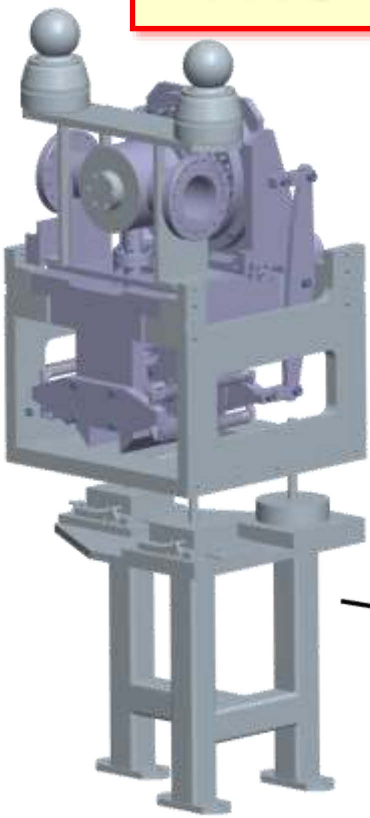
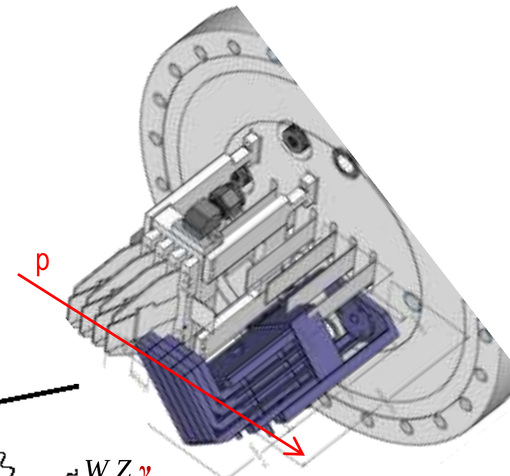
The ATLAS Forward Proton Project

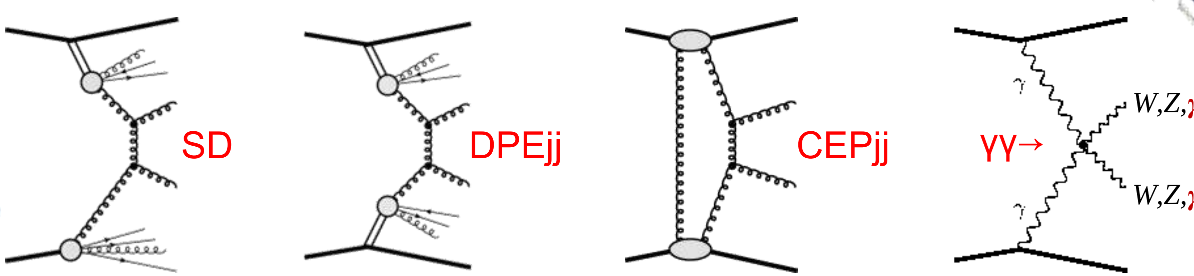


- ✓ Roman Pots and Stations installed
- ✓ Detector Assembly started (lasts 2-6 weeks)
- AFP Physics
- AFP Detectors
- Plans for Run 2 and beyond

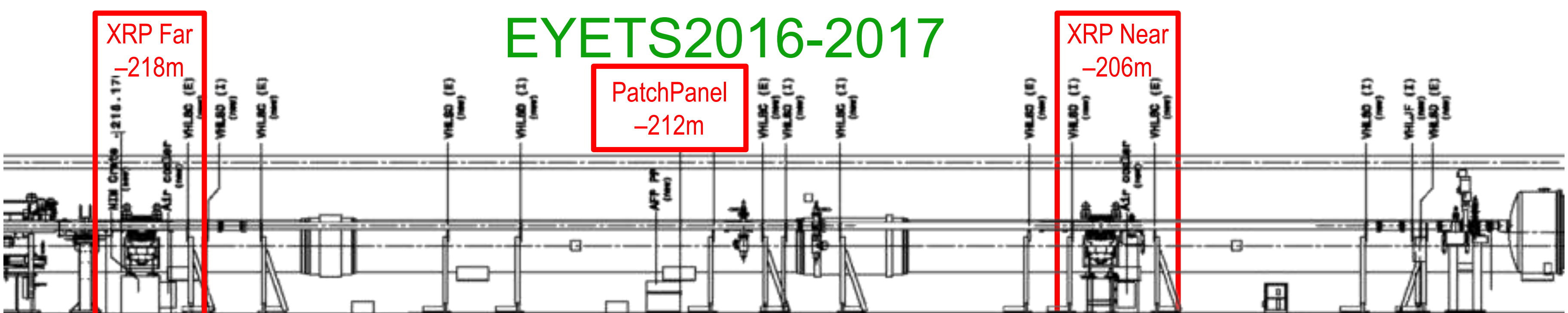
Michael Rijssenbeek
for the AFP Collaboration



2016 2017 →



EYETS2016-2017



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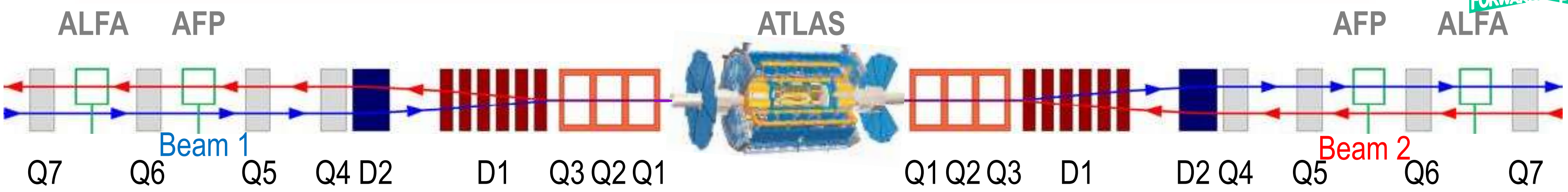


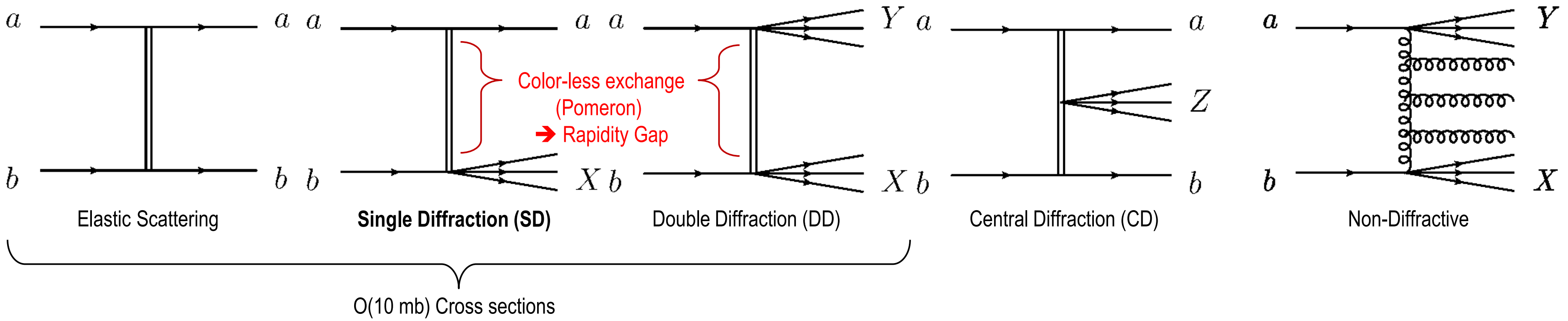
AFP 0+2 – First phase completed in March 2016:

- *single arm with two detectors* (silicon trackers) and a Level-1 Trigger: single proton tag and measurement
- *Physics:*
  - special runs: soft single diffraction, single diffractive jets, diffractive W, jet-gap-jet, exclusive jet production, … 2016: ~10hr (0.5 pb^{-1} at $\mu \lesssim 0.3$)
  - high-lumi runs to gauge beam environment and backgrounds … 2016: $\langle\mu\rangle_{max}$~35, ~15 hr (2 pb^{-1}), NO issues observed, clean beam environment, …

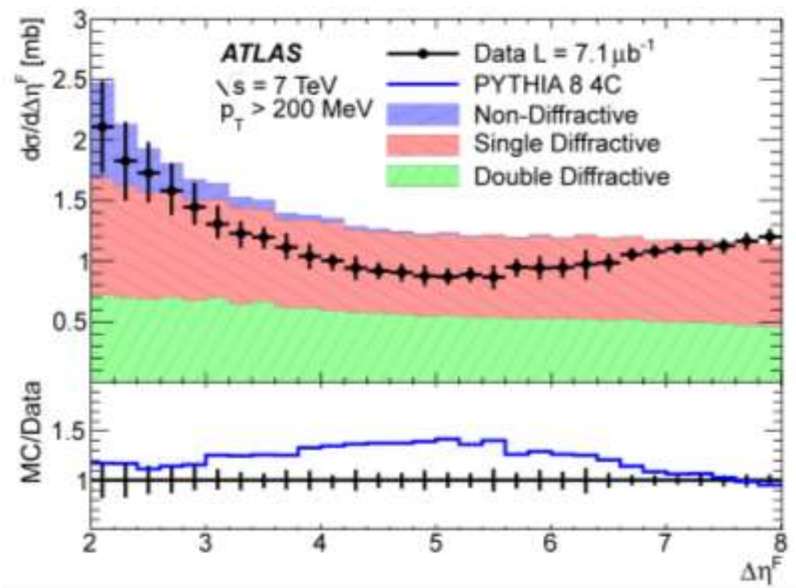
AFP 2+2 – second phase to be completed in March 2017:

- two arms (2 detectors per arm), with time-of-flight detectors in the 2^{nd} (far) stations
- Physics:
  - special runs ~10 hrs @ $\mu \lesssim 3$: soft central diffraction, central diffractive jets, jet-gap-jet, γ+jet
  - standard runs at 15σ: exclusive jet production, anomalous couplings, …

Soft Processes

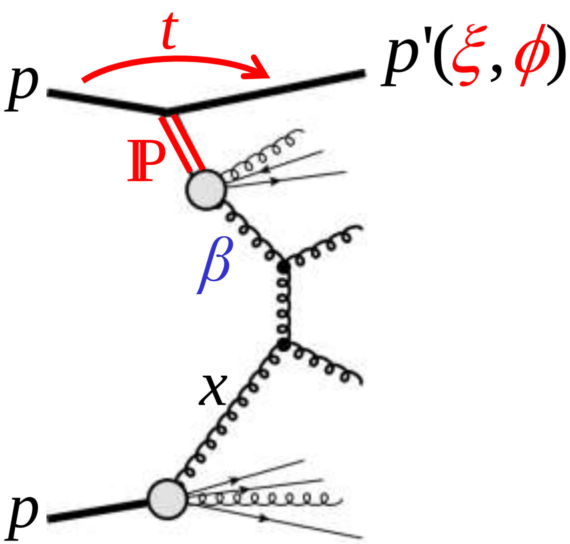


- Rapidity gap based measurement in ATLAS: does not distinguish SD from DD
  - More information about the process is available with forward proton tagging & measurement …
- High cross sections; only low lumi needed
  Good purity requires *low pile-up*
  ➔ Pile-up: at high luminosity many (μ) soft interactions accompany the high pT event
  ➔ special runs

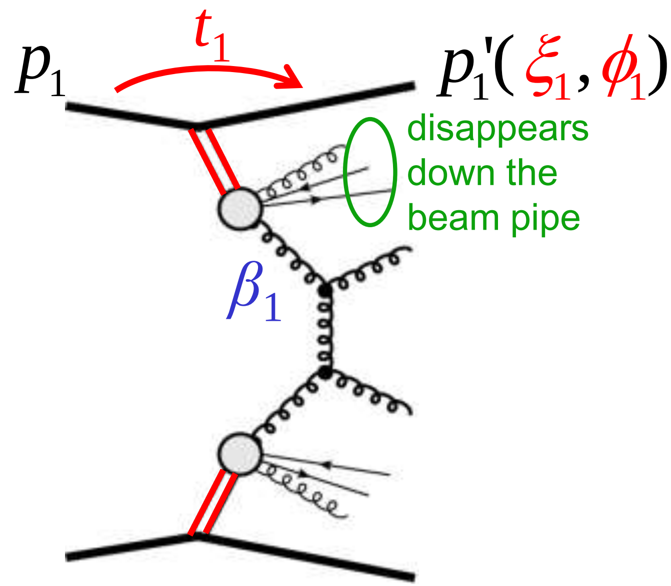


Eur. Phys. J. C72 (2012) 1926

Kinematic Variables



Single Diffractive Production



Double Diffractive Jet Production

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

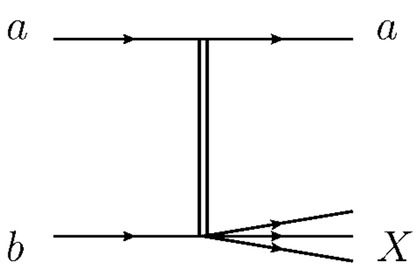
$$\xi_i \equiv 1 - E_i'/E_B$$

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

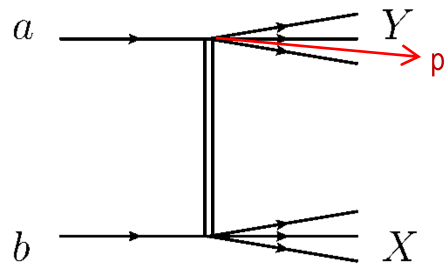
$$M_{jj} \leq M_{pp} = \sqrt{s\xi_1\xi_2}$$

Origin of Forward Protons

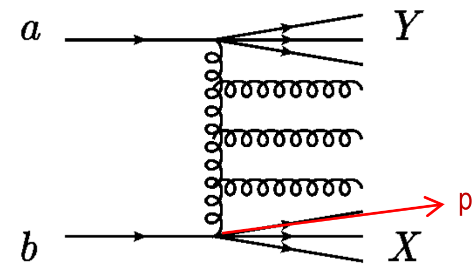
- High-ξ protons in ND and DD due to hadronization
- Significant differences between MC generators ➔ tune
- Important also for simulating cosmic air showers



Single Diffraction (SD)

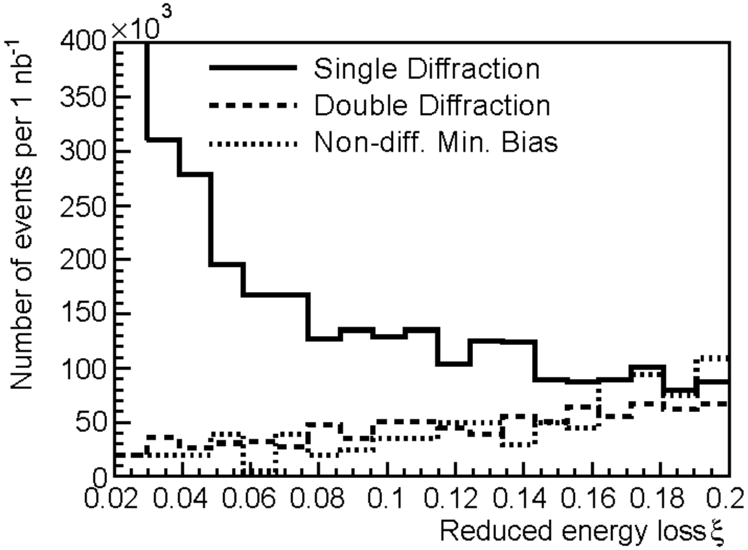


Double Diffraction (DD)

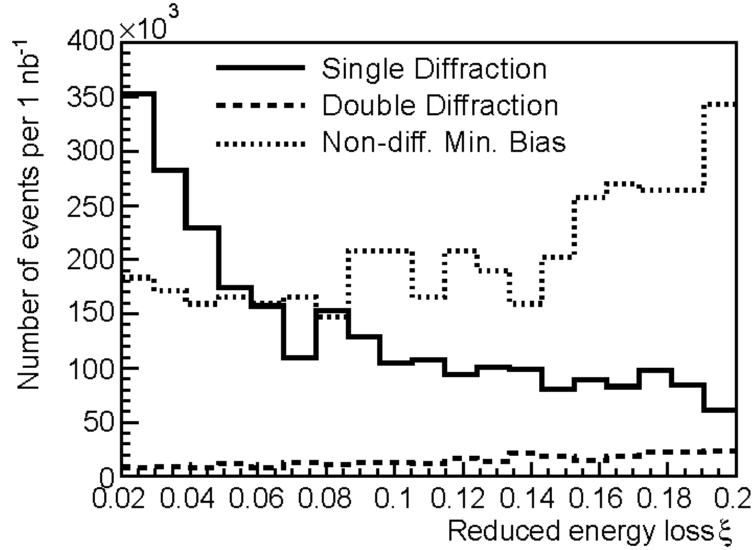


Non-Diffractive

Pythia

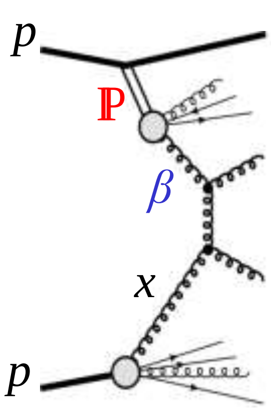


Phojet

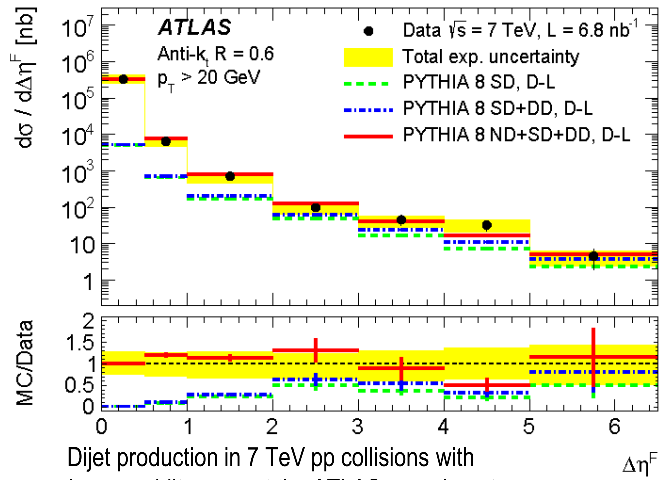


Single Diffractive Jet Production

Motivation:

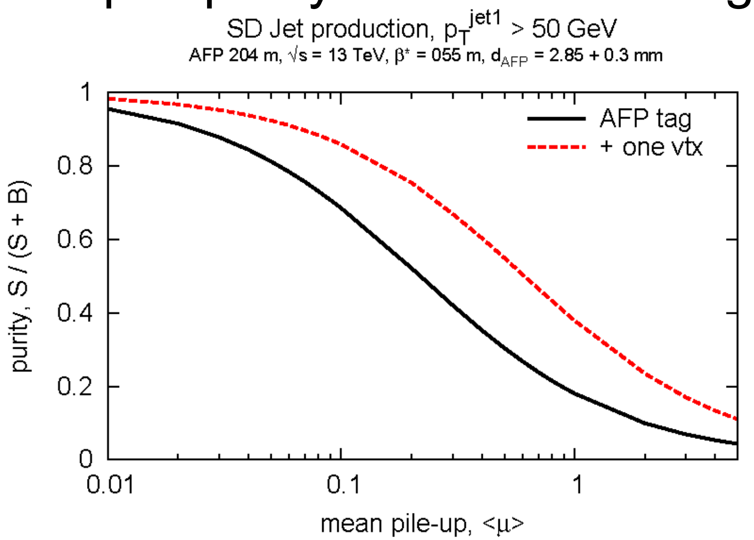


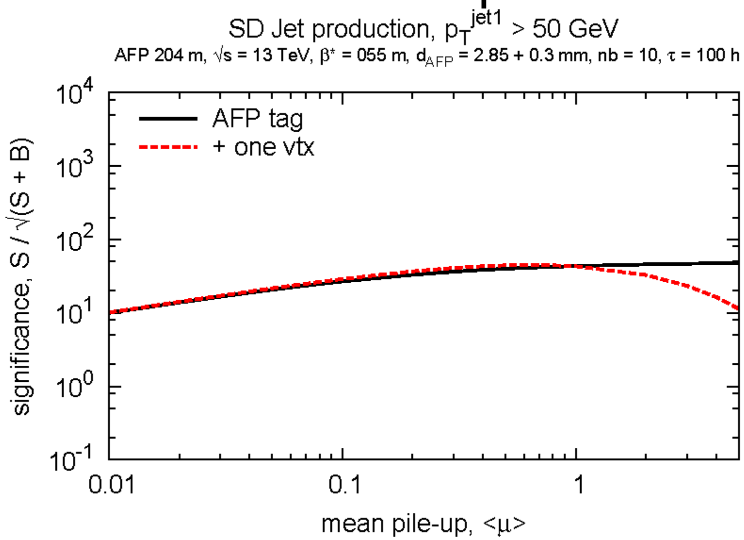
- Measure cross section and gap survival probability
- Possible presence of Reggeon contribution?
- Study Pomeron structure and universality between ep and pp



