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Charm fragmentation tuning in PYTHIA with BELLE II data

DESY 2024 summer student project

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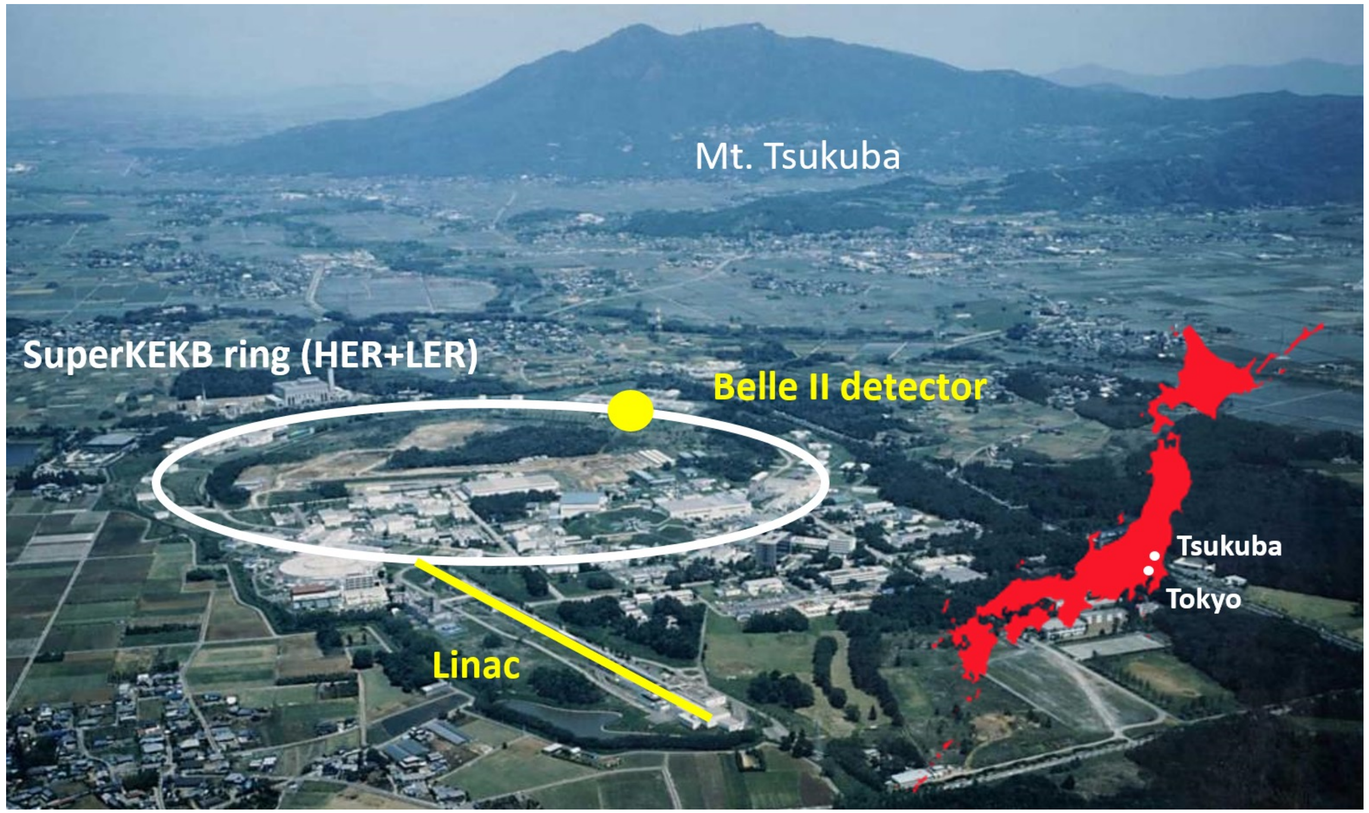
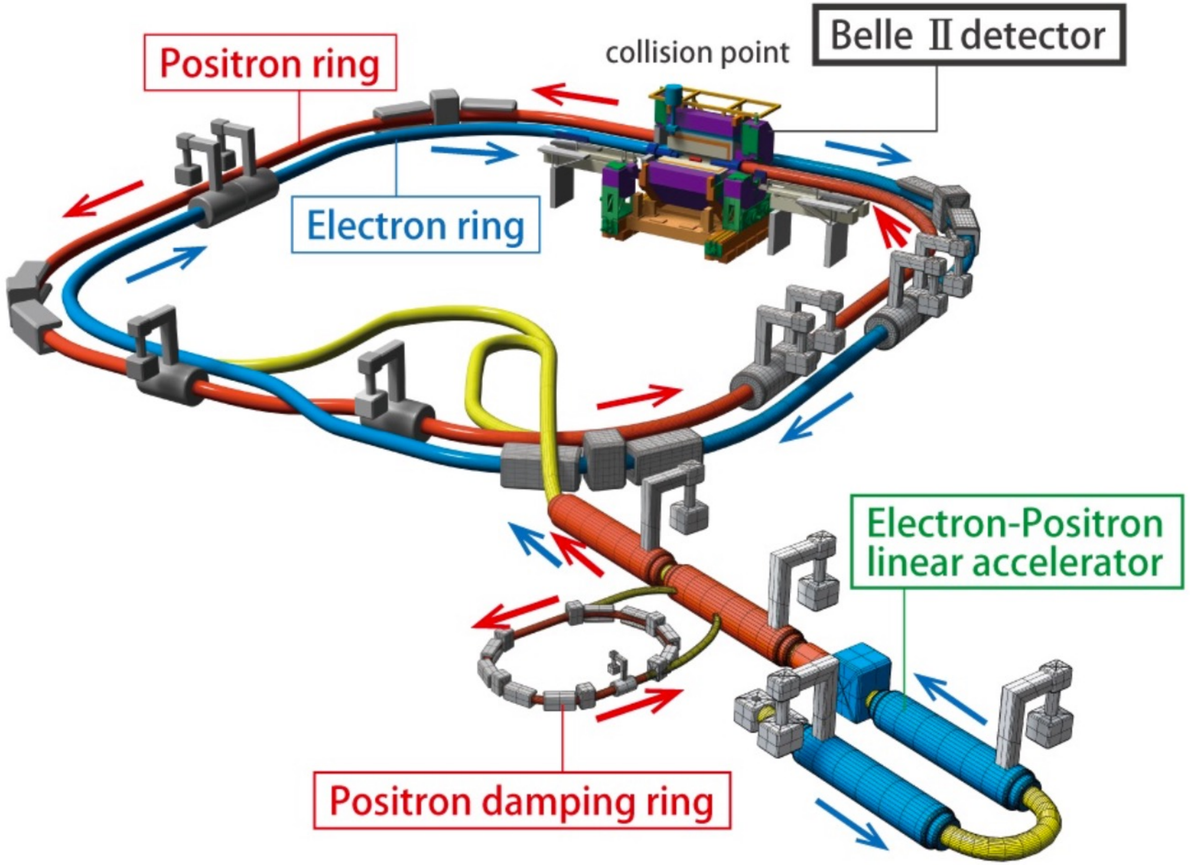
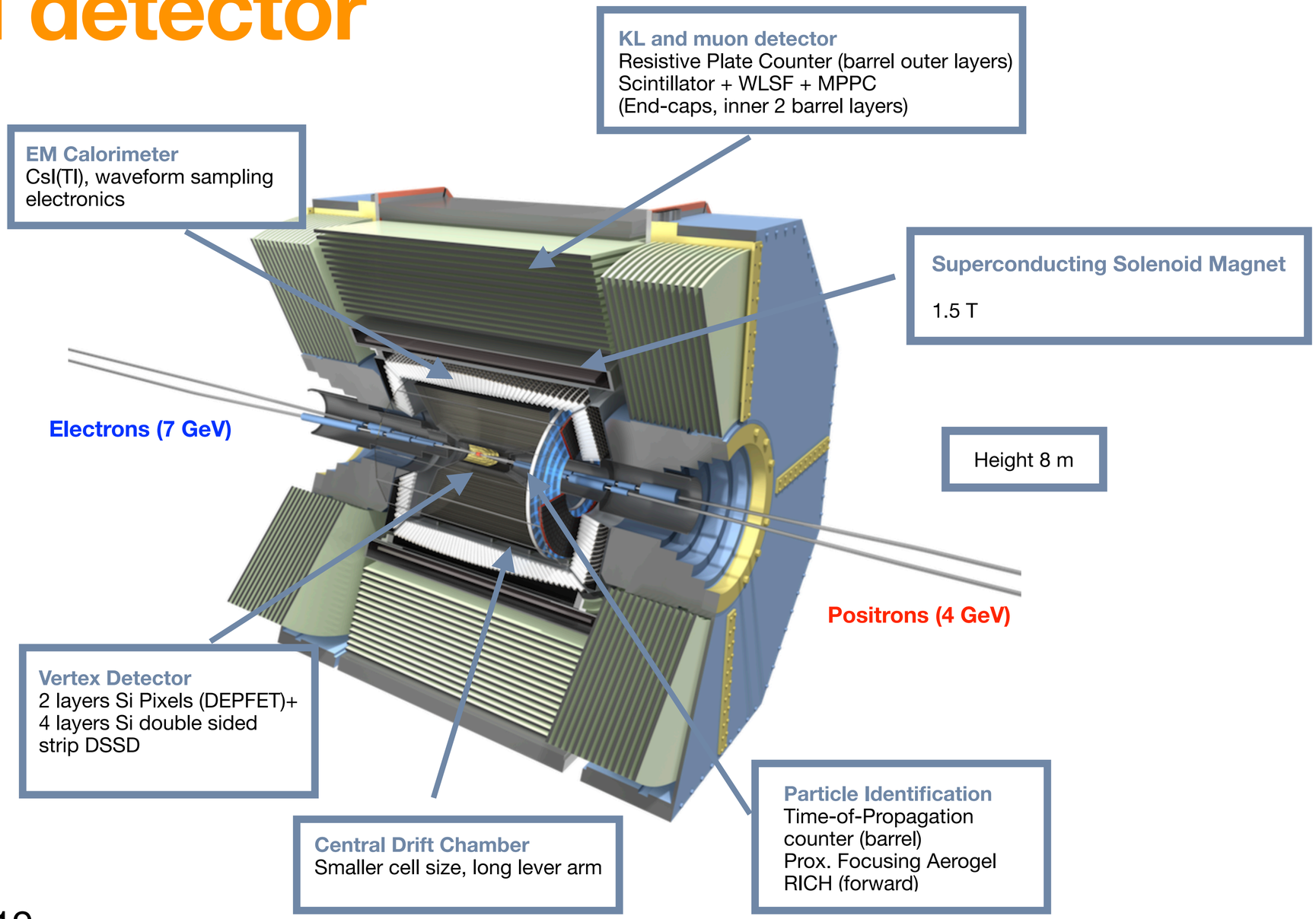
SuperKEKB accelerator





