Charm spectroscopy with PandaRoot:
Reconstruction of DsJ mesons
(The Good, the Bad, the Ugly...)

E. Prencipe

PANDA Meeting - Bochum, 12-09-2013

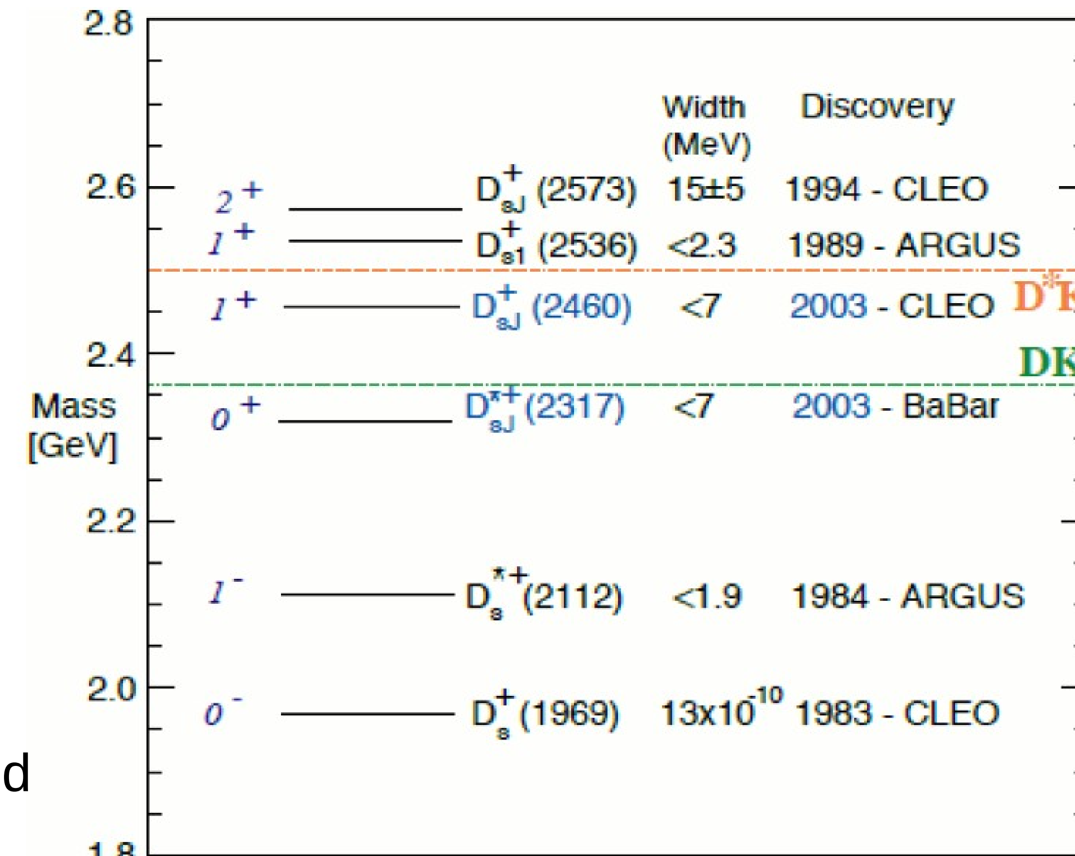
Outline

- Motivation
- Technical aspects
- First tests
- Status of this analysis – trunk 21003
- Summary

PHYSICS MOTIVATION

Introduction

- D_{sJ} are ($c\bar{s}$) mesons: *s* content, **J**=0,1
- $D_{s0}(2317)^+$ discovered by BaBar
  PRL 90 242001 (2003)
- Not understood its nature:
  100 MeV lower than the predicted mass by potential model
- Very thin width
- Observed in $D^{(*)+}\pi^0$ system ⇒
  isospin violating
- Other similar states found
- $D_{s1}(2460)^+$ close to the D*K threshold

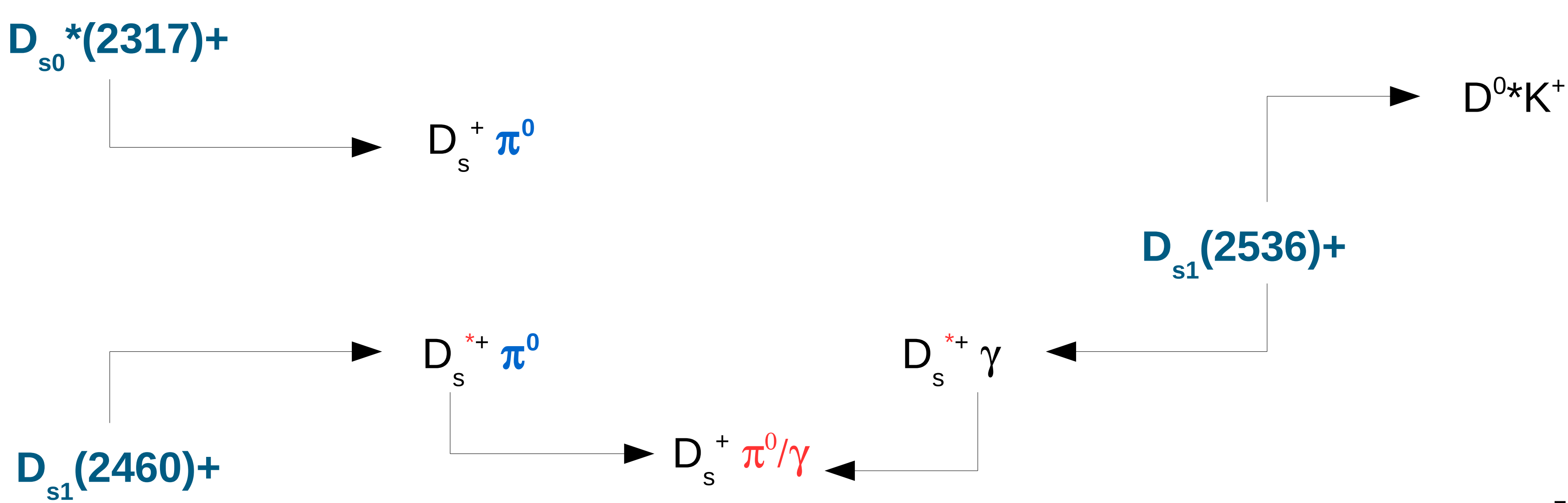


- Width of these states: only UL due to experimental limitations
- PANDA can reach mass resolution >20 times higher than the previous projects; expected high precision
- Depending on the width, several interpretations:
  pure $c\bar{c}$, tetraquark, DK molecule...

Analysis proposal in PANDA

JÜLICH FORSCHUNGSZENTRUM

- Study of the mixing of $D_{s1}(2536)^{+}$ and $D_{s1}(2460)+$
- Study of chiral symmetry breaking
- Study of the excitation function of the cross section in $p\bar{p} \rightarrow D_s^- D_{sJ}^+$



Excitation function of the cross section

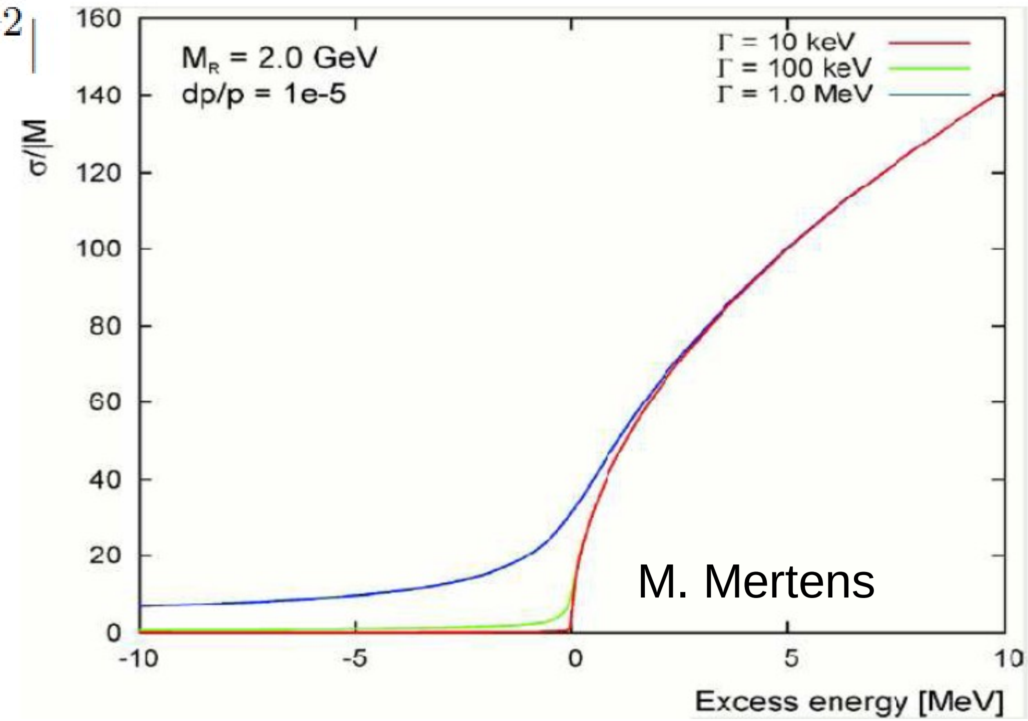
$$\sigma(\lambda) = \sqrt{m_R\Gamma}|M^2|\frac{1}{\pi}\int_{-\infty}^{\lambda} \mathrm{d}x, \frac{\sqrt{\lambda - x}}{x^2+1}$$

$$\sigma(0) = \sqrt{\frac{m_R\Gamma}{2}}|M^2|$$

$$\lambda = (\sqrt{s} - 2M_R)/\Gamma$$

M = proton mass

M_R = mass of D_{sJ}



A precise measurement of the cross section gives a precise determination of the Γ

Expectation in PANDA

Expected number of events in PANDA= $\mathscr{L} * \sigma * \varepsilon$

Cross section: http://arxiv.org/abs/1111.3798 A. Khodjamirian, Ch. Klein, Th. Mannel, Y.M. Wang
20 $\div$ 200 nb

Luminosity = 2 * 10^{32} cm^{-2} s^{-1}
8.64 pb^{-1}/day

N expected = 8.64 pb^{-1}/day * (20$\div$200)nb * ε ~ (160k $\div$2M) * **ε**/day

NB. In high resolution mode: we expect a factor 10 less

TECHNICAL ASPECT

Getting started with PandaRoot...

- Operative system: FEDORA 19
- Root version: 5.34
- Trunk version in pandaroot: **rev-21003** + /rho/ update
- PID algorithm: PidAlgoMvd, PidAlgoStt, PidAlgoDrc, PidEmcBayes
- Analysis package: ***/rho/***

Main problems found: photon reconstruction, low mom. tracking

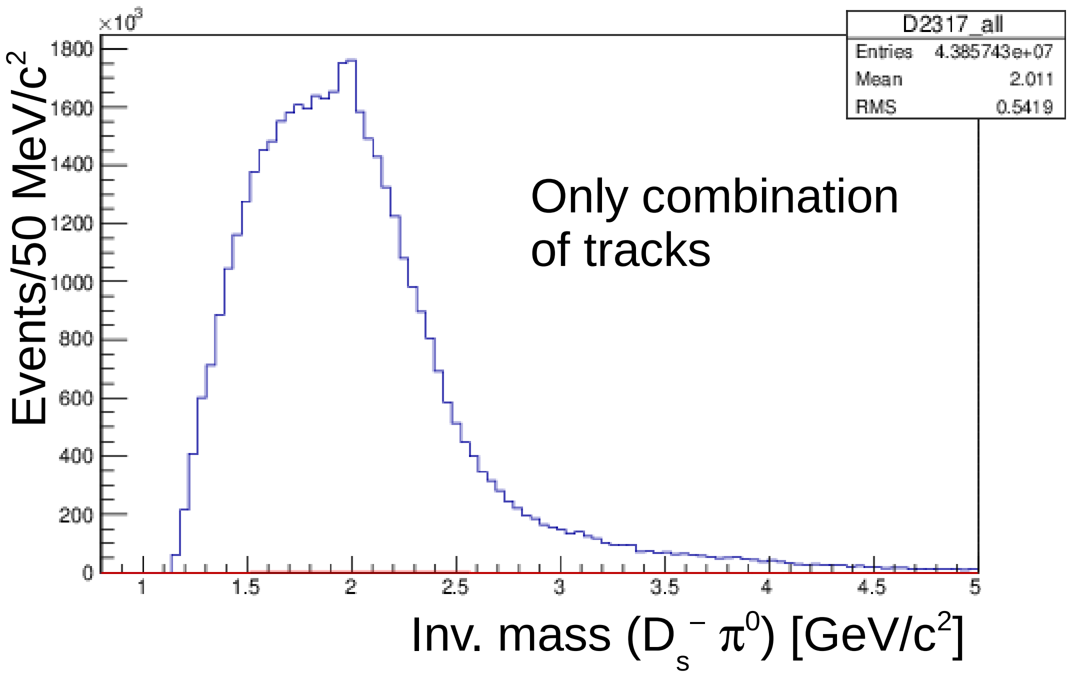
The analysis will be shown for the simulations of $D'_{s1}(2536)^+$, $D_{s0}^*(2317)^+$, $D_{s1}(2460)^+$

$D_{s1}(2460)^+$ → 3-4 photons

$D'_{s1}(2536)^+$ → only 1 photon

$D_{s0}^*(2317)^+$ → 2 photons

$D_{s0}^{*}(2317)^{+}$



Momentum = 8.85 GeV

Test: 5000 generated events

Huge bkg due to low momentum photons

⇒ fix properly a π^0 mass window

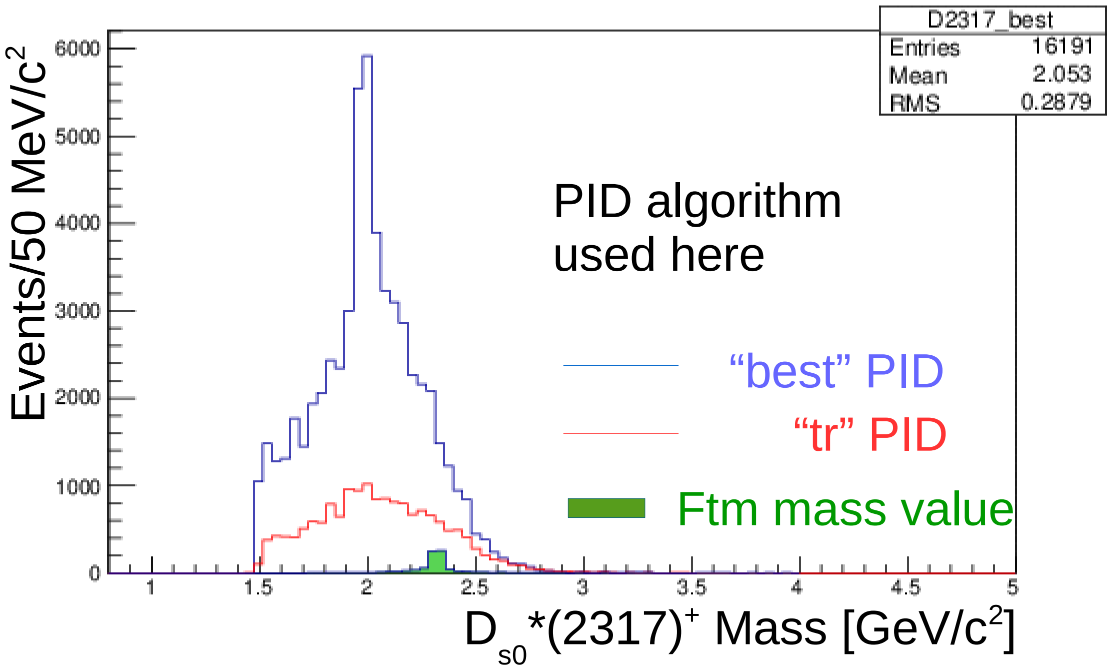
⇒ fix properly a γ energy cut

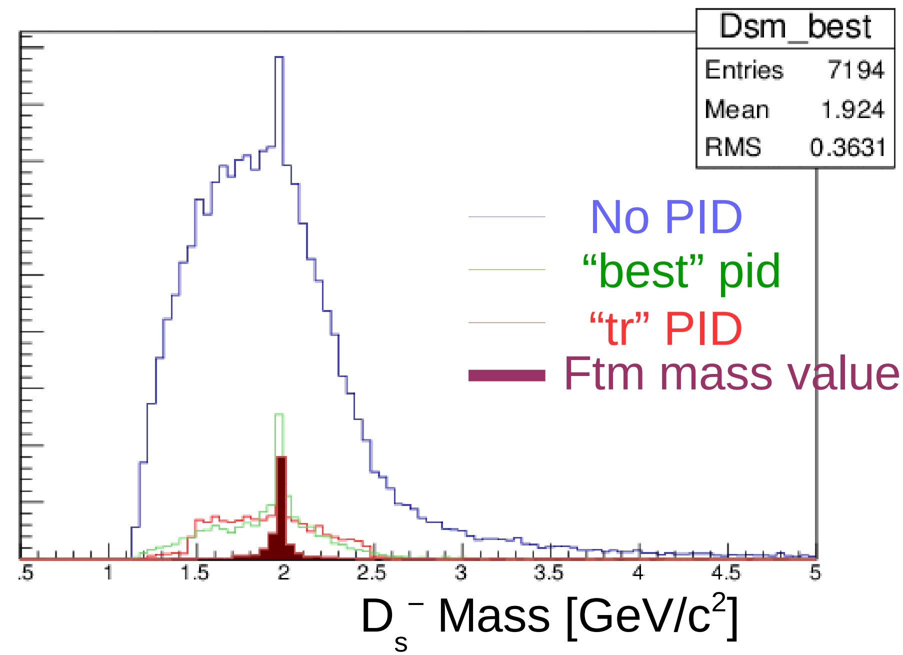
⇒ N_{MAX} photons/event < 50

```
noPhotos
#
Decay pbarpSystem
1.0 D_s0*+    D_s-           PHSP;
Enddecay
#
Decay D_s0*+
  1.0   D_s+  pi0            PHSP;
Enddecay
#
Decay D_s+
  1.0  K- K+ pi+          DS_DALITZ;
Enddecay
Decay D_s-
  1.0  K+ K- pi-          DS_DALITZ;
Enddecay
#
Decay pi0
  1.0  gamma gamma          PHSP;
Enddecay
End
```

