Measurement of charged particle spectra in pp collisions at CMS

Luca Mucibello
Universiteit Antwerpen (Belgium)

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Outline

- Motivation of interest
- State of knowledge
- The CMS Silicon Tracker: layout and performances
- Minimum Bias trigger performances
- CMS proposed analysis
- Conclusions

Motivation

Minimum Bias (mostly non-single diffractive inelastic interactions) ~65% of the total LHC scattering process: $\sigma_{NSD} = \sigma_{tot} - \sigma_{elas} - \sigma_{SD}$

- analyse global properties of hadron production:

higher energies → new opportunity for comprehension, sensitivity to fragmentation models

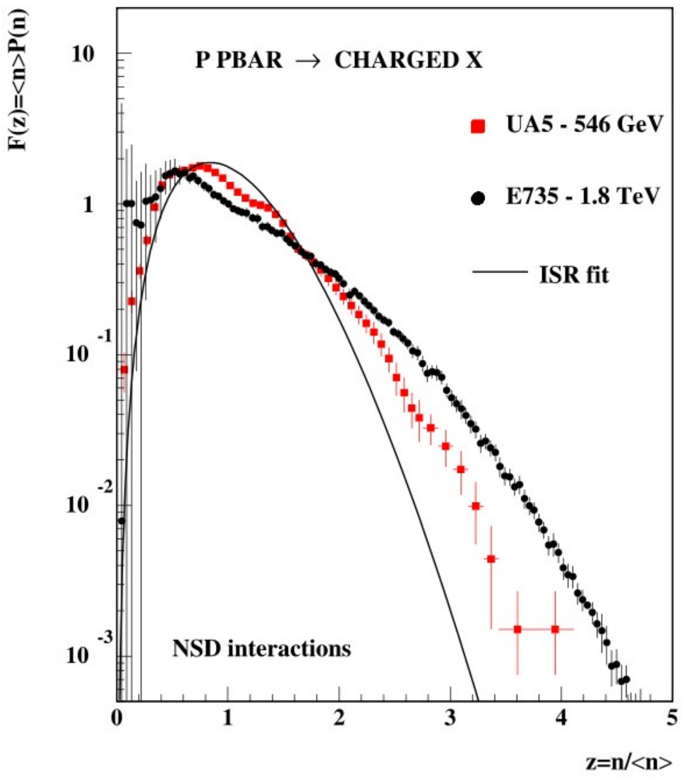
- predict background levels associated to many physics processes:

  at design luminosity of $\mathcal{L}=1.0\times10^{34}$ cm^{-2} s^{-1} and for the final expected beam bunch pattern of 2808×2808 there will be on average 20 collisions per recorded event: 1 signal + ~19 min-bias pile-up

- understand the complex nature of the radiation environment in which LHC's detector systems will operate (particular attention for Si tracker)

History

- asymptotic scaling of multiplicity distribution in hadron-hadron collisions (KNO scaling) predicted in 1972;
- early confirmation at 10-30-60 GeV;
- first observations of violation at higher energies from the UA5 collaboration (c.m. energies of 200-546-900 GeV) → notion of multiple parton interaction [T. Sjöstrand prd 36 (1987) 2019] ;
- CDF at Tevatron:
  - minimum bias trigger events at 1800 and 630 GeV
  - novel approach dividing dataset into “soft” and “hard” subsamples (based on presence of calorimetric activity in the transverse region)



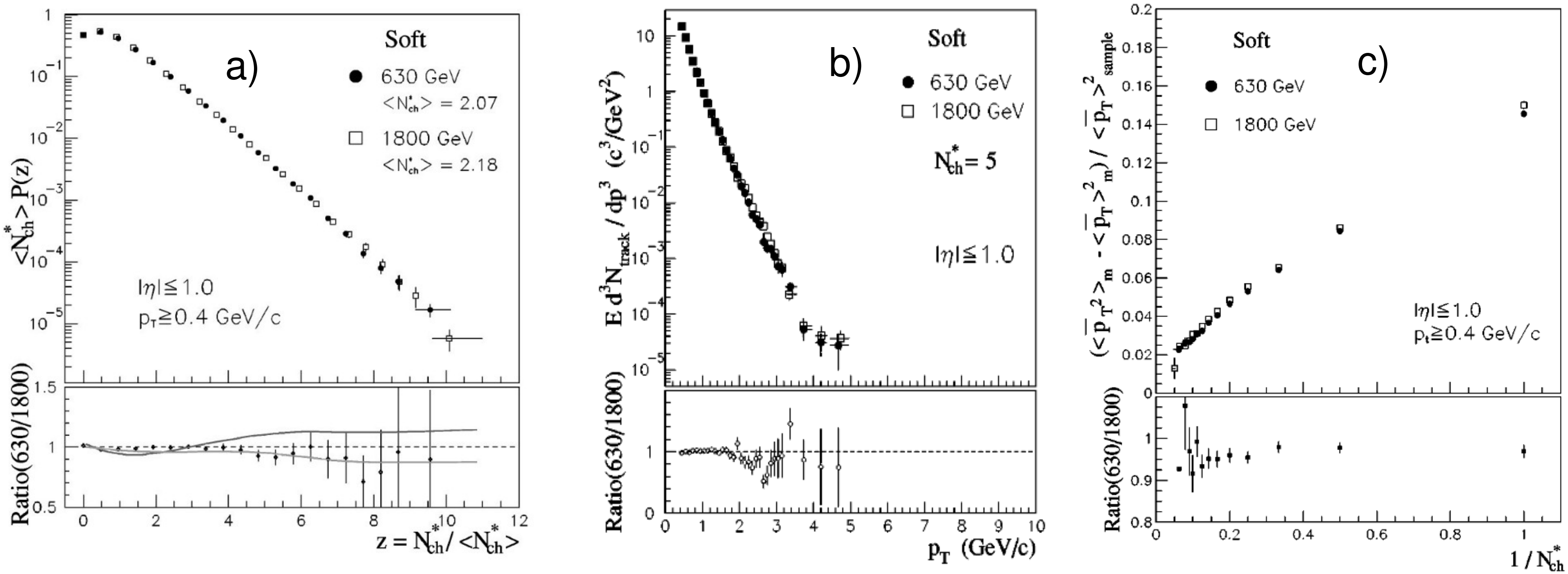
Tevatron studies

Evidence of energy invariance in “soft” sample:

- a) KNO scaling
- b) energy invariant p_T distributions at fixed multiplicities

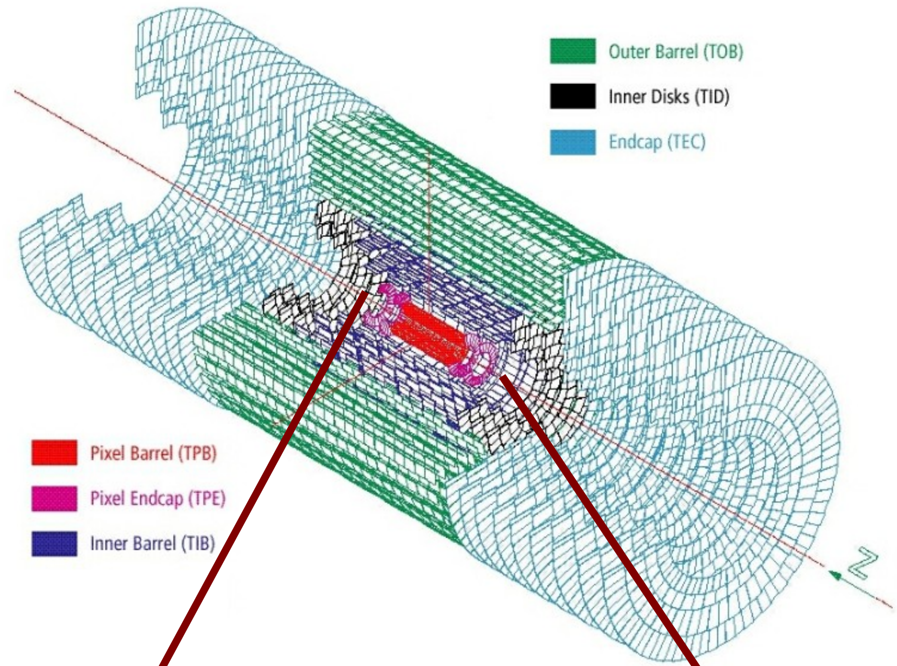
  → in purely “soft” interactions the number of produced charged particles is the only global event variable changing with sqrt s

