Experimental Basis — 2

Lecture 1

- An example analysis
- How to design a good experiment
- Experiments

Lecture 2

- Triggers
- Techniques
- Soft skills
- The future

27/05/2023 — FPCP pre-conference school
[indico]

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BLUF — Bottom Line Up Front

- Experiments need triggers and hence choices
- Master analysis techniques
- . . . and soft skills
- Look out for the future

Triggering

Why do HEP experiments have a trigger

Particle physics experiments have triggers to efficiently select and record the most interesting and relevant events among the vast amount of data generated in particle collisions.

In particle physics experiments, high-energy particles collide at extremely high rates, producing a large number of interactions. However, not all of these interactions are of interest to researchers. Many of them involve well-understood and less significant processes. Therefore, triggers are used to identify and capture the rare and interesting events that may indicate the presence of new particles or phenomena.

Triggers consist of sophisticated algorithms and electronic systems that quickly analyze the characteristics of each collision and make a rapid decision on whether to keep or discard the data. These algorithms are designed to select events that meet specific criteria, such as the production of certain particles or specific patterns of particle interactions. By using triggers, experiments can focus on recording the most promising events while discarding a significant portion of uninteresting background data, which helps manage the large data volumes and limited storage capabilities of the experimental apparatus.

In summary, triggers are essential in particle physics experiments to efficiently select and record the most relevant and intriguing events, allowing researchers to concentrate their analysis on the most promising data.

Cross-sections

Process	Cross-section	Rate at 10^{33}	/BX
Inelastic	80 mb	80 kHz	2.7
charm $(2 < y < 4.5)$	2.4 mb	2.4 MHz	8%
beauty $(2 < y < 4.5)$	144 μb	144 kHz	0.5%
$Z \to \mu^+\mu^-$	195 pb	0.2 Hz	6×10^{-9}
$B_s^0 \to \mu^+\mu^-$	0.2 pb	0.2 mHz	5×10^{-12}

$10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ are $1\,\mathrm{nb}^{-1}/\mathrm{s}$. Assuming a non-empty rate of 30 MHz.

A trigger for just $B_s^0 \to \mu^+\mu^-$ is easy. Keeping lots of inclusive b is hard.

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Process	Cross-section	Rate at 10^{36}	
$B\bar{B}$	1.2 nb	10 kHz	

For Belle II the game is to keep a ∼100% efficiency on signal.

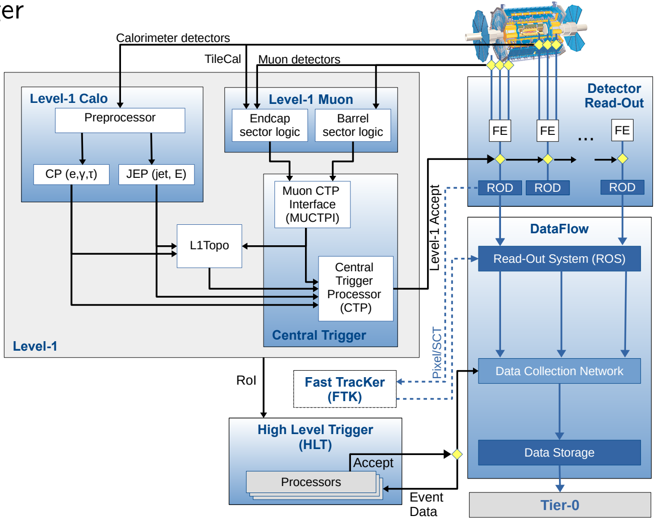
[ATLAS, JINST 15 (2020) P10004, arXiv:2007.12539]

ATLAS Trigger

Typical two-stage trigger

Average event size: 1 MB

→ $\gtrsim 1.2$ GB/s



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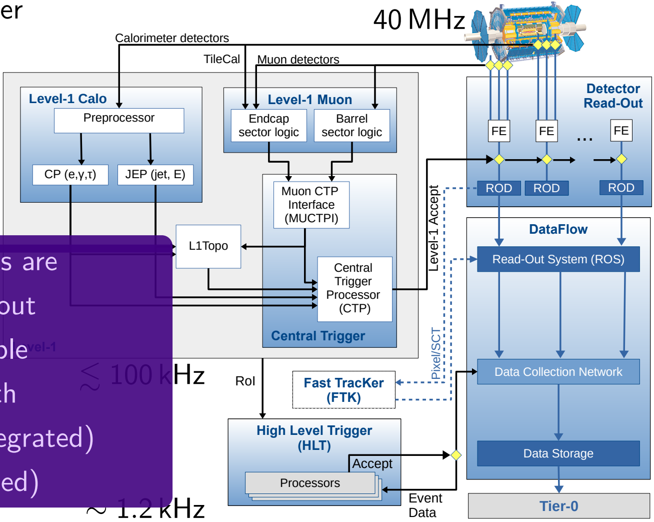

The bottlenecks are

1. Electronics read-out
2. HLT CPU available
3. Output bandwidth
4. Offline CPU (integrated)
5. Storage (integrated)

[ATLAS, JINST 15 (2020) P10004, arXiv:2007.12539]

ATLAS Trigger

Typical two-stage trigger

Average event size: 1 MB

→ $\gtrsim$ 1.2 GB/s

- Output rates adapted to luminosity

The bottlenecks are

1. Electronics read-out
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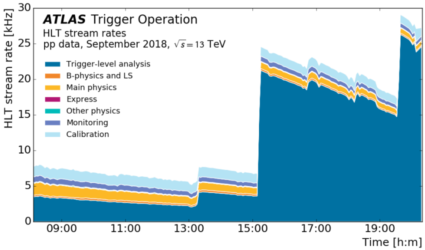
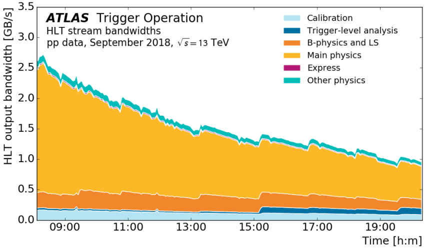
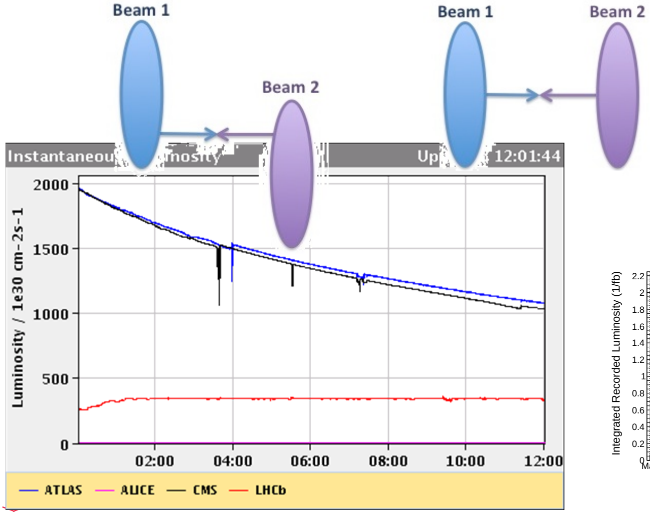
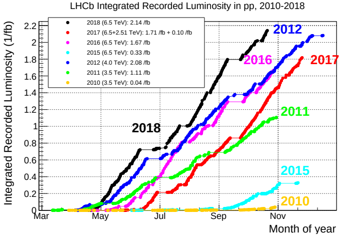




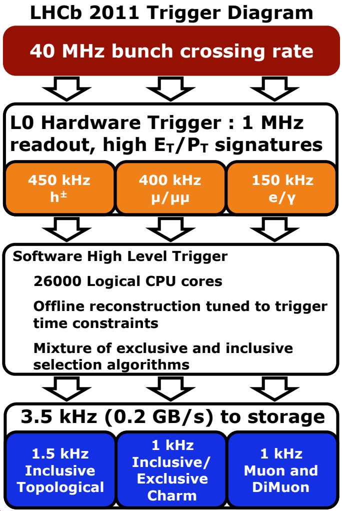
Luminosity levelling



Beams are offset in real time to keep a constant luminosity



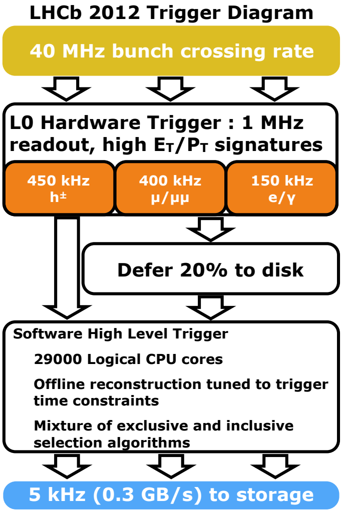
LHCb Trigger in Run 1



Versatile two stage trigger

- Hardware-based L0 trigger: moderate p_{T} cuts → 1 MHz
- L0-accepted data sent to trigger farm
- 3.5 kHz output rate (2011)

LHCb Trigger in Run 1



Versatile two stage trigger

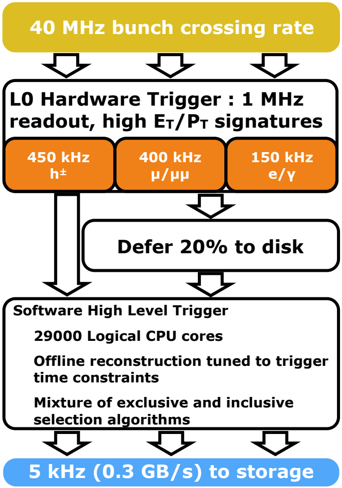
- Hardware-based L0 trigger: moderate p_{T} cuts → 1 MHz
- L0-accepted data sent to trigger farm
- 2012: Defer some L0 data to disk to free CPU cycles

→ 5 kHz in 2012

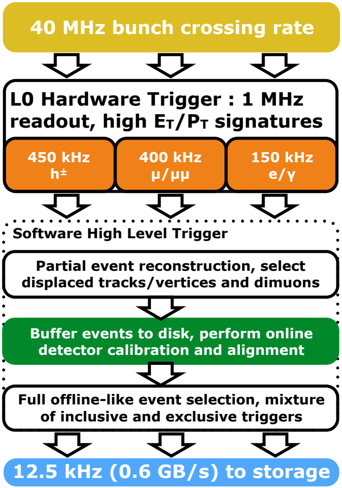
[JINST 14 (2019) P04013, arXiv:1812.10790]

LHCb Trigger in Run 2

LHCb 2012 Trigger Diagram



LHCb Run 2 Trigger Diagram

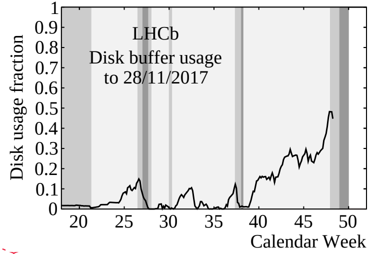


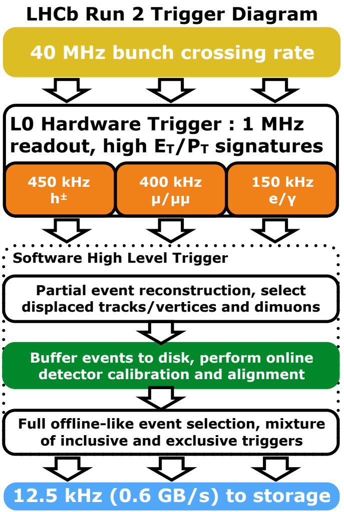
LHCb Trigger in Run 2

Events are buffered on disk (10 PB) while calibrations are being run.

➜ Offline-quality trigger objects available for analysis.

- Disk ➜ more CPU. The full reconstruction can also be run during LHC downtime.





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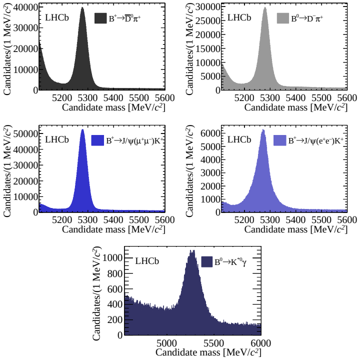
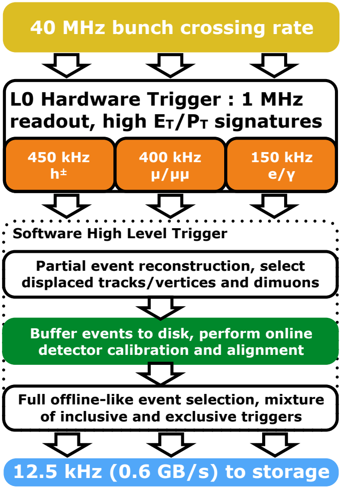


LHCb Run 2 Trigger Diagram

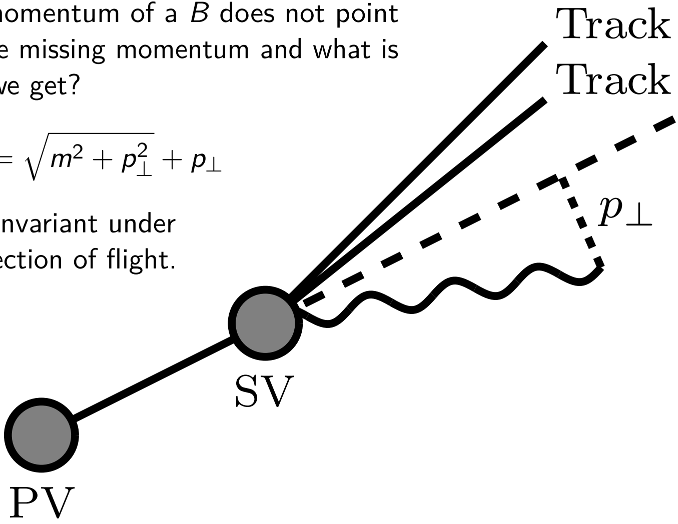


Corrected Mass

The reconstructed momentum of a B does not point to the PV: what's the missing momentum and what is the minimum mass we get?

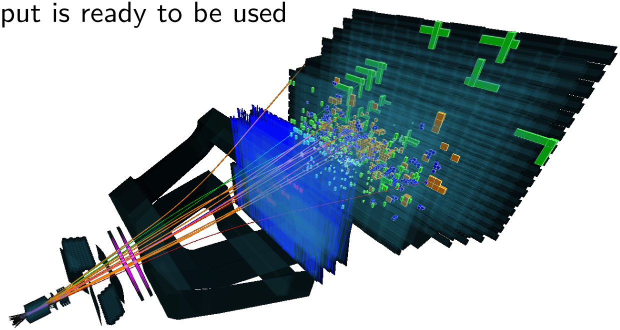
$$m_{\text{corr}} = \sqrt{m^2 + p_\perp^2} + p_\perp$$

Hint: $p_\perp$ is Lorentz invariant under boosts along the direction of flight.



TURBO

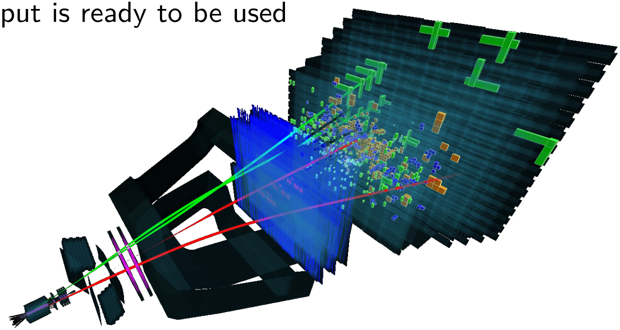
We perform a full calibration in real time. The output is ready to be used for physics.



Plenty of collision events discarded, while the interesting are kept.

TURBO

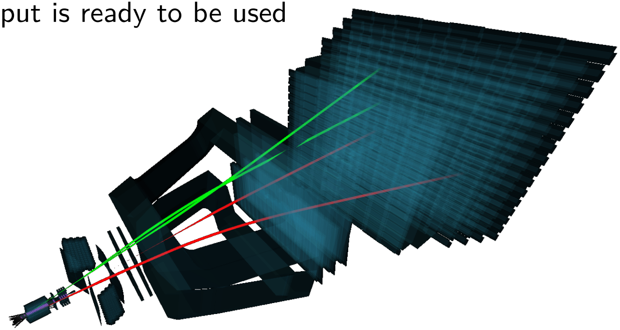
We perform a full calibration in real time. The output is ready to be used for physics.



TURBO stores only the information needed for the analysis
➜ Huge savings in time and cost

TURBO

We perform a full calibration in real time. The output is ready to be used for physics.



TURBO stores only the information needed for the analysis

➜ Huge savings in time and cost

TisTos method

For a given signal candidate define

TOS Event triggered on signal

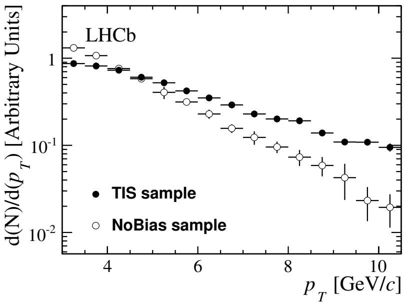
TIS Event triggered on rest of event

Candidates falling in both categories can be used to compute

$$\eta^{\mathrm{TOS}} = \frac{N^{\mathrm{TIS\&TOS}}}{N^{\mathrm{TIS}}}.$$

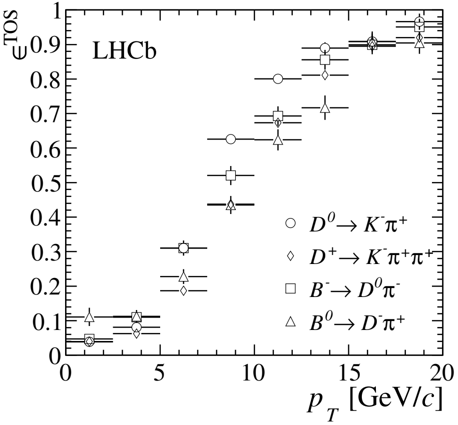
The total trigger efficiency is obtained from

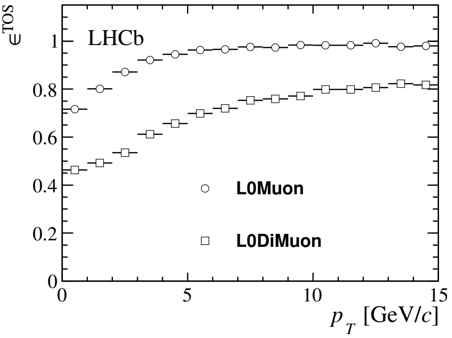
$$\eta^{\mathrm{TIS}} = \frac{N^{\mathrm{TIS\&TOS}}}{N^{\mathrm{TOS}}} \rightarrow \eta^{\mathrm{trig}} = \frac{\eta^{\mathrm{TIS}} N^{\mathrm{trig}}}{N^{\mathrm{TIS}}}$$



TIS events are harder than unbiased events.

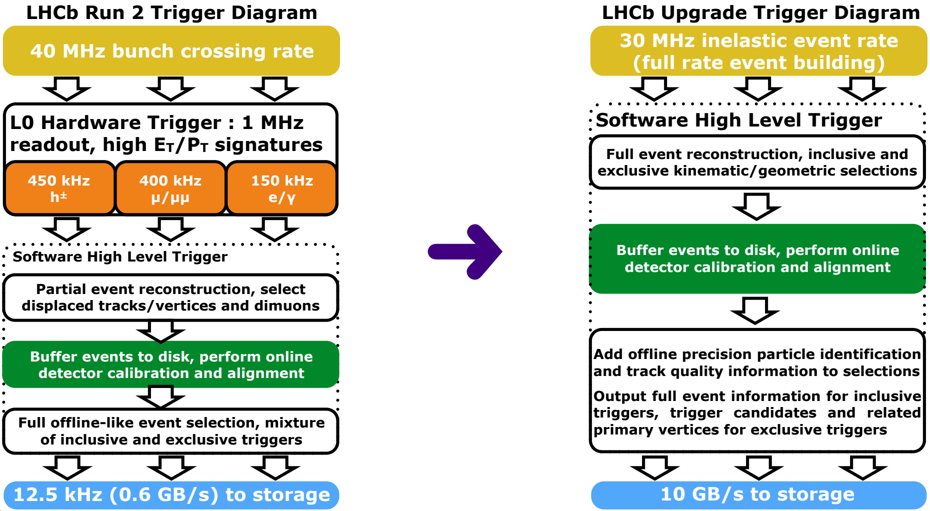
Run 1 Trigger Performance





The L0 efficiency is reasonable for channels with muons, but low for hadrons

LHCb Trigger in Run 3

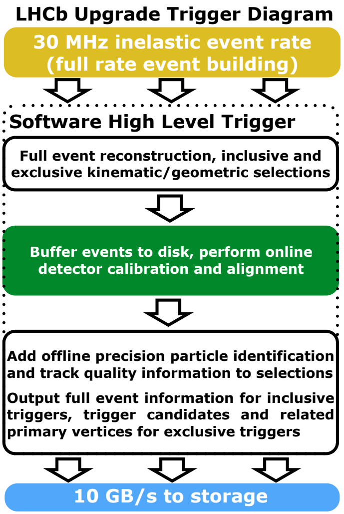


LHCb Trigger in Run 3

New in Run III: No hardware (L0) trigger

- 30 MHz non-empty events go to event filter farm
- Full event reconstruction at 30 MHz
- Full calibration of preselected events
- Offline-like selections

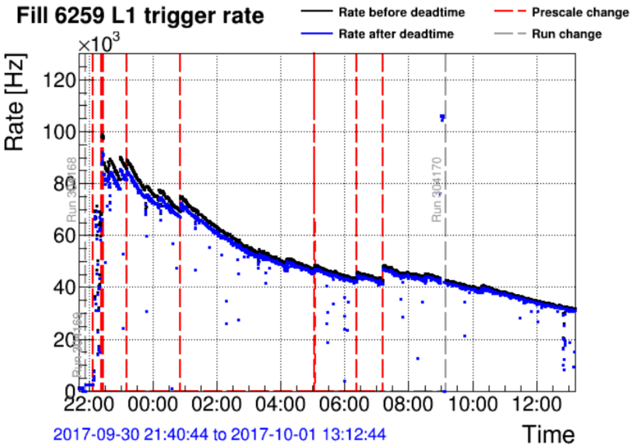
➜ 10 GB/s to storage (most of that TURBO)



