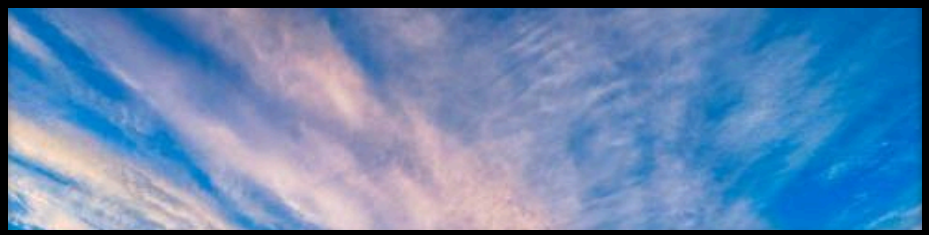





LUIGI Marchese
Oxford university

APERITIVO SCIENTIFICO

Università di Bologna

September 9, 2016

Measurement of low-p_T charm-meson production cross-section at CDF

APERITIVO SCIENTIFICO

Colour by
QCD

September 9, 2016

UNIVERSITY OF OXFORD

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

APERITIVO SCIENTIFICO

Colour by
QCD

September 9, 2016

UNIVERSITY OF OXFORD

CONTENTS

- Motivations
- Signal and Background
- Detector overview
- D^+ extraction
- Efficiency
- Systematics
- Cross Section
- Conclusions

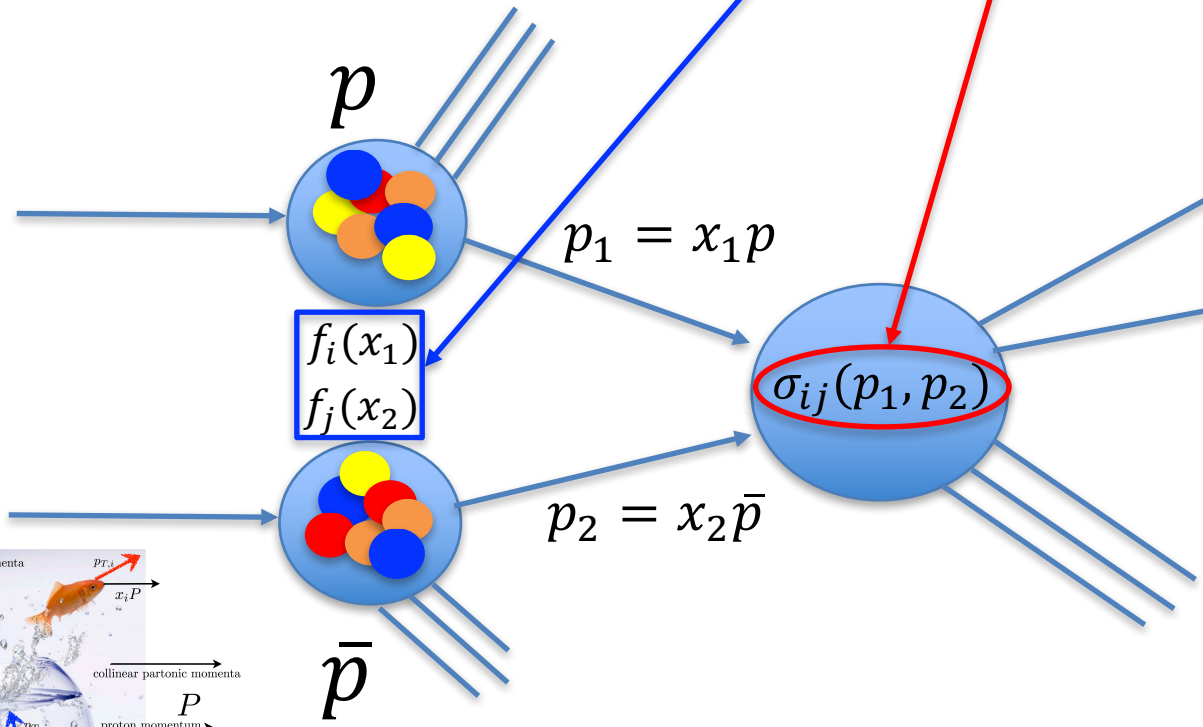
"IT'S BORN. IT'S A CHARM. CONGRATULATIONS!"

HADRONIC PRODUCTION

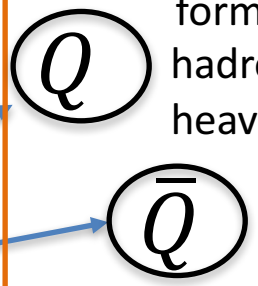
Parton-Density-Function (PDF) within the hadron

Partonic cross section

$$\sigma = \sum_{ij} \int f_i(x_1, \mu_F^2) f_j(x_2, \mu_F^2)\, \sigma_{ij}(p_1, p_2)\, dx_1 dx_2$$

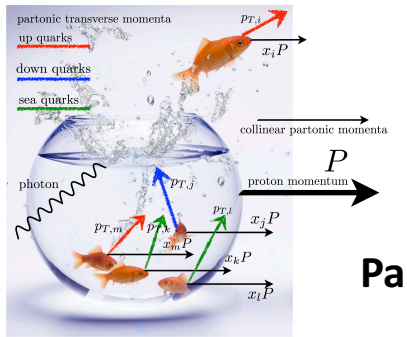


Hadronisation: formation of hadrons with heavy quarks



- if Q = C

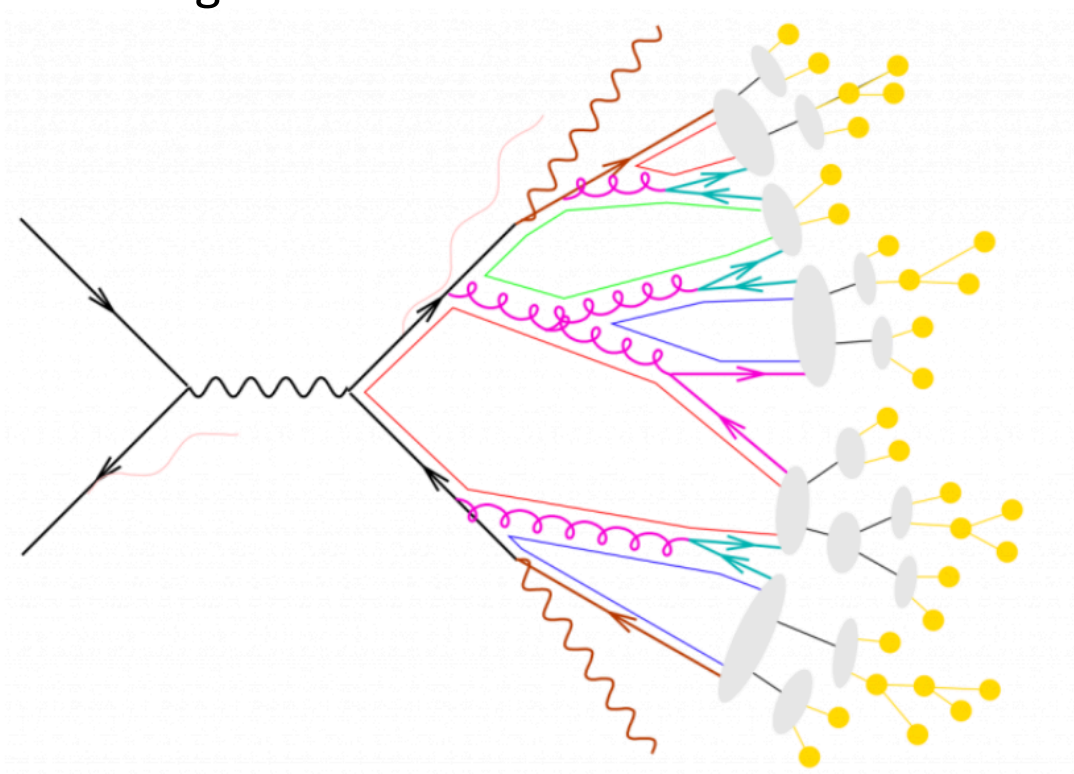
This guy!



Partons (quarks and gluons) are like fishes confined inside a fishbowl (the proton)

CHARM OBSERVABLES

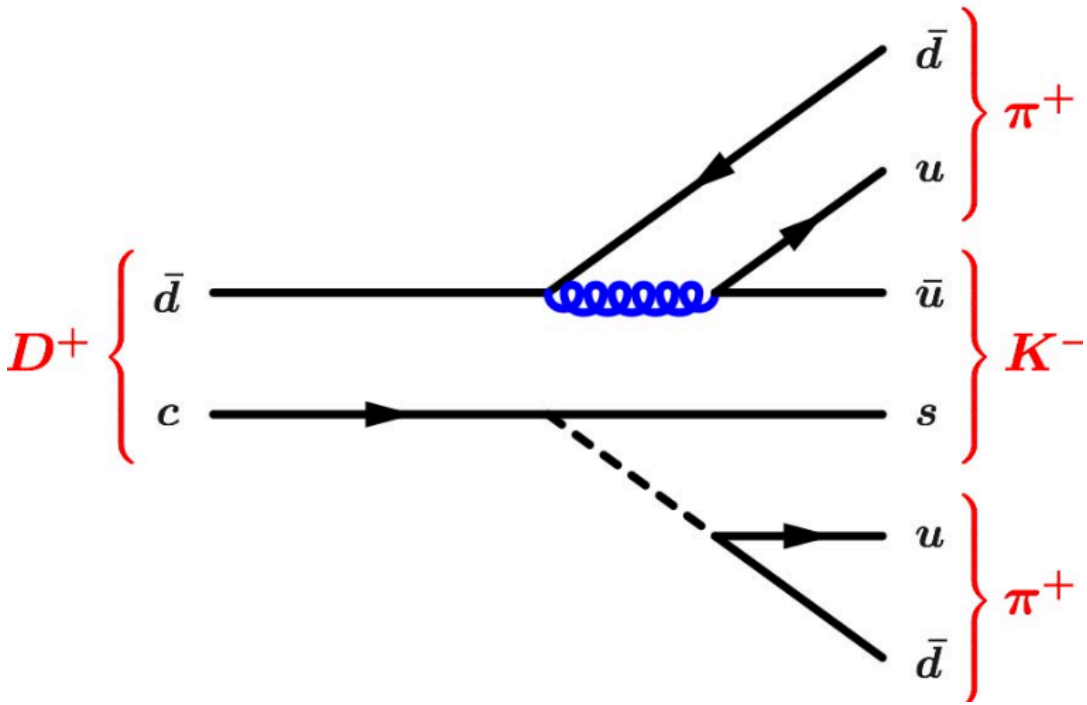
- QCD → $SU(3)_{color}$ symmetry
- Gluons carry color charge



- D hadrons are some of the observables for *c*-quarks

WHY CHARM?

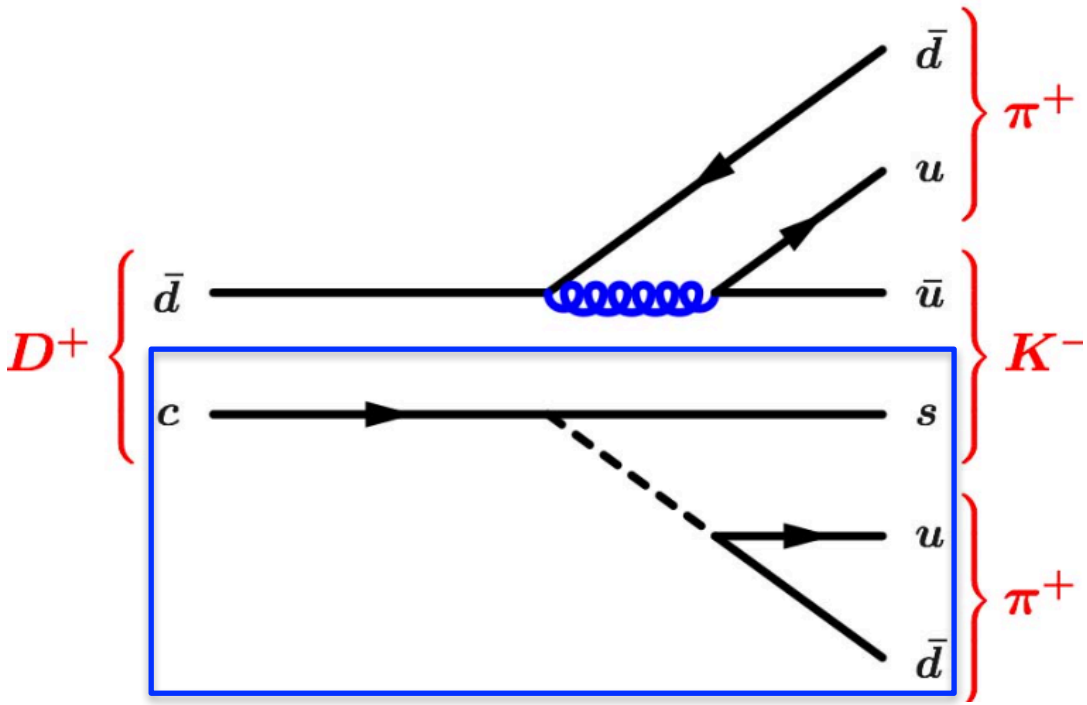
- We can study the production and hadronisation of a heavy up-type quark
- We can study its weak decay



- Lever-arm to study HE neutrinos from charm hadrons produced in cosmic ray interactions with atmospheric nuclei

WHY CHARM?

- We can study the production and hadronisation of a heavy up-type quark
- We can study its weak decay



- Lever-arm to study HE neutrinos from charm hadrons produced in cosmic ray interactions with atmospheric nuclei

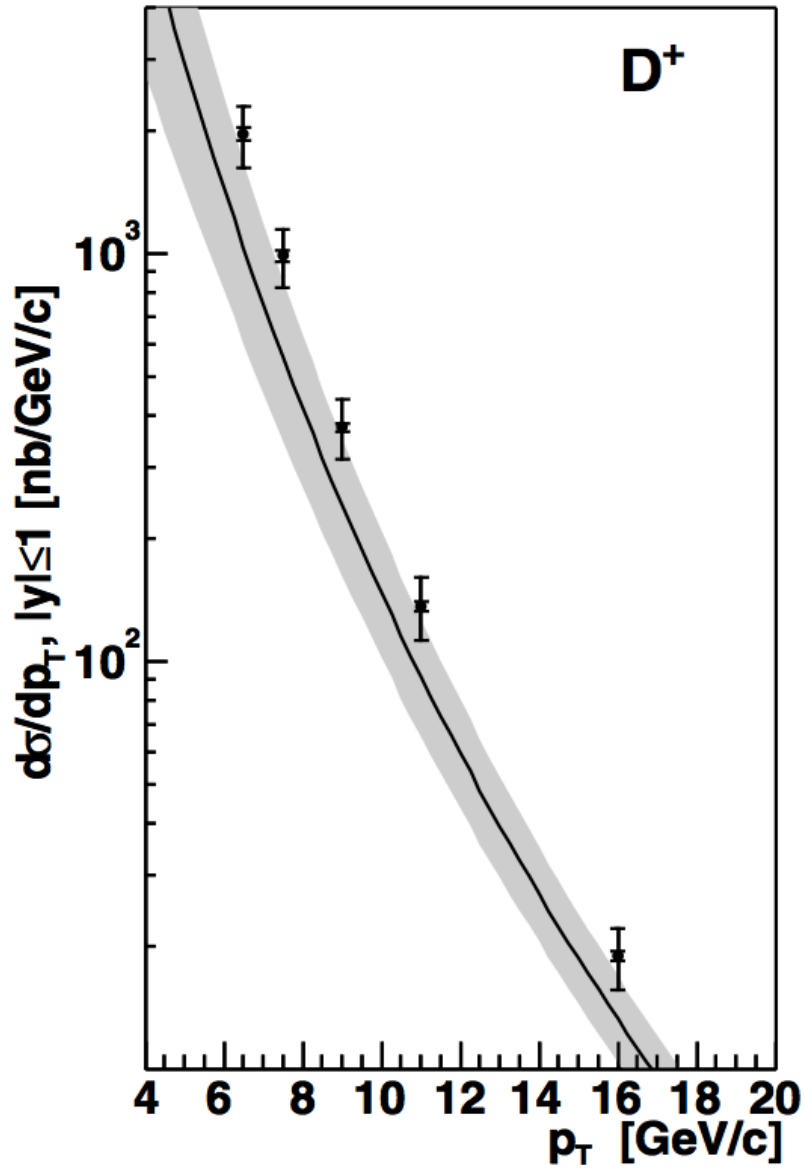
WHY LOW-p_T?

- 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 pQCD have big uncertainties at low-p_T
  [*M. Cacciari et al., JHEP 1210 (2012) 137*]

Experiment	Initial state	√s [Gev]
Many expt's CERN, FNAL	K, p, π Nucl. tgts.	up to 40
LHCb	pp	7, 13 $\cdot 10^3$
ALICE	pp	7, 2.76 $\cdot 10^3$
ATLAS	pp	7 $\cdot 10^3$

PRL 91,241804(2003)



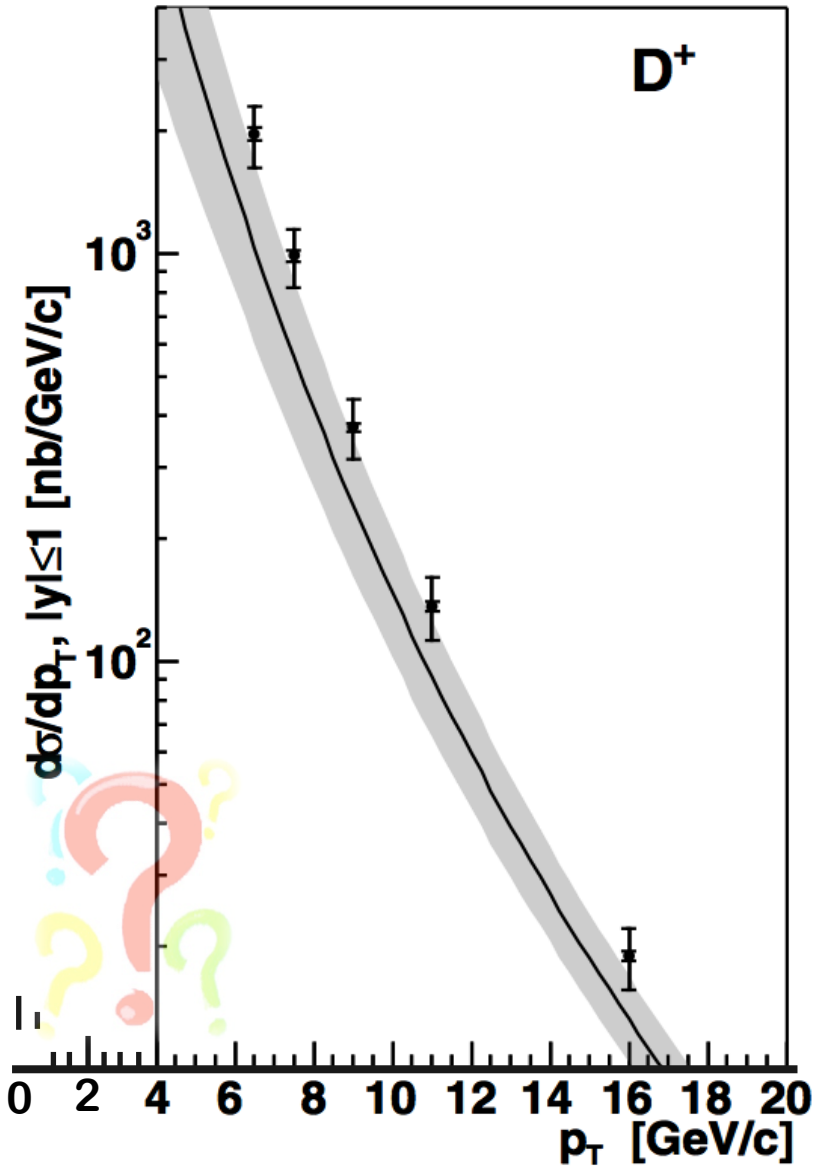
WHY LOW-p_T?

