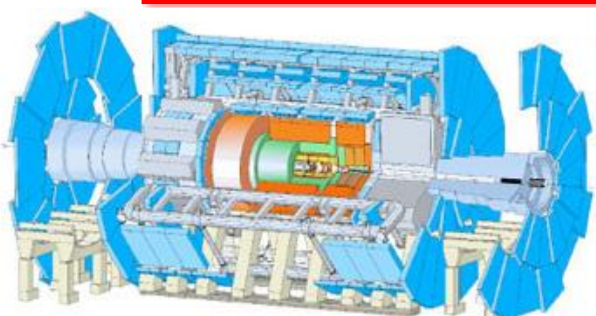
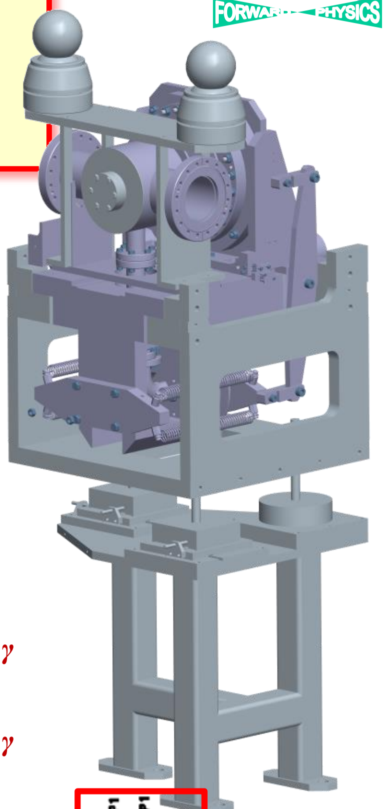
ATLAS Forward Proton Project and Fast Timing

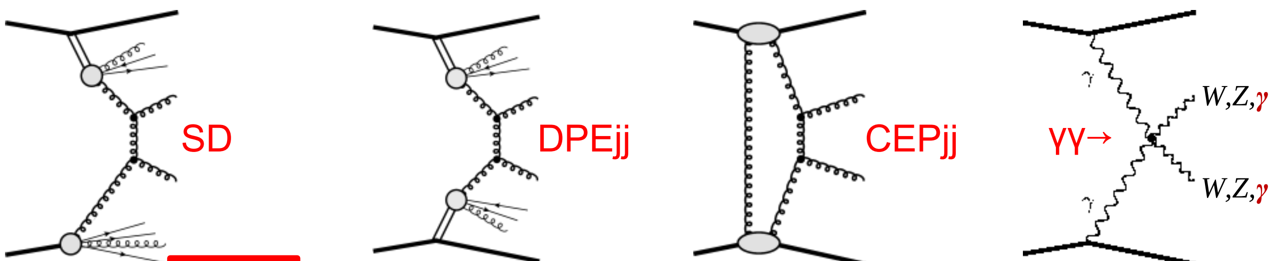
ATLAS-AFP Collaboration



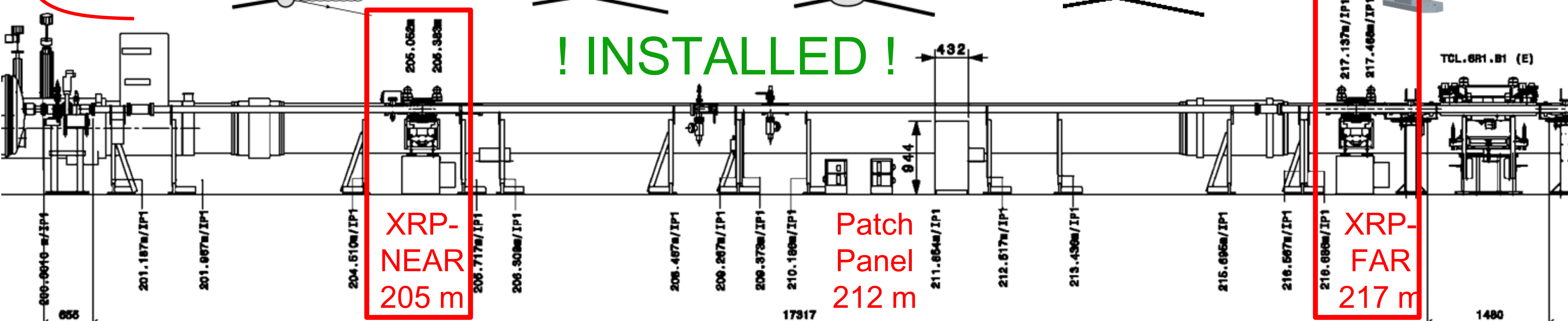


2016

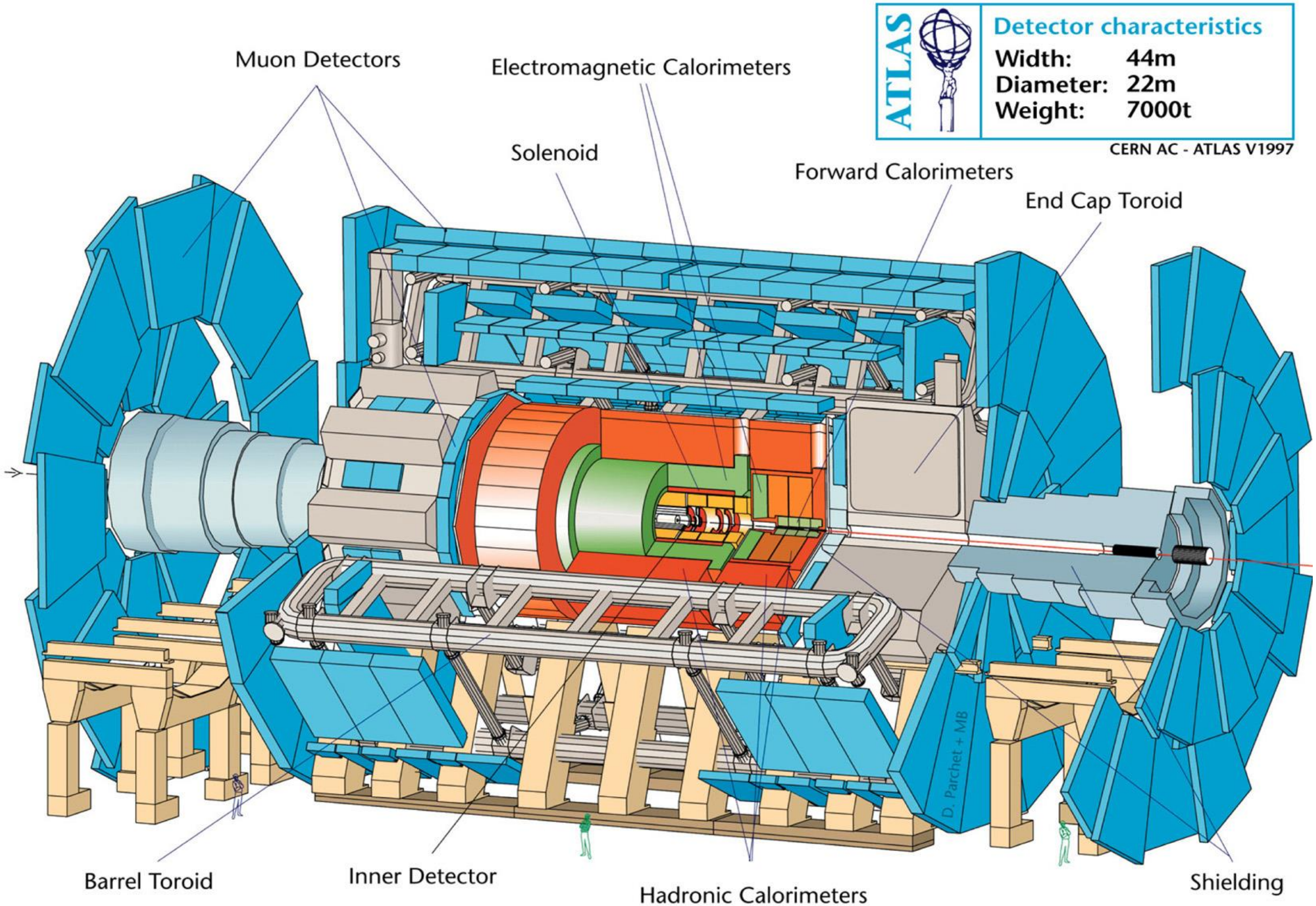
2017 →



! INSTALLED !



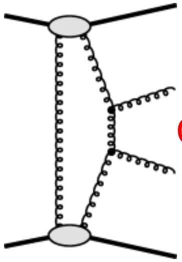
The ATLAS Detector

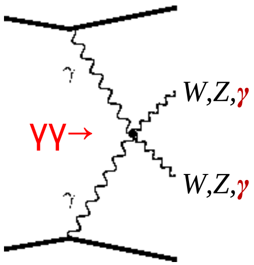


to AFP right arm (200m)

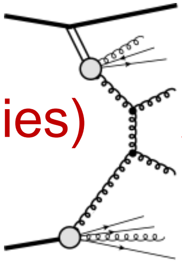
AFP Goals

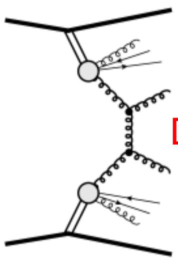
- A *two-forward-proton measurement for each ATLAS event* :
  - forward proton energy and momentum (use $\xi \equiv 1 - E_p / E_{beam}$, θ or t, ϕ)
    - excellent tracking (<10 μm) and two stations/arm with 12 m lever arm
    - use 3D pixel sensors (50 μm × 250 μm pixel size) with FE-I4b readout
  - identify the vertex of origin (remove single-diffraction pileup) by proton time-of-arrival t_L, t_R measurement
    - if both protons come from a single vertex: $z_{vtx} = (t_R - t_L)/2c$
    - excellent proton time resolution needed: ≲10 ps for μ≲50
  - Note: some *rare processes* do not require timing:
    - E.g. pp → p_L+X+p_R, X = γγ, WW, ZZ is almost background-free by requiring *kinematic* match between ($p_L p_R$) measured in AFP and the system X measured in central ATLAS


CEPjj



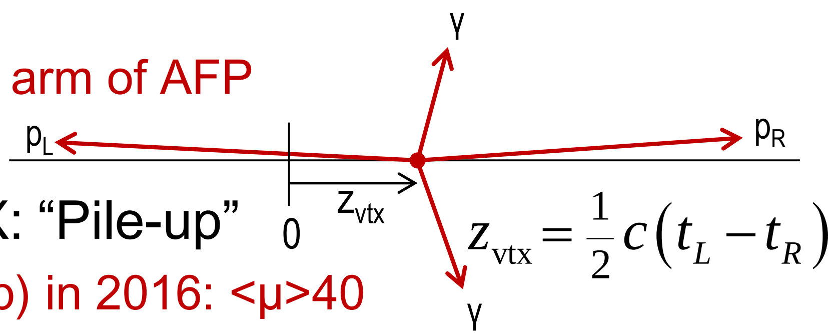
- Low Luminosity (low-μ) runs:
  - Single diffraction studies (single Pomeron studies)
  - Double Pomeron Exchange studies


SD

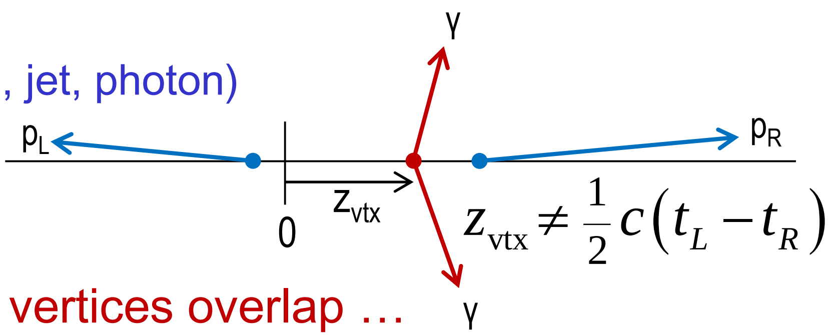

DPEjj

Ultra-Precise Time-of-Flight

- AFP is looking for $pp \rightarrow p_L + X + p_R$
  - $p_{L(R)}$ is a forward proton in the Left (Right) arm of AFP
  - $X \equiv WW, ZZ, jj, \gamma\gamma, \ldots$



- in ATLAS we have 20-60 interactions/BX: "Pile-up"
  - avg number of interactions per BX (pile-up) in 2016: $\langle\mu\rangle 40$
  - 15% of these have a forward proton (Single Diffraction)
    - a SD proton has a 20% acceptance in AFP
    - At high μ, any ATLAS trigger (high p_T lepton, jet, photon) is often accompanied by two forward protons in AFP from pile-up

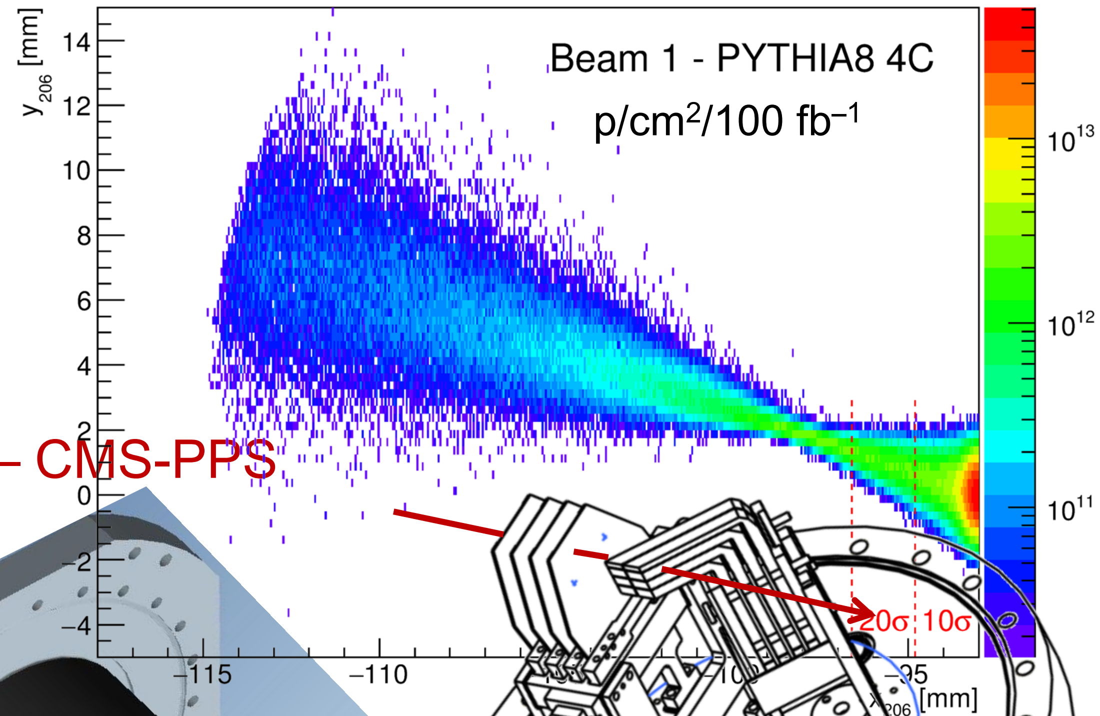


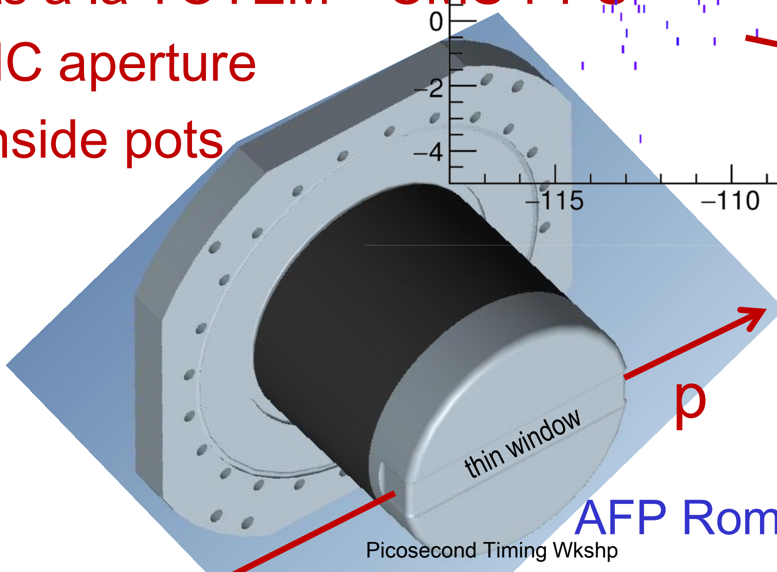
  - A measurement of "t_0" with ATLAS could provide pile-up rejection even when vertices overlap …
- Precise time-of-arrival measurement will help reject pile-up protons:
  - if the two protons come from the *same* vertex (vtx), then: $z_{vtx} = c(t_L - t_R)/2$
  - if z_{vtx} measured by AFP can be matched with a vertex of interest in ATLAS, then the process may be of the type we're looking for …
  - resolution is crucial: $\delta z_{vtx} = (c/\sqrt{2})\delta t$; for $\delta t = 10$ ps ➔ $\delta z_{vtx} = 2.1$ mm
    - z_{vtx} distribution has rms=40 mm, so fake matches increase with δt and with μ

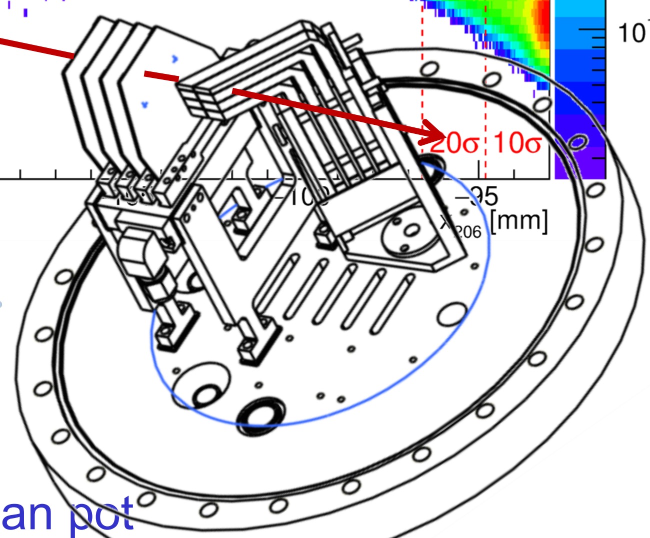
Forward Protons …

Hit pattern at ~210 m for protons with 2% to 15% energy loss is determined by the LHC optics (AFP TDR)

- For β*=0.55 m:
  - upward tilt for protons with energy loss is caused by vertical crossing angle in Point 1
- must get close to the beam
  - ⇨ Roman Pots à la TOTEM – CMS-PPS
  - ⇨ insert in LHC aperture
  - ⇨ detectors inside pots



