Study of the rare decay $\Sigma^{+} \rightarrow p\mu^{+}\mu^{-}$ at LHCb

XXXVI Cycle of PhD in Physics

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a.y. 2022/2023

Outline

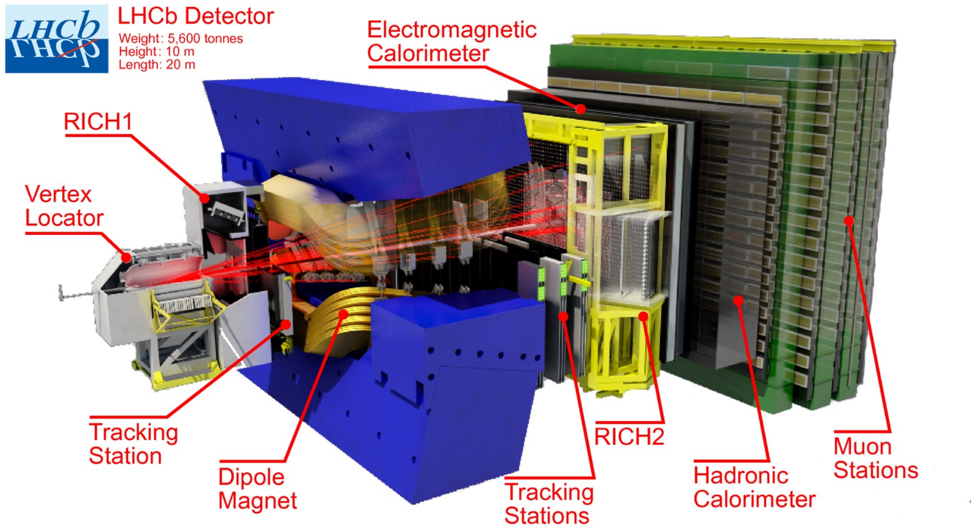
- The LHCb experiment
- $\Sigma^+ \to p\mu^+\mu^-$ state-of-the-art
  - The HyperCP anomaly
  - Theoretical interpretations and experimental tests before LHCb
  - Run 1 search for $\Sigma^+ \to p\mu^+\mu^-$ at LHCb
- $\Sigma^+ \to p\mu^+\mu^-$ analysis with Run 2
  - Observables in Run 2
  - Run 2 analysis strategy
  - Signal and background
  - Normalization
- Conclusion and outlook for the analysis
- LHCb activities
- Educational activities and list of publications

The LHCb experiment

- Large Hadron Collider beauty (LHCb)
  - Experiment dedicated to study differences between matter and antimatter
  - Focus on b and c physics
    (Precision measurements of CKM matrix elements, CP violation, rare decays, …)

- Designed to detect forward particles using a series of subdetectors
  - Detects those particles boosted after the collision in the forward direction

- About 1400 scientists, engineers and technicians from 18 countries partecipate in the collaboration



The HyperCP anomaly

- $\Sigma^+ \to p\mu^+\mu^-$ is a very rare Flavour Changing Neutral Current (FCNC) process
- Short distance in the SM $\mathcal{B} \sim \mathcal{O}(10^{-12})$
- Dominated by long distance constributions:

  $1.2 \times 10^{-8} < \mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) < 10.2 \times 10^{-8}$

  [Xiao-Gang He et al. Phys.Rev. D72 (2005) 074003]

  [Xiao-Gang He et al. – JHEP 1810 (2018) 040]

- 3 events observed by the HyperCP experiment in absence of background
- Measured branching fraction is:

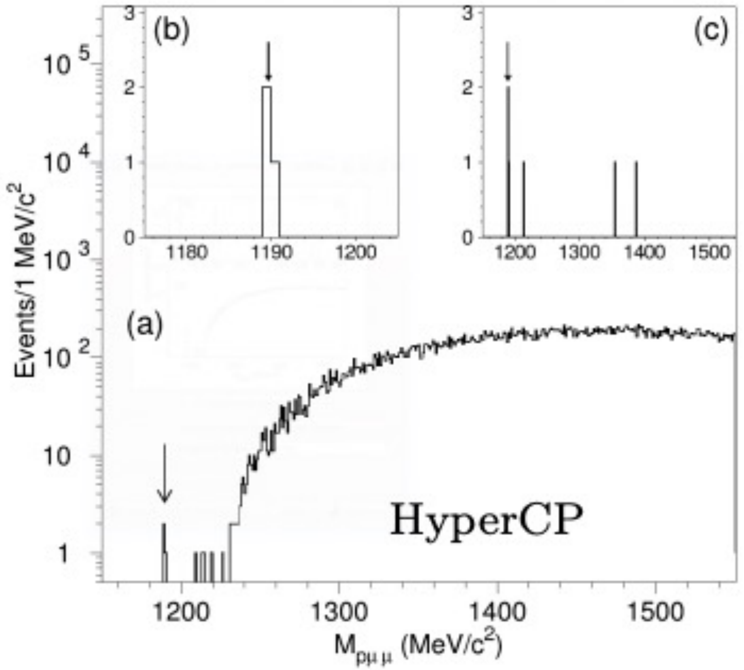
  $\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = \left(8.6^{+6.6}_{-5.4} \pm 5.5\right) \times 10^{-8}$

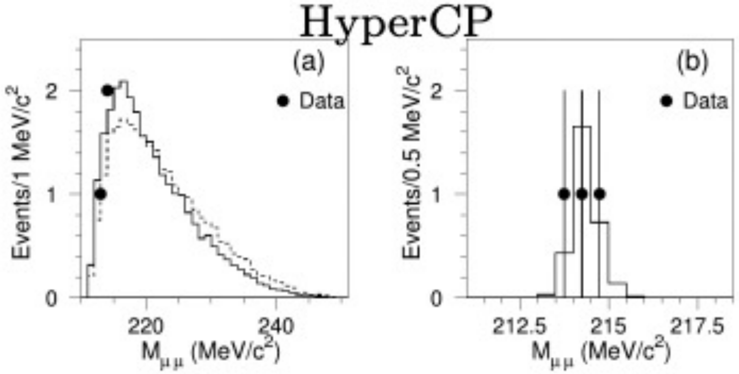
  [Phys. Rev. Lett. 94 (2005) 021801]

- All the **3** observed signal events have the same dimuon invariant mass pointing towards a $\Sigma^+ \to pX^0(\to \mu^+\mu^-)$ decay with

  $m_{X^0} = 214.3 \pm 0.5\ MeV$

  $\mathcal{B}(\Sigma^+ \to pX^0(\to \mu^+\mu^-)) = (3.1^{+2.4}_{-1.9} \pm 1.5) \times 10^{-8}$





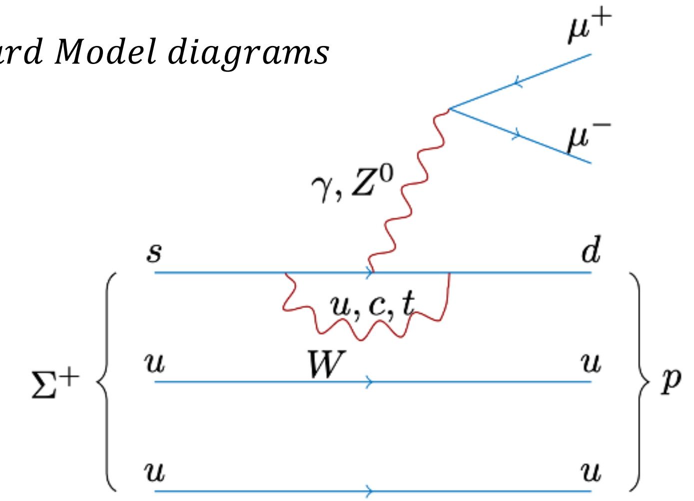
Theoretical interpretations and experimental tests before LHCb

