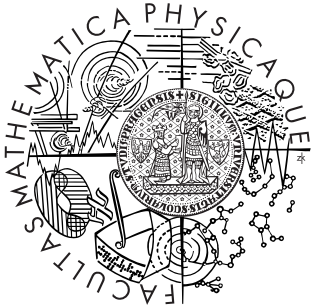
Research experience and plans

IHEP interview

Ina Carli

IPNP Charles University
Prague, Czech Republic

22. 4. 2019



About me

Education:

- Charles University in Prague, Czech Republic
- Bachelor and Master's degrees in Nuclear and subnuclear physics
- PhD in Subnuclear physics (Jan 2019), based mostly at CERN

Research experience on ATLAS:

- $B_d \rightarrow K^* \mu^+ \mu^-$ angular analysis with 2012 data (PhD thesis)
- $B_s^0 \rightarrow \phi \, \mu^+ \mu^-$ on simulated dataset (Master's thesis)

Hardware, performance and service:

- detector physics: silicon strip detectors - SCT and ITk strip
- SCT on-call expert (DAQ, DCS and DQ); SCT and Shift Leader shifts
- monitoring of non-collision beam backgrounds

Other work:

- Beamline for Schools 2017 - one of 2 support scientists
- teaching, student supervision and outreach

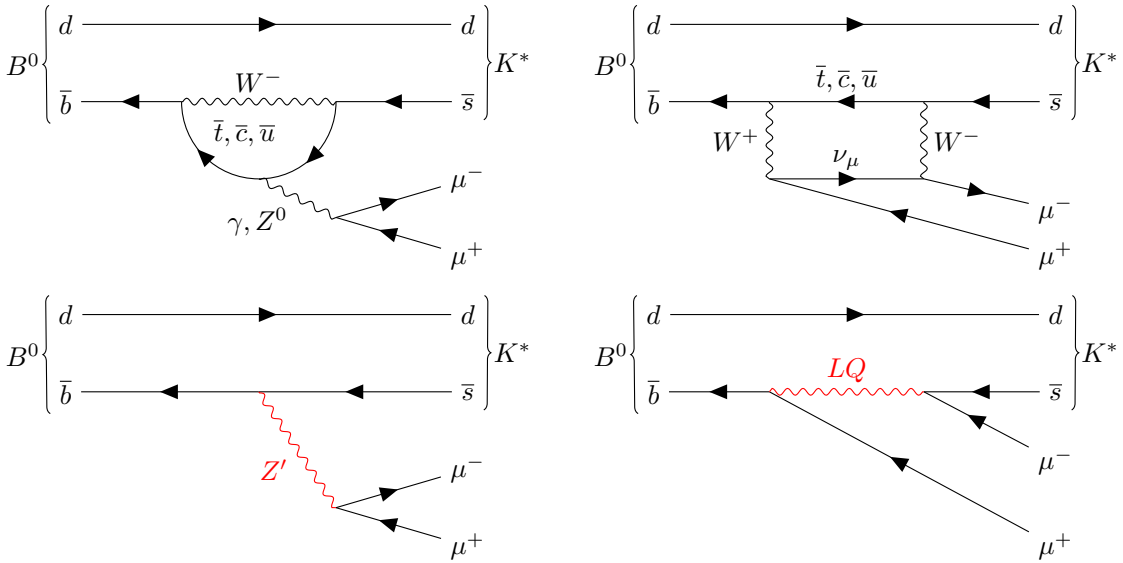
Links: Curriculum Vitae, PhD thesis, Inspire profile

Angular analysis of $B_d \to K^* \mu^+ \mu^-$ with ATLAS 2012 data

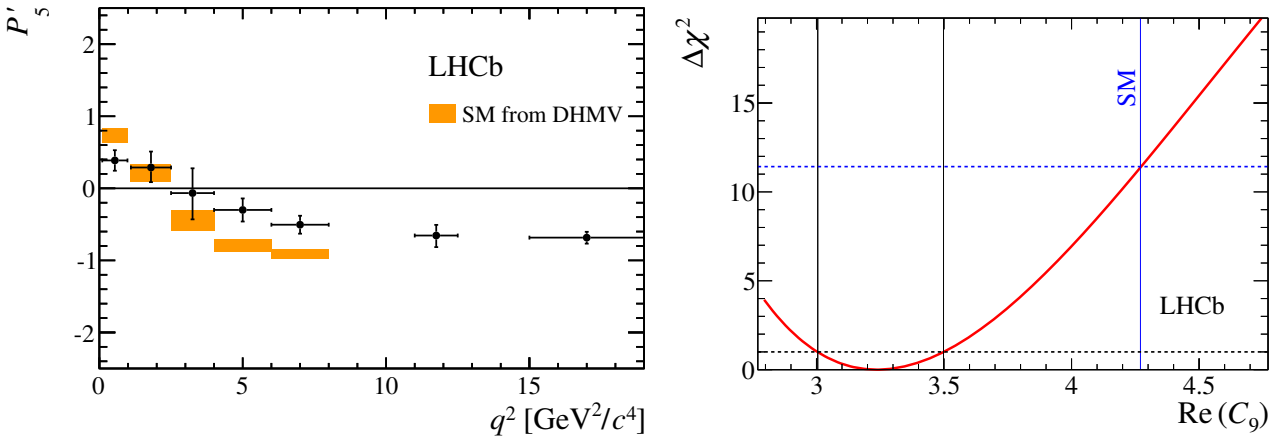
JHEP 10 (2018) 047, arXiv:1805.04000

$B_d \to K^* \mu^+ \mu^-$ decay in SM

- rare B_d decay (BR $\sim 10^{-6}$) mediated by FCNC penguin and box diagrams
- sensitive to BSM contributions which would alter branching ratio or angular distributions



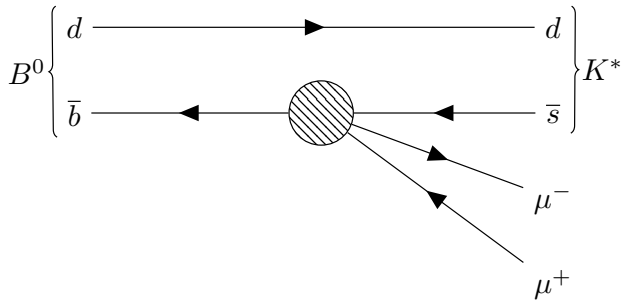
- experimental status after LHC Run 1: LHCb data showed hints for discrepancies from theory



$B_d \to K^* \mu^+ \mu^-$ decay in EFT

Effective field theory Hamiltonian for $b \to s\, \ell^+ \ell^-$

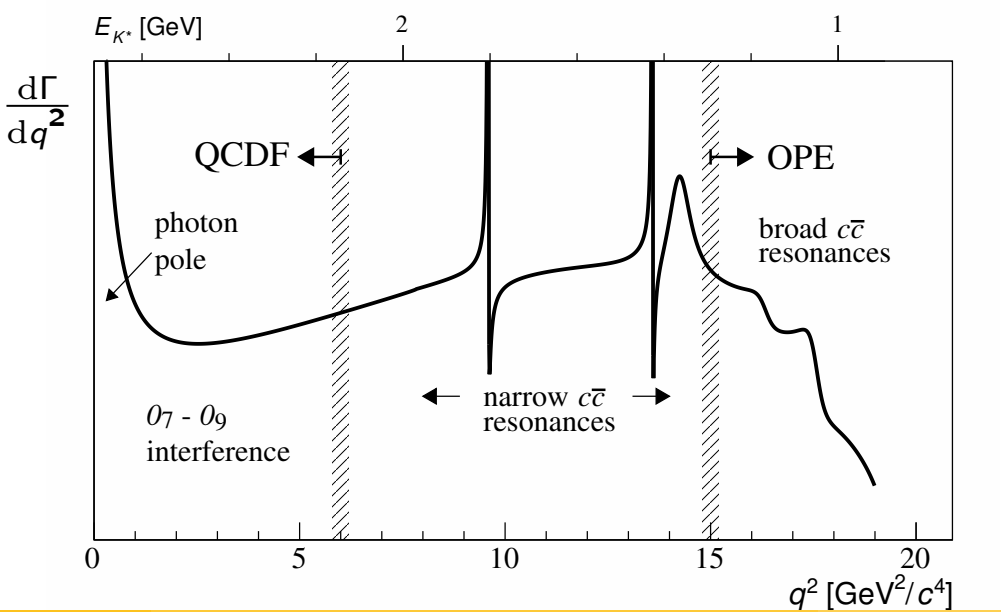
$$\mathcal{H}_{\text{eff}} = -\frac{4\, G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} \sum_i C_i(\mu) \mathcal{O}_i(\mu)$$



Contributing operators

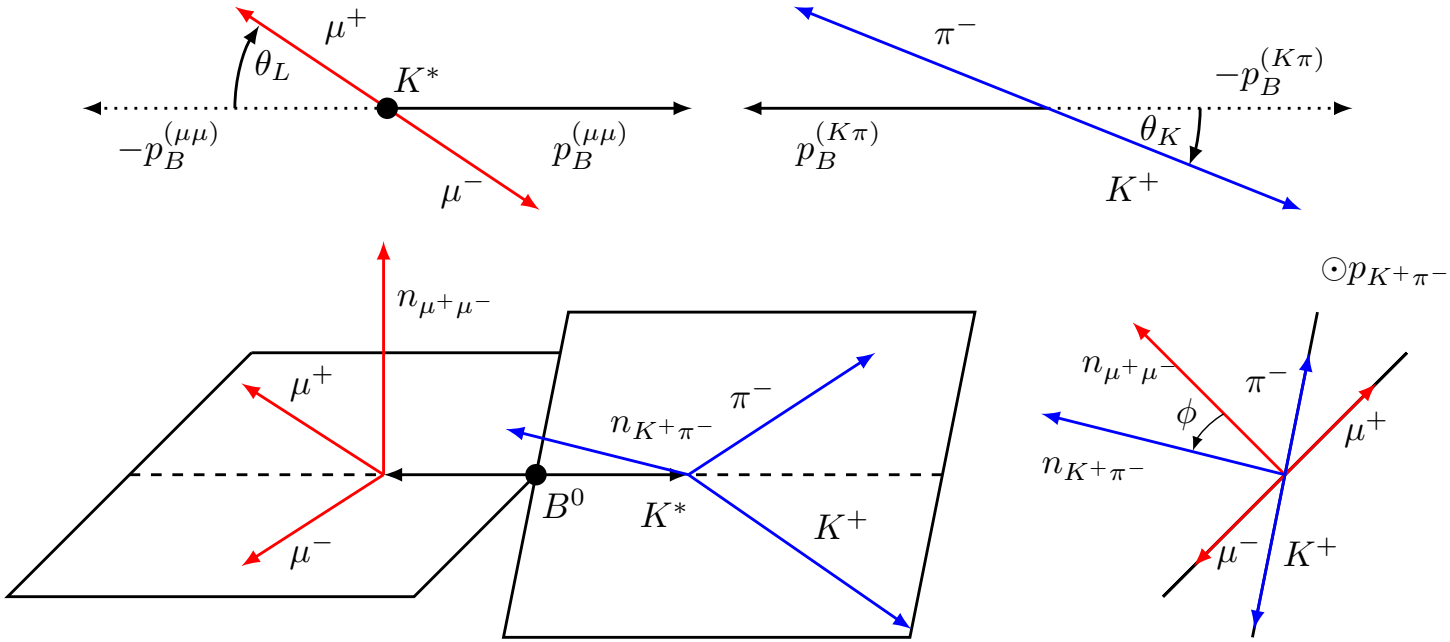
$$\begin{aligned}
\mathcal{O}_7 &= \frac{m_b}{e}(\bar{s}\sigma^{\mu\nu} P_R b) F_{\mu\nu}\,, & \mathcal{O}_7' &= \frac{m_b}{e}(\bar{s}\sigma^{\mu\nu} P_L b) F_{\mu\nu}\,,\\
\mathcal{O}_9 &= (\bar{s}\gamma_\mu P_L b)\,(\bar{\ell}\gamma^\mu \ell)\,, & \mathcal{O}_9' &= (\bar{s}\gamma_\mu P_R b)\,(\bar{\ell}\gamma^\mu \ell)\,,\\
\mathcal{O}_{10} &= (\bar{s}\gamma_\mu P_L b)\,(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, & \mathcal{O}_{10}' &= (\bar{s}\gamma_\mu P_R b)\,(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,.
\end{aligned}$$

Dependence on dimuon invariant mass squared q^2



$B_d \to K^* \mu^+ \mu^-$ observables

- reconstruct final state with $K^* \to K^+ \pi^-$
- self-tagging decay (B^0or $\overline{B^0}$ if $K^+\pi^-$ or $K^-\pi^+$) - set mass hypotheses (no PID)
- 4 particles $\to$ 3 helicity angles



Measurements: usually as a function of q^2

- traditional: A_{FB}, F_L, A_I, $R_{K^{(*)}} = \mathrm{d}\Gamma(K^*\mu\mu)/\mathrm{d}\Gamma(K^*ee)$, BR, zero-crossing points
- optimized: F_L and S_i, F_L and $P_i^{(\prime)}$

$B_d \to K^* \mu^+ \mu^-$ decay in SM

Differential decay rate - 8 parameters

$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell d\cos\theta_K\, d\phi dq^2} = \frac{9}{32\pi}\left[\frac{3(1-F_L)}{4}\sin^2\theta_K + \frac{1-F_L}{4}\sin^2\theta_K\cos 2\theta_\ell\right.$$
$$+ F_L\cos^2\theta_K - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell$$
$$\left.+ S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\ \sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\right].$$

Small number of events $\to$ 4 angular transformations (folding) $\to$ 3 parameters each fit

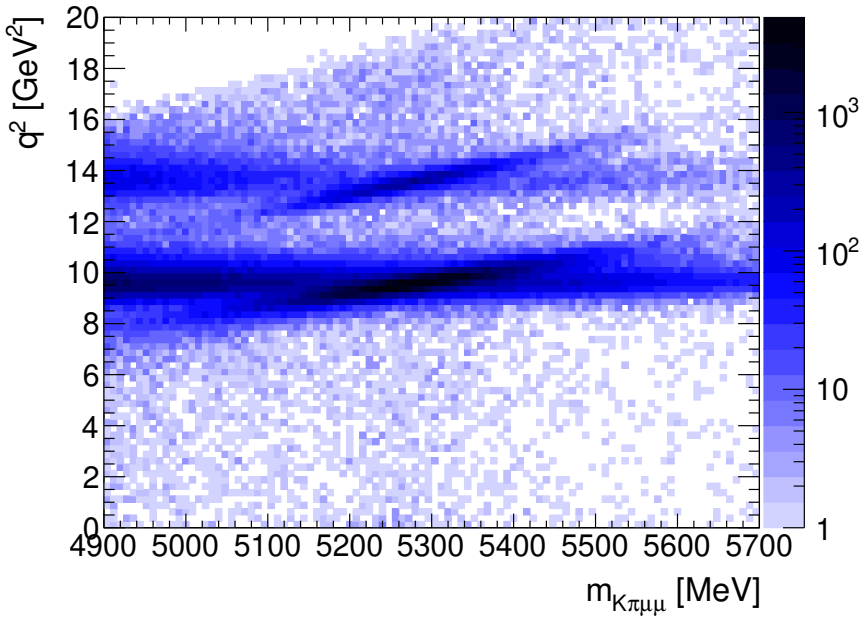
$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell d\cos\theta_K\, d\phi dq^2} = \frac{9}{8\pi}\left[\frac{3(1-F_L)}{4}\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1-F_L}{4}\sin^2\theta_K\cos 2\theta_\ell\right.$$
$$\left.- F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi\right]$$

