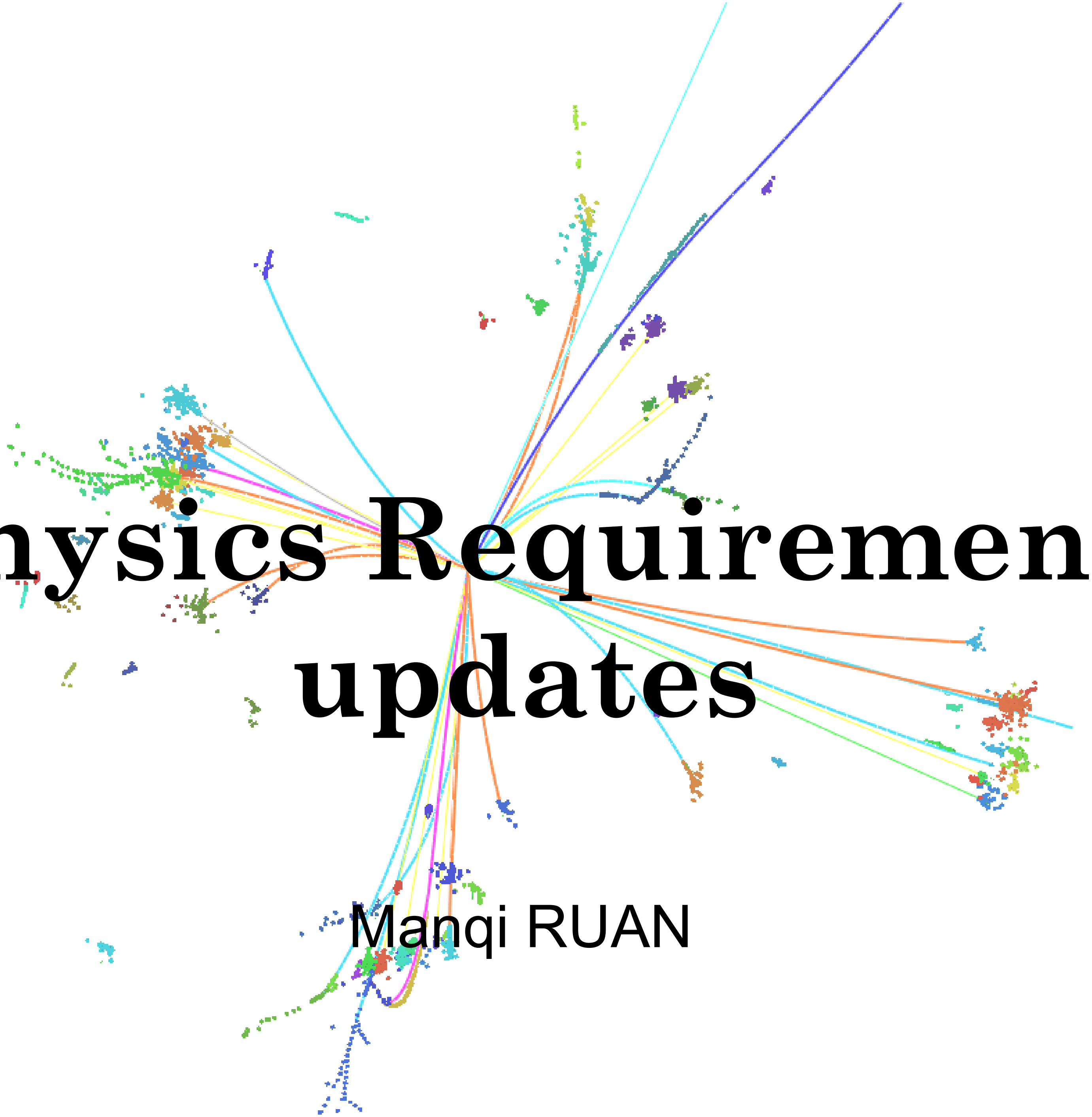


Physics Requirement: updates

Manqi RUAN

Requirement study: basic logic

- Principle: the detector performance shall not be the bottleneck for objective physics measurement!
  - ...Within the current/projective technology/cost allowance...
  - ...Better is better, especially for multi-propose experiment(s)...

- Key operations:
  - Select benchmarks
  - Quantify the high-level performance requirements –
    - Dependence of measurement accuracy on the signal/noise separation power & measurement precision -> as a function of key physics object reconstruction performance: efficiency, purity, accuracy.
  - Translate the requirements on high-level object reconstruction performance requirements into those of intrinsic sub-detector performance with appropriate reconstruction Algorithm...

Requirements at the CDR

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

Table 3.3: Physics processes and key observables used as benchmarks for setting the requirements and the optimization of the CEPC detector.

Update

Summary

- The CEPC, a high precision Higgs/Z factory, has very rich physics program and mı stringent requirements on its detector performance
- Higgs factory:
  - Hadronic system
    - The majority of Higgs events has jet final states; many important EW measurements relies on multi-jet processes.
    - BMR < 4%: to separate qqH signal from qqX background with recoil mass
    - To investigate innovative color singlet identification algorithm (optimize jet clustering-matching or beyond)
  - Relative track momentum resolution ~ 0.1%
  - Isolated Leptons and taus;
    - Isolated leptons: eff*purity > 99% (eff > 0.995%, mis-id < 1%);
    - Isolated Tau finding: eff*purity > 70%.
  - VTX: efficiently separate the b, c, and light jets.
    - eff*purity of c-tagging at $H \to jj$ events. Aim for eff*purity >> 10% (i.e. 25%?

Summary

- Z factory: finding objects inside jets...
  - Tracks: energy threshold ~o(100) MeV, $\delta p/p$ << 0.1%;
  - Photon: energy threshold ~o(100) MeV;
  - π^0 reconstruction:
    - separate photons from 30 GeV π^0, count #π^0 in tau decay.
    - EM resolution of ~5%/sqrt(E), for π^0 finding in hadronic events
  - Leptons: eff > 99.5% & mis-id < 1% for all leptons, especially jet leptons
  - 3σ Pi-K separation up to 20 GeV, to identify hadrons decay into kaon & proton
  - VTX: to reconstruct all 2nd vertex (with more than 2 tracks) with sufficient accuracy.
    - Identify & characterize the b-jet ($b \to B^* \to B \to D^* \to D \to \ldots$), c-jet, light jets...
    - Separate 3 prong tau from D background
    - Need to associate those requirements on VTX performance (position, efficiency, occupancy...)
  - Missing energy/momentum measurements
- In general: Z factory has extremely rich physics program, and a better detector always leads to better physics reach. More benchmark study & iterations are needed, to further quantify the Z factory physics potential & corresponding requirements.

...from CEPC workshop (Oct 2020)...

On top of Higgs/EW, Flavor Physics requirement - potential is critical.

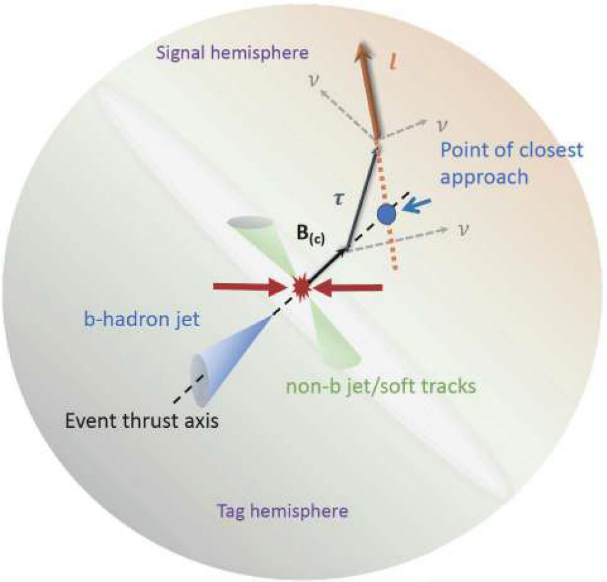
Benchmarks

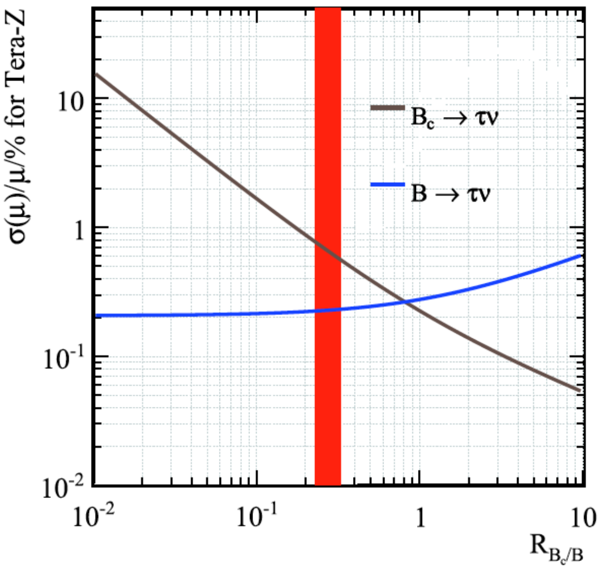
- A good benchmark:
  - Strong Physics motivation
  - Strong comparative advantages V.S. Other facilities
  - Strong dependence on Sub-detector performance: better the stringent requirement

- For CEPC Z pole operation:
  - Heavy B mesons: Bc, Bs;
  - Neutral & Missing energy final states;
  - Taus;

Benchmarks

- Bc → tau v
  - Percentage level accuracy @ CEPC. Published.
  - Requirement: lepton & tau id inside Jet.
- $B_s/B_0 \rightarrow 2\pi_0$
  - ECAL: π_0 reconstruction & mass peak separation
  - B-tagging: reject light/c jets background
  - Charged & Neutral Kaon id:
- B_s → Phi + vv
  - Pid & VtX: Phi reconstruction
  - Missing Energy/momentum (~ hadronic system reco.)
  - Jet lepton: Veto backgrounds from leptonic B-decay
- B_s → J/psi + Phi
  - Jet Charge measurement(eff*(1-mis)^2): ~ 5 times better than LHCb, same side Kaon is essential
- *Discussion/Feedbacks from Snowmass studies, etc.*





In this talk...