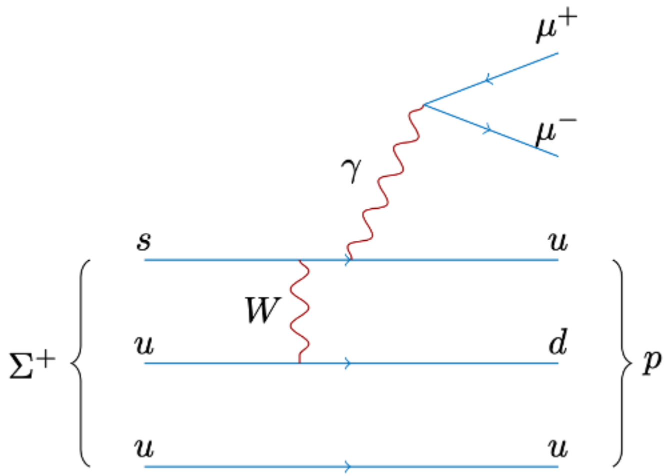
- Several interpretations were proposed
  - Light Higgs boson
    [He, Tandean Valencia, PRL.98081802 (2007)]
  - Sgoldstino
    [Gorbunov, Rubakov PRD 73 035002]
  - Many others
  - In general pseudoscalar favoured over scalar and lifetime of order 10^{-14} s

- Many experimental searches for low mass resonances in dimuons
  - CLEO, E391a, D0, BaBar, Belle, KTeV, BESIII
  - Searched also at LHCb in $B^0 \to \mu^+\mu^-\mu^+\mu^-$ and $B^0 \to K^{*0}\mu^+\mu^-$
  - X^0 particle not confirmed

- No other search for $\Sigma^+ \to p\mu^+\mu^-$ decays

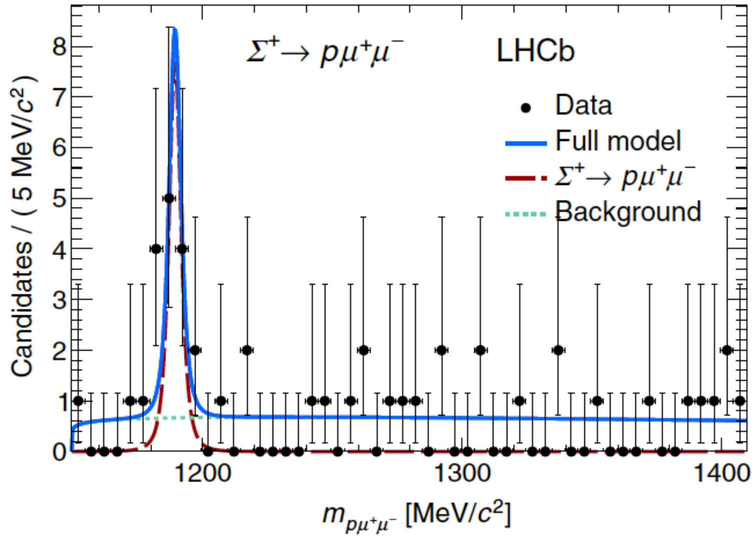
Standard Model diagrams



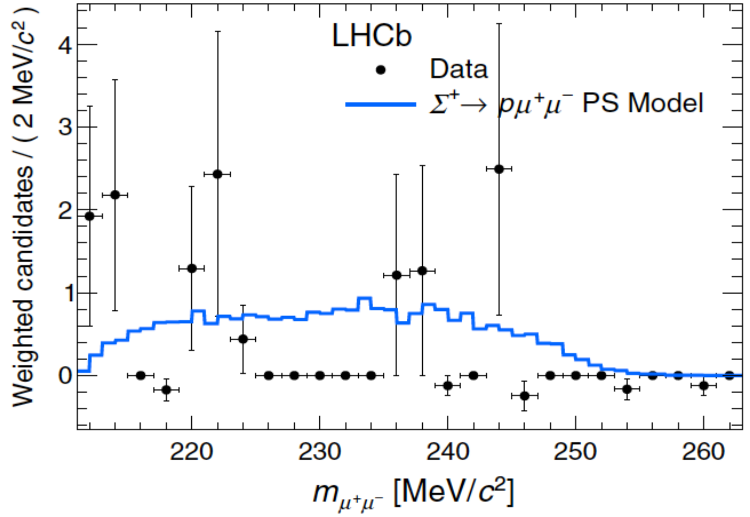


Run 1 search for $\Sigma^+ \rightarrow p\mu^+\mu^-$ at LHCb

- Based on full Run1 ($3\ fb^{-1}$)
- Excess of events at m_{Σ^+} w.r.t. background with a significance of 4.1σ
- Fitted signal yield: $10.2^{+3.9}_{-3.5}$ events
- Measured branching fraction:
  $\mathcal{B}(\Sigma^+ \rightarrow p\mu^+\mu^-) = (2.2^{+1.8}_{-1.3}) \times 10^{-8}$
  Consistent with the SM prediction
- No significant peak found in the dimuon mass:
  $\mathcal{B}(\Sigma^+ \rightarrow pX^0(\rightarrow \mu^+\mu^-)) < 1.4 \times 10^{-8}$ at 90% CL
  HyperCP result excluded
  [Phys. Rev. Lett. 120 (2018) 221803]



Background subtracted distribution



$\Sigma^+ \rightarrow p\mu^+\mu^-$ working group for Run 2
Microgroup of the Very Rare Decays working group

Francesco Dettori[1,2], Francesca Dordei[2]
Gabriele Martelli[3,4], Mauro Piccini[4], Viacheslav Duk[4]
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[1]Università degli Studi di Cagliari, [2]INFN Cagliari, [3]Università degli Studi di Perugia
[4]INFN Perugia, [5]Universitade de Santiago de Compostela

Observables in Run2

- Based on statistics, expect an improvement due to dedicated trigger:
  1) Observation of the channel (eventually hints for new physics beyond SM)
  2) Repeat search for dimuon resonances in the decay spectrum
  3) More precise measurement of its branching fraction
  4) “Direct” CP violation measurement:

$$\mathcal{A}_{CP} = \frac{\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) - \mathcal{B}(\bar{\Sigma}^+ \to \bar{p}\mu^+\mu^-)}{\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) + \mathcal{B}(\bar{\Sigma}^+ \to \bar{p}\mu^+\mu^-)}$$

  5) Differential branching fraction vs dimuon mass
  6) Forward-backward asymmetry in the decay

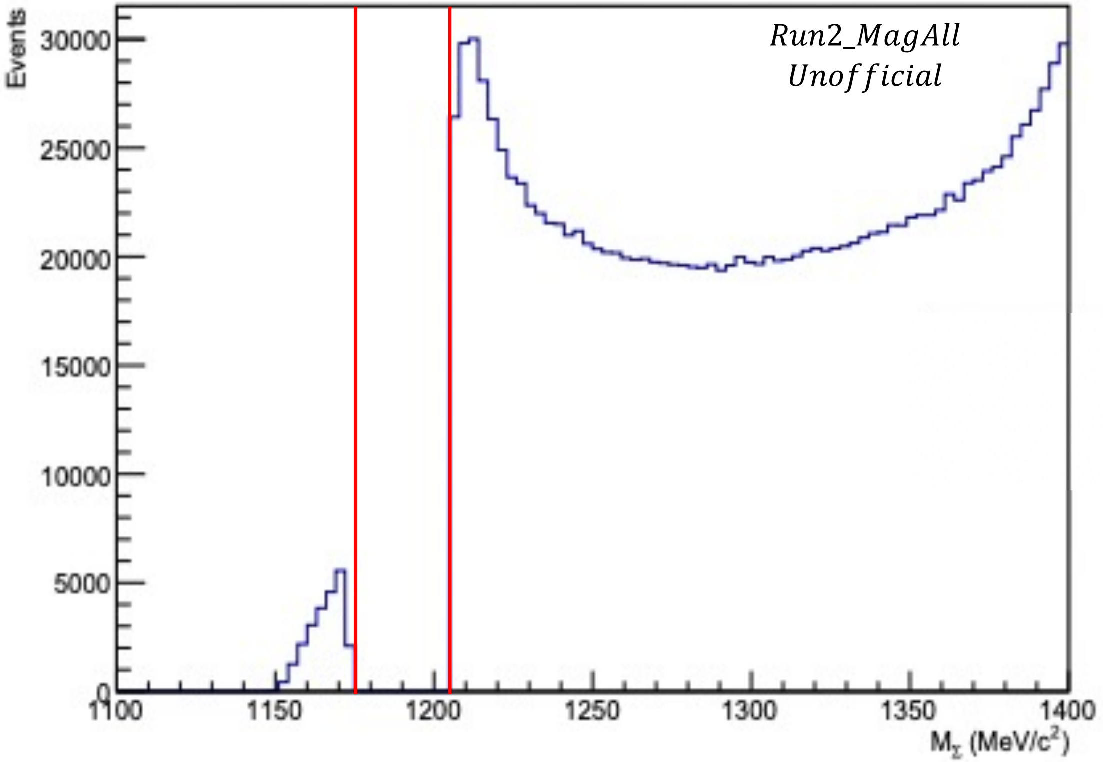
- For the moment we focus on 1) to 3), but we build our analysis ready to perform 4)

