Heavy Ion Physics in CMS

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for the CMS Heavy Ion group

LHC Beam request workshop
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Basel, CERN, Dubna, Kiev, Lyon, MIT, Moscow, Protvino, PSI, Rice, Sofia, Strasbourg,
TAMU, Tbilisi, UC Davis, UC Riverside, UI Chicago, U. Iowa, Yerevan, Warsaw

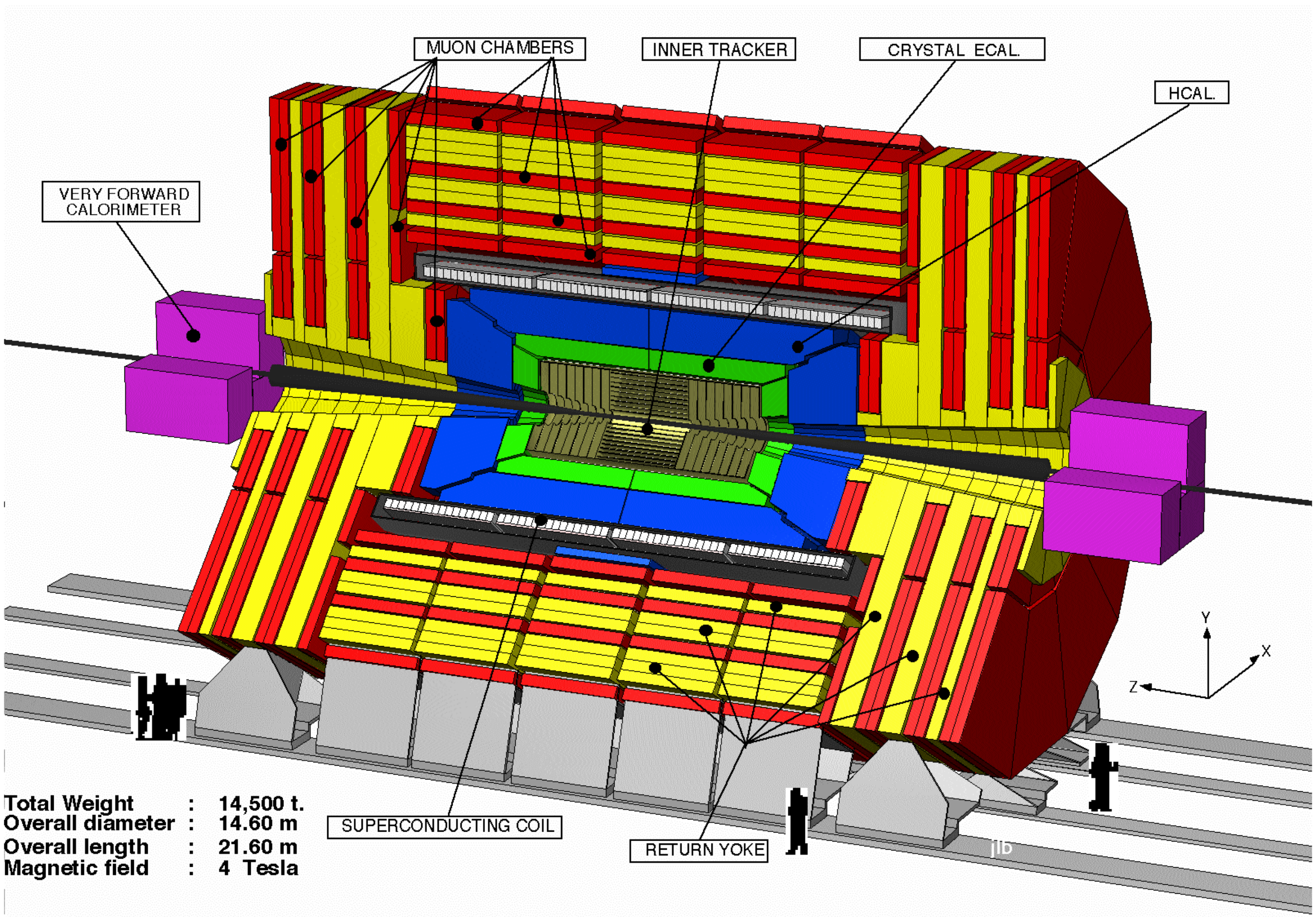
Physics Program Using Ions

- **A+A: Study of hot nuclear matter**
  - **restoration of QCD symmetries**
  - **deconfinement**
  - **properties of quark-gluon plasma**
- **p+A: Study of cold nuclear matter**
  - **better understanding of A initial state**
  - **nuclear structure functions: large Q^2, small x**
  - **reference for A+A data and theory interpretation**
- **Note: ion physics is largely “data driven”: the theoretical models need verification by varying ion species, energies etc.**

The Physics Landscape: Pb+Pb Collisions SPS->RHIC->LHC

	SPS(17)	**RHIC**(200)	**LHC**(5500)
$dN_{ch}/d\eta$	350	700	3000-8000 ?
ϵ [GeV/fm^3] ($t_0 = 1$ fm/c)	≈ 2.5 1	$\approx 3.5 - 7.5$ 2	$\approx 15 - 40$ 10
V_f [fm^3]	$\approx 10^3$ 1	$\approx 7 * 10^3$ 7	$\approx 2 * 10^4$ 20
τ_{QGP} [fm/c]	≤ 1 1	$1.5 - 4$ 3	4-10 7
τ_0	≥ 1	≈ 0.5	≤ 0.2
τ_{QGP}/τ_0	1	6	≥ 30

A Compact Muon Solenoid for LHC:
A Multipurpose detector



Total Weight : 14,500 t.
Overall diameter : 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla

CMS as a Heavy Ion Experiment

- **Excellent detector for high p_T probes:**
  - **Rates and cross sections**
    - quarkonia
    - jet production
    - high energy photons
    - Z^0
  - **Correlated measurements**
    - jet-γ
    - jet-Z^0
    - multi jets
- **"global" quantities**
  - **Energy flow, including very forward region**
  - **Charged Multiplicity**
  - **Centrality Determination**