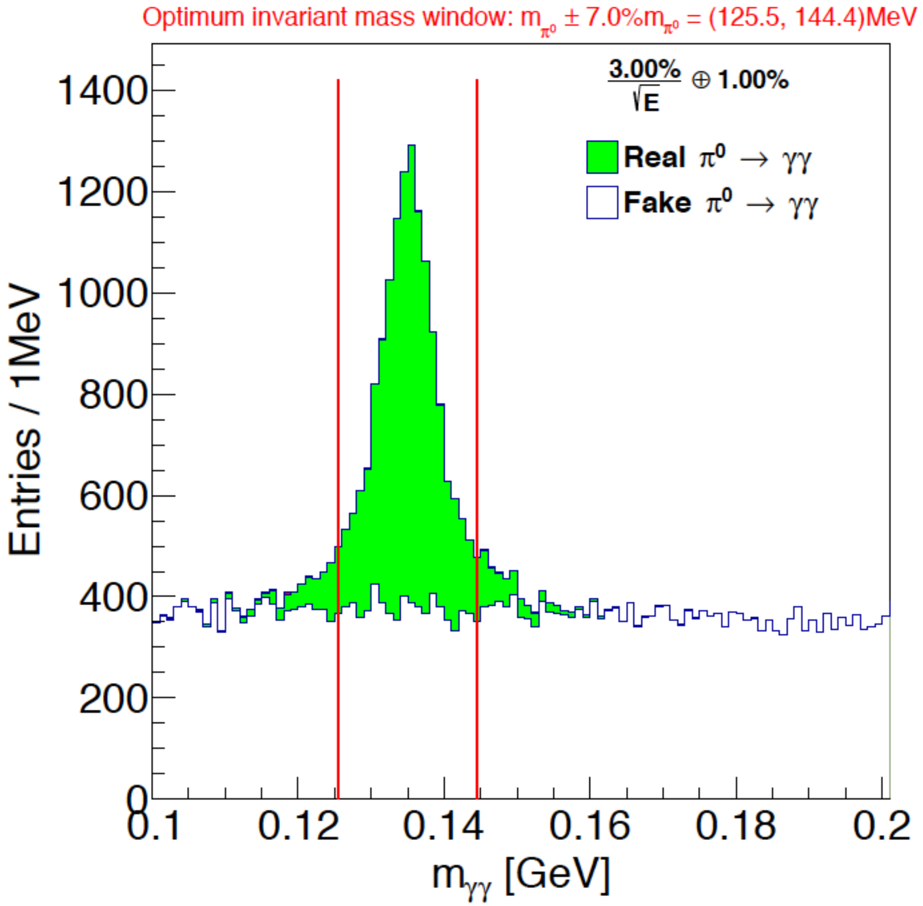
- ECAL, b-tagging & Kaon finding
  - Physics Benchmark analysis with Bs/B0 → 2*pi0

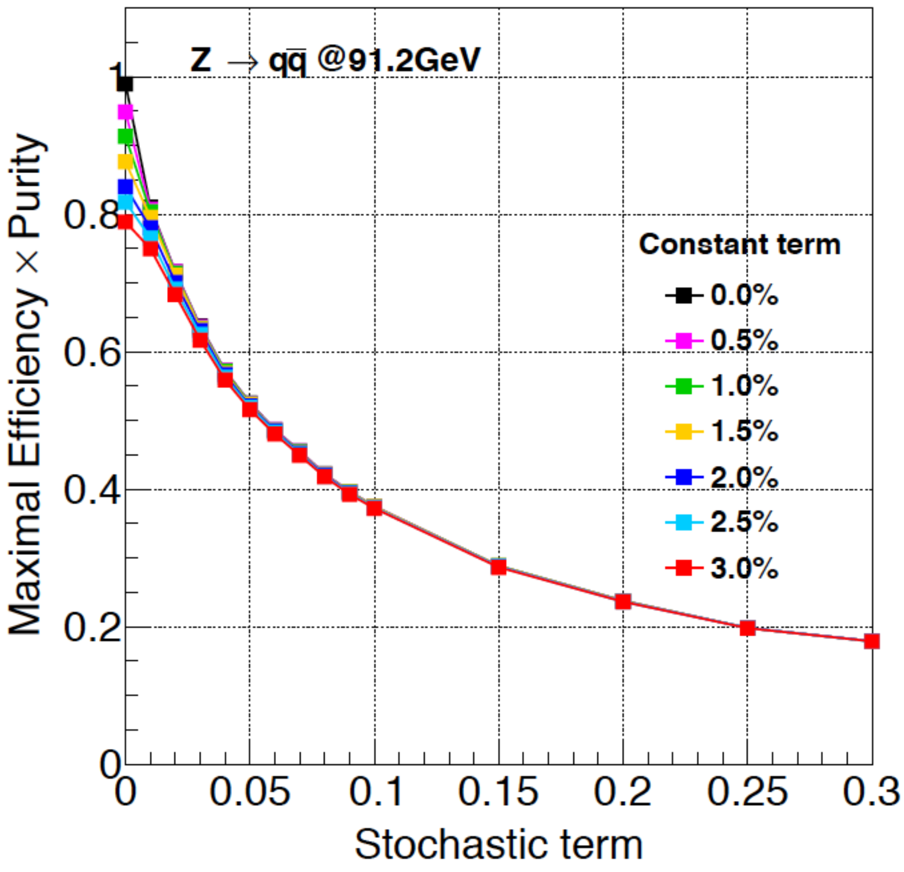
- Separation requirement from 3-prong decay tau

$B_s/B_0 \rightarrow 2\pi_0$

- Characteristic & requirement
  - Pi-0 reconstruction inside jets: final state particle separation
  - ECAL:
    - Reduce fake pi-0
    - Separate the two peak with ~1% relative mass difference: one of the most stringent requirement on CEPC heavy flavor physics.
  - Bs/B0: B-tagging
  - S quark in signal hemisphere:
    - Pid for charged kaons;
    - Kshort/Klong;

pi-0 reco. & ECAL resolution





- pi-0 finding performance in Z->qq: strongly depends on the ECAL resolution...

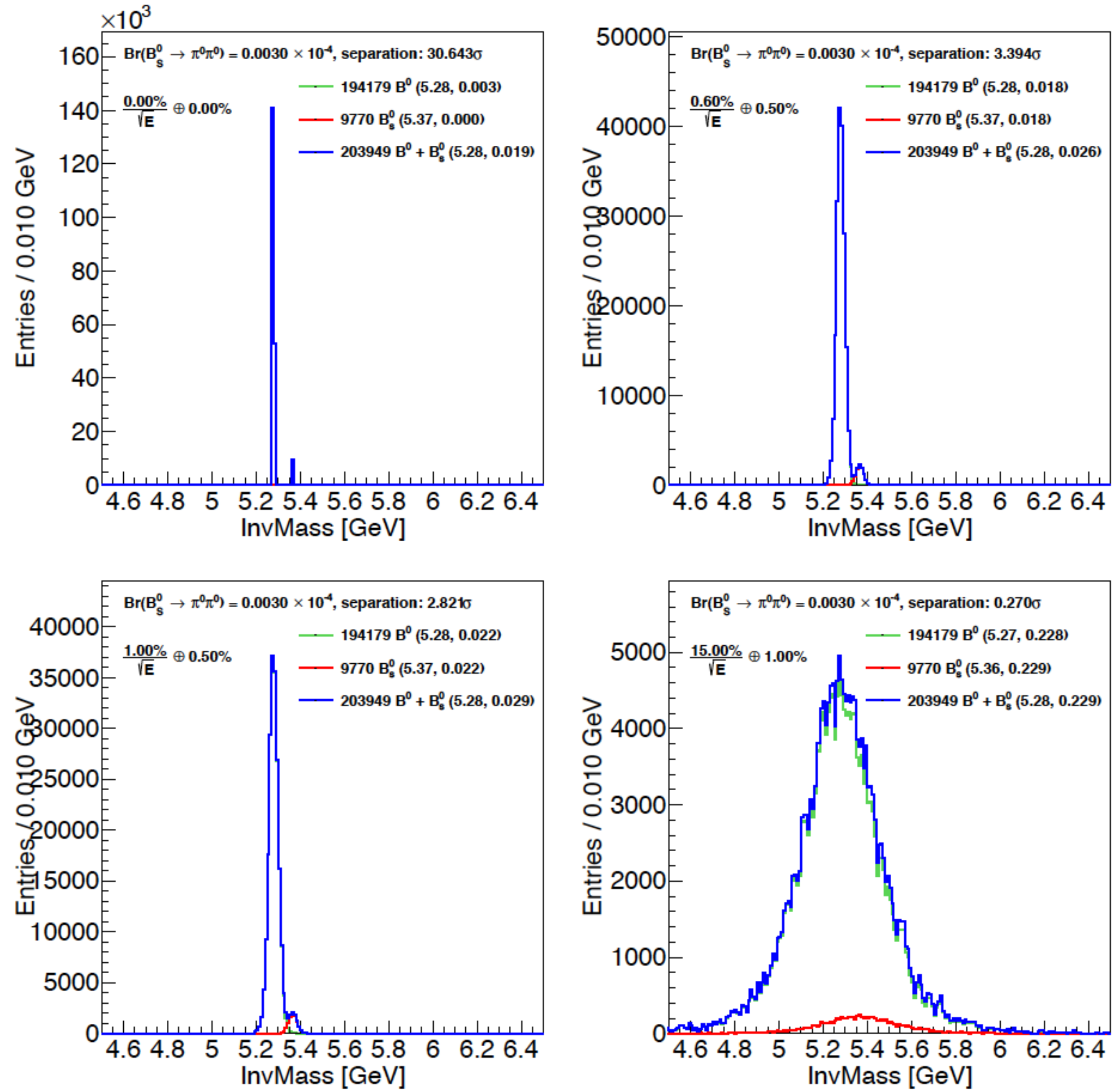
Bs/B0 separation & ECAL resolution

Br(B0->2pi0) ~ 1.3E-6;

