Dlaczego warto szukać czegoś, co może nie istnieć?

→ **motywacja**
→ **wyniki**
→ **wybór**

Piotr Zalewski

National Centre for Nuclear Research

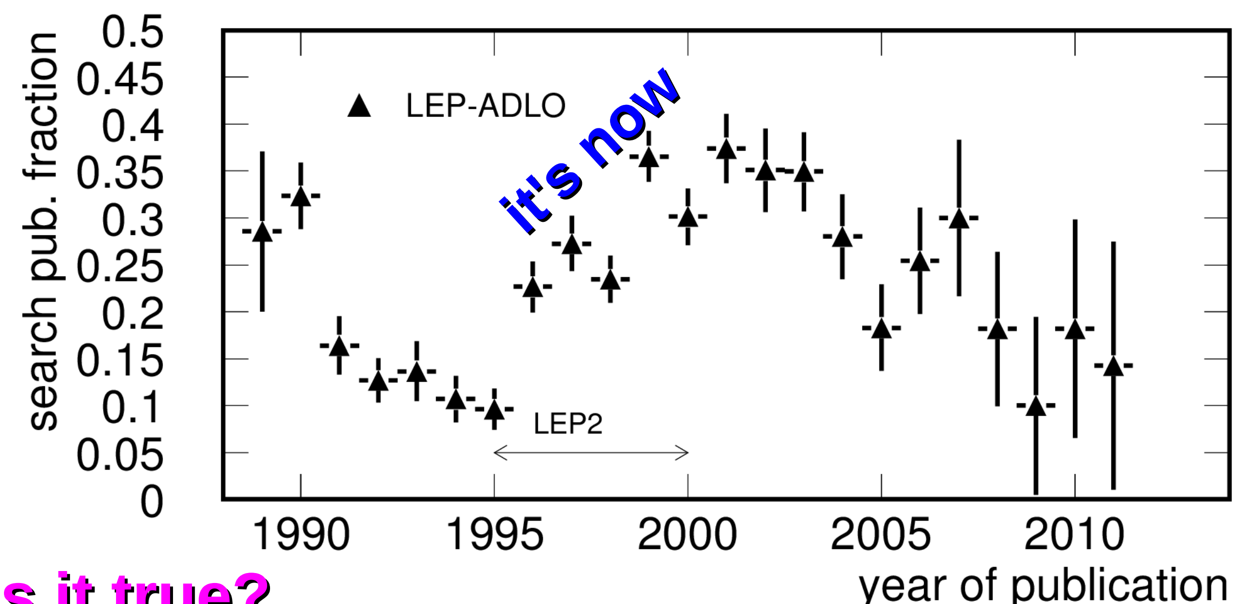
NCN grant N N202 167440

Warszawa 12/14/2013

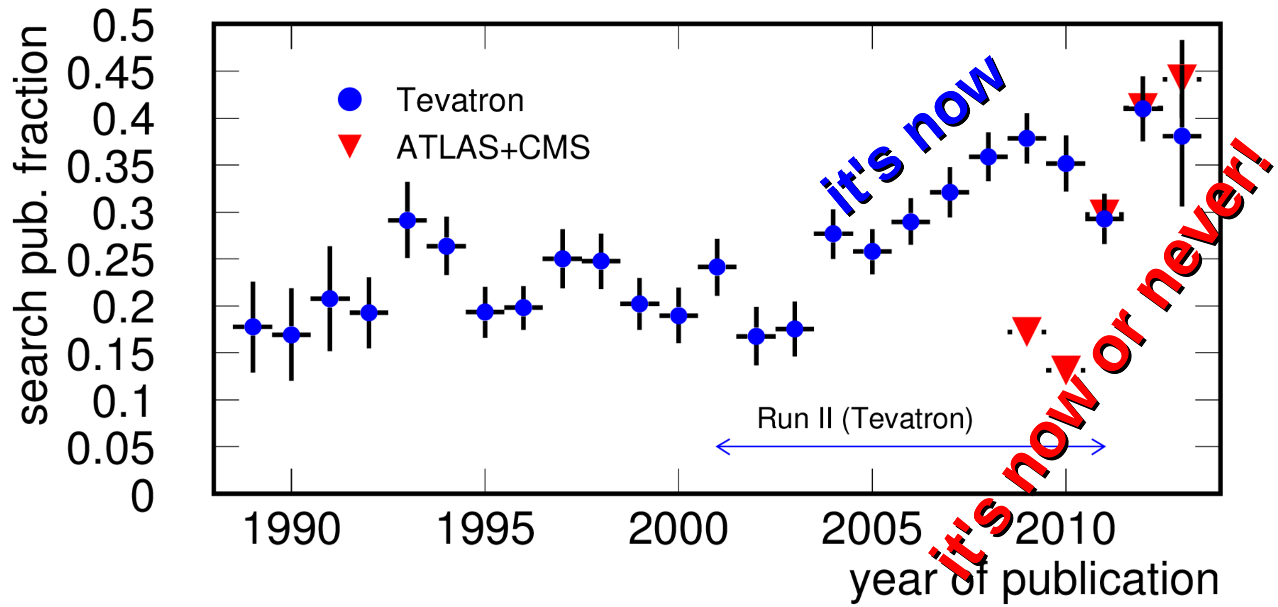
”search” fraction

Piotr Zalewski
NCBJ Warsaw

The fraction of publications with word ”search” in the title is growing when new energy-luminosity region is probed.



Is it true?

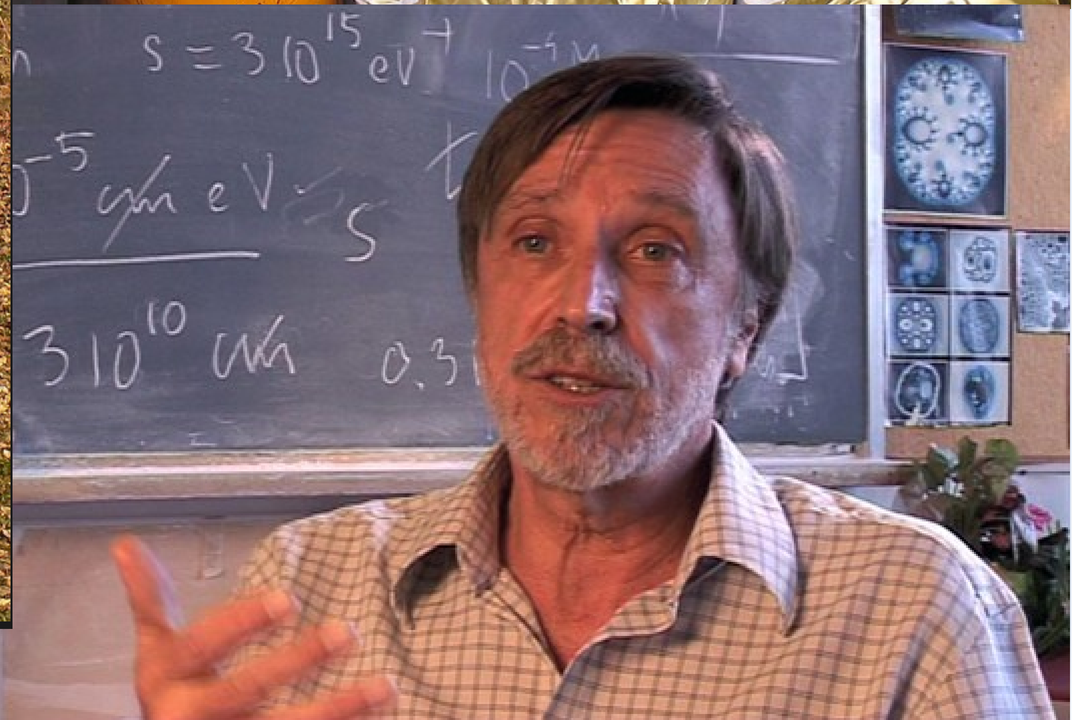


If we will not find something beyond standard model in the LHC should we hope for any continuation of the highest energy collider program?


BOULANGERIE


theory
experiment
discovery
€ 22,00
€39.80


the peasant
a pig
the truffles?



beyond standard model

Piotr Zalewski
NCBJ Warsaw

- extra structure
- extra particles
- extra interactions
- extra symmetry

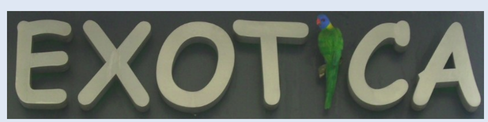
Summary (a kind of)

We have searched for (almost) everything.

We have found nothing.

We will keep searching.

SUSY



B2G

Topological searches for:
jets, leptons, photons,
and transverse momentum imbalance

International Center of Interdisciplinary Science Education

Jean Tran Thanh Van

2013 sessions in

La Thuile, Aosta valley, Italy:

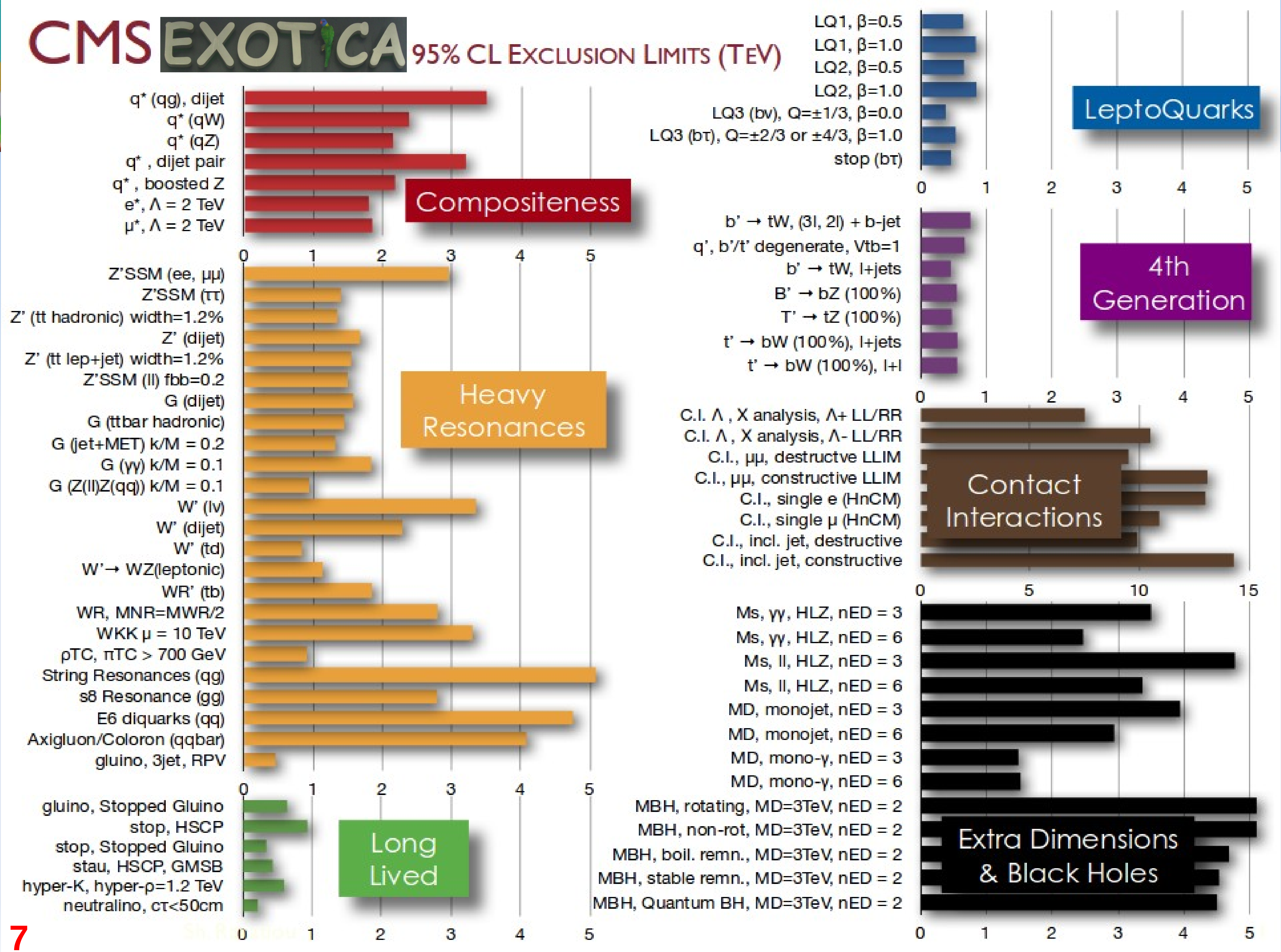
March 2nd - 9th, 2013

EW Interactions and Unified Theories

March 9th - 16th, 2013

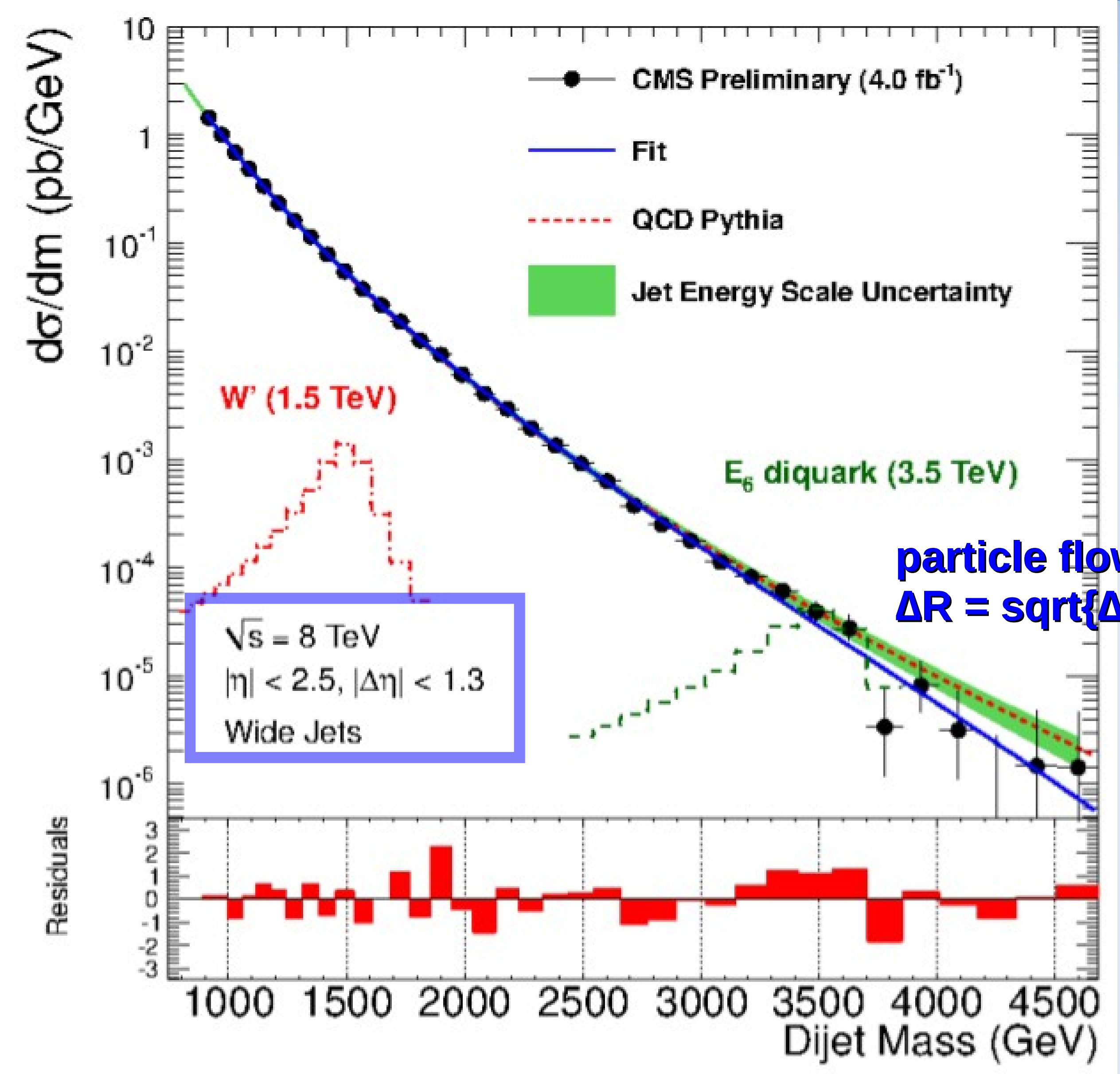
QCD and High Energy Interactions

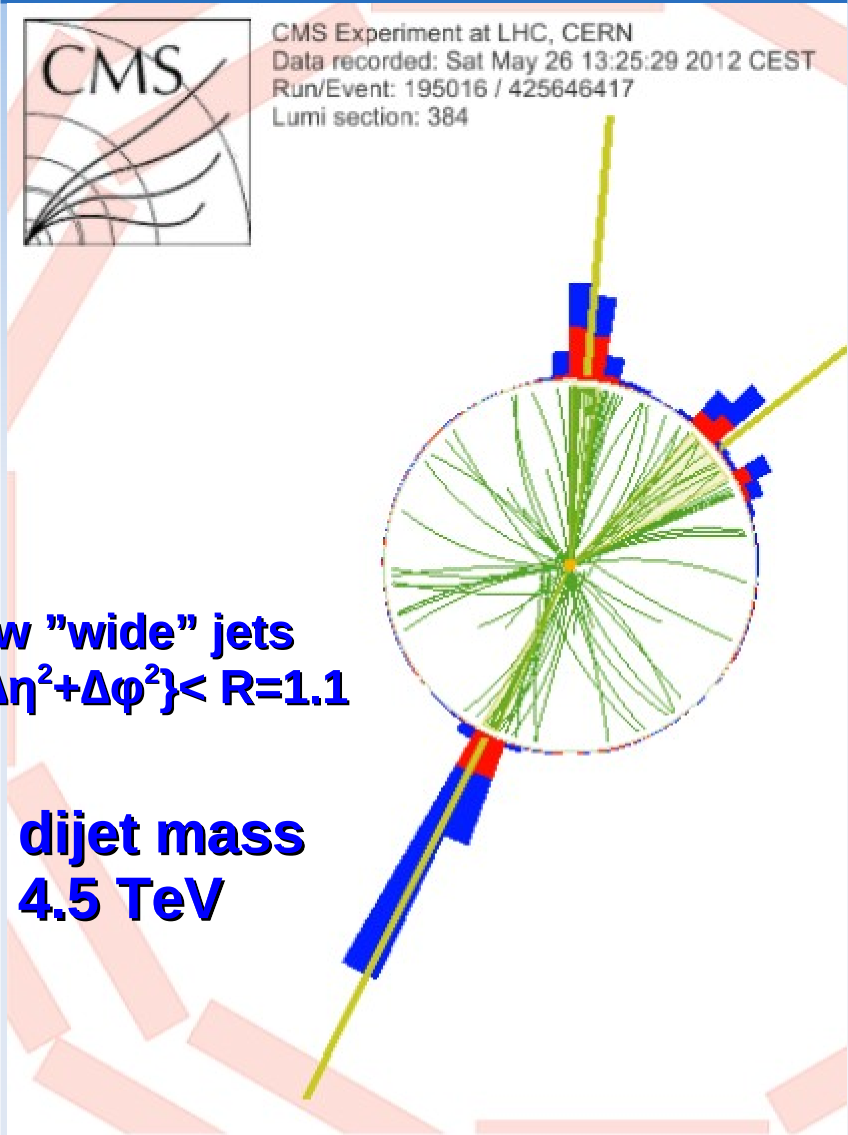
Very High Energy Phenomena in the Universe


CMS EXOTICA
95% CL Exclusion Limits (TeV)
Compositeness
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
Heavy Resonances
Z'SSM (ee, μμ)
Z'SSM (ττ)
Z' (tt hadronic) width=1.2%
Z' (dijet)
Z' (tt lep+jet) width=1.2%
Z'SSM (ll) fbb=0.2
G (dijet)
G (ttbar hadronic)
G (jet+MET) k/M = 0.2
G (γγ) k/M = 0.1
G (Z(ll)Z(qq)) k/M = 0.1
W' (lν)
W' (dijet)
W' (td)
W'→ WZ(leptonic)
WR' (tb)
WR, MNR=MWR/2
WKK μ = 10 TeV
ρTC, πTC > 700 GeV
String Resonances (qg)
s8 Resonance (gg)
E6 diquarks (qq)
Axigluon/Coloron (qqbar)
gluino, 3jet, RPV
Long Lived
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
neutralino, cτ<50cm
LeptoQuarks
LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3 (bν), Q=±1/3, β=0.0
LQ3 (bτ), Q=±2/3 or ±4/3, β=1.0
stop (bτ)
4th Generation
b' → tW, (3l, 2l) + b-jet
q', b'/t' degenerate, Vtb=1
b' → tW, l+jets
B' → bZ (100%)
T' → tZ (100%)
t' → bW (100%), l+jets
t' → bW (100%), l+l
Contact Interactions
C.I. Λ , X analysis, Λ+ LL/RR
C.I. Λ , X analysis, Λ- LL/RR
C.I., μμ, destructve LLIM
C.I., μμ, constructive LLIM
C.I., single e (HnCM)
C.I., single μ (HnCM)
C.I., incl. jet, destructive
C.I., incl. jet, constructive
0 5 10 15
Extra Dimensions & Black Holes
Ms, γγ, HLZ, nED = 3
Ms, γγ, HLZ, nED = 6
Ms, ll, HLZ, nED = 3
Ms, ll, HLZ, nED = 6
MD, monojet, nED = 3
MD, monojet, nED = 6
MD, mono-γ, nED = 3
MD, mono-γ, nED = 6
MBH, rotating, MD=3TeV, nED = 2
MBH, non-rot, MD=3TeV, nED = 2
MBH, boil. remn., MD=3TeV, nED = 2
MBH, stable remn., MD=3TeV, nED = 2
MBH, Quantum BH, MD=3TeV, nED = 2
0 1 2 3 4 5

Search for Narrow Resonances using the Dijet Mass Spectrum in pp Collisions at sqrt(s) = 8 TeV CMS PAS EXO-12-016

Piotr Zalewski
NCBJ Warsaw





particle flow "wide" jets
$\Delta R = \sqrt{\Delta\eta^2+\Delta\varphi^2} < R=1.1$

dijet mass 4.5 TeV

Trigger: $H_T > 650$ GeV .or. dijet mass > 750 GeV & $|\Delta\eta_{jj}| < 1.5$

Search for Narrow Resonances using the Dijet Mass Spectrum in pp Collisions at sqrt(s) = 8 TeV CMS PAS EXO-12-016

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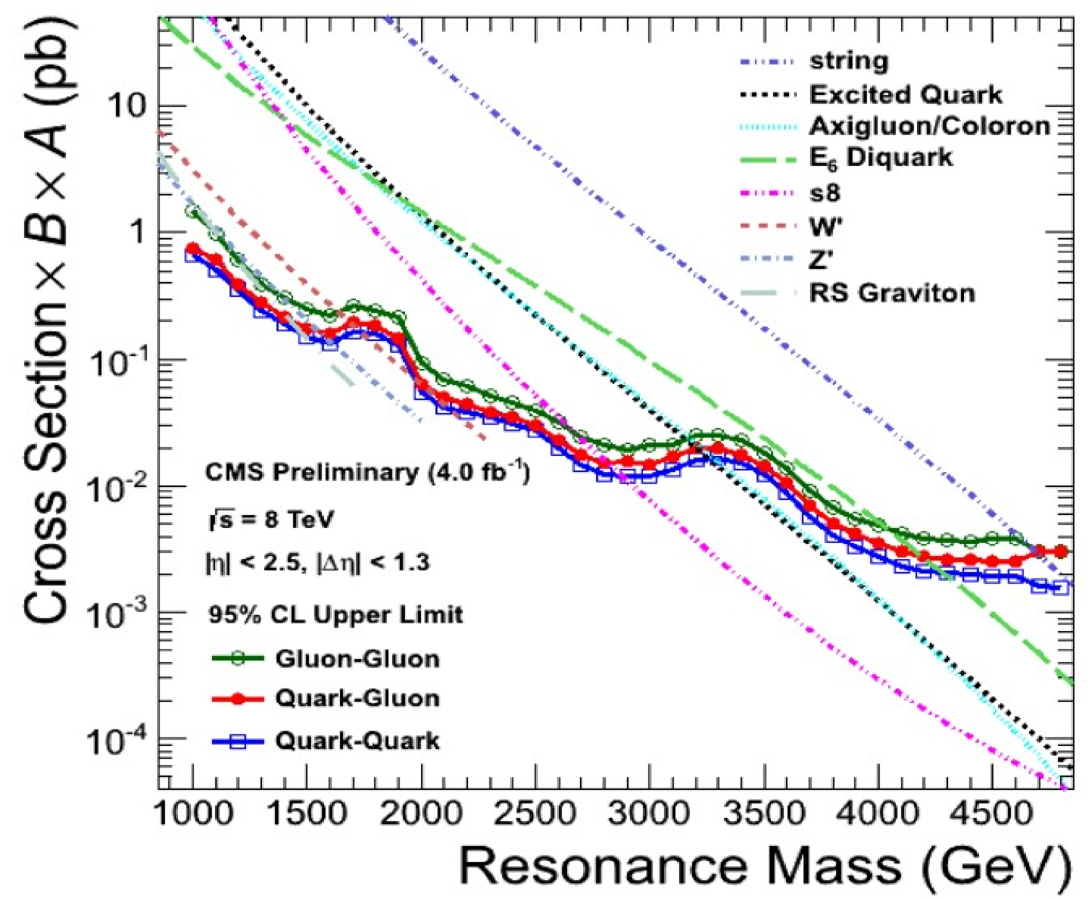
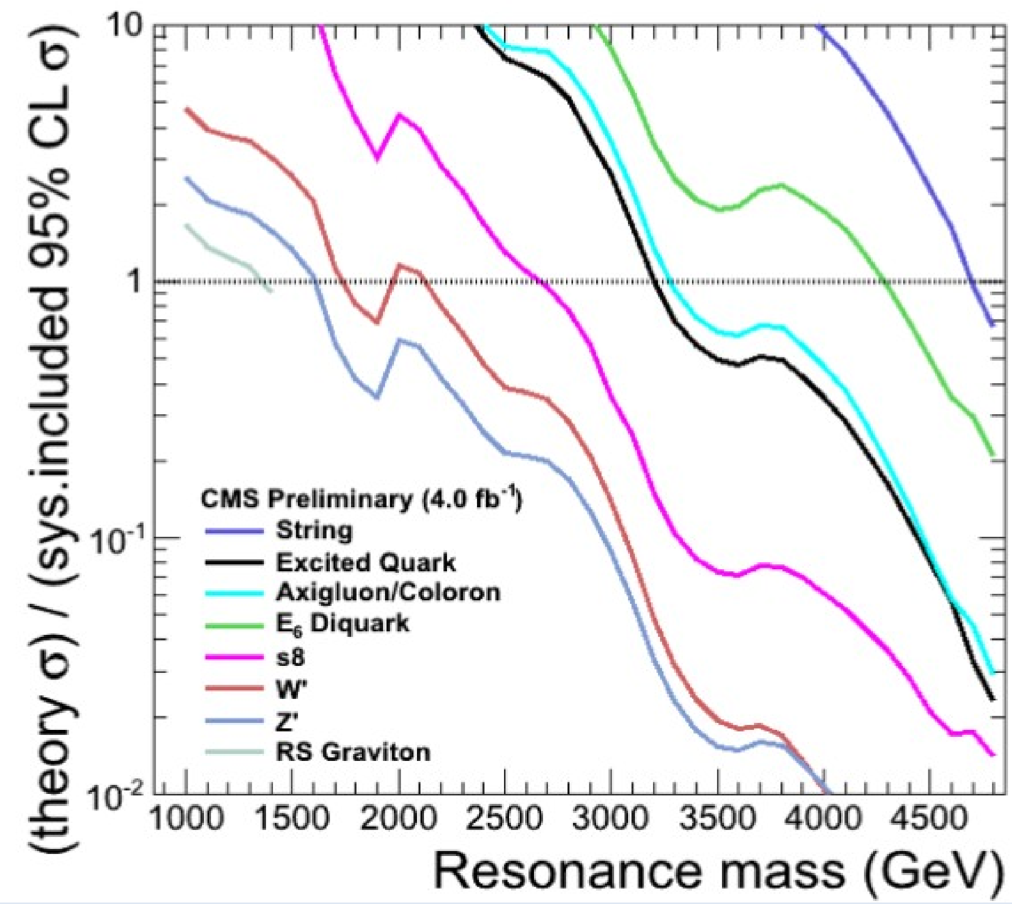




Generic upper limits on the product σ × B × A
It can be applied to any model of dijet resonance production.

