Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

The TOP counter of Belle II: status and first results

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Outline

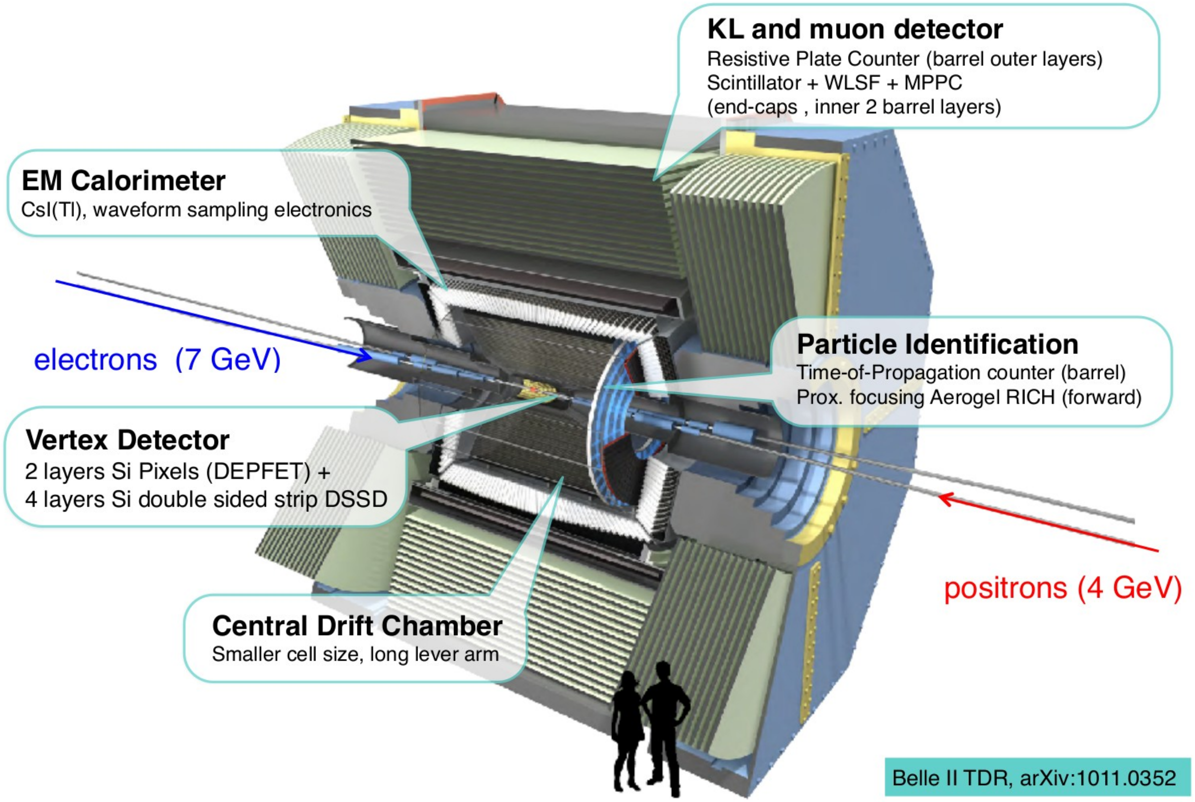
→ Basic features of the Belle II Time-Of-Propagation counter

→ The first PID results

→ Understanding the first PID results

Part I.
The TOP detector (and Belle II)

The Belle II detector



→ CP violation

→ **Every sub-detector provides PID information**

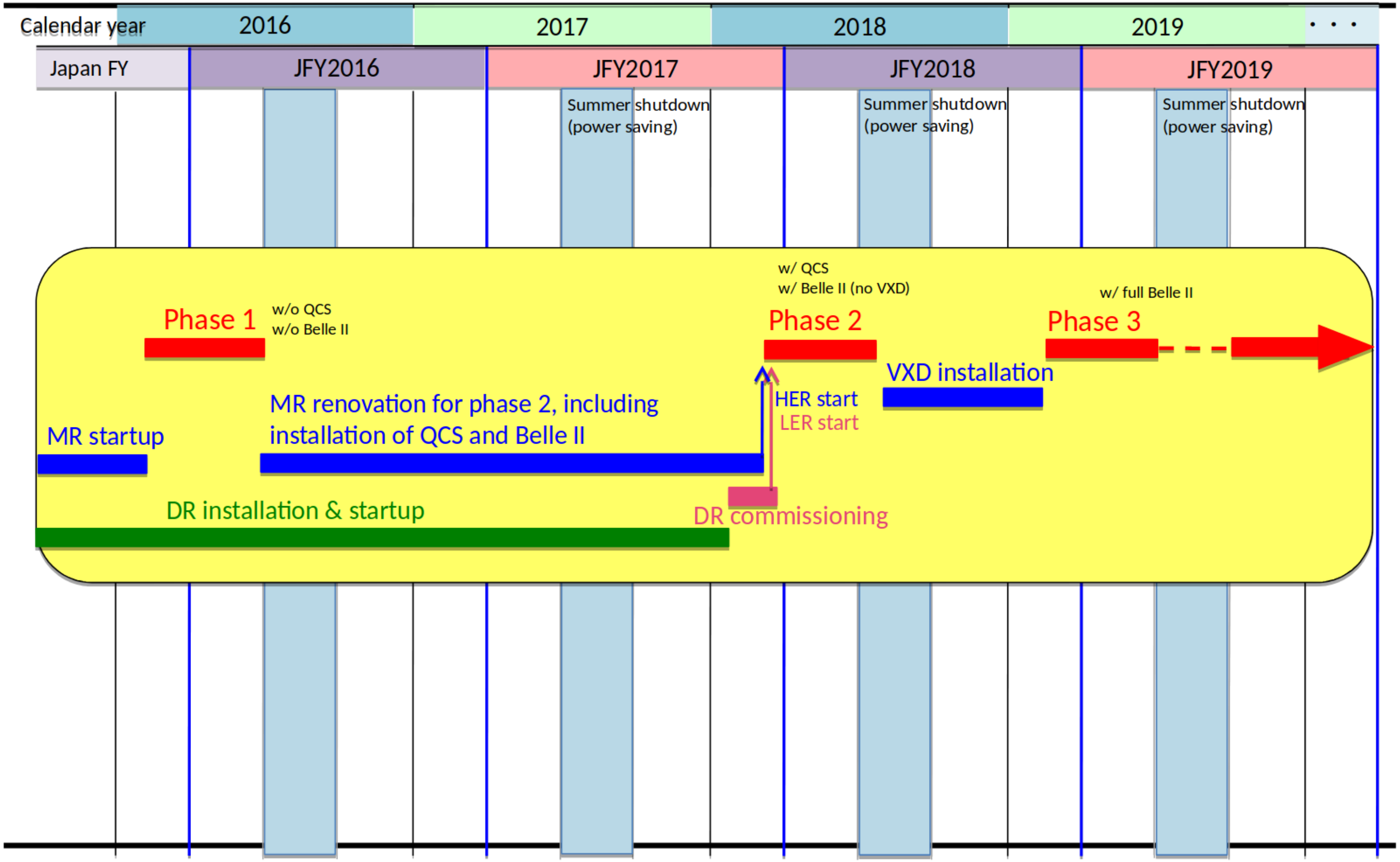
→ dE/dx from Drift Chamber and Vertex detector

→ **Cherenkov signal from TOP and ARICH**

→ Shower shapes from the calorimeter

→ Penetration depth from the muon system

The Belle II experiment: a timeline



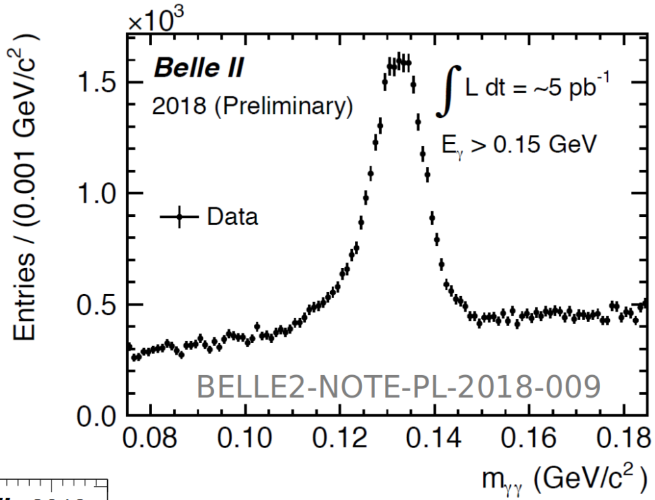
The first Belle II results

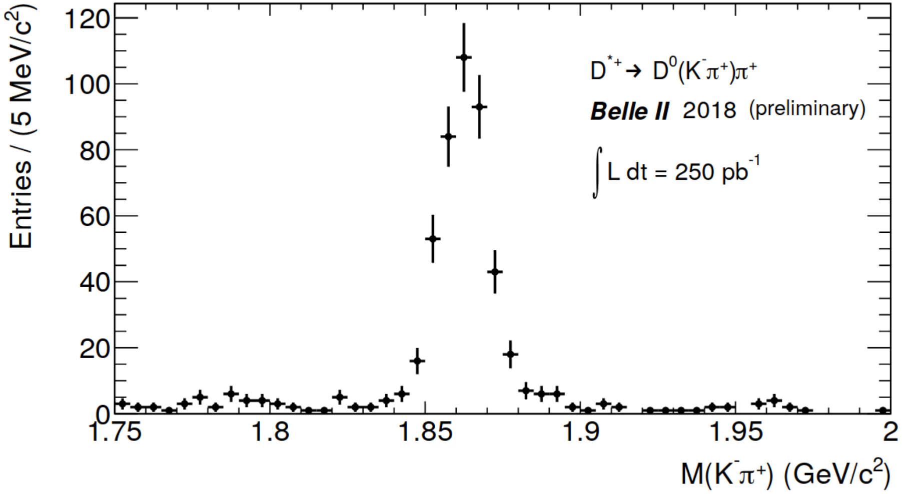
Phase II lasted from April 26th to July 17th

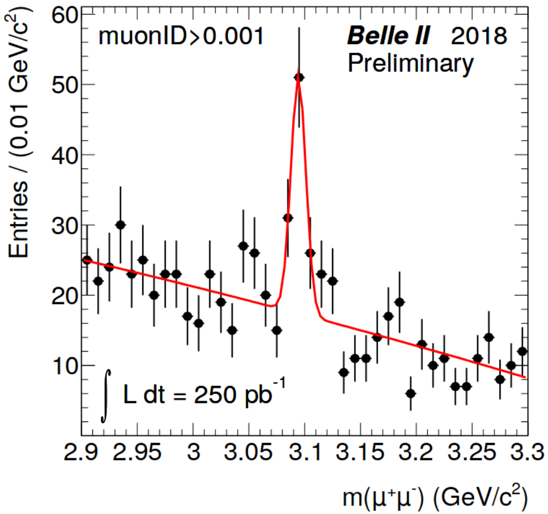
→ 0.5 fb^{-1} of collisions at Υ(4S)

→ 0.55 x 10^{34} $cm^{-2}s^{-1}$ maximum luminosity

→ Very extensive background and accelerator studies





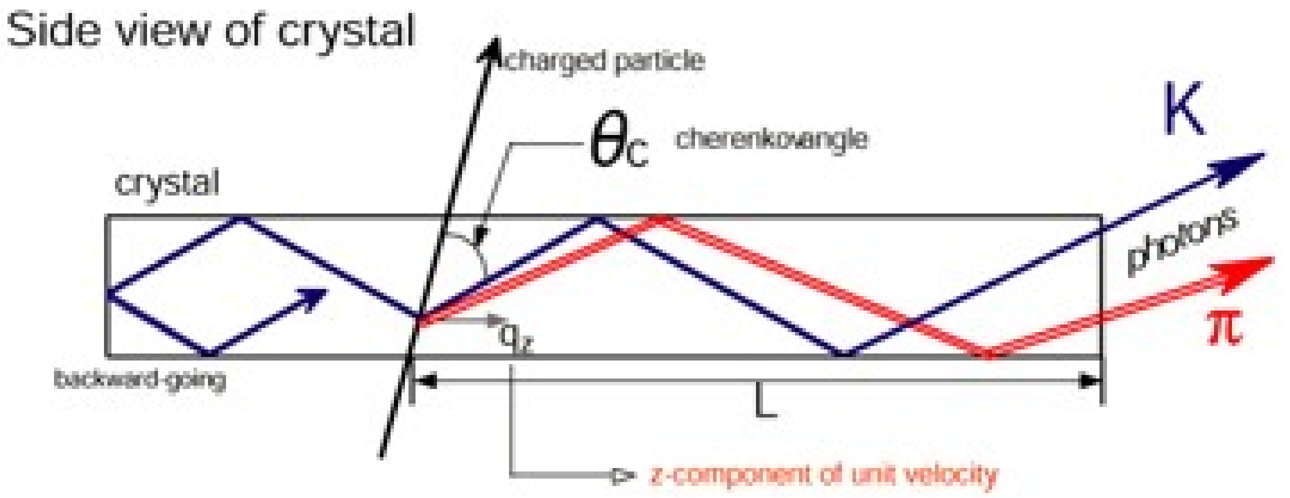


The TOP counter principle

The TOP is a "*DIRC in the time domain*"