Br(Bs->2pi0) ~ 3E-7, SM Prediction

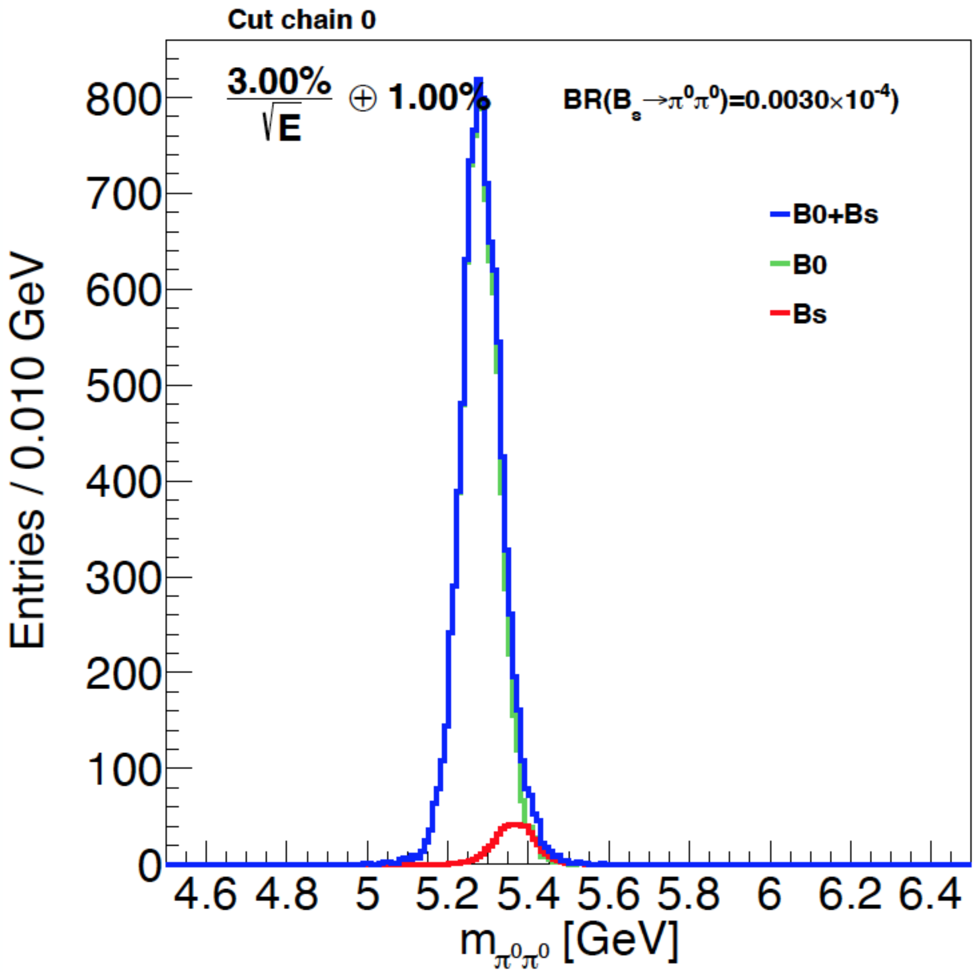
Abundance in Z pole: 4 times more B0 than Bs.

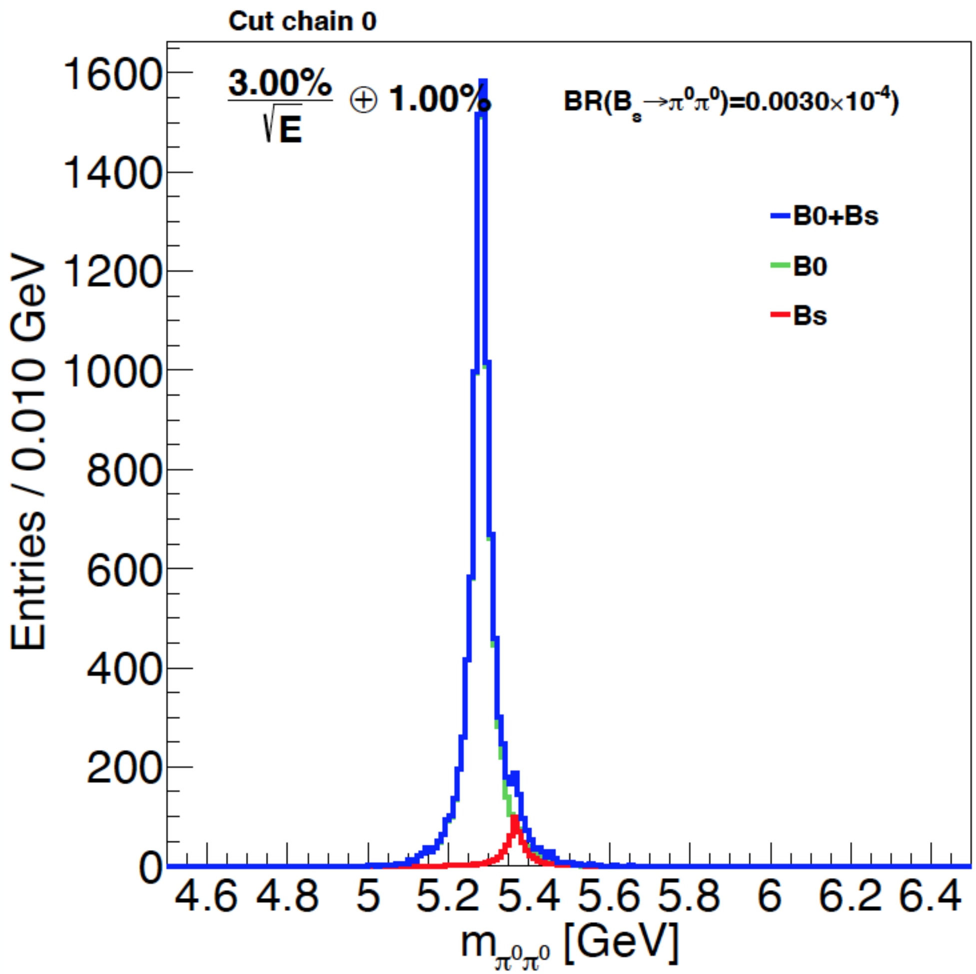
In total: the B0 peak ~ 20 Times larger than the Bs...



