The Third China CMS Winter Camp,
16-20 January, 2025, BUAA-Beijing (China)

Hand-on exercise on muon ID efficiency measurements with Run3 data

Tahir Javaid
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On behalf of the **CMS collaboration**

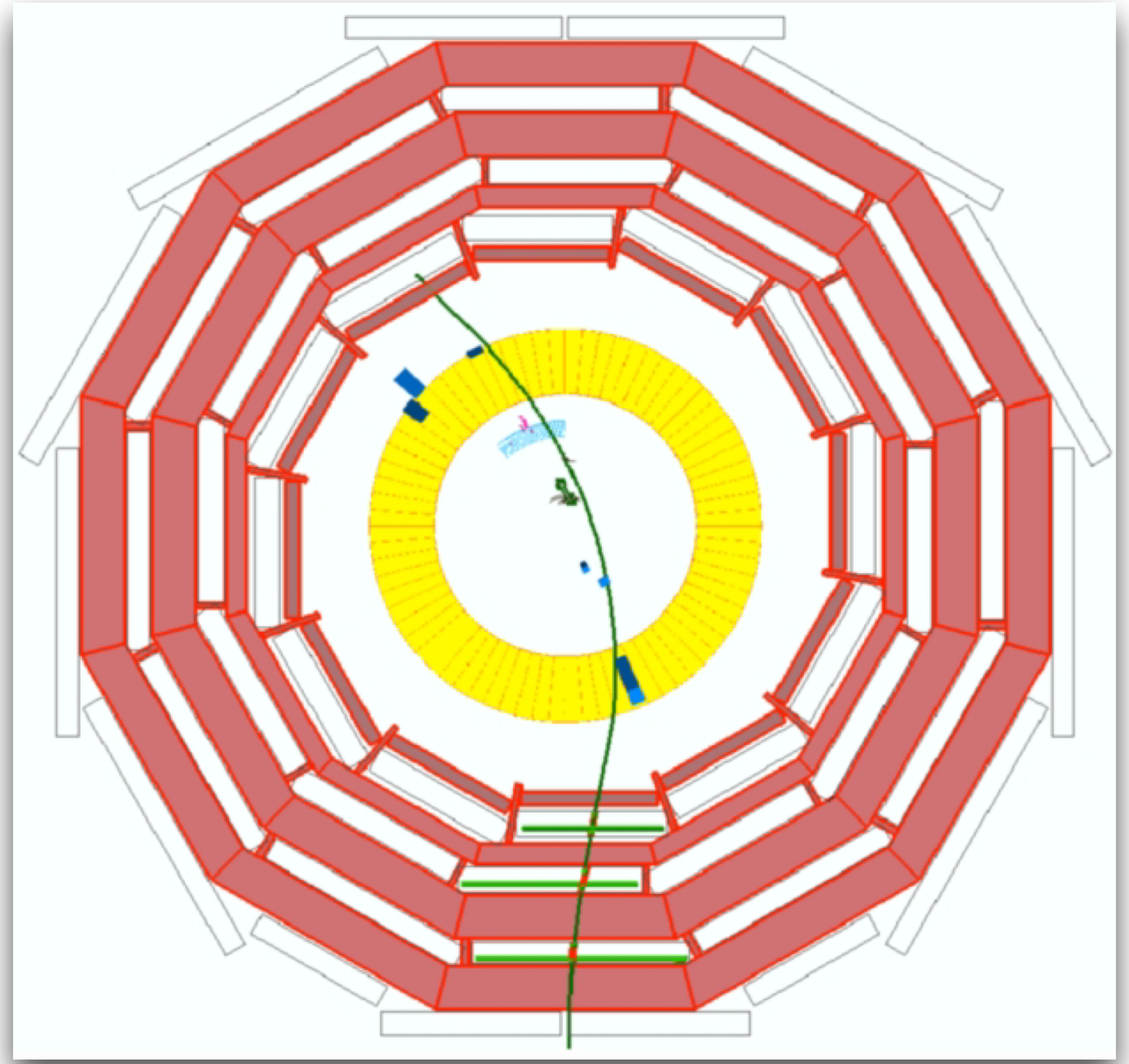
Outline

✳Introduction to muons

✳Motivation: Why we measure the muon efficiencies

✳The Tag and Probe Method

✳Muon Identification efficiency measurement



Event display of a cosmic muon in CMS detector

Introduction to Muons and its Tracking

✳**What is a muon?** (discovered in 1936)

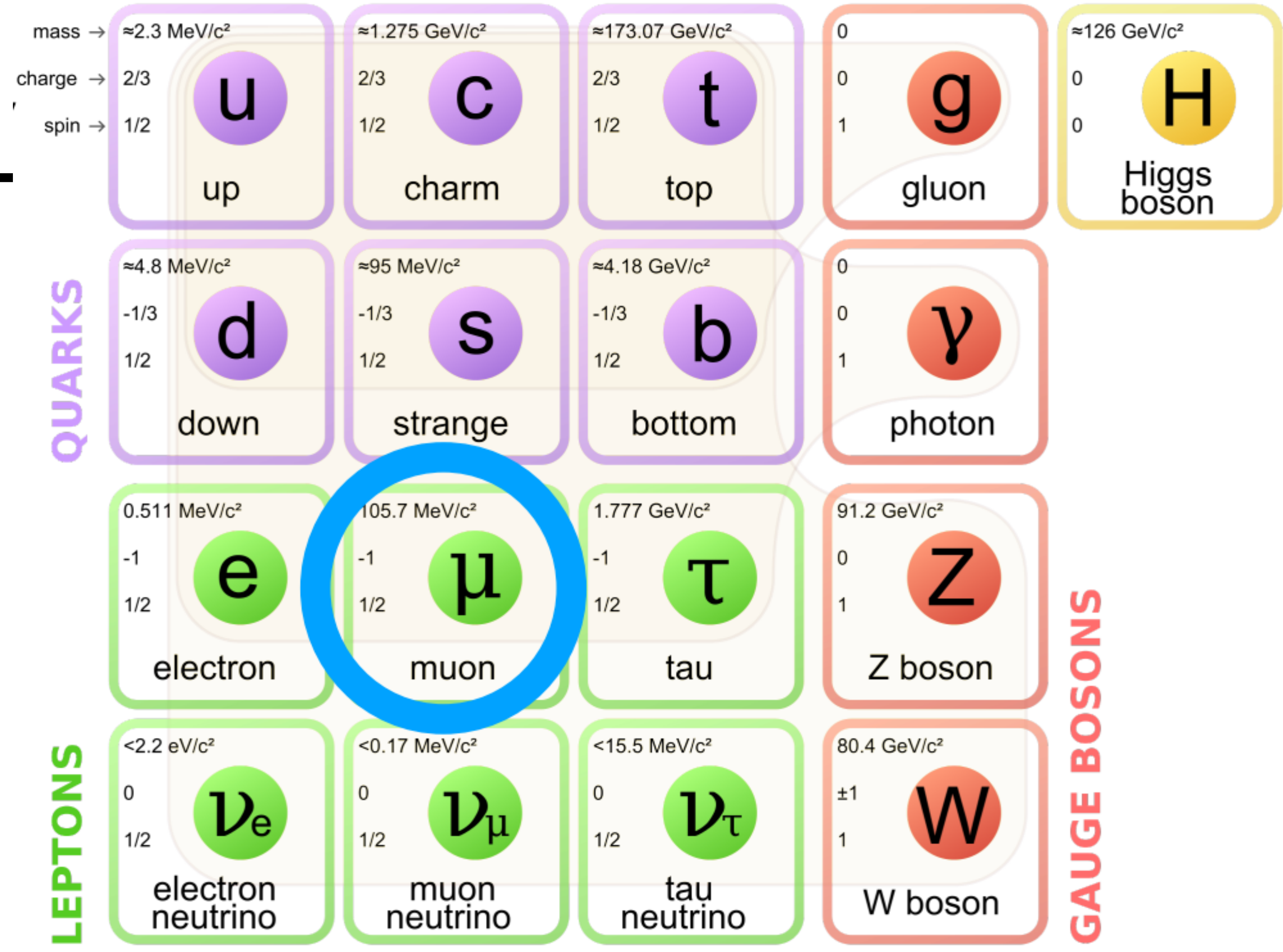
- Muons are heavy cousins of electrons.
- Charged particle, interact minimally with matter → making them ideal for penetrating detectors.

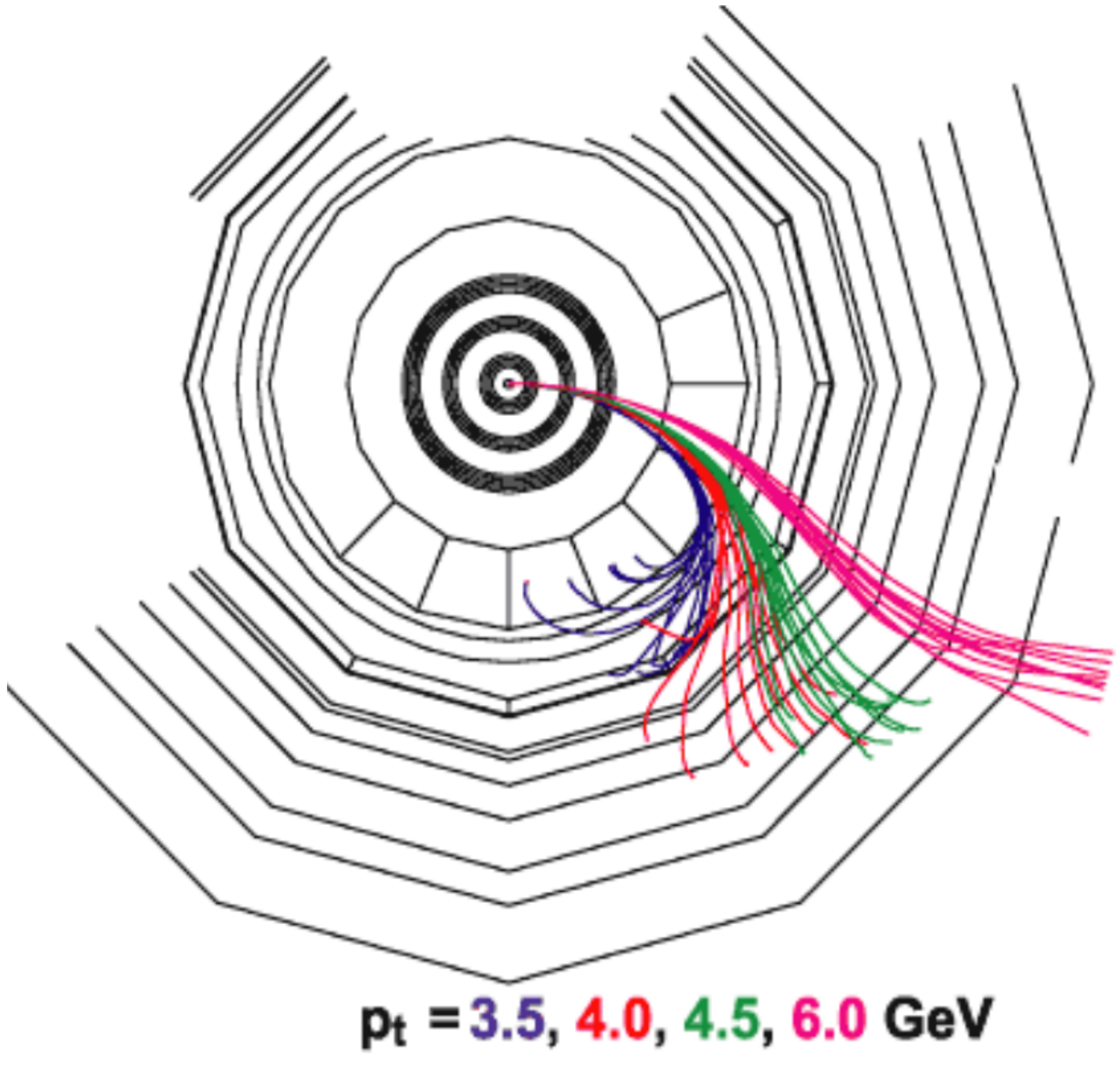
✳**Why track muons?**

- Muons are a signature of many interesting physics processes (e.g., Higgs decay, new physics) [Link for details on Higgs analyses involving muons]
- Muons provide high-resolution momentum measurements.

✳**Muon challenges in CMS:**

- High-energy muons traverse multiple detector layers (tracker, calorimeters, muon chambers)
- Precision tracking is required to identify and measure momentum accurately.





