CP violation and determination of the “flat” (b,s) unitarity triangle at FCC-ee

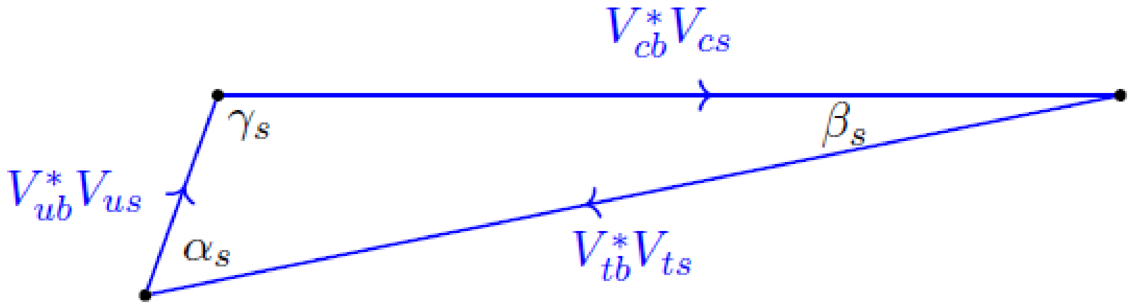
R. Aleksan (CEA/IRFU), L. Oliver (IJCLab), E.Perez (CERN)

ECFA Workshop
WG1 Flavor
25/11/2022

$$V_{ub}^* V_{us} + V_{cb}^* V_{cs} + V_{tb}^* V_{ts} \stackrel{?}{=} 0$$

$$\lambda^4 \quad , \quad \lambda^2 \quad , \quad \lambda^2$$

$$V_{CKM} = \begin{bmatrix} V_{ud} & \boxed{V_{us}} & \boxed{V_{ub}} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$



$$\alpha_s = arg\left(-\frac{V_{ub}^*\, V_{us}}{V_{tb}^*\, V_{ts}}\right), \beta_s = arg\left(-\frac{V_{tb}^*\, V_{ts}}{V_{cb}^*\, V_{cs}}\right), \gamma_s = arg\left(-\frac{V_{cb}^*\, V_{cs}}{V_{ub}^*\, V_{us}}\right) \approx (67°, 1°, 111°)$$

$\boxed{B_s \to D_s K}$ $\boxed{B_s \to J/\psi\phi}$ $\boxed{D^\pm \to D^0(\overline{D}^0)K^\pm}$

- CP violation and determination of the bs "flat" unitarity triangle at FCC-ee, https://arxiv.org/abs/2107.02002
- Study of CP violation in $B^\pm \to D^0(\overline{D^0})K^\pm$ at FCC-ee https://arxiv.org/abs/2107.05311

Detector response

➢ Modelisation of the detector response :

- Detailed description of tracks, accounting for multiple scattering

$$\text{Acceptance} :|\cos\theta| < 0.95$$

$$\text{Track } \mathrm{p_T} \text{ resolution} : \frac{\sigma(p_T)}{p_T^2} = 2. \times 10^{-5} \oplus \frac{1.2 \times 10^{-3}}{p_T \sin\theta}$$

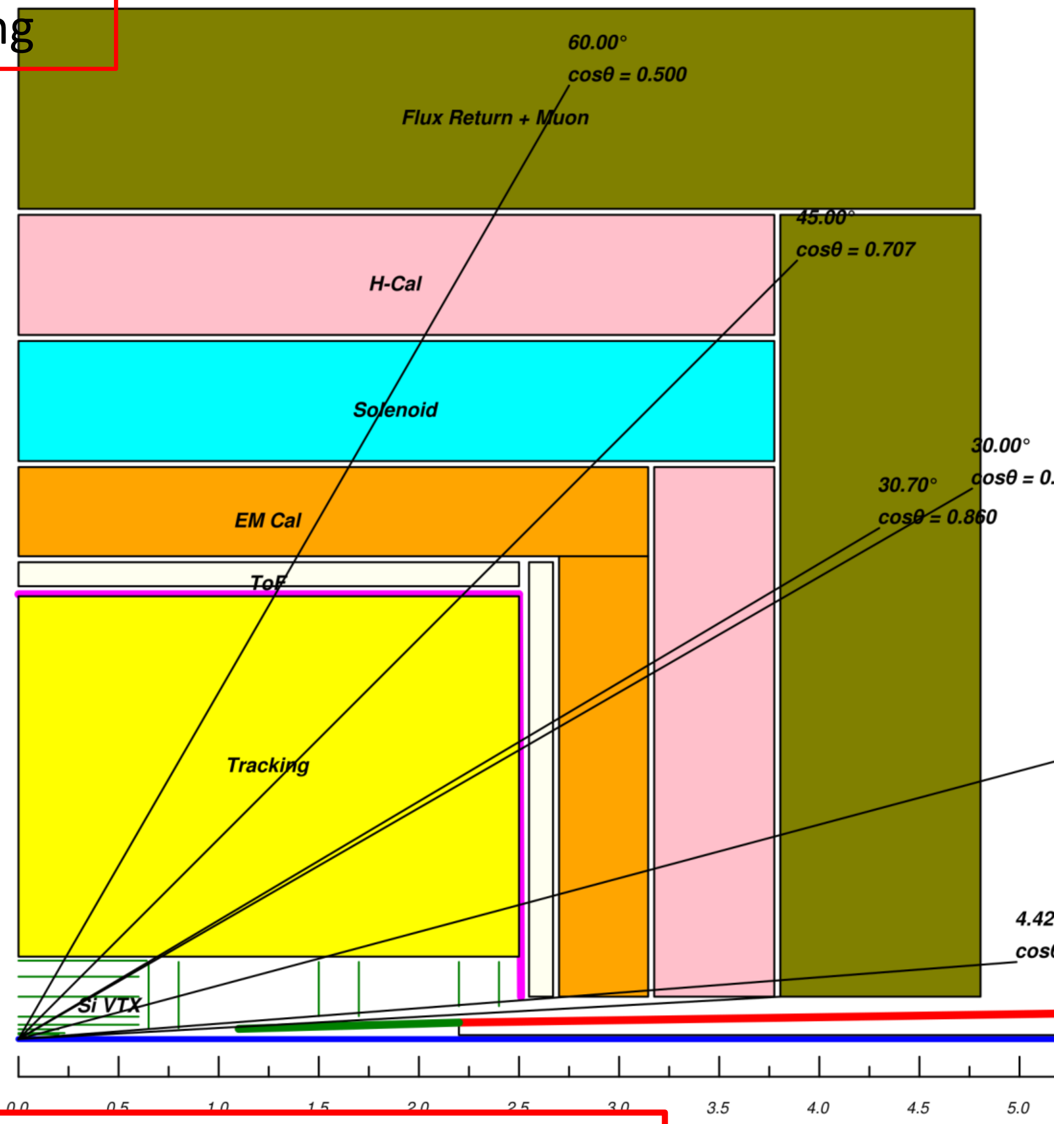
$$\text{Track } \phi, \theta \text{ resolution} : \sigma(\phi, \theta)\ \mu\text{rad} = 18 \oplus \frac{1.5 \times 10^{3}}{p_T \sqrt[3]{\sin\theta}}$$

$$\text{Vertex resolution} : \sigma(\mathrm{d_{Im}})\ \mu\text{m} = 1.8 \oplus \frac{5.4 \times 10^{1}}{p_T \sqrt{\sin\theta}}$$

$$\text{Vertex resolution} : < \sigma(\mathrm{d_{Im}}) > \text{bachelor K in } D_s K$$

$$< \sigma(\mathrm{d_{Im}}) > \simeq 10\ \mu\text{m}$$

$$\text{Calorimeter resolution} : \frac{\sigma(E)}{E} = \frac{3 \times 10^{-2}}{\sqrt{E}} \oplus 5 \times 10^{-3}$$



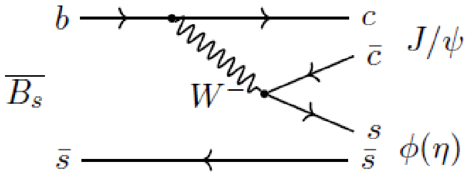
➢ For vertexing Full MC events + response of the IDEA detector with DELPHES

- Genuine vertex fitting

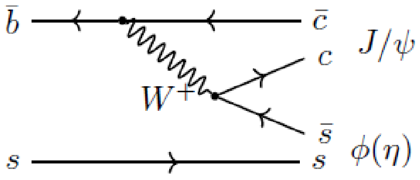
$\beta_s = arg\left(-\frac{V_{tb}^* V_{ts}}{V_{cb}^* V_{cs}}\right)$: CP violation with $B_s \to J/\psi\phi \to \mu^+\mu^- K^+K^-$

$\int Ldt = 150\ ab^{-1}$

$\sim 6 \cdot 10^6\ B_s(\bar{B}_s)$ evts @FCCee



$\overline{B_s} \to B_s$



$V_{cb}\ V_{cs}^*$ $\qquad$ $\frac{V_{tb}\ V_{ts}^*}{V_{tb}^*\ V_{ts}}$ $\qquad$ $V_{cb}^*\ V_{cs}$

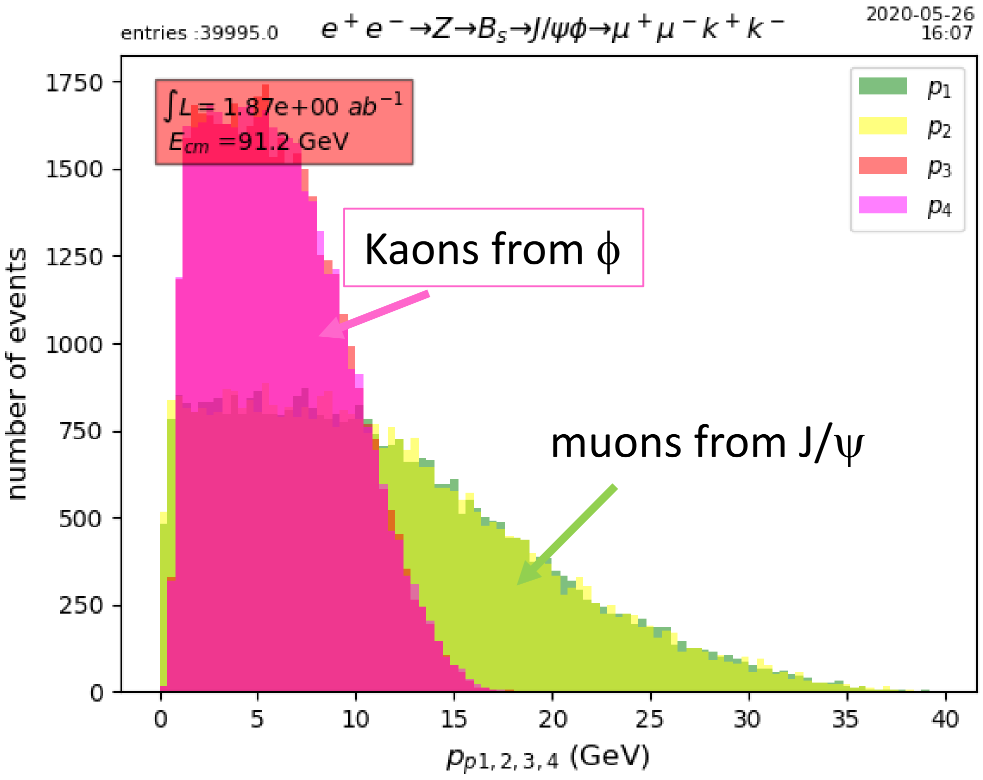
$$\Gamma(B_s(t) \to f_{CP}) = |<f_{CP}|B_s>|^2\ e^{-\Gamma t}\{1 - (1-2\omega)\eta_f \sin\phi_{CP} \sin\Delta m t\}$$

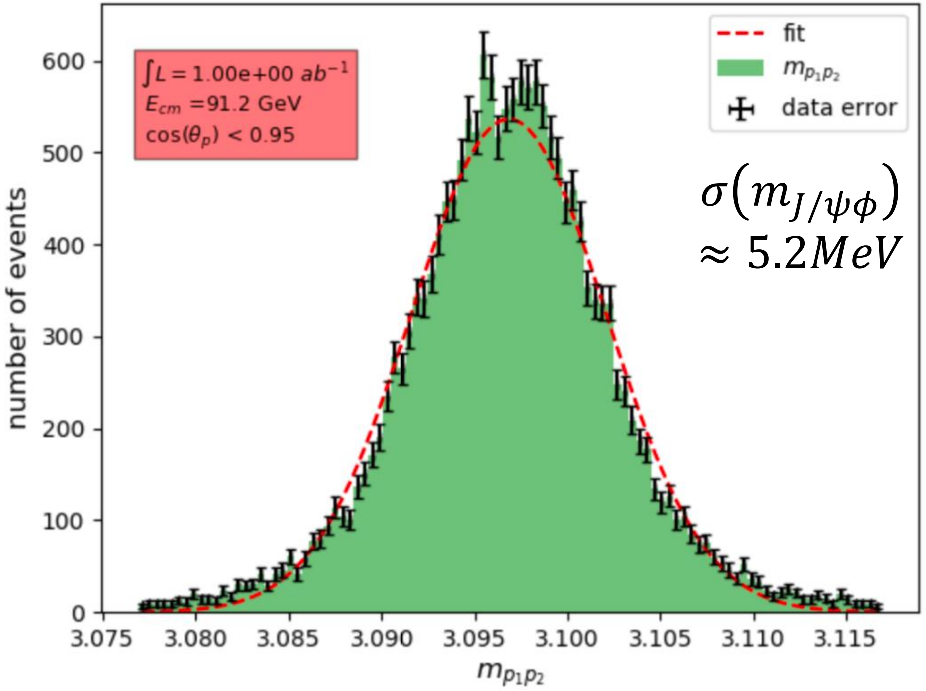
$$\Gamma(\overline{B_s}(t) \to f_{CP}) = |<f_{CP}|B_s>|^2\ e^{-\Gamma t}\{1 + (1-2\omega)\eta_f \sin\phi_{CP} \sin\Delta m t\}$$

$\omega = wrong\ tagging$

	LEP	BaBar	LHCb
$\epsilon(1-2\omega)^2$	25-30%	30%	6%

$$\phi_{CP} = 2\beta_s(+\pi) \approx 2^\circ\ (SM)$$





$\sigma(m_{J/\psi\phi}) \approx 5.2 MeV$

$\beta_s = arg\left(-\frac{V_{tb}^* V_{ts}}{V_{cb}^* V_{cs}}\right)$: CP violation with $B_s \to J/\psi\phi \to \mu^+\mu^- K^+K^-$

