Exclusive B production at CMS with the first LHC data

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On behalf of
the CMS Collaboration

3rd Workshop on Theory, Phenomenology and Experiments in Heavy Flavour Physics
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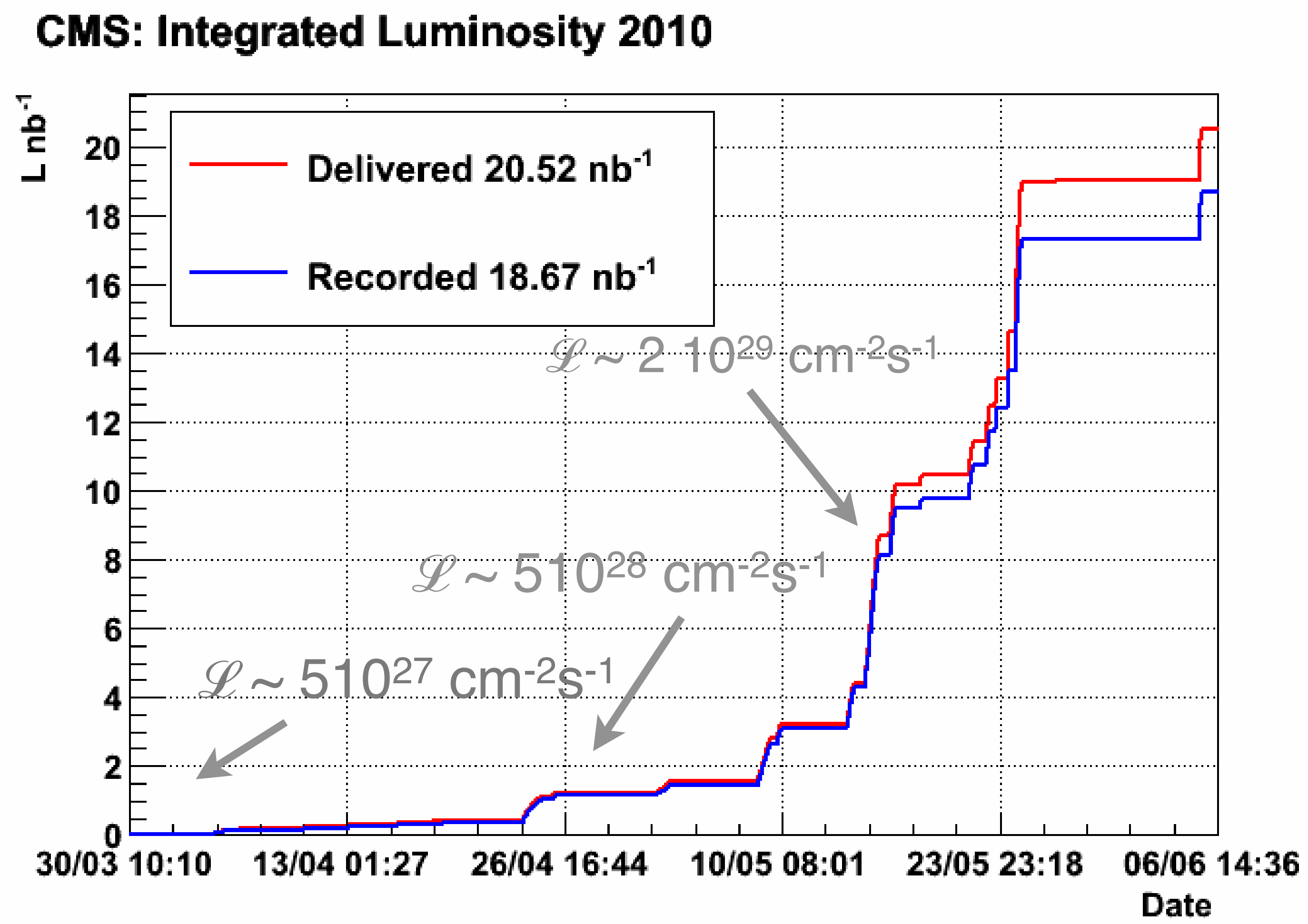
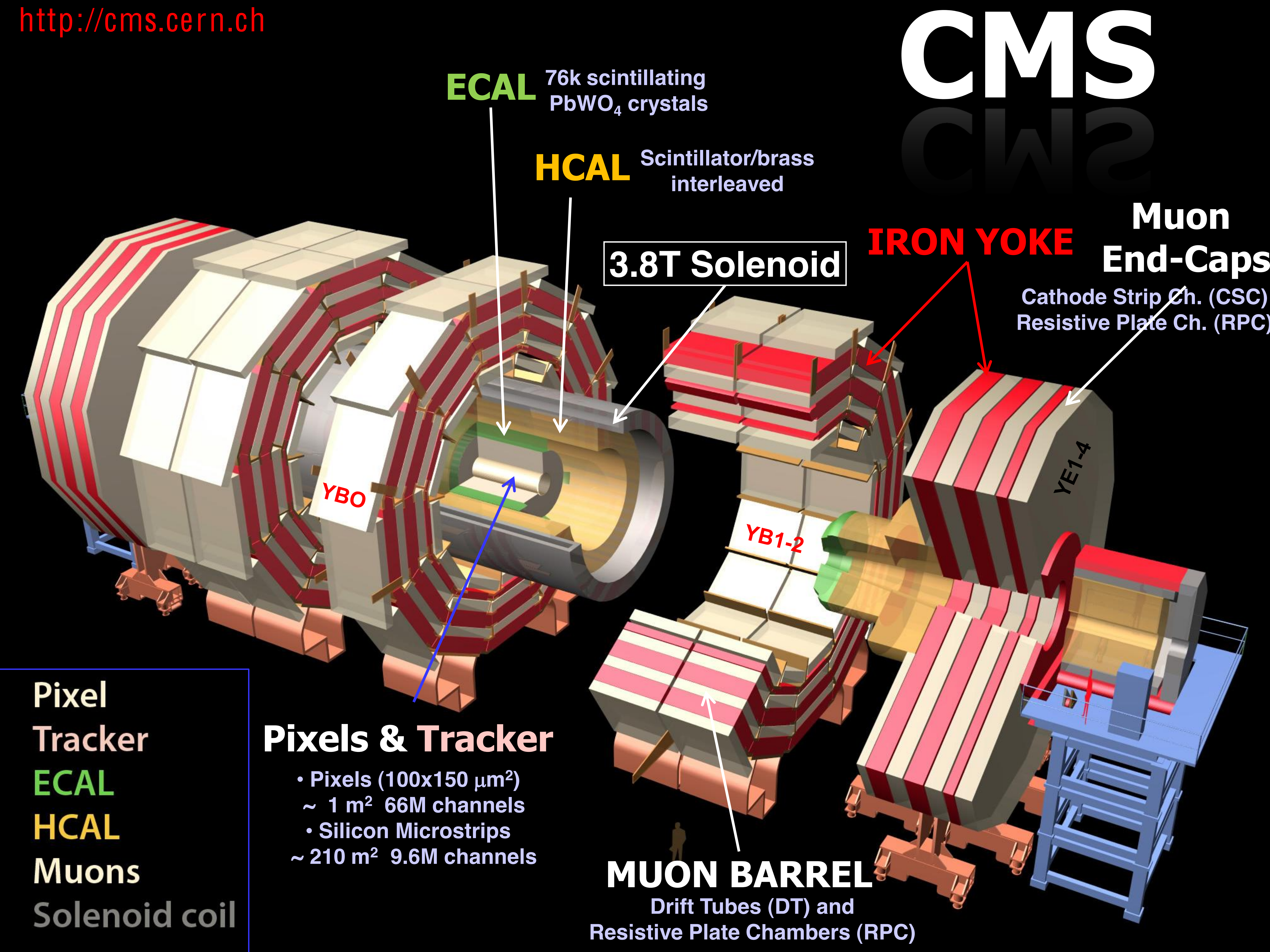
The LHC Accelerator Schedule

- After Sep. 2008 a long effort to repair, consolidate and commission the LHC
- Nov-Dec 2009 - startup:
  - established collisions at **0.9 TeV** and **2.36 TeV**
- 2010:
  - New machine protection and ramp commissioning
  - Established collisions at **7 TeV** (30th March):
    - ✓ system/beam commissioning continued
    - ✓ squeeze beams
    - ✓ increase beam intensities
  - Full machine protection qualification



Plan for ~ continuous running up to the end of 2011. The challenge:

- O(100) pb^{-1} by the end of 2010
- ~ 1 fb^{-1} by the end of 2011
- luminosities up to 10^{+33} $cm^{-2}s^{-1}$



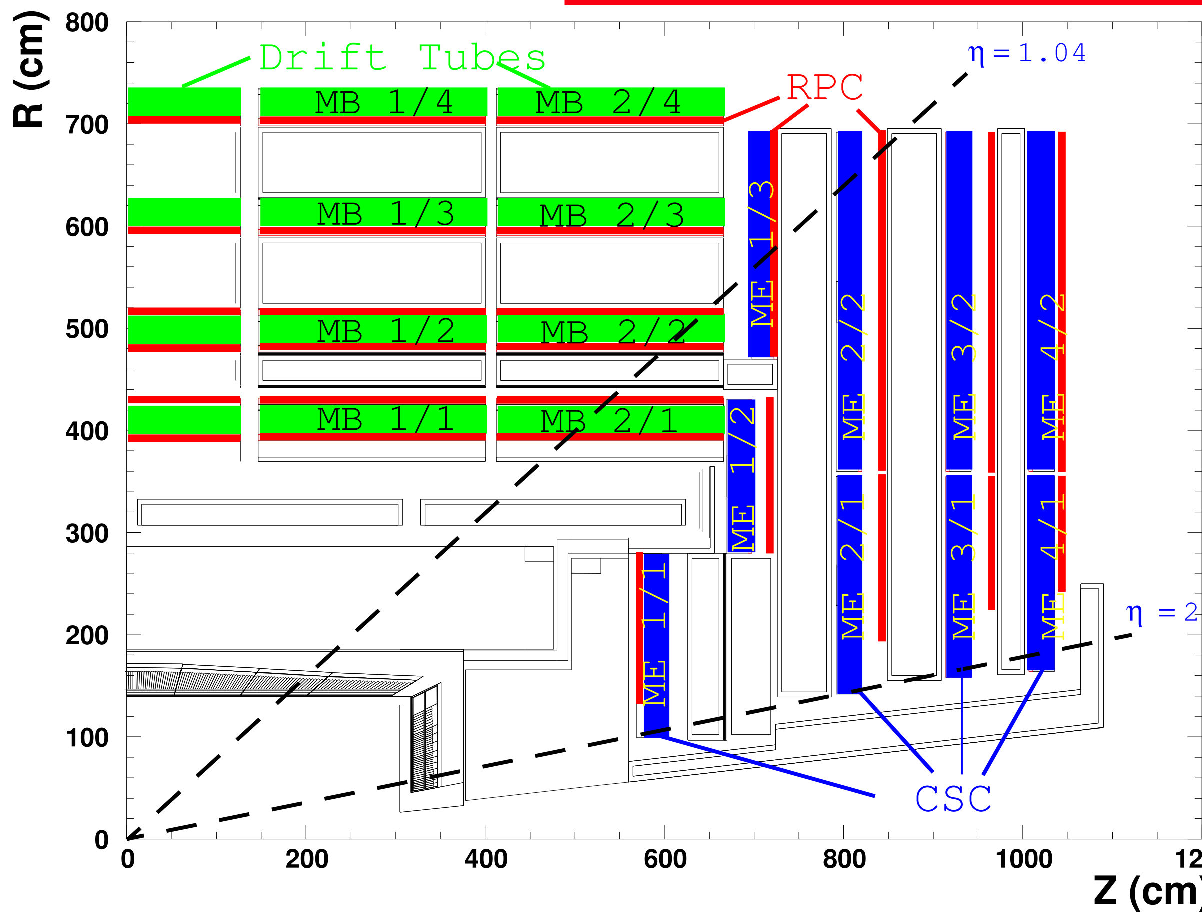
http://cms.cern.ch
CMS
ECAL
76k scintillating PbWO$_4$ crystals
HCAL
Scintillator/brass interleaved
3.8T Solenoid
IRON YOKE
Muon End-Caps
Cathode Strip Ch. (CSC)
Resistive Plate Ch. (RPC)
YE1-4
YBO
YB1-2
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm^2)
~ 1 m^2 66M channels
• Silicon Microstrips
~ 210 m^2 9.6M channels
MUON BARREL
Drift Tubes (DT) and
Resistive Plate Chambers (RPC)

The muon detection

- Large rapidity coverage: $|\eta| < 2.4$
- Excellent muon momentum resolution
- Redundant trigger system
- Three types of reco muons:
  - stand alone muons:
    - ✓ muon spectrometer only
  - global muons
    - ✓ reconstruction initiated in muon detector and matched to a track in the silicon tracker
  - tracker muons
    - ✓ tracks in the tracker matched to segments in the muon chambers
    - ✓ enhance the acceptance for low p_T muons (down to $p_T \sim$ 3GeV in the barrel region)

Drift Tubes (DT): position, momentum and Lv-1 Trigger

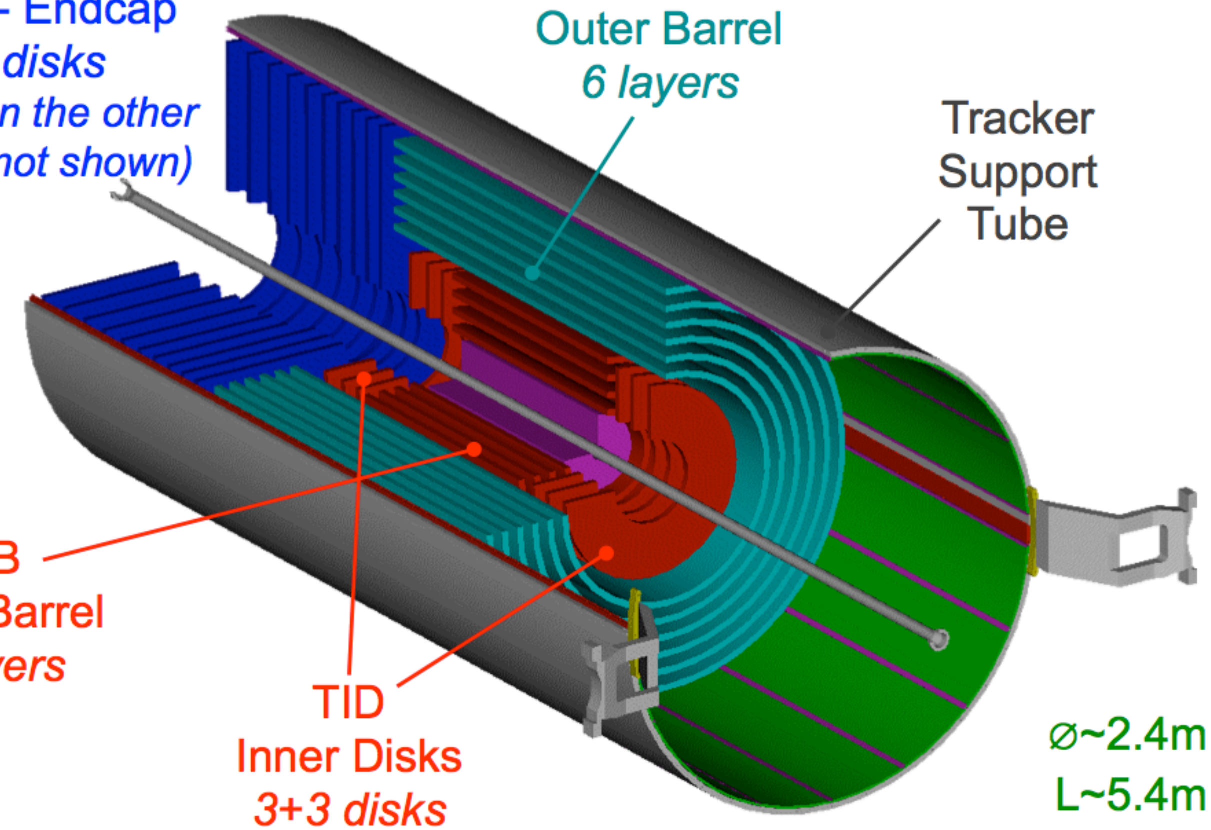
Resistive Parallel Plate Chambers: fast info for the Lv-1 trigger

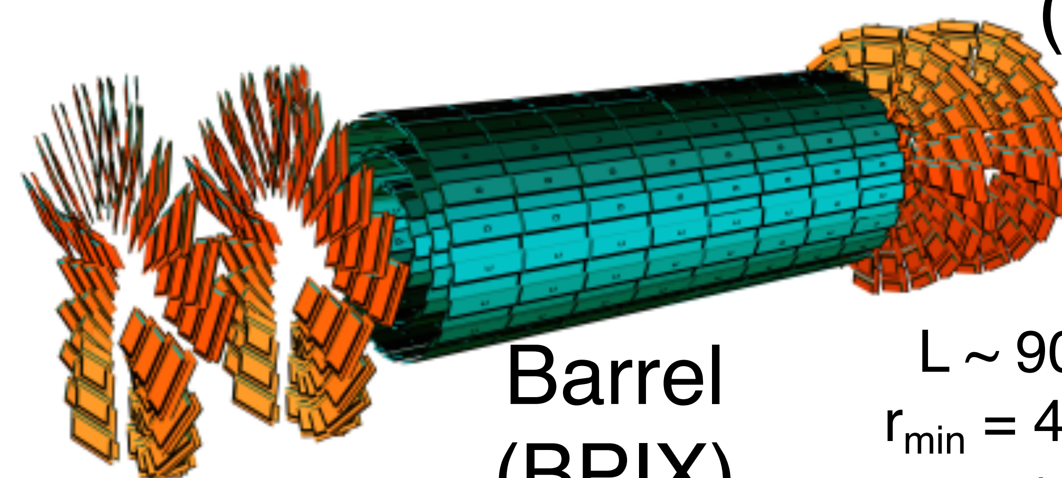


Cathode Strip Chambers (CSC): position, momentum and Lv-1 Trigger

The CMS Silicon Tracker

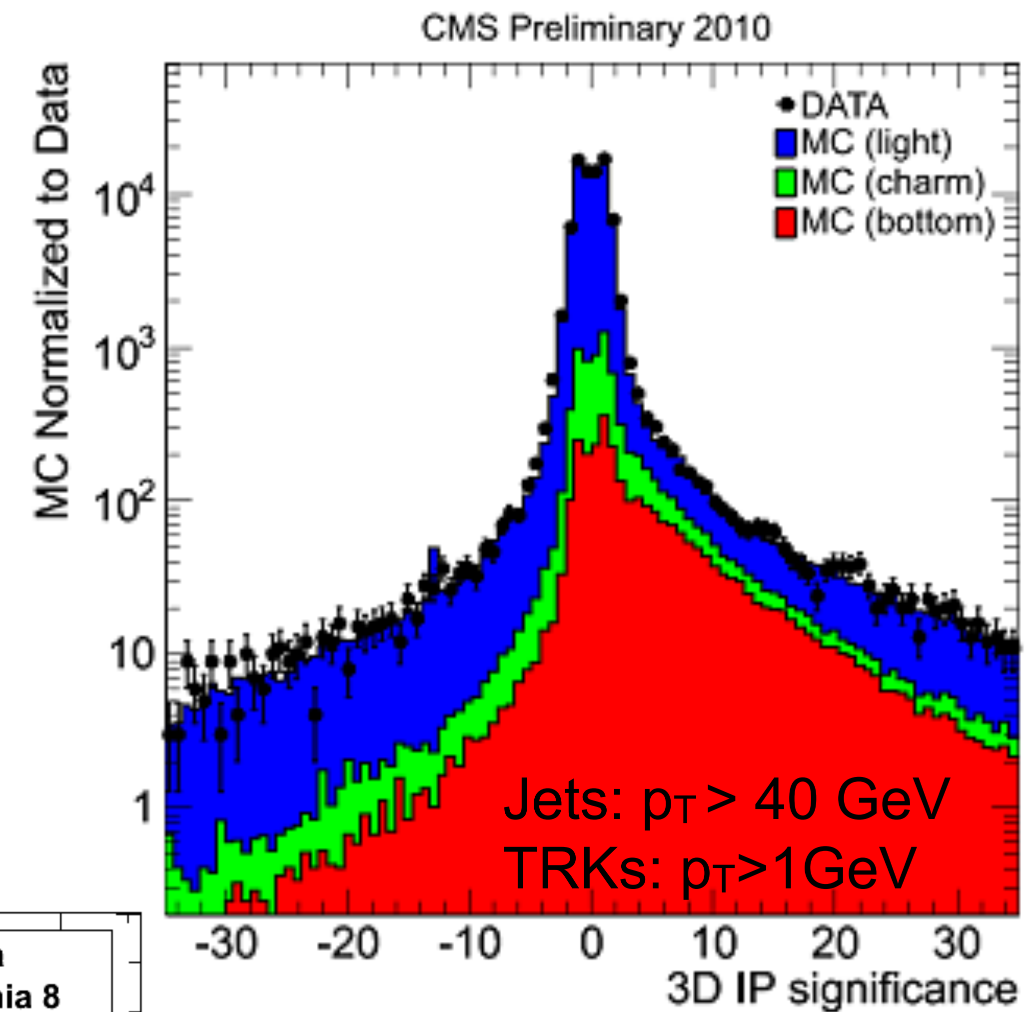
- Pixel:
  - ✓ 66M channels
  - ✓ 100x150 μm^2 pixels
  - ✓ 3 layers + 2 disks at each end
- Strips:
  - ✓ 9.6M channels (198m^2)
  - ✓ pitches: 80-180 μm
  - ✓ 10-12 layers
- Rely on robust and precise point determination along the tracks:
  - ✓ $|\eta| < 1.5$
  - ✓ $\sigma(p_t)/p_t \sim 1\text{-}2\%$ ($p_t \sim 100$ GeV)
  - ✓ IP resolution: ~10-20μm (p_t = 100-10 GeV)