- 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

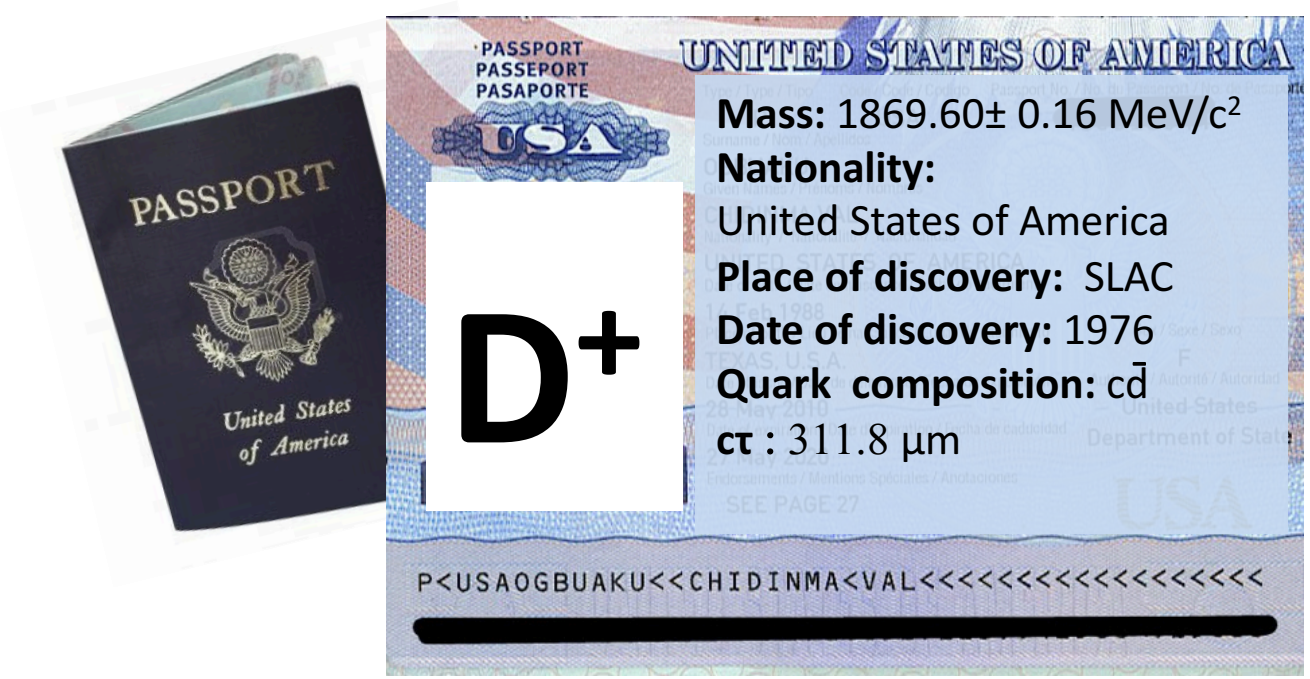
- Theoretical models for pQCD have big uncertainties at low-p_T
  [M. Cacciari et al., JHEP 1210 (2012) 137]

Experiment	Initial state	√s [Gev]
Many expt's CERN, FNAL	K, p, π Nucl. tgts.	up to 40
LHCb	pp	7, 13 $\cdot 10^3$
ALICE	pp	7, 2.76 $\cdot 10^3$
ATLAS	pp	7 $\cdot 10^3$

PRL 91,241804(2003)



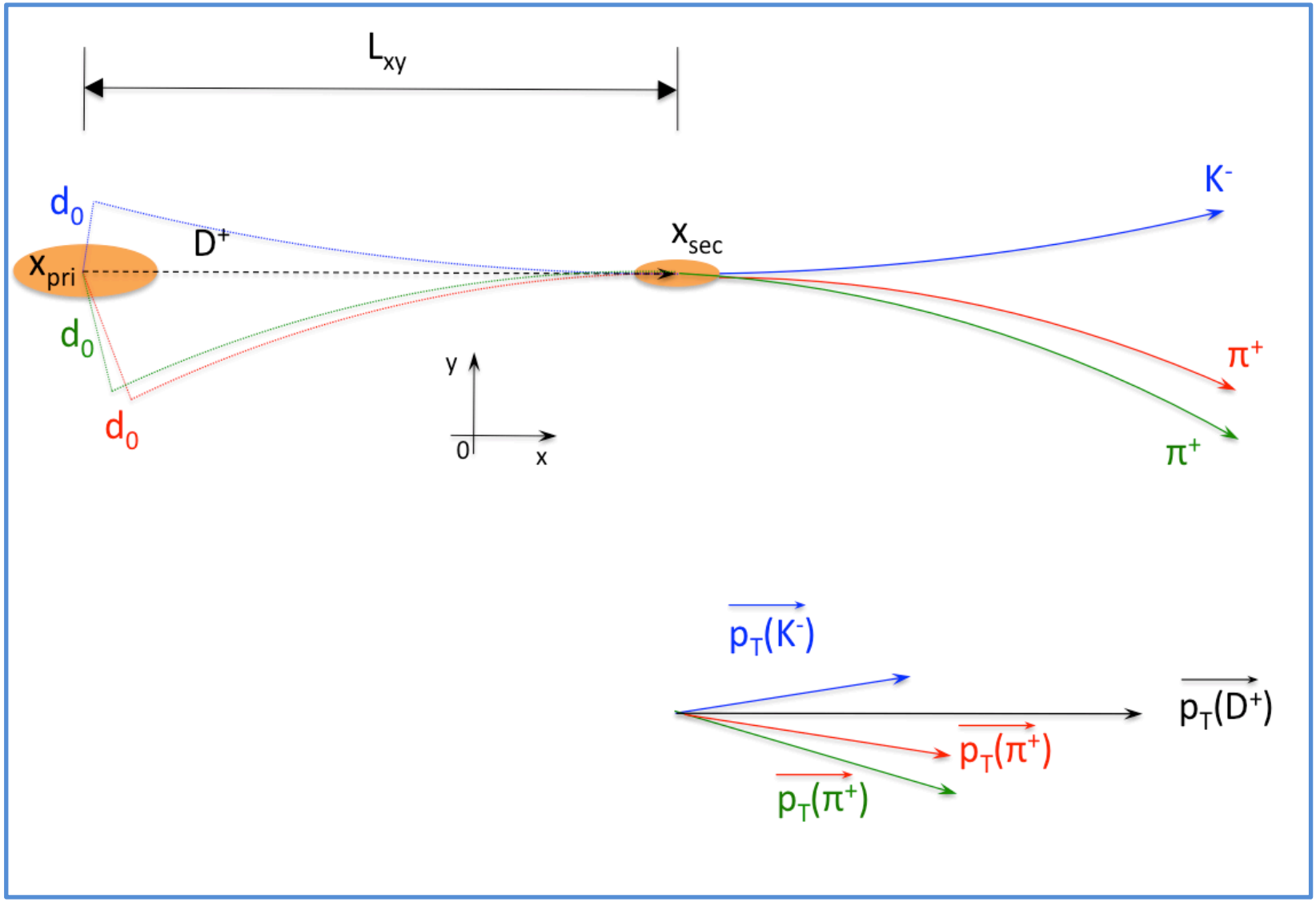
SIGNAL ID



EXPERIMENTALLY …

1. Good spatial resolution to separate primary and secondary vertices
2. Good momentum resolution

SIGNAL: D^+ TOPOLOGY



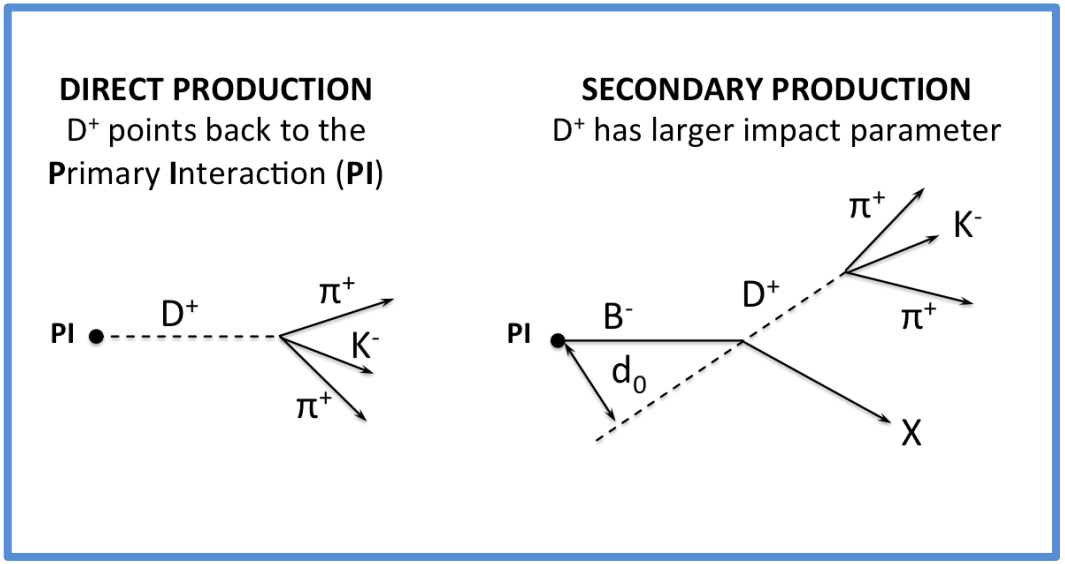
Transverse: plane perpendicular to the proton beam direction

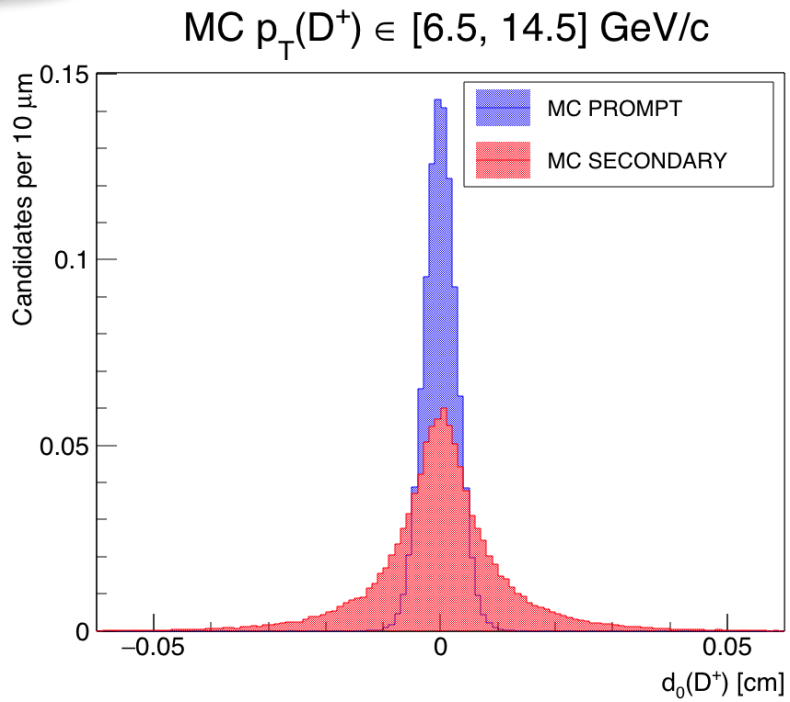
SIGNAL AND BACKGROUND

SIGNAL: $D^+ \rightarrow K^- \pi^+ \pi^+ (+c.c.)$ **BR:** $(9.46 \pm 0.24)\%$

BACKGROUND

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

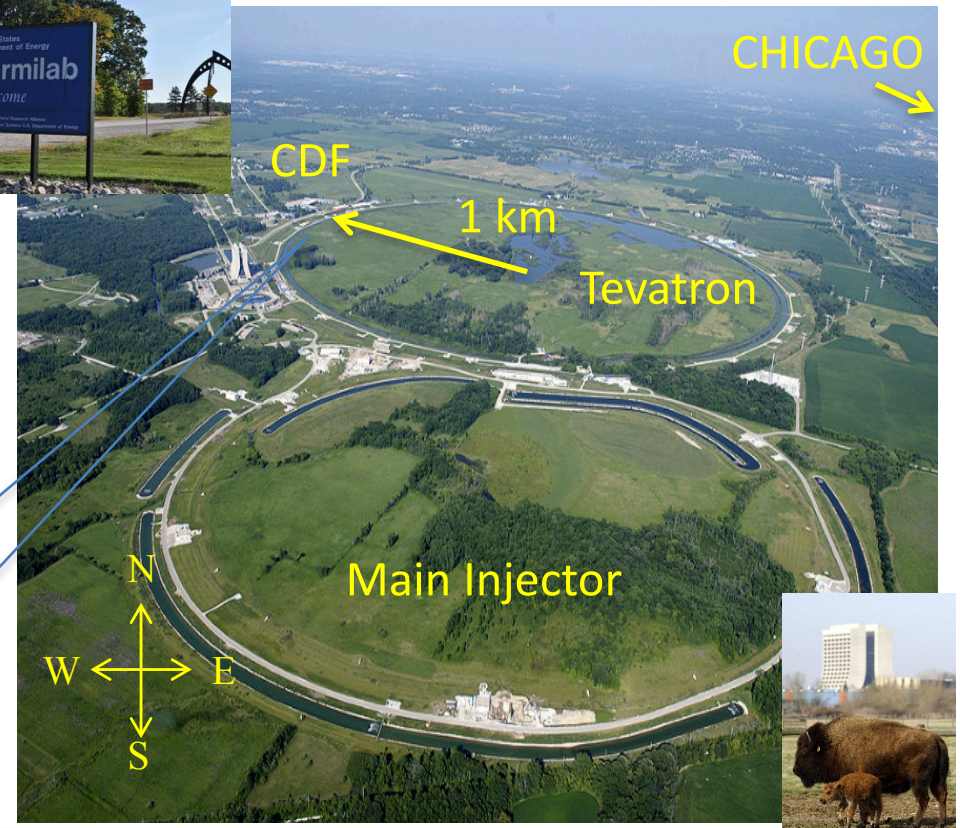


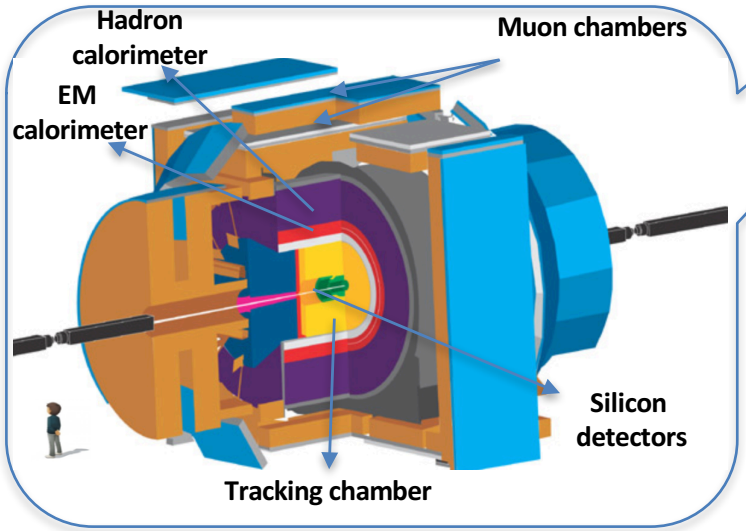


The invariant-mass doesn't distinguish between primary and secondary component

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)
- We use the entire 1.96TeV-dataset





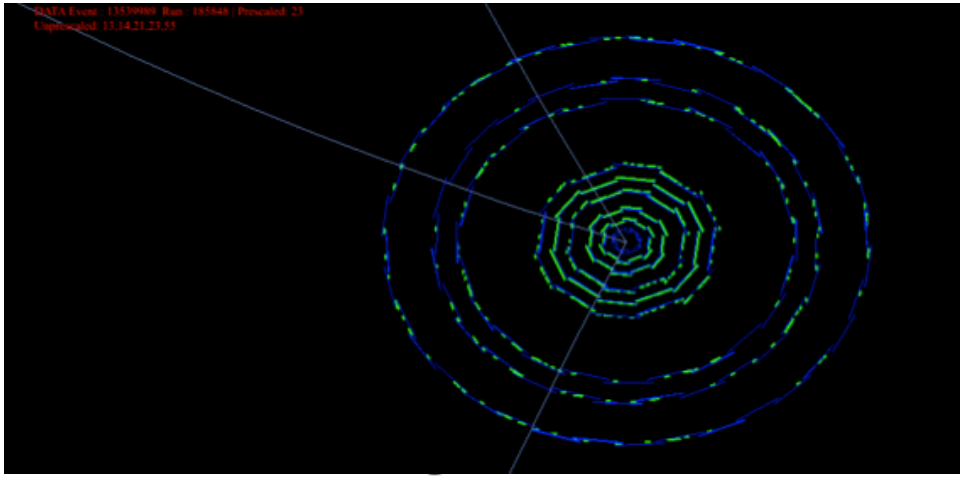
CDF: Collider Detector at Fermilab

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

TRACKING SYSTEM

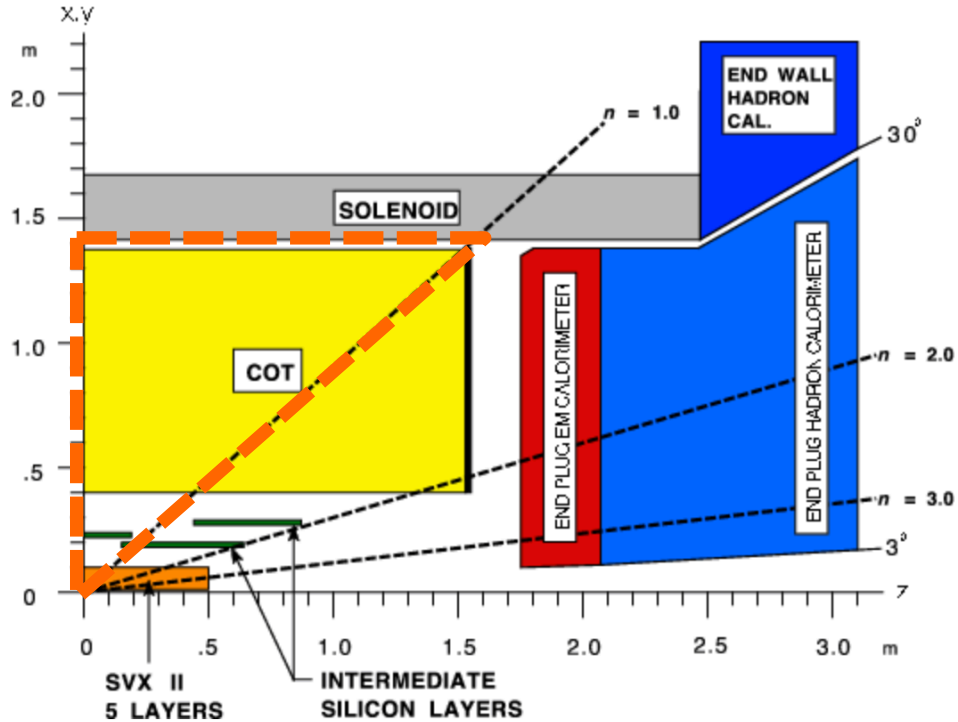
Tracking-system performance

For $|\eta| \leq 1$:
$\sigma_{pT}/p_T^2 \approx 0.0015$ c/GeV
$\sigma_{d0} \approx 40$ µm