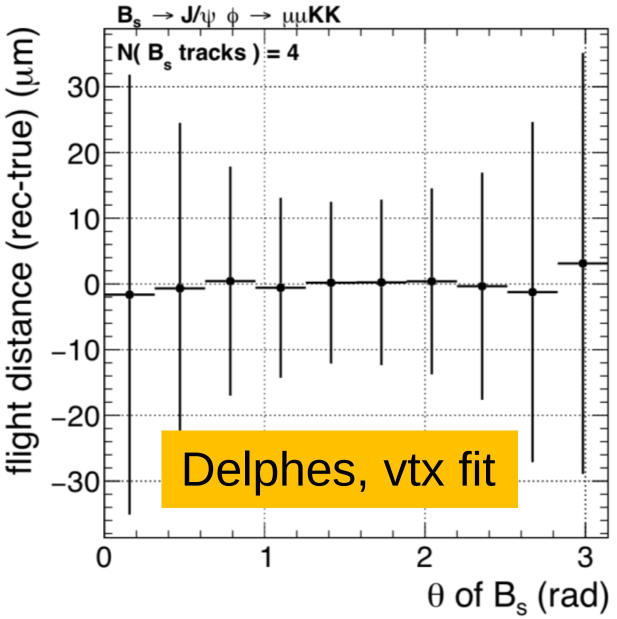
CKM: $\beta_s \approx 1°$

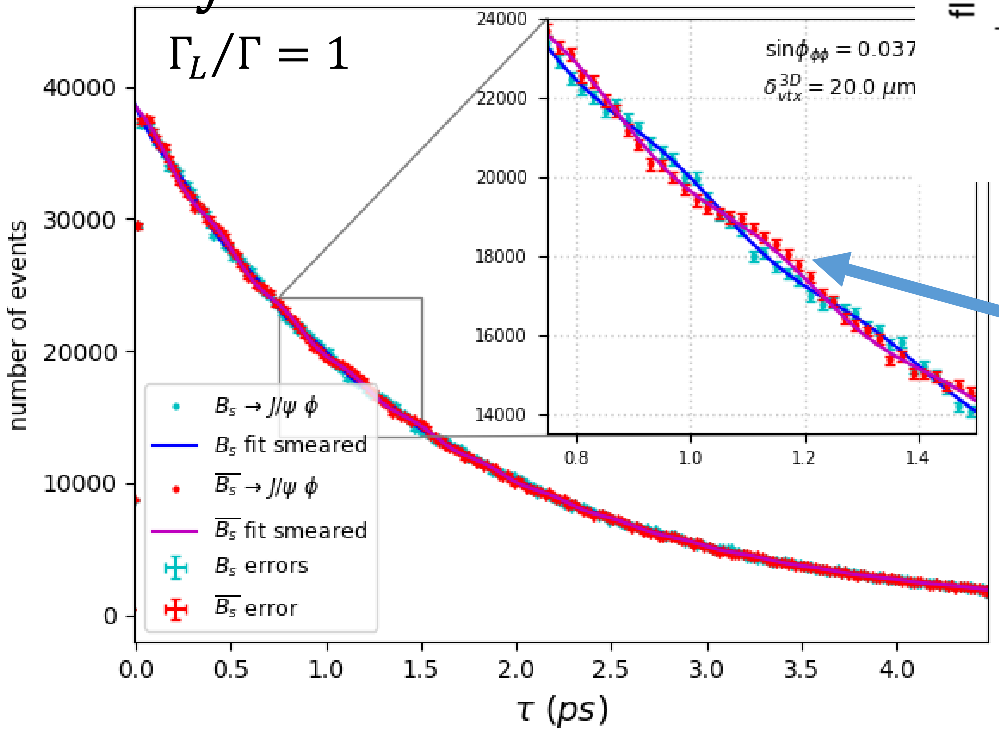
PDG: $\beta_s = (0.60 \pm 0.89)°$

$\sigma(d_{flight}) \approx 20\mu m$

Mean B flight distance ≈ 3000 μm

$\int Ldt = 150\ ab^{-1}$





Excellent vertex resolution required

However for $B_s \to J/\psi\phi$

PDG		
Γ_L/Γ	$\mathbf{0.527 \pm 0.008}$	CP = +
$\Gamma_\parallel/\Gamma$	0.228 ± 0.007	CP = +
$\Gamma_\perp/\Gamma$	0.245 ± 0.004	CP = -

In HQS , $\Gamma_\parallel = \Gamma_\perp \Rightarrow \mathcal{A}^{mix} = \mathcal{A}_L^{mix}$

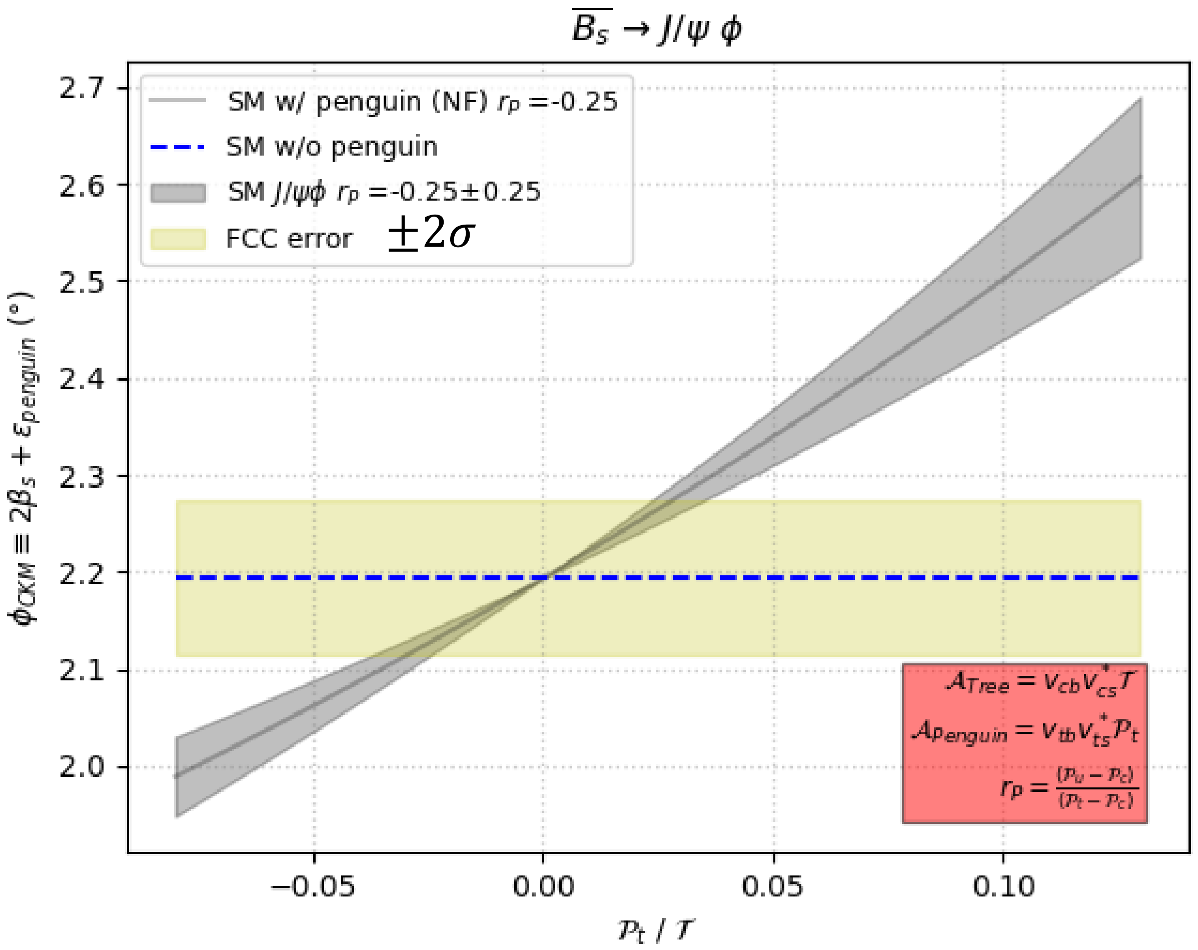
Angular analysis required (tbd)
Otherwise additional sinΦ term
amplitude dilution by factor ~0.5
Slightly reduced sensitivity (can be compensated using $J/\psi \to e^+\ e^-$ and other modes e.g. $J/\psi\eta$)

$$\delta(sin\phi_{CKM}) = \delta(sin2\beta_s) \approx 1.2\ \times 10^{-3}\ \cong \delta(\beta_s) \approx 3.5° \times 10^{-2}(stat.)$$

Effect of penguins in $B_s \to J/\psi\phi$

$$\mathcal{I} = (\mathcal{T}+\mathcal{E})^2 \left[|V_{cs}V_{cb}^*|^2 \frac{V_{tb}V_{ts}^*}{V_{cb}V_{cs}^*} + |V_{tb}V_{ts}^*|^2 \left(\frac{\mathcal{P}_t}{(\mathcal{T}+\mathcal{E})} \right) \right]^2$$

$$\mathcal{P}_t \to (\mathcal{P}_t - \mathcal{P}_c) \times \left[1 + \left(\frac{V_{us}^* V_{ub}}{V_{ts}^* V_{tb}} \right) \frac{\mathcal{P}_u - \mathcal{P}_c}{\mathcal{P}_t - \mathcal{P}_c} \right]$$

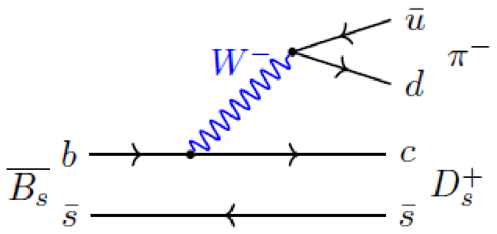


Uncertainty on ϕ_{CKM} is dominate by FCC statistical error as long as $\mathcal{R} = \frac{\mathcal{P}_t}{\mathcal{T}} < \sim 3\%$

Important input from theory is very important

Mistag and B_s Mixing Measurement with $B_s \to D_s\pi$

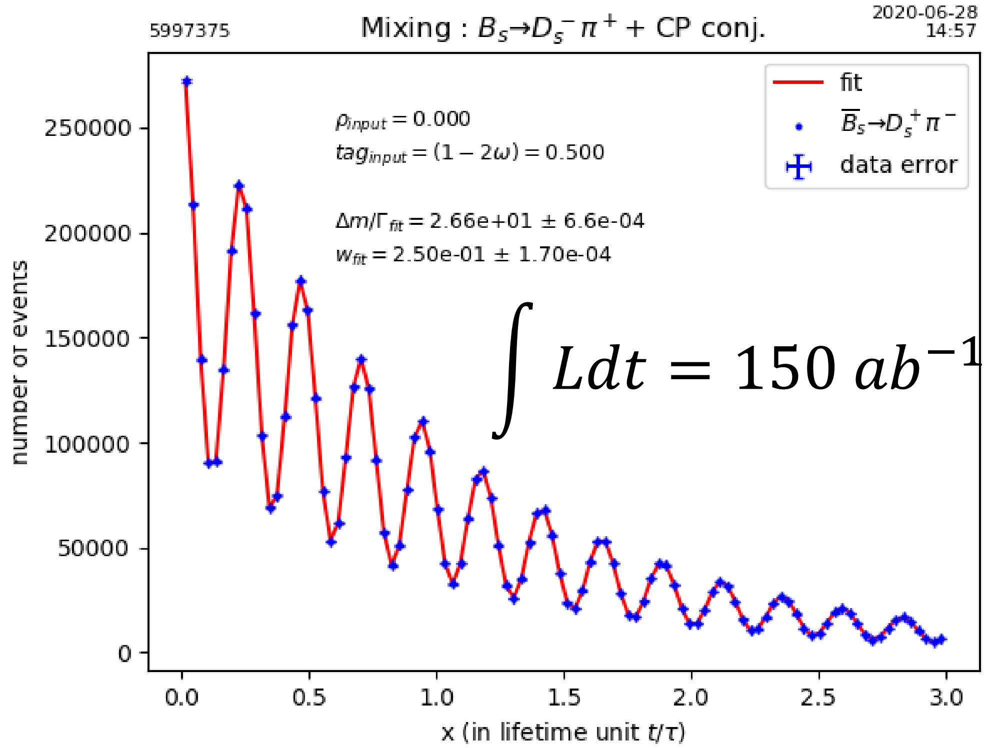
Golden channel



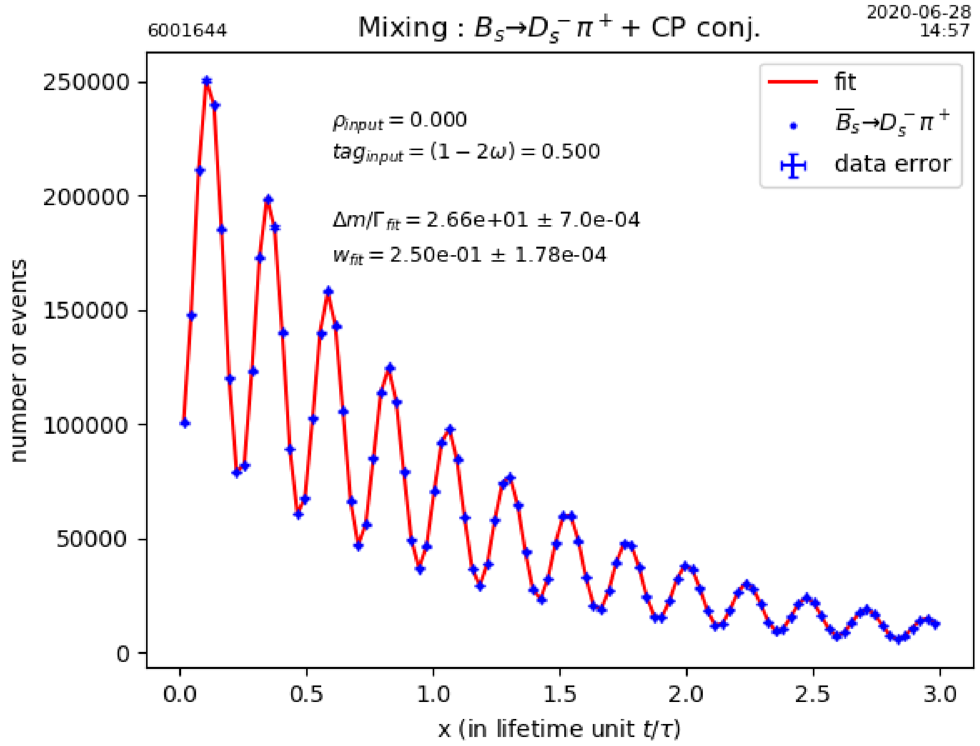
Expect $\sim 14 \cdot 10^6$ evts with very small Background (mainly combinatorics)

- No direct decay Bs → Ds+ π-, i.e. Flavour specific decay
- no CP violation in this mode.

$$\Gamma(\bar{B}_s \to D_s^+\pi^-) \propto e^{-\Gamma t}[(1-\omega)\cos^2 \Delta m t/2 + \omega \sin^2 \Delta m t/2]$$
$$\Gamma(B_s \to D_s^+\pi^-) \propto e^{-\Gamma t}[\omega \cos^2 \Delta m t/2 + (1-\omega) \sin^2 \Delta m t/2]$$



$\int Ldt = 150\ ab^{-1}$



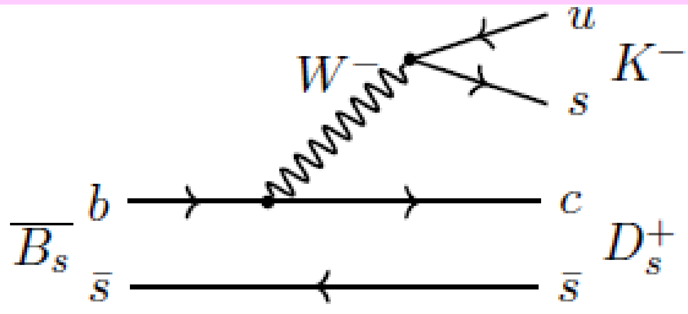
$$\delta(\Delta m_{Bs})_{stat} \approx (5 \times 10^{-4})\, 10^{12} \hbar s^{-1}\ [LHCb: (6.0 \times 10^{-3})\, 10^{12} \hbar s^{-1}]$$

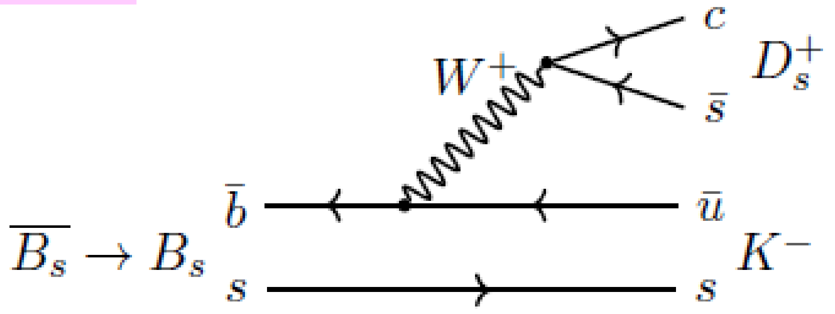
$$\boxed{\delta(\omega)_{stat} = 1.4 \times 10^{-4}}$$ ⇒ **Wrong tagging measured very precisely**

$\alpha_s = arg\left(-\frac{V_{ub}^* V_{us}}{V_{tb}^* V_{ts}}\right)$: CP violation with $B_s \to D_s^{\pm} K^{\mp} \to \phi\pi^{\pm}K^{\mp} \to K^+K^-\pi^{\pm}K^{\mp}$

Expect $\sim 10^6$ evts with very small Background

R.A. , I. Dunietz, B. Kayser Z. Phys. C54, 653 (1992)