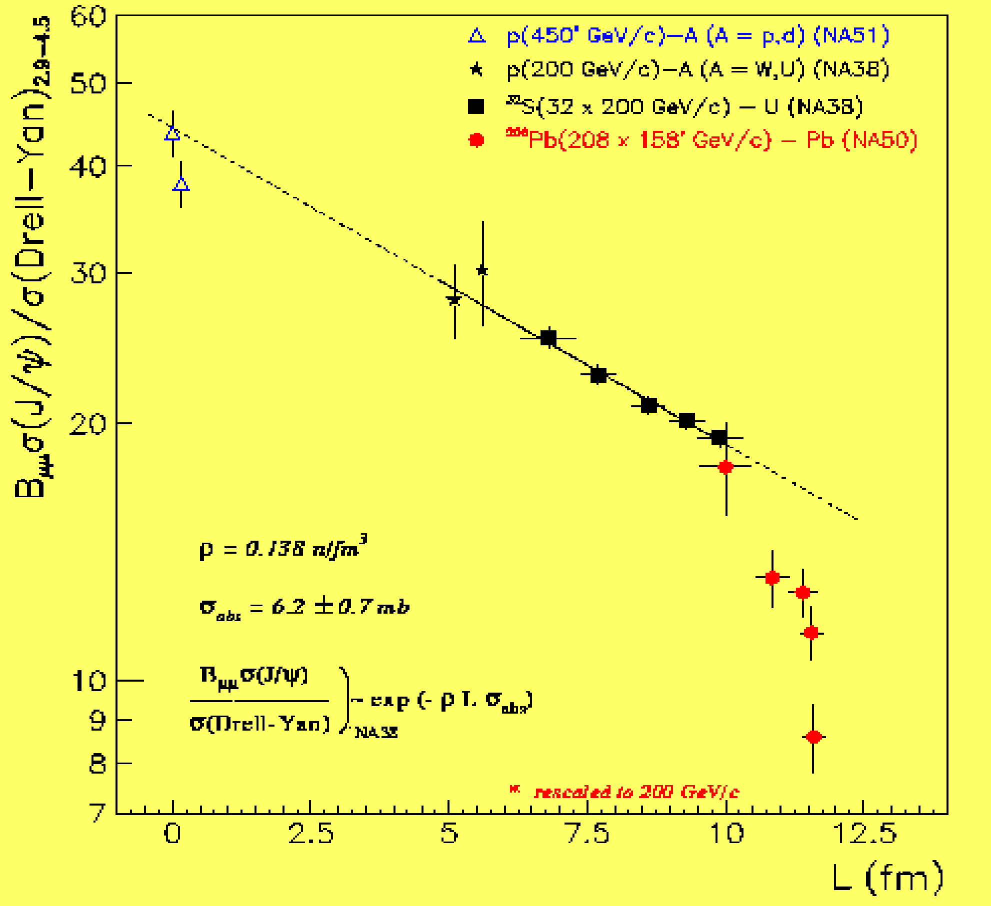
Experimental Assets for Heavy Ions

- Large coverage, high granularity calorimeters
- Large acceptance muon detector
- Pixel detectors
- Silicon Tracker (evaluation in progress…)
- High rate data acquisition

- Detector additions to fully exploit heavy ion capabilities:
  - Zero Degree Calorimeter
  - Forward calorimeter: “CASTOR”

- **Suppression of quarkonia production has been advocated as a signal of deconfinement**
- **J/y suppression observed by NA50 at SPS, a "trigger" for CMS HI program**
- **Major part of RHIC program: results on J/y expected shortly (QM2002?)**
- **At LHC we will be able to measure production of different quarkonium states, ratio ¡'/ ¡ as a function of Et, pt, y, centrality**

NA50 Collaboration, CERN



L(fm): Average distance travel by the J/y inside the Nuclear Matter.

Quarkonia Cross Section at LHC

Quarkonia cross sections

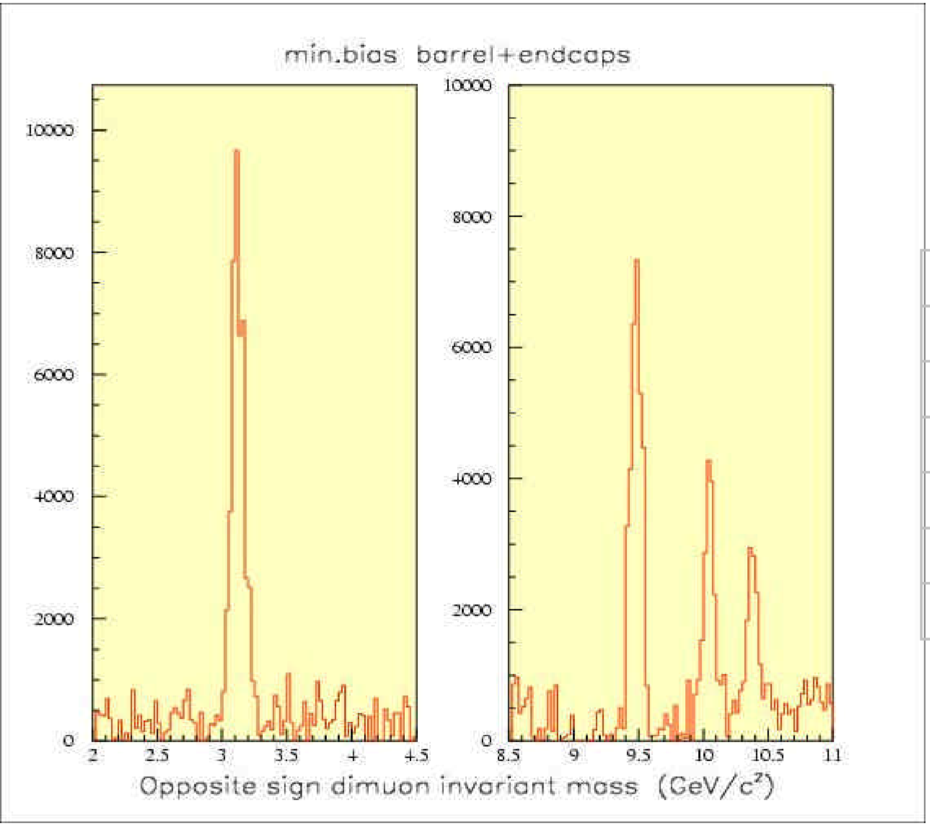
- estimated for minimum bias collisions
- scaling » A^{2a} with a= 0.90 for J/y and a= 0.95 for ¡ (approx scaling with number of nucleon pairs: binary)

	Pb	Sn	Kr	Ar
J/ψ →2μ (mb)	60	23	12	3.5
Υ(1S) →2μ (mb)	380	137	72	19

y¢/y = 2%   ¡¢/¡= 0.47   ¡²/¡= 0.25

Quarkonia in CMS

J/ψ ϒ family



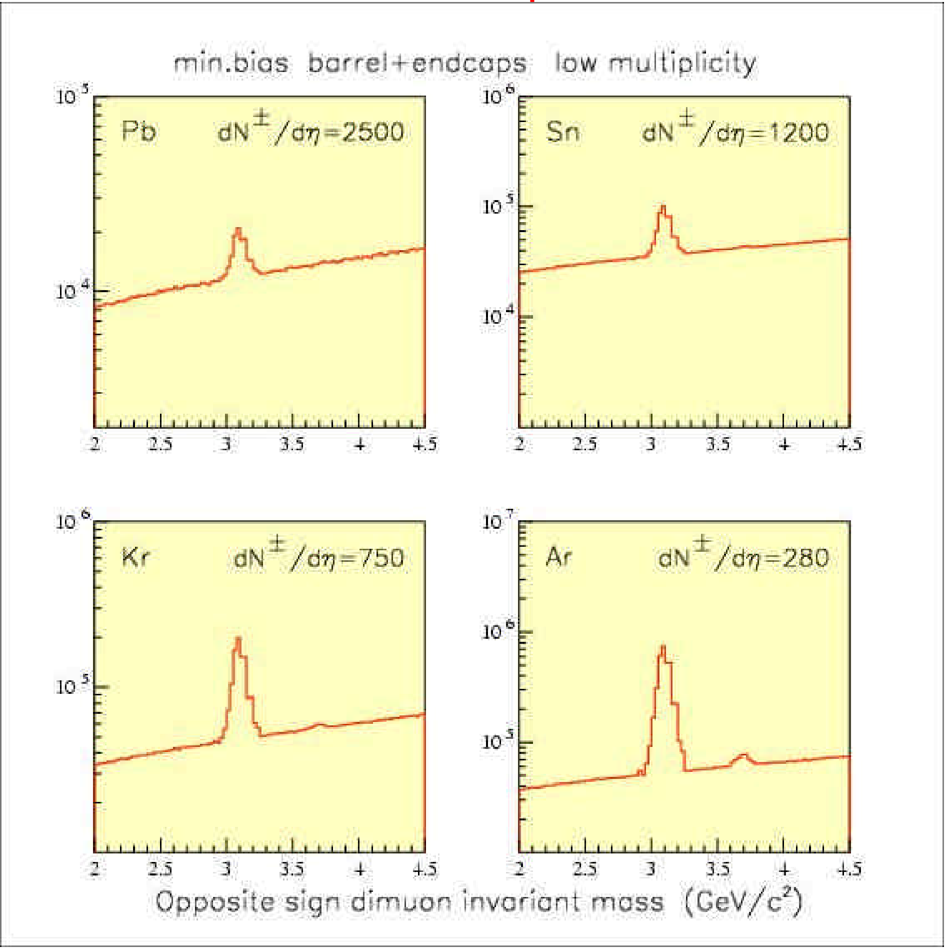
Yield/month (kevents, 50% eff)
Nominal luminosity for each ion species