- e^+e^- collisions at $\sqrt{s} = 10.58$ GeV, $p_z(e^-) = +7$ GeV and $p_z(e^+) = -4$ GeV

BELLE II detector



- Operating since 2019

String fragmentation model

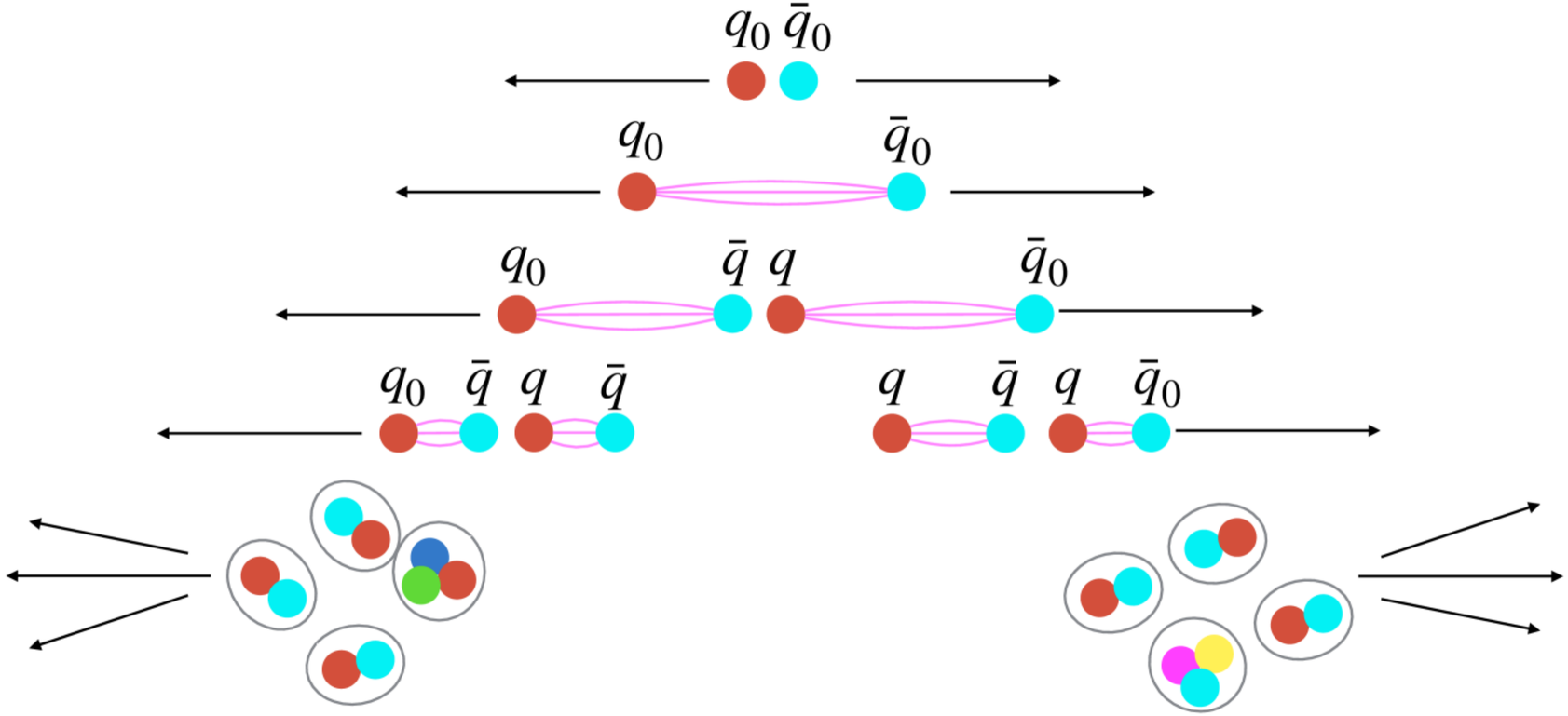
$e^+e^- \to q\bar{q}$ i)

color string ii)

string breaking iii)

more breaking iv)

