Measurement of B_s^0 meson lifetime in the $B_s^0 \to J/\psi\phi$ decay channel at CMS experiment.

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Introduction

Study of B-hadrons physics:

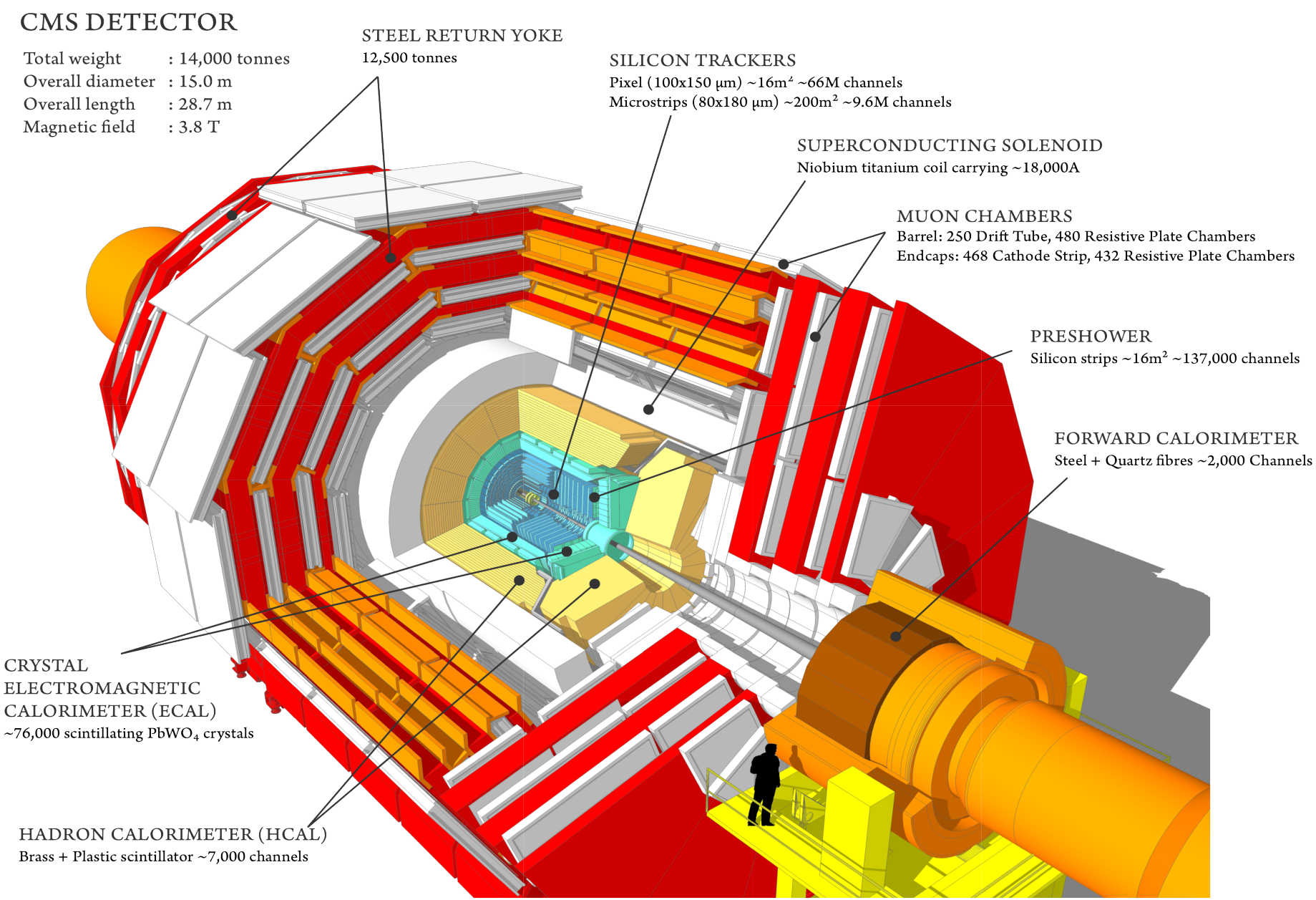
- useful in the search for New Physics beyond the Standard Model
- decay $B_s^0 \to J/\psi\phi$, $J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$ is particularly interesting

B_s^0 mass eigenstates:

- neither flavor eigenstates nor CP eigenstates
- flavor oscillations and CP violation in the decay do occur
  - mass and width difference
  - CP violation phase
- small lifetime difference
  - very high precision is required.

The goal of this thesis is to quantify the systematic effect on the B_s^0 mean lifetime measurement introduced in the estimation of its creation point.

The CMS Experiment



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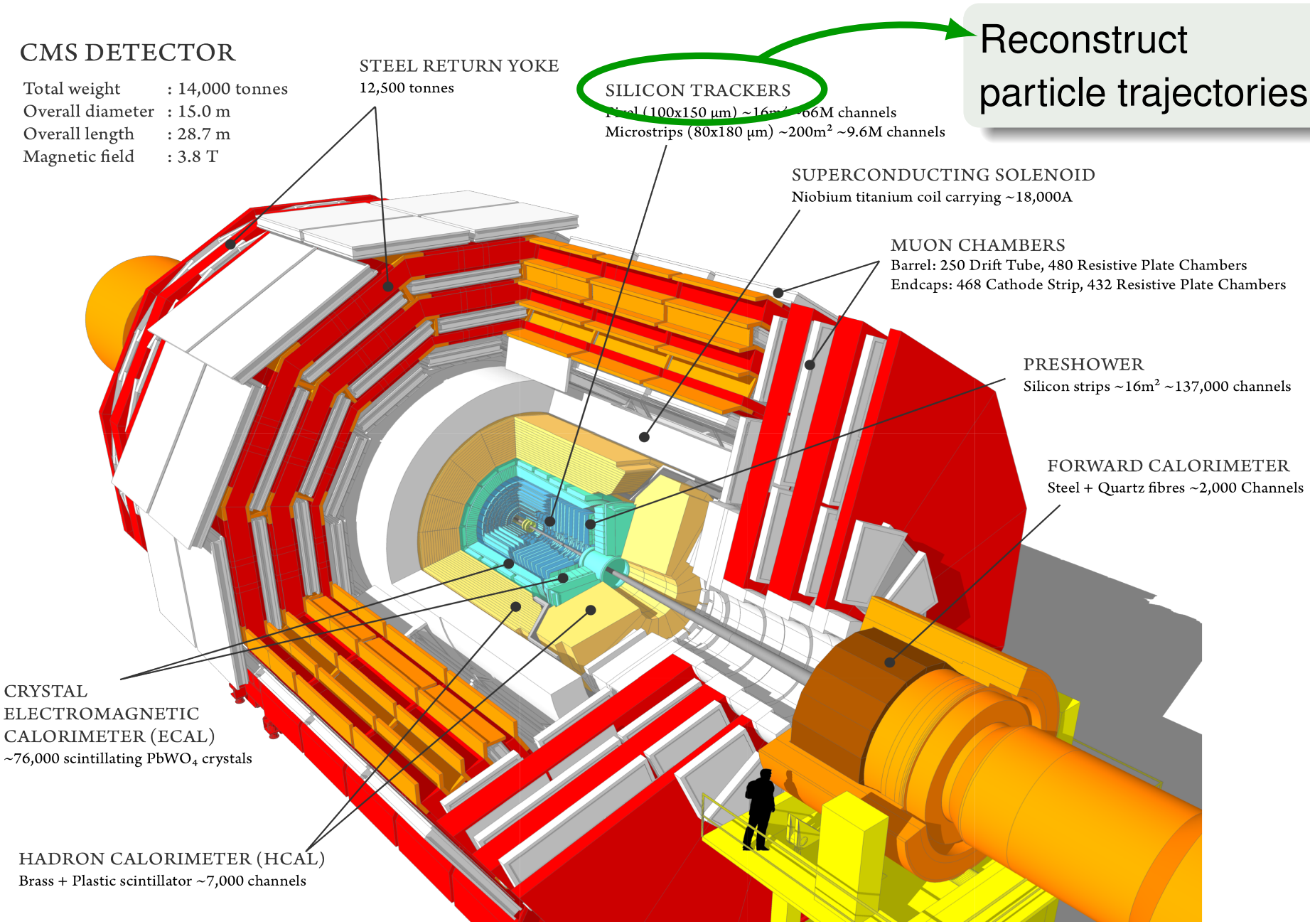