	Pb+Pb	Sn+Sn	Kr+Kr	Ar+Ar
L	10^27	1.7 10^28	6.6 10^28	10^30
J/psi	28.7	210	470	2200
psi'	0.8	5.5	12	57
Upsilon	22.6	150	320	1400
Upsilon'	12.4	80	180	770
Upsilon''	7	45	100	440

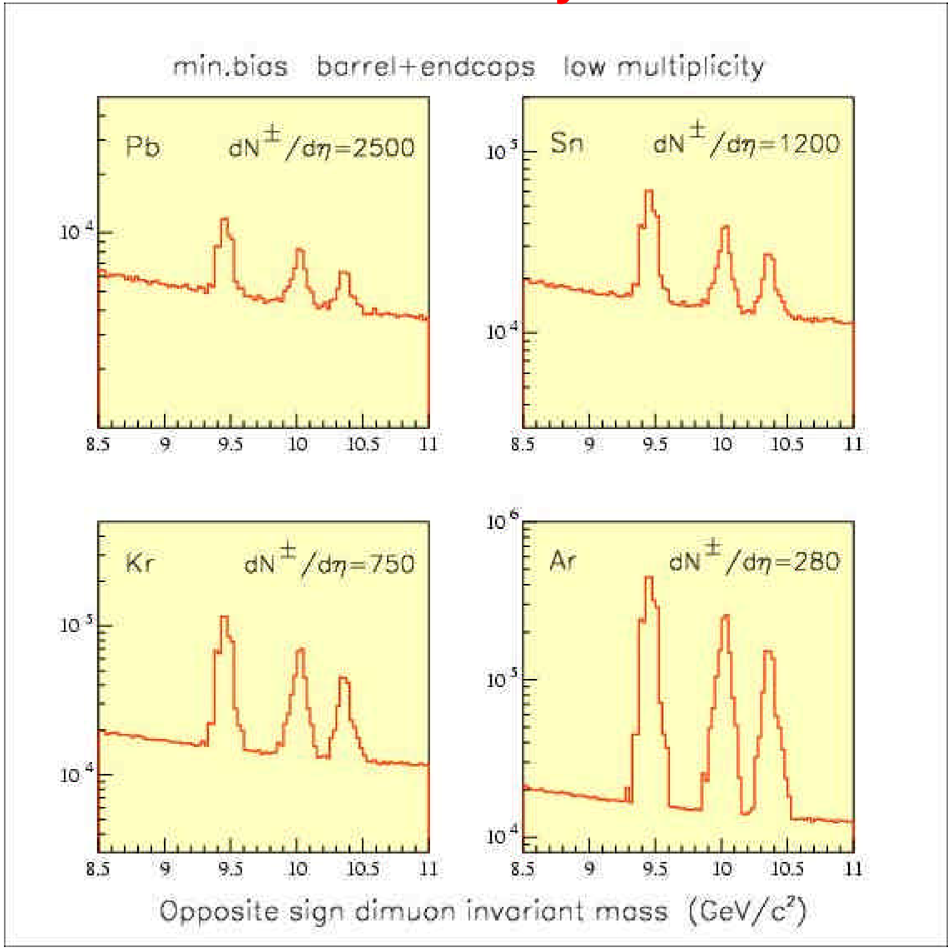
Pb+Pb, 1 month at $L=10^{27}$

Quarkonia from Different Ion Species

J/ψ

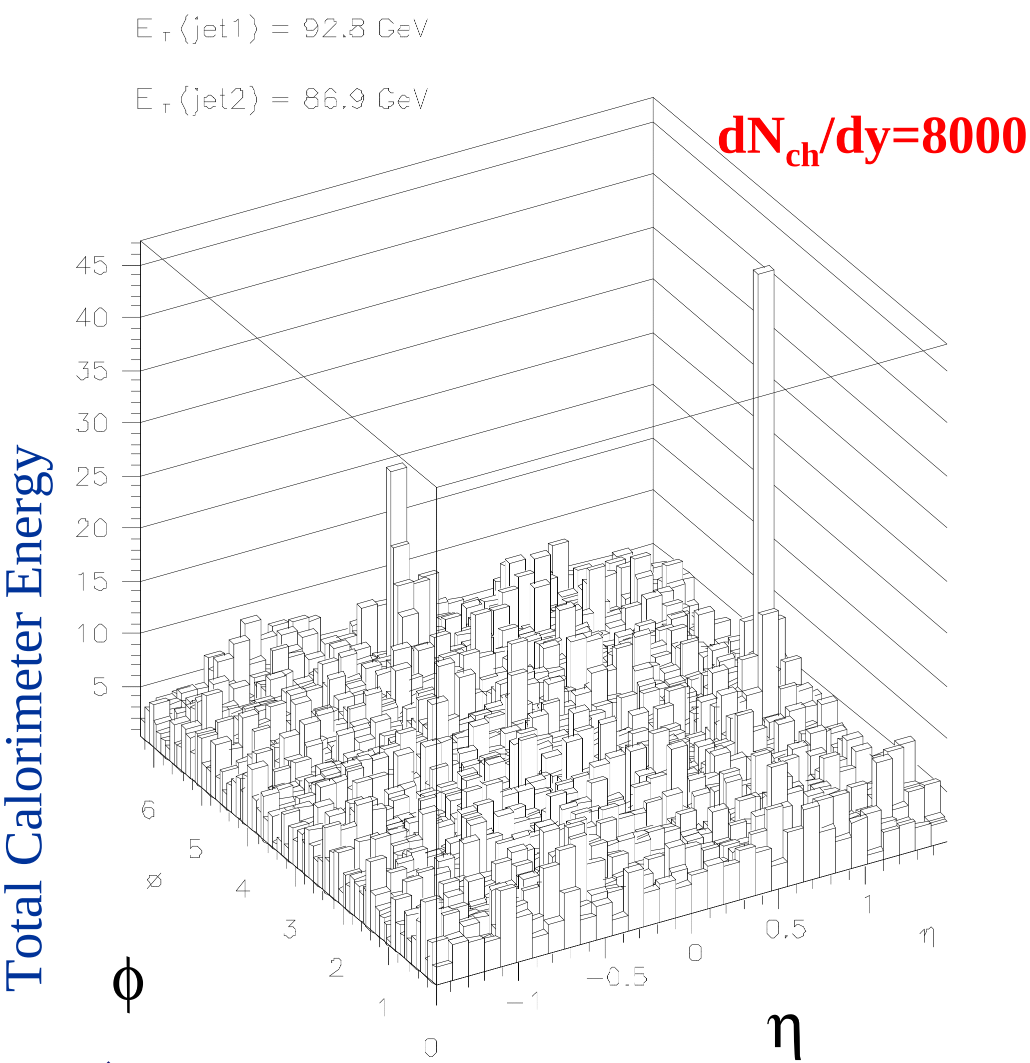


Υ family



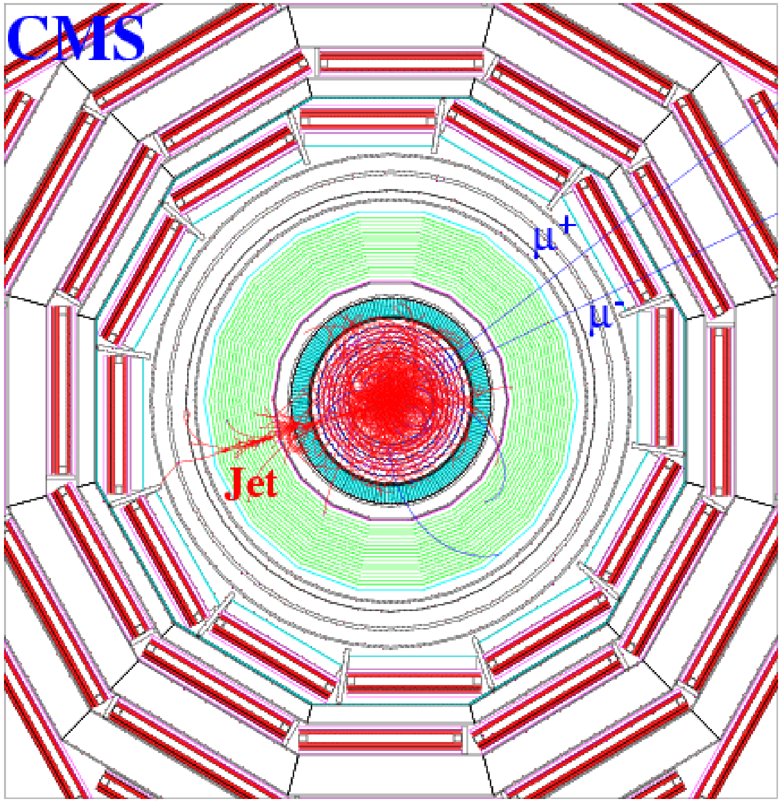
Need statistics to do systematic studies: p_T, centrality, energy
