Ultra granular calorimeter and flavour physics

J-C Brient (**LLR)**

I would like to convince you that

An ultragranular e.m. calorimeter is the best choice for flavour physics

A paradigm claimed by people working on flavour physics or ECAL based on energy resolution

" An ECAL with very good energy resolution is mandatory for flavour physics at FCCee/CEPC"

With a benchmark list among which we can find the list below

1. Bs decays to Ds $\pi^{\pm}$, Ds $K^{\pm}$

1. $B^{\circ} \rightarrow \pi^{\circ} \pi^{\circ}$

2. Transition from quark $b \rightarrow s \gamma$

3. τ physics rare decays

4. τ polarisation and AFB measurement

FAST SIMULATION

In order to deal with very low branching fraction, Fast Simulation is mandatory
It is based on

- ILD like geometry (ILD-L)
- New reconstruction of photon(s) based on 5D calo (x,y,z,E,t) was tested with GEANT4
- With a photon energy threshold at 50 MeV (effic =70% , 100% at 150MeV) a fantastic 100% purity of the photon(s) sample is observed (no debris from charged, no KL, no neutron) . No misid γ/π° as soon as the distance between 2 photons are > 1.5 cm at the entrance of the ECAL
- the ECAL energy resolution is taken at $\Delta E/E = 16\%/\sqrt{E} \oplus 0.005$ (standard Si-W)
- A very precise position resolution (see DRD meeting at Ancona *) much below 1mm at 2m at 1 GeV
- efficiency about 100 % to reconstruct the photon for distance larger than 1.5 cm from the position of charged tracks in entrance of the ECAL

- for charged tracks reconstruction, 100% efficiency above 0.15GeV Pt is used
- resolution is taken as $\delta P/P^2 = 10^{-4}$ (a little bit more pessimistic than ILD official value)
- k/π id. Larger than 3σ up to 15 GeV
- d0 track resolution 15 μm
- vertex (2 tracks) resolution at 20 μm

* https://indico.cern.ch/event/1551941/contributions/6656570/attachments/3138669/5569958/DRD%20Anconna%20JC%20V7.pdf

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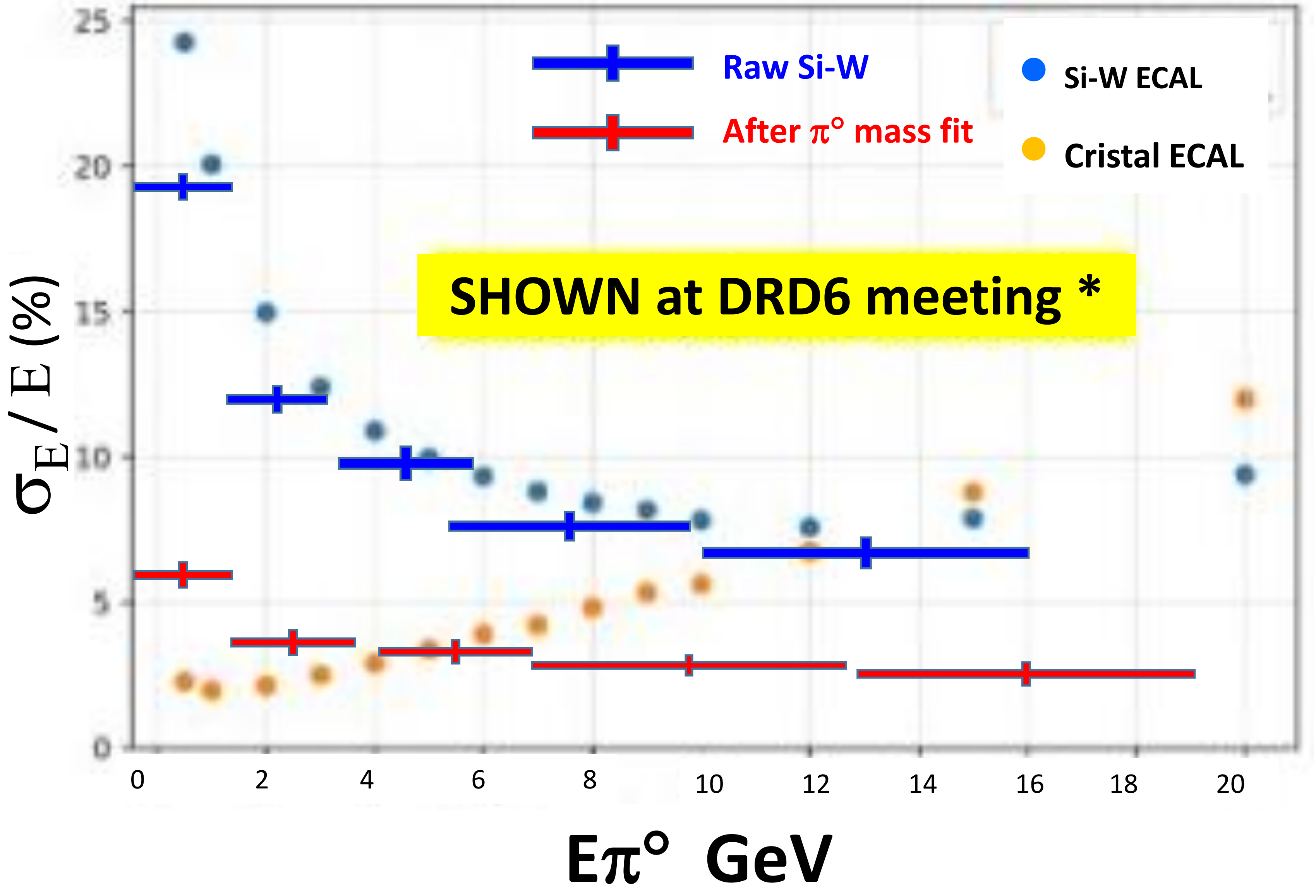
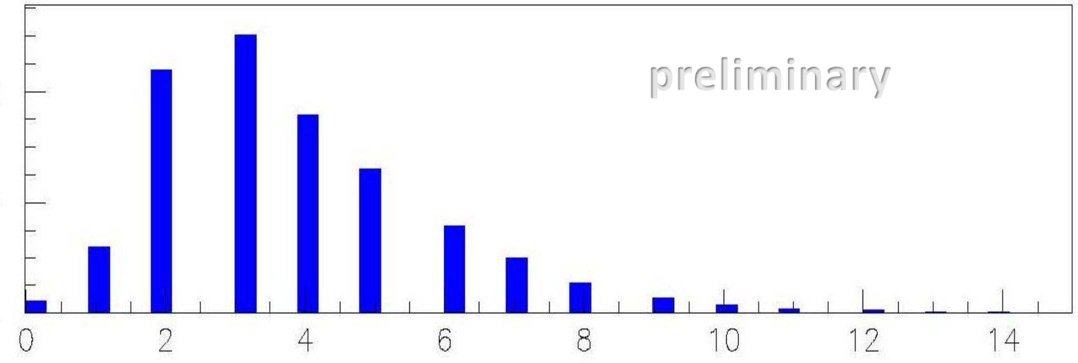


How the fit of the mass $\gamma\gamma$ to the π° mass improve the π° energy resolution

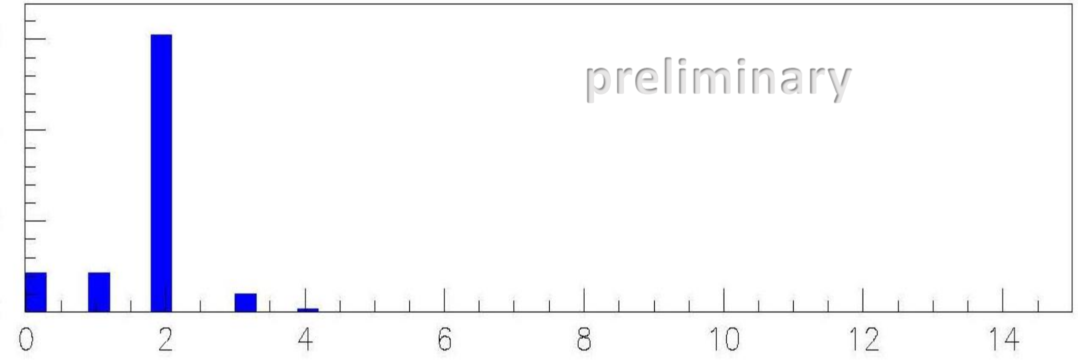
https://indico.cern.ch/event/1551941/contributions/6656570/attachments/3138669/5569958/DRD%20Anconna%20JC%20V7.pdf

1. Bs decays → Ds π, DsK

with Ds $\to\phi\rho\to k^+k^-\pi^\pm\pi^\circ$



Number of photon(s) in the jet



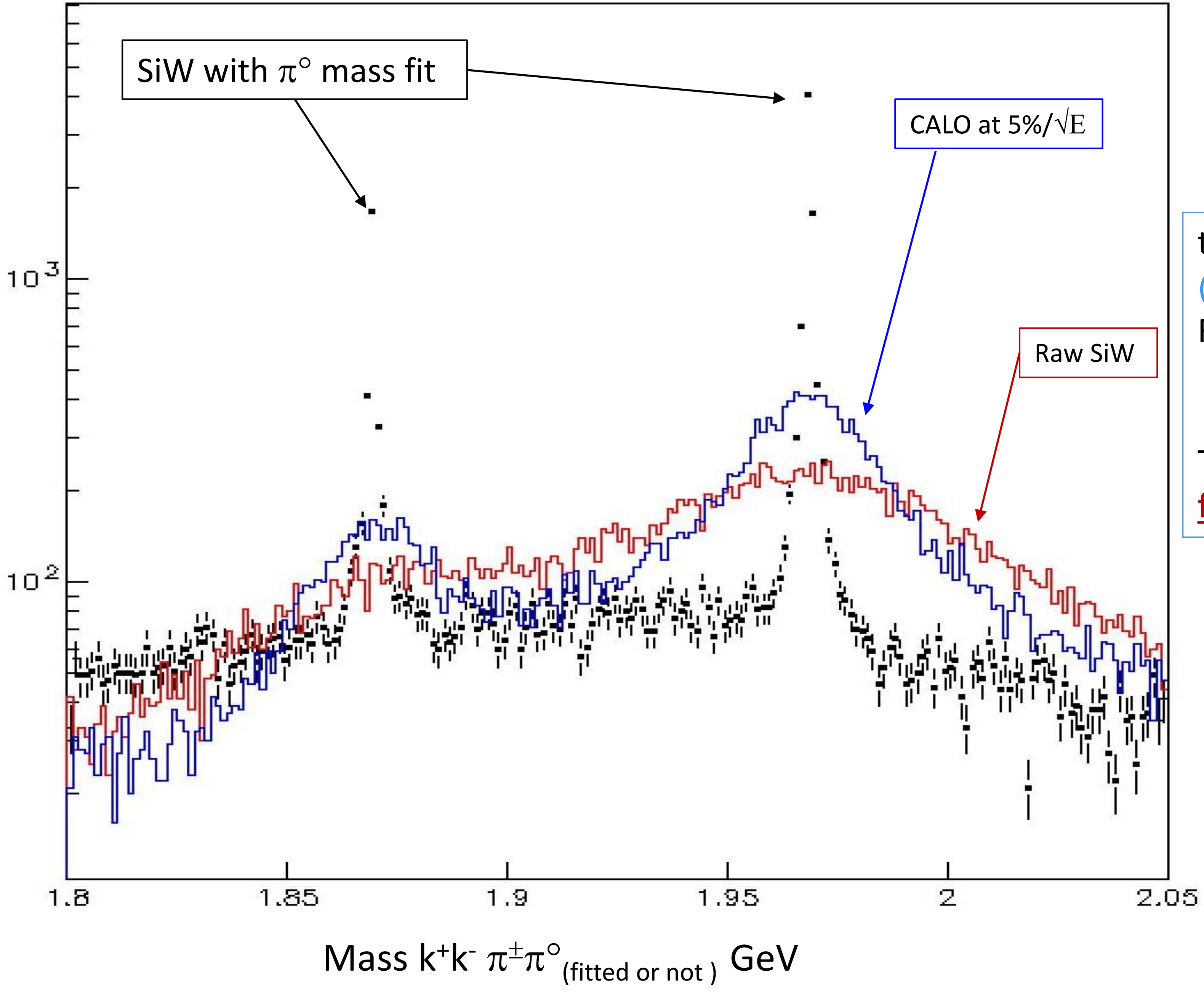
Selected photon(s)