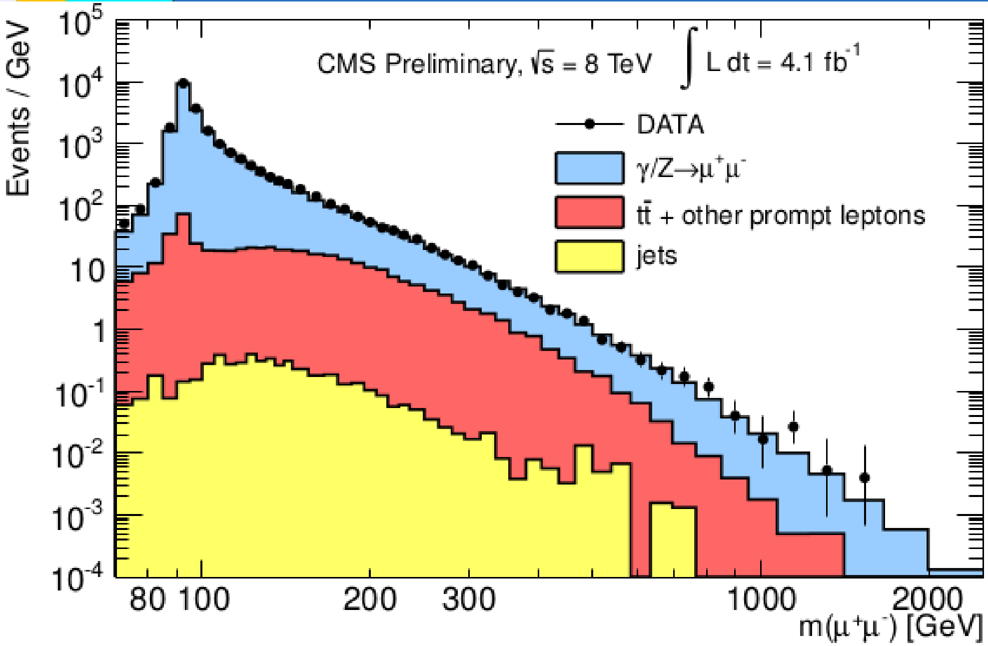
Specific lower limits on the mass of string resonances, excited quarks, axigluons, colorons, s8 resonances, E6 diquarks, W' and Z' bosons, and RS gravitons

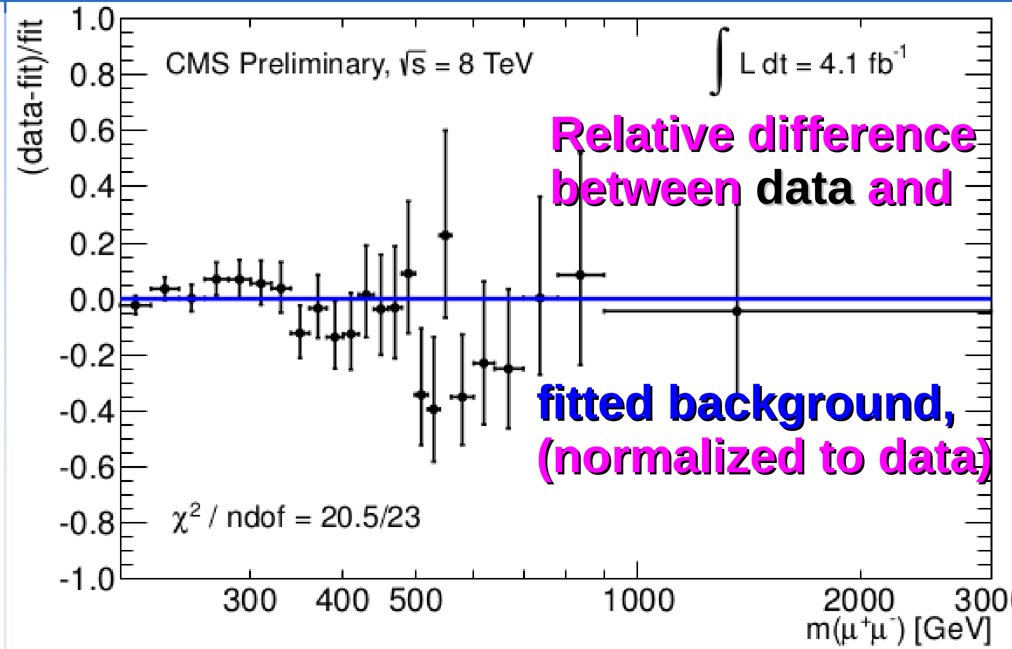
Many extend previous exclusions from the dijet mass search technique

Search for Resonances in Dilepton Mass Spectra in pp Collisions at sqrt(s)=8TeV

CMS PAS EXO-12-015

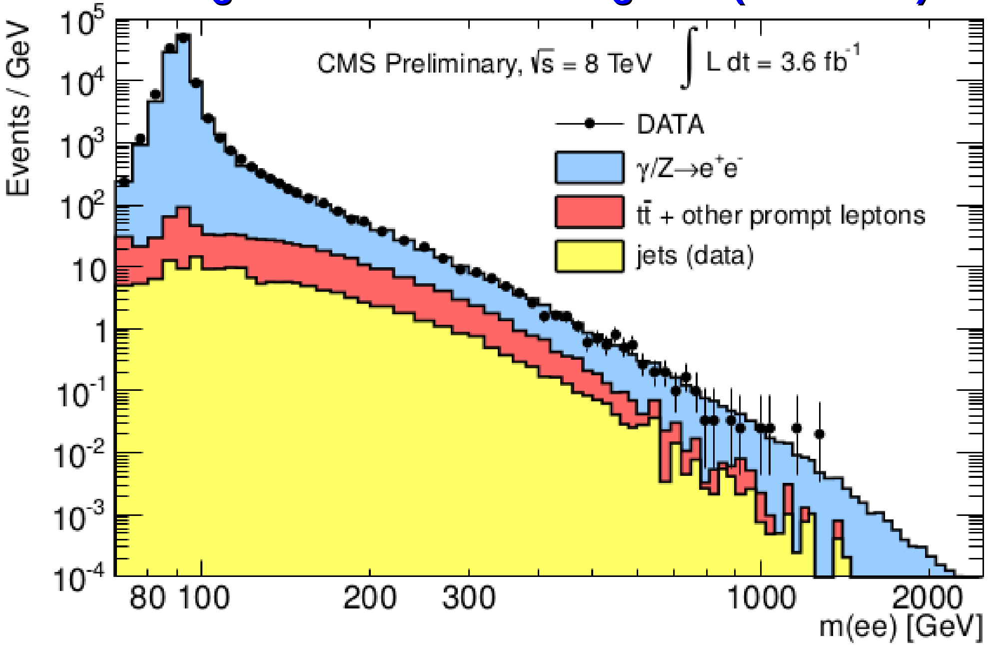
Piotr Zalewski
NCBJ Warsaw

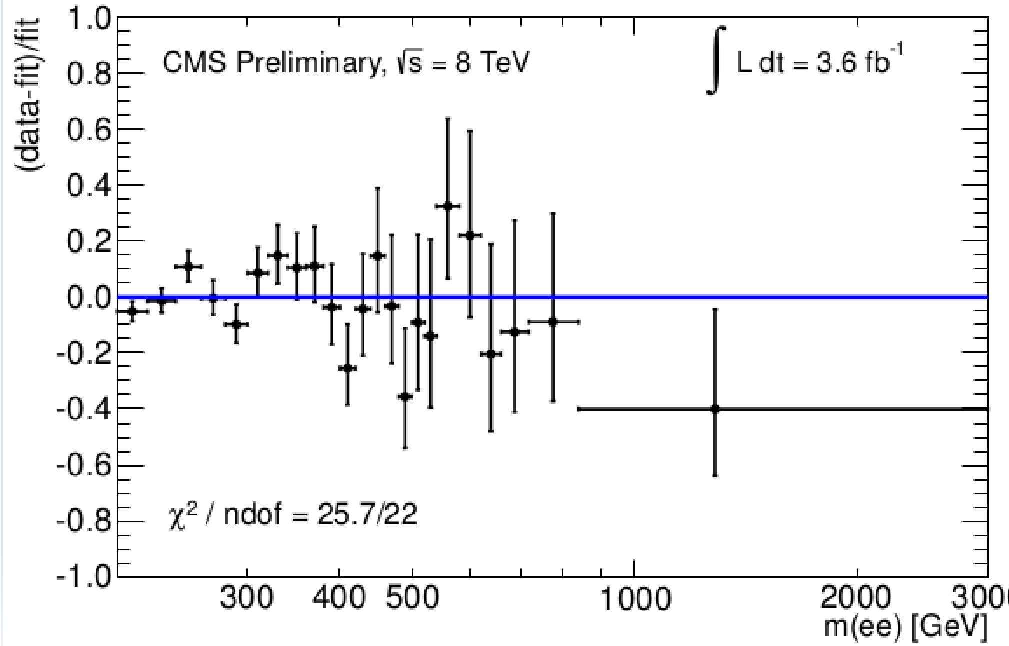




Relative difference between data and fitted background, (normalized to data)

Background estimated using data (next slide)

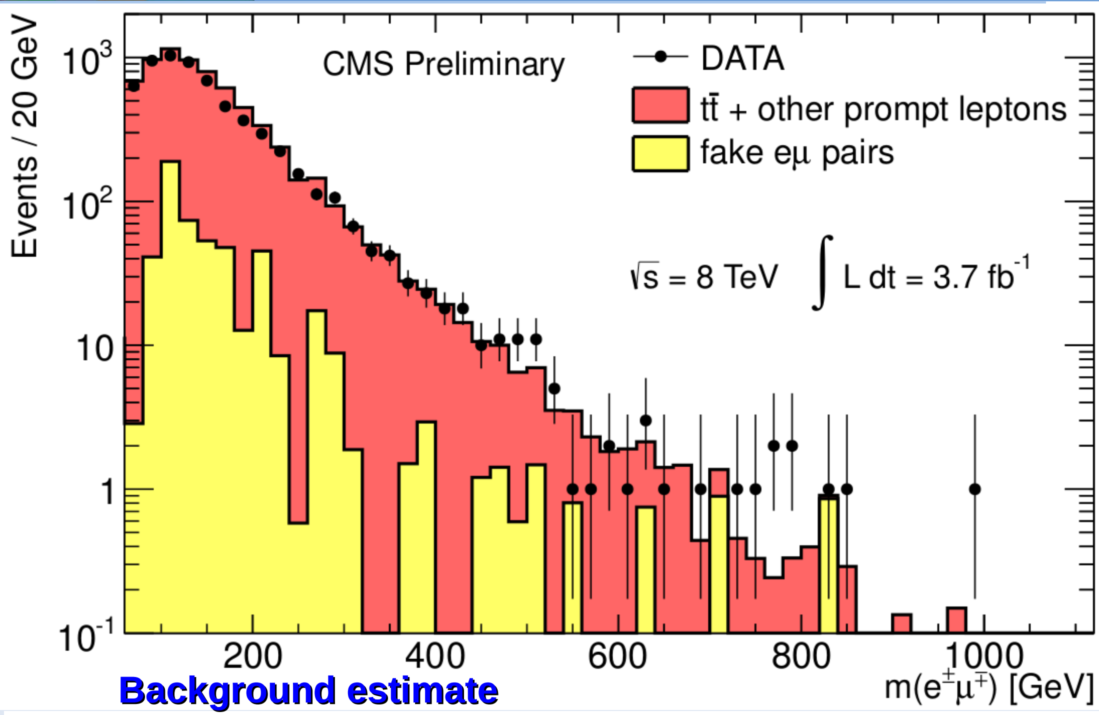




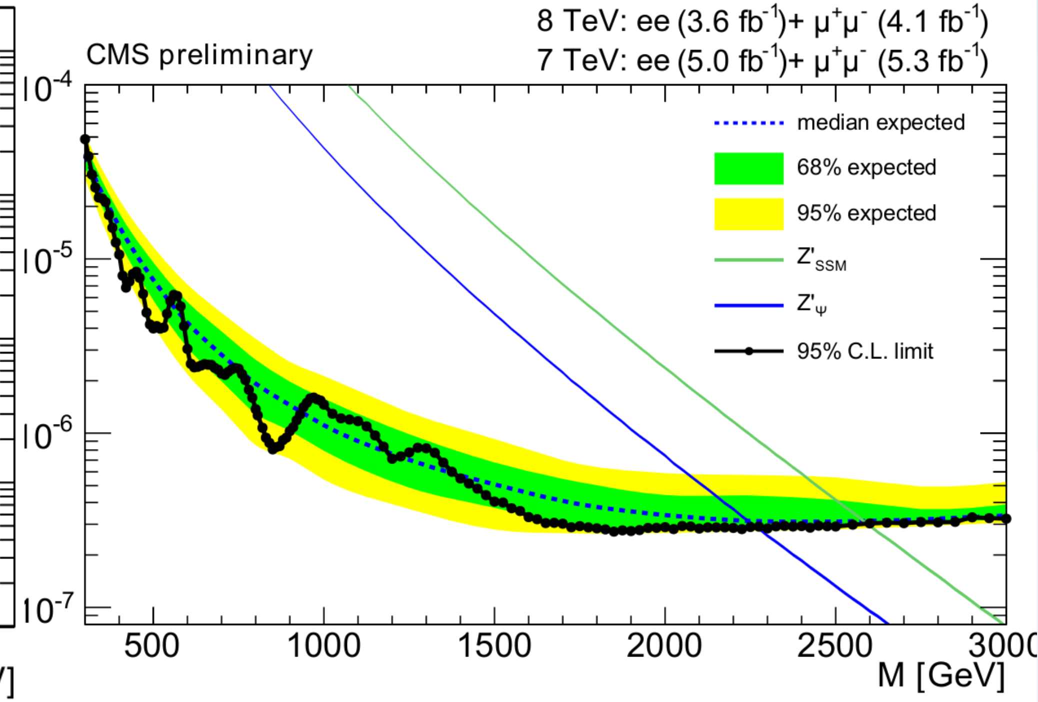
Search for Resonances in Dilepton Mass Spectra in pp Collisions at sqrt(s)=8TeV

CMS PAS EXO-12-015

Piotr Zalewski
NCBJ Warsaw



Background estimate



Source	Dimuon sample (120 – 200) GeV	Dimuon sample >200 GeV	Dielectron sample (120 – 200) GeV	Dielectron sample >200 GeV
Data	13831	3503	12030	2904
Total background	13007 ± 589	3627 ± 160	12241 ± 592	2968 ± 258
Z/γ^*	11703 ± 571	2919 ± 139	10657 ± 533	2198 ± 220
$t\bar{t}$ + others	1278 ± 146	698 ± 78	1222 ± 183	557 ± 84
jets	26 ± 3	10 ± 1	362 ± 181	213 ± 106

(Number of events)

Upper limits on x-sec * BR for new boson vs Z prod.

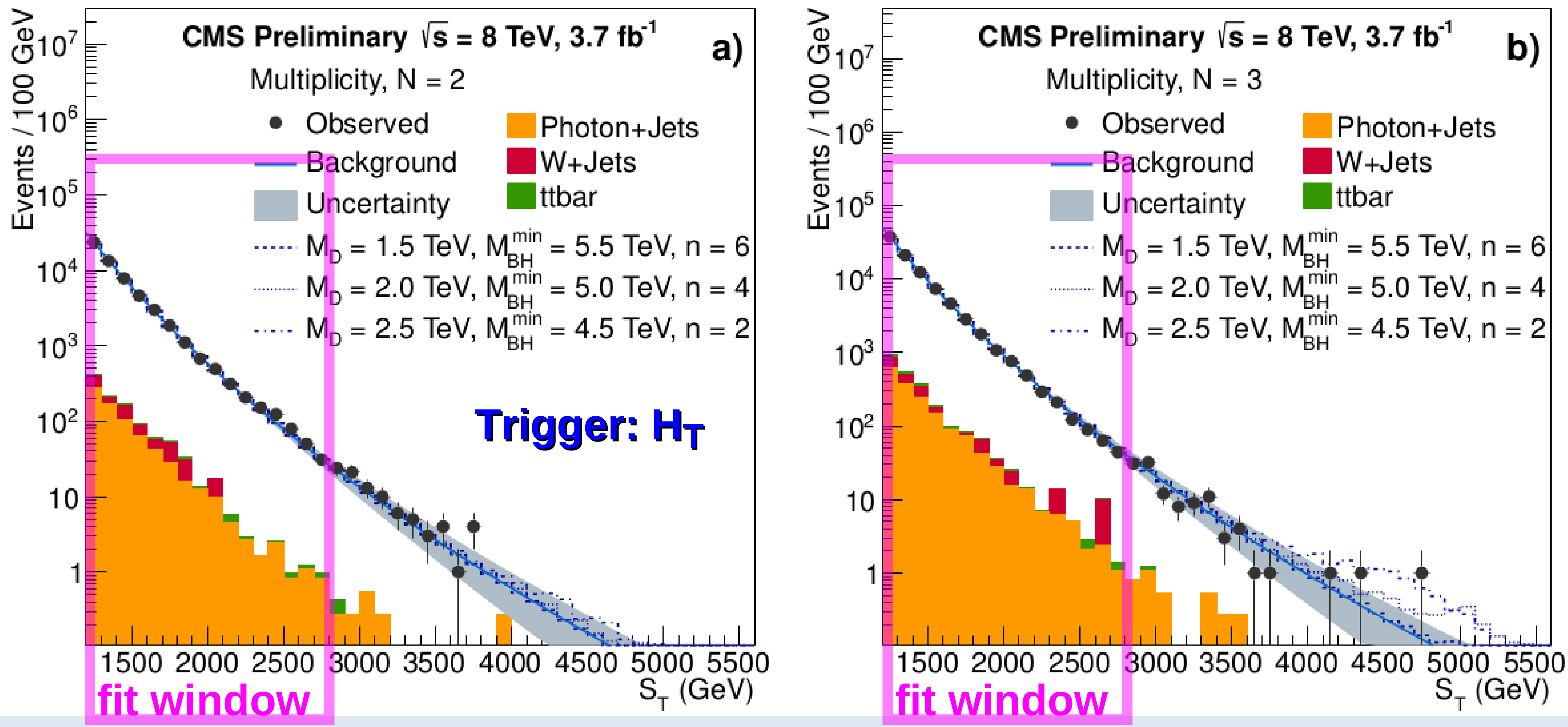
m(Z') > 2590 GeV;

superstring-inspired m(Z_ψ) > 2260 GeV

Search for microscopic black holes at sqrt(s) = 8 TeV with the CMS detector

CMS PAS EXO-12-009

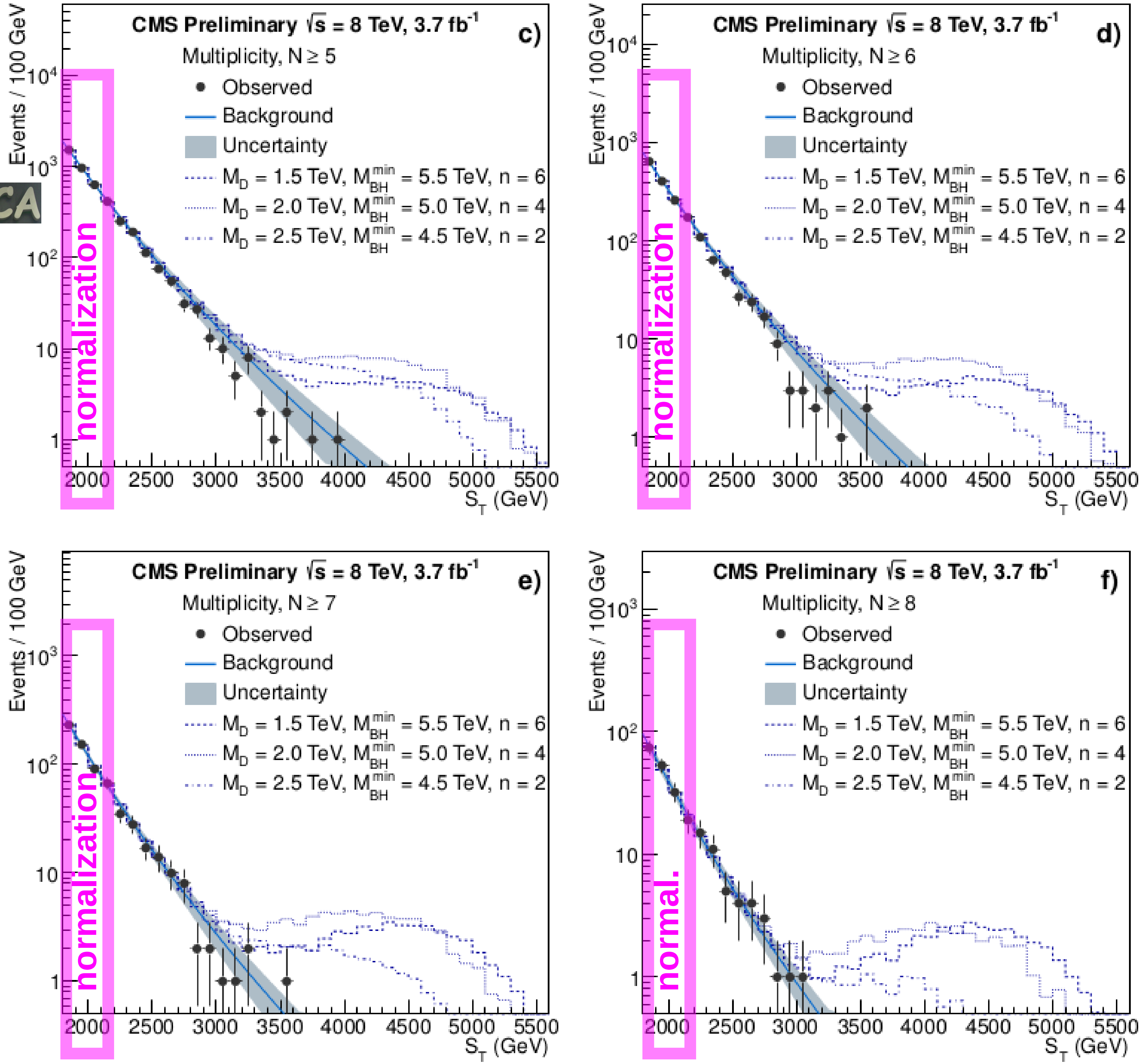
Piotr Zalewski
NCBJ Warsaw



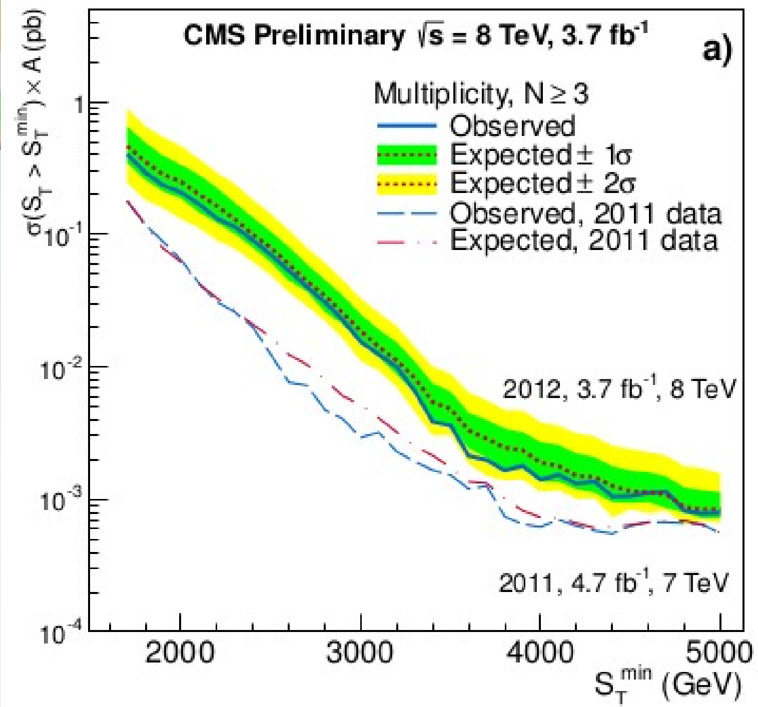
S_T → scalar sum of the transverse momenta of individual objects(with p_T > 50 GeV): jets, electrons, photons, muons and missing E_T

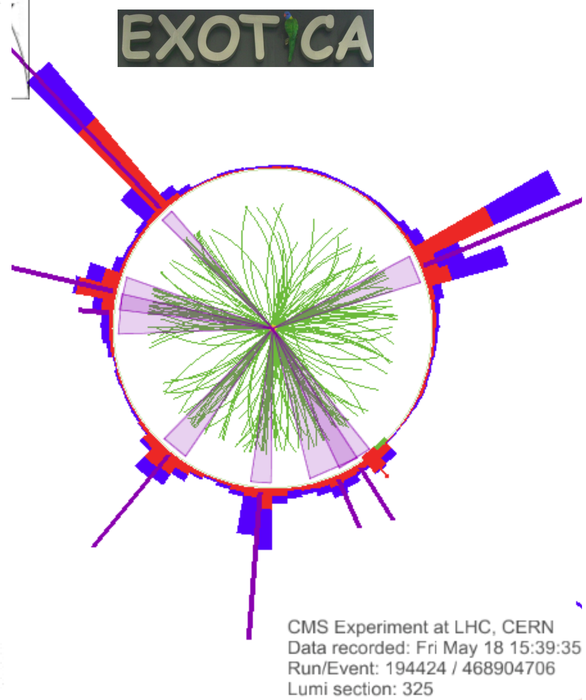
all such objects except missing E_T are counted towards the final-state multiplicity N

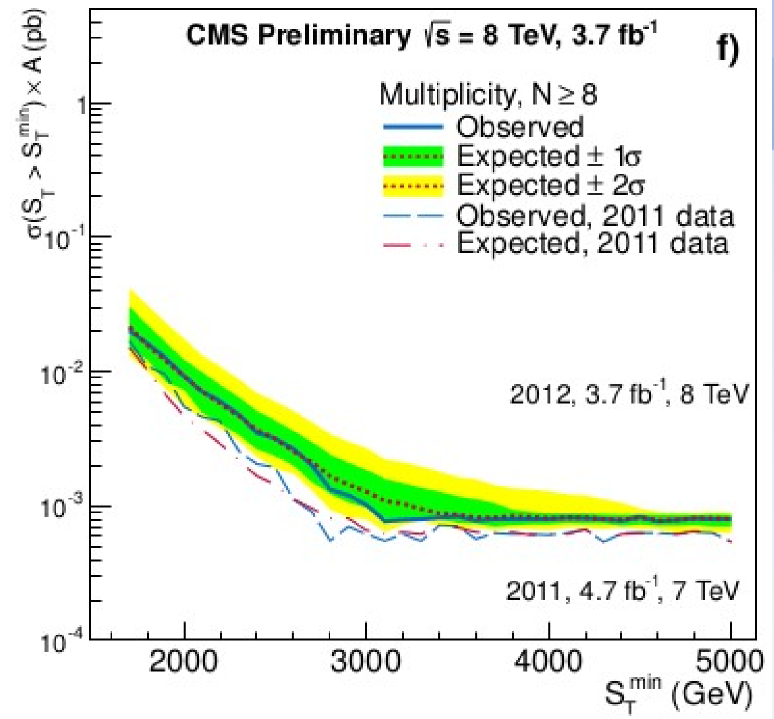
S_T multiplicity invariance method at work