Also, compare to pA

Jet Detection



Z+jet event in the Heavy Ion collision

dN_{ch}/dy=5000



Pt(Z) = Et(Jet) = 100 GeV.

Jet reconstruction

1. Subtract average pileup
2. Find jets with sliding window
3. Build a cone around E_T^{max}
4. Recalculate pileup outside the cone
5. Recalculate jet energy

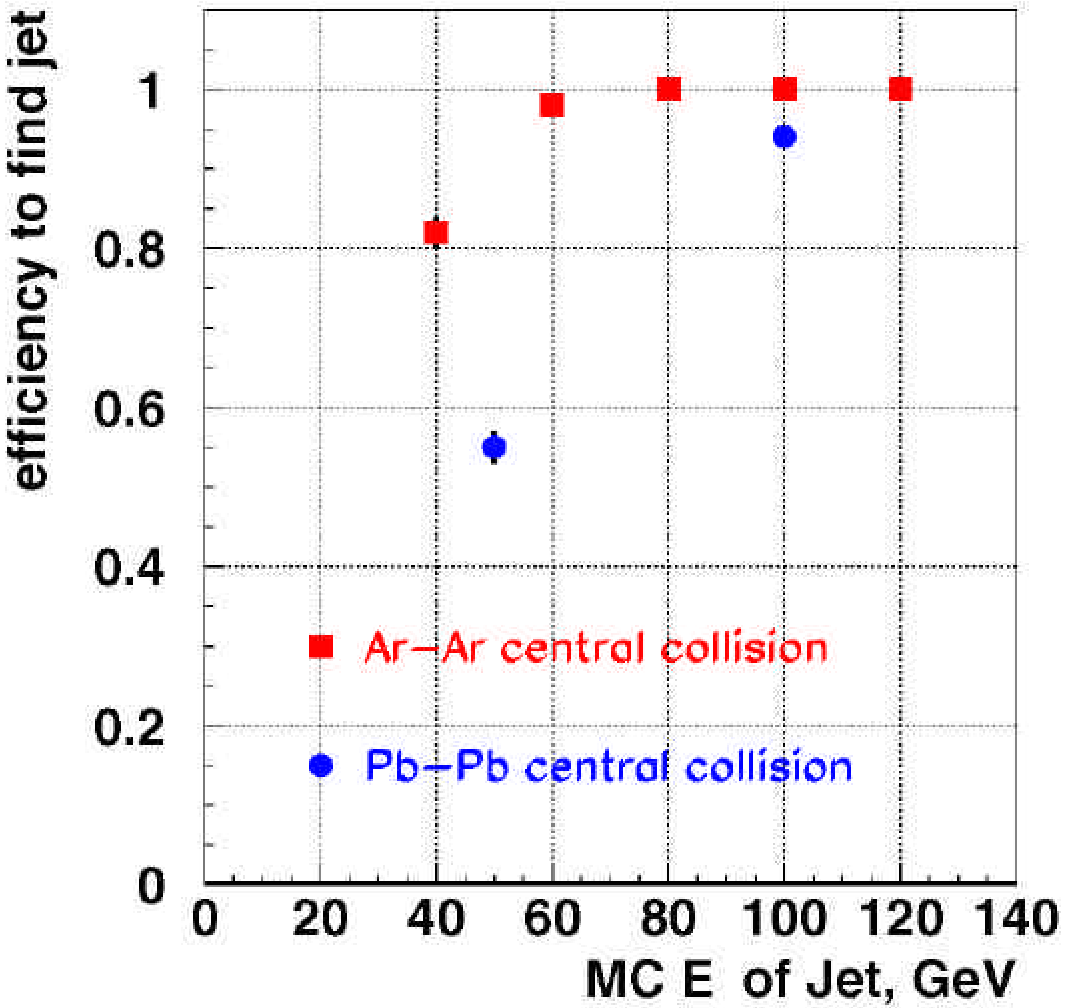
Efficiency:

>90% for jets with

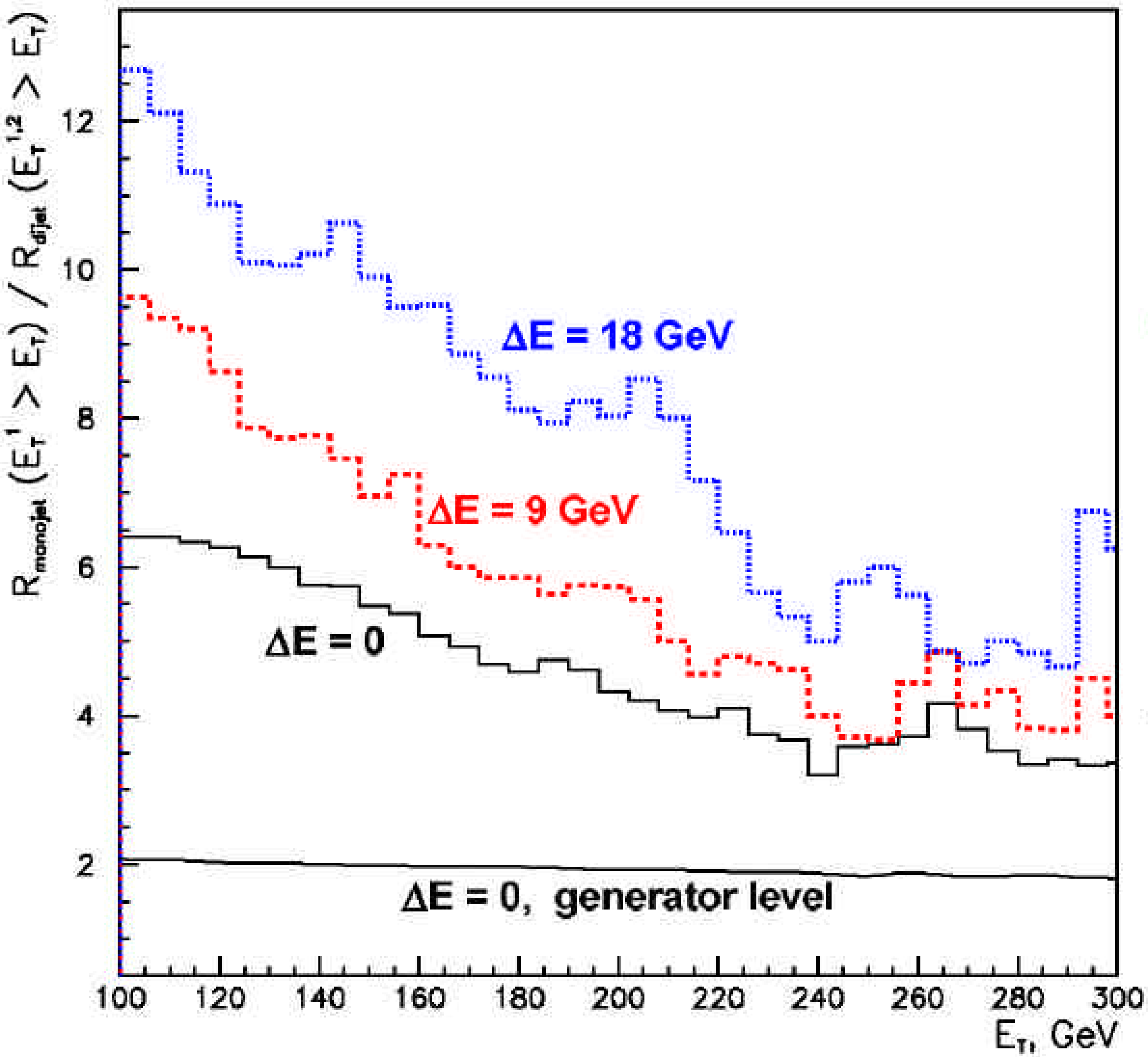
- E_T> 50 GeV in Ar-Ar
- E_T>100 GeV in Pb-Pb

