Λ_c^+ polarisation measurement in pNe SMOG data

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Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DEGLI STUDI DI MILANO

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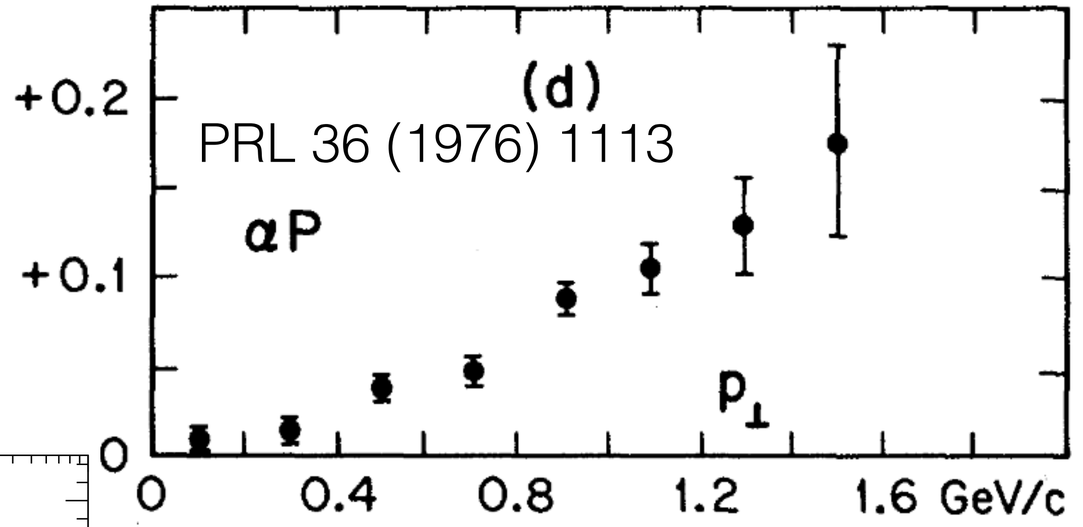
Hyperon Λ^0 polarisation from unpolarised collisions

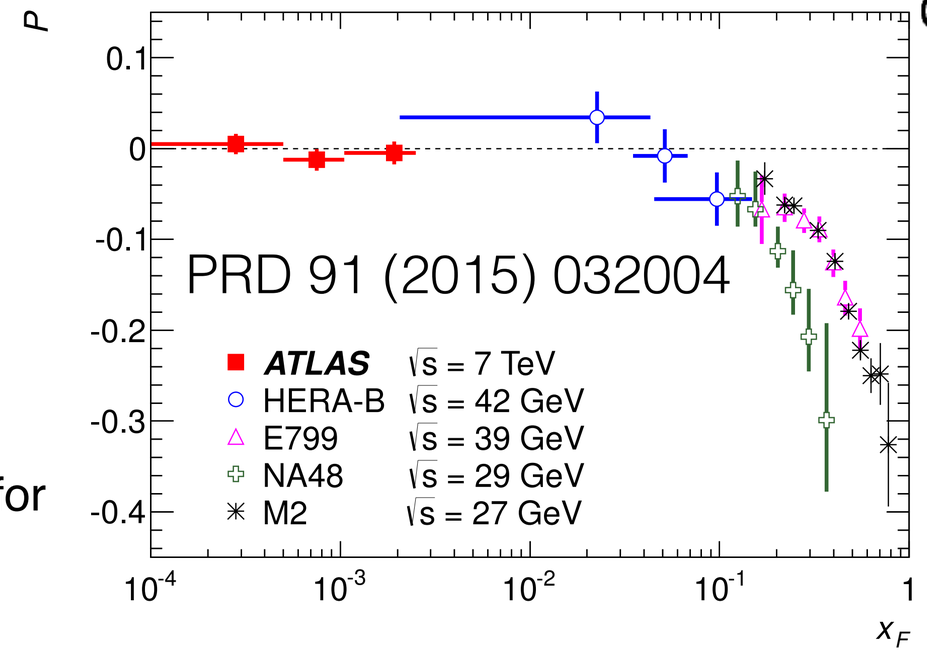
- In 1976 Λ^0 polarization discovery: p+Be, 300 GeV beam
- Polarization transverse to production plane up to ~20% for forward-angle Λ^0production
- Confirmed 1977 at CERN, p+Pt, 24 GeV beam (and by various proton-nucleus and proton-proton experiments afterwards . . .)

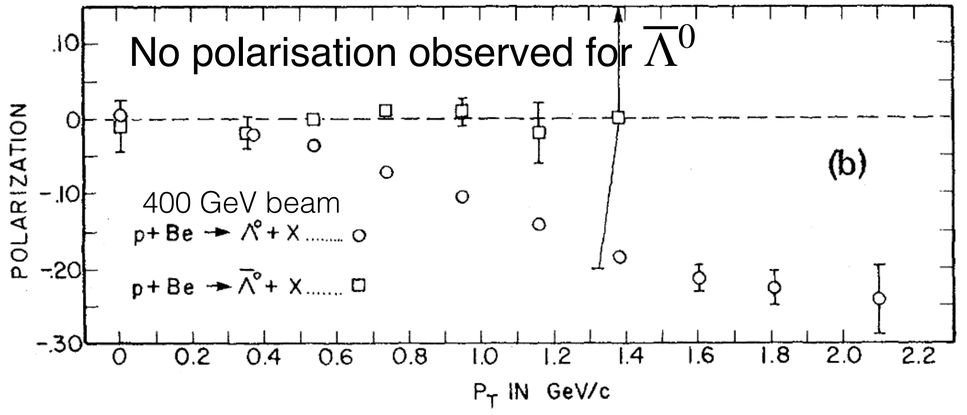


$$x_F = \frac{p_L}{\max p_L} \sim x_1 - x_2$$

p_L in c.m. frame

- Fixed target collisions tests higher x_F wrt pp collisions
- High polarisation observed for $x_F \approx 0.1 - 1$





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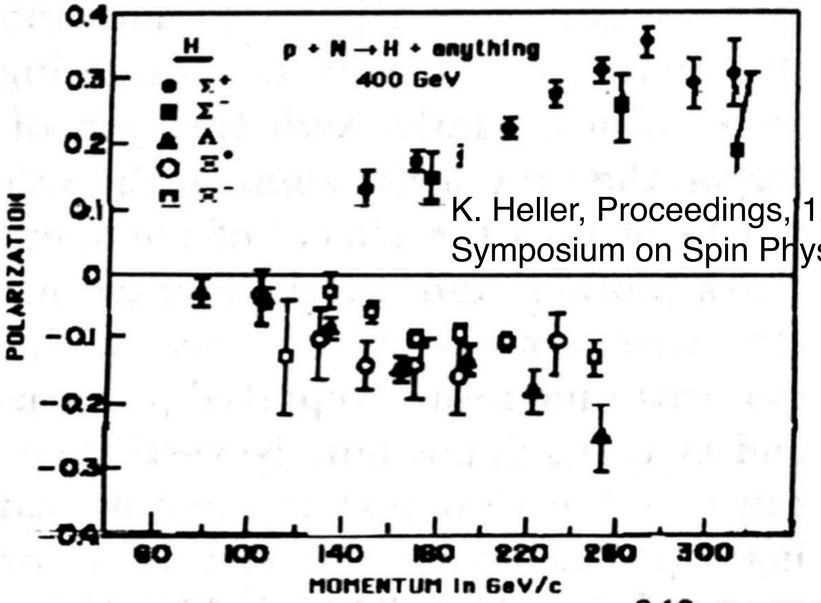
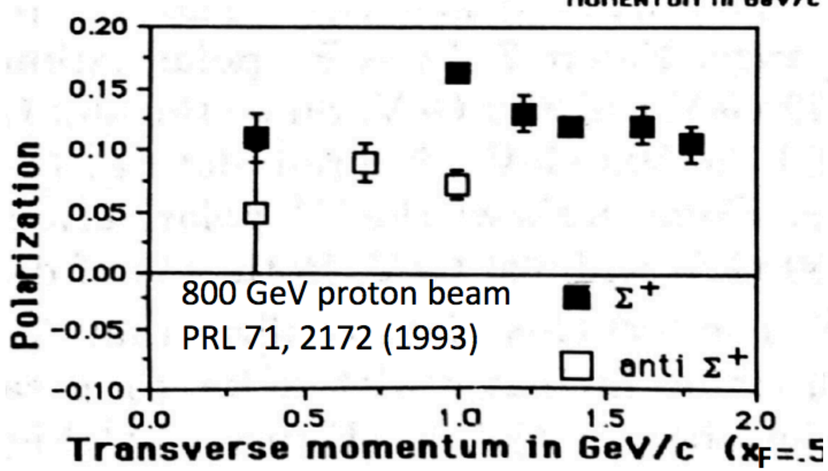
And many other baryons with strangeness

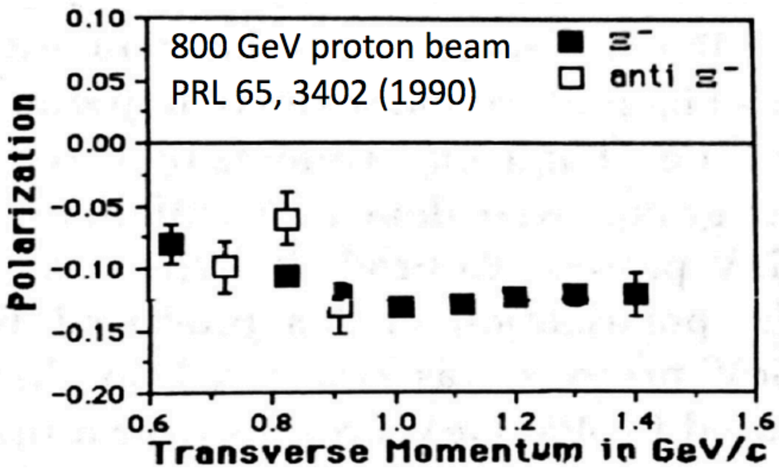
- Σ^+ and Σ^- polarised with opposite sign wrt Λ^0
- Ξ^0 and Ξ^- polarisation similar to Λ^0



K. Heller, Proceedings, 12th International Symposium on Spin Physics, Amsterdam, 1996

- Another surprise: Polarized antibaryons from (unpolarized) proton beams!
- No valence quarks in produced baryons same as valence quarks in proton beam, but polarization still observed for particles produced in the more forward region