Muon Tracking Techniques in CMS

✳Tracking Process *(Seeding from pixels/strips)*

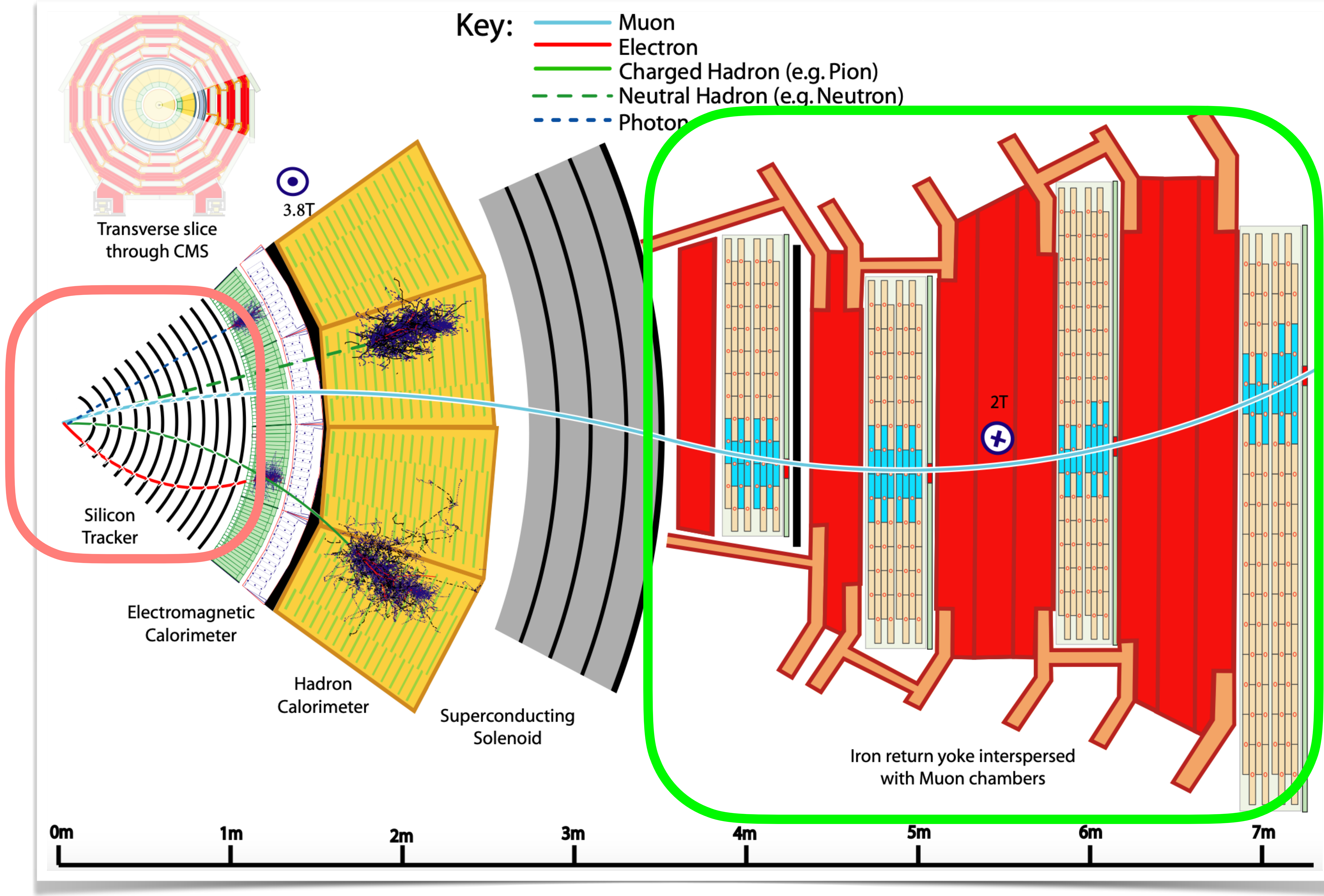
- **Inner Tracker:** High-granularity silicon tracker reconstructs tracks at the interaction point.
- **Muon Chambers:** Hits are matched to inner tracker tracks to form global muon tracks.
- **Global Fit:** Combined fit of tracker and muon chamber information for precise *momentum*

✳**Muon System Layout:**

- Drift Tubes (DT): Barrel region
- Cathode Strip Chambers (CSC): Endcaps.
- Resistive Plate Chambers (RPC): Fast timing in both barrel and endcaps

✳**Key parameters**

- Momentum resolution: Better for muons with higher transverse momenta (p_T)
- Coverage: Pseudorapidity range $|\eta| < 2.4$



SILICON TRACKERS
Pixel (100x150 μm) ~1m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers

Muon reconstruction and identification at CMS

✳Muons interact with the detector while passing through it

✳Local hit - segment reconstruction (RPC - DT/CSC)

✳Reconstruction of muon stand-alone track(s) (p_T estimation)

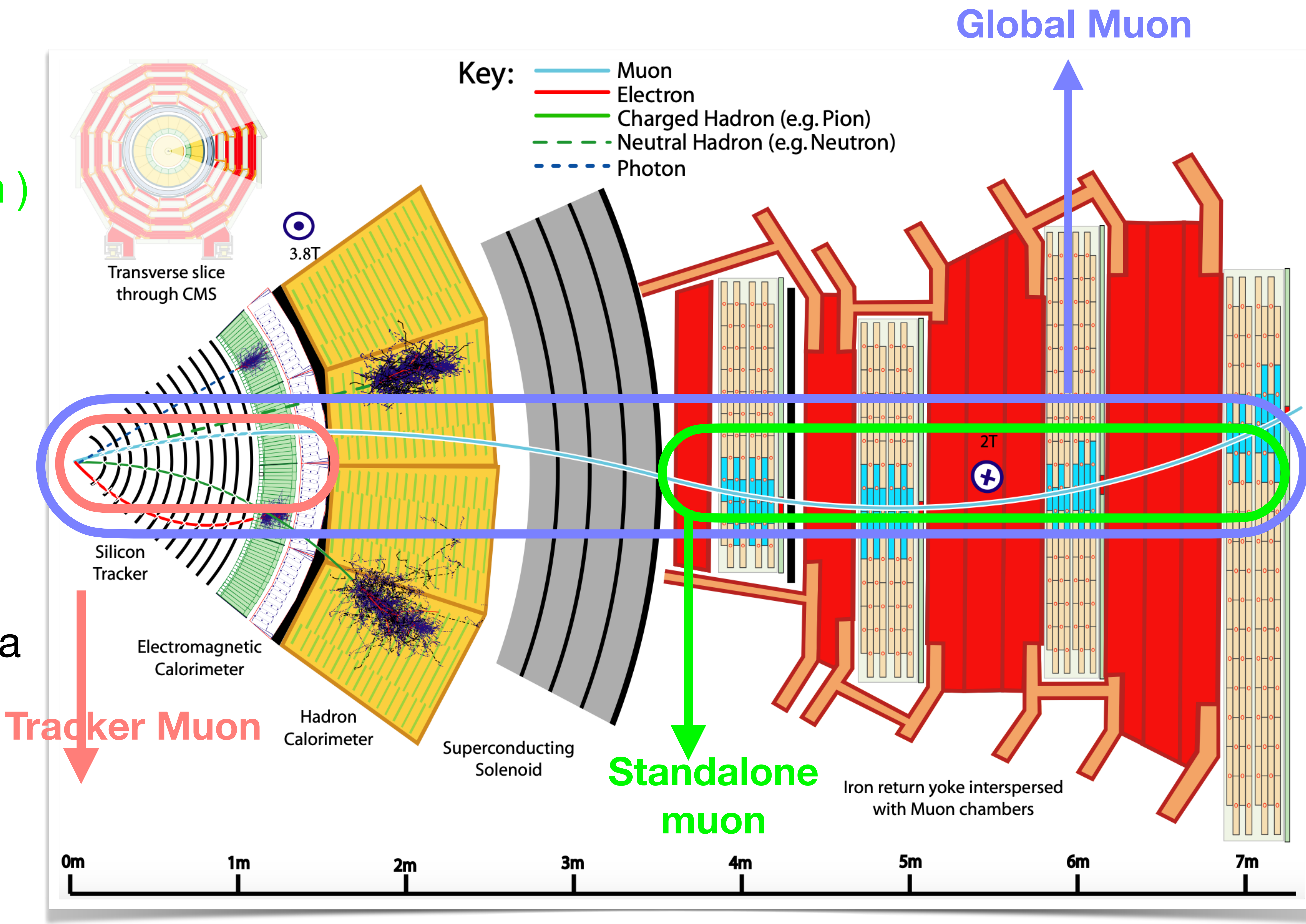
✳Reconstruction of inner track(s) using silicon detector

✳Global Muon are defined from standalone + inner tracks

(combined fit performed - pT re-evaluated: outside-in)

✳Main **identification** types for physics analyses:

- **Loose ID**
  - Muon selected by the PF algorithm that is also either a tracker or a global muon
- **Medium ID**
  - **Loose** muon with a tracker track that uses hits from more than 80% of the inner tracker layers it traverses
- **Tight ID**
  - **Loose** muon with a tracker track that uses hits from at least six layers of the inner tracker including at least one pixel hit



Identification is achieved by matching hits of at least 2 of possible 4)

(Link for more details and all IDs inclusing soft and high-pT muons)

Physics with muons

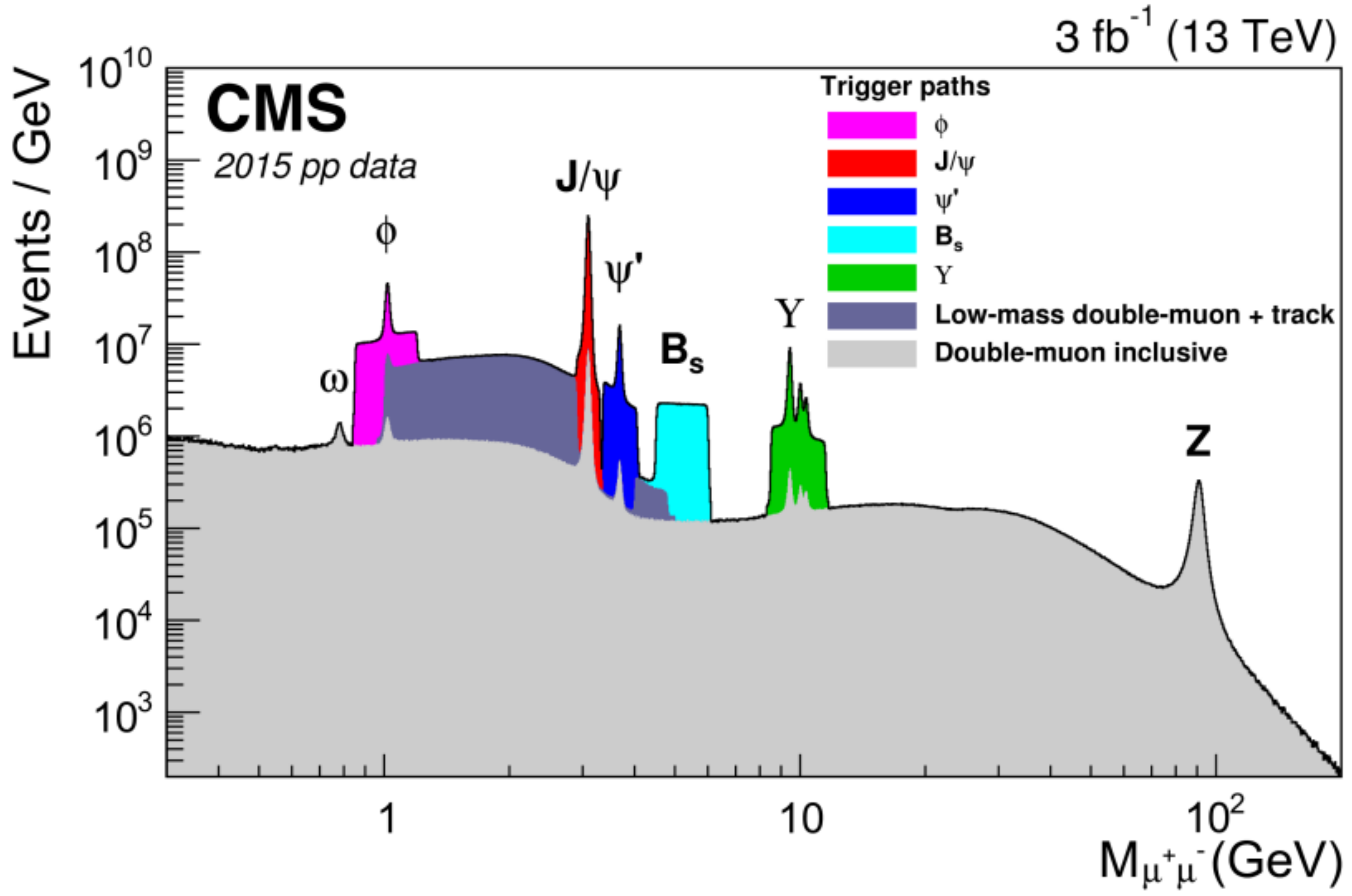
✳Muon is produced in the decay of many particles (discovered/potential new)

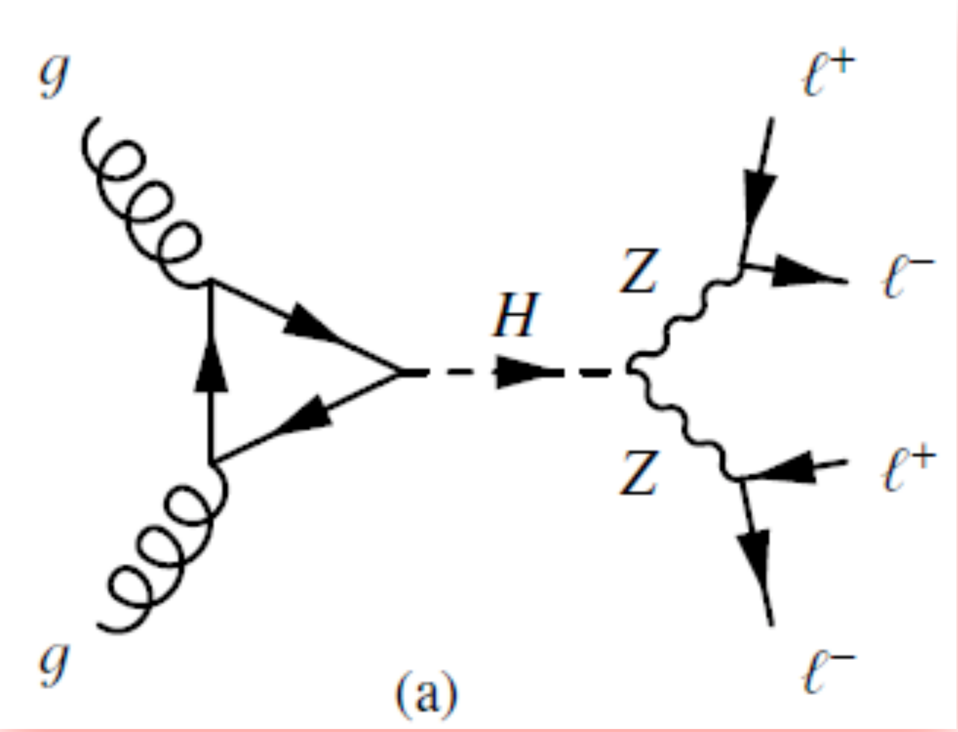
✳Physics with Muons (low and high p_T):

