Constraints on Calorimetry from (some) CP violation and electroweak physics

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20/1/2021

Foreword : ILC detector studies have concentrated on Higgs Physics and Physics at 250-500 GeV. FCC has an ADDITIONNAL HUGE physics potential at lower energies (90-161 GeV) as an electroweak factory*.

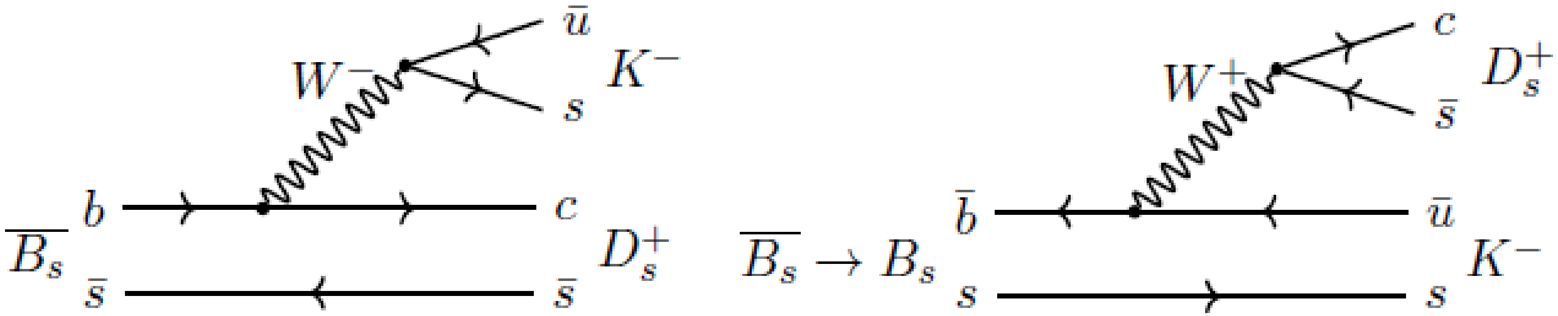
It is thus necessary to look at the constraints on the detectors coming from that physics, which may require a different optimization.

Two examples are used to study the subsequent constraints on the Calorimetry:

⇨Study of CP violation with $B_s^{\pm} \rightarrow D_s^{(*)} K^{\pm}$ at the Z pole
⇨Measurement of the $\nu_e - Z$ coupling at WW threshold (161 GeV)

ESPP: « Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron* ***Higgs and electroweak factory* *as a possible first stage. »*

Study of B_s -> D_s K at FCC-ee and constraints on detector



$$\phi_{CKM} = \gamma + \gamma_{ds} - 2\beta_s$$

UT

tiny

small

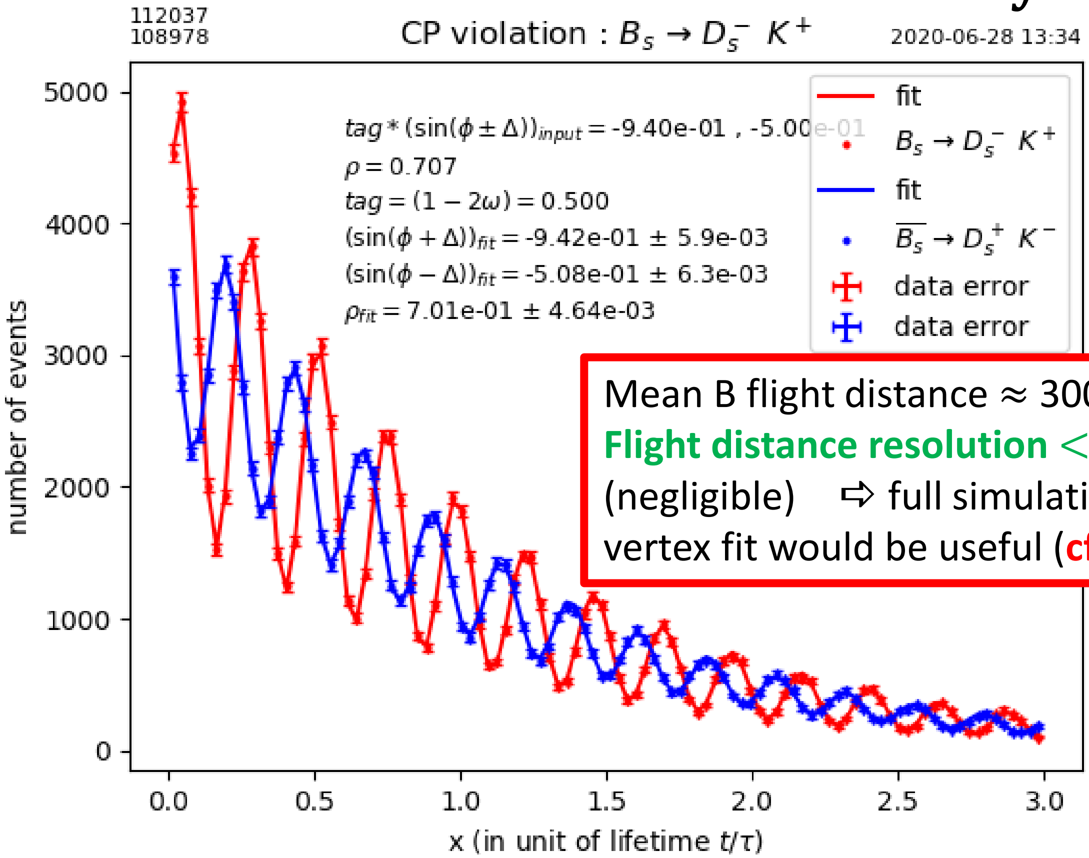
Motivations

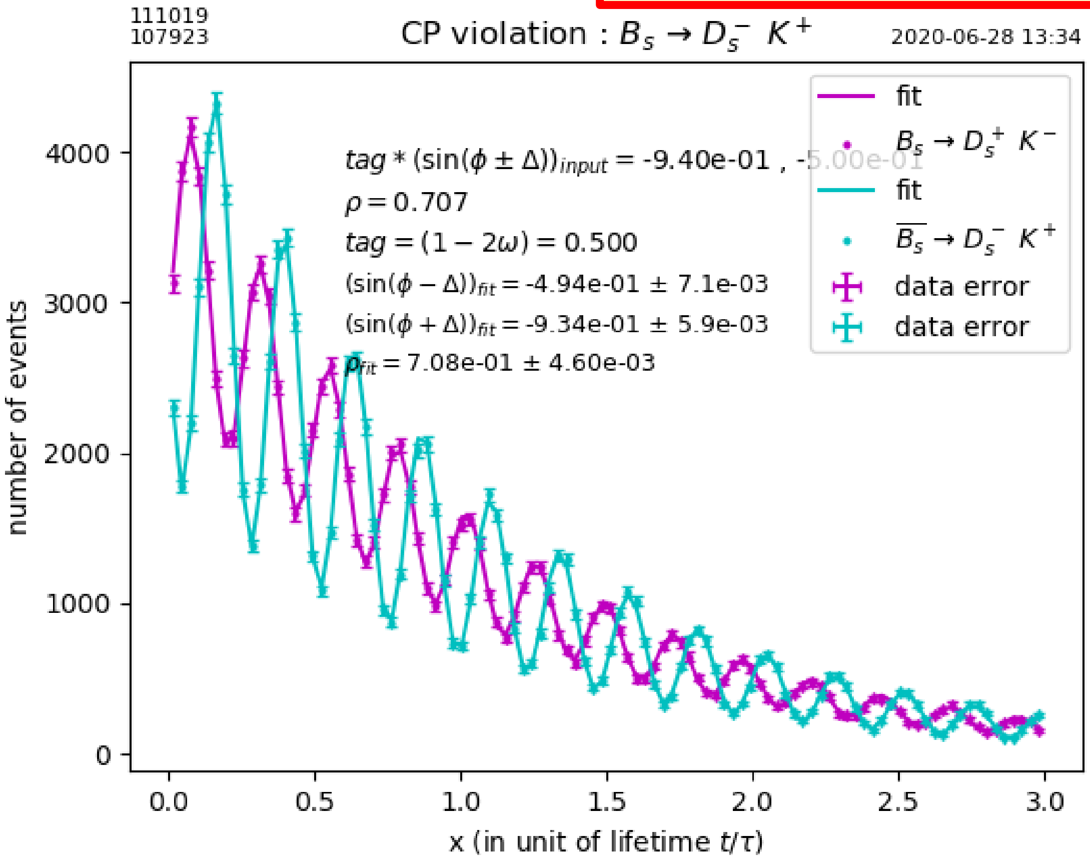
- Study of CP violation :
  - Sensitivity on UT_{CKM} angle γ
- Study of CP detector resolutions :
  - Tracking
  - PID
  - Calorimetry

Measurement of CP violation with $B_s \to D_s K \to \phi\pi K$

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

PDG: $\gamma = (71.1^{+4.6}_{-5.3})°$





Mean B flight distance ≈ 3000 μm
Flight distance resolution < 20 μm
(negligible) ⇨ full simulation and vertex fit would be useful (**cf E. Perez**)

Result 1 :

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

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

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 later)+
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)

Inclusion of neutrals for $B_s \to D_s^{\pm} K^{\mp} \to \phi\rho^{\pm} K^{\mp} \to K^+ K^- \pi^{\pm} \pi^0 K^{\mp}$ reconstruction

PID off

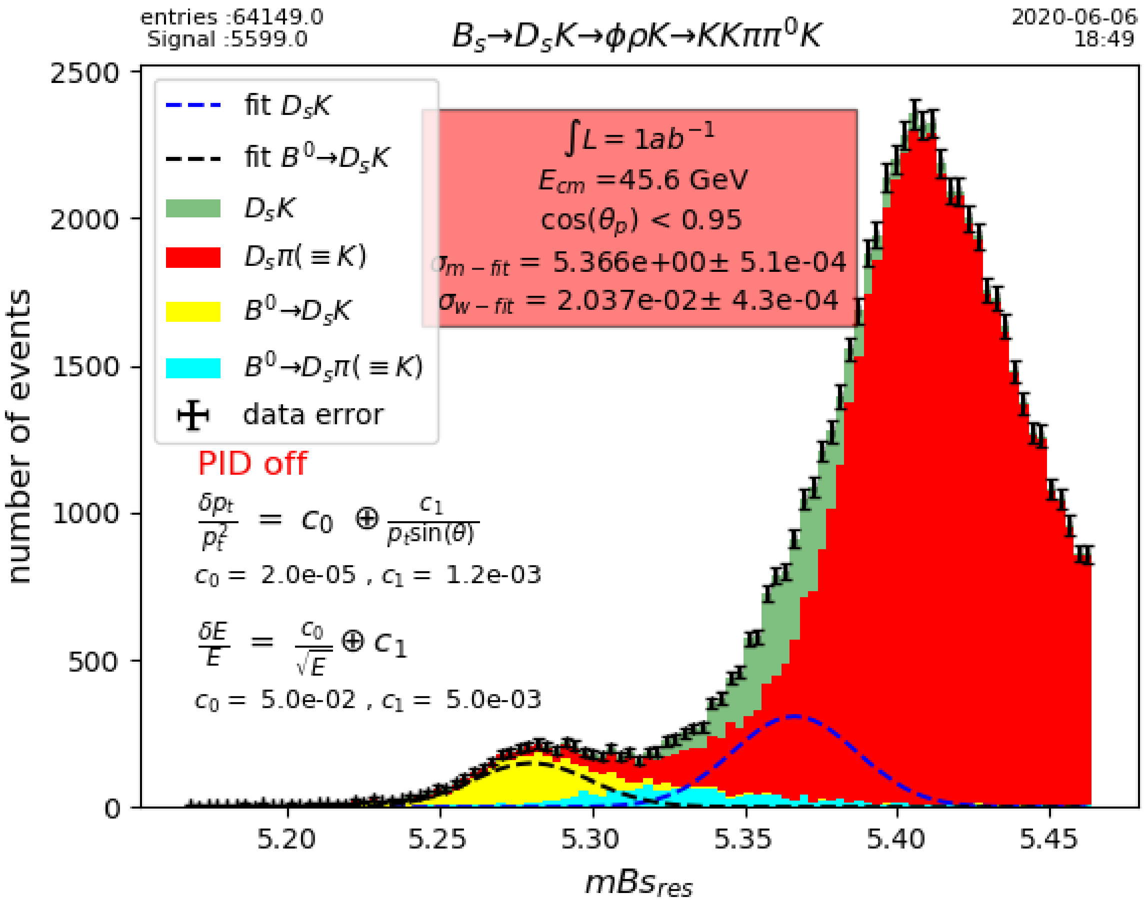
e.g. could potentially increase statistics (x 3) by adding $D_s^{\pm} \to \phi\rho^{\pm}$

$$\frac{D_s^{\pm} \to \phi\rho^{\pm}}{D_s^{\pm} \to \phi\pi^{\pm}} \approx 1.9$$

(several other modes with neurtrals ($D_s^{\pm} K^{*\mp}, D_s^{*\pm} K^{\mp}$...) ➯ stat. x ~10

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)

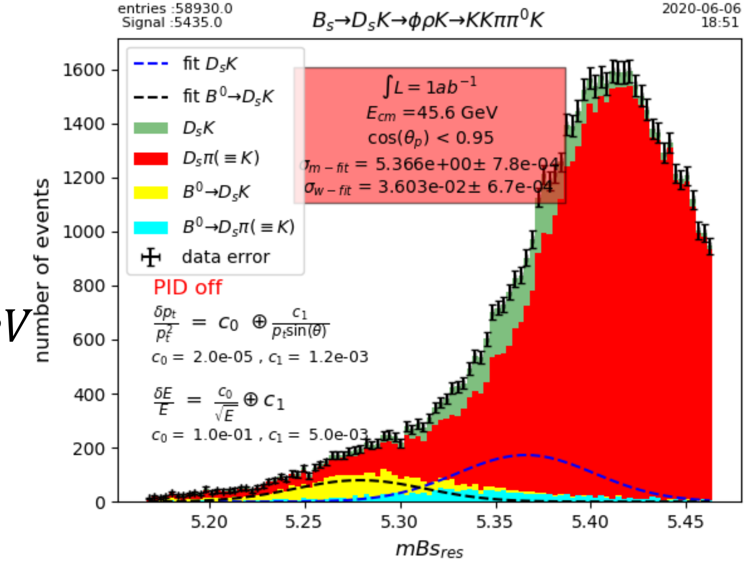
$\sigma(D_s^{\pm}(\phi\pi^{\pm})K^{\mp}) \approx 5.6MeV \to \sigma(D_s^{\pm}(\phi\rho^{\pm})K^{\mp}) \approx 20MeV$

➯ Background $D_s^{\pm}(\phi\rho^{\pm})\pi^{\mp}$ huge

Result 2 : ➯ PID mandatory

Much worse with LAr type Cal.

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

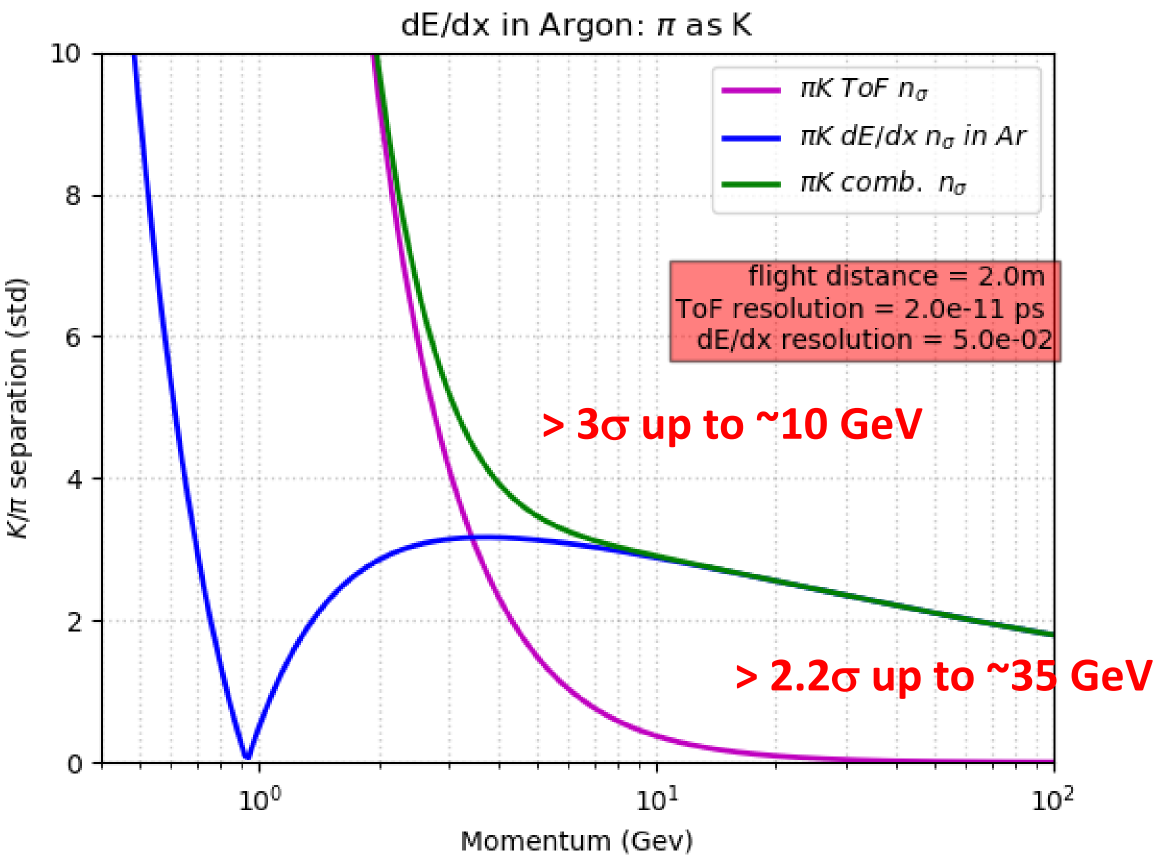


Inclusion of « standard and modest/conservative » PID (dE/dx and ToF)