- The events are split in 2 hemisphere with the Thrust axis
- select a displaced vertex with $K^+K^-\pi^\pm$ ($K^\pm$) in one hemisphere
- Select the ϕ mass region for K^+K^-
- Define the jet direction as the direction of $K^+K^-\pi^\pm$ ($K^\pm$)
- Photon(s) in the cone such cosine(γ/jet)>0.75

How to select the good photons !! ?
It is possible with a crude algorithm

(Same problem for any type of calorimeter)

A very crude analysis is used optimising the number of photons to be 2 in the "$\phi\pi$ " jet, but using only photons with kinematics compatible with the full decays chain (i.e. total mass in 4-6 GeV range)



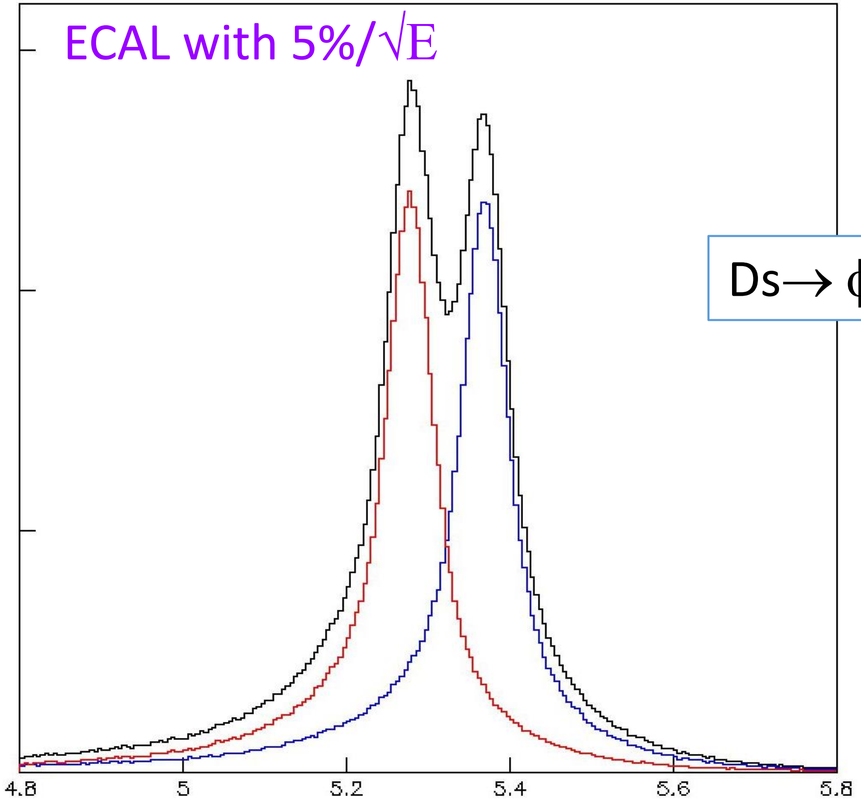
the selection of the Ds mass region , (Ds→ φρ→ k⁺k⁻ π±π°) is clearly not efficient For Raw Si-W or for an ECAL with 5%/√E

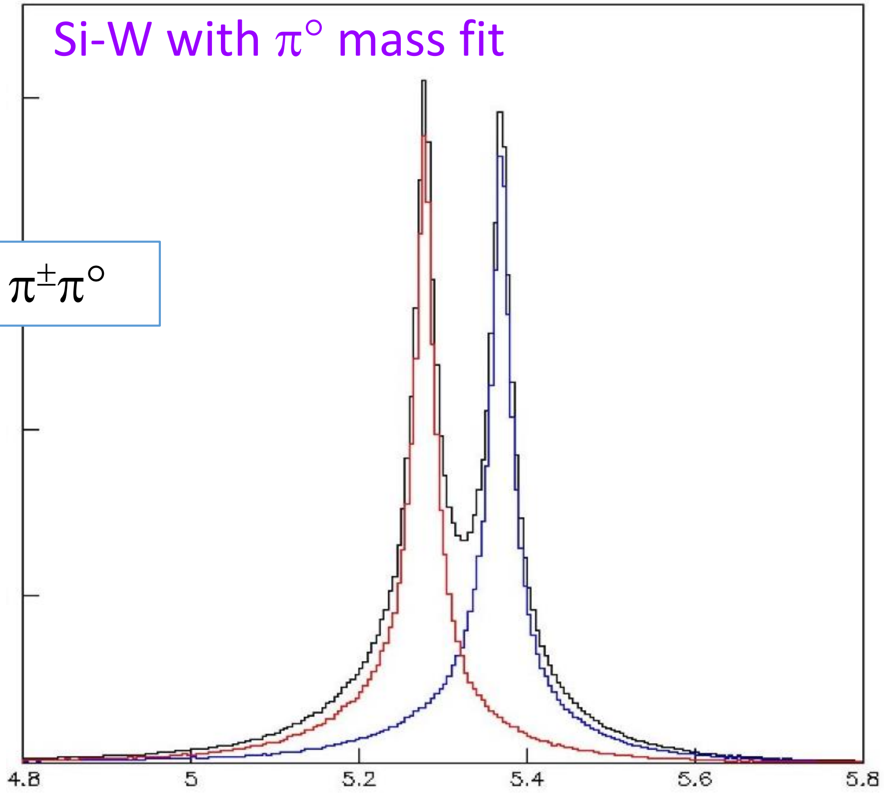
The plot shows that it would be a problem <u>for the efficiency and for the purity</u>

How it affect B°- Bs separation

Full sim. + Recons. ECAL-5D + Fast Sim.

$Ds \to \phi\rho \to k^+k^- \pi^\pm\pi^\circ$





For final state Ds π, B^0 vs Bs ,

the separability is **0.7σ** when using ECAL with ΔE/E= 5% / √E (crystal like)

This value become 1.6 σ , when using ultragranular +fit π°

$\sigma^2 = \sigma_1{}^2 + \sigma_2{}^2$, σ_1 (σ_2) is the resolution on the Ds π mass for B0 (Bs)

CONCLUSION for the Bs decays to Ds π or Ds K

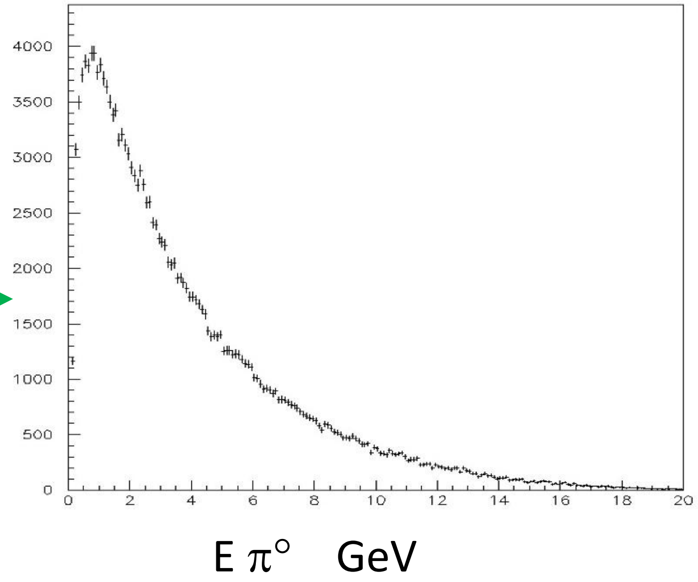
For this channel, with Bs to Dsπ or DsK , with Ds →φ ρ,

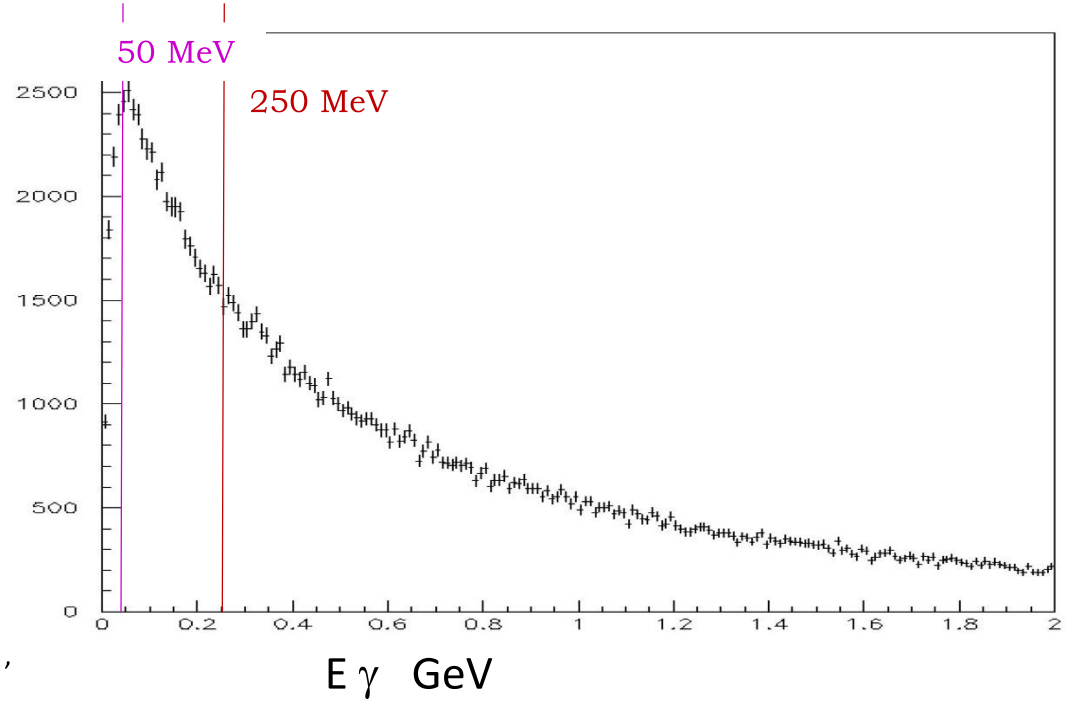
The improvement with π° mass fit is interesting only with

- A good precision on the position (see my talk at the last DRD6 meeting)
- Find the good pairing, means that a good purity of the photon(s) sample, versus debris of charged hadrons, K_L, n, π°(at high π° energy)
- A very good efficiency to reconstruct the photon down to very low energy

An ULTRA GRANULAR ECAL with **π° mass fit** is **significantly better** than an ECAL at 5%/√E

Here, I didn't address the problem of the energy threshold for the photon(s) sample which could be a major problem for this channel *





* In order to have a good purity, the photon energy threshold could be relatively high for many ECAL (i.e. 250 MeV) , for ultragranular Si-W ECAL , a threshold at 50 MeV seems totally possible (see my talk at the last DRD6 meeting)

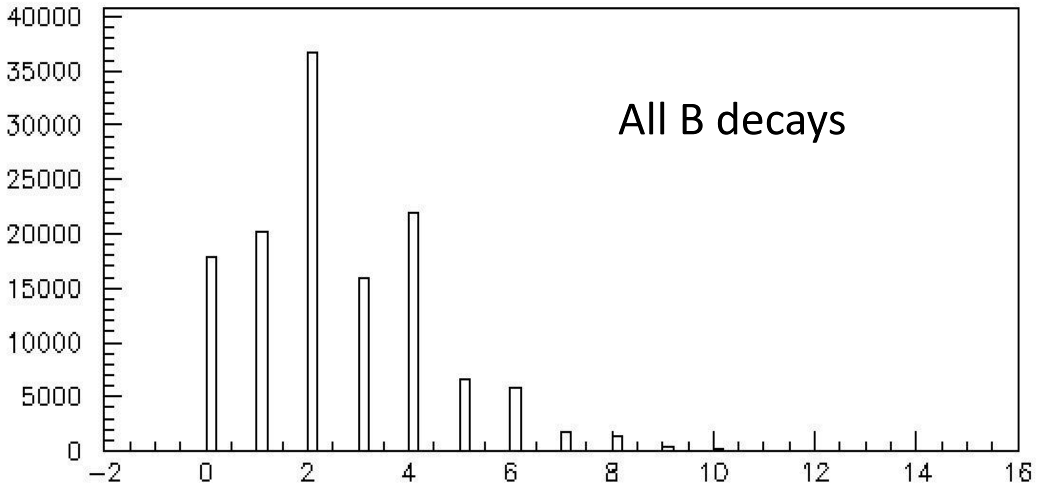
2 . $B^\circ \rightarrow \pi^\circ \pi^\circ$

Tag the B on one side of the **thrust axis** and study the opposite side of the thrust

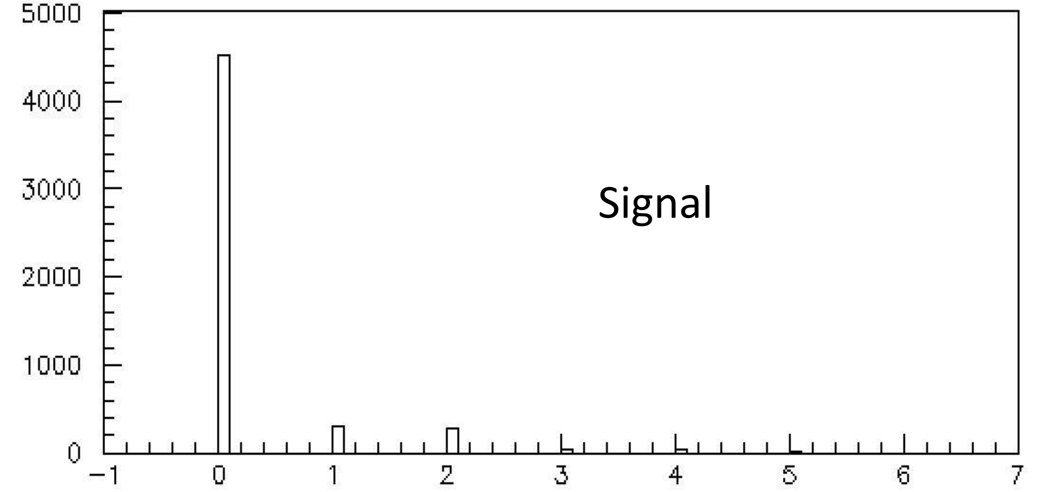
The tracks in this hemisphere are coming from fragmentation,
A priori, small number of displace vertex ,
therefore, tracks comes from Primary vertex.