  ← consequence/confirmation: mean $p_T(N)$ invariance
- c) $<p_T>_{event}$ dispersion scaling and compatibility with no dynamical fluctuations

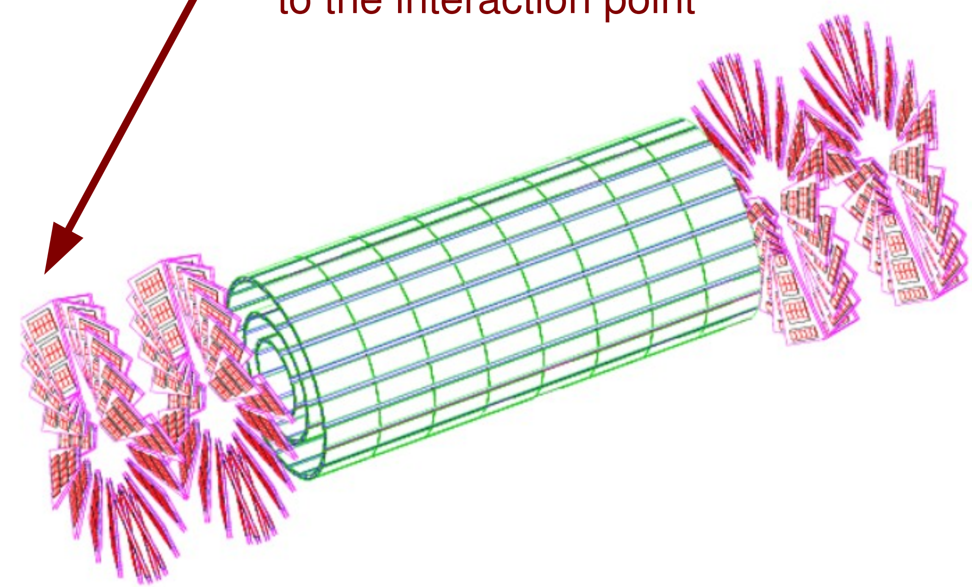


The Pixel Tracker

- ~1 m total length
- 3 barrel layers at radii of 4 , 7 and 11 cm
- 2 disks on each side at 34 and 46 cm
- about 60 million of pixels with shape of $100 \times 150\ \mu m^2$
- design resolution of about 10 μm for the r-φ measurement and about 20 μm for the z measurement



Pixel subdetector close to the interaction point



High resolution three dimensional space points:

→ primary vertex reconstruction
→ track seeding
→ fast HLT track reconstruction

Performances

TRACKER:

November cosmic ray data acquisition with magnetic field (CRAFT)

- **Operational Fraction:**
  - Barrel pixels: 99.1%
  - Forward pixels: 94.0%

  (readout chips without bias voltage, reparation in course)

- **Cosmic Track Finding Efficiency:**

  - Tag&Probe technique:

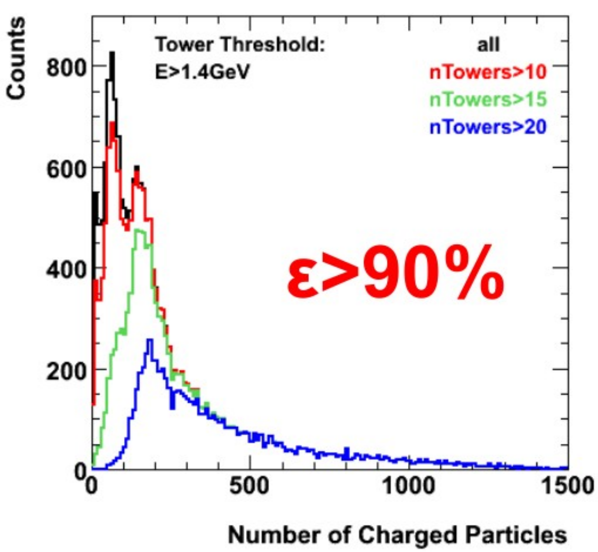
    tag = cosmic tracks in muon systems

    probe = tracker tracks CKF track algorithm

  - Combinatorial Track Finder, standard for collision (Kalman filter)

Efficiency (%)	Data	MC
CKF	99.5 ±0.1	99.9 ±0.1

MB trigger: hadronic forward based



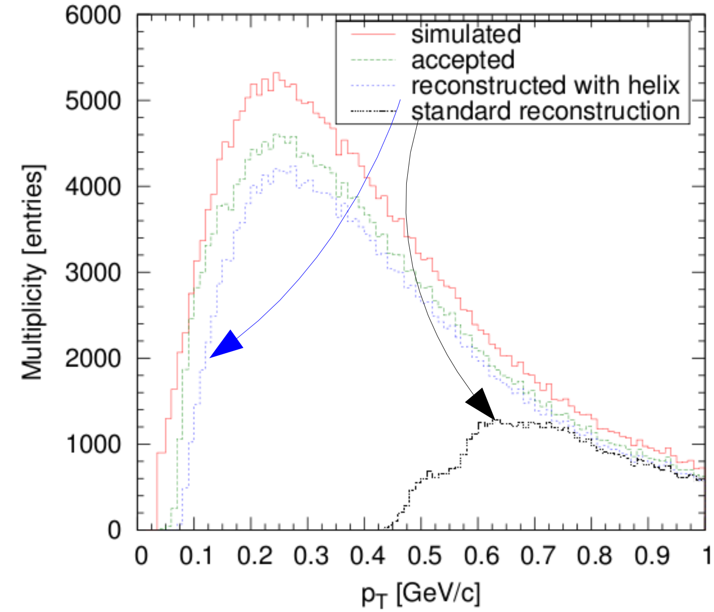
- Backgrounds:

  - **Beam-gas** collisions: at start up (43×43 bunch pattern) expected rate of 5 mHz; for the full luminosity (2808×2808 bunch pattern) expected rate of 35 kHz. Comparing to the beam bunch crossing-clock collision rate (32 MHz): 1 collision per 1000 would be a beam gas interaction;
  - **Beam-halo** collisions: no events triggered out of 10^4 MC events;
  - **Cosmics**: measured negligible during cosmic data acquisition with magnetic field;

CMS proposed analysis

- Charged spectra with reconstructed particle and low-p_T adapted algorithm
- Pseudorapidity distribution with hit-counting
- {Tracklets: work in progress}

Low p_T tracks recostruction (I)



Pixel subdetector permits:

- specific low p_T algorithm
- same analysis for pp and PbPb interaction (thanks to low occupacy)

Basic logic (both standard and low pT tracks):

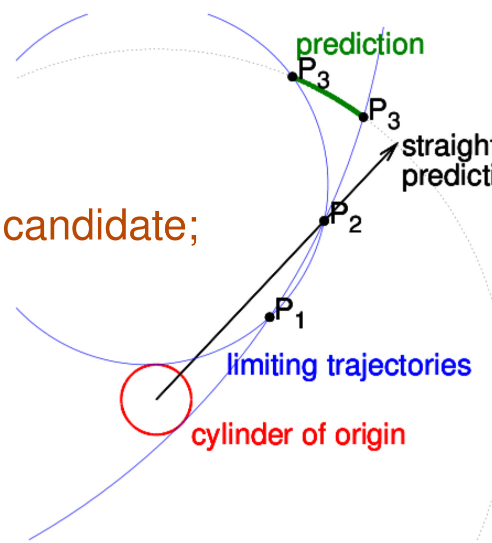
make hit pairs then predict range of possible coordinates of the third hit

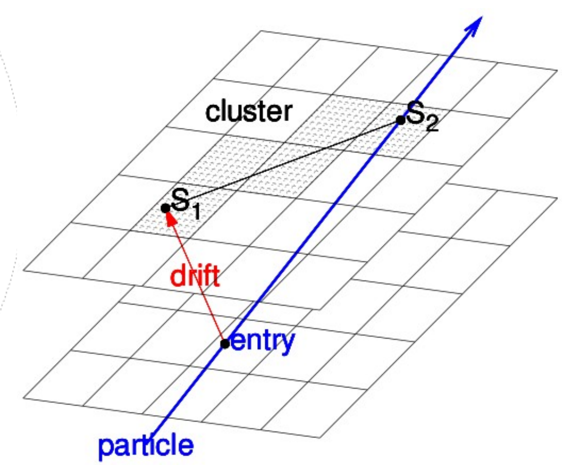
Criteria specific for low pT:

tracks coming from a cylinder of origin;
mimimum p_T requirement (0.075GeV/c);
the track must be able to reach the third hit layer candidate;
helix propagation;