$D_{s0}^*(2317)^+$

$p\bar{p} \rightarrow D_s^- \, D_{s0}^*(2317)^+$





Requirements:
Inv mass 2γ in ±100 MeV/c^2
P_{MIN} (π^0)>150 MeV/c
N_{MAX} photons/event < 50

D_s^- PDG mass = 1.9867 GeV/c^2
$D_{s0}^*(2317)^+$ PDG mass = 2.317 GeV/c^2

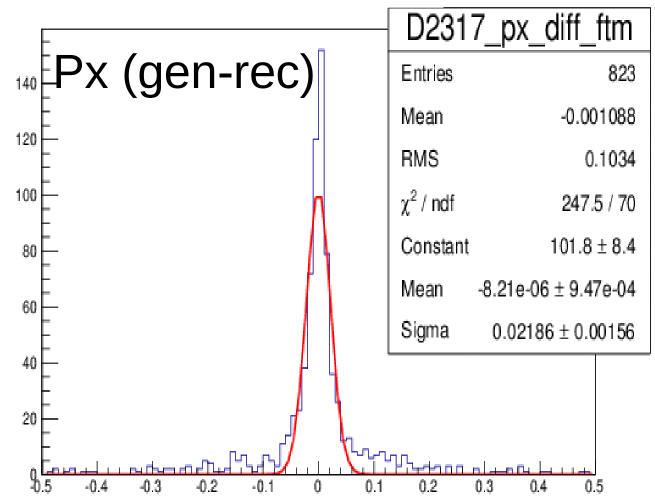
PID algorithm: likelihood
Kaon(3), pion(2)

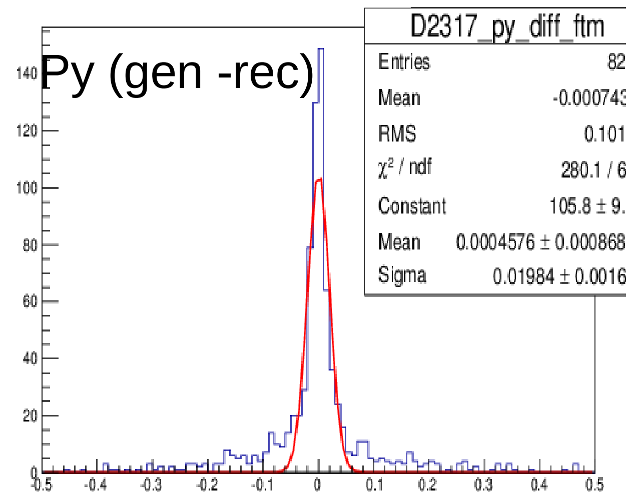
MVD: de/dx vs p
STT: p, de/dx
DRC: θ Cherencov vs p
EMC: E/p, LAT, Z53
GEANE request: p>100 MeV/c

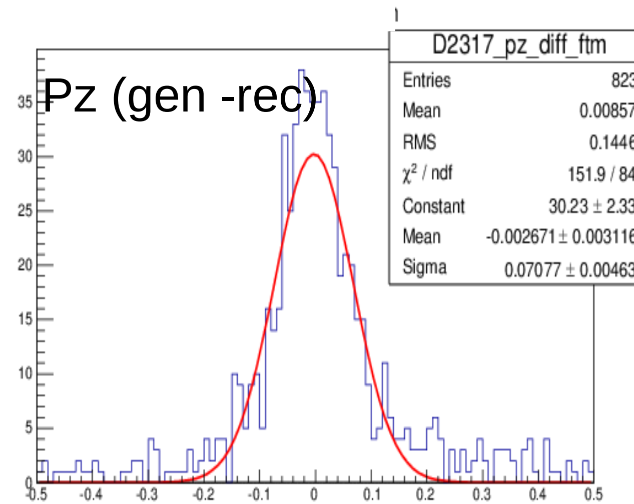
$D_{s0}^{*}(2317)^{+}$

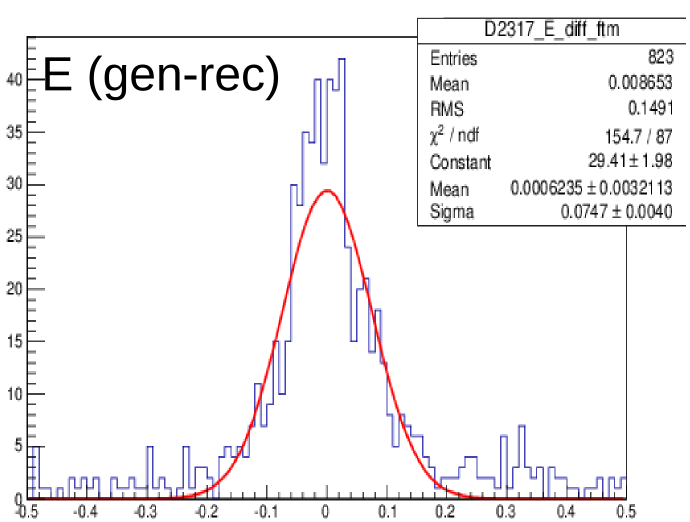
JÜLICH FORSCHUNGSZENTRUM

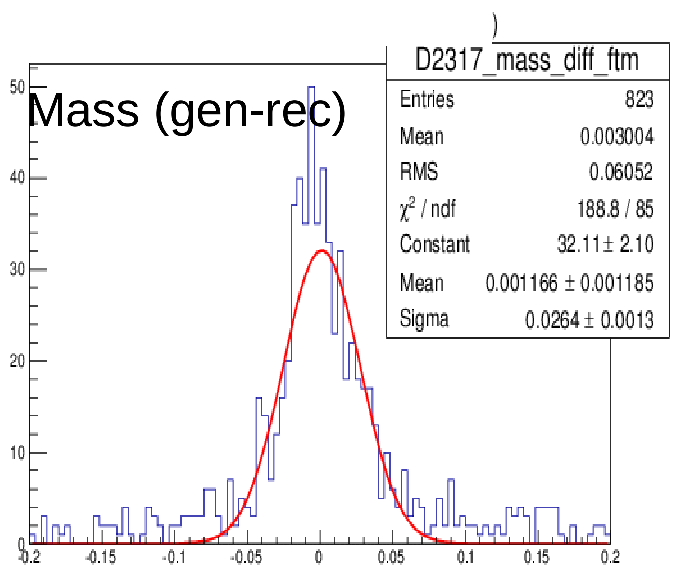
D_{s0}*(2317)$^{+}$ BEFORE ANY MASS FIT:











D_{s0}*(2317)$^{+}$ mass resolution:

Before mass fit: 26 MeV

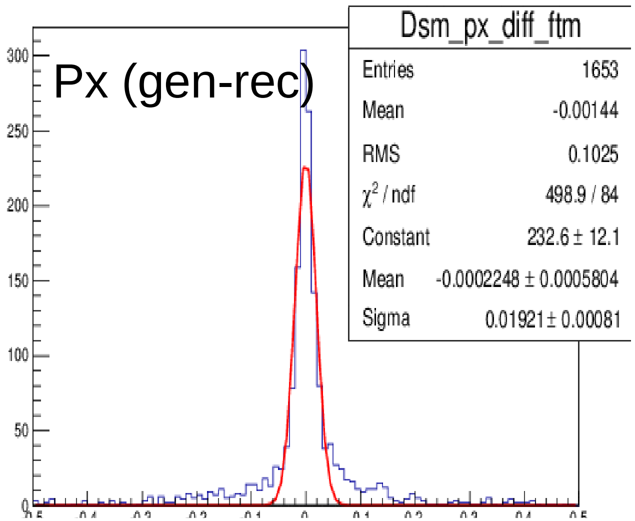
After vertex fit: 20 MeV

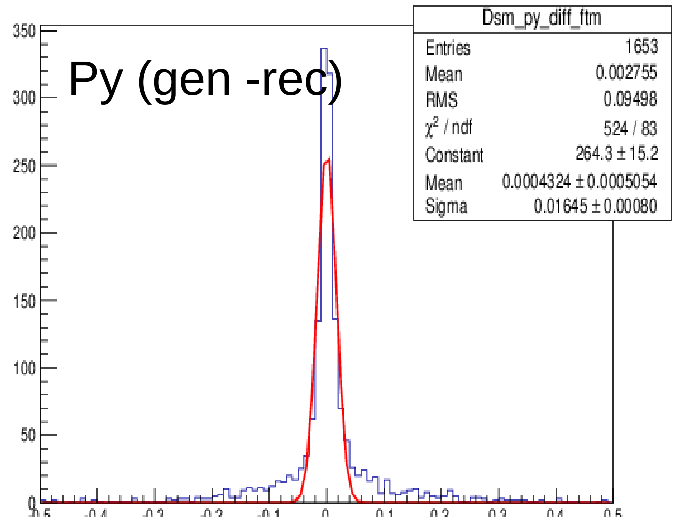
After mass fit: 17 MeV

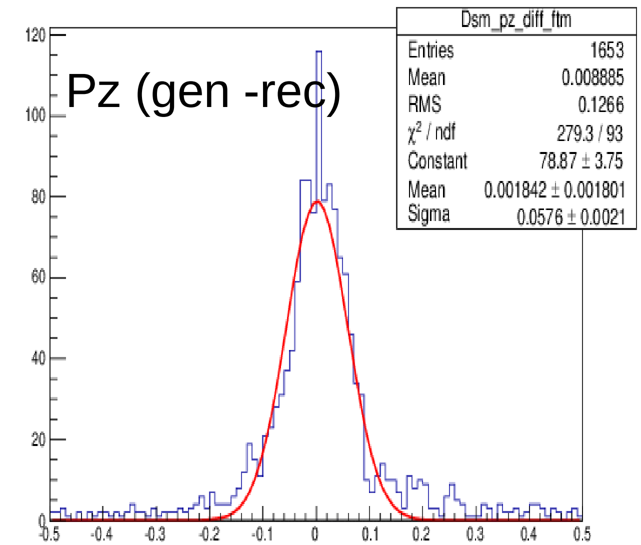
Efficiency: **~16%**

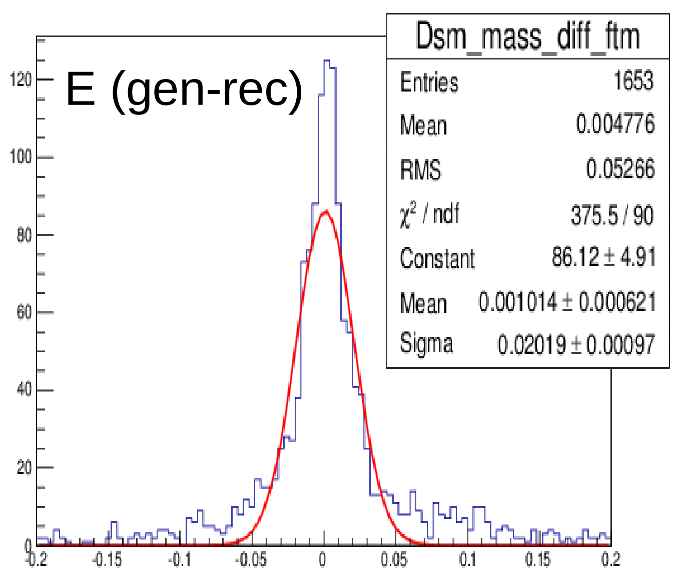
D_s^-

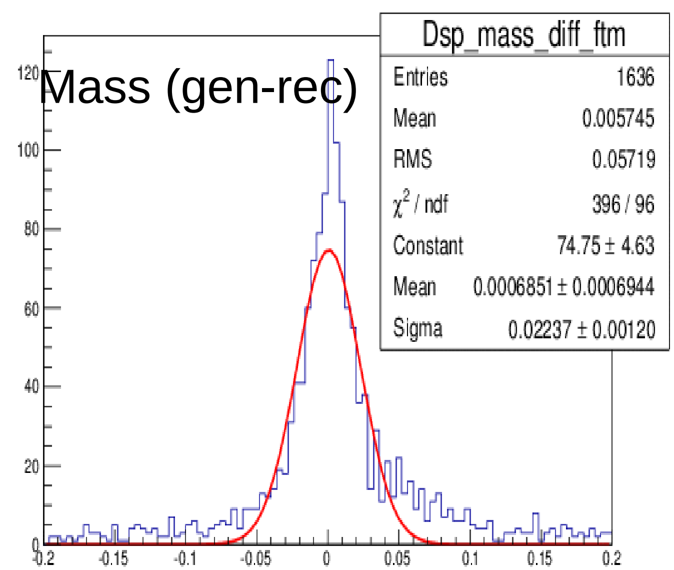
D_s^- BEFORE ANY MASS FIT:











D_s^- mass resolution:

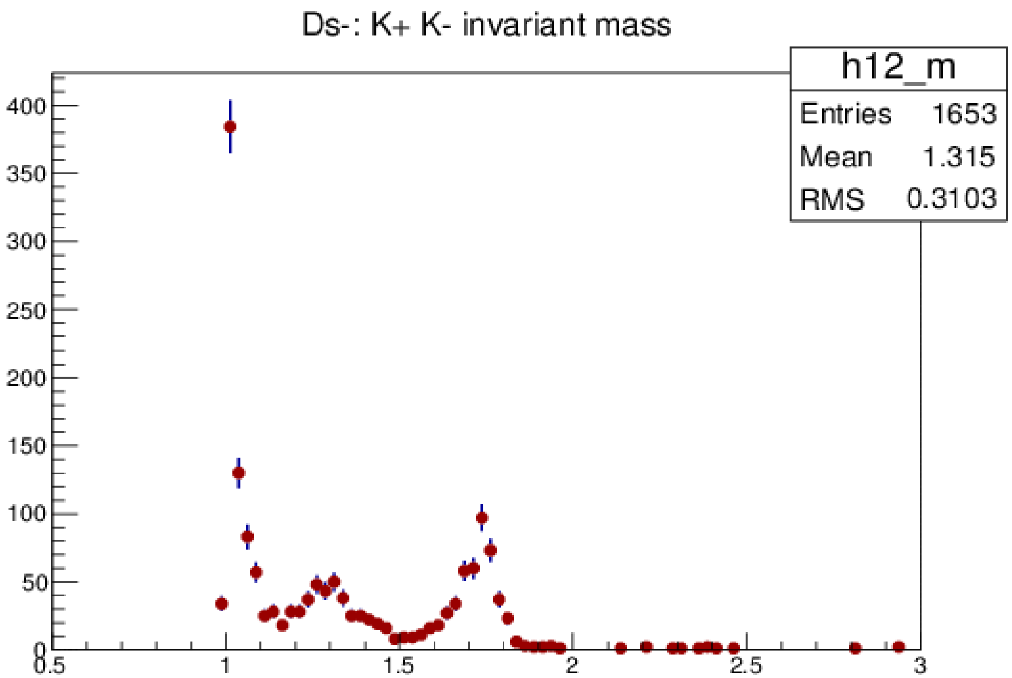
Before mass fit: 22 MeV

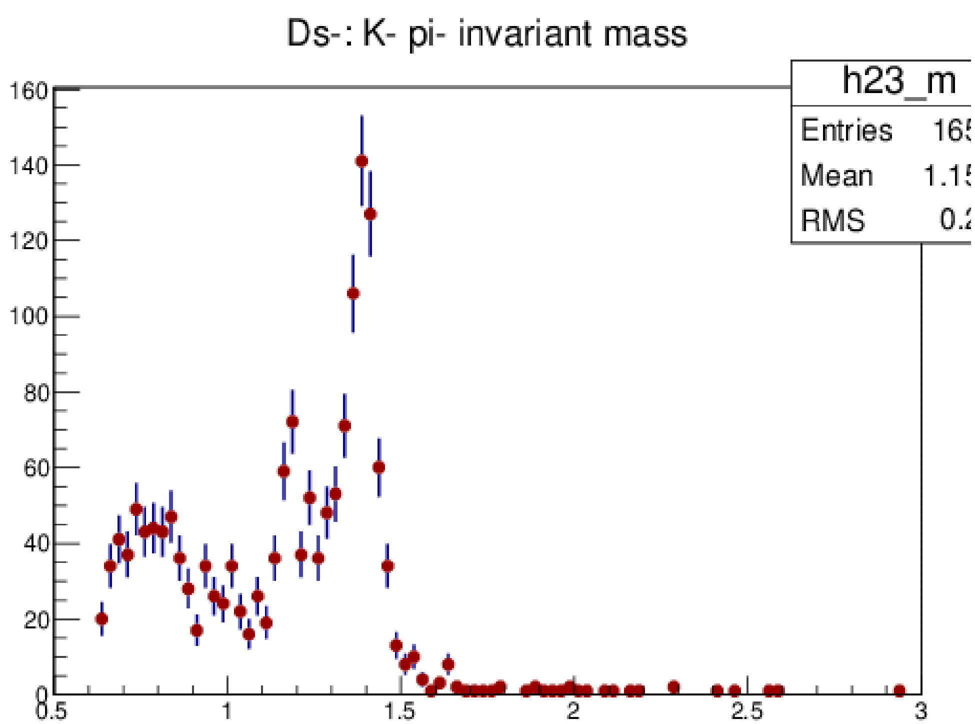
After vertex fit: 18 MeV

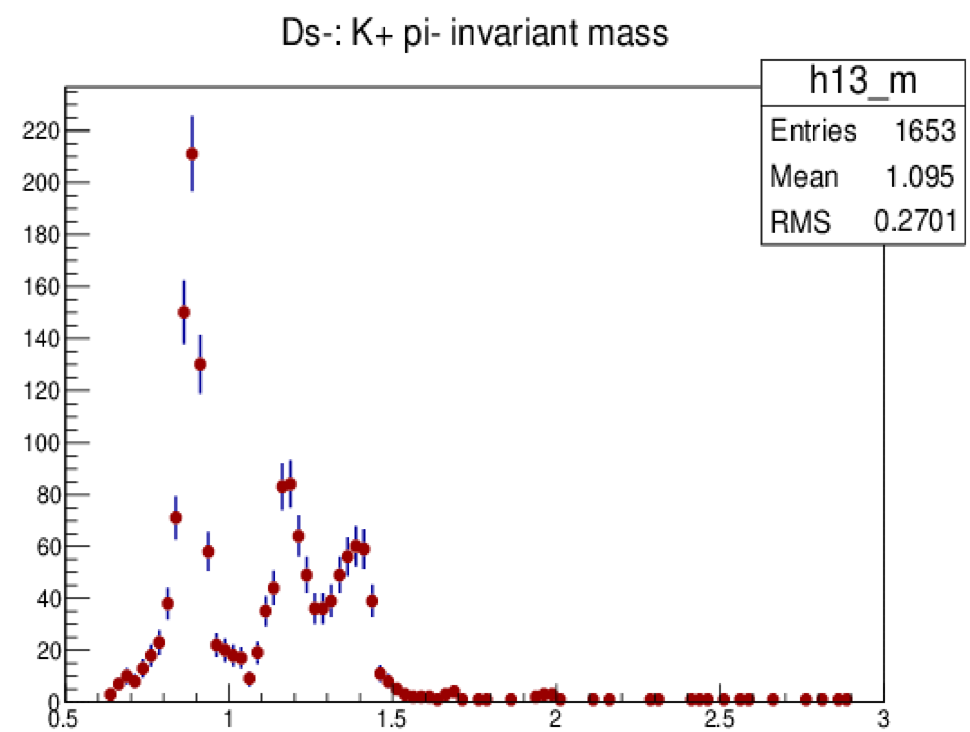
After mass fit: 11 MeV

Efficiency: **33%**

Ds- from Dalitz



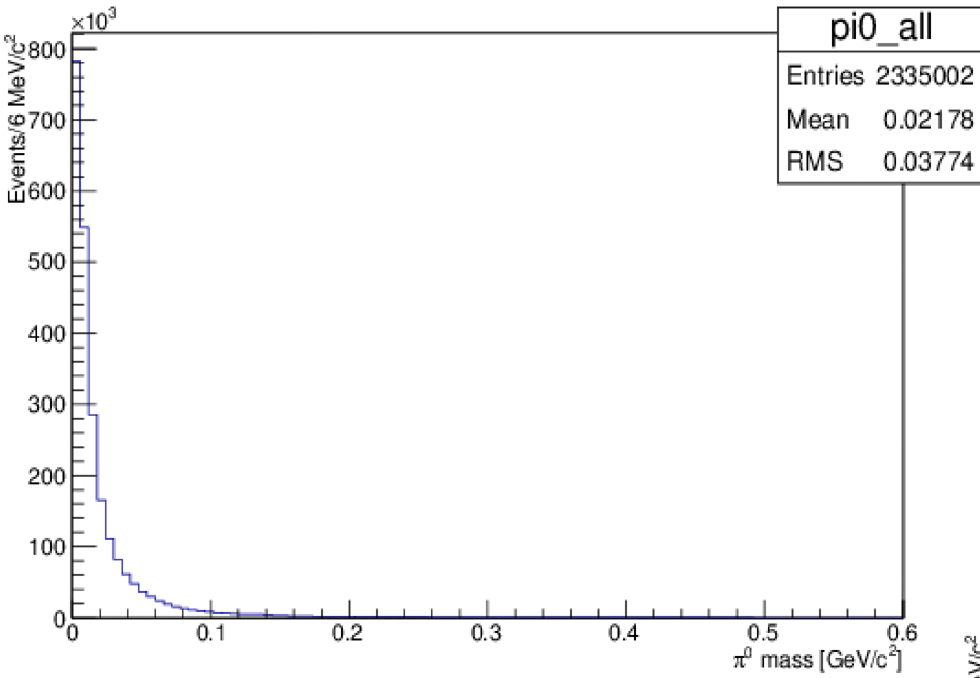




$D_{s0}^*(2317)^+ \to D_s^+ \pi^0$

$D_s^+ \to K^+ K^- \pi^+$

$\pi^0 \to \gamma\gamma$



Combination of 2 photons only
No selection done here

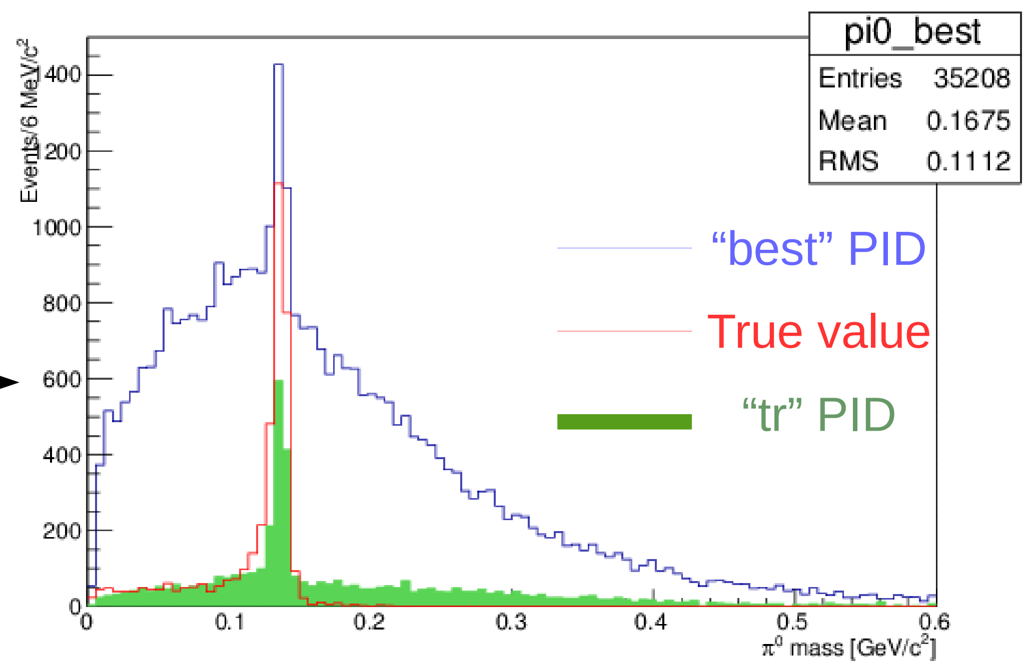
π^0 reconstruction

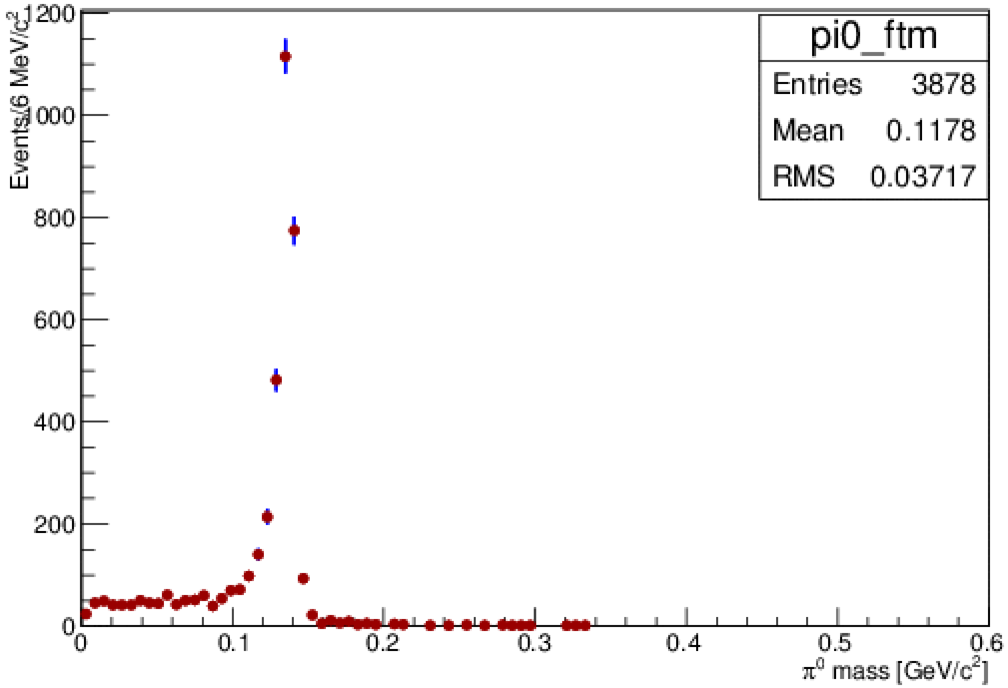
<u>Selection</u>:

π^0 mass window: 100 MeV/c^2

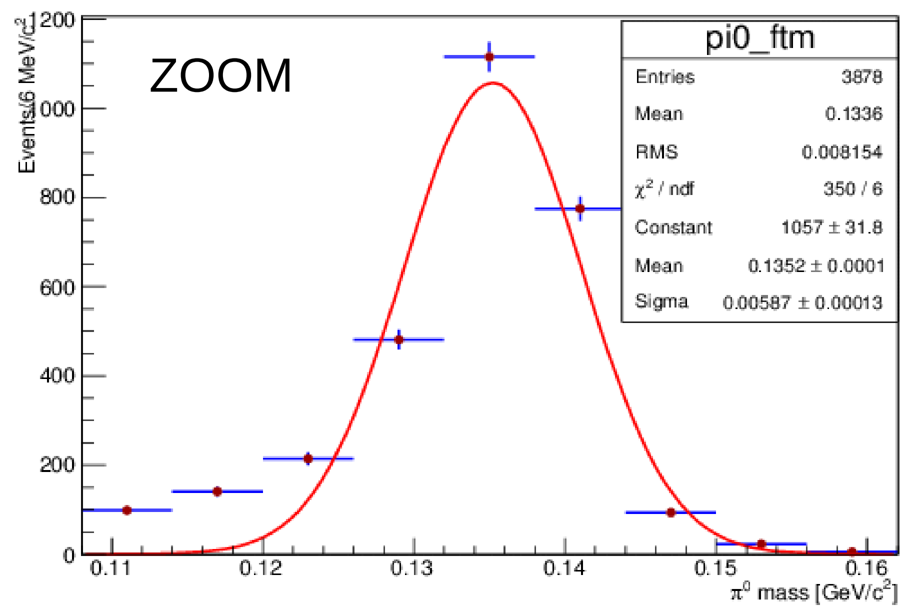
$P(\pi^0)$ >150 MeV/c^2

$N_{MAX}(\gamma,\pi^0)$/event < 50





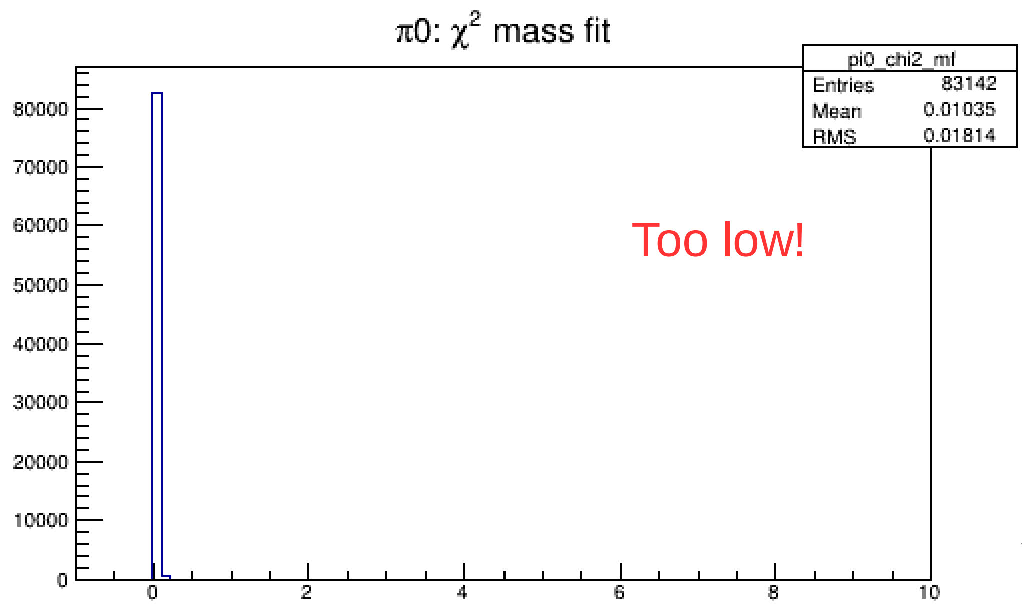
π^0 reconstruction



Before mass constraint fit:
Mass resolution ~ 6 MeV
After the mass constraint fit: 4 MeV