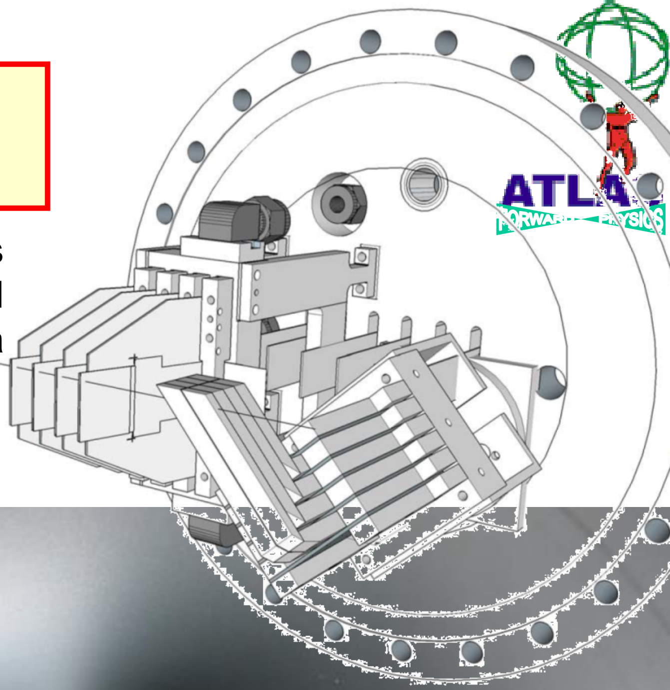


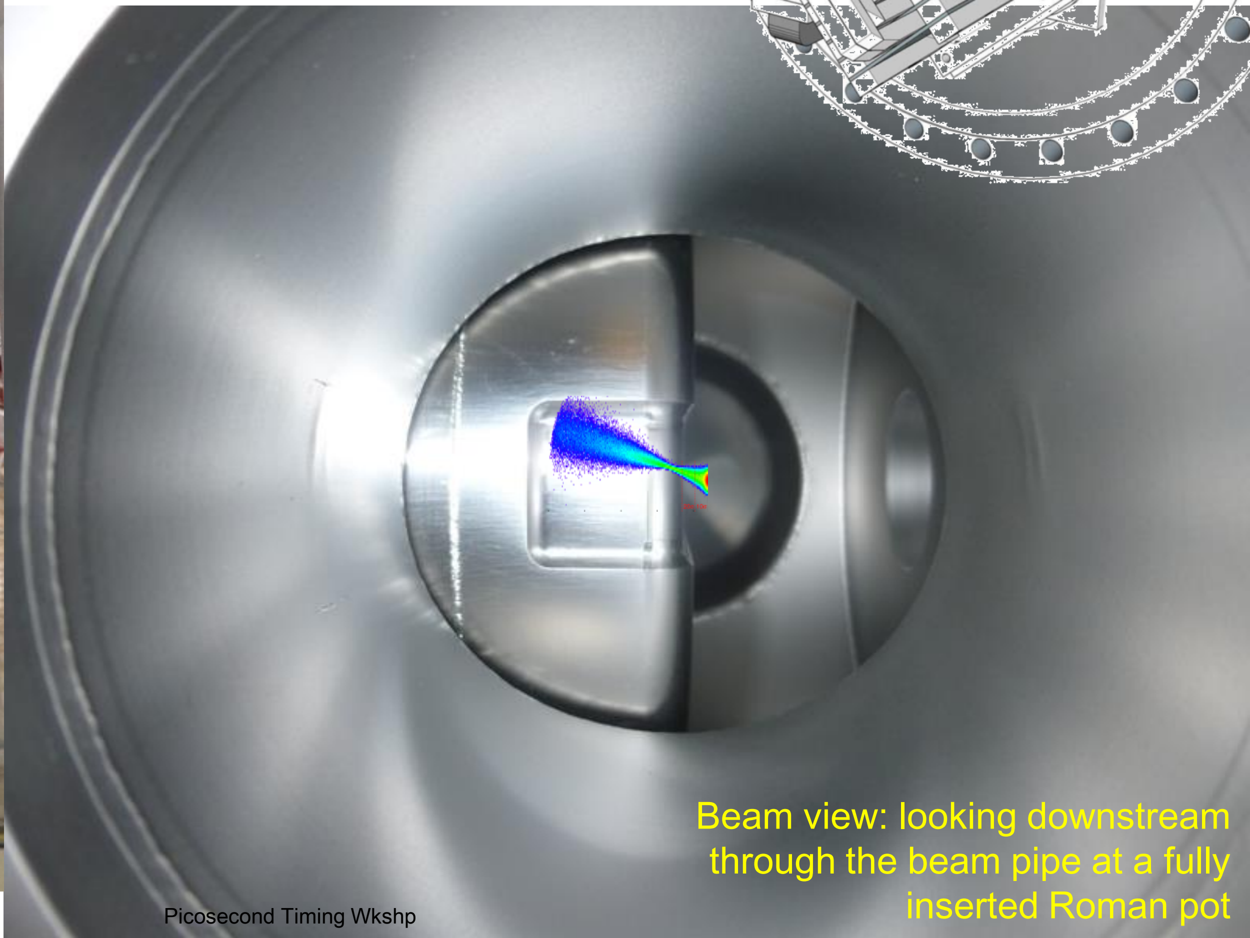


Roman Pot with Detector

3D silicon pixel detectors
size 50µm (x) × 250µm (y)

➔ Design of the tracker plus Time-of-Flight system mounted on a feedthrough flange for a Roman pot …

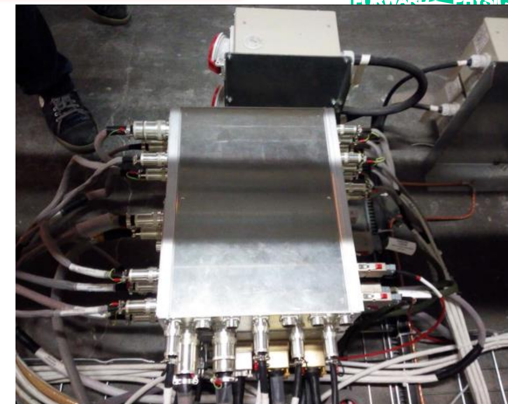




AFP in 2016 – RP Installation

- Two stations validated on 13 Jan'16
- **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
  - Secondary Vacuum
  - 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 at 211 m



station at 217 m, BPM, BLM, TCL6

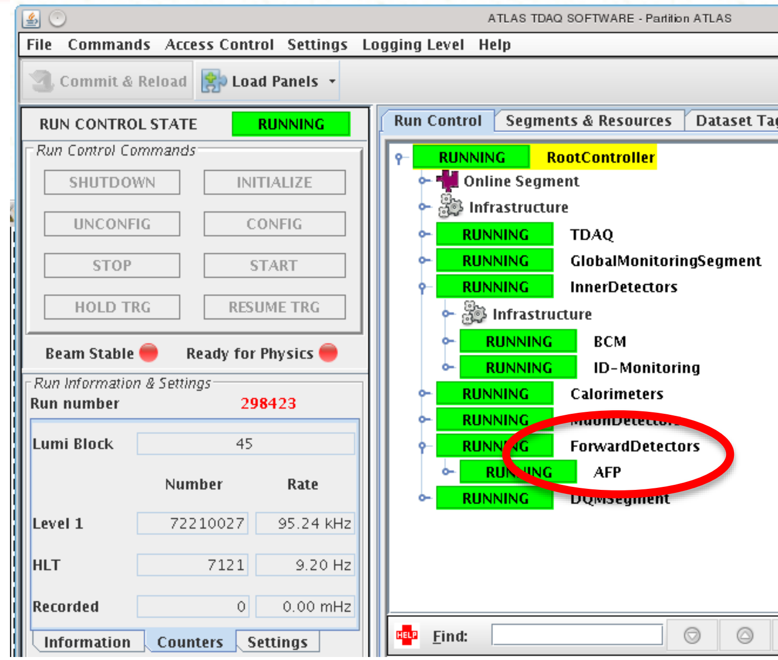
Status Detectors

- NEAR Station: 3 3D pixel detector layers; 50μm×250μm/pixel
- FAR Station: 4 3D pixel detector layers – HV short on 1st layer but still 95% efficient
  - modules are tuned and timed
- 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

- Note: the new batch of 3D pixel sensors are much superior to the existing sensors – will be installed during the EYETS

TDAQ & DCS Status

- AFP TDAQ integration
  - AFP running smoothly in ATLAS partition for all combined runs during 5-13 May
  - Since 13 May AFP-ATLAS TDAQ integration:
    - Collaboration with ATLAS and IT TDAQ experts
    - Integrated running since July 2016



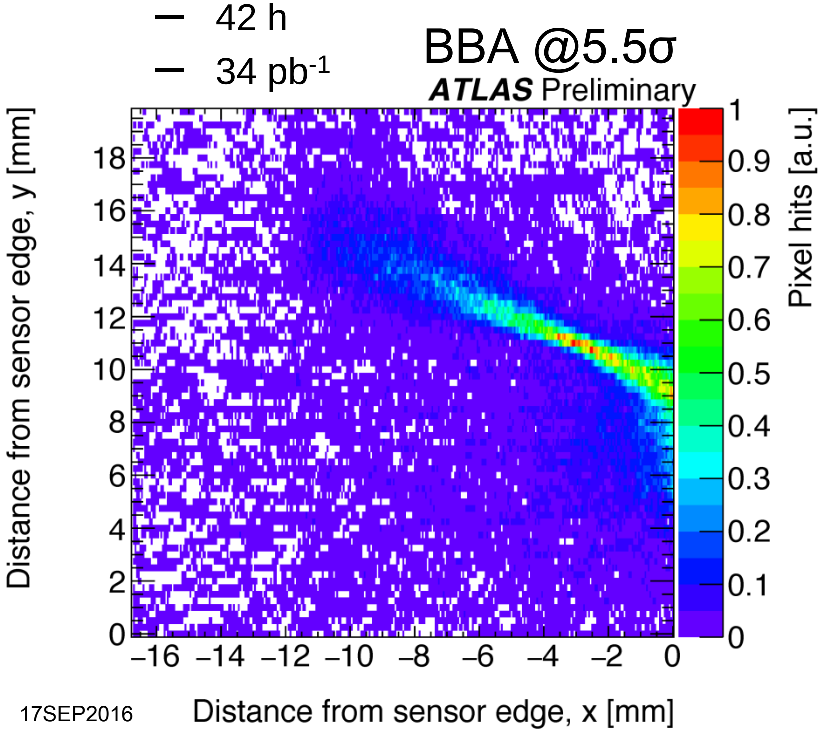
- DCS integration
  - Ongoing integration in ATLAS DCS (coordinated with central DCS)
  - Work by the AFP DSC team and ATLAS DCS Experts

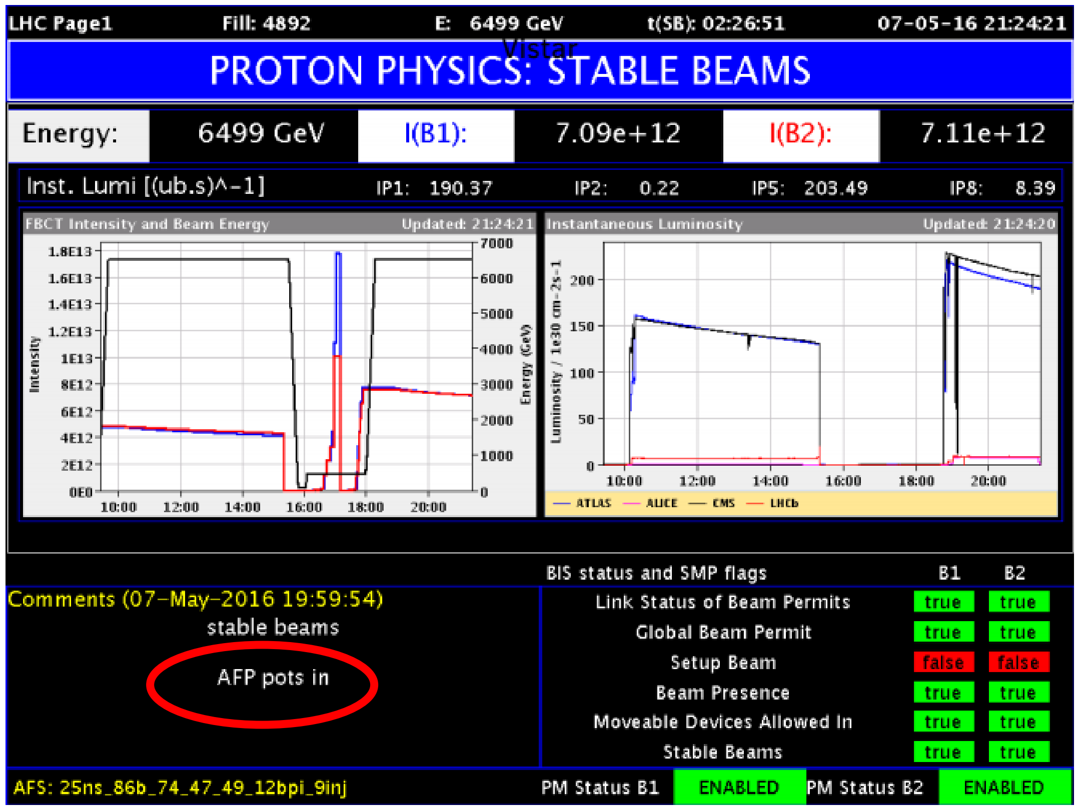
- AFP insertions at high luminosity:
  - 13 May: 600b, 1:14 hr AFP inserted + 0:50 hr TCL6 closed
  - Triggers enabled in AFP calibration stream with pre-scale 1000 ➔ ~300 Hz
    - HLT_calibAFP_L1AFP_C_ANY and …_AND
- Successful Low-µ special AFP+ATLAS run on Aug 2, 2016

AFP Insertions

Date	Fills	TDAQ Mode
19-22 April	**B**eam-**B**ased **A**lignment and Loss Maps (6 & 3 hrs)	Stand-alone
23 April	3b: 2nd fill (no 3rd fill)	Stand-alone
24-25 April	12b: 2nd + 3rd fill	Stand-alone
29 April – 5 May	Weasel break ➔ TDAQ integration	
7 May	49/86b: 2nd + 3rd fill; 8.1pb^{-1}	Integrated
9 May	300b: 4th fill (2nd+3rd ended before AFP in); 7.9pb^{-1}	Integrated
13 May	600b: 2nd fill (1:14h); 9.3pb^{-1}	Integrated

- **Total (TCL6 and/or AFP in):**
  - 42 h
  - 34 pb^{-1}

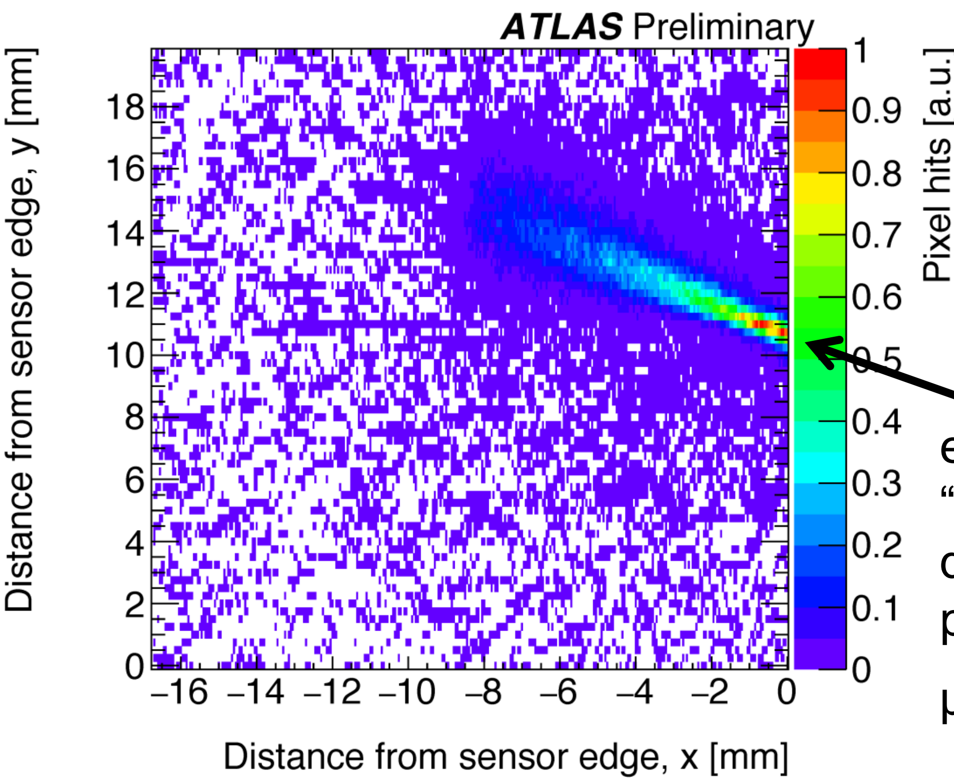




Preliminary Performance Plots

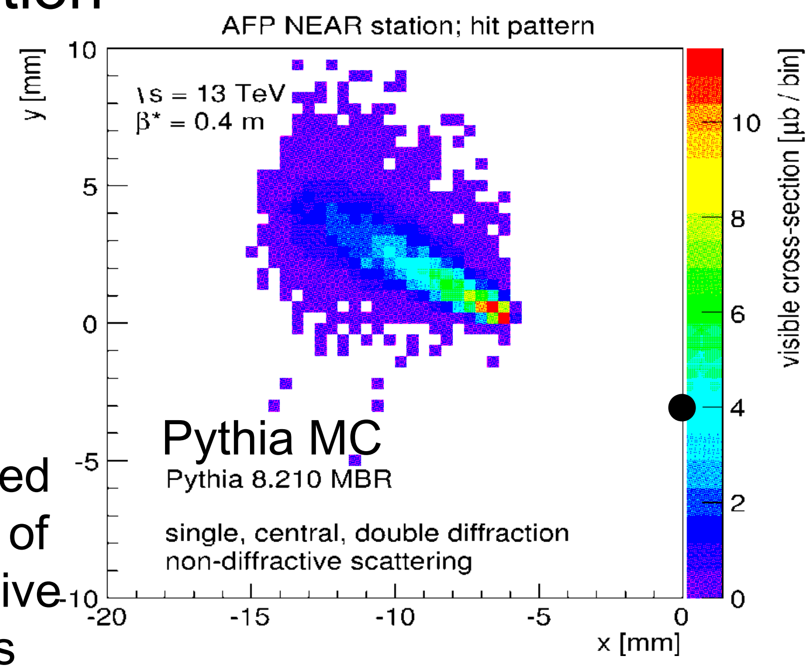
300 b fill #4906, AFP readout but triggered by ATLAS

- Hit pattern first plane of NEAR station



expected "band" of diffractive protons

μ≲26, 2:16 hrs



Caution: hit pattern and MC plots are in somewhat different coordinate systems …

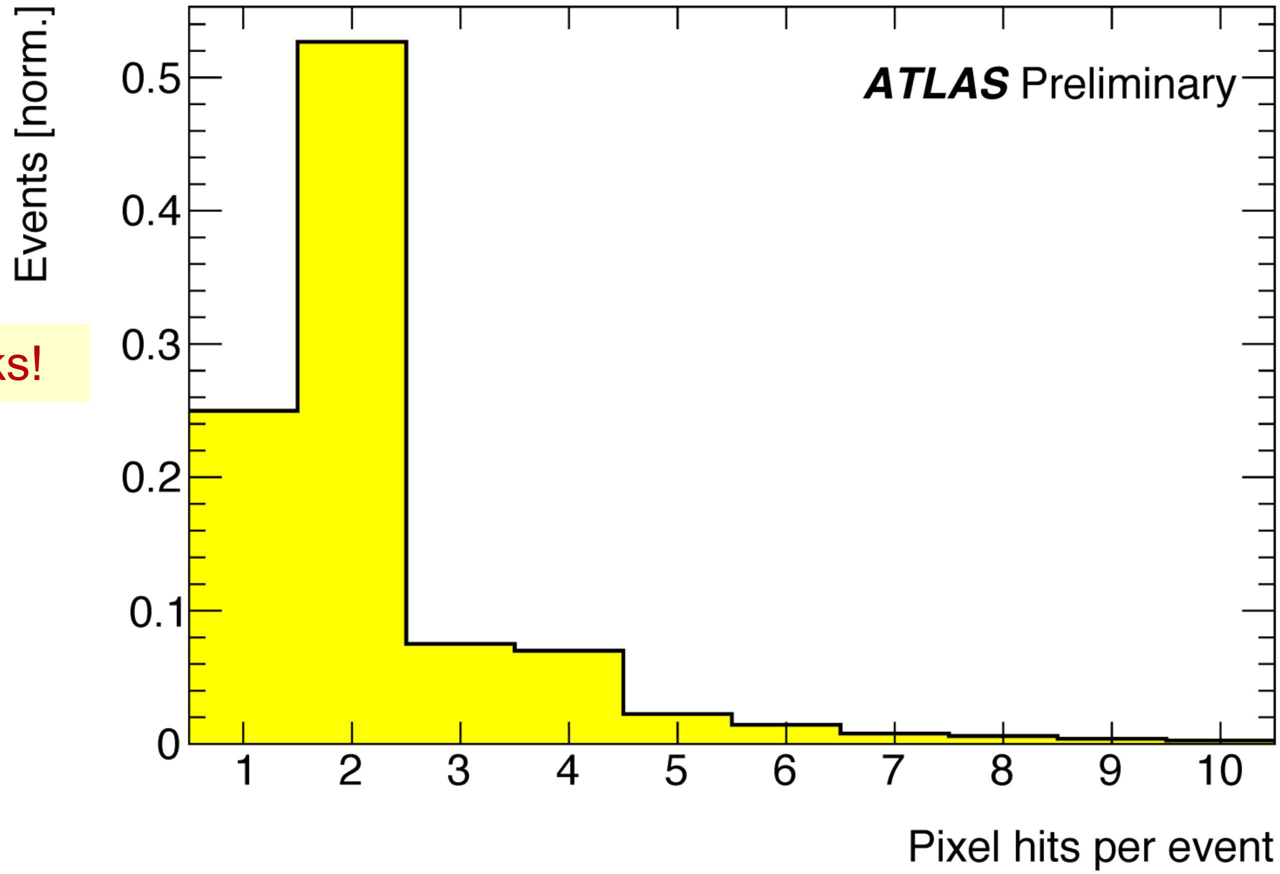
Preliminary Performance Plots

300 b fill #4906, AFP readout but triggered by ATLAS

- 87.7% of events have no hits (in this plane); remainder is mostly single “tracks”:

Note:
we expect ~2 pixels per “hit” because of the 14° tilt of the 3D sensors

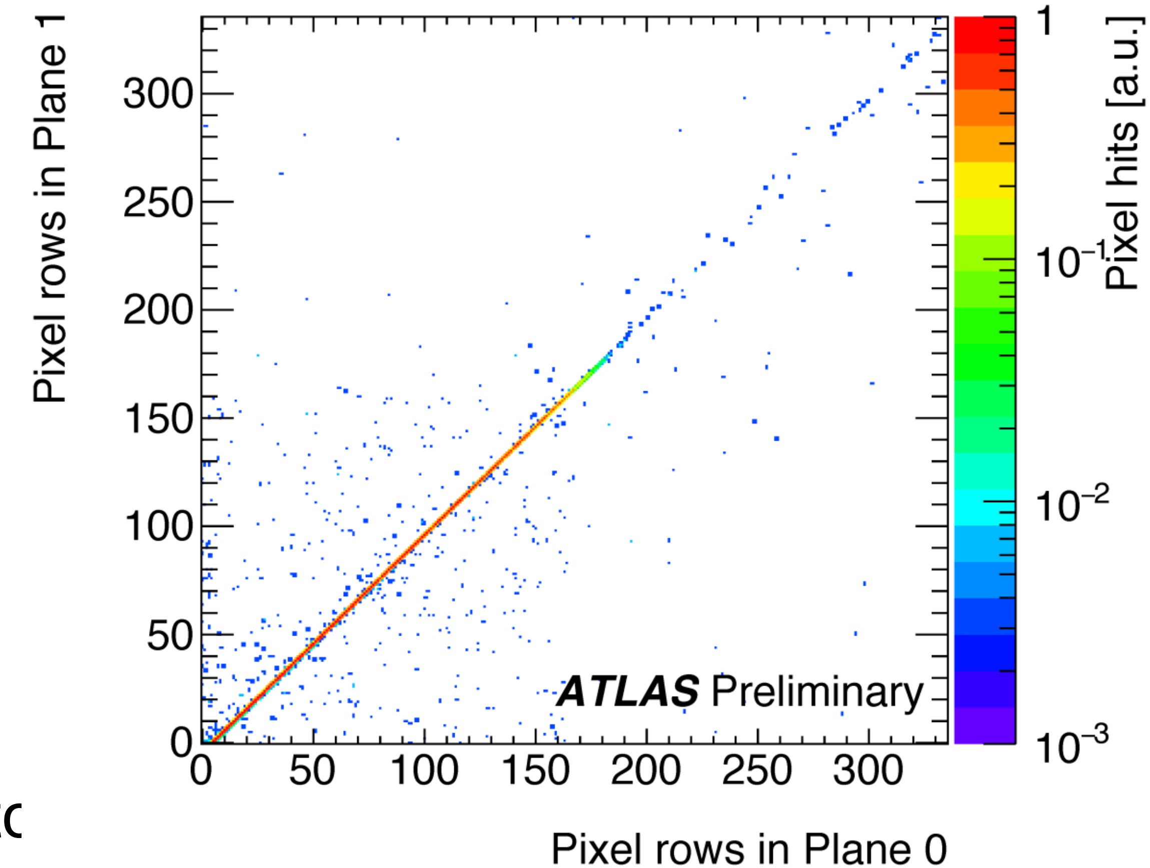
➔mostly single particle tracks!



Preliminary Performance Plots

300 b fill #4906, AFP readout but triggered by ATLAS

- Correlation of hit pixel row (x) in Plane 0 vs. hit pixel row (x) in Plane 1:
  - strong correlation indicates mostly good, parallel tracks
  - mostly single tracks
  - smattering of non-correlated hit pairs from additional tracks?



- Started work on hit reconstruction, tracking, alignment, etc

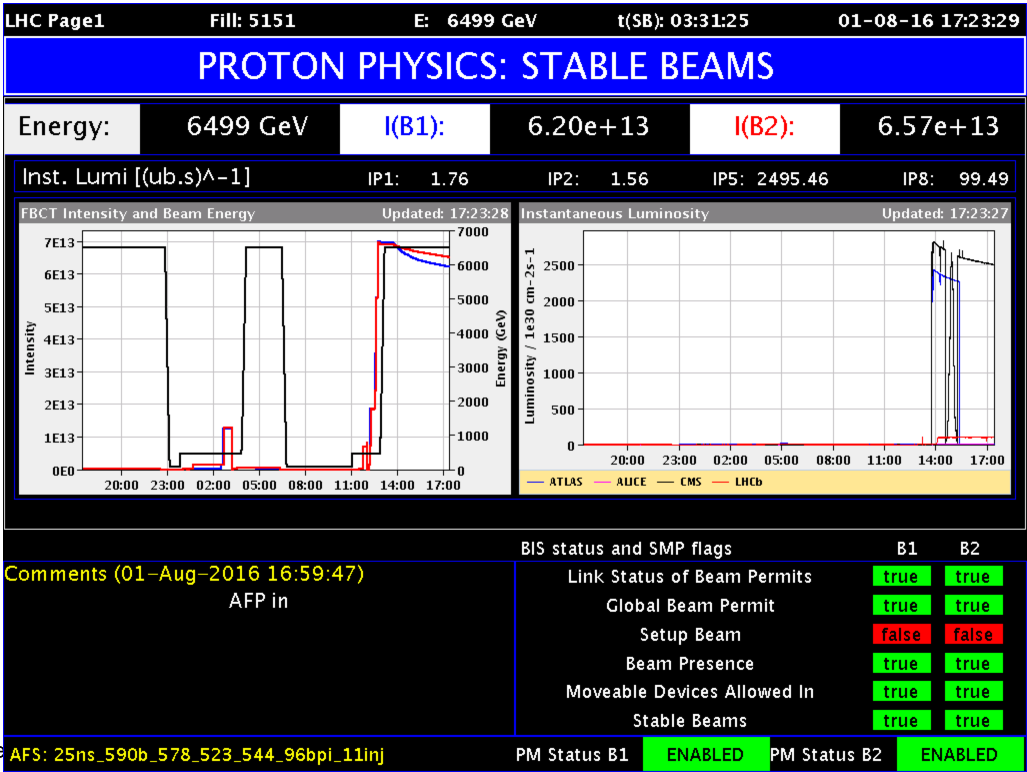
AFP – ALFA Insertion conflict

- When AFP runs at standard luminosity (high-μ):
  - TCL4 and TCL5 must be opened to give large-ξ acceptance to AFP
  - TCL6 (after AFP) must be closed to 20σ to protect Q6 and downstream
    - this increases the radiation levels at ALFA by a factor ~10
    - ALFA electronics is NOT radiation-hard
    - ALFA still needs its large β*=2500 m run (Sept 2016), and possibly a follow-up early in 2017 …

- AFP will limit its insertions in 2016 to 0.25 pb–1
- ALFA & AFP are considering shielding to protect ALFA electronics
  - studies by the FLIUKA team are encouraging: already a factor 3-4 reduction in dose
  - further studies are ongoing
  - expect a result and proposal (+ECR) in September

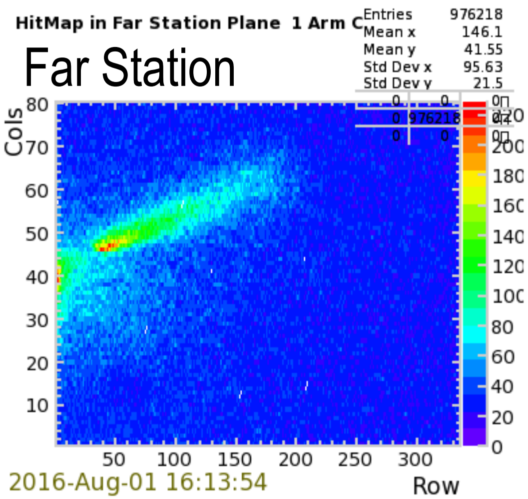
2016 Low-μ Special Run for AFP

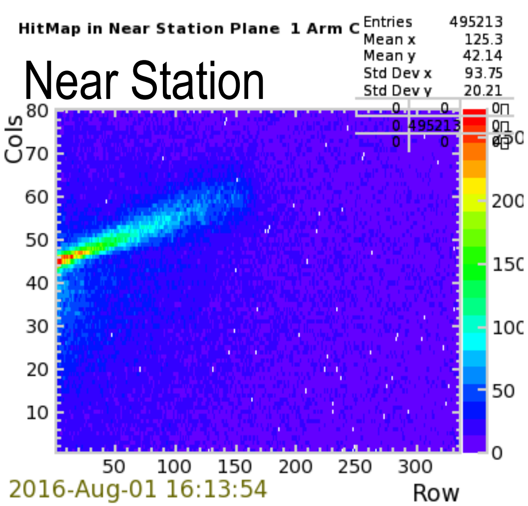
- 600b fill on 01.08 (fill 5151, run 305359)
  - Filling scheme: 25ns_590b_578_523_544_96bpi_11inj
  - 15:20 Start to separate beams
    - 15:24 beams at 5 σ_H^* separation; ➔ μ_{peak}=0.26
  - 15:30 beams adjusted to peak μ_{peak}=0.13, <μ>~0.03; lumi=2.7e30; beam separation: σ_H^*=5, σ_V^*=2.5
  - 15:35 Start to insert RPs
  - 15:42 AFP inserted!
    - AFP at 20 σ,
      TCL4/5/6 at 15/35/20 σ
- Total time in beam: 4h37; after Pre-Scale adjustments: 3h58
  - Integrated luminosity: 0.033 pb^{-1}
- Next low-μ run: after TS2 (~23 Sep)

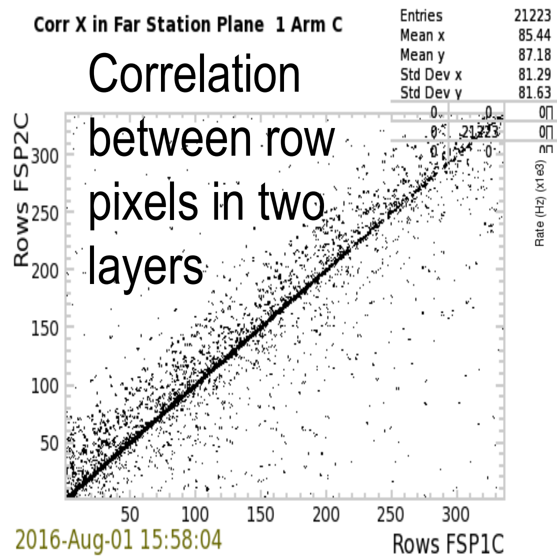


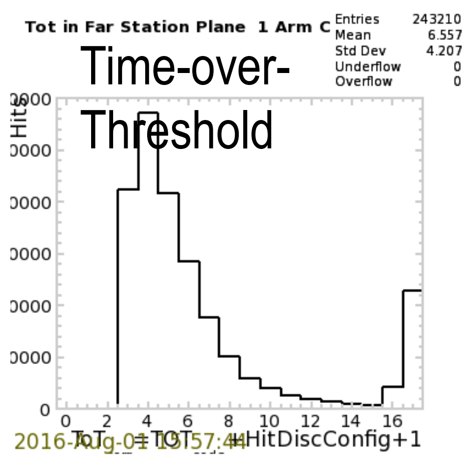
Low-μ Special Run

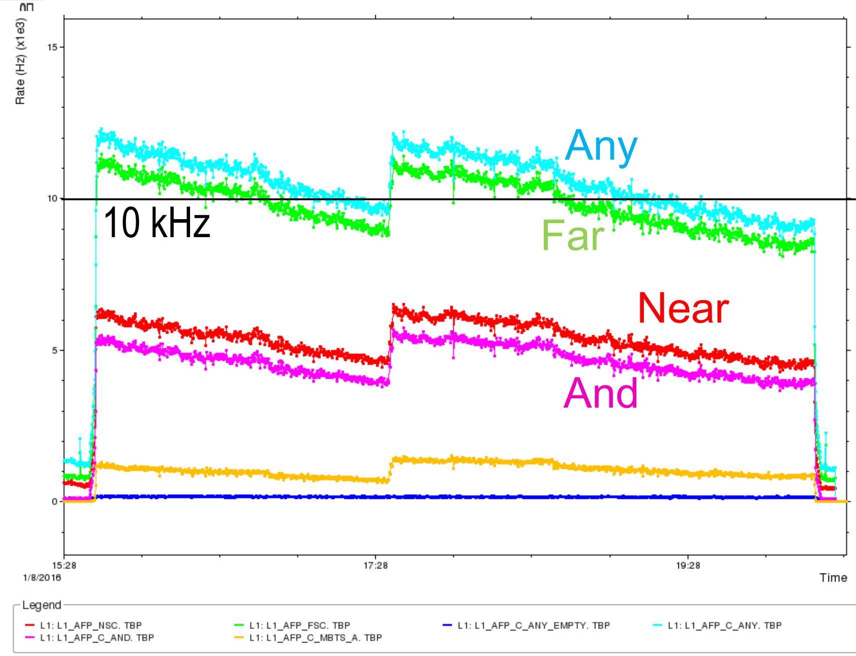
- *Predict* per hour using Pythia :
  - 7M Soft SD events (proton rate in AFP 2 kHz)
  - 15k SDjj evts with p_T>20 GeV
  - 500 SDjj evts with p_T>50 GeV
  - O(5) SD+W evts











- Analysis ongoing …

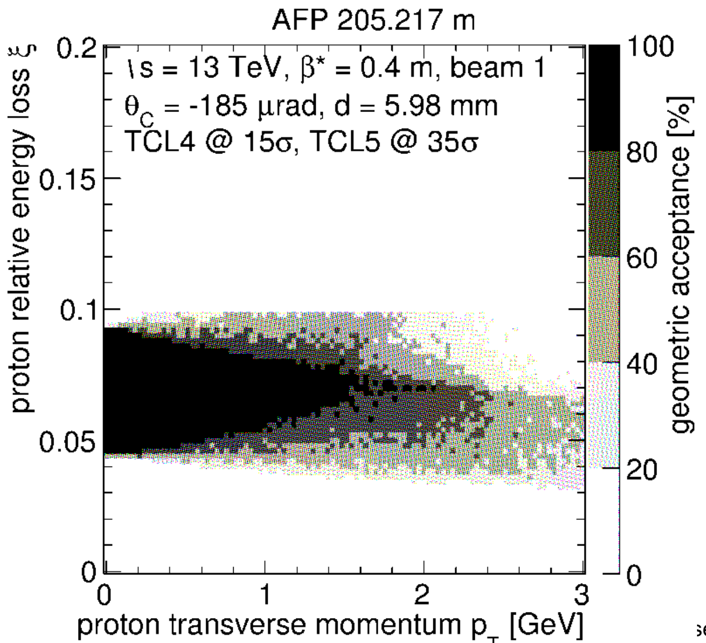
Physics with Low-μ Single-Arm AFP

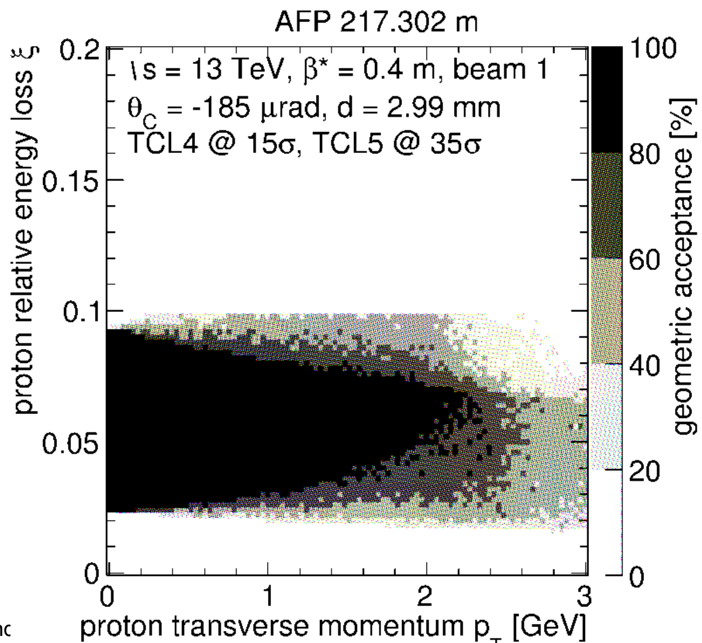
- Predict using Pythia and AFP acceptance at β^*=55cm:
  - for μ=0.1, nb=300, standard bunch density, 1 hr:
    - 7M Soft SD events (proton rate in AFP 2 kHz)
    - 15k SDjj evts with pT>20 GeV
    - 500 SDjj evts with pT>50 GeV
    - 3 SD+W evts

