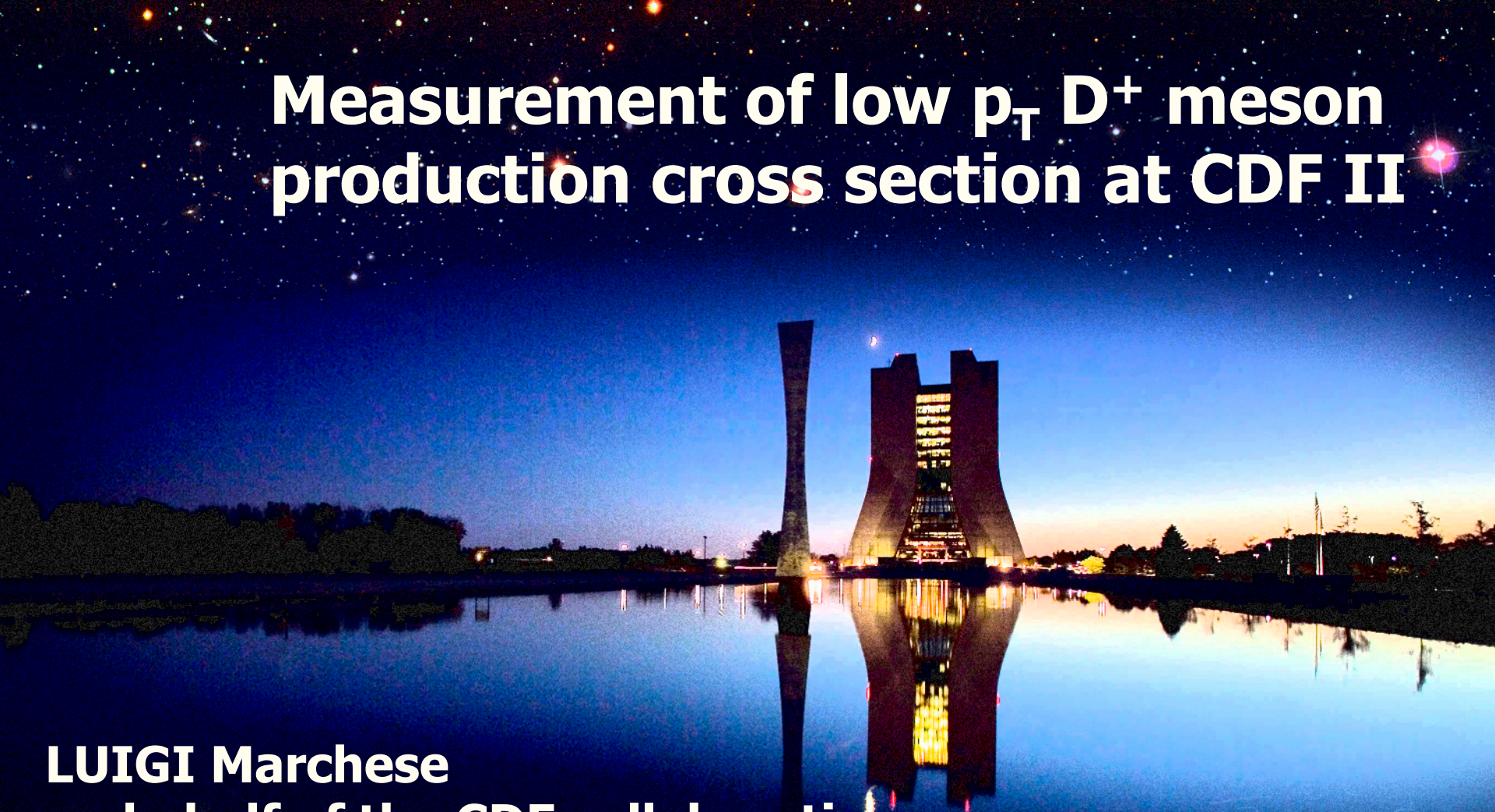
Measurement of low p_T D^+ meson production cross section at CDF II



LUIGI Marchese
on behalf of the CDF collaboration

OUTLINE

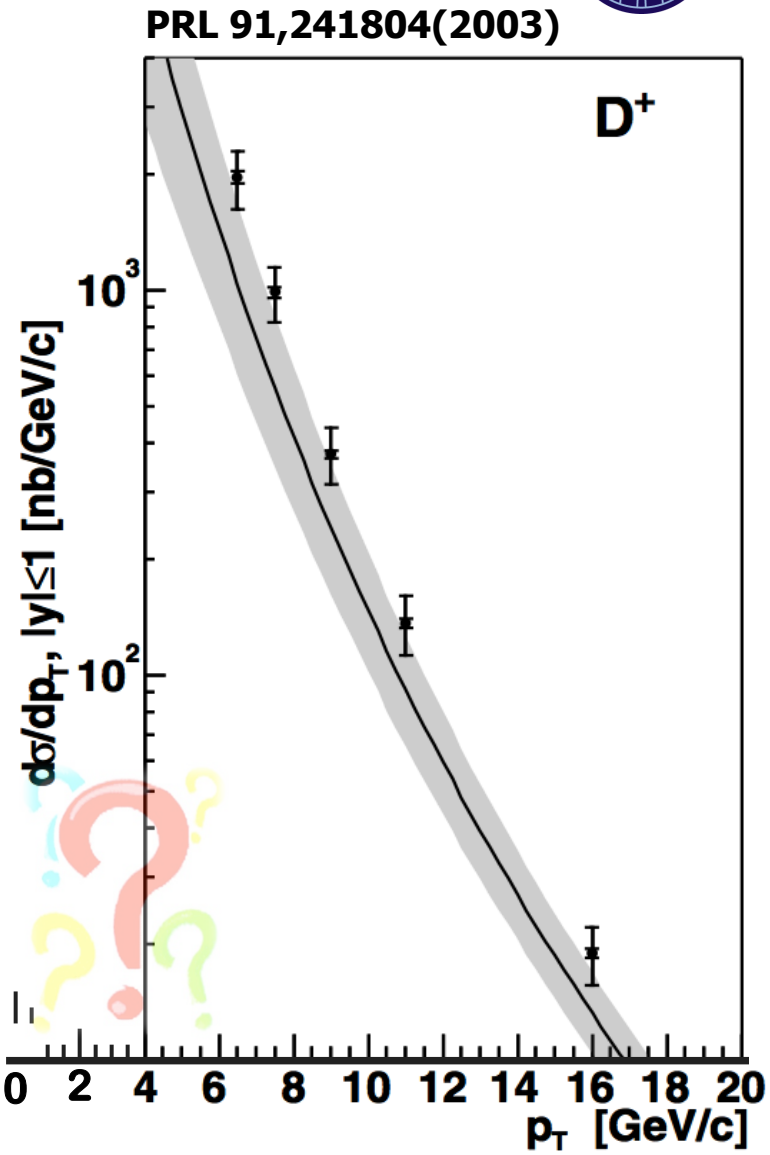
- Motivations
- Signal and Background
- Detector overview
- Optimization procedure
- Fit strategy
- D^+ yields
- Conclusions

MOTIVATIONS

- Differential cross section for the inclusive hadro-production of charm mesons at low p_T with initial state $p\bar{p}$ and $\sqrt{s} = 1.96 TeV$: extension of the previous CDF measurements

- Theoretical models for npQCD have big uncertainties at low p_T
  (M. Cacciari et al., JHEP, 05:007, 1998)

Experiment	Initial state	√s [Gev]
Many expt's CERN, FNAL	K, p, π Nucl. tgts.	up to 40 See backup
LHCb	pp	7000
ALICE	pp	7000



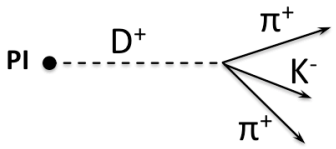
SIGNAL AND BACKGROUND

SIGNAL: $D^+ \to K^-\pi^+\pi^+(+c.c.)$ **BR:** $(9.13 \pm 0.19)\%$

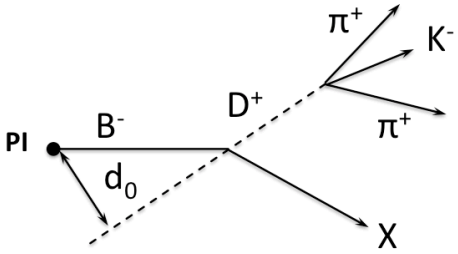
BACKGROUND

- **Secondary component:** $B \to D^+X$
- **Combinatorics**

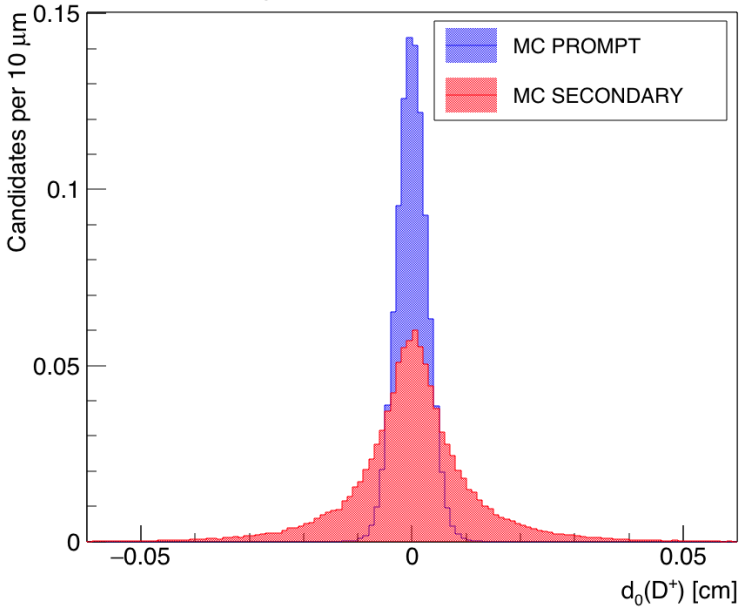
DIRECT PRODUCTION
D^+ points back to the **P**rimary **I**nteraction (**PI**)



SECONDARY PRODUCTION
D^+ has larger impact parameter

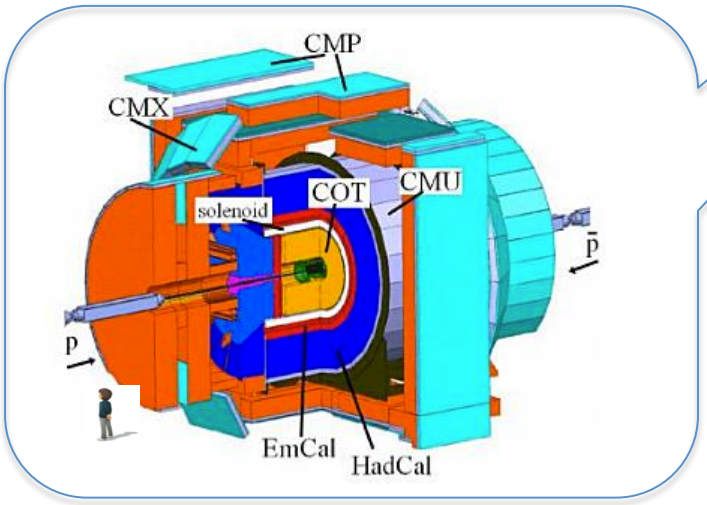


MC $p_T(D^+) \in [6.5, 14.5]$ GeV/c



TEVATRON AND CDF

- $p\bar{p}$ hadron collider $\sqrt{s}$ = 1.96 TeV
- Peak Luminosity: $\mathcal{L} \approx 3.8 \bullet 10^{32}\ cm^{-2}\ s^{-1}$
- CDF recorded luminosity: 10 fb^{-1} (2002 – 2011)
- Minimum Bias sample corresponds to 16 nb^{-1}



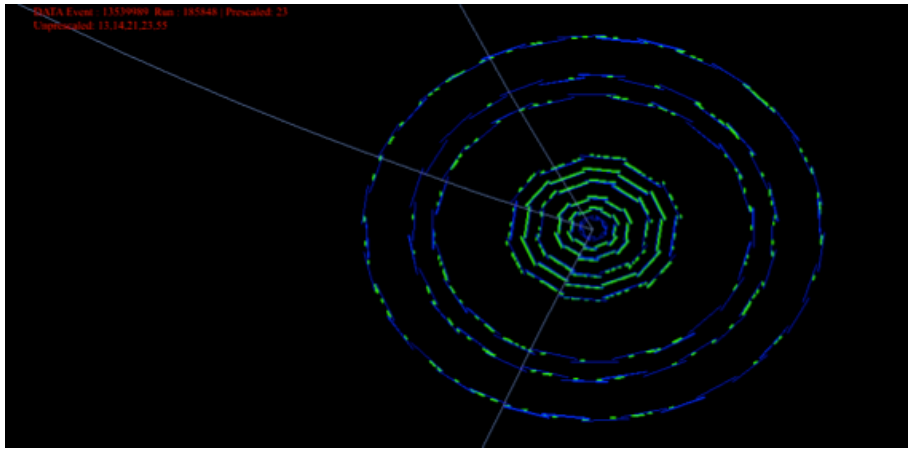
CDF: Collider Detector at Fermilab

- Multi purpose detector
- Inner tracking system, solenoidal magnet (1.4 T)
- Calorimeters and muon detectors

TRACKING SYSTEM

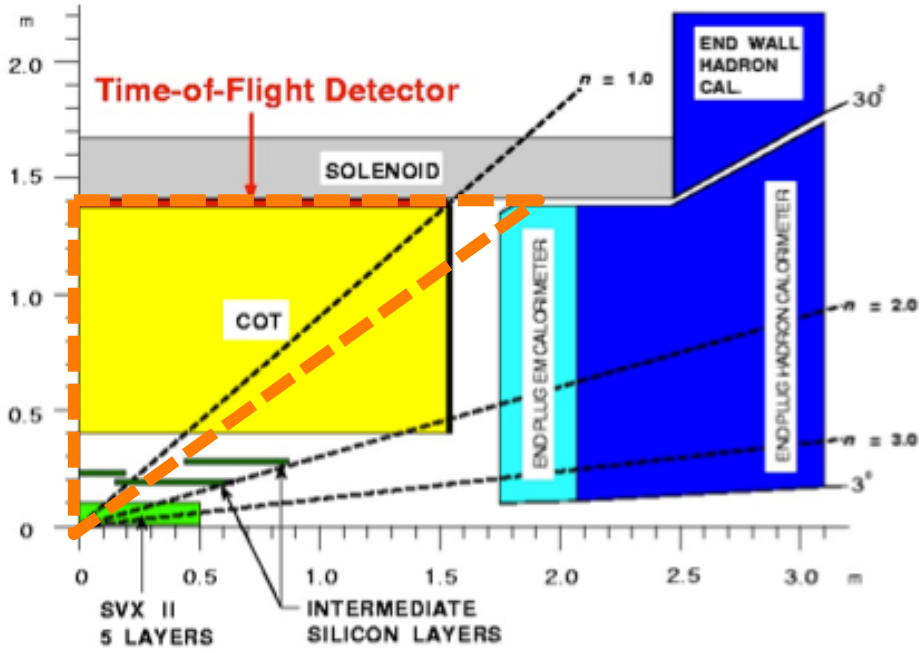
Tracking-system performance

For $|\eta| \leq 1$:
$\sigma_{pT}/p_T^2 \approx 0.0007$ c/GeV
$\sigma_{d0} \approx 40$ μm



