Status of the AFP Project in ATLAS

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On behalf of the ATLAS AFP collaboration

Diffraction 2016, Acireale-Sicily, Italy - Sept 3-7 2016

1) Concept
2) Status
3) First data
4) Plans
**Concept of AFP = ATLAS Forward Proton**

Proton leaves the interaction intact, travels through LHC optics and is detected at ~210 m.

(x,y)-distribution of protons at ~210 m from IP1 using all processes in Pythia 8 [upward deflection due to vertical crossing angle in IP1]

Diffractive protons deflect horizontally (given by LHC beam optics)

Only horizontal pots needed

Good acceptance for diffractive protons is close to the beam

Put detectors in Roman Pots and insert in LHC aperture (ample experience in Totem and ALFA)

Detector acceptance covers $\xi$ of 0.02-0.15, where $\xi$ = proton fractional energy loss

**Currently AFP approved with 2 arms for low pile-up**

Ultimate goal for AFP: 2 stations on each side of IP1 with tracking detectors at 205 and 217m and timing (ToF) detectors at 217m – to run continuously at nominal lumi

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**What is AFP?**

1) **Array of radiation-hard near-beam Silicon detectors** with resolution ~10 $\mu$m, 1 $\mu$rad

2) **Timing detectors** with up to ~10 ps resolution for overlap background rejection (SD+JJ+SD)

3) **Roman Pots**

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**Beam 1 - PYTHIA8 4C**

(x,y)-distribution of protons at ~210 m from IP1 using all processes in Pythia 8 [upward deflection due to vertical crossing angle in IP1]
What does AFP Provide?

- Mass and rapidity of centrally produced system
  \[ M = \sqrt{\xi_1 \xi_2} \cdot \sqrt{s} \]
  \[ y = \frac{1}{2} \ln(\frac{\xi_1}{\xi_2}) \]
  where \( \xi_{1,2} \) are the fractional momentum loss of the protons

- Acceptance > 40% for wide range of produced mass

- Allows ATLAS to use LHC as a tunable \( \sqrt{s} \) Pomeron-Pomeron or \( \gamma \gamma \) collider while simultaneously pursuing standard physics program

- Acceptance > 40% for wide range of produced mass

- Mass resolution of 5-10 GeV per event
Primary goals of AFP (low & medium $\mu$)

In a fraction of Forward Physics: one or both protons stay intact: measure them with AFP and provide $\xi$ & $t$ (these make up around 20% of total pp x-section)

**Single-tag: Single Diffraction**
- Jets, $W$, $Z$: Soft survival prob. $S^2$
- Particle spectra, Gap spectra: SD vs. DD

**Double-tag: Double-Pomeron Exchange**
- Dijet: constrain gluon content of Pomeron
- $\gamma$+Jet: constrain quark content of Pomeron
- Jet-gap-jet: test BFKL IP

**Double-Photon Exchange**
- $\gamma\gamma \rightarrow WW/ZZ/\gamma\gamma$: Anomalous quartic couplings $\rightarrow$ sens. 30-100x better than only central det.
- $\gamma\gamma \rightarrow \mu\mu$: calibration/alignment of AFP

**Central Exclusive Production**
- Dijets, Trijets: constrain predictions to CEP of Higgs ($S^2$, Sudakov suppr., unintegr. $f_g$)
January-March 2016: AFP2+0 INSTALLED !!!

The C-side (6R1) fully installed and operational

Beam pipe support needs to be moved

Quadrupole Q5

PP2 @212m

217m

TCL6 collimator

BPM (at 217m)

station at 217 m, BPM, BLM, TCL6
Roman Pot Installation

- Two stations validated and installed on ATLAS C-side

  **Cabling:**
  - Fast Cabling finished for both arms
  - Control cables finished for both arms
  - All C-side cables connectorized and tested

  **Services:**
  - Compressed air for Cooling (CZ)
  - Secondary Vacuum (EP-DT)
  - BPM, BLMs connected

- Installation done, connected to Beam Pipe, pump-down and bake-out done …

- Pot Motion calibrated in tunnel:
  - Survey of slide vs motor position, vs switches and LVDT 20 Feb’16