Triplet cleaning:

fake rejection checking compatibility between predicted incidence angle and cluster shape

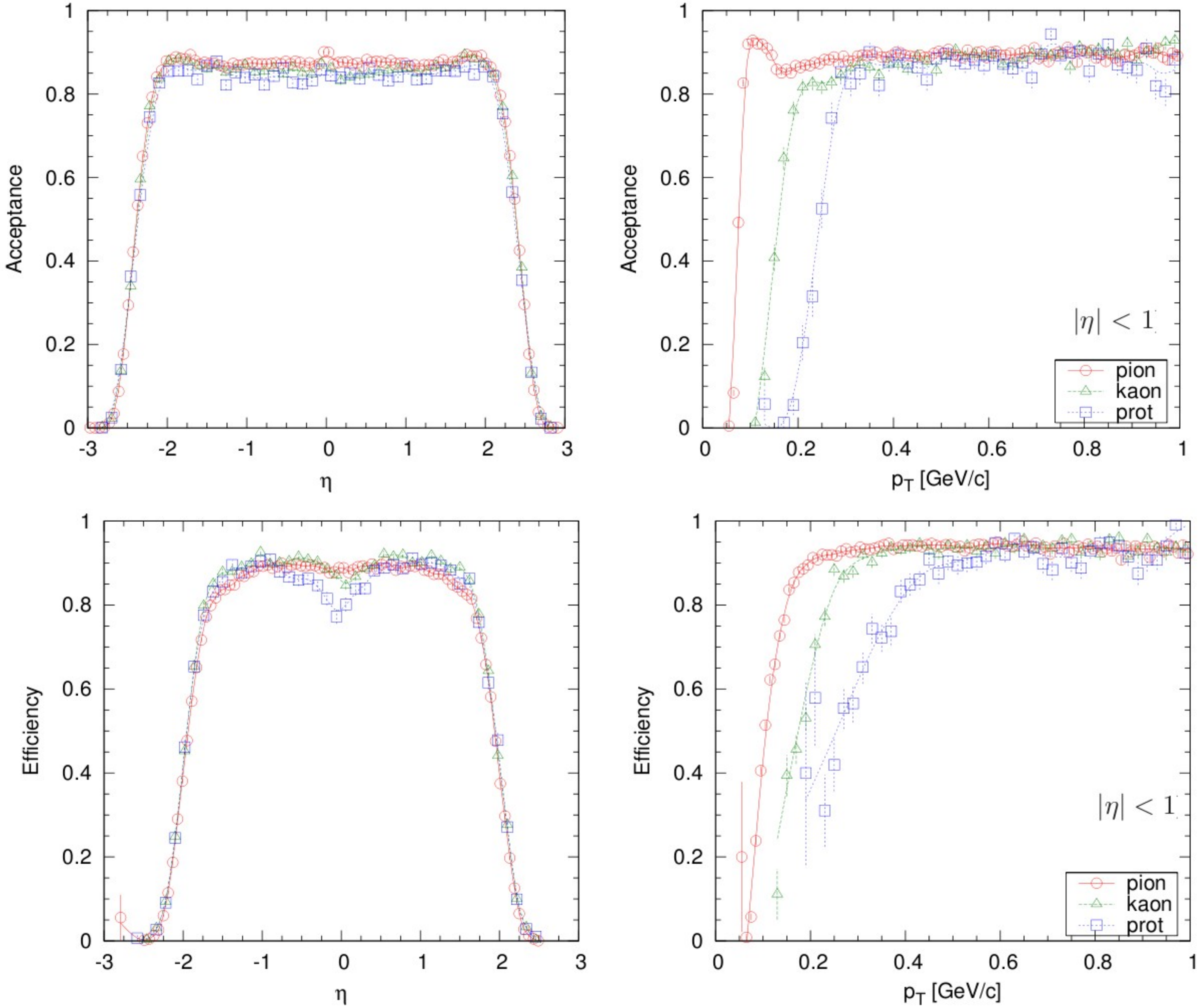




Low p_T tracks reconstruction (II)

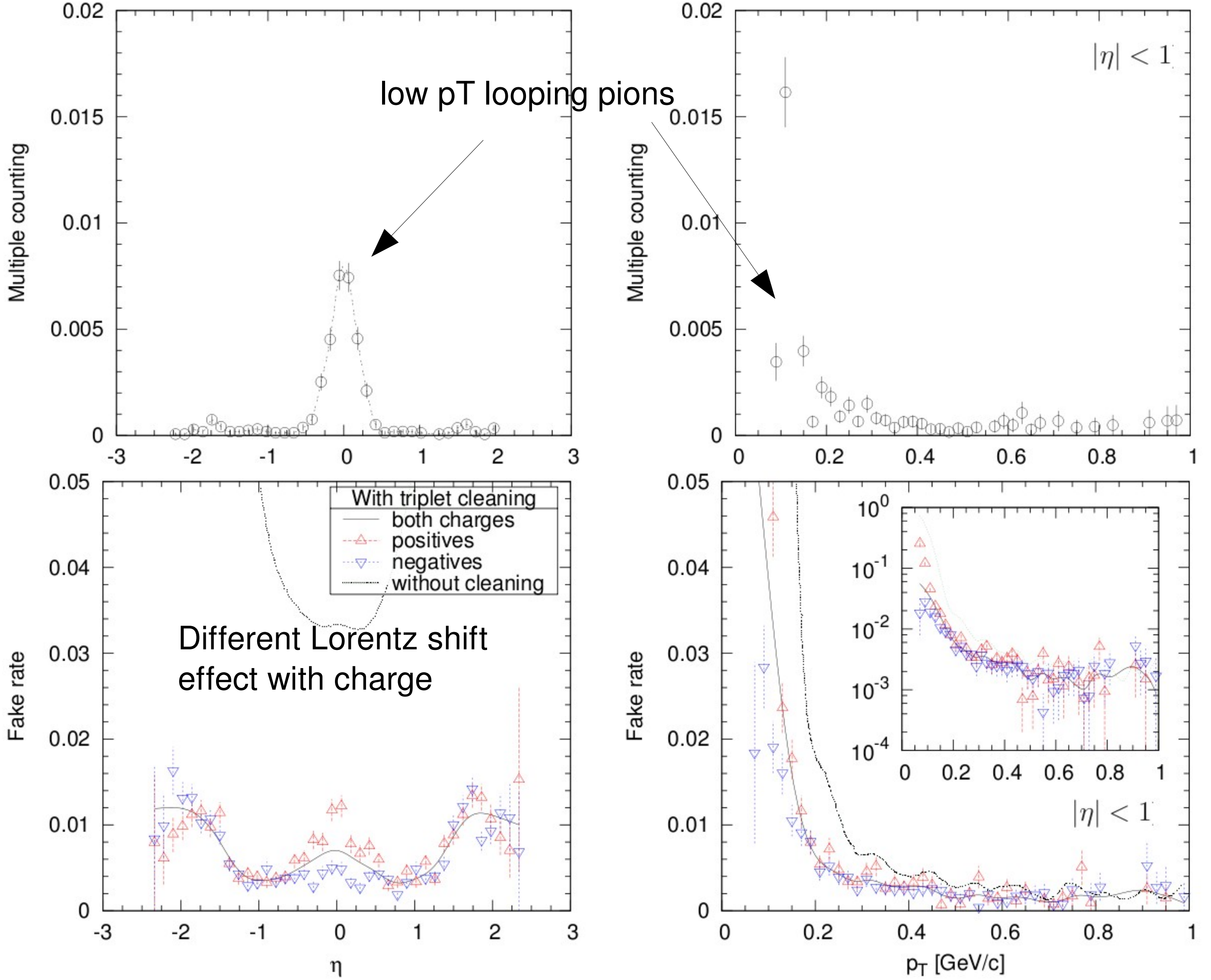
Essentially flat acceptance above p_T of 0.1, 0.2 and 0.3 GeV/*c* for pions, kaons and protons

Flat efficiency in the range $|\eta|<1.5$, except for protons



Low p_T tracks recostruction (III)

Multiple counting (essentially looper) below 1% around $\eta = 0$, quickly to zero for $|\eta| > 0.5$



Clean up imposing vertexing + cluster-shape/incident-angle relation:

low fake rate at 0.5%(2%) for $\eta = 0$ ($|\eta| = 2$), below 1% for p_T>0.16GeV/*c*