[Trigger TDR]

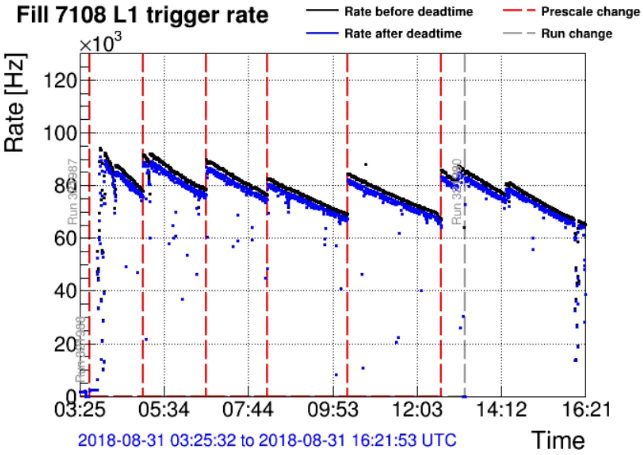
Parked *B* sample at CMS

- L1 rate of fill 6259 in September 2017



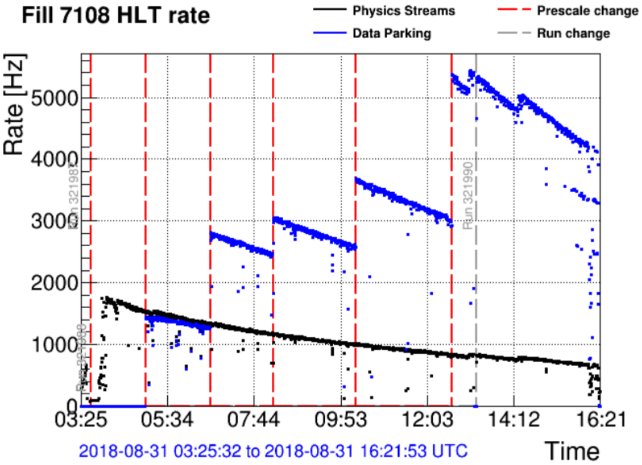
Parked B sample at CMS

- L1 rate of fill 6259 in September 2017
- L1 rate of fill 7108 in August 2018

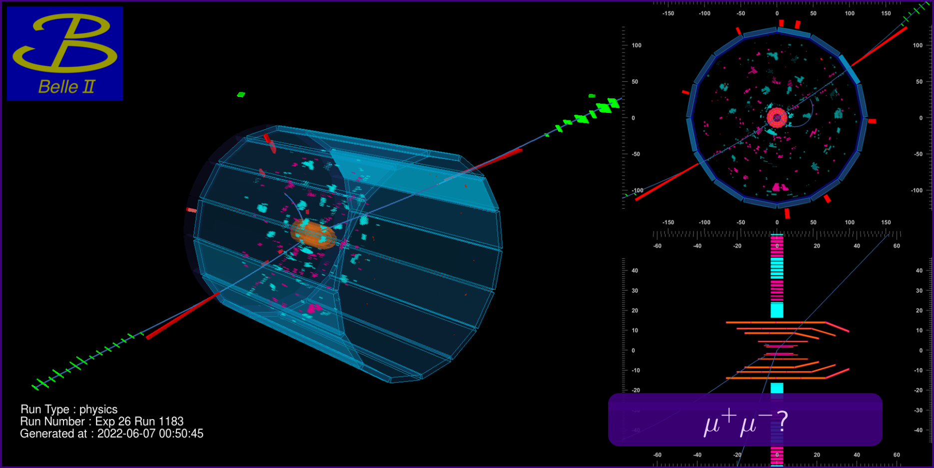


Parked *B* sample at CMS

- L1 rate of fill 6259 in September 2017
- L1 rate of fill 7108 in August 2018
- Hlt rate of fill 7108 in August 2018

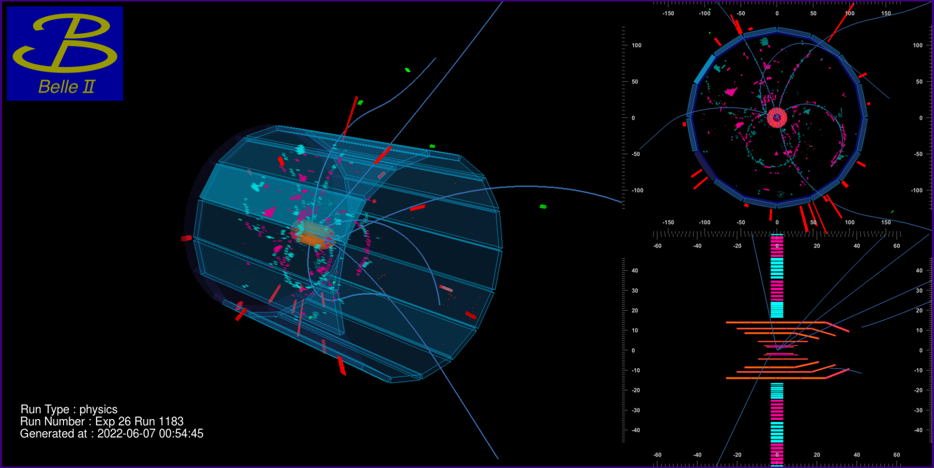


Belle II event

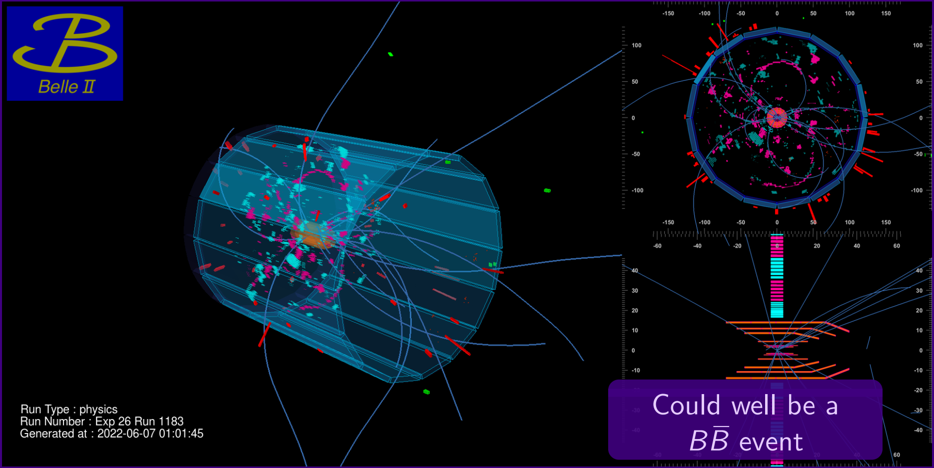


$\mu^+\mu^-$?

Belle II event

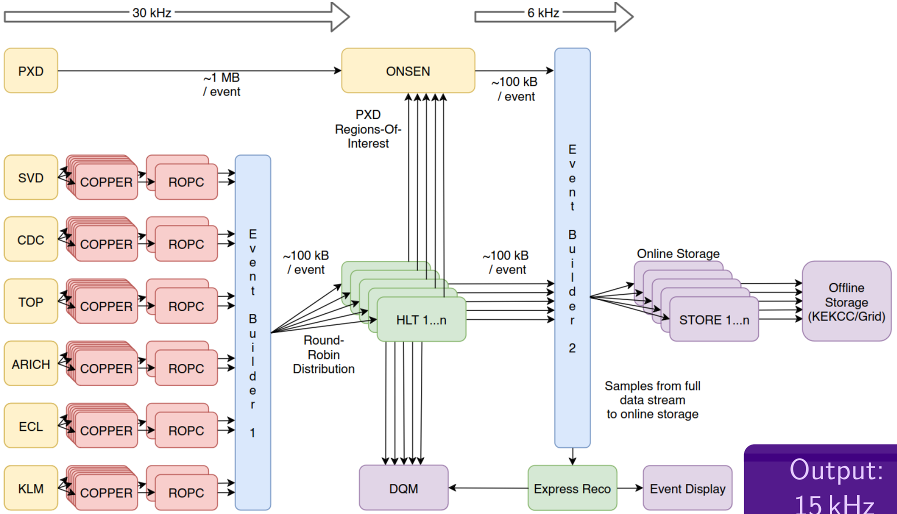


Belle II event



Could well be a $B\overline{B}$ event

Trigger



Output: 15 kHz

Techniques

1. Full-event Tagging
2. Flavour Tagging
3. Blinding
4. Uncertainties
5. Dalitz Plots
6. sPlot
7. Machine Learning
8. Fitting ➜ Backup
9. Good computing practices

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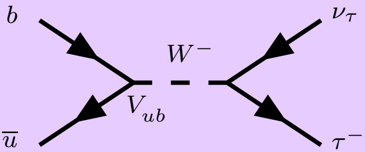
Techniques

1. Full-event Tagging

$B^+ \to \tau^+ \nu$ BRANCHING FRACTION

$$\mathcal{B} = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right) f_B \left|V_{ub}\right|^2 \tau_B$$

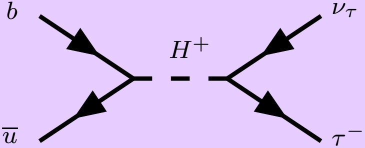
$$\stackrel{\text{SM}}{=} \left(0.75\,^{+\,0.10}_{-\,0.05}\right) \cdot 10^{-4}$$



[FLAG'14] (f_B) [CKMFitter'14]

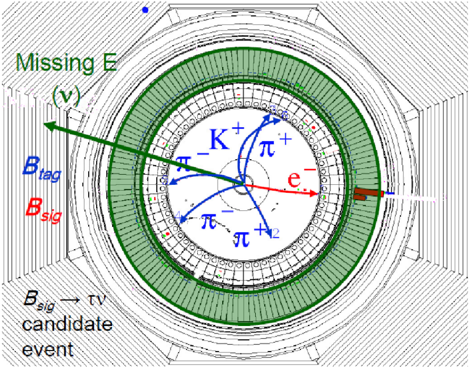
(For $B^+ \to \mu^+ \nu$, replace m_τ by m_μ)

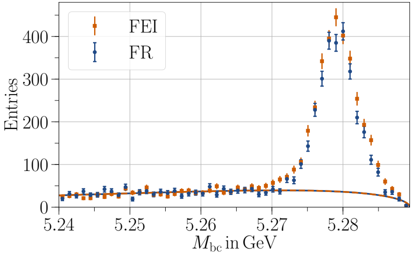
Higgs-mediated diagram **reduces** (small $\tan\beta$) or **enhances** the $\mathcal{B}$:



$$\frac{\mathcal{B}_{\text{MSSM}}}{\mathcal{B}_{\text{SM}}} = \left(1 - \frac{m_B^2}{m_{H^\pm}^2}\frac{\tan^2\beta}{1+\epsilon\tan\beta}\right)^2$$

Full Event Interpretation

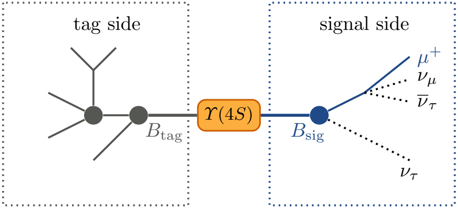


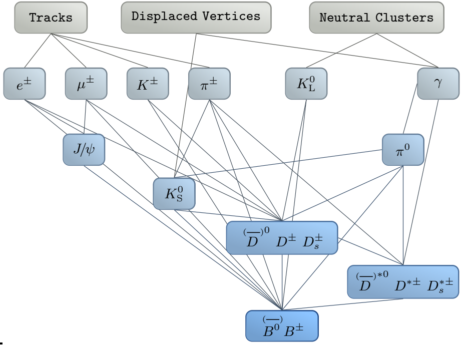


Tag B mass with FEI [Keck et al.] and FR [Feindt et al, NIM A654 (2011) 432]

The tag B is fully reconstructed ($B^+ \to \overline{D}^0(\to K^-\pi^+\pi^-\pi^+)\pi^+$), which completely determines the 4-momentum of the signal B ($B^- \to \tau^-(\to e^-\overline{\nu}\nu)\overline{\nu}$)

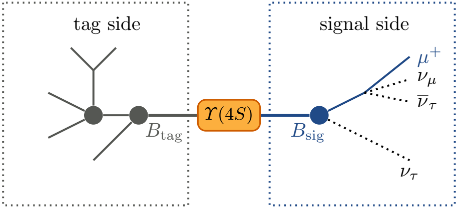
Full Event Interpretation

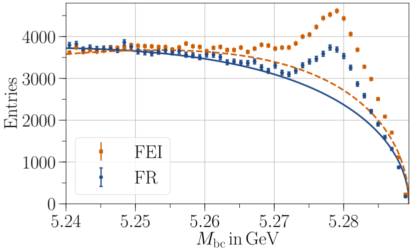




The full event interpretation algorithm reconstructs all plausible B decays and computes a probability using gradient-boosted decision trees.

Full Event Interpretation





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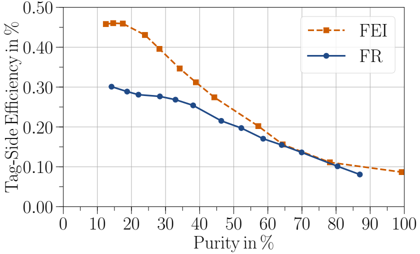


It surpasses the Belle full reconstruction algorithm (FR) [Feindt et al, NIM A654 (2011) 432]

$B^+ \to \tau^+ \nu$

Using full Belle sample (772 million $B\bar{B}$), reconstruct $B^+ \to \tau^+ \nu$

- Use semileptonic tag of the other B
- Consider τ^+ decays to e^+, μ^+, π^+, ρ^+ (all with 1 charged track)
- See 220 ± 50 decays (3.8σ)

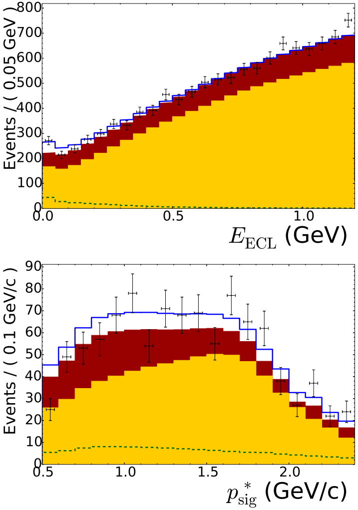
$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.25 \pm 0.28 \pm 0.27) \times 10^{-4}$$

Combine with hadronic tagging [PRL 110 (2013) 131801] to get

$$\mathcal{B}(B^+ \to \tau^+ \nu) = (0.92 \pm 0.19 \pm 0.11) \times 10^{-4}$$

$$\mathcal{B}^{\text{SM}} = \left(0.75\,^{+0.10}_{-0.05}\right) \cdot 10^{-4}$$

[FLAG'14] [CKMFitter'14]



Techniques

1. Full-event Tagging
2. Flavour Tagging

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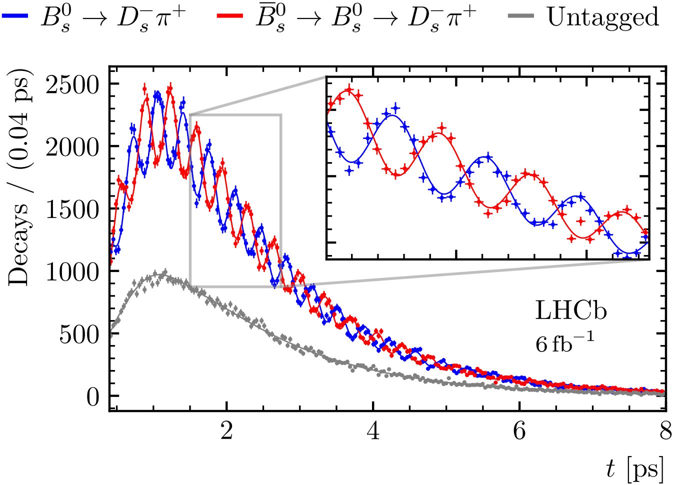
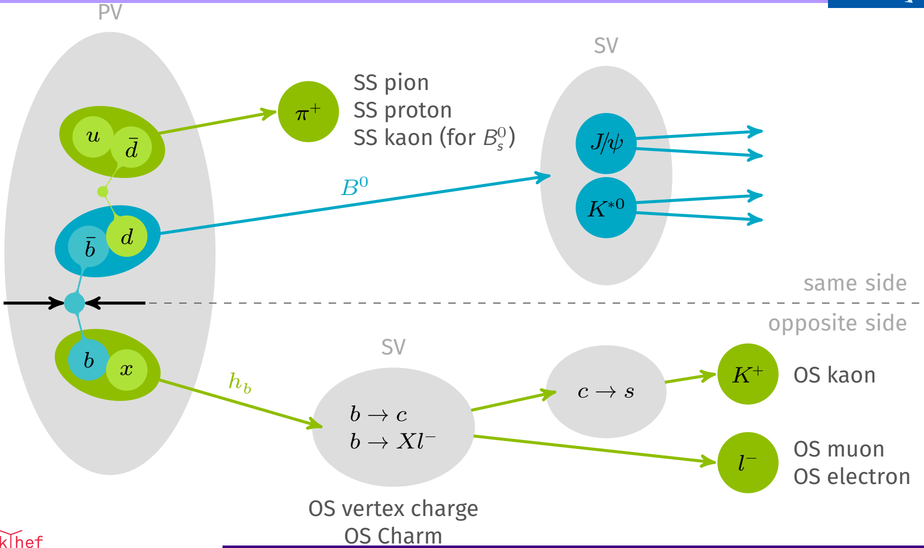
Δm_s WITH $B_s^0 \to D_s^- \pi^+$



380k $B_s^0 \to D_s^- \pi^+$ in 6 fb^{-1} Run 2 data ➜ $\Delta m_s = 17.7656 \pm 0.0057\,\text{ps}^{-1}$

[LHCb, EPJC 77 (2017) 238, arXiv:1610.06019]

Flavour Tagging at the LHC



Flavour Tagging

We start with a sample of N B and $\bar{B}$ mesons. We need flavour tagging to know their flavour at origin.

N^{tag} of those have a tagging decision, with $\eta^{\text{tag}} = \frac{N^{\text{tag}}}{N}$. The remaining $N^{\text{tag}} - N$ are not useful for CP violation but may be used for other observables.

The fraction of wrongly tagged B is ω

$$N_B^{\text{tag}} = \eta(1-\omega)N_B + \eta\omega N_{\bar{B}}$$
$$N_{\bar{B}}^{\text{tag}} = \eta(1-\omega)N_{\bar{B}} + \eta\omega N_B$$

The CP asymmetry is

$$A_{\text{meas}}^{CP} = \frac{N_B^{\text{tag}} - N_{\bar{B}}^{\text{tag}}}{N_B^{\text{tag}} + N_{\bar{B}}^{\text{tag}}} = (1-2\omega)\underbrace{\frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}}}_{=A_{\text{true}}^{CP}} \quad \rightarrow \quad A_{\text{true}}^{CP} = \frac{A_{\text{meas}}^{CP}}{1-2\omega}$$

Flavour Tagging

The CP asymmetry is

$$A^{CP}_{\text{meas}} = \frac{N^{\text{tag}}_{B} - N^{\text{tag}}_{\bar{B}}}{N^{\text{tag}}_{B} + N^{\text{tag}}_{\bar{B}}} = (1-2\omega)\underbrace{\frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}}}_{=A^{CP}_{\text{true}}} \quad \rightarrow \quad A^{CP}_{\text{true}} = \frac{A^{CP}_{\text{meas}}}{1-2\omega}$$

To correctly measure A^{CP} it is necessary to know ω.

The uncertainty is

$$\Delta A^{CP}_{\text{true}} = \frac{\Delta A^{CP}_{\text{meas}}}{1-2\omega} = \frac{1}{1-2\omega}\sqrt{\frac{(1-A^{CP}_{\text{true}})^2}{N^{\text{tag}}}} = \frac{1}{1-2\omega}\sqrt{\frac{(1-A^{CP}_{\text{true}})^2}{\eta^{\text{tag}} N}}$$
$$= \frac{1}{\sqrt{\eta^{\text{tag}}}(1-2\omega)}\Delta A^{CP}_{\text{true}}$$

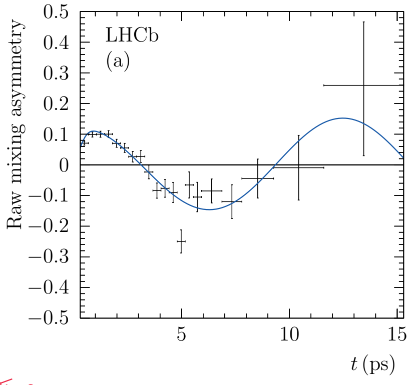
The effect of the imperfect tagging is the same as reducing the sample by a factor

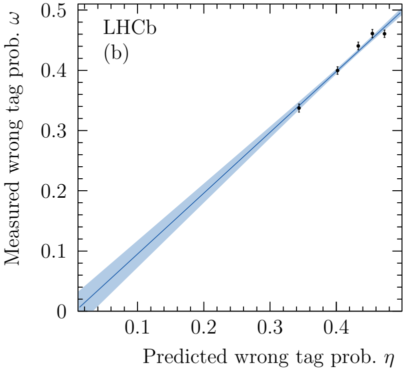
$$\eta_{\text{eff}} = \eta^{\text{tag}}(1-2\omega)^2$$

Flavour Tagging

To correctly measure A^{CP} it is necessary to know ω.

The wrong-tag fraction is calibrated on self-tagging control samples. Here $B^0 \to J/\psi K^{*0}(\to K^+\pi^-)$ for $B^0 \to J/\psi K^0_S$ [LHCb, PRL 115 (2015) 031601, arXiv:1503.07089]





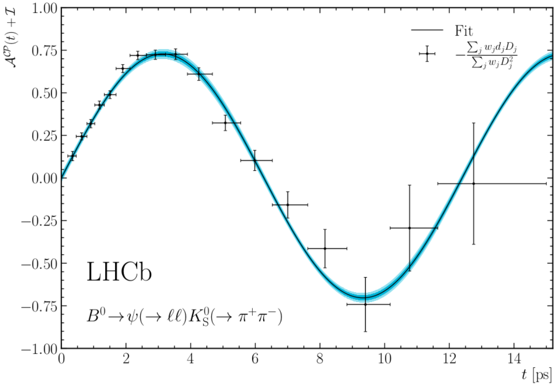
Flavour Tagging

To correctly measure A^{CP} it is necessary to know ω.

