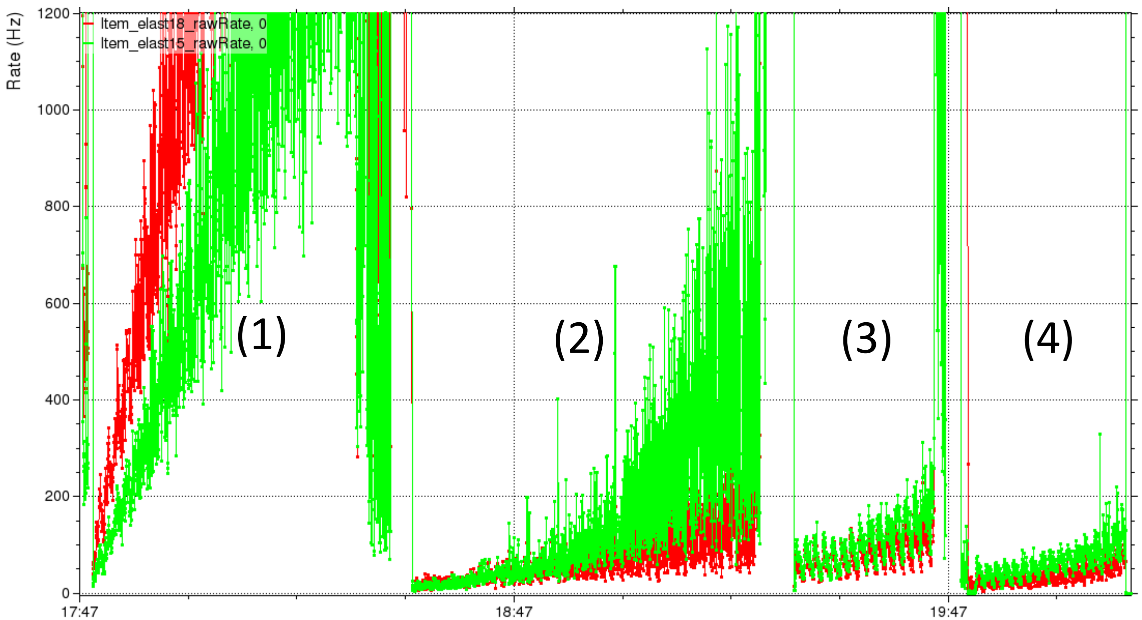
- Roman Pots at 3 σ (at least the outer stations).
- Three earlier test 2017 Nov 8 and 22 and 2018 May 8 failed.
- Background rate 2 to 3 orders of magnitude too high.
- Next three slides for demonstration …
- A special effort of the collimation team found a solution.
- **Successful 900 GeV test performed at October 2, 2018.**

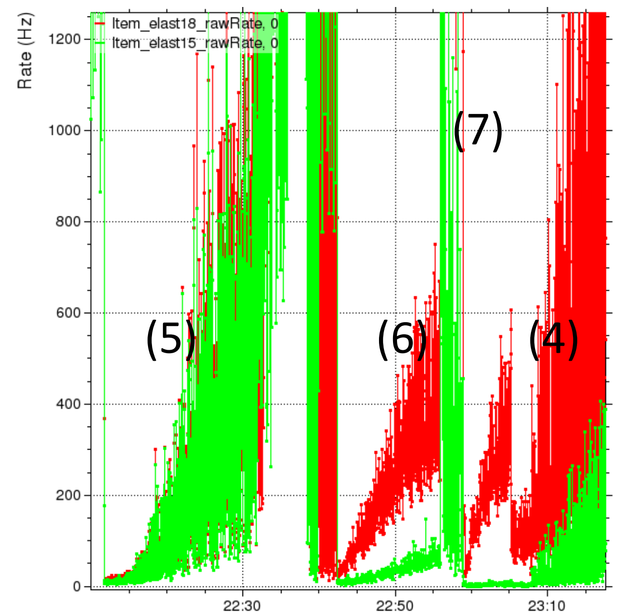
900 GeV test @ trigger rate

Altogether 7 collimator configurations tested:

1) TCP only.
2) TCLAs (like in 2016).
3) TCT at IP2 for B1 + TCT at IP8 for B2.
4) TCT at IP2 for B1 + TCT at IP8 for B2 + TCLAs.
5) TCT at IP2 for B1 + TCT at IP8 for B2 + TCLAs + TCT at IP1&5 at 3 $\sigma_{norminal}$ V and 5 $\sigma_{norminal}$ H.
6) TCTs at IP2&8 (both beams).
7) TCT at IP2 for beam 2 + TCT at IP8 for beam 1.