3D charged-particle tracking

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



DATA SELECTION

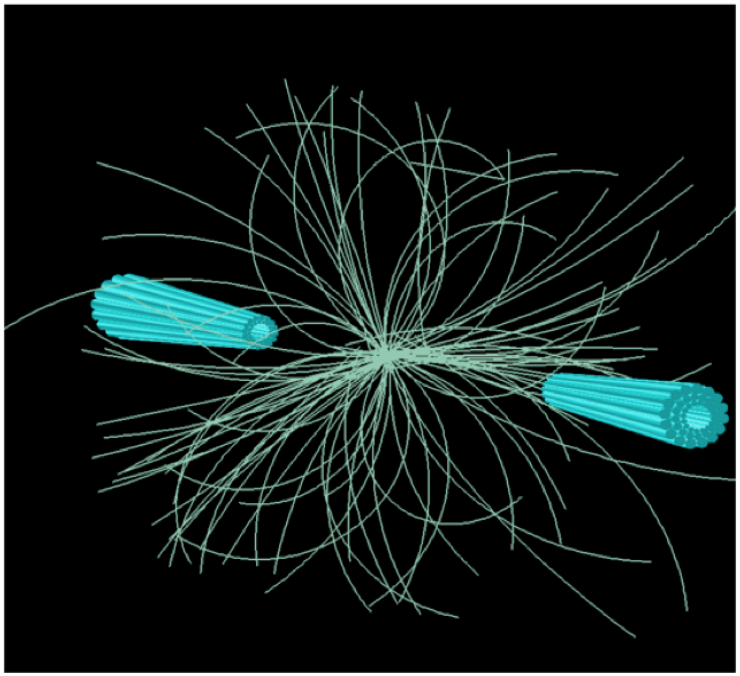
Data collected by two triggers:

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

- Events collected every bunch crossing whether or not collisions occur
- Rate ~ 1.7 ev/s

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

- At least one inelastic $p\bar{p}$ collision
- CLC, "Cherenkov Luminosity counter ($3.7 < |\eta| < 4.7$) Coincidence"
- Rate ~ 1 ev/s.



FULL ANALYSIS IN A NUTSHELL

The goal is to measure the p_T-averaged and y-integrated cross section

$$\frac{d\sigma_{D^+\to K^-\pi^+\pi^+}}{dp_T}\left(p_T;|y|\leq 1\right)=\left.\frac{N_{D^+}\left(p_T\right)}{\Delta p_T\cdot L\cdot\varepsilon\cdot BR\left(D^+\to K^-\pi^+\pi^+\right)}\right|_{|y|\leq 1}$$

- **DATA-DRIVEN OPTIMIZATION in each $p_T(D^+)$ with the EVEN/ODD method**
- **2D-FITTING PROCEDURE on the (mass, d_0) –space to extract the YIELD as a function of $p_T(D^+)$:** $N_{D^+}\left(p_T\right)$
- **INTEGRATED LUMINOSITY OF OUR SAMPLE:** L
- **DECAY BRANCHING RATIO of the channel:** $BR\left(D^+\to K^-\pi^+\pi^+\right)$
- **RECONSTRUCTION (based on MC simulations) and TRIGGER EFFICIENCY:** ε

SIGNAL: BASE SELECTION

D^+ reconstruction:

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

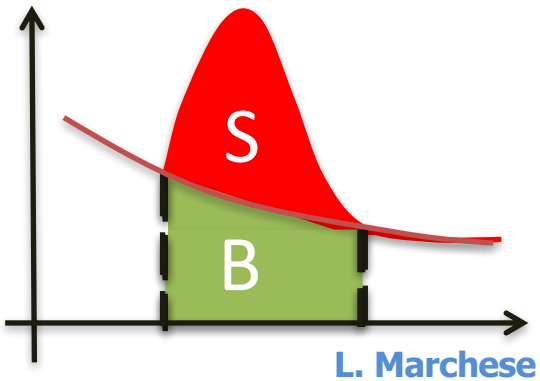
$L_{xy} \geq 0$ µm
Transverse decay length

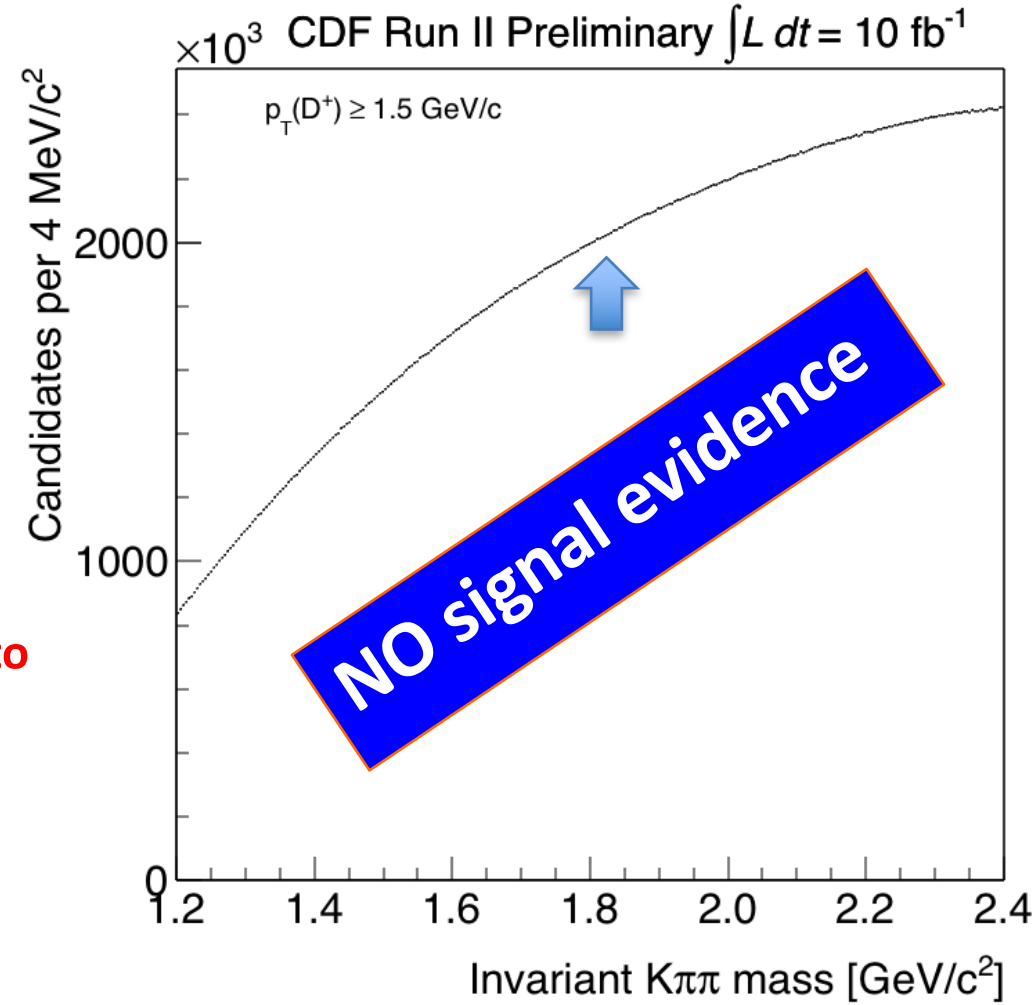
$|y(D^+)| \leq 1$

$\chi^2 \leq 10$

1. **Selection optimization is mandatory to unfold the signal**
2. **We perform it in five $p_T(D^+)$-bins**