How the baryon polarisation arise in fixed target collisions is not yet clear

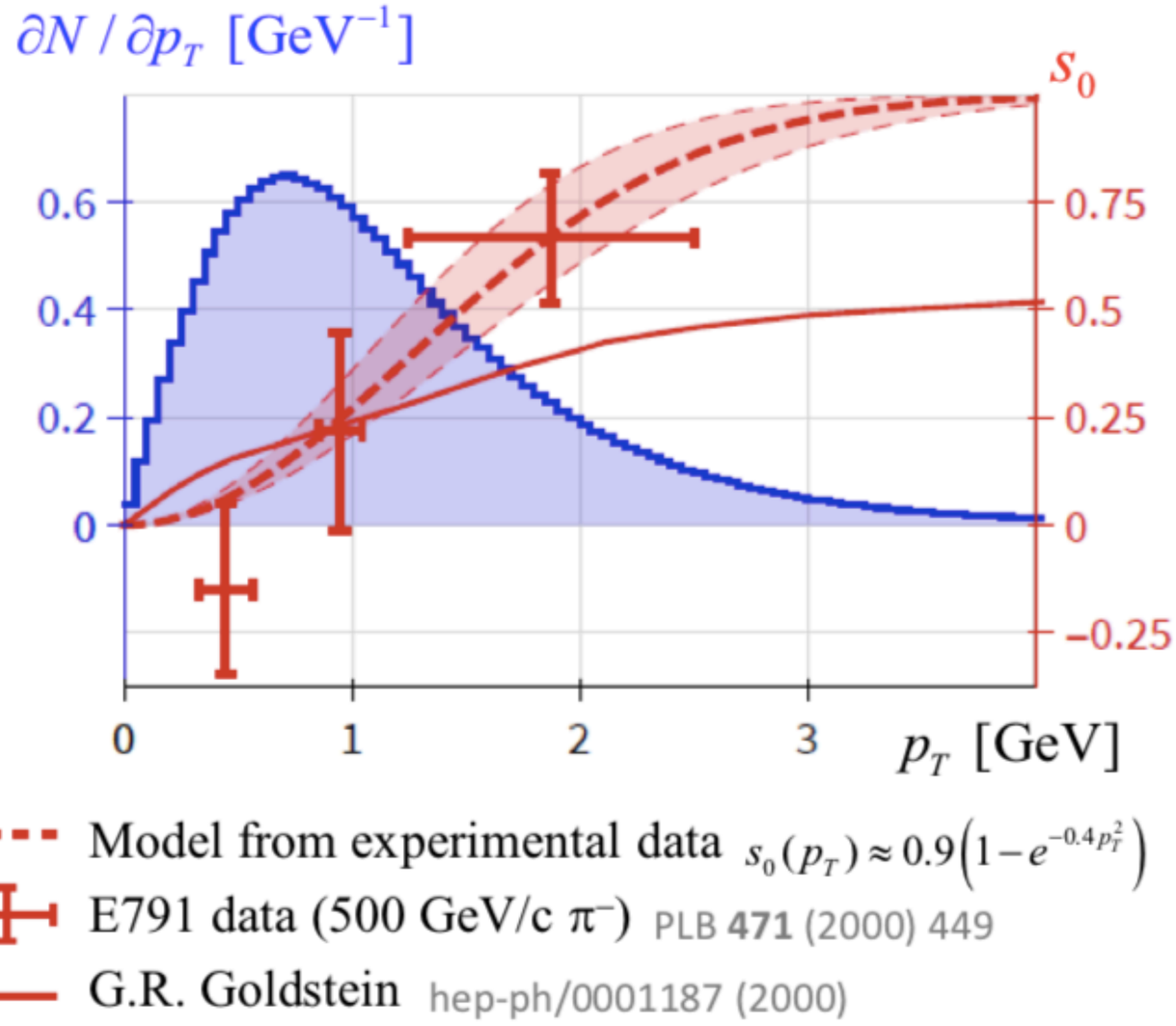
Polarisation of charm baryons: what do we know?

- Λ_c^+ polarisation (P) is a crucial input to sensitivities for magnetic and electric dipole moment (DP) measurements proposal with bent crystals:

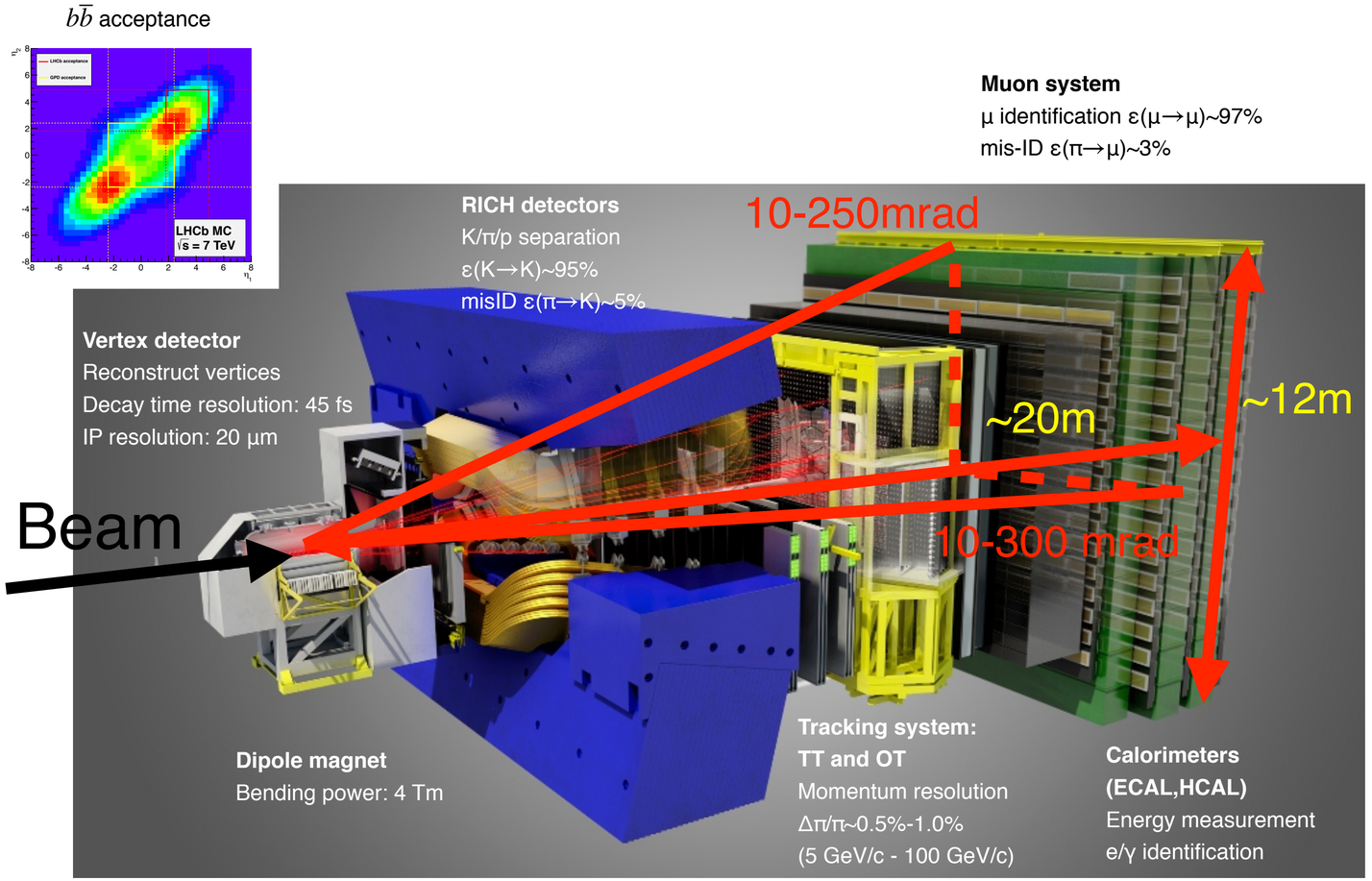
$$\sigma_{DP} \propto \frac{1}{P}$$

- For Λ_c^+ unknown for p-N at $\sqrt{s} \approx 110$ GeV
- Only 500 GeV/c π– data (E791)
- Model gives average polarisation $\approx 21\,\%$
- Crystals are at $0.1 < x_F < 0.5$ and $p_T < 2$ GeV/c —> expect significant polarisation

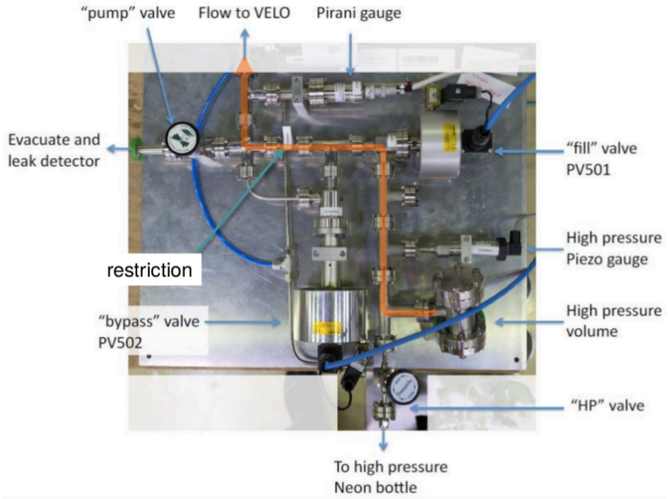
At LHC the beam energy is high enough to produce a relatively large number of Λ_c^+



The LHCb detector



- Excellent performances
- Unique system to inject gas (SMOG) originally designed for luminosity measurements
- Injection valve

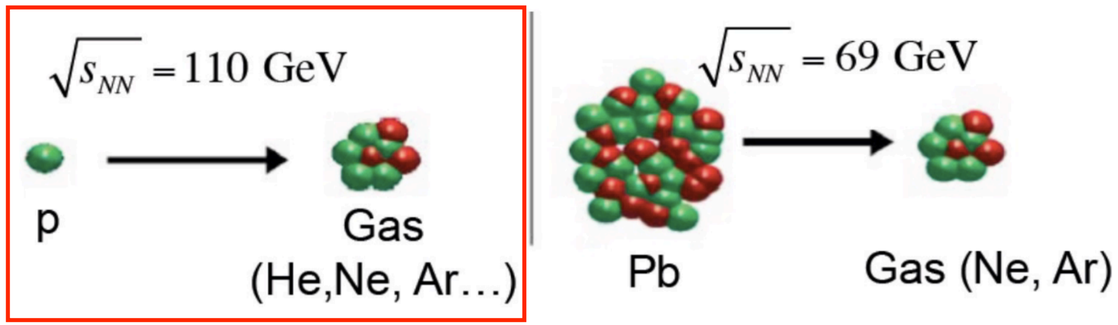


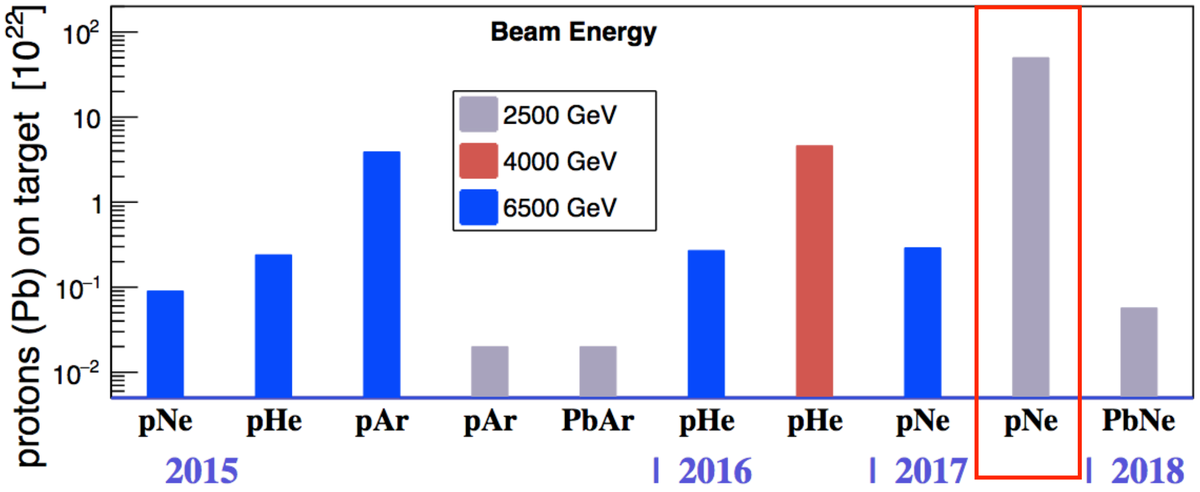
Forward acceptance + gas at rest = fixed target experiment

SMOG

- SMOG: System for Measuring Overlap with Gas
- A noble gas (He, Ne, Ar) at ~ 2 ×10^{-7} mbar pressure injected into the LHC beam pipe around the interaction region (~ meters - outside the pressure/reconstruction efficiency is low)
- Energy between SPS (29 GeV) and RHIC (200 GeV)
- Selected pNe collisions sample with highest expected signal yield
- Upgrade: SMOG2 up to x100 pressure in the region z∈[-500,-300] mm