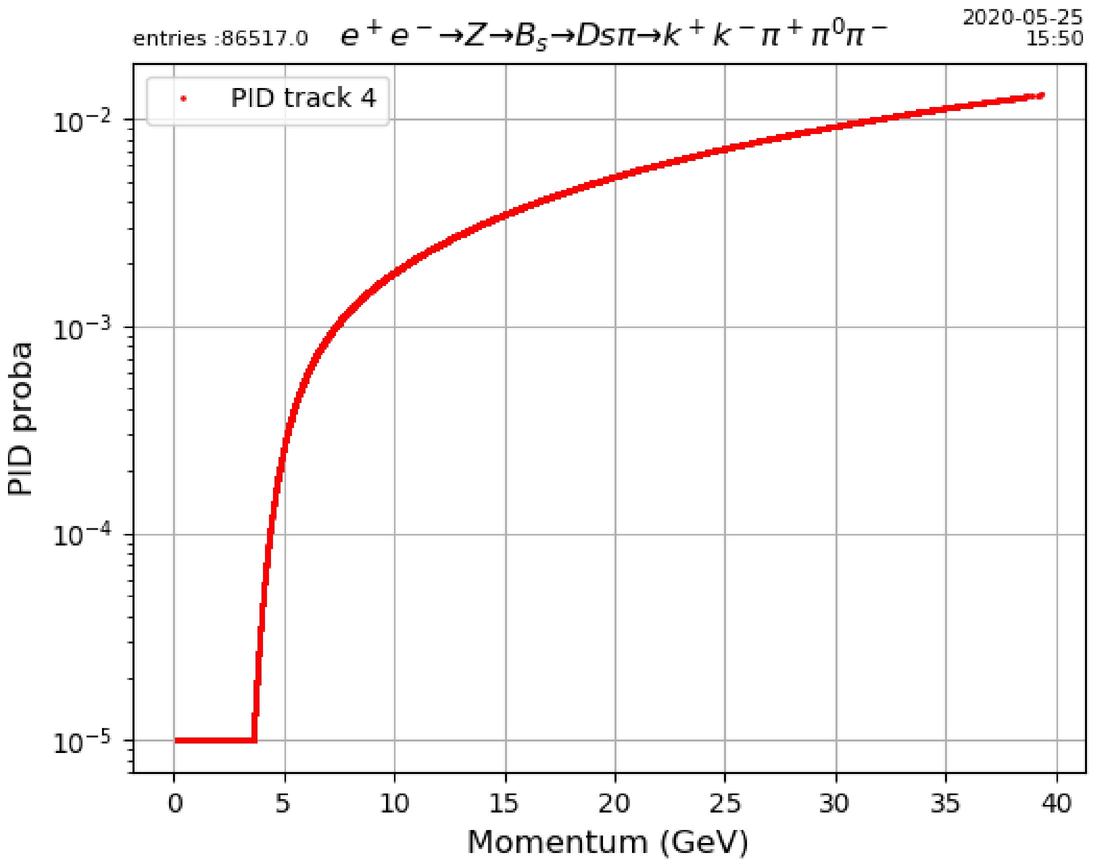
Resolution $\sigma\left(\frac{dE}{dx}\right) = 5\%$

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

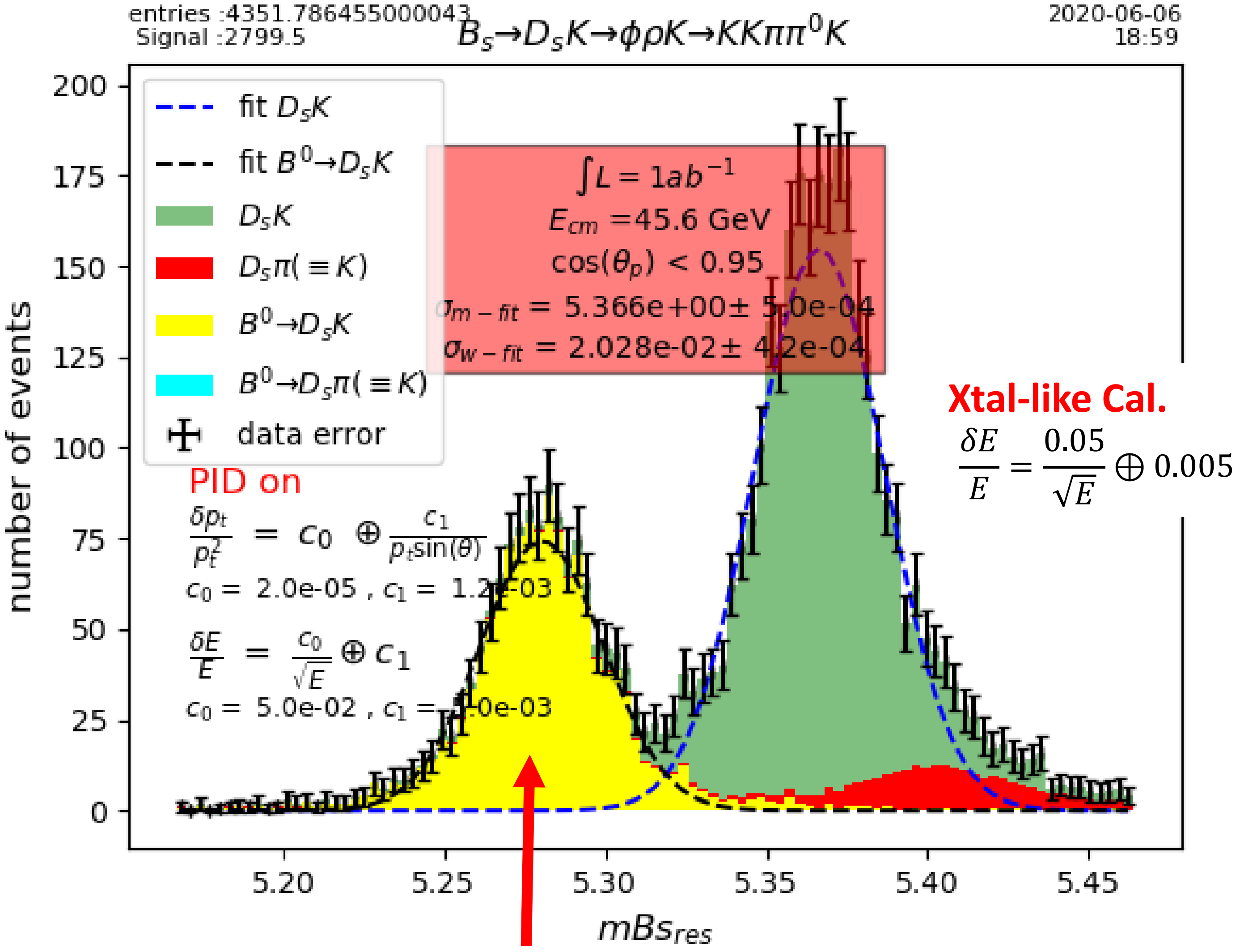
Detector location : 2m from IP



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



Effect of dE/dx and ToF

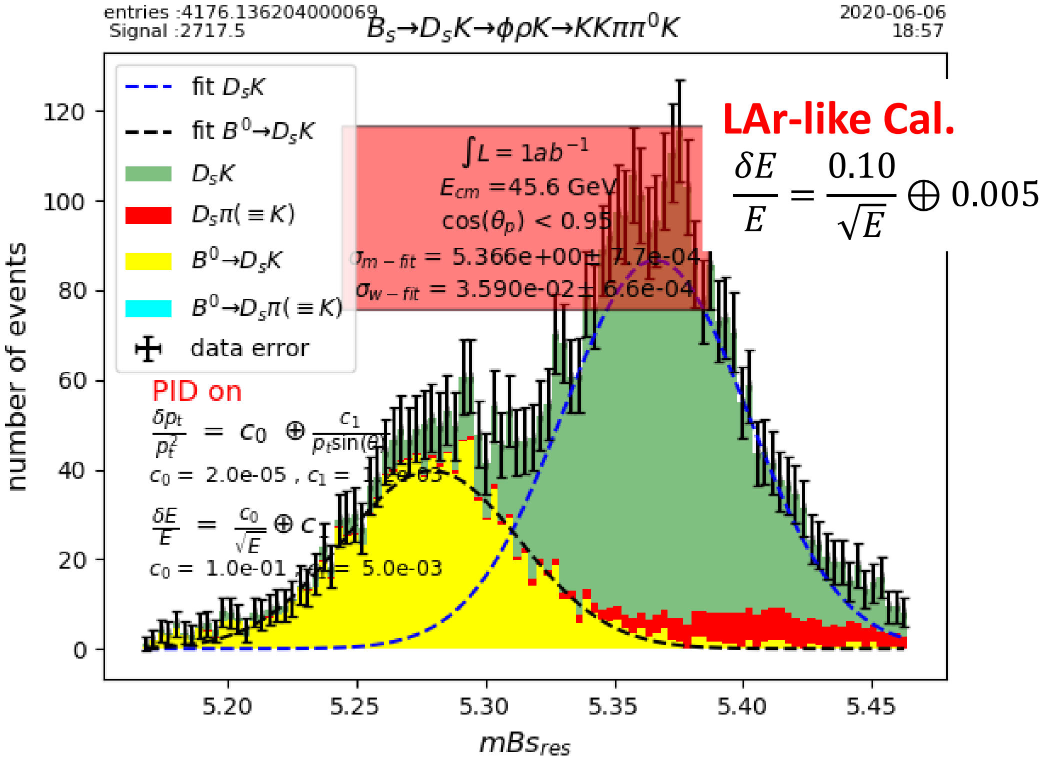


« Irreducible bkg » , only mass resolution can beat it

Result 3 : Xtal-like (or Xenon) calorimetry is 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



Inclusion of neutrals for $B_s \to D_s^{*\pm} K^{\mp} \to \phi\rho^{\pm} K^{\mp} \to \gamma K^+ K^- \pi^{\pm} \pi^0 K^{\mp}$ reconstruction

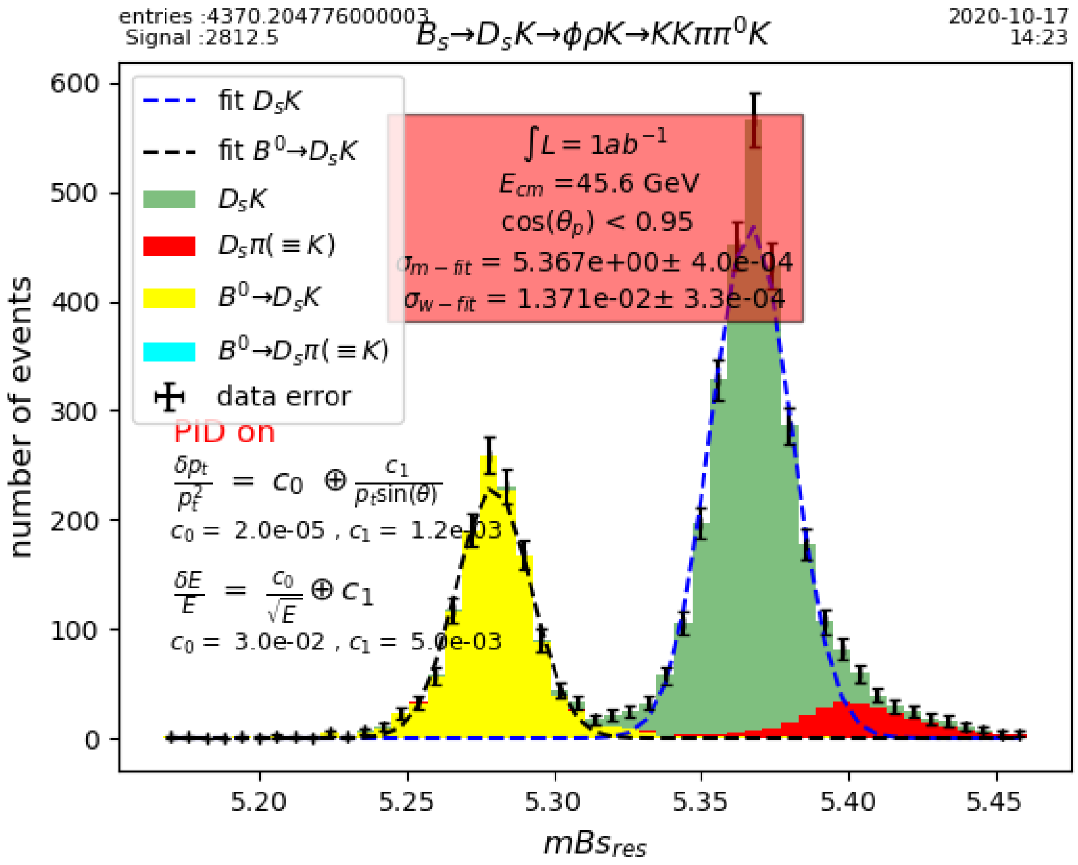
PID on

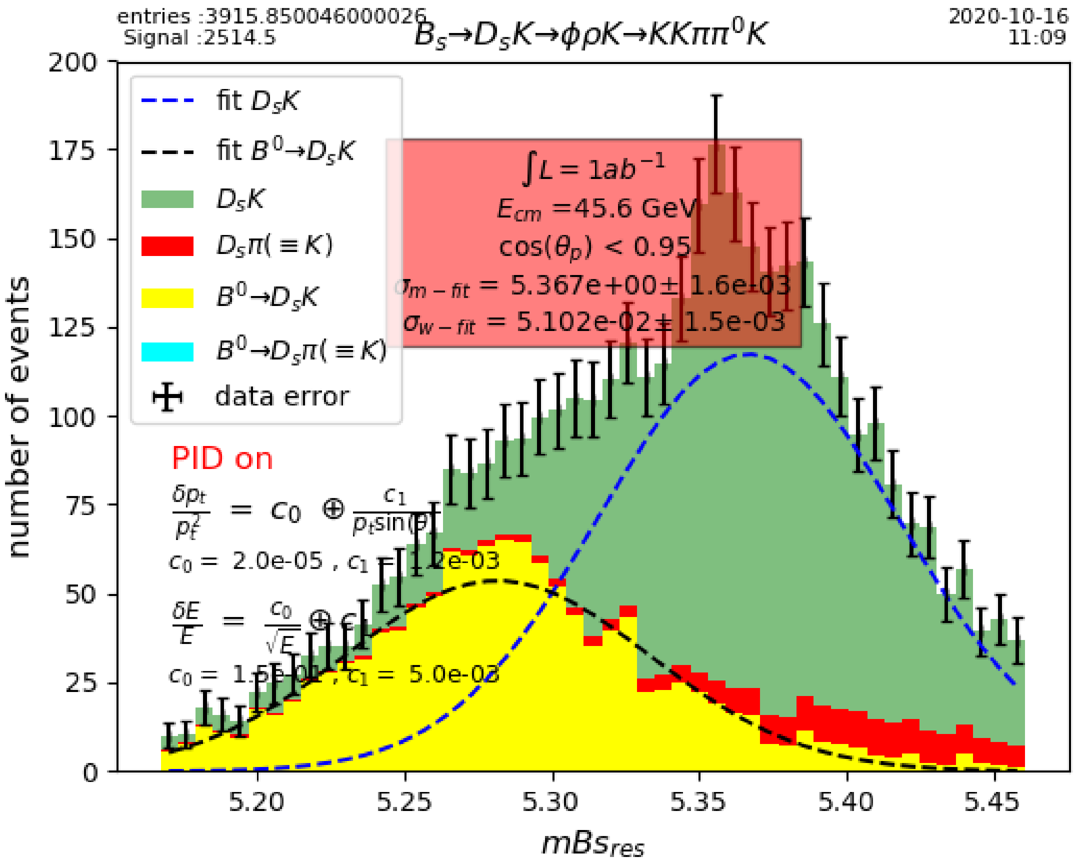
Assuming **state-of-the-art** calorimeter with

$$\frac{\delta E}{E} = \frac{0.03}{\sqrt{E}} \oplus 0.005$$

Assuming **HGCal like** calorimeter with

$$\frac{\delta E}{E} = \frac{0.15}{\sqrt{E}} \oplus 0.005$$





State-of-the-art **Xtal-type** to **HGCal-type** : $\sigma\left(D_S^{\pm}(\phi\rho^{\pm})K^{\mp}\right) \approx 14MeV \to 51MeV$