S.Jakobsen

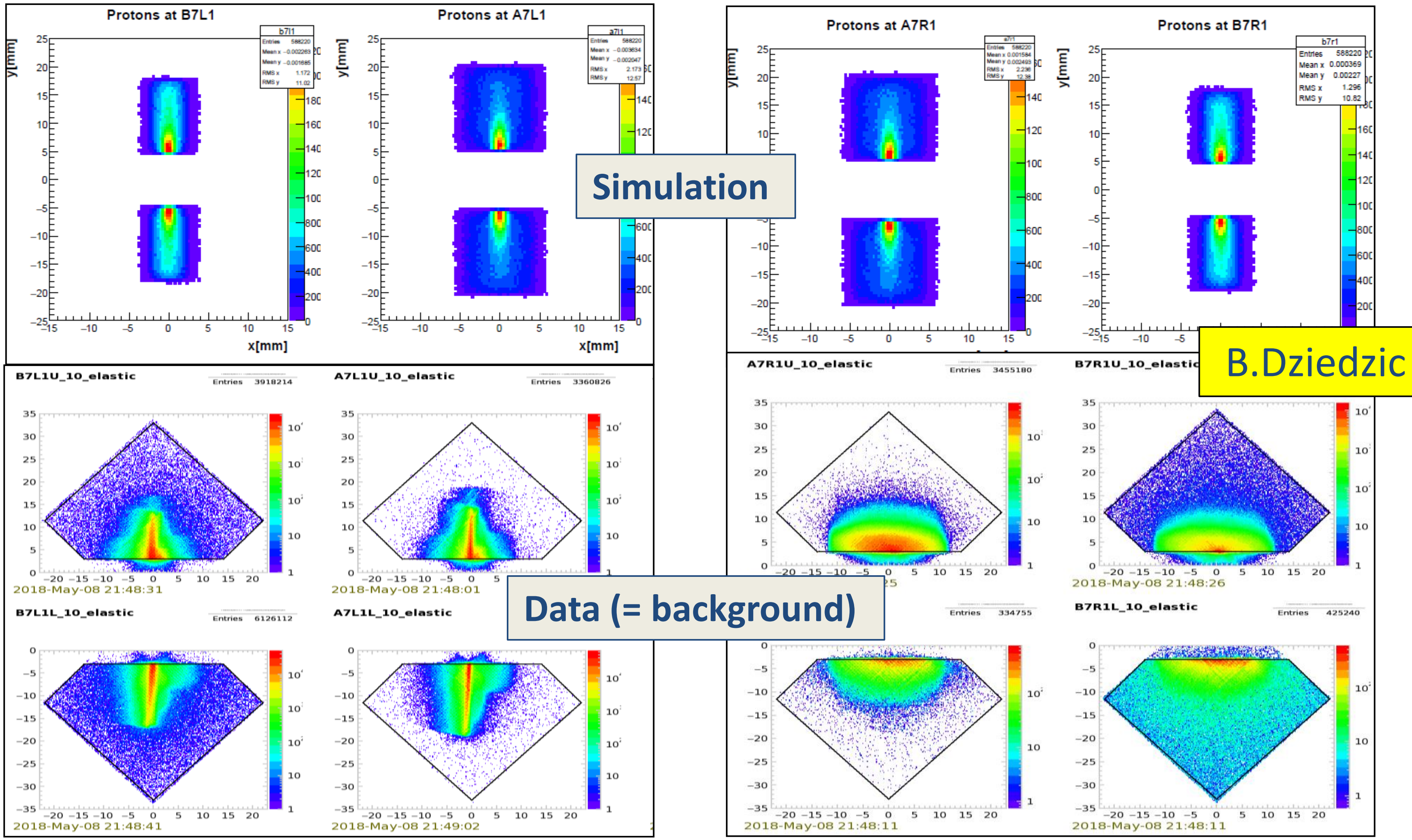




In all cases after a few minutes the elastic trigger rate was in the range of kHz, should be 0(10Hz) !!

900 GeV test @ elastic pattern

Due to the high β* optics the typical elastic track pattern in the detectors is a narrow vertical ellipse.



900 GeV test @ background rate

- Offline feedback from test at May 8, 2018.
- Estimate of background from so-called anti-golden topologies.

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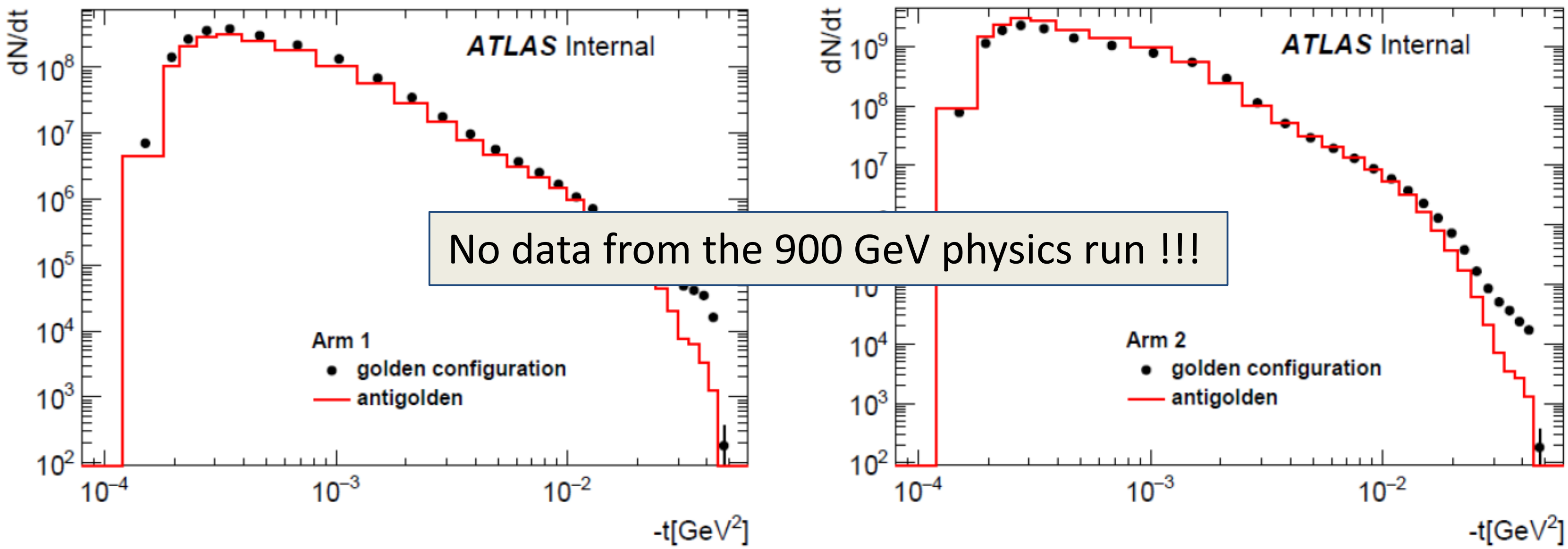


No data from the 900 GeV physics run !!!

- Elastic trigger rate fully consistent with background rate, no chance for any physics.

Collimation breakthrough

"Progress of the collimation system for special physics runs":

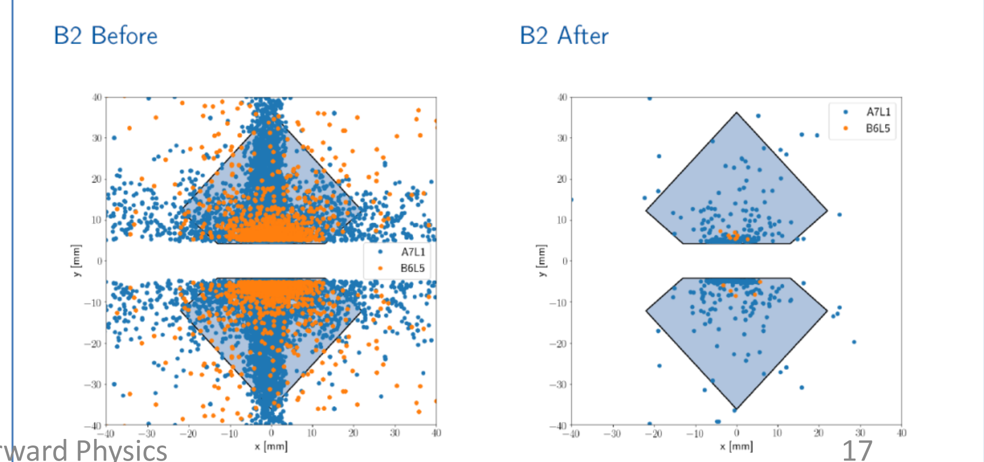
H. Garcia-Morales, R.Bruce, S.Radelli & LHC-collimation team

https://indico.cern.ch/event/752722/

- New 2-stage collimation scheme
- RPs / secondary/ primary collimators in 0.5 σ (3.0 σ, 2.7 σ, 2.5 σ).
- Simulations indicate a better betatron and momentum cleaning.
- Challenging, never so tight settings used before …
- But simulations very promising … ?
- **Excellent data quality confirmed in the last 900 GeV test at October 2, 2018.**

Collimator	Half gap [σ]
TCLA.A6[R/L]7.B[1/2]	2.5
TCLA.A5[R/L]3.B[1/2]	2.7
TCTPV.4L2.B1	2.7
TCTPV.4R8.B2	2.7
TCTPV.4[L/R]1.B[1/2]	2.7
TCTPV.4[L/R]5.B[1/2]	2.7
TCLA.C6[L/R]7.B[1/2]	2.7
TCP.6[L/R]3.B[1/2]	5.3
TCP.C6[L/R]7.B[1/2]	5.7
TCP.D[L/R].B[1/2]	3.0
Roman Pots	3.0