Run 2 analysis strategy

- Dedicated triggers implemented in Run 2 since 2016: good gain expected (near a factor 10) in efficiency
- Use 2016-2018 data, $5.6\ fb^{-1}$(No 2015 due to the lack of triggers)
  Factor ~ 4 in statistics just from luminosity and cross-section
- Soft preselection to produce the data samples
- Hard selection on Multivariate discriminant against combinatorial background and PID against $\Lambda \to p\pi^-$
- Search optimised for the observation of the channel minimizing the background
- Develope analysis not to create structures in $m_{p\mu\mu}$ or $m_{\mu^+\mu^-}$
- Normalised to $\Sigma^+ \to p\pi^0$
- Study dimuon mass and measure branching fraction
- $\mathcal{A}_{CP}$ measurement after publishing the other results, it will be part of a second paper eventually

Signal selection

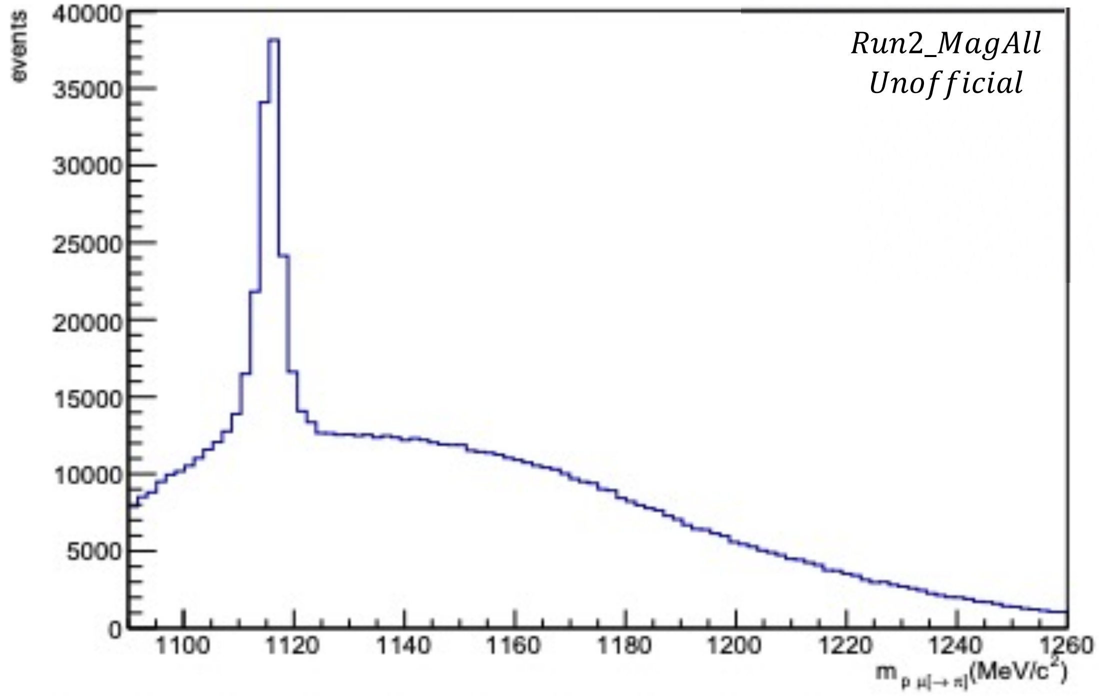
- Current soft preselection
  - Blind region mass
  - Loose μ PID (final cut optimised at the end)
  - Fiducial decay volume



muplus e muminus $ProbNNmu > 0.05$
proton $ProbNNp > 0.1$
$M_\Sigma < 1400$ MeV
$Sigma\,ENDVERTEX\ Z < 1000$ mm
$M_\Sigma < 1173$ MeV e $M_\Sigma > 1205$ MeV

Background

- Out of stripping line
  - Combinatorial background
  - "Λ background", from $\Lambda \to p\pi^-$ decays with an misidentified (or decaying) pion and additional muon track
  - Nothing else seems to contribute due to very tight phase space

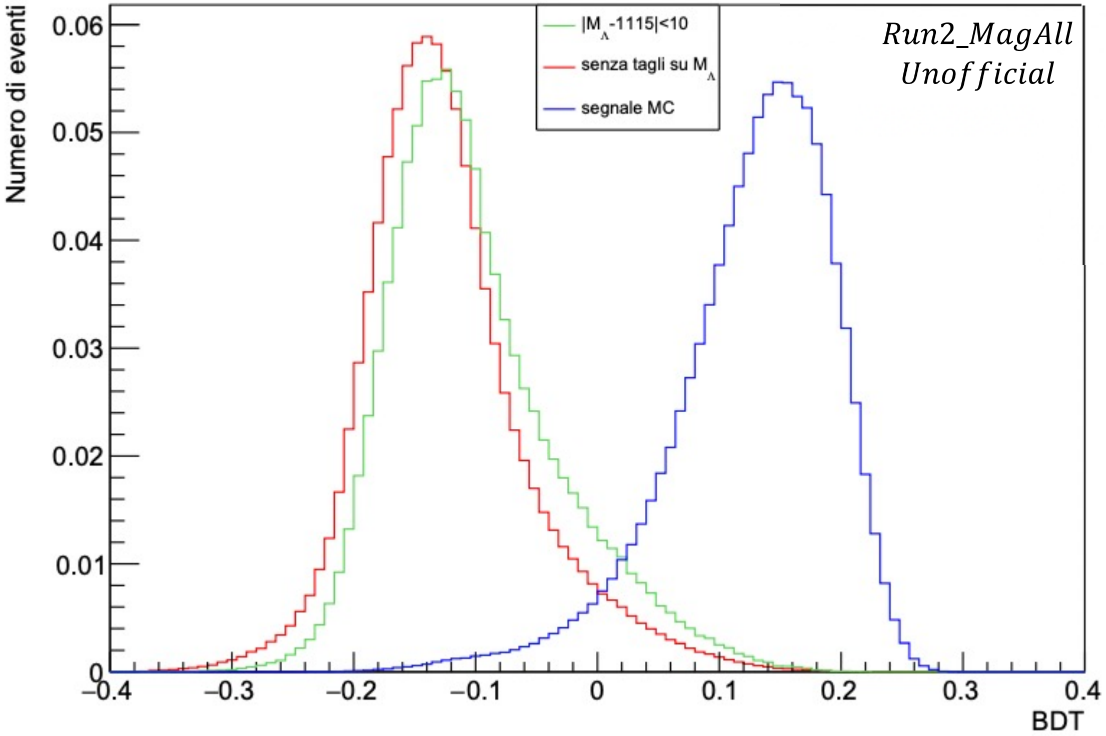


Optimisation of the final cuts

- Build multivariate discriminant (BDT)
- Trained on data sidebands
- Apply trigger, and Λ veto to train only on combinatorial background