The wrong-tag fraction is calibrated on self-tagging control samples.

The measured *CP* asymmetry (*i.e.* $\sin 2\phi_1$) is proportional to the oscillation amplitude. A wrong value of $\sqrt{\eta^{\text{tag}}}(1-2\omega)$ directly translates into a bias.

[LHCb, LHCb-PAPER-2023-013, in preparation]



Tagging Performance

Channel	$\epsilon_{\rm eff}$ [%] 2011	Run 1	Run 2	Imprvt	Reference
$B_s^0 \to \phi\phi$	3.29	5.38	6.00	82%	[LHCb-PAPER-2023-001]
$B_s^0 \to D_s^+ D_s^+$		5.33			[PRL 113 (2014) 211801]
$B_s^0 \to D_s^+ K^-$	5.07	5.80		14%	[JHEP 03 (2018) 059]
$B_s^0 \to J/\psi K^+ K^-$	3.13	3.73	4.30	50%	[LHCb-PAPER-2023-016]
$B_s^0 \to J/\psi \pi^+ \pi^-$	2.43	3.89		60%	[PLB 797 (2019) 134789]
$B^0 \to J/\psi K_{\rm S}^0$	2.38	3.03	4.71	98%	[LHCb-PAPER-2023-013]
$B^0 \to J/\psi (e^+ e^-) K_{\rm S}^0$			6.48		[LHCb-PAPER-2023-013]
$B_s^0 \to J/\psi \phi$	1.45	1.49	1.75	20%	[EPJC 81 (2021) 342]
$B_s^0 \to J/\psi \phi$	0.97	1.31	10.5		[PLB 816 (2021) 136188]

Red means not full run 2.

Impressive improvements in tagging performance in the last years

Tagging Performance

	Channel	ϵ_{eff} [%] 2011	Run 1	Run 2	Imprvt	Reference
	$B_s^0 \to \phi\phi$	3.29	5.38	6.00	82%	[LHCb-PAPER-2023-001]
	$B_s^0 \to D_s^+ D_s^+$		5.33			[PRL 113 (2014) 211801]
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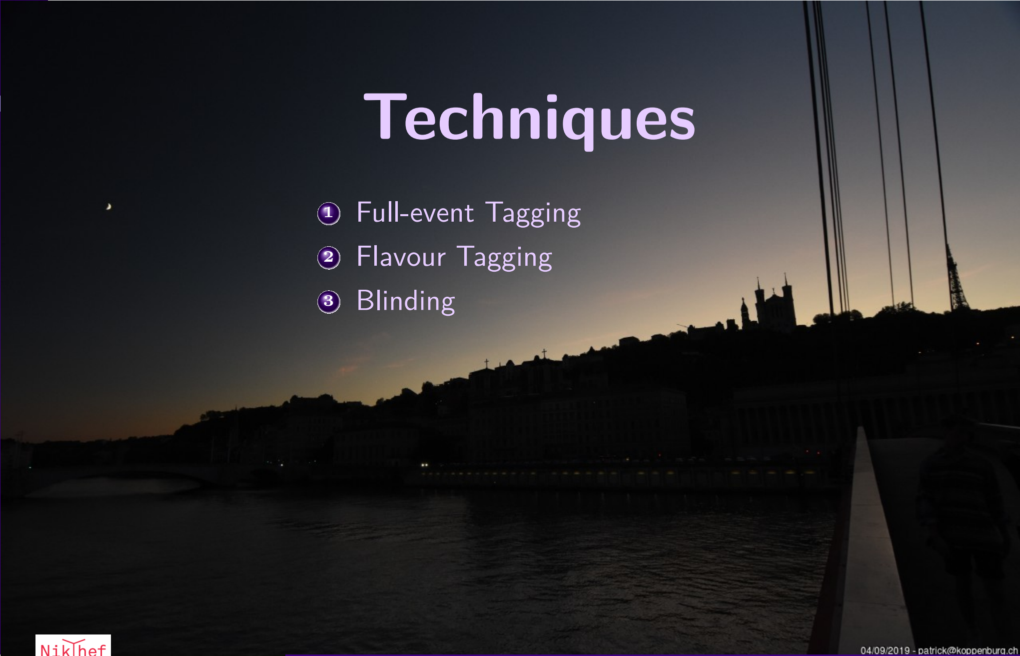
	$B^0 \to J/\psi K_S^0$	2.38	3.03	4.71	98%	[LHCb-PAPER-2023-013]
	$B^0 \to J/\psi (e^+ e^-) K_S^0$			6.48		[LHCb-PAPER-2023-013]
	$B_s^0 \to J/\psi \phi$	1.45	1.49	1.75	20%	[EPJC 81 (2021) 342]
	$B_s^0 \to J/\psi \phi$	0.97	1.31	10.5		[PLB 816 (2021) 136188]

Red means not full run 2. CMS triggers on tagging muon.

Impressive improvements in tagging performance in the last years

Techniques

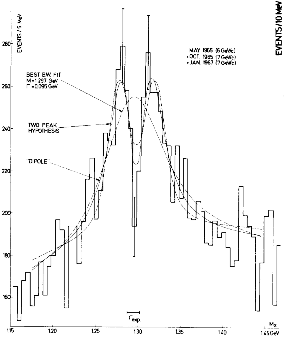
1. Full-event Tagging
2. Flavour Tagging
3. Blinding

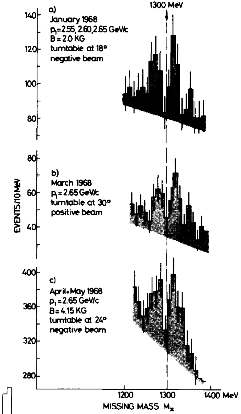


Pathological Science

In 1967 the Missing Mass Spectrometer (MMS) at CERN report that the a_2 meson (now $1316.9 \pm 0.9\,\text{MeV}$ [PDG]) has a split structure [Chikovani et al., PLB 25 (1967) 44].

- Confirmed in 1968 by the CERN Boson Spectrometer (CBS) [Benz et al., PLB 28 (1968) 233].





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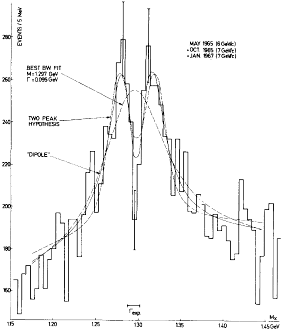
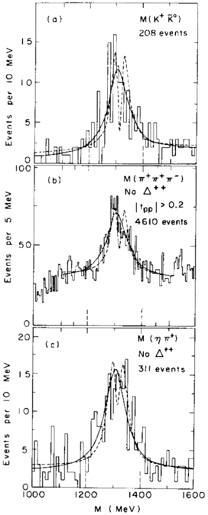
Not seen at LRL (Berkeley), which has a better resolution [PLB 33 (1970) 607].





Pathological Science

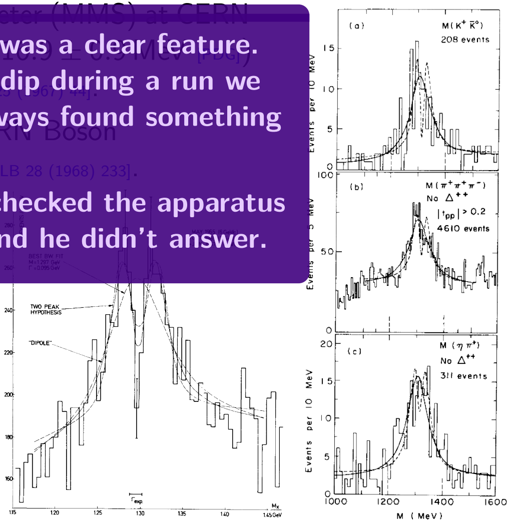
In 1967 the Missing Mass Spectrometer (MMS) at CERN report that the a_2 meson (now 1318.9 ± 0.5 MeV [PDG]) has a split structure [Chikovani et al., PLB 25 (1967) 44].

- Confirmed in 1968 by the CERN Boson Spectrometer (CBS) [Benz et al., PLB 28 (1968) 233].

Schübelin (CDS): "The dip was a clear feature. Whenever we didn't see the dip during a run we checked the apparatus and always found something wrong."

Stone then asked him if they checked the apparatus when they did see the dip, and he didn't answer.

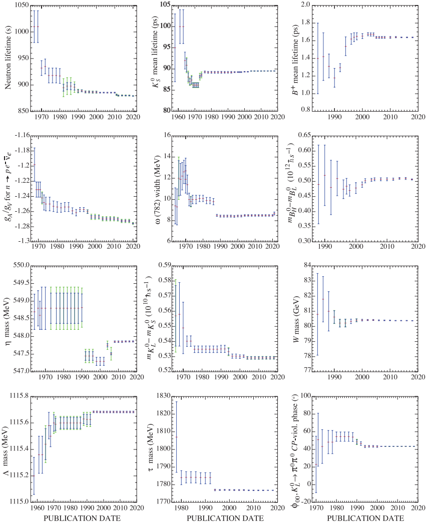
Not seen at LRL (Berkeley), which has a better resolution [PLB 33 (1970) 607].



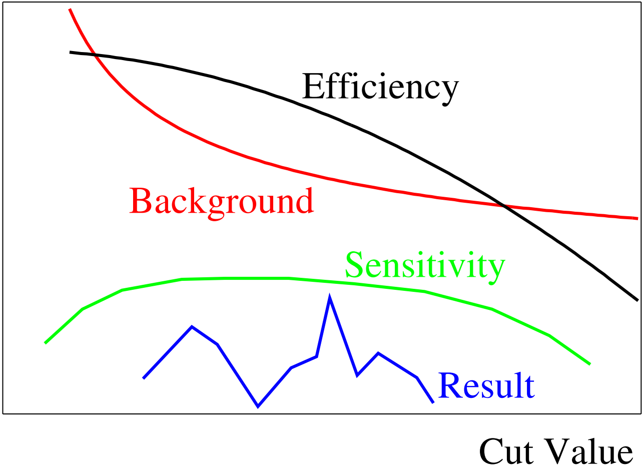
PDG History plots

History plots show how precision has improved

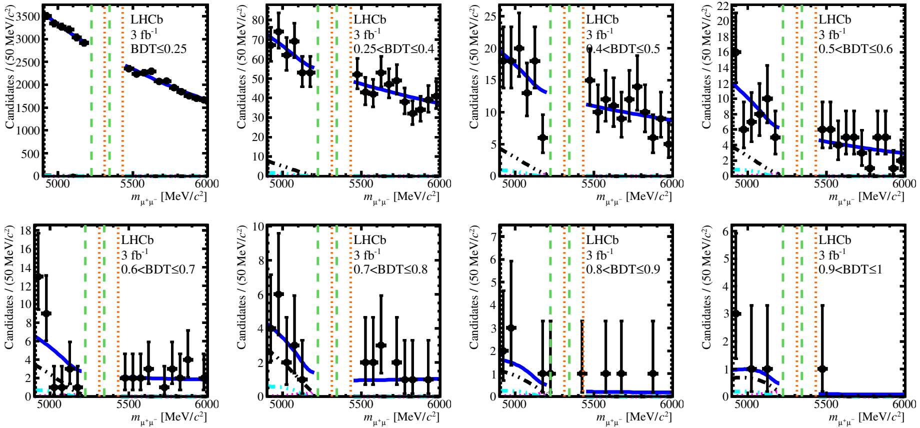
But also how we are biased by previous results



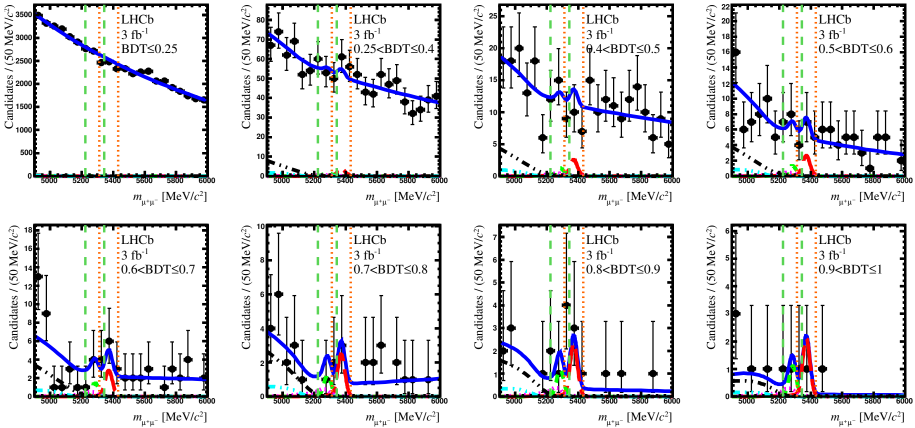
Blind Analysis in Particle Physics



$B_s^0 \to \mu^+\mu^-$ BLINDING

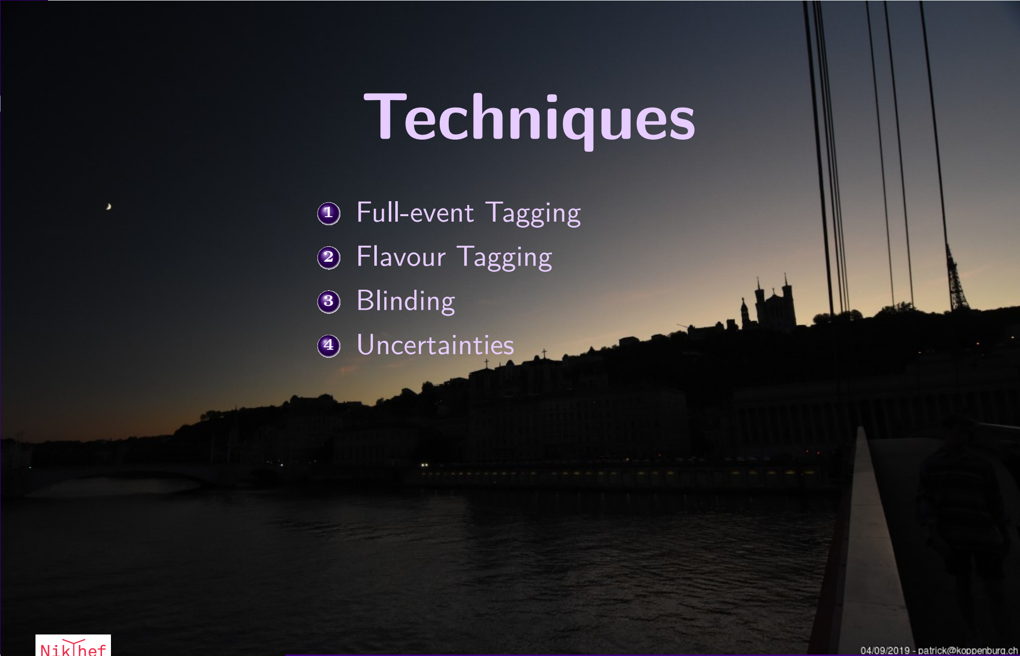


$B_s^0 \to \mu^+\mu^-$ UNBLINDING

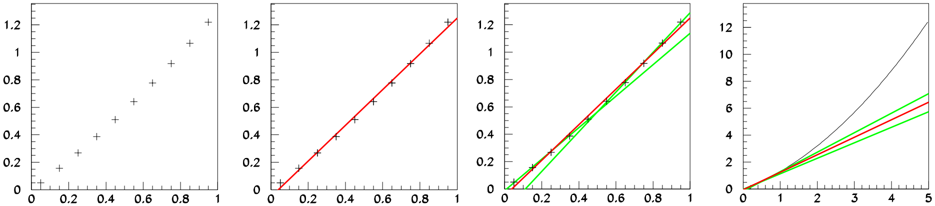


Techniques

1. Full-event Tagging
2. Flavour Tagging
3. Blinding
4. Uncertainties



Uncertainties: Facts and fictions



The data, a straight line fit, two fits in subranges, the actual quadratic function.

Using the fits in subranges to set a systematic uncertainty overestimates by a lot the uncertainty on the slope, but wildly underestimates it in the larger range.

This illustrates the point that there is no ‘correct’ procedure for incorporation of a check that fails. If you fold it into the systematic errors this is almost certainly wrong, and should only be done when all other possibilites have been exhausted.

Uncertainties: Facts and fictions

Once a bias is known, it can be corrected for: an estimator with known bias can be trivially replaced by an unbiased estimator. If the bias is unknown and unsuspected then one can by definition do nothing about it. The match between 'bias' and 'systematic error' under our definition is the case where a bias is known to exist, but its exact size (systematic effect) is unknown (systematic uncertainty).

We apply this to the example of measurements with an expanding steel rule.

1. If the expansion coefficient is known, as are the two temperatures of calibration and actual measurement, then the measurements can be corrected and the bias is removed; the systematic effect is known exactly and there is no systematic error.
2. If the effect is ignored then this is a mistake. Hopefully consistency checks will be done and will (through statistical techniques) reveal a discrepancy for which the physicist will (through common sense, experience and intuition) realise the cause.
3. If the effect is known to exist but the temperature at which the actual measurements was taken was not recorded, and one can only give the laboratory temperature to within a few degrees, that is a systematic uncertainty on a systematic effect, and a systematic error in the accepted sense.

Uncertainties: Facts and fictions

The following should be printed in large letters and hung on the wall of every practising particle physicist.

I Thou shalt never say 'systematic error' when thou meanest '**systematic effect**' or 'systematic mistake'.

II Thou shalt not add uncertainties on uncertainties in quadrature. If they are larger than chickenfeed thou shalt generate more **Monte Carlo** until they shrink to become so.

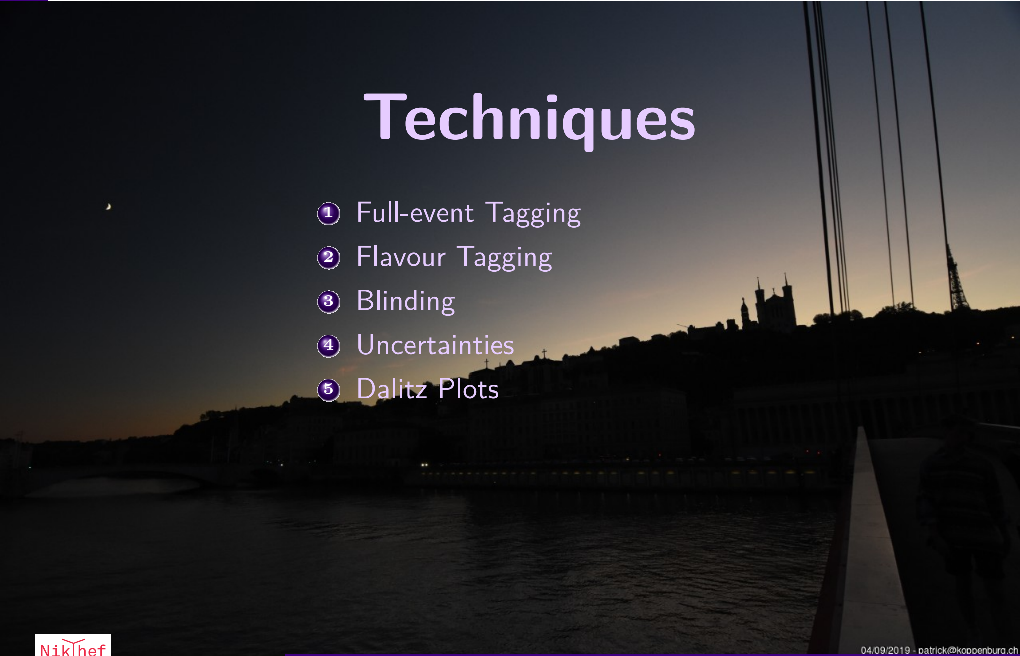
III Thou shalt know at all times whether what thou performest **is a check** for a mistake or an evaluation of an uncertainty.

IV Thou shalt not incorporate successful check results into thy total systematic error and make thereby **a shield behind which to hide thy dodgy result**.

V Thou shalt not incorporate failed check results unless thou art truly at thy wits' end.

VI **Thou shalt say what thou doest**, and thou shalt be able to justify it out of thine own mouth; not the mouth of thy supervisor, nor thy colleague who did the analysis last time, nor thy local statistics guru, nor thy mate down the pub.

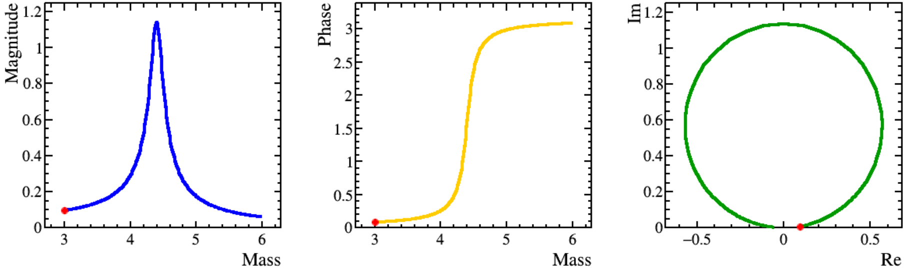
Do these, and thou shalt flourish, and thine analysis likewise.