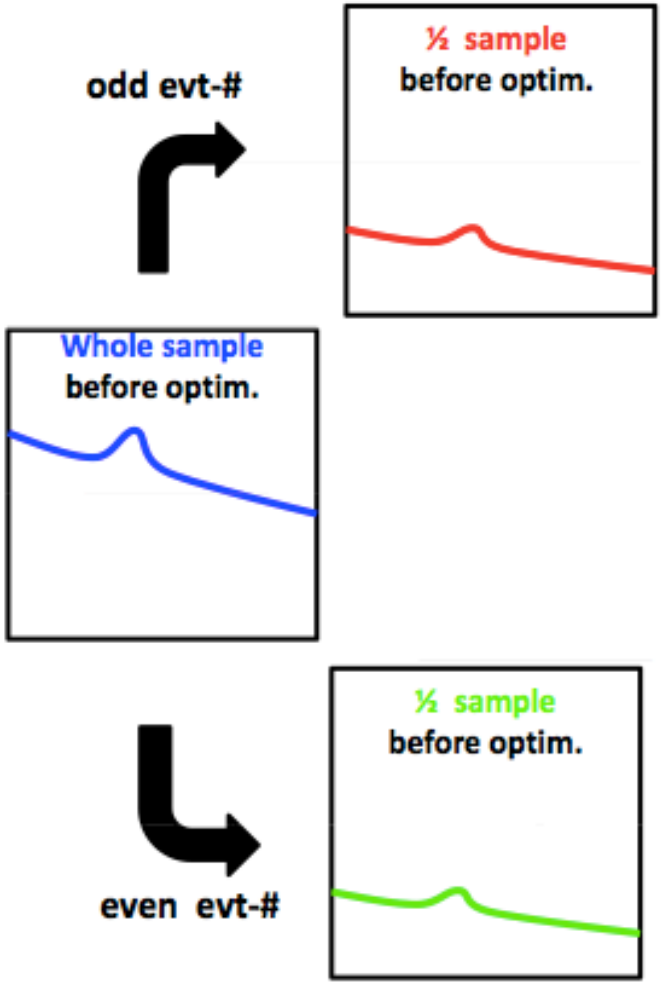
$$f(S,B) = \frac{S}{\sqrt{S+B}}$$



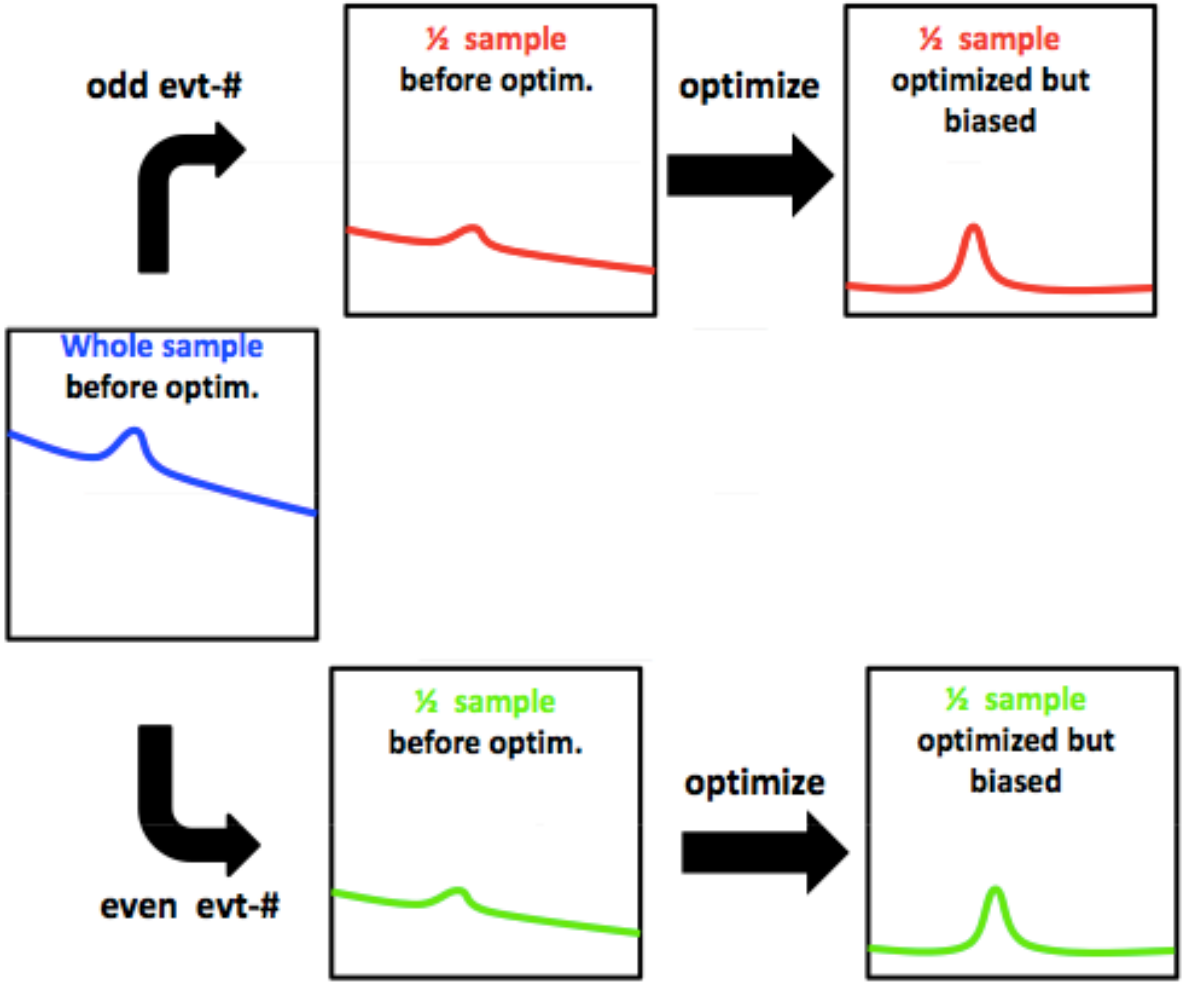


3 OPTIMIZATION VARIABLES:
p_T(tracks), χ^2 and L_{xy}

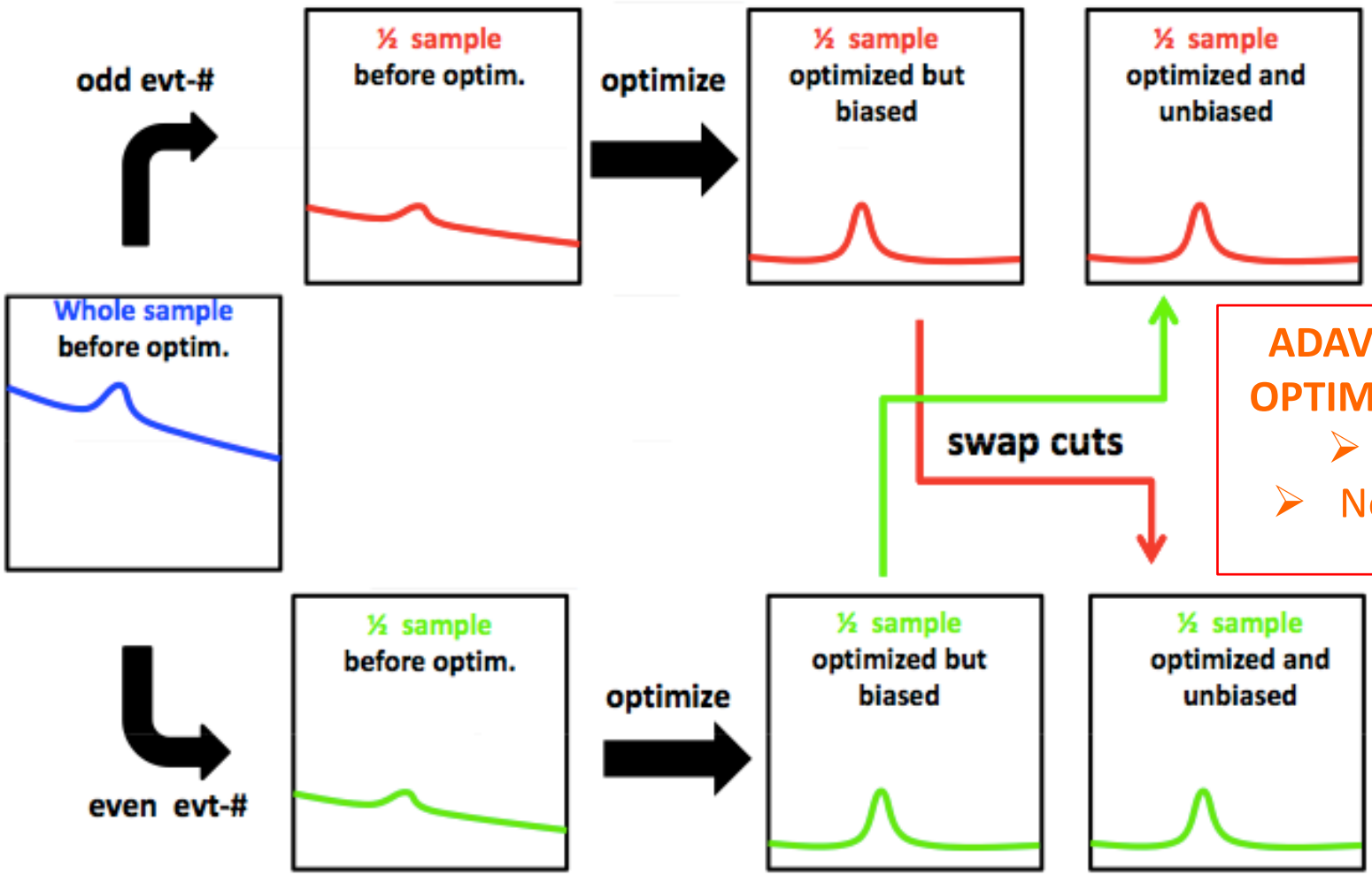
SELECTION OPTIMIZATION



SELECTION OPTIMIZATION



SELECTION OPTIMIZATION



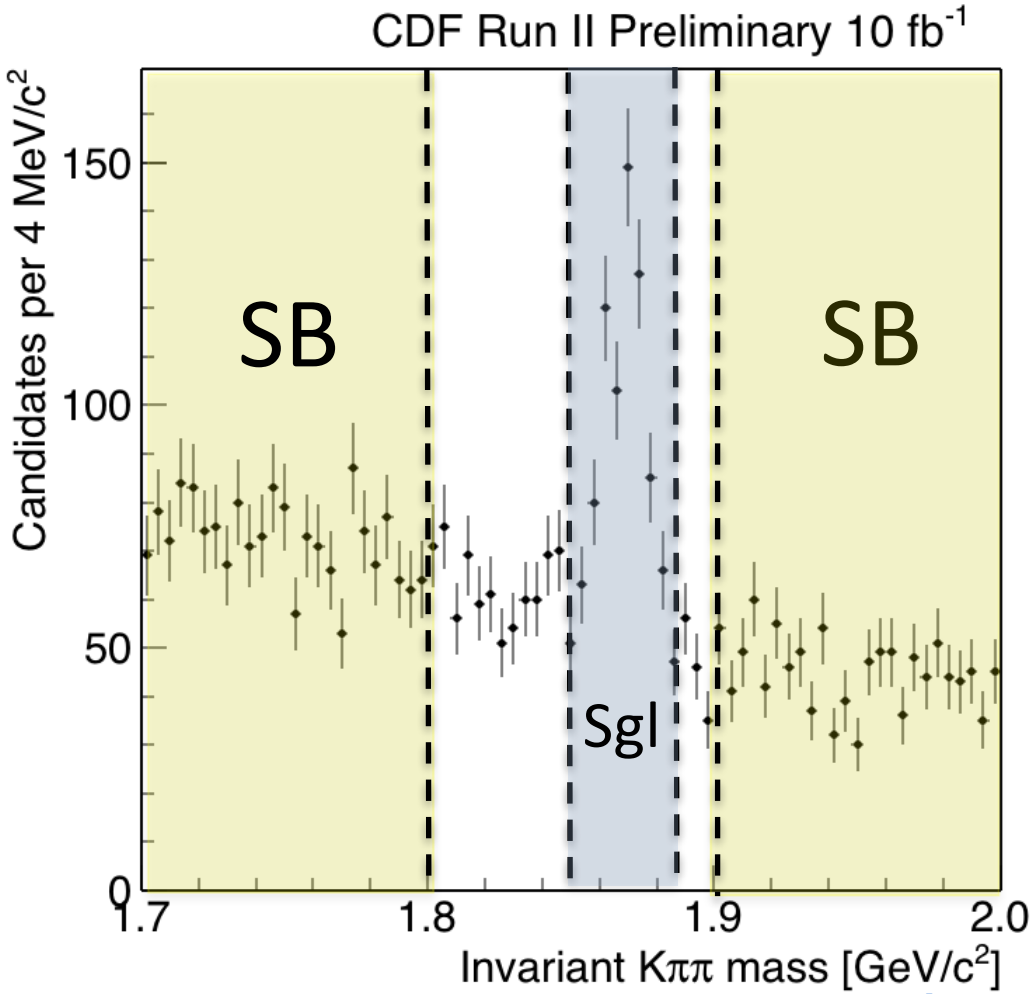
ADAVANTAGES OF THE OPTIMIZATION METHOD

- All data used
- No bias introduced

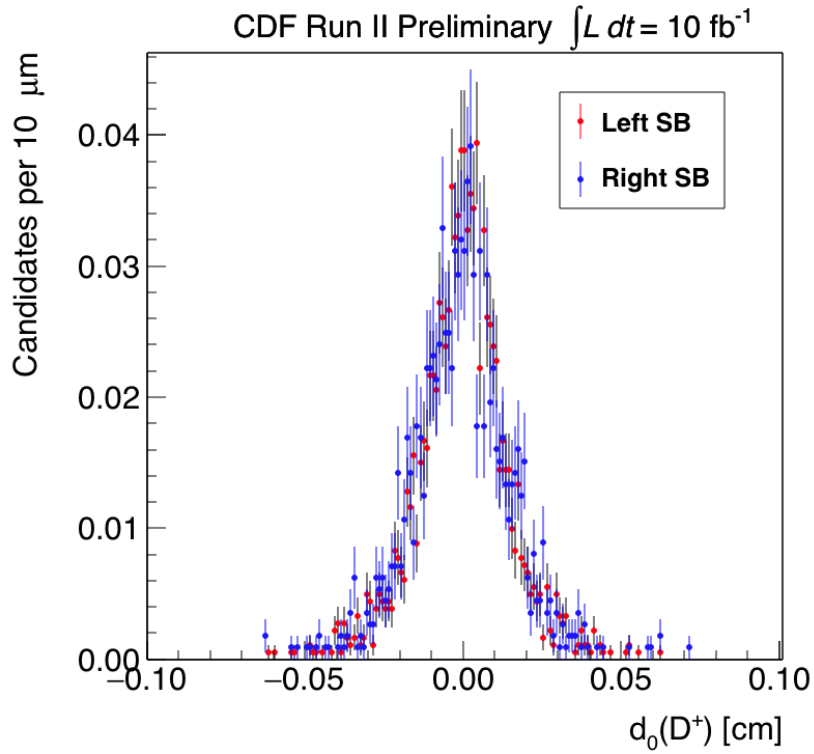
DEFINITIONS

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

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



Compare d_0 distributions for left and right Sidebands



KOLMOGOROV – SMIRNOV TEST: 90%

We handle them together

PROMPT SIGNAL EXTRACTION

- Assumption:
  in the signal region three components

Primary **S**econdary **C**ombinatorics

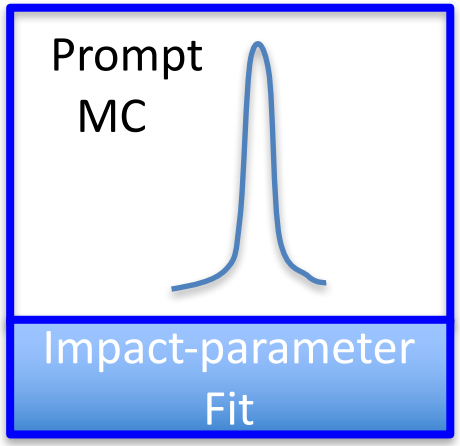
- For each component, the distributions in mass (**m**) and impact parameter (***d_0***) are **uncorrelated**

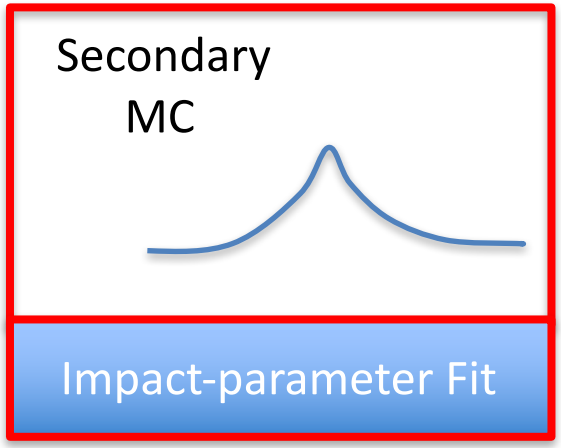
- **Two parameters (f_P, f_S)-unbinned likelihood fit**

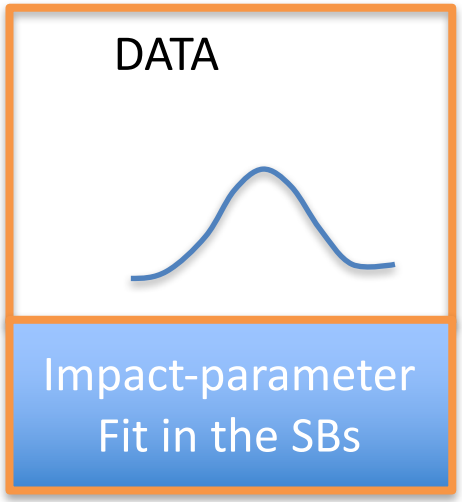
$$\mathcal{L}(f_P, f_S) = f_P \cdot F_{S,P}(m) F_P(d_0) + f_S \cdot F_{S,P}(m) F_S(d_0) + (1 - f_P - f_S) \cdot F_C(m) F_C(d_0)$$

SHAPE EXTRACTION

$d_0(D^+)$

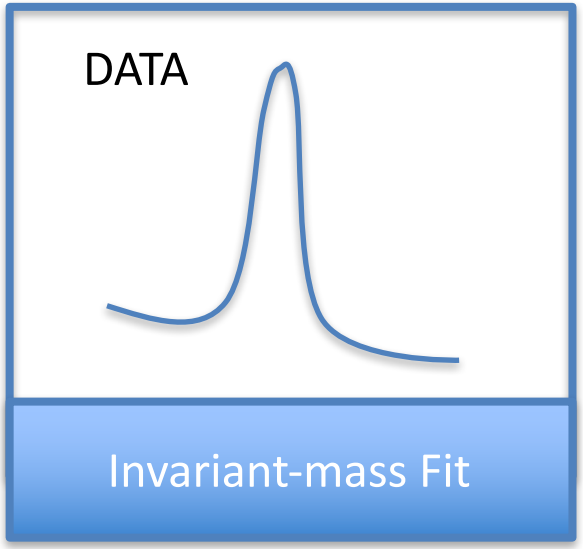






$$L(f_P, f_S, \vec{\theta}_P, \vec{\theta}_S, \vec{\theta}_C) = f_P \cdot F_P(m, d_0; \vec{\theta}_P) + f_S \cdot F_S(m, d_0; \vec{\theta}_S) + (1 - f_P - f_S) \cdot F_C(m, d_0; \vec{\theta}_C)$$

MASS

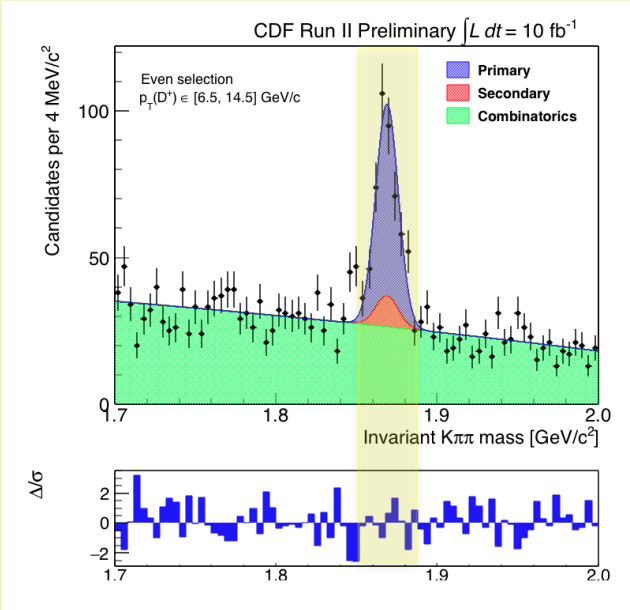


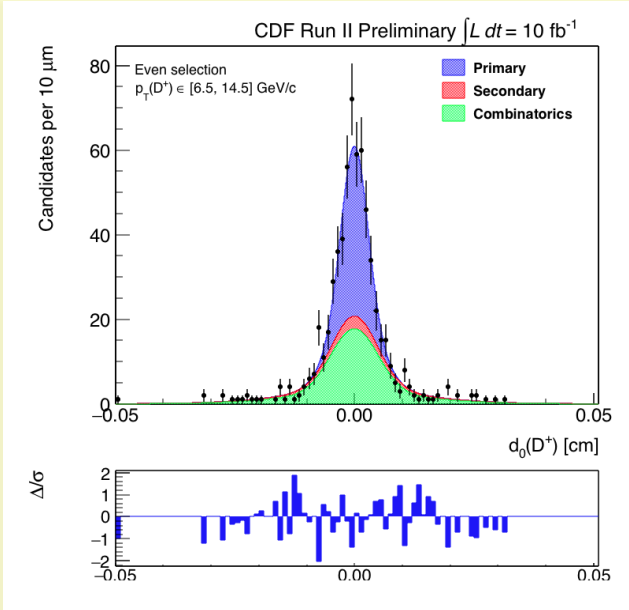
- Primary component
- Secondary component
- Combinatorics