Redefine variables (optimized set)

$$P_1 = \frac{2S_3}{(1-F_L)}, \quad P'_{4,5,8} = \frac{S_{4,5,8}}{\sqrt{F_L(1-F_L)}}, \quad P'_6 = \frac{S_7}{\sqrt{F_L(1-F_L)}}$$

Analysis strategy

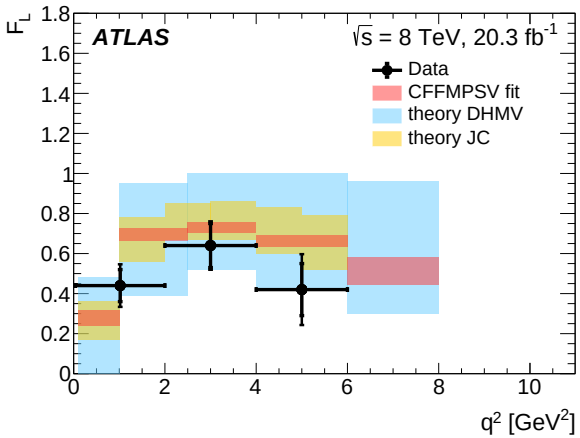
- reconstruction and cut-based selection
- divide in q^2 bins:
  - signal q^2= [0.04,6] GeV^2 except of ϕ region q^2= [0.98,1.1] GeV^2
  - control regions: J/ψ q^2= [8,11] GeV^2, $\psi(2S)$ q^2= [12,15] GeV^2
- angular folding $\rightarrow$ 4 sets of fits
- 4D fit: m_B, $\cos\theta_K$, $\cos\theta_\ell$, ϕ in q^2 bins
- acceptance functions from MC sample generated with flat angular distributions
- nuisance parameters from control regions - m_B, σ_{mB} (Gauss)
- mass prefit - fix number of signal a bkg events

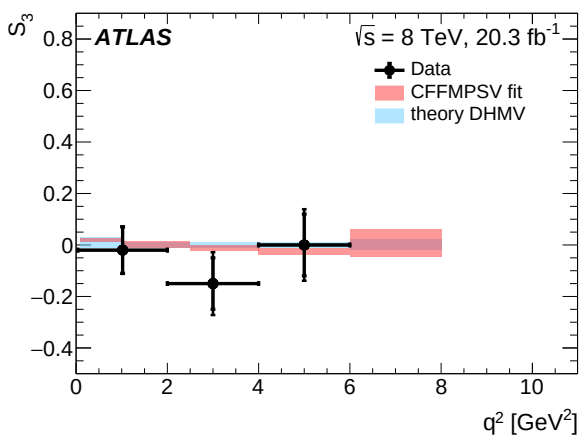


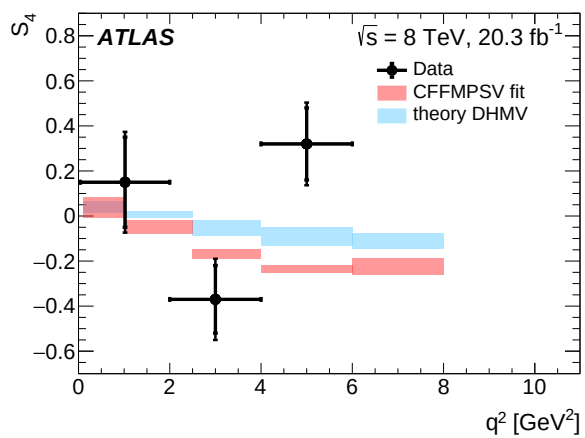
q^2[GeV^2] bin	n_{signal}	$n_{\text{background}}$
[0.04, 2.0]	128 ± 22	122 ± 22
[2.0, 4.0]	106 ± 23	113 ± 23
[4.0, 6.0]	114 ± 24	204 ± 26
[0.04, 4.0]	236 ± 31	233 ± 32
[1.1, 6.0]	275 ± 35	363 ± 36
[0.04, 6.0]	342 ± 39	445 ± 40