Techniques

1. Full-event Tagging
2. Flavour Tagging
3. Blinding
4. Uncertainties
5. Dalitz Plots

Breit-Wigner

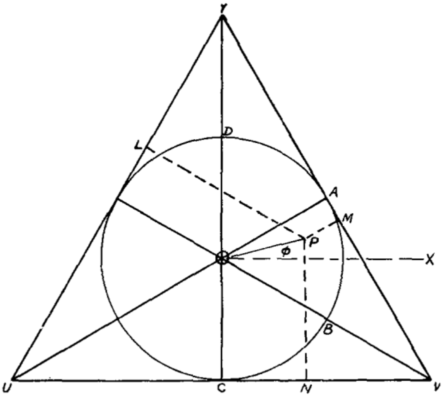


For narrow resonances far away from the threshold, the Breit-Wigner parametrisation is suitable

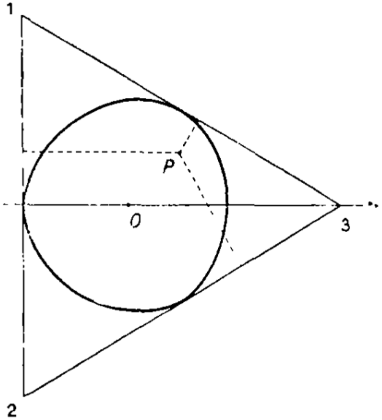
$$\mathcal{A}(s) = \frac{\alpha}{M_{\mathrm{BW}}^2 - s - i\sqrt{s}\,\Gamma_{\mathrm{BW}}} \simeq \frac{\alpha}{M_{\mathrm{BW}}^2 - s - i\,M_{\mathrm{BW}}\,\Gamma_{\mathrm{BW}}}$$

[PDG]

Dalitz Plots

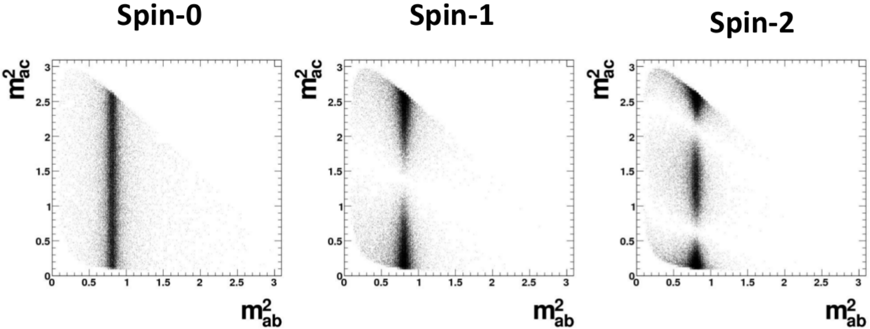


Dalitz plot



Fabri plot, with relativistic corrections

Dalitz Plot

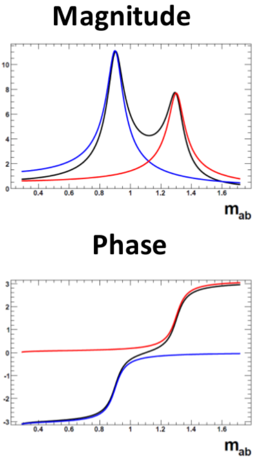


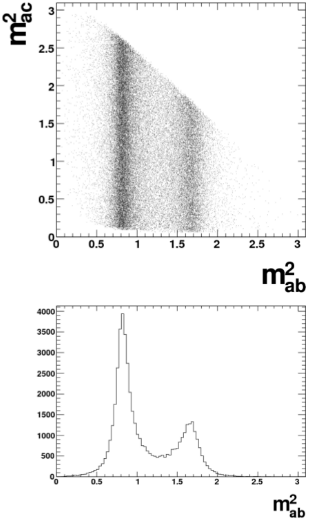
$A \to abc$ where A has spin S and a, b, c are spinless, the decay amplitude will have zeroes corresponding to a Legendre polynominal.

$$\mathcal{A} \sim \mathcal{A}_{\mathrm{BW}} P_S(\cos\theta)$$

There will be S zeroes in the amplitude.

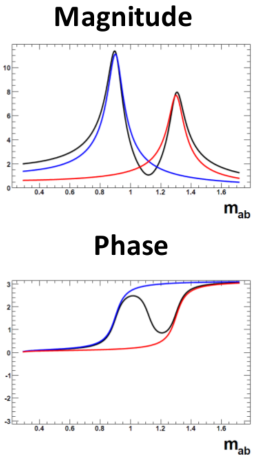
Constructive interference

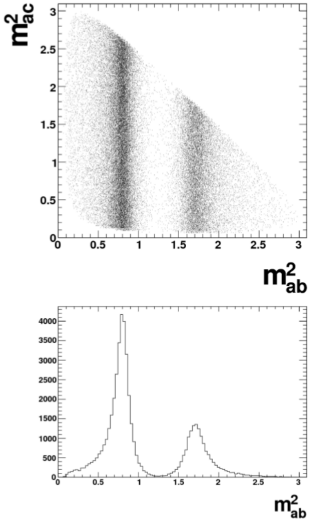




[B]

Destructive interference

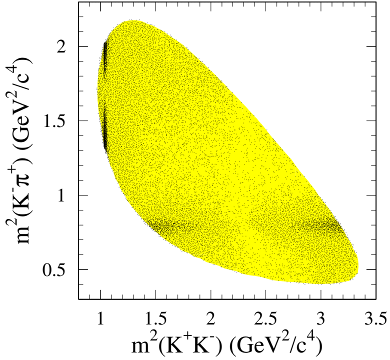




[B]

[BaBar, PRD83 (2011) 052001, arXiv:1011.4190]

Dalitz plot of $D_s^+ \to K^+K^-\pi^+$



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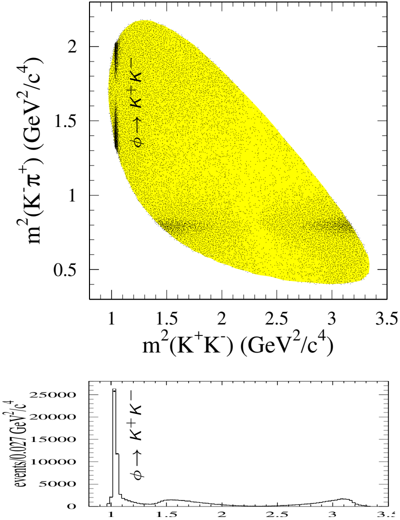
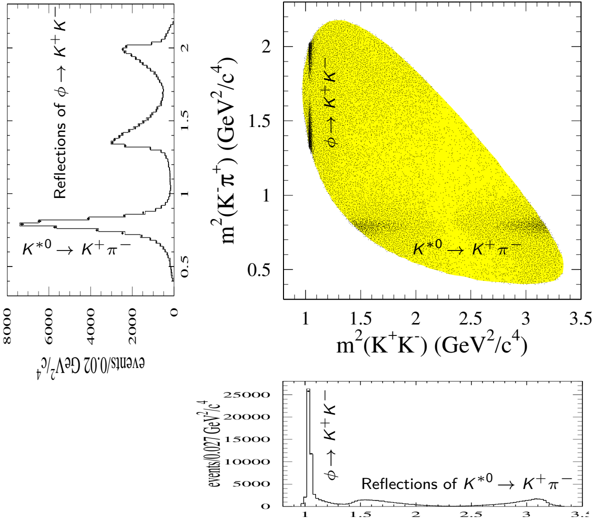
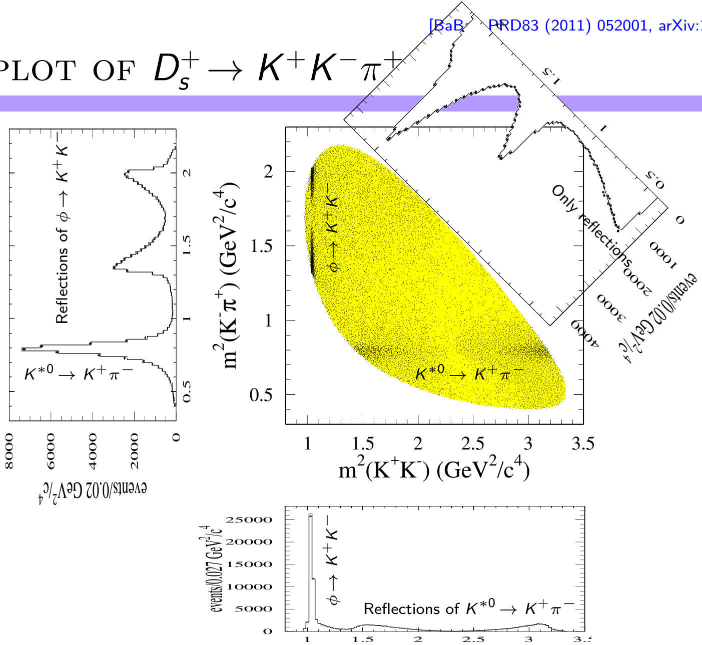


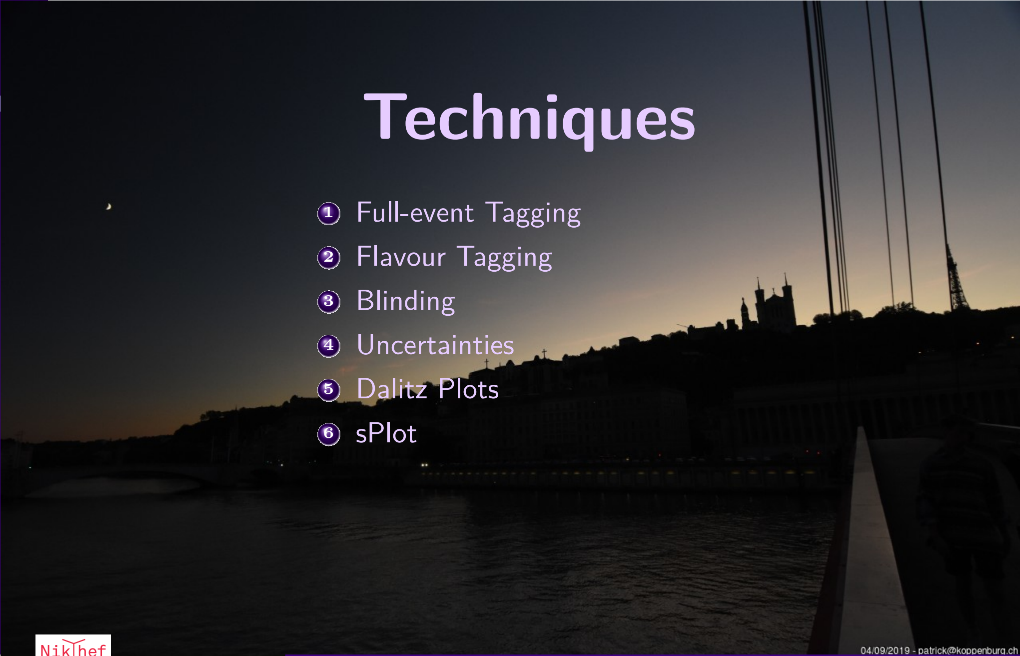
Dalitz plot of $D_s^+ \to K^+K^-\pi^+$



[BaBar PRD83 (2011) 052001, arXiv:1011.4190]

Dalitz plot of $D_s^+ \to K^+K^-\pi^+$



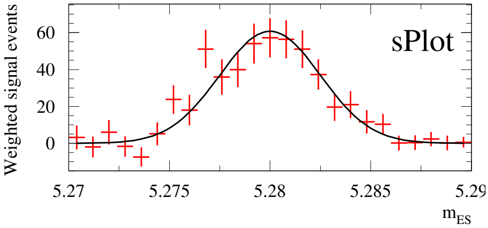


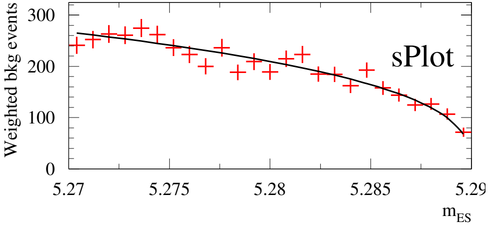
Techniques

1. Full-event Tagging
2. Flavour Tagging
3. Blinding
4. Uncertainties
5. Dalitz Plots
6. sPlot

sPlot

sPlot determines weights from a fit, allowing to statistically subtract backgrounds (or signal)

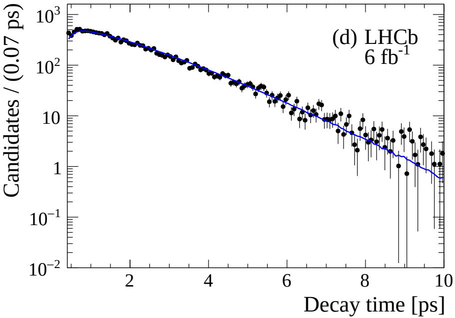




sPlot

sPlot determines weights from a fit, allowing to statistically subtract backgrounds (or signal)

1. Fit signal only

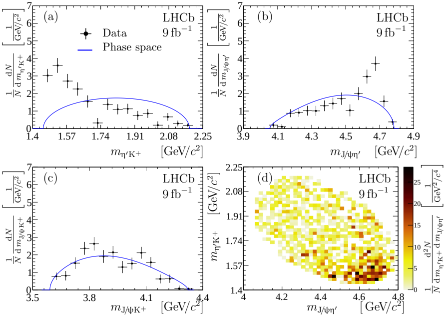


$B_s^0 \to \phi\phi$ [LHCb-PAPER-2023-001]

sPlot

sPlot determines weights from a fit, allowing to statistically subtract backgrounds (or signal)

1. Fit signal only
2. Study distributions

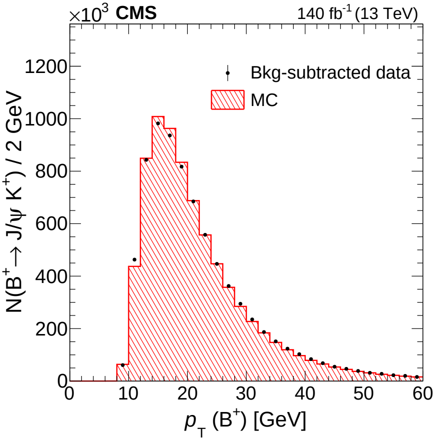


Dalitz distributions in $B^+ \to J/\psi\eta' K^+$ [arXiv:2303.09443]

sPlot

sPlot determines weights from a fit, allowing to statistically subtract backgrounds (or signal)

1. Fit signal only
2. Study distributions
3. Use signal to weight simulation



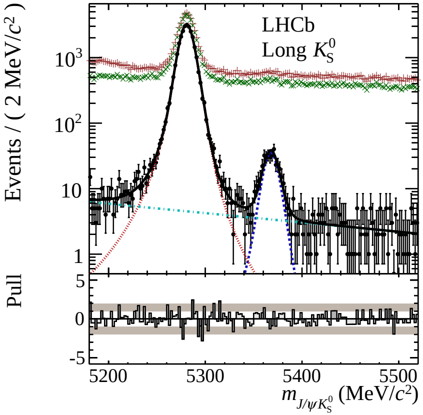
$B^+ \to J/\psi K^+$ for $B_s^0 \to \mu^+\mu^-$ [CMS, arXiv:2212.10311]

sPlot

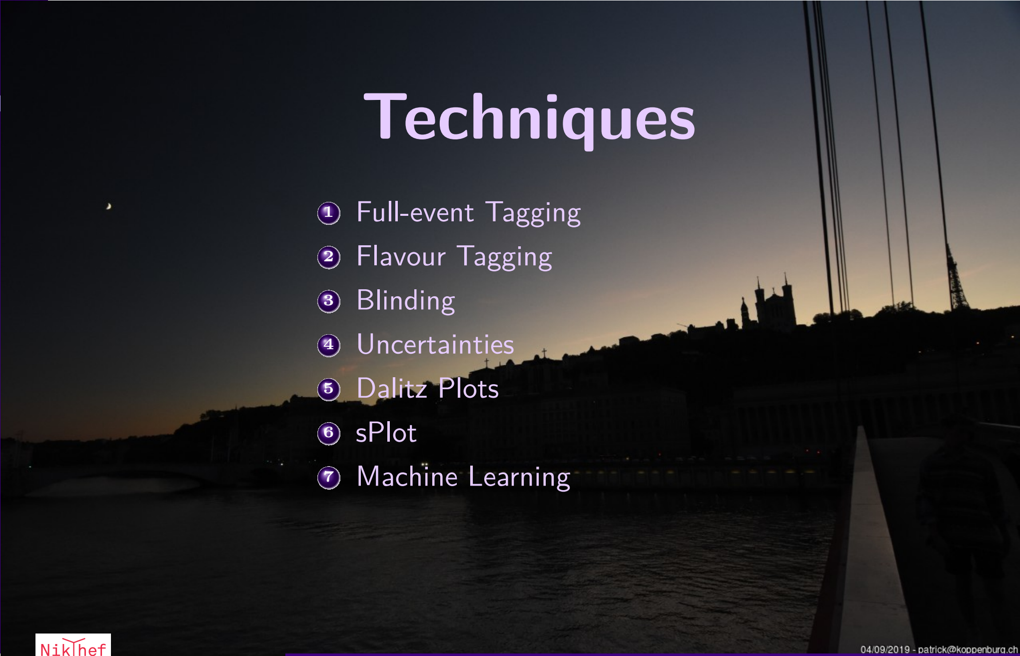
sPlot determines weights from a fit, allowing to statistically subtract backgrounds (or signal)

1. Fit signal only
2. Study distributions
3. Use signal to weight simulation
4. Use signal to train MVA

Warning: it assumes uncorrelated variables



$B^0_s \to J/\psi K^0_S$ selection using $B^0 \to J/\psi K^0_S$ [JHEP 06 (2015) 131]



Techniques

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2. Flavour Tagging
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4. Uncertainties
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6. sPlot
7. Machine Learning

Write a GBT in python using tensorflow

In this example, we use the breast cancer dataset from scikit-learn. We split the data into training and testing sets and convert them into TensorFlow Dataset format.

We then define the feature columns using `tf.feature_column.numeric_column` for each numerical feature in the dataset.

Next, we define the Boosted Decision Trees classifier using tf.estimator.BoostedTreesClassifier. We specify the feature columns, the number of trees (`n_trees`), maximum tree depth (`max_depth`), and the learning rate.

To train the model, we call the train method of the estimator, passing the training data using an input function that shuffles the data and creates batches.

After training, we evaluate the model on the test set using the evaluate method of the estimator, passing the test data using an input function that creates batches.

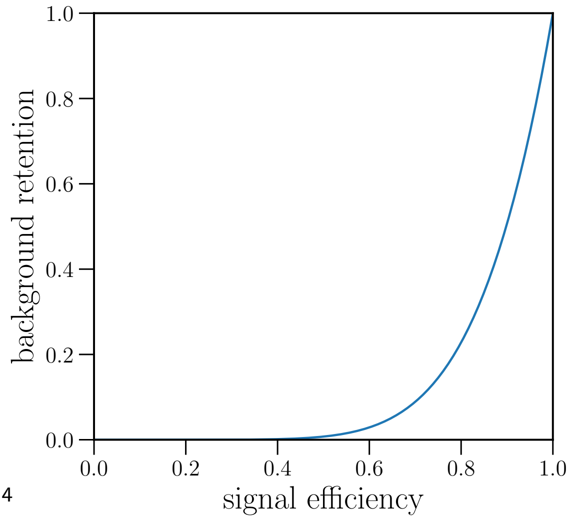
Finally, we extract the accuracy from the evaluation result and print it.

Note: Make sure you have TensorFlow 2.x installed (pip install tensorflow) before running this code.

```
import tensorflow as tf
from sklearn.datasets import load_breast_cancer
from sklearn.model_selection import train_test_split
from sklearn.metrics import accuracy_score

# Load the breast cancer dataset (example dataset from scikit-learn)
data = load_breast_cancer()
X = data.data
y = data.target

# Split the data into training and testing sets
X_train, X_test, y_train, y_test = train_test_split(X, y,
                                                     test_size=0.2, random_state=42)

# Convert the data into TensorFlow Dataset format
train_dataset = tf.data.Dataset.from_tensor_slices((X_train, y_train))
test_dataset = tf.data.Dataset.from_tensor_slices((X_test, y_test))

# Define the feature columns
feature_columns = []
for i in range(X.shape[1]):
    feature_columns.append(tf.feature_column.numeric_column(str(i)))

# Define the Boosted Decision Trees estimator
estimator = tf.estimator.BoostedTreesClassifier(
    feature_columns=feature_columns,
    n_trees=100,
    max_depth=3,
    learning_rate=0.1
)

# Train the Boosted Decision Trees model
estimator.train(input_fn=lambda: train_dataset.shuffle(1000).batch(32))

# Evaluate the model on the test set
eval_result = estimator.evaluate(input_fn=lambda: test_dataset.batch(32))
accuracy = eval_result['accuracy']
print("Accuracy: {:.2f}%".format(accuracy * 100))
```

ROC curve

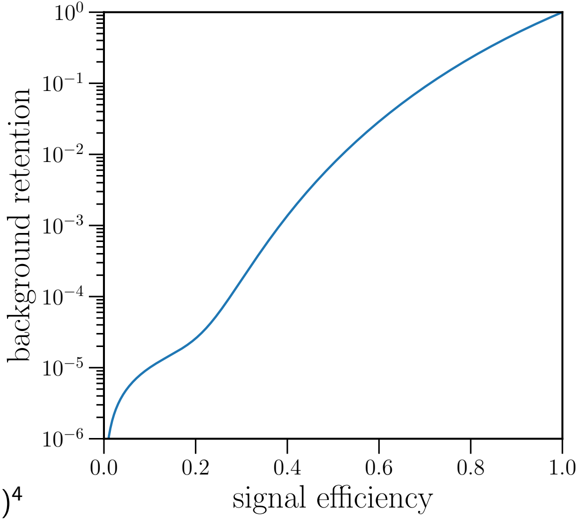
A random ROC curve



$\eta_B = 10^{-}4\eta_S + (1 - \cos(\frac{\pi}{2}\eta_S))^4$

ROC CURVE

A random ROC curve

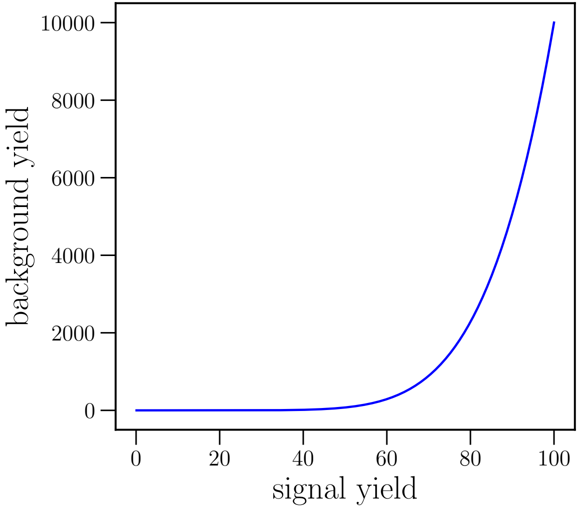


$\eta_B = 10^{-}4\eta_S + (1 - \cos(\frac{\pi}{2}\eta_S))^4$

ROC curve

A random ROC curve

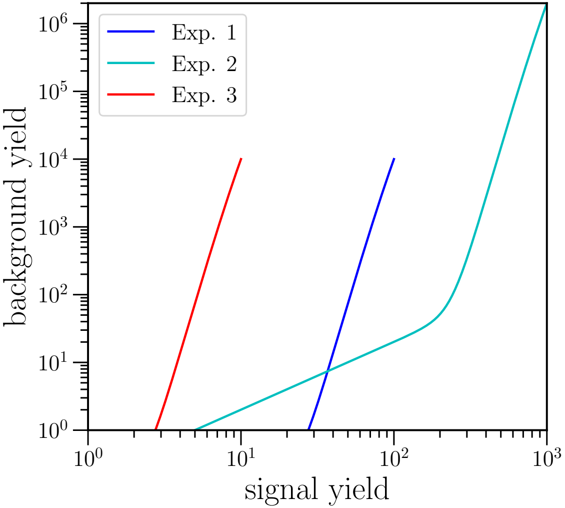
1. $S_1 = 100, B_1 = 10^4$



ROC CURVE

A random ROC curve

1. $S_1 = 100, B_1 = 10^4$
2. $S_2 = 1000, B_2 = 2 \times 10^6$
3. $S_3 = 10, B_3 = 10^4$