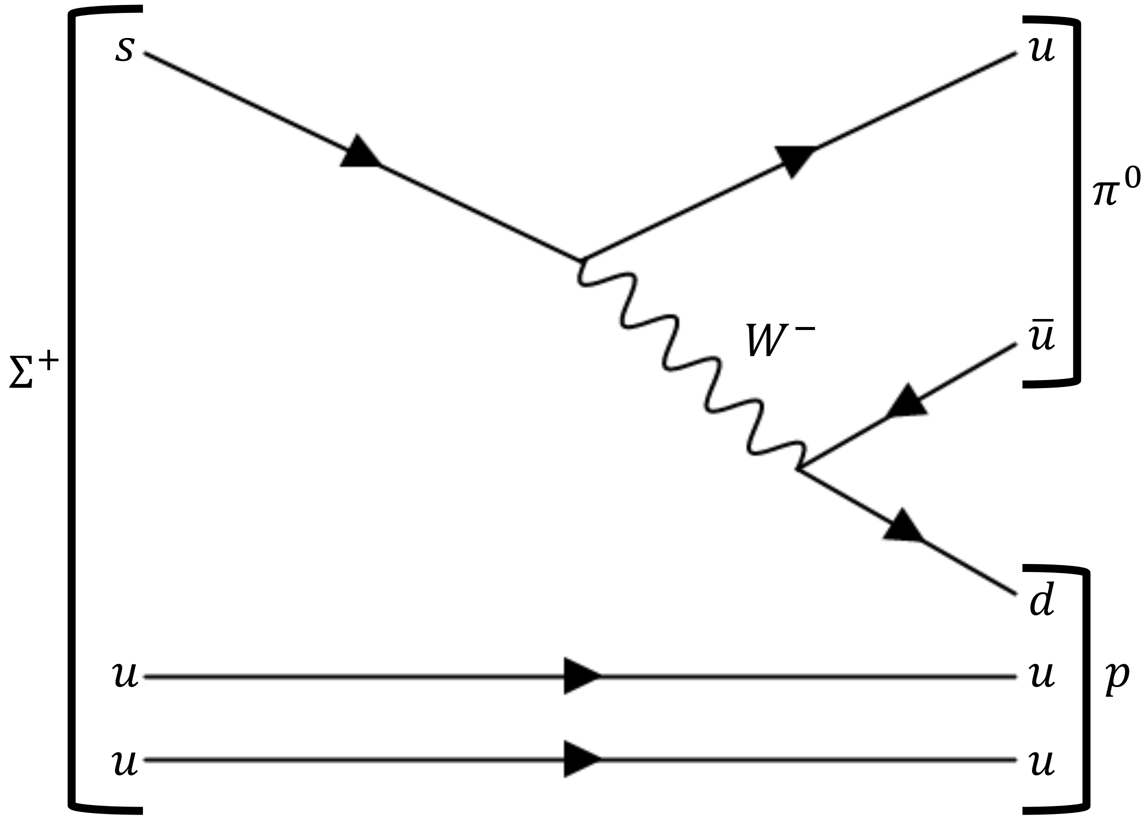
MC sample	data sample (*opposite sign*)
$(M_\Lambda - 1115,683) > 5\,\mathrm{MeV/c^2}$	$(M_\Lambda - 1115,683) > 5\,\mathrm{MeV/c^2}$
$\theta > 0.003$ rad	$\theta > 0.003$ rad
Sigma_L0Global_Dec==1	$M_\Sigma < 1168\mathrm{MeV/c^2}$ e $M_\Sigma > 1210\,\mathrm{MeV/c^2}$
Sigma_Hlt1Phys_Dec==1	
Sigma_Hlt2Phys_Dec==1	

- Original plan: BDT against combinatorial, some other cut (PID, pointing, veto...) against Λ background
- Optimising we realised Λ efficiently removed by BDT
 Similar distribution to combinatorial



Normalization

- In order to measure the $\Sigma^+ \to p\mu^+\mu^-$ branching fraction a normalization is required
- No fully charged final state available in the Σ^+ to normalize
  - Finding a suitable normalization is far from trivial …
- Only the $\Sigma^+ \to p\pi^0$ and $\Sigma^+ \to p\gamma$ decays are reconstructible in the final state
- Use high Branching Fraction $\Sigma^+ \to p\pi^0$
  - $\mathcal{B}(\Sigma^+ \to p\pi^0) = (51.77 \pm 0.30)\%$



$\Sigma^+ \to p\pi^0(\pi^0 \to \gamma\gamma)$ as normalization

- The $\Sigma^+ \to p\mu^+\mu^-$ branching fraction estimate follows the formula

$$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = \frac{\varepsilon_{\Sigma^+\to p\pi^0}}{\varepsilon_{\Sigma^+\to p\mu^+\mu^-}} \frac{\mathcal{B}(\Sigma^+ \to p\pi^0)}{N_{\Sigma^+\to p\pi^0}} N_{\Sigma^+\to p\mu^+\mu^-}$$

$$= \alpha N_{\Sigma^+\to p\mu^+\mu^-}$$

- ✓ $\varepsilon_{Channel}: Overall\ efficiency$
- ✓ $N_{Channel}: Yield$
- ✓ $\alpha: Single\ event\ sensitivity$

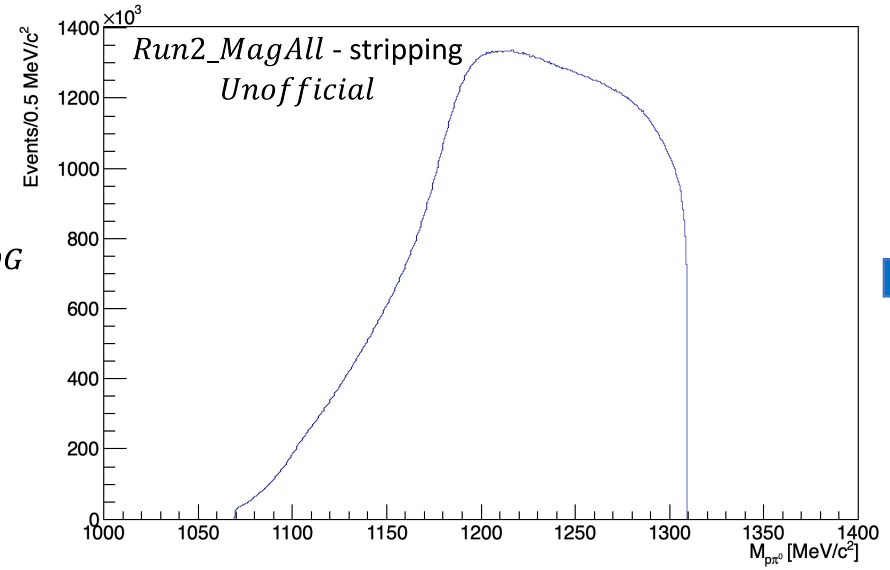
- $\Sigma^+ \to p\pi^0$ is reconstructed as a charged track plus a $\pi^0 \to \gamma\gamma$ in the electromagnetic calorimeter (ECAL)
  - The π^0 reconstruction is possible at LHCb as "resolved" i.e. as reconstructed from the two photon clusters in the ECAL, or "merged" i.e. $\gamma\gamma$ are reconstructed as a single cluster
- Selection for $\Sigma^+ \to p\pi^0$ with π^0reconstructed as resolved for this analysis

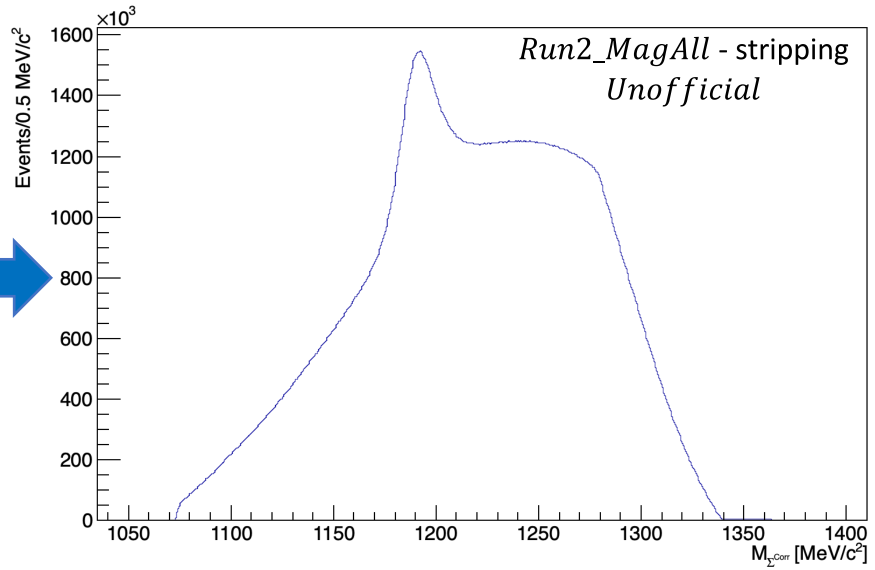
Stripping and offline selection

- Current stripping and offline selection
  - $proton$ and π^0 PIDs
  - Various kinematic variables
- The $m_{\gamma\gamma}$ as reconstructed from the energy deposit in the calorimeter has poor energy resolution
- A modified invariant mass is defined for the Σ^+ candidates