Here , multiplicity of tracks outside of 20 µm d0
(in other words, we expect no displaced tracks among the particles created by the fragmentation)

Hemisphere side opposite to the B tagging



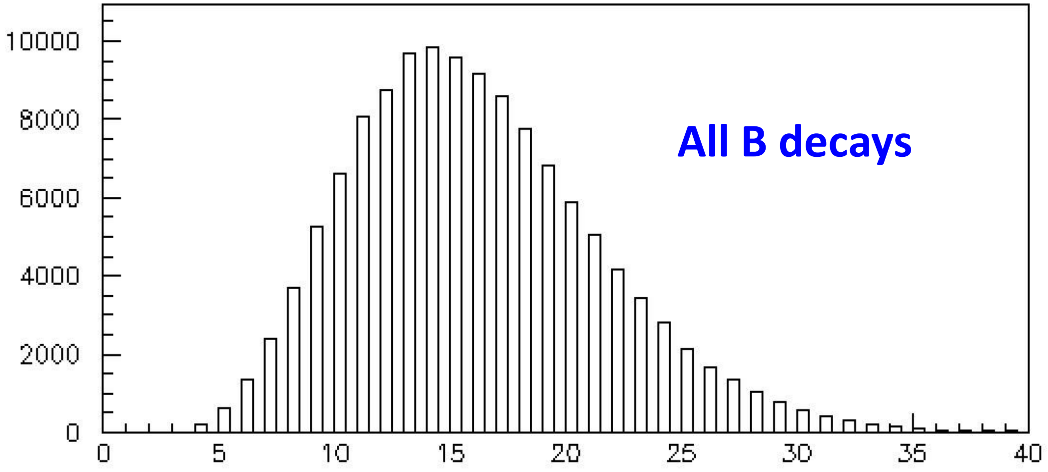
Number of charged tracks out of IP



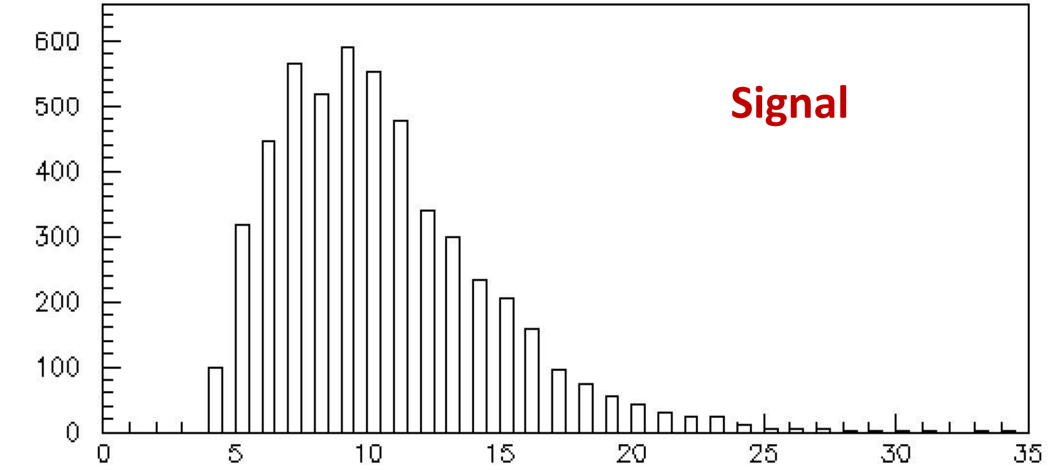
Number of charged tracks out of IP

2 . B° → π° π°

Hemisphere side opposite to the B tagging

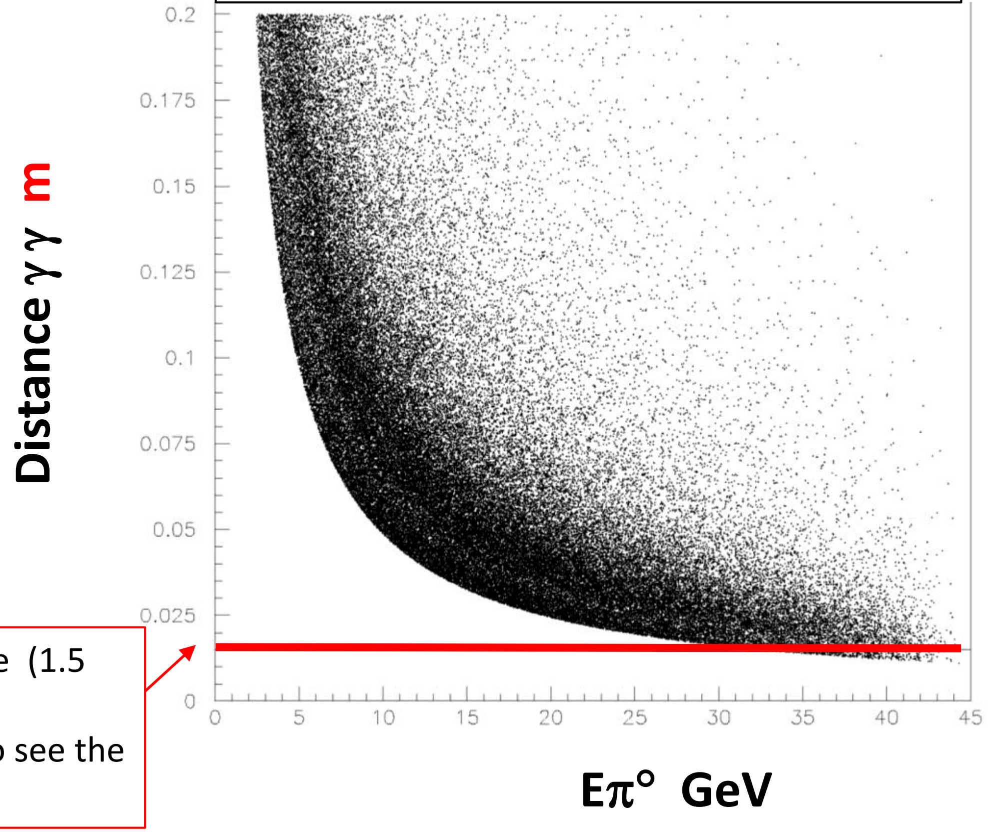


Photon(s) multiplicity in the hemisphere



Photon(s) multiplicity in the hemisphere

The γ/π° identification

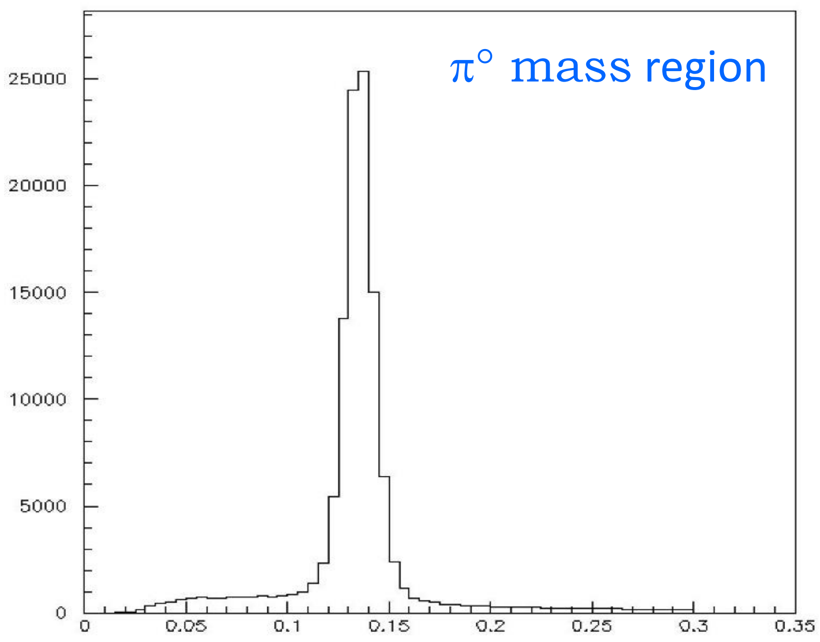


3 pixels distance (1.5 cm) ECAL entry
= no problem to see the 2 photons

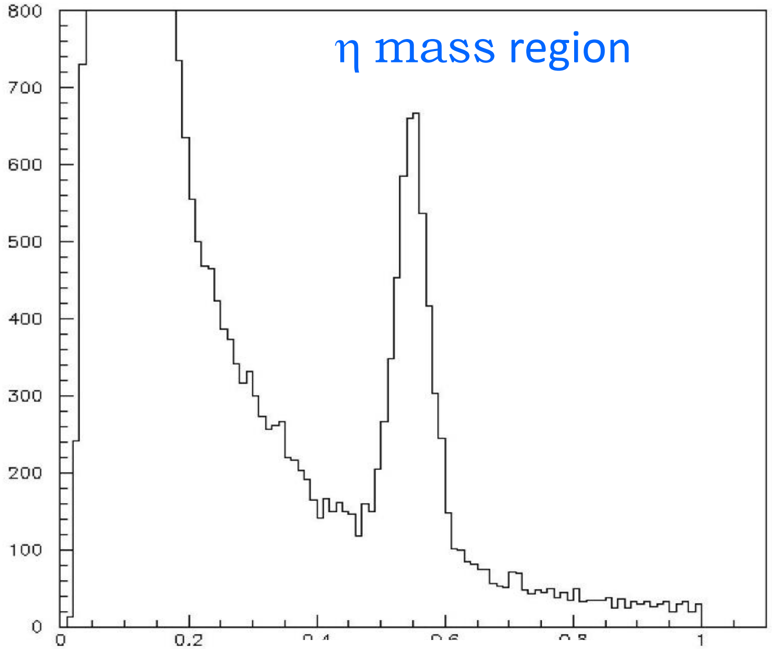
With the bulos mass method,
we can probably goes higher than 35 GeV

2 . B° → π° π°

Choose the **largest energy photon in the thrust hemisphere** , and then,
take its "companion" (the closest to the first photon). Plot the mass of these 2 photons



$\gamma_1\gamma_2$ mass (GeV)



$\gamma_1\gamma_2$ mass (GeV)

Since the energy of the π° is large,
The Id. γ/π° at large energy
Is the key parameter
(thanks to very small pixel size)

Define the B "jet" as the direction of this 2 photons and take
the highest energy photon among the remaining photon(s) in the cone jet
Use the rest of the photon(s) in the "jet" , take a "good" combination
(2 π° mass in 4-7 GeV and γ γ mass in the pi0 mass region)