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

EVEN EVENTS

$D^+_{prompt} = 278 \pm 24$

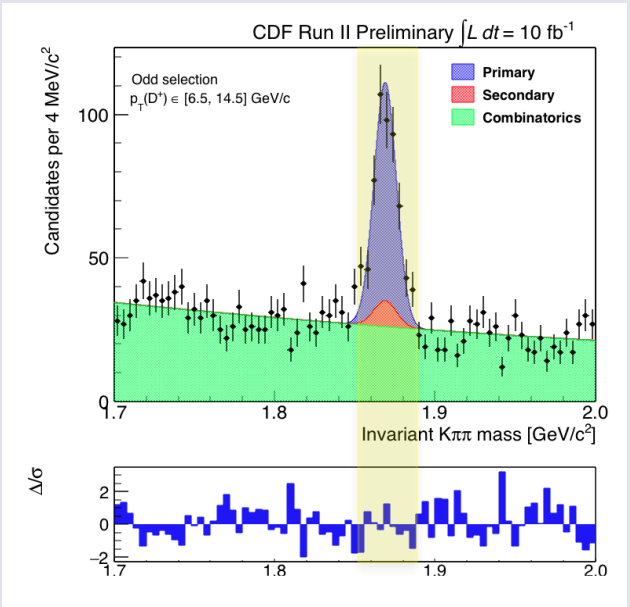


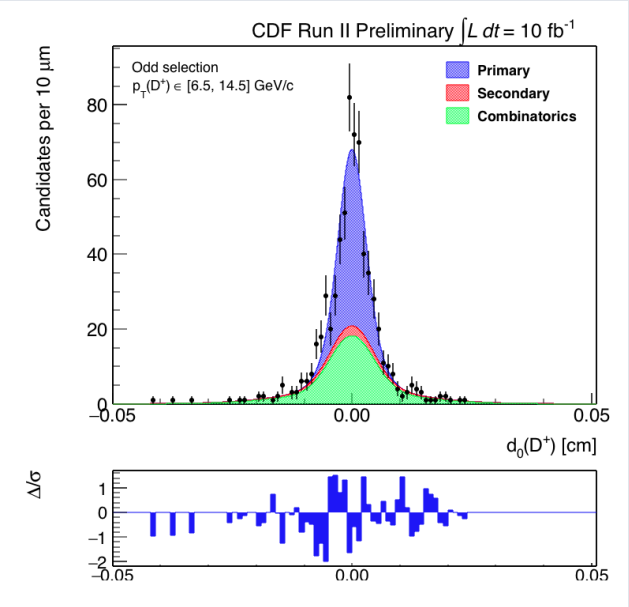


$d_0(D^+)$ **SIGNAL REGION**

ODD EVENTS

$D^+_{prompt} = 327 \pm 27$



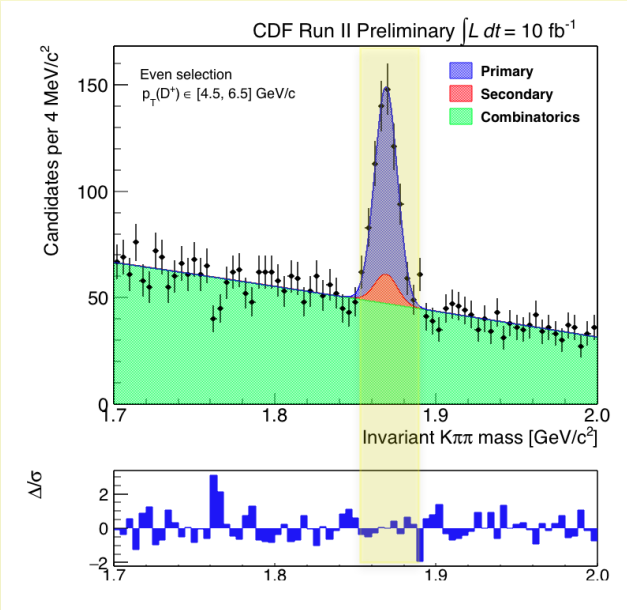


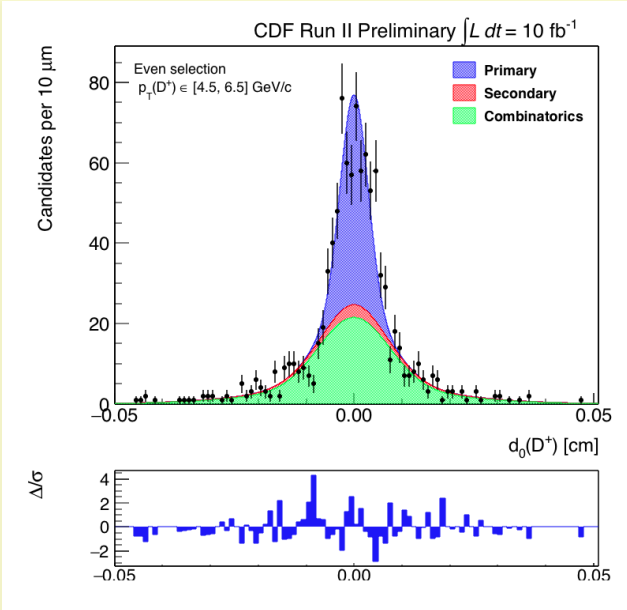
$d_0(D^+)$ **SIGNAL REGION**

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

EVEN EVENTS

D^+_{prompt} = 384±29

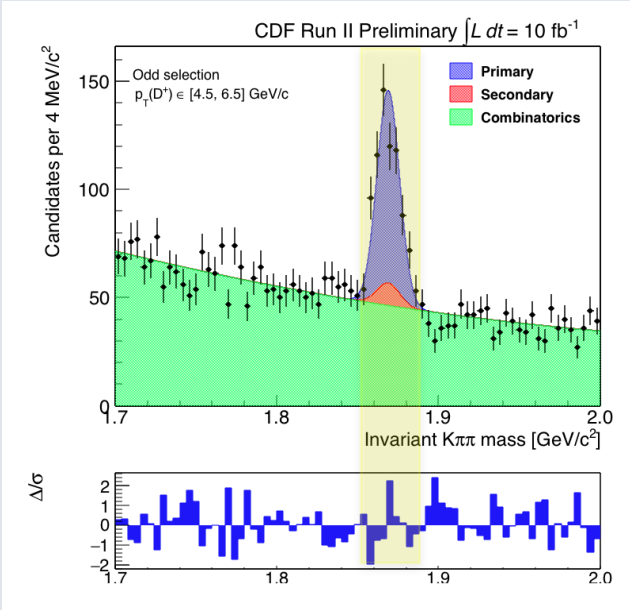


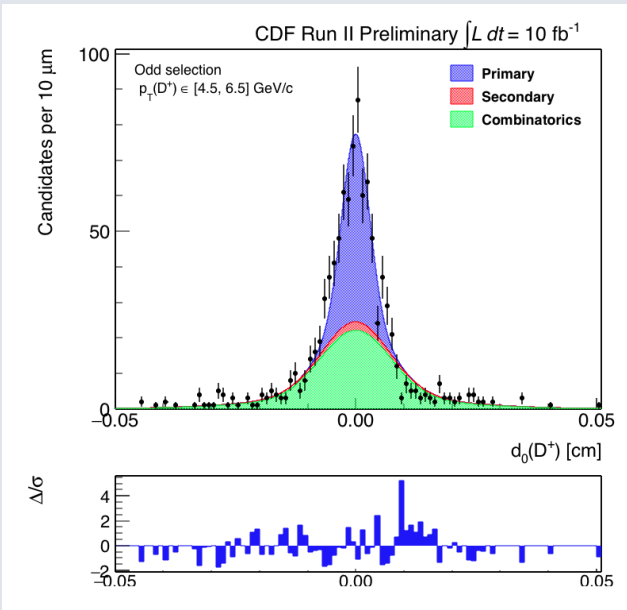


$d_0(D^+)$ **SIGNAL REGION**

ODD EVENTS

D^+_{prompt} = 389±29



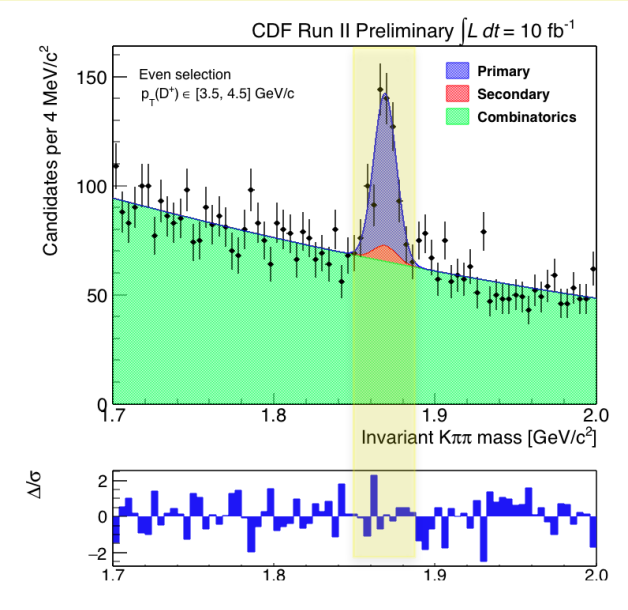


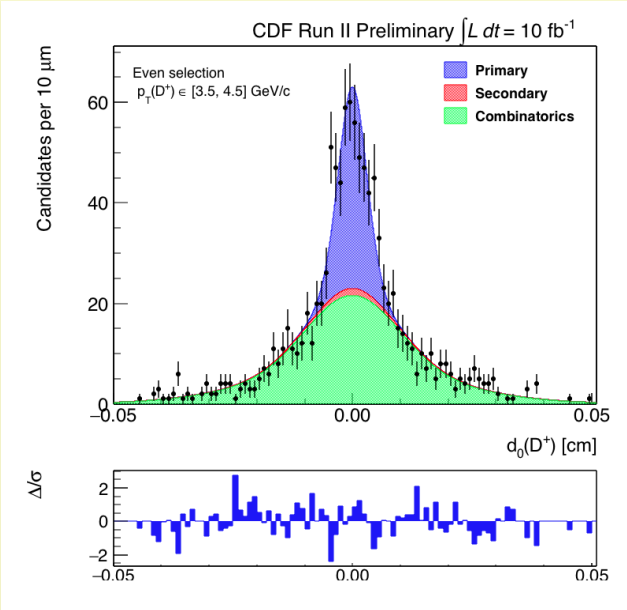
$d_0(D^+)$ **SIGNAL REGION**

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

EVEN EVENTS

$D^+_{prompt} = 301 \pm 28$

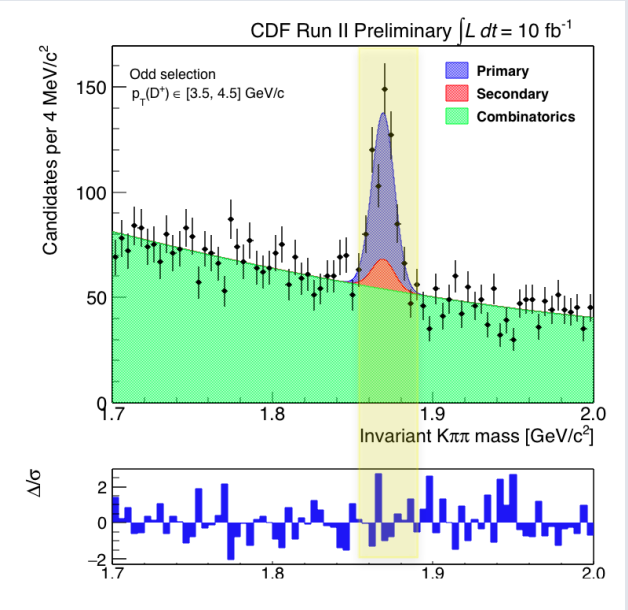


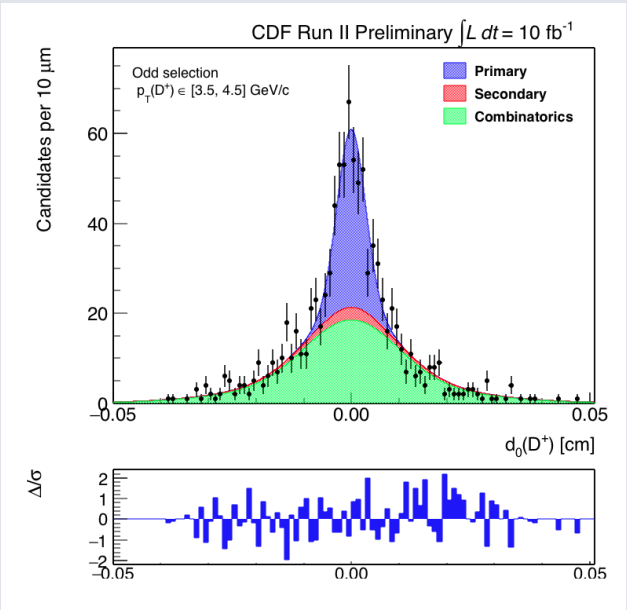


$d_0(D^+)$ **SIGNAL REGION**

ODD EVENTS

$D^+_{prompt} = 304 \pm 28$



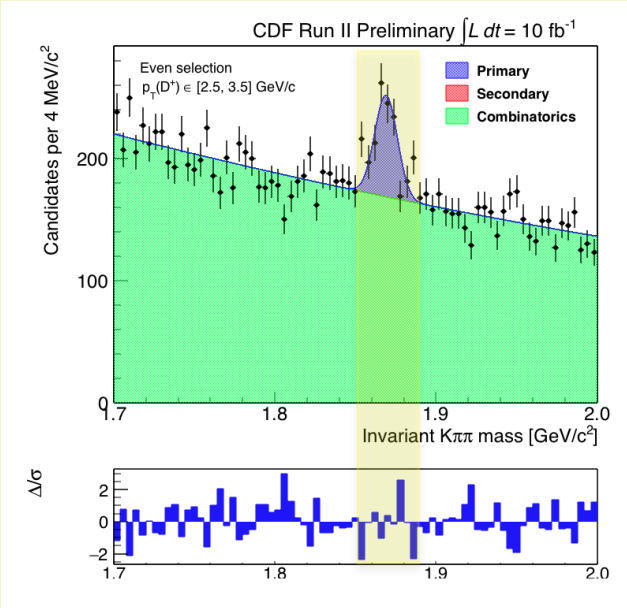


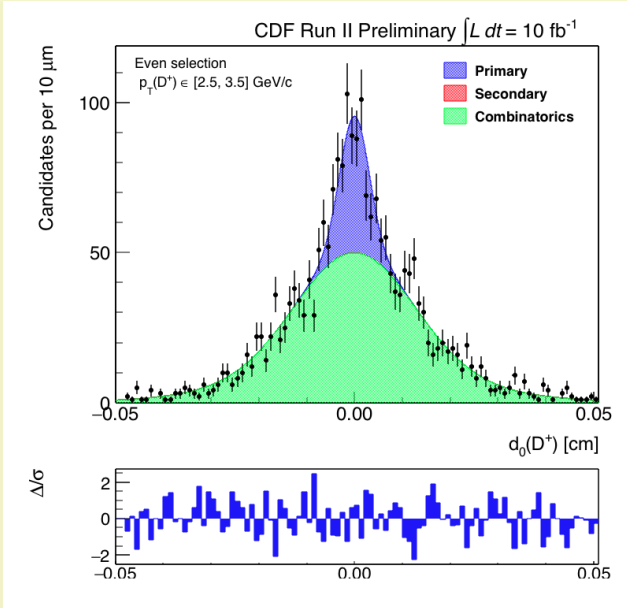
$d_0(D^+)$ **SIGNAL REGION**

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

EVEN EVENTS

$D^+_{prompt} = 366 \pm 27$

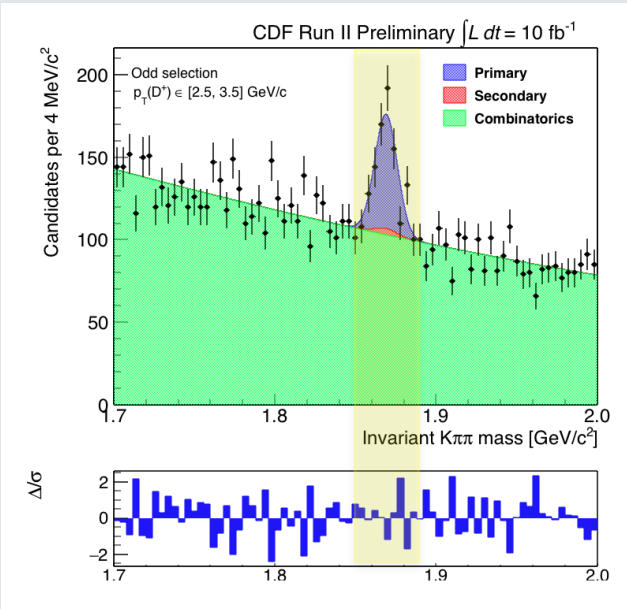


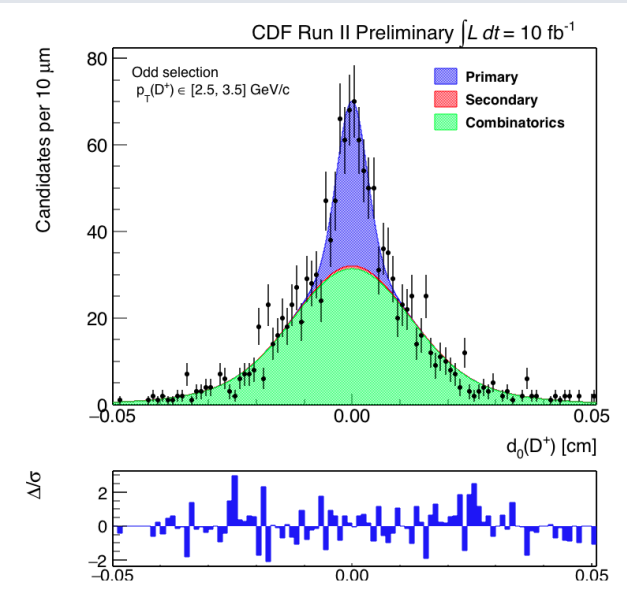


$d_0(D^+)$ **SIGNAL REGION**

ODD EVENTS

$D^+_{prompt} = 307 \pm 34$



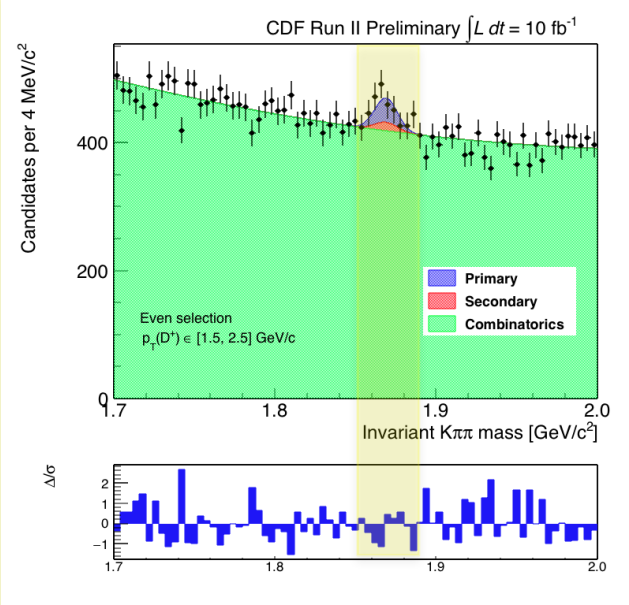


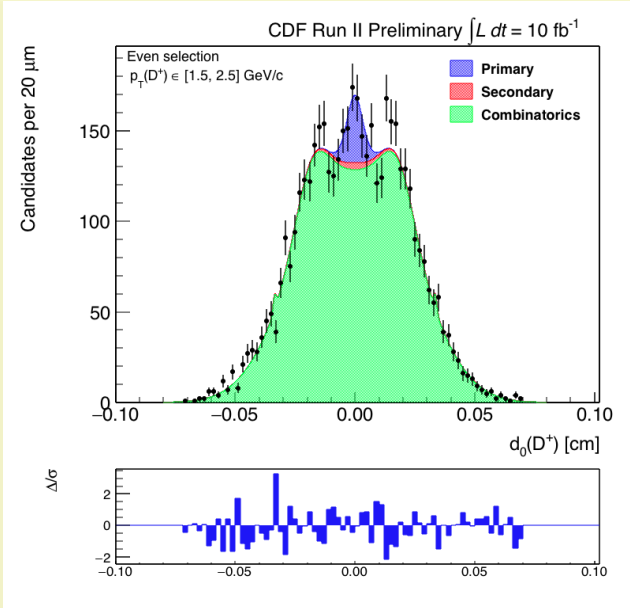
$d_0(D^+)$ **SIGNAL REGION**

$1.5 < p_T(D^+) < 2.5$ GeV/c

EVEN EVENTS

$D^+_{prompt} = 170 \pm 40$

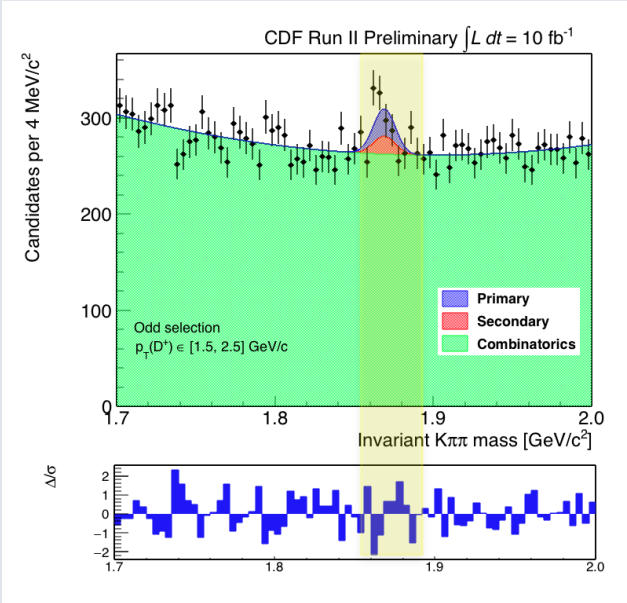


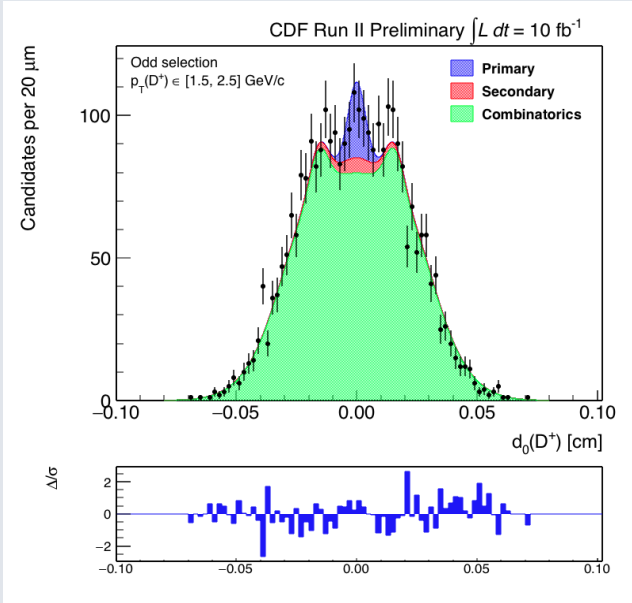


$d_0(D^+)$ **SIGNAL REGION**

ODD EVENTS

$D^+_{prompt} = 125 \pm 40$





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

EFFICIENCY

$$\varepsilon(D^+;p_T) = \varepsilon_{trig} \cdot \varepsilon_{rec}(p_T)\Big|_{|y|\leq 1}$$

$$\varepsilon_{rec}(D^+;p_T) = \frac{N_{Candidates}(p_T)\,passing\_the\_Rec\_Selections}{N_{Generated}(p_T)}\Bigg|_{|y|\leq 1}$$

TRIGGER EFFICIENCY	RECONSTRUCTION EFFICIENCY
➢ No p_T-dependence ➢ Negligible effect: 1.7‰ ➢ We handle it as a systematic uncertainty	➢ p_T-dependence ➢ MC based ➢ Since it is the first CDF low-p_T-cross-section measurement, we performed additional cross-checks

RECONSTRUCTION EFFICIENCY

CDF Run II Preliminary

$p_T(D^+)$ [GeV/c]	Subsample	$\varepsilon_{\rm rec}(D^+)$[%]
1.5–2.5	Even	0.331 ± 0.011
	Odd	0.267 ± 0.010
2.5–3.5	Even	1.142 ± 0.026
	Odd	1.020 ± 0.025
3.5–4.5	Even	2.098 ± 0.047
	Odd	2.110 ± 0.047
4.5–6.5	Even	3.936 ± 0.073
	Odd	3.936 ± 0.073
6.5–14.5	Even	7.46 ± 0.15
	Odd	7.36 ± 0.15

RECONSTRUCTION EFFICIENCY

SINGLE TRACK EFFICIENCY

First measurement of cross section at low p_T for CDF

Is the MC reliable ?