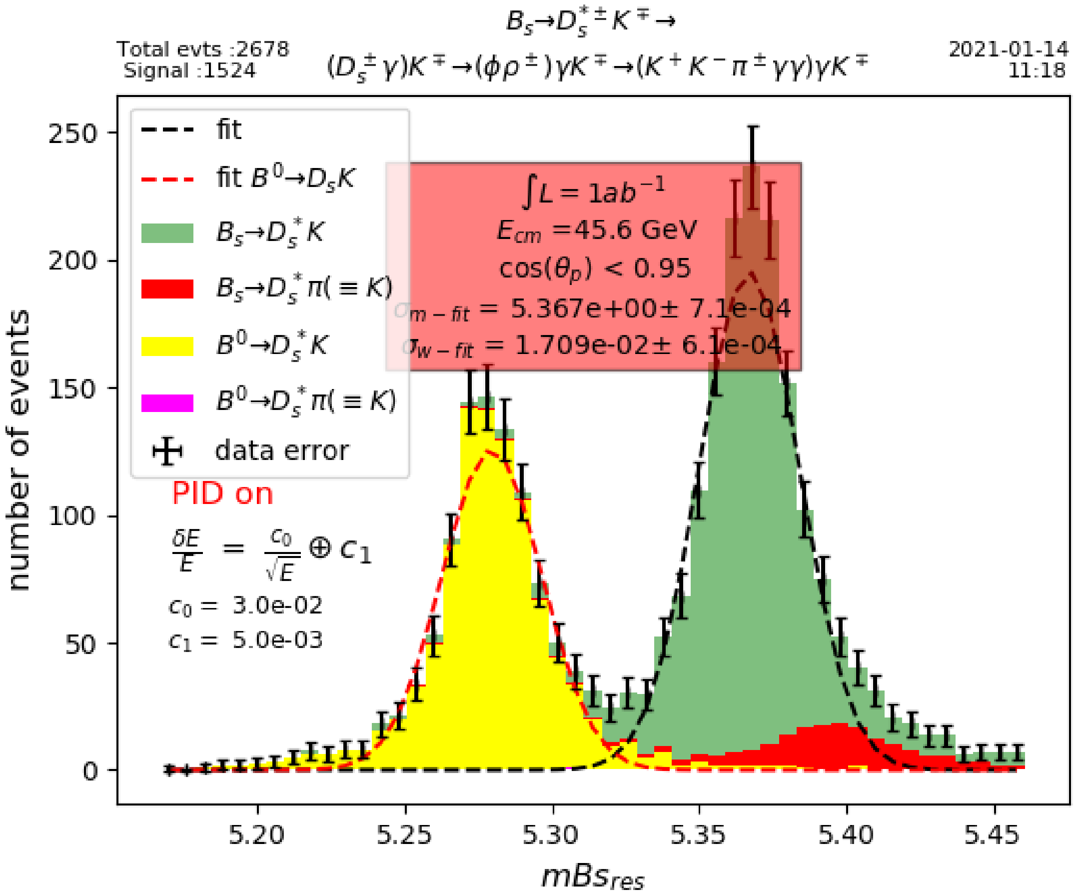
Result 4 : State-of-the-art (Xtal-like) calorimetry is mandatory if one aims at mode with multiple neutral

Inclusion of neutrals for $B_s \to D_s^{*\pm}K^{\mp} \to \phi\rho^{\pm}K^{\mp} \to \gamma K^+K^-\pi^{\pm}\pi^0 K^{\mp}$ reconstruction

PID on

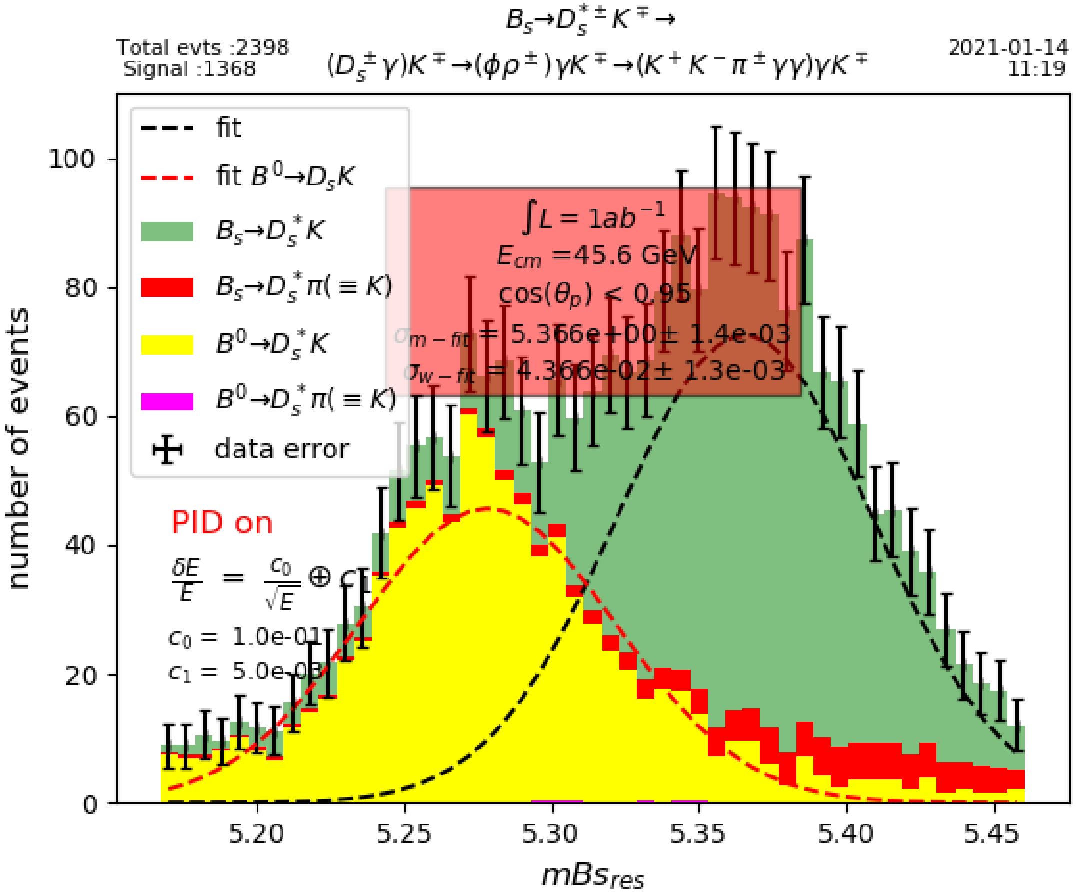
Assuming **state-of-the-art** calorimeter with

$$\frac{\delta E}{E} = \frac{0.03}{\sqrt{E}} \oplus 0.005$$



Assuming **LAr like** calorimeter with

$$\frac{\delta E}{E} = \frac{0.10}{\sqrt{E}} \oplus 0.005$$



State-of-the-art **Xtal-type** to **LAr-type** : $\sigma(D_s^{*\pm}(\phi\rho^{\pm})K^{\mp}) \approx 17MeV \to 44MeV$

Result 4bis : State-of-the-art (Xtal-like) calorimetry is mandatory if one aims at mode with multiple neutral

Summary

$\boldsymbol{B_s \to D_s K}$ is an excellent showcase for

- Studying sensitivity on CP violation (measurement of CKM angle γ)
- Determining constraints on detector (**in particular for calorimeter**)

$\delta(\gamma) \lesssim 0.4° \ (stat.)$ achievable

with only 1 decay mode !!! Using additionnal modes with neutrals could reduce error by factor >2

More that 1 order of magnitude improvement compared to present PDG errors

However this requires

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
⇨ Xtal or Xenon calorimeter

$\boldsymbol{\frac{\sigma(E)}{E} \lesssim \frac{5 \times 10^{-2}}{\sqrt{E}} \oplus 5 \times 10^{-3}}$

Allows to use many other decay mode !!!

AND Excellent PId resolution

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

A full simulation would be useful to refine further analysis, in particular for vertexing

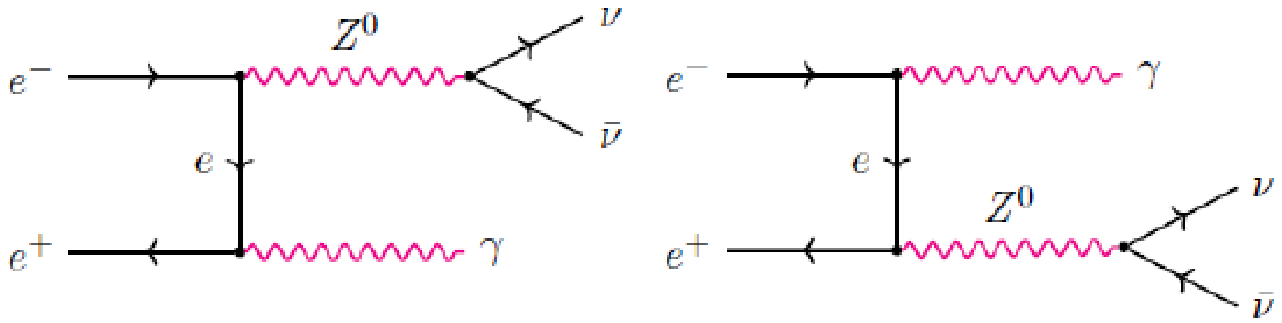
Precision measurement of the Z boson to electron neutrino coupling at the future circular colliders*

« …making the neutrino flavor visible in Z decays »

R.A. and S. Jadach

https://arxiv.org/abs/1908.06338

https://doi.org/10.1016/j.physletb.2019.135034



Neutrino counting measured at LEP with/without radiative γ :

Beam-beam effect correction

G. Voutsinas et al. , arXiv:1908.01704

Improved bhabha Xsection

P.Janot S.Jadach , arXiv:1912.02067

$$N_\nu = 2.9963 \pm 0.0074$$

$$\sigma(e^+e^- \to Z \to \text{invisible}) = (g_Z^{\nu_e}\mathcal{A}_Z^{\nu_e})^2 + (g_Z^{\nu_\mu}\mathcal{A}_Z^{\nu_\mu})^2 + (g_Z^{\nu_\tau}\mathcal{A}_Z^{\nu_\tau})^2 + (g_Z^{X}\mathcal{A}_Z^{X})^2$$

However NO distinction between neutrino flavor

$g_Z^{\nu_e}$ poorly measured

PDG
$$g_Z^{\nu_e} = 1.06 \pm 0.18$$
$$g_Z^{\nu_\mu} = 1.004 \pm 0.034$$

From ν_μ e and ν_e e scattering

$g_Z^{\nu_\tau}$ = ?

Can one do better at FCC-ee? → Test lepton universality in neutrino sector

In the following we assume $N_{inv} \equiv 3\,\nu$ since it will be measured at FCC with negligible error

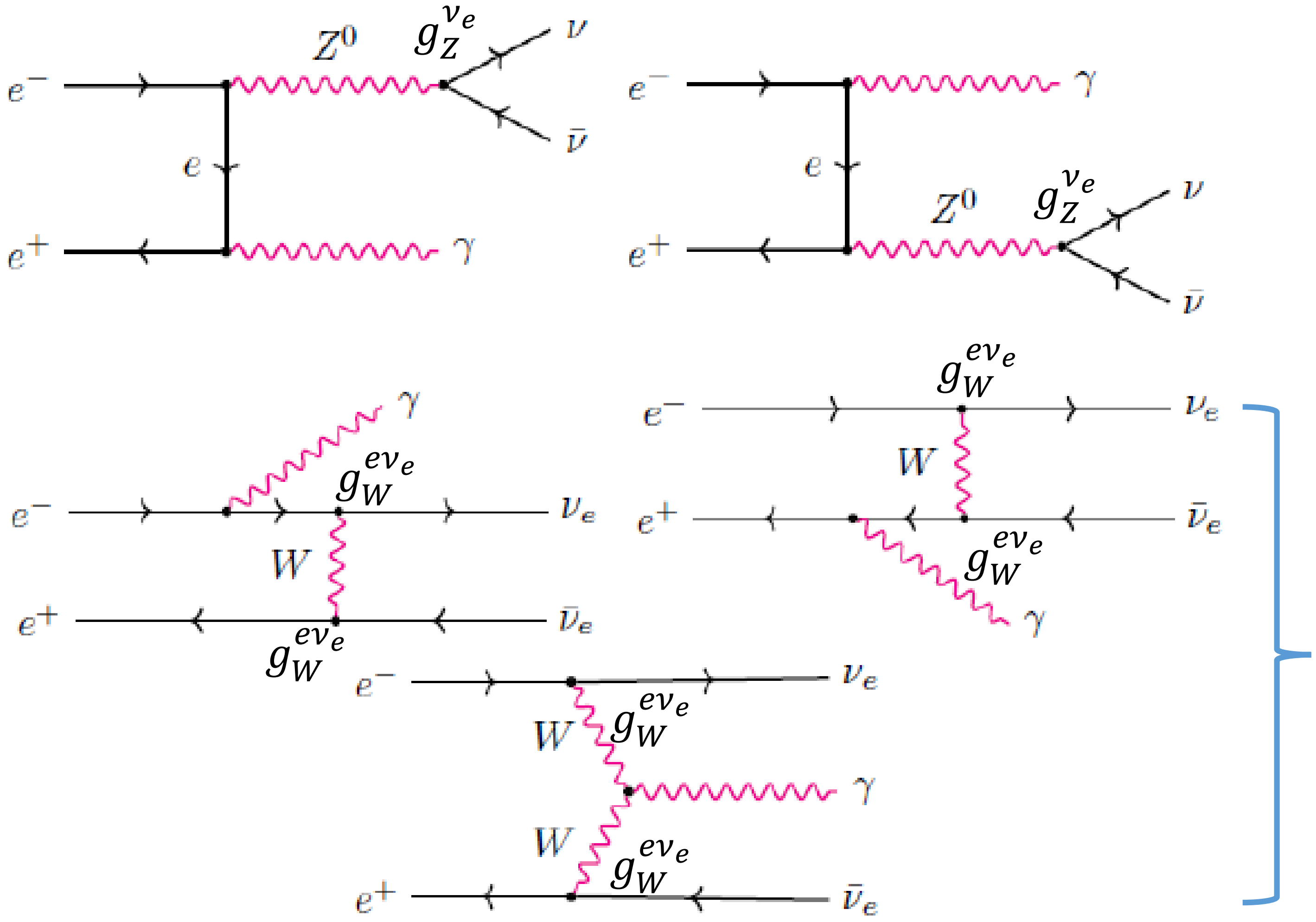
$$N_\nu \equiv (g_Z^{\nu_e})^2 + (g_Z^{\nu_\mu})^2 + (g_Z^{\nu_\tau})^2$$

We introduce the parameter η such as $g_Z^{\nu_e} = \sqrt{1+\eta}\,,\; g_Z^{\nu_\mu} = 1\,,\; g_Z^{\nu_\tau} = \sqrt{1-\eta}$

This preserves $N_{invisible} \equiv 3\,\nu$ in Z width

In Standard Model $\eta = 0$ (lepton universality)

Idea is to look for interference with diagrams with well known couplings

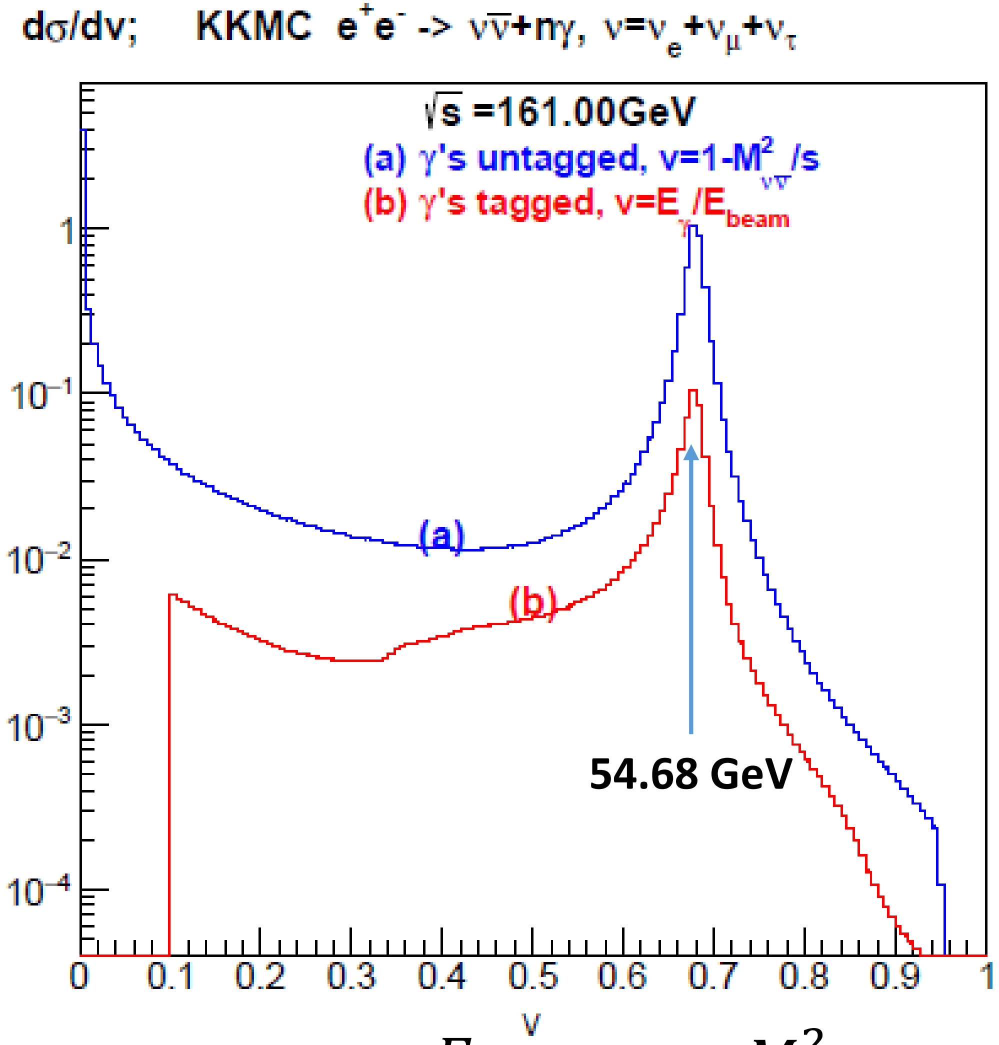


Diagrams with Well known couplings

$$g_W^{e\nu_e} = 1$$

Only ν_e interfere ⇨ interference effect measures $g_Z^{\nu_e}$ but HUGE statistics needed ⇨**FCCee**

We concentrate on $\sqrt{S} = 161\ GeV$ with L=10 ab^{-1} (i.e. with 2 detectors)
MC used KKMC (see Staszek Jadach et al.)



$$\mathcal{V} = \frac{E_\gamma}{E_{beam}} \approx 1 - \frac{M^2_{\nu\bar{\nu}}}{s}$$