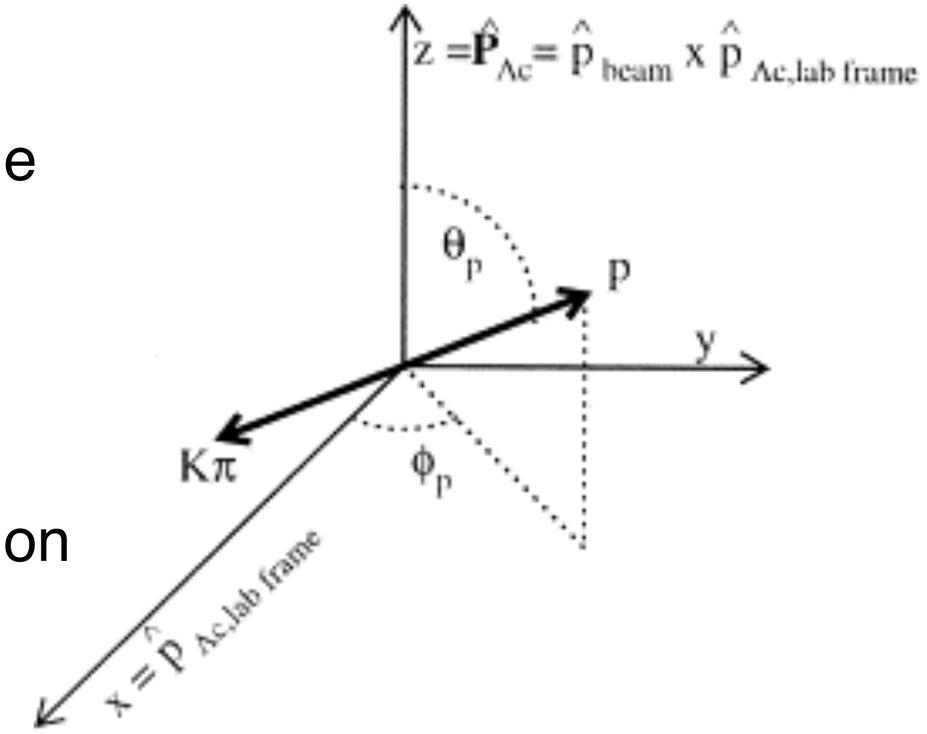
  —> more than x10 in signal yields





Strategy for Λ_c^+ polarisation measurement

- Dalitz fit to the Cabibbo Favoured $\Lambda_c^+ \to pK^-\pi^+$ decay to extract the polarisation
- The decay angular distributions gives the sensitivity to the polarisation
- The model is fixed with high statistics $\Lambda_c^+ \to pK^-\pi^+$ produced in semileptonic b-decays
- Due to parity conserving strong production, the polarisation has to be perpendicular to the production plane
  - The direction is known: 1 dof in the fit (magnitude)



Dalitz model of $\Lambda_c^+ \to pK^-\pi^+$ decay in the past

- Dalitz fit to $\Lambda_c^+ \to pK^-\pi^+$ decays produced in 500 GeV beam $\pi^- - N$ interactions at $\sqrt{s} = 30.6$ GeV by the E791 experiment at Fermilab
- Issues in the $\Lambda^* \to pK^-$ resonant region

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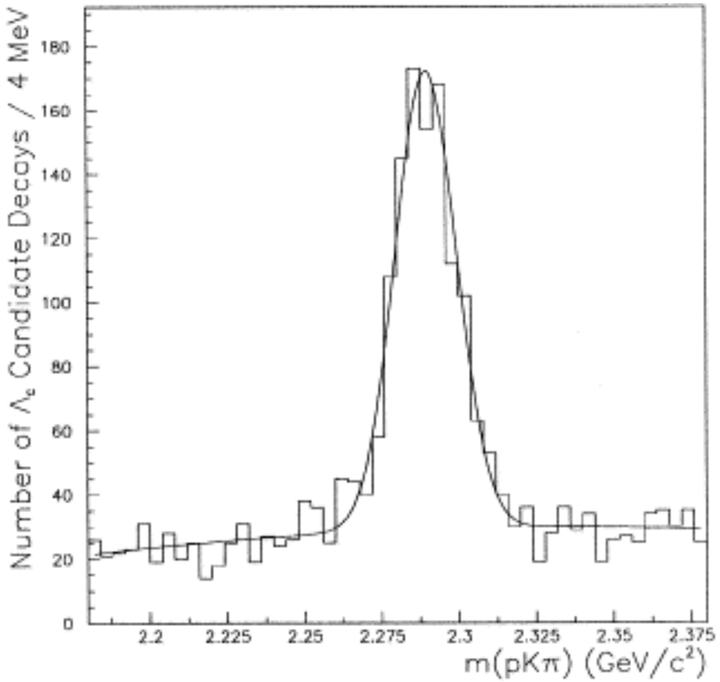
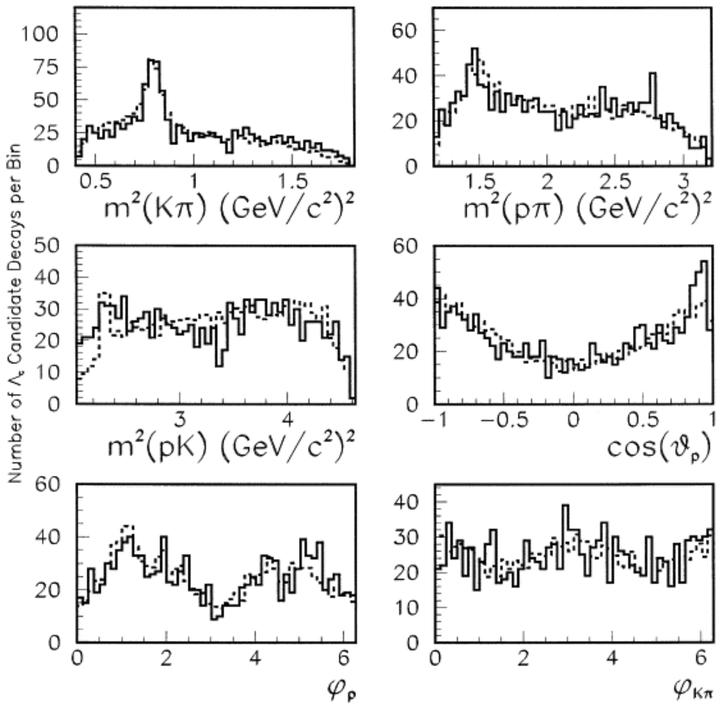


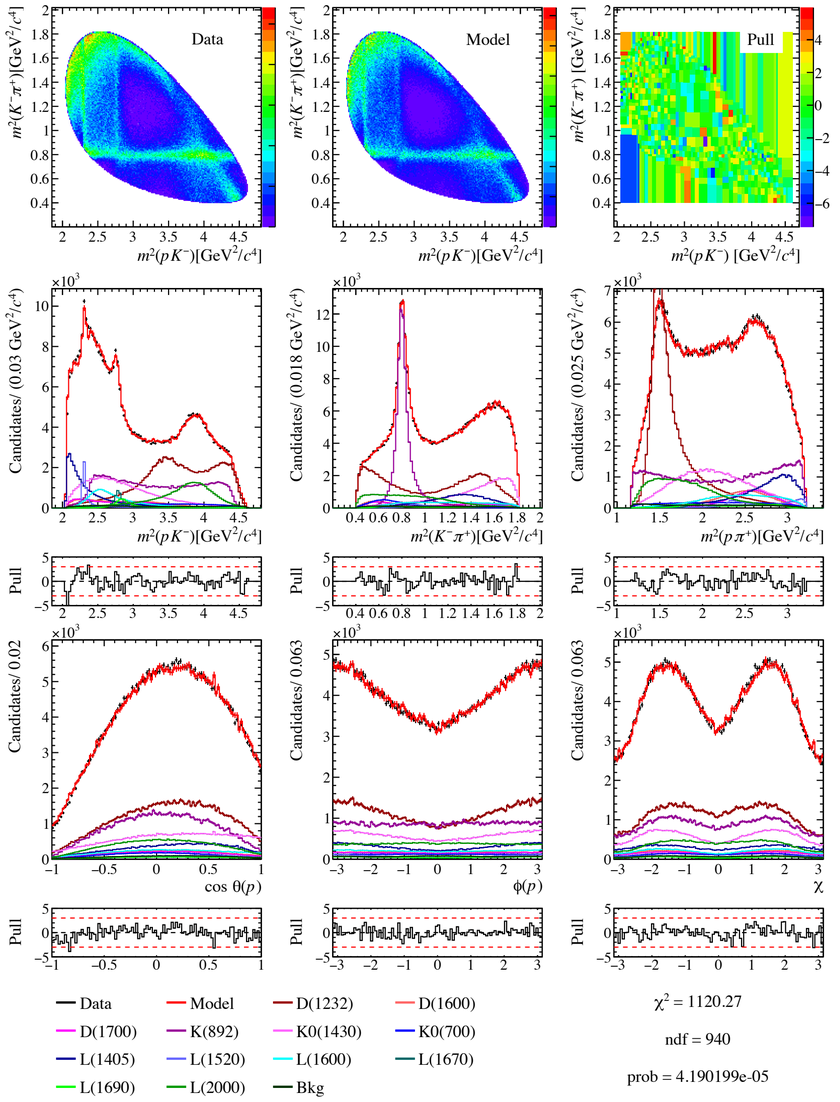


Dalitz model of $\Lambda_c^+ \to pK^-\pi^+$ decay with LHCb data

- $\Lambda_c^+ \to pK^-\pi^+$ sample produced in b-semileptonic decays in pp collisions—> see Daniele's talk
- Huge statistics, the sample is limited to 400k events
- Model parameters are systematically dominated

LHCb-PAPER-2022-002

- In SMOG:
- The statistics of $\Lambda_c^+ \to pK^-\pi^+$ produced in SMOG interactions is ~3k events
- Uncertainty on the model is negligible