Resolution:

$\sigma(E_T)/E_T \sim 19\ \%$



Jet quenching — j / jj ratio



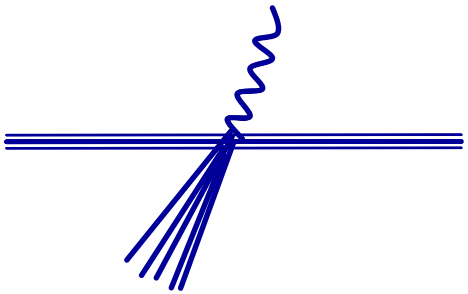
Partons traversing dense matter (QGP) lose their energy

Jets are softer by $\Delta E \sim 10$ GeV

One of 2 jets from e.g. $gg \rightarrow gg$ may not cross the threshold E_T

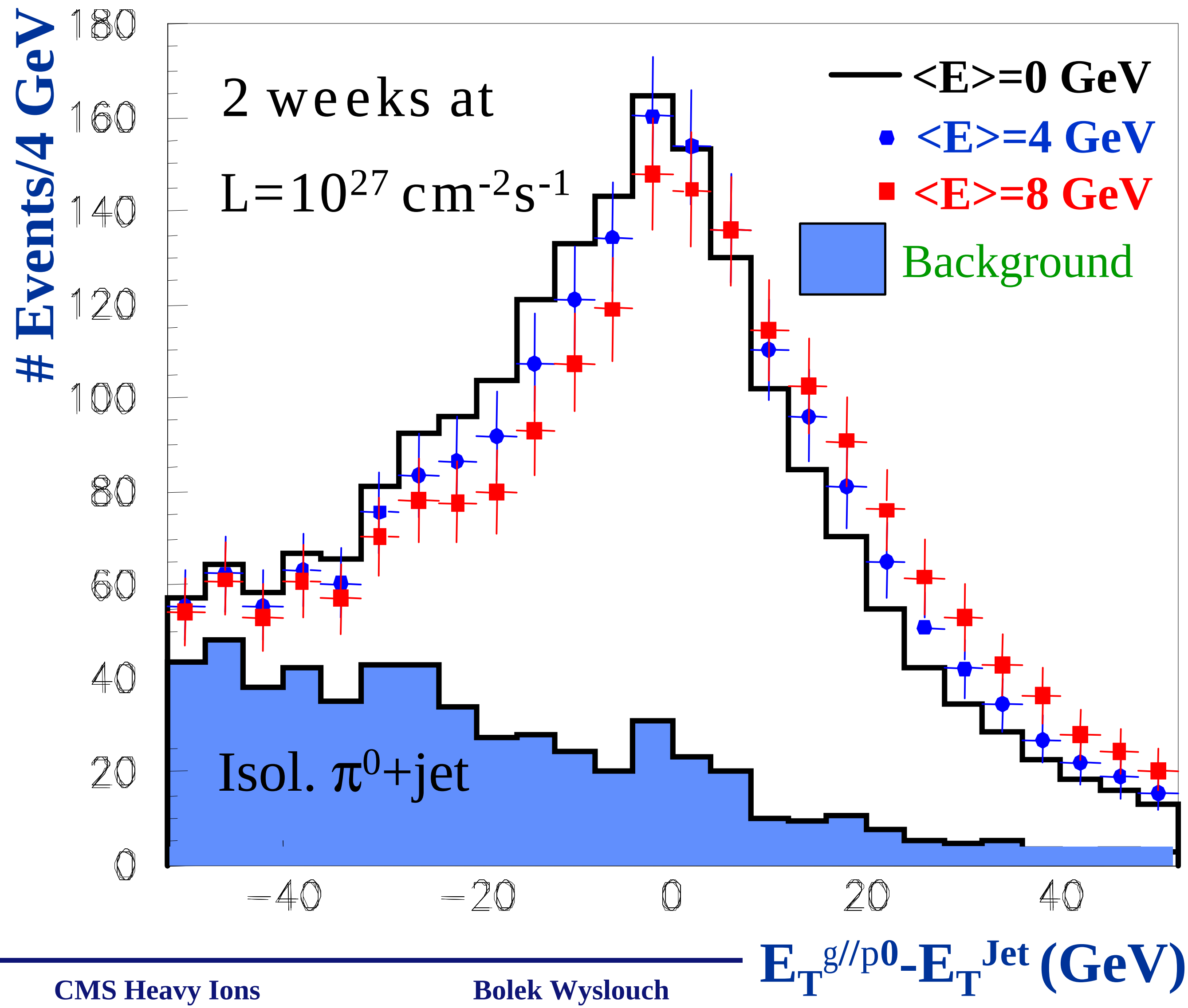
Monojet / dijet rate ratio measures dE/dx for gluons