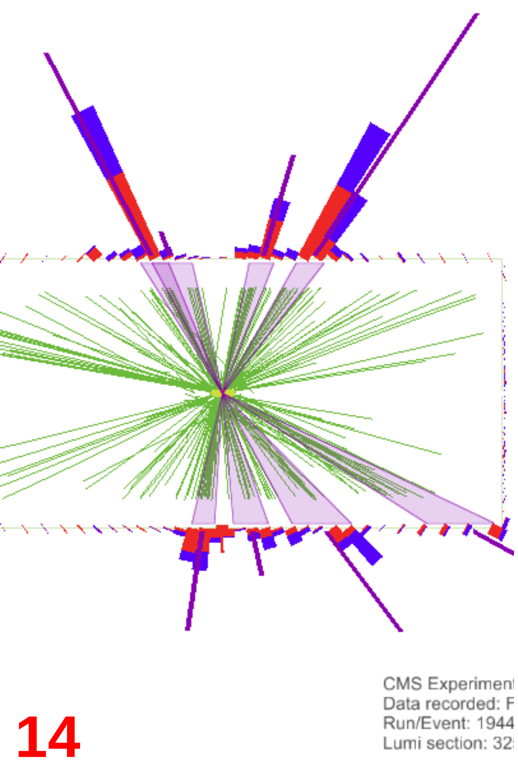


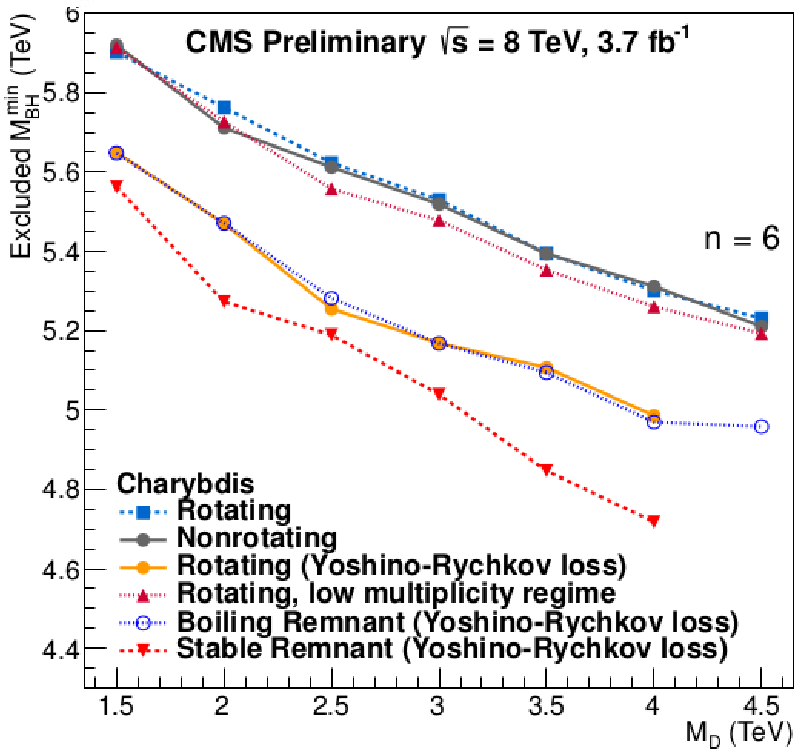
Search for black holes

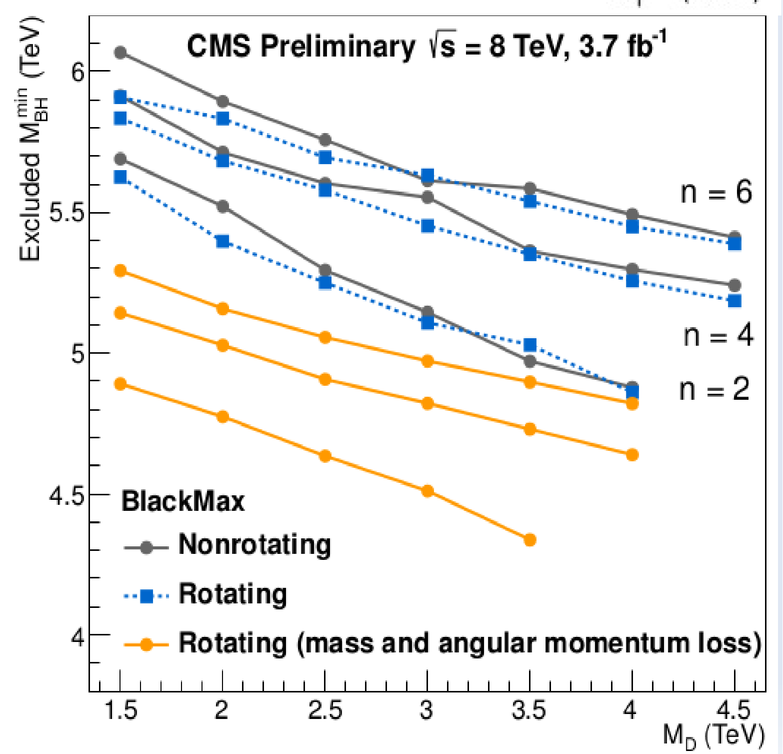




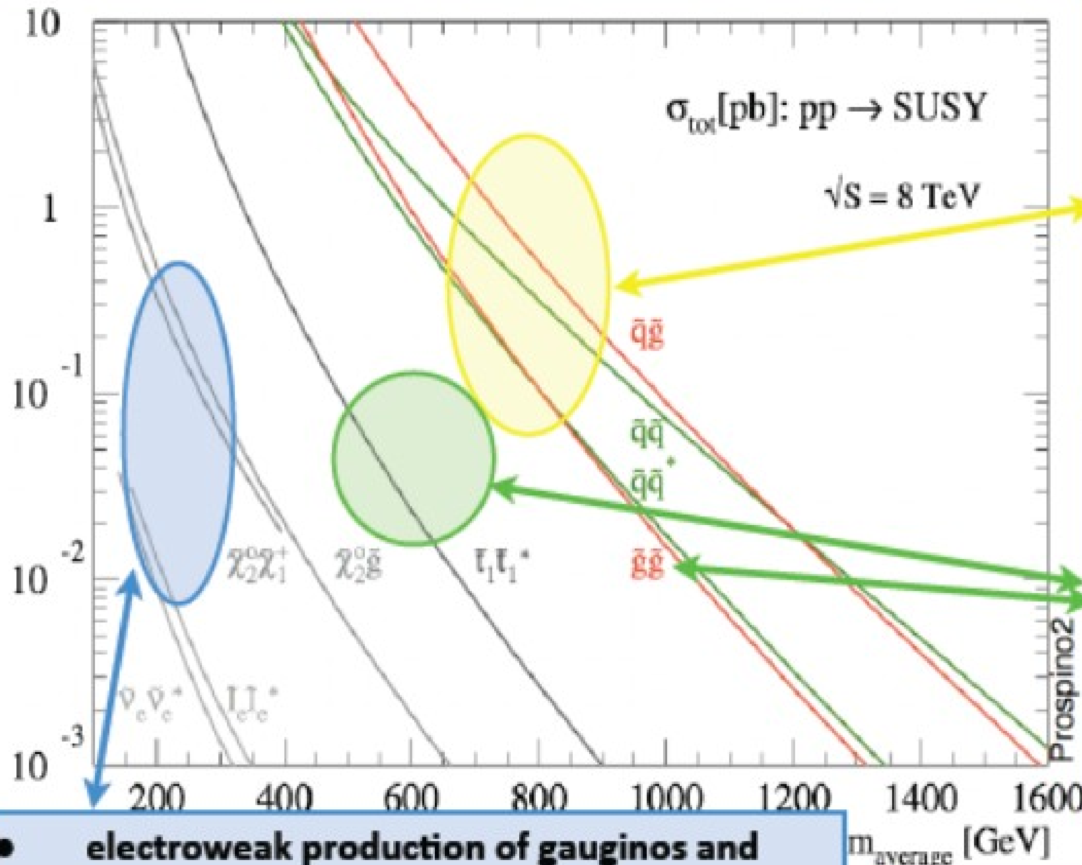








Supersymmetry searches



- **strong production of 1st and 2nd generation scalar quark and gluinos**
  - significant cross section up to more than 1 TeV
  - decay to jets and weakly interacting SUSY particle (LSP): jets and E_T^{miss}

- ***third generation scalar quarks (direct production or gluino-mediated)***
  - significant cross-section for direct production
  - large top background
  - key ingredient in **natural SUSY**

- **electroweak production of gauginos and leptons**
  - small cross section, less than WW, ZZ
  - doable with current integrated luminosity
  - jet veto, leptons, moderate missing E_T

- the SUSY searches at 7 TeV (2010-2011 data) indicate that squark of the first two generations and gluinos might be heavier than ~1 TeV

sbottom-bottom

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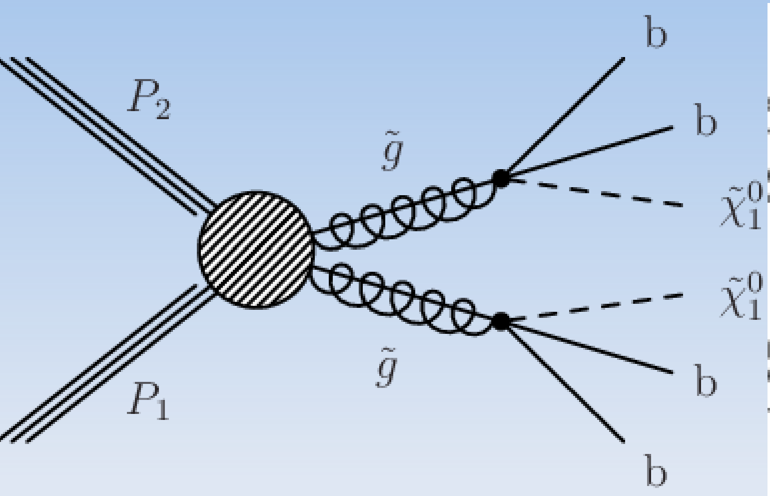
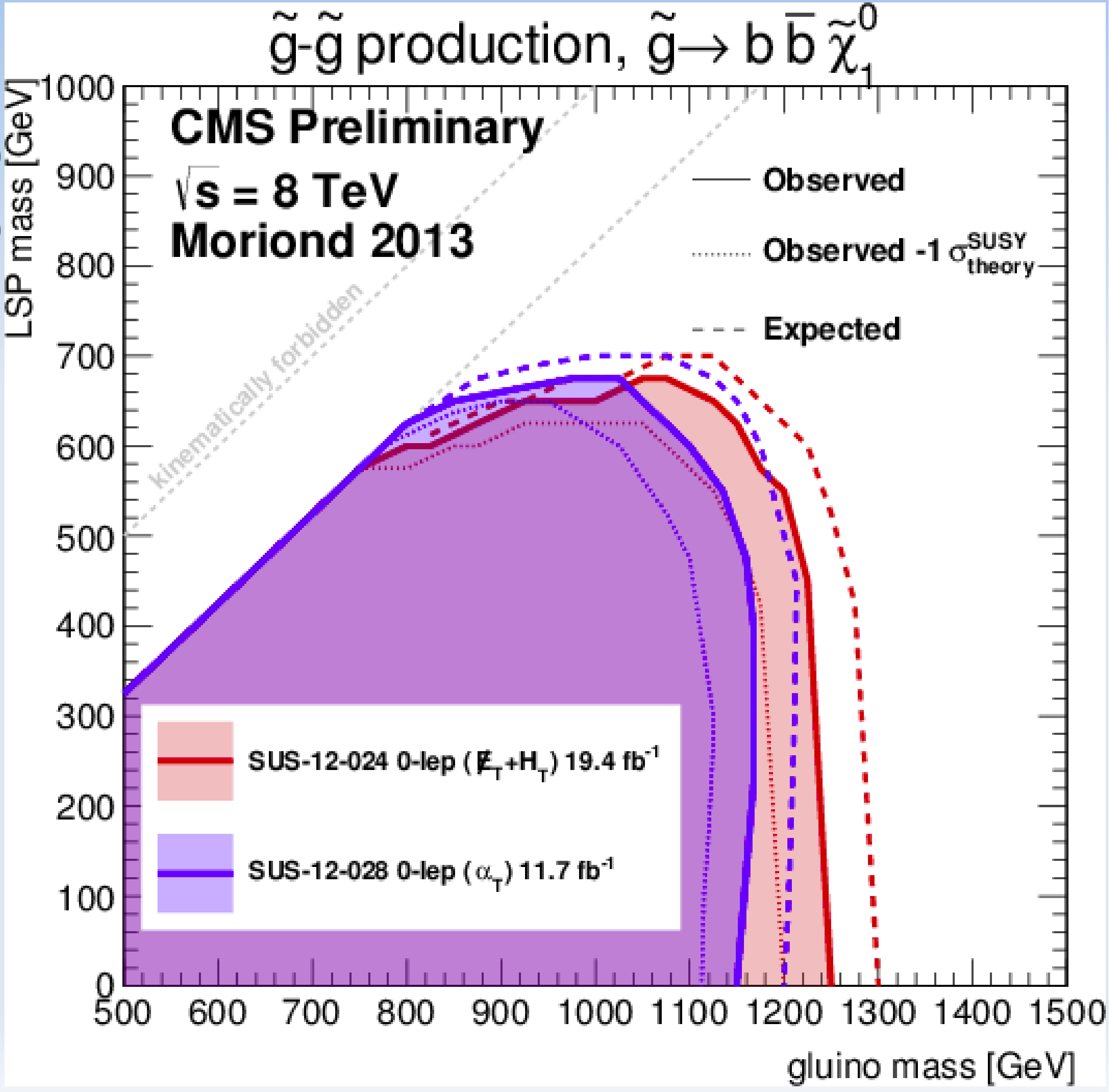
NCBJ Warsaw





stop-top

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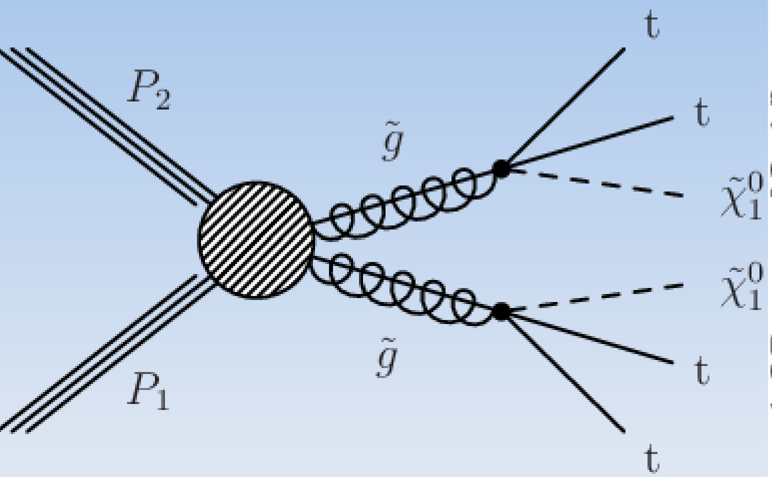
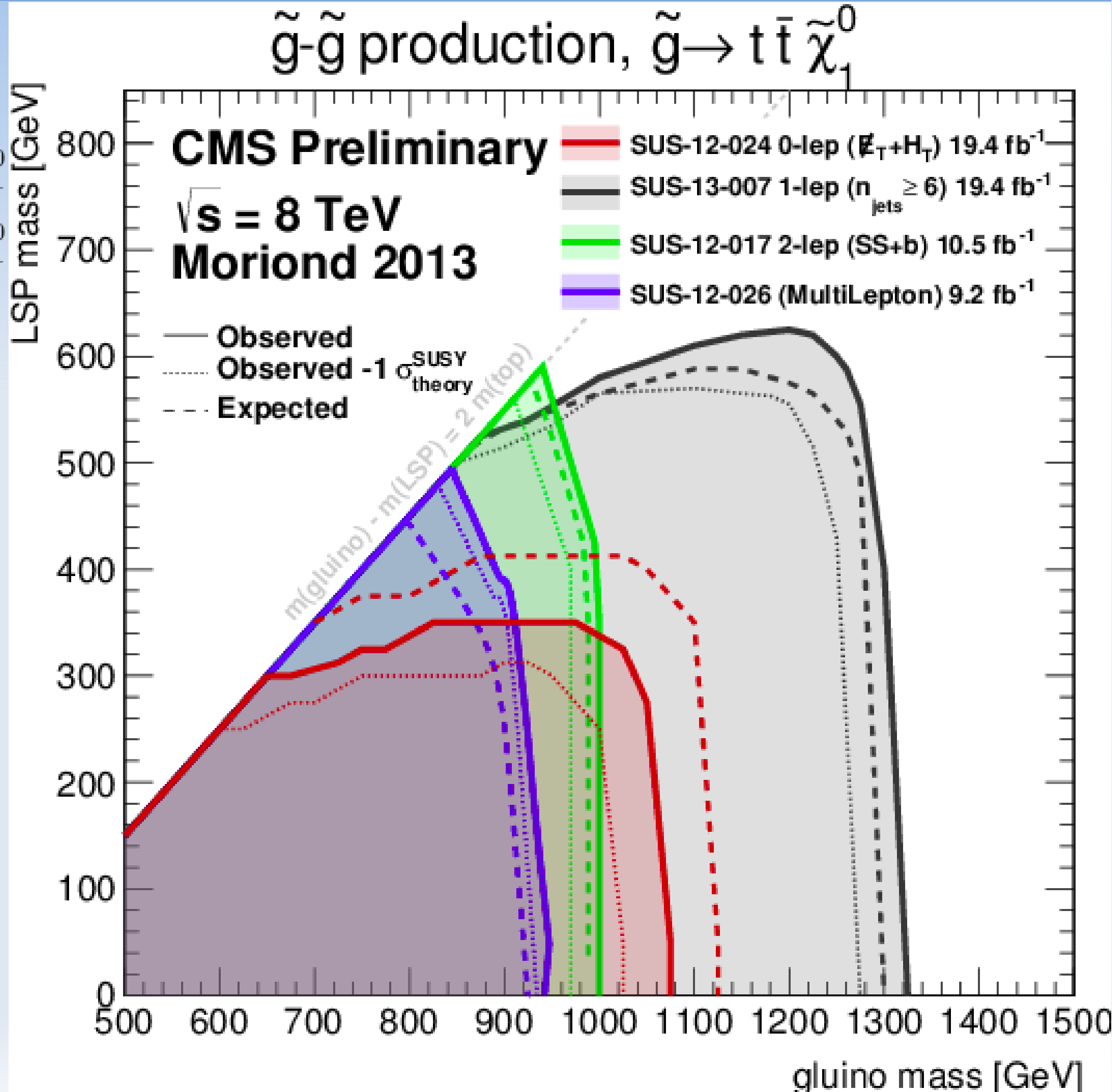
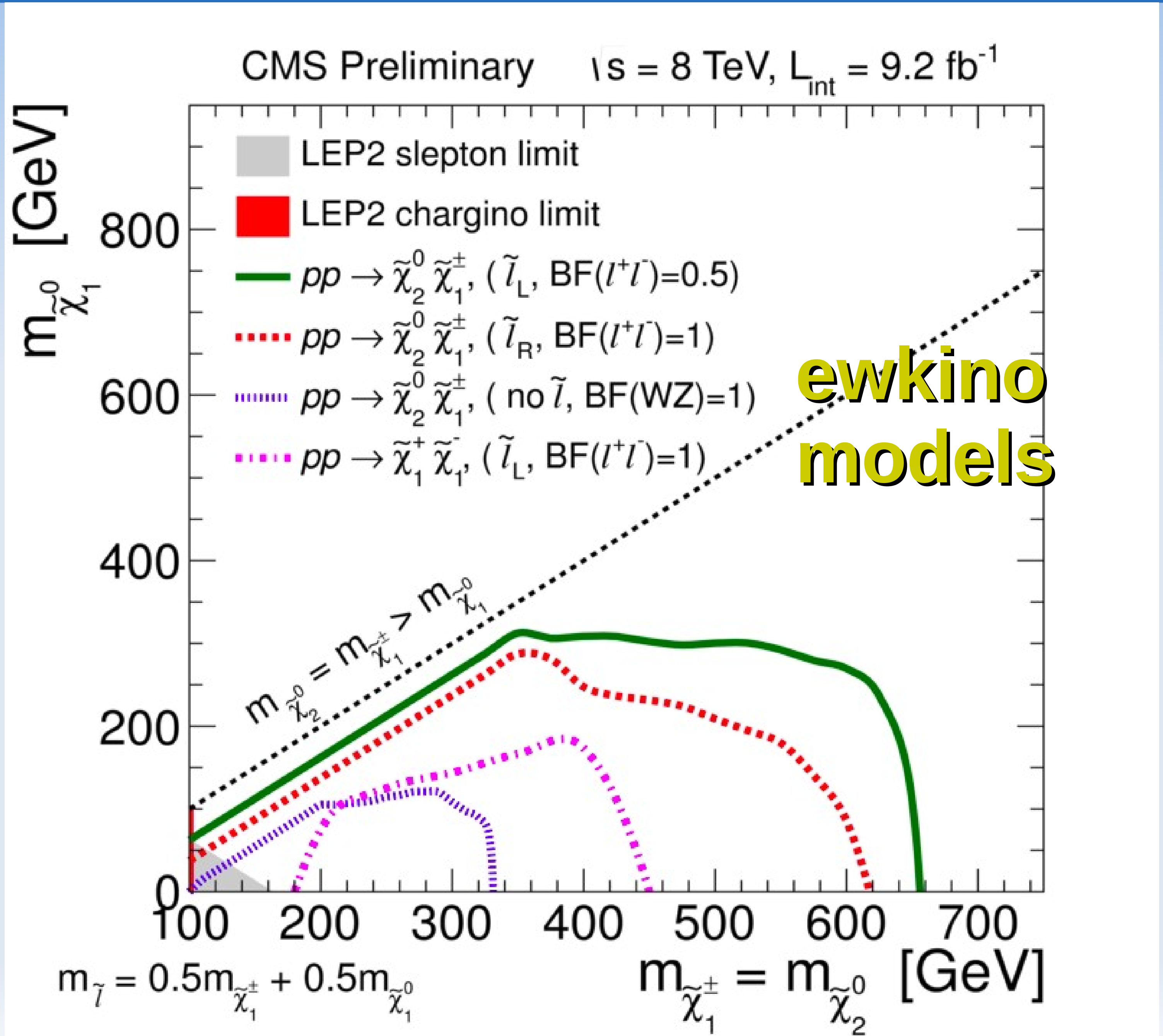
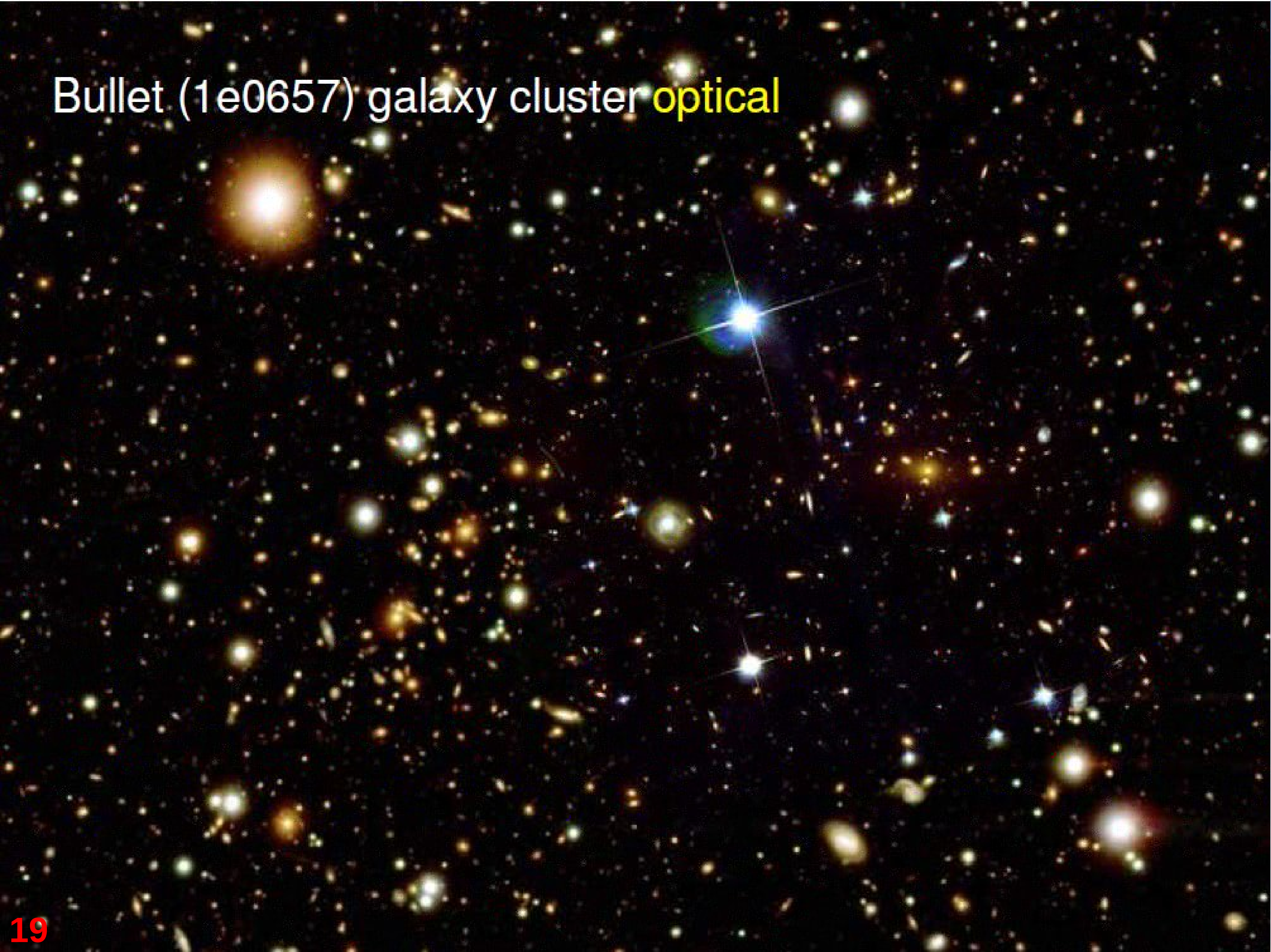
NCBJ Warsaw



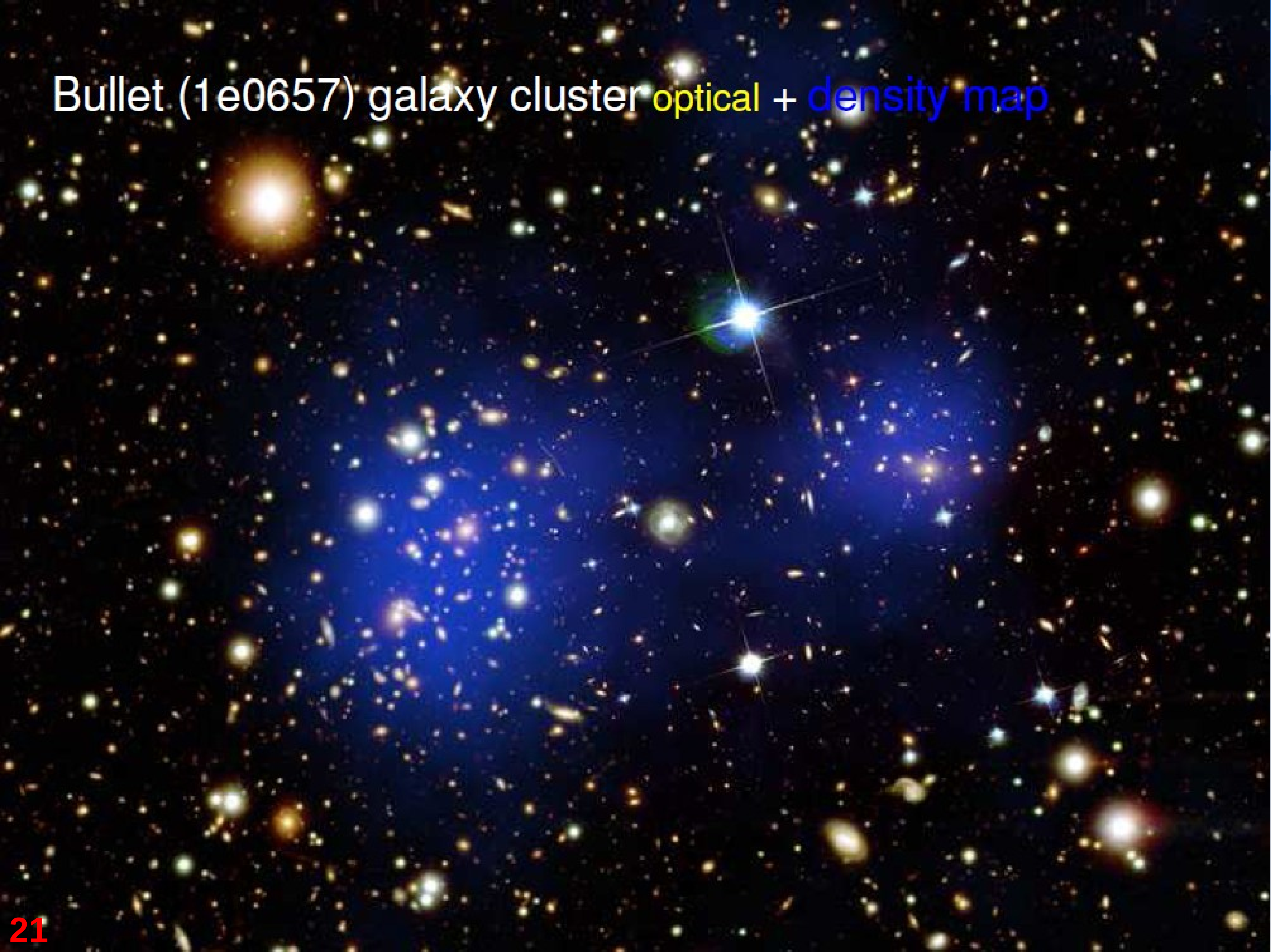


Search for electroweak production of charginos, neutralinos and sleptons using leptonic final states in pp collisions at √s = 8 TeV