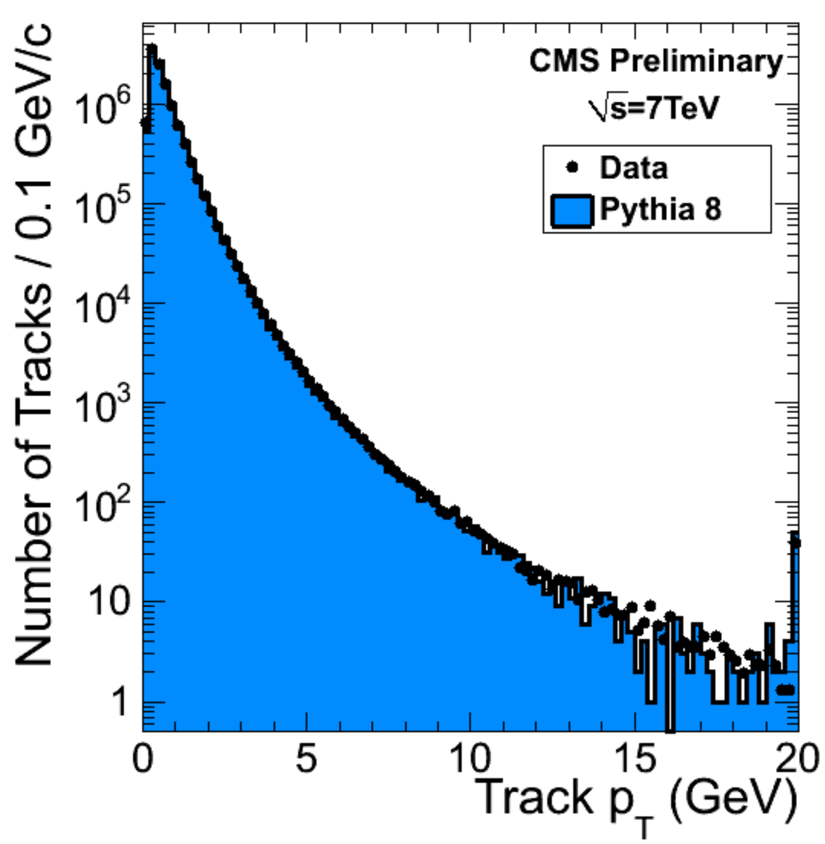


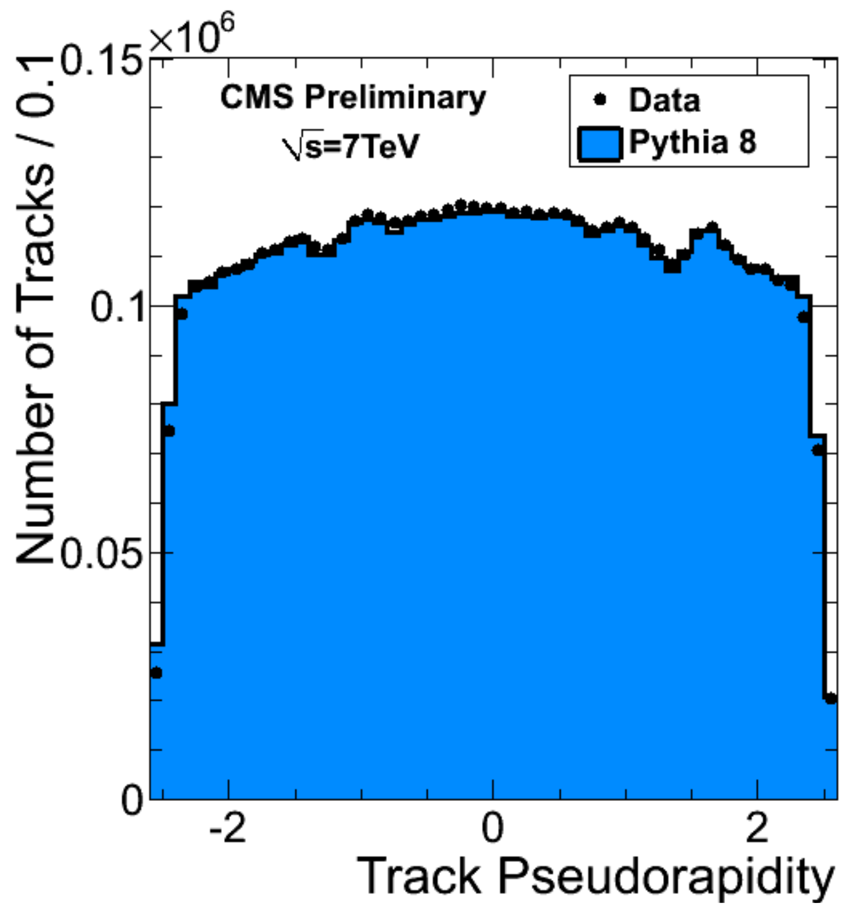


Very good tracker performance

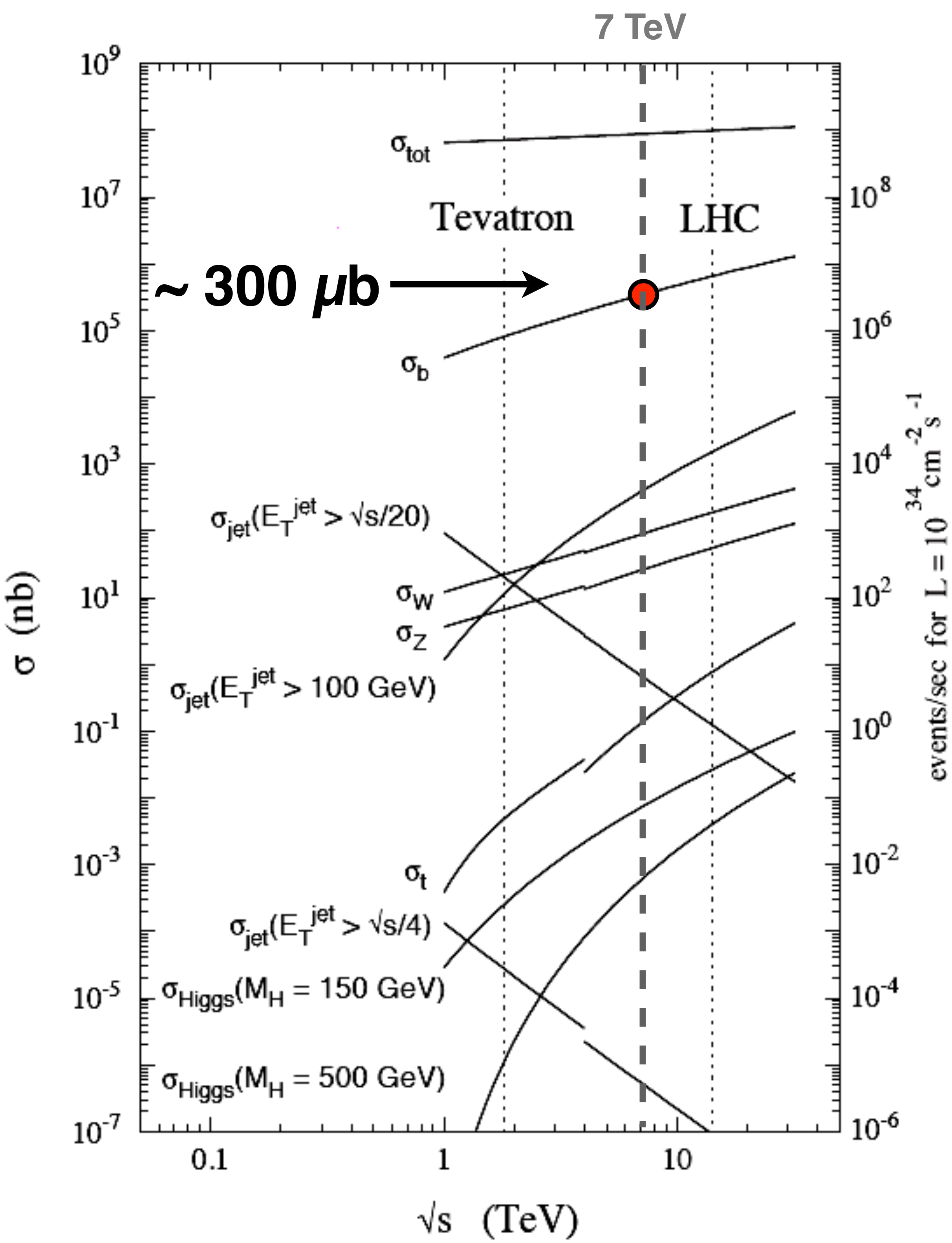
- Tracking is well understood
  - good agreement with MC
- High S/N
- > 98% of detector active
- powerful secondary vertex ID and b-tagging







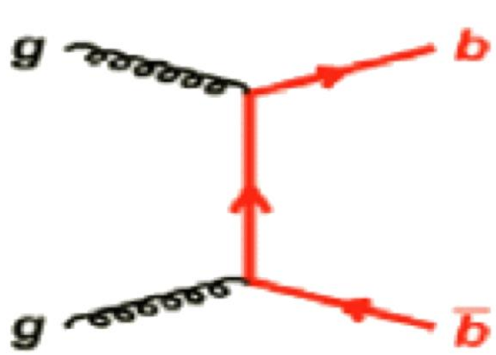
B Physics program at LHC



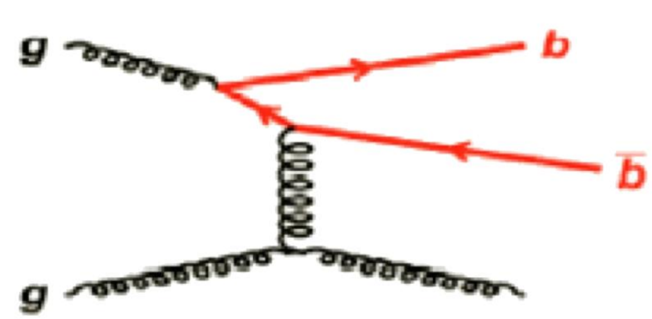
- *O(1 pb^{-1})*
  - Measure $\sigma(pp \rightarrow b\bar{b} + X)$
- *O(10 pb^{-1})*
  - Exclusive B decays:
    - ✓ production σ
    - ✓ lifetime ratios
- *O(100 pb^{-1})*
  - B_c meson
  - Mixing in the B_s sector
- *O(>~1 fb $^{-1}$)*
  - More advanced B_s physics:
    - ✓ $\Delta\Gamma_s$
    - ✓ $B_s \rightarrow \mu^+\mu^-$ FCNC → New Physics

b production at the LHC

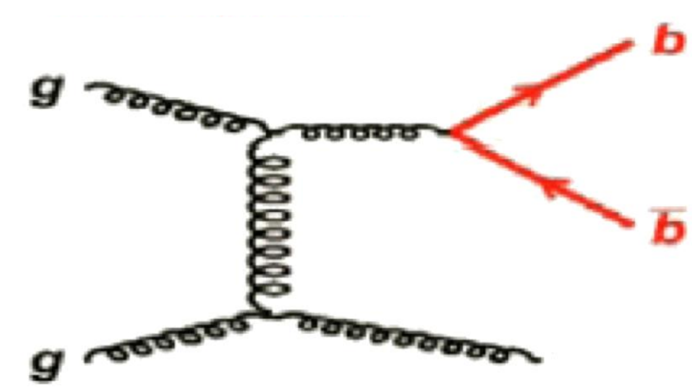
- $b\bar{b}$ pair production is the dominant source of b at the LHC
- Theory-experiment comparison of cross-sections not always straightforward:
  - NLO contributions are important
  - sensitivity to the adopted b-fragmentation models
  - control of exp. systematics and backgrounds
    - ✓ always look for new physics !
- Main contributions come from one LO and two NLO processes:



flavor creation: gluon fusion (dominant). Back-to-back high-p_T b



flavor excitation
Asymmetric transverse momentum for the two b quarks



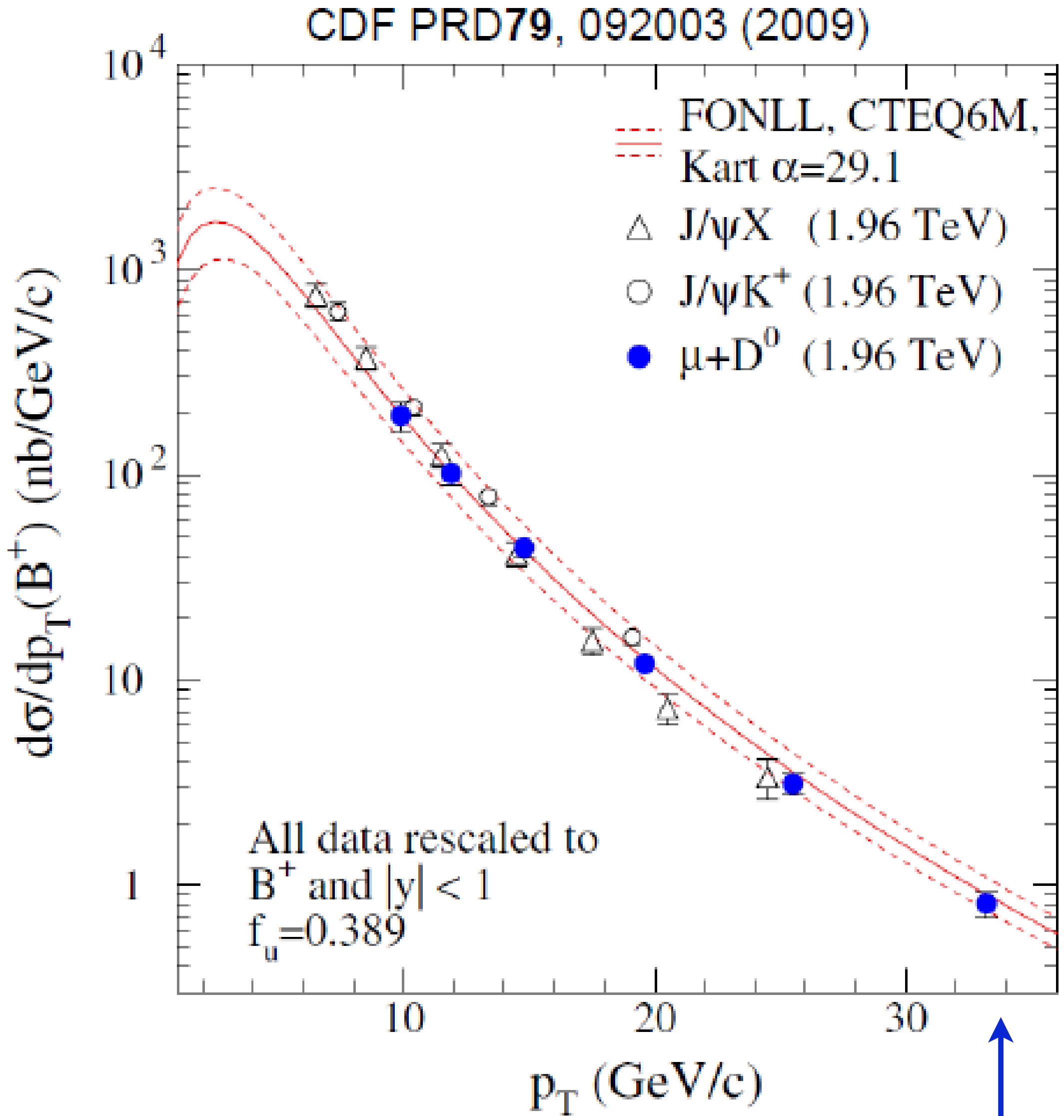
gluon splitting.
b at low p_T and close in direction

Study of the b production at LHC

- The angular correlation between b and $\bar{b}$ quarks is sensitive to the contribution of main NLO processes

- The measurement of the B production cross section using exclusive B decays can test b production theory

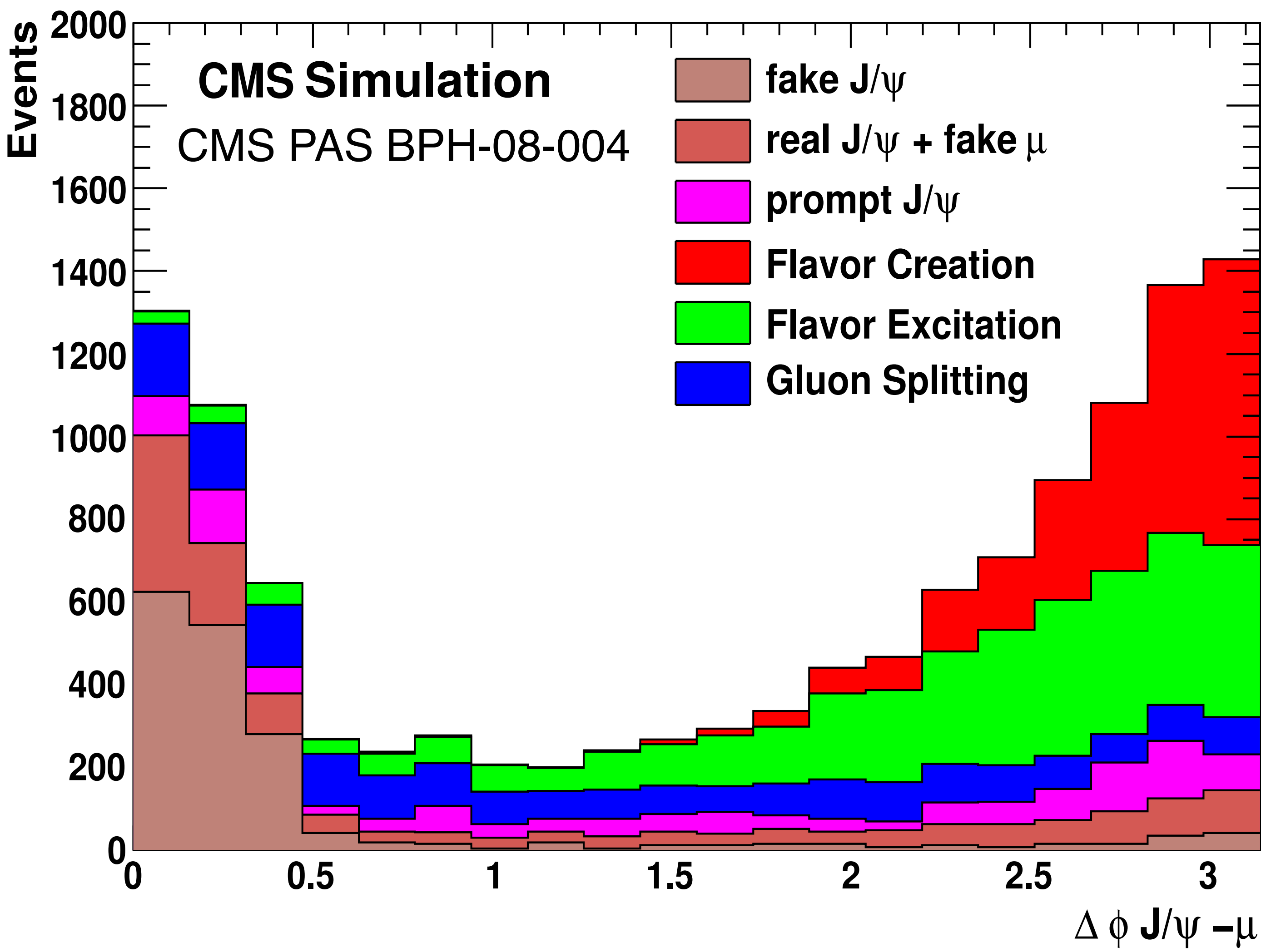
- Both studies may be performed at LHC with the first few tens of pb^{-1} of data



LHC experiments may integrate over a larger rapidity range and explore higher p_T regions

$b\bar{b}$ azimuthal correlations

- CMS plans to measure Δφ correlation in $b\bar{b}$ events:
  - b ($\bar{b}$) → J/ψ + X with J/ψ → $\mu^+\mu^-$
  - $\bar{b}$ (b) → μ + X



- “clean” 3 μ signature accessible right from LHC startup
- keep good efficiency and granularity in the small Δφ region where NLO processes dominate