Balancing Photons and Jets: Energy loss for quarks

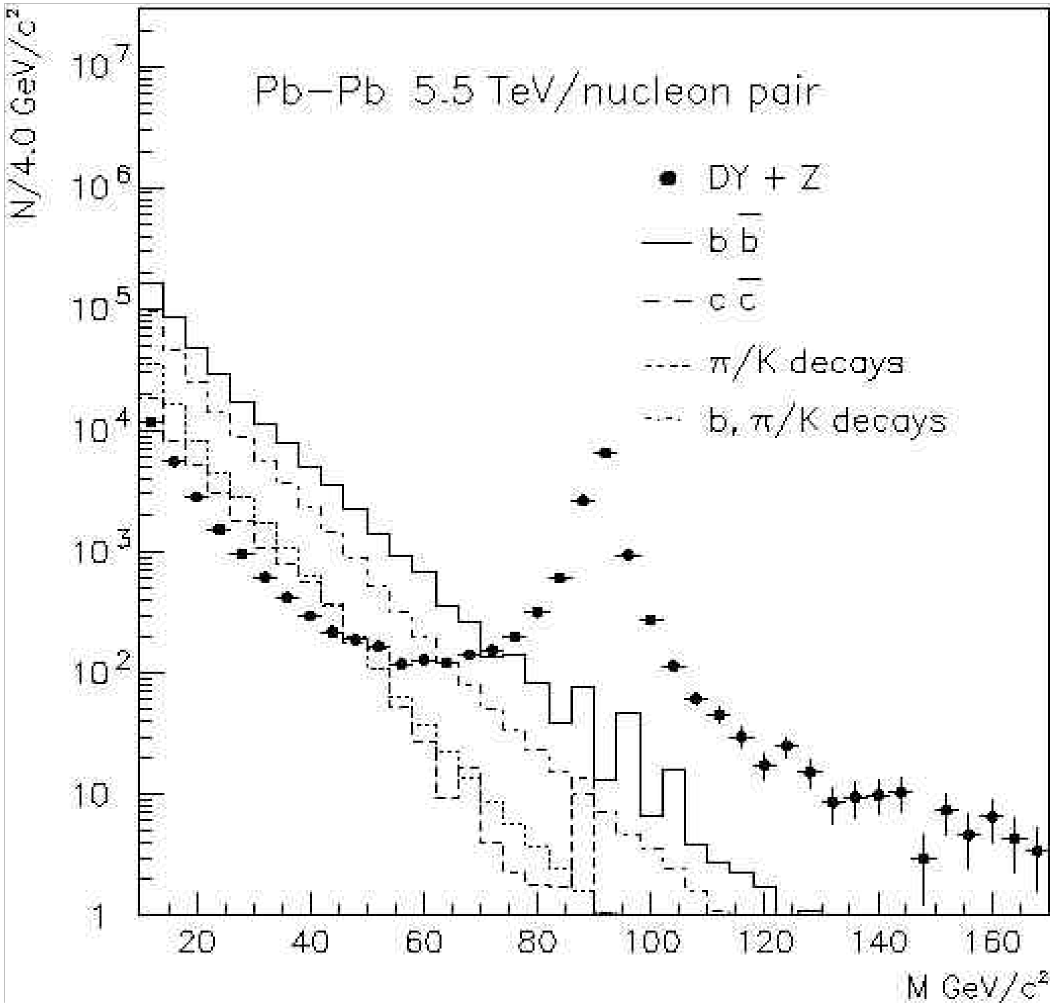


- $E_{Tjet,\,\gamma}$>120 GeV in the barrel
- 1 month
  - 900 events for Pb-Pb
- Example of a process where large acceptance is essential

Jet+Z^0 also possible 100-200 events per month



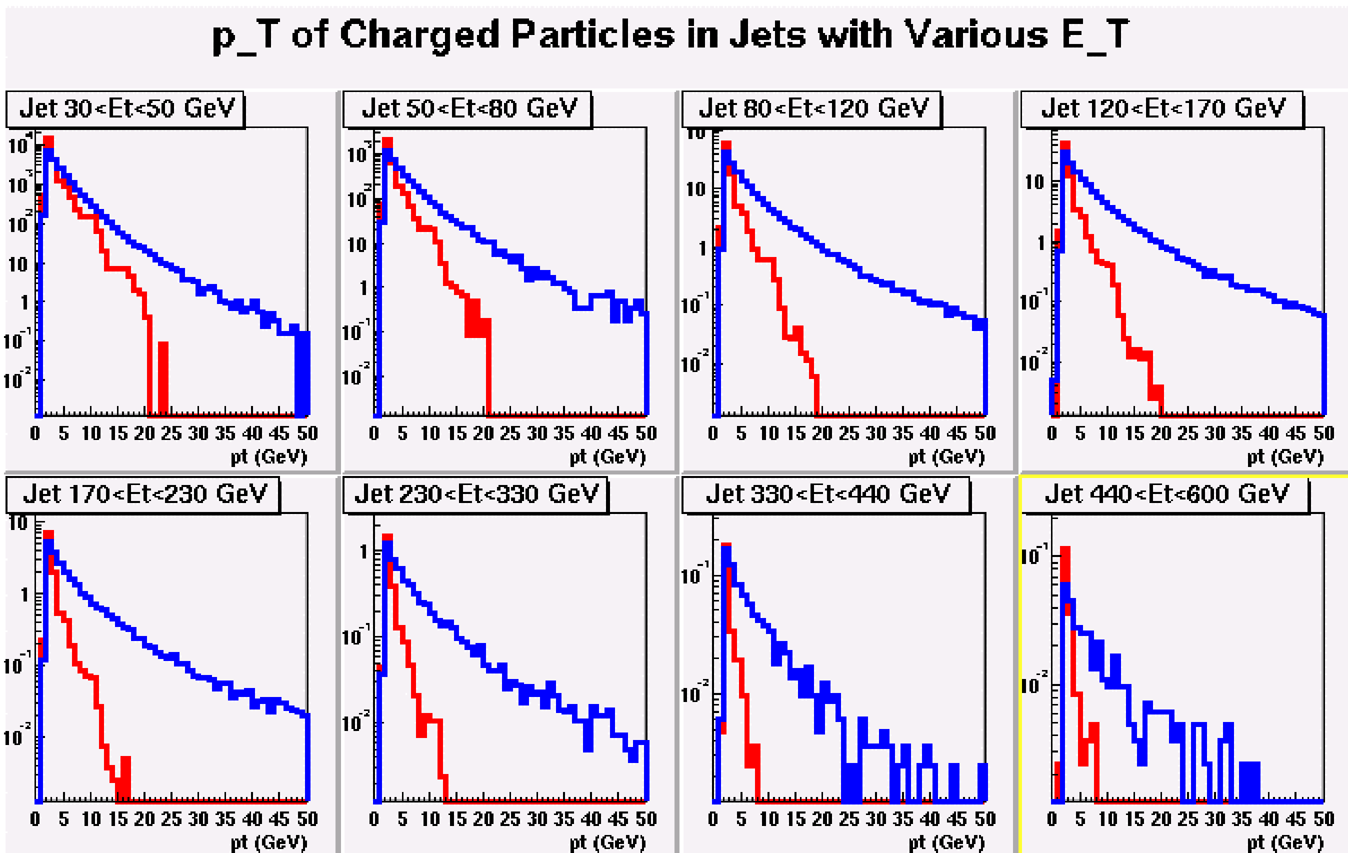
Z^0 production



- **Z^0-mm can be reconstructed with high efficiency**
- **A probe to study nuclear shadowing and parton energy loss**
- **Z^0 also proposed as reference to ¡ production.**
  - **Nuclear effects may depend on mass M_Z>$M_{¡}$**
  - **Different production mechanisms:**
    - Z_0: antiquark-quark, quark-gluon and antiquark-gluon.
    - ϒ: gluon-gluon.
- **~10^4 events/month (full CMS coverage)**

Jet Fragmentation, Effect of Nuclear Matter on Jet Structure

- **Find jets using calorimetry**
- **Study charged particle momenta inside of a jet using the tracker**
- **For this study use 4-5 outer layers of the tracker (use conservative resolution obtained in pp studies: AA plausible with low occupancy in outer layers)**

