$K^+ \to \pi^+\mu^+\mu^-$ AT NA62

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OUTLINE

Introduction to $K^+ \to \pi^+\mu^+\mu^-$ at NA62

Current status and prospects

Future and summary

PREVIOUS (NA48/2) MEASUREMENT

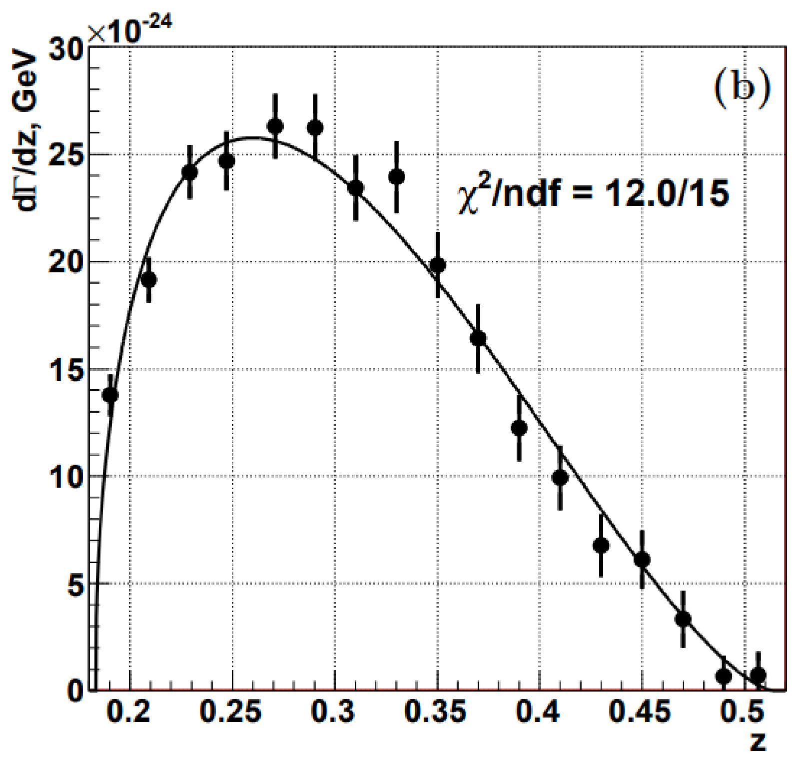
- The $K^+ \to \pi^+\mu^+\mu^-$ decay rate is described in terms of the form factor $W(z)$

$$\frac{d\Gamma}{dz} = \frac{\alpha^2 M_K}{12\pi(4\pi)^4}\lambda^{3/2}(1,z,r_\pi^2)\sqrt{1-4\frac{r_\mu^2}{z}}\left(1+2\frac{r_\mu^2}{z}\right)|W(z)|^2$$

- The functional form of $W(z)$ in χPT is:

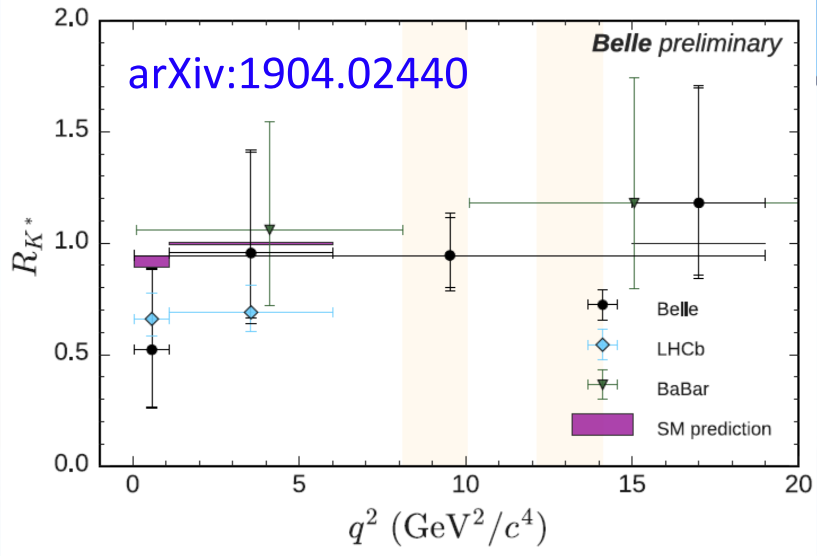
$$W(z) = G_F M_K^2(a_+ + b_+ z) + W^{\pi\pi}(z)$$

- And depends on the observables a_+ and b_+
- These were measured by NA48/2 using $O(3000)$ events



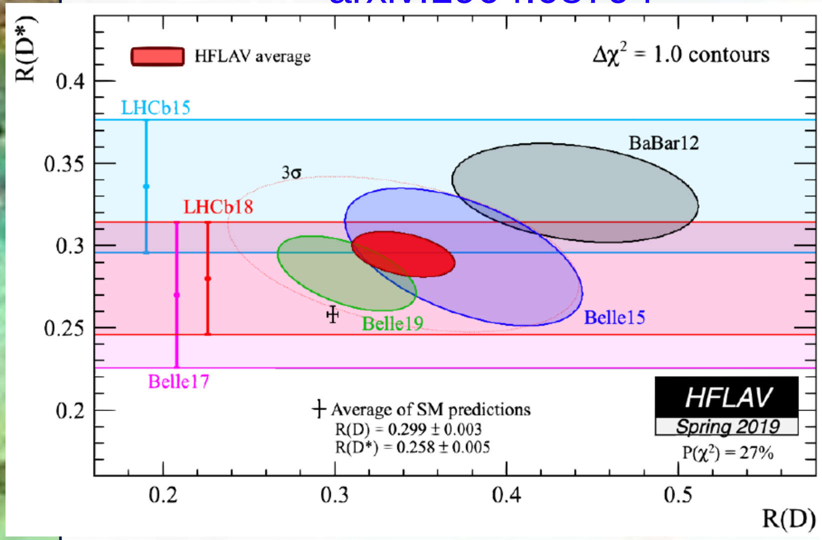
Model (2)	$\rho(a_+, b_+) = -0.976$				$\chi^2/\text{ndf} = 14.8/15$			
$a_+ =$	-0.575	$\pm$	$0.038_{\text{stat.}}$	$\pm\ 0.006_{\text{syst.}}$	$\pm\ 0.002_{\text{ext.}}$	$=$	-0.575	$\pm\ 0.039$
$b_+ =$	-0.813	$\pm$	$0.142_{\text{stat.}}$	$\pm\ 0.028_{\text{syst.}}$	$\pm\ 0.005_{\text{ext.}}$	$=$	-0.813	$\pm\ 0.145$