RareStrangeSigmaPPi0Cal	
Input particles	StdLooseProtons, StdLooseMergedPi0, StdLooseResolvedPi0
p	Track $\chi^2 < 3$, GhostProb< 0.3, ProbNNp> 0.5, $p_{\mathrm{T}} > 500$ MeV
π^0	$p_{\mathrm{T}} > 700$ MeV
$p\pi^0$	$\lvert m_{p\pi^0} - m_{\Sigma+}\rvert < 150$ MeV DOCA< 2mm $p_{\mathrm{T}} > 500$ MeV DIRA> 0.9 IP $\chi^2 < 36$ Vtx $\chi^2 < 36$ $\tau > 6$ ps

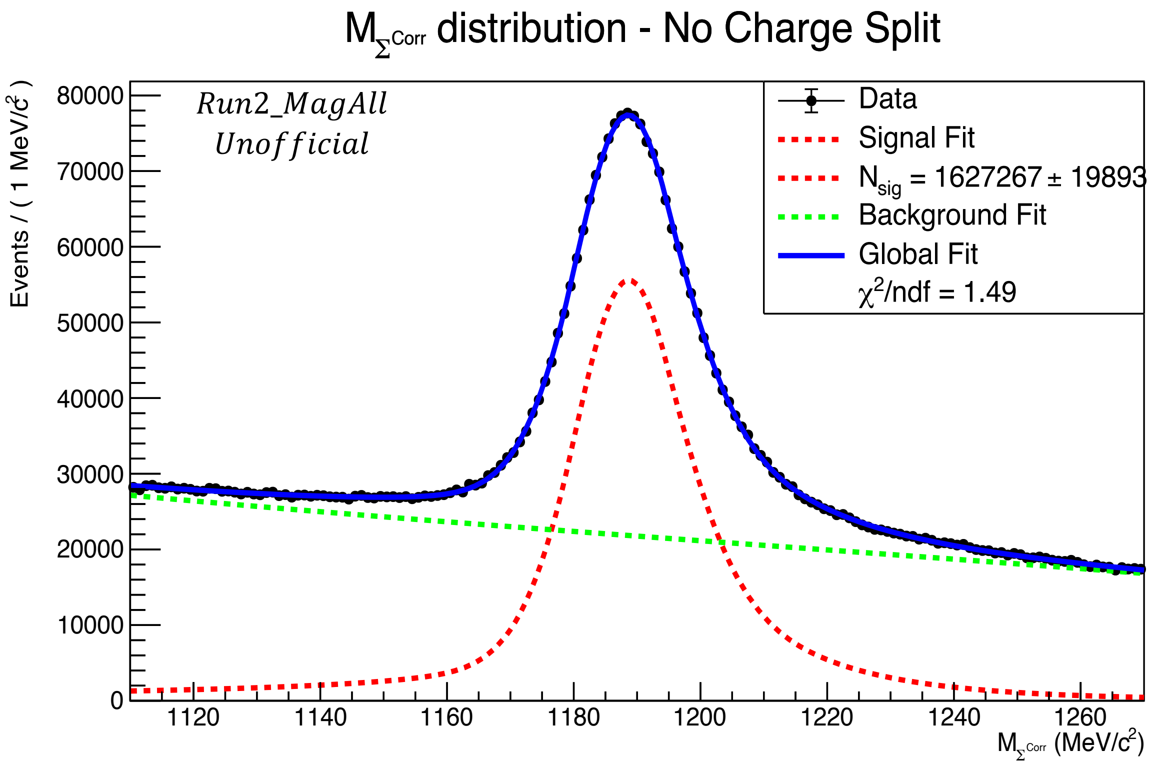
$$M_{p\gamma\gamma}^{Corr} = M_{\Sigma}^{Corr} = m_{p\gamma\gamma}^{REC} - m_{\gamma\gamma}^{REC} + m_{\pi^0}^{PDG}$$

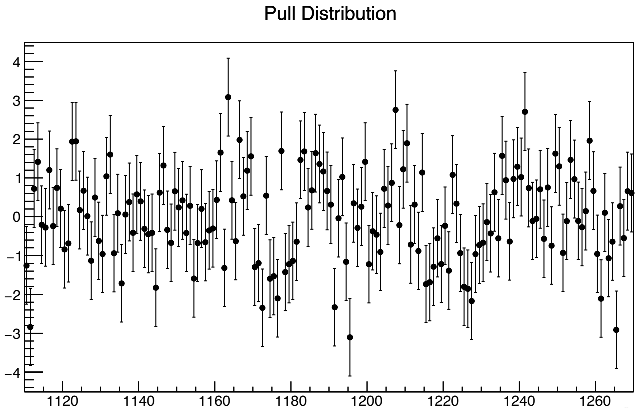




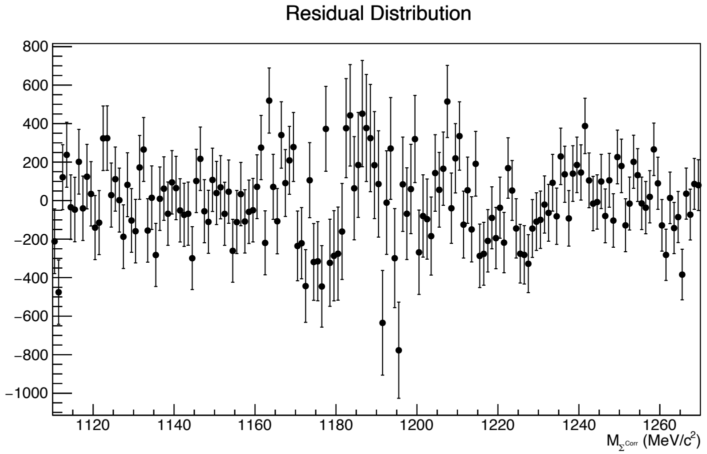
Estimate of the $\Sigma^+ \to p\pi^0$ yield

- Estimate of the $\Sigma^+ \to p\pi^0$ yield made with an extended maximum likelihood fit using RooFit
- $\Sigma^+ \to p\pi^0$ parametrized by **double-sided Crystal Ball** function
- Background by **second degree Chebyshev polynomial** function
- Observed $(1.63 \pm 0.02)\times 10^6$ events on Data





Offline selection
$proton\_ProbNNp > 0.9$
$pizero\_CL > 0.3$
$proton\_ProbNNk < 0.5$



Estimate efficiencies

- Efficiencies are split into the following factors, each including the previous

1) Acceptance - ε_{Acc}
2) Filtering - $\varepsilon_{Filt|Acc}$
3) Selection - $\varepsilon_{Sel|Filt}$
4) PID correction - $\varepsilon^{corr}_{PID|Sel}$
5) Tracking correction - $\varepsilon^{corr}_{Track|Sel}$
6) MVA calibration - $\varepsilon^{corr}_{MVA|Sel}$
7) Trigger - $\varepsilon_{Trig|PID} = \varepsilon^{L0}_{Trig|PID} \cdot \varepsilon^{HLT1}_{Trig|PID} \cdot \varepsilon^{HLT2}_{Trig|PID}$

$$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = \frac{\varepsilon_{\Sigma^+\to p\pi^0}}{\varepsilon_{\Sigma^+\to p\mu^+\mu^-}} \frac{\mathcal{B}(\Sigma^+ \to p\pi^0)}{N_{\Sigma^+\to p\pi^0}} N_{\Sigma^+\to p\mu^+\mu^-}$$

$$= \alpha N_{\Sigma^+\to p\mu^+\mu^-}$$

- The overall efficiency is written as a product

$$\varepsilon_{Tot} = \varepsilon_{Acc} \cdot \varepsilon_{Filt|Acc} \cdot \varepsilon_{Sel|Filt} \cdot \varepsilon^{corr}_{PID|Sel} \cdot \varepsilon^{corr}_{Track|Sel} \cdot \varepsilon^{corr}_{MVA|Sel} \cdot \varepsilon_{Trig|PID}$$