3D charged-particle tracking

- Seven-layer silicon inner detector
- Large outer drift chamber



SIGNAL: BASE SELECTION

D^+ reconstruction:

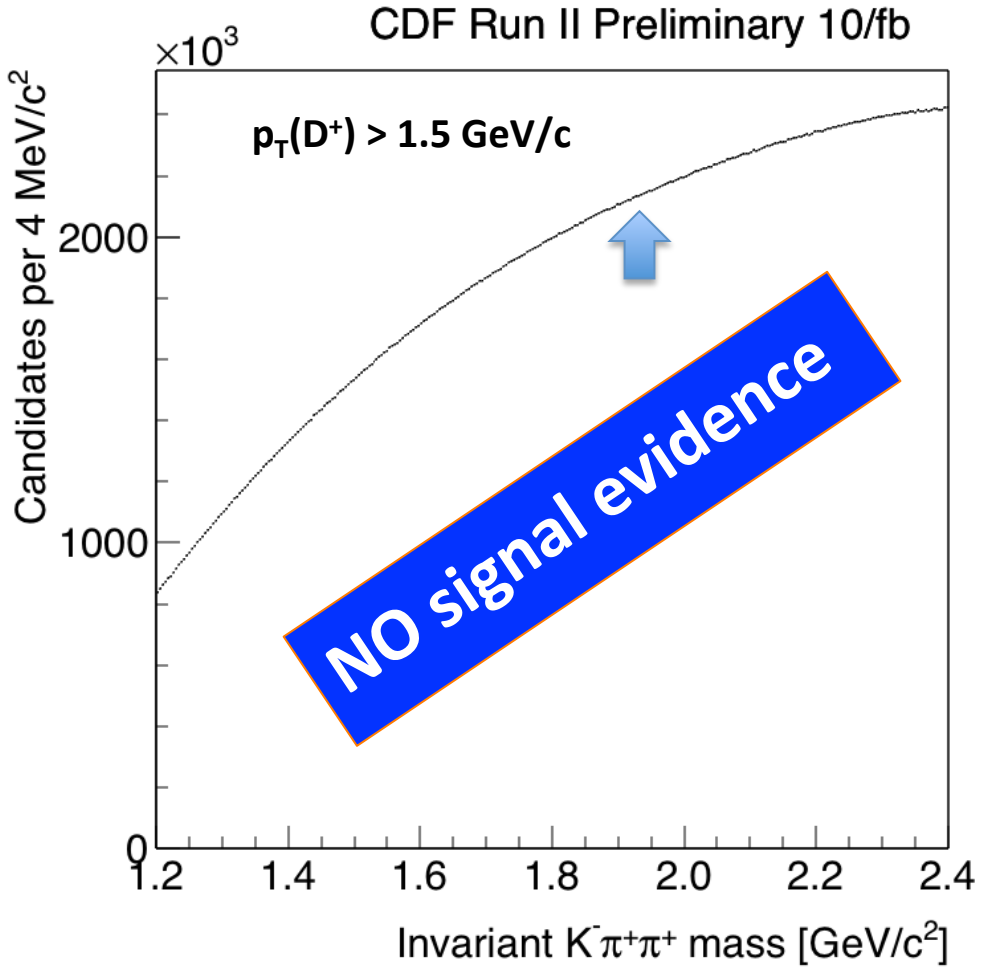
- Fit on triplet of tracks combined together in each event
- Common origin for the triplet of tracks? ➡ **D^+ CANDIDATE**

$L_{xy} \geq 0\ \mu m$

Transverse decay length

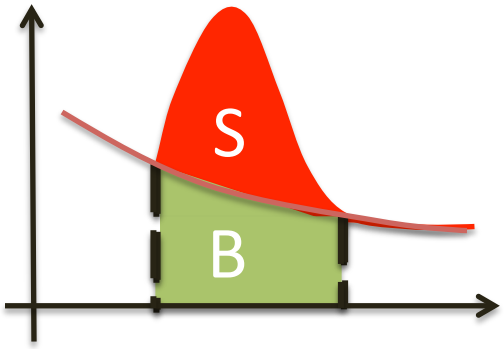
$|y(D^+)| \leq 1$

$\chi^2 \leq 10$



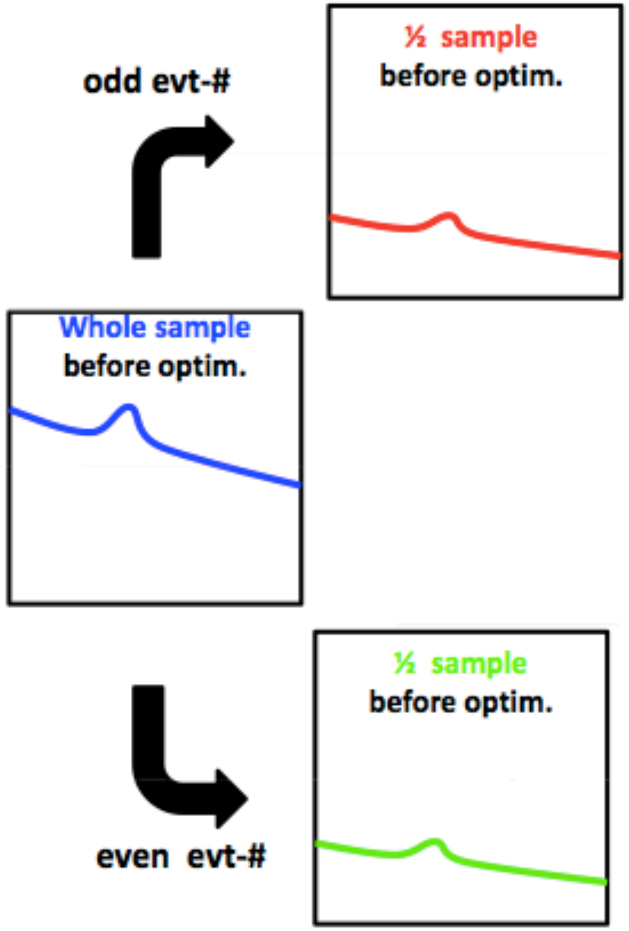
Selection optimization is mandatory to unfold the signal.

$$f(S,B) = \frac{S}{\sqrt{S+B}}$$

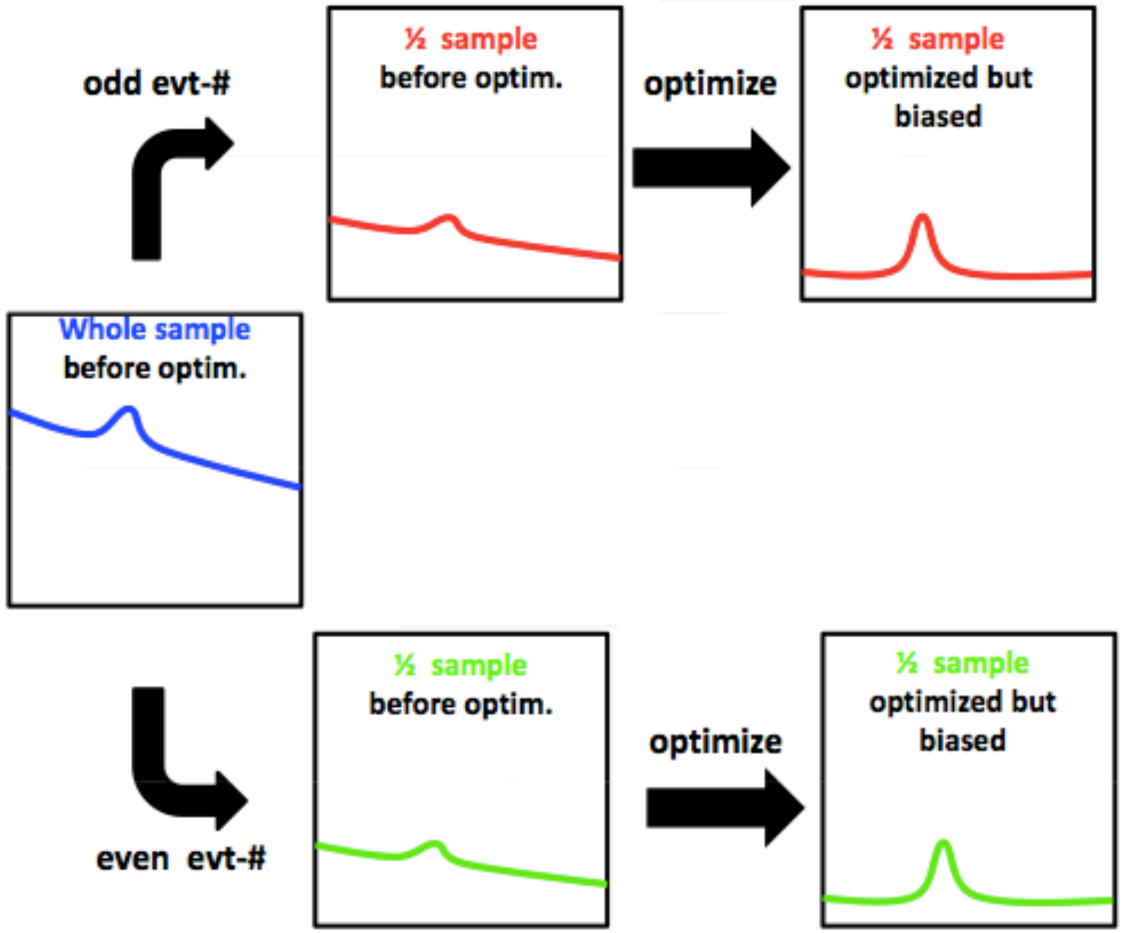


3 OPTIMIZATION VARIABLES:
p_T(tracks), χ^2 and L_{xy}

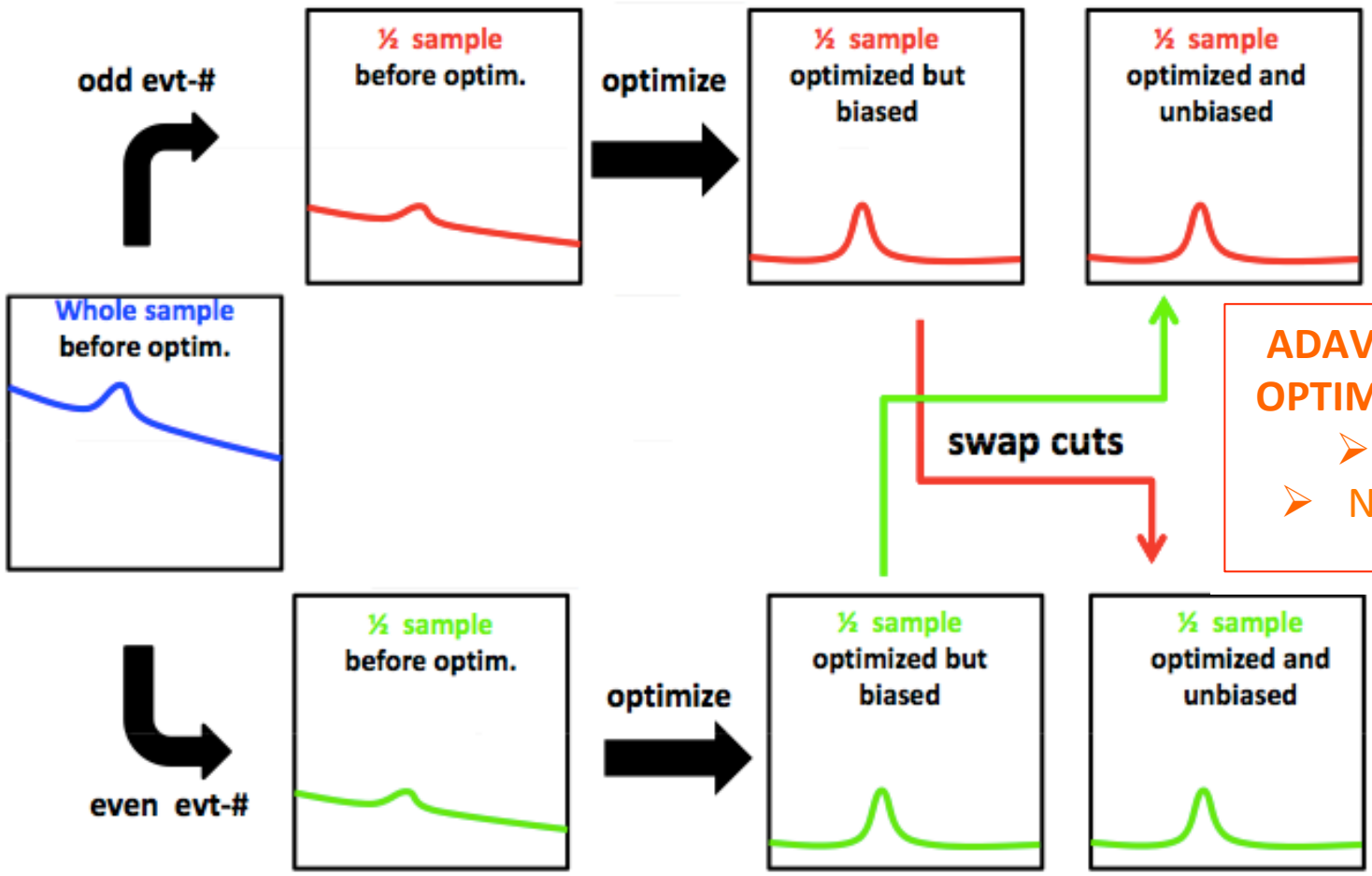
SELECTION OPTIMIZATION



SELECTION OPTIMIZATION



SELECTION OPTIMIZATION



ADAVANTAGES OF THE OPTIMIZATION METHOD

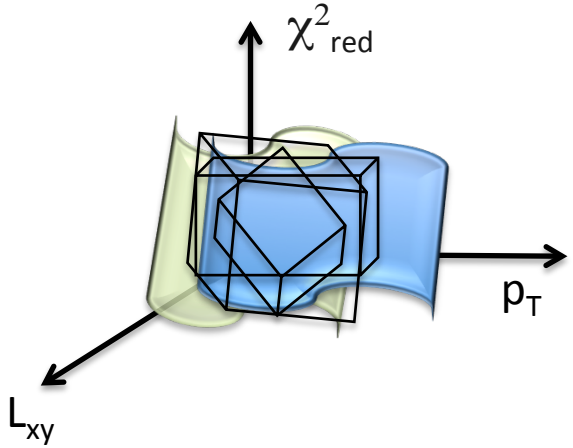
- All data used
- No bias introduced

SELECTION OPTIMIZATION

- We optimize the space of selection configurations

***i*th *selection* configuration**:

VARIABLE	RANGE	STEP
Any two p_T(TRK) ≥	[0.4; 1.3] GeV/c	$p_{T,\,j}$ (0.1 GeV/c)
χ^2_{red} ≤	[10; 0]	$\chi^2_{red,\,m}$ (1)
L_{xy} ≥	[0; 1450] μm	$L_{xy,\,n}$ (150 μm)



- How many selection configurations?