Dijet production in 7 TeV pp collisions with large rapidity gaps at the ATLAS experiment

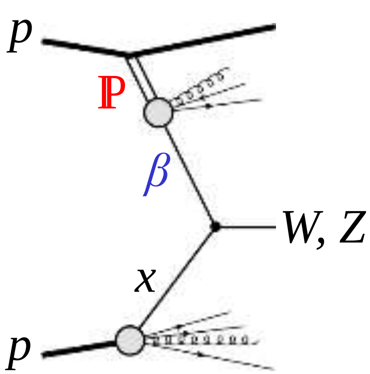
Example: purity and statistical significance for AFP and $\beta^* = 0.55$ m





Details in: "LHC Forward Physics" CERN-PH-LPCC-2015-001, J. Phys. G: Nucl. Part. Phys. 43 (2016) 110201

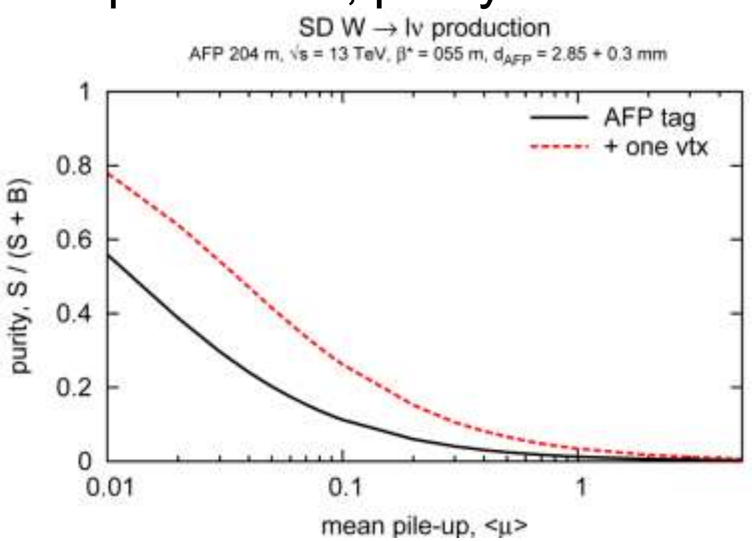
Single Diffractive W/Z Production

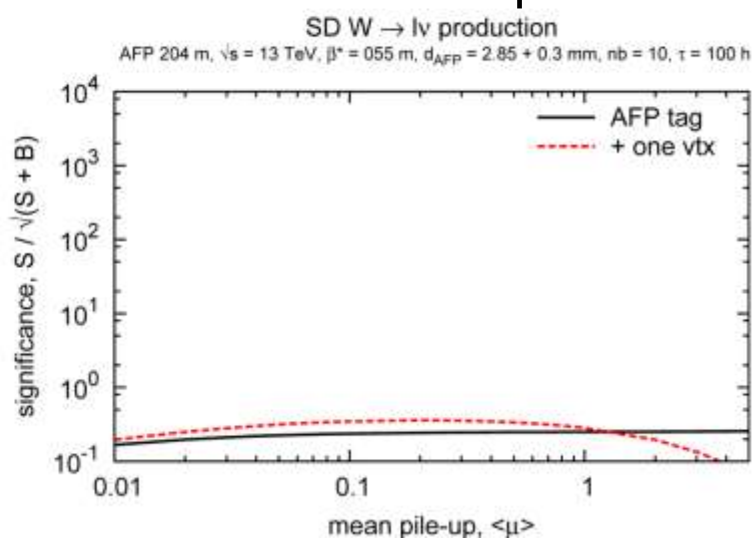


Motivation:

- Measure cross section and gap survival probability
- Study Pomeron structure and flavor composition
- Search for charge-asymmetry

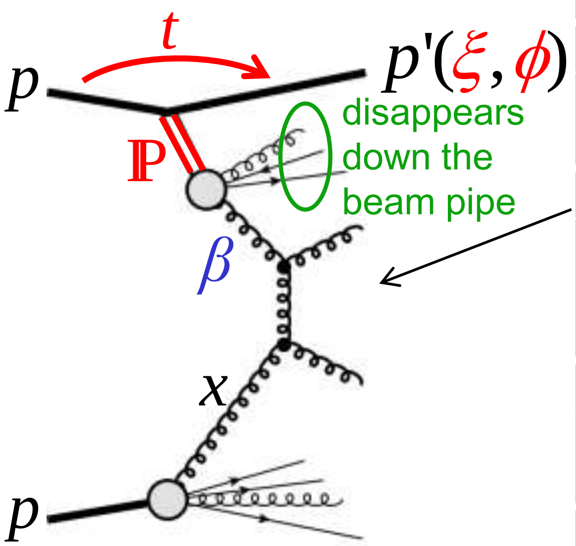
Example: $W \to l\nu$; purity and stat. significance for AFP and β*=0.55 m





W asymmetry studies published in: Phys.Rev. D 84 (2011) 114006; more details in J. Phys. G: Nucl. Part. Phys. 43 (2016) 110201

Summary of Single p-Tag Processes



Single Diffractive Production

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

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

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

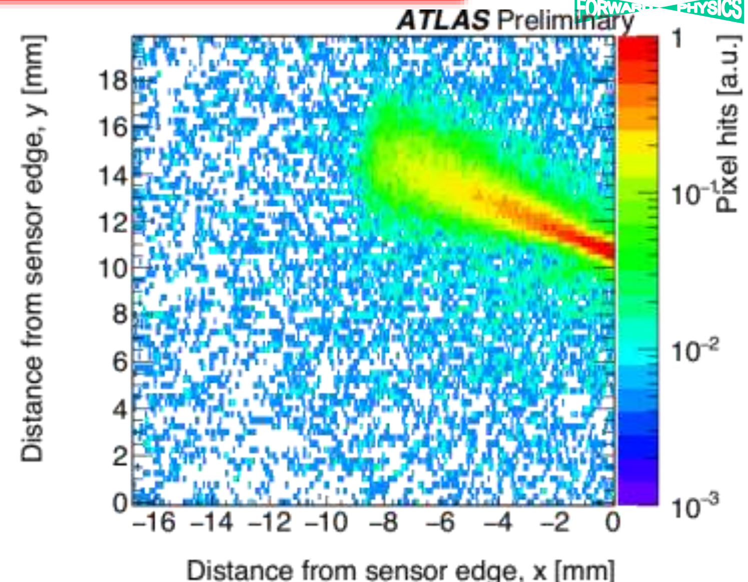
Analysis	**Motivation**	$\int L dt$ [pb^{-1}]	**Optimal μ**
Soft Single Diffraction with AFP0+2			
$d\sigma/dt$, $d\sigma/d\xi$, t-Slope vs. ξ, $dN^{\pm}/dp_T$ vs. t and ξ	Saturation, MC tuning, Cosmic Ray physics	1	$\mu \sim 0.01$
Single Diffractive jet Production [21]			
σ, rapidity gap, Jet structure 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	$10 - 100$	$\mu \sim 1$

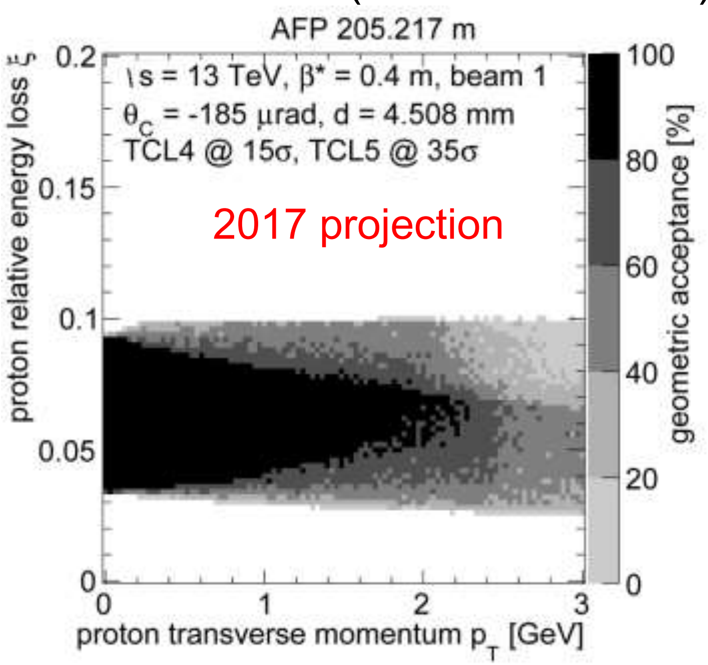
2016 Data: Alignment

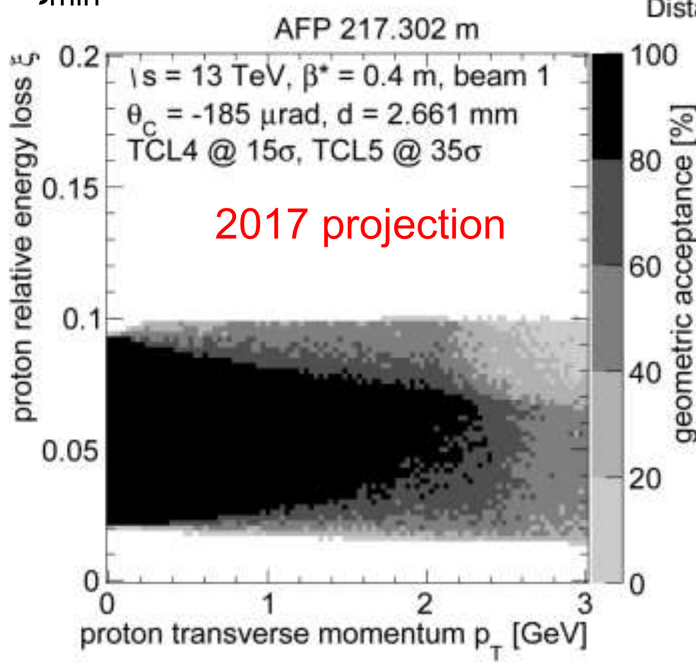
- Geometric Acceptance: position based on Sep 2016 AFP Beam-Based Alignment:

Station	AFP position from x=0 [mm]	Beam position from x=0 [mm]
NEAR	-5.652	-1.612
FAR	-2.576	-0.419

- Pots inserted to 20σ from beam center,
  + dead region: 0.3 mm (thin window)
  + 0.3 mm (to active sensor): $\xi_{min} \simeq 3.5\%$





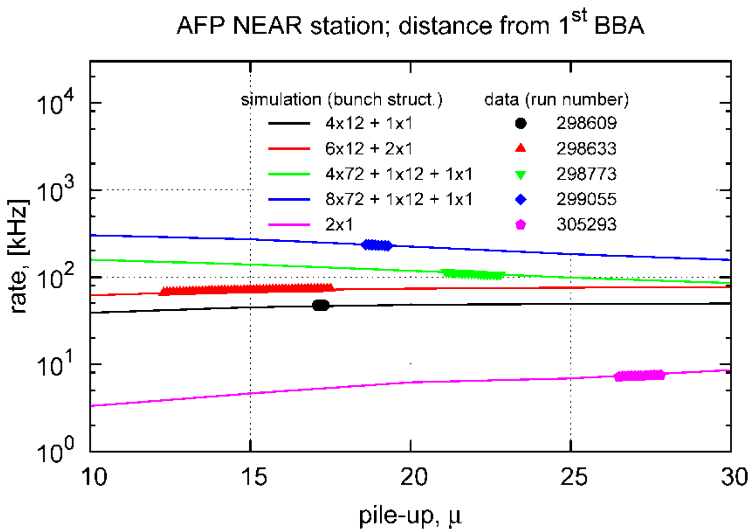


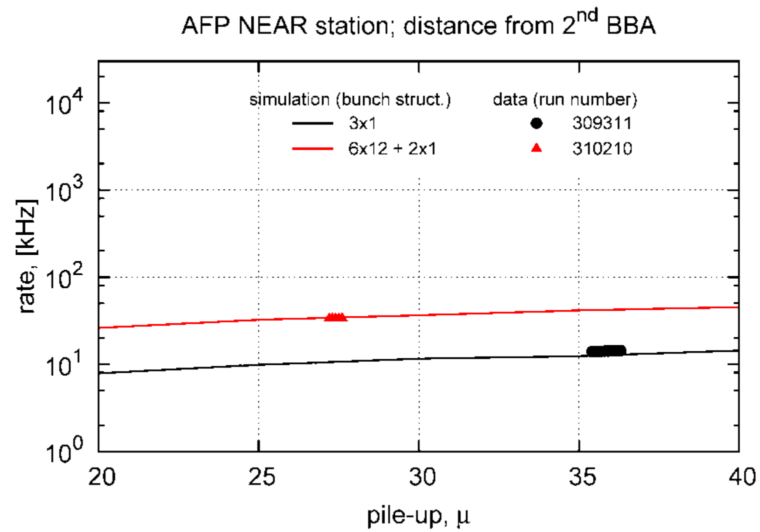
– 2016: Further improvement expected with recent re-calibration of pots & detectors

⇦ 2017: for 15σ approach $\xi_{min} \simeq 2.5\%$

2016 Data: Trigger Rates

- Detailed trigger simulation agrees well with rate data over wide μ-range:

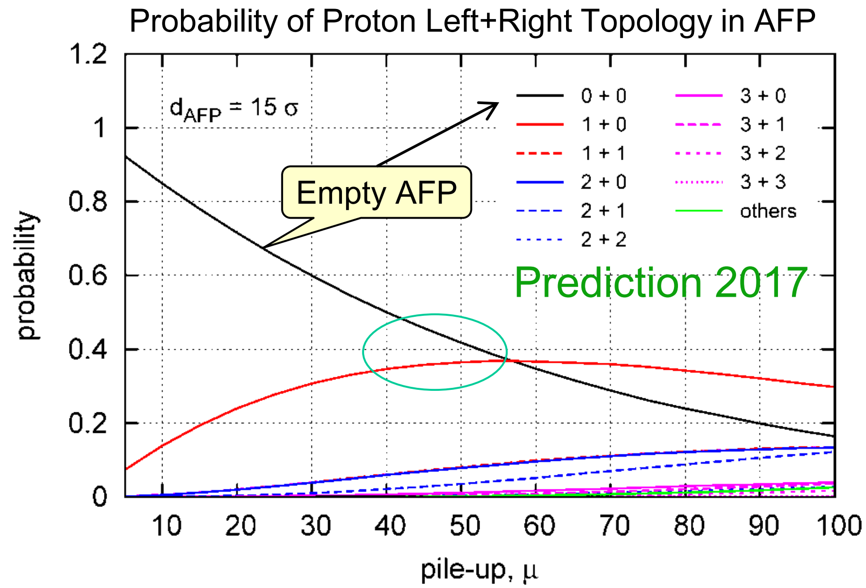




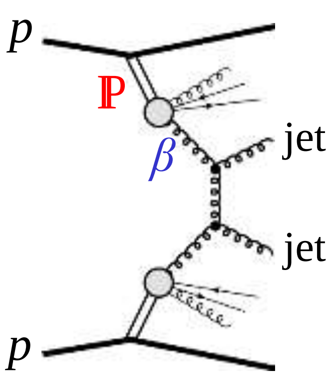
- from this: Mean Hit-in-AFP probability per MinBias interaction (pile-up event):

Hit Probability per Pile-up interaction	NEAR Pot	FAR Pot
Data (many runs)	1.46%	2.06%
Pythia (un-tuned)	0.64%	0.88%

- Pythia predictions lower by 2×; model tune + background ?



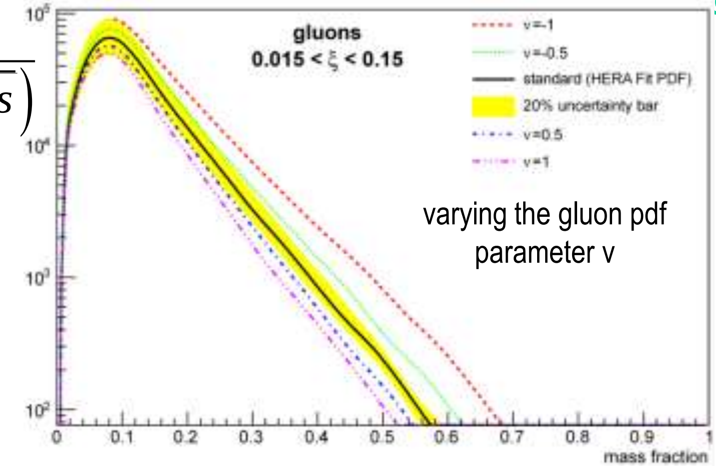
Double Pomeron Exchange Jet Production



Motivation:

$$\frac{d\sigma}{d\left(M_{jj}/\sqrt{\xi_1\xi_2 s}\right)}$$

- Measure cross section and gap survival probability
- Possible presence of Reggeon contribution?
- Study the gluon content of the Pomeron



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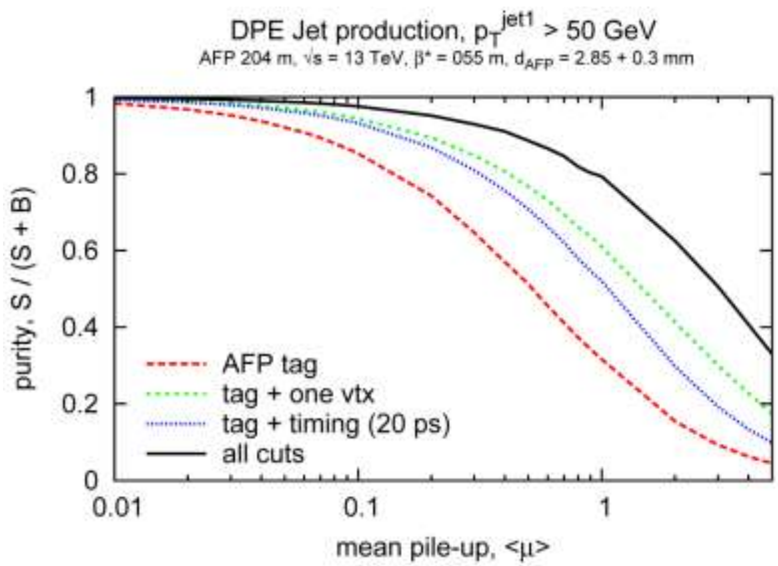
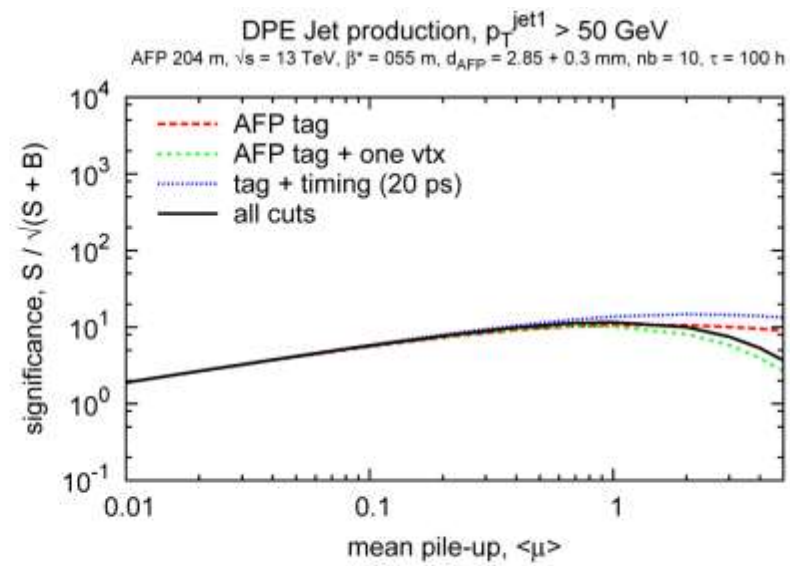
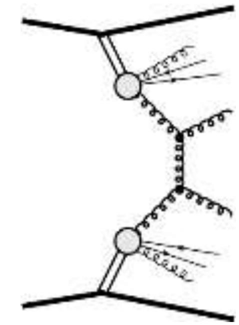