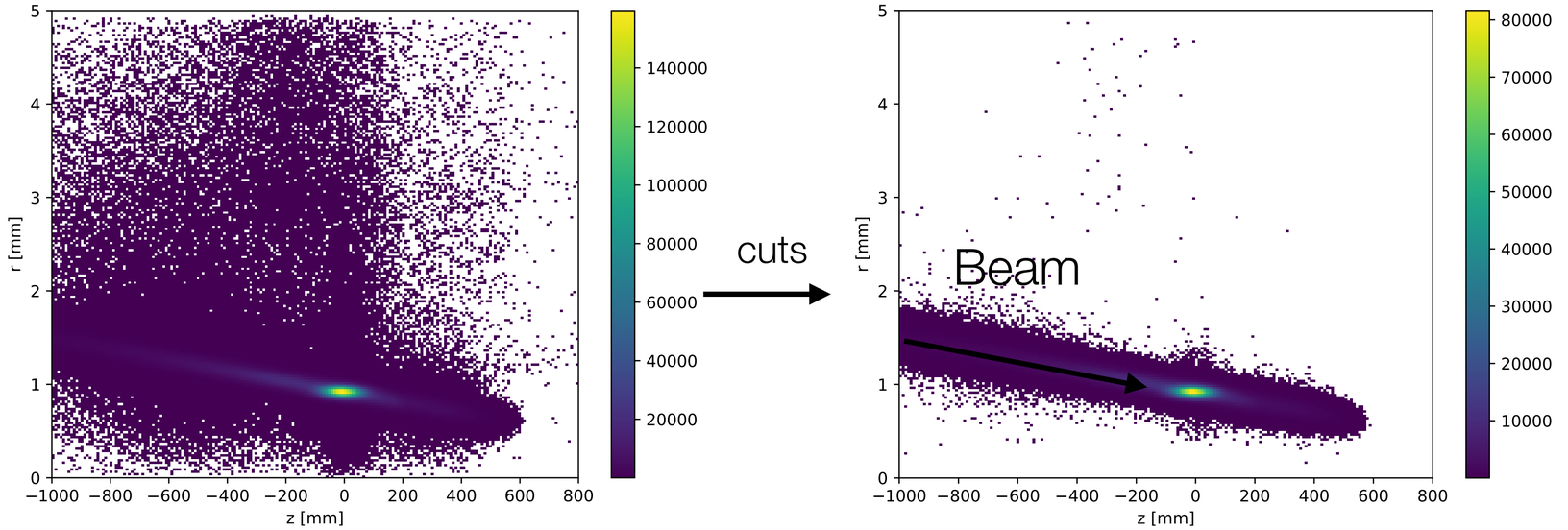


Data

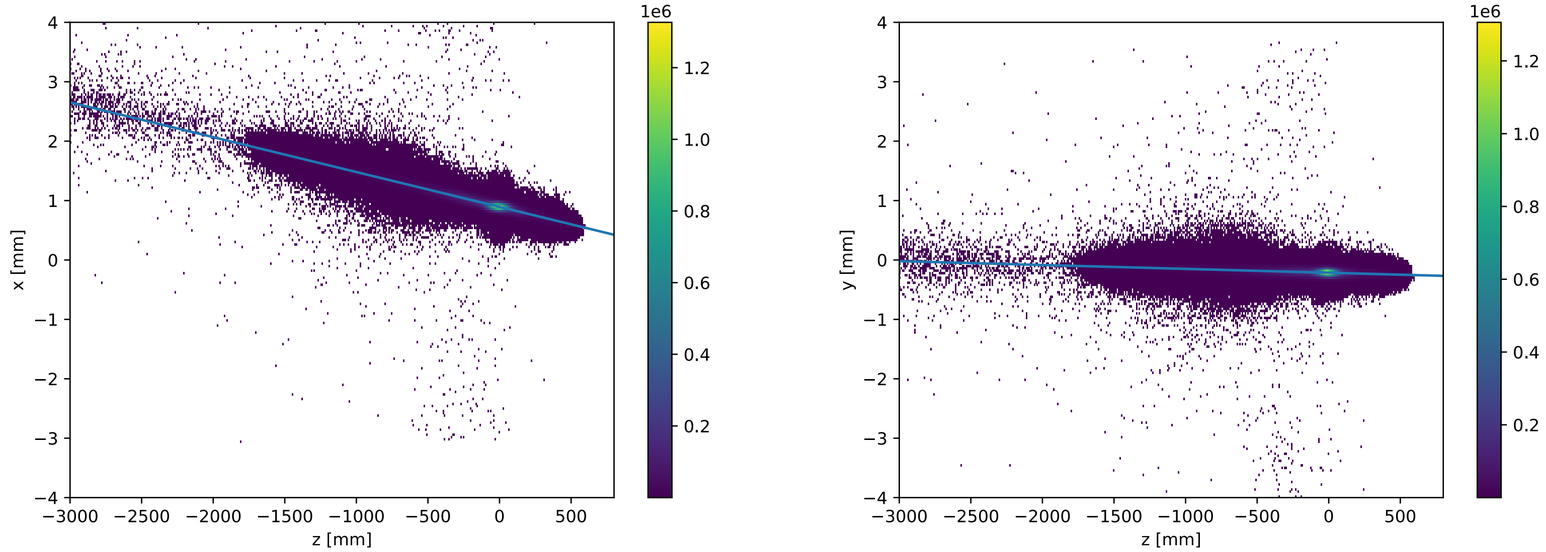
- pNe 2017 SMOG dataset: the one with the highest expected $\Lambda_c^+ \to pK^-\pi^+$ signal yield
- 2.51 TeV p beam, Ne gas: $\sqrt{s_{NN}} = 68.6$ GeV
- 4 filling schemes used by LHC
- trigger:
  - Hardware: low backward activity
  - Software: high pt tracks that form a “good” vertex

Preselection

- Remove fake PV:
  - Λ_c^+ vertex downstream the PV: $Vtx_z^{\Lambda_c^+} > PV_z$
  - $\mathrm{PV}_{\mathrm{ntracks}} > 4$

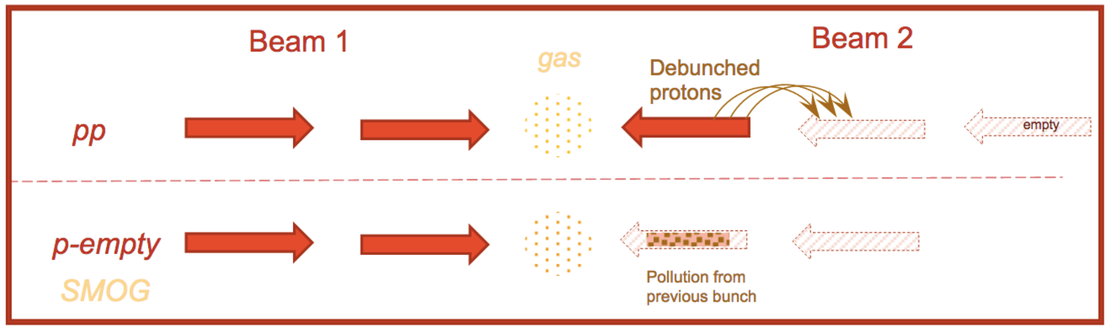


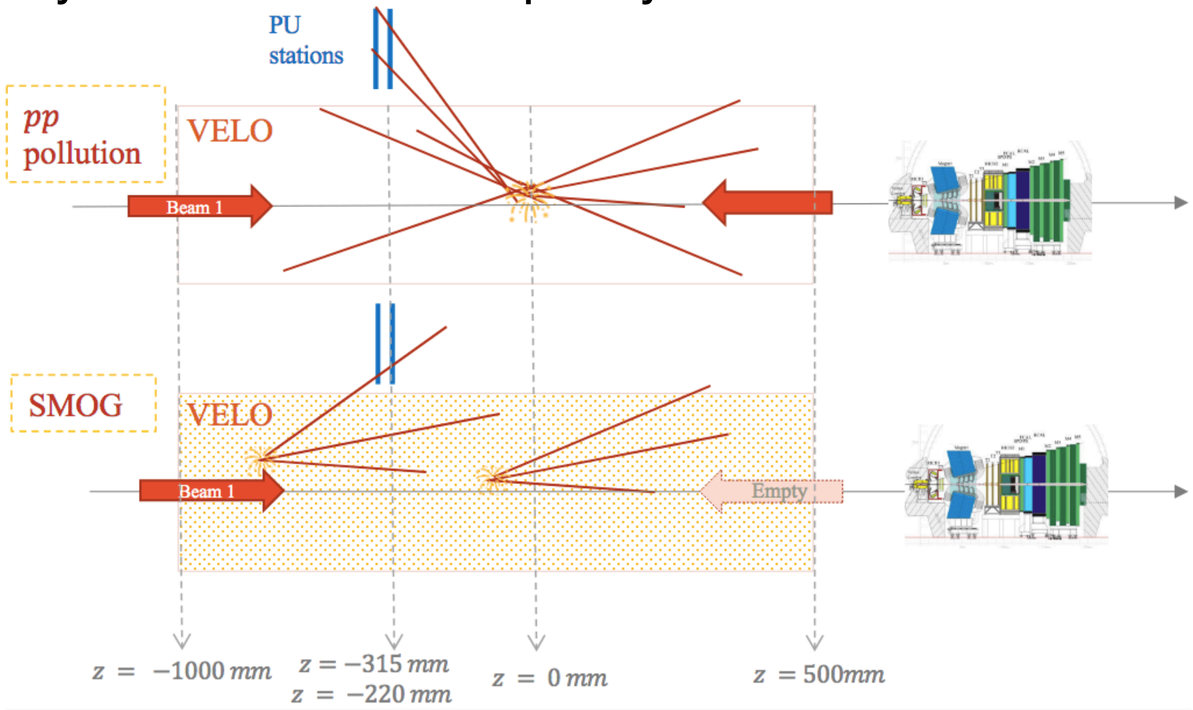
- Determine production plane with beam slope:
- $\frac{dx}{dz} = -5.9 \times 10^{-4}$
- $\frac{dy}{dz} = -6.5 \times 10^{-5}$



SMOG pollution

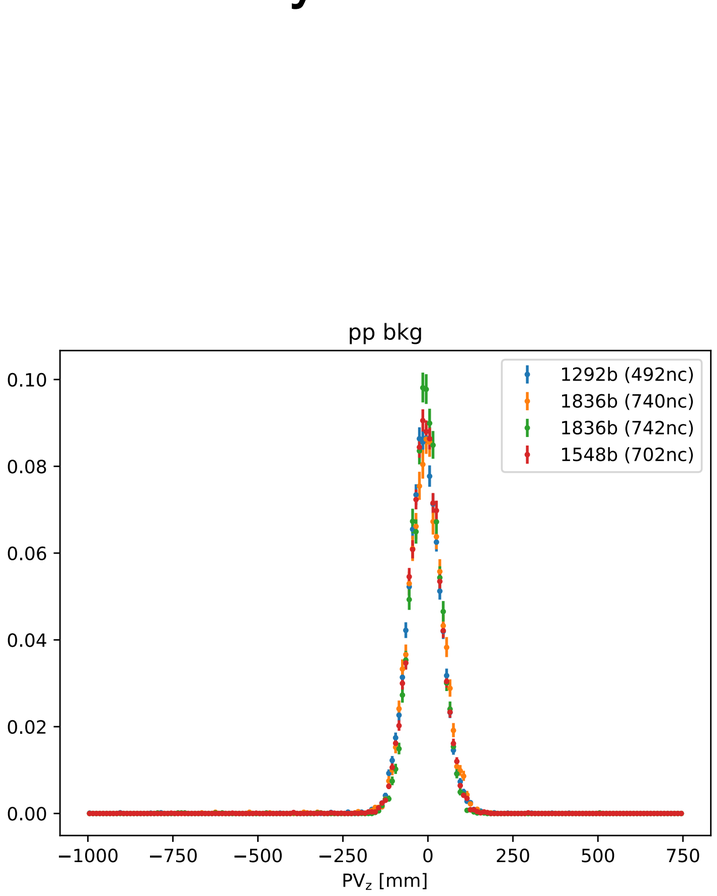
- Data are taken simultaneously with pp collisions at 5 TeV, no special runs —> pollution from pp collisions “ghost charges”
- pp and p-Gas data are taken at the same time alternating full and empty bunches
- Some debunched protons from the previous beam go to the following bunch which is supposed to be empty
- Cleaning using the event topology: backward activity and detector occupancy



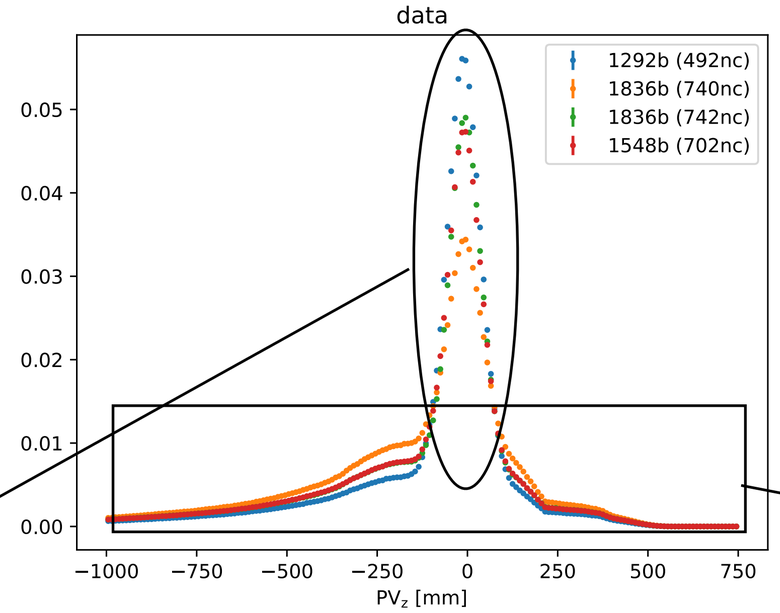


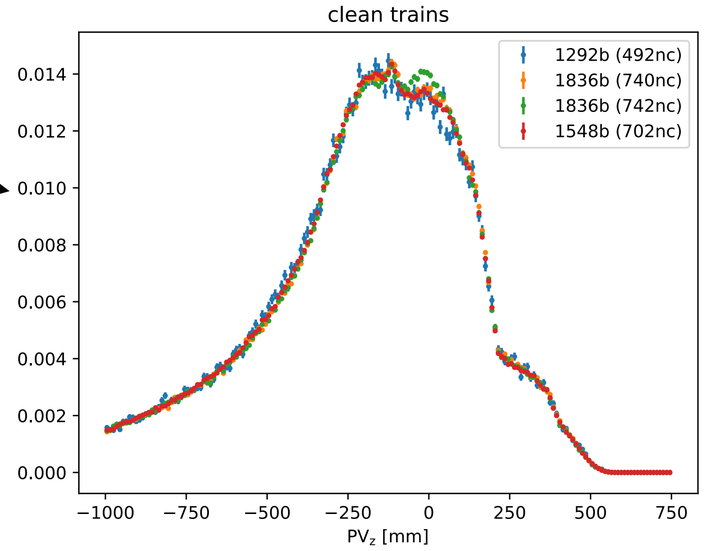
Event topology

- High level of background from pp interactions
- Clearly visible in the PVz distribution of candidate Λ_c^+