Charged hadron spectra with low p_T tracks

Binning measured tracks in $\Delta N_{measured}(\eta, p_T)$ and correcting for all the considered effects:

$$\Delta N_{corrected} = \frac{(1-fakeRate)(1-feedDown)}{geomAccep \cdot algoEffic \cdot (1-multiCount)} \cdot \Delta N_{measured}$$

→ Triple differential invariant yield: $E\frac{d^3N}{dp^3} = \frac{d^3N}{d\phi\, dy\, dp_T} = \frac{1}{2\pi p_T}\frac{d^2N}{dydp_T} = \frac{1}{2\pi p_T}\frac{E}{p}\frac{d^2N}{d\eta\, dp_T}$

Fitted by a reparametrization of a Tsallis function:

$$E\frac{d^3N}{dp^3} = \frac{dN}{dy}\frac{(n-1)(n-2)}{2\pi nT[nT+(n-2)m]}\left[1+\frac{E_T(p_T)}{nT}\right]^{-n}$$

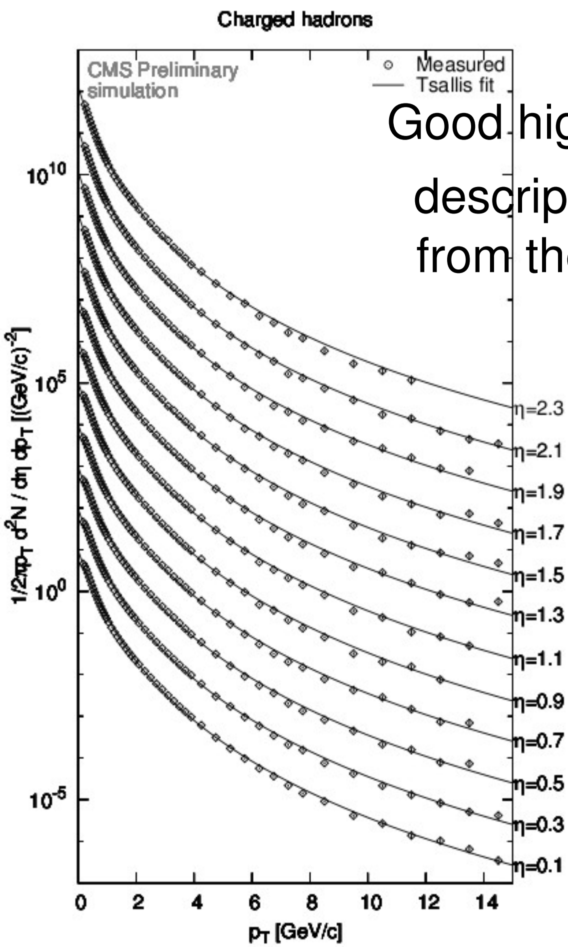
Combining both

→ thermal low p_T: $E\frac{d^3N}{dp^3} = A\exp\left[\frac{-E(p_T)}{T}\right]$

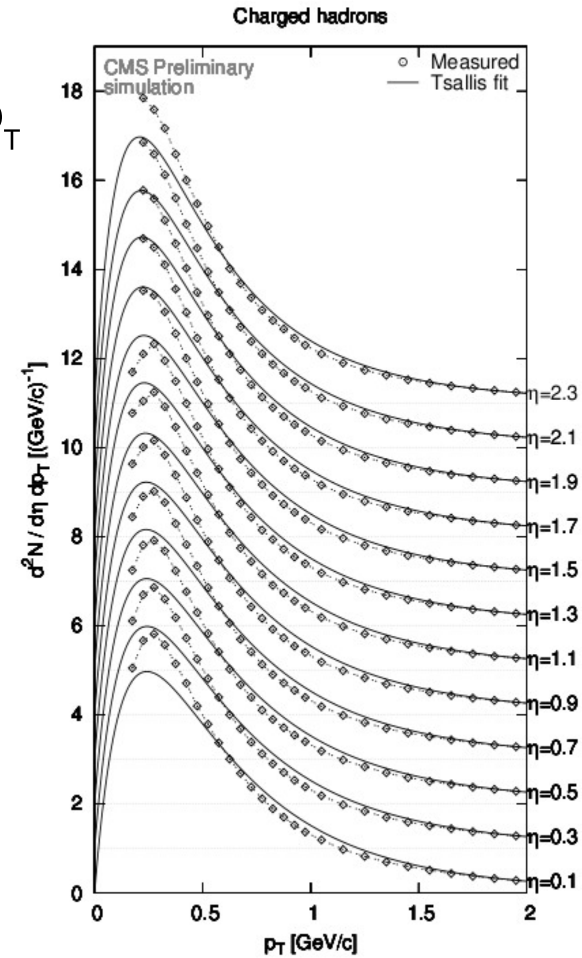
→ high p_T empirical power-law tail: $E\frac{d^3N}{dp^3} = \frac{A}{(1+p_T/p_0)^n}$

obtaining the p_T integrated *dN/dy* distribution from fit !

Charged hadron spectra with low p_T tracks



Good high p_T description from the fit

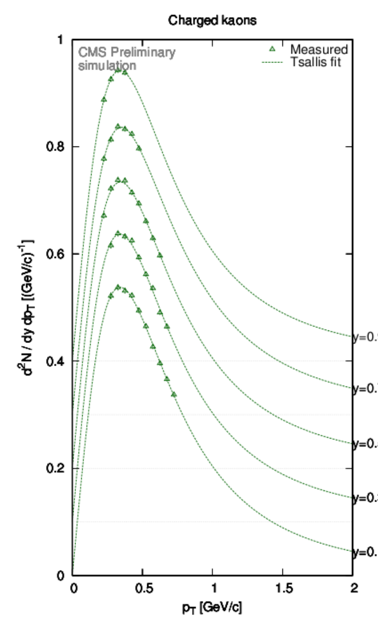


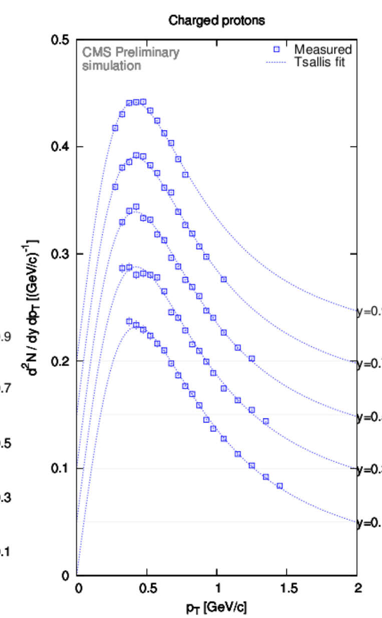
Bad low p_T description for unidentified hadrons

→ sum the measured differential yields for $0.2<p_T<2$GeV/*c*

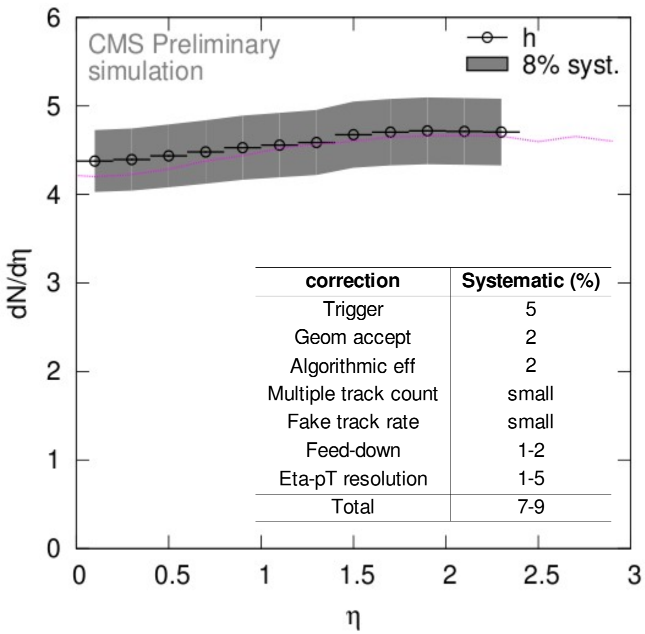
→ thermal fit extrapolation down to 0 GeV/*c*

Better situation for identified hadrons:

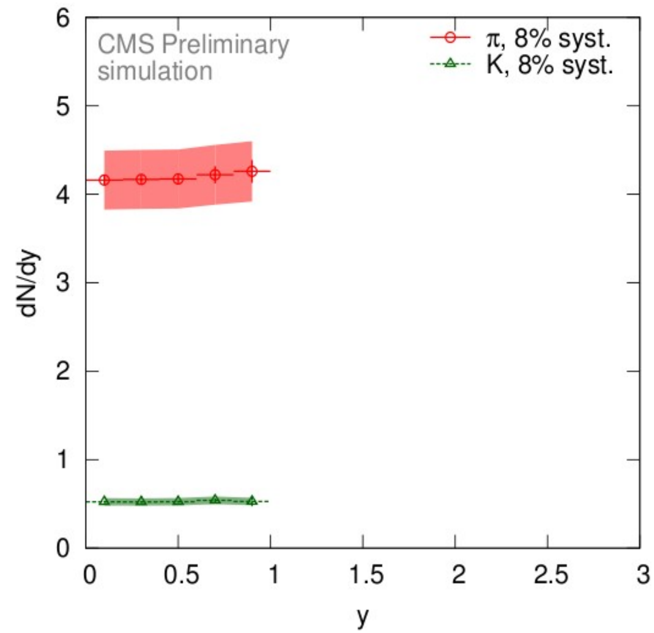


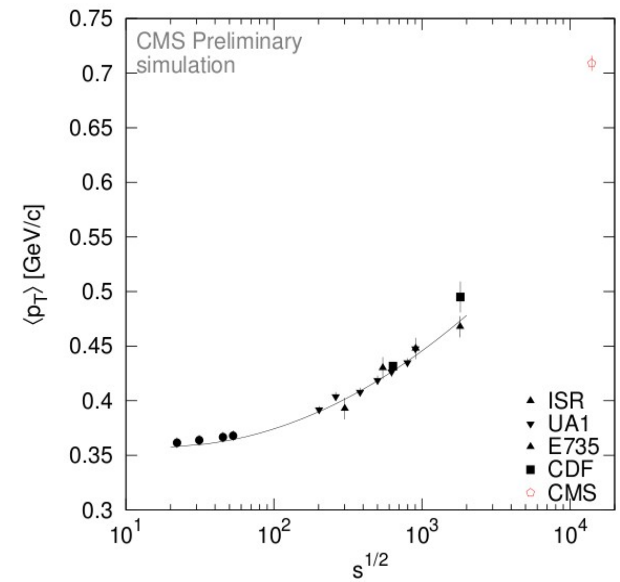


Charged hadron spectra with low p_T tracks



correction	Systematic (%)
Trigger	5
Geom accept	2
Algorithmic eff	2
Multiple track count	small
Fake track rate	small
Feed-down	1-2
Eta-pT resolution	1-5
Total	7-9





- Differential cross-section:

$$d\sigma_{inelastic} = \frac{dN}{\Delta N_{events}} \cdot \sigma_{inelastic} = \frac{dN}{\Delta N_{events}} \cdot \frac{\Delta N_{events}}{Lumi\,\Delta t} = \frac{dN}{Lumi\,\Delta t}$$

(measuring time Δt and Luminosity $Lumi$ known and independently measured)

Hit counting method

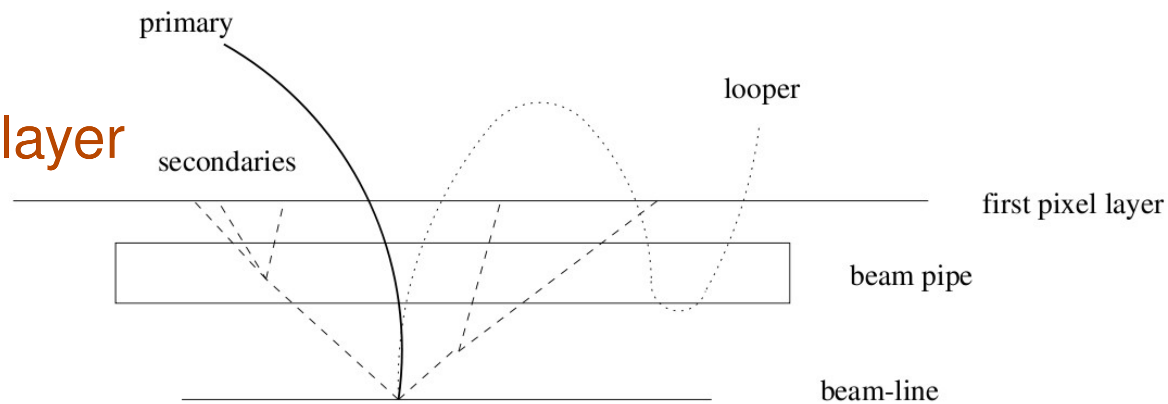
- Early startup:

low luminosity scenario → no pile-up
(needed only 10^4 events here for the analysis)

- Method:

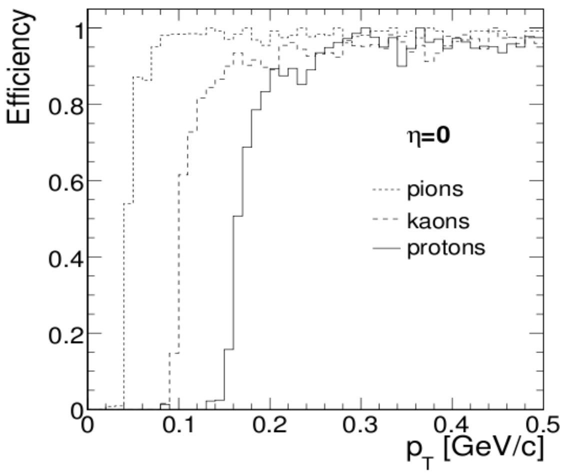
(as PHOBOS@RHIC)
counting hits on one pixel barrel layer
→ correcting for:

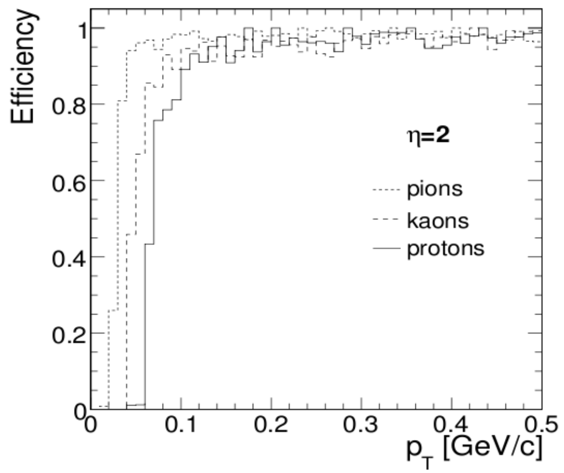
- Looper particle
- Decays from primary
- Particles from beam-pipe interaction



- Small minimum p_T requirement:

~30MeV/*c* to leave hit in the first layer
(to be compared with 75 MeV/*c* request from full tracking)