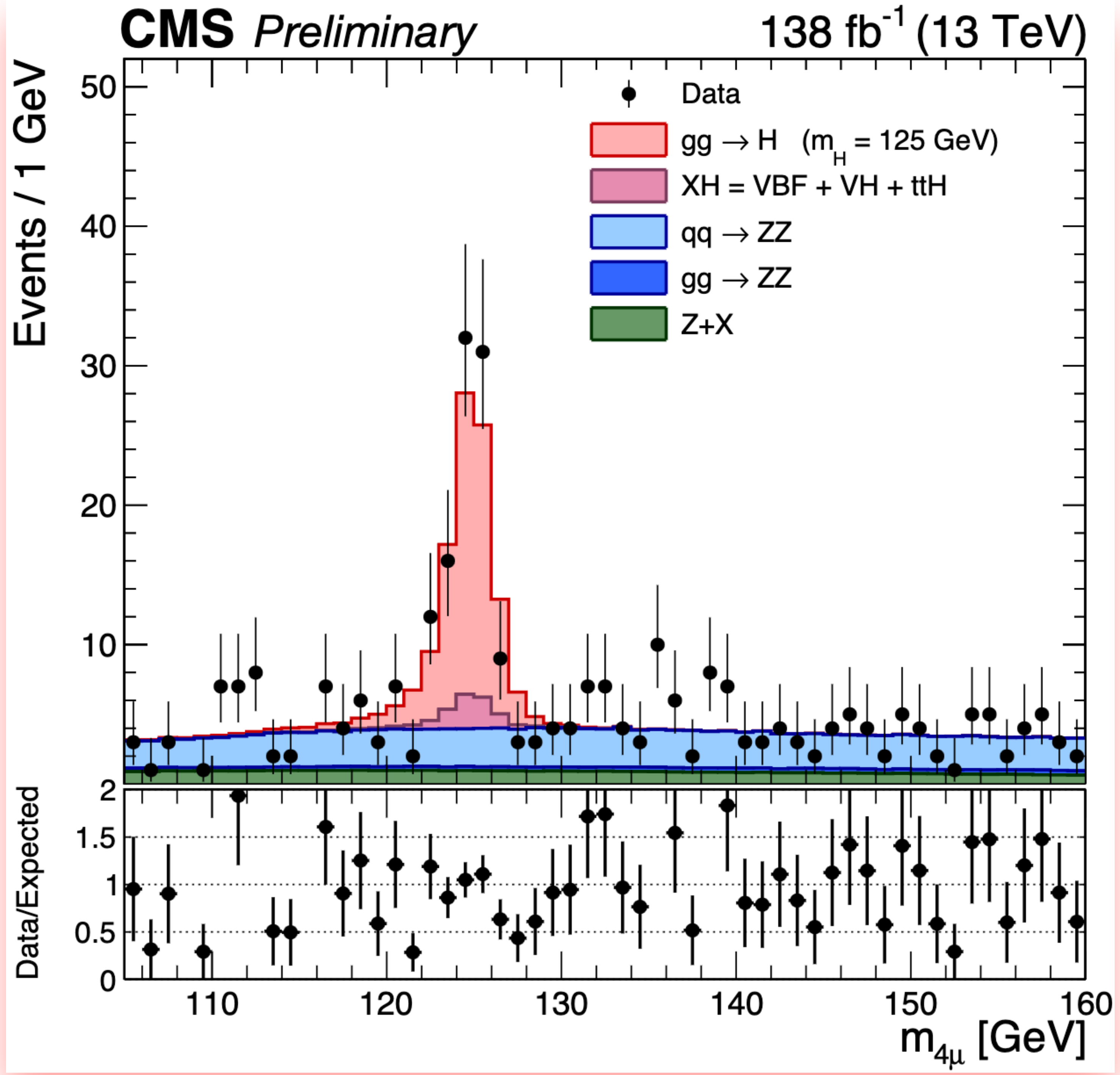
- B Physics Program ($B_s^0 \to \mu\mu, J/\psi \to \mu\mu$)
- Precision measurement of EWK parameters
  - Leptonic signatures of $W, Z,$ $and\ top$
- Higgs physics ($H \to ZZ\ (\to 4\mu)$, $WW,\ HZ,\ HW,\ ttH$)
- BSM searches
  - MSSM $A/H/h \to \mu\mu$
  - Z', W', leptoquarks
  - SUSY searches

✳Robust muon **reconstruction** for different p_T regions with CMS detector

- High efficiency and purity, excellent resolution and momentum scale

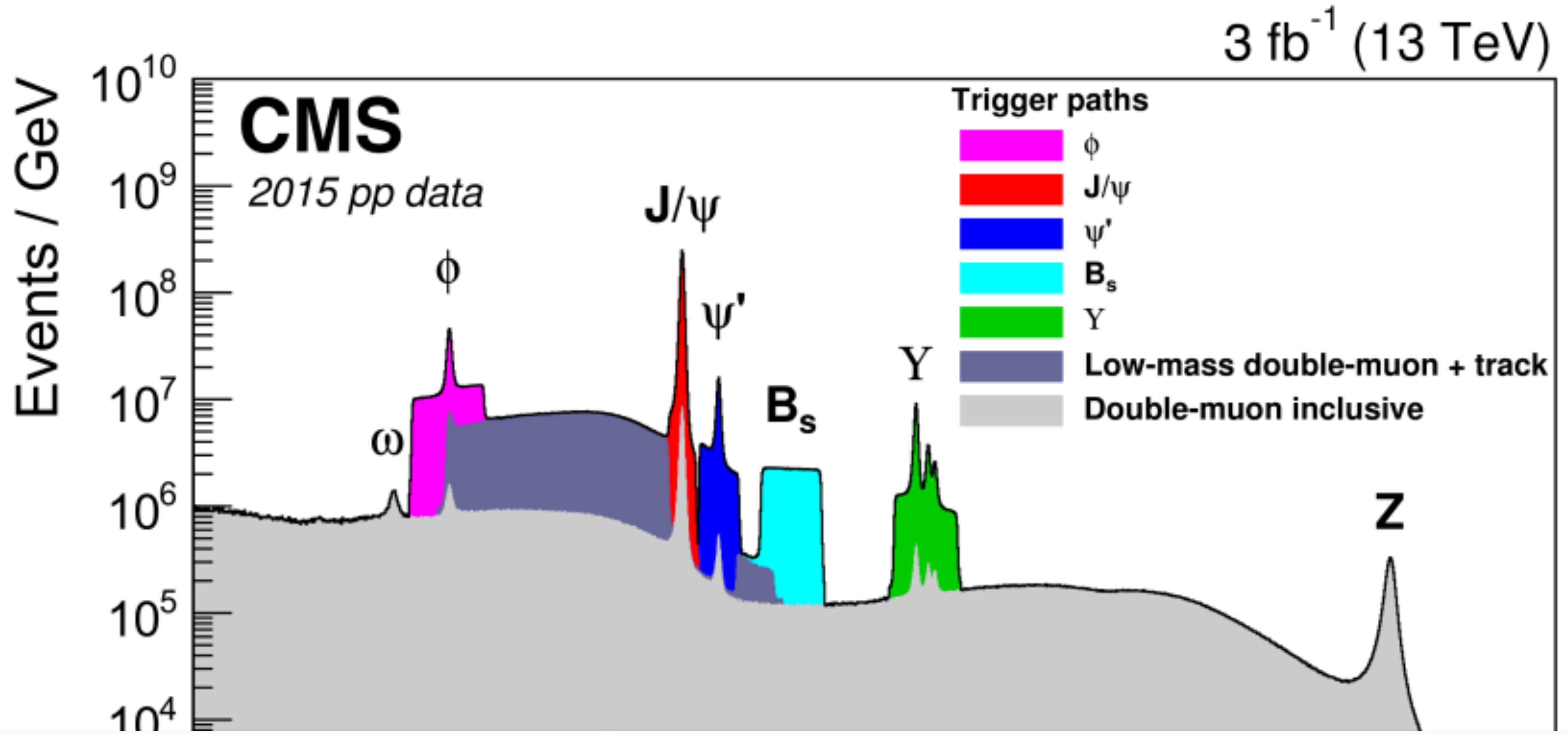






Link for details on Higgs analyses involving muons

Physics with muons



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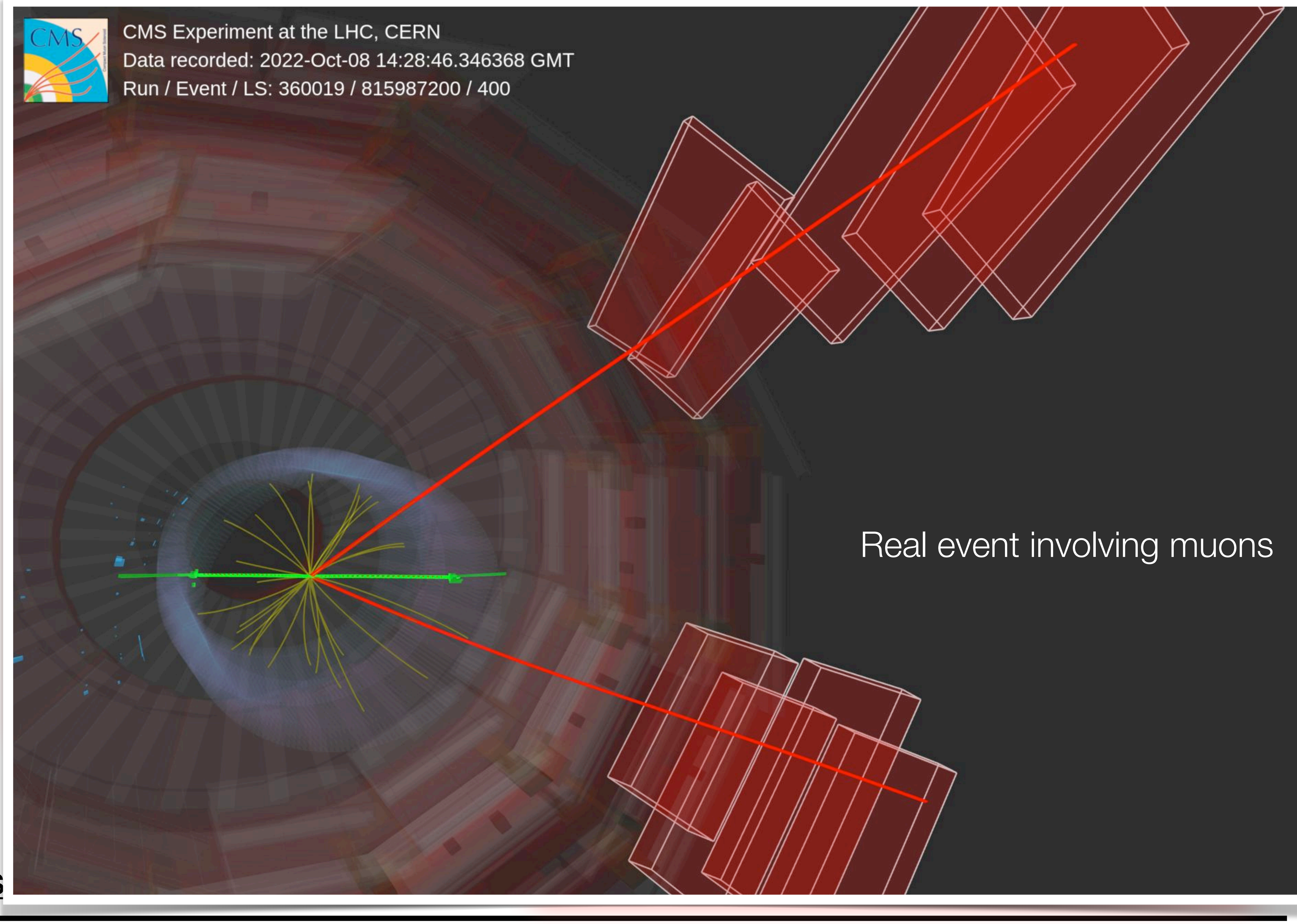