Enriched pp bkg sample

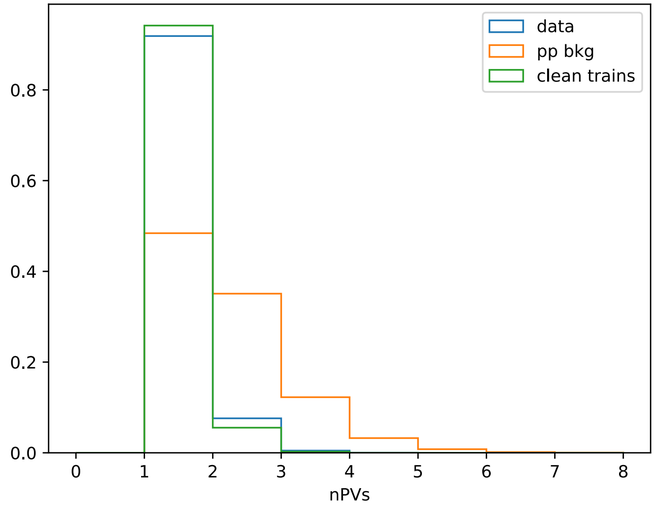


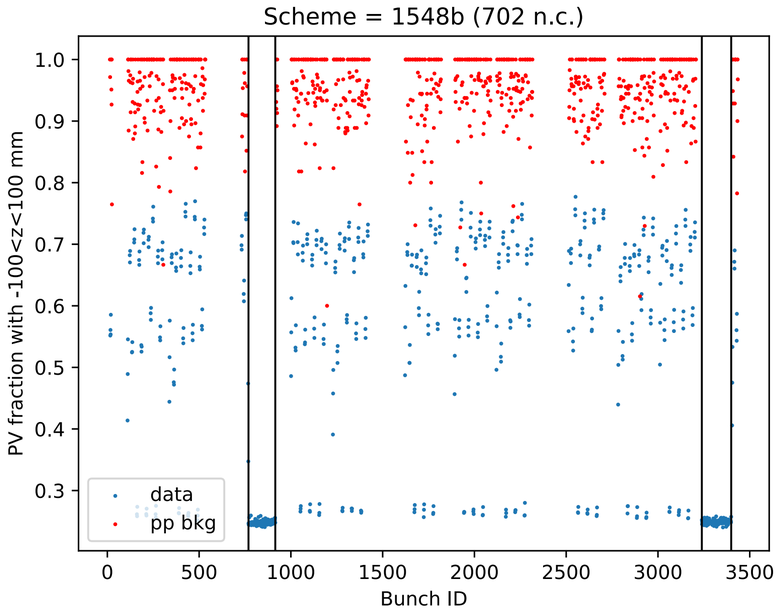


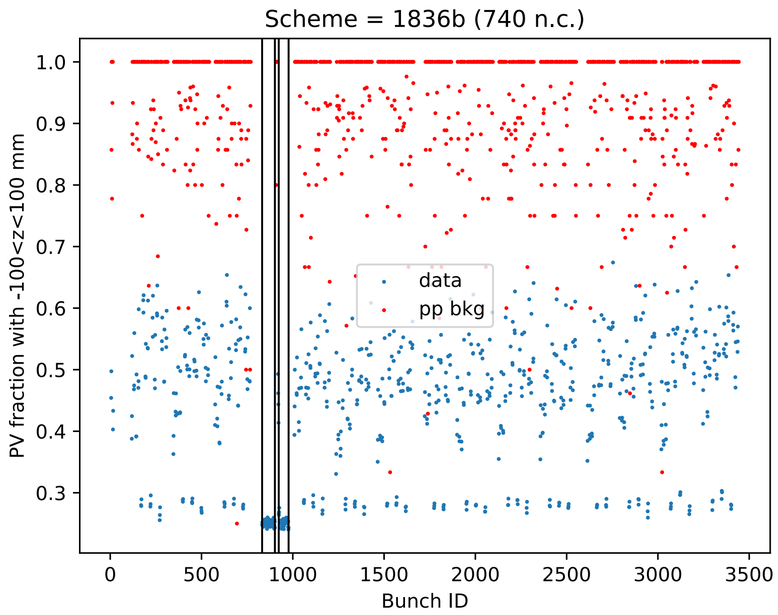
Enriched SMOG sample

Control sample selection

- Enriched pp bkg sample
  - Trigger on beam-beam collisions
  - Heavy prescale at 10-4
  - Selected nPV=1 to match occupancy in data
- Clean trains selected by the “clean” bunches of the LHC machine
  - It depends on the filling scheme

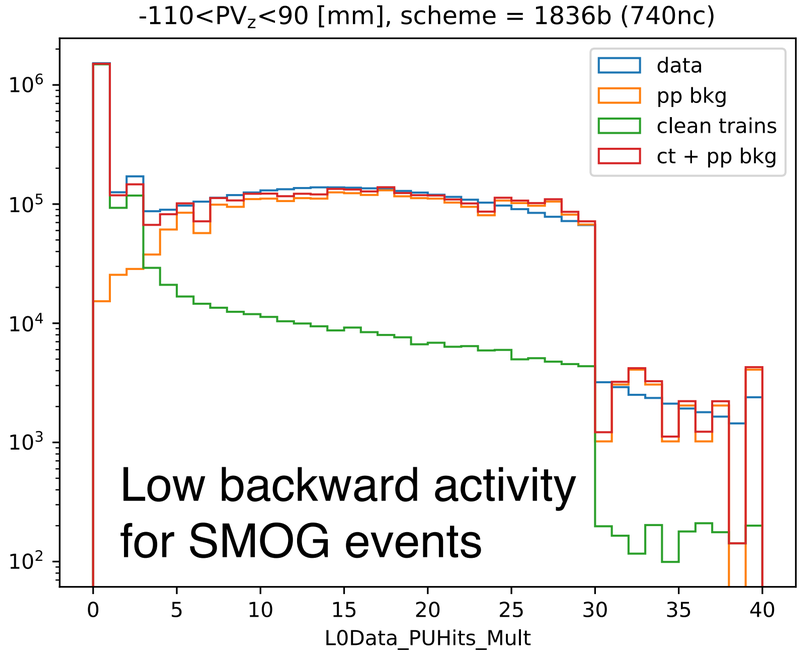


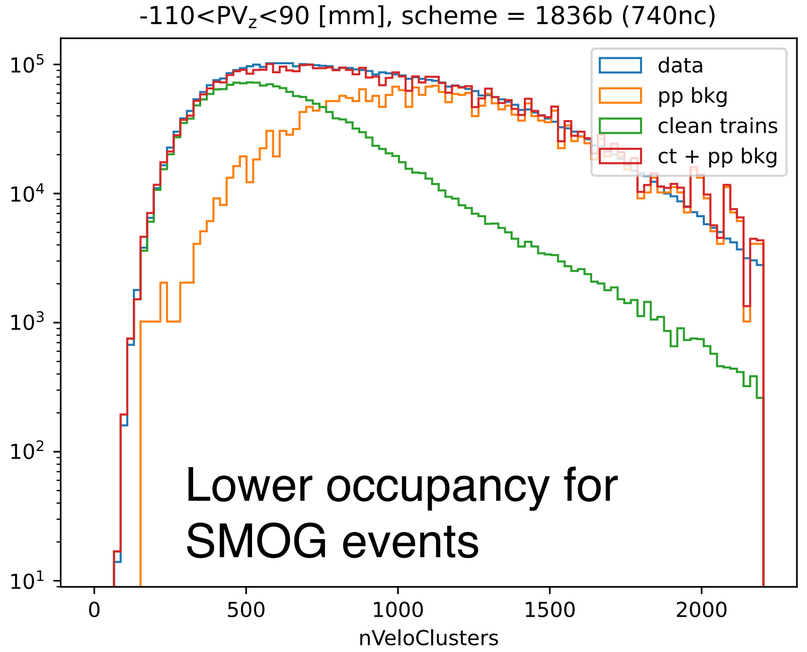


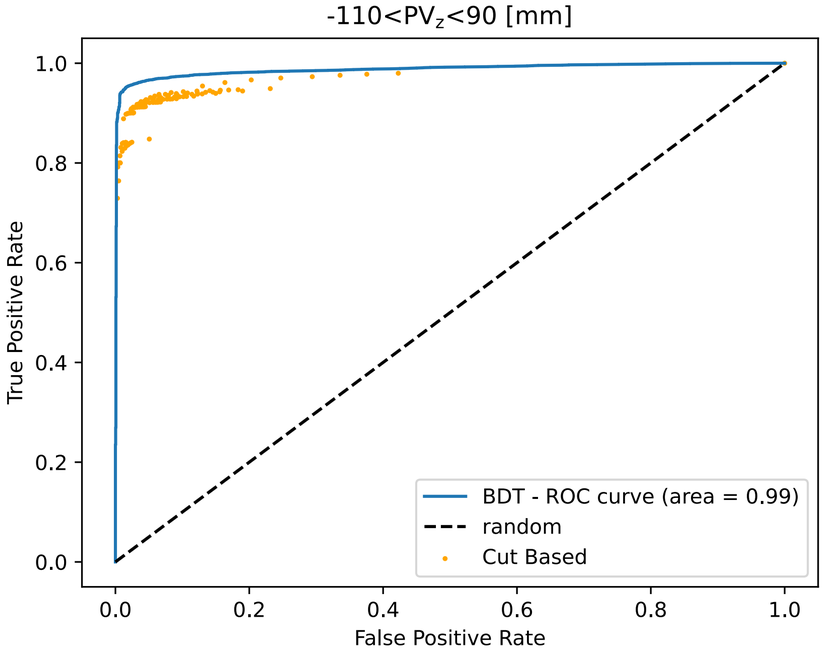


Global Event Cuts (GEC)

- Improved selection with multivariate approach to distinguish pp and pNe collisions
- Normalisation of control samples is done in background region and signal region
  - Background region: $|PV_z| < 100$ mm & nPUHits > 10 & nBackTracks > 10
  - Signal region: $100 < |PV_z| < 200$ mm & nPUHits $= 0$ & nBackTracks $= 0$

