Physics with AFP0+2 and AFP2+2

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LHC Working Group on Forward Physics and Diffraction
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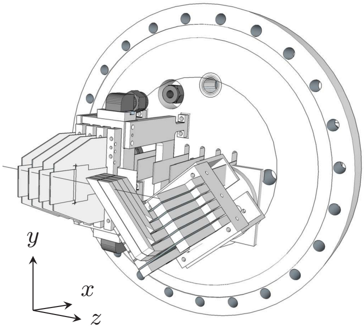
Contents

AFP Detector

- Detectors to measure diffractively scattered protons
- Four stations foreseen on both sides of ATLAS Interaction Point
- Near station (205 m from IP) – tracking
- Far station (217 m from IP) – tracking + ToF

Tracking detector

- 3D edgeless (150 μm) Silicon pixel detectors
- pixel size 50x250 μm (x vs y)
- 4 layers
- tilted in x for full efficiency
- staggered in y



ToF detector

- QUARTIC: quartz Cherenkov detectors
- 4 x 4 quartz bars
- fast MCP-PMT, fast electronics

The AFP Detector for Run 2

Goals:

- commission the detector; explore the environment close to the LHC beam
- special runs at low-μ, focusing on high-rate diffractive physics processes
- staged installation:
  - Winter 2015-2016 shutdown – installation of a single AFP 'arm' with two Roman pot stations, the '0+2' AFP configuration (AFP0+2) **DONE!**
  - Winter 2016-2017 shutdown – installation of the second detector arm

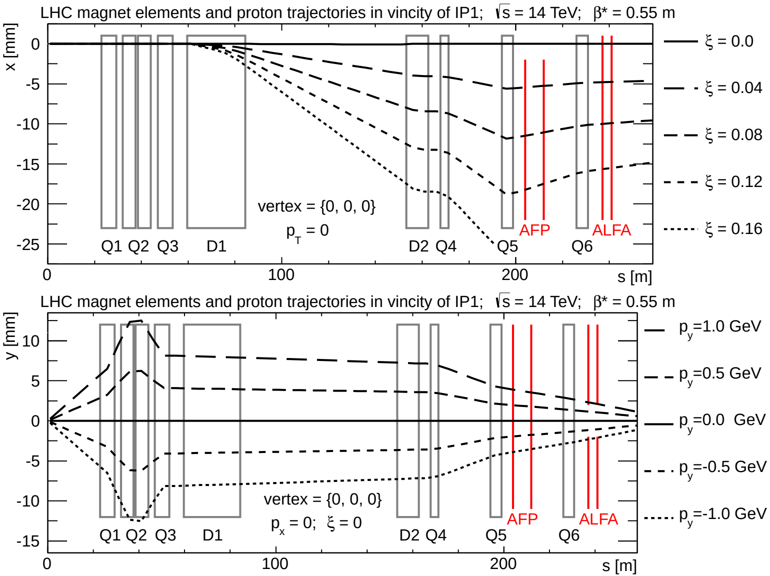
AFP 0+2:

- two silicon tracking detectors and a Level-1 Trigger
- physics: soft single diffraction, single diffractive jets, W, jet-gap-jet, exclusive jet production (one tag)

AFP 2+2:

- two silicon tracking detectors on second arm and time-of-flight detectors on both far stations
- physics: soft central diffraction, central diffractive jets, jet-gap-jet, γ+jet, exclusive jet production, anomalous couplings, 750 GeV resonance

Machine optics (collision optics)



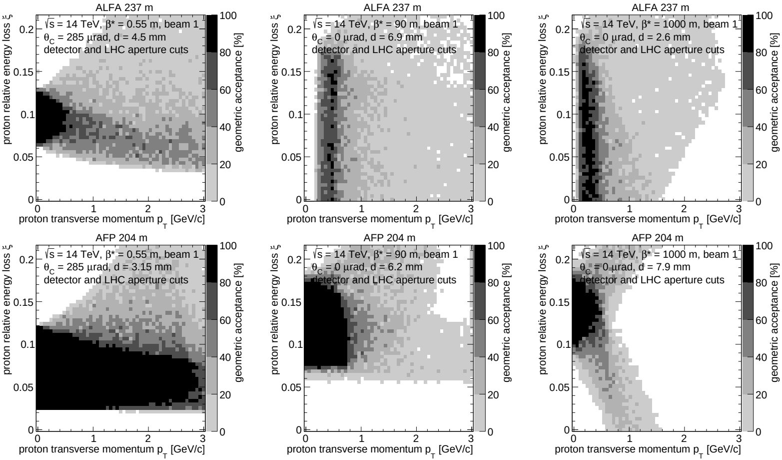
M. Trzebiński, Proc.SPIE Int.Soc.Opt.Eng. 9290 (2014) 929026