$V_{cb}\ V_{us}^*$ $\quad \frac{V_{tb}\ V_{ts}^*}{V_{tb}^*\ V_{ts}}$ $\quad V_{ub}^*\ V_{cs}$

$$\alpha_s = \arg\left(-\frac{V_{ub}^* V_{us}}{V_{tb}^* V_{ts}}\right)$$

$$\boxed{\phi_{CKM} = -(\alpha_s - \beta_s)\ (+\pi)}$$

$$\begin{aligned}
\Gamma(B_s(t) \to f) &= |<f \mid B_s>|^2 \ e^{-\Gamma t}\{[1-\omega(1-\rho^2)]\cos^2\tfrac{\Delta mt}{2} \\
&+ [\rho^2 + \omega(1-\rho^2)]\sin^2\tfrac{\Delta mt}{2} \\
&- (1-2\omega)\rho\sin\phi_{CP}^{+}\sin\Delta mt\} \\
\Gamma(\overline{B_s}(t) \to f) &= |<f \mid B_s>|^2 \ e^{-\Gamma t}\{[\rho^2+\omega(1-\rho^2)]\cos^2\tfrac{\Delta mt}{2} \\
&+ [1-\omega(1-\rho^2)]\sin^2\tfrac{\Delta mt}{2} \\
&+ (1-2\omega)\rho\sin\phi_{CP}^{+}\sin\Delta mt\} \\
\Gamma(B_s(t) \to \overline{f}) &= |<f \mid B_s>|^2 \ e^{-\Gamma t}\{[\rho^2+\omega(1-\rho^2)]\cos^2\tfrac{\Delta mt}{2} \\
&+ [1-\omega(1-\rho^2)]\sin^2\tfrac{\Delta mt}{2} \\
&- (1-2\omega)\rho\sin\phi_{CP}^{-}\sin\Delta mt\} \\
\Gamma(\overline{B_s}(t) \to \overline{f}) &= |<f \mid B_s>|^2 \ e^{-\Gamma t}\{[1-\omega(1-\rho^2)]\cos^2\tfrac{\Delta mt}{2} \\
&+ [\rho^2+\omega(1-\rho^2)]\sin^2\tfrac{\Delta mt}{2} \\
&+ (1-2\omega)\rho\sin\phi_{CP}^{-}\sin\Delta mt\}
\end{aligned}$$

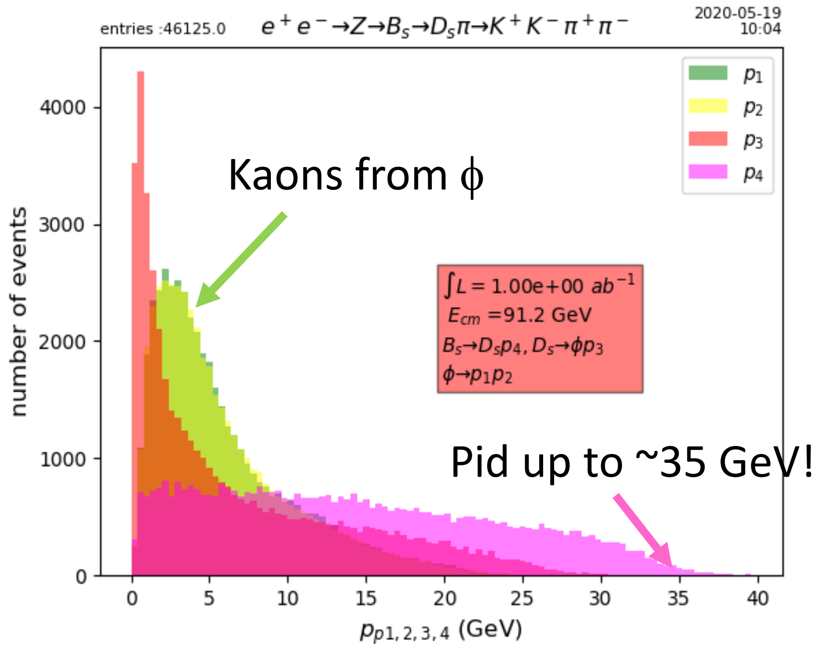
- No penguin pollution
- $\rho = |\lambda_f| = \left|\frac{q\langle f|\bar{B}_s\rangle}{p\langle f|B_s\rangle}\right|$
- There is a strong phase δ
  $$\phi_{CP}^{\pm} = \phi_{CKM} \pm \delta$$
- 4 time dependent distributions

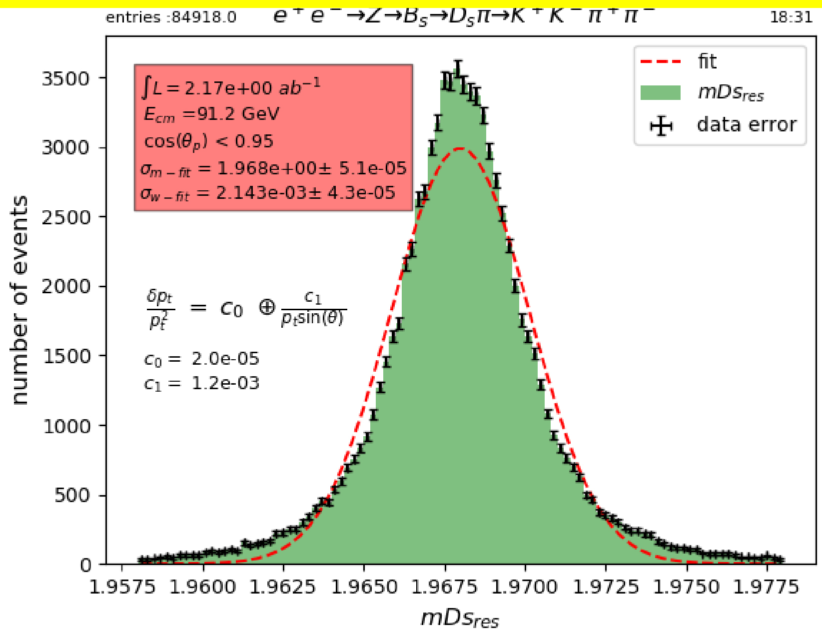
ϕ_{CKM} (with 2-fold ambiguity)

$$\boxed{\sin^2\phi_{CKM} = \frac{1 + \sin\phi_{CP}^{+}\sin\phi_{CP}^{-} \pm \sqrt{(1-\sin\phi_{CP}^{+\,2})(1-\sin\phi_{CP}^{-\,2})}}{2}}$$

Note: $\Delta\Gamma_s$ neglected , which helps remove ambiguity

$\alpha_s = arg\left(-\frac{V_{ub}^* V_{us}}{V_{tb}^* V_{ts}}\right)$: CP violation with $B_s \to D_s^{\pm} K^{\mp} \to \phi\pi^{\pm}K^{\mp} \to K^+K^-\pi^{\pm}K^{\mp}$



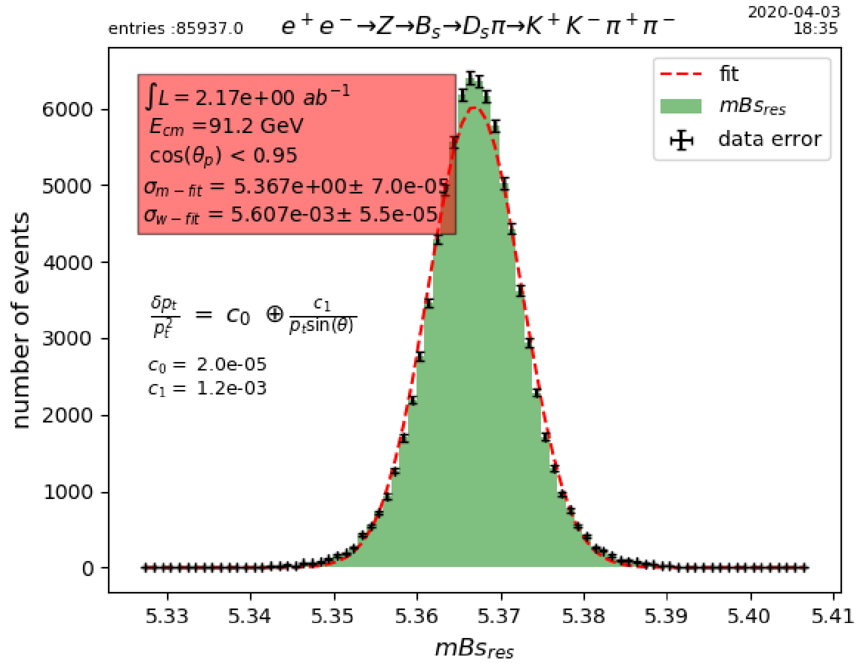


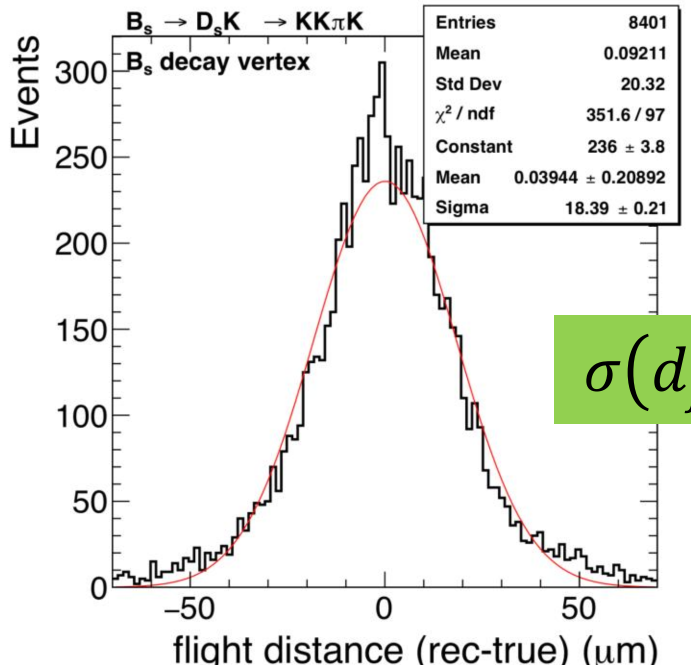
Charged final state only

	unit	value
acceptance	%	86
$\sigma(m_{D_s})$	MeV	~ 2.1
$\sigma(m_{B_s})$	MeV	~ 5.6

To be compared to

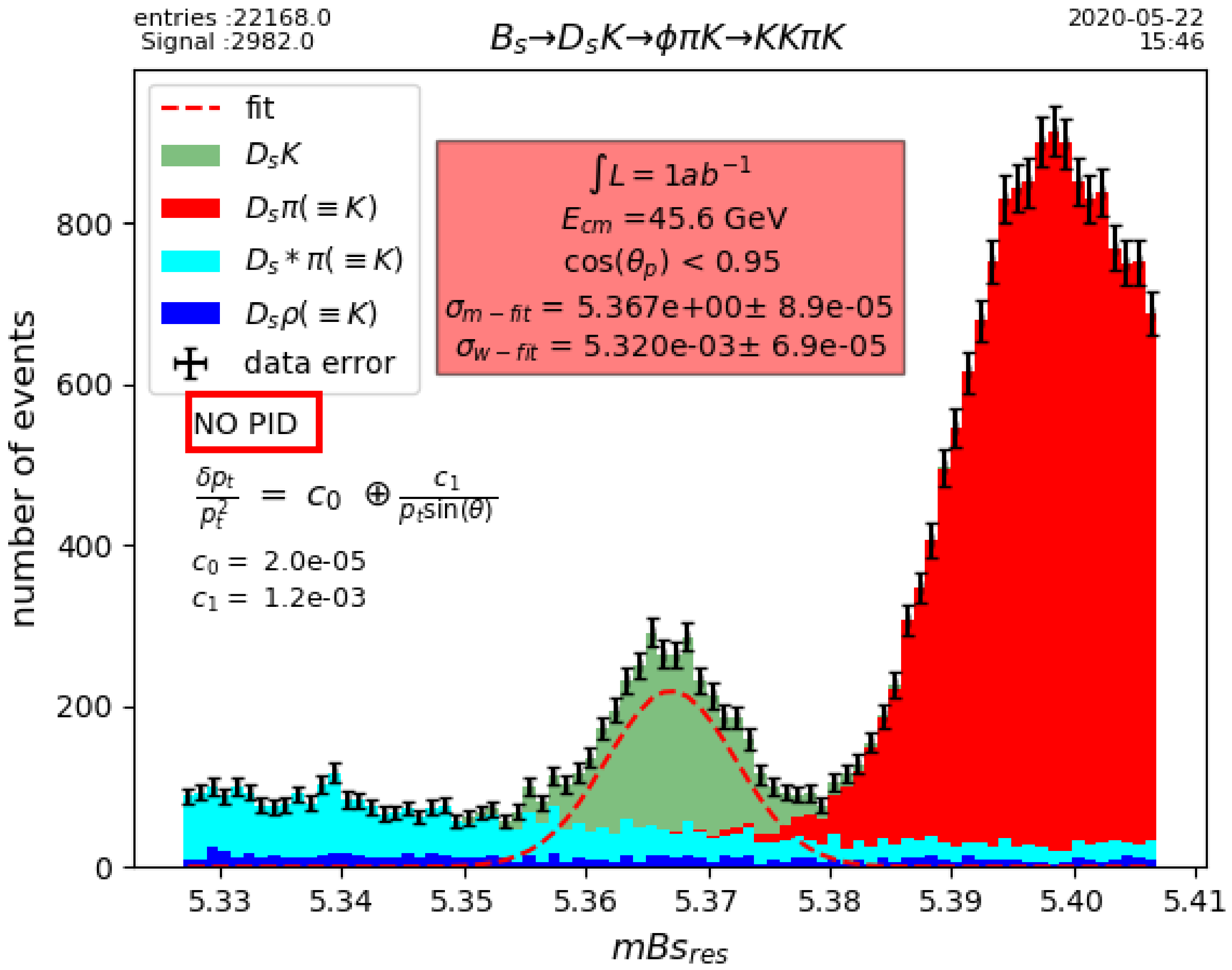
$\boldsymbol{\sigma(mB_s)_{LHCb} \approx 17\ MeV}$



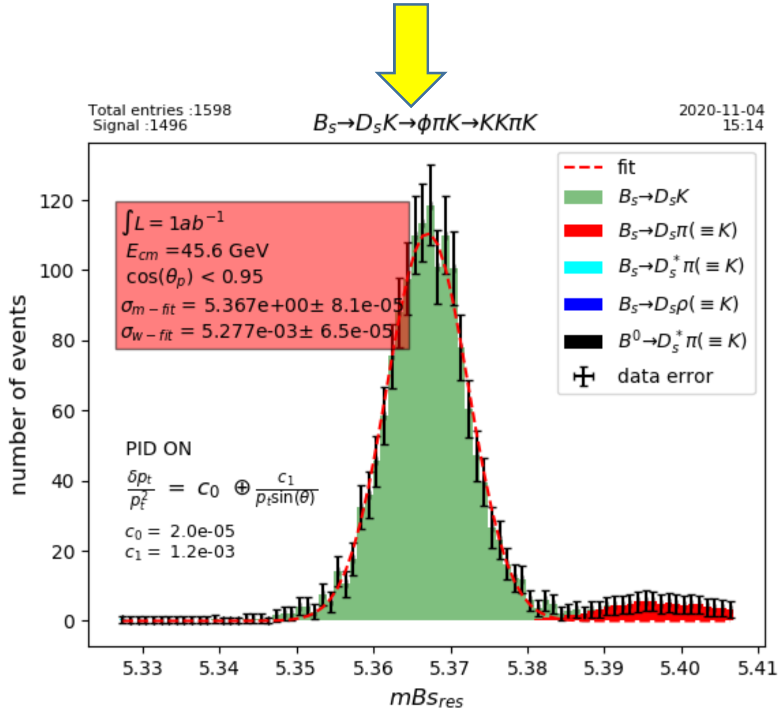


$\sigma(d_{flight}) \approx 20\mu m$

$\alpha_s = arg\left(-\frac{V_{ub}^* V_{us}}{V_{tb}^* V_{ts}}\right)$: CP violation with $B_s \to D_s^{\pm} K^{\mp} \to \phi\pi^{\pm} K^{\mp} \to K^+ K^- \pi^{\pm} K^{\mp}$