Patch Panels & LV Regulators (Milano) at 211 m

station at 217 m, BPM, BLM, TCL6
Tracking Detectors

Tracker requirements:
- Close to the beam → detectors with slim edges
  - dead area < 150 μm already reached
- High lumi operation → non-uniform radiation hard
  - From $5 \times 10^{12}$ up to $3 \times 10^{15}$ neq for 10 fb$^{-1}$ in beam position
- Resolution
  - 2-3% in M → ~ 10μm in X, ~10% in pT → ~ 30μm in Y
- Suppress pile-up → add ToF detector
  - 10 ps gives a suppression ~ 19/18/16/15 at lumi of 1/2/5/10 x $10^{33}$ cm$^{-2}$s$^{-1}$

AFP 3D Si detectors:
- Column-like electrodes: inter-electrode distance 67μm, detector thickness 230μm
  - Lower voltage (~10V) for full depletion (before irradiation) At 1V & 14° tilt: >99% efficient
  - Shorter drift distance -> lower trapping prob. -> radiation hard
- FE-I4 readout chip
  - Tunable down to 1.5 ke threshold, 4-bit charge measurement (Time-over-threshold, TOT)
  - HitOR (at least one hit per plane) signal used for L1 trigger
- Sensors
  - (x,y)=(40μm,250μm) pixels, 336x80 pixels
- Validated in IBL to be hard to uniform irradiation of $10^{15}$ neq/cm$^2$

3D Si detectors successfully used in IBL (and AFP)
Tracker resolutions and installation

Resolution in X:
- Digital resolution ~ 14 μm (50μm/√12)
- But: FE-I4 has a 4-bit TOT measurement (Q collected)
- Maximize statistics of 2-hit events by tilting detectors by 14° along z-axis

Resolution in Y:
- Digital resolution ~ 72 μm (250μm/√12)
- Staggering necessary: resolution 19-72 μm (depending on the staggering achieved)

Installation:
- NEAR station: 3 planes
- FAR station: 4 planes (one module short in HV line, cannot be biased but still usable at 0V – still 95% eff.)
- Trigger (each station): 2-out-of-3 layers with HitOR ON
  - Local Trigger Board (HitBUS chip) → Air-core Cables → CTP
  - AFP is within the (last BX of the) ATLAS latency!
- Readout:
  - Tunnel (FE-I4→HitBUS chip→Optoboard) → USA15 (HSIO2/RCE system) → ROS

A new batch of 3D Si sensors with better characteristics is being produced and will replace the existing ones during EYETS2016

Results from TB 2016

![Diagram of tracker resolution and installation](image-url)
Towards first data and what’s next

Beam view: looking downstream through the beam pipe at a fully inserted Roman pot
## AFP Insertions

<table>
<thead>
<tr>
<th>Date</th>
<th>Fills</th>
<th>TDAQ Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>19-22 April</td>
<td><strong>Beam-Based Alignment and Loss Maps (6 &amp; 3 hrs)</strong></td>
<td>Stand-alone</td>
</tr>
<tr>
<td>23 April</td>
<td>3b: 2nd fill (no 3rd fill)</td>
<td>Stand-alone</td>
</tr>
<tr>
<td>24-25 April</td>
<td>12b: 2nd + 3rd fill</td>
<td>Stand-alone</td>
</tr>
<tr>
<td>29 April – 5 May</td>
<td><strong>Weasel break ➔ TDAQ integration</strong></td>
<td>Stand-alone</td>
</tr>
<tr>
<td>7 May</td>
<td>49/86b: 2nd + 3rd fill; 8.1pb⁻¹</td>
<td>Integrated</td>
</tr>
<tr>
<td>9 May</td>
<td>300b: 4th fill (2nd+3rd ended before AFP in); 7.9pb⁻¹</td>
<td>Integrated</td>
</tr>
<tr>
<td>13 May</td>
<td>600b: 2nd fill (1:14h); 9.3pb⁻¹</td>
<td>Integrated</td>
</tr>
<tr>
<td>10 June</td>
<td>2b: Totem loss maps</td>
<td>Integrated</td>
</tr>
<tr>
<td>11 June</td>
<td>7b: collimator test</td>
<td>Integrated</td>
</tr>
<tr>
<td>01 August</td>
<td>3b (0.023 pb⁻¹)</td>
<td>Integrated</td>
</tr>
</tbody>
</table>

- **Total (TCL6 and/or AFP in):**
  - 42 h, 34 pb⁻¹ **BBA @5.5σ**

### PROTON PHYSICS: STABLE BEAMS

- **Energy:** 6499 GeV
- **|kB1|:** 7.09e+12
- **kB2:** 7.11e+12
- **Inst. Lumi [(ub.s)⁻¹]:**
  - IP1: 190.37
  - IP2: 0.22
  - IP3: 203.49
  - IP8: 8.39