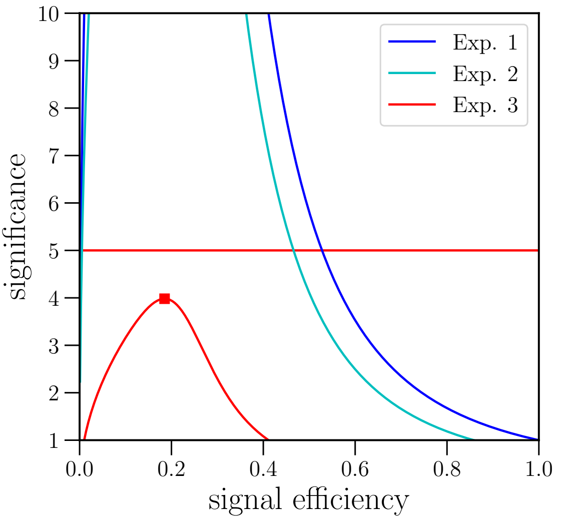


ROC curve

A random ROC curve

1. $S_1 = 100, B_1 = 10^4$
2. $S_2 = 1000, B_2 = 2 \times 10^6$
3. $S_3 = 10, B_3 = 10^4$

- Significance versus cut

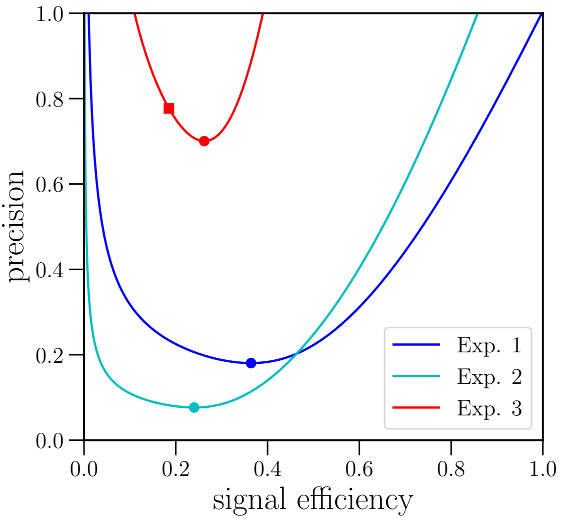


ROC curve

A random ROC curve

1. $S_1 = 100, B_1 = 10^4$
2. $S_2 = 1000, B_2 = 2 \times 10^6$
3. $S_3 = 10, B_3 = 10^4$

- Significance versus cut
- Precision on S yield
  - ➜ The optimal point is not the same
  - The best precision is not at the best significance
  - I like to sit at the low edge of the plateau
    - ➜ study backgrounds



Sven Sachsalber finds the needle in the haystack

[Brown et al., arXiv:2005.14165]

Is AI in HEP overrated?

The role of AI in particle physics is certainly important, but whether it is overrated or not depends on who you ask and what specific application of AI you are considering.

On one hand, AI has already played a significant role in particle physics research, particularly in areas such as data analysis and simulation. For example, machine learning algorithms have been used to classify particle events in large particle accelerators like the Large Hadron Collider (LHC), enabling physicists to better identify interesting signals from background noise. AI has also been used to optimize simulations of particle interactions, allowing researchers to explore theoretical models more efficiently.

However, it is worth noting that AI is not a panacea for all problems in particle physics. While it can be a powerful tool for certain applications, it is not a substitute for theoretical or experimental expertise. Some experts in the field argue that AI should be seen as a complement to traditional methods, rather than a replacement for them.

Additionally, some applications of AI in particle physics have faced criticism or skepticism. For example, some researchers have raised concerns about the use of AI in making decisions about which data to analyze, arguing that such decisions should be made by human experts with a deep understanding of the physics involved. Others have expressed skepticism about the ability of AI to uncover truly new and unexpected physics, as opposed to simply optimizing existing methods.

Overall, the role of AI in particle physics is an ongoing and evolving area of research, and opinions on its usefulness may vary depending on the specific application and perspective of the individual researcher.

Techniques

1. Full-event Tagging
2. Flavour Tagging
3. Blinding
4. Uncertainties
5. Dalitz Plots
6. sPlot
7. Machine Learning
8. Fitting ➜ Backup

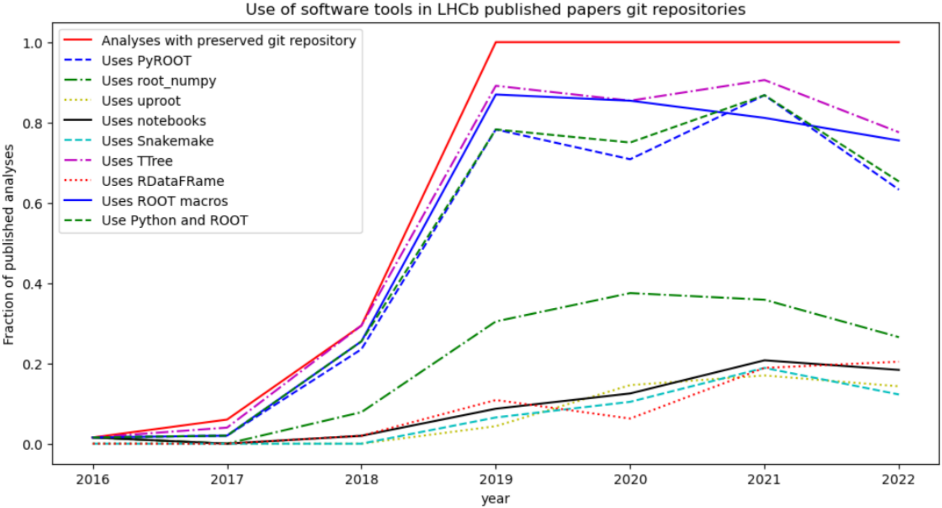
04/09/2019 - patrick@koppenburg.ch

Techniques

1. Full-event Tagging
2. Flavour Tagging
3. Blinding
4. Uncertainties
5. Dalitz Plots
6. sPlot
7. Machine Learning
8. Fitting ➜ Backup
9. Good computing practices

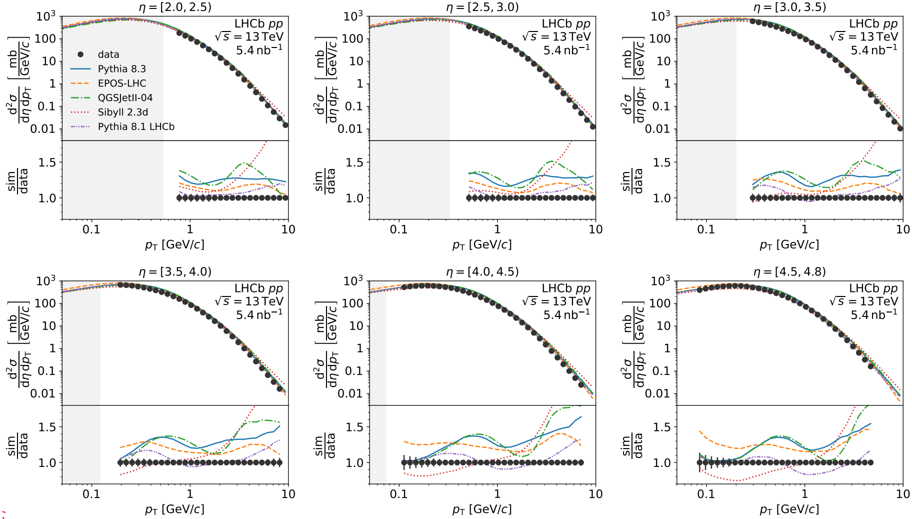
[Ben Couturier]

Software tools



[LHCb, JHEP 01 (2022) 166, arXiv:2107.10090]

Charged multiplicity at $\sqrt{s} = 13\,\text{TeV}$



Charged multiplicity at $\sqrt{s} = 13$ TeV

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This paper consistently and correctly cites all high-level software used in the analysis.

Good Enough Practices

1. Data Management
   a) Save the raw data.
   b) Create the data you wish to see in the world.
   c) Create analysis-friendly data.
   d) **Record all the steps used to process data.**
   e) Anticipate the need to use multiple tables.
   f) Submit data to a reputable DOI-issuing repository so that others can access and cite it.
2. Software
   a) **Place a brief explanatory comment at the start of every program.**
   b) **Decompose programs into functions.**
   c) **Be ruthless about eliminating duplication.**
   d) **Always search for well-maintained software libraries that do what you need.**
   e) **Test libraries before relying on them.**
   f) **Give functions and variables meaningful names.**
   g) **Make dependencies and requirements explicit.**
   h) **Do not comment and uncomment sections of code to control a program's behavior.**
   i) **Provide a simple example or test data set.**
   j) Submit code to a reputable DOI-issuing repository.
3. Collaboration
   a) Create an overview of your project.
   b) Create a shared public "to-do" list.
   c) Make the license explicit.
   d) Make the project citable.

Good Enough Practices

4. Project Organization
   a) Put each project in its own directory, which is named after the project.
   b) Put text documents associated with the project in the `doc` directory.
   c) Put raw data and metadata in a `data` directory, and files generated during cleanup and analysis in a `results` directory.
   d) Put project source code in the `src` directory.
   e) Put external scripts, or compiled programs in the `bin` directory.
   f) Name all files to reflect their content or function.
5. Keeping Track of Changes
   a) **Back up (almost) everything created by a human being as soon as it is created.**
   b) **Keep changes small.**
   c) Share changes frequently.
   d) **Create, maintain, and use a checklist for saving and sharing changes to the project.**
   e) Store each project in a folder that is mirrored off the researcher's working machine.
   f) Use a file called `CHANGELOG.txt` to record changes, and
   g) Copy the entire project whenever a significant change has been made, OR
   h) **Use a version control system to manage changes**
6. Manuscripts
   a) Write manuscripts using online tools with rich formatting, change tracking, and reference management, OR
   b) **Write the manuscript in a plain text format that permits version control.**

Techniques

1. Full-event Tagging
2. Flavour Tagging
3. Blinding
4. Uncertainties
5. Dalitz Plots
6. sPlot
7. Machine Learning
8. Fitting ➜ Backup
9. Good computing practices
10. Uncovered

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Soft Skills

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Contact: ATLAS Administration

Search...

ATLAS Organisation

Organisation

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Upgrade Coordination

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Inner Detector (ID)

ID System Project Leader *Koichi Nagai (Oxford)*

Inner Tracker for Phase-II (ITk)

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Muon Spectrometer

Muon System Project Leader *Philipp Fleischmann (Michigan)*

Tile Calorimeter

Tile System Project Leader *Oleg Solovyanov (Clermont-Ferrand)*

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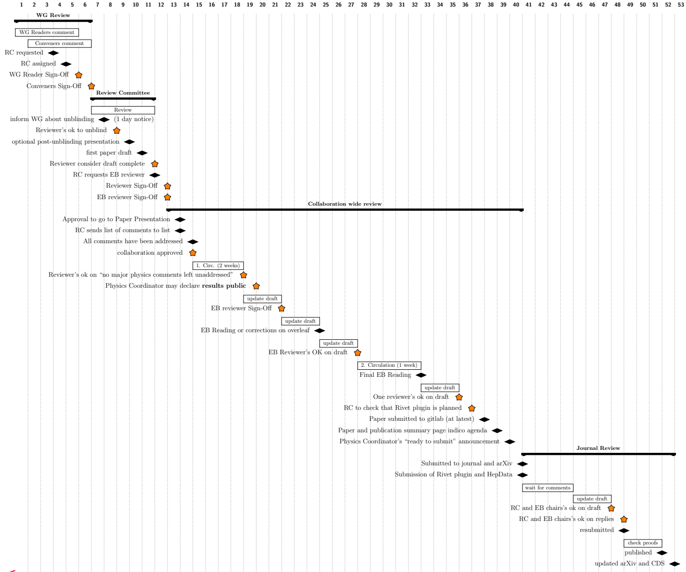
TDMT Member *Stefano Veneziano (Roma I)*
Thorsten Wengler (CERN)
Wainer Vandelli (CERN)

[flowchart]

LHCb Publication Procedure (PAPER)

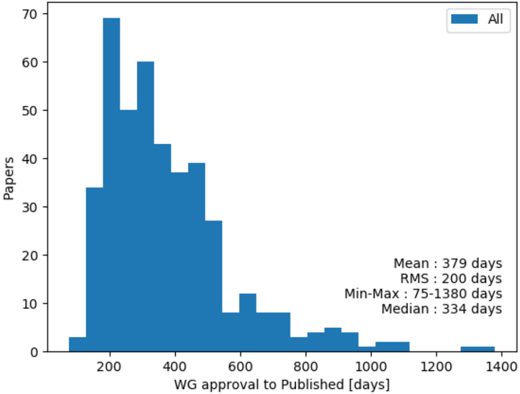
dated: March 14, 2019

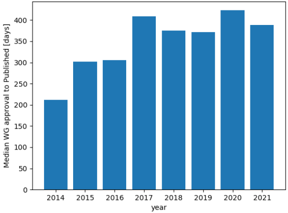


[Flowchart]

How long does it take

(left) Distribution of time from WG approval to publication, (right) median. The grand total.





Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	6
Submission	1
EB process	71
Peer review	60
Proofs	29
Journal	91
Total	334

[B]

IArXiv

From date 2023/05/21 To date 2023/05/26 Search

2023/05/25

[1] 2305.14854 (hep-ph) [score: 0.83]

A global analysis for determined and undetermined hadronic two body weak decays of anti-triplet charmed baryons

Zhi-Peng Xing - Xiao-Gang He - Fei Huang - Chang Yang
Comments: *9pages, 2 figures, 3 tables*

A large amount of data on hadronic two body weak decays of anti-triplet charmed baryons $T_{c\bar{3}}$ to an octet baryon T_8 and an octet or singlet pseudoscalar meson P, $T_{c\bar{3}} \to T_8 P$, have been measured. The SU(3) flavor symmetry has been applied to study these decays to obtain insights about weak interactions for charm physics. However not all such decays needed to determine the SU(3) irreducible amplitudes have been measured forbidding a complete global analysis. Previously, it has been shown that data from measured decays can be used to do a global fit to determine all except one parity violating and one parity conserving amplitudes of the relevant SU(3) irreducible amplitudes causing 8 hadronic two body weak decay channels involving Ξ_c^0 to η or η' transitions undetermined. It is important to obtain information about these decays in order to guide experimental searches. In this work using newly measured decay modes by BESIII and Belle in 2022, we carry out a global analysis and parameterize the unknown amplitudes to provide the ranges for the branching ratios of the 8 undetermined decays. Our results indicate that the SU(3) flavor symmetry can explain the measured data exceptionally well, with a remarkable minimal $\chi^2/d.o.f.$ of 1.21 and predict 80 observables in 45 decays for future experimental data to test. We then vary the unknown SU(3) amplitudes to obtain the allowed range of branching ratios for the 8 undetermined decays. We find that some of them are within reach of near future experimental capabilities. We urge our experimental colleagues to carry out related searches.

2023/05/26

[2] 2305.15457 (hep-ph) [score: 0.80]

Discriminating $B \to D^* \ell \nu$ form factors via polarization observables and asymmetries

Marco Fedele - Monika Blanke - Andreas Crivellin - Syuhei Iguro - Ulrich Nierste - Silvano Simula - Ludovico Vittorio
Comments: *10 pages, 3 figures*

Form factors are crucial theory input in order to extract $|V_{cb}|$ from $B \to D^{(*)} \ell \nu$ decays, to calculate the Standard Model prediction for $\mathcal{R}(D^{(*)})$ and to assess the impact of New Physics. In this context, the Dispersive Matrix approach, a first-principle calculation of the form factors, using no experimental data but rather only lattice QCD results as input, was recently applied to $B \to D^{(*)} \ell \nu$. It predicts (within the Standard Model) a much milder tension with the $\mathcal{R}(D^*)$ measurements than the other form factor approaches, while at the same time giving a value of $|V_{cb}|$ compatible with the inclusive value. However, this comes at the expense of creating tensions with differential $B \to D^* \ell \nu$ distributions (with light leptons). In this article, we explore the implications of using the Dispersive Matrix method form factors, in light of the recent Belle (II) measurements of the longitudinal polarization fraction of the D^* in $B \to D^* \ell \nu$ with light leptons, F_L^ℓ, and the forward-backward asymmetry, $A_{\rm FB}^\ell$. We find that the Dispersive Matrix approach predicts a Standard Model value of F_L^ℓ that is in significant tension with these measurements, while mild deviations in $A_{\rm FB}^\ell$ appear. Furthermore, F_L^ℓ is very insensitive to New Physics such that the latter cannot account for the tension between Dispersive Matrix predictions and its measurement. While this tension can be resolved by deforming the original Dispersive Matrix form factor shapes within a global fit, a tension in $\mathcal{R}(D^*)$ reemerges. As this tension is milder than for the other form factors, it can be explained by New Physics not only in the tau lepton channel but also in the light lepton modes.

2023/05/23

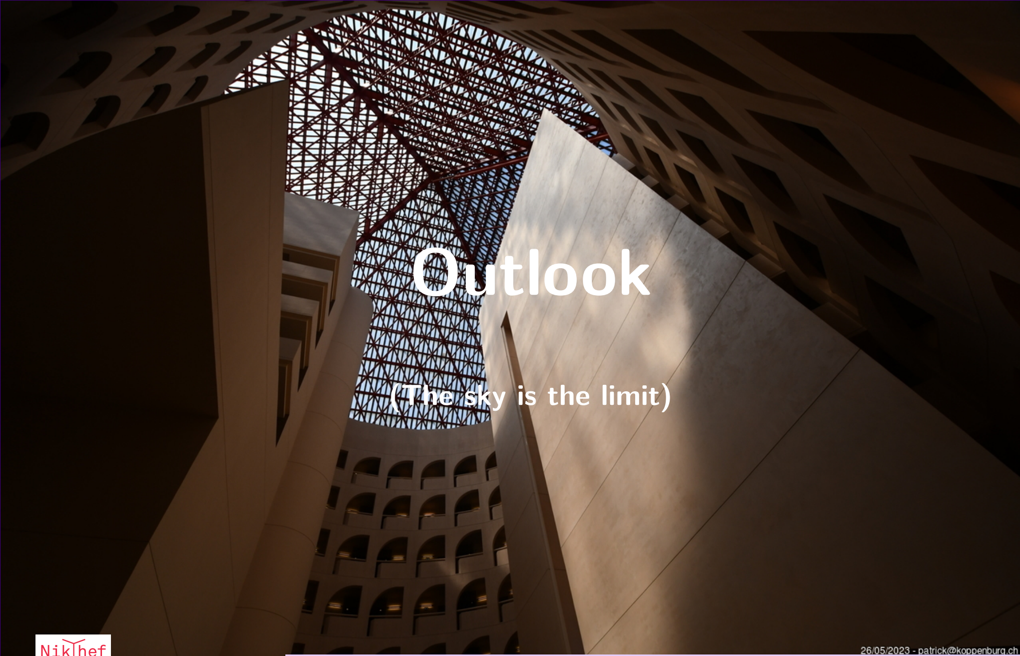
[3] 2305.11951 (hep-ph) [score: 0.79]

Final-state interactions in the CP asymmetries of charm-meson two-body decays

Antonio Pich - Eleftheria Solomonidi - Luiz Vale Silva

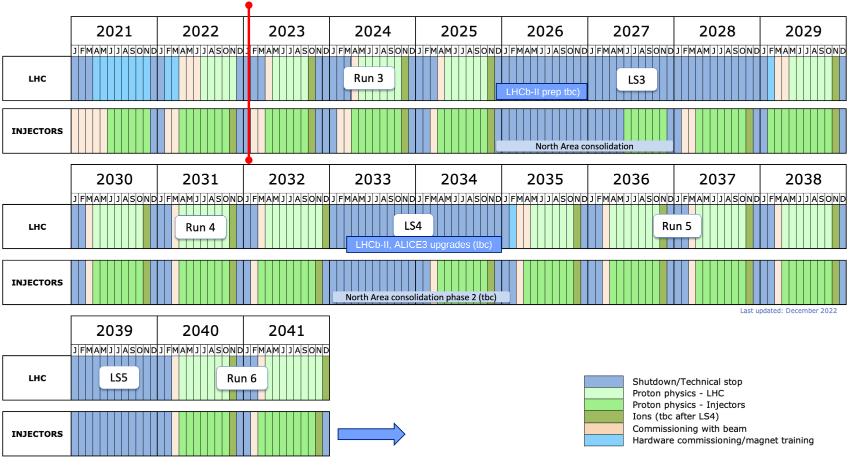
Outlook

(The sky is the limit)



LHC schedule (Jan 2023)