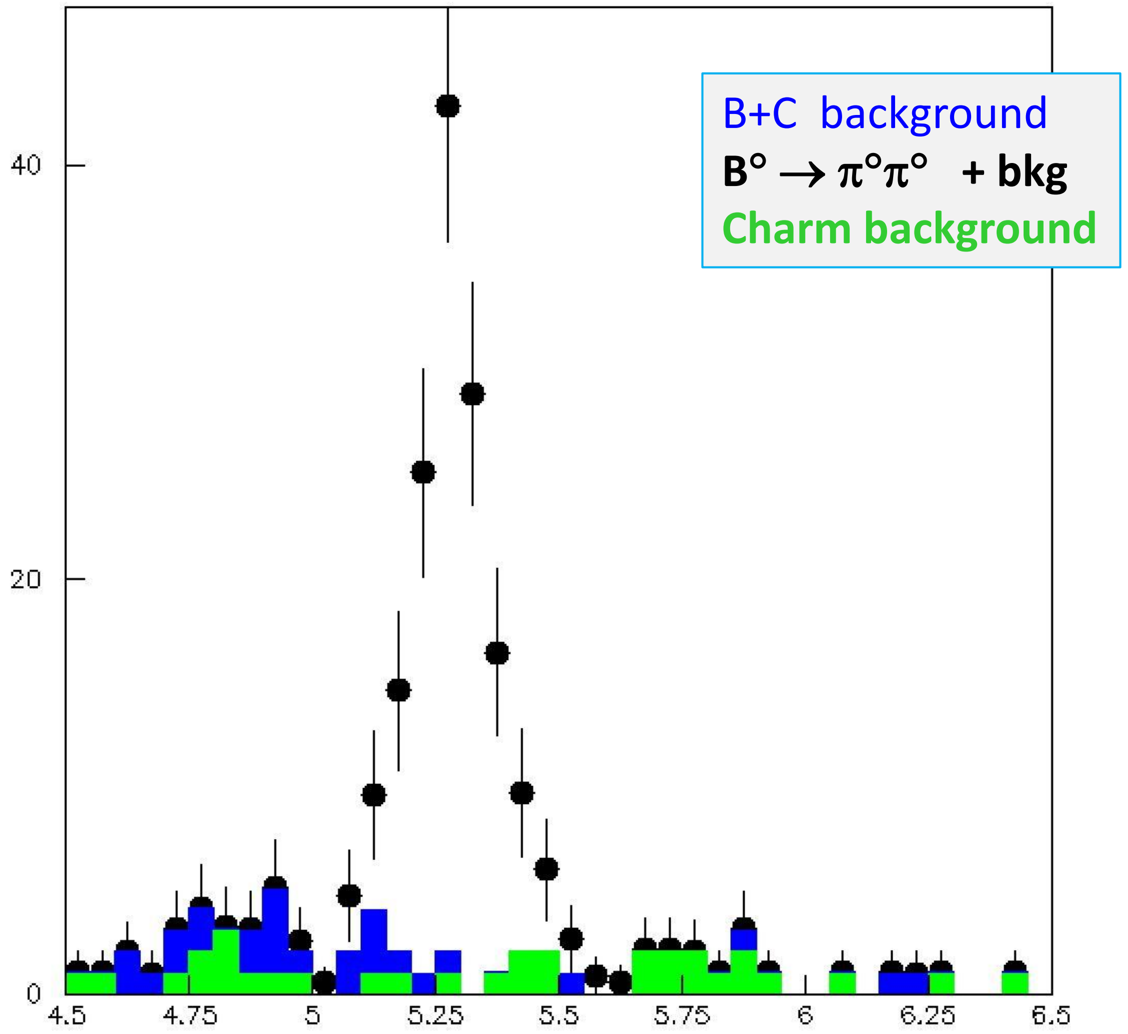
Additional cuts on the angular distribution and kinematic
→ B° and π° are spin-zero , energy of the components are
symmetric , while background is very asymmetric

2 . B° → π° π°

- Since we tag the b quark on one side, the background is coming from the standard b decays and from the charm quarks misid. (u,d,s neglected)
- The PDG values 1.55 10^{-6} BR for B°→ π° π° is used
- No comparison with other ECAL, since I don't know their performances
  - γ/π° identification as a function of Eπ°
  - γ/K°/n/debris (of charged) identification
  - the γ position precision (mandatory for fitting the π° mass varying only the photons energies)

About 100 B° → π° π° for 10^9 Z produced
With a purity of about **90%**

100K B° → π° π° for **10^{12} Z**

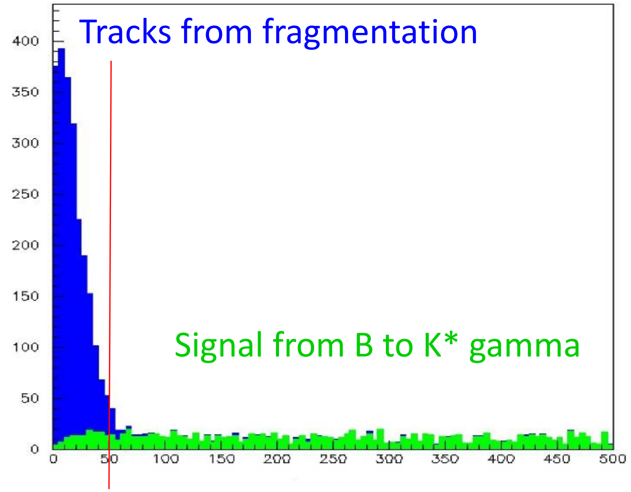


Mass (π°π°) (GeV)

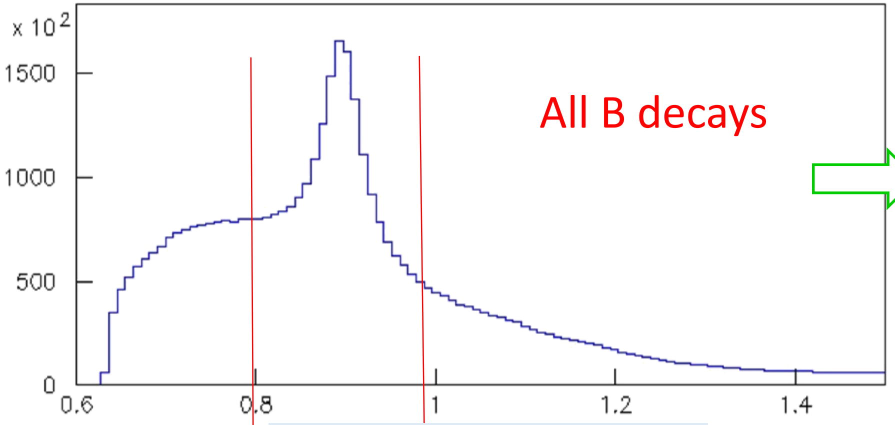
3 . B°→ K* γ

Signal selection : a K*(890) with displaced vertex !!

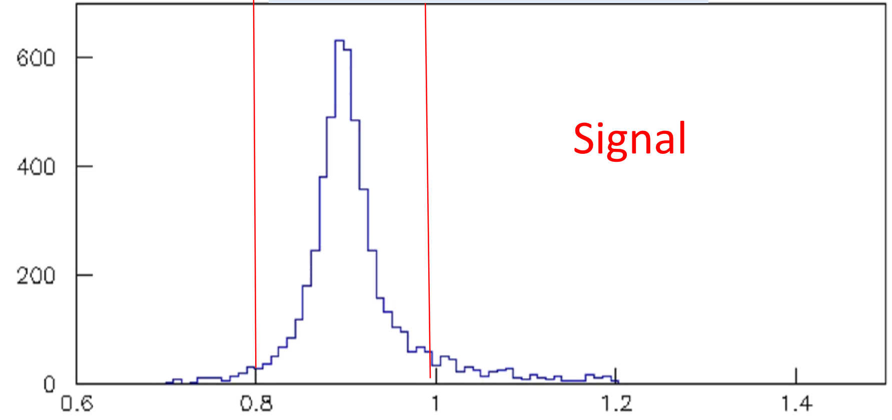
a charged $K^{+(-)}$ and a charged $\pi^{-(+)}$ with a same vertex and at some distance to collision point



Distance to collision point (μm)



Mass $K^+\pi^-$ or $K^-\pi^+$ GeV

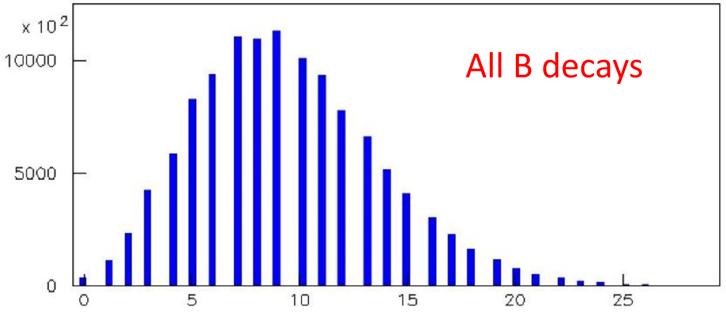


Mass $K^+\pi^-$ or $K^-\pi^+$ GeV

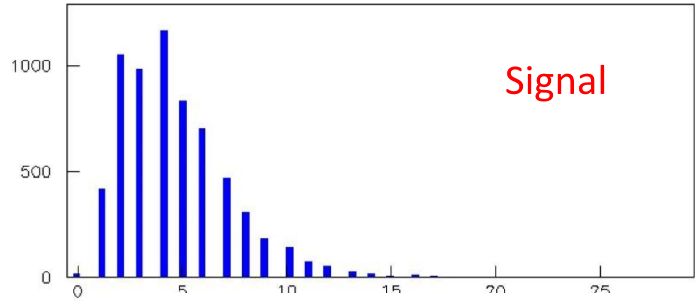
Now, we have to find the good photon

Define the direction of jet with the tracks vertex (K,π)

Photons inside the cone of 30 degres



Number of photon(s) in the K* jet



Number of photon(s) in the K* jet

From Experts,

The precision on the vertex is about σ= 15 μm. I use this value and the cut is at 50 μm