**Comments (07 May 2016 19:59:54)**
- Stable beams
- **AFP pots in**

**B1** | **B2**
---|---
- Link Status of Beam Permit: true
- Global Beam Permit: true
- Setup Beam: false
- Beam Presence: true
- Moveable Devices Allowed in Stable Beams: true
- **AFS: 25ns_86b_74.47_49_12bp1_9inj**
- PM Status B1: ENABLED
- PM Status B2: ENABLED
Performance at 300 bunches and $\mu \leq 26$

- AFP inserted during several fills with different intensities up to 600 bunches (meanwhile working on AFP TDAQ integration)

Aim was to study:
- Detector performance and alignment
- Beam background and AFP triggers
- Time-in detector to read 1BC and send triggers within ATLAS latency

Fill 4906: 300 bunches, AFP read out but triggered by ATLAS, $\beta^*=0.4m$, $\sqrt{s}=13$ TeV, $L \sim 9.3$ pb$^{-1}$

Hit pattern, 1st plane at NEAR station

Expected		Observed

AFP inserted during several fills with different intensities up to 600 bunches (meanwhile working on AFP TDAQ integration)

- AFP TDAQ fully integrated.
- However, only high-$\mu$ available ($\sim 26$)
- not useful for AFP2+0 physics (one arm, no ToF)

- DCS: full integration done during TS1

At the last step of intensity ramp-up (600 b),
- Measured AFP trigger rates

Hit pattern, 1st plane at NEAR station

DCS: full integration done during TS1

Measured AFP trigger rates
Fill 4906: 300 bunches, AFP read out but triggered by ATLAS, $\beta^*=0.4\,\text{m}$, $\sqrt{s}=13\,\text{TeV}$, $L\sim9.3\,\text{pb}^{-1}$

**Performance at 300 bunches and $\mu \leq 26$**

- **92**% of events have no hits
- Hit = 2 pixels because of tilt $14^\circ$ of 3D sensors
- Most of events have just one track (i.e. proton)

**Hit pixel row in Plane 0 vs. Hit pixel row in Plane 1**

- Good correlation means tracks parallel to z-axis and mostly single track events
- Non-correlation may mean additional tracks
First physics AFP special run (low $\mu$)

- Filling scheme: 25ns_590b_578_523_544_96bpi_11inj
  - 15:20: start to separate beams
  - 15:24: beams at $5\sigma_H$ separation $\rightarrow \mu_{peak} = 0.26$
  - 15:30: beams adjusted to $5\sigma_H$ and $2.5\sigma_V$ separation $\rightarrow \mu_{peak} = 0.13$, $<\mu> = 0.03$, $L = 2.7E30$
  - 15:35: start to insert AFP
  - 15:42: AFP inserted!

- AFP at 20$\sigma$, TCL4/5/6 at 15/35/20 $\sigma$
- Total time in beam: 4h37m (3h58 – presc. corr)

Next Low-$\mu$ run: after TS2 (Sept 23-24)

01.08.2016: Fill 5151 (run 305359): 600 bunches, AFP triggers at work, $\beta^* = 0.4m$, $\sqrt{s} = 13$ TeV, $L = 0.033$ pb$^{-1}$
AFP aims to take data regularly in standard conditions (high $\mu$). High $\mu$ requires:
- TCL4 & TCL5 must be opened to give large-$\xi$ acceptance
- TCL6 (behind AFP) must be closed to 20$\sigma$ to protect Q6 and downstream
- This increases radiation levels to ALFA by a factor $\sim$10
- ALFA does not have radiation hard electronics
- ALFA is still eager to take the $\beta^+$=2.5km data (Sept.2016) and possibly follow-up early 2017

Agreement: AFP limits its insertions to 0.25 $fb^{-1}$ in 2016
Meanwhile: AFP+ALFA working together on a shielding to protect ALFA in 2017 and beyond
- Studies by FLUKA team encouraging: already a factor of 3-4 reduction
- Studies ongoing, proposal (+ECR) expected in Sept 2016

So far total (high-$\mu$ equivalent) lumi this year by AFP: 67 $pb^{-1} \ll 250$ $pb^{-1}$.
Still Run2 in Sept planned (~4h), then maybe insertions during Heavy Ion run.
Preparing for the 2nd arm