From R.Staszewski see:
https://indico.cern.ch/event/492863/
2 Feb'16

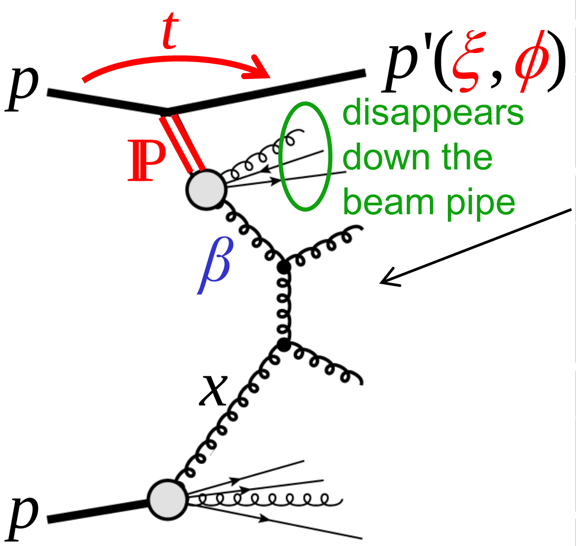
- Acceptance in ξ and p_T:

$$\xi = 1 - E_{\mathrm{proton}} / E_{\mathrm{beam}}$$





Summary of Single p-Tag Processes



Single Diffractive Production

$$t \equiv (p' - p)^2$$

$$\xi \equiv 1 - E'/E$$

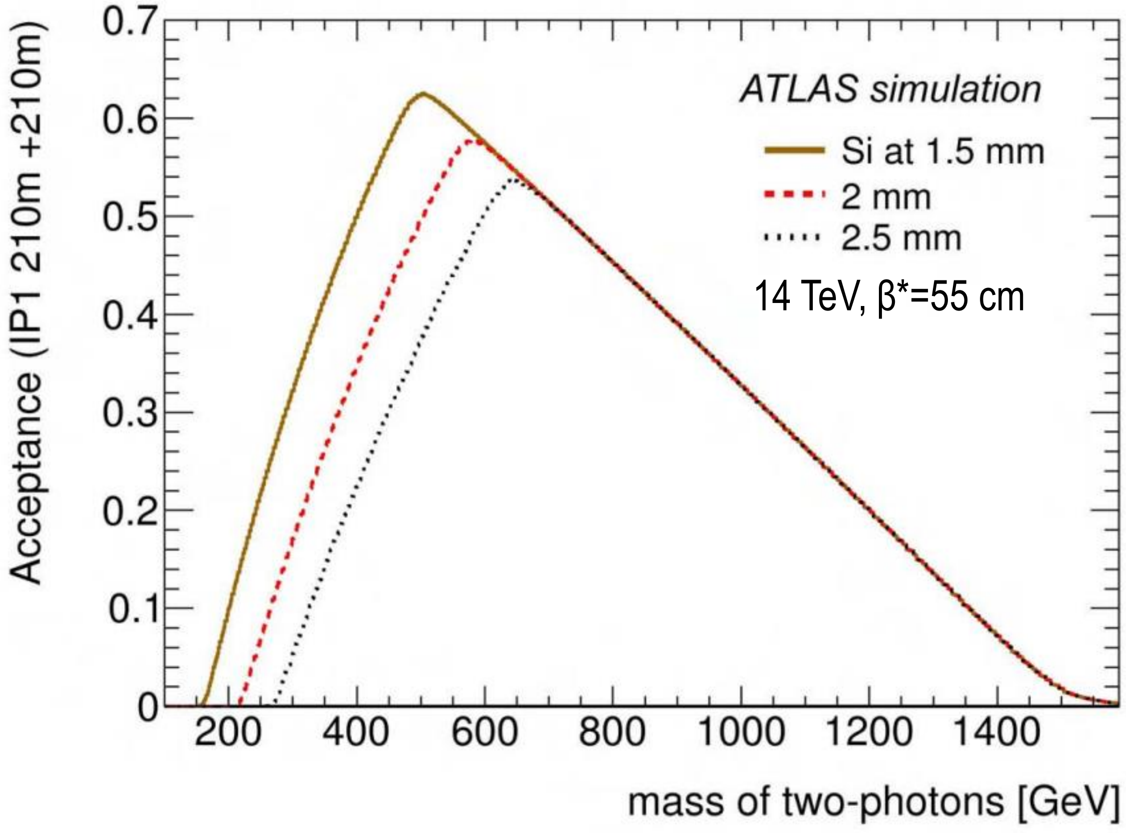
$$\beta \equiv x_{\mathbb{P}}$$

Analysis	**Motivation**	$\int Ldt$ [pb^{-1}]	**Optimal μ**
Soft Single Diffraction with AFP0+2			
$d\sigma/dt$, $d\sigma/d\xi$, t-Slope vs. ξ, $dN^{\pm}/dp_T$ vs. t and ξ	Saturation, MC tuning, Cosmic Ray physics	1	$\mu \sim 0.01$
Single Diffractive jet Production [21]			
σ, rapidity gap, Jet structure and p_T, event shape (MPI [21]); vs. t, ξ, and β	gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$
Single Diffractive jet-gap-jet Production [22, 23, 24]			
σ, central gap distribution, Jet p_T; vs. t, ξ, and β	observation of a new process, test of BFKL dynamics	1 – 100	$\mu \sim 1$
Single Diffractive Production of γ + jet [25]			
σ, rapidity gap, Jet structure and p_T, Photon p_T, event shape (MPI); vs. t, ξ, and β	observation of a new process, mechanism of hard diffraction, gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$
Single Diffractive Z Production			
σ, rapidity gap, charge-asymmetry; vs. t, ξ, and β	gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$
Single Diffractive W Production			
σ, rapidity gap; vs. t, ξ, and β	gap survival probability, Pomeron structure and flavor composition	10 – 100	$\mu \sim 1$

ATLAS Forward Proton Technical Design Report, CERN-LHCC-2015-009 ATLAS-TDR-024-2015

Preparing for the 2nd AFP Arm

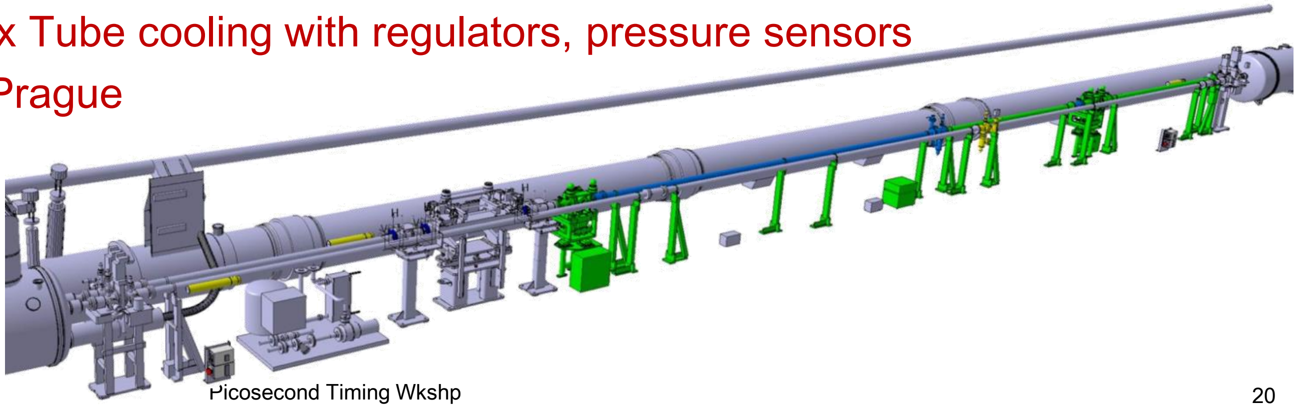
- AFP has excellent two-proton missing mass acceptance:
  - e.g. for an object produced by pp→p+X+p, X→γγ :



Preparing for the 2nd AFP Arm

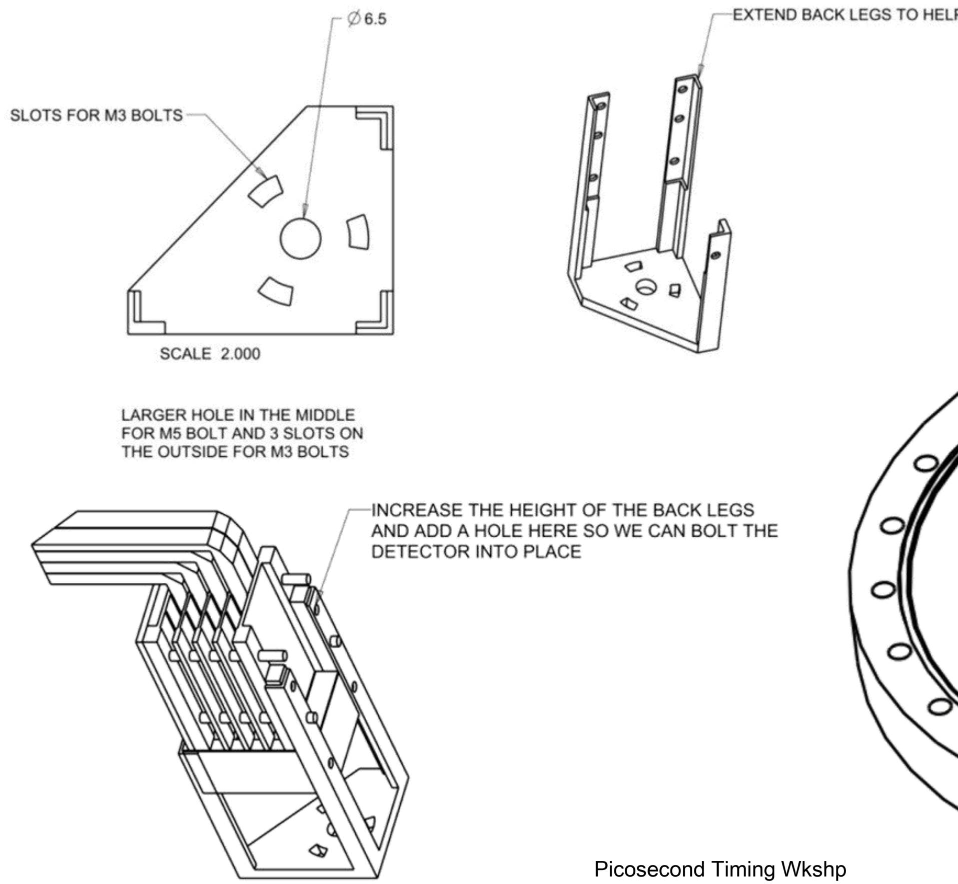
- ECR 2nd Arm (6L1): in circulation …
  - TE-VSC-BVO started the production of the beam pipe elements
  - BLMs, BPM(s): have BPM; notified BLM group
- Cabling:
  - tunnel cabling was all done
  - Must complete cabling in USA15

- Cooling:
  - Compressed-air Vortex Tube cooling with regulators, pressure sensors
  - “AirCoolers” by CTU, Prague
- Secondary Vacuum:
  - pump system available, must be installed in RR13

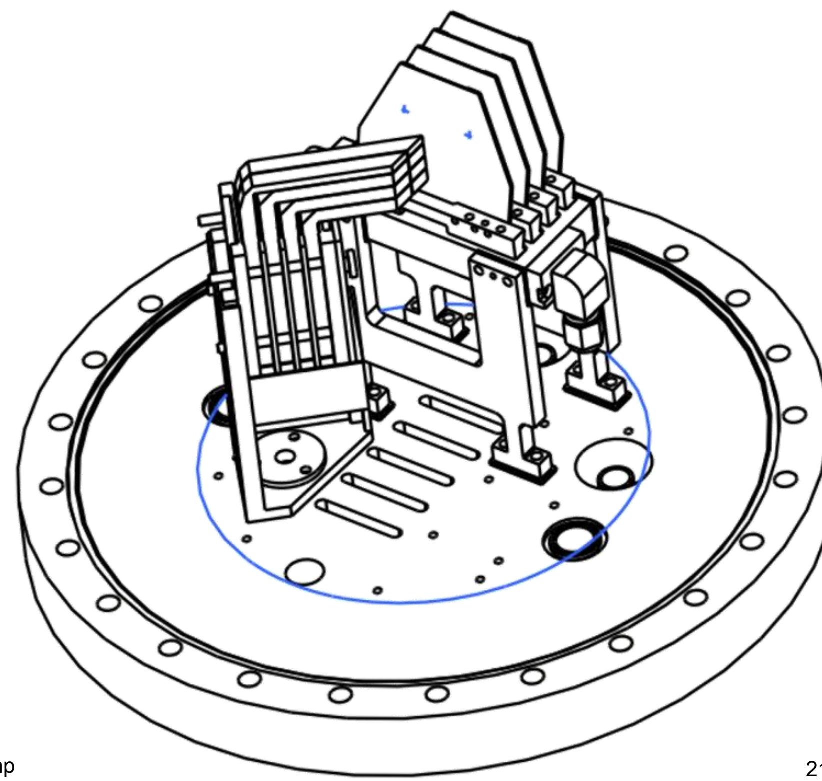


2^{nd} AFP Arm – the ToF

- Time-of-Flight detector is the CRUCIAL component here!
  - very non-trivial! prototype holder design ready
  - beam tests (H6, June & September) are critical: R&D is not finished!
  - electronics is crucial: CFD, HPTDC, Trigger, Clock

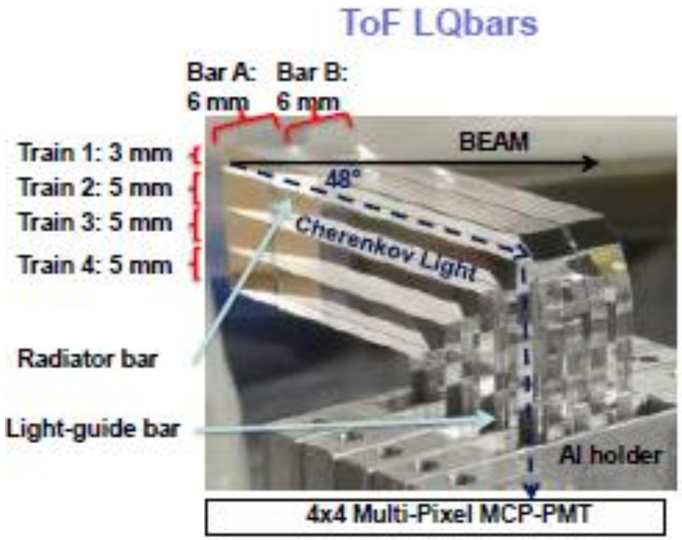


Chris Ng, Tomas Sykora, Libor Nozka



AFP ToF Detector

- Detector: (see talk by Libor Nozka at this Workshop)
  - Quartz bars (~6×5 mm cross section) at the 48° Cerenkov angle, reflecting into the MCP-PMT ("LQbars")
  - up to 4 bars in series – limits the time resolution requirements per channel …

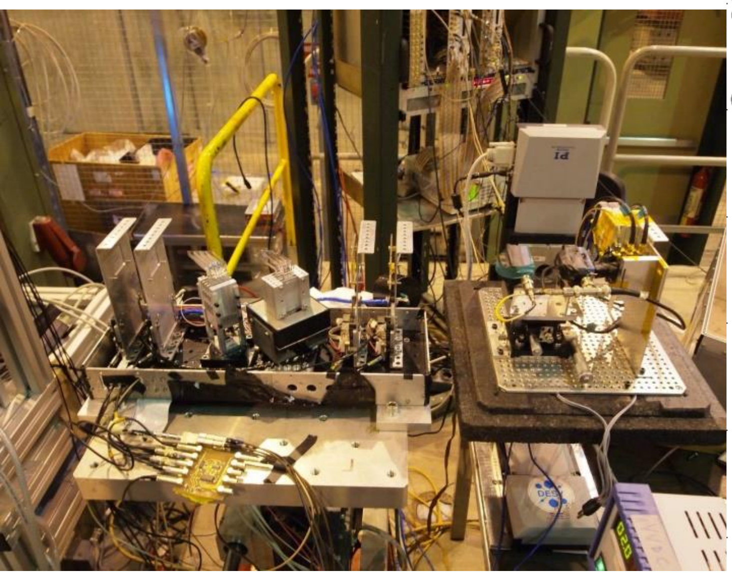


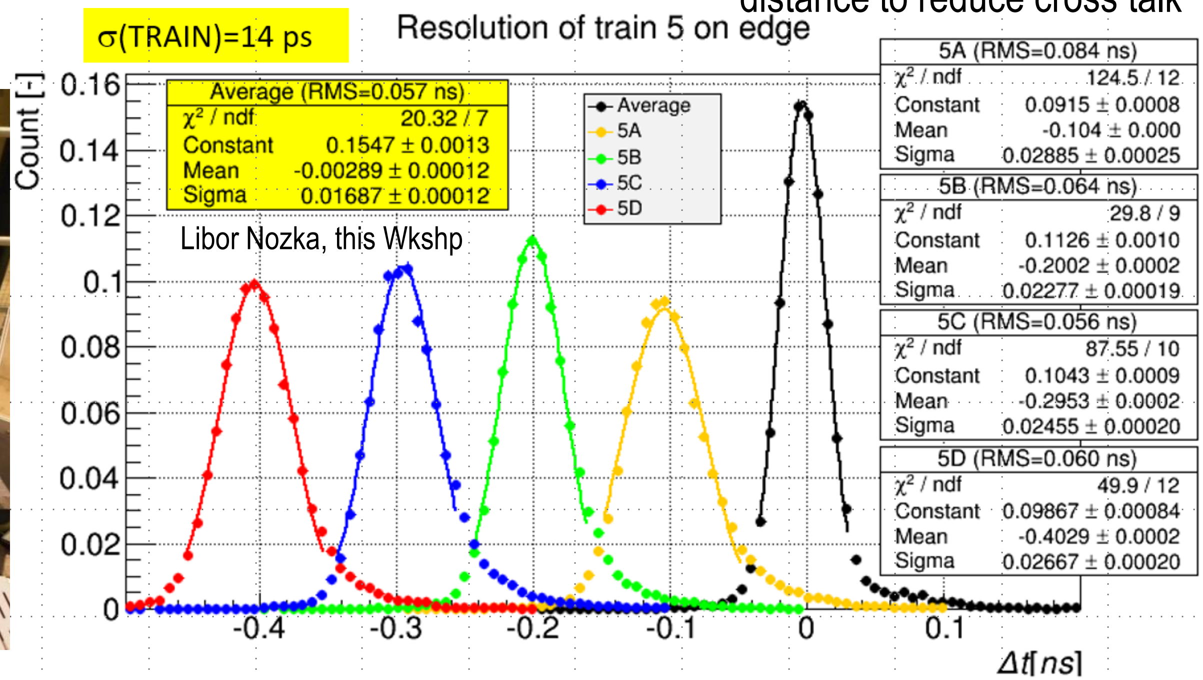
- MCP-PMT:
  - 10/6μm pore MCP mini-Planacon (4×4 pixels) by PHOTONIS
    - Reduced MCP-Anode gap distance for reduced inter-pixel cross talk!
    - Atomic Layer Deposition on MCP for long life
      - needed for 10x increase in lifetime (and possibly better gain)

ToF Performance in Beam Test

- Test Beam 2014 & 2015: J. Lange et al., submitted to JINST
  - Very good tracker performance: σ_x(track)≤3 μm
- Test Beam in June 2016 (2 weeks):
  - Characterization and optimization of the ToF front-end: radiator bars, cross talk, MCP-PMT, CFD delay and threshold …
  - Excellent performance of the new 10 μm pore MCP-PMT
  - Early results shown in ICHEP Poster