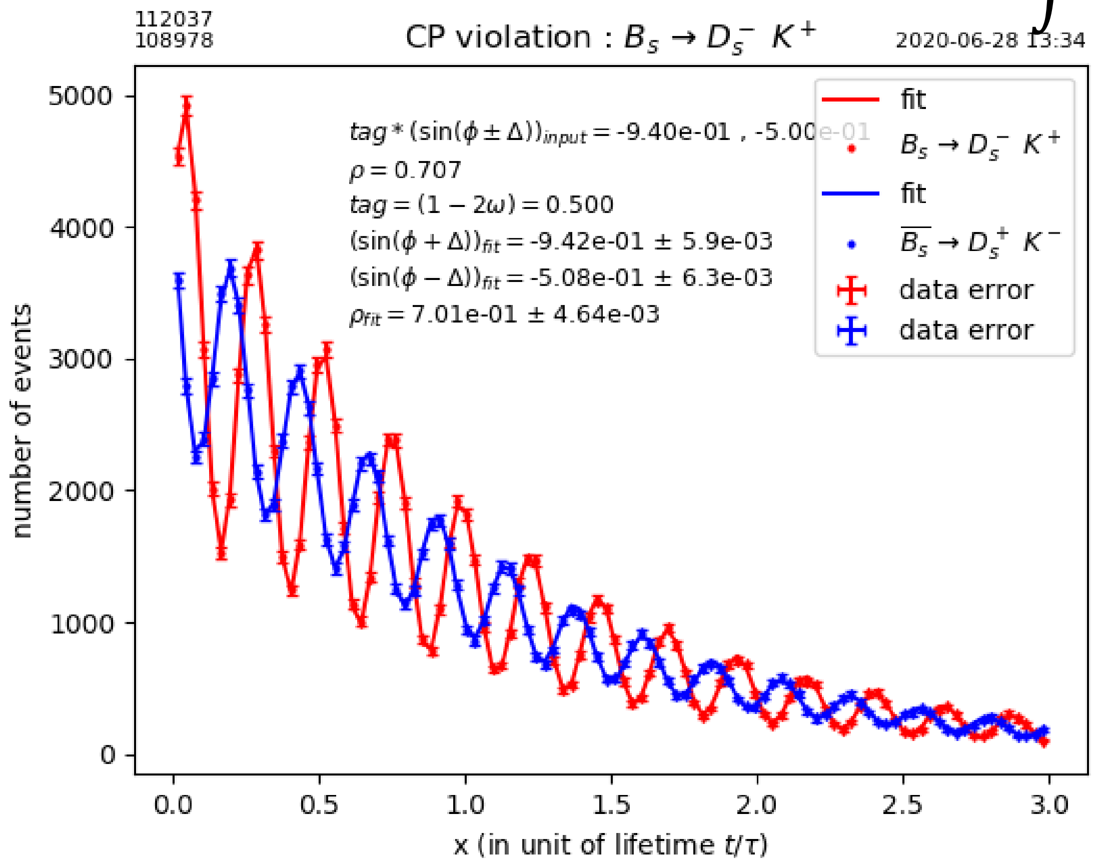
- **Tracking resolution crucial to reduce background**
- **Combinatoric background to be added (but expected to be relatively small)**
- **A realistic PId (ToF + dE/dx) enough**

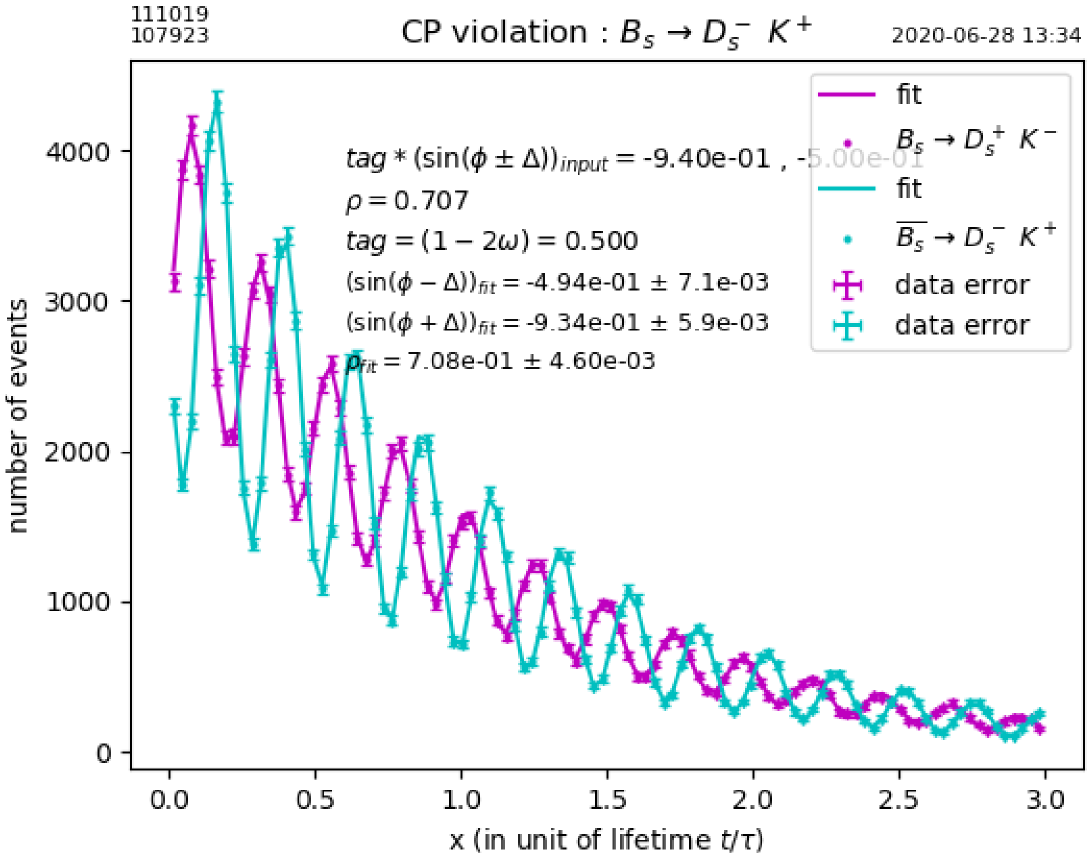


$\alpha_s = arg\left(-\frac{V_{ub}^* V_{us}}{V_{tb}^* V_{ts}}\right)$: Measurement of CP violation with $B_s \to D_s K$

$$\int L dt = 150\ ab^{-1}$$

PDG: $\gamma = (71.1^{+4.6}_{-5.3})°$





$$\delta(\rho) \approx 3.2 \times 10^{-3} (stat.)$$

$$\delta(sin^2\phi_{CKM}) \approx \delta(sin^2\alpha_s) \approx 5 \times 10^{-3} (stat.) \cong \delta(\alpha_s) \approx 0.4° \ (stat.)$$

Potential statistical gain of factor 4-5 with $D_s^{\pm} \to\ K^{*0}K^{\pm}, \phi\rho^{\pm}$, ... but background needs to be studied (see backup)+

Additionnal potential gain (another factor ~2) with $B_s \to D_s^{*\pm}K^{\mp}, D_s^{\pm}K^{*\mp}, D_s^{*\pm}K^{*\mp}$, most modes including γ(s)

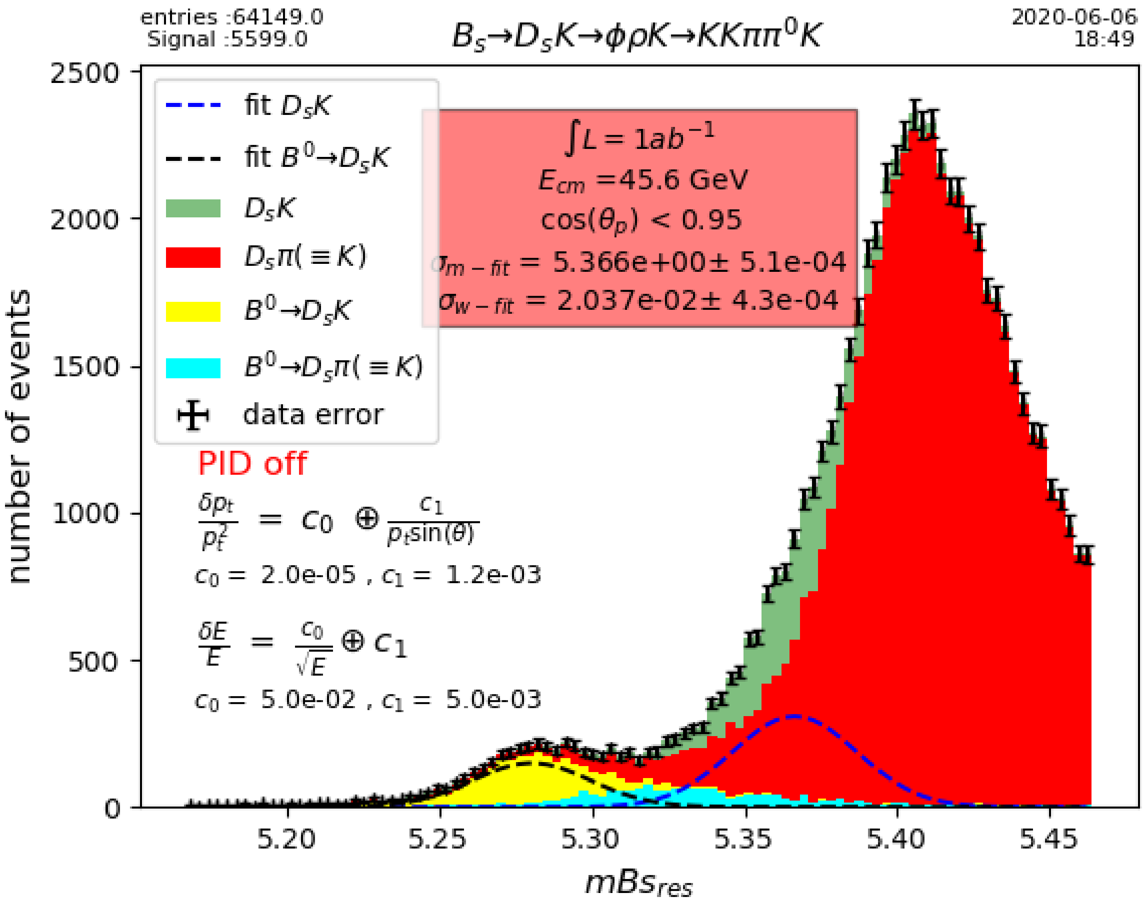
NO PId

Inclusion of neutrals for $B_s \to D_s K$ reconstruction

e.g. could potentially increase statistics (x 3) by adding $D_s^\pm \to \phi\rho^\pm$ $\quad \dfrac{D_s^\pm \to \phi\rho^\pm}{D_s^\pm \to \phi\pi^\pm} \approx 1.9$

More generally many physics topics (such as flavor physics) would benefit by using neutrals

➪ Significant advantage compared to LHCb ➪ constraint on calorimeter and PId



With very good calorimeter resolution (Xtal type)

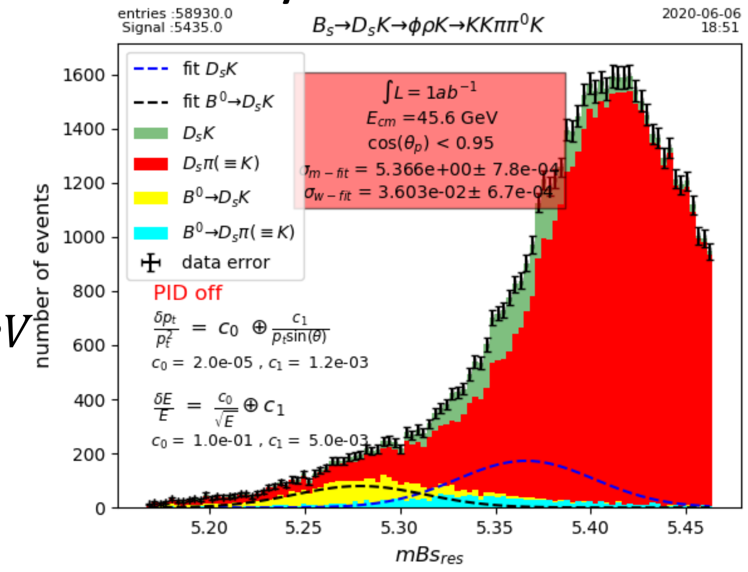
$\sigma\left(D_s^\pm(\phi\pi^\pm)K^\mp\right) \approx 5.6 MeV \ \to \sigma\left(D_s^\pm(\phi\rho^\pm)K^\mp\right) \approx 20 MeV$

➪ Background $D_s^\pm(\phi\rho^\pm)\pi^\mp$ huge

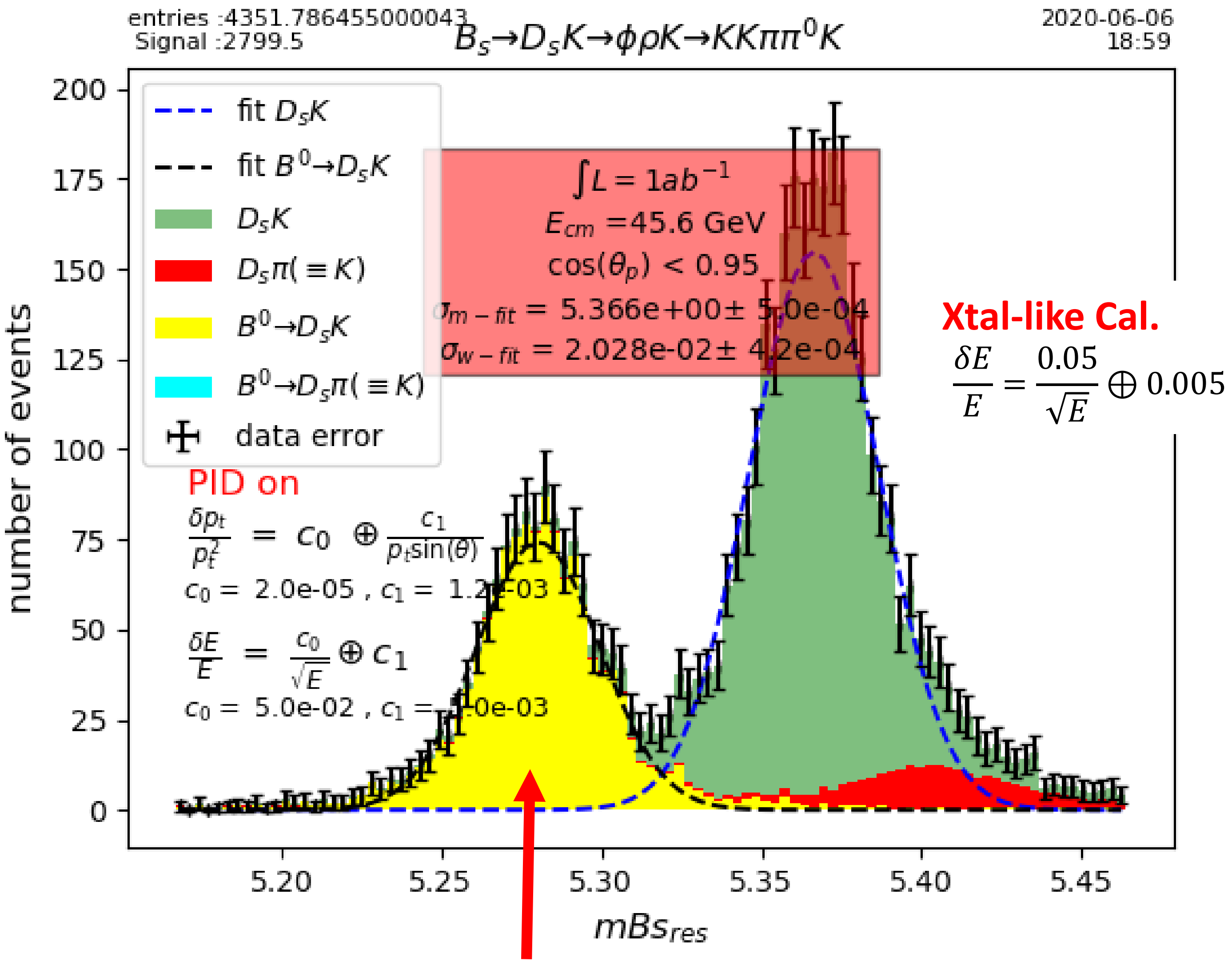
➪ **Excellent PId mandatory**

Much worse with LAr type Cal.