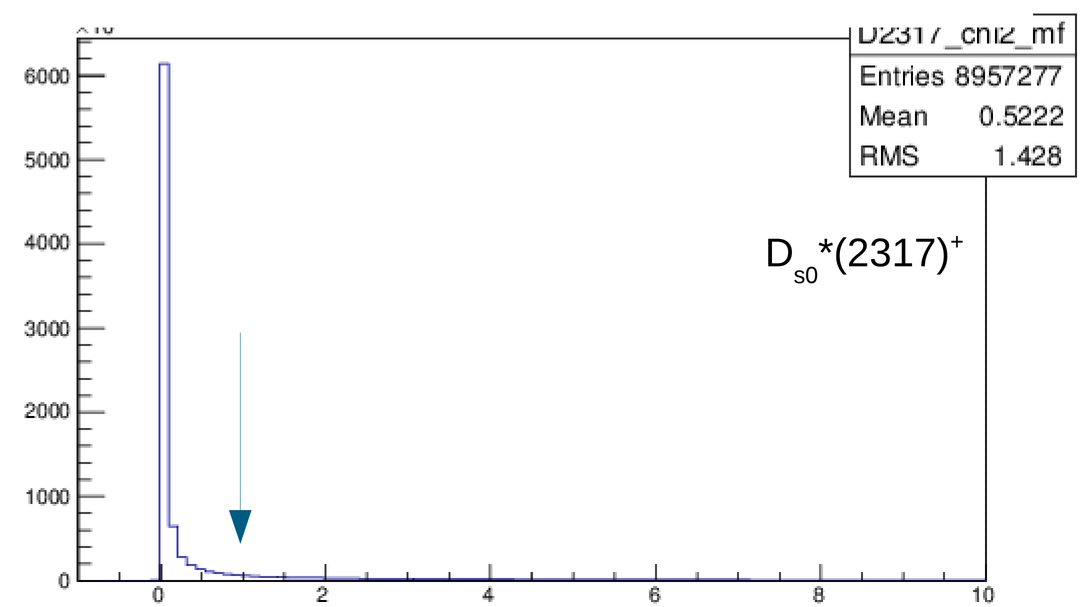
Efficiency: **78%**

χ^2 distribution of mcf

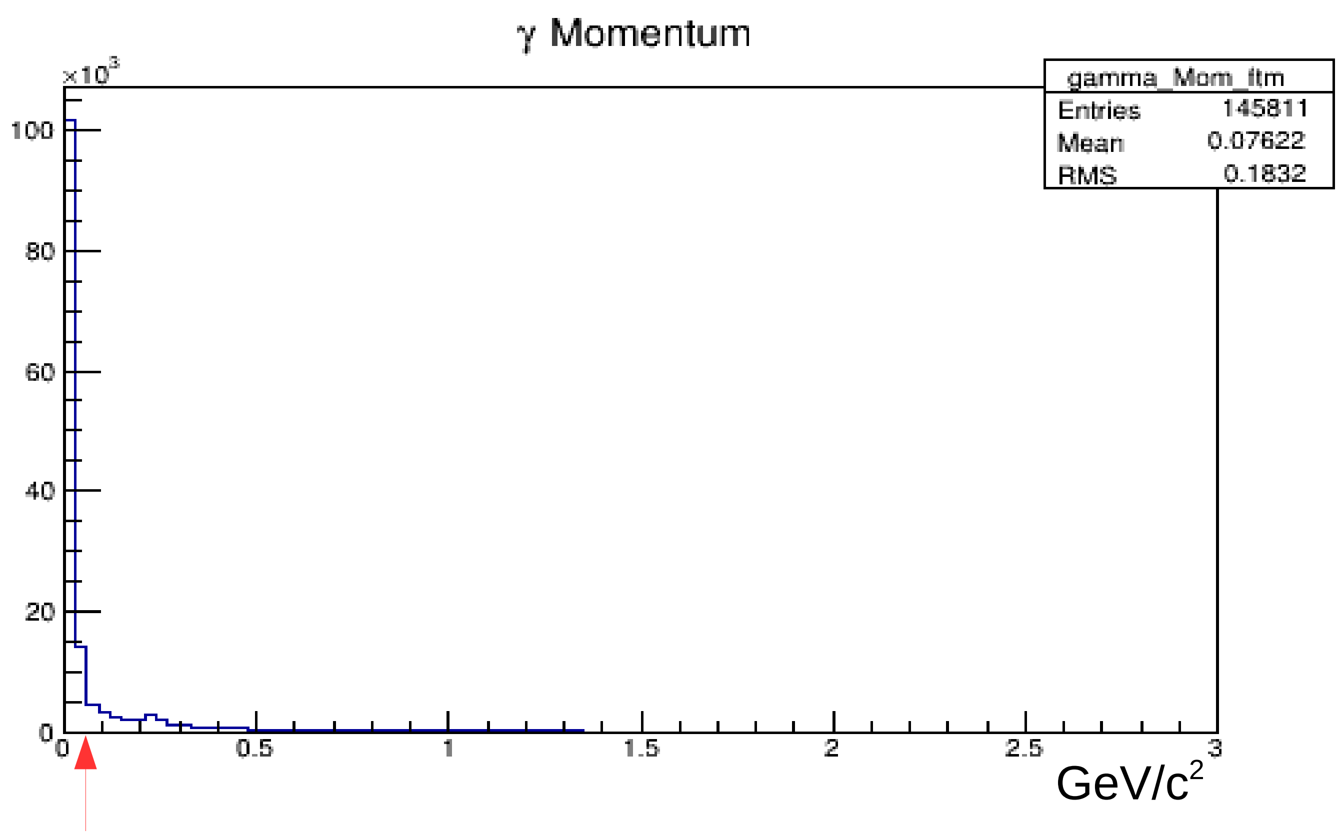


Tight mass cut around π^0 needed to reduce bkg and the CPU time
χ^2 distribution is not good!

P(γ)>30 MeV/c reduces a lot bkg and CPU time: without this cut 70h needed to run over 5000 generated events.
After this cut: 4h/5000 events



Momentum of the photons



Still to do: optimize the mass cut on γ momentum

Make use of the RhoSelectors: it saves time!
Put your macro in a PndTask: it saves YOUR time!

$D_{s1}(2460)^+$

Updated trunk: **rev 21655**

Momentum = 9.9 GeV

$E(\gamma)$>30 MeV
$p(\pi^0)$ >100 MeV/c
N_{MAX} photons/event < 50

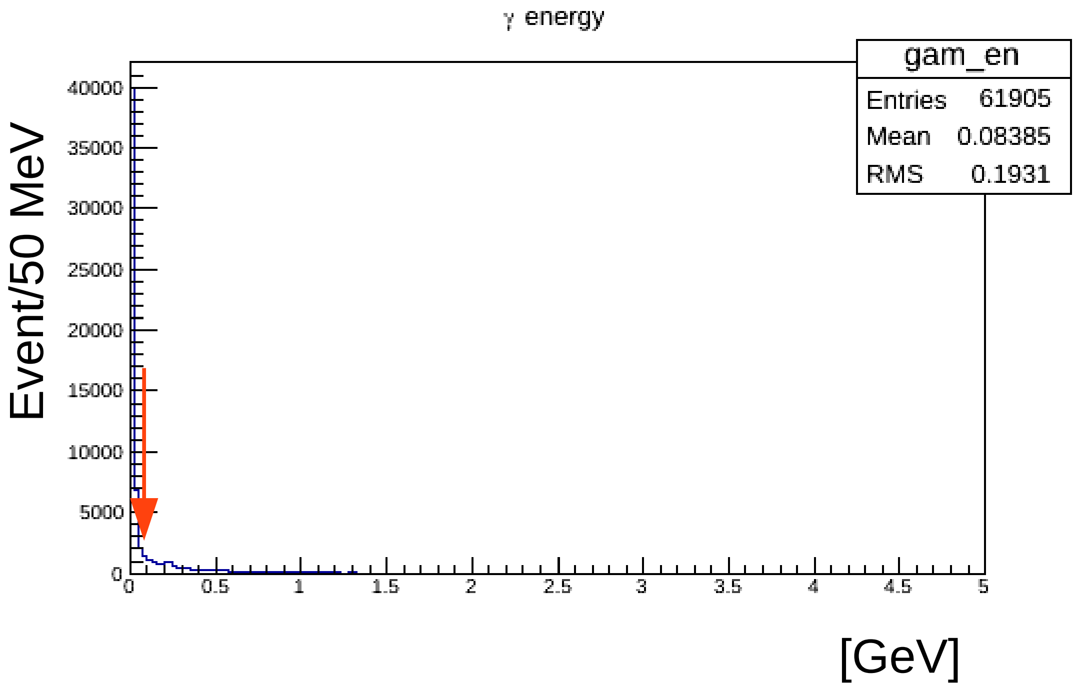
π^0 mass window: 30 MeV/c^2
D_s^- mass window: 300 MeV/c^2
D^*_s+ mass window: 300 MeV/c^2

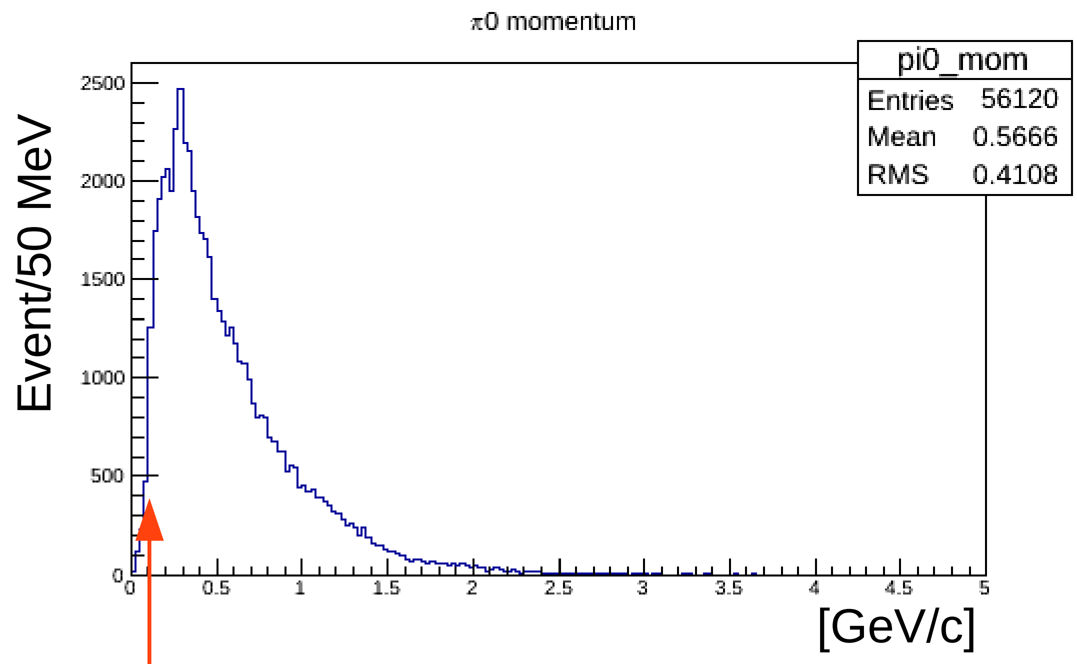
Test: 2000 events available
Time needed: >1.5h/2000 events

PID: likelihood “best”

```
noPhotos
#
Decay pbarpSystem
1.0 D_s1+    D_s-            PHSP;
Enddecay
#
Decay D_s1+
  1.0   D_s*+  pi0      PARTWAVE 1.0 0.0 0.0 0.0 0.0 0.0;
Enddecay
#
Decay  D_s*+
   1.0  D_s+   gamma           VSP_PWAVE;
Enddecay
#
Decay D_s+
  1.0  K- K+ pi+                  DS_DALITZ;
Enddecay
Decay D_s-
  1.0  K+ K- pi-                  DS_DALITZ;
Enddecay
#
Decay pi0
  1.0  gamma gamma             PHSP;
Enddecay
End
```

Selection cut for π^0 and γ





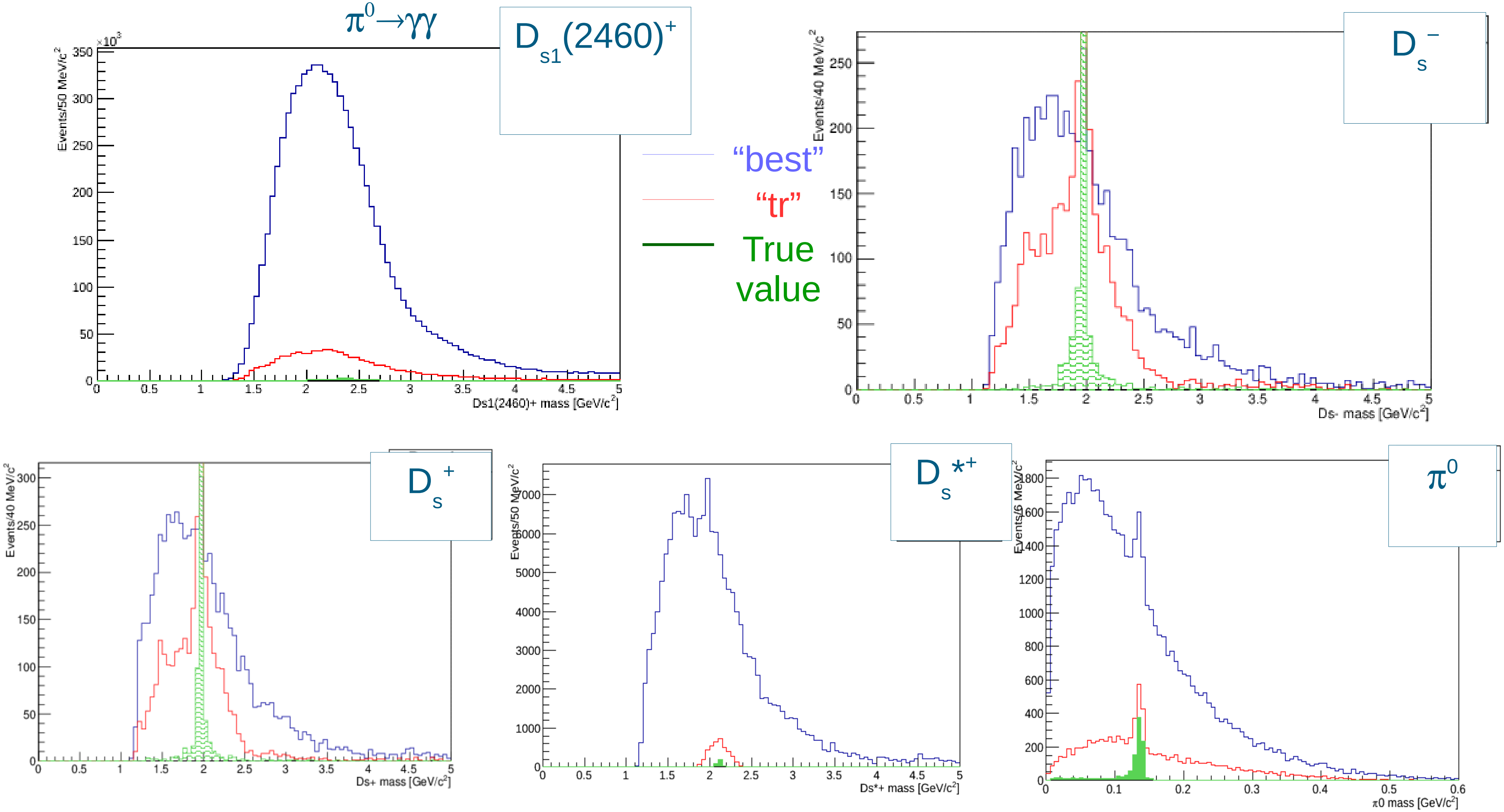
$\bar{p}p \rightarrow D_s^- D_{s1}(2460)^+$