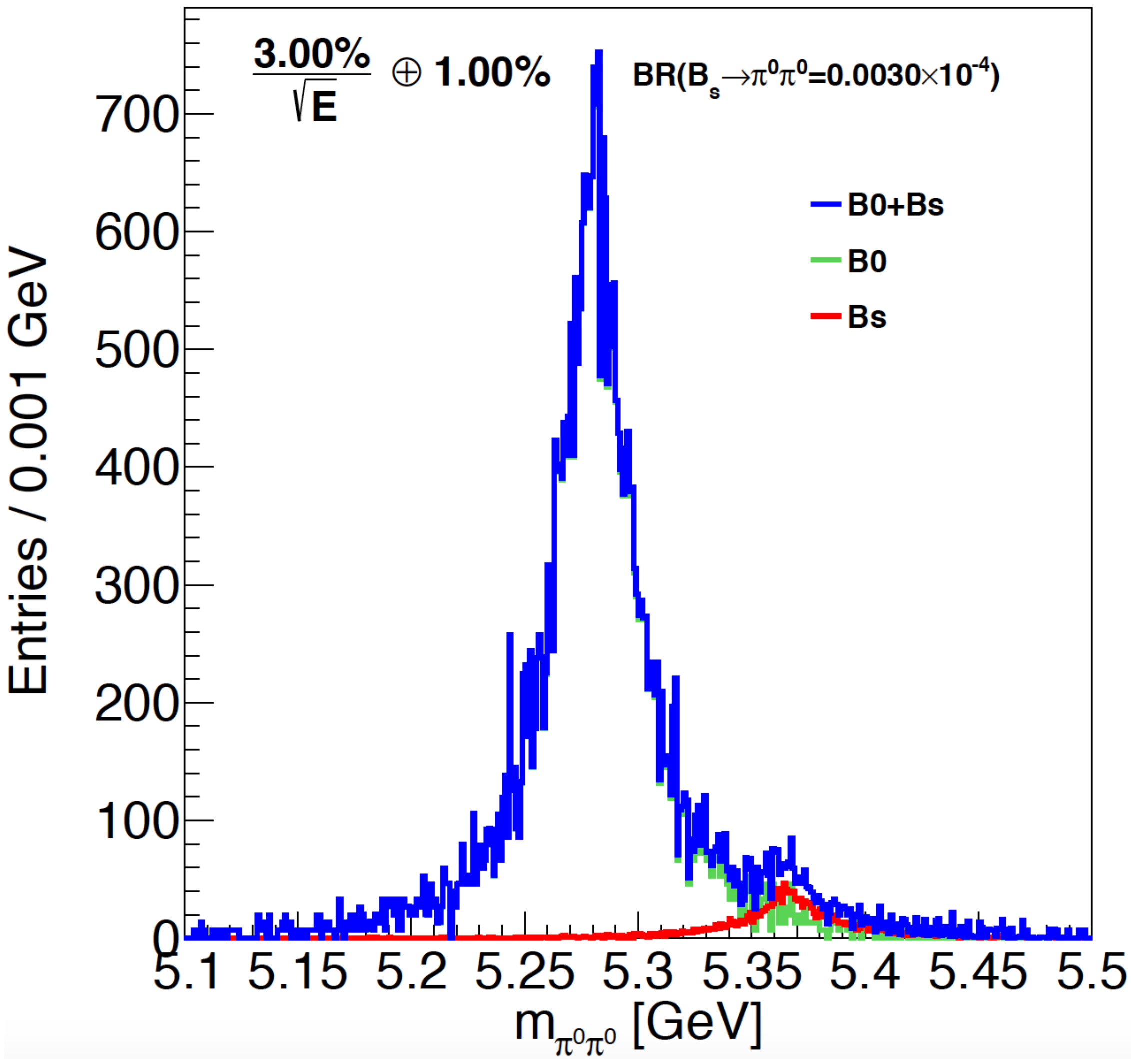
https://hflav-eos.web.cern.ch/hflav-eos/osc/PDG_2019/#FRACZ