$\sigma\left(D_s^\pm(\phi\rho^\pm)K^\mp\right) \approx 36. MeV$



Effect of dE/dx and ToF

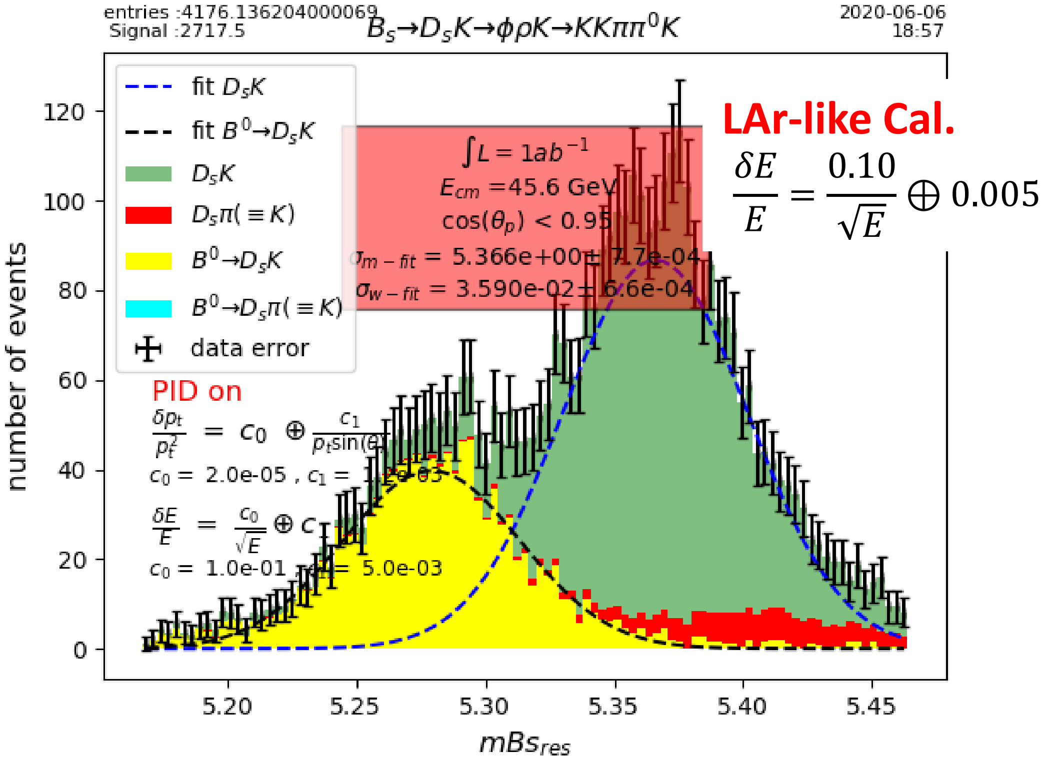


« Irreducible bkg » , only mass resolution can beat it

Excellent calorimetry (Xtal like) is also mandatory

Other backgrounds have to be added dE/dx + simple ToF probably not enough unless

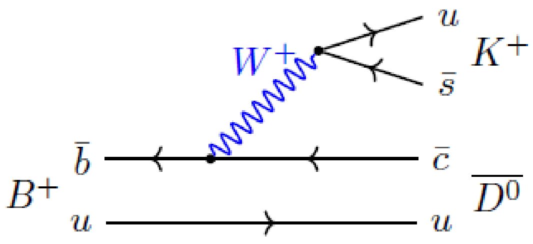
- beyond state-of-the-art is achieved for dE/dx and ToF
- or addition of a dedicated PId system



$\gamma_s = arg\left(-\frac{V_{cb}^* V_{cs}}{V_{ub}^* V_{us}}\right)$: Direct CP violation with $B^\pm \to D^0(\bar{D}^0)K^\pm, (D^0 \to K^+K^-, K_s\pi^0)$

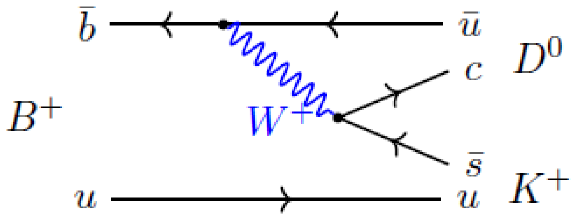
well-known method to measure the γ angle of the "usual" UT

Gronau, London ; Gronau , Wyler



$\begin{cases} \bar{D}^0 \to K^+K^- & (\eta_{CP} = +1) \\ \bar{D}^0 \to K^0\pi^0 & (\eta_{CP} = -1) \end{cases}$

$V_{cb}^*\ V_{us}$ $\qquad$ $V_{cs}\ \ V_{us}^*$



$\begin{cases} D^0 \to K^+K^- \\ D^0 \to \bar{K}^0\pi^0 \end{cases}$

$V_{ub}^*\ V_{cs}$ $\qquad$ $V_{cs}^*\ V_{us}$

With a final state f that is accessible to both D0 and D0 : interference, and CPV.

$\Gamma\,(\,B^+\ \to\ f_{(D)}K^+)\ \neq\ \Gamma\,(\,B^-\ \to f_{(D)}K^-) \Rightarrow$ Asymmetry $\mathcal{A}_{CP}^{\pm}$

$\boxed{\phi_{CKM}\ =\ \pi + \gamma_s}$

$$\mathcal{A}_{CP}^{\pm} = \frac{\pm 2\mathcal{R}\sin\Delta\cos\gamma_s}{1+\mathcal{R}^2 \mp \mathcal{R}\cos\Delta\cos\gamma_s}$$

$$\mathcal{R}^2 = \frac{Br(B^+ \to D^0K^+)}{Br(B^+ \to \overline{D^0}K^+)}$$

R already known to 5%, can be much improved with D0 semi-leptonic decays

Δ = strong phase difference. PDG: $-130° \pm 5°$

Combination of $\mathcal{A}_{CP}^{+}$ (K^+K^-) and $\mathcal{A}_{CP}^{-}$ $(K^0\pi^0)$ gives Δ and γ_s (8-fold ambiguity)

$\gamma_s = arg\left(-\frac{V_{cb}^* V_{cs}}{V_{ub}^* V_{us}}\right)$: Direct CP violation with $B^{\pm} \to D^0(\bar{D}^0)K^{\pm}, (D^0 \to K^+K^-, K_s\pi^0)$

- $B^+ \to (K^+K^-)_D K^+$: Relatively easy thanks to excellent mass resolution and PID :

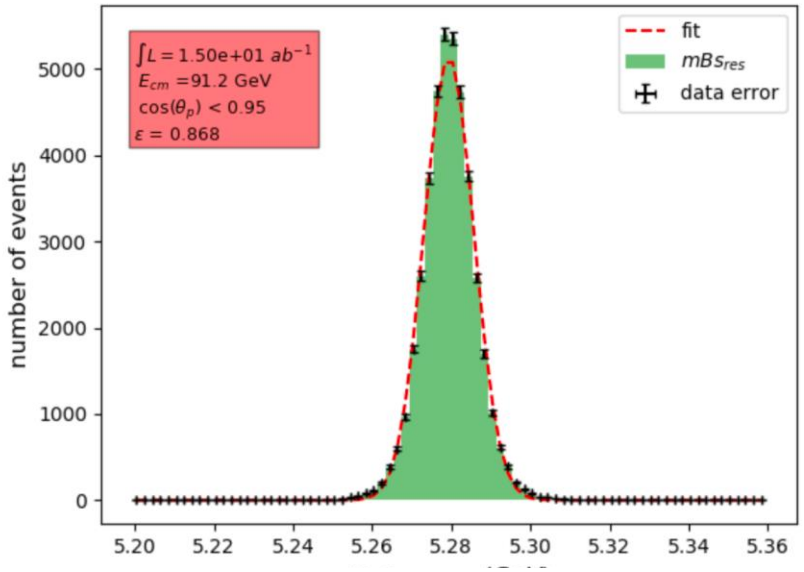
$$\sigma(D^0) \sim 2\ MeV \quad \text{and} \quad \sigma(B^+) \sim 6\ MeV$$

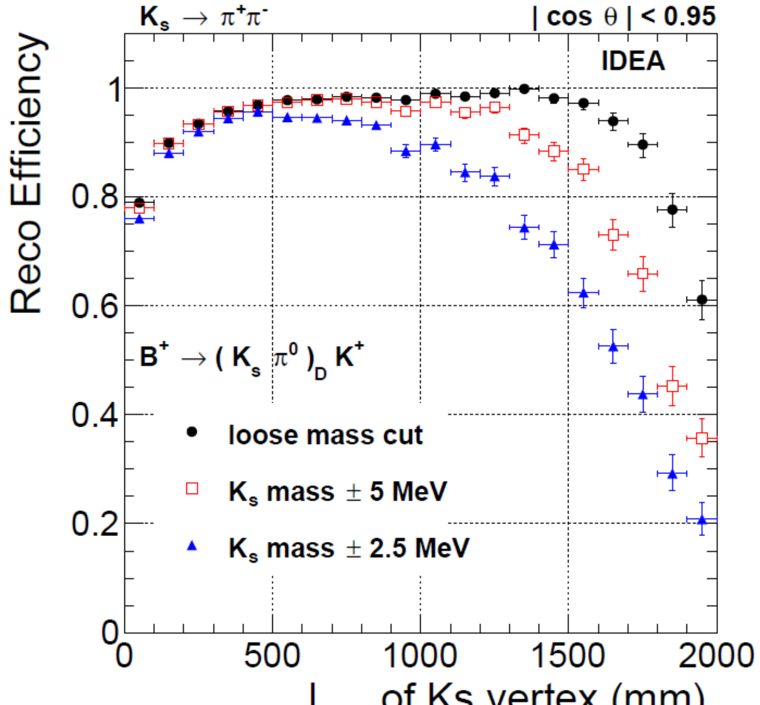
- $B^+ \to (K_s\pi^0)_D K^+$: more challenging :
  - Displaced pion tracks from Ks decay :Up to O(1m) from the IP. Requires a large enough tracker <efficiency> > 90% up to 1.5m feasible
  - Excellent photon energy resolution : Requires Crystal like Calorimeter

$$\sigma(K_s) \sim 2.5\ MeV$$

$$\sigma(B^+) \sim 20\ MeV \text{ with } \frac{\sigma_{E_\gamma}}{E_\gamma} = \frac{3\%}{\sqrt{E}}$$

$$\sigma(B^+) \sim 80\ MeV \text{ with } \frac{\sigma_{E_\gamma}}{E_\gamma} = \frac{15\%}{\sqrt{E}}$$





$\gamma_s = arg\left(-\frac{V_{cb}^* V_{cs}}{V_{ub}^* V_{us}}\right)$: Direct CP violation with $B^{\pm} \to D^0(\bar{D}^0)K^{\pm}, (D^0 \to K^+K^-, K_s\pi^0)$

$$\int Ldt = 150\ ab^{-1}$$

$B^+ \to \bar{D}^0 K^+ \to K^+K^-K^+$	$\sim 5.8 \cdot 10^5$
$B^+ \to D^0 K^+ \to K^+K^-K^+$	$\sim 5.7 \cdot 10^3$
$B^+ \to \bar{D}^0 K^+ \to K_s\pi^-K^+$	$\sim 1.2 \cdot 10^6$
$B^+ \to D^0 K^+ \to K_s\pi^-K^+$	$\sim 1.2 \cdot 10^4$

Asymmetries are sizable. E.g. with Δ = -130° and γ_s = 108° (SM) :

$$\mathcal{A}_{CP}^{+}(K^+K^-) \approx -15\% \qquad \text{and} \qquad \mathcal{A}_{CP}^{+}(K_s\pi^0) \approx 14\%$$

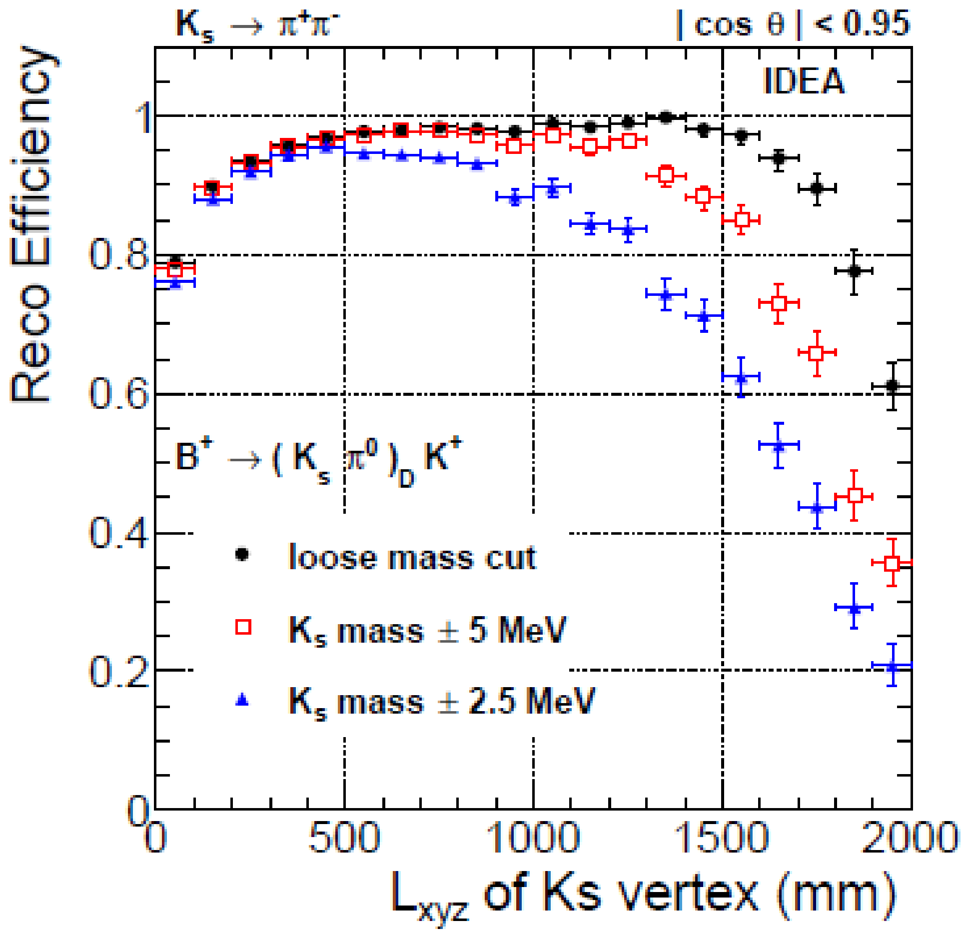
with expected statistical uncertainties of ~ 0.1% (absolute, accounting for approx. acceptance and efficiencies), which corresponds to $\sigma_{\gamma_s} \approx 2.8°$

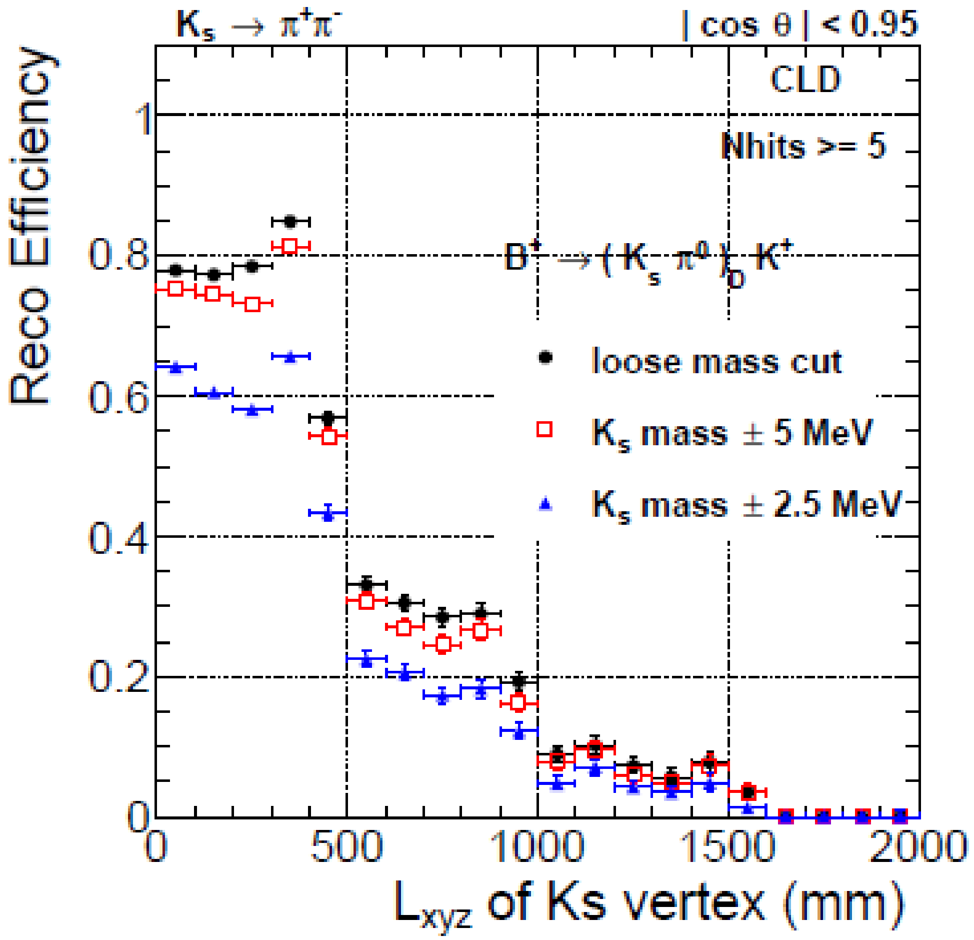
(uncertainty on γ_s depends on the value of Δ – ranges between < 1° to a few °)

Possible improvements with additional modes, e.g. $D \to K_s\,\eta,\ B^+ \to D^0K^{*+}$

Measurement of γ_s to 1° – 2° within reach.