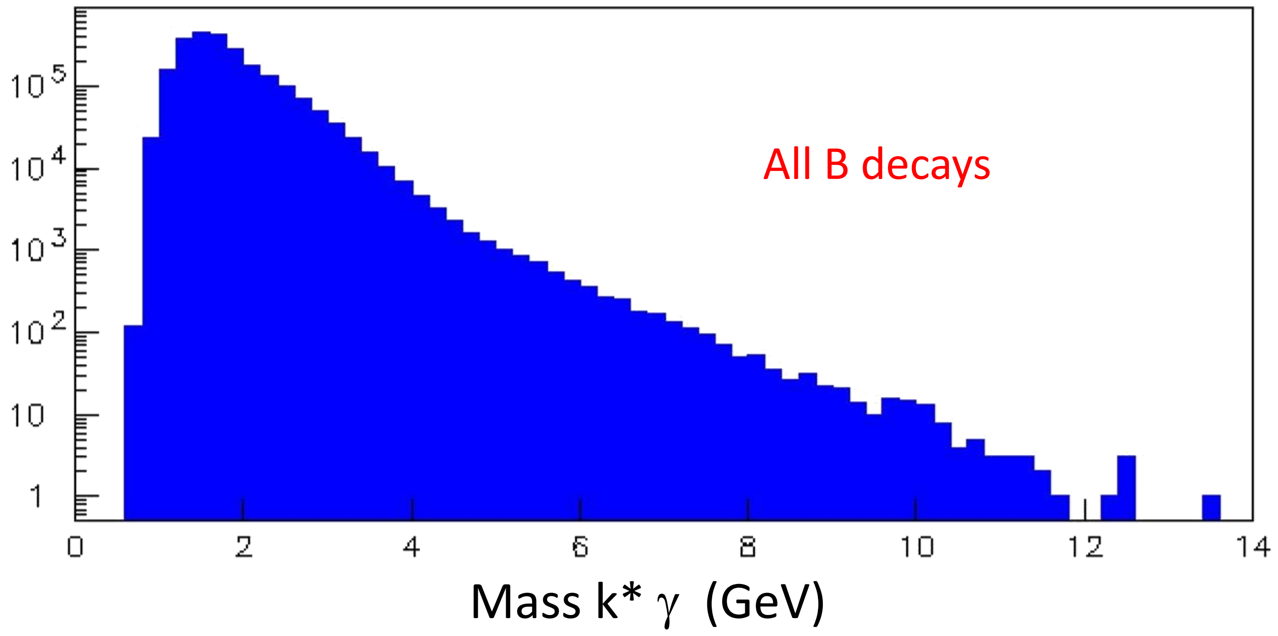
3 . B°→ K* γ

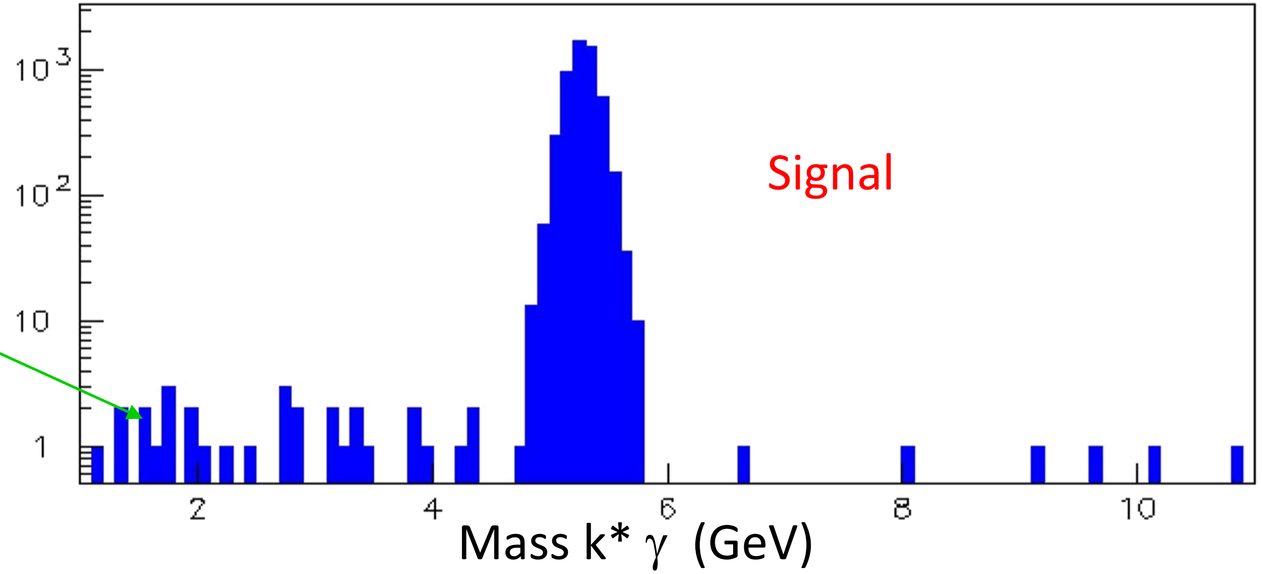
Since the photon could be at large energy
It is important to take into account
the separability γ/π°

Therefore,
When 2 photons are closer than **1.5 cm**,
There merged to form a single cluster

select
the cluster with the largest energy
in the jet cone,

When the choice of the good
Photon is not correct





3 . B°→ K* γ

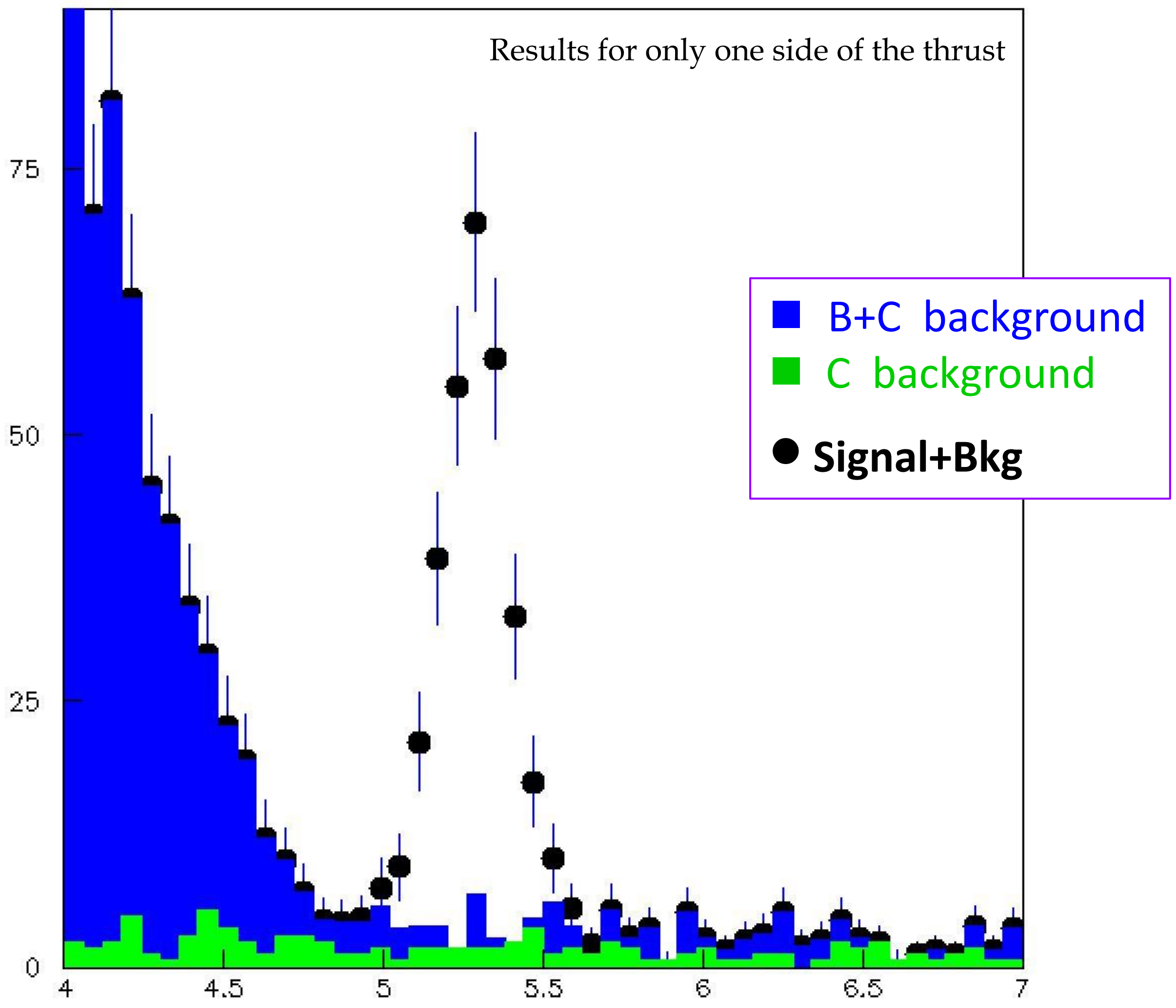
- Displaced (>50μm) K* (cut 0.85-1.0 GeV)
- Jet energy (system K*γ) > 30 GeV
- Photon energy > 5 GeV
- Only one displaced K* in the thrust hemisphere

Almost **1000** **B°→ K* γ** for **10^9 Z** decays,
The sample has a purity of 90%
1M for **10^{12} Z**

WARNING **Asumptions**

- The efficiency of the b tagging is taken at 95% and the b/c misid. at 10% for c quark
- The BR(B°→ K* γ) is taken from PDG 4.18 10^{-5}
- u,d,s background is neglected
- no 2-photons background added (a priori , small contribution , since a displaced K* and one photon above 5 GeV!!)
- The selection efficiency is about 50% (not perfect for sure)

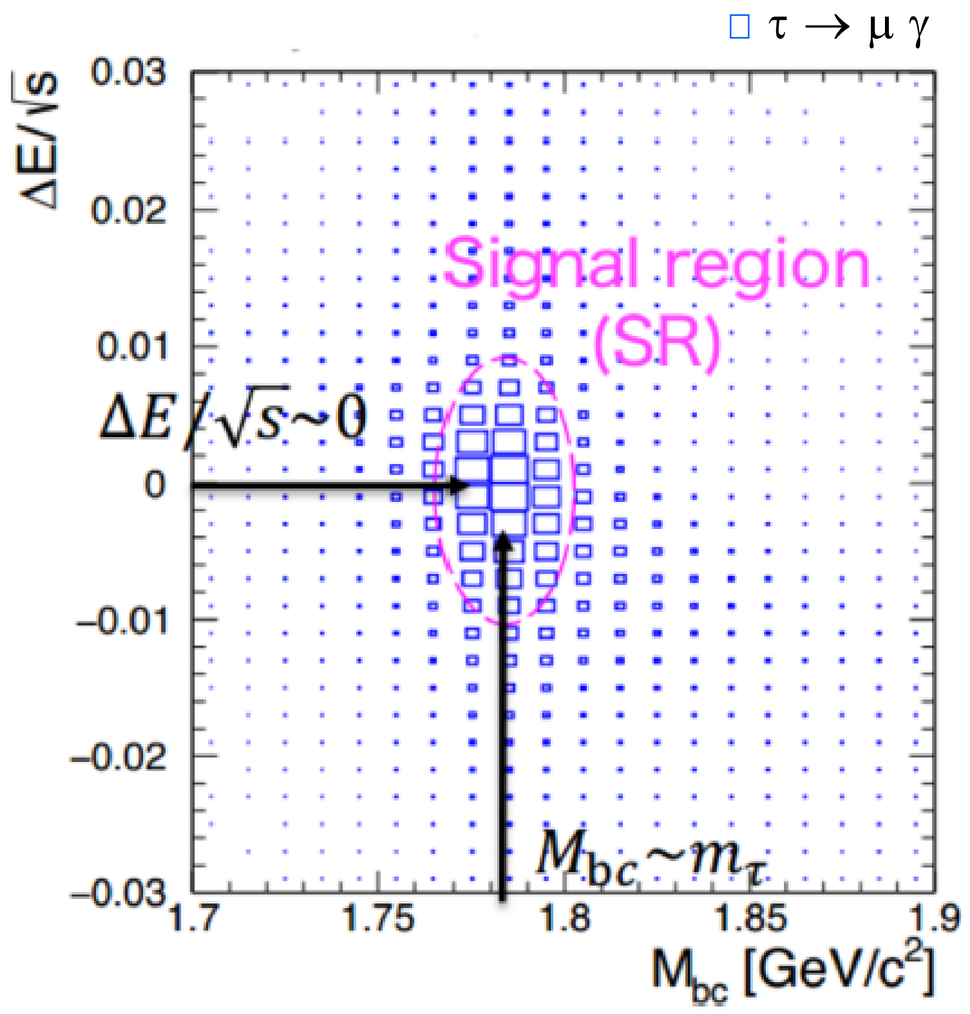
Si-W ECAL + New calo-5D reconstruction



Mass k* γ (GeV)

4. τ physics rare decays

Taking the example of $\tau \to \mu\gamma$ (example of backgrounds in the backup slides)



