The ATLAS Forward Proton Time-of-Flight detector: use and projected performance for LHC Run3

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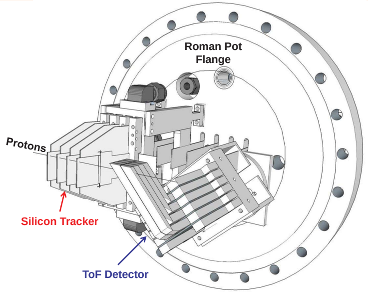
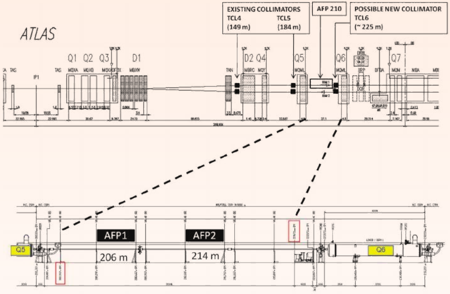
The AFP project

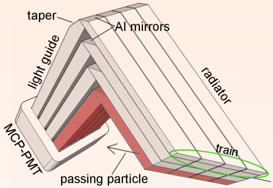
- **A**TLAS **F**orward **P**roton
- Forward detector focused on diffractive protons
- Placed in Roman Pots (RP) $\sim 210\,\mathrm{m}$ from the ATLAS IP
- 3D silicon tracker + ToF (only far stations)

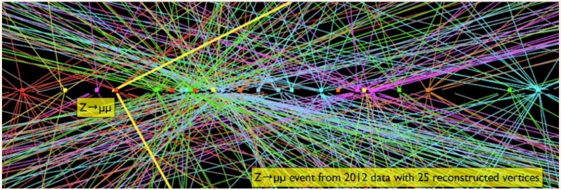




ToF detector

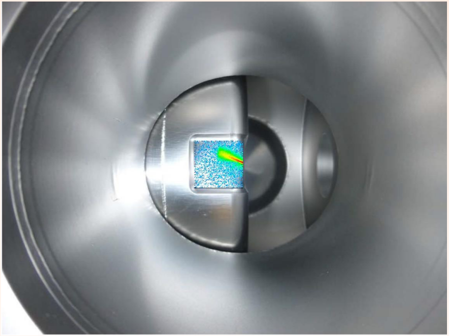
- A fast Cherenkov timing detector
- Purpose:
  - assign protons detected by AFP to individual collisions in IP1
    $\rightarrow$ timing measurement determines vertex position to match

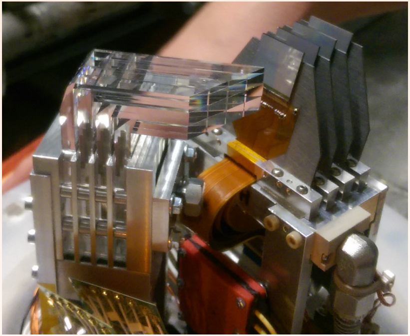




- Reduces background in high pileup situations
- Expected performance few tens of ps, strong impact on background suppression!

AFP – how the real thing looks like



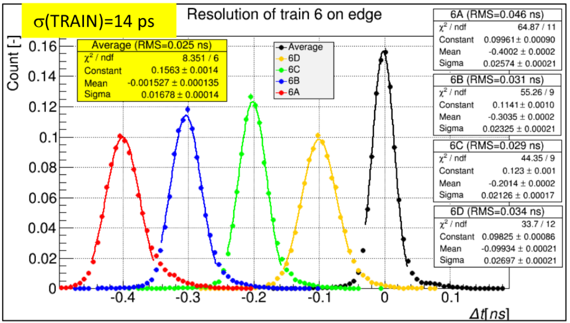


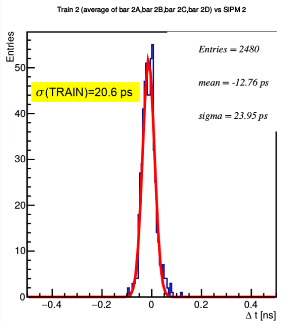
Past performance

Beam tests – timing resolution

Best results so far obtained at SPS NA beam test (140 GeV pions)
Raw signal: 20 ps single channel, 14 ps train combination
HPTDC: 20.6 ps train combination