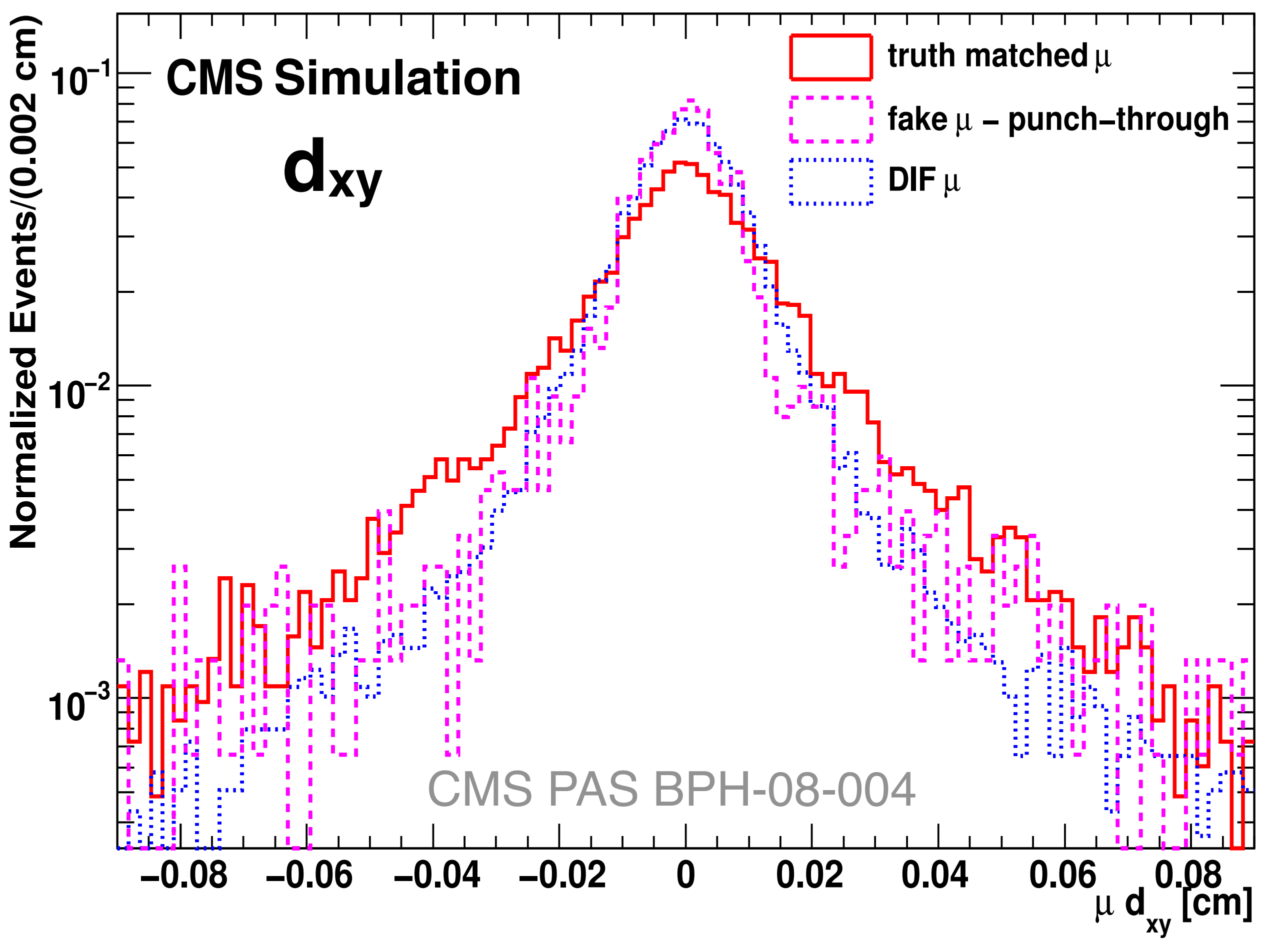
Events with μ + J/ψ → $\mu^+\mu^-$ in the final state are selected and analyzed in bins of Δφ(J/ψ,μ)

- Analysis requirements:
  - Good vertexing for J/ψ → $\mu^+\mu^-$
  - High quality reconstruction for third muon
  - Pt > 3 GeV and IηI<2.4 for all three muons

on the basis of these variables: ⟺ These background categories:

- $M_{\mu+\mu-}$: the reconstructed J/ψ mass
- L_{xy}: the J/ψ vertex displacement from PV in the transverse plane
- d_{xy}: the μ impact parameter in the transverse plane

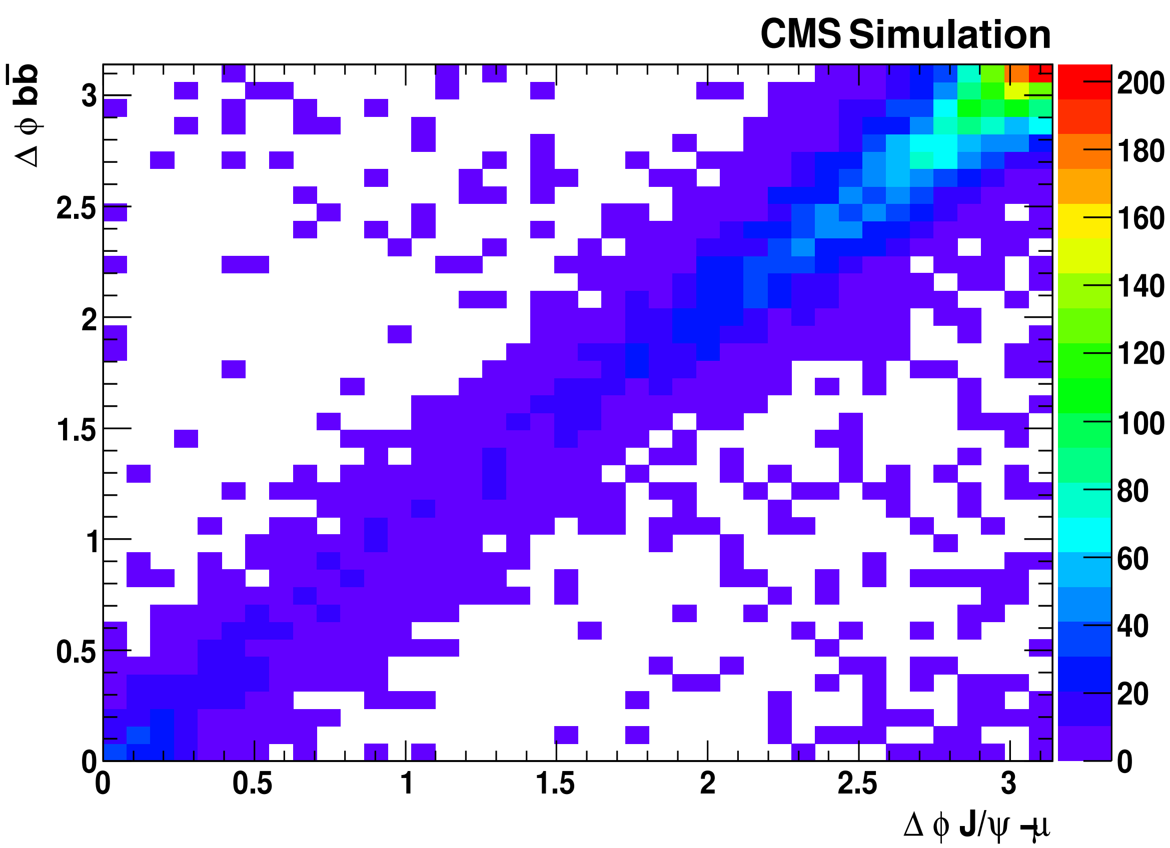
- *Prompt* J/ψ → "non flying" J/ψ
- Fake Muon → low d_{xy}
  - ✓ μ not from b: mis-reconstructed muons ("punch through") or K,π decays in flight (*DIF*)
- Fake J/ψ → flat $M_{\mu+\mu-}$
  - ✓ These include real bb~ events where the wrong μ combination is used to reconstruct the J/ψ



Probability Density Functions for $M_{\mu+\mu-}$, L_{xy} and d_{xy} are worked out on MC for the signal and each background category

In each $\Delta\Phi(J/\psi,\mu)$ bin the yield for the signal process is derived through a simultaneous unbinned Max Likelihood fit to $M_{\mu+\mu-}$, L_{xy} and d_{xy} .

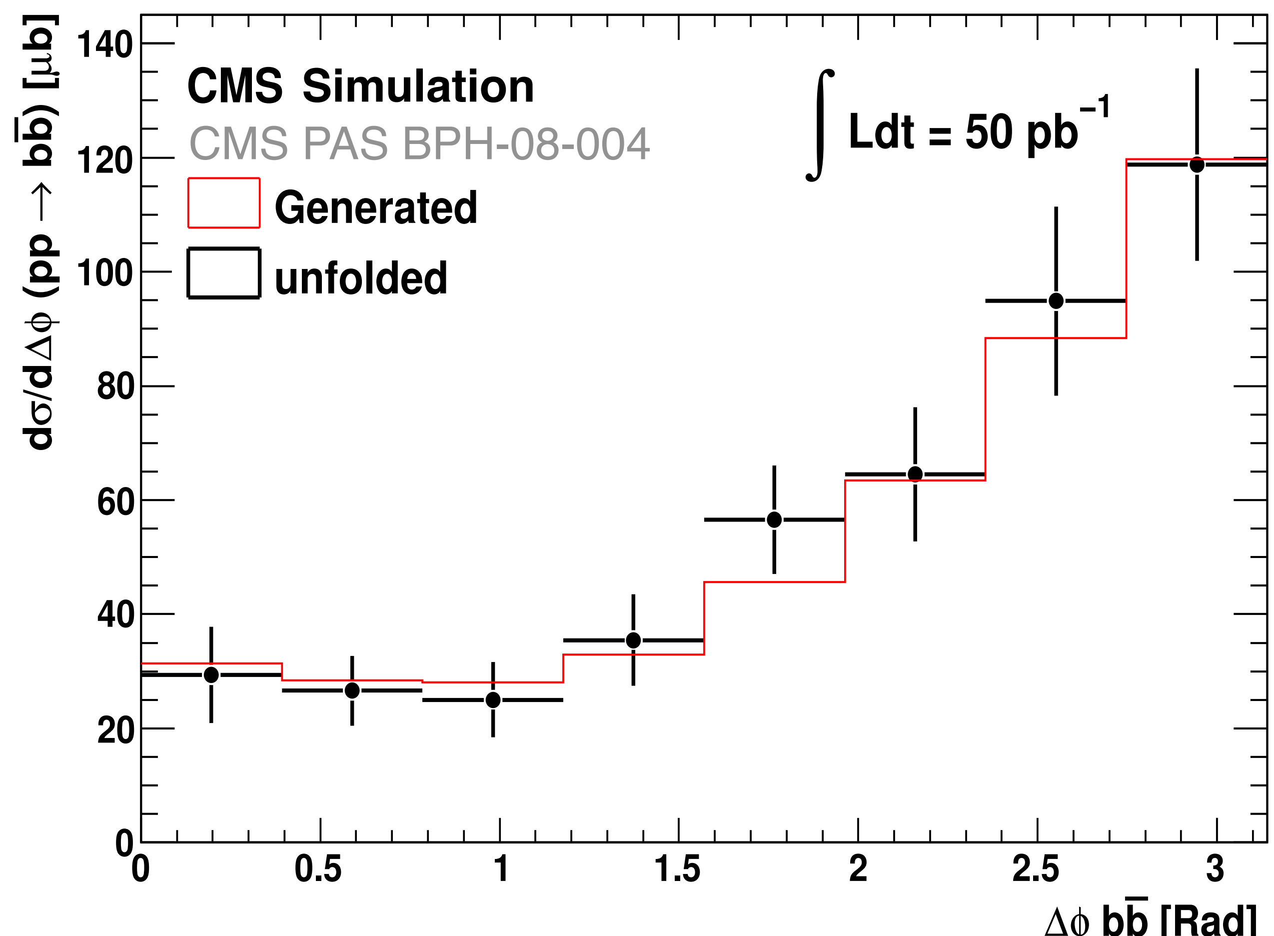
Unfolding required:
$\Delta\Phi(J/\psi,\mu) \rightarrow \Delta\phi(b,\bar{b})$



Perspective:

MC study @ √s = 10 TeV and L_{int} = 50 pb^{-1} (CMS PAS BPH-08-004)

- > 7000 signal events
- $d\sigma/d\Delta\phi$ measured with 15-25 % accuracy in each $\Delta\phi$ bin.



Analysis wih 7 TeV data is ongoing

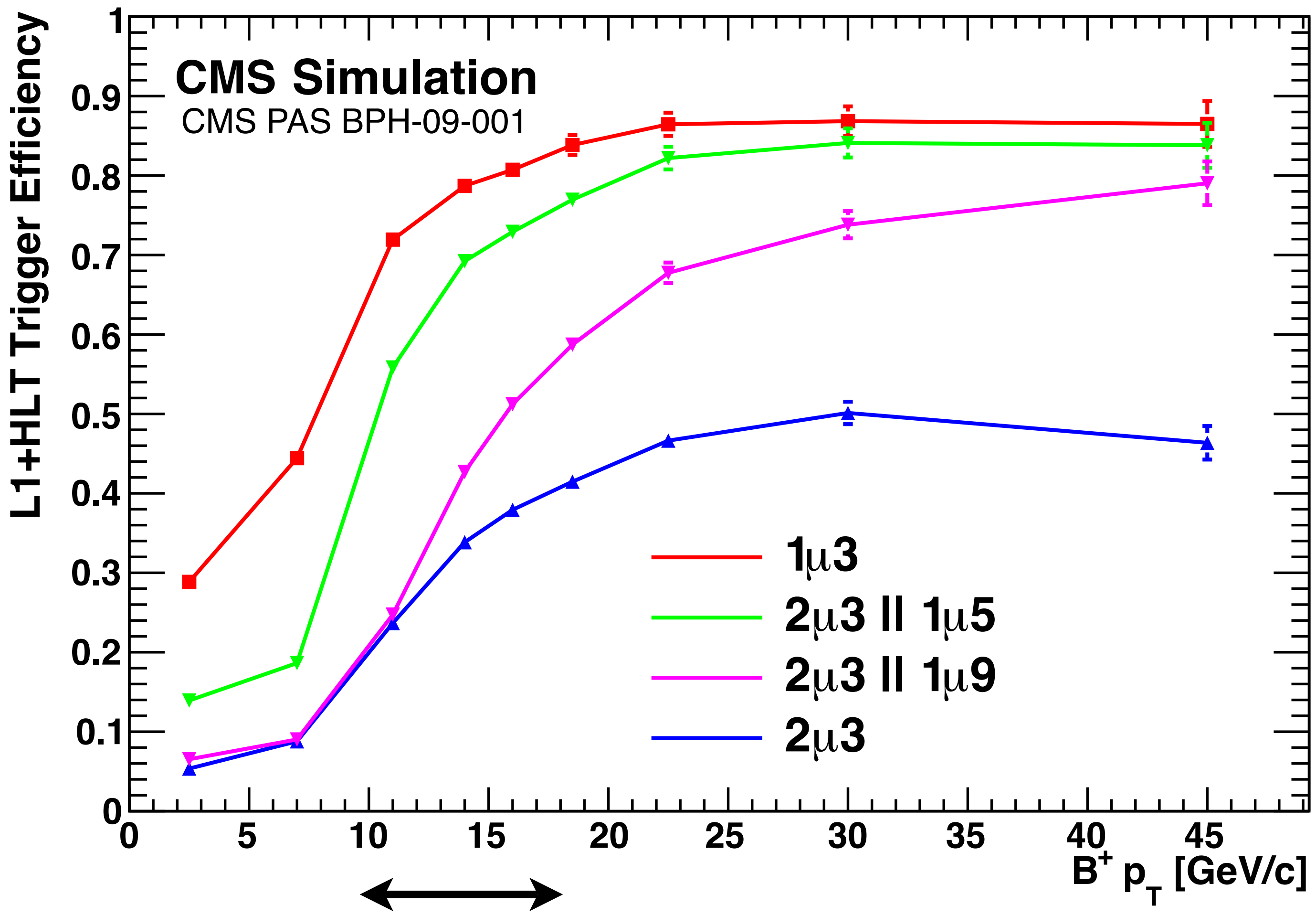
Measurement of the differential production cross section for B^+ and B^0 mesons

- $B^+ \to J/\psi\ K^+$ and $B^0 \to J/\psi\ K^{0*}$ channels
  - $Br(B \to J/\psi\ K) \sim O(10^{-3})$
    - ✓ branching, mass, lifetime, decay dynamics known very accurately
    - ✓ systematics reduced w.r.t inclusive $B \to J/\psi\ X$
    - ✓ dominant background processes (*prompt* J/ψ + incl. b) are identified using M_B and proper decay length of the reconstructed B.
- Also measure the lifetime ratio: τ_{B+}/τ_{B0}
    - ✓ sensitive tests of the CMS detector commissioning with very early data
- Feasibility of this measurement with first Lint~ 10 pb^{-1} demonstrated via a MC study @ $\sqrt{s}$ = 10 TeV

  CMS PAS BPH-09-001
  - Expected 100-200 evts/pb^{-1}

Acceptance and trigger

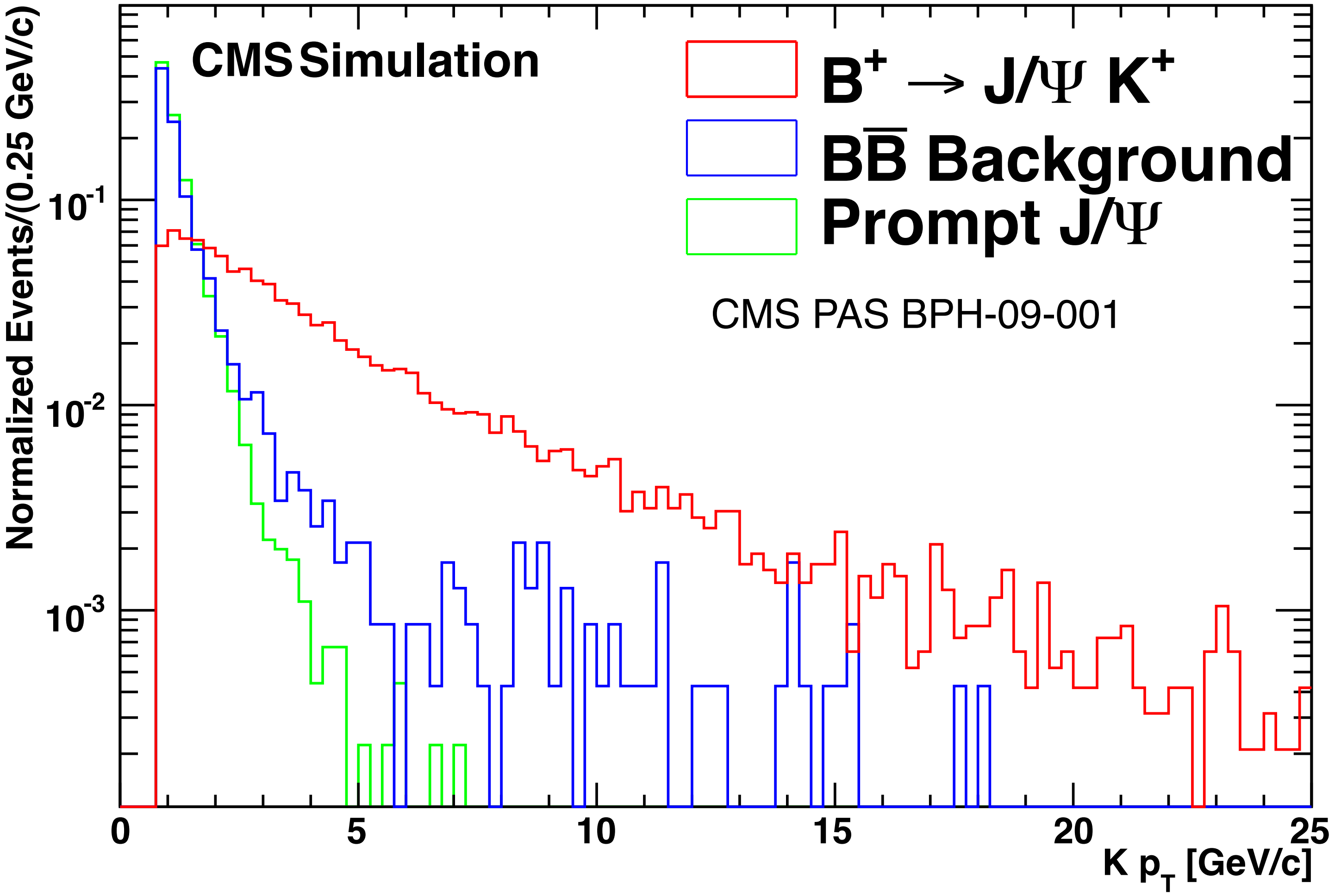
- μ-acceptance: $P_{t\mu}$>2.5 GeV, |η|<2.4
- Dimuon trigger: p_t > 3 GeV



At present LHC luminosities HLT rate sustainable also with Single_Mu_3

Acceptance x $\epsilon_{Trigger}$ ~ 2.2 %

B Reconstruction

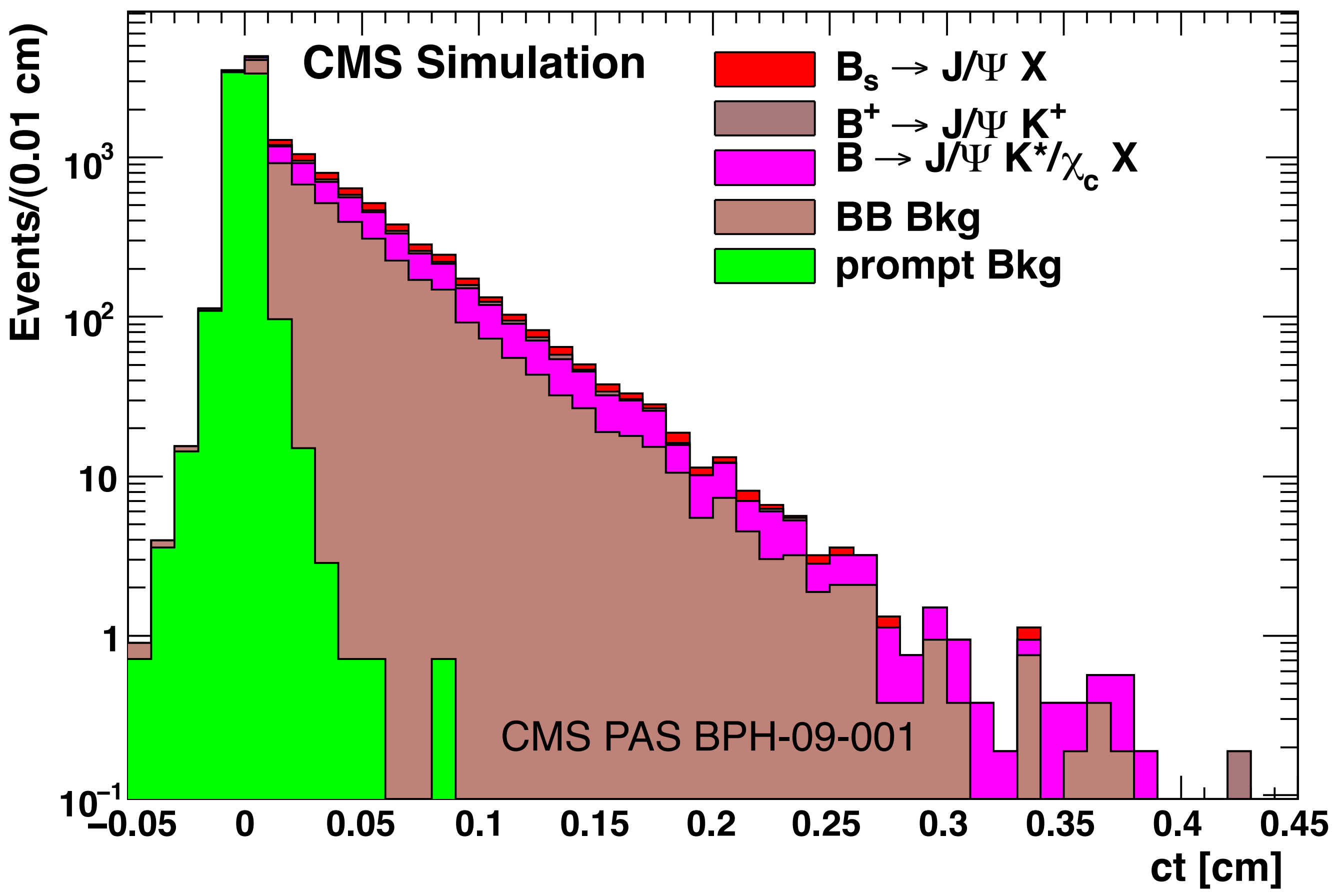


- $J/\psi \to \mu^+\mu^-$:
  - muon vertexing
  - opposite charge
  - tracker matching
  - $M(\mu^+\mu^-) = M_{J/\psi} \pm 150$ MeV
- K^+:
  - good quality track
    - $N_{hits} > 3$, $\chi^2/ndf < 5$
  - $p_t > 0.8$ GeV
- $K^{0*} \to K\pi$:
  - two good quality tracks
  - opposite charge
  - $p_t > 0.5$ GeV
  - $M(K\pi) = M(K^{0*}) \pm 120$MeV

- Kinematic fit of J/ψ + track(s)
  - $M(\mu^+\mu^-)$ constrained to the J/ψ mass
- One B candidate per event selected based on the best vertex probability
  - $4.95 < M(B) < 5.55$ GeV required
- Selection efficiency:
  - 11.6% for $B^+ \to J/\psi\ K$
  - 8.6% for $B^0 \to J/\psi\ K0^*$

Background categories based on inv. mass and vertex displacement:

- $B \to J/\psi\, \pi$
  - constant fraction of $B \to J/\psi\, K$ ($|V_{cd}/V_{cs}|^2 \sim 5\%$)
- "Peaking" B
  - deriving from partially or mis-reconstructed B decays, mis-reco Bs, decays with a χ_c, …
- "Combinatorial" B
  - $b \to J/\psi\, X$ + track
    - ✓ can be either displaced or close to primary vertex)
- Prompt $J/\psi \to \mu^+\mu^-$ decays
- QCD background:
  - $\mu^+\mu^-$ pairs not from a J/ψ decay
    - ✓ b,c semi-leptonic, decays in flight, punch through ...