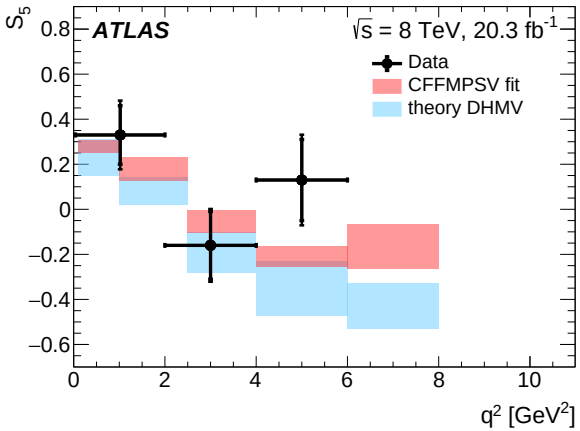
Results

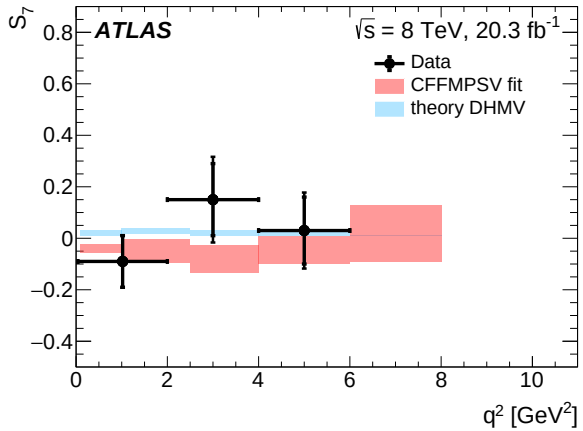
F_L and S_i parameters

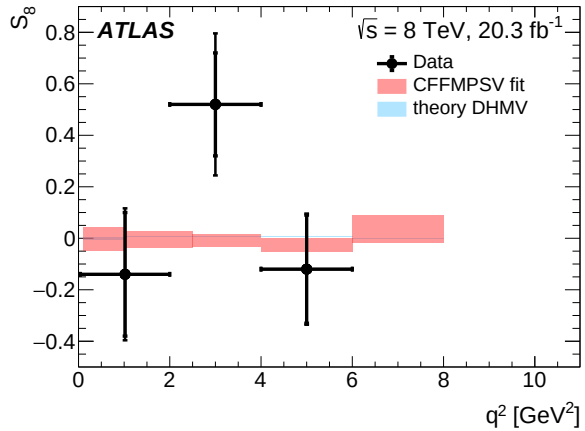






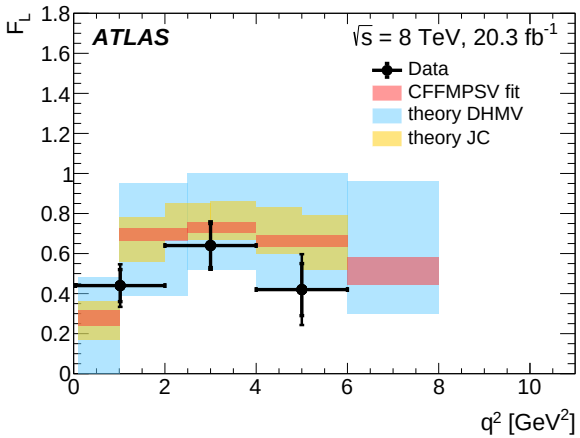


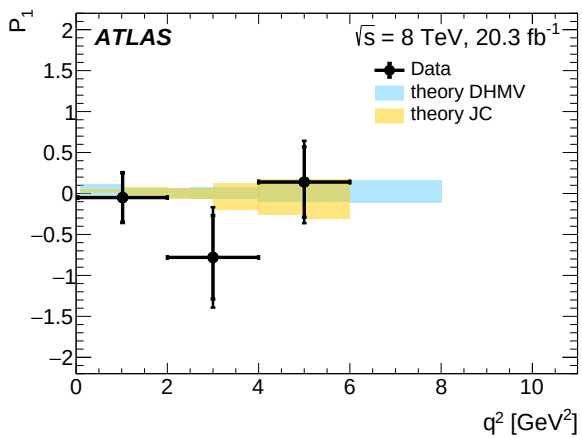


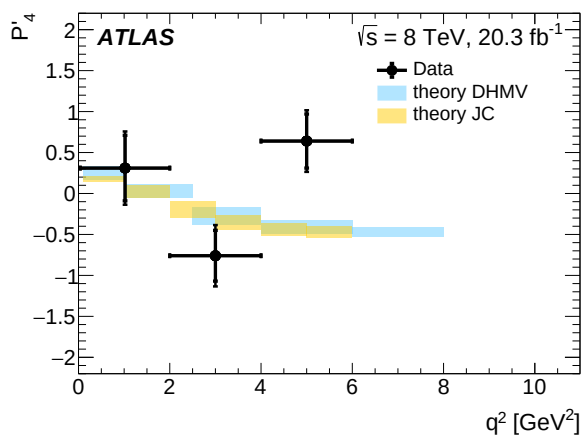


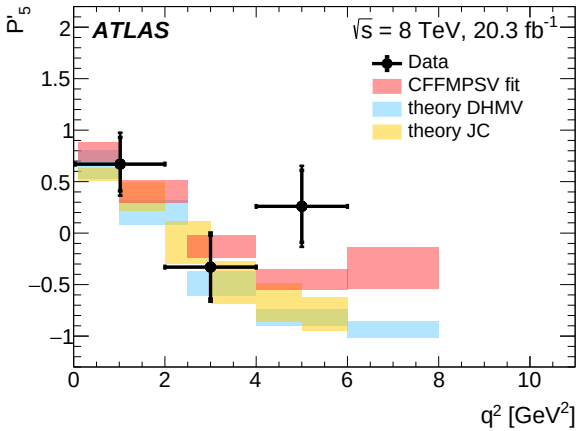
Results

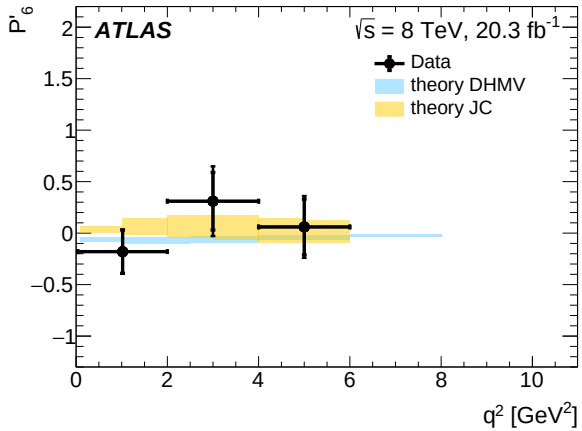
P_i parameters

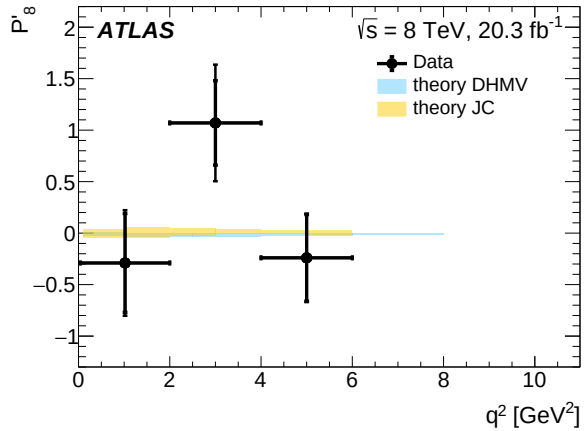






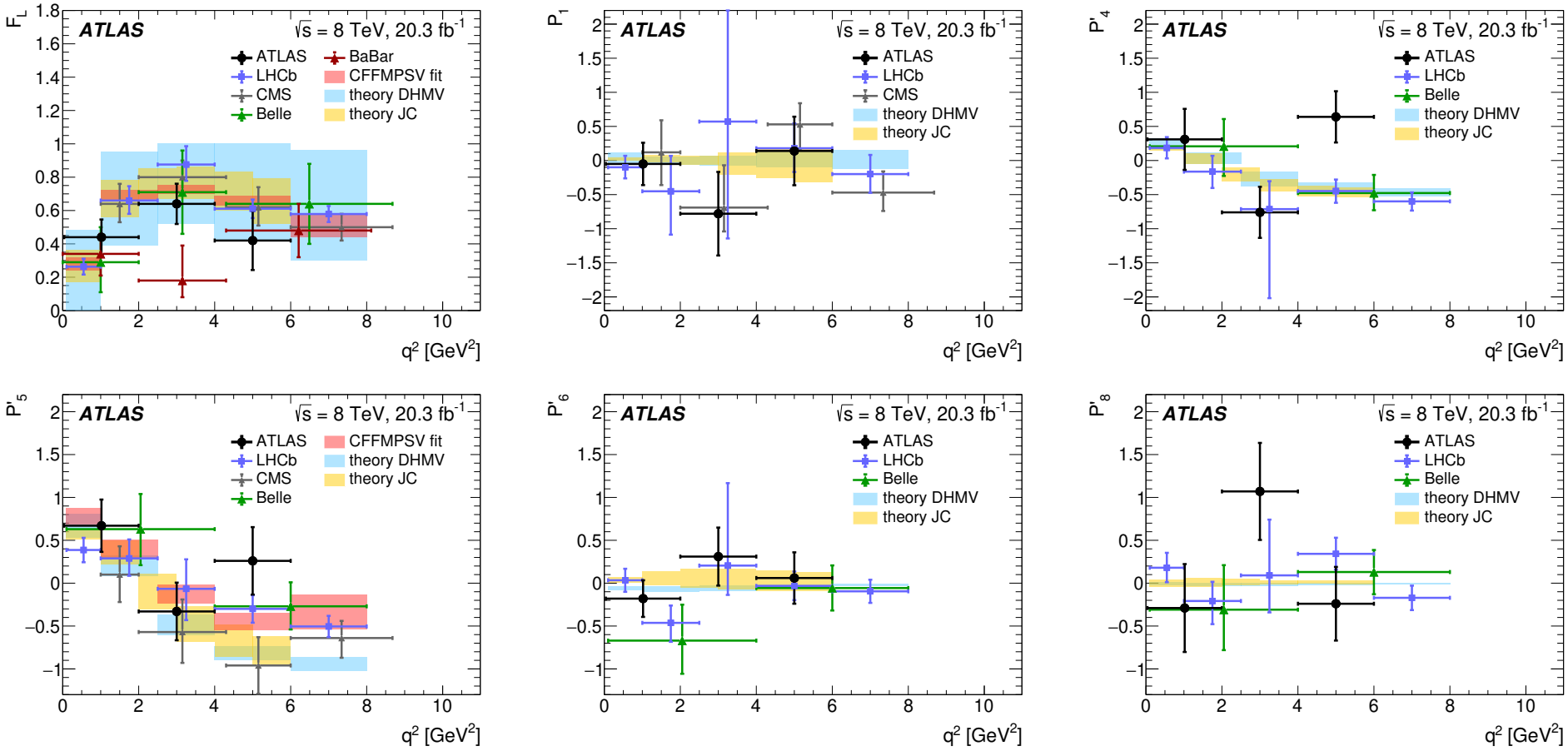






Results

P_i parameters in context

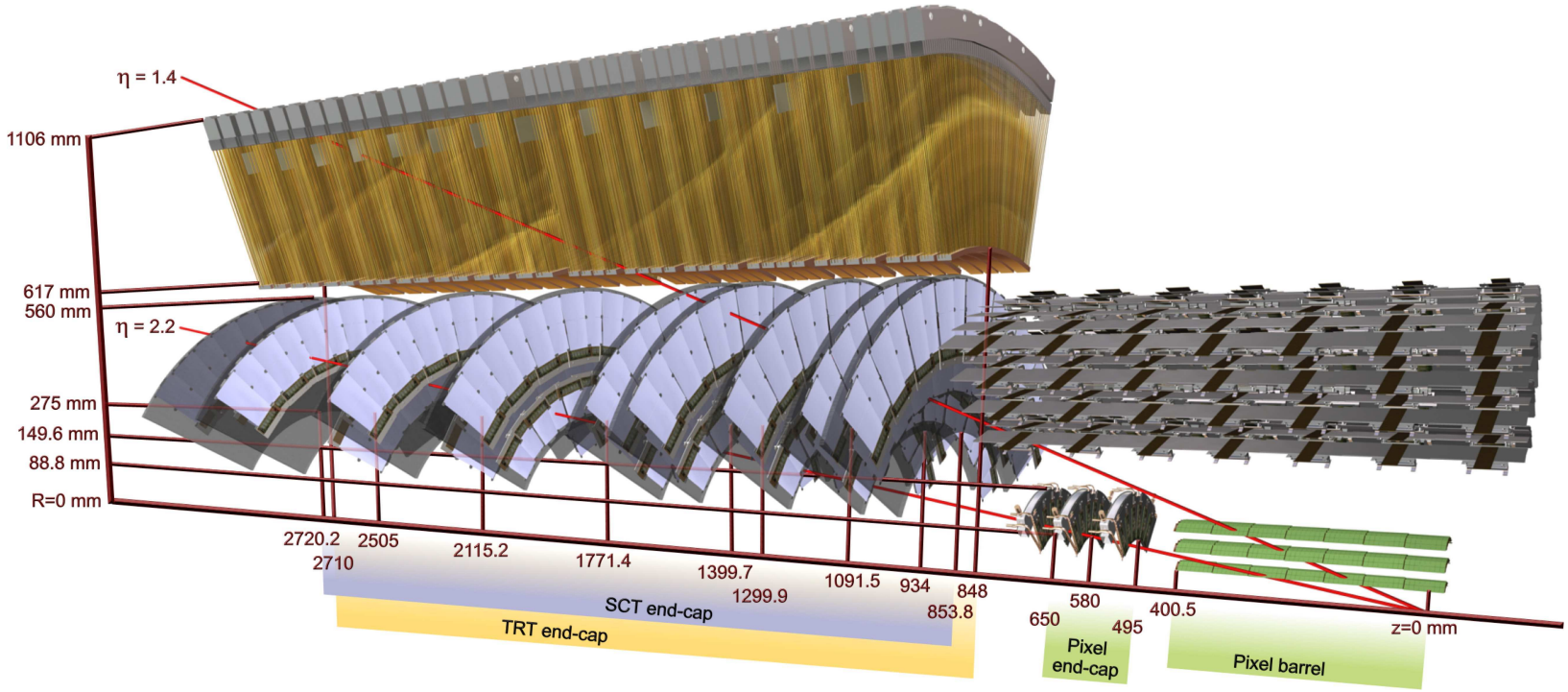


- 2.7σ from DHMV prediction in P_4' and P_5', 1.9σ in P_8' one bin each
- confirms discrepancy in P_4' observed by LHCb

Silicon strip detectors

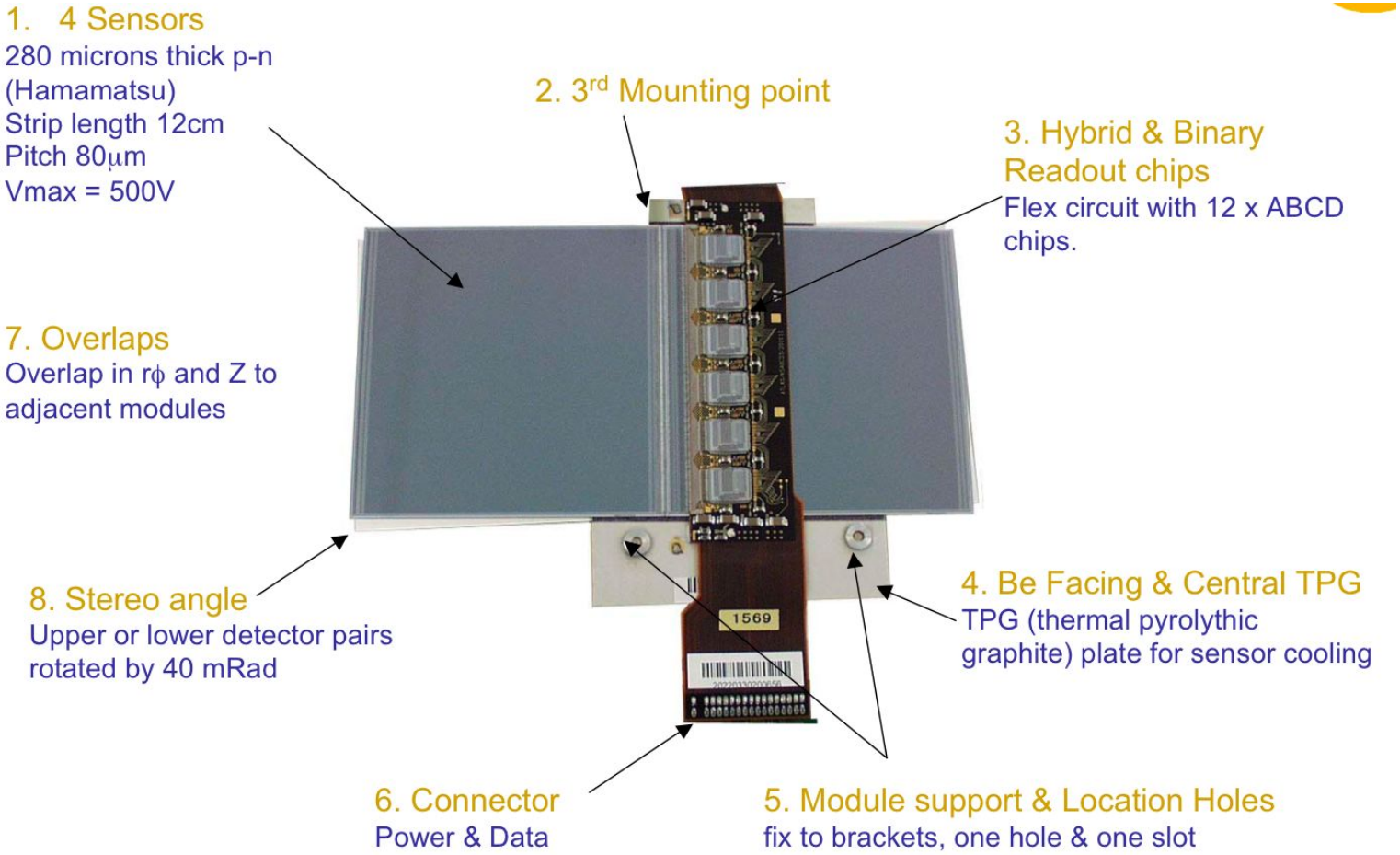
ATLAS SemiConductor Tracker

- silicon strip tracker with 4088 double-sided modules, 60 m^2 of silicon



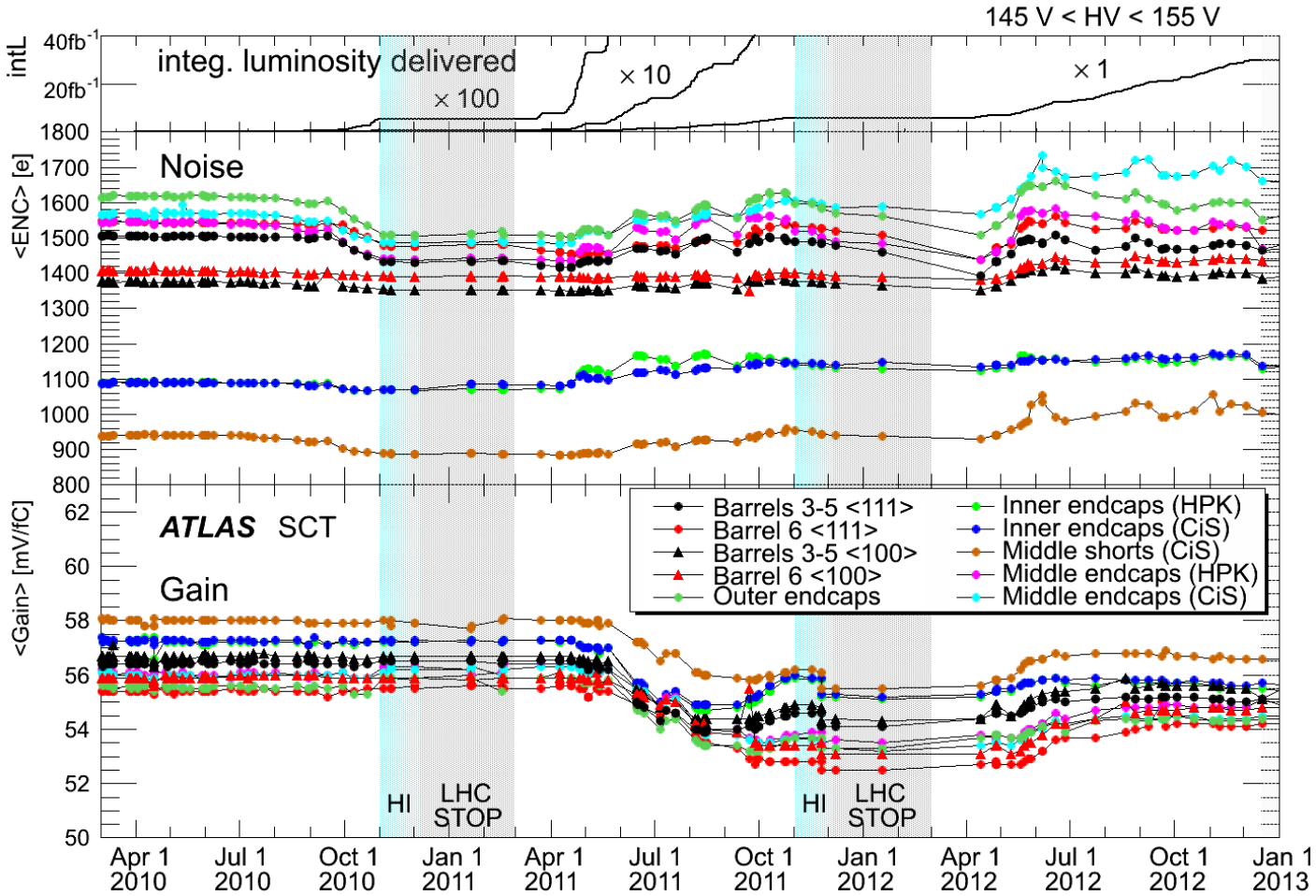
ATLAS SemiConductor Tracker

- silicon strip tracker with 4088 double-sided modules, 60 m^2 of silicon
- p^+-in-n Hamamatsu and CiS sensors, bias voltage 150 V
- 6.3M channels with binary readout



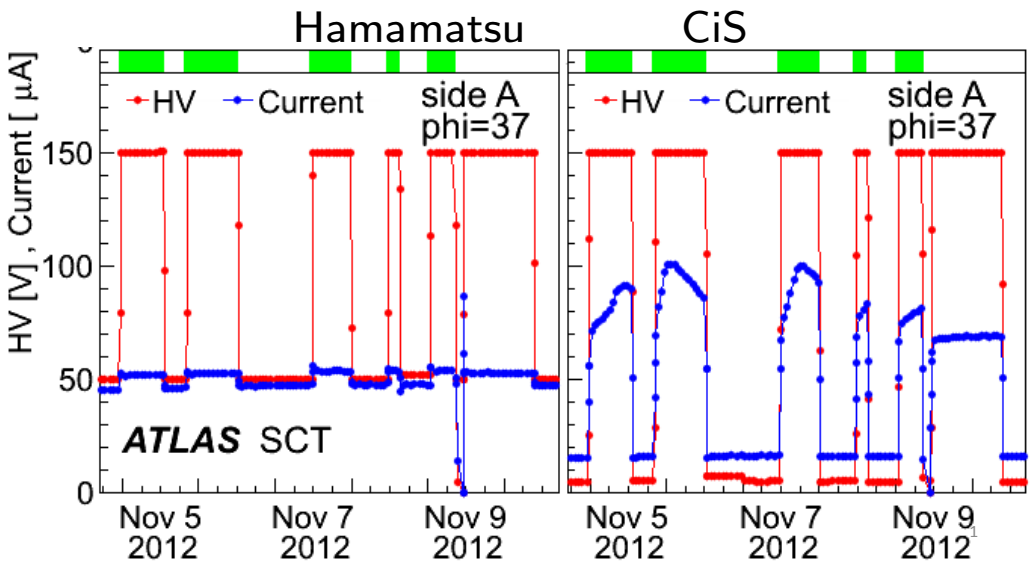
ATLAS SCT

- served as SCT on-call expert for DCS and DAQ (2011-13) and DQ expert
- some of observed issues:
  - unexpected changes of noise and gain due to radiation damage



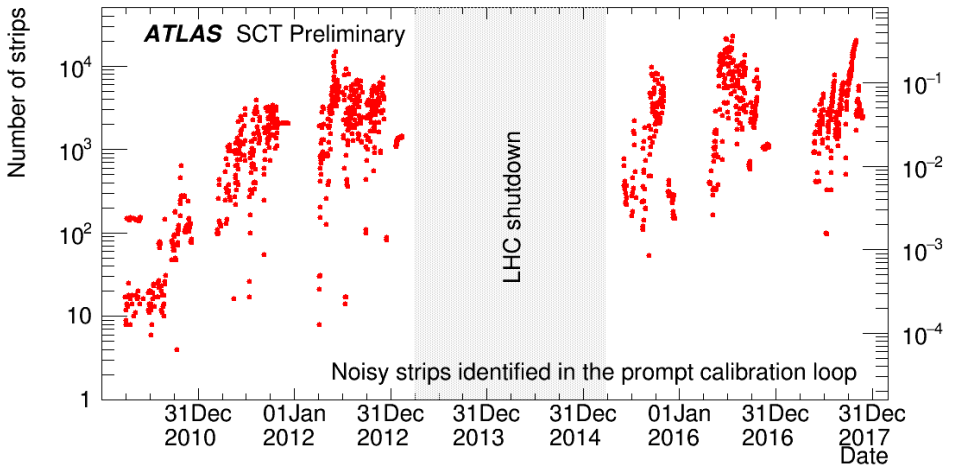
ATLAS SCT

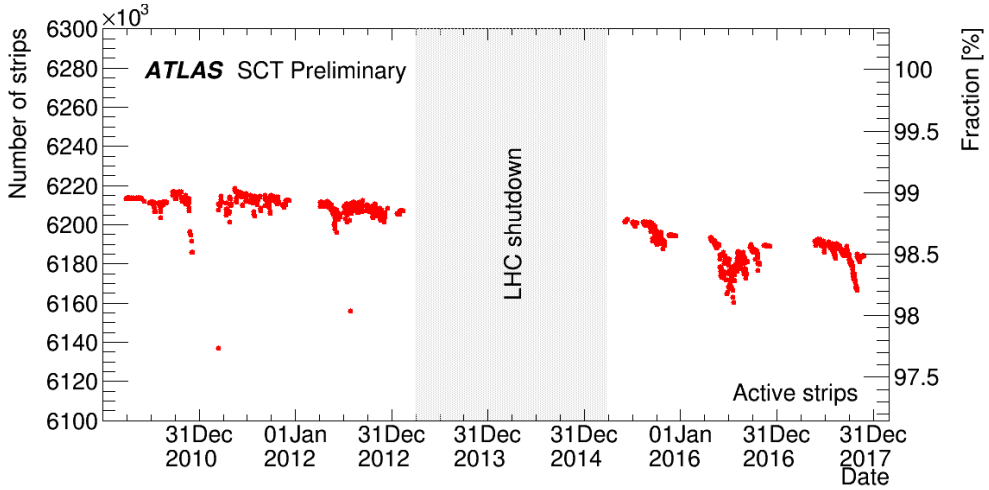
- served as SCT on-call expert for DCS and DAQ (2011-13) and DQ expert
- some of observed issues:
  - unexpected changes of noise and gain due to radiation damage
  - high leakage current and noise bursts causing busy DAQ for CiS sensors