Geometric Acceptance

optics	$\beta^* = 0.55$ m nominal (*collision*)	$\beta^* = 90$ m special (*high-β^**)	$\beta^* = 1000$ m special (*high-β^**)

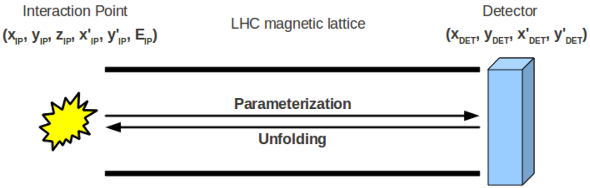
ALFA

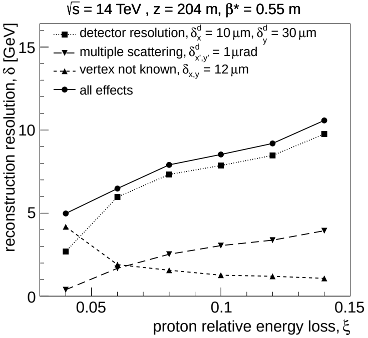
AFP

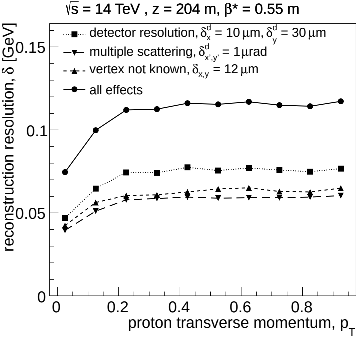


M. Trzebiński, Proc.SPIE Int.Soc.Opt.Eng. 9290 (2014) 929026

Reconstruction resolution







3 µm resolution in x measured in beam tests!

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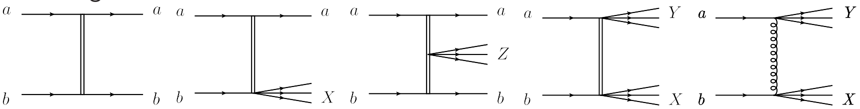
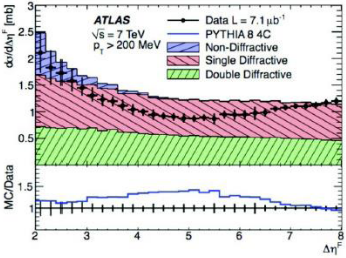
Soft Processes

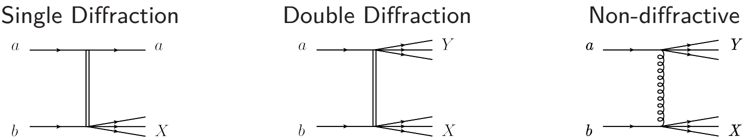


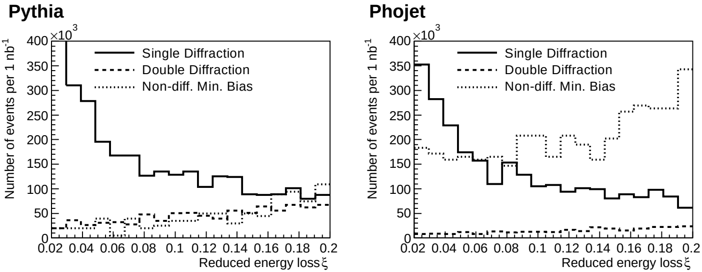
- Gap measurement in ATLAS does not distinguish SD from DD
- More information about events with forward proton tagging
- High cross sections → low lumi needed → possible with lowest pile-up
- AFP 0+2 – single diffraction
  AFP 2+2 – central diffraction
- Goal for 2016 running