Kinematic fit... separation enhanced

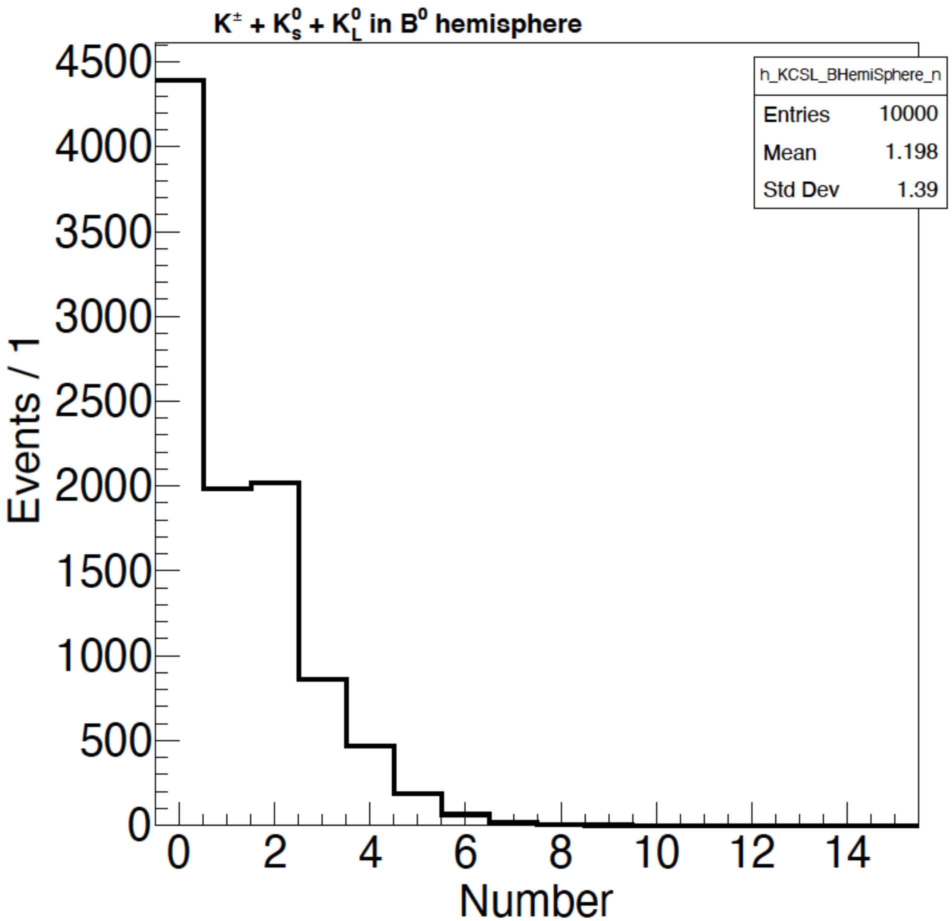


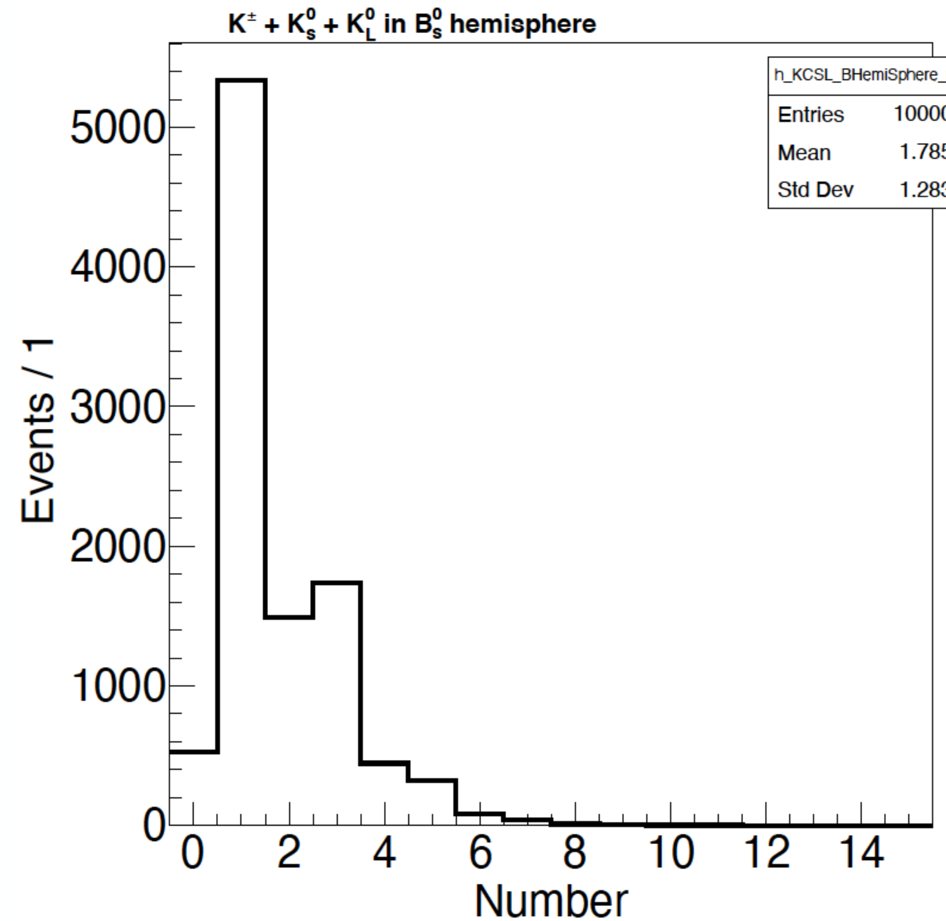


Kinematic Fit



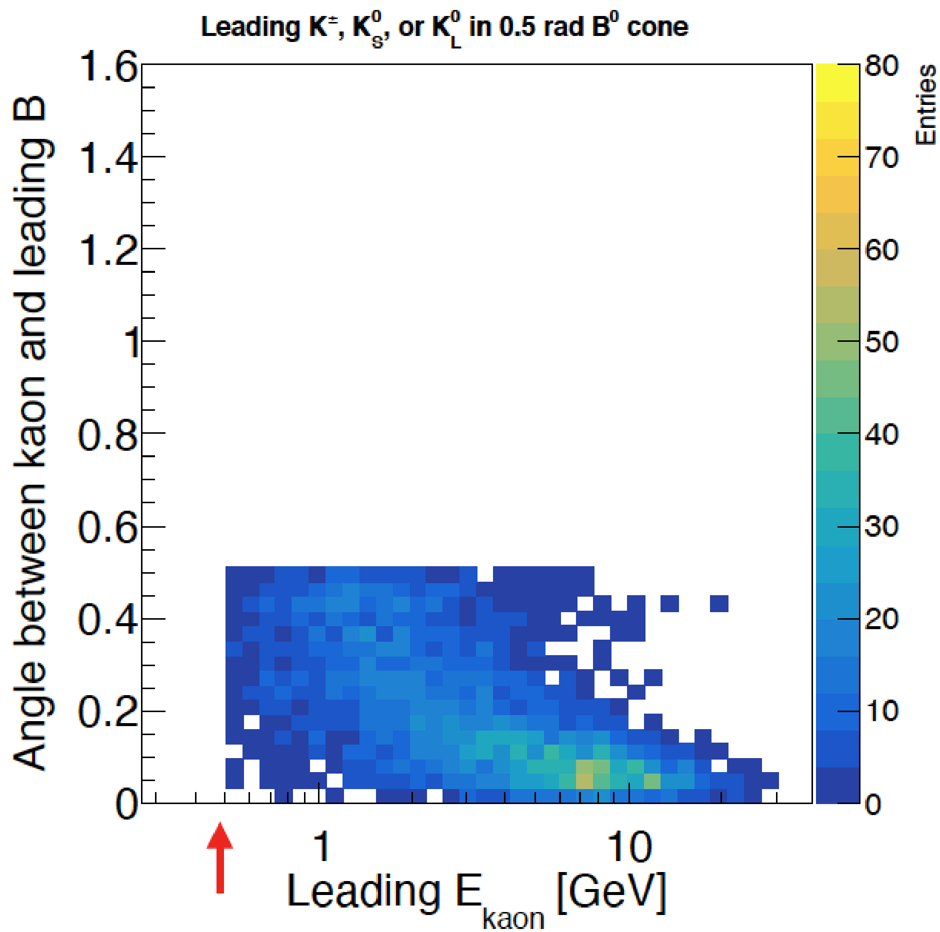
Kaon in the signal Hemisphere

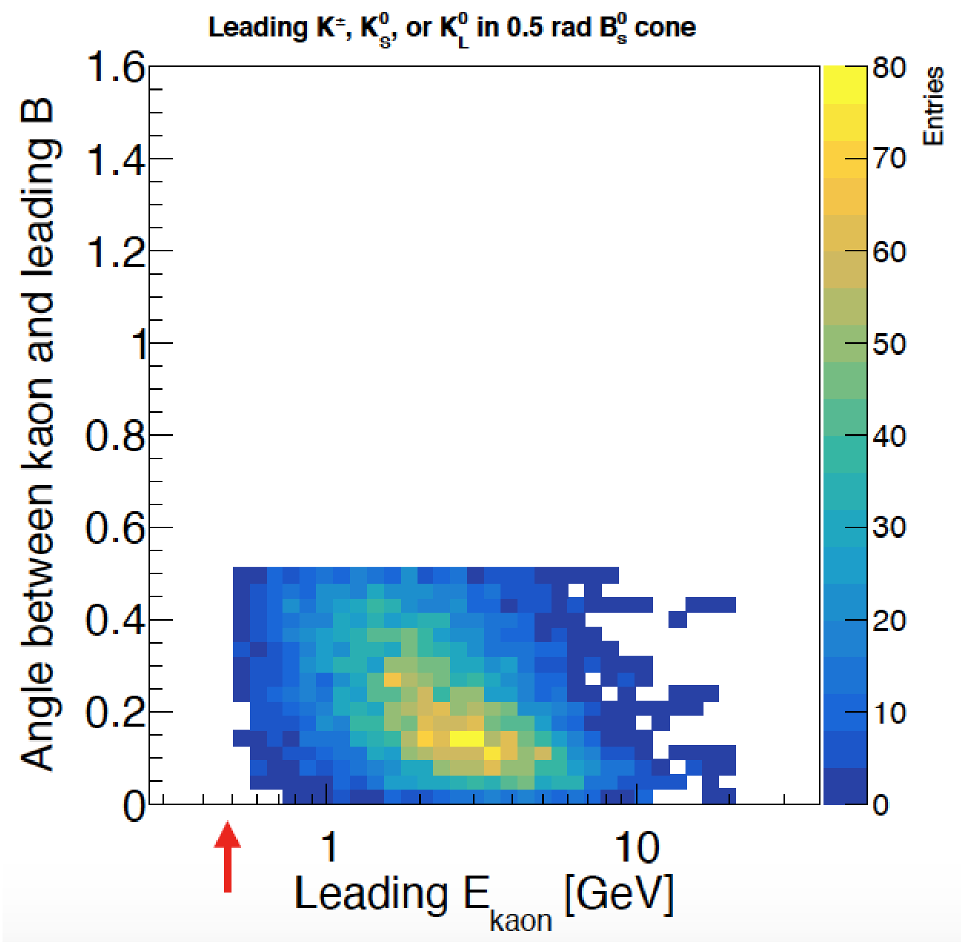




Can reject ~ 40% of B0 at a cost of 5% Bs signal efficiency...

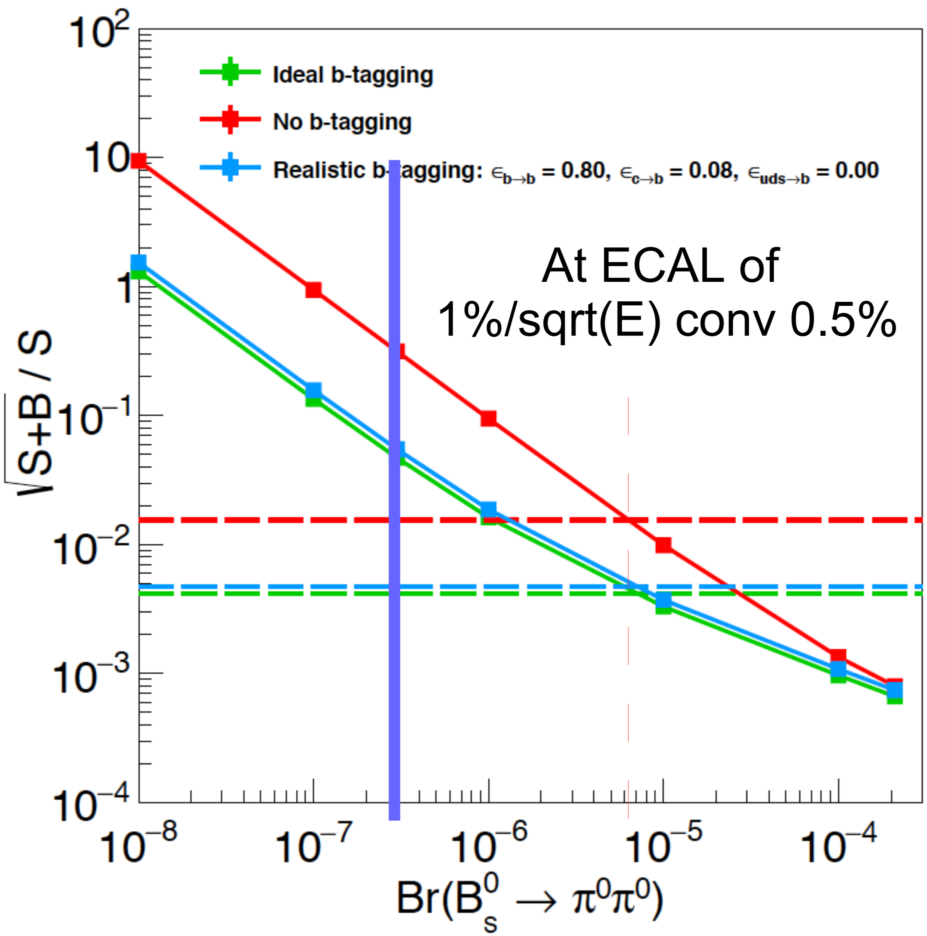
Leadign Kaon in the signal Hemisphere (if exist)

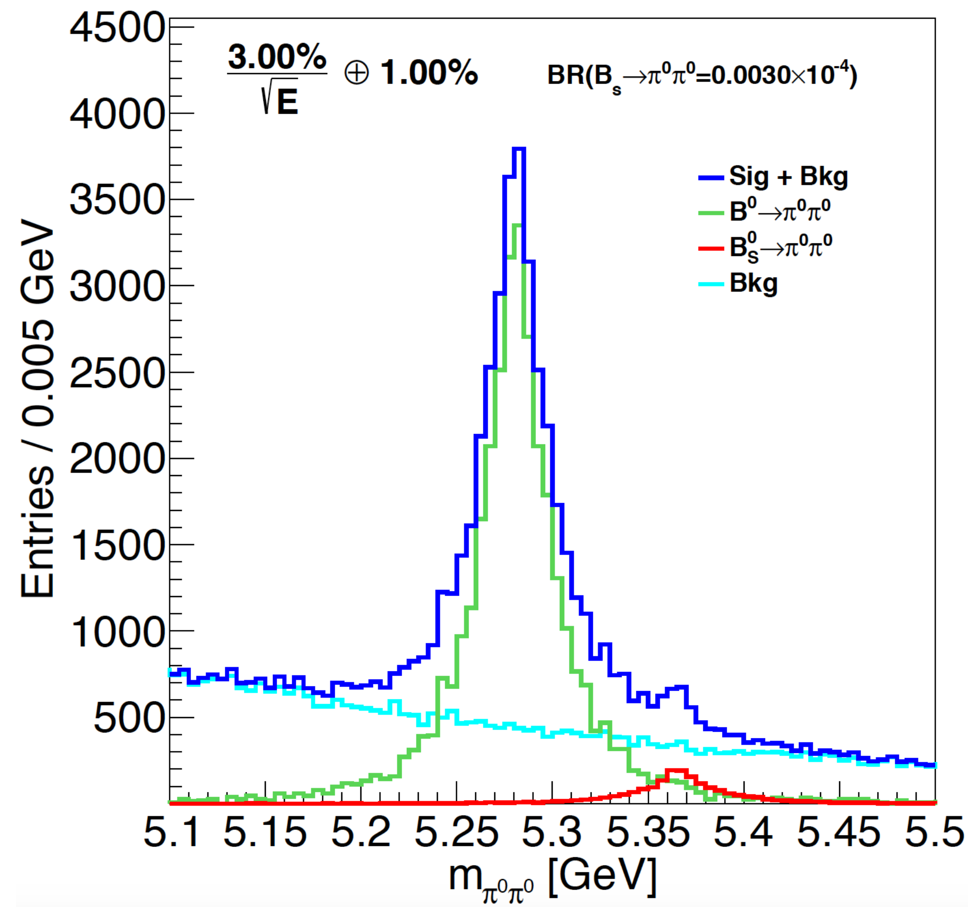




Visible difference...