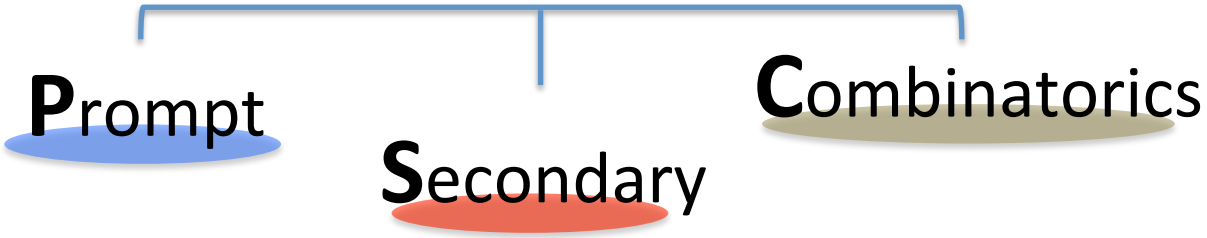
2 Subsamples • 5 $p_T(D^+)$ bins •10•10•10 Variables cuts = 10^4 SELECTIONS

10^4 HISTOGRAMS!

PROMPT-based optimization: $|d_0(D^+)| \leq 100$ μm

PROMPT SIGNAL EXTRACTION

- Assumption:
  in the signal region <u>three components</u>



- For each component, the distributions in mass (**m**) and impact parameter (d_0) are **uncorrelated**

$$PDF(m,d_0)=f_P\cdot F_{S,P}(m)F_P(d_0)+f_S\cdot F_{S,P}(m)F_S(d_0)+(1-f_P-f_S)\cdot F_C(m)F_C(d_0)$$

FIT STRATEGY

- For each $p_T(D^+)$ bin, **2D fit (m, d_0)** of the event distribution
  Better than SB subtraction for low statistics

- **Two parameters (f_P, f_S) unbinned likelihood fit**

- **PDF is normalized to unity for every (f_P, f_S)**

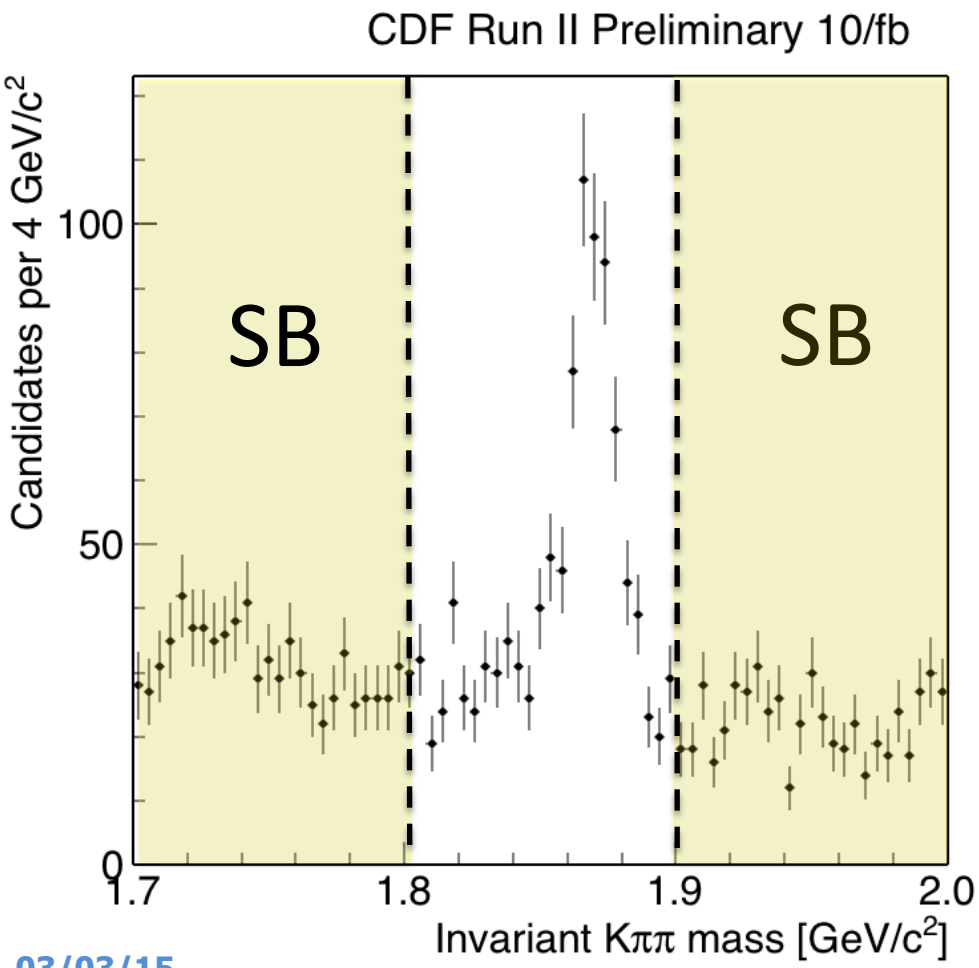
for each event:

$$\mathcal{L}(f_P, f_S) = f_P \cdot F_{S,P}(m) F_P(d_0) + f_S \cdot F_{S,P}(m) F_S(d_0) + (1 - f_P - f_S) \cdot F_C(m) F_C(d_0)$$

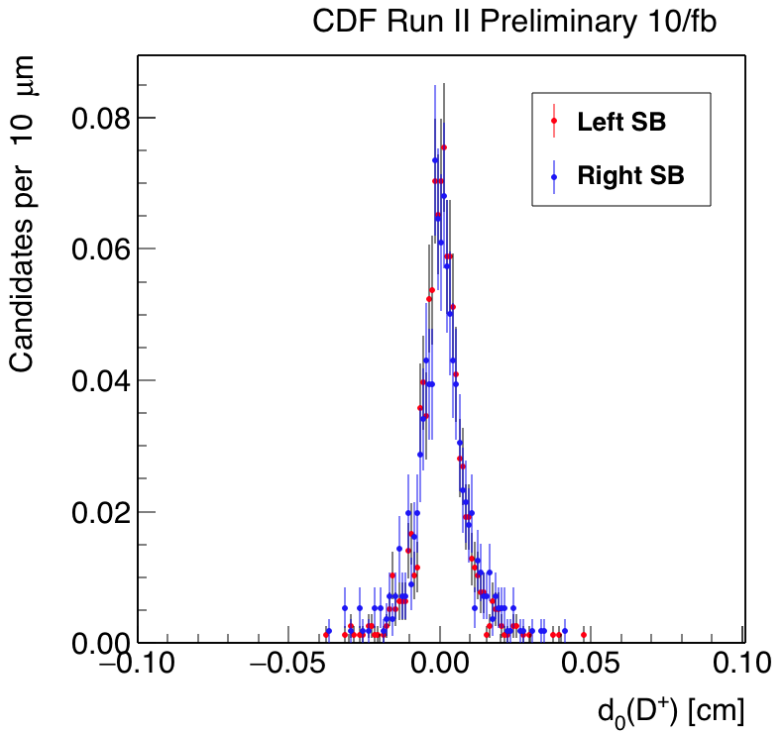
SIGNAL AND BACKGROUND

SIGNAL REGION: $\left[m_D - 3\sigma, m_D + 3\sigma\right]$ σ from MC

ODD sample 6.5 <$p_T(D^+)$ < 14.5 GeV/c



Compare d_0 distributions for left and right Sidebands

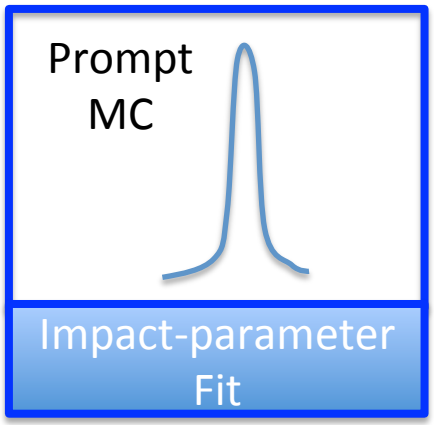


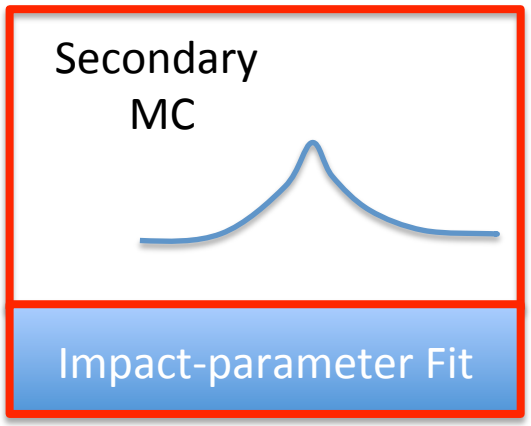
KOLMOGOROV – SMIRNOV TEST: 90%

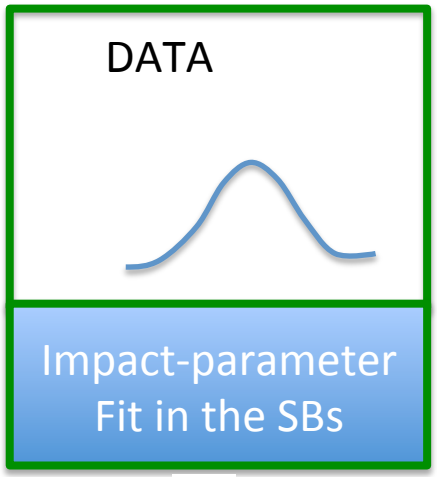
We handle them together

SHAPE EXTRACTION

$d_0(D^+)$

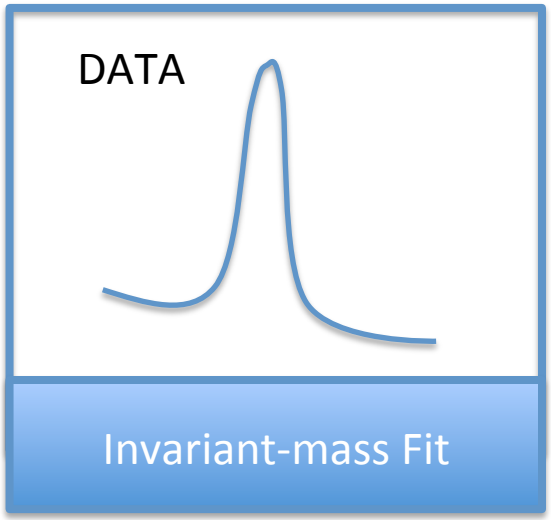






$$L(f_P, f_S, \vec{\theta}_P, \vec{\theta}_S, \vec{\theta}_C) = f_P \cdot F_P(m, d_0; \vec{\theta_P}) + f_S \cdot F_S(m, d_0; \vec{\theta_S}) + (1 - f_P - f_S) \cdot F_C(m, d_0; \vec{\theta_C})$$