Eur. Phys. J. C72 (2012) 1926

Origin of forward protons

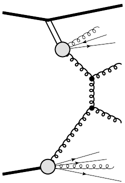




- High-ξ protons in ND and DD due to hadronisation
- Significant differences between MC generators
- Important also for simulating cosmic air showers

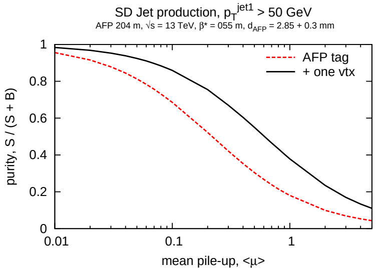
Contents

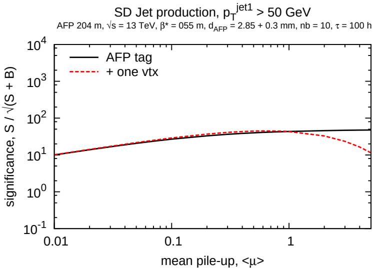
Single Diffractive Jet Production



Motivation:

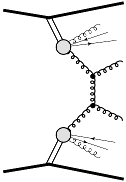
- gap survival probability
- Pomeron structure studies
- Reggeon contribution
- Pomeron universality between ep and pp
- CERN-PH-LPCC-2015-001





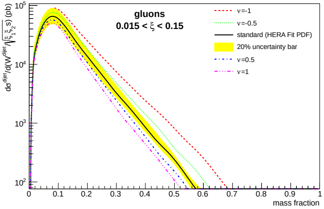
Goal for 2016 running

Central diffractive jets

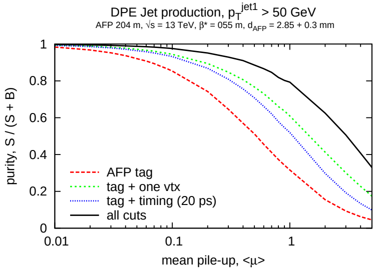


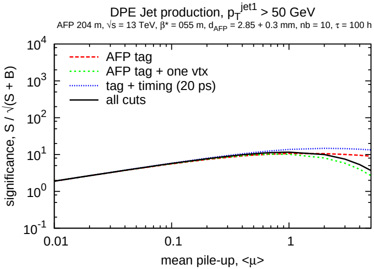
Motivation:

- measure cross section and gap survival probability
- search for the presence of an additional contribution from Reggeon exchange
- Pomeron structure



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





CERN-PH-LPCC-2015-001

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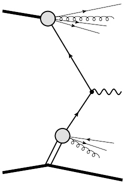
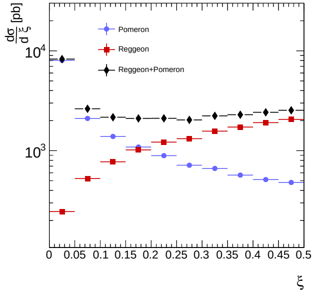
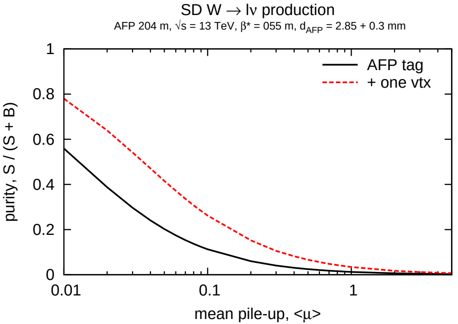
Single Diffractive W Production



Motivation:

- gap survival probability
- Pomeron structure
- Pomeron flavour composition
- possible also in central diffractive events, but cross section probably too small





A. Chuinard, C. Royon, R.S., arxiv:1510.04218; CERN-PH-LPCC-2015-001

Charge asymmetry of diffractive W

- Definition: $\mathcal{A} = (\sigma_{W^+} - \sigma_{W^-})/(\sigma_{W^+} + \sigma_{W^-})$
- Some experimental systematic uncertainties cancel
- 4 processes (neglecting Cabibbo suppressed ones)
  $u_{\mathbb{P}} + \bar{d}_p \to W^+$, $d_{\mathbb{P}} + \bar{u}_p \to W^-$
  $\bar{u}_{\mathbb{P}} + d_p \to W^-$, $\bar{d}_{\mathbb{P}} + u_p \to W^+$