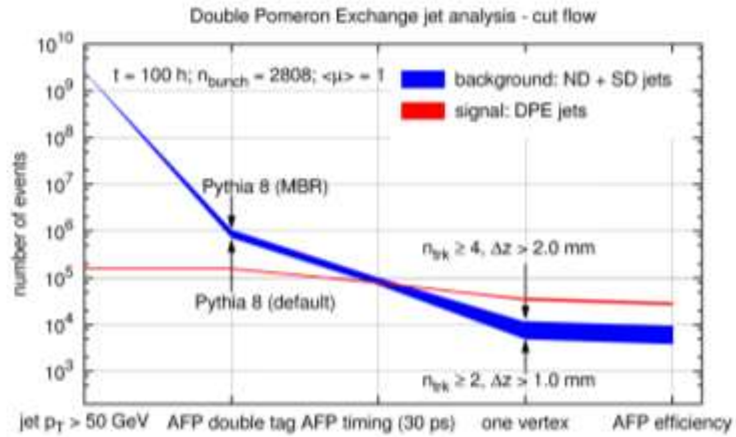


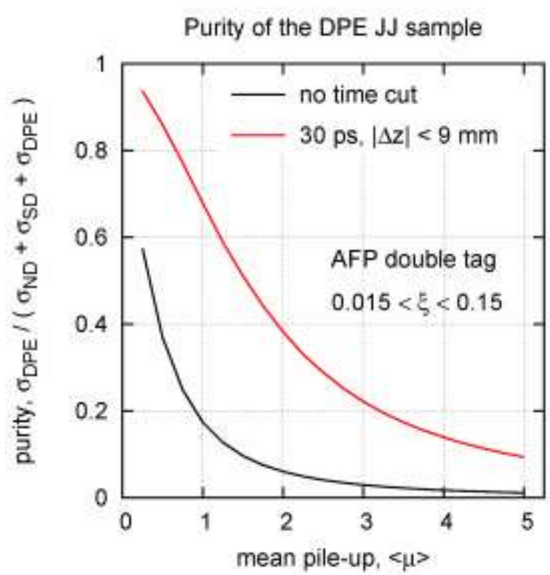
See: J. Phys. G: Nucl. Part. Phys. 43 (2016) 110201

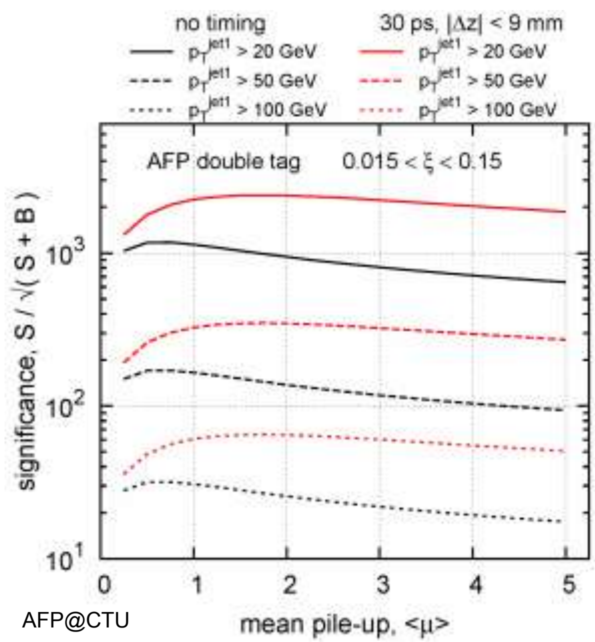
Benchmark: DPEjj Process

– 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

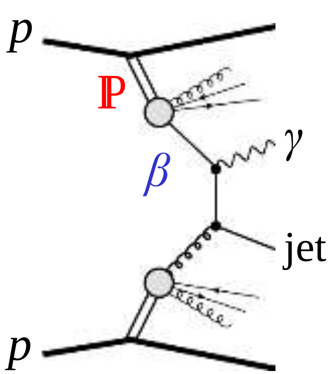








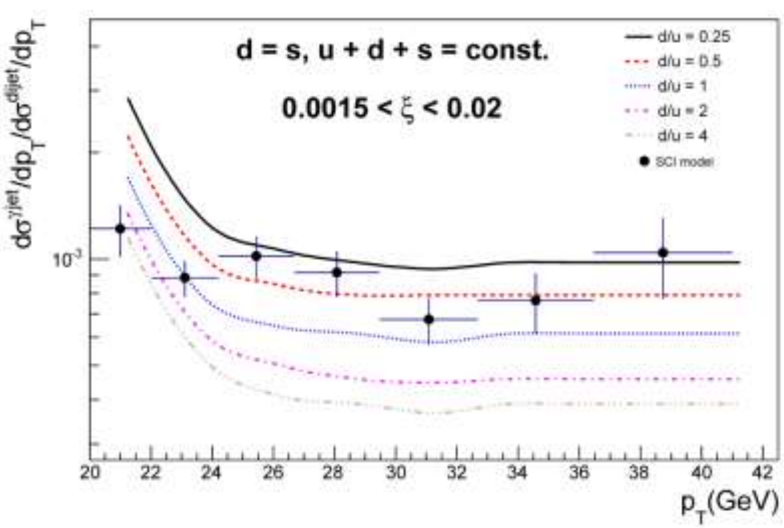
DPE γ+Jet Production

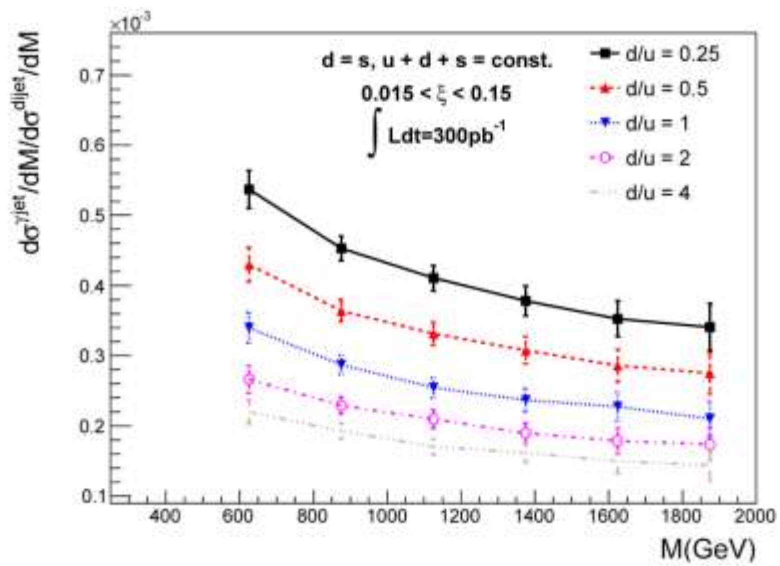


Motivation:

– Measure cross section and gap survival probability

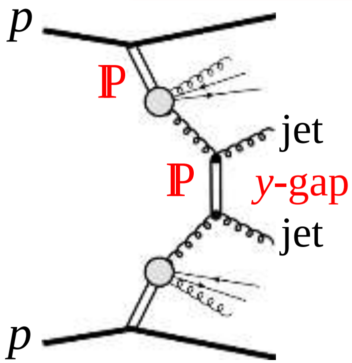
– sensitive to quark content in Pomeron (at HERA one assumed that $u = d = s = \bar{u} = \bar{d} = \bar{s}$)





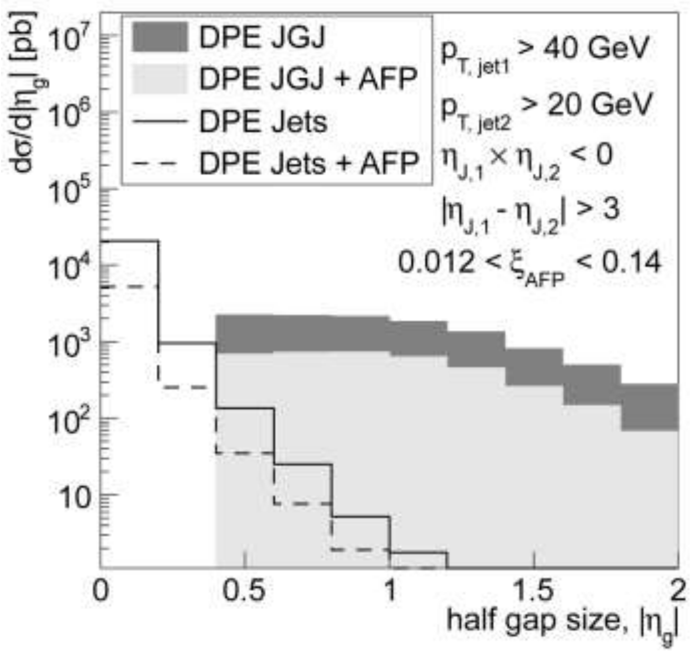
See: Phys. Rev. **D** 88 (2013) 7, 074029

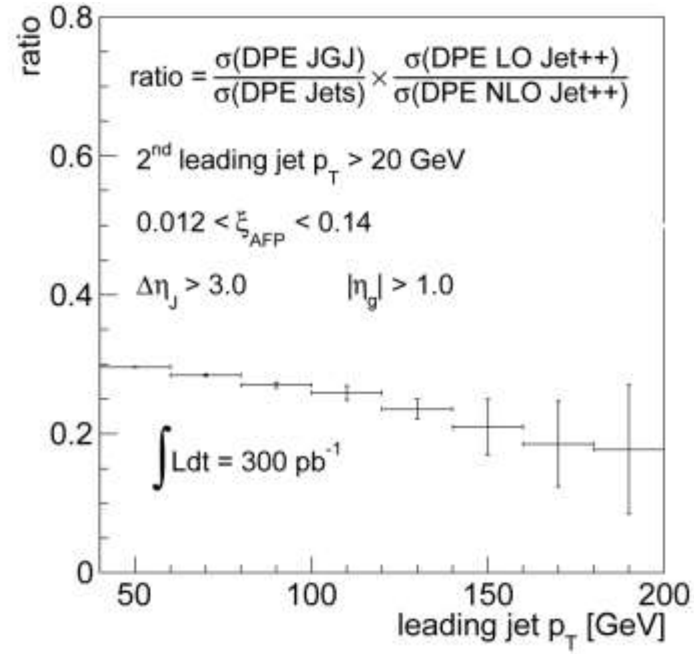
DPE Jet-Gap-Jet Production



Motivation:

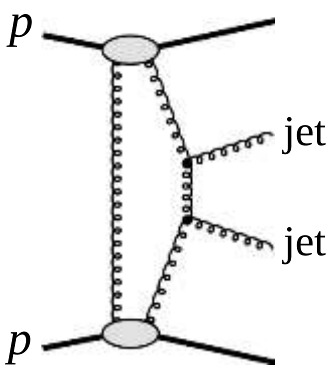
- Measure cross section and gap survival probability
- test the BFKL model





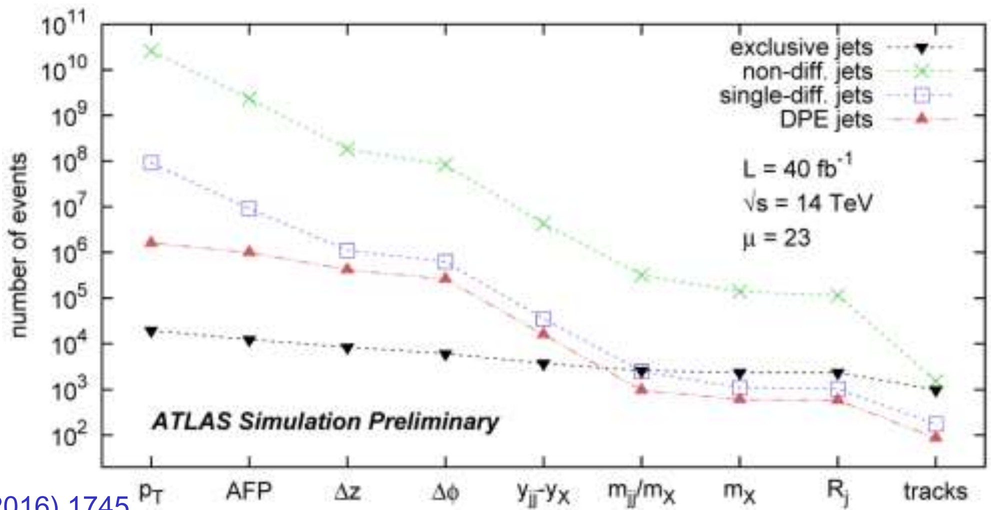
See: Phys. Rev. **D** 87 (2013) 3, 034010

Central Exclusive Jet Production



Motivation:

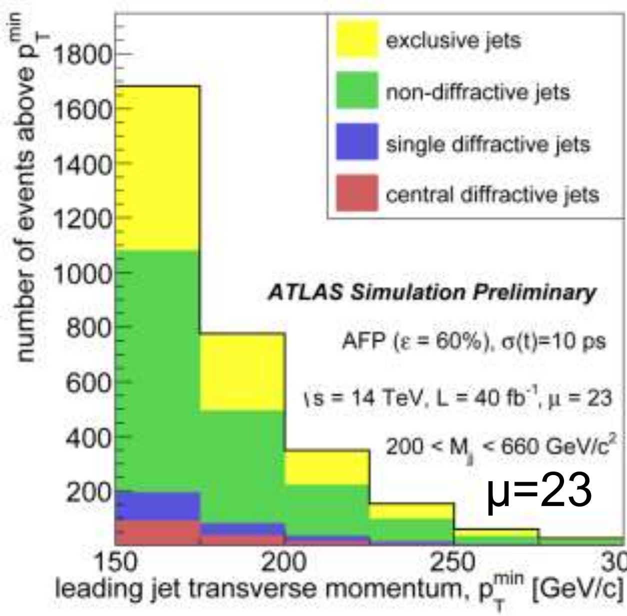
- Measure cross section at the LHC, gap survival probability
- constrain other exclusive production processes (e.g. Higgs)

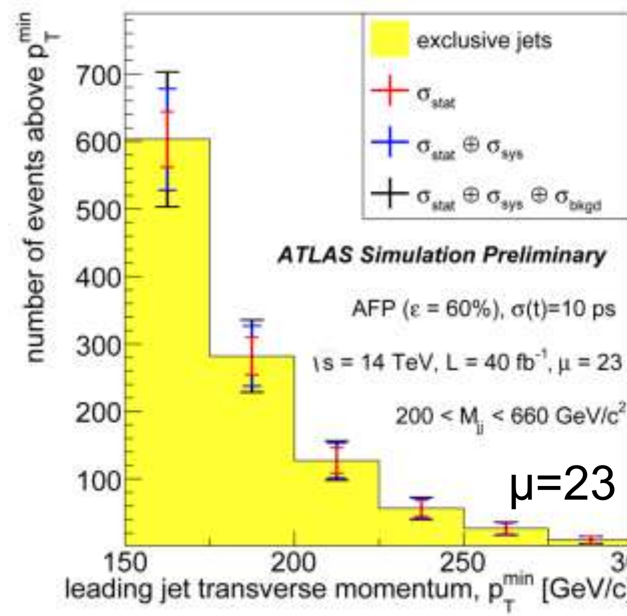


– also possible with single-tag !

See: Eur. Phys. J. C 75 (2015) 320 and Acta Phys. Pol. B 47 (2016) 1745

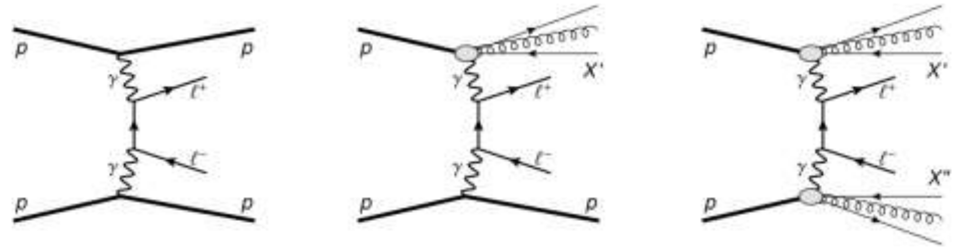
small σ ➔ high(er) luminosity needed !

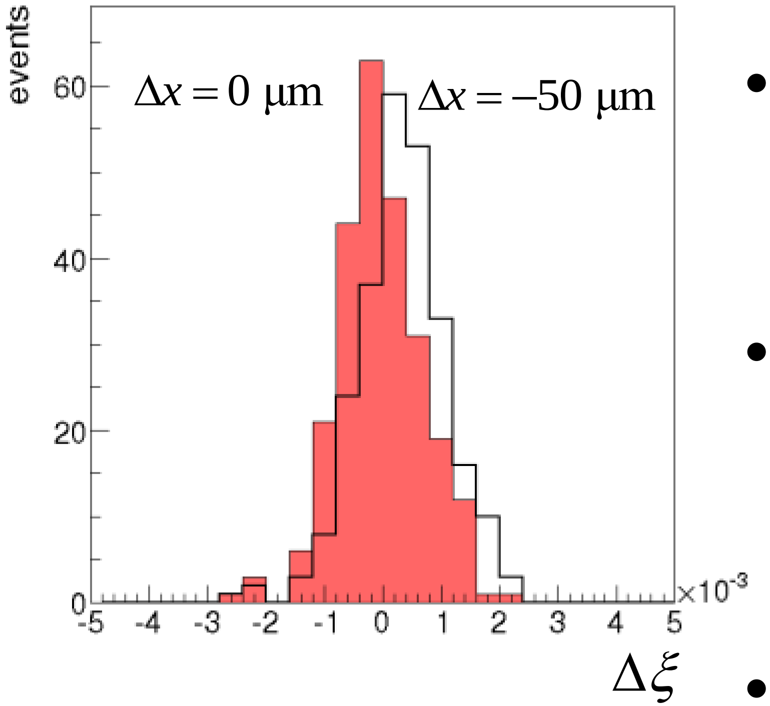




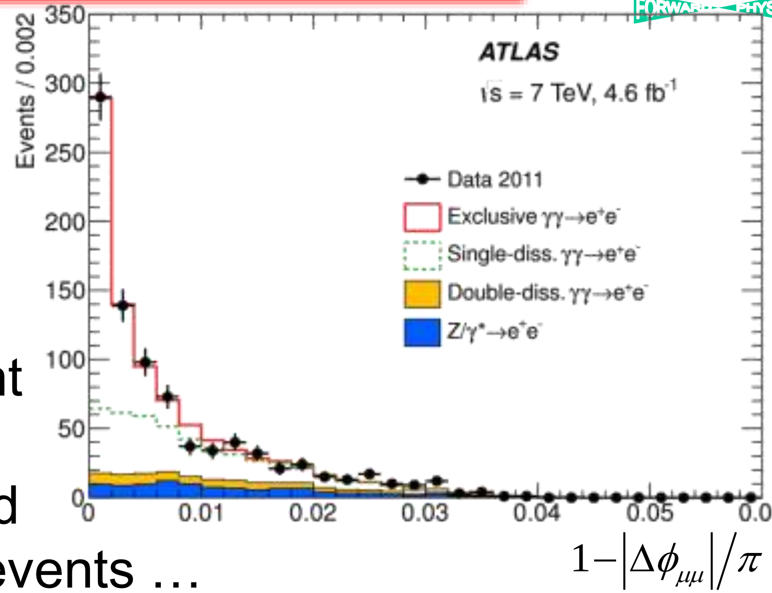
See: ATL-PHYS-PUB-2015-003

EM: Di-Muon Production $\gamma\gamma \rightarrow \mu\mu$





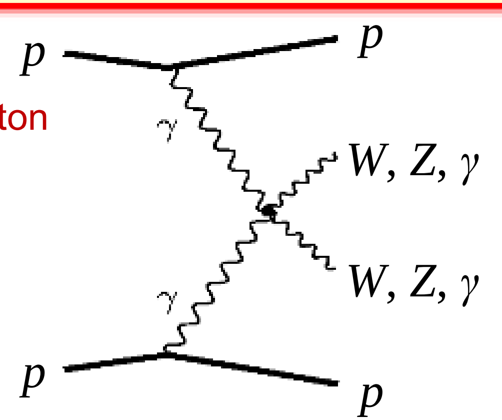
Difference $\Delta\xi = \xi_{AFP} - \xi_{\mu\mu}$



- Measurement without AFP: exclusive and dissociated events …
- But: cross section with AFP is too small for *double-tag* measurement
  - Add selections based on kinematic correlations
  - Single tag: σ=40 fb for $p_T \geq 10$ GeV and AFP at 2 mm from the beam
- Use for alignment and optics calibration !