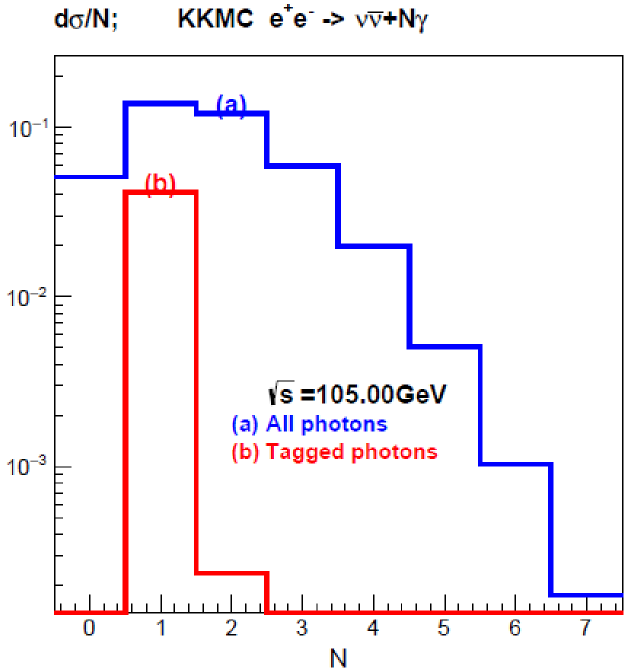
Cuts for **(b)** curve

$$\sum E_\gamma > 0.1 E_{beam}$$

$$\theta_\gamma > 15°$$

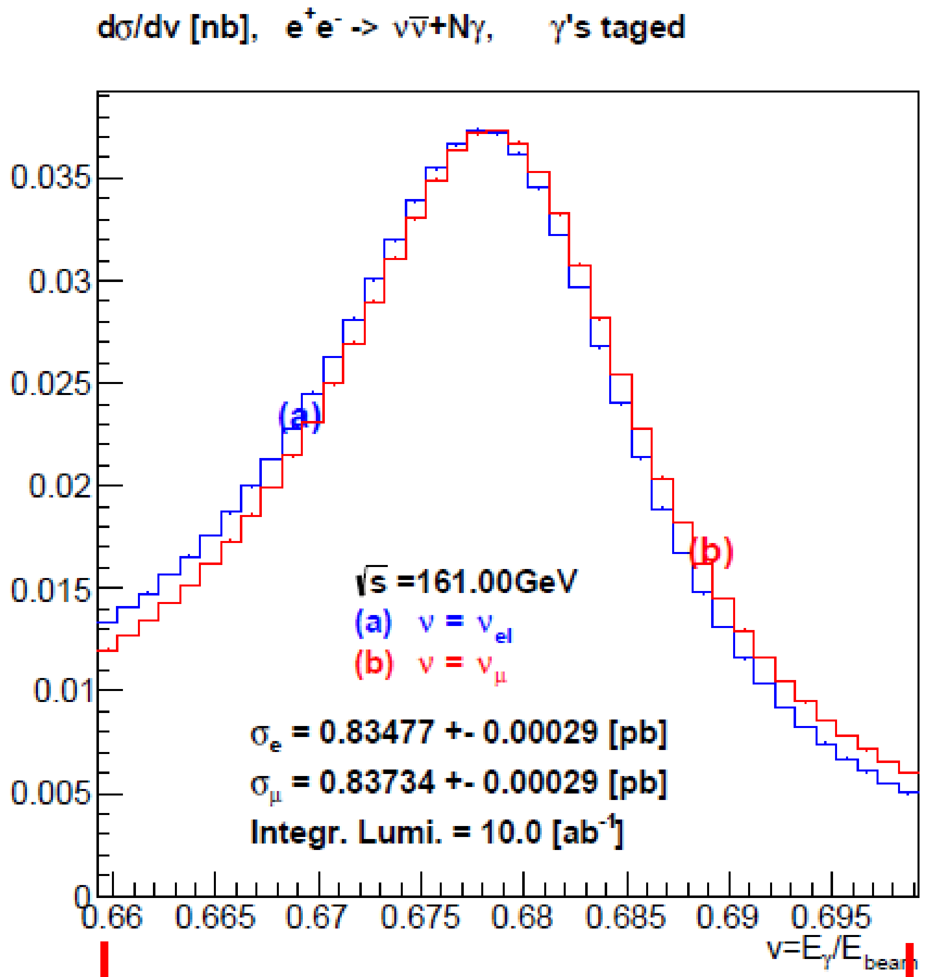
$$E_{T\gamma} > 0.02\ E_{beam}$$

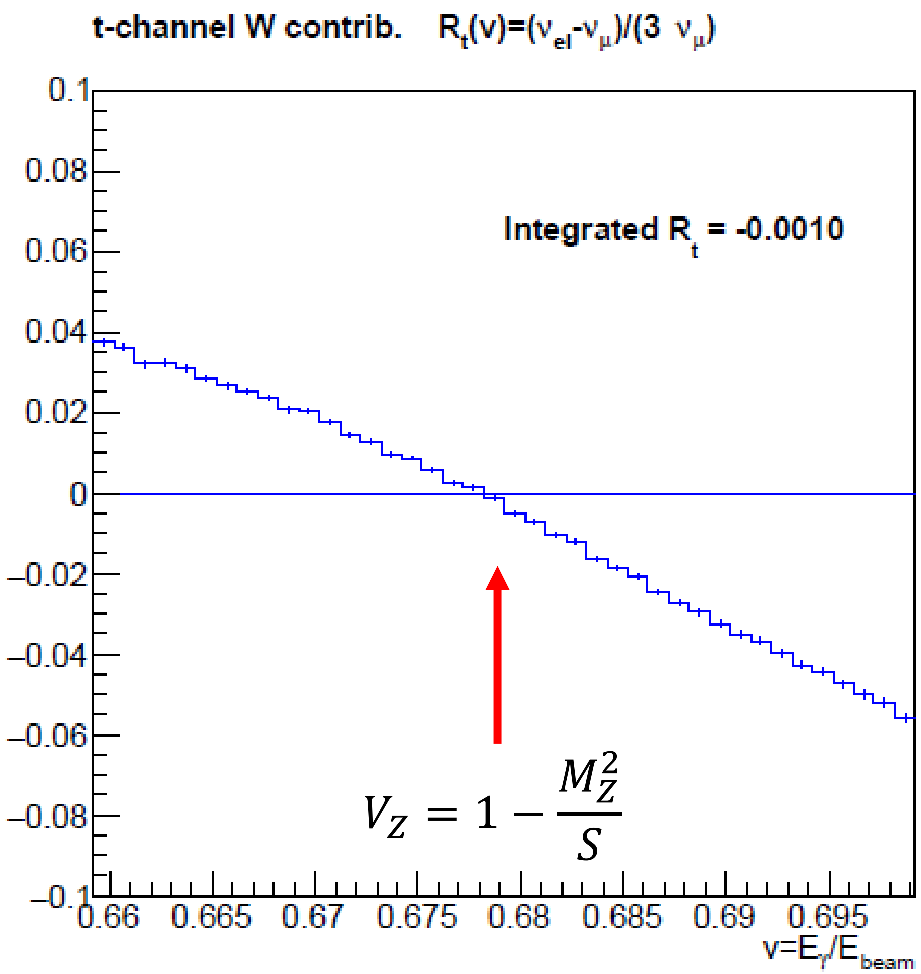
Essentially 1 γ after cuts



Zoom on Z Radiative Return (ZRR)

Difference between $\nu_{\mu(\tau)}$ and ν_e



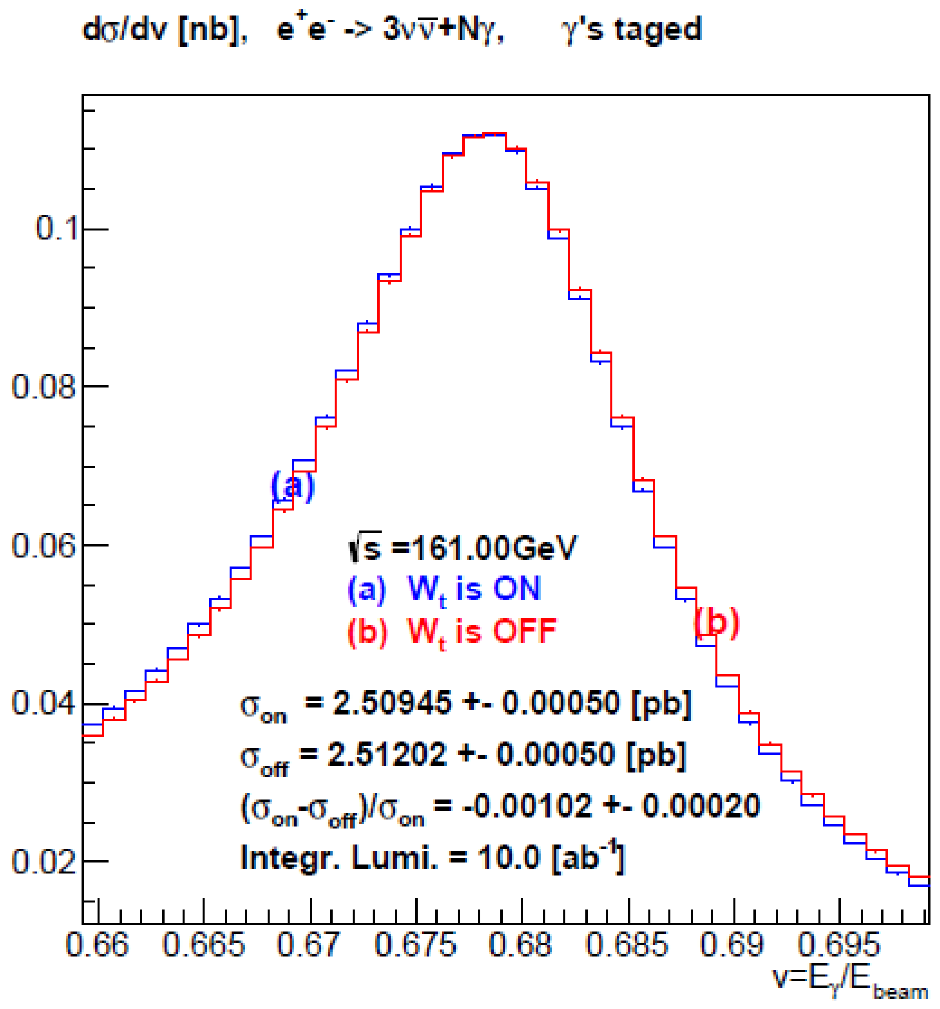


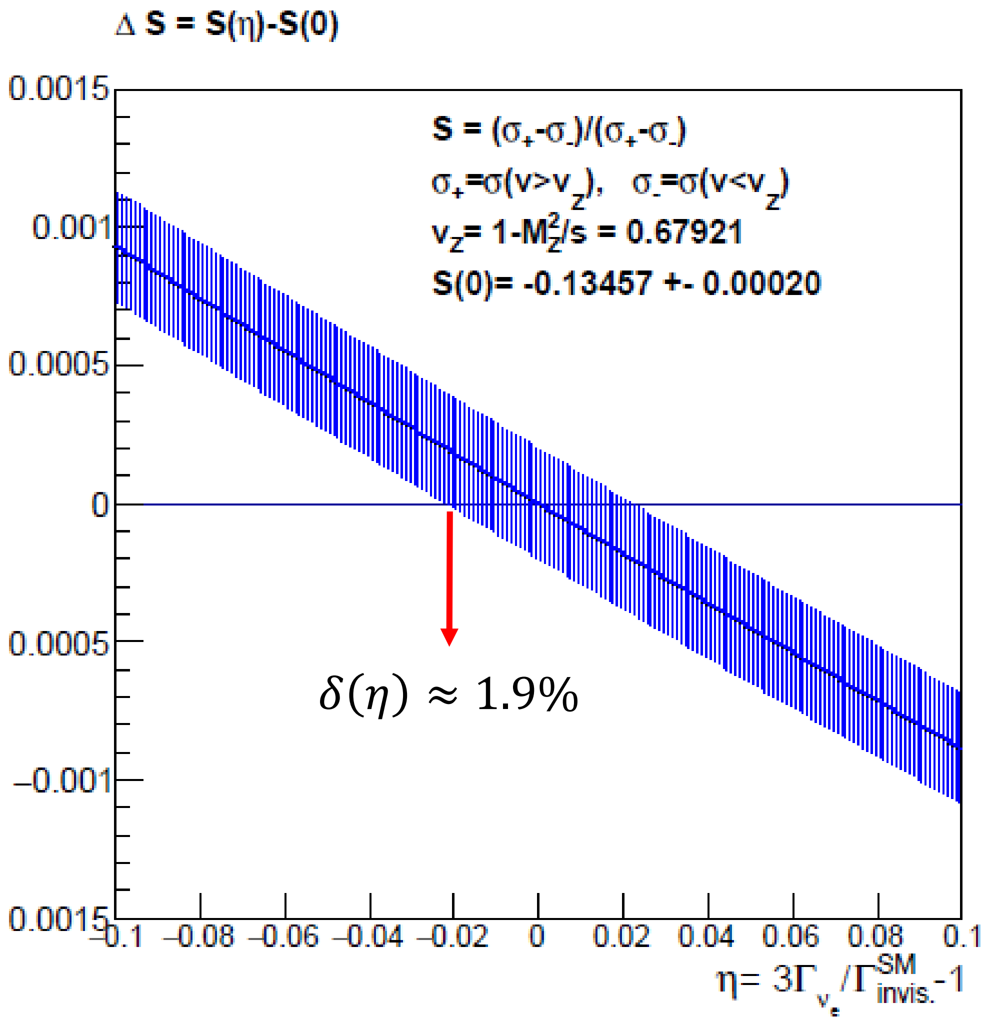
$E_\gamma = 53.13\ GeV$ ⟷ $E_\gamma = 56.35\ GeV$

Interference effects may look small but
Huge statistics is available ~25 x 10^6 events

For simplicity let's define the Asymmetry $S = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$

with $\sigma_+ = \sigma(v>v_z)$, $\sigma_- = \sigma(v<v_z)$





MC can be checked with μμγ events, although not exactly same diagrams involved

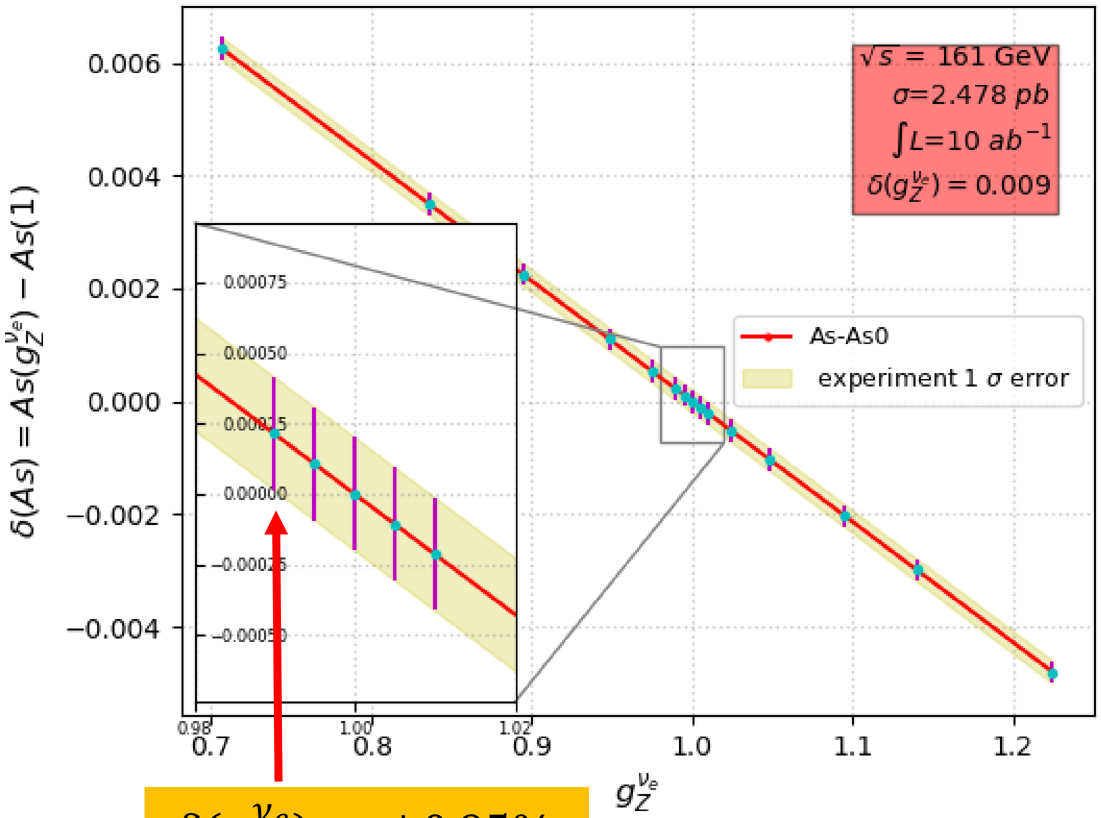
Error on $g_Z^{\nu_e}$

With detector resolution dilution effects

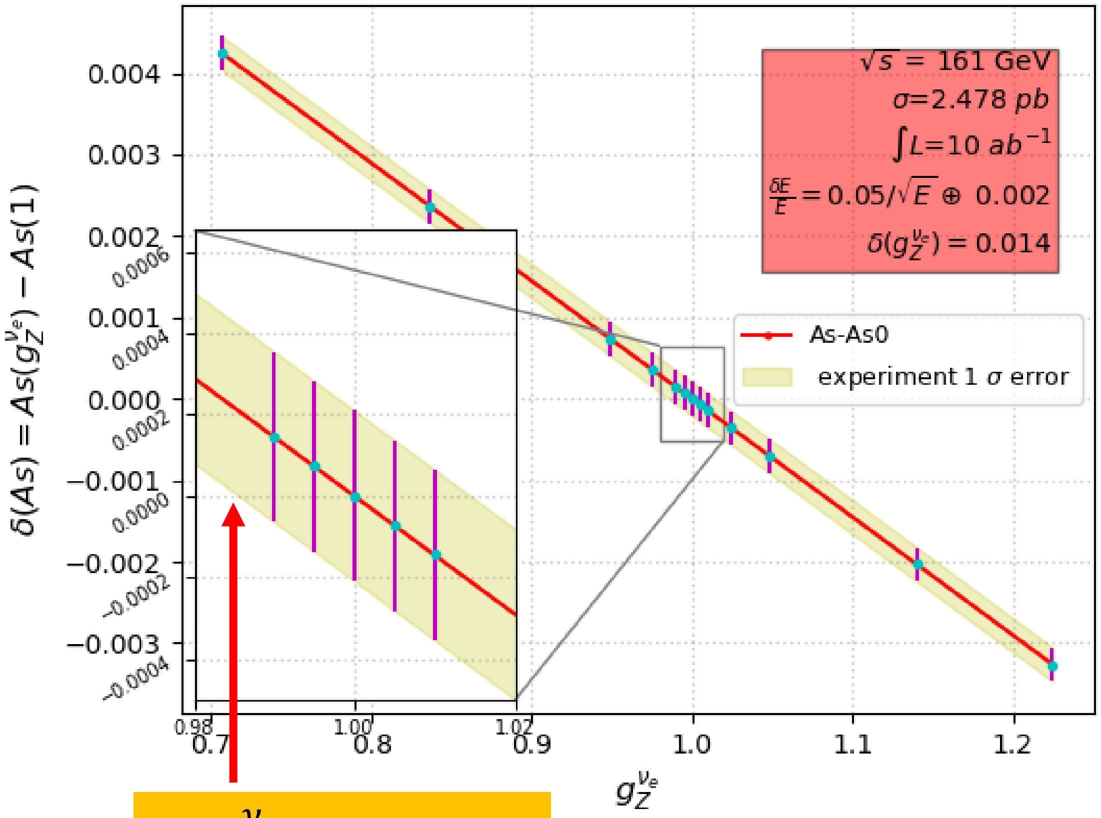
$$\frac{\delta E_\gamma}{E_\gamma} = \frac{\mathbf{0.05}}{\sqrt{E_\gamma}} \oplus 0.005$$