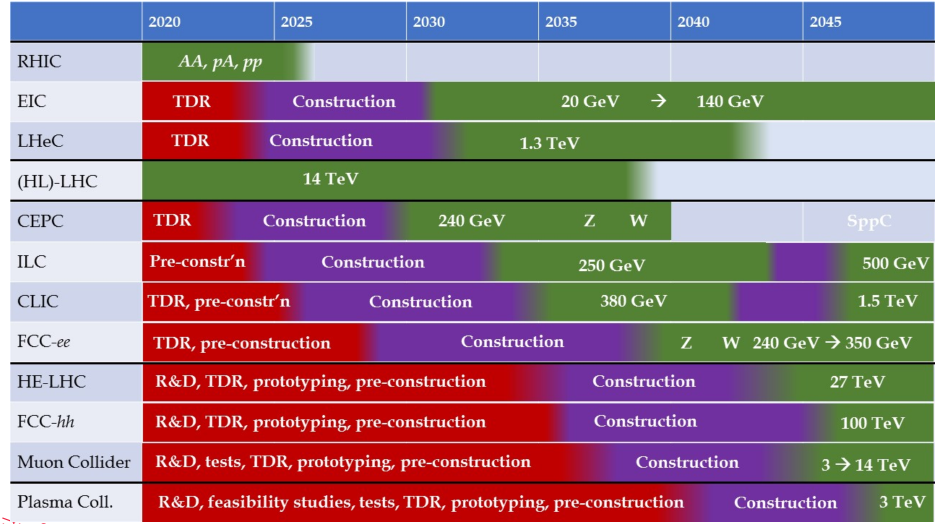
Indicative timeline



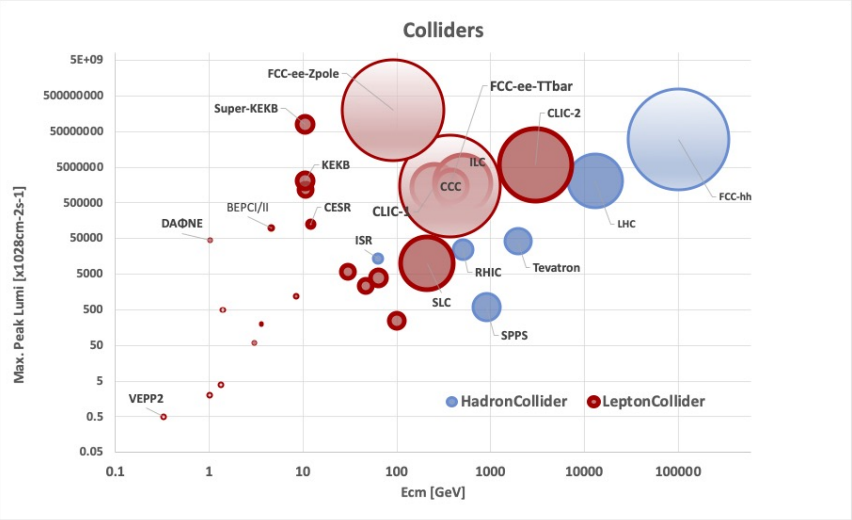
The P{h}ysics case

[LHCb U2 Physics case, arXiv:1808.08865]

Colliders


2020
2025
2030
2035
2040
2045
RHIC
AA, pA, pp
EIC
TDR
Construction
20 GeV → 140 GeV
LHeC
TDR
Construction
1.3 TeV
(HL)-LHC
14 TeV
CEPC
TDR
Construction
240 GeV
Z
W
SppC
ILC
Pre-constr'n
Construction
250 GeV
500 GeV
CLIC
TDR, pre-constr'n
Construction
380 GeV
1.5 TeV
FCC-ee
TDR, pre-construction
Construction
Z
W
240 GeV → 350 GeV
HE-LHC
R&D, TDR, prototyping, pre-construction
Construction
27 TeV
FCC-hh
R&D, TDR, prototyping, pre-construction
Construction
100 TeV
Muon Collider
R&D, tests, TDR, prototyping, pre-construction
Construction
3 → 14 TeV
Plasma Coll.
R&D, feasibility studies, tests, TDR, prototyping, pre-construction
Construction
3 TeV

Colliders


Colliders
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50000000
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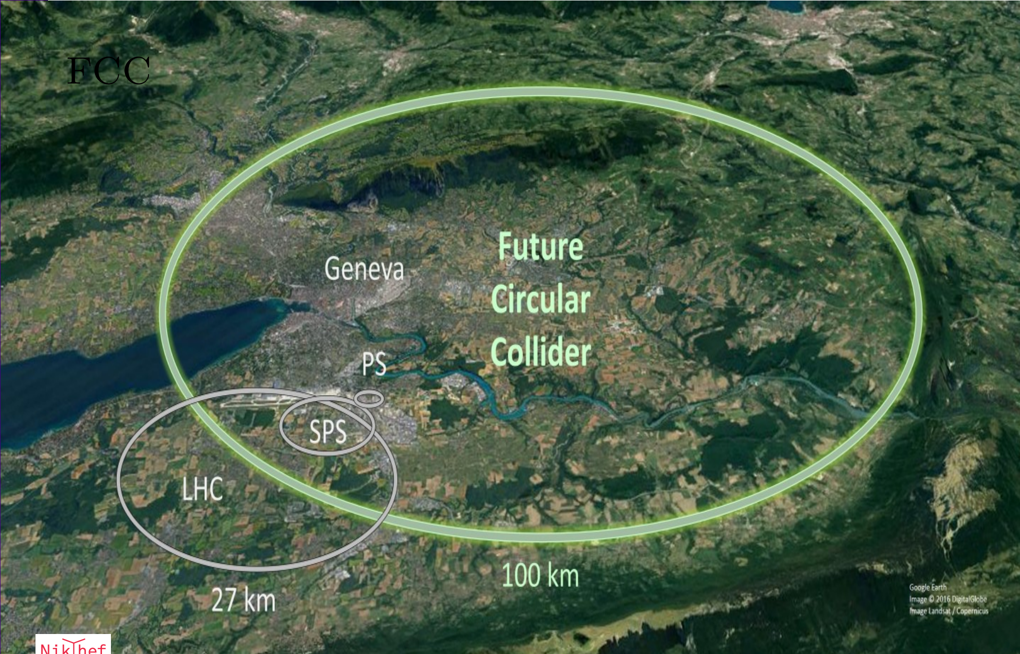
5000
500
50
5
0.5
0.05
Max. Peak Lumi [x1028cm-2s-1]
0.1
1
10
100
1000
10000
100000
Ecm [GeV]
FCC-ee-Zpole
Super-KEKB
FCC-ee-TTbar
CLIC-2
ILC
CCC
KEKB
BEPCI/II
CESR
CLIC-1
DAΦNE
ISR
RHIC
Tevatron
LHC
FCC-hh
SLC
SPPS
VEPP2
HadronCollider
LeptonCollider

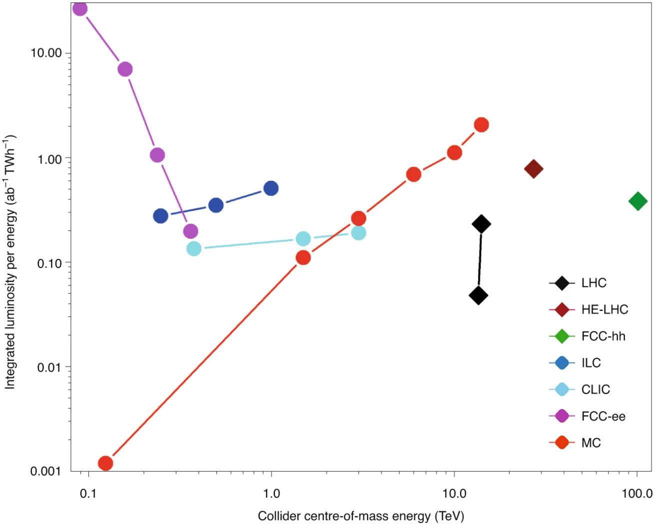
FCC


Future
Circular
Collider
Geneva
PS
SPS
LHC
100 km
27 km
Google Earth
Image © 2016 DigitalGlobe
Image Landsat / Copernicus

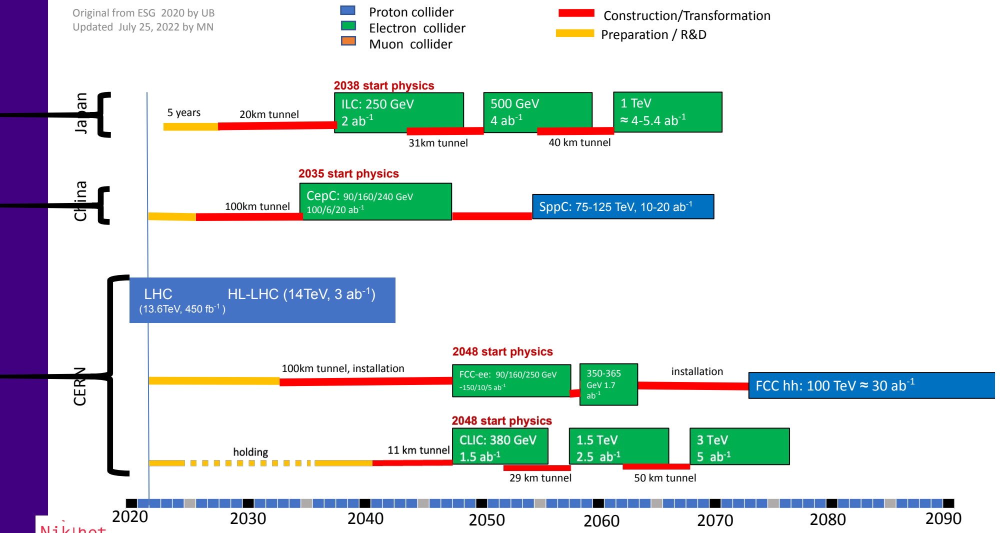
ILC

[B]

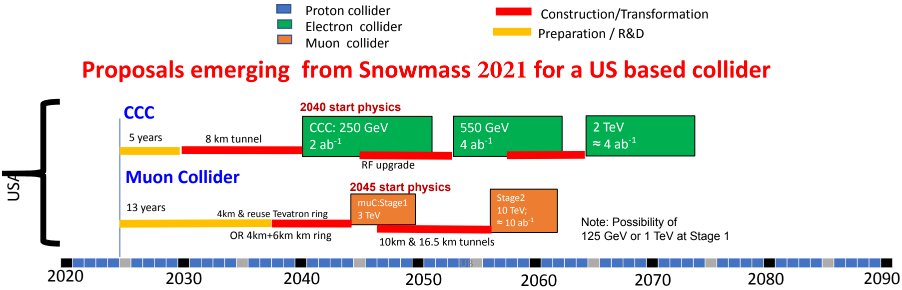
Muon Collider



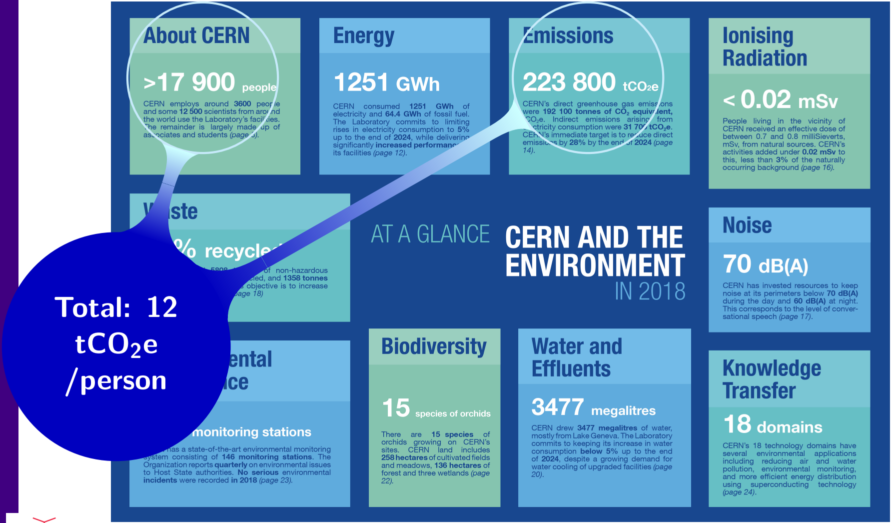
Snowmass Energy Frontier Report



Snowmass Energy Frontier Report



CERN Environment Report 2017–18



SESAME

[sesame.org.jo] [CDS]

The first accelerator powered by renewable energy

Conclusion

- Experiments need triggers and hence choices
- Master analysis techniques
- . . . and soft skills
- Look out for the future

[@pkoppenburg@sciencemastodon.com] [@pkoppenburg] [patrick.koppenburg@nikhef.nl]


THE
OTHER SIDE
Why do you need a reason?
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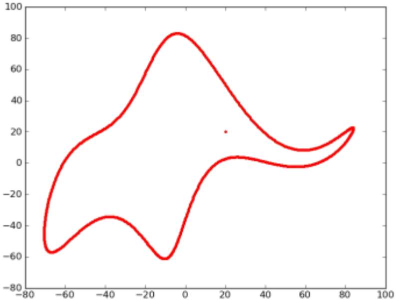
Backup

John von Neumann

With four parameters I can fit an elephant, and with five I can make him wiggle his trunk.



[Boué, arXiv:1904.12320]

Anything can be fitted with one parameter

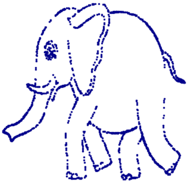
Any shape can be fitted by a single-parameter function

$$f_\alpha(x) = \sin^2(2^{x\tau} \arcsin \sqrt{\alpha})$$

with α the parameter fitting a dataset in $x \in [0 \ldots n], f(x)$, ($\tau \in \mathbb{N}$ is a constant which controls the desired accuracy).

The reason is that a real number contains an infinite amount of information

$\alpha = 0.28495951 \cdots$



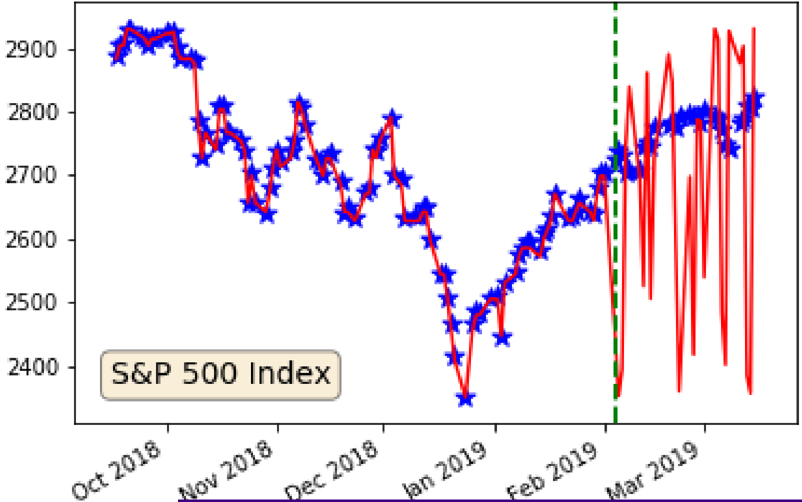
$\alpha = 0.74933466 \cdots$

$\alpha = 0.70704013 \cdots$

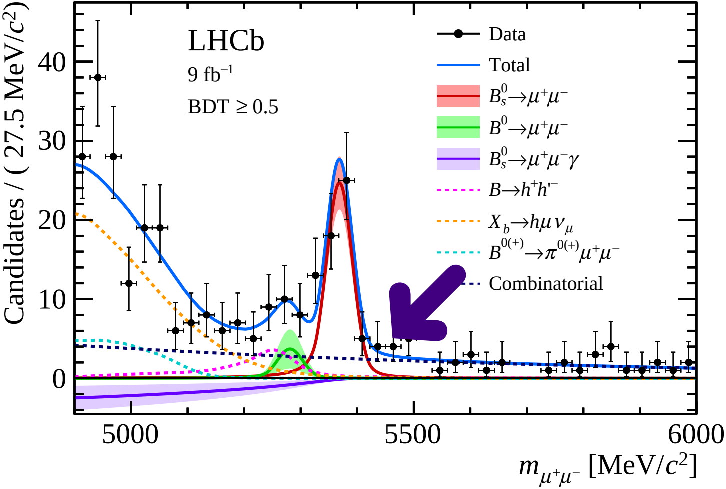
$\alpha = 0.46799746 \cdots$

Anything can be fitted with one parameter

$p_d = \sin^2(2^{d\tau} \arcsin\sqrt{\alpha})$

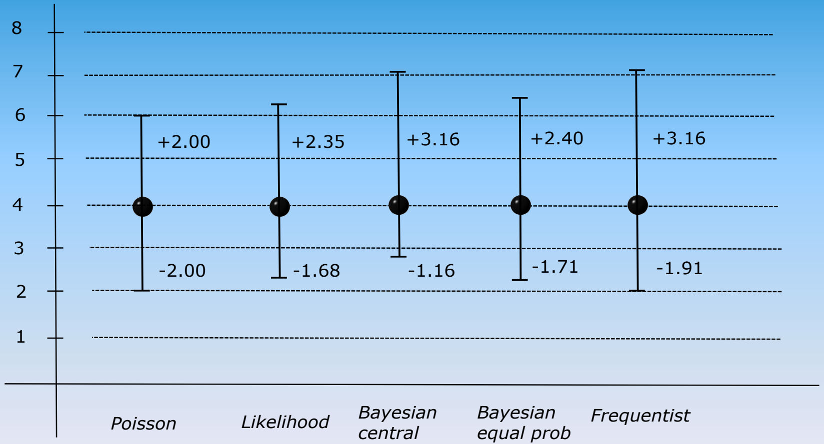


Asymmetric uncertainties in RooFit



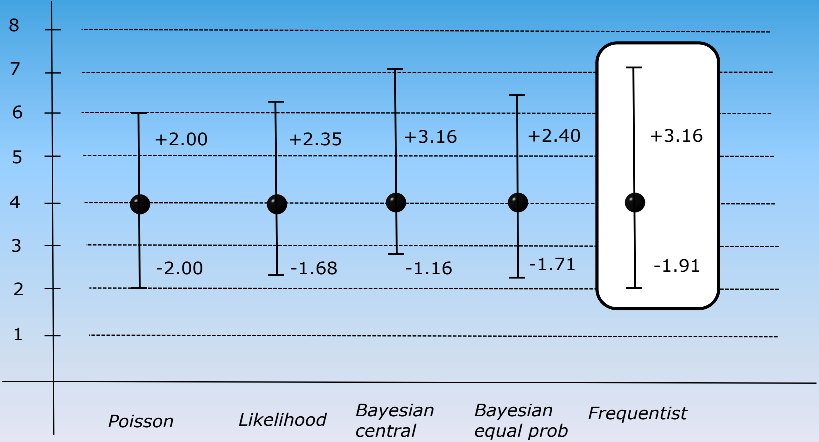
Ivo van Vulpen

The options



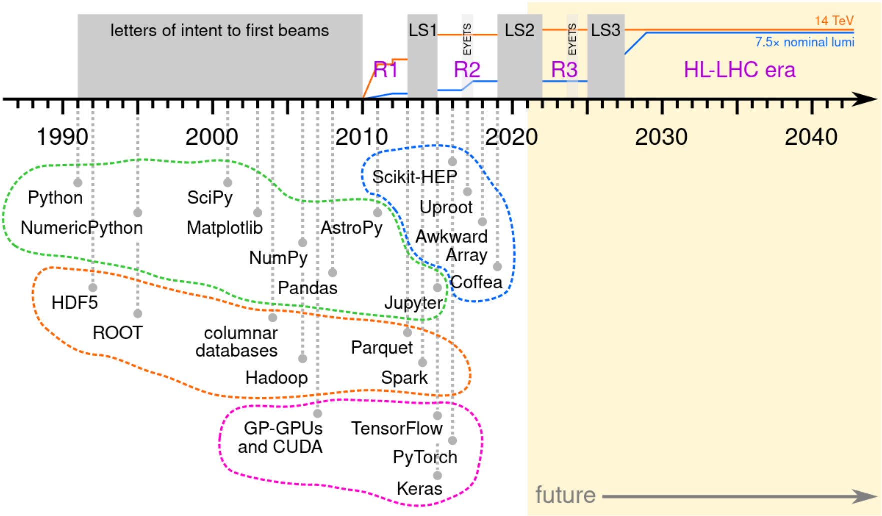
$\Delta\lambda$:	4.00	4.03	4.32	4.11	5.07

The options



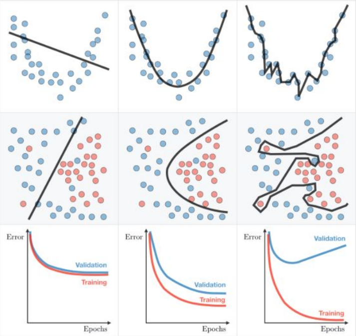
$\Delta\lambda$:	4.00	4.03	4.32	4.11	5.07

Python in HEP

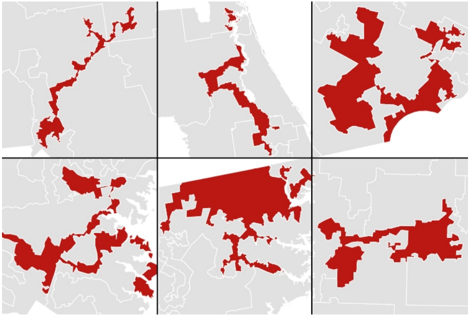


Overtraining is Gerrymandering

	Underfitting	Just right	Overfitting
Symptoms	• High training error • Training error close to test error • High bias	• Training error slightly lower than test error	• Very low training error • Training error much lower than test error • High variance
Regression illustration			
Classification illustration			
Deep learning illustration			
Possible remedies	• Complexify model • Add more features • Train longer		• Perform regularization • Get more data



[Kaggle]



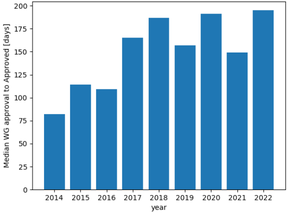
[Washington Post, 2014]

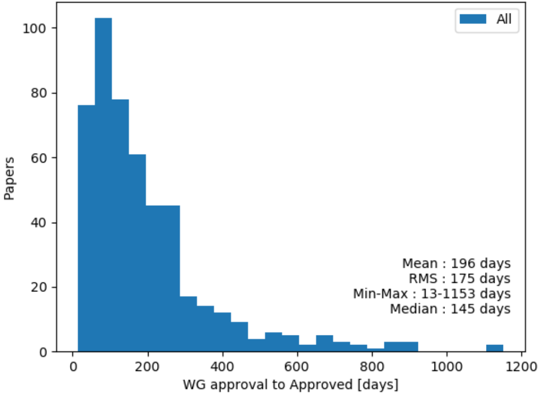
[29/8/2022]

[Flowchart]

How long does it take

(left) Distribution of time from WG approval to approval-to-go-to-paper, (right) median. This is the length of the internal CWR.