Simulations - Old/New configuration - B2

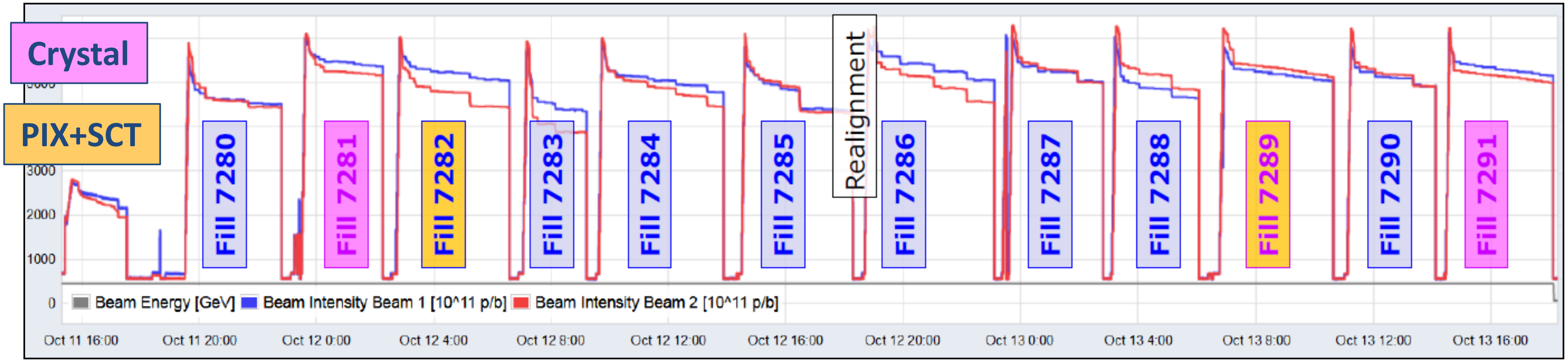


The 900 GeV data run

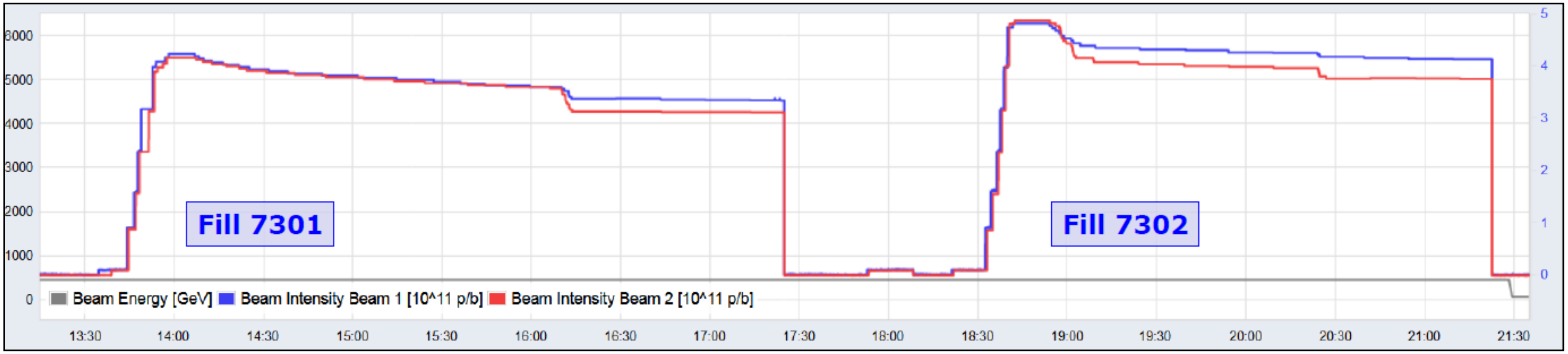
- Four days to accumulate enough statistics: October 11-14, 2018.
- Complex program:
  - High β^* for 1M elastic events
  - A vdM scan for luminosity calibration
  - Short run at $\beta^* = 11m$ to extend t-range
  - First time a crystal collimation scheme used for data taking
- Basic offline analysis to cross check data quality
- No physics data analysis yet due to shortage of man power.

Time line of data taking

- 12 fills at injection energy with β*_x/y =50/100m (3 fills crystal), interrupted by scraping.



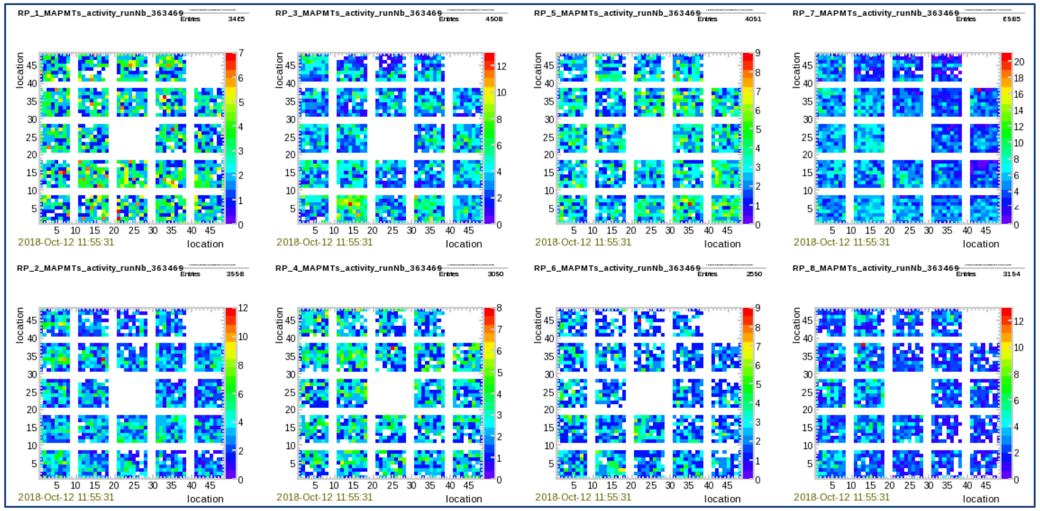
- 2 fills with higher beam intensity for vdM luminosity calibration: #7301, #7301.
- 2 fills at β* = 11m for the "high-*t*" extension of the elastic differential cross section.



The whole campaign lasted about 4 days from Oct 11 to 14, 2018.