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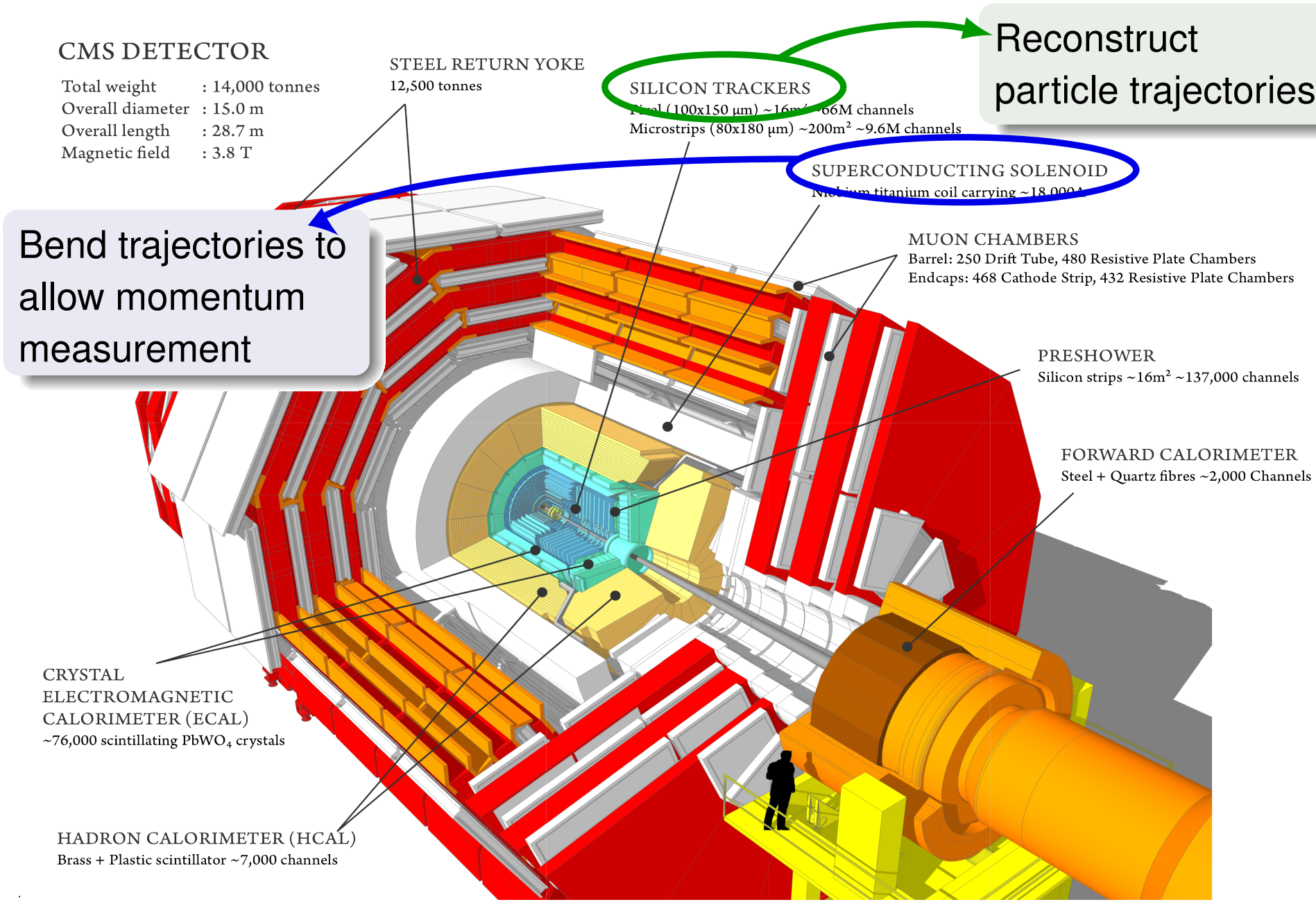
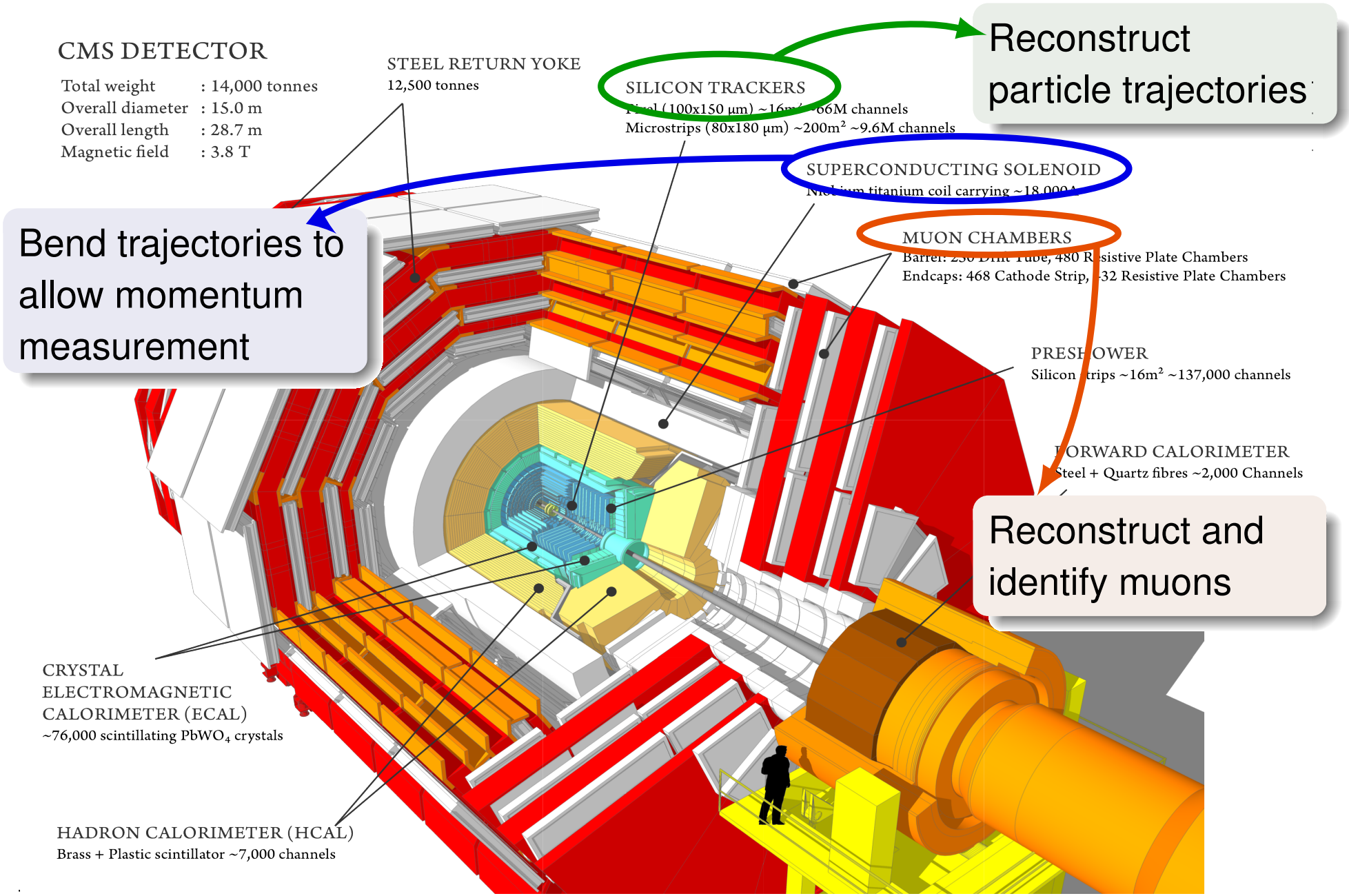


Reconstruct particle trajectories

Bend trajectories to allow momentum measurement

The CMS Experiment



Trigger and data samples

Data stored for analysis are events selected by the trigger.
For this work 3 triggers with different requirements have been used:

- **Displaced**: opposite sign muon pair with an invariant mass compatible with the J/ψ mass, displaced from the interaction point (significance $L/\sigma_L > 3$) and 2 additional tracks assumed as kaons,
- **Additional Muon**: opposite sign muon pair with an invariant mass compatible with the J/ψ mass, plus an additional muon track from the same interaction; used only in Logic OR with the "Displaced" one,
- **Inclusive**: charmonium decaying to $\mu^+\mu^-$.

An additional data sample containing Monte Carlo $B_s^0 \to J/\psi\phi$ simulated events was also used.

Particle reconstruction

- Particle mass is computed from momenta and rest mass of decay products
- Particle decay point is fitted from tracks to a common vertex

Cascade decay reconstruction

- $J/\psi \to \mu^+\mu^-$
  - From 2 muon tracks
- $\phi \to K^+K^-$
  - From 2 tracks of particles assumed to be kaons
- $B_s^0 \to J/\psi\phi$
  - Tracks from J/ψ and ϕ
  - Mass from fit constraining $m_{\mu\mu}$ to $m_{J/\psi}$

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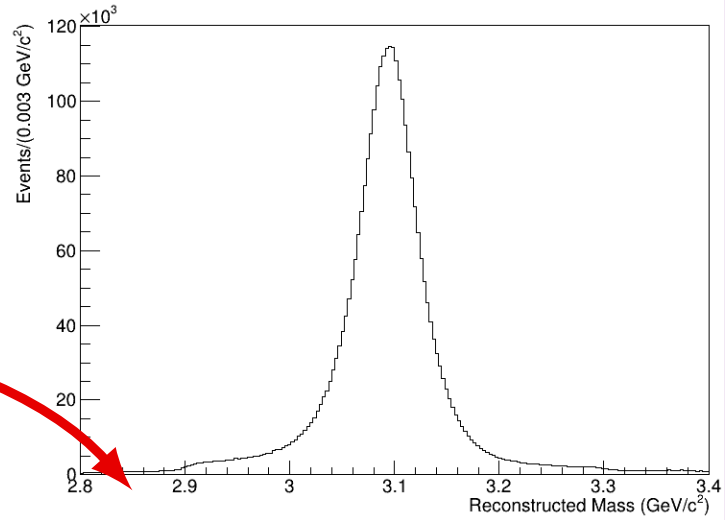

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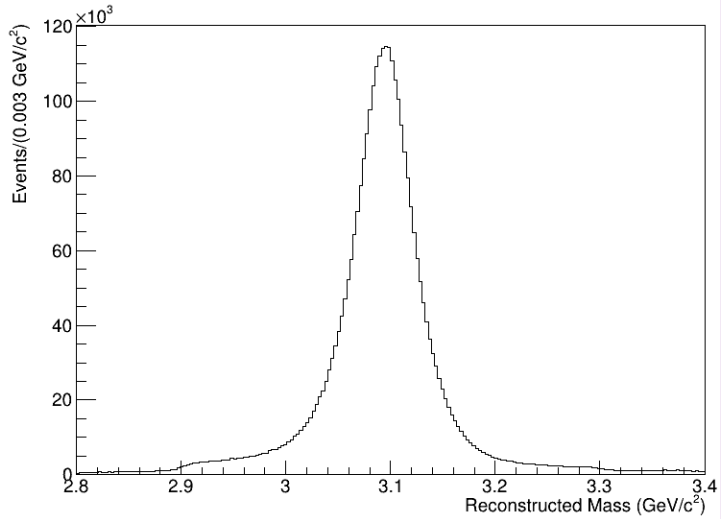

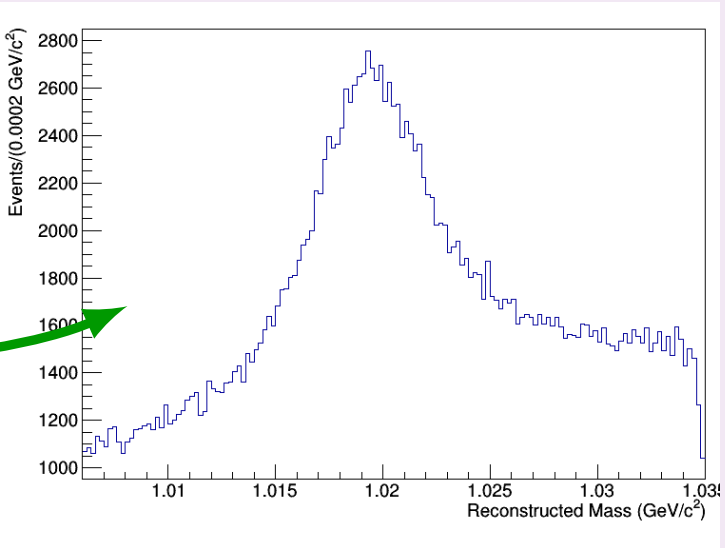

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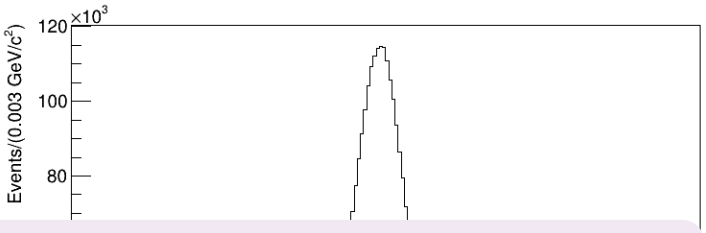