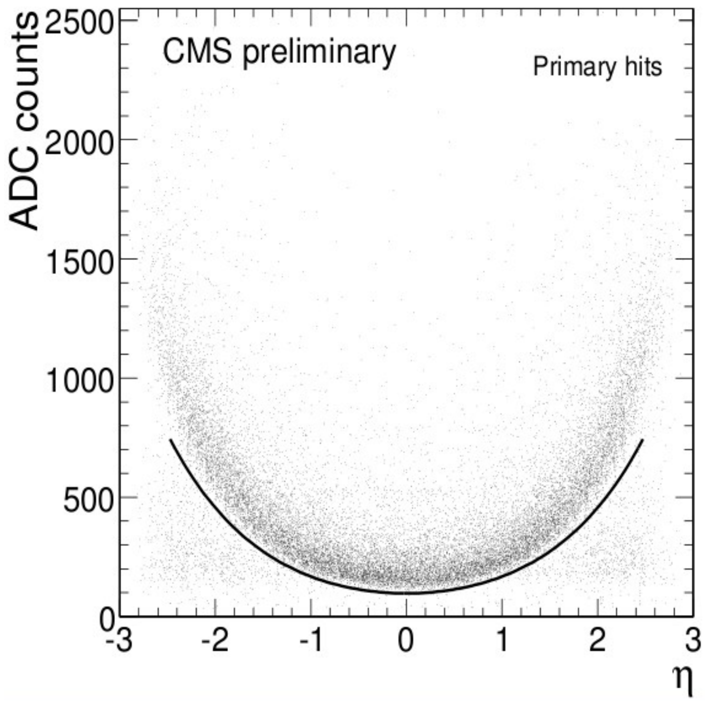


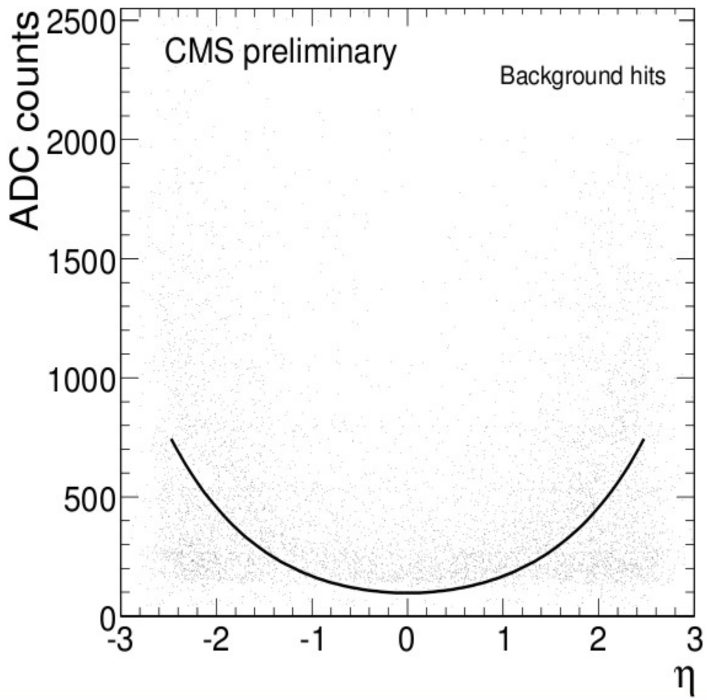


Hit counting method

Hit selection criteria: release of energy *dE/dx* in the Silicon

Primary: avarage energy deposit proportional to cosh(eta) and Landau-distributed around the mean
Background: no strict relation crossing-angle/pseudorapidity





Hit counting method

Ingredients* for calculating the pseudorapidty distribution of charge hadrons:

$$\frac{dN}{d\eta}=\frac{\Sigma_M E_t^{real}\cdot\frac{1}{\epsilon(M)}\cdot\frac{dN}{d\eta}(M)}{\Sigma_M E_t^{real}\cdot\frac{1}{\epsilon(M)}}$$

(* more in backup)

Systematics:

•MODEL DEPENDECES from corrections

the anaysis uses 2 MC dataset: one giving the correction, one acting as the “real” measure
→ need to evaluate the response in case of mometum and multiplicity distribution extreme differences between MC and “real” data;
simulated scenarios:

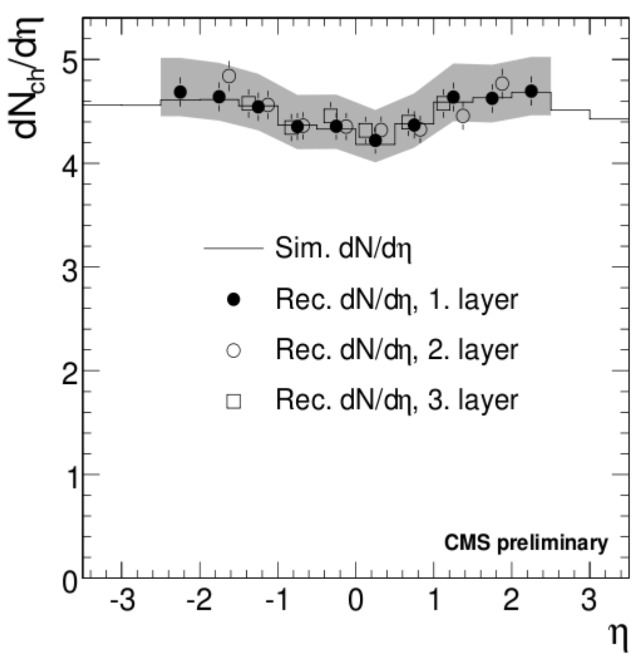
a)multiplicty-distribution*0.5 (random removal), multiplicty-distribution*2 (merging datatset), unchanged pT-distribution;
b)p-distribiton*0.5, p-distribiton*1.5, unchanged multiplicity

•VERTEXING

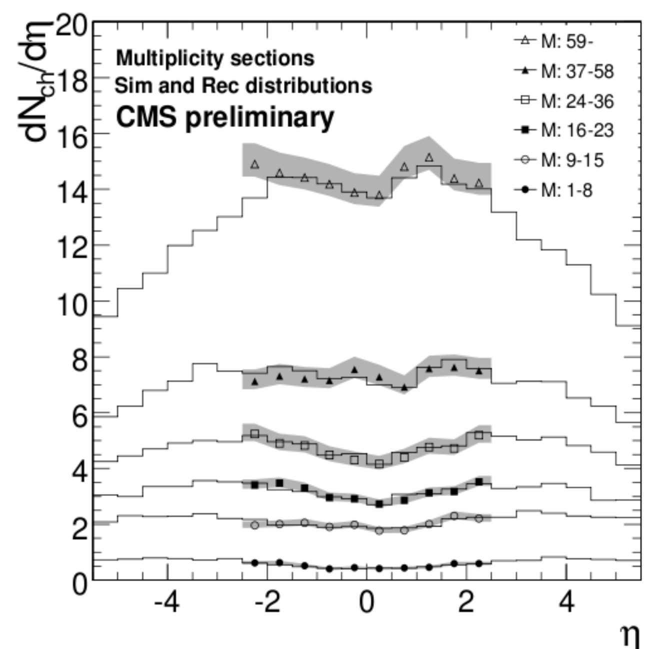
estimated effect of uncertainty on actual vertexing efficiency (eff_V):

analysis without vertex reconstruction → calculated the vertex bias → $sys_V=(1-eff_V)$*vertex-bias

Hit counting method



8% of systematics



Conclusion

- CMS is ready for first collisions analysis
- Results feed through to detector + physics community
- Interesting results available after 1 month of collisions (1st analysis) or even few days (2nd analysis)