PHOTONIS MCP-MA-PMT with reduced MCP-anode distance to reduce cross talk



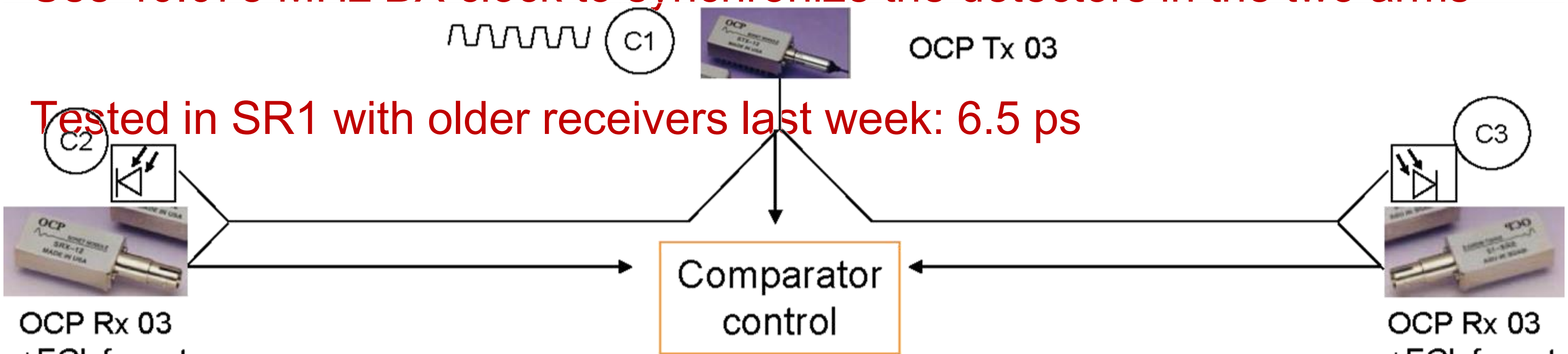


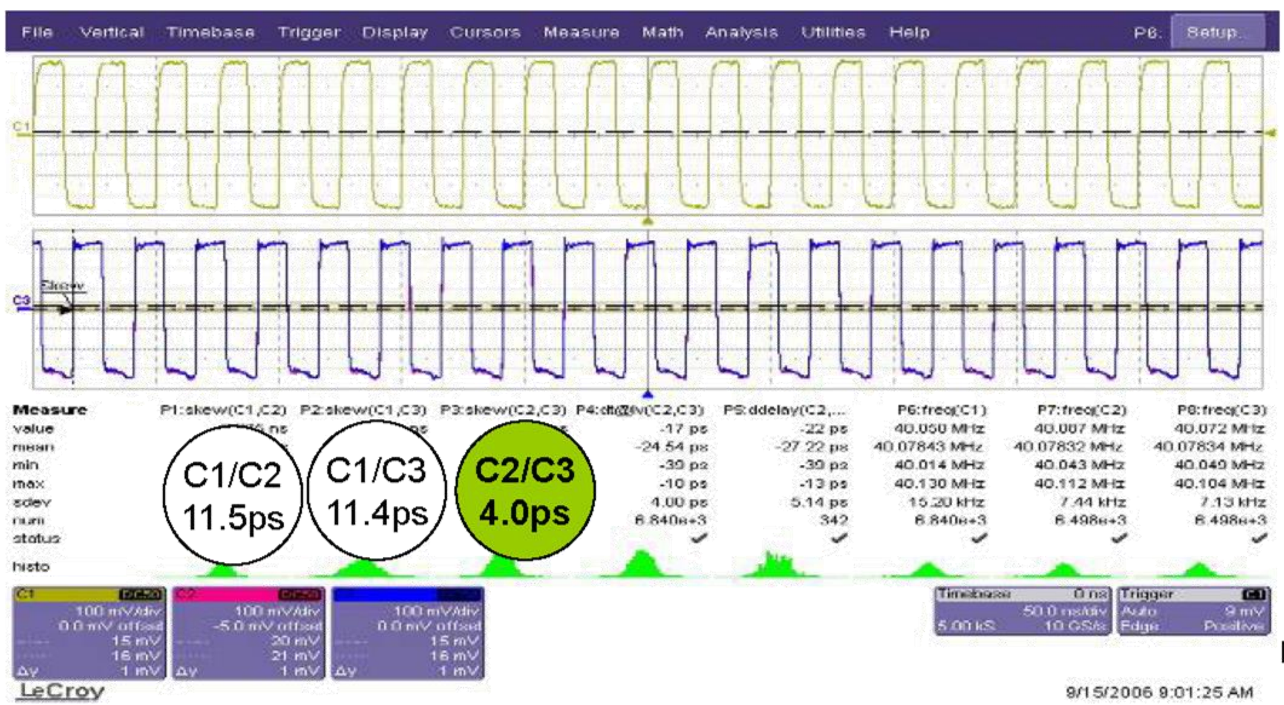
- Test Beam Sep’16: optimize ToF back-end electronics (HPTDC, Trigger)

TTC derived Reference Clock

Use 40.078 MHz BX clock to synchronize the detectors in the two arms

Tested in SR1 with older receivers last week: 6.5 ps



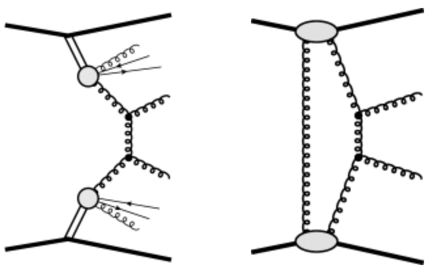


Sophie Baron, FP420 Collaboration Meeting, 2008

Lecroy Wavepro 7100 1GHz

Physics in 2017 and Beyond

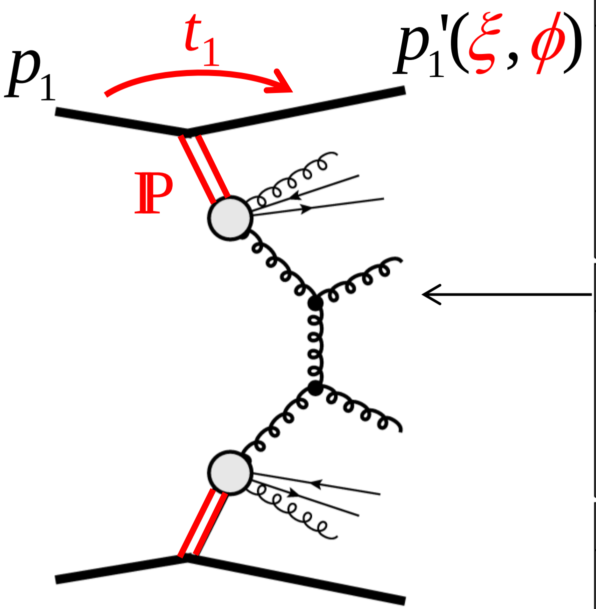
- In Dec 2016: AFP and Pb+p? Discussions between HI and AFP communities ongoing …
- AFP aims to continuously be in the ATLAS standard luminosity running
  - provide a **double-proton tag with vertex matching** to ATLAS
  - must resolve problems of cohabitation with ALFA !
- Special low-μ (μ~1) runs
  - continuation of diffraction program:



- Plans to run **after LS2**
  - currently under discussion within AFP
  - will depend on AFP physics results before LS2 !
  - must be reviewed by ATLAS before going to an TDR and LHCC

Summary of Double p-Tag Processes

DPE jet-jet



$$t_i \equiv (p_i' - p_i)^2$$

$$\xi_i \equiv 1 - E_i'/E_B$$

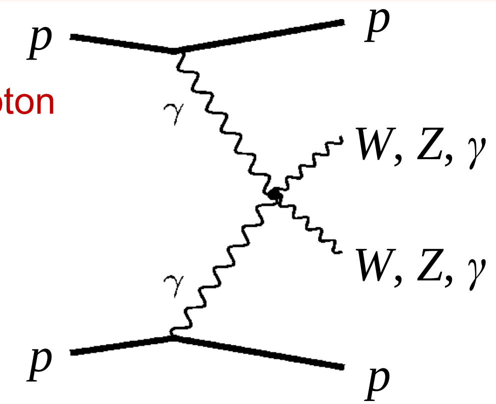
$$\beta_i \equiv x_{\mathbb{P},i}$$

$$M_{jj} \le M_{pp} = \sqrt{s\xi_1\xi_2}$$

Analysis	**Motivation**	$\int Ldt$ [pb^{-1}]	**Optimal μ**
Soft Central Diffraction with AFP2+2			
$d\sigma/dt_{1,2}$, $d\sigma/d\xi_{1,2}$, t-Slope vs. ξ, Mass M and y of the central diffractive system, ϕ_1 vs. ϕ_2, $dN^{\pm}/dp_T$; vs. $t_{1,2}$, $\xi_{1,2}$, M.	general understanding of DPE processes	1	$\mu \sim 0.1$
Central Diffractive jet Production (DPEjj) [28]; see also Sect. A			
$d\sigma/dt_{1,2}$, $d\sigma/d\xi_{1,2}$, t-Slope vs. ξ, $d\sigma/dp_T^{jet}$, Mass M and y of the central dijet system, ϕ_1 vs. ϕ_2	gap survival probability for DPE processes, Pomeron structure, general understanding of DPE processes	10 – 100	$\mu \sim 1$
Jet-gap-jet Production [22, 24]			
$d\sigma/dt_{1,2}$, $d\sigma/d\xi_{1,2}$, $d\sigma/dM_{jj}$, central gap distribution, $d\sigma/dp_T^{jet}$, ϕ_1 vs. ϕ_2	observation of a new process, test of BFKL dynamics	10 – 100	$\mu \sim 1$
γ + jet Production			
σ, rapidity gap(s), Jet structure and p_T, Photon p_T; vs. $t_{1,2}$, $\xi_{1,2}$, and M_{jj}	observation of a new process, mechanism of hard diffraction, gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$

Anomalous Quartic Couplings

- Low Cross sections: ~few fb
  - AFP has a Missing-Mass resolution (from the proton measurements) of 2-4 %
- Match with invariant central object mass is efficient: (*Z→ee, γγ*)
  - powerful rejection of non-exclusive backgrounds
- Much interest in this from theory side
  - e.g. LHC Forward Physics WG (C. Royon et al.)

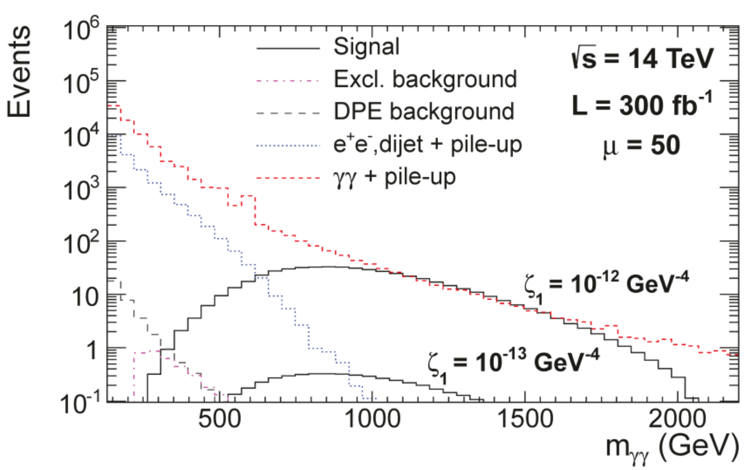


"Probing anomalous quartic gauge couplings using proton tagging at the Large Hadron Collider", M. Saimpert, E. Chapon, S. Fichet, G .von Gersdorff, O. Kepka, B. Lenzi, C. Royon; 23/05/2014

$$\mathcal{L}_{\gamma\gamma\gamma\gamma} = \zeta_1^{\gamma} F_{\mu\nu}F^{\mu\nu}F_{\rho\sigma}F^{\rho\sigma} + \zeta_2^{\gamma} F_{\mu\nu}F^{\nu\rho}F_{\rho\sigma}F^{\sigma\mu}$$

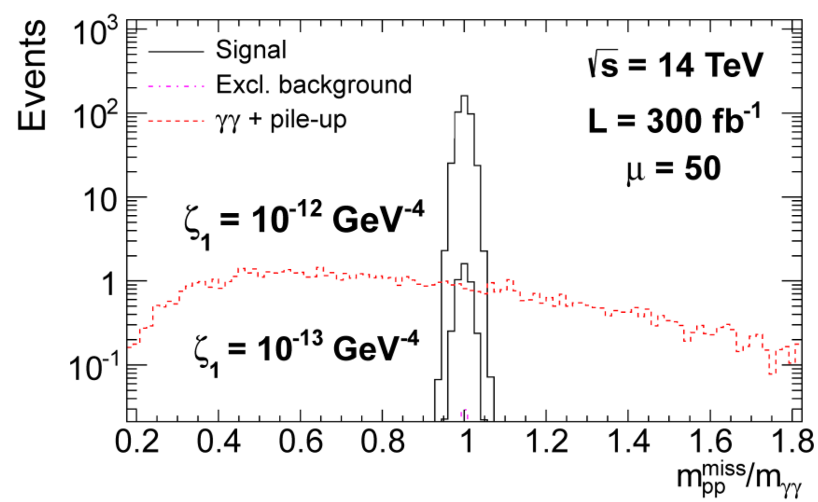
Mass distribution of signal and backgrounds for γγγγ

- $0.015 < \xi < 0.15$, $|\eta| < 2.37$, $p_{T1,2}^{\gamma} > 50$ GeV ONLY



- By requesting $m_{\gamma\gamma} > 600$ GeV, Only pile-up backgrounds remain

γγγγ: Mass matching and pile-up



Summary

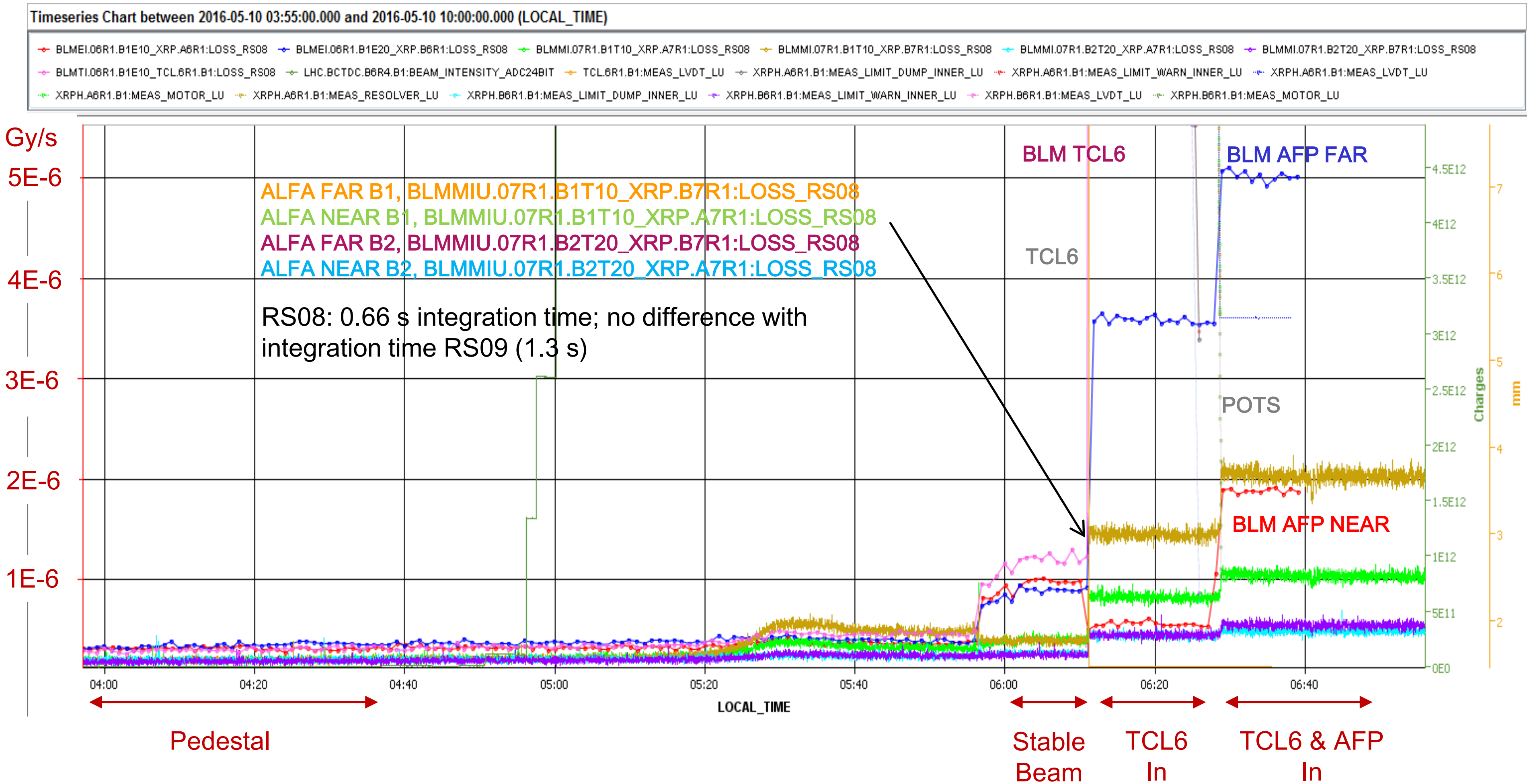
- ATLAS Forward Proton project:
  - AFP is installed in one arm and fully operational
  - AFP DCS & TDAQ integrated, AFP is within standard ATLAS latency
  - data taking at high-pileup (~35) was successful
    - intensity qualification up to n_b=600 (to limit radiation dose on ALFA) ☹
    - background seems low and environment very clean ☺
  - Low-μ data taking: 4hrs, and 4hrs more to come …
  - Rich physics program of soft and hard diffraction!
- Preparation for second AFP arm (6L1) underway
  - ECR approved
  - Time-of-Flight is the critical item
  - 2 H6 Beam tests:
    - June: 15ps/4 LQbars (w/o HPTDC !) ☺
    - September: ongoing; optimize the HPTDC + Trigger
  - Production of other critical items is well underway

Backup

- Note: older slides with detector details

Irradiation of ALFA Electronics

- Fill 4906: Radiation pedestal and Nominal level with beam are well measurable:



Radiation Dose to ALFA

- Worry: Radiation to non-rad hard ALFA electronics
- Measure in Fill 4919, 601 b:
  - Stable beam 12-13 May 2016
  - TCL6 & AFP in: ~10× increase in dose to ALFA FAR station …

⇨ limit AFP insertion at high-μ to 0.15 fb^{-1} in 2016

⇨ $n_b \lesssim 600$

FILL 4919			BLMMI.07R1	BLMMI.07R1	BLMMI.07R	BLMMI.07R1
start	end	type	ALF NEAR	ALF FAR	ALF NEAR2	ALF FAR2
5/12/16 20:30	5/12/16 20:40	Pedestal	2.13E-07	2.03E-07	1.90E-07	1.78E-07
	NDF= 11	rms	3.66E-09	2.02E-09	2.27E-09	1.69E-09
5/12/16 23:30	5/13/16 0:07	Stable Beam	4.94E-07	4.79E-07	2.82E-07	2.49E-07
	NDF= 38	rms	5.43E-09	6.90E-09	3.89E-09	3.59E-09
5/13/16 0:09	5/13/16 0:28	TCL6 in	1.19E-06	2.25E-06	5.59E-07	5.65E-07
	NDF= 20	rms	7.28E-09	7.28E-09	4.03E-09	4.89E-09
5/13/16 0:32	5/13/16 0:52	AFP in	1.56E-06	3.26E-06	6.36E-07	7.33E-07
	NDF= 21	rms	9.84E-09	2.13E-08	4.05E-09	5.38E-09
5/13/16 1:30	5/13/16 1:42	AFP in 2	1.51E-06	3.13E-06	6.17E-07	7.08E-07
	NDF= 13	rms	6.26E-09	1.87E-08	5.00E-09	3.50E-09
5/13/16 1:44	5/13/16 2:10	TCL6 in 2	1.12E-06	2.10E-06	5.30E-07	5.34E-07
	NDF= 27	rms	7.18E-09	1.23E-08	3.66E-09	5.75E-09
5/13/16 2:13	5/13/16 2:30	Stable Beam 2	3.67E-07	4.48E-07	2.41E-07	2.24E-07
	NDF= 18	rms	4.09E-09	8.17E-09	2.64E-09	2.36E-09
5/13/16 7:12	5/13/16 7:40	Pedestal 2	1.59E-07	1.64E-07	1.68E-07	1.46E-07
	NDF= 29	rms	2.00E-09	2.43E-09	2.23E-09	2.77E-09
Start Edge						
Standard dose with 600b		SB'=SB - Pedestal	2.81E-07	2.76E-07	9.15E-08	7.06E-08
Increase with TCL6		(TCL6-SB)/SB'	2.49E+00	6.40E+00	3.03E+00	4.48E+00
Increase with TCL6 & AFP		(TCL6&AFP-SB)/SB'	**3.82E+00**	**1.01E+01**	**3.87E+00**	**6.87E+00**
End Edge						
Standard dose with 600b		SB'=SB - Pedestal	2.08E-07	2.84E-07	7.24E-08	7.78E-08
Increase with TCL6		(TCL6-SB)/SB'	3.60E+00	5.82E+00	4.00E+00	3.99E+00
Increase with TCL6 & AFP		(TCL6&AFP-SB)/SB'	**5.48E+00**	**9.46E+00**	**5.20E+00**	**6.22E+00**