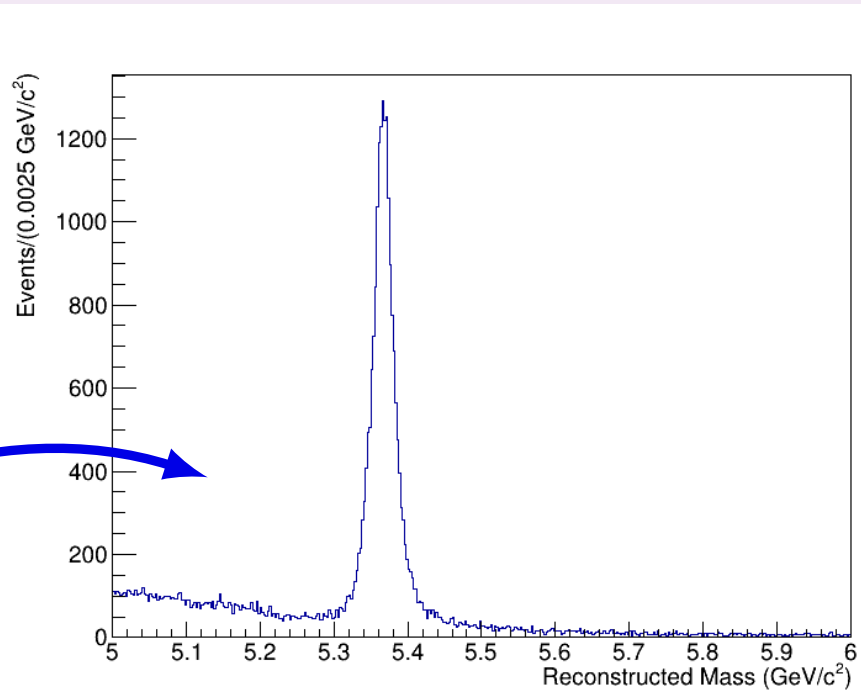

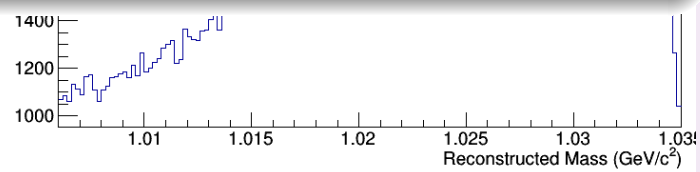

Estimation of the creation point

Primary vertices

- Several pp interactions per bunch crossing
- Many primary vertices are reconstructed (~ 30), each linked to a set of tracks
- Among all the possible PV one is chosen as the B_s^0 creation point

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PV linked to at least 3 tracks from $B_s^0 \to J/\psi\phi$ decay

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PV from Angle

PV minimizing the momentum angle with the PV-SV vector

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PV from Angle

PV minimizing the momentum angle with the PV-SV vector

Refitted PV

- Presence of tracks from the decay in the PV $\to$ position bias
- PV is refitted excluding $\mu^{\pm}$ and $K^{\pm}$ tracks:
  - using all tracks or only the ones from Particle Flow algorithm
  - with or without Beam Spot constraint

Flight distance estimation: comparison with simulation

Flight distance in the particle rest frame:

$$d^{Rest} = ct = \frac{\vec{d}_{xy} \cdot \vec{p}_{xy}\, m_B}{p_T^2}$$

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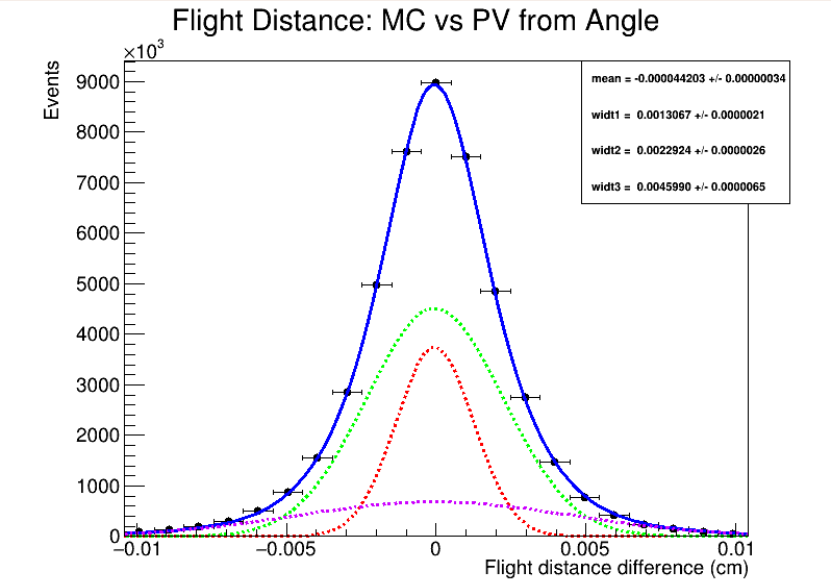
  - compute flight distance
  - compare with MC truth



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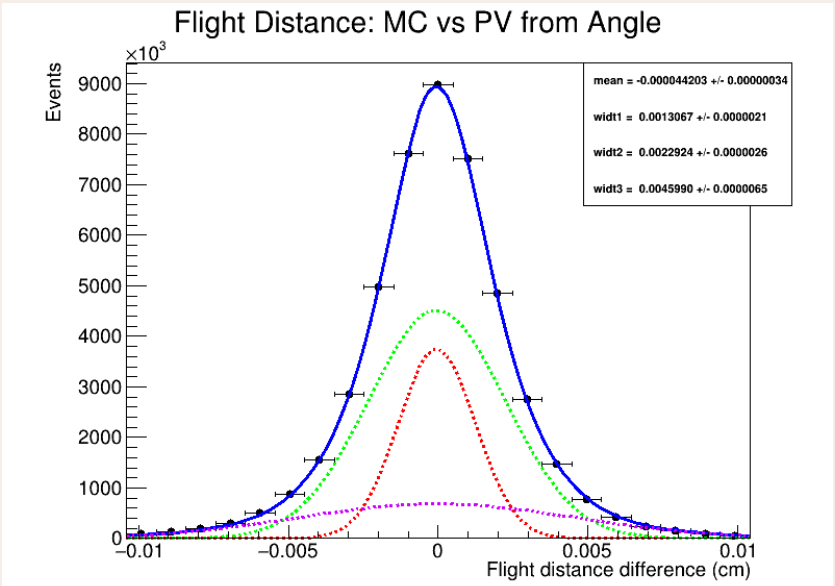
- Difference distributions:
  - fit with 3 gaussians
  - compute total width σ



Vertex	$\sigma(\cdot 10^{-3} cm)$
Tracks	3.274 ± 0.007
Angle	3.062 ± 0.006
All Tracks	3.228 ± 0.006
All no BS	3.919 ± 0.009
PF only	3.214 ± 0.007
PF no BS	3.899 ± 0.009

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- For each PV choice:
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- Difference distributions:
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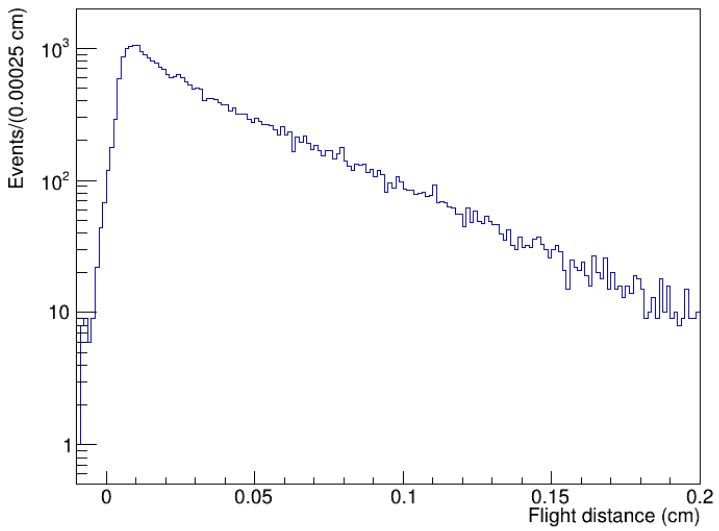
  - compute total width σ
- As best estimation the PV with the one with smallest width is chosen



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Efficiency Measurement

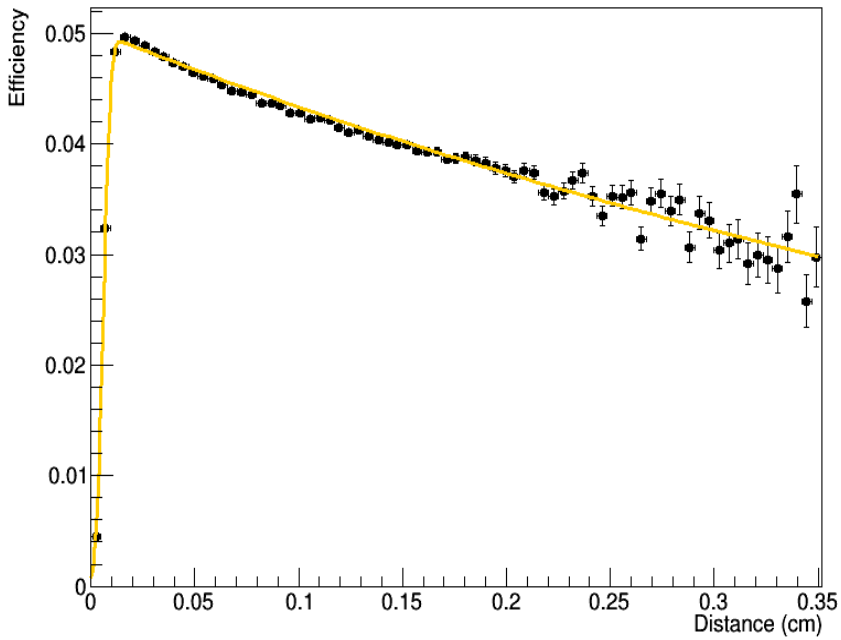
In the extraction of the lifetime from flight distance distribution the efficiency dependence from the distance must be known.