→ Cherenkov light trapped and propagated to the readout in a wide bar of fused silica

→ The Cherenkov angle is measured by the **time of propagation** rather than the ring image on the PMT surface



The TOP counter at Belle II

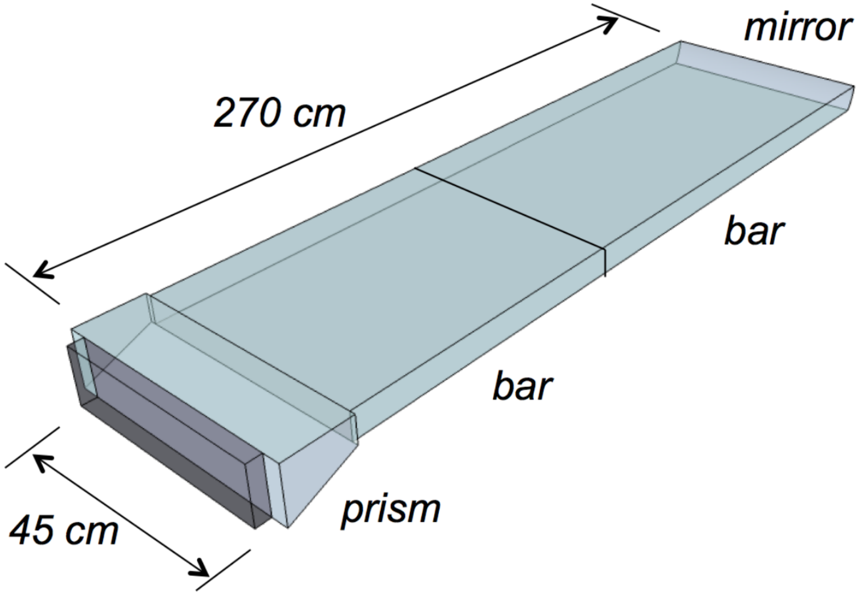
TOP implementation in Belle II:

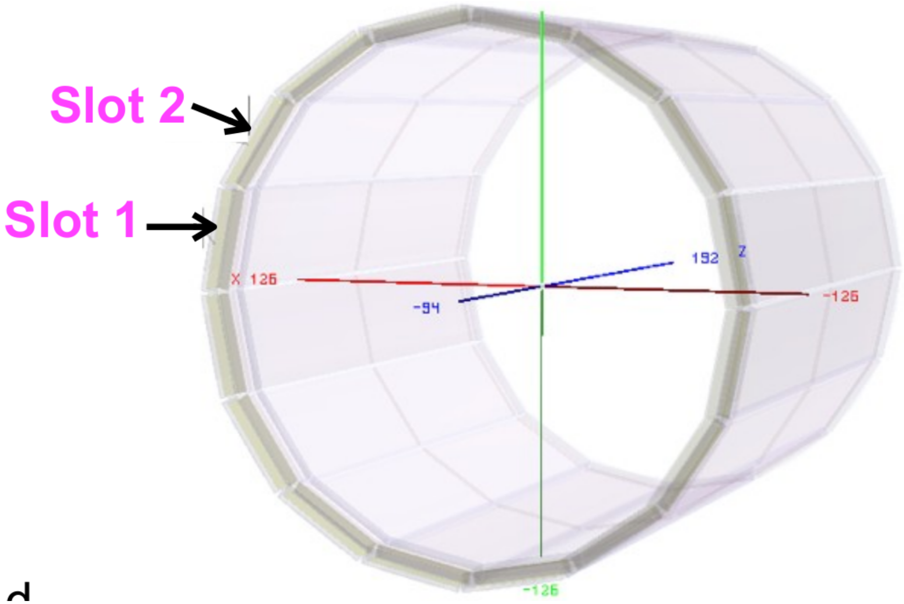
→ 16 modules (or slots) arranged around the interaction point

→ Each module is made of two identical bars of fused silica glued together

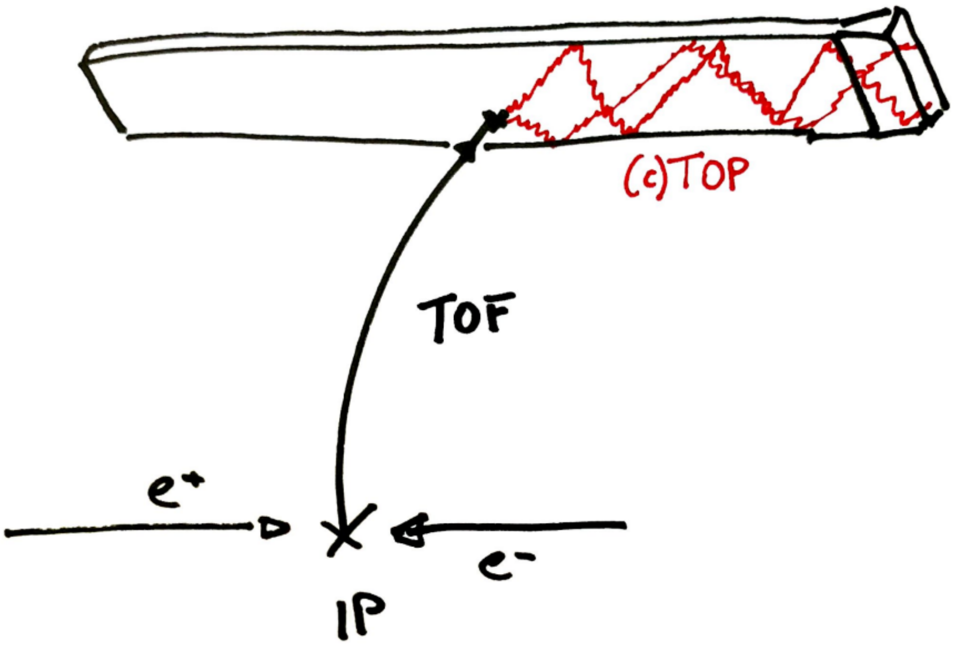
→ Backward side: expansion prism, PMTs and readout

→ Forward side: spherical mirror





What does the TOP measure?



At a collider machine, we can combine the **ToF** and the **Cherenkov angle** in one single measurement

Key ingredients:

→ Impact point on the detector

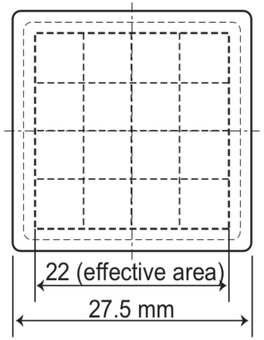
→ Single p.e. time resolution (PMT + readout only)$<$ 100 ps

→ RF locking resolution $<$ 10 ps

Readout: The PMTs

The single photoelectron time resolution is the key parameter for the TOP

Our target is σ(1 p.e.) < 100 ps



Hamamatsu MCP-MPTs

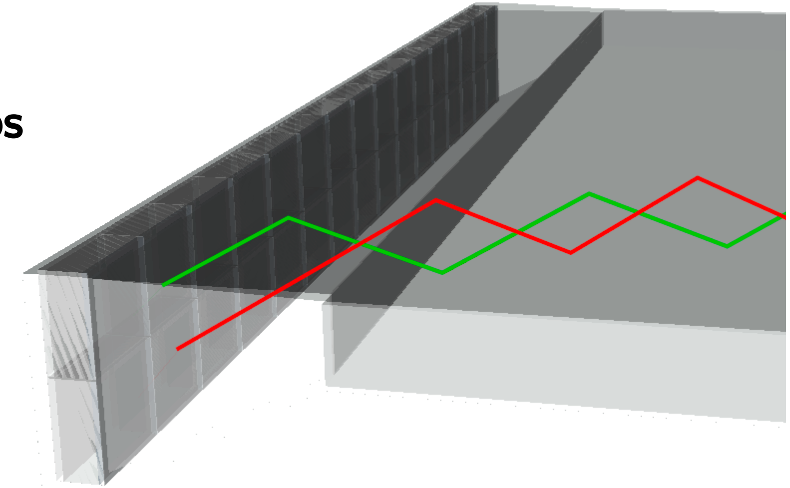
→ (1 x 1) in, ~70% active area

→ NaKSbCs photocathode; QE ≥ 24% (28% on average) at 380 nm

→ 55% collection efficiency

→ Gain = $10^5 - 10^6$

→ **Transient time spread < 40 ps**



Readout: The electronics

TOP front end electronics is based on the ***IRSX chip*** developed by Hawaii University
arXiv:1804.10782

Scope-on-a-chip

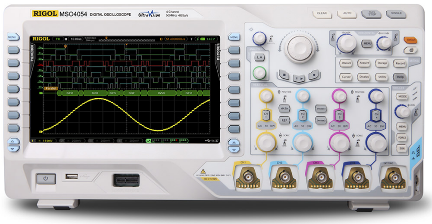
→ 8 channel waveform digitizer

→ 500 MHz Bandwidth

→ 2.7 GSa/s

→ 11.6 μs storage buffer

→ ***Full waveform output***

2 x 

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Controlled by Xilinx Zinq FPGAs

→ Online pedestal subtraction

→ Online waveform analysis

See Maeda-san's poster for more information!

Part II.
First physics results

TOP performances in Phase II

TOP in phase II:

→ Uptime > 90%

→ Active channels = 97.5%

→ Trigger capabilities verified*

→ Preliminary calibrations

→ First evidences of particle identification capabilities

* the TOP does not provide a trigger, but a T0 determination

TOP impact on physics

The PID in Belle II is managed using **only likelihood values**

→ Each sub-detector provide a set of likelihood values for 6 mass hypotheses (from electron to deuteron)

→ Likelihoods are then combined

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$\rightarrow$ Likelihoods are then combined

Basic figure for two particle separation:

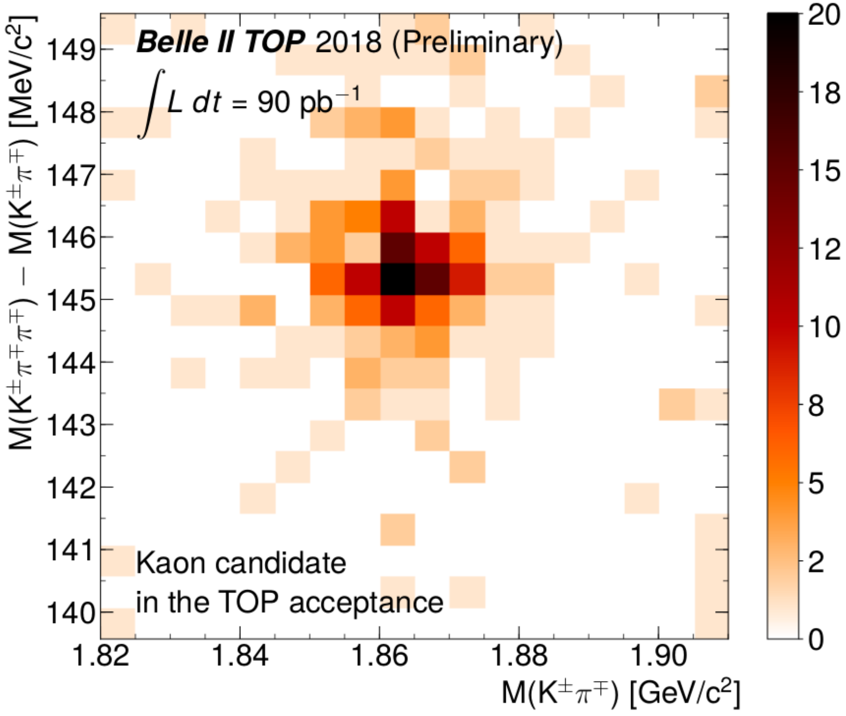
Log-Likelihood difference

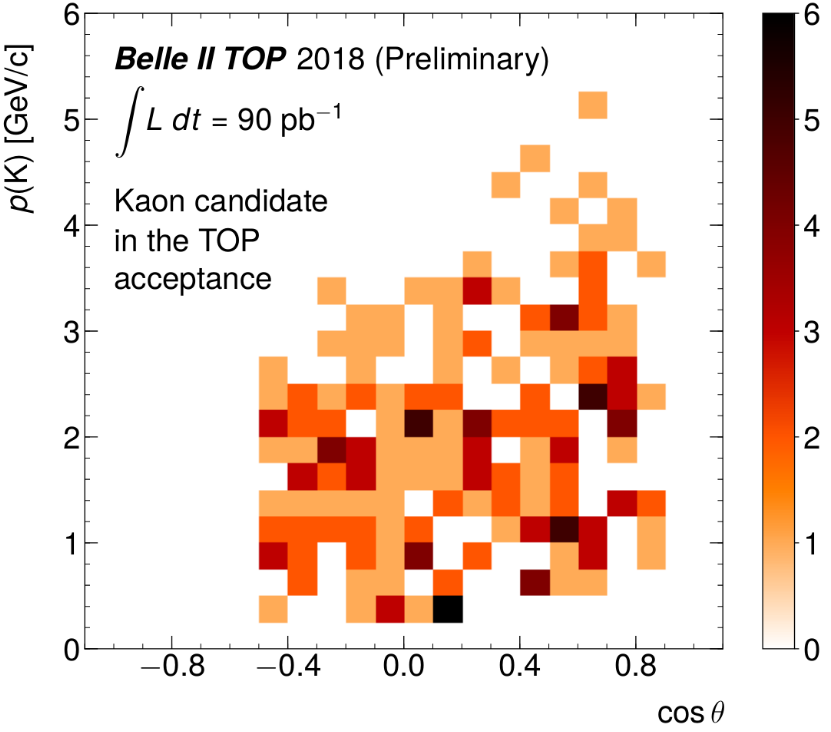
A particle is identified as x rather than y if $LL(x) > LL(y)$

Visualizing the Cherenkov rings

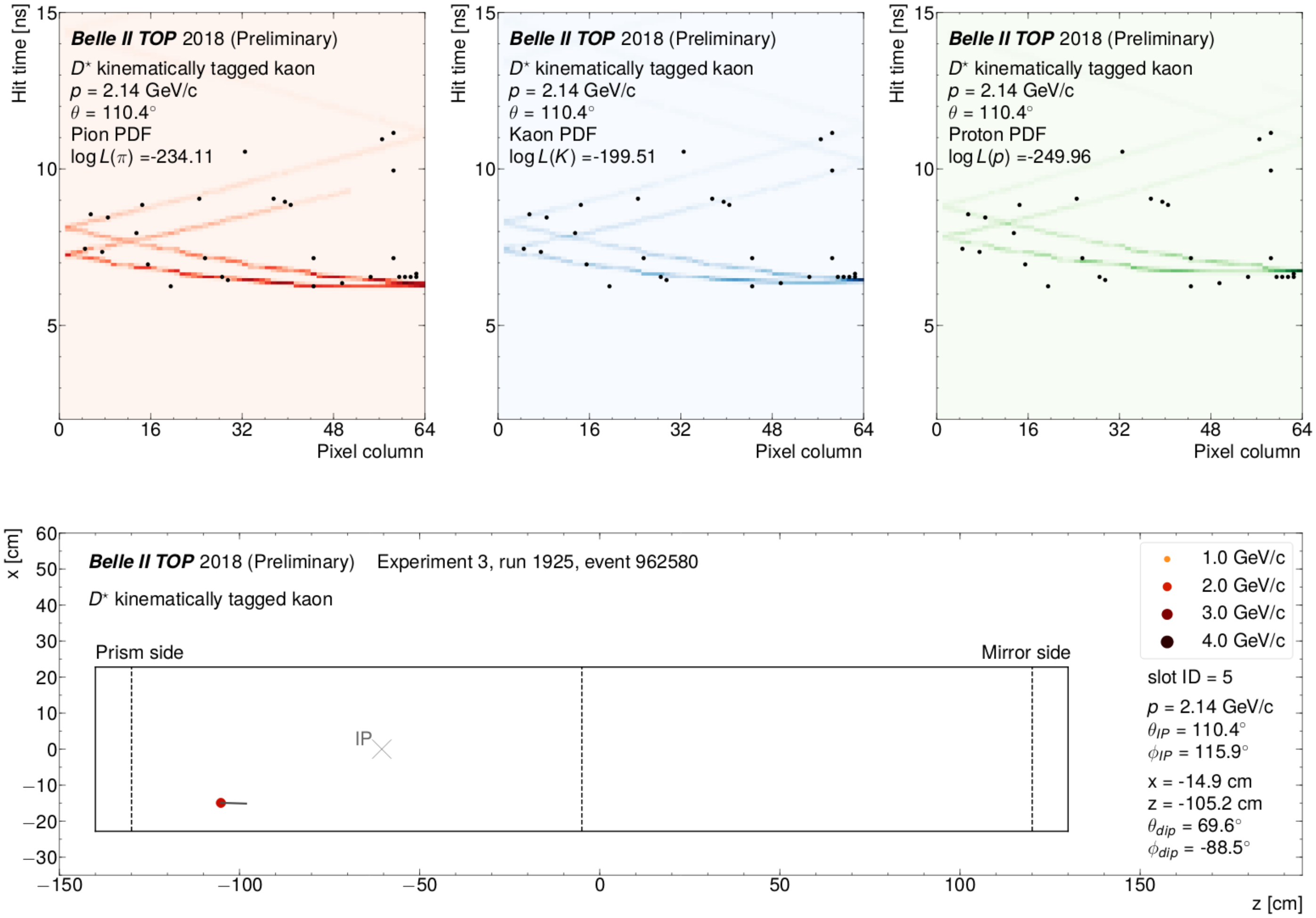
Compare the expected PDF with the observed hits for a known particle species

→ **Pure Kaon sample from $D^* \rightarrow D^0\pi \rightarrow K\pi\pi$**





Visualizing the Cherenkov rings



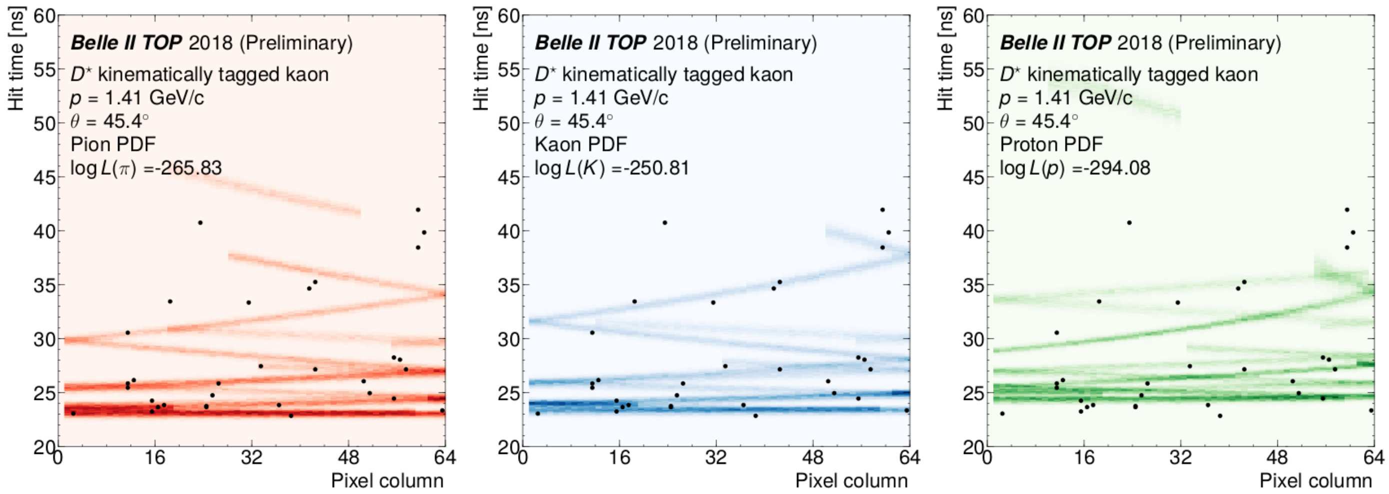
2.14 GeV

prism-facing event

Little room for the Cherenkov cone to open up

ID is dominated by the PDF shift (i.e. ToF) rather than the shape difference

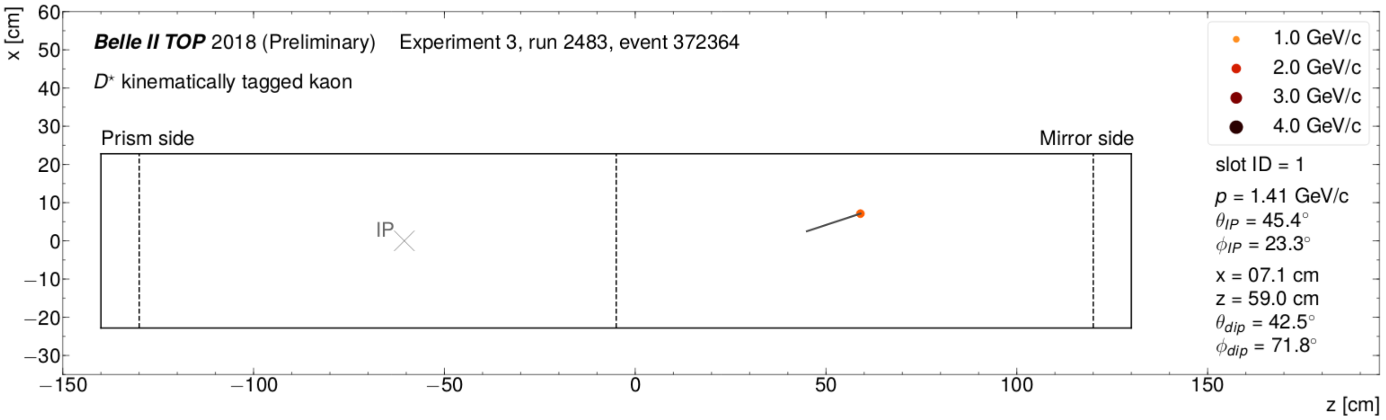
Visualizing the Cherenkov rings



1.41 GeV

mirror-facing event

ID is dominated by the PDF shape (i.e. Cherenkov ring) rather than the global offset