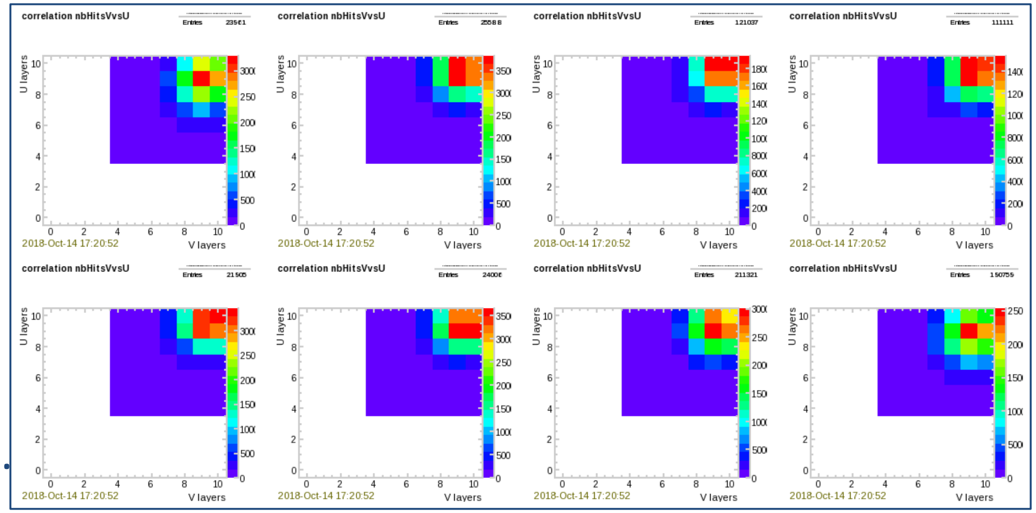
Detector performance

For the main part of the campaign all **PMFs/MAPMTs** were well configured (two holes are normal).



B.Dziedzic

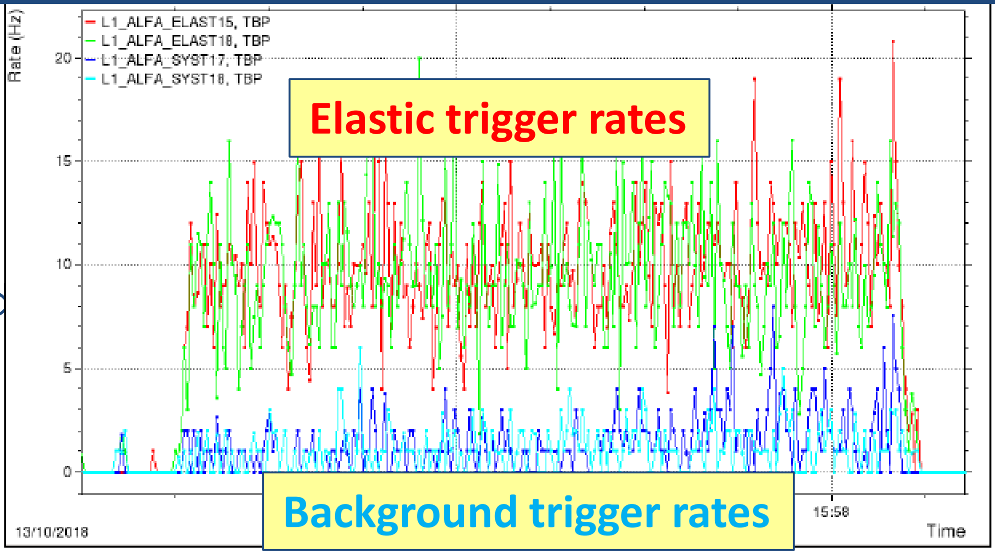
Multiplicity of track hits in both projections peaks at 9-10 (max 10) what ensures a high tracking efficiency.



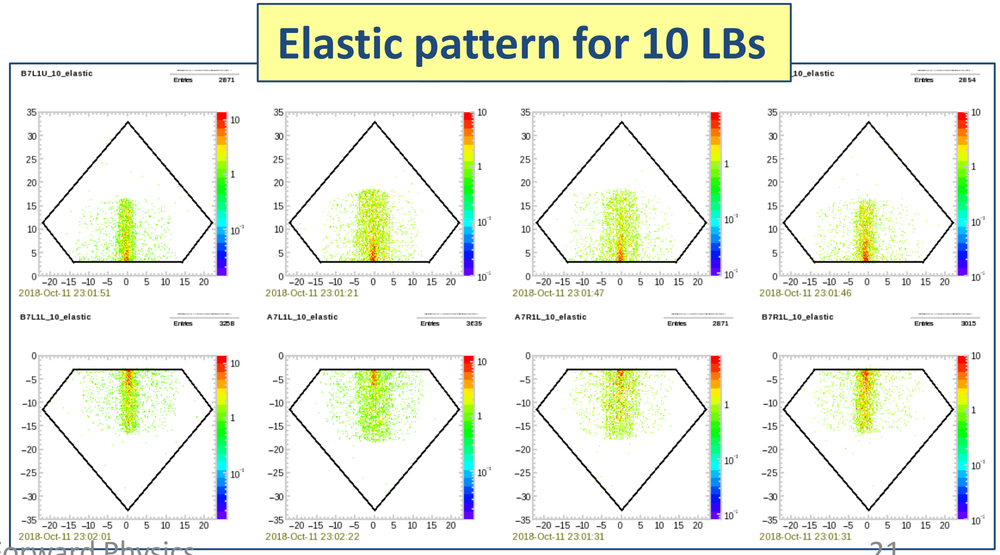
Main issue: MB6 lost configuration
→ 1 detector w/o tracking,
→ 1 elastic arm lost, about 300k (?)events.

Data quality online

- Elastic trigger rates at right level: 0(10 Hz).
- Background rate a factor 10 smaller.
- Both rates 3 orders of magnitudes reduced compared to all failed 900 GeV tests !
- Slow increase of rates, re-scraping done after 30 – 60 minutes of data taking.



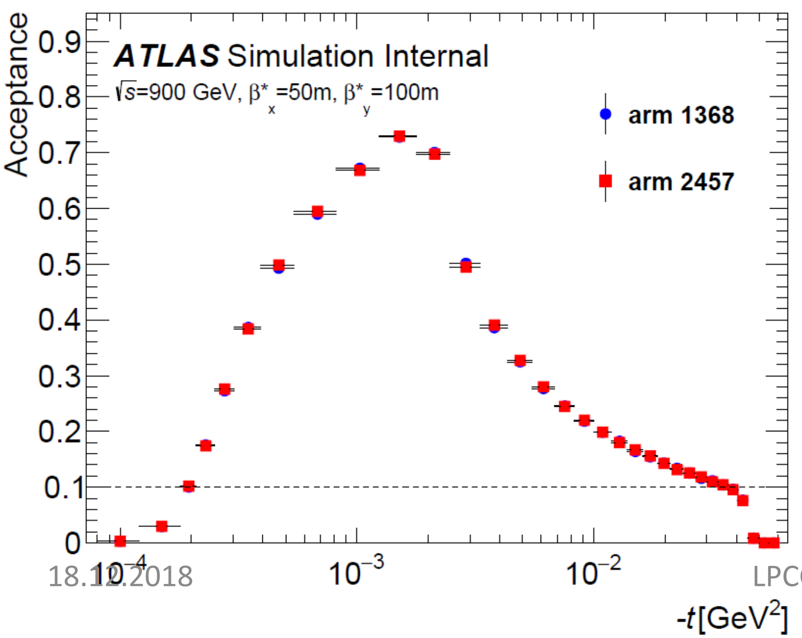
- The typical elastic patter visible in all fills.
- From inspection by eye no dramatic differences between standard and crystal collimation visible.