Link for details on Higgs

Muon Efficiency Measurement: Motivation

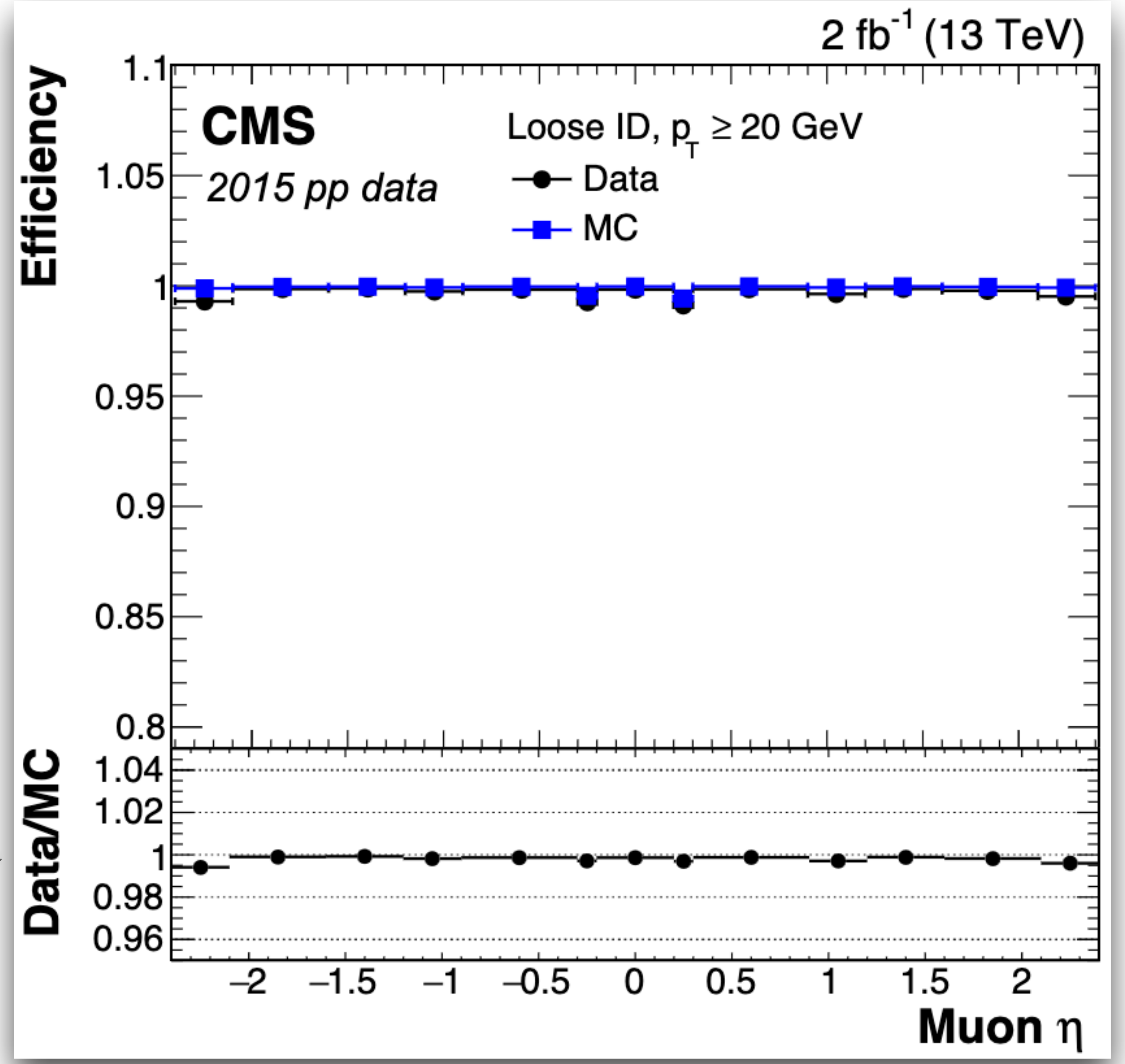
✳MC simulation is an important component of physica data analysis

✳MC does not describe the real data well

✳In the measurement, MC is corrected with correction or scale factors

✳Scale factors are computed by measuring the *selection* efficiencies

$$Scale\ Factor = \frac{Selection\ Efficiency\ in\ Data}{Selection\ Efficiency\ in\ MC}$$



✳Scale factors are then applied to MC

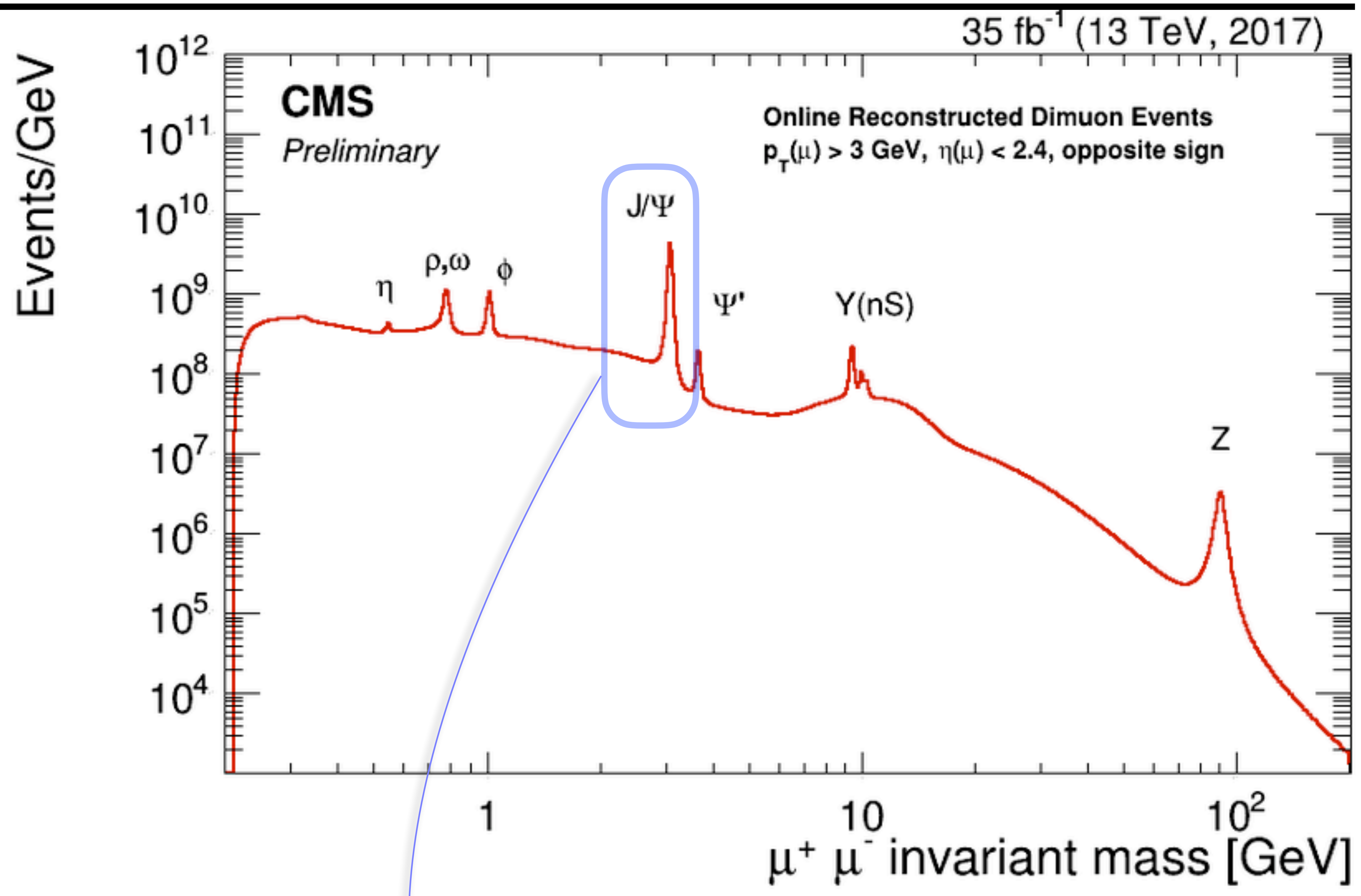
✳After applying the correction factors, MC is supposed to match the data

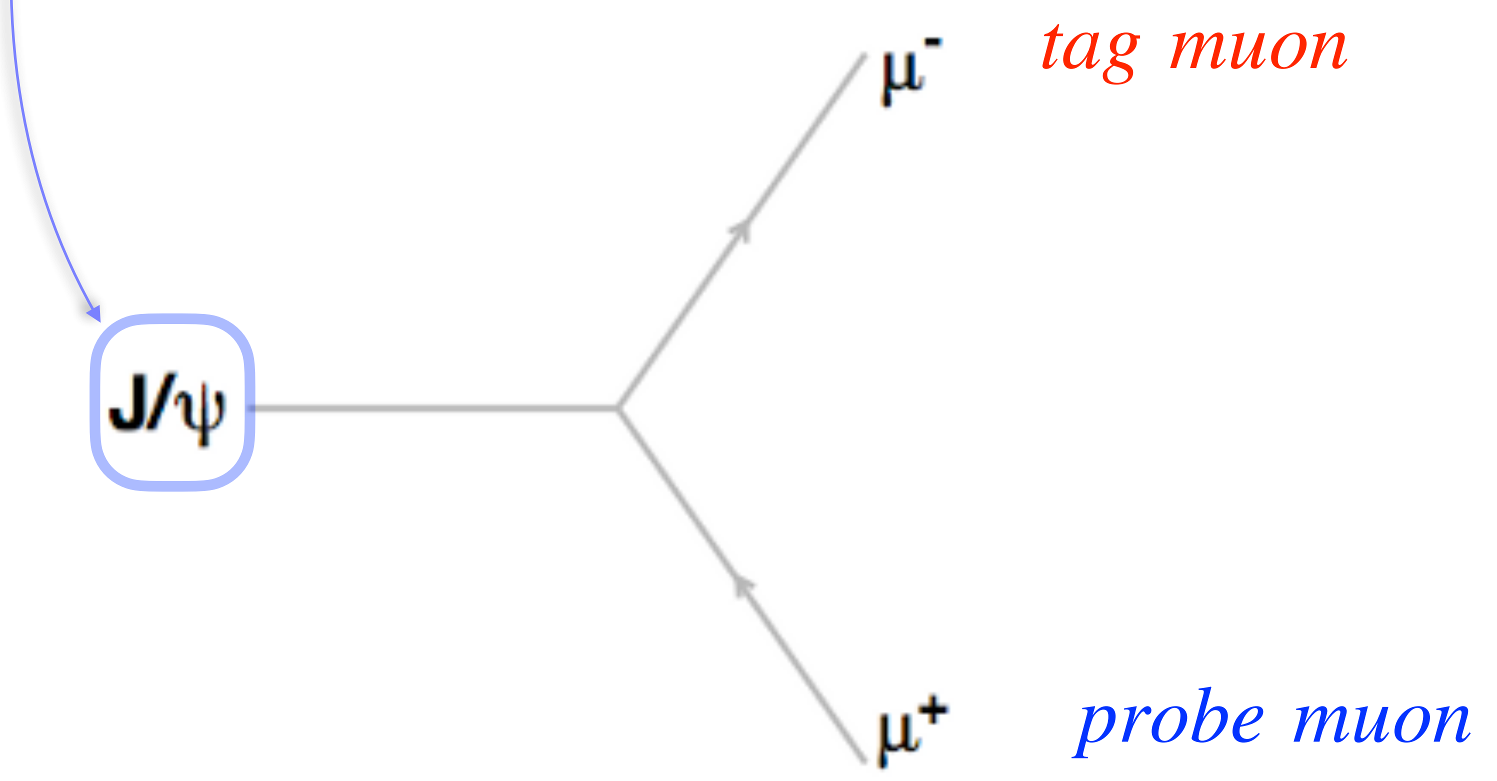
- Introduces additional uncertainty source to the measurement

Muon Efficiency Measurement: Tag and Probe Method

✳A **data-driven technique**

- Based on the decays of known resonances (e.g. J/ψ, Υ, Z) to pairs of the particles being studied
- Resonance, used to calculate the efficiencies, decays to a pair of muons: *one muon as "tag" and the other as "probe"*
  - **Tag muon:** well-identified, triggered muon (tight selection criteria)
  - **Probe muon:** muon candidates (very loose selection criteria), either passing or failing the criteria for which the efficiency is to be measured





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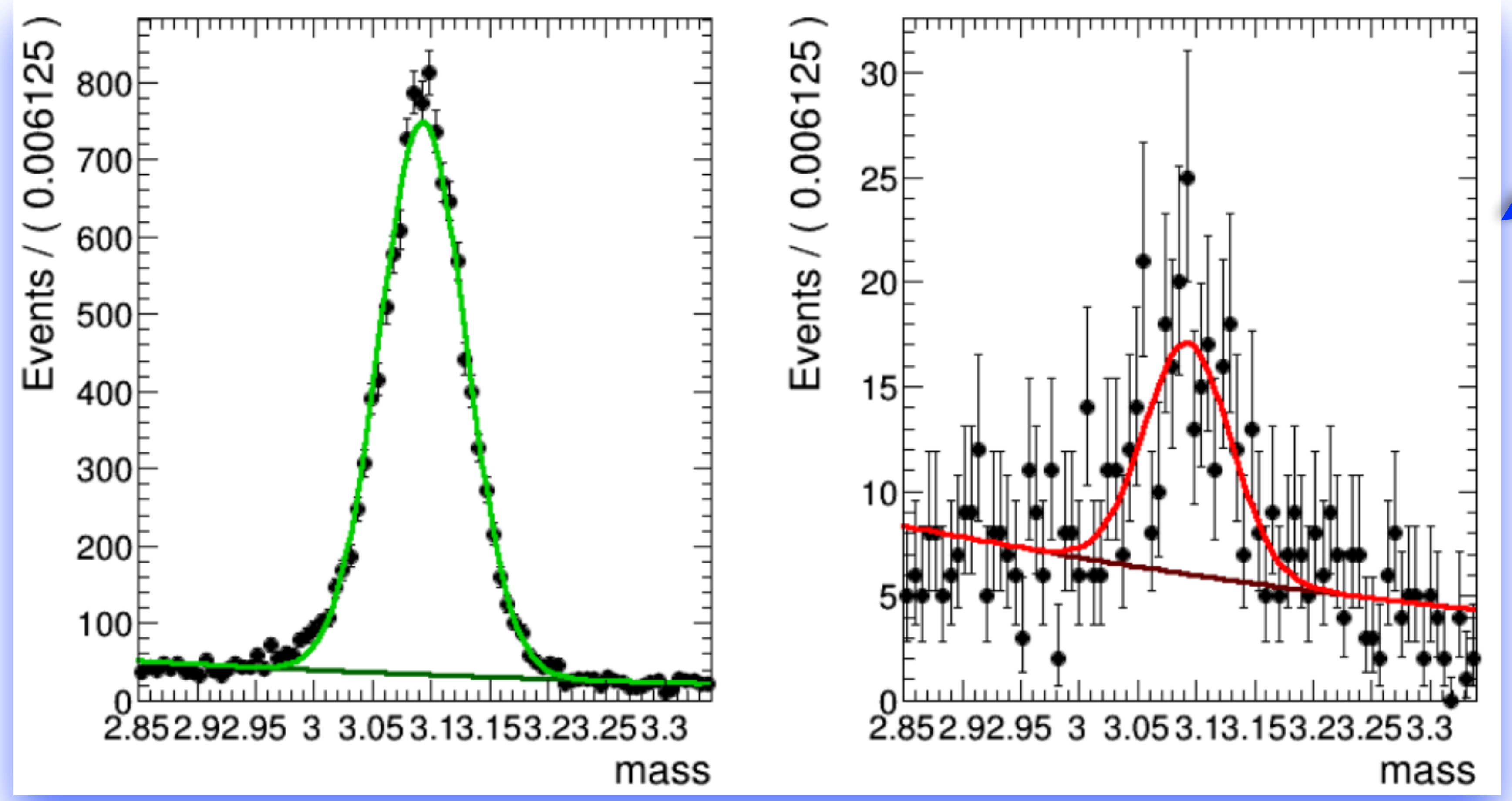
$tag + probe_{passing}$ $tag + probe_{failing}$