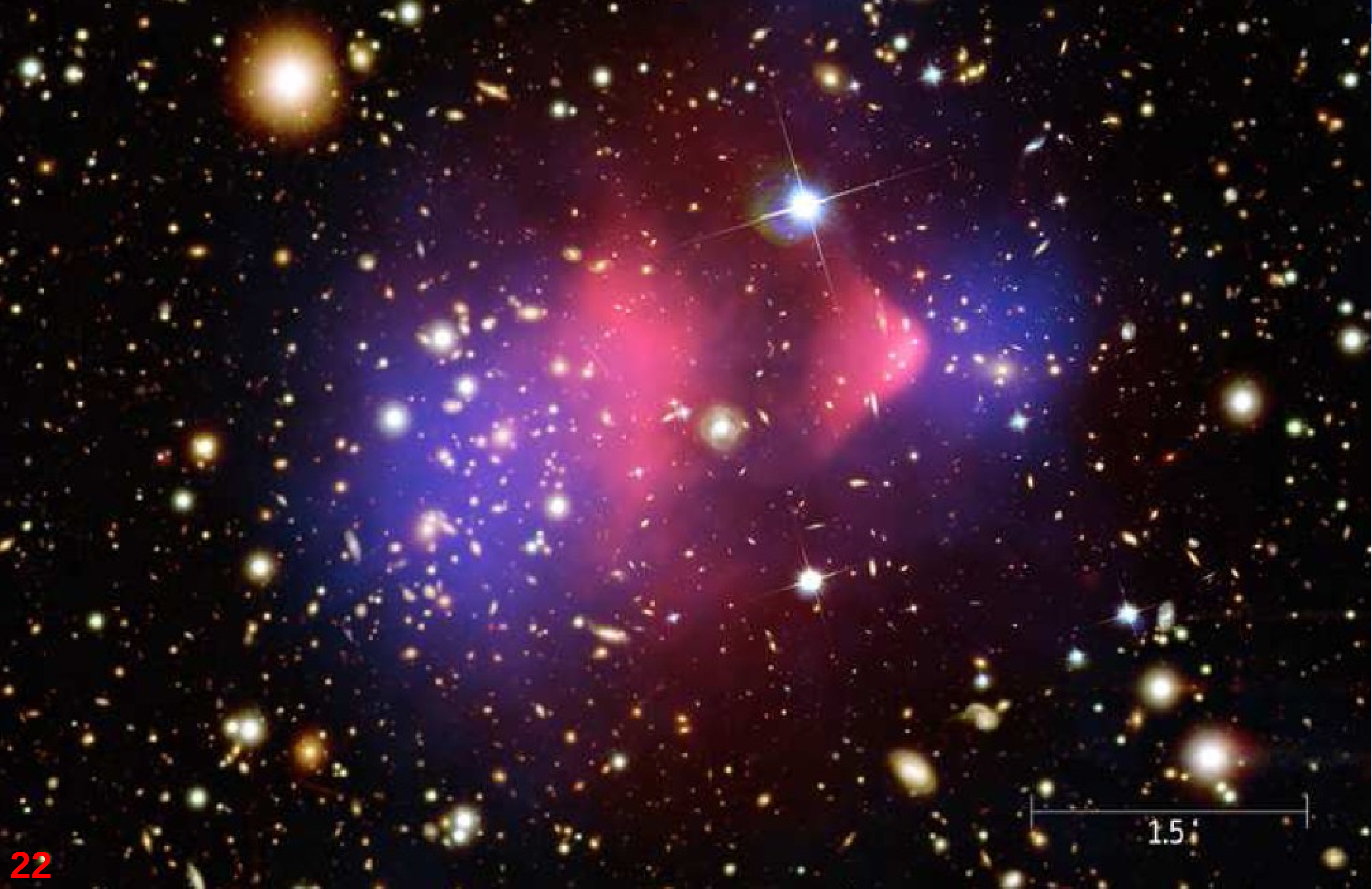



Bullet (1e0657) galaxy cluster optical

Bullet (1e0657) galaxy cluster optical + density map



Bullet (1e0657) galaxy cluster optical + X-ray + density map



Galaxy Cluster Abell 520

HST WFPC2 • CFHT • CXO

NASA, ESA, CFHT, CXO, M.J. Jee (University of California, Davis), and A. Mahdavi (San Francisco State University) STScI-PRC12-10a

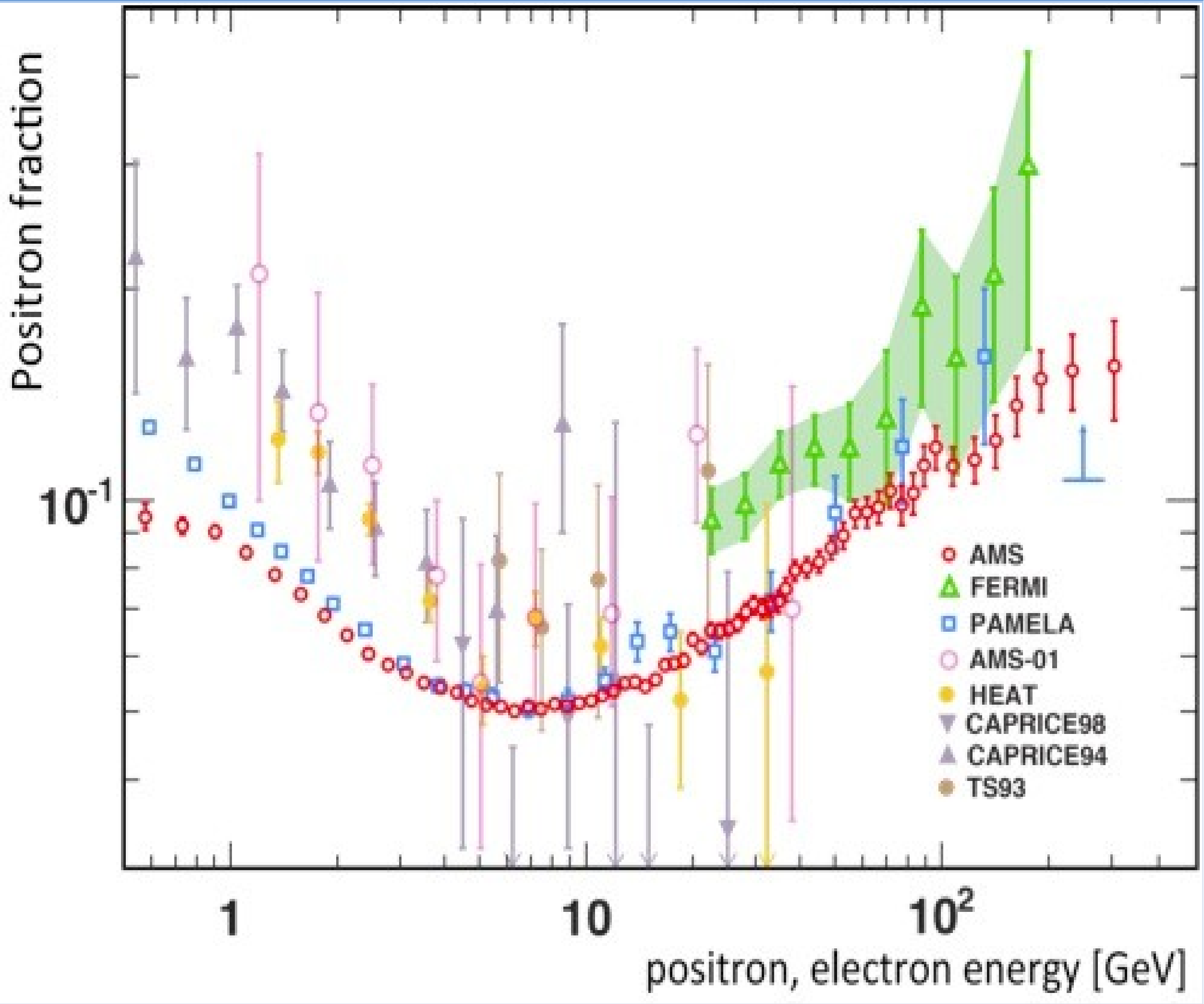
AMS-02 (3 April 2013)

**High quality result
from excellent experiment**

No discovery whatsoever

Dangerous publicity

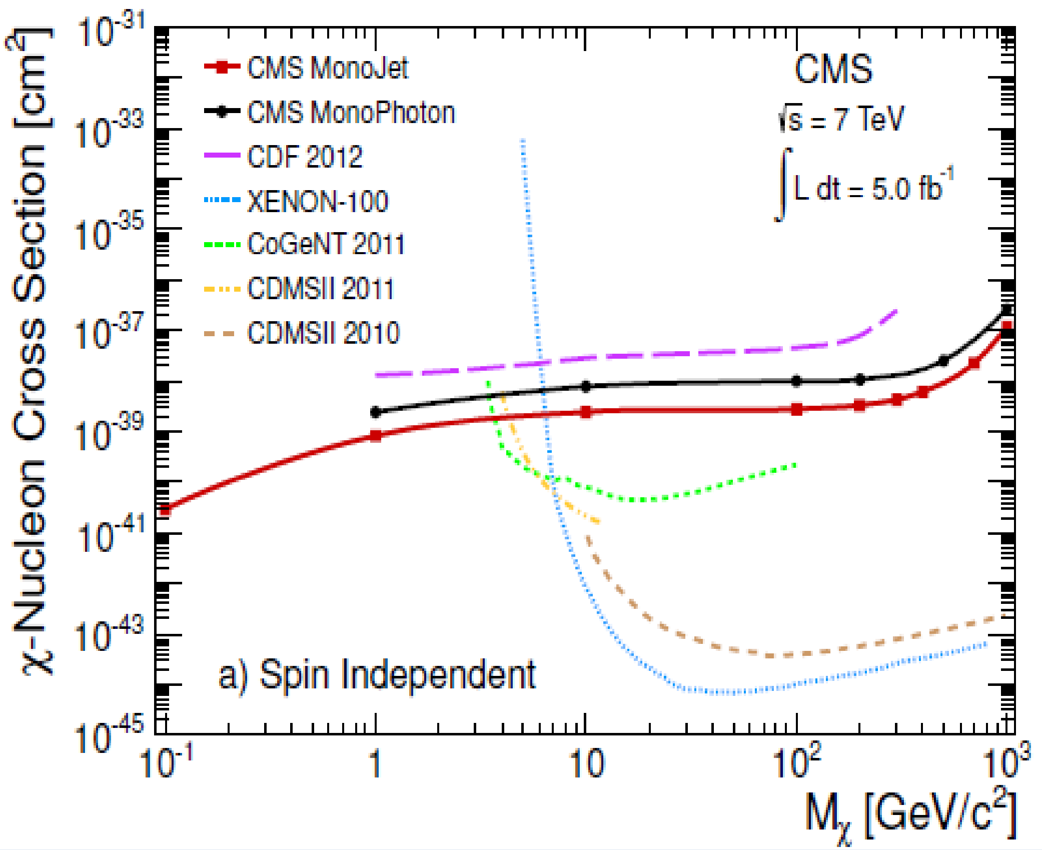
In (not only) my opinion

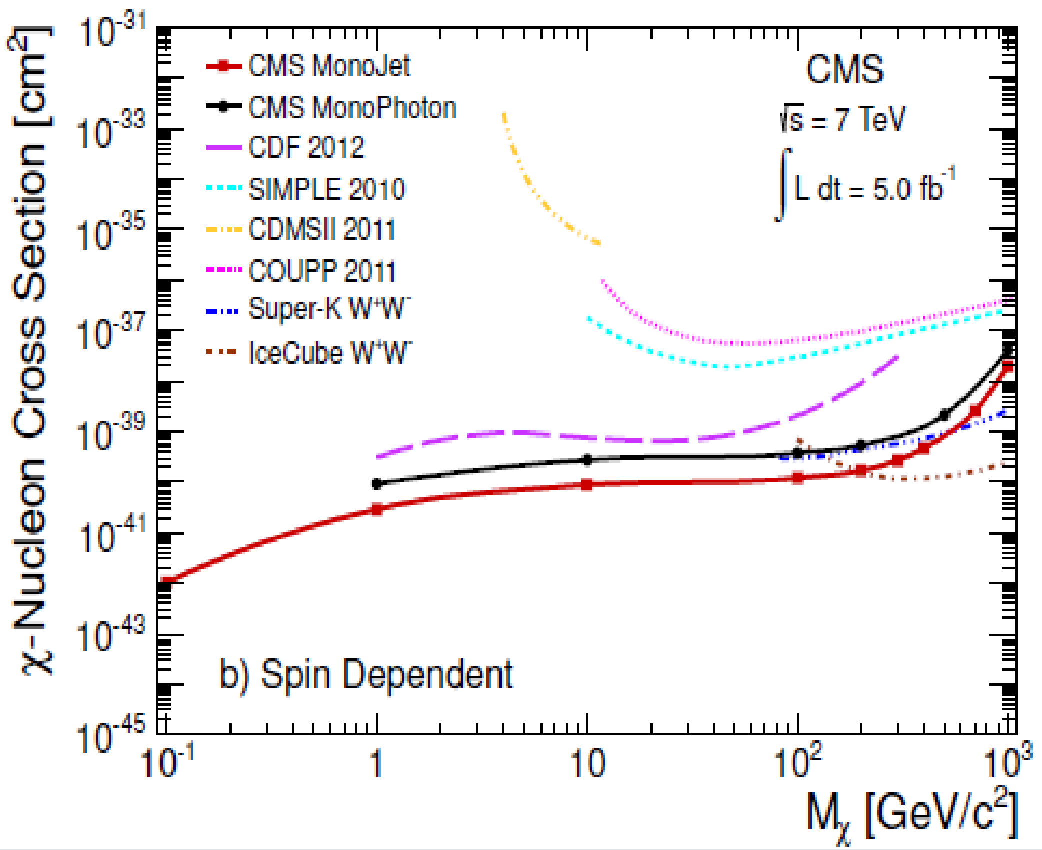


Do not ask what cosmology can do for you ...

Search for dark matter at LHC via ISR

Piotr Zalewski
NCBJ Warsaw



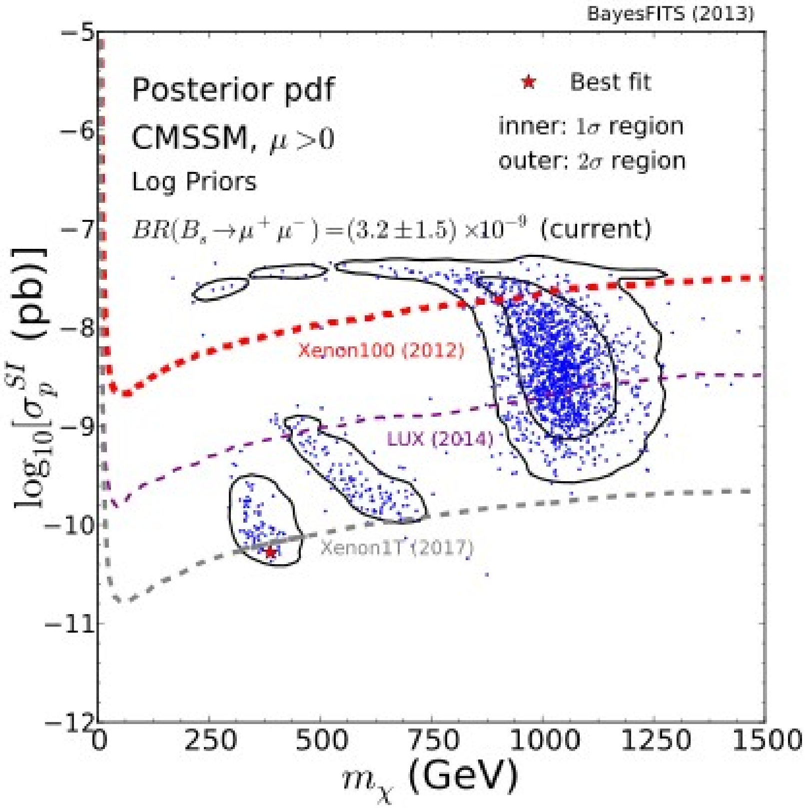


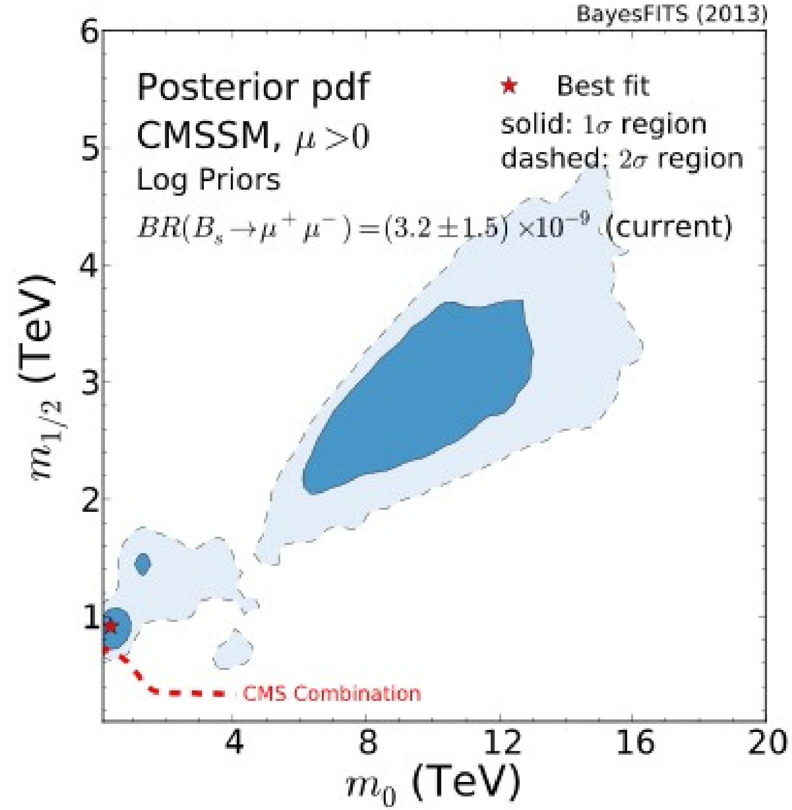
→ *Search for Dark Matter and Large Extra Dimensions in pp Collisions Yielding a Photon and Missing Transverse Energy;* arXiv:1204.0821, Phys. Rev. Lett. 108 (2012) 261803

→ *Search for dark matter and large extra dimensions in monojet events in pp collisions at sqrt(s) = 7 TeV;* arXiv:1206.5663

CMSSM and 1-tonne DM detectors

$\mu > 0$





1-tonne DM detectors to cover most of CMSSM predictions

...over ALL multi-TeV ranges of mass parameters

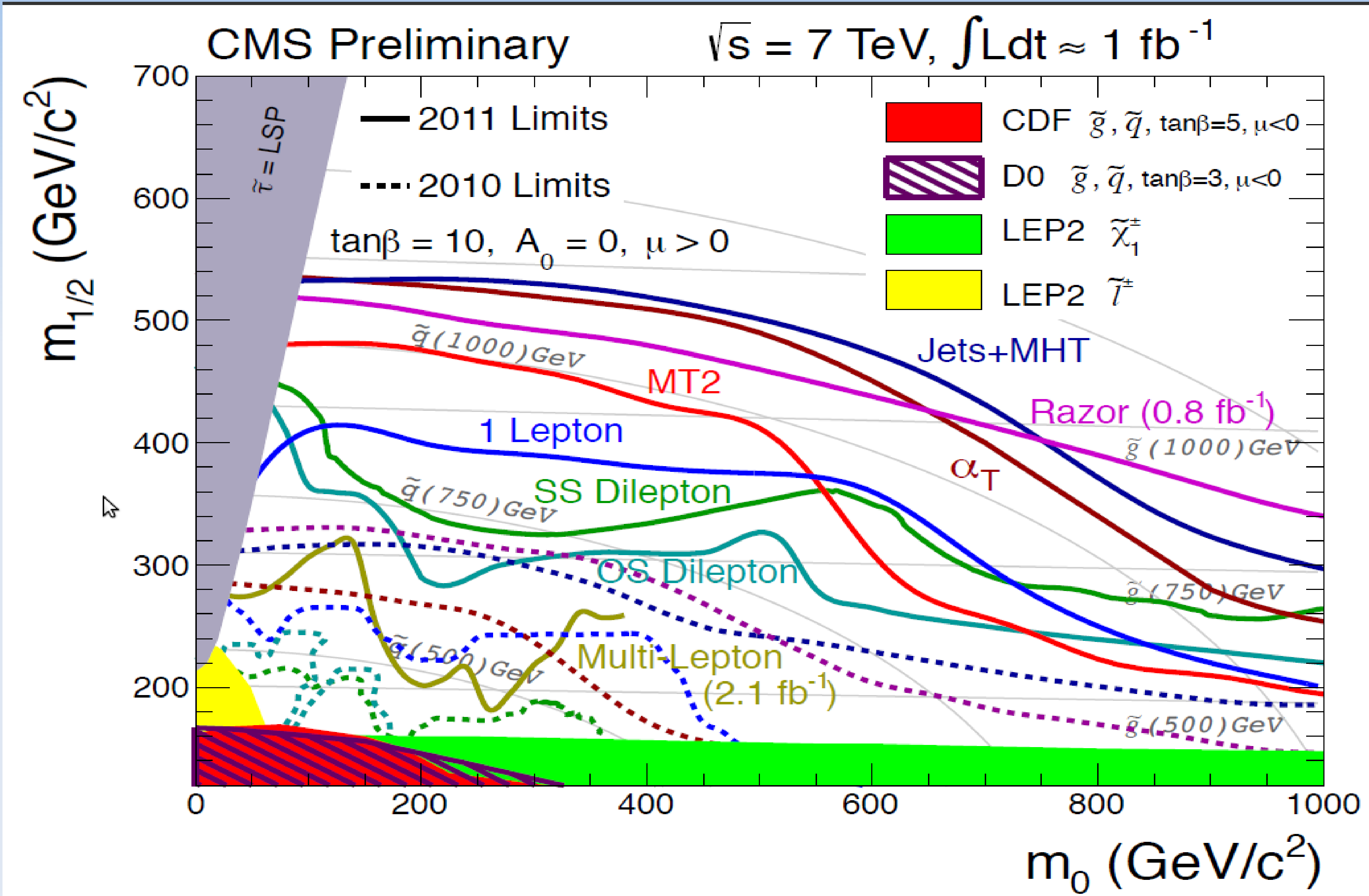
(Except for some cases at mu<0)

Generic prediction of multi-TeV SUSY: ~1TeV LSP (higgsino)

LUX (2014) to improve sensitivity by ~1 decade

Ograniczenia CMSSM (2011)

Piotr Zalewski
NCBJ Warsaw



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NCBJ Warsaw

So where is  ?

Are we sure that levelling is the best way to search for a golf ball?

Isn't long lived creatures interesting?

Piotr Zalewski
NCBJ Warsaw

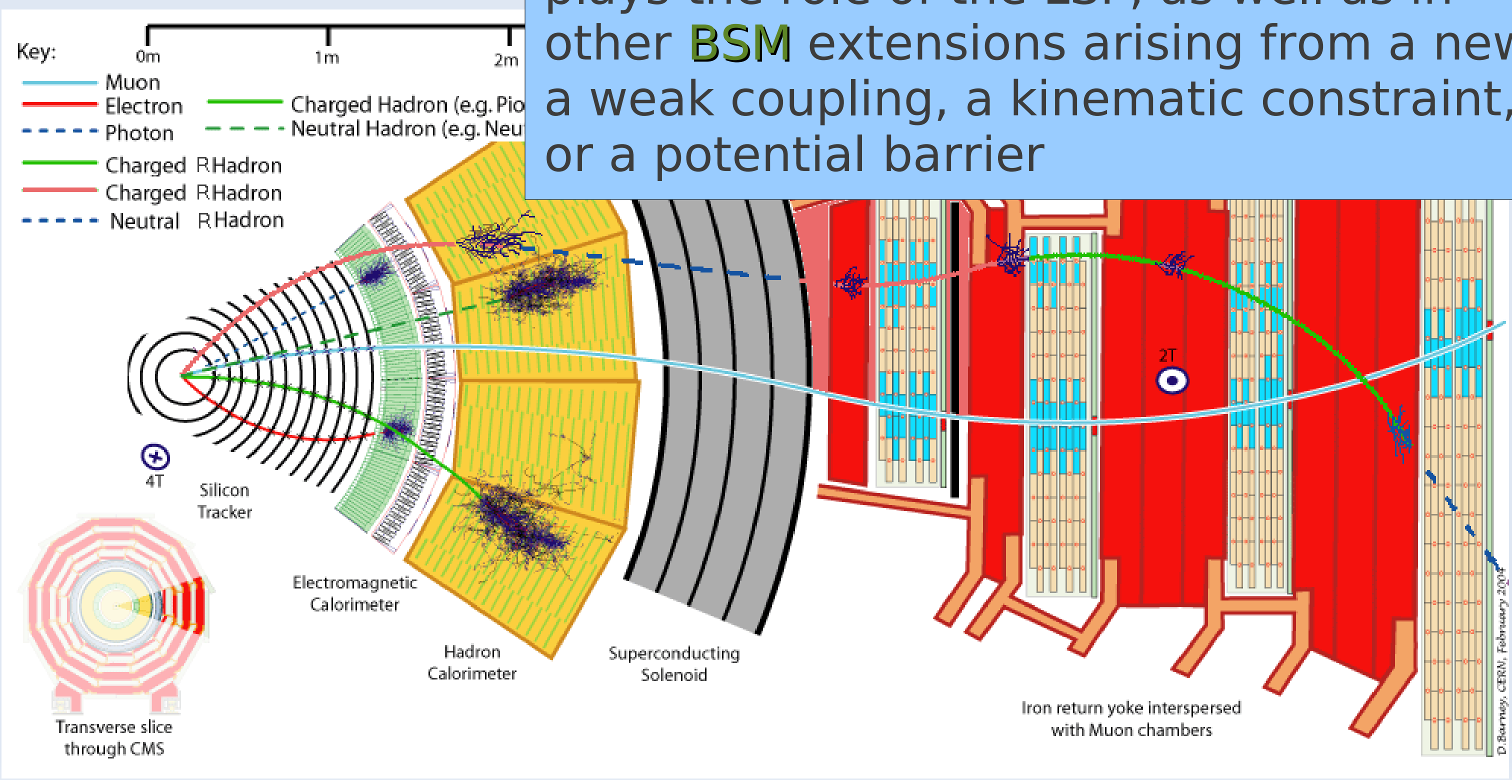
Heavy quasi-Stable Charged Particles

Piotr Zalewski
NCBJ Warsaw

Flying through
- lepton like (stau)
- R-hadrons
- fractional charge
- mulitple charge

Stopped in the detector
R-hadrons

HSCPs - heavy quasi-stable charged particles
(or CHAMPs – charged massive particles)
are hipotetical objects that appear in various extensions of the standard model (SM) in which gravitino or axino plays the role of the LSP, as well as in other BSM extensions arising from a new symmetry, a weak coupling, a kinematic constraint, or a potential barrier



muon, stau

R-hadron

EXOTICA

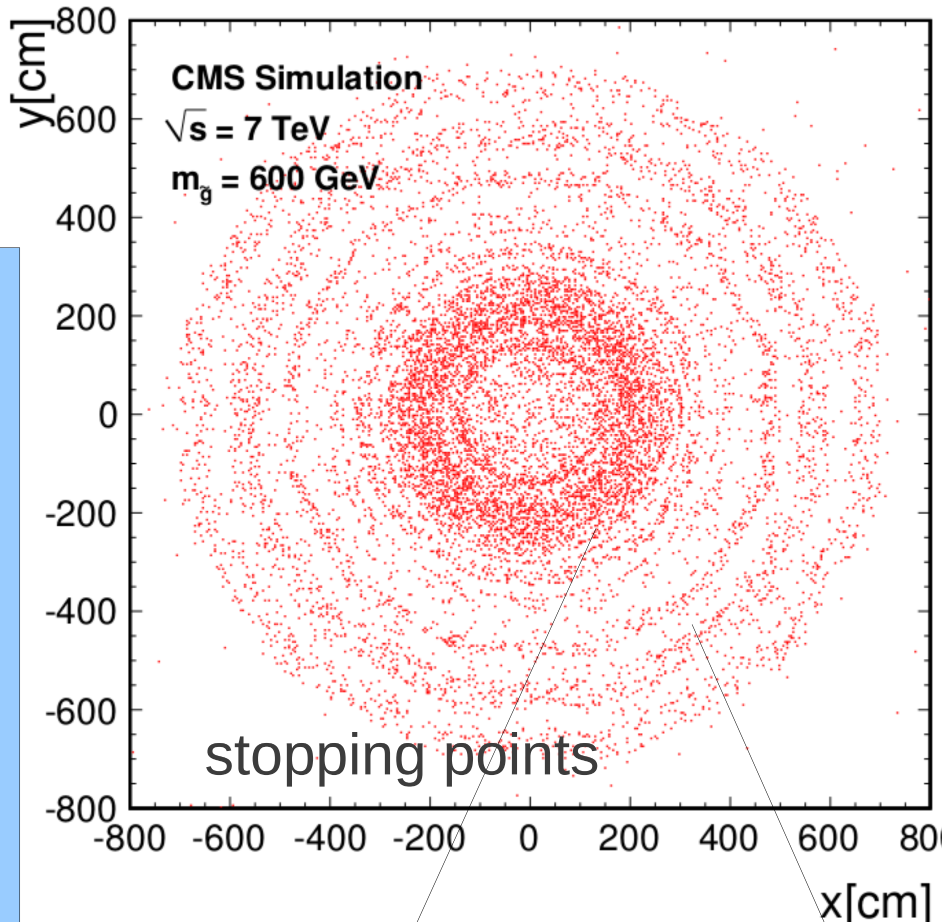
Stopped HSCP

Piotr Zalewski
NCBJ Warsaw

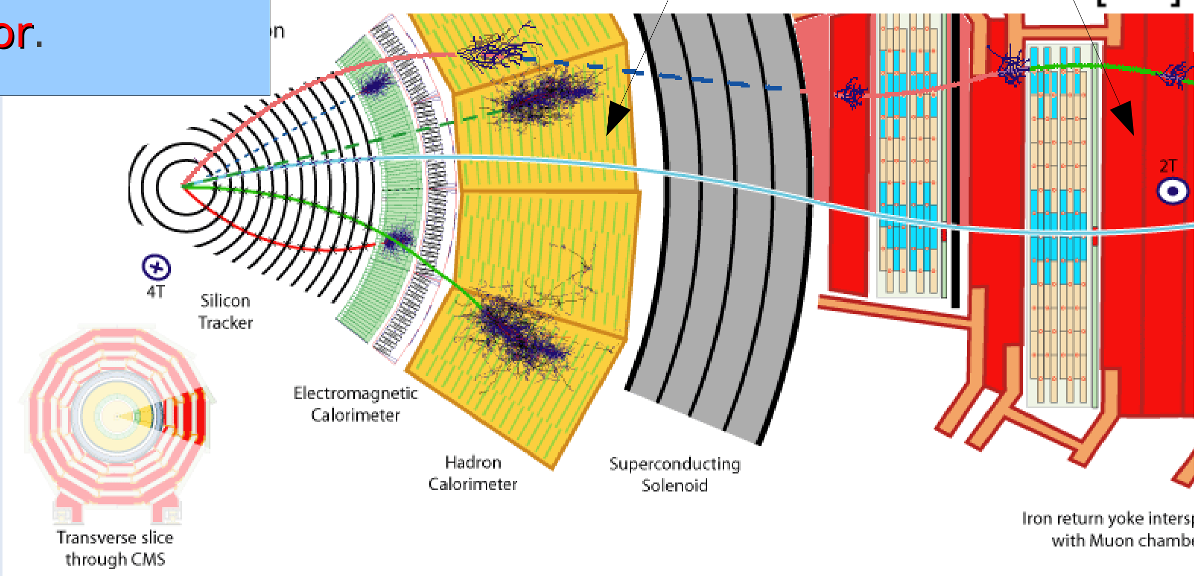
Stopped in the detector
R-hadrons

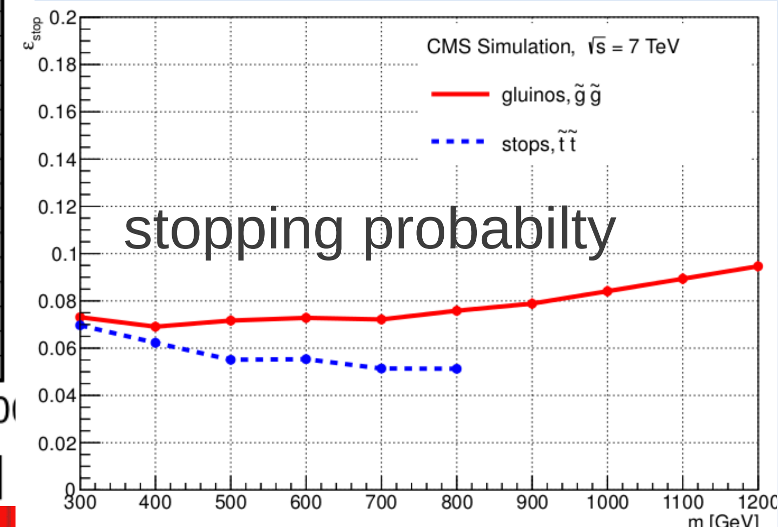
R-hadrons are hadronized semi-stable gluinos or squarks (stops, sbottoms) predicted by split-SUSY (among others).