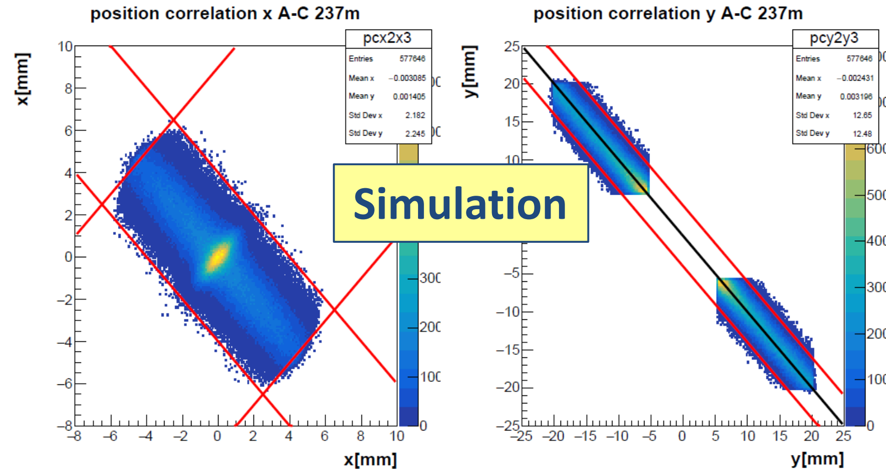


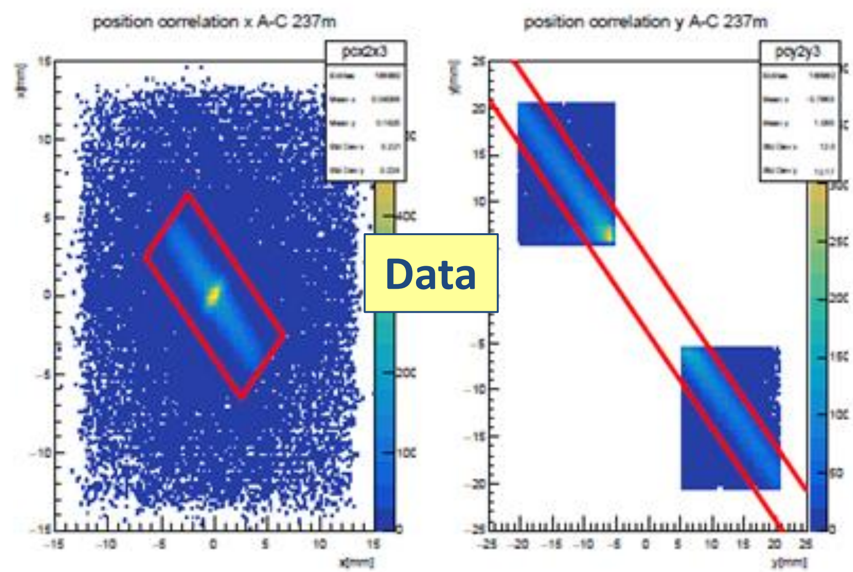
Selection cuts & acceptance

Selection cuts based on the elastic back-to-back topology applied to correlations of positions and angles of tracks on opposite and same sites.

Acceptance calculated from simulation for the actual distance of the RPs to the beam. Physics range about 2E-4 to 4E-2 GeV2.







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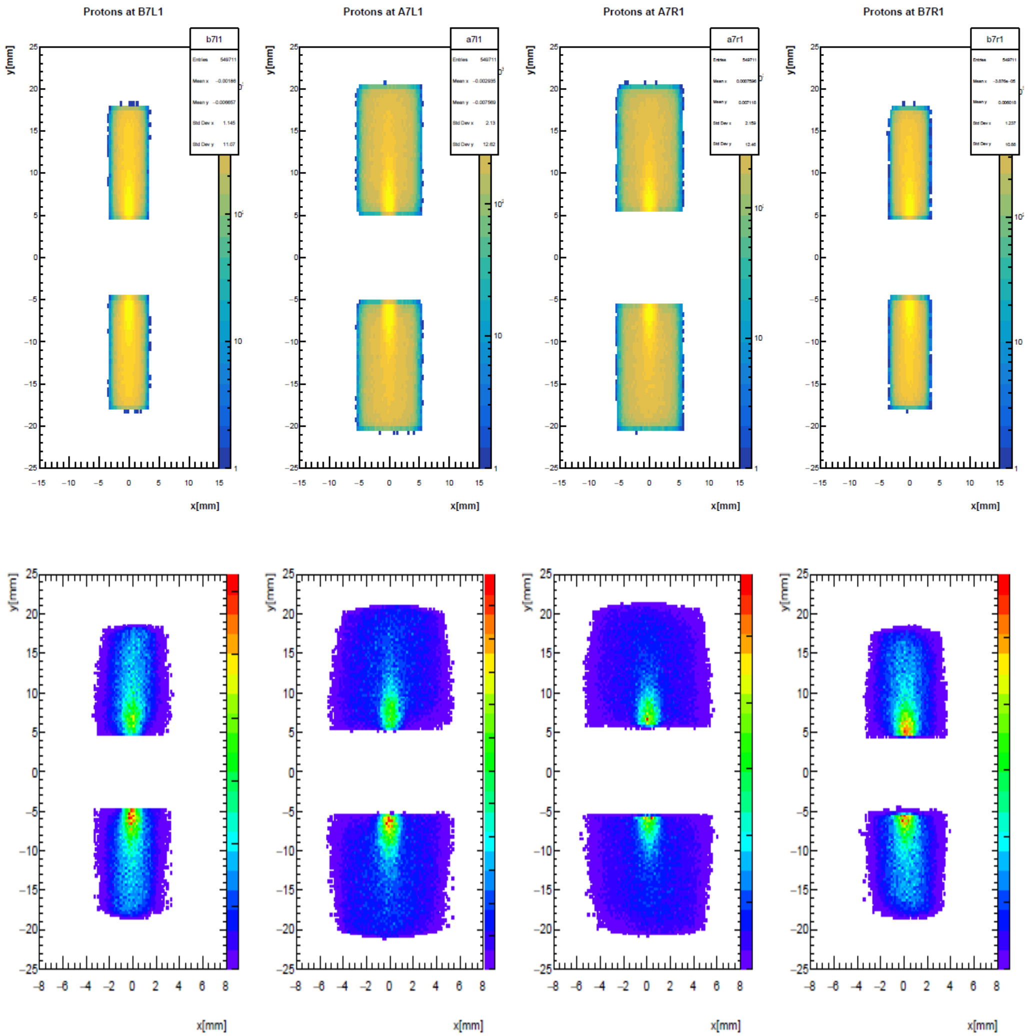
Elastic pattern offline

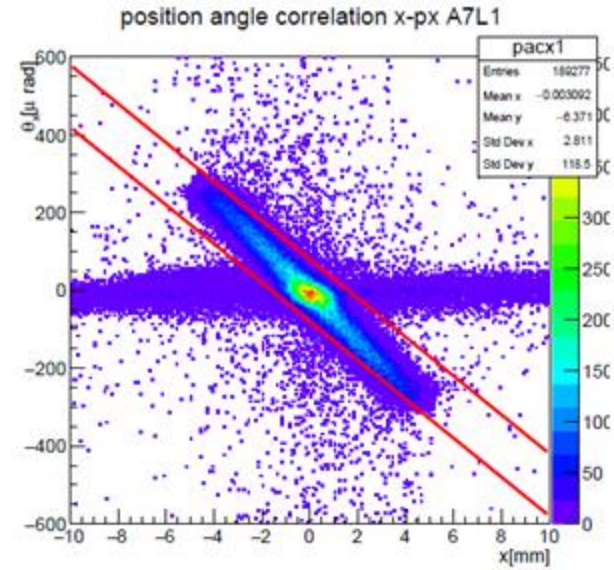


Simulation:
Elastic hit pattern with cuts applied for the elastic topology.