Can be calibrated with μμγ events

Without detector resolution dilution effects



$\delta(g_Z^{\nu_e}) = \pm 0.95\%$



$\delta(g_Z^{\nu_e}) = \pm 1.4\%$

If stochastic term =**3%** (Excel. Xtal detector) ⇨ $\delta(g_Z^{\nu_e}) = \pm 1.2\%$

If stochastic term =**7%** (sampling detector) ⇨ $\delta(g_Z^{\nu_e}) = \pm 1.8\%$

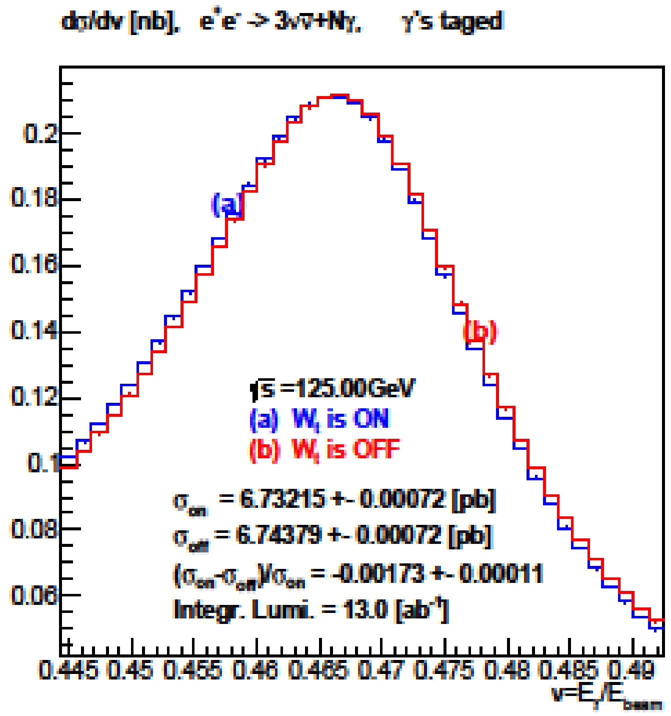
If stochastic term =**10%** (sampling detector) ⇨ $\delta(g_Z^{\nu_e}) = \pm 2.4\%$

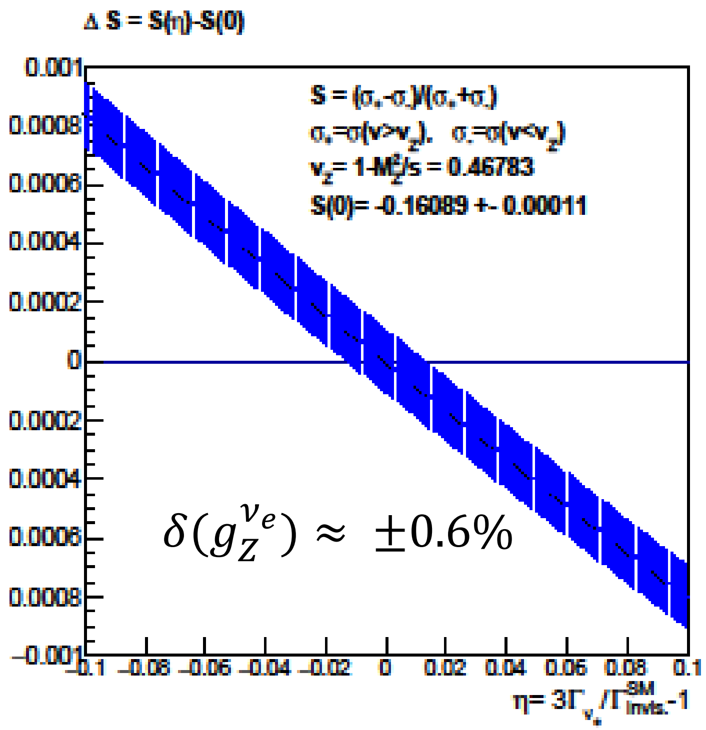
Result 6
Xtal-type calorimeter is highly desired

Caveat : Study of the optimal range of E_γ is to be done to optimize the sensitivity. However general conclusion for calorimeter is likely to be the same

Summary

- The method proposed would lead to a considerable improvement on the presicion on $g_Z^{\nu_e}$
  ⇨ $\boldsymbol{\delta(g_Z^{\nu_e}) = \pm 1.2\%}$ **with a excellent Xtal-type calorimètre (**$\frac{\delta E_\gamma}{E_\gamma} = \frac{\mathbf{0.03}}{\sqrt{E_\gamma}} \oplus 0.005$**)**
- Assuming 3 ν and no new physics coupled to Z, one would derive
  ⇨ $\boldsymbol{\delta(g_Z^{\nu_\tau}) = \pm 4.6\%}$ (limited by resolution on $g_Z^{\nu_\mu}$)
- $\sqrt{S} = 161\ GeV$ may not be optimal (but we will run there anyway), e.g. 11 months at $\sqrt{S} = 125\ GeV \equiv 13\ ab^{-1}$ would potentially allow for ~ twice smaller errors. Optimization of C.o.M. energy to be done.





Final remarks :
This is a preliminary study and several complementary studies needed

- virtual corrections for W contribution in KKMC matrix element has still to be checked
- the size and shape of the QED deformation of the Z peak in ZRR obtained from KKMC should be cross-checked using independent calculation
- EW corrections were included in the presented KKMC calculation - their size and role should be examined quantitatively
- dominant O(α^3) QED non-soft corrections (in our convention) should be estimated/calculated.
- Main backgrounds are $\ell^+\ell^-\gamma$, where all leptons tracks are missed, is small, but needs to simulated in more details. Detector efficiency performance crucial to avoid missing tracks.

There are also several other improvements in the analysis front, which needs to be studied:

- carrying a full fit of the v spectrum instead of measuring its asymmetry
- optimizing the v range.
- study of the interference effect at low and high v range might be useful to improve the sensitivity on $g_Z^{\nu_e}$
- Carrying an analysis with full detector simulation will be ultimately needed

Overall conclusions

Besides Higgs and Top physics, the huge physics potential for electroweak (Z/W) and Flavor physics at FCC calls for an **overall optimization** of the detectors in particular concerning Particle Identification and **Calorimetry**.

Two examples have been shown Enabling beyond state-of-the-art physics reach both in Flavor ($\delta(\gamma) < 0.4°$) and electroweak ($\boldsymbol{\delta(g_Z^{\nu_e}) <\ \pm 1.2\%}$) physics

From the physics cases presented in this talk,

Excellent calorimetry resolution is required $\boldsymbol{\frac{\sigma(E)}{E} \lesssim \frac{5\times10^{-2}}{\sqrt{E}} \oplus 5 \times 10^{-3}}$ **,**

ideally $\boldsymbol{\frac{\sigma(E)}{E} \approx \frac{3\times10^{-2}}{\sqrt{E}} \oplus 3 \times 10^{-3}}$ **(possibly not giving (too much!) up granularity)**

⇨ **Xtal or Xenon calorimeter should be investigated**

Final comment : FCC is a machine surpassing all previous accelerators by orders of magnitude, we should thus design detectors outperforming previous ones by large factors as well!

Backup Slides

Expected number of events

$E_{cm} = 91.2$ GeV and $\int L = 150 ab^{-1}$

$\sigma(e^+e^- \to Z)$ nb	number of Z	$f(Z \to \overline{B}_s)$	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	
$J/\psi\phi$	$J/\psi \to \mu^+\mu^-$	$\mu^+\mu^-K^+K^-$	$\sim 3.2\ 10^6$
$\phi\phi$	$\phi \to K^+K^-$	$K^+K^-K^+K^-$	$\sim 4.8\ 10^5$

Detector response is parametrized

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

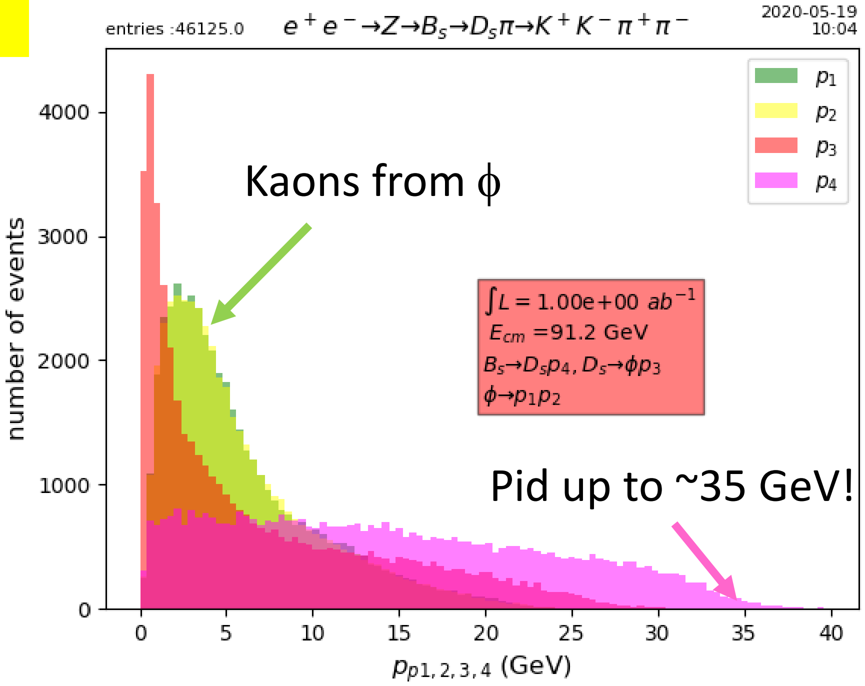
$$\text{Track } p_T \text{ resolution}: \quad \frac{\sigma(p_T)}{p_T^2} = 2.\times 10^{-5} \oplus \frac{1.2\times 10^{-3}}{p_T \sin\theta}$$

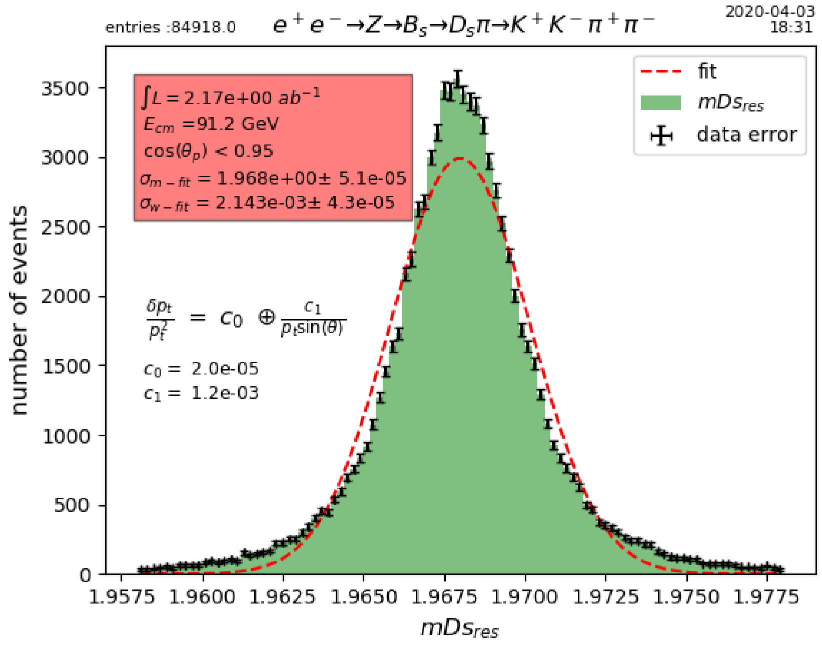
$$\text{Track } \phi,\theta \text{ resolution}: \quad \sigma(\phi,\theta)\ \mu\text{rad} = 18 \oplus \frac{1.5\times 10^{3}}{p_T \sqrt[3]{\sin\theta}}$$

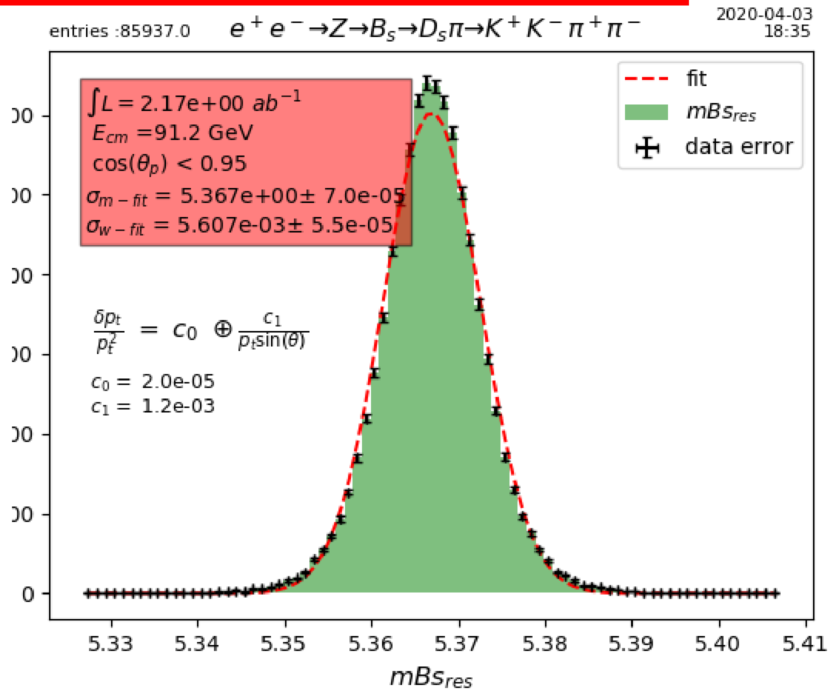
$$\text{Vertex resolution}: \quad \sigma(\mathrm{d_{Im}})\ \mu m = 1.8 \oplus \frac{5.4\times 10^{1}}{p_T \sqrt{\sin\theta}}$$

$$\text{Vertex resolution}: \quad <\sigma(\mathrm{d_{Im}})> \simeq 10\ \mu m$$ (Bachelor π/K)