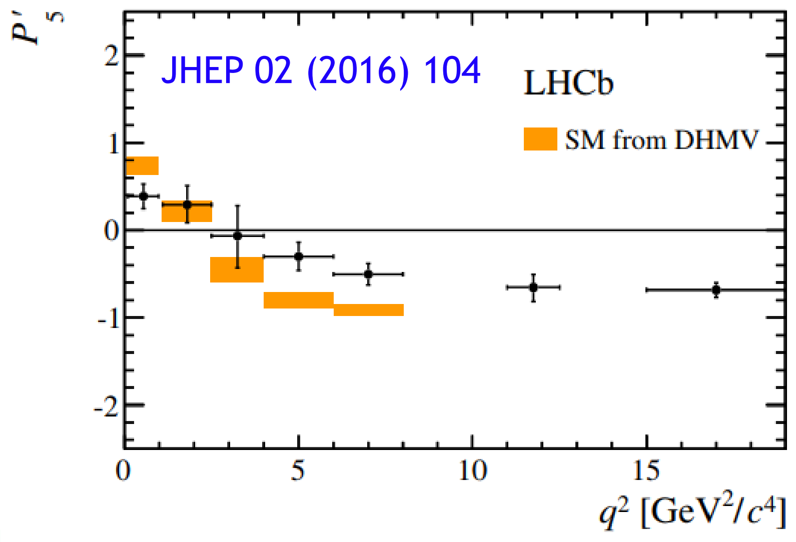
MOTIVATION

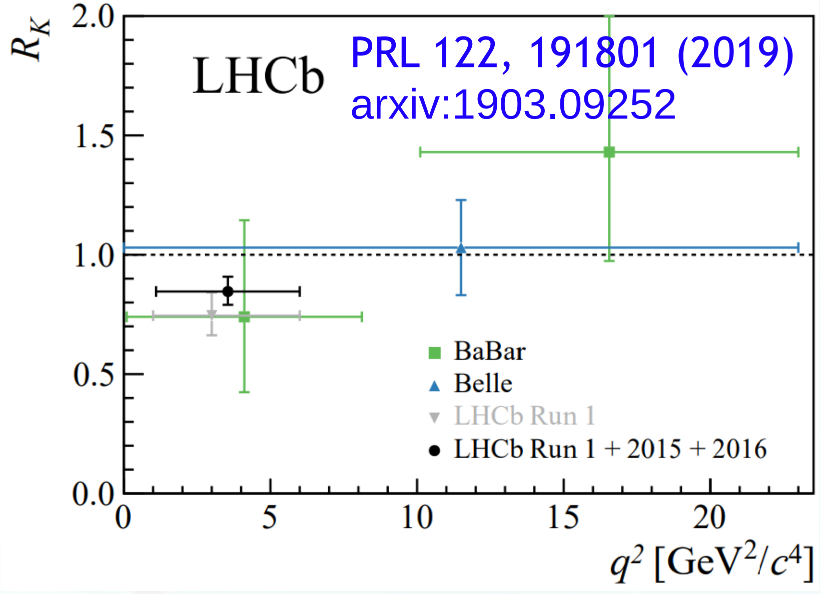


- Considerable interest generated by the "B anomalies"
  - In b $\rightarrow s\ell\ell$ transitions ($R_K, R_{K^*}, \mathrm{P}_5{}'$)
  - In $b \rightarrow c\tau\nu$ transitions ($B \rightarrow D^*\tau\nu, B \rightarrow D\tau\nu$)

arxiv:1904.08794

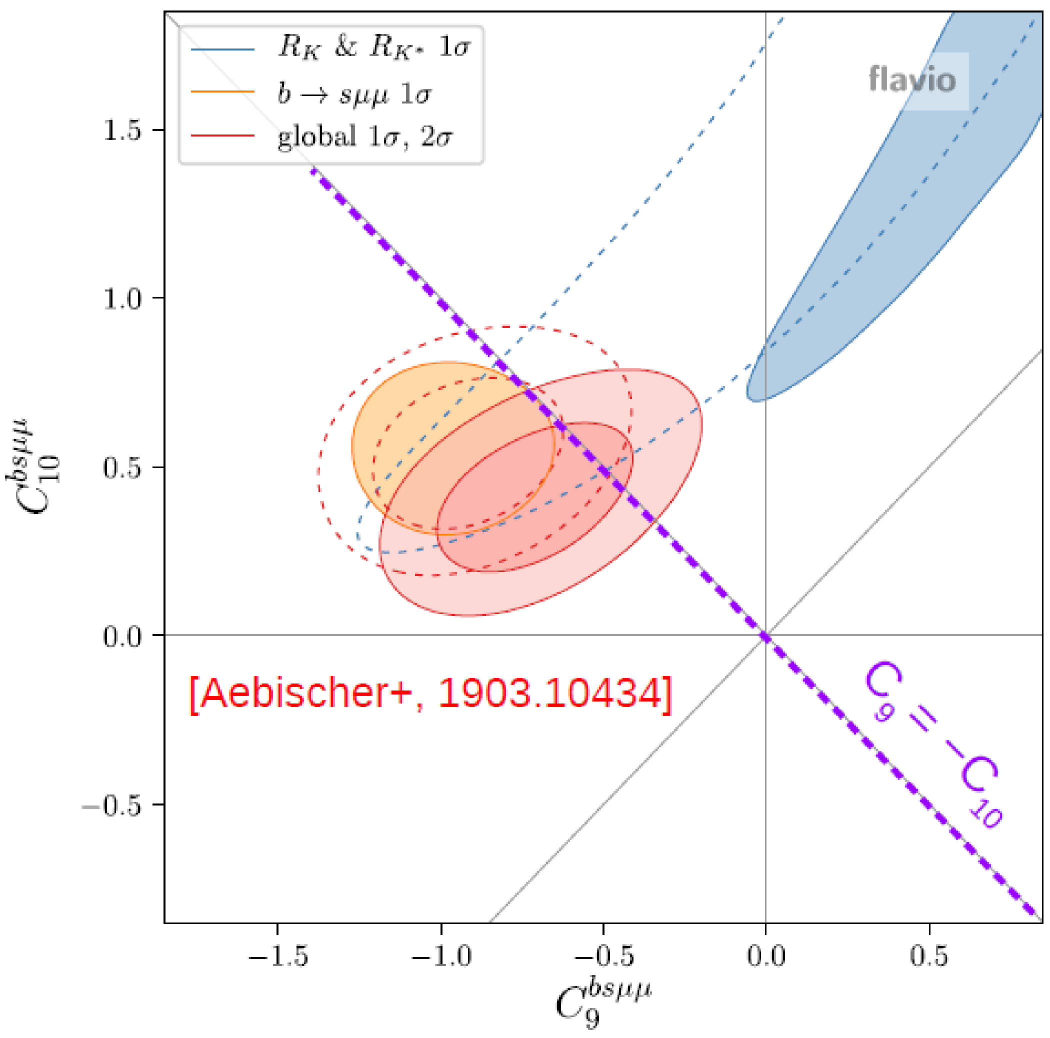






MOTIVATION

- A consistent fit to the anomalies implied a change to WCs C_9 and C_{10} (until Moriond 2019)
- Common explanations include Z', W', LQ
- Can more information be obtained from the kaon sector?