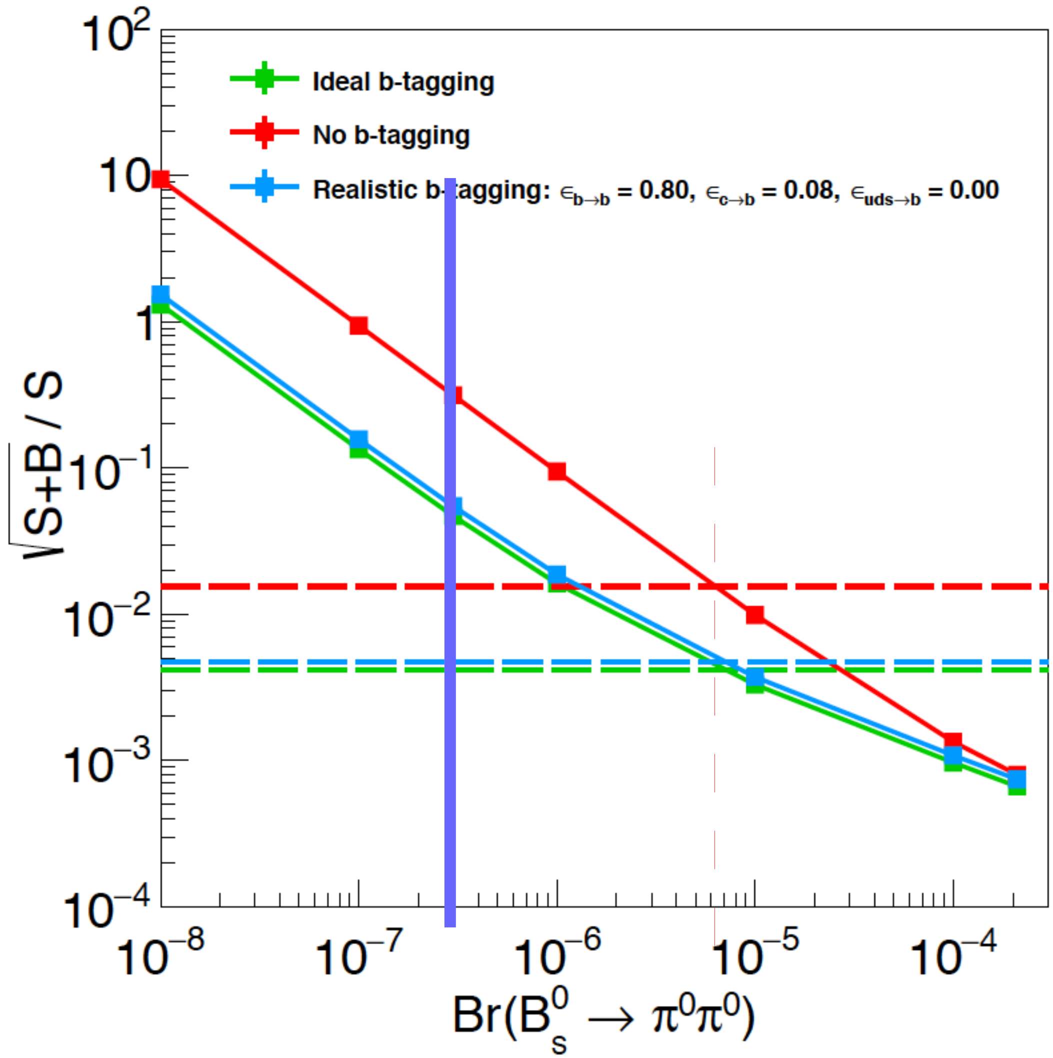
B-tagging: essential

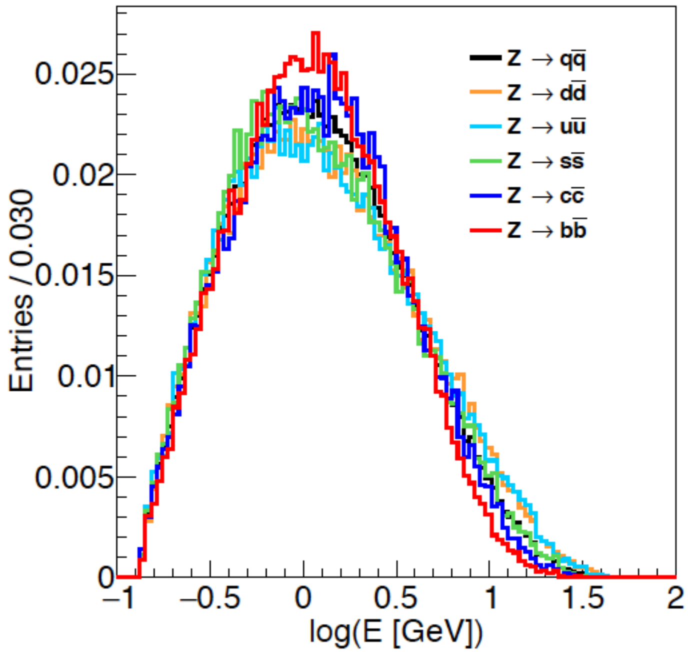




- Baseline b-tagging (eff ~ 80%, purity ~ 90%) is pretty good
- Right Plot: Realistic (Baseline) b-tagging, Kinematic Fit, No Kaon Finding

B-tagging: essential





Event Selection：

Leading Pion-0 Energy > 14 GeV;
Sub-leading Pion-0 Energy > 6 GeV;
Bs candidate energy > 22 GeV.

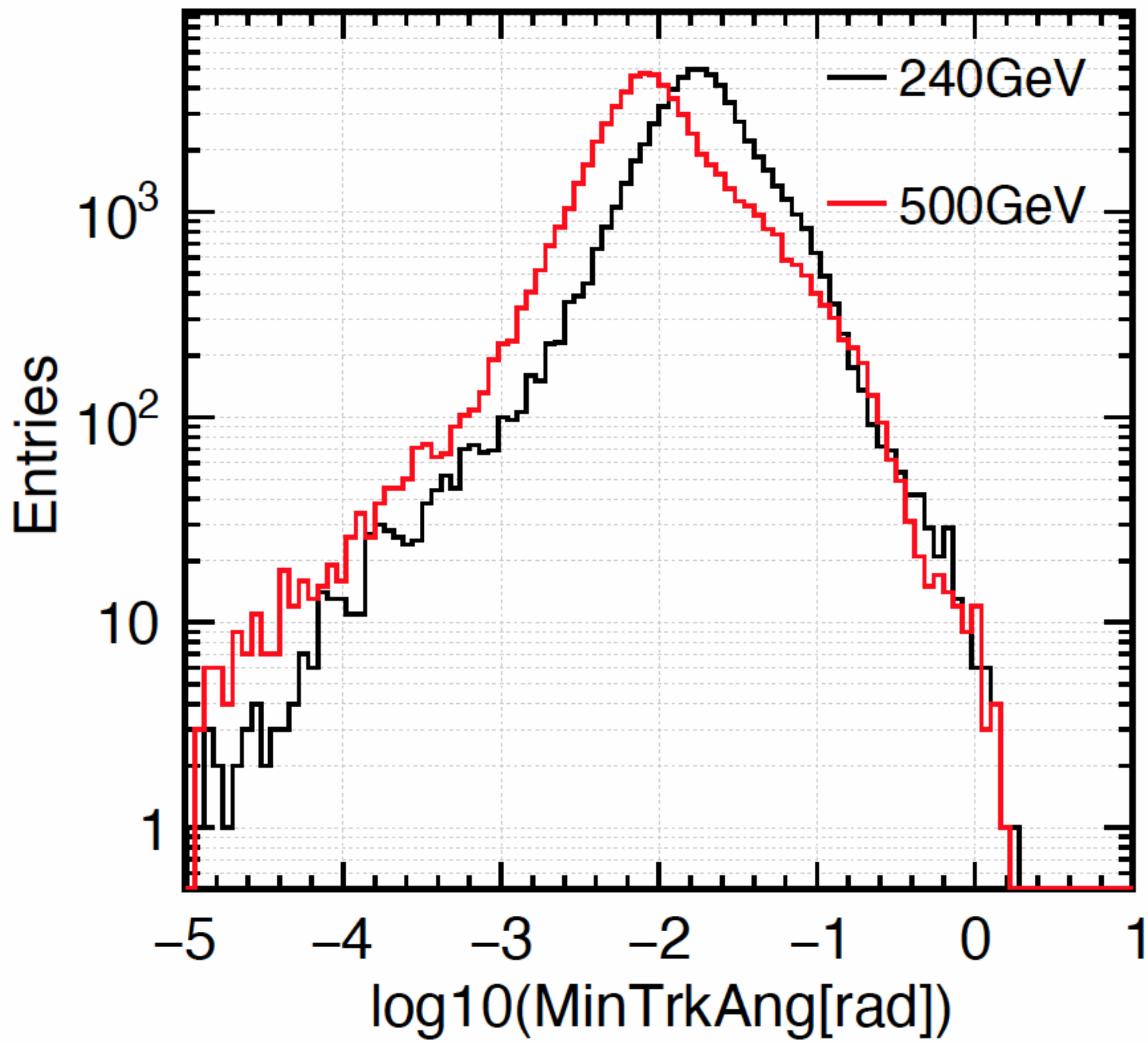
- Baseline b-tagging (eff ~ 80%, purity ~ 90%) is pretty good