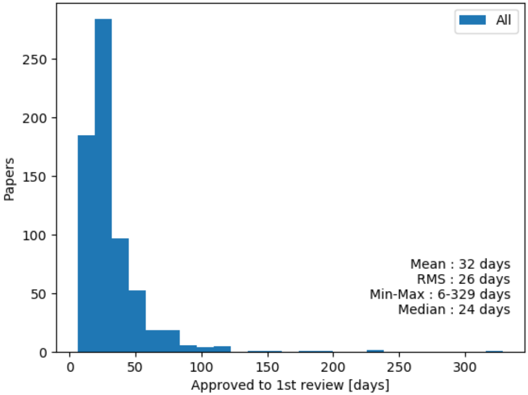


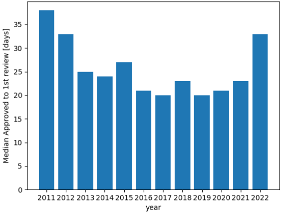


Step	[Days]
Review	145
1st circ.	
EB reading	
2nd EB	
Final version	
Submission	
EB process	
Peer review	
Proofs	
Journal	
Total	

How long does it take

(left) Distribution of time from approval to end of 1st circulation, (right) median.

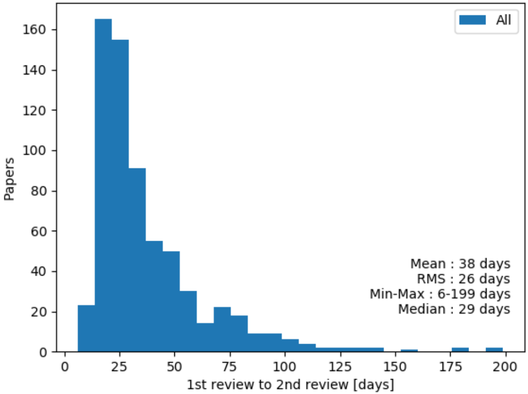


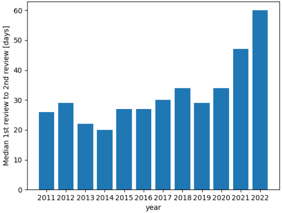


Step	[Days]
Review	145
1st circ.	24
EB reading	
2nd EB	
Final version	
Submission	
EB process	
Peer review	
Proofs	
Journal	
Total	

How long does it take

(left) Distribution of time from first to second circulation, (right) median.

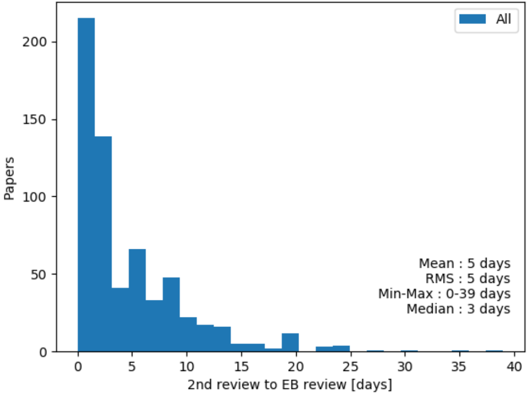


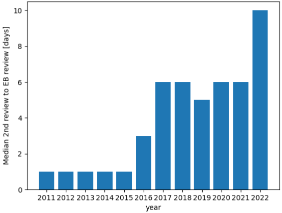


Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	
Final version	
Submission	
EB process	
Peer review	
Proofs	
Journal	
Total	

How long does it take

(left) Distribution of time from second circulation to EB meeting, (right) median.



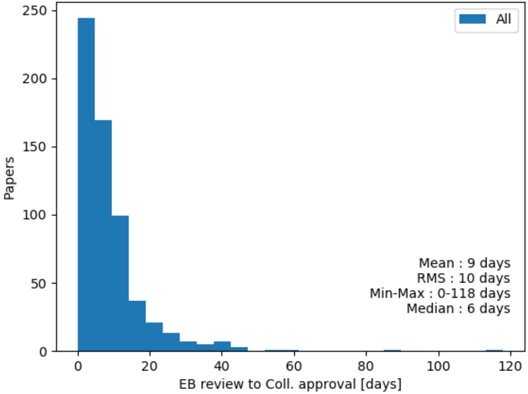


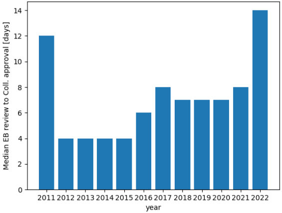
Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	
Submission	
EB process	
Peer review	
Proofs	
Journal	
Total	

[Flowchart]

How long does it take

(left) Distribution of time from EB meeting to approval-to-submit, (right) median.

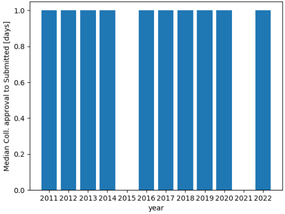


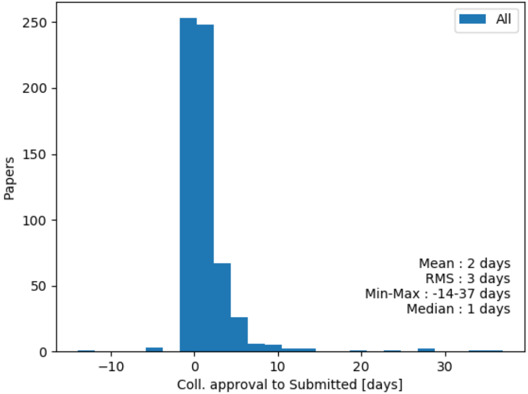


Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	6
Submission	
EB process	
Peer review	
Proofs	
Journal	
Total	

How long does it take

(left) Distribution of time from approval-to-submit to submission (could be negative), (right) median.



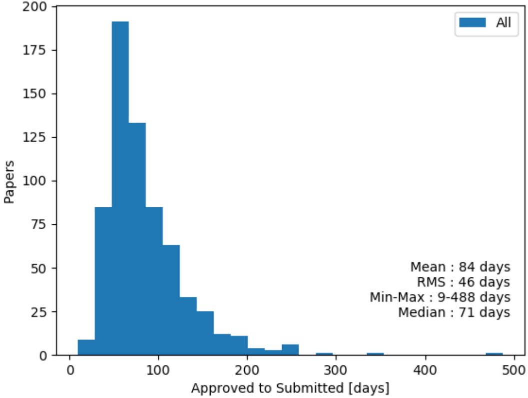


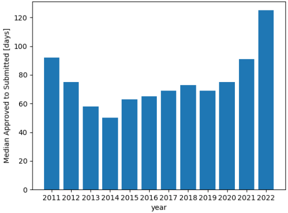
Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	6
Submission	1
EB process	
Peer review	
Proofs	
Journal	
Total	

[Flowchart]

How long does it take

(left) Distribution of time from approval to submission, (right) median. This is the duration of the EB process.

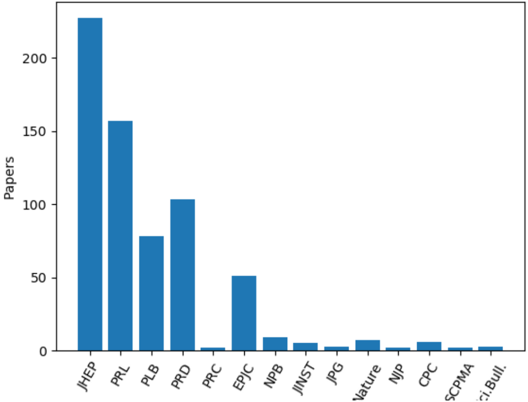


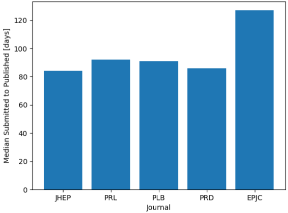


Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	6
Submission	1
EB process	71
Peer review	
Proofs	
Journal	
Total	

How long does it take

From this moment, we don't control the timing any more. We submit the paper to one of these journals.



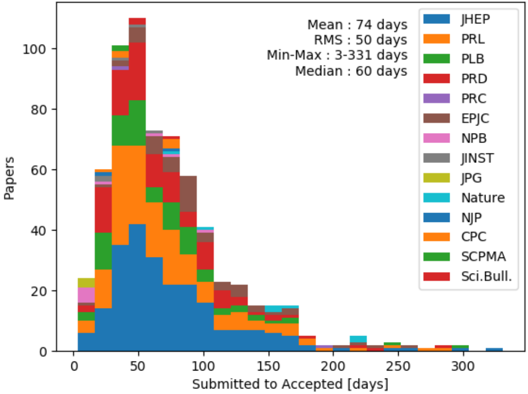


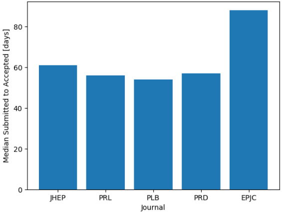
Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	6
Submission	1
EB process	71
Peer review	
Proofs	
Journal	
Total	

[Flowchart]

How long does it take

(left) Distribution of time from submission to journal accept, (right) median by journal.



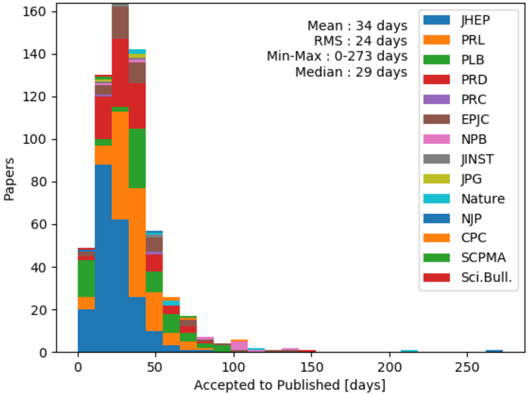


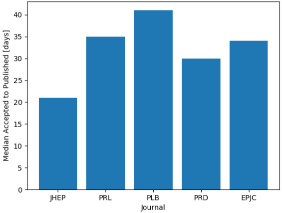
Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	6
Submission	1
EB process	71
Peer review	60
Proofs	
Journal	
Total	

[Flowchart]

How long does it take

(left) Distribution of time from journal accept to publication, (right) median by journal.



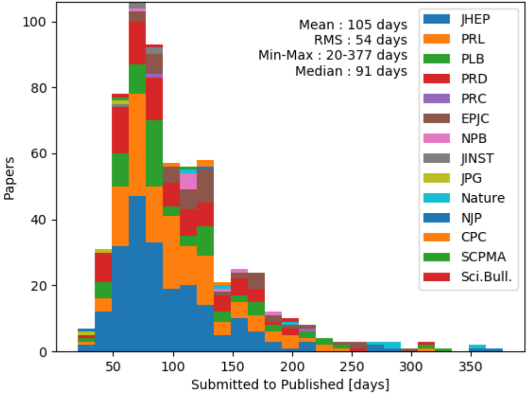


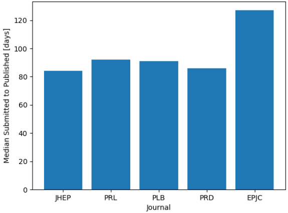
Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	6
Submission	1
EB process	71
Peer review	60
Proofs	29
Journal	
Total	

[Flowchart]

How long does it take

(left) Distribution of time from submission to publication, (right) median by journal. This is the time with the journal.



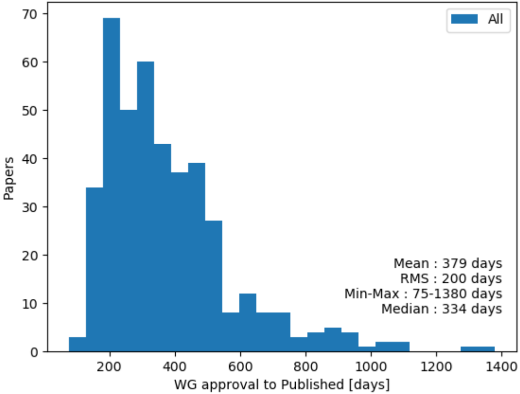


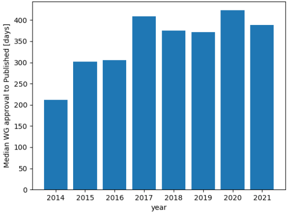
Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	6
Submission	1
EB process	71
Peer review	60
Proofs	29
Journal	91
Total	

[Flowchart]

How long does it take

(left) Distribution of time from WG approval to publication, (right) median. The grand total.





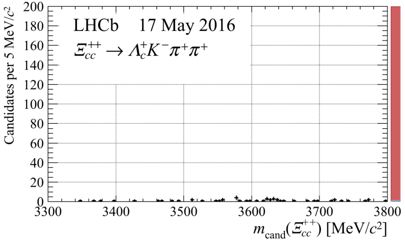
Step	[Days]
Review	145
1st circ.	24
EB reading	29
2nd EB	3
Final version	6
Submission	1
EB process	71
Peer review	60
Proofs	29
Journal	91
Total	334

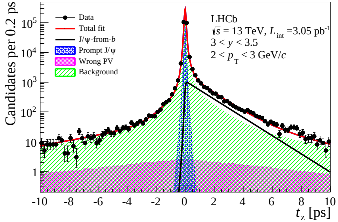
TURBO STREAM

- 5 kHz of 12 kHz go to TURBO:
- Only trigger information is saved: tracks and vertices that caused the event to trigger
  - ➜ No raw event — no offline reconstruction

✔ Smaller events, faster analysis

- Used for high-yield exclusive trigger lines :
  - ✔ J/ψ [JHEP 10 (2015) 172]
  - ✔ charm [JHEP 03 (2016) 159]
  - ✔ spectroscopy [PRL 119 (2017) 112001]
- Most of the events will be saved by TURBO from Run 3 [LHCb-TDR-016, 2014]





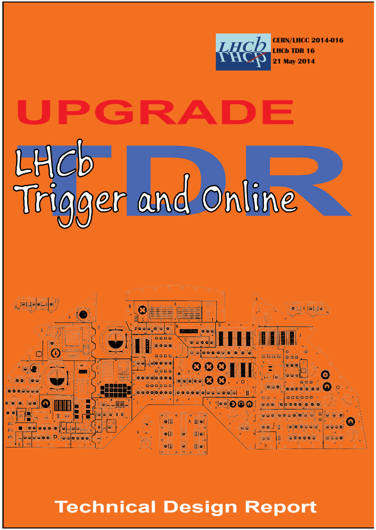
J/ψ pseudo-proper-time.

[B]

[JINST 14 (2019) P04013, arXiv:1812.10790]

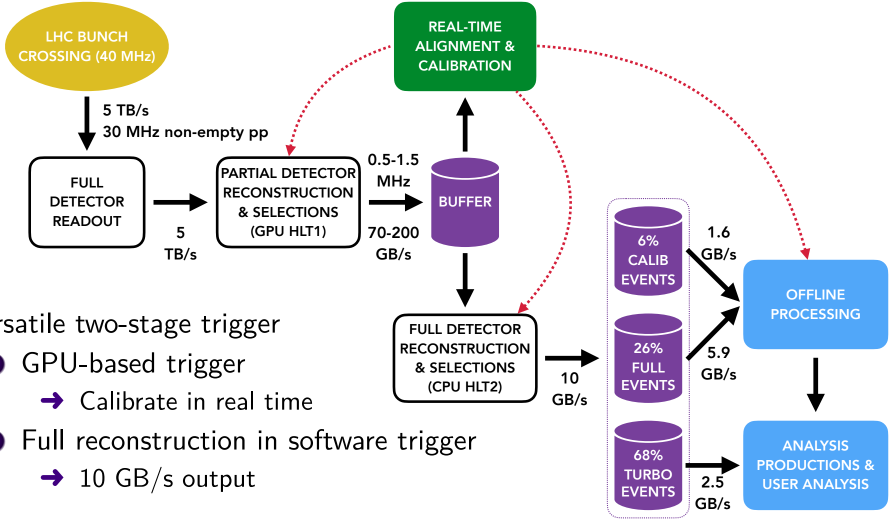
TURBO STREAM

- 5 kHz of 12 kHz go to TURBO:
- Only trigger information is saved: tracks and vertices that caused the event to trigger
  - ➜ No raw event — no offline reconstruction
- ✔ Smaller events, faster analysis
- Most of the events will be saved by TURBO from Run 3 [LHCb-TDR-016, 2014]



[B]

LHCb dataflow in Run 3



Versatile two-stage trigger

1. GPU-based trigger
   - → Calibrate in real time
2. Full reconstruction in software trigger
   - → 10 GB/s output

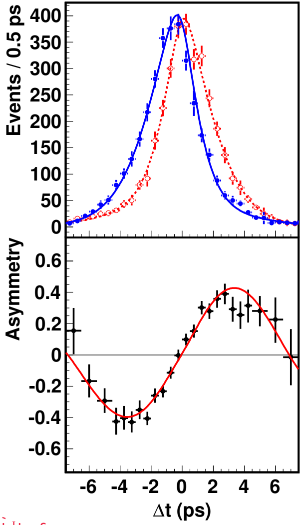
Operations Statistics Run 1–2

Quantity		unit	TDR	2011	2012	Run 1	2015	2016	2017	2018	Run 2	Tot/Avg
Peak Luminosity	$\mathcal{L}_{\text{peak}}$	$\mu b^{-1}/s$	280	461	492	480	302	422	453	493	447	458
Average Luminosity	$\mathcal{L}_{\text{avg}}$	$\mu b^{-1}/s$	200	250	330	298	140	240	280	310	268	278
Seconds of running	t	10^6 s	10.0	4.3	6.2	10.5	1.6	6.9	4.6	6.9	20.0	30.5
Integrated luminosity	$\int\mathcal{L}\mathrm{d}t$	fb^{-1}	2.0	1.1	2.1	3.2	0.5	1.9	1.5	2.5	6.4	9.6
Bunches	N_{b}		2600	1320	1320	1320	1710	2036	2332	2332	2193	1905
Energy	E	TeV	14	7	8	8	13	13	13	13	13	11
Inelastic cross-section	σ_{inel}	mb	80	64	67	66	77	77	77	77	77	73
Charged multiplicity	$\frac{\mathrm{d}N_{\text{ch}}}{\mathrm{d}\eta}$		6	6	6	6	6	6	6	6	6	6
$b\bar{b}$ cross-section (acc.)	$\sigma_{b\bar{b}}$	μb	150	72	83	79	144	144	144	144	144	122
pp interactions/BX	$\mu = \frac{\mathcal{L}\sigma_{\text{inel}}}{f_{\text{LHC}}N_{\text{b}}}$		0.55	1.08	1.49	1.32	0.56	0.81	0.82	0.91	0.83	0.99
Non-empty rate	$f_{\text{LHC}}N_{\text{b}}(1-e^{-\mu})$	MHz	12.3	9.8	11.5	10.8	8.3	12.7	14.7	15.7	14.0	12.9
Avg. MB rate	$\sigma_{\text{inel}}\mathcal{L}_{\text{avg}}$	MHz	16.0	16.0	22.1	19.7	10.8	18.5	21.6	23.9	20.7	20.3
MB events	$\sigma_{\text{inel}}\int\mathcal{L}_{\text{avg}}\mathrm{d}t$	10^{12}	160	70	141	113	38	146	116	192	149	137
Peak particle flow	$\frac{\mathrm{d}N_{\text{ch}}}{\mathrm{d}\eta}\sigma_{\text{inel}}\mathcal{L}_{\text{peak}}$	10^6	134	177	198	189	140	195	209	228	207	201
Irradiation	$\frac{\mathrm{d}N_{\text{ch}}}{\mathrm{d}\eta}\sigma_{\text{inel}}\int\mathcal{L}\mathrm{d}t$	10^{15}	1.0	0.4	0.8	1.3	0.2	0.9	0.7	1.2	3.0	4.2
$b\bar{b}$ rate	$\sigma_{b\bar{b}}\mathcal{L}_{\text{avg}}$	kHz	30	18	27	24	20	35	40	45	39	34
$b\bar{b}$ yield	$\sigma_{b\bar{b}}\int\mathcal{L}\mathrm{d}t$	10^9	300	79	174	254	72	274	216	360	922	1175
Output rate	λ_{HLT}	kHz	2.0	2.6	4.5	3.7	10.4	6.1	7.5	5.8	6.6	5.7
Stored events (bkk)	$\lambda_{\text{HLT}}t$	10^9	20	11	28	39	17	42	35	40	133	172
Event size	S_{ev}	kB	2	53	59	56	48	55	58	58	56	56
HLT B/W	$S_{\text{ev}}\lambda_{\text{HLT}}$	MB/s	5	136	263	212	501	333	438	333	371	319
Total storage	$S_{\text{ev}}\lambda_{\text{HLT}}t$	EB	0.1	0.6	1.6	2.2	0.8	2.3	2.0	2.3	7.4	9.6

Operations Statistics Run 3

Quantity		unit	Run 1	Run 2	UTDR	2022	Tot/Avg
Peak Luminosity	$\mathcal{L}_{\text{peak}}$	$\mu\text{b}^{-1}/\text{s}$	480	447	2000		
Average Luminosity	$\mathcal{L}_{\text{avg}}$	$\mu\text{b}^{-1}/\text{s}$	298	268	2000		
Seconds of running	t	10^6 s	10.5	20.0	5.0		
Integrated luminosity	$\int\mathcal{L}\text{d}t$	fb^{-1}	3.2	6.4	5.0		
Bunches	N_b		1320	2193	2808		
Energy	E	TeV	8	13	14		
Inelastic cross-section	σ_{inel}	mb	66	77	80		
Charged multiplicity	$\frac{\text{d}N_{\text{ch}}}{\text{d}\eta}$		6	6			
$b\overline{b}$ cross-section (acc.)	$\sigma_{b\overline{b}}$	μb	79	144			
pp interactions/BX	$\mu=\frac{\mathcal{L}\sigma_{\text{inel}}}{f_{\text{LHC}}N_\text{b}}$		1.32	0.83	5.07		
Non-empty rate	$f_{\text{LHC}}N_\text{b}(1-e^{-\mu})$	MHz	10.8	14.0	31.4		
Avg. MB rate	$\sigma_{\text{inel}}\mathcal{L}_{\text{avg}}$	MHz	19.7	20.7	160.0		
MB events	$\sigma_{\text{inel}}\int\mathcal{L}_{\text{avg}}\text{d}t$	10^{12}	113	149	400		
Peak particle flow	$\frac{\text{d}N_{\text{ch}}}{\text{d}\eta}\sigma_{\text{inel}}\mathcal{L}_{\text{peak}}$	10^6	189	207			
Irradiation	$\frac{\text{d}N_{\text{ch}}}{\text{d}\eta}\sigma_{\text{inel}}\int\mathcal{L}\text{d}t$	10^{15}	1.3	3.0			
$b\overline{b}$ rate	$\sigma_{b\overline{b}}\mathcal{L}_{\text{avg}}$	kHz	24	39			
$b\overline{b}$ yield	$\sigma_{b\overline{b}}\int\mathcal{L}\text{d}t$	10^9	254	922			
Output rate	λ_{HLT}	kHz	3.7	6.6	10.8		
Stored events (bkk)	$\lambda_{\text{HLT}}t$	10^9	39	133	54		
Event size	S_{ev}	kB	56	56	61		
HLT B/W	$S_{\text{ev}}\lambda_{\text{HLT}}$	MB/s	212	371	659		
Total storage	$S_{\text{ev}}\lambda_{\text{HLT}}t$	EB	2.2	7.4	3.3		

Quantum entanglement

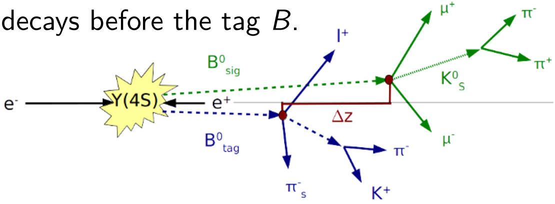


The B^0 and $\bar{B}^0$ originate from a $\Upsilon(4S)$ resonance. They are produced in a quantum-entangled state of a superposition of B^0 and $\bar{B}^0$. The flavour of the one is only fixed once the other decays.