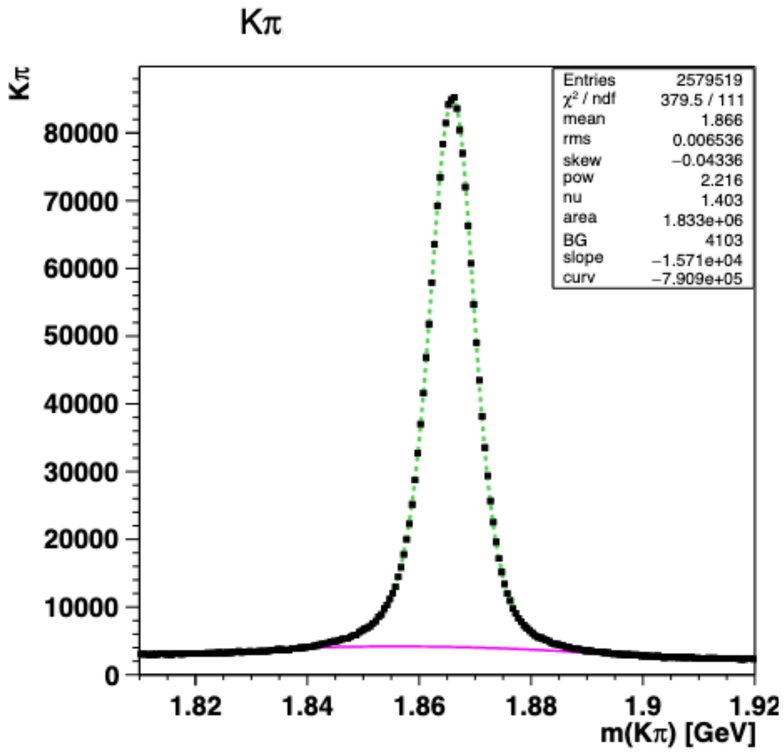
hadronization v)

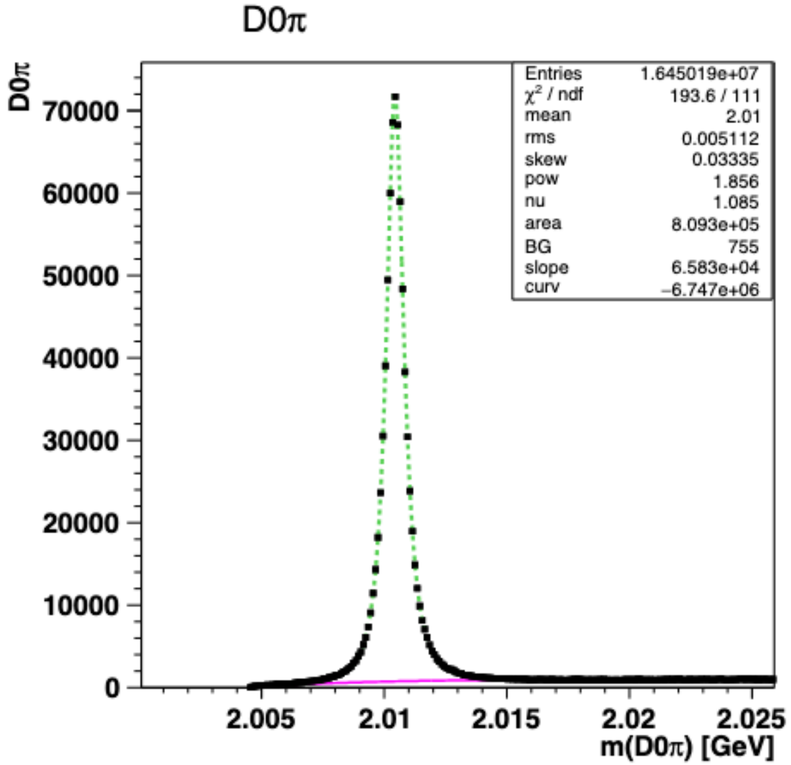


This QCD inspired model is implemented in PYTHIA with a lot of empirical parameters

D^0 and D^{*+} charm mesons

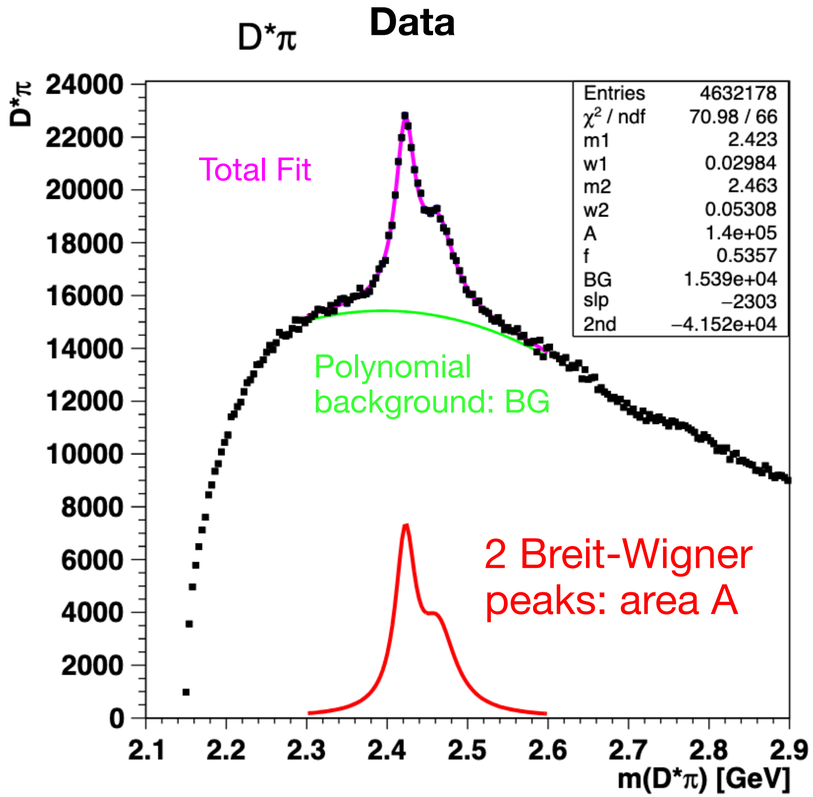
- The decays considered are: $D^0 \to K^-\pi^+, \quad D^{*+} \to D^0\pi^+$ and their respective charge conjugate decays.