YES for the COT simulation

NO for the Silicon simulation

The time dependence doesn't take into account some dead channels in time

We should check and eventually correct …

◆ We use DATA ⟹ **$J/\psi \longrightarrow \mu^+\mu^-$ DATASET**

$D^{*+} \longrightarrow D^0\pi^{\pm}_{soft}$ DATASET

SINGLE-TRACK EFFICIENCY

HOW TO

In principle the Silicon efficiency per single track already seen in the COT is a 5D-function:

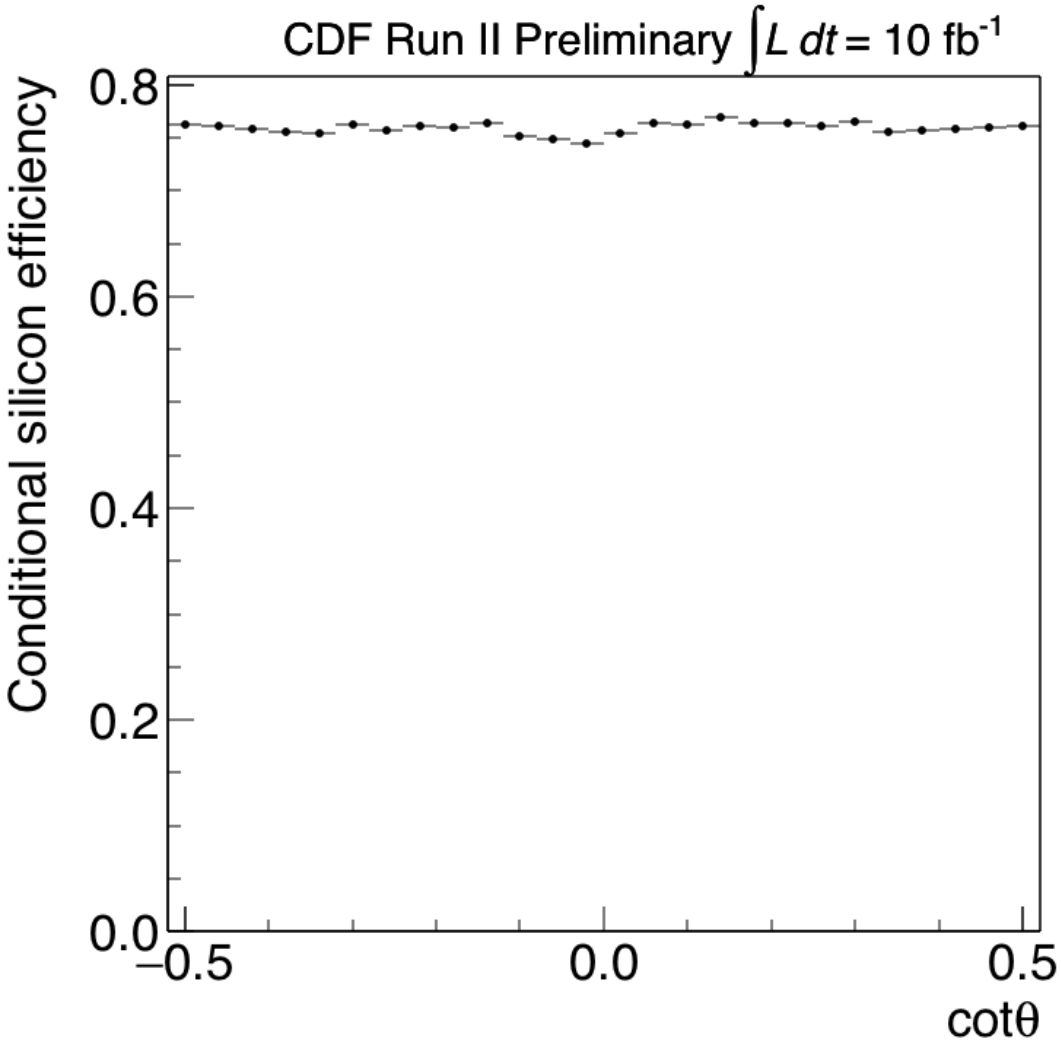
$$\varepsilon(\phi_0, z_0, \theta_0, p_T, t) \Rightarrow \equiv \varepsilon(\phi_0, z_0, t) \cdot \frac{\varepsilon(\cot\theta, t) \cdot \varepsilon(p_T, t)}{\varepsilon_0^2}$$

Normalization constant

In our case no $\varepsilon(\cot\theta, t)$-dependence is observed, then:

$$\boxed{\varepsilon \equiv \varepsilon(\phi_0, z_0, t) \cdot \frac{\varepsilon(p_T, t)}{\varepsilon_0}}$$

SINGLE-TRACK EFFICIENCY



CONDITIONAL-SILICON EFFICIENCY as a function of p_T

- The J/Ψ DATASET implements a trigger cut for $p_T < 1.5$ GeV/c

- Our phase space is densely populated for $p_T < 1.5$ GeV/c
  ISSUE: **J/Ψ-muons don't probe p_T as low as we need**

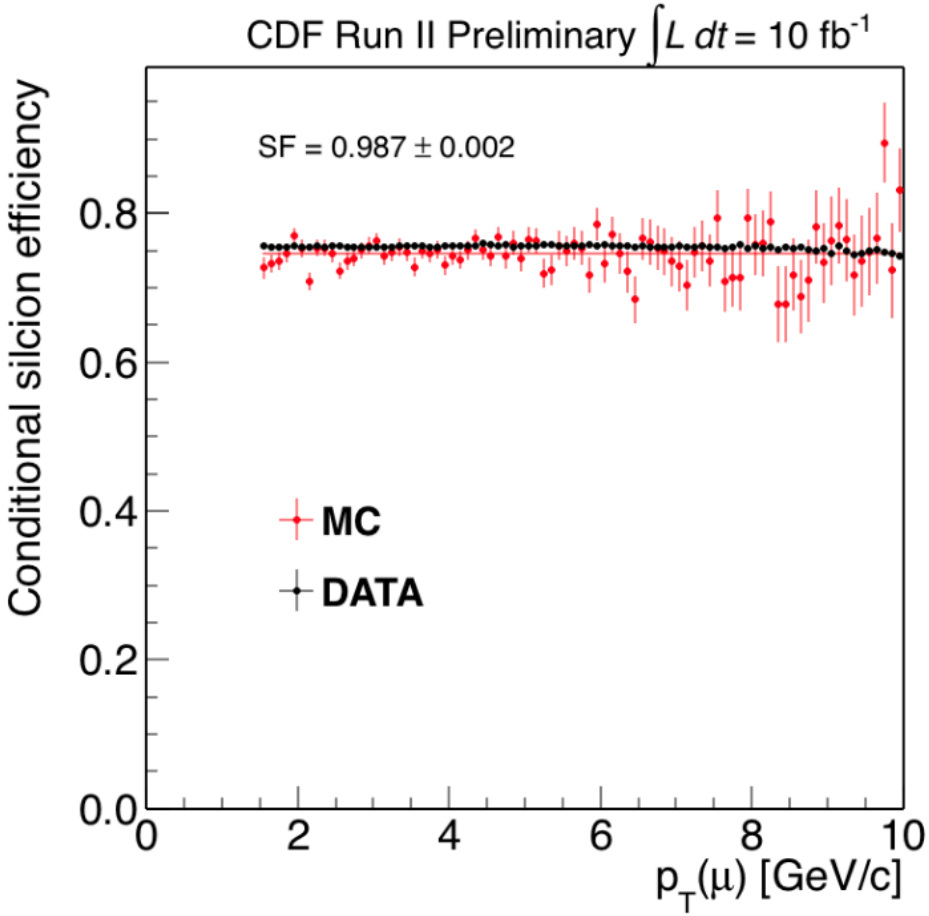
- We expand the DATASET in the low p_T-region including the Silicon p_T-efficiency per soft π (from $D^{*\pm} \longrightarrow D^0 \pi^\pm$) already seen in the COT

$$\varepsilon(p_T, t) \begin{cases} p_T \geq 1.5 \text{ GeV/c from } J/\Psi \\ p_T < 1.5 \text{ GeV/c from } \pi_{soft} \end{cases}$$

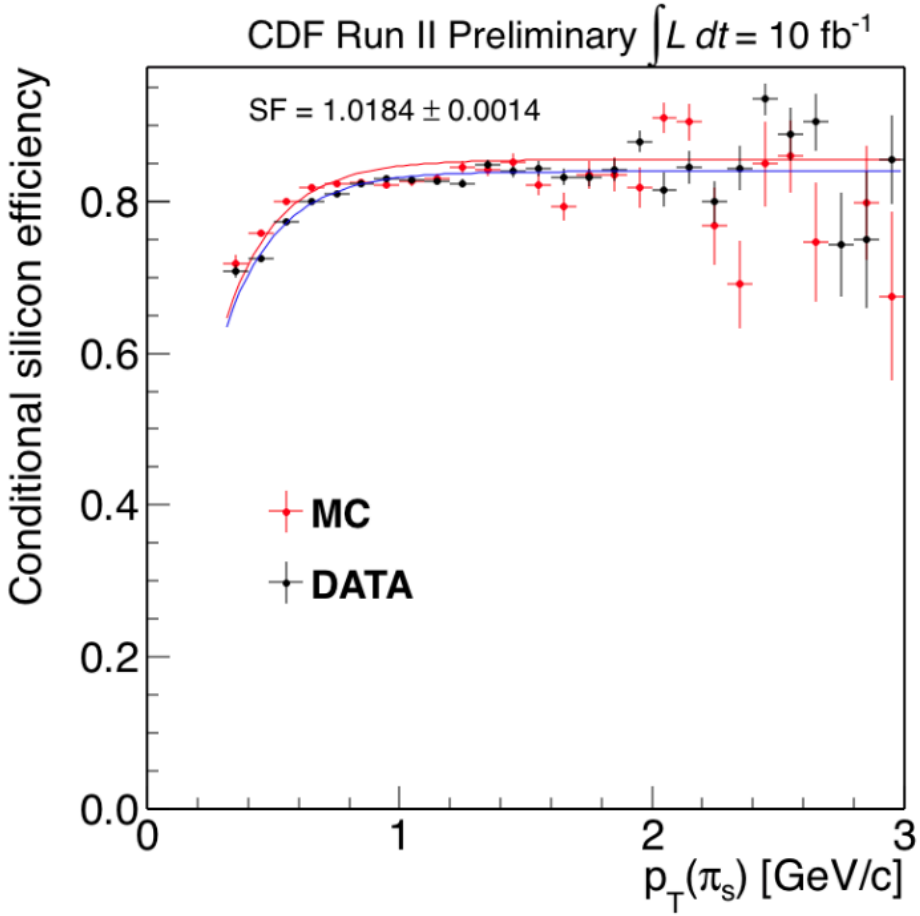
- We perform some Data/MC tests with both the samples

MC/DATA-test

High momenta



Low momenta



CONDITIONAL-SILICON EFFICIENCY

- The MC/Data tests for both π_{soft} and μ-samples have confirmed MC-conditional-silicon efficiency doesn't reproduce correctly the real conditional-silicon efficiency per single track.
- The effect is small
- We perform the study as a function of the time
- To be conservative, we apply the maximum correction observed to our D^+-sample.

3 Tracks
1.037^3

→

Systematic unc. D^+
11.5%

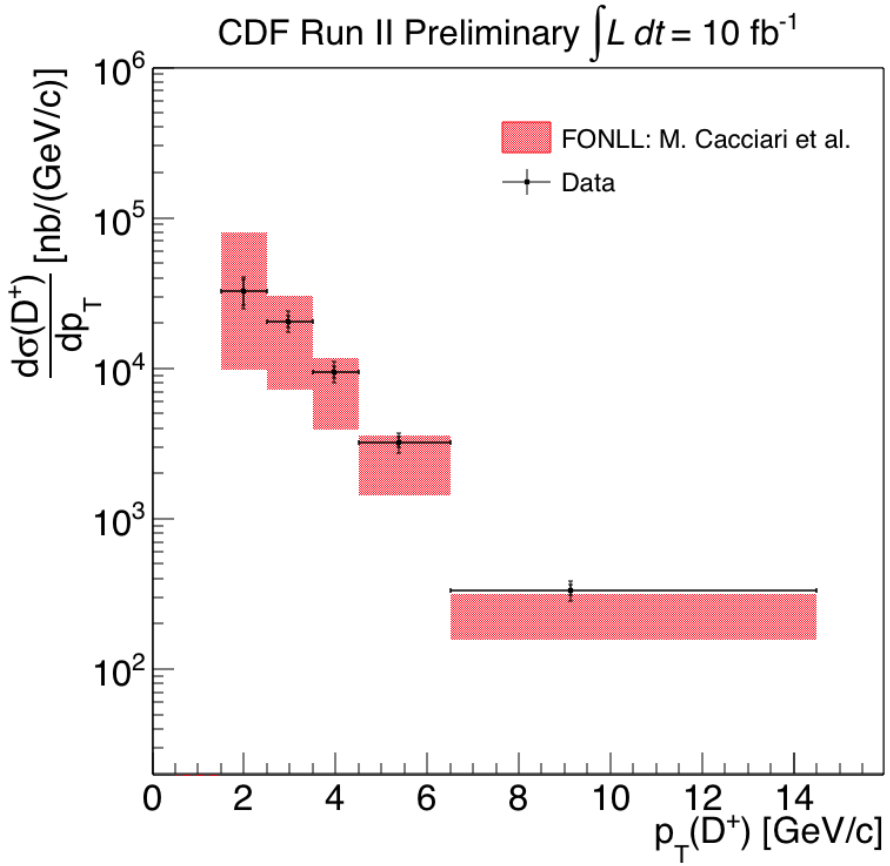
SYSTEMATIC UNCERTAINTIES

- **Reconstruction-efficiency procedure**
  We perform some MC/Data tests on control-samples to evaluate possible inaccuracies in the MC simulation of the silicon
- **Background and signal shape**
  We change the signal or the background shape and evaluate the effect on the final number
- **Trigger Efficiency**
- **Luminosity**
- **D^+ Branching Ratio**

CDF Run II Preliminary

$\sigma^{sys}_{L_{trig}}$ [%]	σ^{sys}_{shape} [%]	$\sigma^{sys}_{\varepsilon_{trig}}$ [%]	$\sigma^{sys}_{\varepsilon_{rec}}$ [%]	$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$ [%]	σ^{sys}_{tot} [%]
5.8	0.9-1.5 depending on the bin	0.17	11.5	0.24	13

RESULTS: CROSS SECTION



The cross section we measure is **p_T-AVERAGED and y-INTEGRATED**

The horizontal bars represent the p_T-interval over which we average in p_T

The markers are placed at the p_T point-value at which the cross section equals the predicted values of the cross section.

FONLL reference: *M. Cacciari et al., JHEP **1210** (2012) 137*

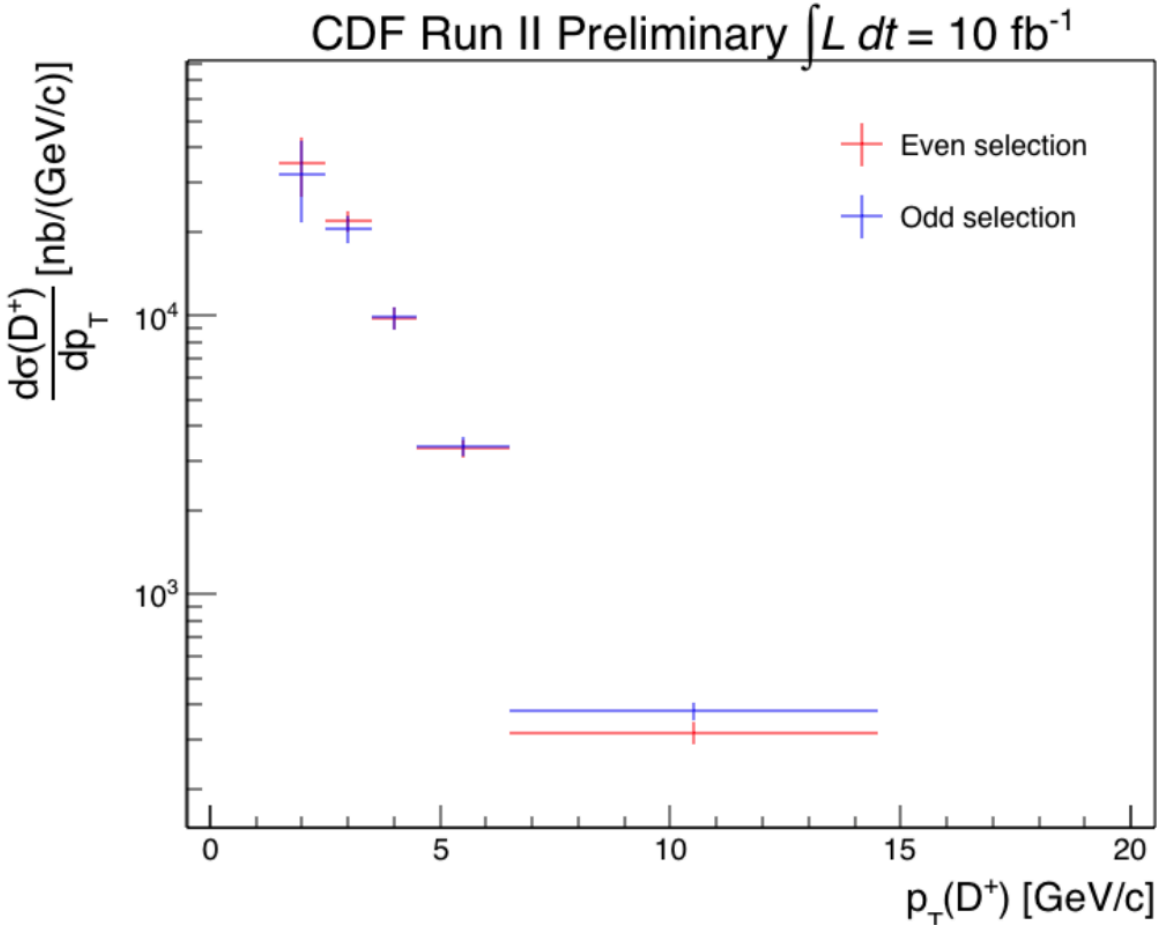
Uncertainties on scales, masses and PDFs have been considered for the theoretical prediction

CONSISTENCY CHECKS

We perform some consistency checks to be sure that all the procedures of the analysis are well performed

1. Optimization procedure
2. Fitting procedure
3. Charge-related effects
4. Triggers consistency
5. Global procedure

OPTIMIZATION PROCEDURE



The numbers are consistent within errors

Only statistical uncertainties are considered for both the subsamples

FITTING PROCEDURE

- To test the robust fitting-procedure, for each $p_T(D^+)$-bin we have produced 1000 simulated pseudo-experiments that mimic each component (prompt, secondary and combinatorics) according to its pdf.