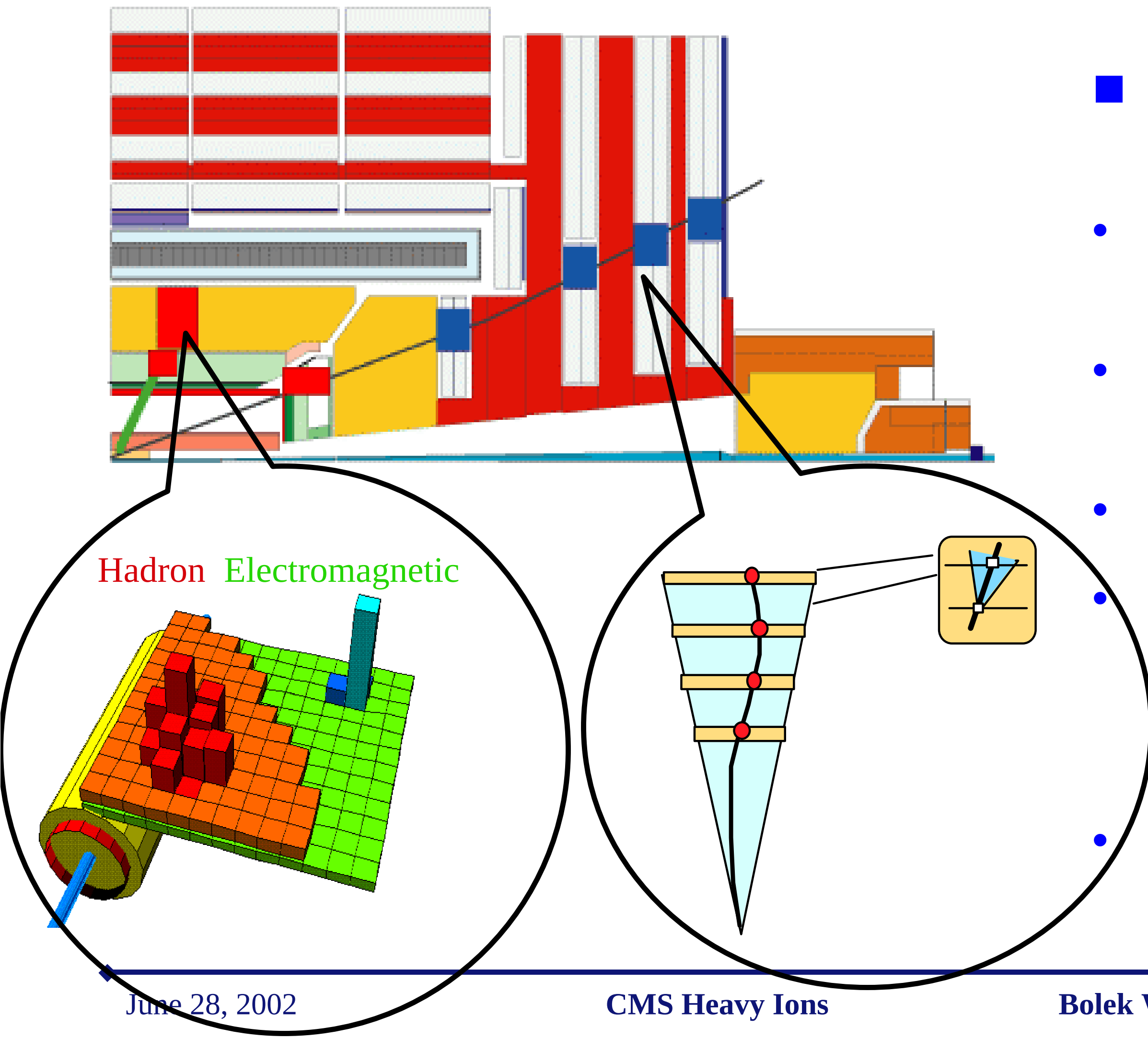


Particles in jet

Background

Similar analysis can be done with π^0

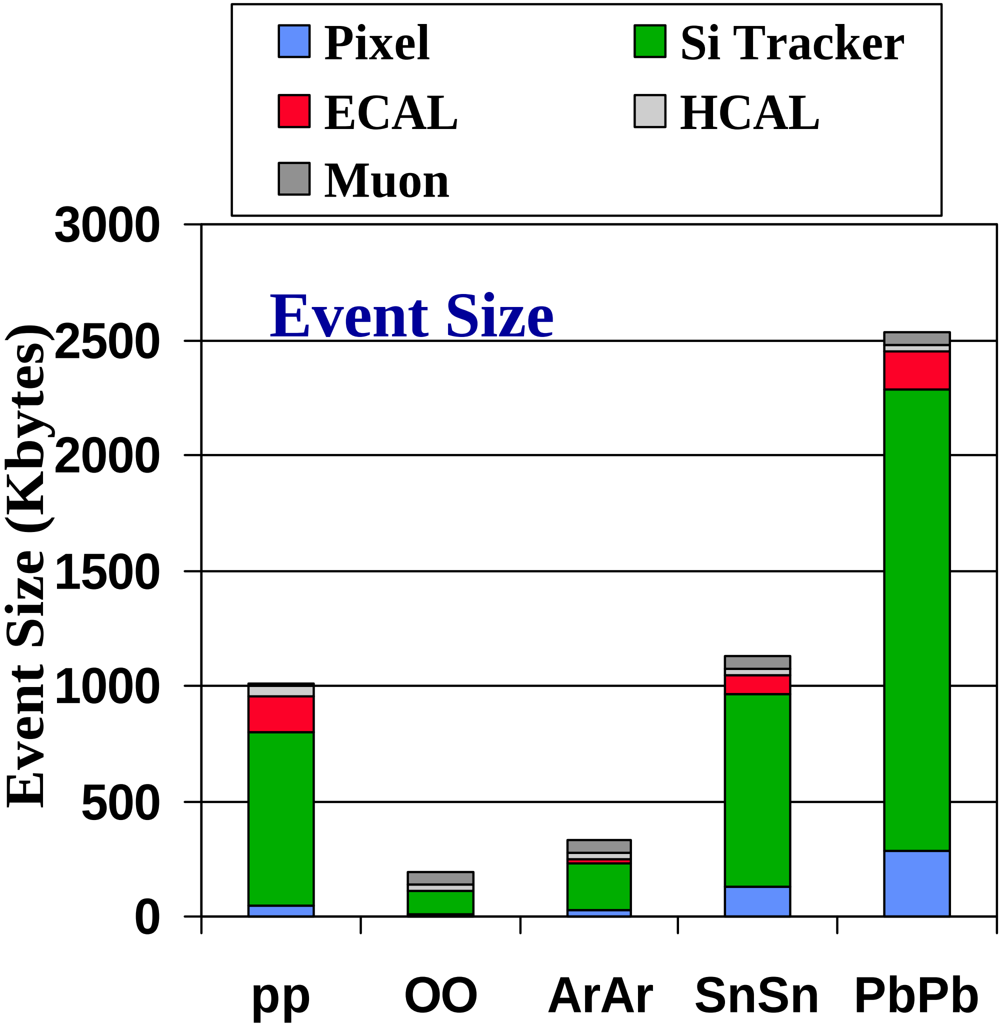
High Rate Capabilities: Level-1 Trigger



- Fast algorithms: 3 μs with coarse local data
- Only Calorimetry and Muon Detectors
- Special purpose hardware (ASICS)
- Centrality with ECAL, HCAL (including HF)
- ZDC for minbias.
- Trigger on e, μ, jets, Missing E_T. Rates steep function of p_T thresholds
- A+A higher backgrounds

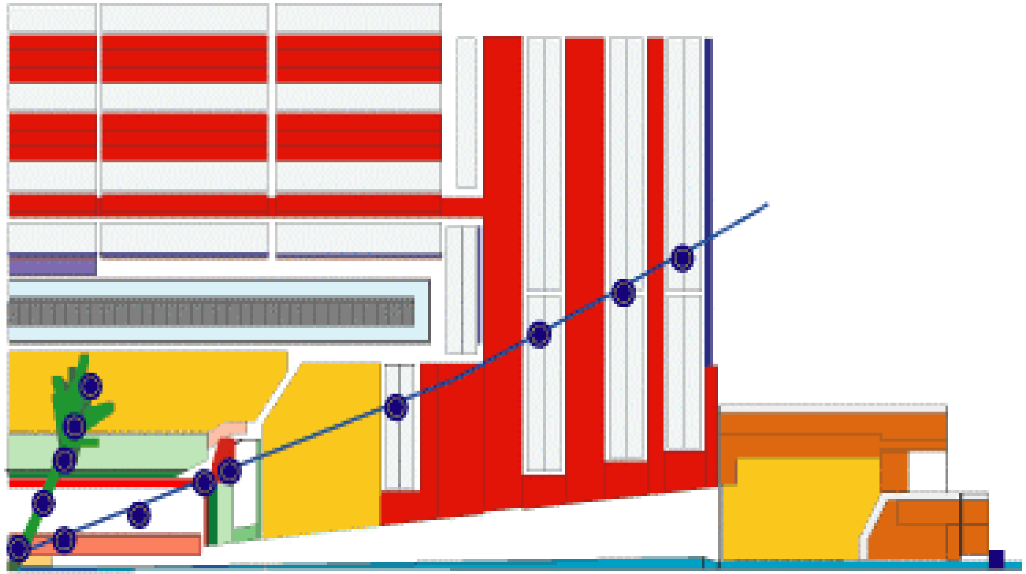
AA Event Size & Data Flow

Detector	# Channels (1000)
Pixel	45,000
Si Tracker	12,000
ECAL	230
HCAL	14
Muon Det.	400
Total	57,644