THE KAON PERSPECTIVE

1601.00970

- It is possible to probe LFU (violation), in the "B physics" Wilson coefficients using $K^+ \to \pi^+\mu^+\mu^-$ information

$$C_9^{B,\mu\mu} - C_9^{B,ee} = -\frac{a_+^{\mu\mu} - a_+^{ee}}{\sqrt{2}V_{td}V_{ts}^*} = -19 \pm 79$$

- To probe this WC at a comparable level to the B physics anomalies, which are $O(1)$, require $O(10)$ improvement
- This implies $O(100)$ more events (300k) with systematic effects controlled to a similar level (0.5%)

Is this possible at NA62?

The Kaon Perspective

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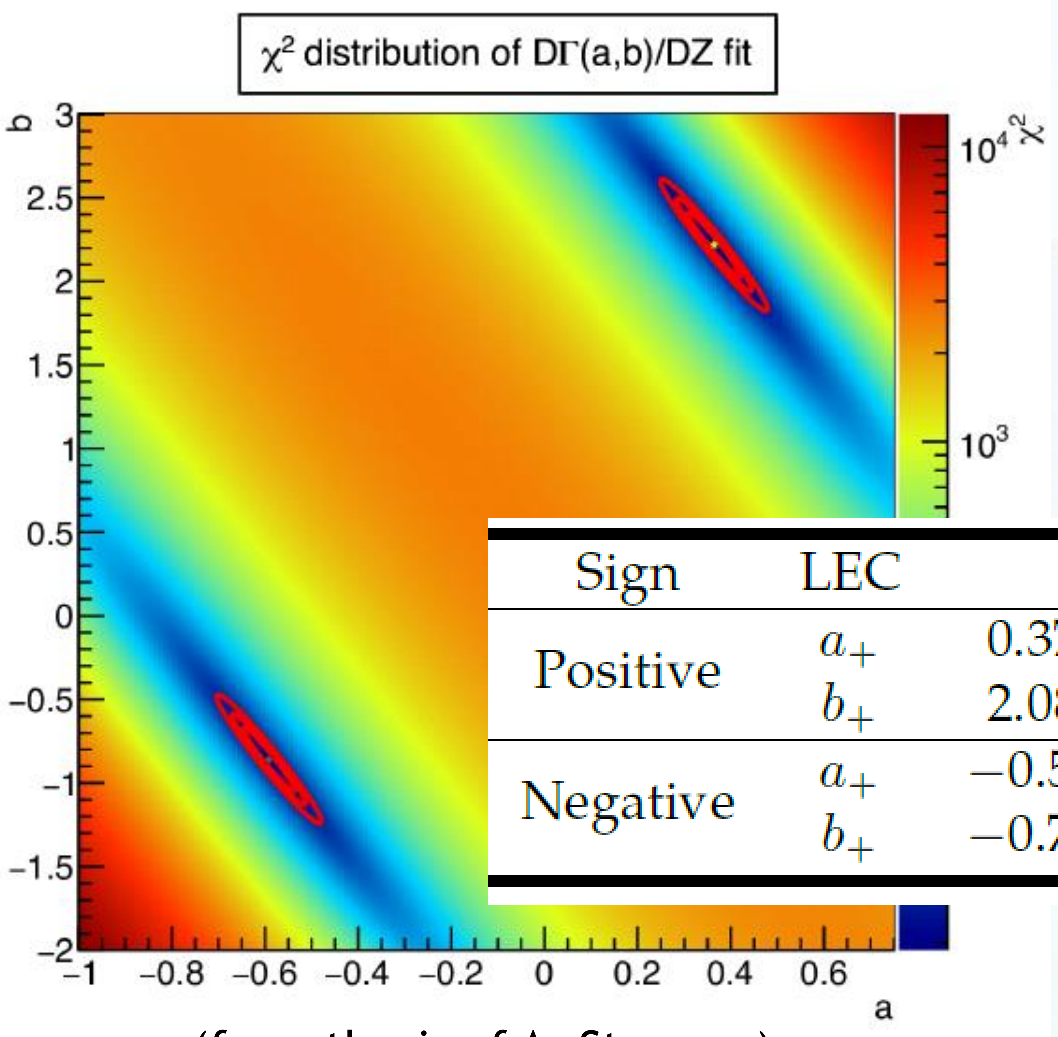
- The decay $K^+ \to \pi^+e^+e^-$ hard to acquire at NA62 due to trigger rate, geometry
  - Rely on previous measurement - no double ratio to cancel systematics ☹
- In nominal 2 years of NA62 running:
  - Collect $O(10^{13})$ K^+ decays
  - $N_{\pi\mu\mu} = 10^{13} \cdot 10^{-7} \cdot 0.1 = O(100\text{k})$
- ½ downscale in dimuon trigger means only $O(50\text{k})$ will be collected per run
- Running at 60-80% intensity: $O(35\text{k})$
  - Less than 2% stat. uncertainty
- NA62 can improve constraints on parameter space with sample 10x larger than that of NA48/2
  - But very challenging to reach sensitivity to the B anomalies