$u_p \neq d_p$, $u_p \neq \bar{u}_p$, $d_p \neq \bar{d}_p$

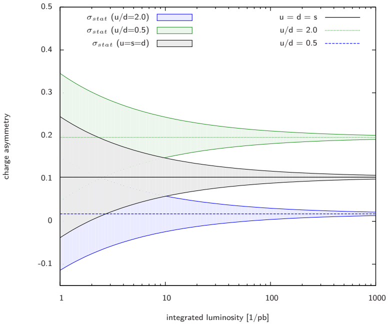
$\downarrow$

$\mathcal{A}$ is sensitive to R_{ud}

- FPMC results:

R_{ud}	$\mathcal{A}$
½	0.185
1	0.096
2	0.019

statistical uncertainty



A. Chuinard, C. Royon, R.S., arxiv: 1510.04218

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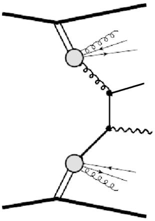
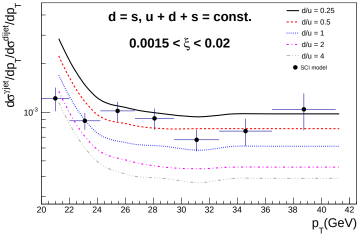
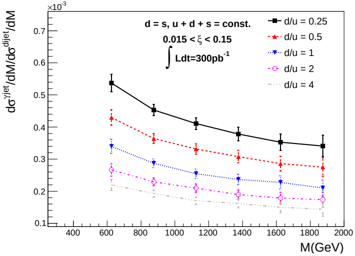
Diffractive γ+Jet



Motivation:

- process observation
- gap survival probability
- Pomeron structure
- Pomeron flavour composition
- possible also in single diffractive processes





C. Marquet, C. Royon, M. Saimpert, D. Werder, Phys.Rev. D 88 (2013) 7, 074029

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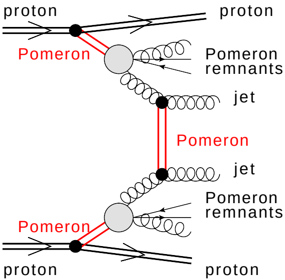
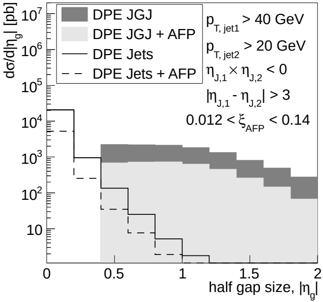
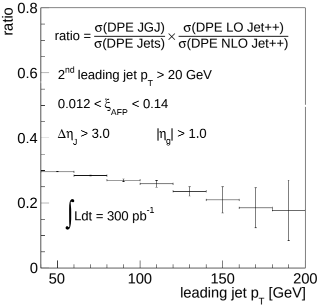
Diffractive Jet-Gap-Jet



Motivation:

- process observation
- gap survival probability
- BFKL effects
- possible also in single diffractive processes





C. Marquet, C. Royon, M. Trzebiński, R. Žlebčík, Phys.Rev. D 87 (2013) 3, 034010

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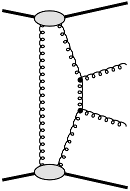
Exclusive Jets