- At this stage everything is taken from MC for a preliminary estimate
- $\varepsilon^{corr}_{PID|Sel}, \varepsilon^{corr}_{Track|Sel}, \varepsilon^{corr}_{MVA|Sel}, \varepsilon_{Trig|PID}$ will all be calibrated from Data

Efficiencies for Σ^+ and $\overline{\Sigma^+}$ fluxes

Sample	$\varepsilon_{FiltSel\|Acc}$	$\varepsilon^{L0}_{Trig\|PID}$	$\varepsilon^{Hlt1}_{Trig\|PID}$	$\varepsilon^{Hlt2}_{Trig\|PID}$	$N_{\Sigma^+\to p\pi^0}$
$Run2\_all$	0.050 ± 0.003	0.032 ± 0.001	0.90 ± 0.01		$(7.10 \pm 0.10)\times10^5$
$\overline{Run2}\_all$	0.064 ± 0.004	0.037 ± 0.001	0.78 ± 0.02		$(7.96 \pm 0.05)\times10^5$
$Run2\ MagDown$	0.051 ± 0.007	0.027 ± 0.002	0.95 ± 0.01	**Next time!!!**	$(3.55 \pm 0.09)\times10^5$
$\overline{Run2}\ MagDown$	0.064 ± 0.007	0.036 ± 0.002	0.75 ± 0.02		$(4.30 \pm 0.20)\times10^5$
$Run2\ MagUp$	0.051 ± 0.010	0.033 ± 0.002	0.71 ± 0.03		$(3.58 \pm 0.05)\times10^5$
$\overline{Run2}\ MagUp$	0.064 ± 0.010	0.037 ± 0.002	0.80 ± 0.02		$(3.97 \pm 0.04)\times10^5$

- $HLT2$ **work in progress!!!**
- Need also ε_{Acc}, $\varepsilon^{corr}_{PID|Sel}$, $\varepsilon^{corr}_{MVA|Sel}$ and $\varepsilon^{corr}_{Track|Sel}$ to evaluate single event sensitivity
- Samples splitted also by charge and magnet polarity in order to measure a “Direct” CP violation in the future

Expected signal

- While the calibration of the normalization channel is difficult, the signal is reliable from MC
- Rescale the number of observed signals to the luminosity, cross-section and efficiency of Run 2

	Run 1	Run 2	Ratio
ε_{filter}		0.011524 ± 0.000010	
ε_{presel}		0.7221 ± 0.0009	
ε_{sel}	$(6.59 \pm 0.04) \times 10^{-3}$	$(8.322 \pm 0.012) \times 10^{-3}$	1.264 ± 0.008
ε_{trig}	0.0143 ± 0.0005	0.1203 ± 0.0004	8.41 ± 0.29
ε_{final}	0.3793 ± 0.0031	0.12697 ± 0.00035	0.3347 ± 0.0028
Lumi	3	4.6	1.86667
xsec			2
N Obs/exp	10.9 ± 3.3	145 ± 44	

Unofficial

Conclusion and outlook for the analysis

- Where are we?
  - Analysis performed blind to estimate expected signal
  - We believe we are in a clear situation: we expect a large signal over a small background
  - Efficiencies are from MC, exact numbers will change but not dramatically
  - This is not unexpected: we have a factor 10 increase in statistics and a factor 10 increase in signal trigger efficiency

- What to do next? Where do we go from here?
  - We plan to unblind the $m_{p\mu\mu}$ mass region **very soon**
  - We will keep the dimuon mass blind for the moment
  - After unblinding the next steps will be
    1) Check if data description in $m_{p\mu\mu}$ and/or $m_{p\pi}$ has any problem
    2) Calibrate residual trigger, PID, BDT efficiencies from Data
    3) Decide publication strategy depending on the amount of signal

LHCb activities: Run 3 data taking

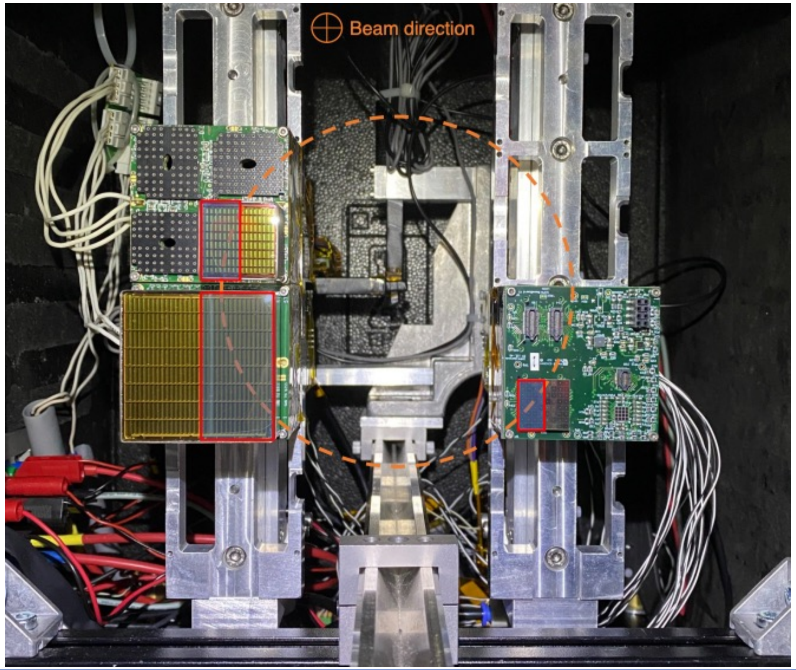
- I am actively contributing to the data taking participating with shifts in control room

- My shifter roles are
  - Shift leader (responsible of the control room)
  - Data manager (assistant to the shift leader)
  - RICH piquet (expert on call 24/7)

- Up today I spent **80** hours as a data manager/shift leader and **1** week as RICH piquet

LHCb activities: Test beam

- Perugia has joined the LHCb RICH group over the last two years
- Up today I partecipated at three test beams for the future upgrade of the LHCb RICH at SPS
- The group is composed by many institutes from all around the world:
  - Cambridge
  - Bucharest
  - Ferrara
  - Perugia
  - Ljubljana
  - Edinburgh
  - Krakow
  - Genova
  - CERN



Educational activities

Courses
- Introduction to Space Physics (Perugia)
- Flavour Physics (Perugia)

Schools
- ML-INFN-Hackathon 2021 (Online)
- INFN School of Statistics 2022 (Paestum)

Seminars:
- Progress Towards the realization of a Plasma Based FEL
- Spintronic logic gates based on spin waves
- The role of INFN in the development and modeling of ECR ion sources and their applications
- Il pi greco delle sarte
- Conferenza Istituzionale. La complessita' dal punto di vista di un fisico
- First Science Results from the LUX-ZEPLIN (LZ) Experiment
- On the tracks of elementary particles. Special focus: silicon trackers for High Energy Physics
- High Energy Neutrinos from Cosmic Accelerators

Workshops and LHCb weeks:
- First FCC-Italy Workshop (Rome)
- 102th LHCb Week 6-10 December 2021 (Cern)
- 103th LHCb Week 28 February - 4 March 2022 (Cern)
- 104th LHCb Week 13-17 June 2022 (Cern)
- 105th LHCb Week 5-9 September 2022 (Dortmund)
- LHCb Italia Collaboration meeting (LNF)

Other activities
- *Tutor per il corso di Fisica1 a.a. 2021/2022*
- *LHCb@International Masterclass 2021*
- *LHCb Commissioning, Analysis, Technical meetings*
  (Analysis/Technical meetings every 7 days)

[Updated to 27/10/2022]

List of publications and papers

- **Corresponding author**
  1) Ciafaloni, P.;Martelli, G.; Raggi, M. Searching for dark sectors in multi lepton final states in e+e − collisions JHEP 2021, 04, 163. *https://doi.org/10.1007/JHEP04(2021)163*
  2) G. Martelli, P. Ciafaloni, M. Raggi Searching for New Physics with multilepton events at PADME. Il Nuovo Cimento C. 2021, 56. 10.1393/ncc/i2021-21056-y