$D_{s1}(2460)^+ \rightarrow D_s^{*+} \pi^0$

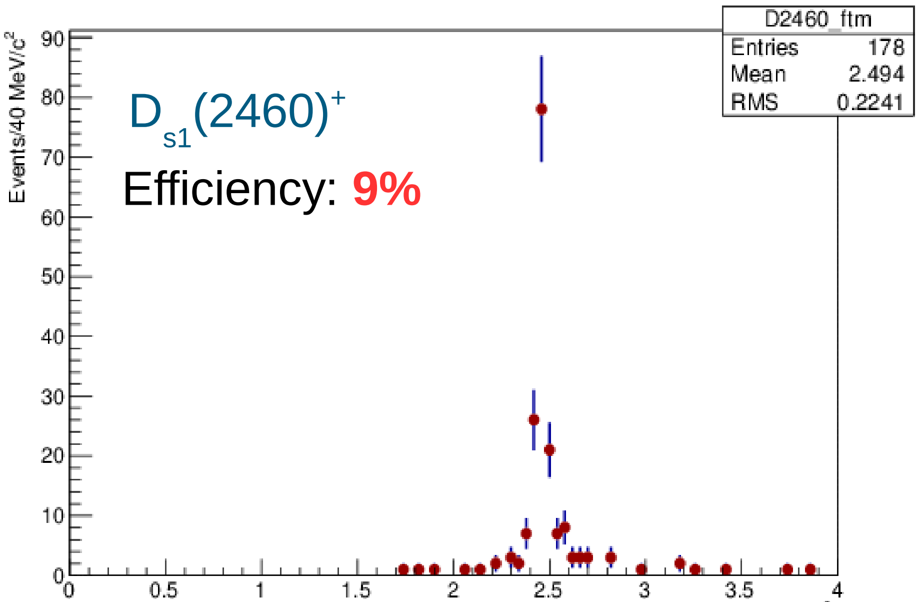
$D_s^{*+} \rightarrow D_s^+ \gamma$

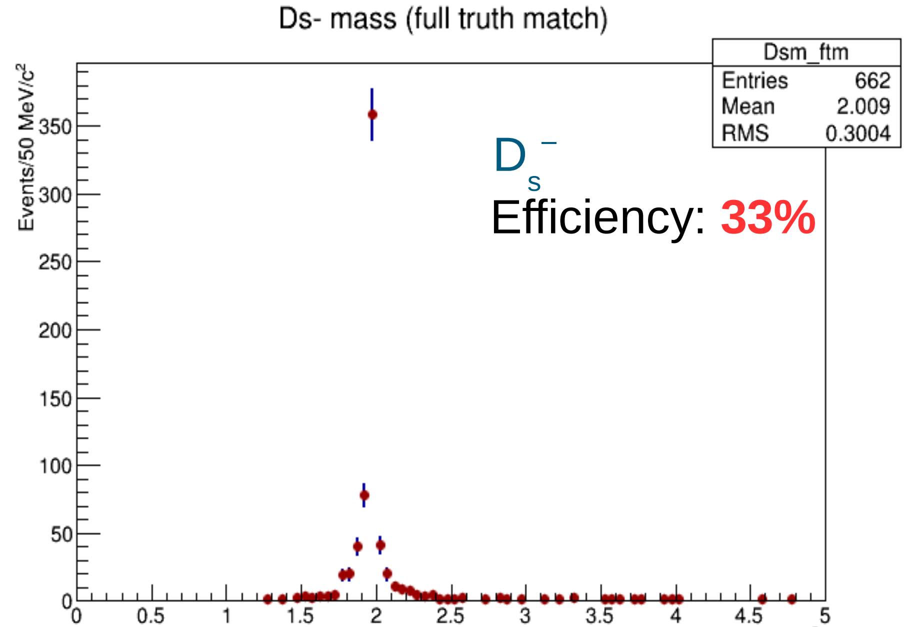
$D_s^{+/-} \rightarrow K^+ K^- \pi^{+/-}$

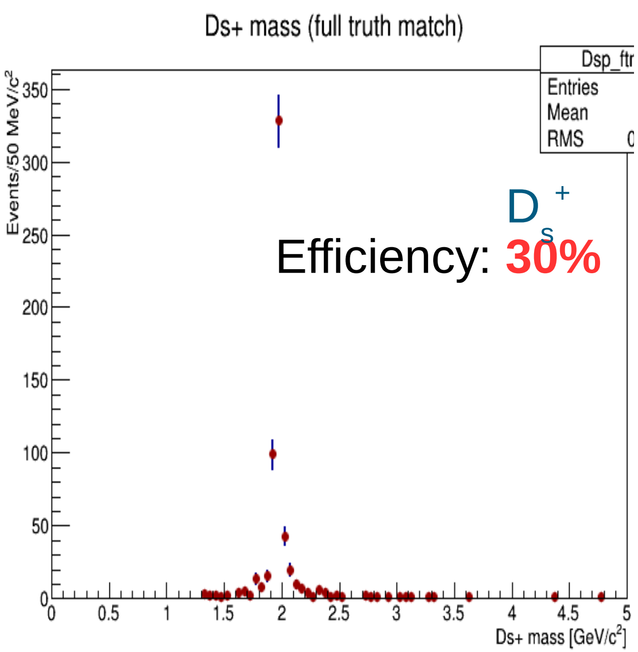
$\pi^0 \rightarrow \gamma\gamma$

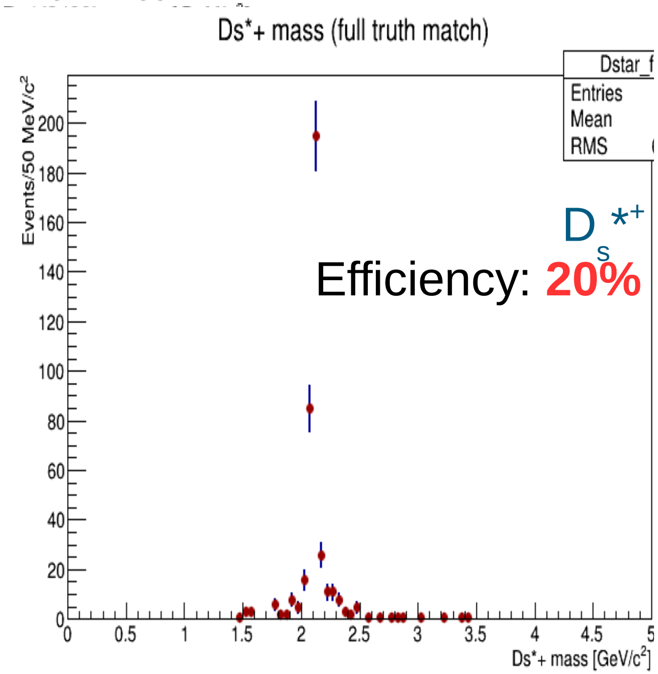


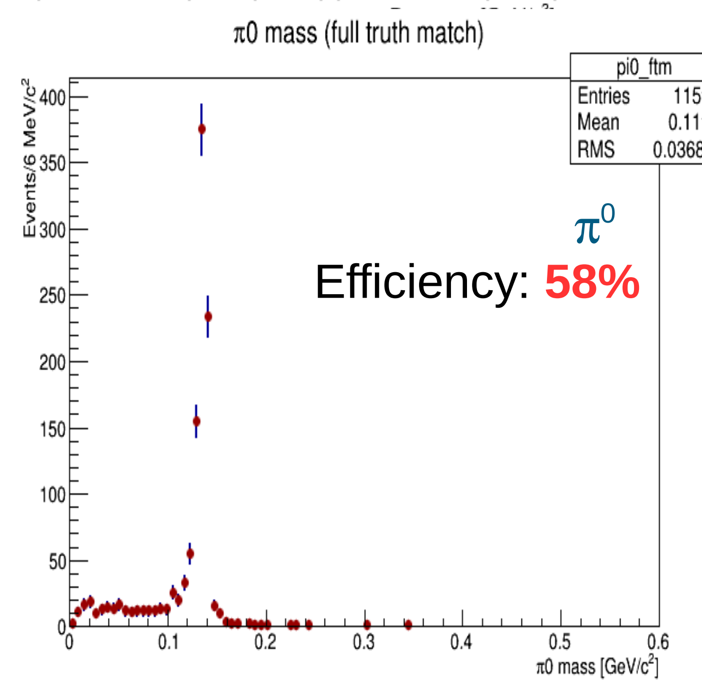
$D_{s1}(2460)^+$


D2460_ftm
Entries 178
Mean 2.494
RMS 0.2241
Events/40 MeV/c²
D_s1(2460)+
Efficiency: 9%

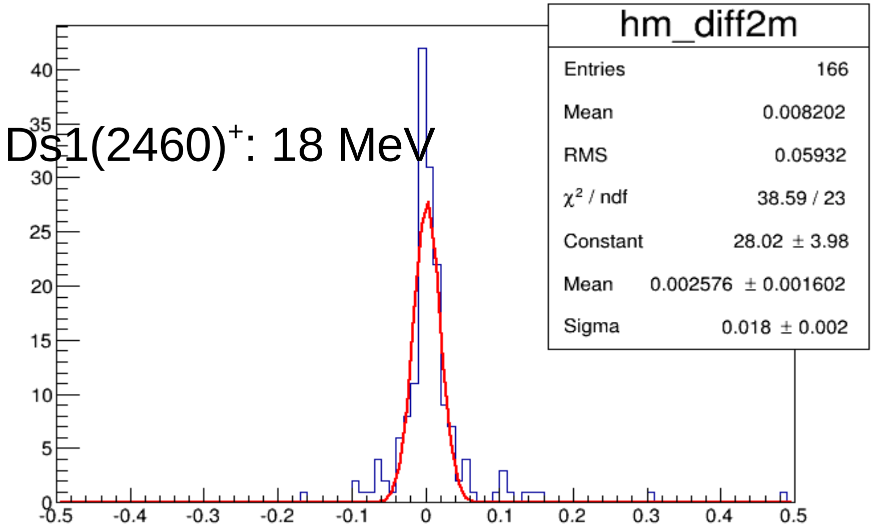

Ds- mass (full truth match)
Dsm_ftm
Entries 662
Mean 2.009
RMS 0.3004
Events/50 MeV/c²
D_s−
Efficiency: 33%

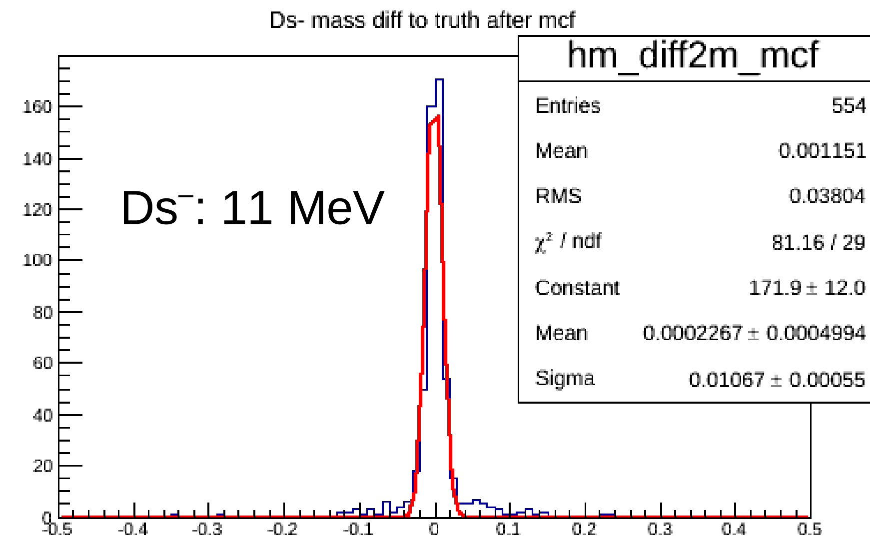

Ds+ mass (full truth match)
Dsp_ftr
Entries
Mean
RMS
Events/50 MeV/c²
D_s+
Efficiency: 30%
Ds+ mass [GeV/c²]

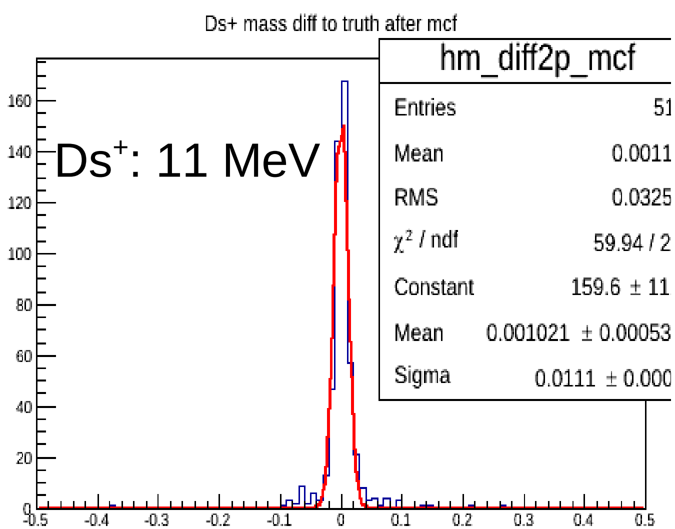

Ds*+ mass (full truth match)
Dstar_f
Entries
Mean
RMS
Events/50 MeV/c²
D_s*+
Efficiency: 20%
Ds*+ mass [GeV/c²]

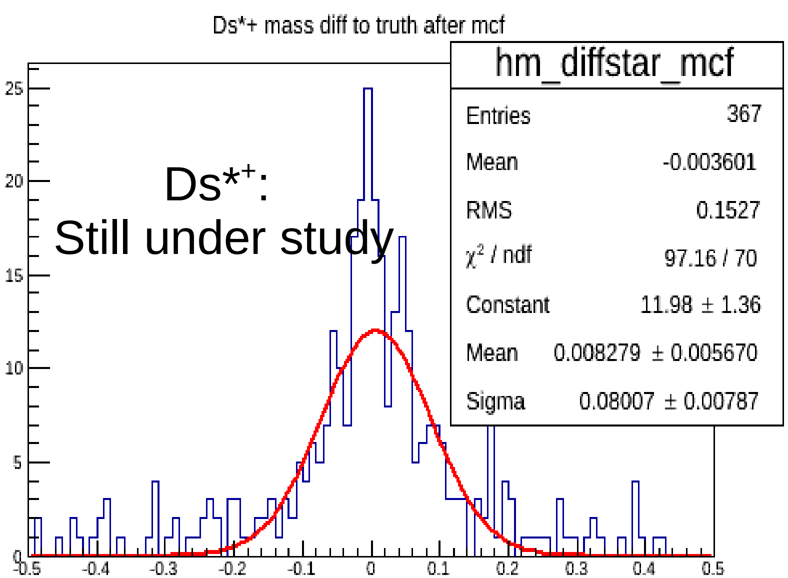

π0 mass (full truth match)
pi0_ftm
Entries 1159
Mean 0.119
RMS 0.03681
Events/6 MeV/c²
π0
Efficiency: 58%
π0 mass [GeV/c²]