ATLAS SCT

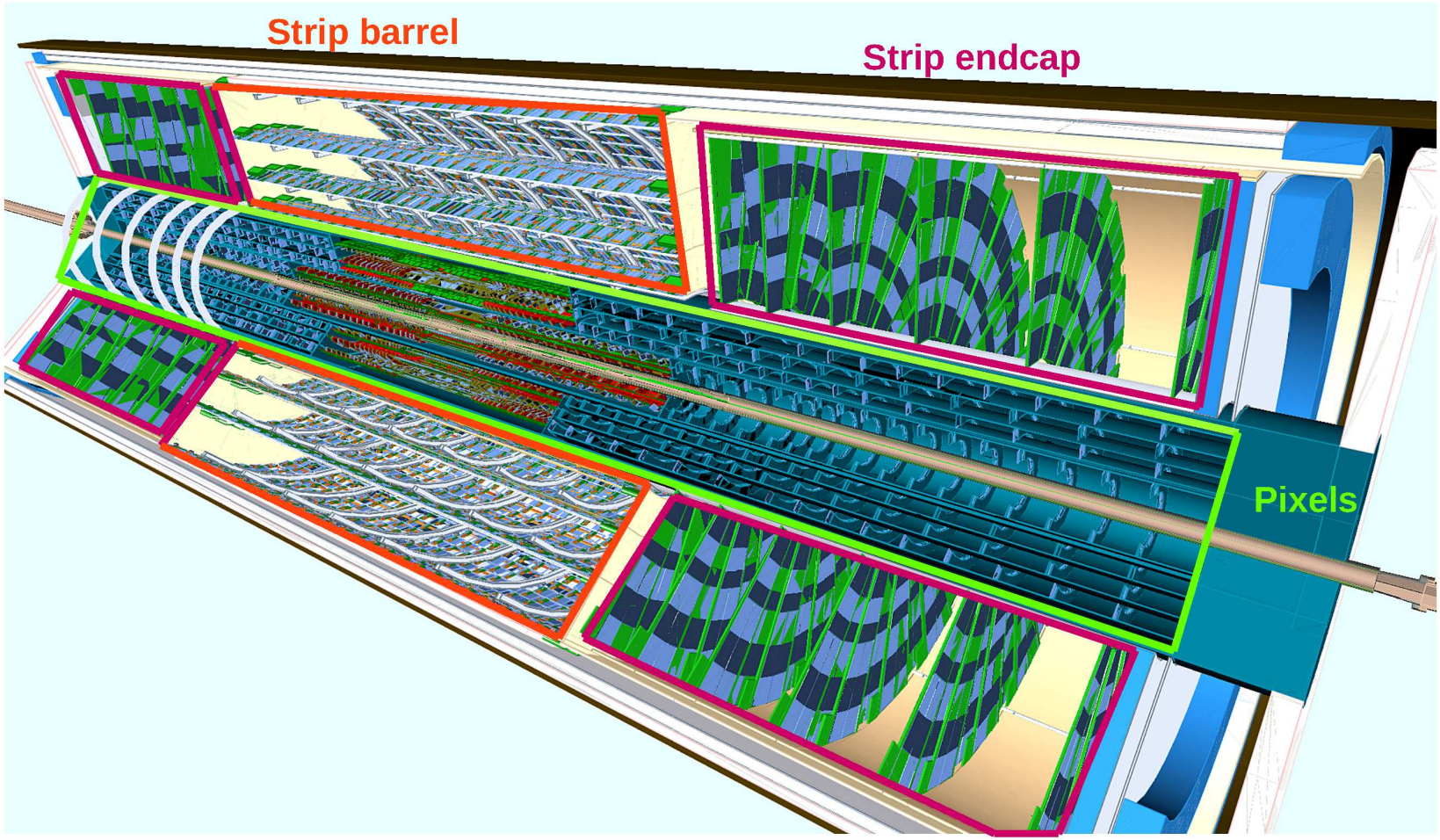
- served as SCT on-call expert for DCS and DAQ (2011-13) and DQ expert
- some of observed issues:
  - unexpected changes of noise and gain due to radiation damage
  - high leakage current and noise bursts causing busy DAQ for CiS sensors
  - failures of off-detector optical transmitters (TX VCSEL) due to humidity - twice changed the supplier (True-light $\rightarrow$ AOC $\rightarrow$ LightABLE)
  - high luminosity and trigger rate $\rightarrow$ high occupancy $\rightarrow$ problems with DAQ
- continuous improvements
  - extend readout during LS1 (add off-detector readout cards)
  - automatise turn on, reconfiguration and recoveries
- performance in Run 2: 99.7% hit efficiency, 99.8% of data good for physics





ATLAS Phase II Upgrade - ITk strip

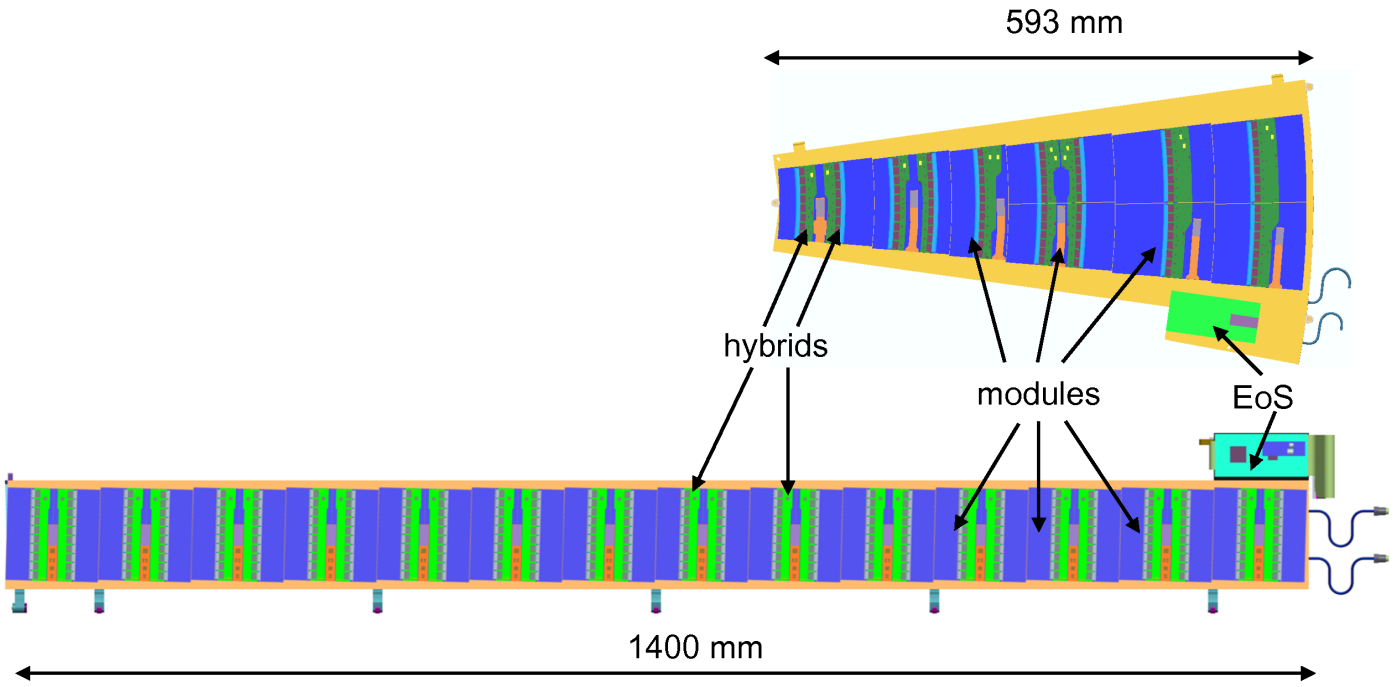
New inner tracker to be installed in LS3 and operate from 2026



ATLAS Phase II Upgrade - ITk strip

New inner tracker to be installed in LS3 and operate from 2026
ITK Strip:

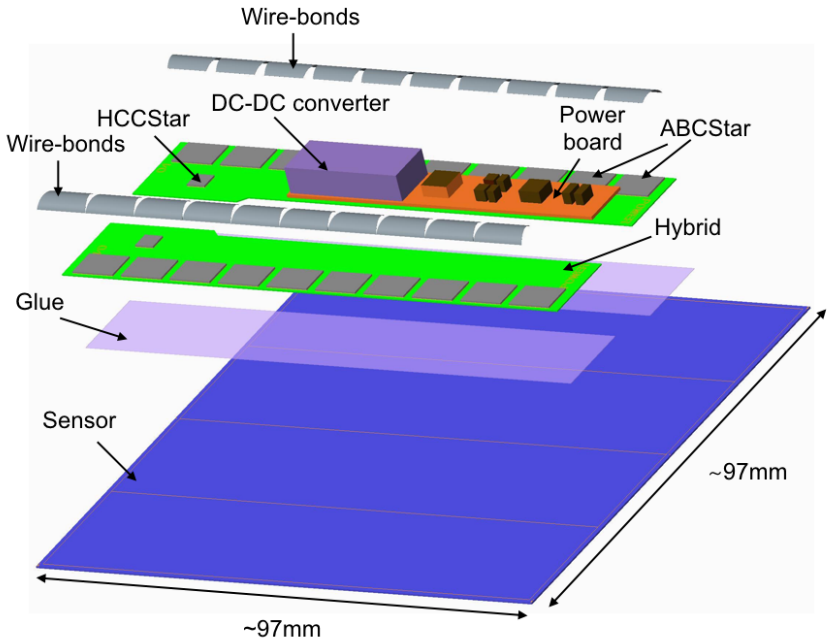
- 4 barrel layers built from staves and 6 endcap disks built from petals

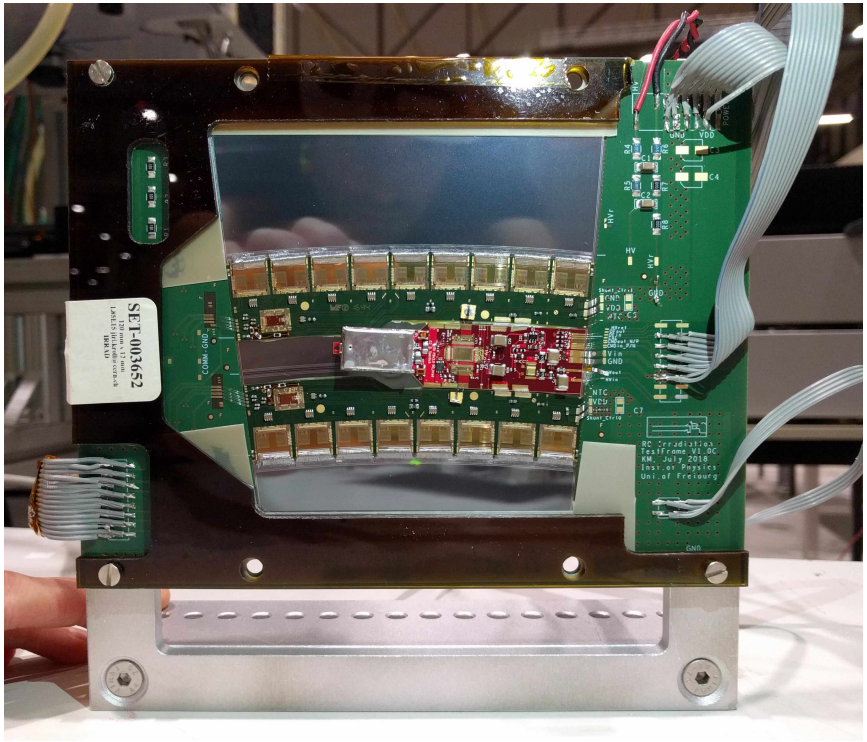


ATLAS Phase II Upgrade - ITk strip

New inner tracker to be installed in LS3 and operate from 2026
ITK Strip:

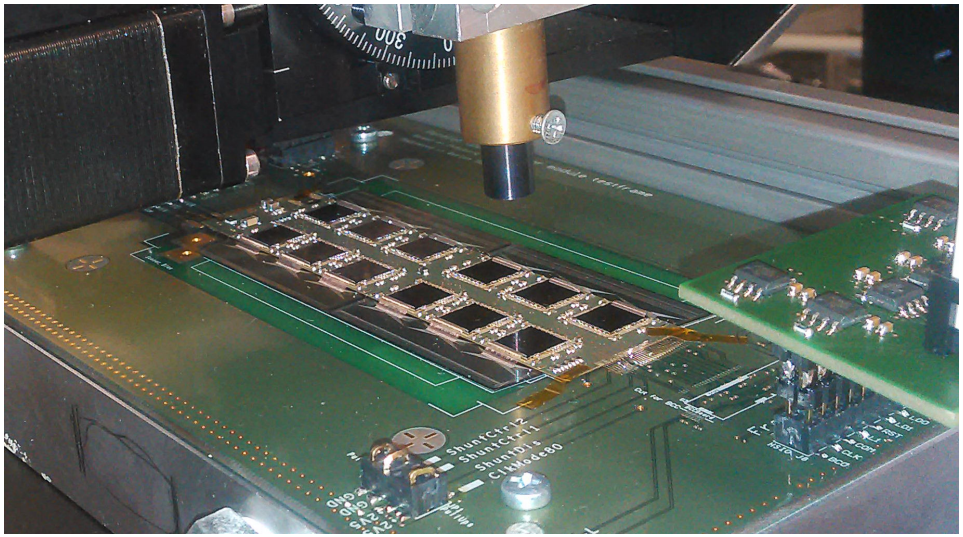
- 4 barrel layers built from staves and 6 endcap disks built from petals
- 1 + 6 module shapes