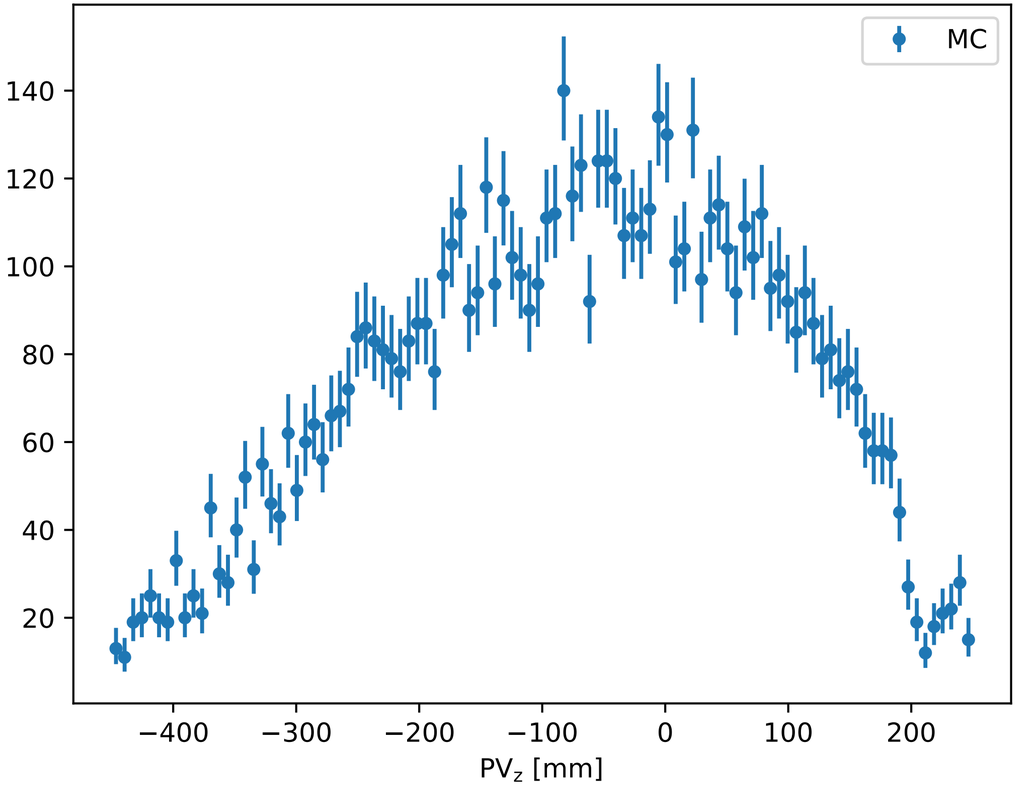






Simulation

- Signal Λ_c^+ generated with Pythia8 v1.86
- Underlying event generated with minimum bias EPOS v1.5.6
- PVz generated flat in [-450,250] mm, outside the rec. efficiency is low



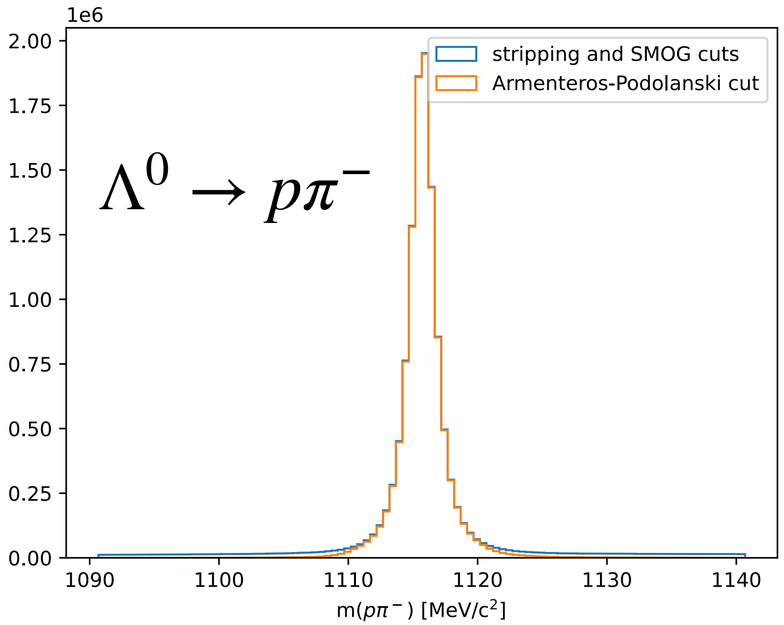
PID calibration in simulation

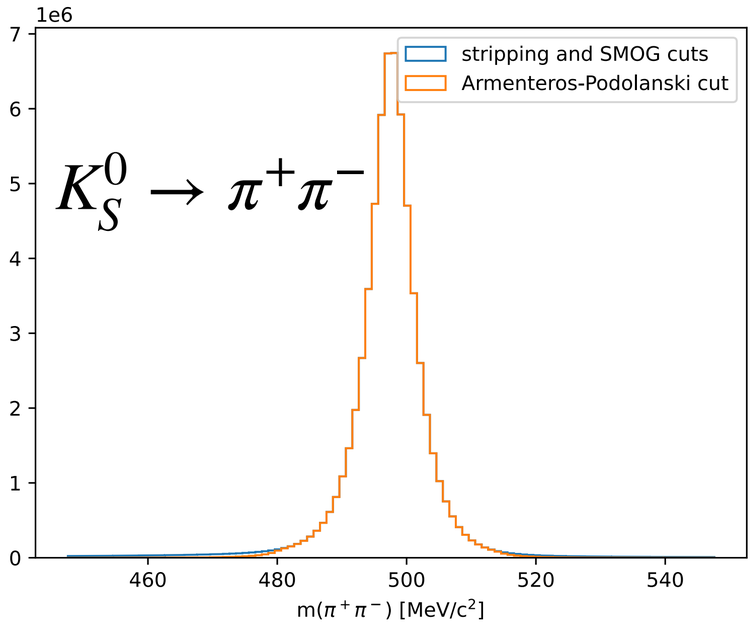
- Half of the SMOG MC is in regions not covered by calibration samples from pp collisions (mainly due to lower nTracks)
- p/K/pi calibration sample in SMOG:

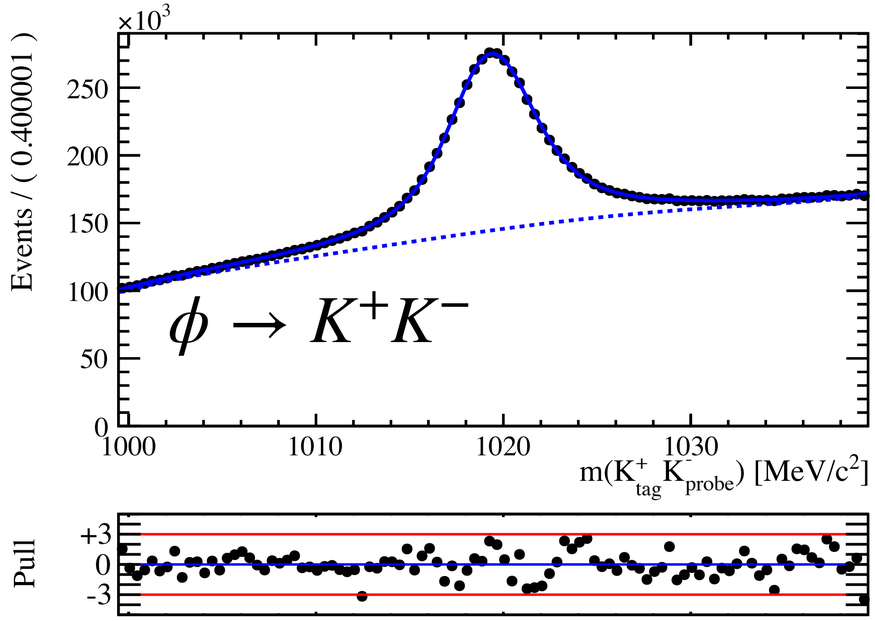
$$\overrightarrow{PID} = f(\overrightarrow{MC})$$

PID recalibrated — The input MC

Calibration sample

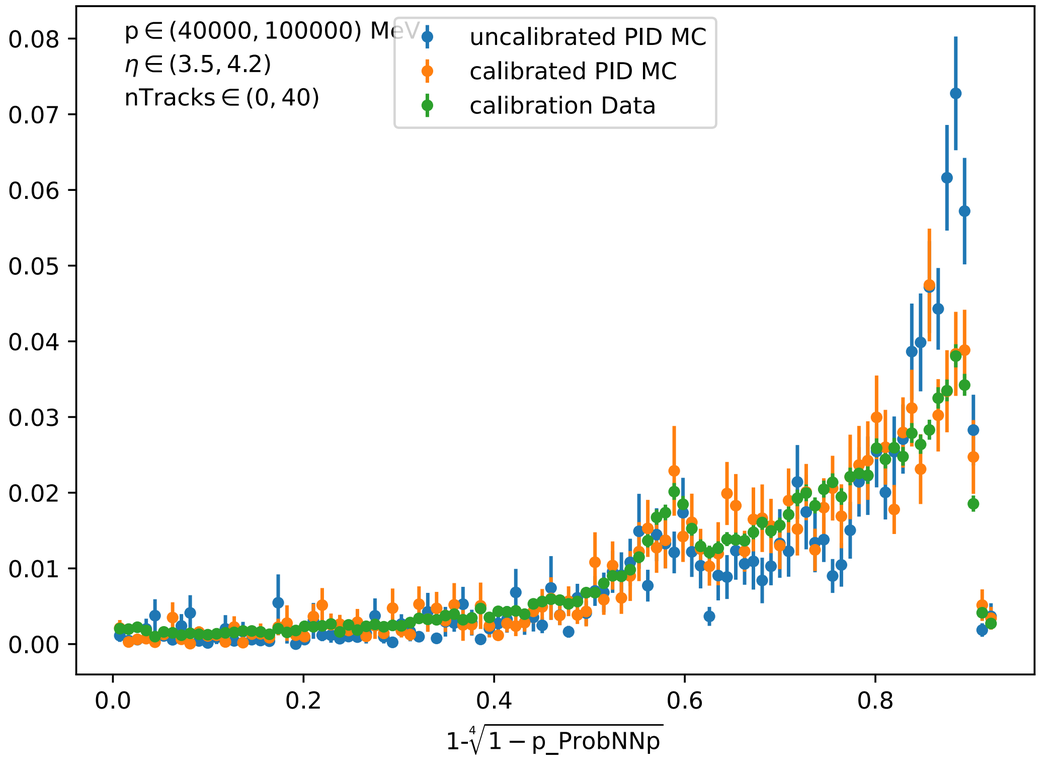


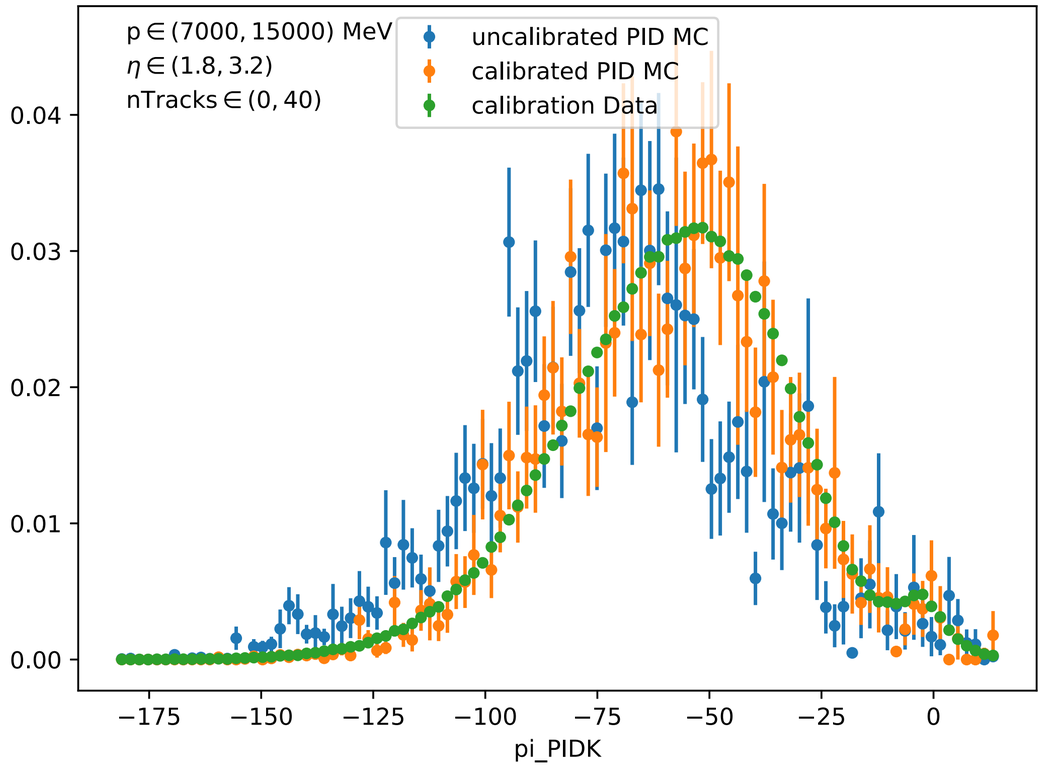




Strategy to calibrate PID in MC

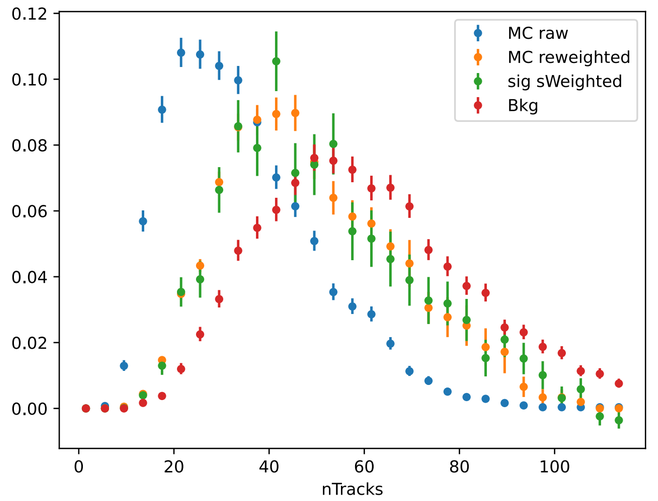
- Implemented first PID tool in LHCb capable to:
  - resamble 5 PID variables per track at once
  - correlations taken from data