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







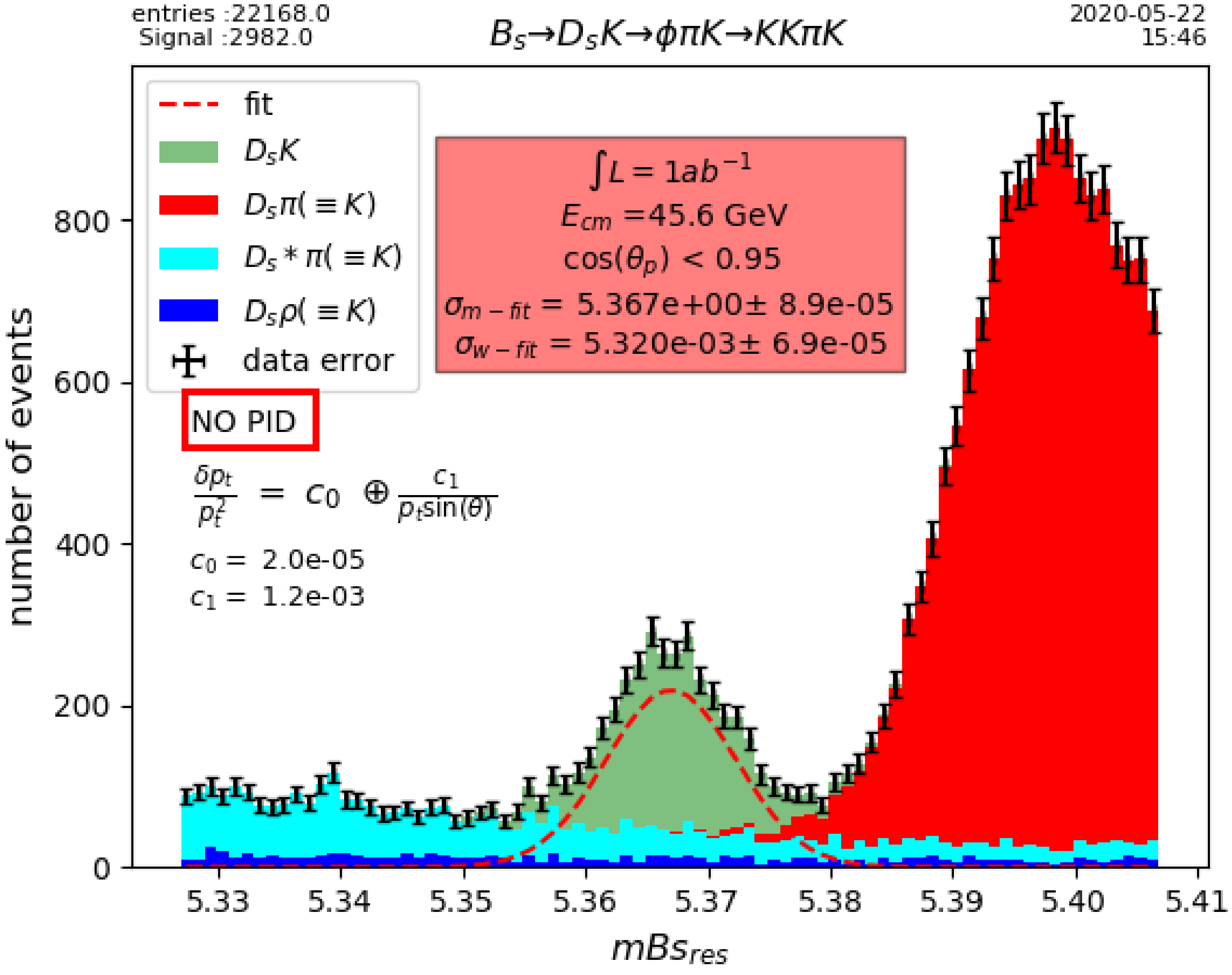
Charged final state only

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

To be compared to

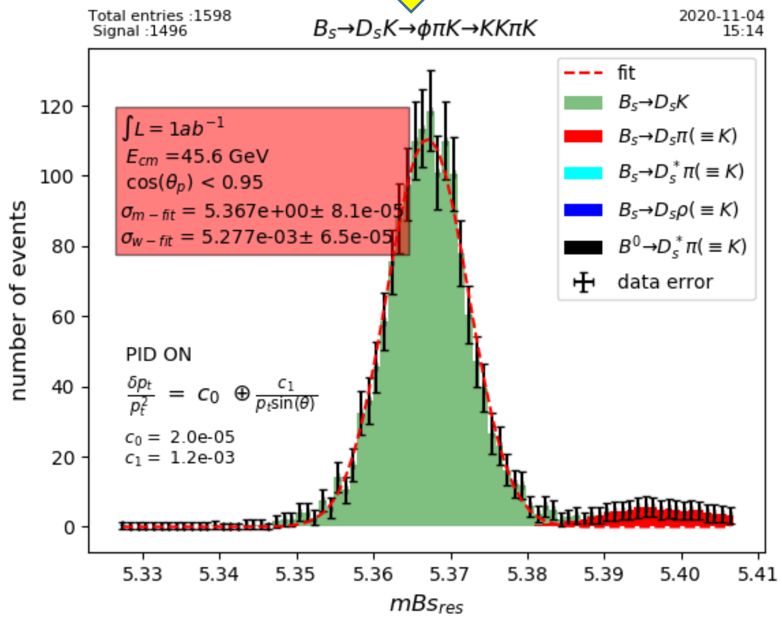
$$\boldsymbol{\sigma(mB_s)_{LHCb} \approx 17\ MeV}$$

Measurement of CP violation with $B_s \to D_s K \to \phi\pi K$



Result 1 :

- **Tracking resolution crucial to reduce background**
- **Combinatoric background to be added (but expected to be relatively small)**
- **A modest PId (ToF + dE/dx) enough (see presentation later this afternoon)**



Time dependent B_s decay

R.A. , I. Dunietz, B. Kayser Z. Phys. C54, 653 (1992)
https://doi.org/10.1007/BF01559494

$$\Gamma(B_s \to f) = |<f|B_s>|^2 \times e^{-\Gamma t}\{[1-\omega(1-\rho^2)]\cos^2\frac{\Delta m t}{2} + [\rho^2+\omega(1-\rho^2)]\sin^2\frac{\Delta m t}{2} - (1-2\omega)\rho\sin\phi^+_{CP}\sin\Delta m t\}$$

$$\Gamma(\overline{B_s} \to f) = |<f|B_s>|^2 \times e^{-\Gamma t}\{[\rho^2+\omega(1-\rho^2)]\cos^2\frac{\Delta m t}{2} + [1-\omega(1-\rho^2)]\sin^2\frac{\Delta m t}{2} + (1-2\omega)\rho\sin\phi^+_{CP}\sin\Delta m t\}$$

$$\Gamma(B_s \to \overline{f}) = |<f|B_s>|^2 \times e^{-\Gamma t}\{[\rho^2+\omega(1-\rho^2)]\cos^2\frac{\Delta m t}{2} + [1-\omega(1-\rho^2)]\sin^2\frac{\Delta m t}{2} - (1-2\omega)\rho\sin\phi^-_{CP}\sin\Delta m t\}$$

$$\Gamma(\overline{B_s} \to \overline{f}) = |<f|B_s>|^2 \times e^{-\Gamma t}\{[1-\omega(1-\rho^2)]\cos^2\frac{\Delta m t}{2} + [\rho^2+\omega(1-\rho^2)]\sin^2\frac{\Delta m t}{2} + (1-2\omega)\rho\sin\phi^-_{CP}\sin\Delta m t\}$$

Note: $\Delta\Gamma_s$ neglected

$$\rho = \frac{A(B_s \to D_s^+ K^-)}{A(\overline{B_s} \to D_s^+ K^-)} \approx 0.7$$

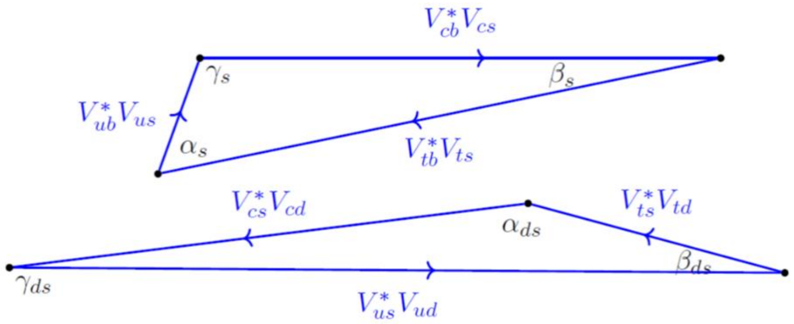
$$\rho(D_s^+\pi^-) = 0$$

ω = *wrong tagging*

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

$$\phi^{\pm}_{CP} = \phi_{CKM} \pm \delta_{strong}$$

$$\phi_{CKM} = \gamma + \gamma_{ds} - 2\beta_s$$



$\gamma_{ds} \approx 0.04°$
$\beta_s \approx 1°$ ($B_s \to J/\psi\,\phi$)

$$\sin^2\phi_{CKM} = \frac{1}{2} \times \{1 + \sin\phi^+_{CP}\sin\phi^-_{CP} \pm \sqrt{(1-\sin{\phi^+_{CP}}^2)(1-\sin{\phi^-_{CP}}^2)}\}$$

2-fold ambiguity

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

➪ well defined CKM angle measured

➪ no direct CP violation expected

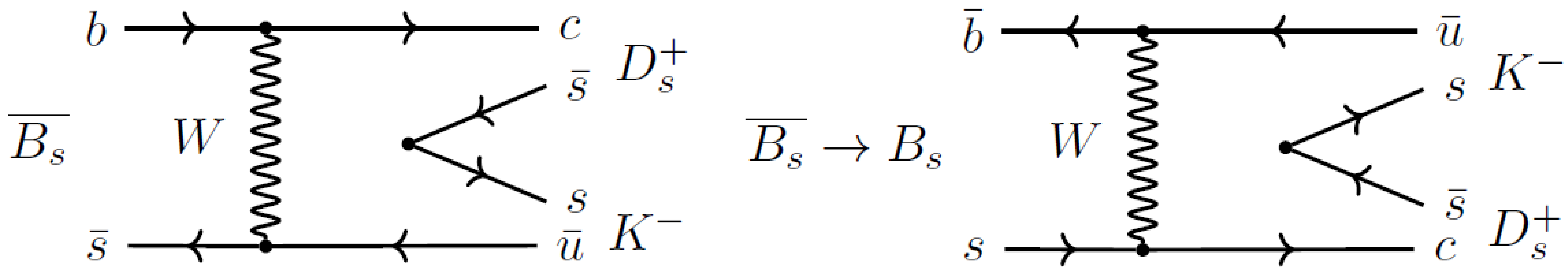


Figure 5: Exchange (sub-dominant) diagrams for $\bar{B}_s \to D_s^+ K^-$

Simulated detector configuration

B= 3.8T

Silicon vertex and tracking detector 2020-10-01 14:56

layer	r (cm)	δ (μm)	x0
1	1.60e+00	3.00e+00	1.50e-03
2	1.80e+00	6.00e+00	1.50e-03
3	3.70e+00	4.00e+00	1.50e-03
4	3.90e+00	4.00e+00	1.50e-03
5	5.80e+00	4.00e+00	1.50e-03
6	6.00e+00	4.00e+00	1.50e-03
7	1.53e+01	7.00e+00	6.50e-03
8	3.00e+01	7.00e+00	6.50e-03

Silicon outter detector

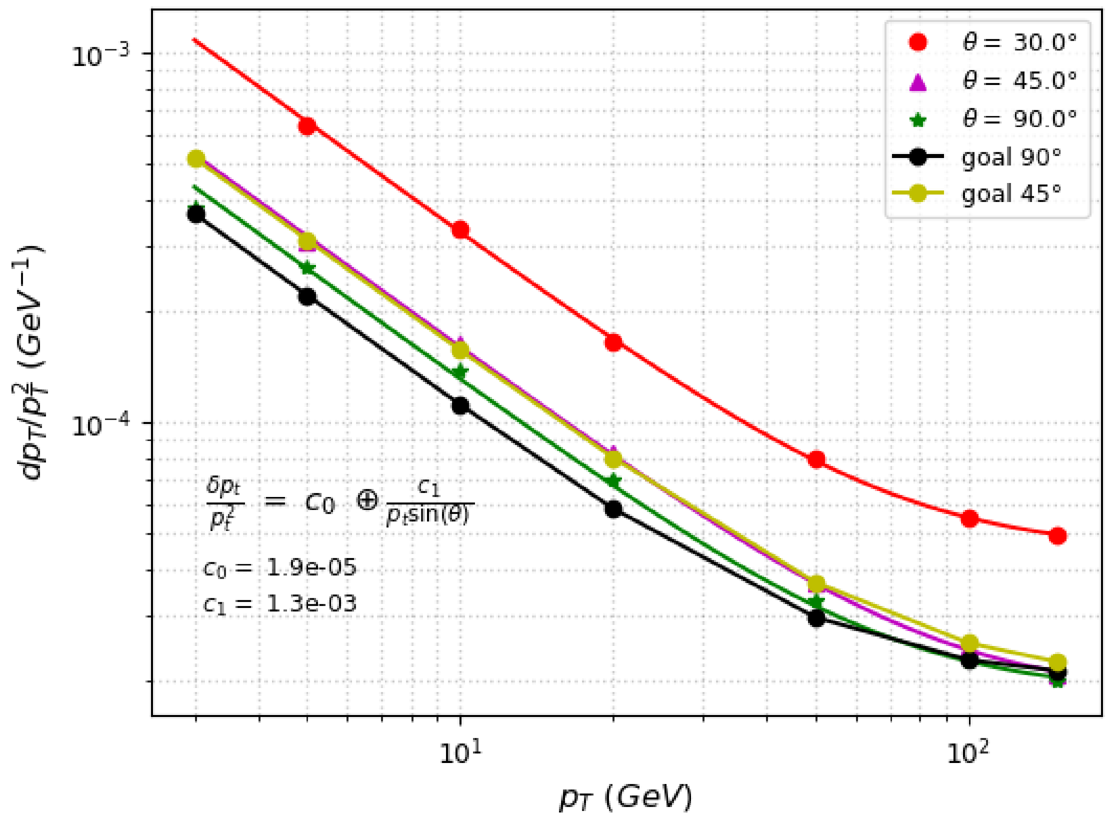
layer	r (cm)	δ (μm)	x0
1	1.81e+02	7.00e+00	1.00e-02

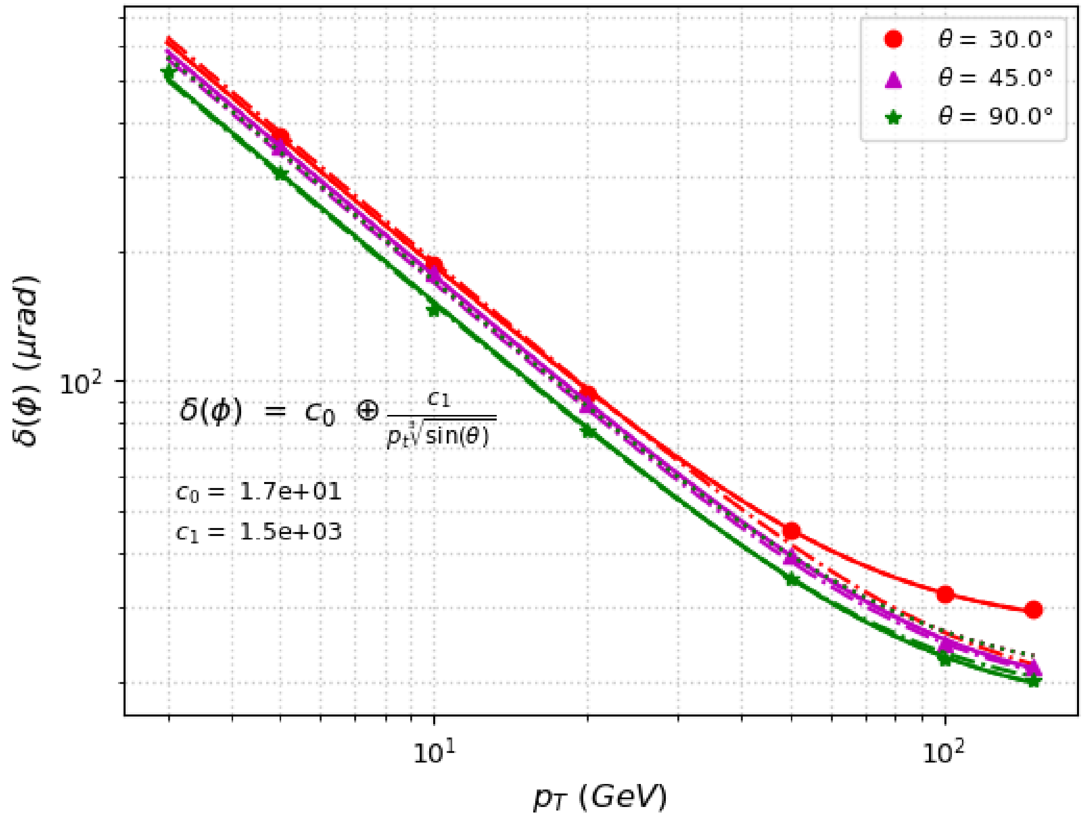
TPC detector

layer	r (cm)	δ (μm)	x0
1	4.00e+01	1.00e+02	5.95e-05
...	4.07e+01	1.00e+02	5.95e-05
200	1.80e+02	1.00e+02	5.95e-05

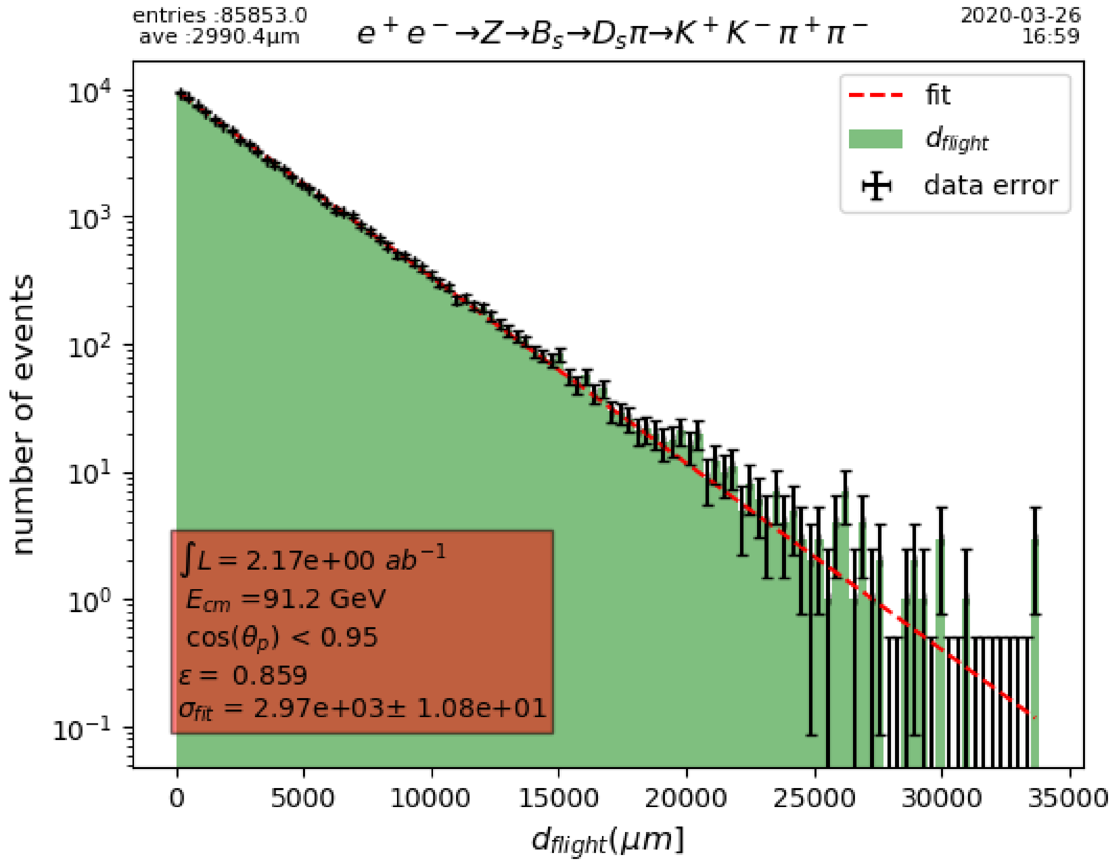
Detector resolutions

ILD type detector (6 vertex Si layers + 2 Inner Si layers + TPC + 1 outer Si layer)