Comparison of K_s reconstruction with 2 detector models





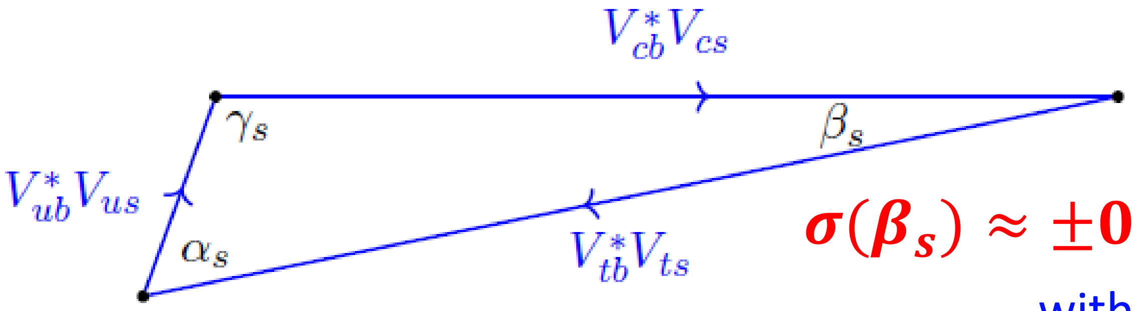
Large tracking volume with many measurement points is very important for Ks reconstruction

Conclusions

- FCC should enable a precise measurement of the three angles of the “flat” (b,s) UT :

with $B_s \to J/\psi\,\phi$, D_sK and $B^\pm \to D^0(\overline{D^0})K^\pm$

$\sigma(\gamma_s) \approx \pm 1°$ via $B^\pm \to D^0(\bar{D}^0)K^\pm \to K^+K^-K^\pm, K_s\pi^0K^\pm$
with possible improvement with other modes



$\sigma(\beta_s) \approx \pm 0.035°$ via $B_s \to J/\psi\,\phi \to \mu^+\mu^-K^+K^-$
with possible improvement with other modes

- 25x better than the current precision

$\sigma(\alpha_s) \approx \pm 0.4°$ via $B_s \to D_s^\pm K^\mp \to K^+K^-\pi^\pm K^\mp$

with possible improvement with other modes

- Simple relation between the 3 phases directly measured in these three processes :

$$-\phi_{D_sK} + \phi_{J/\psi\,\Phi} + \phi_{D^0K} = 0 \ (\mathrm{mod}\,\pi)$$

should hold in the Standard Model.

Conclusions

- These modes are excellent showcases for setting requirements/specifications on detector

- **Excellent tracking and vertexing resolution** , $\frac{\sigma(p_T)}{p_T^2} \leq 2.\times 10^{-5} \oplus \frac{1.2\times 10^{-3}}{p_T sin\Theta}$

- **Excellent calorimetry resolution**, ideally $\frac{\sigma(E)}{E} \lesssim \frac{5\times 10^{-2}}{\sqrt{E}} \oplus 5\times 10^{-3} \oplus \frac{5\ \mathrm{MeV}}{E}$

Allows to use many other decay mode !!!

- **Excellent PId resolution**

$> 3\ \sigma\ K/\pi$ separation up to 25 GeV (covers also K tagging), Ideally up to 35 GeV

- **Excellent Ks reconstruction** (crucial for many flavour analyses)

Additionnal Slides

In SM , only few other possible diagrams with same CKM element as tree diagram

⇨ well defined CKM angle measured

⇨ no direct CP violation expected

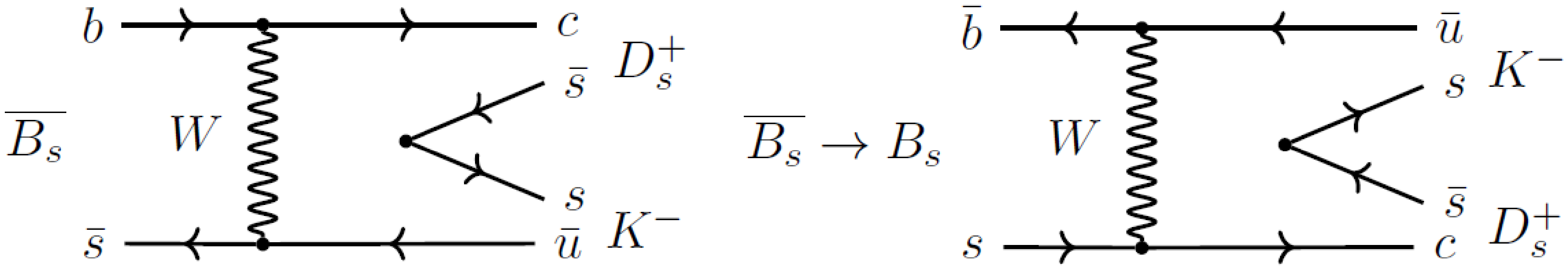


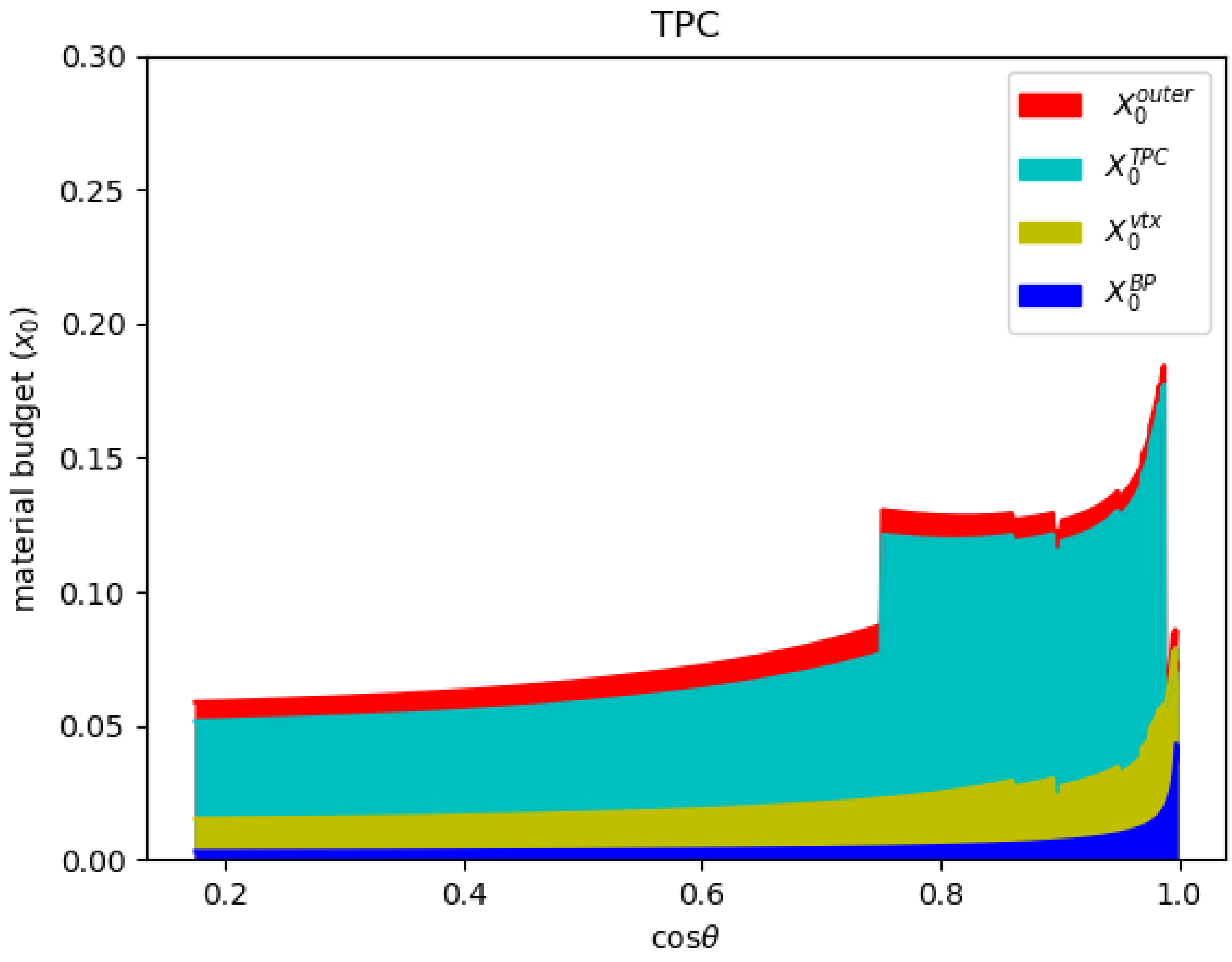
Figure 5: Exchange (sub-dominant) diagrams for $\bar{B}_s \to D_s^+ K^-$

Expected number of events

$\sigma(e^+e^- \to Z)$ nb	number of Z	$E_{cm} = 91.2$ GeV and $\int L = 150ab^{-1}$ $f(Z \to \overline{B}_s)$	Number of produced $\overline{B}_s$
~ 42.9	$\sim 6.4\ 10^{12}$	0.0159	$\sim 1\ 10^{11}$

(To be x 2 for B_s)

$\overline{B}_s$ decay Mode	Decay Mode	Final State	Number of $\overline{B}_s$ decays
		nonCP eigenstates	
$D_s^+\pi^-$	$D_s^+ \to \phi\pi$	$K^+K^-\pi^+\pi^-$	$\sim 6.9\ 10^6$
$D_s^+\pi^-$	$D_s^+ \to \phi\rho$	$K^+K^-\pi^+\pi^-\pi^0$	$\sim 12.9\ 10^6$
$D_s^+K^-$	$D_s^+ \to \phi\pi$	$K^+K^-\pi^+K^-$	$\sim 5.2\ 10^5$
$D_s^+K^-$	$D_s^+ \to \phi\rho$	$K^+K^-\pi^+K^-\pi^0$	$\sim 9.8\ 10^5$
$D^0\phi$	$D^0 \to K\pi$	$K^-\pi^+K^+K^-$	$\sim 6.1\ 10^4$
$D^0\phi$	$D^0 \to K\rho$	$K^-\pi^+K^+K^-\pi^0$	$\sim 1.7\ 10^5$
		CP eigenstates	
$J/\psi\phi$	$J/\psi \to \mu^+\mu^-$	$\mu^+\mu^-K^+K^-$	$\sim 3.2\ 10^6$
$\phi\phi$	$\phi \to K^+K^-$	$K^+K^-K^+K^-$	$\sim 4.8\ 10^5$



TPC
0.30
0.25
0.20
0.15
0.10
0.05
0.00
material budget (X_0)
0.2
0.4
0.6
0.8
1.0
cosθ
X_0^{outer}
X_0^{TPC}
X_0^{vtx}
X_0^{BP}

Inclusion of « standard and modest » PID (dE/dx and ToF)

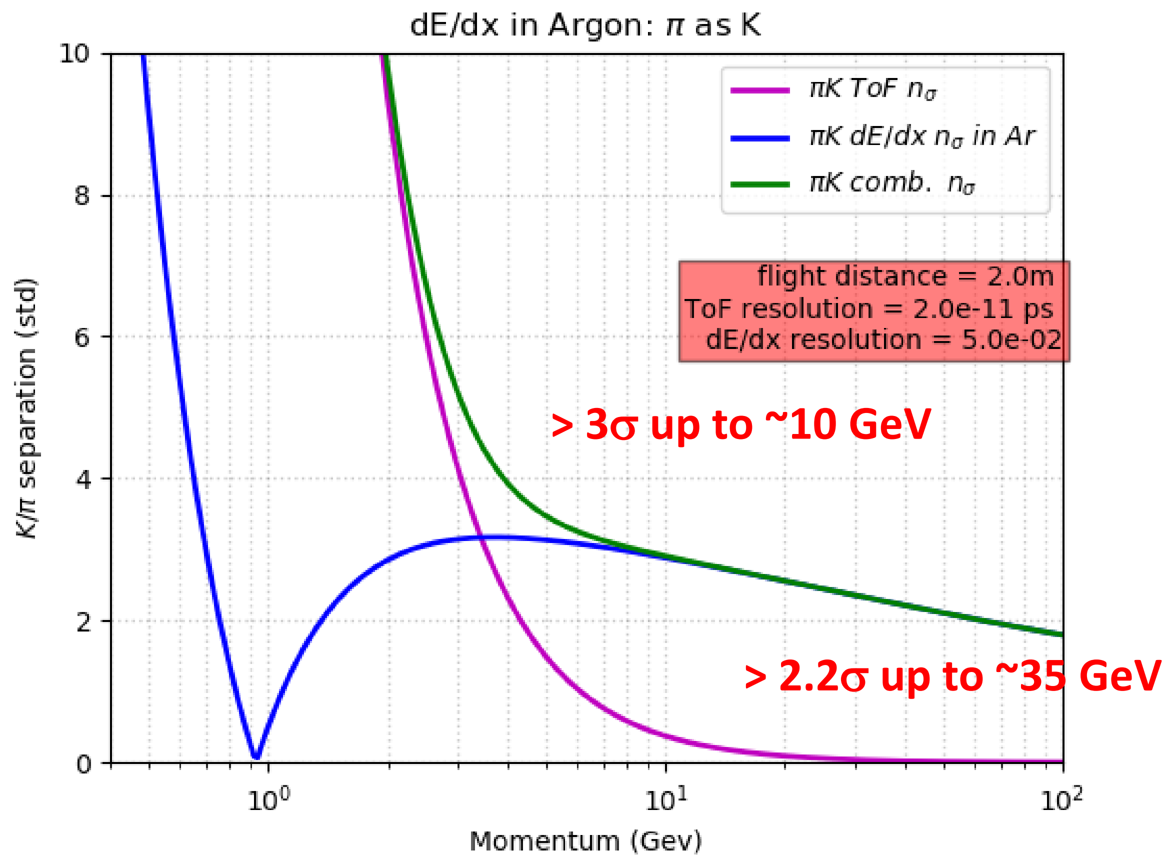
Somewhat conservative PID

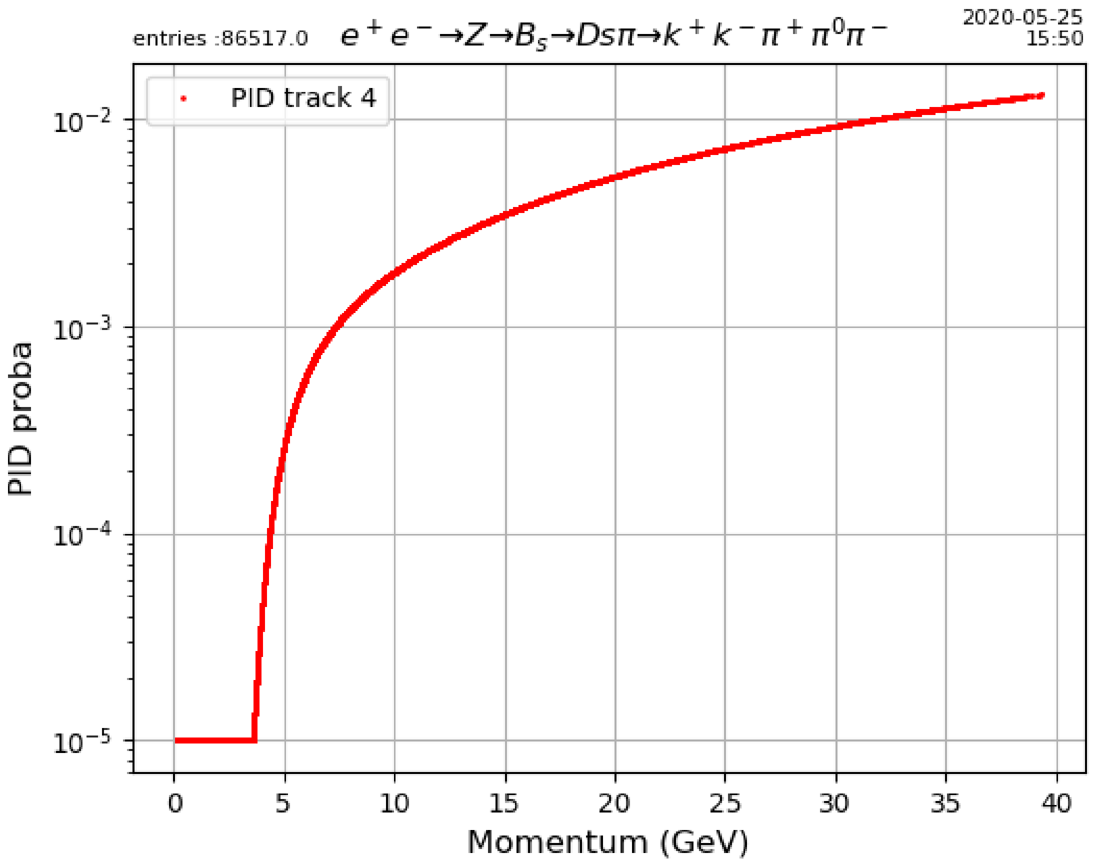
Resolution $\sigma\left(\frac{dE}{dx}\right) = 5\%$