Efficiency is estimated in MC by comparing the flight distance histograms from:

- recontructed events
- full simulated sample

$$\epsilon = \frac{N_R}{N_S} \quad \sigma_\epsilon = \sqrt{\frac{\epsilon(1-\epsilon)}{N_S}}$$

Fitted with an exponential convoluted with a gaussian



Lifetime Fit

Fit Procedure

- B_s^0 lifetime is obtained from an unbinned max-likelihood 2D fit to mass and distance distributions
- Performed in several steps to improve stability

Fit steps

1. Mass (background only)
2. Mass (full distribution)
3. Flight distance (backgound)
4. Flight distance and mass (full distribution)

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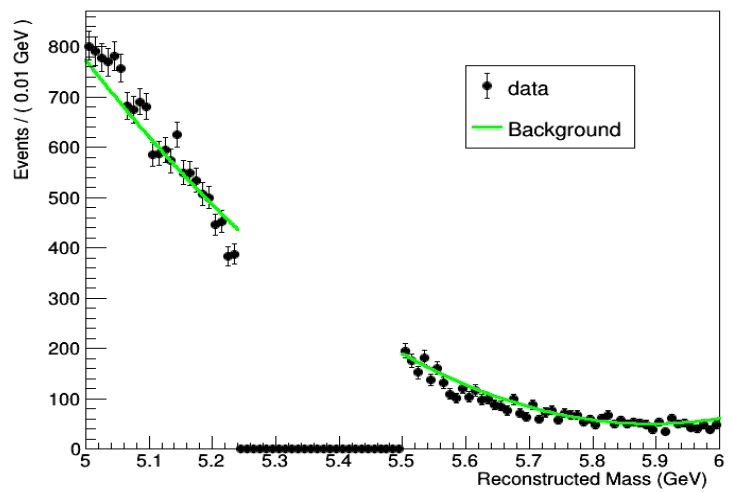
Mass PDF

Background: Second degree polynomial



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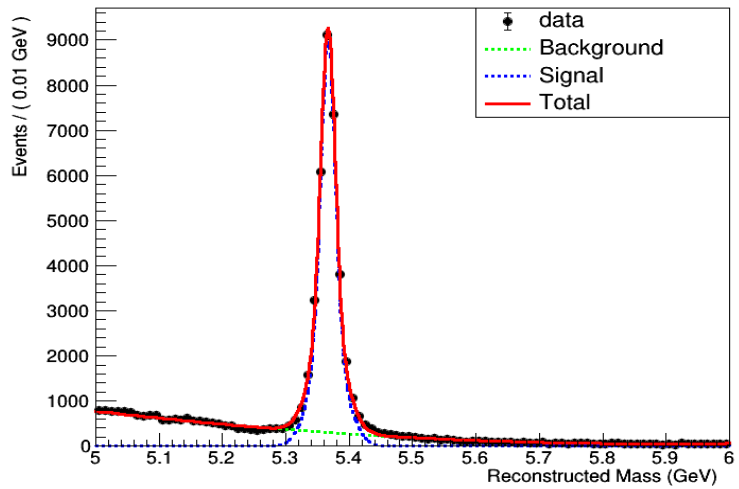
Mass PDF

Signal: Sum of two gaussians.
Background: Second degree polynomial

Mass Fit Value (GeV/c^2)

$$m_B^{Fit} = 5.36664 \pm 0.00010$$
$$m_B^{PDG} = 5.36688 \pm 0.00017$$



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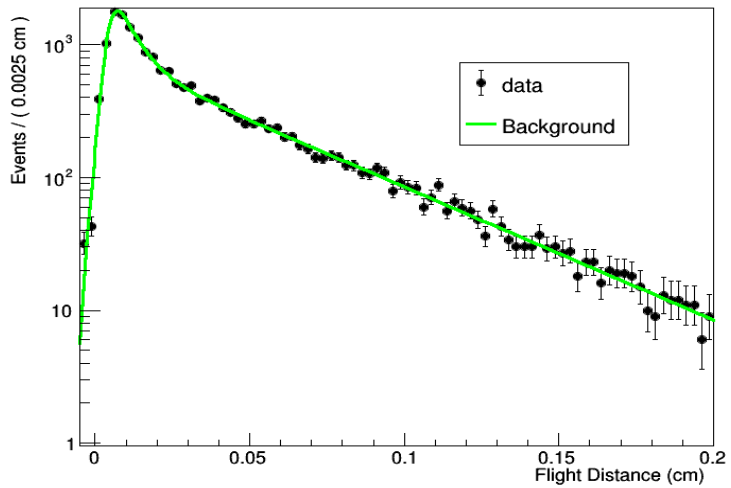
Distance PDF

Background: Two exponentials convoluted with a gaussian plus a gaussian prompt



Lifetime Fit

Fit Procedure

Final fit perfomed with background/signal parameters kept fixed or left free

Total PDF

$$\mathcal{F}(d,m) = \mathcal{M}(m) \cdot [f_s \cdot \mathcal{S}(d) \otimes \mathcal{R}(d) \cdot \mathcal{E}(d) + (1 - f_s)\mathcal{B}(d)]$$

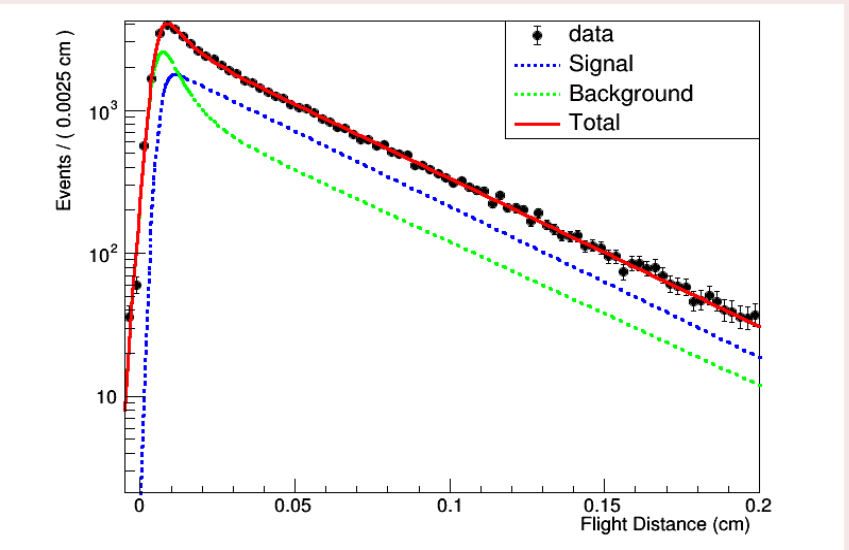
Distance PDF

Signal: Exponential convoluted with a gaussian product with the efficiency fuction

Background: Two exponentials convoluted with a gaussian plus a gaussian prompt

Fit steps

3. Flight distance (background)
4. Flight distance and mass (full distribution)



Results

Lifetime fit is performed for each choice of the primary vertex.

Lifetime results

Vertex	$c\tau(cm)$
All no BS	0.0437 ± 0.0003
All tracks	0.0432 ± 0.0003
Angle	0.0434 ± 0.0003
PF Only	0.0436 ± 0.0003
PF no BS	0.0432 ± 0.0003
Tracks	0.0431 ± 0.0003

Systematic error

Final value from "Angle" PV choice:

$\tau^{Fit} = 1.448 \pm 0.010$ ps (stat only)

$\tau^{PDG} = 1.510 \pm 0.004$ ps

Systematic uncertainty from half max difference

$$\delta_\tau = 0.010 \text{ ps}$$

Conclusions

- The $B_s^0 \to J/\psi\phi$, $J/\psi \to \mu^+\mu^-$ $\phi \to K^+K^-$ decay has been studied
- With a Montecarlo data sample the reconstructed decay proper time has been compared with the simulated one
- Lifetime has been extracted by a fit to real data
- Systematic uncertainty due to the creation point choice has been estimated

THANKS FOR YOUR ATTENTION

BACKUP

Quality cuts and trigger selection

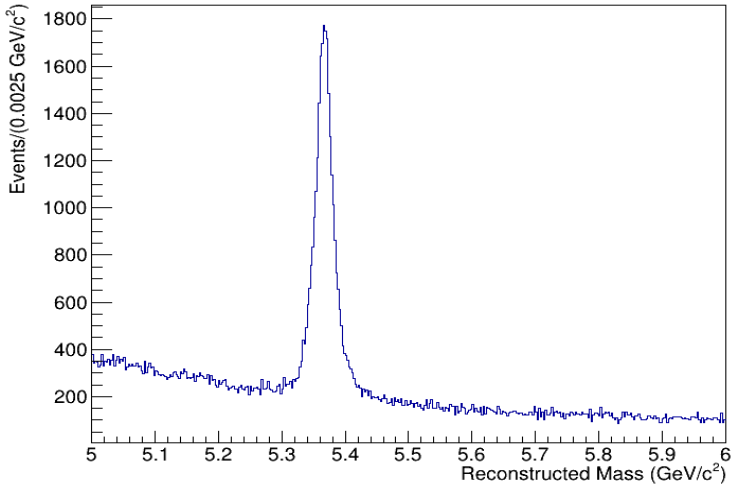
J/ψ requirements	$p_T(J/\psi) > 8.0\,\text{GeV}$ $p_T(\mu^{\pm}) > 4.0\,\text{GeV}$ $\lvert M(J/\psi) - M_{PDG}(J/\psi)\rvert < 0.150\,\text{GeV/c}^2$ $\lvert\eta(\mu^{\pm})\rvert < 2.2$
ϕ requirements	$p_T(K^{\pm}) > 1.2\,\text{GeV}$ $\lvert M(\phi) - M_{PDG}(\phi)\rvert < 0.010\,\text{GeV/c}^2$
B_s^0 requirements	$p_T(B_s^0) > 27.0\,\text{GeV/c}$ Vertex Probability $> 10\%$

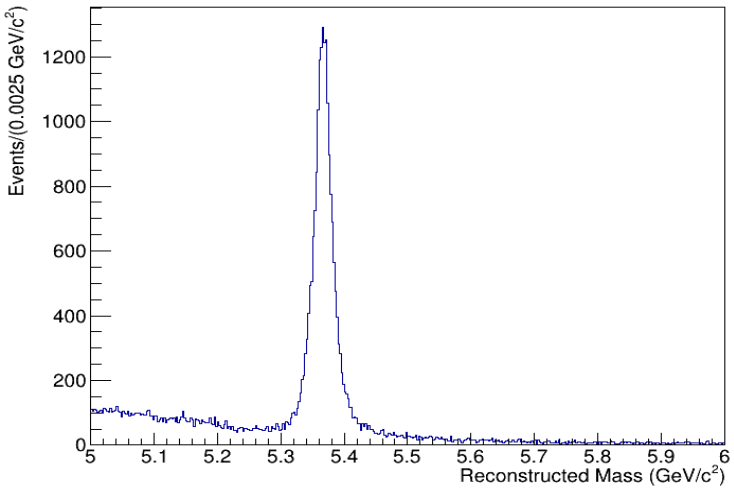
Selection	Events ($*10^6$)	Fraction
Selected events	7.78	1
Displaced trigger	4.09	0.527
Additional muon trigger	0.025	0.003
Logic OR of triggers	4.11	0.528

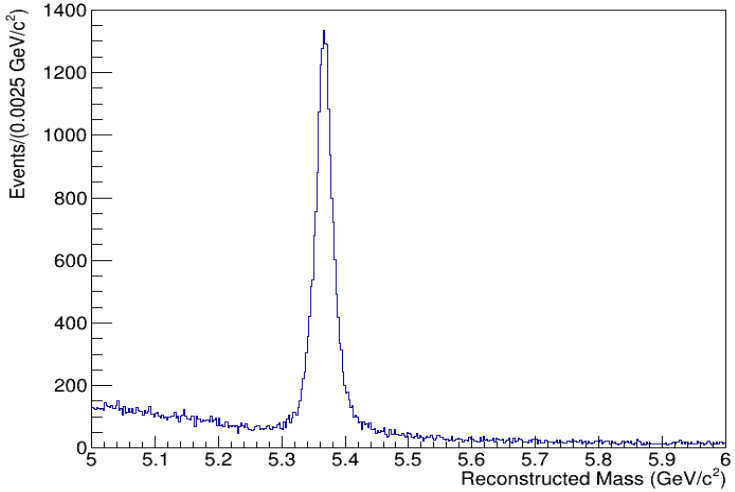
Selection	Events
Inclusive trigger	183704
Displaced trigger	60603
OR trigger	72199

Reconstructed mass

Reconstructed mass obtained from the 3 data samples with different trigger requirements.