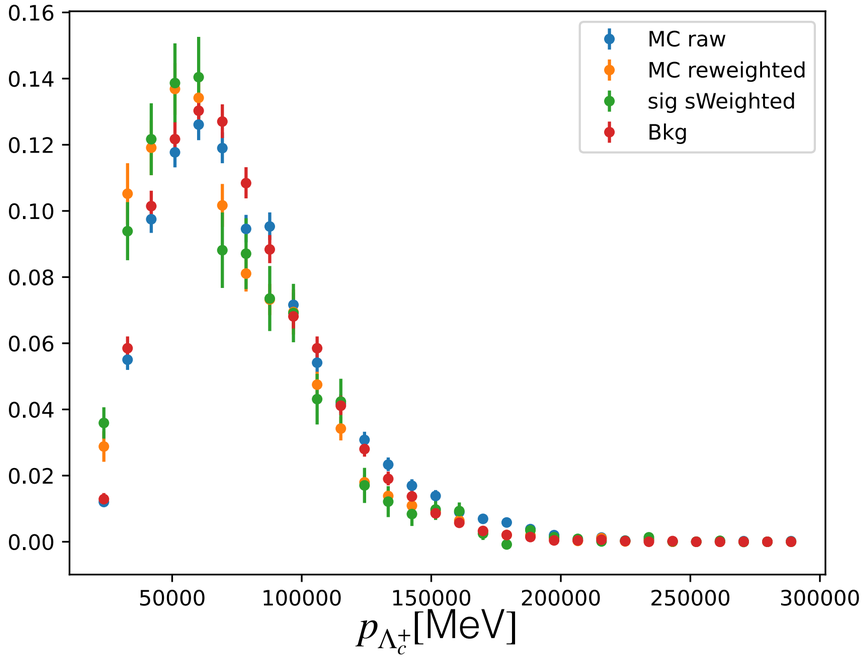


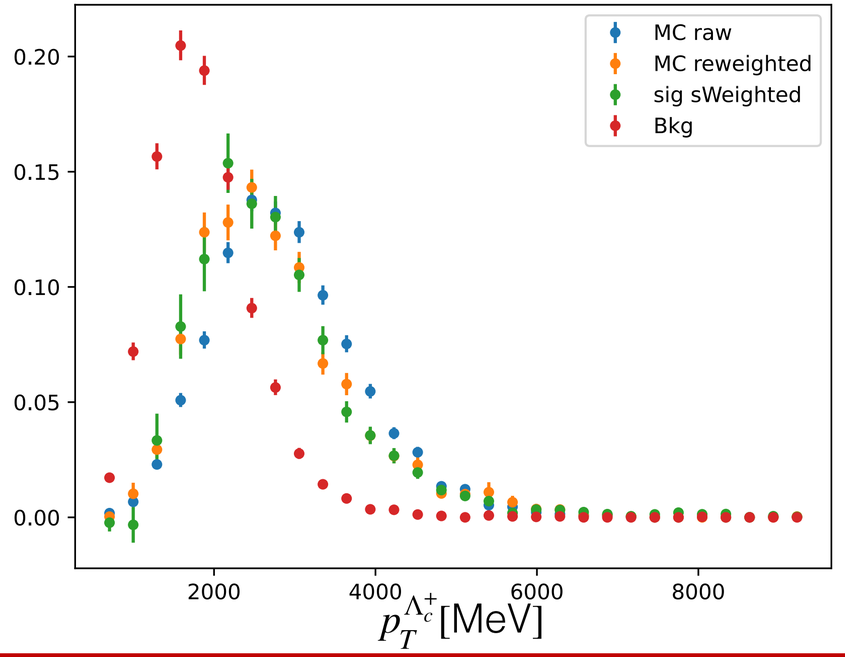


MC reweight

- Reweight MC in 2D $\left(p^{\Lambda_c^+}, p_T^{\Lambda_c^+}\right)$, overestimated in the MC
- The nTracks distribution is completely off in MC wrt data
  - Expected: minimum bias (EPOS), hard interaction (data)

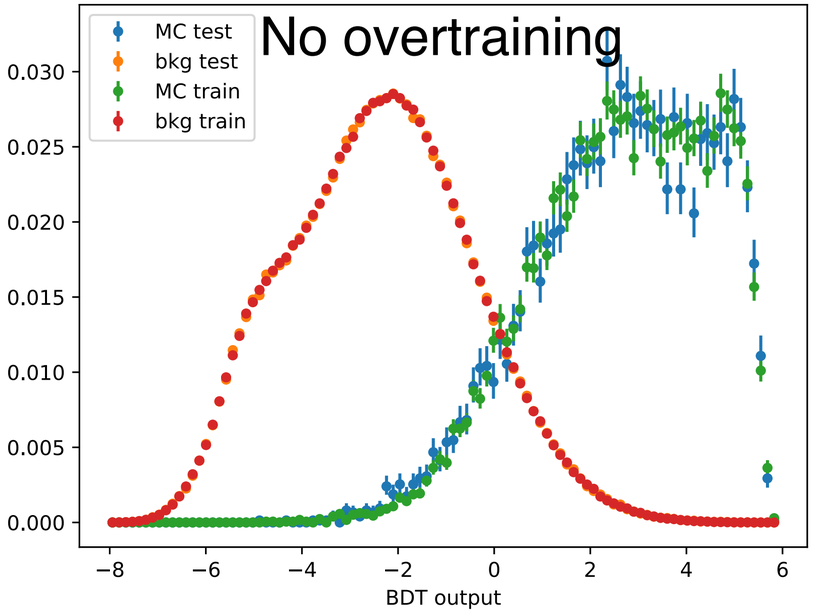


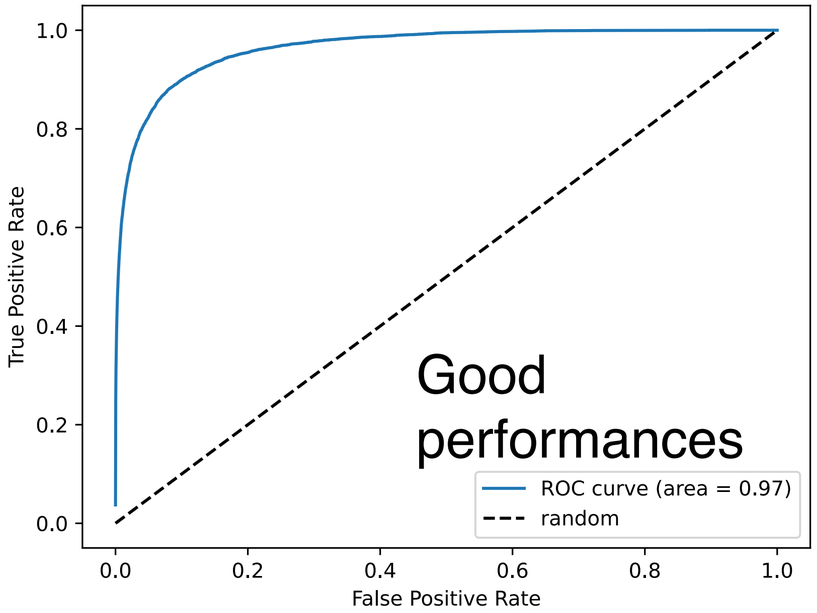


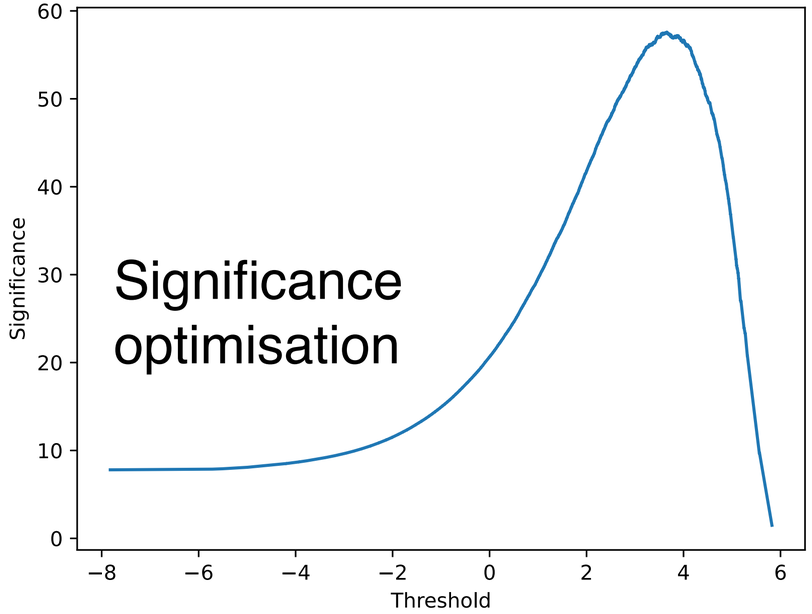


Final selection with BDT

- Train the BDT with the reweighed MC
- 29 variables as input: kinematic variables, chi2_vtx (DTF), PID, nTracks