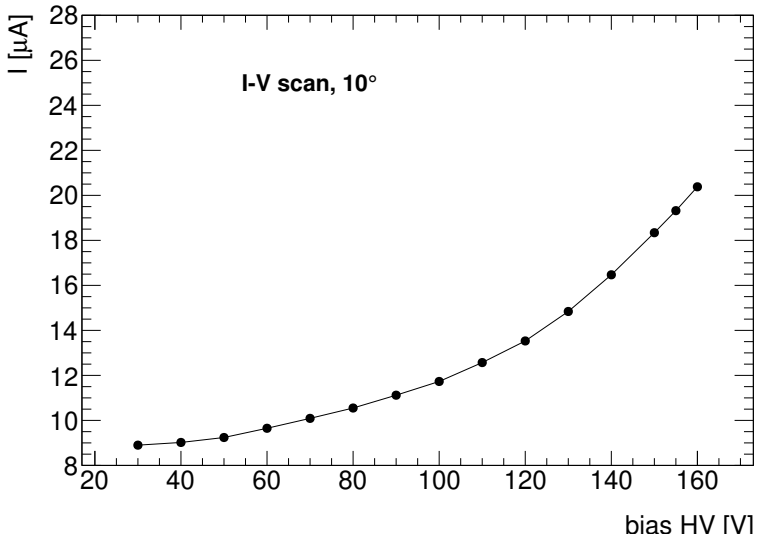


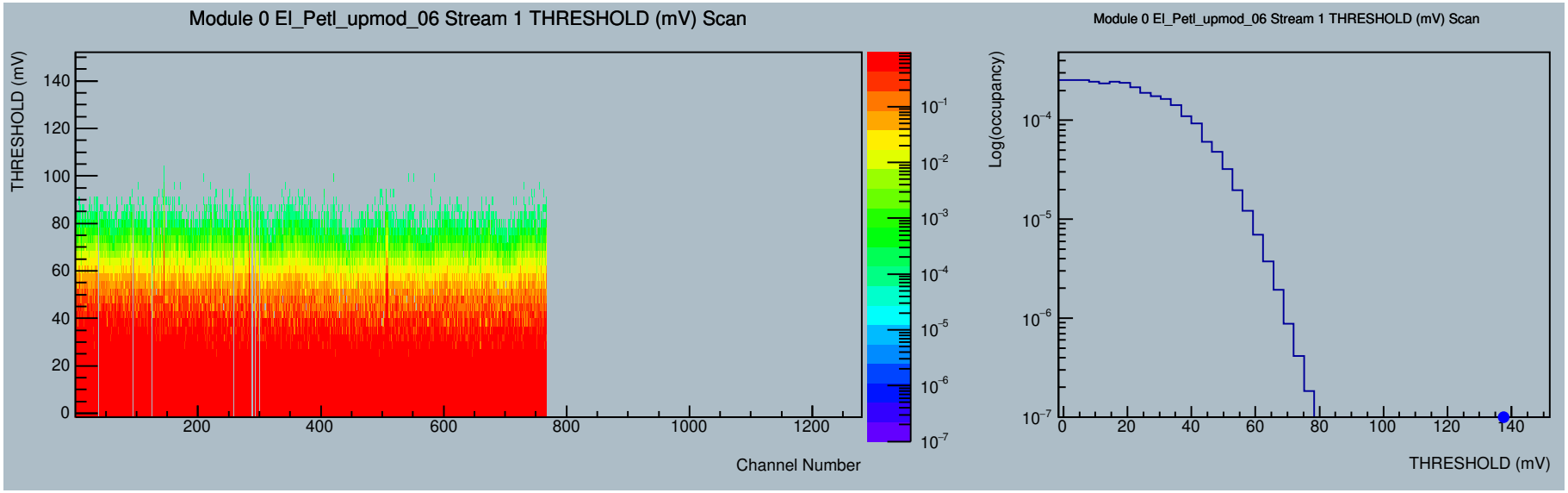


ITk strip

- prototype testing in lab and testbench



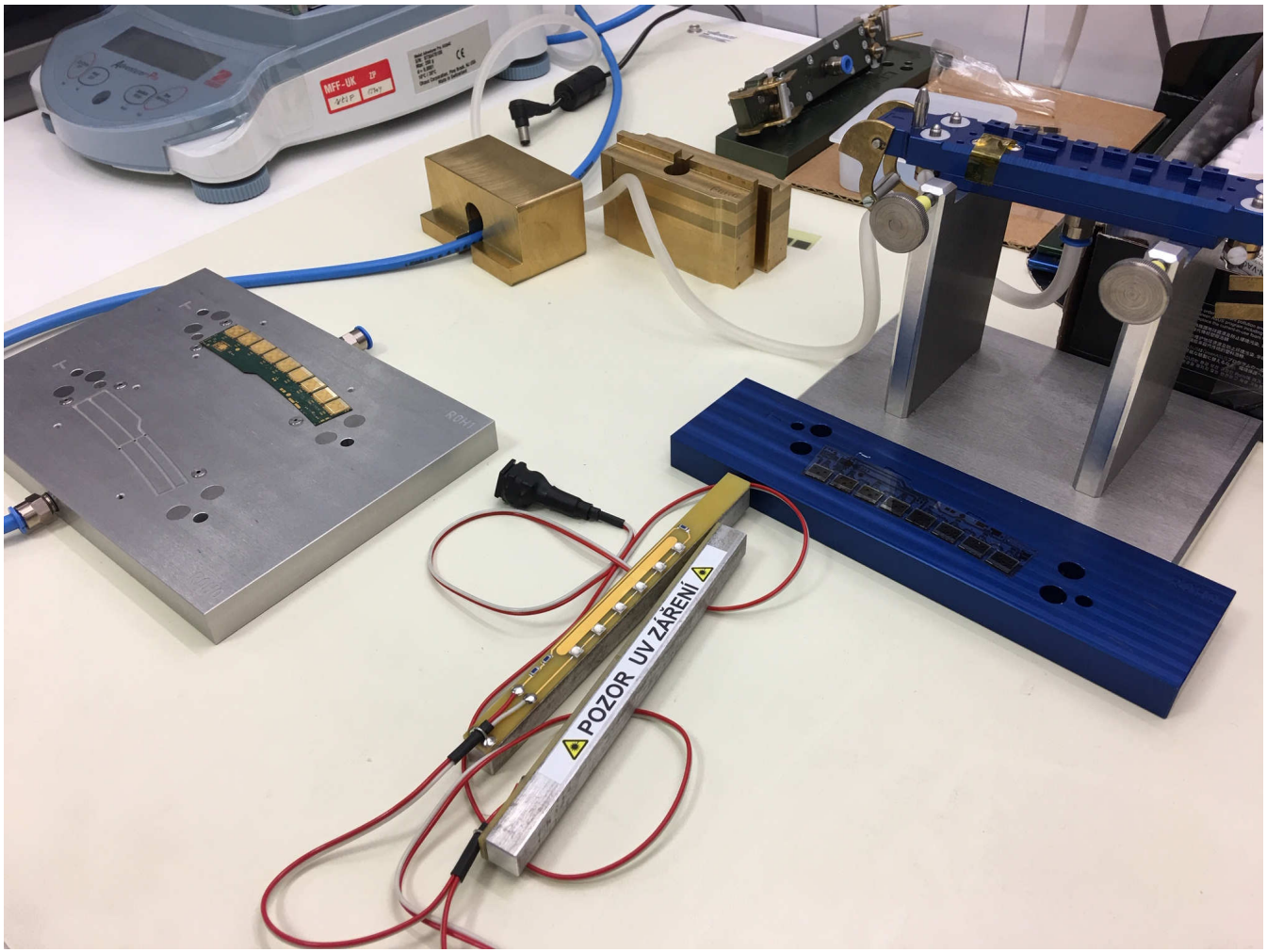




ITk strip

Setting up production site in Czech Republic

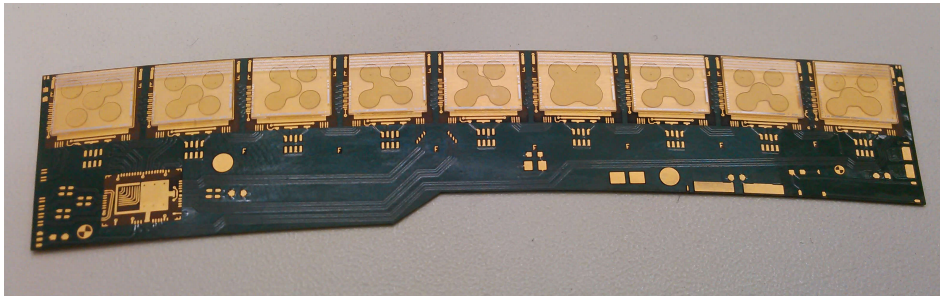
- learn procedures and transfer them to private company
- module assembly - gluing, bonding

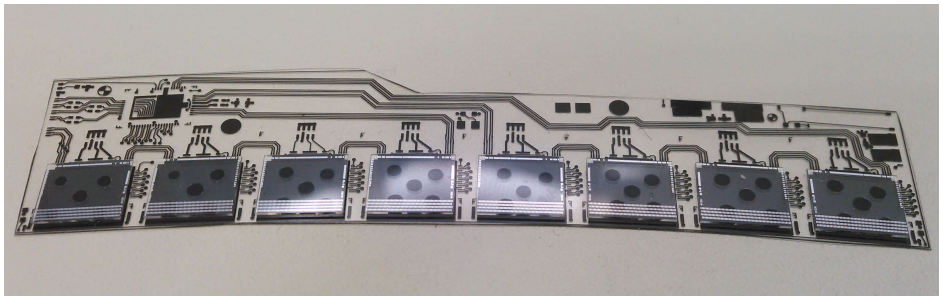


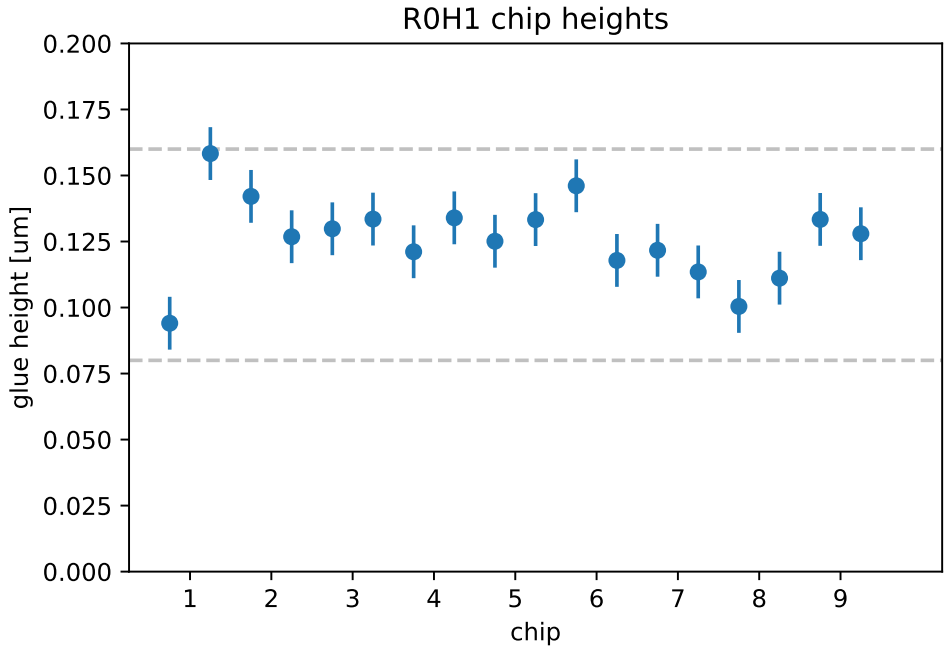
ITk strip

Setting up production site in Czech Republic

- learn procedures and transfer them to private company
- module assembly - gluing, bonding
- metrology, QA/QC







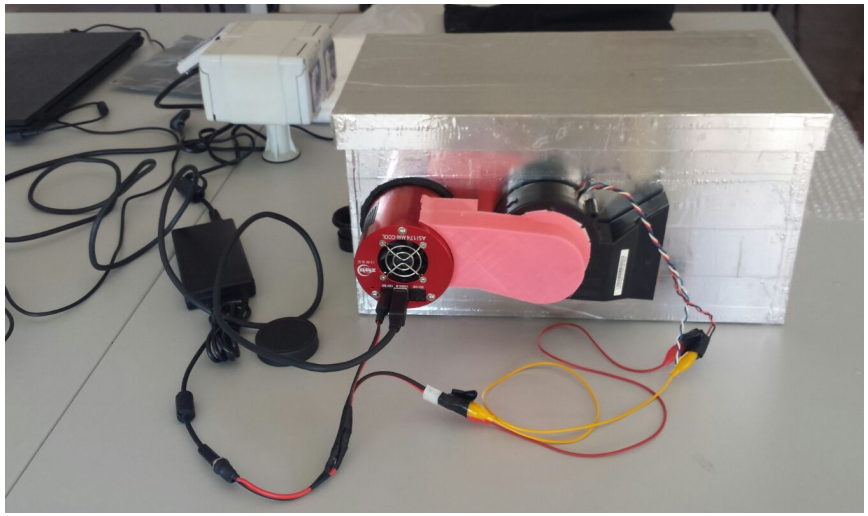
Other work

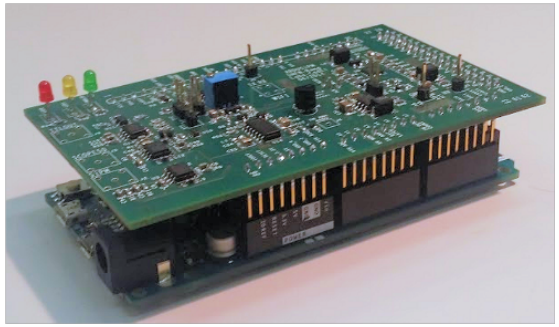
Beamline for Schools 2017 and 2018

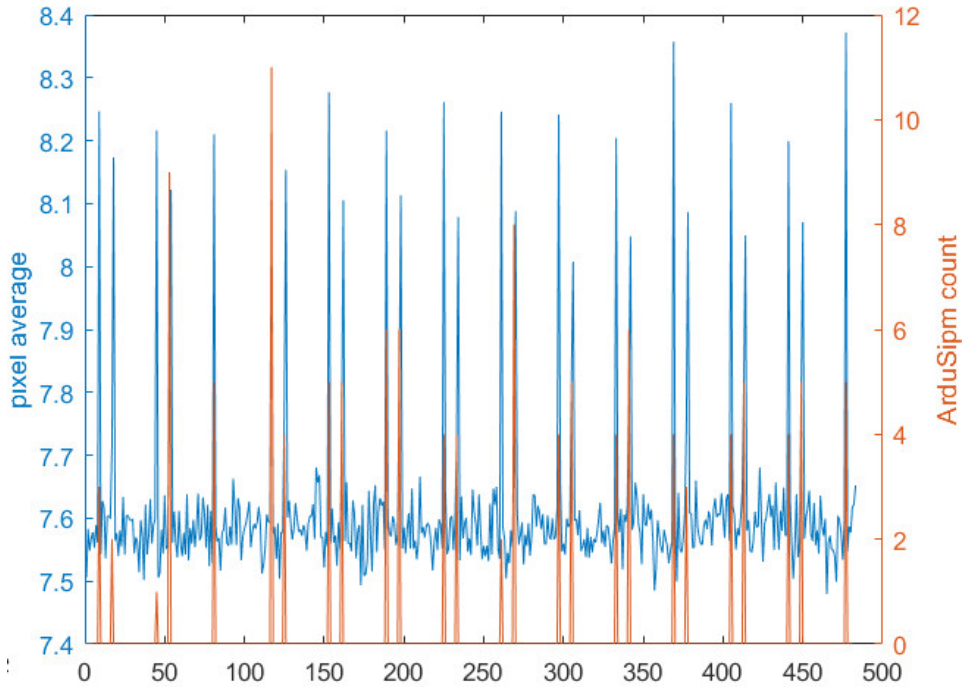
Support scientist tasks:

- prepare and calibrate detectors, Micromegas construction in 2017
- select and prepare two experiments proposed by high-school students
- setup: trigger (NIM), readout (ATLAS TDAQ)
- testbeam and data taking (CERN PS T9, mixed beam)
- help students with data analysis and paper writing

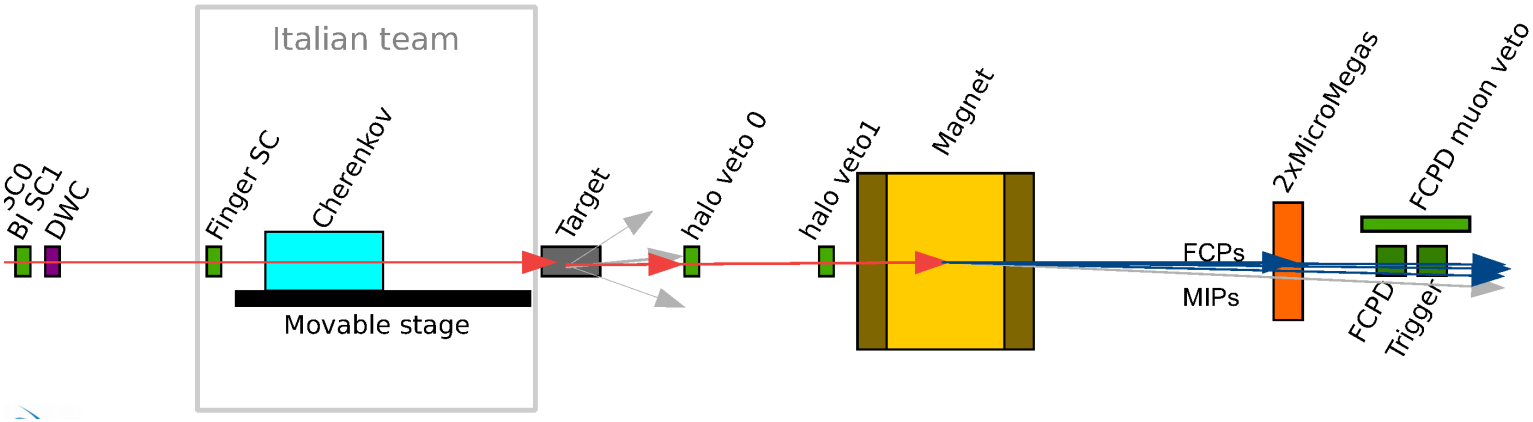
2017 experiment: student-built Cherenkov detector

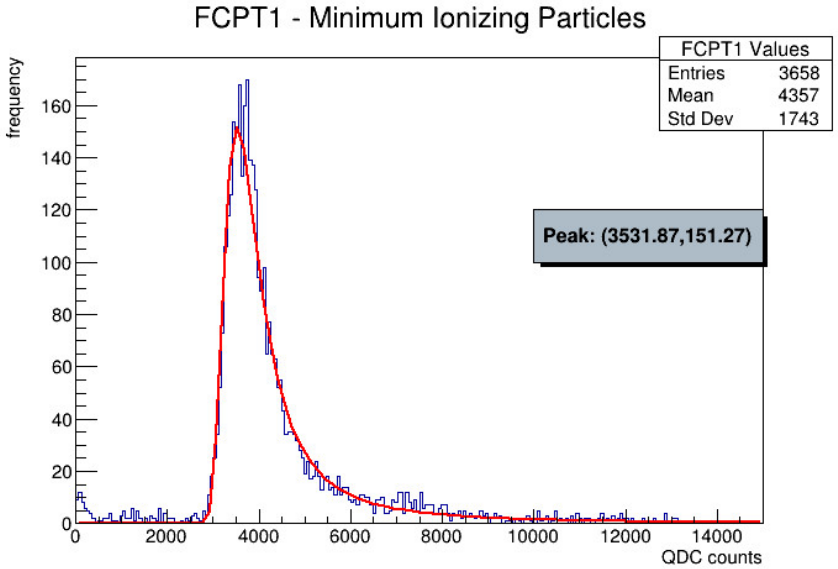


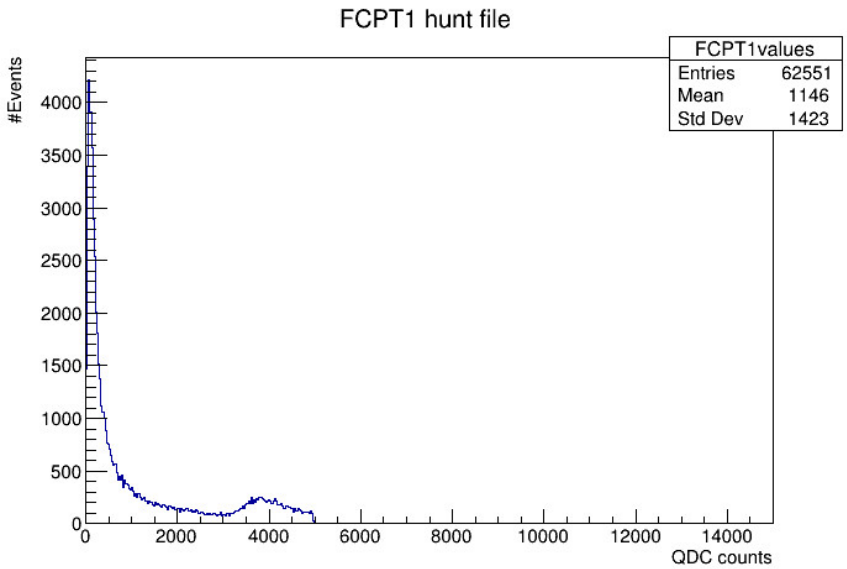




2017 experiment: search for fractionally charged particles



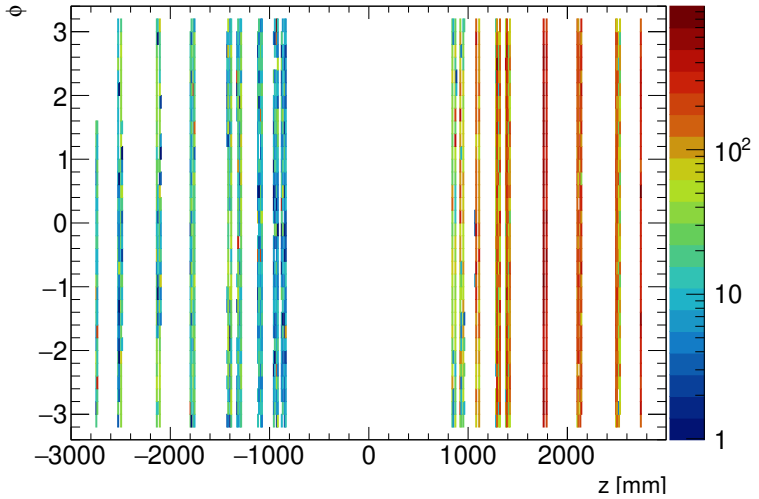


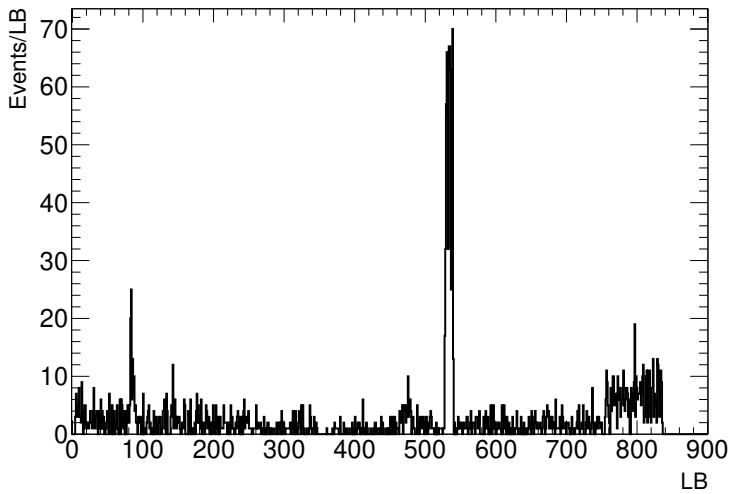


ATLAS beam background monitoring

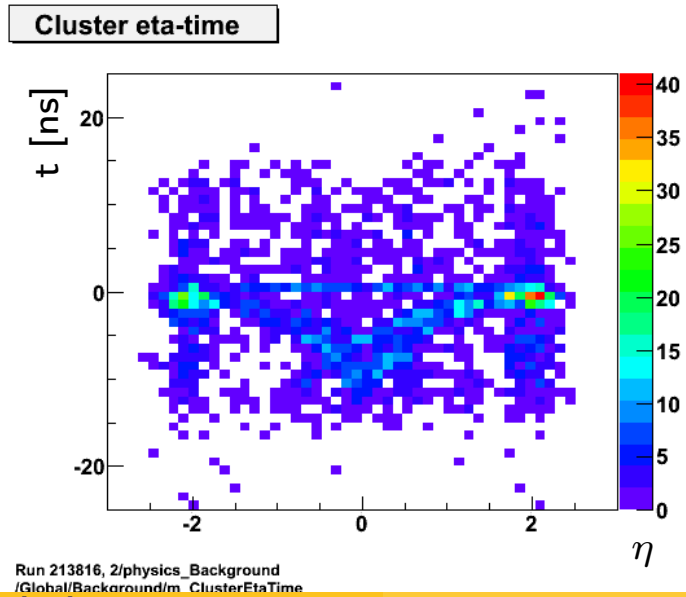
Implementation of online and offline monitoring for beam and cosmic background

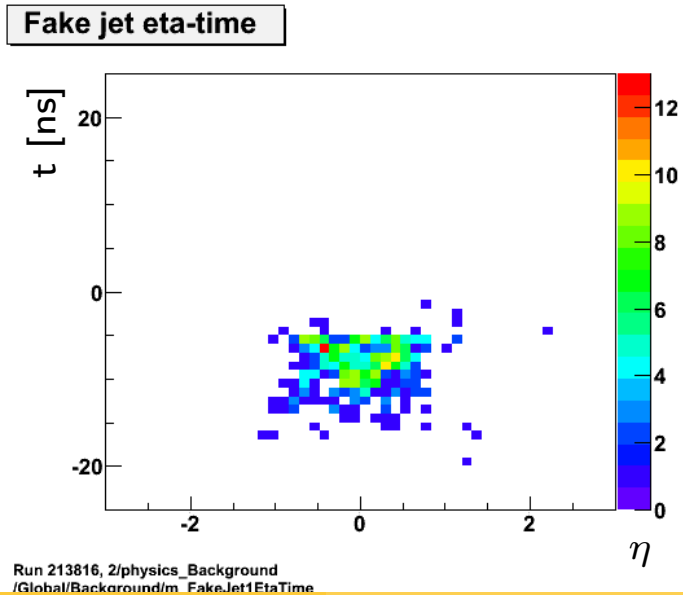
- SCT early hits asymmetry





- calorimeter clusters eta-time, fake jets, etc.





Research interests and plans

Detector:

- contribute to construction, integration and commissioning of LHCb Upstream Tracker
- learn more about specific readout, experiment control system and trigger
- operation, performance studies, input for tracking etc.

Physics analysis:

- continue in B-physics
- interested in rare decays, search for new exotic hadron states

Other:

- student mentoring and outreach

Backup slides

$B_d \to K^* \mu^+ \mu^-$ reconstruction and selection

- preselection: track p_{T}, ID hits, min. 1 combined muon
- baseline: $|\eta| < 2.5$, $m(K^*) = [846, 946]$ MeV, $m(B) = [5150, 5700]$ MeV
  $p_{\mathrm{T}}(\mu) > 3.5$ GeV, $p_{\mathrm{T}}(\pi, K) > 0.5$ GeV
- final cuts: $\sigma_\tau/\tau > 12.75$, pointing $\cos\theta > 0.999$, $\chi^2/ndf(B) < 2$, $p_{\mathrm{T}}(K^*) > 3$ GeV,
  $|(m(B) - m_{PDG}(B)) - (m(\mu\mu) - m_{PDG}(J/\psi))| < 130$ MeV
- trigger - 15 most frequent triggers
- signal q^2= [0.04,6] GeV^2 except of ϕ region q^2= [0.98,1.1] GeV^2
- control regions: J/ψ (q^2= [8,11] GeV^2), $\psi(2S)$ (q^2= [12,15] GeV^2)
- if > 1 candidate/event: candidate with higher $\sigma_m(K^*)/m(K^*)$

$B_d \to K^* \mu^+ \mu^-$ systematics

Largest systematic uncertainties across q^2 bins for F_L and S_i

Source	F_L	S_3	S_4	S_5	S_7	S_8
Background peaking in $\cos\theta_K$	0.03	0.03	0.05	0.04	0.06	0.16
Background peaking in $\cos\theta_\ell$	0.11	0.04	0.05	0.04	0.01	0.06
Background from Λ_b, B^+ and B_s^0	0.01	0.01	0.01	0.01	0.01	0.01
Combinatorial background PDF shape	0.04	0.04	0.03	0.03	0.03	0.01
Acceptance functions	0.01	0.01	0.07	0.01	0.01	0.01
Mass fit range	0.03	0.05	0.02	0.08	0.05	0.06
Data/MC differences in p_{T}	0.02	0.02	0.01	0.01	0.01	0.01
Alignment and tracking (B field)	0.02	0.04	0.05	0.04	0.04	0.04
Intrinsic fit bias	0.01	0.01	0.02	0.03	0.01	0.05
Non-resonant $B^0 \to K^+\pi^-\mu^+\mu^-$	0.01	0.01	0.01	0.01	0.01	0.03
Nuisance parameters	0.01	0.01	0.01	0.01	0.01	0.01
Wrong flavour tag	0.01	0.01	0.01	0.01	0.01	0.01
Dilution	–	–	–	< 0.01	–	< 0.01

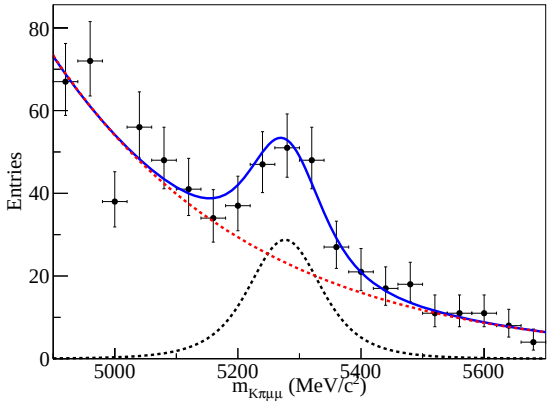
$B_d \to K^* \mu^+ \mu^-$

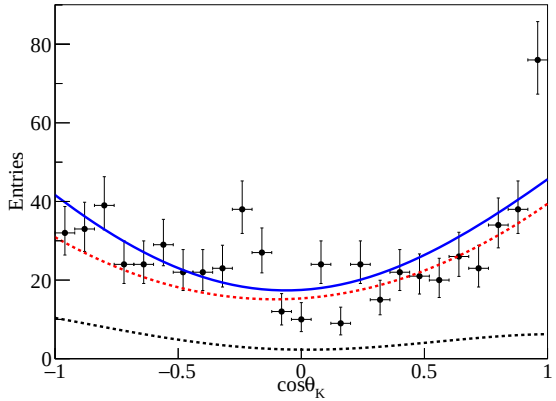
Proposed improvements for Run2 analysis:

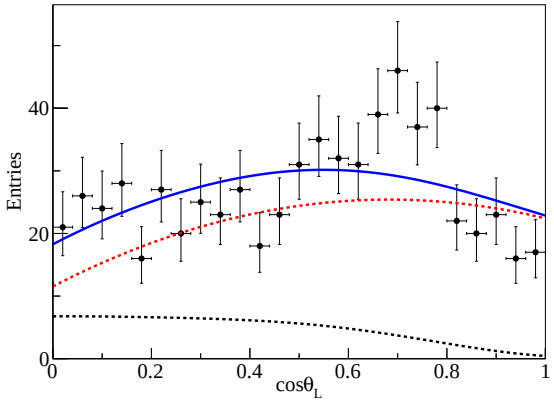
- larger dataset $\to$ full angular and mass fit (non-sequential)
- improve selection - machine learning
- studies of peaking background
- add background components and S-wave in fit
- extend measurements to $B^0 \to K^* e^+ e^-$
- measurement of $R(K^*) = \mathcal{B}(B_d \to K^* \mu^+ \mu^-)/\mathcal{B}(B^0 \to K^* e^+ e^-)$

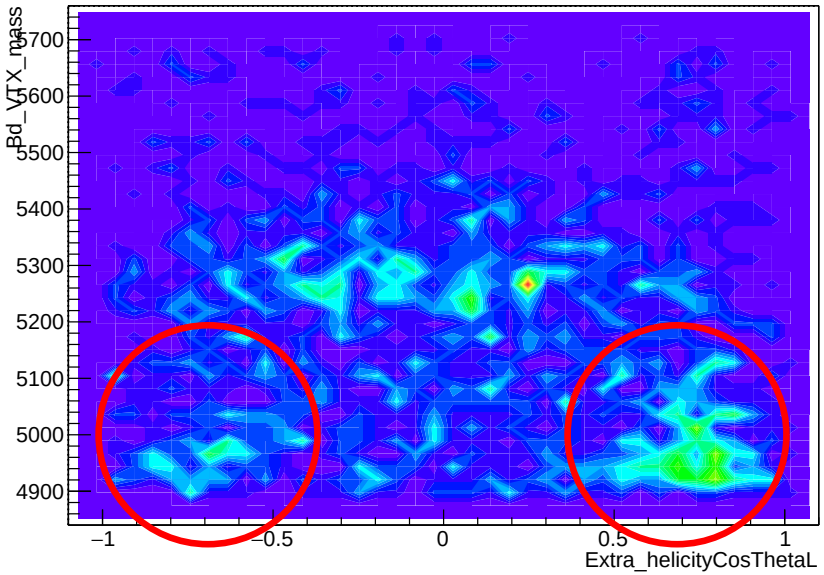
Background

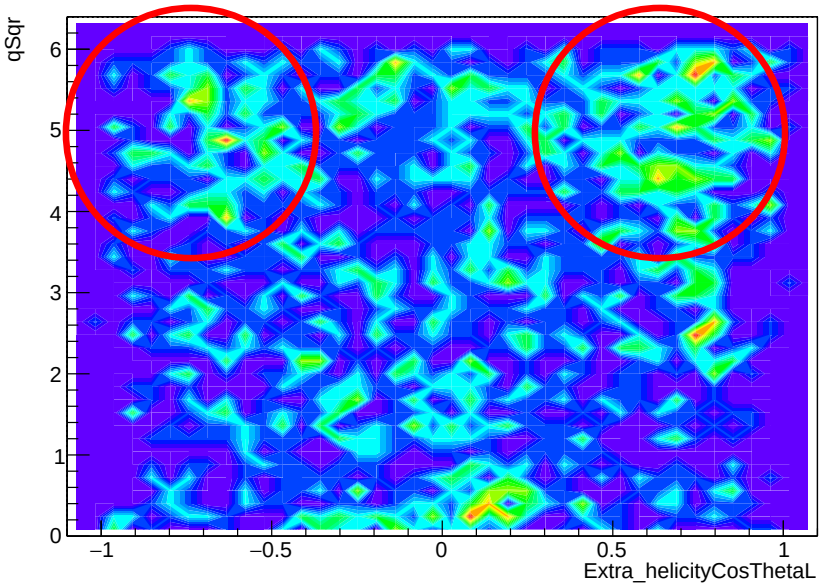
Data q^2= [4,6] GeV^2: background peaking in $\cos\theta_K$ =1 and $|\cos\theta_\ell| = 0.7$





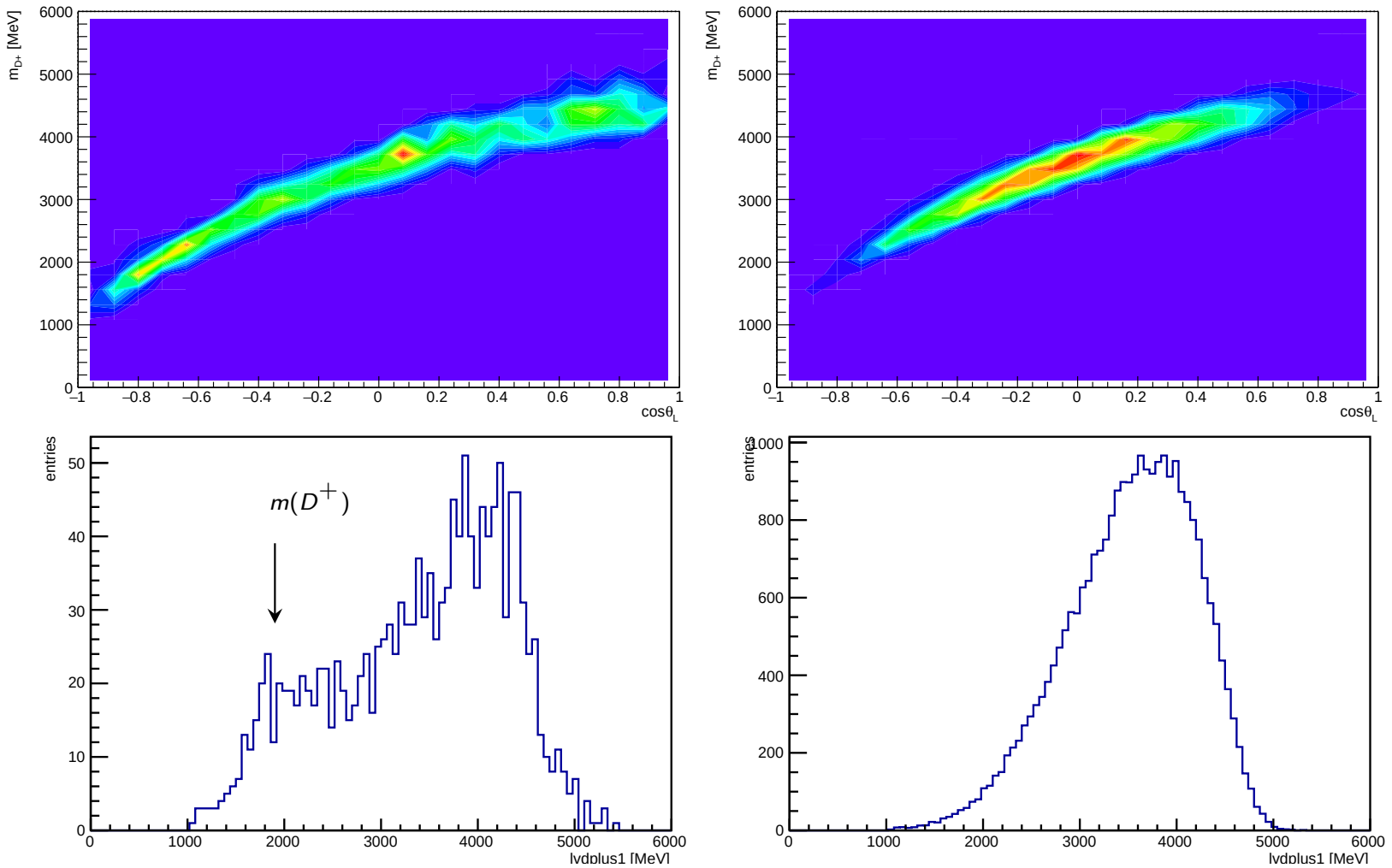






Background: partially reconstructed decays $B \to D \to X$

Example for $m(D^+) = m(K^+, \pi^-, \mu^+_{m=\pi^+})$, data vs. $B_d \to K^* \mu^+ \mu^-$ signal MC

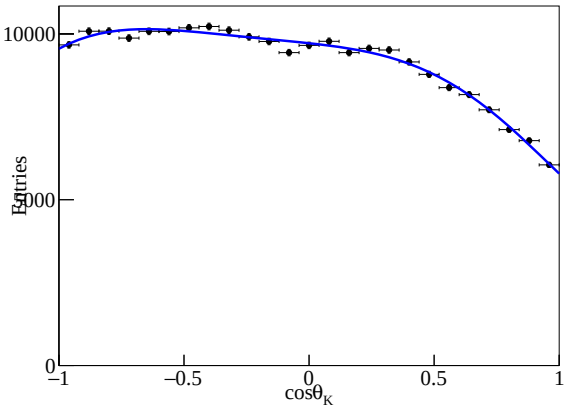


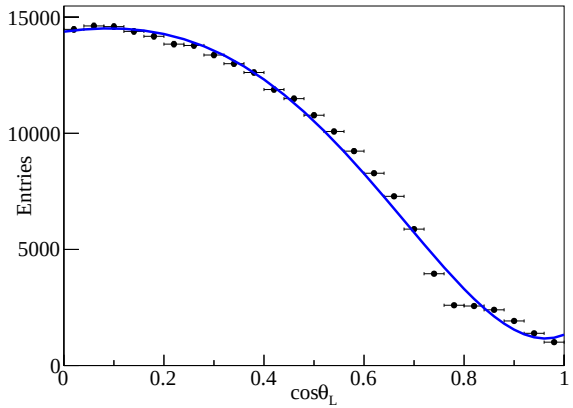
- $D^0 \to K\pi$, $D^\pm \to K\pi\pi$, $D_s^\pm \to KK\pi$, $D_s^{*+} \to KK\pi$
- $B^+ \to K^+\mu^+\mu^-$, $B^+ \to \pi^+\mu^+\mu^-$

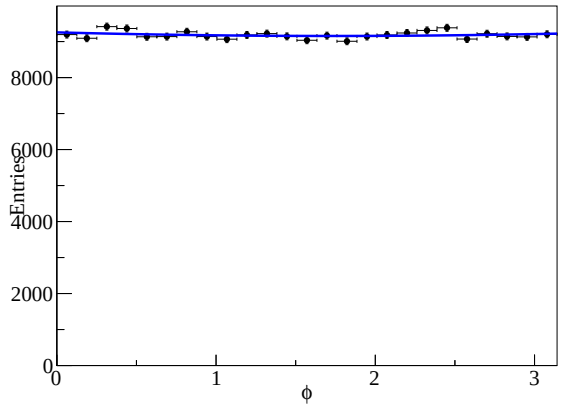
Background

Result:

- apply D veto 30 MeV and B veto 50 MeV around $m(D^{(\pm)})$ or $m(B^{\pm})$
- extract acceptance maps, e.g. q^2= [0.04,6] GeV^2







Decision not to use vetoes in nominal fit

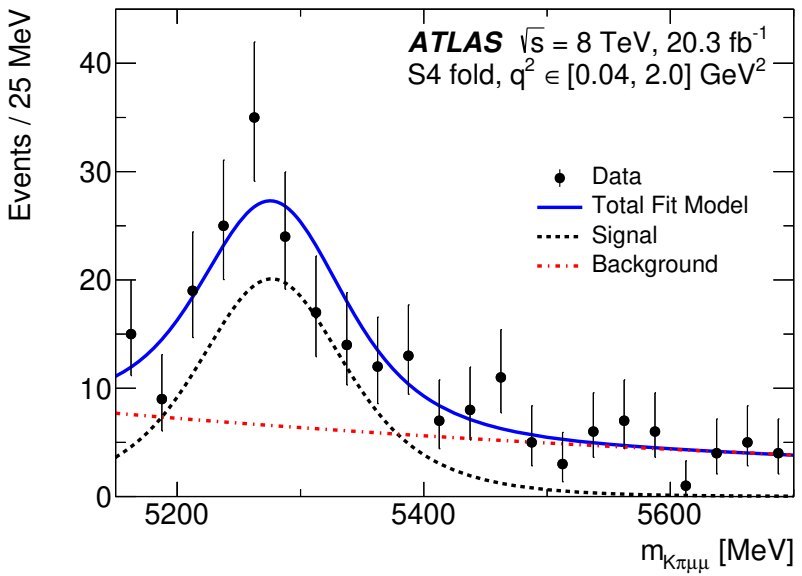
- cut off $m(B)$ =[4900,5150] GeV
- do all angular fits
- difference of fit wrt. nominal fit = systematics
- inclusive $B \to D \to X$ simulated samples needed for Run 2 analysis

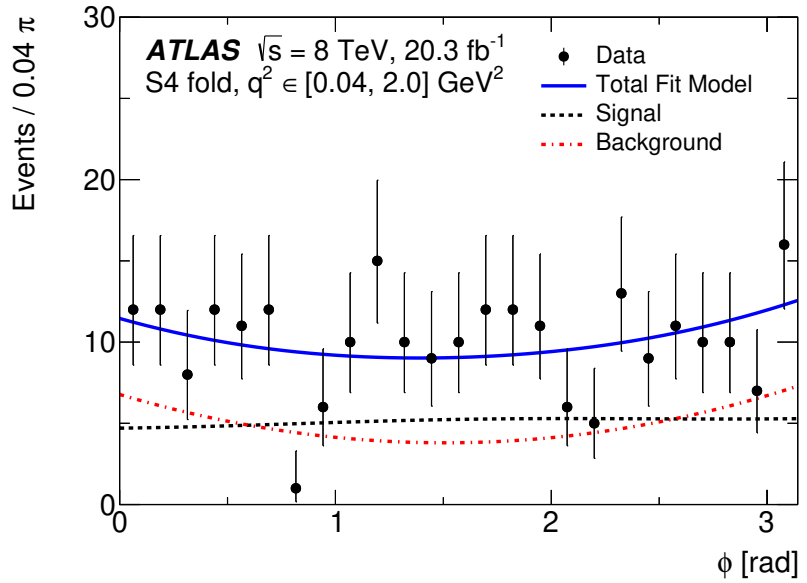
$B_d \to K^* \mu^+ \mu^-$ background: partially reconstructed decays

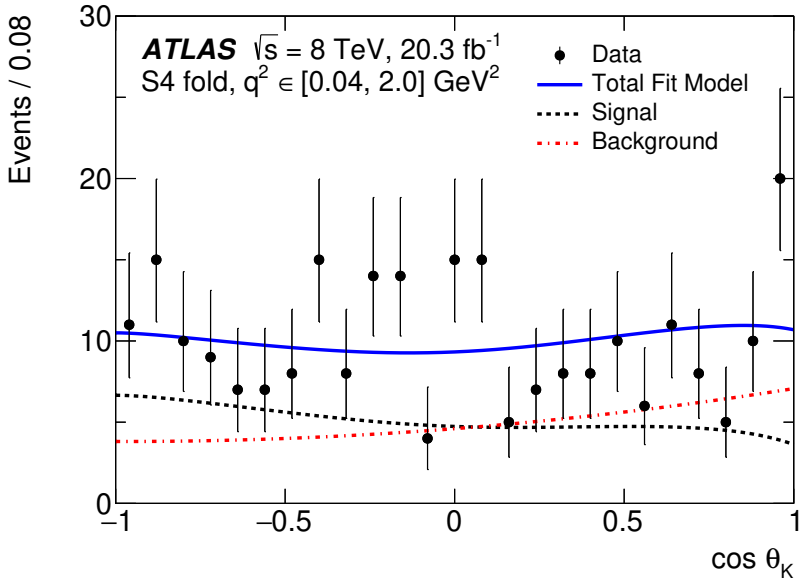
Other checked hypotheses: checked but not found