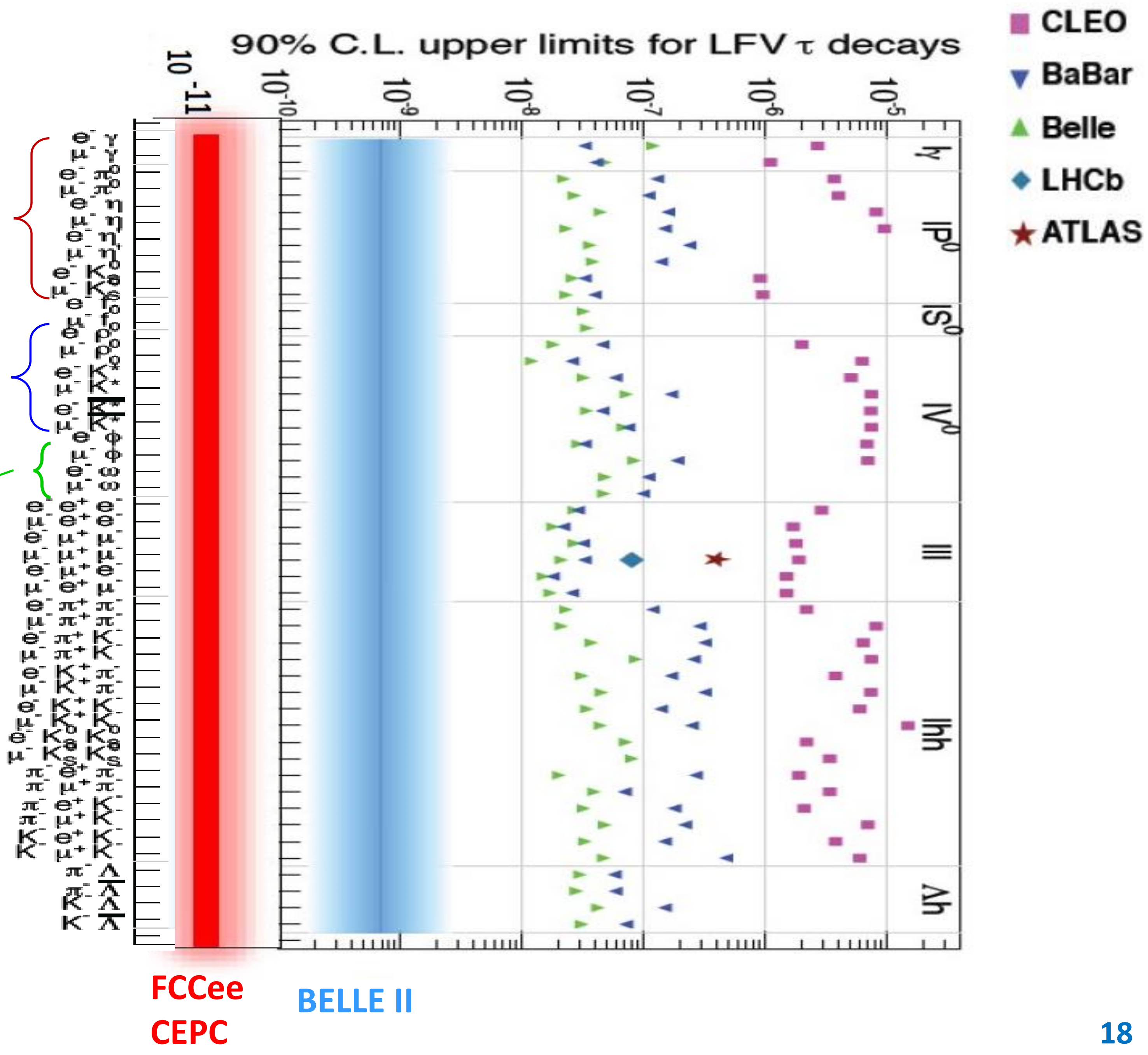
signal region

- $M_{bc} = \sqrt{(E^{CM}_{beam})^2 - (p^{CM}_{\ell\gamma})^2} \sim M_\tau$
- $\Delta E = (E^{CM}_{\ell\gamma} - E^{CM}_{beam}) \sim 0 \text{ GeV}$
- for background M_{bc} distribution will vary smoothly without peaking
- signal region is blinded during the analysis!

4. τ physics rare decays

- BC mass,
- γ/π°,η Identification
- Meson mass fit (π°, η)

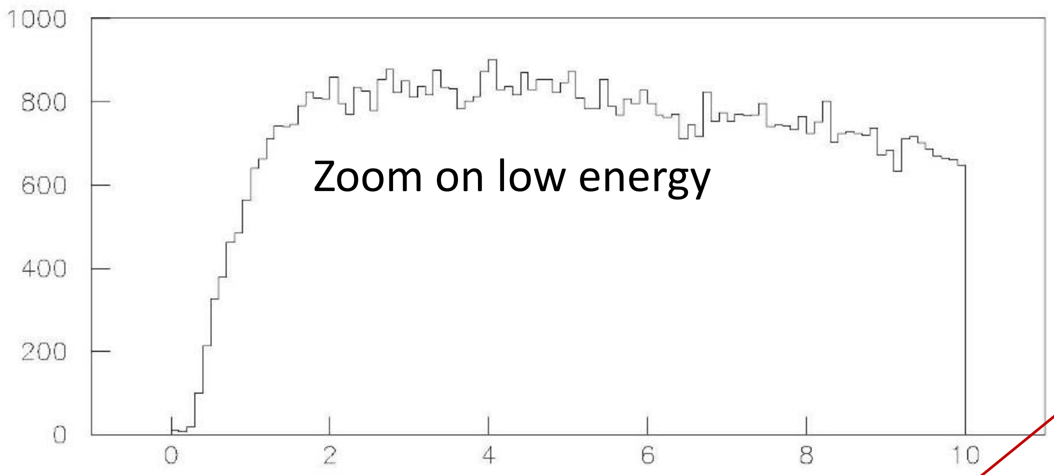
- BC mass,
- γ/π°,η and γ/K° Identification
- Meson mass fit (π°, η)



BC for Beam Constraint

4. τ polarisation

The best sensitivities to measure the polarisation are in the channels $\tau^{\pm} \rightarrow \rho^{\pm}\ \nu$ and $\tau^{\pm} \rightarrow \pi^{\pm}\ \nu$



Eπ° GeV

tau decays $\tau^{\pm} \rightarrow \rho^{\pm}\ \nu \rightarrow \pi^{\pm}\ \pi^{\circ}\ \nu$

The essential parameter is the photon counting (efficiency and purity)

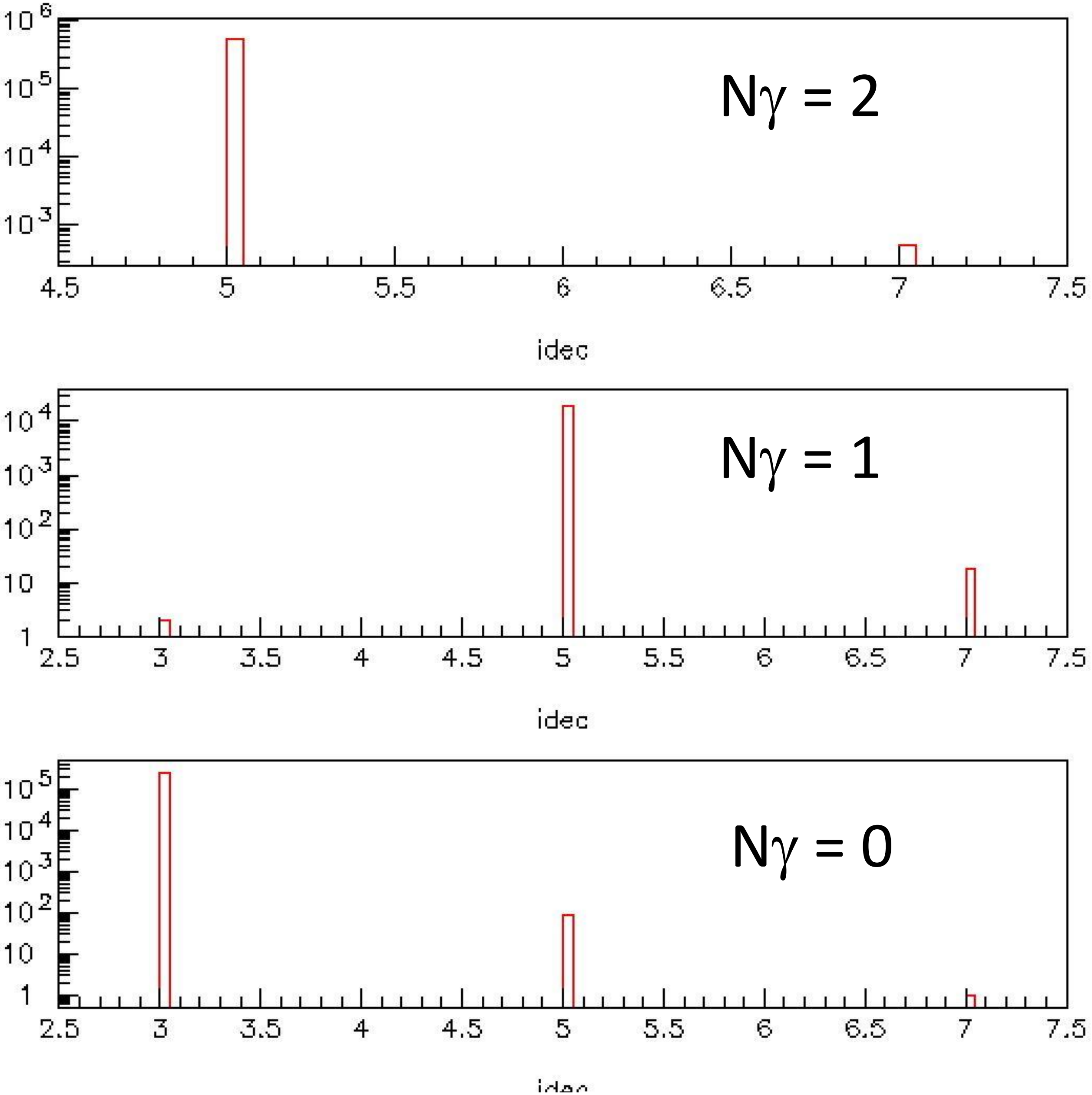
- **The energy threshold for Photon(s) reconstruction**
- The threshold on the distance in ECAL between the closest charged/photon (to avoid debris of charged hadrons)
- **Identification $\gamma/\pi^{\circ}/K^{\circ}_{L}/n$**

The channels Id. between $h^{\pm}\nu$ from $\rho^{\pm}\ \nu$ is the key parameter for the $\tau^{\pm}$ polarisation measurement

The energy resolution is a second order variable *

* With the new 5D rec. about 98.% the 2 photons are reconstructed, allowing the π° mass fit, improving a lot the resolution

Selection of the decays channel with the 5D reconstruction in SiW

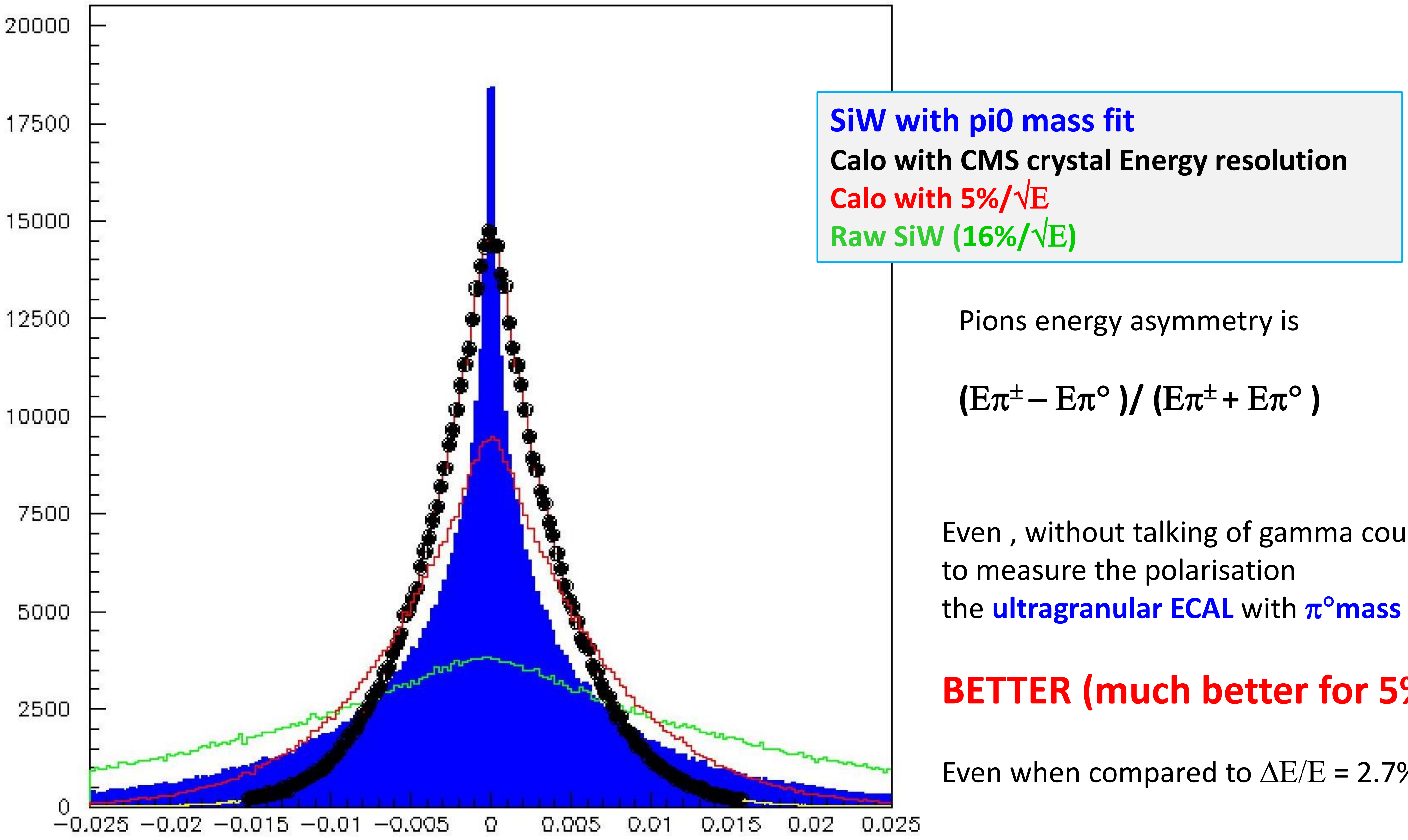


Idec =

3 for $\tau^{\pm} \rightarrow \pi^{\pm} \nu$

5 for $\tau^{\pm} \rightarrow \rho^{\pm} \nu$

7 for $\tau^{\pm} \rightarrow \pi^{\pm} 2\pi^{\circ} \nu$



Pions energy asymmetry (MC-Rec)

Pions energy asymmetry is

$$(E\pi^{\pm} - E\pi^{\circ})/(E\pi^{\pm} + E\pi^{\circ})$$

Even , without talking of gamma counting,
to measure the polarisation
the **ultragranular ECAL** with **π°mass fit** is

BETTER (much better for 5% calo)

Even when compared to $\Delta E/E = 2.7\% / \sqrt{E}$

Ultra granular calorimeter and flavour physics

- The calorimeter Si-W **F**ast **S**imulation (**FS**) was used to **study Bs → Ds K or Ds π** (Ds → ϕ ρ → KK $\pi^{\pm}\pi^{\circ}$)
  (Thanks to π° mass fit, good position resolution, a very low energy threshold for photon and a very good γ/K°_{L} Identification)
the "B" mass resolution is better than a 5%/√E like in crystal calo.