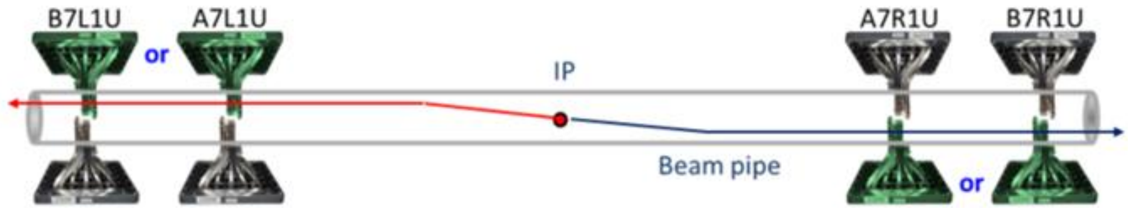
Data: Fill 7289
Elastic sample with soft selection cuts applied.

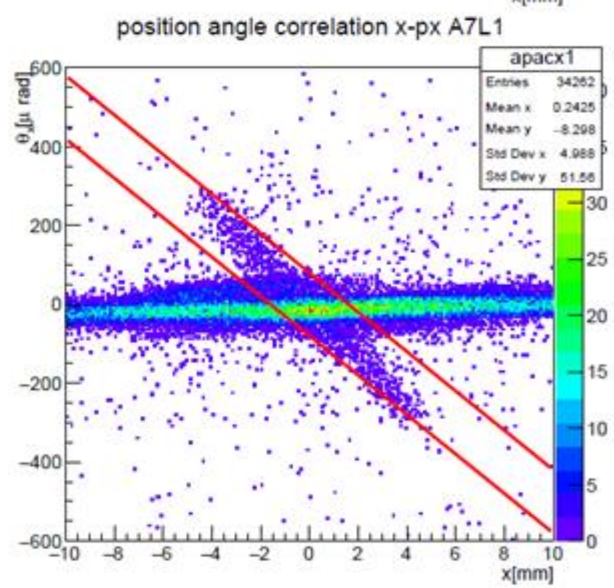
Nice agreement with simulation!

Estimation of background

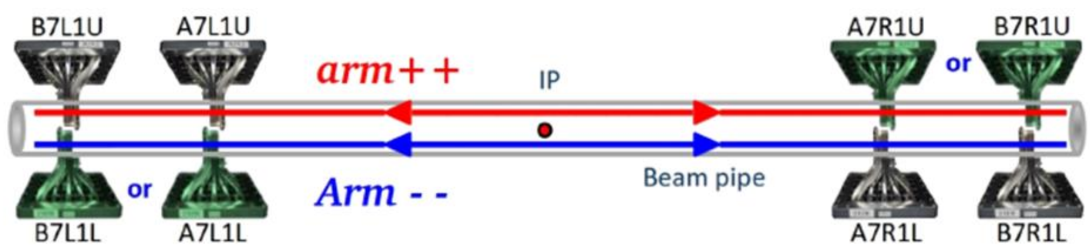


Elastic signal in the back-to-back topologies.



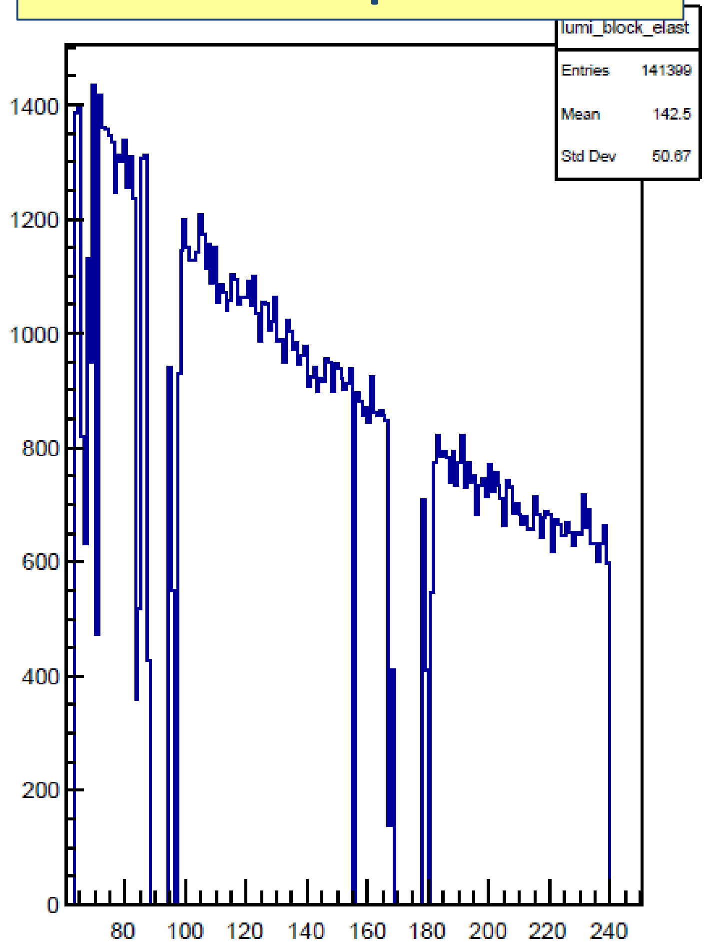


Background estimate from events with all tracks in upper or lower detectors ("anti-golden").