In DESY (6 GeV electron beam) results not as nice, but able to do comparative studies (impact of upgrades)

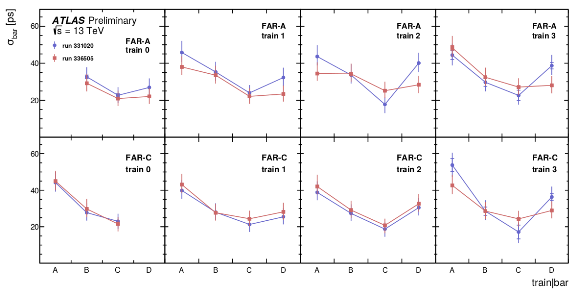


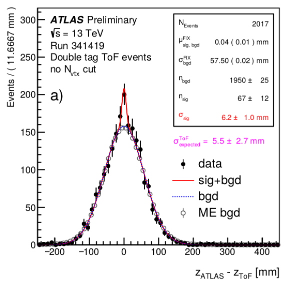


Note: fits in raw plot (left) without timing reference resolution subtraction (9 ps)

ToF detector performance analysis

- Performance analysis of 2017 data
- Poor efficiency of few percent
  (due to fast PMT degradation, new PMTs don't suffer from this)
- Good timing resolution nonetheless!
  (single bars $20 - 50\,\mathrm{ps}$, first in train worst as expected from simulation, following bars mostly $< 30\,\mathrm{ps}$)



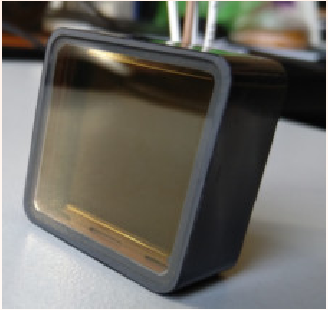


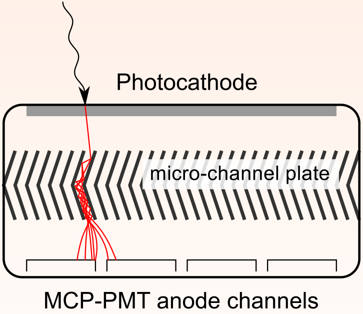
Performance of the ATLAS Forward Proton Time-of-Flight Detector in 2017, ATL-FWD-PUB-2021-002

Upgrades for Run 3

Photomultipliers

- Need for long-life tubes with relatively low MCP R ($\sim 20 - 30\,\mathrm{M\Omega}$)
- Low target PMT gain 2×10^3 to further improve rate capability (previously $\sim 10^5$), requires additional amplification stage
- New custom backend with proper HF connectors and better crosstalk behaviour
- Original fixed ratio HV divider might not be optimal at lower HV operation – exploring alternative options and their impact

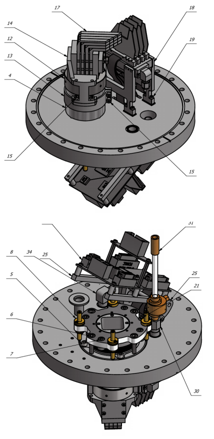


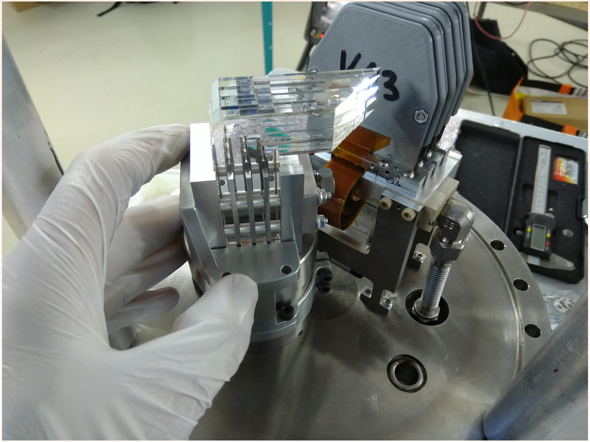


Out of Vacuum solution

Out of vacuum redesign – PMT moved out of the pot, behind window

- Fixes trouble with HV in secondary vacuum, better cooling
- Able to replace PMT or preamps without opening pot!
  (eg. during short TS)
- Got rid of non-optimal signal feedthroughs