- **Author**
  1) LHCb collaboration, R. Aaij et al., Measurement of the charm mixing parameter yCP−yKπCP using two-body D0D0 meson decays *Phys. Rev. D* 105 (2022) 092013, 10.1103/PhysRevD.105.092013
  2) LHCb collaboration, R. Aaij et al., Observation of the doubly charmed baryon decay Ξ++cc→Ξ′+cπ+ *JHEP* 2205 (2022) 038, 10.1007/JHEP05(2022)038
  3) LHCb collaboration, R. Aaij et al., Study of charmonium and charmonium-like contributions in B+→J/ψηK+B+→J/ψηK+ decays *JHEP* 2022 (2020) 046, 10.1007/JHEP04(2022)046
  4) LHCb collaboration, R. Aaij et al., Observation of the decay Λ0b→Λ+cτ−ντ *Phys. Rev. Lett.* 128 (2022) 191803, 10.1103/PhysRevLett.128.191803
  5) LHCb collaboration, R. Aaij et al., Observation of the B0→D-∗0K+π− and B0s→D-*0K−π+ decays *Phys. Rev. D* 105 (2022) 072005, 10.1103/PhysRevD.105.072005
  6) LHCb collaboration, R. Aaij et al., Constraints on the CKM angle γ from B±→Dh± decays using D→h±h′∓π0 final states *JHEP* 2207 (2022) 099, 10.1007/JHEP07(2022)099
  7) LHCb collaboration, R. Aaij et al., Precision measurement of forward ZZ boson production in proton-proton collisions at s√=13s=13 TeV *JHEP* 2207 (2022) 026, 10.1007/JHEP07(2022)026
  8) LHCb collaboration, R. Aaij et al., Observation of Λ0b→D+pπ−π− and Λ0b→D∗+pπ−π− decays *HEP* 2203 (2022) 153, 10.1007/JHEP03(2022)153
  9) LHCb collaboration, R. Aaij et al., Measurement of the photon polarization in Λ0b→ Λγ decays *Phys. Rev. D* 105 (2022) L051104, 10.1103/PhysRevD.105.L051104
  10) LHCb collaboration, R. Aaij et al., Searches for rare B0s and B0 decays into four muons *JHEP* 2203 (2022) 109, 10.1007/JHEP03(2022)109
  11) LHCb collaboration, R. Aaij et al., Study of B+c decays to charmonia and three light hadrons *JHEP* 2201 (2022) 065, 10.1007/JHEP01(2022)065
  12) LHCb collaboration, R. Aaij et al., Angular Analysis of D0→π+π−μ+μ− and D0→K+K−μ+μ− Decays and Search for CPCP Violation *Phys. Rev. Lett.* 128 (2022) 221801, 10.1103/PhysRevLett.128.221801
  13) LHCb collaboration, R. Aaij et al., Tests of lepton universality using B0→K0Sℓ+ℓ− and B+→K∗+ℓ+ℓ− decays *Phys. Rev. Lett.* 128 (2022) 191802, 10.1103/PhysRevLett.128.191802
  14) LHCb collaboration, R. Aaij et al., Search for massive long-lived particles decaying semileptonically at s√=13 TeV *Eur. Phys. J. C* 82 (2022) 373, 10.1140/epjc/s10052-022-10186-3
  15) LHCb collaboration, R. Aaij et al., Observation of Two New Excited Ξ0b States Decaying to Λ0bK−π+ *Phys. Rev. Lett.* 128 (2022) 162001, 10.1103/PhysRevLett.128.162001
  16) LHCb collaboration, R. Aaij et al., Simultaneous determination of CKM angle γ and charm mixing parameters *JHEP* 2112 (2021) 141, 10.1007/JHEP12(2021)141
  17) LHCb collaboration, R. Aaij et al., Observation of the suppressed Λ0b→DpK− decay with D→K+π− and measurement of its CPCP asymmetry *Phys. Rev. D* 104 (2021) 112008, 10.1103/PhysRevD.104.112008
  18) LHCb collaboration, R. Aaij et al., Study of ZZ bosons produced in association with charm in the forward region *Phys. Rev. Lett.* 128 (2022) 082001, 10.1103/PhysRevLett.128.082001
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  20) LHCb collaboration, R. Aaij et al., Study of the doubly charmed tetraquark T+cc *Nature Commun.* 13 (2022) 3351, 10.1038/s41467-022-30206-w
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  22) LHCb collaboration, R. Aaij et al., Observation of an exotic narrow doubly charmed tetraquark 10.1038/s41567-022-01614-y
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[Updated to 27/10/2022]

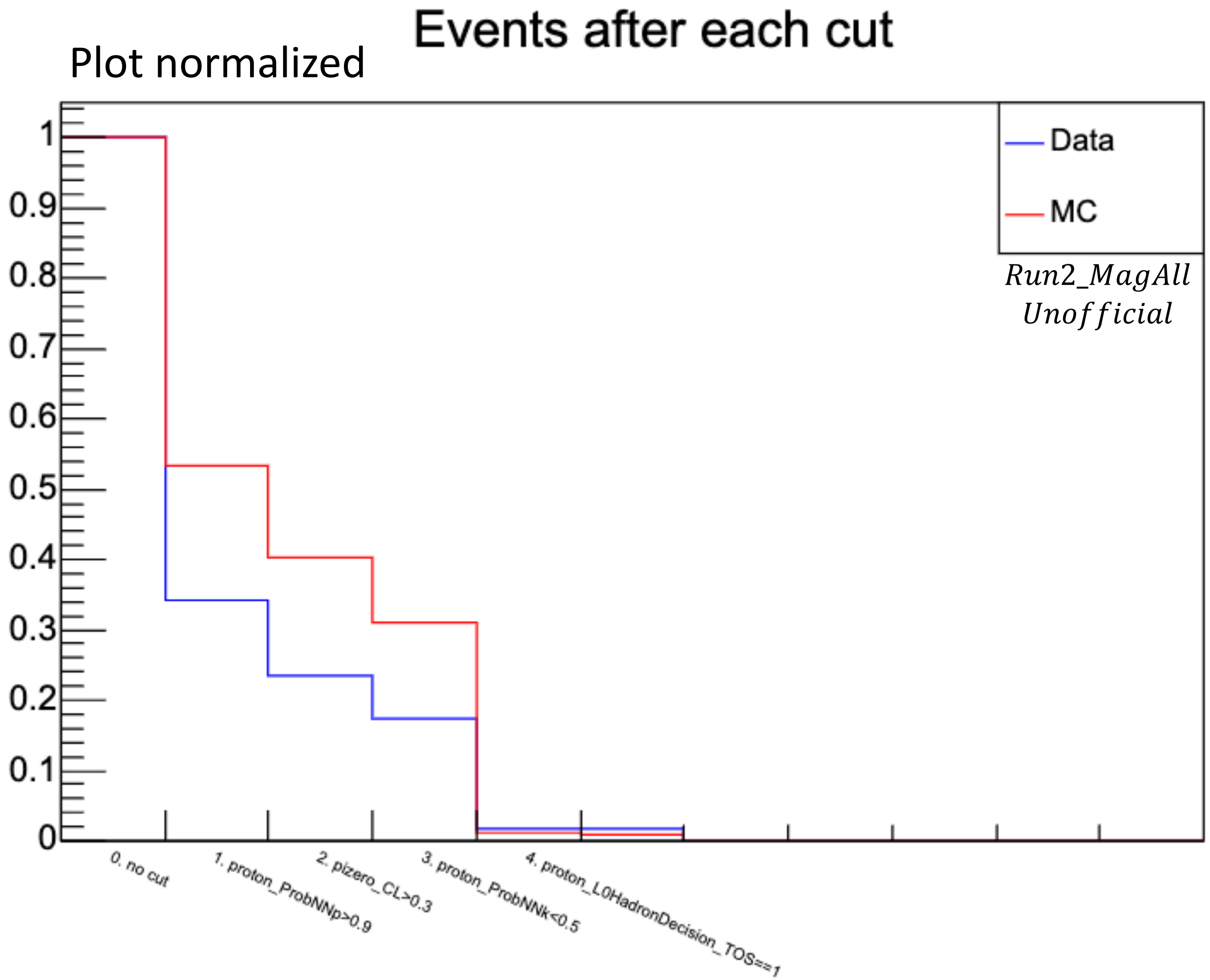
Thank you for your attention!!