Expected 2016 LumInt	25	fb-1
Allowed ALFA dose increase	10.00%	
worst case AFP LumInt	0.26	fb-1
avg case AFP LumInt	0.39	fb-1

Radiation Dose to ALFA

- Fill 4906, 313 bunches, Stable Beam @ 10.05.2016 06:02
- discussed with ALFA colleagues and ATLAS RC

FILL 4906			BLMEI.06R1.B1E10_XRP.A6R1:LOSS_RS09	BLMEI.06R1.B1E20_XRP.B6R1:LOSS_RS09	BLMMI.07R1.B1T10_XRP.A7R1:LOSS_RS09	BLMMI.07R1.B1T10_XRP.B7R1:LOSS_RS09	BLMMI.07R1.B2T20_XRP.A7R1:LOSS_RS09	BLMMI.07R1.B2T20_XRP.B7R1:LOSS_RS09	BLMTI.06R1.B1E10_TCL.6R1.B1:LOSS_RS09
start	end	type	AFP NEAR	AFP FAR	ALF NEAR	ALF FAR	ALF NEAR2	ALF FAR2	BLM TCL6
5/10/16 3:57	5/10/16 4:35	Pedestal	2.87E-07	3.08E-07	1.72E-07	1.71E-07	1.71E-07	1.60E-07	2.69E-07
	NDF= 38	rms	1.26E-08	1.69E-08	4.42E-09	4.37E-09	3.37E-09	4.03E-09	1.56E-08
5/10/16 6:02	5/10/16 6:10	Stable Beam	9.38E-07	8.52E-07	3.62E-07	3.56E-07	2.37E-07	2.19E-07	1.15E-06
	NDF= 8	rms	1.81E-08	3.71E-08	3.57E-09	5.49E-09	2.10E-09	3.54E-09	3.82E-08
5/10/16 6:12	5/10/16 6:25	TCL6 In	5.22E-07	3.48E-06	7.70E-07	1.38E-06	4.00E-07	4.07E-07	3.40E-05
	NDF= 13	rms	1.63E-08	5.22E-08	5.88E-09	8.92E-09	4.39E-09	2.71E-09	1.48E-07
5/10/16 6:29	5/10/16 6:47	AFP in	1.82E-06	4.87E-06	9.80E-07	1.95E-06	4.43E-07	5.00E-07	3.55E-05
	NDF= 18	rms	5.85E-08	5.42E-08	1.22E-08	2.56E-08	3.63E-09	5.48E-09	4.81E-07
					uncertainties ≤3%				
Standard dose with 300b		SB'=SB - Pedestal	6.50E-07	5.44E-07	1.89E-07	1.84E-07	6.64E-08	5.98E-08	8.82E-07
Increase with TCL6		(TCL6-SB)/SB'	-6.39E-01	4.84E+00	2.15E+00	5.54E+00	2.45E+00	3.14E+00	3.73E+01
Increase with TCL6 & AFP		(TCL6&AFP-SB)/SB'	1.35E+00	7.40E+00	**3.26E+00**	**8.66E+00**	**3.09E+00**	**4.70E+00**	3.90E+01

Expected 2016 $\int \mathcal{L} dt$: 25 fb^{-1}

To limit ALFA Dose Increase to 10%: ➔ AFP insertion limited to **0.29** fb^{-1}

Agreed with ALFA & RC: stop at **0.15** fb^{-1} ➔ AFP stops Intensity Qualification at **600 b**

(Note: so far ~0.034 fb^{-1} accumulated with TCL6 & AFP in)

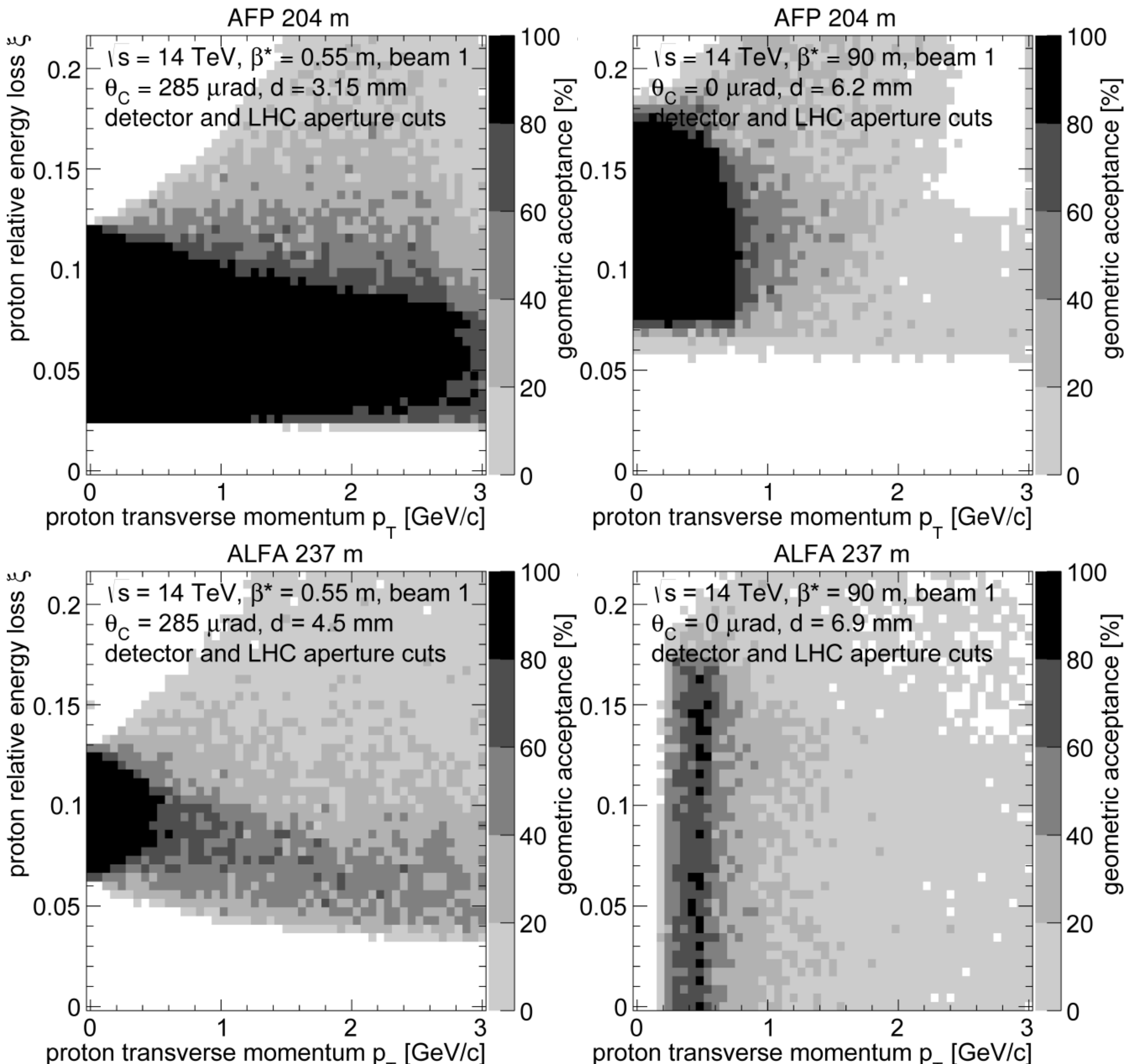
AFP and ALFA: Complementarity

AFP – Horizontal Pots:

- large t acceptance
- ξ range shifts with optics
- high β^* and low β^*=0.5 m

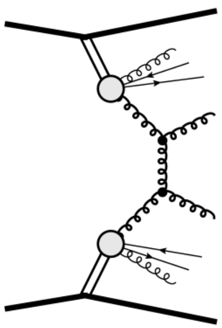
ALFA – Vertical Pots:

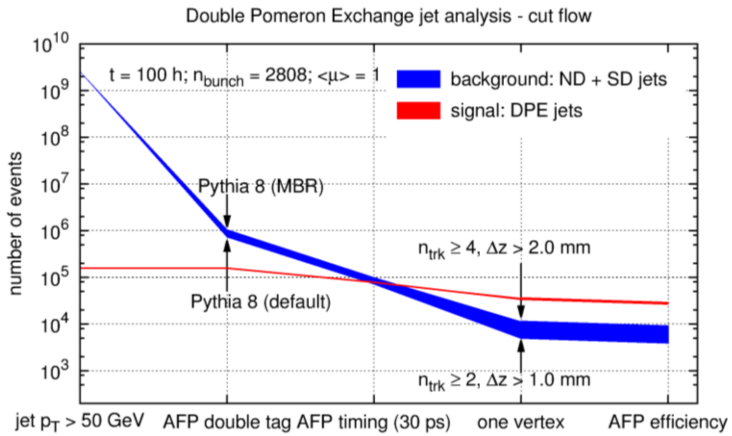
- limited t acceptance
- ξ=0 acceptance for β^*≥90, elastics
- only low-Luminosity, high β^* runs

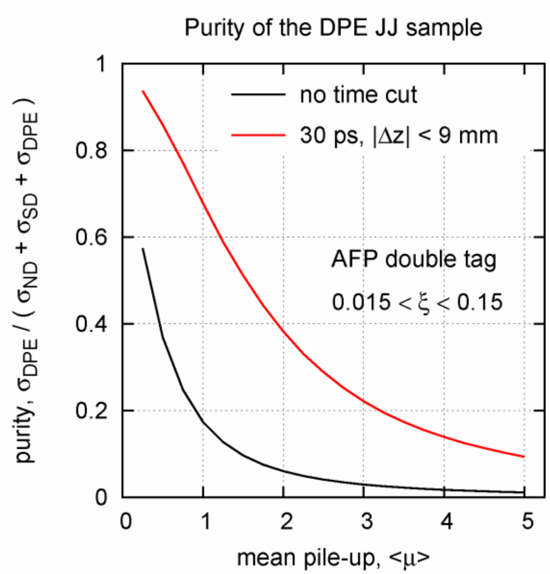


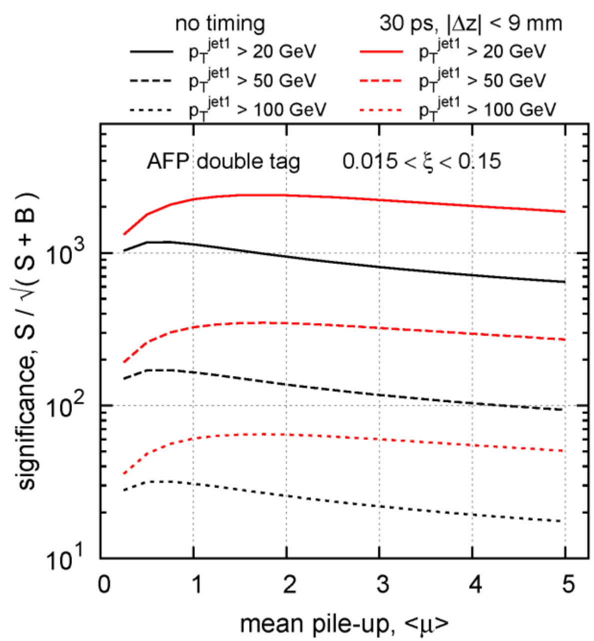
Benchmark: DPEjj Processes

- Fast & Full simulation of AFP + ATLAS, including pile-up
  - generator: PYTHIA 8.165 with POMFLUX = 1, 5(MBR)
  - 100 h (1 wk); 2808 bunches, μ=1
- Event Selections:
  - p_T(jet)> 20, 50, 100 GeV
  - double proton tag in AFP
  - *matching* with AFP vertex from timing (σ_t= 30 ps)
  - *single* vertex in ATLAS









Anomalous Quartic Couplings WWγγ

- Sensitivities predicted at the LHC (P. J. Bell, ArXiV:0907.5299): around a few 10^{-4} GeV^{-2}
- Sensitivities predicted with AFP:

30 fb^{-1}

	form factor	$\|a_0^W/\Lambda^2\|$	$\|a_C^W/\Lambda^2\|$	$\|a_0^Z/\Lambda^2\|$	$\|a_C^Z/\Lambda^2\|$
		limits $[10^{-6}\,\mathrm{GeV}^{-2}]$			
95% c.l	$\Lambda_{cut} = \infty$	1.2	4.2	2.8	10
	$\Lambda_{cut} = 2\,\mathrm{TeV}$	2.6	9.4	6.4	24
3σ evidence	$\Lambda_{cut} = \infty$	1.6	5.8	4.0	14
	$\Lambda_{cut} = 2\,\mathrm{TeV}$	3.6	13	9.0	34
5σ discovery	$\Lambda_{cut} = \infty$	2.3	9.7	6.2	23
	$\Lambda_{cut} = 2\,\mathrm{TeV}$	5.4	20	14	52

200 fb^{-1}

	form factor	$\|a_0^W/\Lambda^2\|$	$\|a_C^W/\Lambda^2\|$	$\|a_0^Z/\Lambda^2\|$	$\|a_C^Z/\Lambda^2\|$
		limits $[10^{-6}\,\mathrm{GeV}^{-2}]$			
95% c.l	$\Lambda_{cut} = \infty$	0.7	2.4	1.1	4.1
	$\Lambda_{cut} = 2\,\mathrm{TeV}$	1.4	5.2	2.5	9.2
3σ evidence	$\Lambda_{cut} = \infty$	0.85	3.0	1.6	5.7
	$\Lambda_{cut} = 2\,\mathrm{TeV}$	1.8	6.7	3.5	13
5σ discovery	$\Lambda_{cut} = \infty$	1.2	4.3	4.1	8.9
	$\Lambda_{cut} = 2\,\mathrm{TeV}$	2.7	9.6	5.5	20

- improvement by a factor ~100 over non-AFP measurements

$$\mathcal{L}_6 = \frac{-e^2}{8}\frac{\alpha_0^W}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha + \frac{-e^2}{16\cos^2\theta_W}\frac{\alpha_0^Z}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$
$$+\frac{-e^2}{16}\frac{\alpha_C^W}{\Lambda^2} F_{\mu\alpha}F^{\mu\beta}\left(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta\right) + \frac{-e^2}{16\cos^2\theta_W}\frac{\alpha_C^Z}{\Lambda^2} F_{\mu\alpha}F^{\mu\alpha}Z^\alpha Z_\beta$$

M. Saimpert, E. Chapon, S. Fichet, G. von Gersdorff, O. Kepka, B. Lenzi, C. Royon, “Probing anomalous quartic gauge couplings using proton tagging at the Large Hadron Collider”, Trento,16 April 2014.
C. Royon, O. Kepka, Phys. Rev. D 78 (2008)
E. Chapon, C. Royon, O. Kepka, Phys. Rev. D 81 (2010)

3-D SiT & ToF Beam Test

Trigger:

- AND of 3 planes (FE-I4 HitOR)

DAQ:

- RCE-based (AdvancedTCA)
- used for IBL stave testing
- worked **VERY** well in test beam!

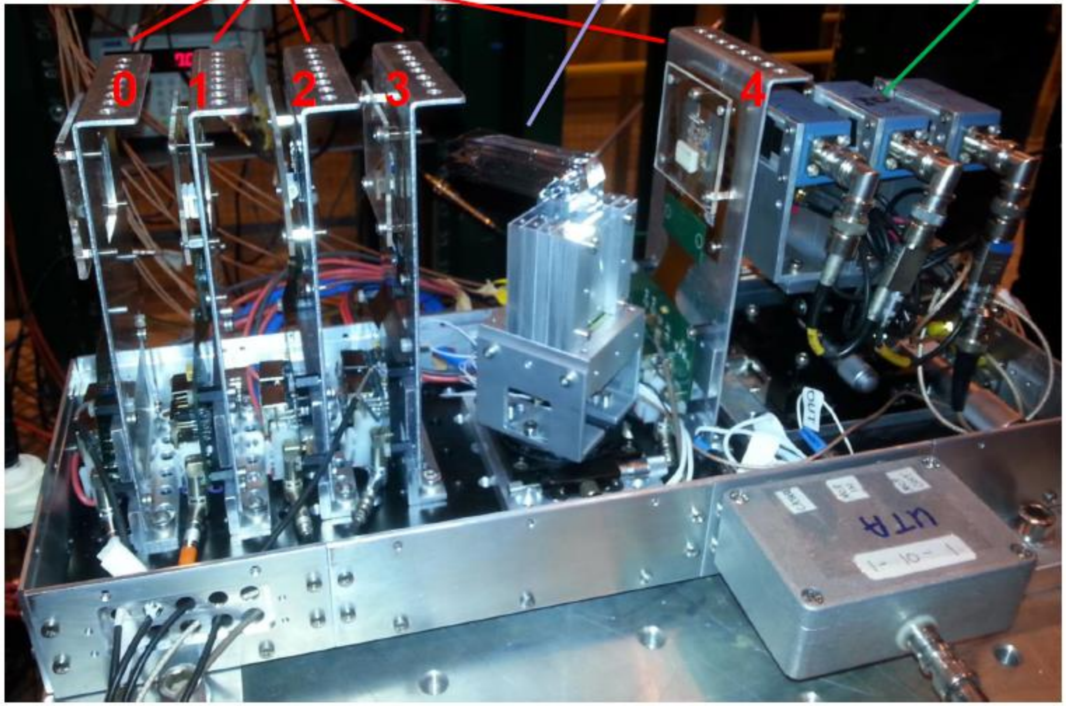
Performance:

- Efficiency ≥98%/plane
- 98% single track events, 0.4% empty triggers
- Track CoG resolution: σ_x=7 μm, σ_y=36 μm

Production Status:

- Sensors cut, Under Bump Metallization done
- FE-I4 in house, to be sent for UBM
- Flexes designed, prototype available 🡐 critical path
- Sensor card and holder designed and produced