These particles have relitivelly large probability to stop in the detector.

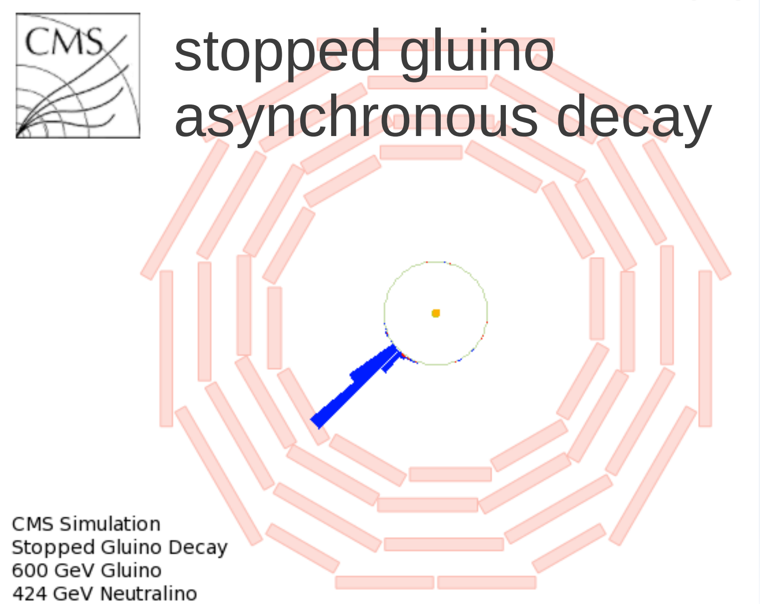


stopping points





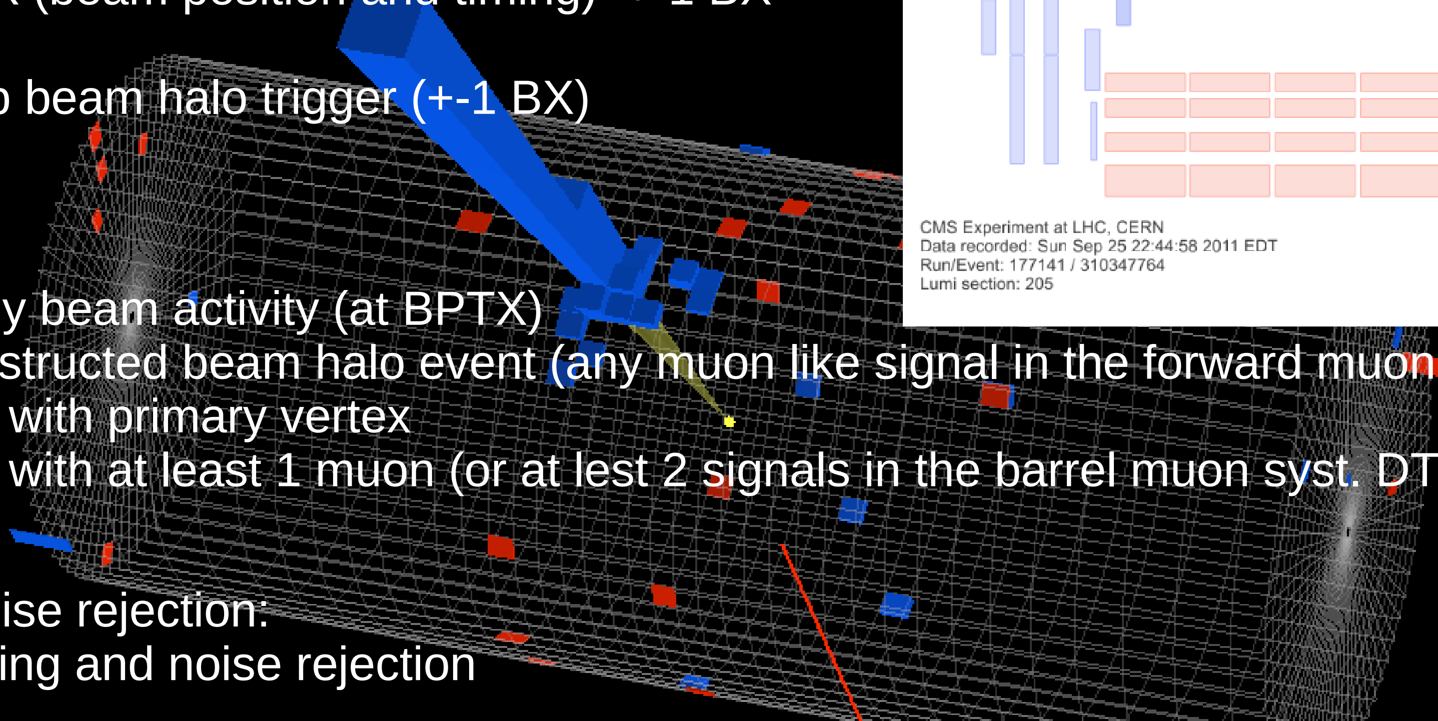
stopping probabilty



stopped gluino asynchronous decay

Trigger + offline veto & cleaning

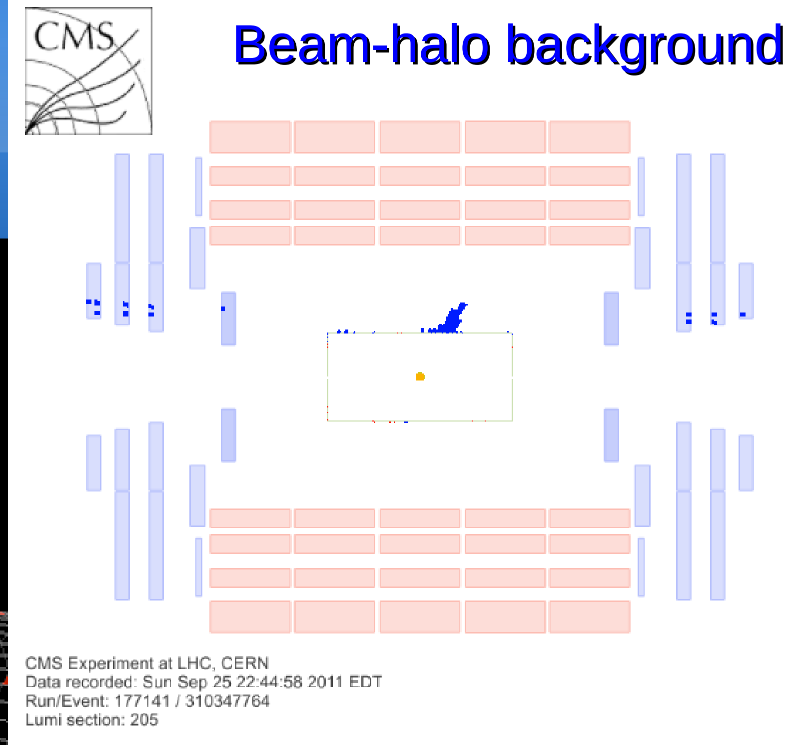
Jet trigger in coincidence with ”no beam” condition:
- 32 GeV E_T threshold at L1 and 50 GeV at HLT
- veto both BPTX (beam position and timing) +-1 BX
- $|\eta| < 3$
- veto L1 endcap beam halo trigger (+-1 BX)



Offline veto:
- veto +-2 BX any beam activity (at BPTX)
- veto any reconstructed beam halo event (any muon like signal in the forward muon syst. CSC)
- veto any event with primary vertex
- veto any event with at least 1 muon (or at lest 2 signals in the barrel muon syst. DT or RPC)

Cleaning and noise rejection:
- standard cleaning and noise rejection
- $|\eta| < 1$
- reconstructed jet energy > 70 GeV
- spacial distribution of the deposits requirements
- pulse time shape requirements

Beam-halo background



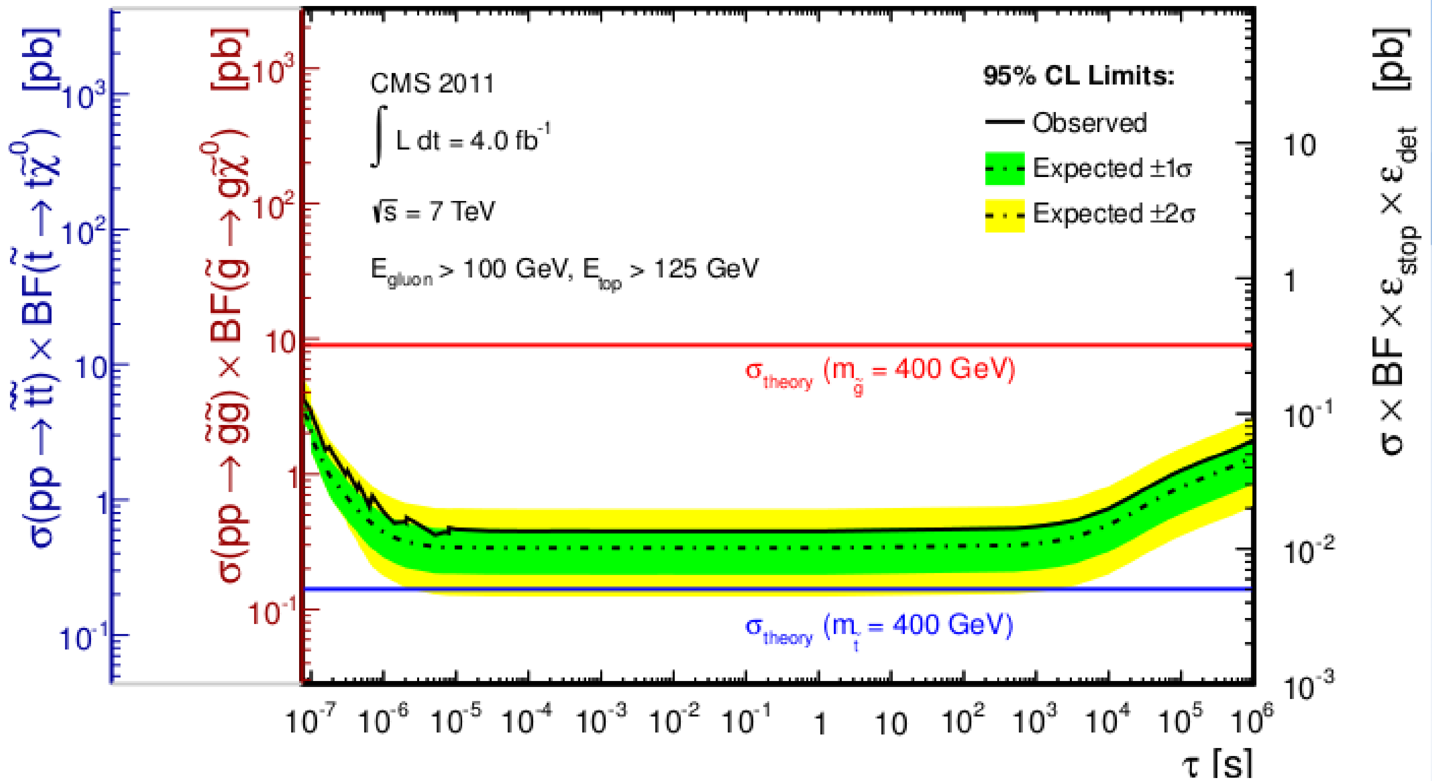
Cosmic rays	Beam-halo	Noise	Total
5.71 ± 0.62	1.50 ± 0.70	1.4 ± 2.2	8.6 ± 2.4

Background estimate
- cosmic rays background by MC (validated by real data)
- beam-halo by tag & probe (two endcaps)
- noise using 2010 control sample

Stopped HSCP

95 % CL X-sec limits (top) & mass limits (bottom) as a function of lifetimes

The structure visible for small lifetimes is due to time window 1.3*τ used for lifetimes shorter than LHC orbit (89μs).



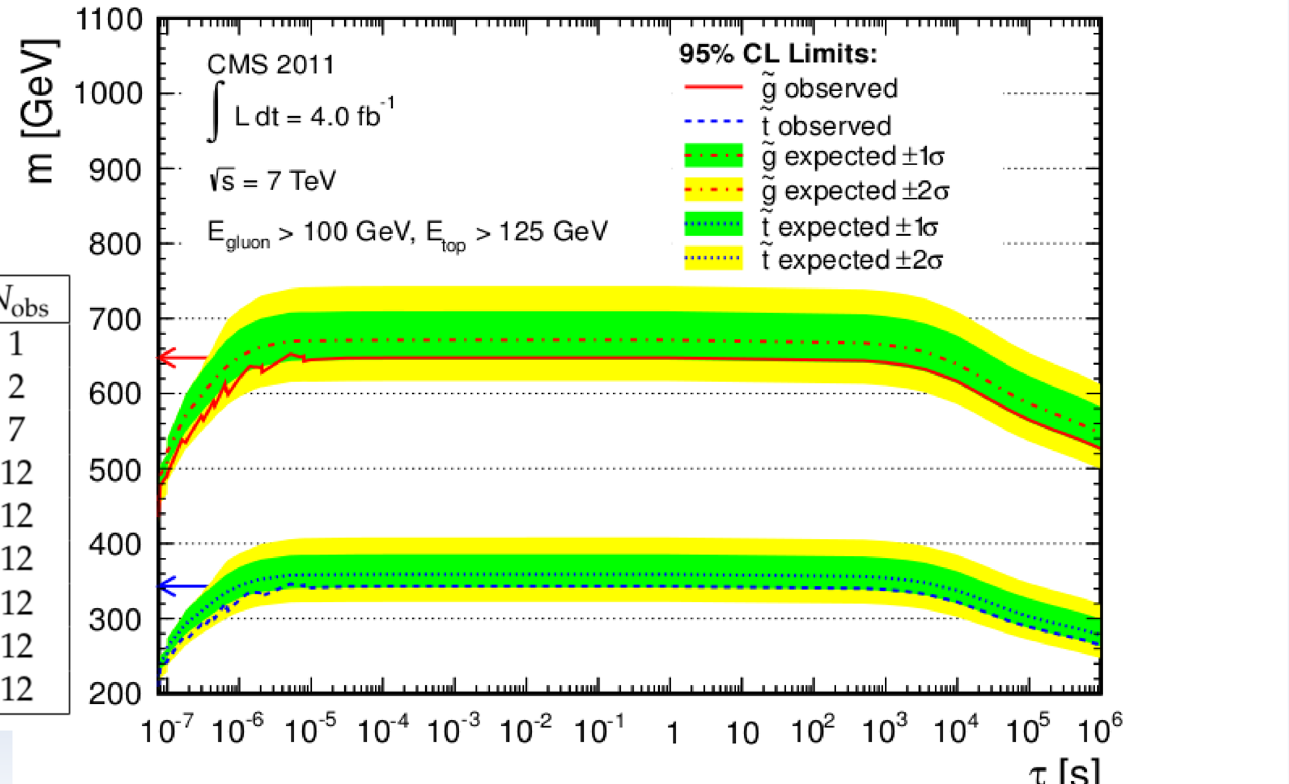


Table:
Results of countig experiments
(*Nexp* → background events)

τ	L_{eff} (pb^{-1})	Live time (s)	N_{exp}	N_{obs}
75 ns	19.6	2.06×10^4	0.200 ± 0.056	1
100 ns	57.8	6.17×10^4	0.60 ± 0.17	2
1 μs	508	4.41×10^5	4.3 ± 1.2	7
10 μs	913	8.67×10^5	8.5 ± 2.4	12
100 μs	935	8.86×10^5	8.6 ± 2.4	12
10^3 s	866	8.86×10^5	8.6 ± 2.4	12
10^4 s	636	8.86×10^5	8.6 ± 2.4	12
10^5 s	332	8.86×10^5	8.6 ± 2.4	12
10^6 s	198	8.86×10^5	8.6 ± 2.4	12

complementarity

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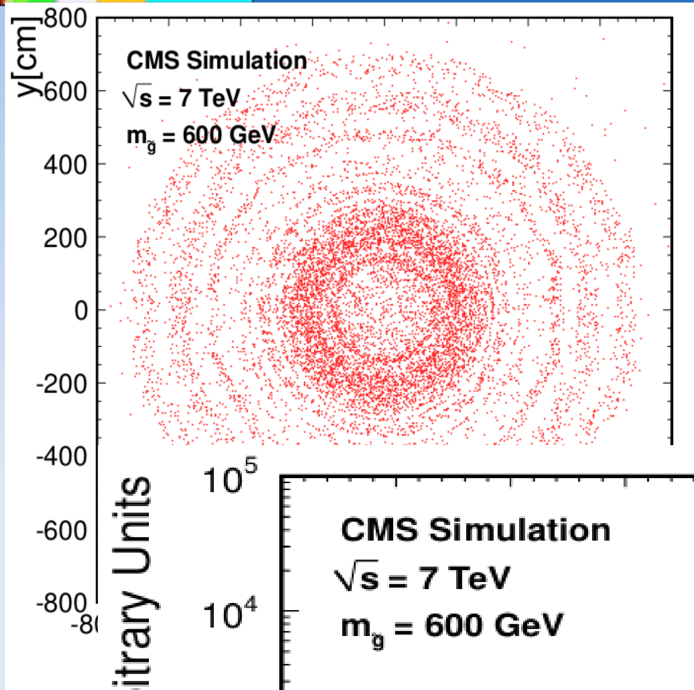
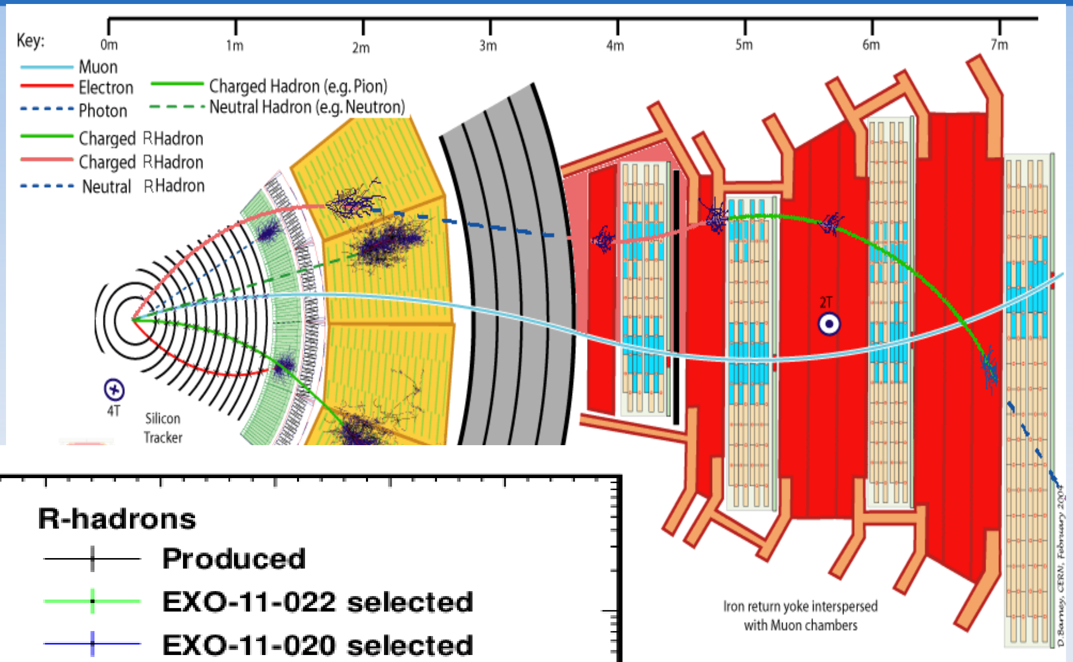
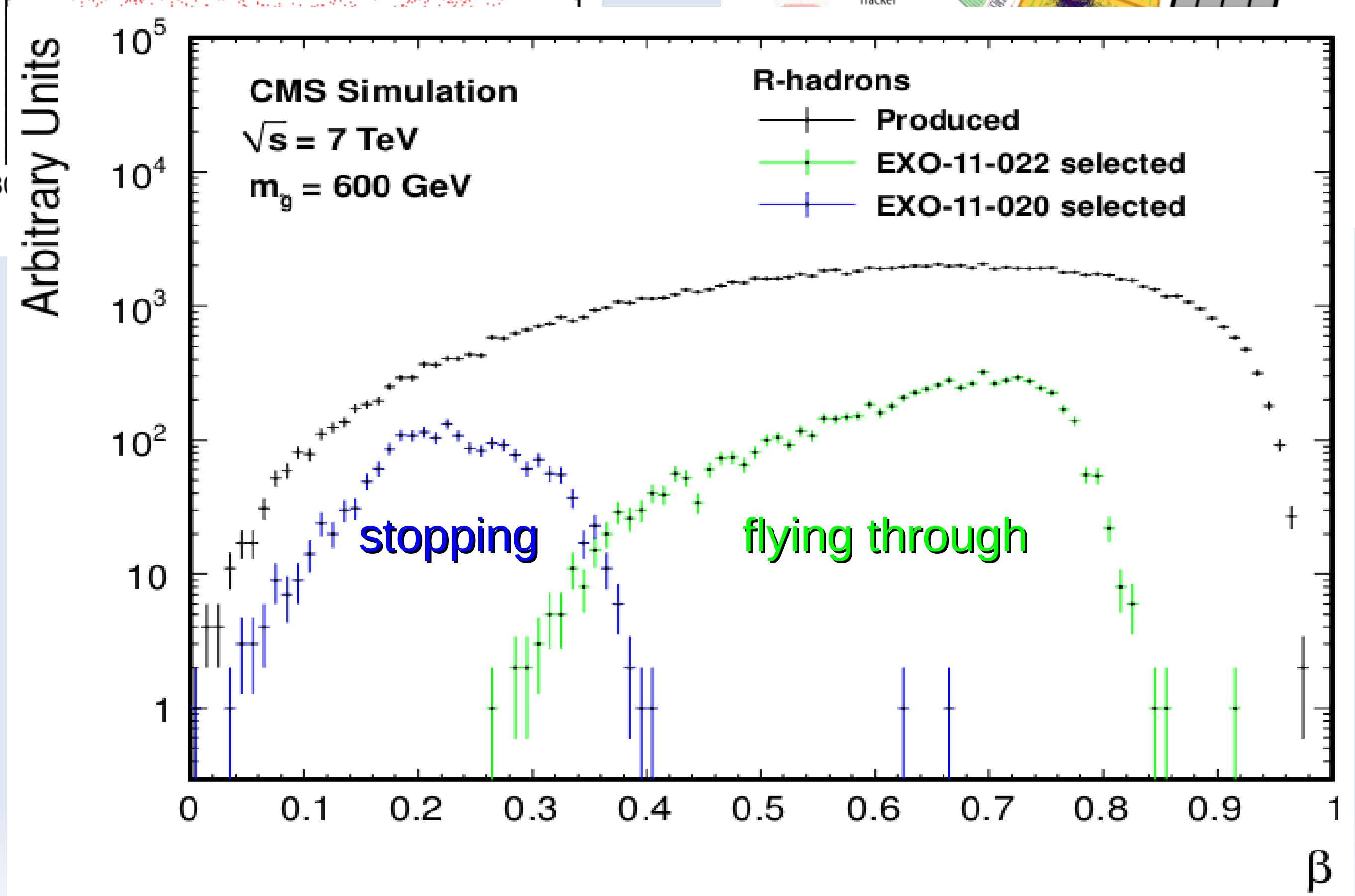
NCBJ Warsaw





R-hadron



If the lifetime of HSCP is longer than a few nanoseconds, the particle will flight through detector.