TWO SOLUTIONS

$$W(z) = G_F M_K^2 (a_+ + b_+ z) + W^{\pi\pi}(z)$$

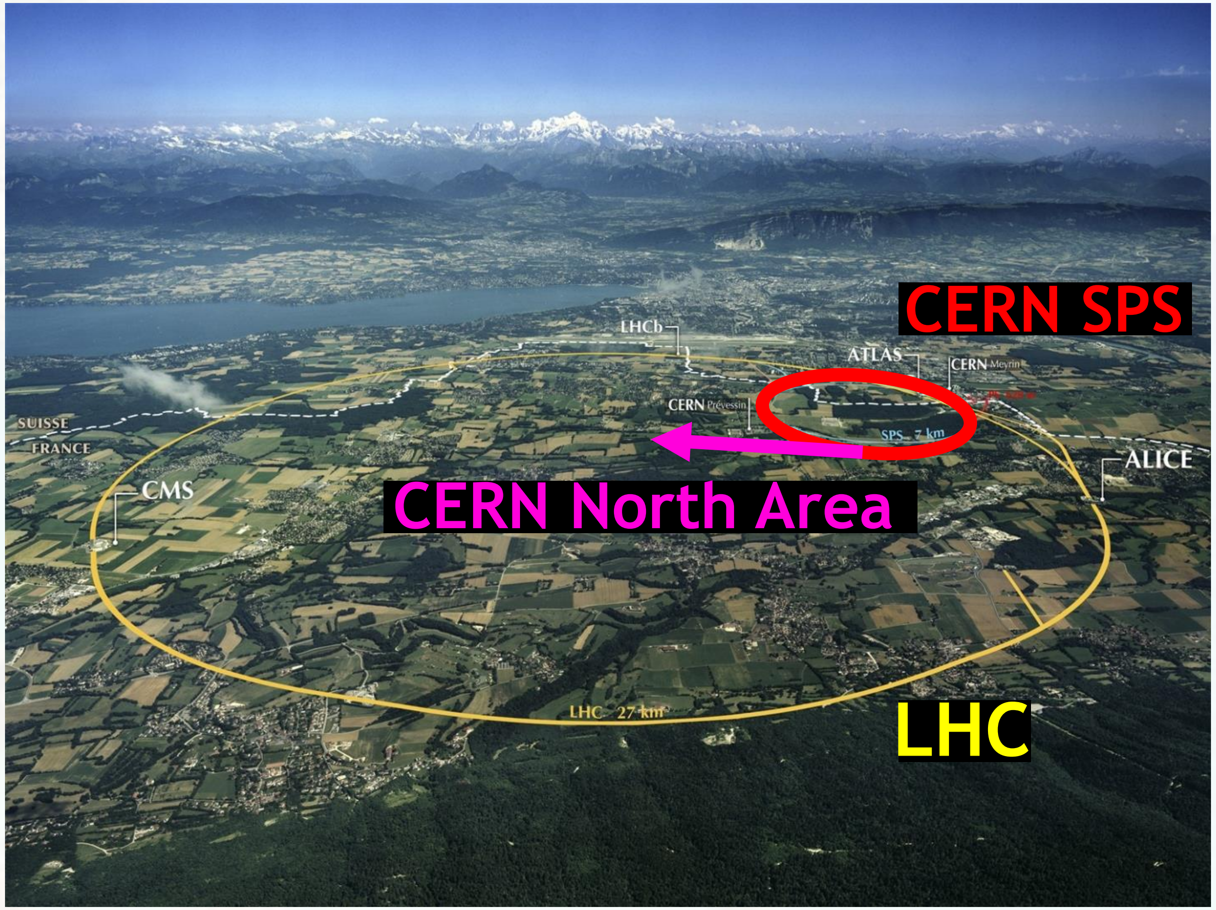
- When determining the values of a_+ and b_+ there are two possible solutions
- The two are differentiated only by the $W^{\pi\pi}(z)$ term
- The magnitude of (a_+, b_+) are quite different in the two solutions
  - Are theory predictions affected, in a meaningful way, if the (+ve,+ve) solution is used instead?
- **NB.** existing measurements only quote the (-ve –ve) results



Sign	LEC	
Positive	a_+	0.370
	b_+	2.080
Negative	a_+	−0.593
	b_+	−0.735

(from thesis of A. Sturgess)

THE NA62 EXPERIMENT AT CERN



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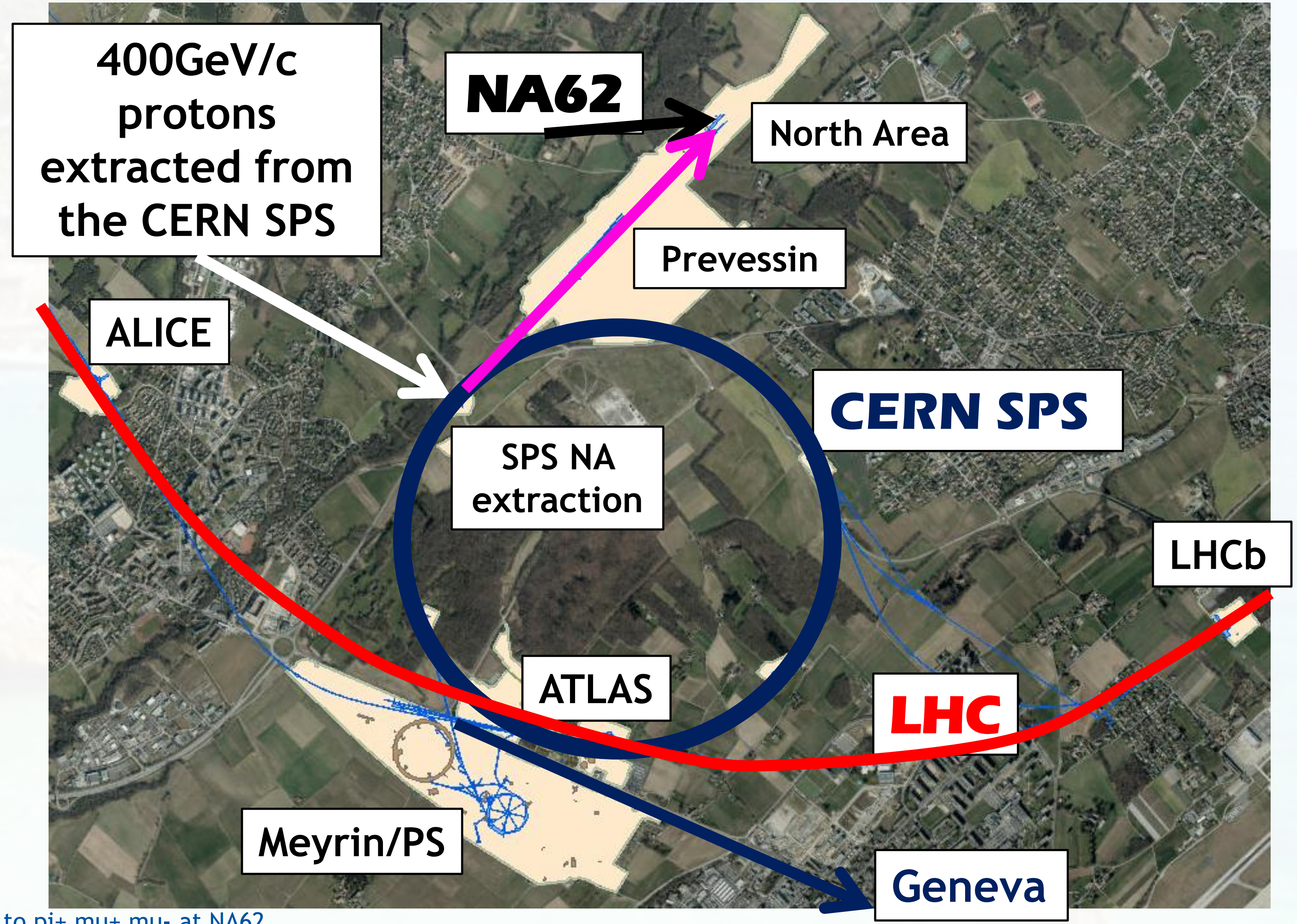