An example fit plot from J/ψ resonance (2017 data)

✶**Methodology:**

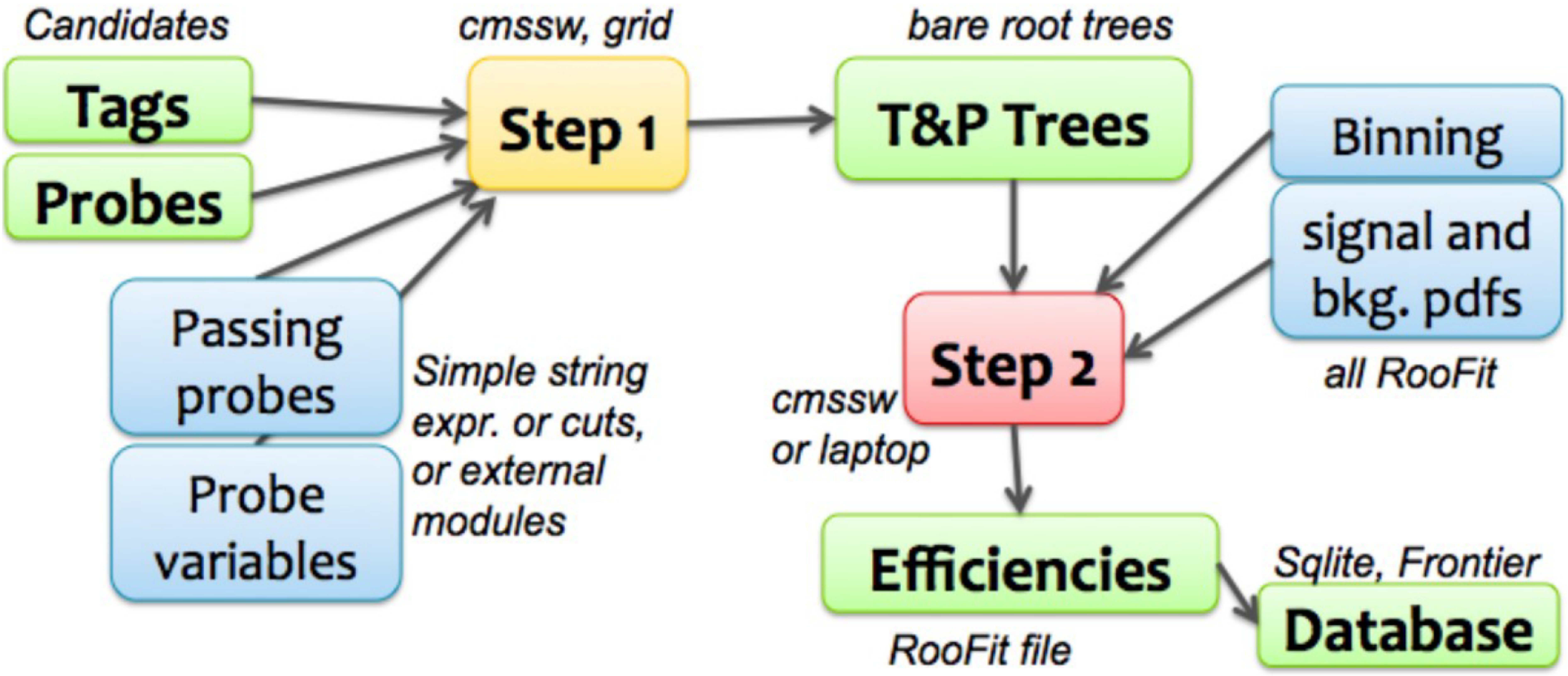
- Processing of the Data and MC samples **(root files)**
- Keep all possible information e.g. muon kinematics **(root branches)**
- Construct mass distributions of tag+passing probe and tag+failing probe muons
- Simultaneously fit the distributions using suitable polynomials (RooFit) (in bins of probe p_T, η,..)
- Using the integral from fits, a certain efficiency (in Data or MC) is measured over the "*probe*" muons:

$$\epsilon = \frac{N_{passing\ probes}}{N_{passing\ probes} + N_{failing\ probes}}$$

- Systematic Unc. measured by varying the tag muon def., fit functions, the mass range where the fits are performe and etc.

$$\epsilon_{total} = \epsilon_{tracking} * \epsilon_{Identification} * \epsilon_{IP} * \epsilon_{isolation} * \epsilon_{trigger}$$

Muon Efficiency Measurement: Overall workflow



Muon Efficiency Measurement: Hands-on exercise

How to login to an IHEP machine?

```
ssh -XY {USERNAME}@lxlogin.ihep.ac.cn
```

Setup Instructions

```
export PATH=/cvmfs/container.ihep.ac.cn/bin/:$PATH
hep_container shell CentOS7
export SCRAM_ARCH=slc7_amd64_gcc700
source /cvmfs/cms.cern.ch/cmsset_default.sh
cmsrel CMSSW_10_2_5
cd CMSSW_10_2_5/src
cmsenv
git clone -b CMS-China-WC3-2022data https://github.com/tjavaid/TnP-scripts.git
OR
git clone -b CMS-China-WC3-2022data git@github.com:tjavaid/TnP-scripts.git

git clone -b 102x https://github.com/cms-analysis/HiggsAnalysis-CombinedLimit.git HiggsAnalysis/
CombinedLimit
OR
git clone -b 102x git@github.com:cms-analysis/HiggsAnalysis-CombinedLimit.git HiggsAnalysis/
CombinedLimit

cd $CMSSW_BASE/src/HiggsAnalysis/CombinedLimit
git fetch origin
git checkout v8.2.0
scramv1 b clean; scramv1 b
```

Excercises plan

✳Measuring muon efficiencies for Muon **Identification (ID)**:

- **Loose** (with and without systematic studies) Exercise-I (lecture)
- **Medium** (with and without systematic studies) Exercise-II (homework)
- **Tight** (with and without systematic studies) Exercise-III (homework)

✳Using partial Run 3 data from CMS (2022 year only) (muon POG twiki link)

- Muons from J/ψ resonance (used for muon p_T upto 20 GeV)

The setup is now ready !!

Muon Efficiency Measurement: Samples used

Samples (Run2022: separate for BCD and EFG eras)

data era:"Run2022" Total(BCD):(L=7.7 fb^{-1})	**Run2022 B(0.08fb^{-1})**	**/SingleMuon/Run2022B-PromptReco-v1/MINIAOD**
	Run2022 C(4.84fb^{-1})	**/SingleMuon/Run2022C-PromptReco-v1/MINIAOD** **/Muon/Run2022C-PromptReco-v1/MINIAOD**
	Run2022 D(2.74fb^{-1})	**/Muon/Run2022D-PromptReco-v1/MINIAOD** **/Muon/Run2022D-PromptReco-v2/MINIAOD**
data era: "Run2022EE" Total(EFG):(L=34.2 fb^{-1})	**Run2022 E(4.77fb^{-1})**	**/Muon/Run2022E-PromptReco-v1/MINIAOD**
	Run2022 F(26.4fb^{-1})	**/Muon/Run2022F-PromptReco-v1/MINIAOD**
	Run2022 G(3.055fb^{-1})	**/Muon/Run2022G-PromptReco-v1/MINIAOD**
mc era: "Run2022"	**/JpsiTo2Mu_JpsiPt8_TuneCP5_13p6TeV_pythia8/Run3Summer22MiniAODv3-MUO_POG_124X_mcRun3_2022_realistic_v12-v2/MINIAODSIM - ** before ERA E	
mc era: "Run2022EE"	**/Jpsito2Mu_JpsiPT8_TuneCP5_13p6TeV_pythia8/Run3Summer22EEMiniAODv3-MUO_POG_124X_mcRun3_2022_realistic_postEE_v1-v2/MINIAODSIM - ** after ERA E	

Muon Efficiency Measurement: Selections and fit parameters

Category	Conditions or selections
Tag muon	pT > 8 GeV & |η| < 2.4 - Tight ID - Matched to a trigger object from a single muon trigger requiring pT > 8 (or 15 or 17 or 19 or 20) GeV or IsoMu24
Probe muon	- Tracker muon - p T > 2 GeV - |dZ| < 0.5 cm
Mass Range	2.9 < m(μμ) < 3.3 GeV
Pair Condition	- ΔR(tag, probe) >=0.3 - |dZ| < 0.5 cm - pair multiplicity==1 (pairs whose probe muon is associated to only one tag)
Fitting functions	-**Signal:** Gaussian function, Crystalball function -**Background:** Exponential function, Bernstein and Chebychev polinomials

Systematic source	Systematic Variations
Choice of PDFs	**Signal PDFs:** Jgauss, JCB **Background PDFs:** Expo, bern3, bern4, cheb
Mass Range	- Default/nominal: 2.9-3.3 GeV - Extended: 2.85-3.35 GeV - Reduced: 2.95-3.25 GeV
No. Of bins in default mass range	- Default/nominal: 20 - Extended: 30 - Reduced: 15

Variable	Binning	
2D (pT x |η|)	**pT**	[3,4.5,6,7.5,9,12,15,20]
	| η |	[0,1.2,2.4]
1D (η) (pT > 2 GeV)	**η**	[-2.4,-2.1,-1.6,-1.2,-0.9,-0.3,-0.2, 0.2,0.3,0.9,1.2,1.6,2.1,2.4]

Muon Efficiency Measurement: Running for the fits and the efficiency plots

✳Navigate to the directory containing the tag and probe scripts:

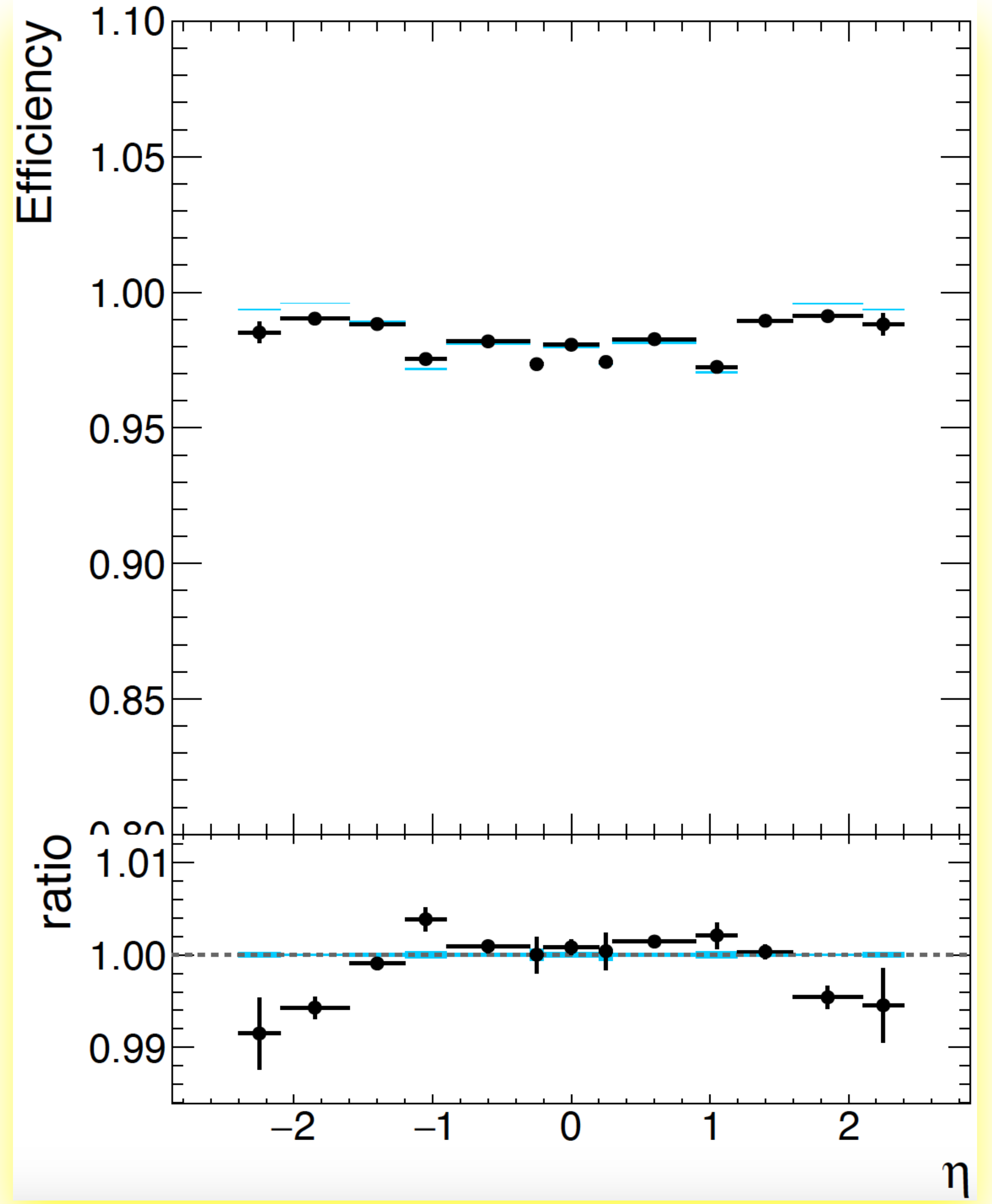
```
cd $CMSSW_BASE/src/TnP-scripts
```

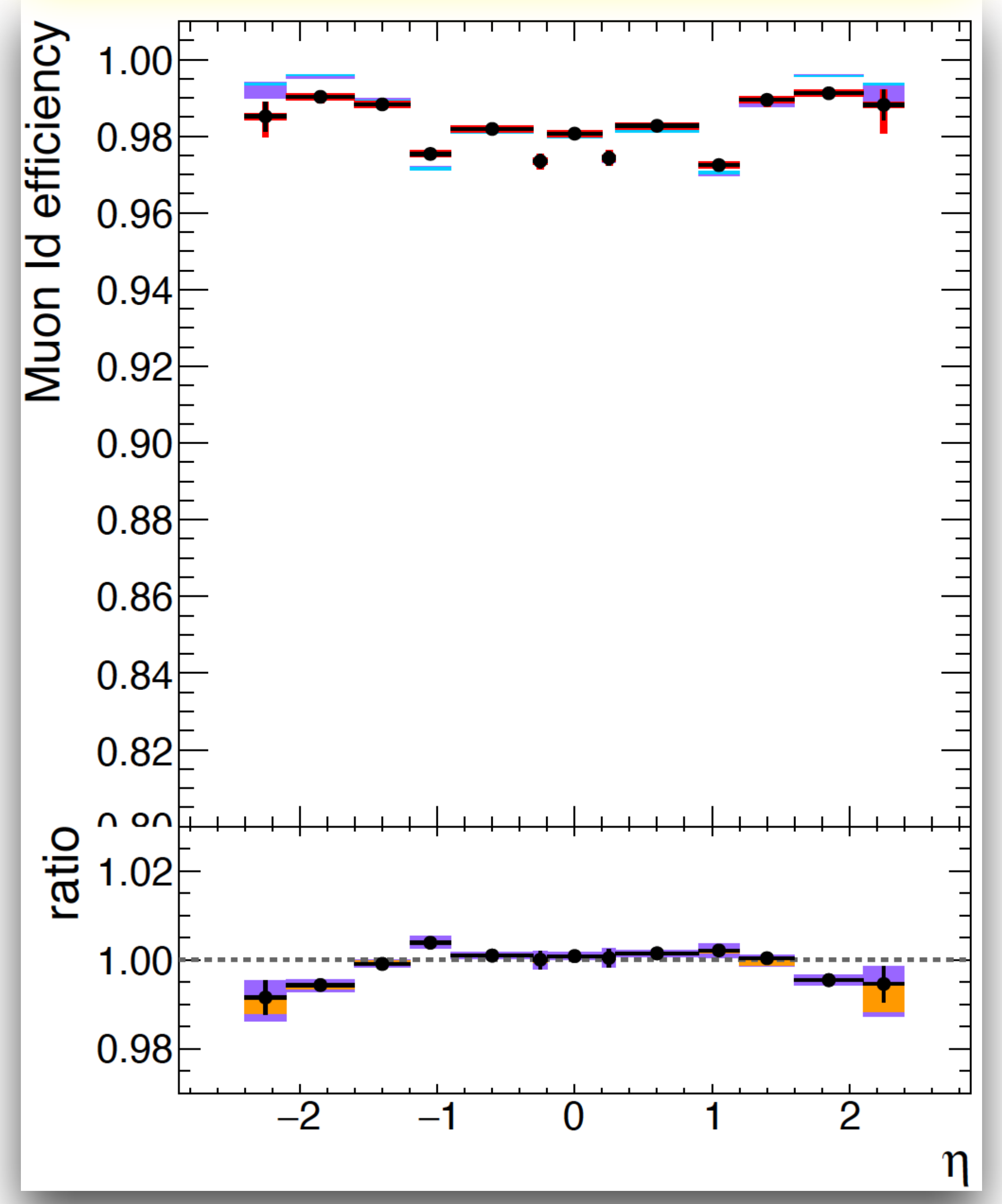
✳Run for the fits, using the macro **`runTnP_MuPOG_jpsi_2022.sh;`**

- Runs over **`tnpEfficiency.py`** module; needs 3 arguments:
  - `sh runTnP_MuPOG_jpsi_2022.sh {arg1} {arg2} {arg2}`
    - `{arg1}` = **2022BCD** or **2022EFG** ; era of processing
    - `{arg2}` = **nominal** or **syst** or **all** ; stat-only or alternate systematic scenarios
    - `{arg3}` = **loose**, **medium** or **tight**, etc. ; type of muon ID to process
- To run fits and efficiency plots for Loose ID, nominal/default (stat-only) for 2022BCD:
  - `sh runTnP_MuPOG_jpsi_2022.sh 2022BCD nominal loose`
  - Fit output is stored in `{arg1}_TnP/mupog_RecoId` (`ls 2022BCD_TnP/mupog_RecoId`)
- To run fits for other alternatives for systematics. Use:
  - `sh runTnP_MuPOG_jpsi_2022.sh 2022BCD syst loose`

✳Run to include systematics and produce updated efficiency & scale factor plots

- `sh harvestTnP_MuPOG_ID_2022.sh 2022BCD loose`
  - Runs over **`tnpHarvest.py`** module





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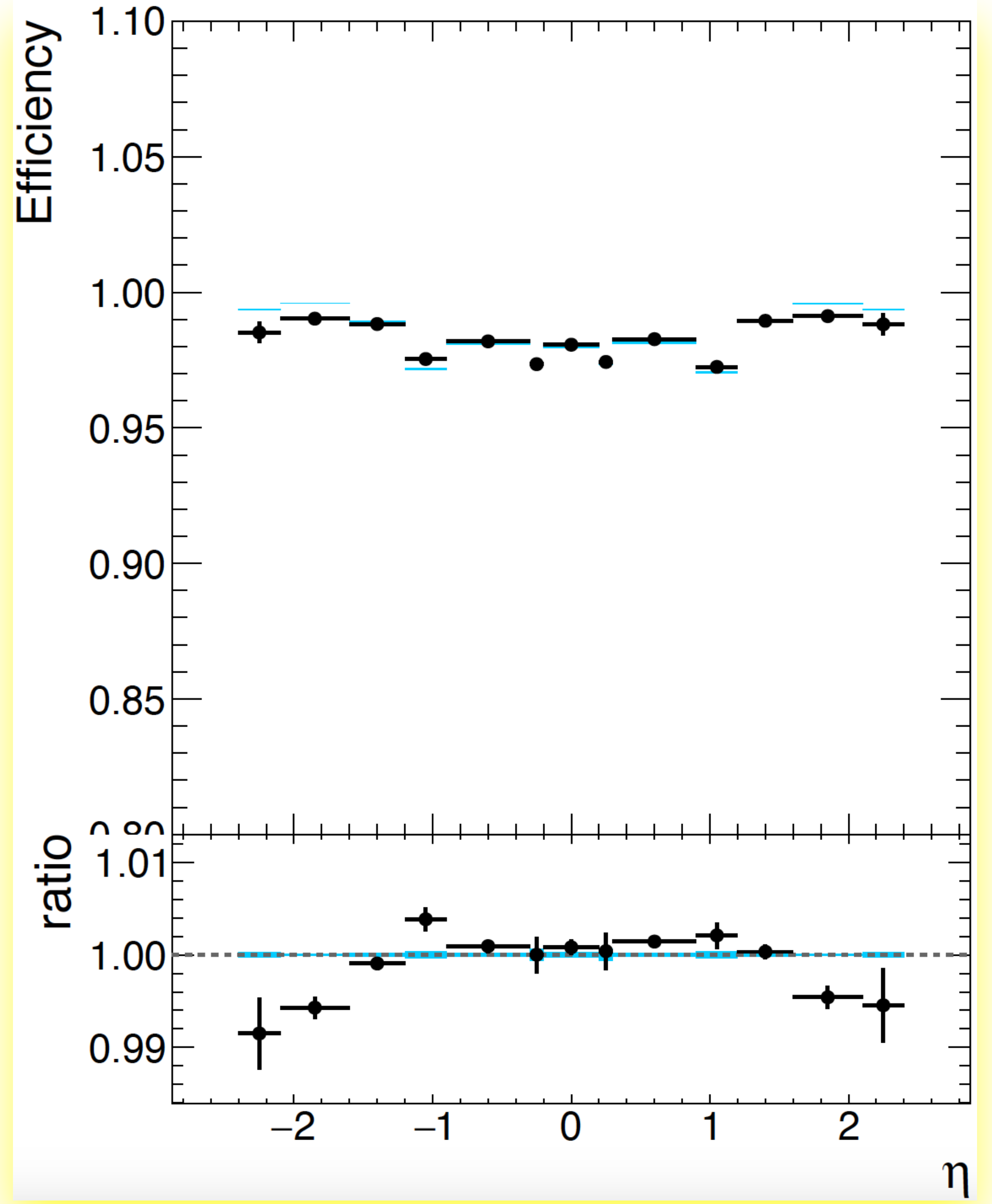
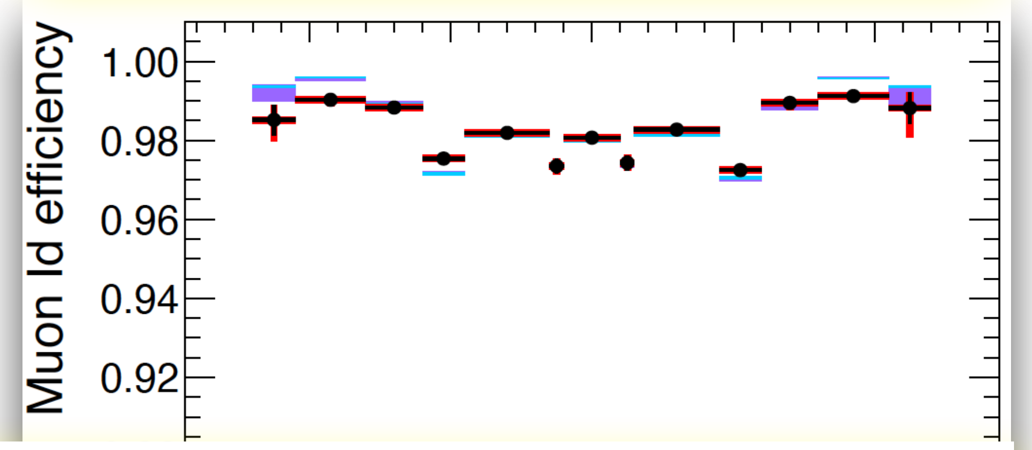
- To run fits and efficiency plots for Loose ID, nominal/default (stat-only) for 2022BCD:
  - `sh runTnP_MuPOG_jpsi_2022.sh 2022BCD nominal loose` (~6 minuts)
  - Fit output is stored in `{arg1}_TnP/mupog_RecoId` (`ls 2022BCD_TnP/mupog_RecoId`)






```
Singularity> ls 2022BCD_TnP/mupog_RecoId/
index.php                                  mu_JCB_cheb_probe_CutBasedIdLoose_pt2.png   mu_JGauss_bern3_probe_CutBasedIdLoose_pt2.dir   mu_JGauss_cheb_probe_CutBasedIdLoose_pt2.root
mu_JCB_bern3_probe_CutBasedIdLoose_pt2.dir   mu_JCB_cheb_probe_CutBasedIdLoose_pt2.root  mu_JGauss_bern3_probe_CutBasedIdLoose_pt2.pdf   mu_JGauss_cheb_probe_CutBasedIdLoose_pt2.txt
mu_JCB_bern3_probe_CutBasedIdLoose_pt2.pdf   mu_JCB_cheb_probe_CutBasedIdLoose_pt2.txt   mu_JGauss_bern3_probe_CutBasedIdLoose_pt2.png   mu_JGauss_expo_probe_CutBasedIdLoose_pt2.dir
mu_JCB_bern3_probe_CutBasedIdLoose_pt2.png   mu_JCB_expo_probe_CutBasedIdLoose_pt2.dir   mu_JGauss_bern3_probe_CutBasedIdLoose_pt2.root  mu_JGauss_expo_probe_CutBasedIdLoose_pt2.pdf
mu_JCB_bern3_probe_CutBasedIdLoose_pt2.root  mu_JCB_expo_probe_CutBasedIdLoose_pt2.pdf   mu_JGauss_bern3_probe_CutBasedIdLoose_pt2.txt   mu_JGauss_expo_probe_CutBasedIdLoose_pt2.png
mu_JCB_bern3_probe_CutBasedIdLoose_pt2.txt   mu_JCB_expo_probe_CutBasedIdLoose_pt2.png   mu_JGauss_cheb_probe_CutBasedIdLoose_pt2.dir    mu_JGauss_expo_probe_CutBasedIdLoose_pt2.root
mu_JCB_cheb_probe_CutBasedIdLoose_pt2.dir    mu_JCB_expo_probe_CutBasedIdLoose_pt2.root  mu_JGauss_cheb_probe_CutBasedIdLoose_pt2.pdf    mu_JGauss_expo_probe_CutBasedIdLoose_pt2.txt
mu_JCB_cheb_probe_CutBasedIdLoose_pt2.pdf    mu_JCB_expo_probe_CutBasedIdLoose_pt2.txt   mu_JGauss_cheb_probe_CutBasedIdLoose_pt2.png
```