MASS

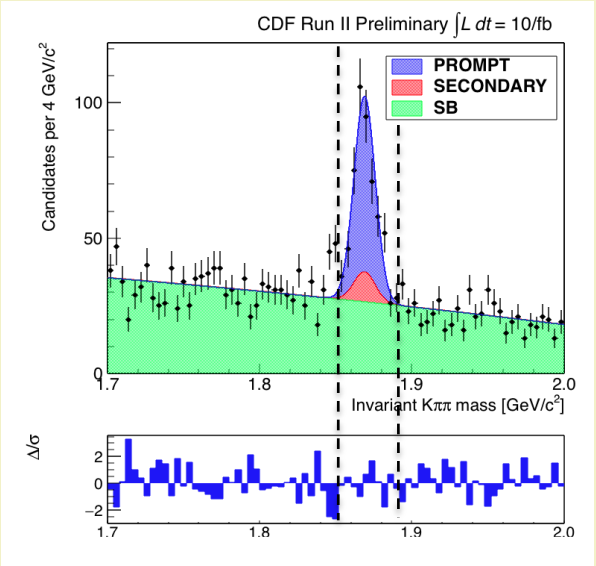


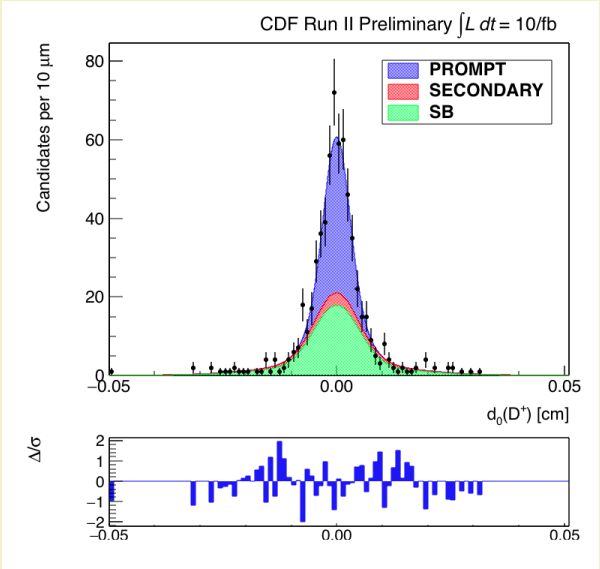
$6.5 < p_T(D^+) < 14.5$ GeV/c

EVEN EVENTS

$N_D = 278 \pm 24$

Invariant mass



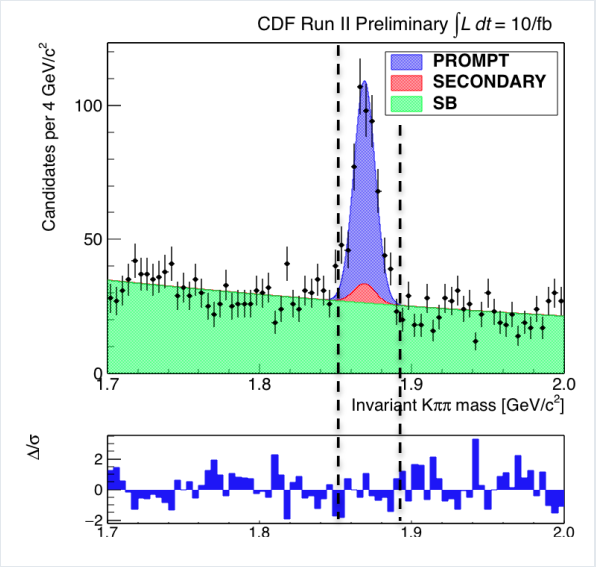


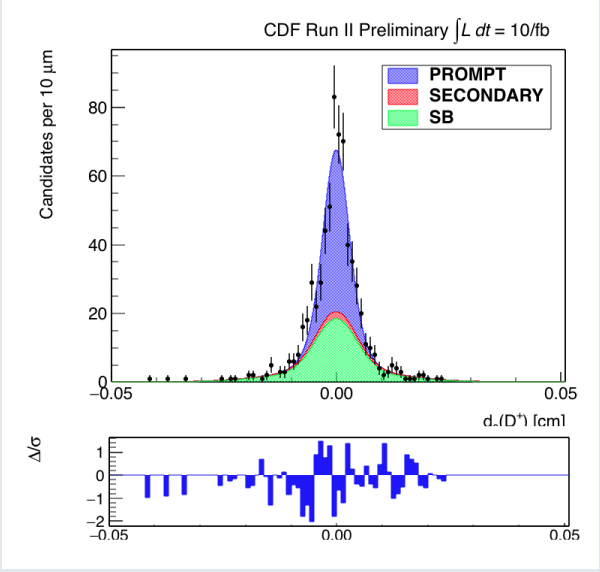
$d_0(D^+)$ **SIGNAL REGION**

ODD EVENTS

$N_D = 327 \pm 24$

Invariant mass





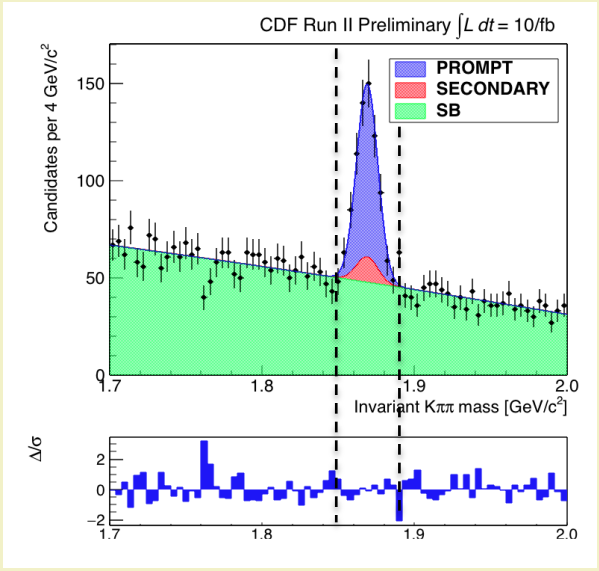
$d_0(D^+)$ **SIGNAL REGION**

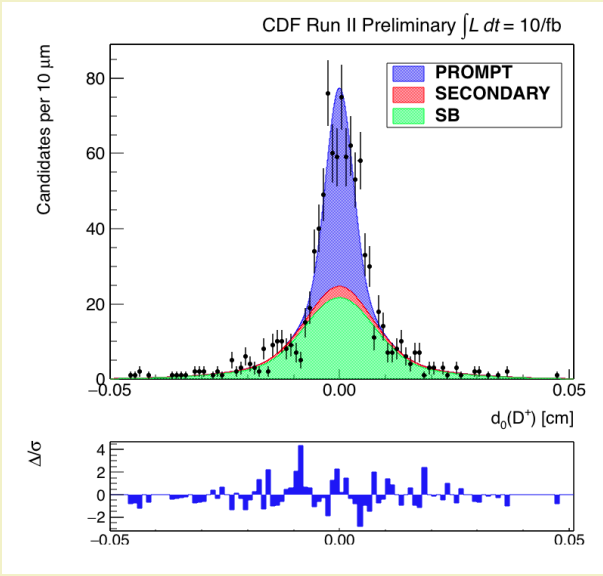
$4.5 < p_T(D^+) < 6.5$ GeV/c

EVEN EVENTS

$N_D = 384 \pm 29$

Invariant mass



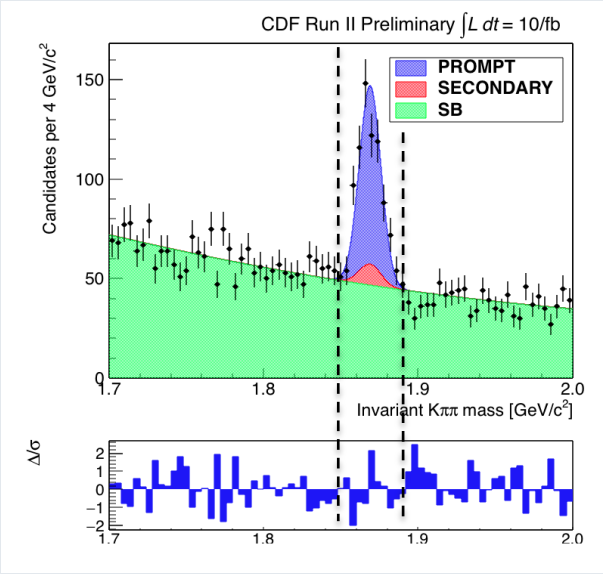


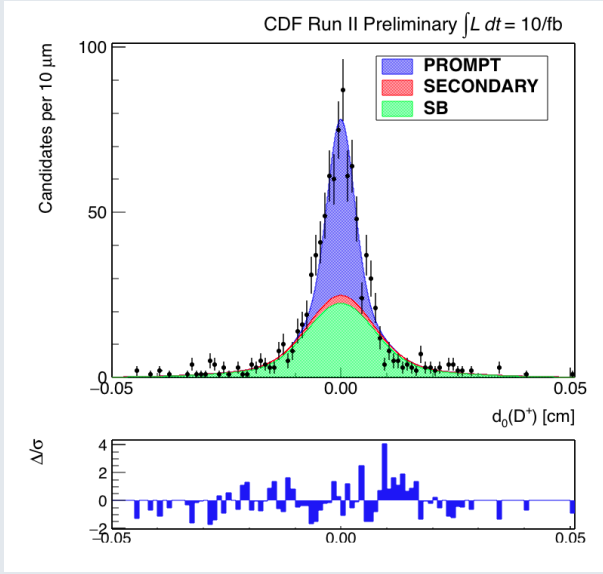
$d_0(D^+)$ **SIGNAL REGION**

ODD EVENTS

$N_D = 389 \pm 30$

Invariant mass





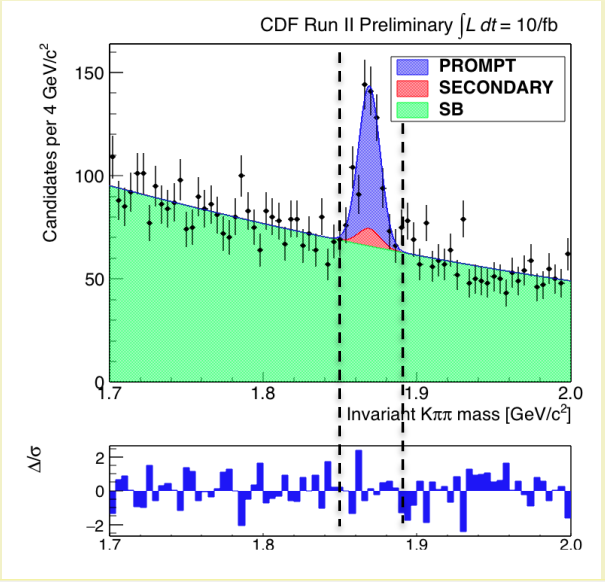
$d_0(D^+)$ **SIGNAL REGION**

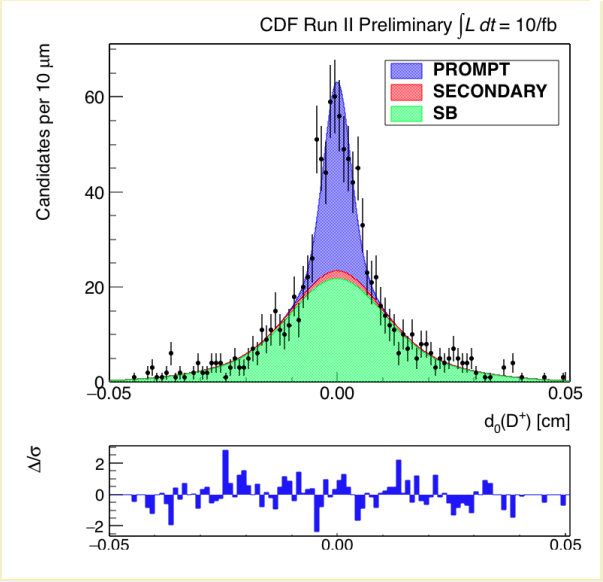
$3.5 < p_T(D^+) < 4.5$ GeV/c

EVEN EVENTS

$N_D = 301 \pm 28$

Invariant mass



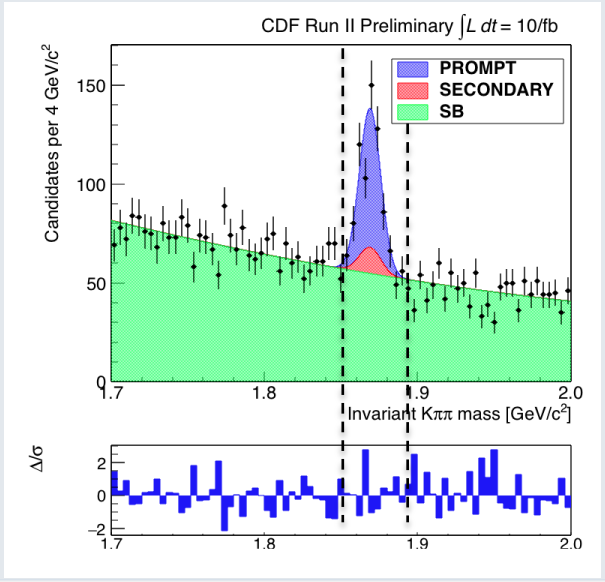


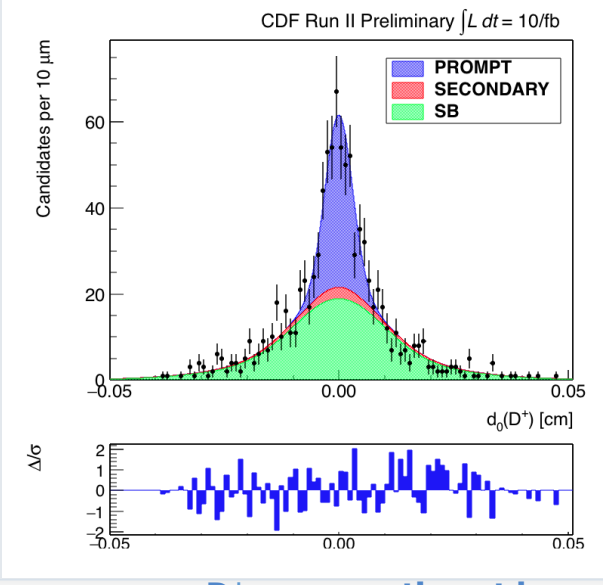
$d_0(D^+)$ **SIGNAL REGION**

ODD EVENTS

$N_D = 304 \pm 28$

Invariant mass





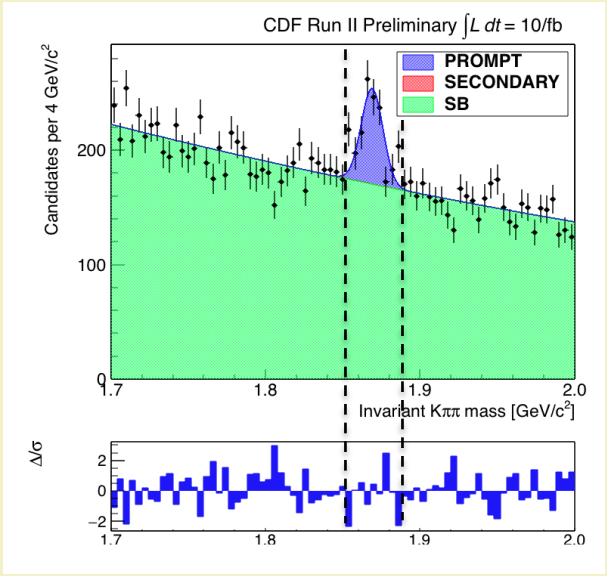
$d_0(D^+)$ **SIGNAL REGION**

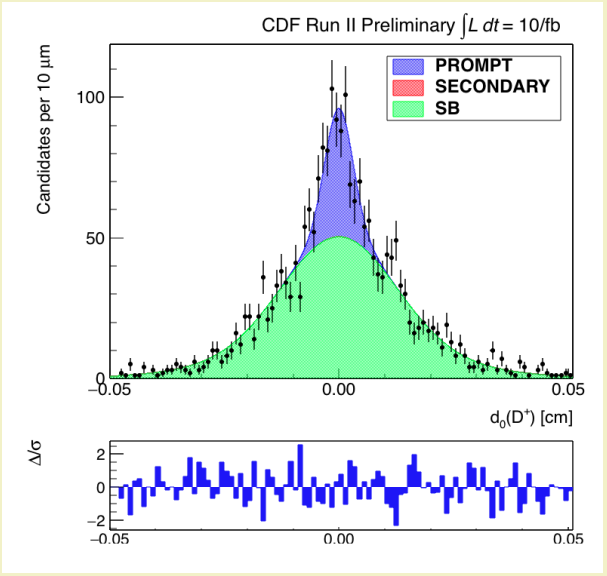
$2.5 < p_T(D^+) < 3.5$ GeV/c

EVEN EVENTS

$N_D = 366 \pm 33$

Invariant mass



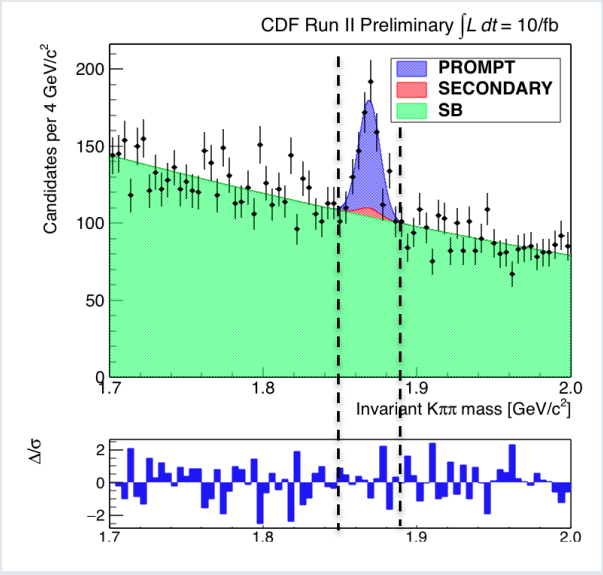


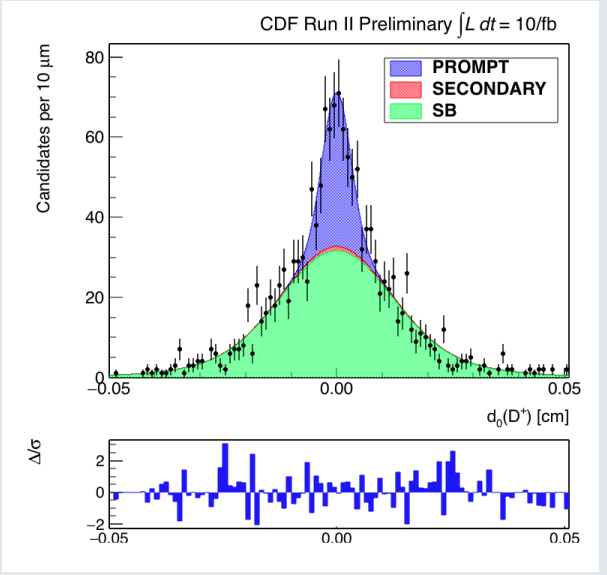
$d_0(D^+)$ **SIGNAL REGION**

ODD EVENTS

$N_D = 307 \pm 34$

Invariant mass

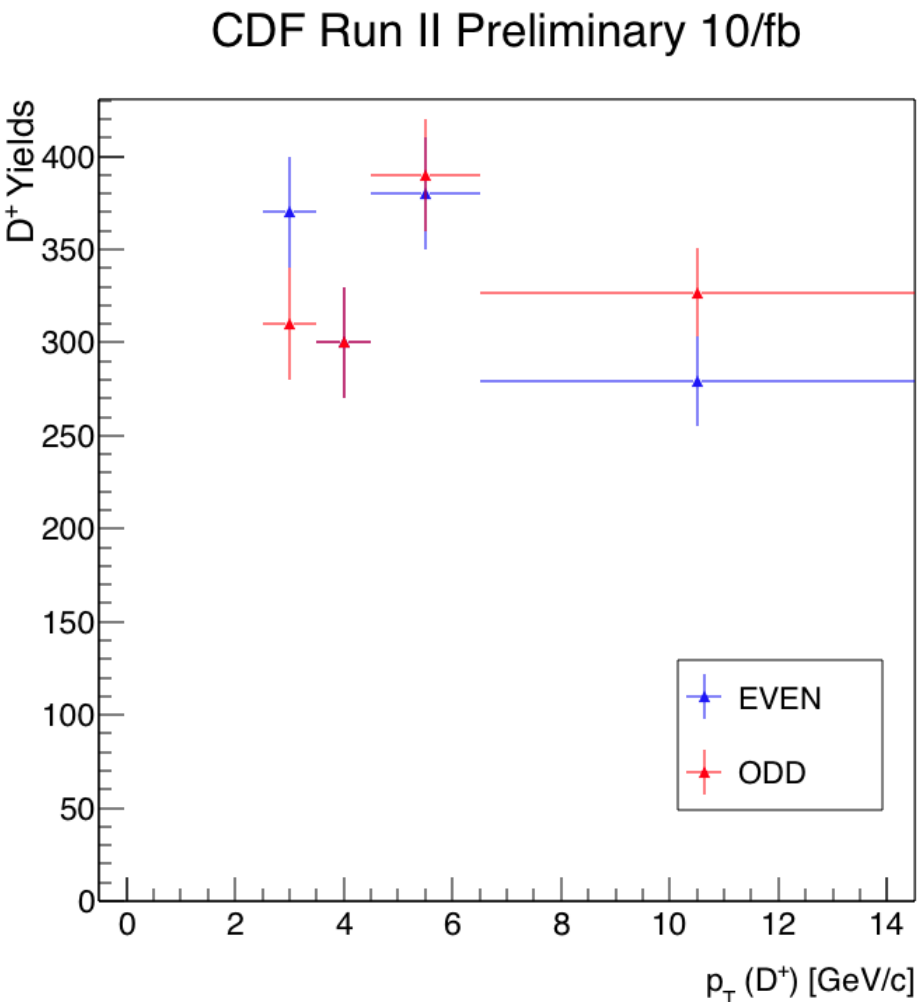