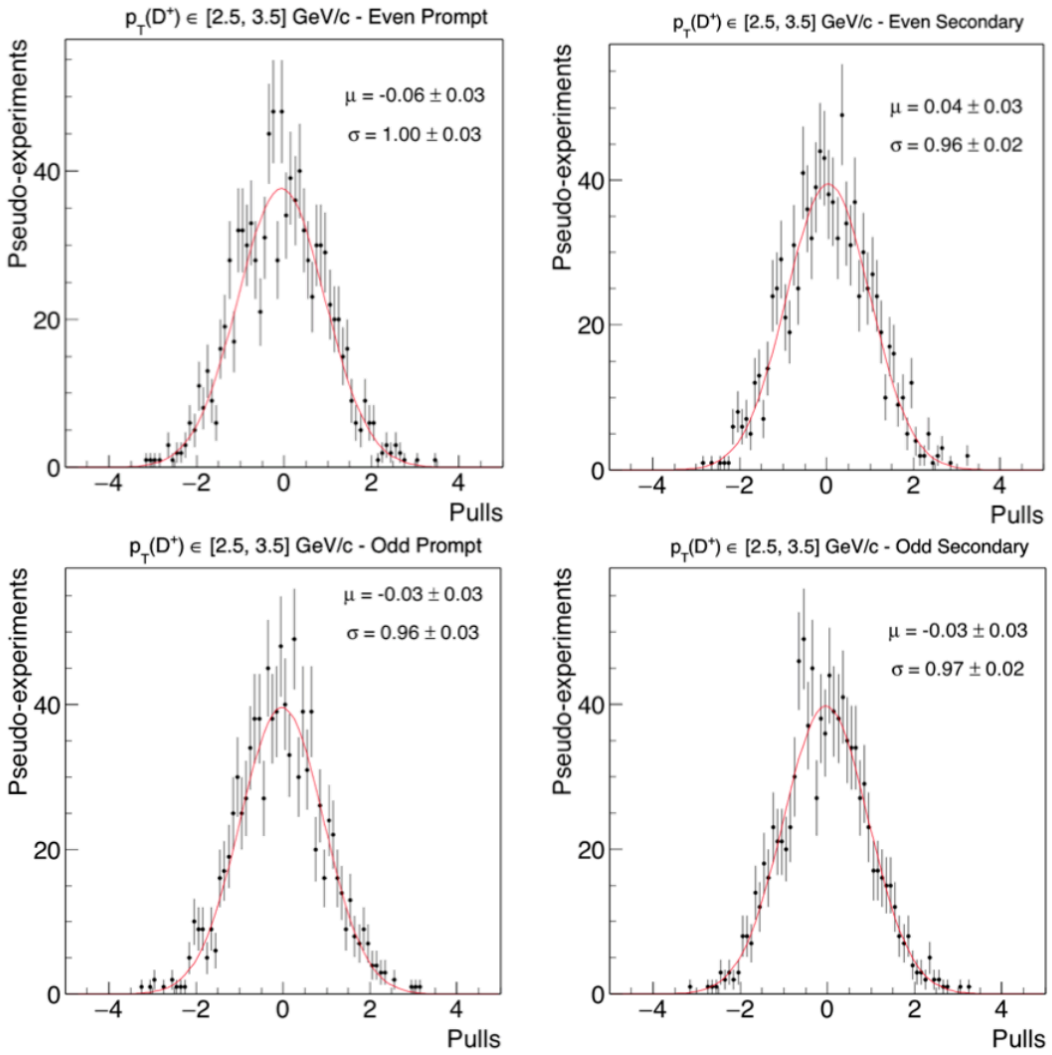
- The input values for the fraction in generations are those determined by the fit in data.

- We have performed the 2D-fit on each sample

- We have evaluated the pulls distribution

- No biases are introduced by the fitting procedure

FITTING PROCEDURE



CHARGE-RELATED EFFECTS

We have measured separately the D^+ and the D^- production cross section:

- **No new optimization**
- **We perform separately the fitting procedure and the efficiency measurement for the D^+ and the D^- sample**
- **Only statistical uncertainties have been considered**
- **It was not possible for the lowest bin, $p_T(D^+)$ in [1.5; 2.5] GeV/c, because of low statistics**

CDF Run II Preliminary

$p_T(D^+)$ [GeV/c]	$d\sigma/dp_T(D^-)$ [nb/(GeV/c)]	$d\sigma/dp_T(D^+)$ [nb/(GeV/c)]
2.5–3.5	20 600 ± 2 200	24 040 ± 3 100
3.5–4.5	10 200 ± 1 200	9 900 ± 1 100
4.5–6.5	3 100 ± 304	3 700 ± 360
6.5–14.5	383 ± 38	384 ± 40

No charge-related effects are observed

TRIGGERS CONSISTENCY

We have measured separately the D^+ cross section in the ZB and MB sample:

- **No new optimization or efficiency measurement**
- **We perform the fitting procedure using the ZB and MB separately**
- **Only statistical uncertainties have been considered**
- **It was not possible for the lowest bin, $p_T(D^+)$ in [1.5; 2.5] GeV/c, because of low statistics**

CDF Run II Preliminary

$p_T(D^+)$ [GeV/c]	Subsample	$d\sigma/dp_T(D^+)$ [nb/(GeV/c)]
2.5–3.5	ZB	20 200 ± 2 500
	MB	20 100 ± 1 900
3.5–4.5	ZB	9 900 ± 1 100
	MB	9 200 ± 950
4.5–6.5	ZB	3 220 ± 314
	MB	3 226 ± 298
6.5–14.5	ZB	315 ± 34
	MB	351± 33

The two results are consistent

GLOBAL PROCEDURE

For each $p_T(D^+)$-bin we have evaluated the production cross section as a function of the data-taking periods

It was not possible for the lowest bin, $p_T(D^+)$ in [1.5; 2.5] GeV/c, because of low statistics

Only statistical uncertainties have been considered

For each subsample a new optimization has been performed

$p_T(D^+)$ bins

- **Period 0** → EVEN / ODD → **CrossSec 0**
- **Period 1** → EVEN / ODD → **CrossSec 1**
- **Period 2** → EVEN / ODD → **CrossSec 2**
- **Period 3** → EVEN / ODD → **CrossSec 3**
- **Period 4** → EVEN / ODD → **CrossSec 4**

5 • 5 • 2 = 50

No time-dependence is observed

COMPARISON WITH PREVIOUS CDF-RESULT

- The comparison with the previous CDF result, *PRL 91*-measurement, is an important consistency check of the analysis, but doing it properly is not straightforward:

  1. **The *PRL91*-analysis published the cross section at a given p_T value within each bin while we measure the cross section averaged across each bin**

  2. **The *PRL91* and this measurement cover different** p_T ranges: **[6, 20] vs [1.5, 14.5] GeV/c**

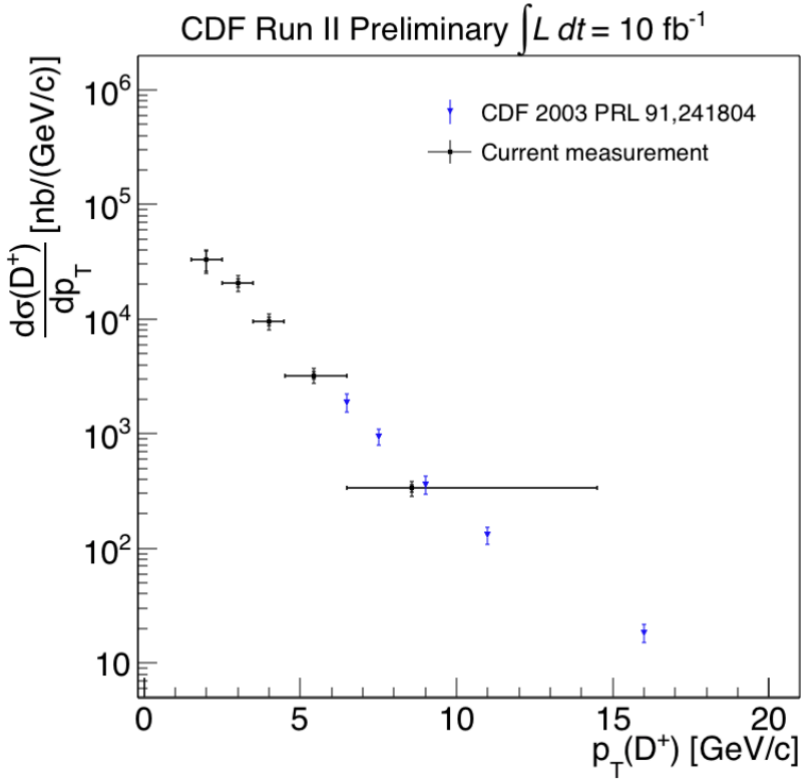
- A simple direct comparison is not possible

COMPARISON WITH PRL-91RESULT

- To overcome the problem of the different binning and different cross-section definition we compare the measurements by using the theoretical prediction as a reference to normalize both measurements

- We consider all experimental uncertainties except the common luminosity contribution

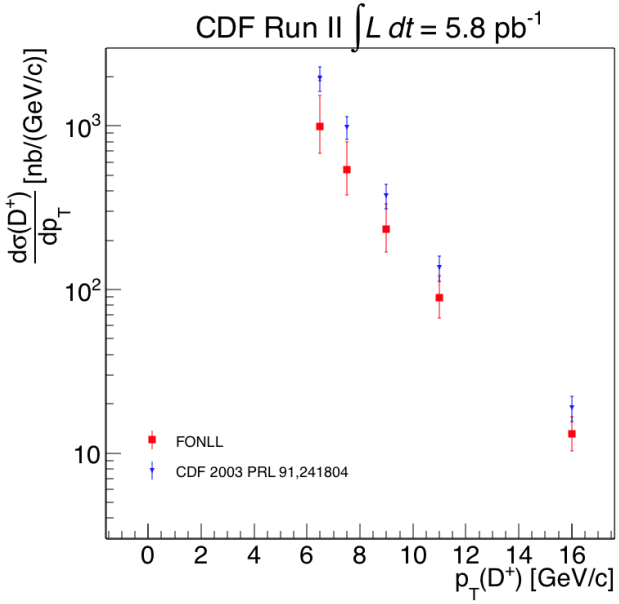
- We agree within $\Delta/\sigma = 0.5$



The markers for this measurement are placed at the average-p_T within the bin.

COMPARISON WITH PRL-91RESULT

PRL91-MEASUREMENT AND THEORY

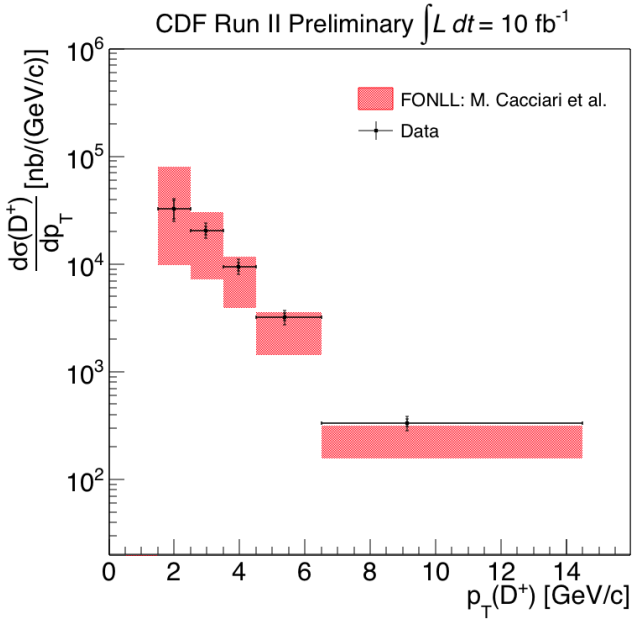


CDF Run II Preliminary

$p_T(D^+)$ [GeV/c]	PRL91-meas.[nb/(GeV/c)]*	Theory	PRL91-Data/Theory ratio
6–7	1 886±309	997±541	1.89±1.07
7–8	948±143	537±259	1.77±0.89
8–10	361±57	233±99	1.54±0.70
10–12	131±22	89±32	1.47±0.59
12–20	18.3±3.0	13.0±3.6	1.40±0.46

*scaled to take into account the current value of the BR = 9.46 ± 0.24 %

THIS MEASUREMENT AND THEORY

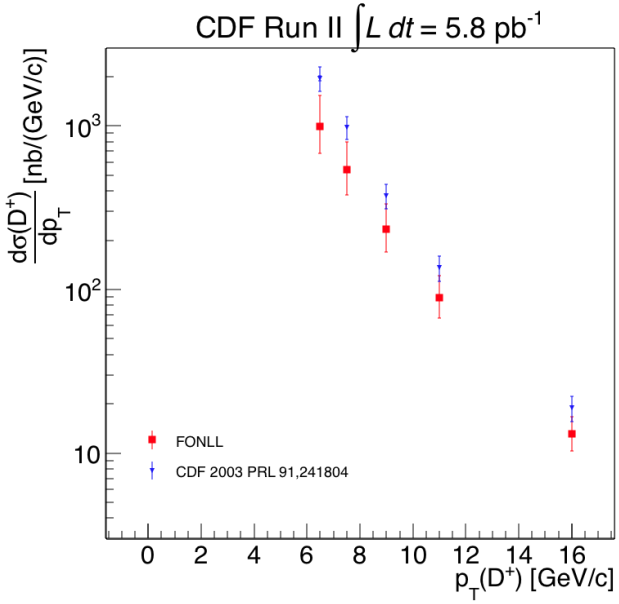


CDF Run II Preliminary

$p_T(D^+)$ [GeV/c]	This meas.[nb/(GeV/c)]	Theory	This Data/Theory ratio
1.5–2.5	32 700±7 509	36 009±25 847	0.91±0.69
2.5–3.5	20 600±2 975	15 565±14 663	1.32±1.27
3.5–4.5	9 500±1 378	6 538±5 070	1.45±1.15
4.5–6.5	3 230±453	2 176±1 378	1.48±0.97
6.5–14.5	336±47	218±99	1.54±0.74

COMPARISON WITH PRL-91RESULT

PRL91-MEASUREMENT AND THEORY

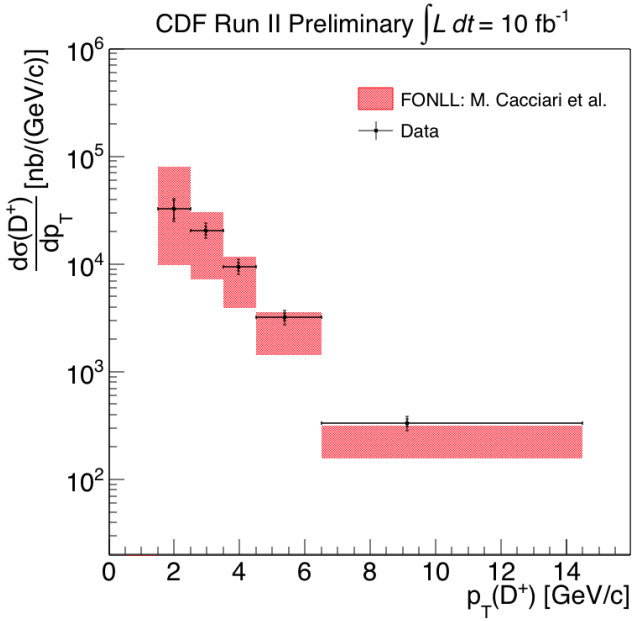


CDF Run II Preliminary

$p_T(D^+)$ [GeV/c]	PRL91-meas.[nb/(GeV/c)]*	Theory	PRL91-Data/Theory ratio
6–7	1 886±309	997±541	1.89±1.07
7–8	948±143	537±259	1.77±0.89
8–10	361±57	233±99	1.54±0.70
10–12	131±22	89±32	1.47±0.59
12–20	18.3±3.0	13.0±3.6	1.40±0.46

*scaled to take into account the current value of the BR = 9.46 ± 0.24 %

THIS MEASUREMENT AND THEORY



CDF Run II Preliminary

$p_T(D^+)$ [GeV/c]	This meas.[nb/(GeV/c)]	Theory	This Data/Theory ratio
1.5–2.5	32 700±7 509	36 009±25 847	0.91±0.69
2.5–3.5	20 600±2 975	15 565±14 663	1.32±1.27
3.5–4.5	9 500±1 378	6 538±5 070	1.45±1.15
4.5–6.5	3 230±453	2 176±1 378	1.48±0.97
6.5–14.5	336±47	218±99	1.54±0.74

Weighted-averages of the data/theory ratios

CDF Run II Preliminary

This <Data/Theory ratio>	PRL-91<Data/Theory ratio>	Δ/σ
1.54±0.15	1.64±0.13	0.48

CONCLUSIONS

- We have measured the low p_T D^+-meson production cross section at CDF
- While the measurements lie within the band of theoretical uncertainty, there is a systematic variation suggesting that the shape of the theoretical cross section can benefit by further refinement taking account these results
- We agree with earlier determination at high momenta
- Since it is the first measurement of the silicon low p_T efficiency, it is a benchmark for all other CDF cross section-measurements in these kinematic conditions
- Further information can be found at: http://goo.gl/ai9mj2

Thank you

Enjoy your "aperitivo scientifico"!