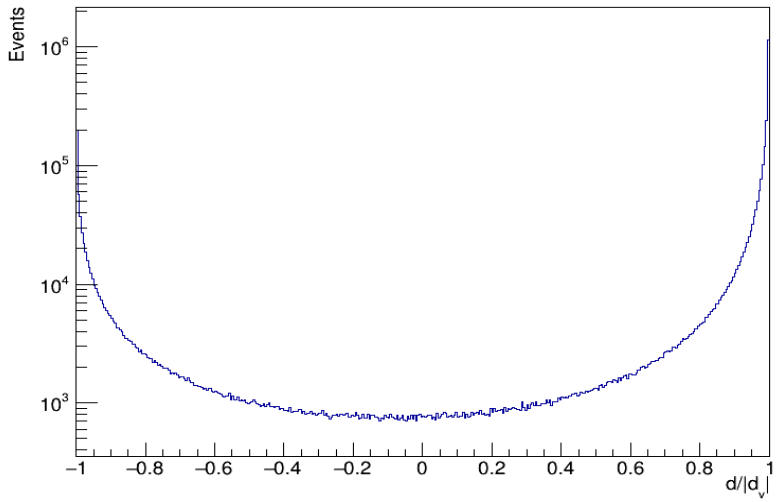




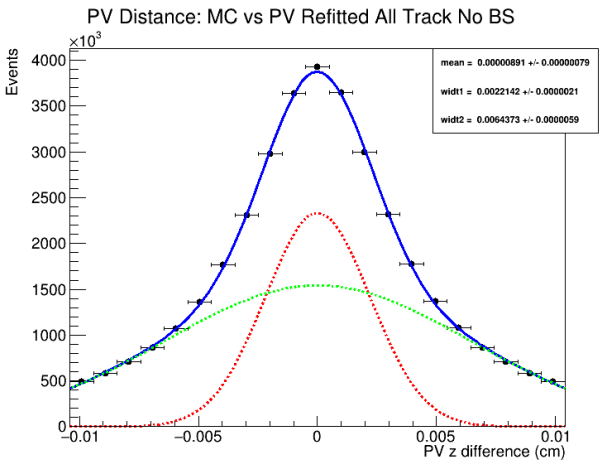
PV from track and angle analysis

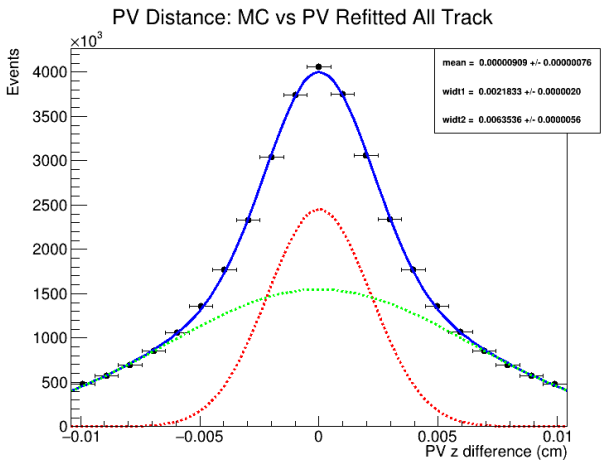
Event Type	Number of events $\cdot 10^5$	Fraction
Total number of events	32.2	1
4 Tracks with same PV	23.5	0.728
3 Tracks with same PV	5.49	0.172
2 Tracks with same PV	3.02	0.094
No Tracks with same PV	0.18	0.006

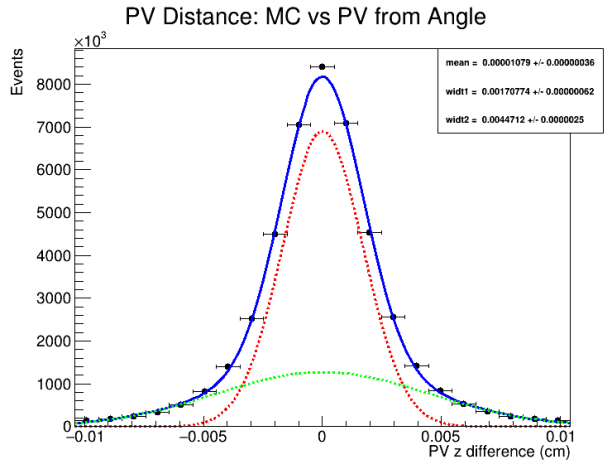
Range	Events $(\cdot 10^5)$	Fraction
Total events	32.2	1
$[0.95, 1]$	19.2	0.597
$[0.9, 0.95]$	2.2	0.068
$[0.8, 0.9]$	1.6	0.049
$[0.7, 0.8]$	0.7	0.022
$[-1, -0.95]$	4.3	0.132
$[-0.95, -0.9]$	0.8	0.024
$[-0.9, -0.8]$	0.7	0.023

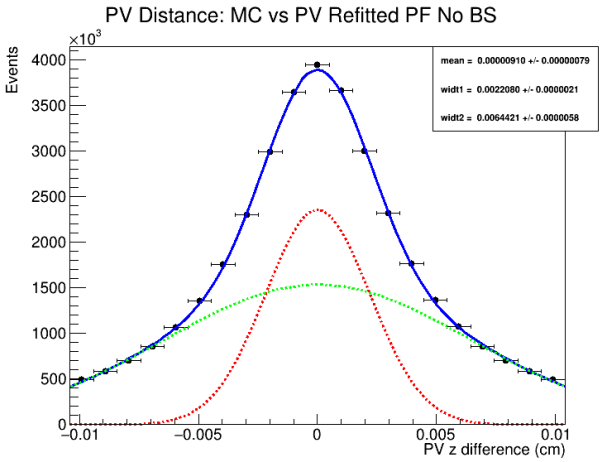


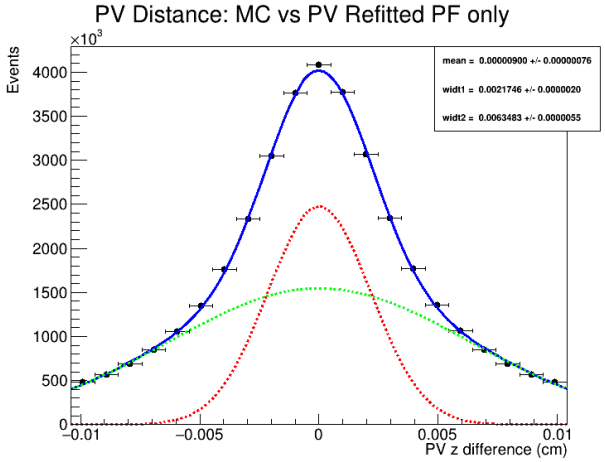
PV distance from MC creation point on z axis