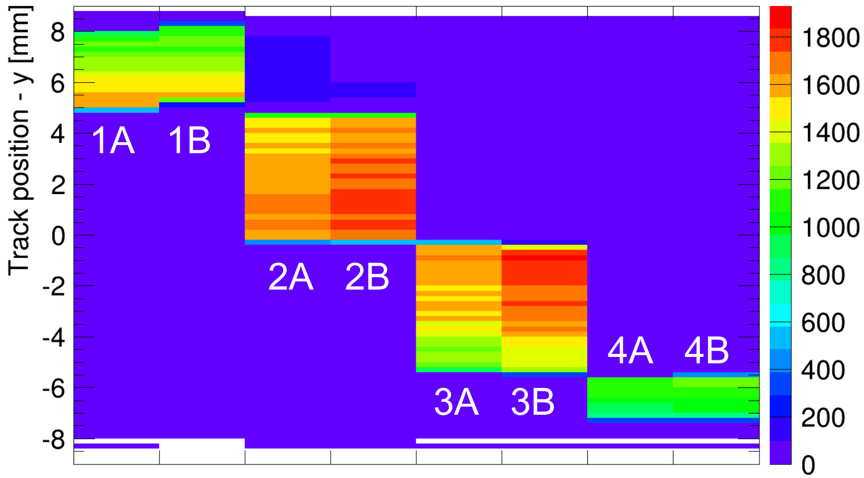
Setup in test beam Nov 2014 CERN SPS

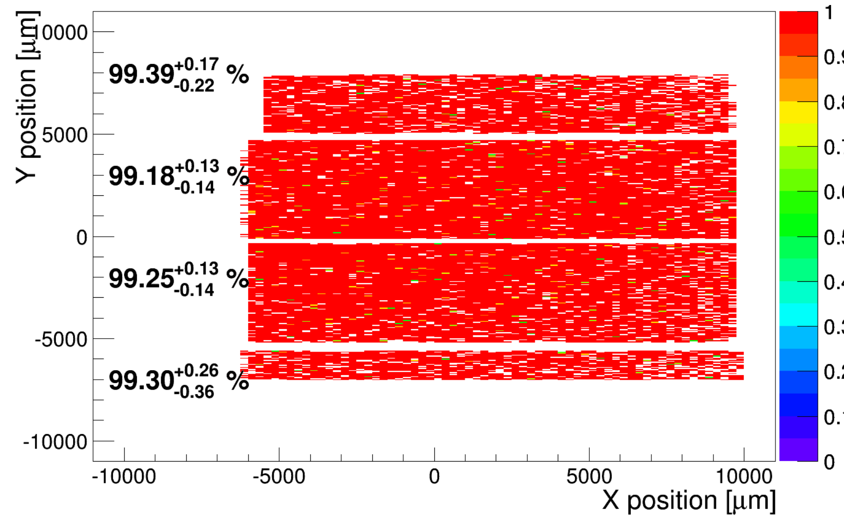


Beam Test: Time-of-Flight Detector

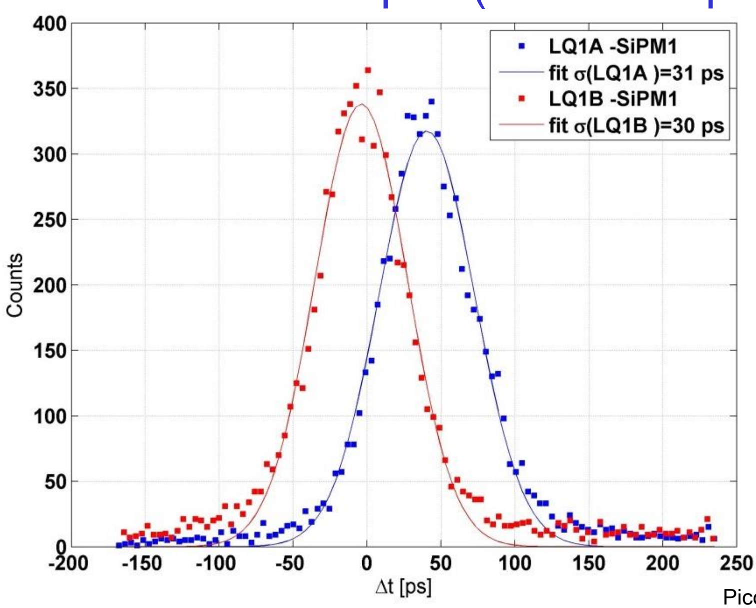
– Sit-ToF correllation: excellent (but some X-talk)

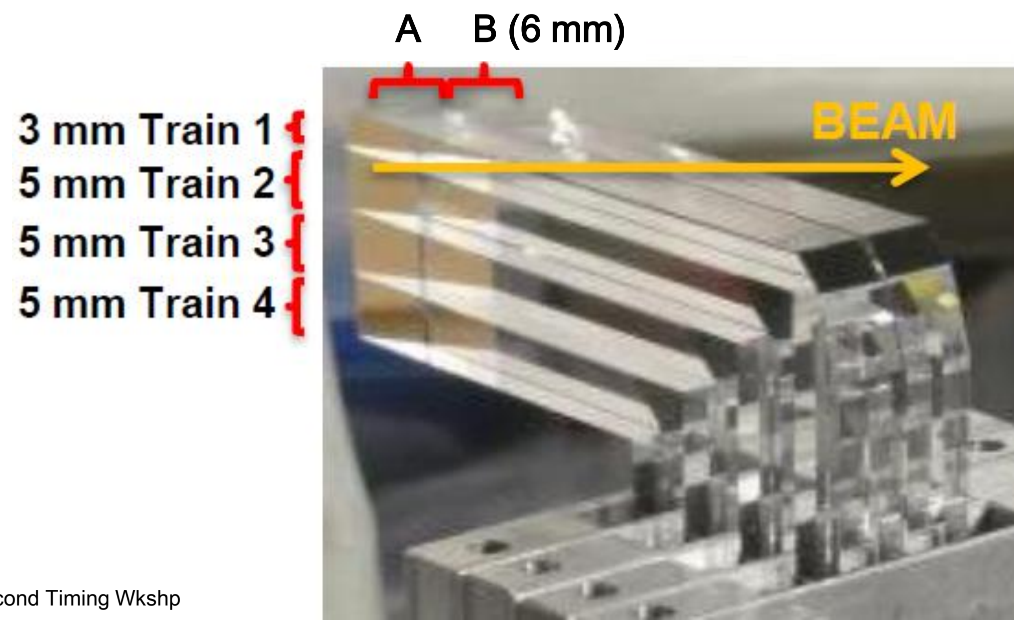
ToF efficiency: >99%





– Resolution: ~30 ps (Oscilloscope)





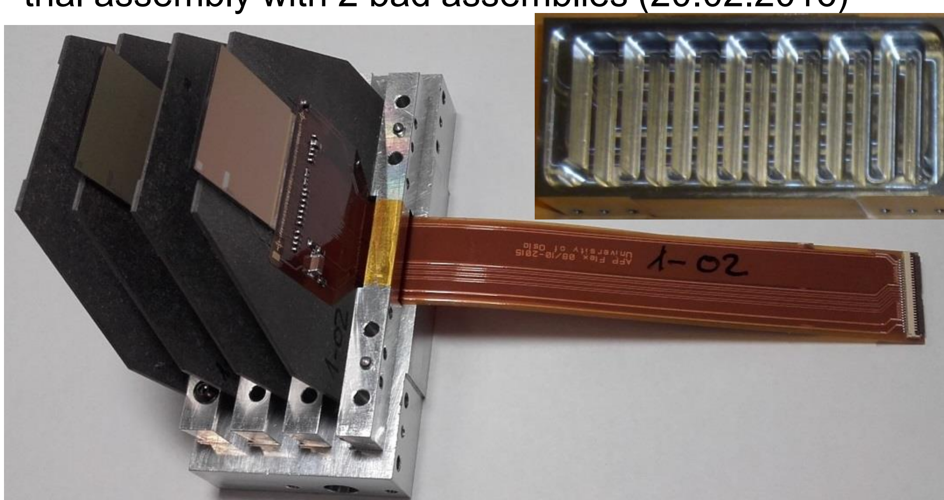
AFP in 2016 - Detectors

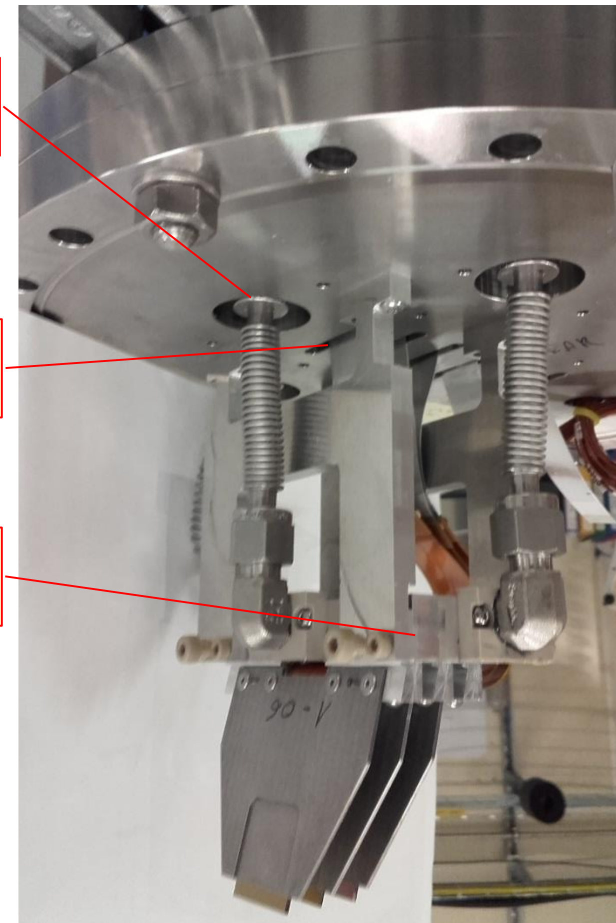
11 Silicon 3D detector assemblies produced at IFAE (more in coming months)

- **7 assemblies are operational**
- Assemblies precision-mounted on Al-CF carrier cards (Bergen)
- FLEX (Oslo)
- Heat Exchanger holds Tiltbars (Bergen)
- –40 C air from AirCooler (Stony Brook)

- **<u>Installation: this week</u>**
  - leak testing Mo-Tu

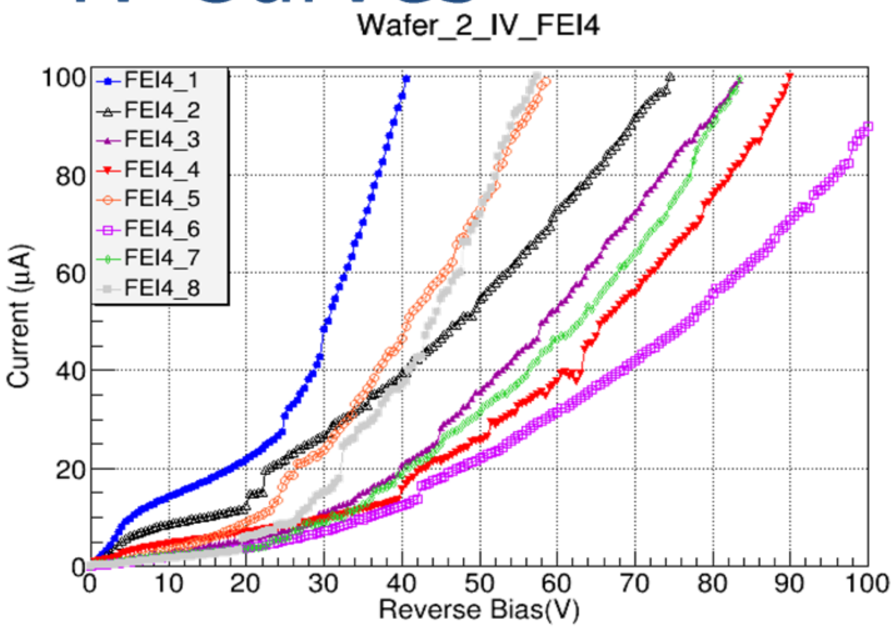
trial assembly with 2 bad assemblies (20.02.2016)

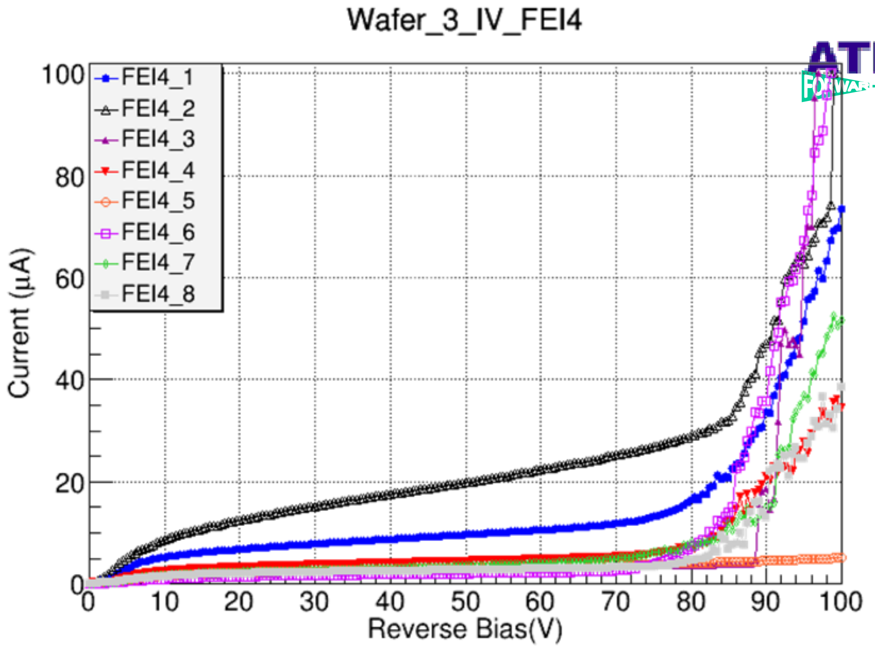


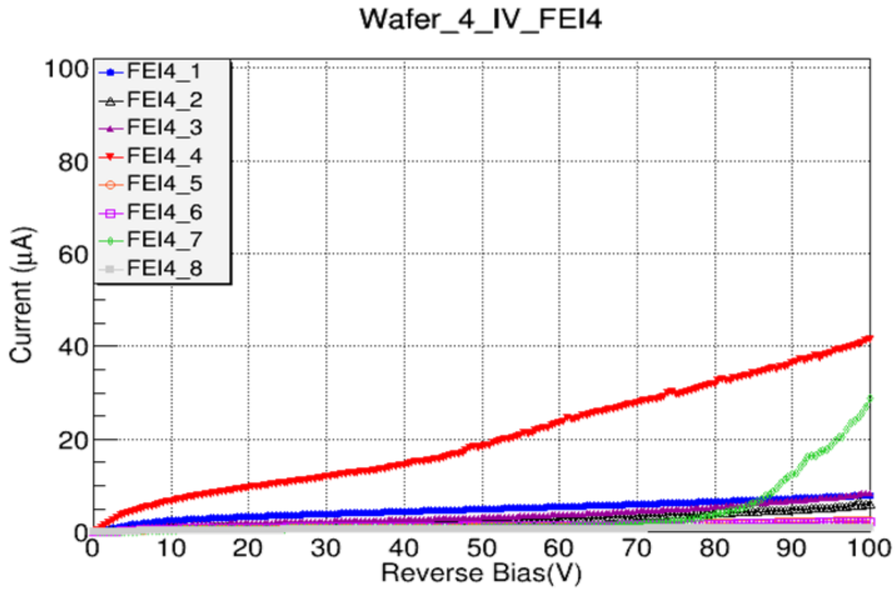


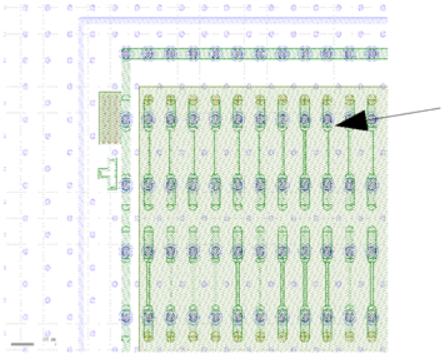
Maria Manna, Sebastian Grinstein, IFAE

IV Curves









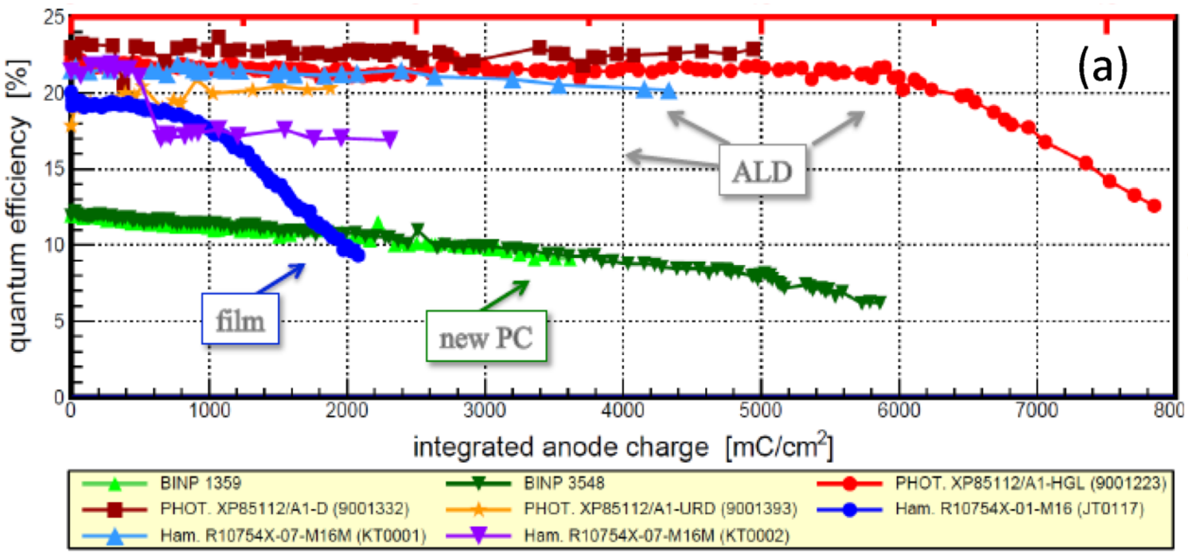
- Preliminary measurements of the active area of the three wafers are very encouraging!!

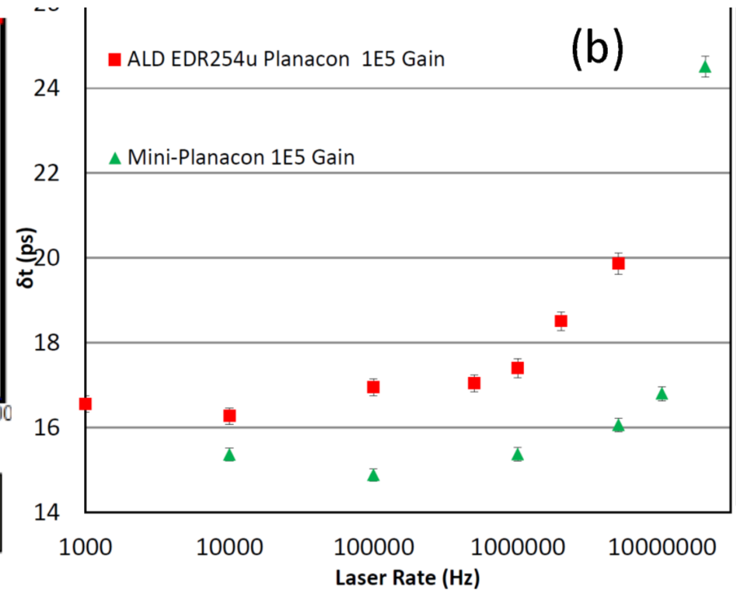
Other Items for the 2nd Arm

- Stations:
  - stations are in production at Vakuum Praha – expect by mid-June/July
  - pedestals & supports all done by ATLAS TC
  - small parts (done)
- Roman Pots:
  - 2 production Pots: Alberta – June/July
- Detectors:
  - Tracker:
    - new wafers look very good (next slide)
    - Al-CF carrier cards (ordered)
    - heat exchanger (in production)
    - other holder parts (done by Bergen)
- Other Infrastructure:
  - LVregs for ToF (Milano)
  - Local crates for ToF electronics & trigger (PA-b, Trig, CFD, HPTDC)
  - Patch panels & local cables