Assuming 100 MB/s
~40 Hz Pb+Pb to tape
limited by mass storage
dominated by tracker

High Rate Capabilities: High Level Trigger (HLT)

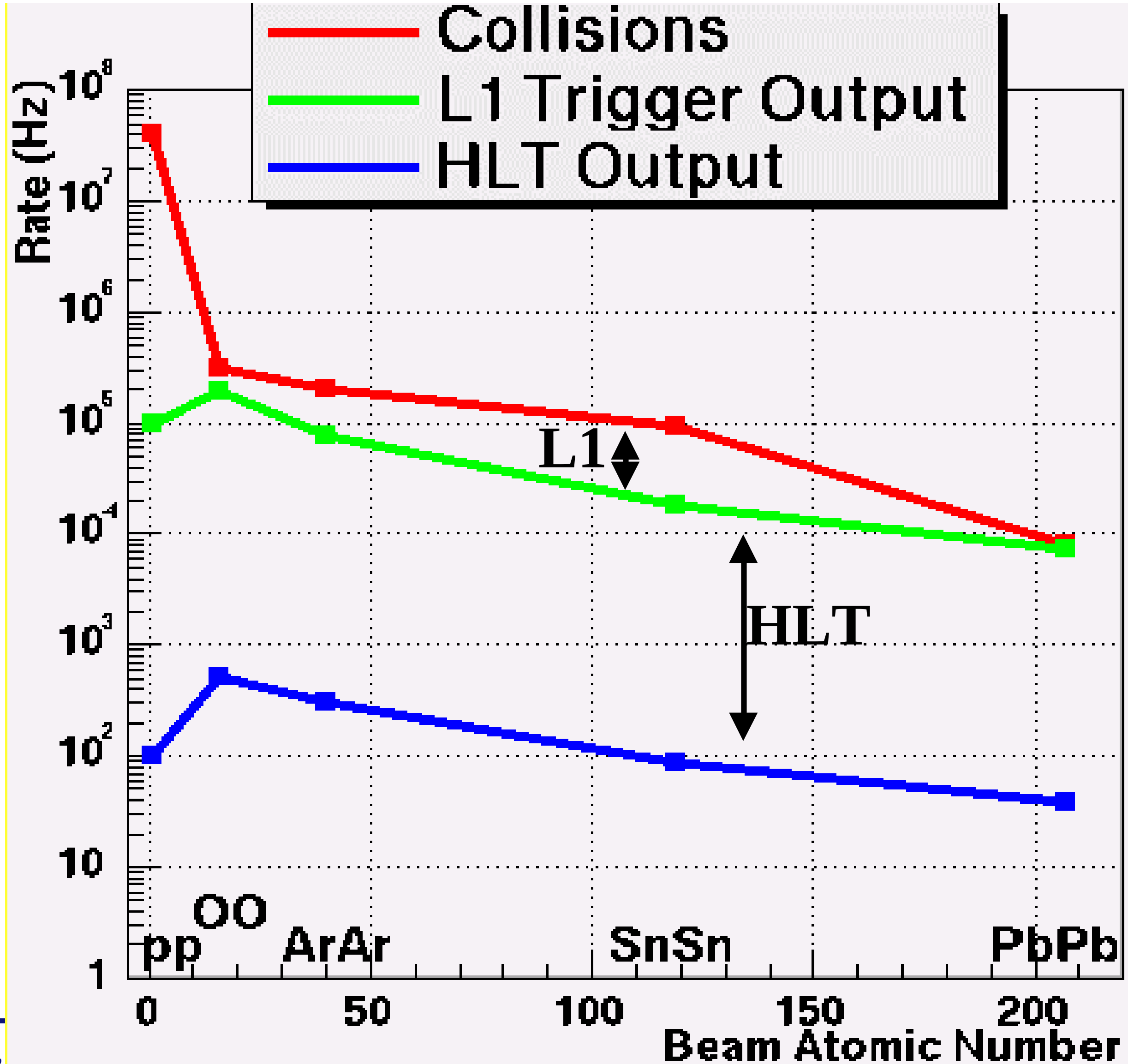


- **All event data available:**
  - **Final data for Calorimetry and Muon Detectors**
  - **Tracker**
- **Refine triggered object**
- **Allows to go lower in p_T**
- **Processing time O(s)**
- **Filtering Farms of commodity processors (Linux)**

HLT Can analyze large fraction of AA events: great opportunity

- **L1 in AA has larger backgrounds than in pp due to underlying event.**
- **Efficiency trigger requires more careful analysis. <u>HLT can do a better job than L1</u>.**
- **HLT to play a greater role in AA**

Data Flow and Rates



HLT better trigger job

LHC List of Possibilities

- **Pb+Pb at highest energy, maximum luminosity**
  - **new territory: complete physics program of CMS**
    - systematic studies of all processes
    - centrality dependence (number of participants)
    - dependence on kinematics: p_T, rapidity
- **A+A (lighter ions)**
  - **dependence of nuclear effects on the number of participants**
    - higher luminosity, high statistics for small number of participants
    - systematic check of all the processes
- **p+A (or d+A)**
  - **nuclear structure functions, "cold nuclear matter"**
  - **reference for A+A**
- **Varying beam energies for p+p, p+A, A+A**
  - **important check of systematics, scaling of processes with energy**

CMS Planning Assumptions

- **6 weeks/year for heavy ions, 4 weeks/year of clean run for physics**
  - **practically no hardware changes needed in CMS to switch from pp to non-pp**
    - Change to trigger software
    - Adjustment of gains and thresholds, timing (software)
- **CMS is most interested in high p_T measurements requiring long stable runs**
  - **assume one set of conditions/year, always running at maximum luminosity**
  - **possible exception: early “engineering run” with ions**
- **Statistics limited measurements:**
  - **quarkonia**
  - **high p_T jets**
  - **Z^0**
  - **jet-g,jet-Z^0 correlations**

Specific Wishes, 5 Year Plan

- **Year 1: Pb+Pb, max energy, max luminosity**
- **Year 2: Pb+Pb, max energy, max luminosity**
- **Year 3-5: less clear, may be influenced by results from years 1-2, present thinking, *prioritized*:**
  - **pA or dA, *ideally at energies corresponding to A+A***
  - **Light Ions**
  - **p+p d+d, p+A d+A Pb+Pb at lower energies**
- **Eventually we want all of the above, the question is in what sequence: *physics driven***
- **Each run should maximize available luminosity given accelerator restrictions (e.g. lower energy may mean lower luminosity)**

Conclusions

- CMS is planning a rich physics program using heavy ion capabilities of the LHC
- The high rate capabilities and large acceptance make CMS an excellent detector for high p_T phenomena
- CMS can use highest luminosities available at LHC both in A+A and p+A mode
- We need to work closely with the accelerator group to optimize luminosity vs. physics goals