Kinematic fit: mass resolution





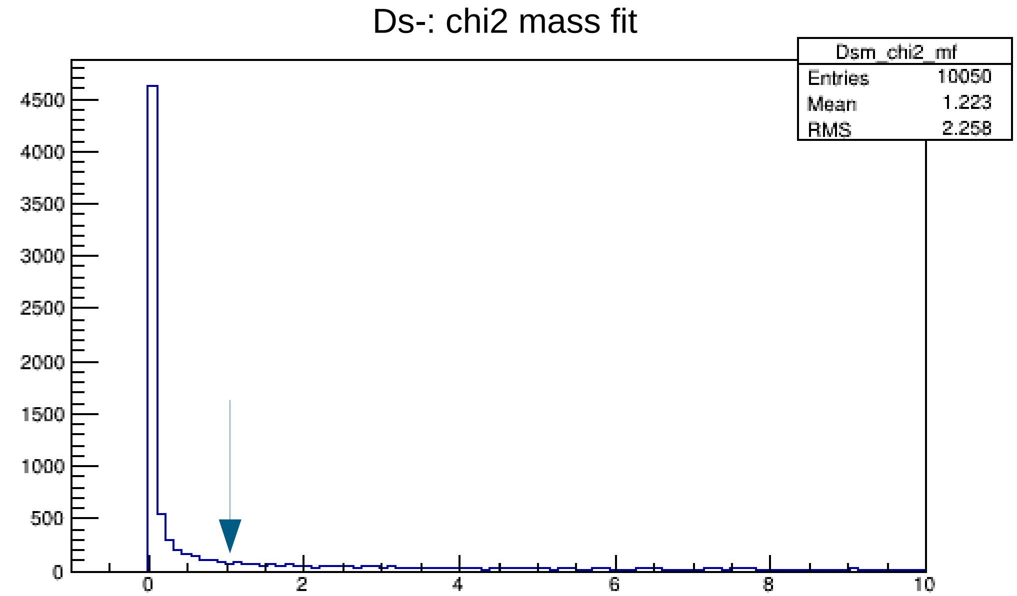


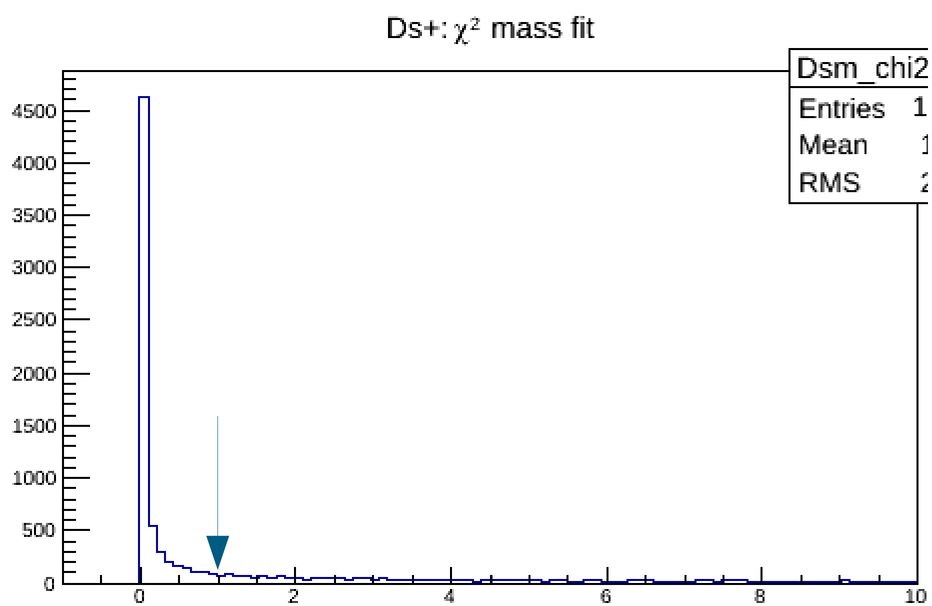


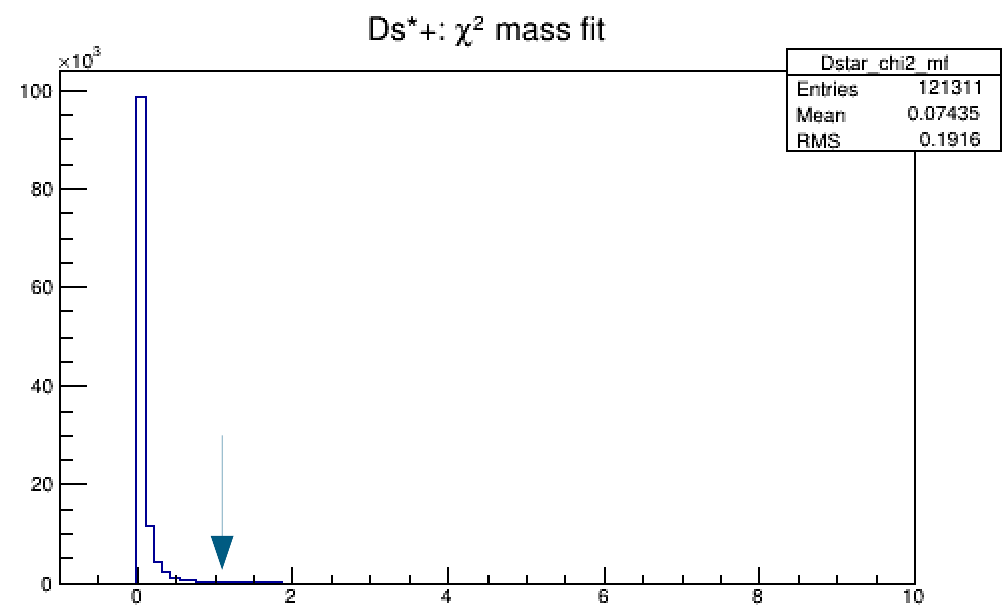
Kinematic fit: χ^2 distribution

For π^0 and $D_{s1}(2460)+$

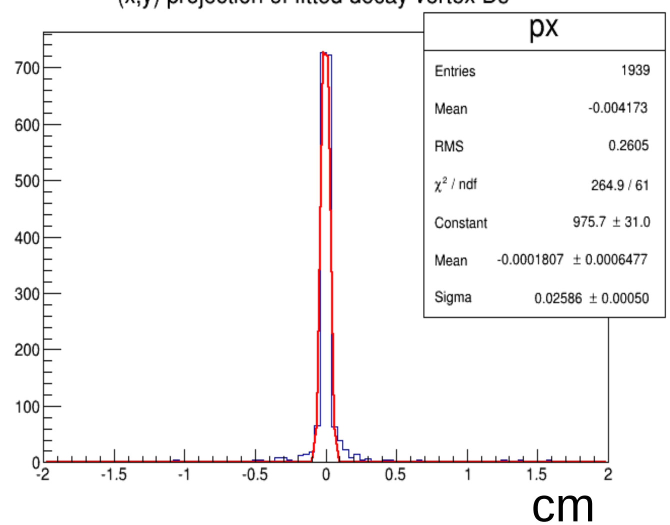
the distribution of χ^2 is a spike ~ 0

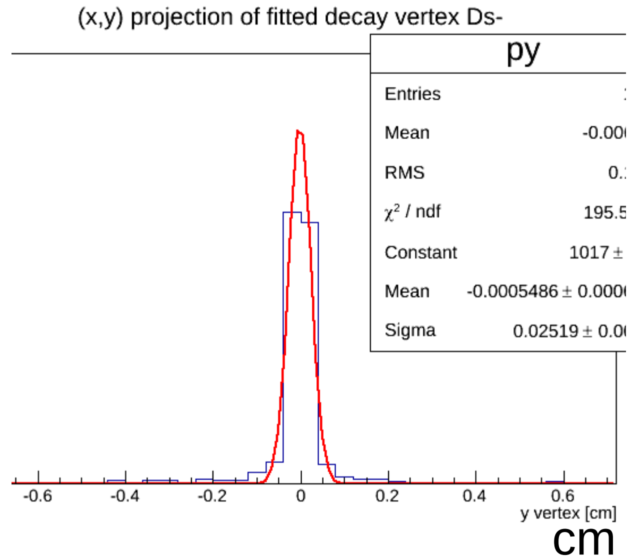


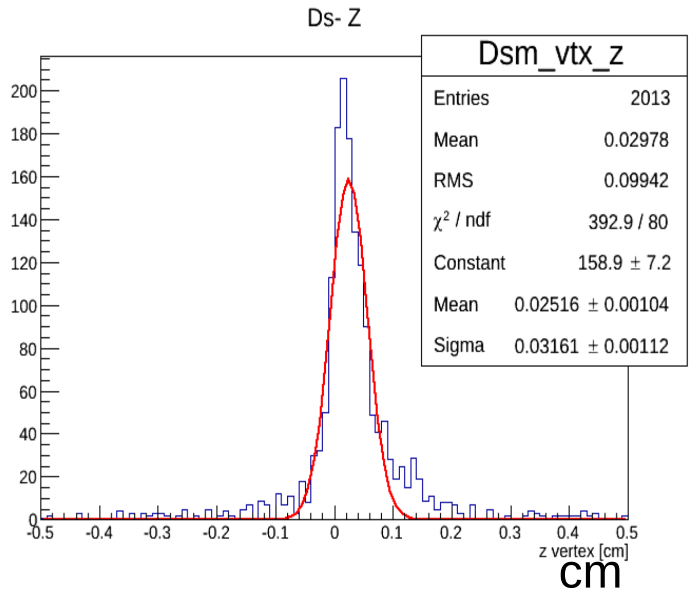




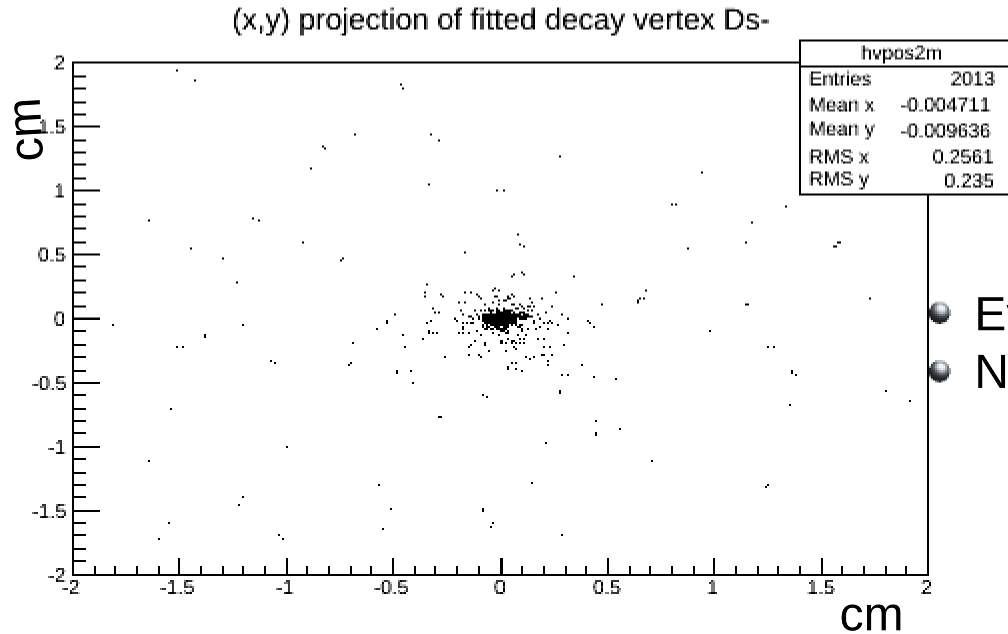
Vertex position







Something to Work on...



- Events with $\chi^2<0$: excluded
- No cut on the Prob()

$D_{s1}(2536)^+$

- Easiest case of today: reconstruction of the $D'_{s1}(2536)+$
- Tricky: it is the one with the most thin width of the family

  Momentum: 10.5 GeV
- $D'_{s1}(2536)^+$ is just above the threshold of $D^0{}^*K$. A simulation to $D^0{}^*$ K will be presented
- 5000 events generated

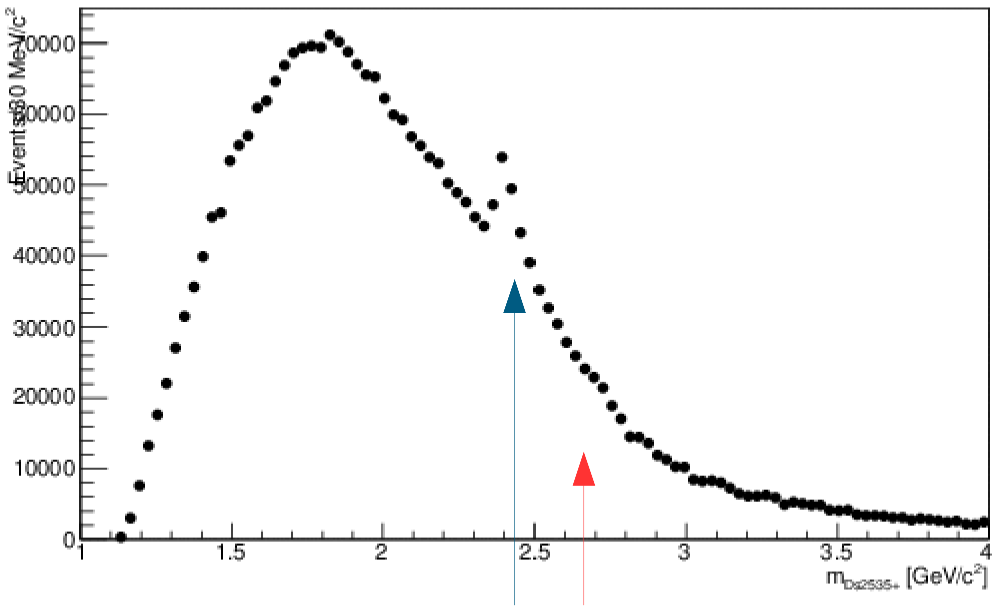
↓

Need to limit number of photons/event?
Need to limit the photon energy?
Yes, so the simulation runs very fast!

```
noPhotos
#
Decay pbarpSystem
1.0 D'_s1+    D_s-     PHSP;
Enddecay
#
Decay D'_s1+
  1.0  D*0     K+      VVS_PWAVE  0.0 0.0 0.0 0.0 1.0 0.0;
Enddecay
#
Decay  D*0
   1.0  D0 gamma       PHSP;
Enddecay
Decay  D0
   1.0  K- pi+         PHSP;
Enddecay
#
Decay D_s-
  1.0  K+ K- pi-       DS_DALITZ;
Enddecay
#

End
```

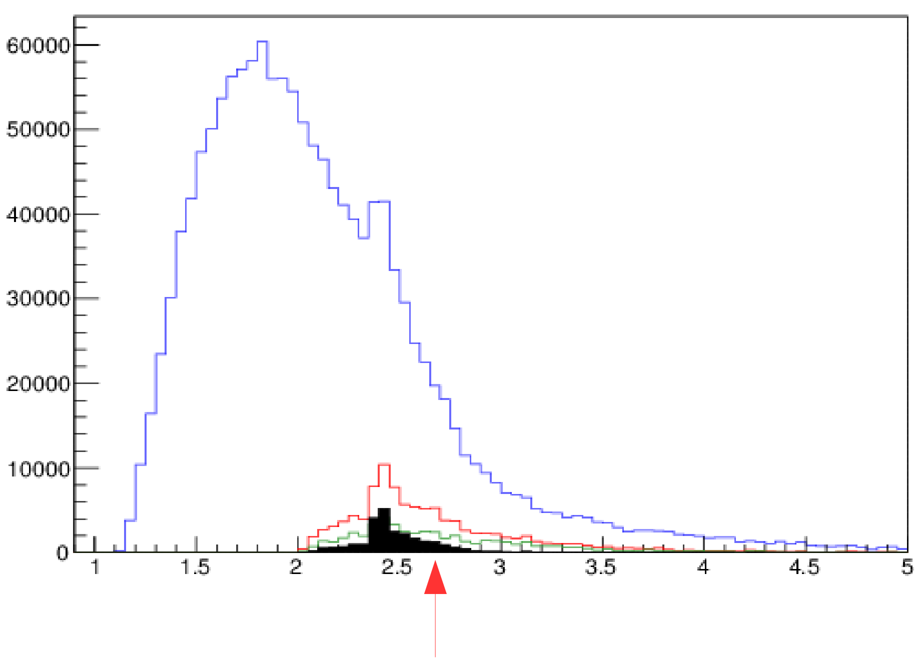
Ds'1+ mass (all)