Spare slides

Offine selection for $\Sigma^+ \rightarrow p\pi^0$

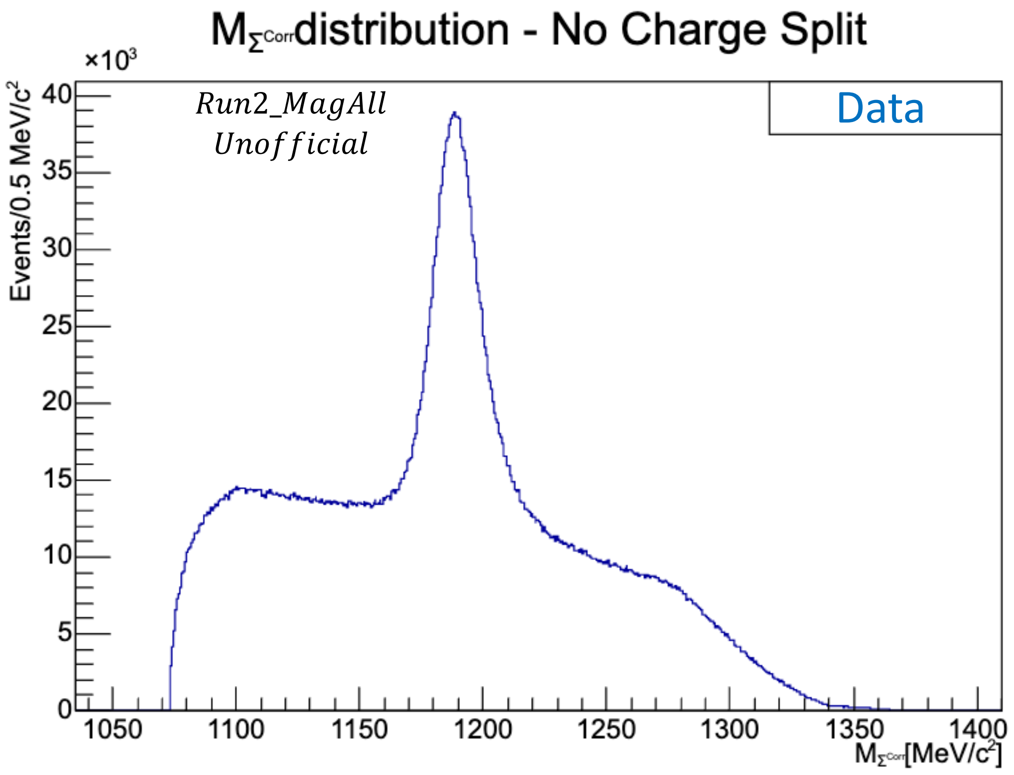
Offline selection: $\Sigma^+ \rightarrow p\pi^0(\pi^0 \rightarrow \gamma\gamma)$
$proton\_ProbNNp > 0.9$
$pizero\_CL > 0.3$
$proton\_ProbNNk < 0.5$
$proton\_L0HadronDecision\_TOS == 1$
$proton\_Hlt1TrackMVADecision\_TOS == 1$

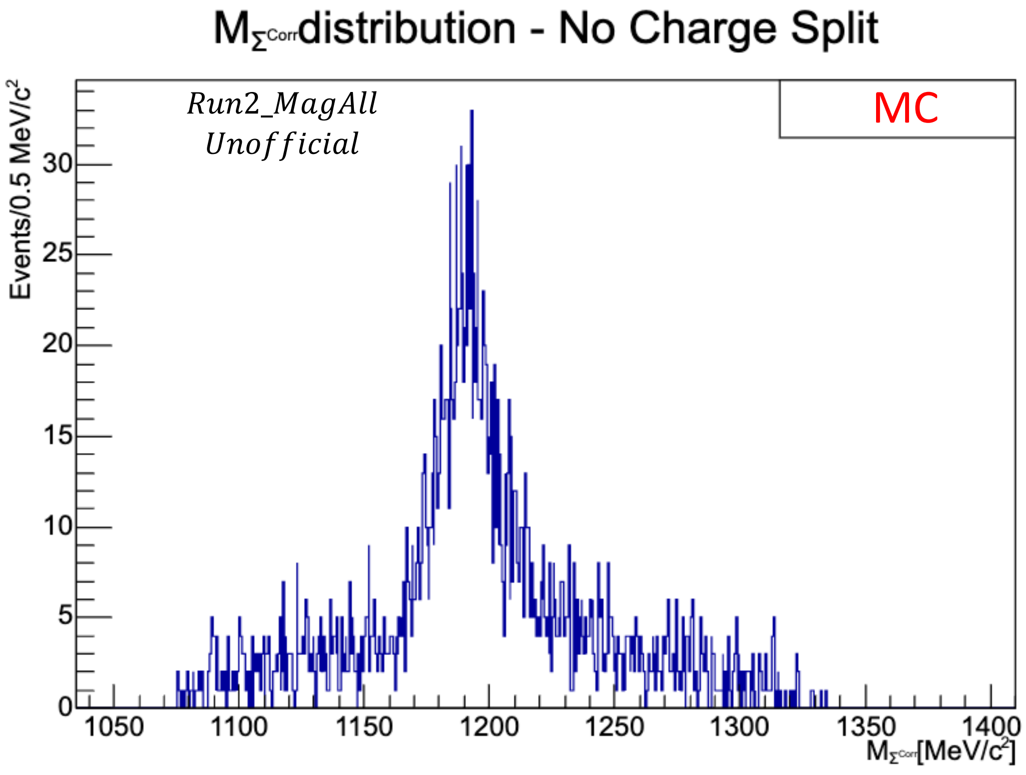
Plot normalized



Data and MC for $\Sigma^+ \to p\pi^0$

- Original plan: Fit the MC first then parametrize the fit on Data using the results coming from MC
- Since the MC does not faithfully reproduce the shape of both signal and background on Data, we decided to use the MC only for the estimation of efficiencies (for now …)





Filtering and Selection - $\varepsilon_{FiltSel|Acc}$

- $\varepsilon_{Filt|Acc}$ is the filtering efficiency and contains reconstruction and stripping as these samples need to be produced filtered

- $\varepsilon_{Sel|Rec}$ is the offline selection efficiency

- $\varepsilon_{Filt|Acc}$ and $\varepsilon_{Sel|Filt}$ are estimated together as

$$\varepsilon_{FiltSel|Acc} = \varepsilon_{Filt|Acc} \cdot \varepsilon_{Sel|Filt} = \frac{N_{FiltSel}}{N_{Gen}}$$

- $N_{FiltSel}$: $N_{\Sigma^+ \to p\pi^0}$ evaluated from the fit
- N_{Gen}: MC generated events

Trigger - $\varepsilon_{Trig|PID}$

- $\varepsilon_{Trig|PID}$ is the trigger efficiency
- The following trigger lines are used
  1) $proton\_L0HadronDecision\_TOS$ at L0
  2) $proton\_Hlt1TrackMVADecision\_TOS$ at Hlt1
  3) Hlt2 **work in progress**
- $\varepsilon_{Trig|PID}$ is estimated as

$$\varepsilon_{Trig|PID} = \frac{N_{L0}}{N_{FiltSel}} \cdot \frac{N_{Hlt1}}{N_{L0}} \cdot \boxed{\frac{N_{Hlt2}}{N_{Hlt1}}}$$

- $N_{L0}, N_{Hlt1}, N_{Hlt2}$: $N_{\Sigma^+ \to p\pi^0}$ evaluated from the fit after the corresponding trigger line
- $N_{FiltSel}$: see previous slides

Proton and antiproton p_T spectra

- Before applying the trigger request we observe that the p_T spectrum of antiproton is more populated at high values respect to the proton one (small effect)
- Such difference is enough to favour antiprotons with respect to protons once the offline TOS request is applied

- Data (left) and MC (right) proton/antiproton spectra comparison