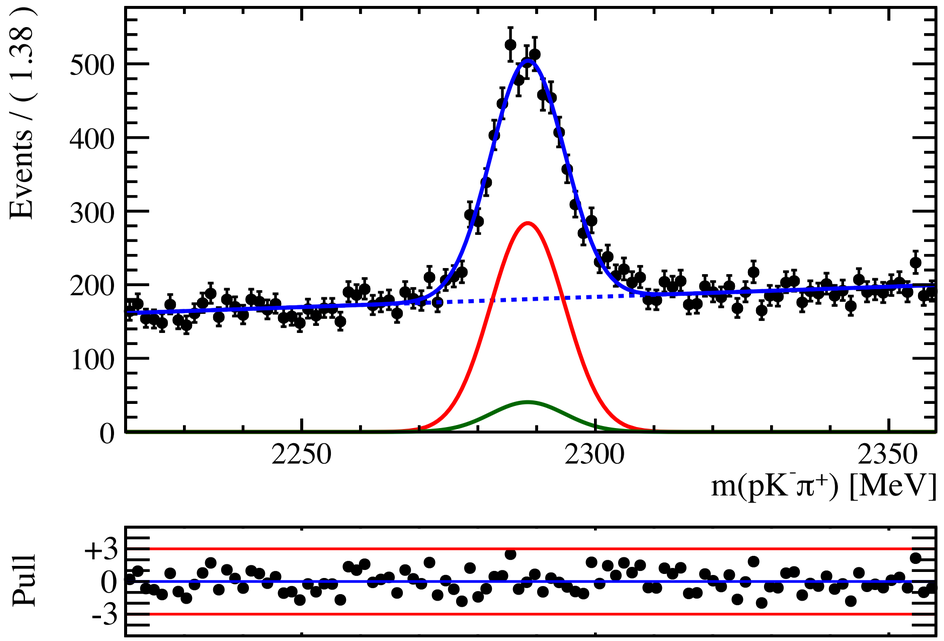


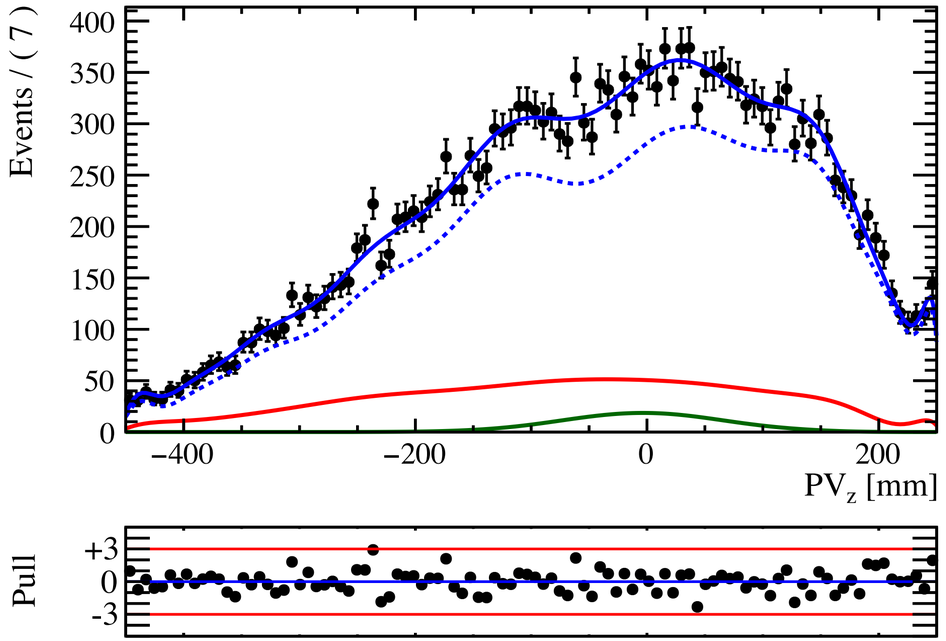


Extraction of signal yields

- 2D fit: PVz and invariant mass
- $N_{sig}^{pNe} = 3258 \pm 161$
- $N_{sig}^{pp} = 465 \pm 141$

- $\mu = 2288.5 \pm 0.2$ MeV
- $\sigma = 6.3 \pm 0.2$ MeV



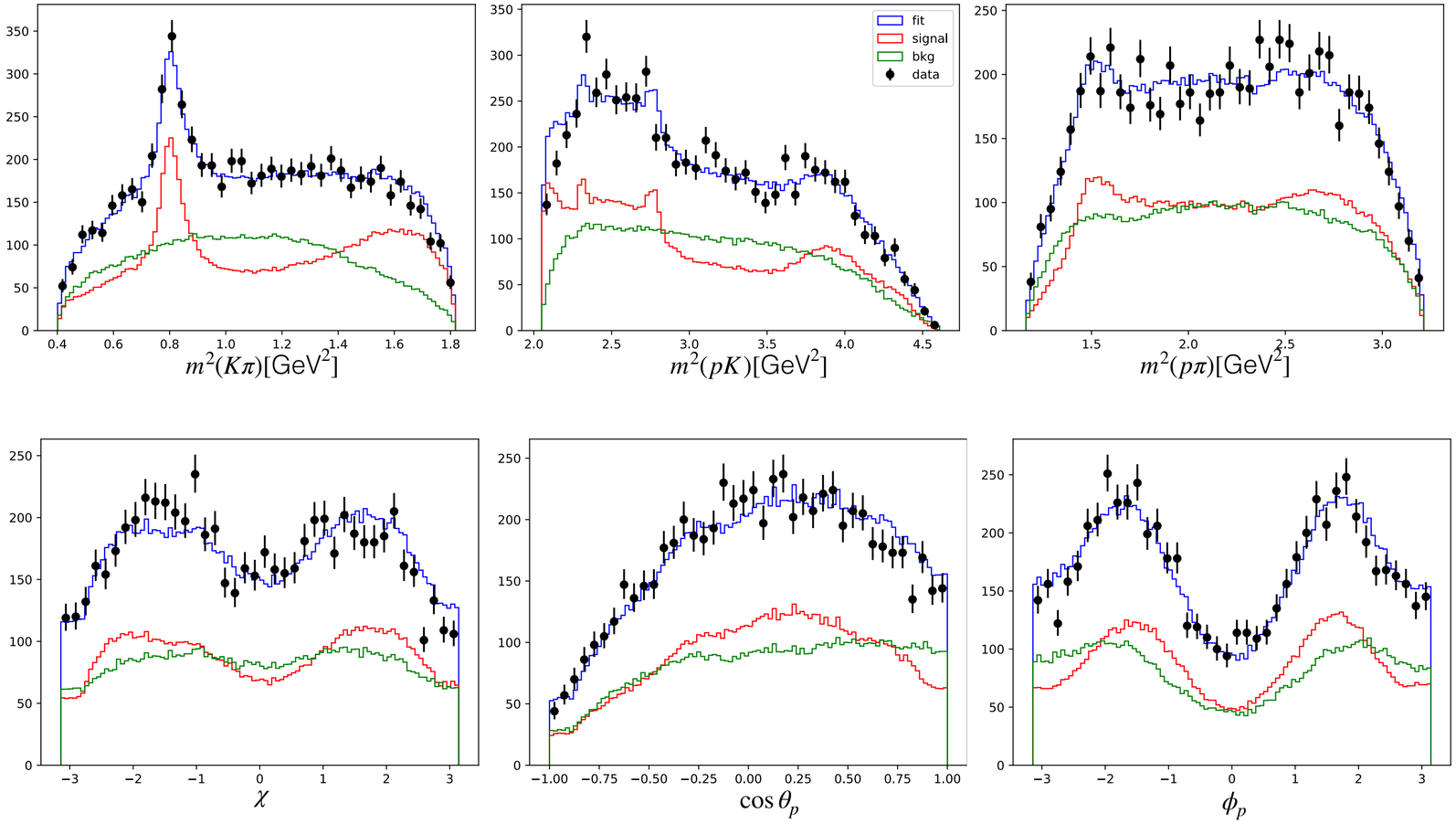


Extraction of polarisation

- Efficiency map extracted from simulations
- Background from mass sidebands
- Increase yields in simulation to determine better the 5D efficiency map

$\Lambda_c^+ \to pK^-\pi^+$

comb. bkg



Conclusions

- Selected ~3250 Λ_c^+ signal candidates produced in SMOG interactions. Ξ_c^+ selection ongoing
- Refine amplitude fit to extract polarisation:
  - Separate Λ_c^+ from SMOG and pp
  - Fix efficiency and background map
  - Separate $\Lambda_c^+/\overline{\Lambda}_c^-$
- Polarisation measured at 5% sensitivity with the full statistics
- Polarisation measurement in bins of p_T, x_F (#3/4)
- Luminosity available for these runs. Possibility to perform production cross section measurements, ratio particle/antiparticle production —> see Elisabeth's talk

Backup

Trigger

- L0 lines efficiency on MC raw
- SumEtBElooseDecision present only in 0x11641725

Level	Trigger
L0	SumEtBE (Dec) or SumEtBEloose (Dec) or HadronBE (TOS)
Hlt1	Hlt1SMOGSingleTrack (TOS)
Hlt2	Hlt2SMOGLc2KPPi (TOS)

Trigger	Efficiency [%] Dec	TOS	TIS
MuonDecision	0.47	0.14	0.33
B1gasDecision	0.47	/	/
MuonBEDecision	3.00	0.72	2.29
B2gasDecision	0.00	/	/
SPDBElowmultDecision	0.46	0.19	0.32
SumEtBElooseDecision	80.14	/	/
MuonEWDecision	0.18	0.03	0.16
ElectronDecision	0.16	0.03	0.14
HadronBEDecision	5.00	4.73	4.83
SumEtBEDecision	68.30	/	/
SumEtBE or SumEtBEloose		80.14	
SumEtBE_Dec or HadronBEDecision_TOS		69.80	
SumEtBEloose_Dec or HadronBEDecision_TOS		81.07	
SumEtBEloose_Dec or HadronBEDecision_Dec		81.16	

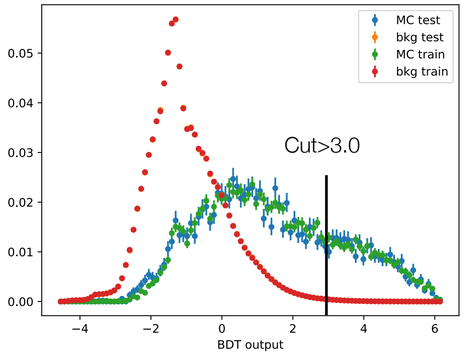
Bunch crossing type	Beam-empty crossing
track	$p_T > 1\,\text{GeV}$ ghost prob. < 0.2

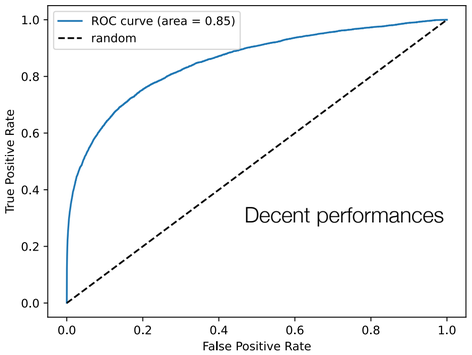
- Searches “good” p/K/pi tracks that form a “good” vertex

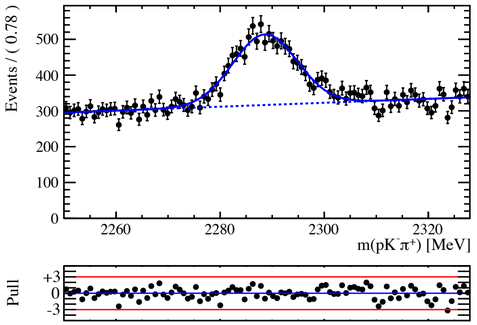
BDT w/o momentum info

- We train a rough BDT to select a signal sample without affecting the momentum signal distribution
- 10 variables as input (chi2_vtx, chi2_DTF, IPCHI2, TAU, …)

- Extract sWeights from the fit to the invariant mass
- Gaussian + polynomial model
- $N_{sig} = 3921 \pm 172$
- $\mu = 2288.6 \pm 0.2$ MeV, shifted by ~2 MeV from the true value?
- $\sigma = 6.2 \pm 0.3$ MeV



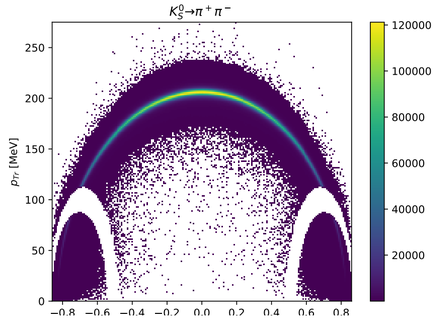


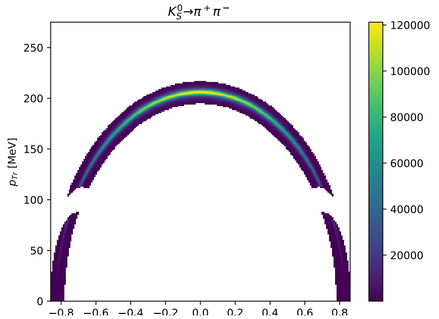


Calibration sample for protons and pions

- Cut on backward activity to obtain a pure sample of tracks from SMOG interactions: nPUHits==0 and nBackTracks==0
- Armenteros cuts

Before Arm. cuts





After Arm. cuts

Calibration sample for kaons

- High level of background (ϕ doesn't flight)
- Tag and Probe method
- Fit to the calibration sample to extract sWeights. Here just showed ~1/5 of the statis
- Fitted model (signal pdf = Breit Wigner convoluted with Gaussian, bkg pdf polynomi

$$\underbrace{f\,BW\left(m_{KK};m_0,\Gamma\right)\otimes G\left(m_{KK};0,\sigma=\beta\left(m_{KK}-2m_K^{PDG}\right)\right)}_{\text{signal pdf}}+\left(1-f\right)\underbrace{Cheb_6\left(m_{KK};c_0,\ldots,c_5\right)}_{\text{bkg pdf}}$$