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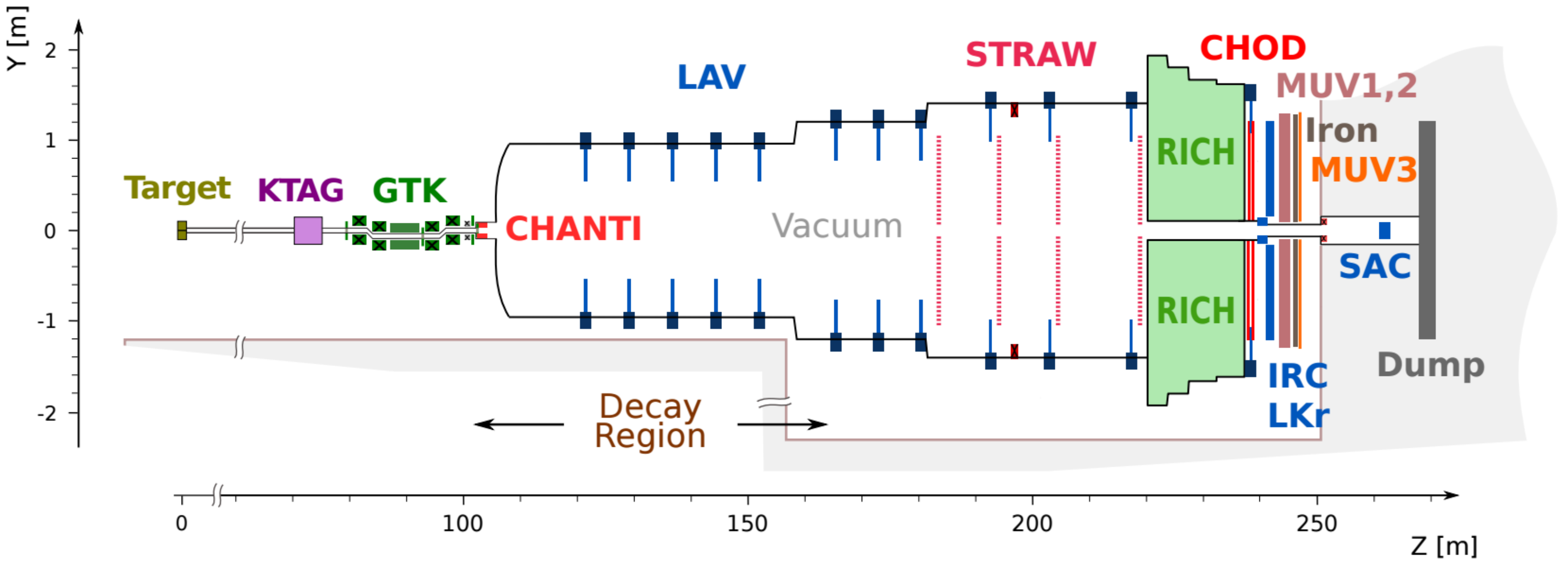


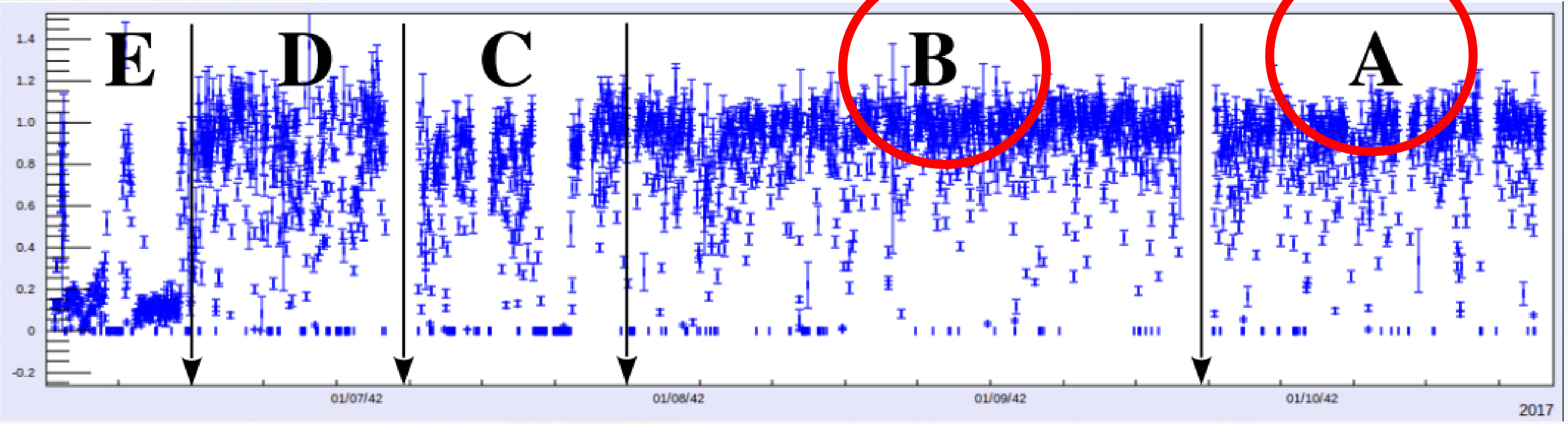
- Beam measurement
  - KTAG: L1 trigger
  - GTK: **Beam intensity measurement**
  - CHANTI: not used
  - Vacuum: fiducial decay volume

Daughter particle measurements:

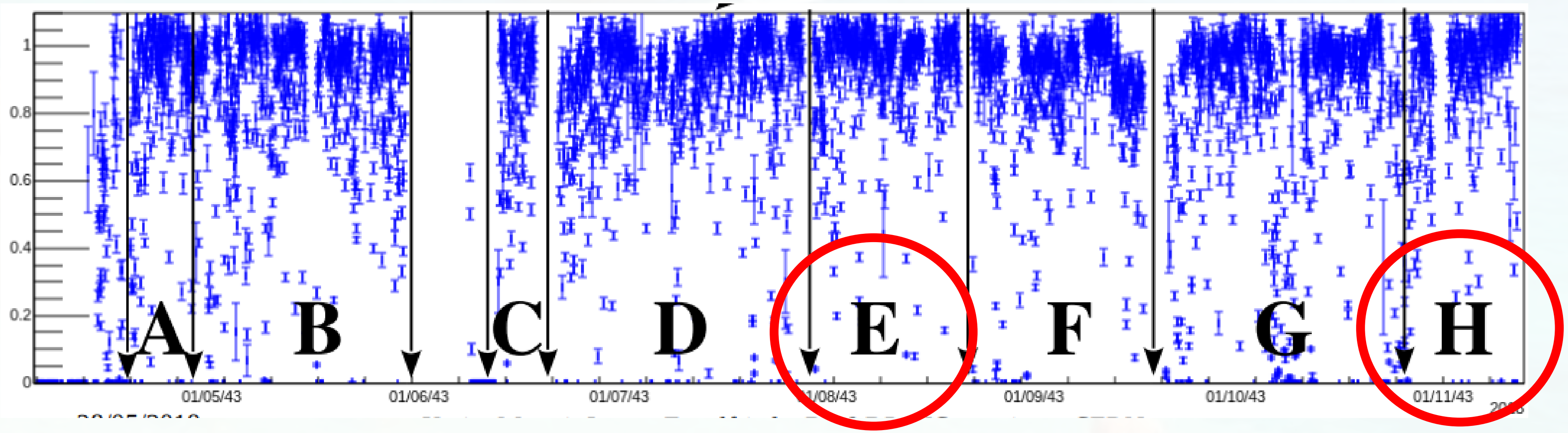
- STRAW: spectrometer, $\sigma_p = (0.3 \oplus 0.005 \cdot p)\%$ [GeV]
- (New) CHOD: hodoscope(s), L0 trigger
- RICH, LKr: L0 trigger, EoP for particle ID
- LAV/LKr/IRC/SAC: photon vetoes not used
- MUV1,2,3: L0 trigger, dimuon selection