- The ultimate goal of AFP is a two-arm system

- Installation of 2nd arm during EYETS (12 Dec 2016 – 30 Apr 2017 (BE-OP: 14 Apr 2017))

- Crucial component: ToF detectors in both arms
  - design of the prototype holder ready
  - beam tests in 2016 (June, Sept) important: R&D not finished yet
  - electronics is crucial: CFD, HPTDC, Trigger, Clock

- Status of preparation:
  - ECR for 2nd arm in circulation:
    - TE-VSC-BVO started the production of the beam pipe elements
    - BPM ready, BLM group notified
  - Cabling:
    - tunnel cabling is all done
    - still must complete cabling in USA15
  - Cooling:
    - complete compressed air for cooling with regulators, pressure sensors
    - 2+1 more air coolers ordered
  - Secondary vacuum:
    - pump system available – must be installed in RR13
Beam tests & ToF results

AFP is very active in TB campaigns: several in 2014-2015, and 3 in 2016!

- TB 2014-2015: excellent spatial resolution: $\sigma_x(\text{track}) \sim 3\mu$m
- TB 2016 June: ToF: full (4 bars) trains, characterization and optimization of ToF front-end: radiator bars, cross talk, MCP-PMT, CFD delay and threshold
  - $\sigma(\text{TRAIN}) = 14$ ps

Excellent performance of new 6 µm pore MCP-PMT (Photonis):
- Reduced MCP-Anode dist $\rightarrow$ improves cross-talk
- 6 µm pores $\rightarrow$ faster read-out
- Atomic Layer Deposition in pores $\rightarrow$ 10x longer lifetime

J. Lange et al., arXiv: 1608.01485 [physics-ins.det], subm. to JINST

- TB 2016 Sept: optimize ToF back-end electronics (HPTDC, Trigger), full integration on RP flange
Physics with low-$\mu$ and 2017 and beyond

• Pythia and AFP acceptance predict (per hour):
  - $\beta^*=0.55m$, $\mu=0.1$, nb=300, stand. bunch density.

• 7M Soft SD events (proton rate in AFP 2 kHz)
• 15k SDjj evts with $p_T>$20 GeV
• 0.5k SDjj evts with $p_T>$50 GeV
• 3 SD+W evts

Running plans:

- Run 2 goal: 15pb$^{-1}$ (4h @ 600b, $\mu$~0.5-1 $\rightarrow$ ~1.3pb$^{-1}$), aim is $15\sigma$ approach
- Dec. 2016: HI run: ongoing discussions if AFP can be put in for Pb+p runs
- Ultimate goal of AFP: regular data taking with whatever $\beta^*$ and $\mu$ (concentrate on high-$\mu$):
  - must work out the shielding to protect ALFA from irradiation
  - of course: must install the 2nd arm and ToF
  - aim is $15\sigma$ approach, AFP in ATLAS TDAQ permanently, probably L1 AFP+Calo/mu, AFP in HLT
- Special (low-$\mu$ ~ 1) runs: clean environment to study diffraction
- Plans to run after LS2:
  - Currently under discussion in AFP
  - Will depend on the outcome from runs before LS2
  - Must be reviewed by ATLAS before going to TDR and LHCC (review planned for 2nd half of Oct 2016)
1) One arm of AFP (6R1) is installed and fully operational

2) AFP has taken data in fills with various intensity and high $\mu$ during which many checks were done (Detector performance and alignment, Beam background and AFP trigger rates, sending AFP triggers to ATLAS CTU) plus AFP TDAQ (DCS) integration into ATLAS TDAQ (DCS)

✓ Backgrounds seem to be under control

3) AFP has recently taken data with low $\mu$ (0.03). They look promising and analysis is ongoing (enough statistics for SD jets). Another low-$\mu$ run (0.5-1.0) expected in Sept 2016

4) ALFA and AFP teams work on the shielding to protect ALFA from irradiation caused by AFP

5) AFP is preparing for the 2nd arm (to be installed beg. 2017):

✓ ECR recently approved
✓ ToF detector most critical item (two Beam tests in 2016)
✓ Production of other critical items is well underway

6) AFP is preparing for running after LS2:
   - ultimate goal is to be in beams permanently
   - this still has to be approved by ATLAS
BACKUP SLIDES
AFP in ATLAS simulation (1): SiD hits