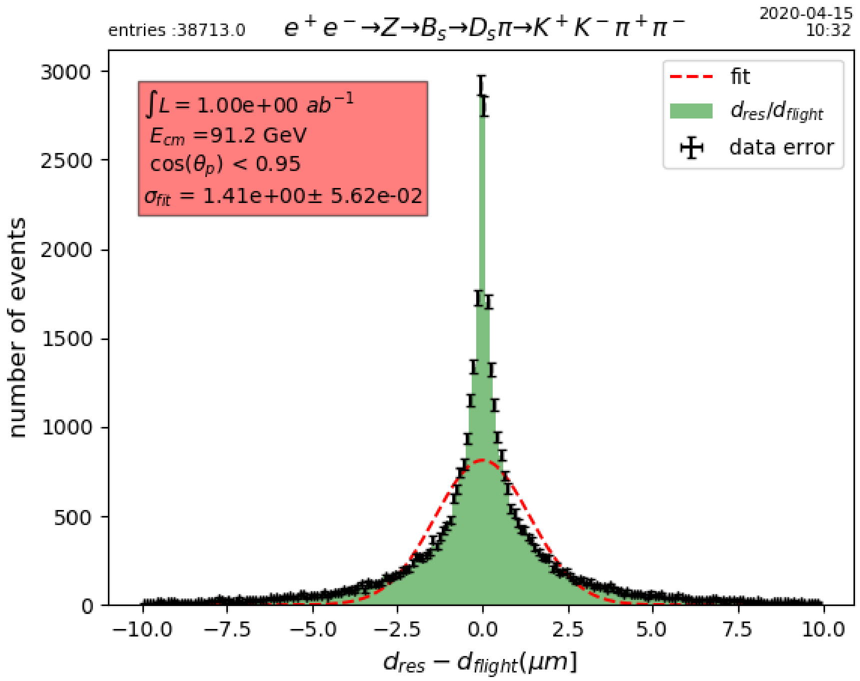




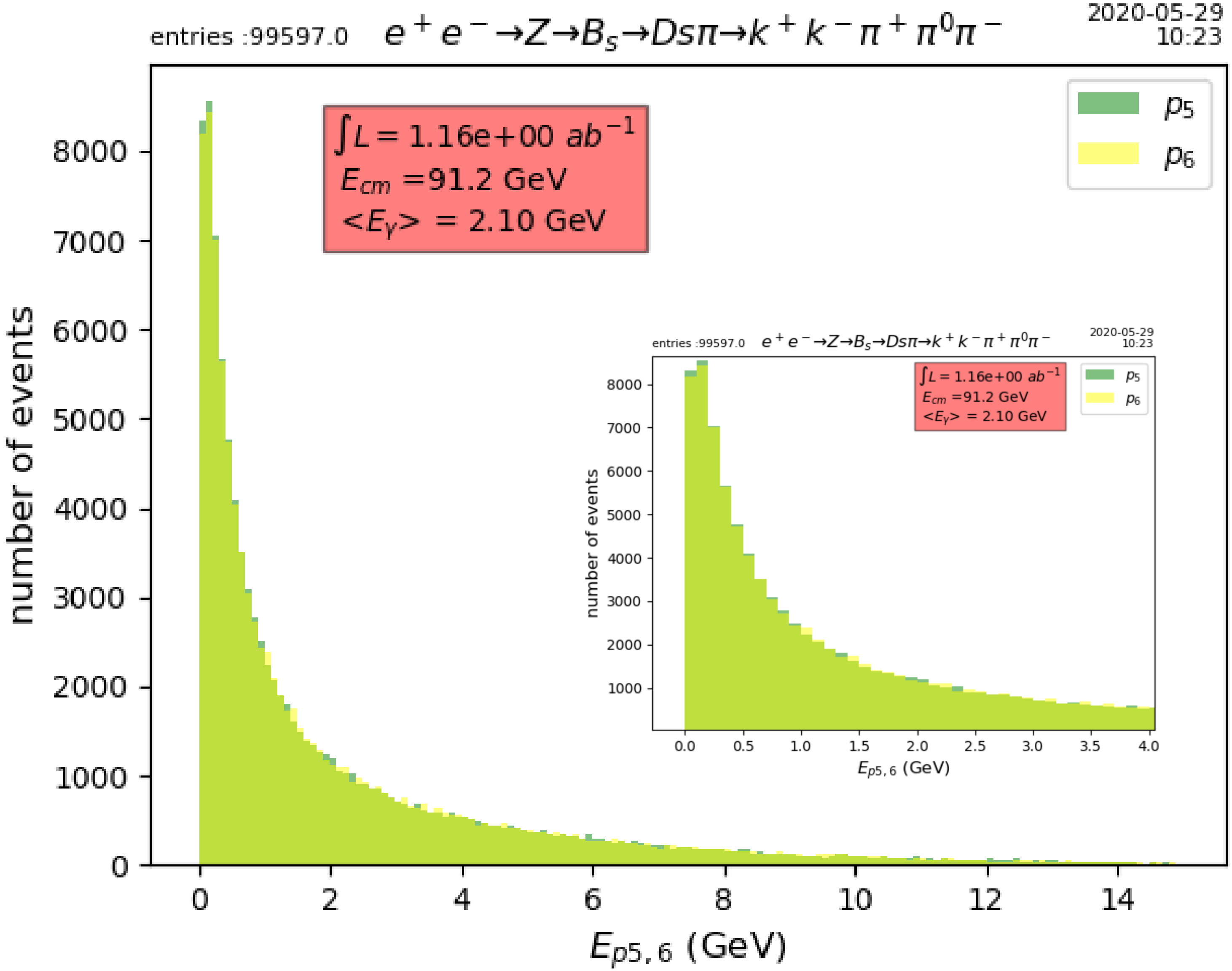
< B flight distance > ≈ 3000 μm

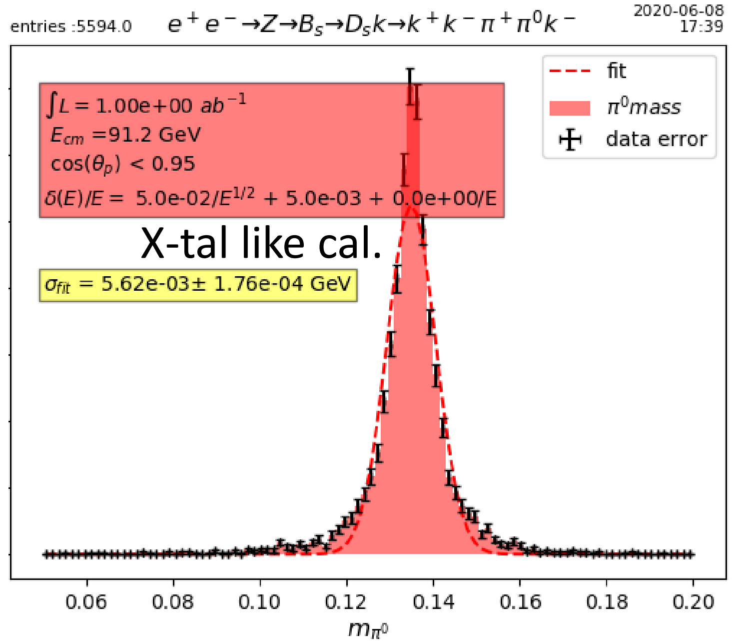


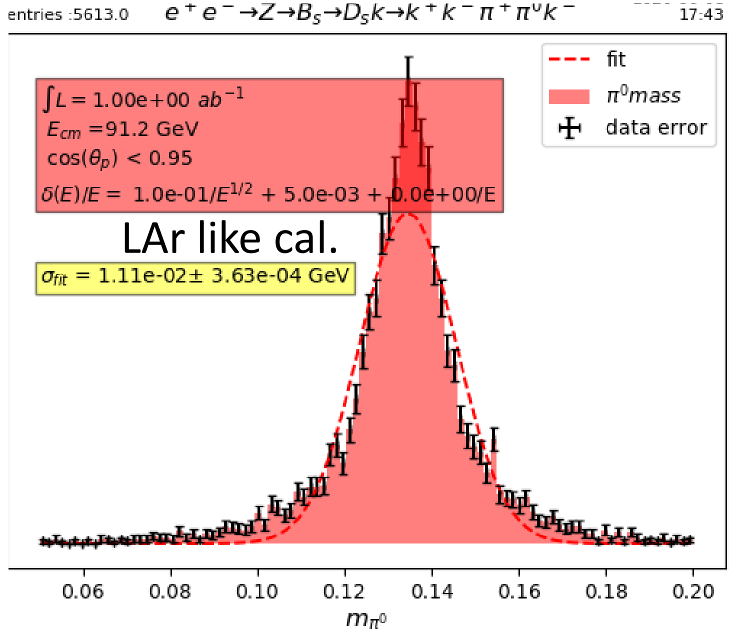
B Flight distance error due to error on B momentum measurement



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



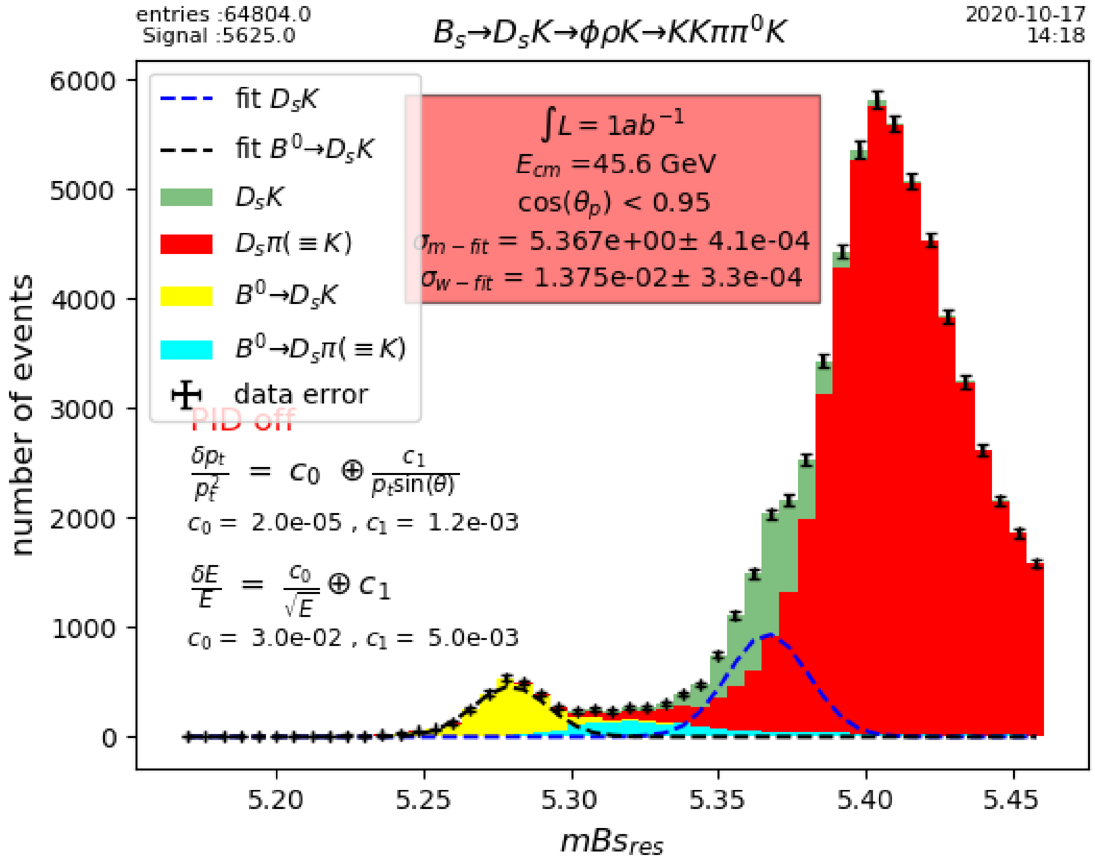




Inclusion of neutrals for $B_s \to D_s K$ reconstruction (NO PID)

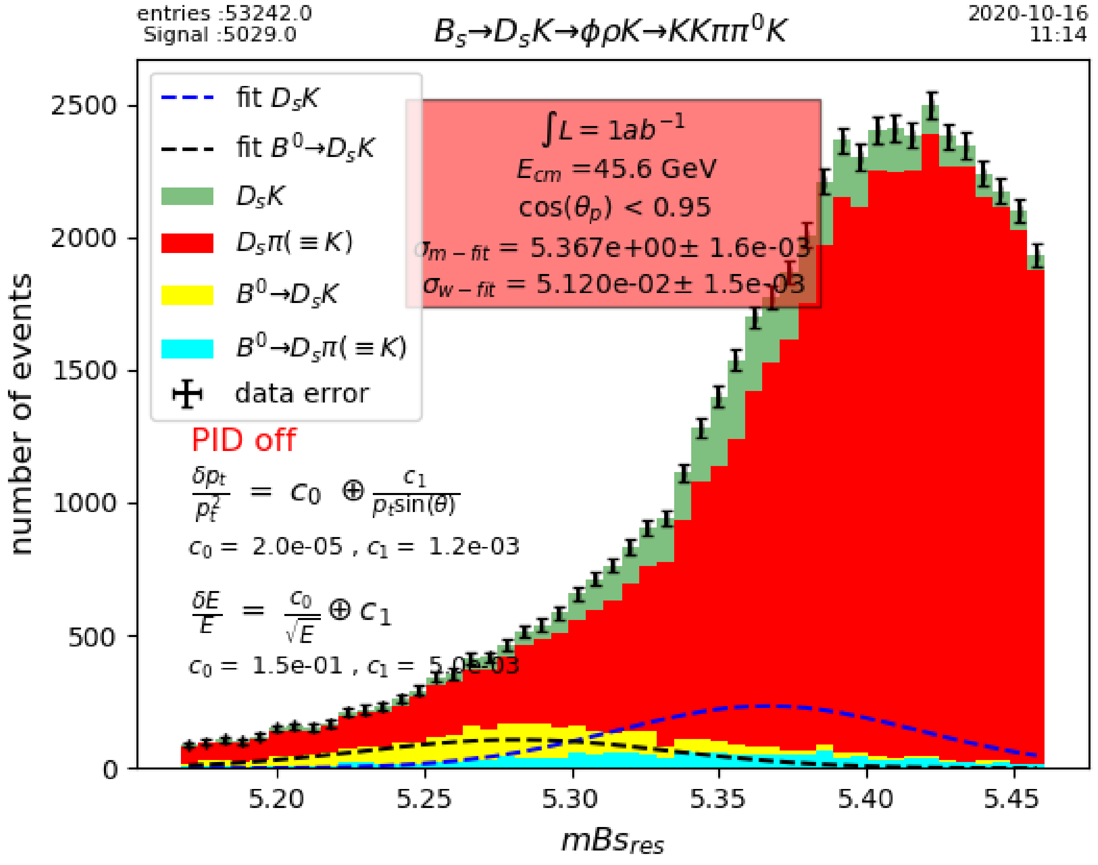
Assuming excellent Xtal like calorimeter with