It clould be regarded as stable from the detection point of view

The idea of the HSCP search

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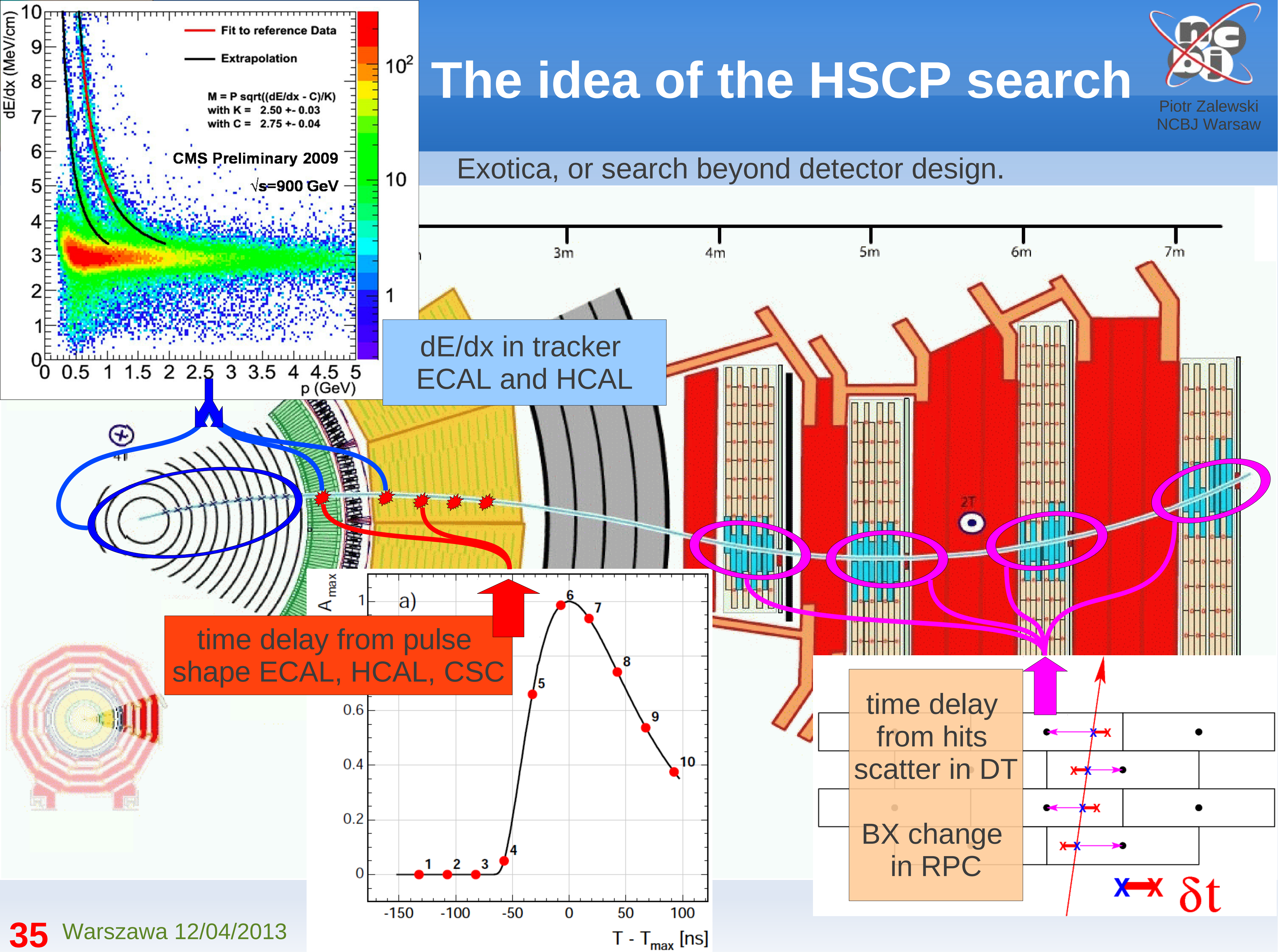
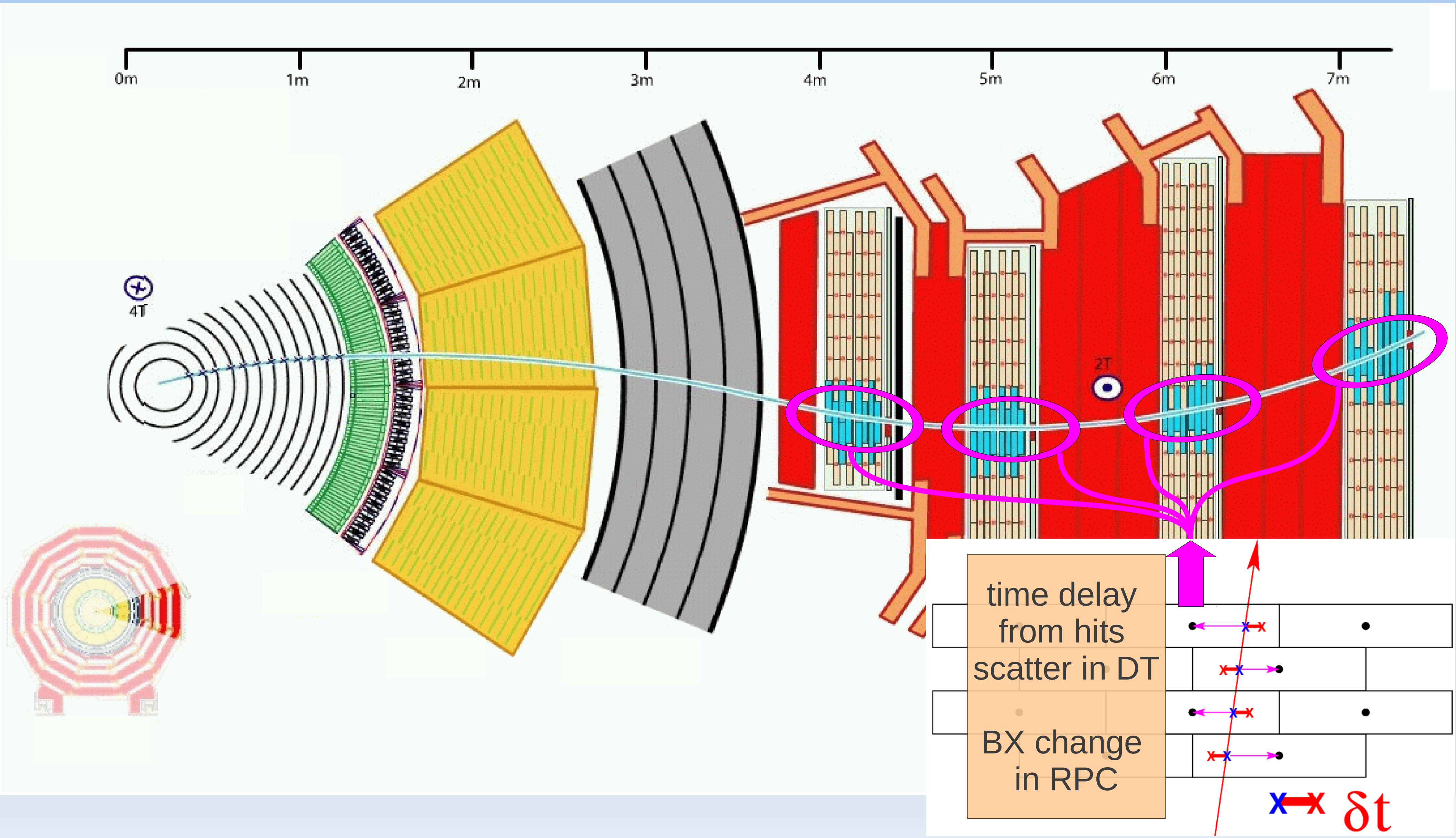
Exotica, or search beyond detector design.



TOF DT method



Muon System

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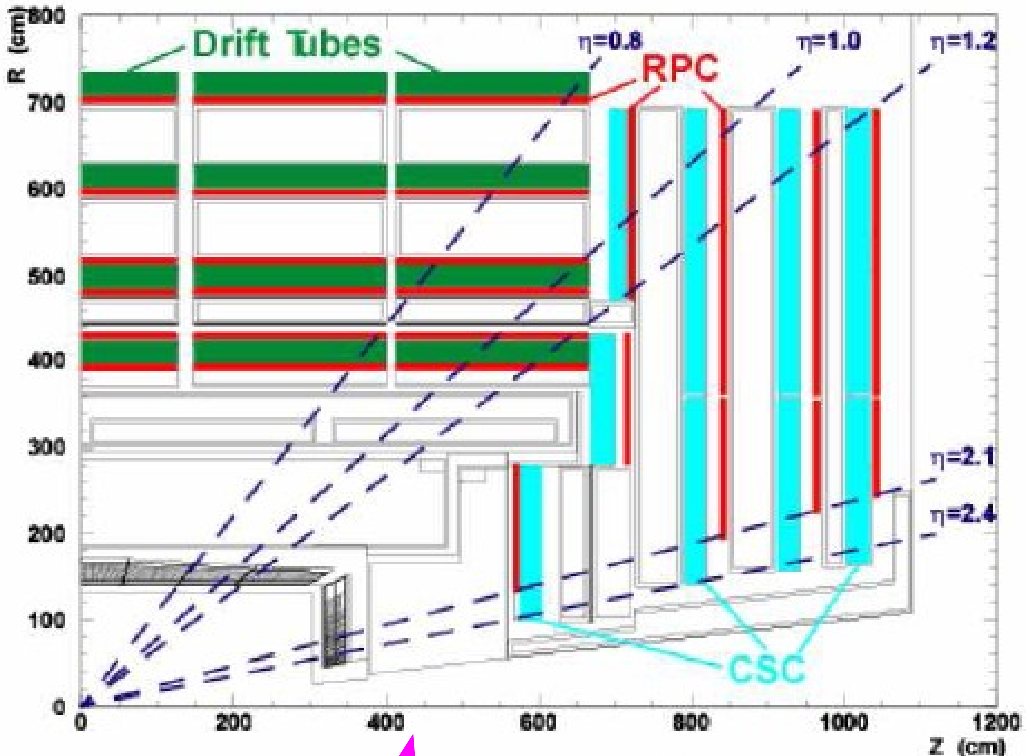
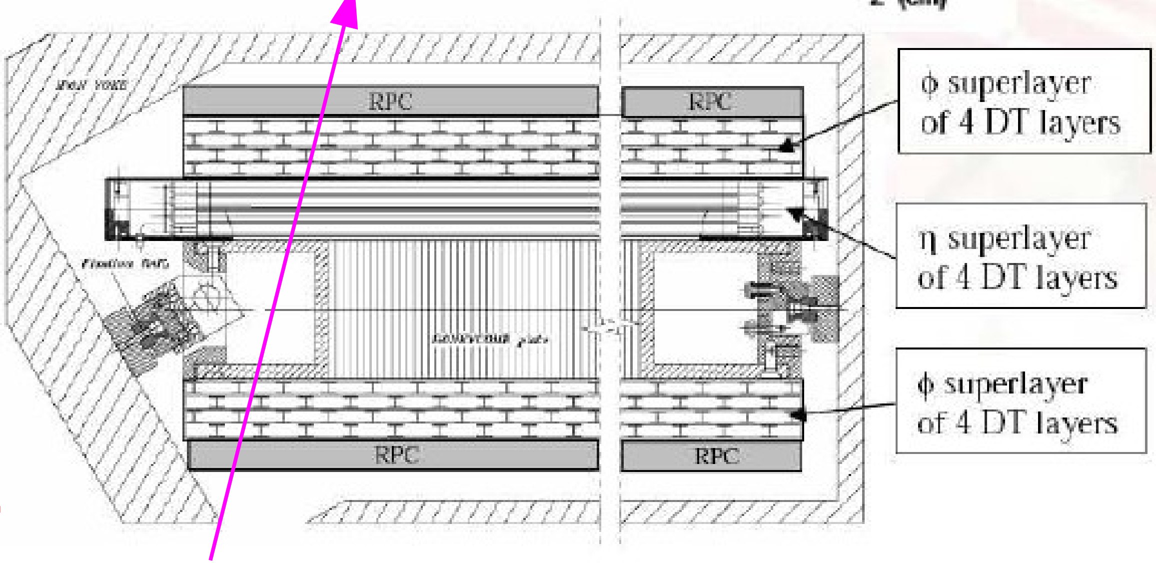


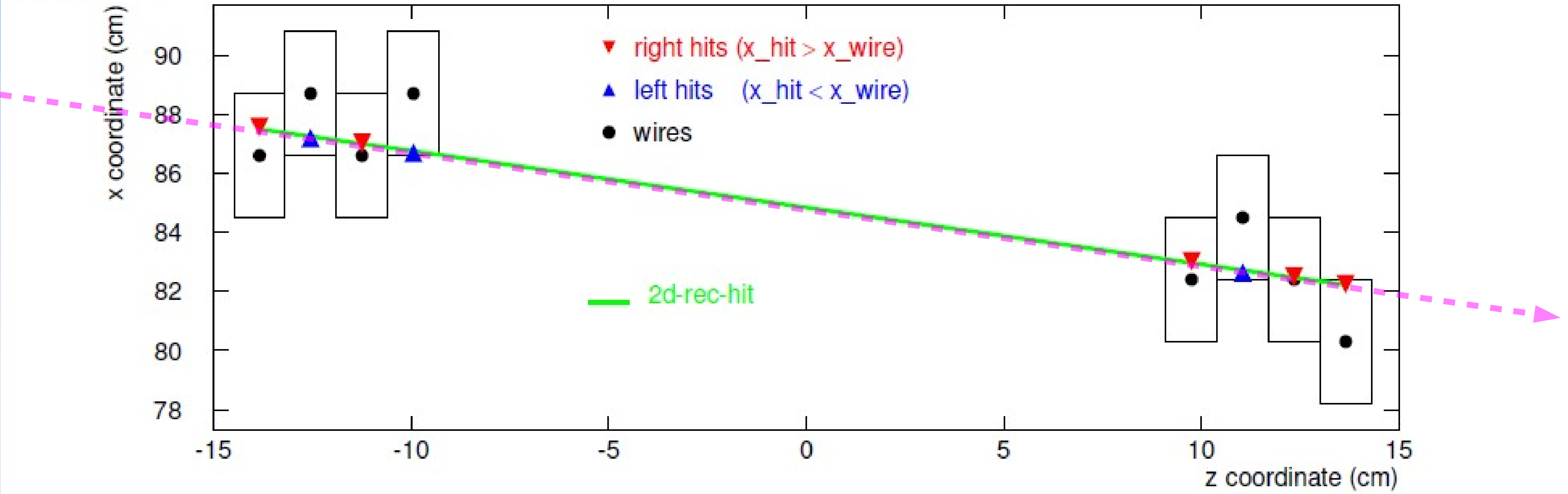
Position measurement:
Drift Tubes (DT) in barrel
Cathode Strip Chambers (CSC) in endcaps

Trigger:
Resistive Plate Chambers (RPCs) in barrel and endcaps



195000 DT channels
210816 CSC channels
162282 RPC channels

DT: invers beta



Double ϕ super-layer display for delayed track

DT: invers beta

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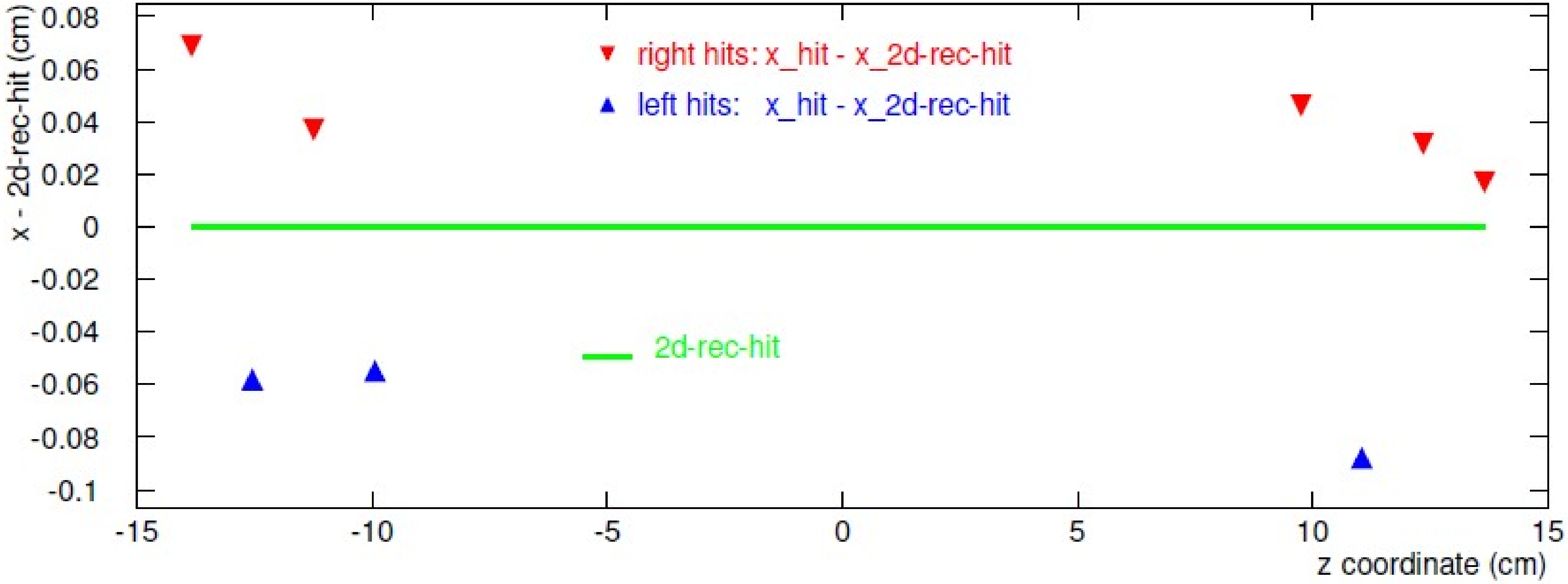
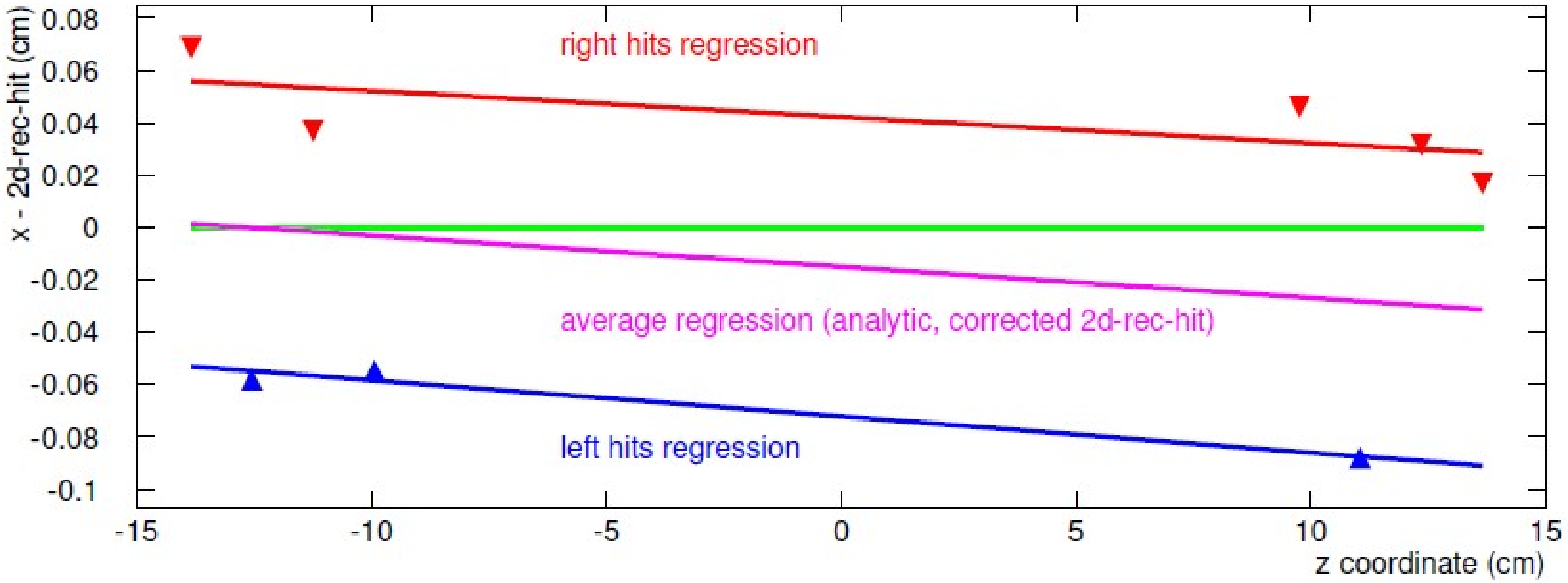
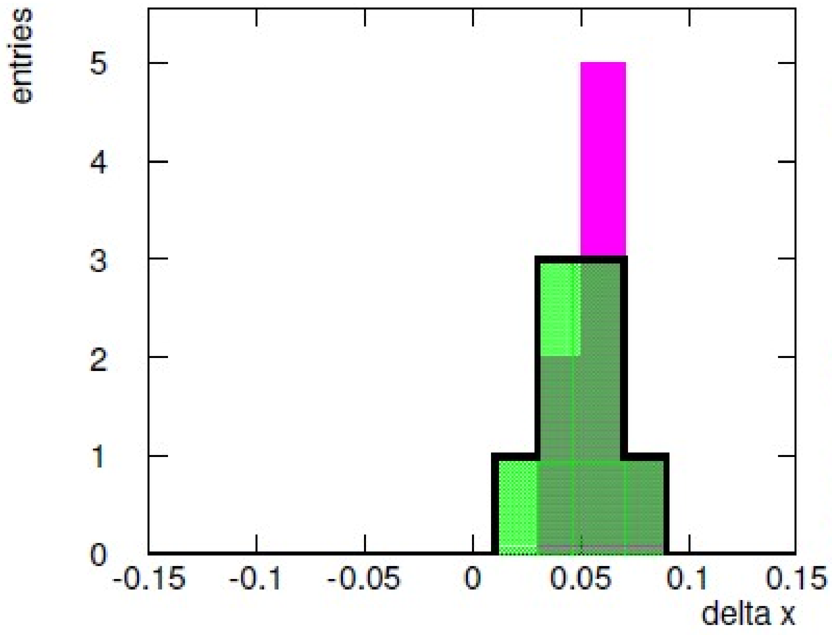


Difference: rec_hit - local 2d rec_hit

DT: invers beta





x_A – analytic, corrected “2d rec_hit”

$$x_\mathrm{A} = \frac{a_\mathrm{R} + a_\mathrm{L}}{2} + \frac{b_\mathrm{R} + b_\mathrm{L}}{2} z$$

$$\delta_x = |x - x_\mathrm{wire}| - |x_\mathrm{A} - x_\mathrm{wire}|$$

x_M – standard, local 2d rec_hit

$$\delta_x = |x - x_\mathrm{wire}| - |x_\mathrm{M} - x_\mathrm{wire}|$$

DT: invers beta

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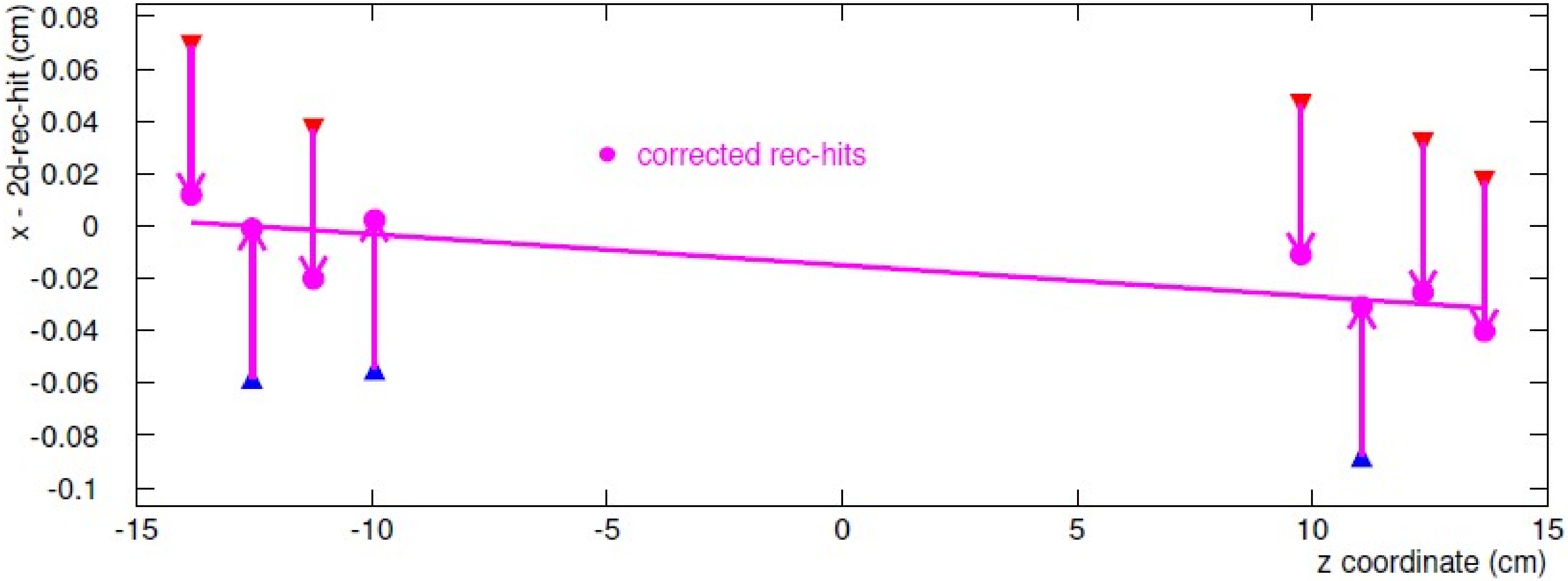

Hits alignment after correction by $\langle \delta_x \rangle$.

However, our goal is not to estimate $\langle \delta_x \rangle$ but candidate velocity β.

$$\delta_x = v_\mathrm{d} \cdot \delta_t = v_\mathrm{d} \cdot \left(\frac{L}{\beta c} - \frac{L}{c} \right)$$

$$\frac{1}{\beta} = 1 + \frac{c}{v_\mathrm{d}} \frac{\delta_x}{L}$$

TOF by the muon system

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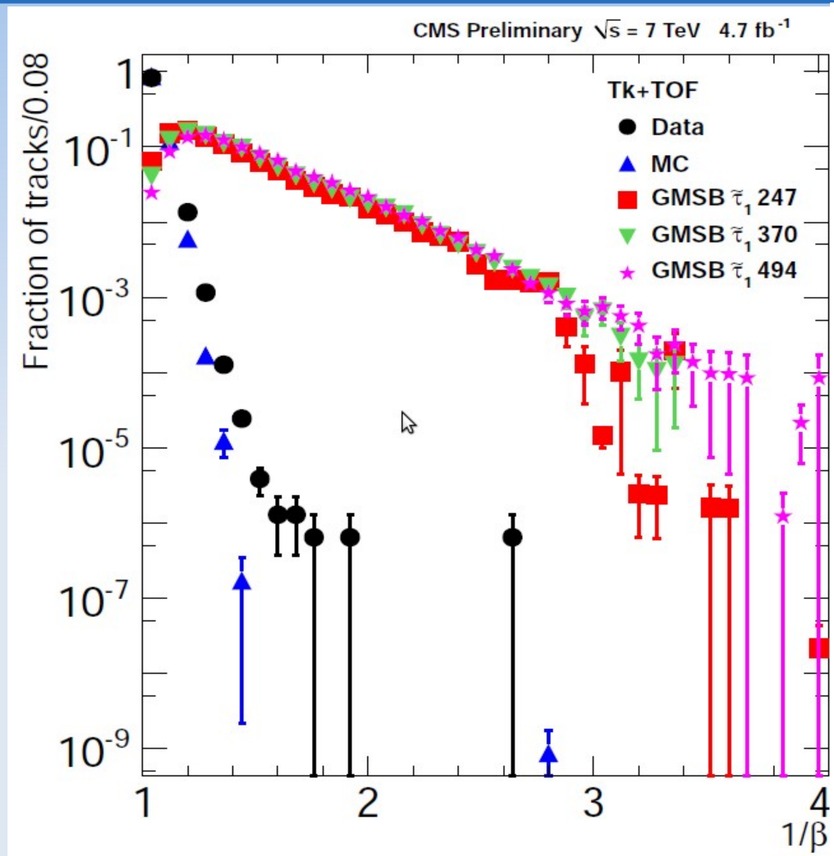

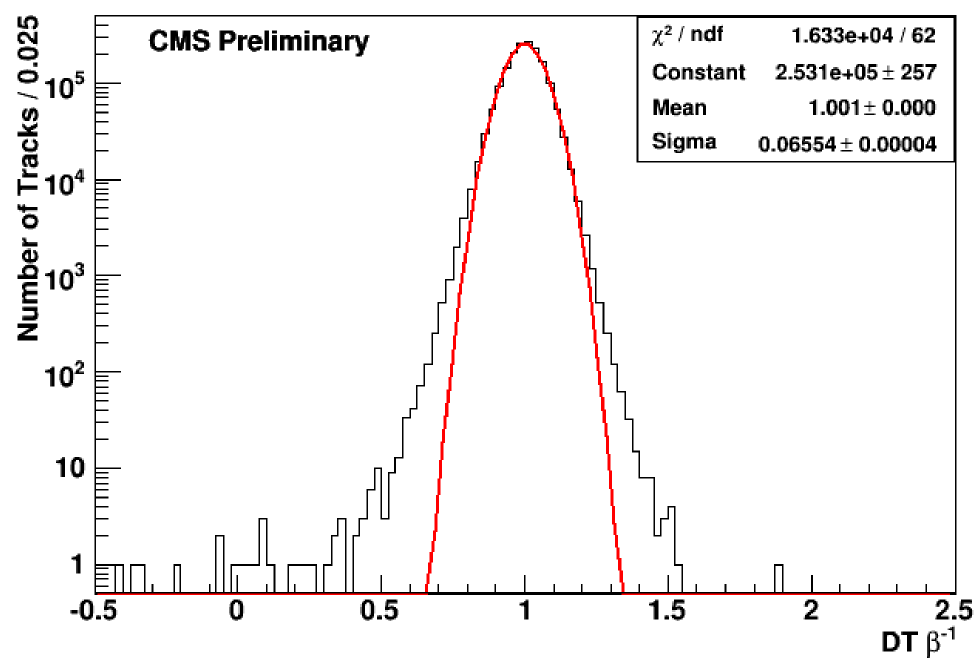

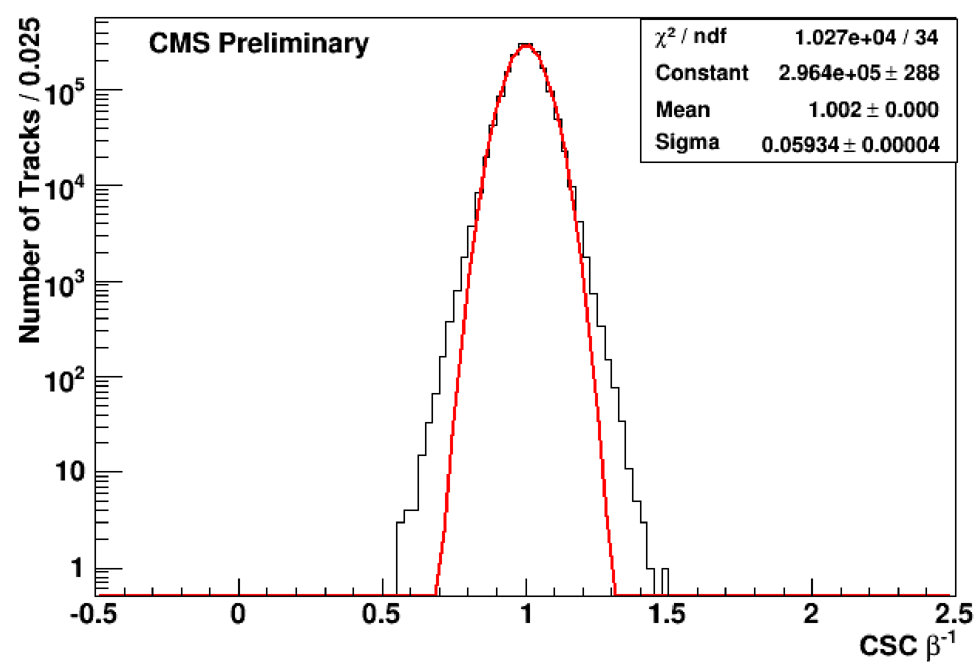

Relation between candidate velocity and the time delay *delta_t* at a distance *L.*

$$\frac{1}{\beta} = 1 + \frac{c\delta_t}{L}$$

The third idependent measurement (if aplicable).