- Using the same **FS** for **$B^0 \to \pi^{\circ}\pi^{\circ}$,** a very good S/N could be obtained.
  (Thanks to π° mass fit, good position resolution and almost perfect γ/π° identification)

- The calorimeter Si-W **FS** was used study **b → s γ (B° → K* γ) .** A purity of **90%** with a reasonable statistic could be obtained (the key there is the very good γ/K°_{L} /n and γ/π° Identification)

- The rare decays of the tau decays (i.e. τ→μ γ) has been investigated. the BC mass could be very useful but
  A very good γ/K°_{L} ,n and γ/π° Identification is mandatory

- For the measurement of the τ polarisation , **the efficiency and purity of the photon counting** (sample) is the relevant parameter .... NOT the Energy resolution

The paradigm about energy resolution for flavour physics is not always true
In many case, an ultragranular ECAL is a better choice

Calorimetry – Requirements

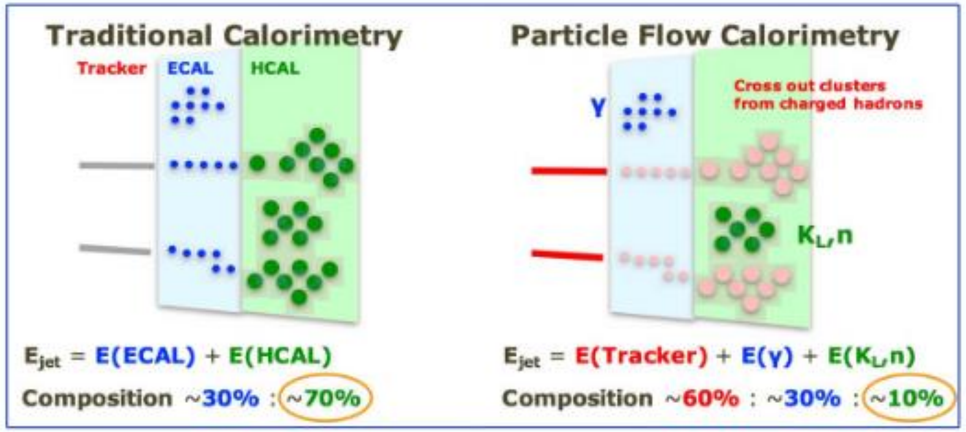
Energy coverage < 180 GeV ⇒ moderate depth: **22 X_0, 6-8 λ_{int}**

3-4 % di-jet mass resolution needed to differentiate between W- and Z-origin of di-jet systems

☞ Translates into requirement on jet energy resolution:

Jet energy: $\delta E_{jet}/E_{jet} \simeq 30\% / \sqrt{E}$ [GeV]

Improved jet energy resolution via **Particle Flow** method

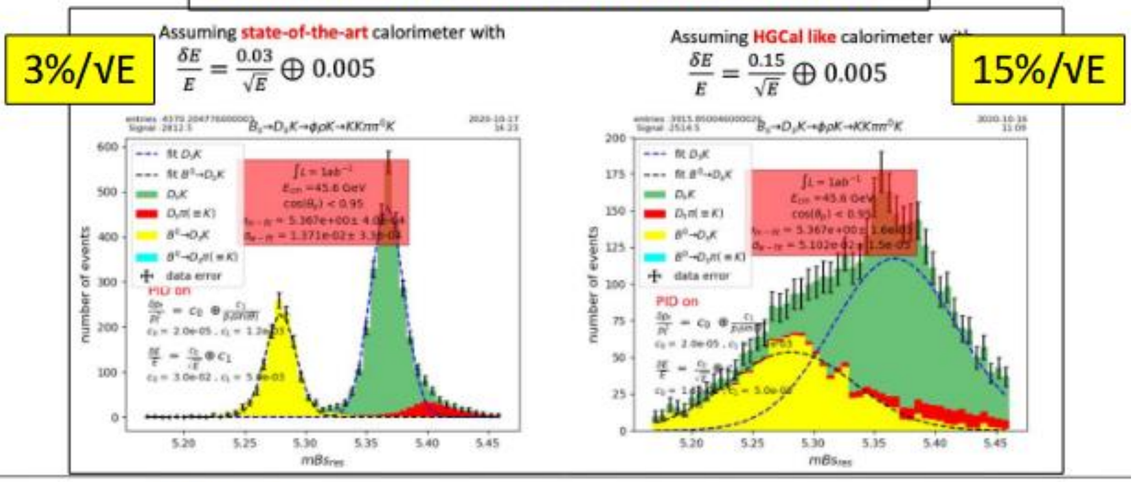


☞ High granularity !
☞ Possibly combined with Dual Readout

Requirements include

- Energy resolution
  - γs & neutral hadrons for Pflow; e/π separation via E/p
- Dynamic range: 200 MeV – 180 GeV
  - Flavour & τ phys: sensitivity to π^0s down to few-100 MeV
- Granularity: for Pflow and PID
  - e/π separation from shower shape; γ/π^0 separation
- Hermeticity, uniformity, calibrability, stability
  - Reduce systematics !!!

Example of B-physics final state with π^0



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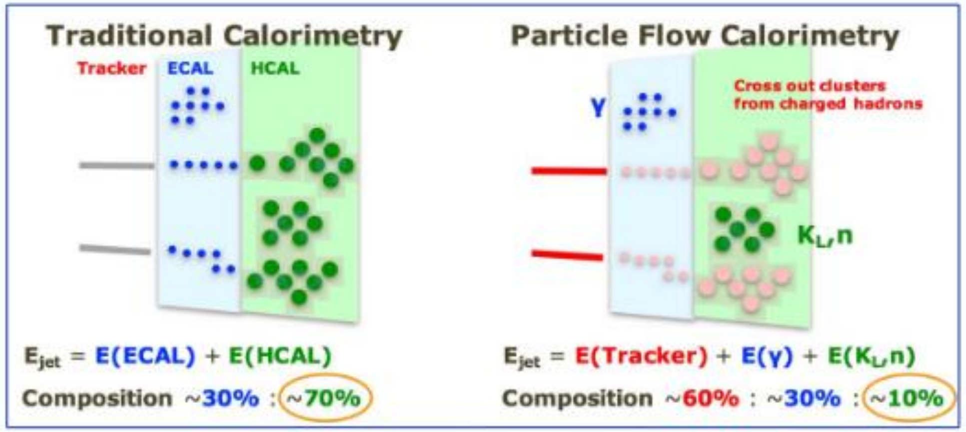

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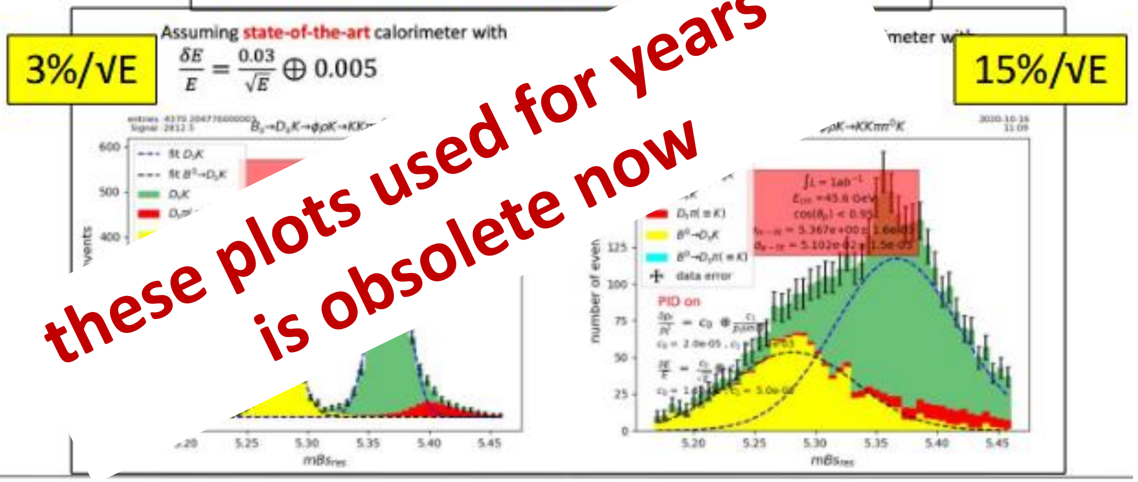
Down to O(50) MeV

Example of B-physics final … π^0



Conclusion

- Ultra granular Si-W ECAL is **a good choice also for flavour physics**

It is true for FCCee , CEPC as well as for LCF , It allows with $\pi°$ mass fit, to have statistically interesting samples with **90% purity , In some case, ultragranular ECAL is the best choice**

(good stat. and purity, opening the possibility to have an interesting precision on this physics i.e. CKM, CPV, Rare decays, etc)

NEXT :

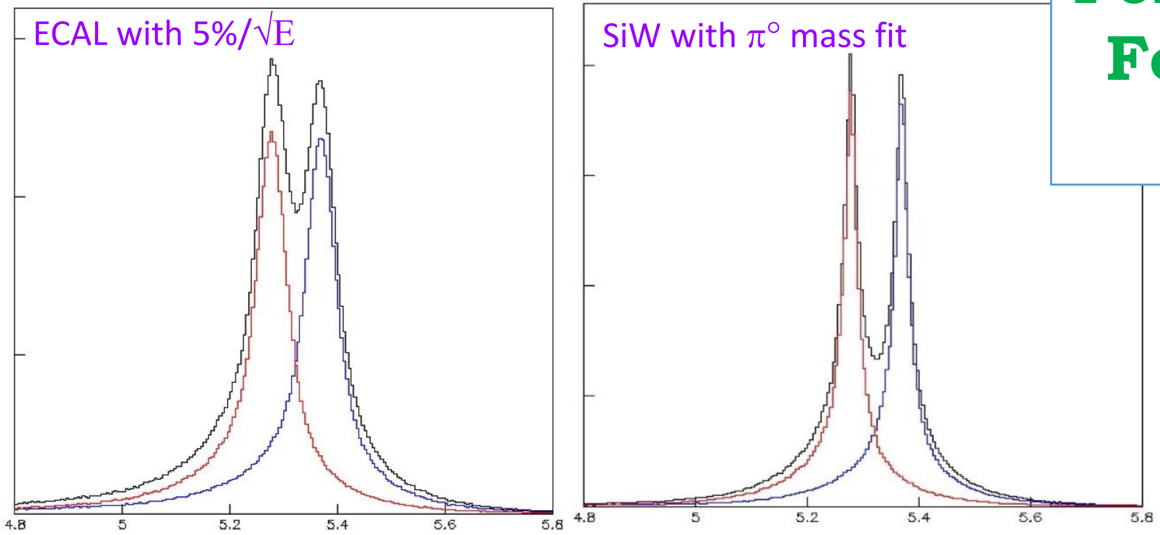
- Analysis with all b and c background for Bs to Ds K or Bs to Ds π, using the same method (the $\pi°$ mass fit)