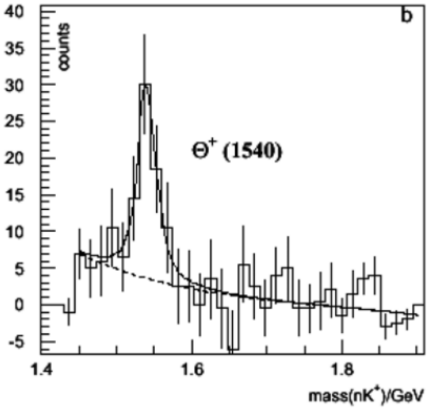
Unlike at the LHC, the clock only starts at the time the other B decays.

➜ The difference in flight time is relevant

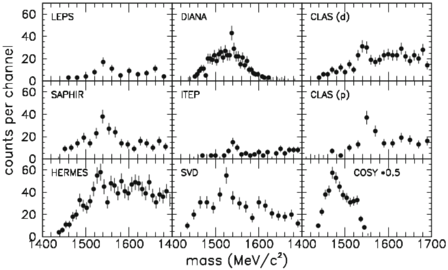
- This difference can be negative, if the signal B decays before the tag B.



The Conundrum of the Θ^+ pentaquark

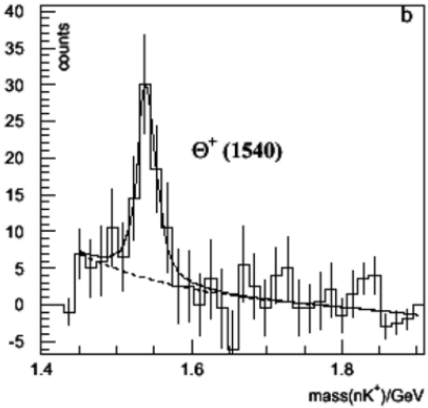


SAPHIR [PLB 572 (2003) 127]

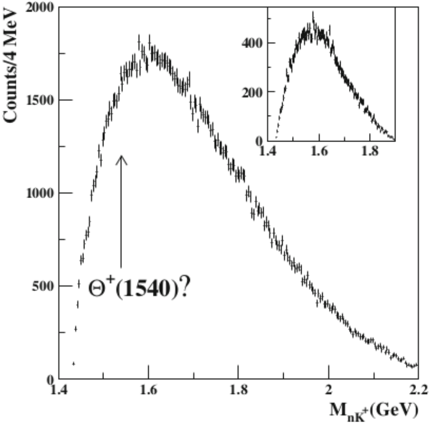


[J. Pochodzalla, arXiv:hep-ex/0406077]

THE CONUNDRUM OF THE Θ^+ PENTAQUARK

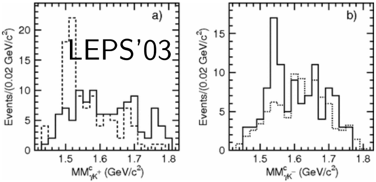


SAPHIR [PLB 572 (2003) 127]

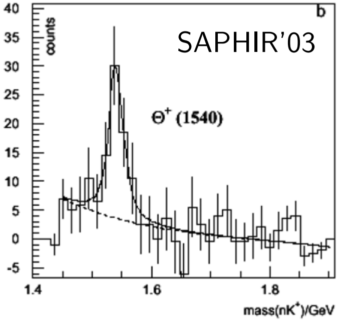


CLAS [PRL 96 (2006) 042001]

THE $\Theta(1540)^+$ PENTAQUARK



In 2003 a $uudd\bar{s}$ state was allegedly found in data from LEPS [Nakano et al.,PRL 91 (2003) 012002], DIANA [Phys.Atom.Nucl. 66 (2003) 1715], CLAS [PRL 91 (2003) 252001], SAPHIR [PLB 572 (2003) 127].



EXOTIC BARYONS

Minimum quark content: $\Theta^+ = uudd\bar{s}$, $\Phi^{--} = ssdd\bar{u}$, $\Phi^+ = ssuu\bar{d}$.

$\Theta(1540)^+$ $I(J^P) = 0(?^?)$

It is difficult to deny a place in the Summary Tables for a state that six experiments claim to have seen. Nevertheless, we believe it reasonable to have some reservations about the existence of this state on the basis of the present evidence.

Mass $m = 1539.2 \pm 1.6$ MeV
Full width $\Gamma = 0.90 \pm 0.30$ MeV

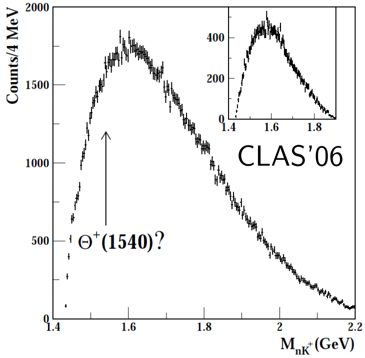
PDG2004

NK is the only strong decay mode allowed for a strangeness $S=+1$ resonance of this mass.

$\Theta(1540)^+$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
KN	100%	270

[B]

The $\Theta(1540)^+$ Pentaquark



In 2003 a $uudd\bar{s}$ state was allegedly found

In 2006 CLAS reported from a large-yield dedicated run and failed to find the particle

[PRL 96 (2006) 042001]

Read *On the conundrum of the pentaquark* by Hicks [EPJH 37 1 (2012)] **Allegedly 6 experiments?**

Citation: W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006) (URL: http://pdg.lbl.gov)

$\Theta(1540)^+$ $I(J^P) = 0(?^?)$ Status: $*$

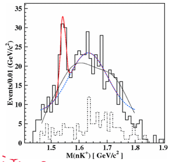
OMITTED FROM SUMMARY TABLE

PENTAQUARK UPDATE

PDG2006

Written February 2006 by G. Trilling (LBNL).

In 2003, the field of baryon spectroscopy was almost revolutionized by experimental evidence for the existence of baryon states constructed from five quarks (actually four quarks and an antiquark) rather than the usual three quarks. In a 1997

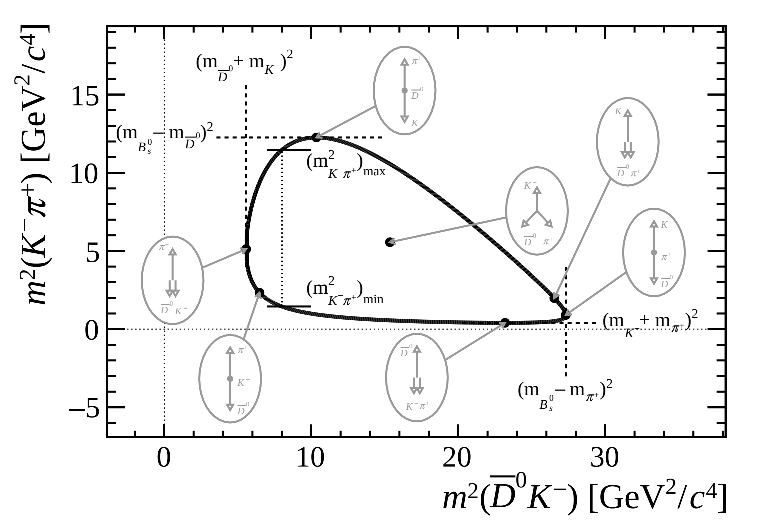


CLAS'03 [PRL 91 (2003) 252001]

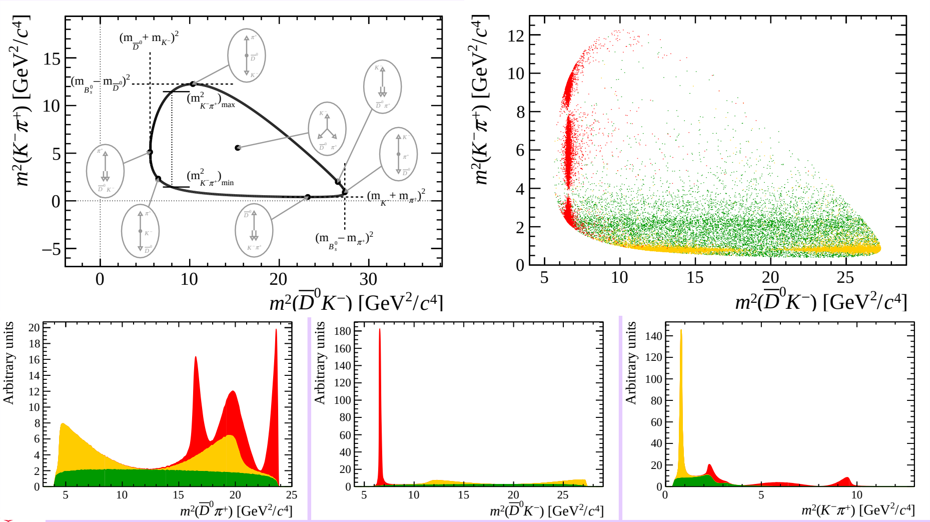
[B]

Nikhef

Dalitz Plots

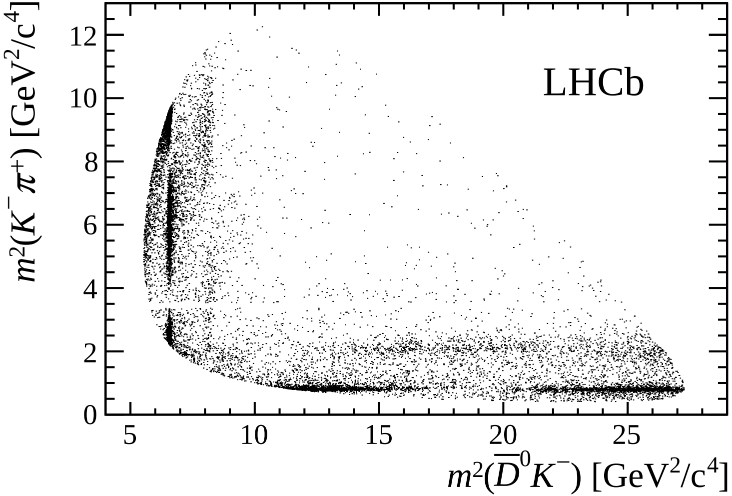


Dalitz Plots



[LHCb, PRL 113 (2014) 162001, arXiv:1407.7574]
[LHCb, PRD 90 (2014) 072003, arXiv:1407.7712]

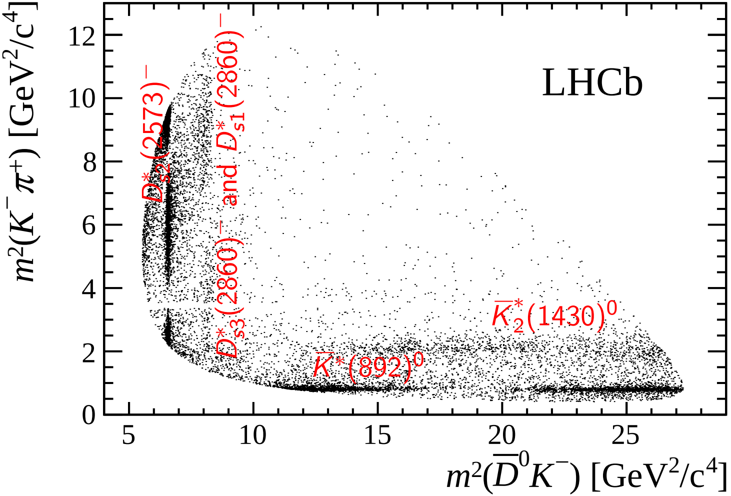
Dalitz of $B_s^0 \to \overline{D}^0 K^- \pi^+$



[B]

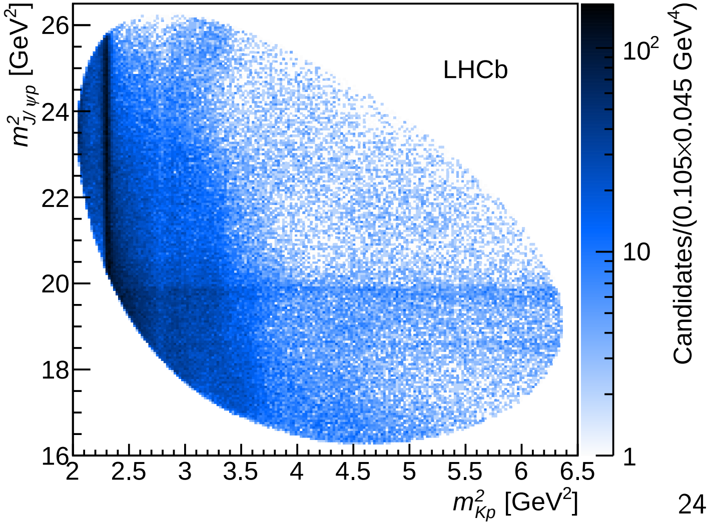
Dalitz of $B_s^0 \to \overline{D}^0 K^- \pi^+$

[LHCb, PRL 113 (2014) 162001, arXiv:1407.7574]
[LHCb, PRD 90 (2014) 072003, arXiv:1407.7712]



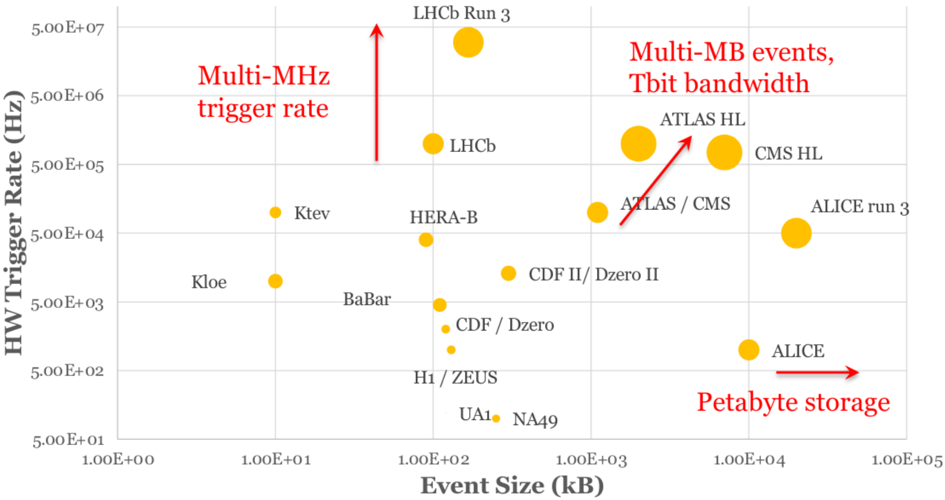
[B]

Observation of narrow pentaquarks

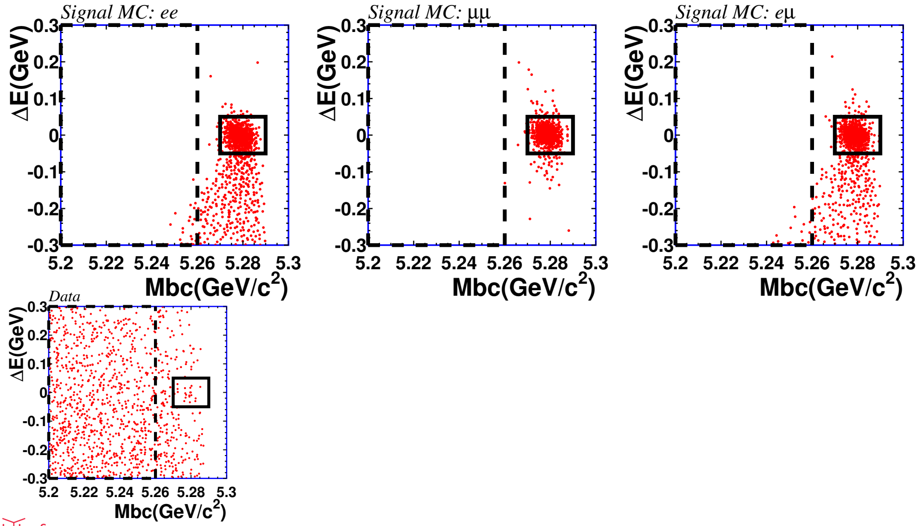


246 000 Λ_b^0

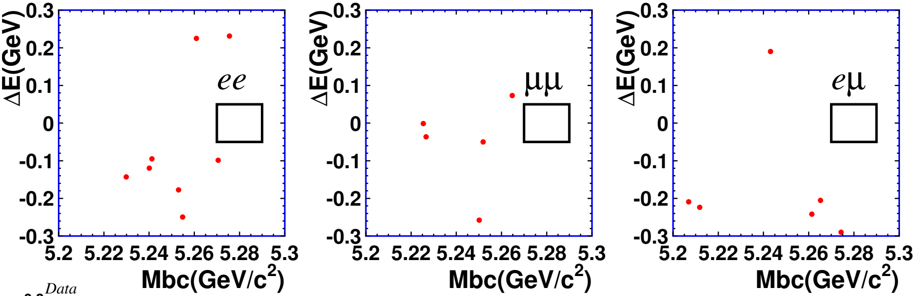
Event sizes and rates

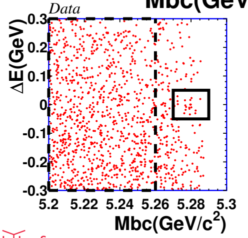


$B \to \ell^+\ell^-$ search at Belle



$B \to \ell^+\ell^-$ search at Belle



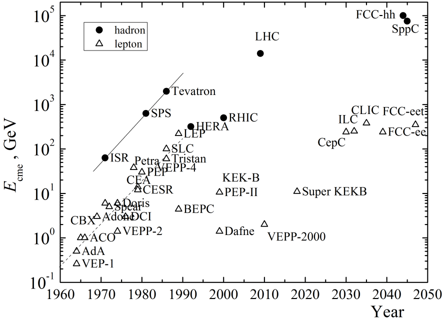


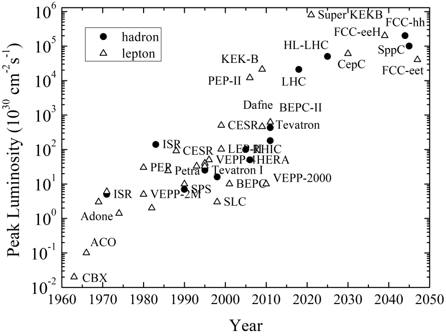
$$\mathcal{B}(B \to e^+e^-) < 1.9 \times 10^{-8}$$

$$\mathcal{B}(B \to \mu^+\mu^-) < 1.6 \times 10^{-7}$$

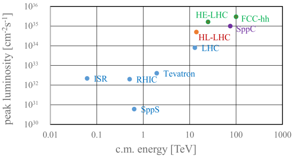
$$\mathcal{B}(B^0 \to e^\pm\mu^\mp) < 1.7 \times 10^{-7}$$

Colliders



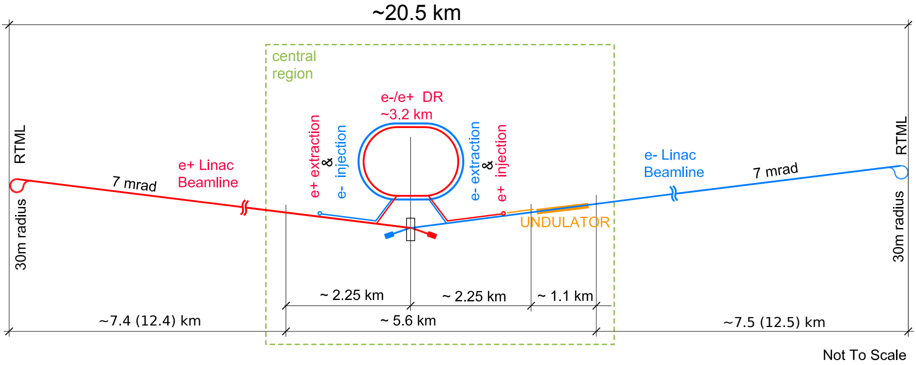


Each decade, energy increases by a factor 5 and luminosity by a factor 7



[B]

ILC


~20.5 km
central
region
e-/e+ DR
~3.2 km
e+ extraction & e- injection
e- extraction & e+ injection
RTML
e+ Linac
Beamline
7 mrad
30m radius
e- Linac
Beamline
7 mrad
RTML
30m radius
UNDULATOR
~ 2.25 km
~ 2.25 km
~ 1.1 km
~7.4 (12.4) km
~ 5.6 km
~7.5 (12.5) km
Not To Scale