B lifetime and global yield determination

- The proper decay length in the transverse plane is measured by projecting the 2-d distance between the primary and secondary vertices onto P_t^B:

$$ct = \frac{M_B}{p_t^B} \cdot L_{xy}$$

- Yield and B lifetime are obtained through a simultaneous fit to mass and proper decay length distributions for the whole sample with $p_t^B > 9$GeV

$$\mathcal{L} = \exp\left(-\sum_i n_i\right) \prod_j \left[\sum_i n_i \mathcal{P}_i(M_B; \vec{\alpha}_i) \mathcal{P}_i(ct; \vec{\beta}_i)\right].$$

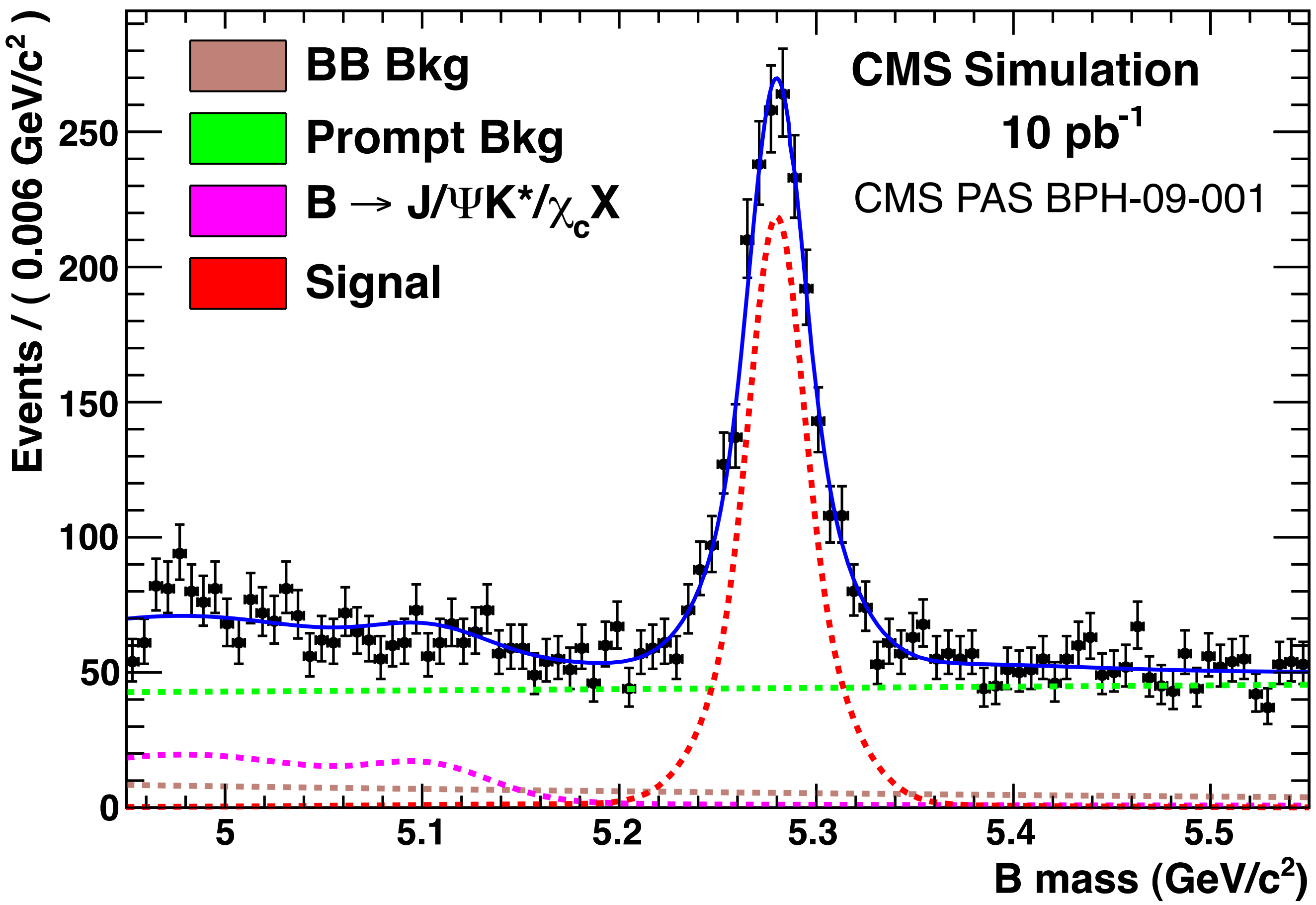
yields for signal and individual background sources and B lifetime are floated in the fit

probability density functions for M_B and *ct* are modeled “a-priori” for signal and each background source on independent MC samples

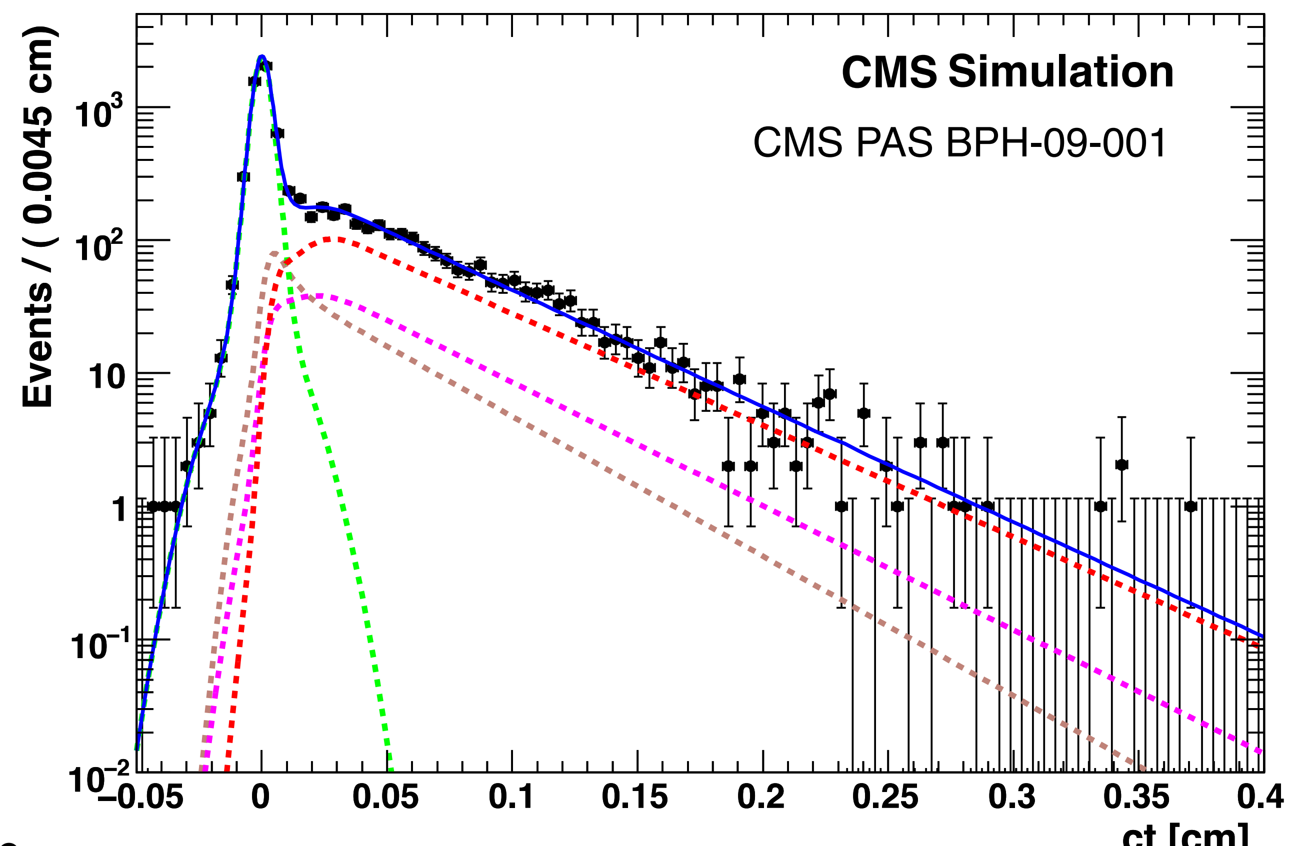
The effect of the “QCD” background is negligible and is included in the systematic error

MC results with $\int \mathscr{L}\, dt$ = 10 pb^{-1} @ $\sqrt{s}$ = 10 TeV

- Yield: 1731 B$^+$

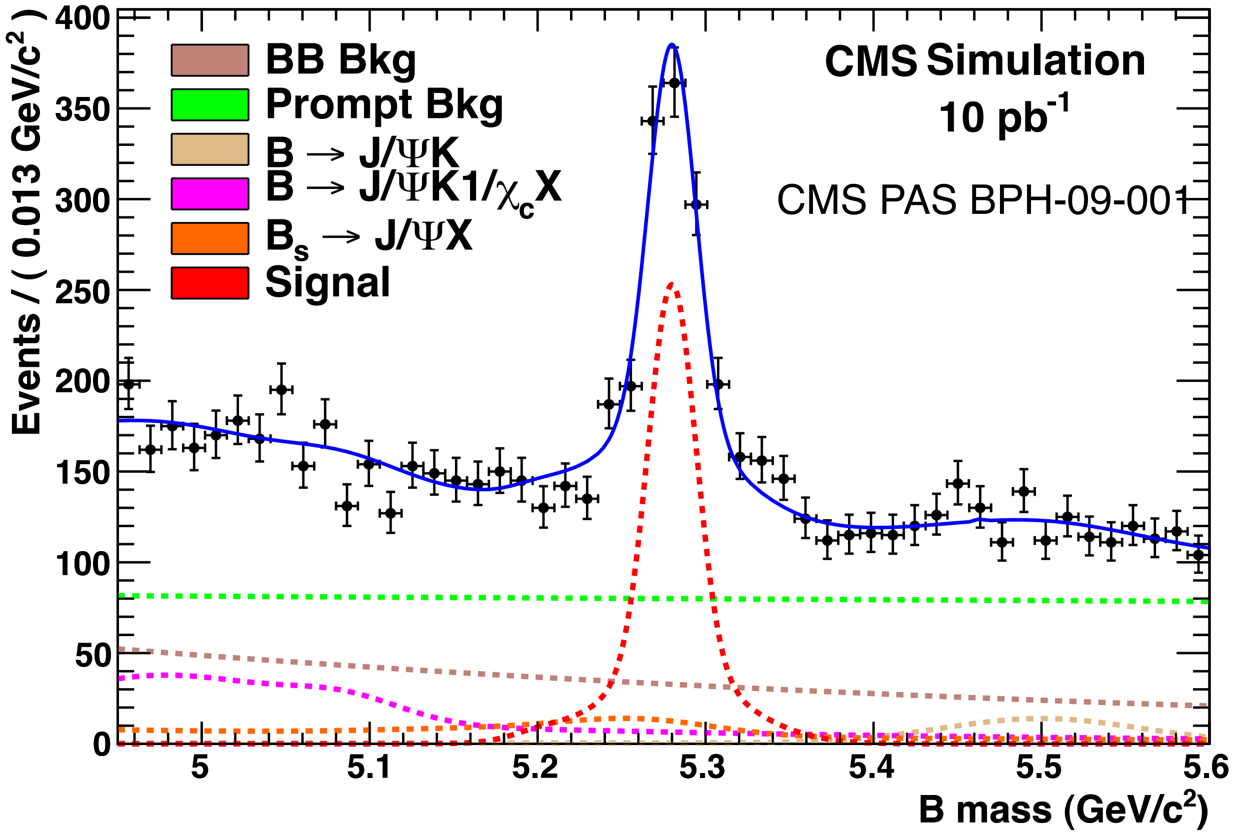


Component	$B^+ \to J/\psi K^+$
Signal	1731 ± 46
λ (μm)	495 ± 13
$J/\psi\pi$	fixed
Feeddown $b\bar{b}$	595 ± 44
Feedup $b\bar{b}$	NA
B_s decays	NA
Comb. $b\bar{b}$	613 ± 66
Prompt J/ψ	4408 ± 70

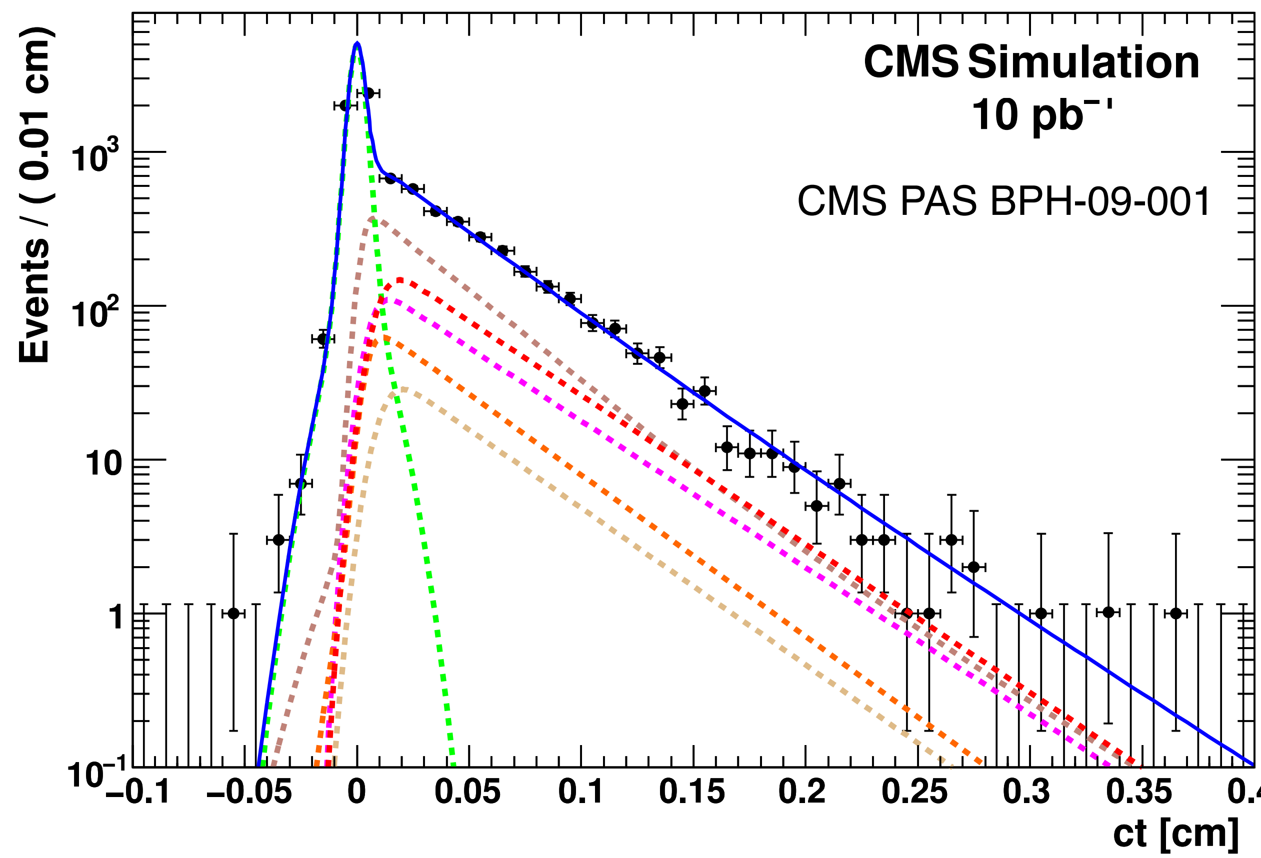


MC results with $\int \mathscr{L}\,dt$ = 10 pb^{-1} @ $\sqrt{s}$ = 10 TeV

- Yield: 890 B^0



Component	$B^0 \to J/\psi K^{*0}$
Signal	890 ± 39
λ (μm)	449 ± 18
$J/\psi\pi$	NA
Feeddown $b\bar{b}$	651 ± 97
Feedup $b\bar{b}$	170 ± 36
B_s decays	fixed
Comb. $b\bar{b}$	1710 ± 149
Prompt J/ψ	4000 ± 68