$d_0(D^+)$ **SIGNAL REGION**

D^+ YIELDS

$p_T(D^+)$ [GeV/c]	SAMPLE	YIELDS
[2.5, 3.5]	EVEN	366±33
	ODD	307±34
[3.5, 4.5]	EVEN	301±28
	ODD	304±28
[4.5, 6.5]	EVEN	384±29
	ODD	389±30
[6.5, 13.5]	EVEN	278±24
	ODD	327±24



The numbers need not be the same within errors when the selection criteria are different

CONCLUSIONS

- ☑ We have presented the D^+ yields extraction as a function of $p_T(D^+)$
- ❑ Reconstruction and Triggers efficiency
- ❑ Systematic uncertainties

- This will be the first collider measurement of the production cross section of the D^+ in the range

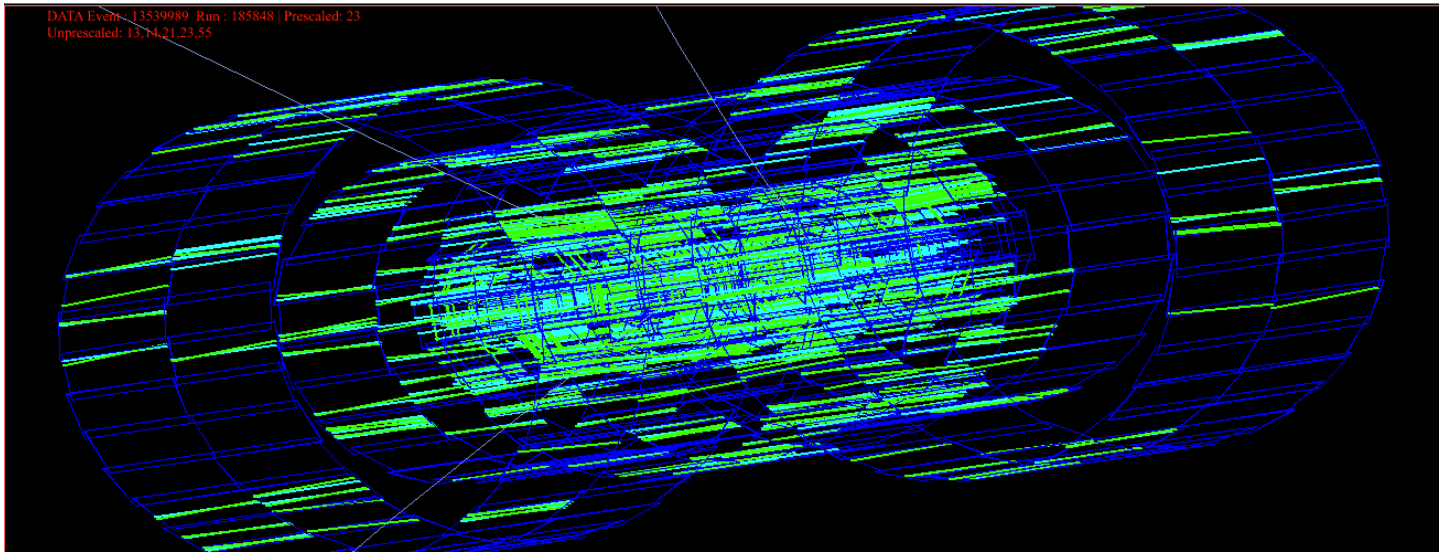
$$p_T(D^+) \in [1.5; 20] GeV/c$$

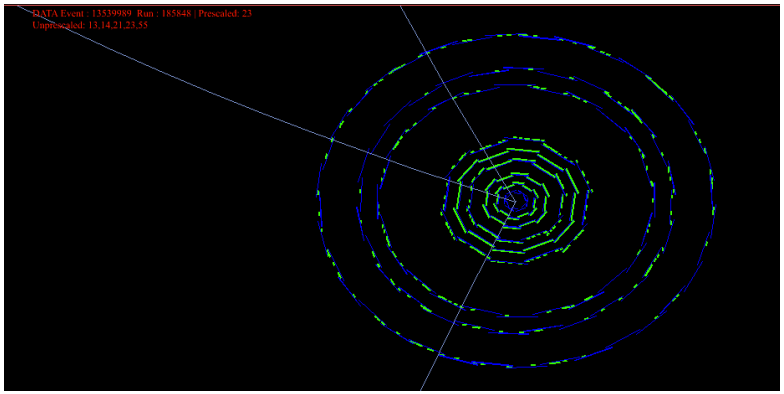
- Even if ALICE and LHCb will probe the same range, this measurement still has unique value: different initial state ($p\bar{p}$) and different $\sqrt{s} = 1.96 TeV$

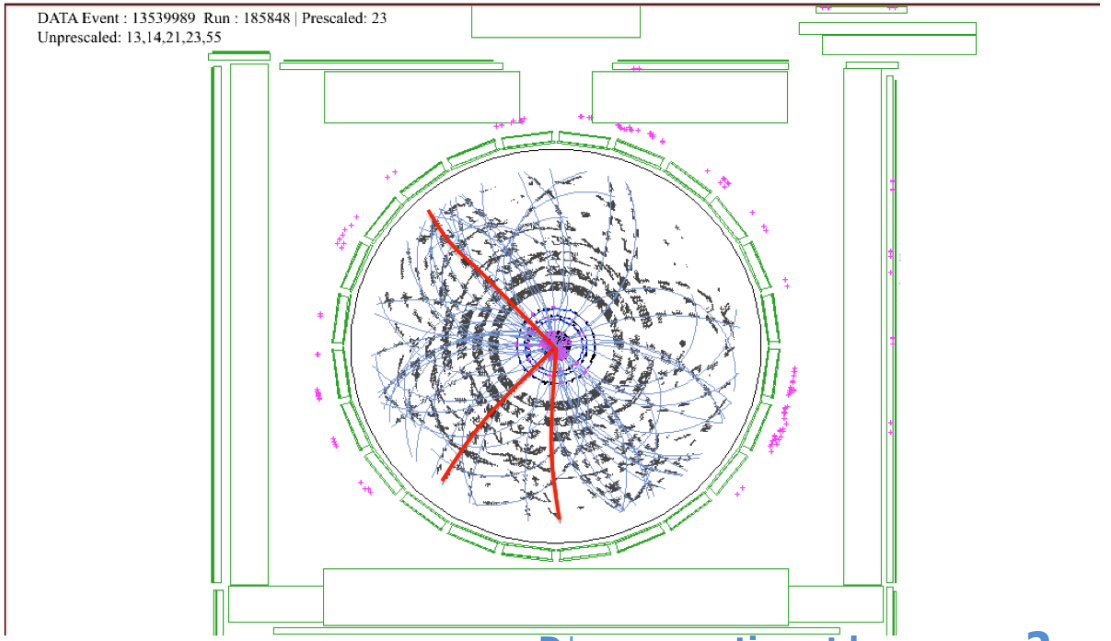

THANKS

BACKUP

SIGNAL: EVENT DISPLAY







DATA SELECTION

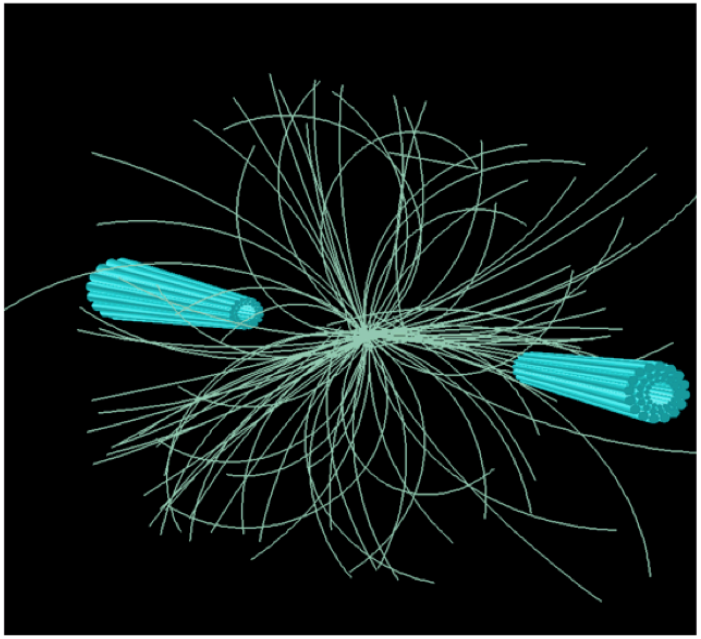
Data collected by two triggers:

1. **Z**ero **B**ias (ZB)

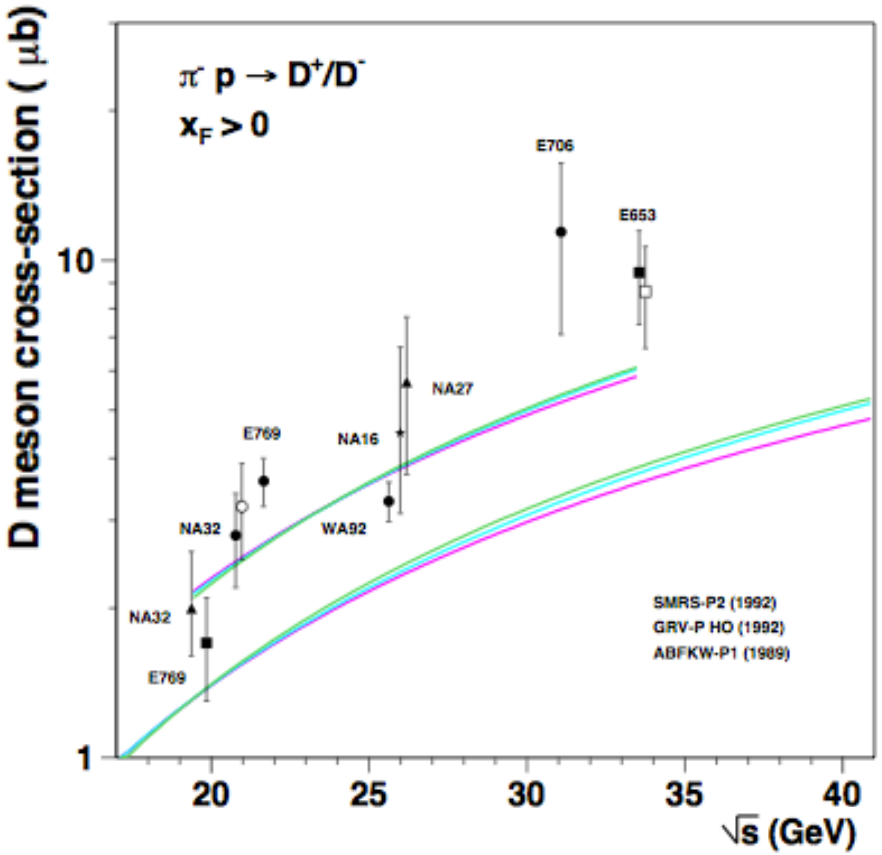
- Events collected every bunch crossing whether or not collisions occur
- Prescale: 10^6
- Rate ~ 1.6 ev/s

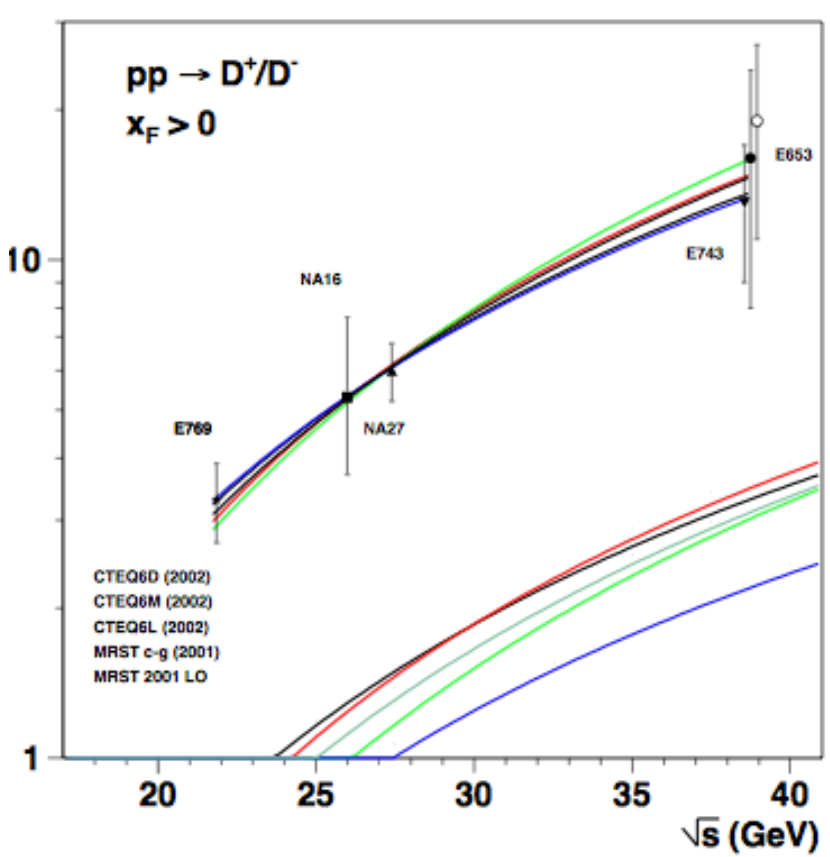
2. **M**inimum **B**ias (MB)

- At least one inelastic $p\bar{p}$ collision
- CLC (Cherenkov Luminosity Counters) signal coincidence
- Prescale: 10^5 + rate limit to 1 Hz at Level 3
- Rate ~ 1 ev/s.