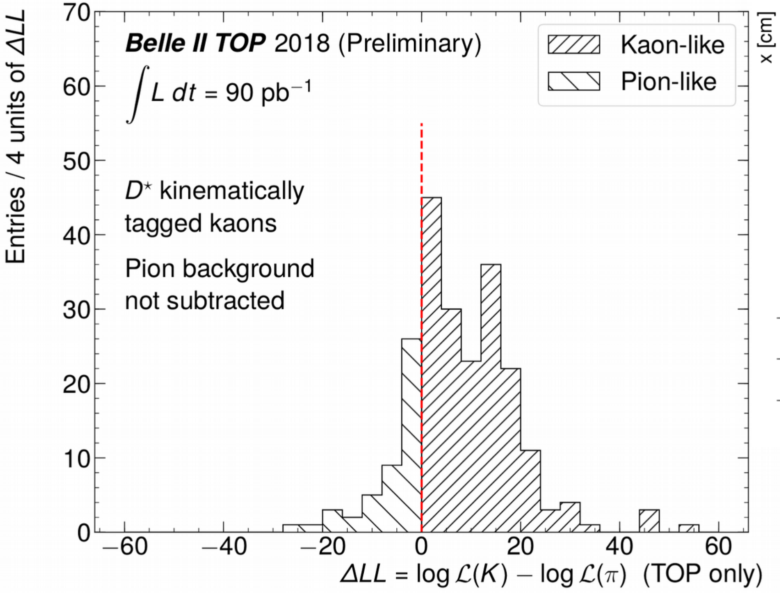


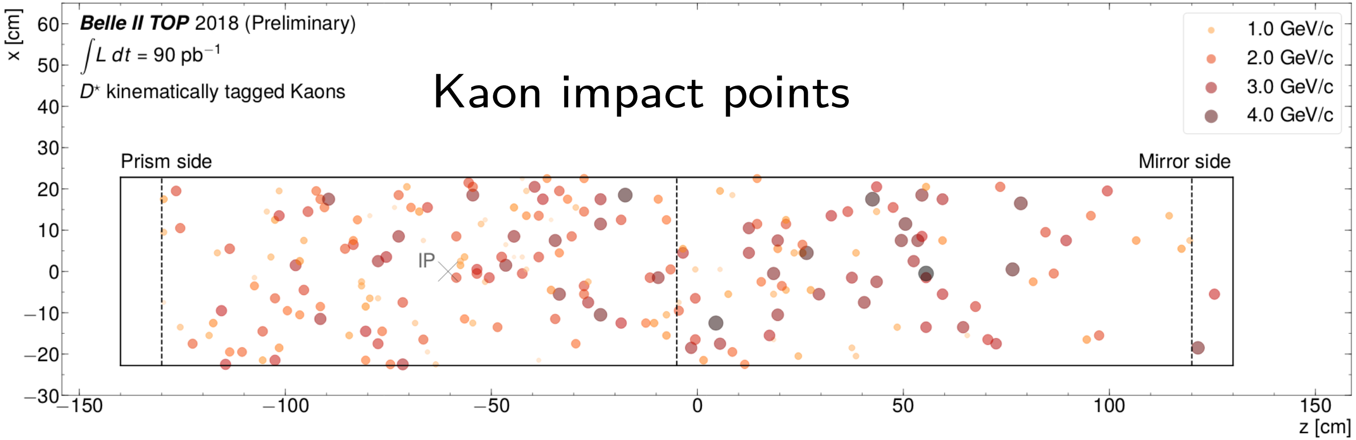
From event displays to likelihoods

The PID in Belle II is managed using only likelihood values

→ Each sub-detector provide a set of likelihood values for 6 mass hypotheses (e → deuteron)

→ Likelihoods are then combined



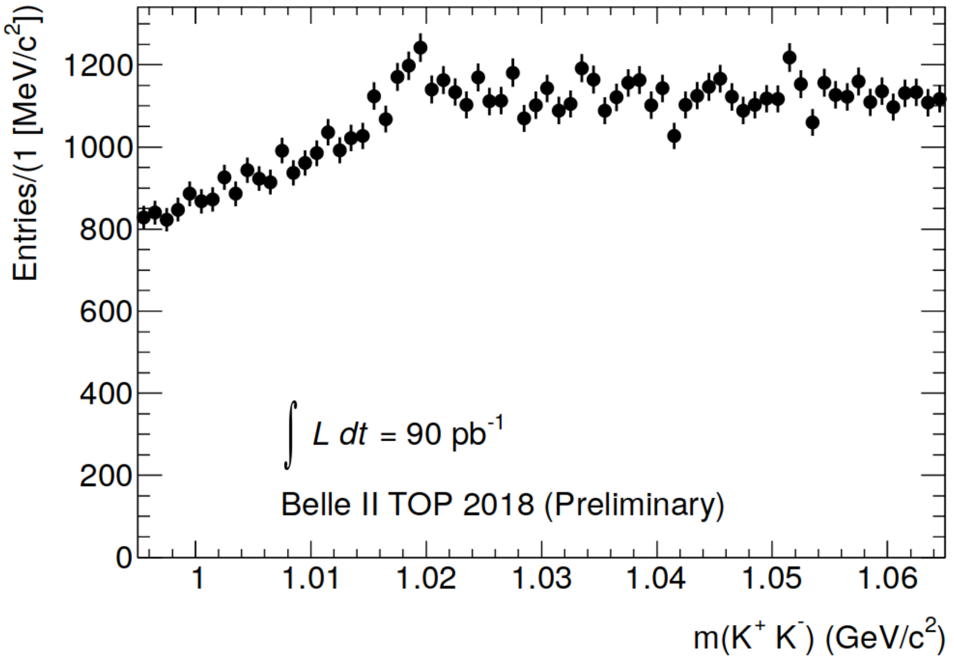


Result from all the D* - tagged kaons in the first 90 pb^{-1} of data

TOP impact on physics: K-π separation

$\phi \rightarrow K^+K^-$ with both the tracks in the TOP acceptance

No PID



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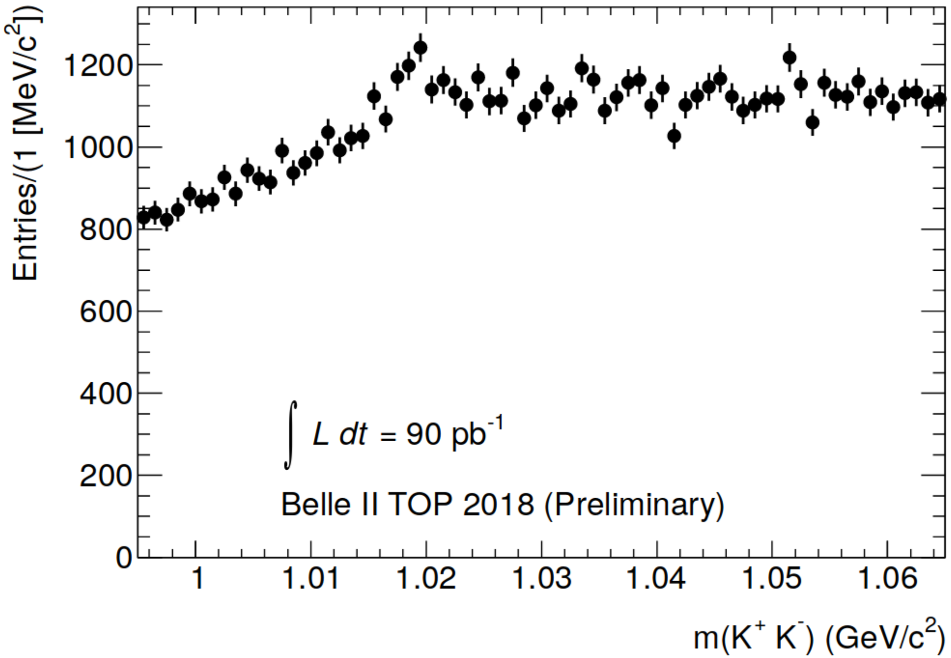
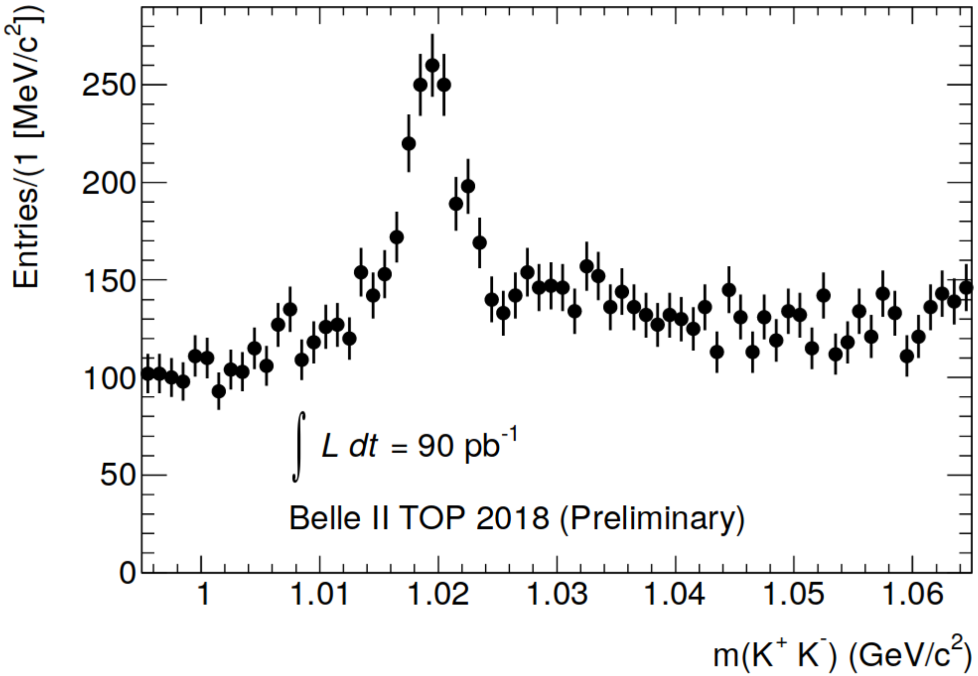


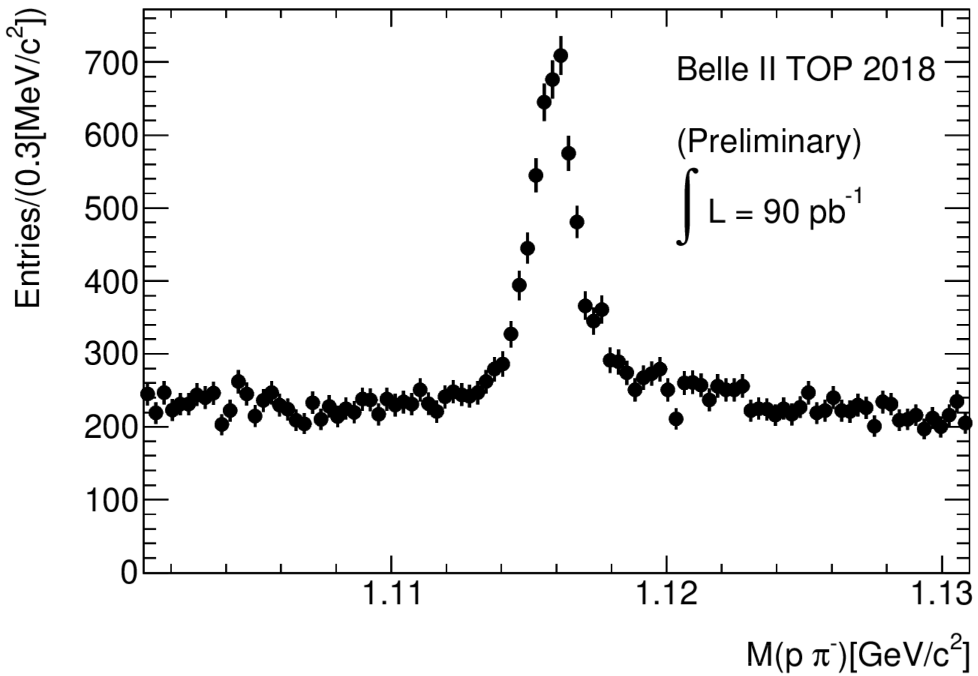
TOP LL(K) > TOP LL(π)