Time in the RPC

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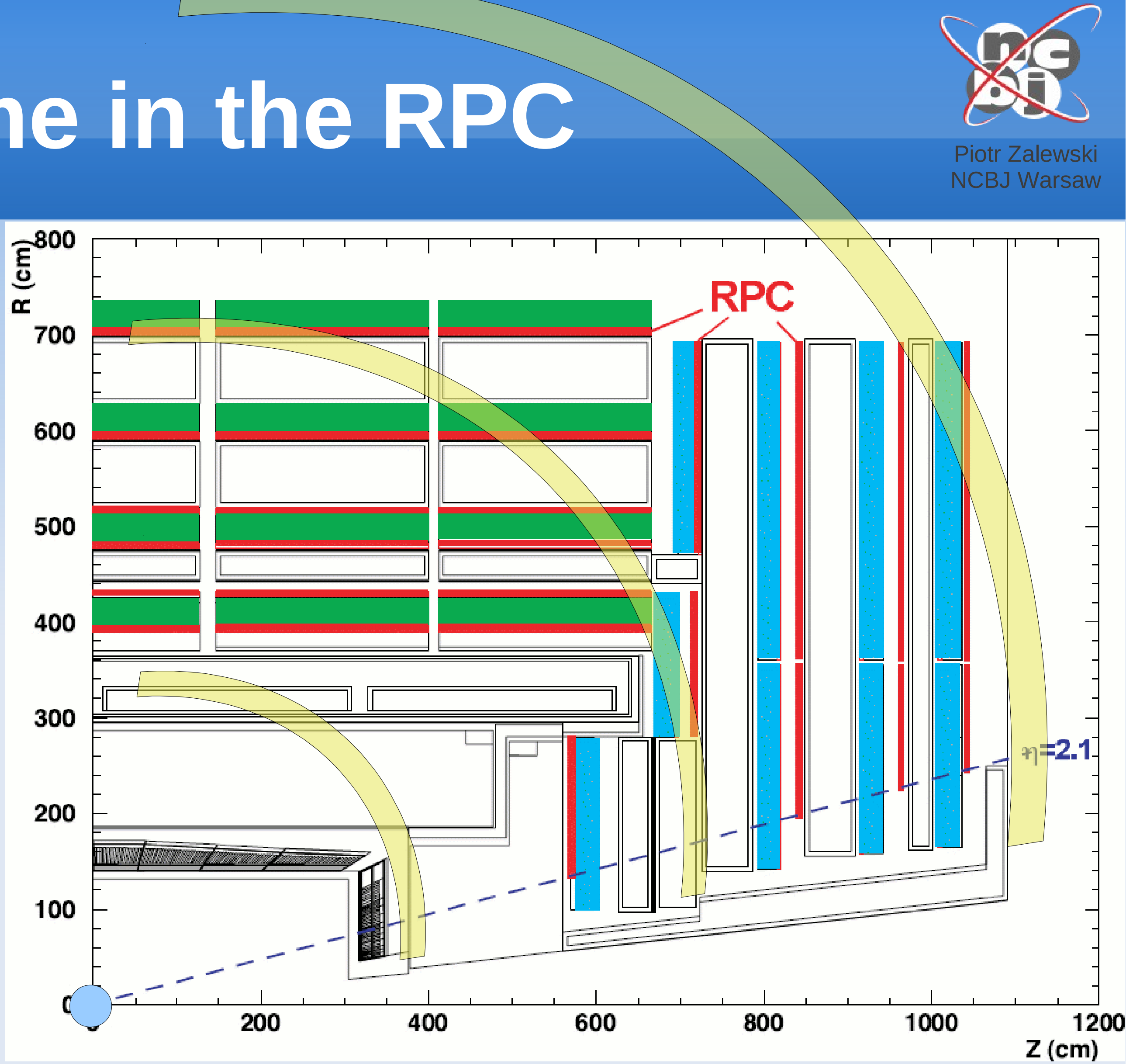
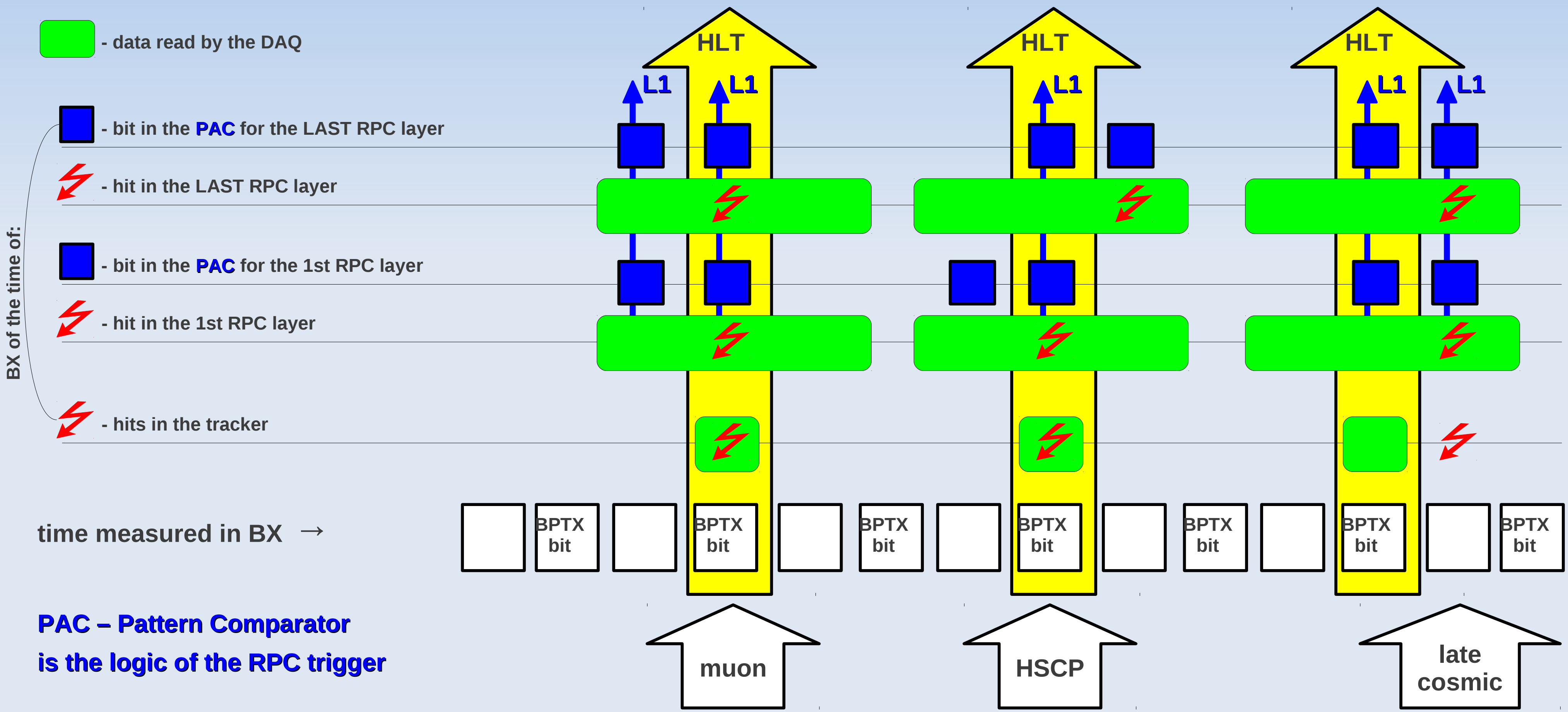
Arcs represent aproximate delay time surfaces for a HSCP with beta ~ 0.5
12.5 ns, 25 ns & 37.5 ns



RPC HSCP

Piotr Zalewski
NCBJ Warsaw

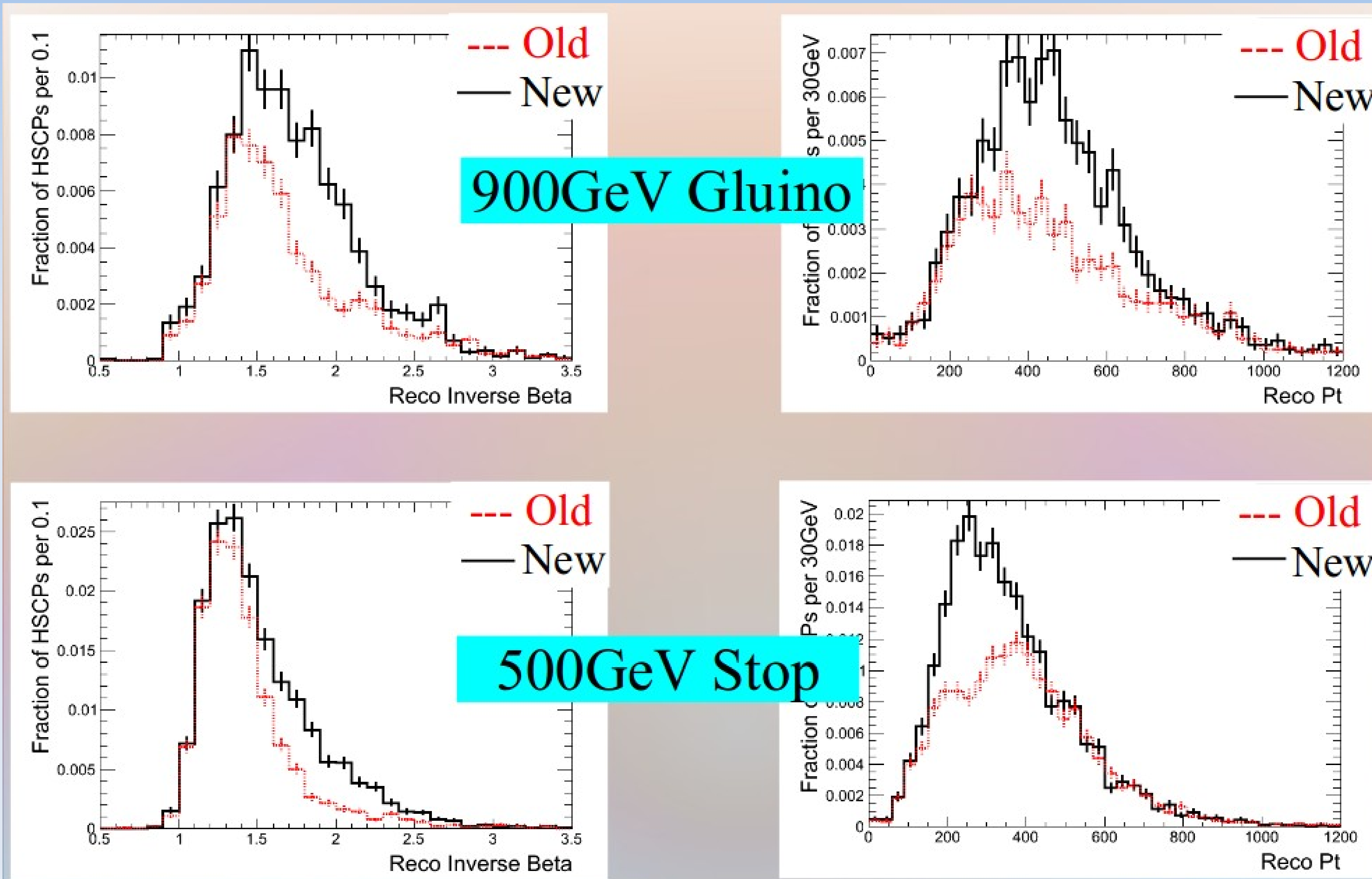
Behavior of the **RPC trigger** and its influence on the data read by the **DAQ**



PAC – Pattern Comparator is the logic of the RPC trigger

Effect of RPC trigger change

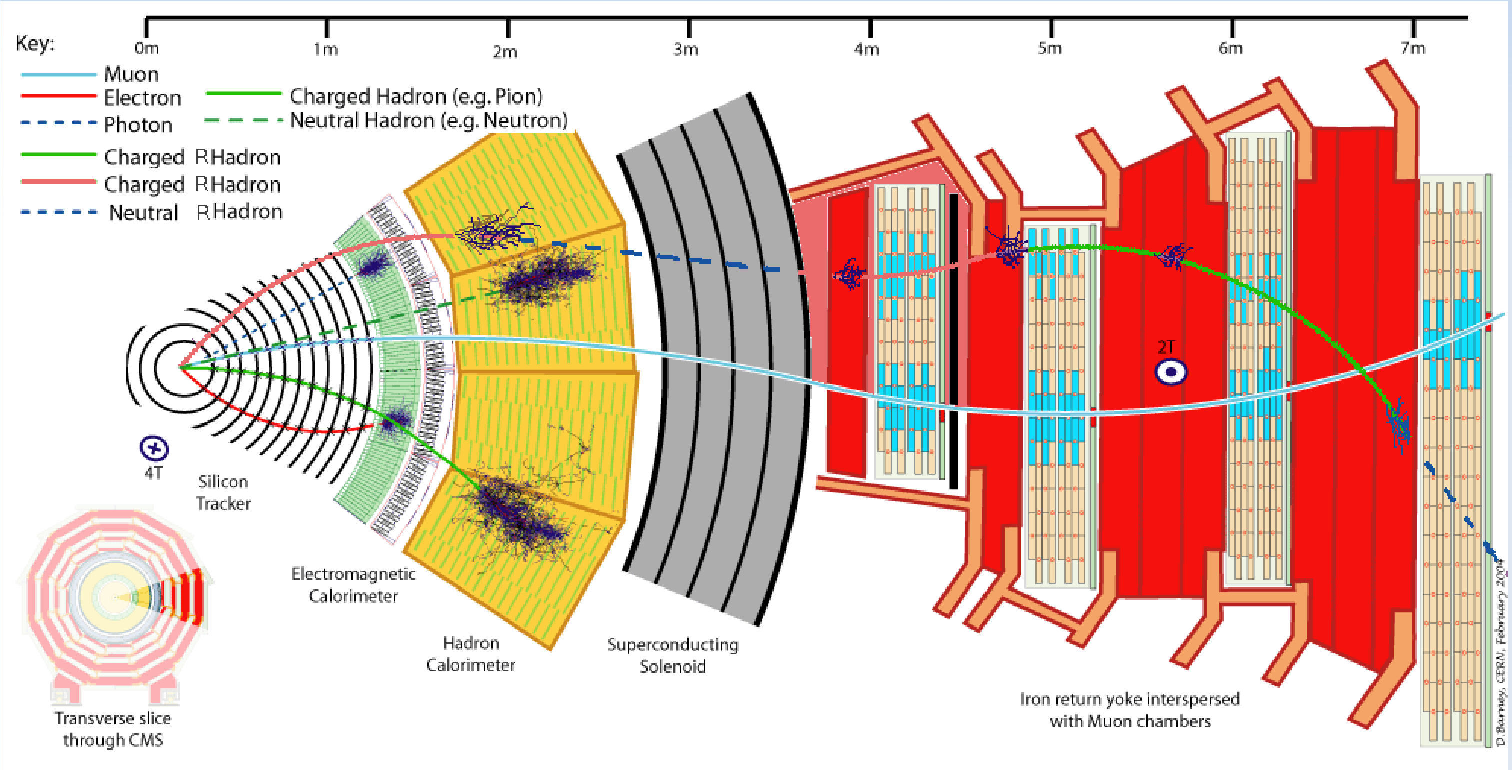
Piotr Zalewski
NCBJ Warsaw



The idea & trigger

HSCP could be slow enough to
- be late with respect to relativistic muons;
- give higher d*E*/dx than MIPs.

Two strategies for flying through HSCPs:
- tracker only (d*E*/dx only) analysis;
- tracker + TOF in the muon system analysis.



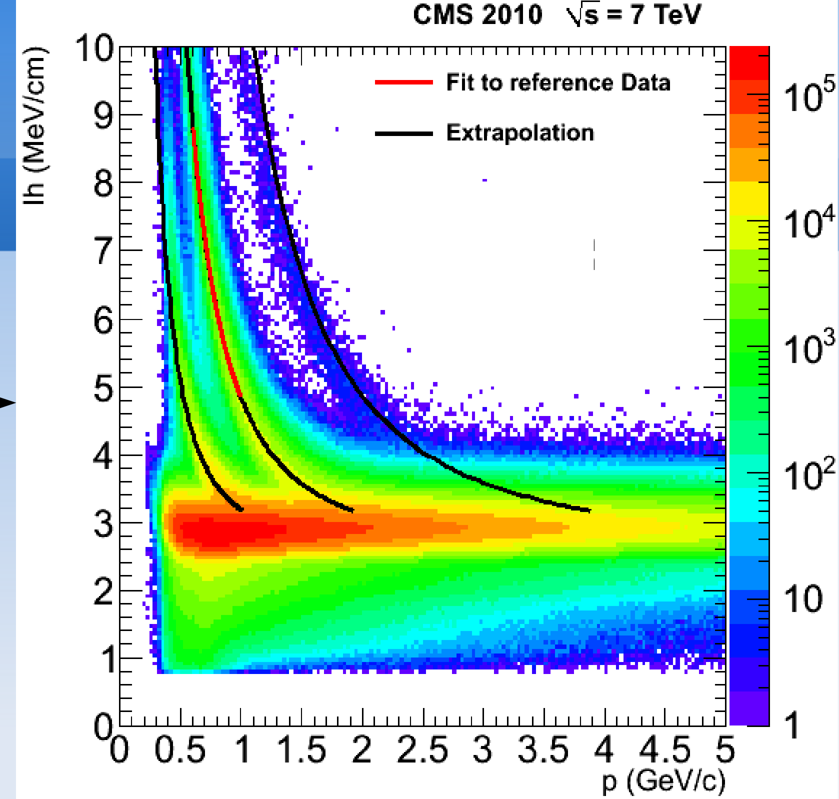
2011 analysis

Triggers:
- MET (particle flow) > 150 GeV
- single muon $p_T > 30$ GeV/c
- **special BX0+BX1 muon trigger (RPC)**

dE/dx in tracker

An estimator:

$$I_h = \left(\frac{1}{N} \sum_i c_i^k \right)^{1/k} \text{ with } k = -2$$



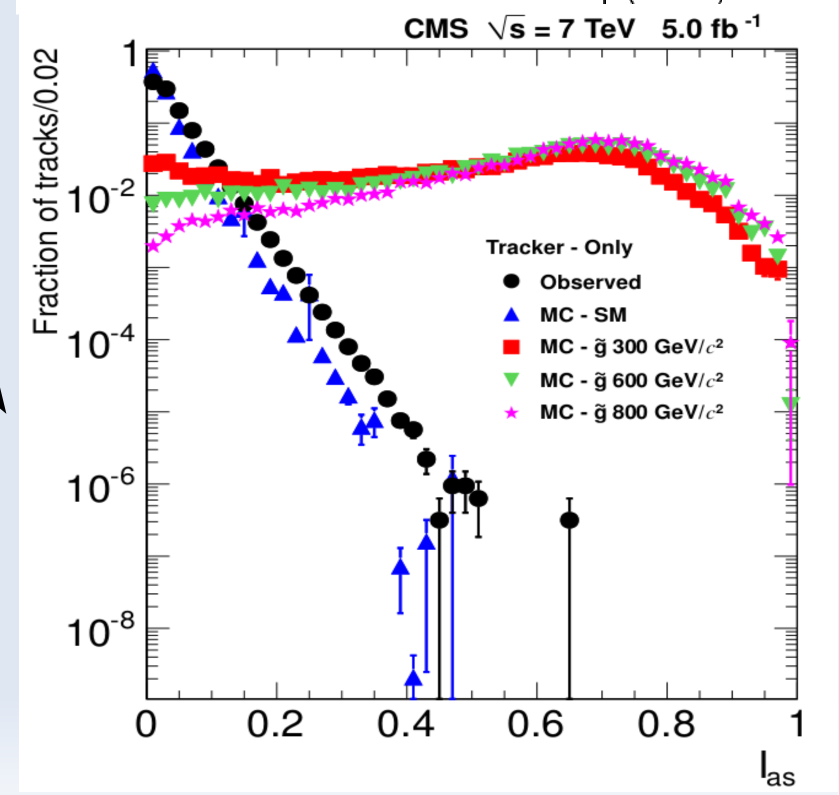
via relation:

$$I_h = K \frac{m^2}{p^2} + C$$

K = 2.559 MeV cm^{-1} c^{-2}
C = 2.772 MeV cm^{-1}

is used to estimate the mass of the HSCP canadidate, whereas value of a discriminator:

$$I_{as} = \frac{3}{N} \times \left(\frac{1}{12N} + \sum_{i=1}^{N} \left[P_i \times \left(P_i - \frac{2i-1}{2N} \right) \right]^2 \right)$$



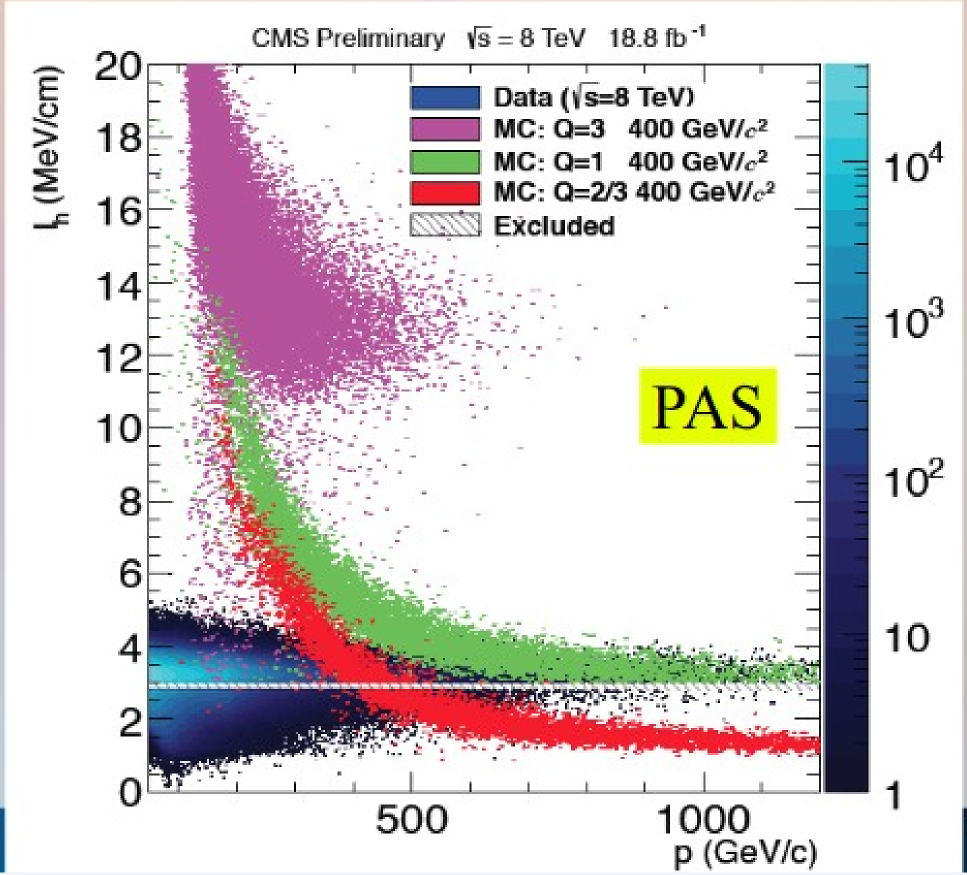
is used to obtain signal and control regions.
P_i is the probability that MIP will give signal smaller than recorded for a given hit *i*.

