

# Search for fractionally charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV

## —Supplemental Material—

The CMS Collaboration  
 CERN  
 (Dated: December 3, 2024)

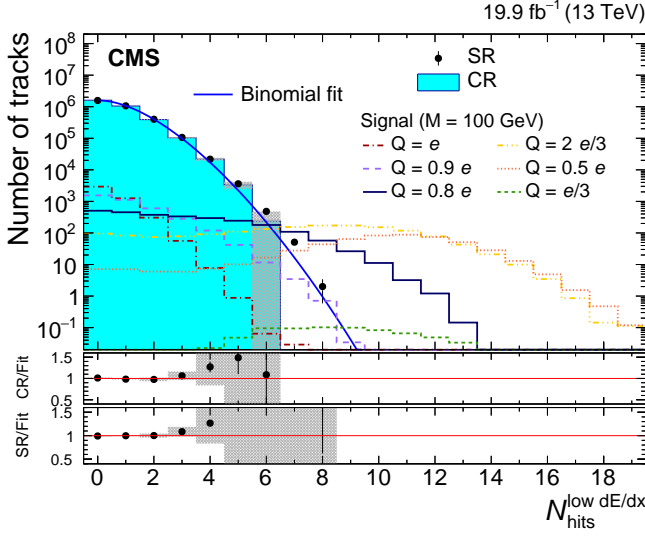


FIG. 1. Distribution of  $N_{\text{hits}}^{\text{low } dE/dx}$  in the SR and the CR for the early 2016 data set, as well as for an FCP signal at a mass of 100 GeV and different charge scenarios. The vertical bars and the shaded area correspond to the statistical uncertainty in the SR and the CR, respectively. The  $p$ -value of the fit is 6%. The two lower panels show the ratio of the number of tracks observed in the CR (upper) and SR (lower), and the fit function. The vertical bars correspond to the uncertainty from statistical sources, while the shaded area shows the systematic uncertainty in the fit due to the choice of the fitting function and the binomial fit range as explained in the main text. Comparing with respect to the binomial fit starting at  $N_{\text{hits}}^{\text{low } dE/dx} = 2$ , and not  $N_{\text{hits}}^{\text{low } dE/dx} = 1$ , is needed to account for the fact that early 2016 data is more strongly affected by instrumental effects that widen the  $N_{\text{hits}}^{\text{low } dE/dx}$  distribution.

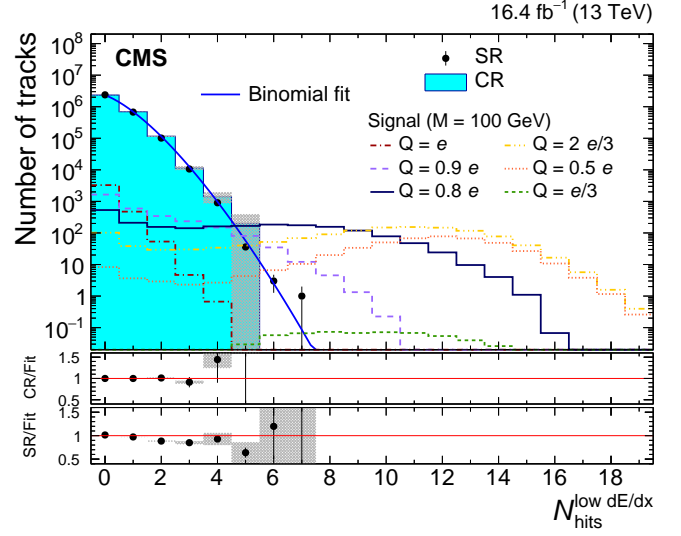


FIG. 2. Distribution of  $N_{\text{hits}}^{\text{low } dE/dx}$  in the SR and the CR for the late 2016 data set, as well as for an FCP signal at a mass of 100 GeV and different charge scenarios. The vertical bars and the shaded area correspond to the statistical uncertainty in the SR and the CR, respectively. The  $p$ -value of the fit is 78%. The two lower panels show the ratio of the number of tracks observed in the CR (upper) and SR (lower), and the fit function. The vertical bars correspond to the uncertainty from statistical sources, while the shaded area shows the systematic uncertainty in the fit due to the choice of the fitting function and the binomial fit range as explained in the main text.