TDC – Time to Digital Convertor

- PicoTDC to replace ageing HPTDC
- No longer at risk of being the bottleneck for timing, readout speed
  - $24.4 \rightarrow 3.05\,\mathrm{ps}$ bin size
  - our "all time best" result was $14\,\mathrm{ps}$ train combination on scope (vs $20.6\,\mathrm{ps}$ with HPTDC)
- Capable of time-over-threshold (amplitude) measurement at full resolution
- Exact deployment timeline still uncertain, fresh hardware!

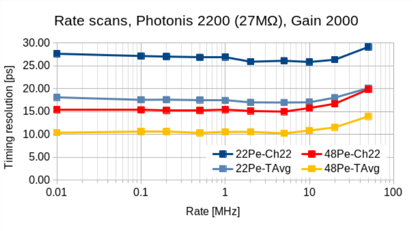
Other upgrades

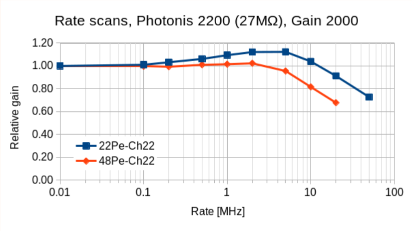
- Glueless bars production
  - expected to give more light, glue (Epotek 305) absorbed shorter wavelengths
  - removed radiation weak point
- Integration of 2. and 3. stage amplifier, remotely controlled attenuation
- Better PMT interference shielding
- Evaluating new experimental HV divider
  - low PMT gain means low HV $\rightarrow$ low voltage on front and back stages with original fixed ratio HV divider
- Integration of light pulse generator for in-situ tests

Test results and expected performance

PMT performance at high rates

- Gain deteriorates at very high event rates (charge depletion from MCP), influencing timing and efficiency
- Low PMT gain and low MCP R help improve rate capability
  - less charge depleted per event, faster recharge through strip current
- Expected in Run 3: $\sim 20\,\mathrm{MHz}$ per train
  - plus some background, but dominated by single diffraction
  - not uniform across trains; depends on LHC optics
- Tested using laser, scanning through different event rates





DESY beam test results

Out of vacuum modification

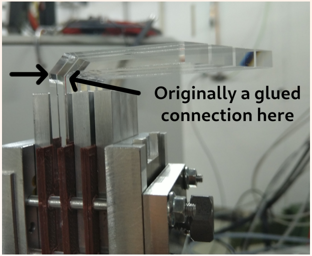
- 13 – 15 % amplitude reduction due to glass (roughly compensated by removed flex feedthroughs)
- Timing resolution not impacted

Glueless bars

- No change of train timing (due to dispersion)
- Significant improvement of efficiency

Efficiency of the ToF measured with respect to the SiPM trigger for the amplitude threshold of -150 mV at the distance of 5 mm from the edge.

		Glued bars				Solid bars			
		Number of bars with detectable signal				Number of bars with detectable signal			
HV [V]	Gain [-]	=4	>=3	>=2	>=1	=4	>=3	>=2	>=1
2050	$3.8 \cdot 10^4$	-	-	-	-	20%	68%	90%	94%
2100	$5.4 \cdot 10^4$	28%	68%	89%	94%	**67%**	**91%**	**93%**	**95%**
2150	$7.6 \cdot 10^4$	**66%**	**90%**	**93%**	**95%**	89%	93%	94%	95%
2200	$1.1 \cdot 10^5$	86%	93%	94%	96%	-	-	-	-



Summary

Expected timing

- $25 - 30\,\mathrm{ps}$ single bar resolution
- $20 - 25\,\mathrm{ps}$ train combined resolution
- Without PicoTDC a bit worse ($\sim 16\,\mathrm{ps}$ contribution)

Impact on analysis

- Need full simulation to evaluate exact impact
- For reference:
  Performance studies of Time-of-Flight detectors at LHC
  DOI: 10.1088/1748-0221/16/01/P01030
- Increased pileup in Run 3 means AFP would benefit from operational ToF at least as much as in Run 2

Thank you

Thank you for your attention!