Bibliography

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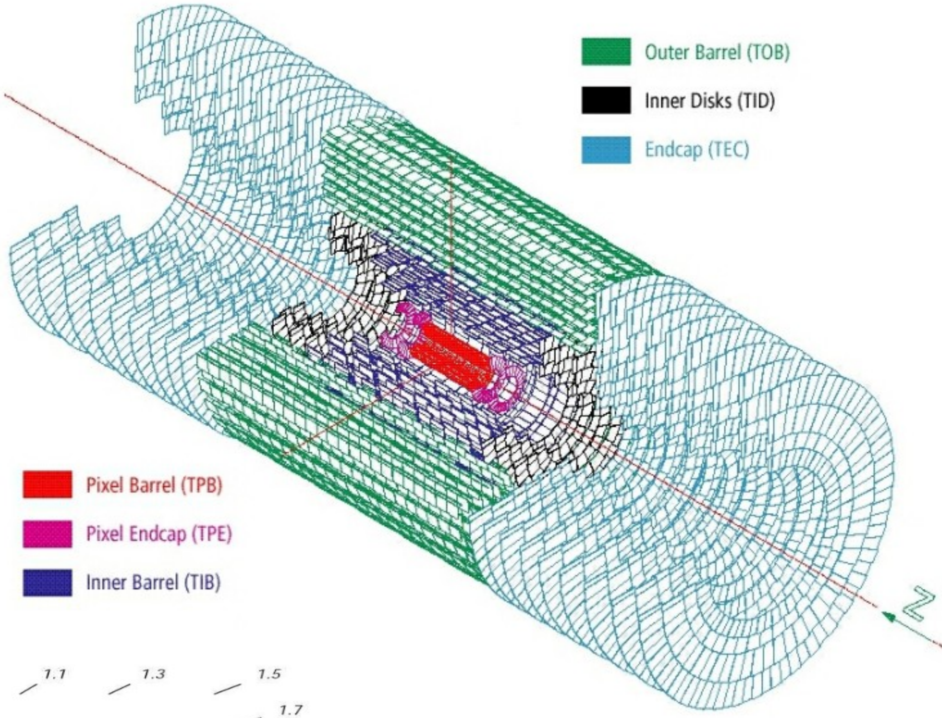
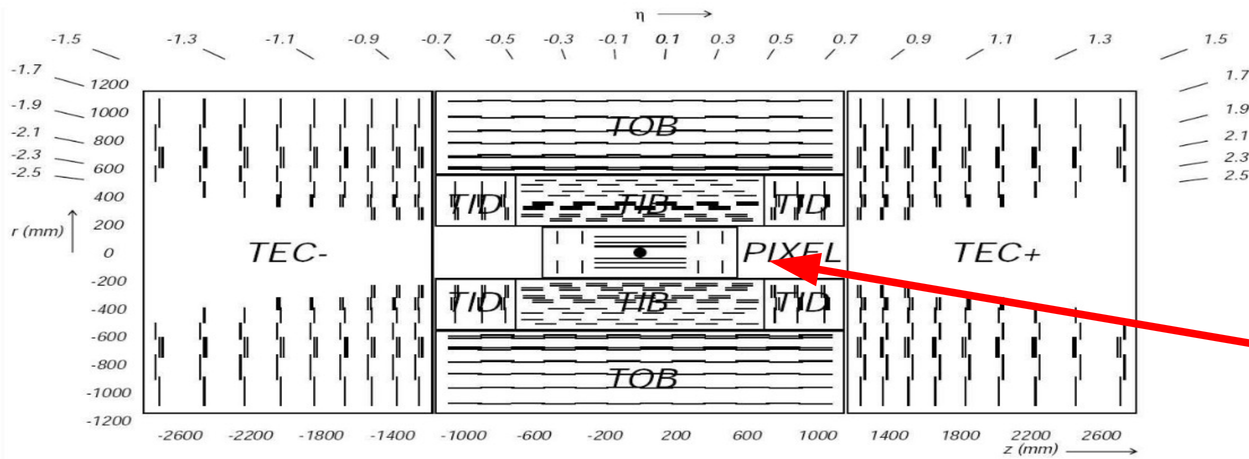
- *Soft and hard interactions in ppbar collisions at sqrt(s)=1800 and 630 GeV, Physical Review D, Volume 65 072005*
- *T. Sjöstrand and M. van Zijl. Phys. Rev. D 36 (1987), p. 2019*
- *Prediction for minimum bias and the underlying event at LHC energies, A. Moraes et al. Eur. Phys. J. C 50, 435-466 (2007)*
- *Richard Hollis and Aneta Iordanova, Minimum bias in pp collisions at 14TeV, section 2.4.2 of "CMS Physics TDR Addendum: High Density QCD with Heavy-Ions", CERN-LHCC-2007*
- *Track reconstruction, primary vertex finding and seed generation with the Pixel Detector, S.Cucciarelli, M.Konecki, D.Kotlinski,T.Todorov, CMS NOTE 2006/026*
- *Reconstruction of low pT charged particles with the pixel detector, Ferenc Sikler, CMS NOTE AN-2006/100*
- *Measurement of charged hadron spectra in proton-proton collisions at sqrt(s)=14TeV, F. Sikler, K.Krajczar, CMS AN-2007/021*
- *Pseudorapidity distributions of charged hadrons in minimum bias p-p collisions at sqrt(s)=14TeV, K.Krajczar, G. Veres, CMS AN 2008/018*

Start of Back up slides

The CMS Silicon Tracker

- Total area: ≈ 1 m^2 (Pixel) + 200 m^2 (Strip)
- Coverage up to $|\eta| < 2.4$
- Active elements:
  66 million pixels + 9.6million silicon strips