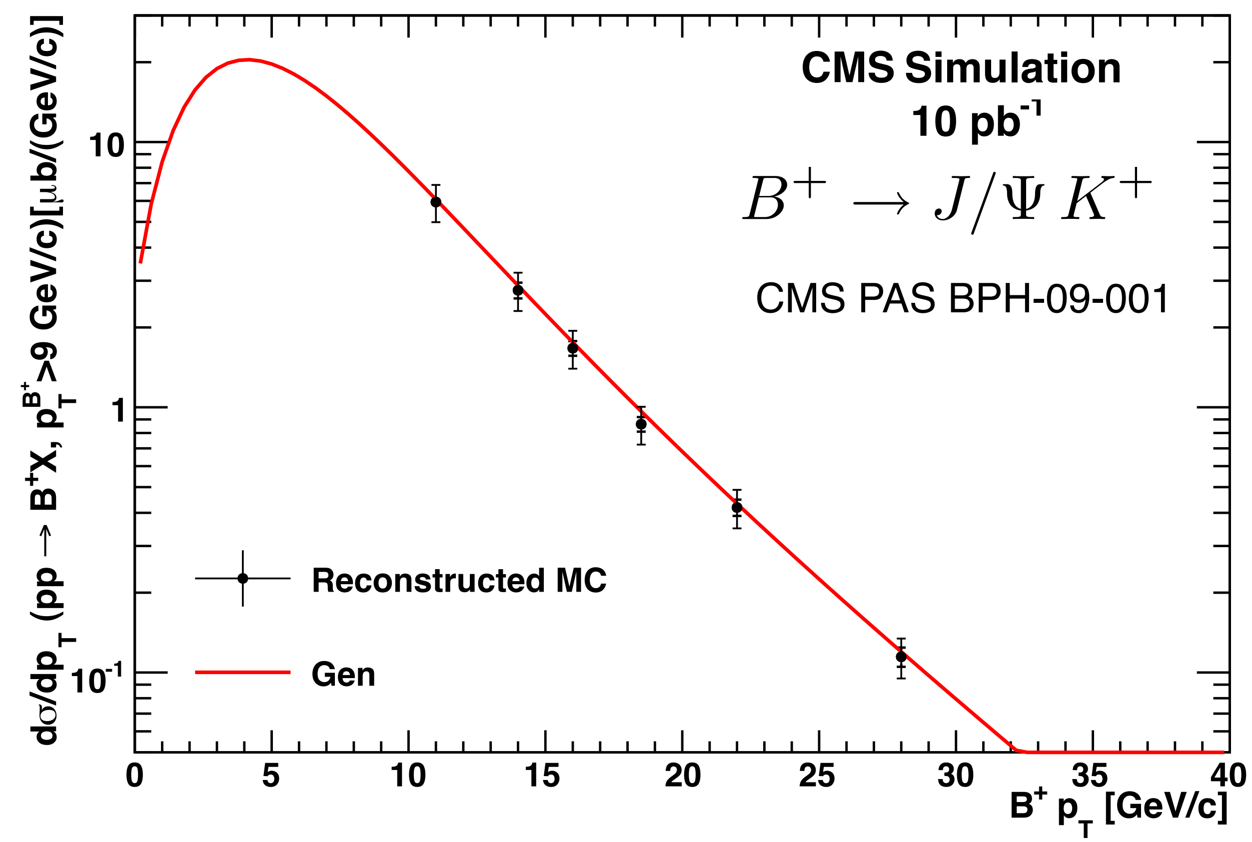


$$R_{+0} = \frac{\tau(B^+)}{\tau(B^0)} = 1.10 \pm 0.05 \pm 0.01,$$

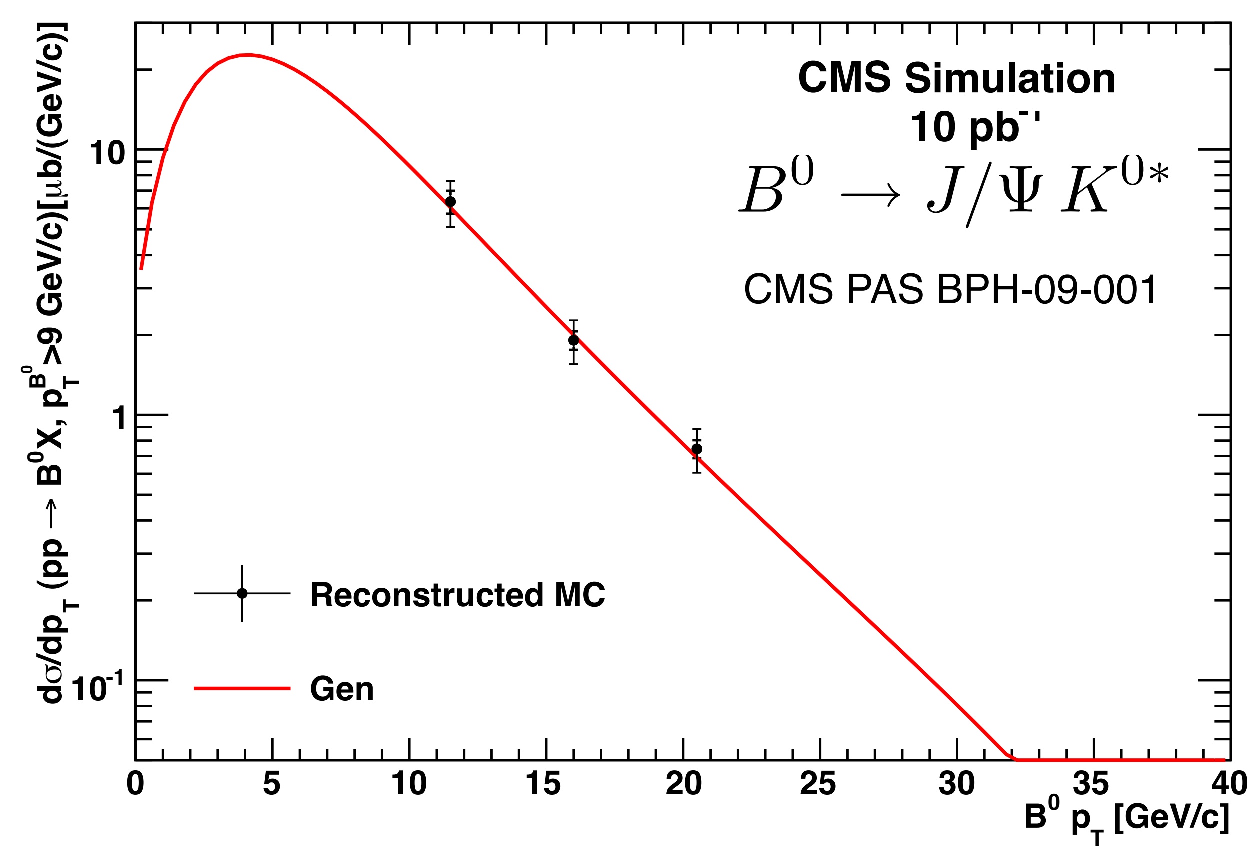
(current PDG value: 1.071 ± 0.009)

Differential cross section

- The same fit procedure is repeated dividing the sample into bins of the p_T of the B candidate
- Only signal and background yields are floated
  - ✓ The B lifetimes are fixed to the global fit values



- $d\sigma(pp \rightarrow B + X)/dp_T^B$ can be measured up to $p_T^B \sim 30$ GeV with a statistical error lower than 10% (the systematic error dominated by the luminosity determination at startup) with $L_{int} = 10\ pb^{-1}$.

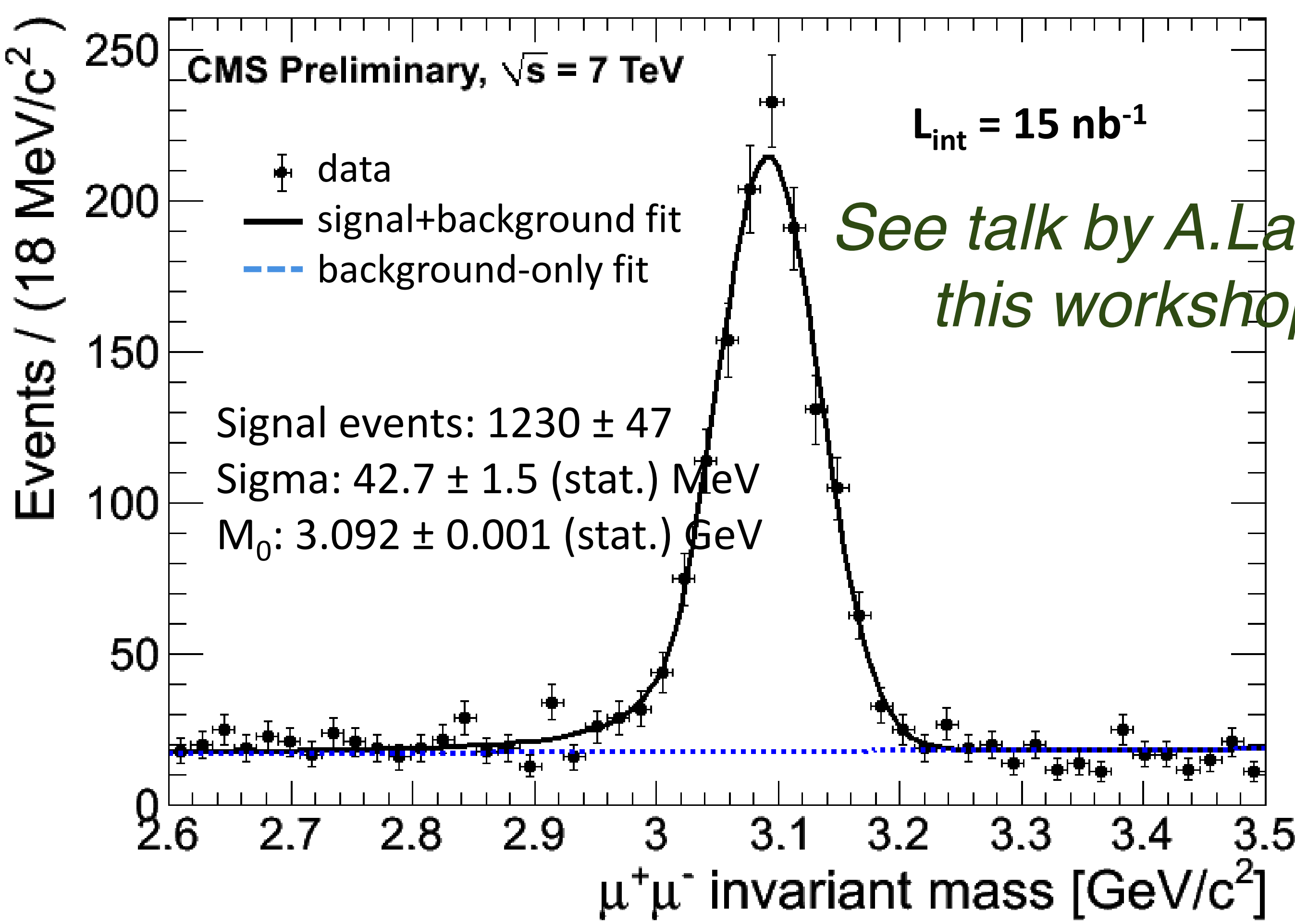


Perspective

- Measurement with data at $\sqrt{s}$ = 7 TeV ongoing
  - ✓ factor ~ 0.75 in cross section w.r.t. $\sqrt{s}$ = 10 TeV
  - ✓ substantial yield gain using lower trigger thresholds
- Also: $B^0 \to J/\psi\ K^0_s$, $B_s \to J/\psi\ \phi$, $\Lambda_b \to J/\psi\ \Lambda_0$

$$N_{B\to J/\Psi+H} = N_{b\to J/\Psi+X} \cdot \frac{Br(B\to J/\Psi+H)\cdot Prob(b\to B)}{Br(b\to J/\Psi+X)} \cdot \frac{\epsilon(B\to J/\Psi+H)}{\epsilon(b\to J/\Psi+X)}$$

O(1-5%) *O(10-15%)*



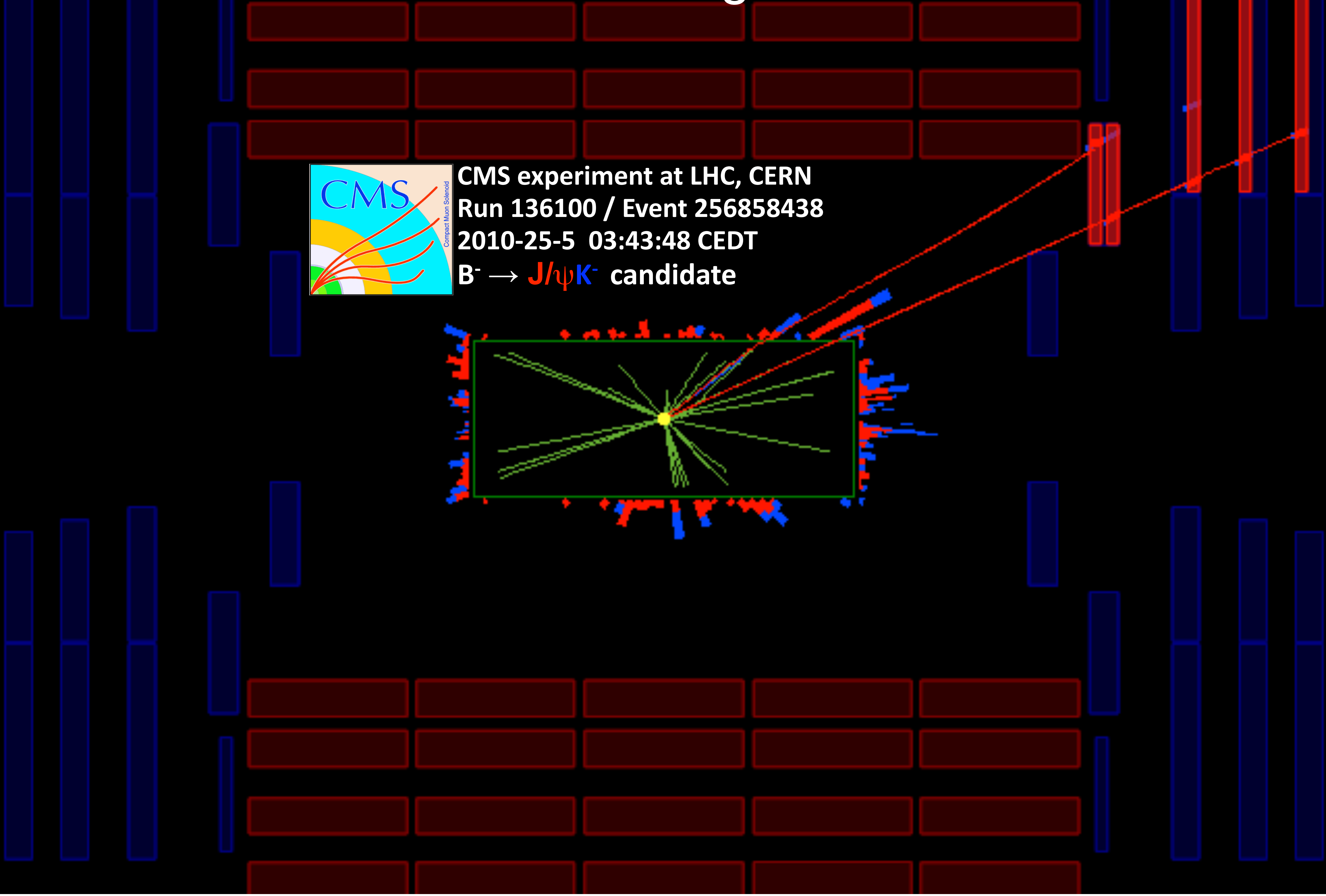
See talk by A.Lanaro this workshop

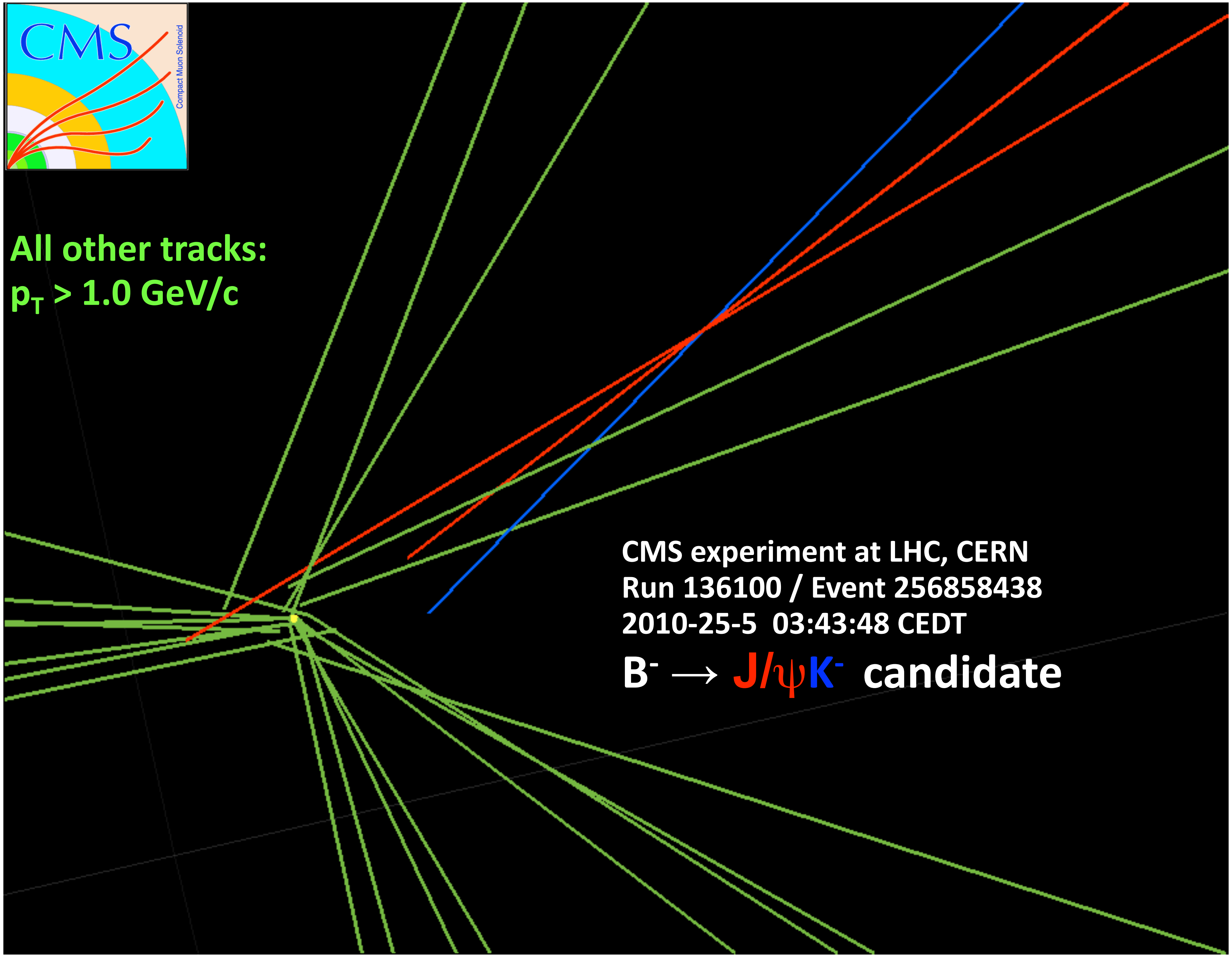
$$N_{b\to J/\Psi+X)} = f_b \cdot N_{J/\Psi}$$

$$f_b \simeq 0.15$$

few events expected in data collected so-far

We start to see interesting candidates ...





Measured parameters:

$M(\mu\mu K) = 5.268\ \mathrm{GeV}/c^2$

$M(\mu\mu) = 3.135\ \mathrm{GeV}/c^2$

$p_T(B) = 18.6\ \mathrm{GeV}/c$

$p_T(\mu^+) = 10.1\ \mathrm{GeV}/c$

$p_T(\mu^-) = 3.4\ \mathrm{GeV}/c$

$p_T(K^-) = 5.3\ \mathrm{GeV}/c$

$\mathrm{Prob}(\chi^2) = 0.844$

$L_{xy} = 1.93\ \mathrm{mm}$

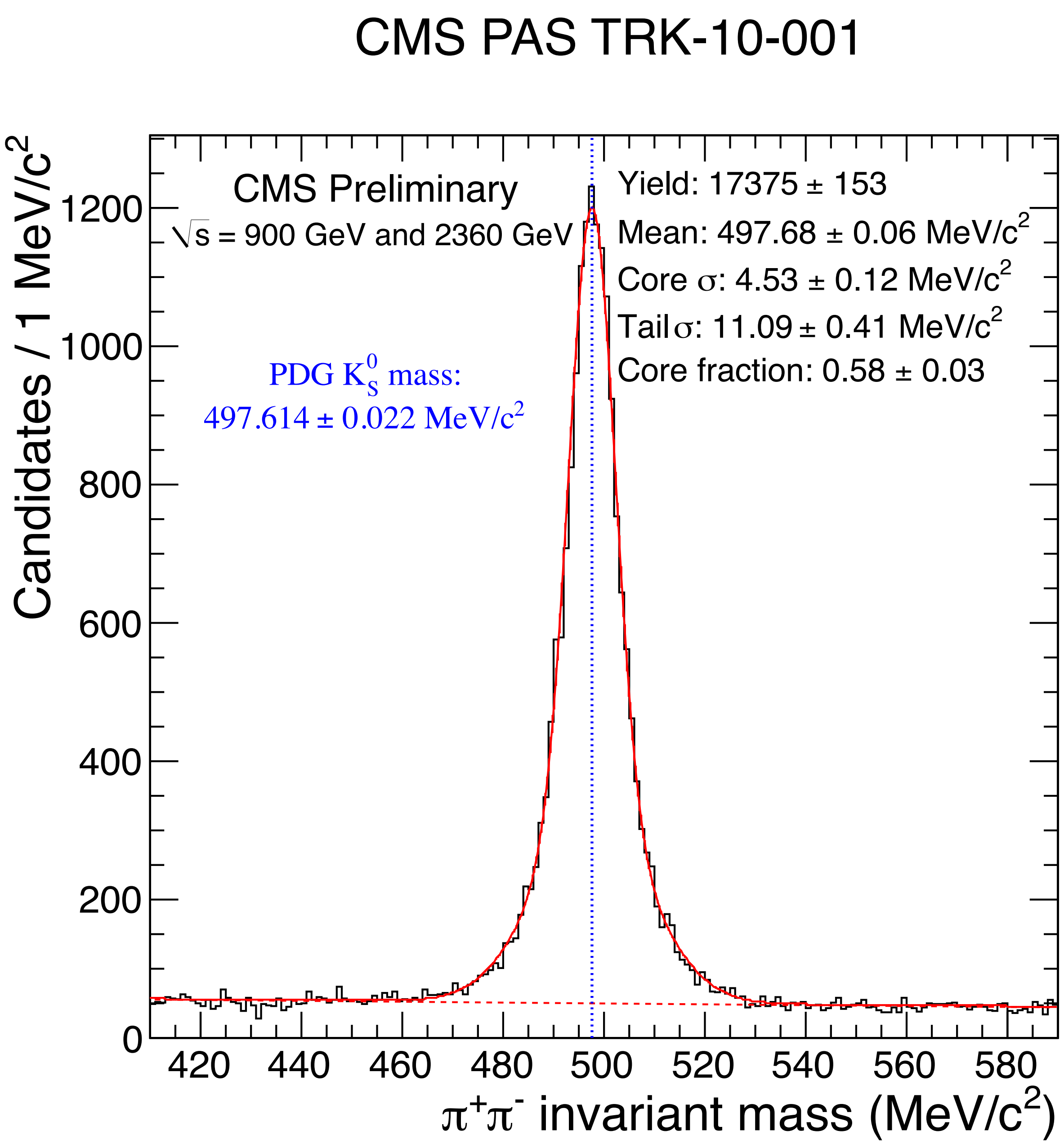
$\sigma(L_{xy}) = 0.11\ \mathrm{mm}$

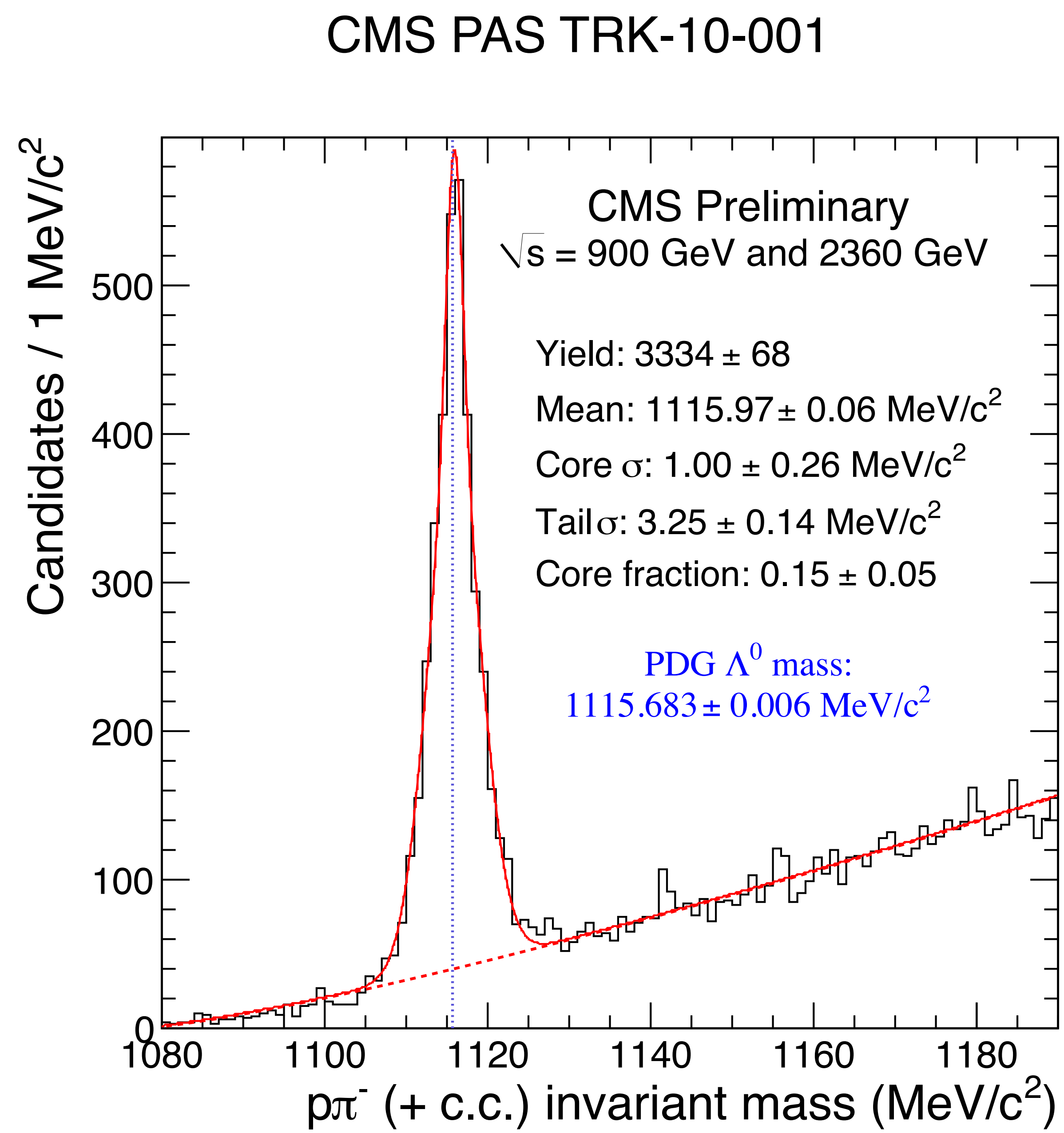
$L_{xy}/\sigma(L_{xy}) = 18$

$\sqrt{s} = 7$ TeV

$\int \mathscr{L}\, dt = 16\ \mathrm{nb}^{-1}$

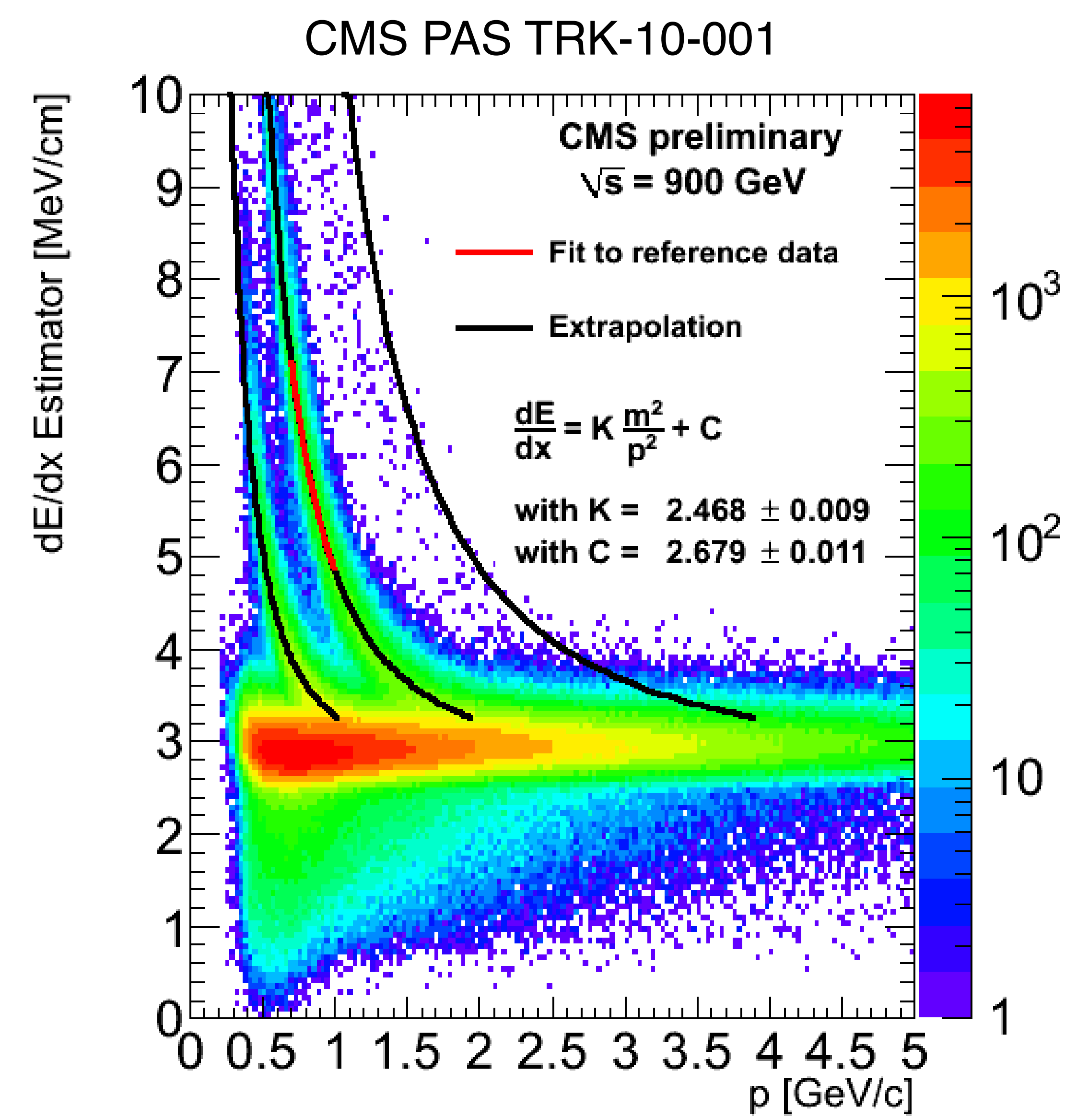
The tools are there ... V0 reconstruction

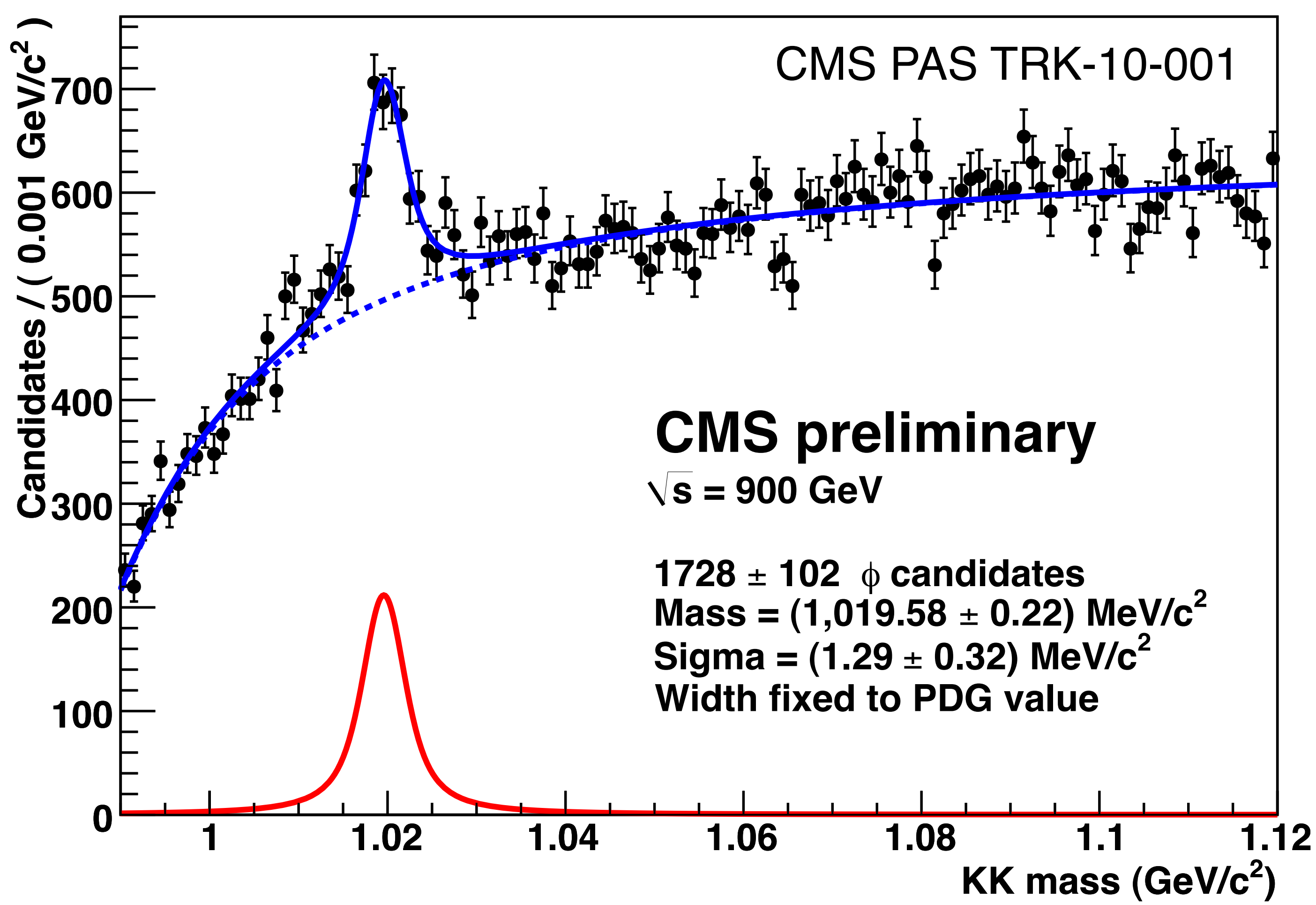




$\Phi \to K^+K^-$

- the Si-strip analog readout allows to reconstruct the charge deposited on hits forming a track
- individual channel calibration is performed via MIP signal
- a correction for the crossed path length is applied
- Particle mass is estimated from p and dE/dx

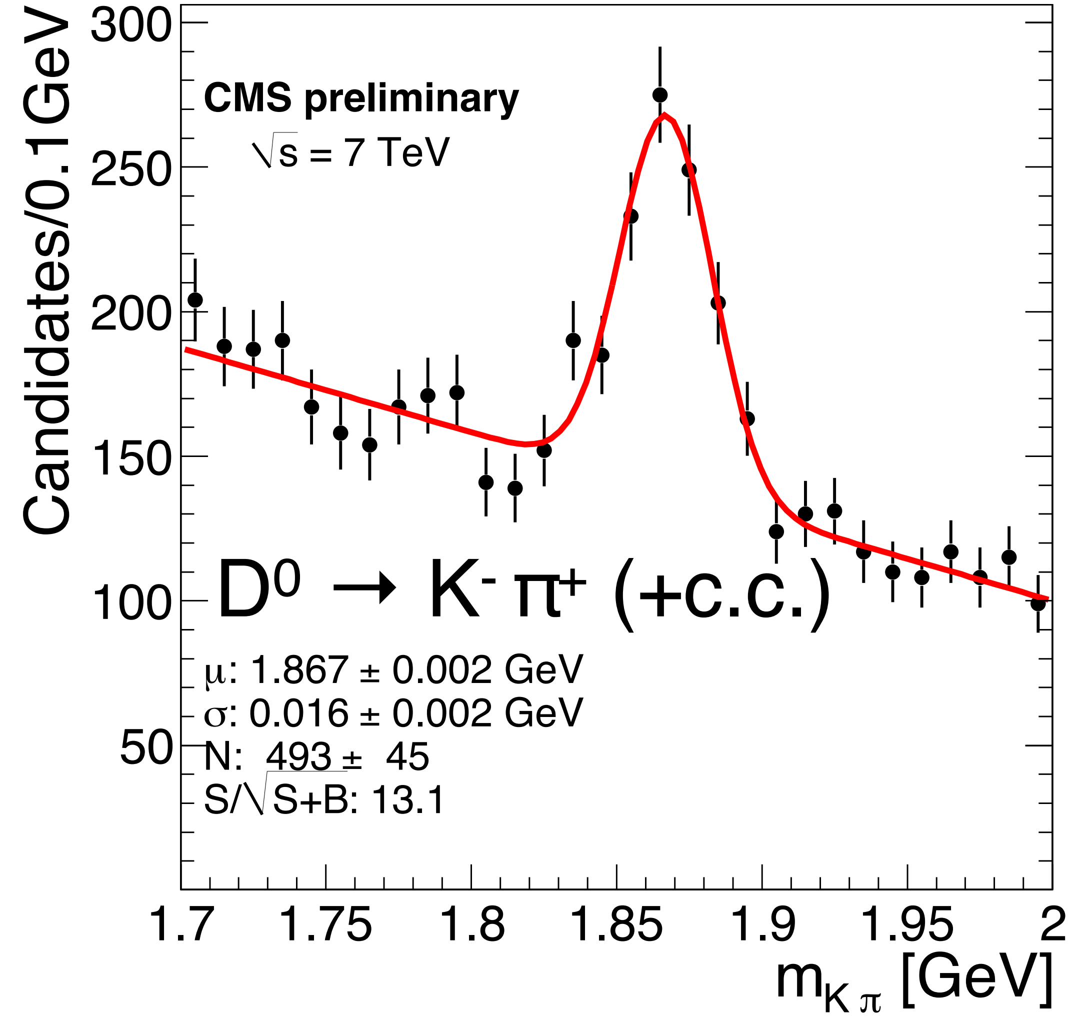




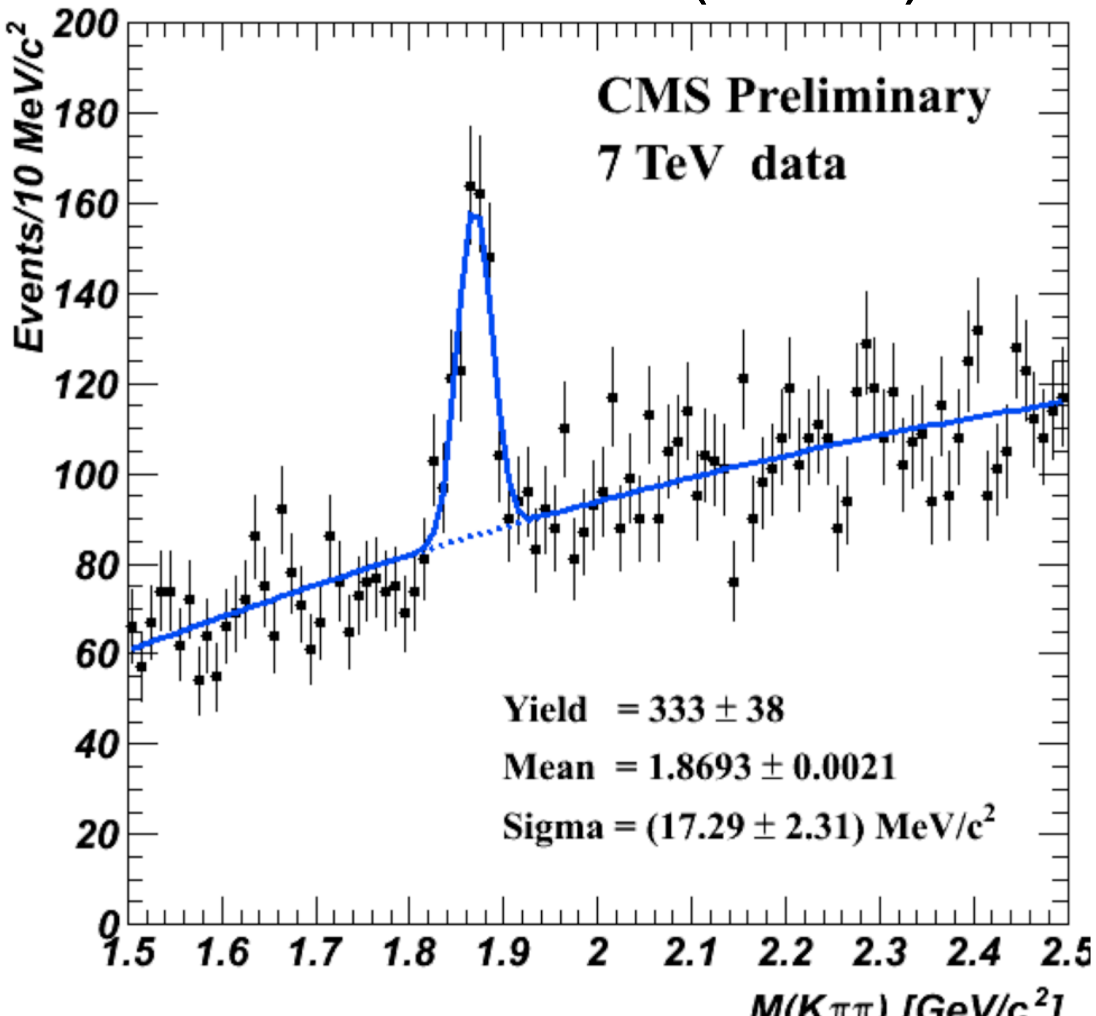
- $p_T > 0.5$ GeV/c;
- normalized $\chi^2 < 2.0$;
- at least 5 hits;
- $|\eta| < 2.0$;
- $|d_{xy}| < 0.3$ cm;
- $p > 1$ GeV/c or dE/dx → $M_K \pm 200$ MeV

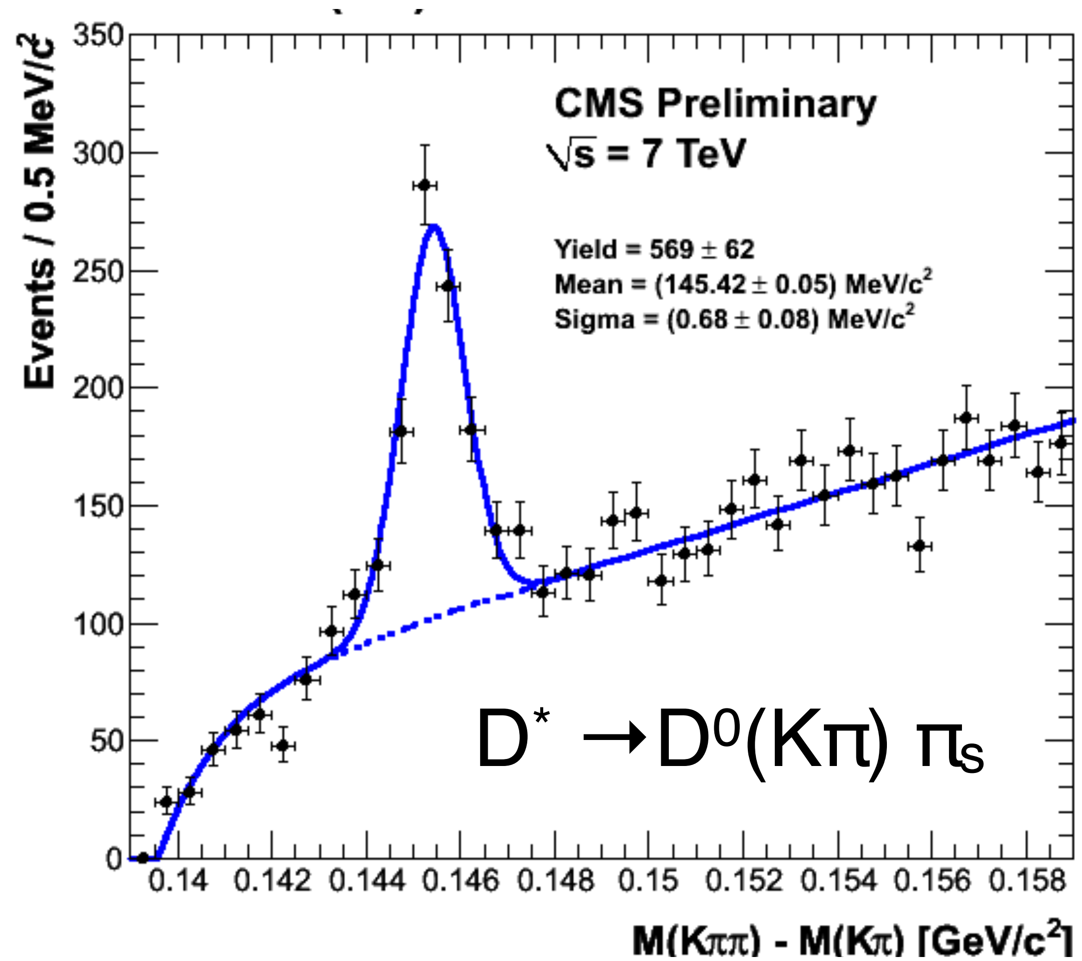
also D reconstruction

- Clear evidence of mass peaks
  - 7 TeV collisions
  - O(10^7) minimum bias events
- mass and σ_M in good agreement with MC
  - validate the tracker pattern recognition, momentum resolution,B-field and p scale, secondary decay vertex quality