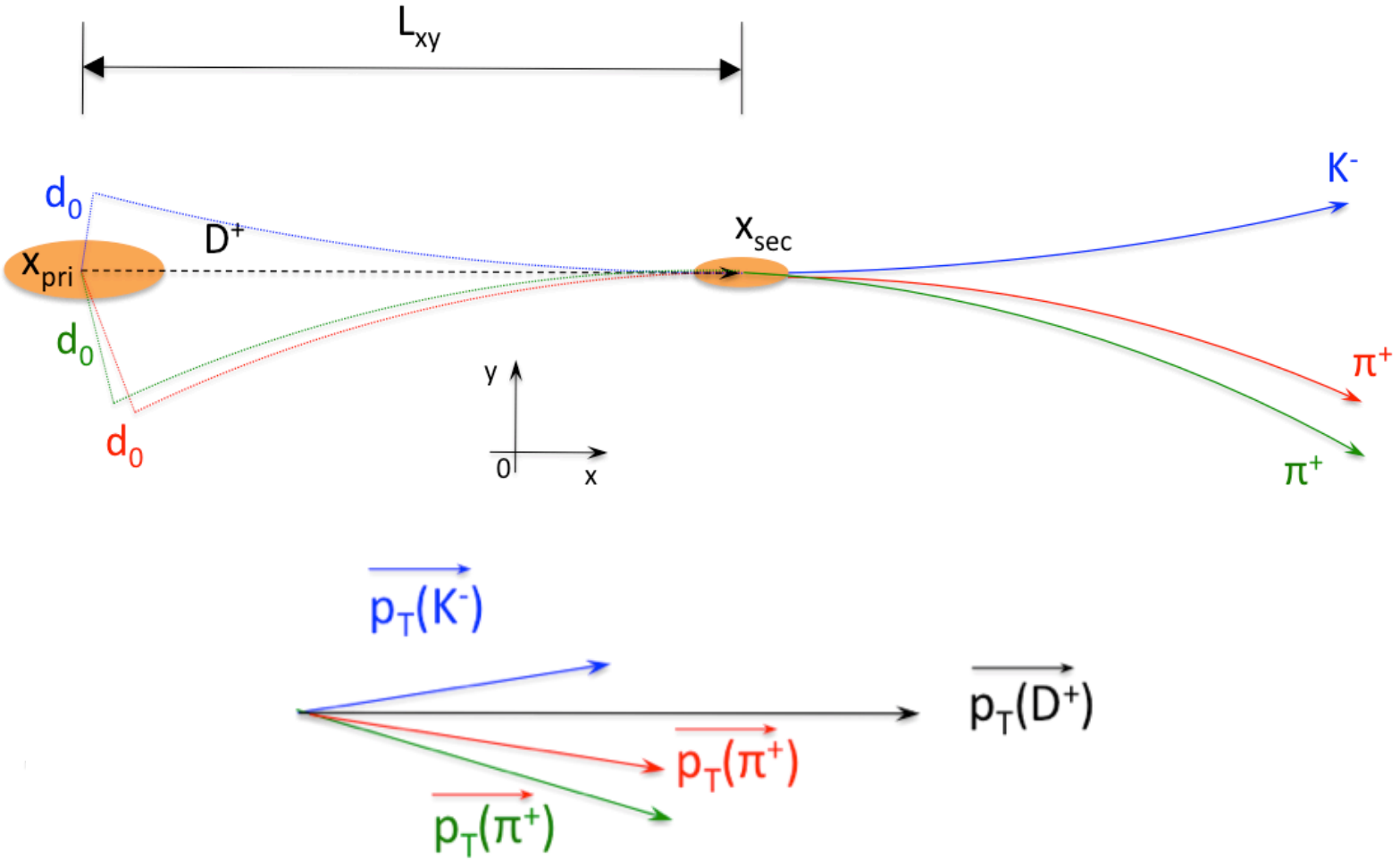


FIXED TARGET EXPERIMENTS





SIGNAL: D^+ TOPOLOGY



OPTIMIZATION VARIABLES

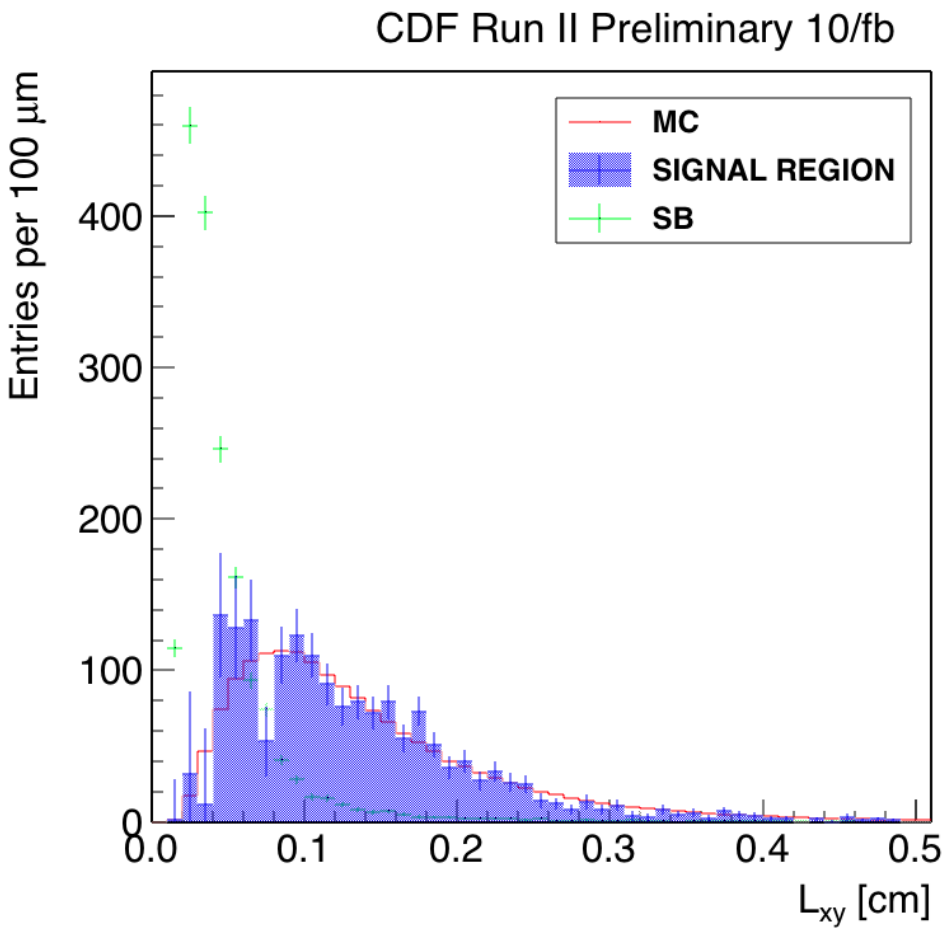
Marginal distributions looking at:

- Sidebands (SBs): **[1.7; 1.8] GeV/c^2 and [1.9; 2.0] GeV/c^2**
- Signal region: **[m_D- 3σ; m_D+ 3σ]**
- Monte Carlo (MC):
  B GENERATOR ➡ SIGNAL ONLY

SELECTION

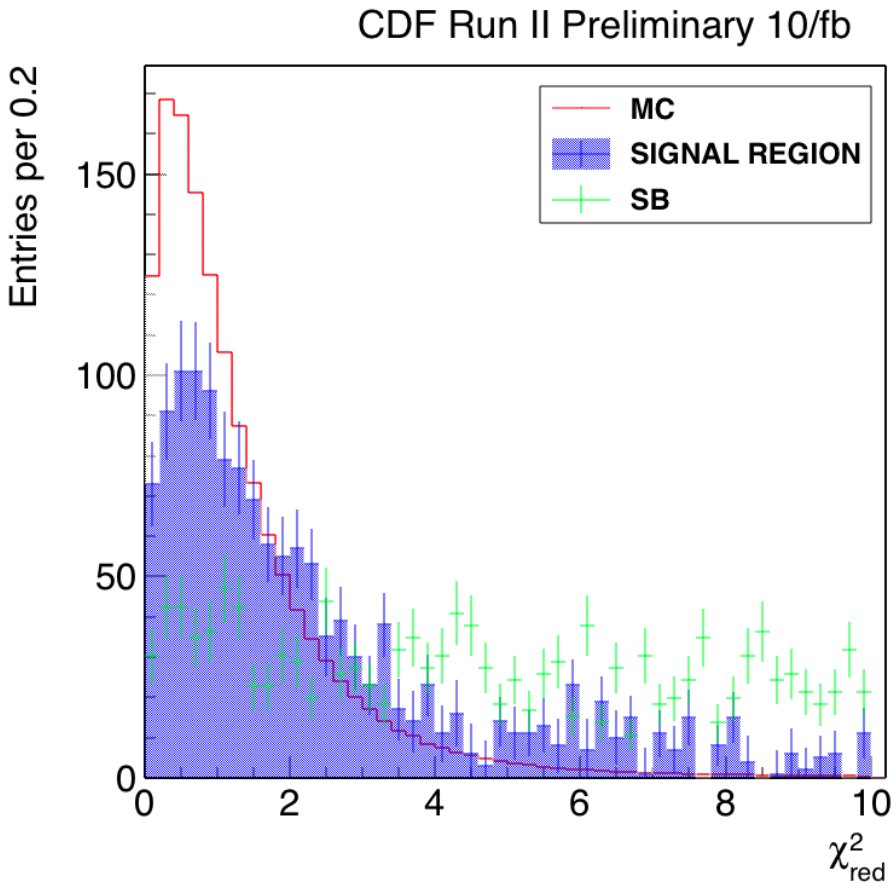
- **Any two p_T(TRK) ≥ 0.8 GeV/c**
- **Maximum and minimum $|d_0|$ of the triplet ≥ 110 μm**
- **χ^2_{red} ≤ 4**
- **L_{xy} ≥ 900 μm**

$p_T(D^+)$ > 1.5 GeV/c

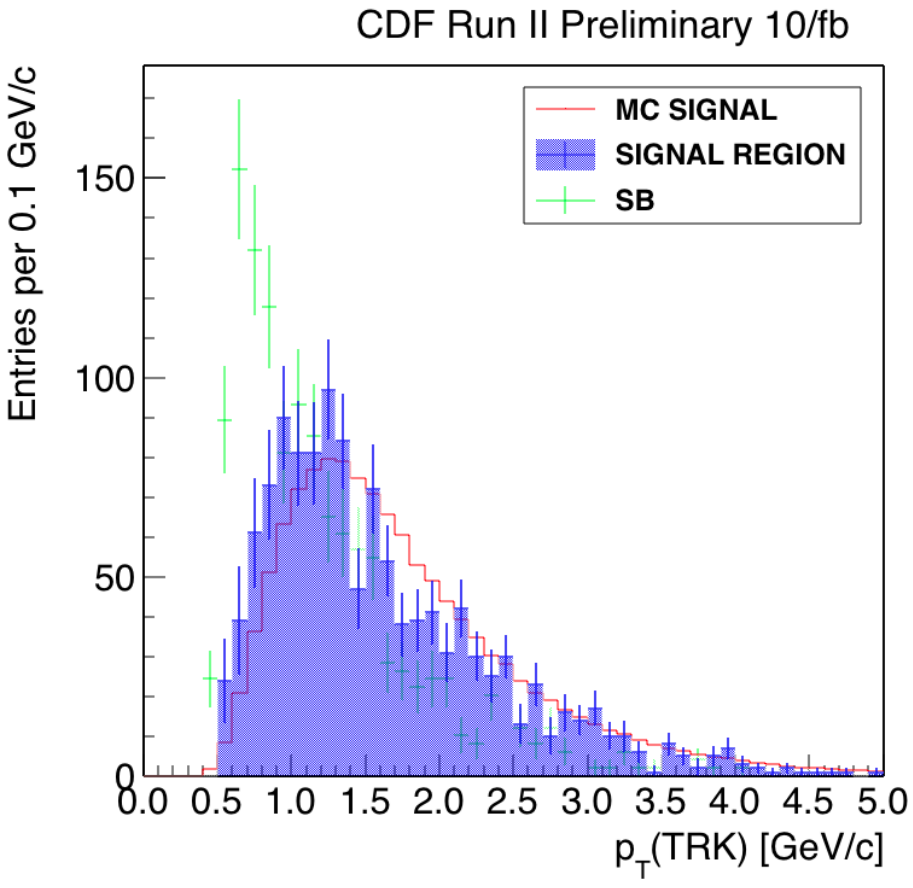


OPTIMIZATION VARIABLES

$p_T(D^+) > 1.5$ GeV/c



$p_T(D^+) > 1.5$ GeV/c



OPTIMIZATION RESULTS

$p_T(D^+)$ [GeV/c]	PARITY	Any two p_T(TRK) ≥ [GeV/c]	χ^2/ndf ≤	L_{xy} ≥ [cm]
[2.5, 3.5]	EVEN	0.6	2	0.0600
	ODD	0.6	3	0.0600
[3.5, 4.5]	EVEN	0.7	5	0.0750
	ODD	0.7	5	0.0750
[4.5, 6.5]	EVEN	0.9	6	0.0750
	ODD	0.9	6	0.0750
[6.5, 13.5]	EVEN	1.1	7	0.0750
	ODD	1.1	7	0.0750
≥ 1.5	EVEN	0.7	4	0.0750
	ODD	0.8	4	0.0750