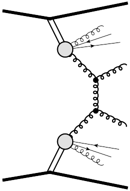
Exclusive jets

- Two intact protons
- No Pomeron remnants
- All particles measured



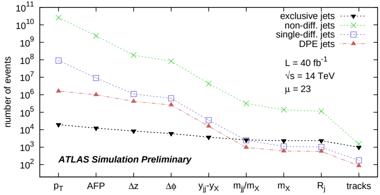
For comparison: CD (DPE) jets

- Two intact protons
- Pomeron remnants
- Remnants escape

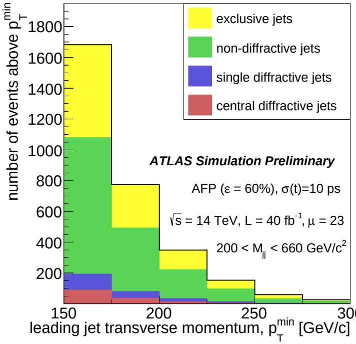


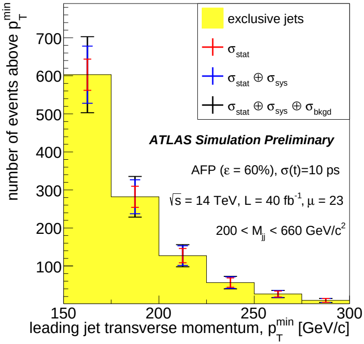
- Motivation: verification of QCD production models, unintegrated gluon PDFs
- Small cross section for exclusive processes → measurement with two proton tags needs high luminosity
- Low luminosity – use only single tag events, but less pile-up background
- All particles measured → strong kinematic constraints between central state and each of the forward protons

Exclusive jets measurement



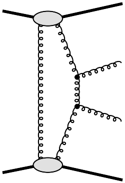
- Low cross section → high pile-up conditions → large backgrounds
- Background reduction possible due to kinematic correlations
- Data-driven background estimation needed





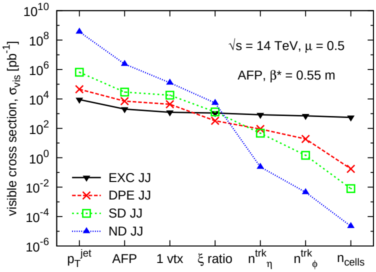
ATL-PHYS-PUB-2015-003

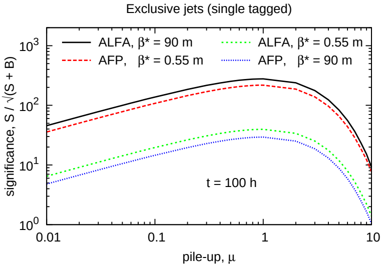
Exclusive Jet Production (Single Tag)



Motivation:

- bigger cross section → lower luminosity necessary
- less background reduction possibilities → low pile-up
- possible contribution from *semi-exclusive* processes (remnant on one side)



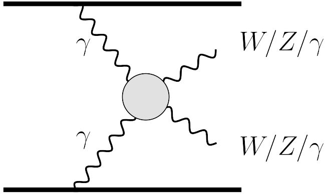


M. Trzebiński, R. Staszewski, J. Chwastowski, Eur. Phys. J. C 75 (2015) 320

Contents

Anomalous couplings

- $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$ quartic couplings
- Testing BSM models
- Constrained kinematics $\rightarrow$ low background (timing not strictly needed)
- Reaching limits predicted by string theory and grand unification models (10^{-14} – 10^{-13} for $\gamma\gamma\gamma\gamma$)



$\gamma\gamma WW$ and $\gamma\gamma ZZ$

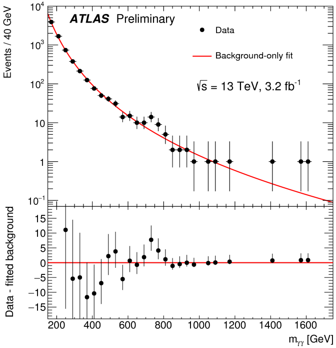
Coupling	OPAL limits [GeV−2]	Sensitivity for 200 fb−1 5σ	95% CL
a_0^W/Λ^2	[-0.020, 0.020]	$2.7 \cdot 10^{-6}$	$1.4 \cdot 10^{-6}$
a_C^W/Λ^2	[-0.052, 0.037]	$9.6 \cdot 10^{-6}$	$5.2 \cdot 10^{-6}$
a_0^Z/Λ^2	[-0.007, 0.023]	$5.5 \cdot 10^{-6}$	$2.5 \cdot 10^{-6}$
a_C^Z/Λ^2	[-0.029, 0.029]	$2.0 \cdot 10^{-5}$	$9.2 \cdot 10^{-6}$