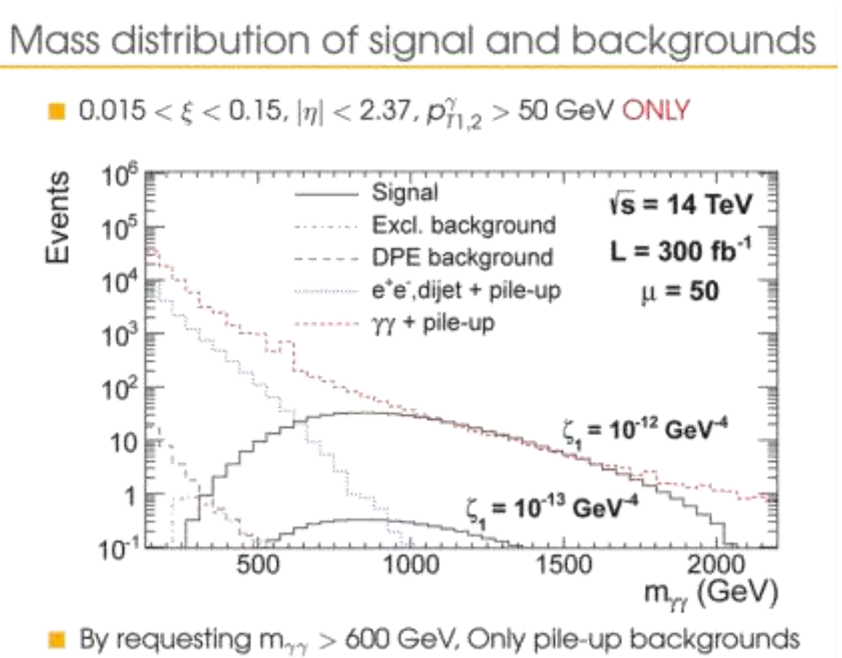
Anomalous Quartic Couplings

- 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: ($Z \to ee$, $\gamma\gamma$)
  - powerful rejection of non-exclusive backgrounds
- Much interest in this from theory side
  - e.g. “LHC Forward Physics” CERN-PH-LPCC-2015-001)

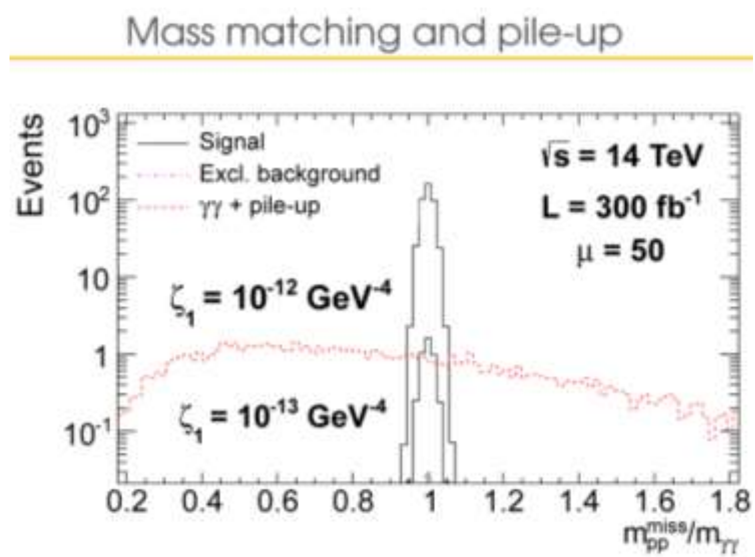


“Probing anomalous quartic gauge couplings using proton tagging at the Large Hadron Collider”, M. Saimpert, E. Chapon, S. Fichet, G. von Gersdorff, O. Kepka, B. Lenzi, C. Royon; 23/05/2014

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



γγγγ



For 300 fb^{-1} and μ=50: 0 background under 15.1 (3.8) signal events for anomalous coupling of 2×10^{-13} (10^{-13})

Anomalous Quartic $WW\gamma\gamma$ and $ZZ\gamma\gamma$ Couplings

$$\mathcal{L}_6^0 = -\frac{e^2}{8}\frac{a_0^W}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

$$\mathcal{L}_6^C = -\frac{e^2}{8}\frac{a_C^W}{\Lambda^2} F_{\mu\alpha}F^{\mu\beta}\frac{1}{2}\left(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta\right) - \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2} F_{\mu\alpha}F^{\mu\beta}Z^\alpha Z_\beta$$

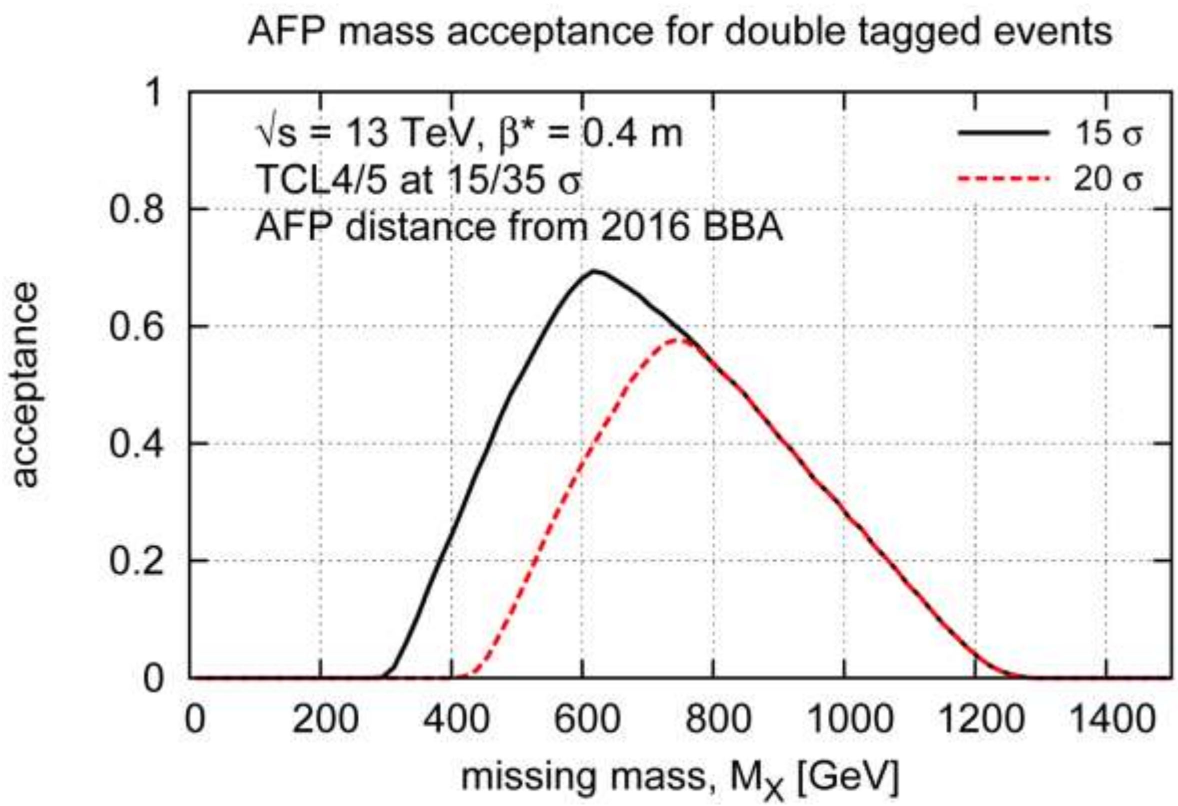
Couplings	Sensitivity at 30 (200) fb^{-1}	
σ_{WW}=95.6 fb, $\sigma_{WW}(\hat{s}>1\text{TeV}^2)$=5.9 fb	5 σ	95% CL
a_0^W/Λ^2	5.4×10^{-6} (2.7×10^{-6})	2.6×10^{-6} (1.4×10^{-6})
a_C^W/Λ^2	2.0×10^{-5} (9.6×10^{-6})	9.4×10^{-6} (5.2×10^{-6})

- Predicted sensitivity using leptonic decays of W/Z and fast ATLAS simulation ATLFast++; full simulations: very similar results (μ=25, 50) …
- Backgrounds modest. >100× Improvement over "standard" LHC method using $pp \to l^\pm \nu\, \gamma\gamma$ (P.J. Bell, arXiv:0907.5299) with 30/200 fb^{-1}
- Sensitive to values expected for higgsless models and models with extra dimensions (C. Grojean, J. Wells, et al.)

Phys. Rev. D81 (2010) 074003; JHEP 1502 (2015) 165

Preparing for the 2nd AFP Arm

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



  - detailed acceptance for 2017 depends on allowed insertion depth (under discussion in MPP) and optics scheme (BCMS?) …

Status and Plans 2017-18

Diffractive physics (~5-10 pb^{-1}):

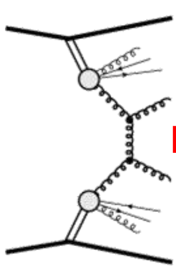
- soft diffraction (particle, gap, spectra, etc.)
- diffractive jets, jet-gap-jet, W, etc.
- exclusive jets (low-pT , single tagged)

- AFP can trigger ATLAS for presence of proton in:
  - one side (single difraction)
  - both sides (double Pomeron exch.)
- Special trigger menu based on AFP
- as in 2016, we expect to have a few low-μ runs (bunch separation)
- we would like to have a majority of bandwidth on L1 and HLT dedicated to AFP items (min-bias stream)

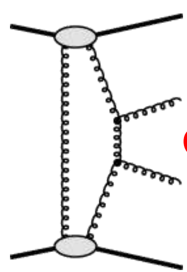
High-Luminosity physics (≥80 fb^{-1}):

- Exclusive events (Pomeron and photon induced), new physics

- Double tag can decrease the rates 10 – 100-fold (depending on the mass of central system)
- For jets, a lower pT threshold is achieved (see ATL-PHYS-PUB-2015-003)
- In case of new, heavy resonances, or anomalous couplings, the prescale can be reduced
- AFP triggers (L1 and HLT) will be present in the physics stream
- for now, one unique item requested: the exclusive jet trigger

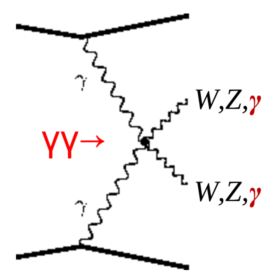


DPEjj



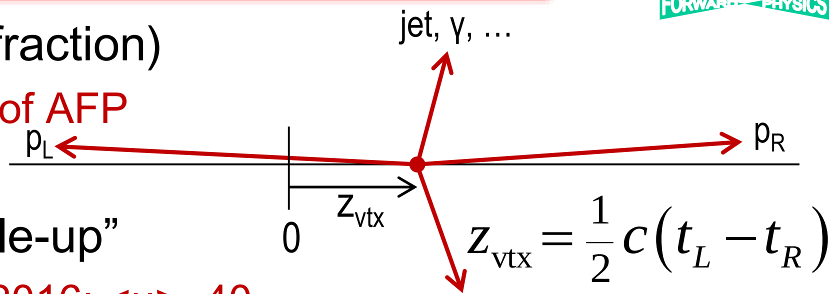
CEPjj

γγ→

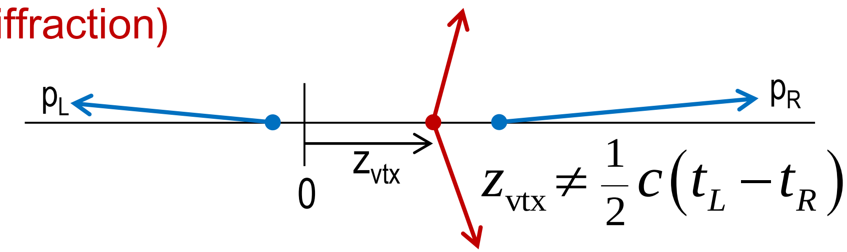


Pile-up Mitigation by Time-of-Flight

- AFP looks for pp → p_L+X+p_R (hard central diffraction)
  - $p_{L(R)}$ is a forward proton in the Left (Right) arm of AFP
  - X ≡ WW, ZZ, jj, γγ, …



- in ATLAS we have 20-60 interactions/BX: "Pile-up"
  - avg number of interactions per BX (pile-up) in 2016: <μ>~40
  - 15% of these have a forward proton (Single Diffraction)
    - a SD proton has a 20% acceptance in AFP
    - At high μ, many ATLAS triggers (high p_T lepton, jet, photon) will be accompanied by two forward protons in AFP from pile-up

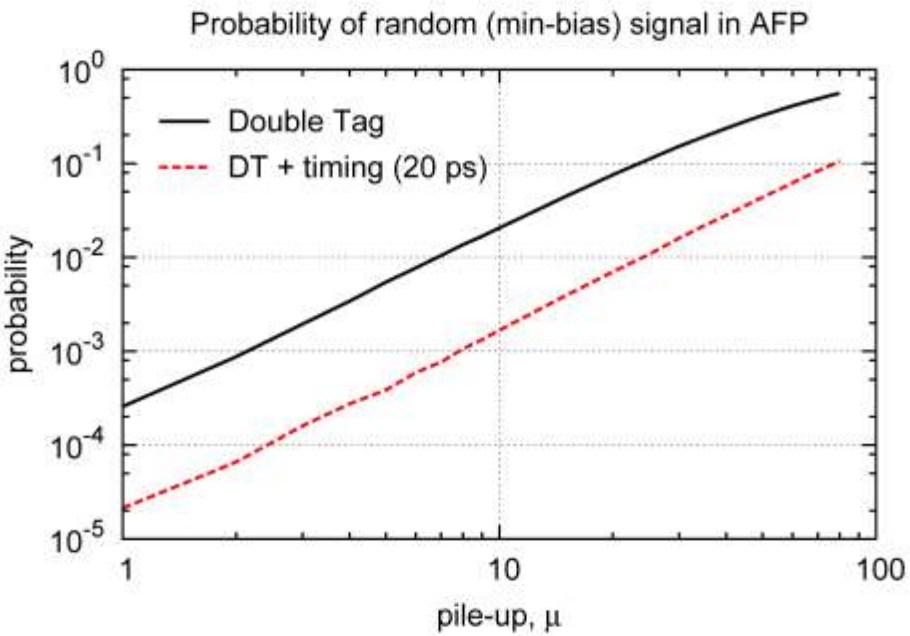


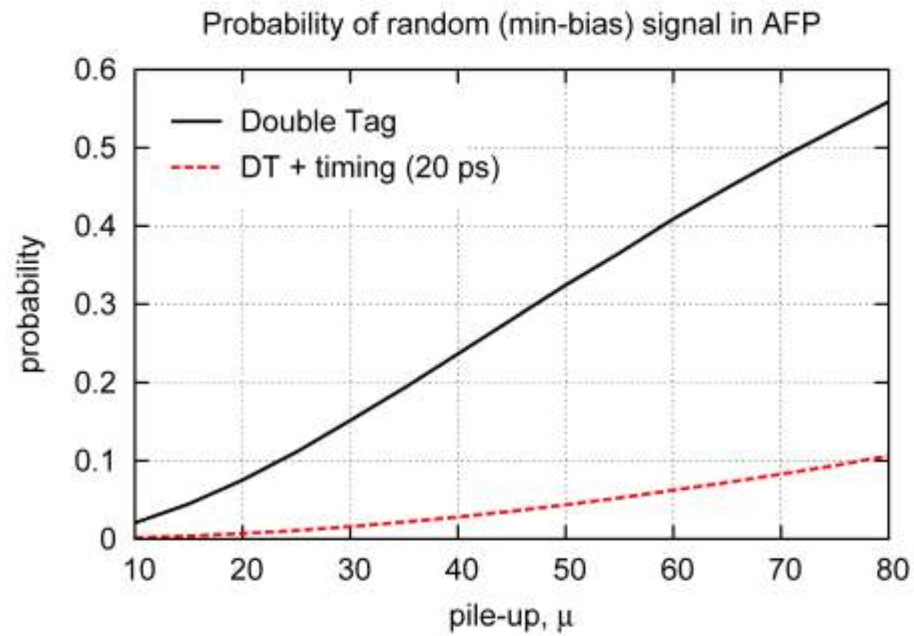
- Precise time-of-arrival measurement will help reject pile-up protons:
  - if the two protons come from the *same* vertex (vtx), then: $z_{vtx} = c(t_L - t_R)/2$
  - if z_{vtx} measured by AFP can be matched with a vertex of interest in ATLAS, then the process may be of the type we're looking for …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

- A double p-tag also helps at trigger level 1:

Pile-up Mitigation at Level 1

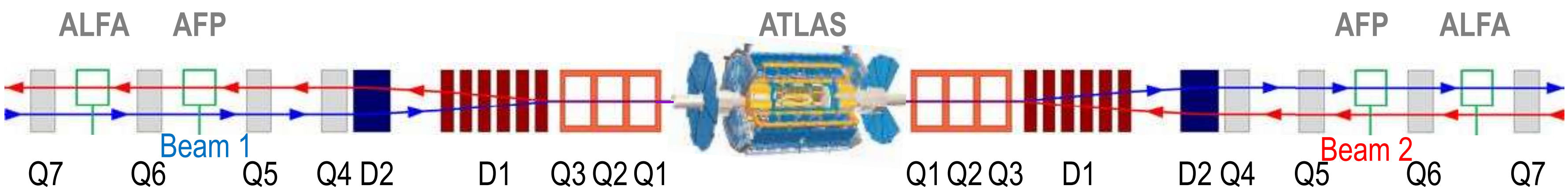
- Requiring a proton tag in *both* AFP arms (double tag) reduces the minbias rate by factor 10(3) at μ=23(50)
  - requiring a **low-ξ** double tag improves this reduction further (3 – 10×) !