TOP impact on physics: p-π separation

$\Lambda \rightarrow p\pi$ with the **proton candidate** in the TOP acceptance

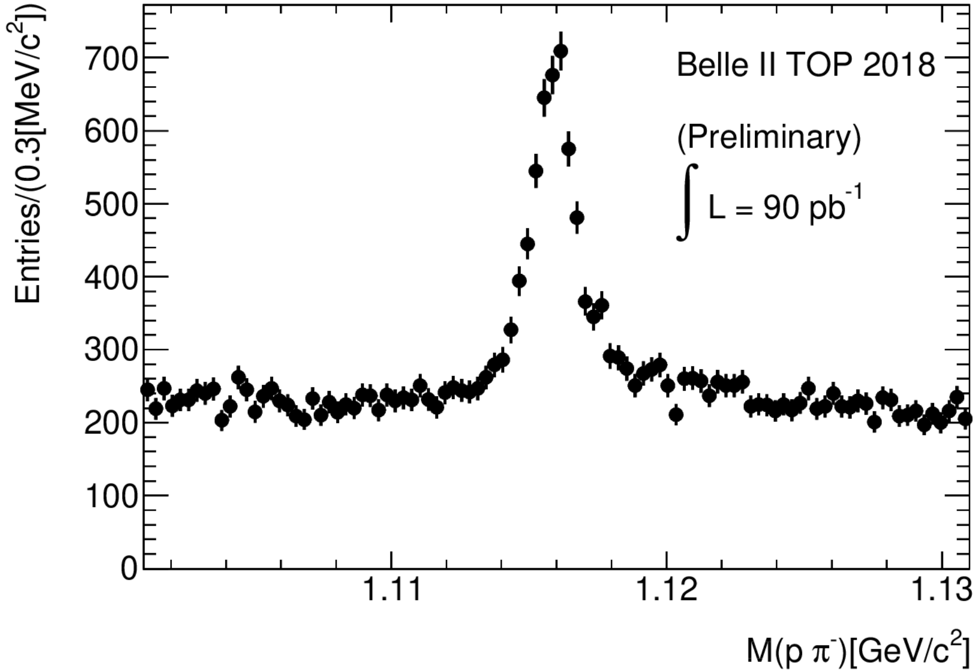
No PID



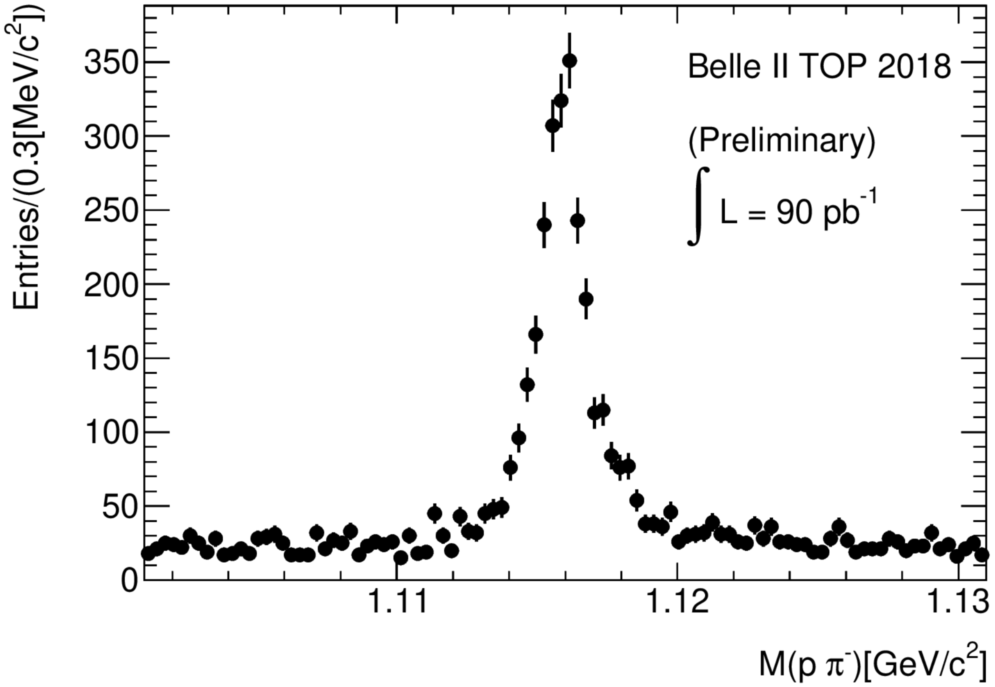
TOP impact on physics: p-π separation

$\Lambda \rightarrow p\pi$ with the **proton candidate** in the TOP acceptance

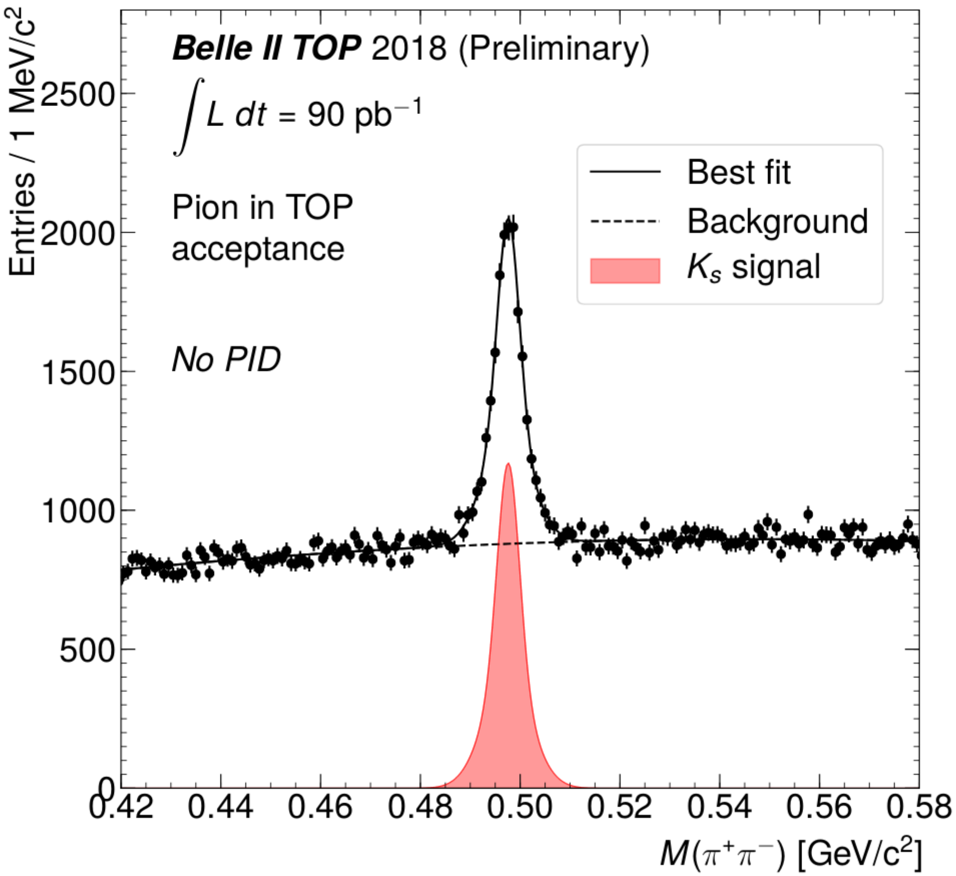
No PID



TOP LL(p) > TOP LL(π)



Quantitative estimations: $K_s \to \pi\pi$



Large sample of pions tagged by the $K_s \to \pi\pi$ decay

→ Test of both identification efficiency and mis-identification probability

→ Measure the Ks yield when requiring, on one of the two pions:

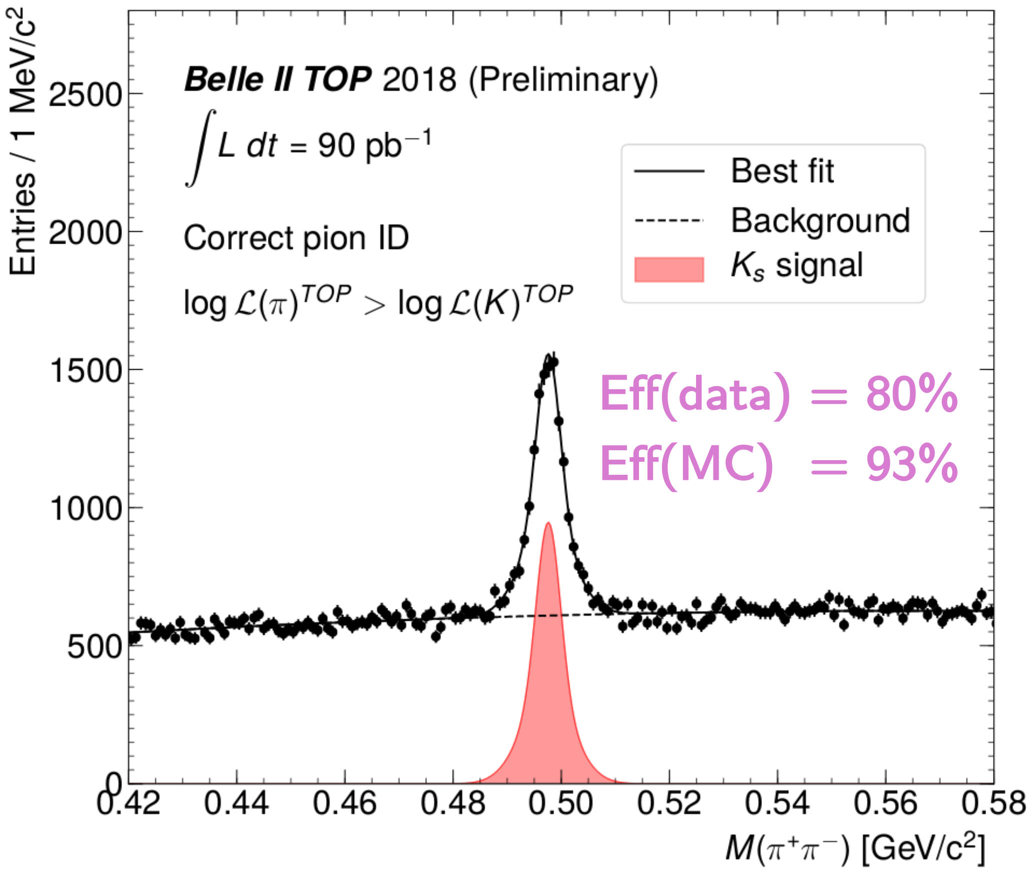
$LL(\pi) > LL(K)$

$LL(K) > LL(\pi)$

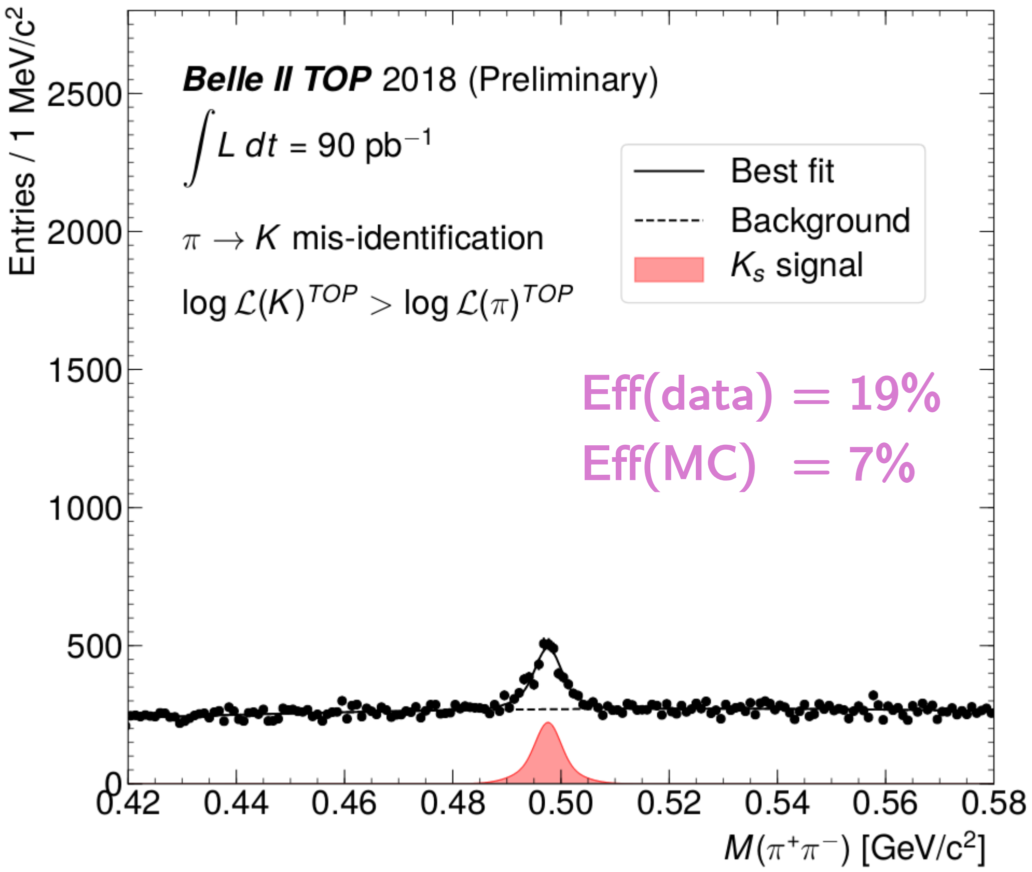
$LL(p) > LL(\pi)$

$LL(e) > LL(\pi)$

Quantitative estimations: $K_s \to \pi\pi$

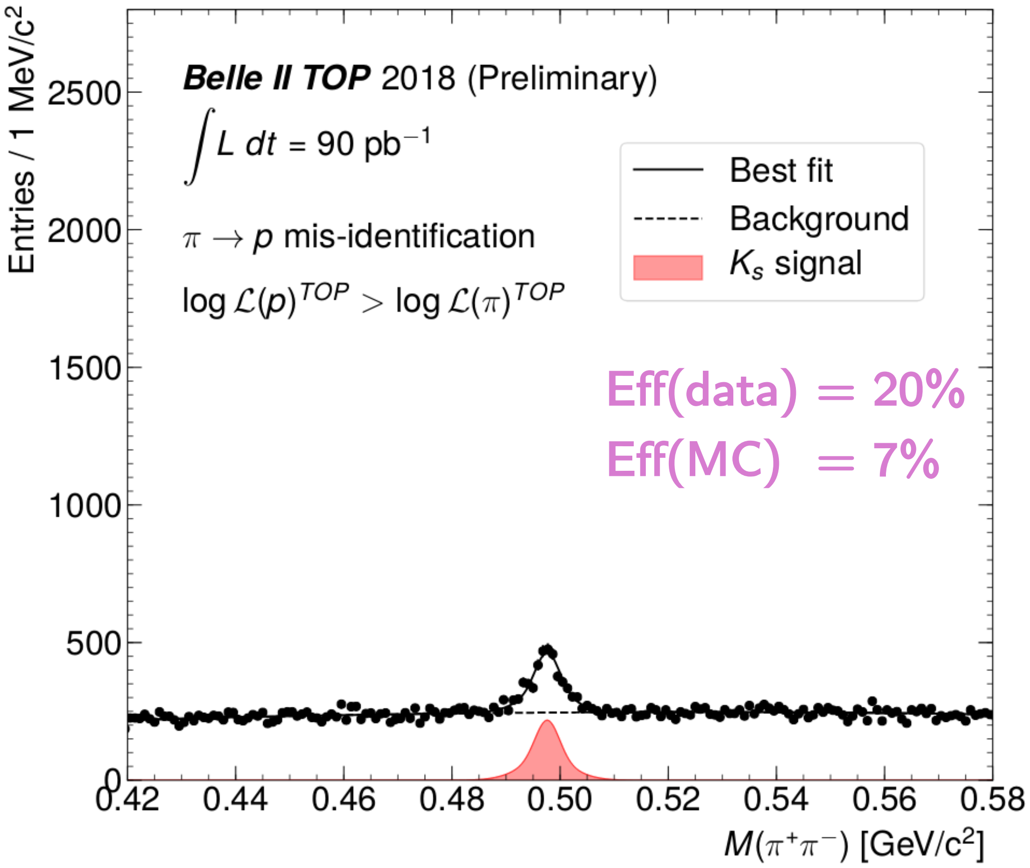


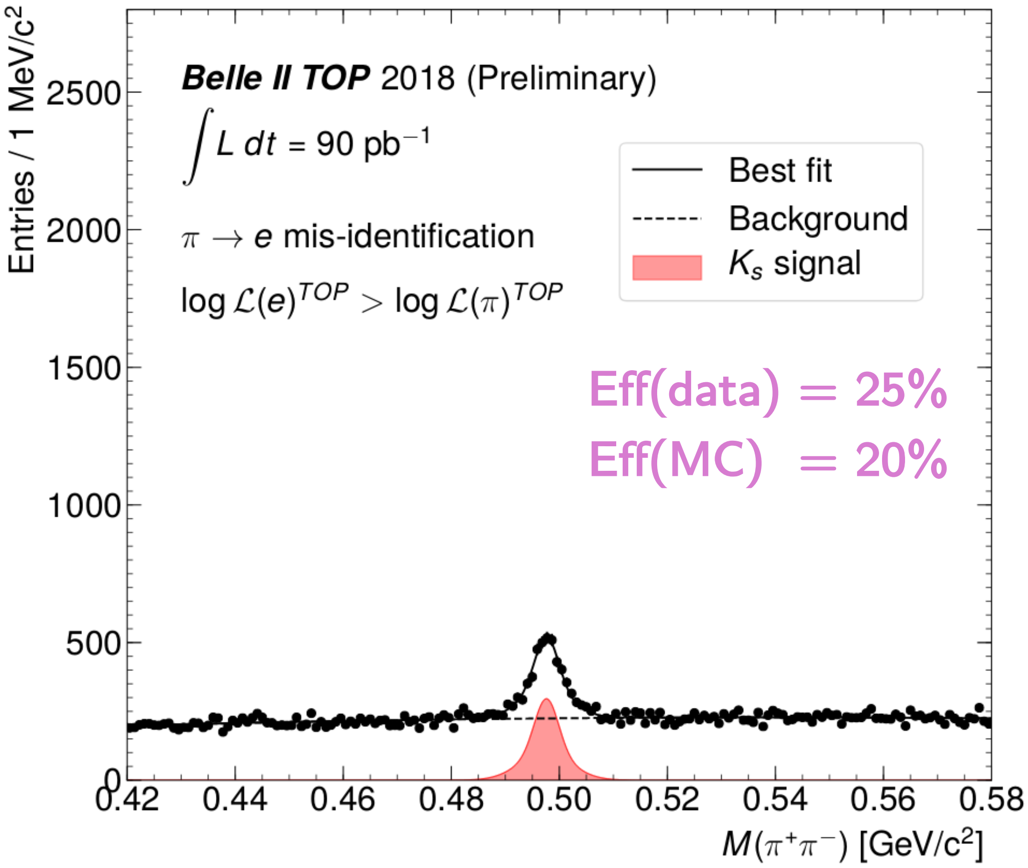
Eff(data) = 80%
Eff(MC) = 93%



Eff(data) = 19%
Eff(MC) = 7%

Quantitative estimations: $K_s \rightarrow \pi\pi$





Part III.
Understanding the performances

TOP Calibration

Most of the TOP calibration is time calibration

IRSX sampling linearity
(electronic pulses)

→

Synchronization of the
channels within one module
(laser flashes)

→

Synchronization of the
modules within each other
(di-muons or cosmics)

→

Geometrical alignment
(di-muons)

→

Synchronization of the whole detector
with the radiofrequency clock
(di-muons)

Most of the TOP calibration is time calibration

IRSX sampling linearity
(electronic pulses)
Preliminary

→

Synchronization of the
channels within one module
(laser flashes)
Preliminary

→

Synchronization of the
modules within each other
(di-muons or cosmics)
Preliminary

→

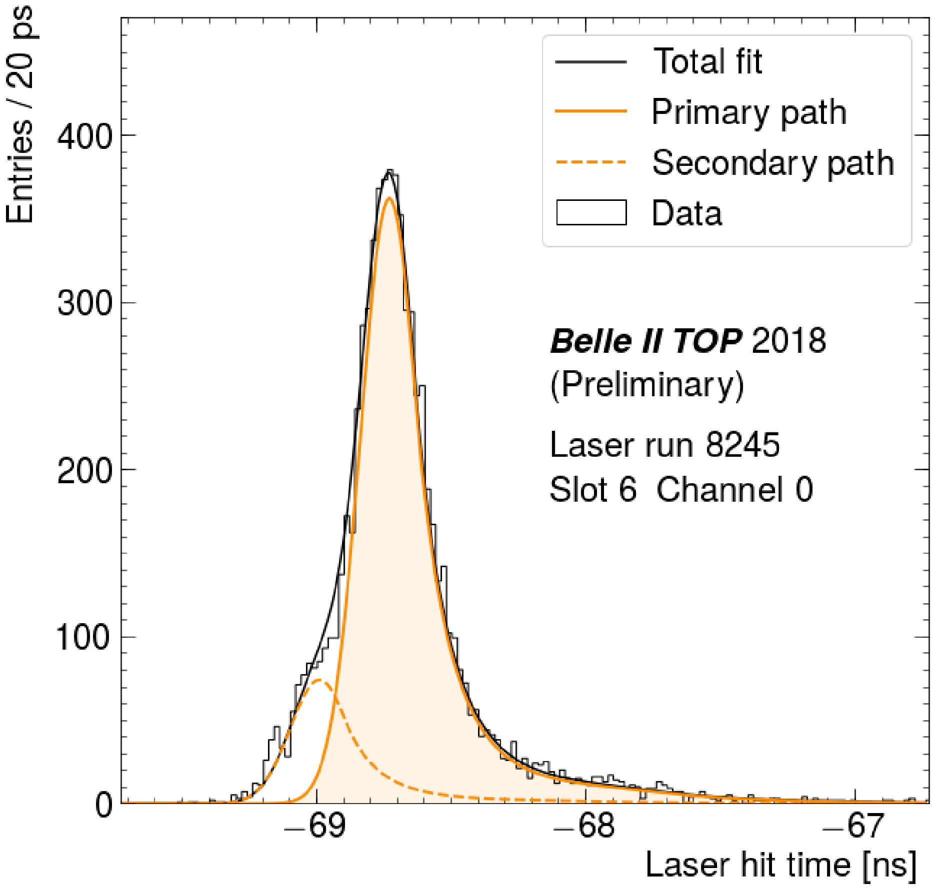
Geometrical alignment
(di-muons)
Not Done

→

Synchronization of the whole detector
with the radiofrequency clock
(di-muons)
Finalized

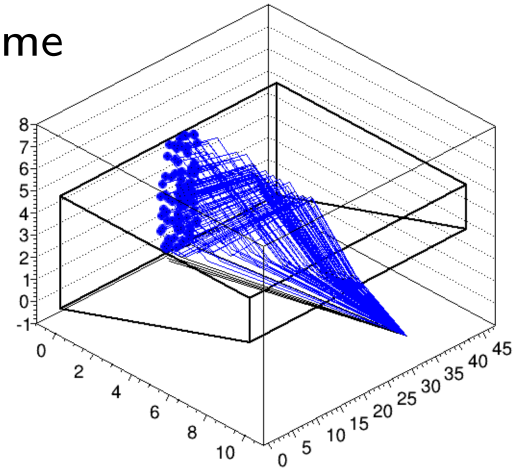
Single channel time resolution

The time resolution on the single channel is estimated using laser flashes



Due to the reflection inside the expansion prism, multiple paths can lead to the same pixel.