Resolution $\sigma(ToF) = 20\text{ps}\ (\cong 6\text{mm})$

ToF Detector location : 2m from IP

Probability of π misidentification as K with ε(K)=50%



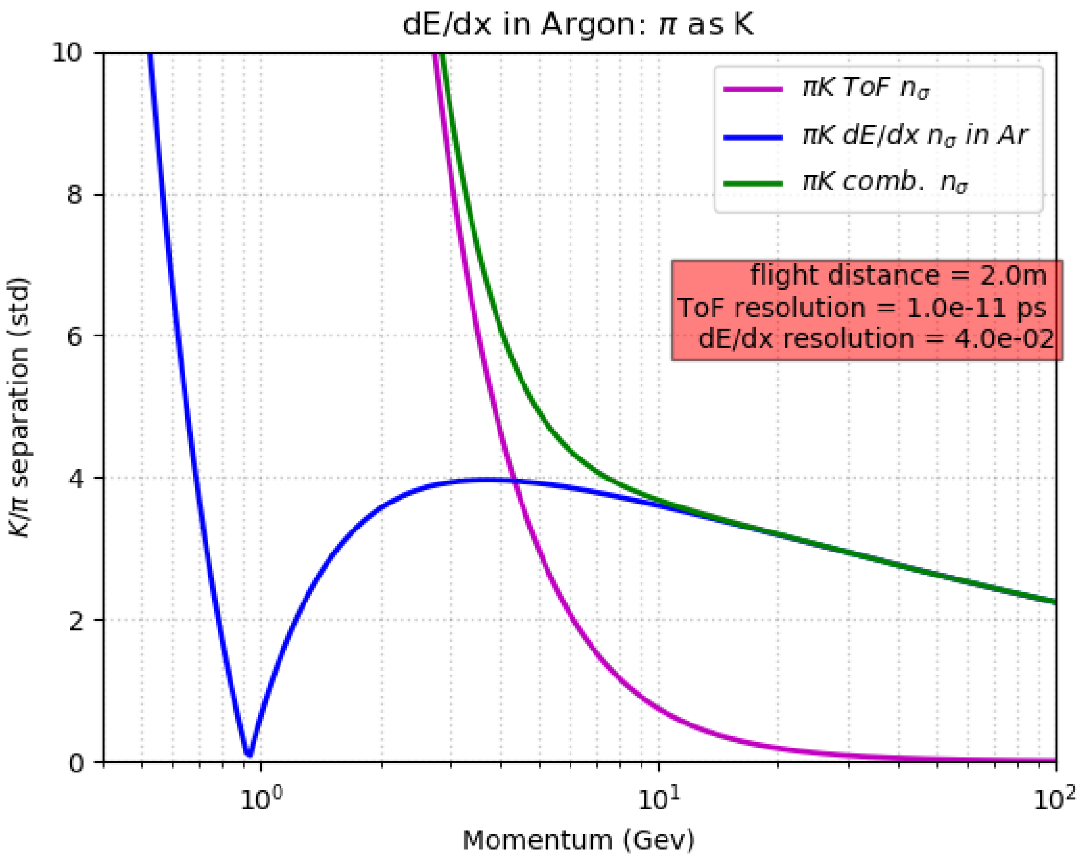


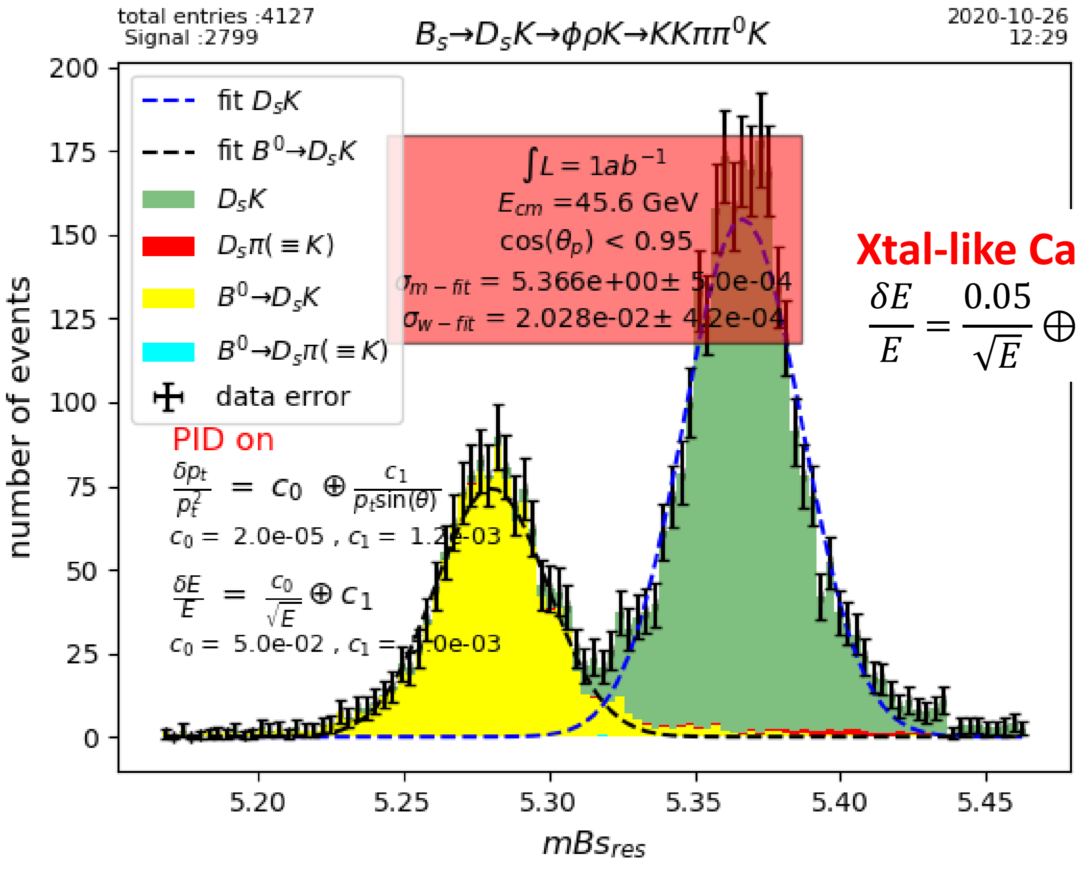
Inclusion of « improved » dE/dx and ToF

Resolution $\sigma\left(\frac{dE}{dx}\right) = 4\%$

Resolution $\sigma(ToF) = 10\text{ps}\ (\cong 3\text{mm})$

Detector location : 2m from IP

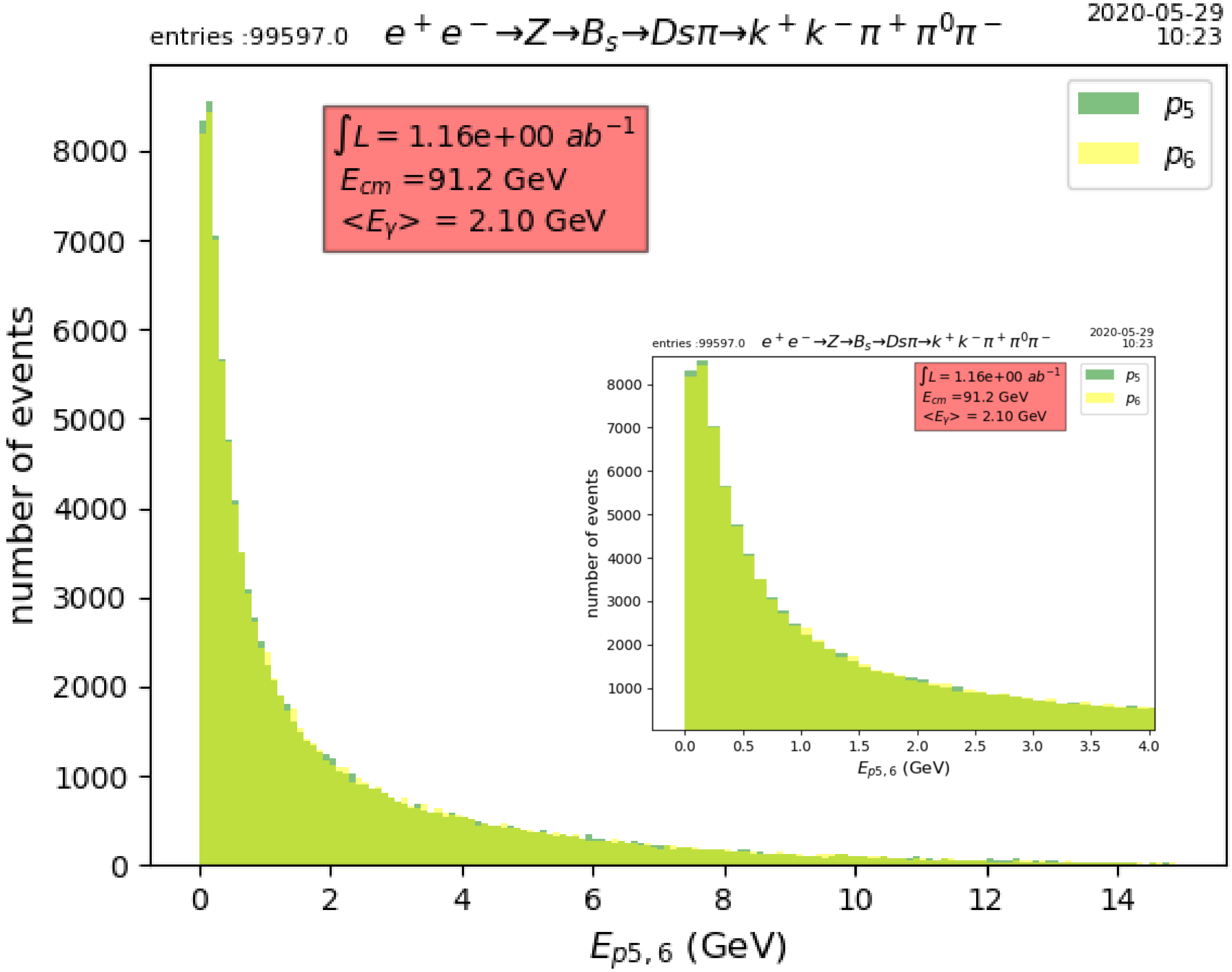


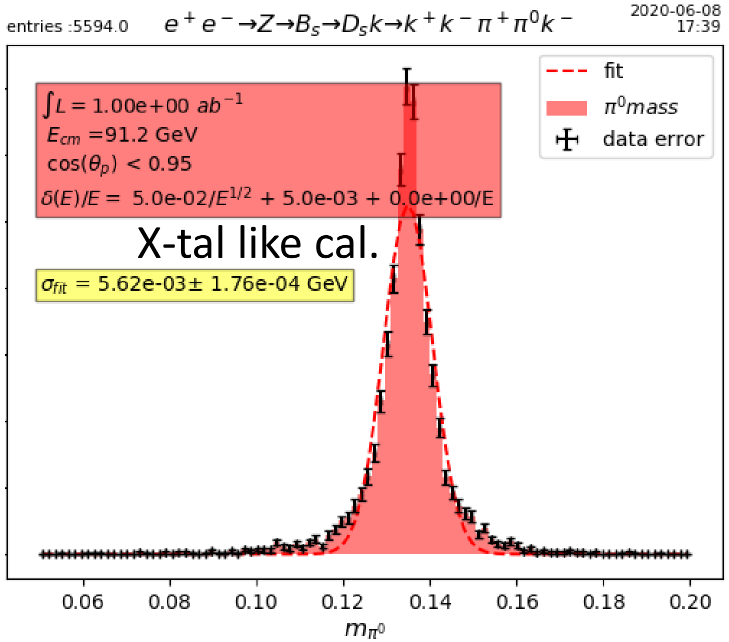


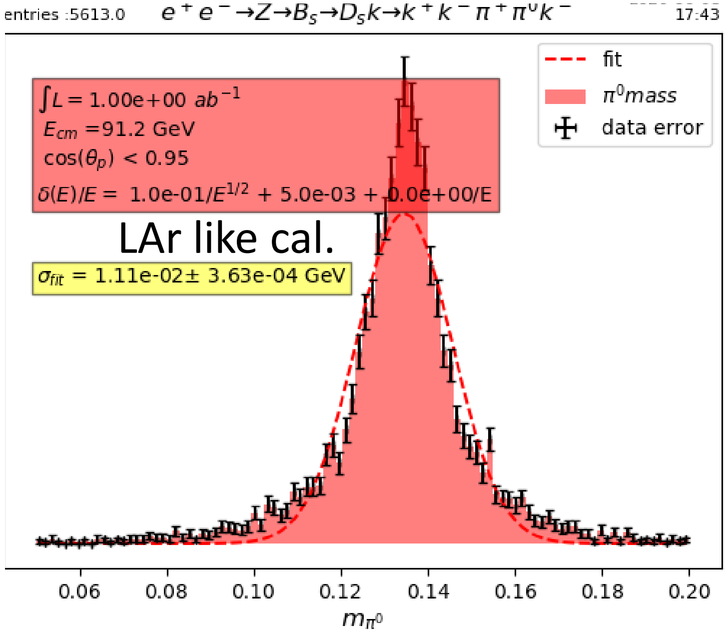
Xtal-like Cal.

$$\frac{\delta E}{E} = \frac{0.05}{\sqrt{E}} \oplus 0.005$$

Energy spectrum of γ from $D_s^- \to \phi\rho^- \to (K^+K^-)_\phi(\pi^-\pi^0)_\rho$