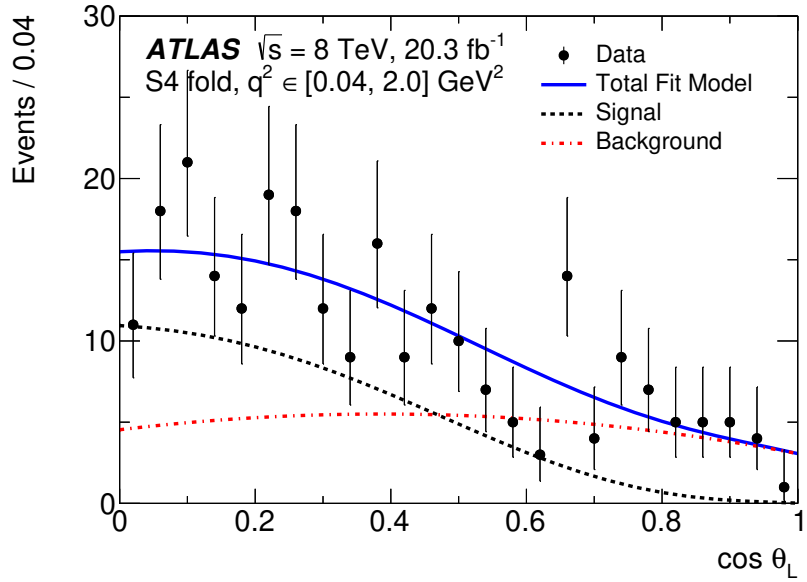
- $B \to J/\psi K^*$ (double-swap) - MC shows isotropic angular distributions
- $B_s \to J/\psi \phi$ - only 1 event
- $B^+ \to K^{*+} \mu\mu$ - MC shows similar angular distributions as signal
- $\Lambda_b \to pK\mu\mu$ and $\Lambda_b \to \Lambda^*(pK)\mu\mu$
- $D \to K\pi\mu\nu$ (bez ν) - covered by D vetoes
- $B \to \Lambda_c^{\pm} \to pK\pi$ - covered by D vetoes
- $B \to \pi\mu\nu$, $B_s \to K\mu\nu$, $\Lambda_b \to p\mu\nu$ - only 1 μ in final state

Fit results: S4, bin q^2= [0.04,2] GeV^2

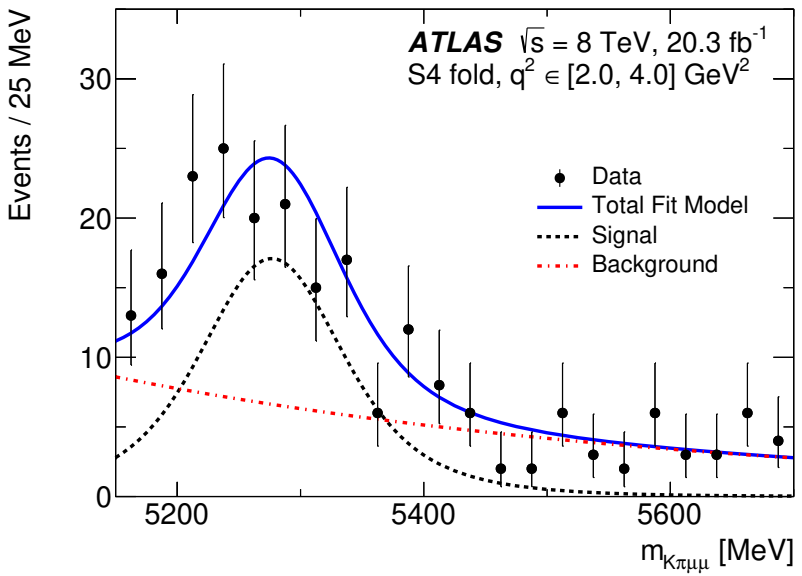


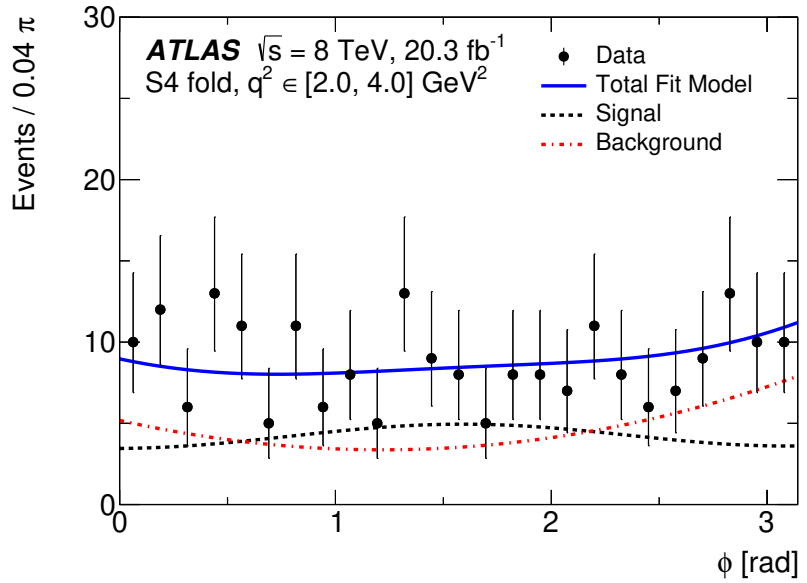


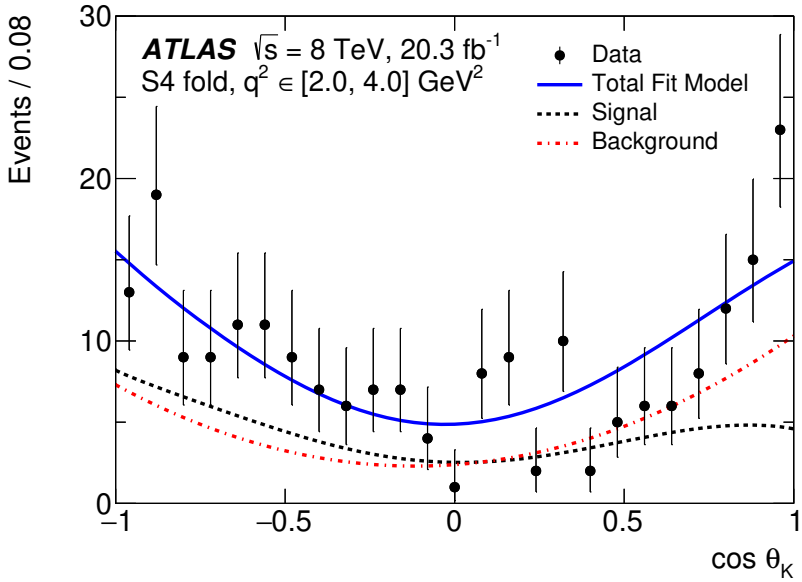


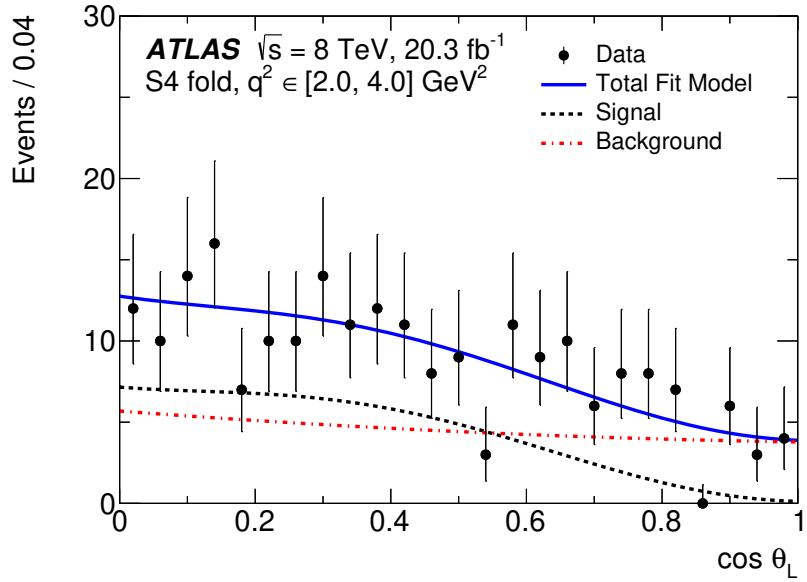


Fit results: S4, bin q^2= [2,4] GeV^2

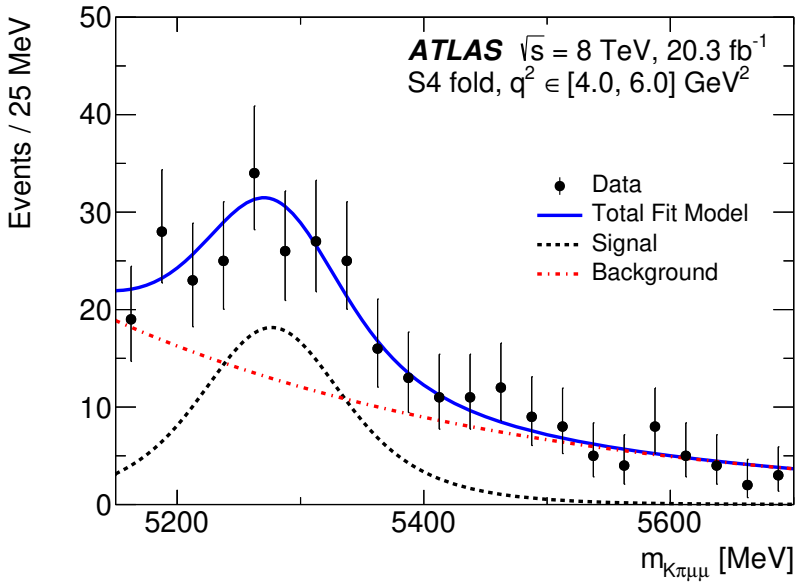


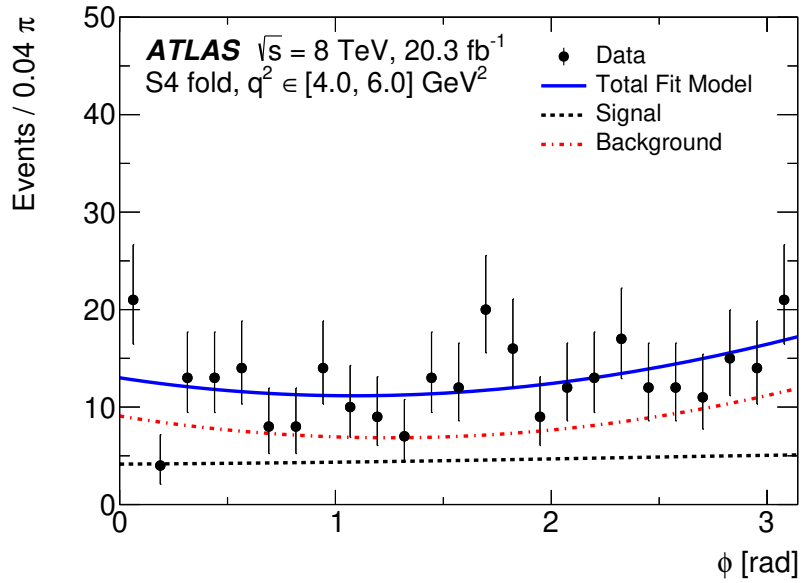


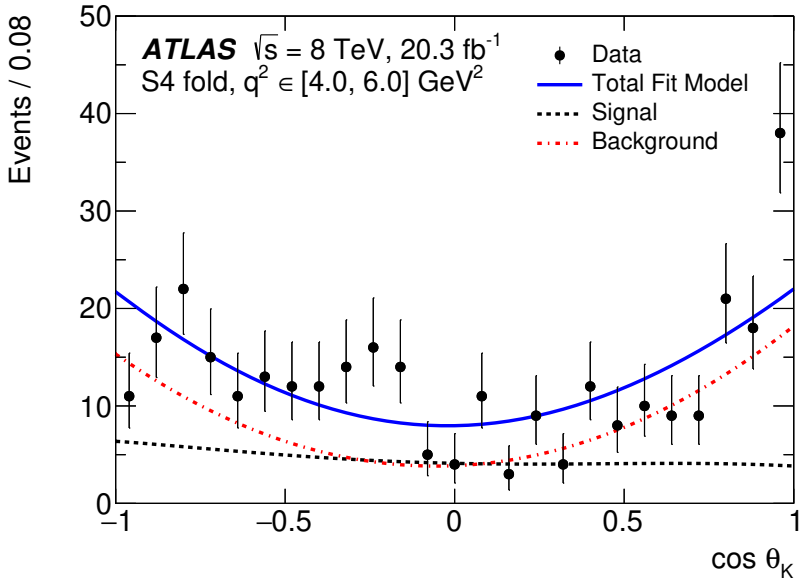


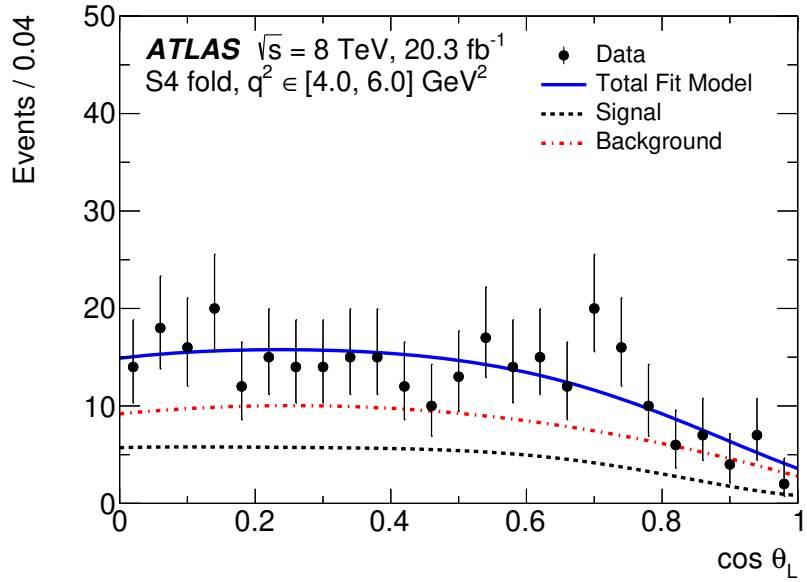


Fit results: S4, bin q^2= [4,6] GeV^2









The ATLAS experiment

- Inner Detector: tracking, vertexing and momentum measurement
  - $|\eta|$ <2.5, $\sigma(d_0) \sim 10\ \mu$m
- Muon Spectrometer: trigger $|\eta|$ <2.4, muon identification $|\eta|$ <2.7

Run1 dataset:
25 fb^{-1} at 7 and 8TeV