Each path is fitted with a crystal ball PDF for reproduce the tails in the PMT response time



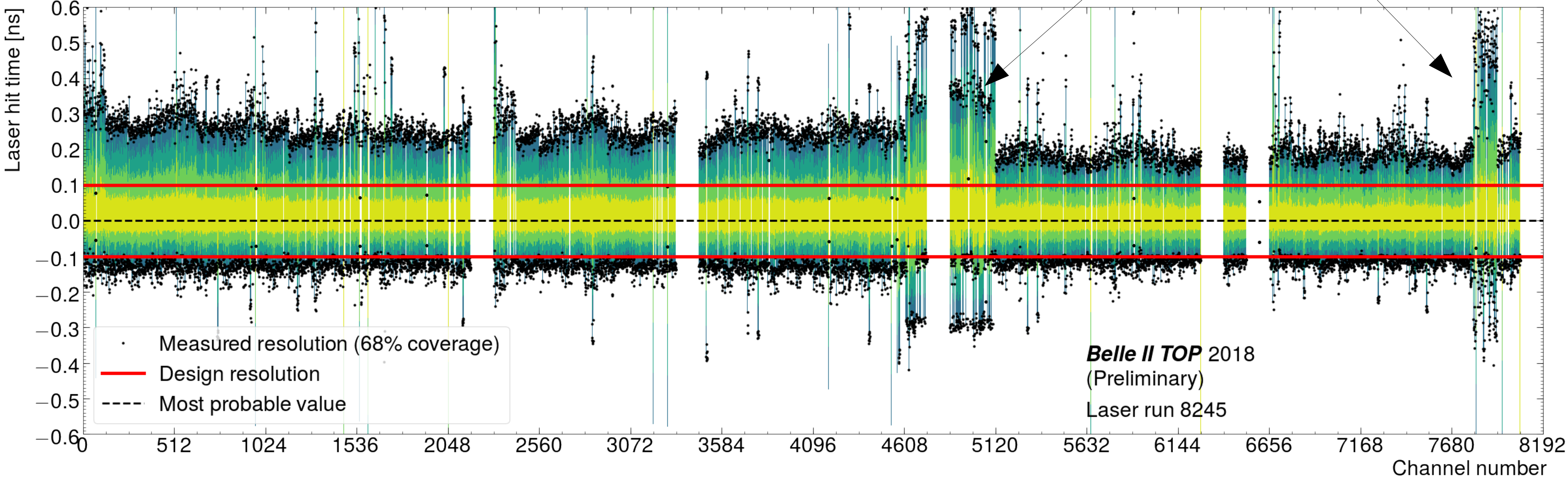
Single channel time resolution

Example of one laser run

→ Color: resolution PDF

→ Points: 68% quantiles

Single modules with temporarily issues



Note: laser and laser-related jitters are **not** deconvolved

TOP synchronization

The TOP sampling clock is locked to the accelerator radio-frequency clock (RF clock)

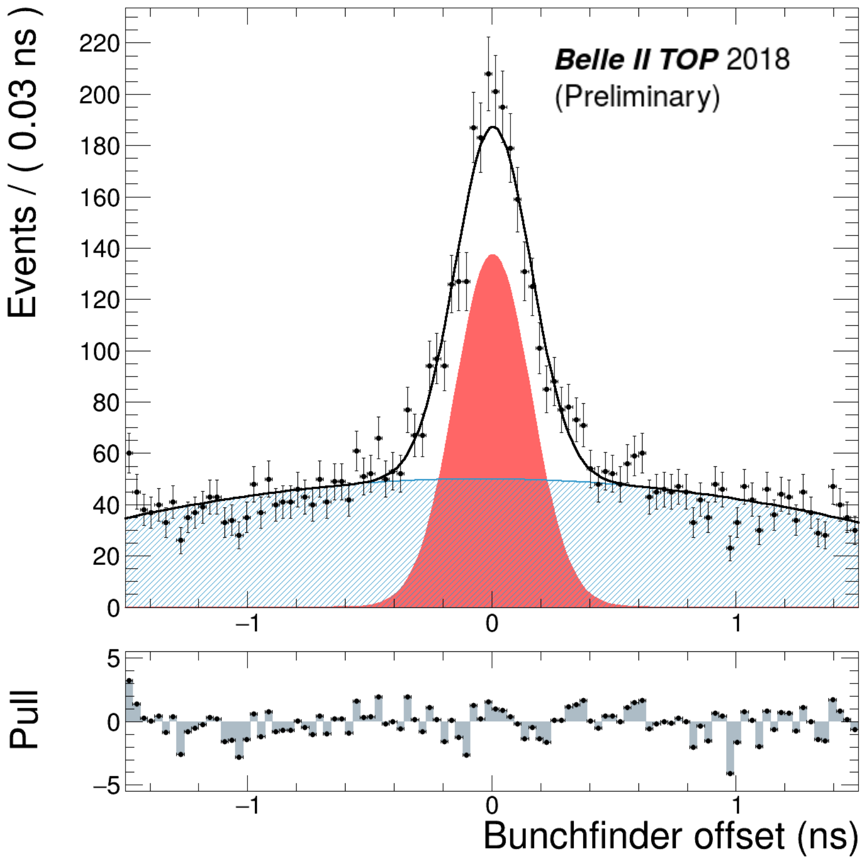
→ Any offset between the two will result in a mis-reconstruction of the PDFs

<u>Most probable collision time</u>

→ reconstructed back-fitting the higher momentum tracks in the event

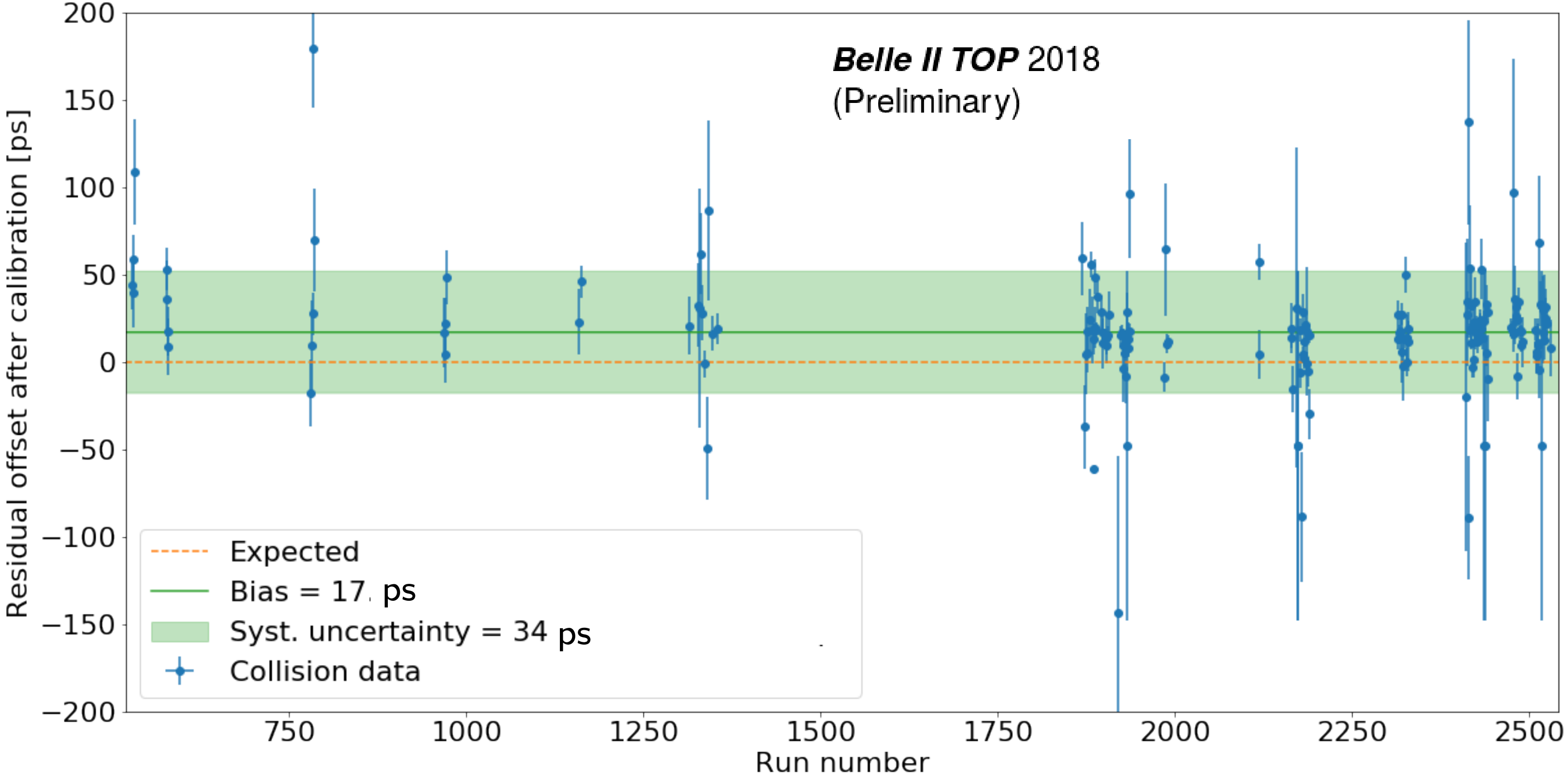
→ If calibrations are correct, it will match with a tick of the RF clock

→ Resolution on data: 150 ps (bunch crossing: 2 ns)



TOP synchronization

Bunch finder residual offset after the calibrations (RF synchronization precision)



→ Synchronization with the RF is still not optimal

What's missing

Where can we improve the TOP performances?

1) Electronics

→ 10-20% firmware inefficiency (partially solved)

→ ASICS parameters not optimized

→ Template fit

→ Amplitude and gain corrections

2) Tracking

→ Any improvement in the tracking will improve the TOP PID

3) Calibrations and time resolution

→ Affected by tracking and electronics performances

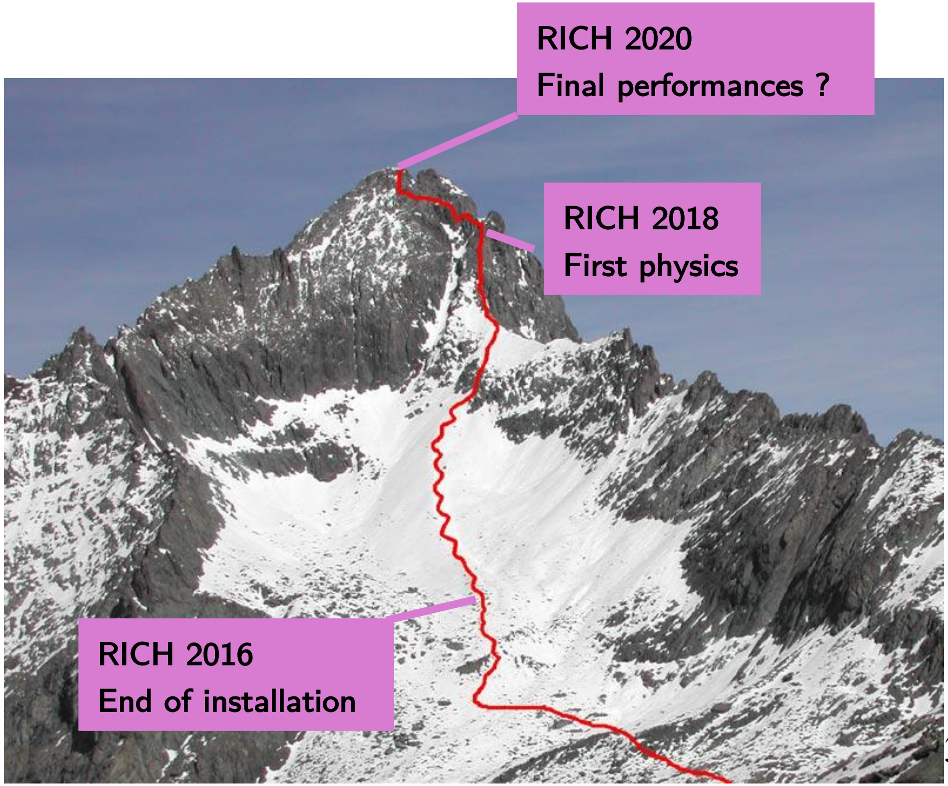
→ Still statistically limited!

Conclusions

The Belle II experiment has successfully concluded the phase II pilot run:

→ The TOP is working

→ The PID performances are still ~10% worst than in the MC



Still lot of work to be done!