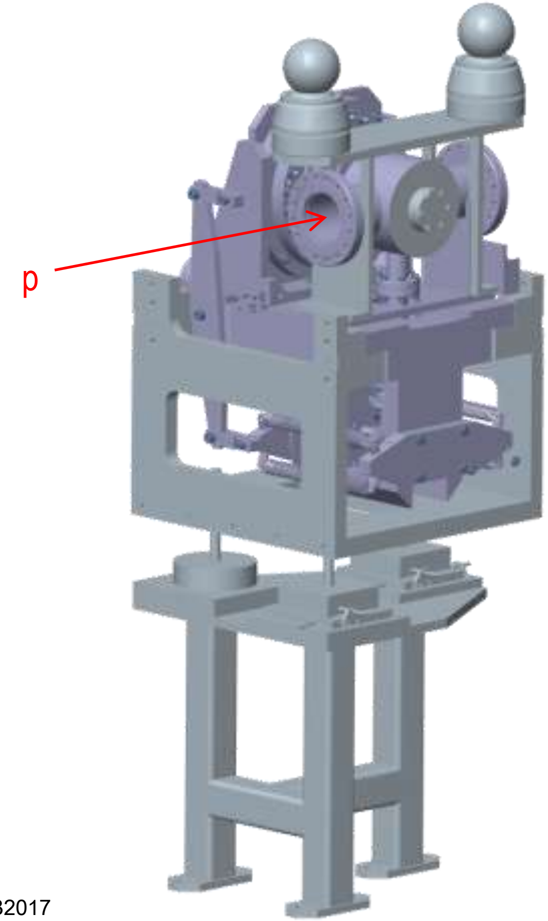


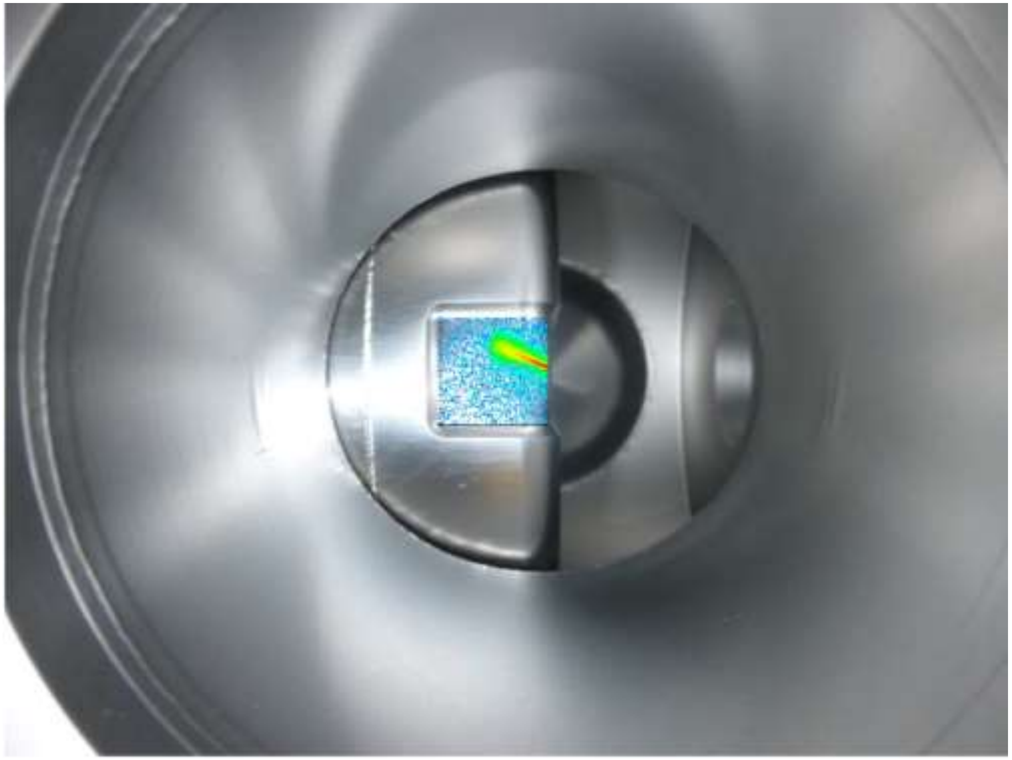


- Time-of-Flight with σ_t=20 ps (at HLT) provides another factor ~10 reduction …

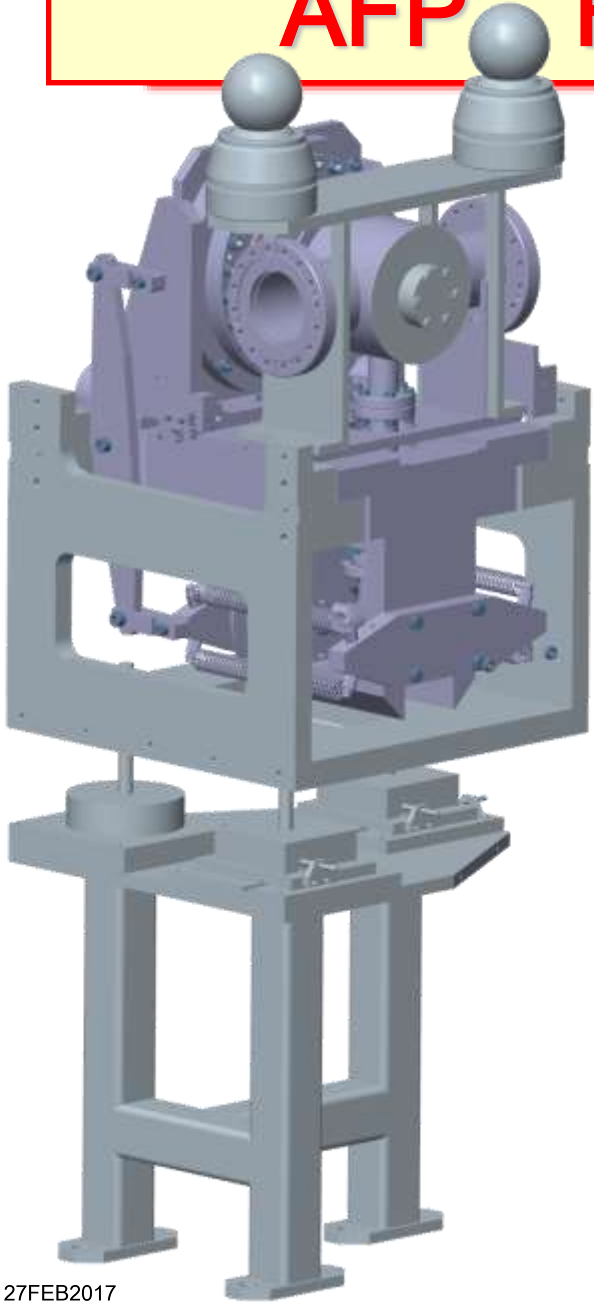
Roman Pot to get near the LHC beam







AFP Roman Pot Stations



almost identical to TOTEM's horizontal stations

View Port to facilitate pot insertion depth metrology

UHV beam pipe Flange

First 2 stations at Vakuum Praha (21.09.2015)

were delivered in-time and within specs !

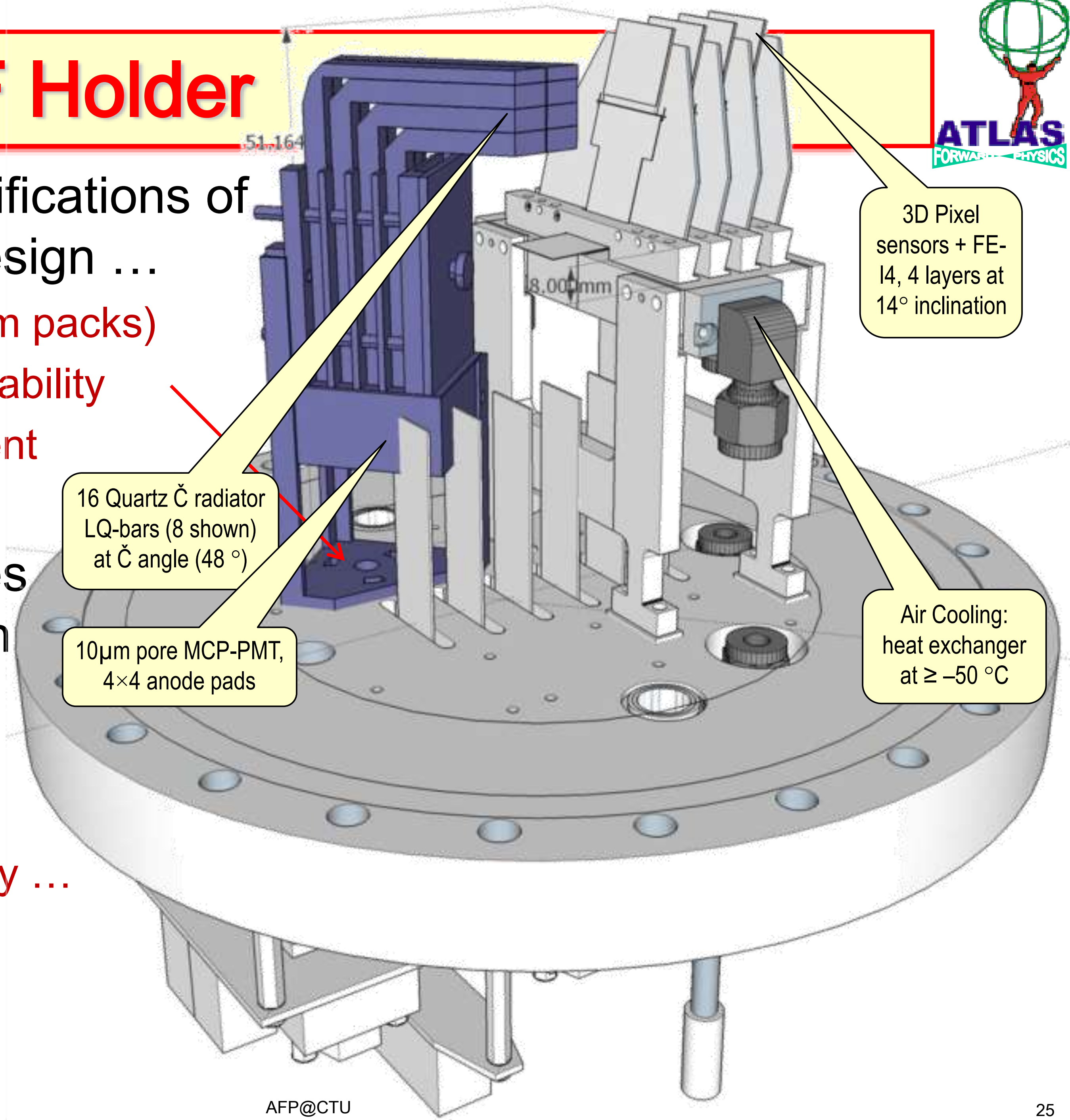
SiT & ToF Holder

Ready to fix modifications of the base plate design …

- Adjust height (shim packs)
- Transverse adjustability
- Rotation adjustment

2 new Base plates were machined in Alberta

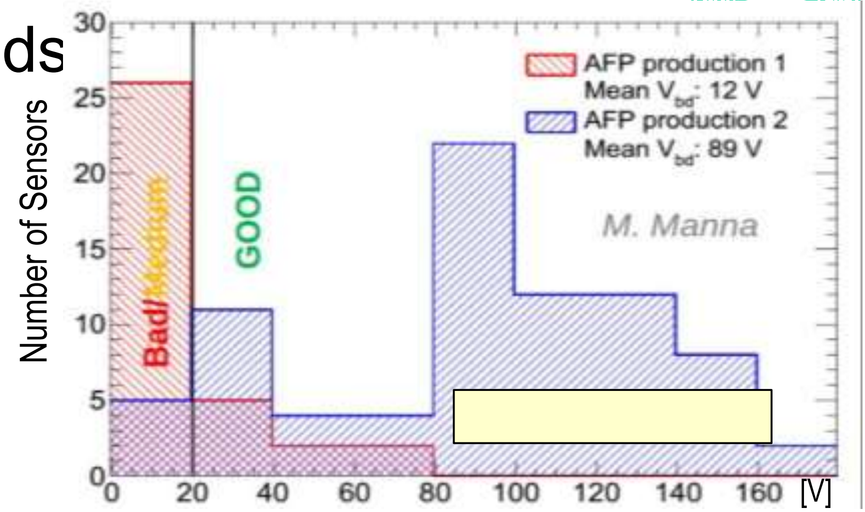
- have 1 at CERN already …
- +2 for tracking only …



3D Silicon Pixel Trackers

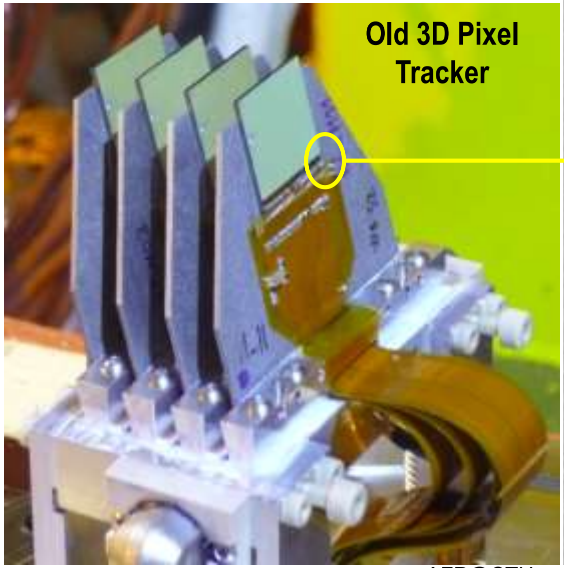
New 3D pixel sensor + FE-I4 hybrids prepared at IFAE

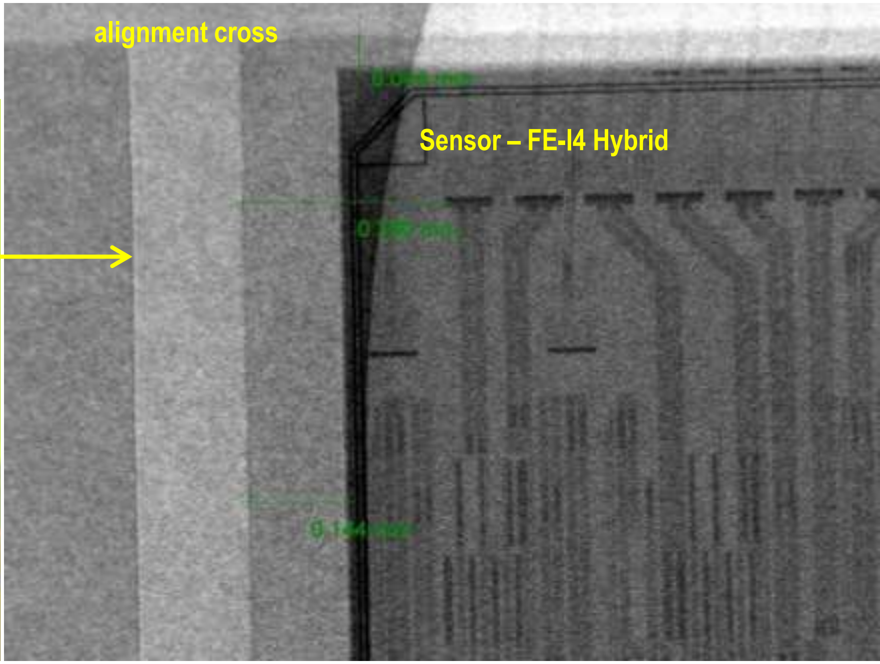
- 50μm×250μm pixel, ≤180μm dead edge much better yield and quality than previous runs (75 GOOD sensors)
- all cards, flexes, holders, and DAQ hardware in house



4×4 hybrids + tracker cards needed

- 24 hybrids mounted on tracker cards and good …



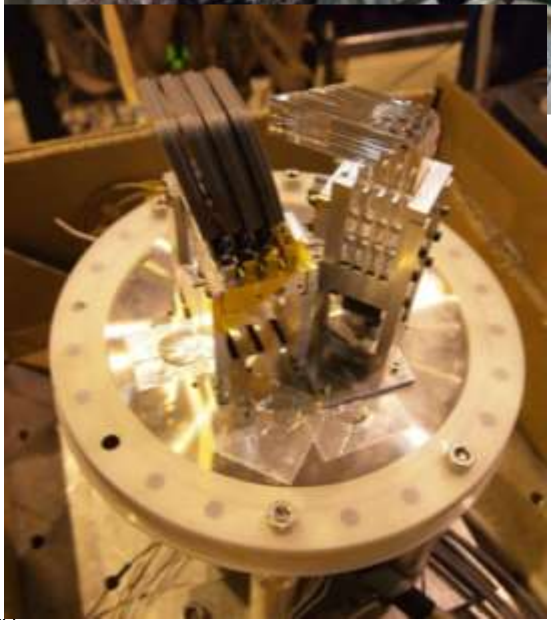


Status of Forward Proton Detectors (AFP)

- Two arms, 4 stations installed
- Cabling, cooling, sec. vacuum, Patch Panel, & BPM hook-up (almost) finished …
- Si 3D Pixel Detectors at CERN: being tested and assembled …
- ToF detectors will arrive Mar 7
- Installation to be completed by 24 Mar …

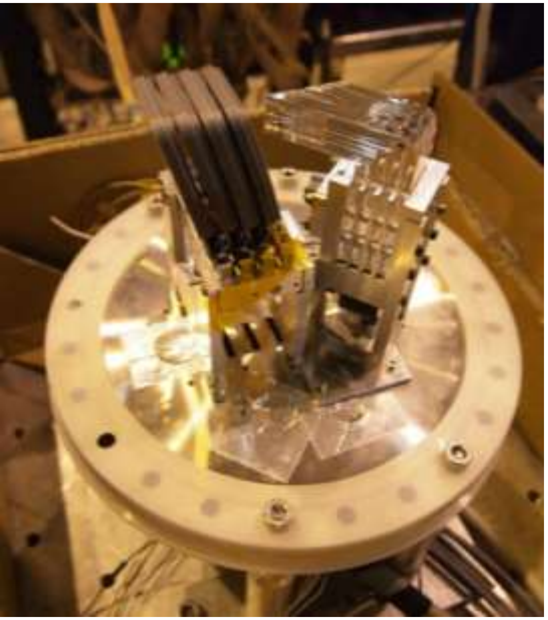
- TDAQ & DCS being updated
- triggers (L1, HLT) prepared

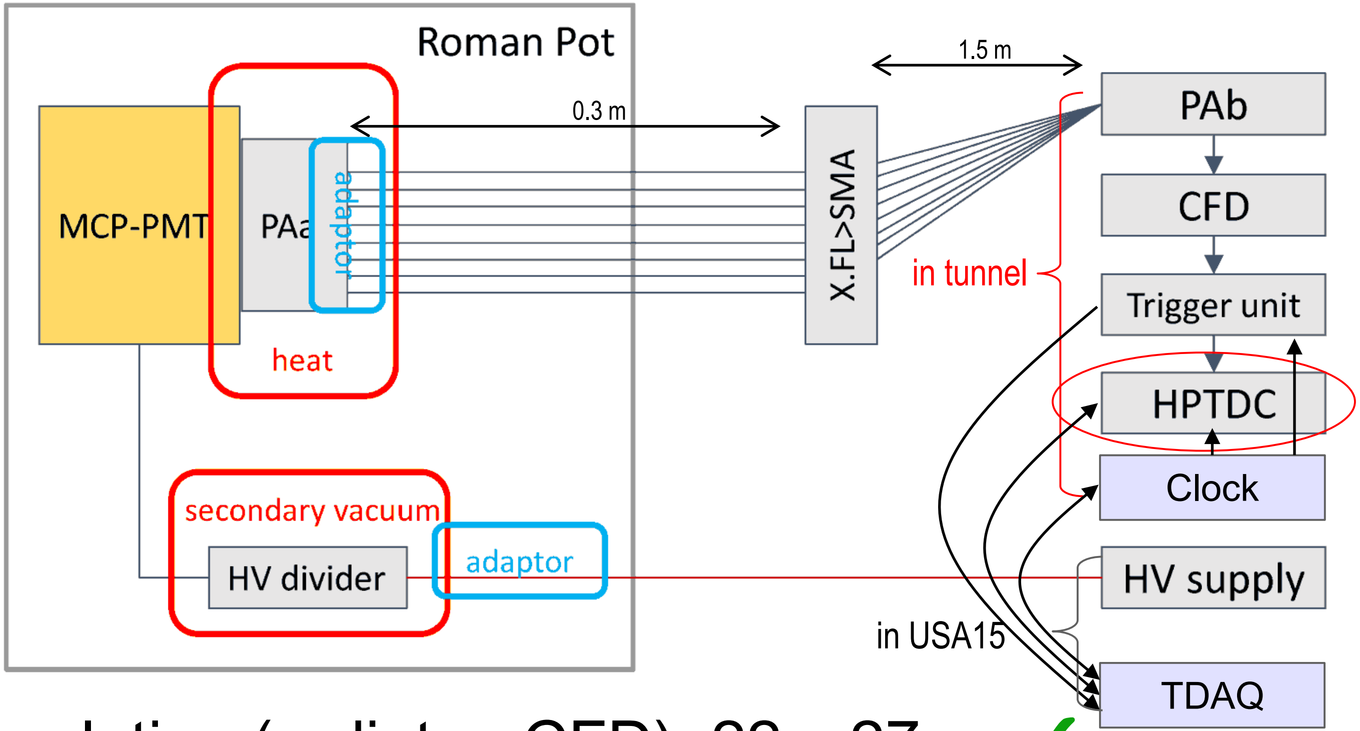
- on track for full-luminosity running in 2017 !