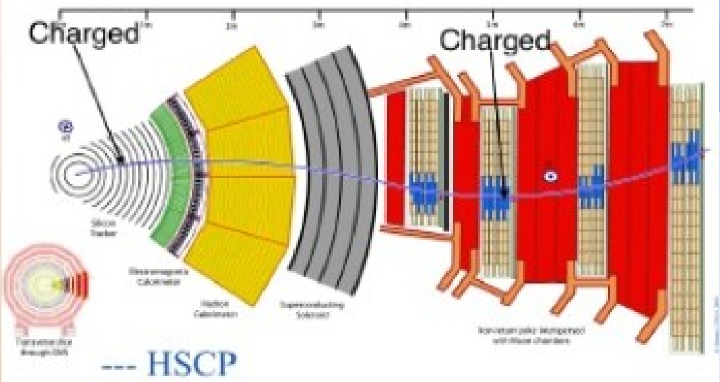
Different Searches

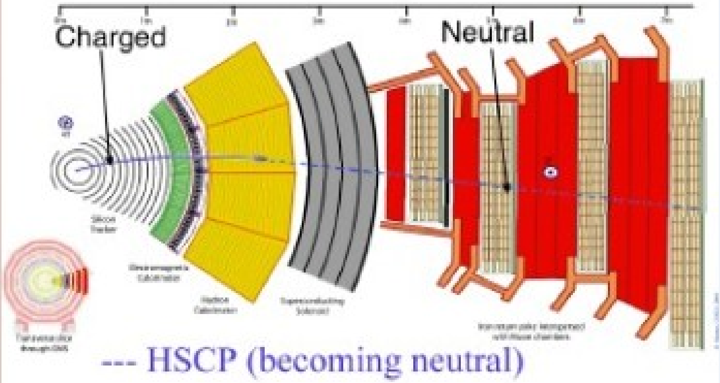
2012 analysis

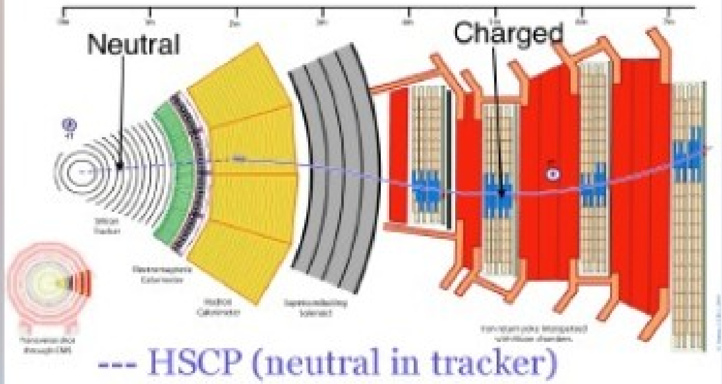
Five different analyses to search for different HSCP signatures

Analysis	Analysis is based on	Useful variables
Tracker-only	tracker	p_T, dE/dx
Tracker+TOF	tracker, muon system	p_T, dE/dx, $1/\beta$
muon-only	muon system	$p_{T\mu}$, $1/\beta$
multiply charged	tracker, muon system	dE/dx, $1/\beta$
fractionally charged	tracker	p_T, dE/dx

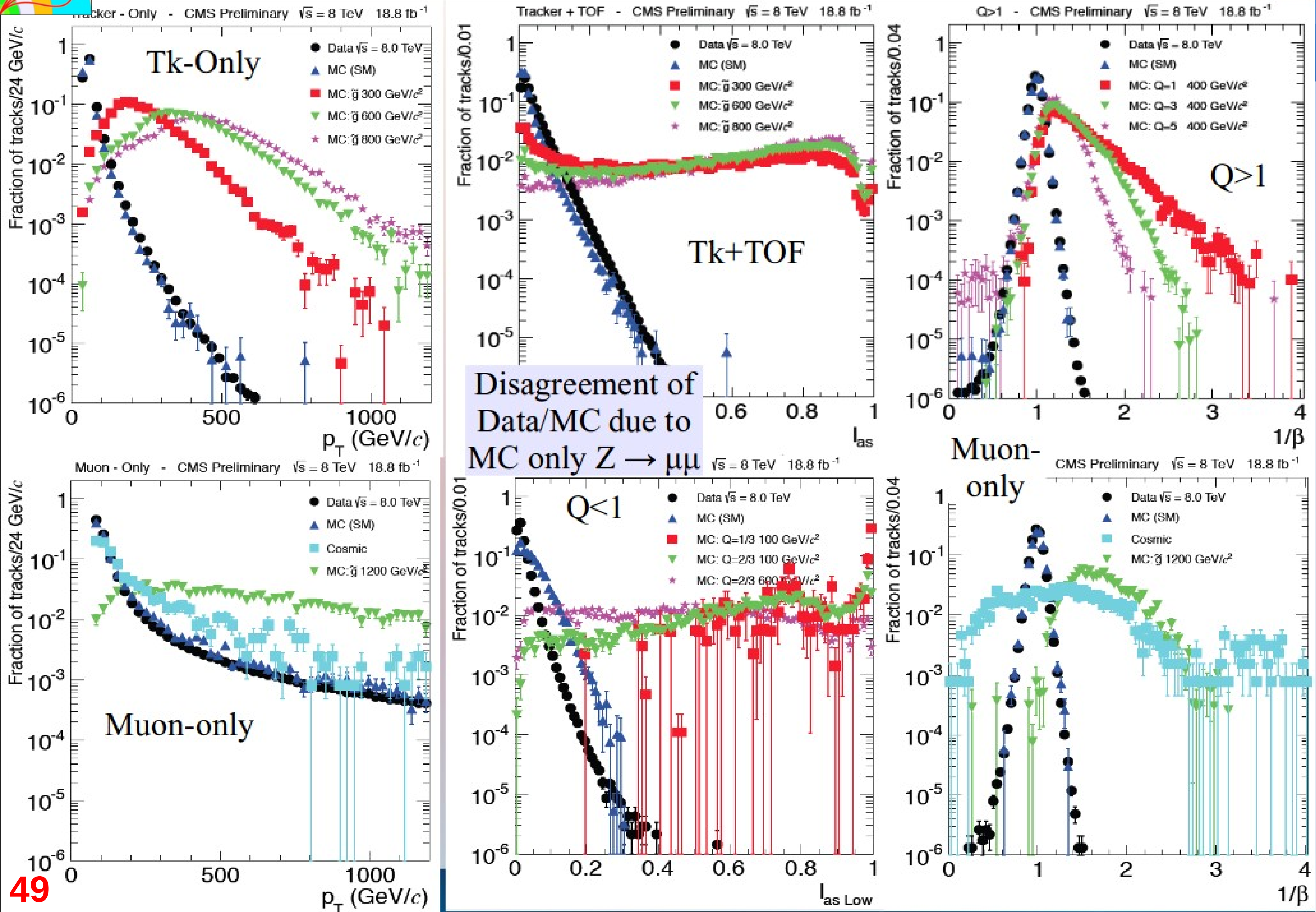








Variable Distributions

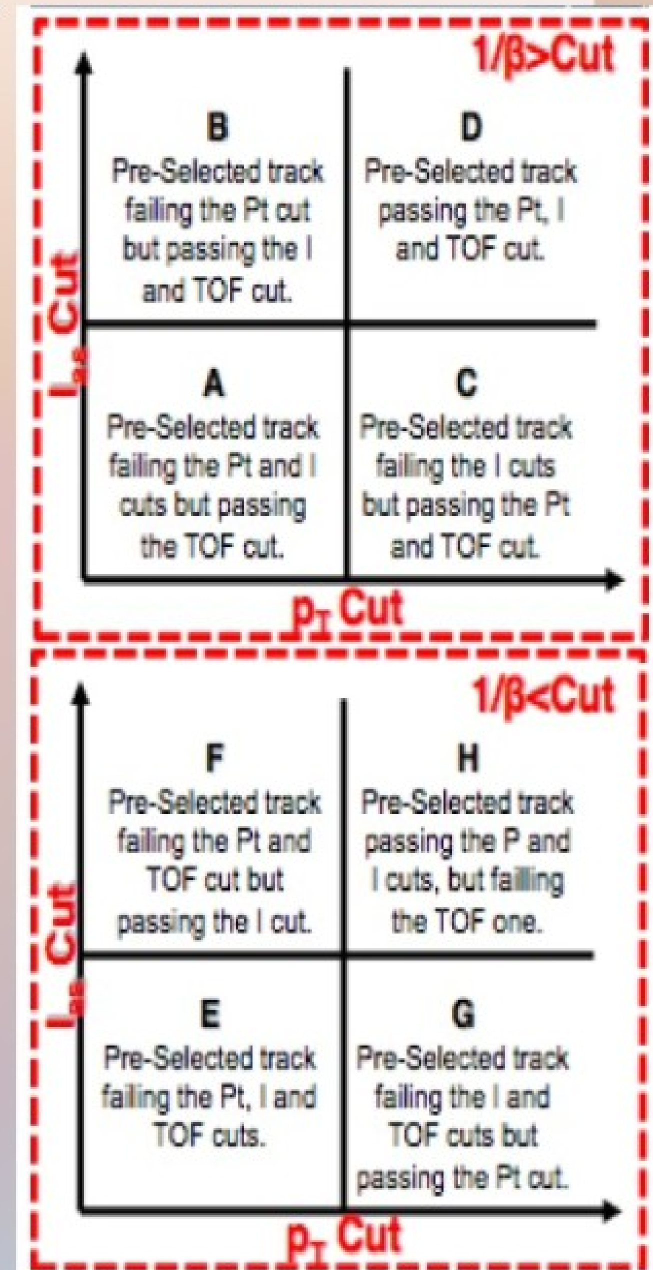


Background Prediction

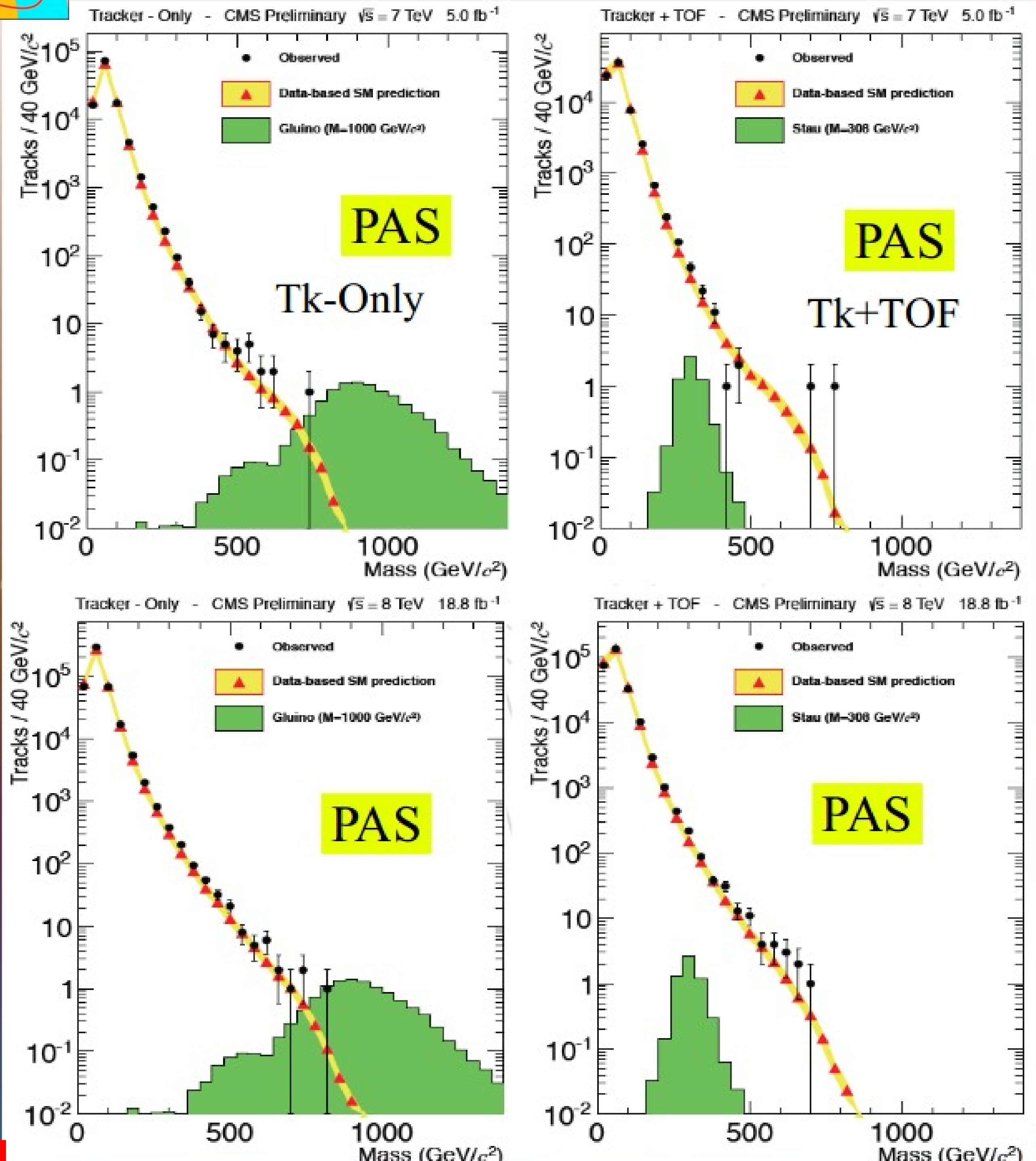
- Collision muons – Data driven ABCD method
  - p_T, Ias, $1/\beta$ used to determine number of events in signal region, D

    Tk-Only: p_T-I_{as}
    Tk+TOF: p_T-I_{as}-$1/\beta$
    Muon-only: p_T-$1/\beta$
    Q>1: I_{as}-$1/\beta$
    Q<1: p_T-I_{as}

    - Tk+TOF uses extended 3-D method – $D = AFG/E^2$
  - Background mass shape for Tk-only and Tk+TOF predicted using I_h and P distributions from control regions and mass equation
    - Tracks for P distribution reweighted to match eta distribution for I_h tracks
    - Search region is signal average $M_{RECO} - 2\sigma_{M\ RECO}$
- Cosmic background for muon-only and Q<1
  - Predicted from vertex sideband regions
  - Normalization for muon-only done with cosmic control sample



Mass Distributions



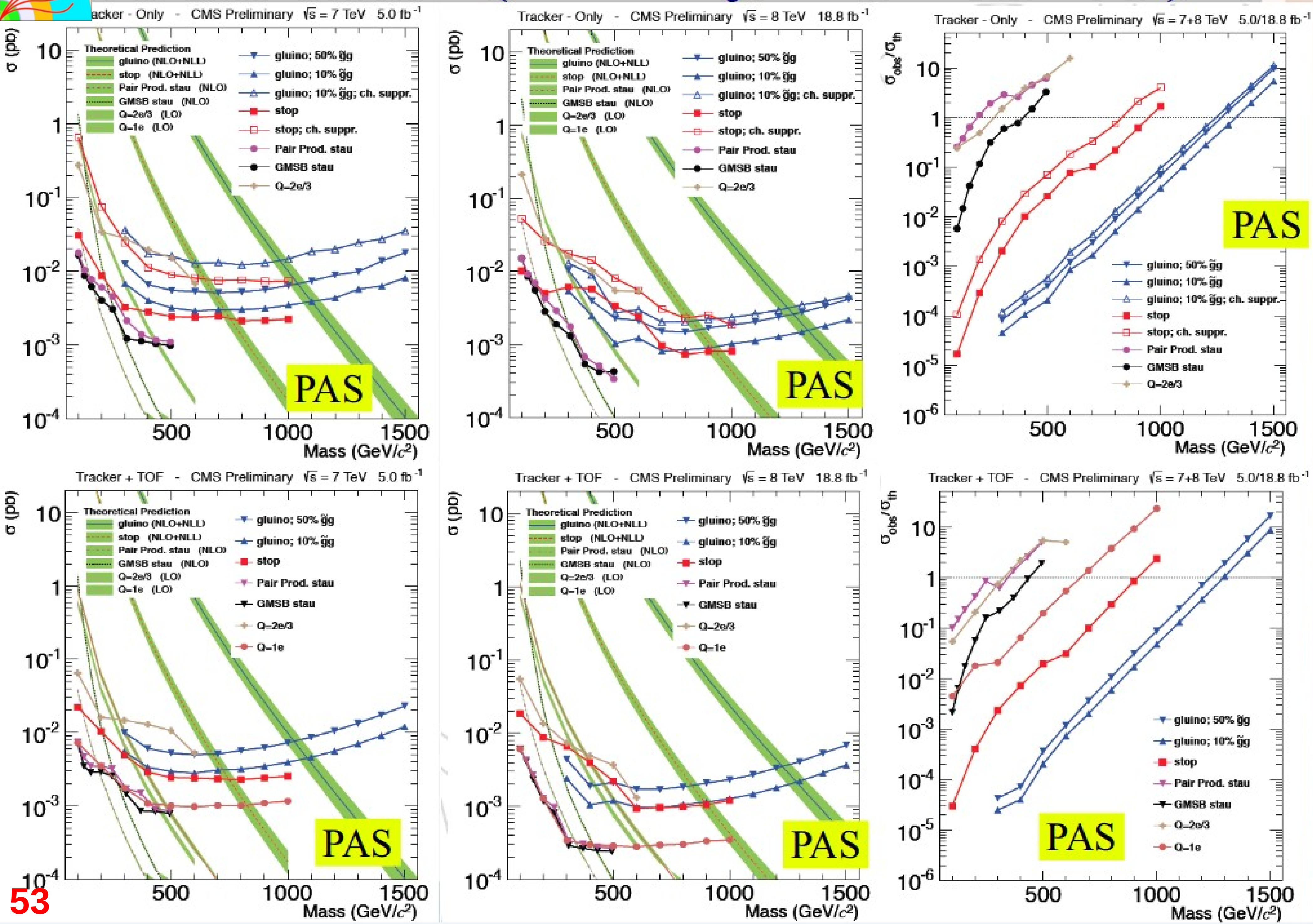
Loose Selection

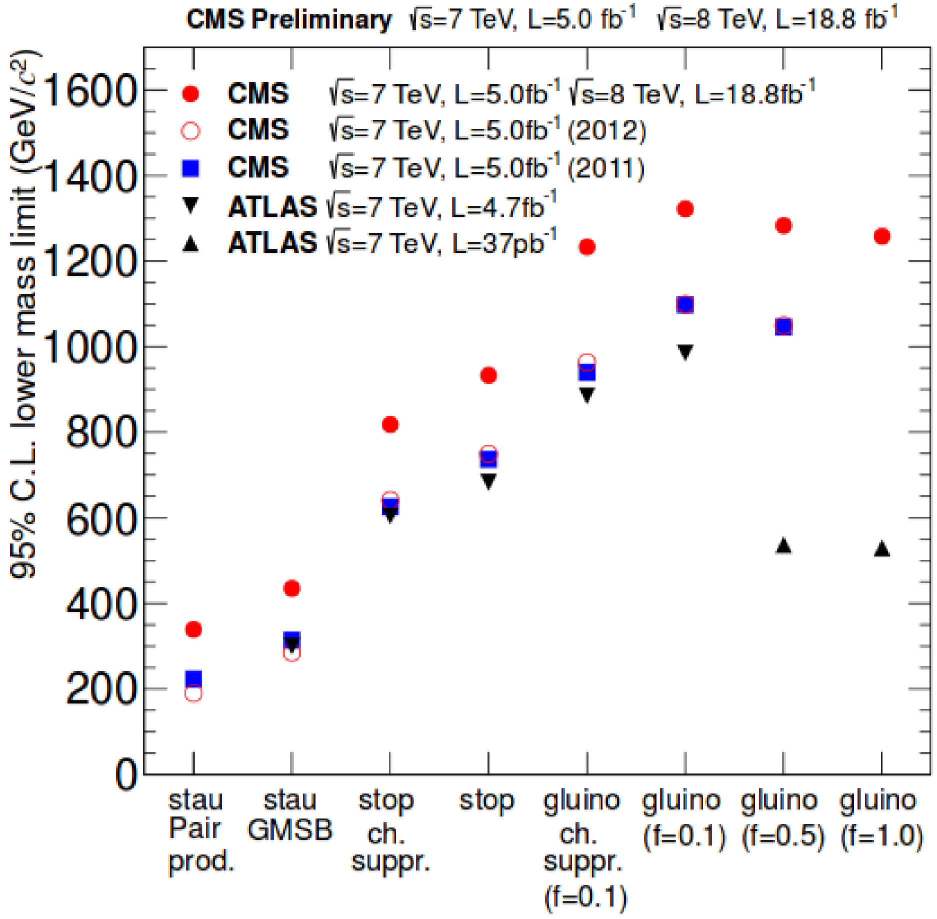
Results

Table 1: Results of the final selections for predicted background and observed number of events. Uncertainties are statistical and systematic.

	Selection criteria				Numbers of events $\sqrt{s} = 7$ TeV		Numbers of events $\sqrt{s} = 8$ TeV	
	p_T (GeV/c)	$I_{as}^{(\prime)}$	$1/\beta$	Mass (GeV/c^2)	Pred.	Obs.	Pred.	Obs.
tracker-only	> 70	> 0.4	-	> 0	7.1 ± 1.5	8	32.5 ± 6.5	41
				> 100	6.0 ± 1.3	7	26.0 ± 5.2	29
				> 200	0.65 ± 0.14	0	3.1 ± 0.6	3
				> 300	0.11 ± 0.02	0	0.55 ± 0.11	1
				> 400	0.030 ± 0.006	0	0.15 ± 0.03	0
tracker+TOF	> 70	> 0.125	> 1.225	> 0	8.5 ± 1.7	7	43.5 ± 8.7	42
				> 100	1.0 ± 0.2	3	5.6 ± 1.1	7
				> 200	0.11 ± 0.02	1	0.56 ± 0.11	0
				> 300	0.020 ± 0.004	0	0.090 ± 0.02	0
muon-only	> 230	-	> 1.40	-	—	—	5.6 ± 2.9	3
$\lvert Q \rvert > 1e$	-	> 0.500	> 1.200	-	0.15 ± 0.04	0	0.52 ± 0.11	1
$\lvert Q \rvert < 1e$	> 125	> 0.275	-	-	0.12 ± 0.07	0	0.99 ± 0.24	0

Limit Plots (Tk-Only and Tk+TOF)





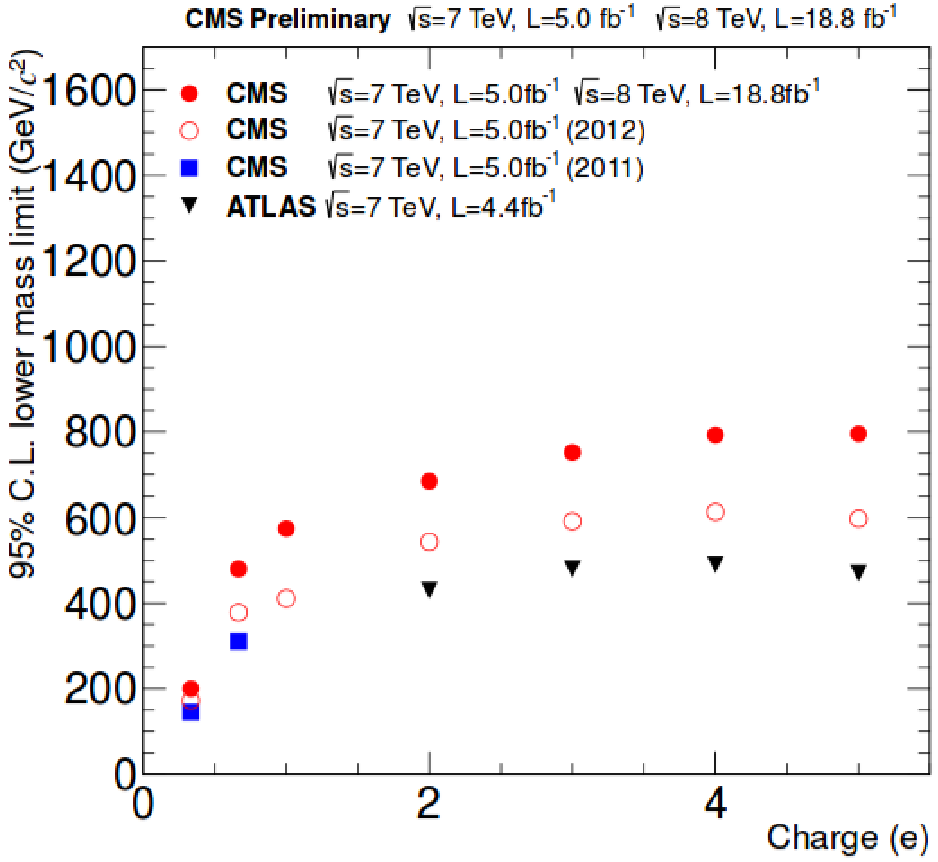


Figure 10: Obtained mass lower limits at 95% C.L. on various models compared with previously published results [18–25]. Left: The model type is defined by the X-axis. Right: Mass limits for Drell-Yan like production versus electric charge.

BooMerang (& other ideas)

Backward off-time off-point Muons

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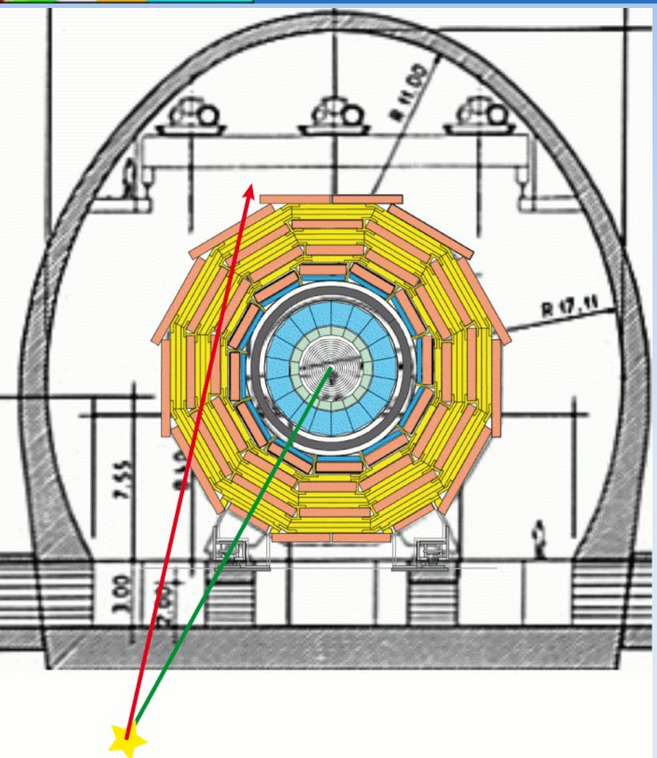


Motivation

- search for HSCP → muon decays (stau NLSP);
- HSCP lifetime determination;
- sensitive to LSP mass;
- spin-off: cosmic veto, CMS as an upward neutrino detector, etc.

How? muon flight direction by RPC at L1

- by using spare RPC trigger hardware;
- a duplicate of the TTU RPC trigger; → → → →
- information form the whole barrel (not wheel based);
- trigger on upward muons only (to reject cosmics).

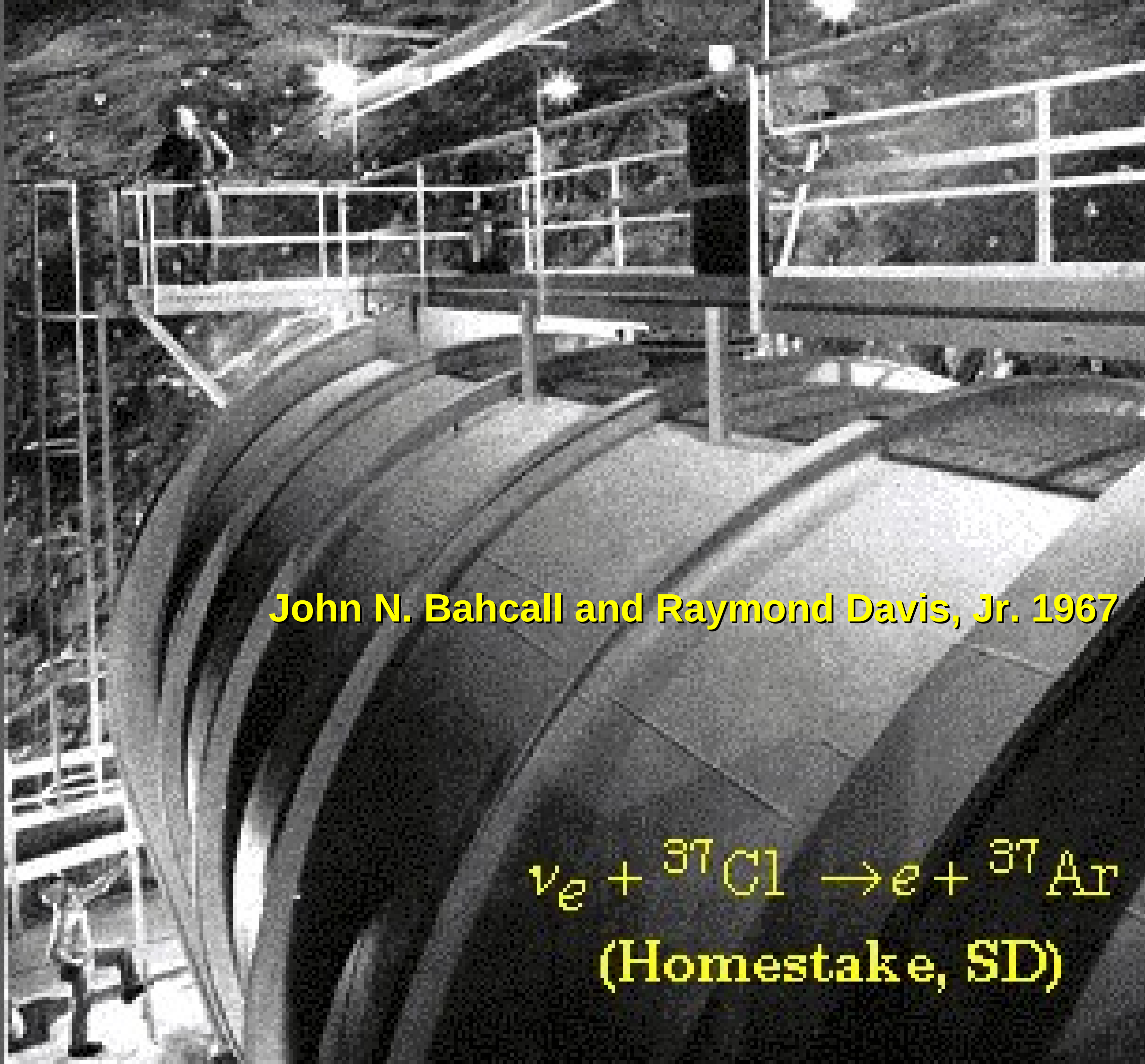
Pros:

- complementary to calorimetric ”stopped gluino” search;
- sensitive also to HSCPs stopped in the iron yoke;
- off-beam inter-wheel cosmic trigger possible;
- ”shower in the ECAL due to cosmic” veto (?).

Cons:

- low geometric efficiency :-(
- impossible to add forward RPC (without an upgrade).

or → water? Xenon? Argon?


John N. Bahcall and Raymond Davis, Jr. 1967
$\nu_e + {}^{37}\mathrm{Cl} \rightarrow e + {}^{37}\mathrm{Ar}$
(Homestake, SD)

Conclusions

We (CMS) have not yet found any exotic beast, but we keep searching.