→ **Preliminary tuning of the electronics**

→ **Preliminary calibrations**

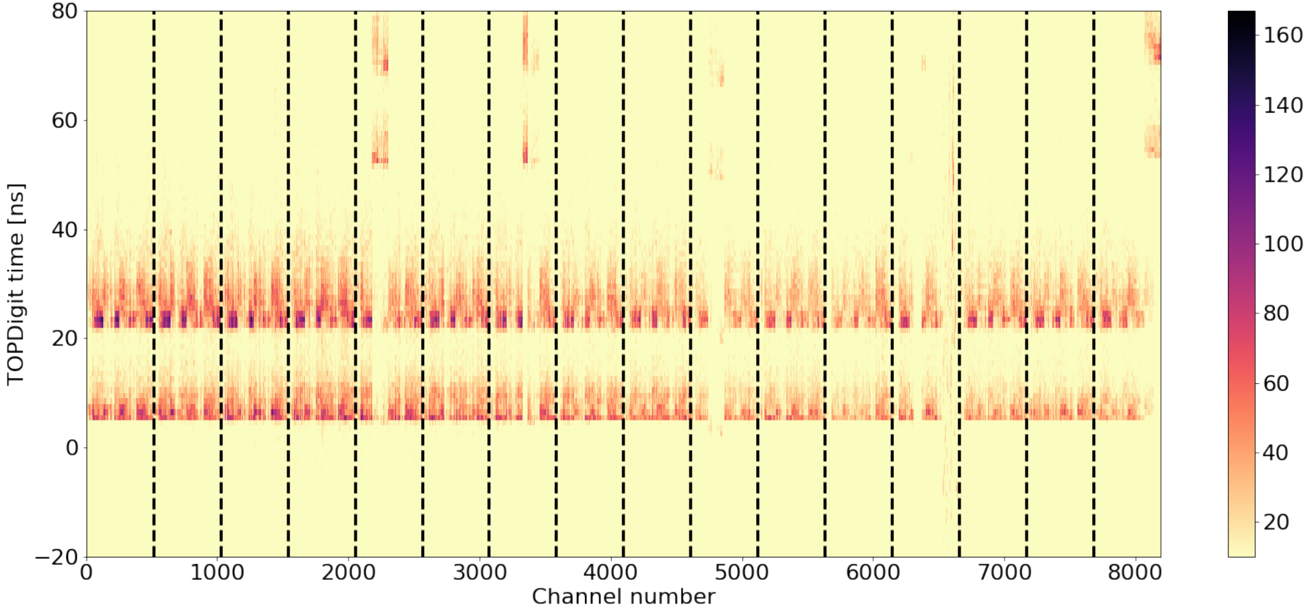
Backup

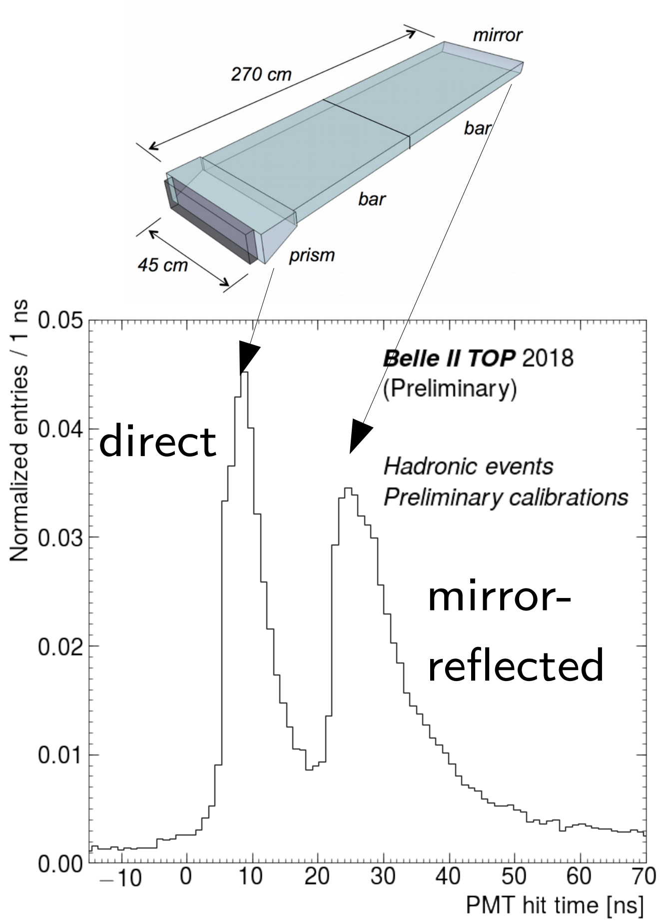
Channel synchronization in collision events

Very first test of the calibrations:

→ All the 8192 channels are aligned correctly

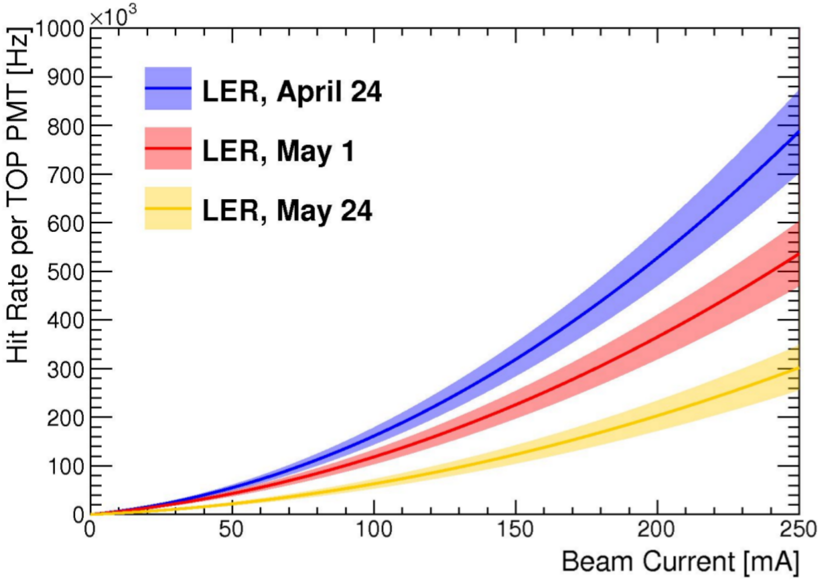
→ Clear distinction of direct and reflected light

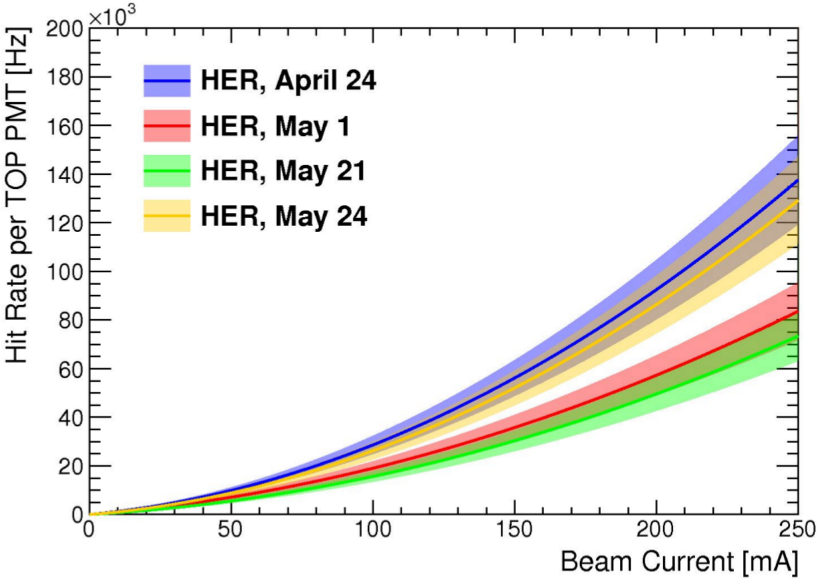




TOP as a background monitor

- From separate LER/HER current scans
- Showing average of all fits (>90% of channels give good fits)



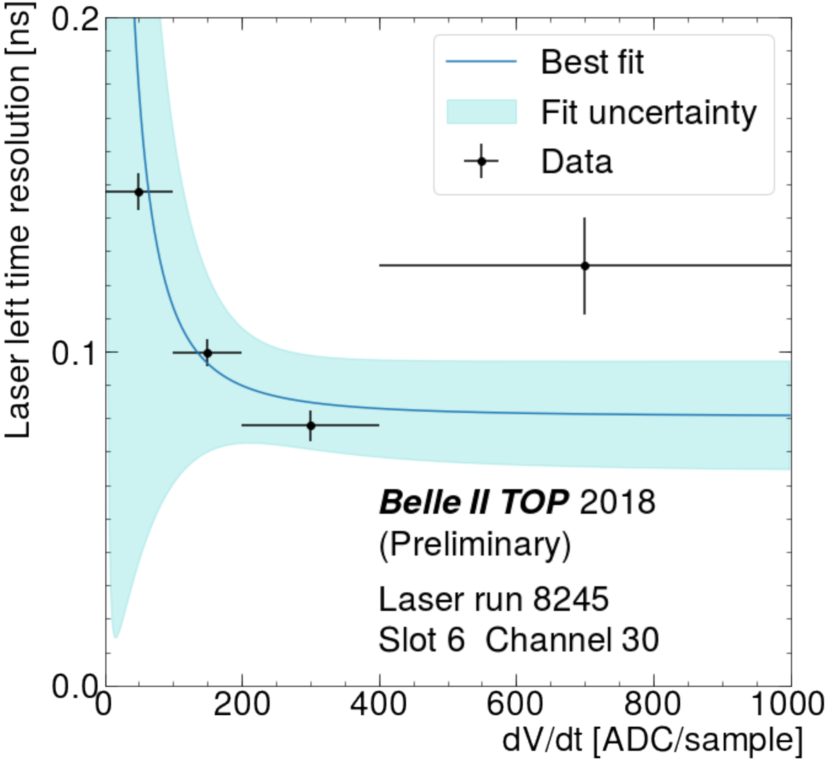


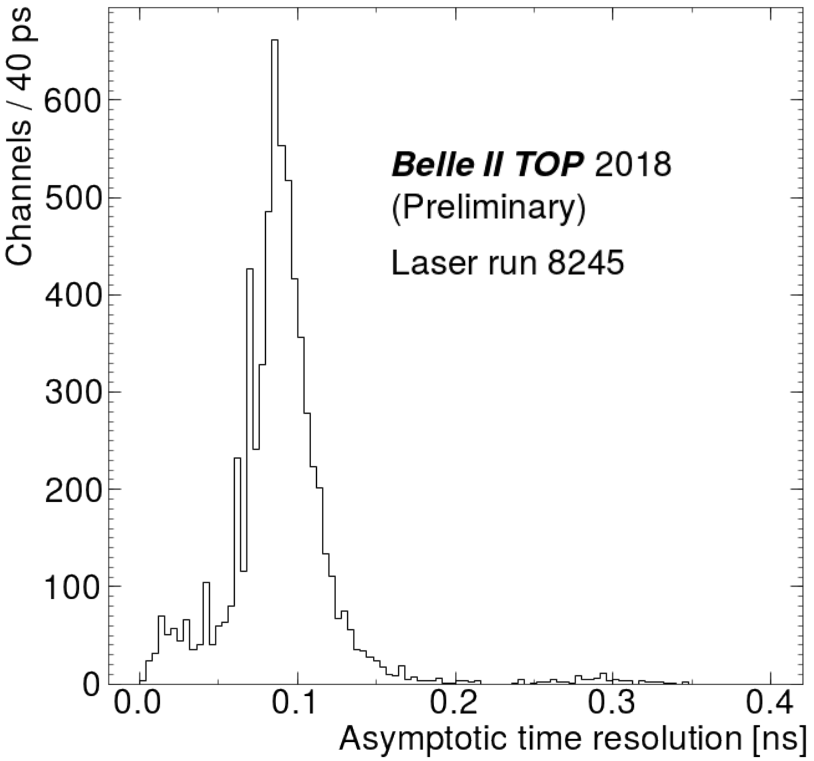
The TOP is an excellent background detector

Asymptotic resolution

The timing has a quite strong dependence on the slope of the hit rising edge (dV/dt).

Steeper pulses get more precise timing, since the noise term gets smaller





Readout: The electronics *ArXiv 1804.10782*

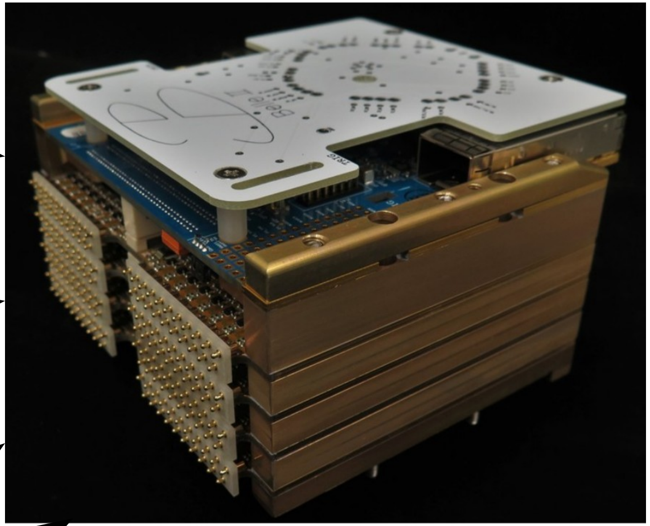
Each module is read by 64 ASICs packed into 4 ***boardstacks***

16 IRSX asics

4 Xilinx Zynq Z-7030
(1 per 4 Asics)

1 Xilinx Zynq Z-7045
(global data flow)

1 HV board



Computing power used mostly for
→ Online pedestal subtraction
→ Online waveform analysis

See Maeda-san's poster for more information!