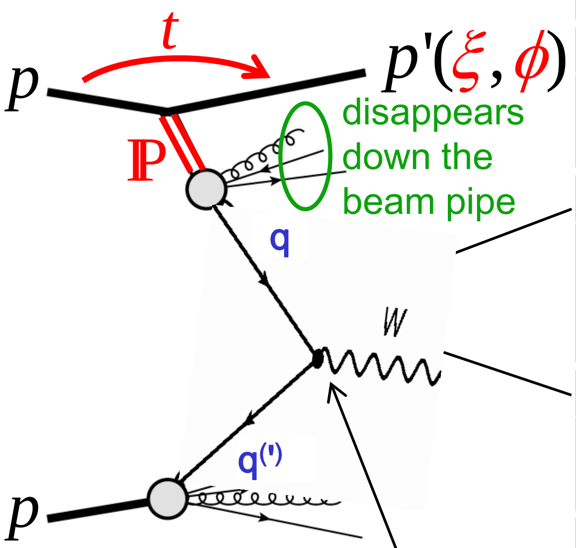
Backup – ToF MCP-PMT

- MCP-PMT Life Time and Rate





Summary of Single p-Tag Processes



Single Diffractive Production

$$t \equiv (p' - p)^2$$

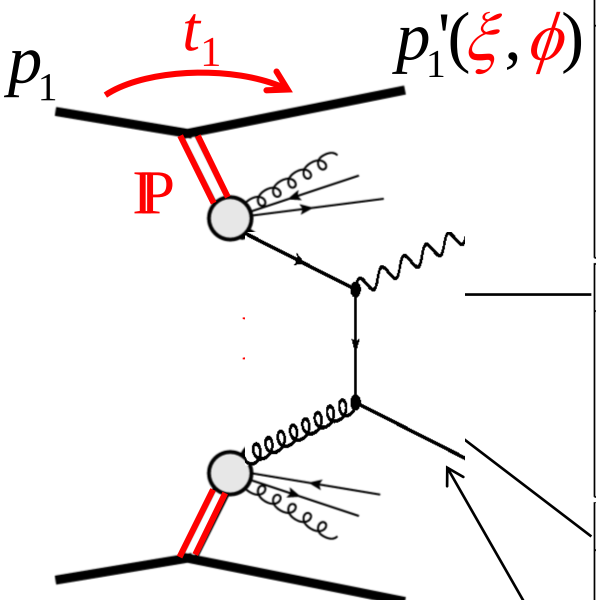
$$\xi \equiv 1 - E'/E$$

$$\beta \equiv x_{\mathbb{P}}$$

Analysis	**Motivation**	$\int Ldt$ [pb^{-1}]	**Optimal μ**
Soft Single Diffraction with AFP0+2			
$d\sigma/dt$, $d\sigma/d\xi$, t-Slope vs. ξ, $dN^{\pm}/dp_T$ vs. t and ξ	Saturation, MC tuning, Cosmic Ray physics	1	$\mu \sim 0.01$
Single Diffractive jet Production [21]			
σ, rapidity gap, Jet structure and p_T, event shape (MPI [21]); vs. t, ξ, and β	gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$
Single Diffractive jet-gap-jet Production [22, 23, 24]			
σ, central gap distribution, Jet p_T; vs. t, ξ, and β	observation of a new process, test of BFKL dynamics	1 – 100	$\mu \sim 1$
Single Diffractive Production of γ + jet [25]			
σ, rapidity gap, Jet structure and p_T, Photon p_T, event shape (MPI); vs. t, ξ, and β	observation of a new process, mechanism of hard diffraction, gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$
Single Diffractive Z Production			
σ, rapidity gap, charge-asymmetry; vs. t, ξ, and β	gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$
Single Diffractive W Production			
σ, rapidity gap; vs. t, ξ, and β	gap survival probability, Pomeron structure and flavor composition	10 – 100	$\mu \sim 1$

Summary of Double p-Tag Processes

DPE jet-jet



$$t_i \equiv (p_i' - p_i)^2$$

$$\xi_i \equiv 1 - E_i'/E_B$$

$$\beta_i \equiv x_{\mathbb{P},i}$$

$$M_{jj} \leq M_{pp} = \sqrt{s\xi_1\xi_2}$$

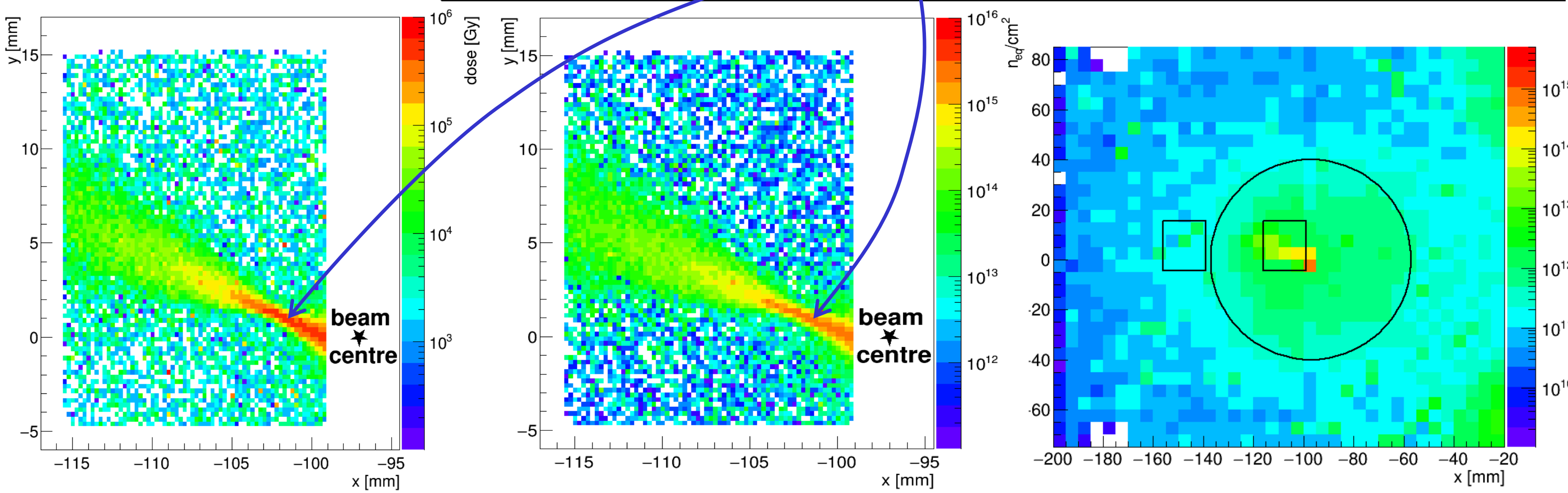
Analysis	**Motivation**	$\int Ldt$ [pb^{-1}]	**Optimal μ**
Soft Central Diffraction with AFP2+2			
$d\sigma/dt_{1,2}$, $d\sigma/d\xi_{1,2}$, t-Slope vs. ξ, Mass M and y of the central diffractive system, ϕ_1 vs. ϕ_2, $dN^{\pm}/dp_T$; vs. $t_{1,2}$, $\xi_{1,2}$, M.	general understanding of DPE processes	1	$\mu \sim 0.1$
Central Diffractive jet Production (DPEjj) [28]; see also Sect. A			
$d\sigma/dt_{1,2}$, $d\sigma/d\xi_{1,2}$, t-Slope vs. ξ, $d\sigma/dp_T^{jet}$, Mass M and y of the central dijet system, ϕ_1 vs. ϕ_2	gap survival probability for DPE processes, Pomeron structure, general understanding of DPE processes	10 – 100	$\mu \sim 1$
Jet-gap-jet Production [22, 24]			
$d\sigma/dt_{1,2}$, $d\sigma/d\xi_{1,2}$, $d\sigma/dM_{jj}$, central gap distribution, $d\sigma/dp_T^{jet}$, ϕ_1 vs. ϕ_2	observation of a new process, test of BFKL dynamics	10 – 100	$\mu \sim 1$
γ + jet Production			
σ, rapidity gap(s), Jet structure and p_T, Photon p_T; vs. $t_{1,2}$, $\xi_{1,2}$, and M_{jj}	observation of a new process, mechanism of hard diffraction, gap survival probability, Pomeron structure	10 – 100	$\mu \sim 1$

Backup – Radiation Levels

Radiation levels for **100 fb^{-1}**

- inputs: ALFA and TOTEM measurements
- AFP Full simulations in minbias events (below)
- early FLUKA calculations (A Mereghetti, 2009)

Position	5 mm from beam	5 cm from beam	Tunnel Floor
Electronics type	3-D sensor & FE-I4	PA-a	PA-b, Trigger, CFD, HPTDC
High-energy hadrons	$< 5 \times 10^{15}/\text{cm}^2$	$5 \times 10^{12}/\text{cm}^2$	$1 \times 10^{11}/\text{cm}^2$
n_{eq}	$< 3 \times 10^{15}/\text{cm}^2$	$3 \times 10^{12}/\text{cm}^2$	$5 \times 10^{10}/\text{cm}^2$
Dose	< 700 kGy	200 Gy	50 Gy



Irradiation of AFP Electronics

estimates for 100 fb^{-1} (need update!)	5 cm from beam @214 m	Tunnel floor @214 m	RR13 @beam level
Electronics exposed:	PA-a	PA-b, Trigger	CFD, HPTDC, Clock
High-Energy hadrons	$5\cdot10^{12}/cm^2$	$10^{10}/cm^2$	$5\cdot10^{9}$–$10^{8}/cm^2$
1 MeV-equiv. neutrons	$5\cdot10^{11}/cm^2$	$5\cdot10^{10}/cm^2$	$10^{9}/cm^2$
Integrated dose	5000 Gy	50 – 10 Gy	1 – 0.1 Gy

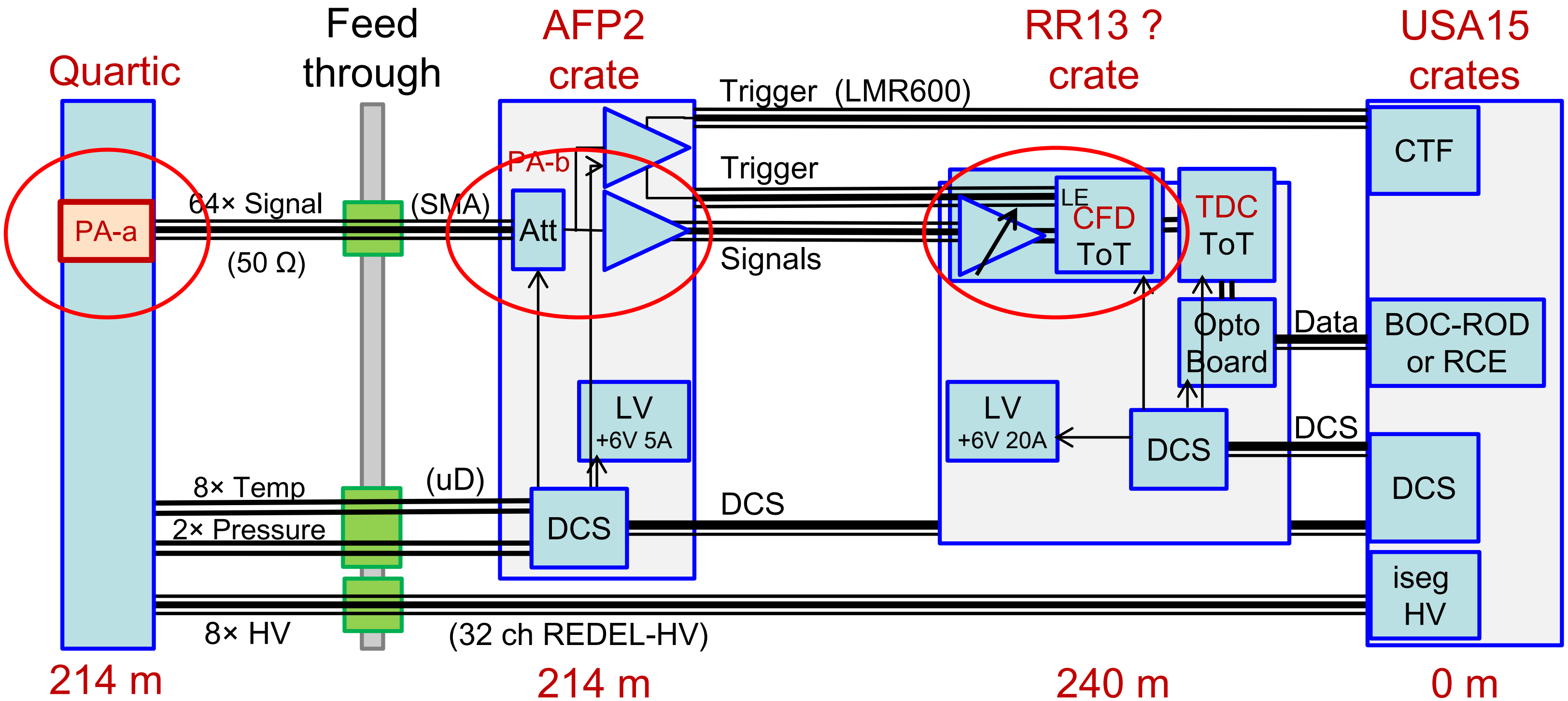
1. HiRad protocol:
   – Neutrons or HE protons: 10^{12} – 10^{13} /cm^2; γ: 1 – 10 kGy.
2. MedRad protocol:
   – Neutrons or HE protons: 10^{11} – 10^{12} /cm^2; γ: 10 – 1 kGy.

- PA-a chips (PSA4-5043+): HiRad
- PA-b boards & trigger: MedRad
- NINO chips (trigger): MedRad
- CFD daughter boards: MedRad
- HPTDC chips: MedRad

Cfr. ALFA radiation dose LHC Run1 measured over 2010–2013 (~30 fb^{-1}): ~20-30 Gy in each pot (≥10 cm from beam)
See: K.Hiller, S.Jakobsen, S.Franz, ALFA General Meeting, Cracow, June 5-7, 201.

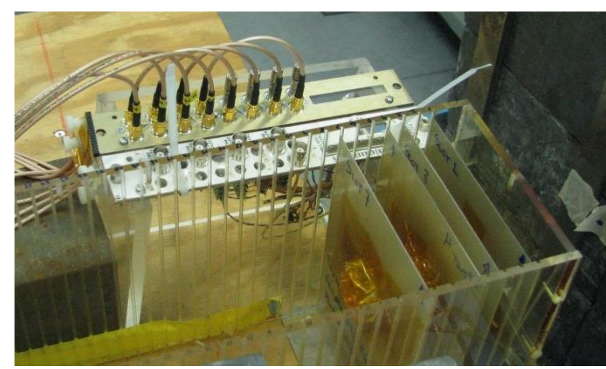
Irradiation – Sep 2013

Irradiated at LANL Sept 2013; S. Seidel *et al.* (UNM), K. Gray (UTA):

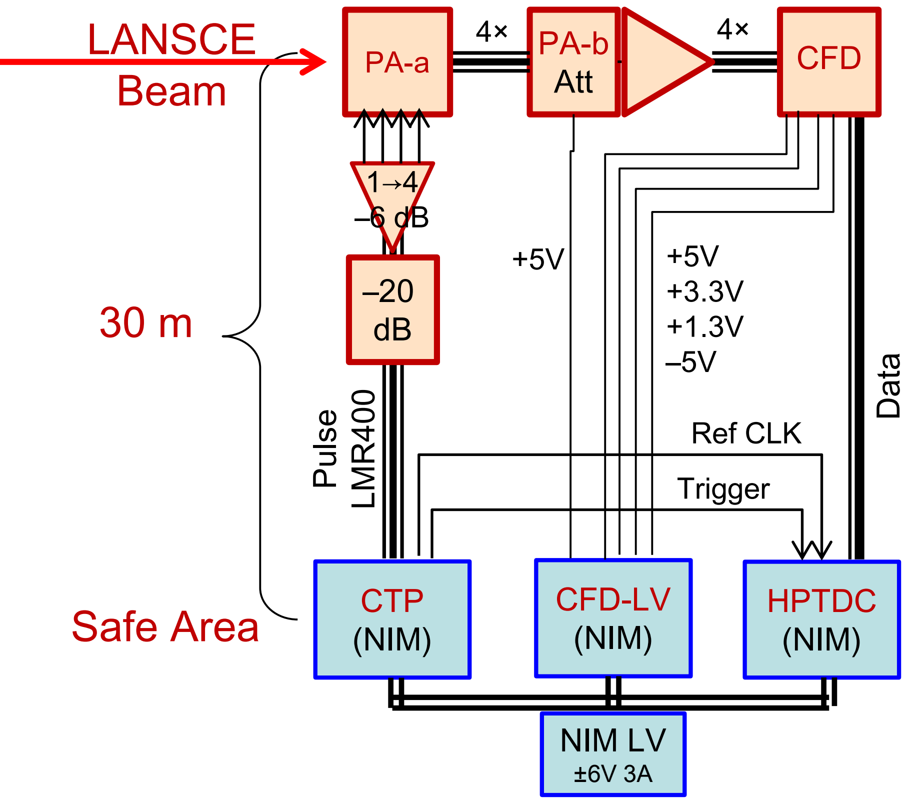


800 MeV p, ~7 cm from direct beam; *passive*

- dose: 6.5-8.7×10^{12} p/cm^2, 2.3-3.1 kGy
- for 100 fb^{-1}: ~expected for PA-a; ~50× expected for PA-b and CFD
- devices are all operational after irradiation!

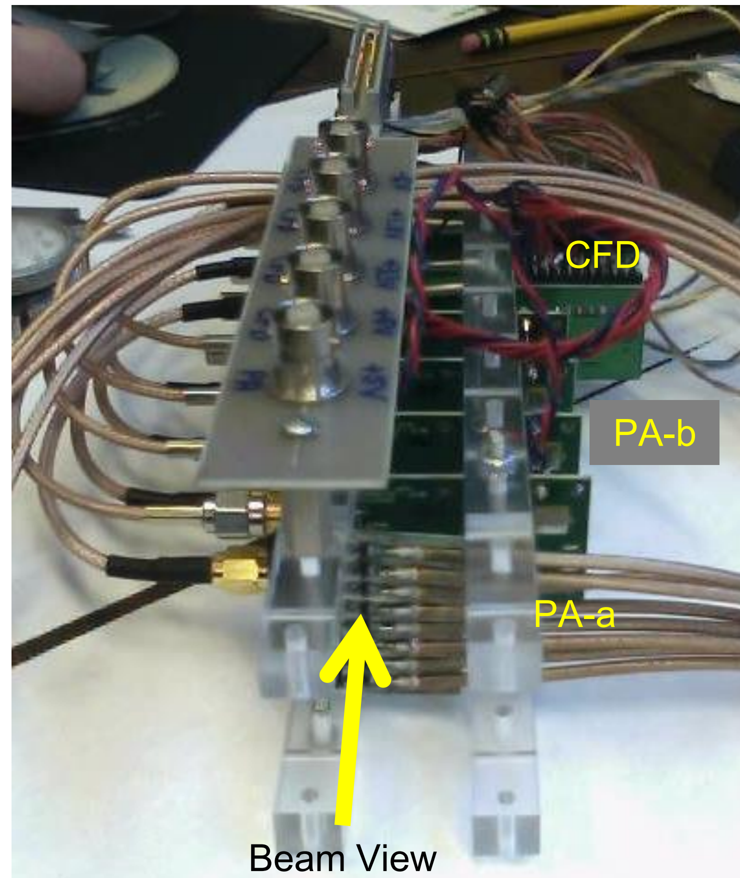


Irradiation @ LANSCE – Jan 2014



4 HPTDC chips

2 HPTDC chips: 1×10^{12} p/cm^2
2 HPTDC chips: 1×10^{13} p/cm^2



Jan 31- Feb 2 irradiation at LANSCE

Protocol:

- Active irradiation
- up to 1.0×10^{13} p/cm^2, in 10 steps of 1×10^{12} p/cm^2
- i.e. 10 pulses of 10^{11} protons per step

January 31- Feb 2 Irradiation

People: Tim Hoffman (UTA); Sally Seidel, Martin Hoeferkamp (UNM)

Protocol: Active irradiation – keep voltages on!

- up to 1.0×10^{13} p/cm^2, in 10 'steps' of 1×10^{12} p/cm^2; **verify operation** before & after each step.
- i.e. 1 'step' equals ~10 pulses of 10^{11} protons/pulse, 1 Hz, ~1 cm Ø

Early results:

- HPTDC readout did not work (cable too short) ➔ 2 Channels were monitored on scope; all 4 channels were powered throughout the run.
- Irradiation to 2.2×10^{13} p/cm^2, 7.8 kGy
- 2 monitored channels were still operating at the end of the run

Next:

- Wait for cool-off and return of parts (any time now …)
- Pre-Amps, CFDs: Re-test performance and compare with non-irradiated parts
- HPTDC chips: mount on HPTDC board and check operation