DATA COLLECTED SO FAR

2017

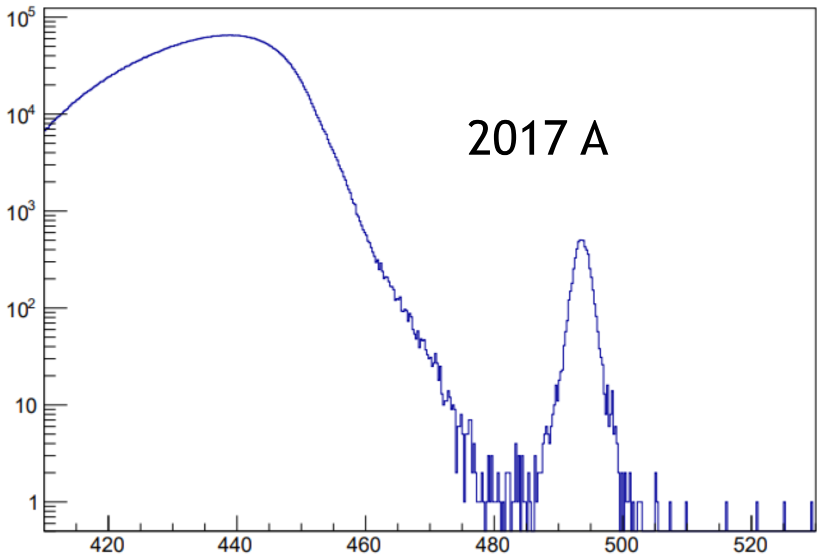


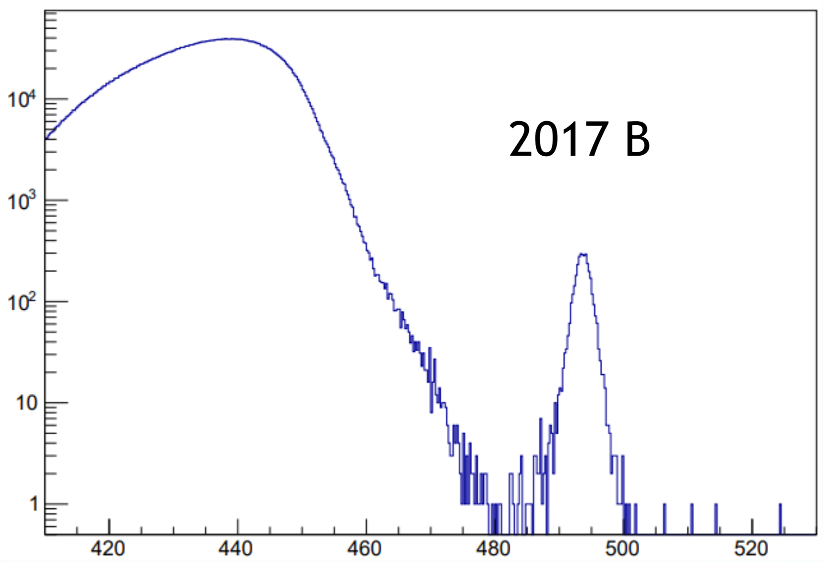
2018

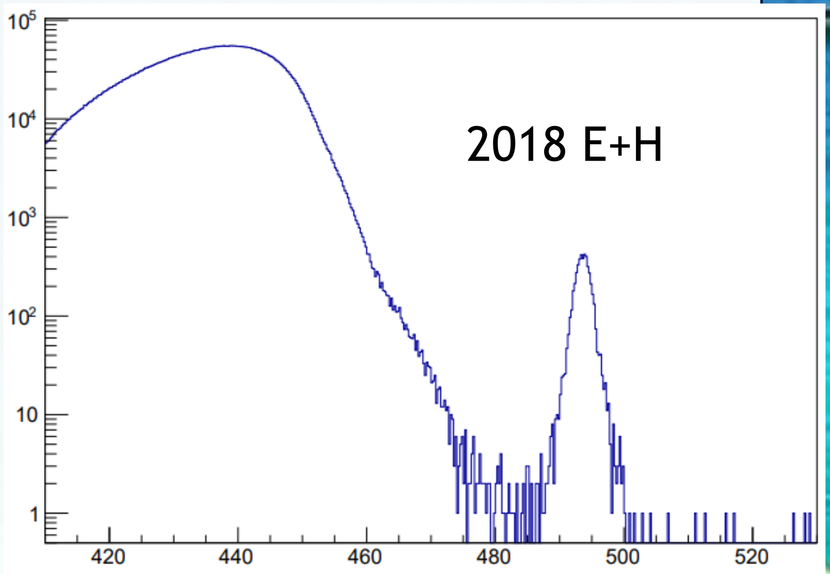


DATA COLLECTED SO FAR

- 2017 (60% nominal intensity):
  - A: 3560 events, 84k bursts
  - B: 5930 events, 150k bursts
  - $O(10\text{k})$ events this year
- 2018 (80% nominal intensity):
  - E+H: 4870 events, 115k bursts
  - Others: 317k bursts → 13500 events
  - $O(20\text{k})$ events this year
- $O(30\text{k})$ events in total