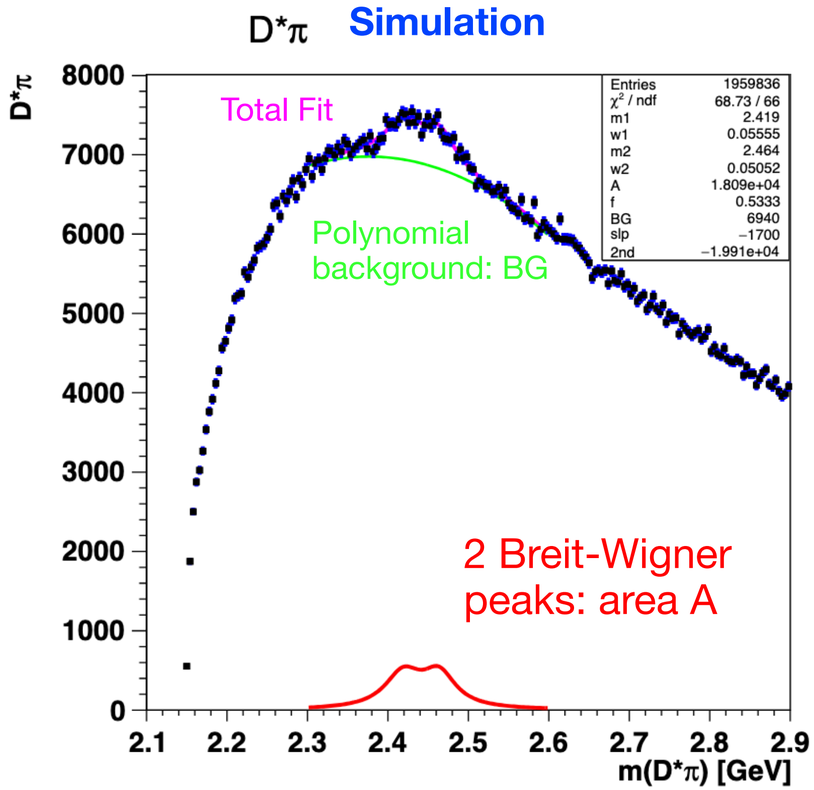




- BELLE II simulation for $c\bar{c}$
- K and π reconstructed in the tracking system
- Using particle identification for K

D_1^0 and D_2^{*0} resonances decaying into $D^*\pi$





States observed:

- D_1^0 at 2.423 GeV, axial-vector
- D_2^{*0} at 2.463 GeV, tensor

The BELLE II simulation uses the PYTHIA event generator.

It underestimates the production of D_1^0 and D_2^{*0}.

The ratio f of D_1^0 to D_2^{*0} is well described by PYTHIA.

- Comparing the two results: $\left(\frac{A}{BG}\right)_{RD} \approx 9.1,$ $\left(\frac{A}{BG}\right)_{B2} \approx 2.9$

  with a precision of 3% for real data.

- Simulation parameters need to be adjusted

Pythia simulation and flavour parameters

- In BELLE II, PYTHIA is used to model production, fragmentation and hadronization of u,d,s,c continuum.
- In PYTHIA, the relative production rates of different particle species are steered by several parameters.

StringFlav:mesonCvector: the relative production rate of vector/pseudoscalar mesons that contain charm quarks.

StringFlav:mesonCL1S0J1: the relative pseudovector production ratio (L=1,S=0,J=1)/pseudoscalar for charm mesons.

StringFlav:mesonCL1S1J0: the relative scalar production ratio (L=1,S=1,J=0)/pseudoscalar for charm mesons.

StringFlav:mesonCL1S1J1: the relative pseudovector production ratio (L=1,S=1,J=1)/pseudoscalar for charm mesons.

StringFlav:mesonCL1S1J2: the relative tensor production ratio (L=1,S=1,J=2)/pseudoscalar for charm mesons.

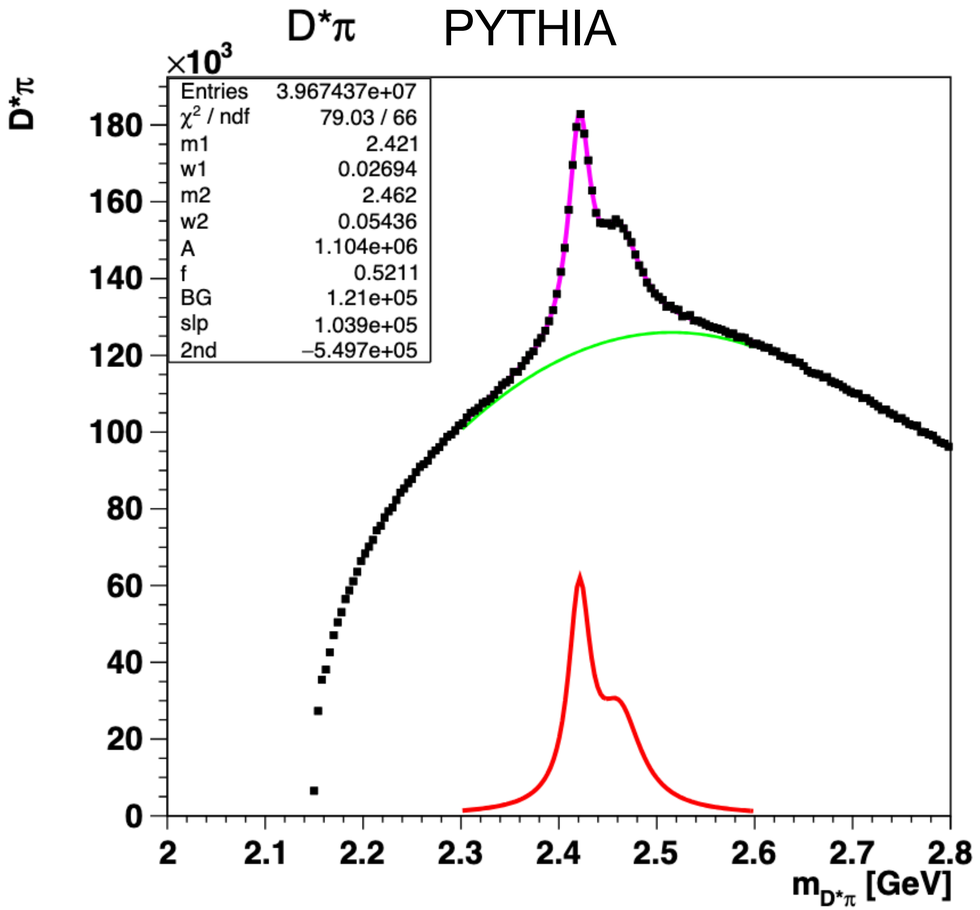
The Monash 2013 tune parameters, based on LEP1 data, used by `PYTHIA` are the following:

- **StringFlav:mesonCvector** = 0.88
- **StringFlav:mesonCL1S0J1** = 0.0990
- **StringFlav:mesonCL1S1J0** = 0.0657
- **StringFlav:mesonCL1S1J1** = 0.2986
- **StringFlav:mesonCL1S1J2** = 0.2986

The following is the list of simulation parameters used by the BELLE II Collaboration:

- **StringFlav:mesonCvector** = 2.8
- **StringFlav:mesonCL1S0J1** = 0.06 Axial – vector
- **StringFlav:mesonCL1S1J0** = 0.1775
- **StringFlav:mesonCL1S1J1** = 0.1868
- **StringFlav:mesonCL1S1J2** = 0.1836 Tensor