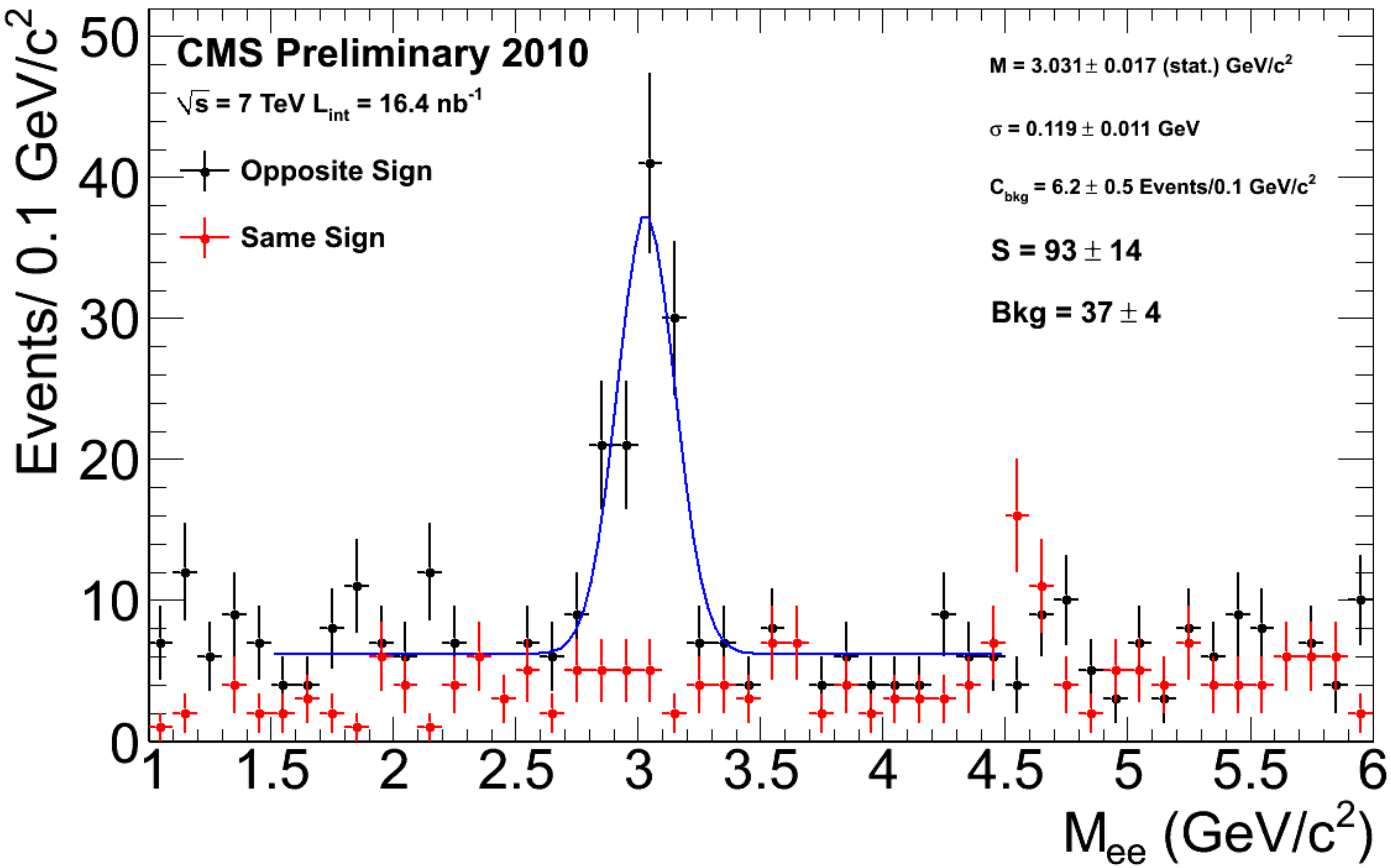


$D^+ \rightarrow K^- \pi^+ \pi^+$ (+ c.c.)





… and J/ψ → e^+e^-



Studies in this channel limited by:

- higher trigger thresholds
- bremsstrahlung in the tracker material
- charged hadrons combinatorial background

Reconstruction of $B_s \to J/\psi\ \Phi$ decays

- The B_S^0 meson at LHC:
  - measure Δm_s, $\Delta\Gamma_s$
  - weak phase Φ_{CKM} → possible hints for NP
- MC study performed by CMS

  (see V. Ciulli et al., CMS NOTE-2006/121. See also: T. Speer, Capri2006, A.Starodumov, M. Biasini, Capri 2008):

  $\Delta\Gamma_s / \Gamma_s$ can be measured @ 20% precision with $\int \mathscr{L} = 1.3\ fb^{-1}$ @14 TeV

- selection based on Pt, vertexing, inv. mass
- unbinned max-like fit to the time evolution of the angular distibution:

$$P = \underbrace{\varepsilon(t, \Theta)}_{\text{efficiency}} \cdot \underbrace{f(\Theta, \alpha, t)}_{\text{diff. decay rate}}$$

$$\frac{d^4 \Gamma(B_s(t))}{d^3 \Theta\, dt} = f(\Theta, \alpha, t) = \sum_i \underbrace{b^{(i)}(\alpha, t)}_{\text{observables}} \underbrace{g^{(i)}(\Theta)}_{\text{theory}}$$

observables: Γ_H, Γ_S, Δm_S

theory

- Updated study for first few pb^{-1} @ 7 TeV ongoing
- Max Likelihood. fit to inv. mass and lifetime distributions for signal and background processes (like for the $B \to J/\psi\ K$)
  - M_{Bs} and τ_{Bs} measurements possible since the first pb^{-1} of data
  - ~ 500 evts. after 10 pb^{-1} of data

Search for the B_c meson

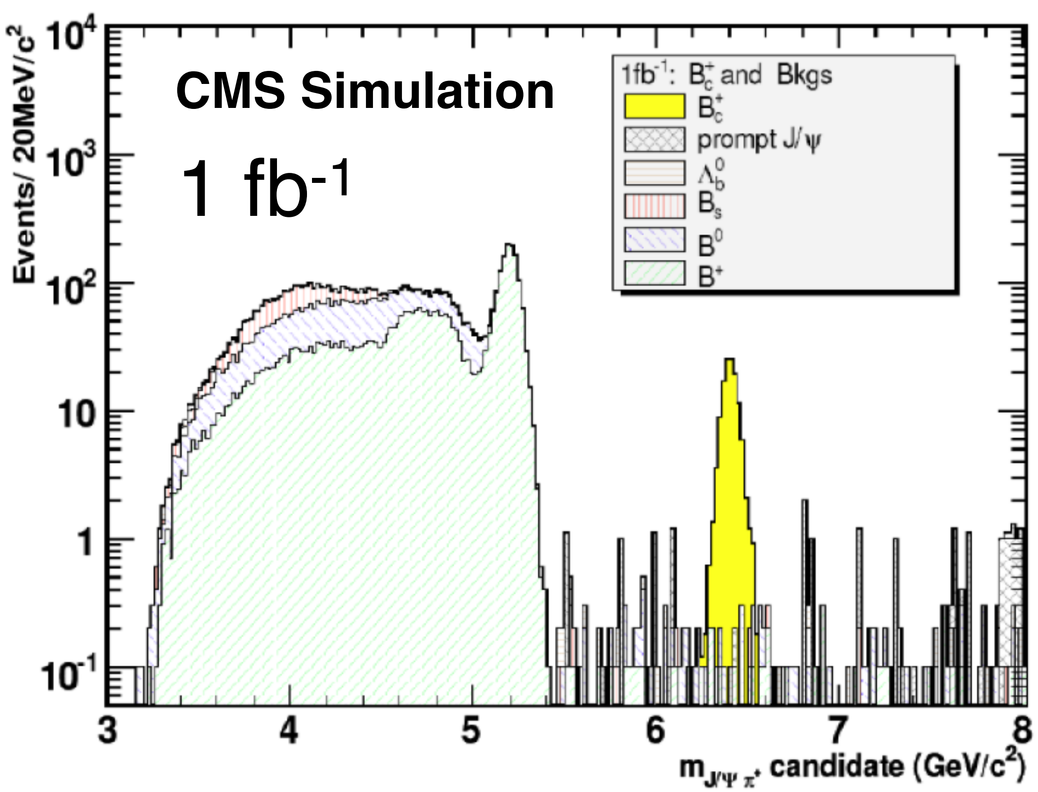
- unique properties of the $B_c^{\pm}$:
  - two heavy quarks of different flavor
  - only weak decays possible
  - $\tau_c < \tau_{Bc} < \tau_b$
- still large the theoretical uncertainties
  - ✓ $\sigma(B_c) \sim 10^{-3}\,\sigma(B^+)$
  - ✓ $\tau_{Bc} \sim 0.46$ ps

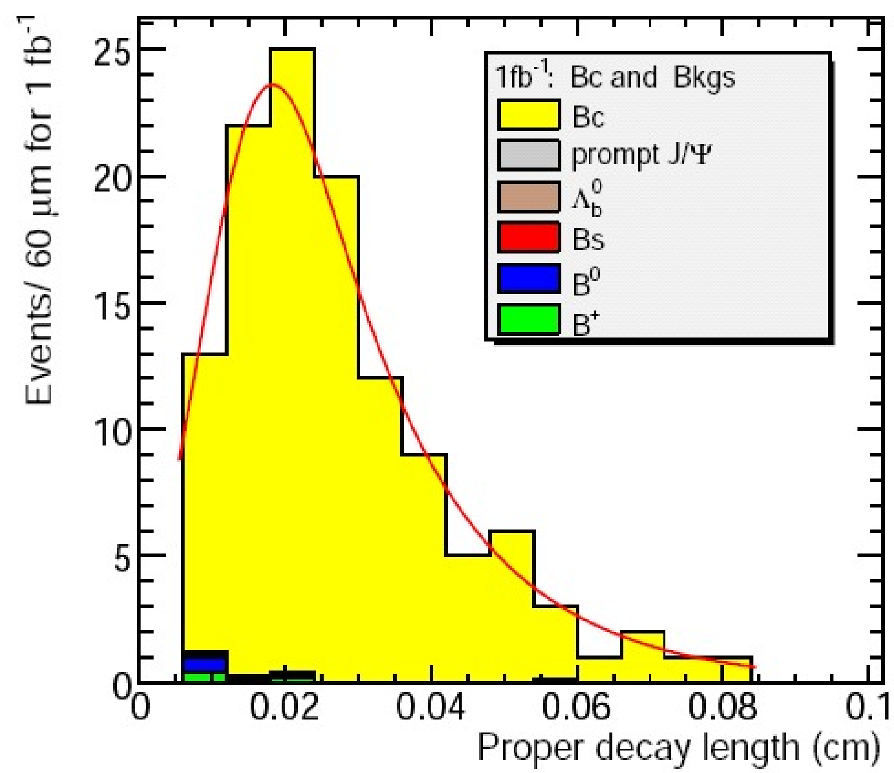
X.W. Meng, J.Q. Tao, G.M. Chen
CMS NOTE- 2006/118

(See also: T. Speer, Capri2006, A.Starodumov, M. Biasini, Capri 2008)

- Based on a MC study @ 14 TeV
  - CMS has the possibility to observe the $B_c \rightarrow J/\psi\,\pi$ decays
  - ~ 120 events in 1 fb^{-1}
  - 15 MeV mass resolution
  - τ_{Bc} measured with 0.045 ps error

Study for 7 TeV ongoing





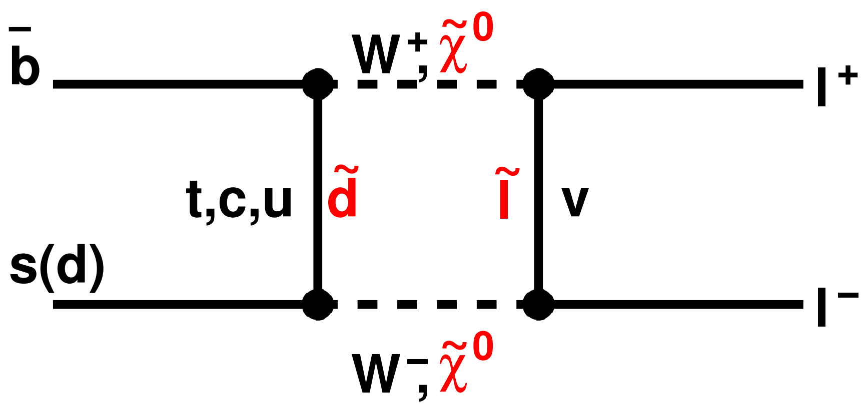
Conclusions

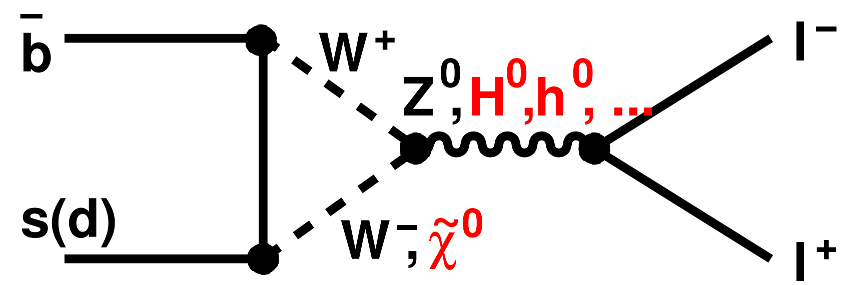
- LHC is delivering proton-proton collisions at $\sqrt{s}$ = 7 TeV
  - luminosity is constantly increasing
    - ✓ up to ~ 1 fb^{-1} integrated luminosity may be expected by the end of 2011
- The CMS experiment is collecting data with excellent quality:
  - exclusive B decays into a J/ψ offer clean experimental signatures well suited for the startup phase
  - Monte Carlo studies at $\sqrt{s}$=10-14 TeV are being ported to the present LHC energy regime of 7 TeV
    - ✓ generally lower trigger thresholds w.r.t. 14 TeV studies are applied
- A rich physics program with exclusive B decays is envisaged:
  - Exclusive B mass peaks (since the first ~1 pb^{-1} of data)
  - b production cross section with exclusive B states and $b\bar{b}$ correlations (requiring order of 10 pb^{-1} of data)
  - B_c observation, mass and lifetime measurements (~ 100 pb^{-1})
  - B_s mixing sector and $\Delta\Gamma_s$ with ~ 1 fb^{-1} .

Reserve

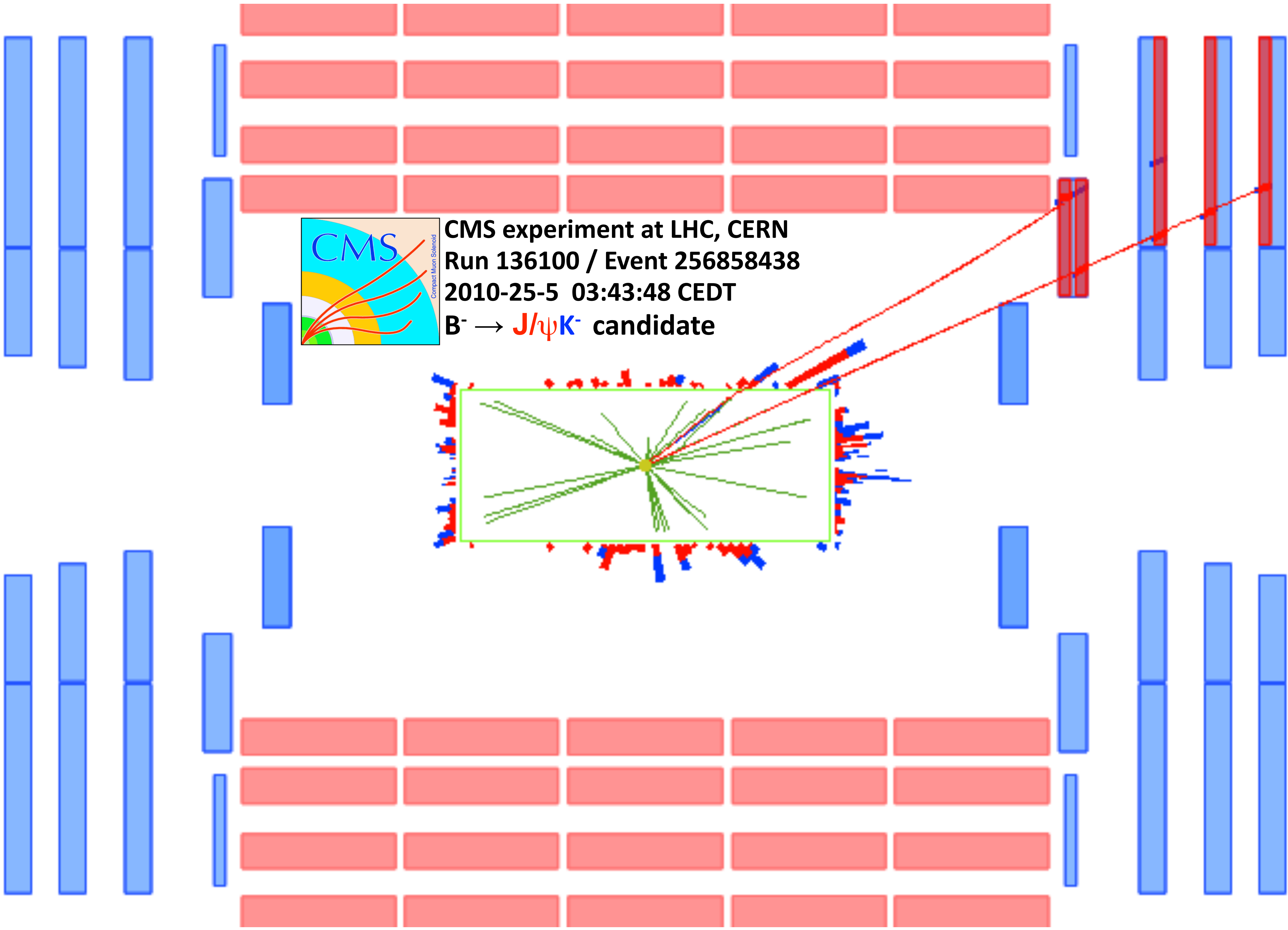
FCNC: Bs → *μ+μ-*

CMS PAS BPH-07-001





- highly suppressed in the SM
  - $Br(B_s^0 \to \mu^+\mu^-) = (3.42 \pm 0.54) \times 10^{-9}$
- sensitive probe of NP
  - MSSM rate proportional to $\tan^6 \beta$
- analysis at MC level performed by CMS
  - yield normalized to the $B^\pm \to J/\psi\ K^\pm$ channel
  - with 1 fb^{-1} luminosity and $\sqrt{s}$ = 14 TeV it is expected to pose a 95% c.l. limit: $Br(B_s^0 \to \mu^+\mu^-) \leq 1.9 \times 10^{-8}$.