$|d_0(D^+)| \leq 100\ \mu m$

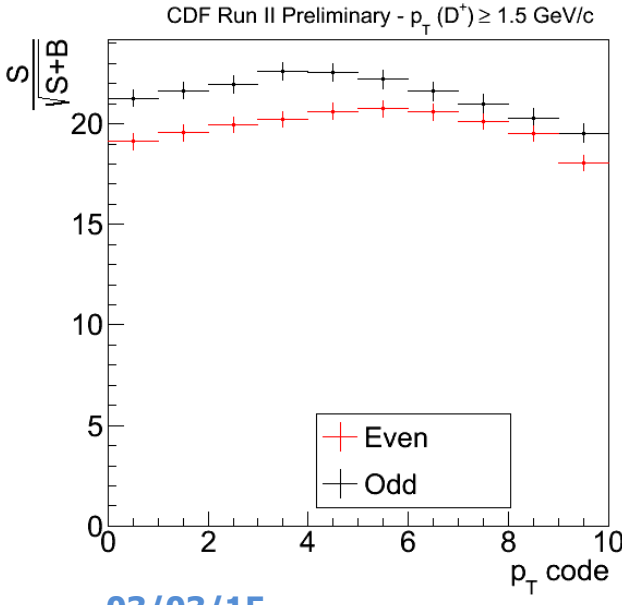
CHECK OF THE OPTIMIZATION

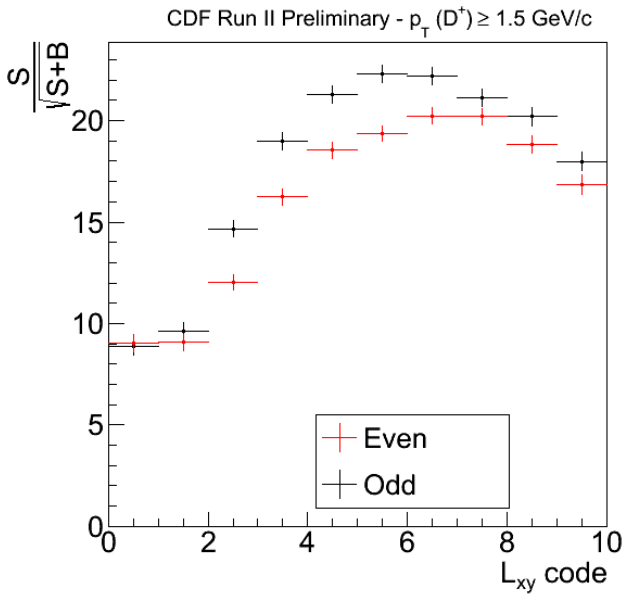
RANDOM criterion used to split the sample in odd and even subsamples

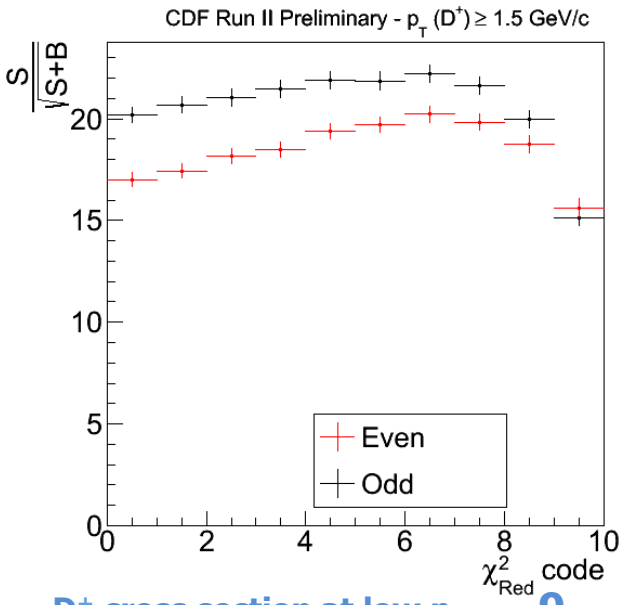
IDEAL CASE: infinite statistics → **SAME** optimized configuration for even and odd subsamples

Strong dependence on the subsamples **?** Fluctuations due to the optimization procedure