4-layer Si Tracker (with protective caps) + 16-bar Time-of-Flight detector in the Sep beam test

ToF Electronics





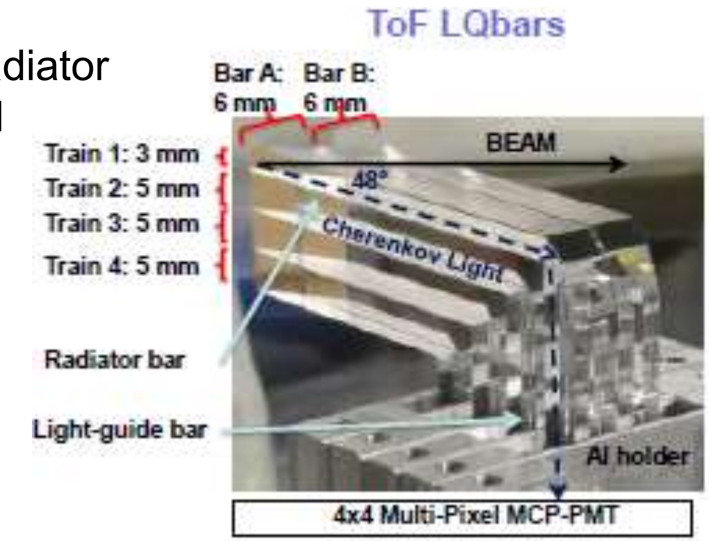
- Per-channel resolution (radiator–CFD): 22 – 27 ps ✓
  - uncorrelated: i.e. 4-bar measurement ➔ 12 – 14 ps
  - PAa-b: Olomouc, CFD-HPTDC: Alberta, Trigger: Plzen, Clock: Stony Brook
  - DAQ: Cracow/SLAC, DCS: Cracow/Lisbon
- HPTDC resolution: 17 ps random $\oplus$ <u>10-20 ps correlated</u> ! ✗
  - is being addressed with new HPTDC board production …

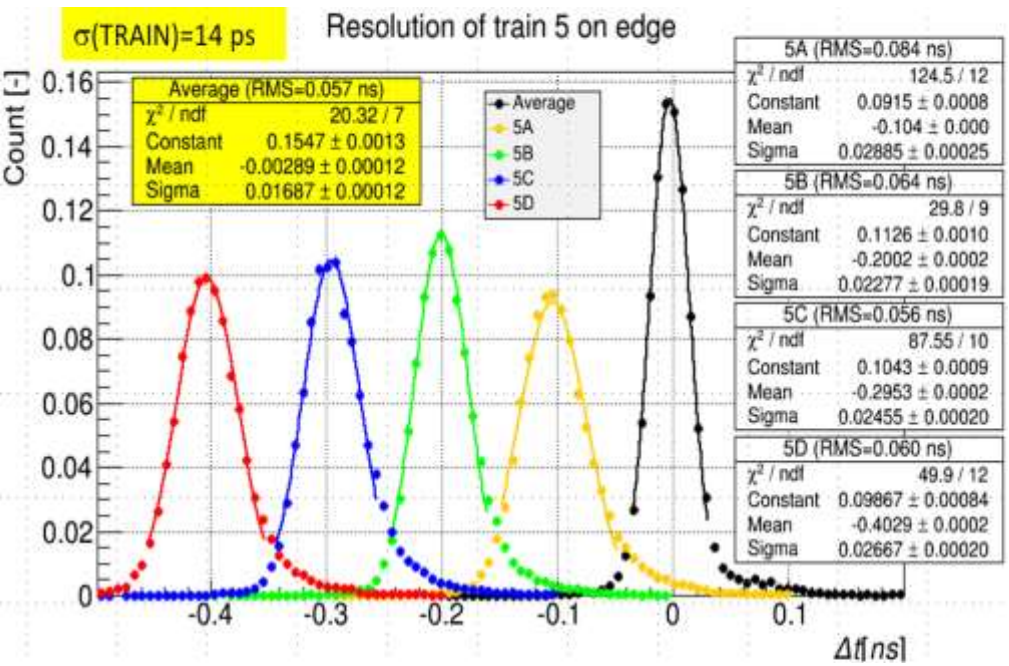
Beam tests & ToF results

- TB 2014-2015: excellent spatial resolution: σ_x(track)~3μm

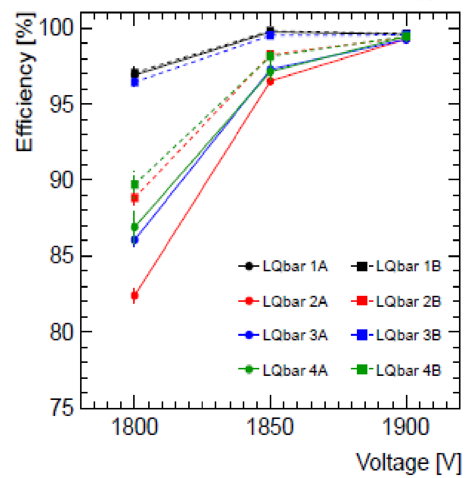
J. Lange et al., JINST10 (2015) C03031

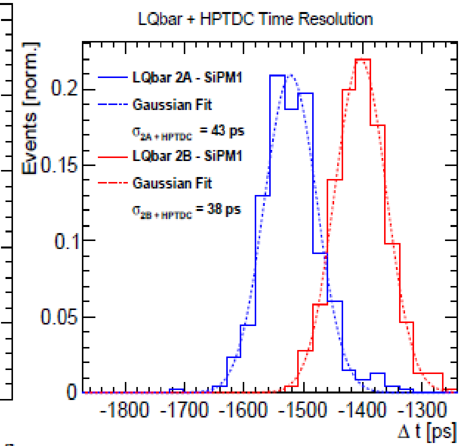
- TB 2016 June: full ToF trains (4 LQbars):
  - ✓ characterization and optimization of ToF front-end: radiator bars, cross talk, MCP-PMT, CFD delay and threshold
  - ✓ Excellent performance of new 10 μm pore MCP-PMT





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





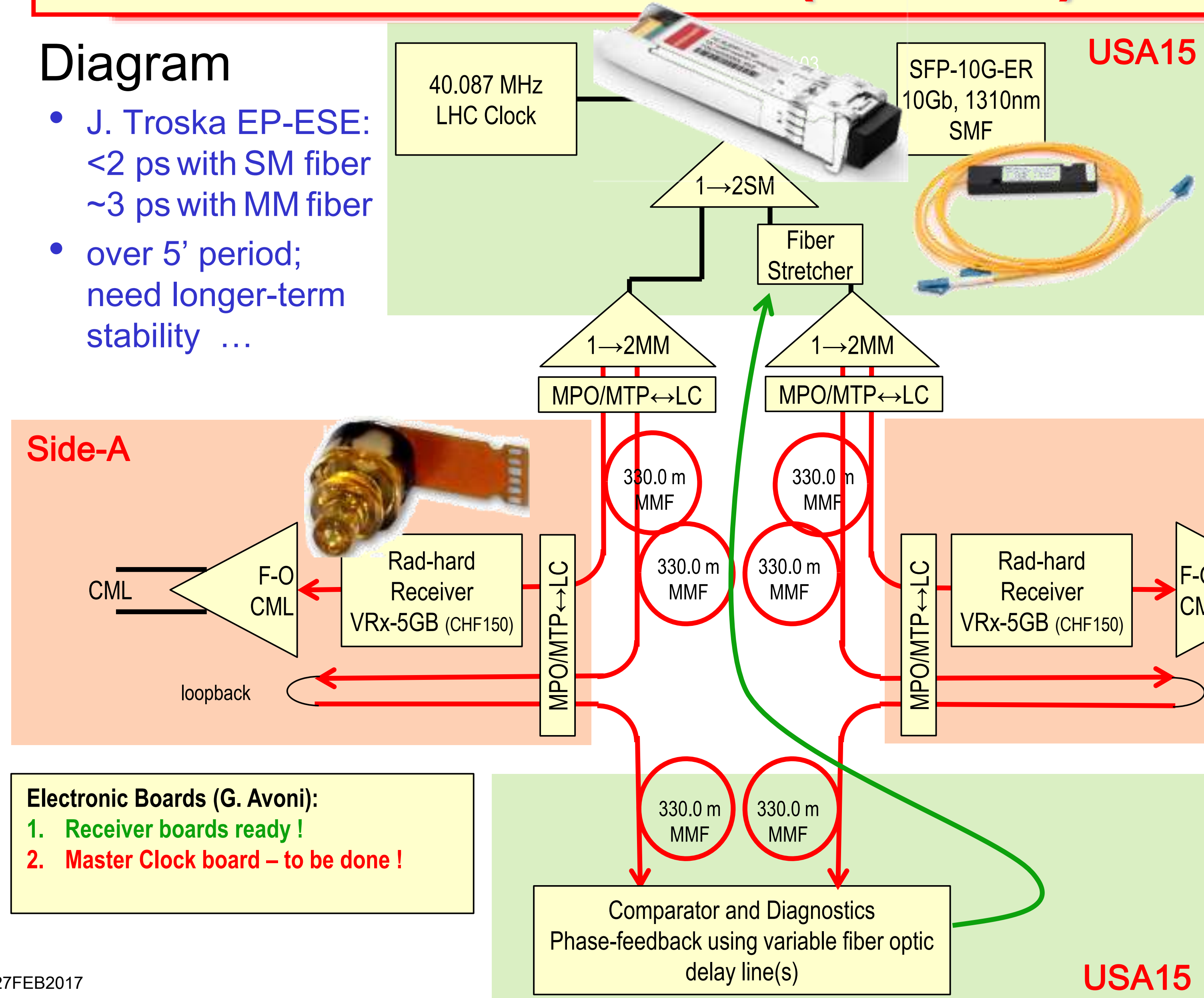
TB Sep 2016: optimize ToF back-end (HPTDC, Trigger), full integration on Roman Pot flange

Master Clock (USA15)

Diagram

- J. Troska EP-ESE: <2 ps with SM fiber ~3 ps with MM fiber
- over 5' period; need longer-term stability …

Transmitter:
SFP(+)-10G-ER
10 Gbps, 1310nm, SMF
(FS.COM CHF100)



Electronic Boards (G. Avoni):
1. Receiver boards ready !
2. Master Clock board – to be done !

All items ordered & delivered. Partially tested the system in SR1

Slow (thermal) phase drift

- depends on thermal expansion of the propagation medium:

Material	Thermal Expansion Coefficient C_T [×10⁻⁶/K]	Δt/L/ΔT [fs/m/K] @ n =1.5
FR4	12 - 14	60 – 70
Cu	16.6	83
Al	22.2	111
Quartz	0.77 - 1.4	4 - 7
Fused Silica Fiber	0.55 (average from 20°C to 320°C)	2.8

- e.g. L(m) of Fiber for temperature difference ΔT:

$$\partial t = \partial\left(L/v\right) = \frac{n}{c}\partial L = \frac{n}{c} L C_T \partial T = \frac{n}{0.3\ \mathrm{mm/ps}} L C_T \partial T$$

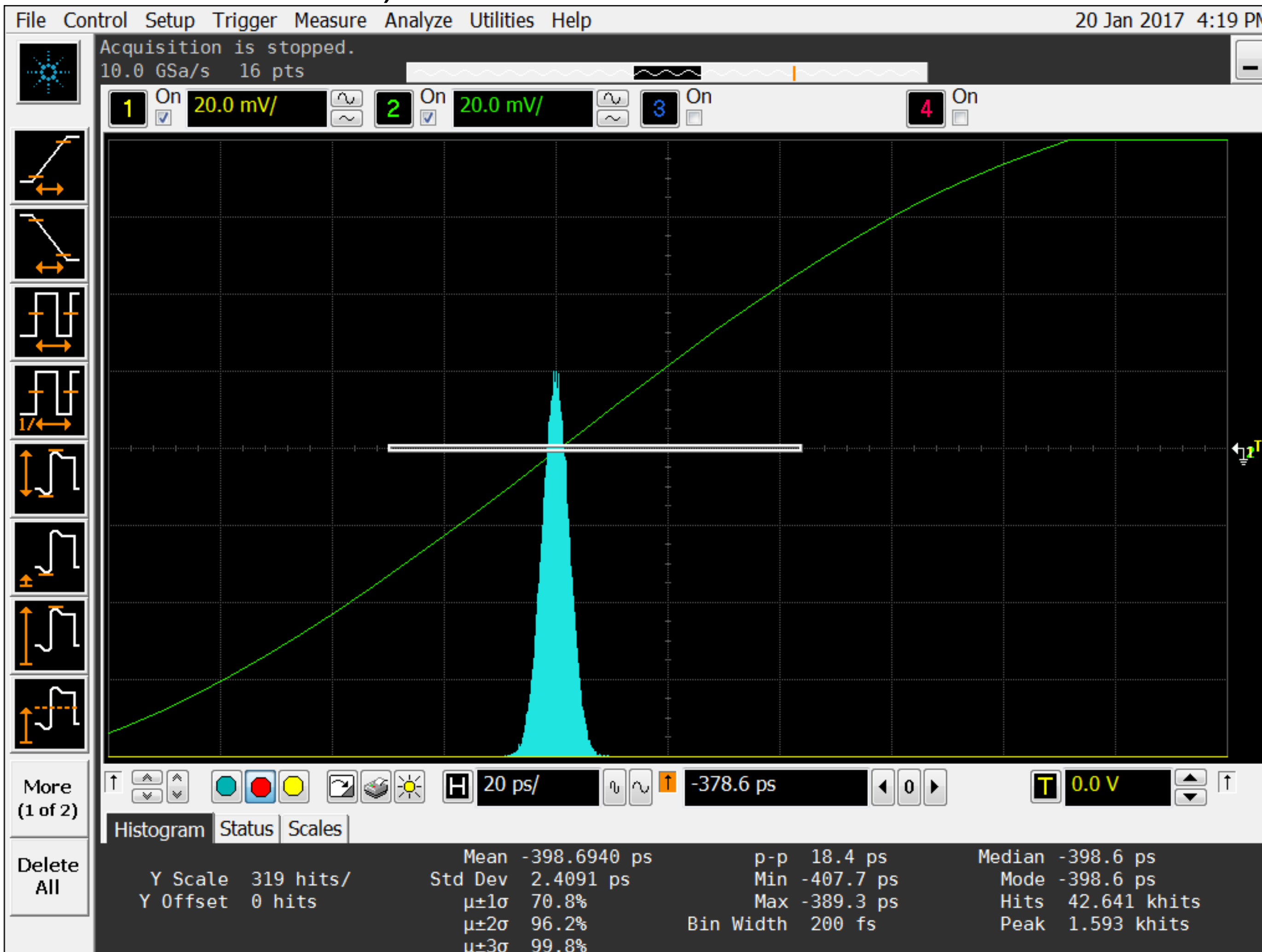
for n=1.5: $\frac{\partial t}{L \partial T} = 5000\ \mathrm{ps} \cdot C_T$; e.g. for 80 m fiber: Δt=0.22 ps/K

for 330 m fiber: Δt=0.91 ps/K

New SM TRx and Long Cables

- SM TRxs replacing both MM TRxs !
- Two Splitters: (loss = -5.5 dB + -5.2 dB)

  Jitter (rms, 30’)
  = 2.4 ps
- Measured with DSO9054A (10 GS/s, 2.5 GHz BW)
  ➔ maybe better ?



Summary: AFP Status for 2017-18

Installation:

- All four stations are installed in tunnel,
- cables, cooling, and vacuum infrastructures are prepared,
- new sets of silicon trackers (SiT) are prepared to be installed in March,
- Time-of-Flight (ToF) detectors and electronics will be installed in March / April.

Commissioning:

- movement system calibration in April,
- Beam Interlock System verification in April / May, followed by Beam Based Alignment and Loss Maps,
- DCS – integration of arm A and ToF system,
- TDAQ – migration to cmake and TDAQ-07 already completed,
- TDAQ – new trigger system (ToF instead of SiT).

Data taking:

- take data at about 15σ distance from the beam
- at least two special runs in 2017: μ~0.01 (~0.1 pb^{-1}), μ~1 (~1 pb^{-1}),
  - plan to collect ~10 pb^{-1} altogether in low luminosity runs in 2017 and 2018,
  - nominal optics (β*= 0.4 m); low pile-up achieved by beam separation, similarly as last year. This may be done at the intensity ramp-up,
- participate in all standard ATLAS physics runs (μ~50).

Beyond 2017 …

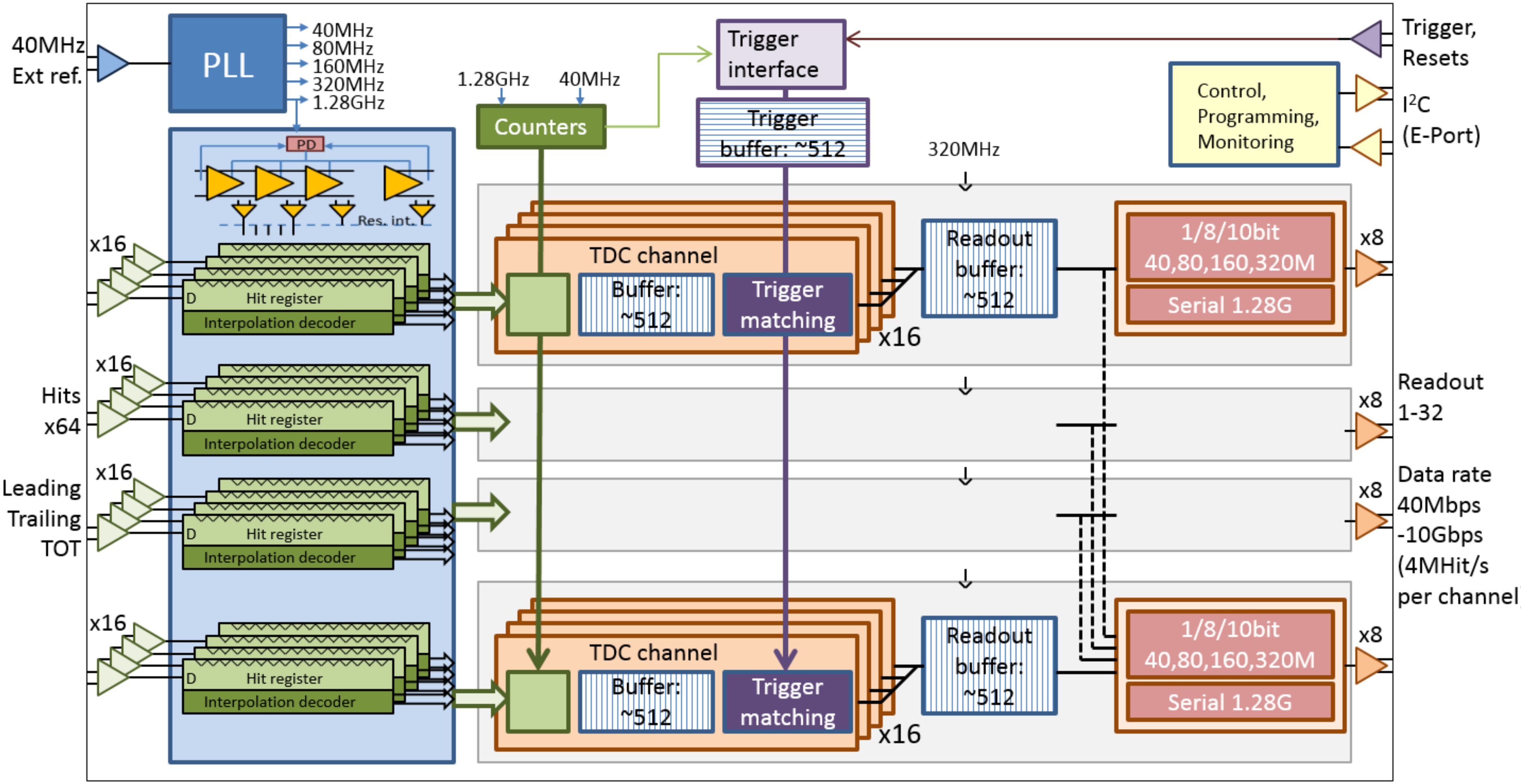
- 2018 Run: replace current HPTDC by PicoTDC
- AFP aims to continue running for rest of Run 2 and Run 3
  - depends, of course, on AFP performance and AFP physics results !
  - during LS2, we may want to upgrade the ALFA detectors ?