$B_s/B_0 \rightarrow 2\pi_0$

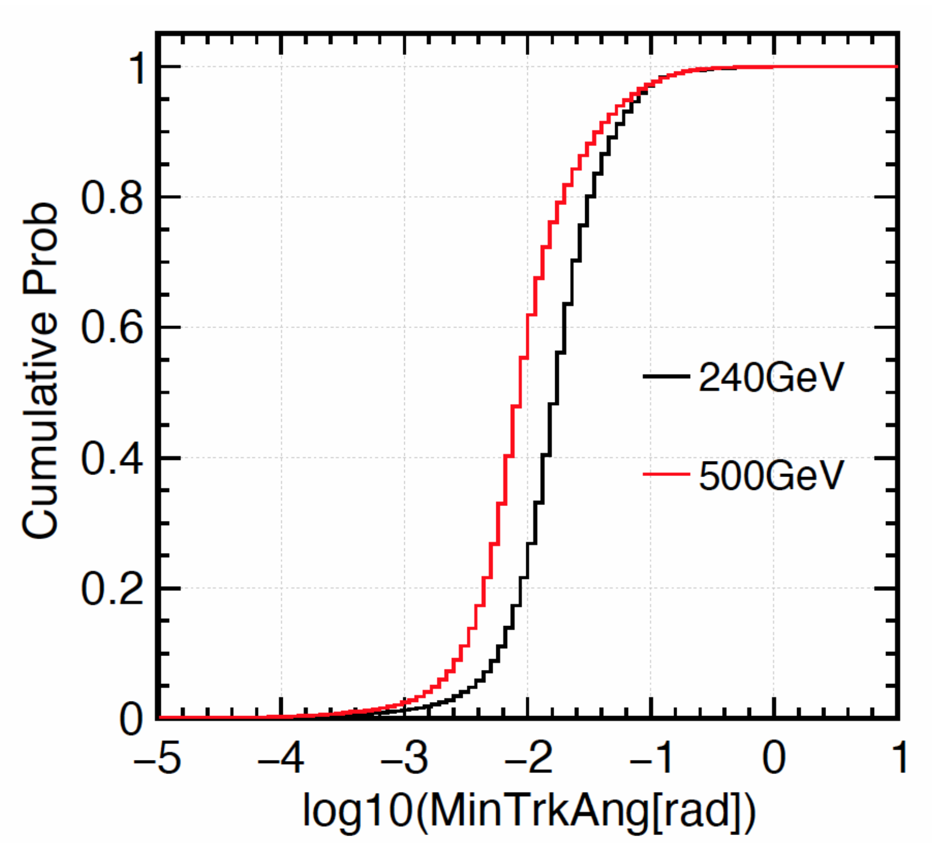
- Characteristic & Requirements
  - Pre-request: good photon reconstruction inside jet, to successfully reconstruct pi-0 candidates. Solution: PFA + Timing...
  - **ECAL: at least 3%/sqrt(E), preferably 2%/sqrt(E)**
    - Reduce fake pi-0 & Separate the Bs/B0 mass peak
    - *Kinematic fit helps.*
  - **B-tagging: baseline performance would be OK**
    - Accuracy differ by 1 order of magnitude (wi/wo b-tagging).
  - Kaon id: improve the final accuracy ~ 20%
    - Not only charged kaons, but also Kshort/Klong finding

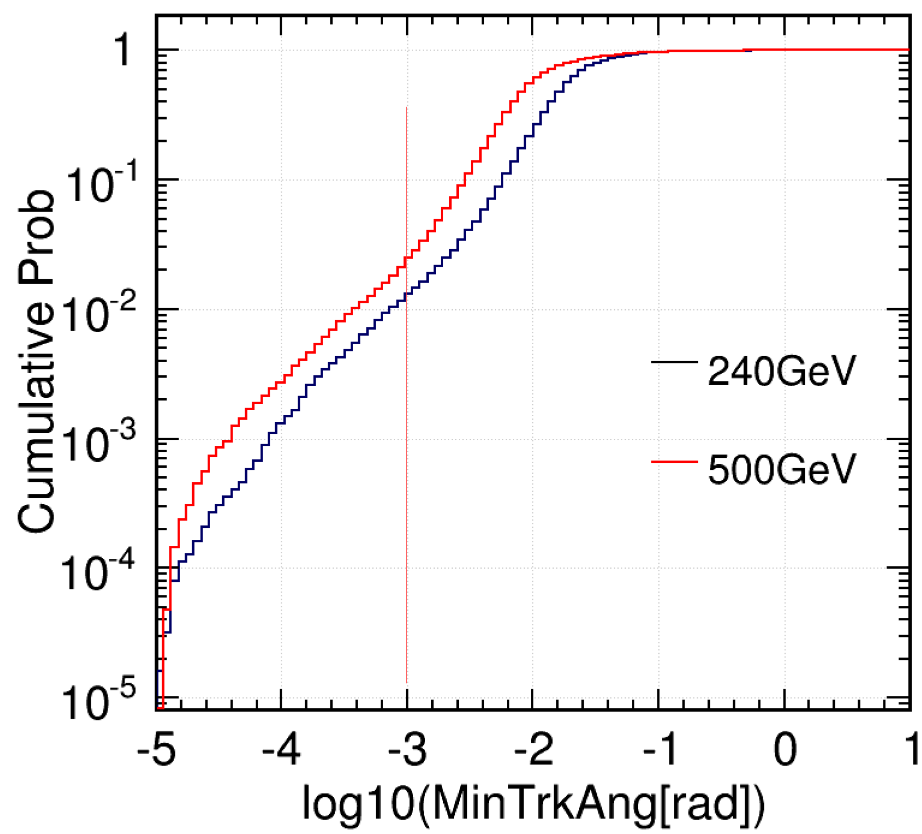
- A detector satisfy the above condition provides ~ 10%/sub-percentage level accuracy at SM Branching ratio of $B_s/B_0 \rightarrow 2\pi_0$

Separation requirement at the Trackers: benchmark with 3-prong decay taus



3 prong decay taus





Separation power of 1 mrad, ensures a successful separation of 98%/99% of 3 prong decay taus of 120/250 GeV.

Summary

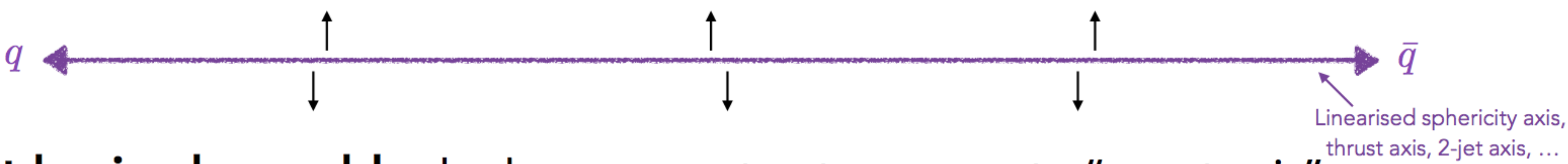
- To quantify the requirement on intrinsic sub-detector:
  - Benchmark analysis & modeling
- Bs->2pi0
  - B-tagging is essential
  - ECAL resolution of 2-3%/sqrt(E) would be needed to separate the B0/Bs peak, with Kinematic fit
  - Other impacts need to be taken into account: photon angular resolution, etc
- 3-prong decay tau
  - Need to separate tracks with 1 mrad angle

Backup

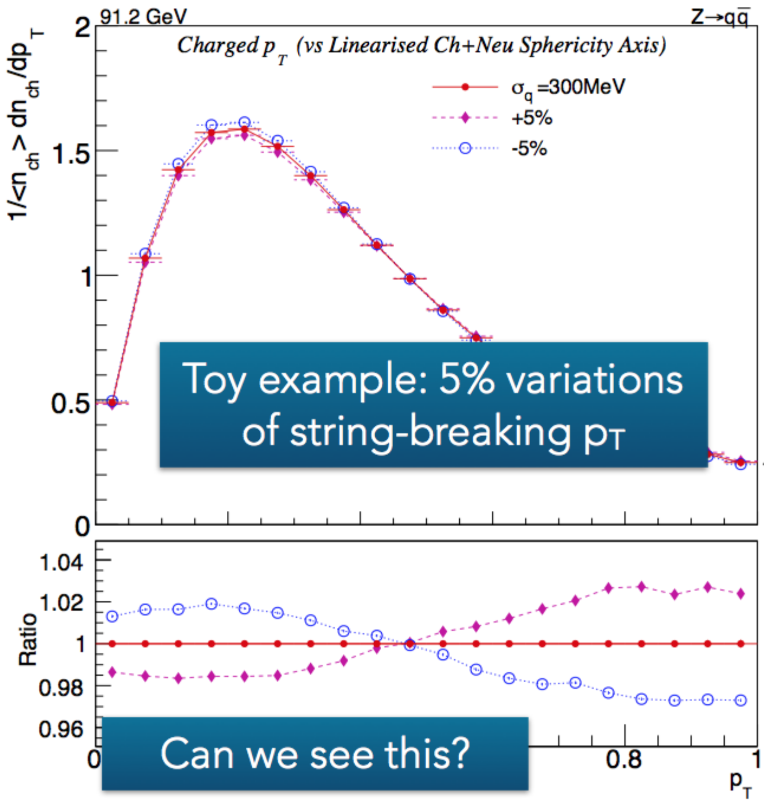
From Discussion with Peter Skand

- ...
- a momentum resolution ~ 50 MeV (or better) would be crucial for studies of non-perturbative dynamics.
- to identify non-relativistic pions, so pions with absolute momenta < 100 MeV would be interesting to study – but less critical
- ...
- ... A dedicated analysis would be appreciated