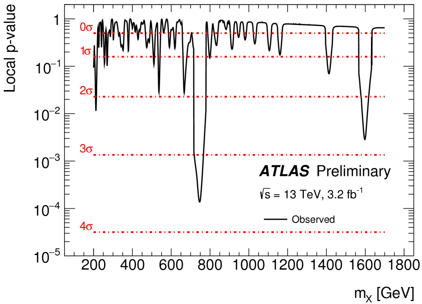
$\gamma\gamma\gamma\gamma$

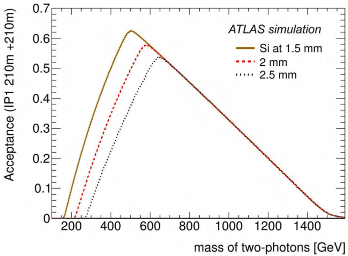
Coupling (GeV^{-4})	1 conv. γ 5σ	1 conv. γ 95% CL	all 95% CL
ζ_1 f.f.	$1 \cdot 10^{-13}$	$7 \cdot 10^{-14}$	$4 \cdot 10^{-14}$
ζ_1 no f.f.	$3 \cdot 10^{-14}$	$2 \cdot 10^{-14}$	$1 \cdot 10^{-14}$
ζ_2 f.f.	$3 \cdot 10^{-13}$	$1.5 \cdot 10^{-13}$	$8 \cdot 10^{-14}$
ζ_2 no f.f.	$7 \cdot 10^{-14}$	$2 \cdot 10^{-14}$	$2 \cdot 10^{-14}$

E. Chapon, C. Royon, and O. Kepka, Phys.Rev. D81 (2010) 074003
S. Fichet , G. von Gersdorff, B. Lenzi, C. Royon, M. Saimpert, JHEP 1502 (2015) 165

Di-photon resonance at 750 GeV







- ATLAS and CMS observed an excess around 750 GeV in $\gamma\gamma$ events
- Decay to $\gamma\gamma$ means that exclusive two-photon production mechanism is possible:

$$pp \to p+\gamma\gamma+p \to p+R+p \to p+\gamma\gamma+p$$

- Within AFP2+2 acceptance!

ATLAS-CONF-2015-081; CMS-PAS-EXO-15-004

CERN-LHCC-2011-012

Contents

Physics plans for AFP

- Understanding of soft processes
  - AFP 0+2: single diffraction at high ξ, Reggeon vs Pomeron, non-diffractive forward protons
  - AFP 2+2: central diffraction
- Diffractive factorisation breaking
  - all hard diffractive processes
  - AFP 0+2 – single diffractive
  - AFP 2+2 – central diffractive
- Pomeron structure
  - gluon – diffractive jets (SD and CD)
  - quark (and flavour) – diffractive W, photon + jet
- BFKL
  - jet-gap-jet processes (SD and CD)
- Exclusive processes
  - AFP 0+2 – single tag, *semi-exclusive*
  - AFP 2+2 – using full AFP potential
- BSM studies:
  - AFP 2+2
  - anomalous $\gamma\gamma WW$, $\gamma\gamma ZZ$, $\gamma\gamma\gamma\gamma$ couplings
  - Exclusive production of 750 GeV $\gamma\gamma$ resonance

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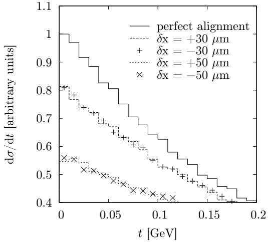
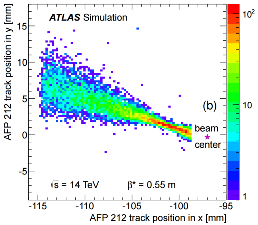
Alignment

Hot-spot method



- Principle: reconstruct t distribution with different assumptions on detector position
- Successfully used in CDF experiment
- At the LHC sensitive to relative alignment between stations
- Better sensitivity in horizontal direction due to better spatial resolution

Kinematic peak method



- Hit pattern in AFP has a complex structure with a characteristic dense area (hot spot)
- Position of the hot spot can be used as reference for alignment
- Sensitivity to physics model and background is small
- Sensitivity to optics – to be understood

Both methods use soft SD events – no problem with statistics