- What about the HL-LHC era (~2025?)
  - again, it depends on AFP performance and AFP physics results !
  - case can be easily made IF new discoveries were made ☺
  - else: we must make the case that AFP can run at μ≃200 AND that interesting SM physics can be done:
    - CED Higgs production; invisible Higgs decay modes?
    - aQGC: increase statistics and excluded range of anomalous couplings
    - … ?
    - special low-μ runs (at most 1 week/yr) for diffractive studies

early 2018:

picoTDC Architecture

Moritz Horstmann, Jorgen Christiansen, Bram Faes (KU Leuven), Lukas Perktold (Now AMS), Jeffrey Prinzie (KU Leuven)
CERN/EP-ESE



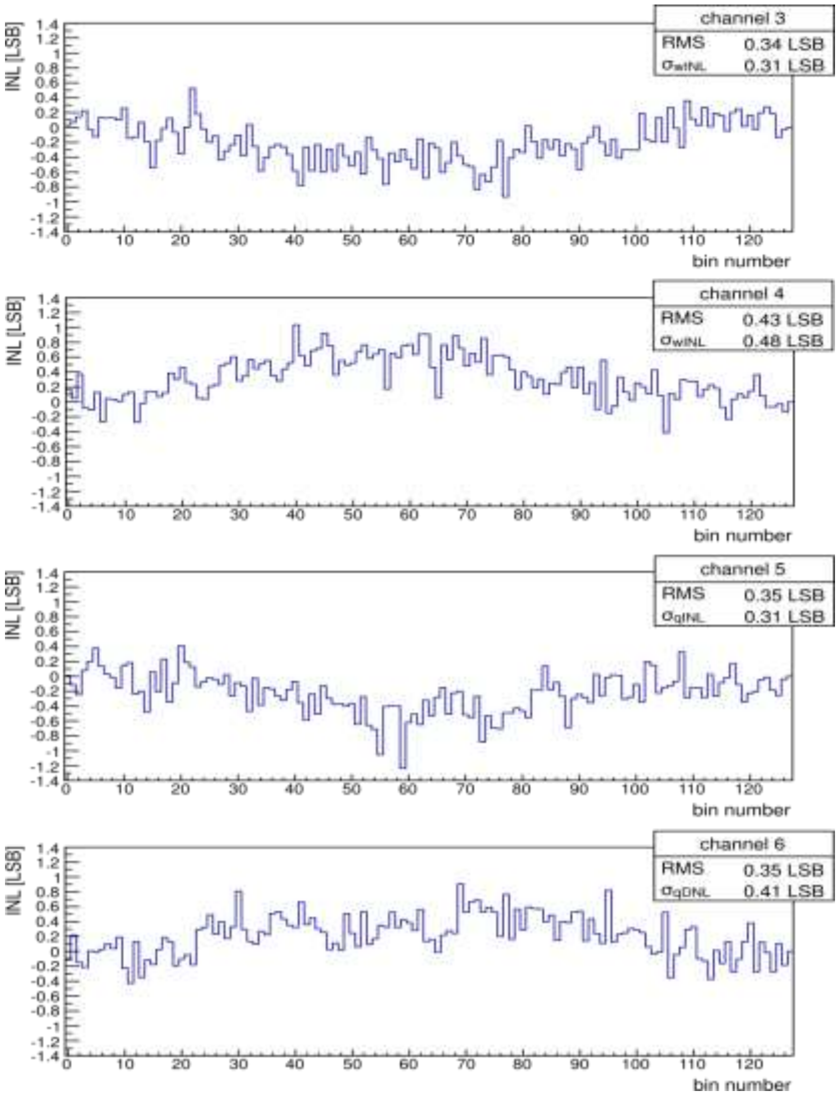
64 channels, 3ps or 12ps time binning, 100us dynamic range

64 channels, 3ps: ~1W; 64 channels, 12ps: ~0.5W; 32 channels, 12ps: ~0.3W

130 µm Prototype (2015): 6 ps LSB

Measured Performance

Moritz Horstmann, Jorgen Christiansen, Bram Faes (KU Leuven), Lukas Perktold (Now AMS), Jeffrey Prinzie (KU Leuven)
CERN/EP-ESE



Code Density Test

INL = ± 1.3 LSB

RMS = < 0.43 LSB (2.2 ps)

Expected RMS resolution from circuit simulatio
including quantization noise, INL & DNL

2.3 ps-RMS < $\sigma_{qDNL/wINL}$ < 2.9 ps-RMS

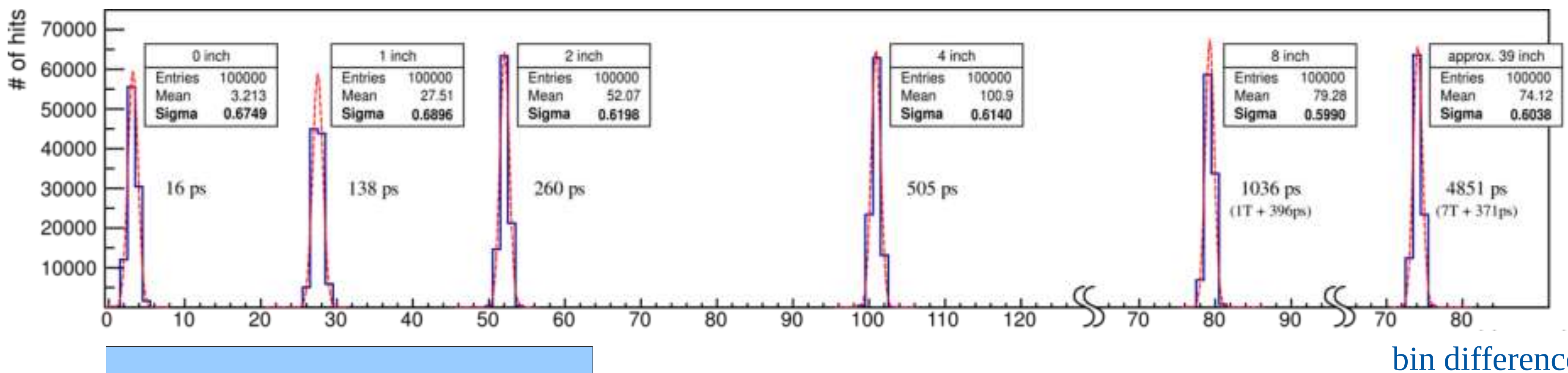
INL can be corrected for in software

DNL, Noise and jitter can not be corrected (single shot measurements)

Single Shot Precision

Moritz Horstmann, Jorgen Christiansen, Bram Faes (KU Leuven), Lukas Perktold (Now AMS), Jeffrey Prinzie (KU Leuven)
CERN/EP-ESE

- Three measurement series using cable delays
  - Both hits arrive within one reference clock cycle
  - Second hit arrives one clock cycle later
  - Second hit arrives multiple clock cycles later (~5ns)



σ_{TDC} < 2.44 ps-RMS

TWEPP2013 slides and paper: https://indico.cern.ch/event/228972/session/6/contribution/61
ESE seminar: https://indico.cern.ch/event/225547/material/slides/0.pdf

Mapping to 65nm

Moritz Horstmann, Jorgen Christiansen, Bram Faes (KU Leuven), Lukas Perktold (Now AMS), Jeffrey Prinzie (KU Leuven)
CERN/EP-ESE

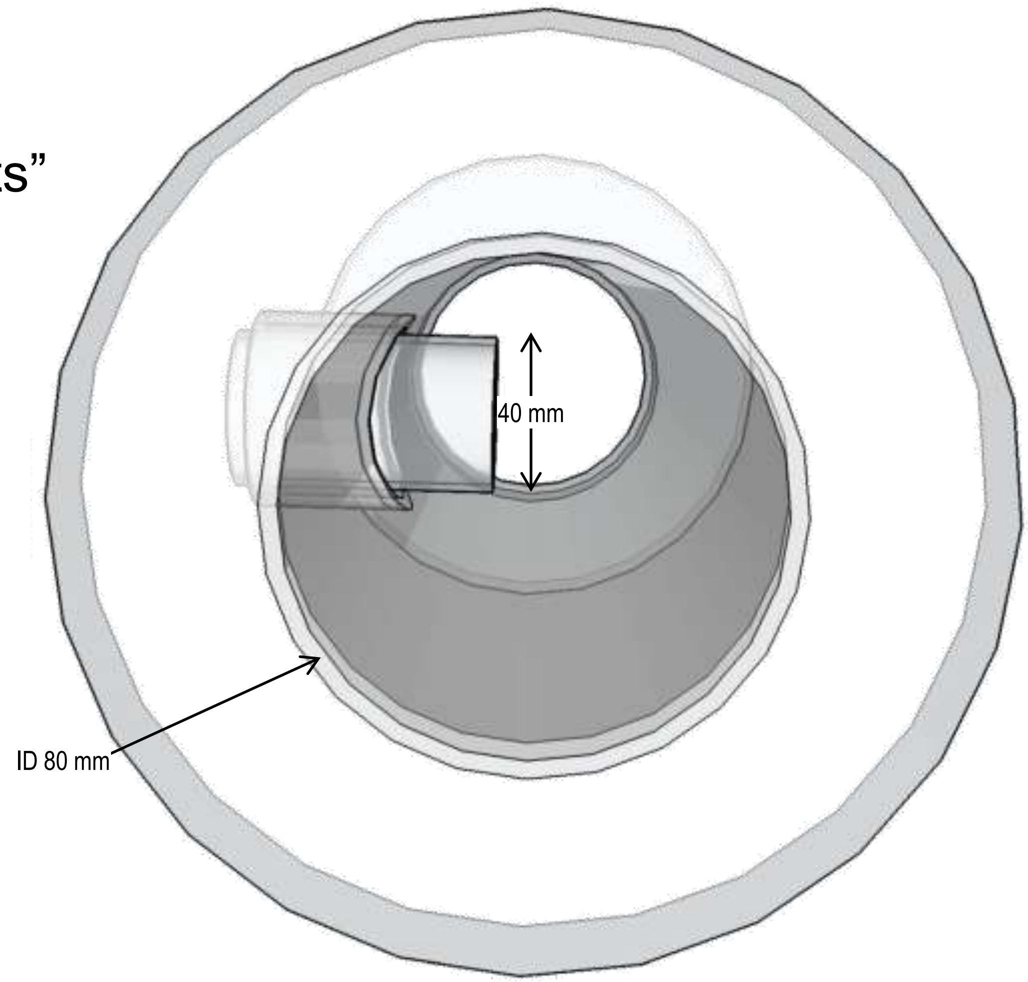
- Uncertain long term availability of IBM 130nm (now Globalfoundries)
- 2x time performance: -> 3ps binning
- Lower power consumption: < ~½
  - ~1/8 if DLL binning of 12ps enough (RMS ~4ps).
- Larger data buffers
- More channels
- Smaller chip
- But higher development costs

AFP @ HL-LHC: Detectors …

- Tracking with small pixels (50x50 um or smaller)
  - profit from ITk upgrade work …
- Time of Flight
  - 1-2 ps resolution and t0 from ATLAS (σ_{t0}≃10 ps?)
    - LGAD or similar?
  - good pixellation (≲1x1 mm2)
- In principle the detector package could be evacuated and vacuum-sealed, and inserted/moved inside the beam aperture via UHV feedthroughs …
  - better LHC protection (no thin windows needed)?
  - needs a detailed feasibility study and prototyping …
- Trigger:
  - need better selectivity at μ=200: try for a two-proton trigger *with vertex match* at L1

AFP @ HL-LHC: New Pot & Stations!

- at the HL-LHC assume:
  - small detectors: 20 x 20 mm2
  - Timing with LGADs or the like
- ➔ we should develop small "pots"
  - simplifies design: smaller forces
    - but: would like better accuracy
  - round or rectangular entry?
    - narrow clearance required
- also: More radiation!
  - motors, switches, motion/position sensors …
- Must do RF simulation to determine the effect on the beam, and pot heating …



- aim to collaborate in FP@LHC Working Group; LoI to ATLAS later this year

The End – Thank You !

I would like to thank all my AFP Colleagues, but today especially my Czech AFP Colleagues for their crucial past and current contributions:

- CTU, Czech Academy of Science, Charles University, Palacky University at Olomouc, and Plzen University
- in Physics, Infrastructure, Detectors, Electronics, and Management!

Also: I'd like to acknowledge the essential contribution by **Vakuum Praha** in building the vacuum equipment on-schedule and within demanding UHV specifications !

- Hope to continue this fruitful collaboration!

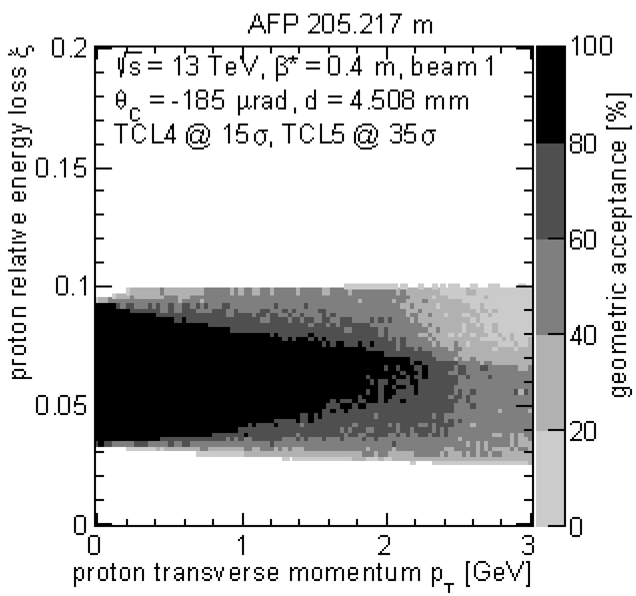
Special thanks to Pavel Hedbavny, Andre Sopczak, Ivan Stekl !

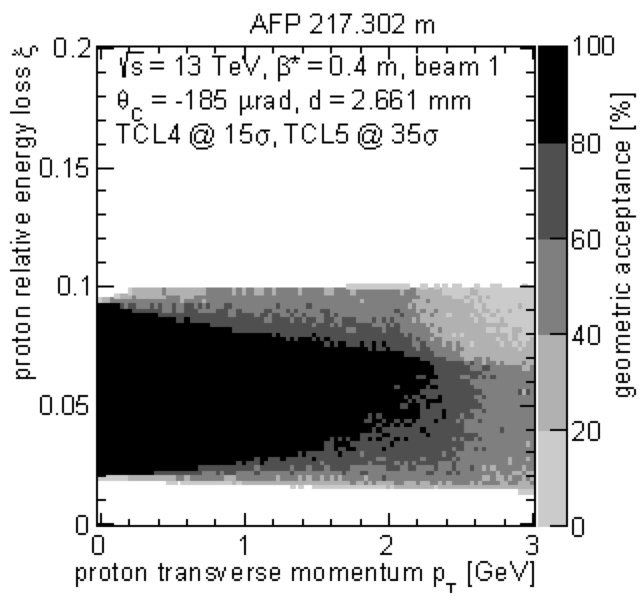
old & back-up slides

Optimizing the β-function at AFP

- Currently for β*=40cm optics, TCL4=15σ, TCL5=35σ:
  - NEAR: σ_b(205m)=202μm, $\xi_{min}(20\sigma_b)$=0.035, ξ_{max}(TCL4,5)=0.09
  - FAR: σ_b(217m)=108μm, $\xi_{min}(20\sigma_b)$=0.020, ξ_{max}(TCL4,5)=0.09

- AFP would like to discuss if the beam size σ_b at the NEAR station could be reduced in order to lower the ξ_{min} reach
  - This should be done while keeping the dispersion at the stations unchanged …





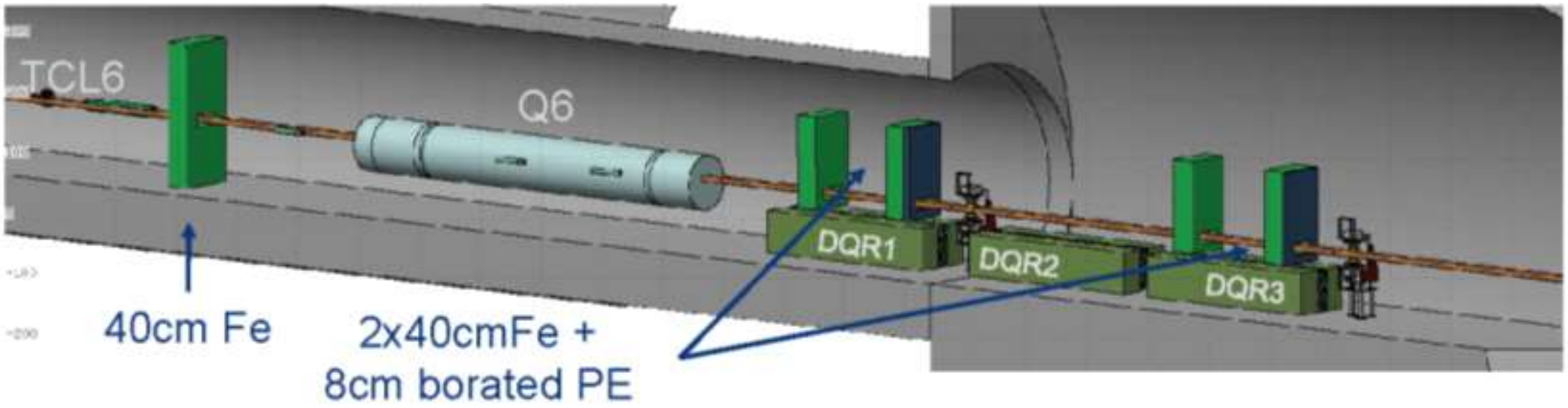
Good News

- ATLAS-AFP Review (Thursday 27 Oct):
  - went very well; convincing talks by Rafal, Maciej, and Tomas
  - Timely input for the ATLAS Forward Detector run plans for 2017 and beyond …
- LPC/LPCC Joint Meeting on Forward Physics at the LHC in 2017 and beyond (Monday 31 Oct): https://indico.cern.ch/event/575250/
  - Friday 28 Oct: ATLAS rehearsal meeting:
    - clear support from ATLAS Management for high-μ AFP running at 15σ all years until LS2
    - ALFA: not so clear what the strategy will be regarding ALFA (see later)
  - ATLAS proposal at the LPC/LPCC Meeting (Ulla Blumenschein):
    - **2017→: AFP high-μ at 15σ (after qualification period)**
    - **2017-18: AFP low-μ (0.05 – 1) at standard β* (sep'd. beams, @ ramp-ups?)**
    - 2017: TOTEM requests β*=30-90m at μ≈1; ALFA&AFP participation?
  - ➢ Request by LPC Chair to specify best low-β* optics for AFP for potential optimization …
- Next steps: LPC recommendation, LHCC recommendation, MPP approval, LMC approval

ALFA Shielding

- Simplest shielding option
- Favored by ATLAS-TC

F. Cerutti, A. Tsinganis, S. Jakobsen



	NO SHIELDING				THIS SHIELDING				
	XRP.7A Up / Down		XRP.7B Up / Down		XRP.7A Up / Down		XRP.7B Up / Down		REDUCTION FACTOR
Dose (in air) (Gy / 10 fb^{-1})	5.4	5.5	7.4	**7.6**	1.8	1.9	3.5	**3.7**	**2.1**
1 MeV neutron equivalent (10^9 cm^{-2} / 10 fb^{-1})	**21**	17	9.9	9.0	5.2	**6.2**	4.7	5.2	**3.4**
High energy hadrons (10^9 cm^{-2} / 10 fb^{-1})	**6.7**	5.5	4.7	4.3	1.6	1.9	1.9	**2.1**	**3.2**

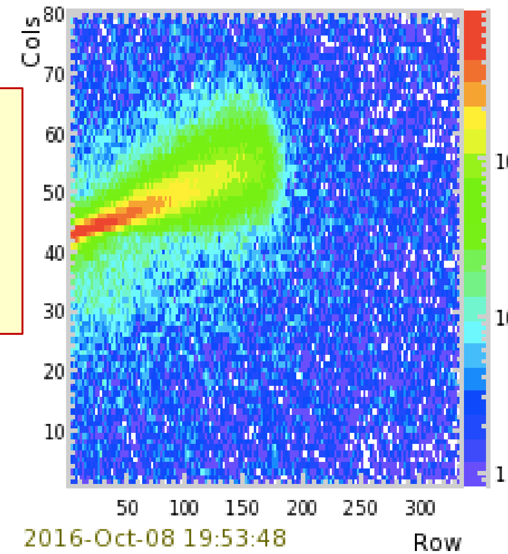
End of Successful AFP Running in 2016 !