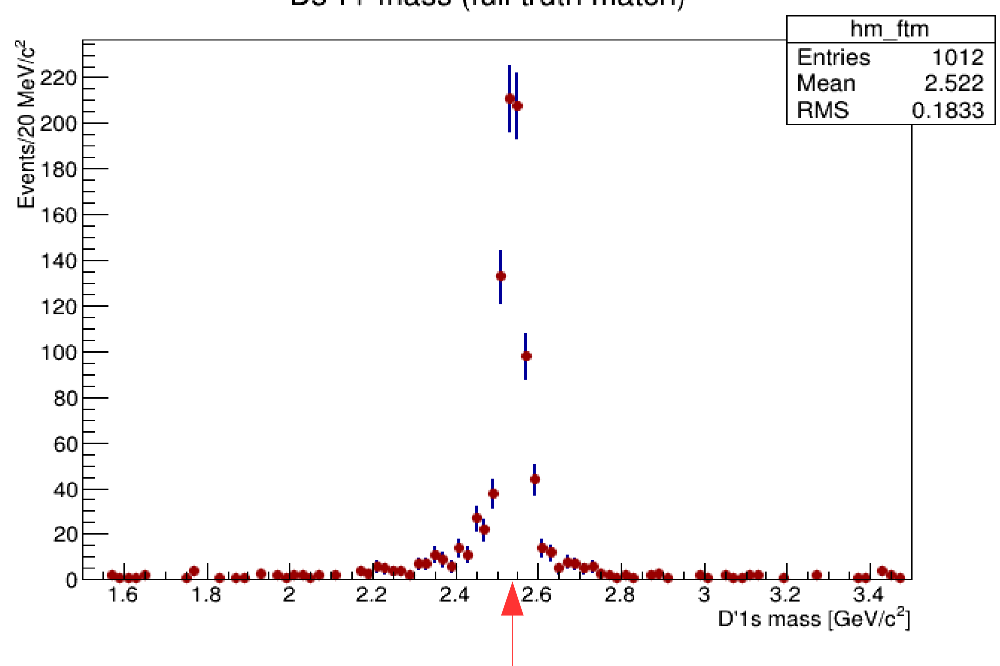
No photon selection applied

Efficiency = **20%**

Ds'1+ mass (pid)



Ds'1+ mass (full truth match)

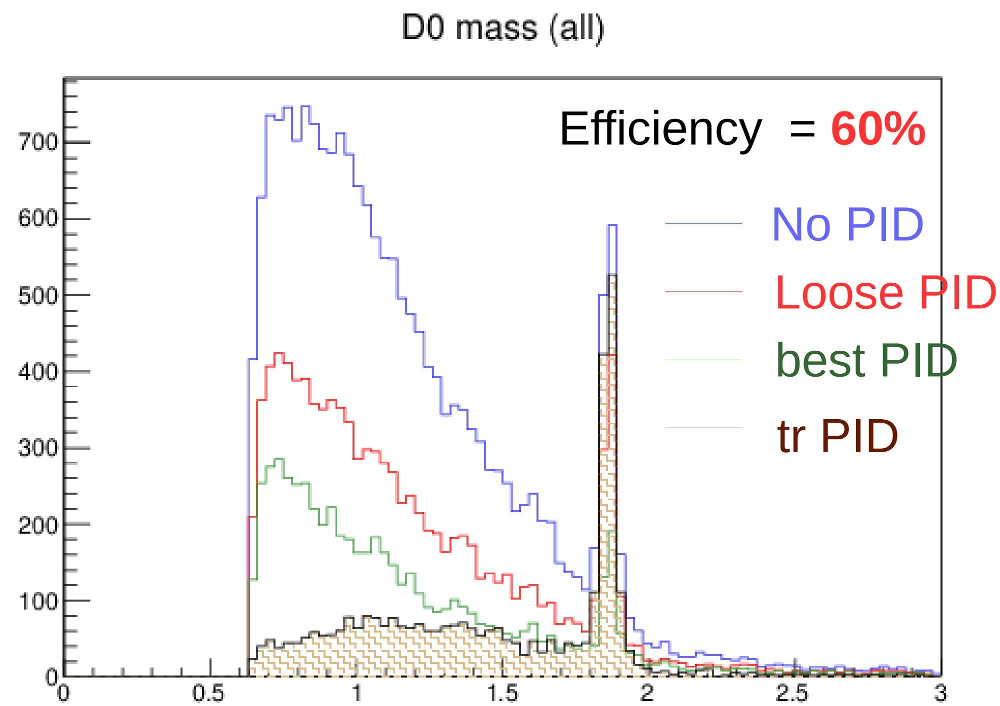


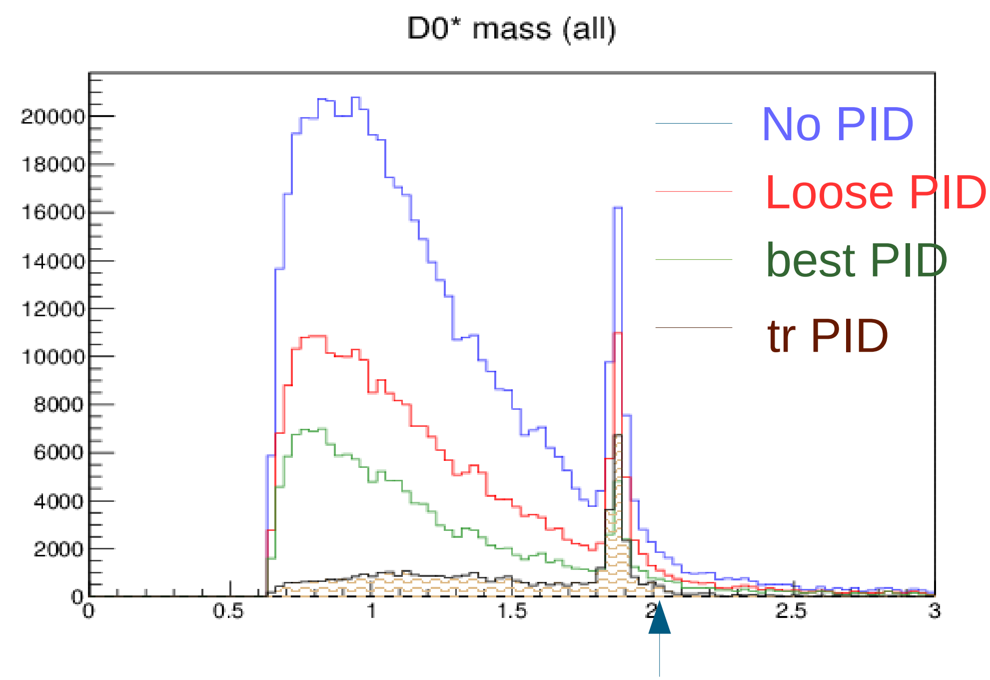
$p\bar{p} \rightarrow D_s^- D'_{s1}(2536)+$

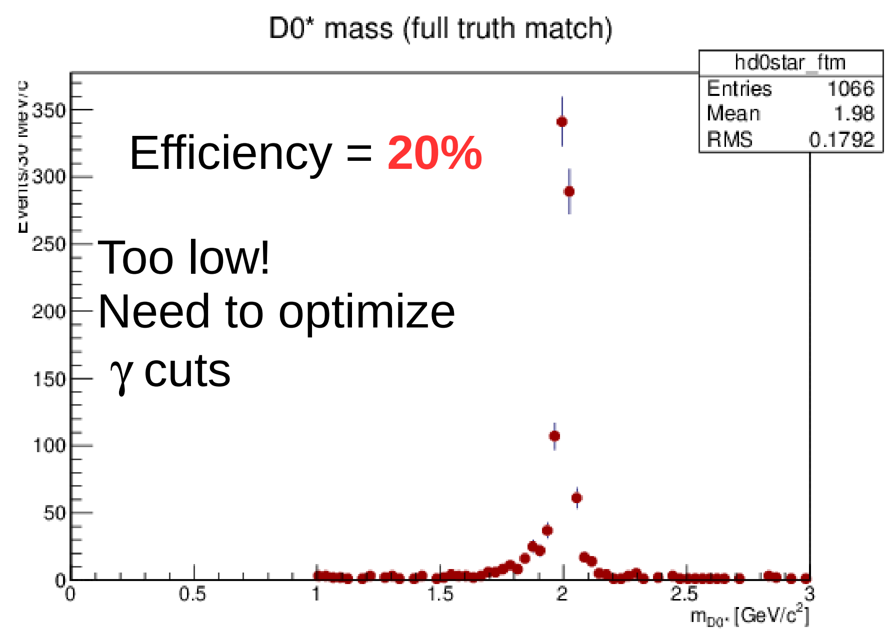
$D'_{s1}(2536)+ \rightarrow D^{0*} K+$

$D^{0*} \rightarrow D^0 \gamma$

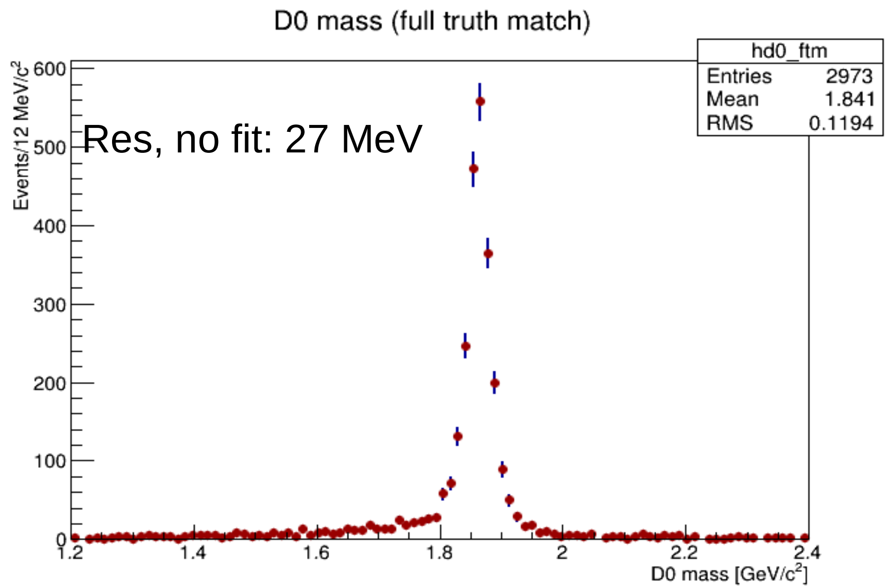
$D^0 \rightarrow K^- \pi^+$

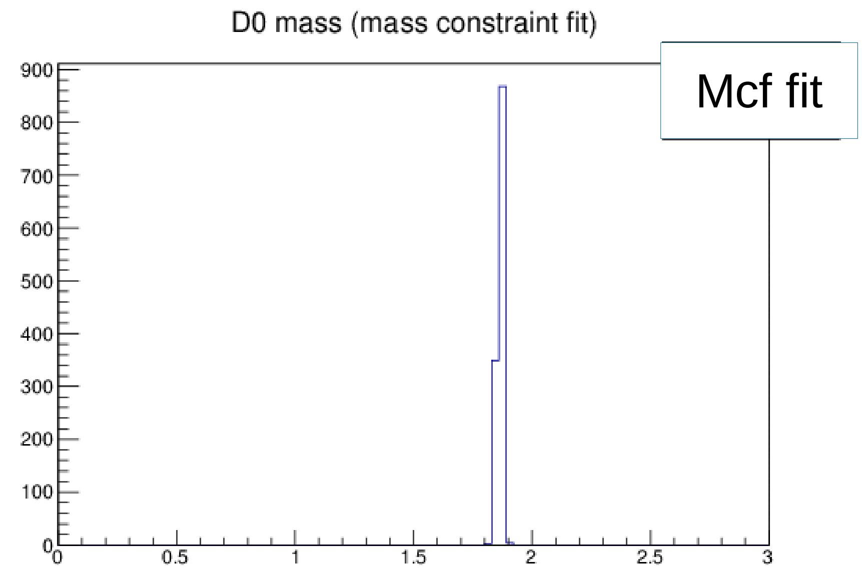


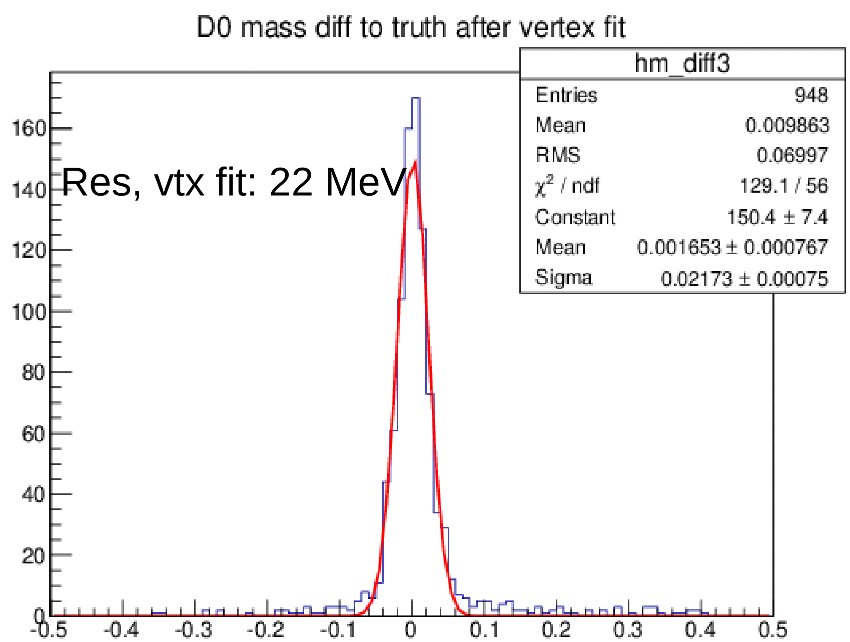


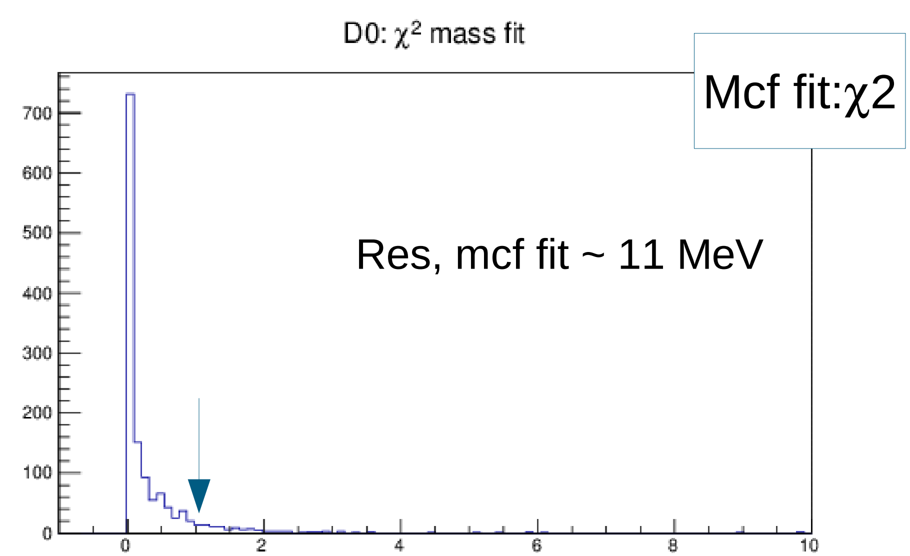


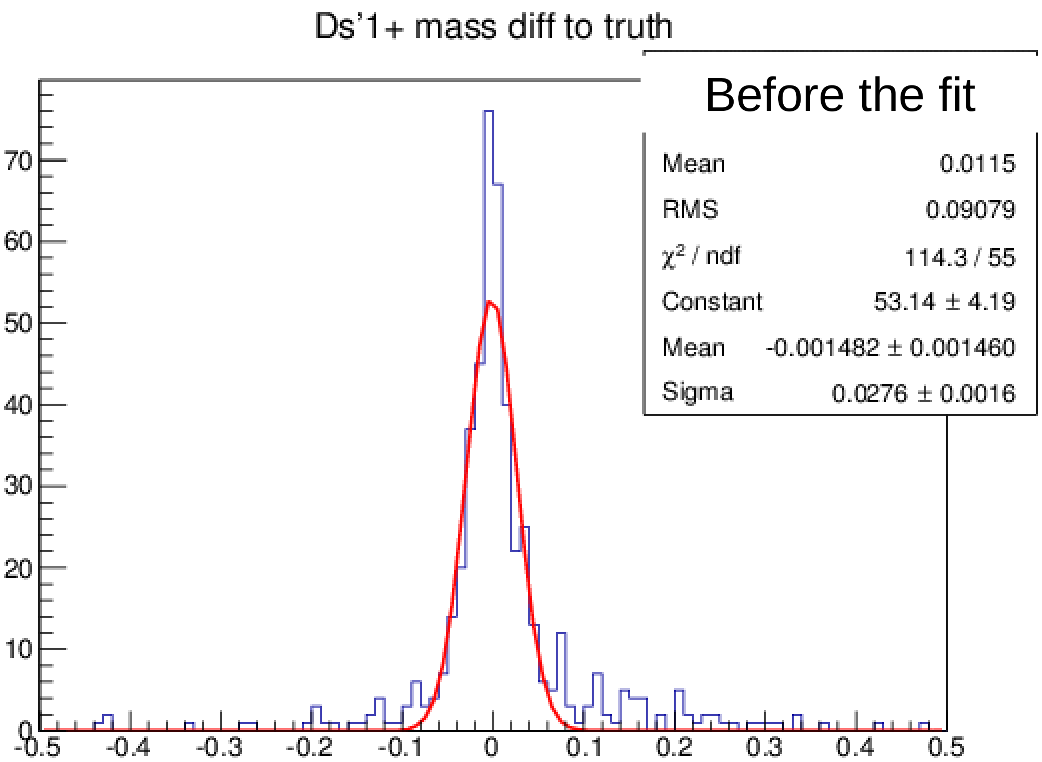
D^0 reconstruction











After mcf fit: Res = 17 Mev

- Problems with vtx fit: bunch of negative entries in χ^2 distribution
- χ^2 of mcf too low
- Efficiency drop when we add photons to the decay channel: more photons, less efficiency
- Mass window for mcf: larger interval, larger resolution. 3σ? 5σ?
- >3% of tracks found with momentum of the last hit larger than at the first hit (p_t=0; 1/p_t....)
- “Evil tracks”
- What is good, then? Reconstruction of particles decaying to charged K/π/e works pretty good!