$$\frac{\delta E}{E} = \frac{0.03}{\sqrt{E}} \oplus 0.005$$



Assuming excellent Xtal like calorimeter with

$$\frac{\delta E}{E} = \frac{0.15}{\sqrt{E}} \oplus 0.005$$

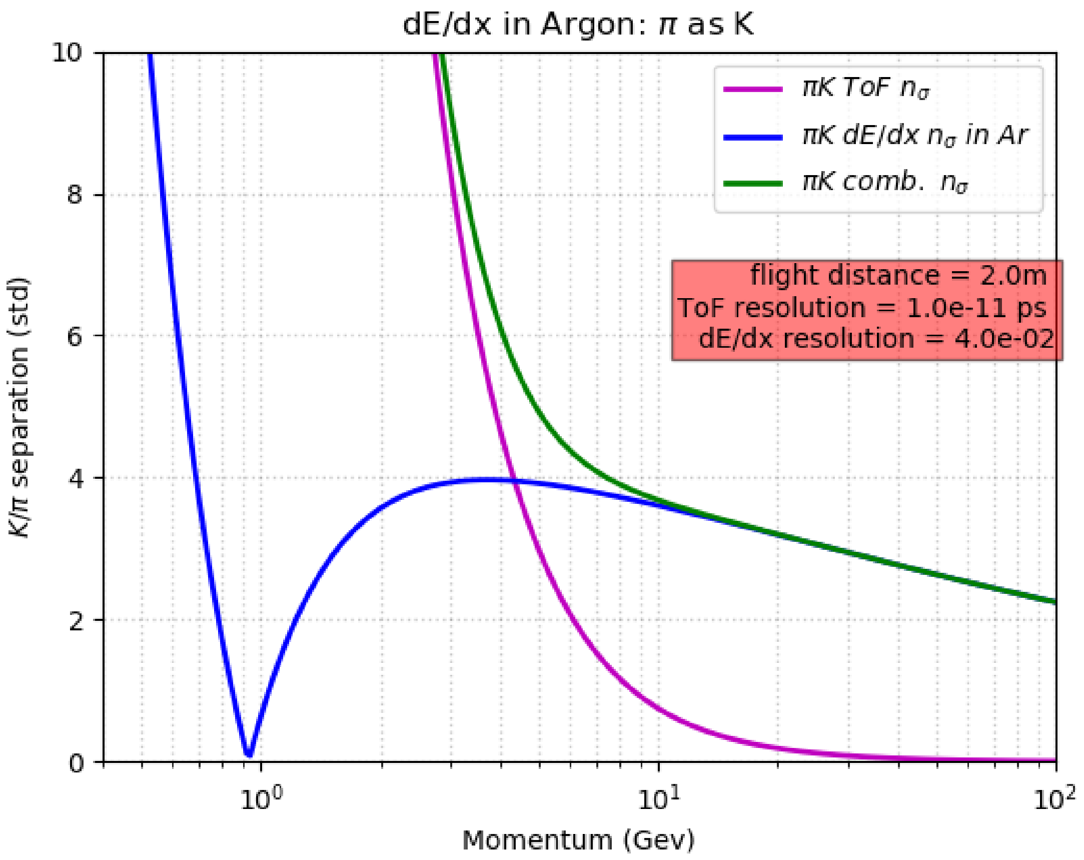


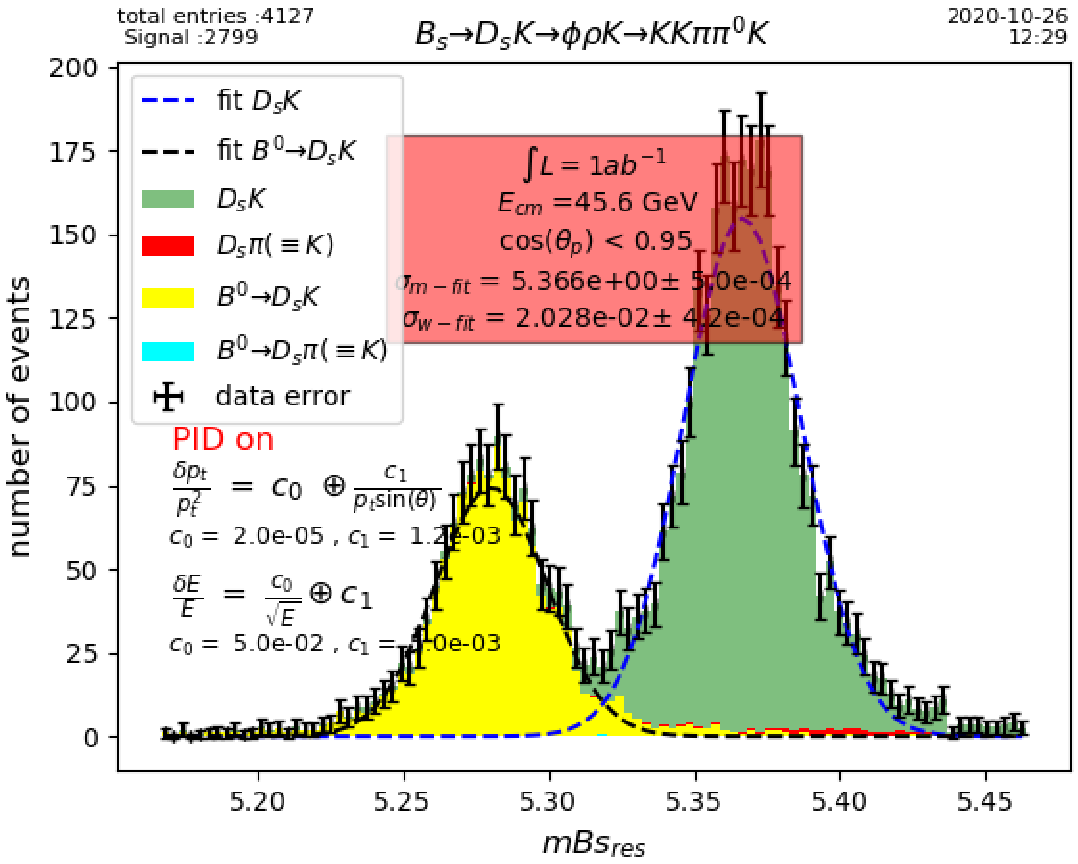
Inclusion of « improved » dE/dx and ToF

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

Resolution $\sigma(ToF) = 10ps$

Detector location : 2m from IP





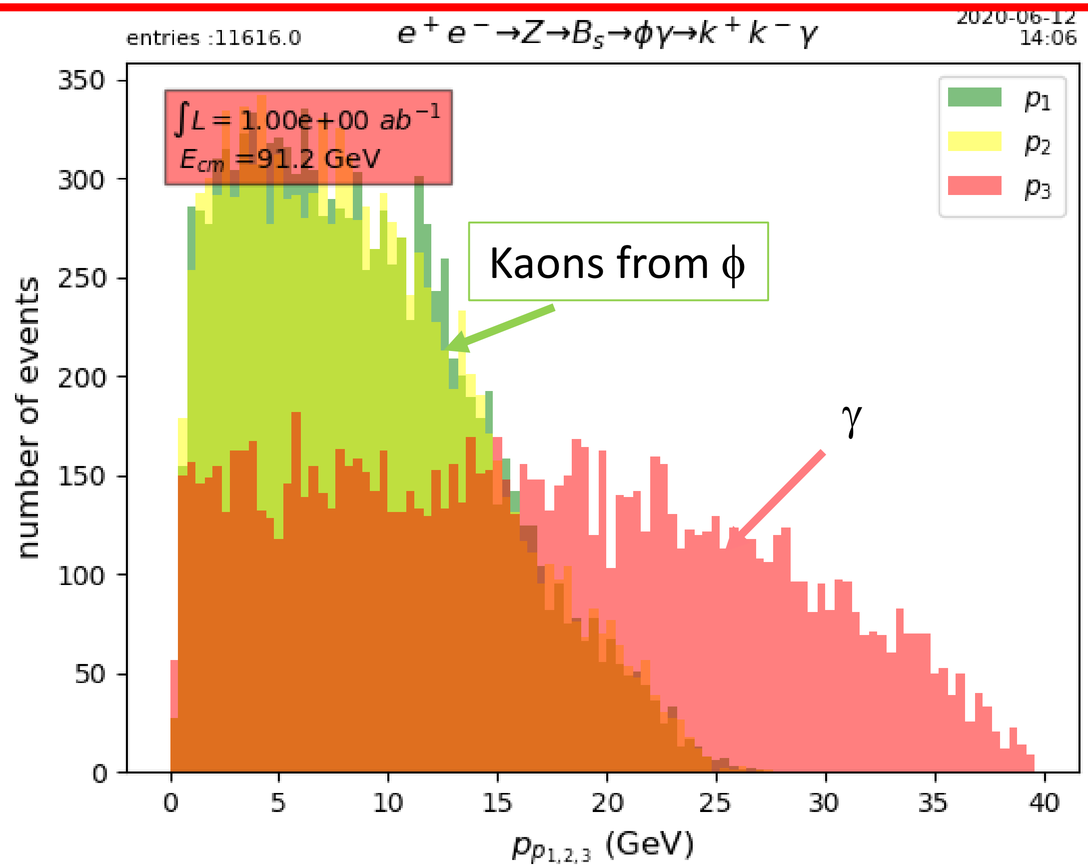
Study of CP violation with $B_s \to \phi\gamma$

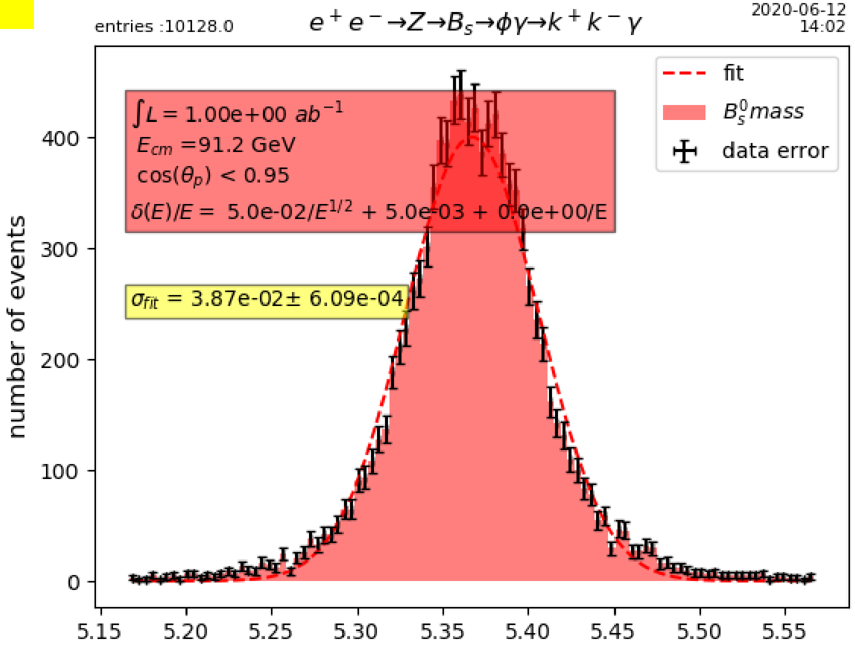
Same as $\boldsymbol{B_s \to \phi\phi}$ $\phi_{CKM} \approx 0°$ $Br(B_s \to \phi\gamma) = 3.4 \times 10^{-5}$

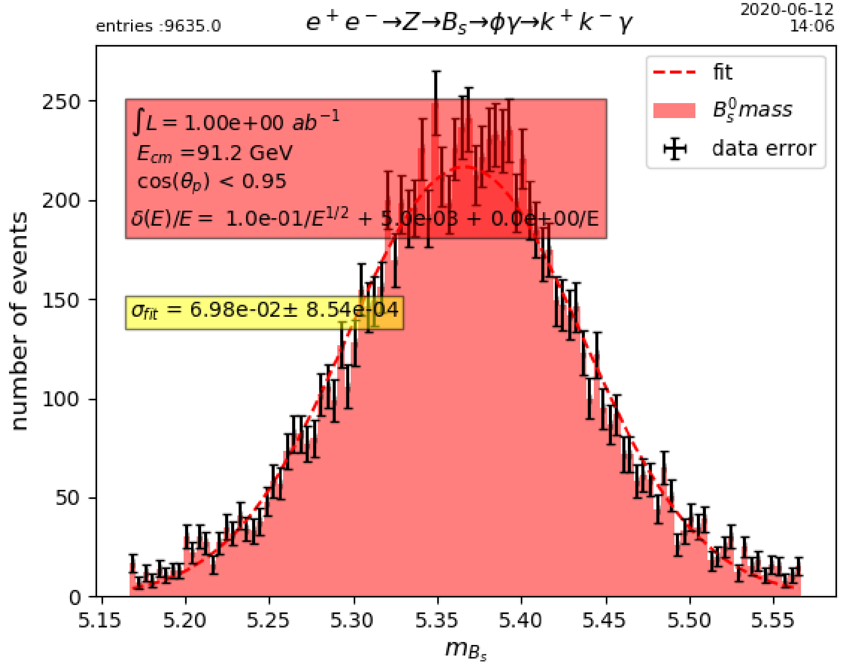
⇨ Very good for probing BSM $\cong 1.7 \times 10^{6}$ *events with* $150\ ab^{-1}$

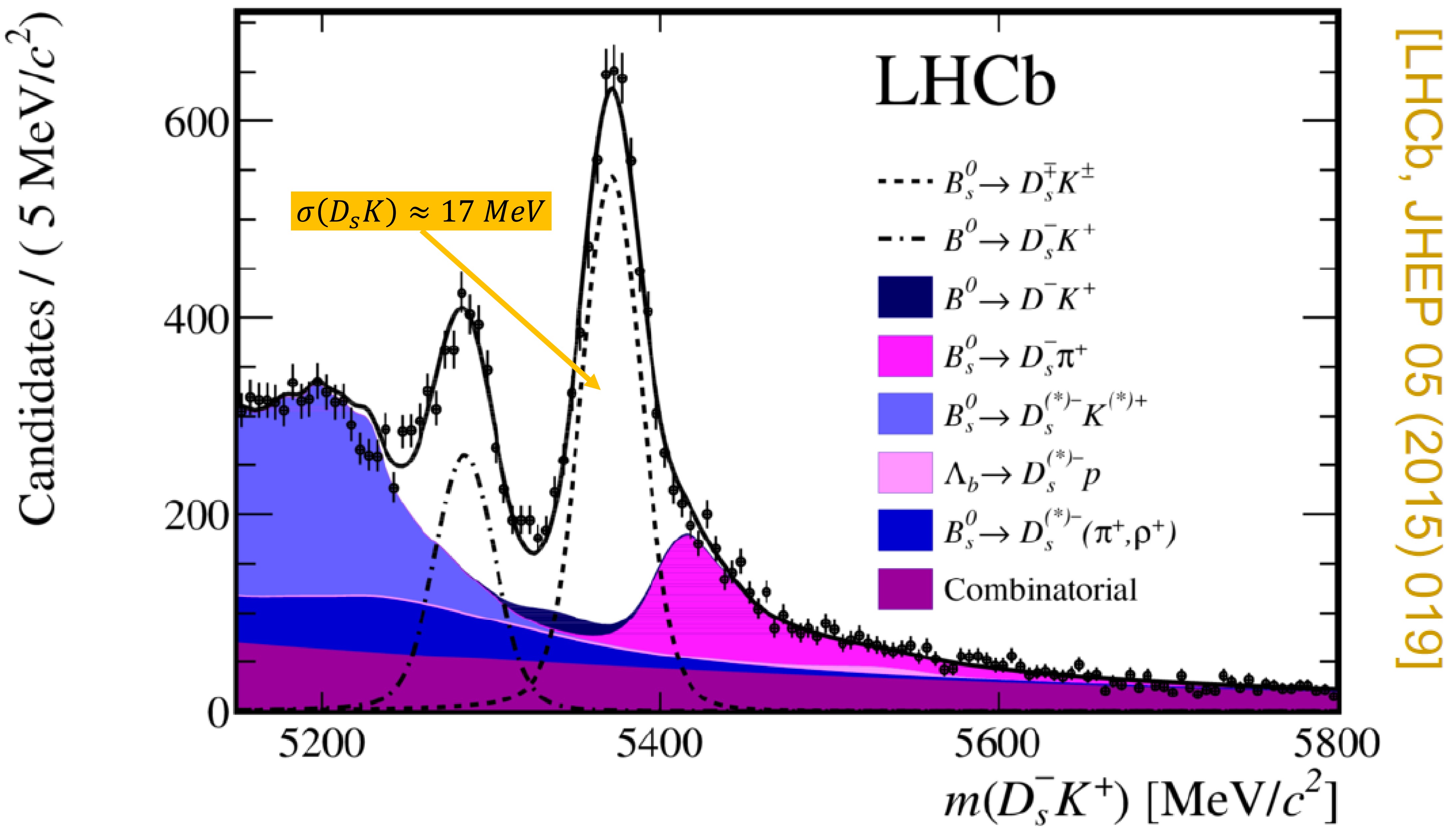
2 main issues requiring dedicated study

- Study of background as mass resolution is poor
  - $\sigma(m_{Bs}) \approx 39\ MeV$ with Xtal like calo.
  - $\sigma(m_{Bs}) \approx 70\ MeV$ with Lar like calo.
- Study of vertex resolution as ϕ is strongly boosted ($\sigma > 400\mu m$!)









Candidates / (5 MeV/c^2)
0
200
400
600
5200
5400
5600
5800
$m(D_s^- K^+)$ [MeV/c^2]
LHCb
$\sigma(D_s K) \approx 17\ MeV$
$B_s^0 \to D_s^{\mp} K^{\pm}$
$B^0 \to D_s^- K^+$
$B^0 \to D^- K^+$
$B_s^0 \to D_s^- \pi^+$
$B_s^0 \to D_s^{(*)-} K^{(*)+}$
$\Lambda_b \to D_s^{(*)-} p$
$B_s^0 \to D_s^{(*)-} (\pi^+, \rho^+)$
Combinatorial
[LHCb, JHEP 05 (2015) 019]

(Side comment) Can one measure Neutrino flavor directly ?

With 150 ab^{-1} at Z-pole, 2.4 10^{12} neutrinos (all species) are produced.

Unfortunately, the cross section for $E_{\nu} = 45\ GeV$ is low , ~0.3 pb

With 1 X_0 in the tracking area (much more than any reasonnable tracker), only ~3 interactions expected !

⇨ A dedicated detector with some 100 X_0 would be needed

Motivation : Complementing tests of lepton universality

$$\Delta_W^{\tau/\ell} = BR(W \to \tau\nu) - BR(W \to \ell\nu) = 0.00711 \pm 0.00237 \qquad (PDG: \approx 3\sigma) \qquad (\ell = e, \mu)$$

$$R_{D*}^{\tau/\ell} = \frac{BR(B \to D^*\tau\nu)_{exp}/BR(B \to D^*\tau\nu)_{SM}}{BR(B \to D^*\ell\nu)_{exp}/BR(B \to D^*\ell\nu)_{SM}} = 1.28 \pm 0.08 \qquad (3.8\ \sigma)$$

$$R_D^{\tau/\ell} = \frac{BR(B \to D\tau\nu)_{exp}/BR(B \to D\tau\nu)_{SM}}{BR(B \to D\ell\nu)_{exp}/BR(B \to D\ell\nu)_{SM}} = 1.37 \pm 0.18 \qquad (2.0\ \sigma)$$

$$R_K^{\mu/e} = \frac{BR(B \to K\mu^+\mu^-)_{exp}}{BR(B \to Ke^+e^-)_{exp}} = 0.745 \pm 0.080 \pm 0.036 \qquad (2.6\ \sigma)$$

$$= 0.846\ ^{+0.060}_{-0.054}\ ^{+0.016}_{-0.014}(syst) \qquad (2.5\sigma, LHCb)$$