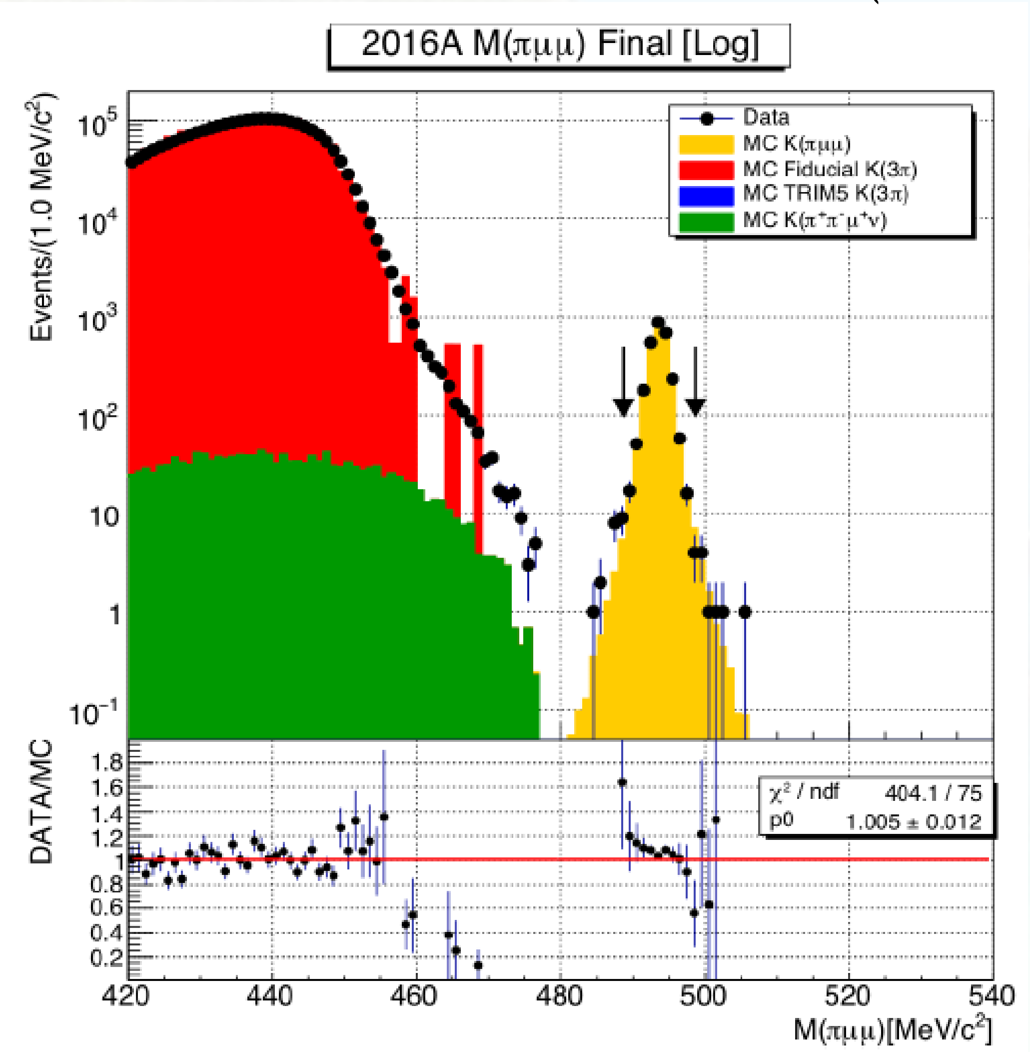




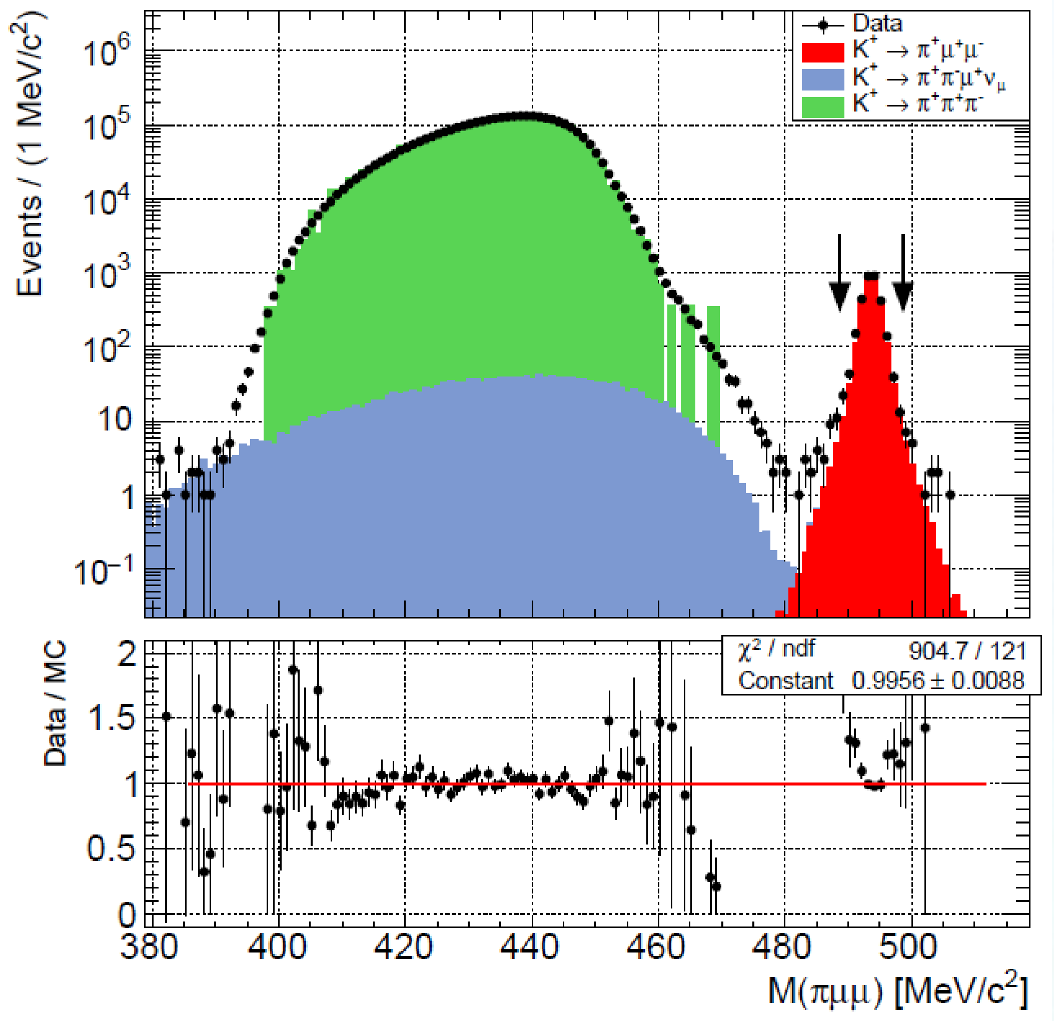


SELECTED DATA SAMPLES

2016 (A. Sturgess)



2017A (L. Bician)



Systematics from Lubos (2017A)

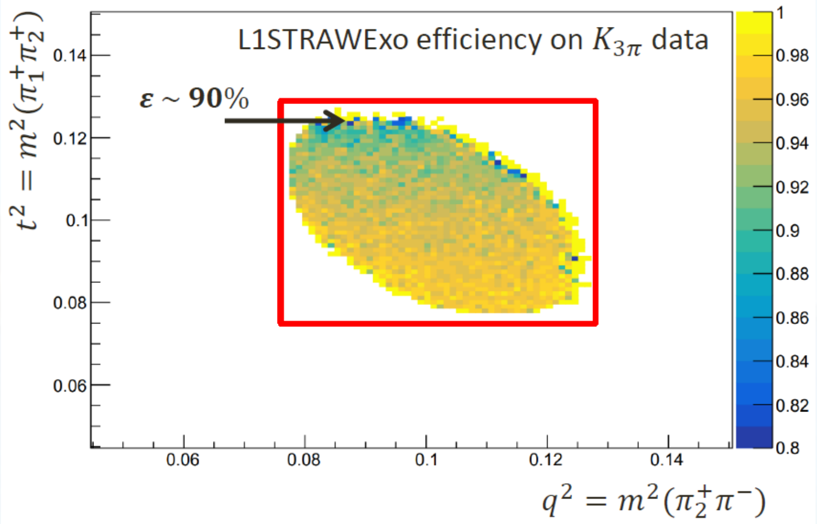
- Total systematic from Lubos is at the level of 4%
- Most of the contributions are $O(0.1\%)$
- Largest contribution is from the straw reconstruction efficiency, followed by the effects of pileup tracks in the spectrometer
- A further (correlated?) systematic from spectrometer track pileup, at the 2% level, is missing from this list
- Trigger efficiency systematics largely cancel, giving only a 0.5% effect