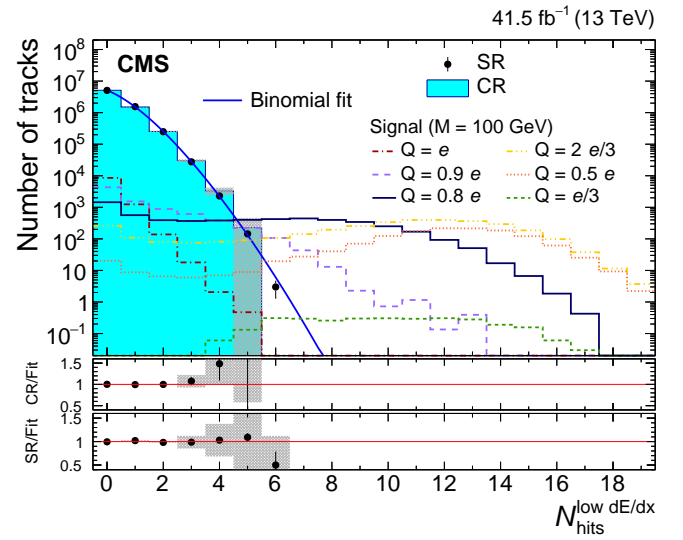


FIG. 3. Distribution of  $N_{\text{hits}}^{\text{low } dE/dx}$  in the SR and the CR for the 2017 data set, as well as for an FCP signal at a mass of 100 GeV and different charge scenarios. The vertical bars and the shaded area correspond to the statistical uncertainty on the SR and the CR, respectively. The  $p$ -value of the fit is 65%. The two lower panels show the ratio of the number of tracks observed in the CR (upper) and SR (lower), and the fit function. The vertical bars correspond to the uncertainty from statistical sources, while the shaded area shows the systematic uncertainty in the fit due to the choice of the fitting function and the binomial fit range as explained in the main text.

TABLE I. Number of tracks observed and expected for background and signal events, in the  $N_{\text{hits}}^{\text{low } dE/dx}$  bin with highest signal significance ( $\geq 9$ ), for early 2016 data. The corresponding systematic uncertainties are also listed. They are considered to follow a log-normal distribution. The results are shown for FCP scenarios at a mass of 100 GeV with a charge of  $2e/3$  (the most sensitive scenario) and  $e/3$  (the lowest considered charge).

$N^{\text{observed}}$	0	
$N_{\text{BG}}^{\text{expected}}$	0.04	
Fit function	$\pm 287\%$	
Fit range	$\pm 109\%$	
	$Q = 2e/3$	$Q = e/3$
$N_{\text{signal}}^{\text{expected}}$	602	0.328
L1 trigger inefficiency	5%	5%
Muon system energy loss simul.	+4%/-3%	75%
Muon detector inefficiency	3%	15%
Integrated luminosity	1.2%	1.2%
Selection	2.0%	2.0%
$dE/dx$ corrections	3.8%	12.2%
Limited signal sample	<1%	2.4%

TABLE II. Number of tracks observed and expected for background and signal events, in the  $N_{\text{hits}}^{\text{low } dE/dx}$  bin with highest signal significance ( $\geq 7$ ), for late 2016 data. The corresponding systematic uncertainties are also listed. They are considered to follow a log-normal distribution. The results are shown for FCP scenarios at a mass of 100 GeV with a charge of  $2e/3$  (the most sensitive scenario) and  $e/3$  (the lowest considered charge).

$N^{\text{observed}}$	1	
$N_{\text{BG}}^{\text{expected}}$	0.09	
Fit function	$\pm 159\%$	
Fit range	$\pm 0.3\%$	
	$Q = 2e/3$	$Q = e/3$
$N_{\text{signal}}^{\text{expected}}$	988	0.454
L1 trigger inefficiency	5%	5%
Muon system energy loss simul.	+4%/-3%	75%
Muon detector inefficiency	3%	15%
Integrated luminosity	1.2%	1.2%
Selection	2.0%	2.0%
$dE/dx$ corrections	1.1%	1.4%
Limited signal sample	<1%	2.6%

TABLE III. Number of tracks observed and expected for background and signal events, in the  $N_{\text{hits}}^{\text{low } dE/dx}$  bin with highest signal significance ( $\geq 7$ ), for 2017 data. The corresponding systematic uncertainties are also listed. They are considered to follow a log-normal distribution. The results are shown for FCP scenarios at a mass of 100 GeV with a charge of  $2e/3$  (the most sensitive scenario) and  $e/3$  (the lowest considered charge).

$N^{\text{observed}}$	0	
$N_{\text{BG}}^{\text{expected}}$	0.2	
Fit function	$\pm 231\%$	
Fit range	$\pm 13.7\%$	
	$Q = 2e/3$	$Q = e/3$
$N_{\text{signal}}^{\text{expected}}$	2720	2.25
L1 trigger inefficiency	5%	5%
Muon system energy loss simul.	+4%/-3%	75%
Muon detector inefficiency	3%	15%
Integrated luminosity	2.3%	2.3%
Selection	2.0%	2.0%
$dE/dx$ corrections	2.3%	3.3%
Limited signal sample	<1%	1.5%

TABLE IV. Number of tracks observed and expected for background and signal events, in the  $N_{\text{hits}}^{\text{low } dE/dx}$  bin with highest signal significance ( $\geq 7$ ), for 2018 data. The corresponding systematic uncertainties are also listed. They are considered to follow a log-normal distribution. The results are shown for FCP scenarios at a mass of 100 GeV with a charge of  $2e/3$  (the most sensitive scenario) and  $e/3$  (the lowest considered charge).

$N^{\text{observed}}$	1	
$N_{\text{BG}}^{\text{expected}}$	0.09	
Fit function	$\pm 19\%$	
Fit range	$\pm 28\%$	
	$Q = 2e/3$	$Q = e/3$
$N_{\text{signal}}^{\text{expected}}$	3622	3.51
L1 trigger inefficiency	5%	5%
Muon system energy loss simul.	+4%/-3%	75%
Muon detector inefficiency	3%	15%
Integrated luminosity	2.5%	2.5%
Selection	2.0%	2.0%
$dE/dx$ corrections	1.7%	2.3%
Limited signal sample	<1%	1.8%