- Quantify the cross talk in tau hadronic decays , how it depends on the low energy photons threshold and $\gamma/\pi°$ id. , etc…
  Quantify the precision on the polarimeter variable, (ultragranular versus crystal) Etc…

BACKUP

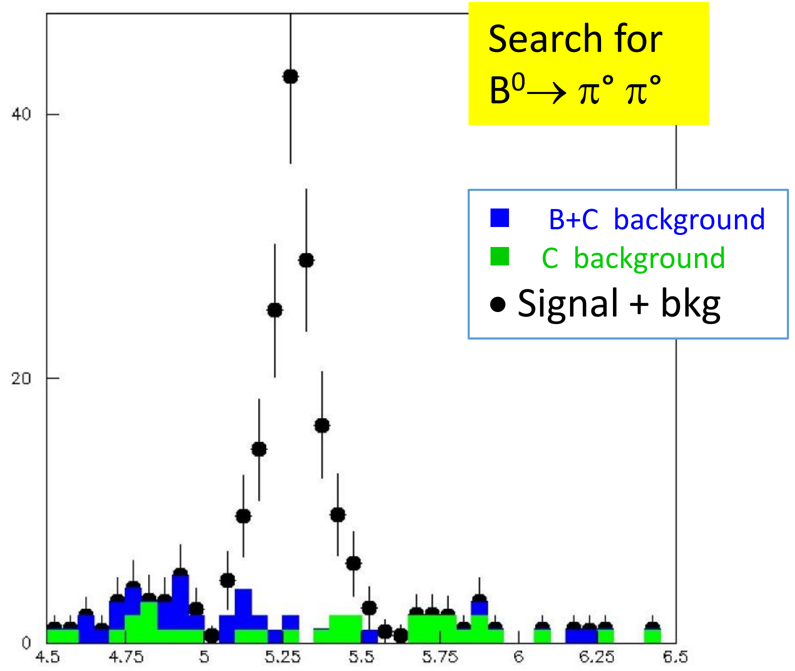
Si-W ECAL Performances For flavour physics

Search for Bs→Ds K±
Ds to φ ρ , φ → k+k-



Mass k^+k^- **K±** π± γ γ **(GeV)**

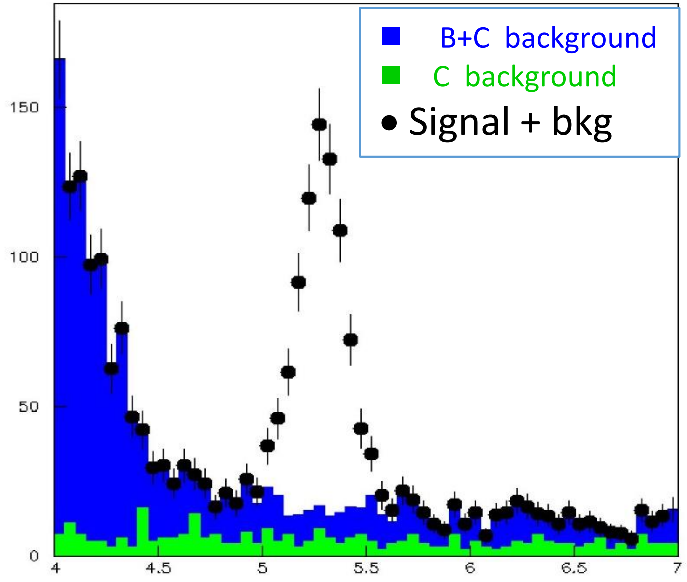
Search for
B^0→ π° π°



Mass π° π° (GeV)

Search for
b → s γ

With
B^0→ K* γ



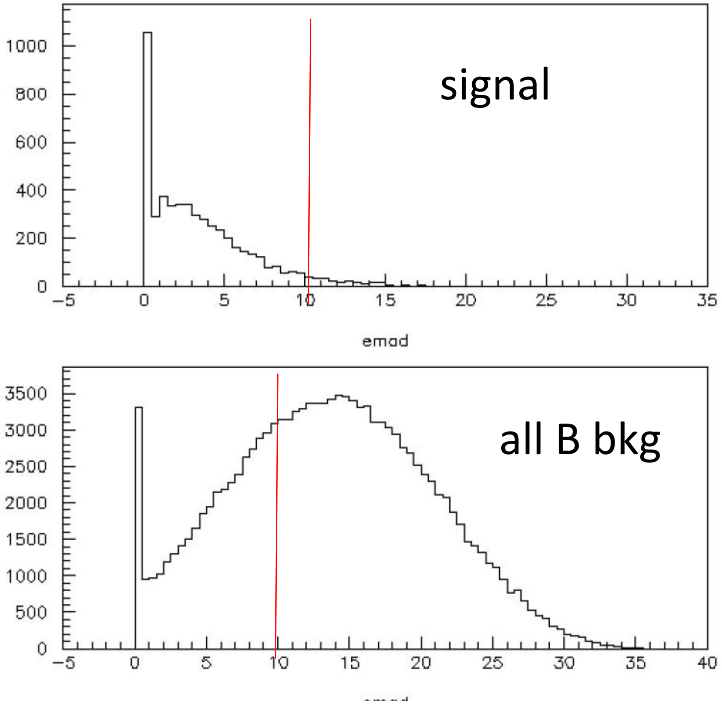
Mass K* γ (GeV)

<u>No bias on the choice of the good photons</u>
It is based on the position and energies,
All photons from fragmentation or
from other b or c decays are taken into account

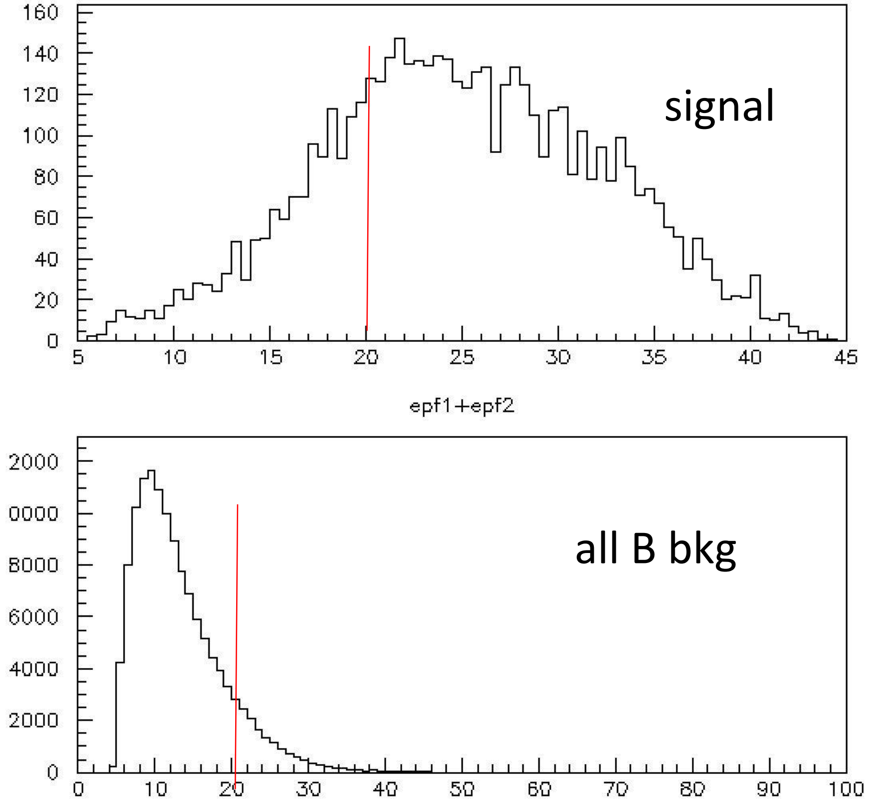
2 . B° $\rightarrow \pi^\circ \pi^\circ$

In the remaining photon, take the largest one, and then find the 4th photon by choosing the one with
The closest mass to the pi zero
Together with a pio pio mass larger than 4 GeV

2 more cuts



Energy in the jet not coming from the 2 pi0

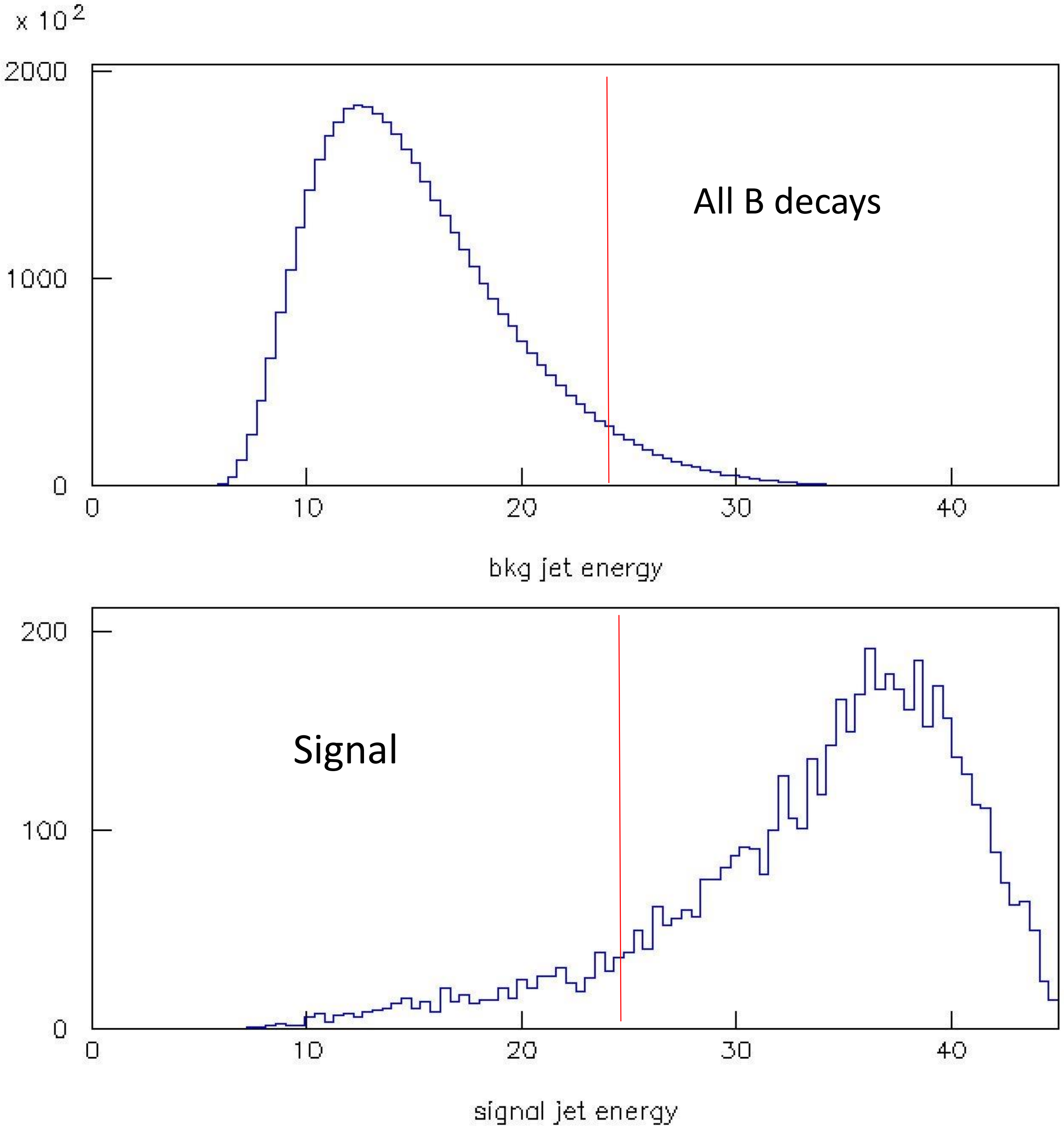


After the π° mass fit, Energy of the B0 candidates

3 . B°→ K* γ

BUT

Defining the jet as the (k*γ) system



Example of background for $\tau \to \mu \gamma$

- $Z \to \tau \tau^*$, $\tau^* \to \tau \gamma$ and $\tau \to \mu \nu_\mu \nu_\tau$, final state is the good one , only energies are different
- $Z \to \tau \tau$, $\tau \to \rho\nu_\tau \to \pi^\pm \pi^\circ \nu_\tau$ and $\pi^\pm \to \mu \nu_\mu \Rightarrow$ Kink finder and photon(s) counting essential
- $Z \to \mu \mu \gamma$ (ISR or FSR) , tau id essential

Etc…