Looking at macro: runTnP_MuPOG_jpsi.sh

```
#PDIR="test/"
PDIR=$1"_TnP"
if [[ $1 != "" ]]; then echo "PDIR:", $PDIR; fi

declare -A ids
ids["loose"]="probe_CutBasedIdLoose"
ids["medium"]="probe_CutBasedIdMedium"
ids["tight"]="probe_CutBasedIdTight"

id=${ids[$3]}
echo "ID is : " $id
JOB="mupog_RecoId"

#XBINS="[3,4,5,6,7,8,9,10,30]" # POG
XBINS="[3,4.5,6,7.5,9,12,15,20]" # defining bins in pT of muons (used for barrel and endcap plots)

EBINS="[-2.4,-2.1,-1.6,-1.2,-0.9,-0.3,-0.2,0.2,0.3,0.9,1.2,1.6,2.1,2.4]" # defining bins in eta of muons (inclusive for pT of muons)
#EBINS="[0,0.3,0.55,0.8,1.1,1.4,1.85,2.4]"   #    arbitrary, HIG-21-009
VBINS="[0.5,5.5,6.5,7.5,8.5,9.5,10.5,11.5,12.5,13.5,14.5,15.5,17.5,20.5]" # bins for no. of vetices


if [[ $1 != "" ]]; then echo "era being processed is:       ", $1; fi
###########################################################################
# Data and MC samples used for the studies
if [[ "$1" == "2022BCD" ]]; then MC='/publicfs/cms/data/hzz/jtahir/WC2/Run3/Run2022/haddOut_JPsi_pythia8_skimmed_weightAdded.root';
DATA='/publicfs/cms/data/hzz/jtahir/WC2/Run3/Run2022/haddOut_RunB_skimmed.root
/publicfs/cms/data/hzz/jtahir/WC2/Run3/Run2022/haddOut_RunC_skimmed.root
/publicfs/cms/data/hzz/jtahir/WC2/Run3/Run2022/haddOut_RunD_skimmed.root
';
elif [[ "$1" == "2022EFG" ]]; then
MC='/publicfs/cms/data/hzz/jtahir/WC2/Run3/Run2022_EE/haddOut_JPsi_pythia8_skimmed_weightAdded.root'
DATA='/publicfs/cms/data/hzz/jtahir/WC2/Run3/Run2022_EE/haddOut_RunE_skimmed.root
/publicfs/cms/data/hzz/jtahir/WC2/Run3/Run2022_EE/haddOut_RunF_skimmed.root
/publicfs/cms/data/hzz/jtahir/WC2/Run3/Run2022_EE/haddOut_RunG_skimmed.root
';
else echo "please enter the era to be processed. Thanks!"; exit
fi

if [[ $2 == "" ]]; then echo "please specify the mode (nominal, syst or all)! "; exit
fi
```

Looking at macro: `runTnP_MuPOG_jpsi.sh` (continued)

```
PDS="$DATA --refmc $MC"

OPTS=" --doRatio  --pdir $PDIR/$JOB -j 5 --mcw weight " #--mcw genWeight
OPTS="$OPTS -t muon/Events  --mc-cut 1 --mc-mass pair_mass   "

MASS="  -m pair_mass 40,2.9,3.3" # the default dimuon invariant mass window and no. of data points i.e. 40

echo $CDEN

# tag muon selections (matched to a trigger object from a single muon trigger)
CDEN="tag_pt > 8 && abs(tag_eta) < 2.4 && tag_isTight==1 && (tag_HLT_Mu8_v==1 || tag_HLT_Mu15_v==1 || tag_HLT_Mu17_v==1 || tag_HLT_Mu19_v==1 ||
 tag_HLT_Mu20_v==1 || tag_HLT_IsoMu24_v==1)"

# probe muon selections
CDEN="$CDEN && probe_isTracker==1 && probe_pt > 2 && abs(probe_dz) < 0.5"

# pair conditions
CDEN="$CDEN && pair_probeMultiplicity==1 && pair_drM1>= 0.3" # pair_probeMultiplicity -> pairs whose probe muon is associated to only one tag m
uon, pair_drM1-> dR between tag and probe muons


for ID in $id ; do
 # if [[ "$SEL" != "" ]] && echo $SEL | grep -q -v $ID; then continue; fi
  NUM="$ID"
  if [[ "$ID" == "Reco" ]]; then   NUM="(Glb || TM)"; fi

  if [[ "$ID" == "LooseIdOnly" ]]; then NUM="Loose"; CDEN="$CDEN && (Glb || TM)"; fi
```

Looking at macro: runTnP_MuPOG_jpsi.sh (continued)

```
  for BMOD in expo bern3 cheb ; do  # other alternate models are bern4, bern5, bern6, bern7, etc....
#    for SMOD in JGauss ; do  # other alternate model is  JDGauss JCB
    for SMOD in JCB JGauss; do  #
        DEN="$CDEN";
        if [ "$2" == "nominal" ] || [ "$2" == "all" ]; then # to execute the nominal part
        echo "running fits for the nominal part"
        POST="";
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>0 && abs(probe_eta)<=1.2 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_barrel -b $BMOD -s $SMOD $MASS --xtitle "p_{T} (GeV)";
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>1.2 && abs(probe_eta)<=2.4 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_endcap -b $BMOD -s $SMOD $MASS --xtitle "p_{T} (GeV)";
        python tnpEfficiency.py $PDS -d "probe_pt > 2 && $DEN" -n "$NUM" $OPTS --x-var probe_eta $EBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_pt2   -b $BMOD -s $SMOD $MASS  --xtitle "#eta" --yrange 0.8 1.1;
        fi
######  adding more  alternate choices ((than the signal and background PDFs)) for systematics purposes
        if [ "$2" == "syst" ] || [ "$2" == "all" ]; then
        echo "running fits for the syst. part";
        MASS2=" -m pair_mass 20,2.95,3.25"; POST="_massReduced";
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>0 && abs(probe_eta)<=1.2 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_barrel -b $BMOD -s $SMOD $MASS2 --xtitle "p_{T} (GeV)";
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>1.2 && abs(probe_eta)<=2.4 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_endcap -b $BMOD -s $SMOD $MASS2 --xtitle "p_{T} (GeV)";
        python tnpEfficiency.py $PDS -d "probe_pt > 2 && $DEN" -n "$NUM" $OPTS --x-var probe_eta $EBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_pt2   -b $BMOD -s $SMOD $MASS2  --xtitle "#eta" ;
#
        MASS2=" -m pair_mass 20,2.85,3.35"; POST="_massExtended"  # with extended mass range (default is 20,2.9,3.3)
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>0 && abs(probe_eta)<=1.2 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_barrel -b $BMOD -s $SMOD $MASS2 --xtitle "p_{T} (GeV)";
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>1.2 && abs(probe_eta)<=2.4 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_endcap -b $BMOD -s $SMOD $MASS2 --xtitle "p_{T} (GeV)";
        python tnpEfficiency.py $PDS -d "probe_pt > 2 && $DEN" -n "$NUM" $OPTS --x-var probe_eta $EBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_pt2   -b $BMOD -s $SMOD $MASS2  --xtitle "#eta" ;
#
        MASS2=" -m pair_mass 15,2.9,3.3"; POST="_binsReduced"  # with reduced bins in mass range (default is 20,2.9,3.3)
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>0 && abs(probe_eta)<=1.2 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_barrel -b $BMOD -s $SMOD $MASS2 --xtitle "p_{T} (GeV)";
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>1.2 && abs(probe_eta)<=2.4 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_endcap -b $BMOD -s $SMOD $MASS2 --xtitle "p_{T} (GeV)";
        python tnpEfficiency.py $PDS -d "probe_pt > 2 && $DEN" -n "$NUM" $OPTS --x-var probe_eta $EBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_pt2   -b $BMOD -s $SMOD $MASS2  --xtitle "#eta" ;
#
        MASS2=" -m pair_mass 30,2.9,3.3"; POST="_binsExtended"  # with extended bins in mass range (default is 20,2.9,3.3)
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>0 && abs(probe_eta)<=1.2 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_barrel -b $BMOD -s $SMOD $MASS2 --xtitle "p_{T} (GeV)";
#        python tnpEfficiency.py $PDS -d "abs(probe_eta)>1.2 && abs(probe_eta)<=2.4 && $DEN" -n "$NUM" $OPTS --x-var probe_pt $XBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_endcap -b $BMOD -s $SMOD $MASS2 --xtitle "p_{T} (GeV)";
        python tnpEfficiency.py $PDS -d "probe_pt > 2 && $DEN" -n "$NUM" $OPTS --x-var probe_eta $EBINS -N mu_${SMOD}_${BMOD}${POST}_${ID}_pt2   -b $BMOD -s $SMOD $MASS2  --xtitle "#eta" ;
        fi;
    done
  done
done
```