Pythia simulation and determination of parameters



- Iterative scan to determine the best option for the charm meson production parameters
- In terms of A/BG and the relative peak fraction f

$$\textbf{StringFlav:mesonCL1S0J1} = 0.2210 \quad (D_1^0\,,\, D_1^+)$$

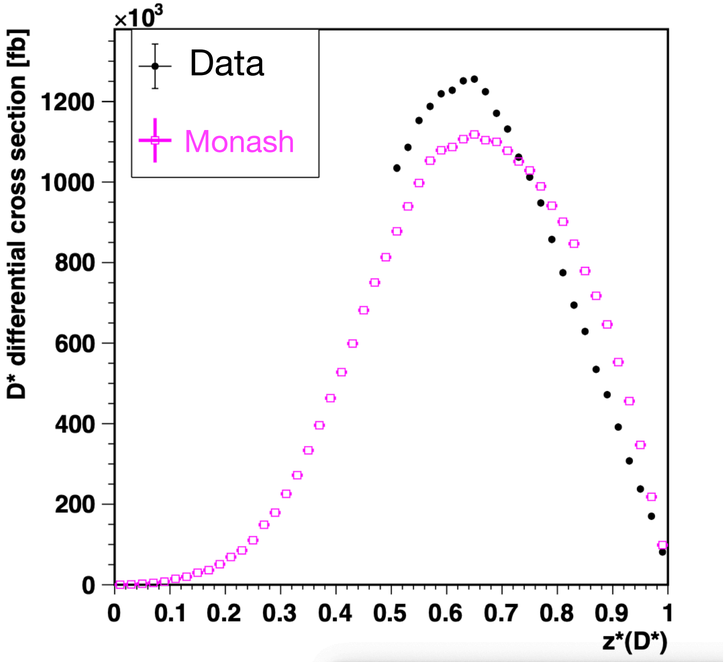
$$\textbf{StringFlav:mesonCL1S1J2} = 0.4845 \quad (D_2^{*0}\,,\, D_2^{*+})$$

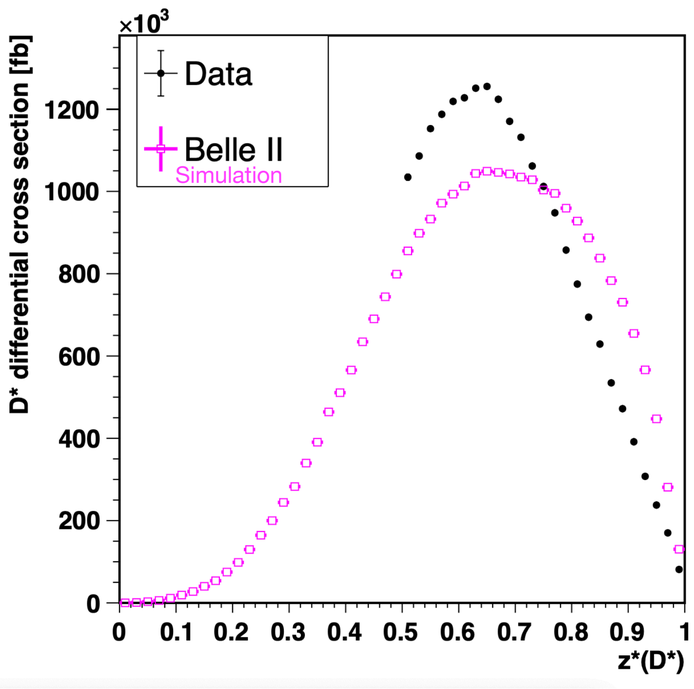
- With this new configuration, the ratio results:

$$\left(\frac{A}{BG}\right) \approx 9.1, \quad f \approx 0.52$$

like in the data.

D^{*+} fragmentation spectrum





- Fragmentation variable: $z^* = p^*/p^*_{max}$ where p^* is the momentum in the center of mass frame and p^*_{max} is its kinematical limit
- For data the analysis starts at $z^* = 0.5$ where only $c\bar{c}$ contributes
- Fragmentation parameters need to be optimized

- The enhanced D_1 and D_2^* production in PYTHIA leads to feed-down for D^*
- The differential cross section for D^* is determined from:

$$\frac{d\sigma}{dz} = \frac{1}{L}\frac{dN_{gen}(z)}{dz} \approx \frac{1}{L\epsilon(z)}\frac{N_{rec}(z)}{\Delta z}$$

- The detection efficiency ϵ is measured in the BELLE II simulation:

$$\epsilon(z) = \frac{N_{rec}(z)}{N_{gen}(z)}$$

Fragmentation in PYTHIA

- The fragmentation function presents the probability that a parton i produces a hadron h carrying a fraction z of the parton's longitudinal momentum

- PYTHIA uses the Lund-Bowler fragmentation function:

$$f(z) = \frac{1}{z^{(1+rbm^2)}}(1-z)^a \exp(-bm_T^2/z)$$

- The parameters a, b, and r can be varied in PYTHIA:

StringZ:aLund (default = 0.68; minimum = 0.0; maximum = 2.0)

StringZ:bLund (default = 0.98; minimum = 0.2; maximum = 2.0)

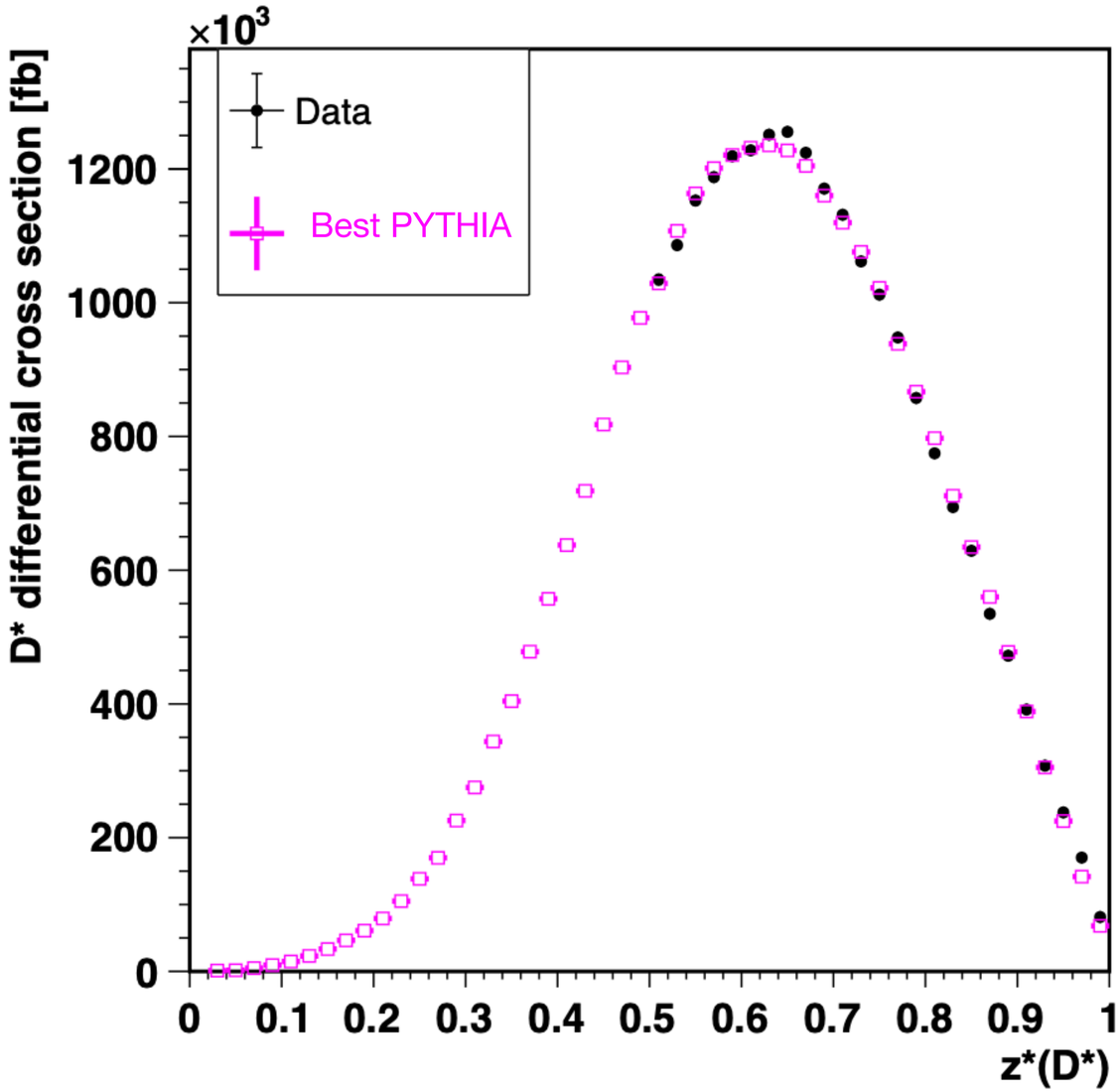
StringZ:rFactC (default = 1.32; minimum = 0.0; maximum = 2.0)