- Actual SiD setup:
  - 2 AFP stations with Si detectors per ATLAS side (SiD 0 - 1 ← IP → SiD 2 - 3)
  - 6 Si layers/station separated by 10 mm (13 deg tilt in the x-z plane)
  - No staggering of the layers (yet)
  - 336 x 80 array of 50 x 250 μm² pixels per layer
  - Kalman filter is used for the tracking reconstruction

- Expected tracking resolution wrt 4 staggered layers:
  - 8 μm in x, 20 μm in y

- Reconstructed track multiplicity with $|x_{\text{slope}}| < 0.003$ and $|y_{\text{slope}}| < 0.003$ cut (per station) to separate proton tracks from showers

- Events are generated without any cut on the proton kinematics (i.e. $\xi < 1$)

- Approximately 50% of protons in the sample do not enter the AFP acceptance region ($0.015 < \xi < 0.15$) which results in no reconstructed tracks
AFP in ATLAS simulation (2): SiD efficiency

- x-y track positions hitmap for outer SiD station before (left) and after (right) track matching included for outer (AFP 212) station
- Tracks matched between inner and outer SiD stations are considered
- Positions are calculated in the ATLAS Coordinate System – beam center at \( x = -97 \) mm

**AFP proton track reconstruction efficiency for different pile-up conditions:**

- matching between tracks in inner and outer stations included
- cuts suppressing showers applied (\( n_{tr_{inner}} \leq 2, n_{tr_{outer}} \leq 5 \))
- improvement expected, subject of further cut optimization

\[ \approx 95\% \text{ in } 0.02 < \xi < 0.11 \text{ and } \mu = 0/1 \]
Example for low luminosity: Gap spectra

ATLAS and CMS measurements without proton tags:

ATLAS EPJ C72 (2012) 1926

CMS PAS FSQ-12-005

ATLAS and CMS agree within systematic uncertainties
(hadron $|\eta|<4.7$ vs. $|\eta|<4.9$: 5% diff. model for unfolding: 10%)

1) CMS systematically above ATLAS !
2) Pythia8 predicts SD~DD !

Could proton-tagging shed light on 1) and 2) ?

- AFP: wide t-range, $\xi$-acceptance depends on beam optics
- ALFA: whole $\xi$-range, limited t-acceptance
  Suitable for high- $\beta^*$ optics
- AFP & ALFA complement each other

$\beta^*=0.55$m, $\sqrt{s}=14$TeV, $d=3$mm

- AFP210 provides limited range of gaps: $0 < \Delta \eta \sim -\ln \xi < 2.5$
- Gap on the side of the detected proton in AFP
- DD shows very different gap spectrum

Running scenarios:
- Statistics not a problem
- Very low $\mu$ necessary
- $\beta^*=90$m: ALFA + AFP common run
- $\beta^*=0.55$m: larger ($\xi,t$)-acceptance with AFP
- Single-tag or Double-tag AFP Trigger
Example for medium luminosity: Pomeron structure

Pomeron structure (dPDFs) measured at HERA

1) Not well constrained at high $\beta$ ($= z = x_{Bj}/\xi$)

2) Assumptions in H1Fit of dPDFs measured at HERA:

- $u=d=s=ubar=dbar=sbar \rightarrow F2D \sim 4/9u + 1/9d + 1/9s$
- Two degrees of freedom: $R_{ud} = u/d$, $R_{sd} = s/d$
- $u = q^* 6 * R_{ud} / (1 + R_{sd} + 4R_{ud})$
- $s = q^* 6 * R_{sd} / (1 + R_{sd} + 4R_{ud})$
- $d = q^* 6 / (1 + R_{sd} + 4R_{ud})$

- Result: different Pomeron flavour structures consistent with HERA

AFP has potential to complement the HERA measurements

- SD W production
  - Sensitive to quark content of dPDFs
  - Measure charge asymmetry

- DPE gamma+jet
  - Sensitive to quark content of dPDFs and to Soft Color Interaction model

- DPE dijet
  - Sensitive to gluon content of dPDFs and to Soft Color Interaction model
Pomeron structure: DPE dijet

Cross-section after cuts ~ 10nb
- Dominantly g+g

MAD-X + MC generator-level:
- 2 jets Et>20 GeV + AFP acceptance

Effect of PU studied:
- Single-tag as well as double-tag
- Two models (Py8 default, Py8 MBR)
- Fast timing det. necessary