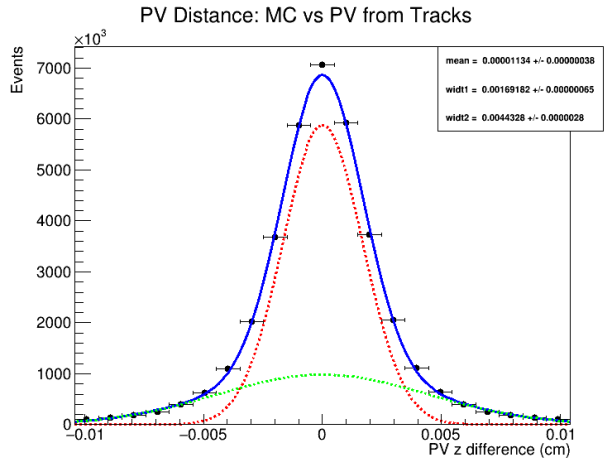




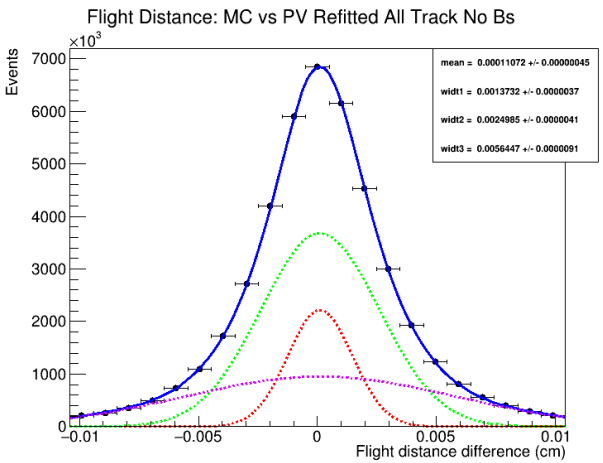


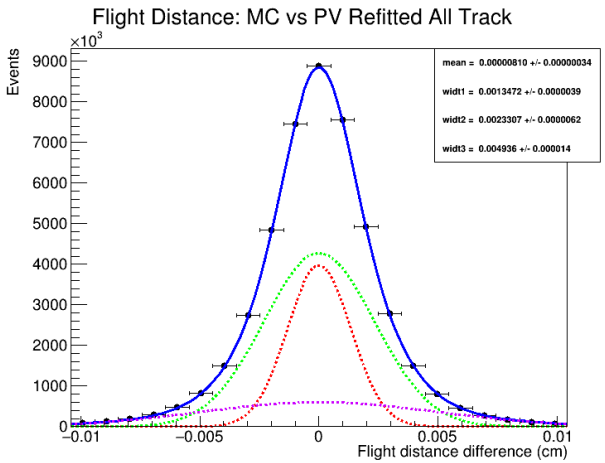


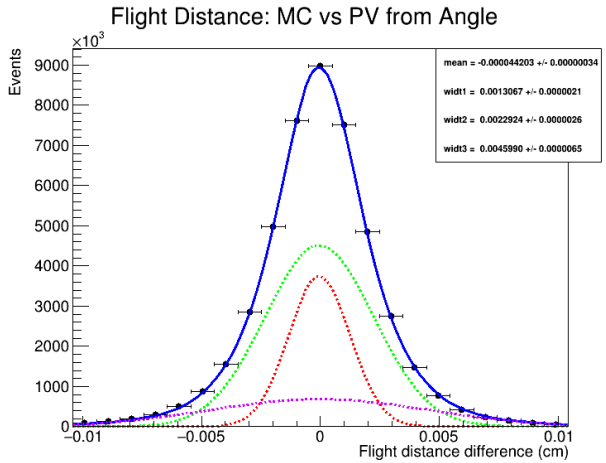


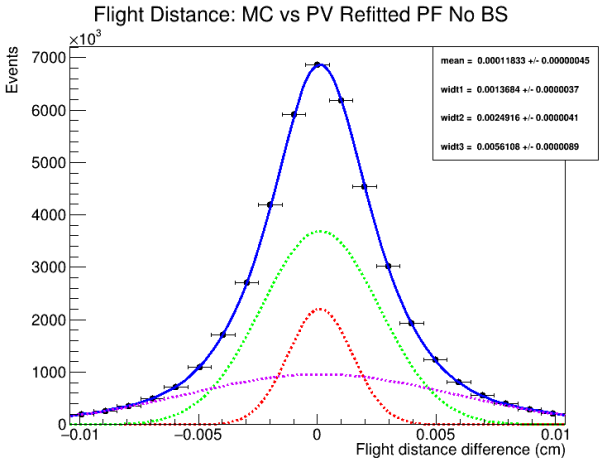


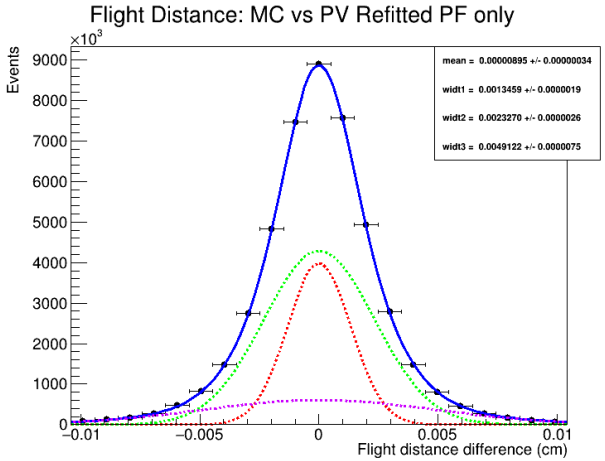
Flight distance difference depending on PV choice

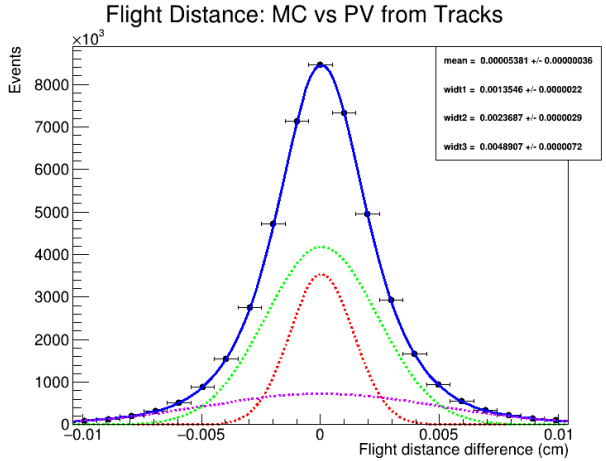












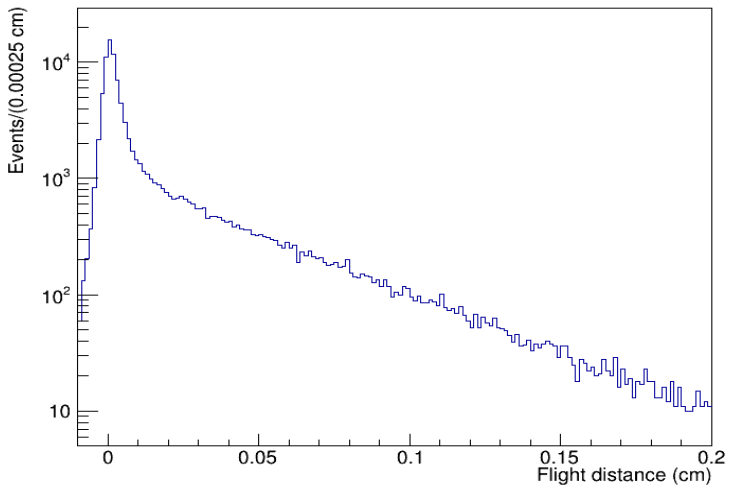
Fit parameters for PV and flight distance fit

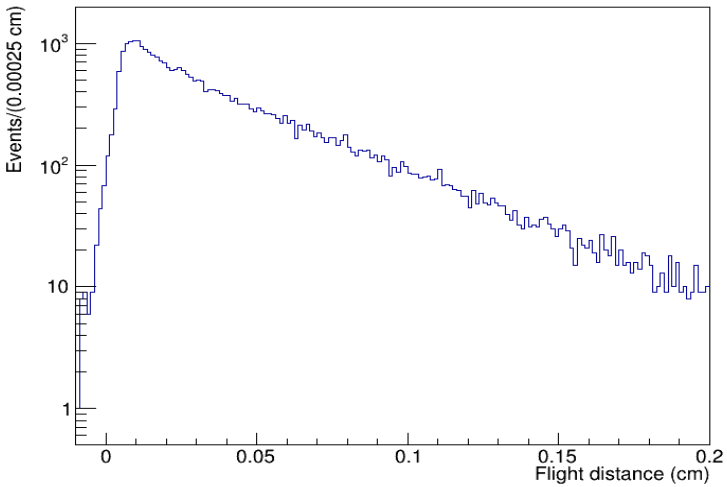
Vertex from:	$\mu(\cdot 10^{-5} cm)$	$\sigma_1(\cdot 10^{-3} cm)$	$\sigma_2(\cdot 10^{-3} cm)$	$\sigma(\cdot 10^{-3} cm)$
Tracks	1.130 ± 0.039	1.6918 ± 0.0007	4.432 ± 0.003	2.811 ± 0.002
Angle	1.075 ± 0.036	1.7076 ± 0.0006	4.471 ± 0.003	2.899 ± 0.002
All Tracks	0.906 ± 0.077	2.1832 ± 0.0020	6.354 ± 0.006	5.191 ± 0.005
All no BS	0.882 ± 0.080	2.2140 ± 0.0021	6.438 ± 0.006	5.291 ± 0.006
PF only	0.896 ± 0.077	2.1744 ± 0.0020	6.349 ± 0.006	5.180 ± 0.005
PF no BS	0.904 ± 0.080	2.2083 ± 0.0021	6.446 ± 0.006	5.287 ± 0.005

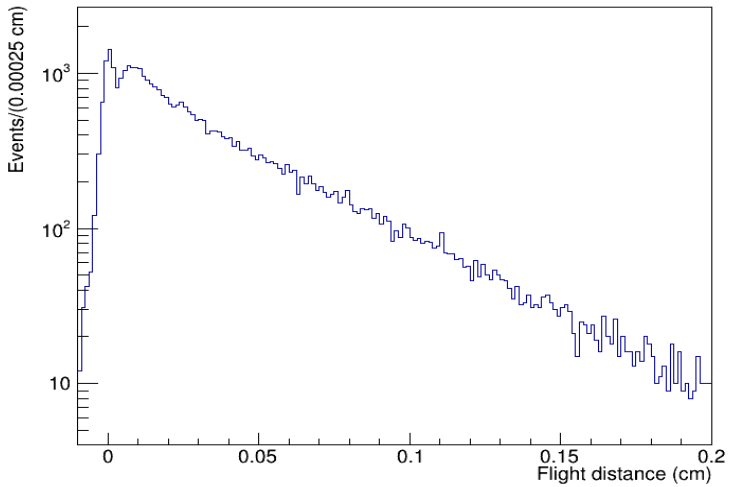
Vertex from:	$\mu(\cdot 10^{-5} cm)$	$\sigma_1(\cdot 10^{-3} cm)$	$\sigma_2(\cdot 10^{-3} cm)$	$\sigma_3(\cdot 10^{-3} cm)$	$\sigma(\cdot 10^{-3} cm)$
Tracks	5.39 ± 0.04	1.354 ± 0.002	2.368 ± 0.003	4.889 ± 0.007	3.274 ± 0.007
Angle	-4.42 ± 0.03	1.306 ± 0.002	2.292 ± 0.003	4.599 ± 0.007	3.062 ± 0.006
All Tracks	0.81 ± 0.03	1.348 ± 0.002	2.332 ± 0.003	4.940 ± 0.008	3.228 ± 0.006
All no BS	11.08 ± 0.05	1.373 ± 0.004	2.500 ± 0.004	5.648 ± 0.009	3.919 ± 0.009
PF only	0.90 ± 0.03	1.346 ± 0.002	2.327 ± 0.003	4.914 ± 0.008	3.214 ± 0.007
PF no BS	11.84 ± 0.05	1.368 ± 0.004	2.492 ± 0.004	5.612 ± 0.009	3.899 ± 0.009

Reconstructed flight distance

Flight distance data samples obtained from different trigger requirement and PV from angle.