MARGINAL-DISTRIBUTIONS

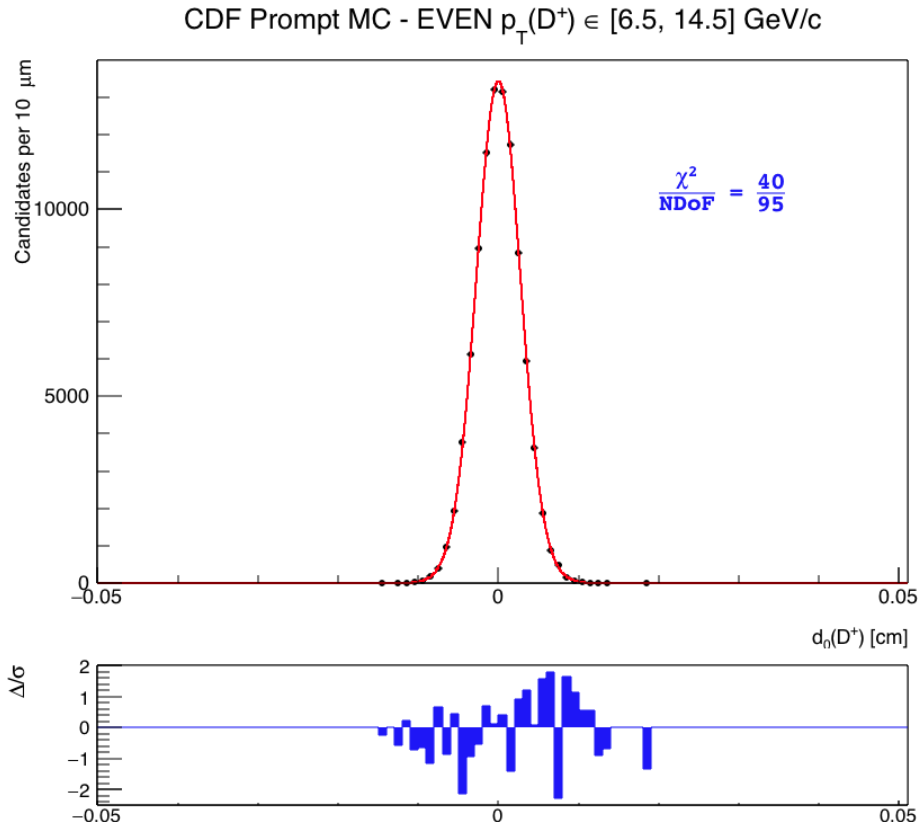


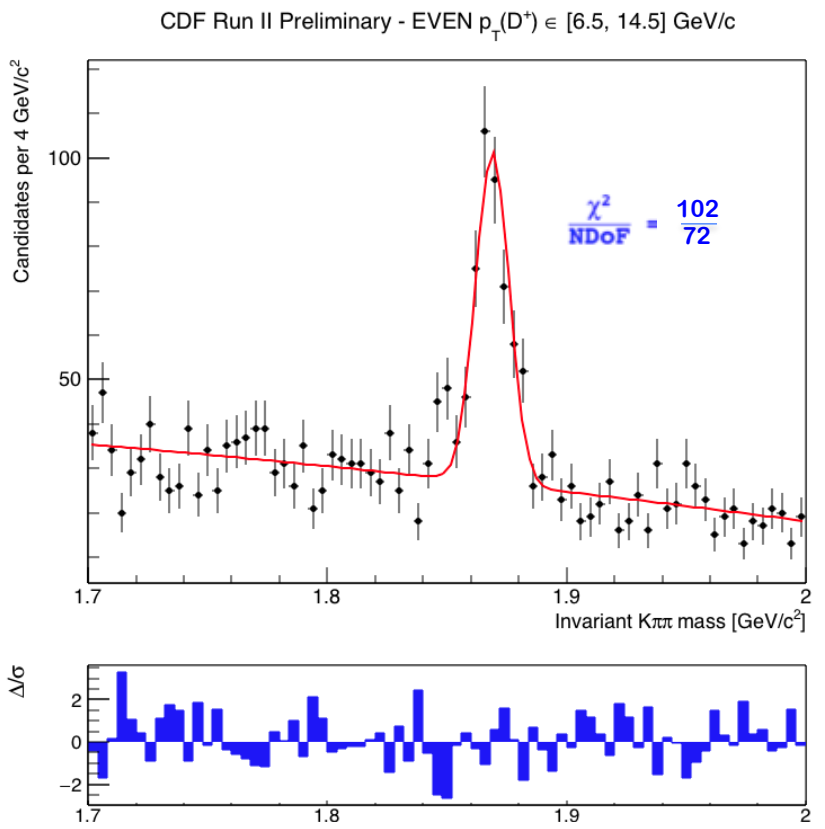




SHAPE EXTRACTION

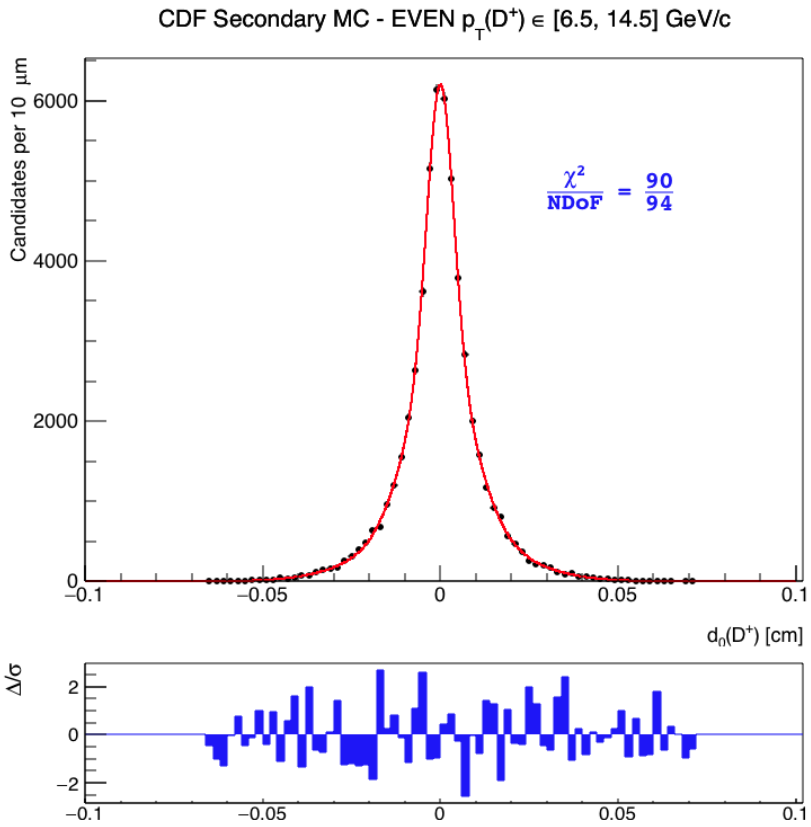
PROMPT COMPONENT

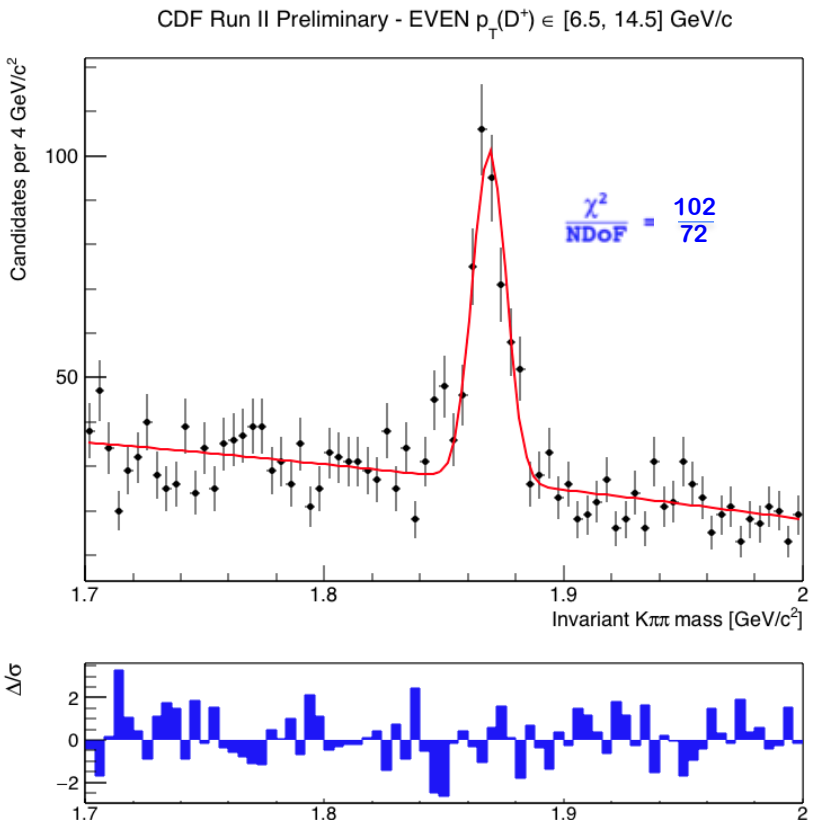




SHAPE EXTRACTION

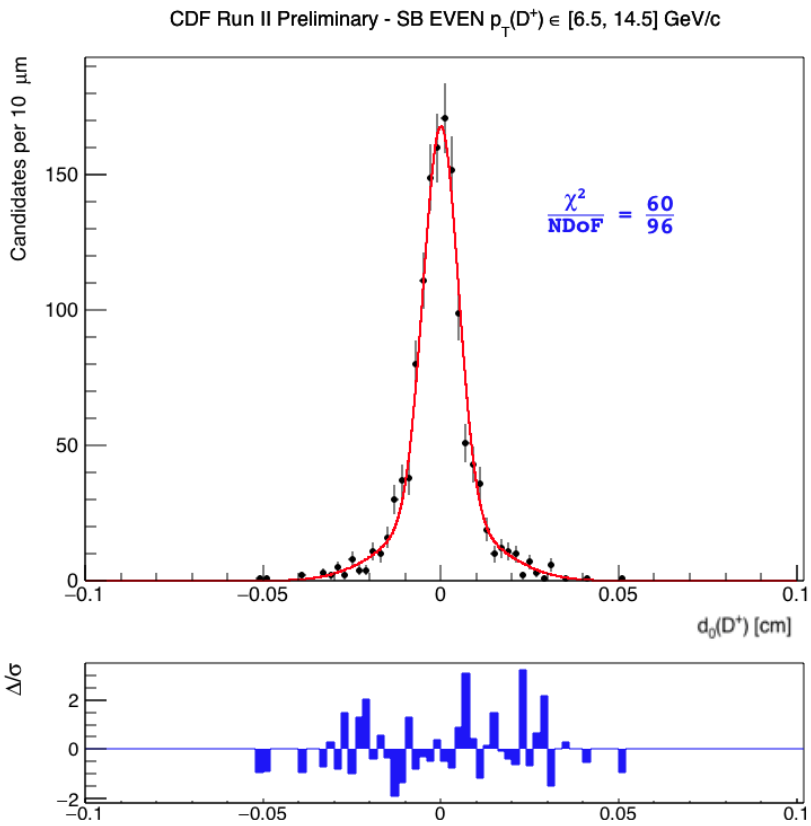
SECONDARY COMPONENT

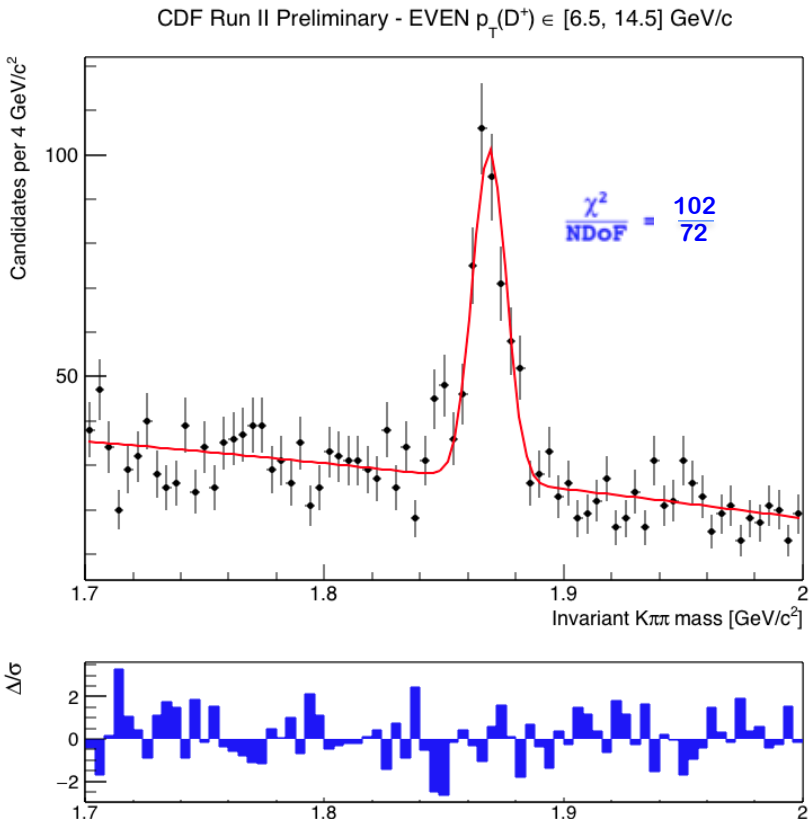




SHAPE EXTRACTION

COMBINATORICS COMPONENT

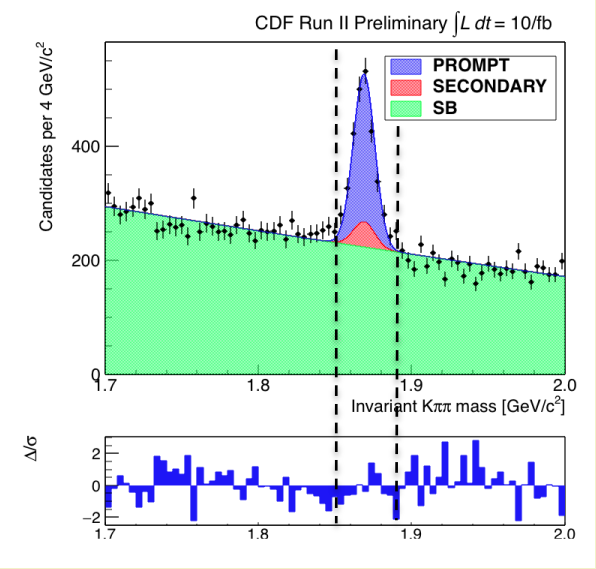


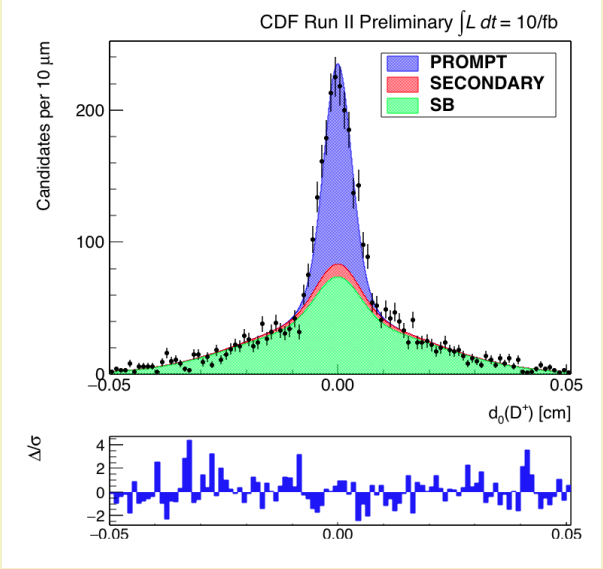


$p_T(D^+) \geq 1.5$ GeV/c

EVEN EVENTS

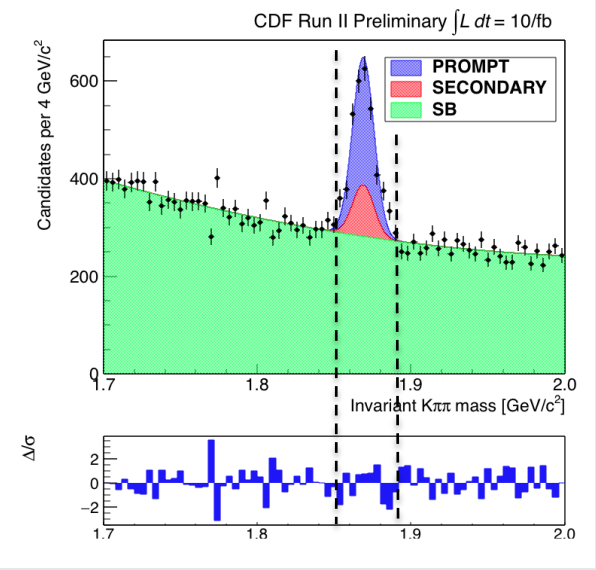
$N_D = 1124 \pm 56$

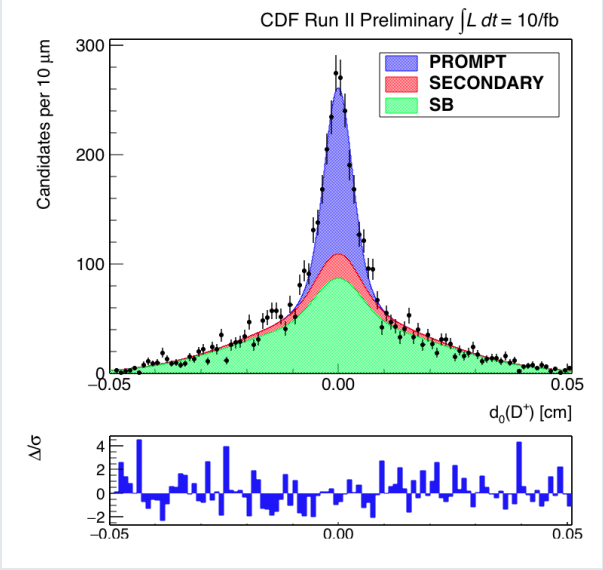




ODD EVENTS

$N_D = 1125 \pm 58$





FIT STRATEGY

WHAT?

- We want to estimate the effect of the statistical uncertainty of the shapes on the final result

We find it to be very small

HINT:

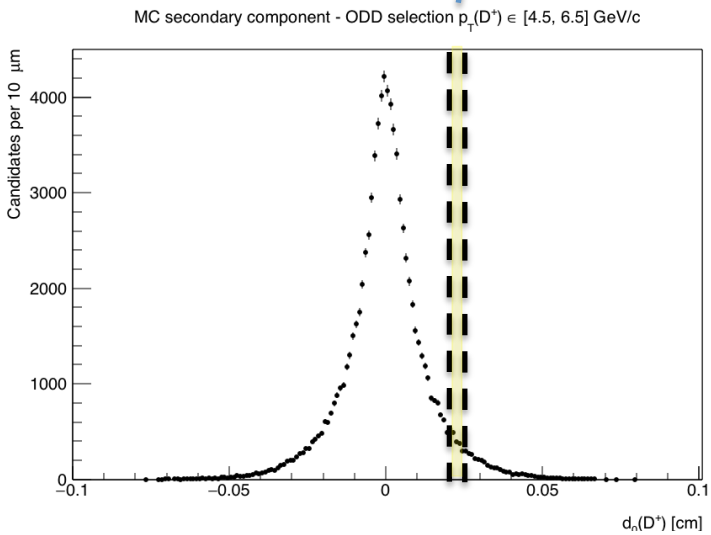
- Unbinned maximum likelihood fit on all the parameters

Troubles in the converging procedure

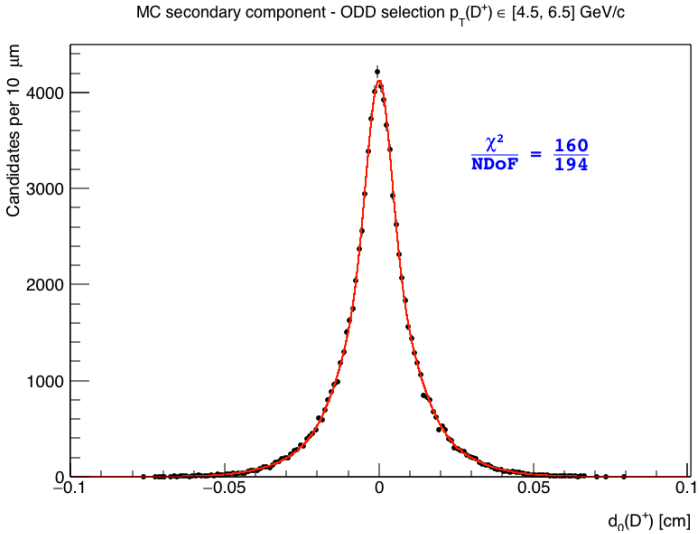
METHOD USED TO EVALUATE THE EFFECT OF THE STATISTICAL UNCERTAINTY OF THE SHAPES

HOW?

- For each template, we Poisson fluctuate the content of each histo bin



New fits to get new shapes

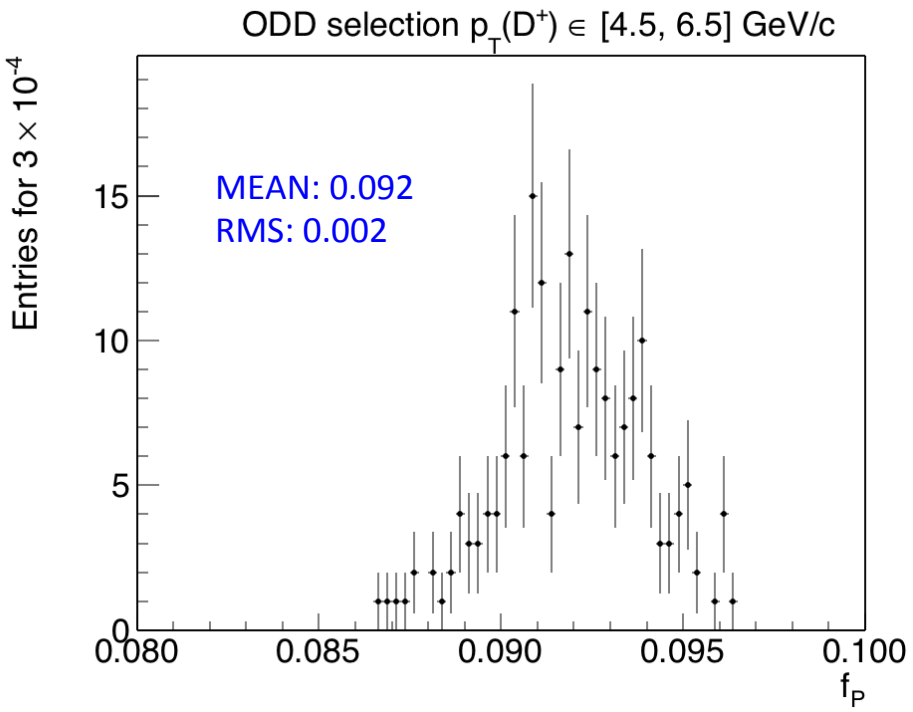


NEW FINAL FIT to determine f_P and f_S

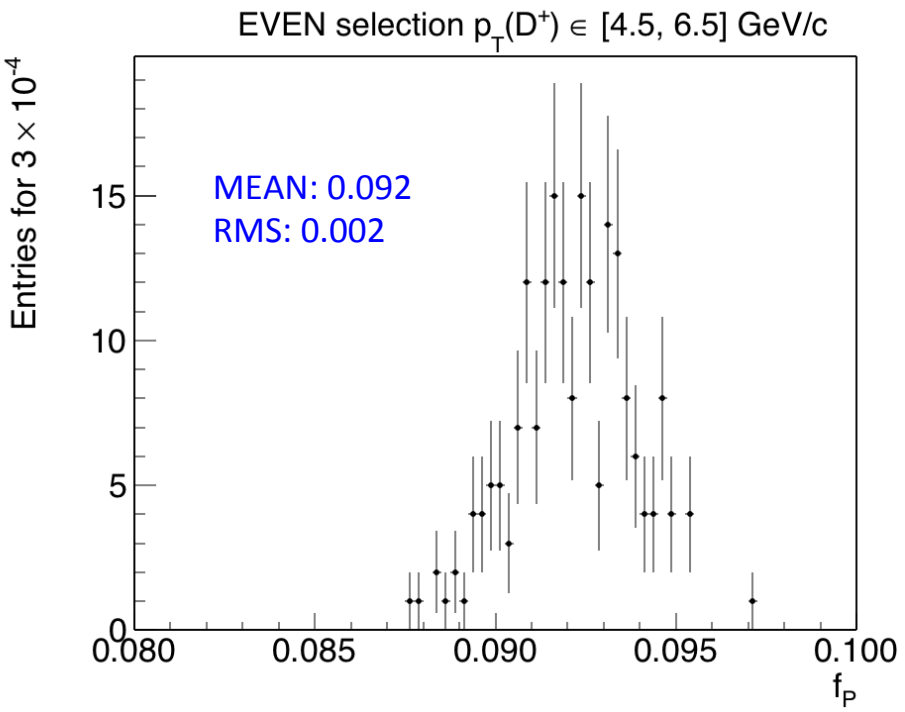
METHOD USED TO EVALUATE THE EFFECT OF THE STATISTICAL UNCERTAINTY OF THE SHAPES

DISTRIBUTIONS of the PROMPT fractions

EVEN EVENTS



ODD EVENTS



METHOD USED TO EVALUATE THE EFFECT OF THE STATISTICAL UNCERTAINTY OF THE SHAPES

$p_T(D^+)$ [GeV/c]	PARITY	YIELD	σ_{Pois} contribution	YIELDS
[2.5, 3.5]	EVEN	366±33	2%	370±33
	ODD	307±34	1%	310±34
[3.5, 4.5]	EVEN	301±28	2%	300±29
	ODD	304±28	2%	300±29
[4.5, 6.5]	EVEN	384±29	2%	380±30
	ODD	389±30	2%	390±31
[6.5, 13.5]	EVEN	278±24	2%	279±25
	ODD	327±24	2%	327±25

LUMINOSITY

$$L = \frac{R_{p\bar{p}}}{\sigma_{in} \cdot \varepsilon_{CLC}}$$

- $R_{p\bar{p}}$: rate of the $p\bar{p}$ inelastic events
- σ_{in} : rate of the inelastic $p\bar{p}$ cross section at $\sqrt{s} = 1.96 TeV$
- ε_{CLC} : CLCs acceptance

INTEGRATED LUMINOSITY

$L = 15.7 \pm 0.9\ nb^{-1}$

SIGNAL AND BACKGROUND

SIGNAL: $D^+ \to K^-\pi^+\pi^+(+c.c.)$ **BR:** $(9.13 \pm 0.19)\%$

BACKGROUND

- **Secondary component:** $B \to D^+X$
- **Combinatorics**