Assuming conservatively resolution of only 30ps for Run II

β∗=0.55m, √s = 14TeV, d=3mm

Running scenarios:
- Effective x-section ~ 10 nb -> medium lumi needed
- µ~1 optimal but µ up to 5 && Etjet up to 100 GeV manageable
- Run of 100h with µ<5
- May be measured with both β*=0.55m and 90m (0.55m preferred due to larger statistics and larger AFP acceptance)
- Double-tag AFP210 + Jet trigger gives sufficiently low rate

With moderate timing resolution 30ps and one-vertex requirement:
1) Excellent purity up to µ~3
2) Event yield and significance optimal at µ~1 but still manageable up to µ~5
## Physics program for Run II

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Lumi req. ([pb^{-1}])</th>
<th>Optimal (\mu) range</th>
<th>(\beta^*) scenario</th>
<th>L1 trigger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle spectra</td>
<td>1</td>
<td>&lt; 0.05</td>
<td>90m(ALFA+AFP) 0.55m</td>
<td>AFP-ST AFP-DT</td>
</tr>
<tr>
<td>Gap spectra</td>
<td>1</td>
<td>&lt; 0.05</td>
<td>90m(ALFA+AFP) 0.55m</td>
<td>AFP-ST AFP-DT</td>
</tr>
<tr>
<td>SD jj</td>
<td>10-100</td>
<td>0.01-1.0</td>
<td>90m 0.55m</td>
<td>AFP-ST &amp;&amp; Jet</td>
</tr>
<tr>
<td>DPE jj</td>
<td>10-100</td>
<td>0.5-5.0</td>
<td>90m 0.55m</td>
<td>AFP-DT &amp;&amp; Jet</td>
</tr>
<tr>
<td>SD W</td>
<td>10-100</td>
<td>0.1-1.0</td>
<td>90m 0.55m</td>
<td>AFP-ST &amp;&amp; Lepton (&amp;&amp; MET)</td>
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<tr>
<td>DPE (\gamma+j/jj)</td>
<td>&gt; 200</td>
<td>1.0-2.0</td>
<td>0.55m</td>
<td>AFP-DT &amp;&amp; Jet/Photon</td>
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<tr>
<td>DPE j-g-j</td>
<td>&gt; 100</td>
<td>0.1-2.0</td>
<td>0.55m</td>
<td>AFP-DT &amp;&amp; Jet</td>
</tr>
</tbody>
</table>

1 week of 100h:
\(\mu = 0.1: \sim 10 \, pb^{-1}\)
\(\mu = 1: \sim 100 \, pb^{-1}\)
Alignment

Hardware:

- **BPM (Beam Position Monitor):** measures the AFP position w.r.t. the actual beam
  - Sub-um precision expected with dedicated electronics
  - BPM → RP → detector calibration less accurate (100µm?) – possible improvement with a quartic window

- **LVDT (Linear Variable Differential Transformer):**
  - Fixed reference frame
  - ALFA experience: 35 µm precision, 250 µm for calibration

Software (Methods):

1) **Kinematic peak:** measure the t-distr. and compare with MC for several detector positions
   - used in CDF experiment
   - at LHC sensitive to the relative alignment (between stations)
   - 100k SD events: 30µm precision in x (preliminary), worse in y (due to worse resolution in y)

2) **Hot spot:** make use of the characteristic dense area (hot spot) in the (x,y)-distribution of AFP hits
   - hot spot is found as a minimum in the distr. of rms of y-position in bins of x-position
   - 100k events: 8µm precision (preliminary)
   - small sensitivity to physics models and optics changes

3) **Distribution shift:** comparing distributions of the x-position of protons from two runs (time periods) using
   the Wilcoxon-Mann-Whitney statistical test
   - search for translation that equalizes distributions shapes. Precision: 13/25/100 µm for 1M/100k/10k evts

4) **Exclusive γγ → μμ:** compare ζ-distributions measured by AFP and by muon pair in central detector
   - Cross section small (40 fb) but precision 10 µm with 100 events only.
AFP tracker module production: Overview

Chip
Sensor
Carrier card
Flex

Flip-Chip

UBM
Solder
Bumps

Bare Assembly

Sensor
Chip

Wire-bonds

Carrier card

Tracker Module

I. López, on behalf of the AFP collaboration
3rd Elba Workshop on Forward Physics @ LHC Energy
31st of May 2016