BACK-UP

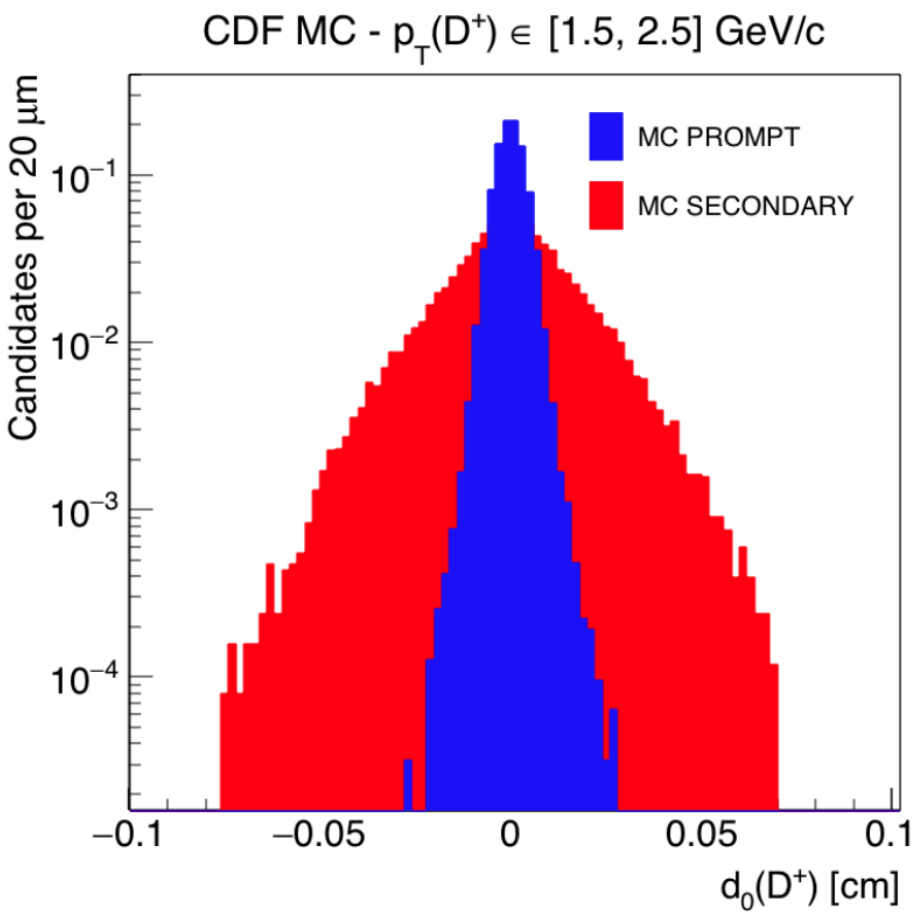
OPTIMIZATION RESULTS

$p_T(D^+)$ [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; 2.5]	EVEN	0.7	4	0.0600
	ODD	0.6	4	0.0600

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

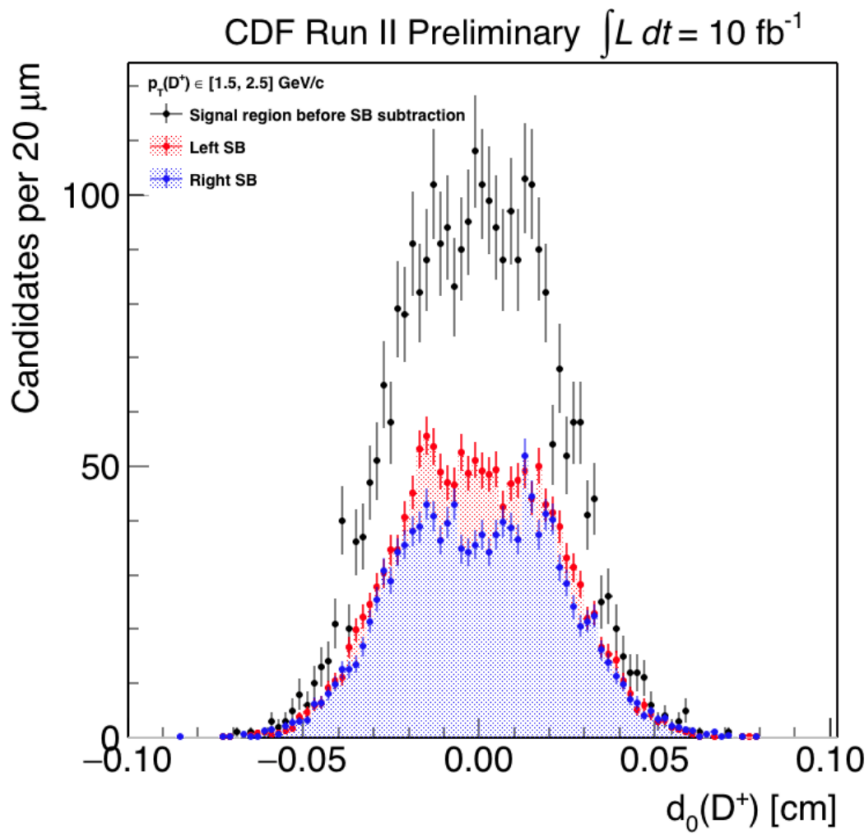
$1.5 < p_T(D^+) < 2.5$ GeV/c: structures

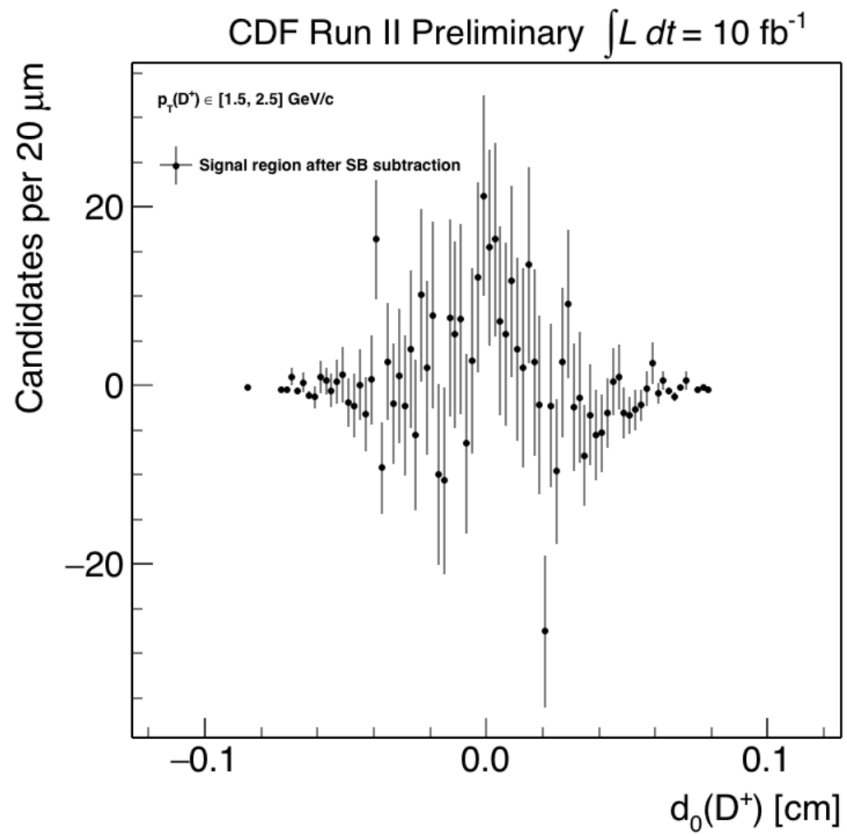
The structures are not related to the Prompt or Secondary component



$1.5 < p_T(D^+) < 2.5$ GeV/c: structures

They are due to the contribution of combinatorics.
In SBs-subtracted region they disappear

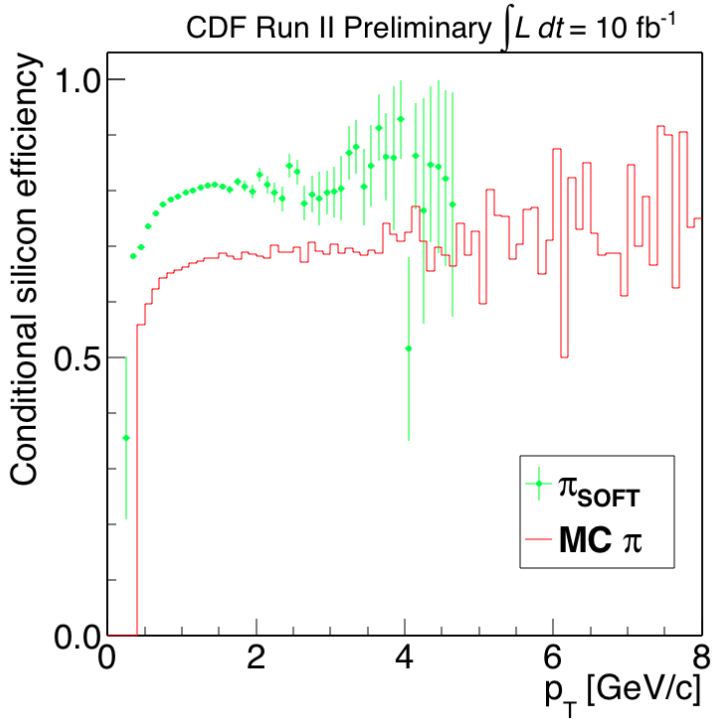


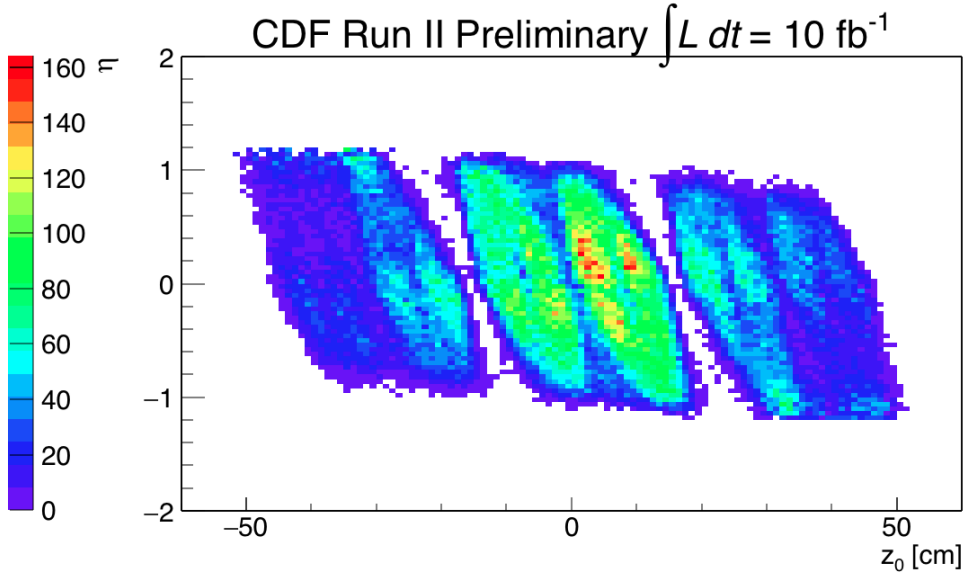


CONDITIONAL-SILICON EFFICIENCY: ALTERNATIVE PROCEDURE

- The D^0 ($D^{*+} \rightarrow D^0 \pi^{\pm}_{soft}$) is detected only when you have good-quality silicon tracks

- The conditional-silicon-efficiency for the soft-π is silicon-biased



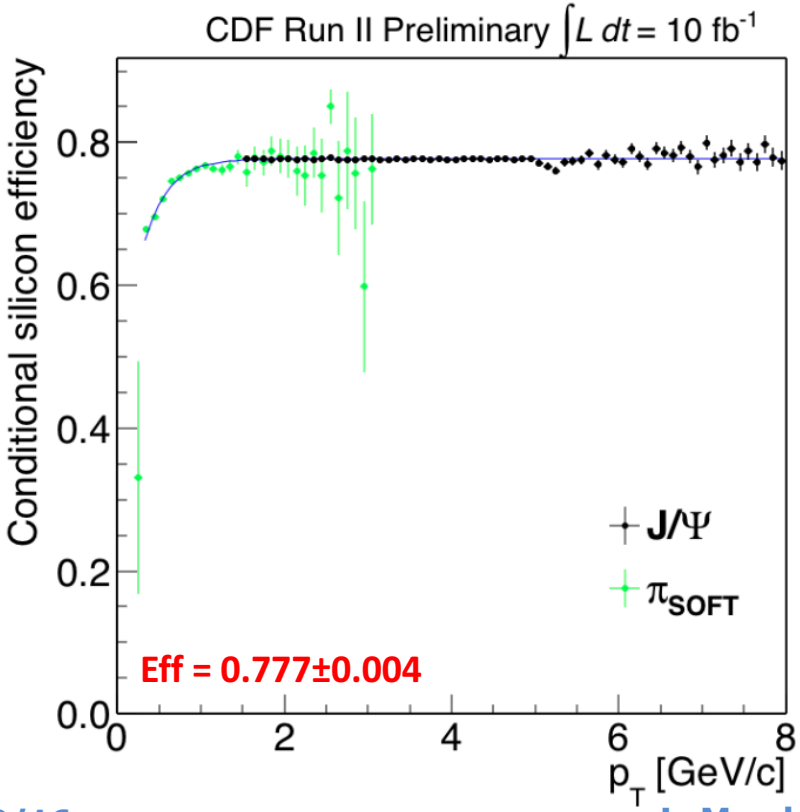


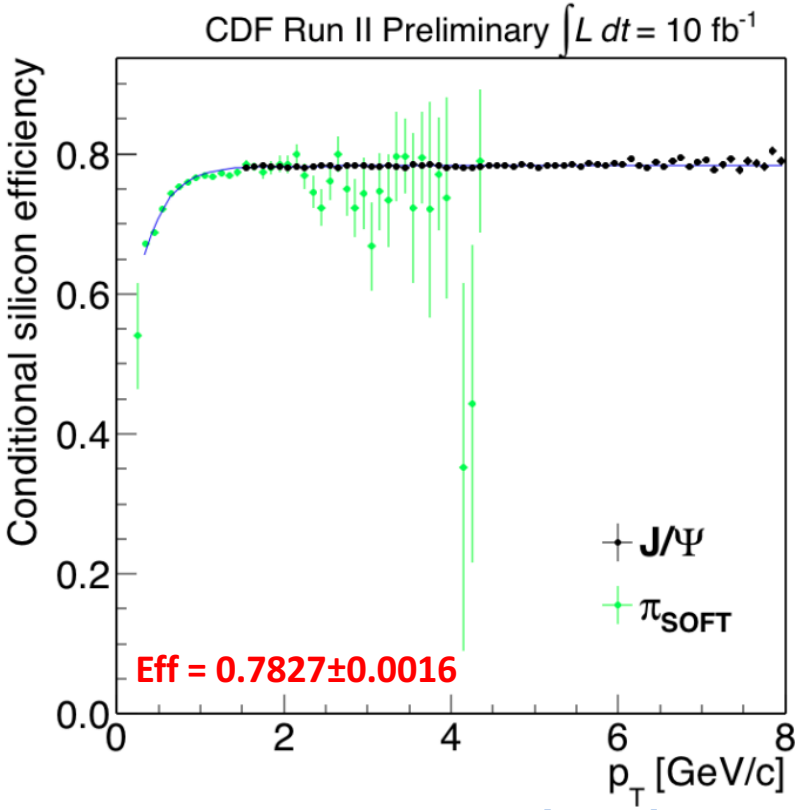
CONDITIONAL-SILICON EFFICIENCY: ALTERNATIVE PROCEDURE

- We use the soft-π to model the shape and the J/Ψ dataset for the plateau

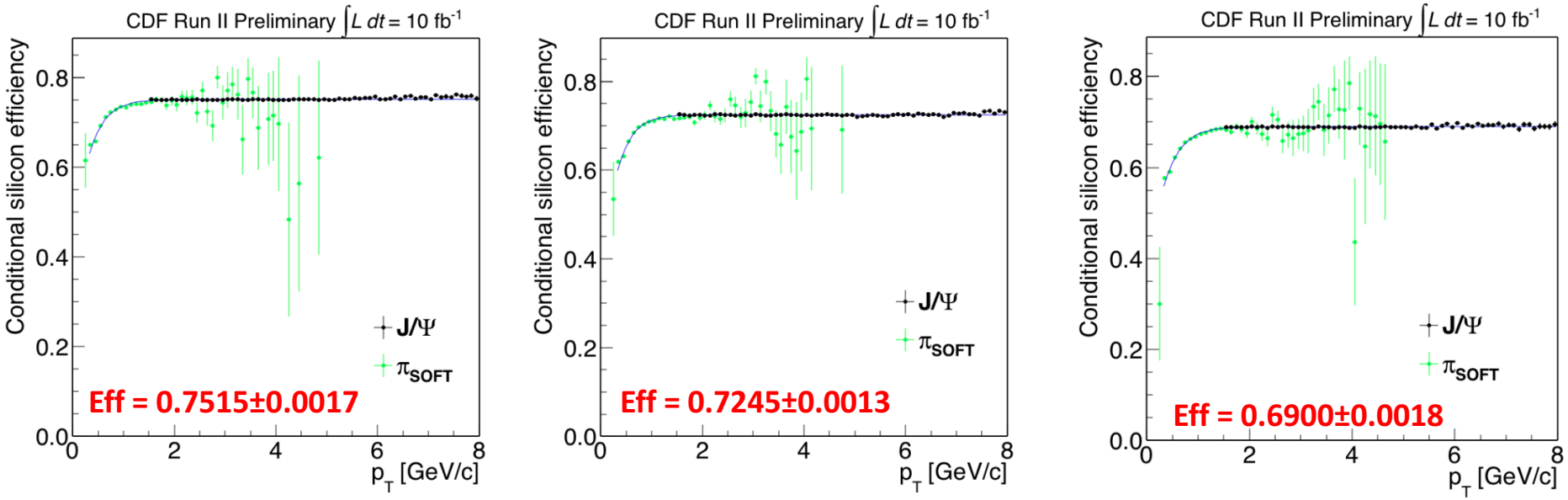
$$Func(p_T) = N \cdot \underbrace{(Const - ae^{-b \cdot p_T})}_{\text{SHAPE from } \pi_{soft}}$$

$$Eff = N \cdot Const$$





CONDITIONAL-SILICON EFFICIENCY: ALTERNATIVE PROCEDURE



D^+ RECONSTRUCTION EFFICIENCY

- ✓ We get the following average data-corrected silicon efficiency for a D^+ already seen in the COT

$$<\varepsilon_{data}(D^+)>=<\varepsilon(K^-)\cdot\varepsilon(\pi^+)\cdot\varepsilon(\pi^+)>$$

- ✓ Assuming that the MC is reliable in the Silicon simulation, we determine

$$<\varepsilon_{MC}(D^+;p_T)>=<\frac{N_{Silicon}(D^+;p_T)}{N_{COT}(D^+;p_T)}>$$

- ✓ For each $p_T(D^+)$ bin we measure the **C**orrection **F**actor as:

$$CF(D^+;p_T)>=\frac{<\varepsilon_{data}(D^+;p_T)>}{<\varepsilon_{MC}(D^+;p_T)>}$$

RECONSTRUCTION EFFICIENCY

CDF Run II Preliminary

$p_T(D^+)$ [GeV/c]	CF
[1.5; 2.5]	0.97 ± 0.09
[2.5; 3.5]	0.96 ± 0.09
[3.5; 4.5]	0.96 ± 0.09
[4.5; 6.5]	0.94 ± 0.08
[6.5; 14.5]	0.94 ± 0.09

- A systematic uncertainty of 6% should be applied to all the $p_T(D^+)$-bins
- We should apply a systematic uncertainty of 11.5 % to all the $p_T(D^+)$-bins following the first procedure
- We prefer to be conservative and apply a systematic uncertainty of 11.5%