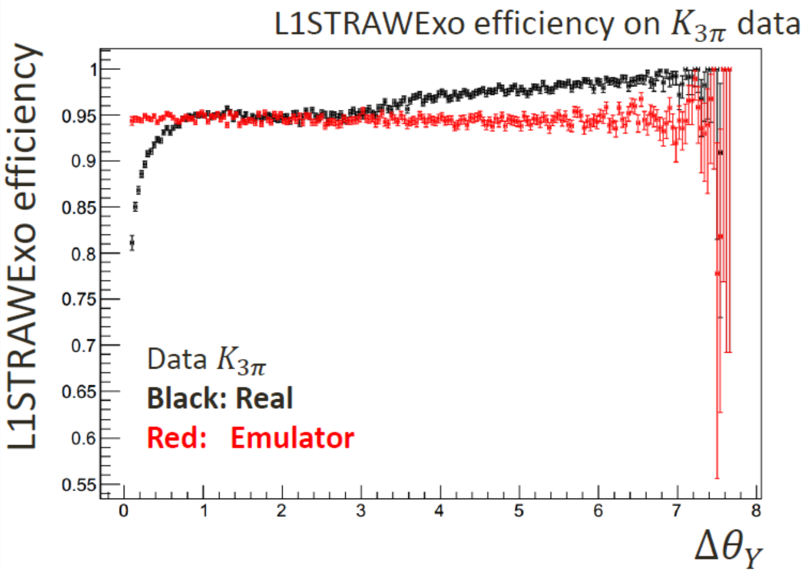
	a	b	$\mathcal{B}(K_{\pi\mu\mu}) \times 10^8$
Central values	−0.564	−0.797	9.32
Errors	δa	δb	$\delta\mathcal{B}(K_{\pi\mu\mu}) \times 10^8$
Statistical	0.034	0.118	0.17
Systematic			
Straw reconstruction efficiency	0.020	0.099	0.18
Trigger efficiency	0.003	0.030	0.12
Beam tuning	0.001	0.005	0.05
Straw pileup tracks	0.012	0.047	0.04
MUV3 pileup	< 0.001	0.004	0.03
MUV3 efficiency	0.001	0.002	0.03
LKr cluster corrections	< 0.001	0.001	0.01
Background	0.001	0.004	0.01
Straw track corrections, α	0.001	0.002	< 0.01
Straw track corrections, β	0.001	0.003	< 0.01
Particle identification	0.003	0.008	< 0.01
Error on $N(K_{3\pi})$	< 0.001	< 0.001	< 0.01
Straw resolution	< 0.001	< 0.001	< 0.01
Total systematic	0.024	0.114	0.23
External			
Error on $\mathcal{B}(K_{3\pi})$	0.001	0.003	0.04
TOTAL	0.042	0.164	0.29

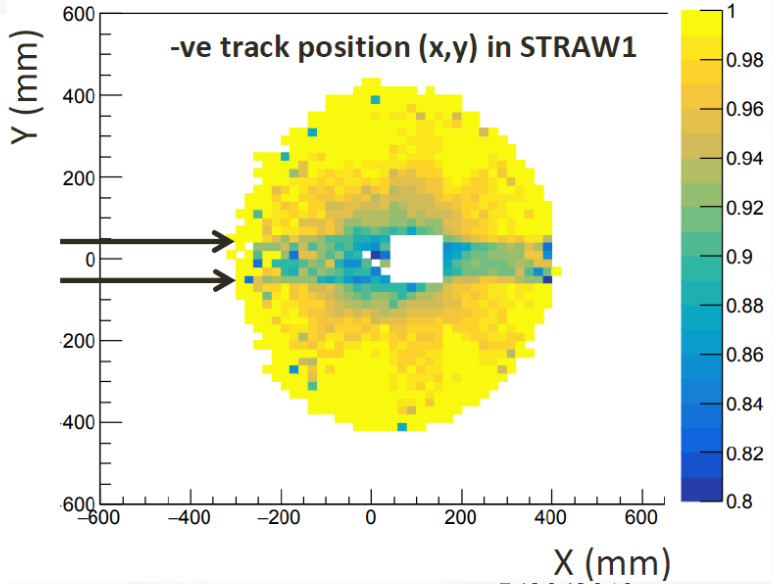
STRAW RECONSTRUCTION EFFECTS

- Changing criteria used to select tracks leads to a $\sim 4\%$ difference in a_+
- Changing criteria used to select vertexes leads to another $\sim 2\%$ shift in a_+
- Pileup tracks suspected to be the culprit
- L1STRAW "exotics" algorithm shows inefficiency due to multiple tracks, related to the geometry

All these points only relevant for 3-track events!







Current Status

- Work progressing to improve Straw reconstruction efficiency for 3T events
- The L1 algorithm results to be available in the simulation
- Full implementation of K12 beamline in Geant4 “G4BeamLine”
  - To incorporate event pileup in the simulation ‘by construction’
  - Vital for spectrometer (reco eff.) and trigger emulation
- Organised within 2 new working groups:
  - Precision measurements WG (M. Koval)
  - MC Validation WG (S. Schuchmann)

FUTURE PROSPECTS

- Running for 3 years (2021-2023) in "2018" conditions, expect $O(20\text{k})$ events per year, meaning $O(100\text{k})$ events in total by 2024.
- Improvements in the trigger (removing the ½ downscale) would make this $O(150\text{k})$
  - And perhaps allow to collect large samples of $K^+ \to \pi^+ e^+ e^-$?
- This much larger dataset would give comparable precision to the "factor of 10" needed to probe the B anomalies
  - Assuming systematic effects can be controlled to the same precision!
- If B anomalies persist, is a dedicated run motivated?
  - Consider "simple" modifications to the experimental setup?

Conclusions

- NA62 has collected $O(30\text{k})$ $K^+ \rightarrow \pi^+\mu^+\mu^-$ decays, the worlds largest sample
  - A factor of 10 larger than the NA48/2 sample, and lower background contamination
- Studies on the 2016 and 2017A data sample are “published” in the thesis’ of A. Sturgess and L. Bician
- Limiting factor coming from systematic effects in the Straw track reconstruction
  - Being attacked on several fronts, work organised by 2 new working groups
- Prospects for worlds best measurement are very good
- Obtaining enough events and systematic control for ‘ultimate’ measurement, to probe B anomalies via the kaon sector, remains very challenging

COULOMB CORRECTIONS

- Coulomb corrections are taken into account in the generation of the simulated events samples, as well as the fitting procedure(s)
- Red areas: opposite-sign charged particles ($\pi^+\mu^-, \mu^+\mu^-$) produced at rest, attractive force
- Green area: same-sign charged particles ($\pi^+\mu^+$) produced at rest, repulsive force
- Model for Ω_C assigned 1% uncertainty in the literature
  [Eur. Phys. J., C53 (2008), pp. 567–571
  arxiv:0709.2439]