Monash Tune 2013

- The value used by BELLE II: a = 0.32, b = 0.62 and r =1.00

- 3D grid scan: a = [0.90; 1.30], b = [0.70;1.10], r = [0.60; 1.20] in steps of 0.05 (~ 2000 jobs on MacProM3)

Differential cross section for D^{*+}



- For each grid point (a, b, r) the χ^2 of the z spectrum with measured differential cross section was computed to find the configuration that gives the best value

- Final best values:

$$a = 1.25$$

$$b = 0.85$$

$$r = 0.70$$

which differ from both the Monash Tune and the BELLE II default parameters.

Conclusions

RECAP:

- Measured production of D_1^0 and D_2^{*0} mesons in BELLE II data.
- Measured the differential cross section for D^{*+} production.
- Compared to PYTHIA simulation.

RESULTS:

- The tuned production parameters in PYTHIA describe the observed yields for D_1^0 and D_2^{*0}.
- With tuned fragmentation parameters the measured differential cross section for D^{*+} is well described.

OUTLOOK:

- A full BELLE II simulation is needed to validate the new parameters determined.

Thank you

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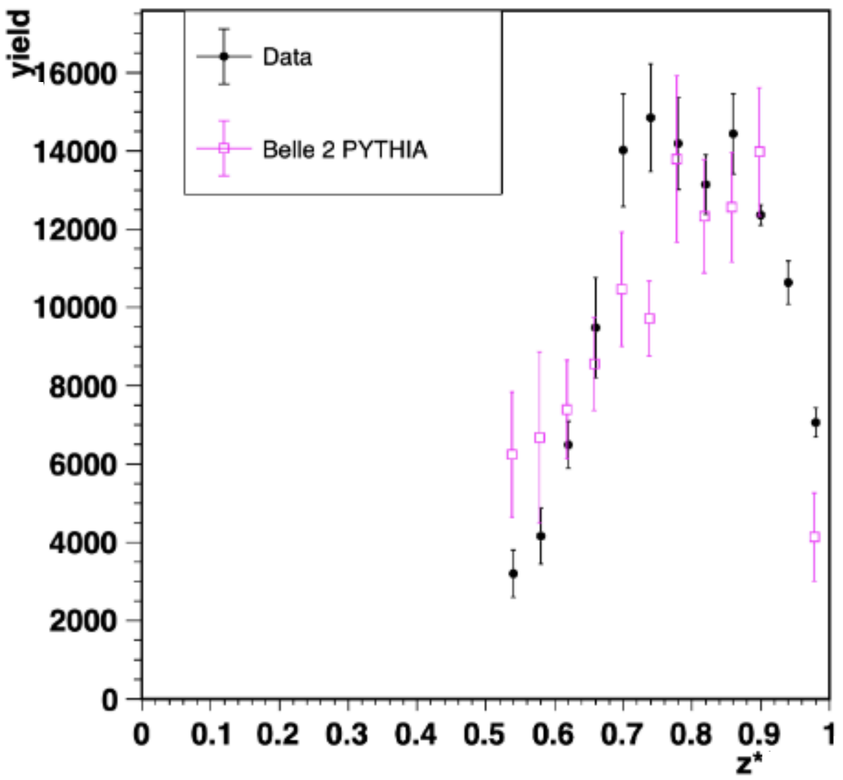
D meson properties

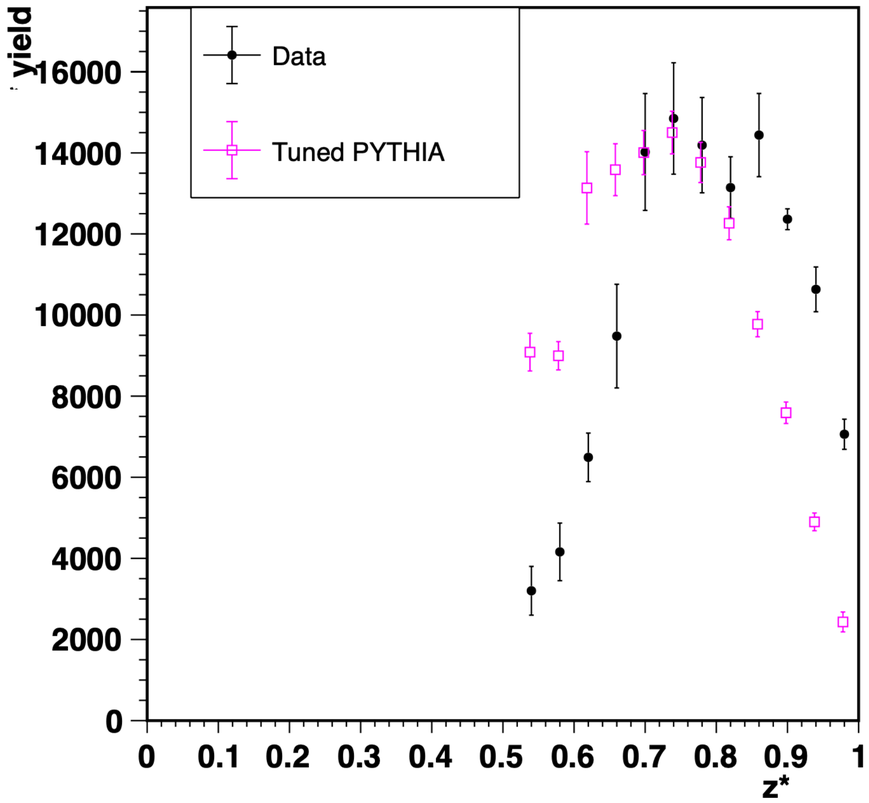
Resonance	Quark Content	Width (MeV)	J^P	L	S
D^0	$c\bar{u}$	< 0.001	0^-	0	0
D^+	$c\bar{d}$	< 0.001	0^-	0	0
D_s^+	$c\bar{s}$	< 0.001	0^-	0	0
D^{*0}	$c\bar{u}$	0.083	1^-	0	1
D^{*+}	$c\bar{d}$	0.096	1^-	0	1
D_s^{*+}	$c\bar{s}$	0.07	1^-	0	1
D_0^{*0}	$c\bar{u}$	267	0^+	1	1
D_0^{*+}	$c\bar{d}$	267	0^+	1	1
D_{s0}^*	$c\bar{s}$	< 3.8	0^+	1	1
D_1^0	$c\bar{u}$	27.4	1^+	1	0
D_1^+	$c\bar{d}$	27.4	1^+	1	0
D_{s1}^+	$c\bar{s}$	0.92	1^+	1	0
D_2^{*0}	$c\bar{u}$	47.3	2^+	1	1
D_2^{*+}	$c\bar{d}$	47.3	2^+	1	1
D_{s2}^{*+}	$c\bar{s}$	17.0	2^+	1	1