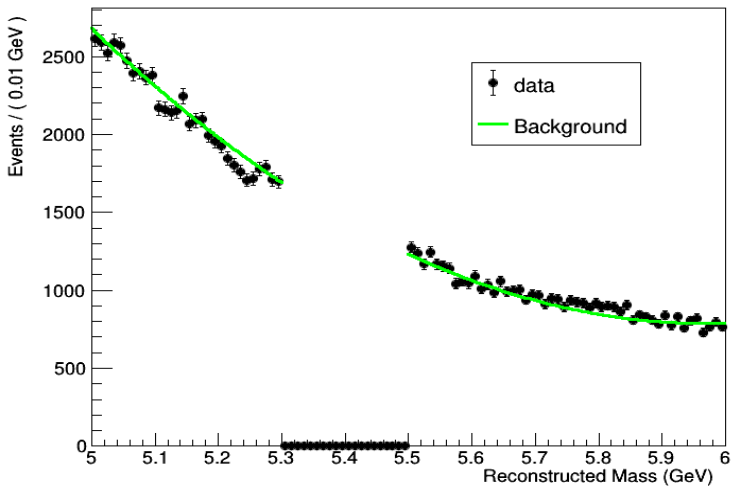


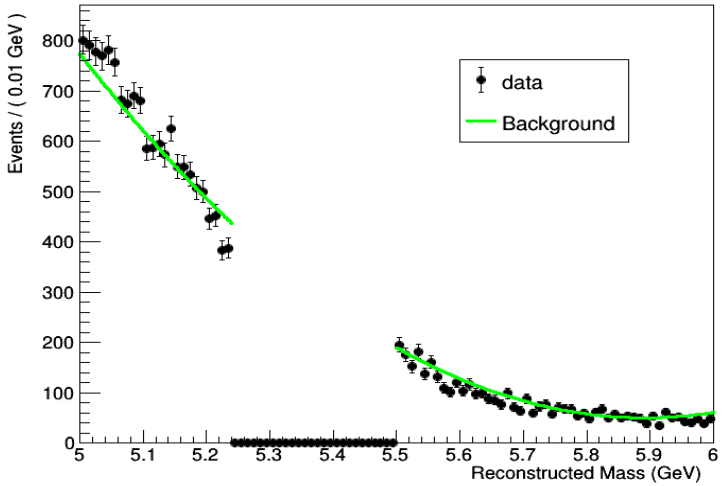


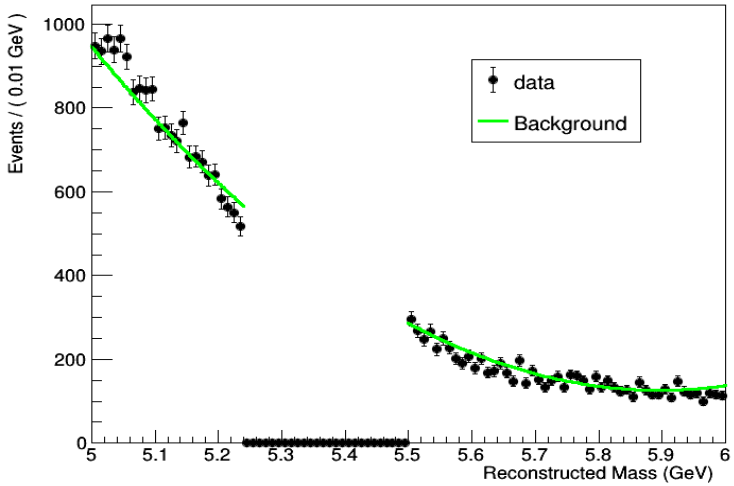


Lifetime fit: reconstructed mass background

Reconstudted mass background fit from different trigger requirement and PV from angle.

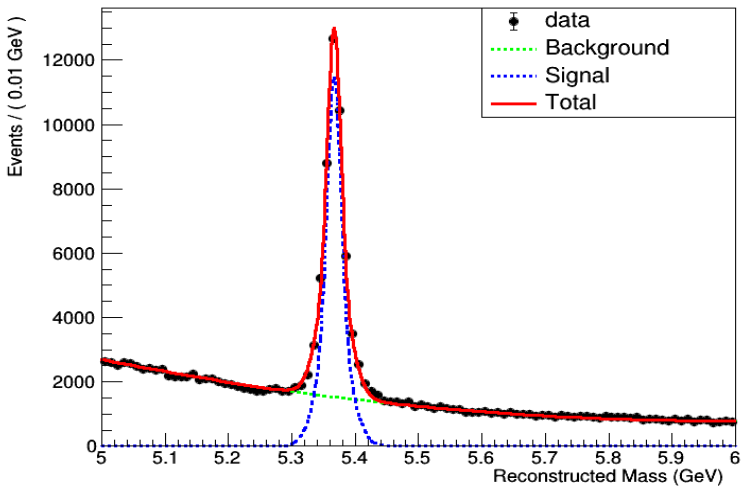


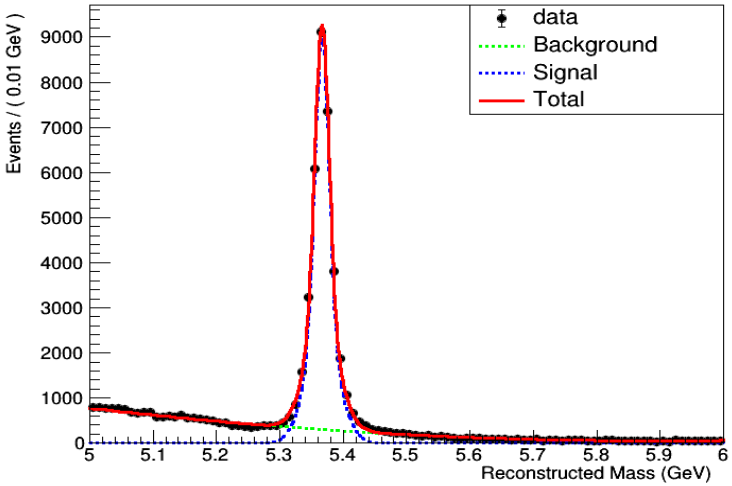


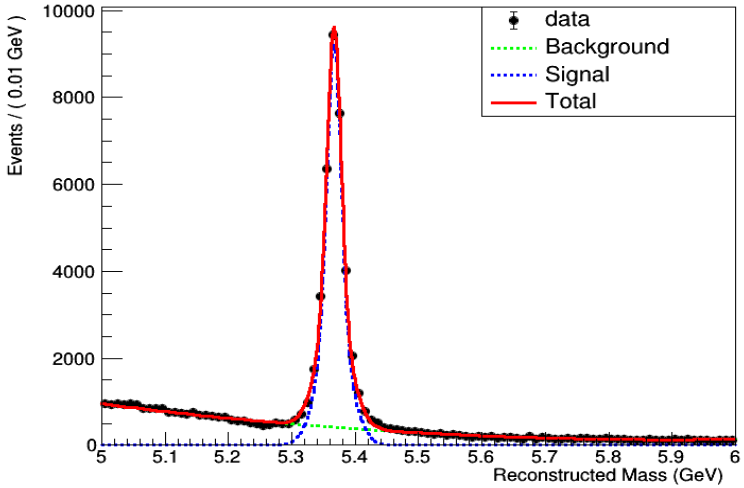


Lifetime fit: reconstructed mass

Reconstudted mass fit from different trigger requirement and PV from angle.

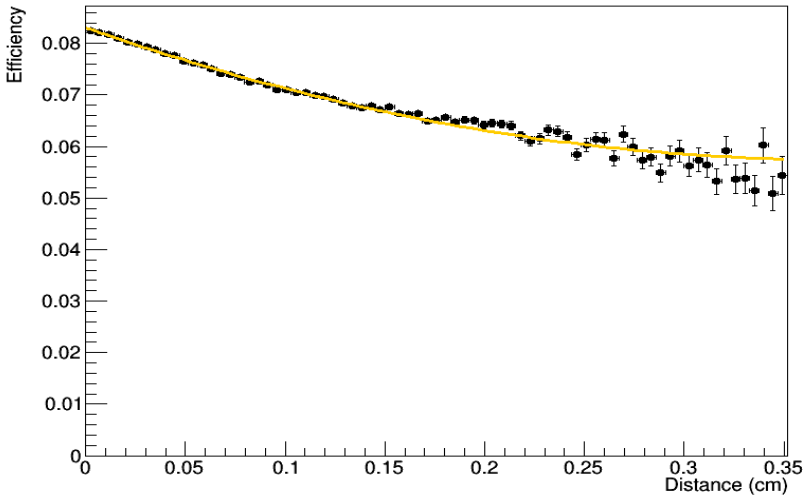


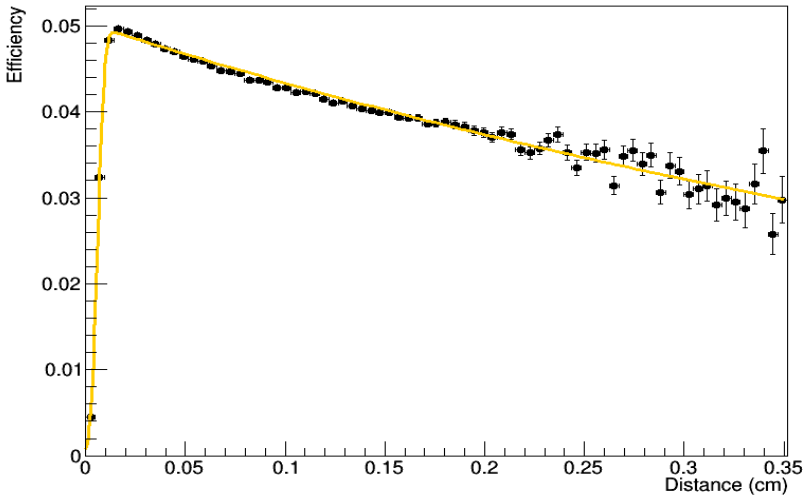


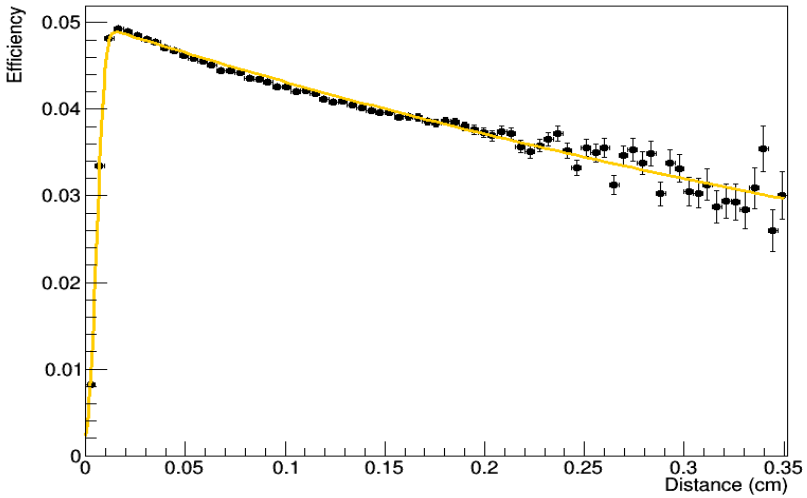


Lifetime fit: efficiency fit

Efficiency fit for different trigger requirement.