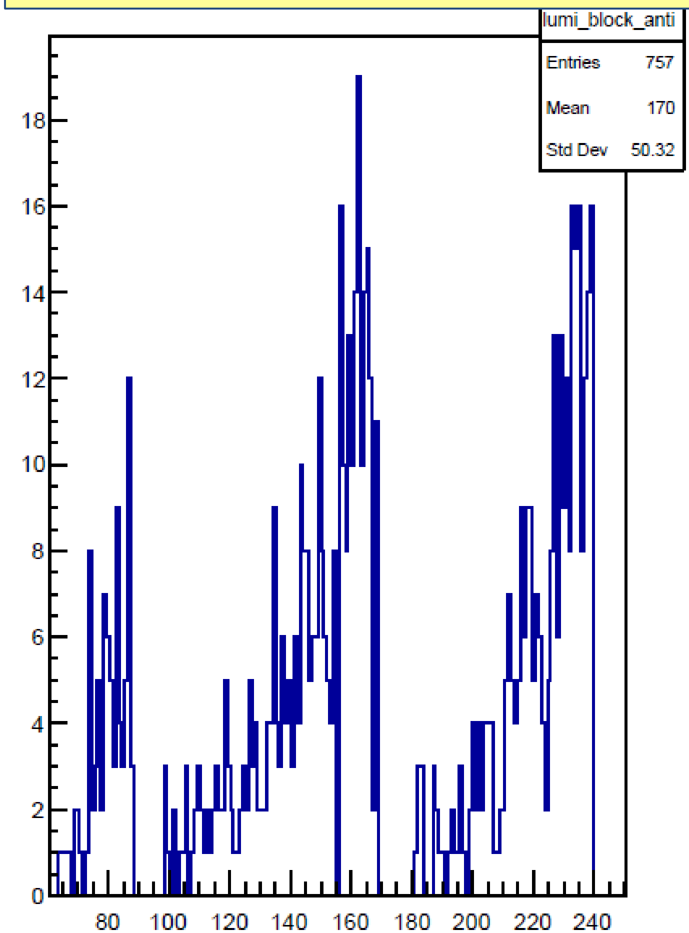


Evolution of signal & background

Elastics events per LB≈ 1min

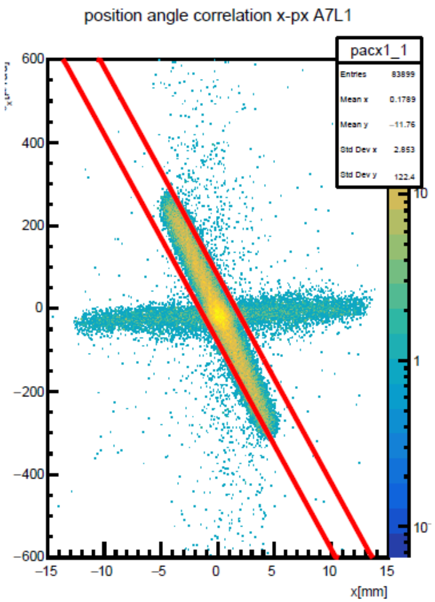


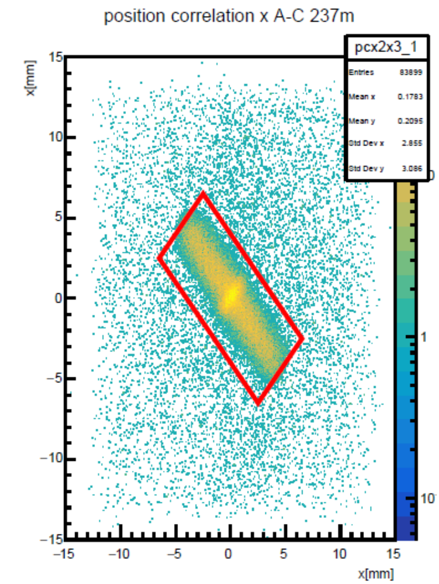
Background rate per LB≈ 1min



By comparison of averages the background fraction of 1% is expected.

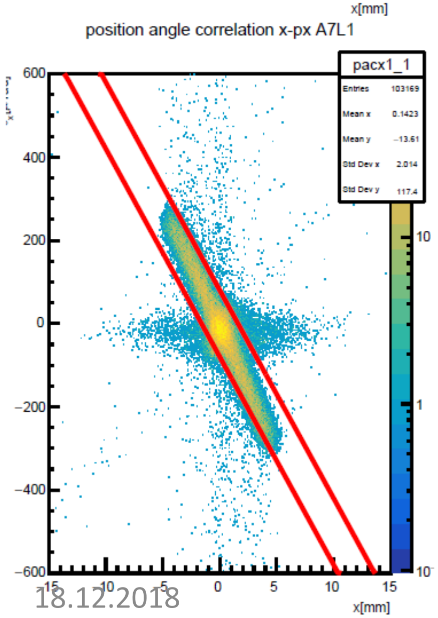
2-stage versus crystal collimation

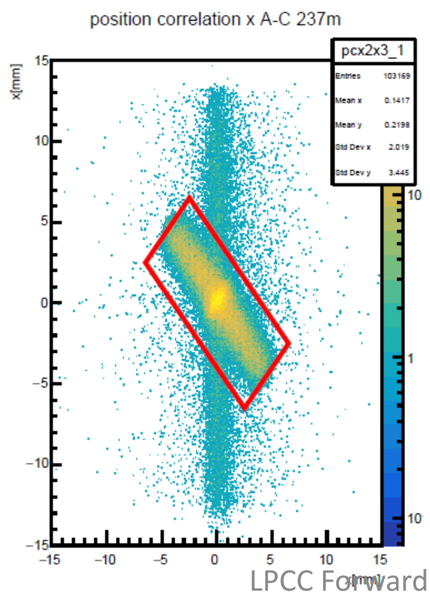




Example: x – Θ_x correlation

2-stage collimation:
background level ~ 0.5%



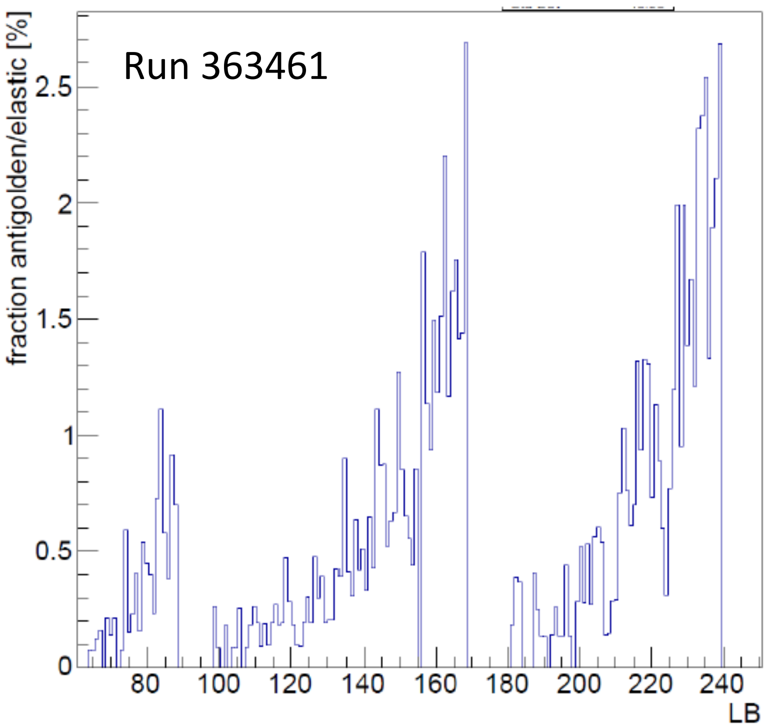


Crystal collimation:
background level ~1.5%

For crystal collimation the background is more condensed underneath the elastic pattern. For the 2-stage collimation it is more spread over the full correlation plane.