Meson	Mass (MeV/c^2)	Main Decay Channels
D^0	1864.84 ± 0.05	$K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$
D^+	1869.66 ± 0.05	$K^-\pi^+\pi^+$, $K^-\pi^+\pi^+\pi^0$
D_s^+	1968.35 ± 0.07	$\overline{K}^0K^+$, $\pi^+\pi^-\pi^+$
D^{*0}	2006.85 ± 0.05	$D^0\pi^0$, $D^0\gamma$
D^{*+}	2010.26 ± 0.05	$D^0\pi^+$, $D^+\pi^0$, $D^+\gamma$
$D_1(2420)^0$	2422.1 ± 0.6	$D^{*+}\pi^-$, $D^0\pi^-\pi^+$
$D_2^*(2460)^0$	2461.1 ± 0.8	$D^{*+}\pi^-$, $D^+\pi^-$
$D_{s1}(2536)^+$	2535.11 ± 0.06	$D^{*+}K_S^0$, $D^{*0}K^+$
$D_{s2}^*(2573)^+$	2569.1 ± 0.8	D^0K^+, $D^+K_S^0$

z^* spectrum for D_1 and D_2^*

- Cross check:



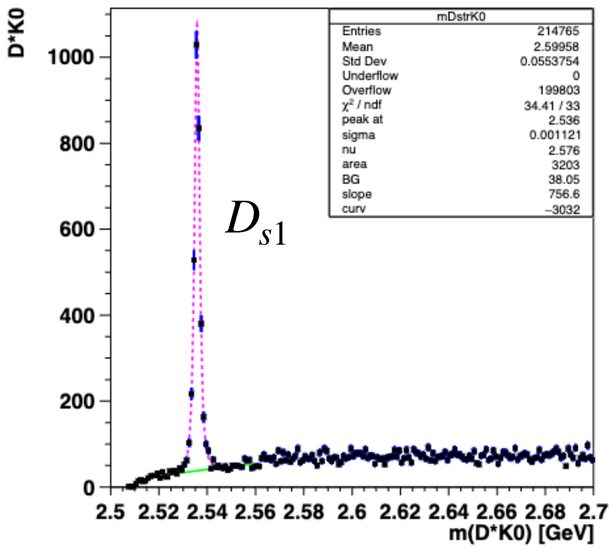


- By adjusting the parameters a, b and r, we are changing the shape of the fragmentation function.
- The best values found for D^{*+} give a too soft spectrum for the D_1 and D_2^* resonances.