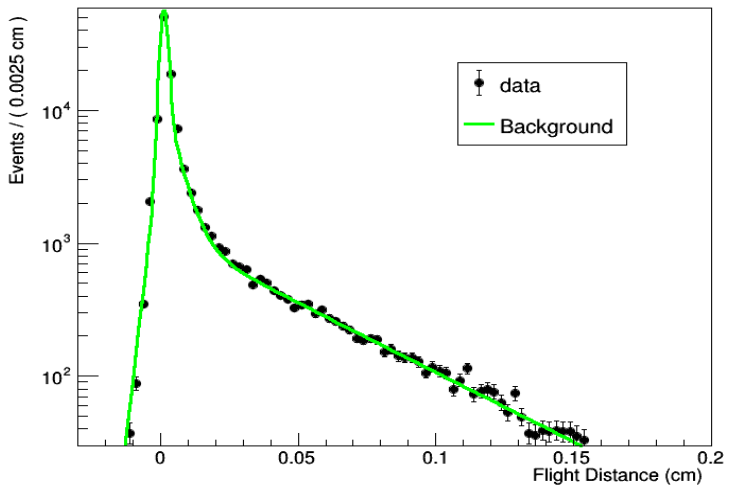


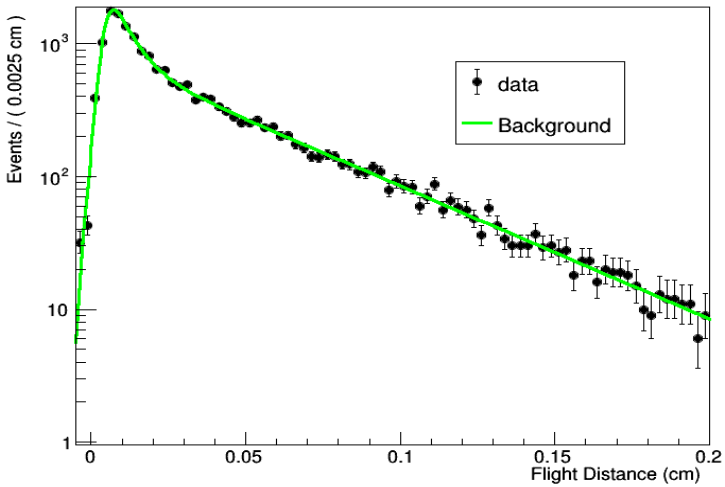


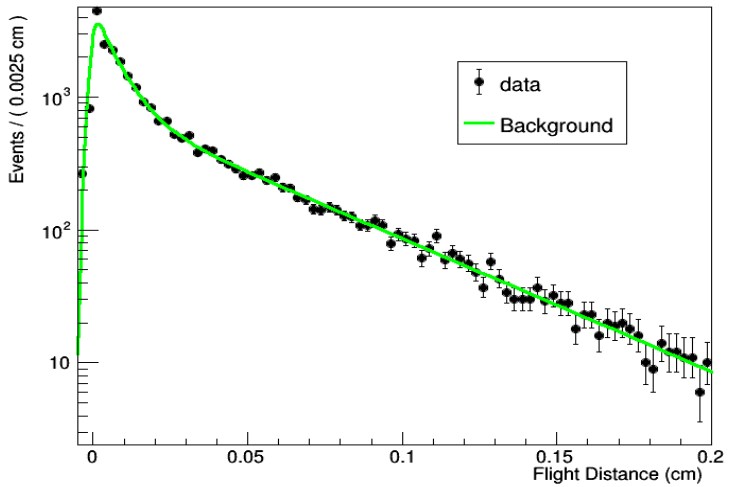


Lifetime fit: flight distance background

Flight distance background fit from different trigger requirement and PV from angle.

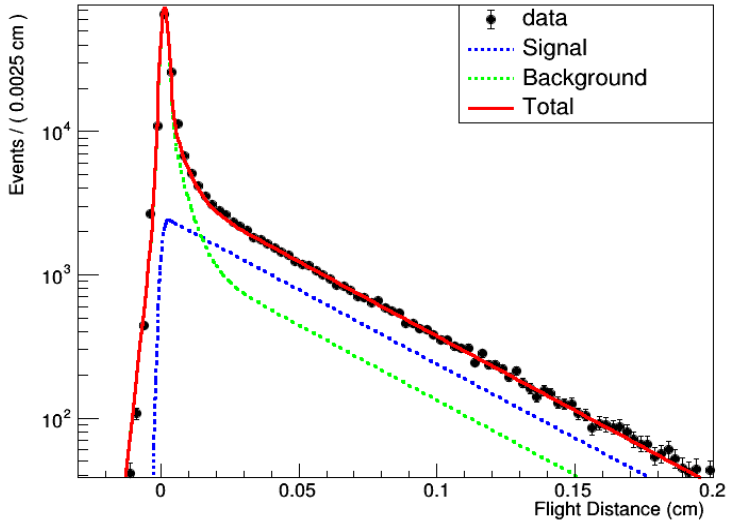


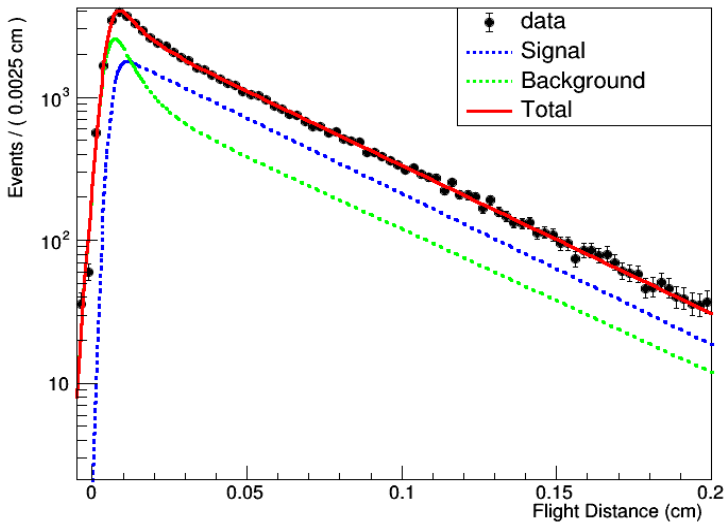


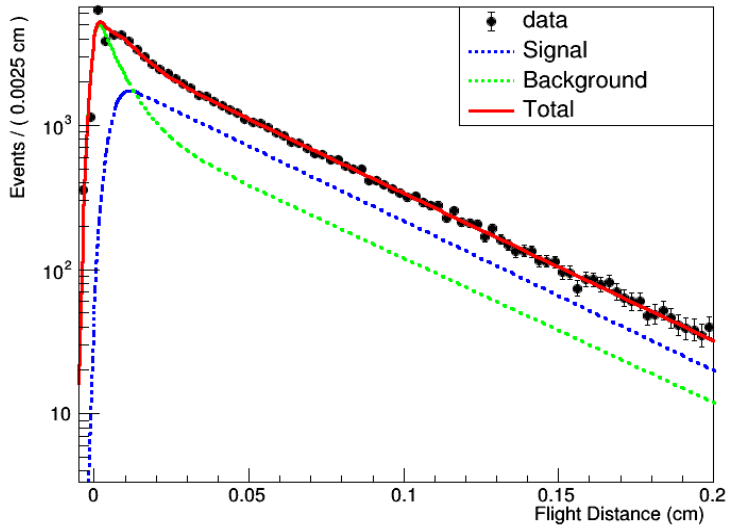


Lifetime fit: flight distance final fit

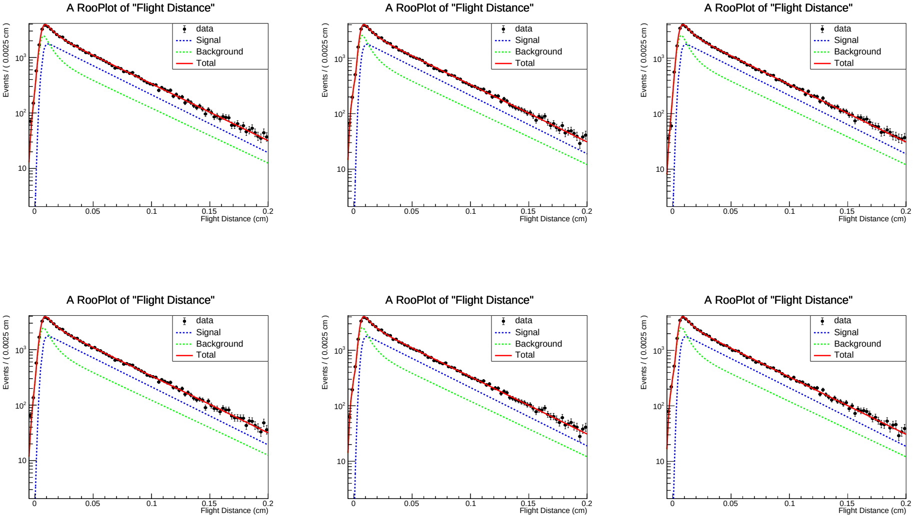
Flight distance fit from different trigger requirement and PV from angle, perfomed over the whole 2D distribution.







Lifetime fit for every PV choice, "Displaced" data sample



Fit result in the "Displaced" data sample

Fit result for B_s^0 mean lifetime ($c\tau$); the fit is perfomed for each choice of the primary vertex in the "Displaced" data sample leaving free of keeping fixed some parameters to observe the consequence on the fit result.

Settings			Primary vertex from:					
Mean	Frac	Reso	All tracks no BS	All tracks	Angle	PF Only	PF no BS	Tracks
Free	Free	Free	0.0437(3)	0.0432(3)	0.0434(3)	0.0436(3)	0.0432(3)	0.0431(3)
Free	Free	Fixed	0.0437(3)	0.0432(3)	0.0434(3)	0.0436(3)	0.0432(3)	0.0431(3)
Free	Fixed	Free	0.0443(3)	0.0440(3)	0.0439(3)	0.0442(3)	0.0434(3)	0.0439(3)
Free	Fixed	Fixed	0.0437(3)	0.0432(3)	0.0434(3)	0.0436(3)	0.0432(3)	0.0431(3)
Fixed	Free	Free	0.0443(3)	0.0434(3)	0.0439(3)	0.0443(3)	0.0440(3)	0.0439(3)
Fixed	Free	Fixed	0.0437(3)	0.0432(3)	0.0434(3)	0.0436(3)	0.0432(3)	0.0431(3)
Fixed	Fixed	Free	0.0443(3)	0.0440(3)	0.0439(3)	0.0443(3)	0.0434(3)	0.0439(3)
Fixed	Fixed	Fixed	0.0443(3)	0.0440(3)	0.0439(3)	0.0444(3)	0.0440(3)	0.0439(3)

PV estimation from pointing angle minimization