Status of DsJ reconstruction

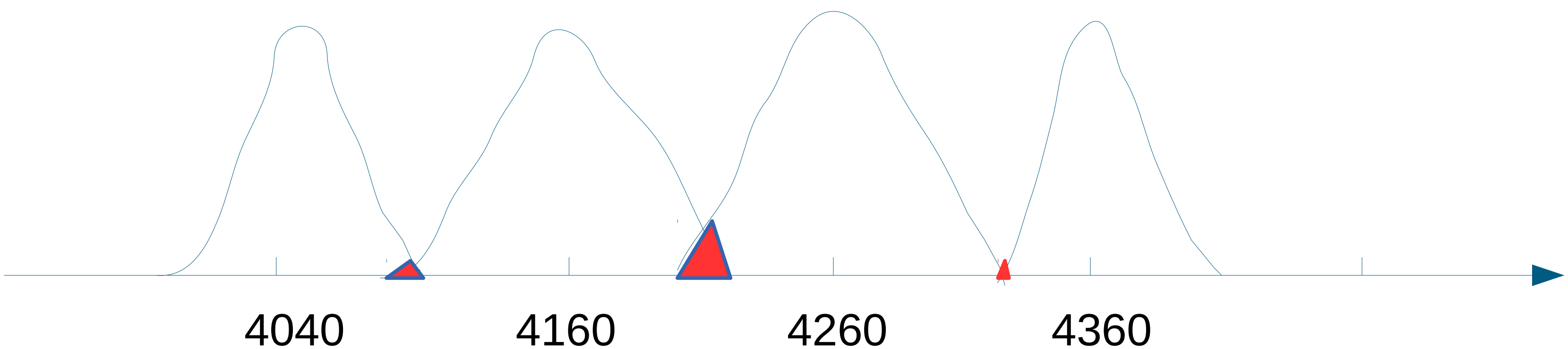
	D_{s0}*(2317)+	D_{s1}(2460)+	D'$_{s1}$(2536)+
Efficiency	16%	9%	20%
Resolution, mcf	17 MeV	18 MeV	17 MeV

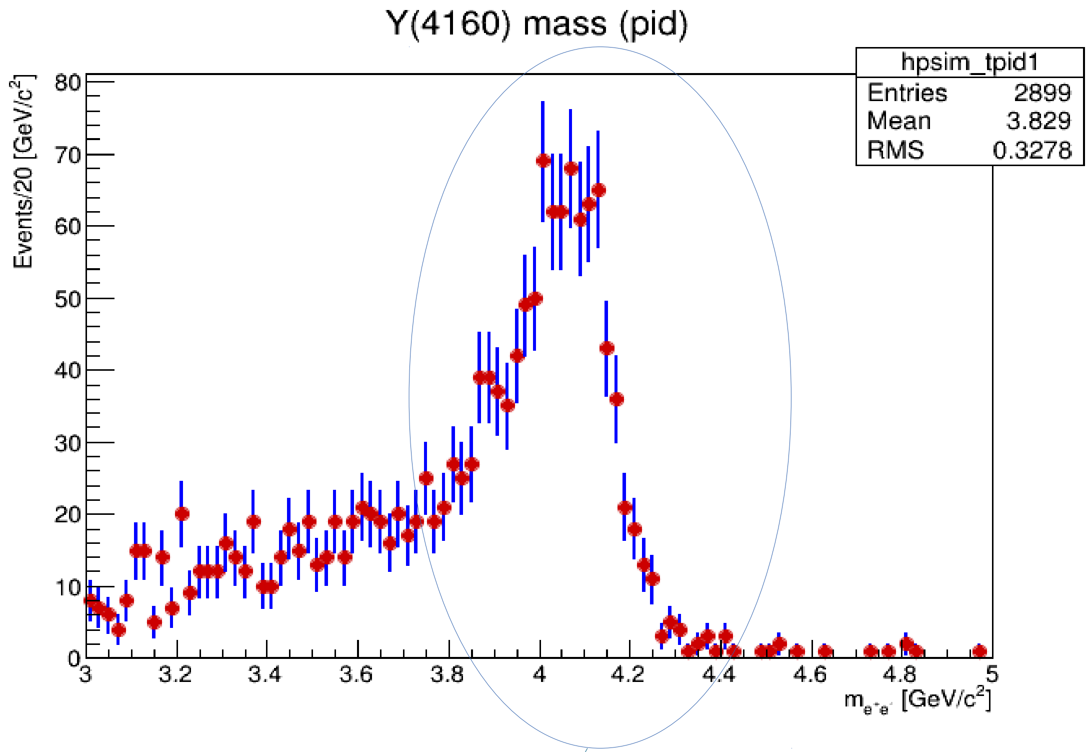
→ Expected improvements in the mass resolution and the efficiency in the next release

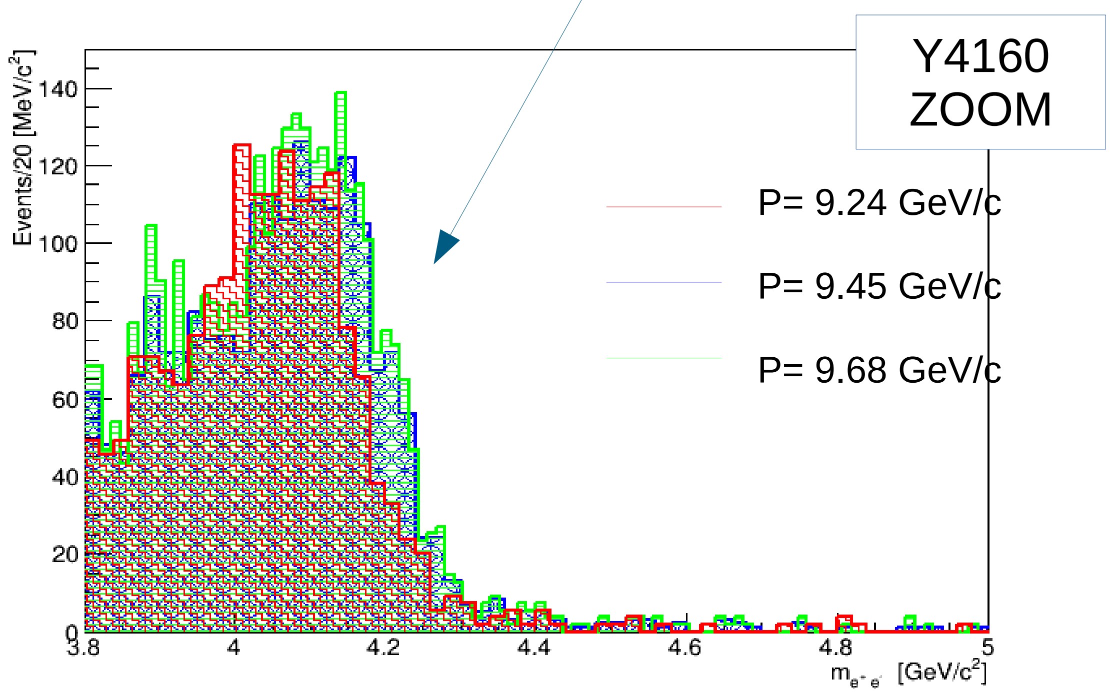
A proposal: $V \to e^+e^-$

Vector state	BR(→e+e-)	Width (MeV)
ψ(4040)	$(1.07 \pm 0.16) \times 10^{-5}$	80 ± 10
ψ(4160)	$(8.1 \pm 0.9) \times 10^{-6}$	103 ± 8
Y(4260)	—	108 ± 12
Y(4360)	—	74 ± 18
Y(4660)	—	48 ± 15

- Vectors: $J^{PC} = 1^{--}$
- Expected to decay to e+e-
- Only 2 measured: very low BR
- Large width, probably they interfere
- PANDA can do better than its predecessors: 16400 Y(4260)/day
  similar Y(4160)/day







- Momentum: 9.24 GeV/c
  Threshold of production of Y(4160)
  Standalone Y(4160)

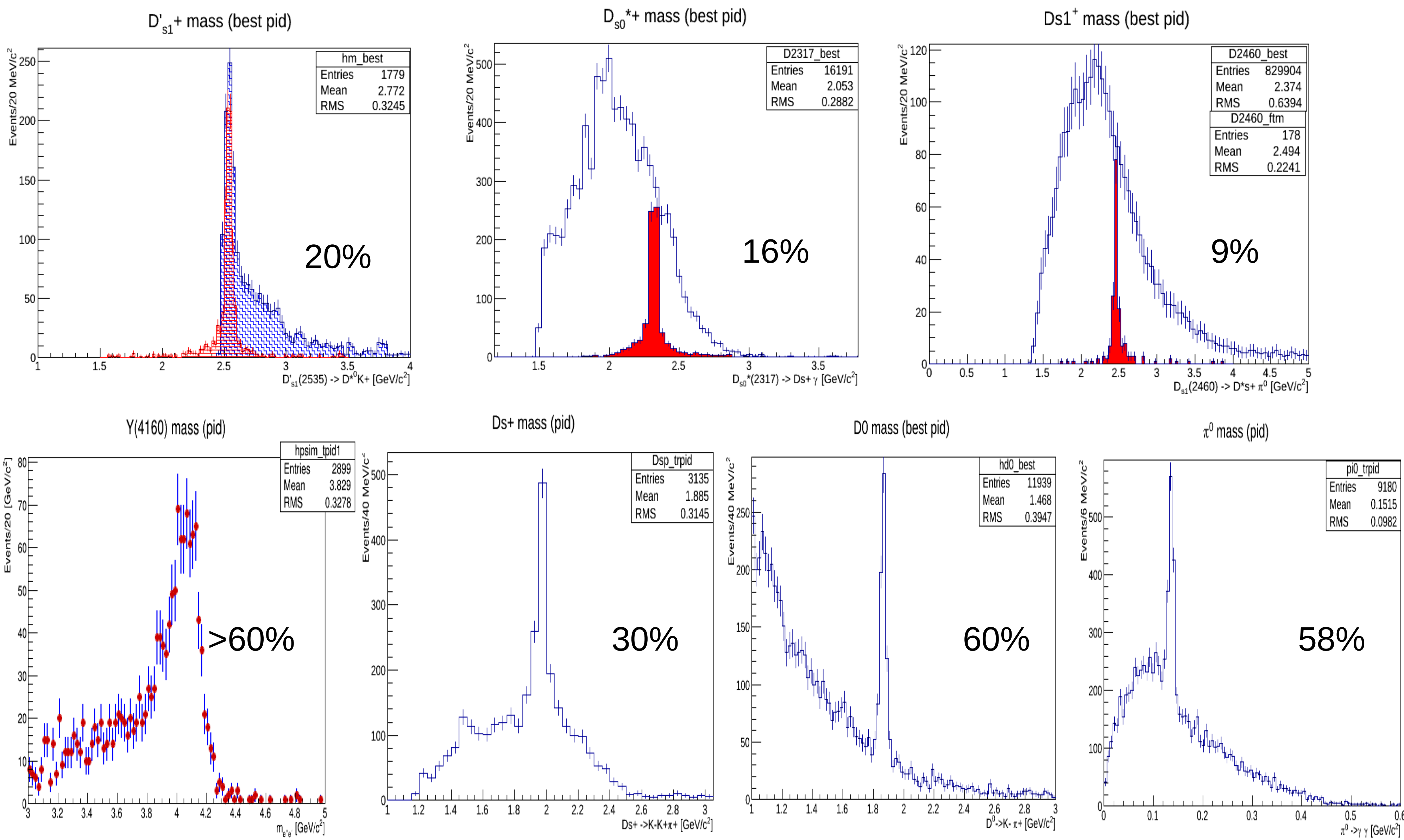
- Momentum: 9.45 GeV/c
  It is between the 2 resonances
  File with Y(4160) and Y(4260)

- Momentum: 9.68 GeV/c
  Threshold of production of Y(4260)
  File with Y(4160) and Y(4260)

Efficiency in reconstruction: (83÷ 88)%
After selection: 60%

Interference can modify the line shape

SUMMARY


D'$_{s1}$+ mass (best pid)
hm_best
Entries 1779
Mean 2.772
RMS 0.3245
20%
Events/20 MeV/c^2
D'$_{s1}$(2535) -> D*^{0}K+ [GeV/c^2]
D$_{s0}$*+ mass (best pid)
D2317_best
Entries 16191
Mean 2.053
RMS 0.2882
16%
Events/20 MeV/c^2
D$_{s0}$*(2317) -> Ds+ γ [GeV/c^2]
Ds1$^+$ mass (best pid)
D2460_best
Entries 829904
Mean 2.374
RMS 0.6394
D2460_ftm
Entries 178
Mean 2.494
RMS 0.2241
9%
Events/20 MeV/c^2
D$_{s1}$(2460) -> D*s+ π^0 [GeV/c^2]
Y(4160) mass (pid)
hpsim_tpid1
Entries 2899
Mean 3.829
RMS 0.3278
>60%
Events/20 [GeV/c^2]
m$_{e^+e^-}$ [GeV/c^2]
Ds+ mass (pid)
Dsp_trpid
Entries 3135
Mean 1.885
RMS 0.3145
30%
Events/40 MeV/c^2
Ds+ ->K-K+π+ [GeV/c^2]
D0 mass (best pid)
hd0_best
Entries 11939
Mean 1.468
RMS 0.3947
60%
Events/40 MeV/c^2
D^0->K- π+ [GeV/c^2]
π^0 mass (pid)
pi0_trpid
Entries 9180
Mean 0.1515
RMS 0.0982
58%
Events/6 MeV/c^2
π^0 ->γ γ [GeV/c^2]

CONCLUSION

JÜLICH
FORSCHUNGSZENTRUM

High reconstruction efficiency of mesons decaying to charged particles only

Need to optimize the selection of the neutral list “a priori”: gain in CPU time and memory

Problem of lack of efficiency with neutrals still to be solved

About problems with tracking and fitters: open discussion!

MANY THANKS TO KLAUS AND STEFANO FOR THEIR SUPPORT!

"...is 1% talent and 99% hard work..."

THANKS!