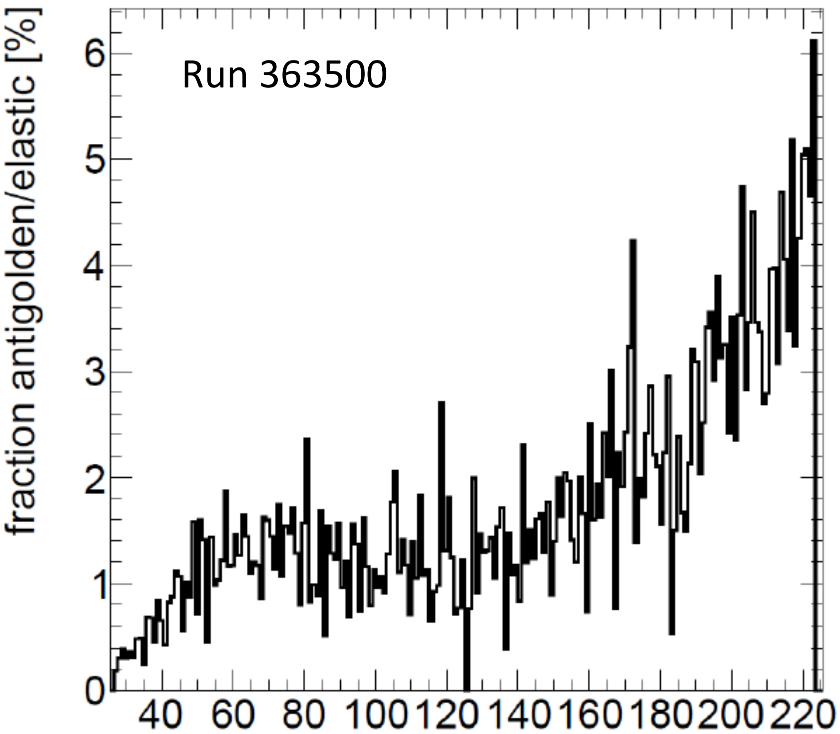
Background: 2-stage vs crystal

2-stage collimation



Overall background fraction = 0.5%

Crystal collimation



Overall background fraction = 1.5%

Further reduction of background seems possible by cost of statistics …

Run summary & background %

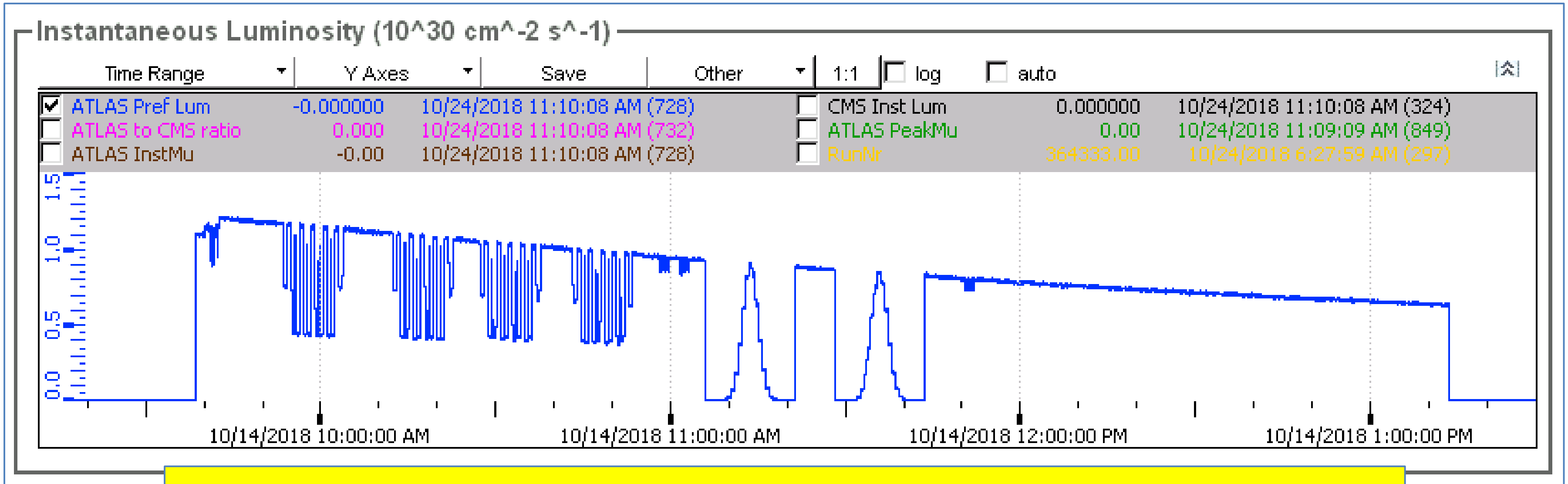
run	events	arm1	arm2	Background fraction [%]	LB range	luminosity [1/mub]	comment
363452	149357173	48051	52022	0.4	177-241, 249-308	64	
363460	177013419	59827	64421	1.4	90-202	80.4	crystal collimation
363461	32012959	67905	73508	0.53	63-88,95-168,178-240	90.2	ID on
363462	110174560	3361	25735	0.24	53-81,90-145	32.7	ALFA6 bad LB 64-End
363469	212284739	27141	63618	0.5	[illegible]0-70,76-118,126-177,184-225,249-275	79.8	ALFA6 bad LB 1-118,218-End
363489	199299061	21	56342	0.52	76-103,111-135,151-236	79	ALFA6 bad all LBs
363495	221603554	24350	90851	0.27	62-91,102-162,169-229,237-281	111	ALFA6 bad LB 1-191
363498	169111977	79839	84854	0.23	59-84,93-166,174-218	105.1	
363499	146942728	61388	65294	0.13	55-72,77-137,145-190	80.6	
363500	33865333	75312	79609	1.57	26-224	99.4	crystal collimation, ID on
363506	136743354	68295	72649	0.14	50-72,82-142,160-196	88.9	
363510	210829813	[illegible]	[illegible]	1.62	46-210	119.9	crystal collimation
Sum		**606400**	**825348**			**1022.1**	

Statistics:
In both arms about 1.4M elastic events collected.
Background:
Typical background fraction for 2-stage collimation 0.2 – 0.5%, and about 1.5% for crystal collimation.
Detector issue: 4 runs with ALFA6 not configured → arm#1 for analysis lost.

First feedback from vdM quality

LPC meeting Oct 29, 2018:
Potential problems with the precision of the vdM calibration (W.Kozaneki).
https://indico.cern.ch/event/768738/

- Oct 14, fills 7299&7300:



- **vdM program completed "as planned"** ***(well, kind of…)***
  - **main issue: severe debunching! Usability of the data to be understood**

- Another vdM scan at Nov 5:
  Fills 7406 & 7407 at the end hampered by hardware faults …
- **Alternatively to be discussed: Coulomb normalization, first ideas appeared.**

Summary

ALFA has successfully participated in all 3 parts of the 900 GeV program:

- at β* = 100m we have collected 1M /0.4 M events with 2-stage/crystal collimation
- at β* = 11m we collected 2M for the extension of the t-range to 0(0.1 GeV2).
- from the vdM scan we hope to get a precise luminosity value for σ_{tot} at 900 GeV, but precisions needs to be clarified …

Using soft selection cuts the background fraction in all fills is on the order of (1%).

- 2-stage collimation ~ 0.5% background
- Crystal collimation ~ 1.5% background
- Applying final selection (incl. alignment, emittance etc.) can further reduce the background fraction.
- No feedback yet about the 11m campaign.

We wish to thank the LHC teams (operation, collimation, optics) for this fantastic success of the 900 GeV campaign. For the ALFA team this was the perfect end of Run2.