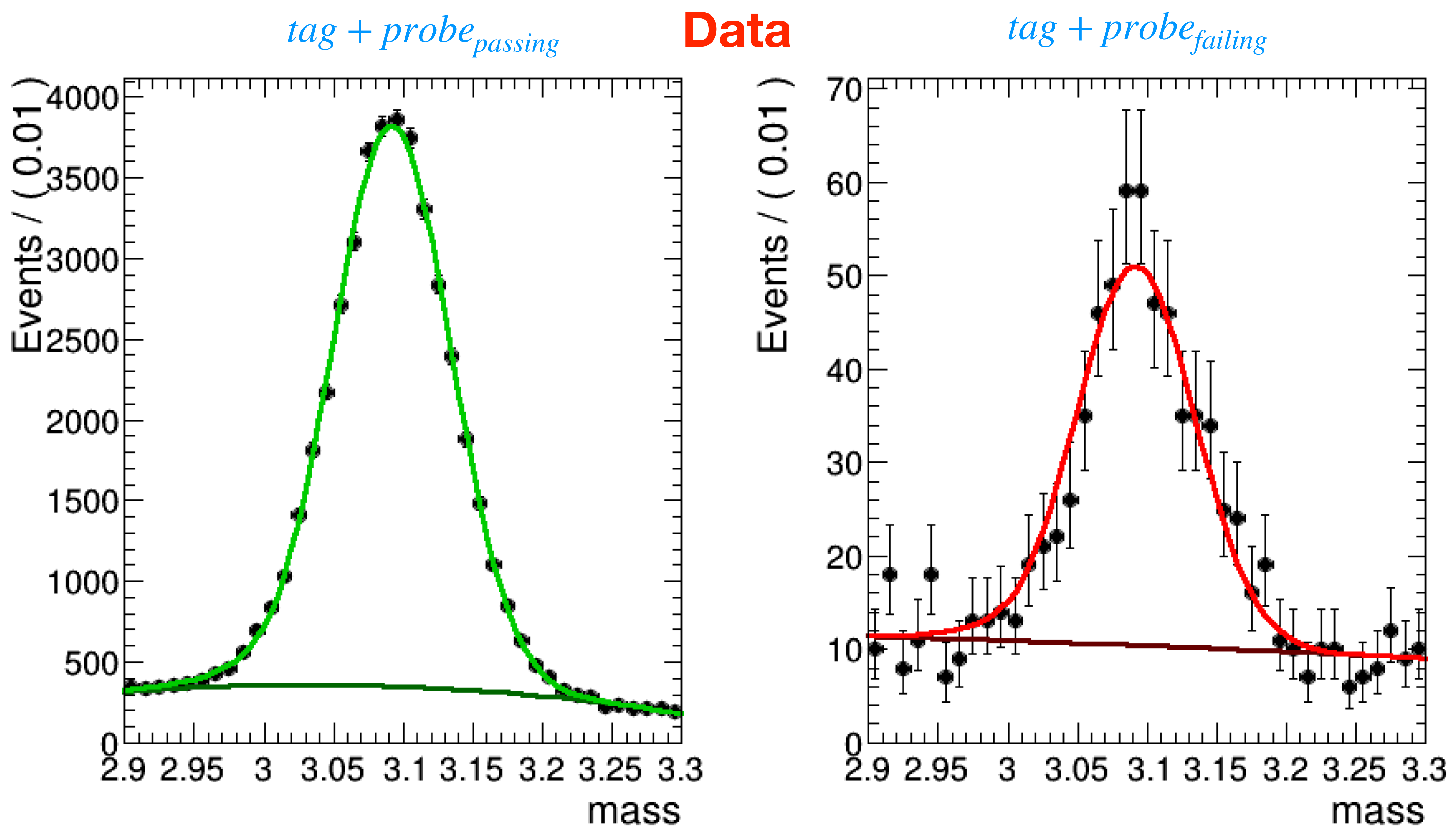
Looking at fits and efficiency plots

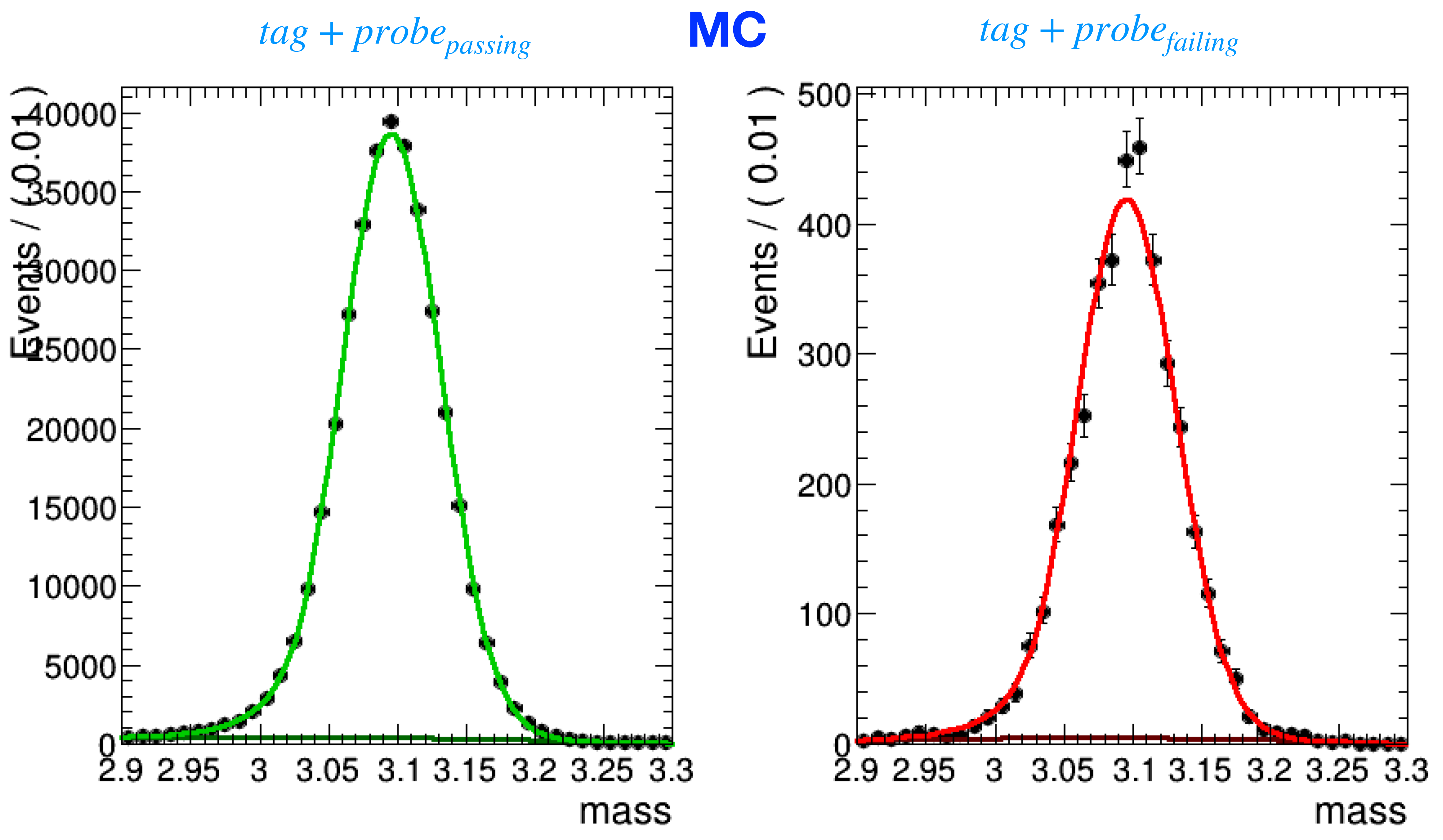
✳View directly from ihep cluster:

- Fit plots

```
display 2022BCD_TnP/mupog_RecoId/mu_JCB_bern3_probe_CutBasedIdLoose_pt2.dir/mu_JCB_bern3_probe_CutBasedIdLoose_pt2_bin3.png
```
(Data distribution for 3rd bin)

```
display 2022BCD_TnP/mupog_RecoId/mu_JCB_bern3_probe_CutBasedIdLoose_pt2.dir/mu_JCB_bern3_probe_CutBasedIdLoose_pt2_bin3_ref.png
```
(MC distribution for 3rd bin)



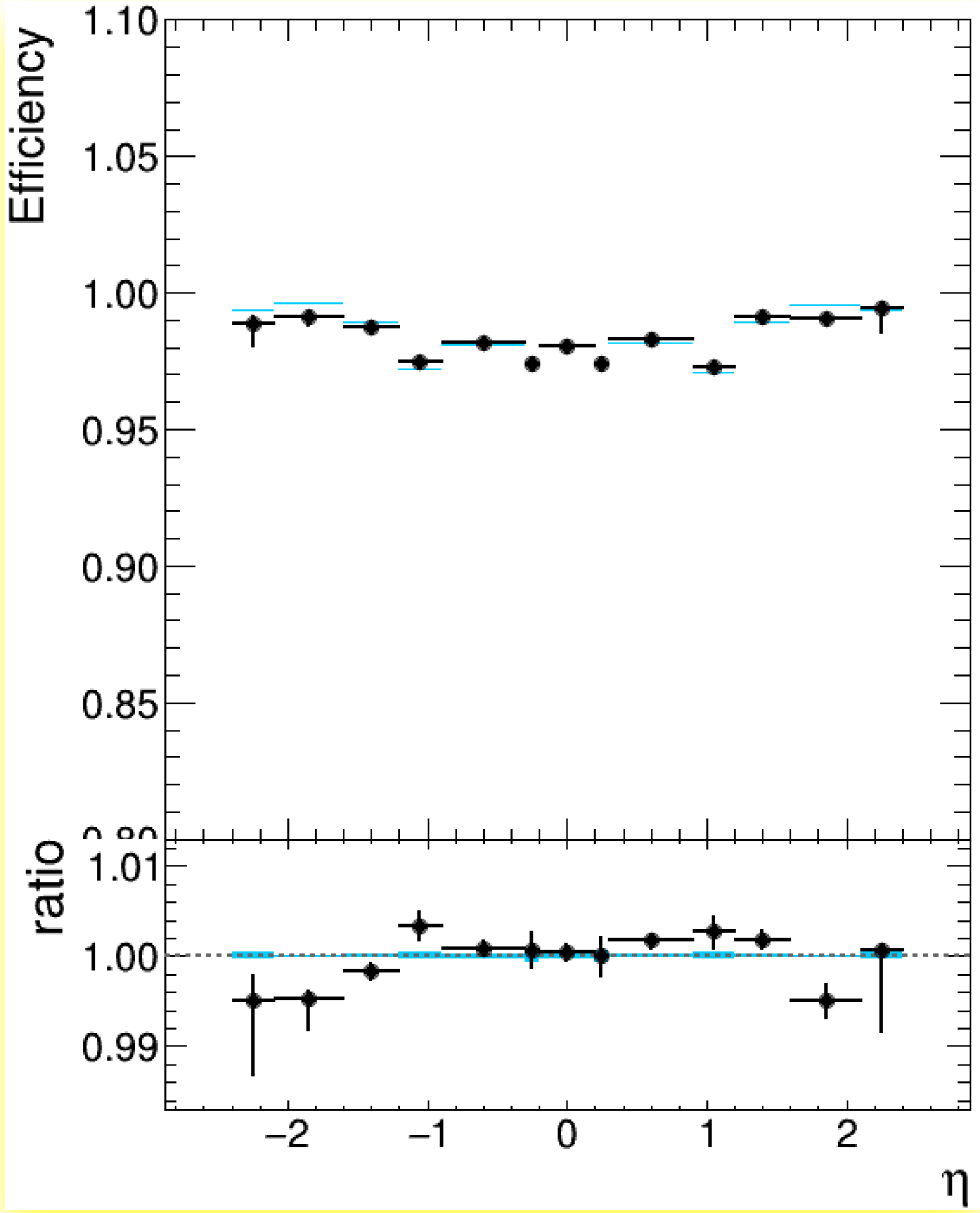


Looking at fits and efficiency plots

✳View directly from ihep cluster:

- Efficiency plots

```
display 2022BCD_TnP/mupog_RecoId/mu_JCB_bern3_probe_CutBasedIdLoose_pt2.png
```



Optional

✳May download the plots to your own laptop. From the terminal of your own laptop, use the following command:

```
scp -r {your_username}@lxlogin.ihep.ac.cn:/publicfs/cms/user/
{your_username}/MuonEff/CMSSW_10_2_5/src/TnP-scripts/2022BCD_TnP/
mupog_RecoId ./
```

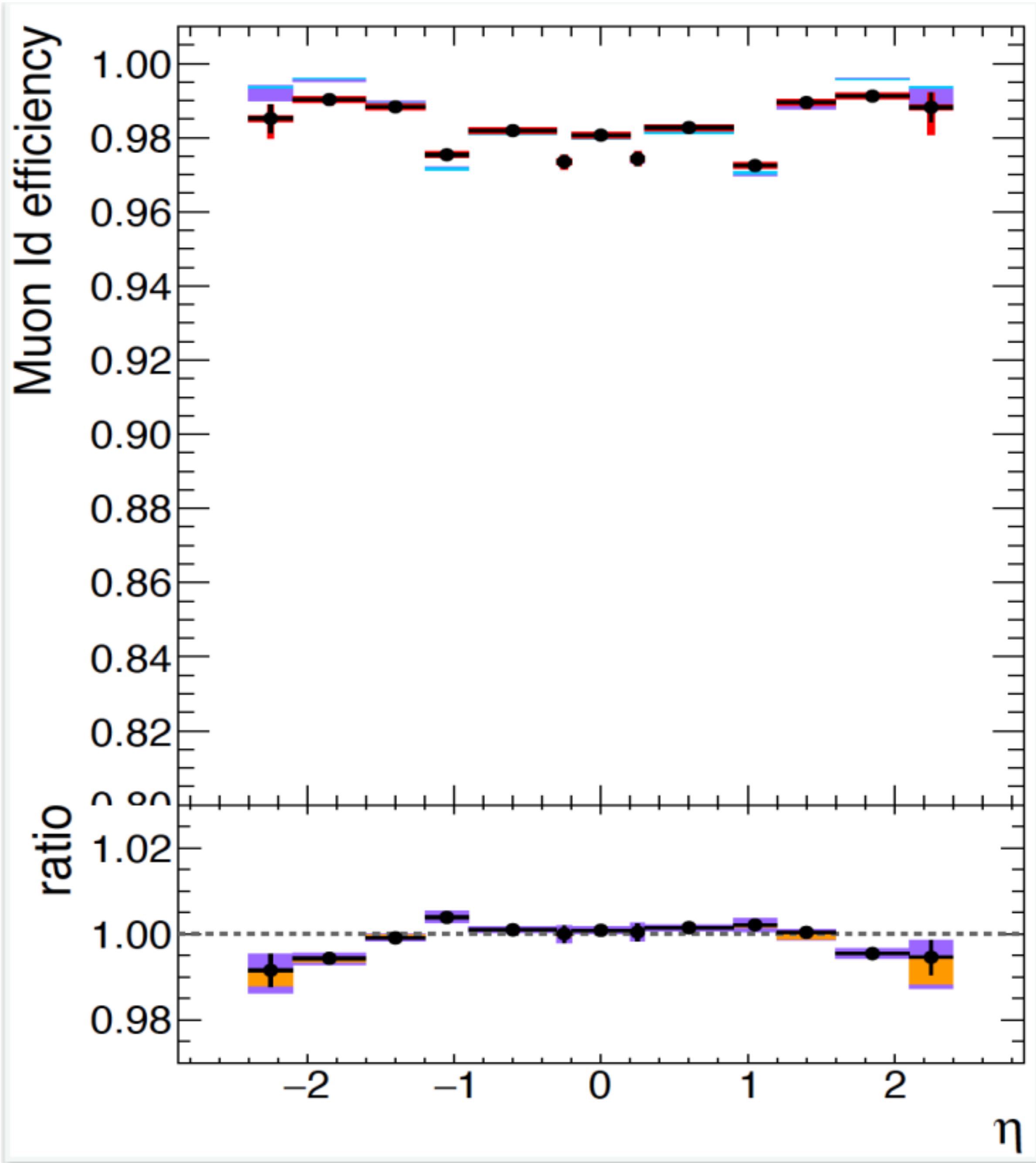
Running the systematic part

✳To run fits for other alternatives for systematics directly from ihep cluster:

`sh runTnP_MuPOG_jpsi_2022.sh 2022BCD syst loose` (~21 minutes)

✳Once you finish running the alternatives for systematics, you can produce updated efficiency & scale factor plots by doing:

`sh harvestTnP_MuPOG_ID_2022.sh 2022BCD loose` (<1 minute)




```
#MEAS="mu_probe_CutBasedIdLoose"                                    # type of measurement
MEAS="mu_"$id

for sig in JGauss JCB; do
    for bkg in bern3 expo; do
        for salt in JGauss JCB; do
            if [[ "$salt" != "$sig" ]]; then
            for balt in bern3 expo ; do
                if [[ "$balt" != "$bkg" ]]; then
                for M in $MEAS; do
                    case $M in
                        mu_$id) MODS=" -s "${sig}" -b "${bkg}"  --balt "${balt}" --salt "${salt}"  ";
                        #mu_$id) MODS=" -s "${sig}" -b "${bkg}"  --balt "${balt}" --salt "${salt}" --alt massExtended --alt massReduced --alt binsExtended --alt binsReduced ";
                        OUT="$IN/${M}_$1_harvest_${sig}_${bkg}_${salt}_${balt}_mupogSysts"
                        TIT='Muon Id efficiency' ;;
                    esac;
                    OPTS=" --doRatio --pdir ${P}/$OUT --idir ${P}/$IN  --rrange 0.97 1.03  --yrange 0.8 1.01 "; XTIT="p_{T} (GeV)"
#                   for BE in barrel endcap ; do
#                       python tnpHarvest.py -N ${M}_${BE} $OPTS $MODS --ytitle "$TIT" --xtit "$XTIT"
#                   done
                    python tnpHarvest.py -N ${M}_pt2 $OPTS $MODS --ytitle "$TIT" --xtit "#eta"
                done
                fi;
done;
fi;
done;
done
done
```

- Uses `tnpHarvest.py` module


Thank you

BACKUP SLIDES