Transverse Fragmentation ⇔ Momentum Resolution

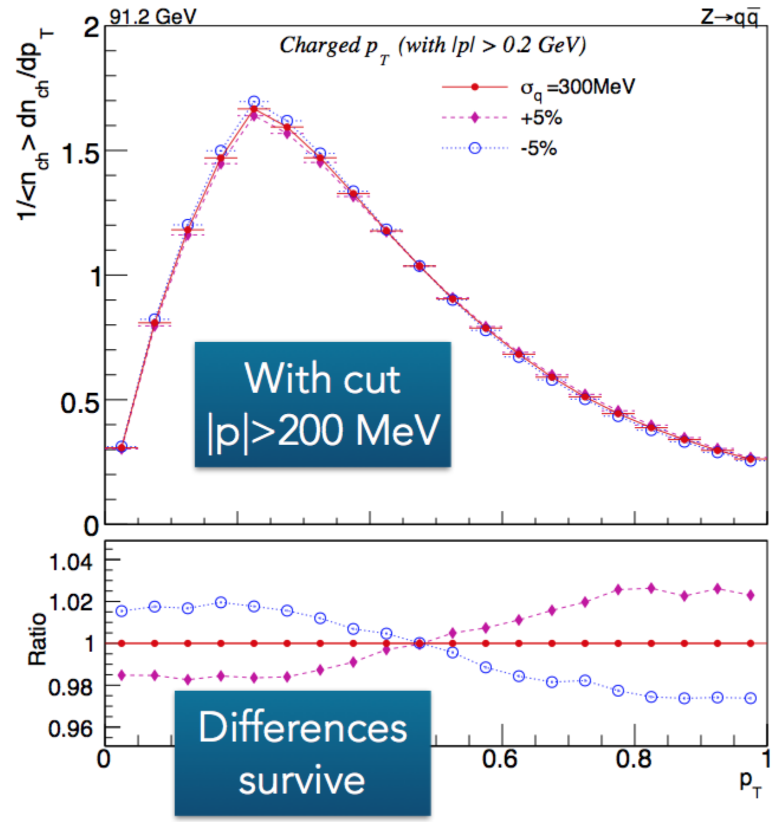


Most basic observable: hadron p_T spectra, transverse to "event axis"



Toy Example

Perturbatively dominated power-law tail



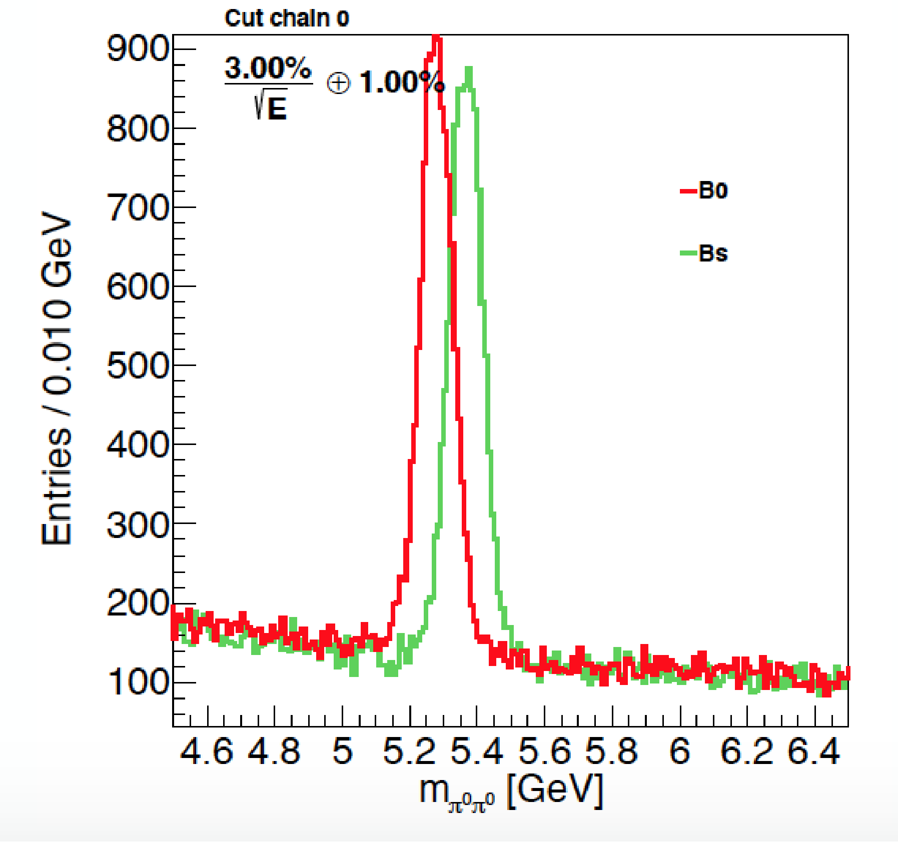
Recent activities

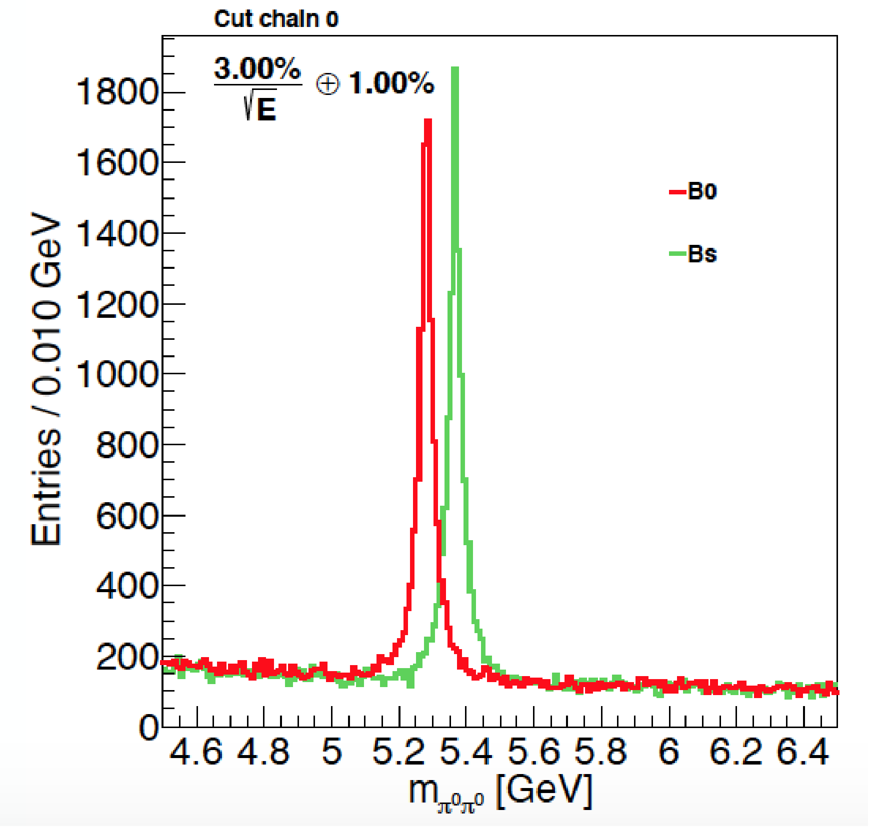
- Pid
  - Current 3-sigma separation of pi-Kaon
  - Quantify on relative resolution of dE/dx & ToF, w.r.t., D & Lambda reconstruction performance
- $B_s/B_0 \rightarrow 2\pi_0$
  - ECAL: π_0 reconstruction & mass peak separation
  - B-tagging: reject light/c jets background
  - Charged & Neutral Kaon id:
- Bs → Phi + vv; Requirement
  - Pid & VtX: Phi reconstruction
  - Missing E/momentum (~ hadronic system reco.)
  - Jet lepton: Veto backgrounds from leptonic B-decay
- Discussion/Feedbacks from Snowmass studies, etc.

Tracker requirements

- ~100% efficiency within detector acceptance/threshold
- Momentum resolution
  - Flavor physics: < 100 MeV (? - need further quantification)
  - QCD studies: < 50 MeV (0.1%)
    - Optional: Momentum threshold: ~100 MeV
- Separated 3-prong decay taus (even up-to ttbar):
  - ~ 1 mrad separation power
- Pid performance: 3-sigma Pi-K for inclusive Kaons

Kinematic Fit: significant impact





...Force the pi-0 candidate mass to be at the expected value...

Key ingredients for any concept(s)

- Geometry:
  - Technology & Basic configuration/dimension for each subsystem
  - Integration
    - Mechanics
    - Power/cooling
    - Bandwidth
    - ...
- Performance:
  - Simulation/Reconstruction tools & algorithms
  - Validation (data ↔ Full Sim ↔ Fast Sim) & Xcheck
  - Modeling