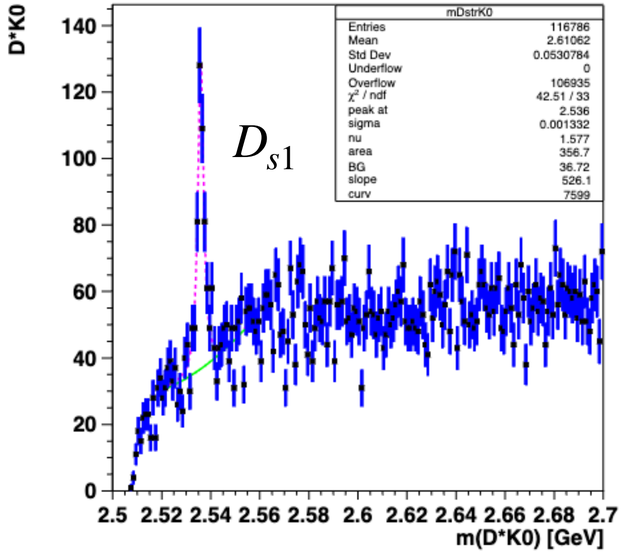
D_{s1}^{+} and D_{s2}^{*+} resonances

- Decay considered: $D_{s1}^{+} \to D^{*+}K^{0}$ $D_{s2}^{*+} \to D^{0}K^{+}$

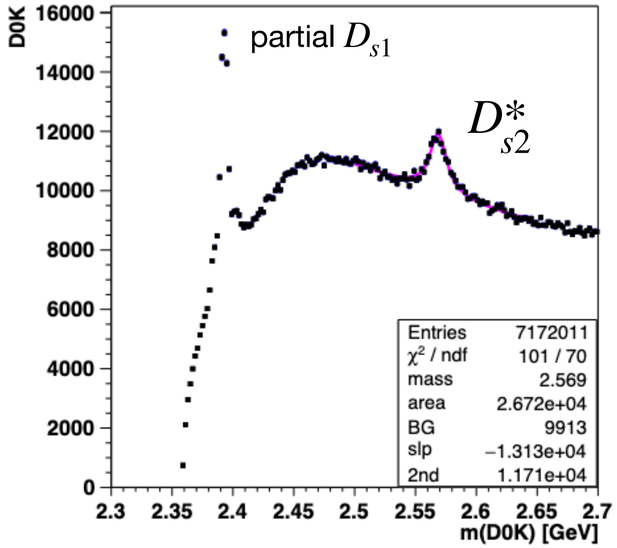
D*K0 Data



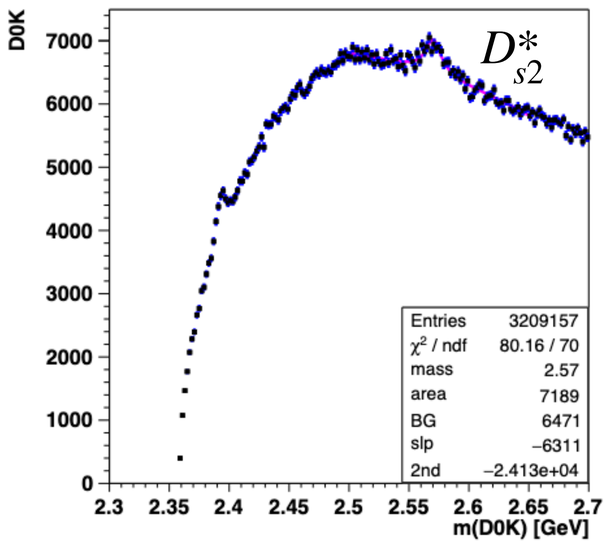
D*K0 BELLE II simulation



D0K Data

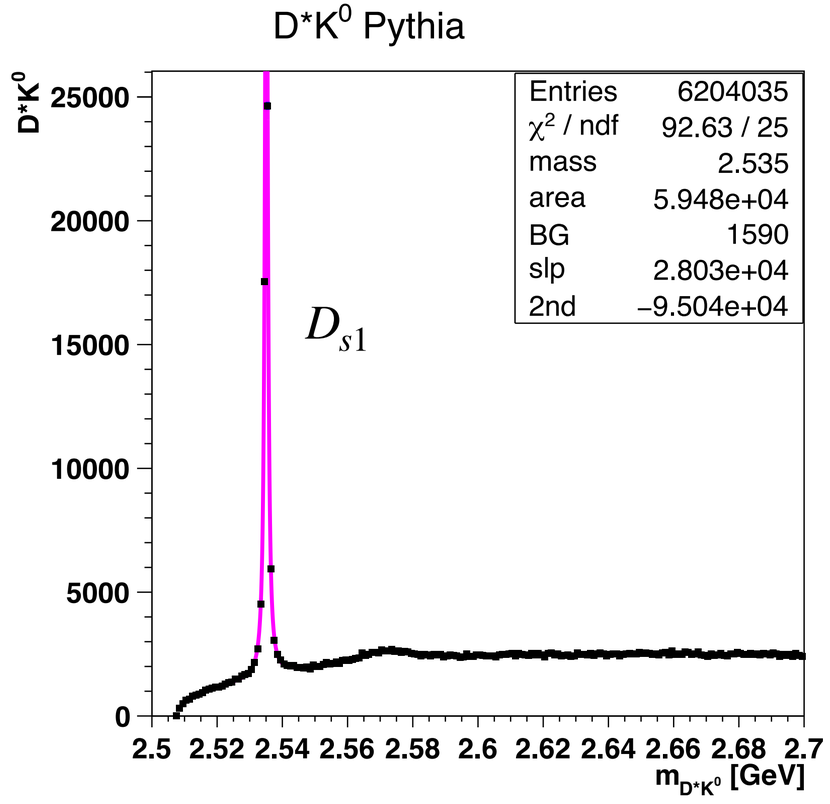


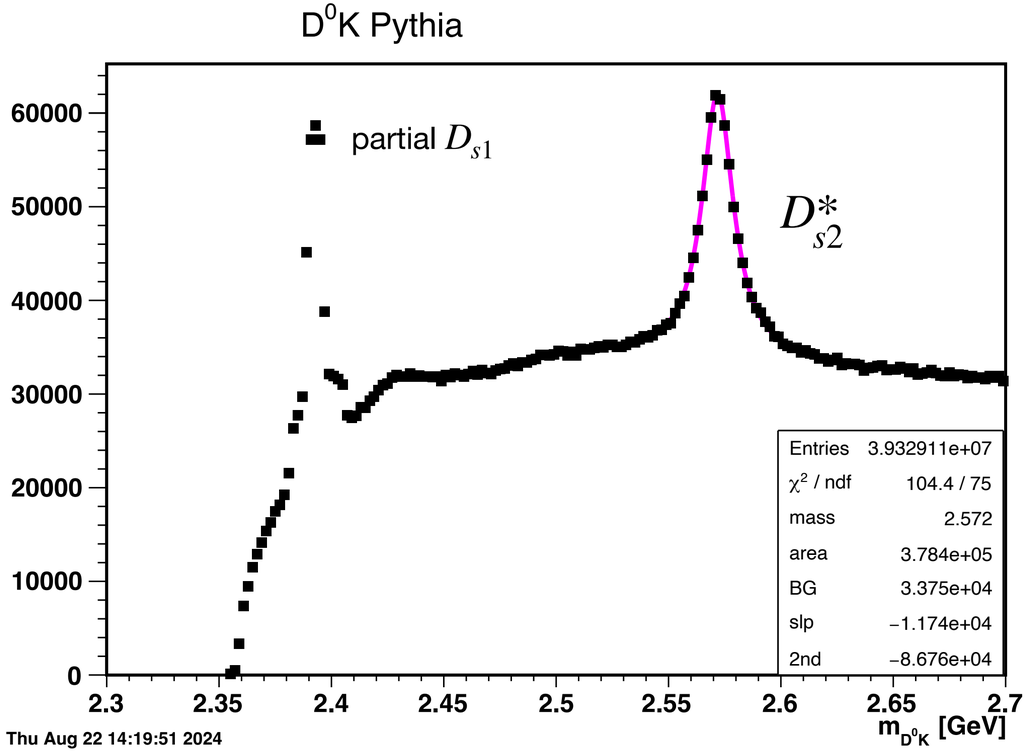
$D^{0}K$ BELLE II simulation



- Again, the default BELLE II simulation underestimates the production rate of axial-vector and tensor mesons

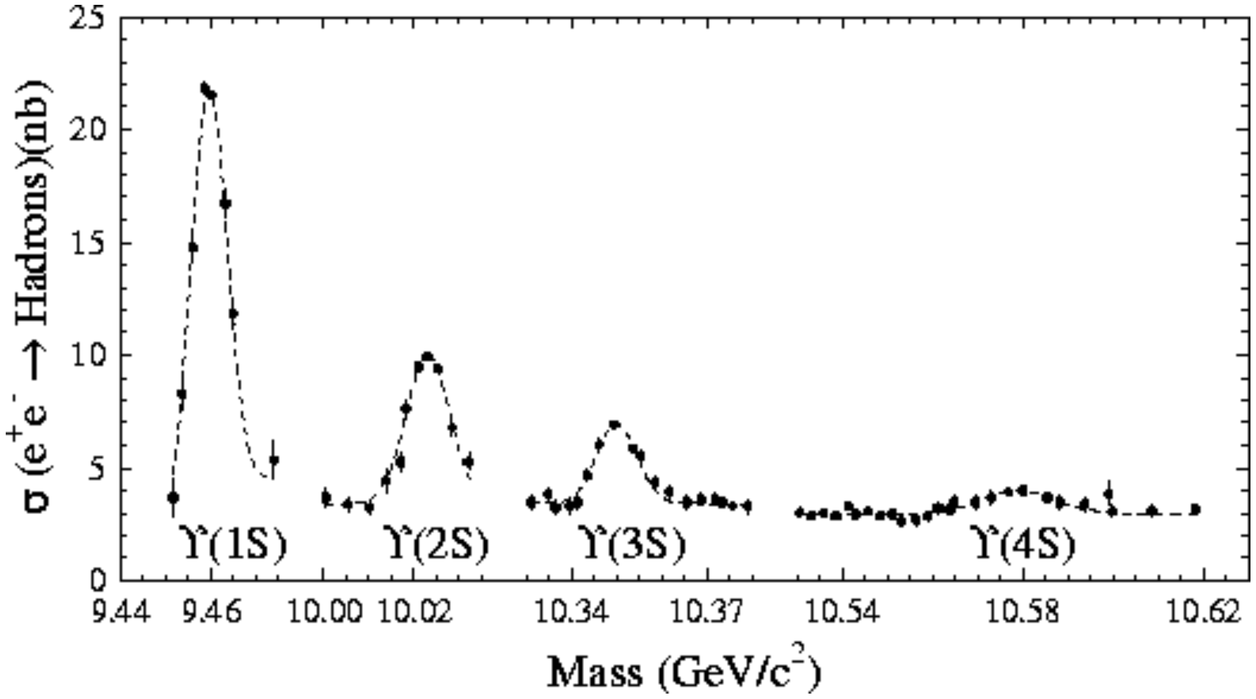
D_{s1}^{+} and D_{s2}^{*+} simulated spectra with the new parameters





- With the new configuration of charm fragmentation parameters, the production of D_{s1}^{+} and D_{s2}^{*+} is also enhanced in PYTHIA as needed by the data

e^+e^- energy scan



- CUSB detector at Cornell USA