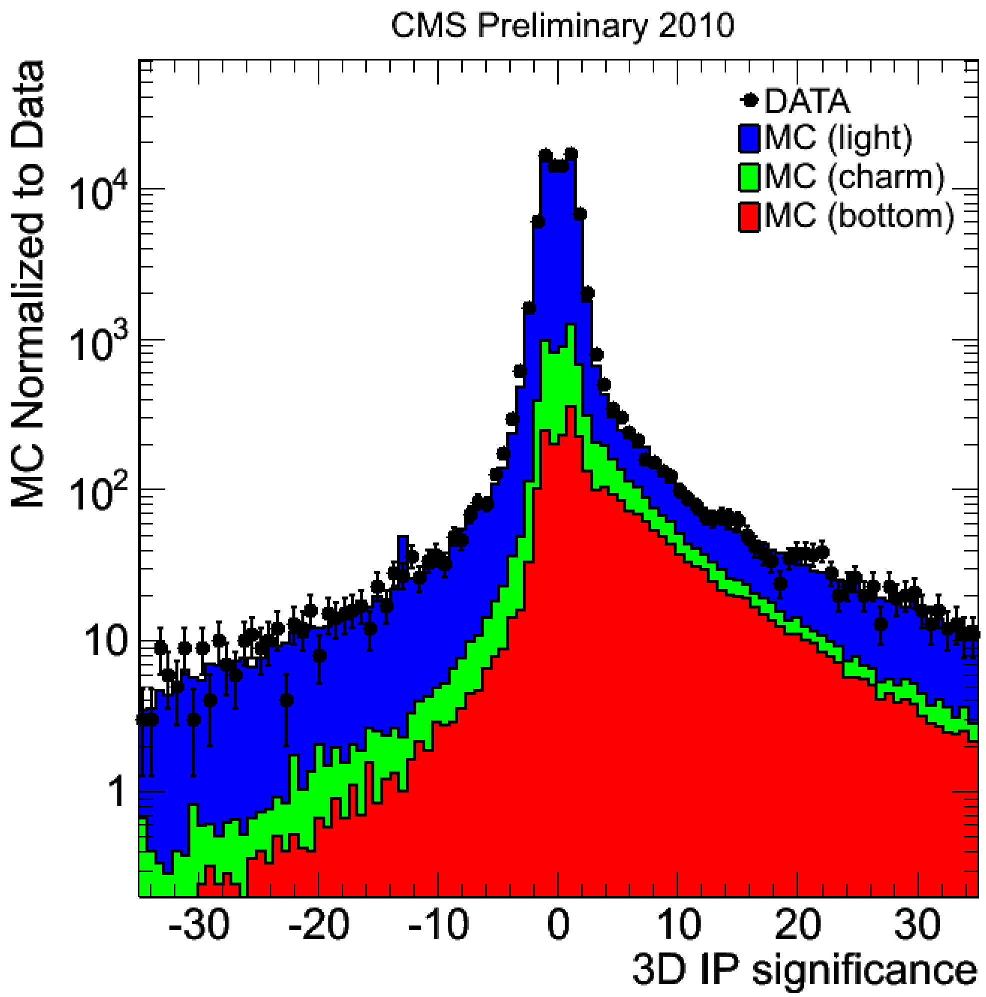

CMS experiment at LHC, CERN
Run 136100 / Event 256858438
2010-25-5 03:43:48 CEDT
$B^{-} \rightarrow J/\psi K^{-}$ candidate

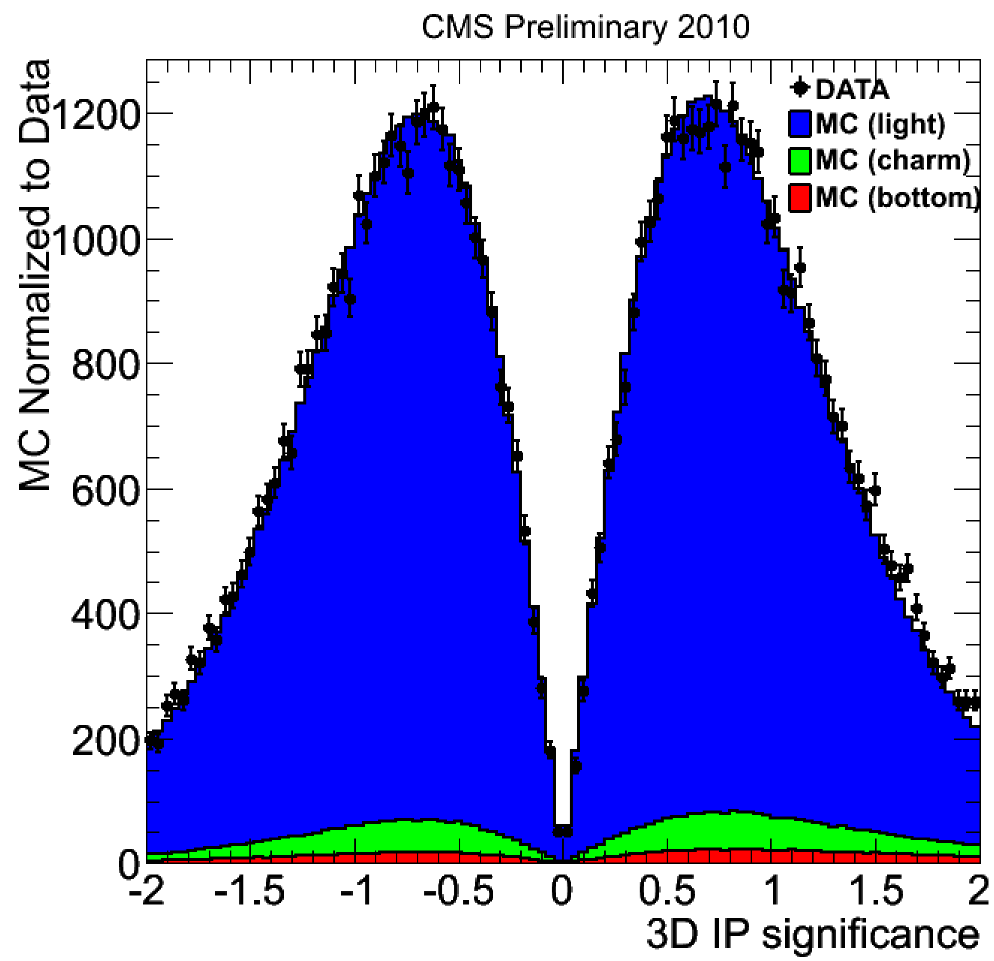
Event Selection and Measured Parameters

- Selection
  - Two muons (global or tracker) satisfying quality criteria, passing the trigger, making a good vertex, and having $p_T > 3.0$ GeV.
  - Charged track with pT > 900 MeV, at least three hits, and χ^2/ndof < 5
  - Require a good 3-trk vertex with mass constraint on the dimuon
- Parameters
  - Prob(χ^2) = probability of 3-trk vertex
  - L_{xy} = transverse decay length of 3-trk vertex relative to primary vertex
  - $\sigma(L_{xy})$ = error on transverse decay length

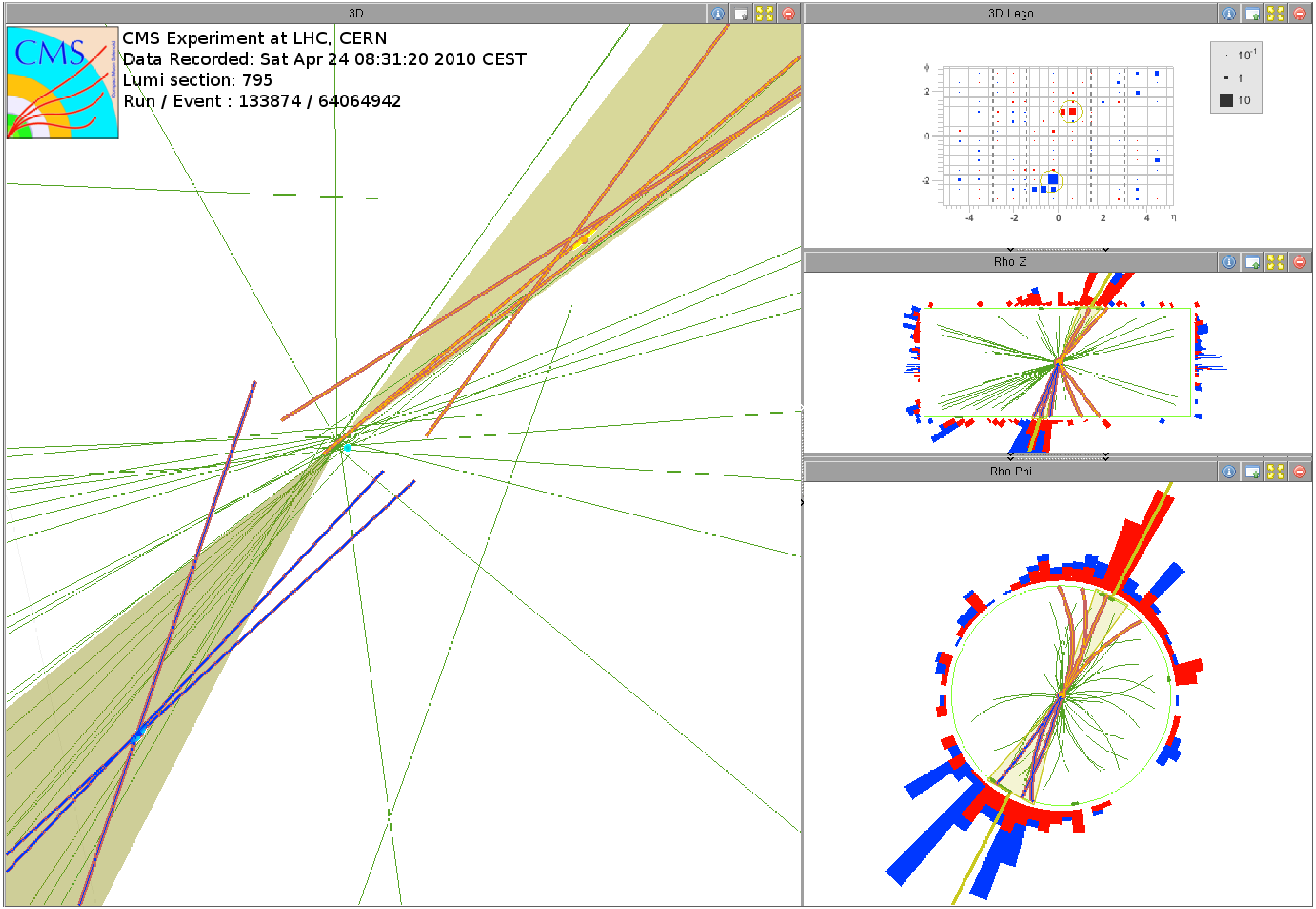
Measured parameters:

$$M(\mu\mu K) = 5.268\ \mathrm{GeV}/c^2$$
$$M(\mu\mu) = 3.135\ \mathrm{GeV}/c^2$$
$$p_T(B) = 18.6\ \mathrm{GeV}/c$$
$$p_T(\mu^+) = 10.1\ \mathrm{GeV}/c$$
$$p_T(\mu^-) = 3.4\ \mathrm{GeV}/c$$
$$p_T(K^-) = 5.3\ \mathrm{GeV}/c$$
$$\mathrm{Prob}(\chi^2) = 0.844$$
$$L_{xy} = 1.93\ \mathrm{mm}$$
$$\sigma(L_{xy}) = 0.11\ \mathrm{mm}$$
$$L_{xy}/\sigma(L_{xy}) = 18$$





- Significance of the signed 3D impact parameter for all tracks selected for b-tagging for jets with $p_T > 40$ GeV and $|\eta| < 1.5$
- Right plot: zoom into the central region



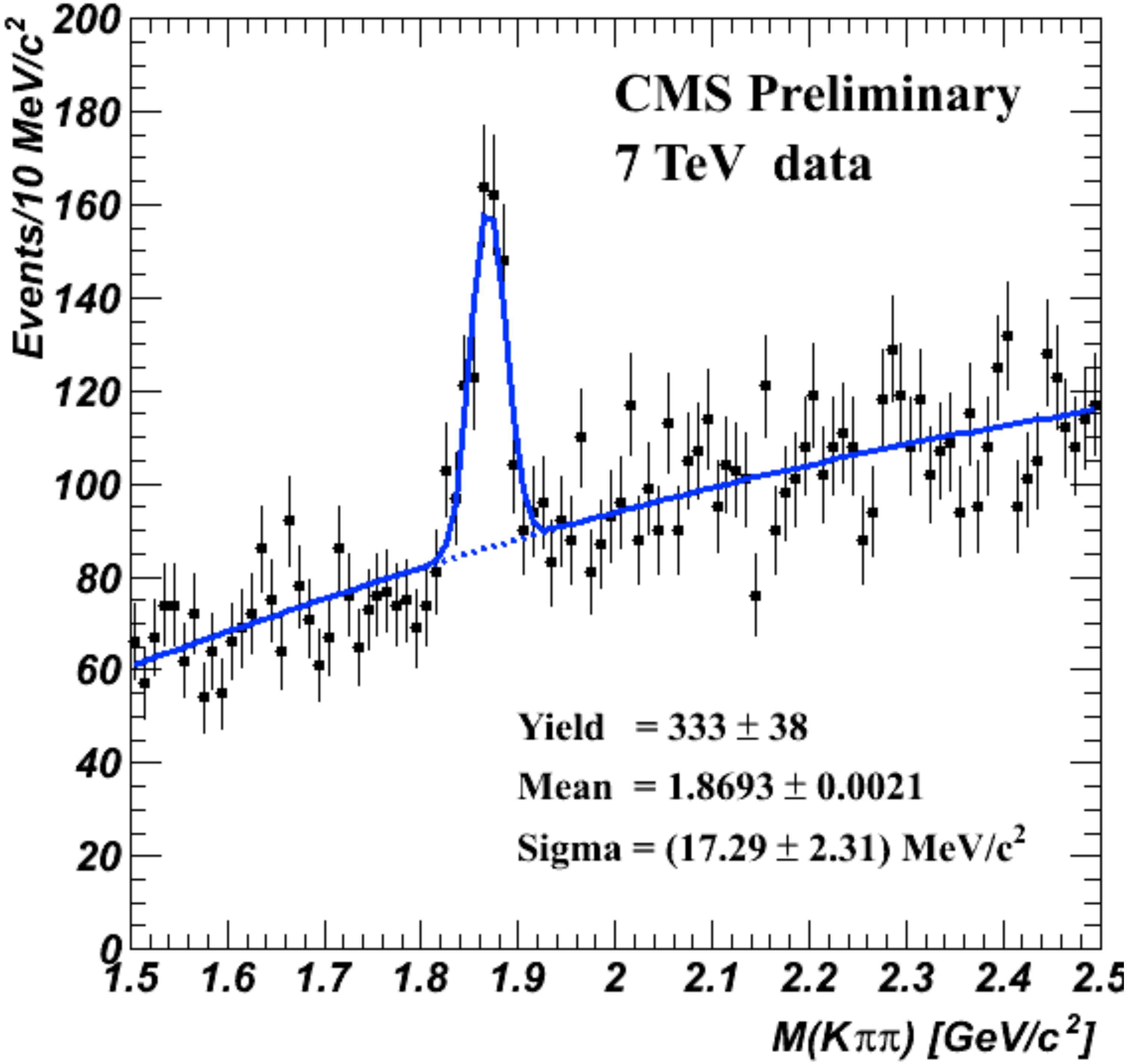
3D
CMS Experiment at LHC, CERN
Data Recorded: Sat Apr 24 08:31:20 2010 CEST
Lumi section: 795
Run / Event : 133874 / 64064942
3D Lego
Rho Z
Rho Phi

Nov-Dec 2009

- $\sqrt{s}$=900 GeV @ LHC injection energy
  - 300K events
  - First LHC collisions December 2009 (~15 μb-1/10μb-1)

- $\sqrt{s}$=2.36 TeV
  - 20K events
  - Delivered/recorded ~ 1.2μb-1/0.4μb-1

D^+ search



Information

- Data: ~24M events
- Search for $D^+ \rightarrow K^- \pi^+ \pi^+$ (and c.c.)
  - secondary vertex formed by 3 tracks with total charge ±1
  - topological approach: L/S and D^+ pointing to the primary
  - Momentum cuts on tracks:
    - p > 1.5 GeV
    - p_T > 0.1 GeV
- Binned ML fit (Minuit)
  - Signal = Gaussian
  - Bkg = 2nd order polynomial

Inclusive D^0

- Selection criteria
  - ‘good’ runs
  - transverse momentum cuts

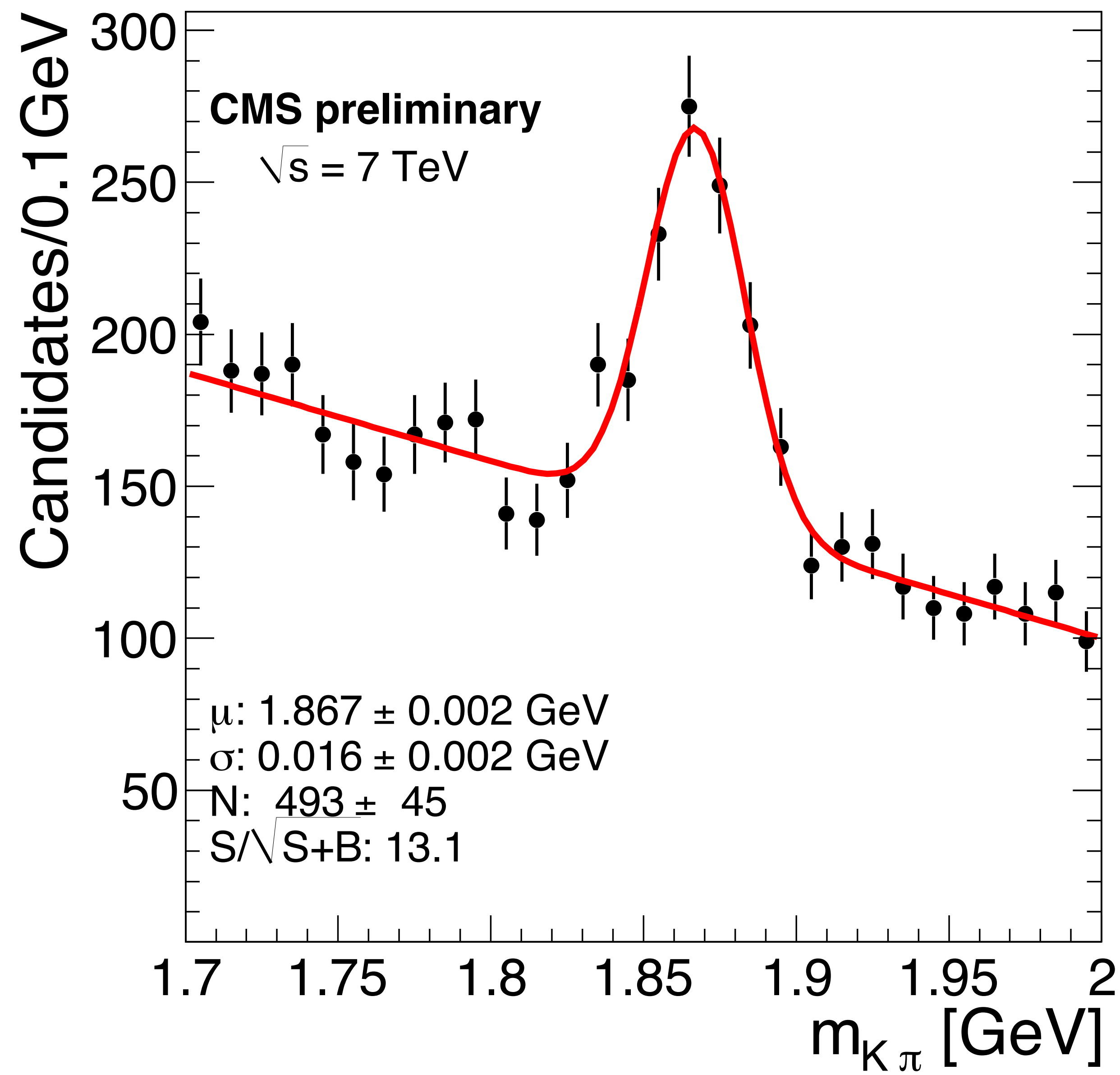
$$p_\perp(K) > 1.25\,\text{GeV}$$
$$p_\perp(\pi) > 1.0\,\text{GeV}$$
$$p_\perp(D^0) > 3.0\,\text{GeV}$$

  - Vertexing cuts

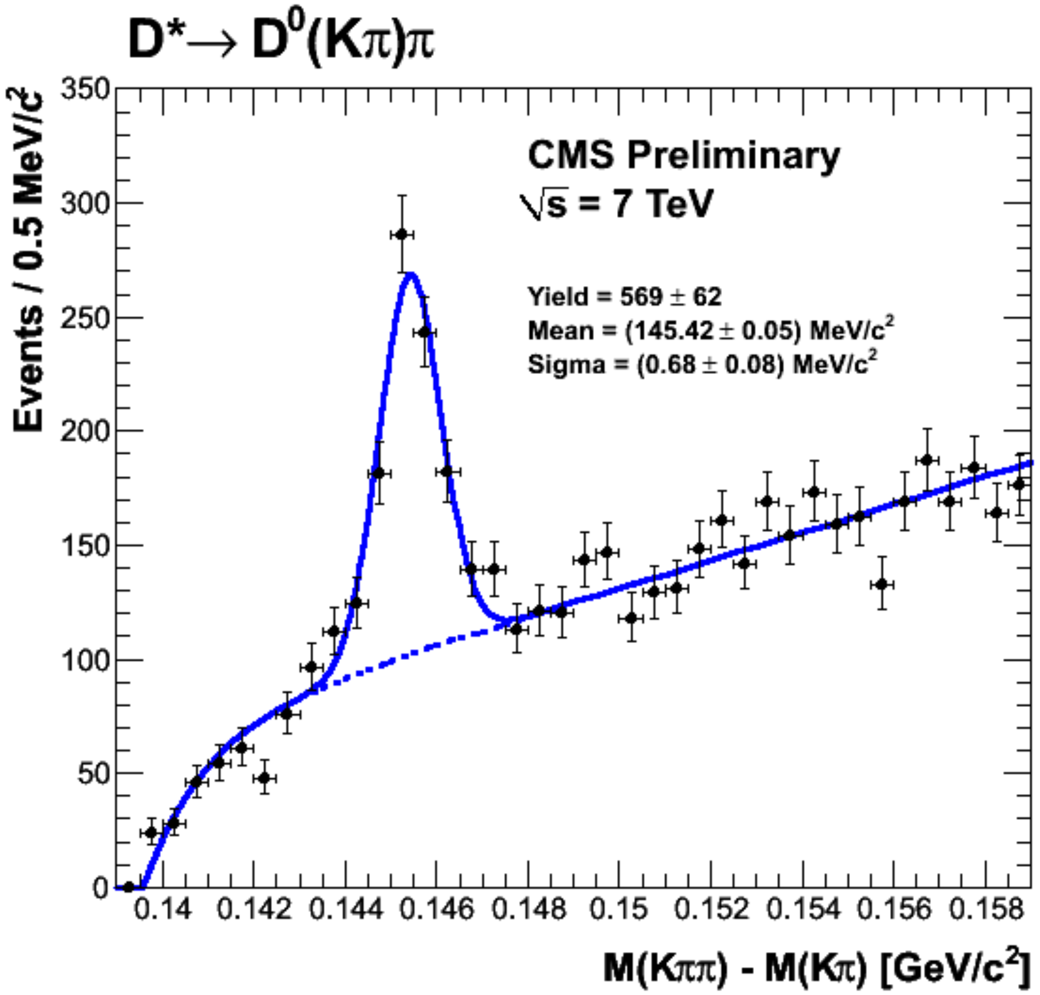
$$d(K,\pi) < 0.025\,\text{cm}$$
$$\chi^2 < 4.5$$
$$3 < l_{xy}/\sigma(l_{xy}) < 20$$
$$\sigma(l_{xy}) < 0.03\,\text{cm}$$

  - D^0 momentum vs. PV-SV direction

$$\angle(\vec{p}_{D^0}, \overline{PV:SV}) < 0.1$$



- MC expectations
  - Peak: 1.863 ± 0.002 GeV
  - Width: 0.014 ± 0.002 GeV



- Data: ~37M events
- Reconstruct $D^* \rightarrow D^0\pi_S$, $D^0 \rightarrow K\pi$
  - Kinematic selection:
    - p_T > 600 MeV/c for K and π
    - p_T > 250 MeV/c for π_S
    - p_T > 5.0 GeV/c for D^*
      - Select D^* candidate with highest p_T if there is more than one in an event
  - Track quality:
    - $N_{hit} > 5$ (except for π_S)
    - χ^2 / ndof < 2.5
    - $|d_{xy}|$ < 1mm; $|\Delta z|$ < 1cm
  - Mass windows
    - $|M(K\pi) - PDG| < 25$ MeV/c^2
  - Unbinned extended ML fit (RooFit)
  - Signal = Gaussian
  - Bkg = threshold function for ΔM and quadratic for $M(K\pi)$