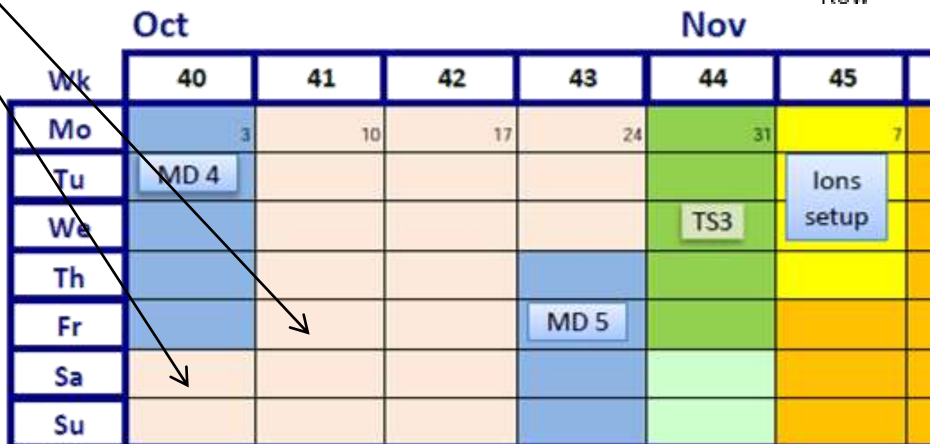
- Successful insertions in β*=40cm optics
  - ≤600 bunch runs (to limit ALFA radiation dose)
  - max <μ>~35, 15 hrs total (>10b), NO issues observed …
- High-μ run – 14 Oct
  - Insert AFP pots at "highest μ"
  - 100b, <μ>≈34 (at AFP insertion) 1 hr (~2 pb^{-1})
- Low-μ runs for AFP – 1 Aug, 8 Oct
  - 600b: AFP run <μ>=0.03,0.5 with ~5σ separation at P1
    - Duration: 4 + 5.5 hours ~0.54 pb^{-1}
    - L1: AFP 25 kHz
    - HLT: AFP ~2 KHz

BIG Thanks to: Joern, Maciej, Petr, Kris, Martin, Ivan, Elzbieta, Jolanta, Luis, Fabian, Davide, Chris Ng, Giulio, and many more …

8 Oct: inserted while beams were being separated

Run 310316 looks clean & as expected for SD
Hit distribution on the FAR station



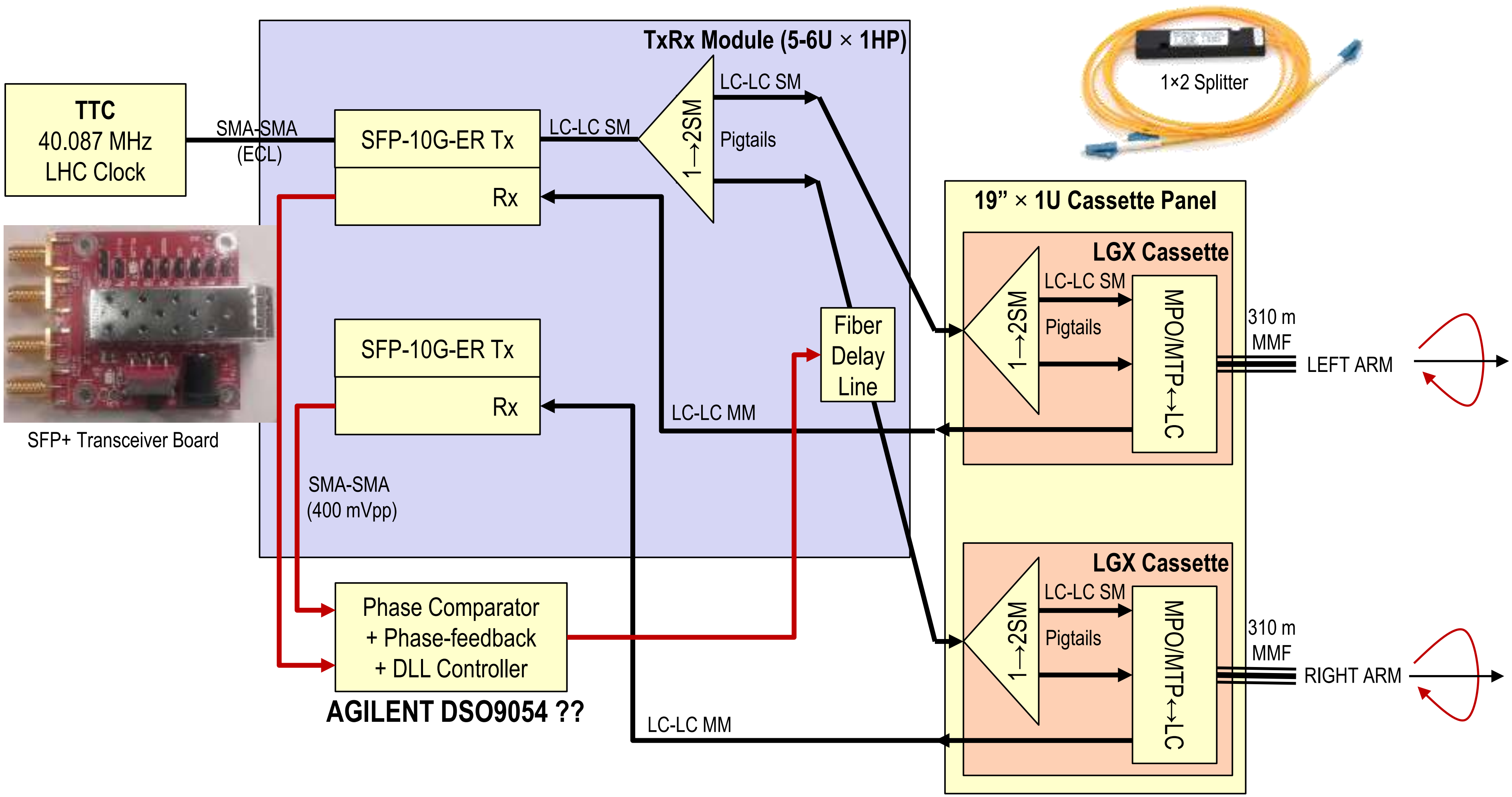


- Goal for Next Year: (subject to ATLAS approval!)
  - insertion for "all" ATLAS runs
  - 15 σ from beam
  - provide a new physics object for ATLAS analyses: "two-forward-protons" + match probability to the vertex of interest (Time-of-Flight)

Master Clock (USA15)

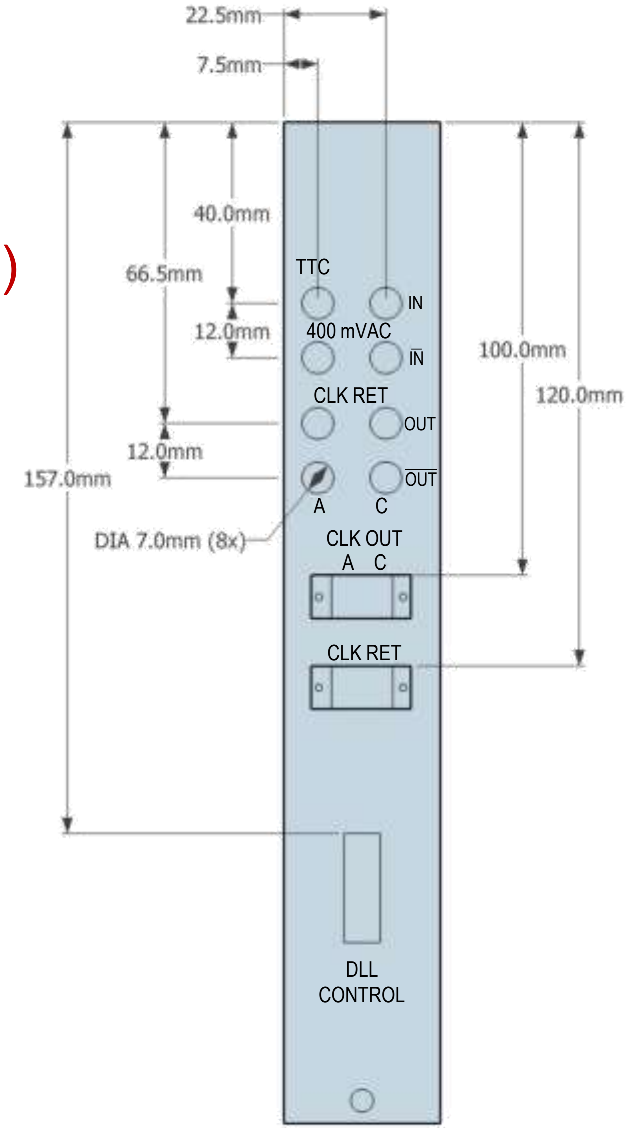
Master Clock Diagram

Transceivers:
SFP(+)-10G-ER 10 Gbps, 1310nm, SMF (FS.COM CHF100)



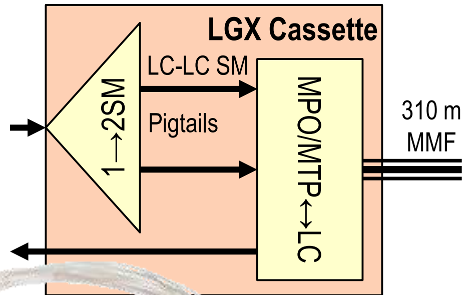
Master Clock Front Panel

- 1HP×5U NIM module
  - +3.3V, 0.5A regulator for transceivers
  - +12V, 0.5A (backplane) for DLL motor drive

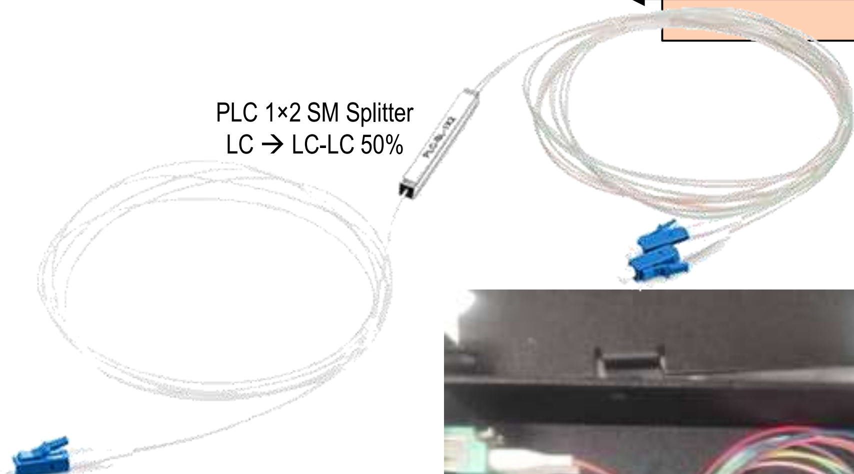


Clock Fiber I/O Junction Box

- 1 LGX Cassette per arm



PLC 1×2 SM Splitter
LC → LC-LC 50%



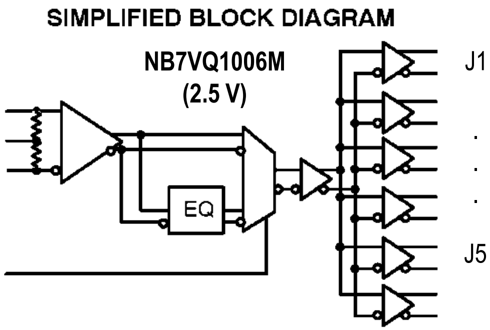
LC Duplex
MMF
Connectors

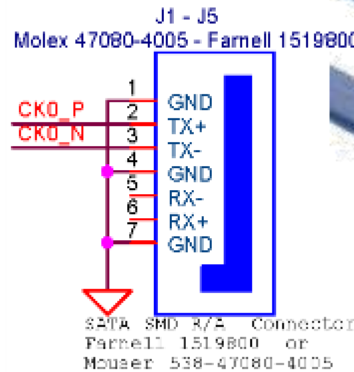
MPO/MTP
Male Connector

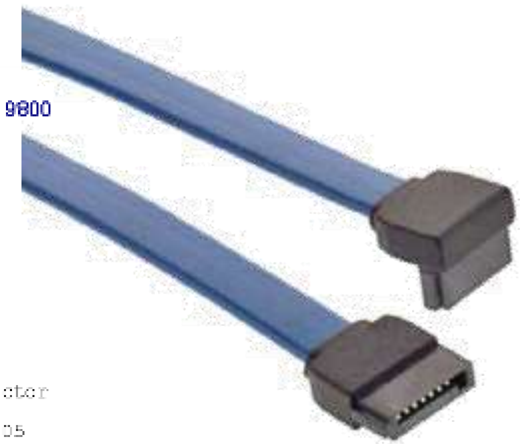
TIA 598-C Standard Colors	
Fiber/Unit Number	Fiber Color
1	Blue
2	Orange
3	Green
4	Brown
5	Slate
6	White
7	Red
8	Black
9	Yellow
10	Violet
11	Rose
12	Aqua
13 and higher	The color code is repeated, Black stripe or dash is added, according to the ANSI/TIA/EIA-598-C specifications

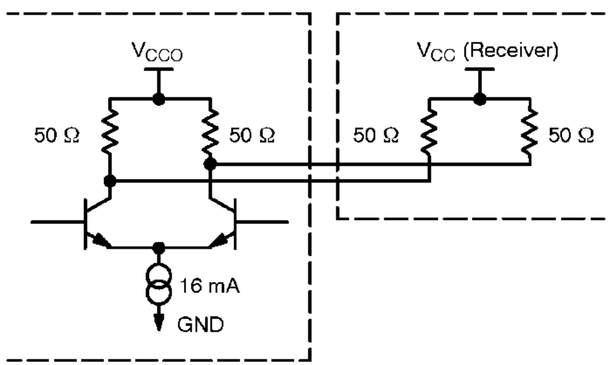
Clock to Trigger and HPTDC

- Clock outputs are CML, 40.087 MHz, 50% duty cycle
- SATA3 cables/connectors

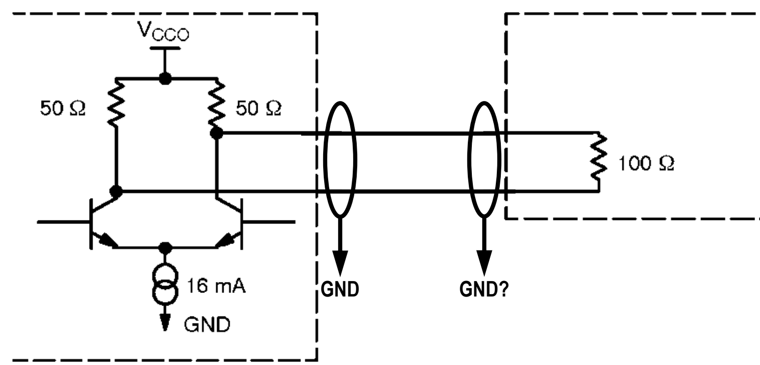








Typical CML Output Structure and Termination



Alternative Output Termination

AFP Commisioning

In sequence:

- Qualification of the AFP Beam Interlock System (BIS)
  - no beam needed, qualification of the safety system
  - The AFP BIS exists already; same test procedure as in March 2016, but now for both arms!

- Beam-Based Alignment
  - low intensity, 3 bunch beam to “calibrate” AFP pots to the beam center and determine the 15σ insertion limits.
  - was done in 2016 without issues …
- ATLAS Latency determination
  - ensuring that the CTP triggers the correct BX data
  - took some weeks in early 2016; will be easier this time …
- Qualification during Ramp-up
  - ensure fault-free operation of the detector from low-bunch to maximum bunch fills. Typically all LHC detectors participate in the ramp-up …

AFP Program 2017

Goals:

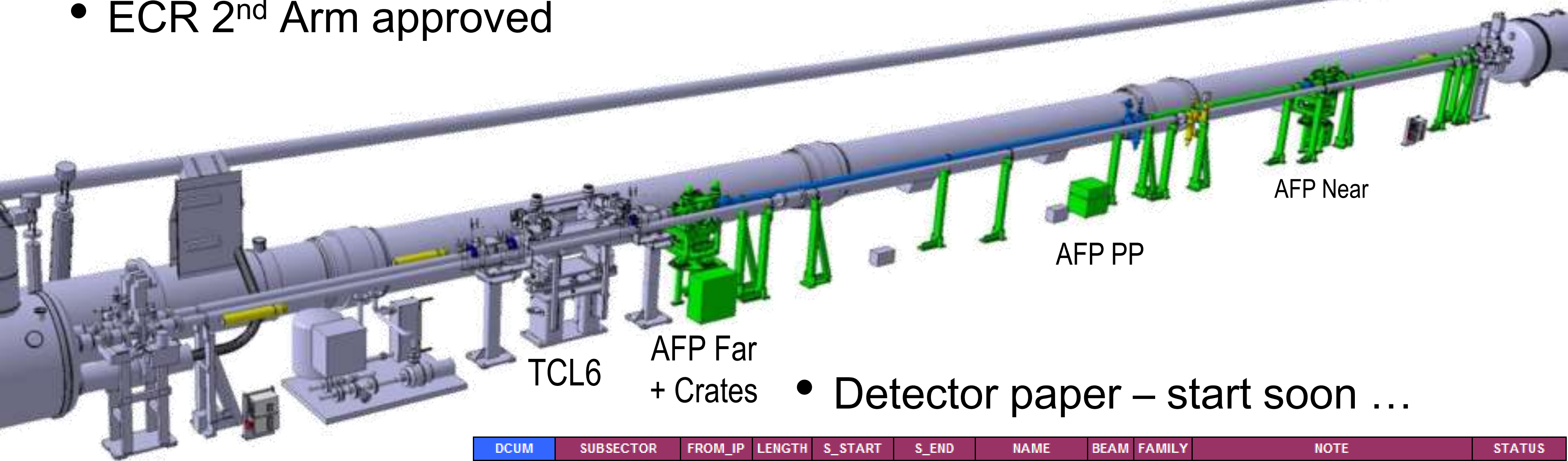
- Provide **a new physics object**: “two forward protons with vertex match probability”
  - provide MM of the protons, and rapidity and p_T of the MM
- can be used in any analysis

- Hi-Lumi running: (requested via ATLAS PC and LPC)
  - approach to 15 σ;
  - AFP in ATLAS DAQ at all times … collect ≥60 fb^{-1} before LS2
  - possibly with L1 AFP + CALO/MU items; and with AFP HLT
  - current data analysis & RECO: crucial for HLT algorithm development
- Low-μ (μ~1) special runs: (requested by SM and Performance groups)
  - aim for approach to 15 σ …
  - AFP L1 trigger items well established now
  - specific request: 1 fill with μ=0.03, 1 fill with μ=1

- Cohabitation with ALFA ?

ECR

- ECR 2nd Arm approved



- Detector paper – start soon …

DCUM	SUBSECTOR	FROM_IP	LENGTH	S_START	S_END	NAME	BEAM	FAMILY	NOTE	STATUS
26426.0752										
26434.3042										
26434.9592	VACSEC.A6L1.R	-223.924	3.104	26434.9592	26438.0632	VCDRZ.C6L1.R	E	R		INSTALLED
26438.0632	VACSEC.A6L1.R	-220.82	0.46	26438.0632	26438.5232	VAMTY	E	R	VMTQA with VAZNP,-,-,-	MODIFIED
26438.5232		-220.36	1.48	26438.5232	26440.0032	TCL.6L1.B2	E	B2		INSTALLED
26440.0032	VACSEC.A6L1.R	-218.88	0.52	26440.0032	26440.5232	VAMTW	E	R	VMTND with VAZNP,-,-,- modified support	MODIFIED
26440.5232	VACSEC.A6L1.R	-218.36	0.285	26440.5232	26440.8082	BPMSA.A6L1.B2	E	R	NEW 4-strips BPM	NEW
26440.8082	VACSEC.A6L1.R	-218.075	0.332	26440.8082	26441.1402	XRPAF.B6L1.B2	E	R	NEW AFP STATION	NEW
26441.1402	VACSEC.A6L1.R	-217.743	0.2	26441.1402	26441.3402	VMAAA.A6L1.R	E	R		RELOCATED
26441.3402	VACSEC.A6L1.R	-217.543	7	26441.3402	26448.3402	VCDA.A6L1.R	E	R	Relocated chamber D = 80mm L = 7 m	RELOCATED
26441.9592										
26442.2592										
26448.3402	VACSEC.A6L1.R	-210.543	0.3	26448.3402	26448.6402	VAMVD.A6L1.R	E	R	VVFM,VGR,-,VGI	RELOCATED
26448.6402	VACSEC.A6L1.R	-210.243	3.668	26448.6402	26452.3082	VCDDM.A6L1.R	E	R	New chamber D = 80mm L = 3.6 m	NEW
26449.2592										
26449.5592										
26452.3082	VACSEC.A6L1.R	-206.575	0.3	26452.3082	26452.6082	VMAAB.A6L1.R	E	R	Relocated vacuum module	RELOCATED
26452.6082	VACSEC.A6L1.R	-206.275	0.285	26452.6082	26452.8932	VCDHA.A6L1.R	E	R	Dummy chamber for BPM	NEW
26452.8932	VACSEC.A6L1.R	-205.99	0.332	26452.8932	26453.2252	XRPAF.A6L1.B2	E	R	NEW AFP STATION	NEW
26453.2252	VACSEC.A6L1.R	-205.658	0.3	26453.2252	26453.5252	VAMEY.A6L1.R	E	R	VMAAE with VPIAN	NEW
26453.5252	VACSEC.A6L1.R	-205.358	3.795	26453.5252	26457.3202	VCDCJ.A6L1.R	E	R	New chamber D = 80mm L = 3.8 m	NEW

Electronics – Goals & Constraints

- preserve timing resolution of the detector: <20 ps/channel
  - **multiple** measurements/proton ➔ <10 ps/proton
  - need multiplicity also for rejection of spurious background rejection!
  - trade multiplicity for resolution: 4 measurements of 20 ps ≃ 10 ps
- provide fast ξ-bin trigger; transverse deflection $x \propto \xi$
  - data rate up to 1 MHz/channel
- radiation-hardness or tolerance
  - fluence/dose estimate for 100 fb^{-1} (1 yr @ 10^{34} $cm^{-2}s^{-1}$)

"FLUKA Calculations for Radiation to Electronics at P1," A Mereghetti, R2E Mtg, 4/29/2009.

estimates for 100 fb^{-1}	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

Cross-checked with ALFA Dose Measdurements from 2009-2012

(1 Gy = 100 rad)