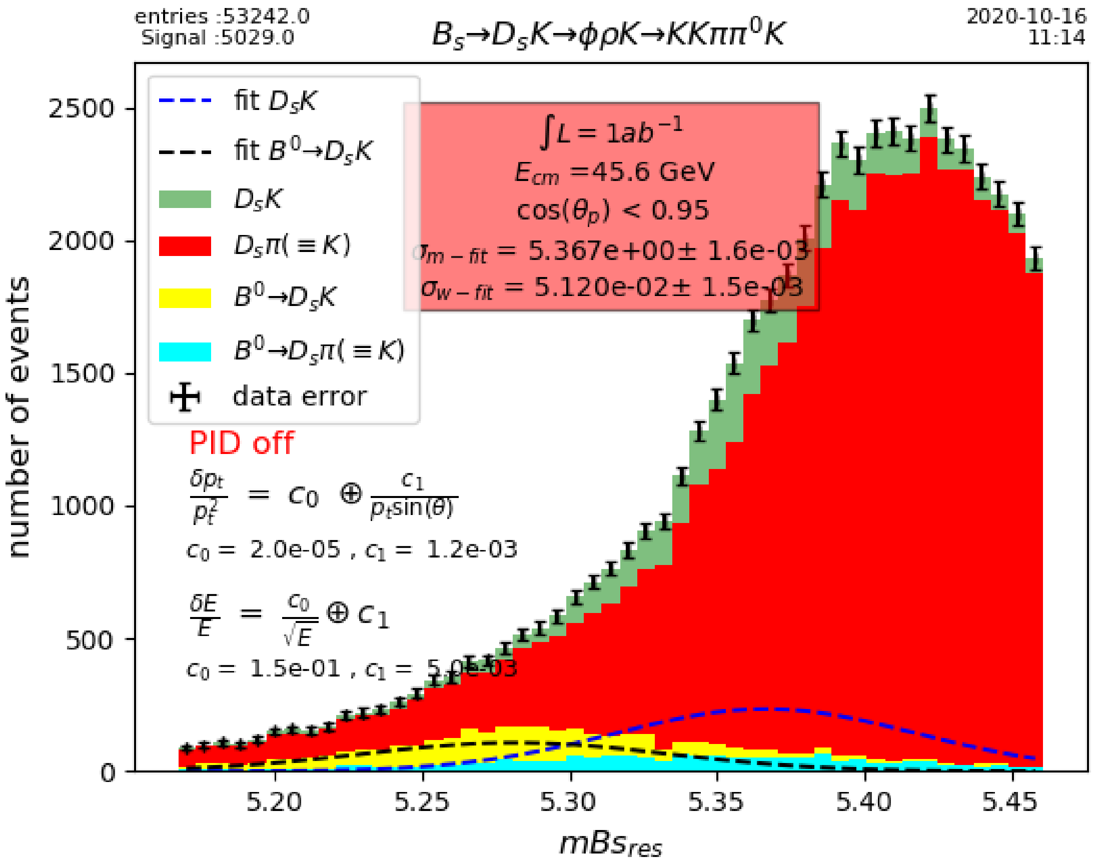


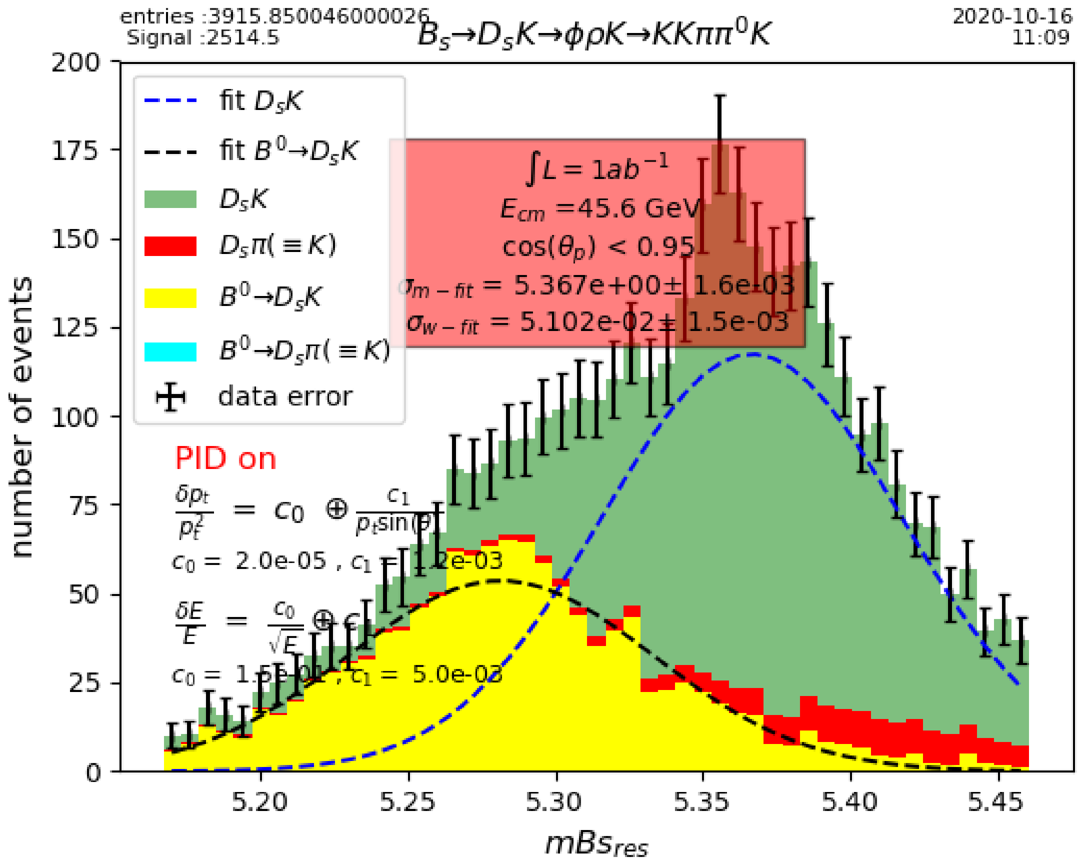




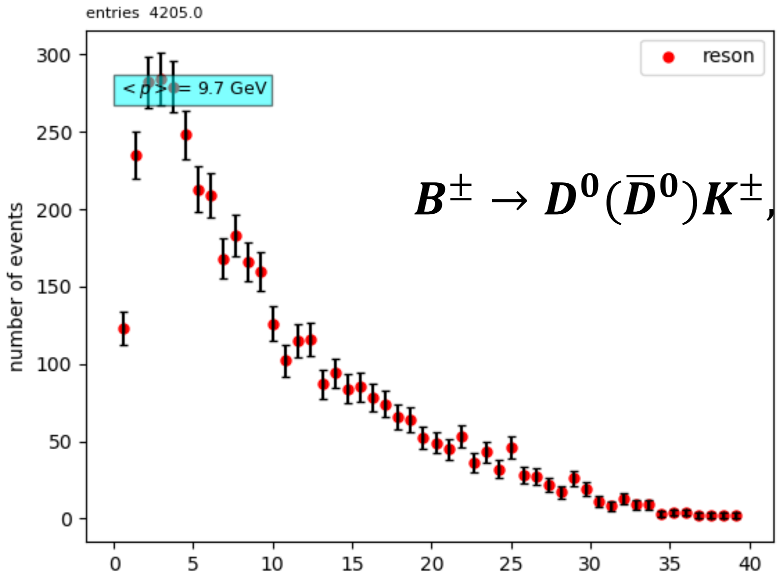
Inclusion of neutrals for $B_s \to D_s K$ reconstruction

Assuming HGCal like calorimeter with $\frac{\delta E}{E} = \frac{0.15}{\sqrt{E}} \oplus 0.005$



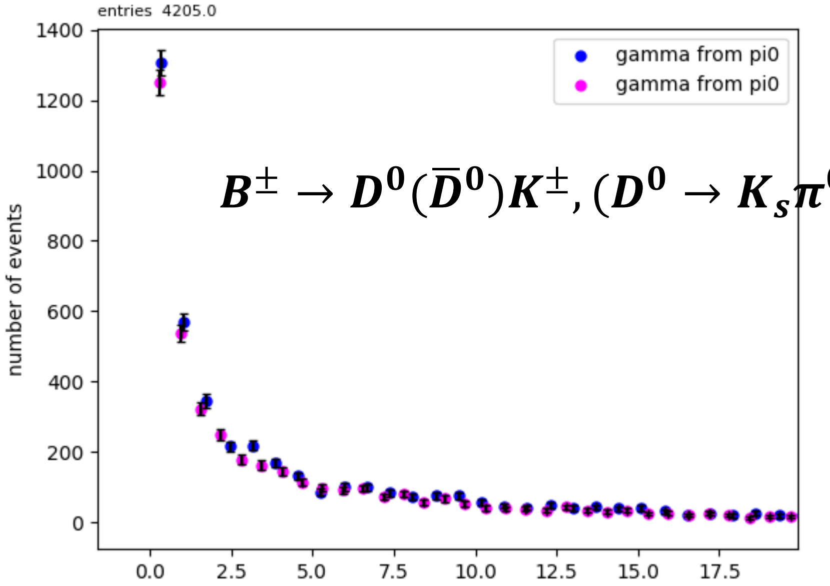


Xtal type to HGCal Type : $\sigma\left(D_s^{\pm}(\phi\rho^{\pm})K^{\mp}\right) \approx 20MeV \to 51MeV$



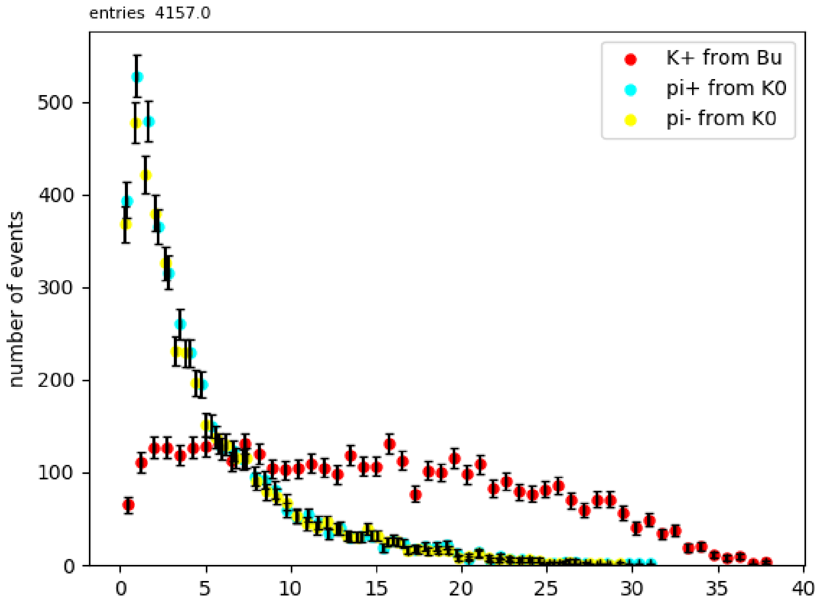
$$B^{\pm} \rightarrow D^0(\bar{D}^0)K^{\pm}, (D^0 \rightarrow K_s\pi^0)$$

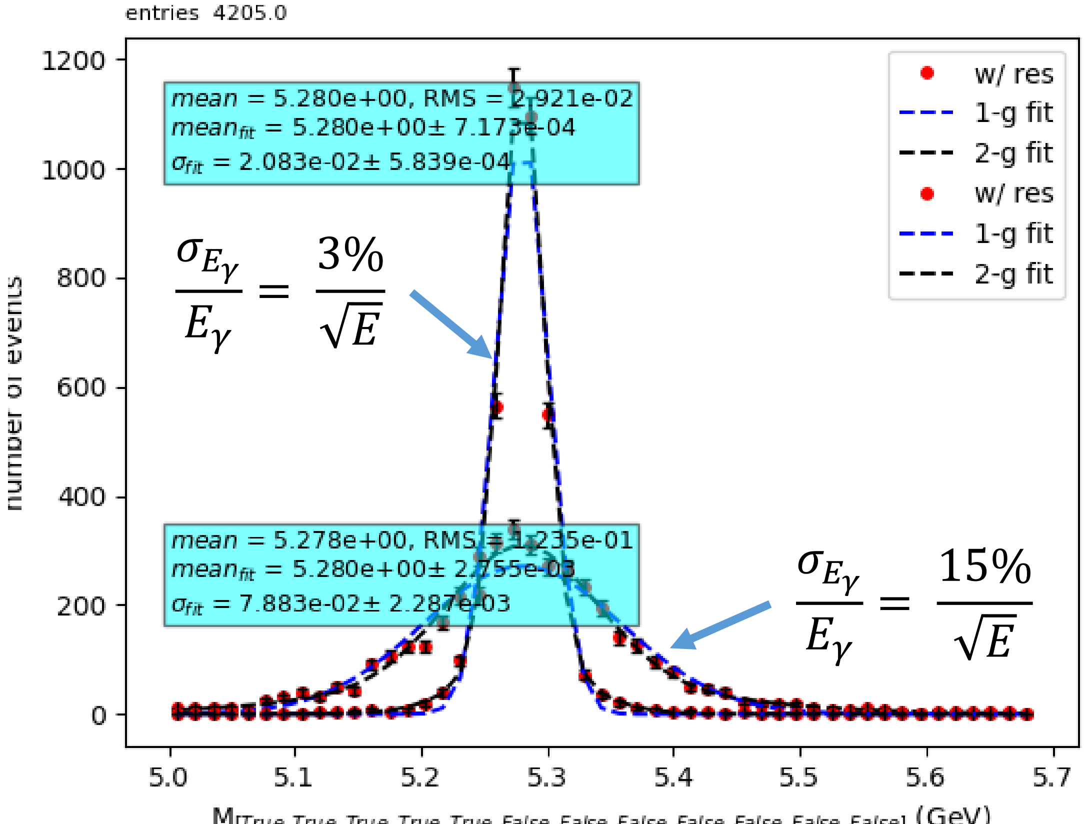
P_{K_s}



$$B^{\pm} \rightarrow D^0(\bar{D}^0)K^{\pm}, (D^0 \rightarrow K_s\pi^0)$$

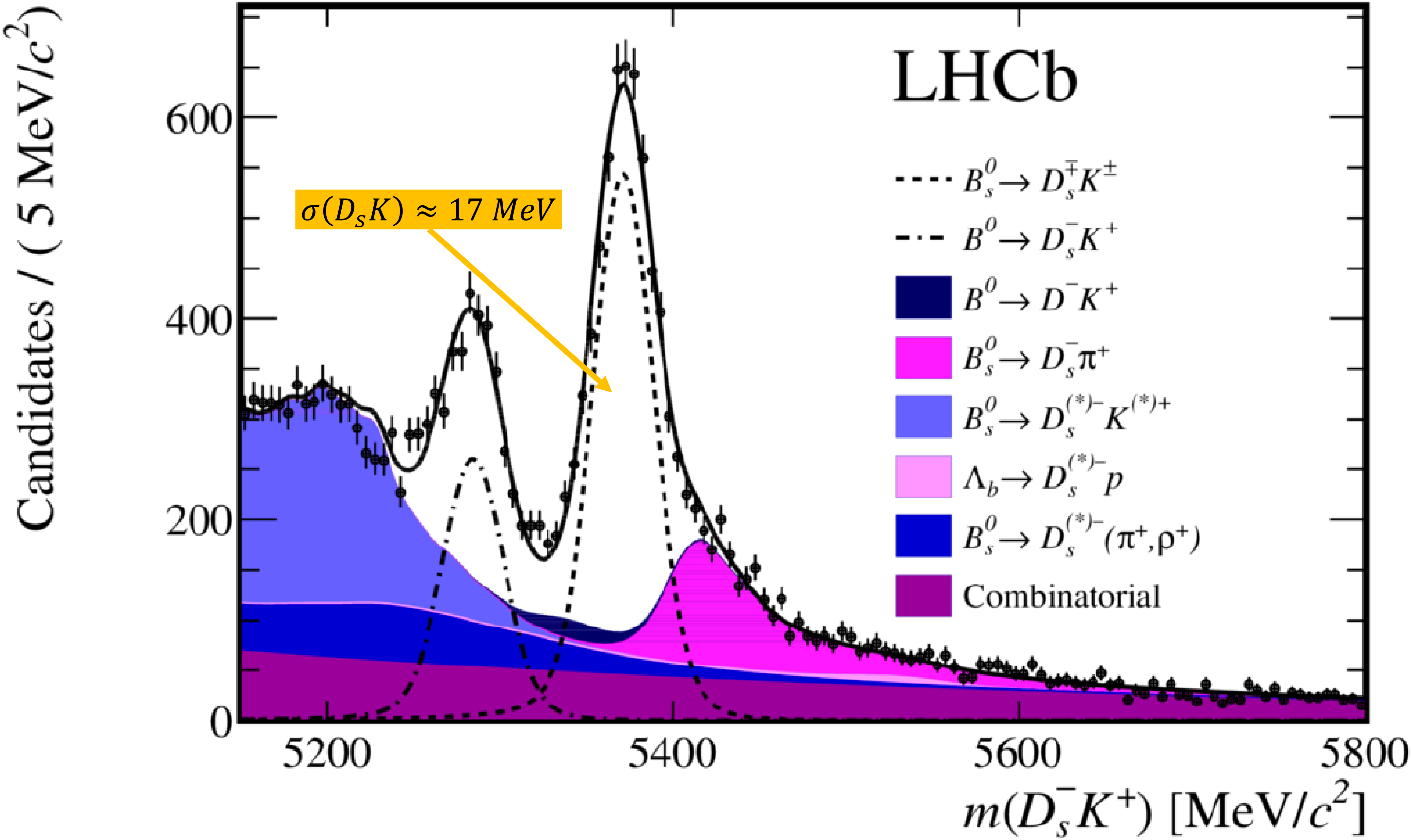
P_{γ}





$$\frac{\sigma_{E_\gamma}}{E_\gamma} = \frac{3\%}{\sqrt{E}}$$

$$\frac{\sigma_{E_\gamma}}{E_\gamma} = \frac{15\%}{\sqrt{E}}$$



[LHCb, JHEP 05 (2015) 019]