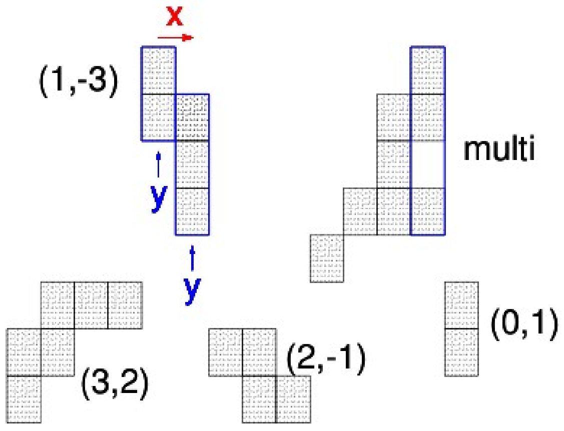


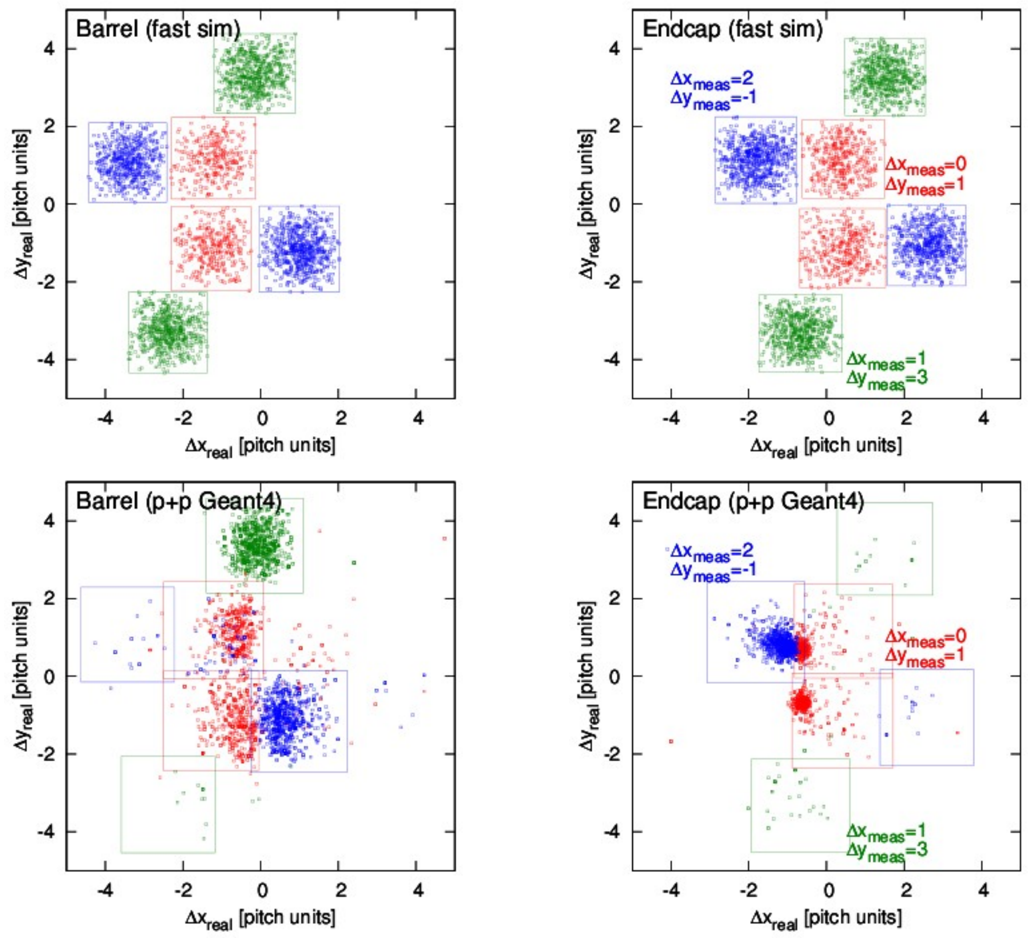


Pixel subdetector close to the interaction point

Track cleaning from shape

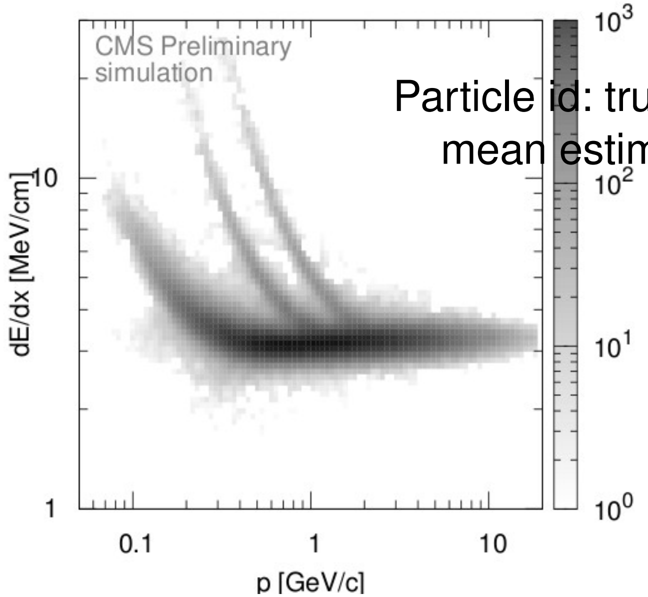
Low p_T track recostruction

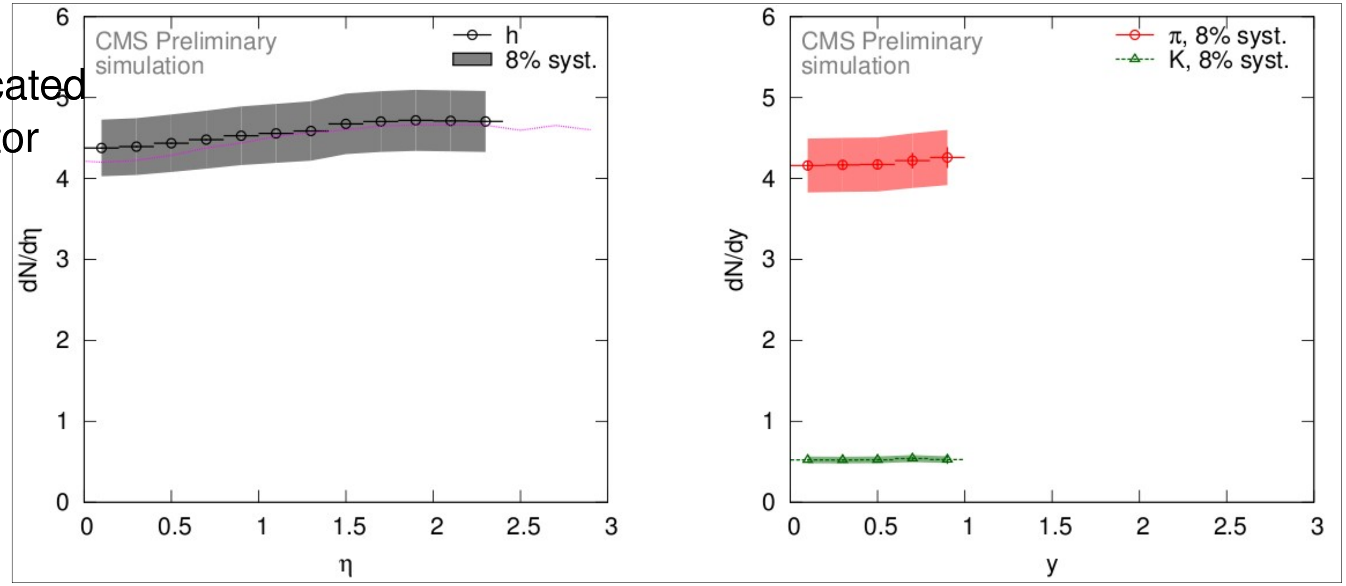


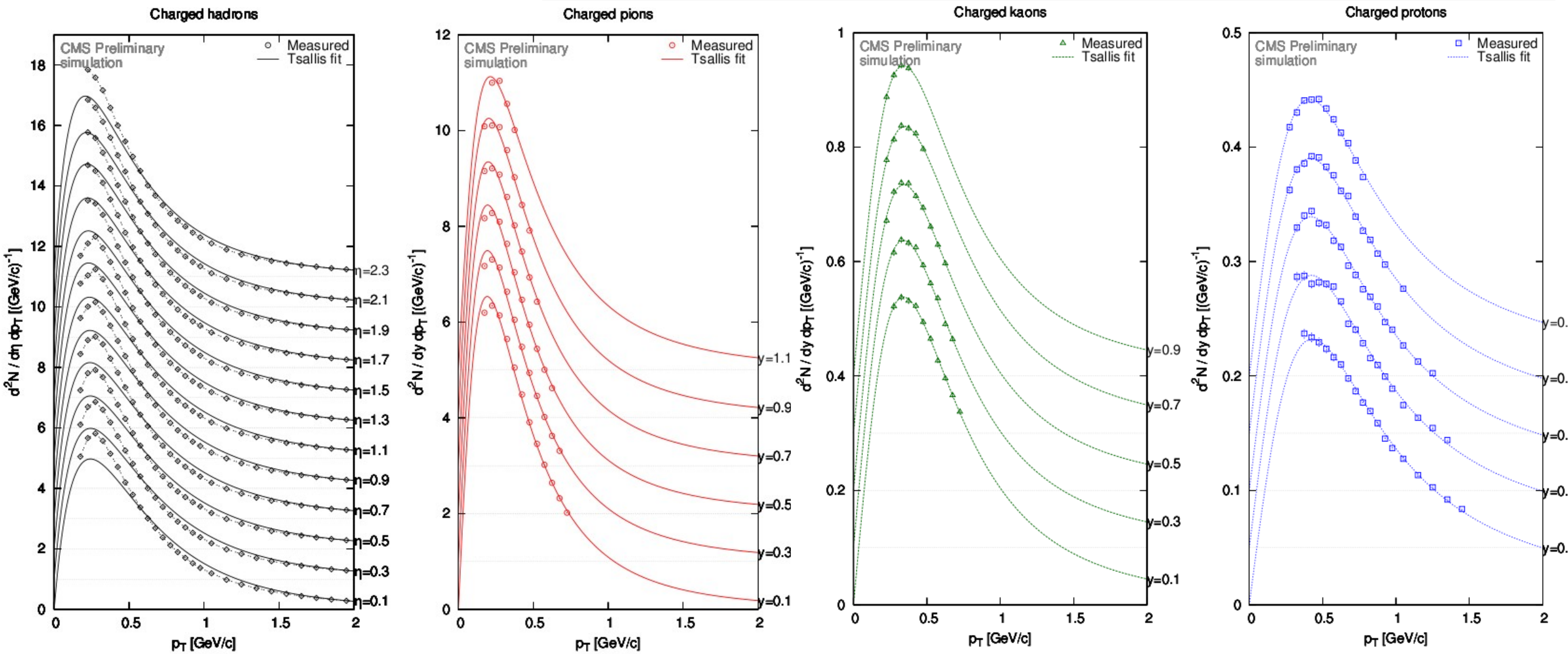


Charged hadron spectra with low pT track

Particle id: truncated mean estimator







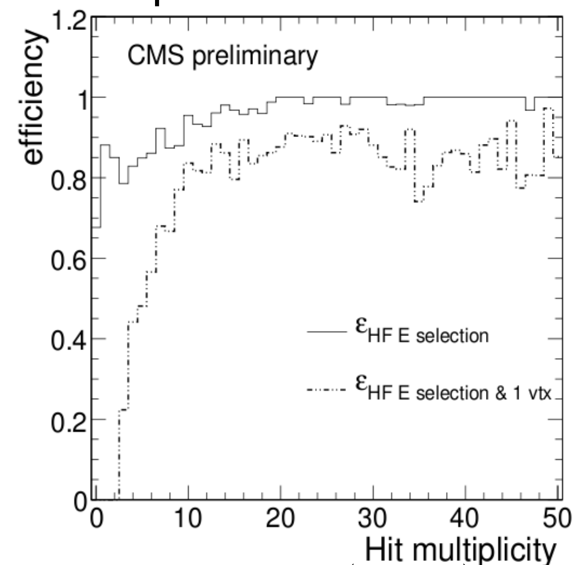
Hit counting method

Corrections

•**Event selection:**

ratio between MC events passing selection cut and total events with M pixel hits:

$$\epsilon(M) = E_t^{MC}(M) / E^{MC}(M)$$



dependent on the number of hits on the layer ("multiplicity" *M*).

→ to correct the *M*-dependent measured multiplicity distribution of charged particle $\frac{dN}{d\eta}(M)$

•**hit/tracks:**

convert the measured number of hits $H(\eta, M)$ into number of charged tracks $T(\eta, M)$ through simulation prediction

$$\chi(\eta, M) = \frac{H^{MC}(\eta, M)}{T^{MC}(\eta, M)}$$

← small model-dependence (only detector geometry)

and finally measure the *M*-dependent multiplicity distribution of charged hadrons: $\frac{dN}{d\eta}(\eta, M) = \frac{1}{\chi(\eta, M)} \frac{H^{real}(\eta, M)}{E_t(M)}$

Hit counting method

Corrections

•**Looper**:
particle with p_T<800MeV/c not reaching calorimeters apparatus;
both primary and secondary;
properly rejected for high eta (|eta|>2) with the *dE/dx* hit selection

→ estimate the hits from looper passing *dE/dx* cut from high-eta rejected hits:

$$looperHit_{passing}^{real} = \left(\frac{looperHit_{passing}^{MC}}{totalHit_{notpassing}^{MC}} \right) \cdot totalHit_{notpassing}^{real}$$